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IRAS (*) catalogues and atlases. Atlas of low-resolution spectra

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Summary. — We present plots of all 5425 spectra in the IRAS catalogue of low-resolution spectra. The catalogue contains the average spectra of most IRAS point sources with 12 μm flux densities above 10 Jy.

Key words : satellite — atlas — infrared — spectroscopy.

1. Introduction.

The Infrared Astronomical Satellite (IRAS) surveyed approximately 96 percent of the sky in four broad wavelength bands centred at about 12, 25, 60, and 100 μm. During the entire survey a low-resolution spectrometer (LRS) measured spectra of the brighter point sources between 7.7 and 22.6 μm with a resolution varying from 20 to 60. The instrument, the observations, and the data processing are described in the IRAS Explanatory Supplement (1985, Chapter IX) and in Wildeman *et al.* (1985).

In section 2 we summarize how the LRS catalogue was produced, and we mention the main results of a preliminary analysis of its contents (Olnon, 1985). Section 3 describes the layout of the atlas.

2. The LRS catalogue.

2.1 INSTRUMENT. — During the survey observations the IRAS telescope made scans at constant solar aspect angle. The LRS was basically an objective prism spectrograph, oriented in such a way that the dispersion was aligned with the scan direction. Therefore, it measured useful spectra of relatively isolated point sources only.

Two overlapping wavelength bands were scanned simultaneously, one ranging from 7.7 to 13.4 μm and the other from 11.0 to 22.6 μm. In both bands the resolution increased from 20 at the short-wavelength to 60 at the long-wavelength side. The integration time per resolution element was 60 ms, which resulted in noise levels equivalent to 1.5 Jy at the shorter and 3 Jy at the longer wavelengths.

The aperture mask in the focal plane measured 6 arcmin in-scan by 15 arcmin cross-scan. This wide field of view ensured a sky coverage identical to that of the IRAS survey : 96 percent of the sky was observed at least twice, and 72 percent three times. To reduce spatial confusion, the aperture width was covered by three detectors at the short wavelengths and by two at the long wavelengths. The detectors were sampled continuously, and the data were received on the ground together with the data from the survey array.

2.2 DATA PROCESSING. — Whenever the data from the survey detectors indicated that a point-like source brighter than about 2 Jy at 12 or 25 μm had crossed the LRS aperture, the corresponding sections of the LRS data stream were extracted. At the end of the mission the database contained 170000 uncorrected spectra linked to 50000 candidate survey sources, and a number of calibration tables.

Each spectrum was interpolated to a standard wavelength grid, various gain corrections were applied using the calibration tables, and a number of quality checks were performed. The spectrum-halves were « joined » using the overlap region from 11 to 13 μm. For each source with at least two complete spectra the « best »

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spectrum was defined as the one with the smallest number of check-flags. Spectra that did not correlate well enough with the best spectrum were rejected. The accepted spectra, if any, were averaged with the best spectrum. The averaged spectra were then classified as will be described in section 2.3.

A source had to pass three tests to be included in the LRS catalogue :

(1) At least two complete spectra must have been accepted. This was the most severe test : nearly 90 percent of the sources in the LRS database failed this test due to the low signal-to-noise ratio in their spectra.

(2) The averaged spectrum must pass a visual inspection. About one hundred sources were rejected because their spectra showed clear evidence of confusion or slight extension.

(3) The source must appear in the IRAS point-source catalogue. About ten sources failed the confirmation test with the point-source processing ; valid « excuses » were found for every one of these.

Finally, a global correction was applied to the LRS flux scale to make it consistent with the flux densities in the point-source catalogue. Each spectrum in the LRS catalogue was convolved with the 12 μm survey passband, and the integrated flux was compared to the average 12 μm survey flux of the source. The mean of the distribution of the ratios between these two fluxes was forced to be one.

The LRS catalogue contains the average spectra of 5425 sources. The overall shape of the spectra is accurate to 2-4 percent and the flux-density scale of individual spectra is consistent with the flux density in the point-source catalogue to within 10-15 percent. The LRS catalogue is certainly less complete than the point-source catalogue due to the additional selection criteria applied. Even at high galactic latitudes it contains only 90 % of the IRAS point sources brighter than 28 Jy at 12 μm (Hacking *et al.*, 1985). Some very bright red stars are conspicuously absent (e.g. Mira and R. Leo).

2.3 CLASSIFICATION. — There are various types of spectra in the catalogue. More than 50 percent show well-defined features : the very broad 9.8 μm silicate band (in emission or absorption), a broad emission band at 11.4 μm (usually ascribed to SiC), an unidentified line or narrow band at 11.3 μm, or atomic lines. Most spectra are relatively blue, but some are very red.

All spectra are characterized by a two-number code (class), which is also included in the point-source catalogue. The first number (main class) describes the type of the spectrum. The second number (subclass) gives more specific information depending on the main class. Apart from the nine regular main classes (1 to 9) we defined a « rest » class 0 for spectra that did not fit into one of these classes. The subclass then indicates the most likely main class. The LRS classes are listed in table I.

The classification is based on spectrometer data only. Spectral indices, band strengths and line fluxes were derived from the fluxes in a number of carefully chosen narrow bands, typically two resolution elements wide. The spectral index, β, is defined by $F_\lambda \propto \lambda^\beta$, where F_λ is the flux density (flux per unit wavelength). β(8-13) and β(14-22) denote the spectral indices between the indicated wavelengths. Band strengths are defined as $B(\lambda) = \ln\left(F_\lambda / F_{\lambda c}\right)$, where λ is the central wavelength of the band (9.8 for silicate and 11.4 for SiC) and $F_{\lambda c}$ the interpolated continuum flux density at that wavelength.

Line spectra. Spectra with emission lines were put in main class 8 when the 11.3 μm « line » was present and in main class 9 when it was not. In both cases, the subclass indicates which atomic line was the strongest. A higher subclass corresponds to a higher excitation level. Compact HII regions and low-excitation planetary nebulae are found in classes 81 and 91 and medium-excitation planetary nebulae in classes 94 and 95.

« Blue » spectra. Spectra with a spectral index $\beta\,(14\text{-}22) < -1$ were classified as « blue ». Those with a significant band were put in main class 2 if $B(9.8) > B(11.4)$, in main class 4 if $B(11.4) > |B(9.8)|$, or else in main class 3. The subclass is equal to $10 \times B$ for emission and $-5 \times B$ for absorption bands, rounded to the nearest integer between 1 and 9. Spectra with strong silicate emission bands were classified as 29 and those with moderately strong SiC bands as 43. In a few spectra the bands has a strange shape and these were classified as 02, 03 or 04 depending on the most likely main class.

« Blue » spectra without features stronger than 5 times the rms noise or 10 percent of the continuum level, were put in main class 1. The subclass is equal to $-2 \times \beta\,(8\text{-}13)$. Rayleigh-Jeans type spectra ($\beta = -4$) were classified as 18. When the spectrum was so noisy that even a medium-strong band would not have been recognized, it was classified as 01.

« Red » spectra. Spectra with a spectral index $\beta\,(14\text{-}22) > -1$ were classified as « red ». Two band classes are defined in the same way as for the « blue » spectra : main classes 6 and 7 correspond with classes 2 and 3, respectively. No « red » equivalent was found for the class 4 spectra. Classes 5*n* and 05 are the « red » equivalents of classes 1*n* and 01, except that the subclass of 5*n* is equal to $2 \times \beta\,(14\text{-}22)$. Most of the « red » spectra are not fundamentally different from the corresponding « blue » types. The « red » classes mainly serve to isolate the relatively small number of very red spectra.

The classification was done automatically. Visual inspection confirmed the classification for more than 98 percent of the spectra, but we accepted the automatic classification for the other spectra. They were all borderline cases : Weak « blue » spectra disappear in the noise at the longest wavelengths, which sometimes leads to a « red » classification. For spectra with emission bands just above the 10 percent level the choice between main classes 2 and 4 is quite arbitrary. Spectra with self-absorption in the 9.8 μm band look very much like class 4 spectra. Knowledge of the 18 μm silicate band is necessary in order to classify these spectra correctly, but

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usually this band is too weak and the classification program did not take it into account.

2.4 CONTENTS OF THE CATALOGUE. — The LRS catalogue contains average spectra of 5425 sources distributed over the whole sky. About 90 percent of the IRAS point sources with flux densities in the 12 μm band above 20 Jy are present in the LRS catalogue, and the completeness falls sharply at 10 Jy (40 %).

Table II gives the number of LRS sources in each class, and in table III we list the types of sources, their estimated numbers, and the LRS classes in which the sources are mainly found. More than 95 percent of the LRS sources are stars, most of them with circumstellar envelopes.

3. The atlas.

3.1 SPECTRA. — Each spectrum consists of two parts : from 7.8 to 13.4 μm we give the average spectrum measured by the short-wavelength detectors, and from 13.4 to 22.4 μm the spectrum measured by the long-wavelength detectors.

Along the vertical axis $\lambda \times F_\lambda$ is given in watts per square meter. « Red » spectra rise in the long-wavelength part and « blue » spectra slope down. For spectra with a maximum flux above 10^{-11} Wm^{-2} the flux scale is variable and chosen such that the maximum and zero values are at fixed positions. The shapes of the spectra can be compared with each other directly. For weaker spectra the flux scale is a fixed one.

Above each spectrum some information concerning the source is given. On the left-hand side from top to bottom : the IRAS source name, the name of an associated source (if any), and a summary of all the associations (see Sect. 3.2). On the right-hand side : the LRS class and the IRAS position (epoch 1950.0) : right-ascension in hours, minutes and seconds, and declination in degrees, arcminutes and arcseconds.

3.2 ASSOCIATIONS. — The positions of all IRAS point sources have been compared with various astronomical catalogues (see IRAS Explanatory Supplement). For each LRS source these catalogues were searched in a special order. First, we divided them into four categories : stellar (S), extra-galactic (X), nebular (N), and various (V). Within each category we gave preference to the catalogue which gives most information on the source type (e.g., the catalogue of Carbon stars has a higher priority than the SAO catalogue).

Table IV lists all association catalogues in the order in which they were searched. Full references to all catalogues can be found in the Explanatory Supplement (IRAS, 1985). Some catalogues give prefixes in the source name, others do not. In some cases we added prefixes ourselves (indicated by asterisks in Tab. IV). The name of the first associated source found (« prime » association) is given in the plot. In most cases this appears to be a proper identification, but in the case of (extended) nebulae caution is warranted.

The association summary, given in the plot underneath the associated source name, consists of the number of the « prime » catalogue followed by the number of associations in each category. For example, if we found an association in the catalogue of emission-line stars and in addition one other stellar, three nebular and two « various » associations, then the association field reads : 7 2S 3N 2V.

In principle, S, X, and N associations are mutually exclusive, but we found 70 S-N, 12 S-X, and 1 S-X-N combination. In all cases the stellar association appears to be the correct identification. There are two main reasons for the « confusing associations » :

(1) Several stars are physically associated with reflection or emission nebulae. 31 of the S-N sources have an entry in the catalogue of emission-line stars, 14 of which are also present in the catalogue of planetary nebulae.

(2) Some catalogues of nebulae and galaxies were inspected with fairly large search radii which makes chance coincidences with stars quite probable. This explains all S-X and about half of the S-N cases. In 11 cases the extragalactic association comes from the Morphological Catalogue of Galaxies, for which the largest search radius (3 arcmin) was used.

A nice example is the single S-X-N case, source 17584+6638A. It is identified as the planetary nebula NGC 6543 which also occurs in the catalogue of emission-line stars. The extragalactic associations are due to a faint galaxy at about one arcmin from NGC 6543.

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TABLE I. — *LRS Spectral Classes.*

Class	Characteristic	Subclass n	Number
Rest classes			
0n	See subclass		363
		n = 1: "blue", low S/N	313
		n = 5: "red", low S/N	32
		n = 0,2,3,4: strange band shape	18
"Blue" classes, β(14-22) < -1 [1]			
1n	Featureless spectrum		2238
		n = -2 × β(8-13)	
2n	10 μm emission band		1730
		n = 10 × B(9.8)	
3n	10 μm absorption band		230
		n = -5 × B(9.8)	
4n	11 μm emission band		538
		n = 10 × B(11.4)	
"Red" classes, β(14-22) > -1			
5n	Featureless spectrum		63
		n = 2 × β(14-22)	
6n	10 μm emission band		78
		n = 10 × B(9.8)	
7n	10 μm absorption band		67
		n = -5 × B(9.8)	
Line classes			
8n	11.3 μm "line" and atomic lines		69
		n = 0: no atomic lines	
		n = 1-6: strongest atomic line	
		1: [Ne II] 12.8 μm	
		2: [S III] 18.8 μm	
		3: [Ar III] 9.0 μm	
		4: [S IV] 10.5 μm	
		5: [Ne III] 15.5 μm	
		6: [Ne V] 14.5 μm	
9n	Only atomic lines		49
		n = 1-6: same as for 8n	

1) β(8-13) and β(14-22) are the spectral indices between 8 and 13 μm and between 14 and 22 μm, respectively. B(9.8) and B(11.4) are the band strengths at the centre of the silicate and the SiC band, respectively. See section 2.3 for further details.

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TABLE II. — *Number of LRS sources in each class* (1).

Main class	Subclass 0	1	2	3	4	5	6	7	8	9
0	1	313	4	1	12	32	-	-	-	-
1	2	1	20	116	324	480	390	349	460	96
2	-	43	151	137	155	163	175	197	210	499
3	-	46	49	30	22	19	9	8	8	39
4	-	26	152	133	113	64	21	15	3	11
5	51	4	4	4	0	0	0	0	0	0
6	-	0	2	3	6	3	4	7	3	50
7	-	7	9	9	7	8	5	3	1	18
8	42	23	3	0	0	1	0	-	-	-
9	-	24	5	0	6	13	1	-	-	-

1) "-" means that the class is not defined

TABLE III. — *Types of LRS sources.*

Source type	Estimated number	LRS classes
Stars with O-rich envelopes	3000	21-29, 14-16, 31-39
Stars with C-rich envelopes	1000	41-49, 14-16
Stars without envelopes	1000	17-19
S-type stars	100	14-19, 21-22, 41-42
Compact HII regions	100	80-81, 91-92, 71-79
Emission-line stars	40	80-82, 61-69
Planetary nebulae	30	91-96
Galaxies	5	80-81

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TABLE IV. — *Association catalogues* (1).

Type	Prefix	Nr	Catalog
S		1	General Catalogue of Variable Stars (Kukarkin et al.)
S		7	Early Type Stars with Emission Lines (Wackerling)
S	BS *	15	Bright Star Catalogue - 4th Ed. (Hoffleit and Jascheck)
S	NS *	18	Catalog of Nearby Stars (Gliese)
S	CS *	17	General Catalogue of Cool Carbon Stars
S	SS *	19	General Catalog of S Stars (Stephenson)
S	DO	2	Dearborn Observatory Catalogue of Faint Red Stars (Lee et al.)
S	SVS *	16	New Catalog of Suspected Variable Stars (Kukarkin et al.)
S	SAO *	13	Smithonian Astrophysical Observatory Star Catalog
X	N,A	6	Second Reference Catalogue of Bright Galaxies (de Vaucouleurs et al.)
X	U	9	Uppsala General Catalogue of Galaxies (Nilson)
X	ZG	12	Catalogue of Galaxies and Clusters of Galaxies (Zwicky et al.)
X	M	10	Morphological Catalog of Galaxies (Vorontsov-Velyaminiov et al.)
X		29	Catalogue of Quasars and Active Nuclei (Veron-Cetty and Veron)
X		25	Catalog of Dwarf Galaxies (van den Bergh)
X	ARP	26	Atlas of Peculiar Galaxies (Arp)
X	MKN	27	Galaxies with an Ultraviolet Continuum (Markarian et al.)
X		28	Catalog of Extragalactic Radio Sources Having Flux Densities Greater than 1 Jy at 5 GHz (Kuhr et al.)
X	#ZW	30	Eight lists of Selected Galaxies (Zwicky et al.)
X	V	31	Atlas and Catalog of Interacting Galaxies (Vorontsov-Velyaminov)
N	PK	11	Strasbourg Planetary Nebulae
N		22	Catalog of CO Radial Velocities Toward Galactic HII Regions (Blitz et al.)
N		21	Bonn HII Region Survey (Altenhoff et al.)
N	G	20	Parkes HII Region Survey (Haynes et al.)
N	DC	5	Globule List (Wesselius)
N	LDN	23	Catalogue of Dark Nebulae (Lynds)
	MRSL		Comparison Catalog of HII Regions (Marsalkova)
	OCL		Catalog of Star Clusters and Associations (Alter et al.)
	CED		Catalogue of Bright Diffuse Galactic Nebulae (Cederblad)
	DG		Untersuchungen Uber Reflexionsnebel am Palomar Sky Survey (Dorschner and Gurtler)
	VDB		A study of Reflection Nebulae (van den Bergh)
	VHE		Catalog of Southern Stars Embedded in Nebulosity (van den Bergh and Herbst)
V	TMSS	4	Two Micron Sky Survey (Neugebauer and Leighton)
V	RAFGL	3	Revised Air Force Geophysical Laboratory Four-Color Survey (Price and Murdock)
V	EIC	8	Equatorial Infrared Catalogue (Sweeny et al.)
V		14	ESO/Uppsala Survey of the ESO(B) Atlas (Lauberts)
V		24	Two Micron Sky Survey with Improved Positions (Kleinmann and Joyce)

1) Full references to these catalogs can be found in the IRAS Explanatory Supplement (1985).

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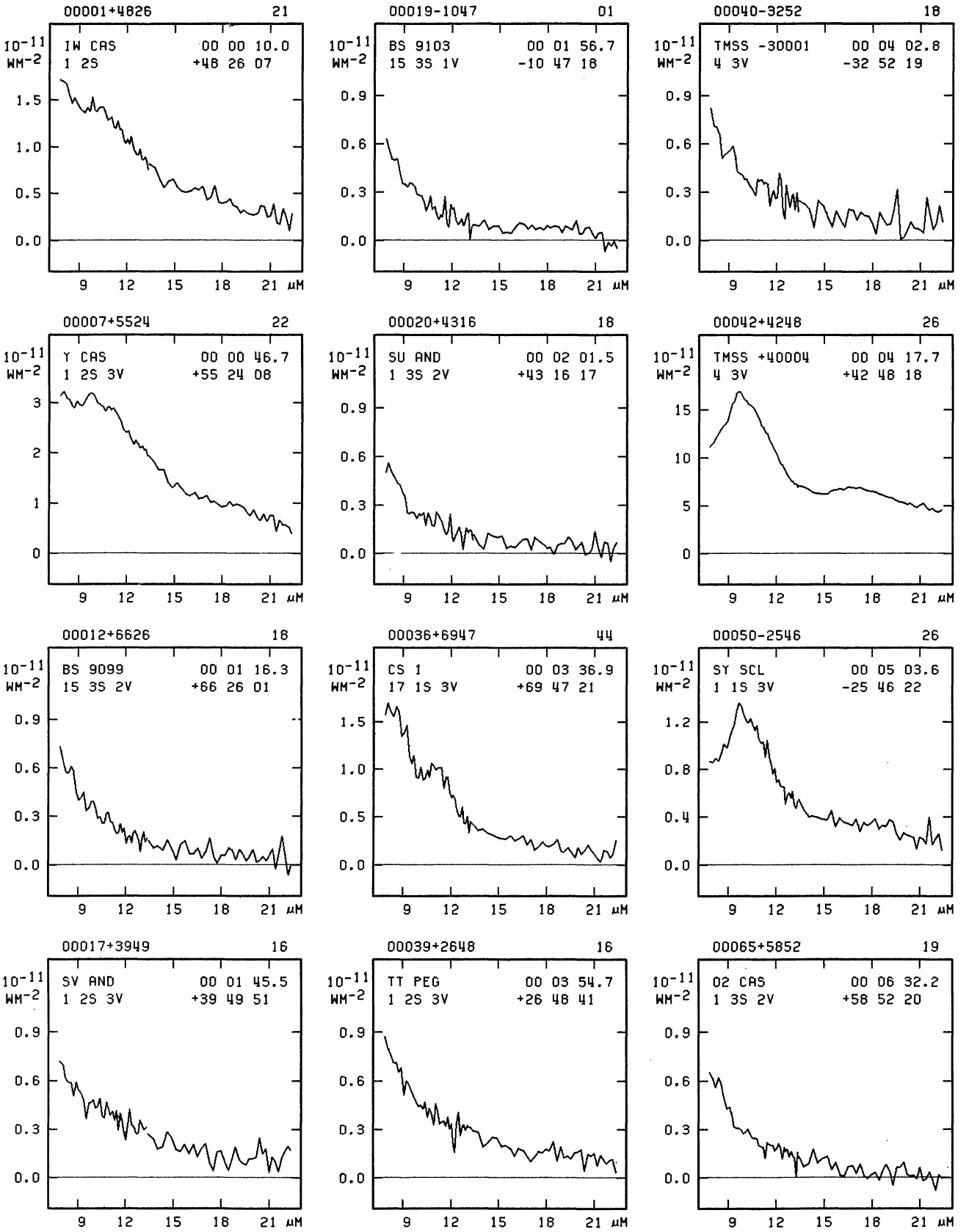

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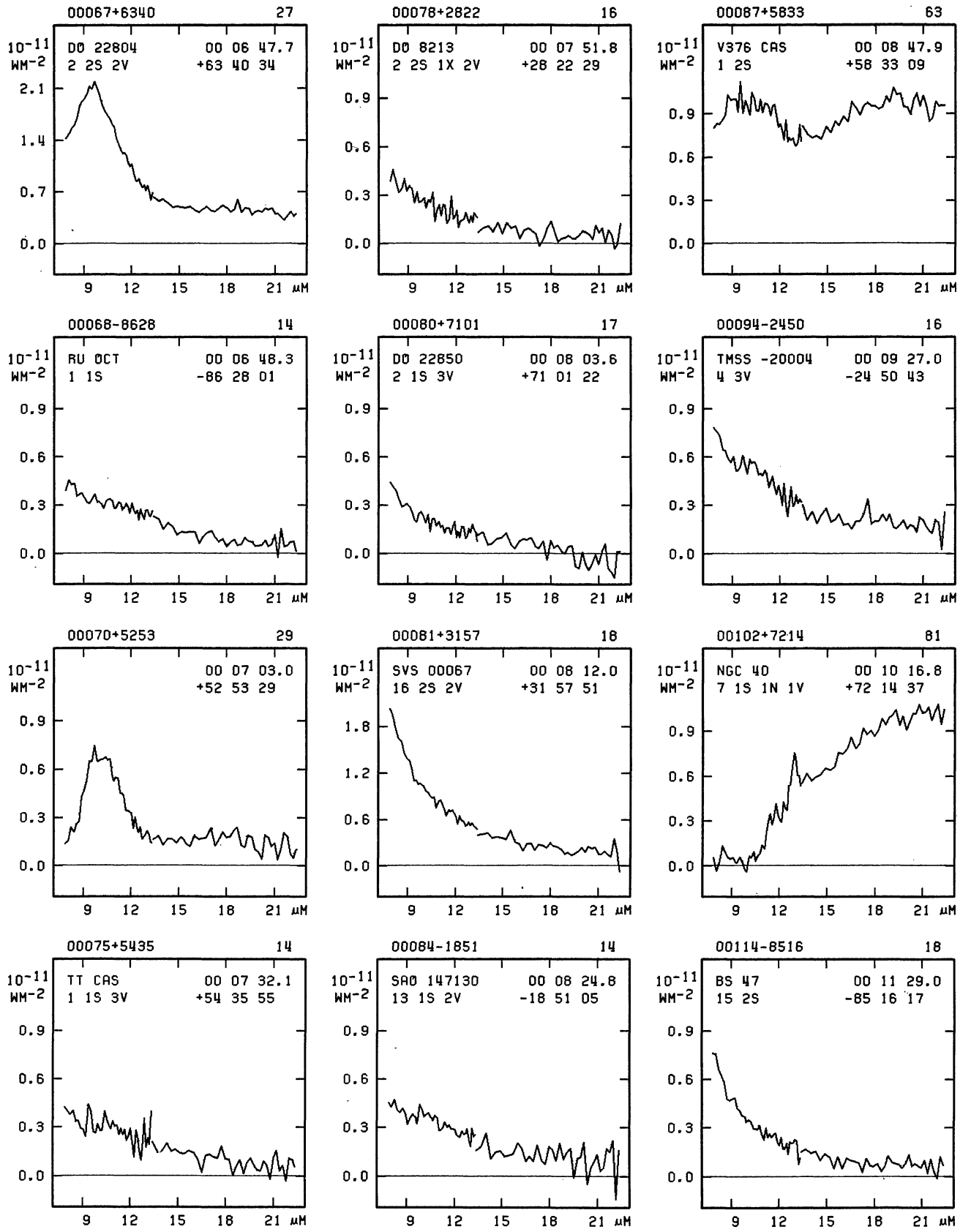

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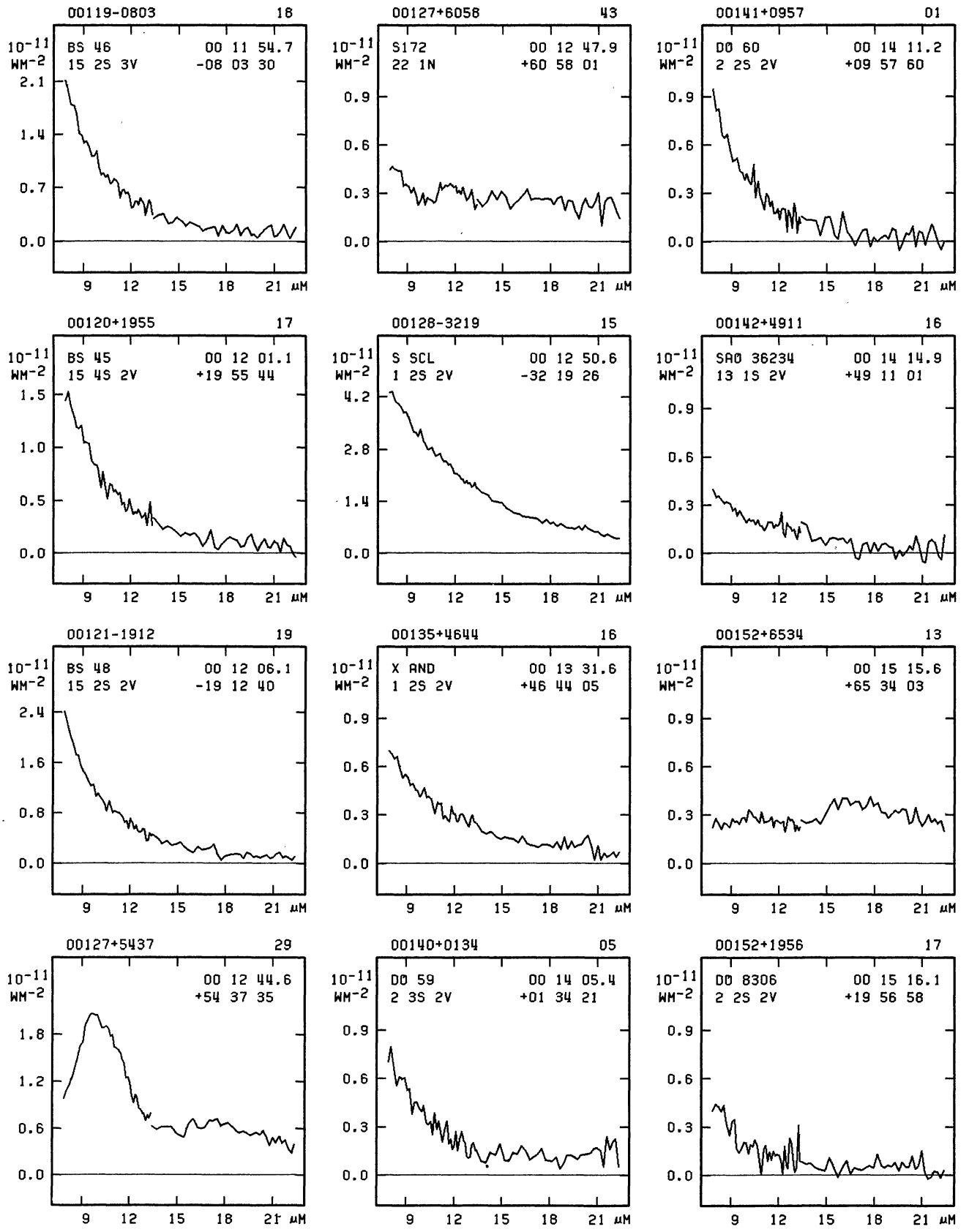

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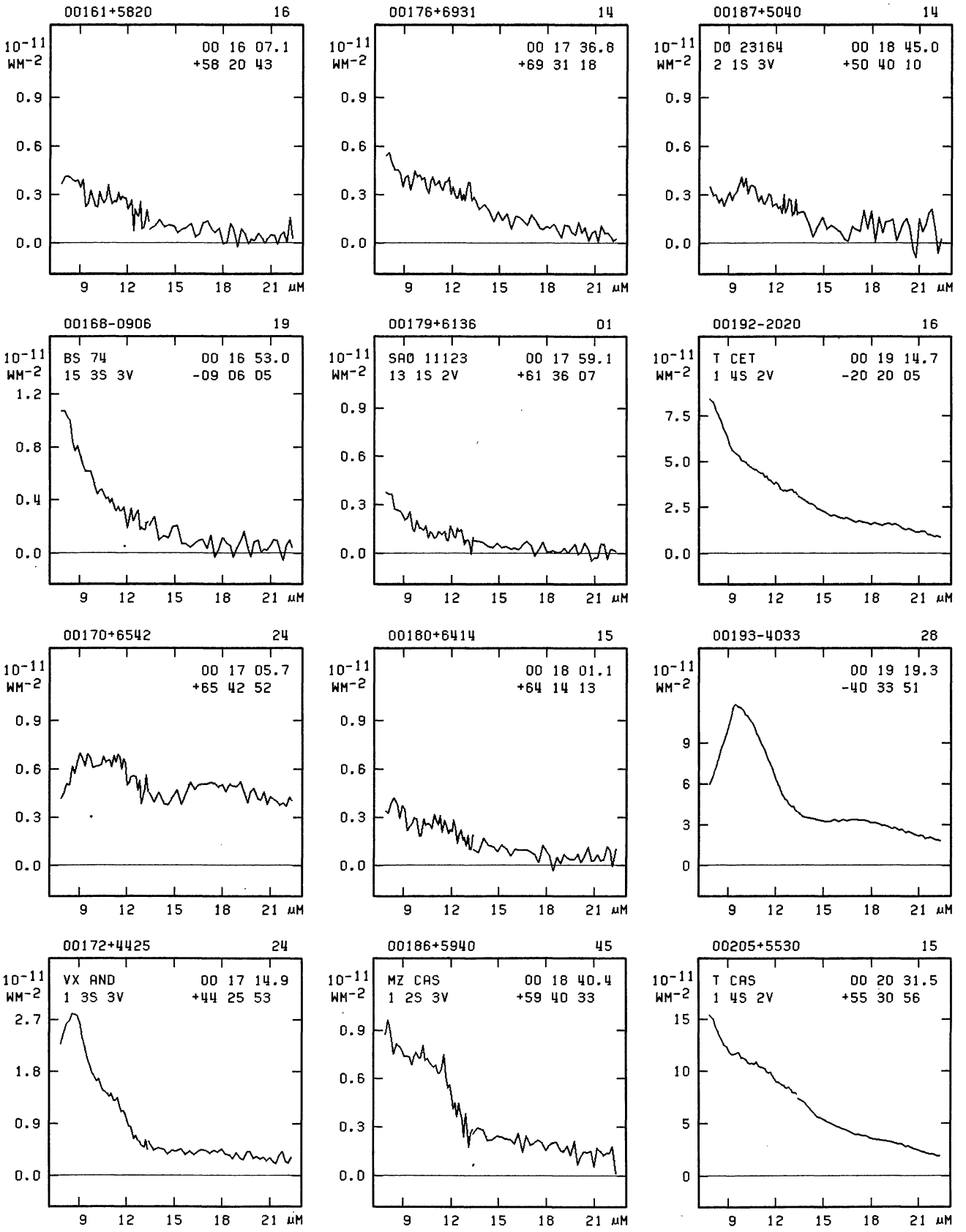

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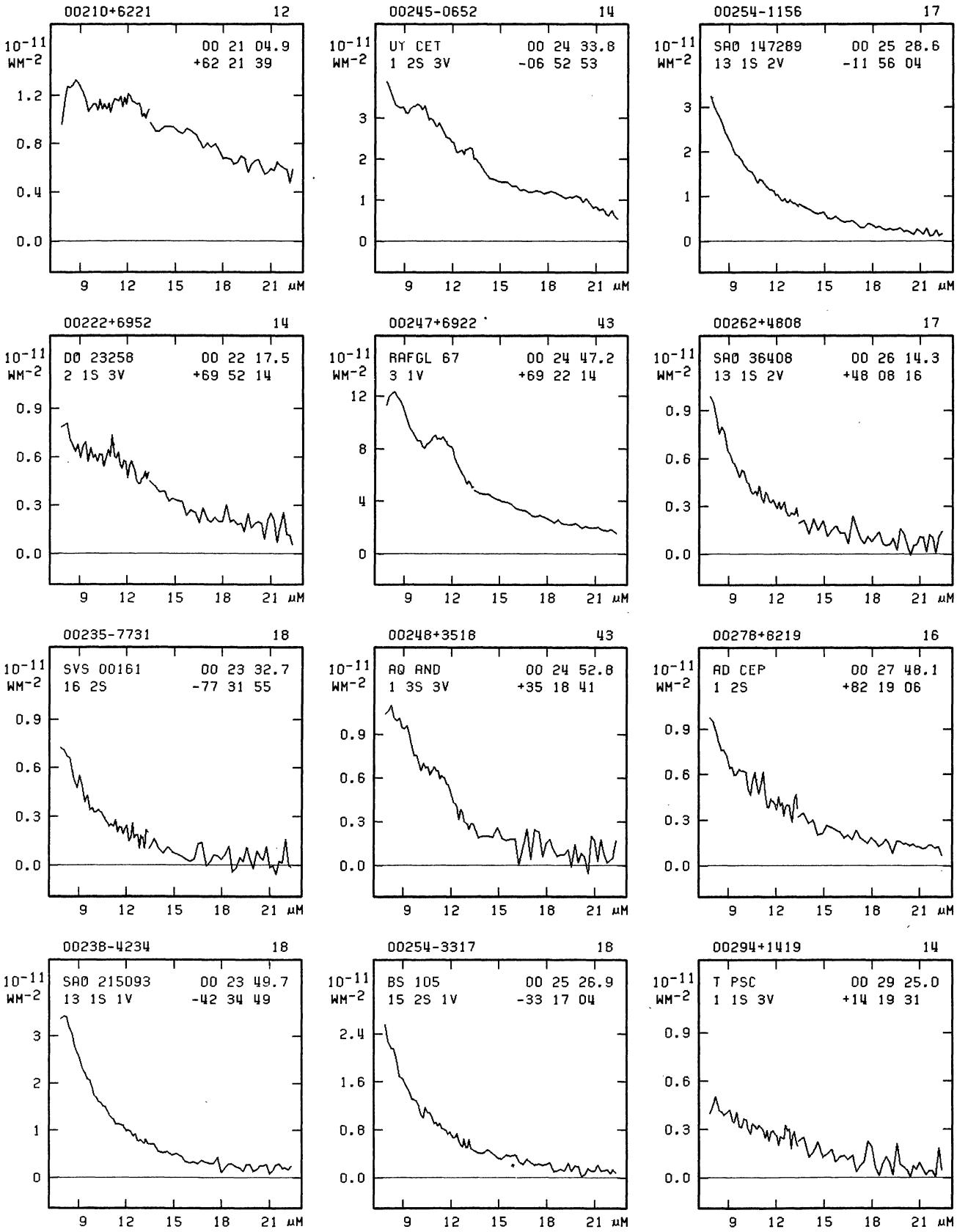

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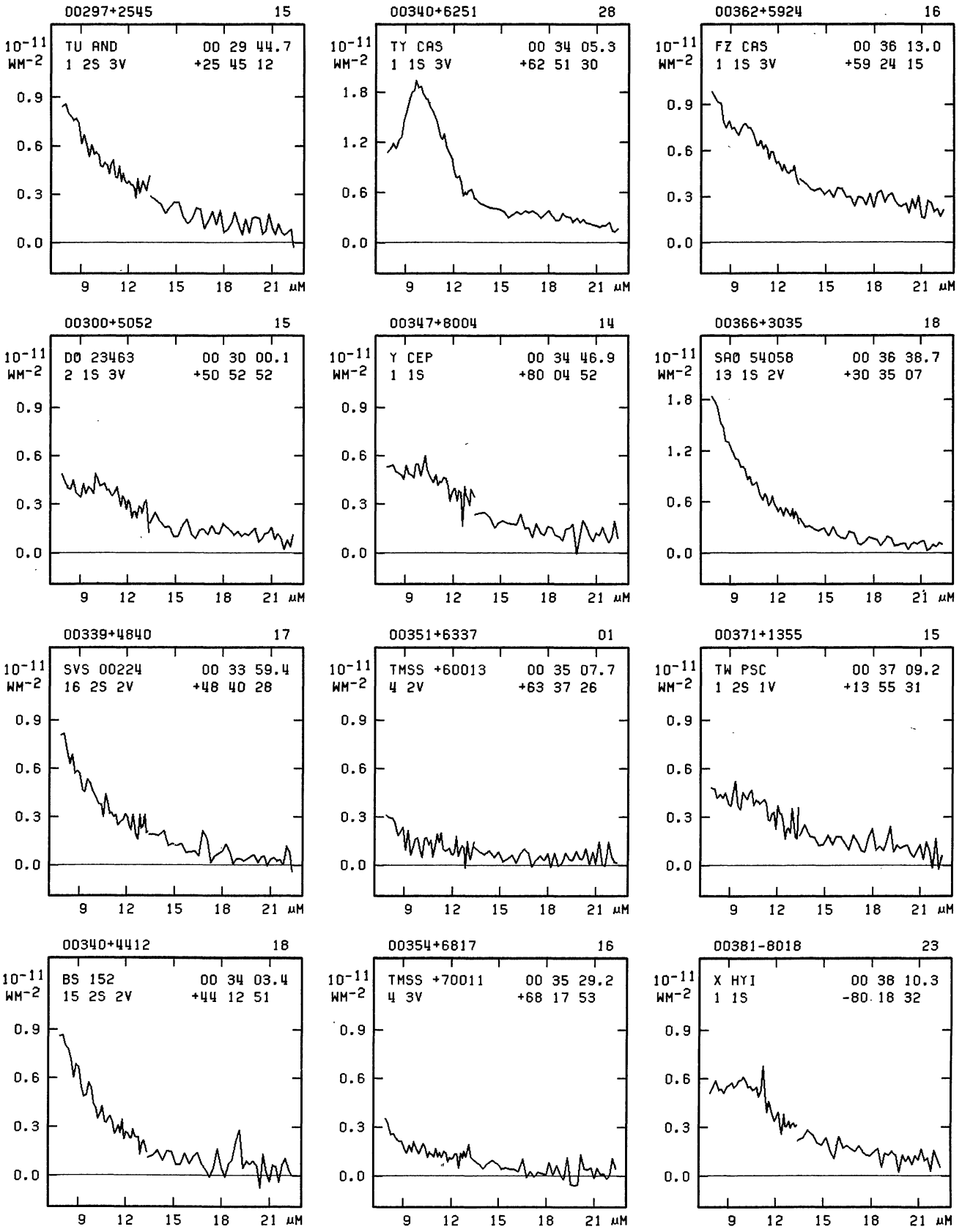

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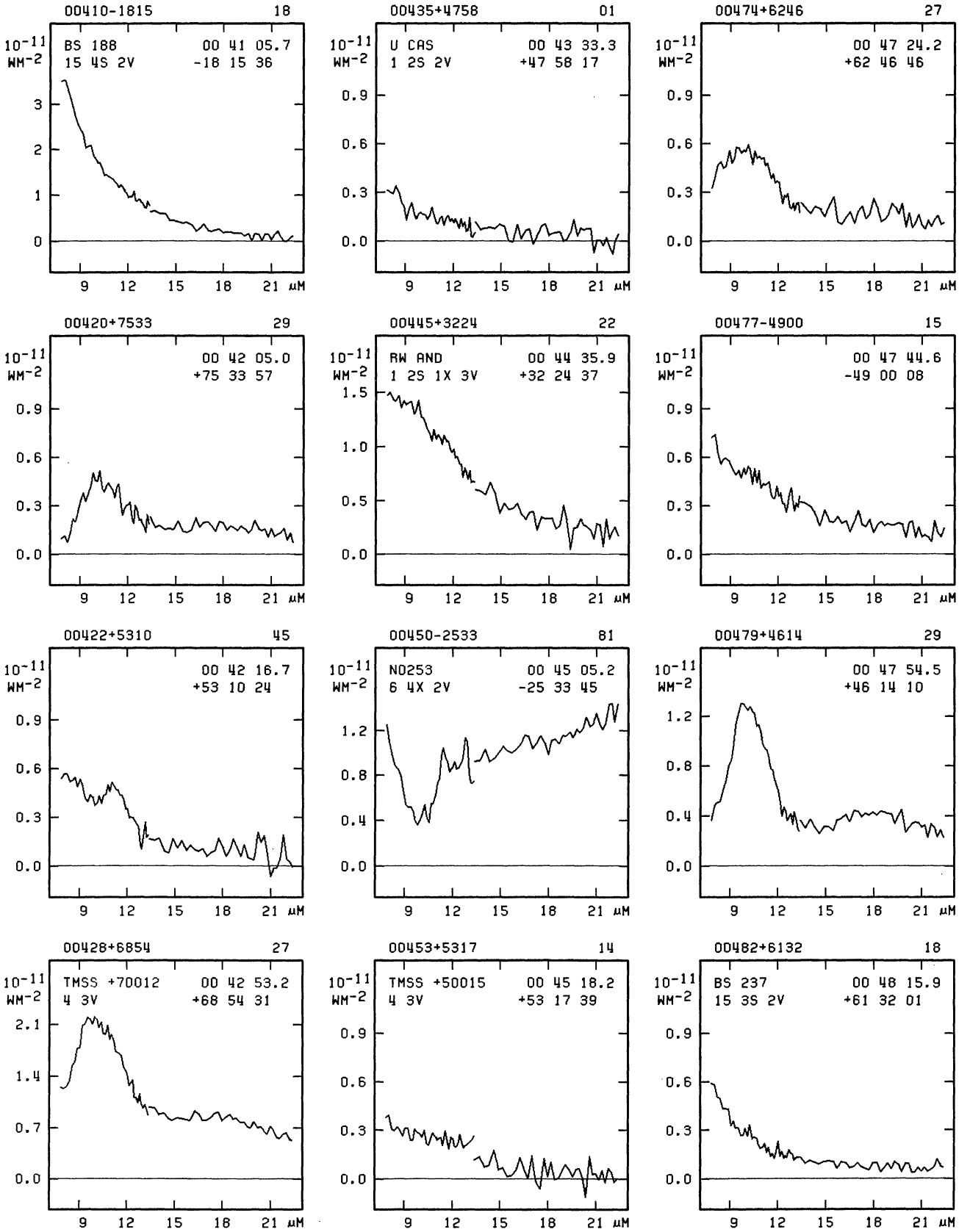

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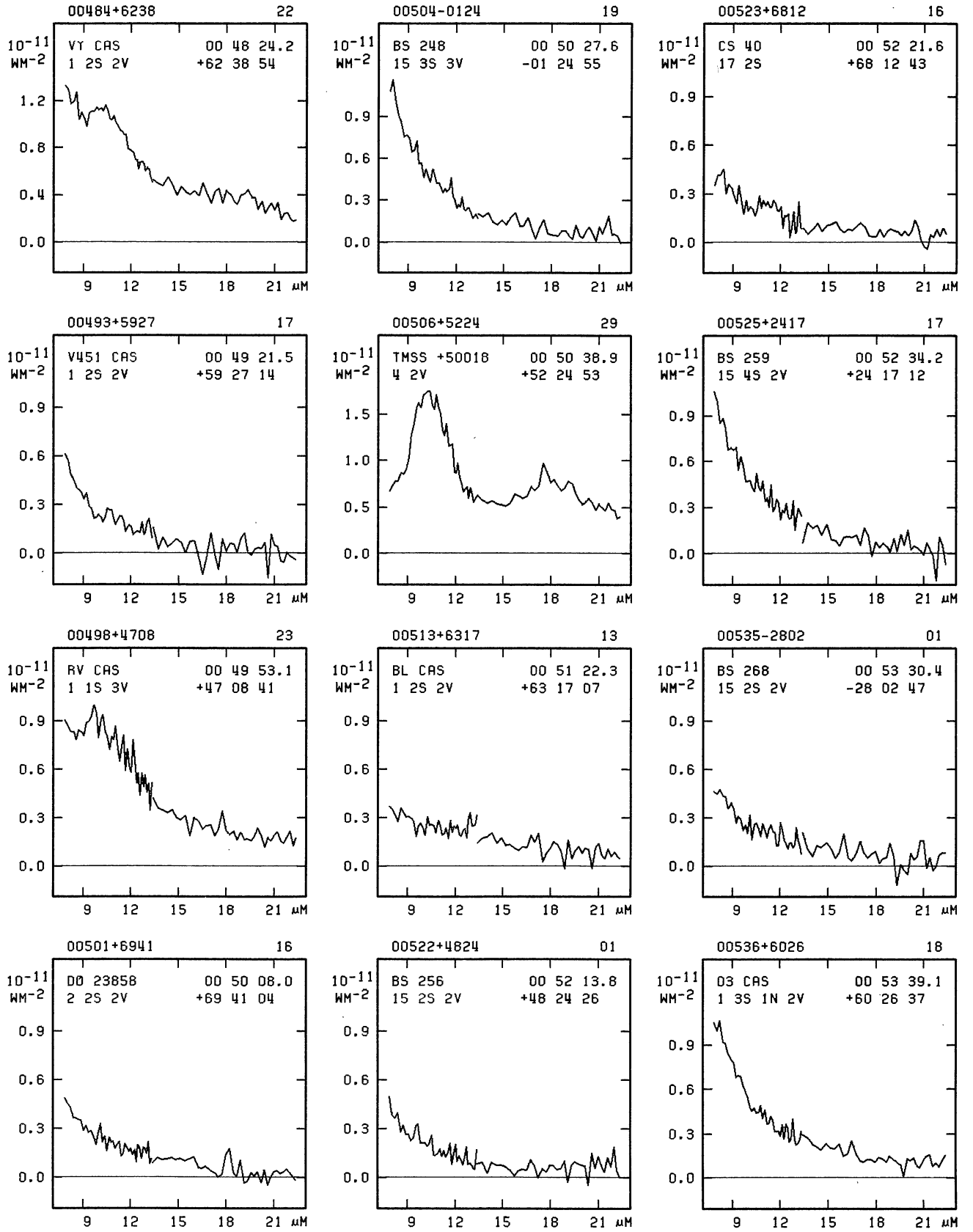

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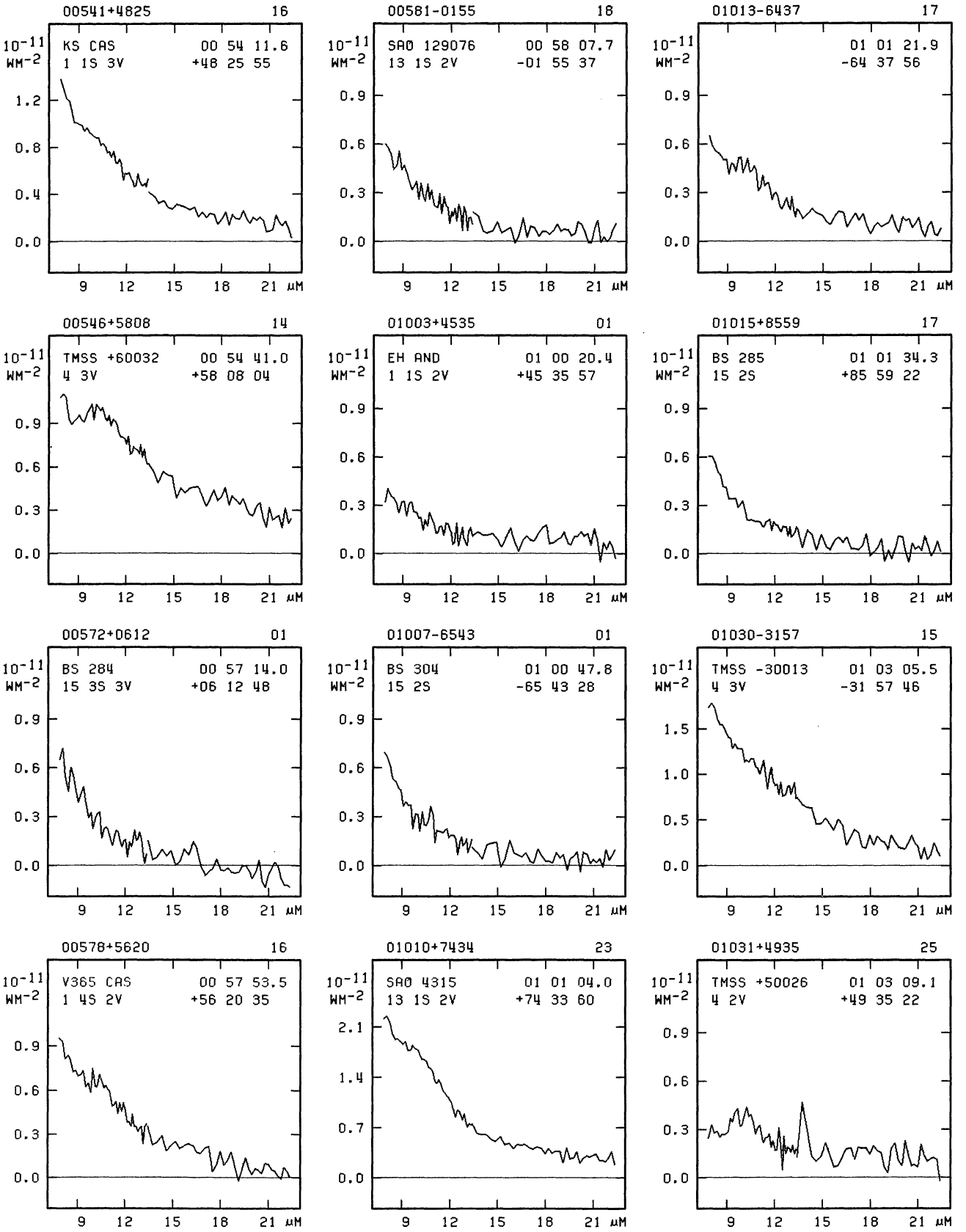

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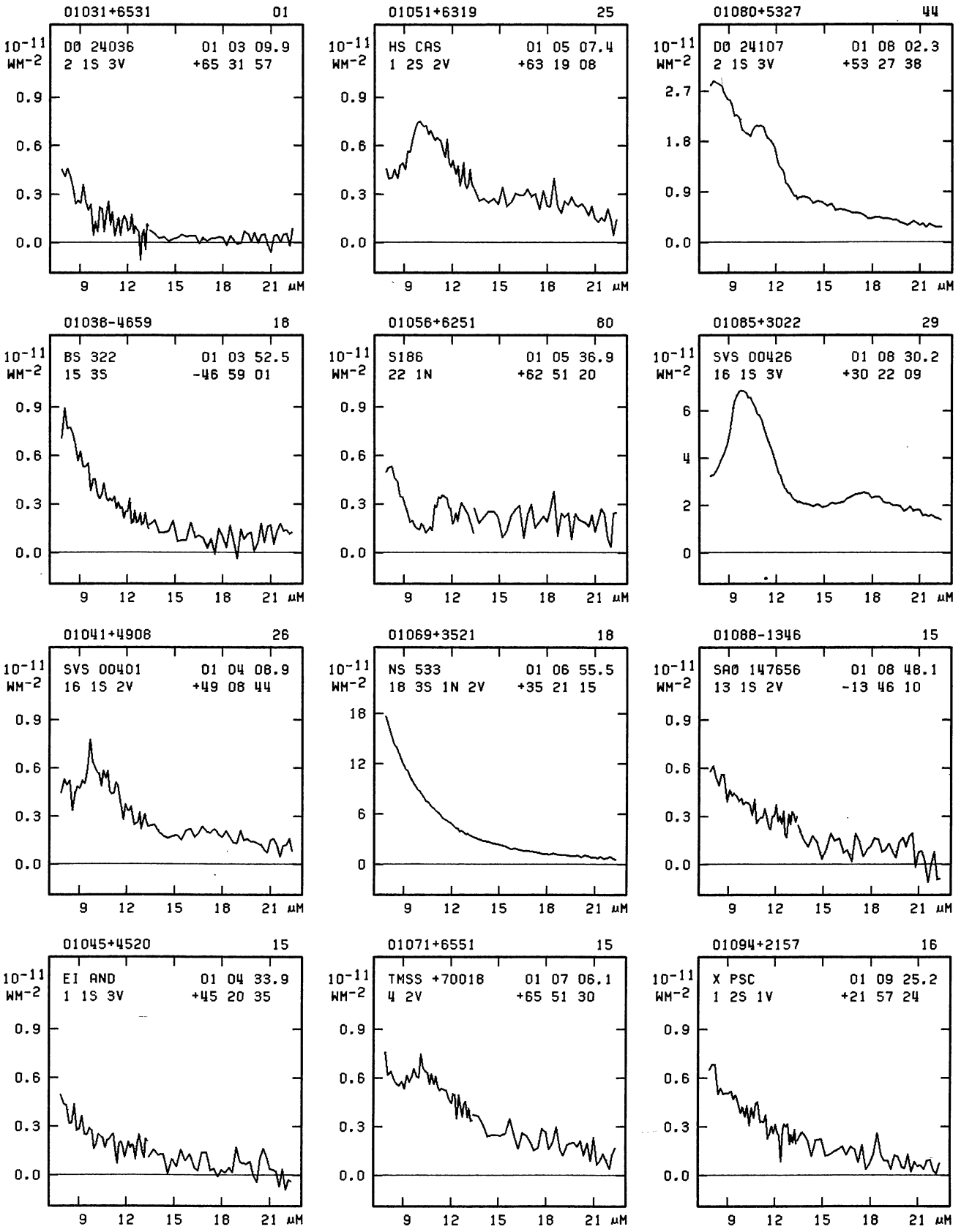

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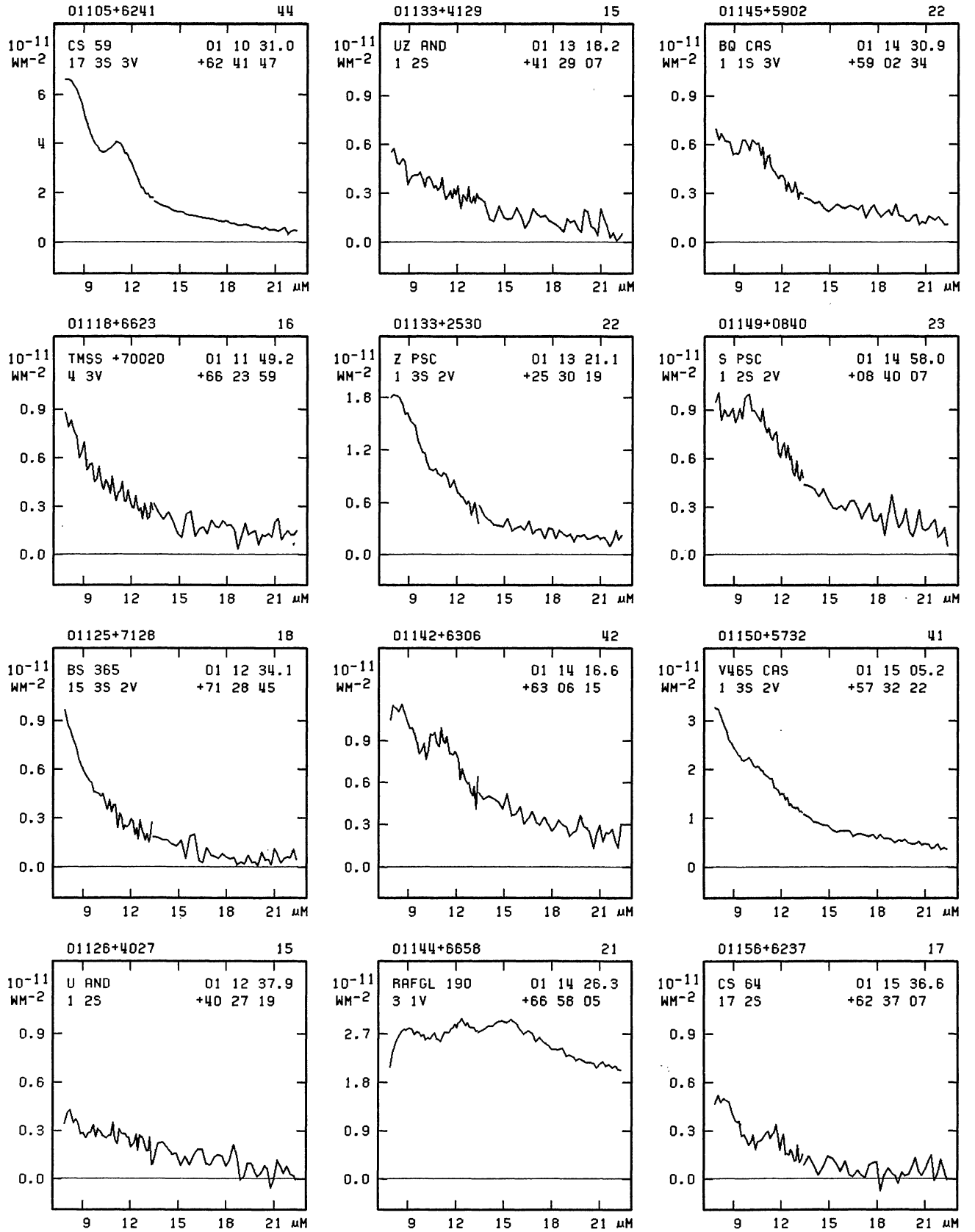

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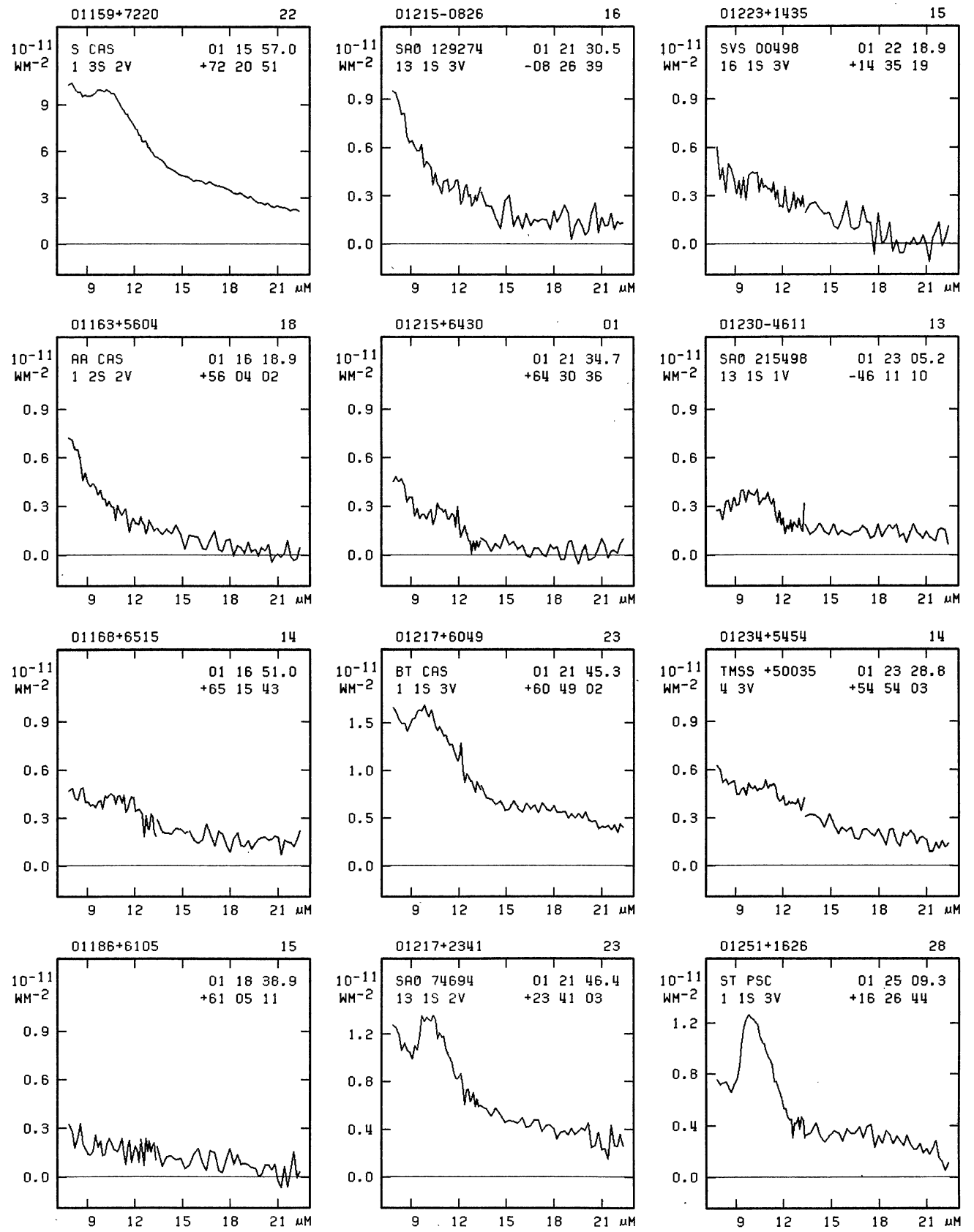

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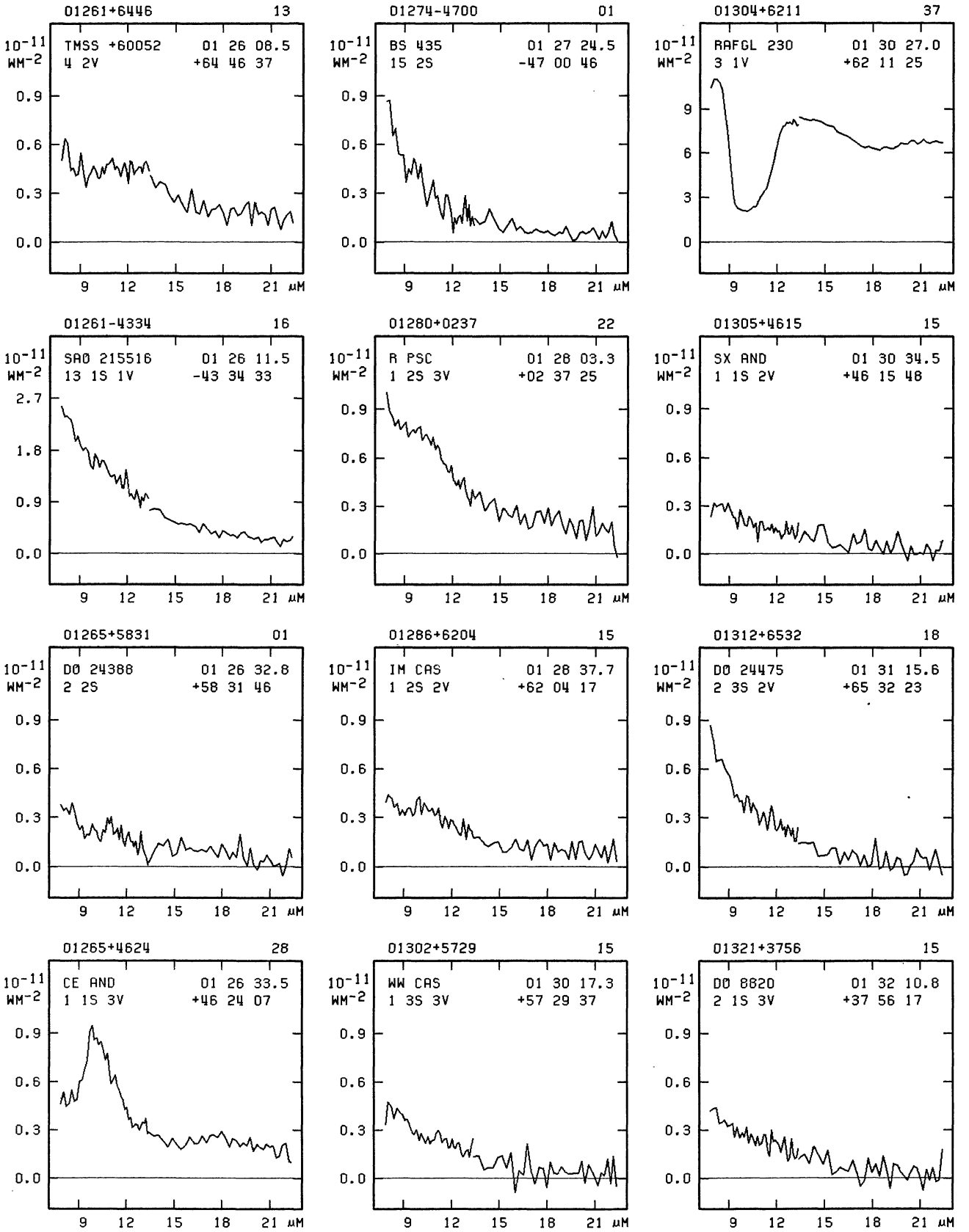

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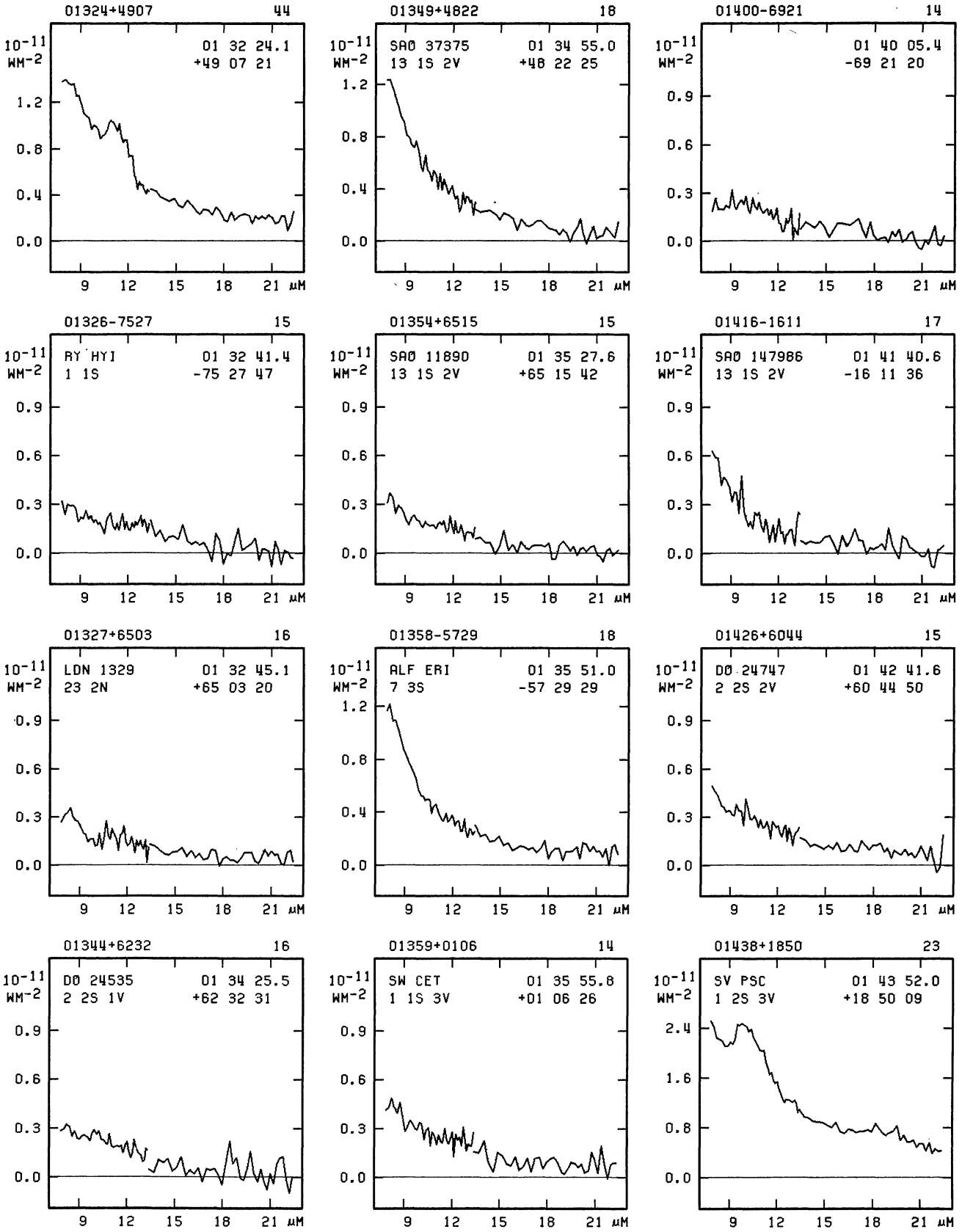

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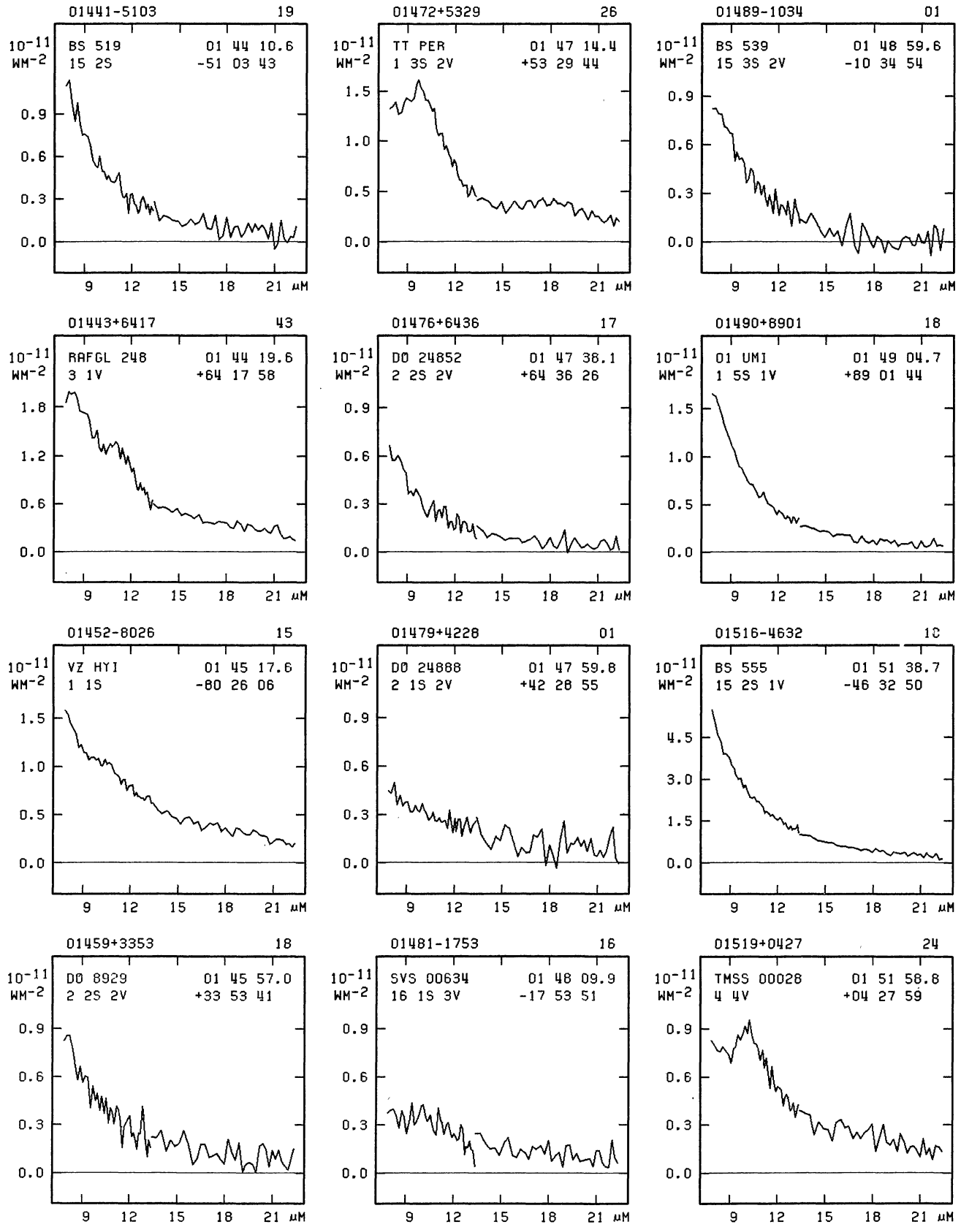

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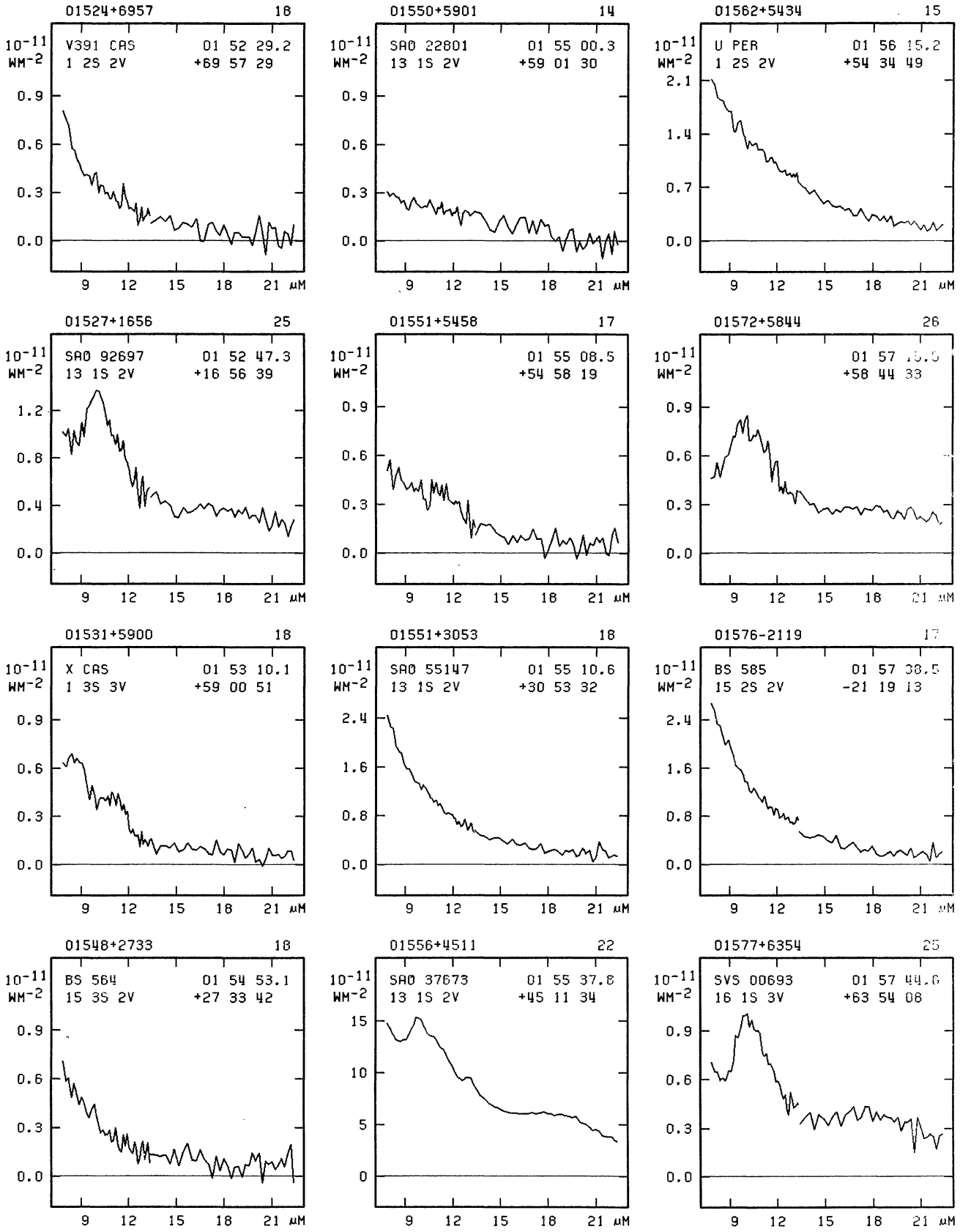

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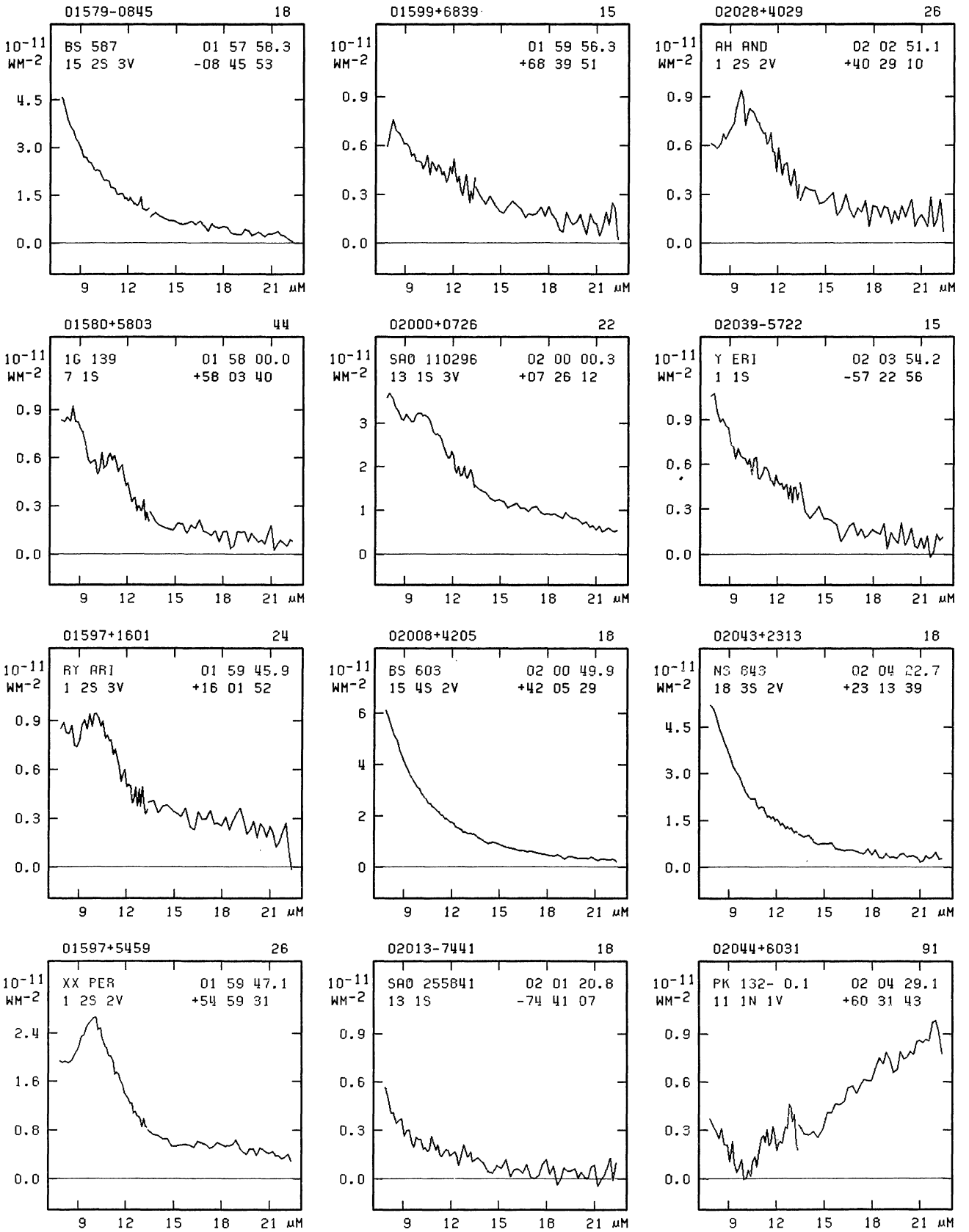

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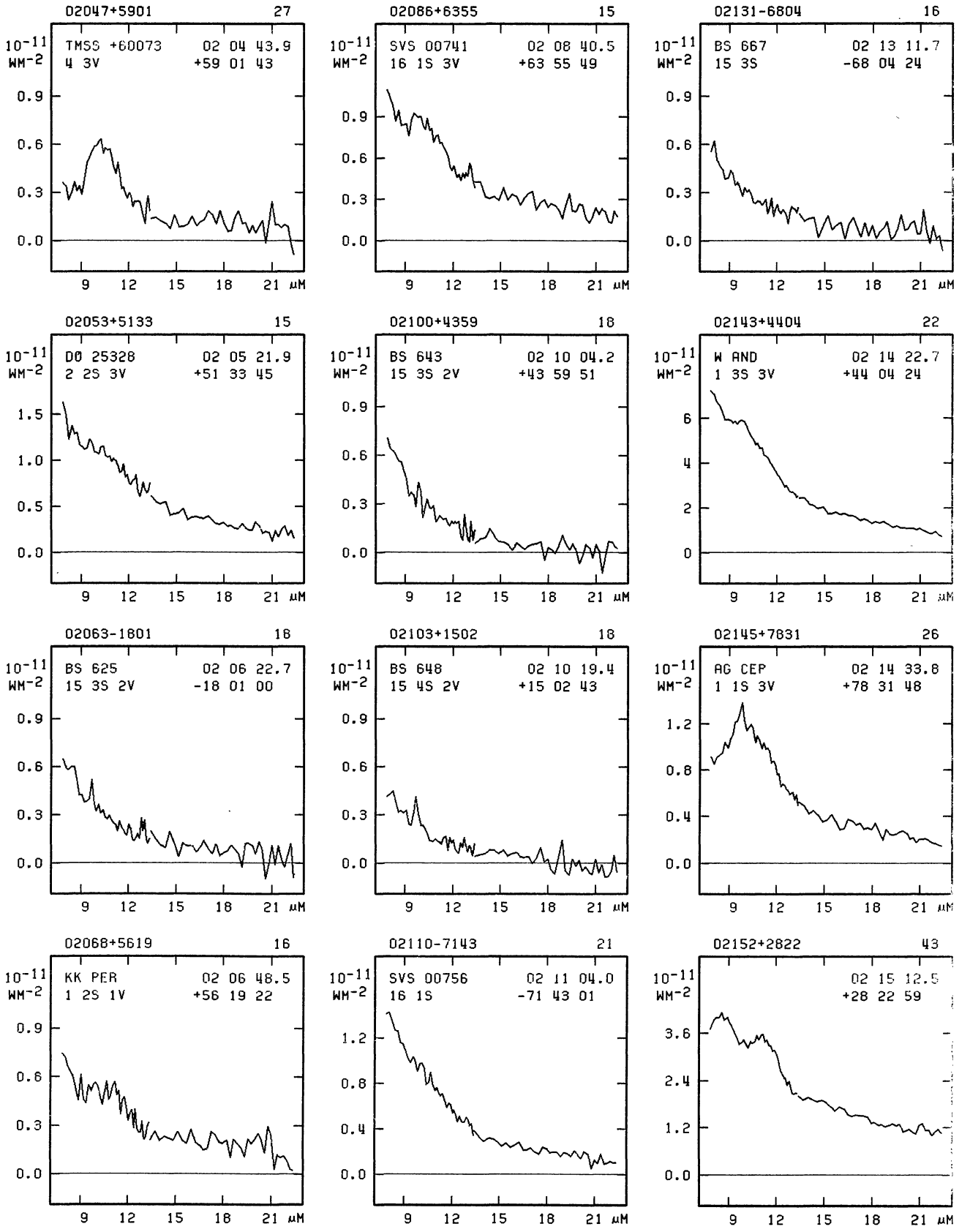

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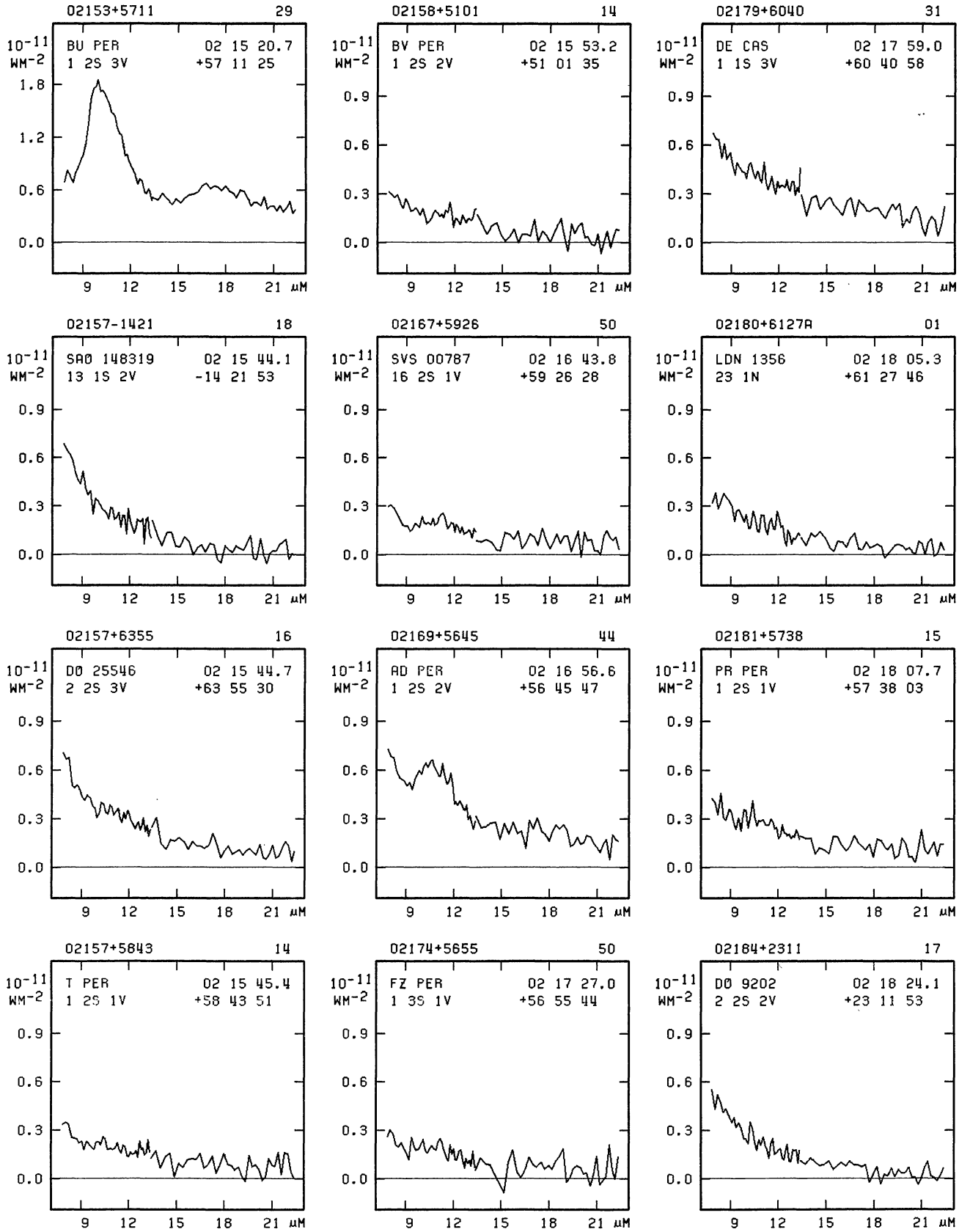

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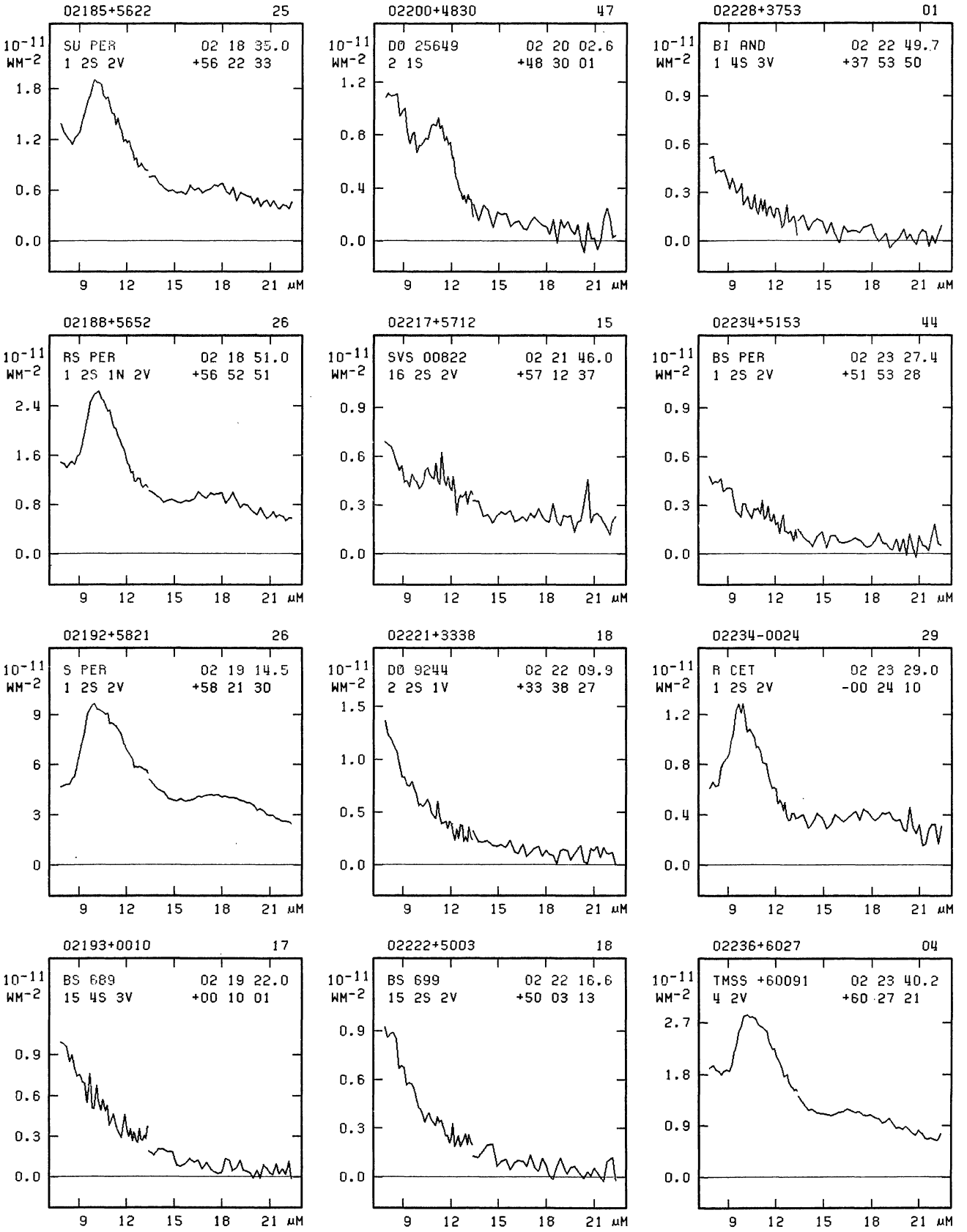

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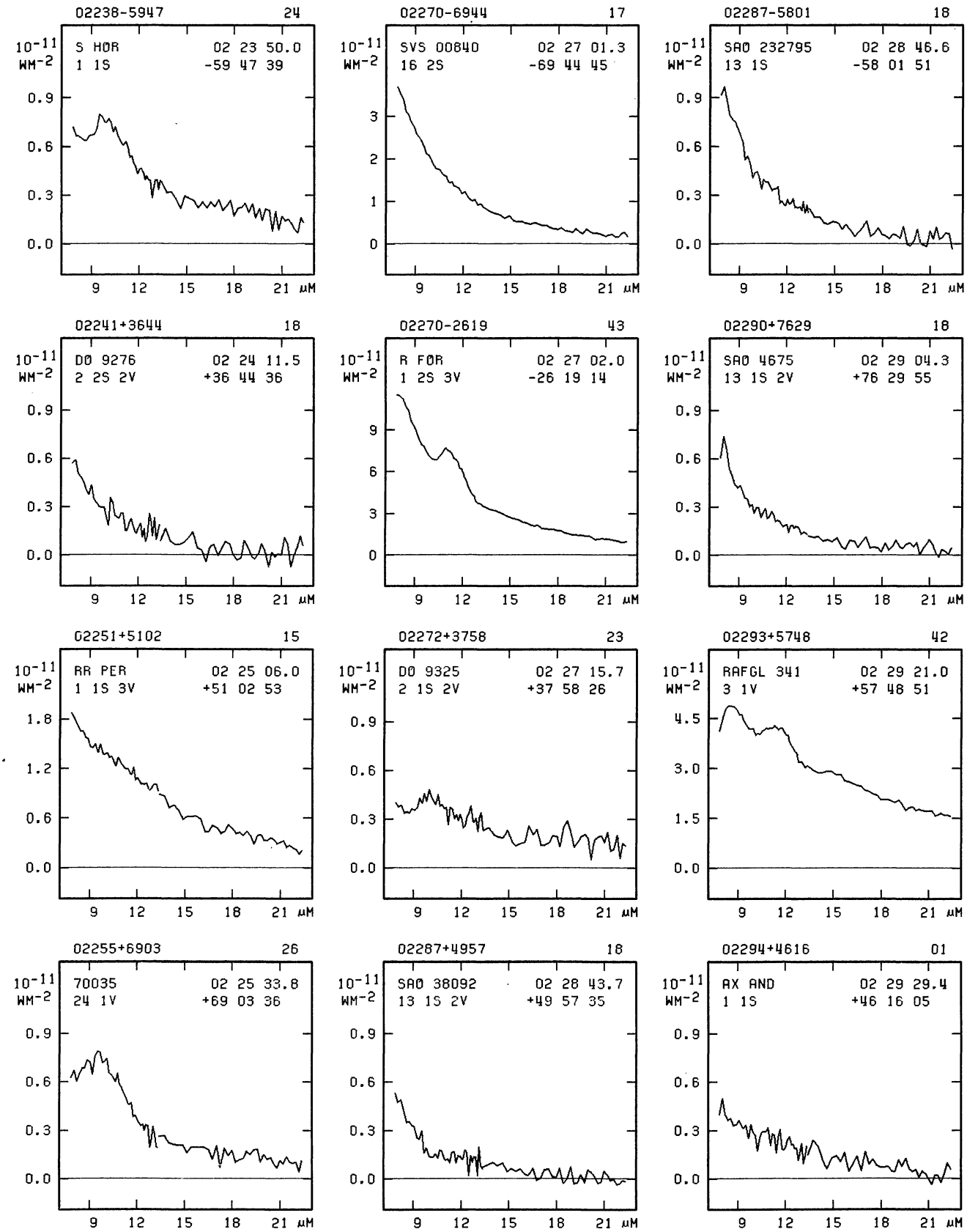

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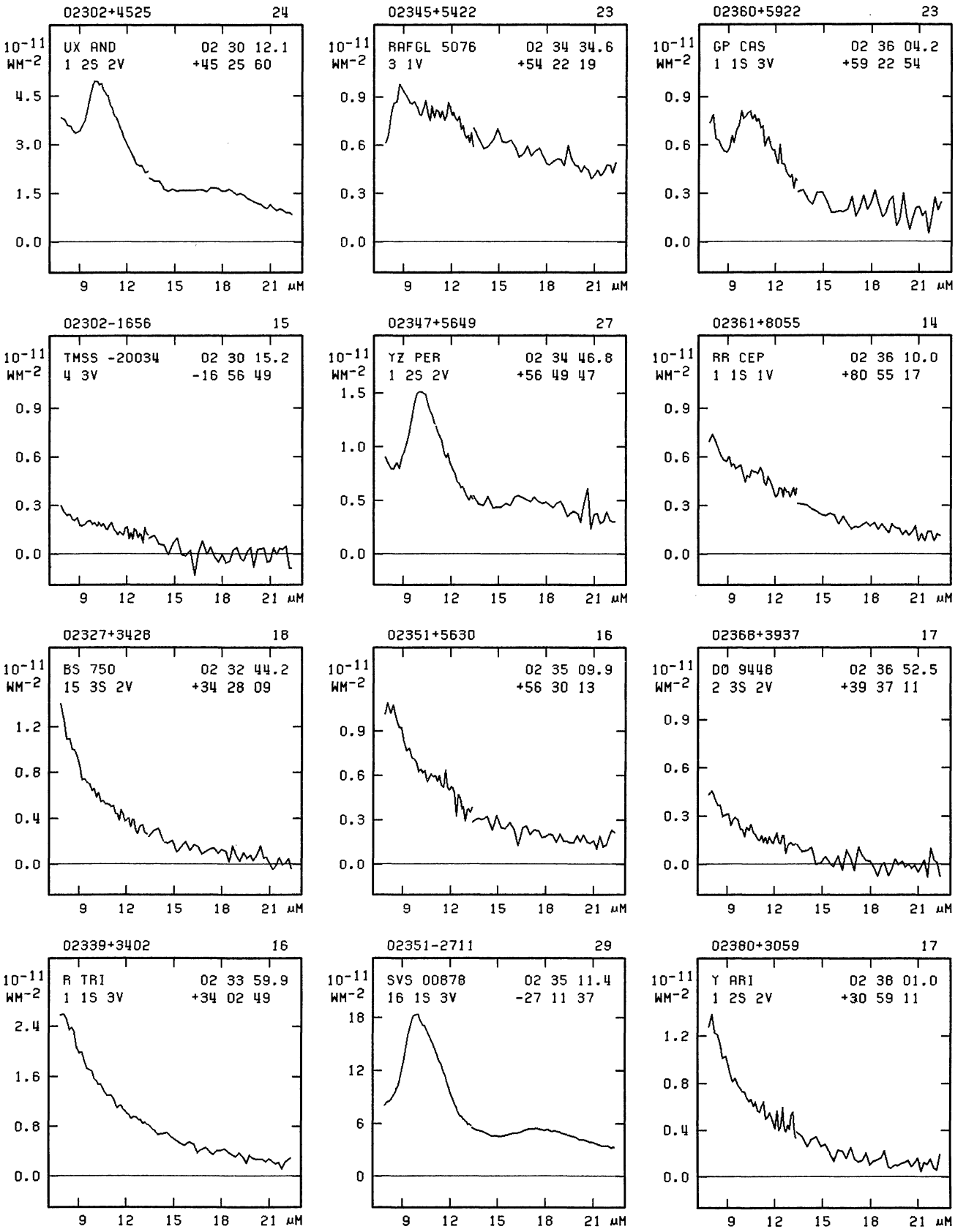

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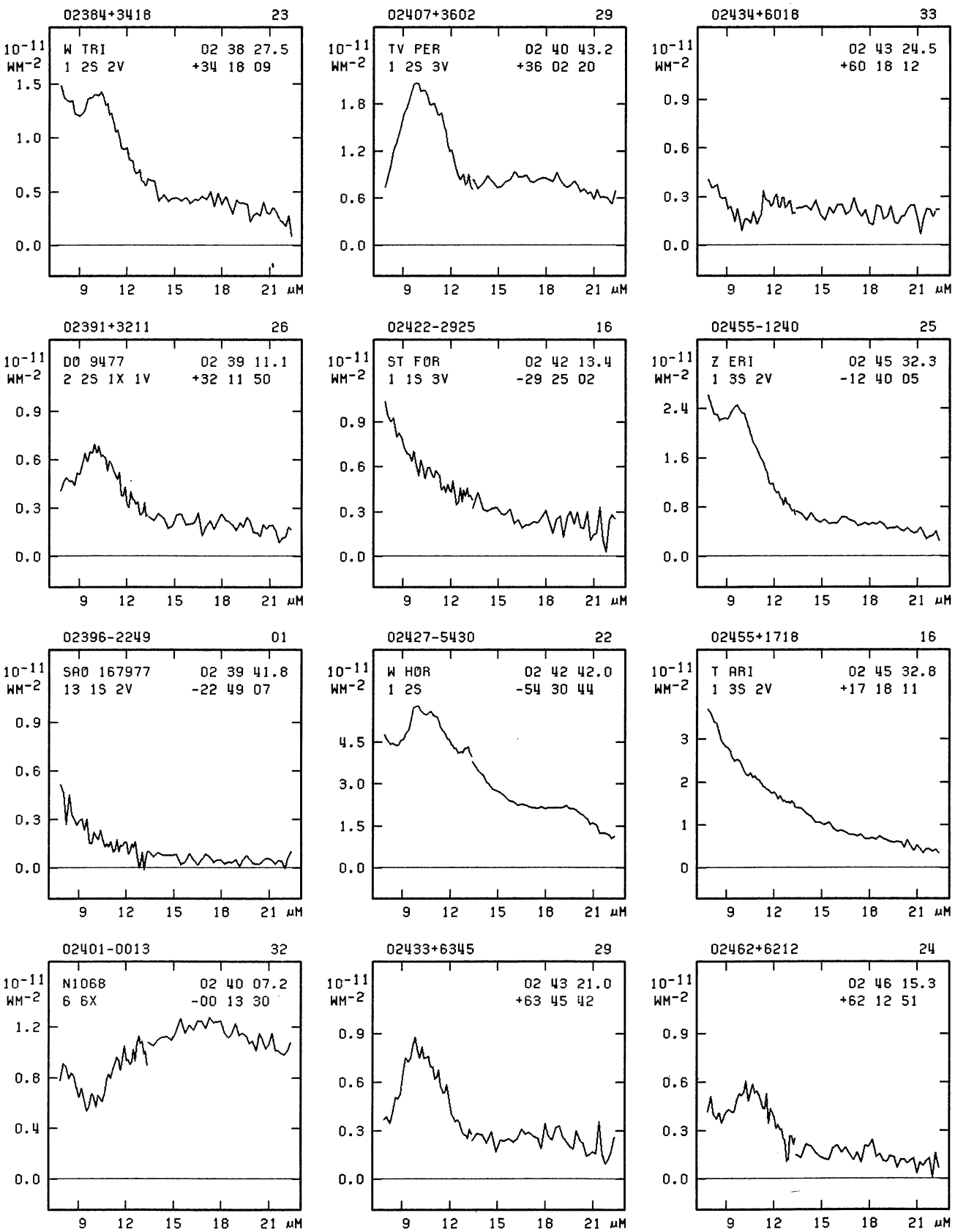

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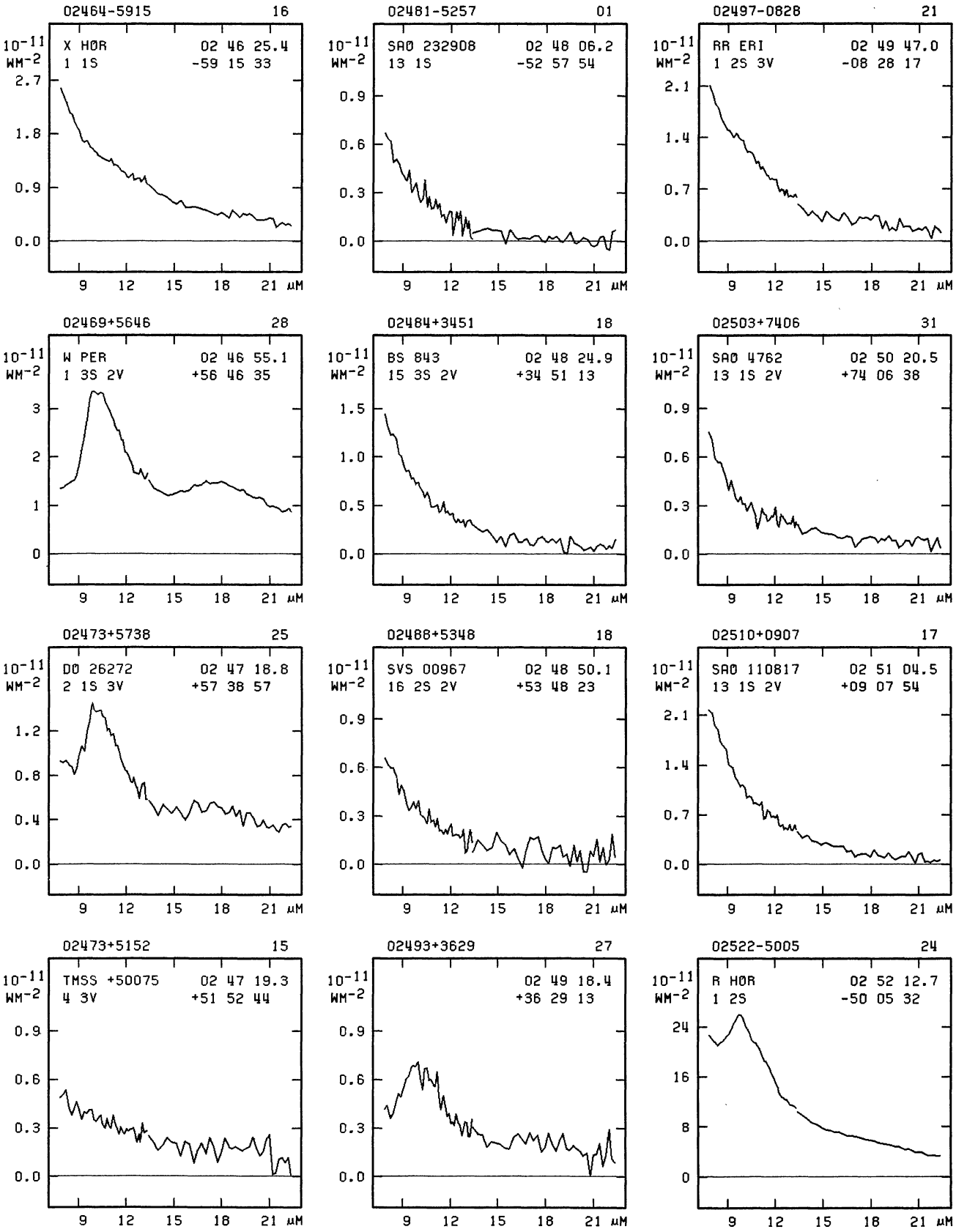

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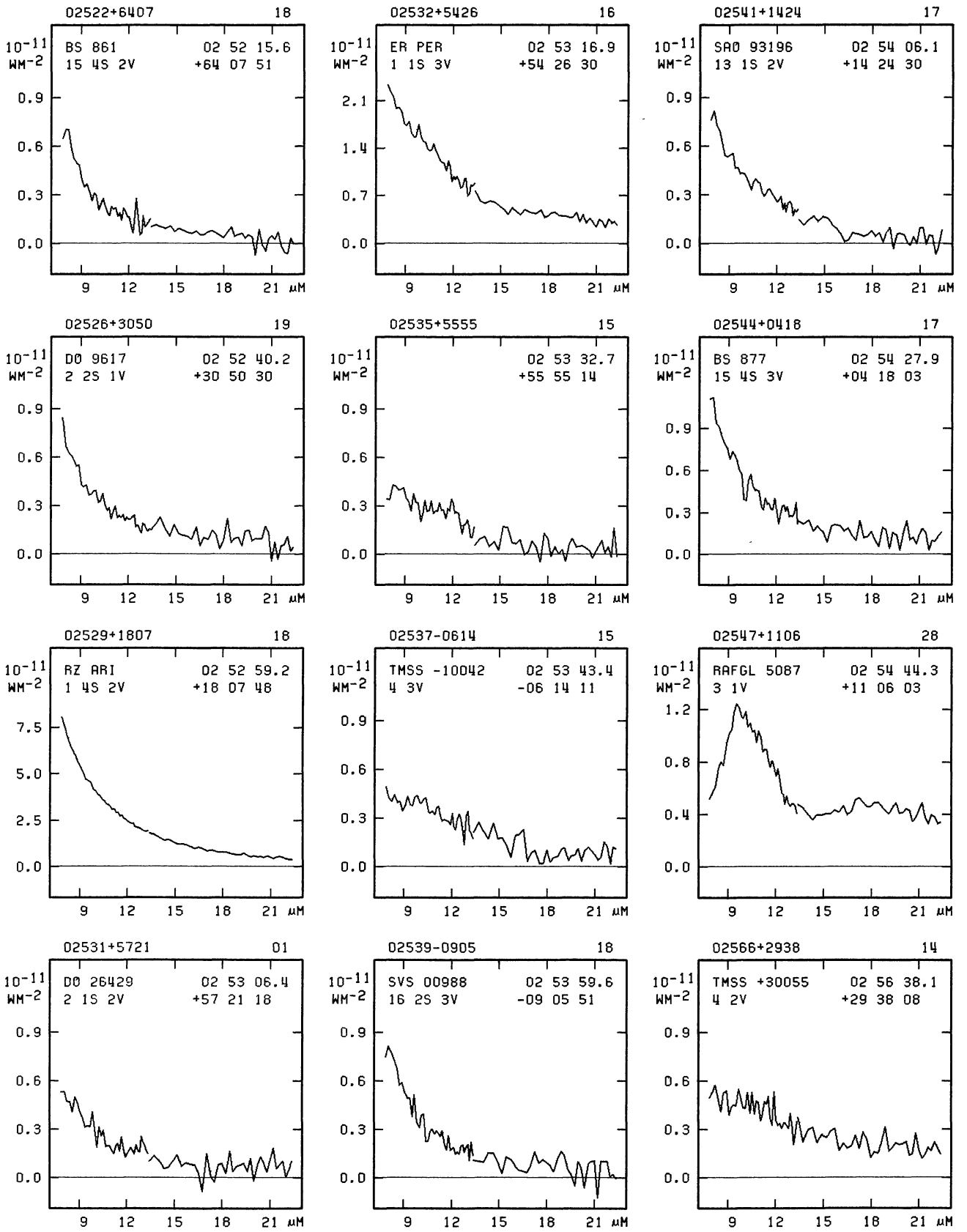

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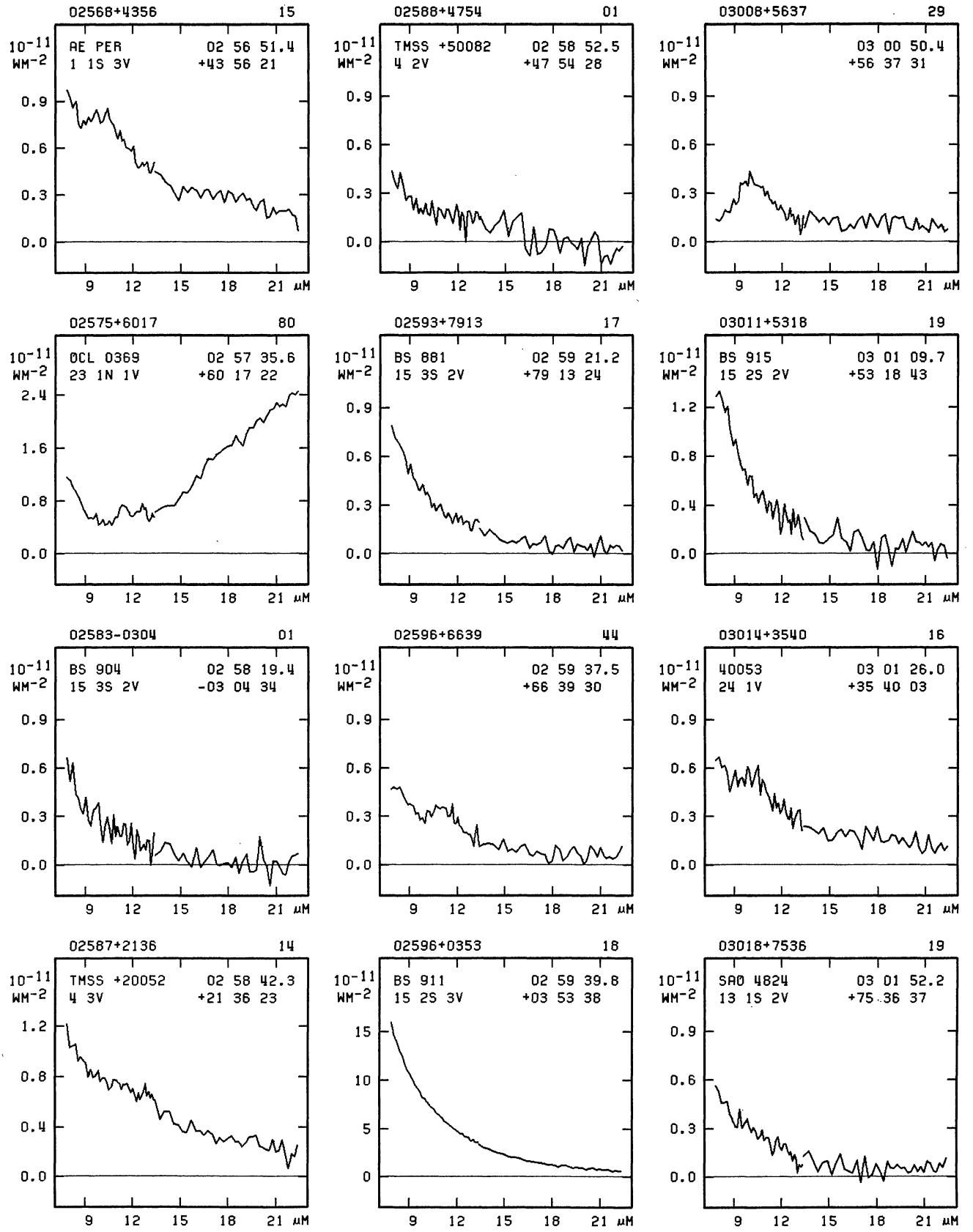

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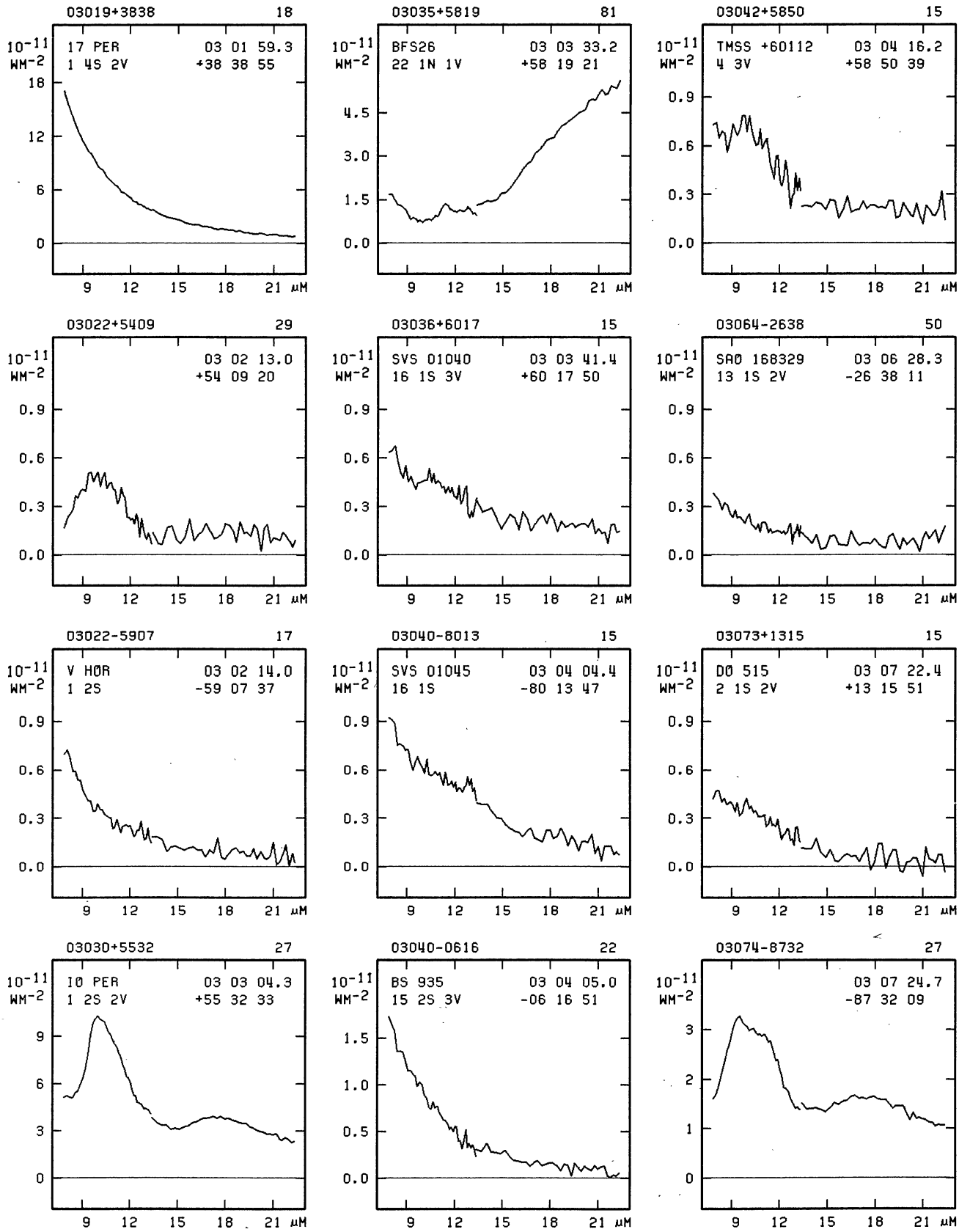

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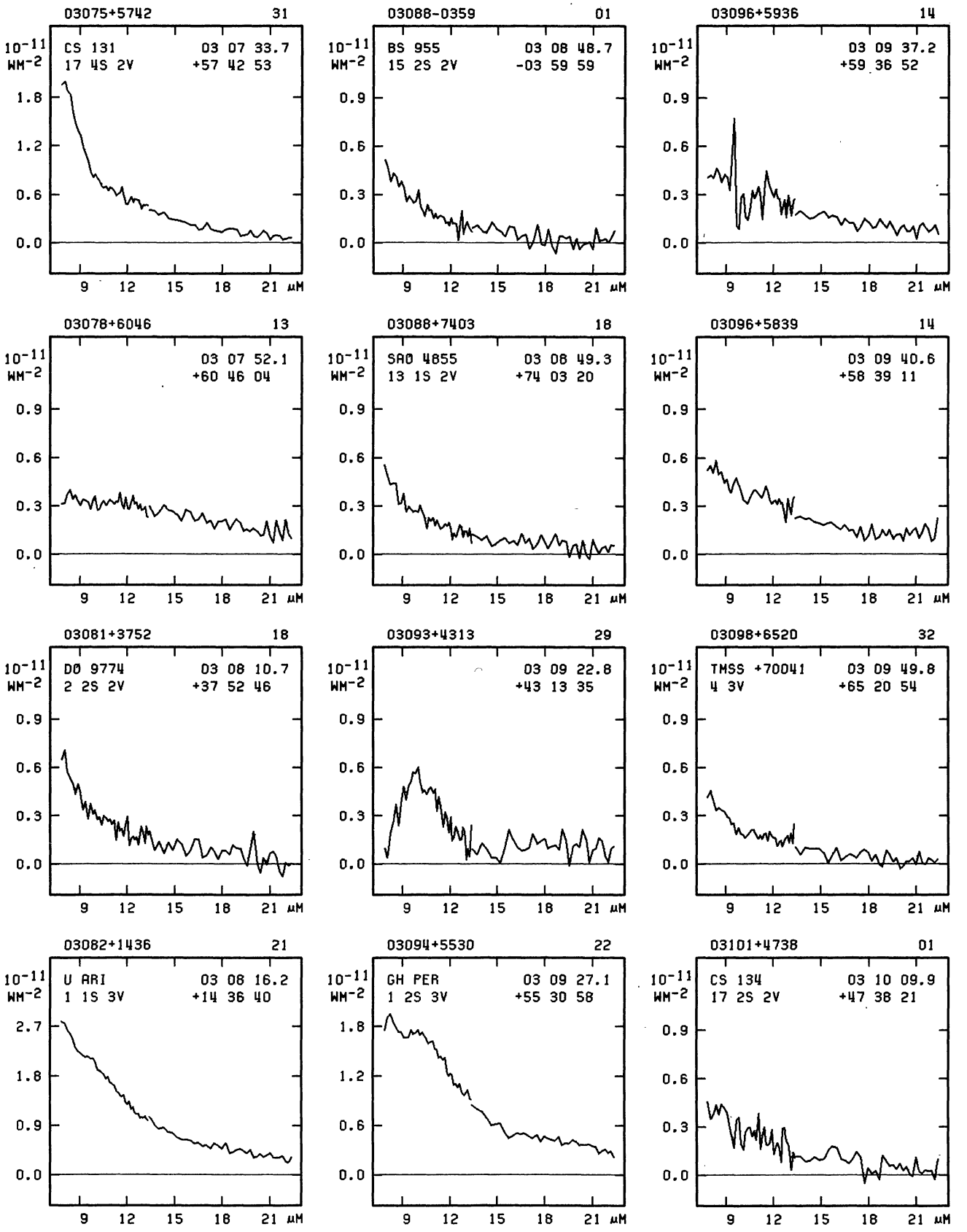

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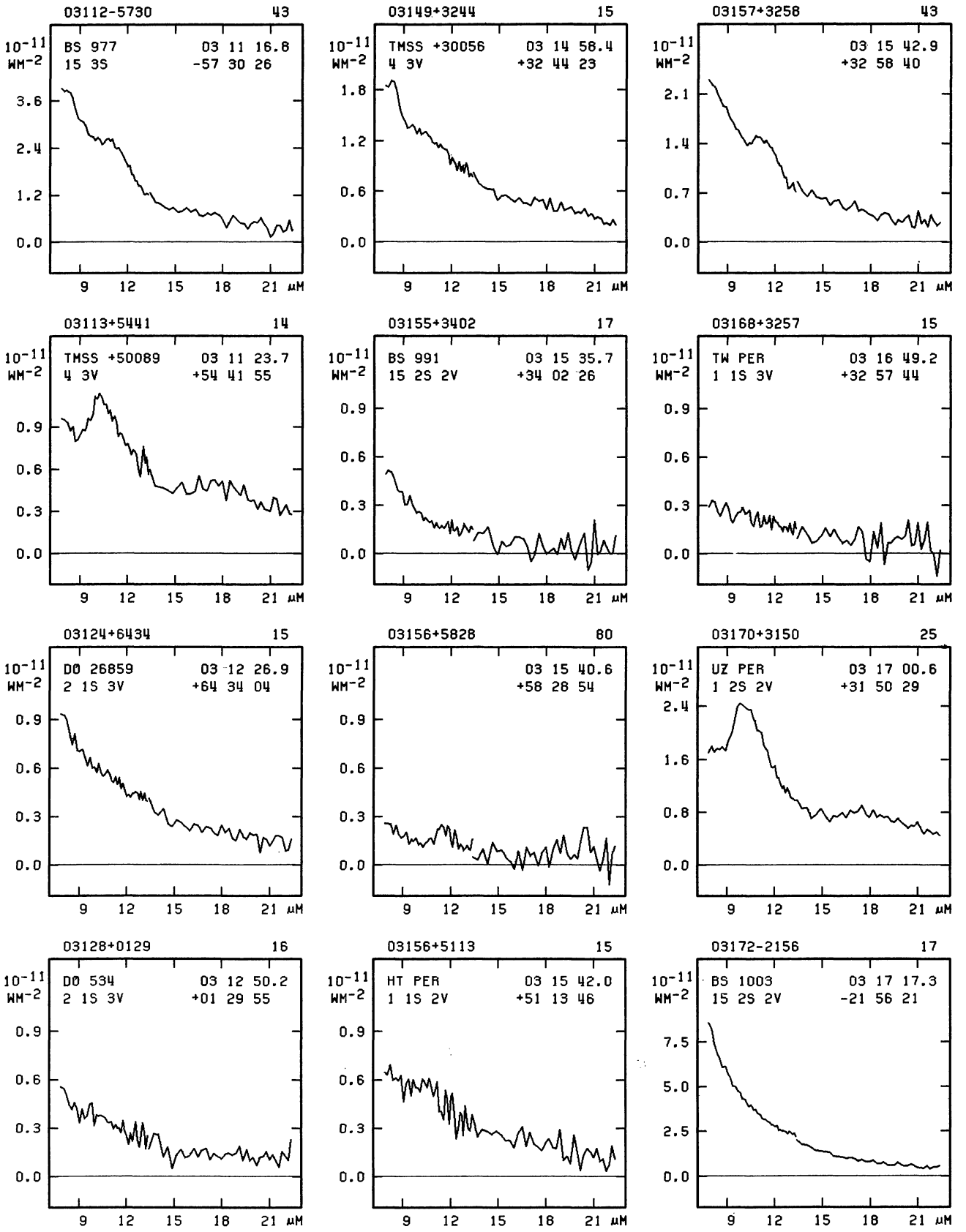

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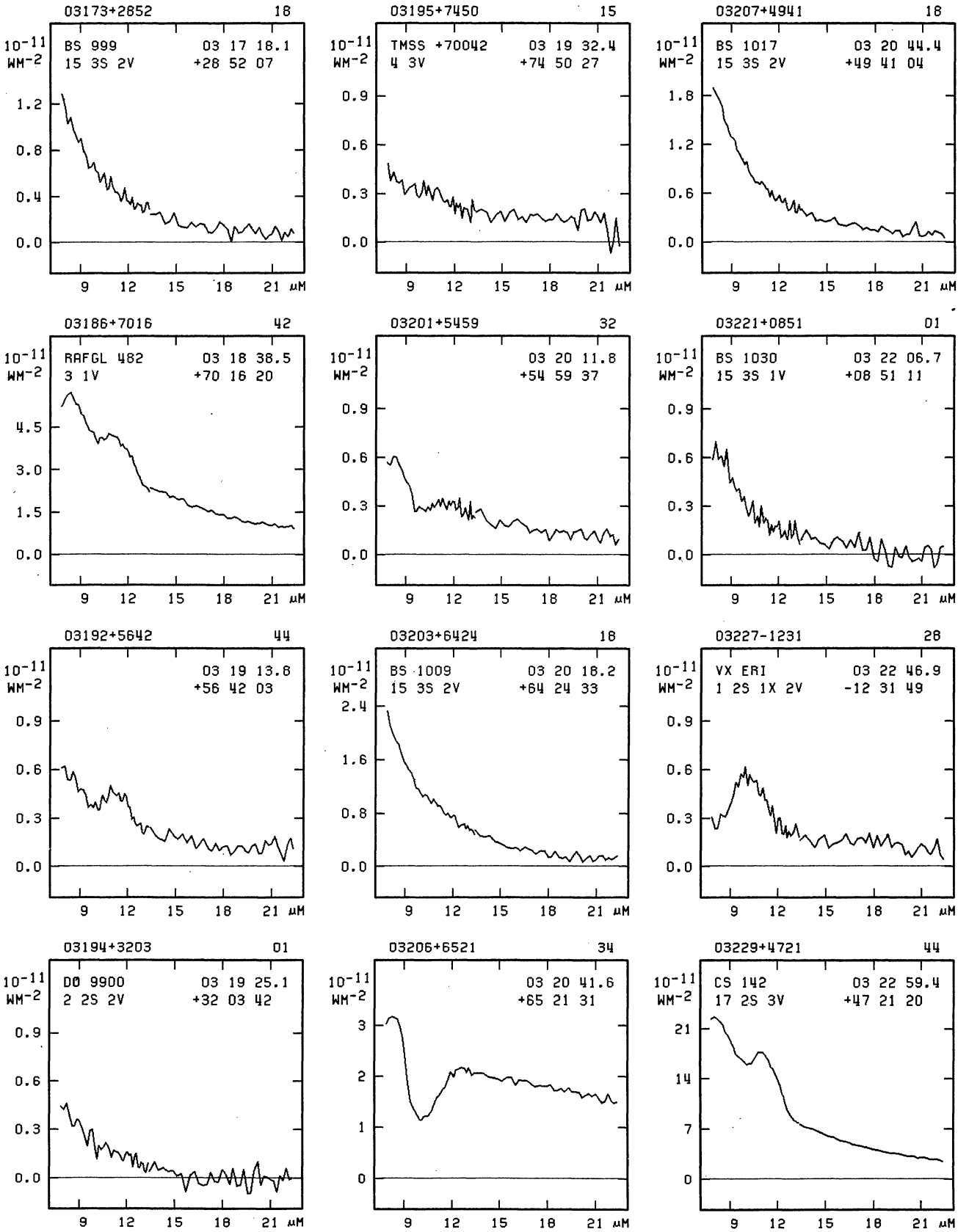

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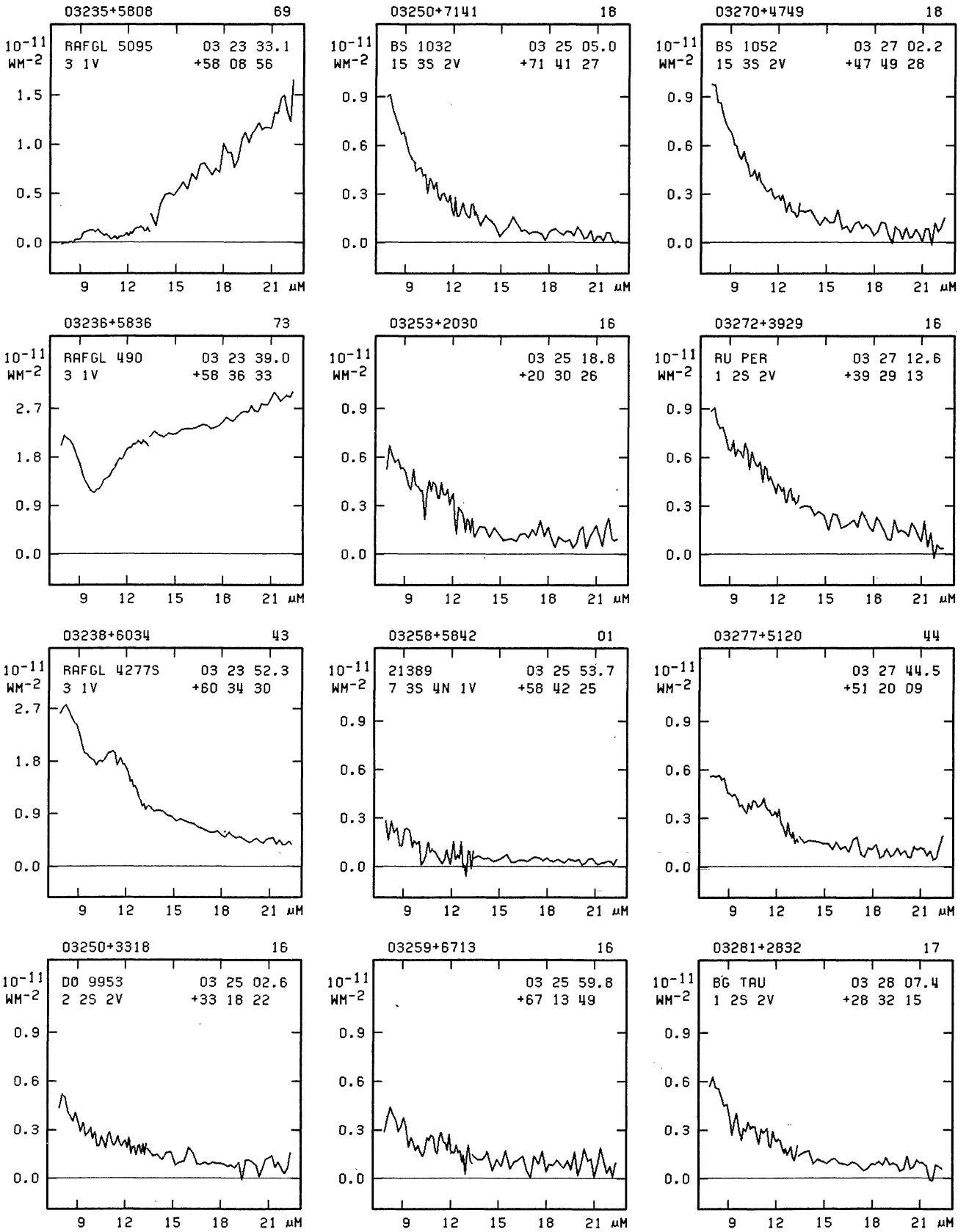

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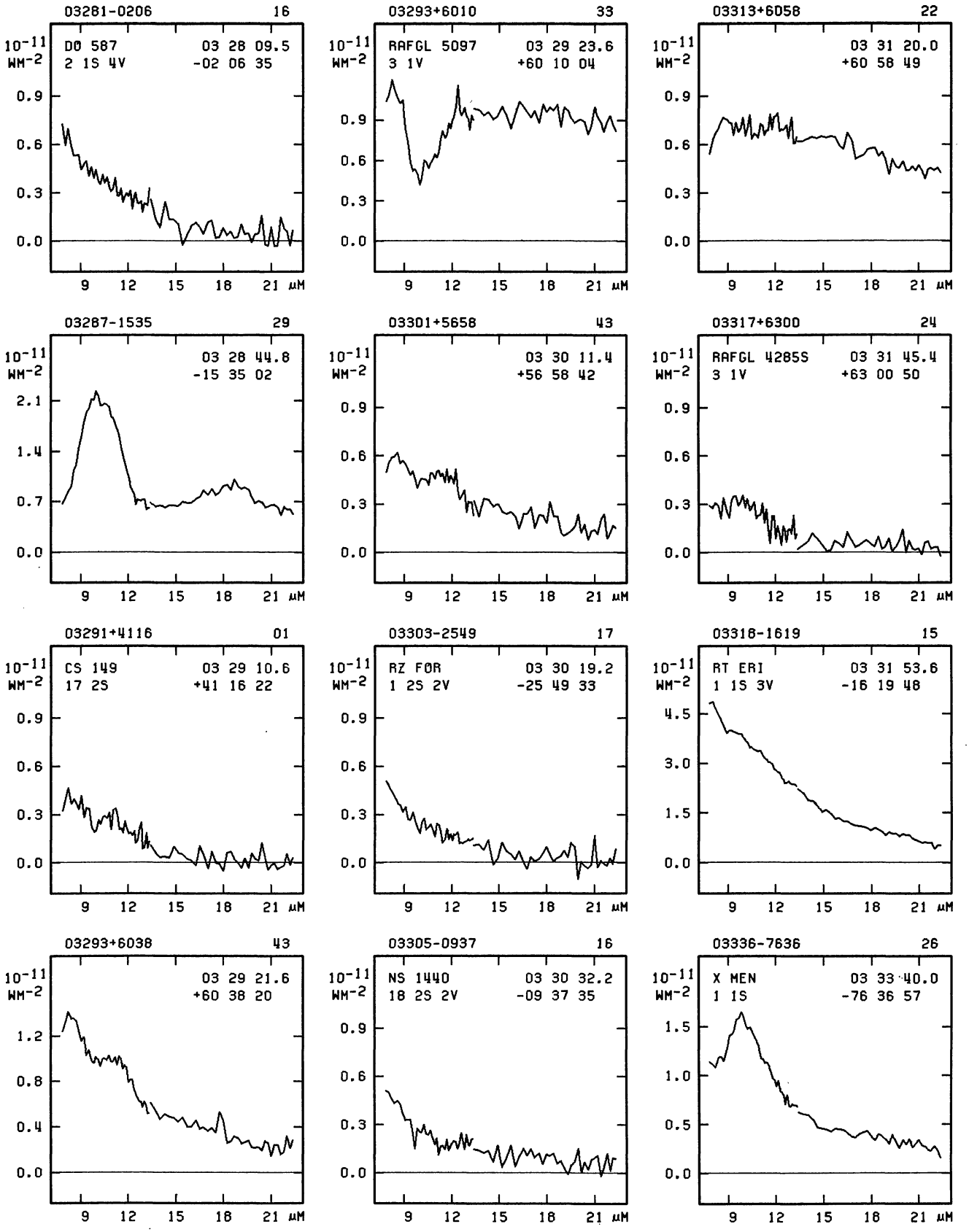

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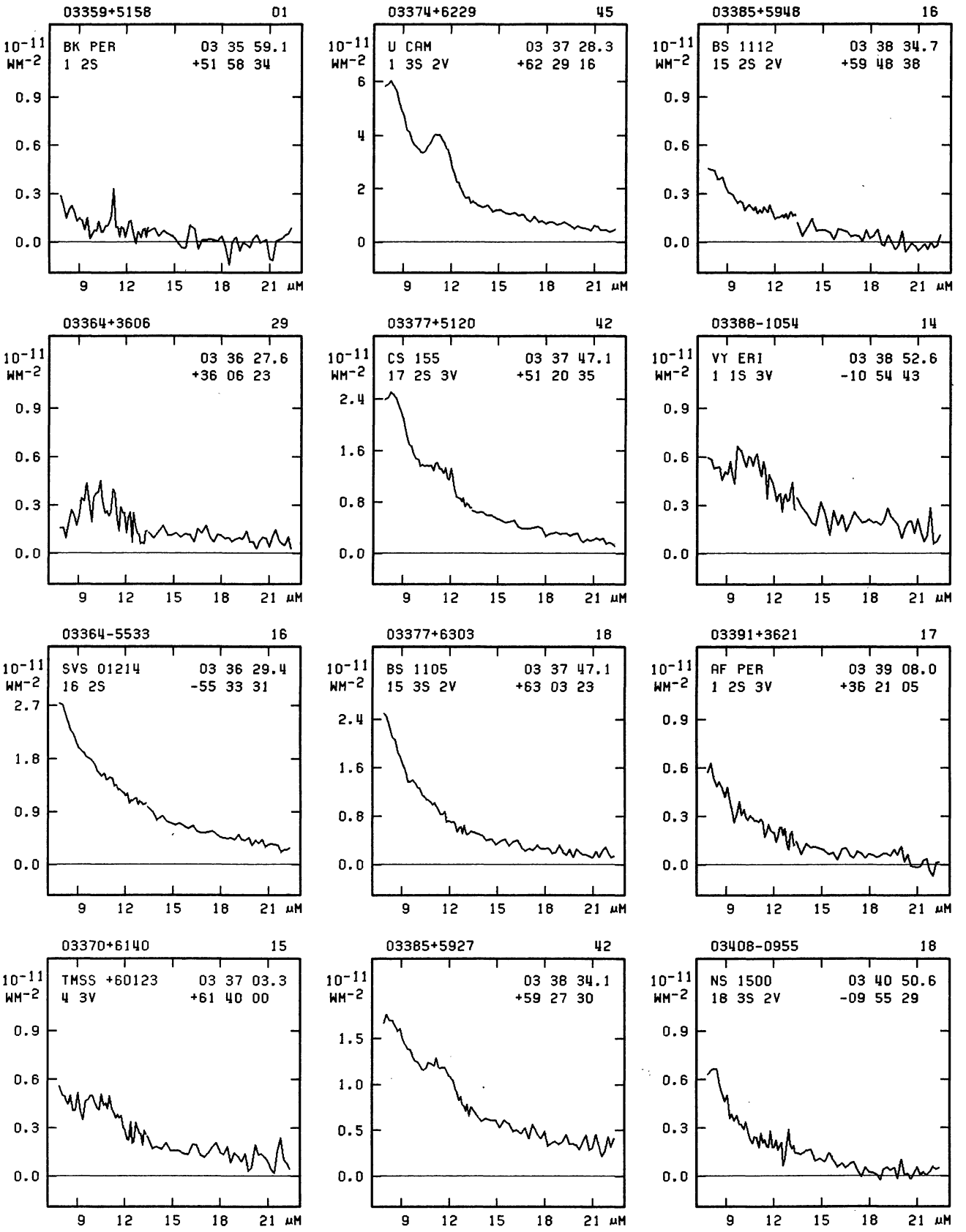

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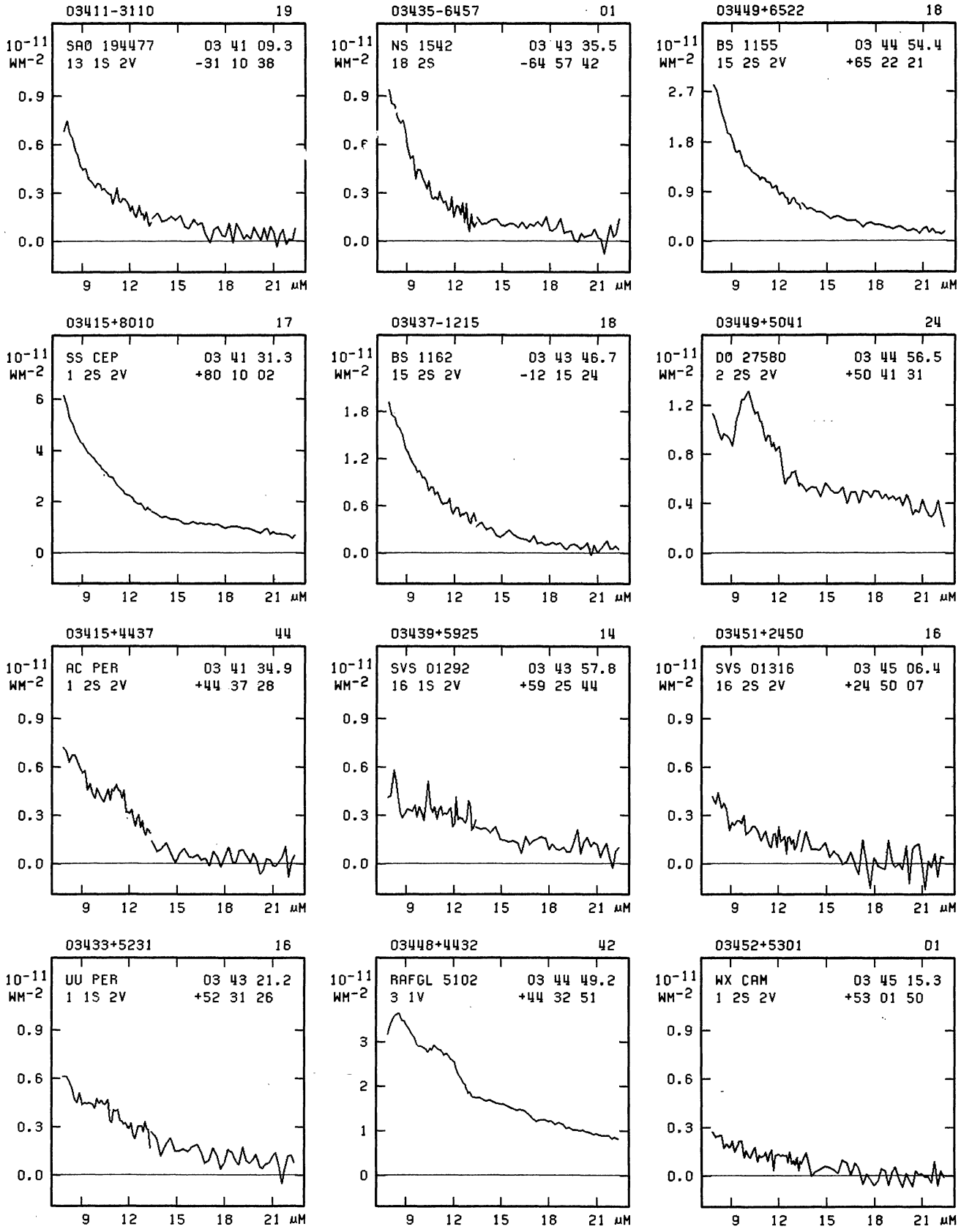

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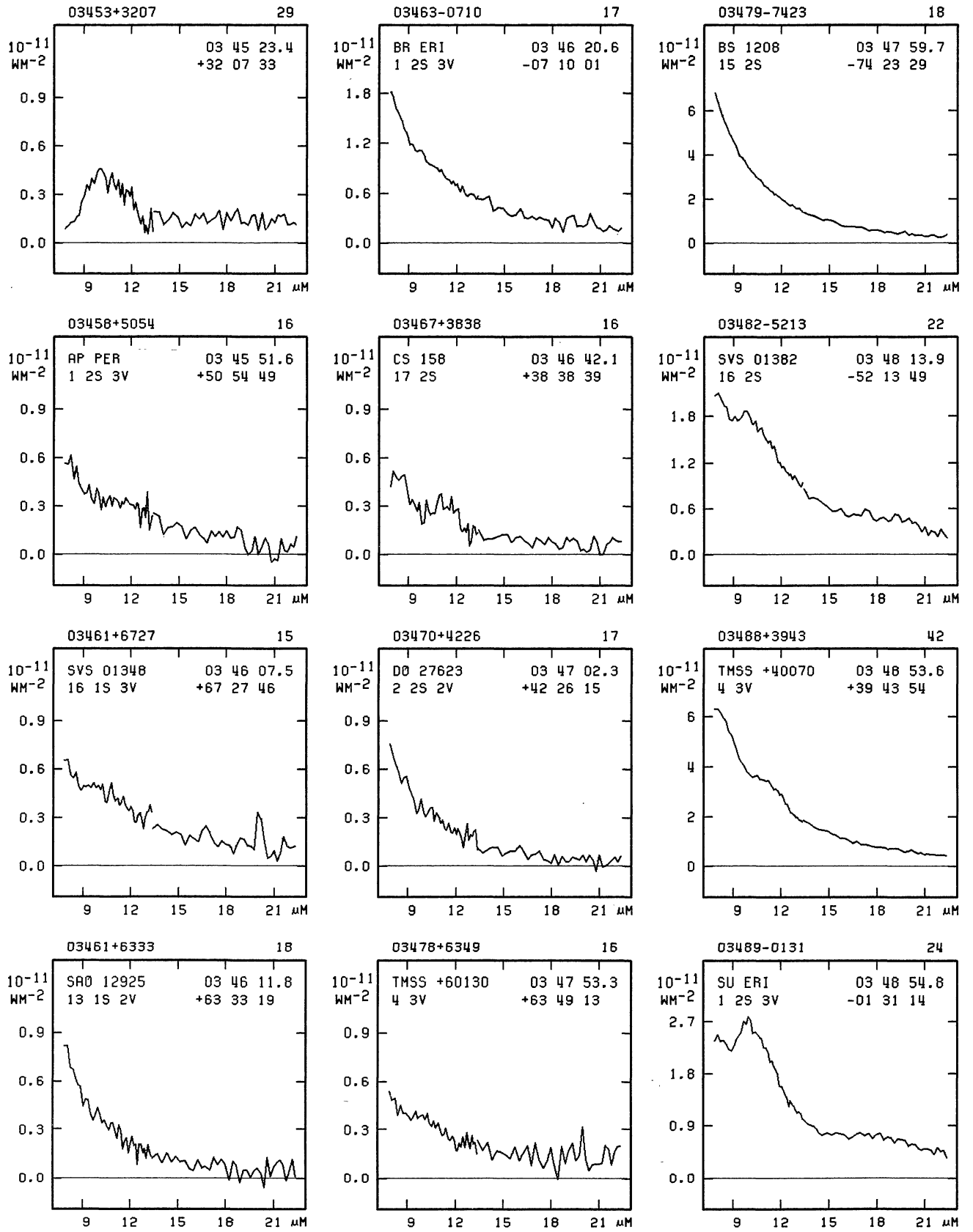

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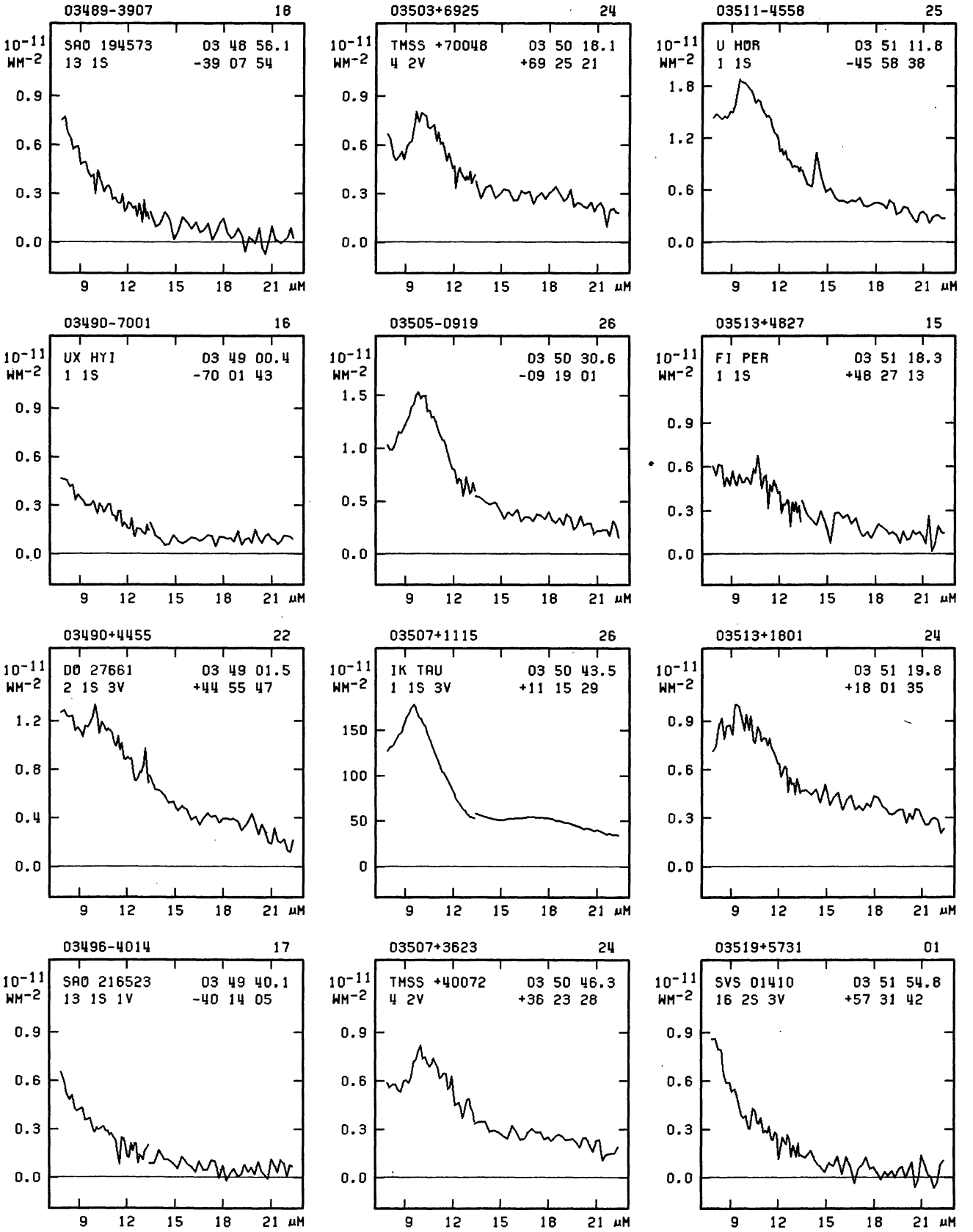

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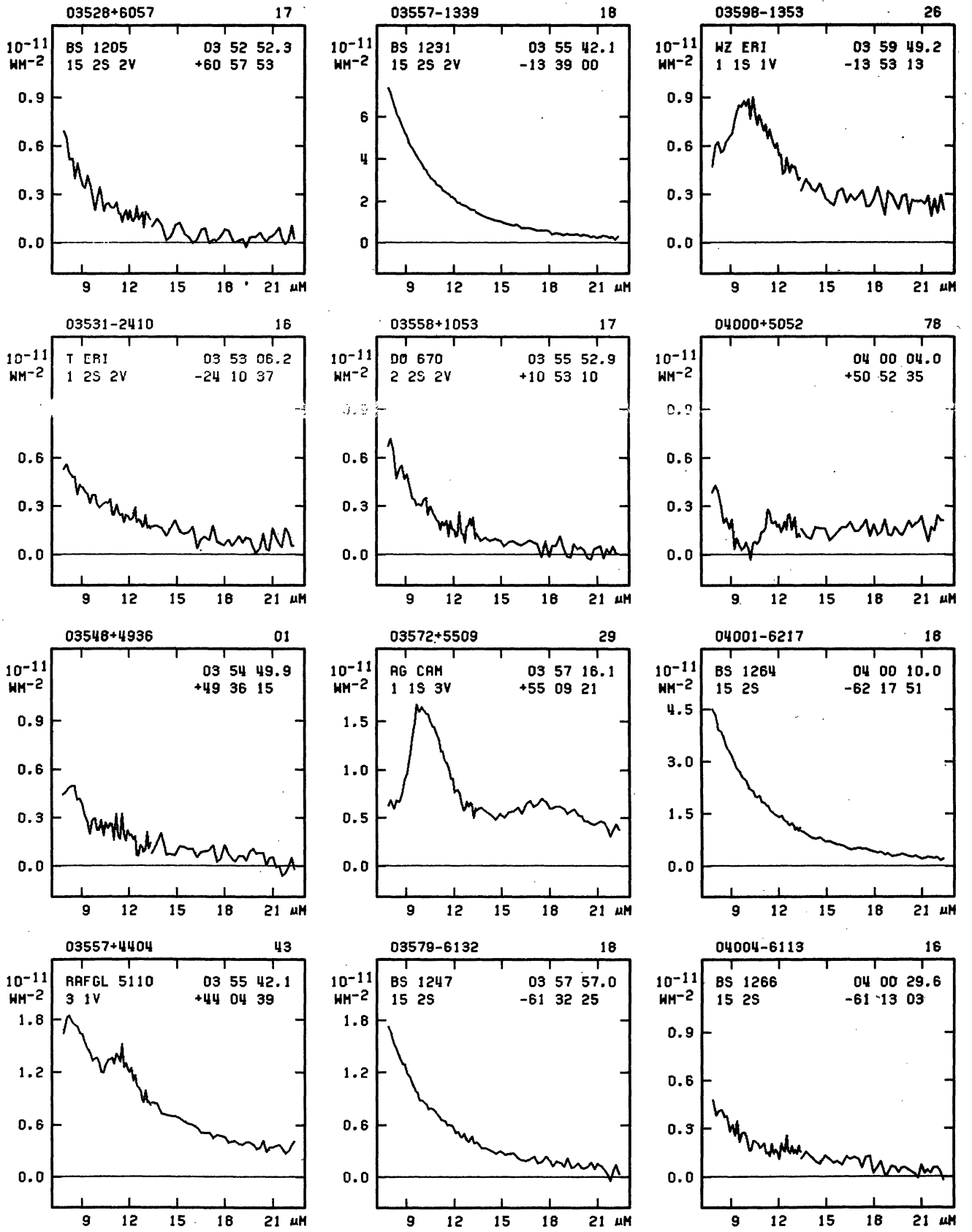

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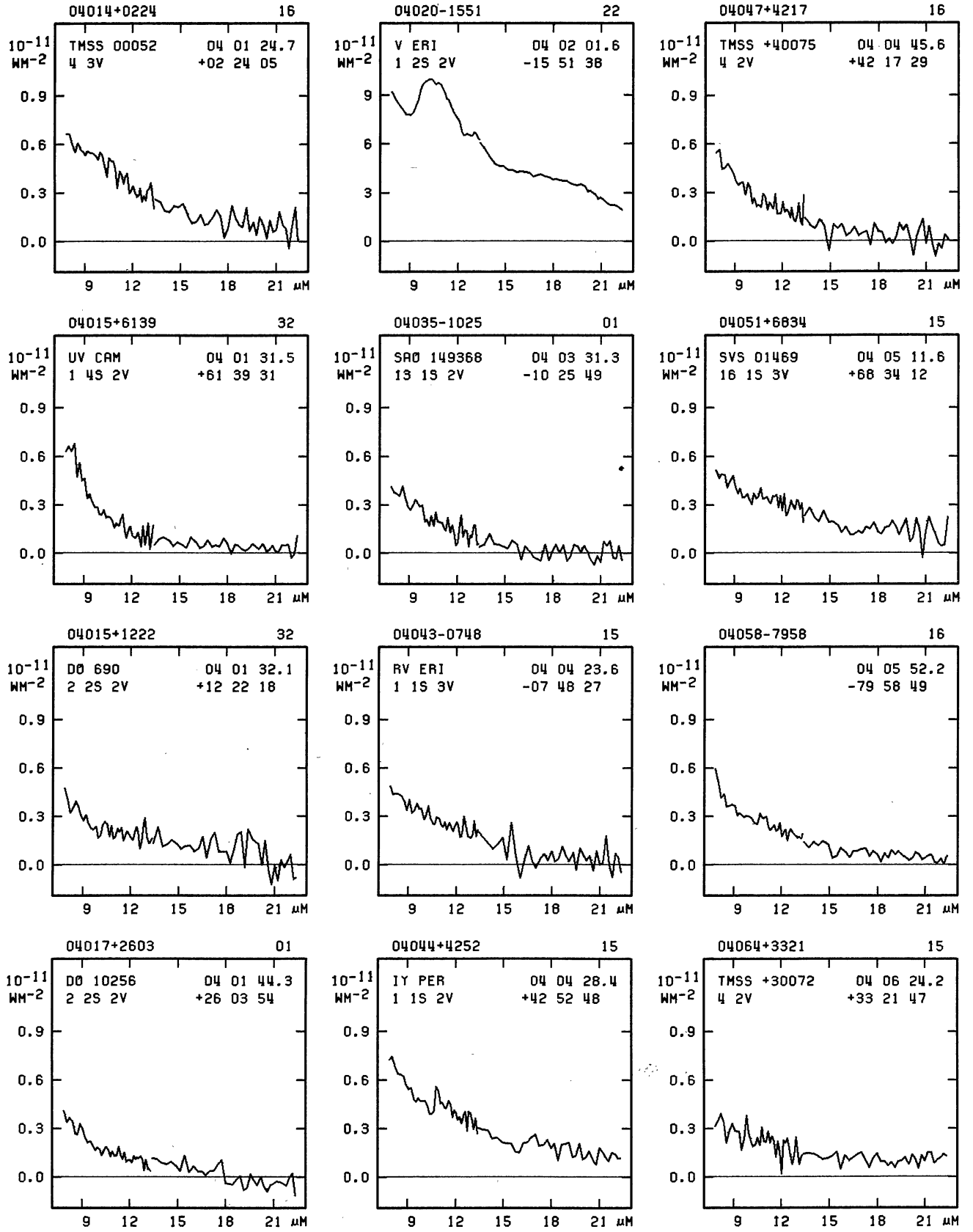

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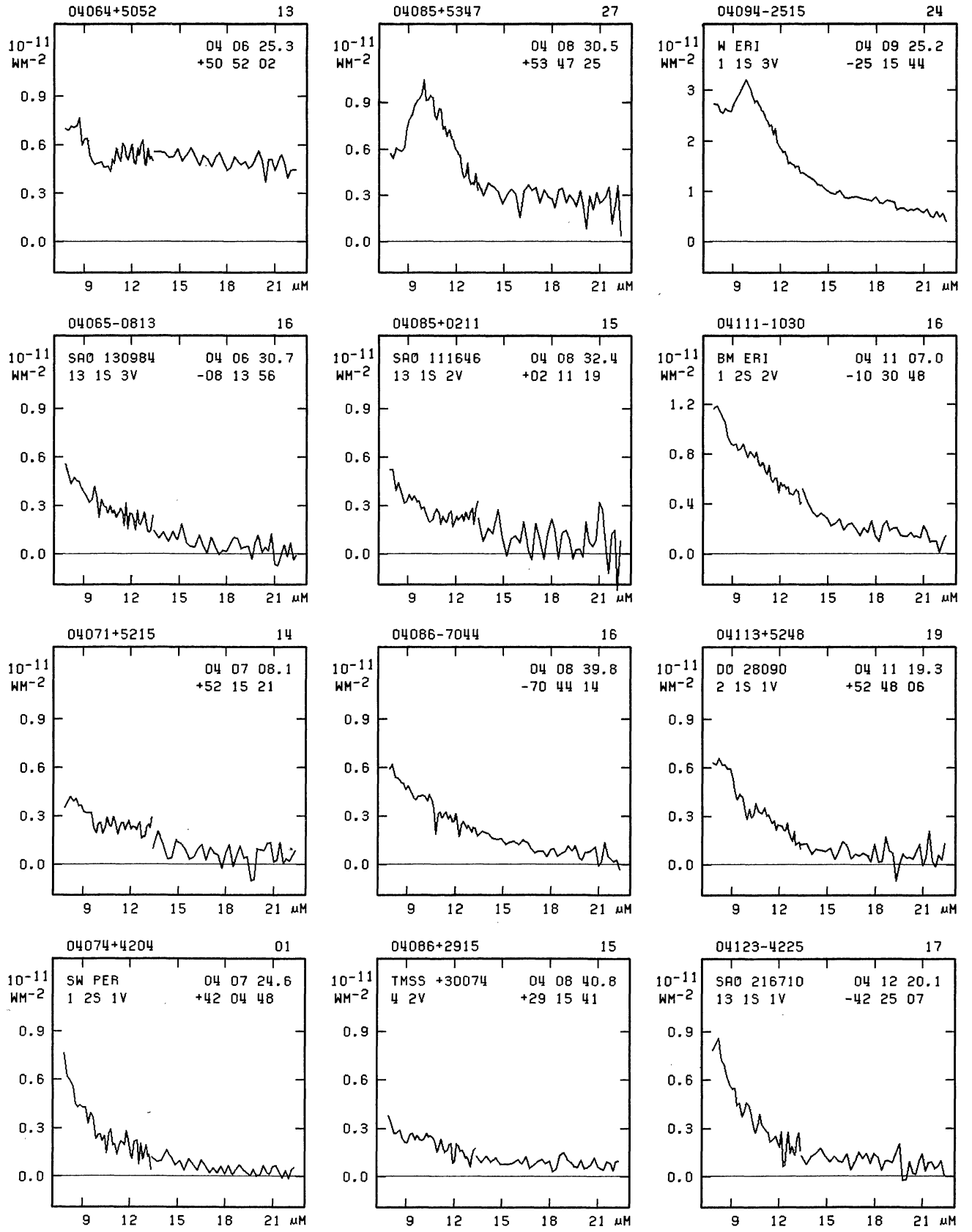

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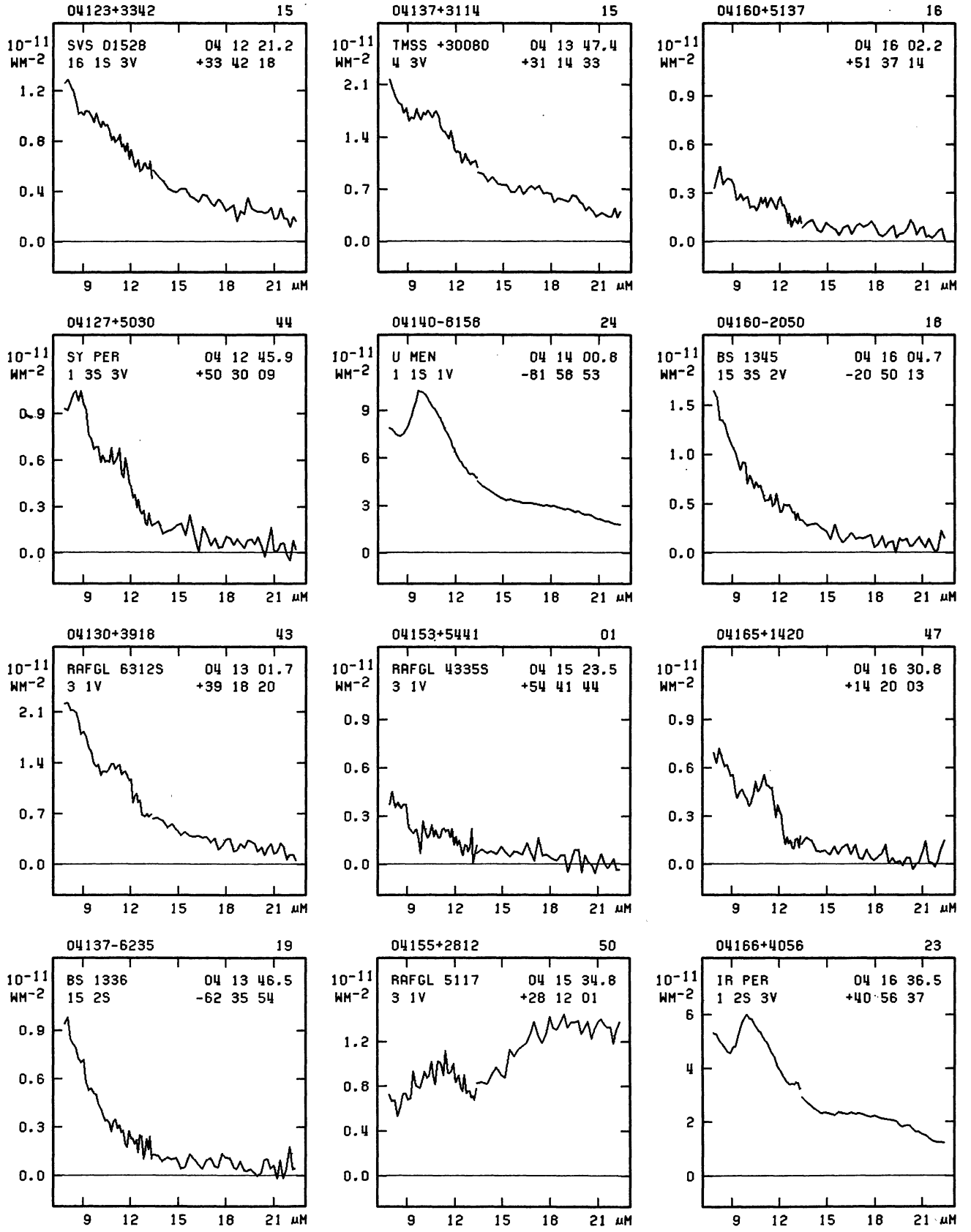

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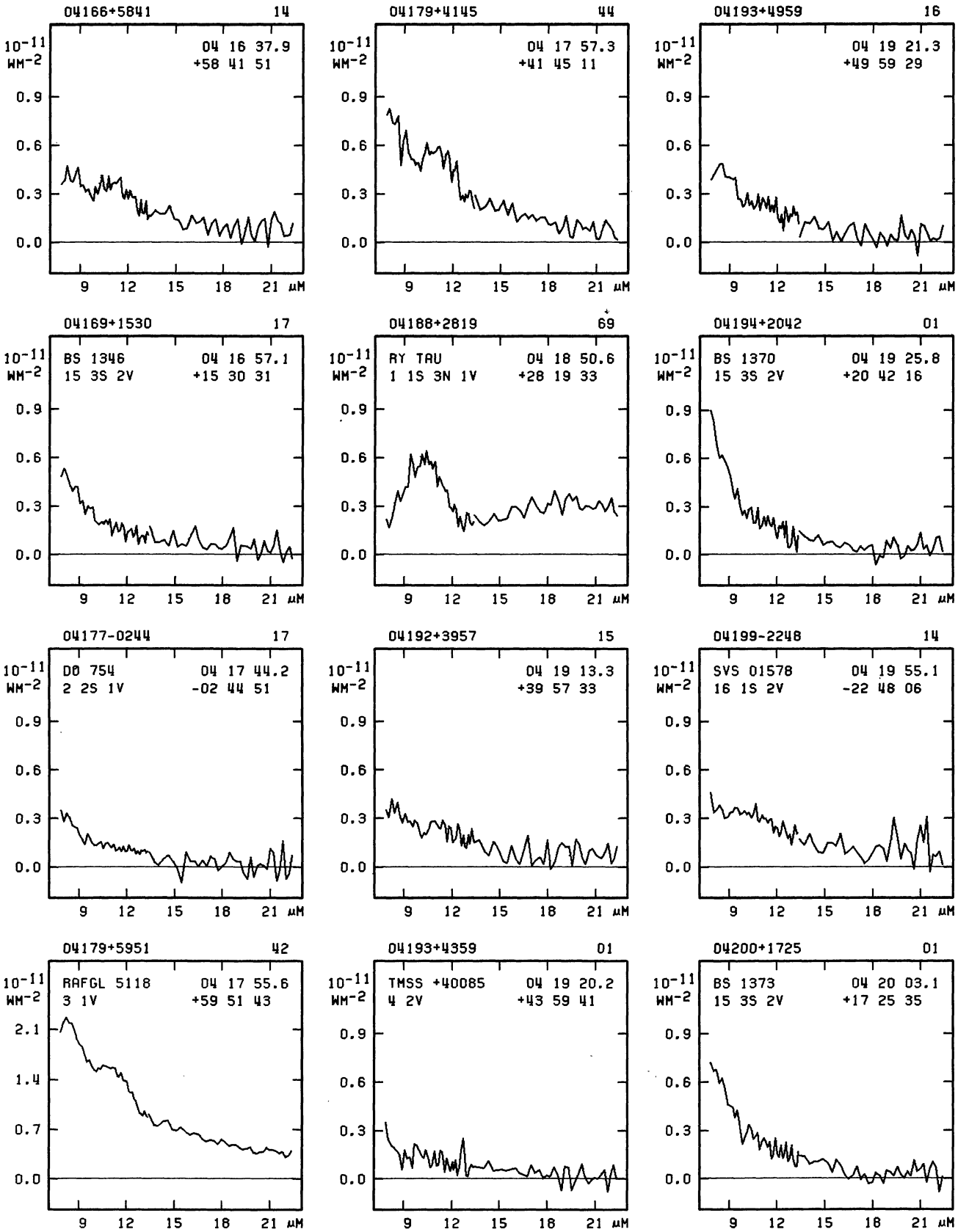

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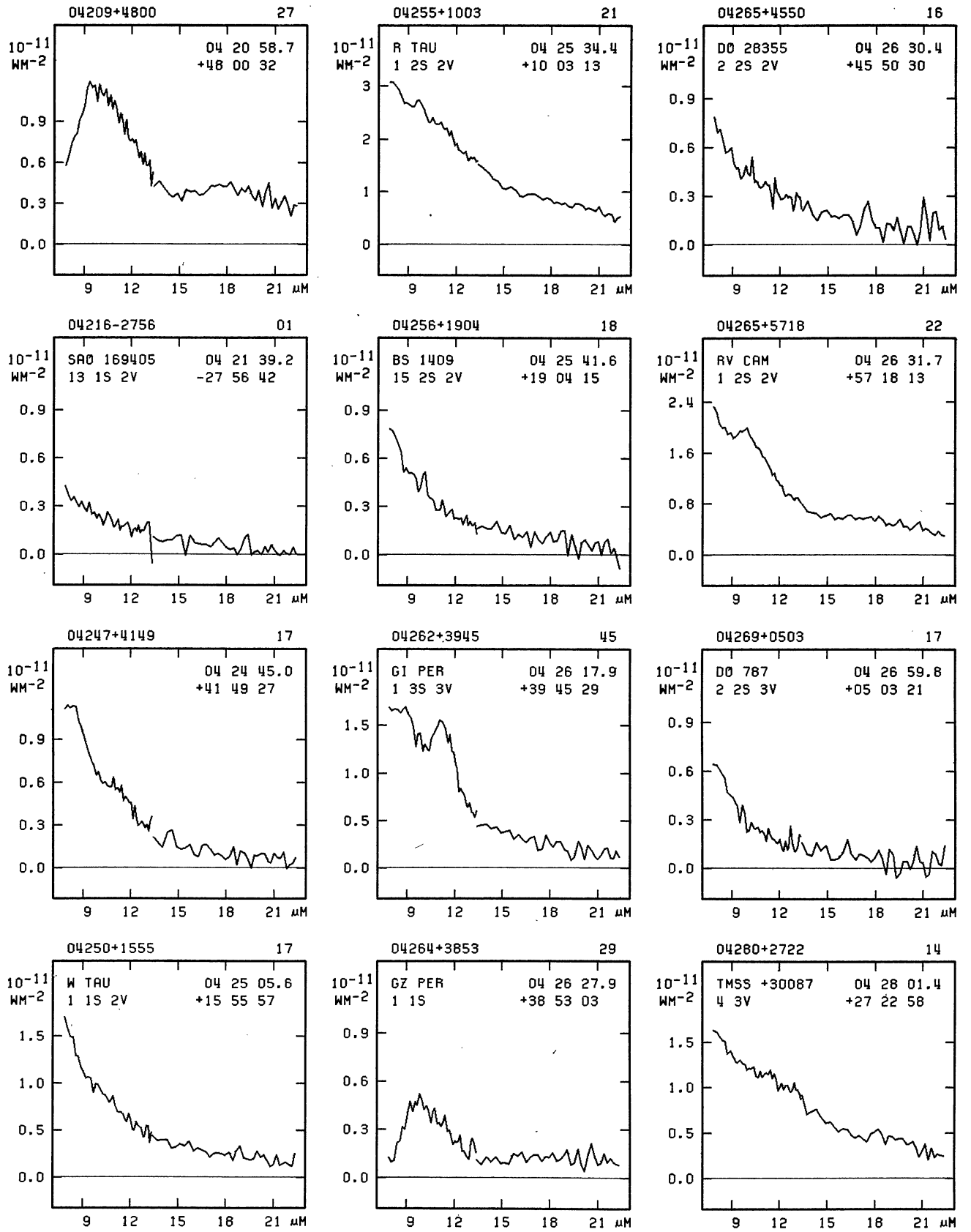

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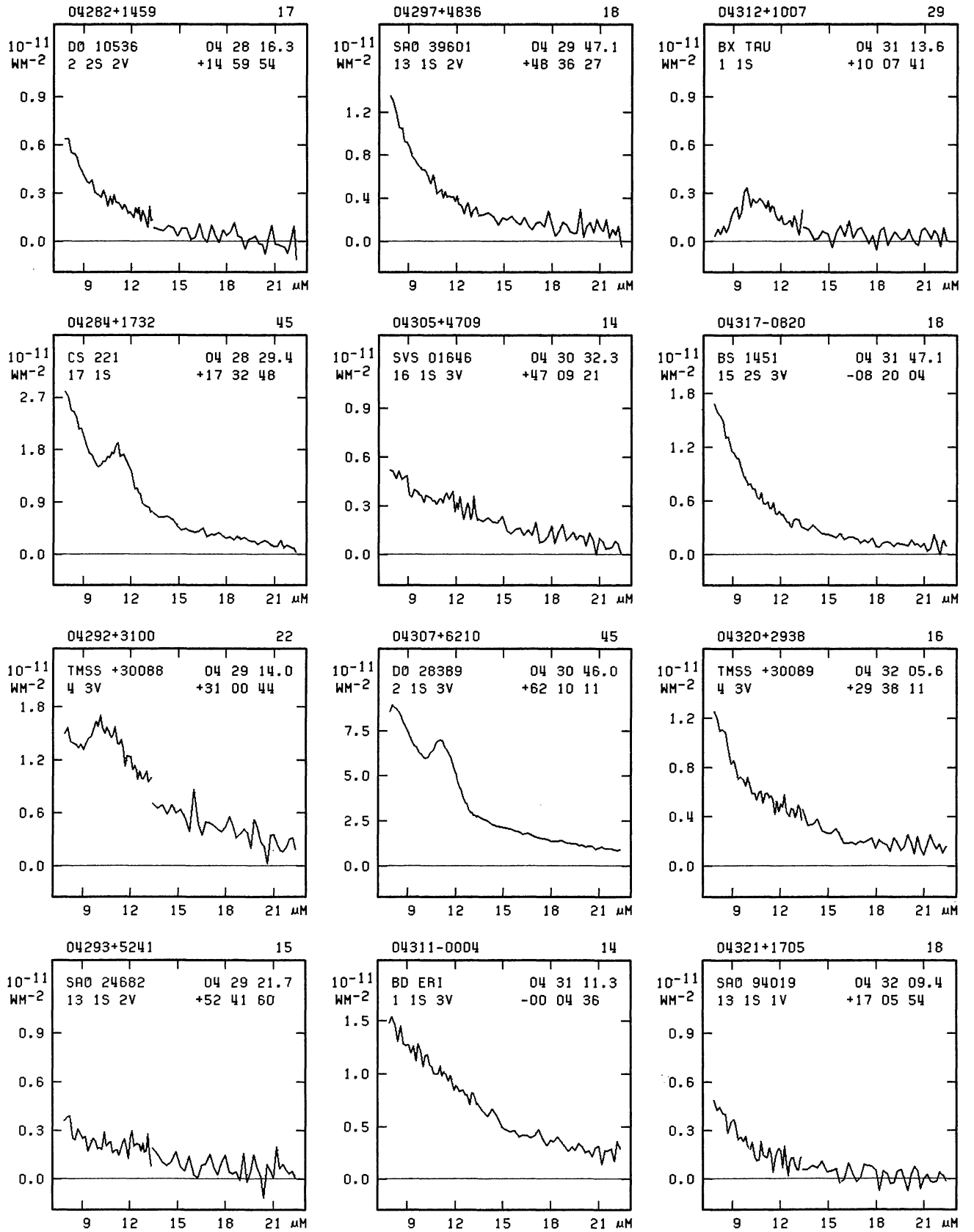

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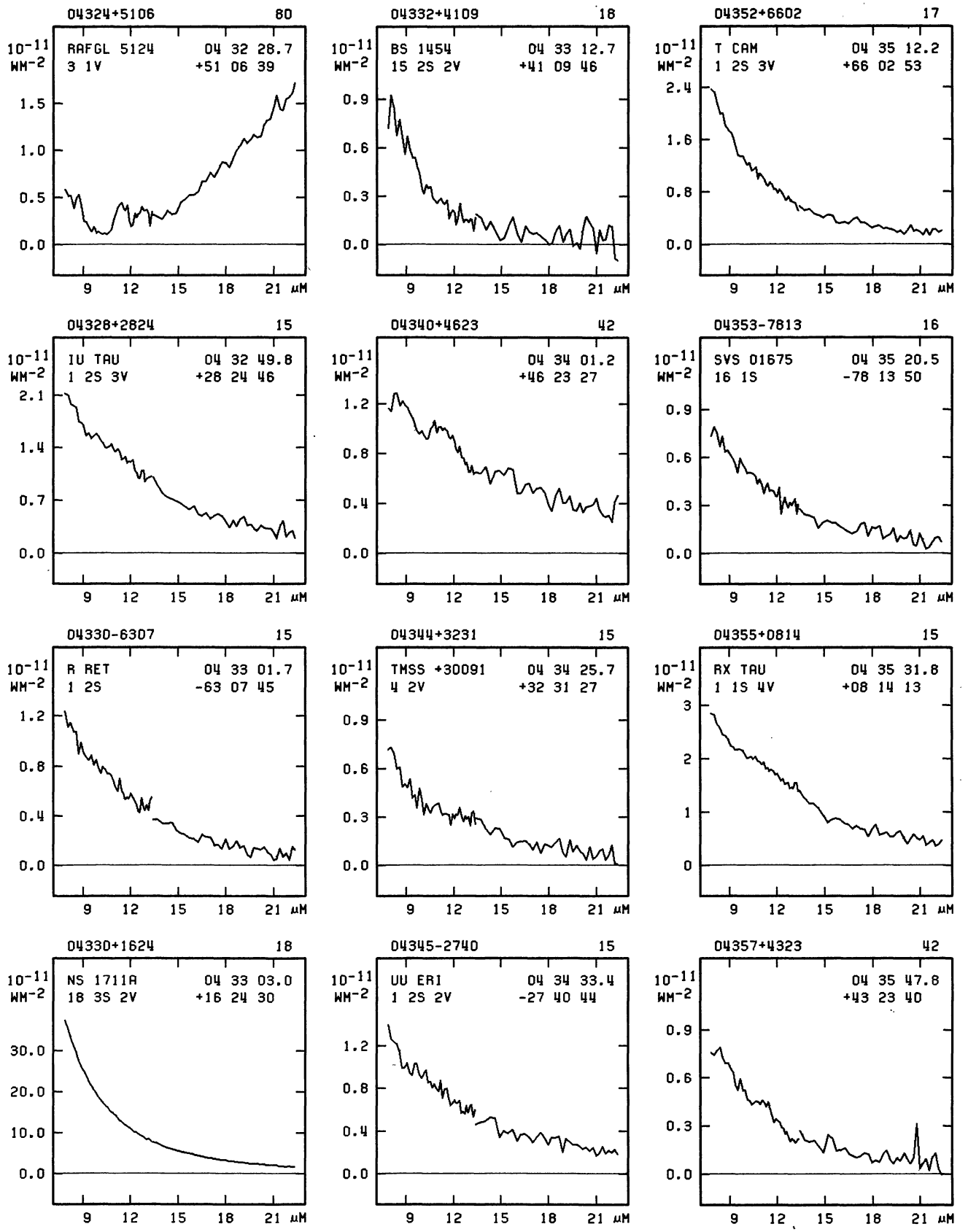

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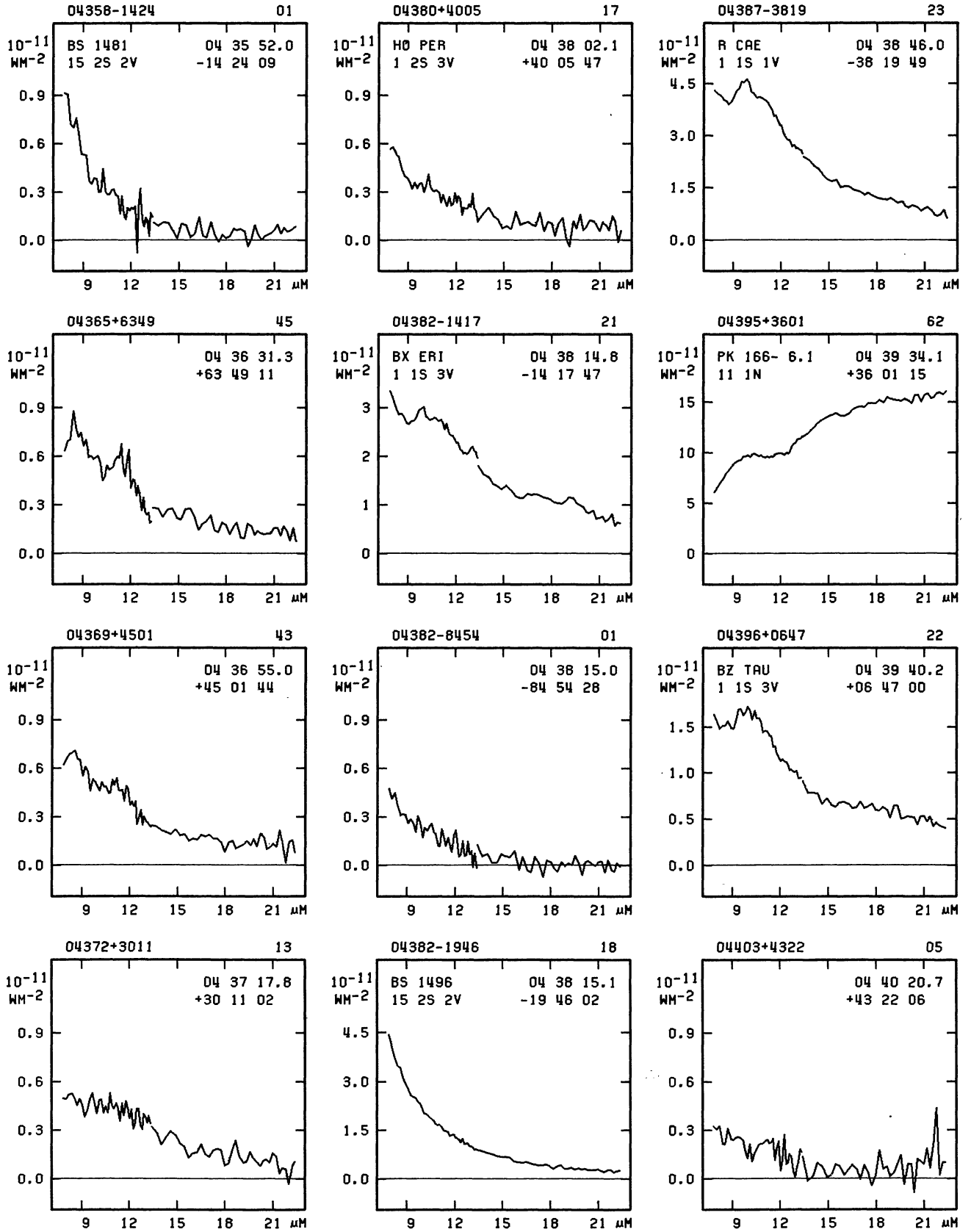

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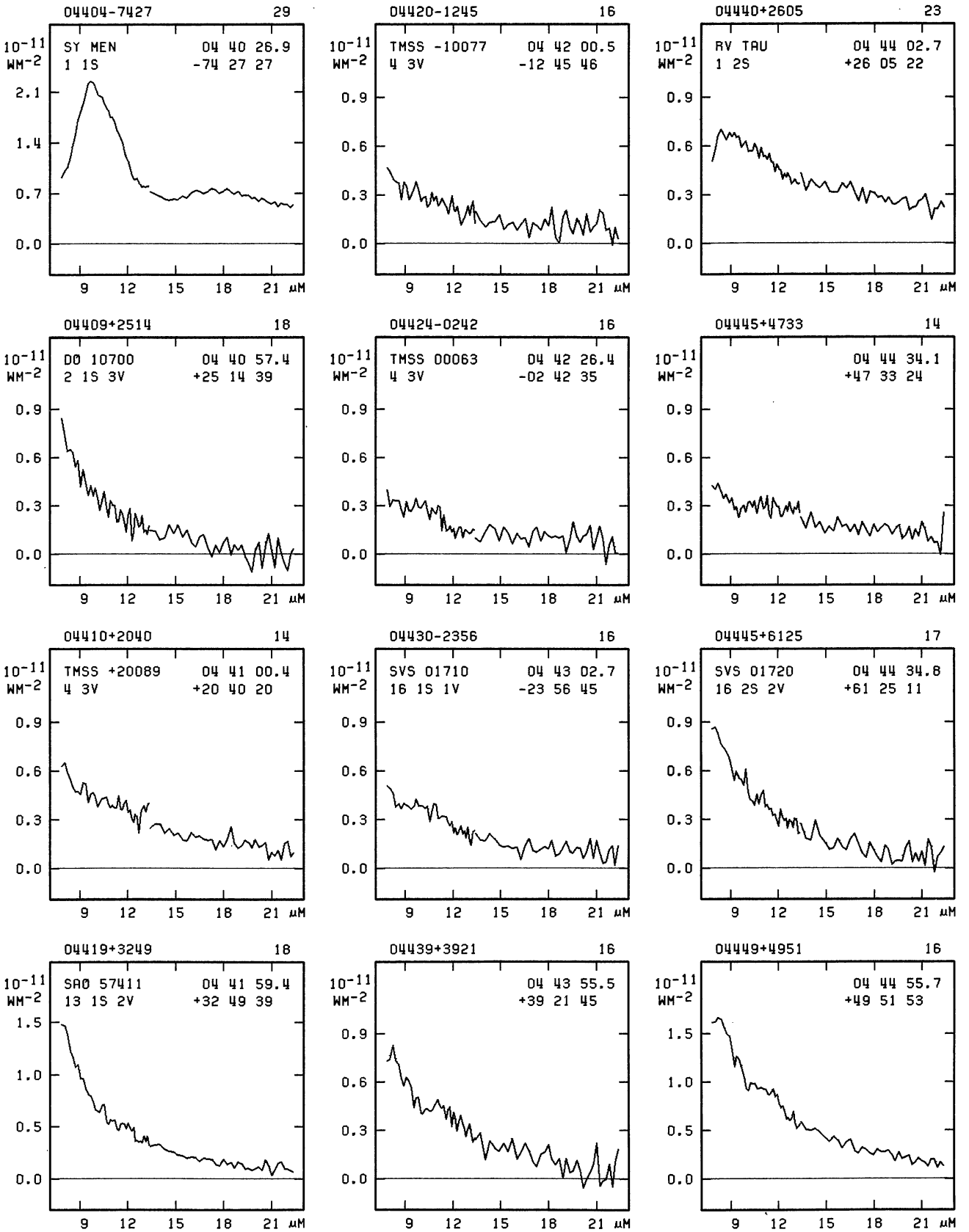

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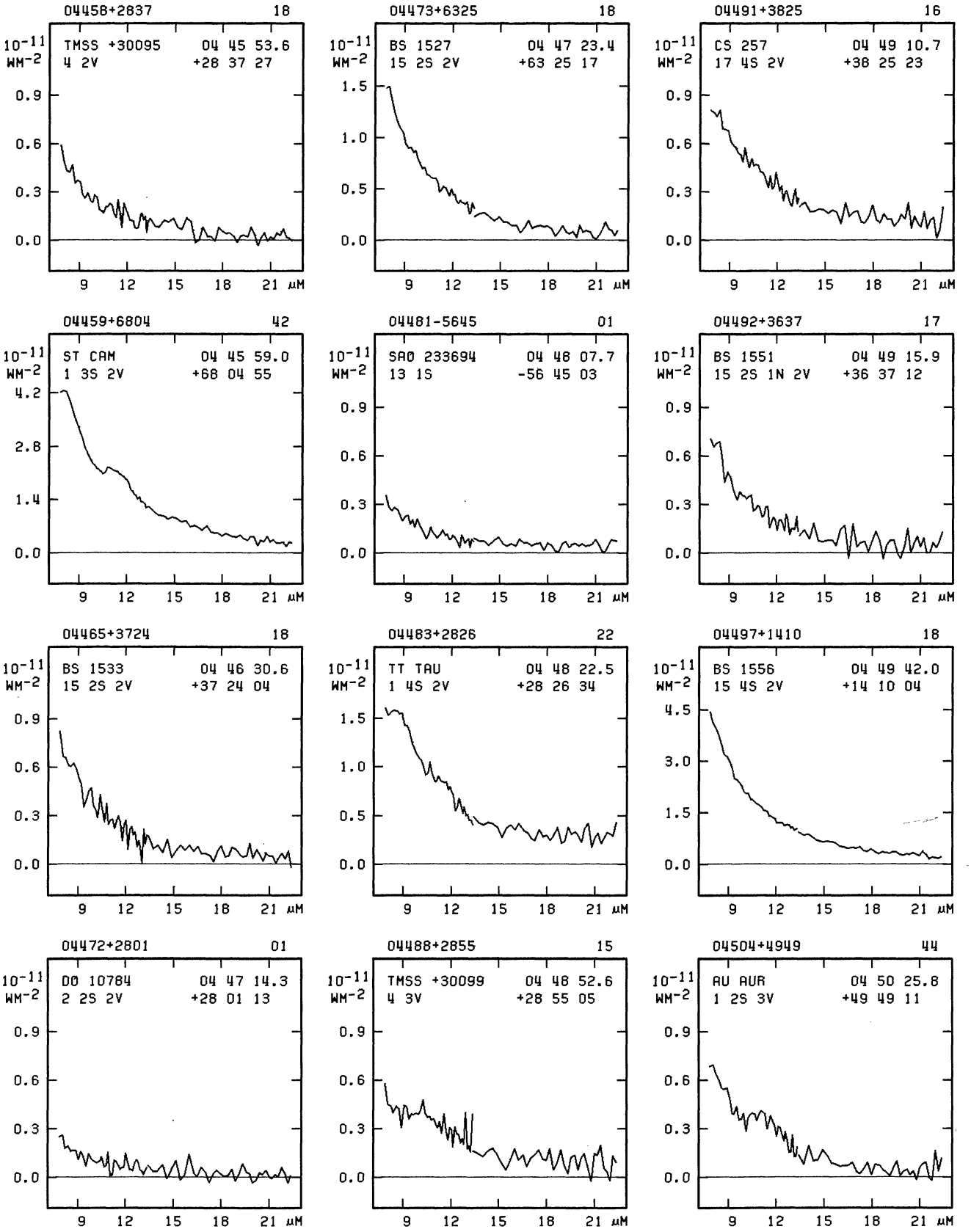

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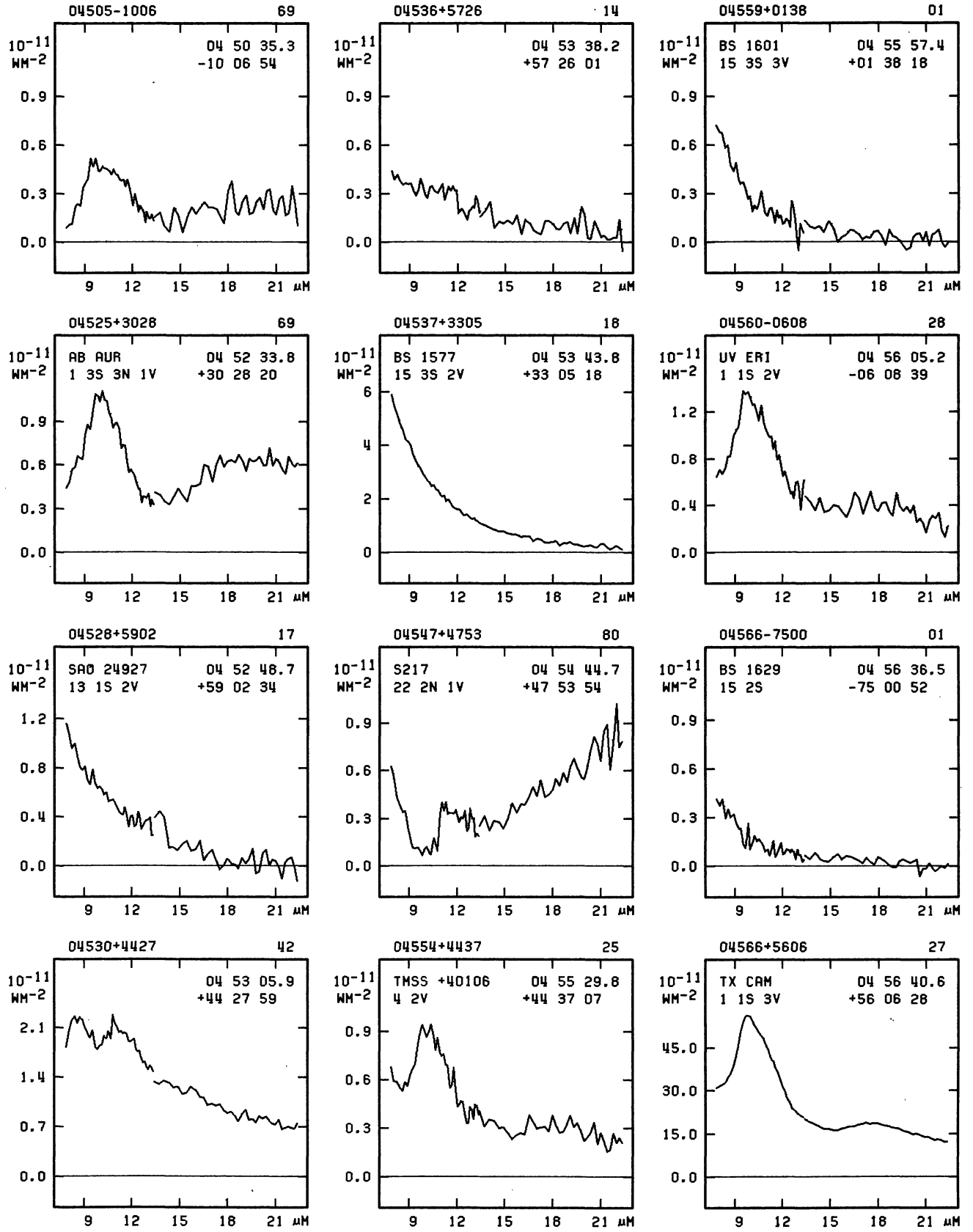

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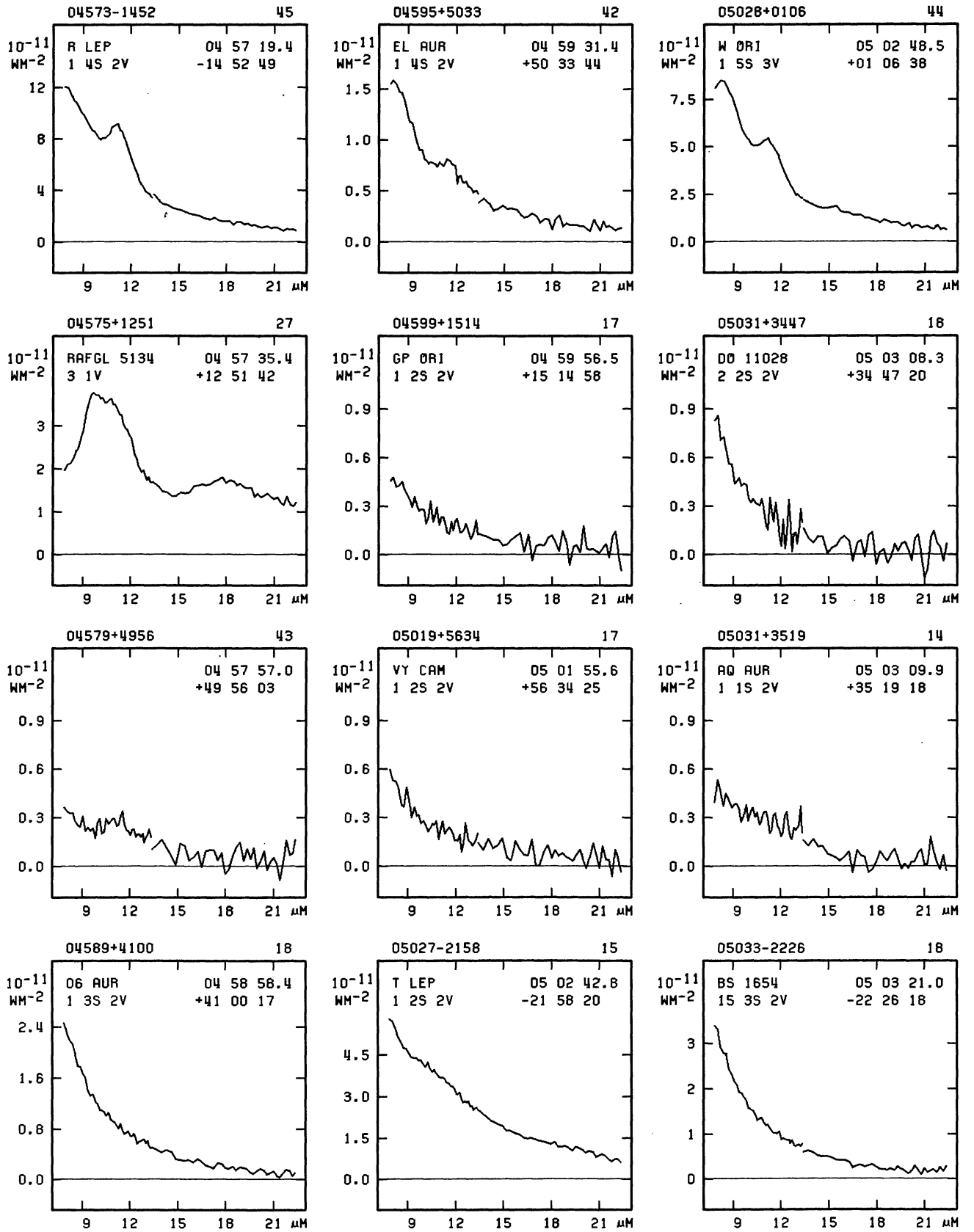

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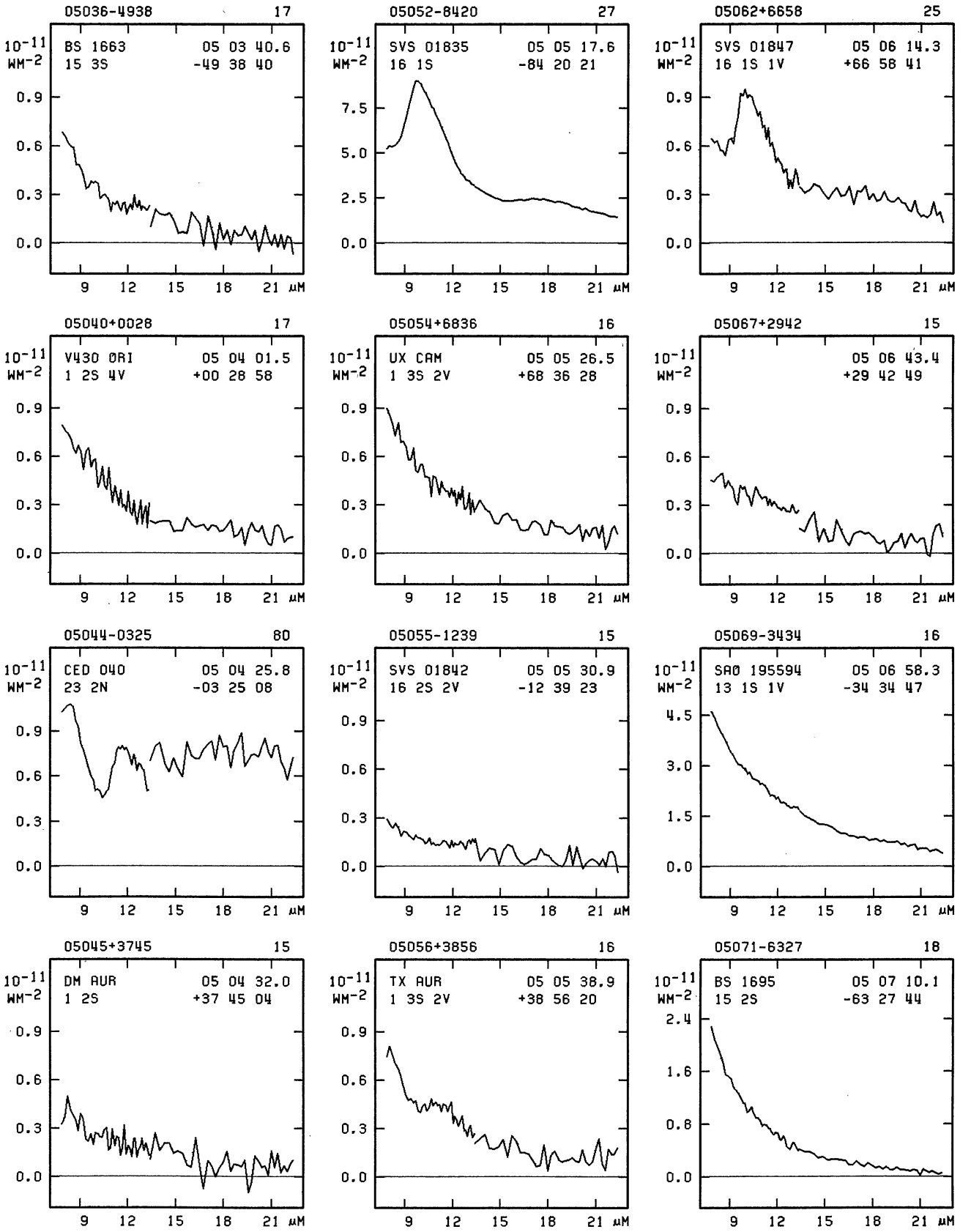

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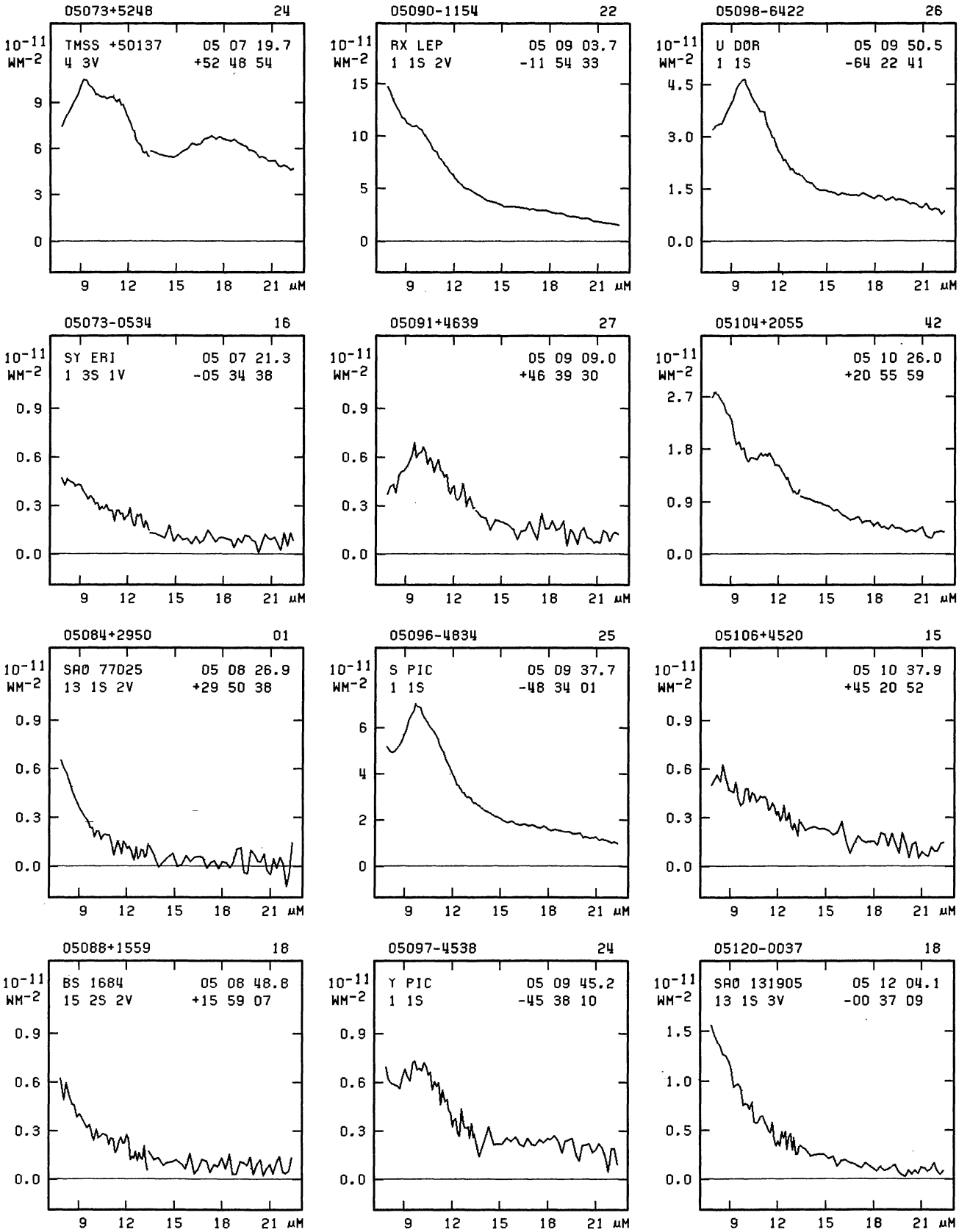

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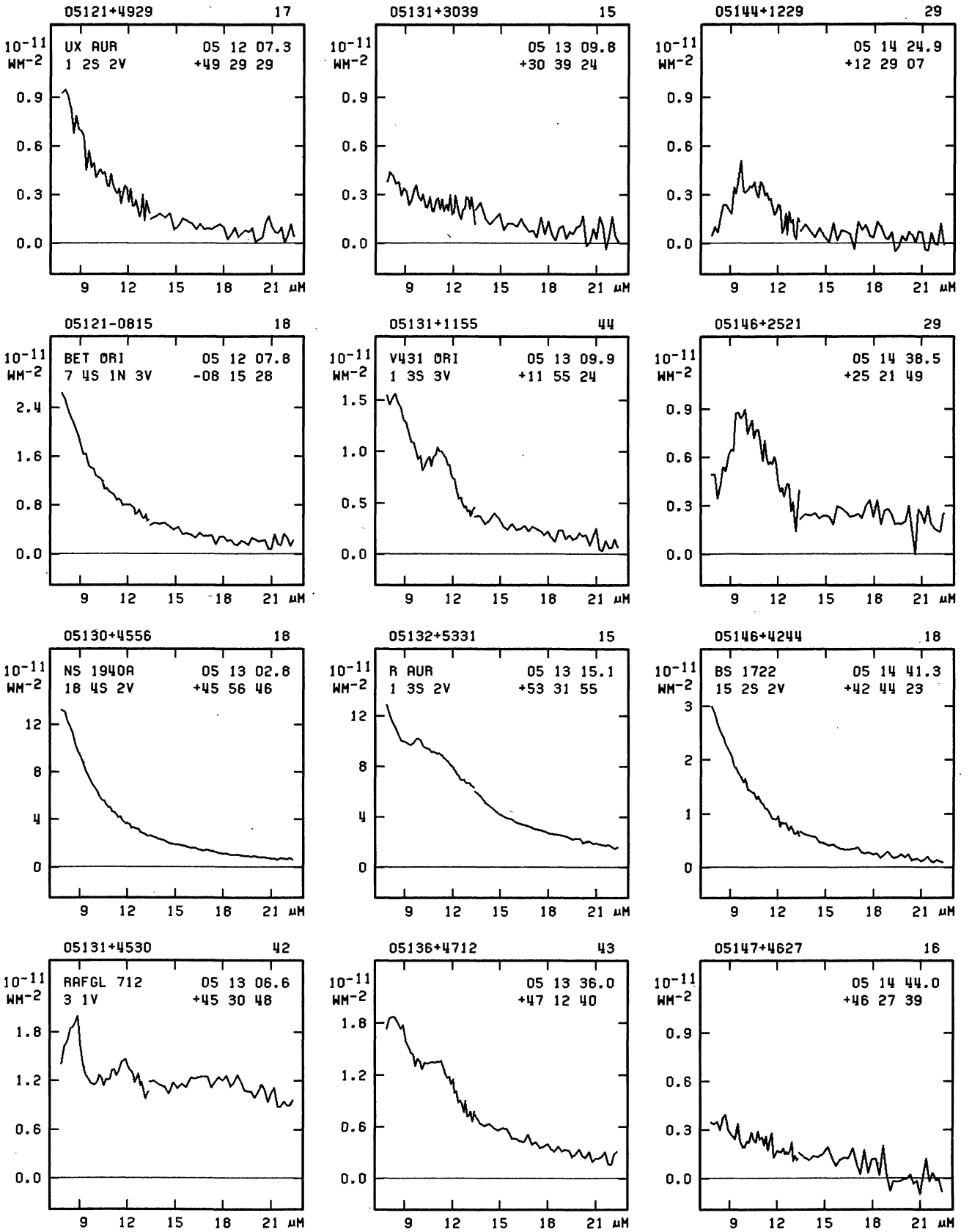

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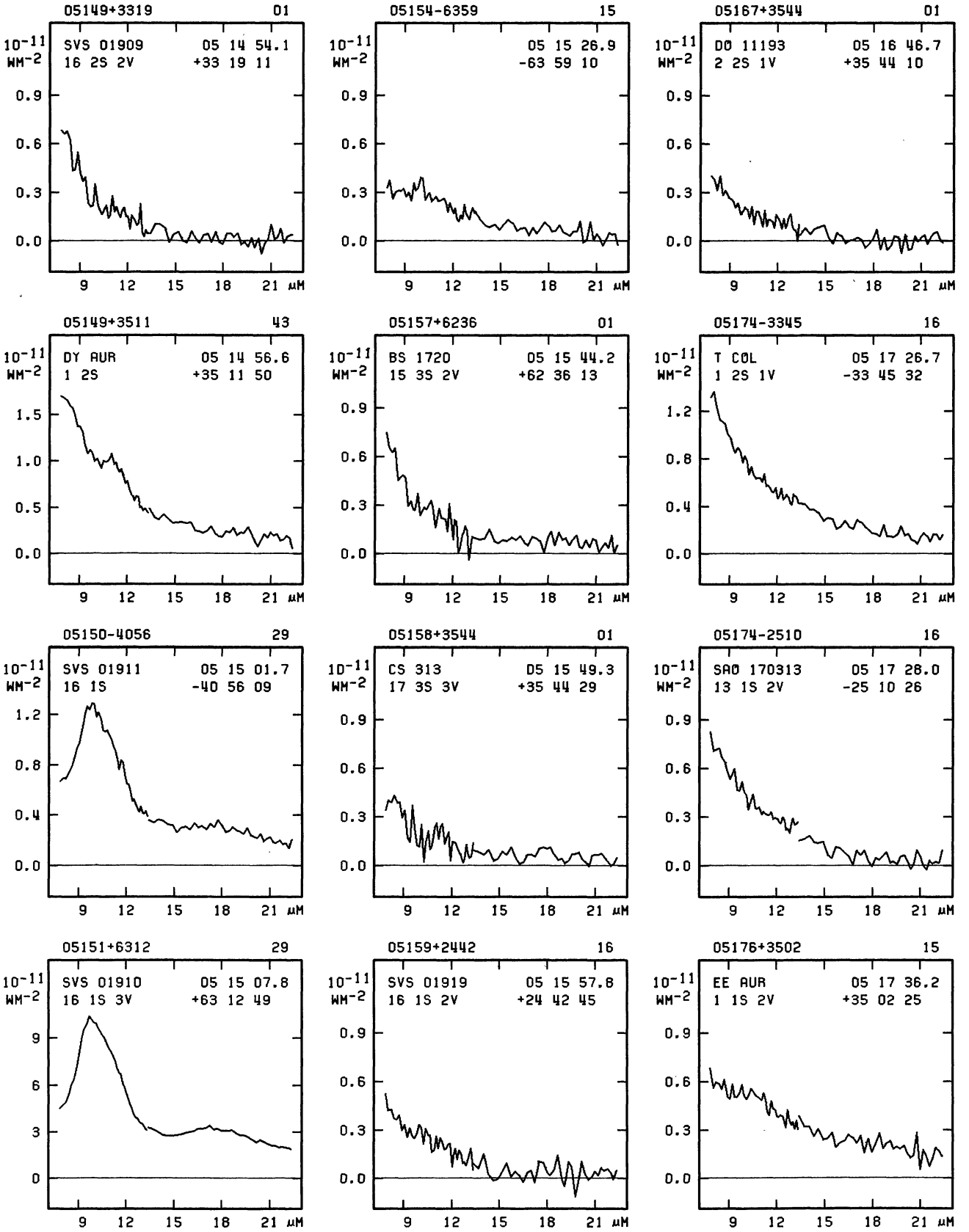

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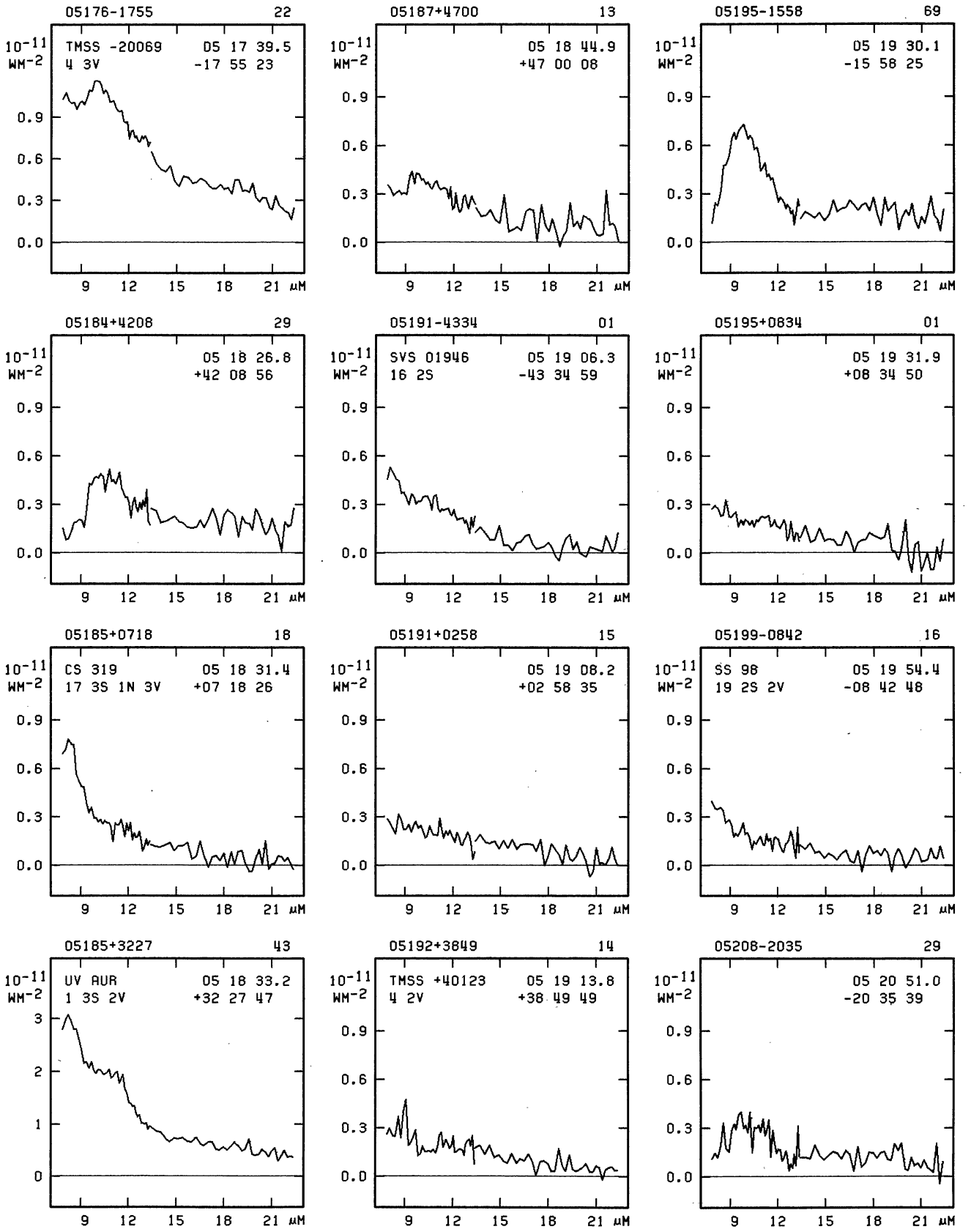

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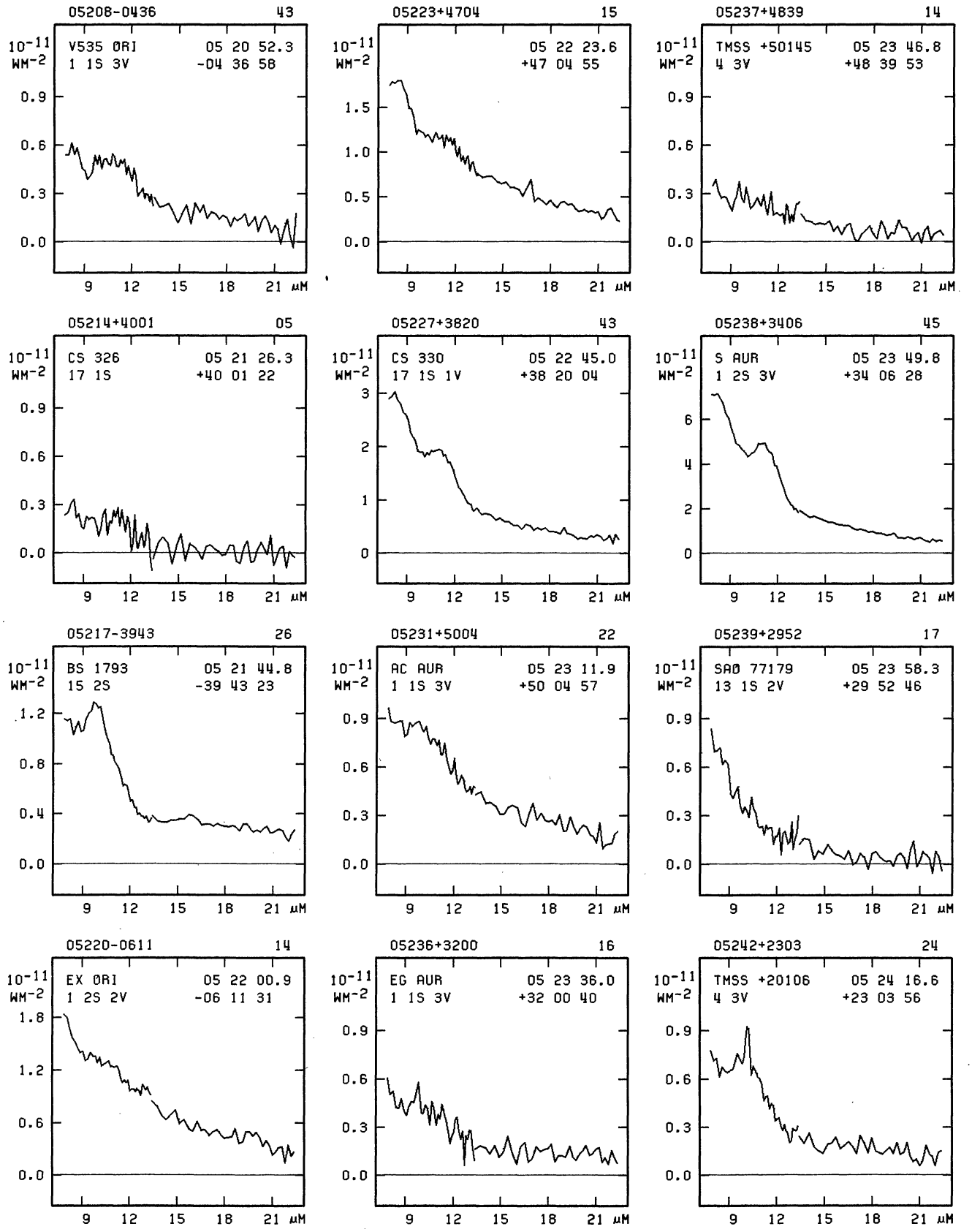

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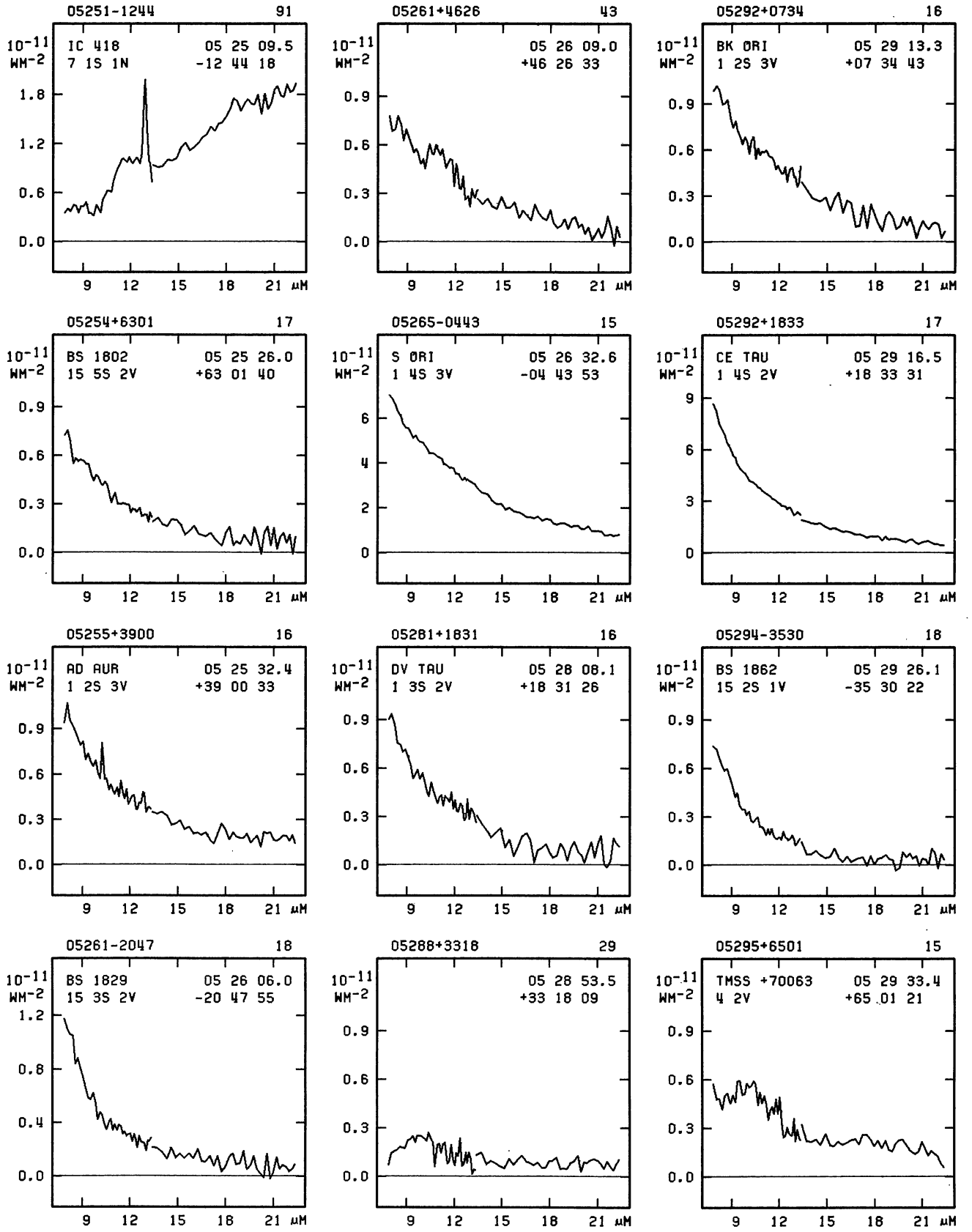

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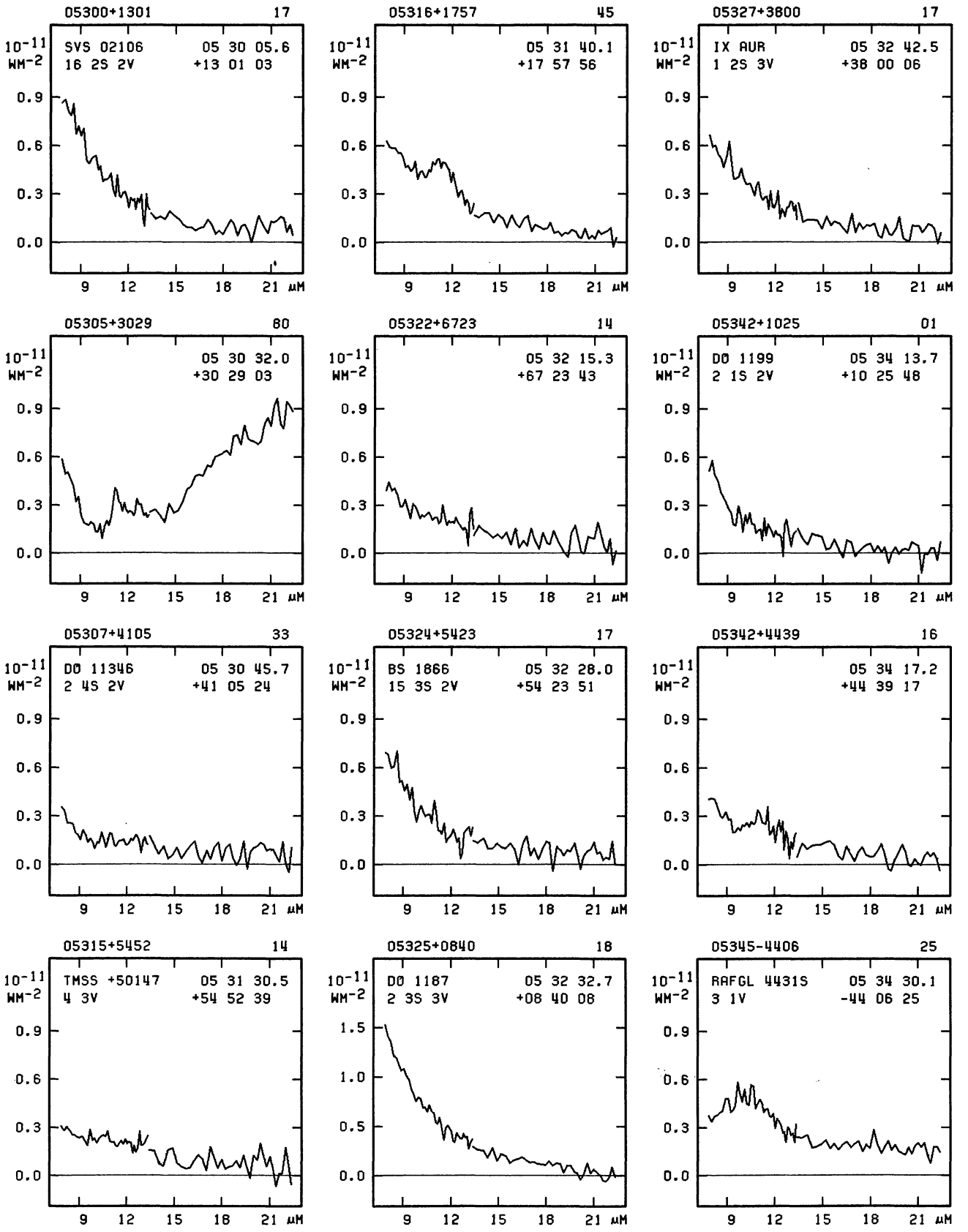

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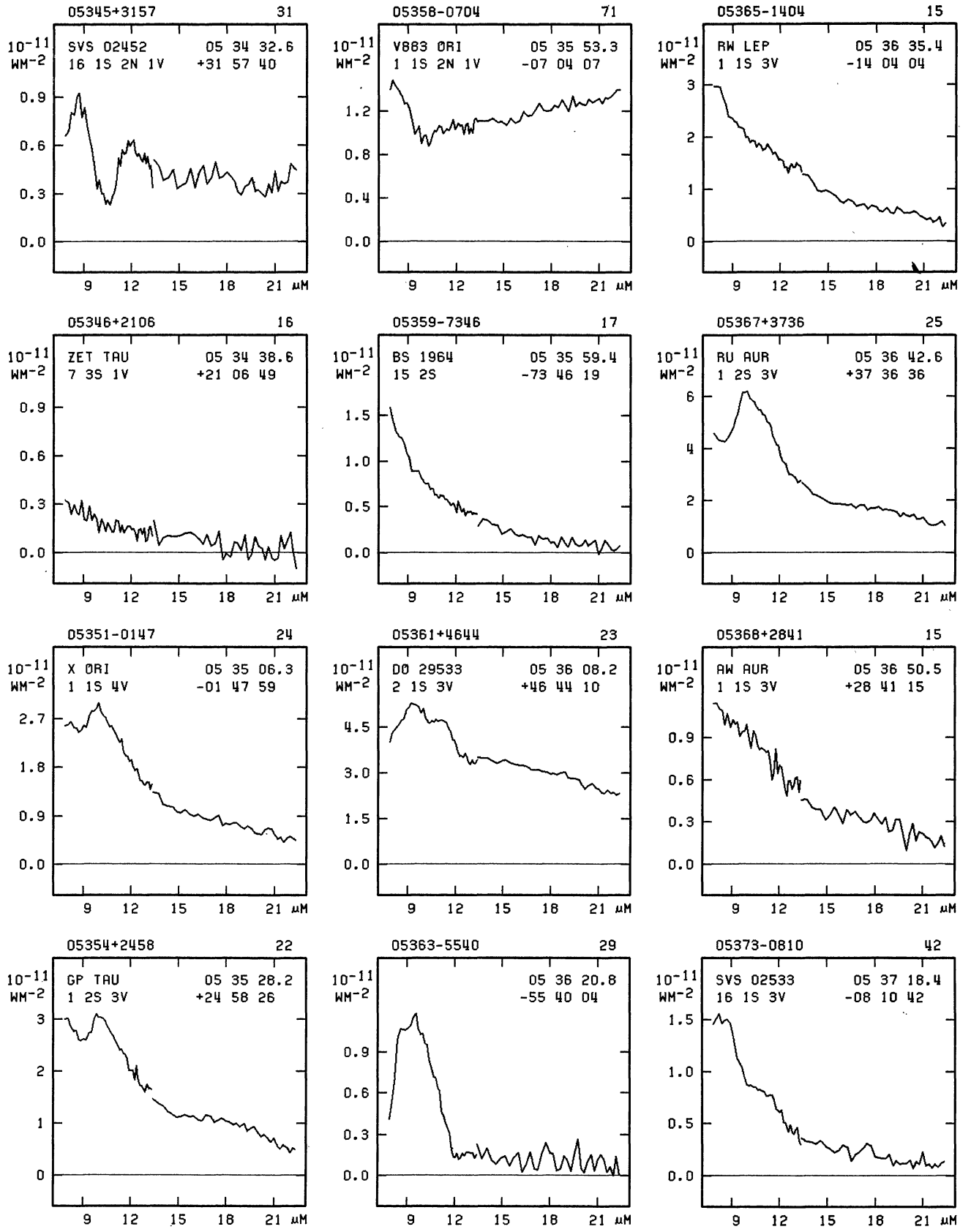

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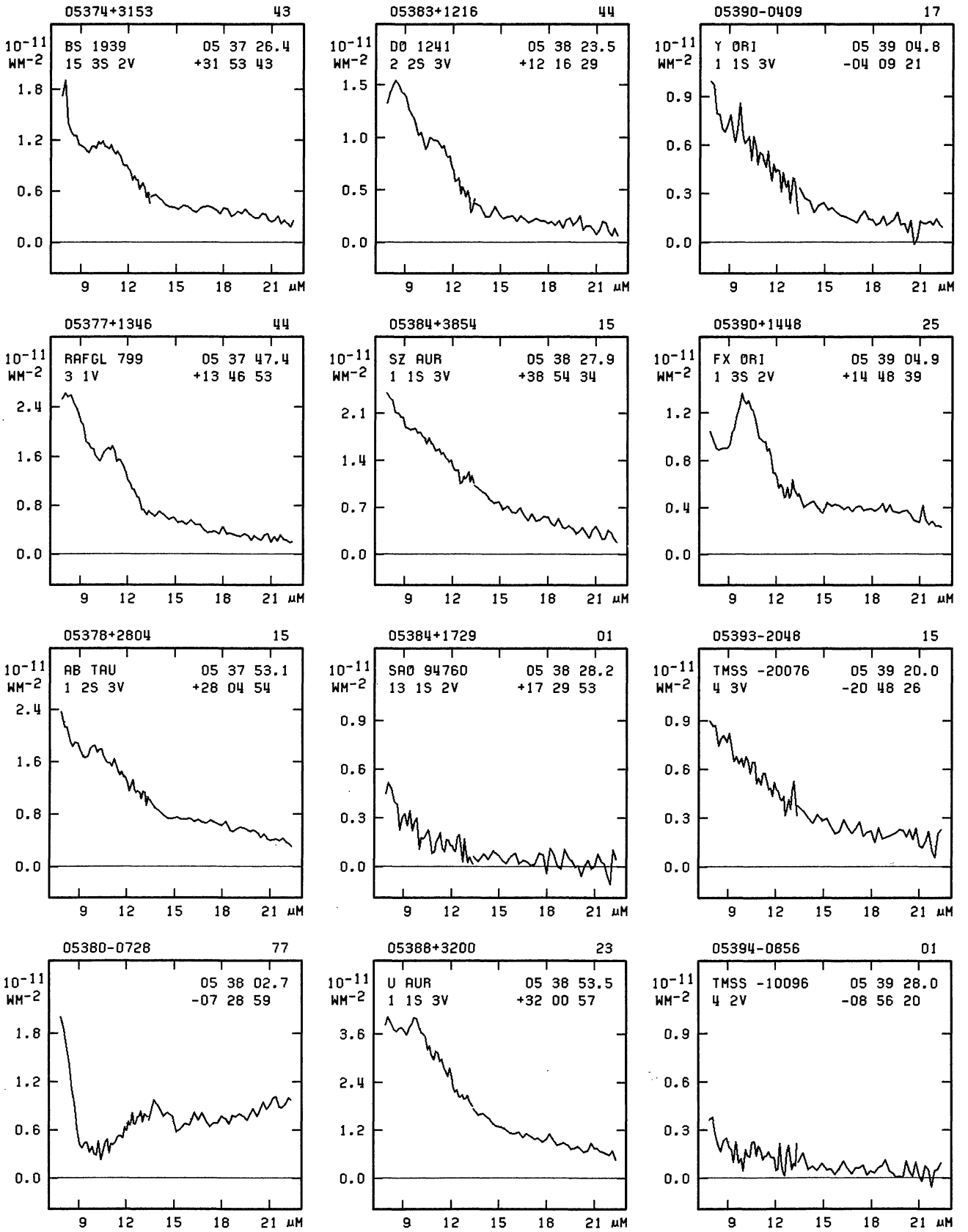

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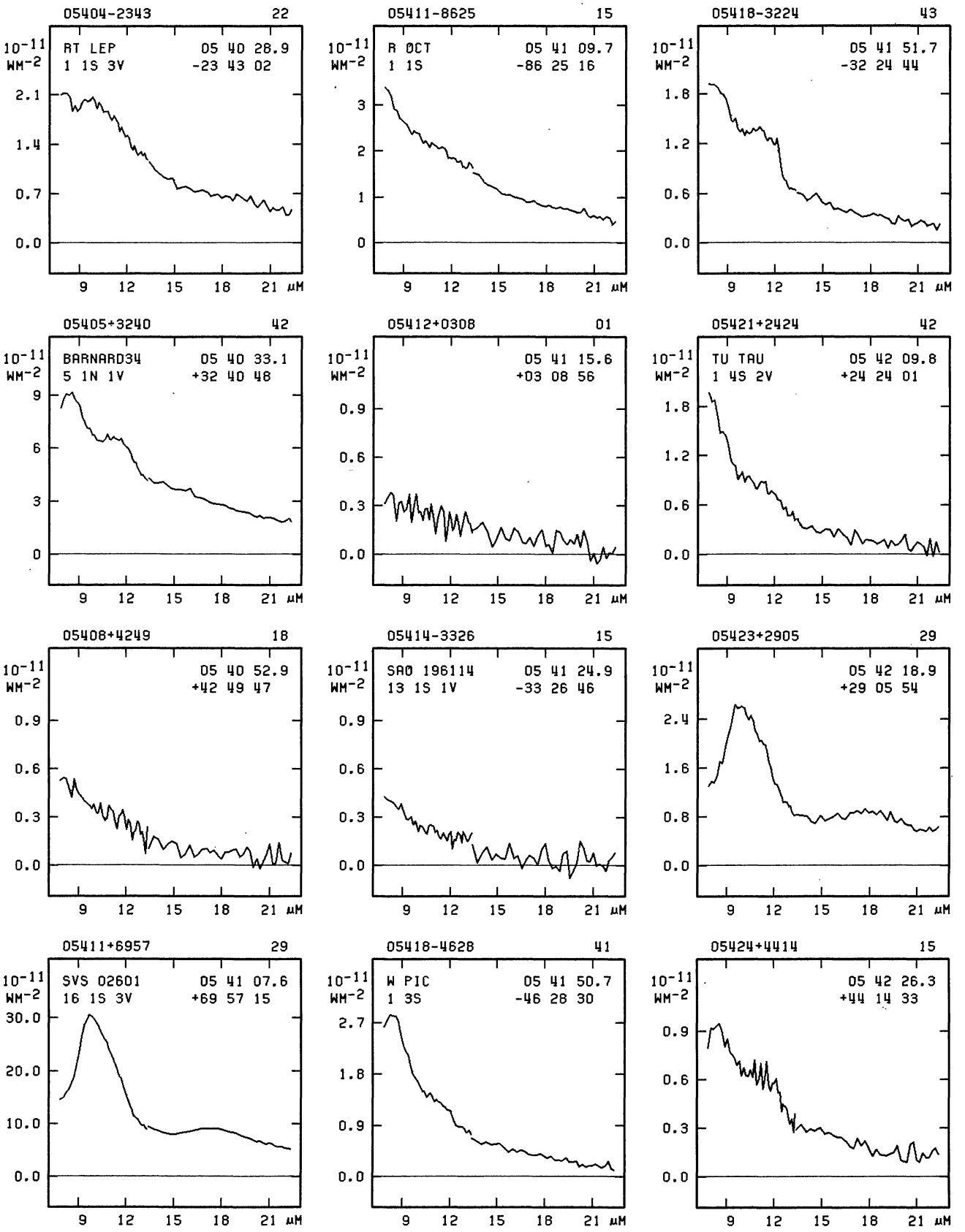

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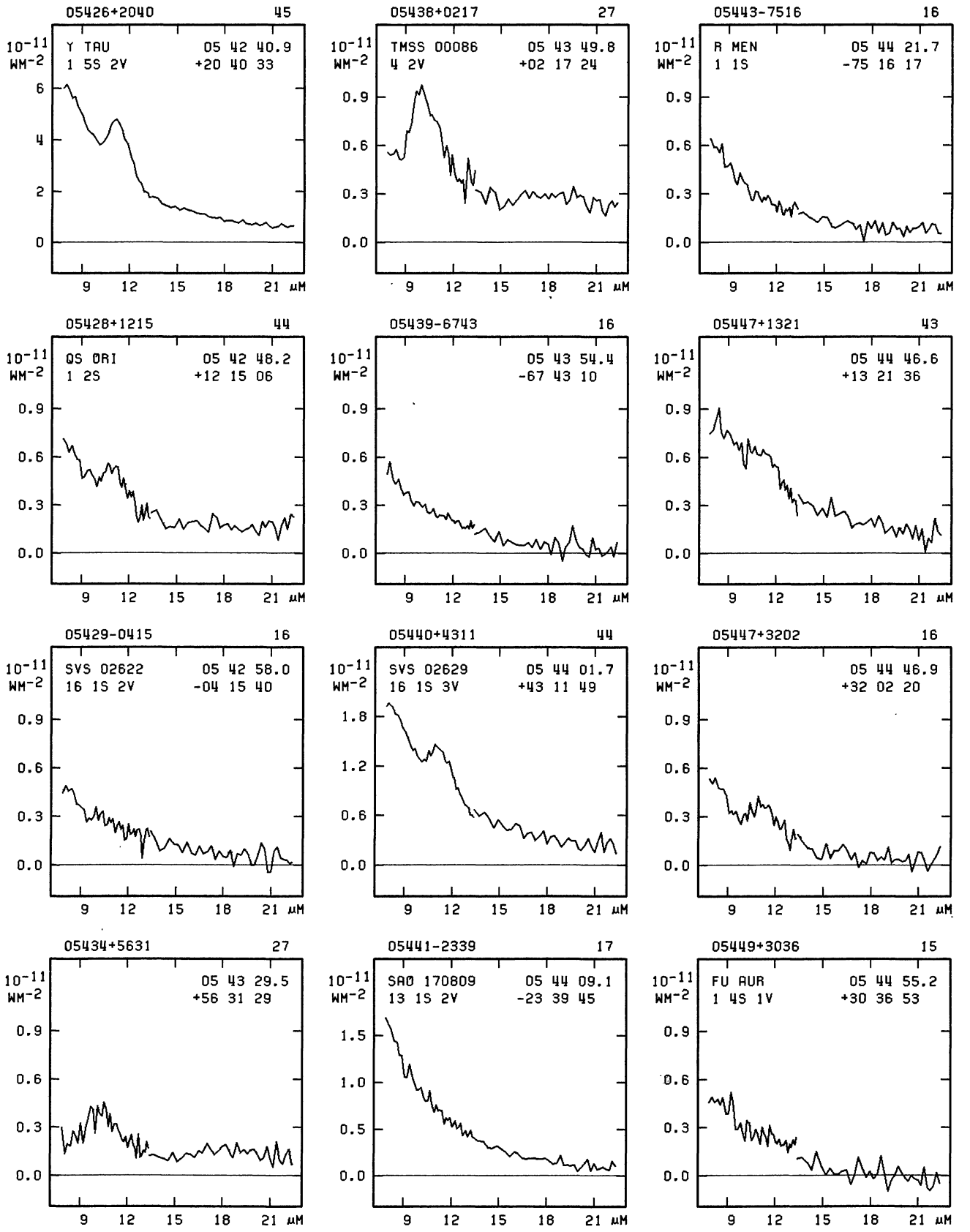

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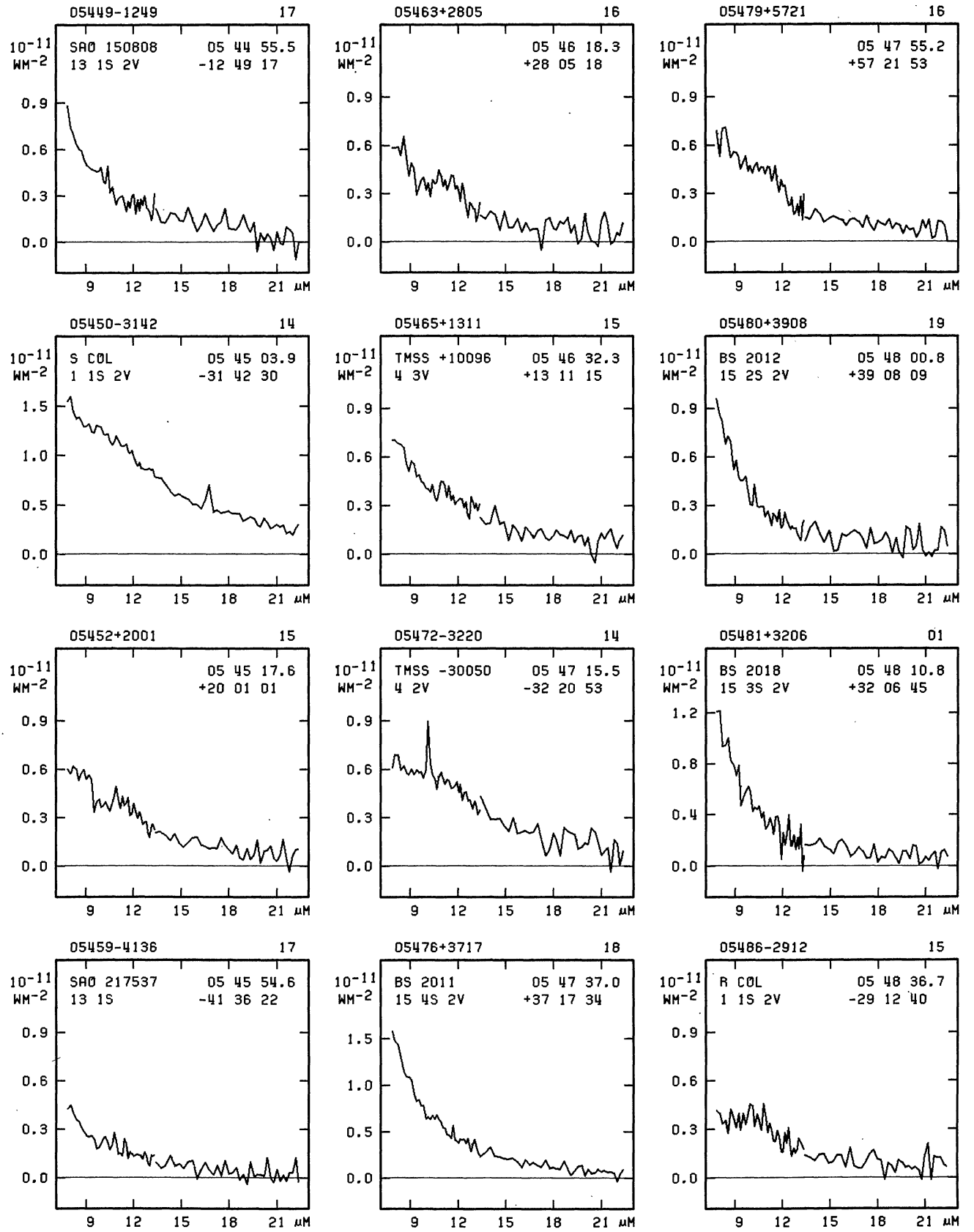

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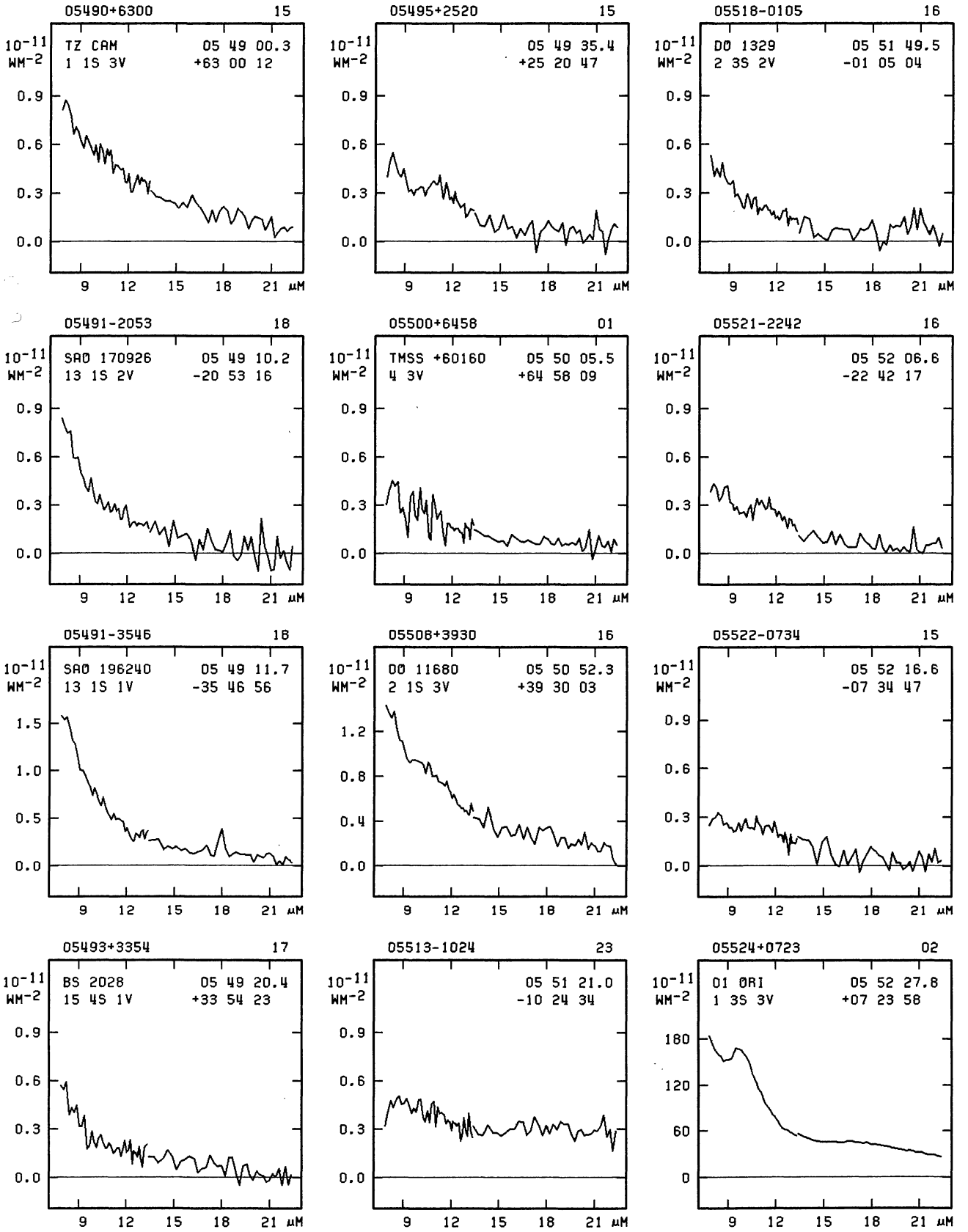

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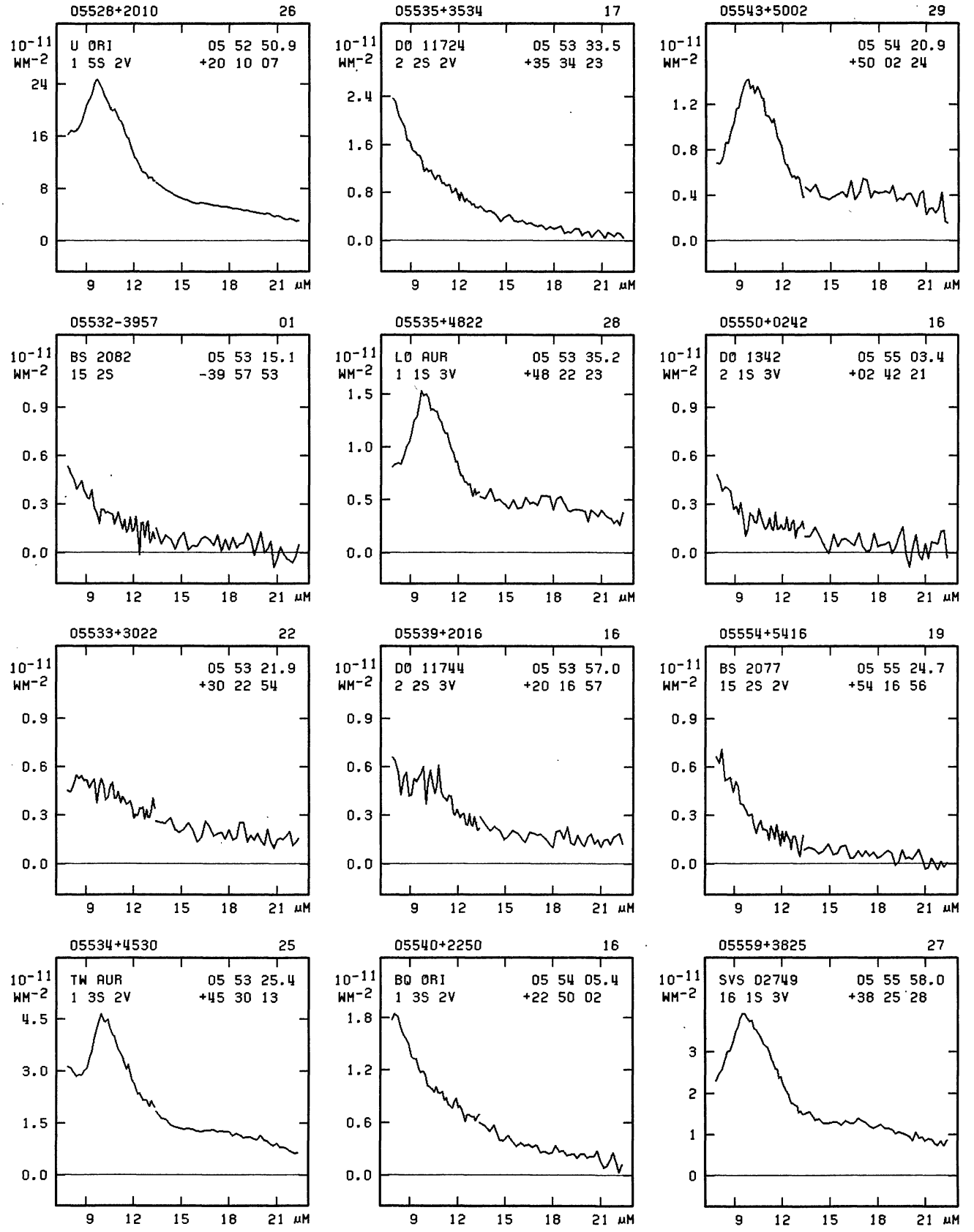

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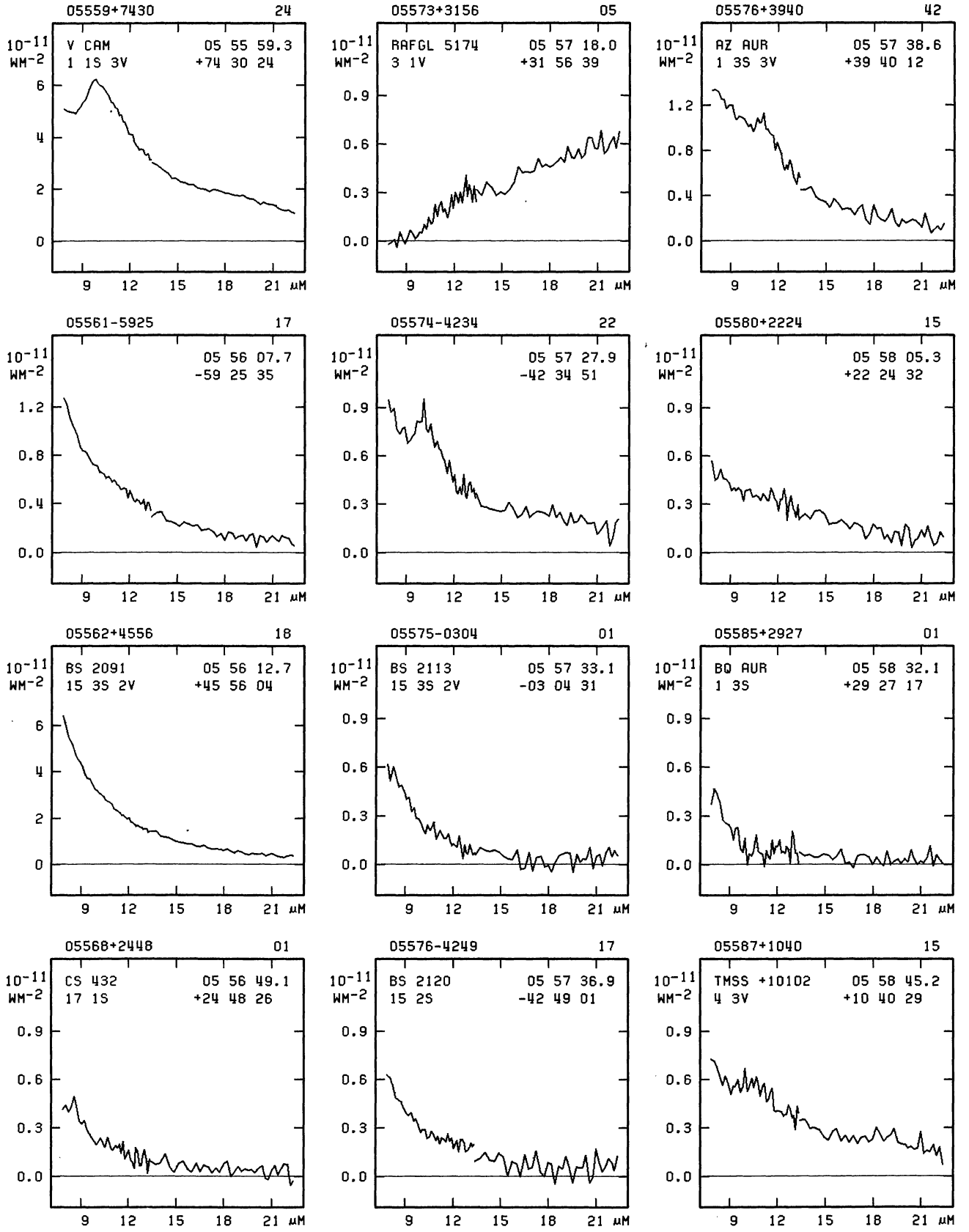

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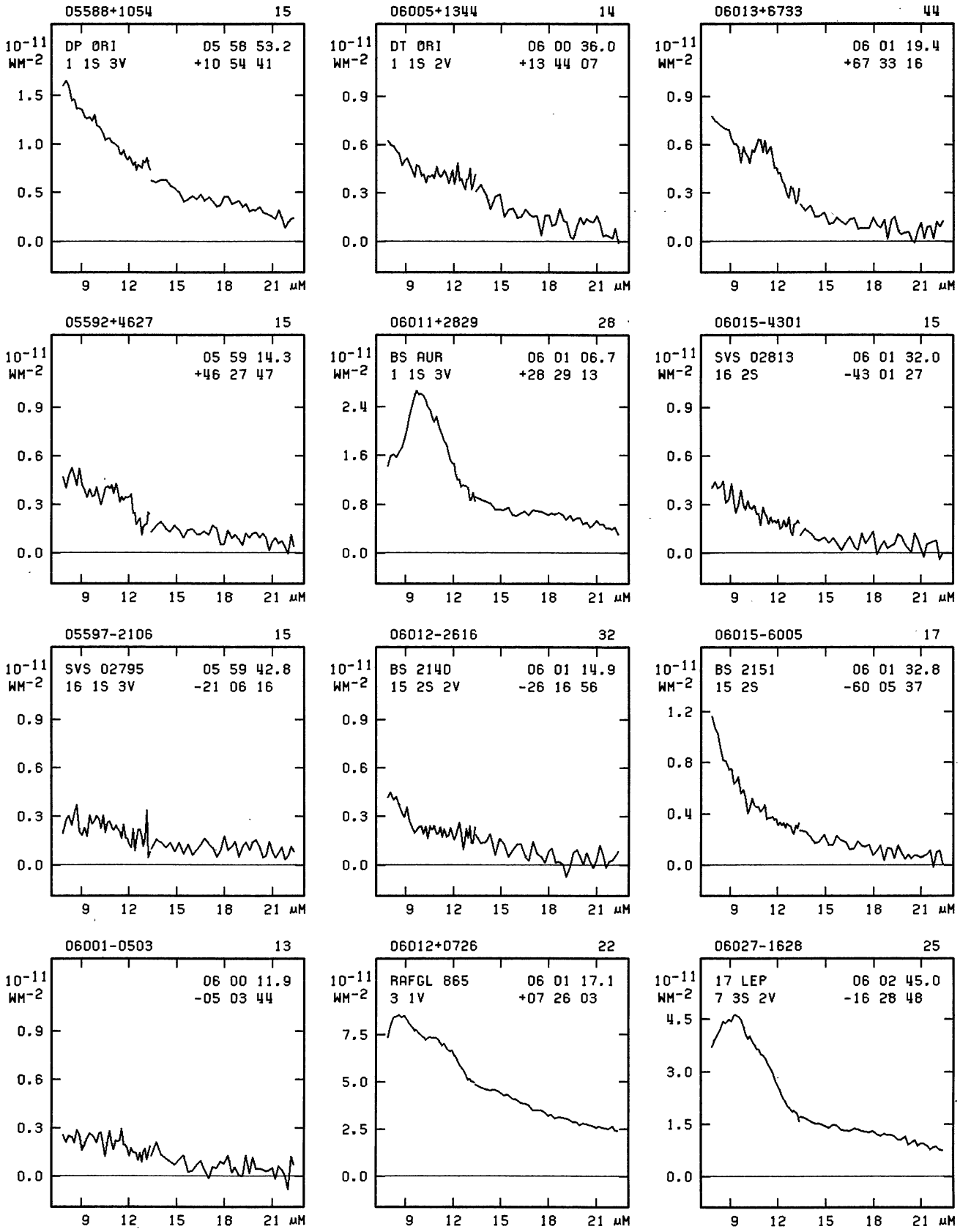

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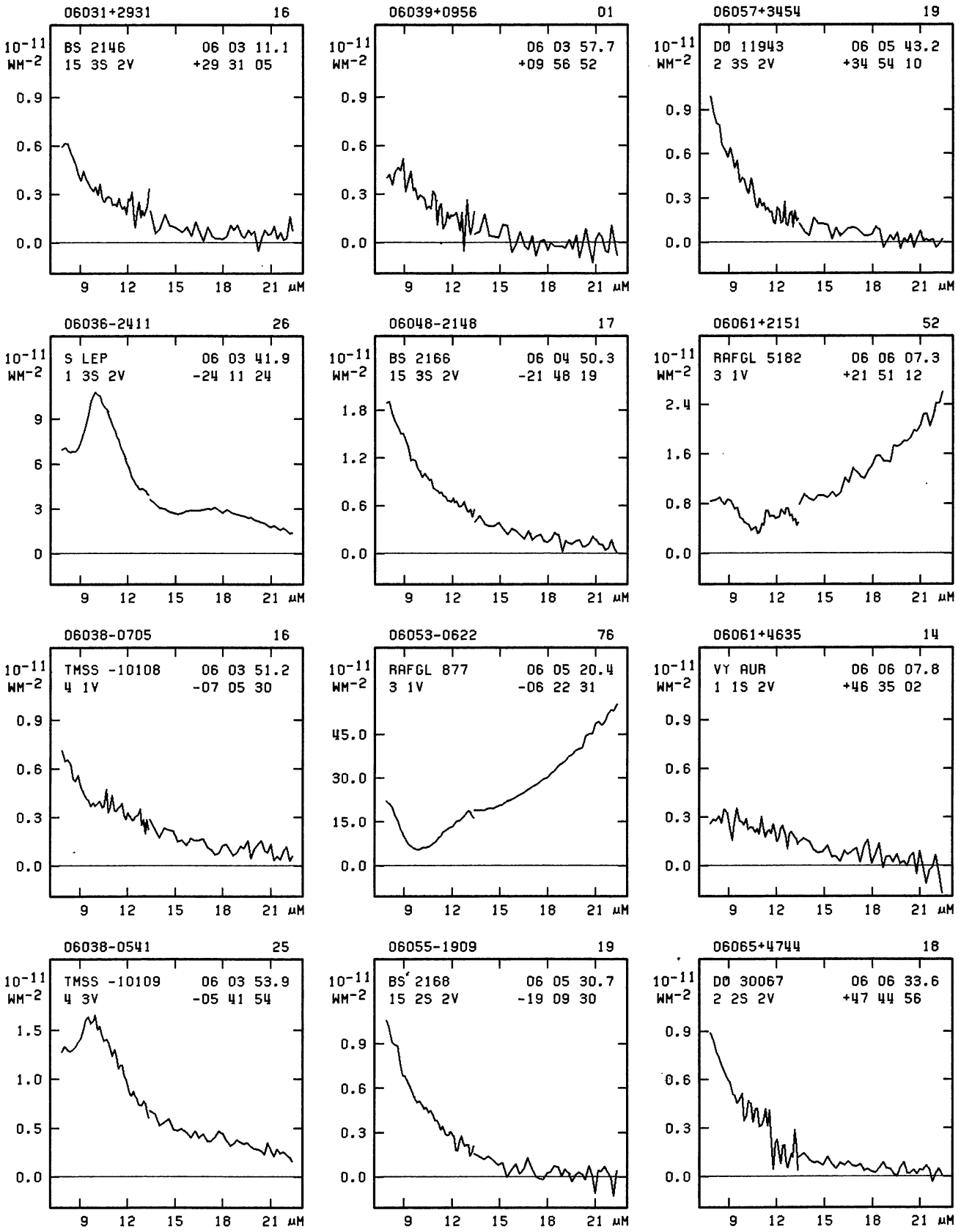

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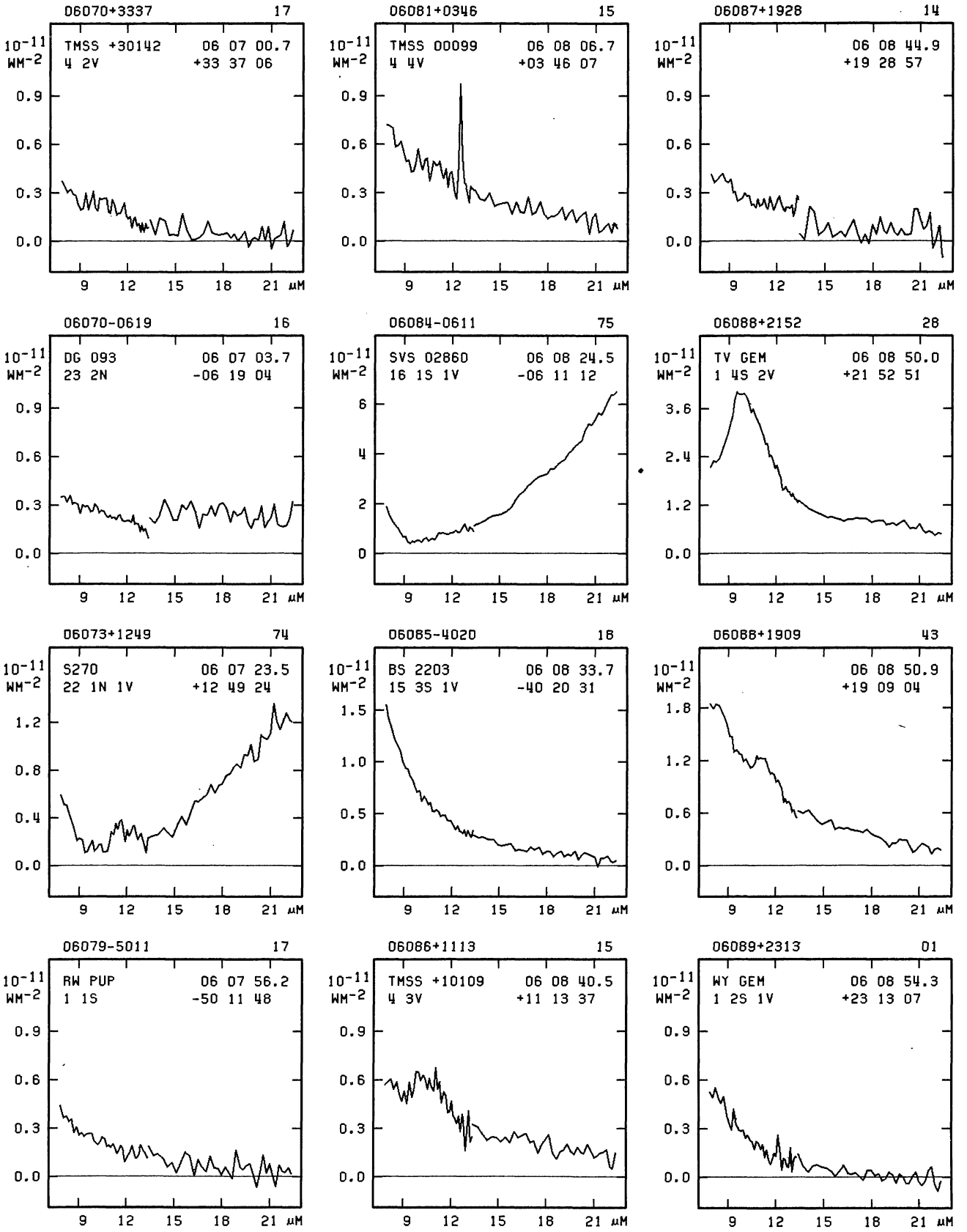

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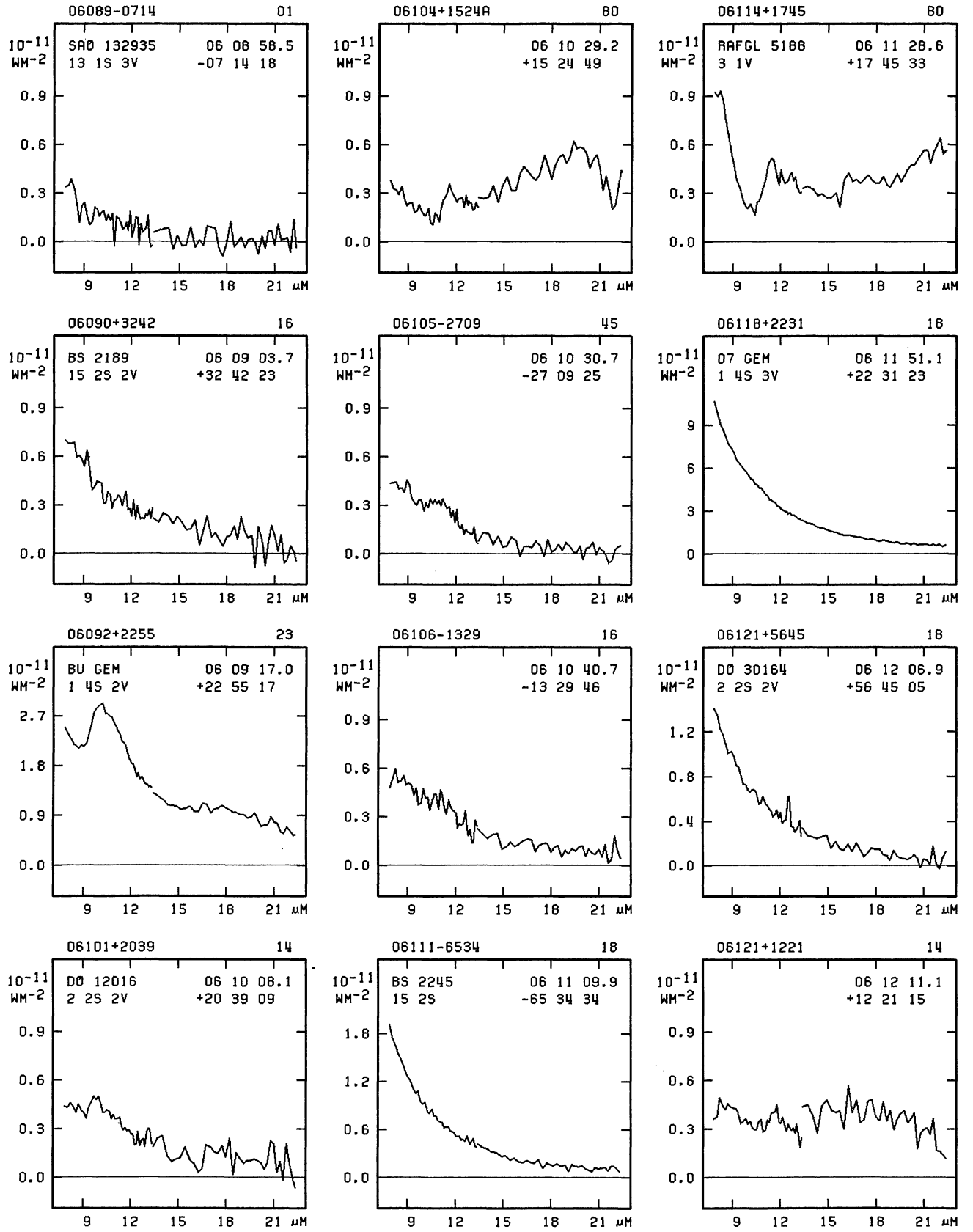

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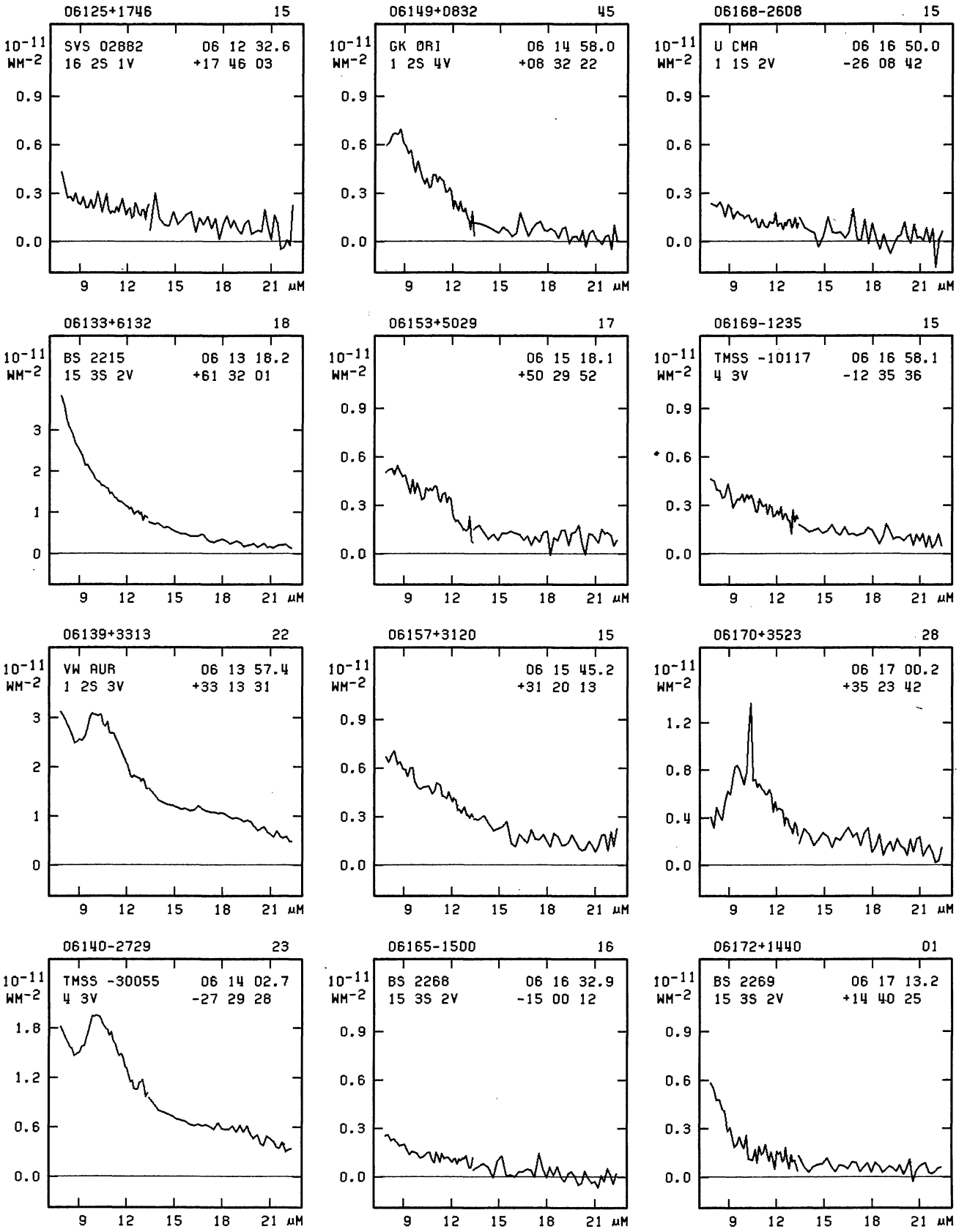

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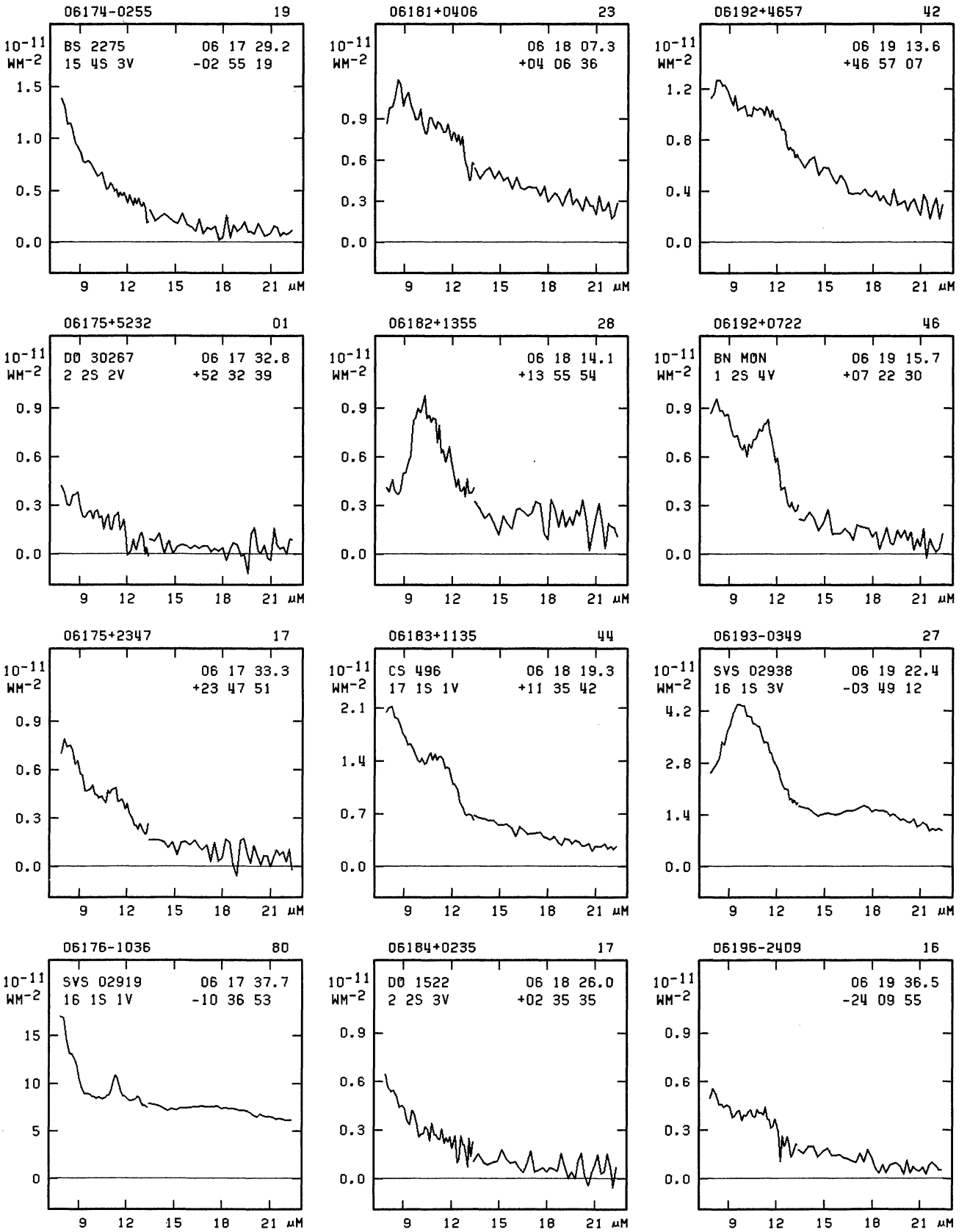

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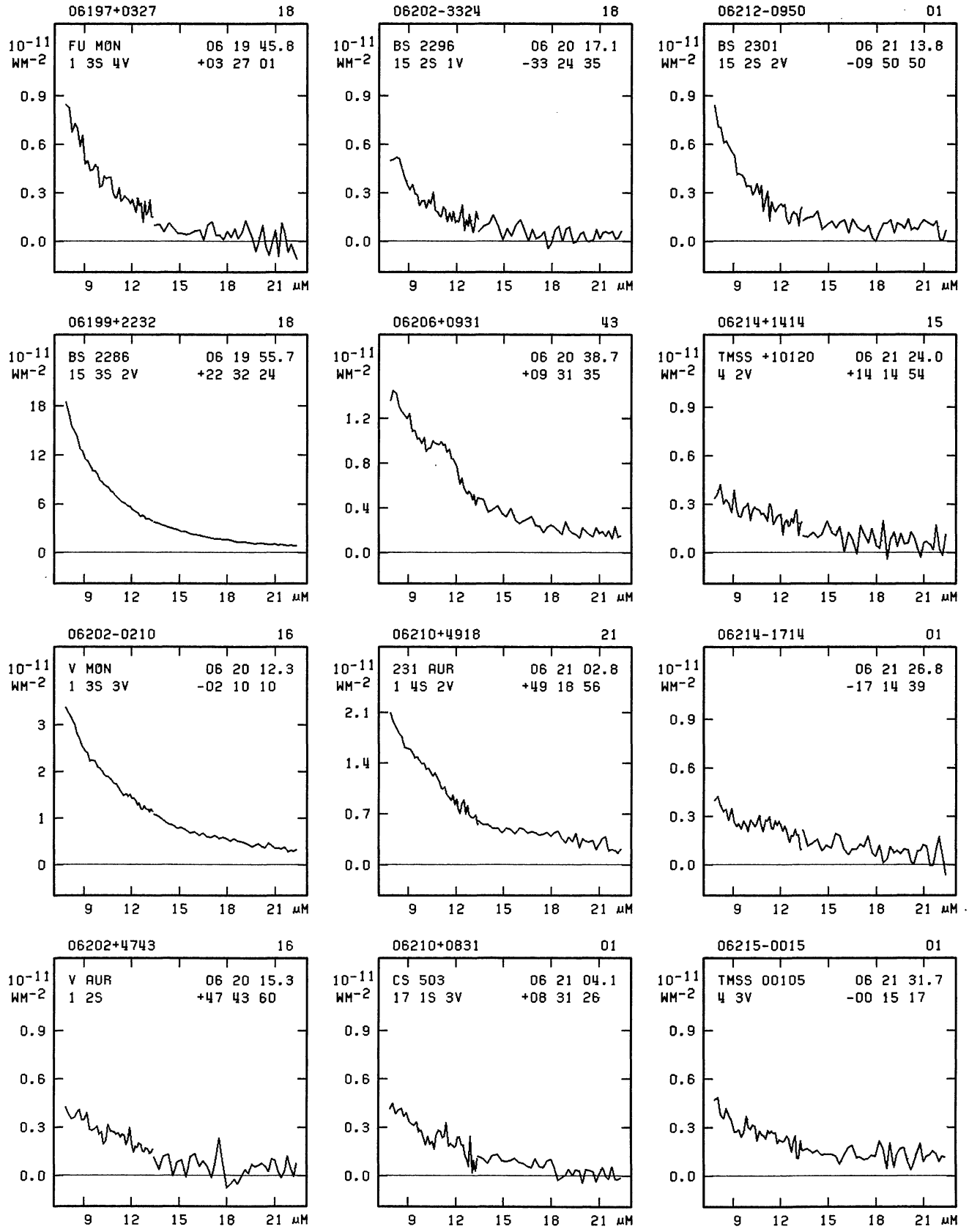

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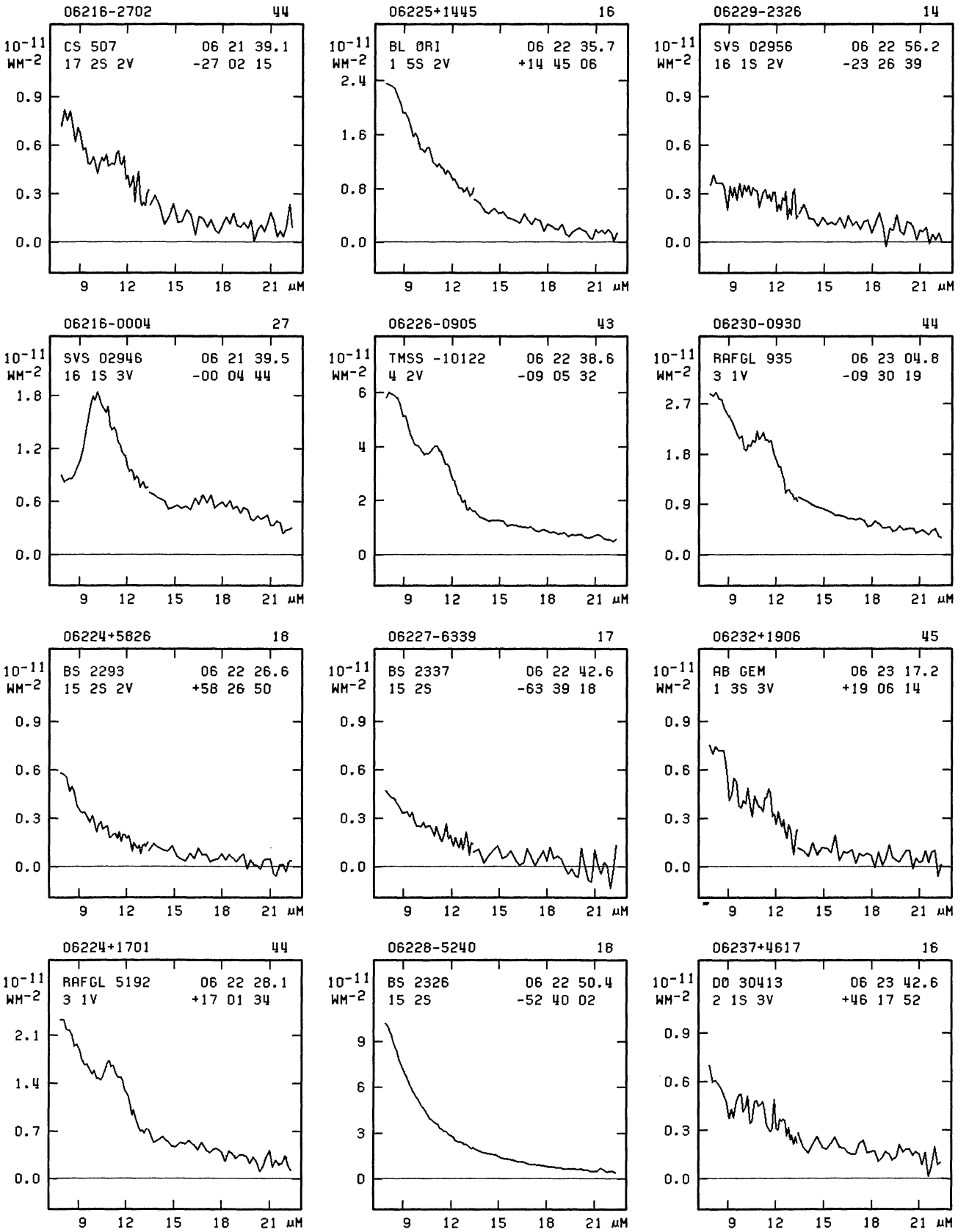

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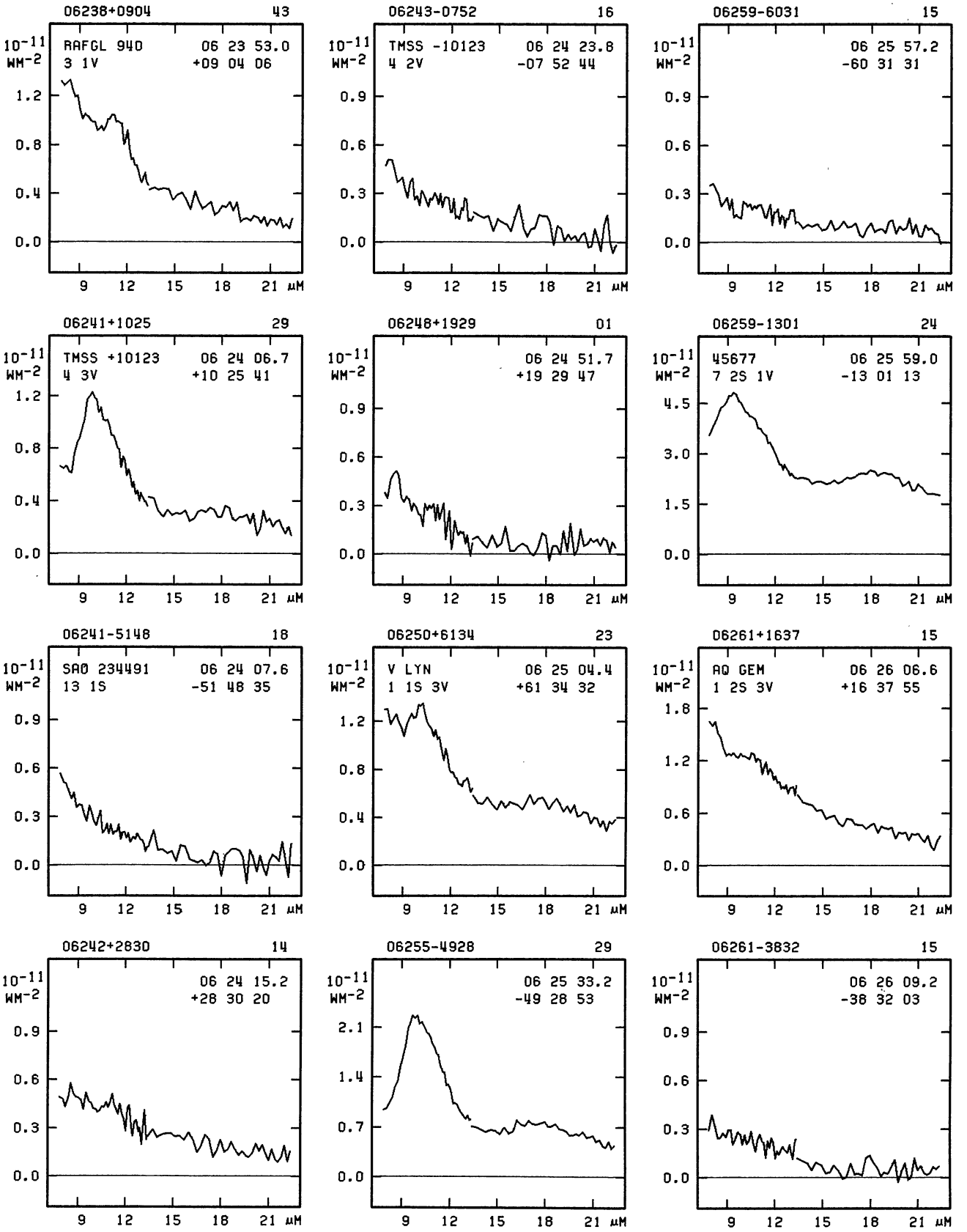

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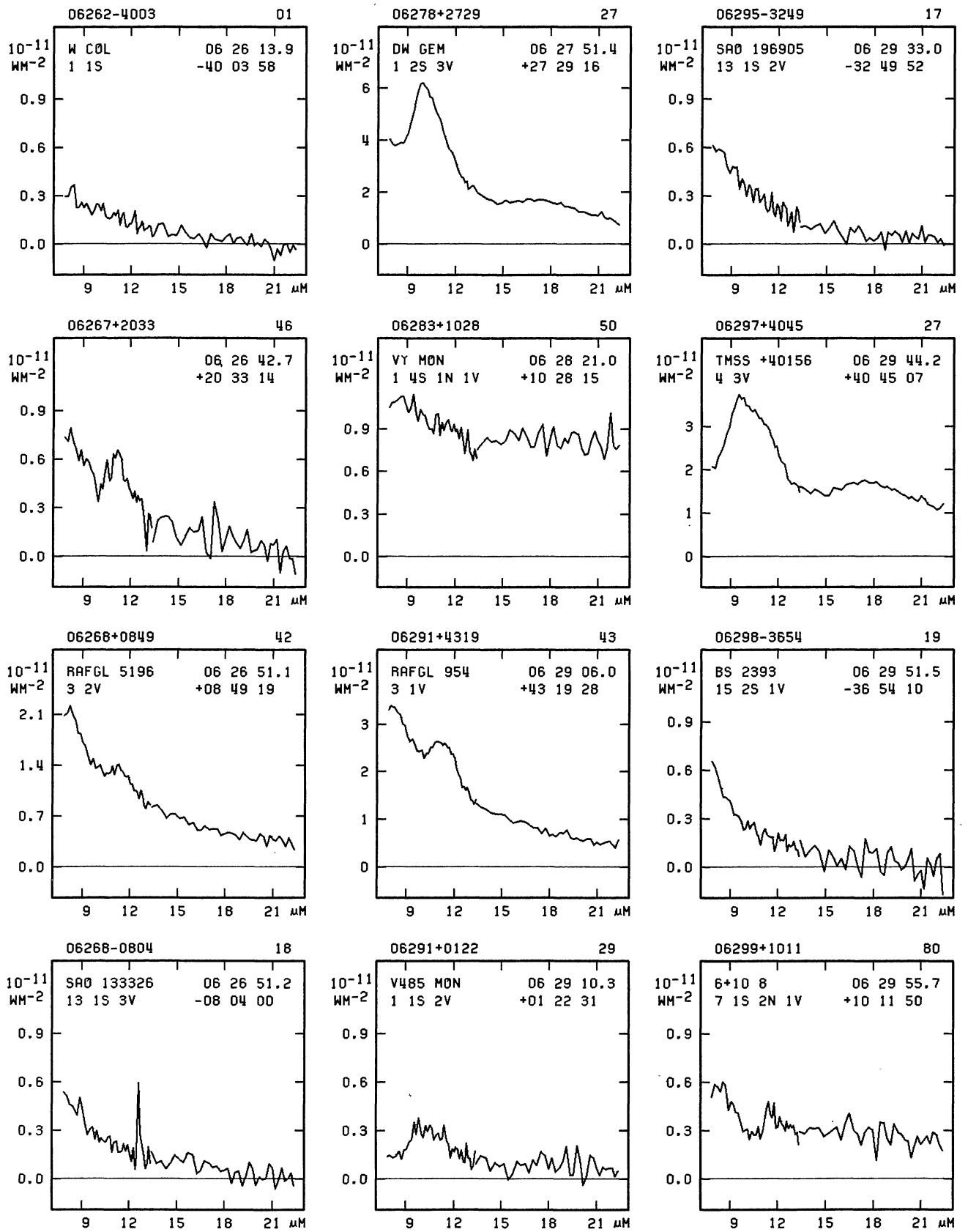

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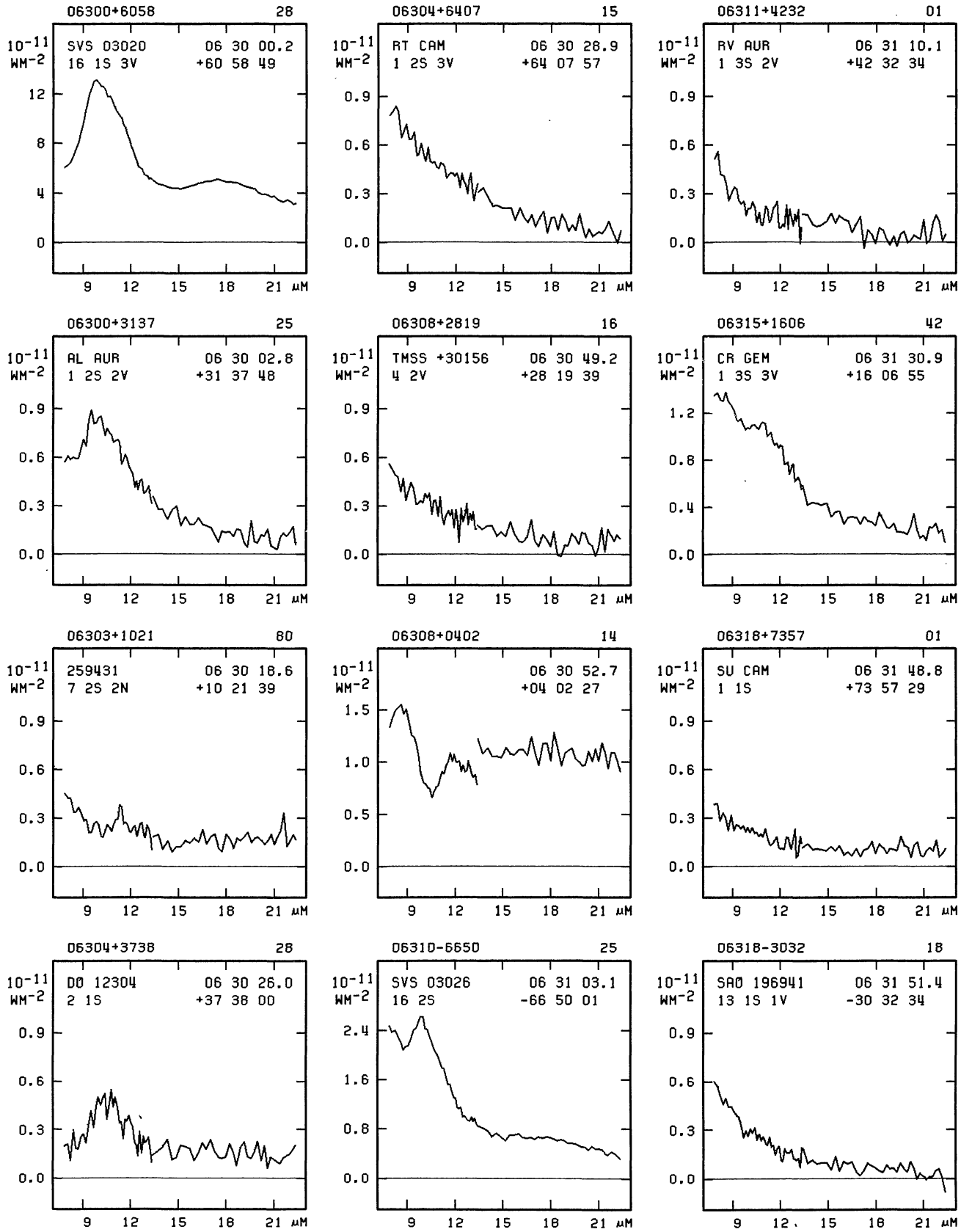

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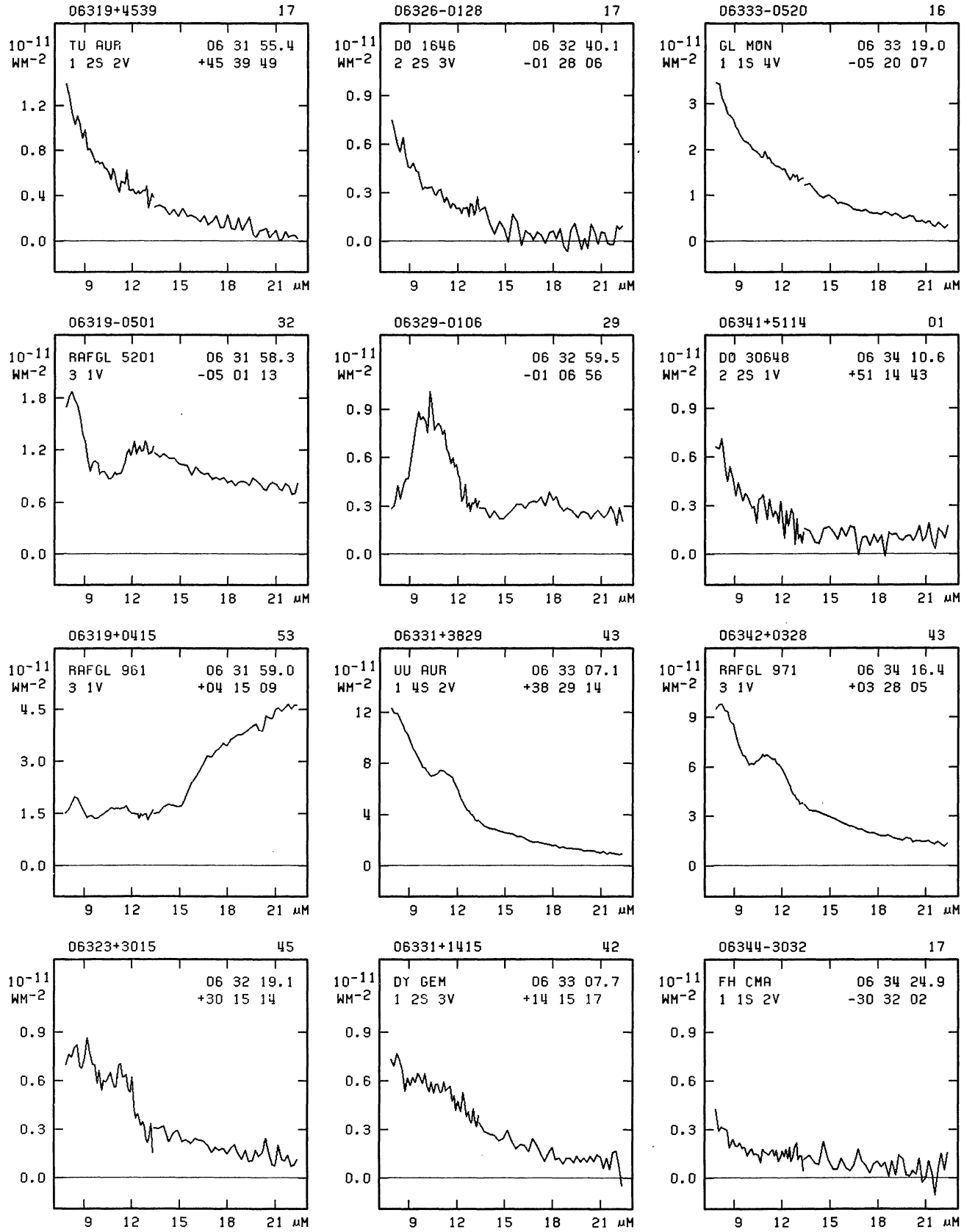

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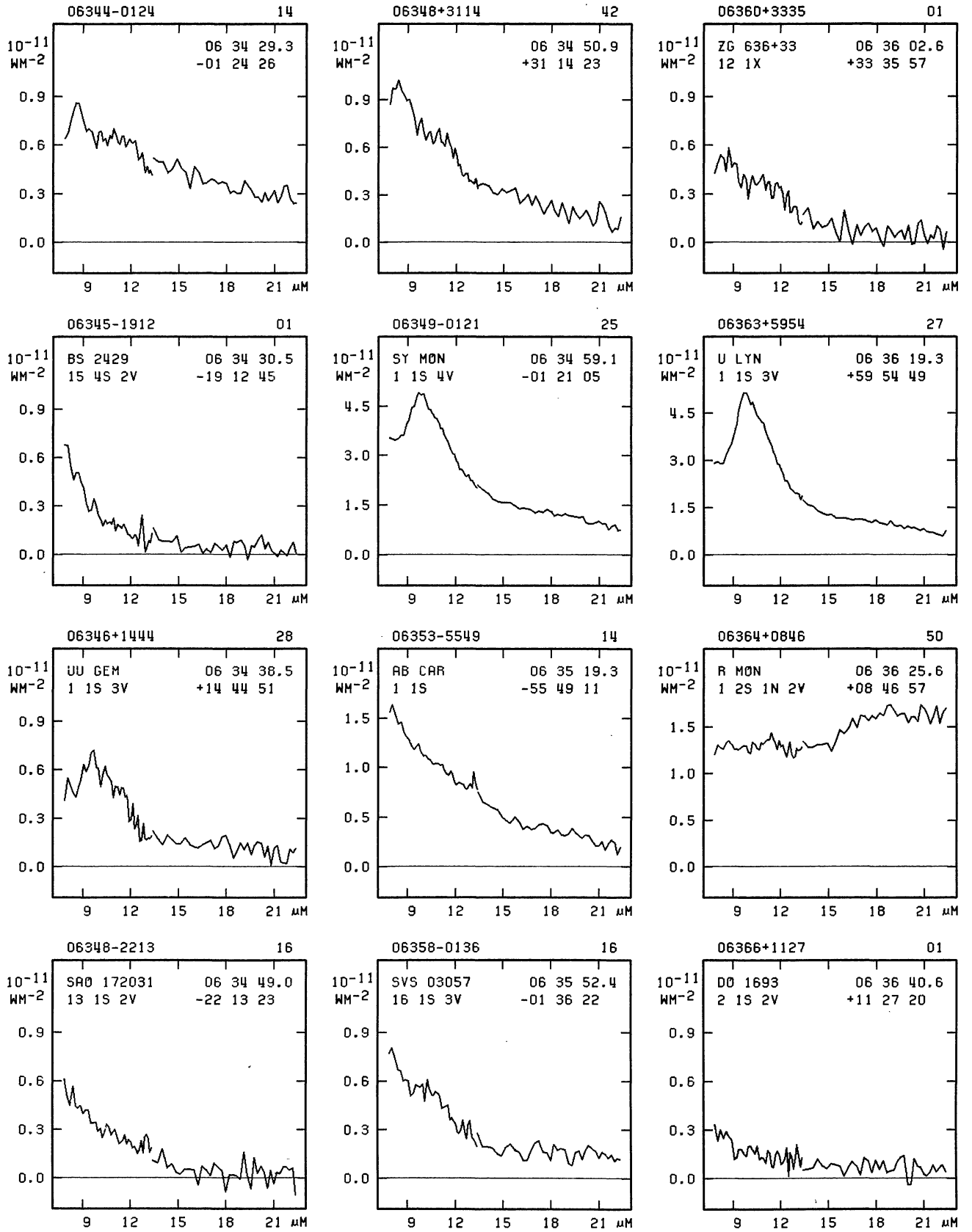

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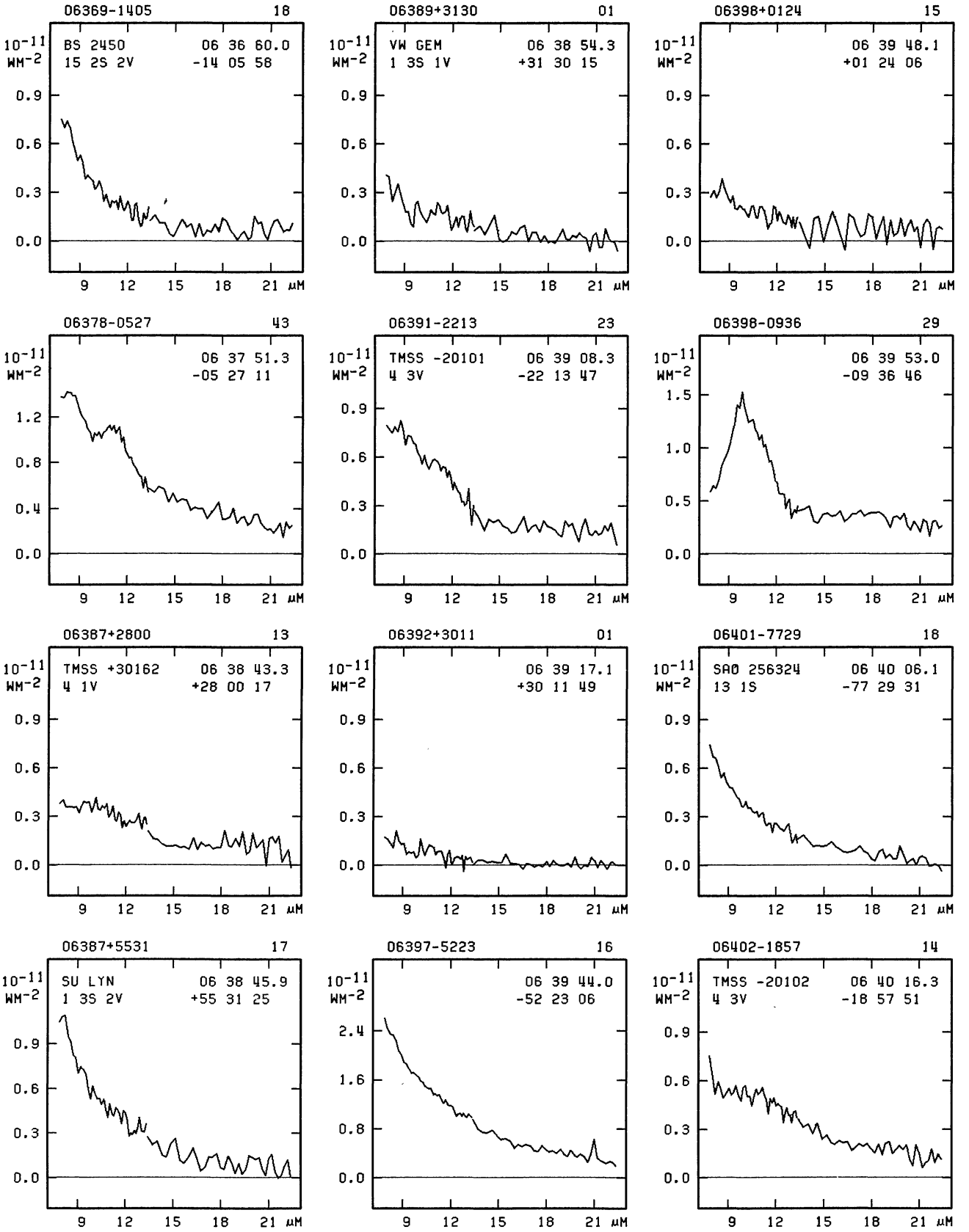

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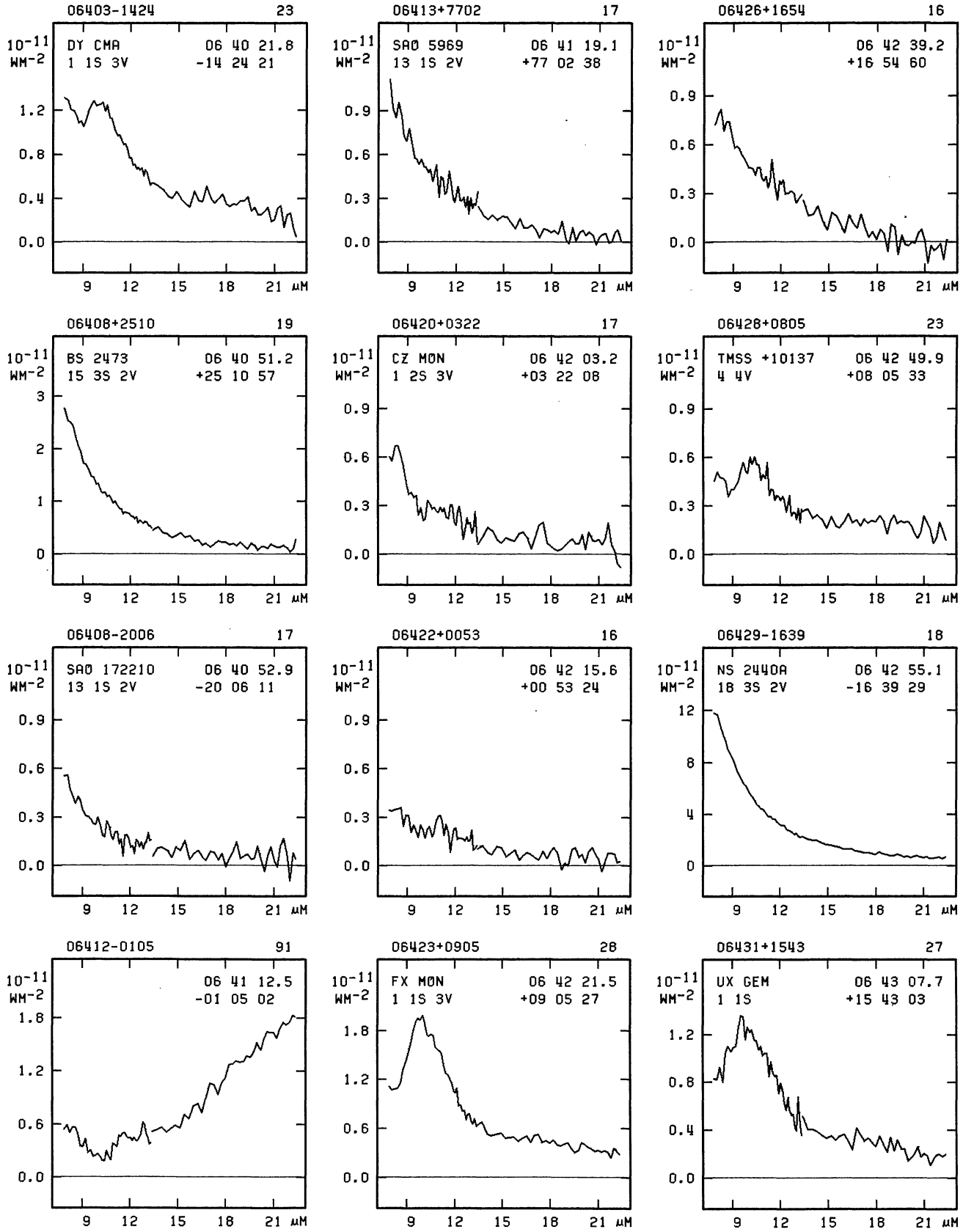

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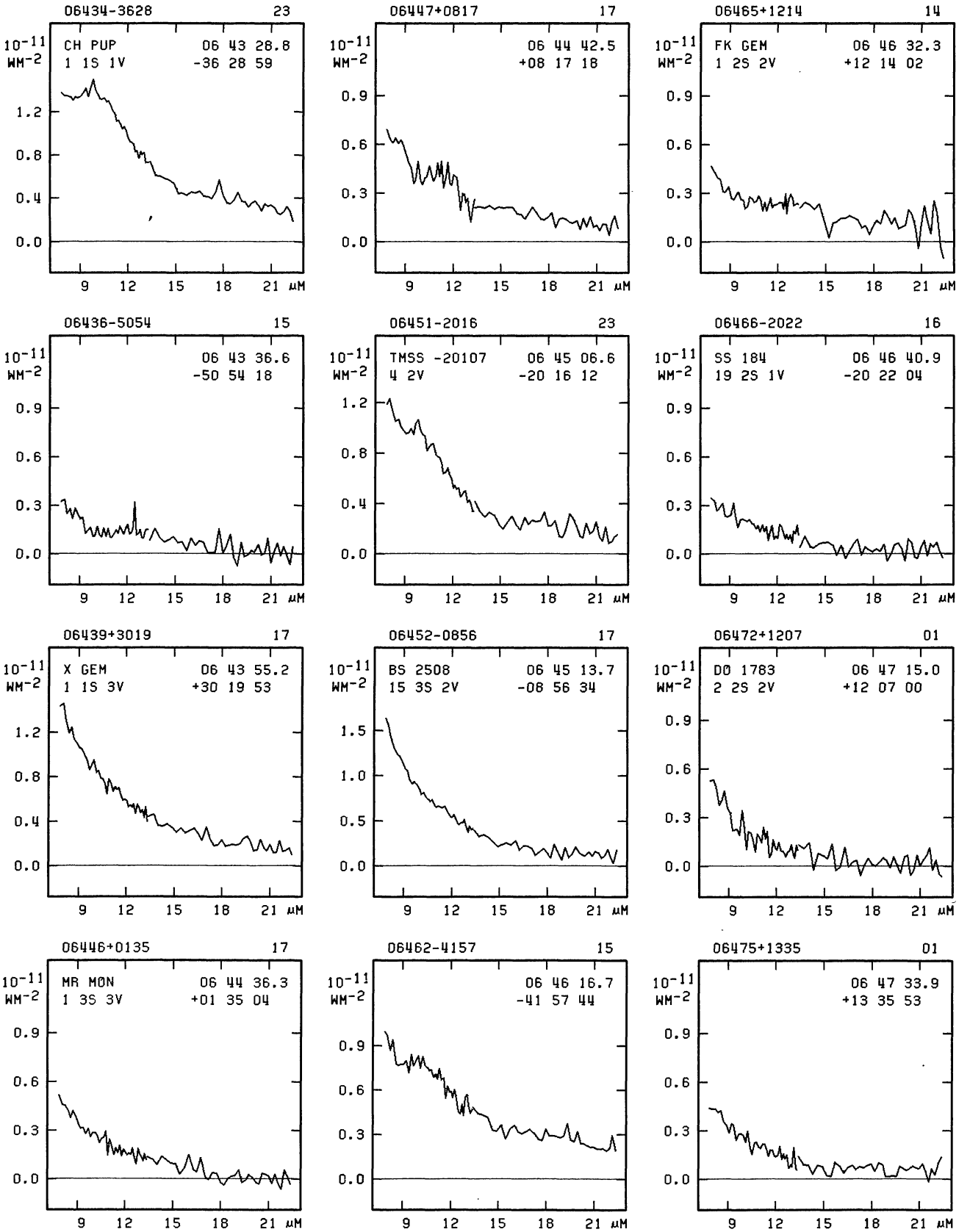

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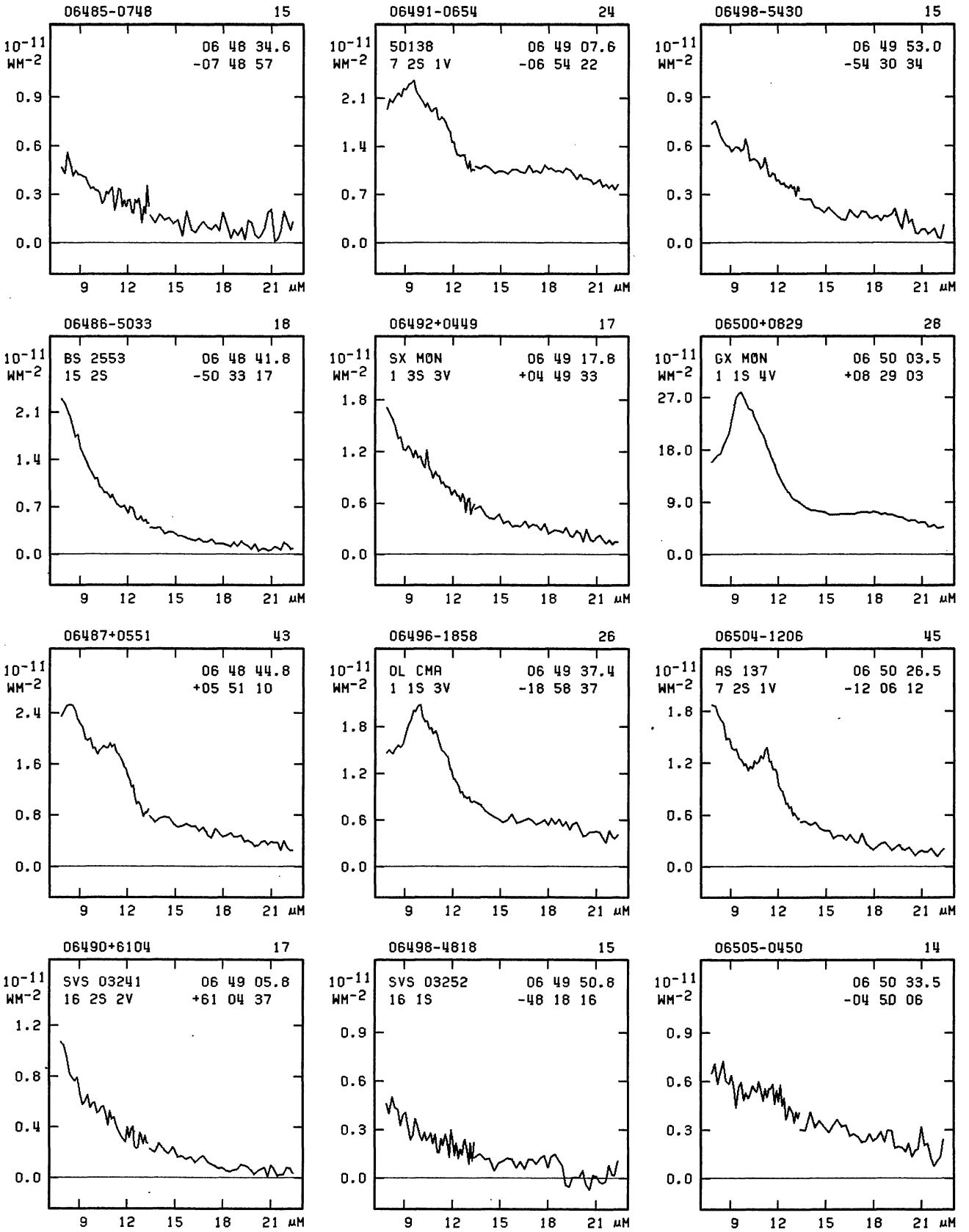

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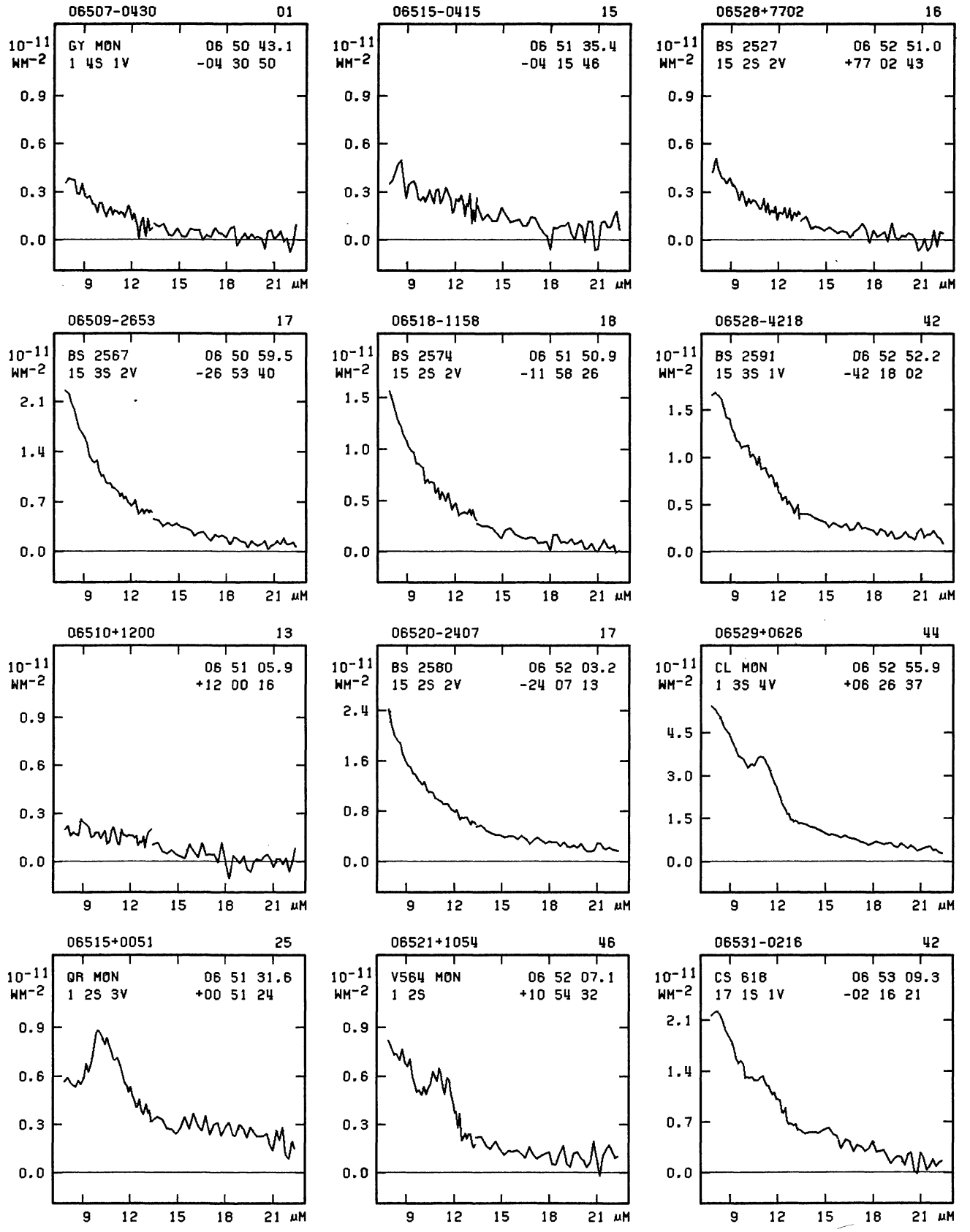

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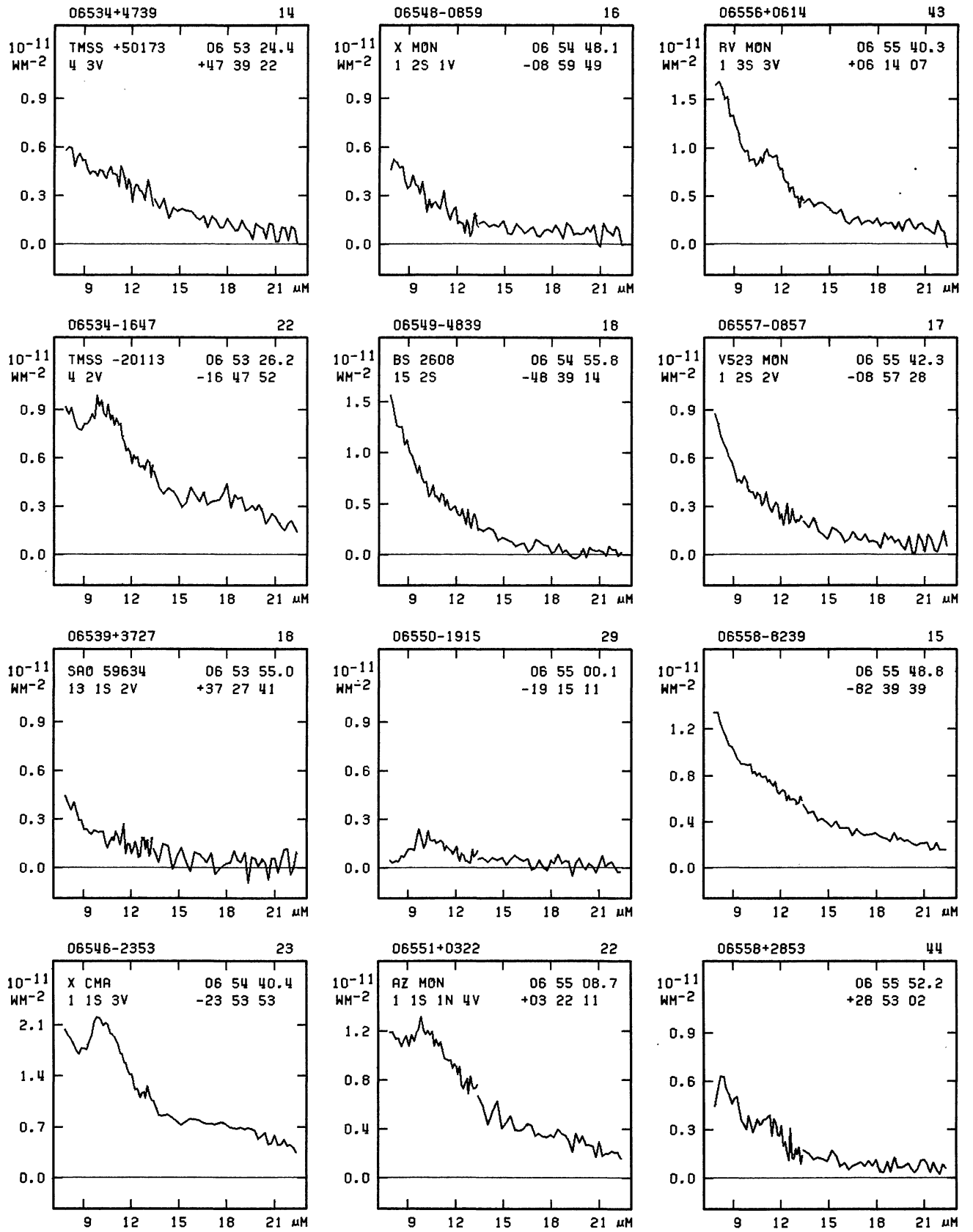

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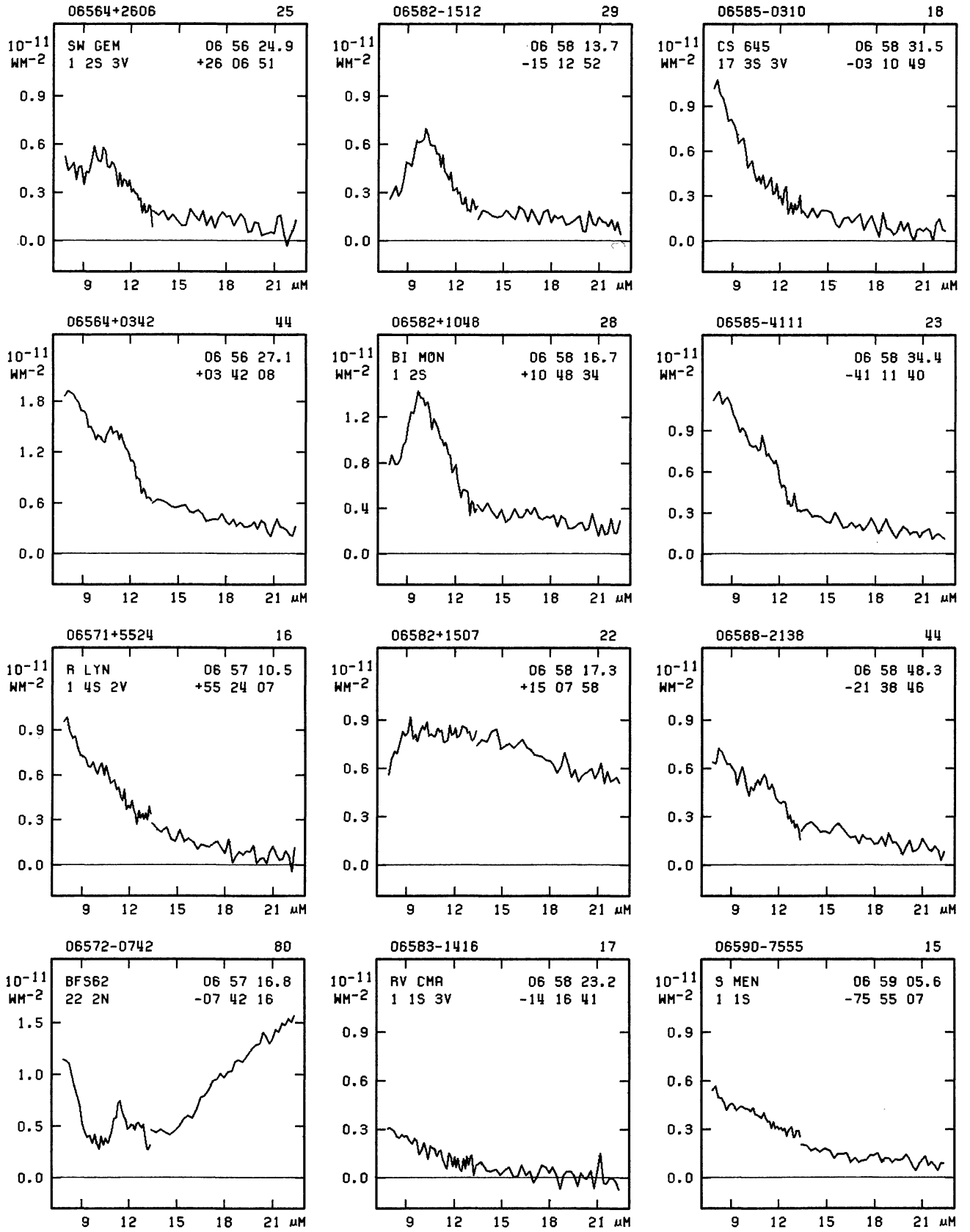

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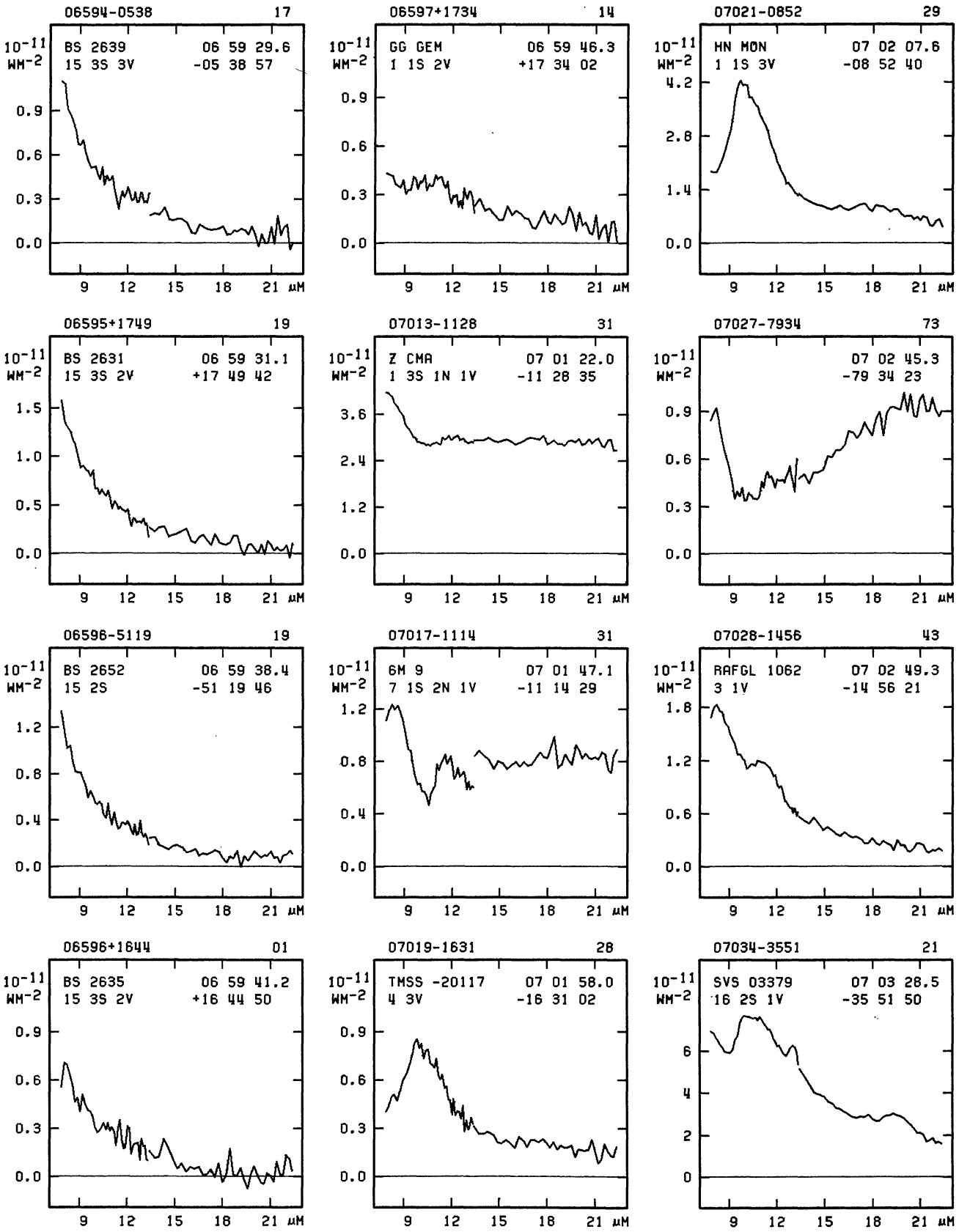

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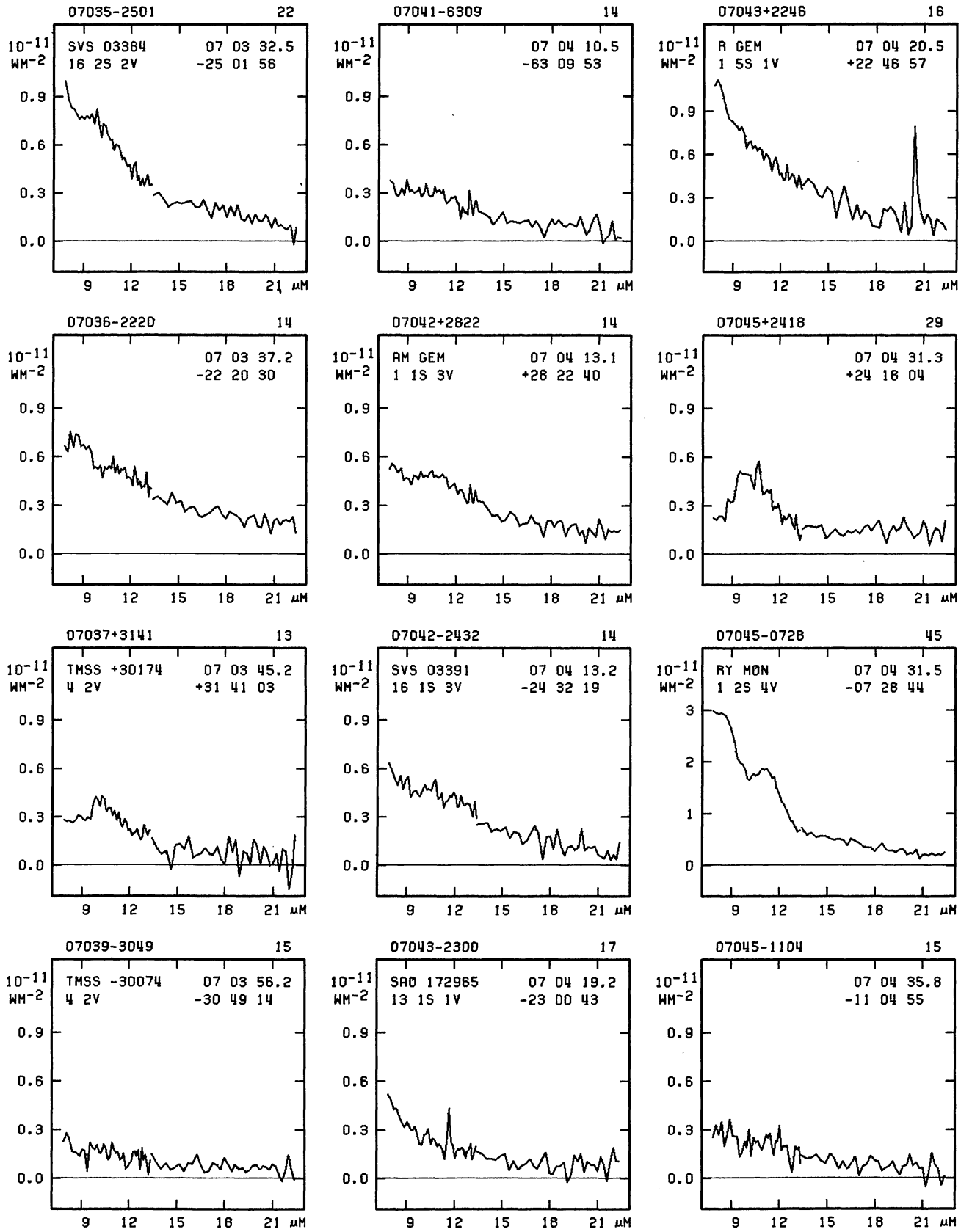

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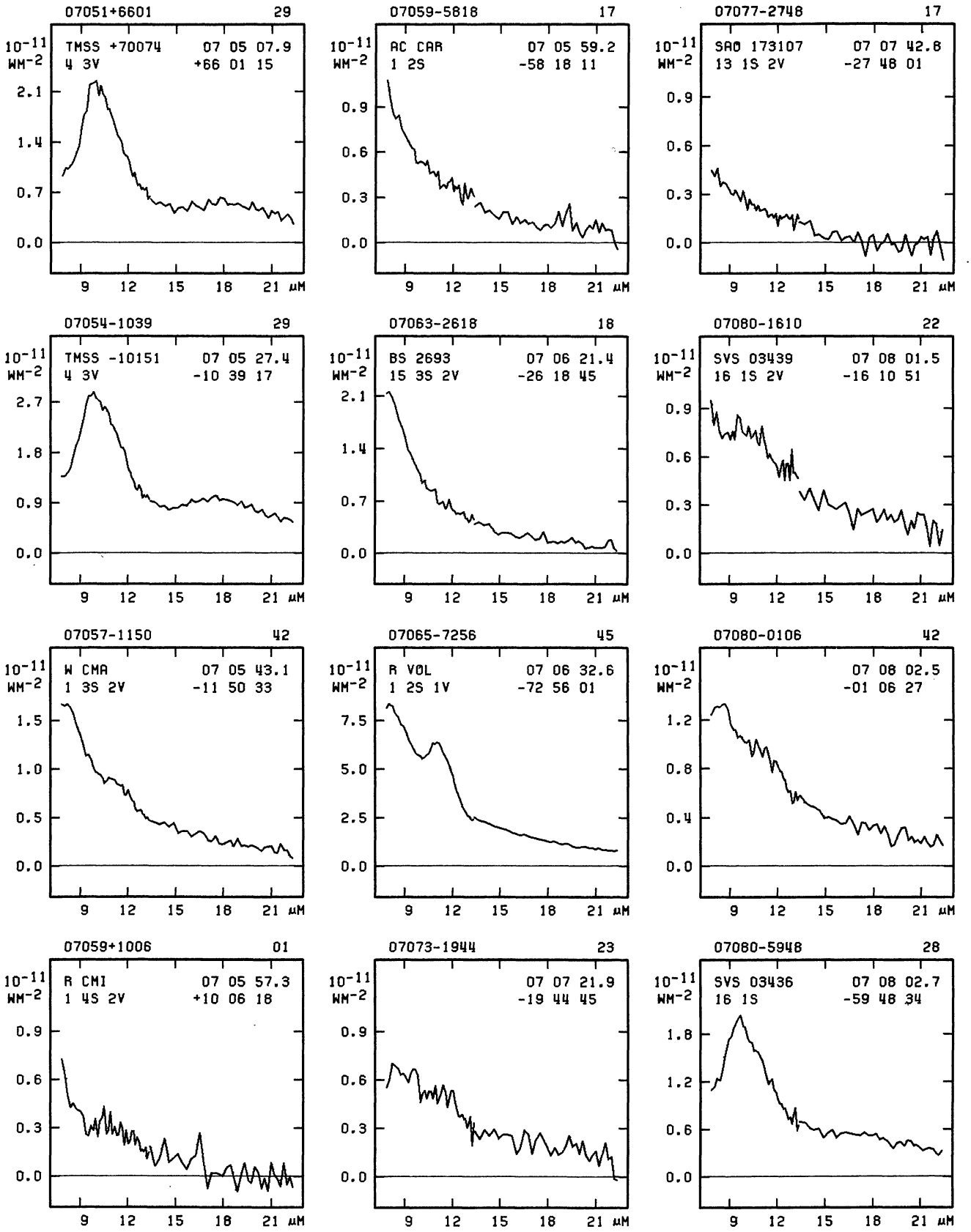

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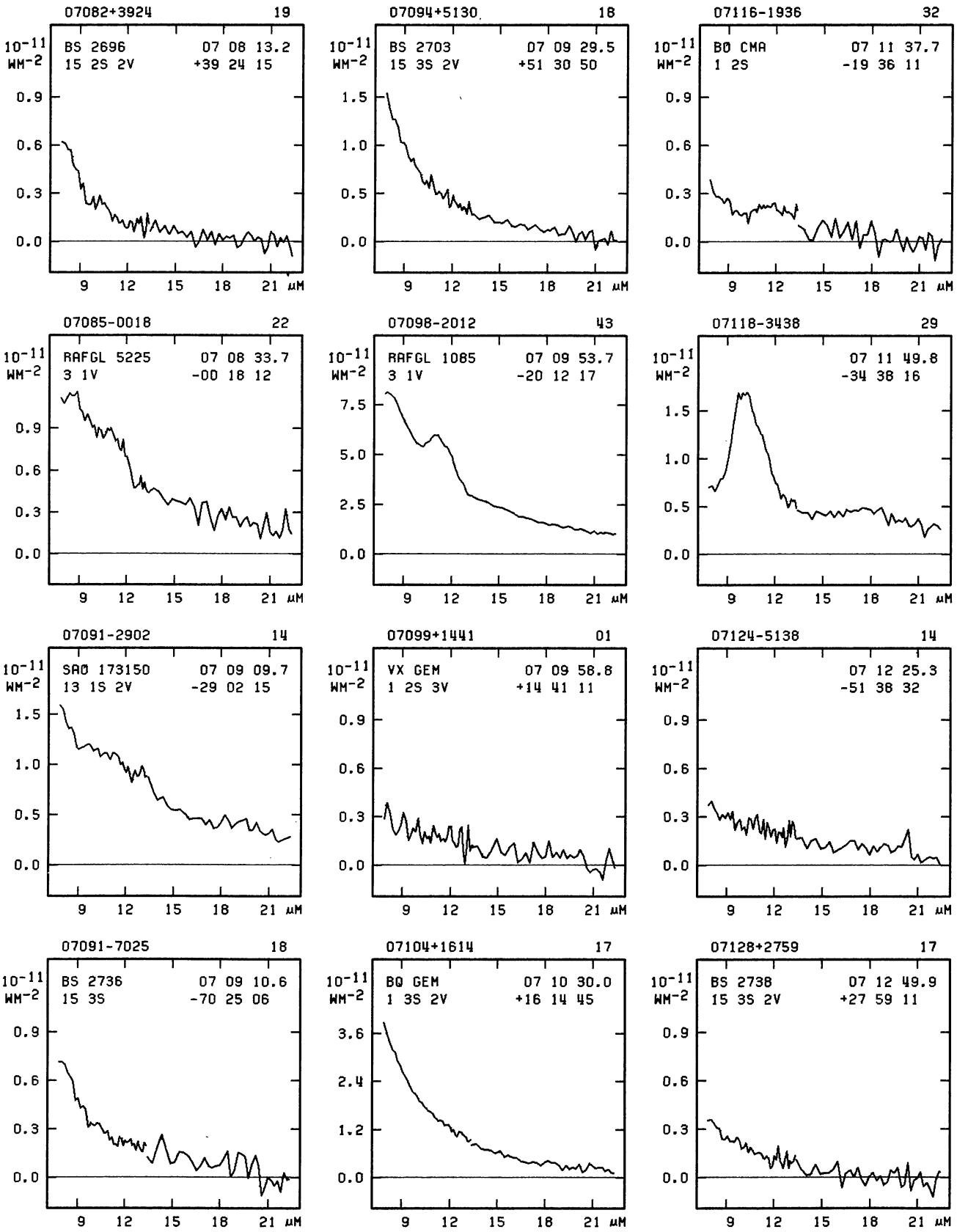

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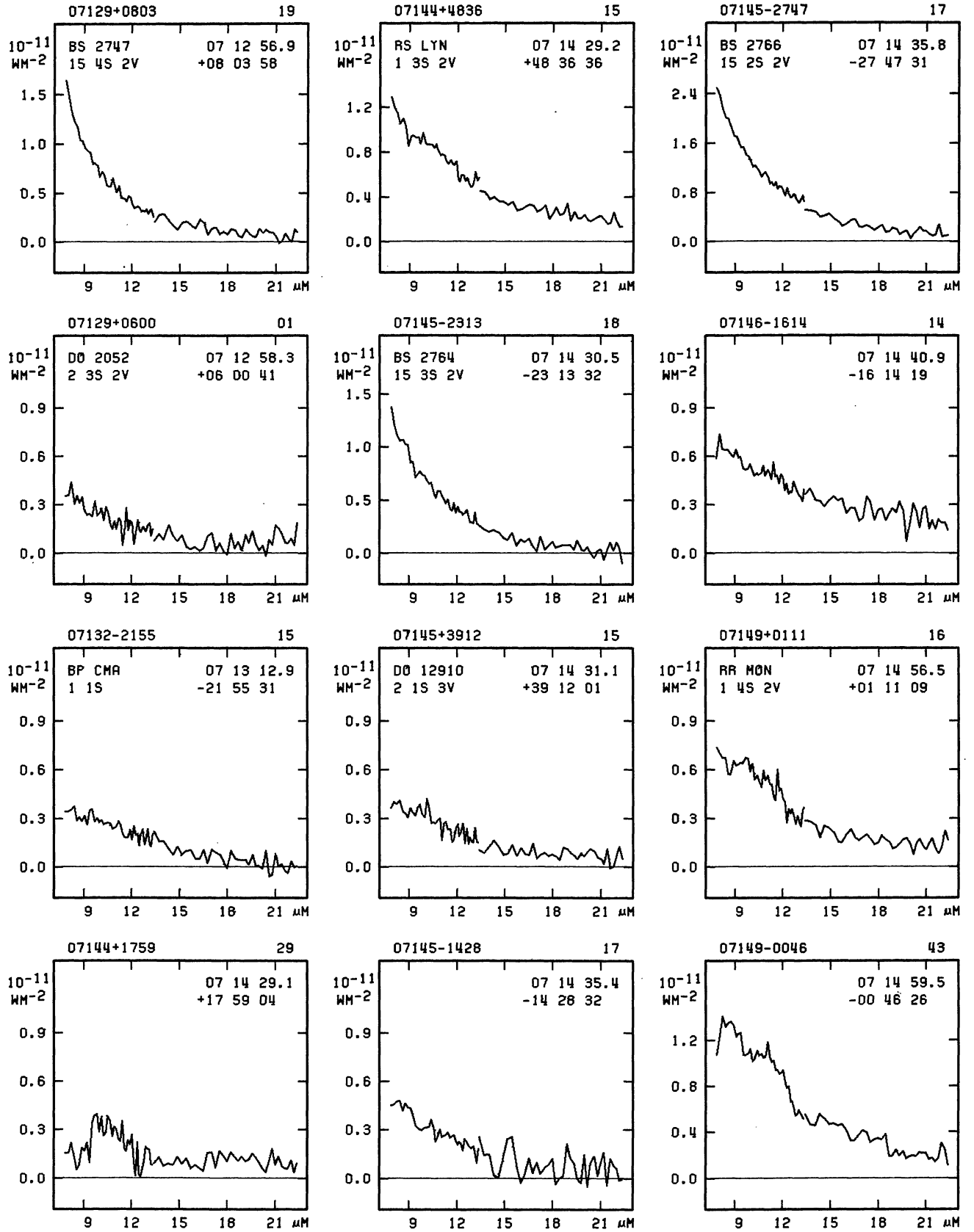

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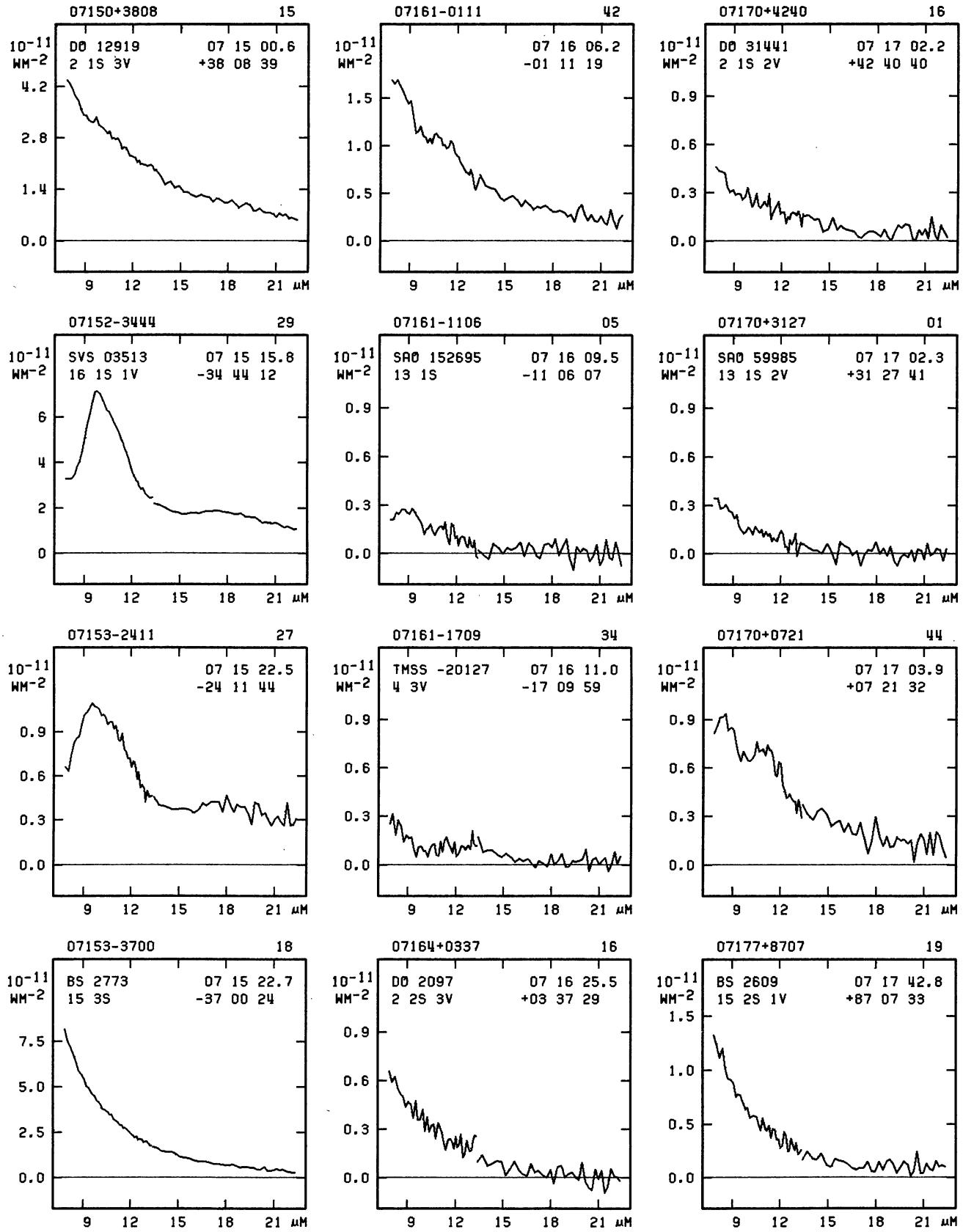

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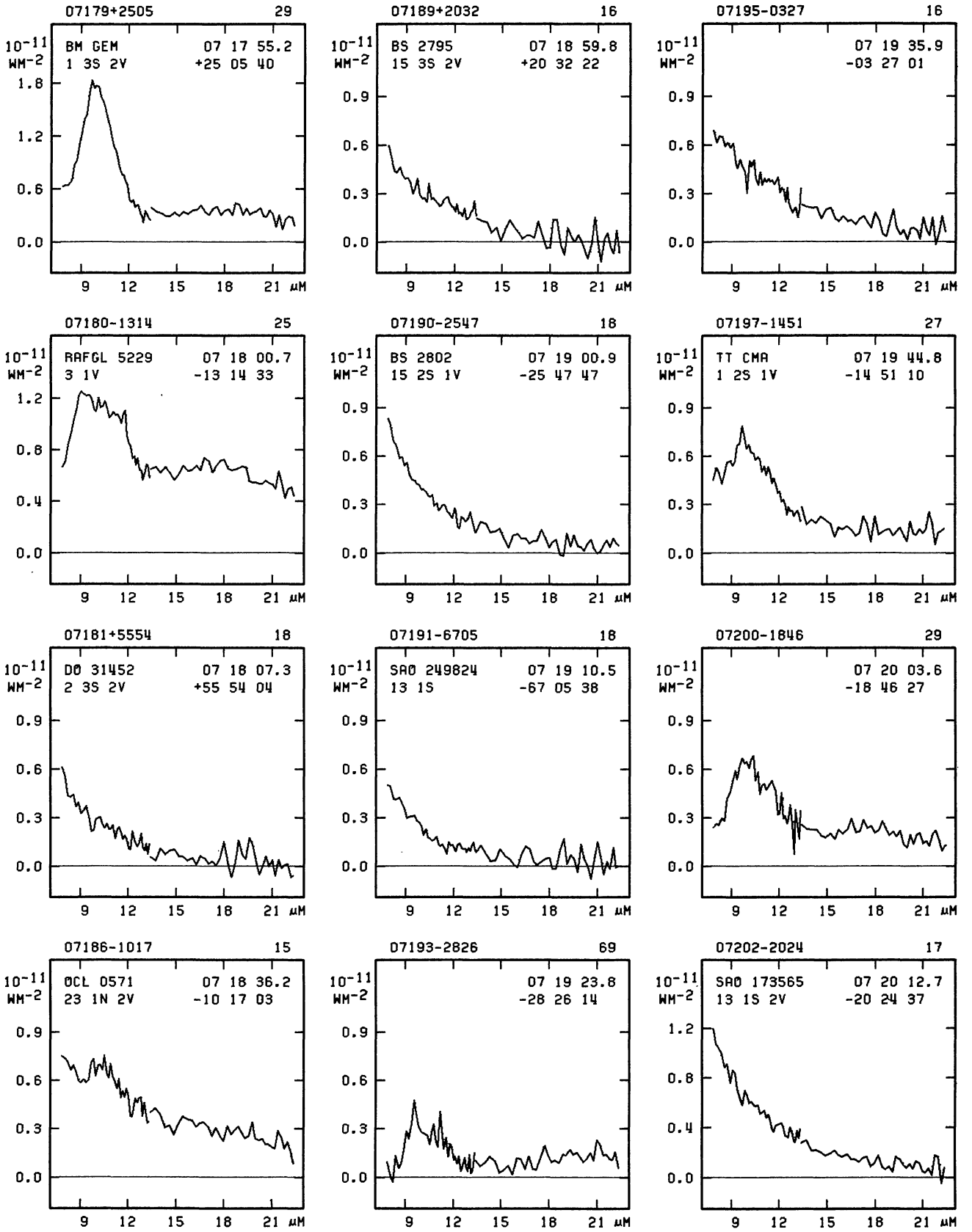

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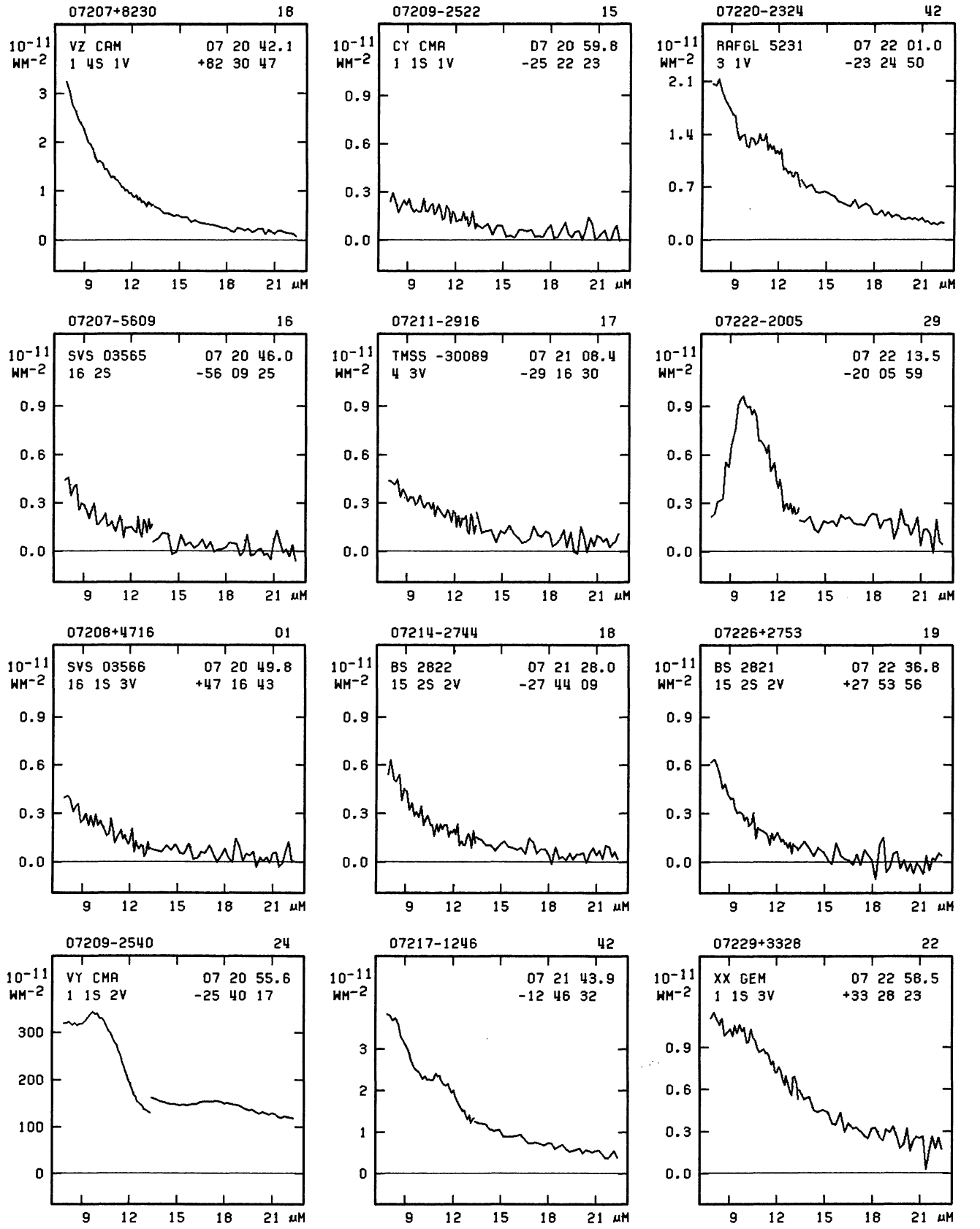

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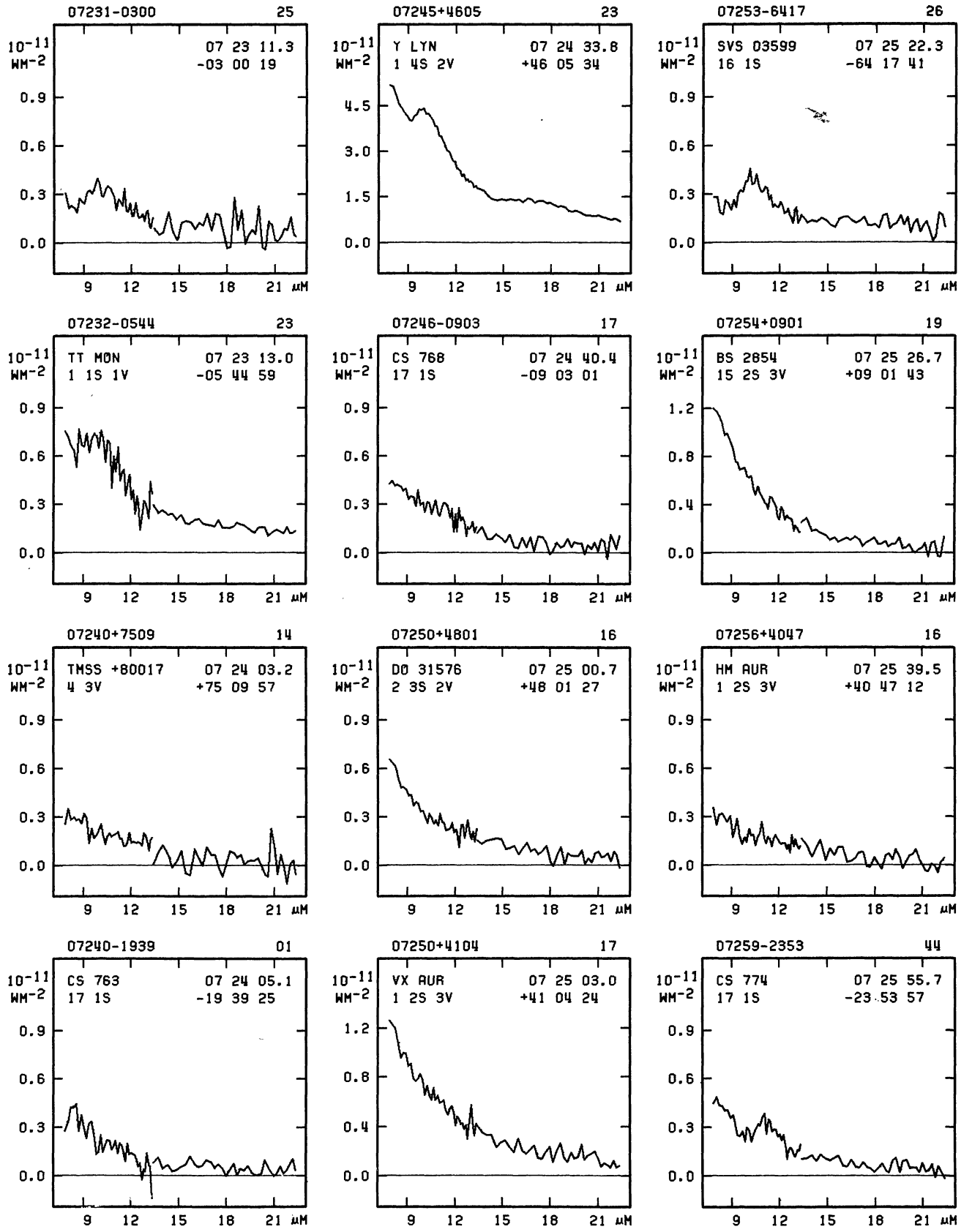

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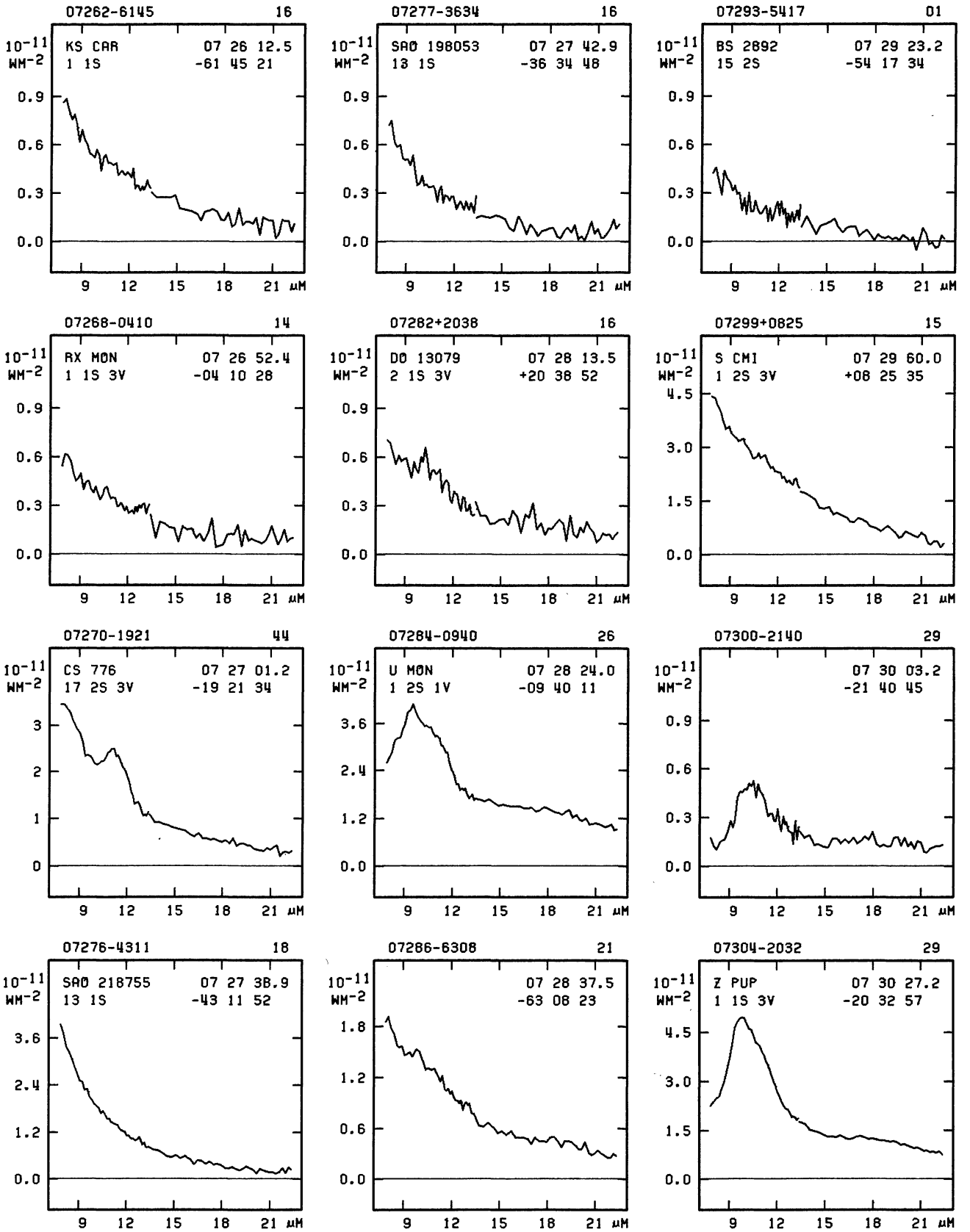

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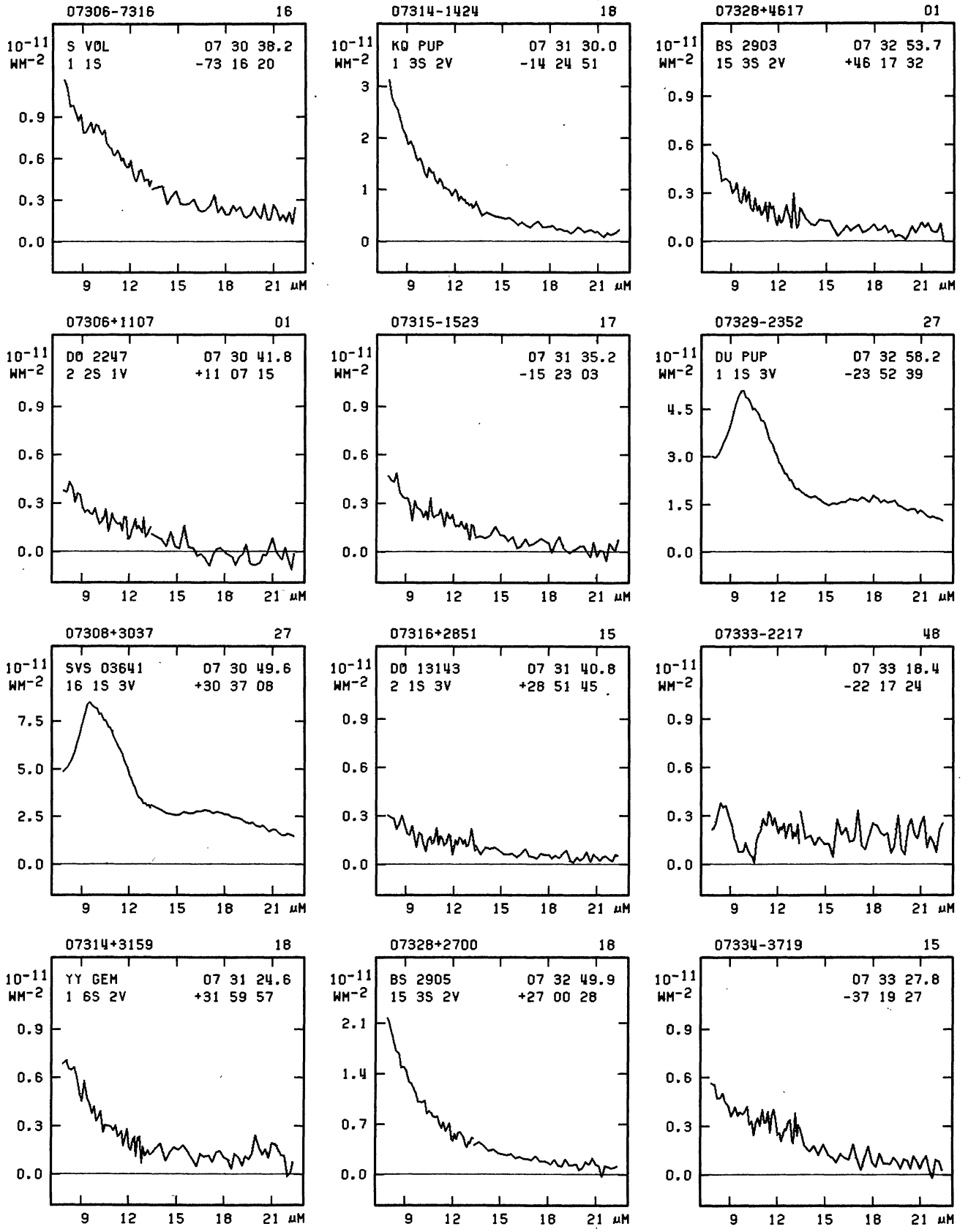

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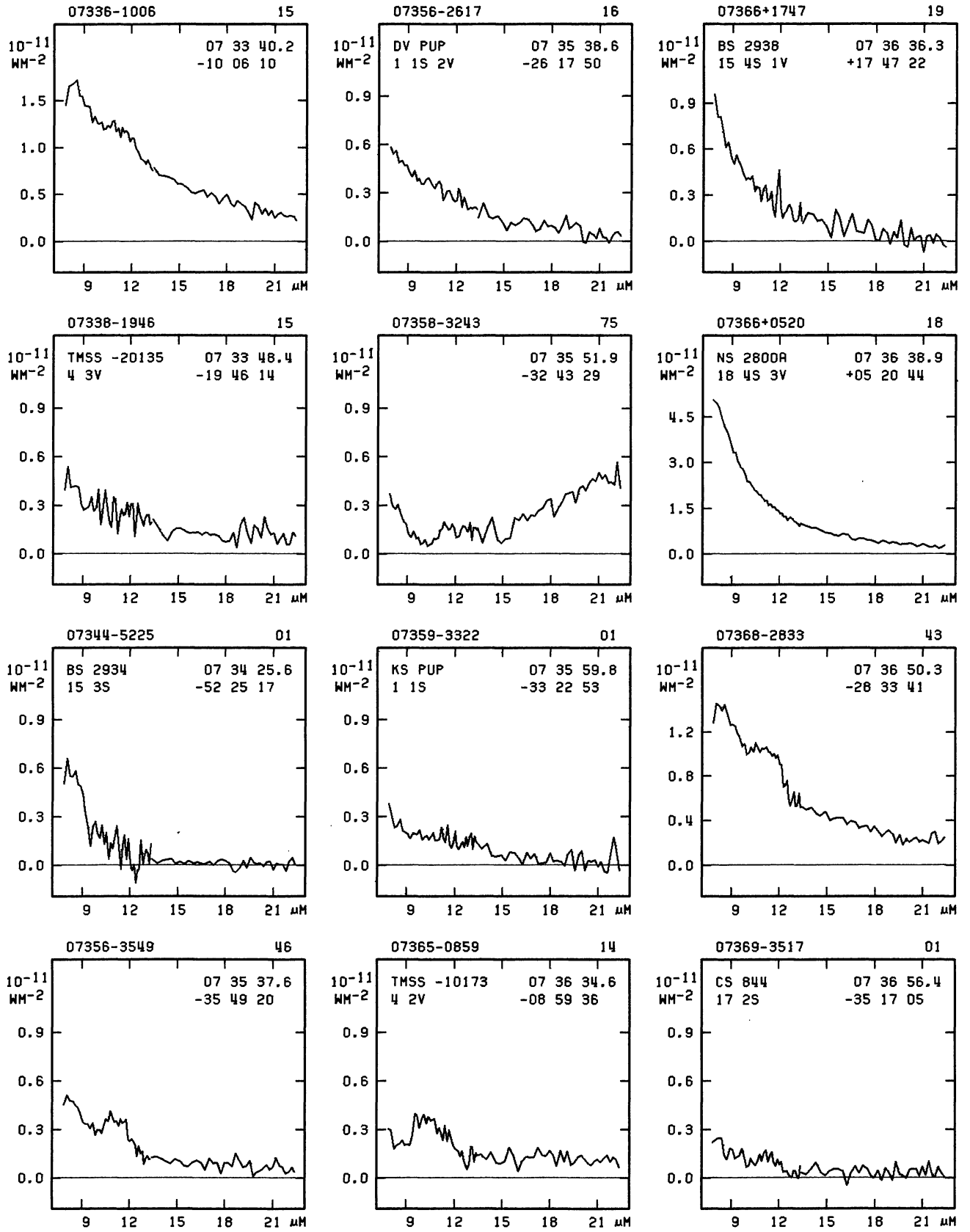

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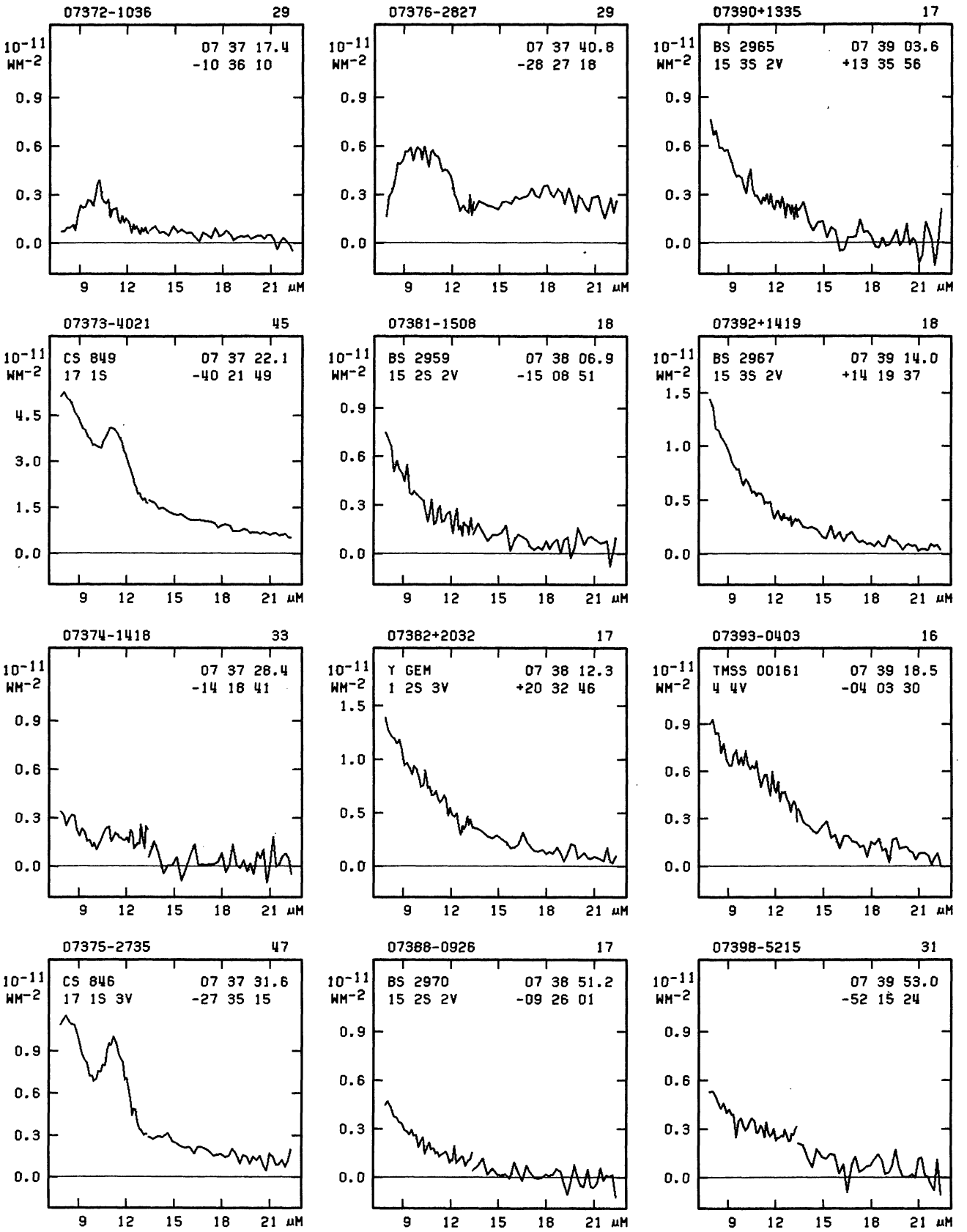

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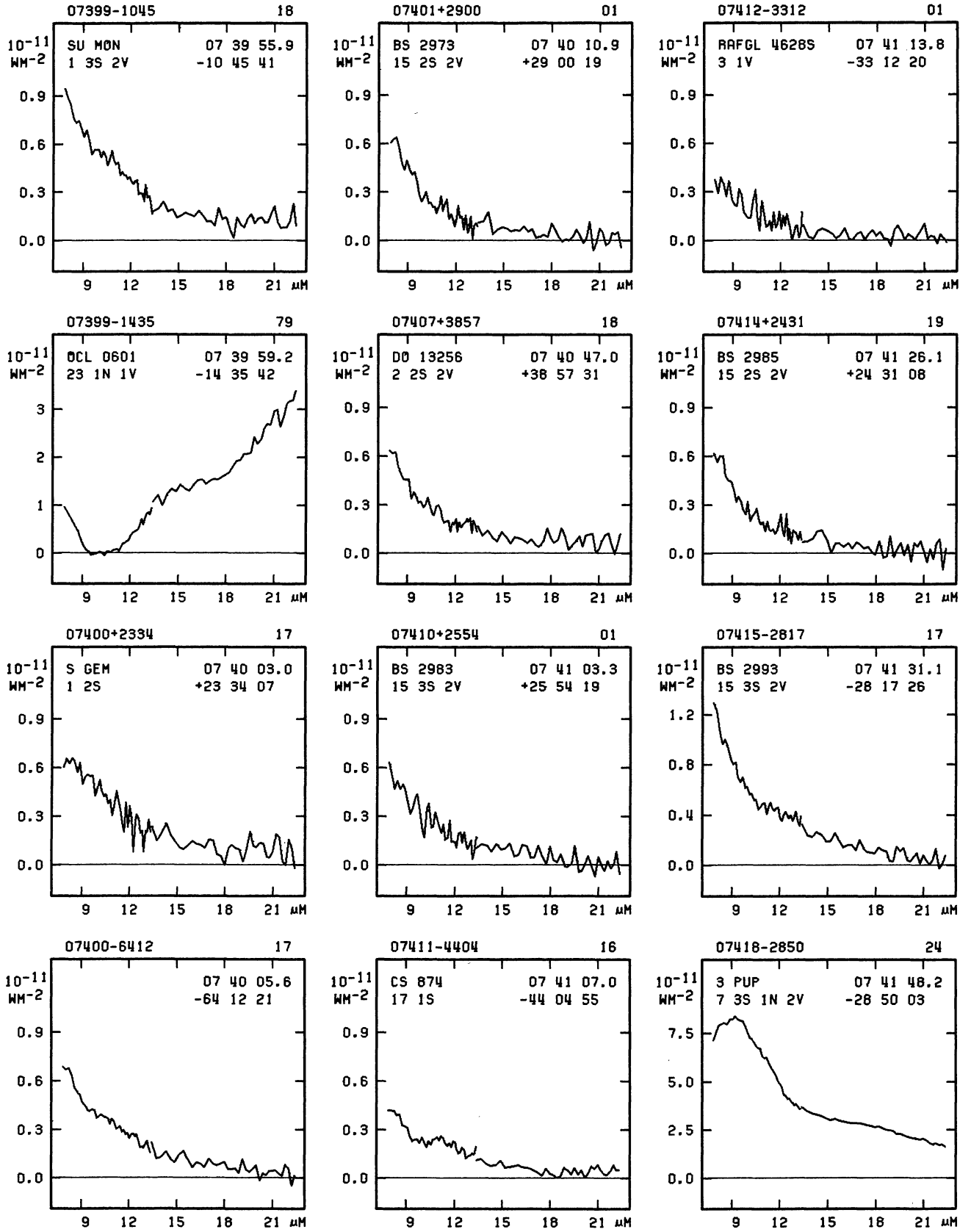

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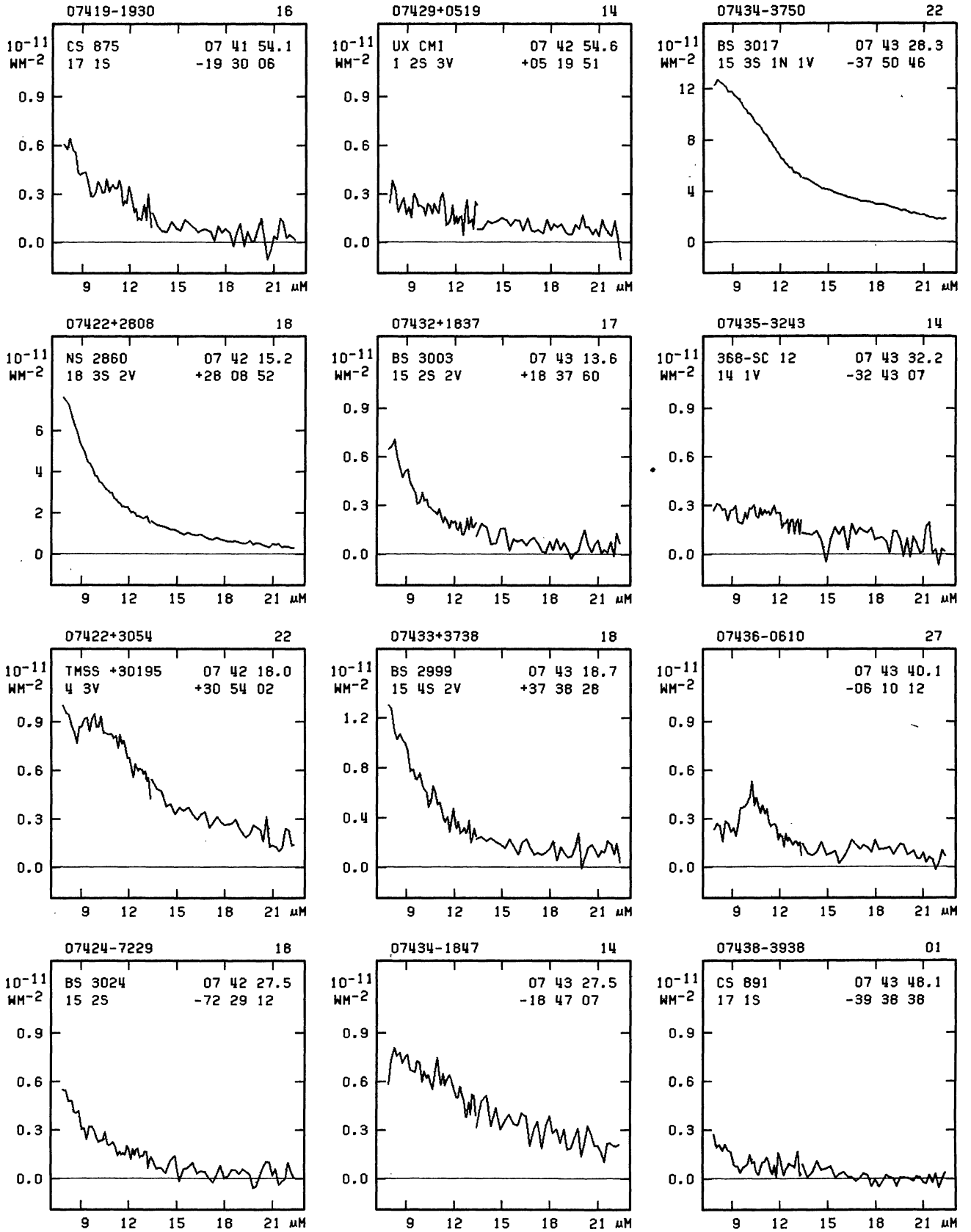

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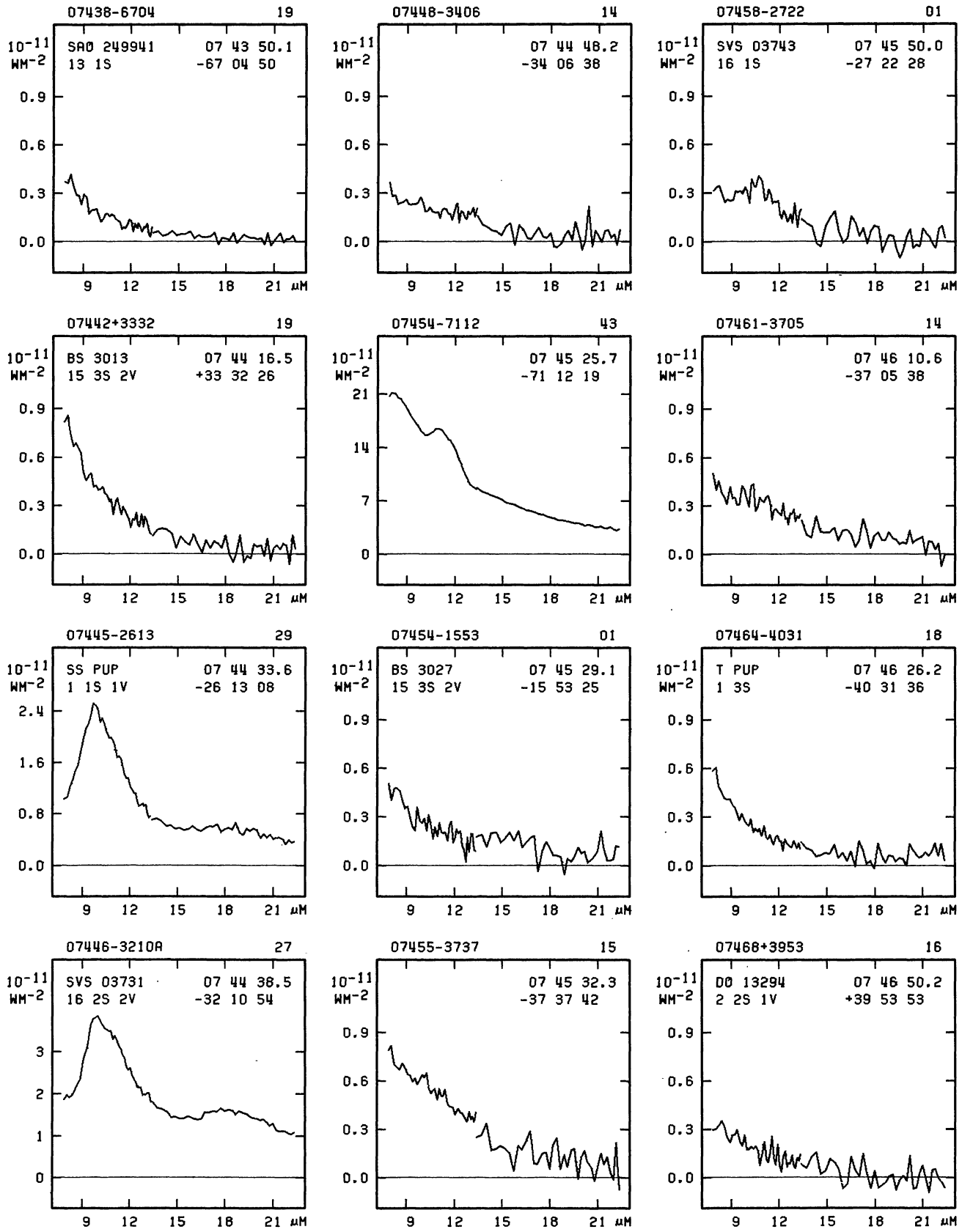

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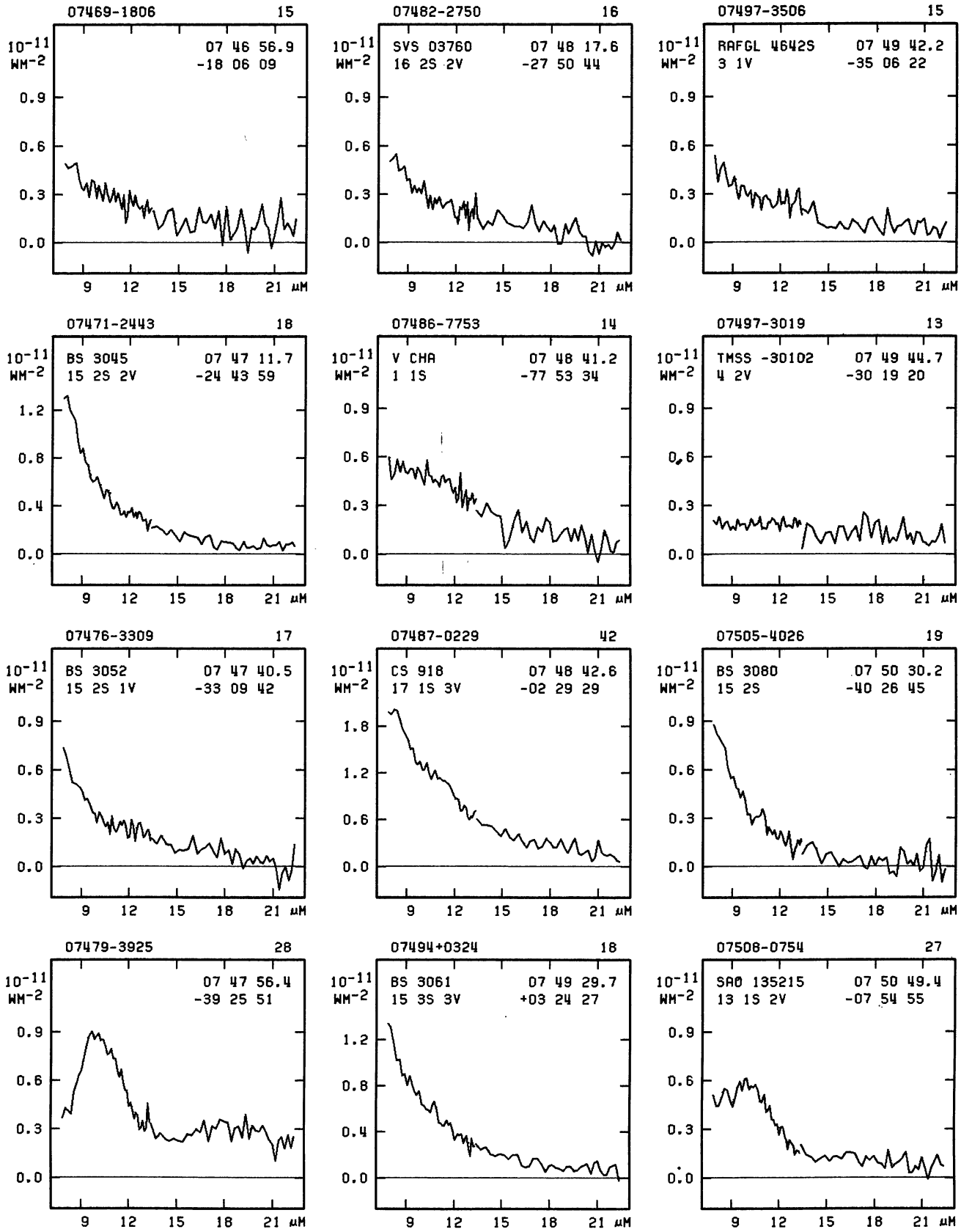

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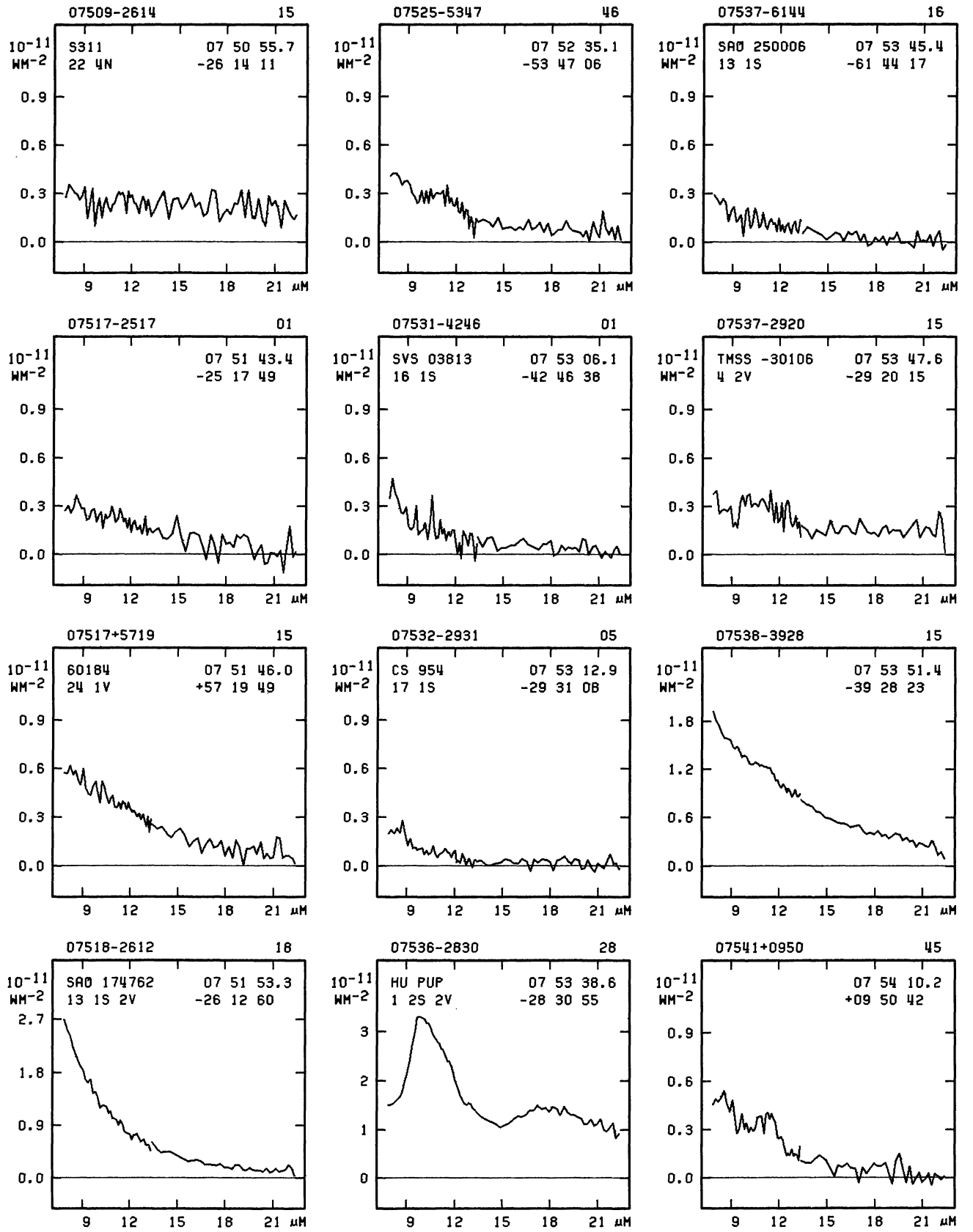

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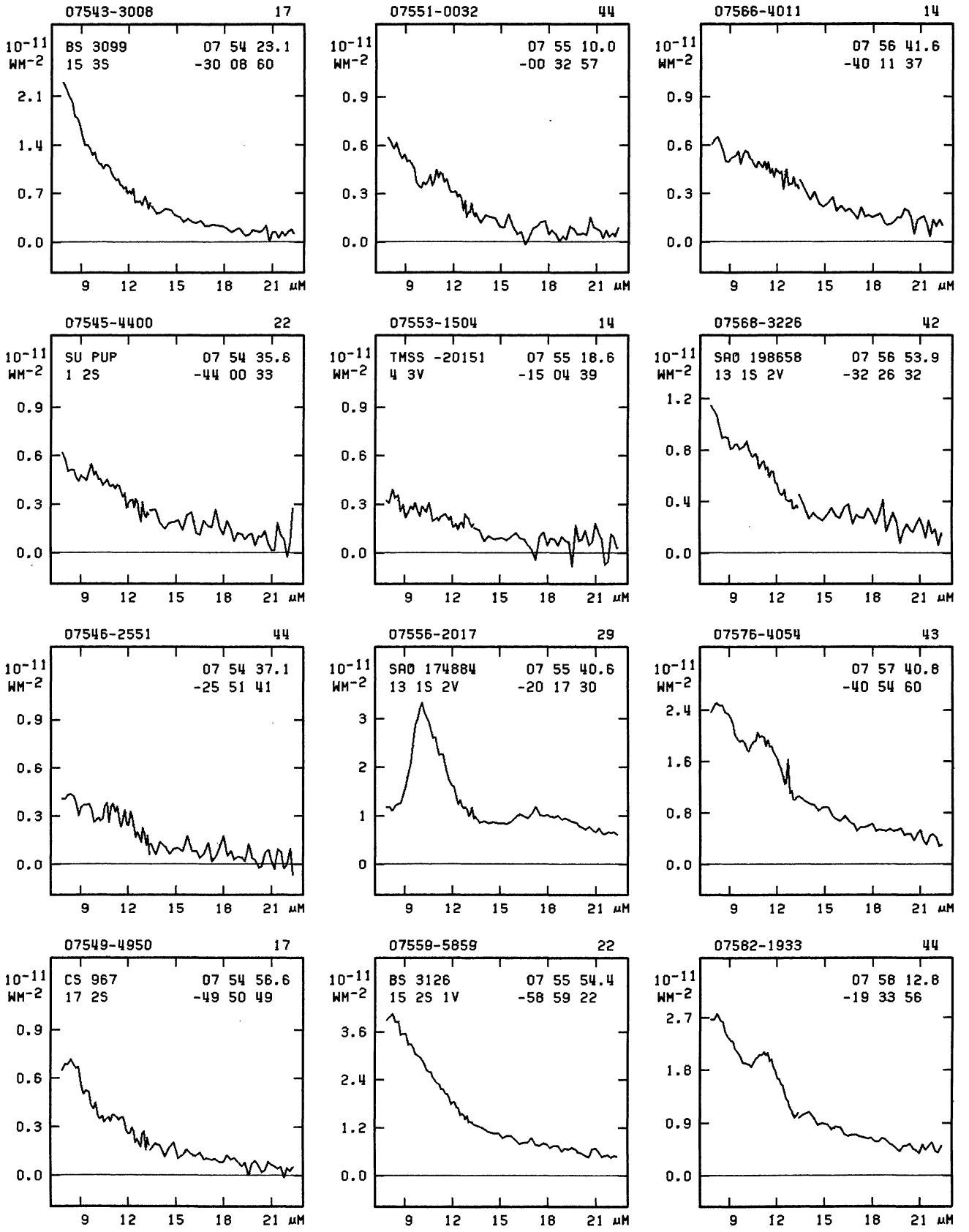

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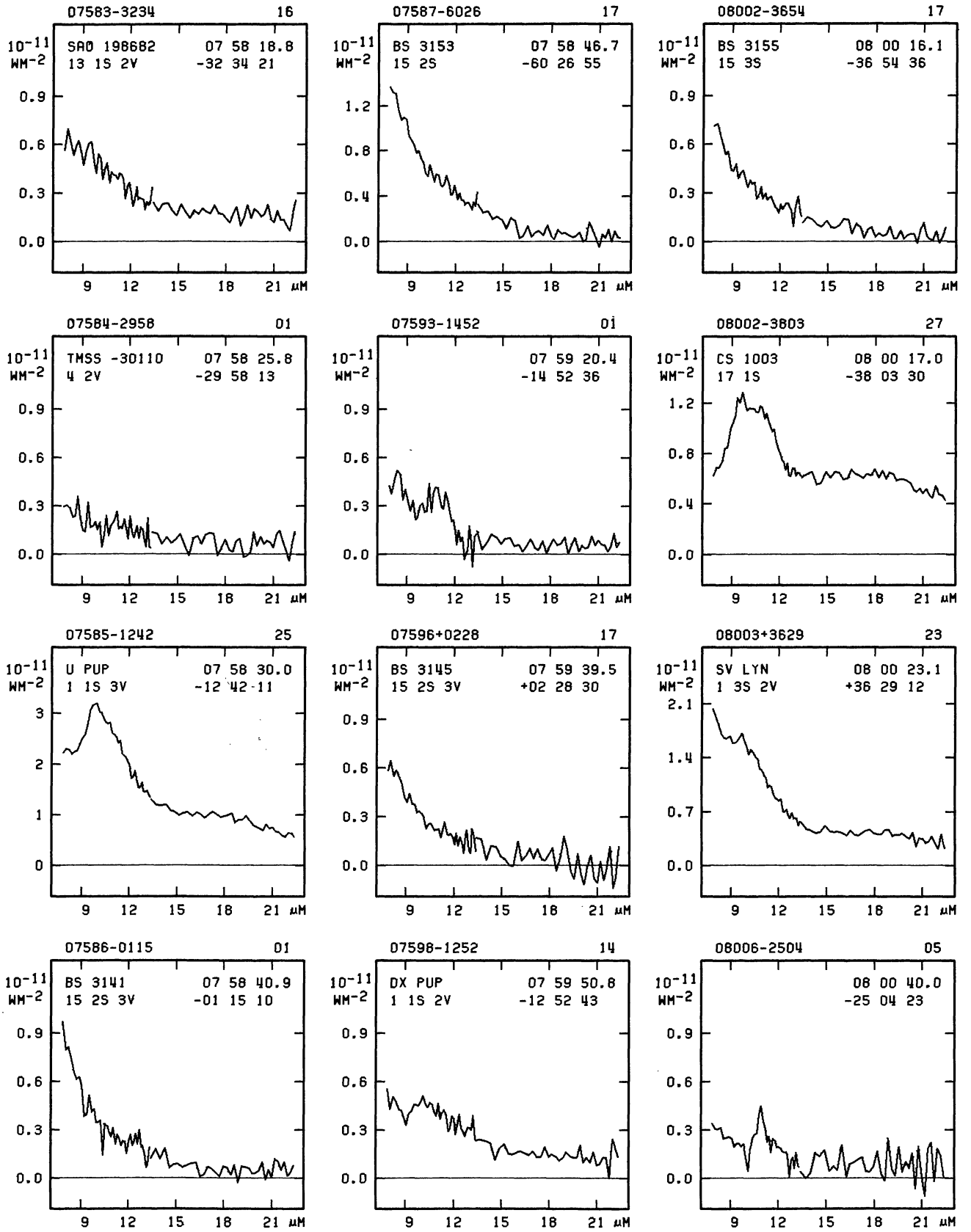

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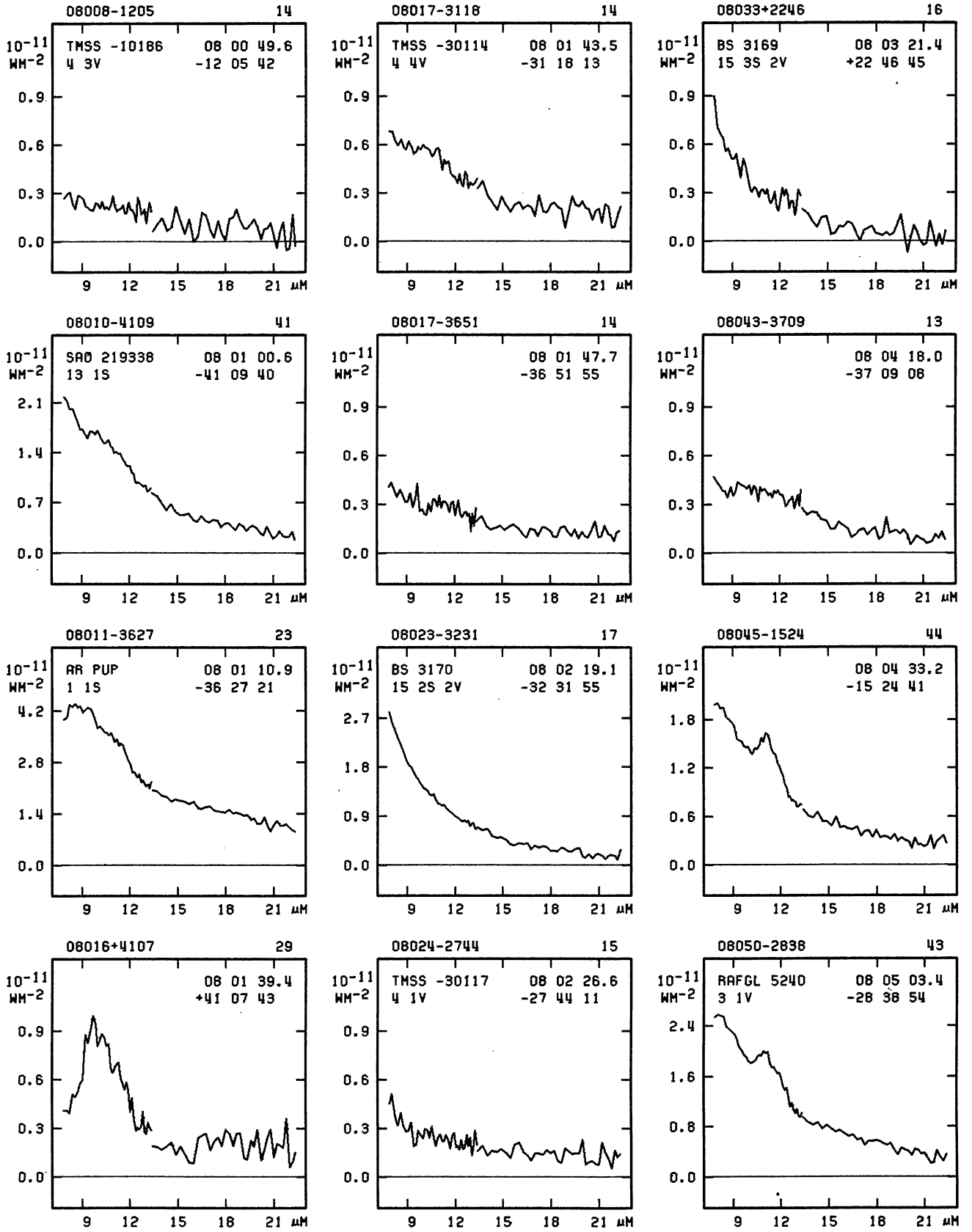

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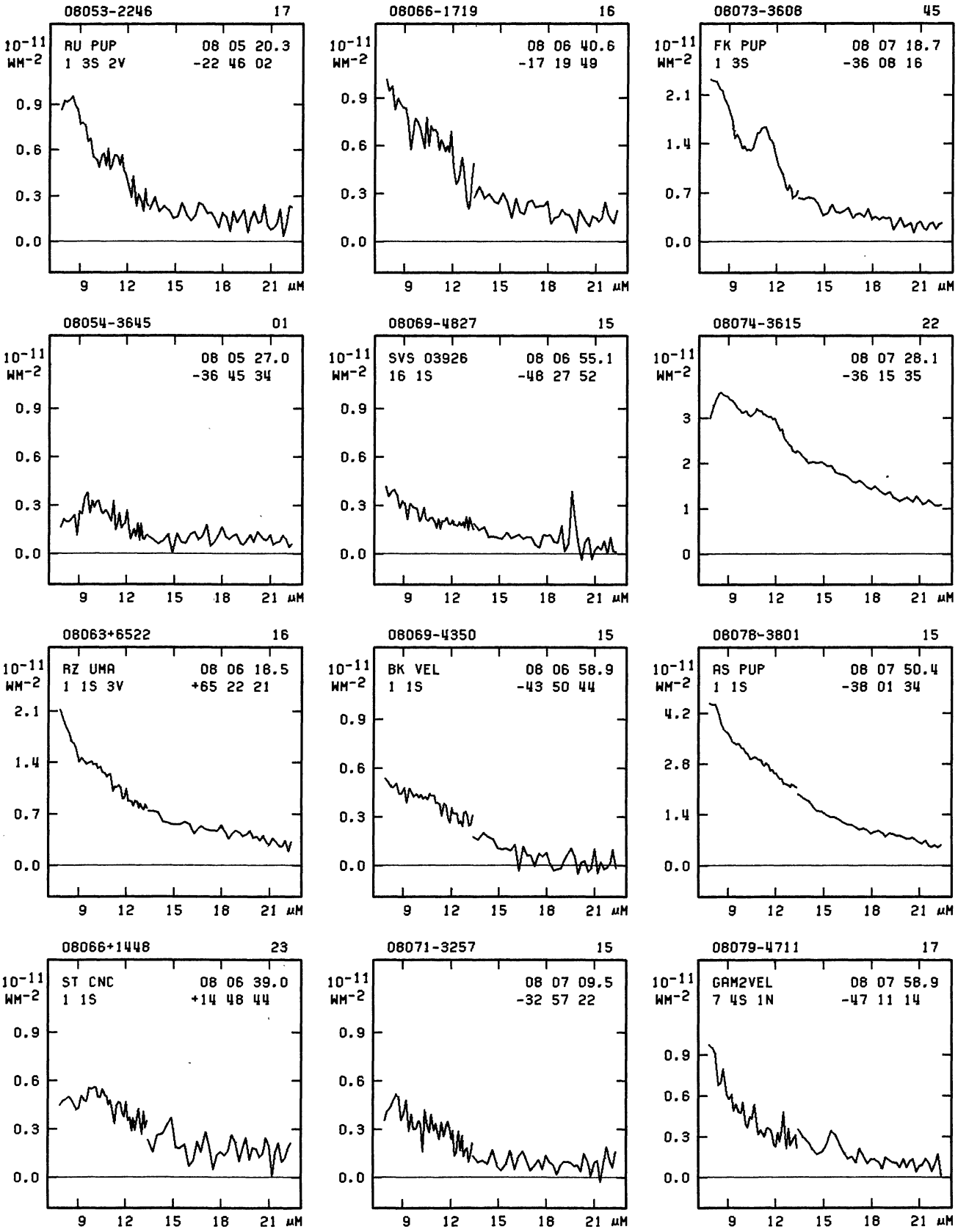

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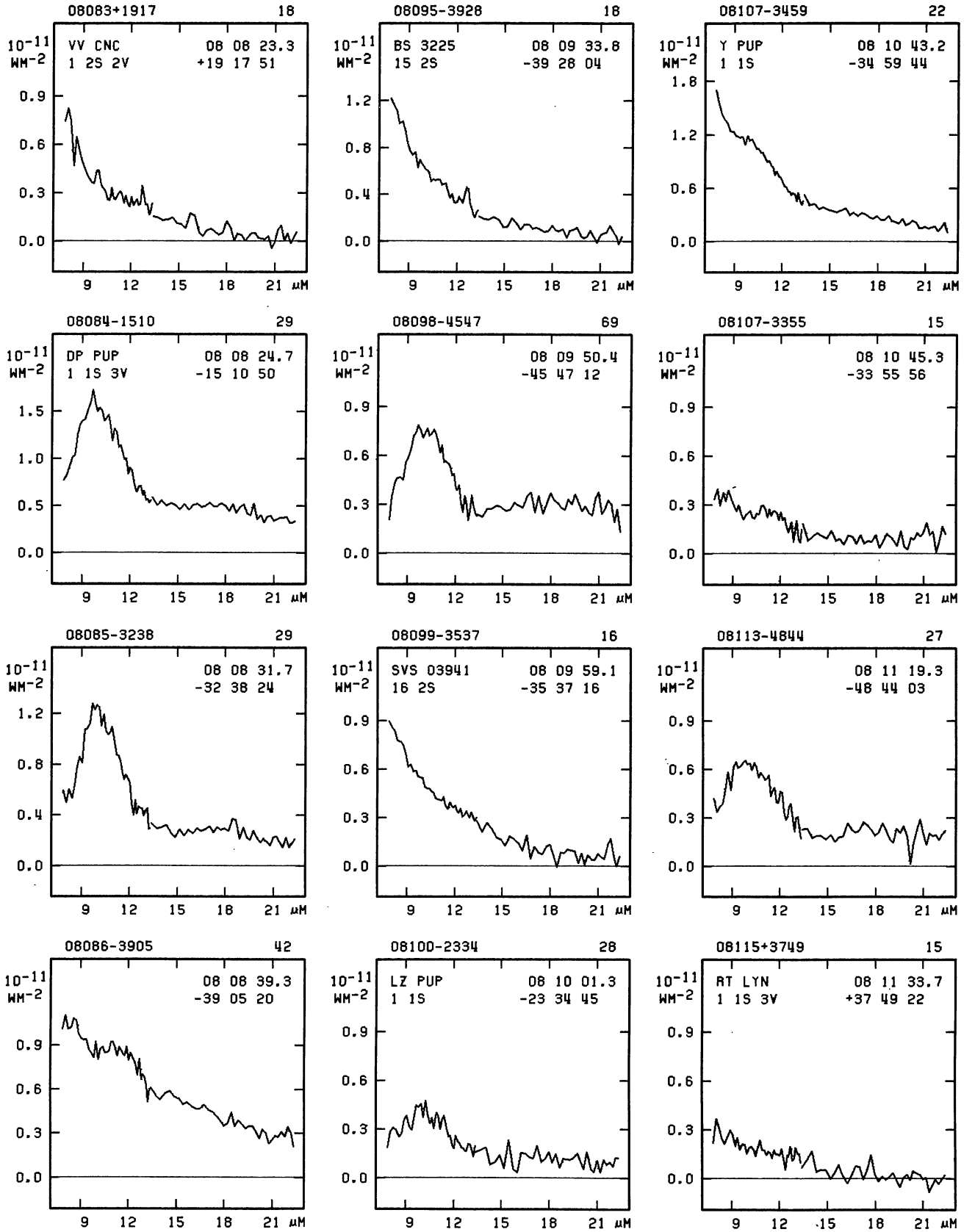

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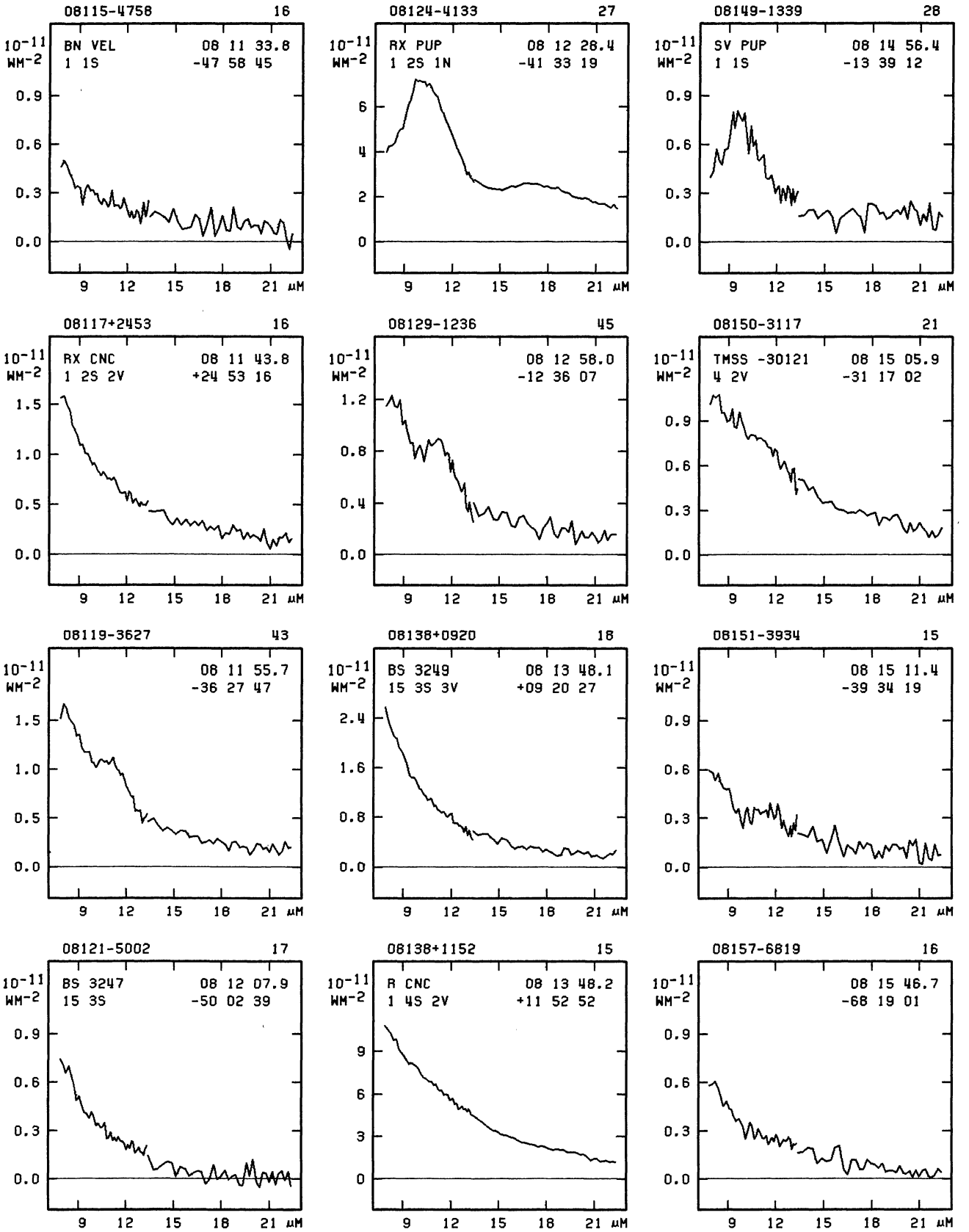

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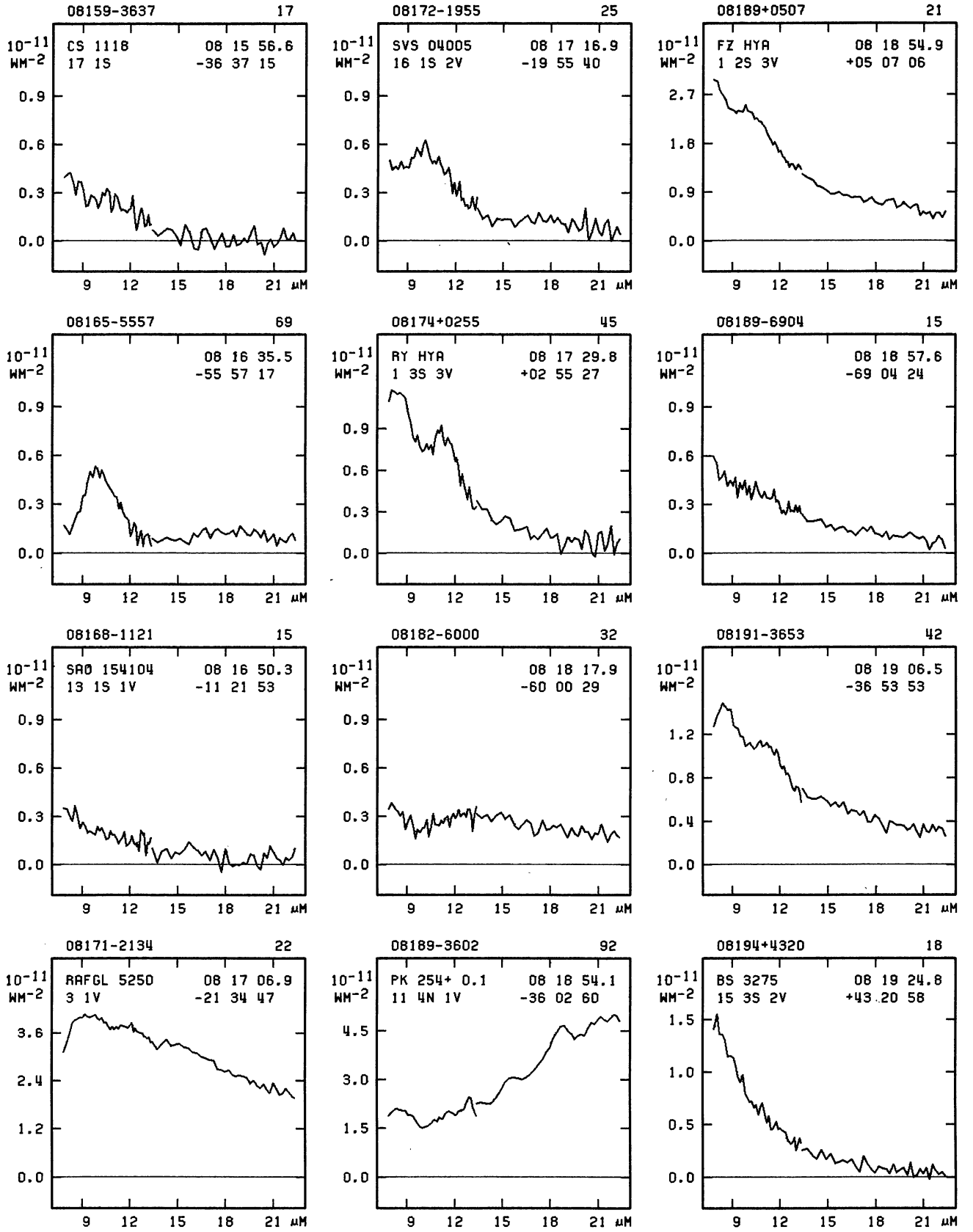

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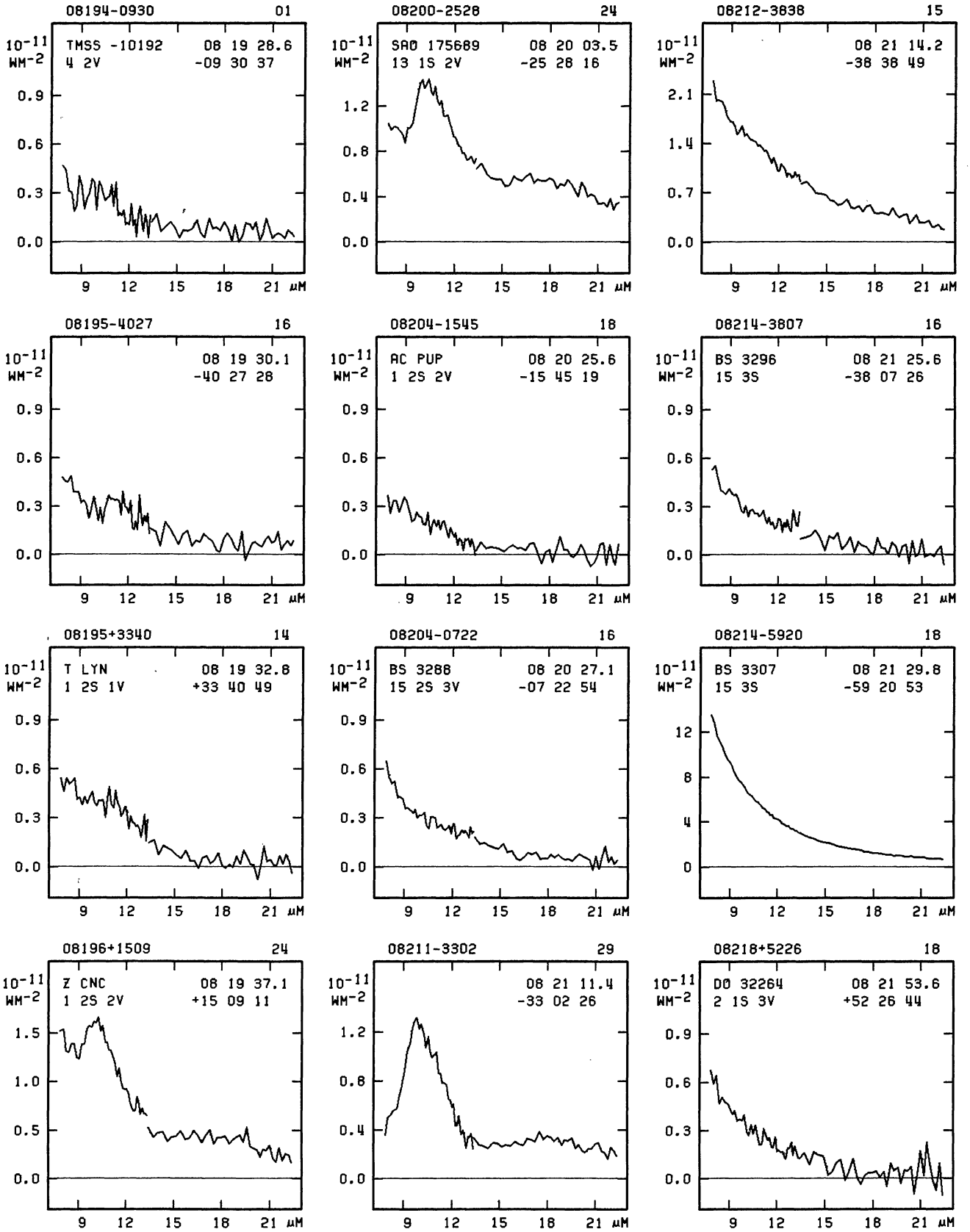

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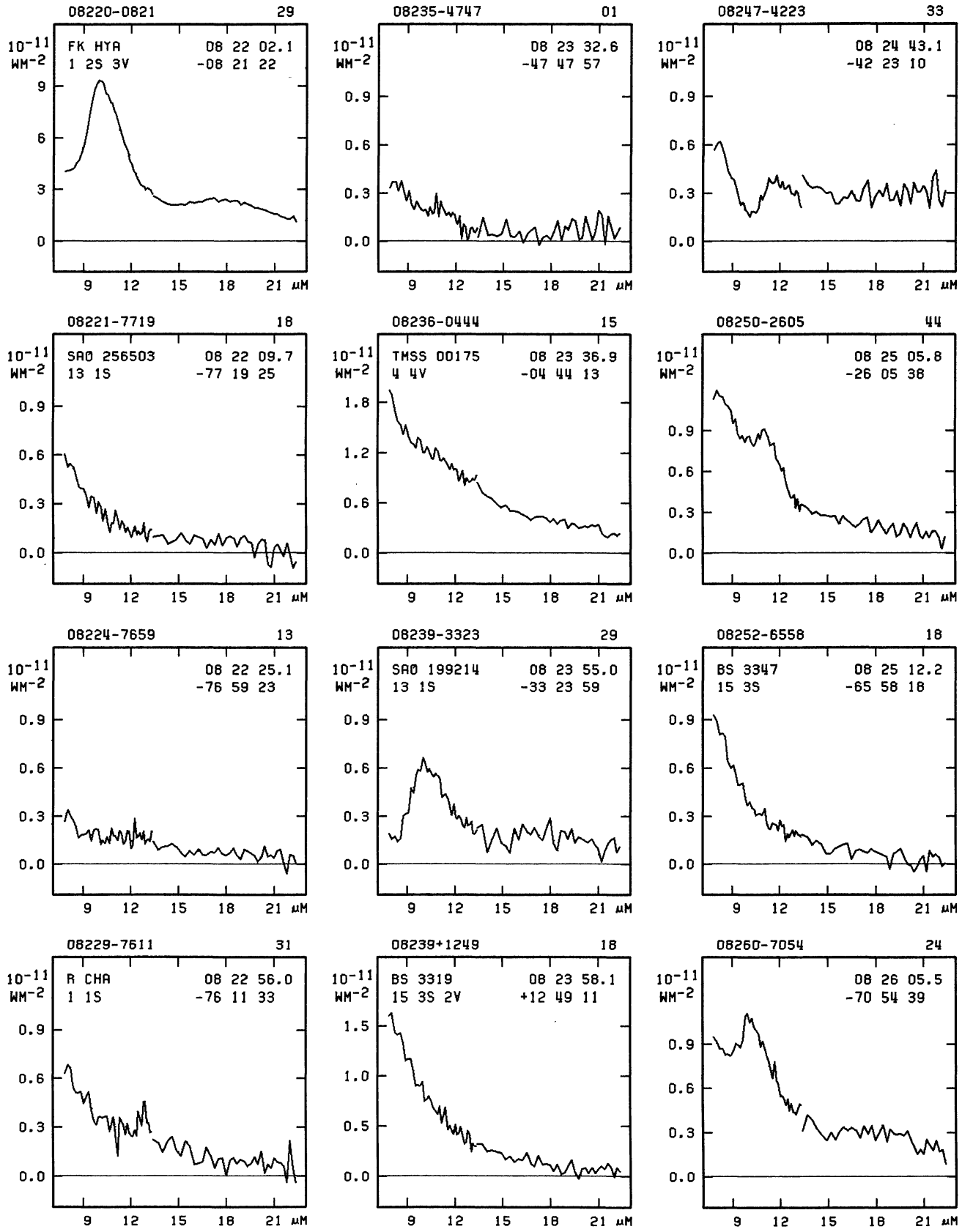

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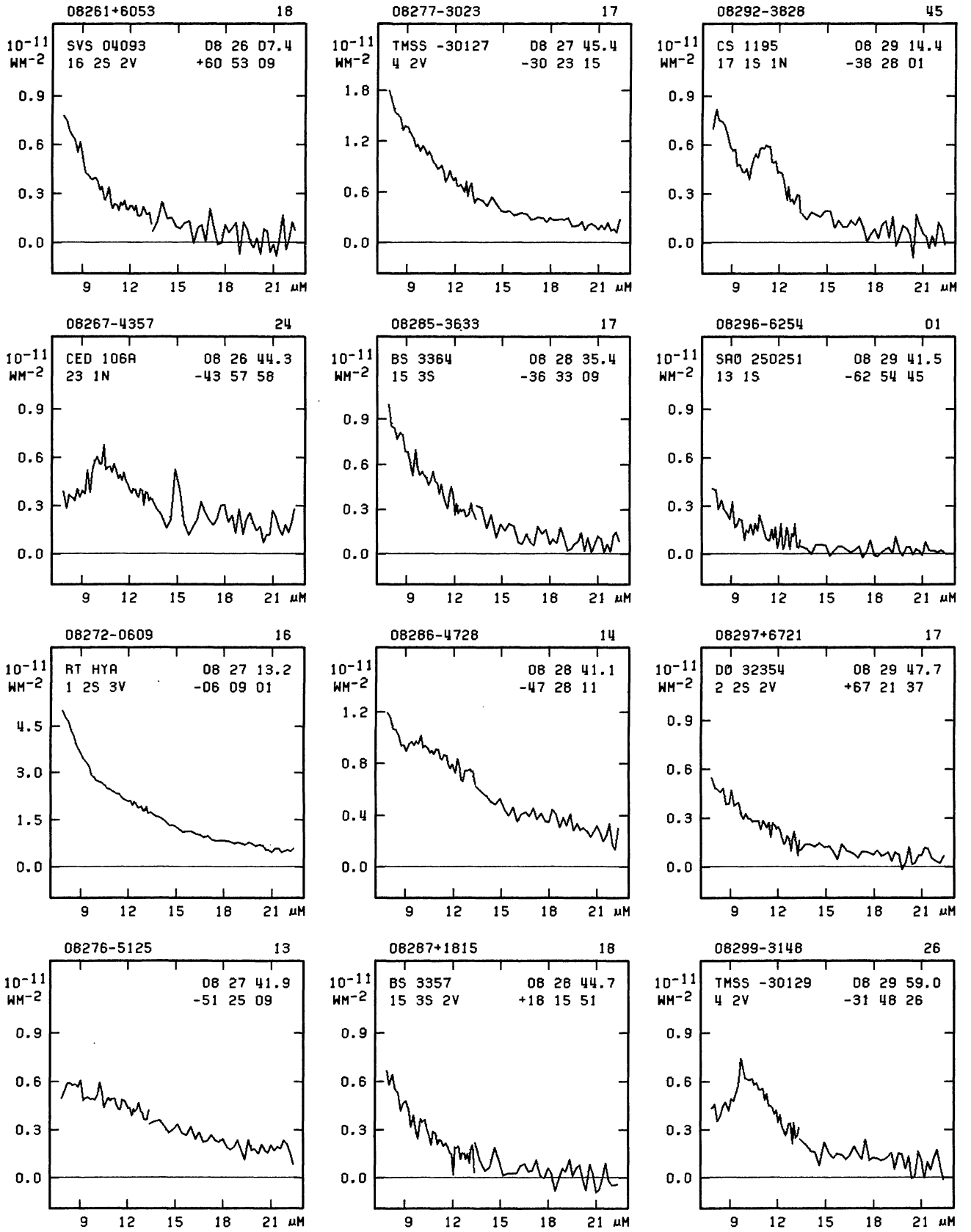

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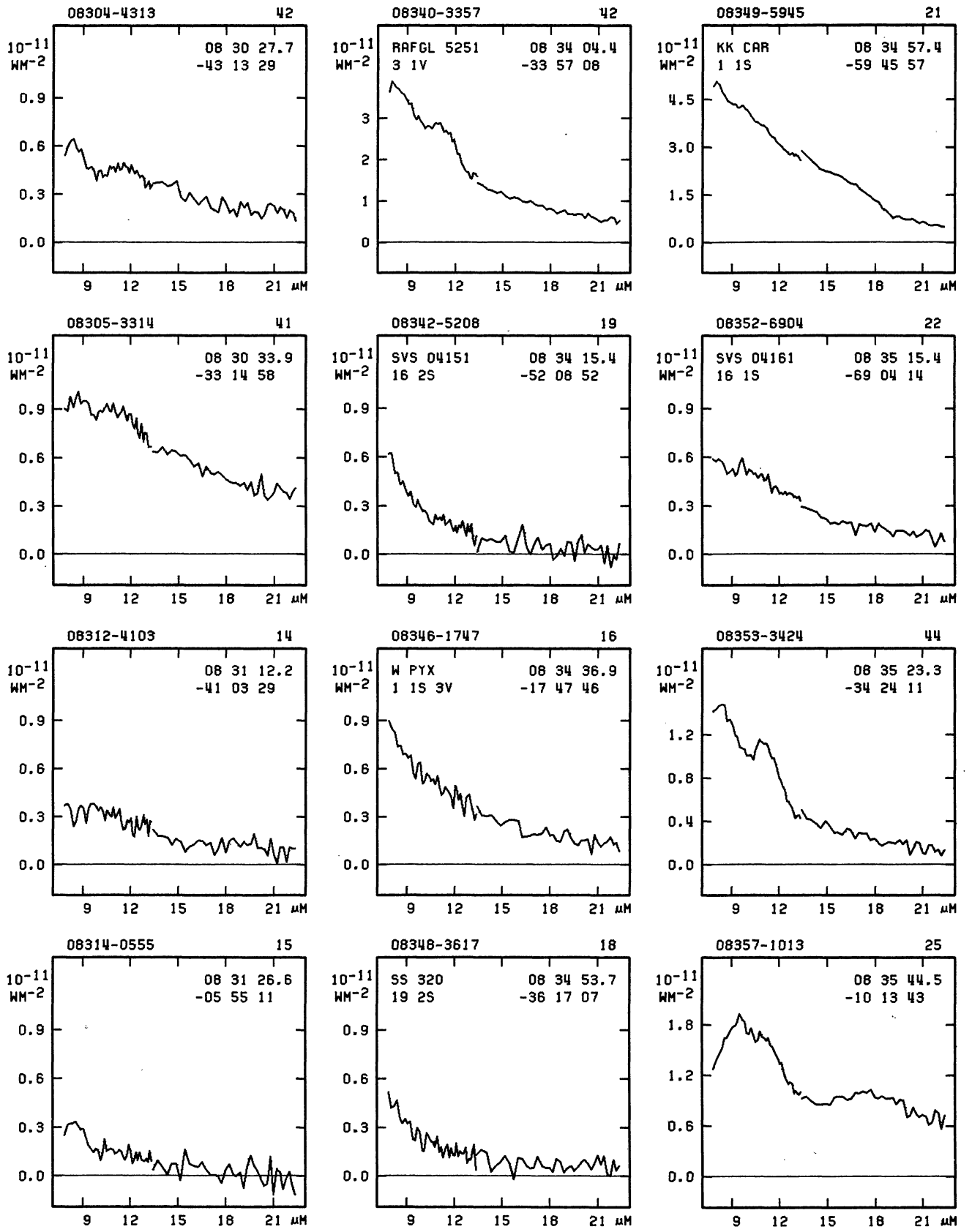

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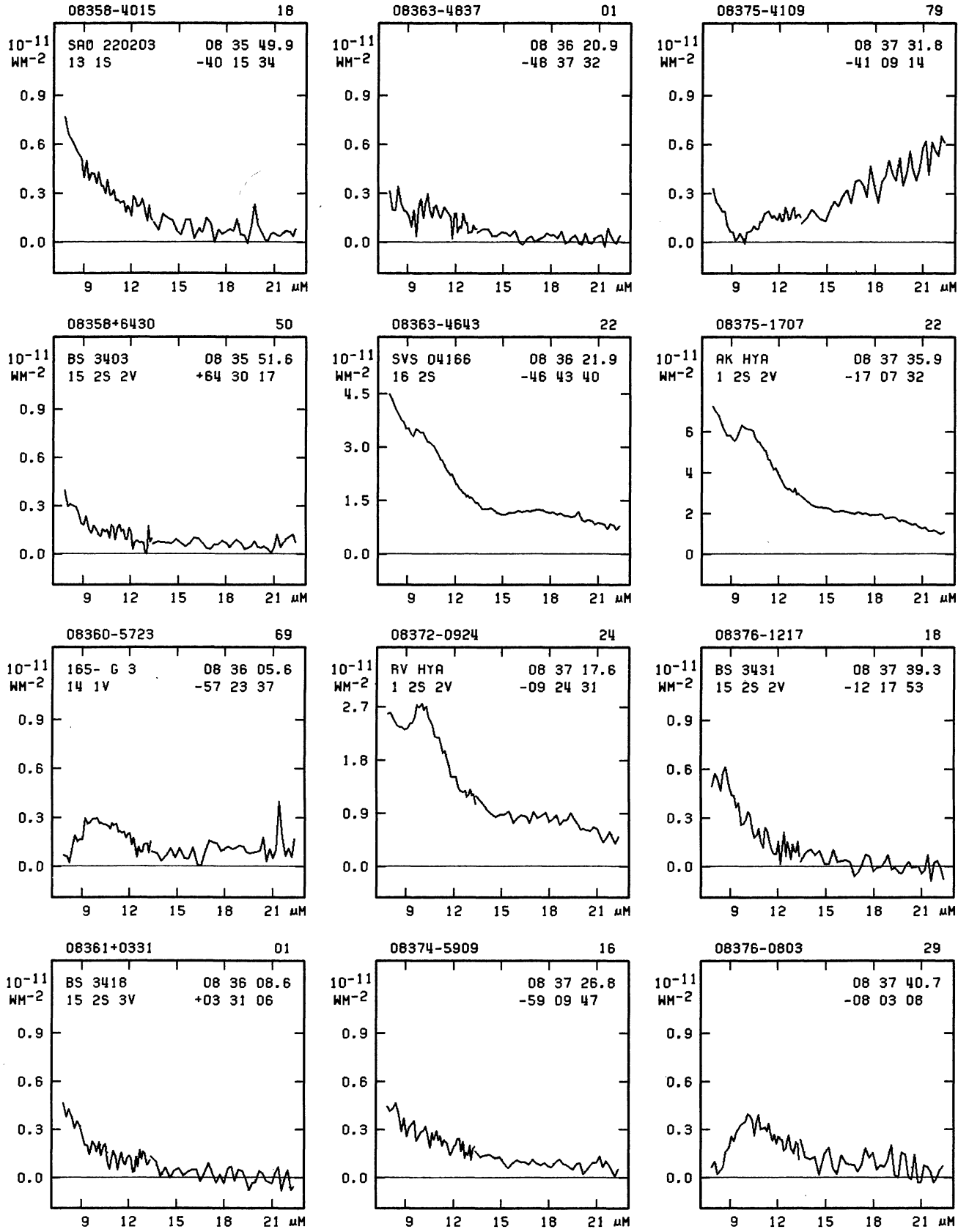

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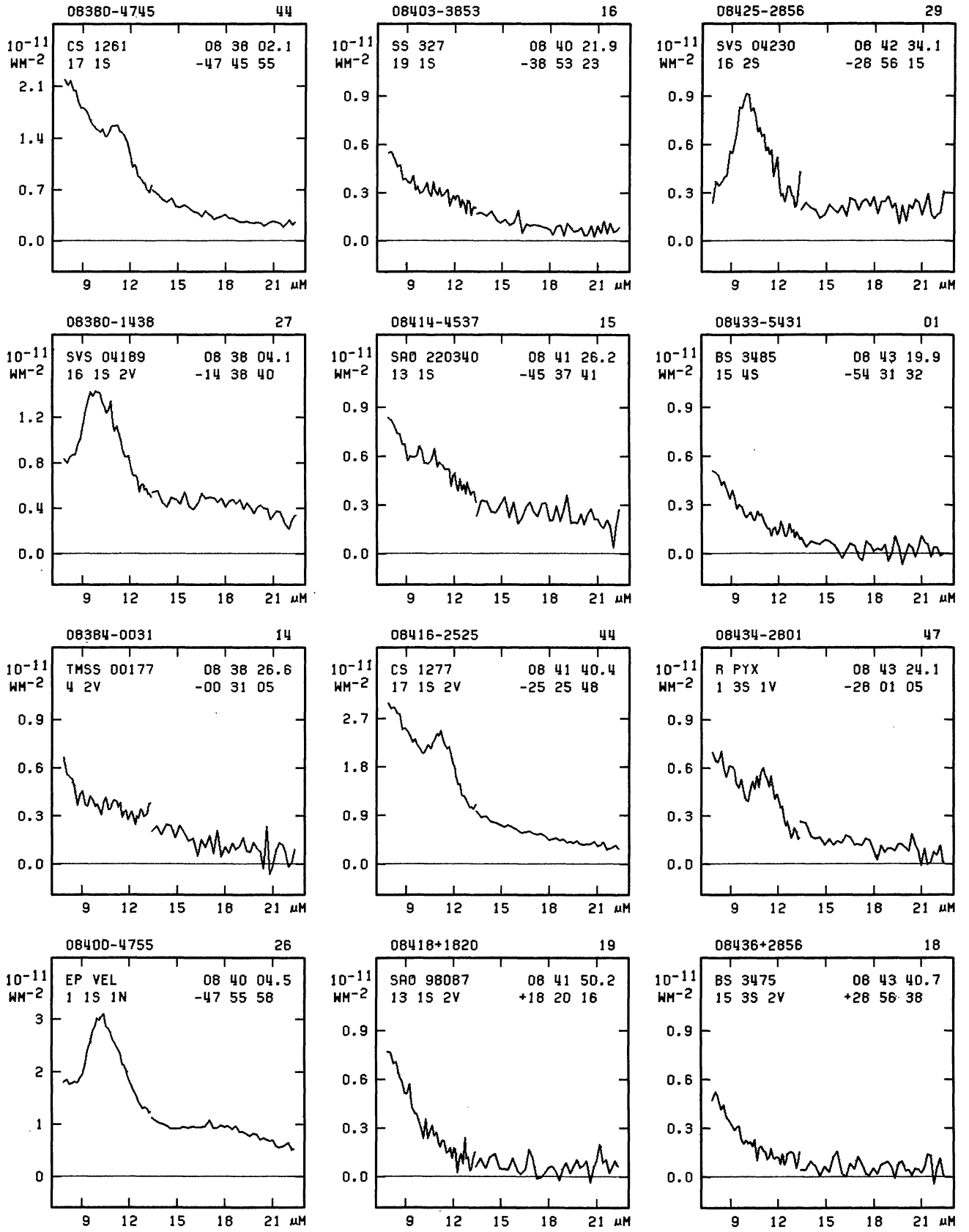

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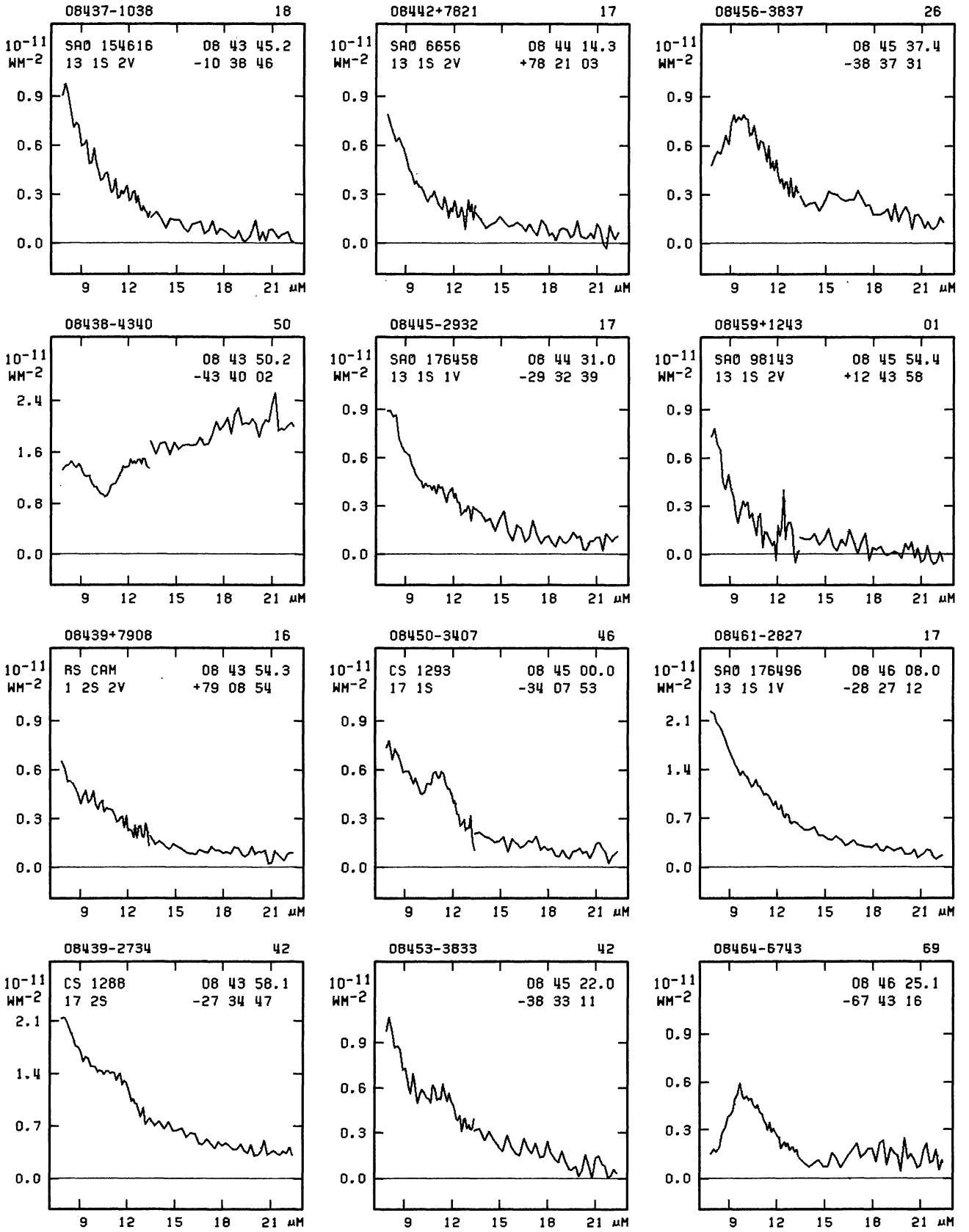

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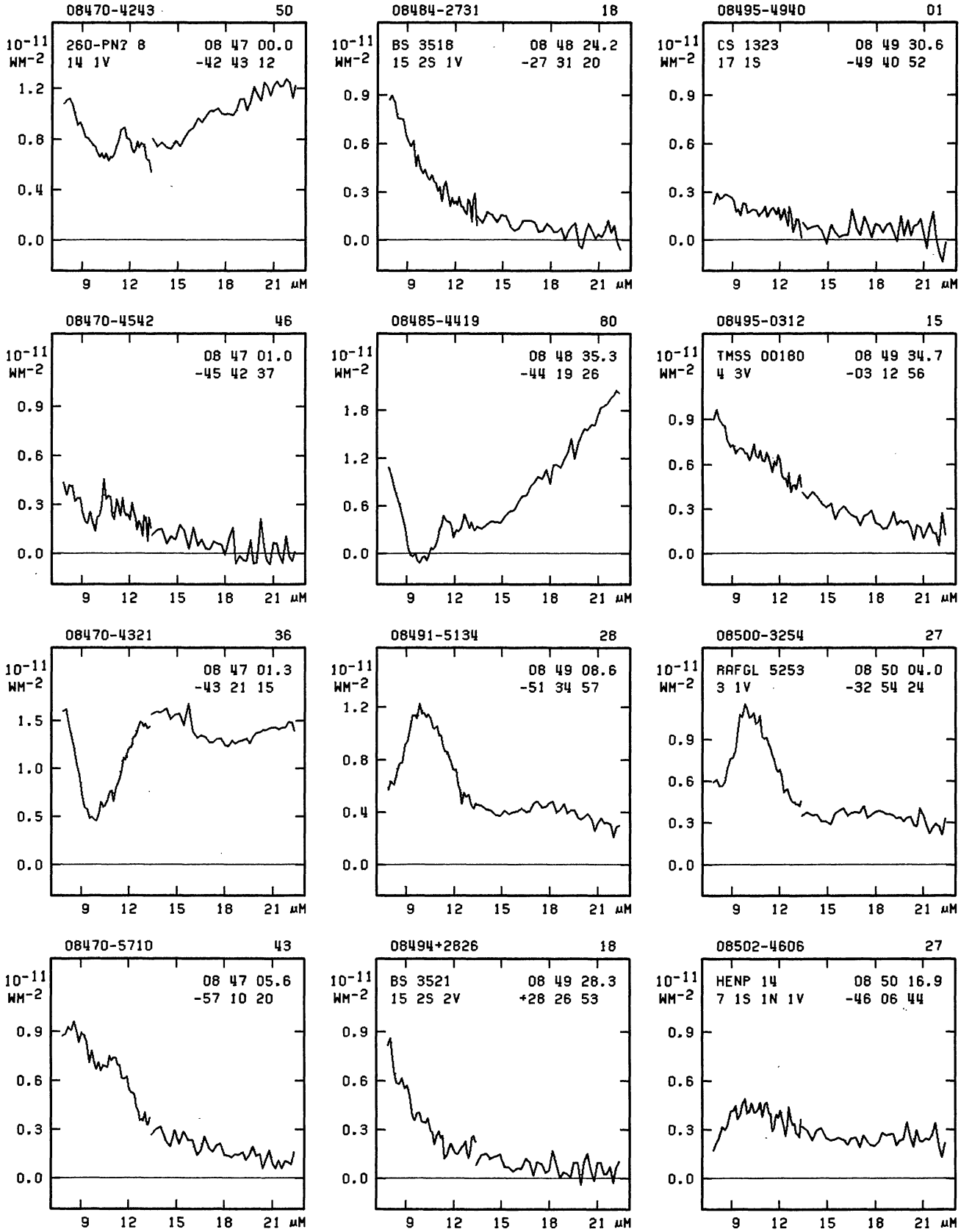

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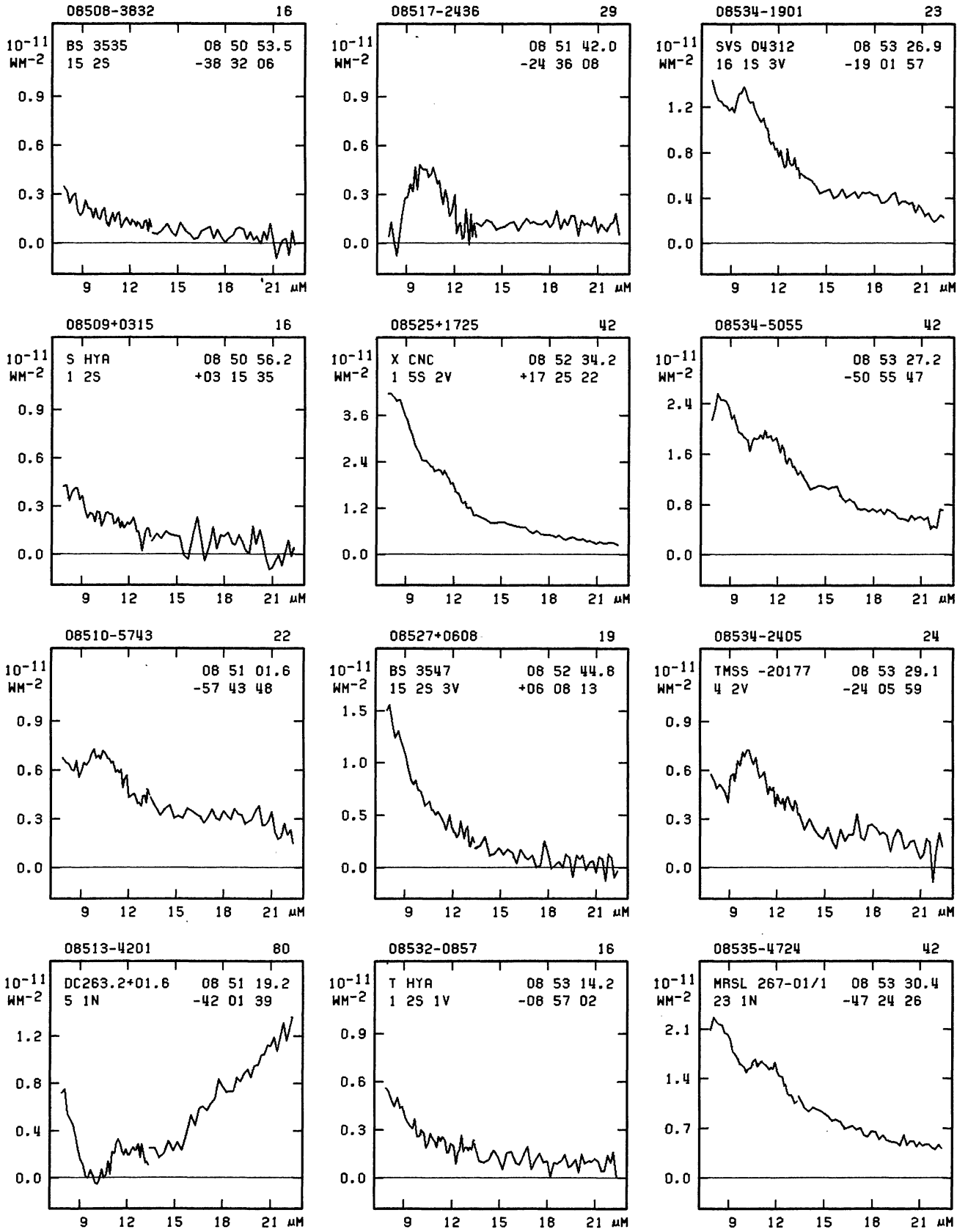

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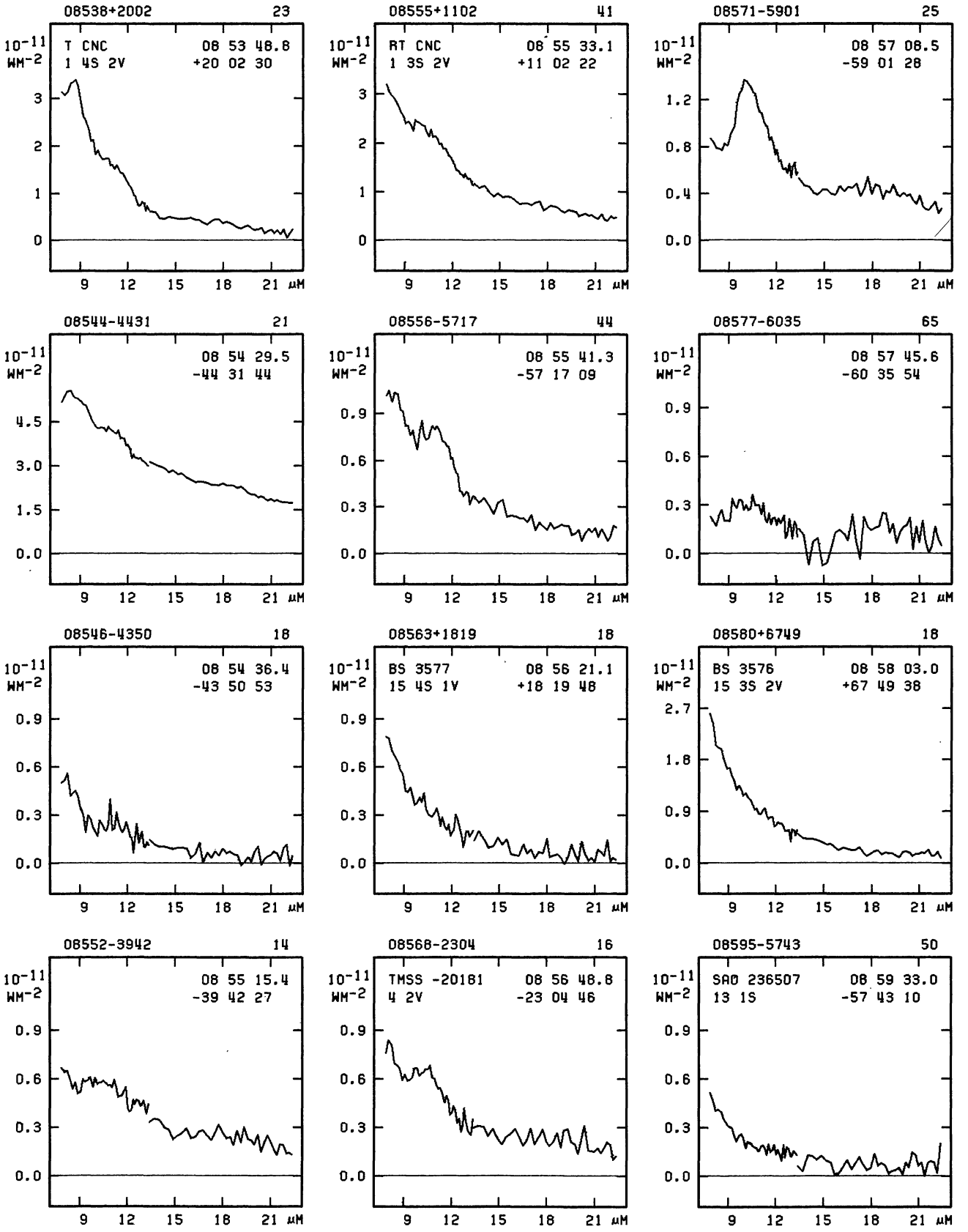

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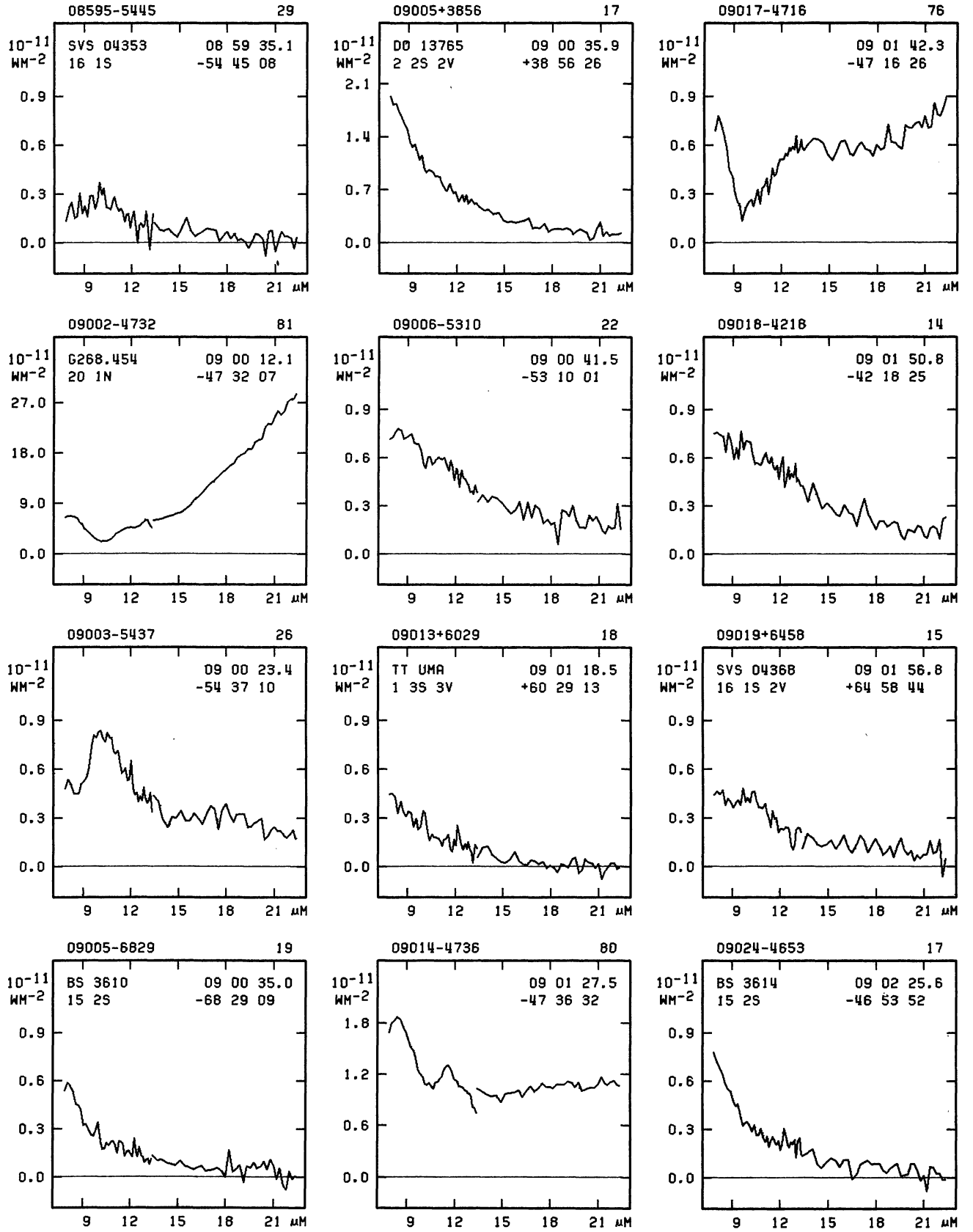

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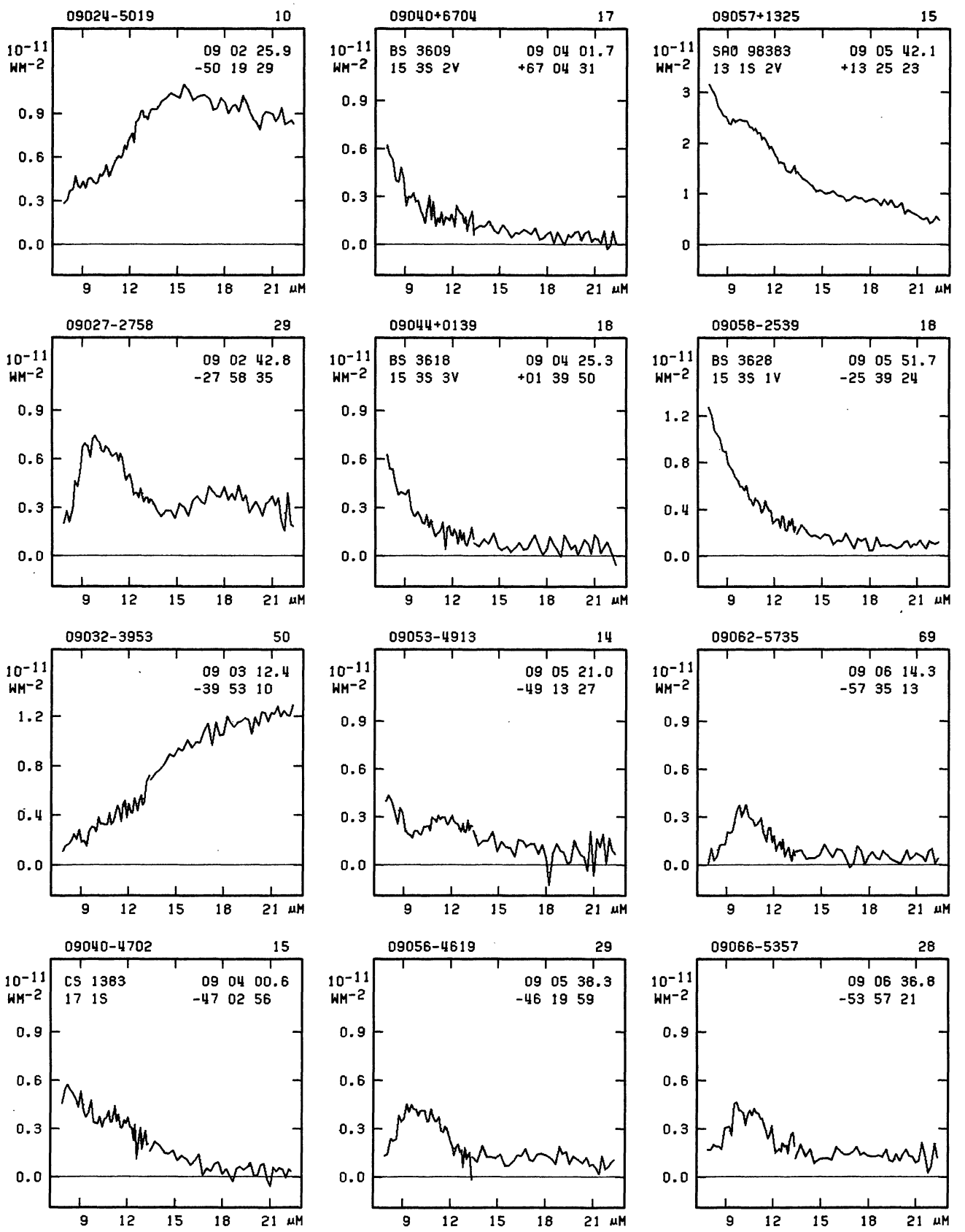

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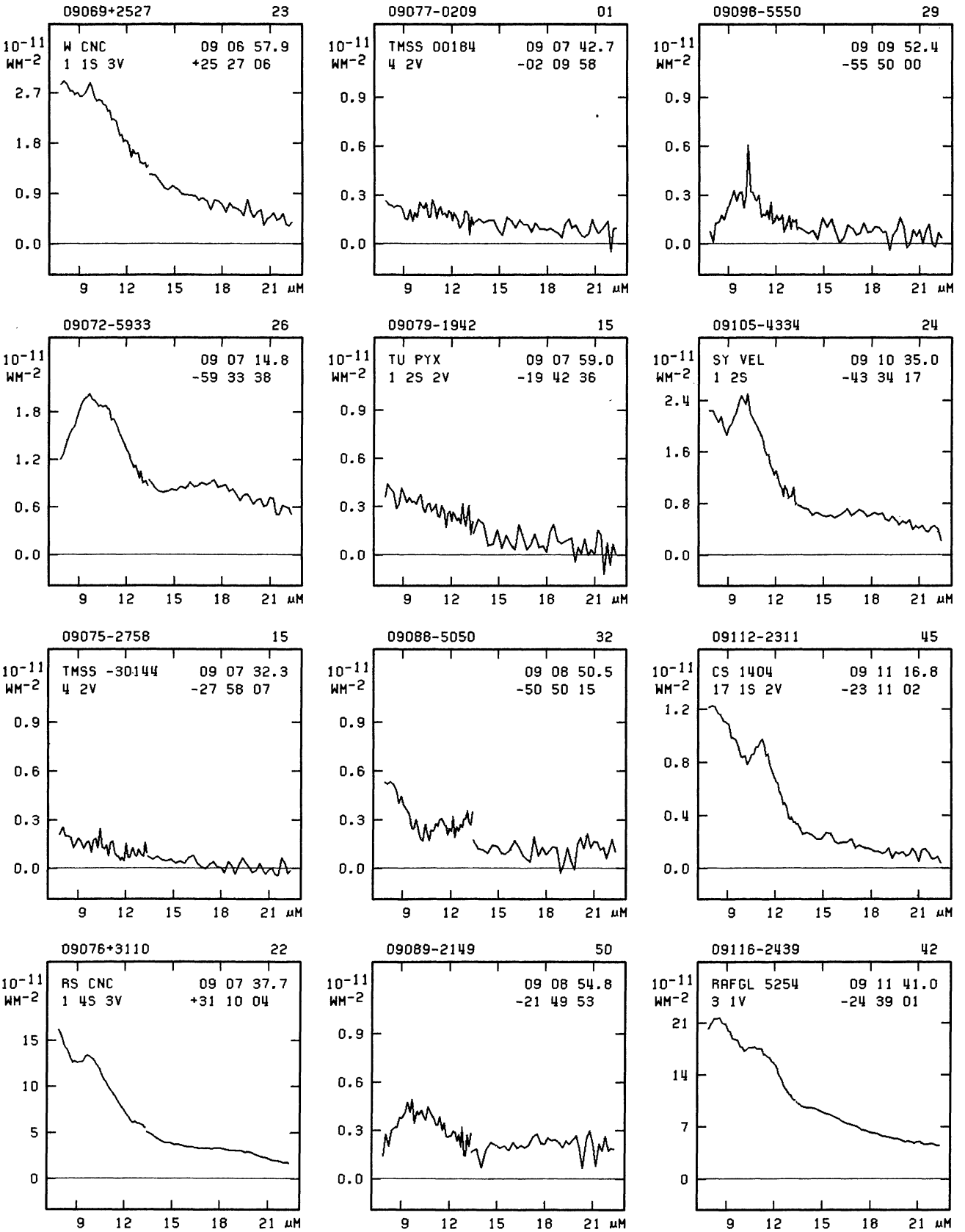

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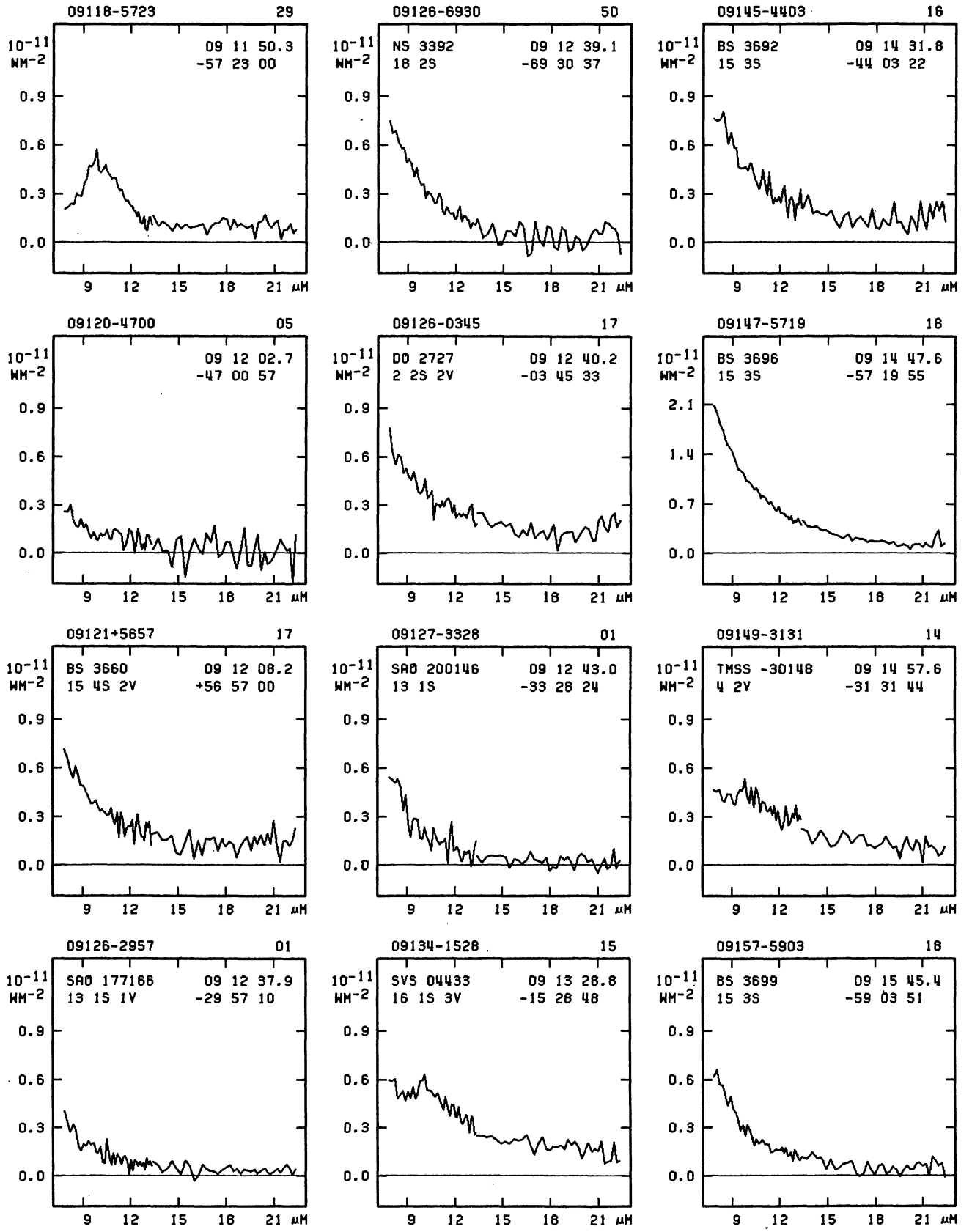

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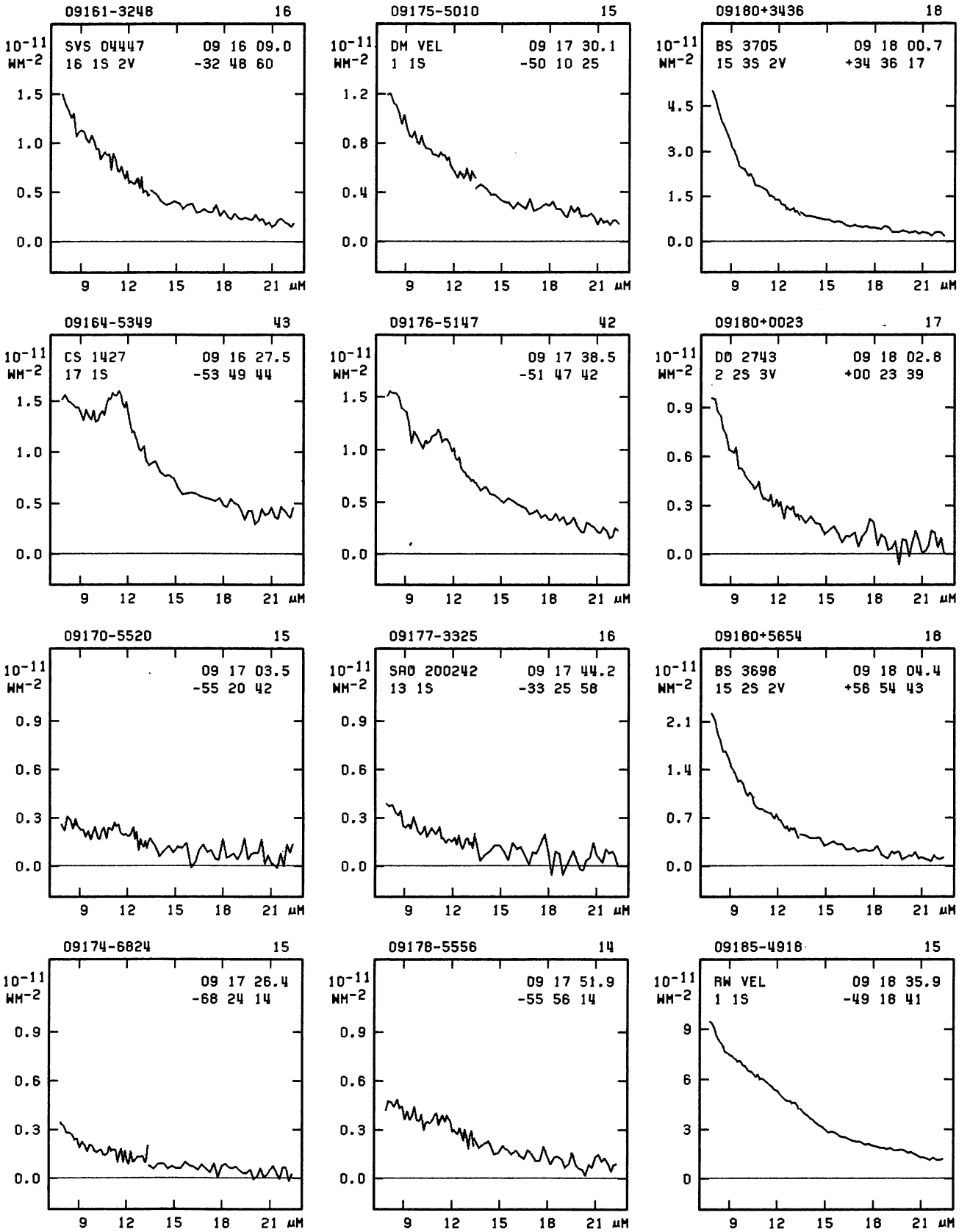

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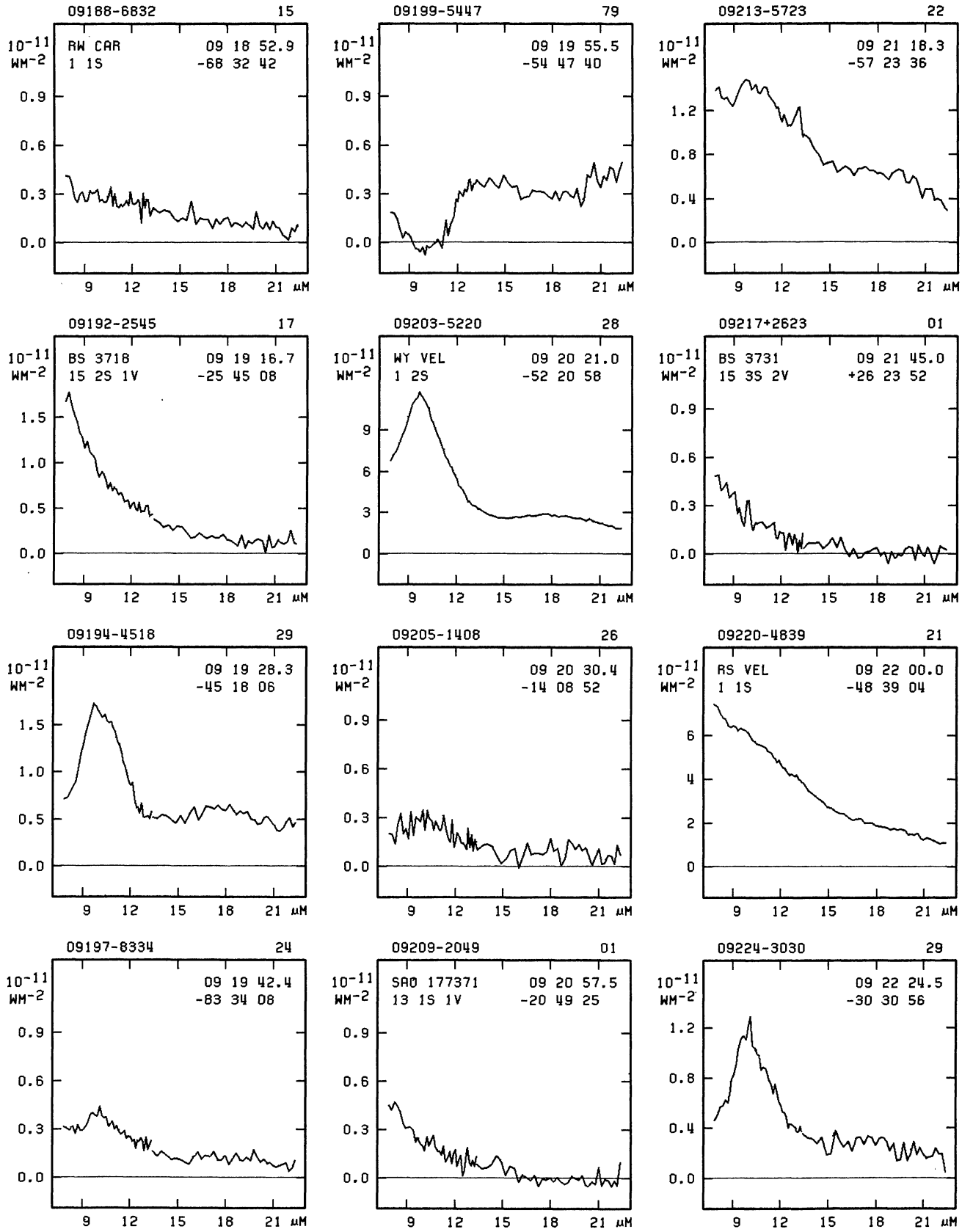

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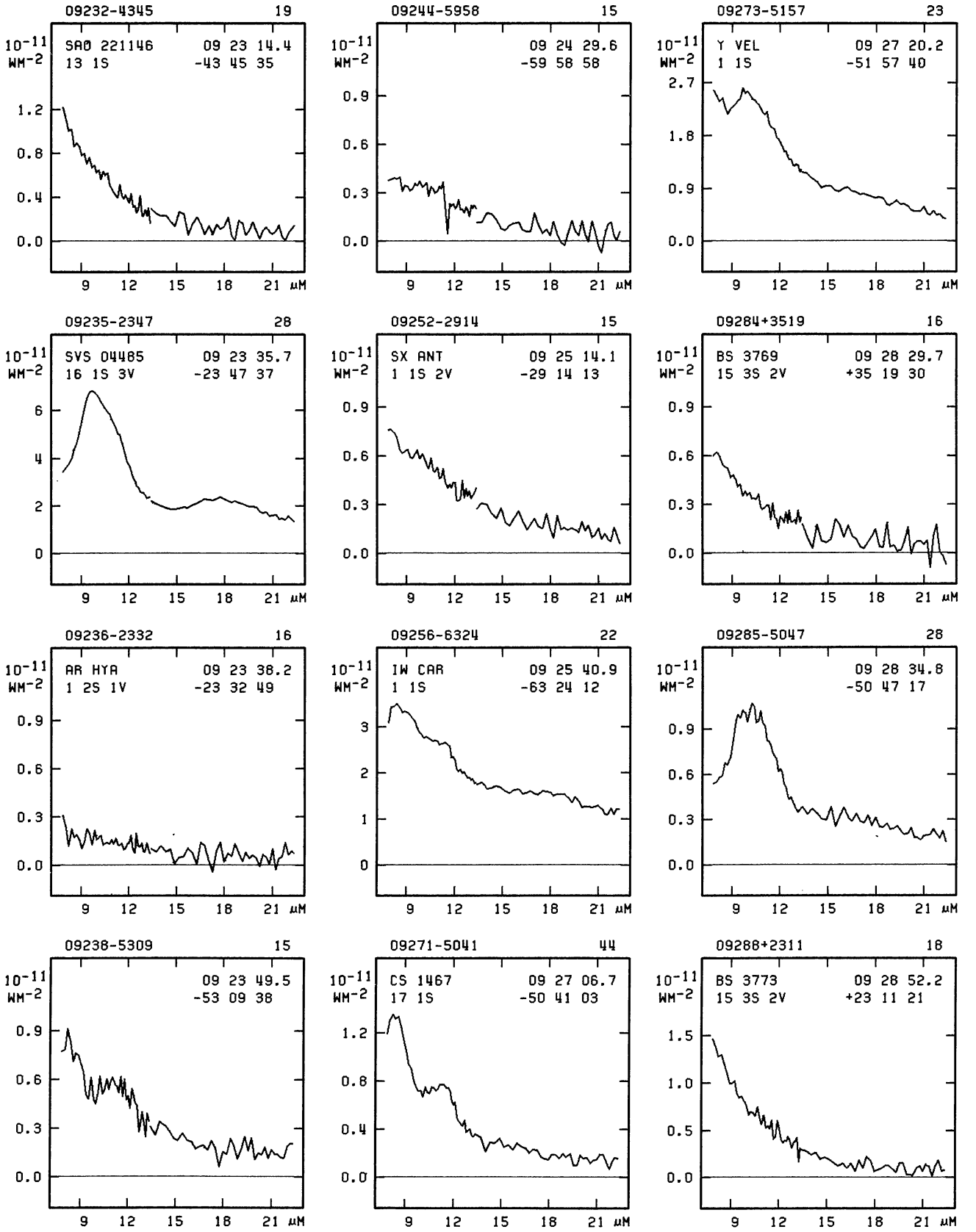

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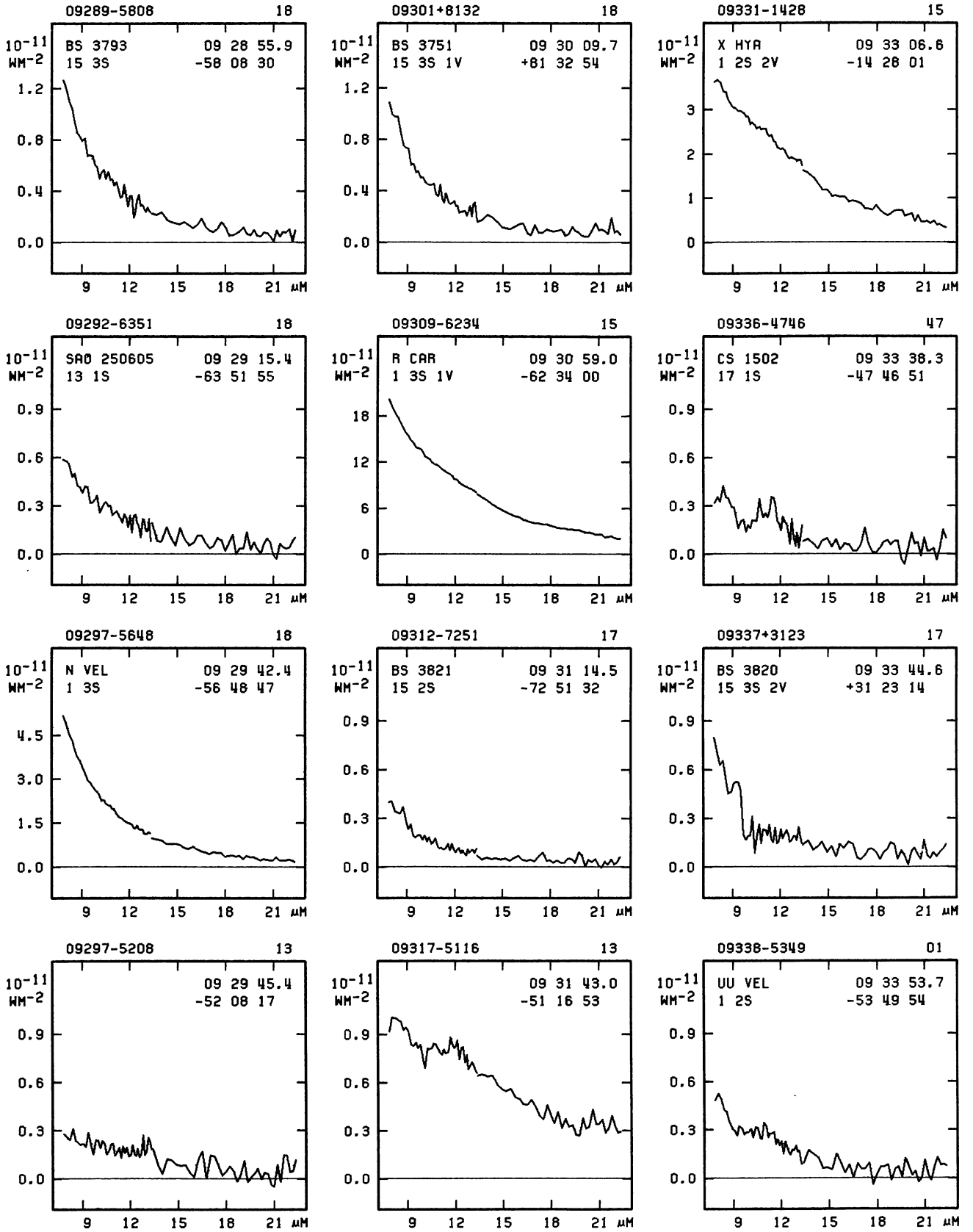

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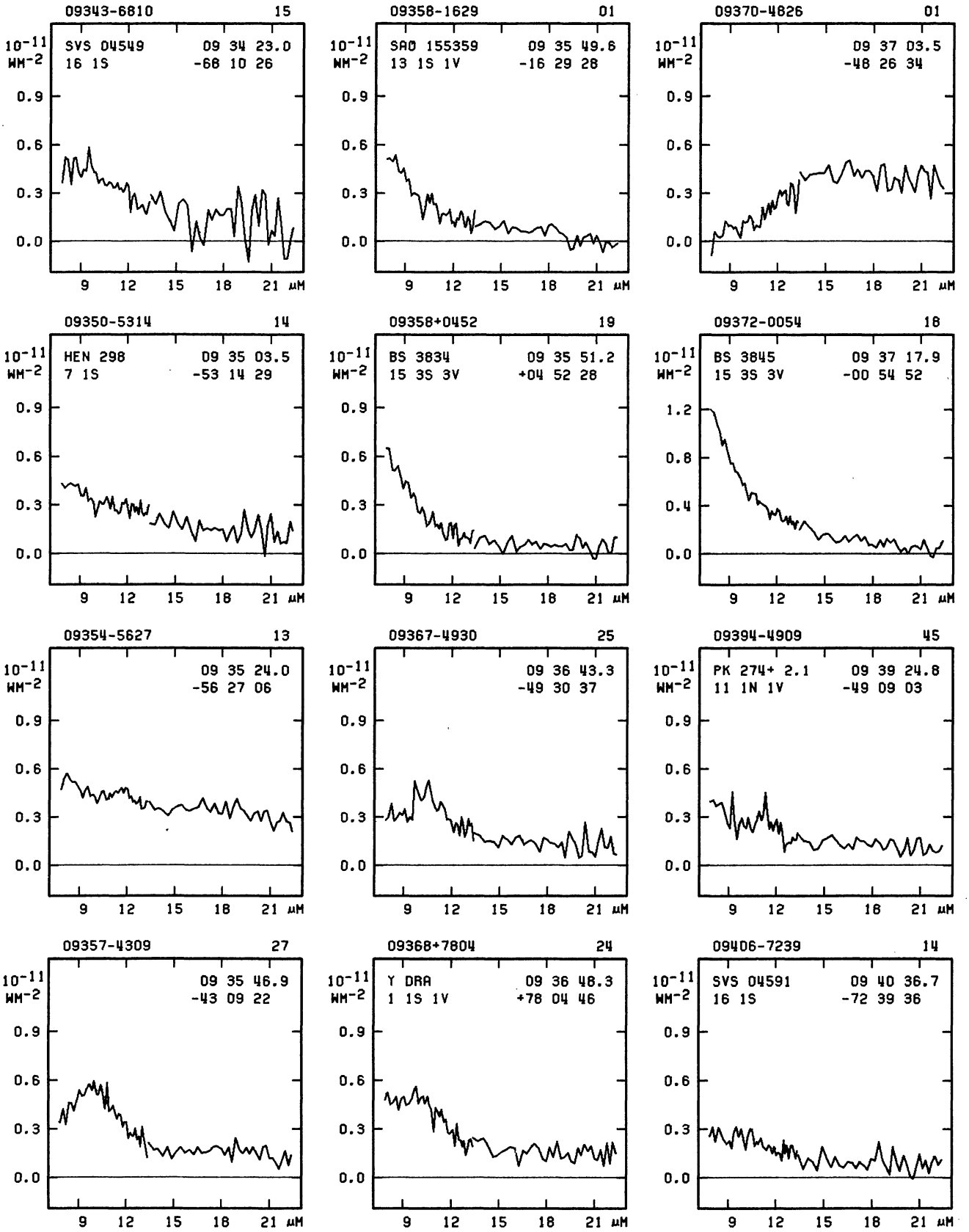

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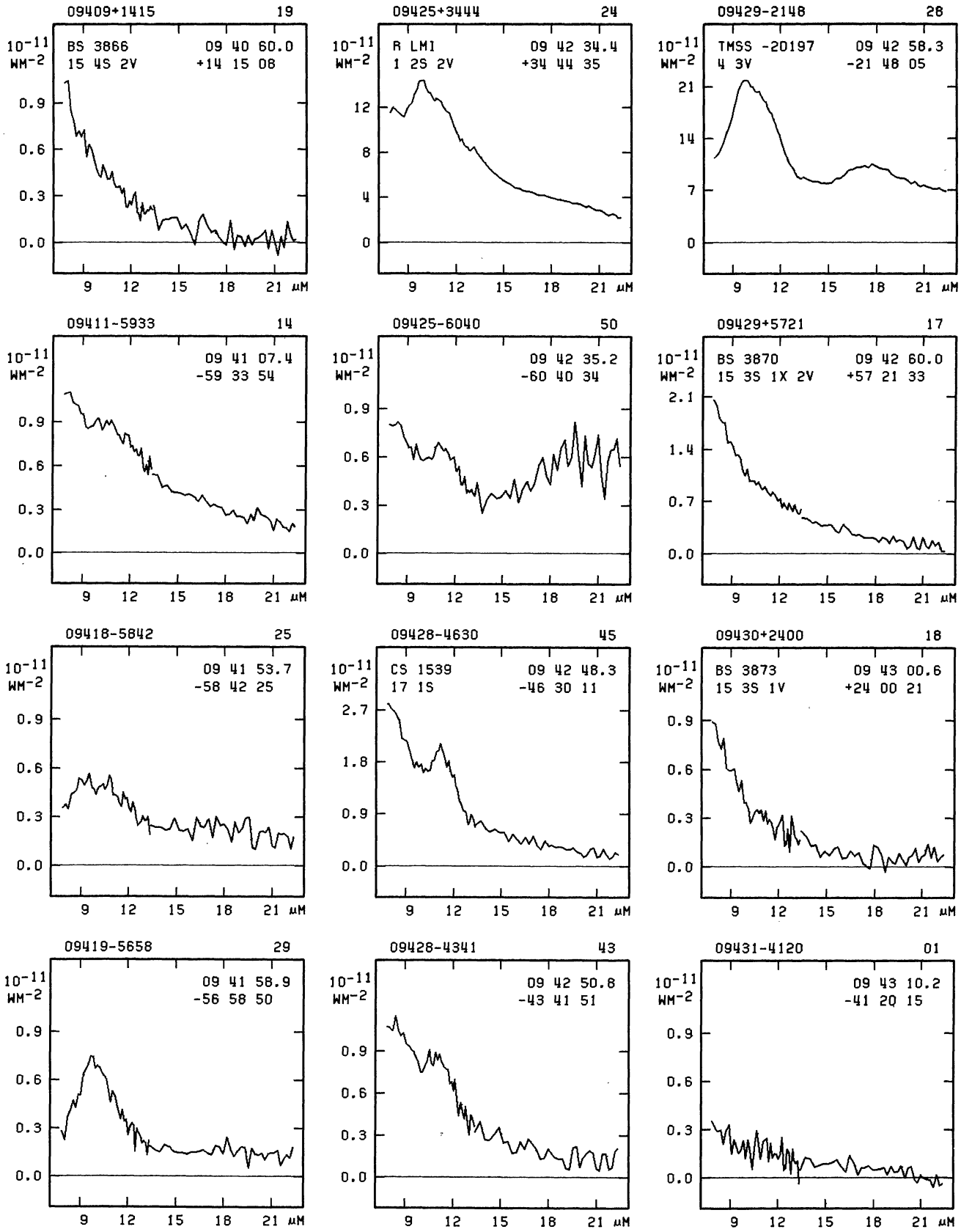

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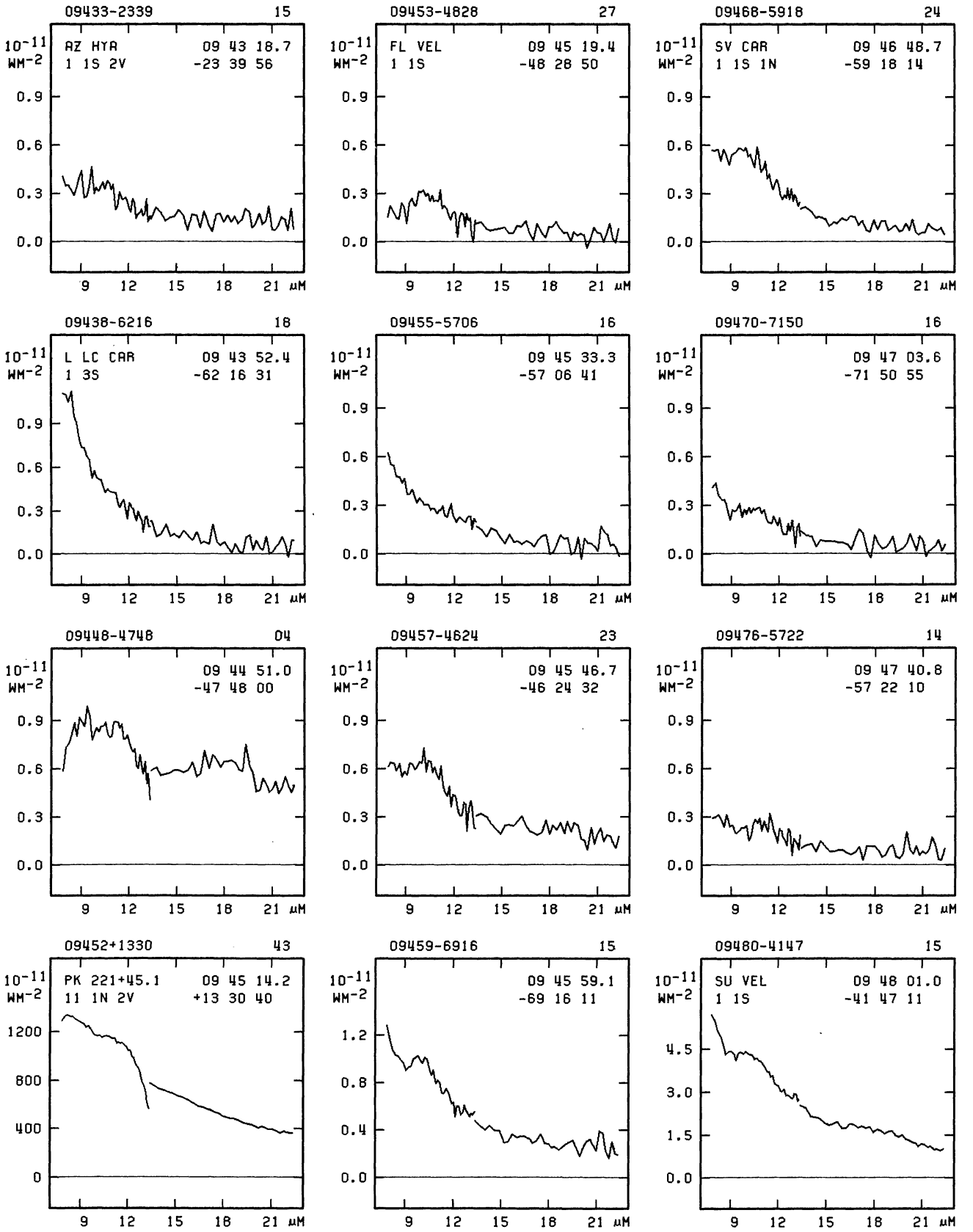

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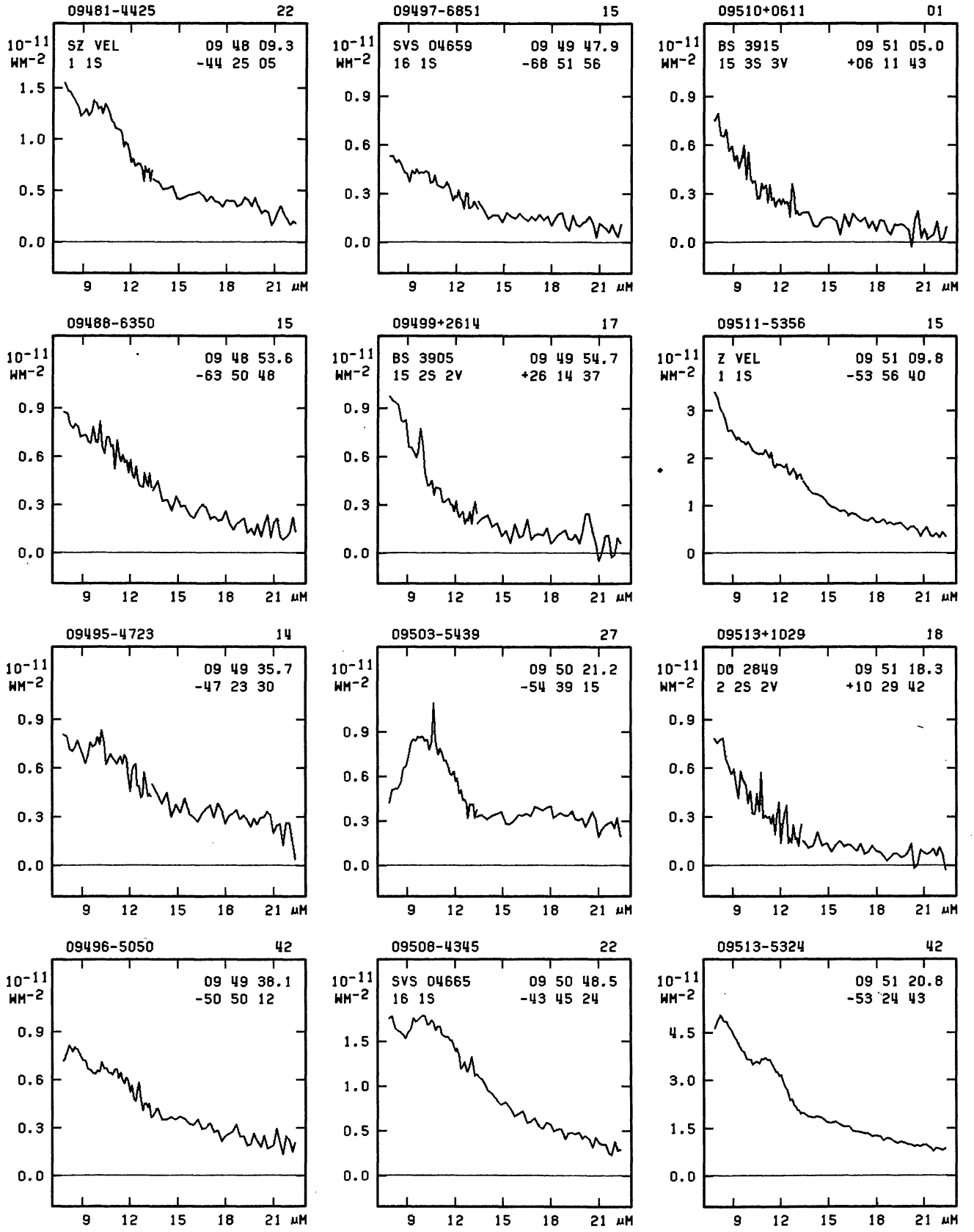

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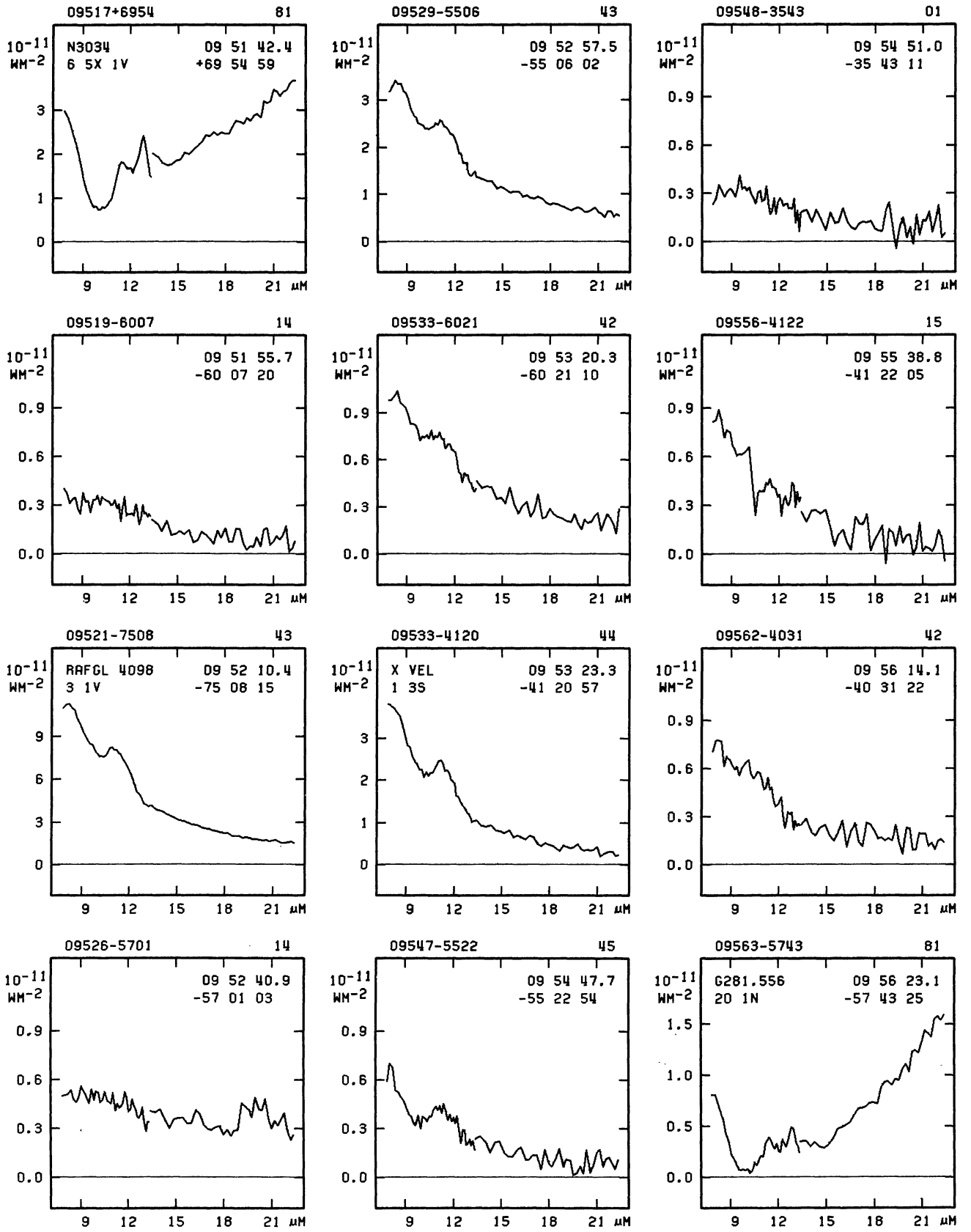

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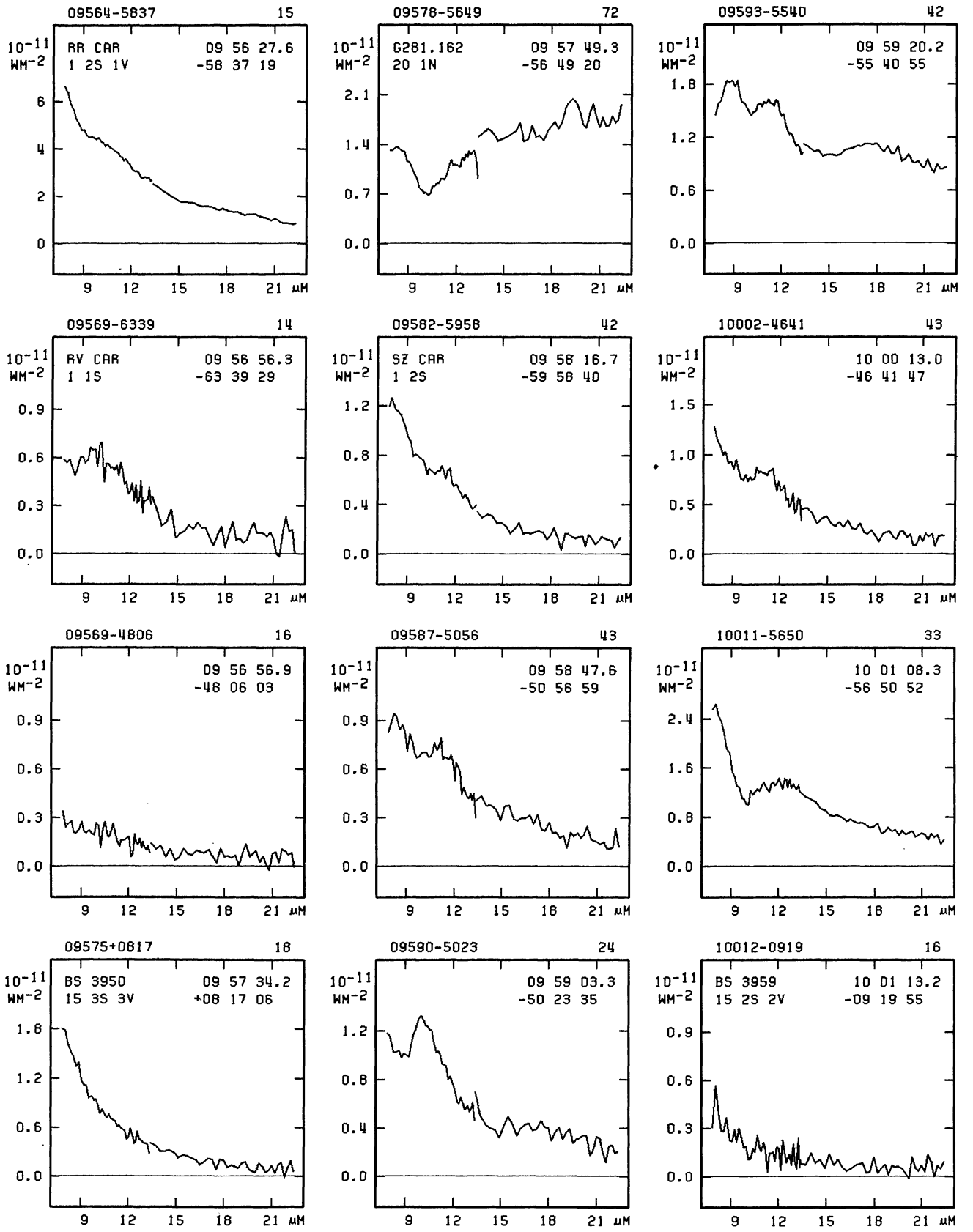

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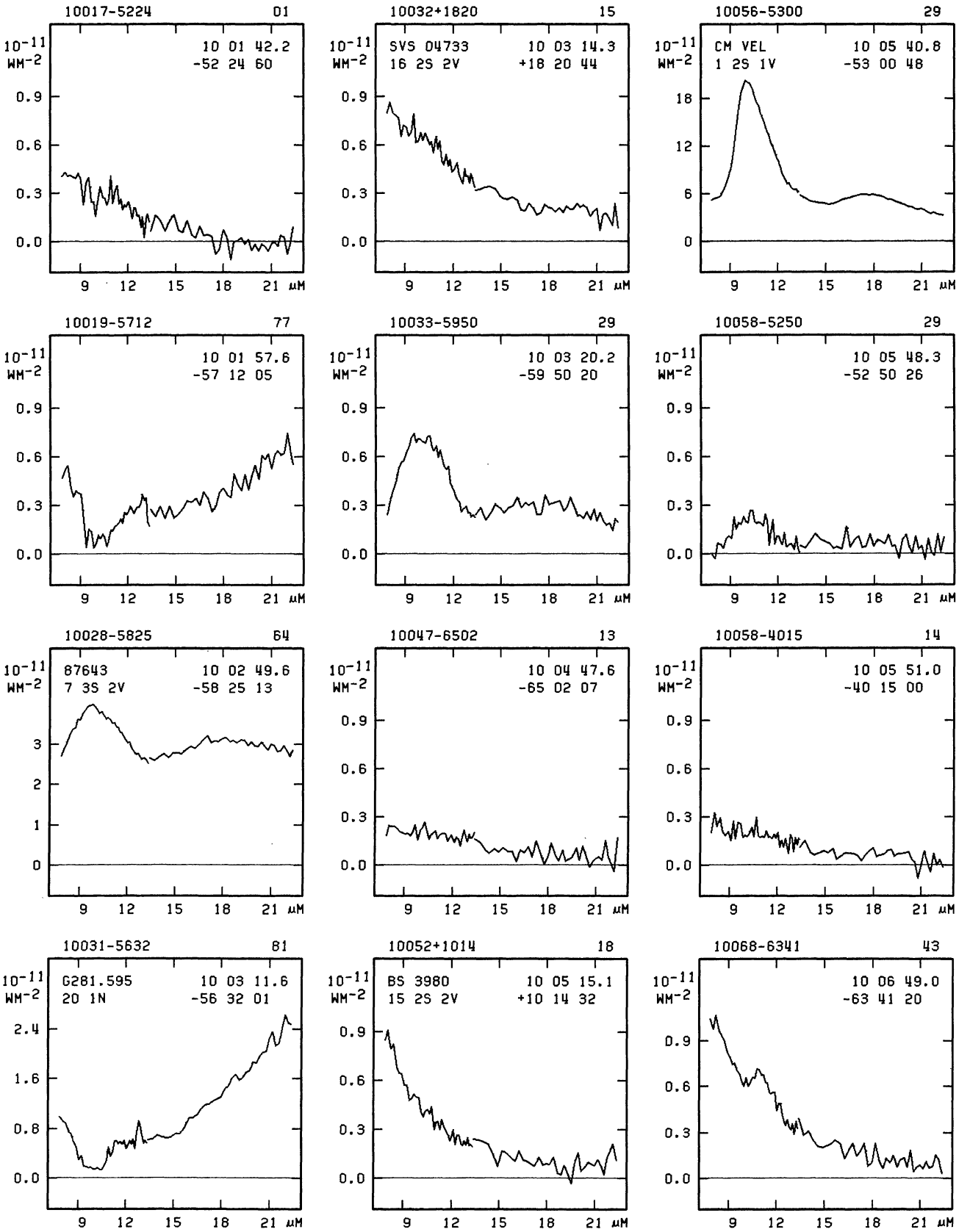

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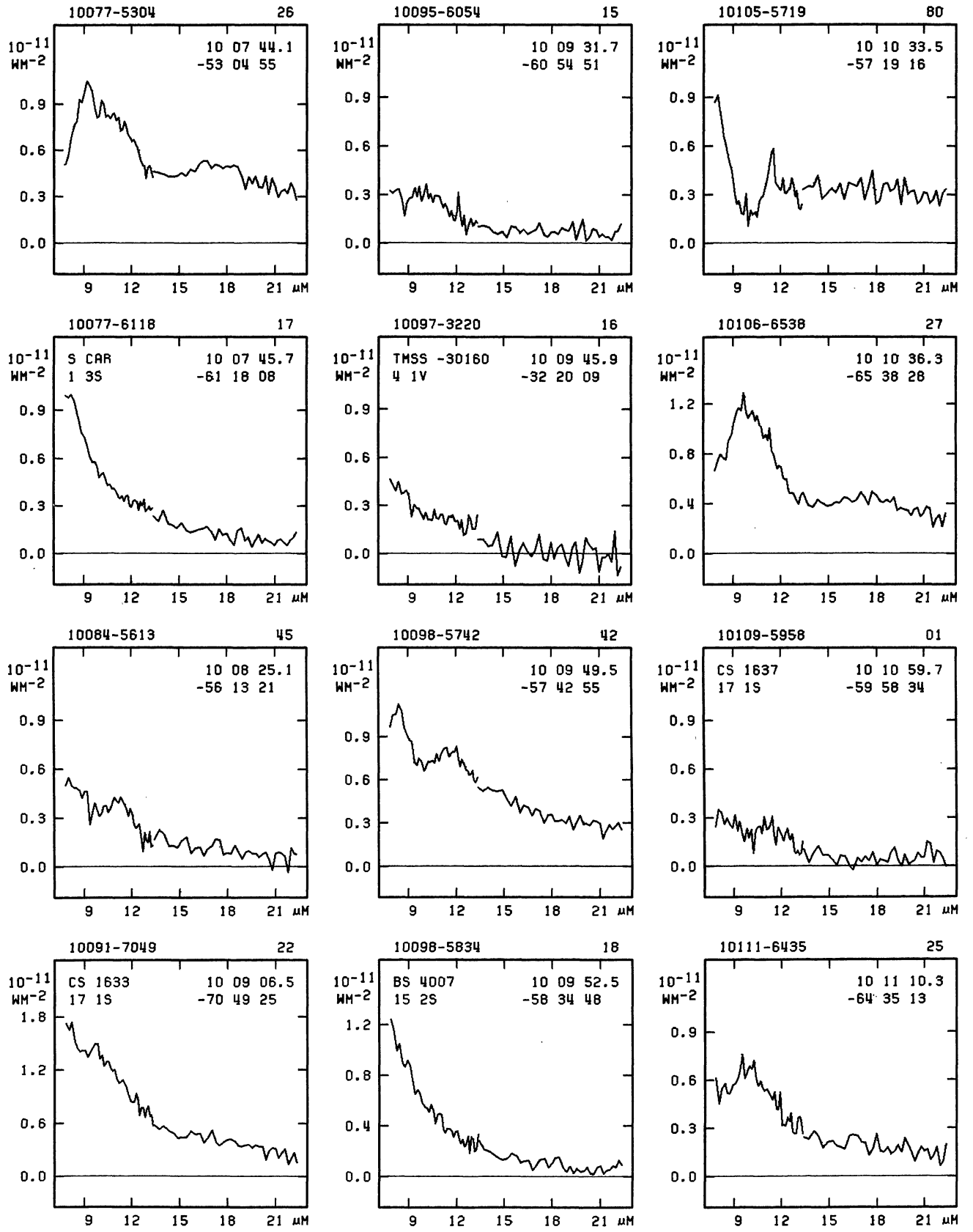

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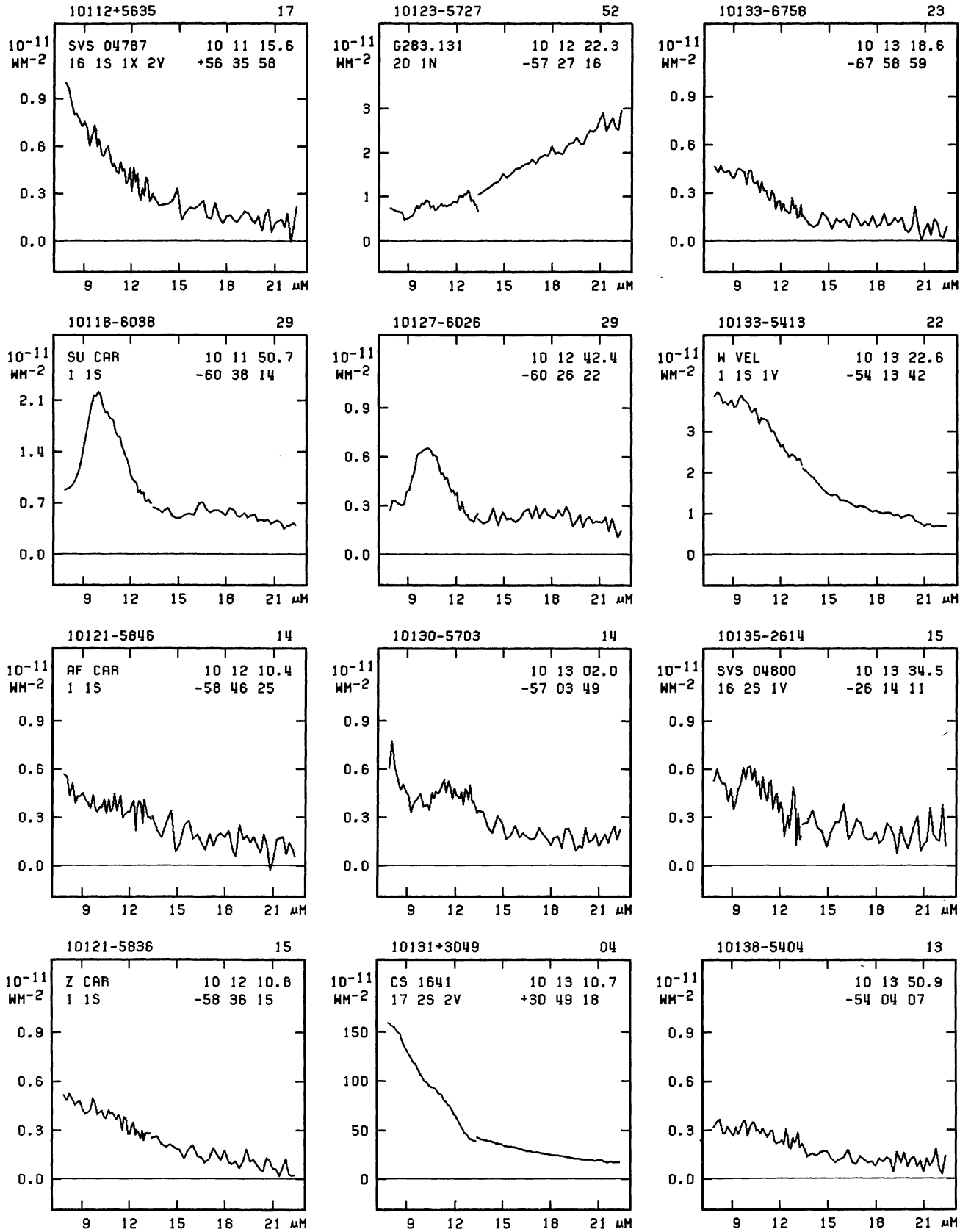

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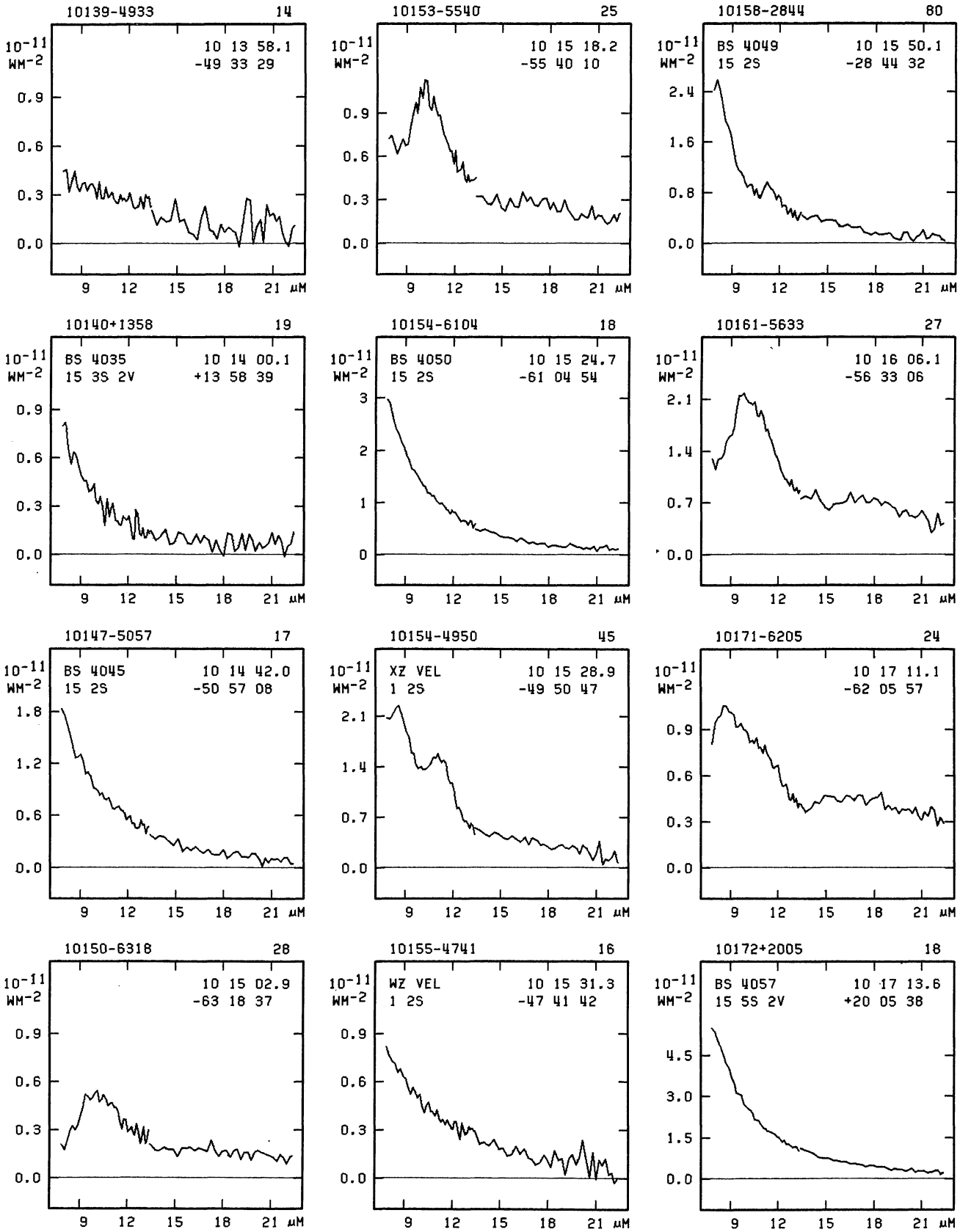

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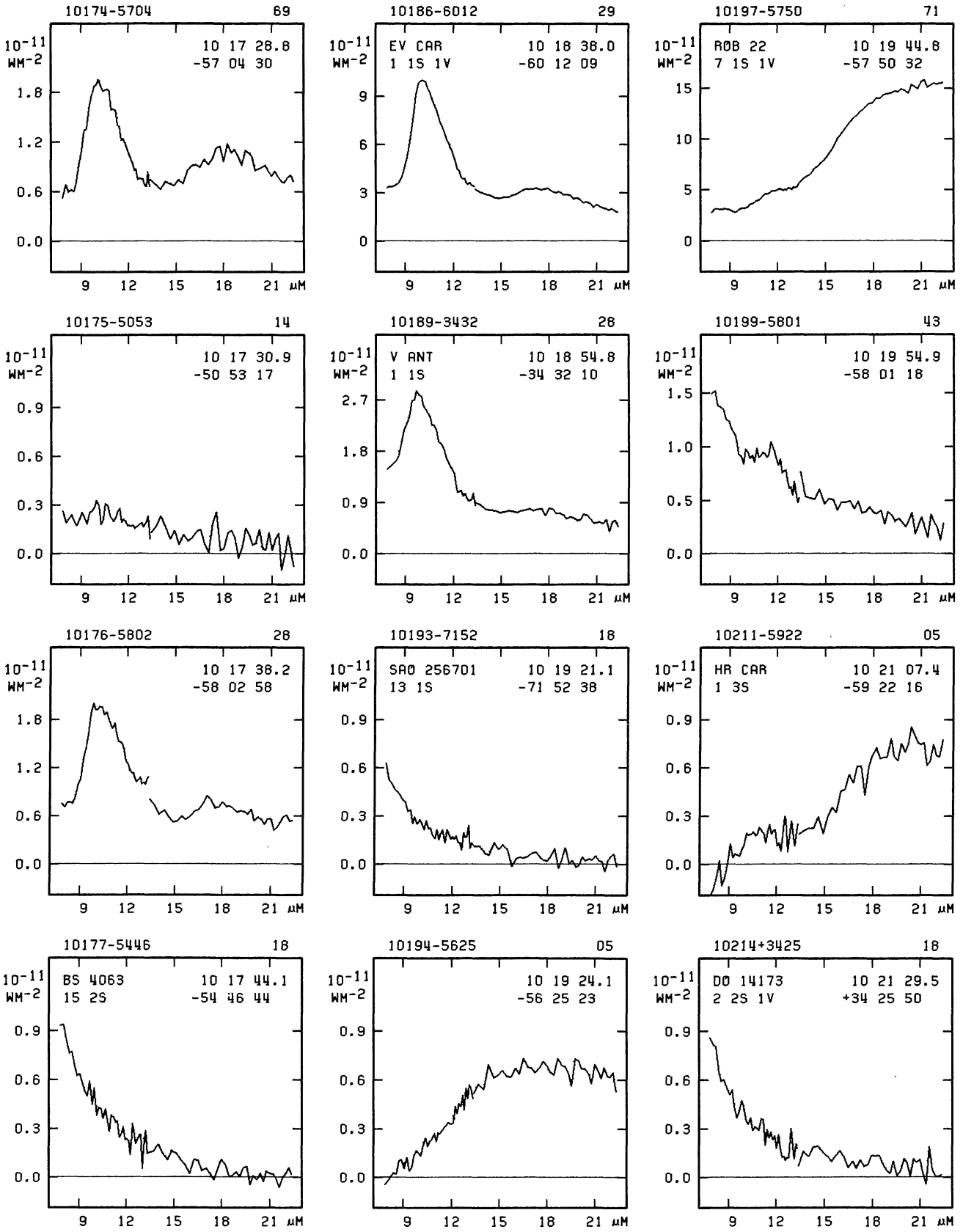

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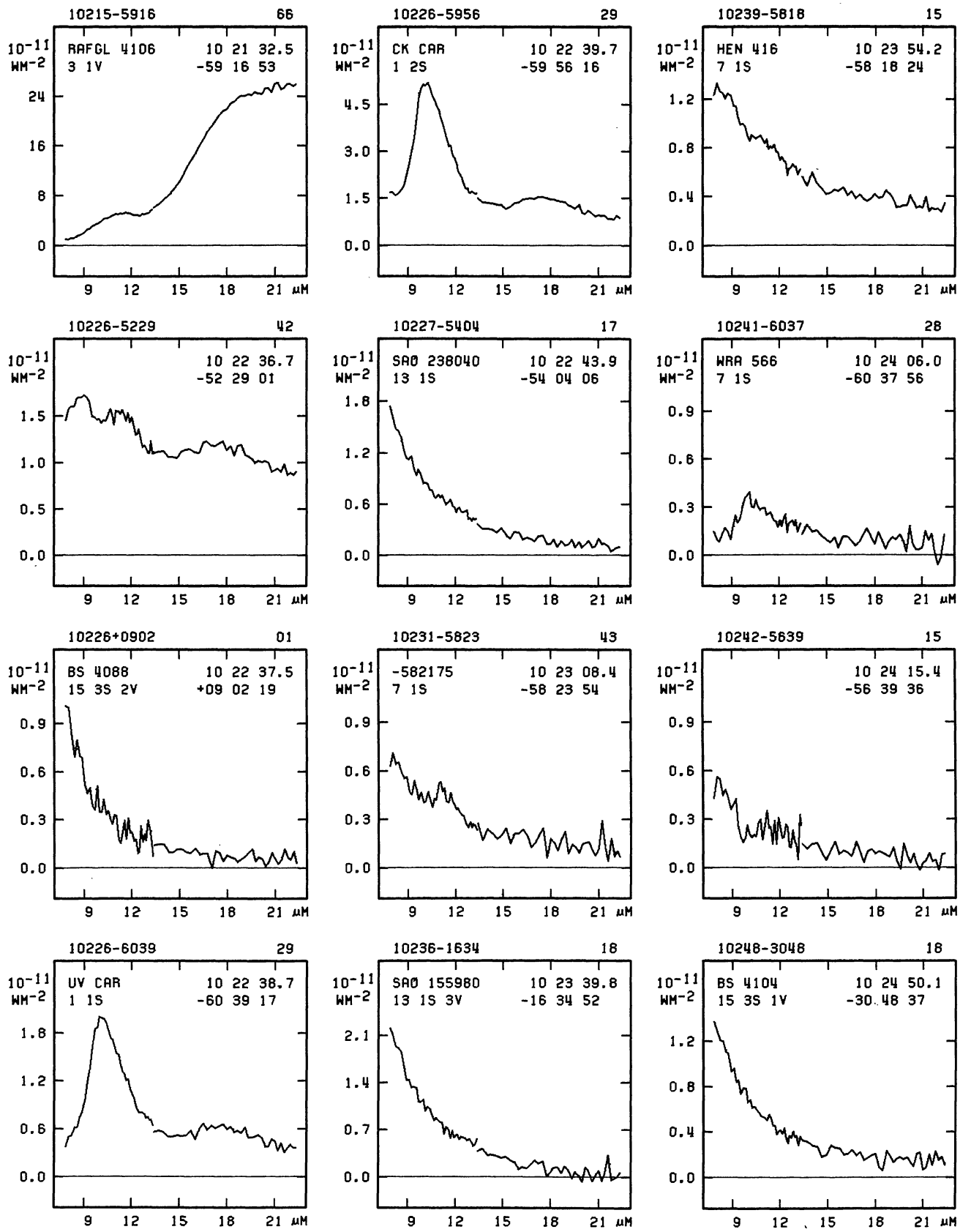

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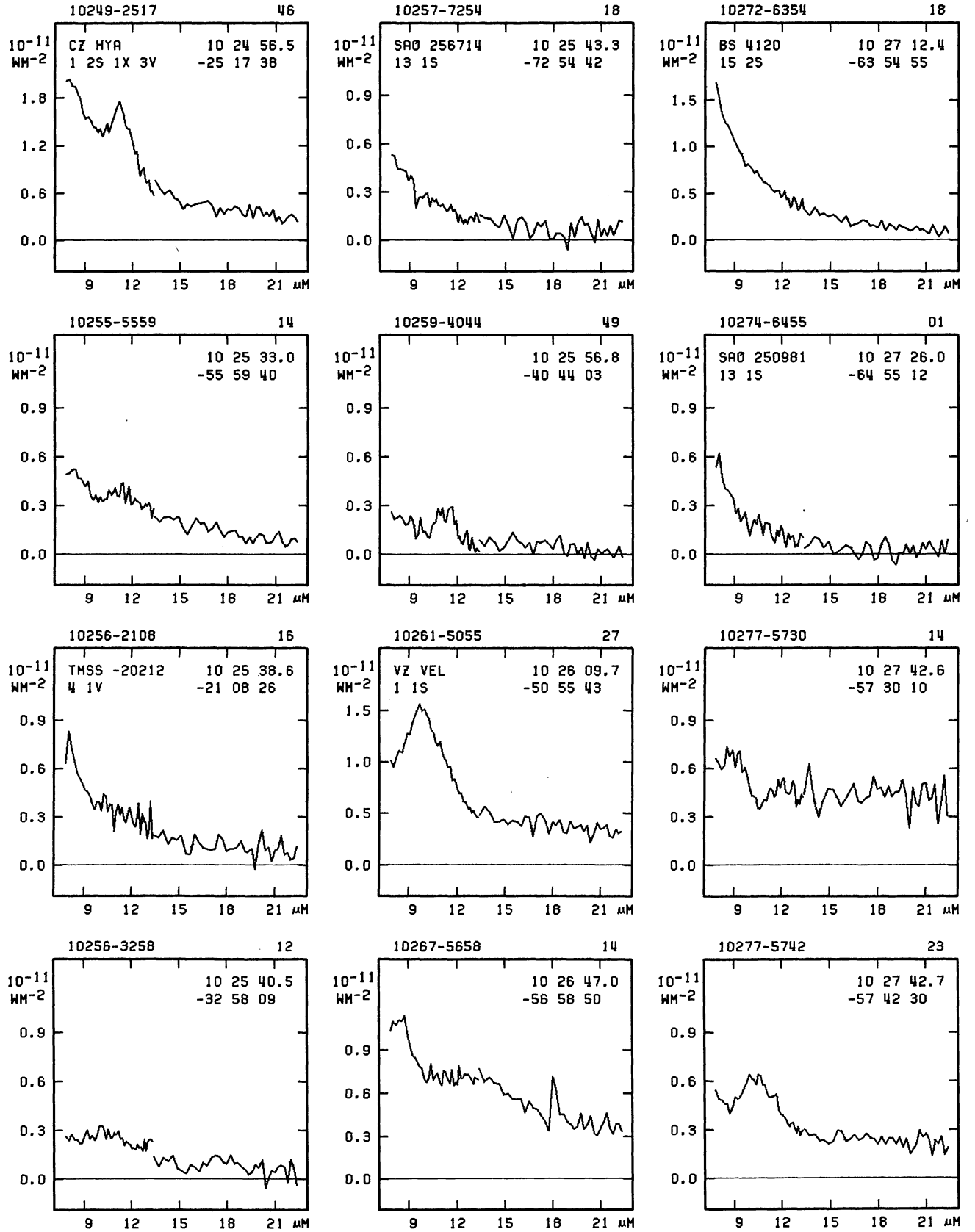

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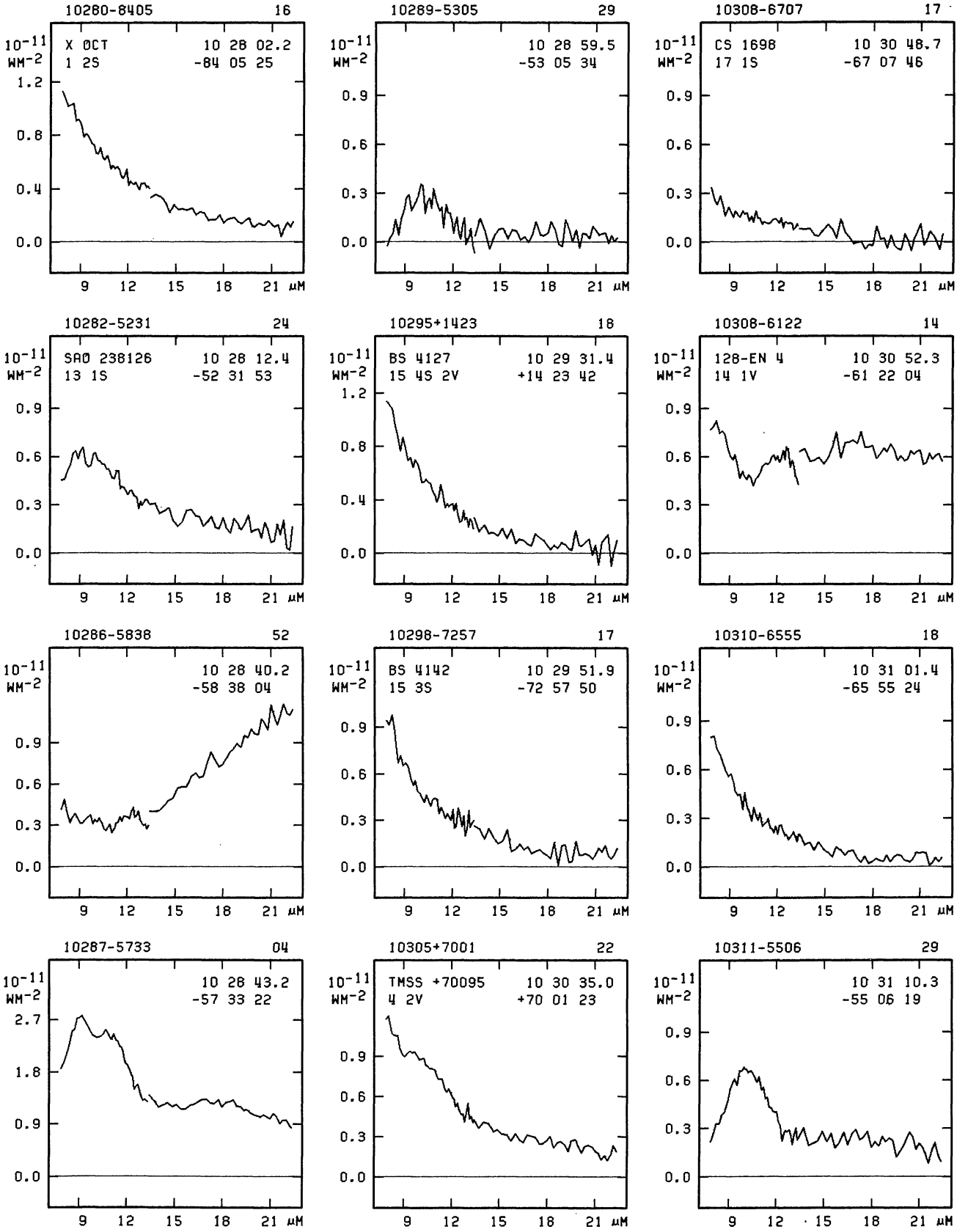

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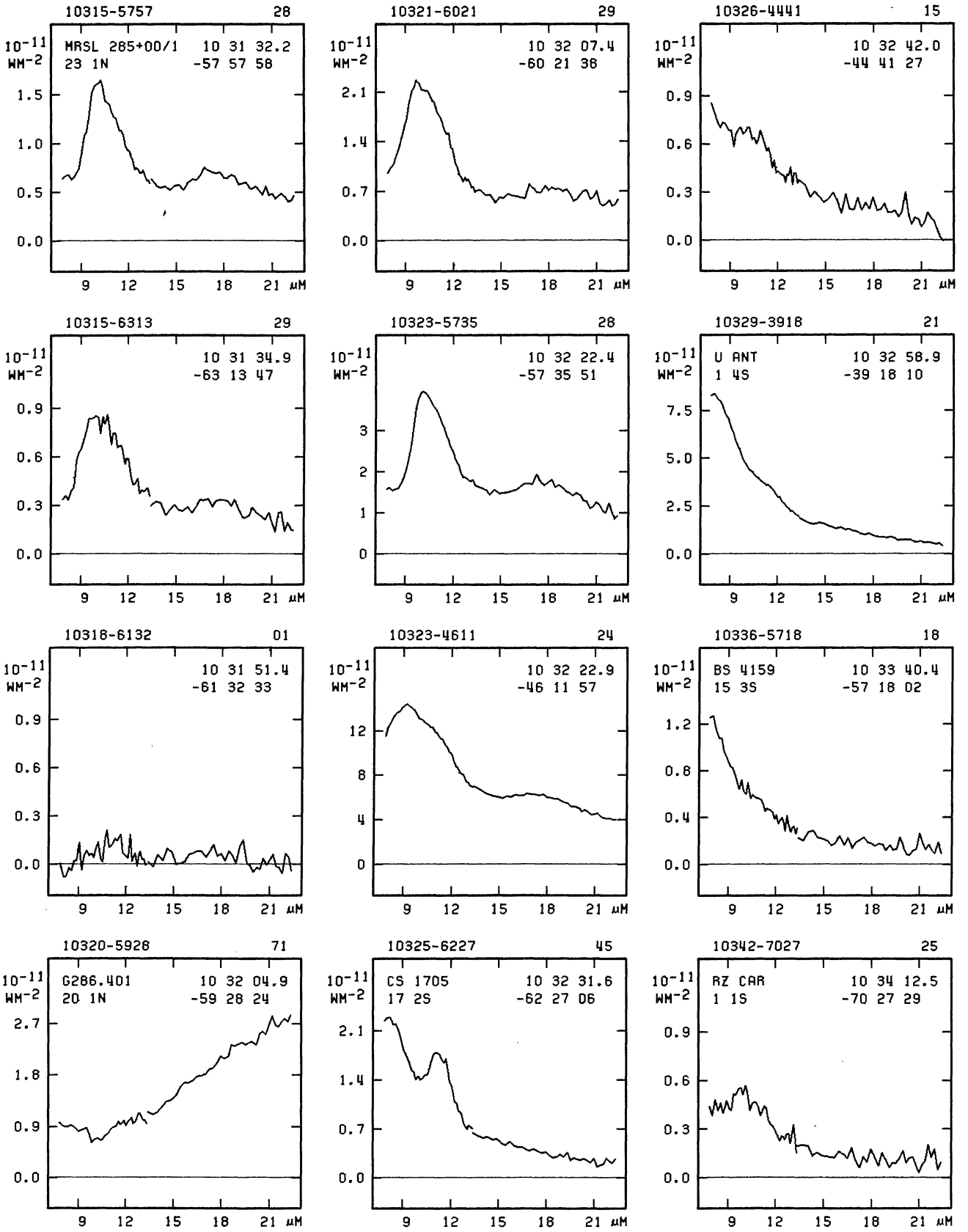

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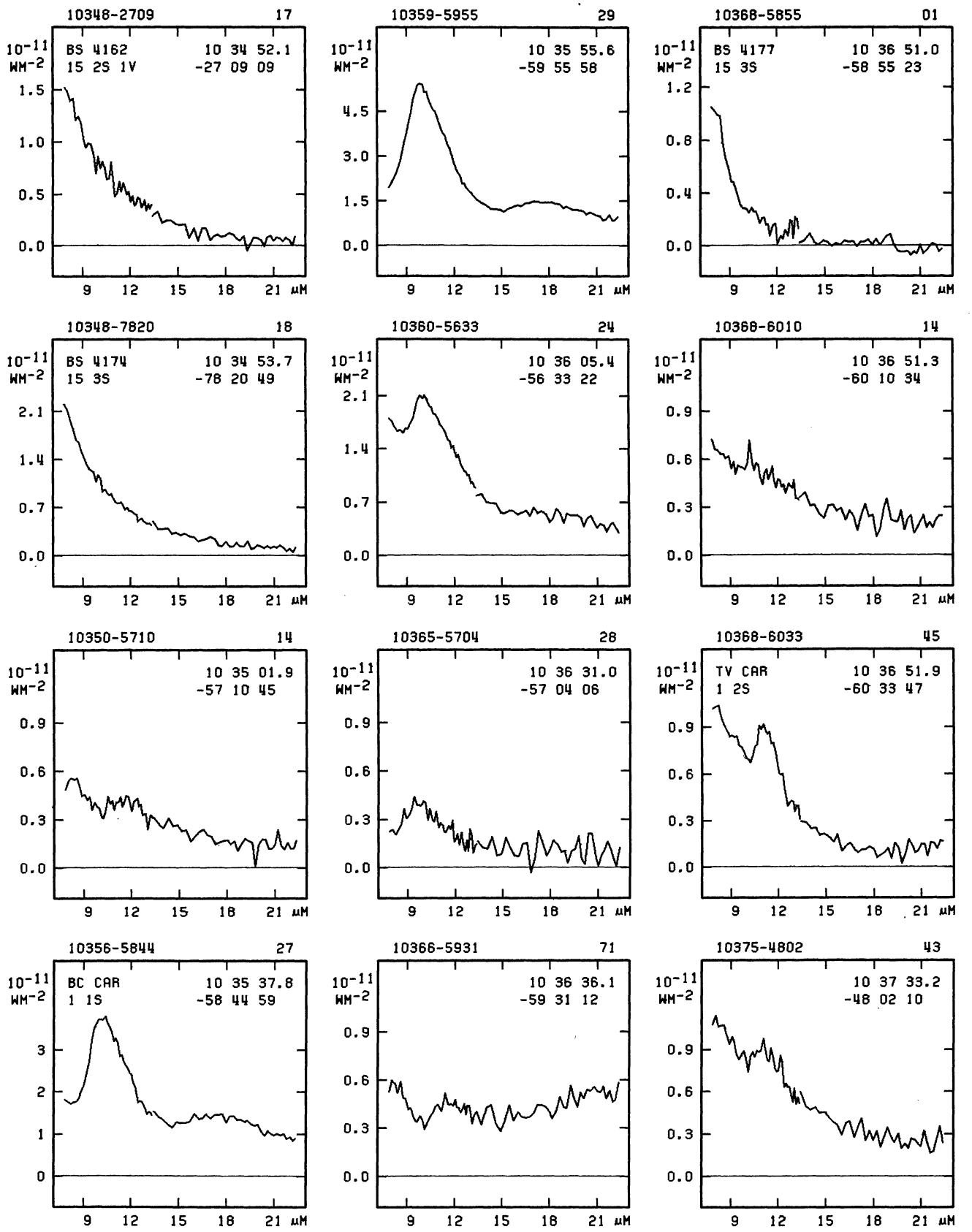

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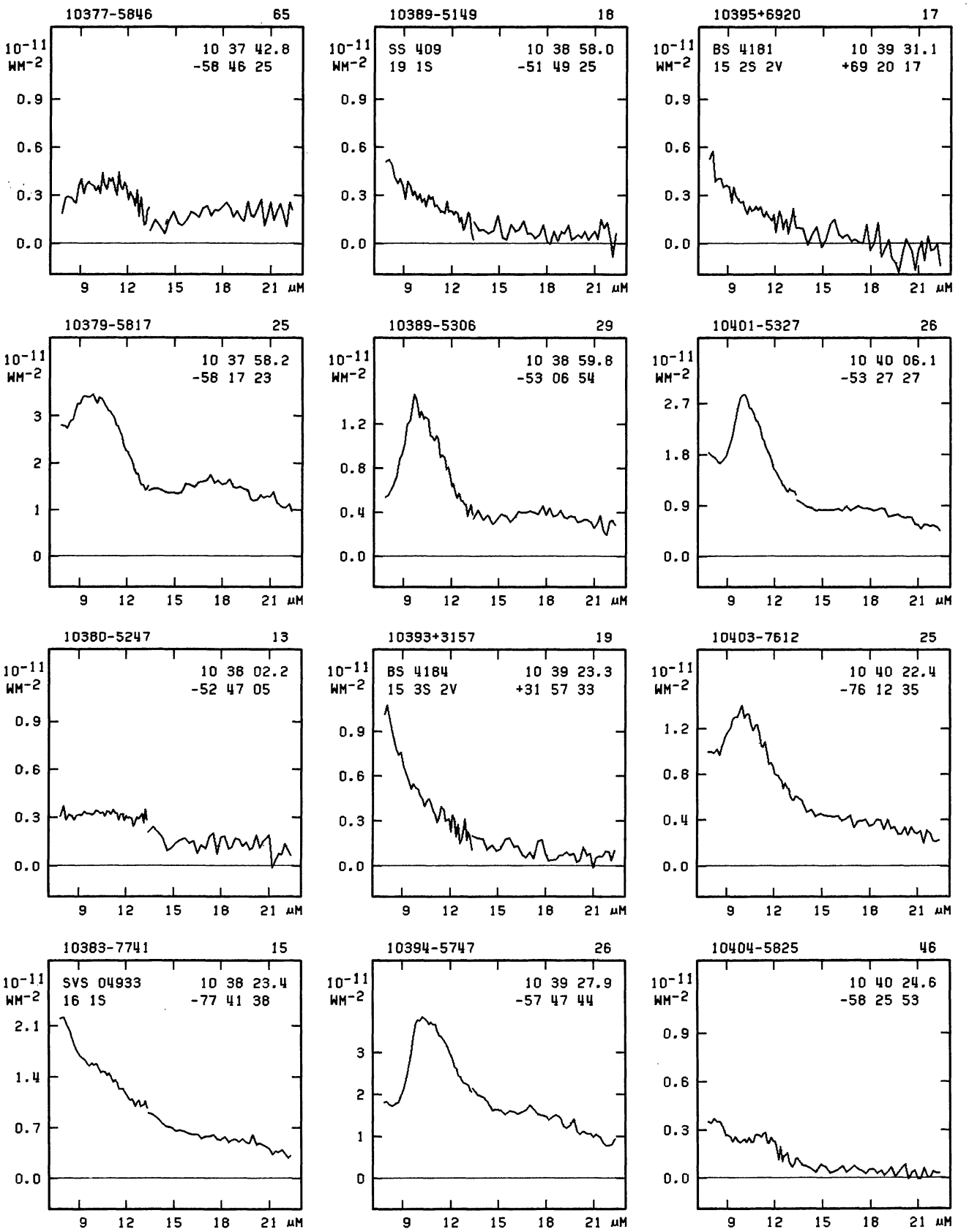

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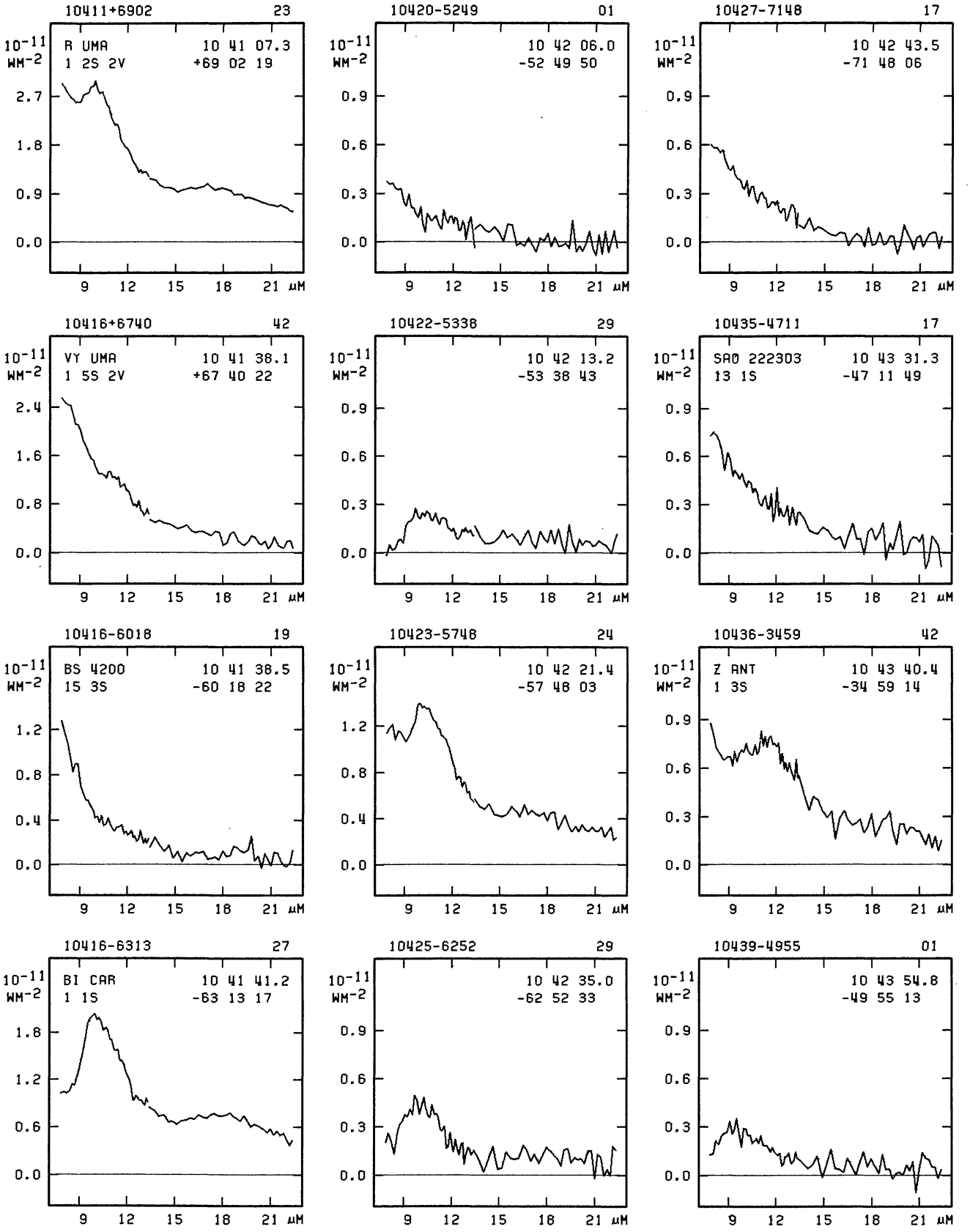

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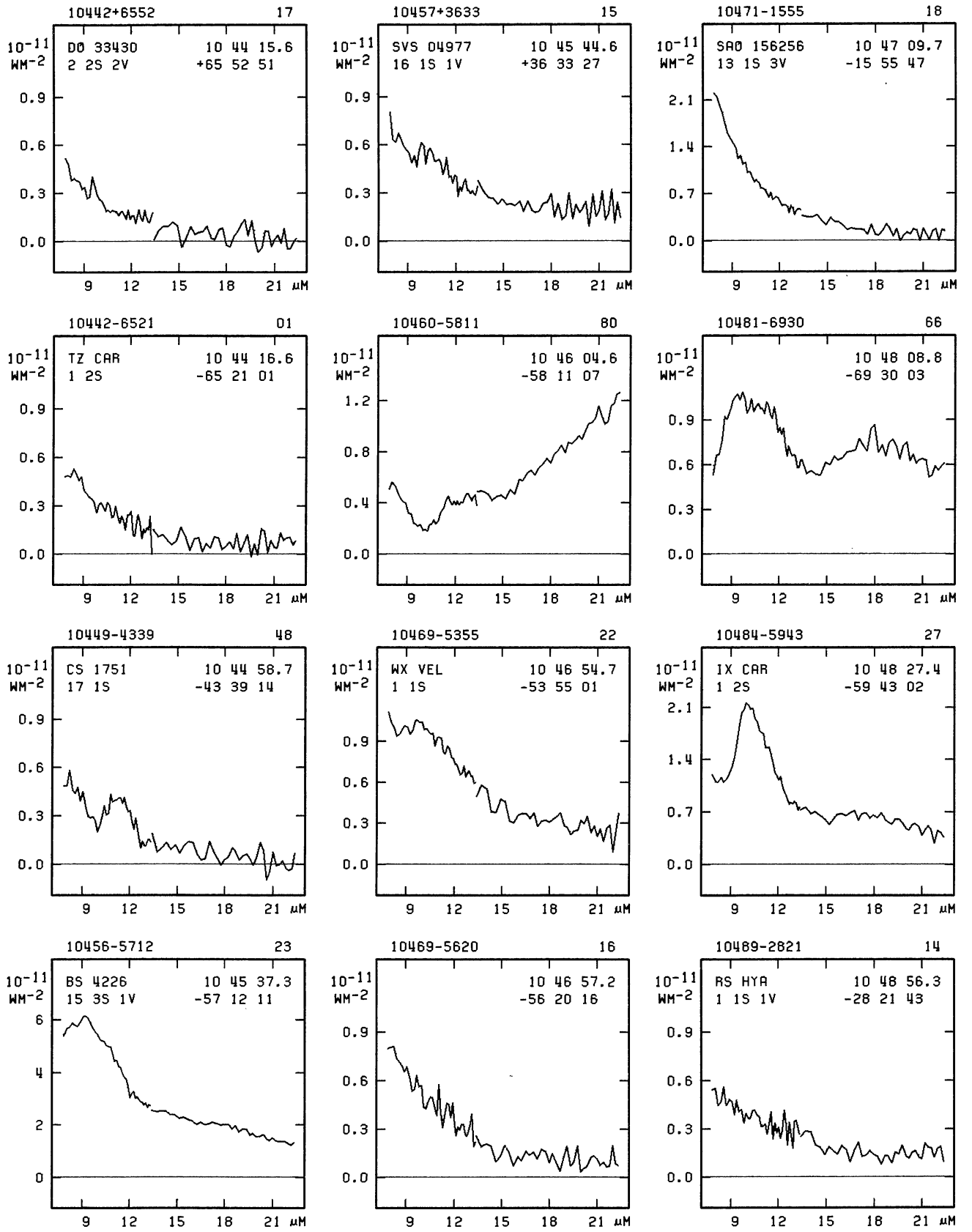

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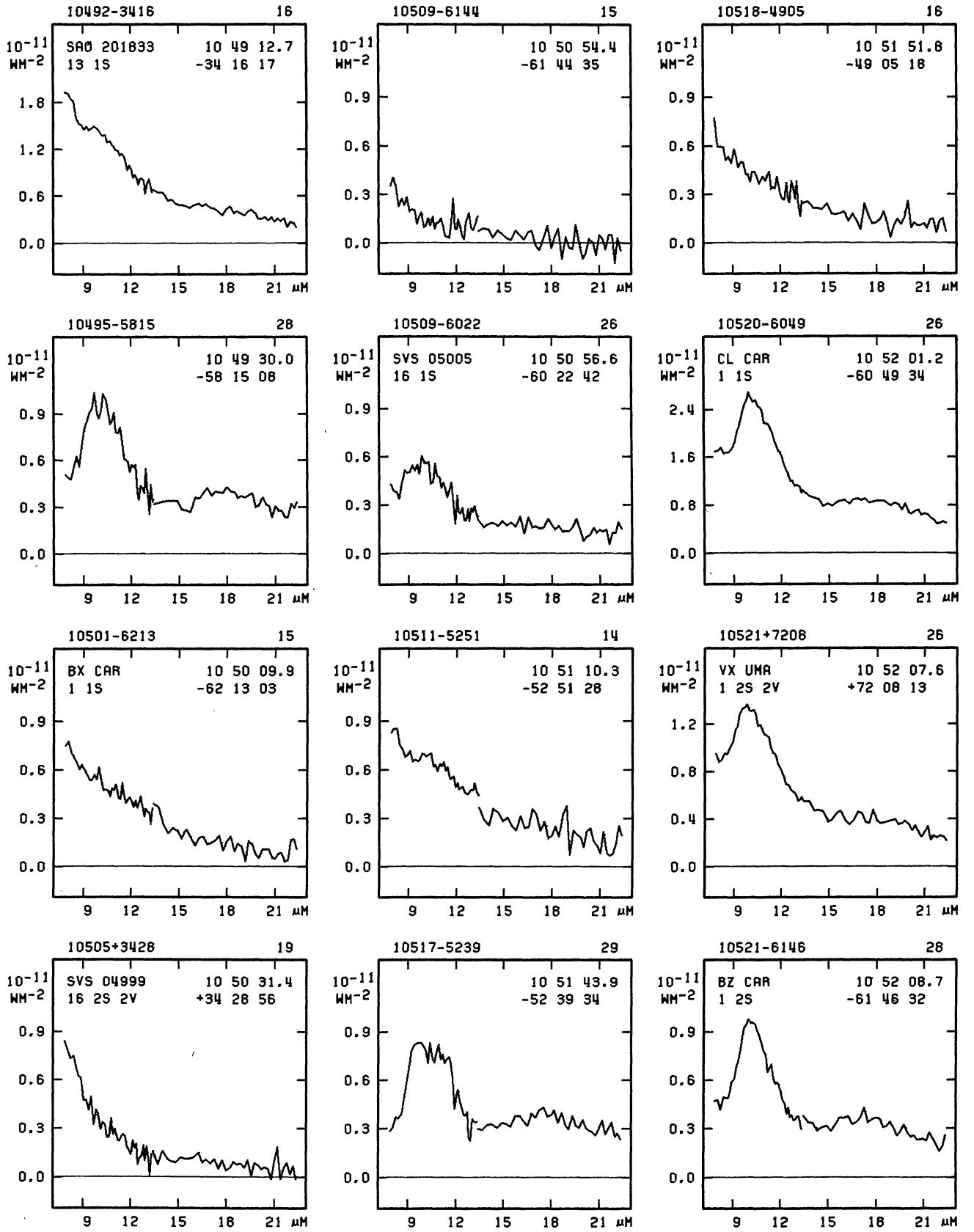

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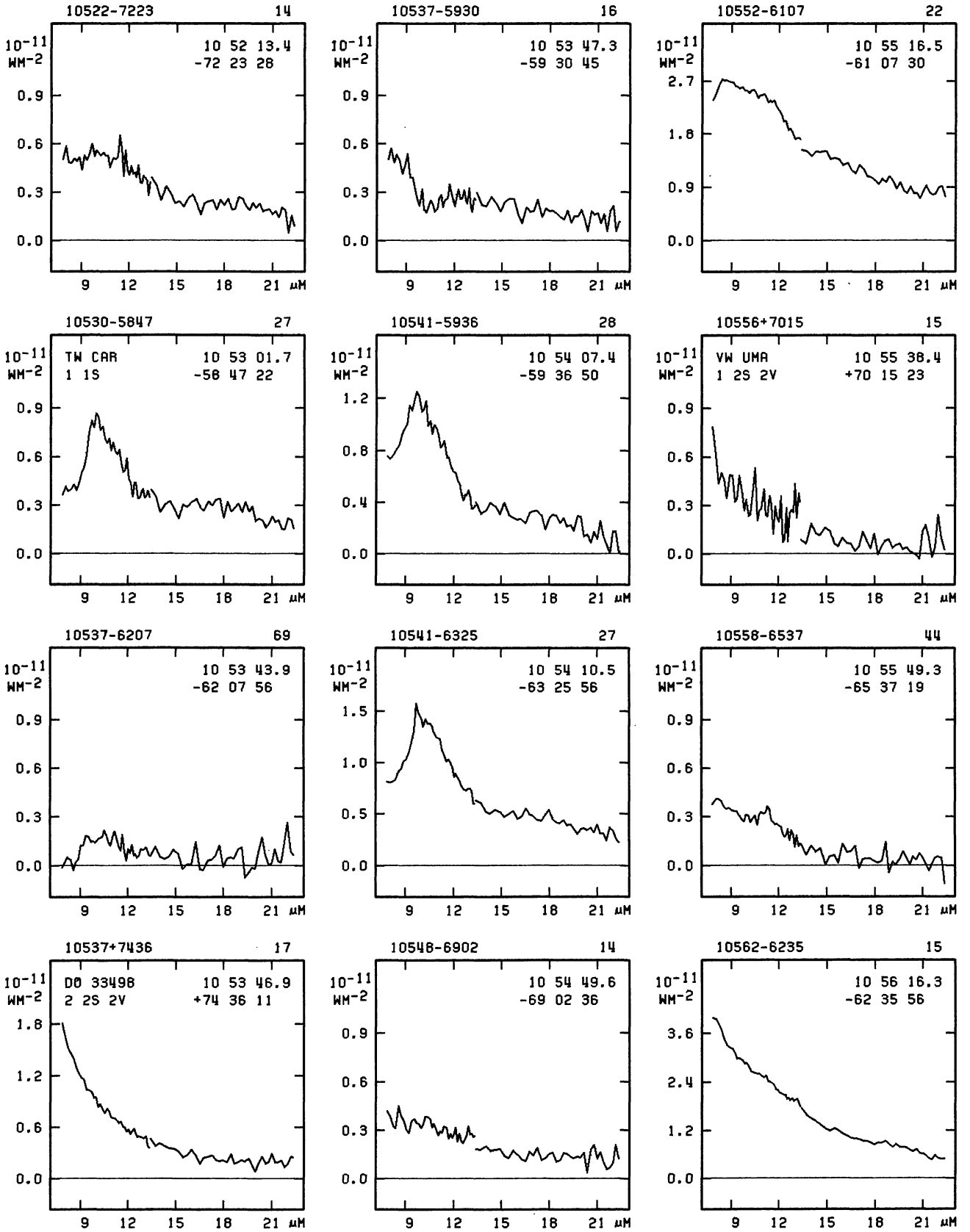

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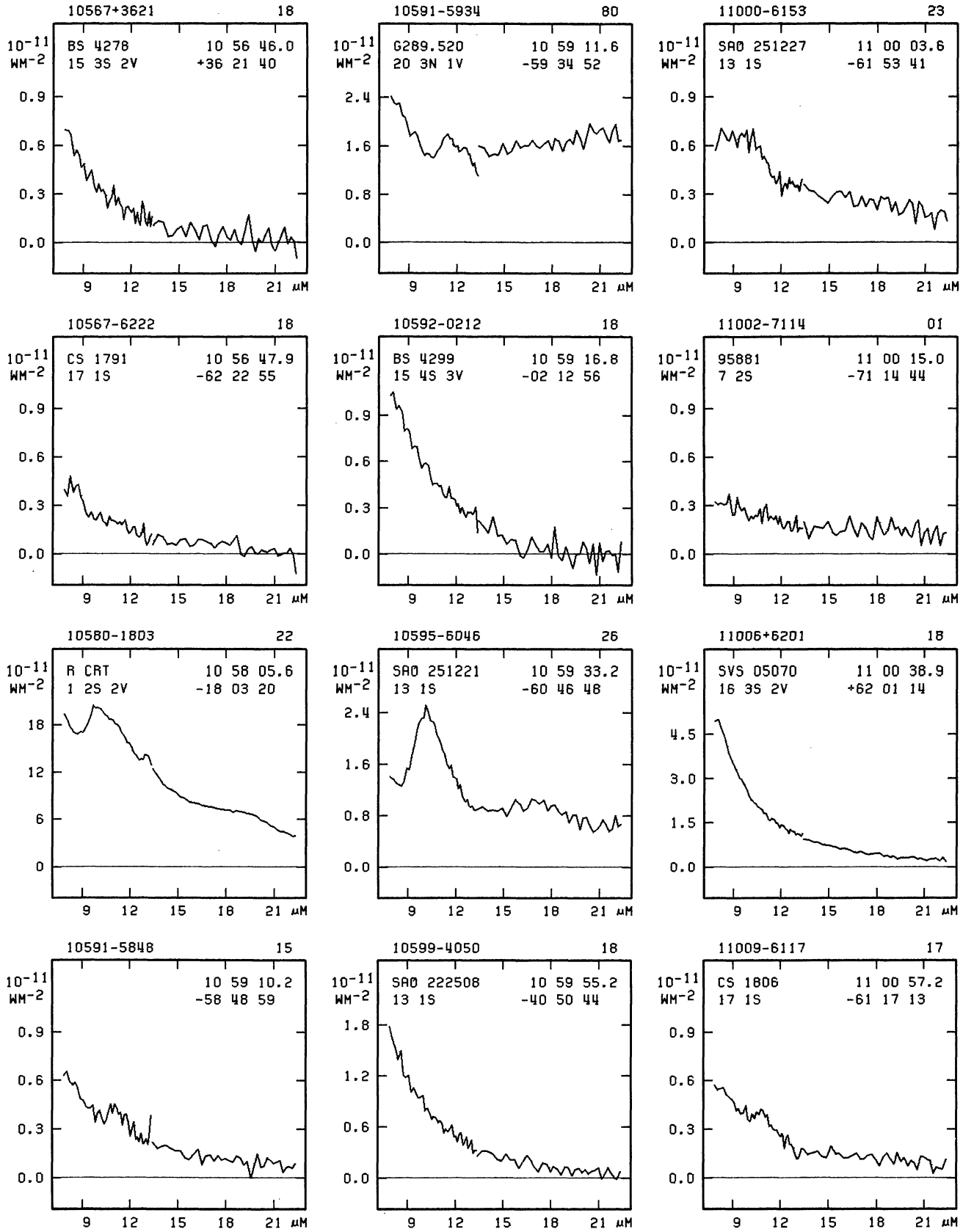

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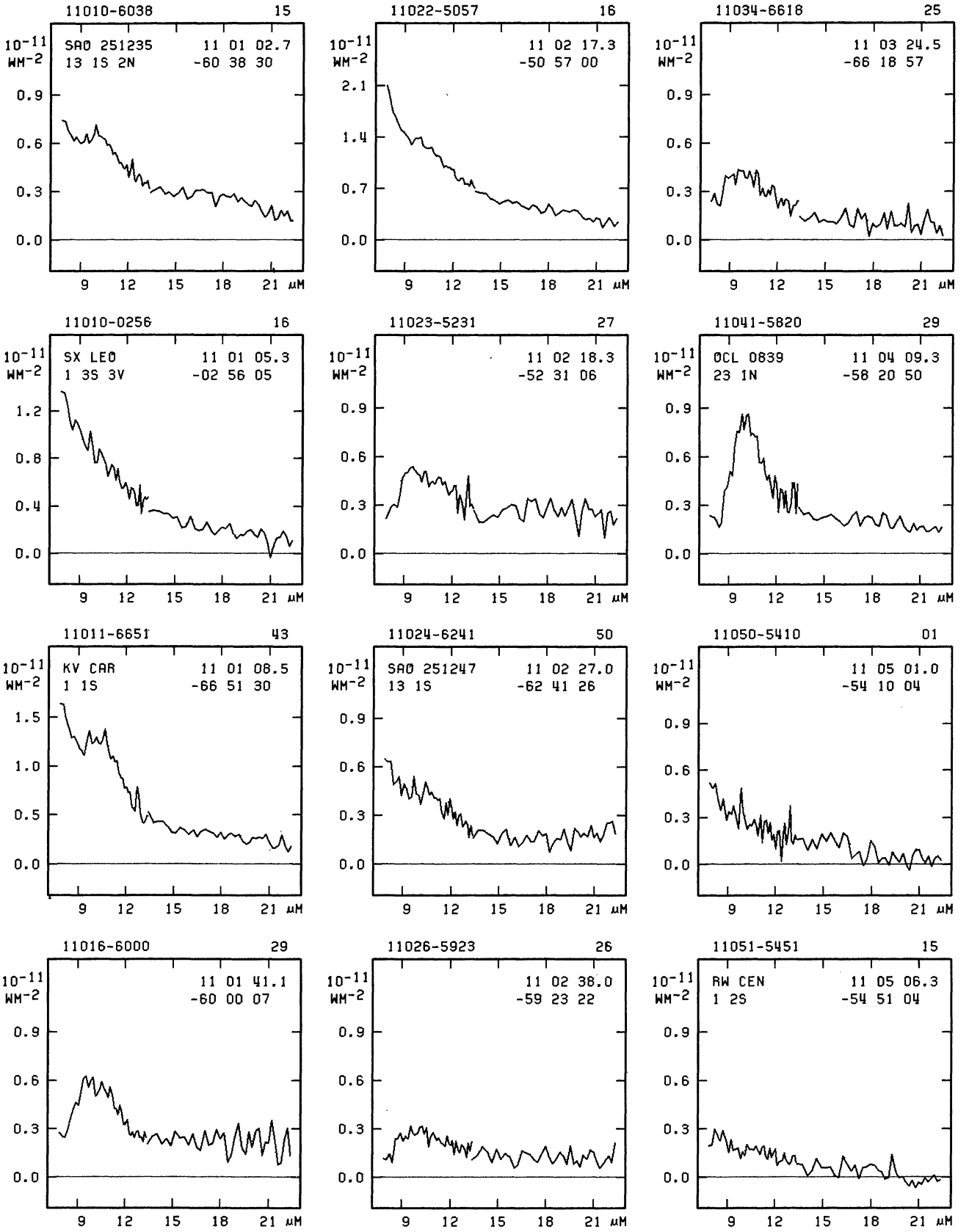

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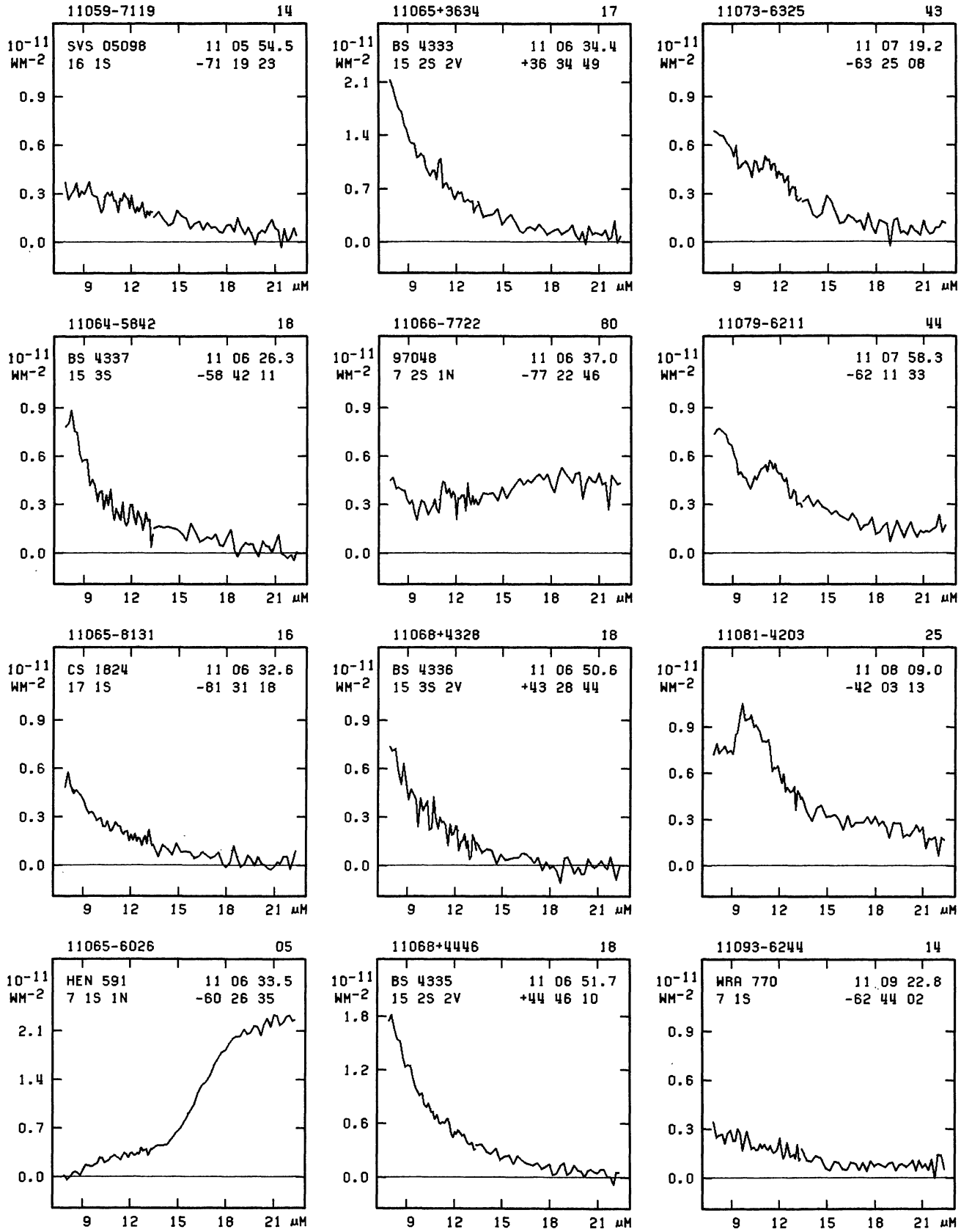

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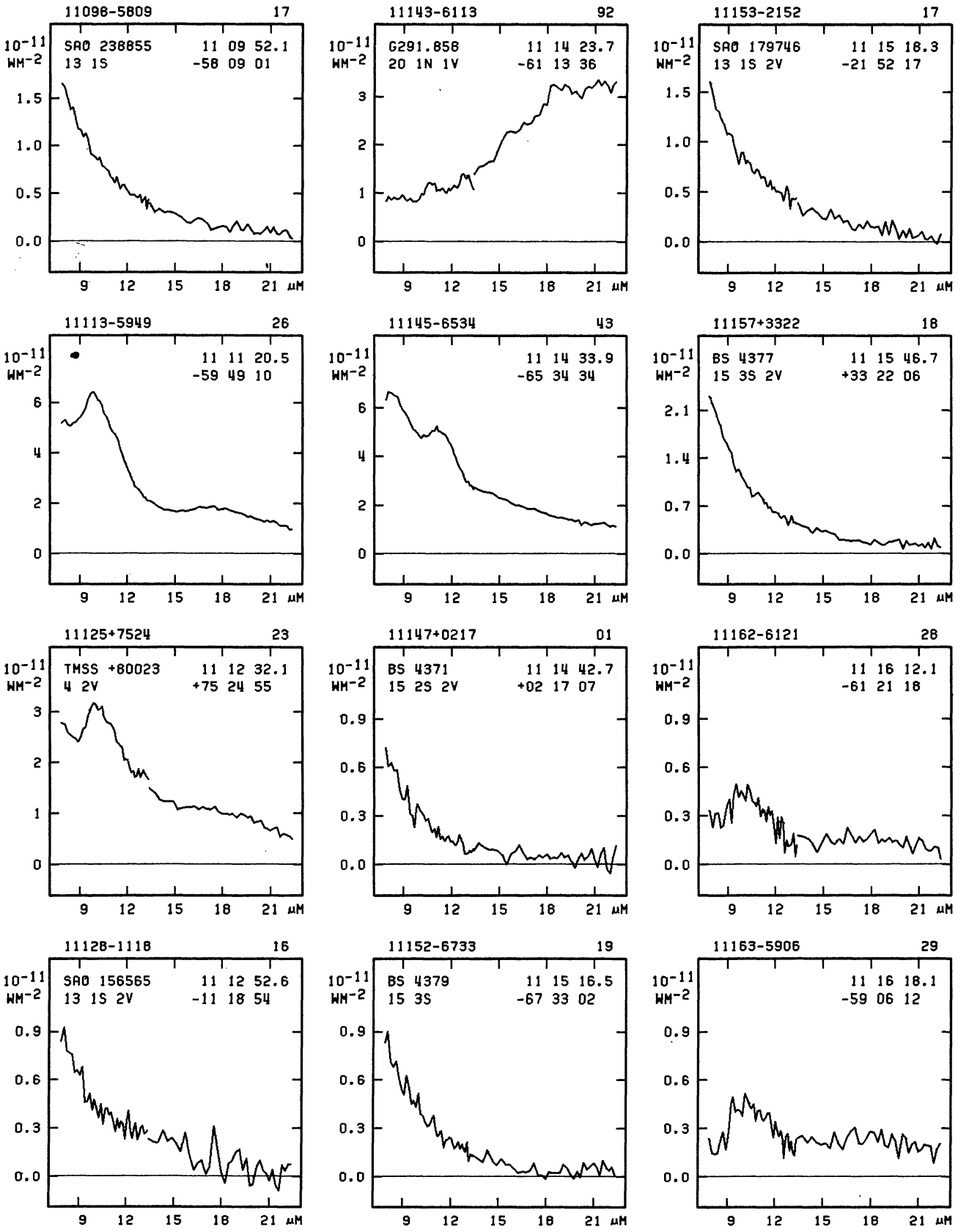

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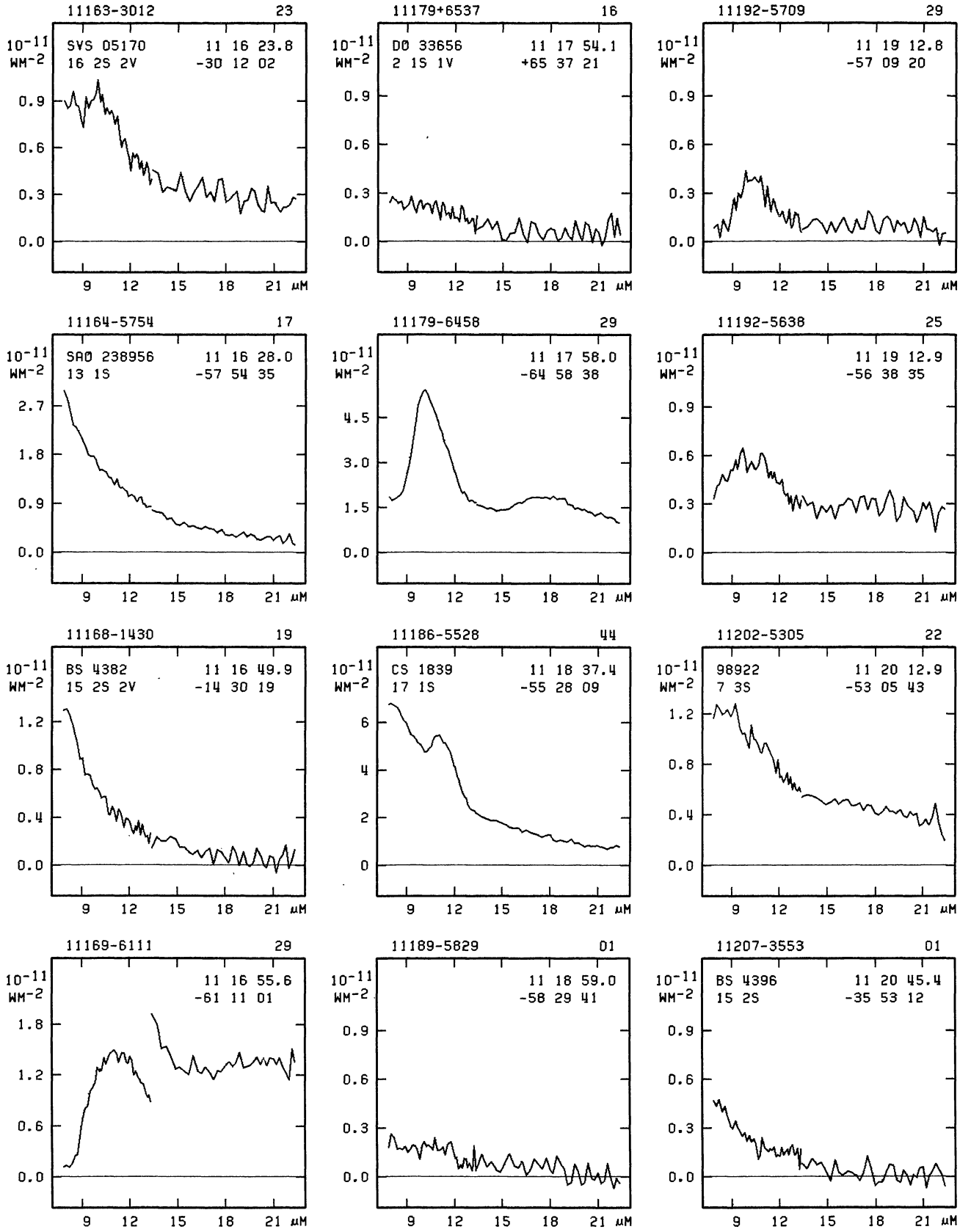

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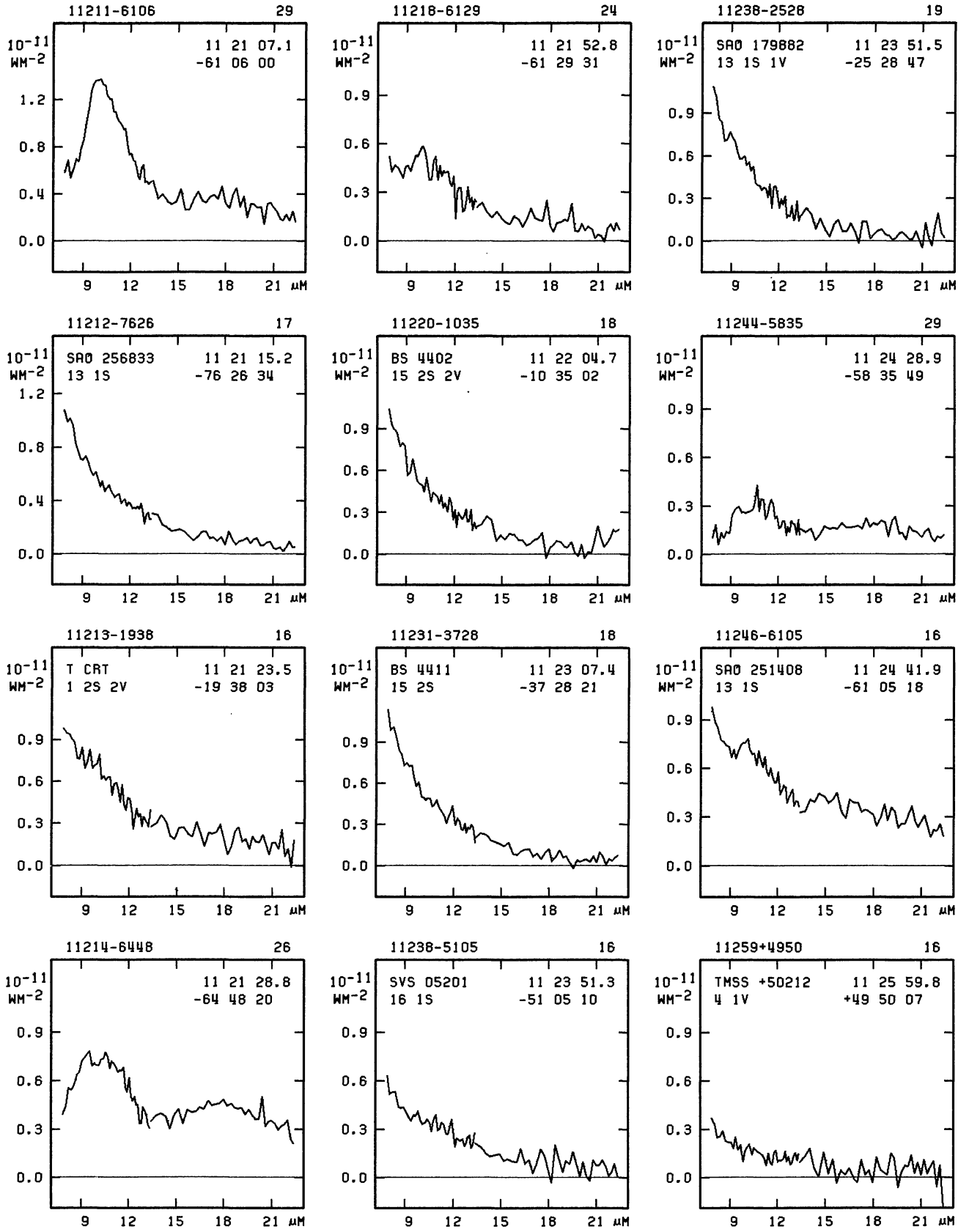

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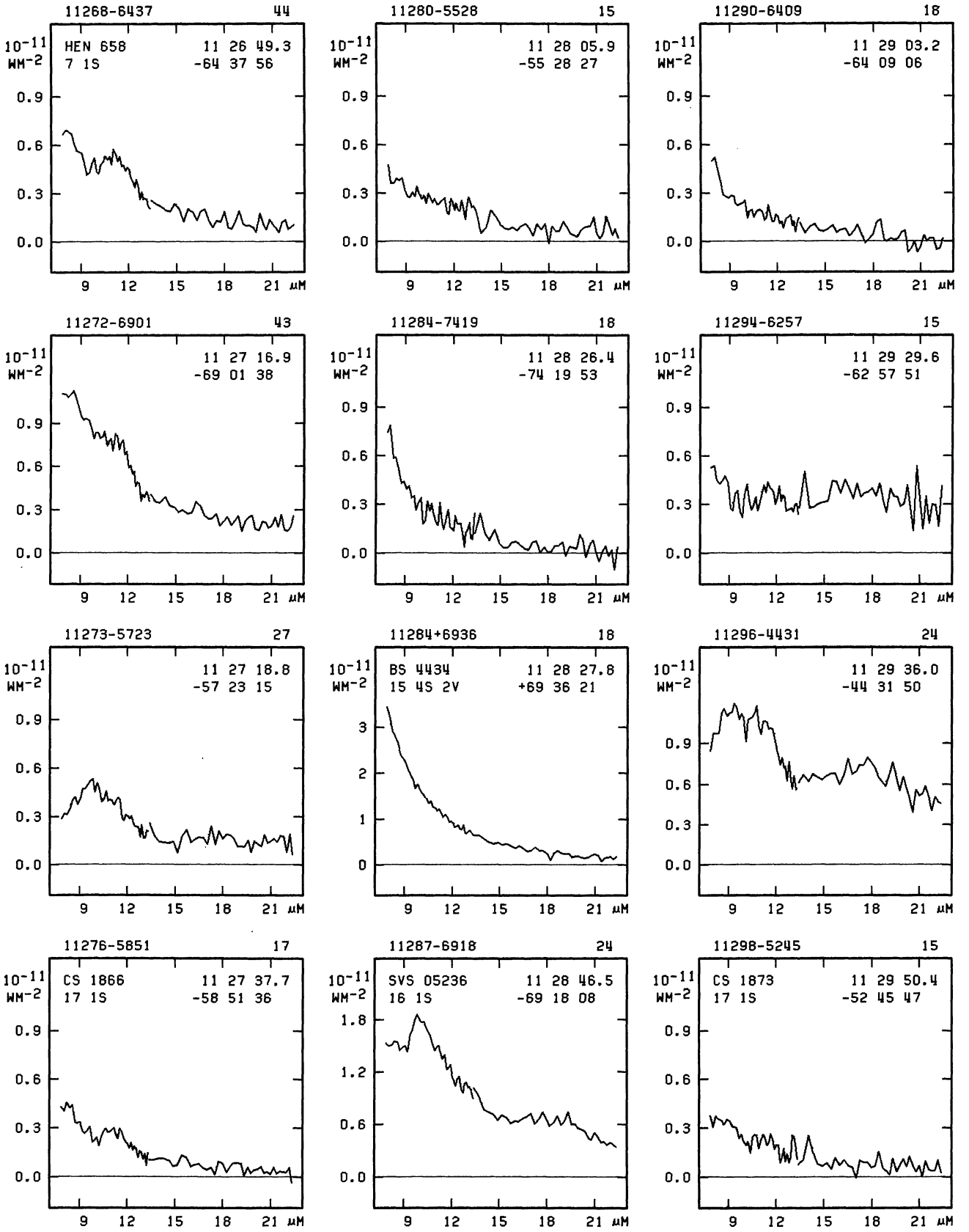

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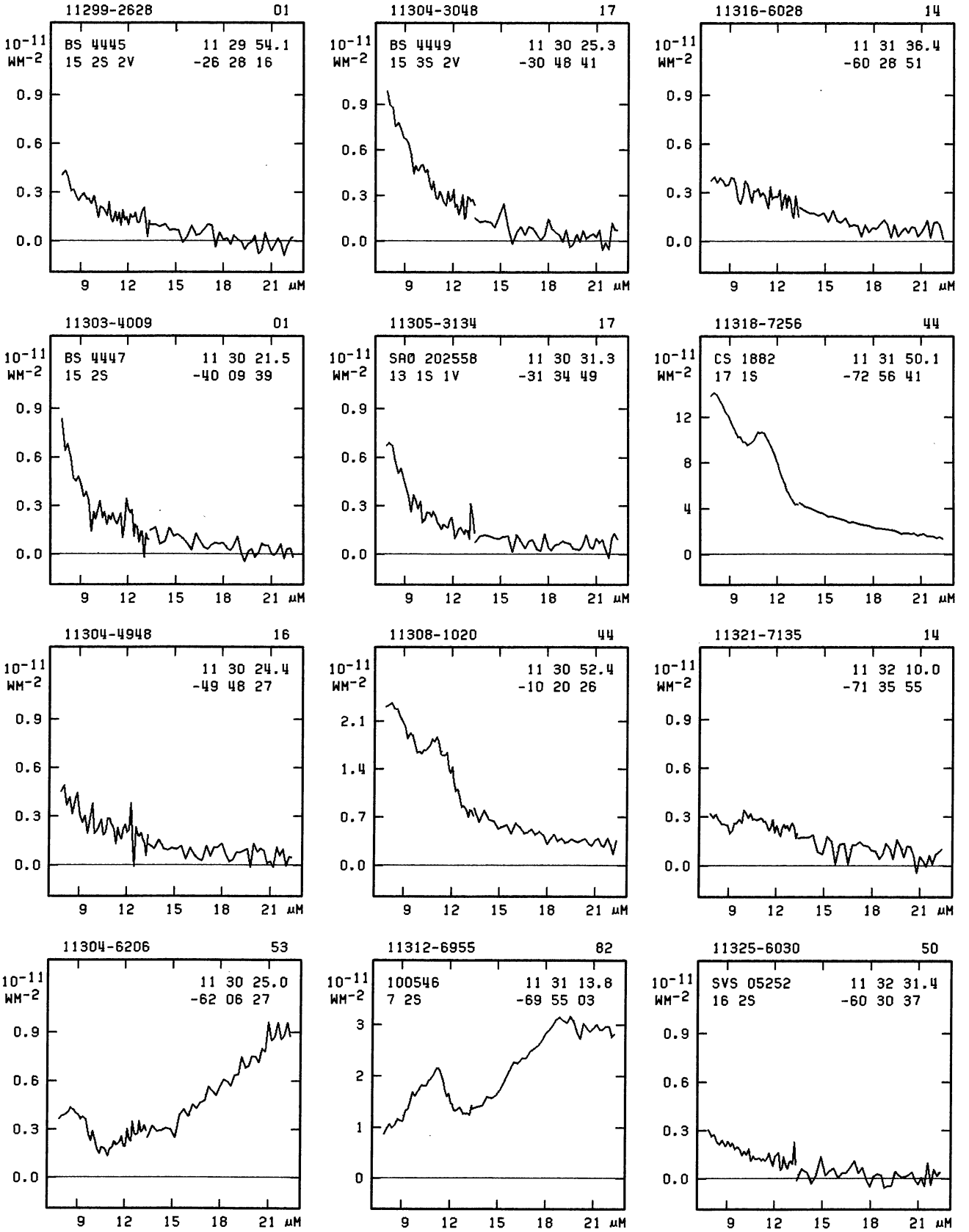

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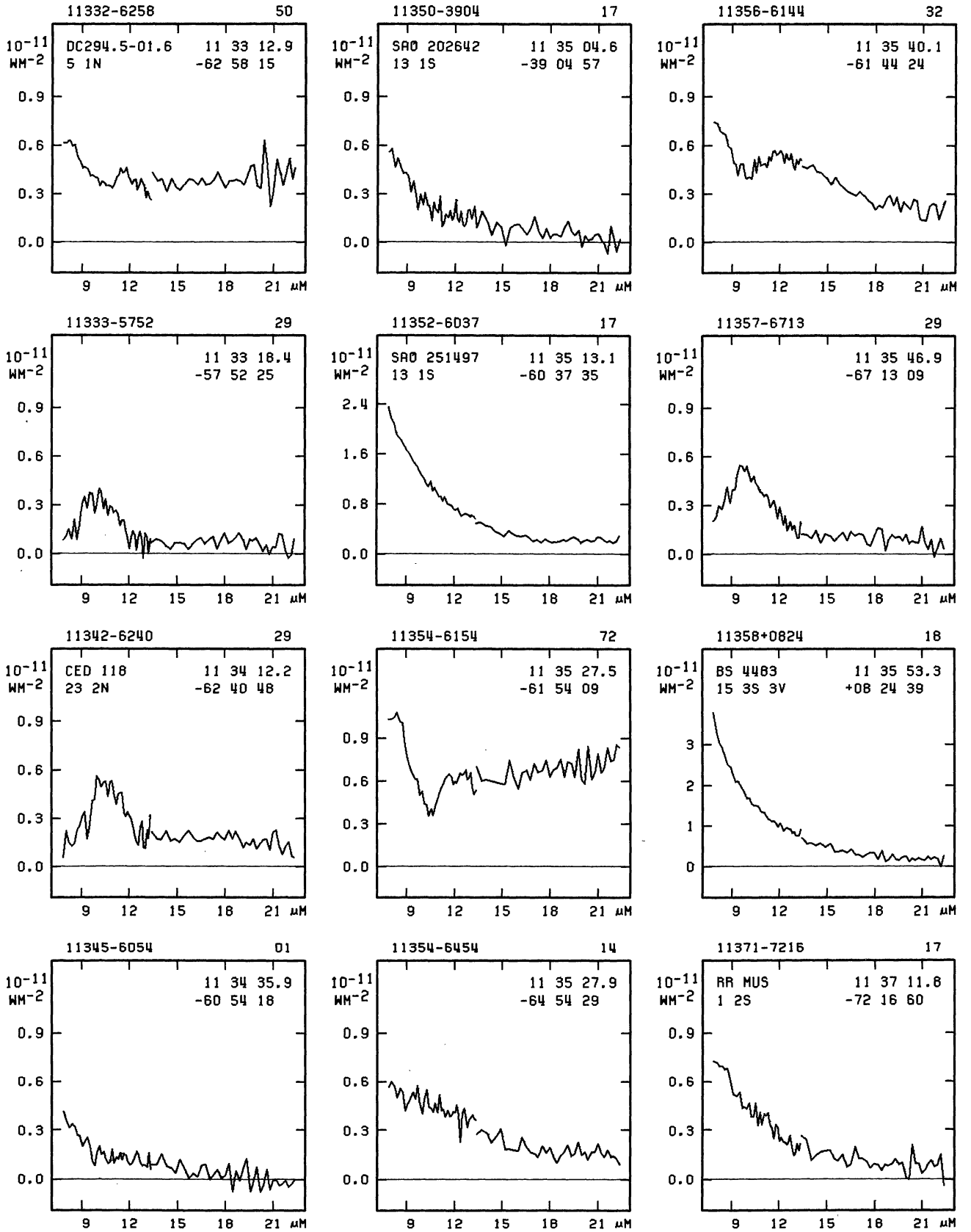

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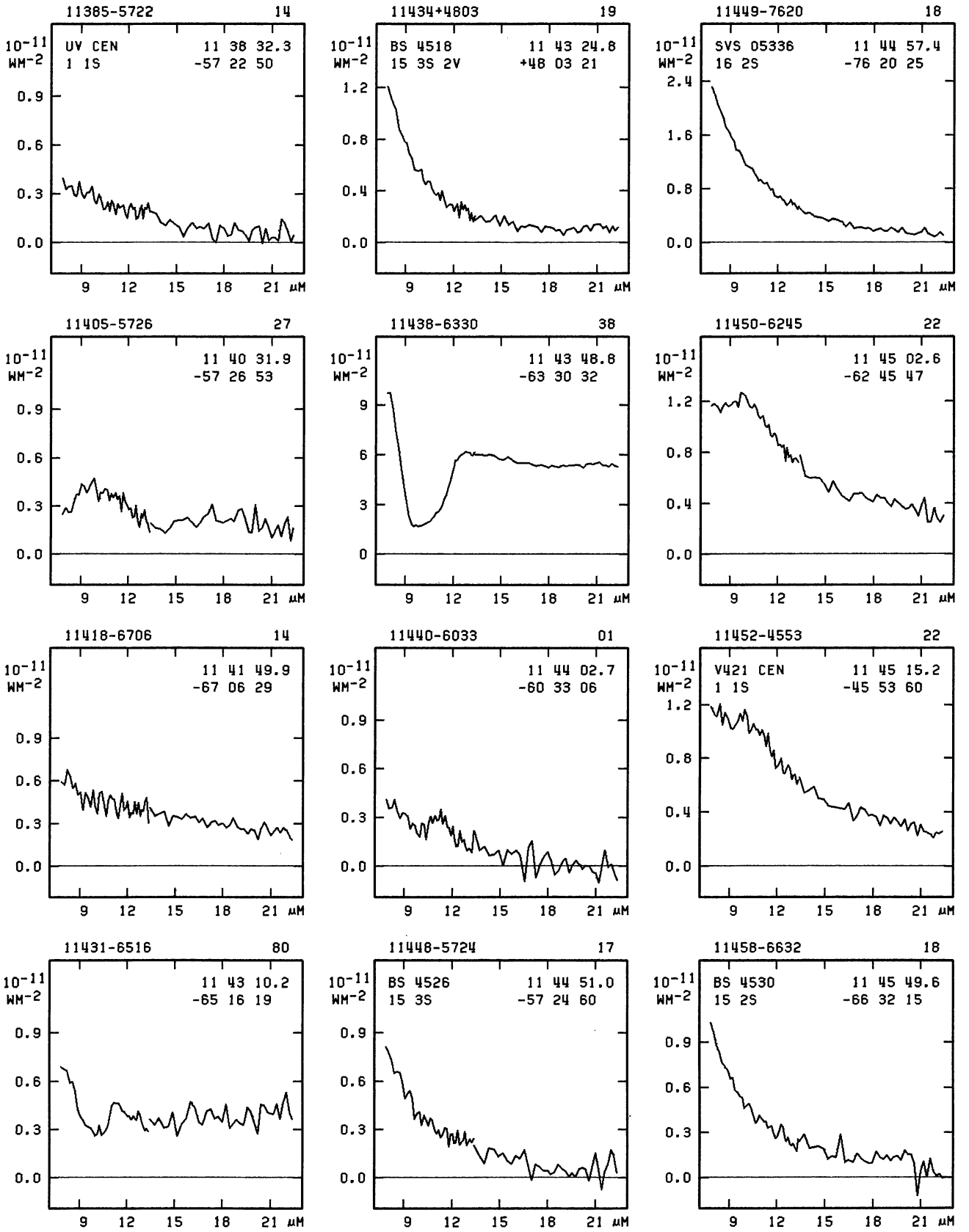

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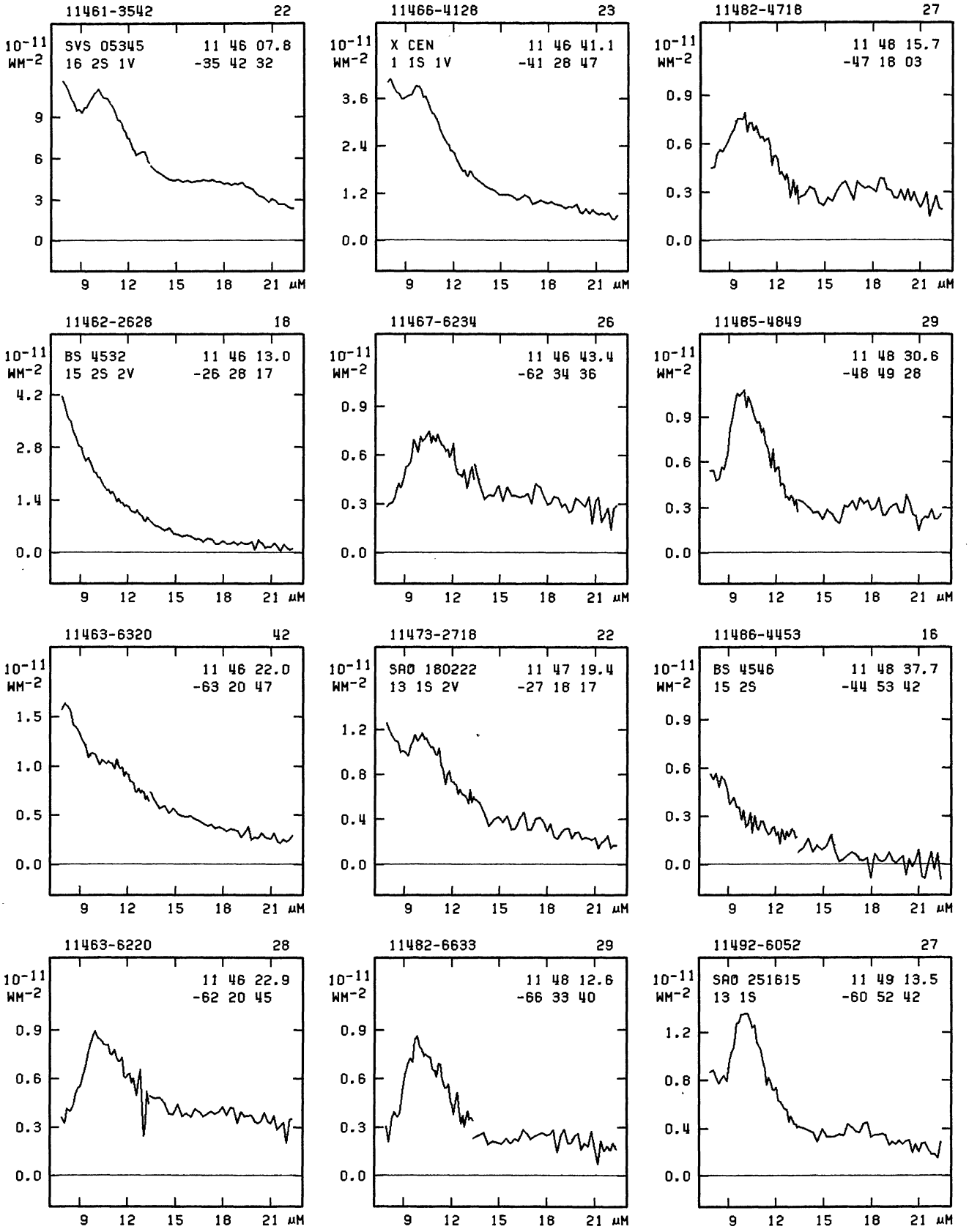

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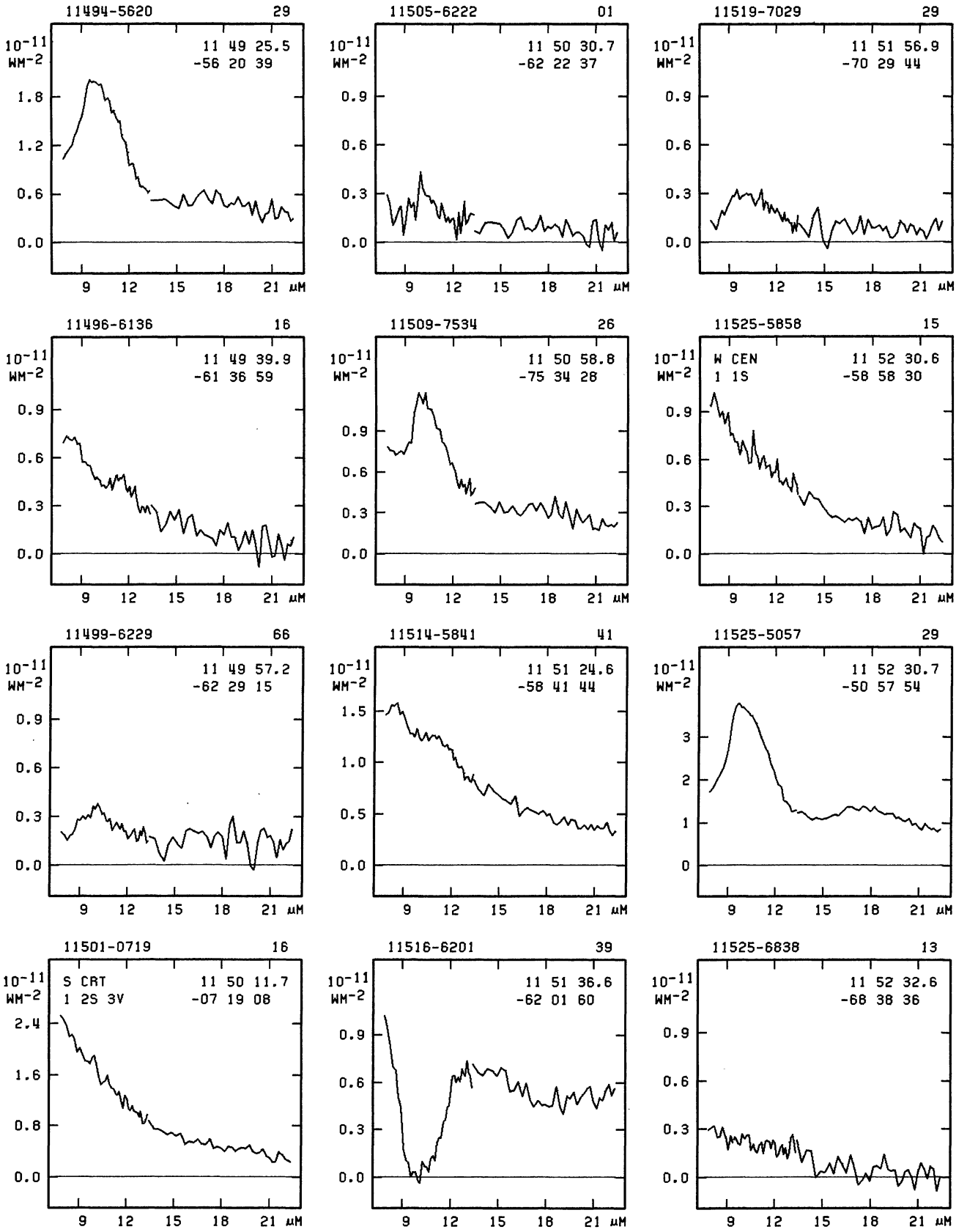

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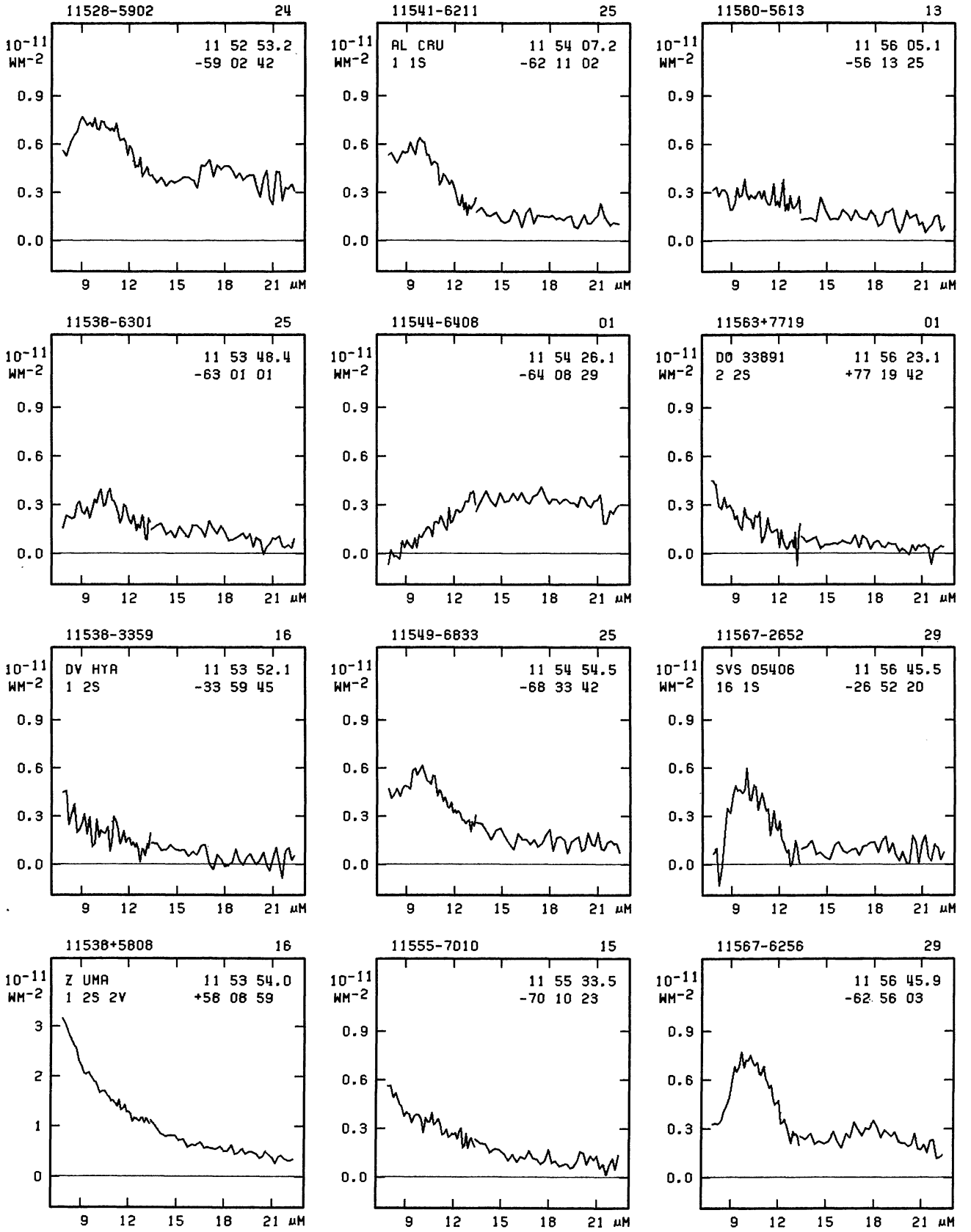

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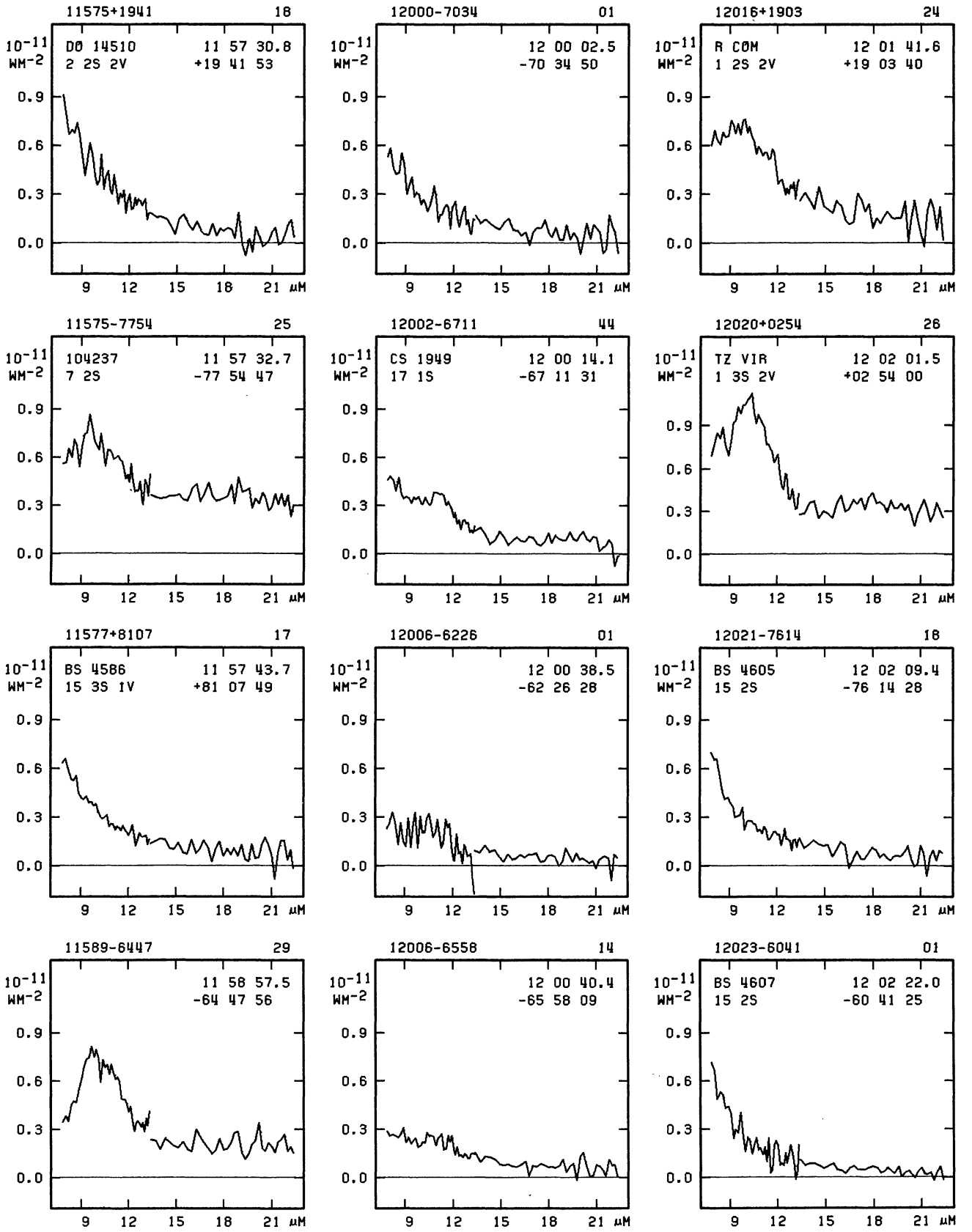

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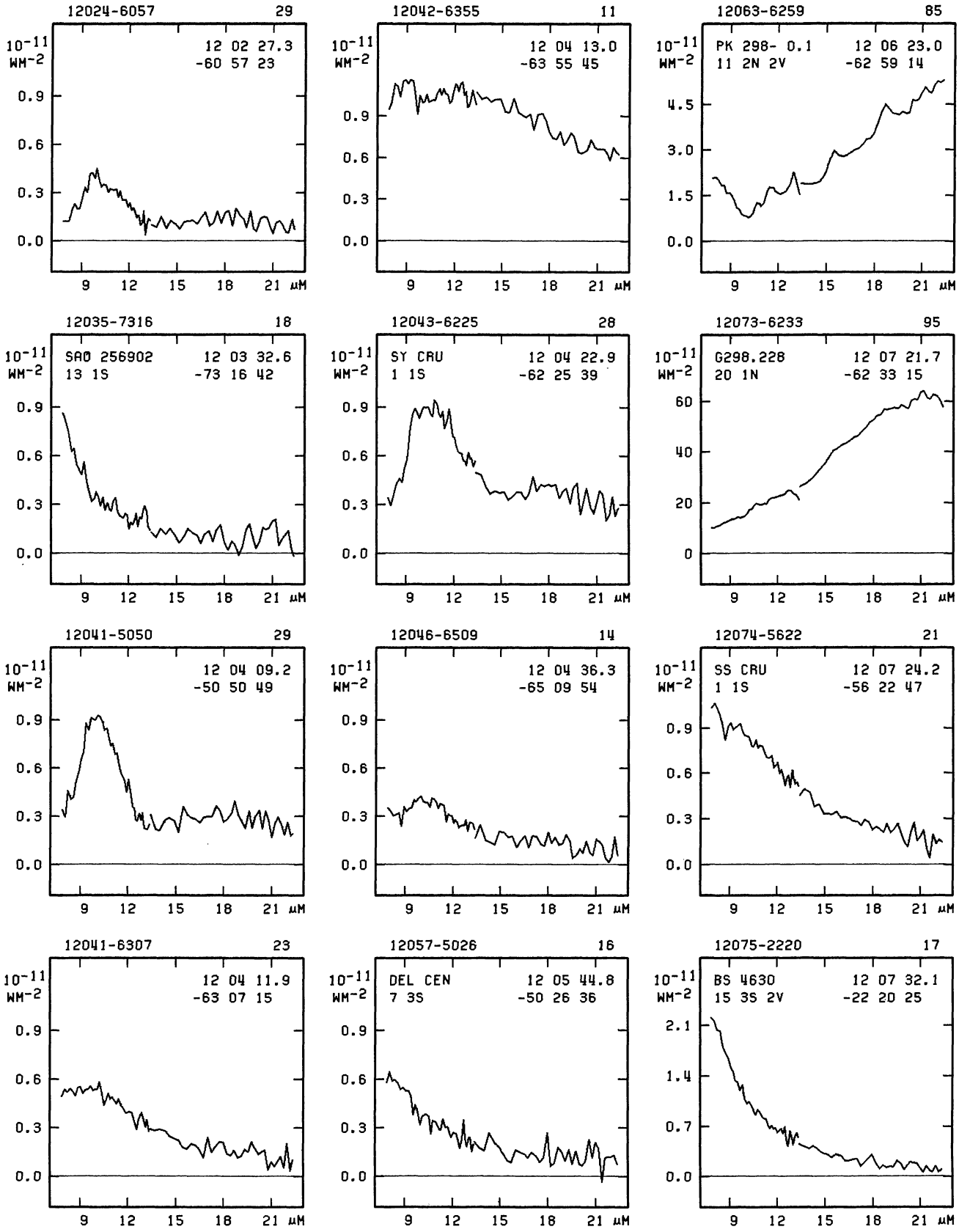

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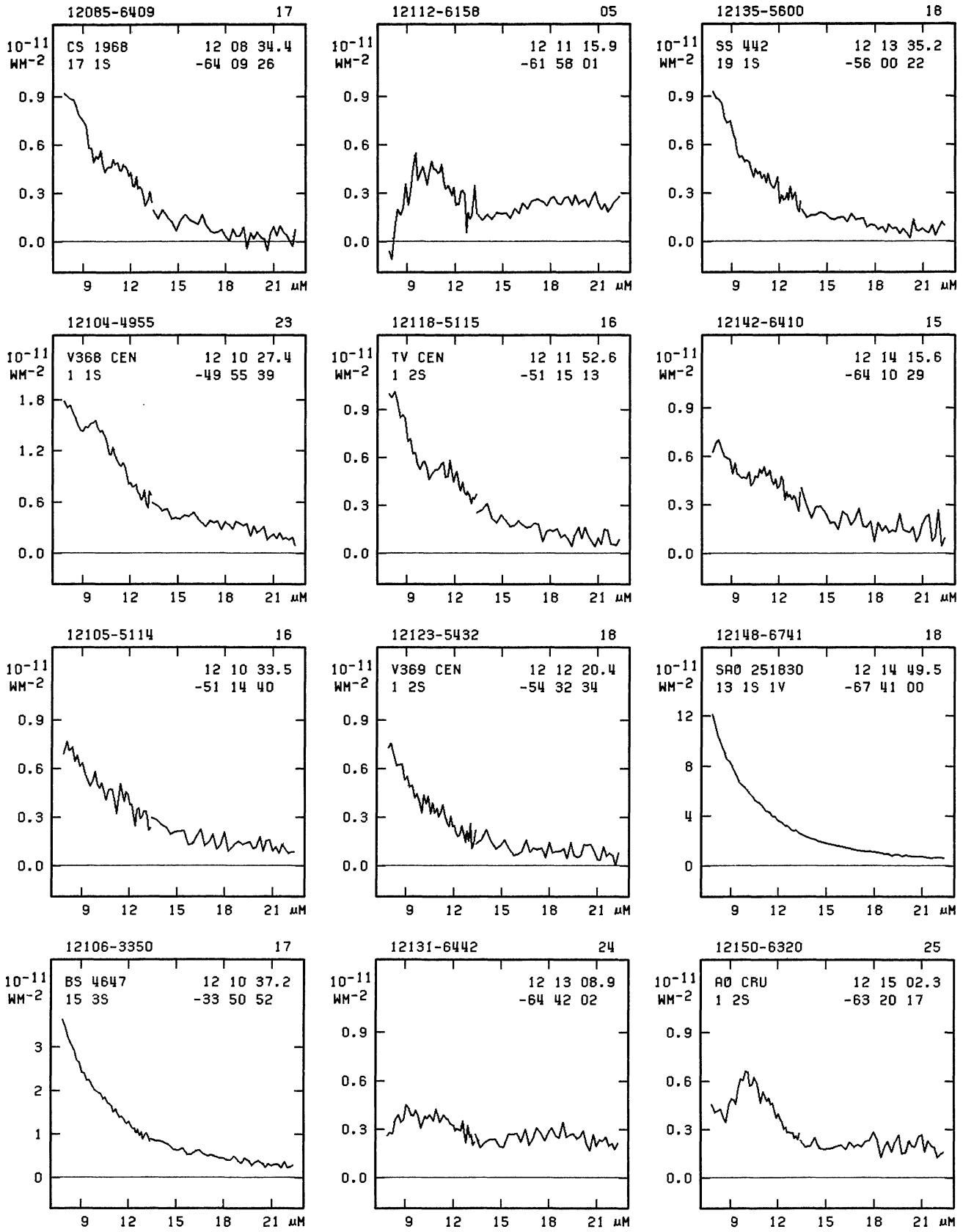

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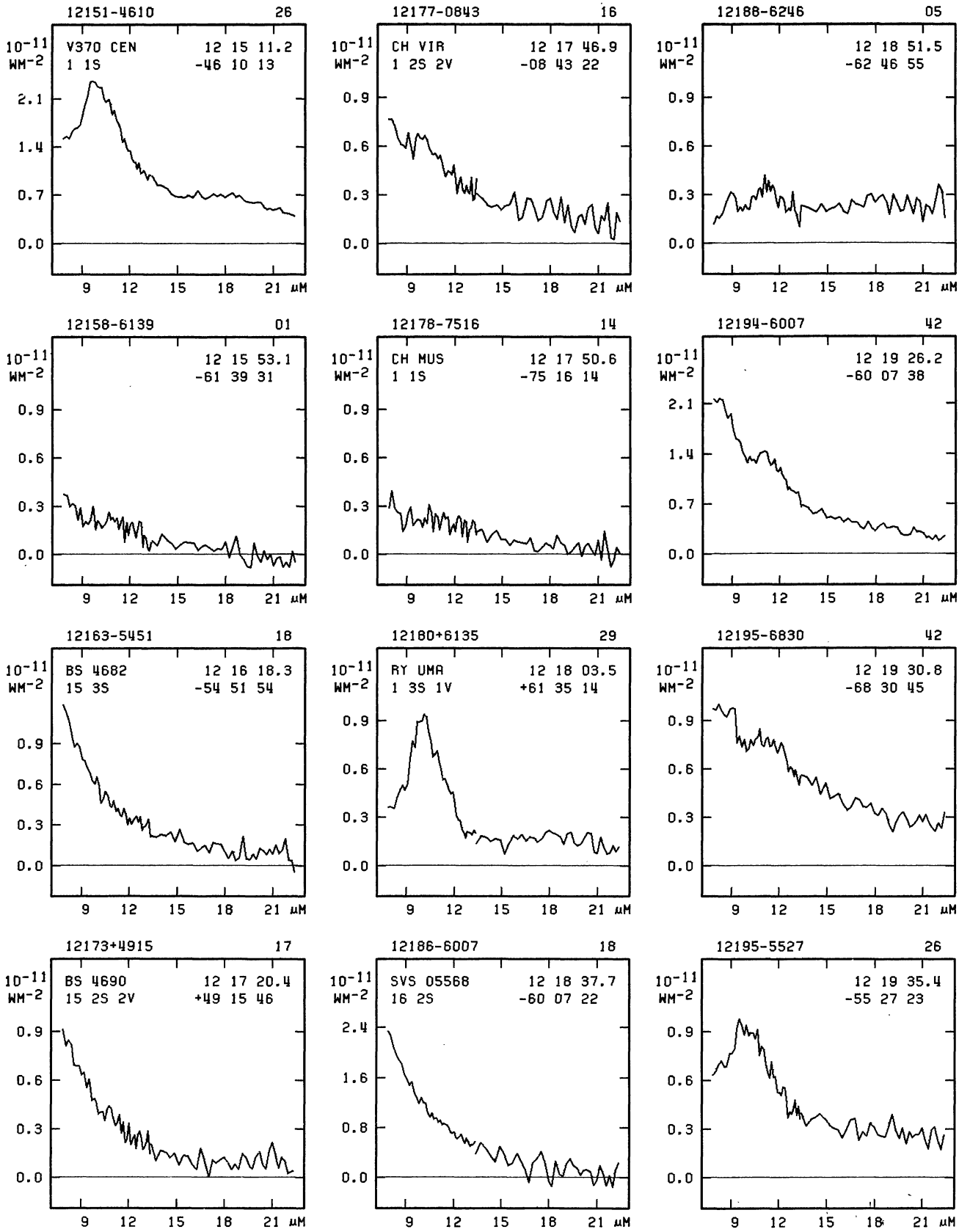

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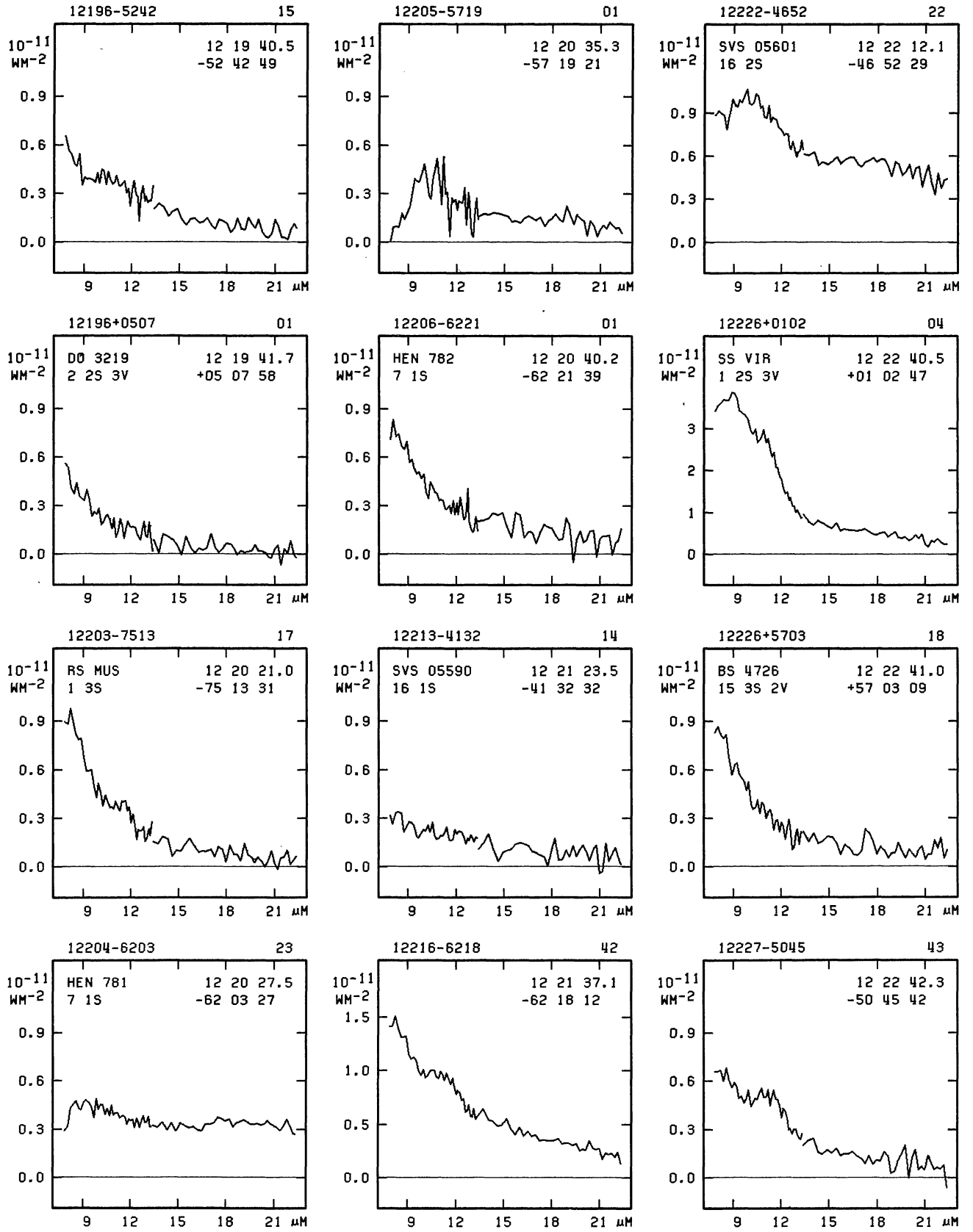

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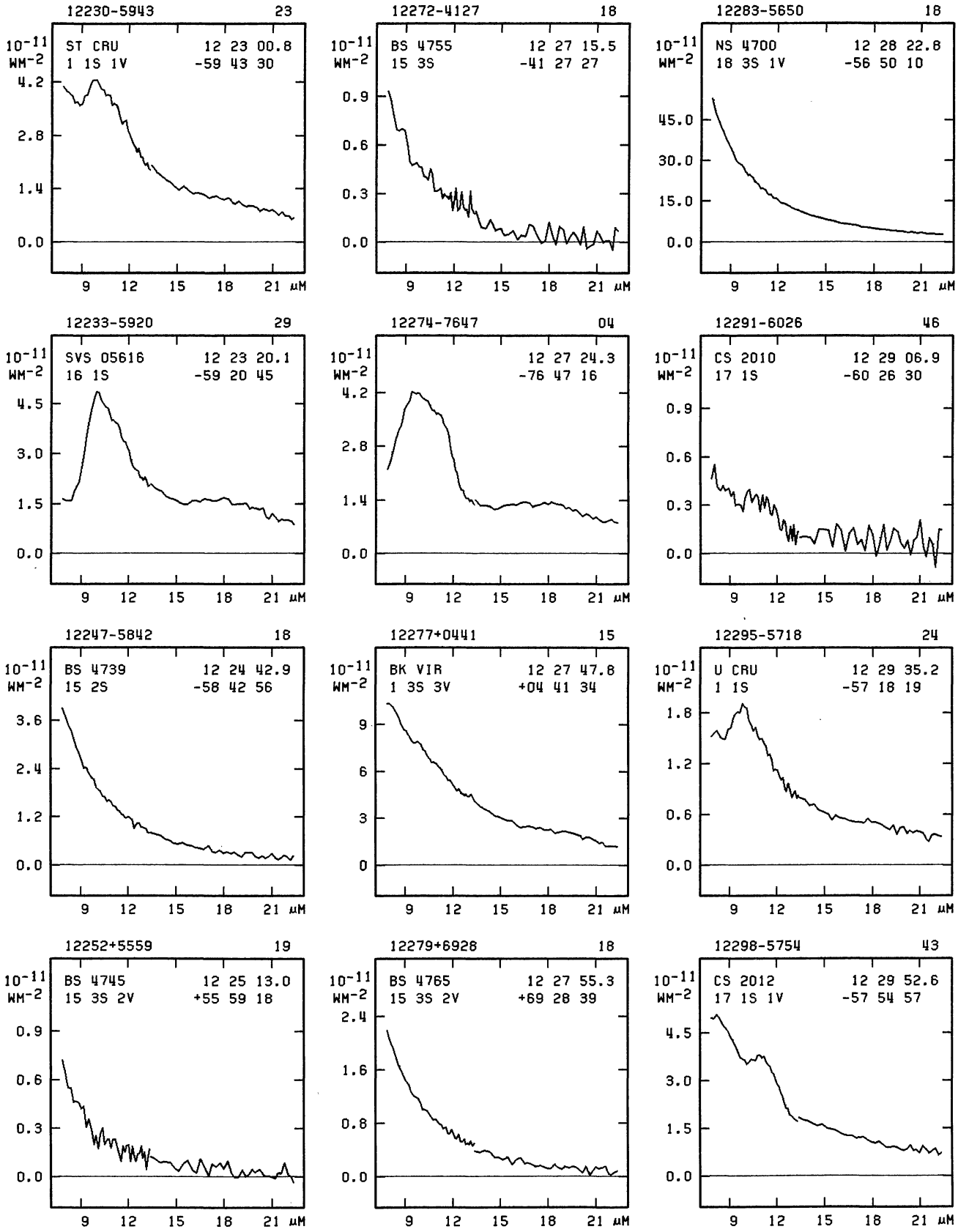

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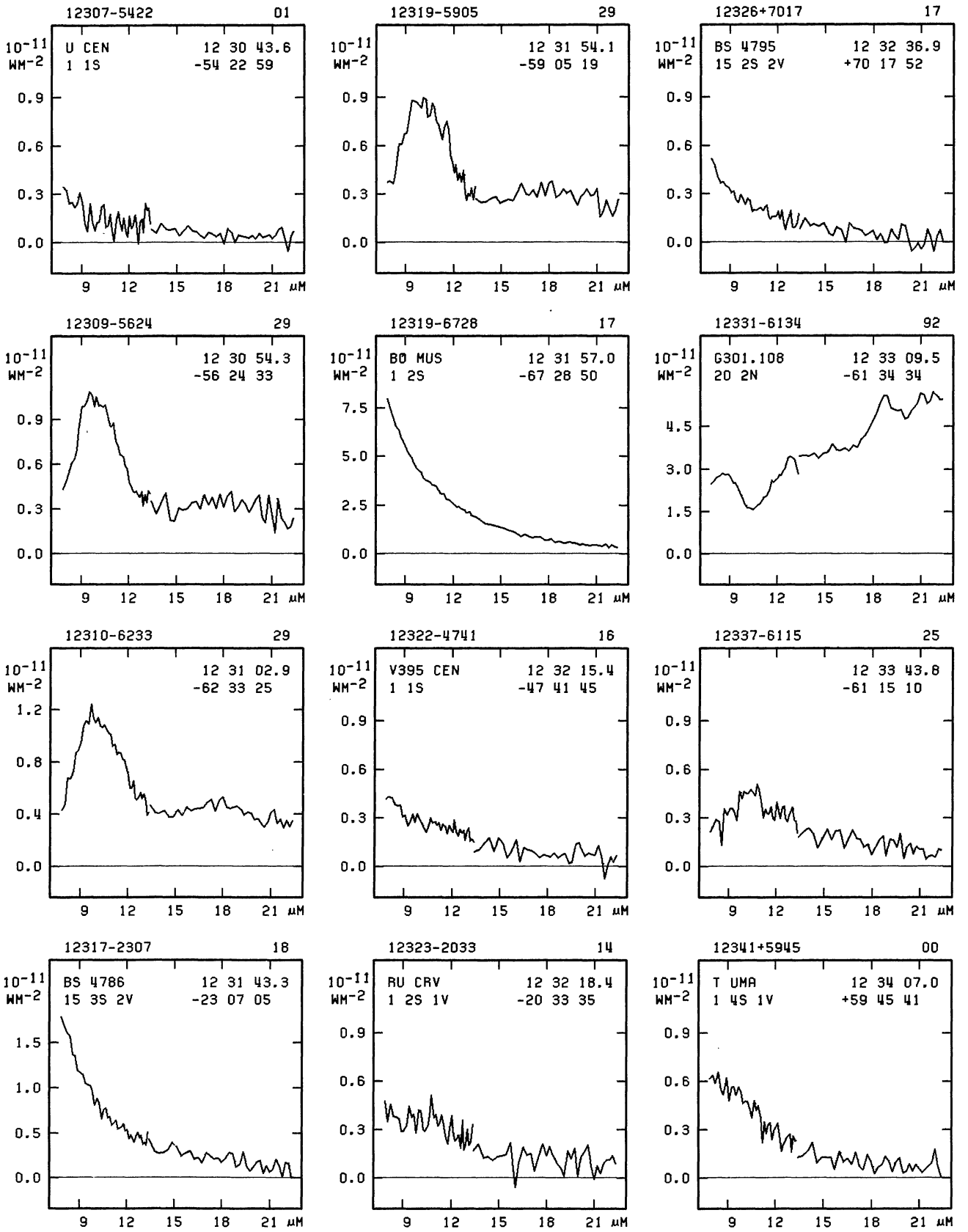

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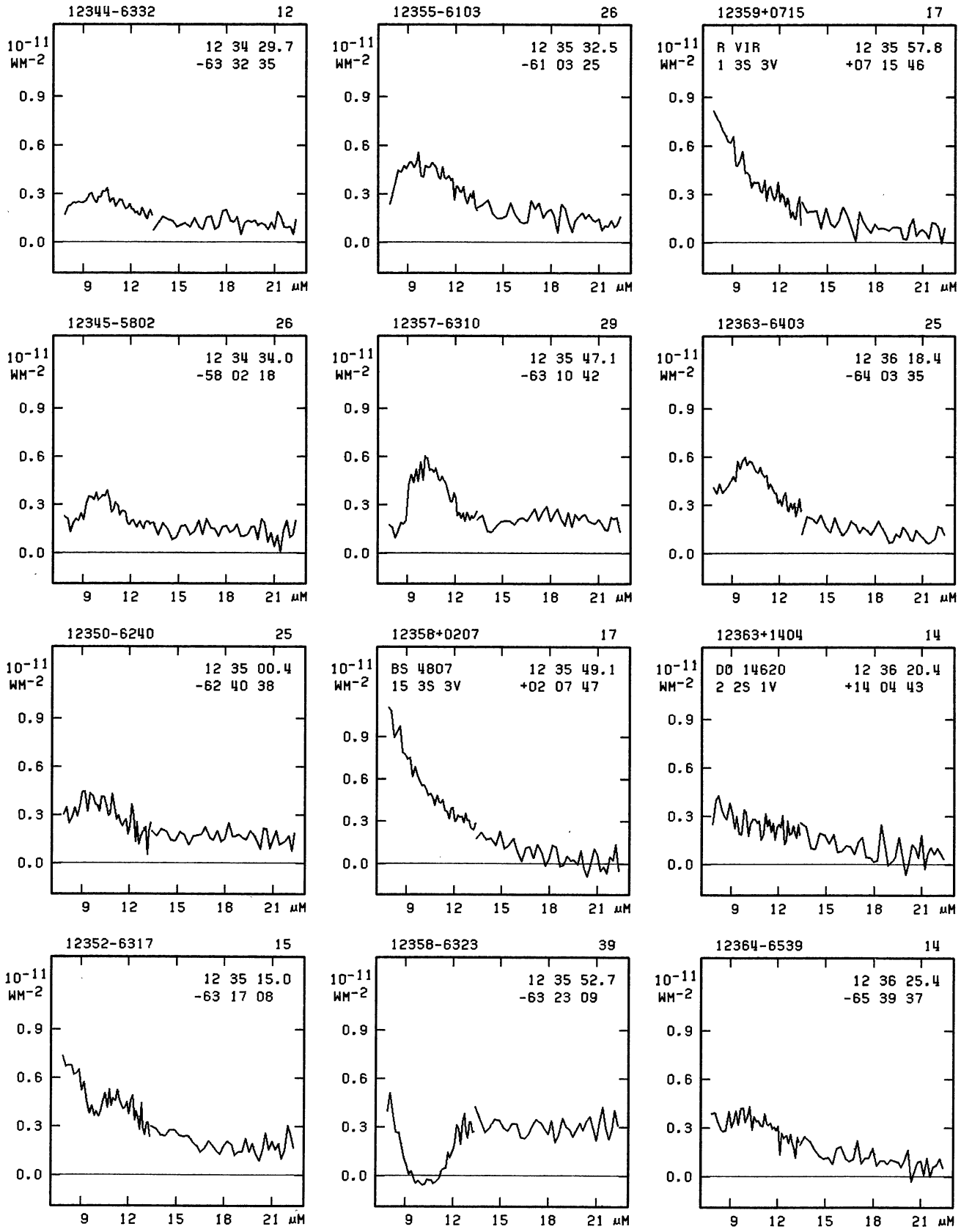

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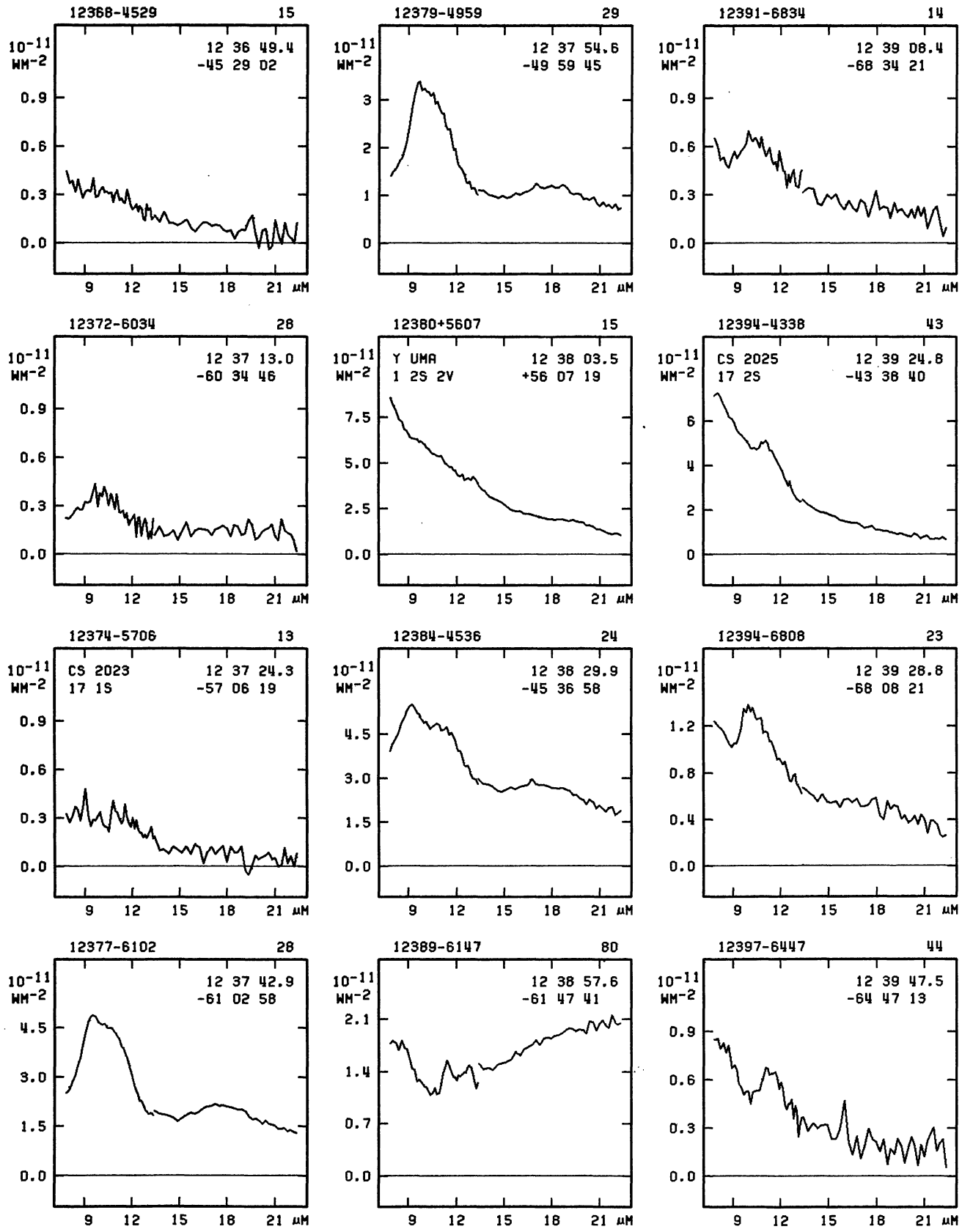

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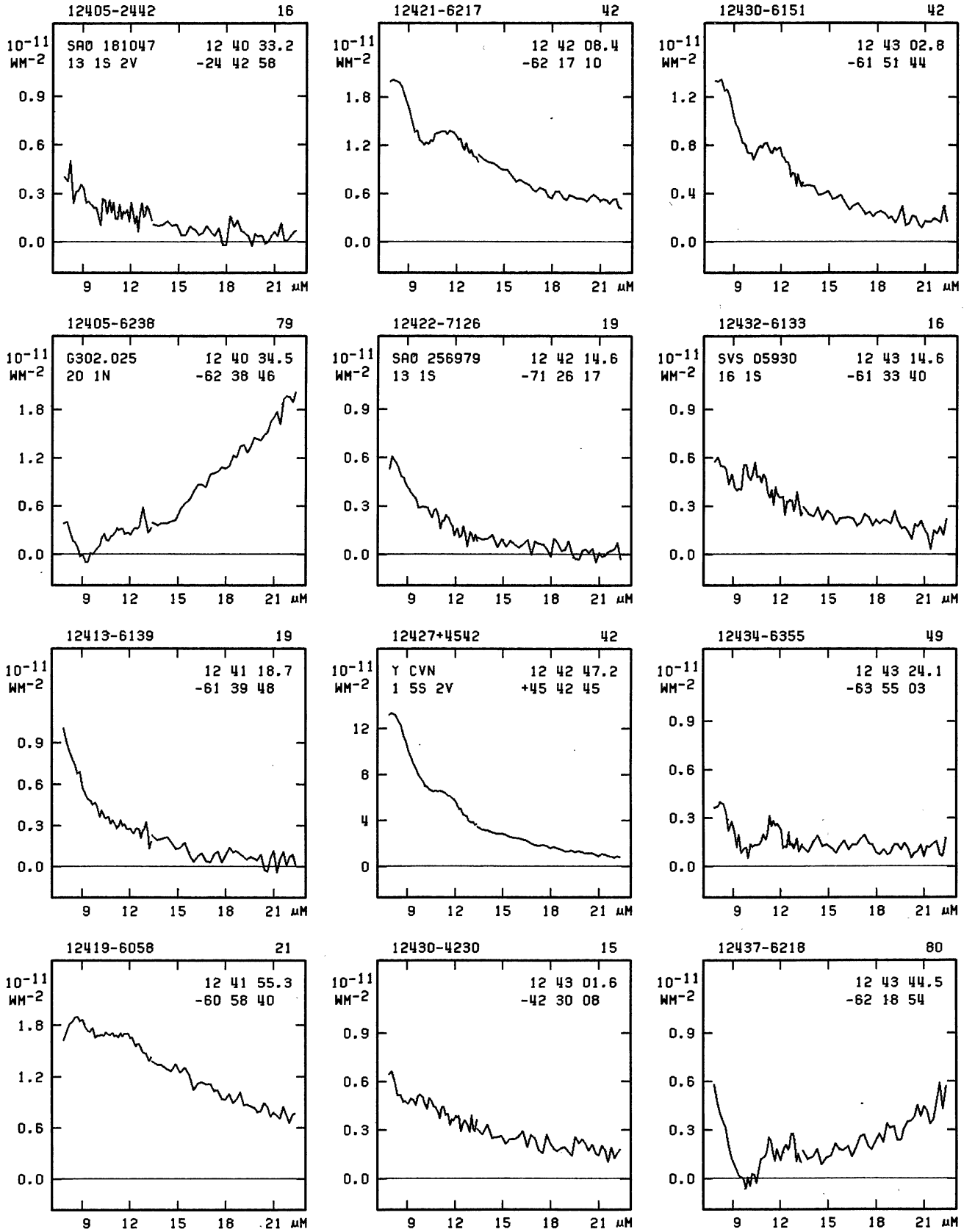

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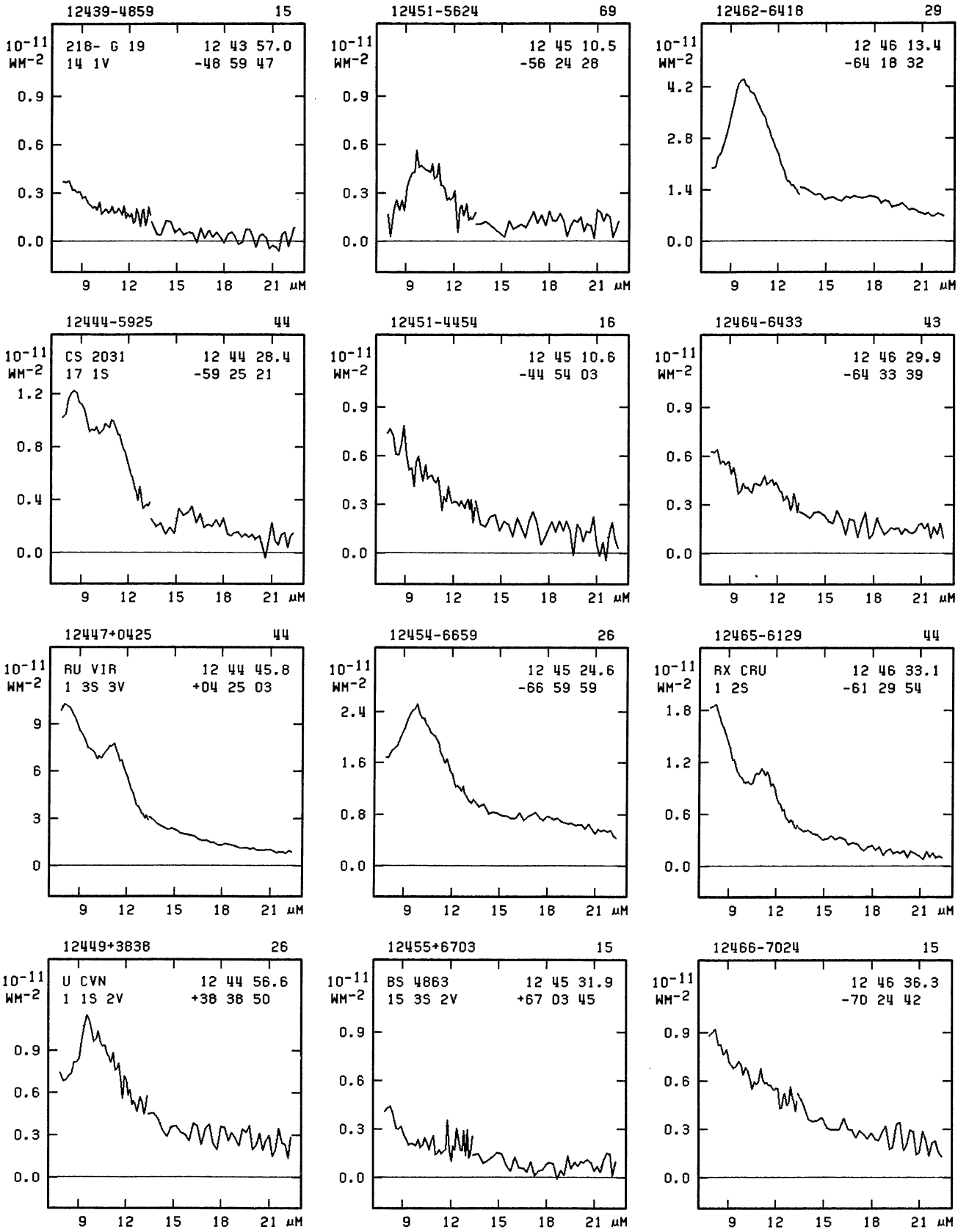

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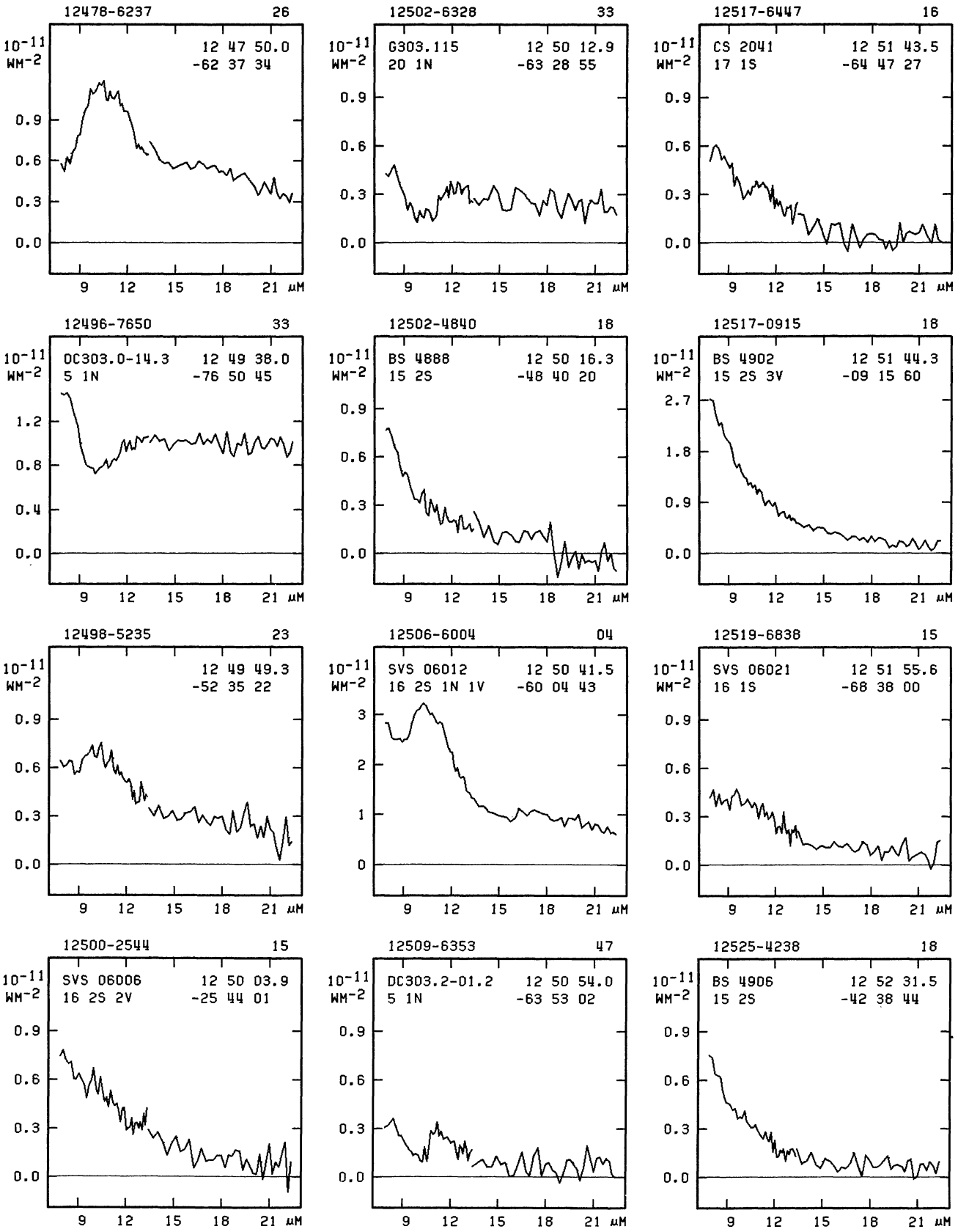

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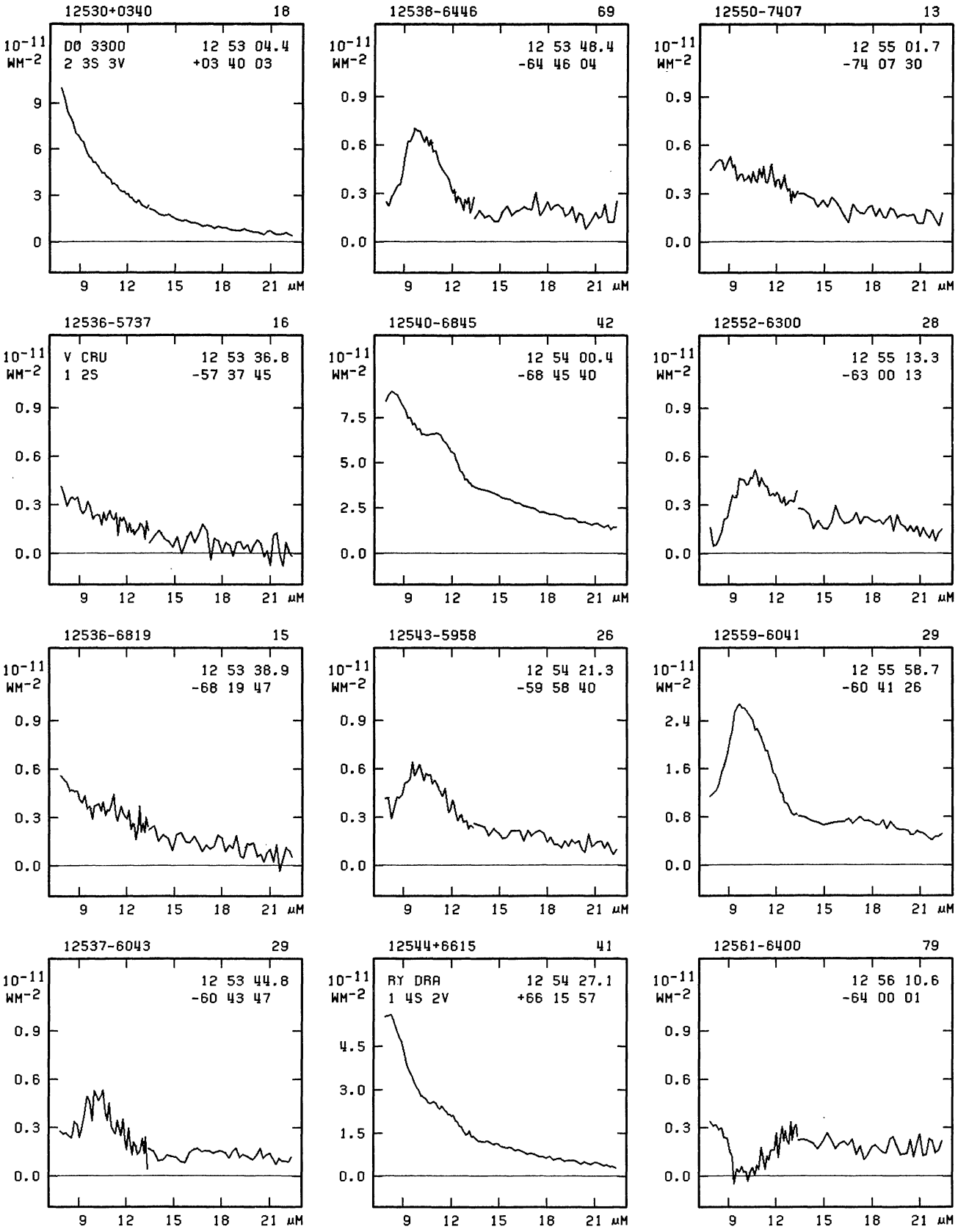

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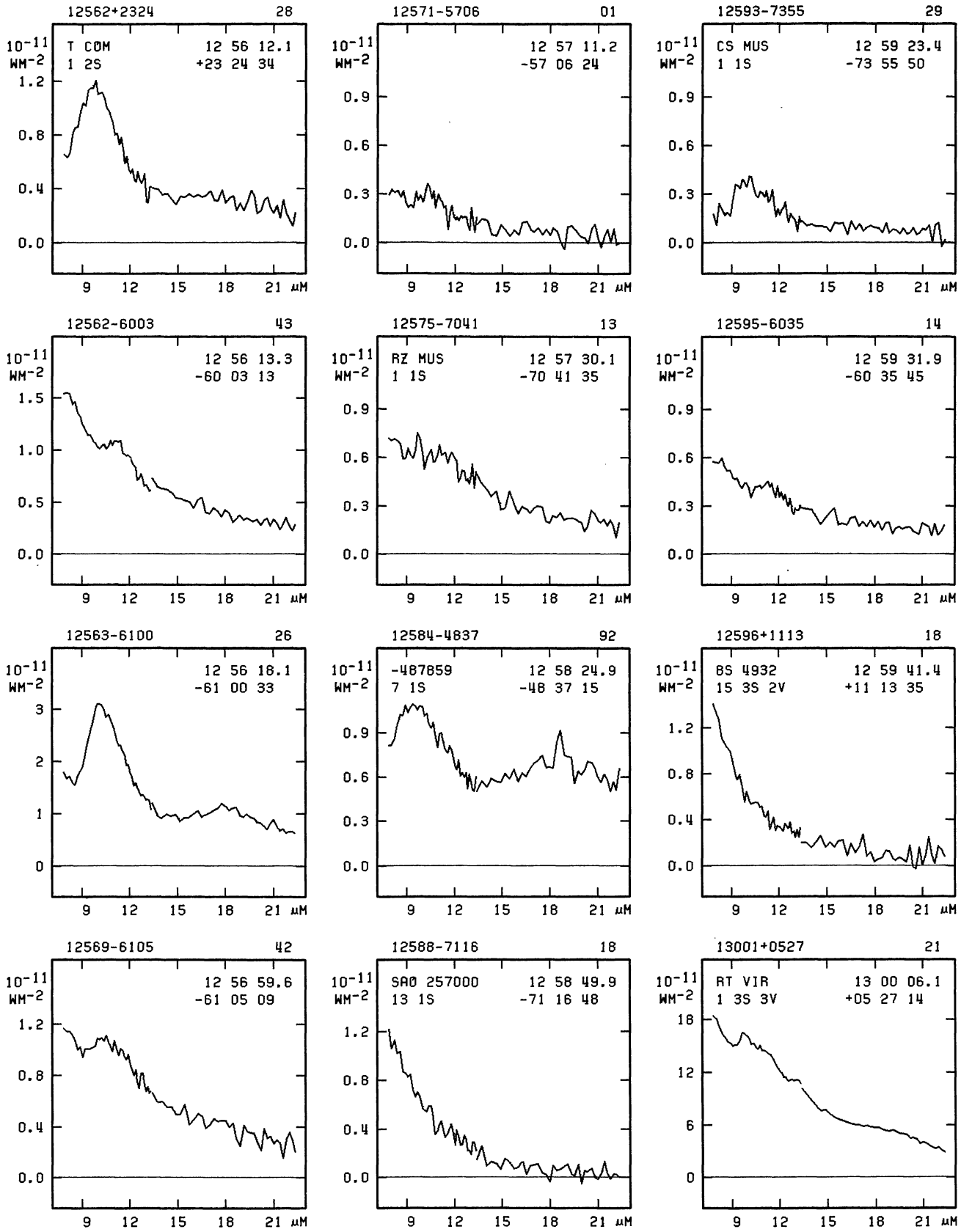

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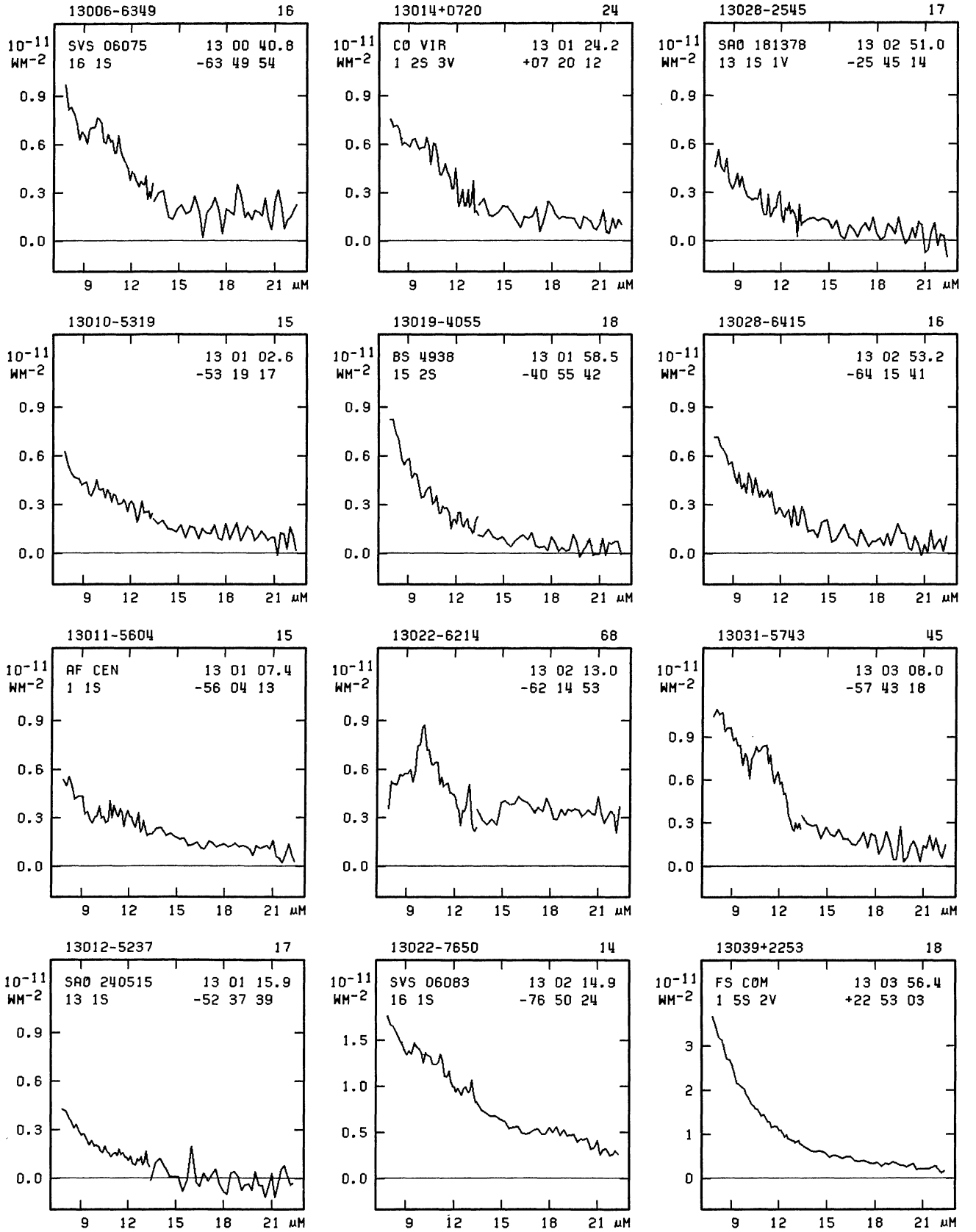

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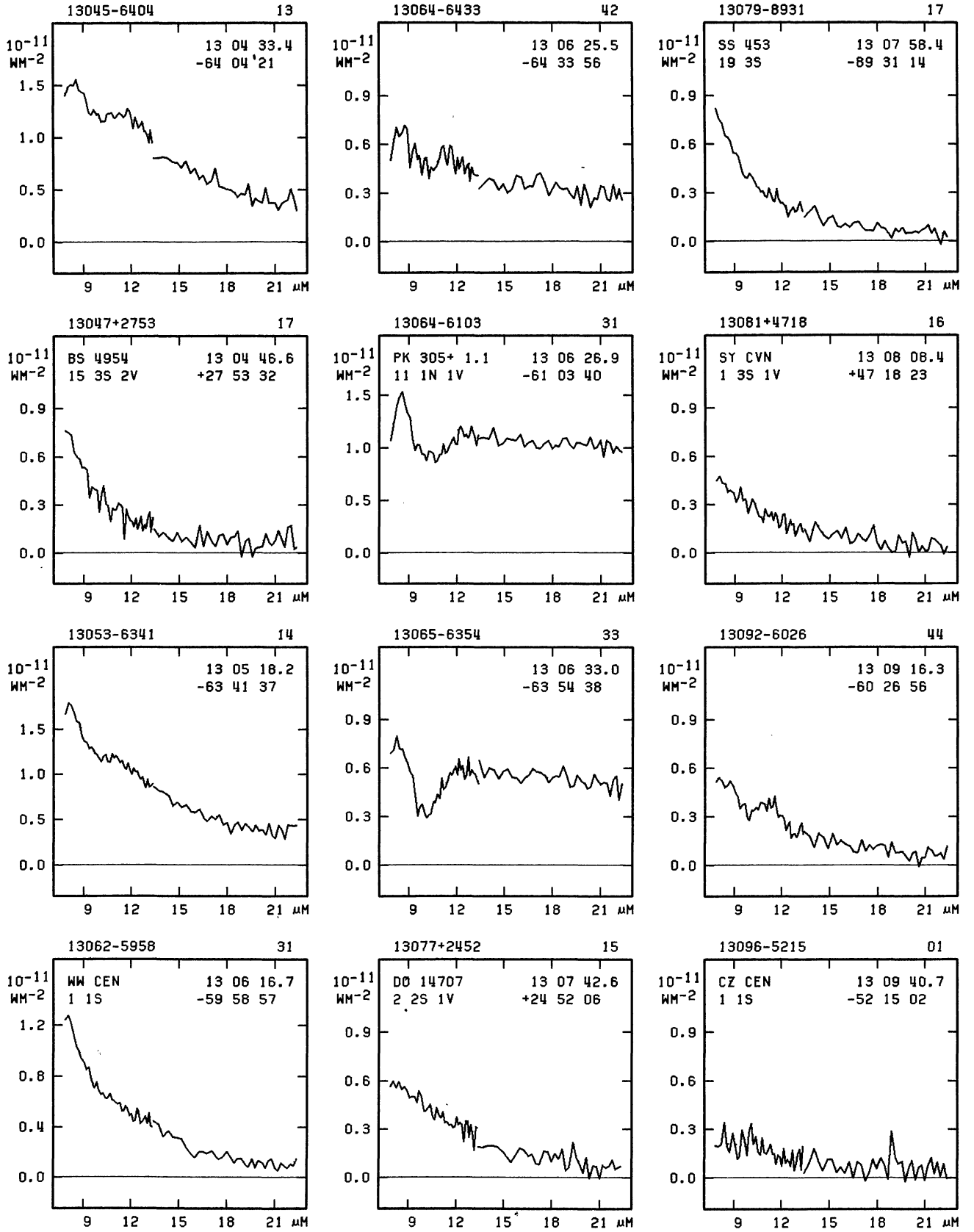

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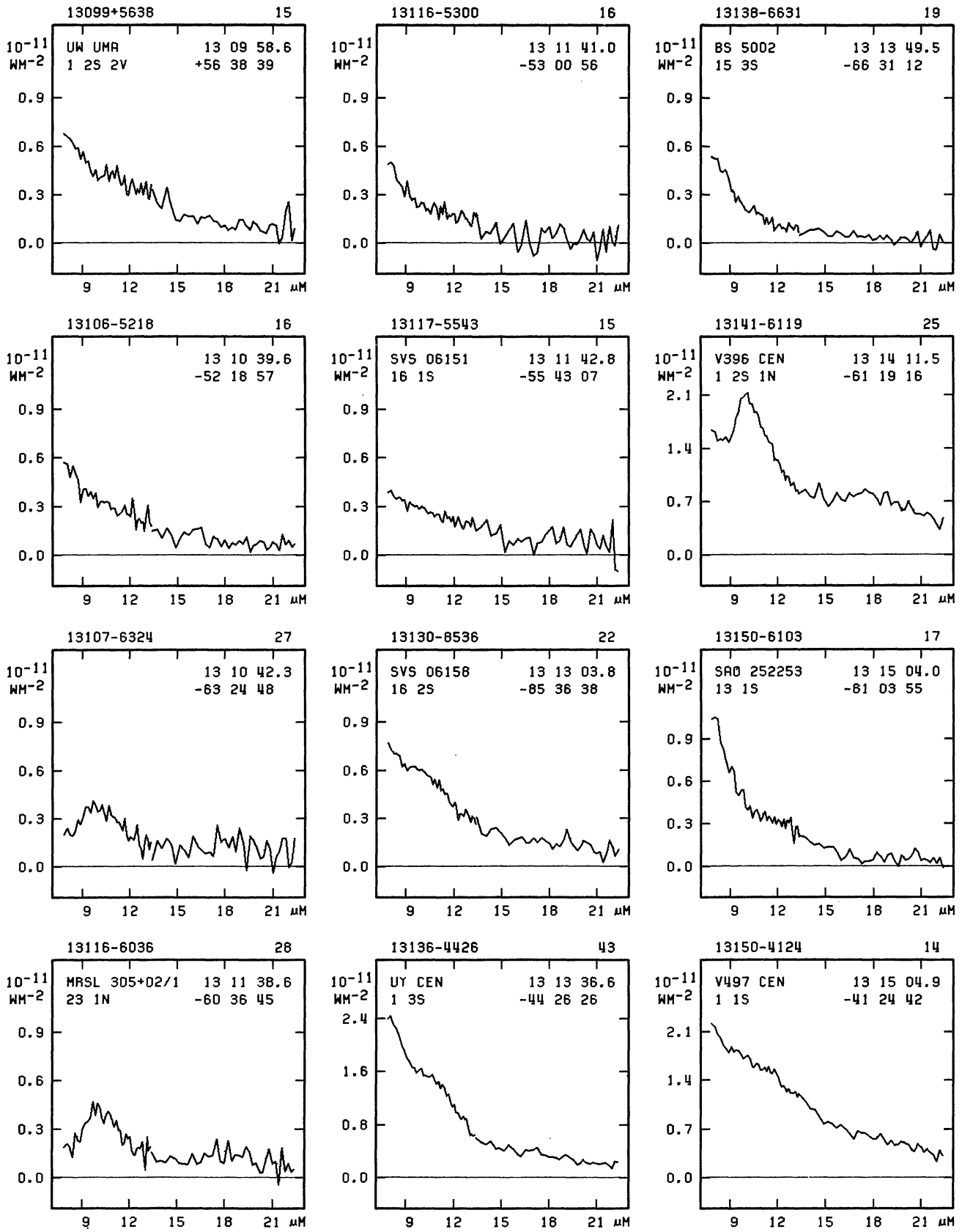

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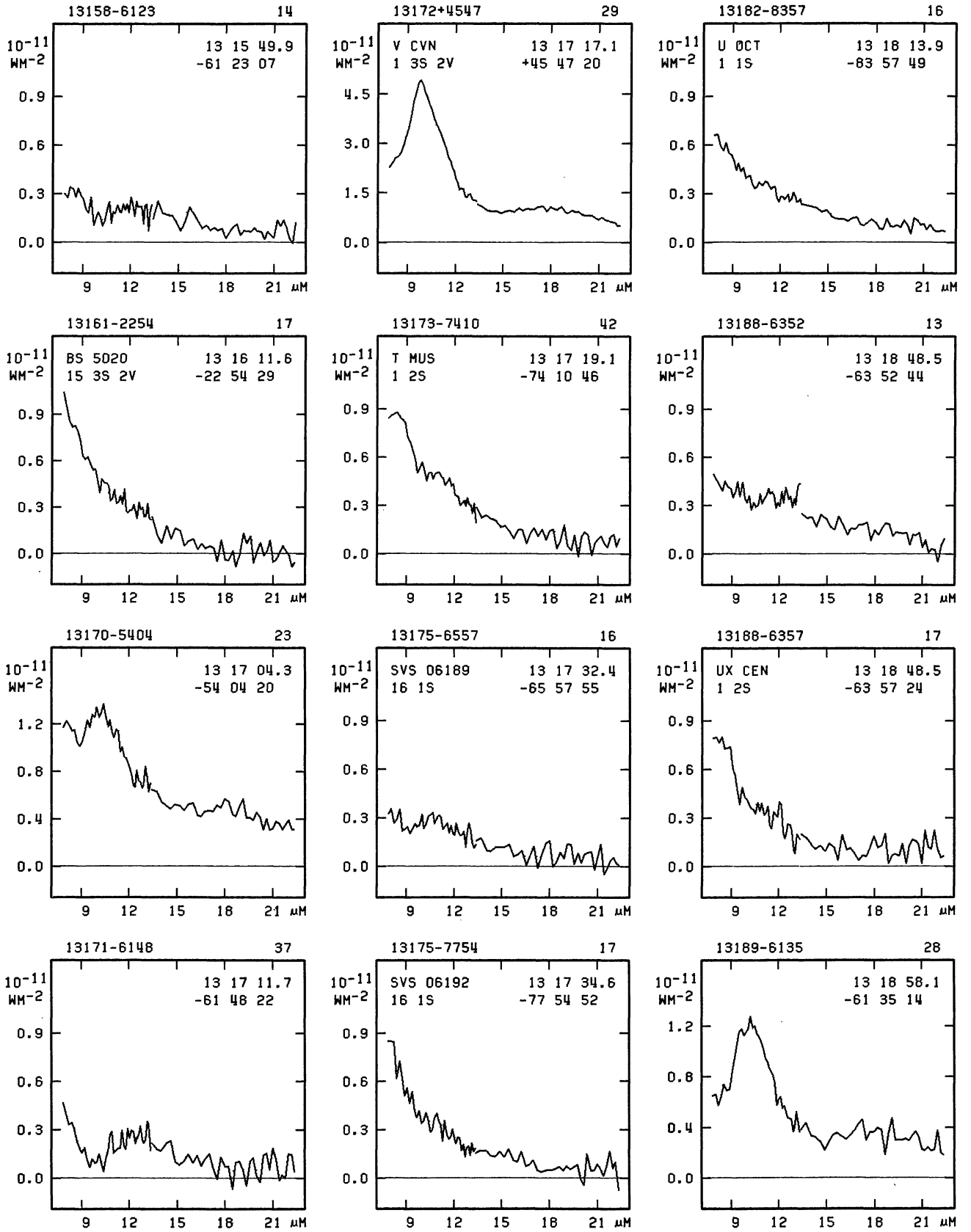

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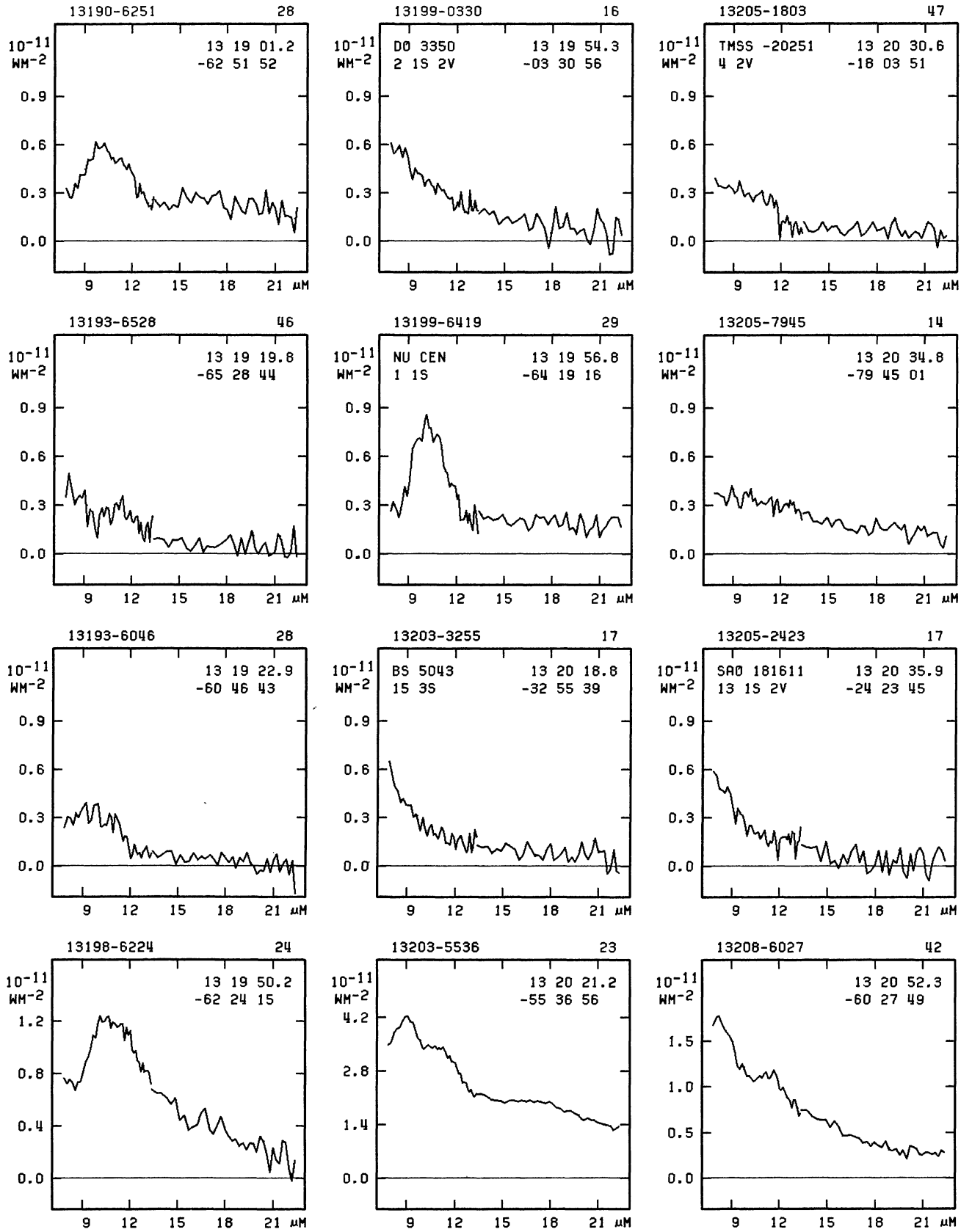

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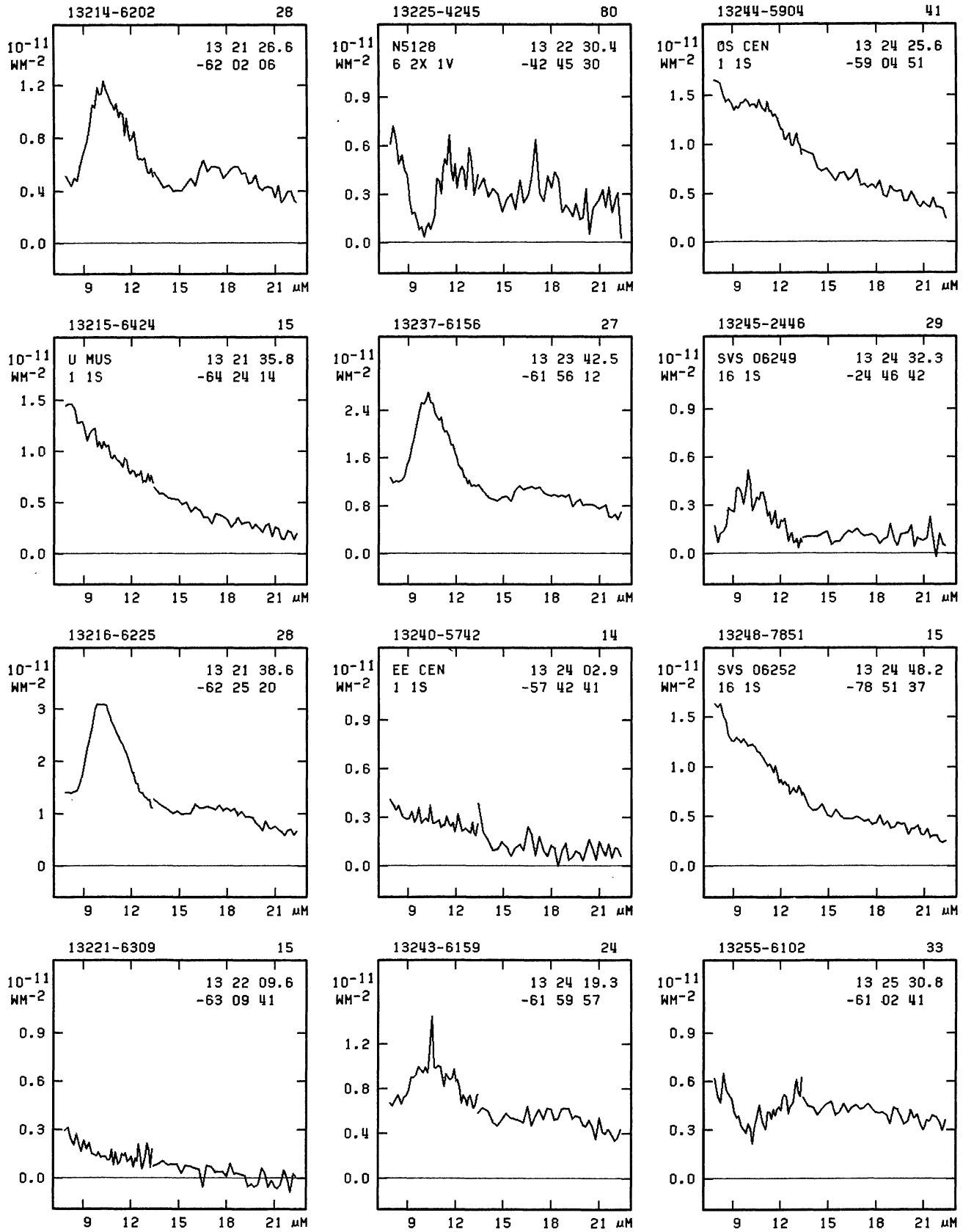

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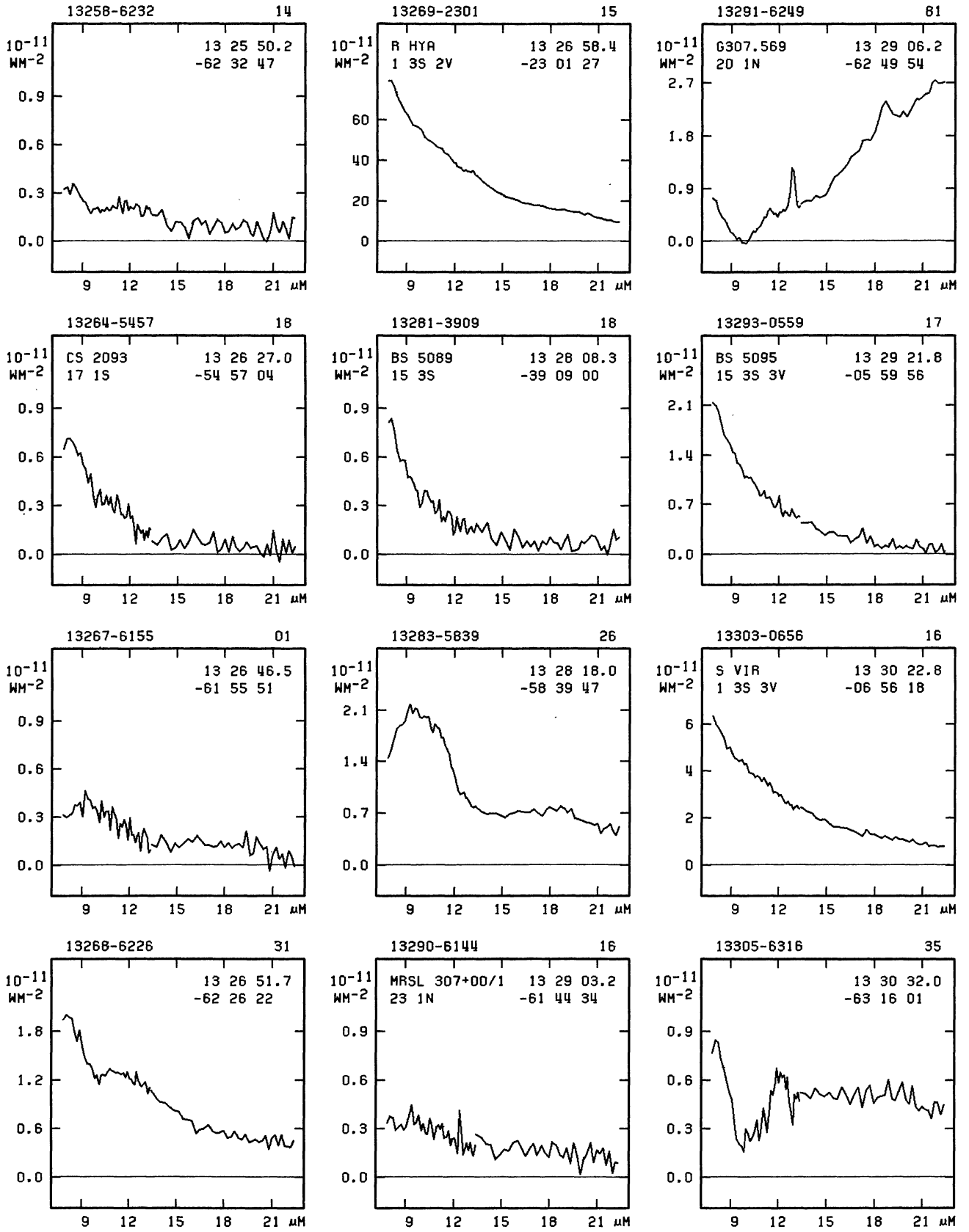

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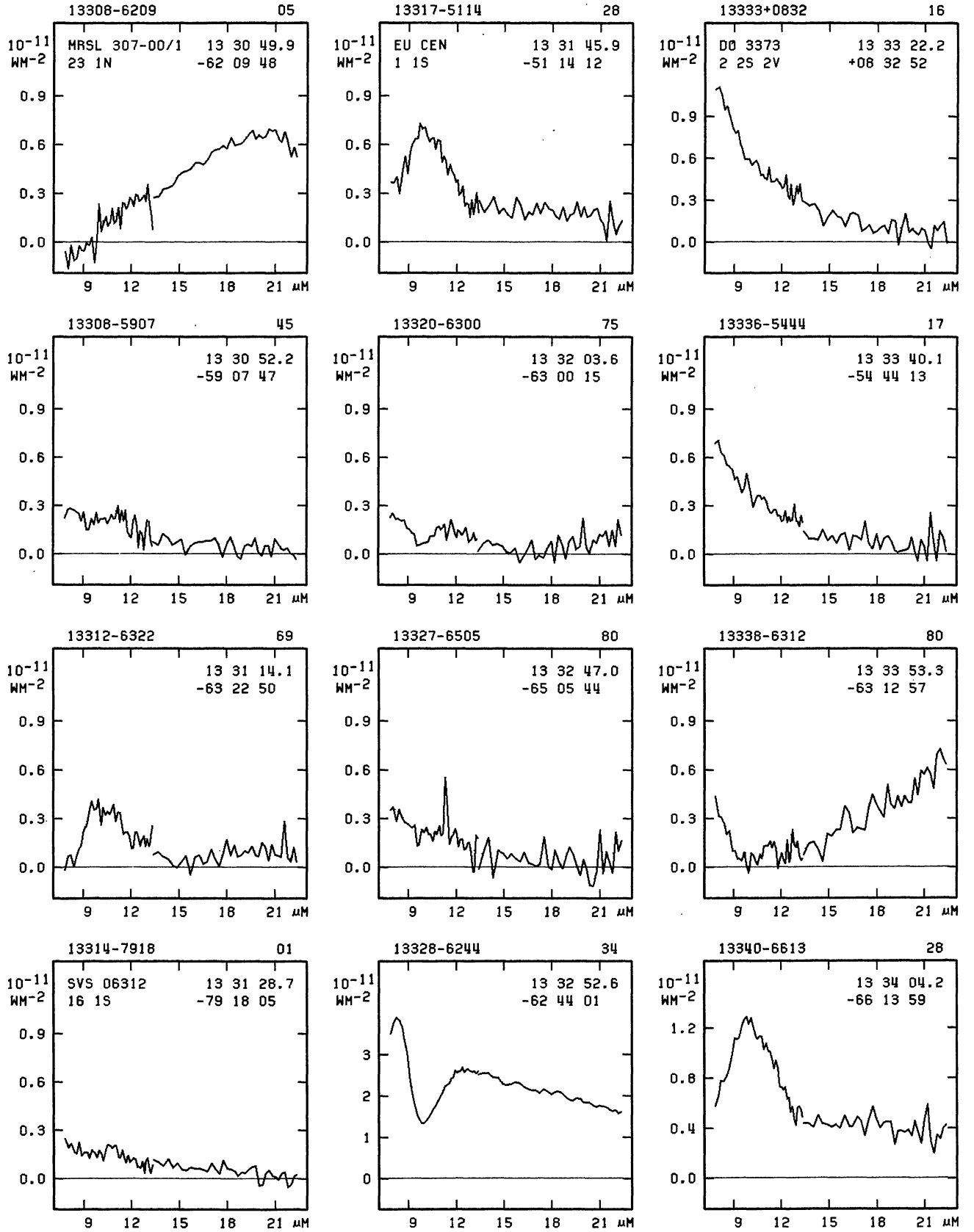

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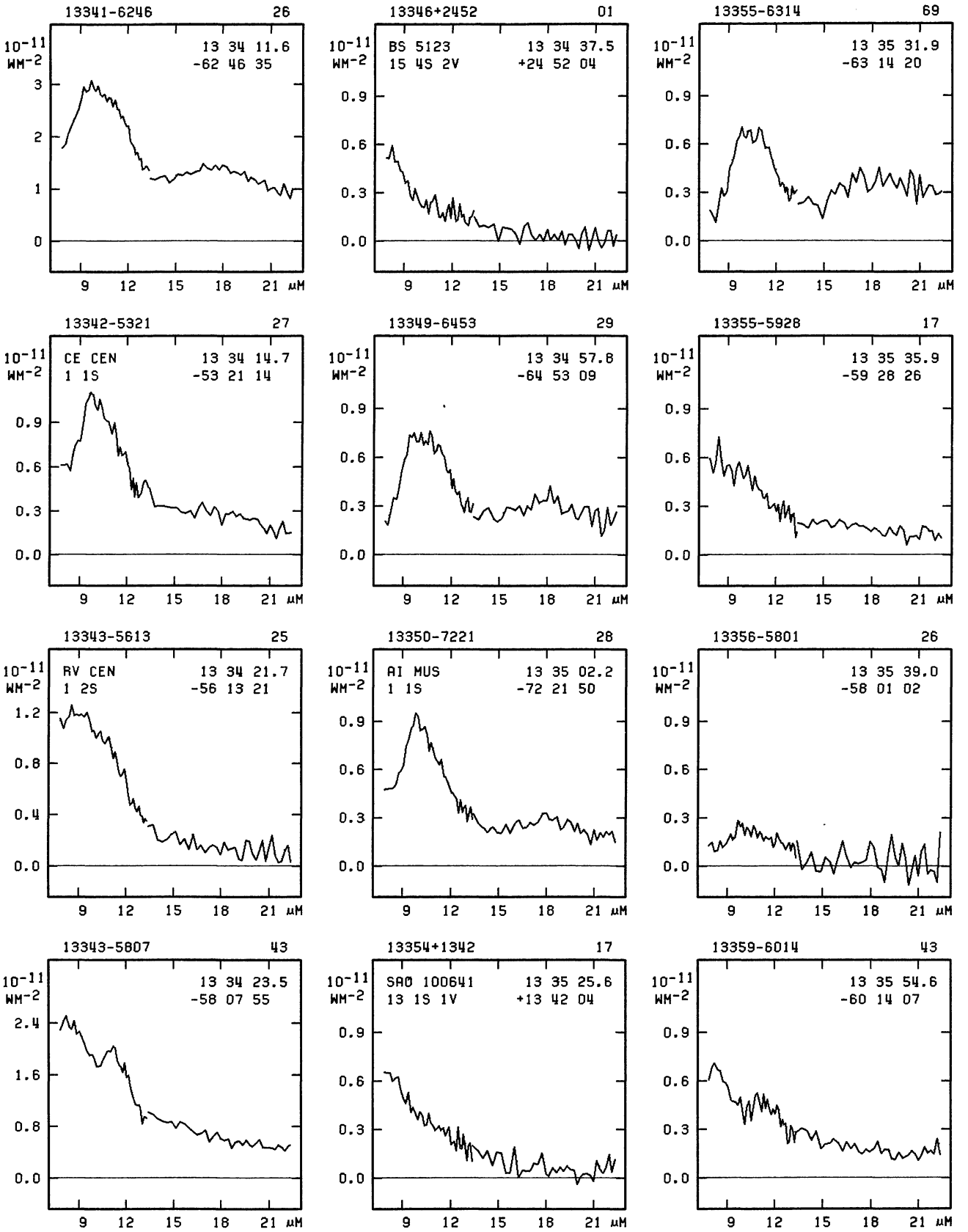

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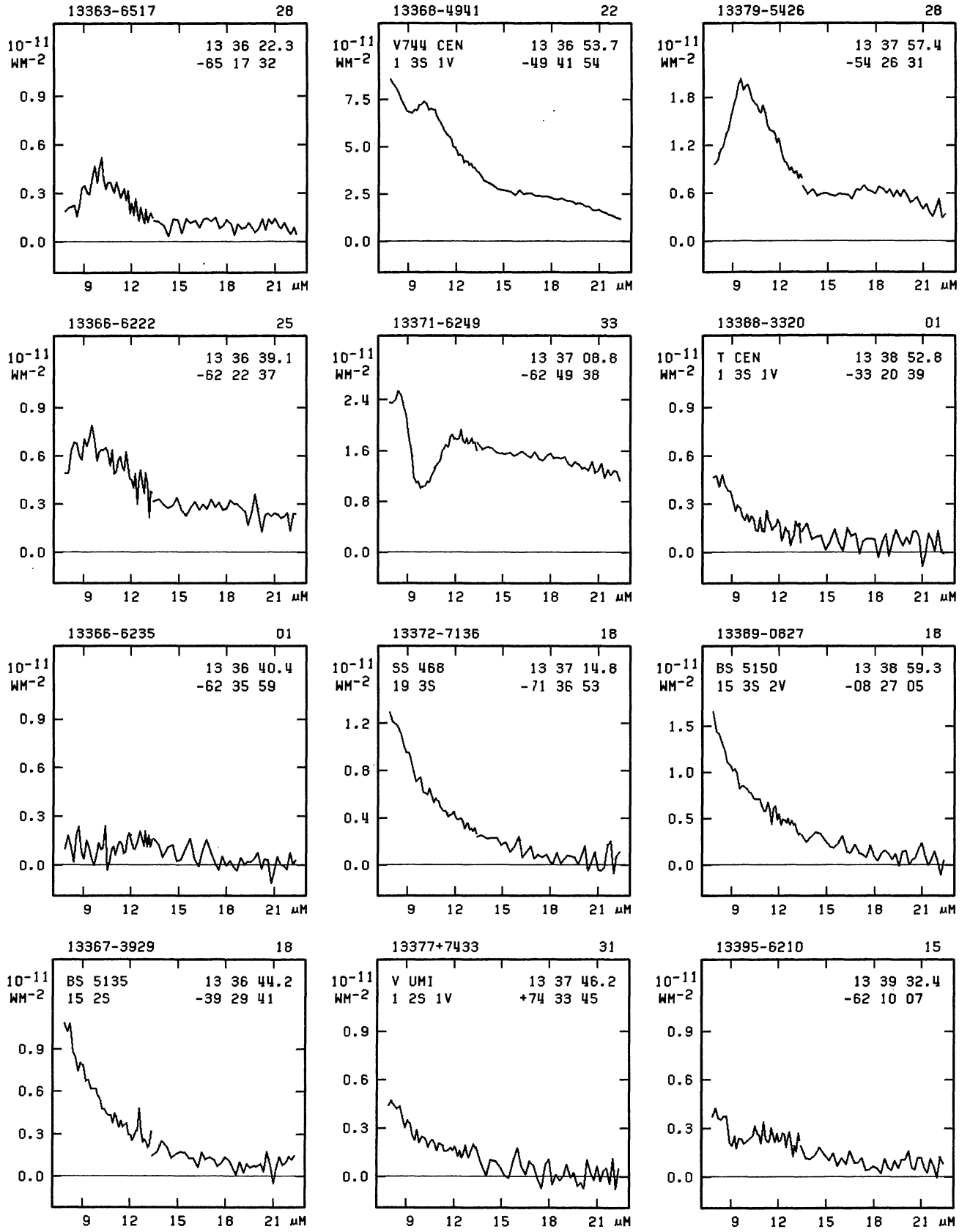

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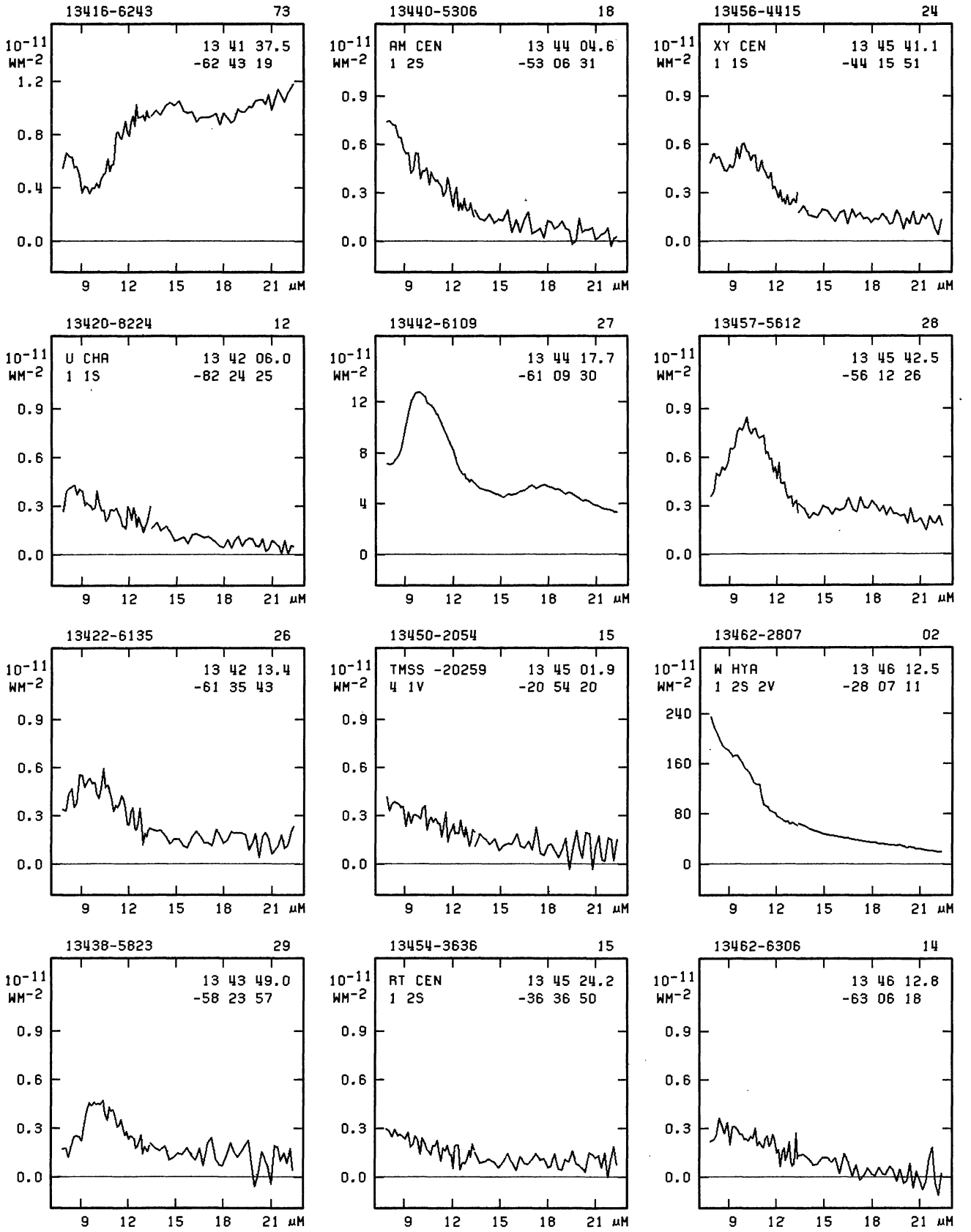

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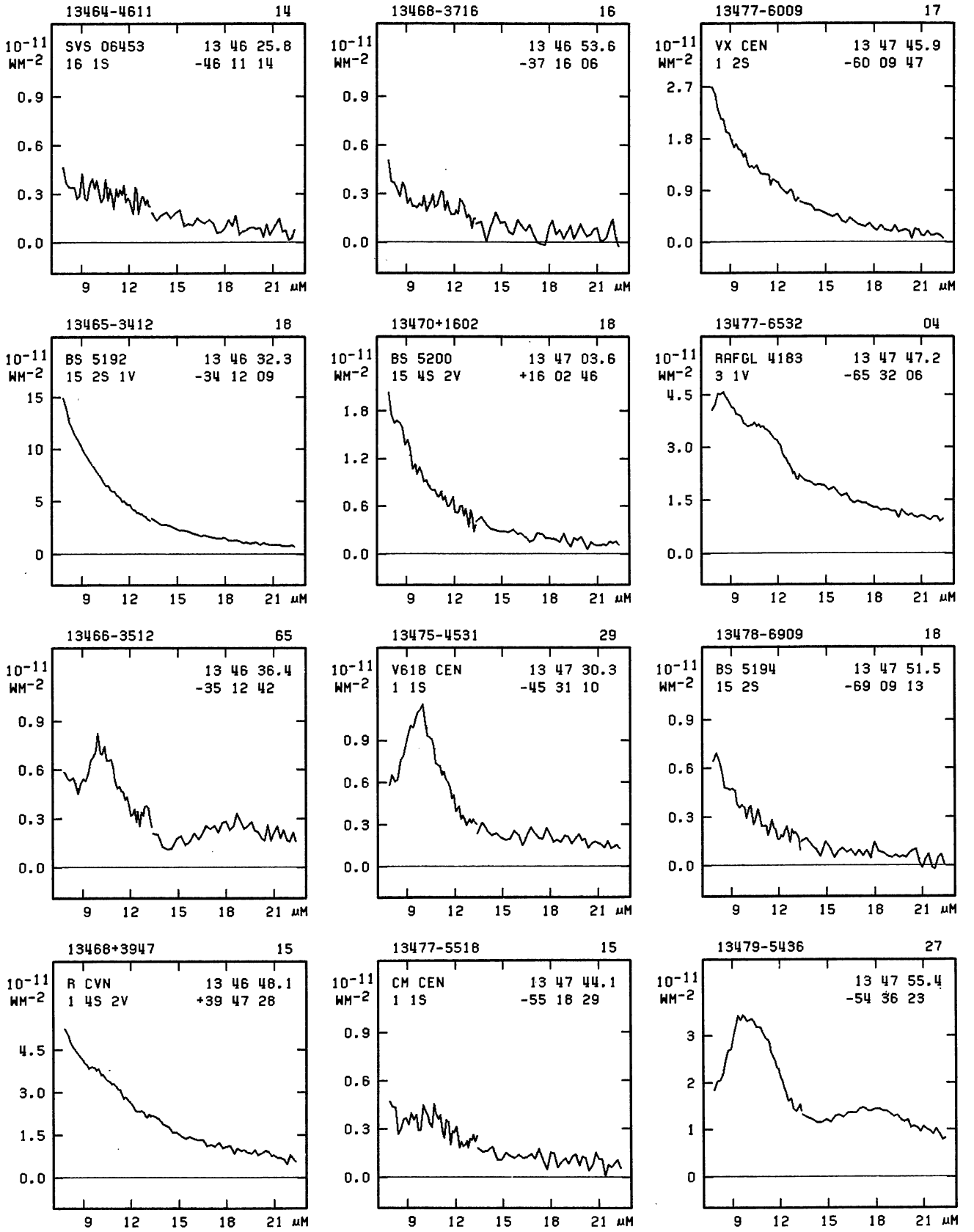

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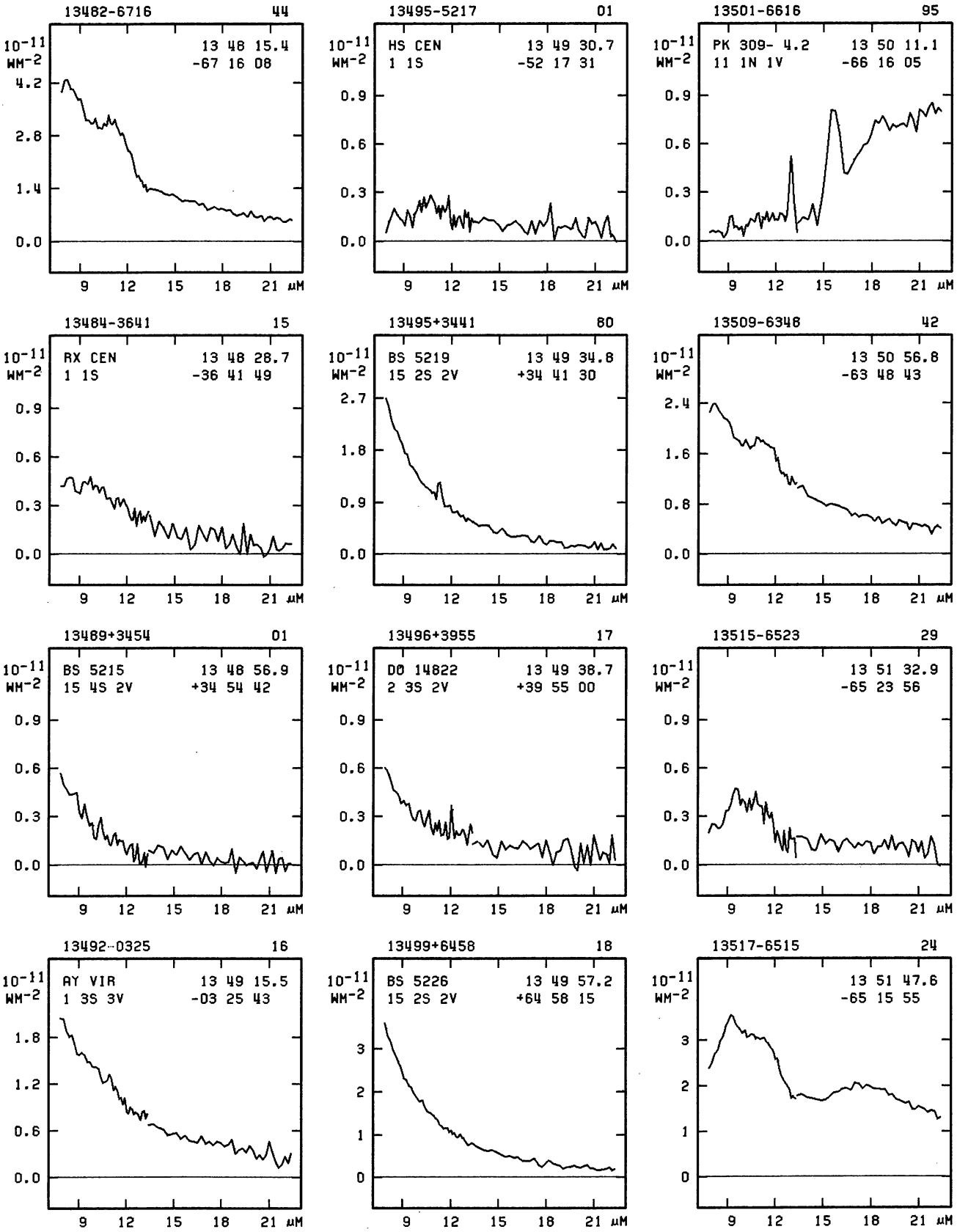

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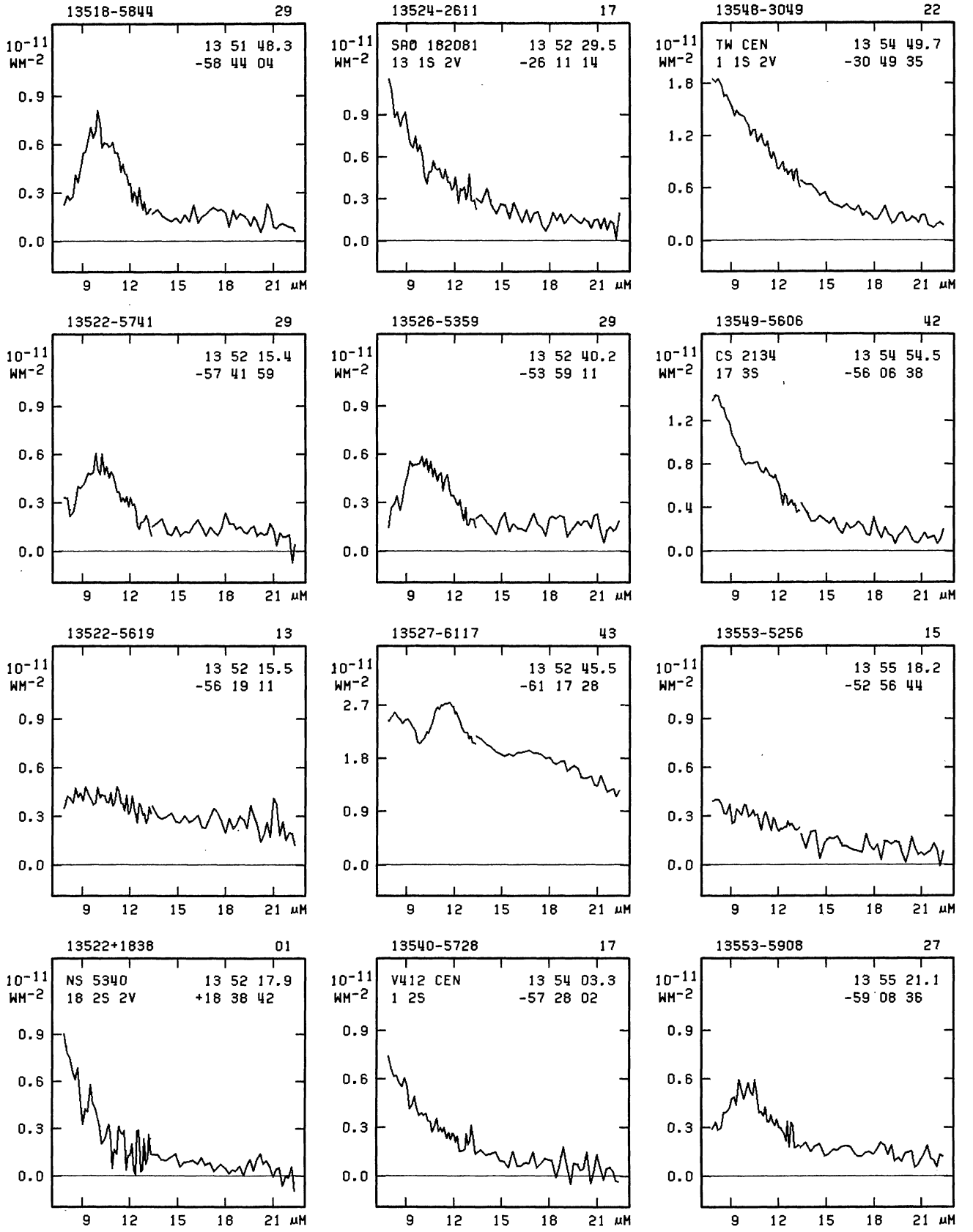

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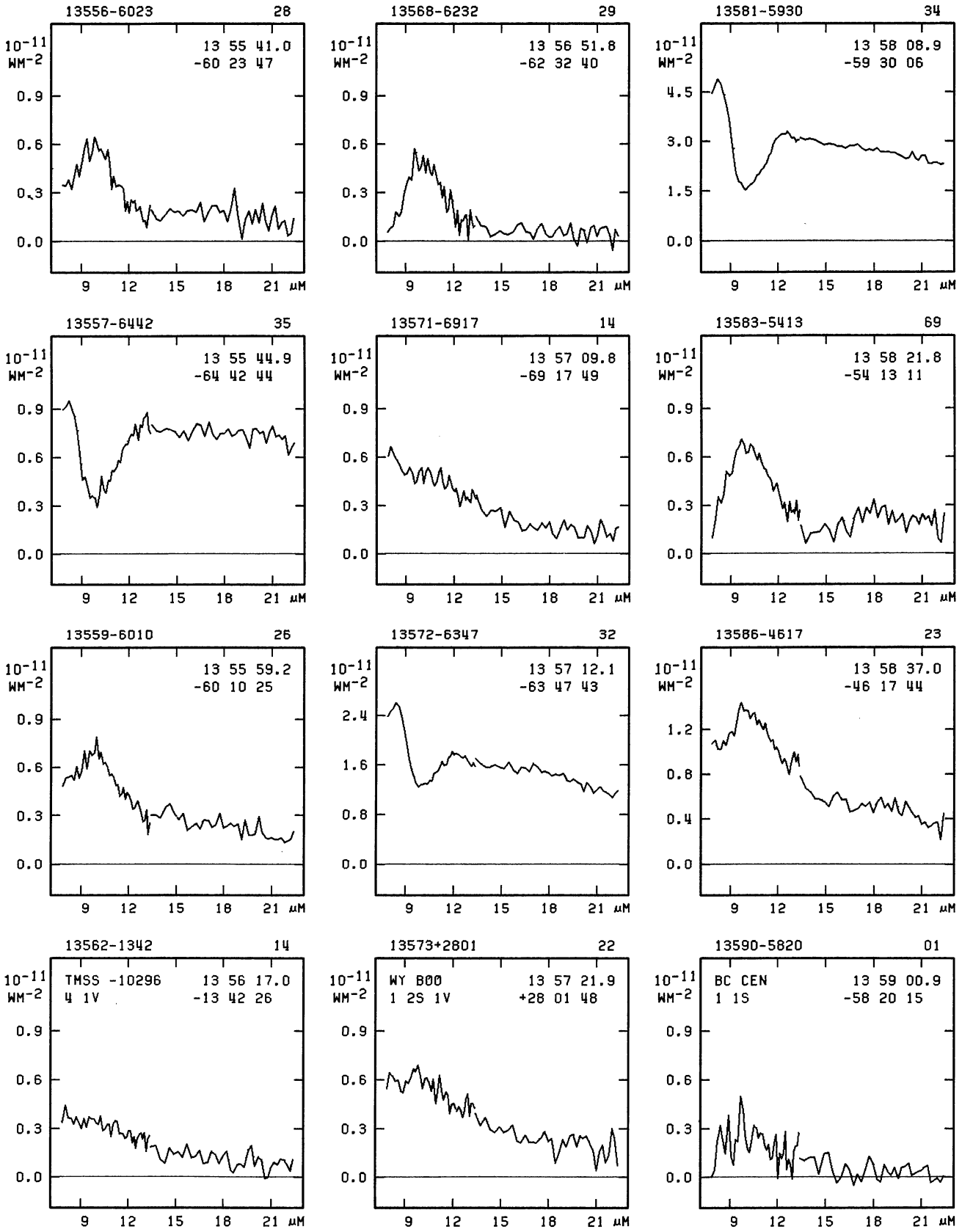

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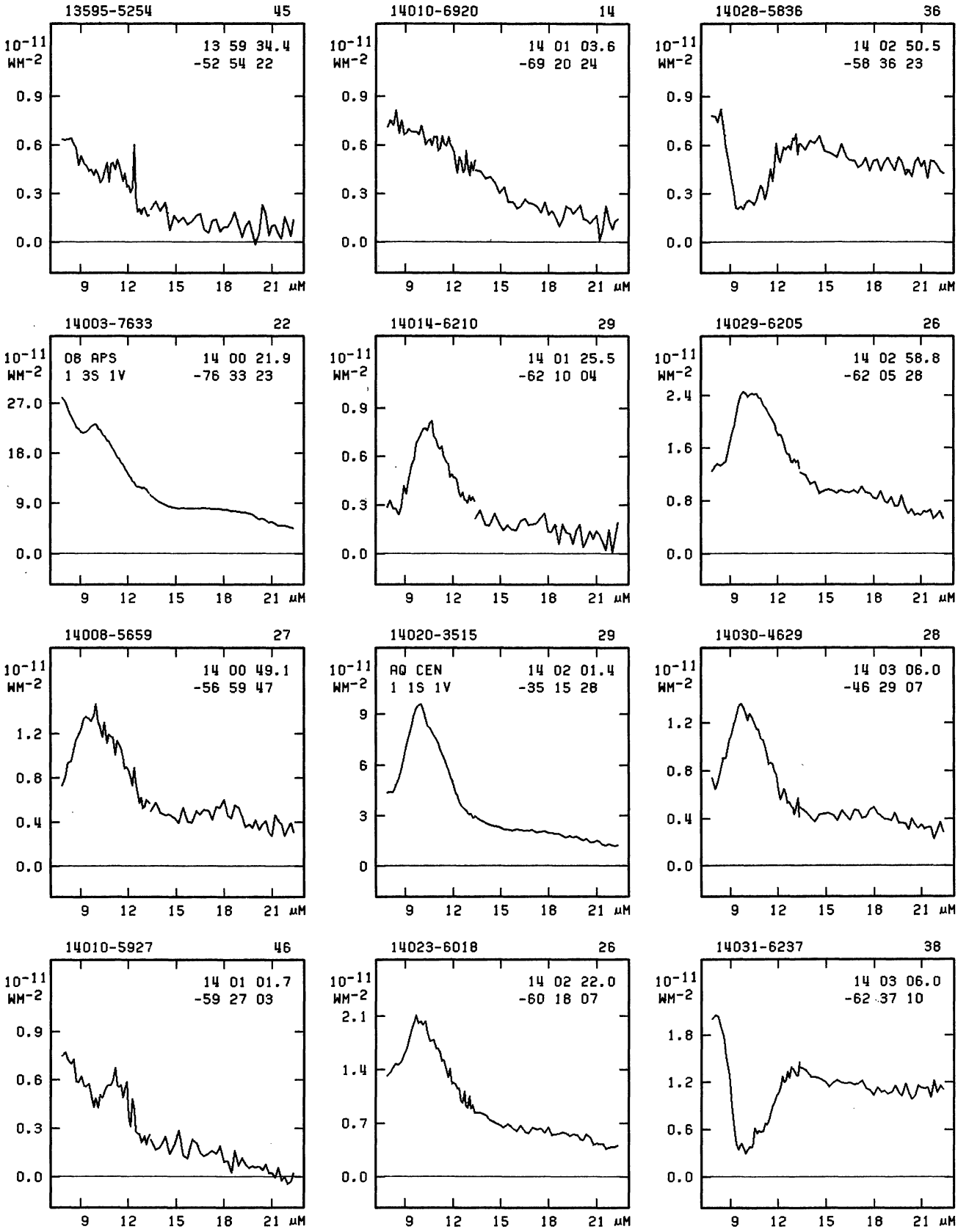

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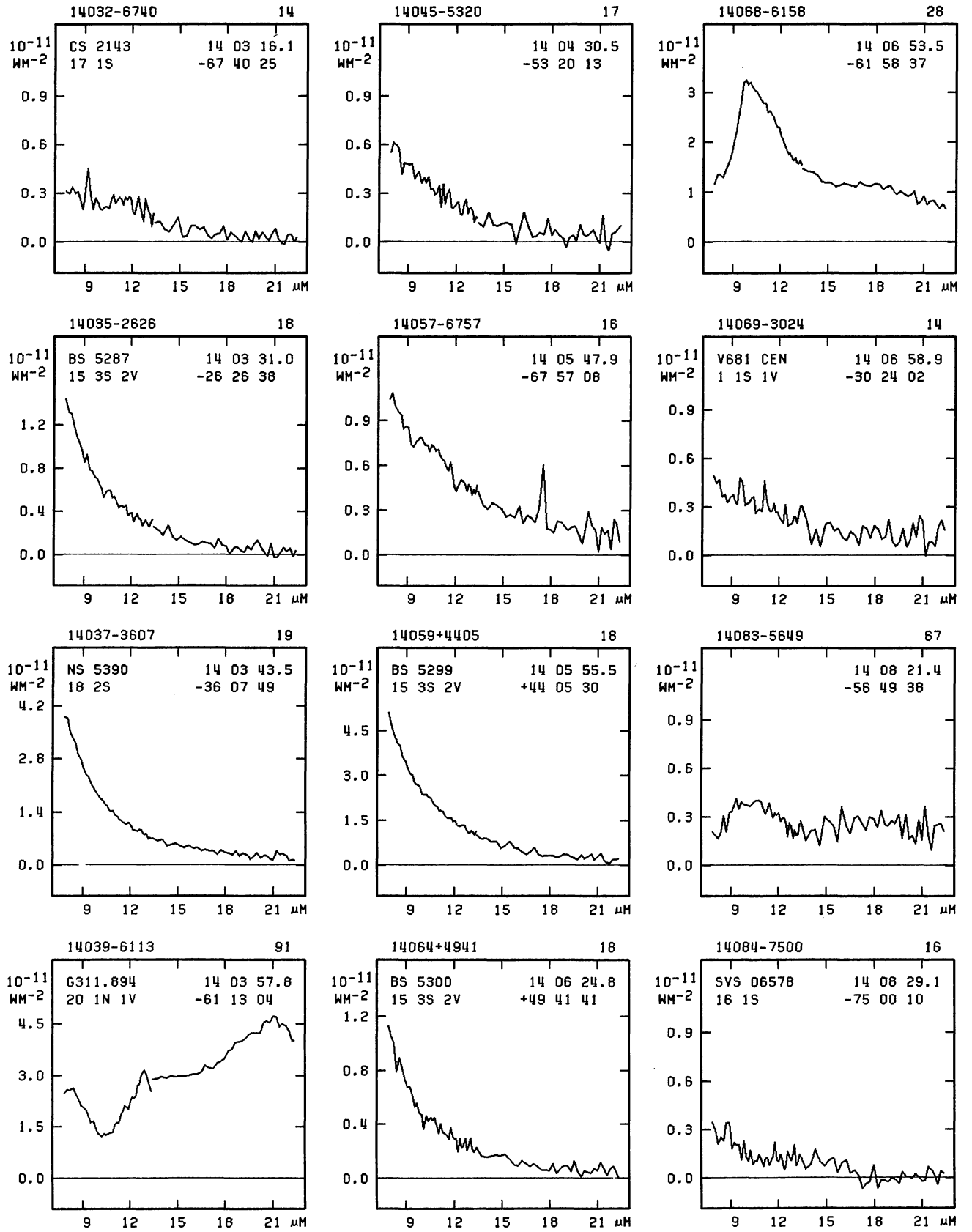

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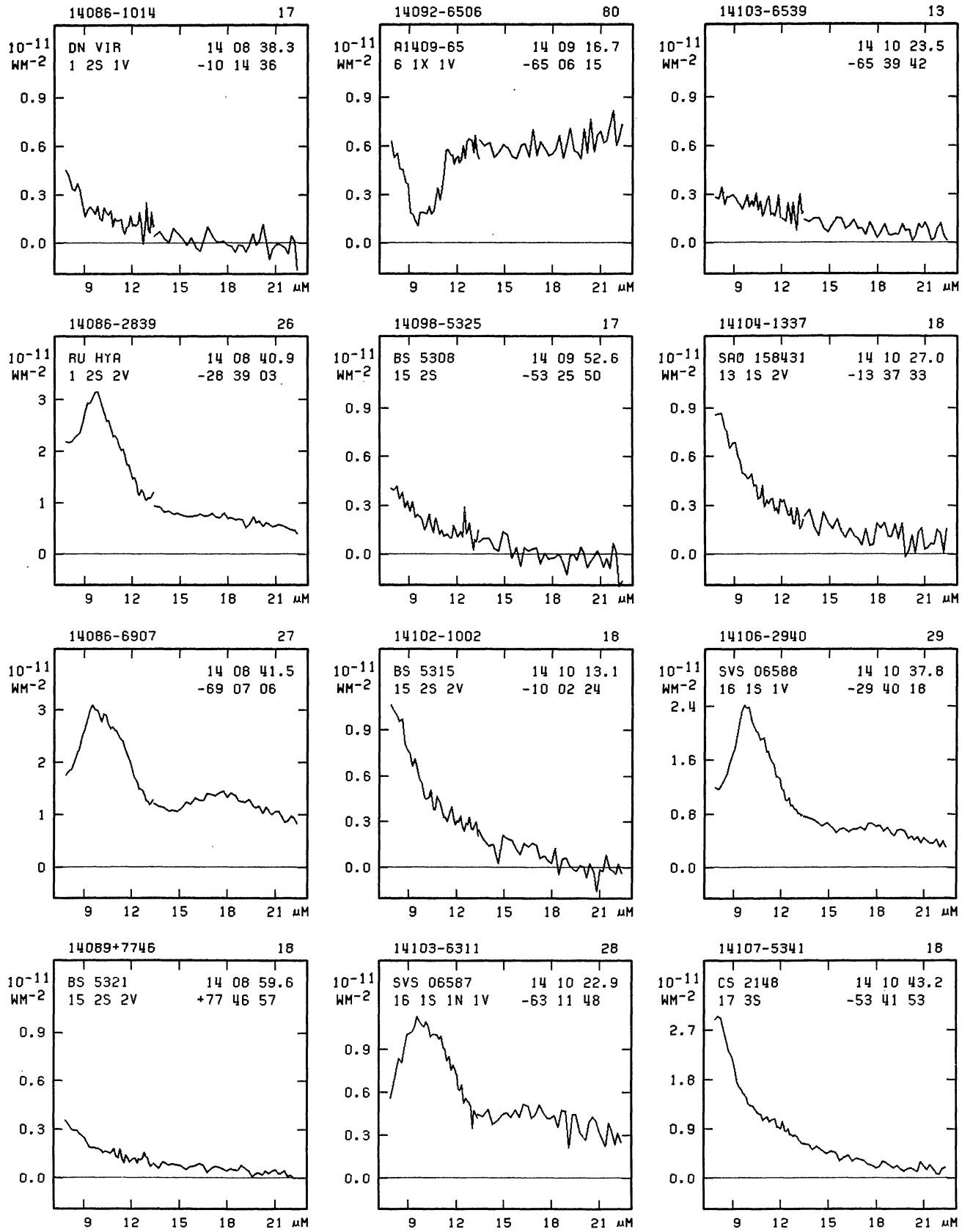

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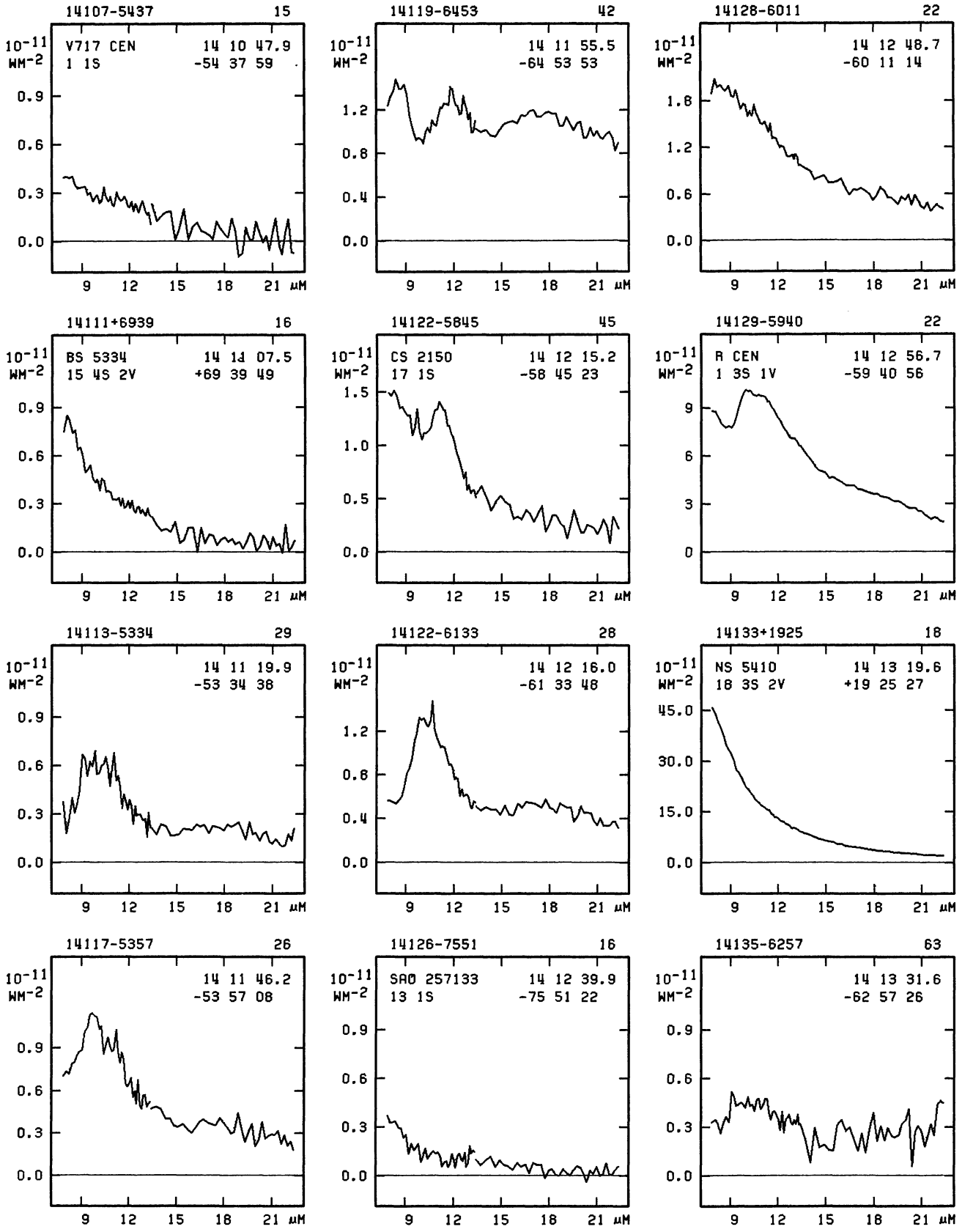

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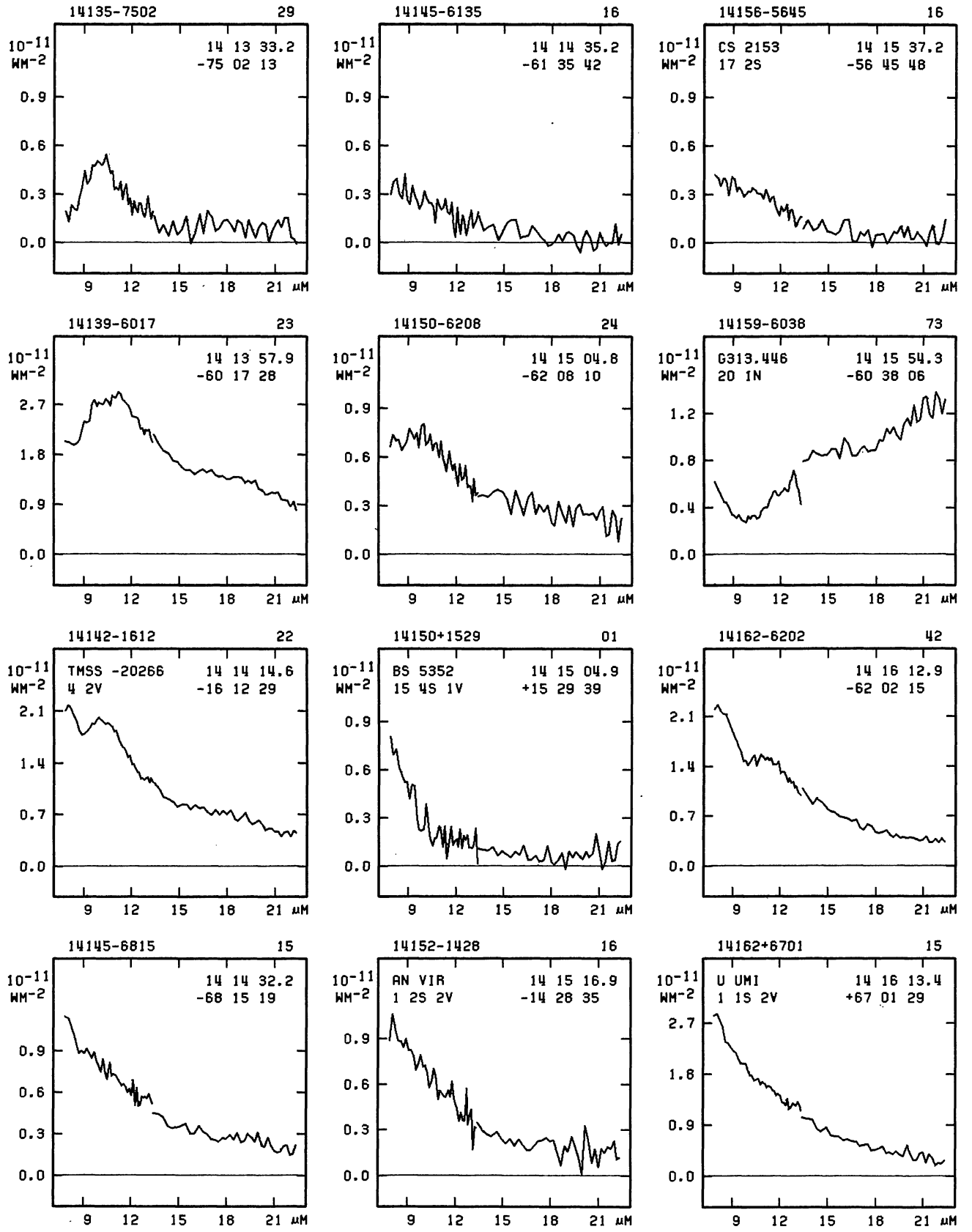

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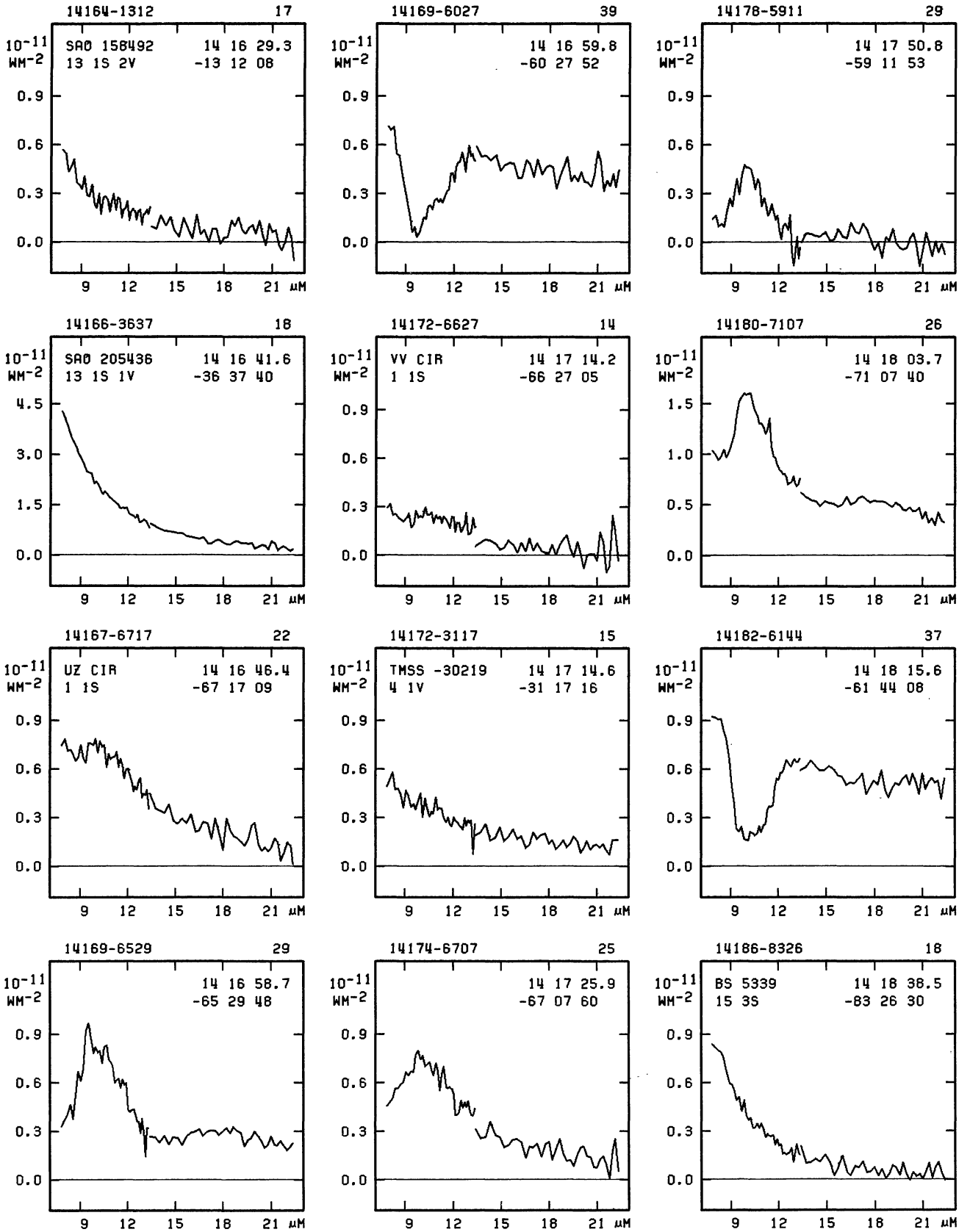

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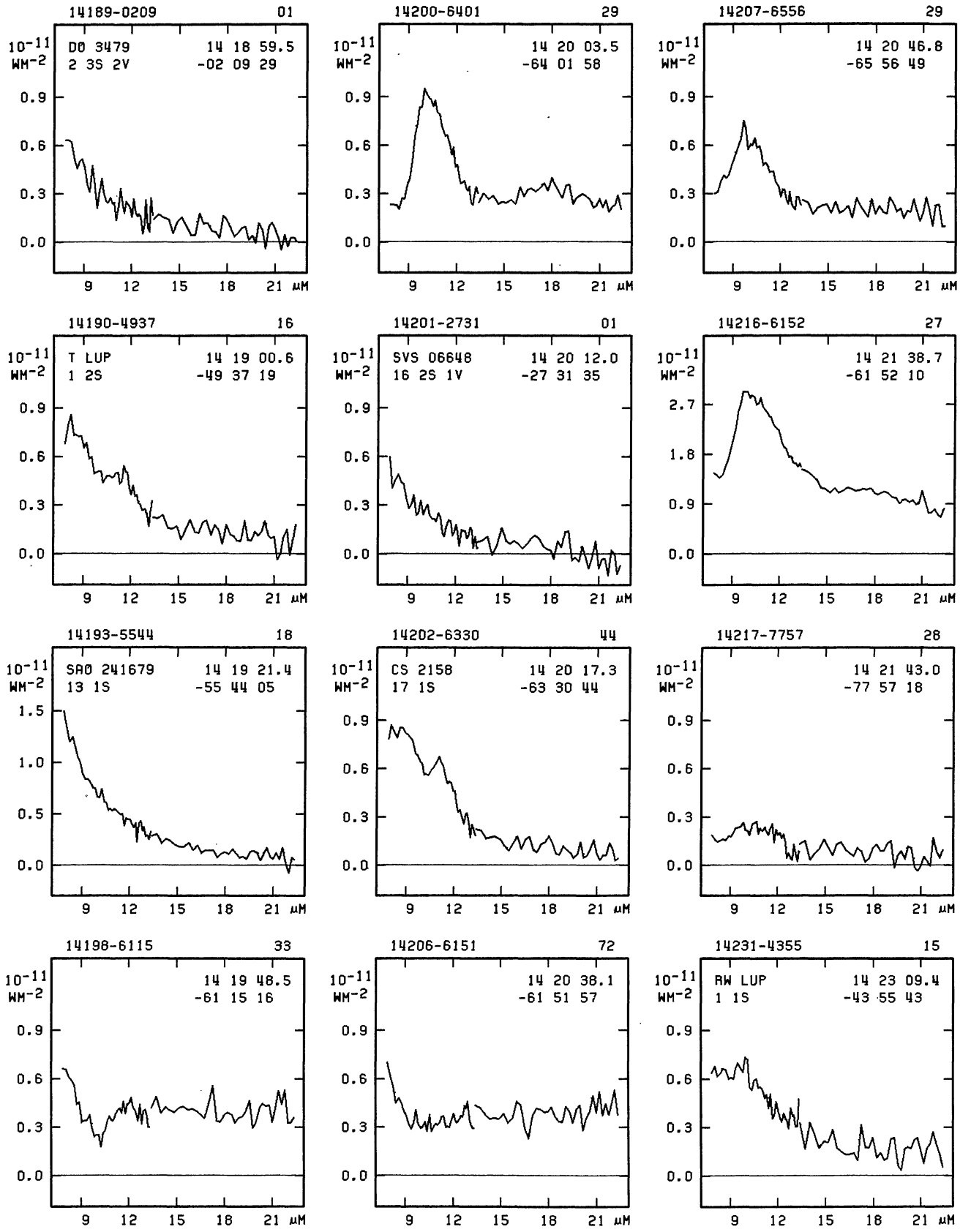

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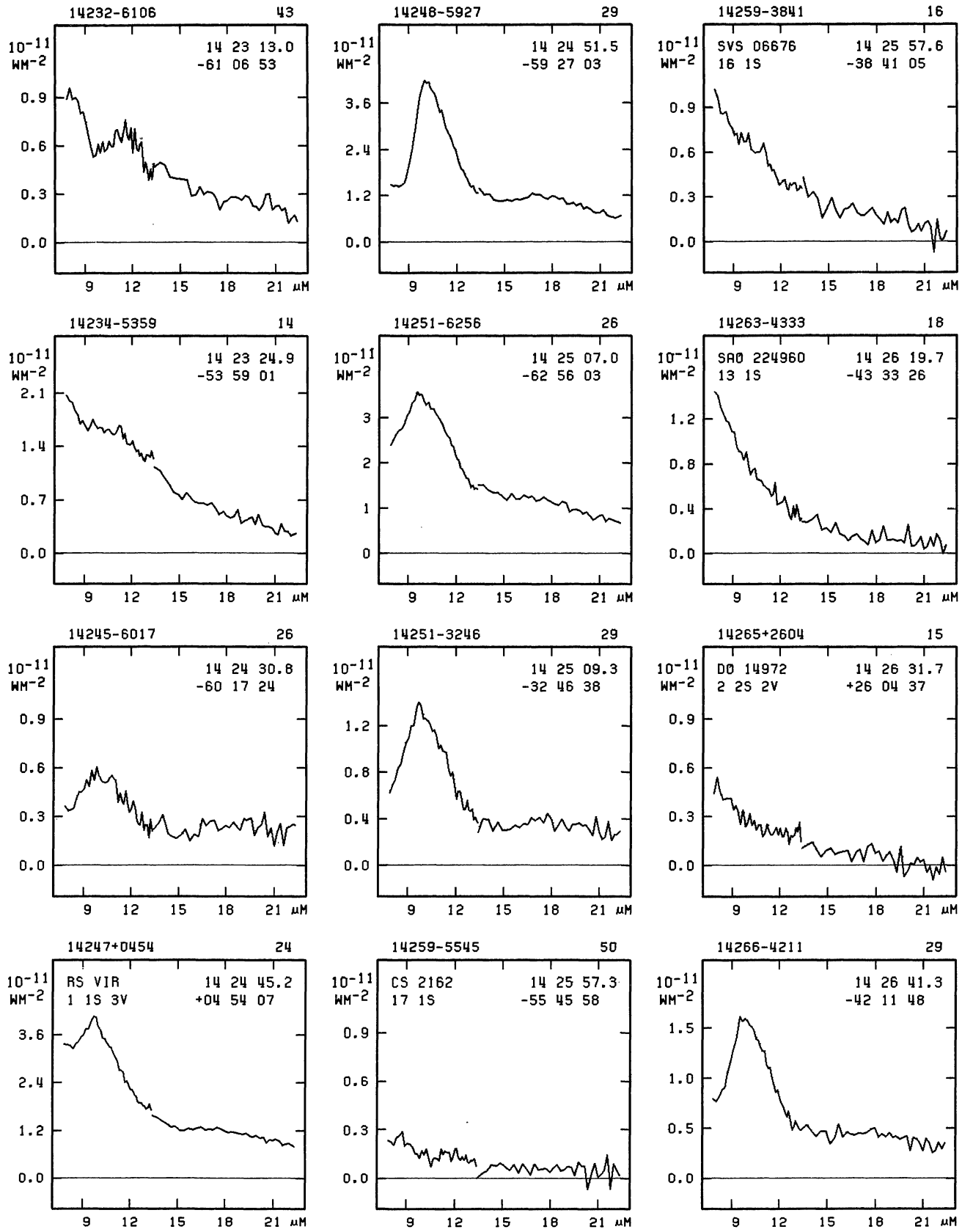

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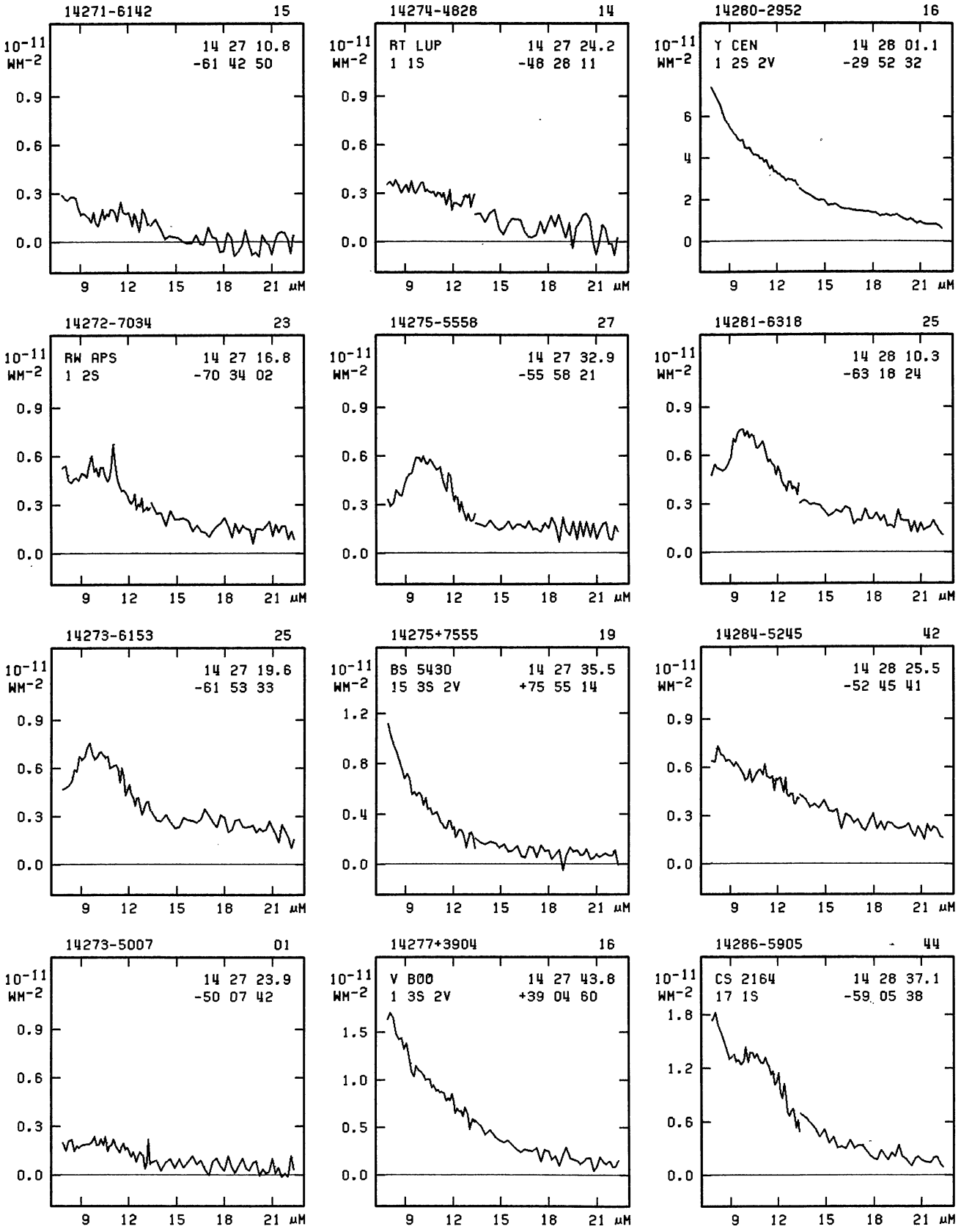

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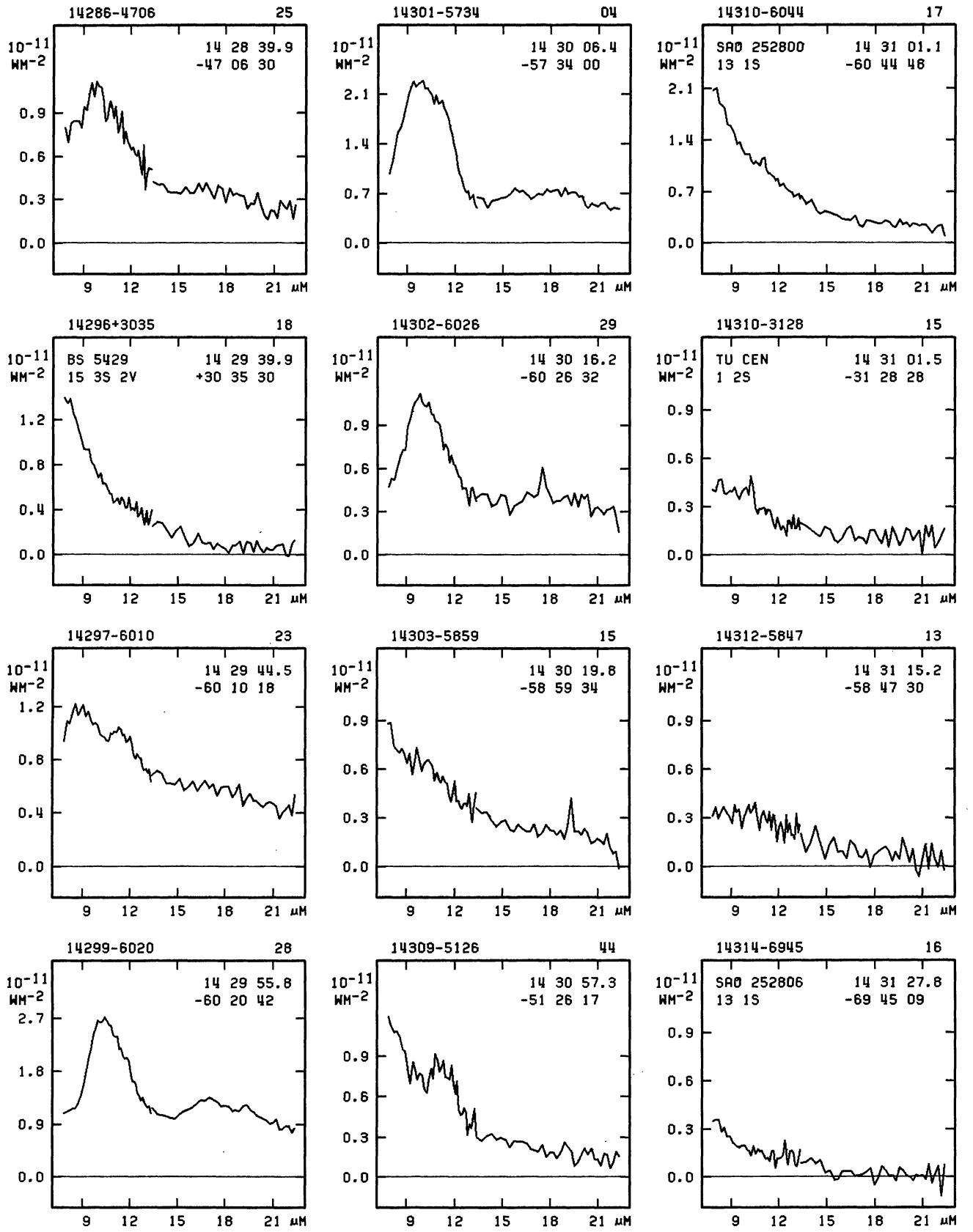

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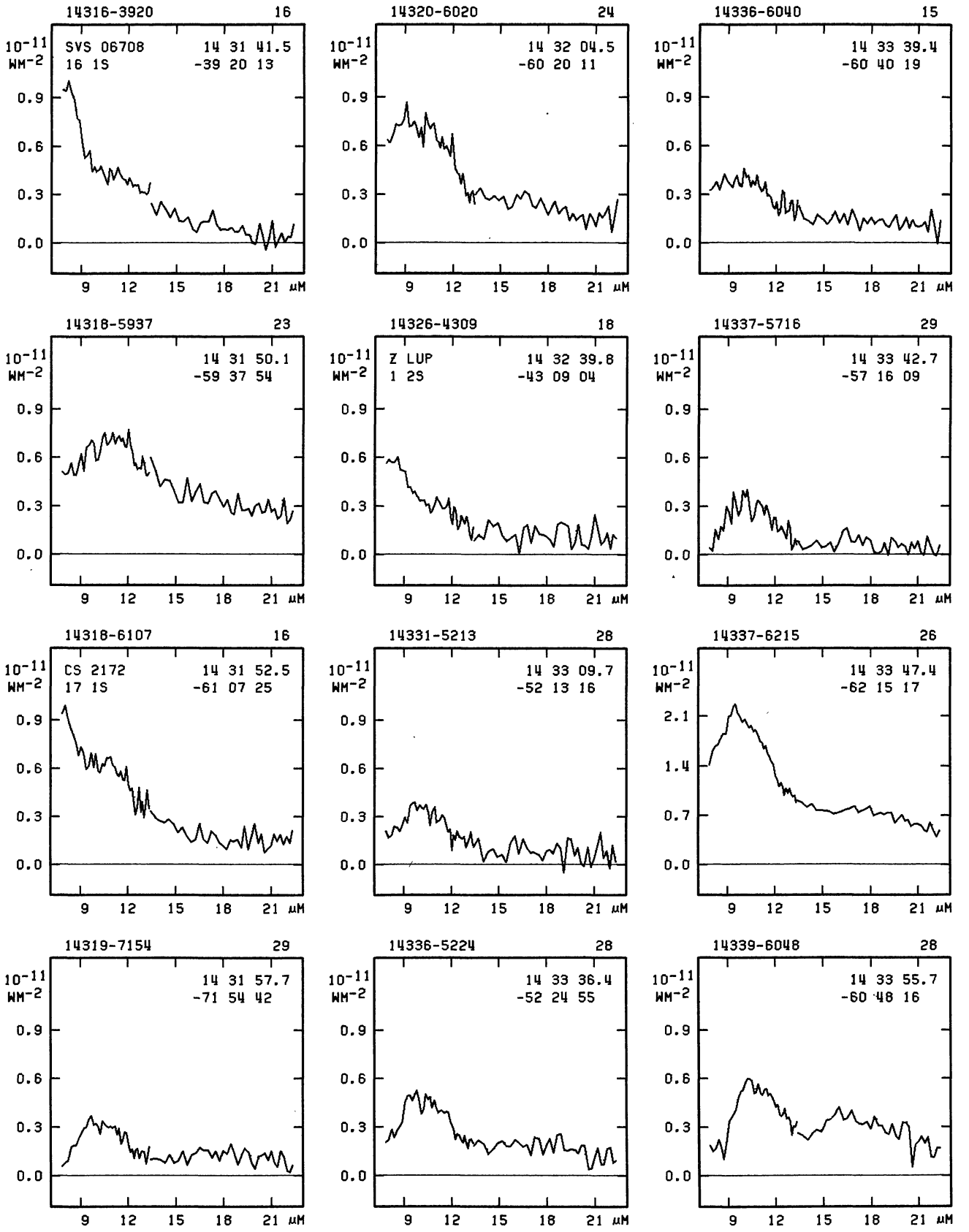

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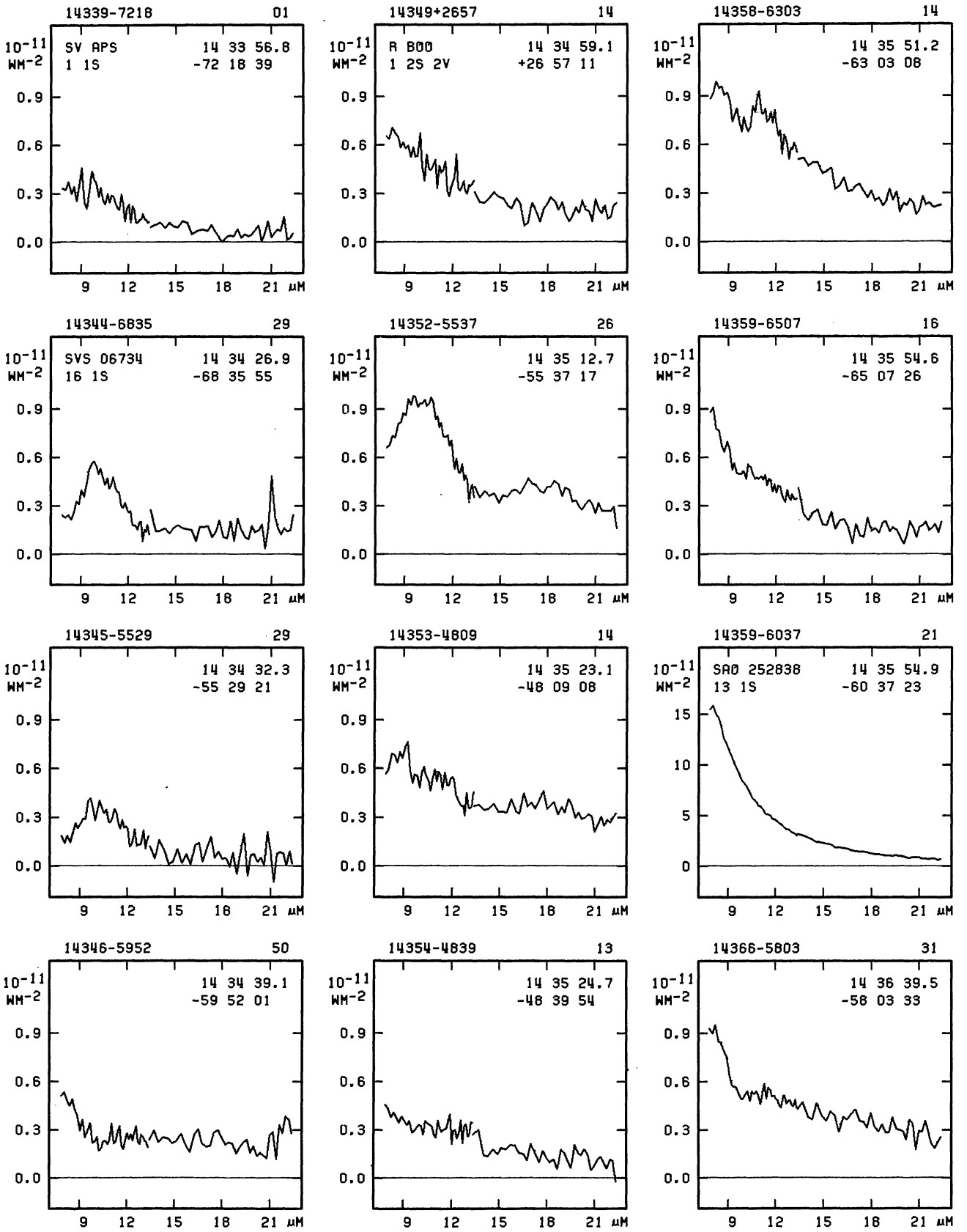

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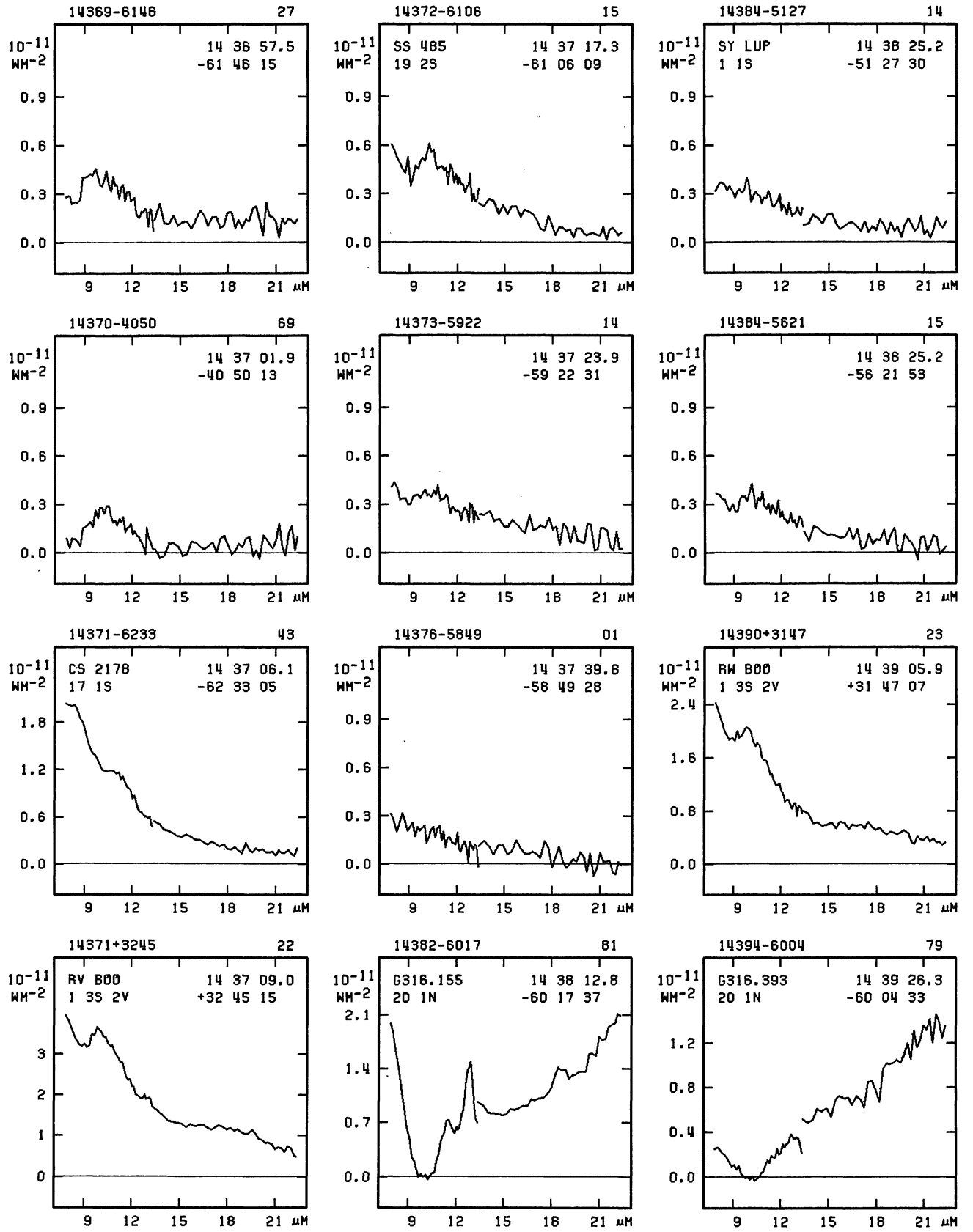

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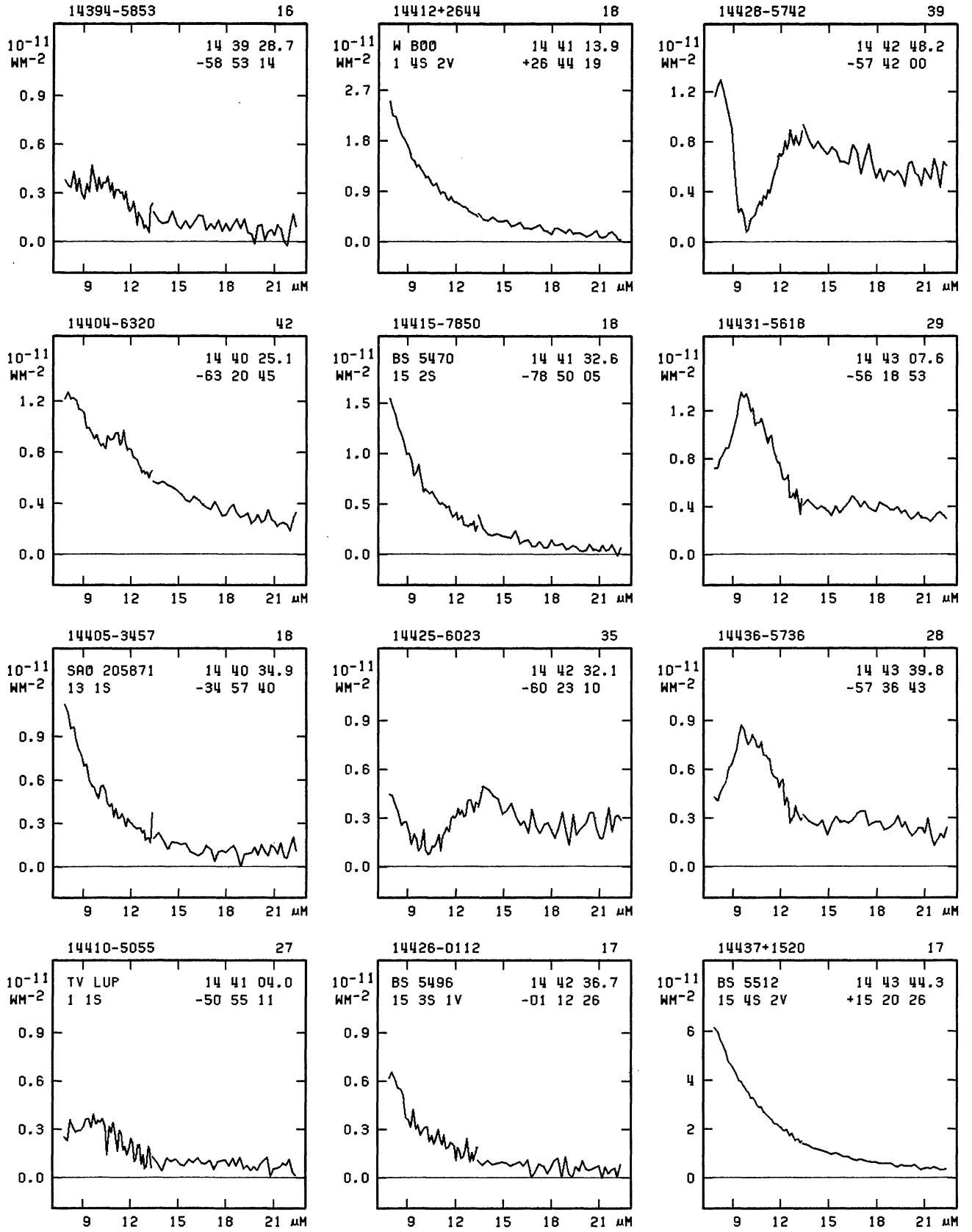

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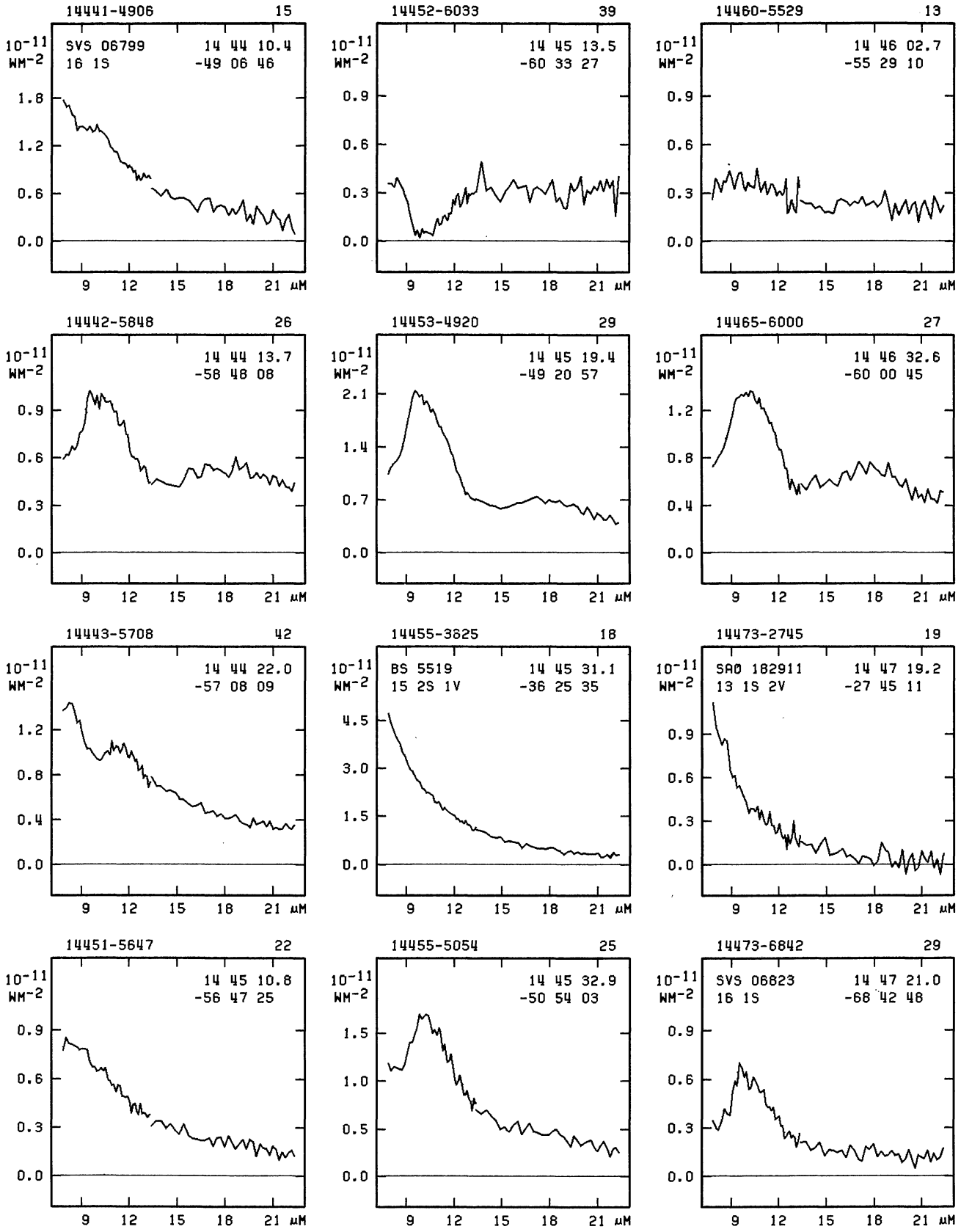

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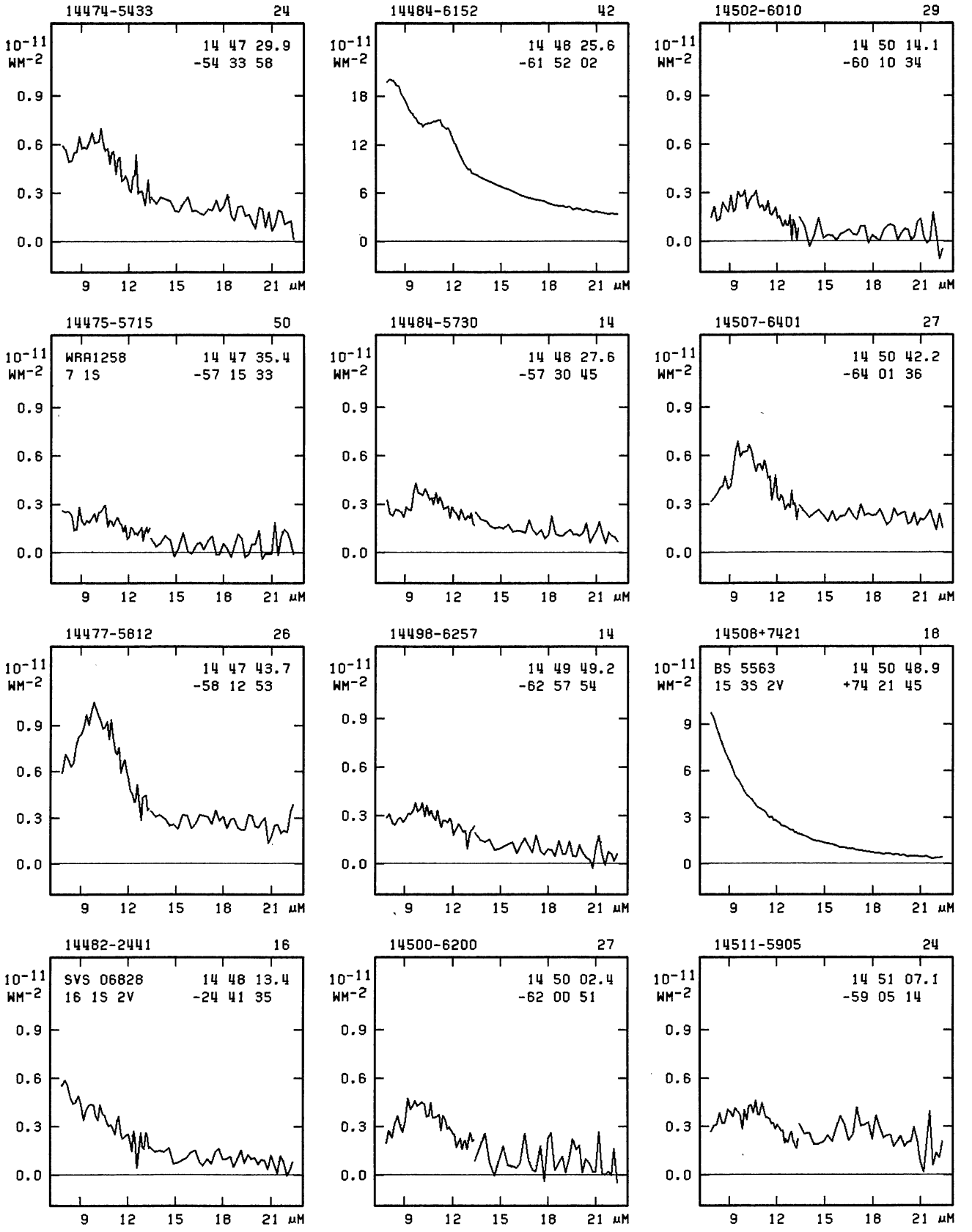

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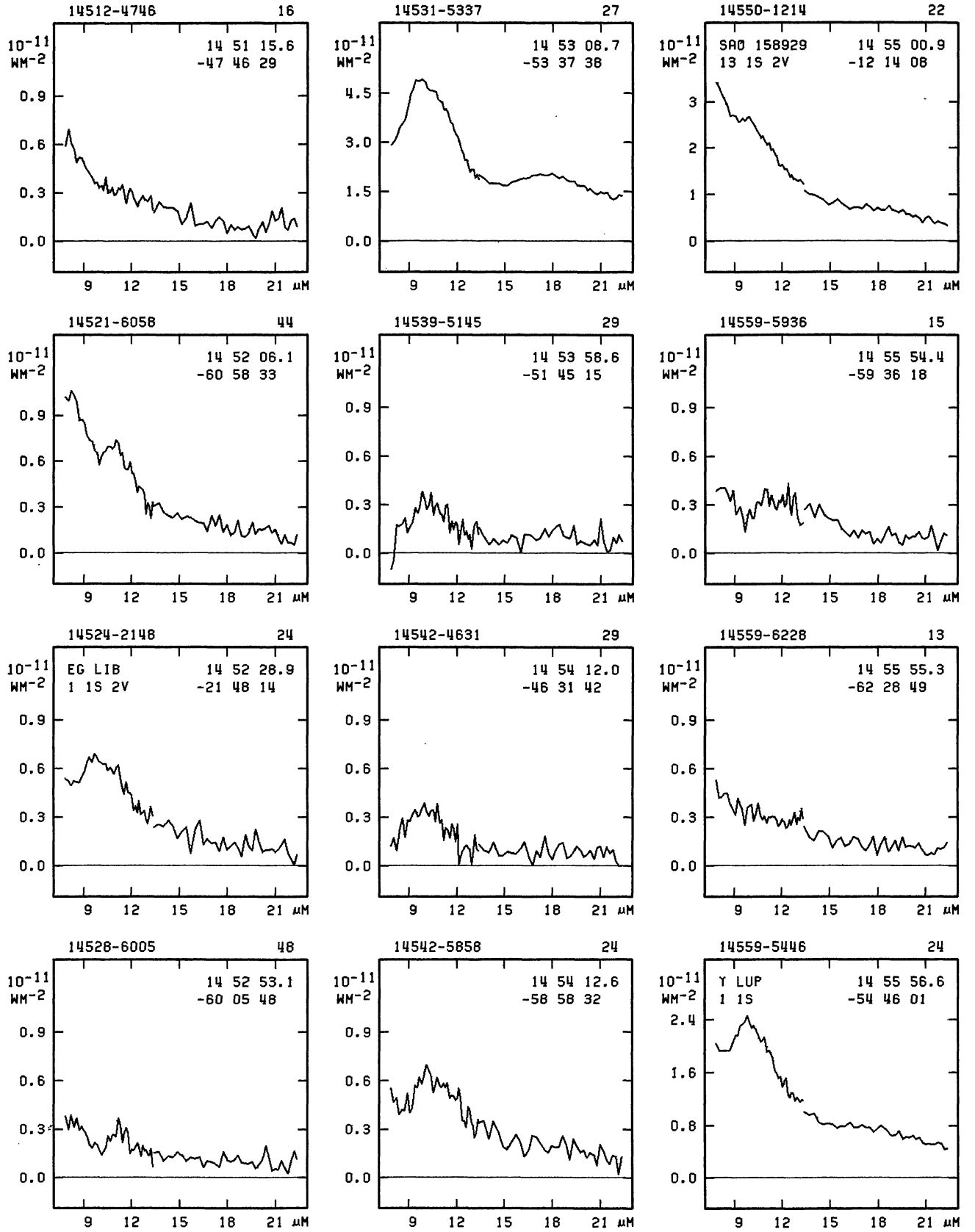

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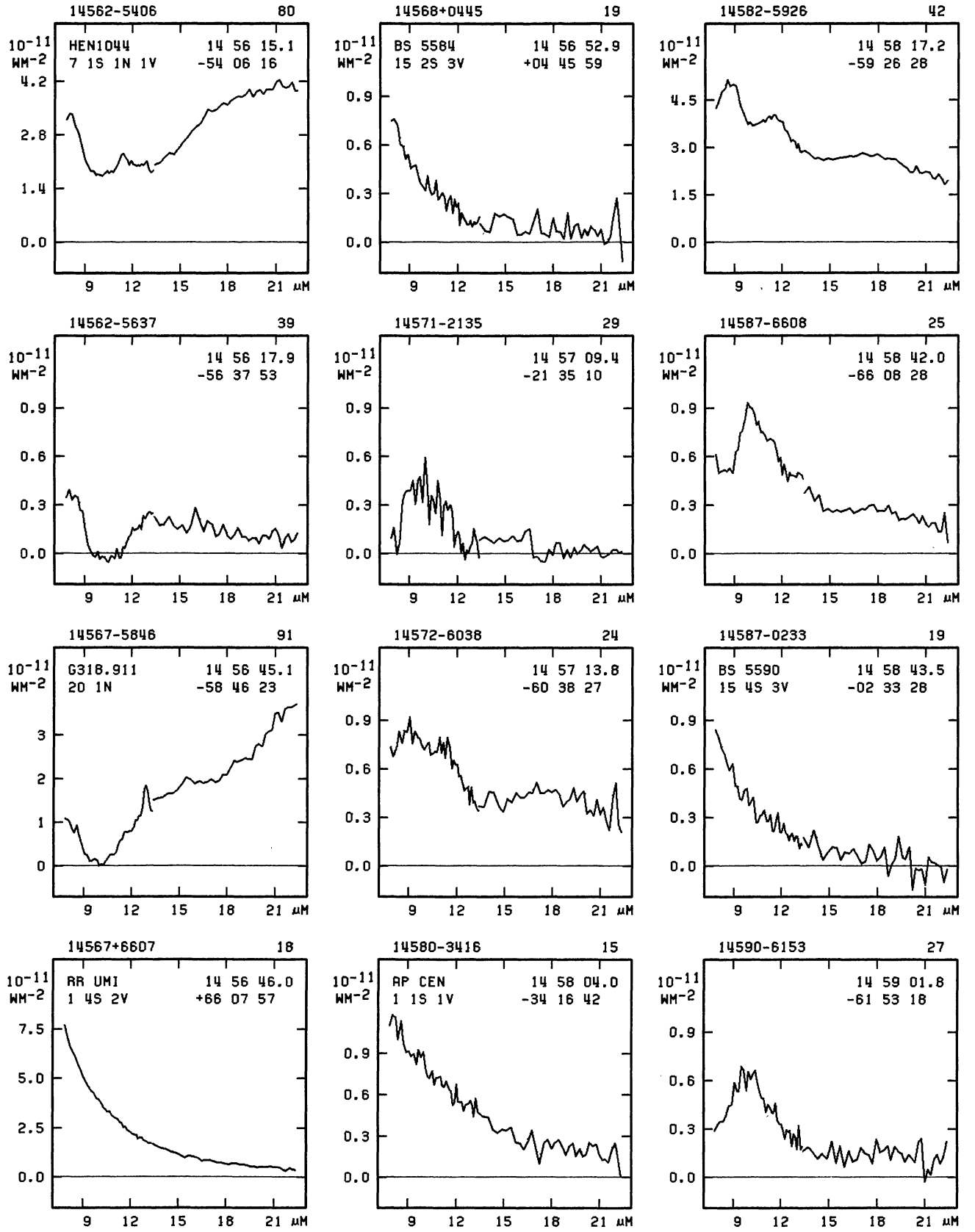

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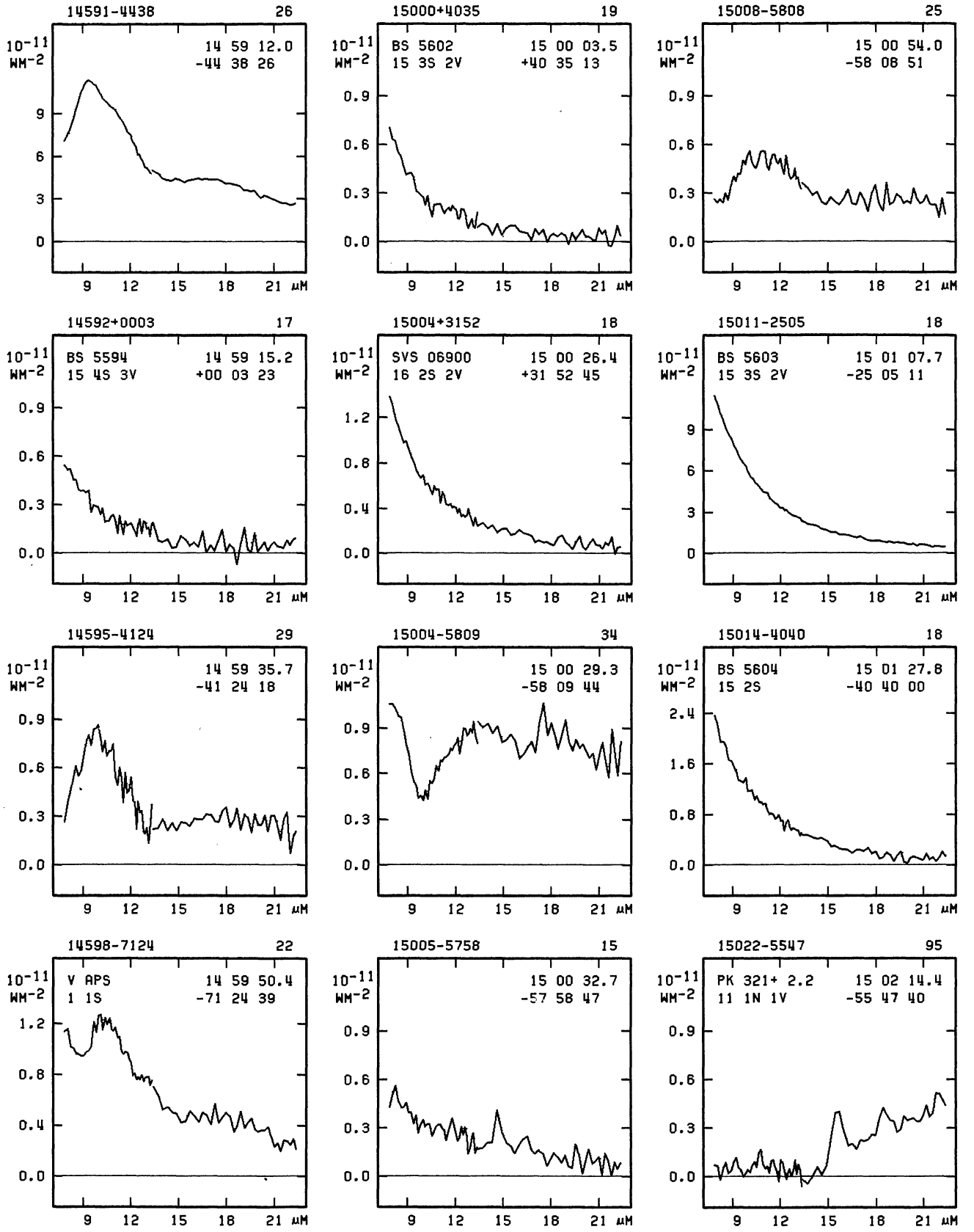

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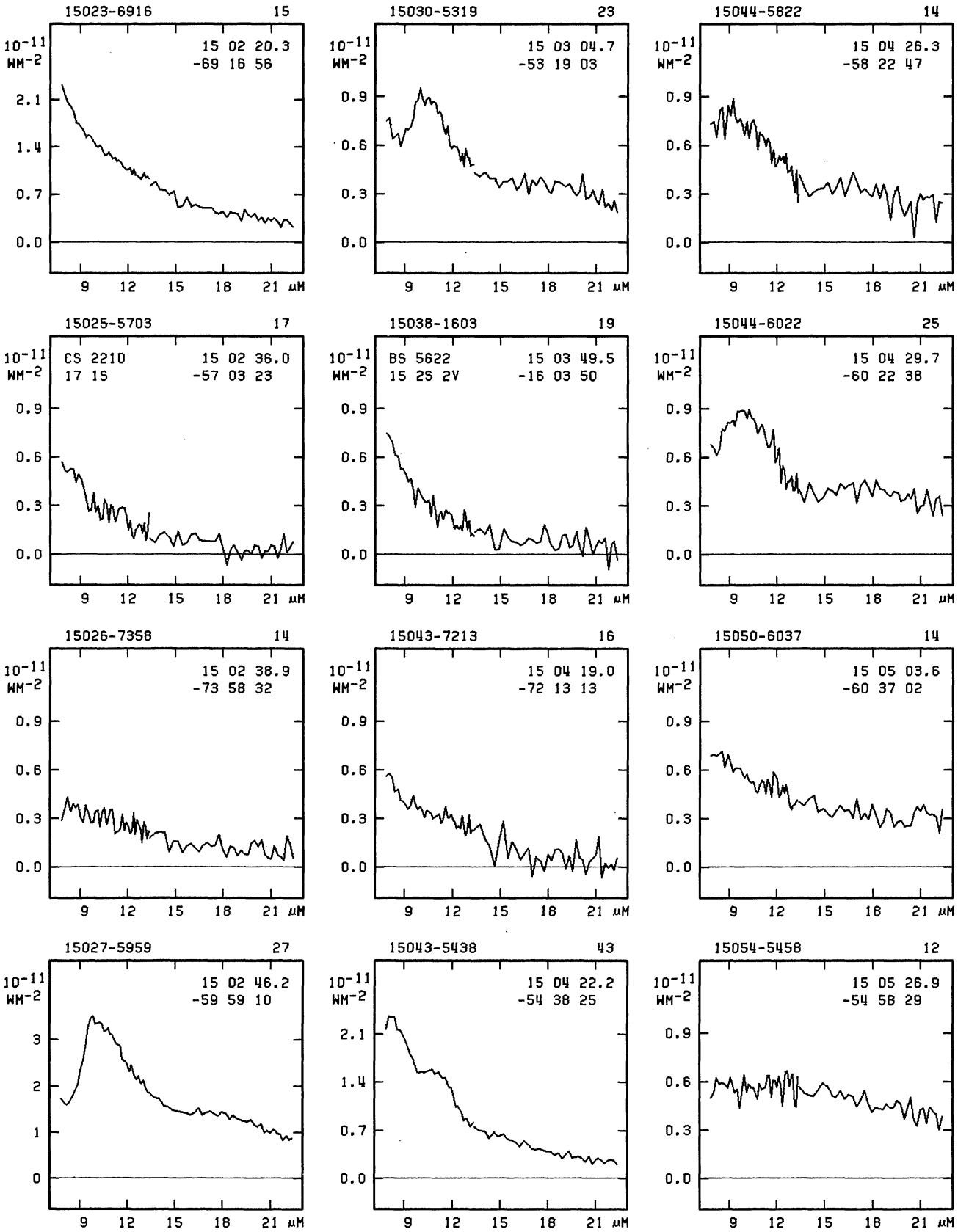

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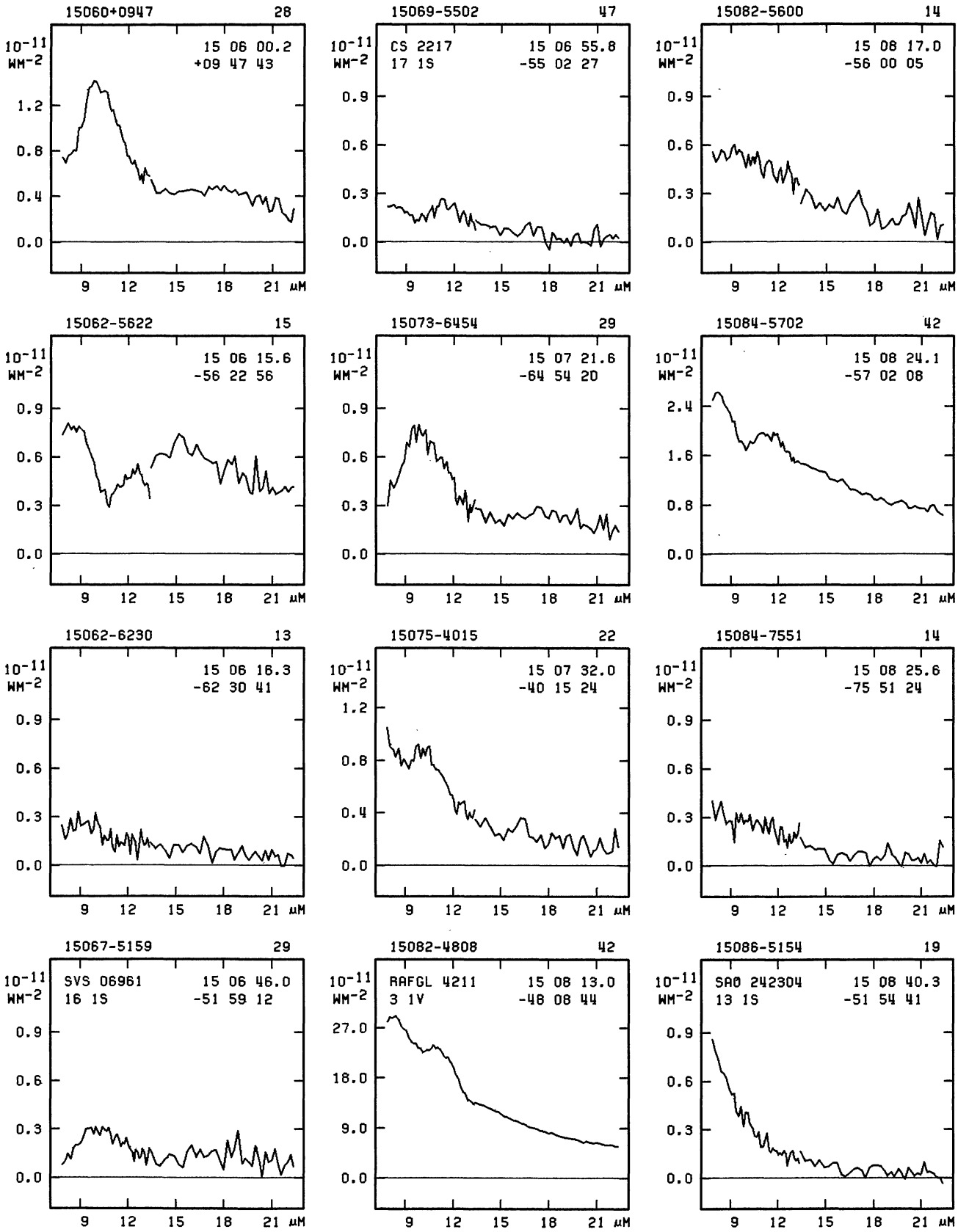

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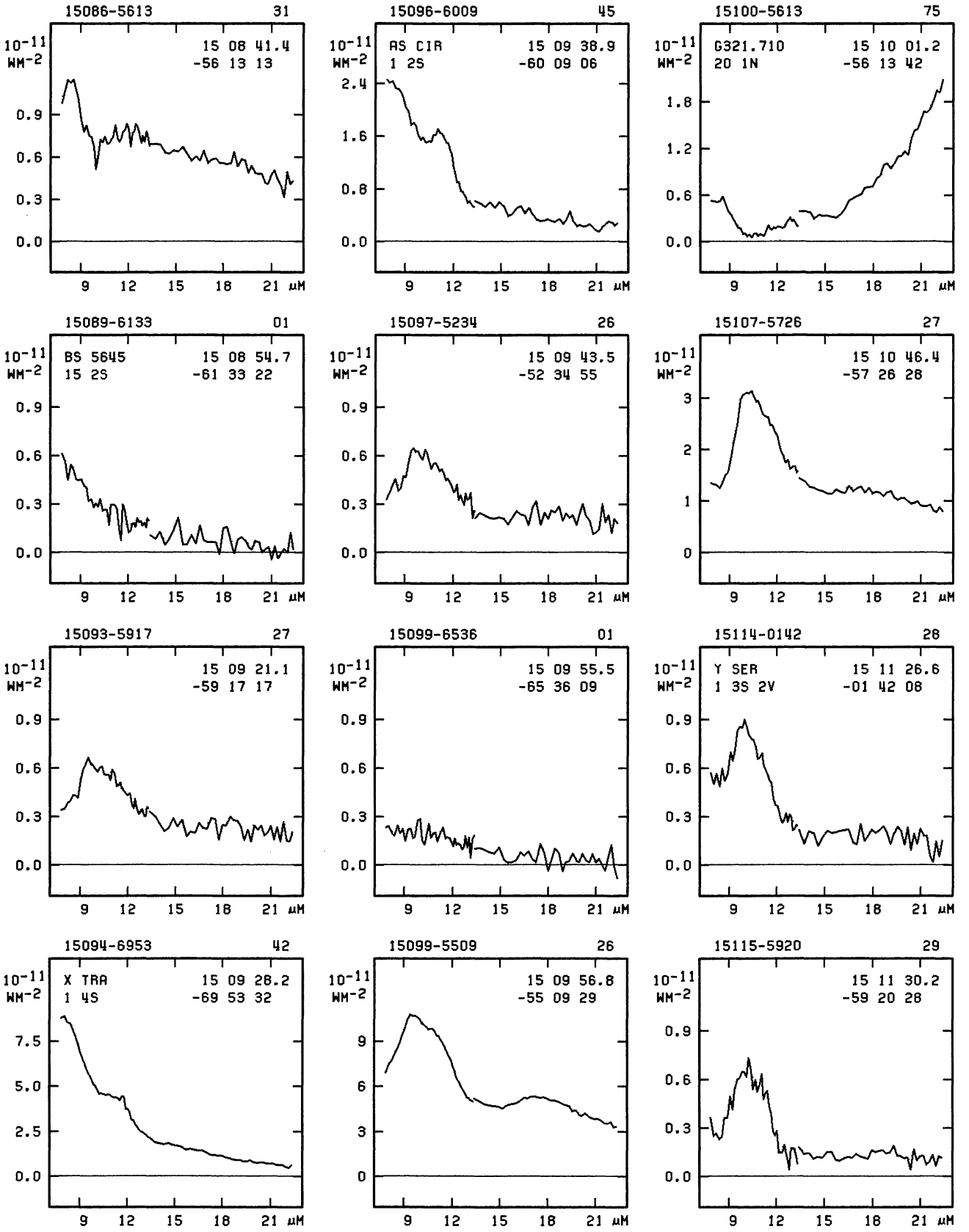

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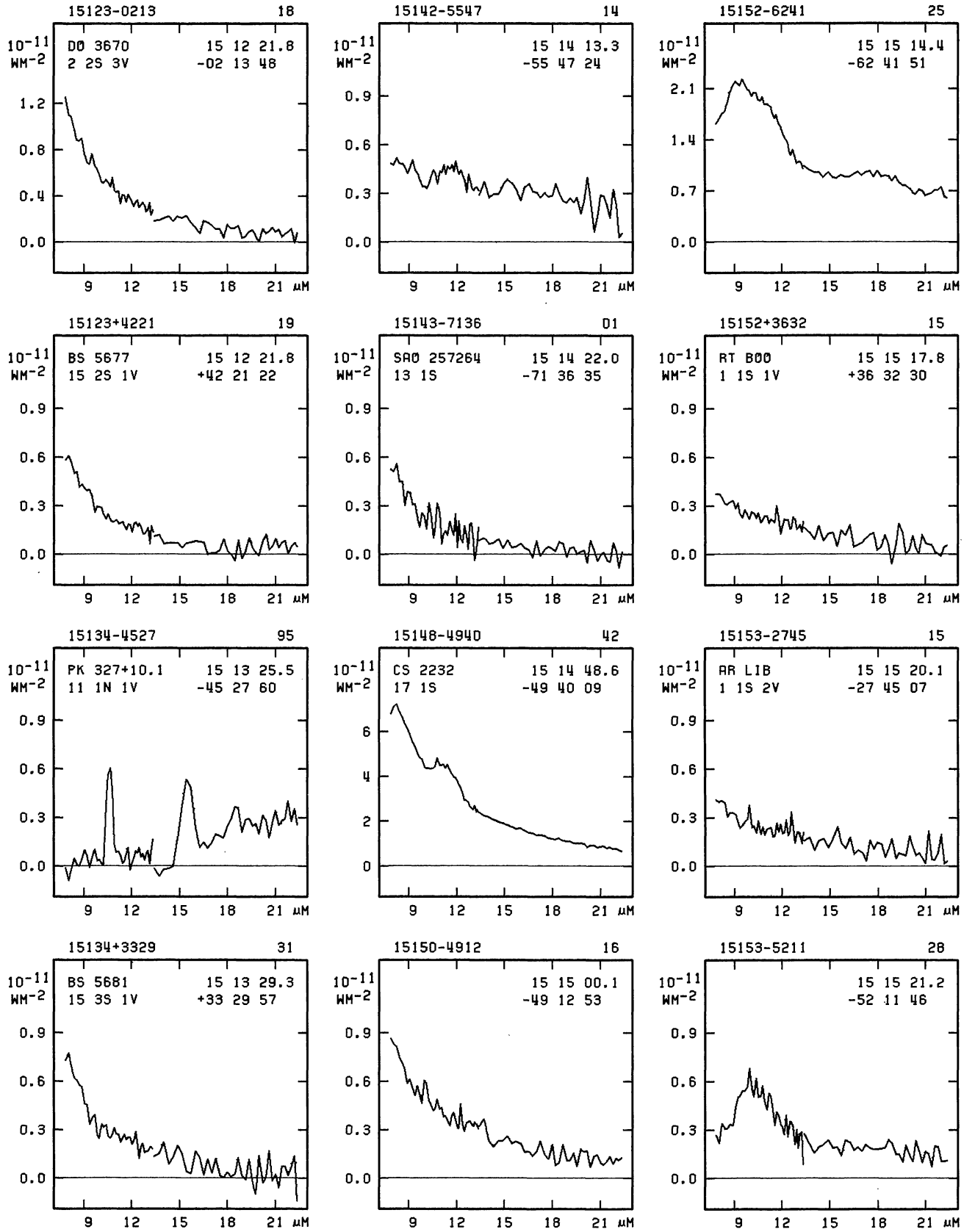

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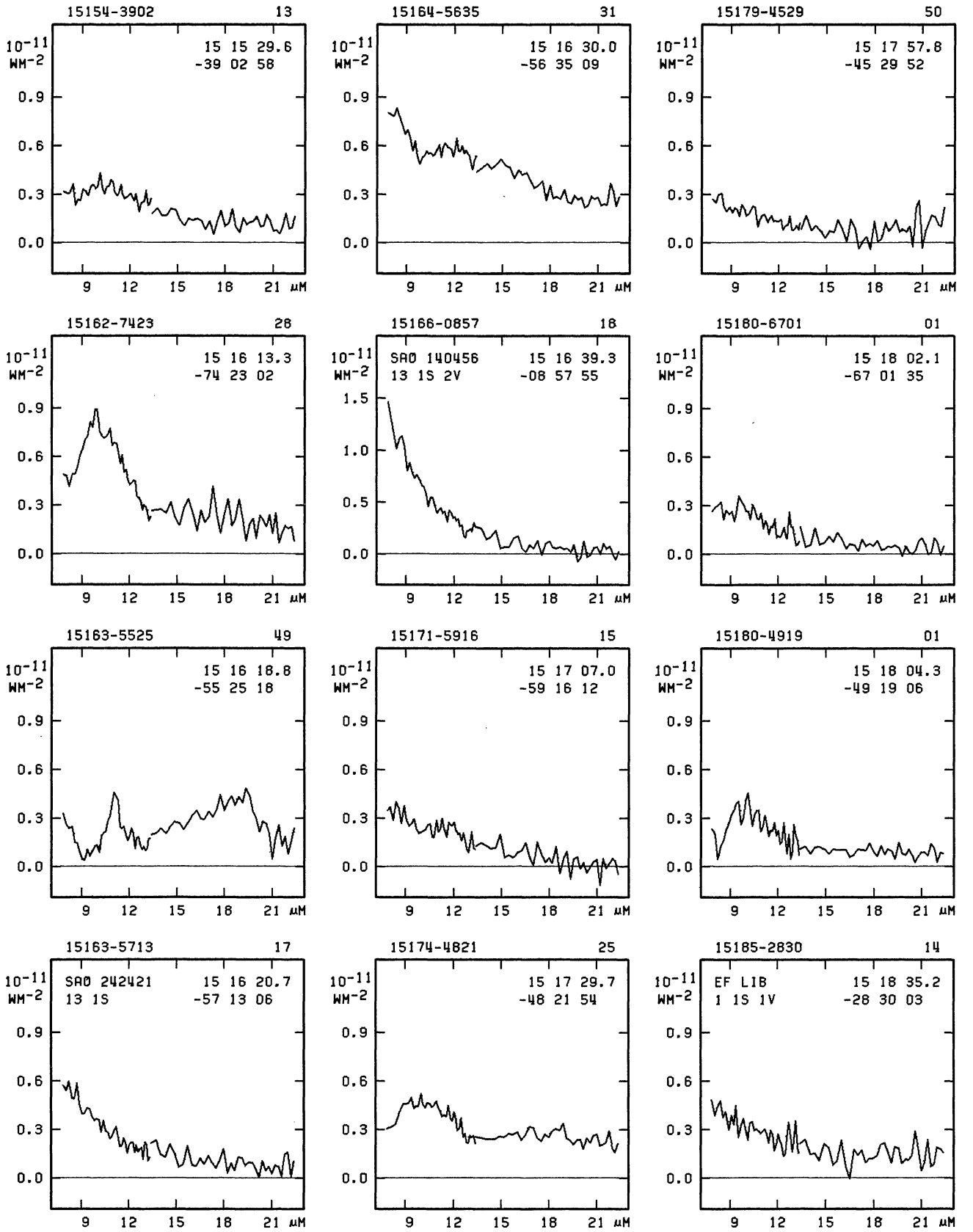

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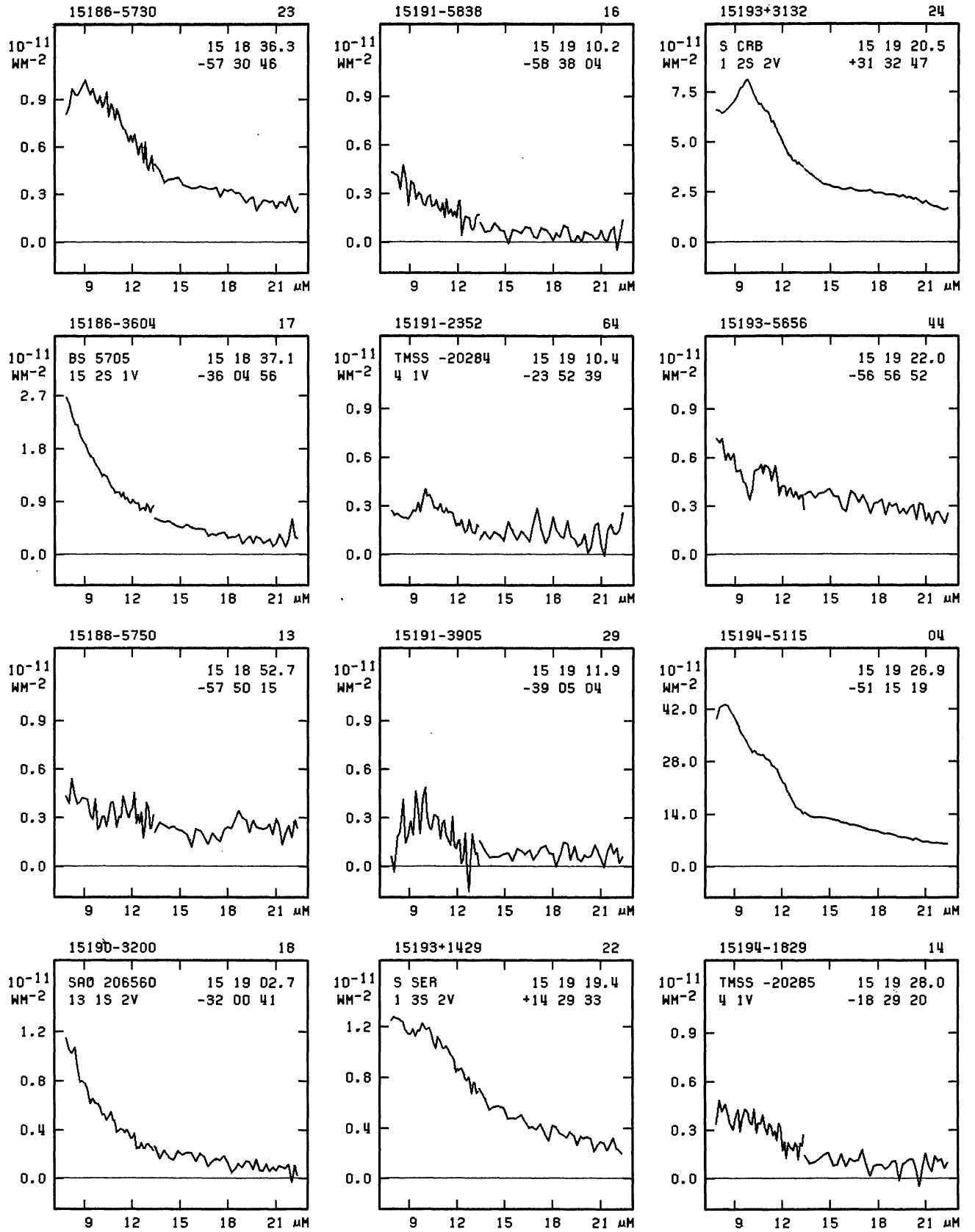

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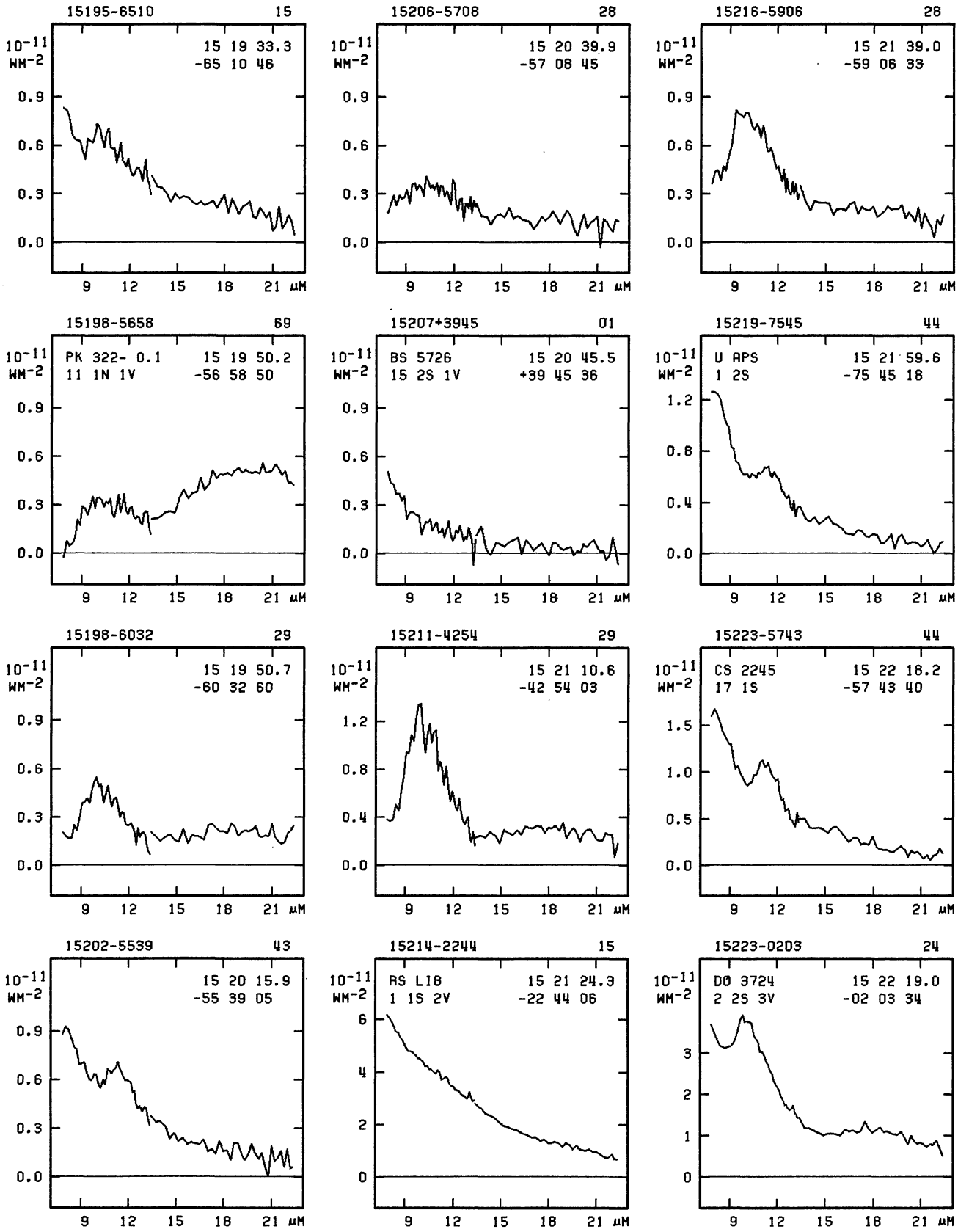

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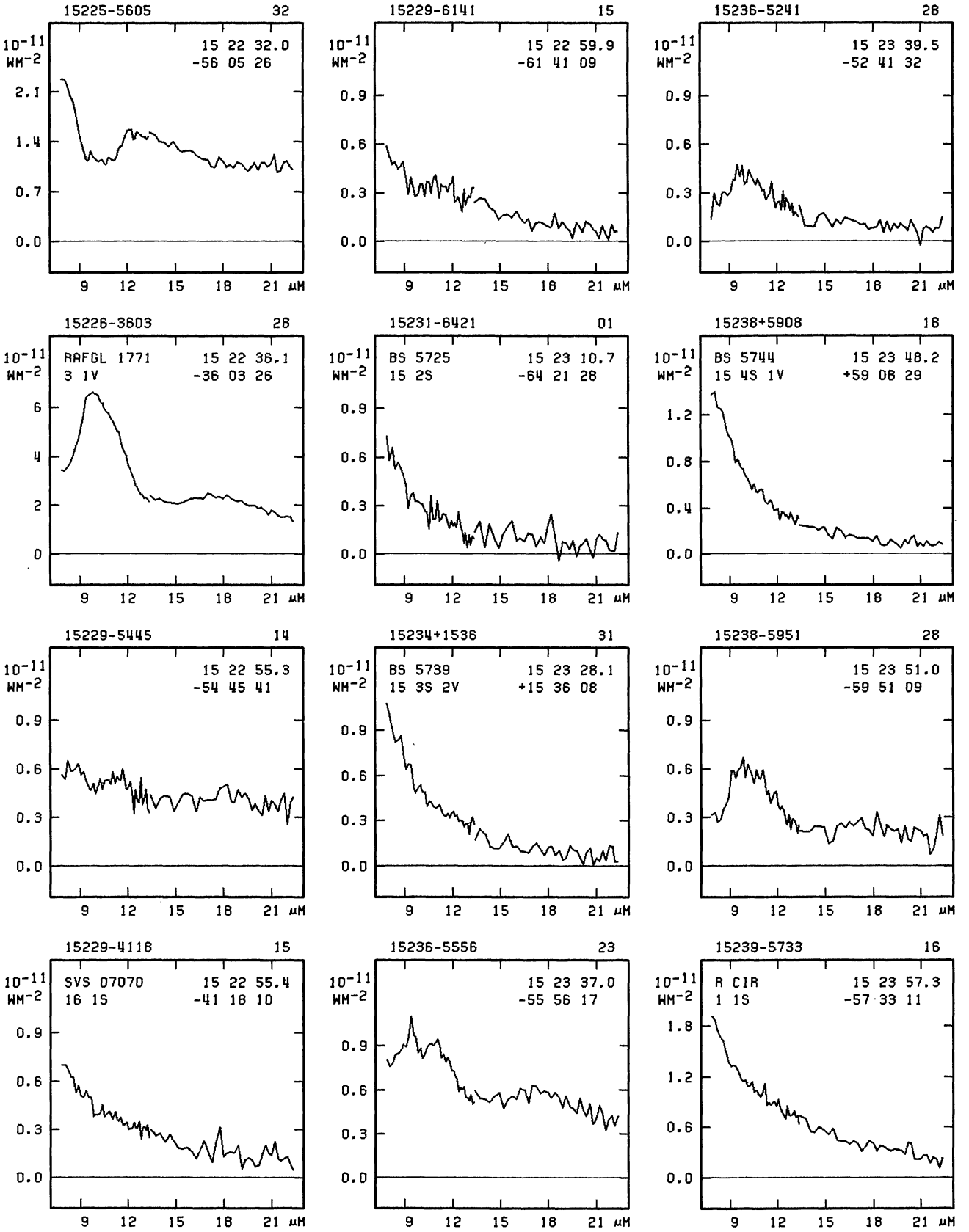

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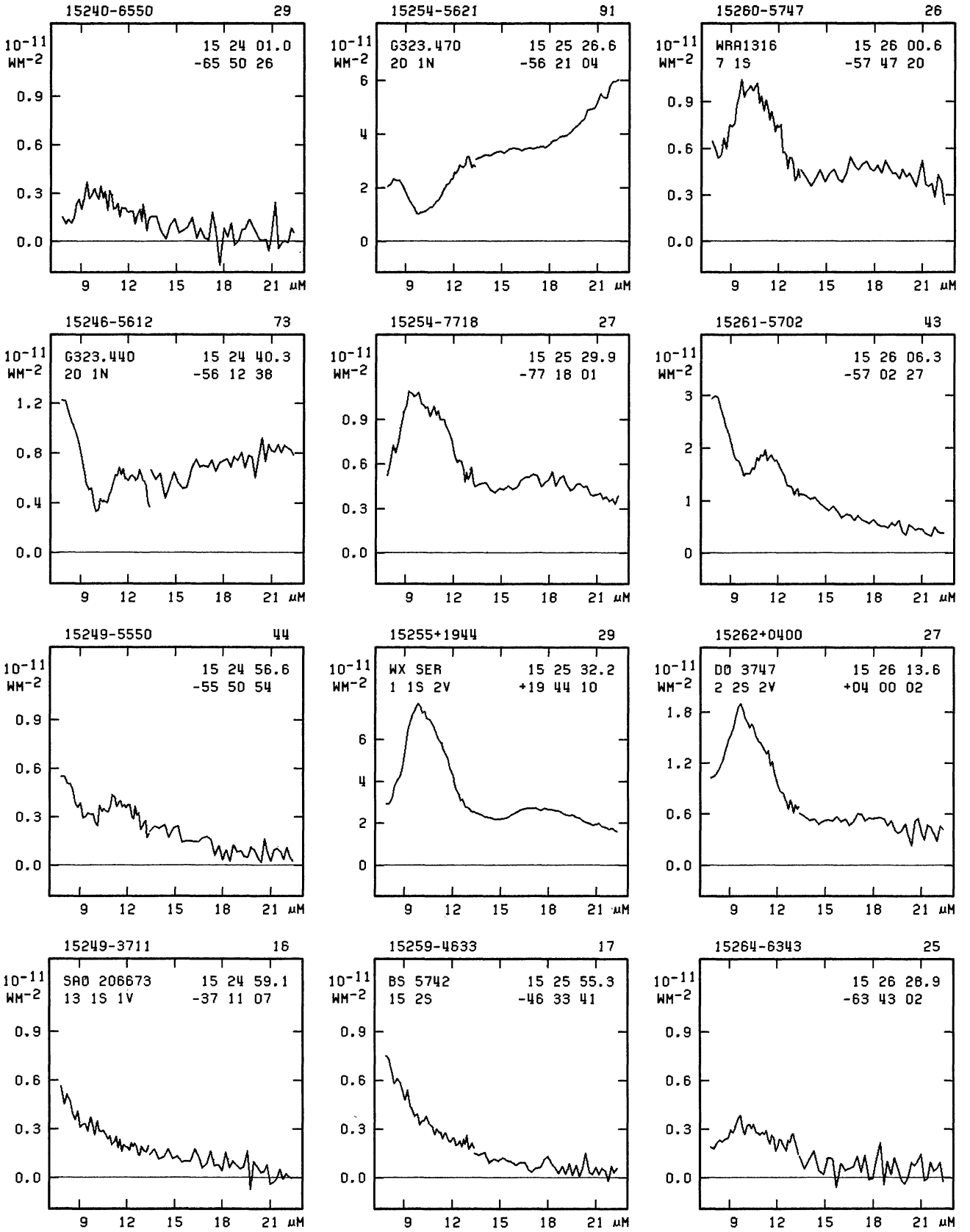

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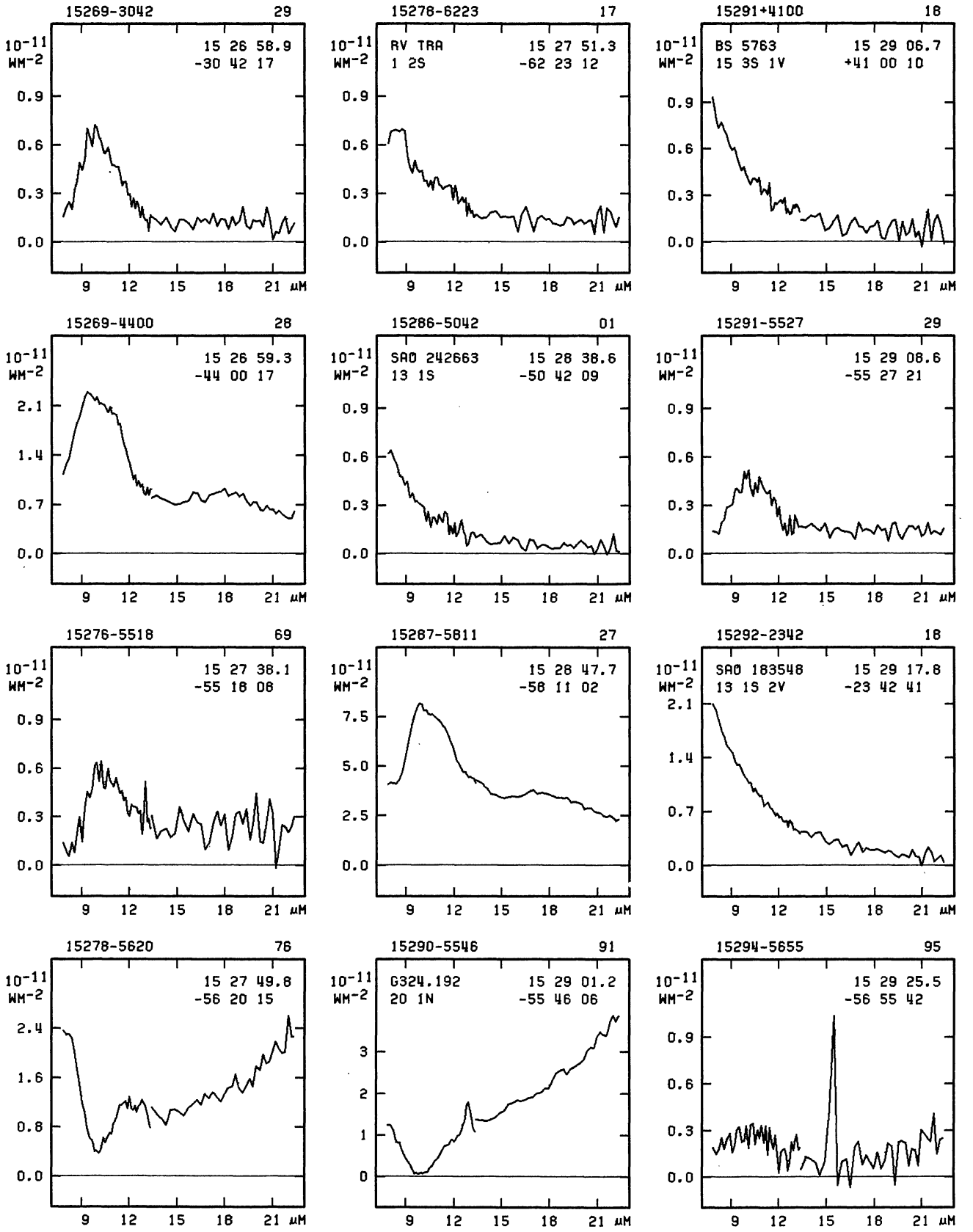

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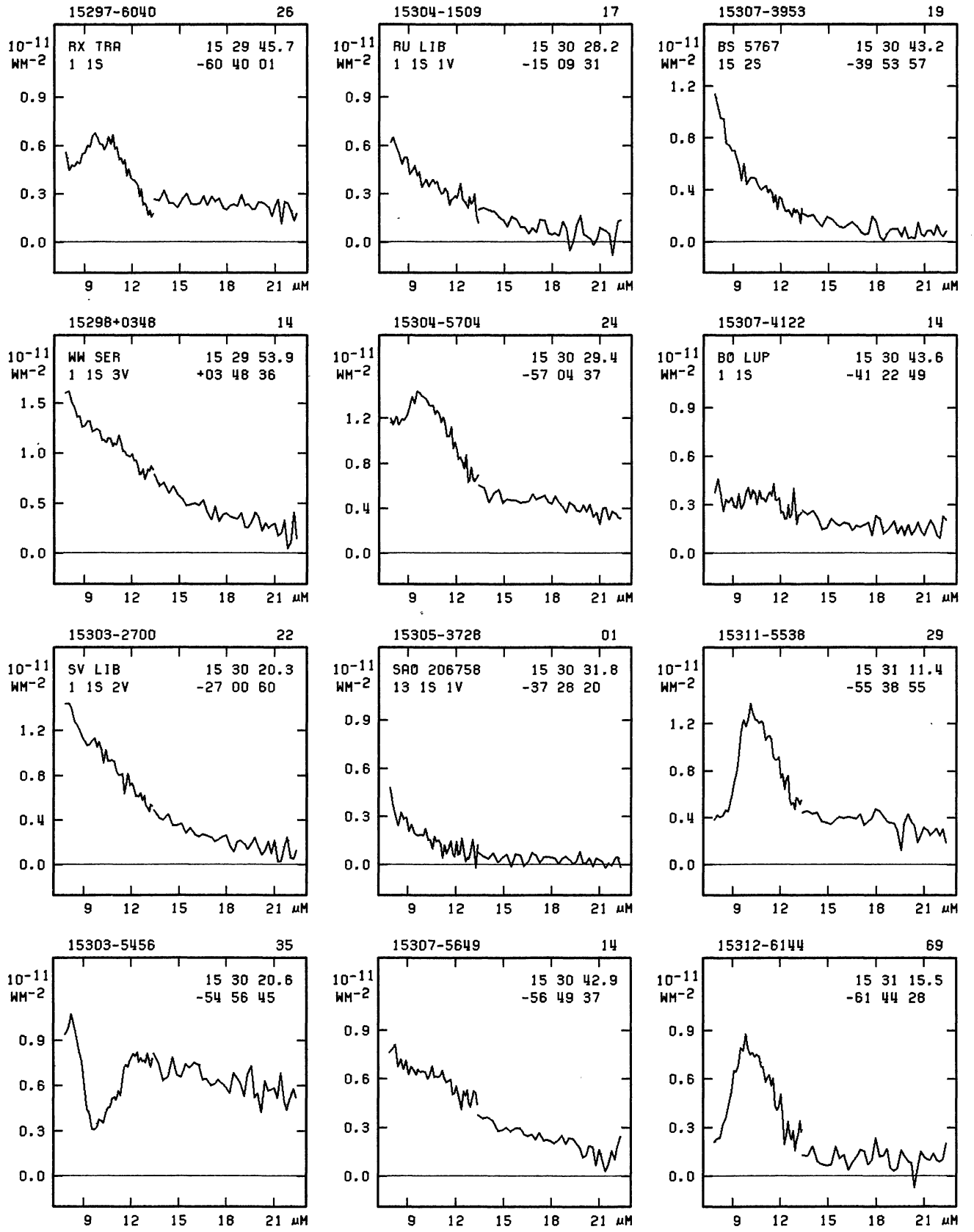

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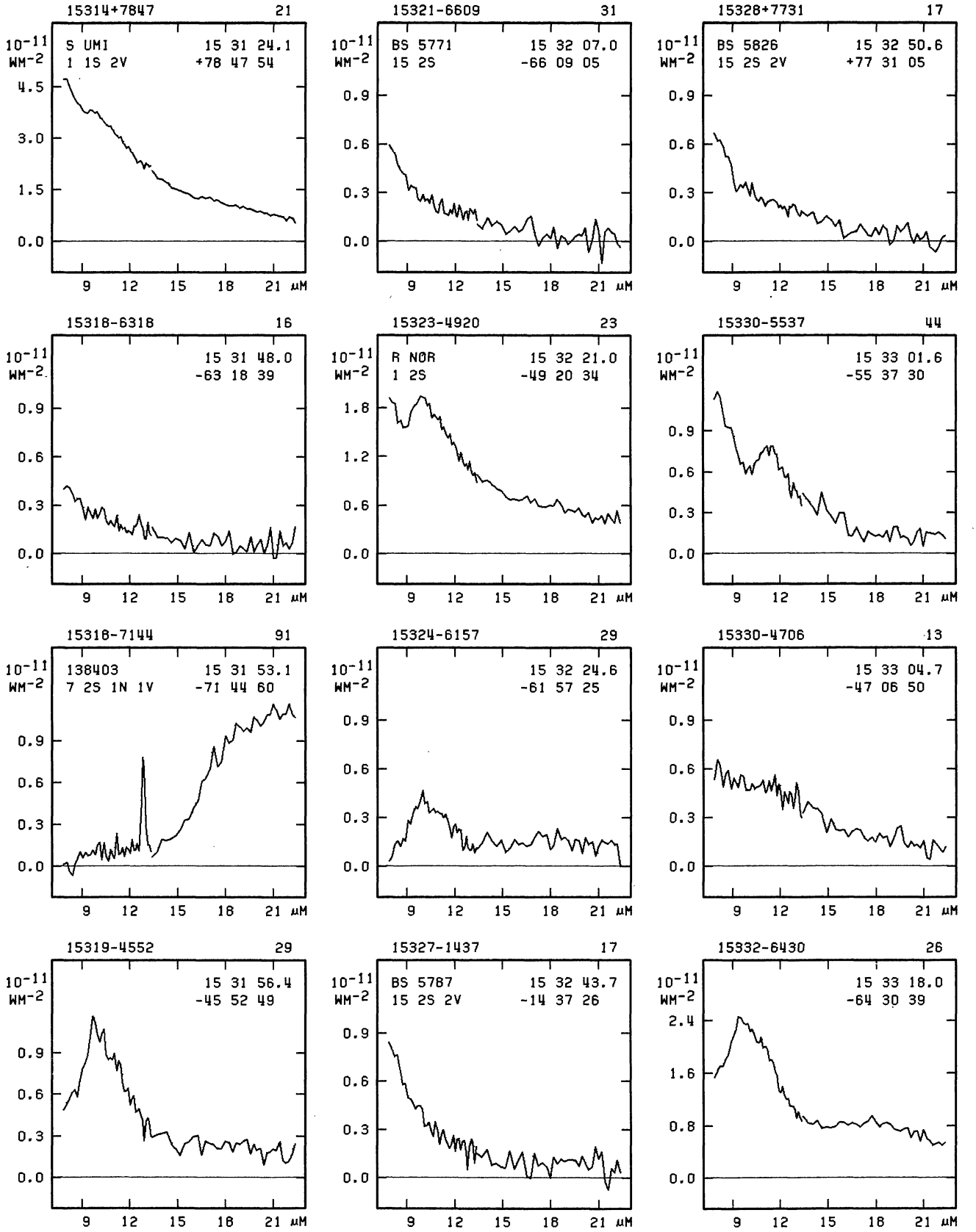

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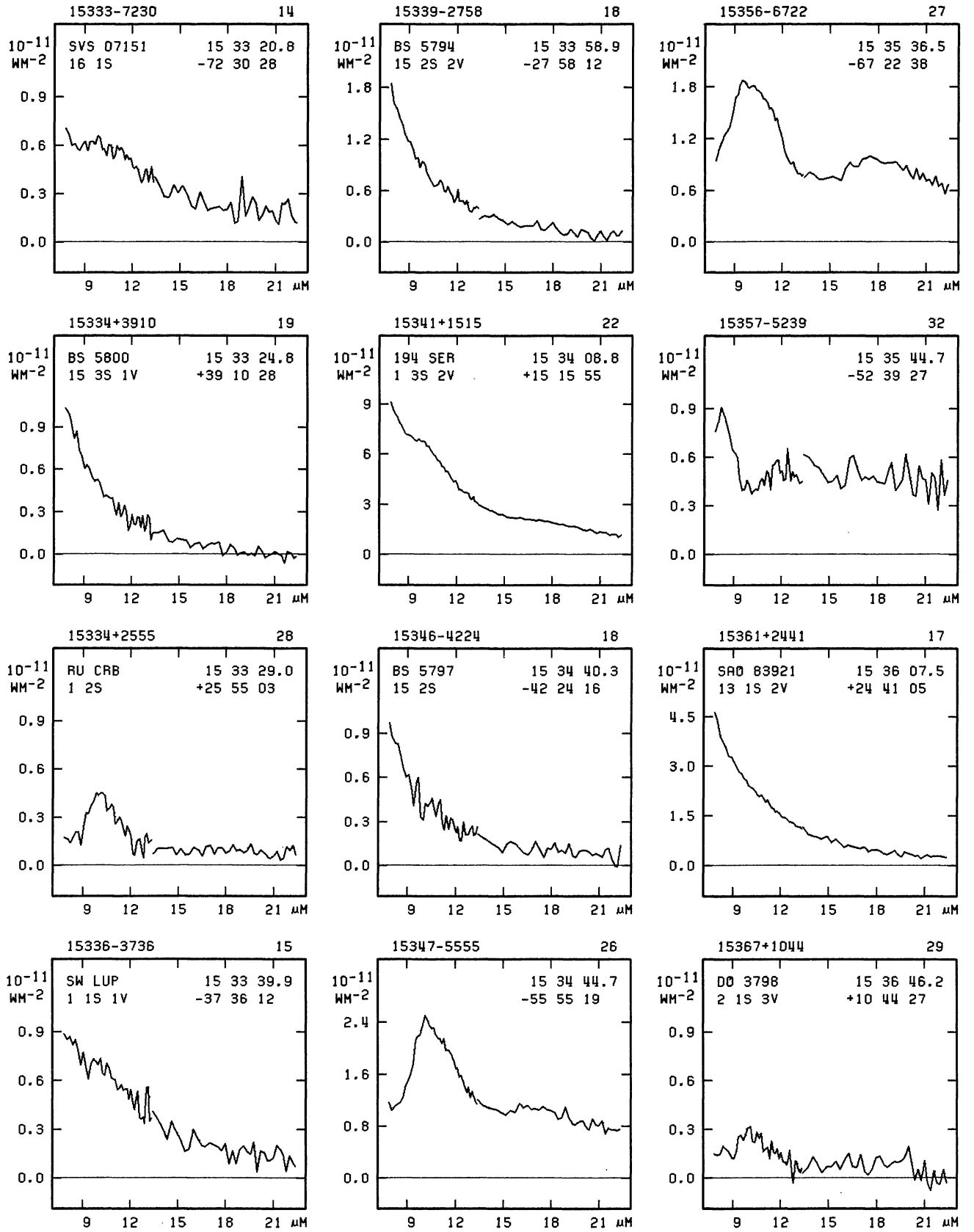

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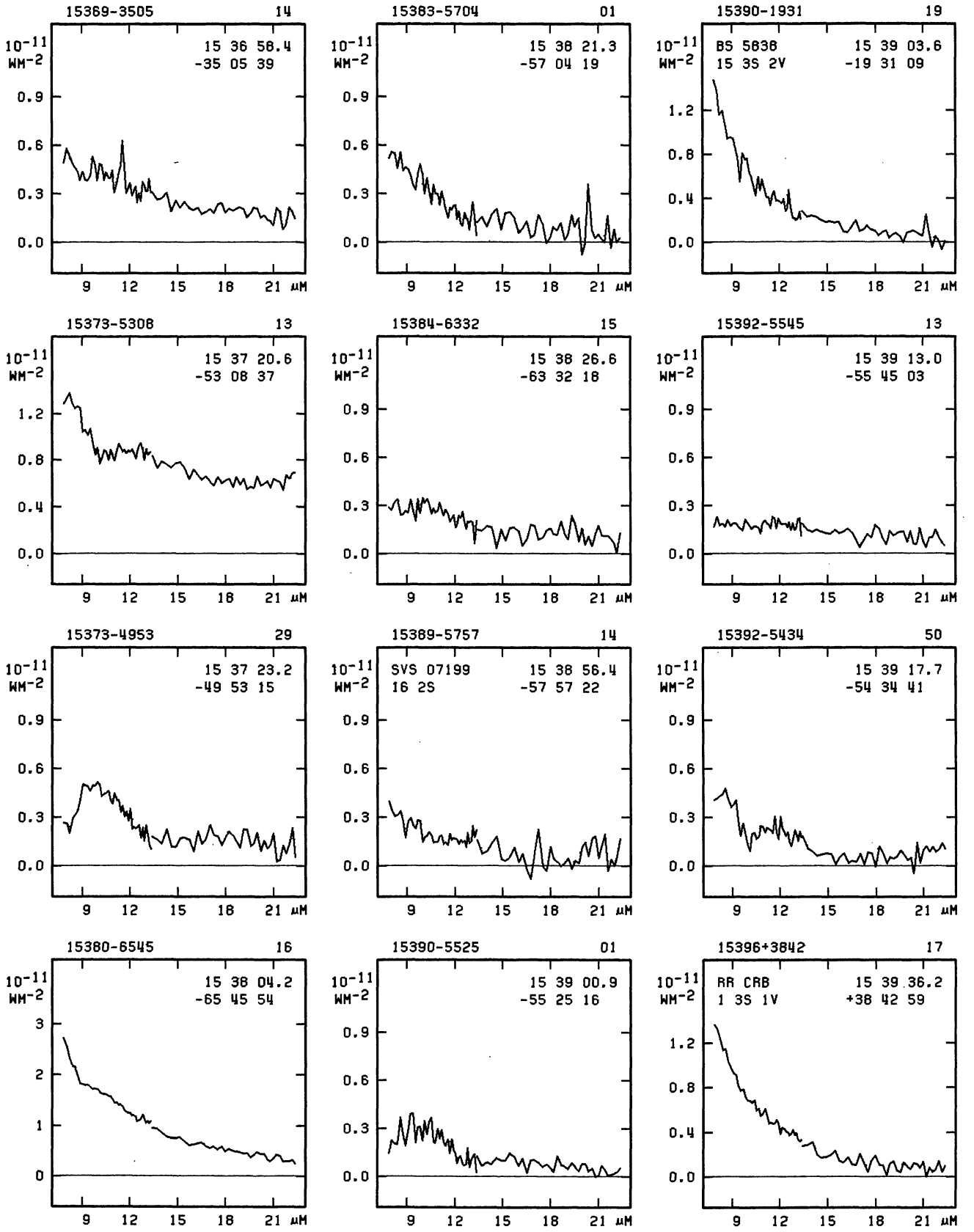

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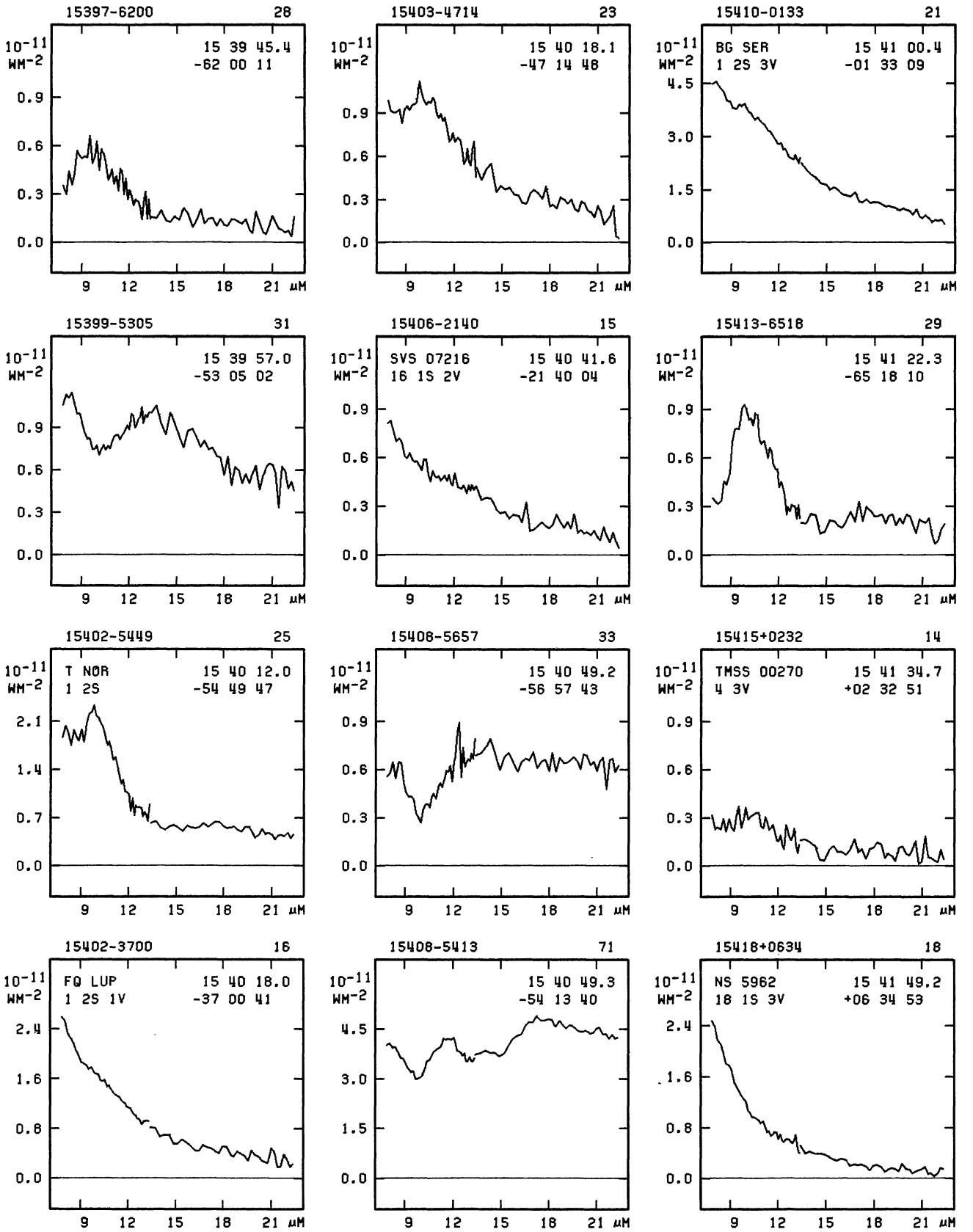

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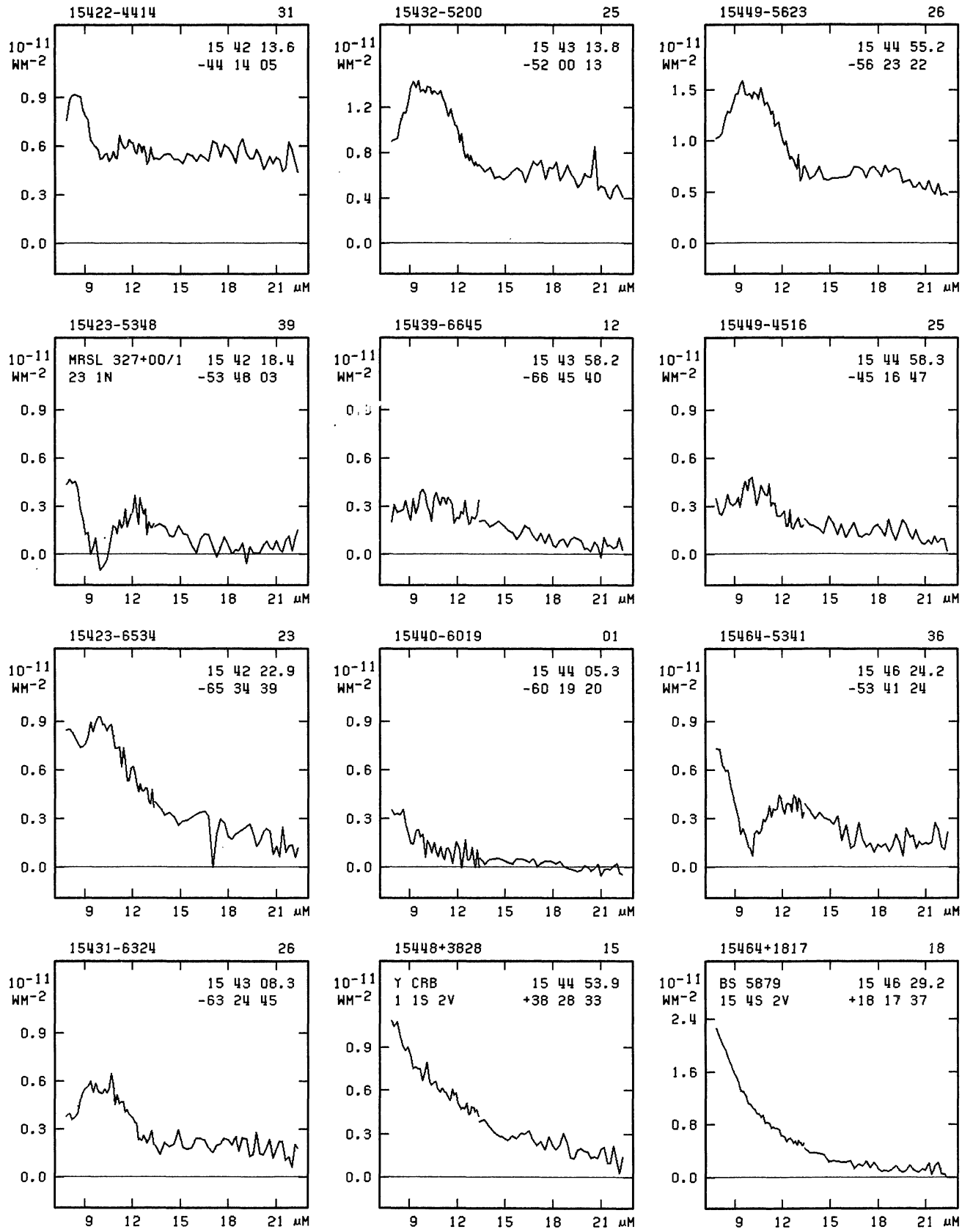

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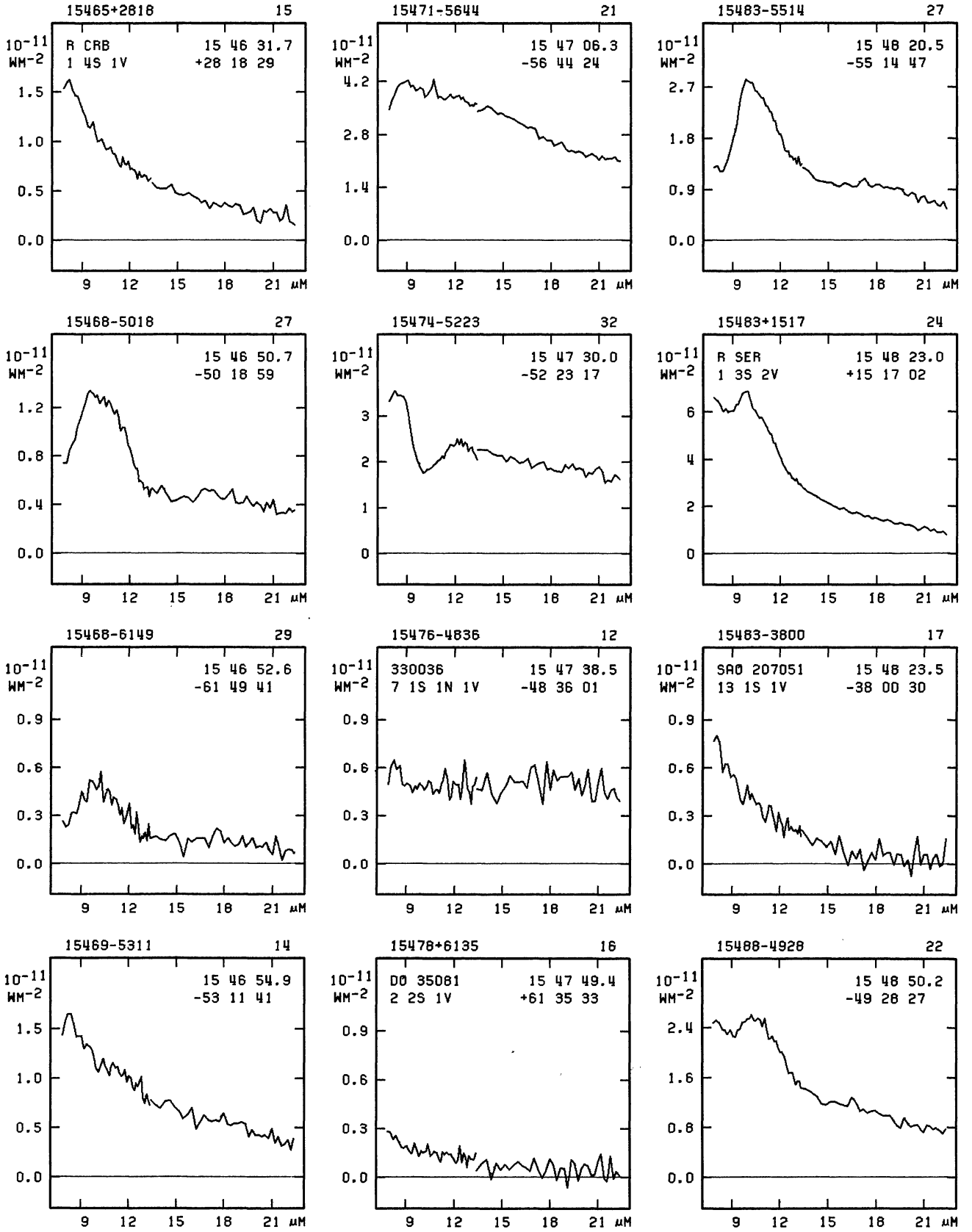

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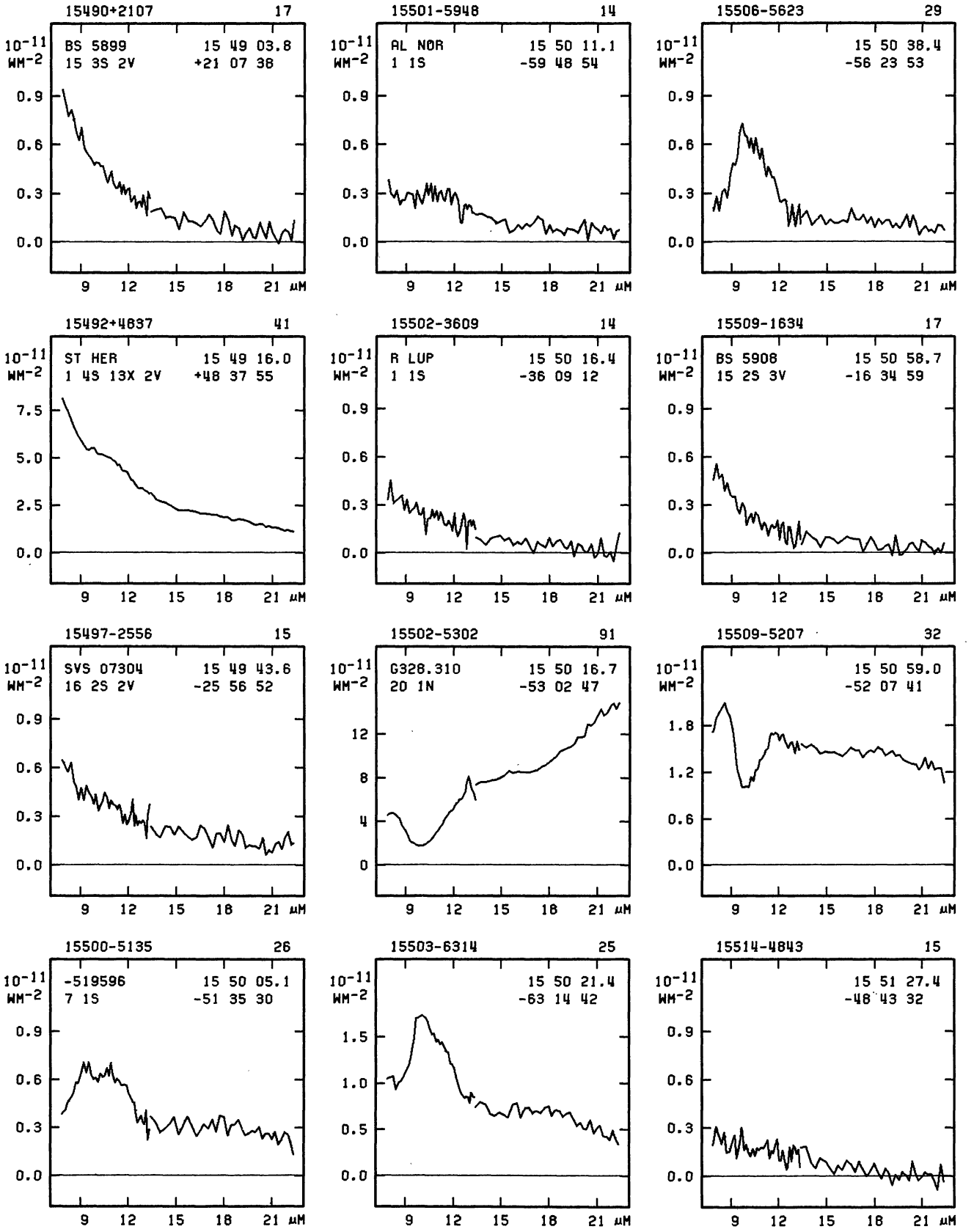

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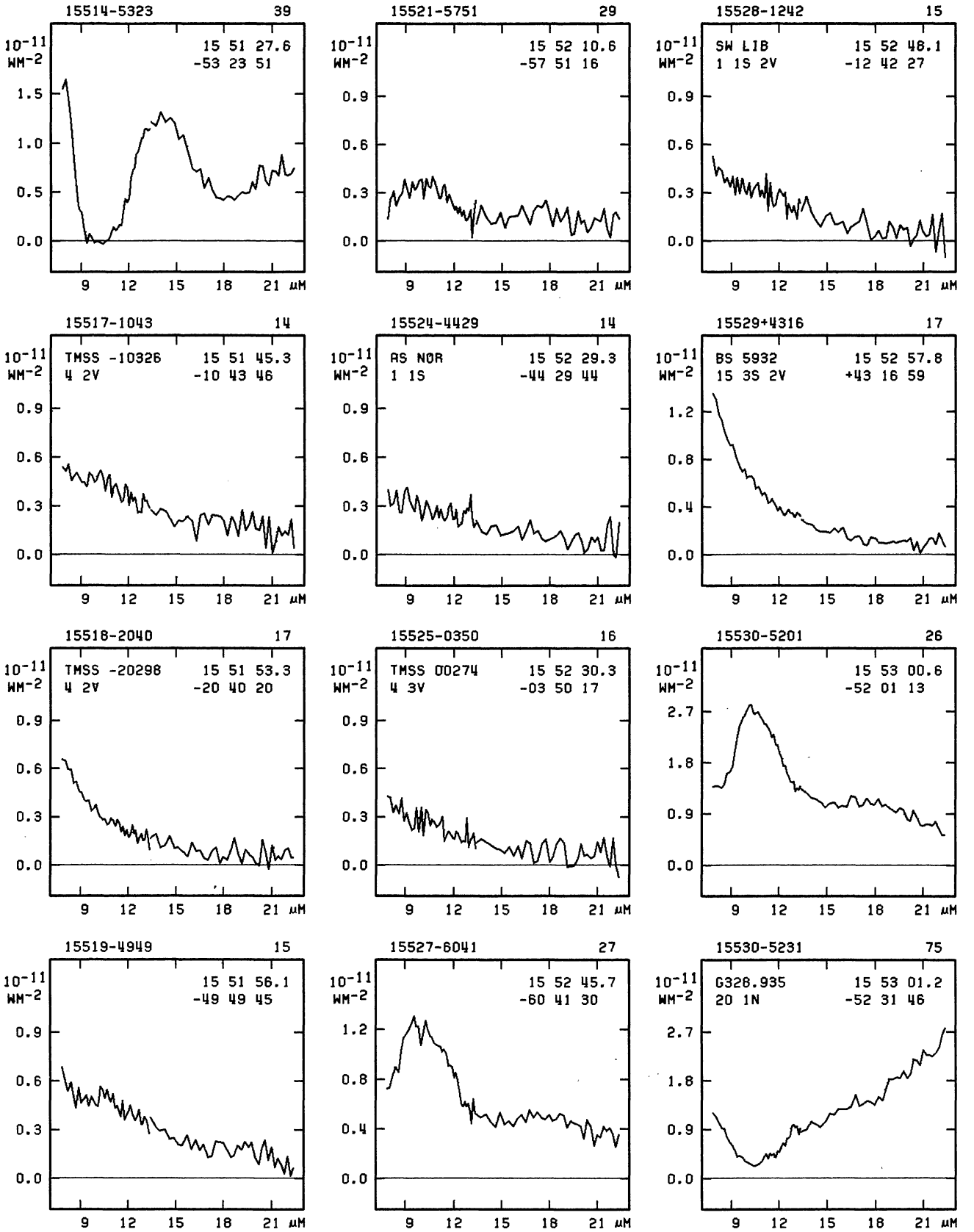

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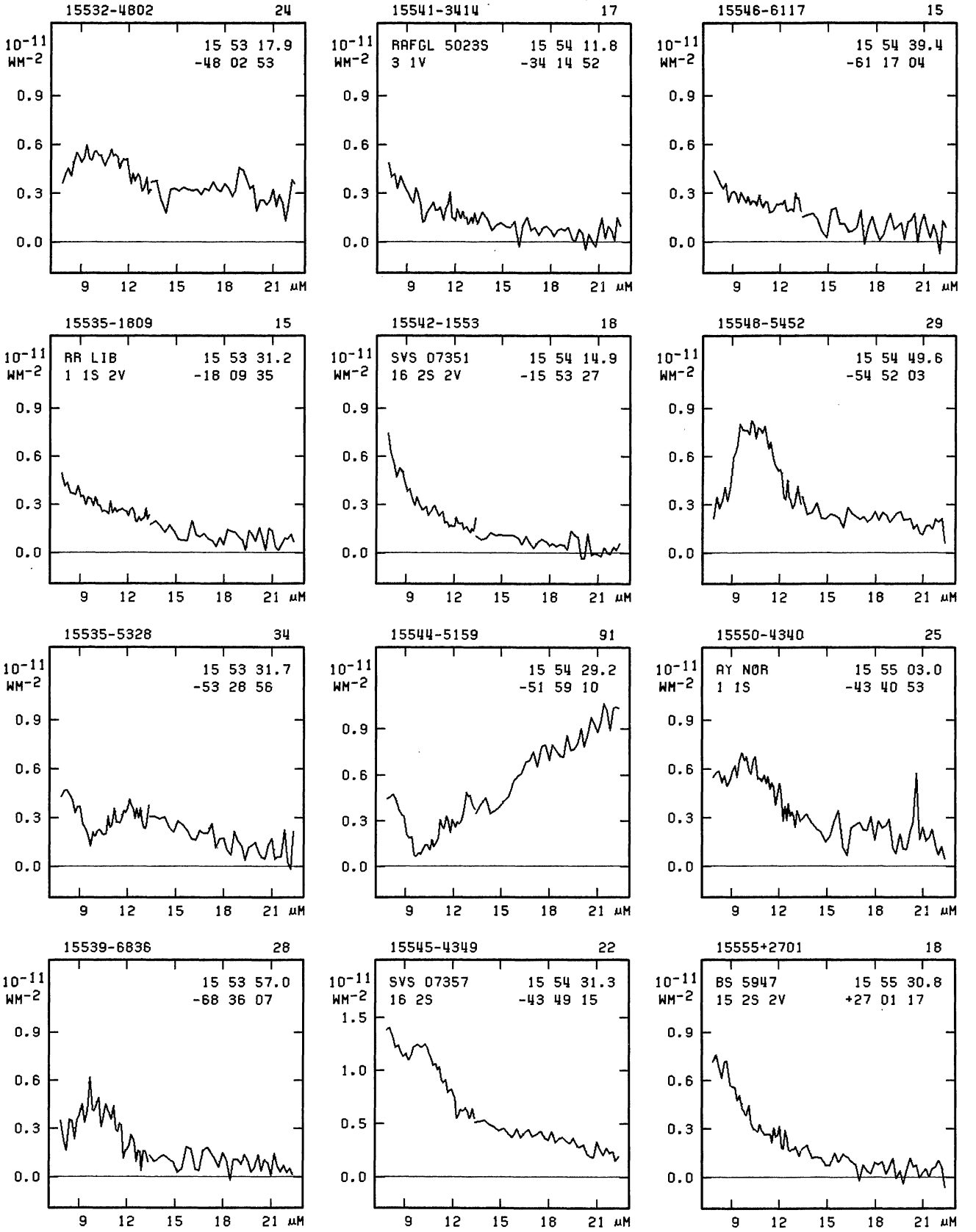

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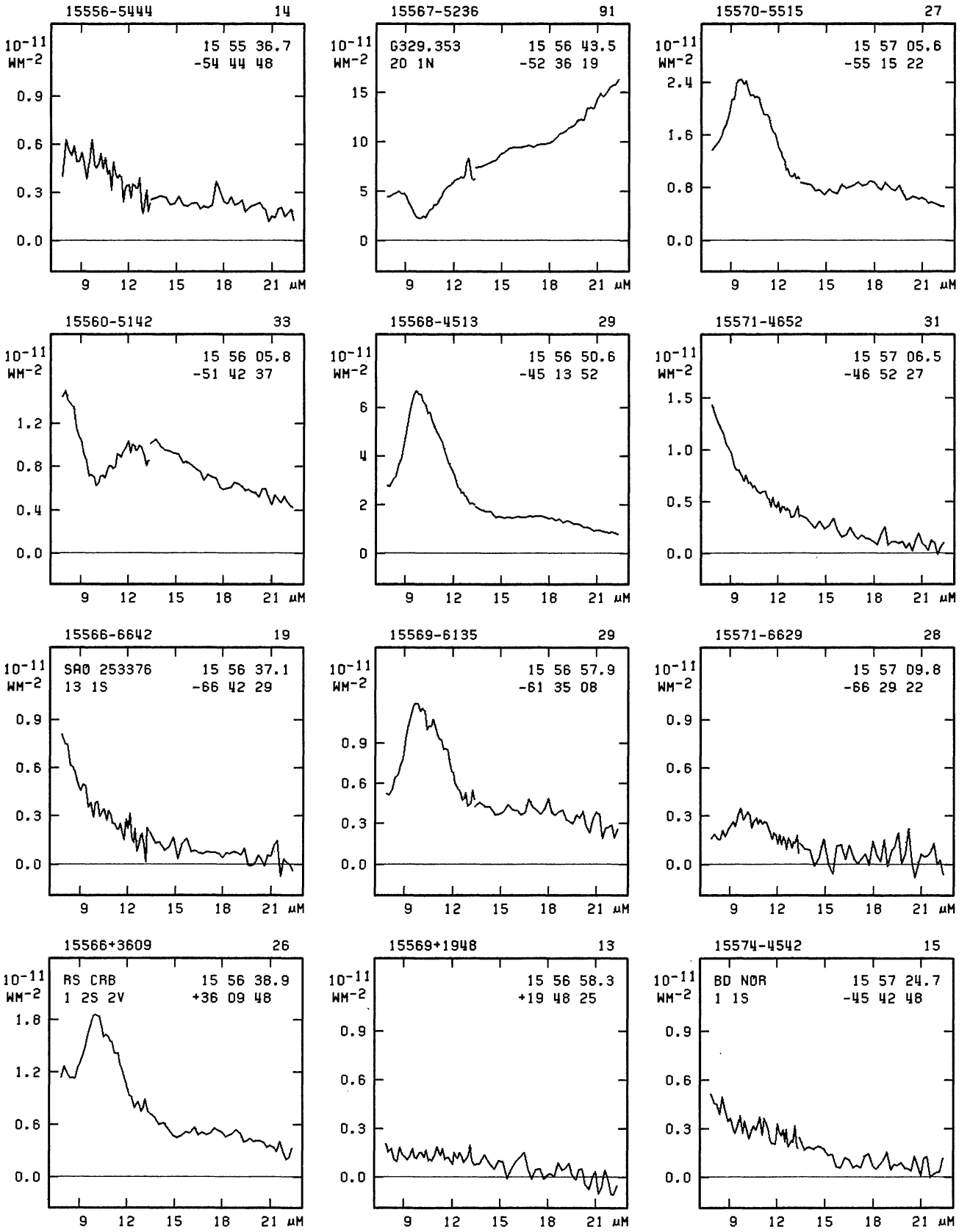

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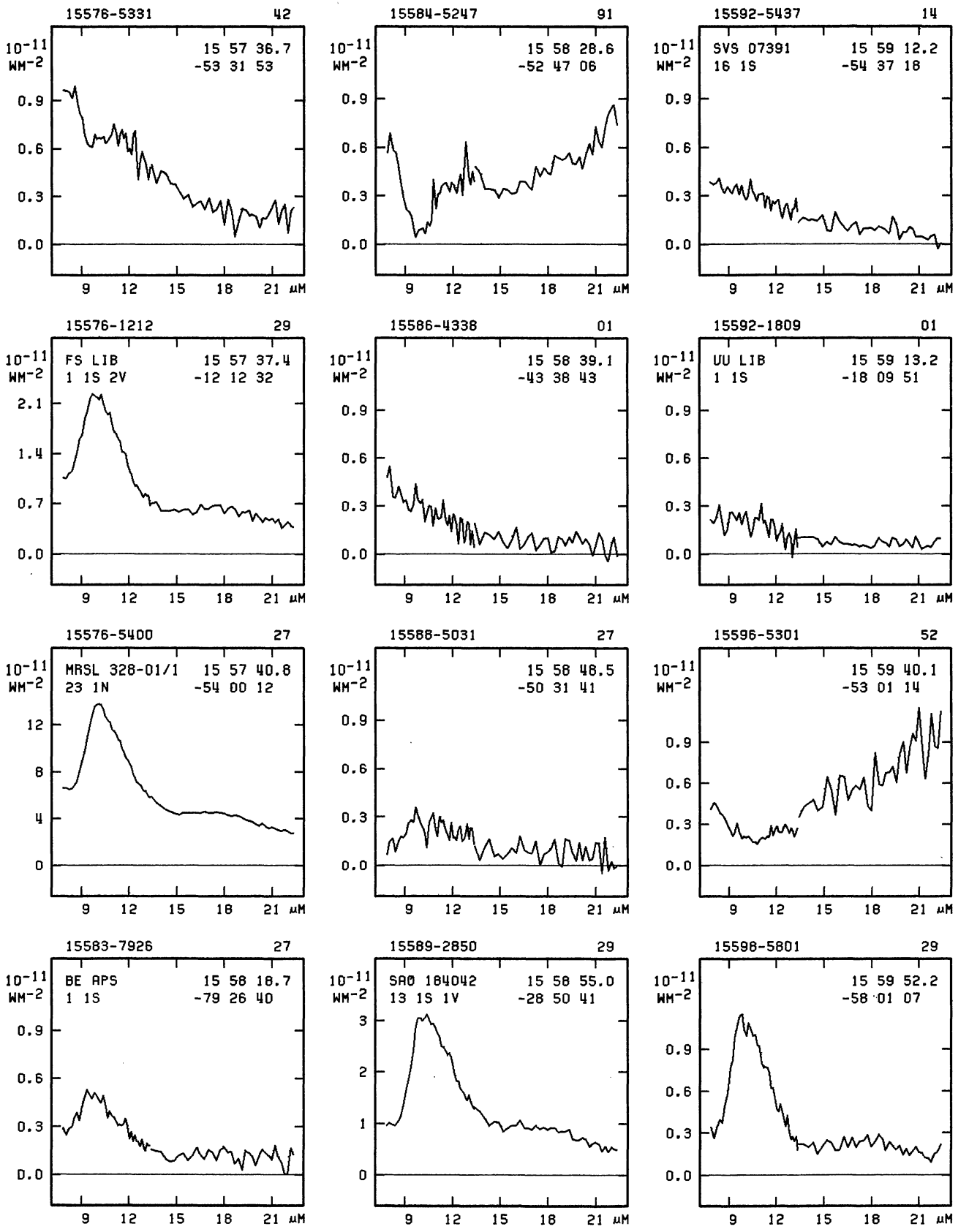

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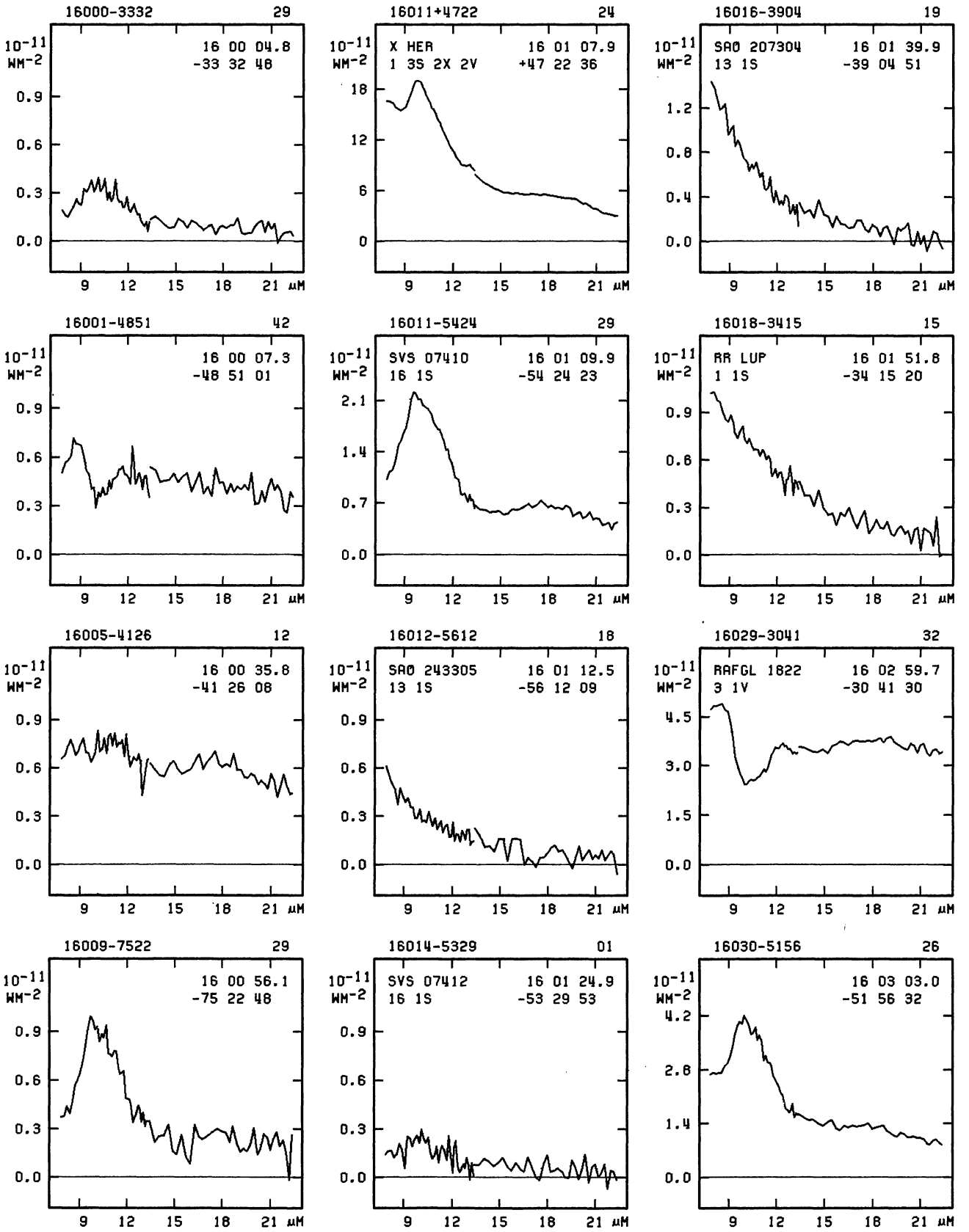

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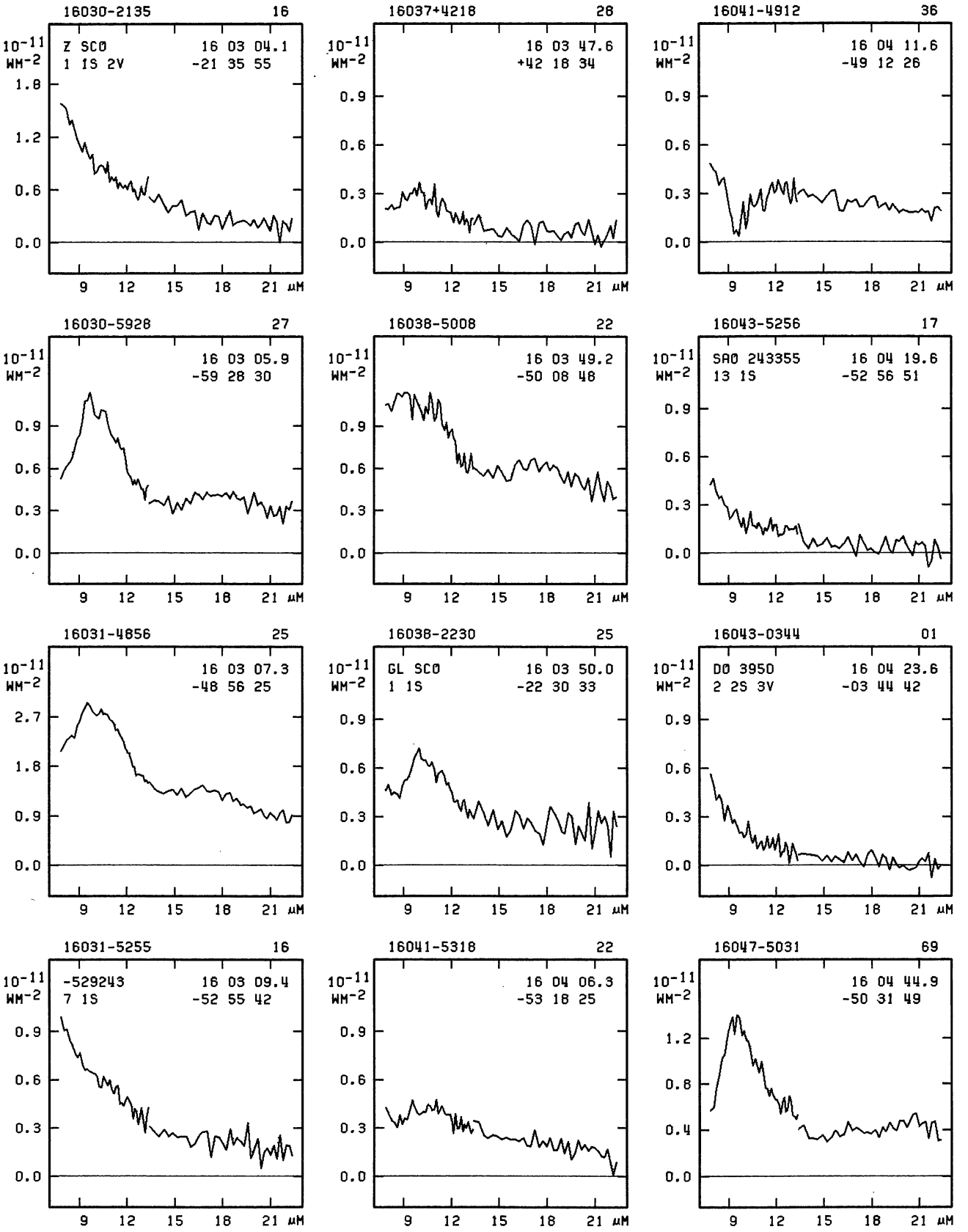

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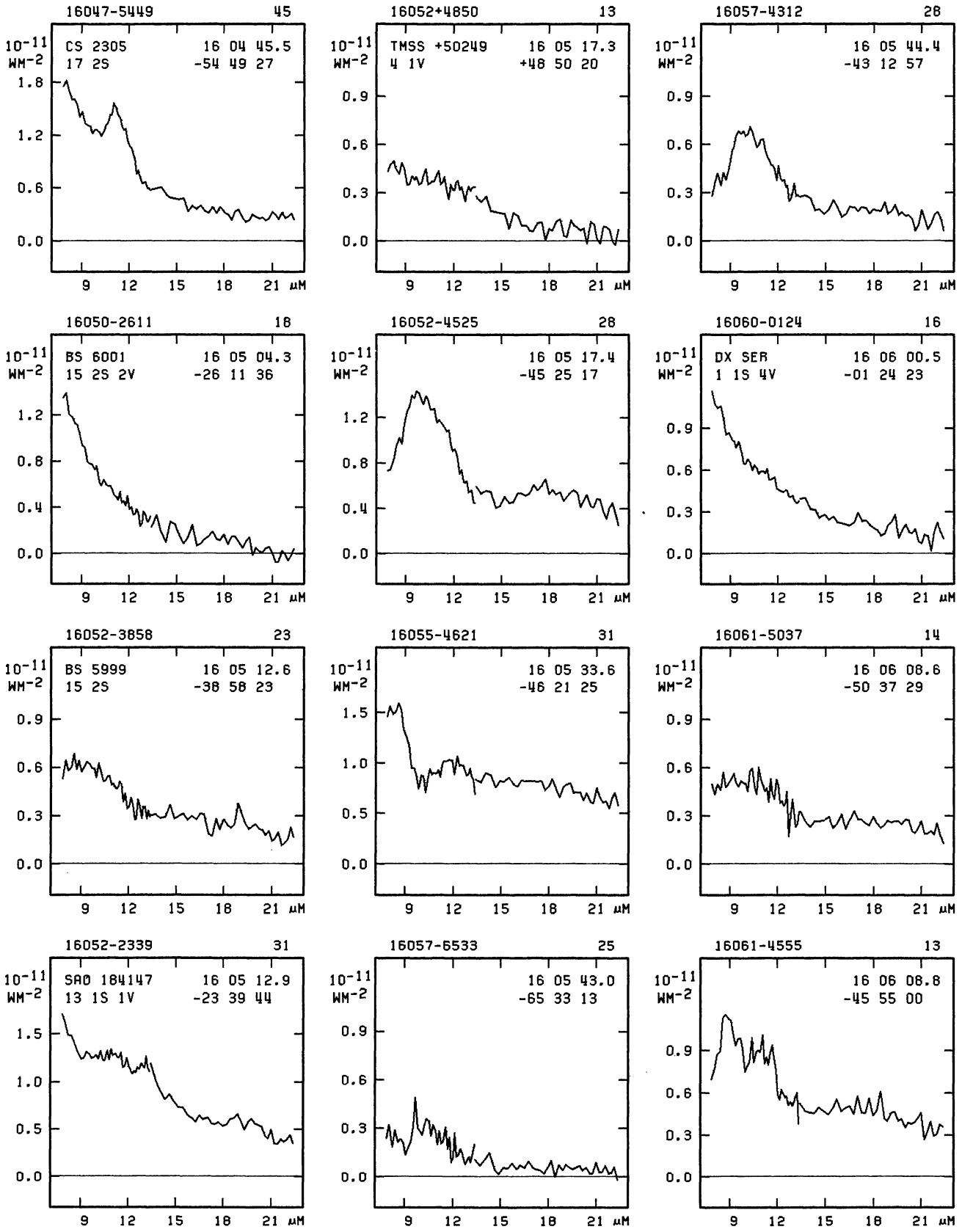

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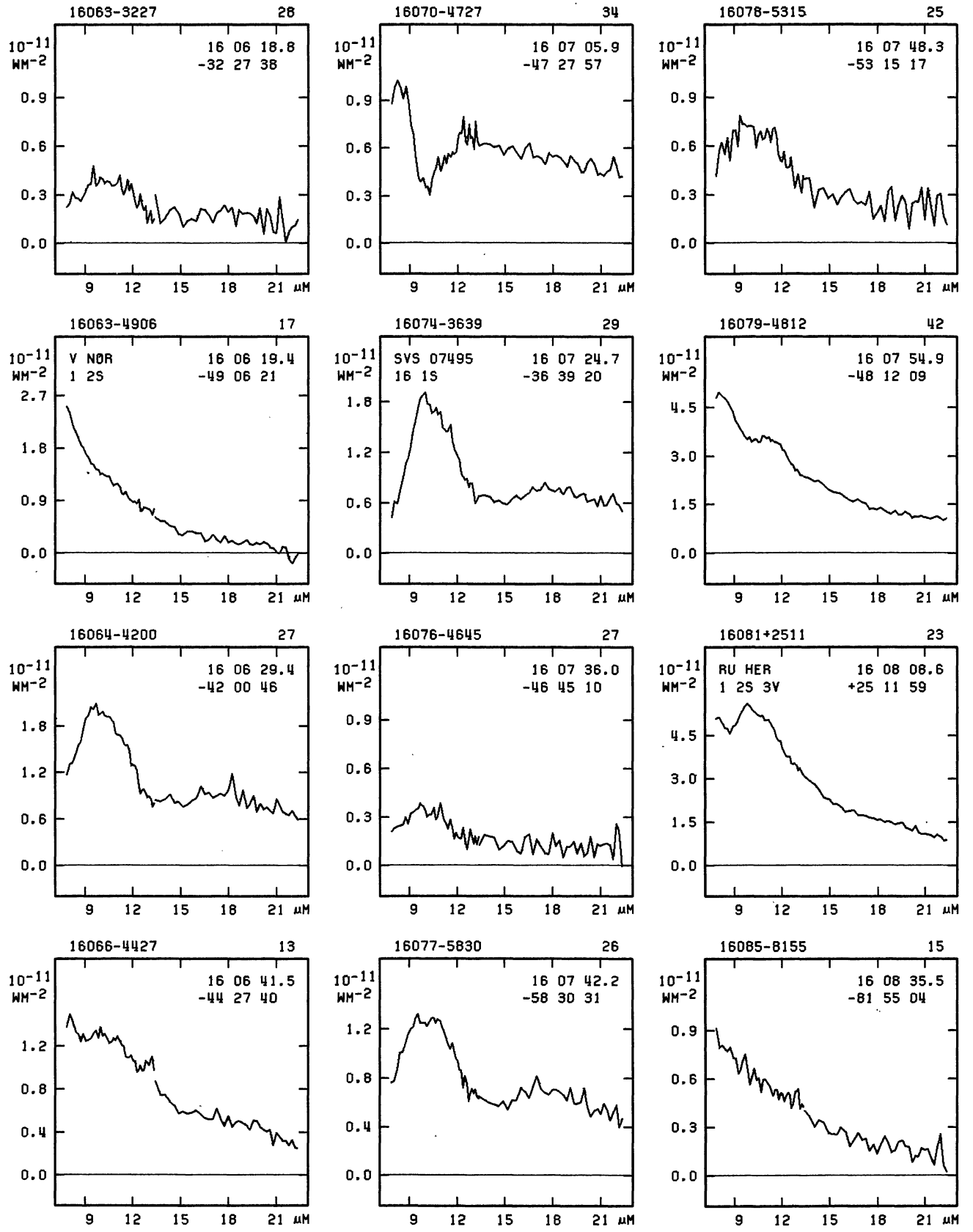

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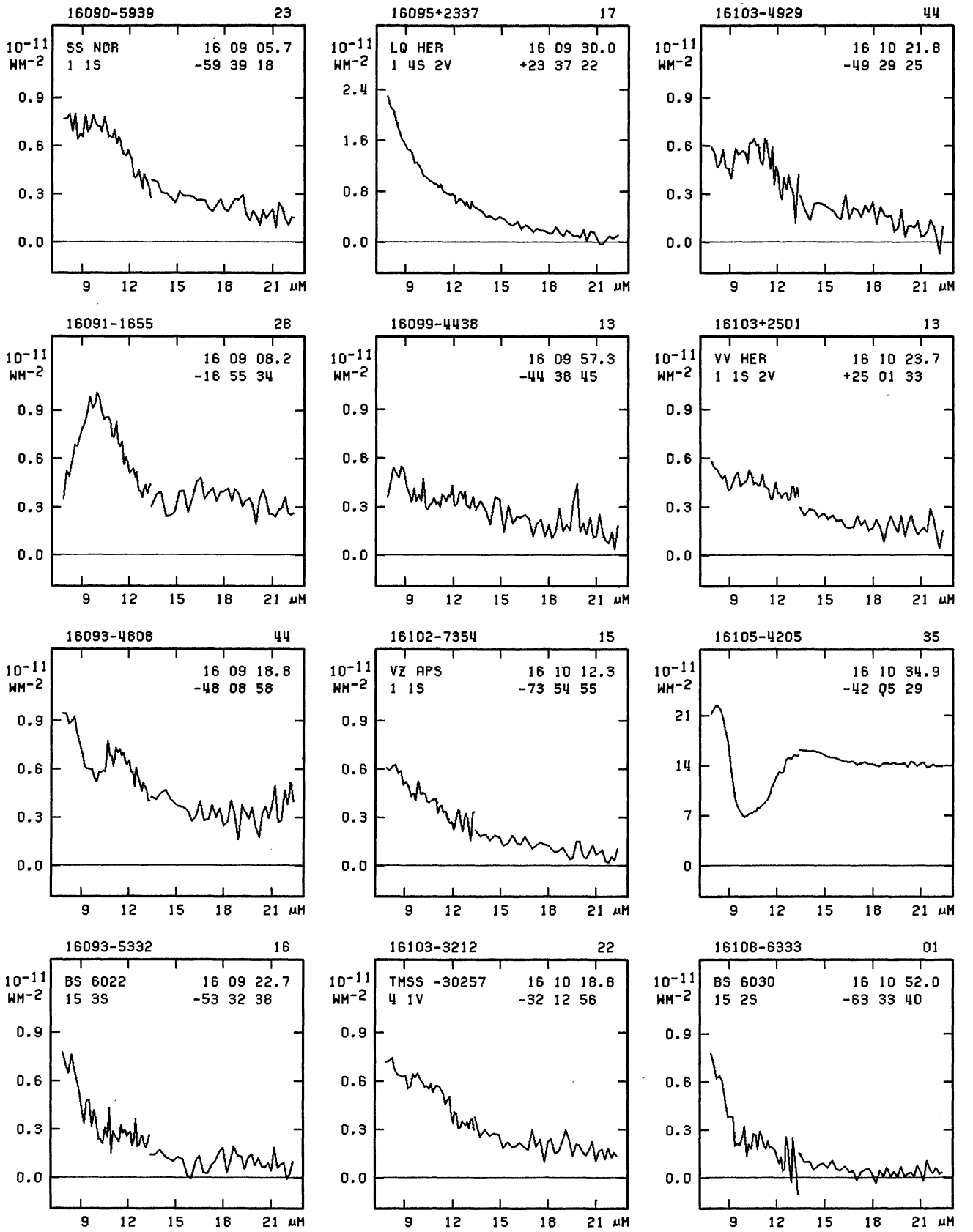

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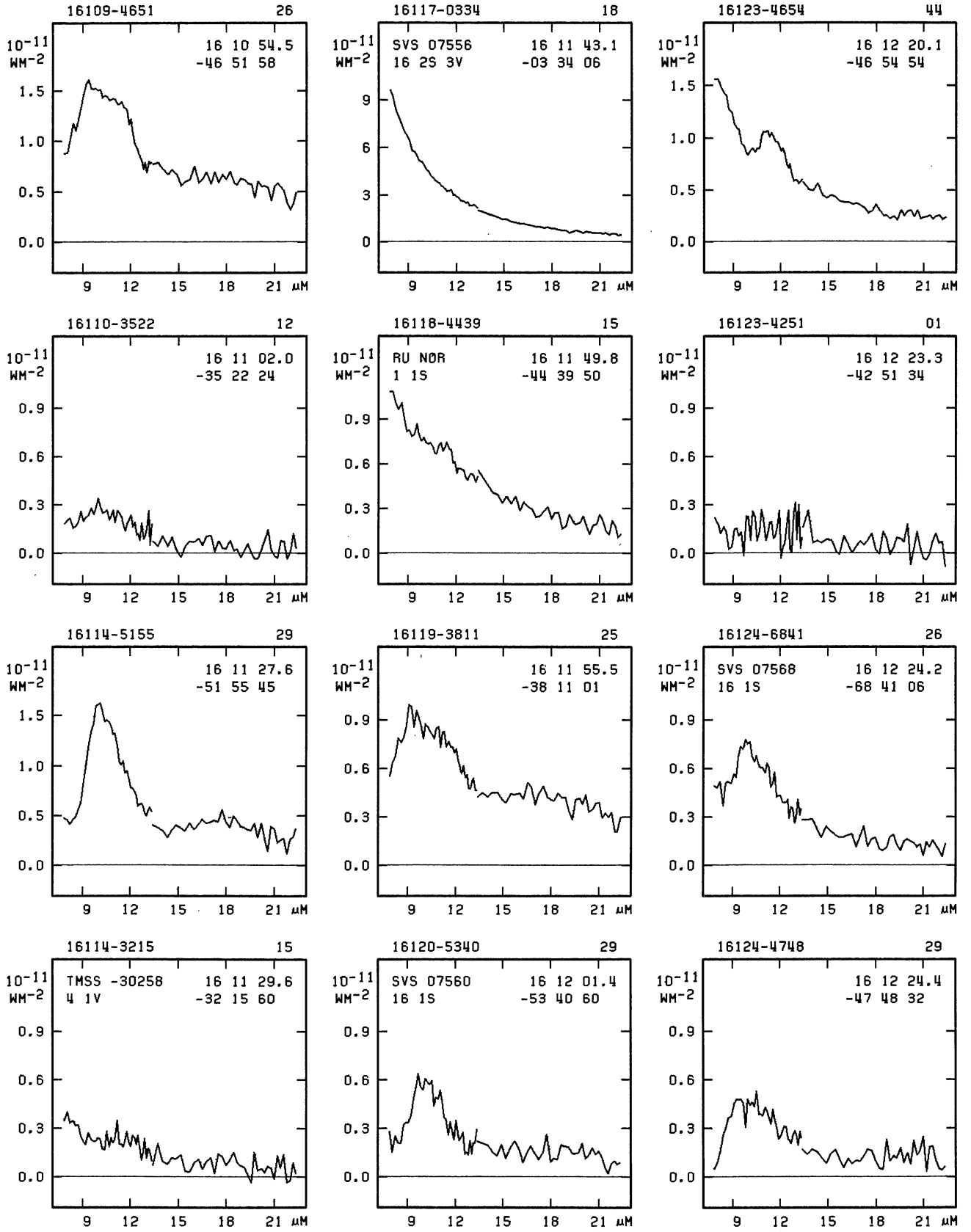

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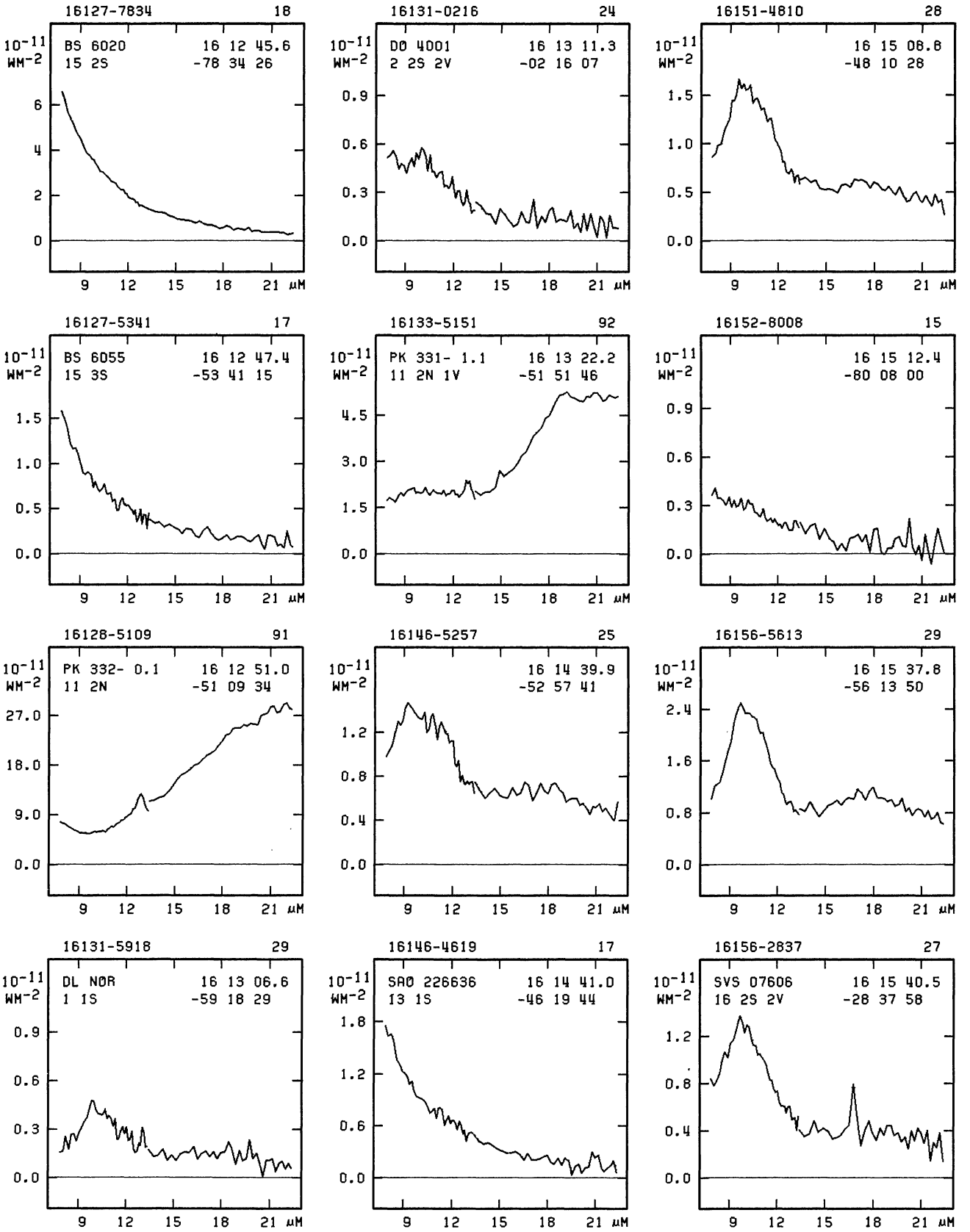

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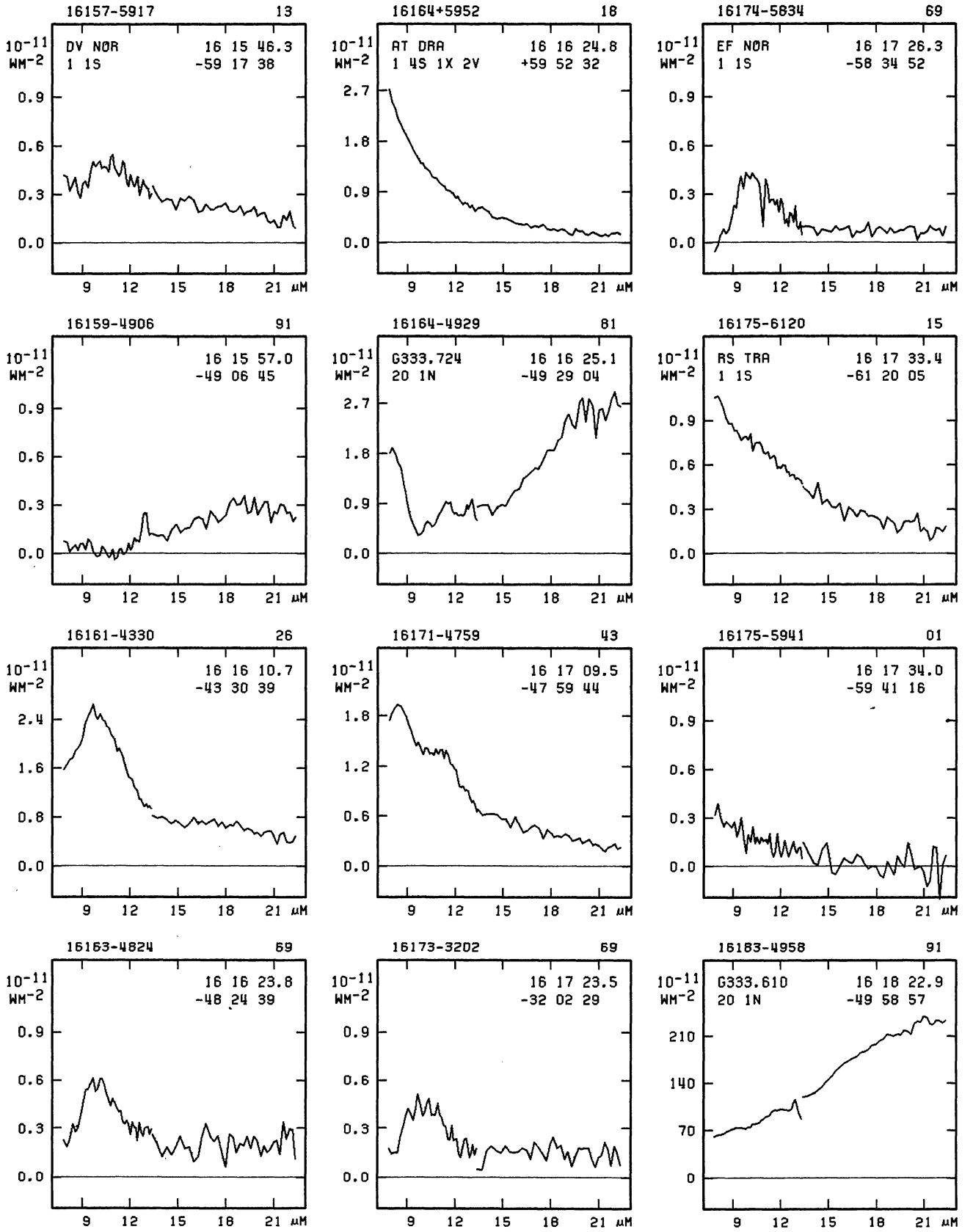

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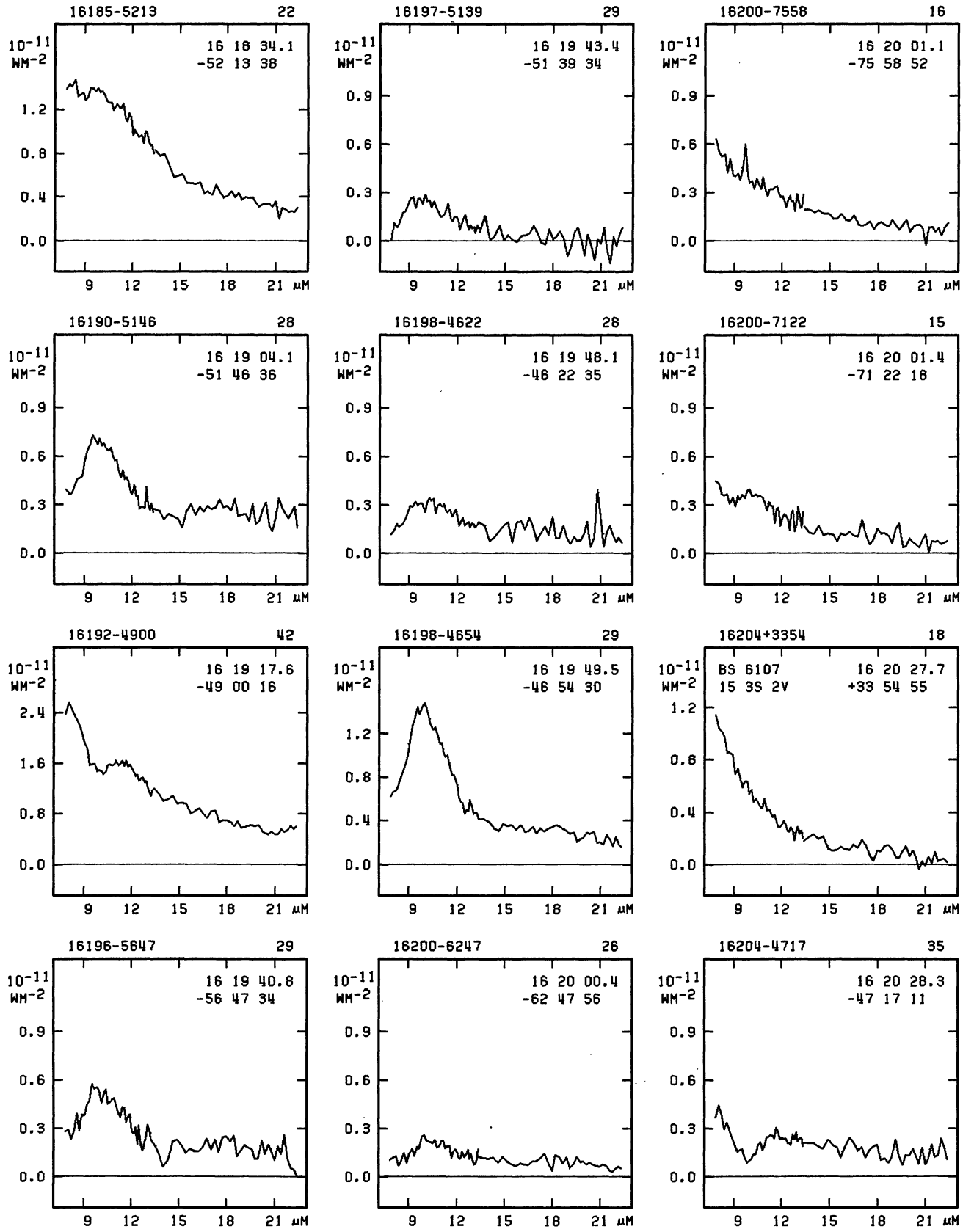

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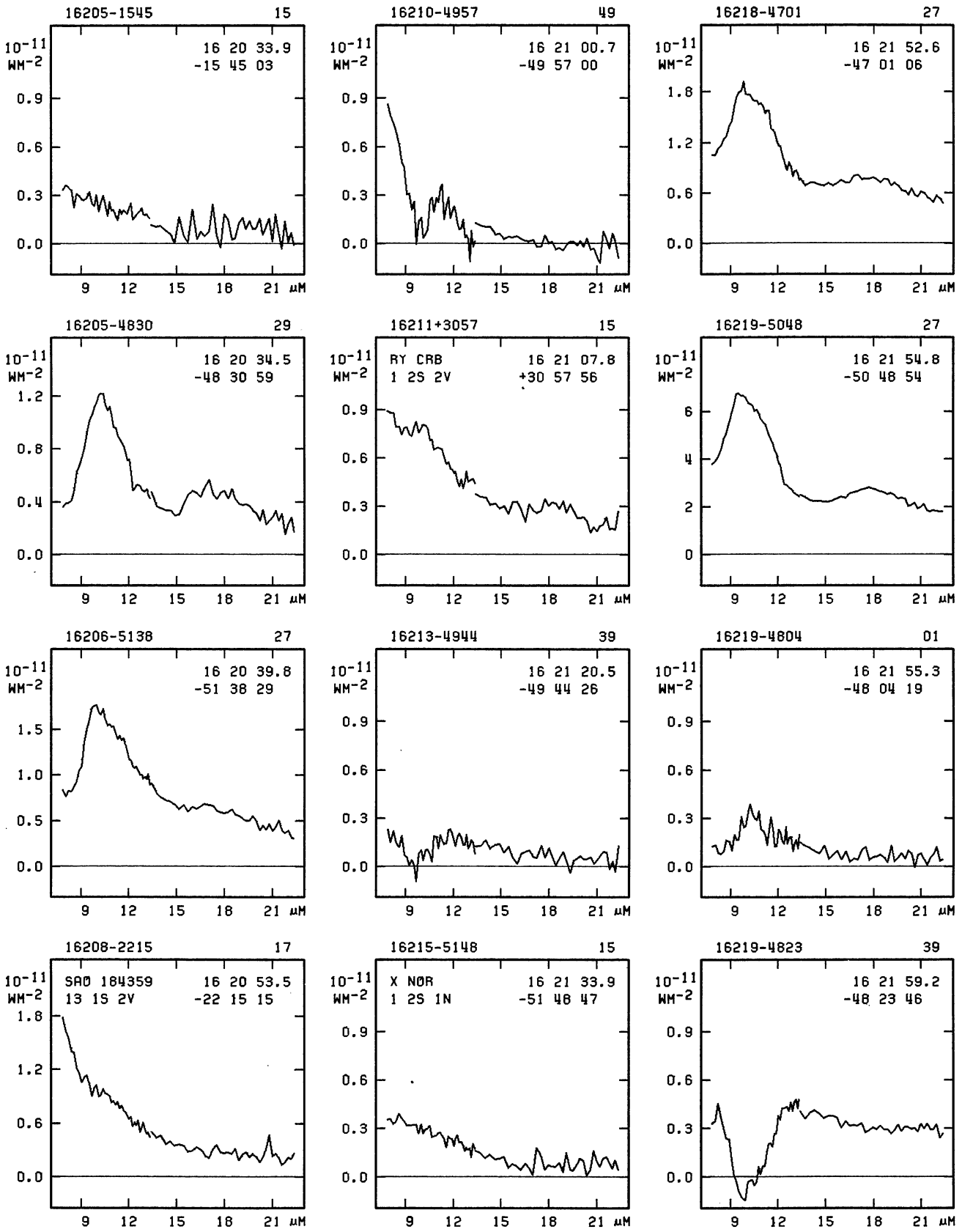

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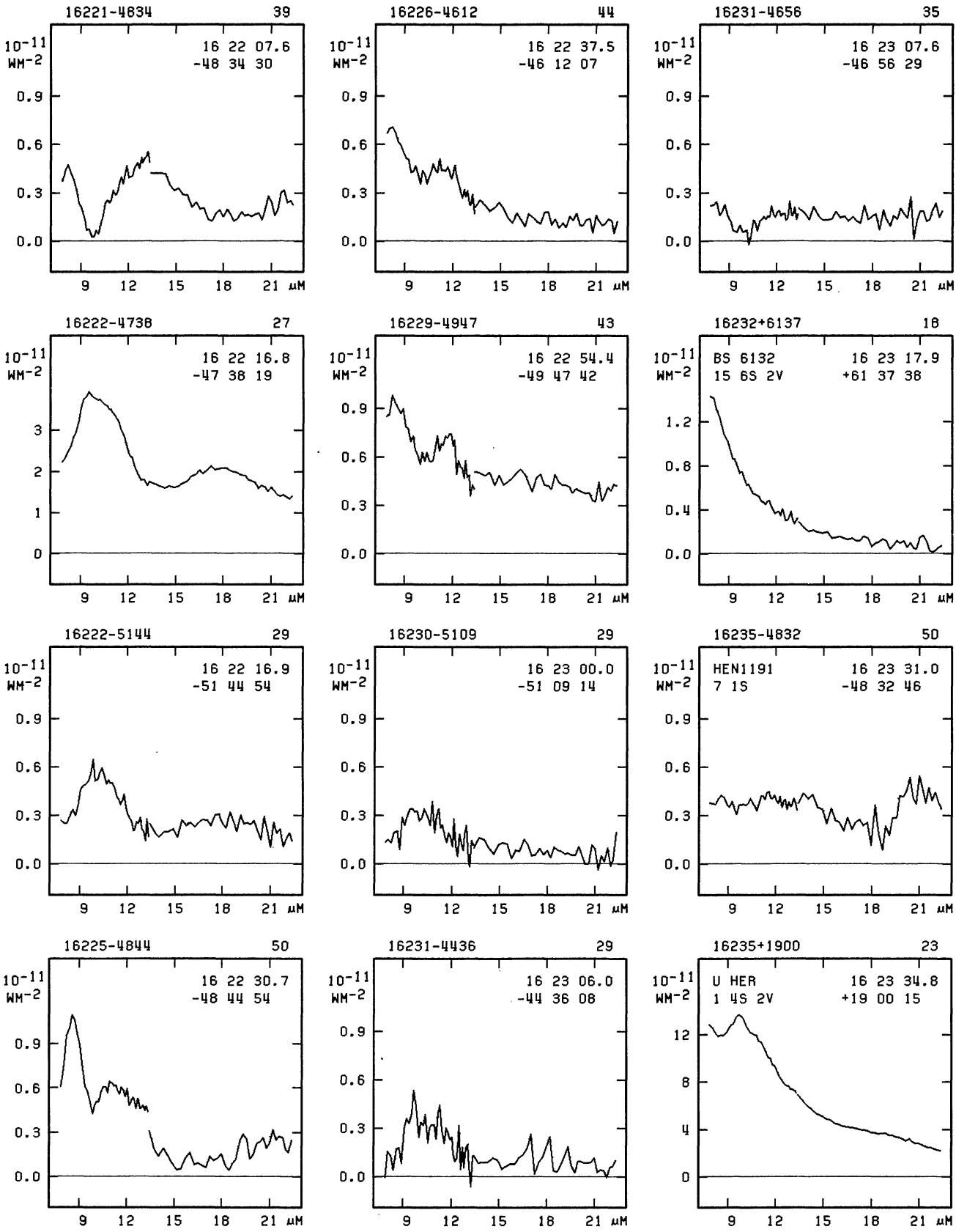

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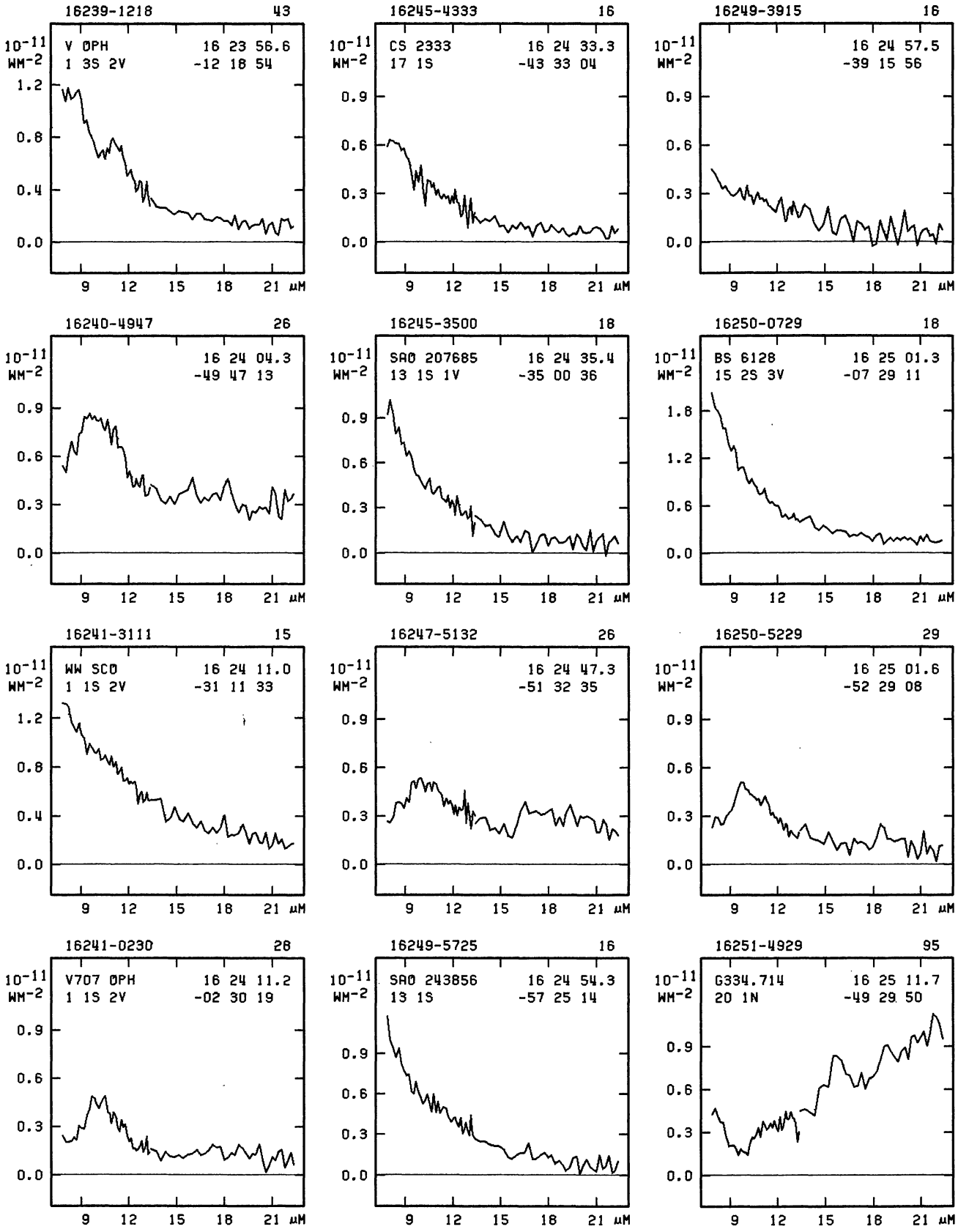

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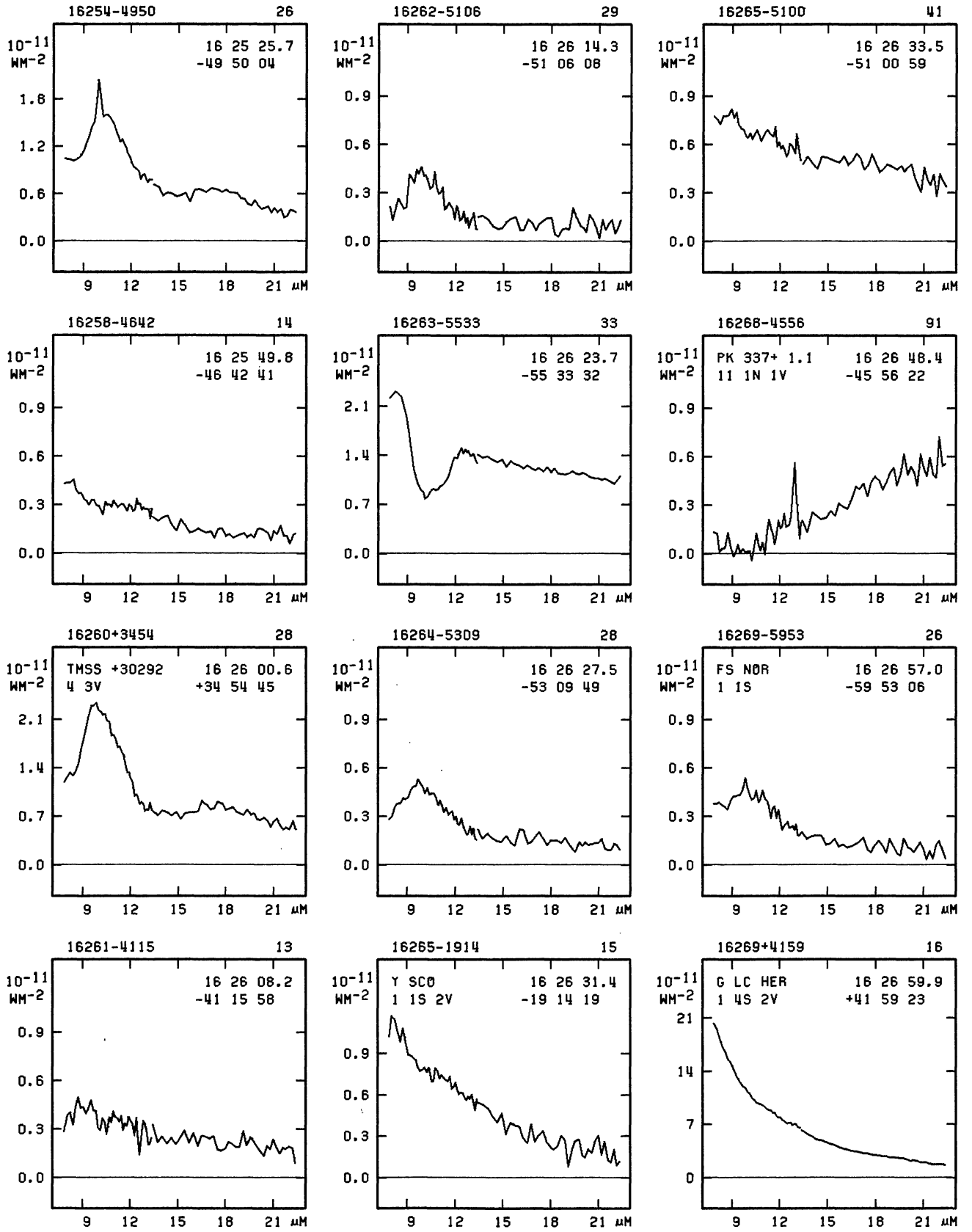

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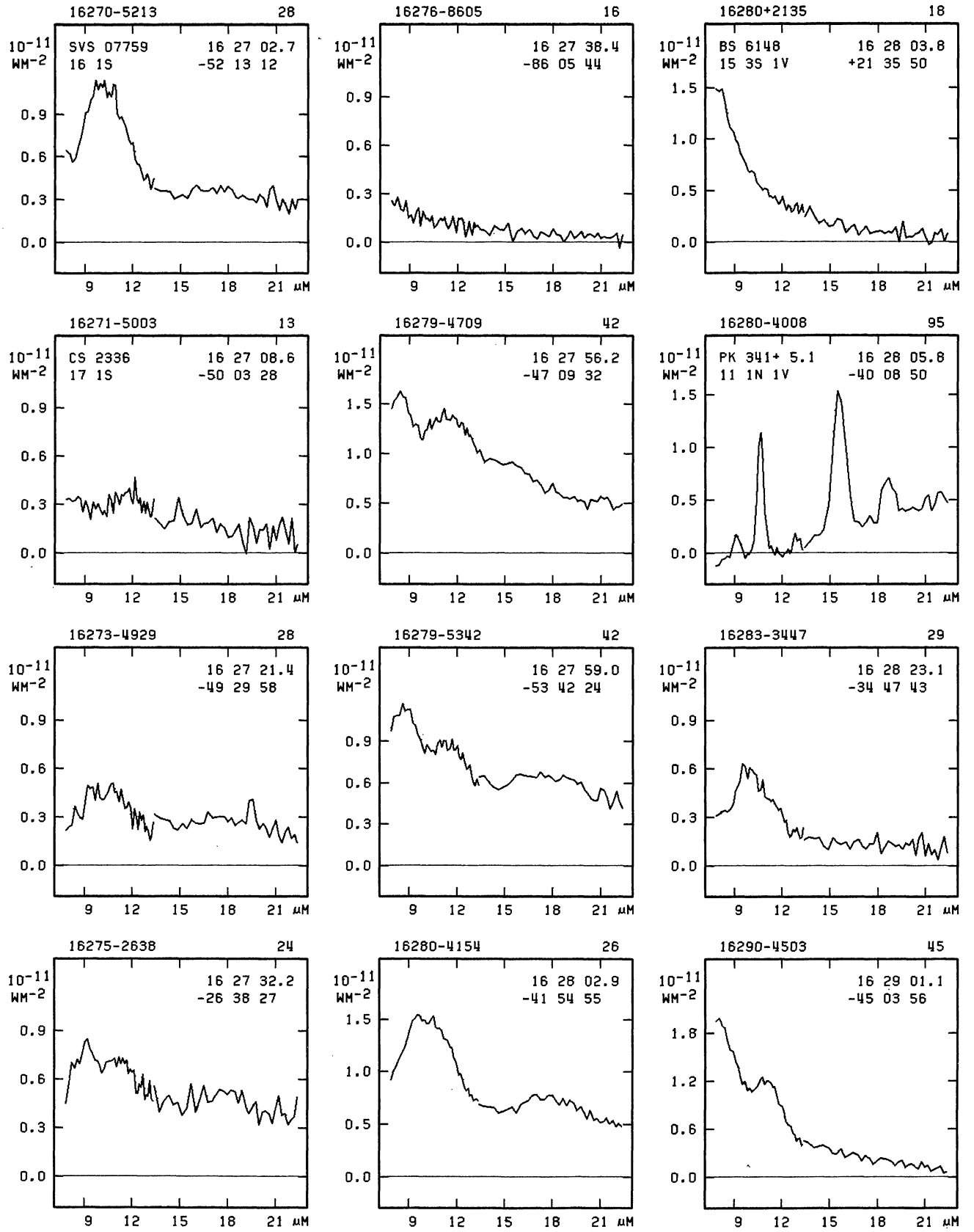

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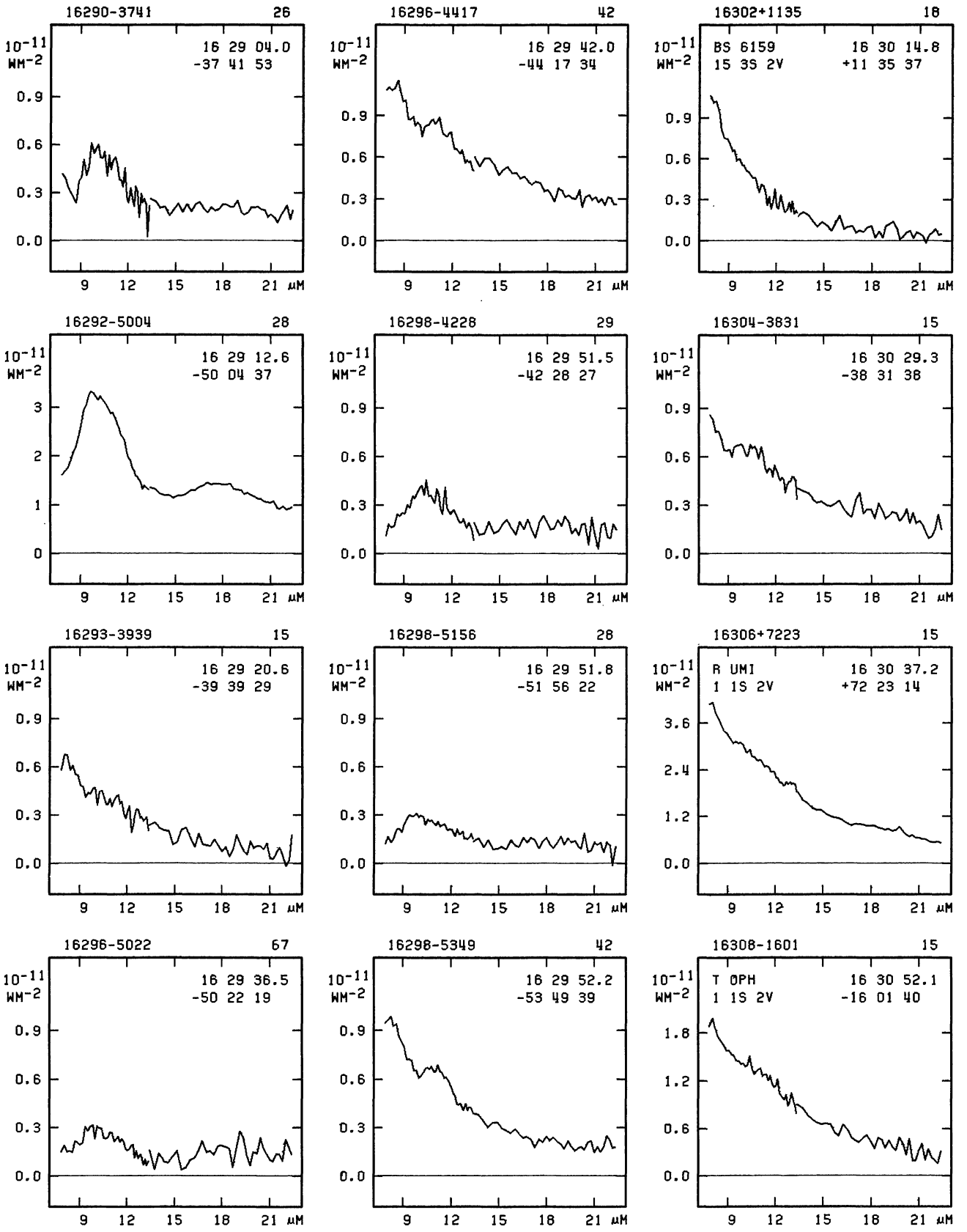

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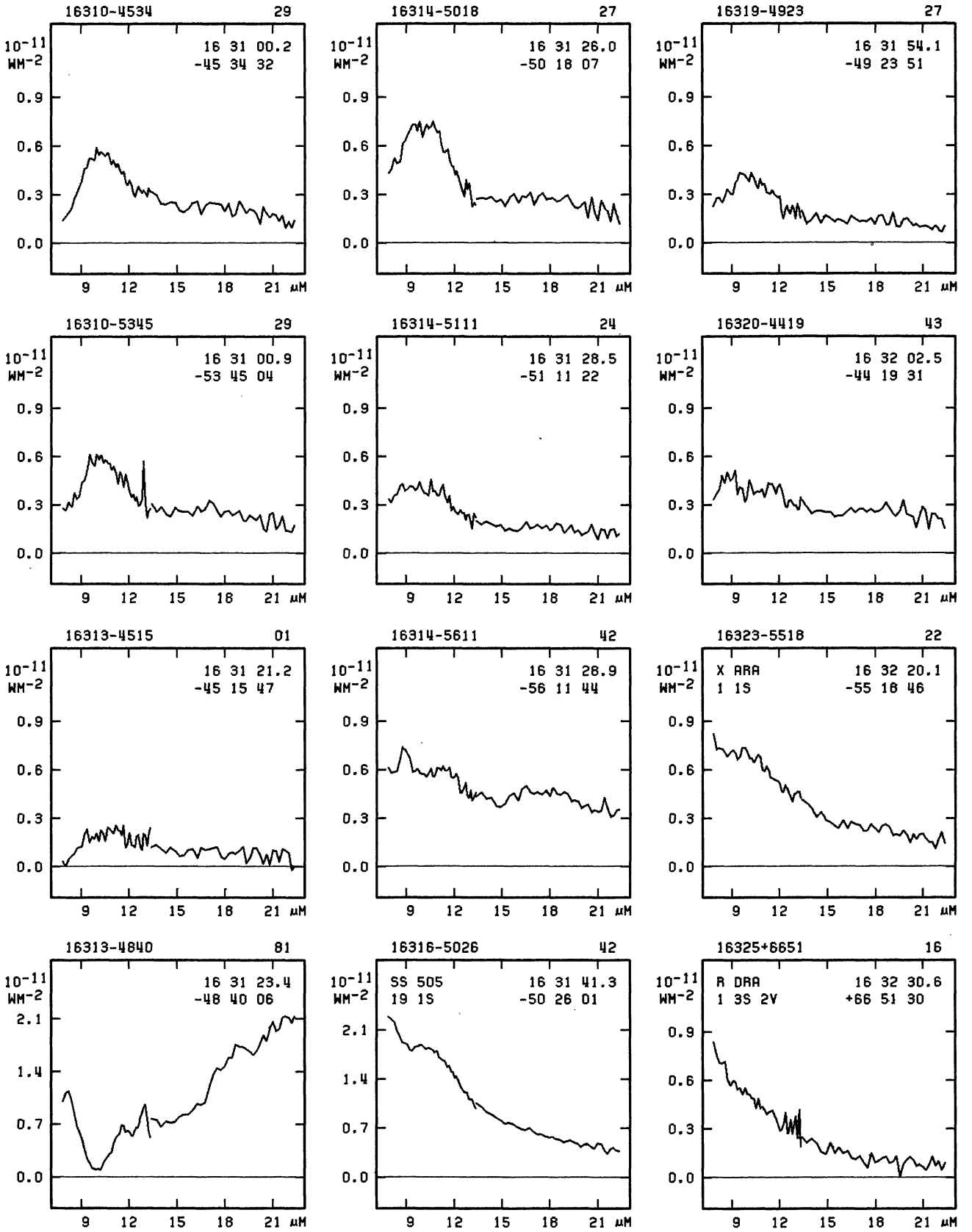

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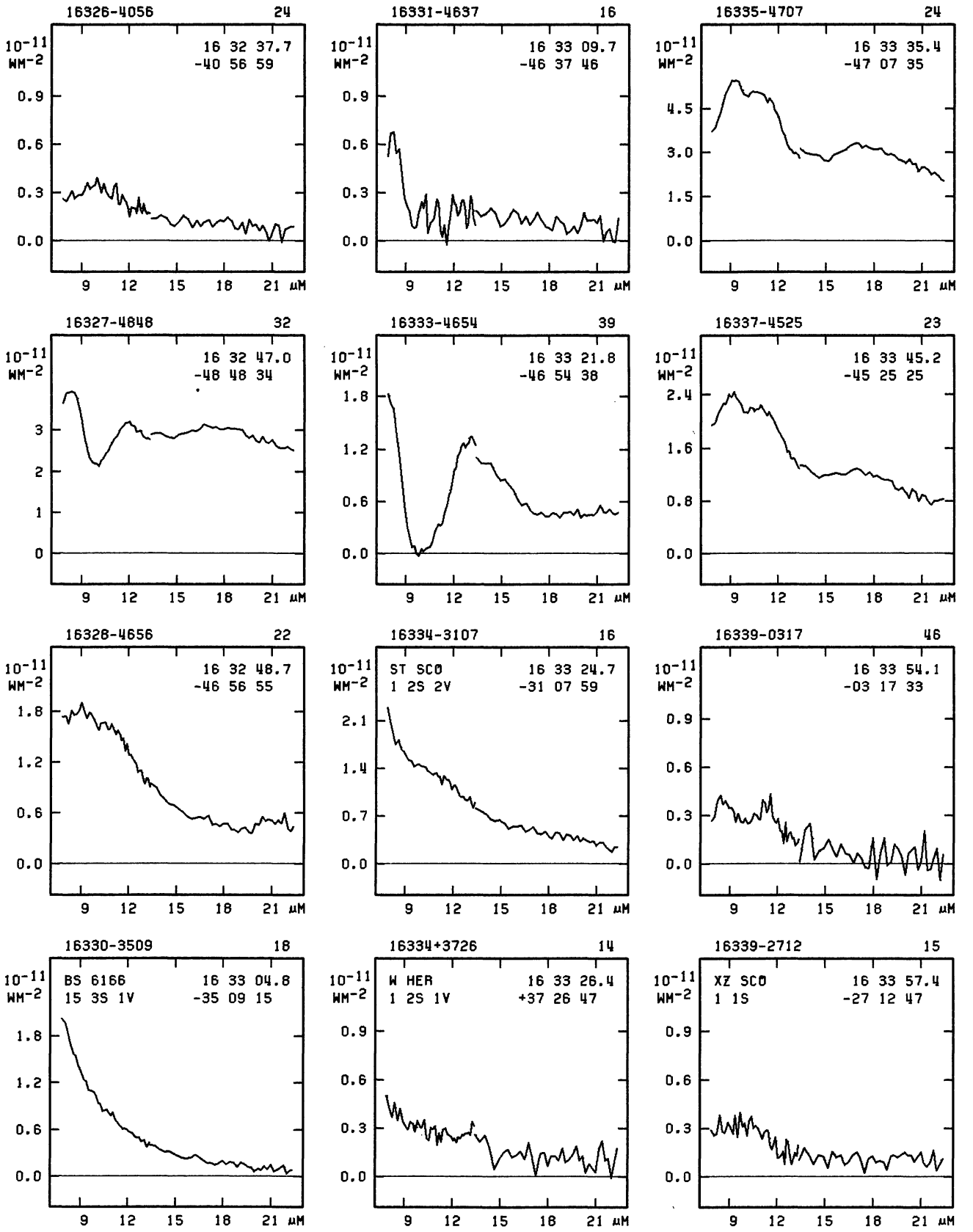

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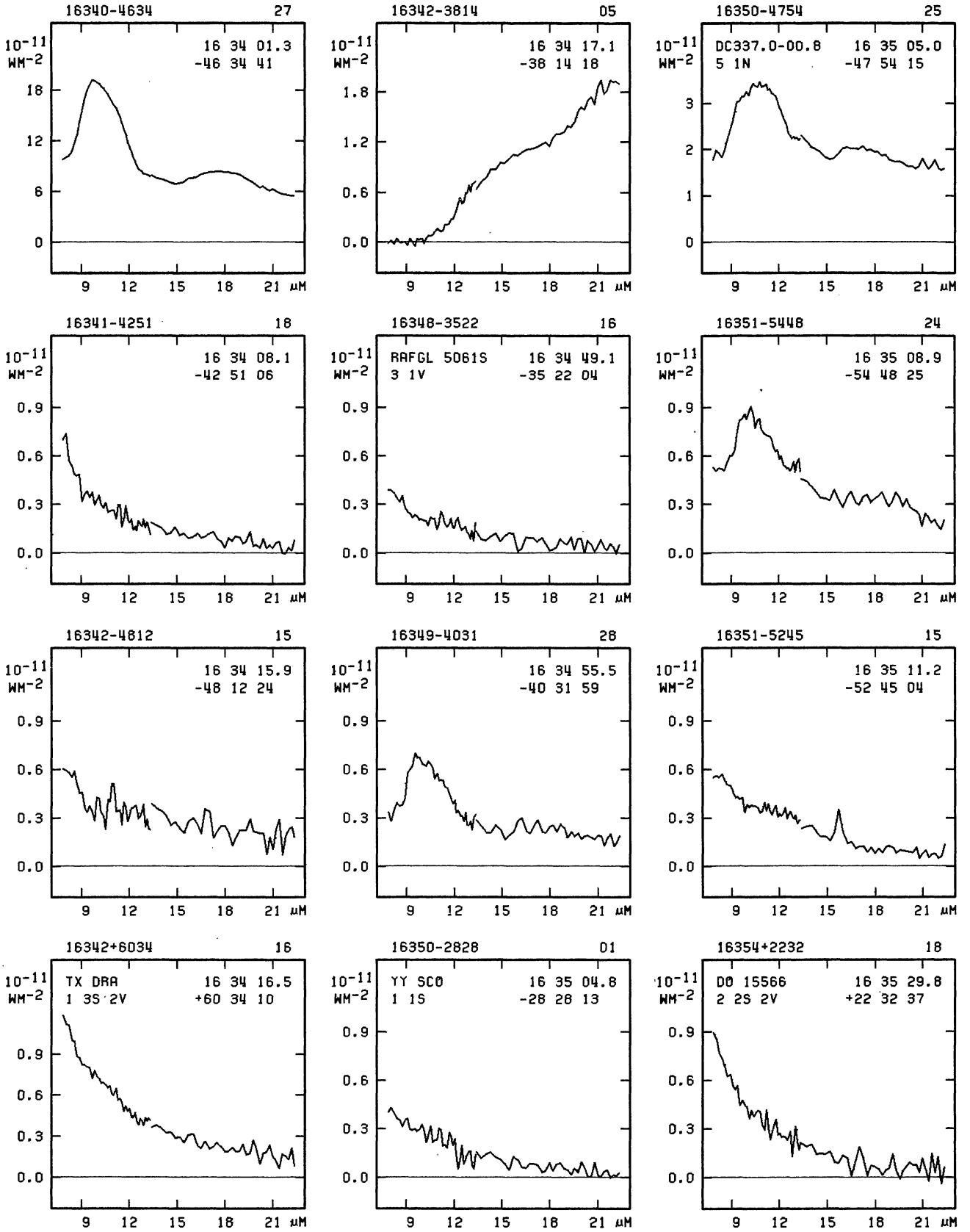

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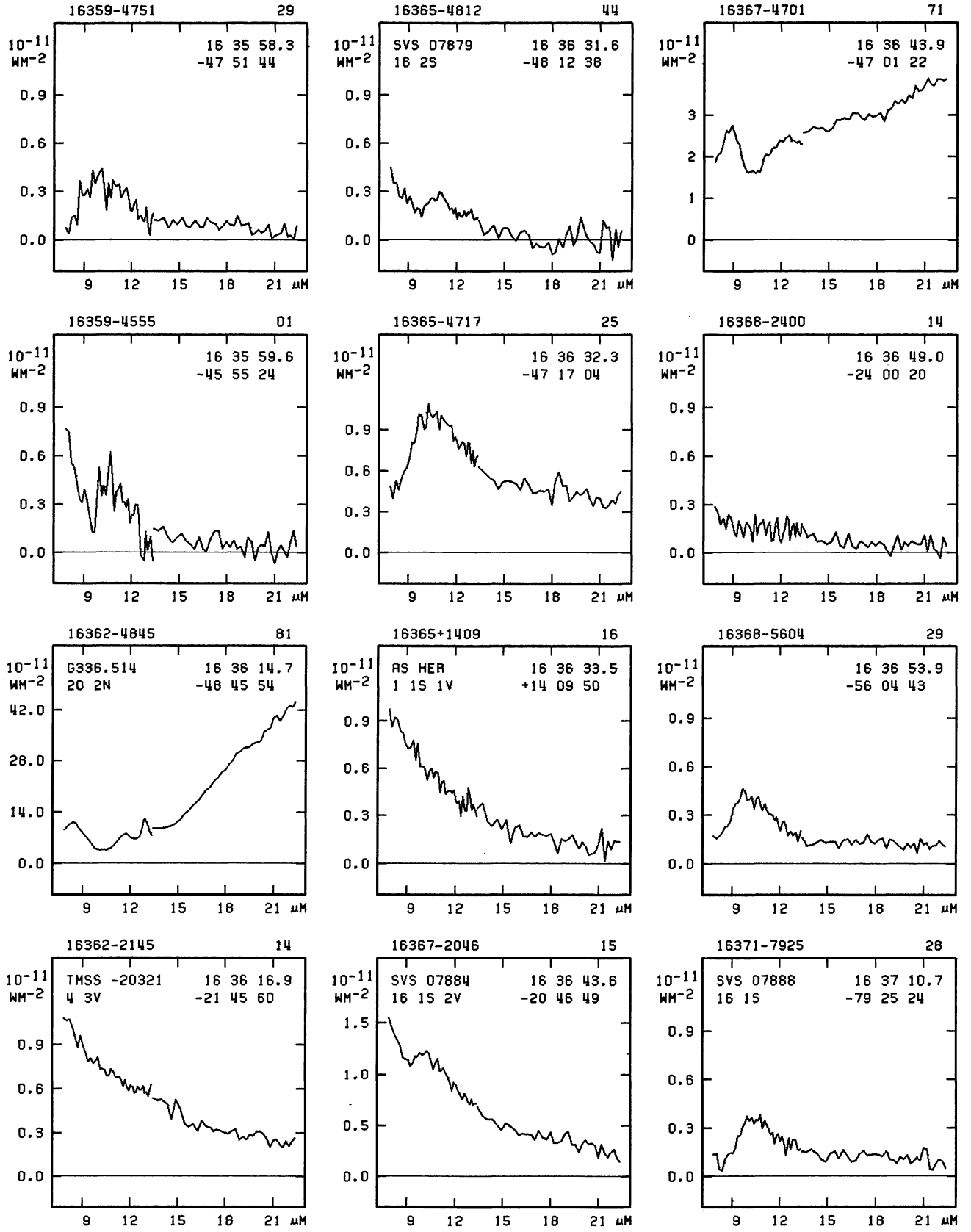

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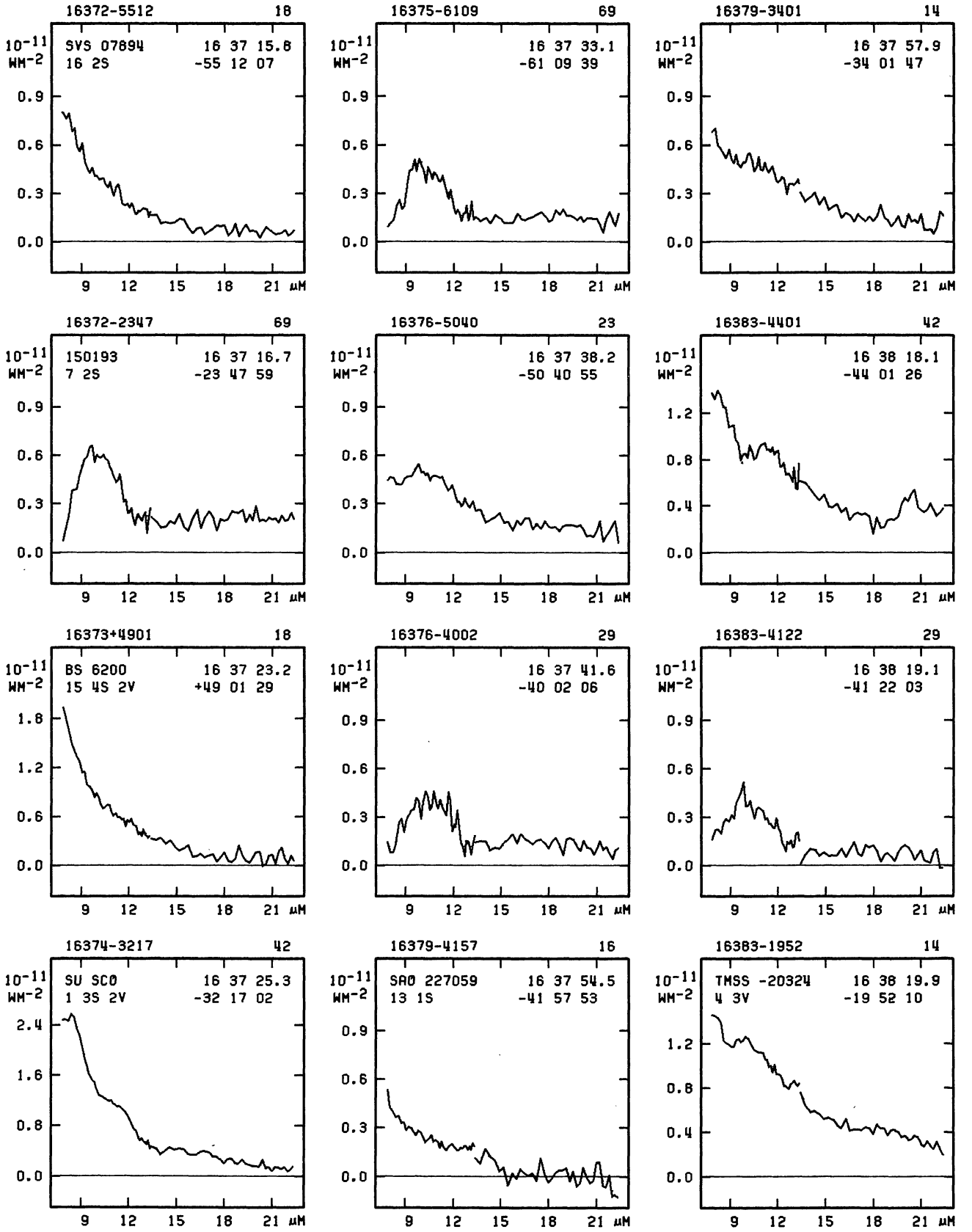

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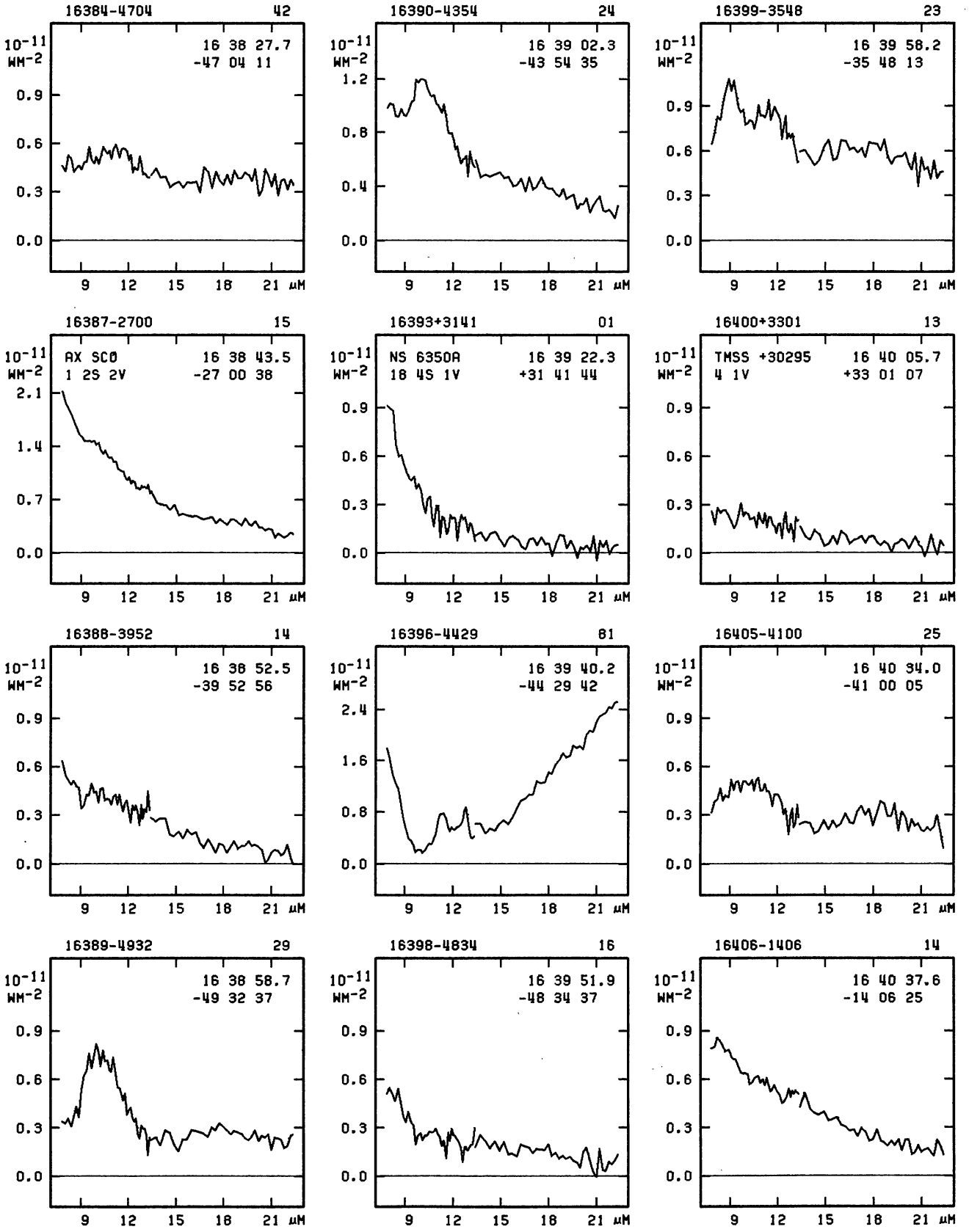

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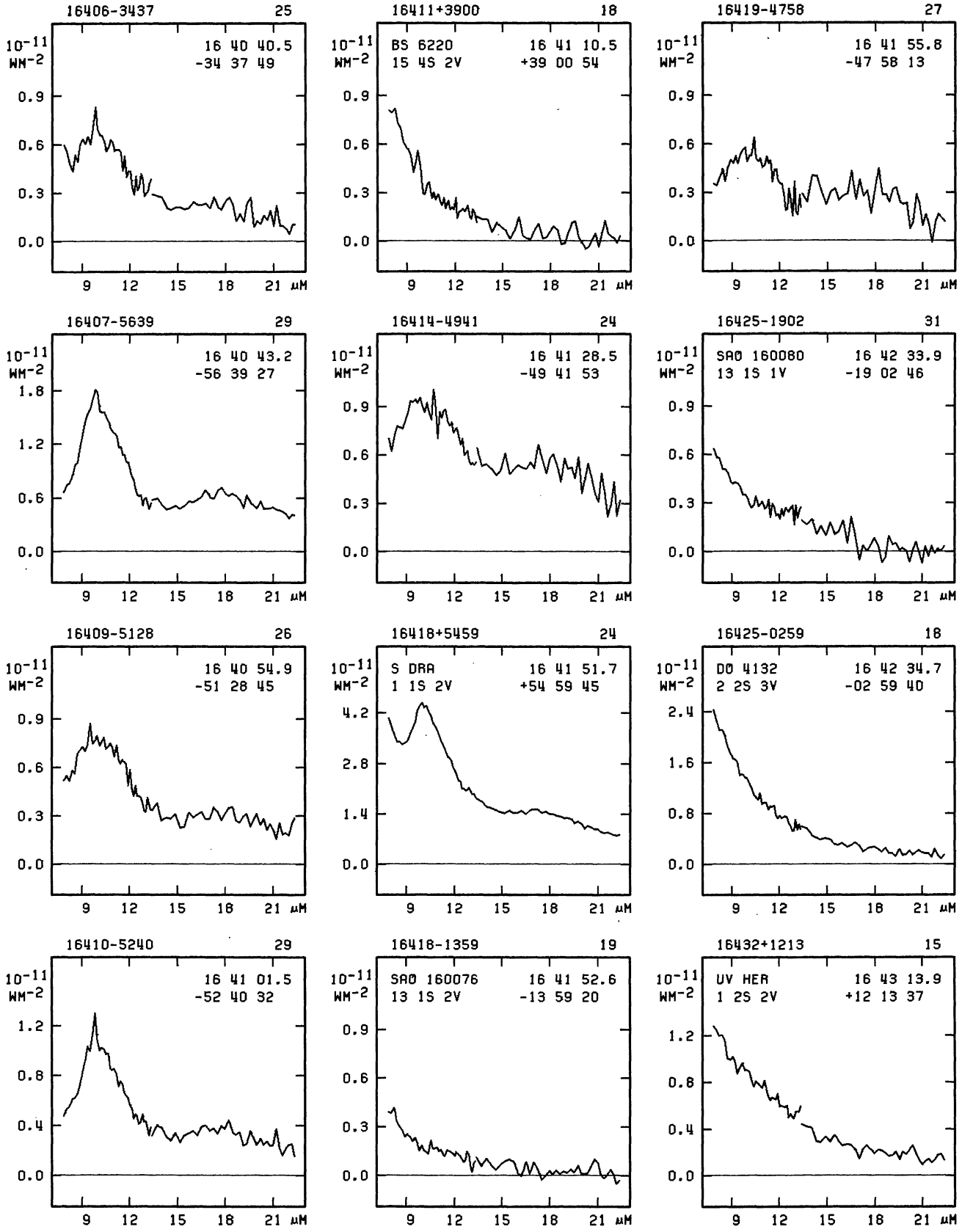

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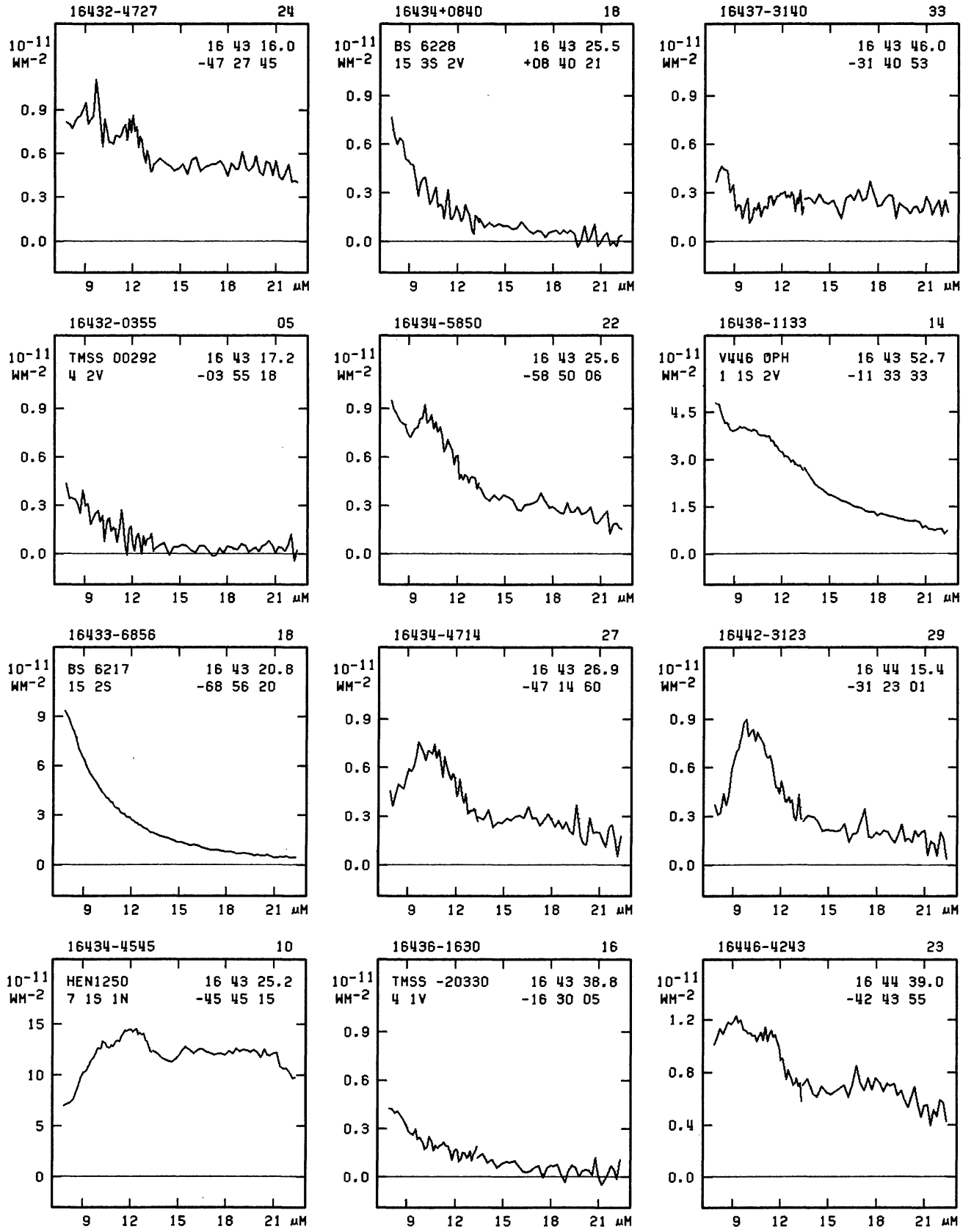

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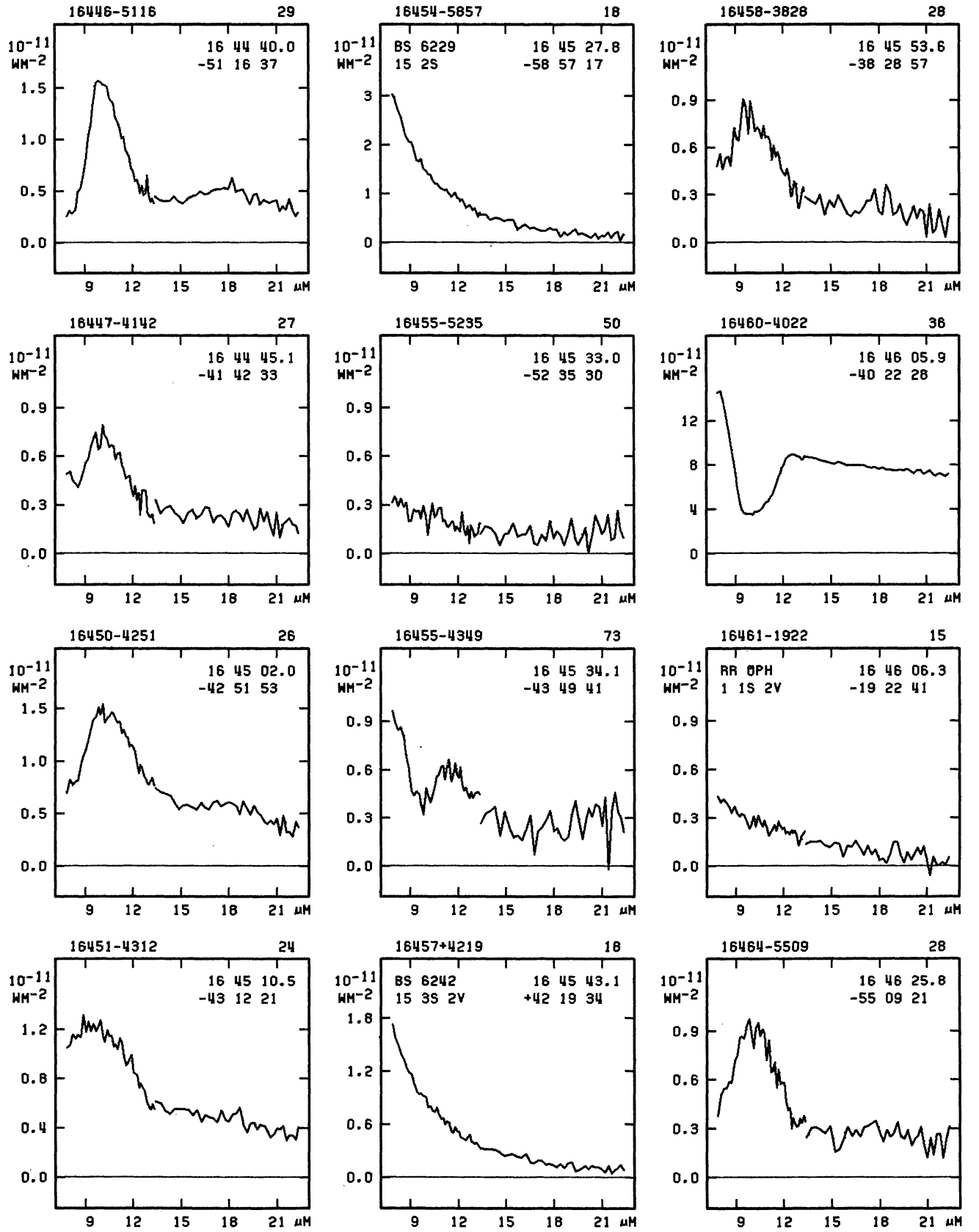

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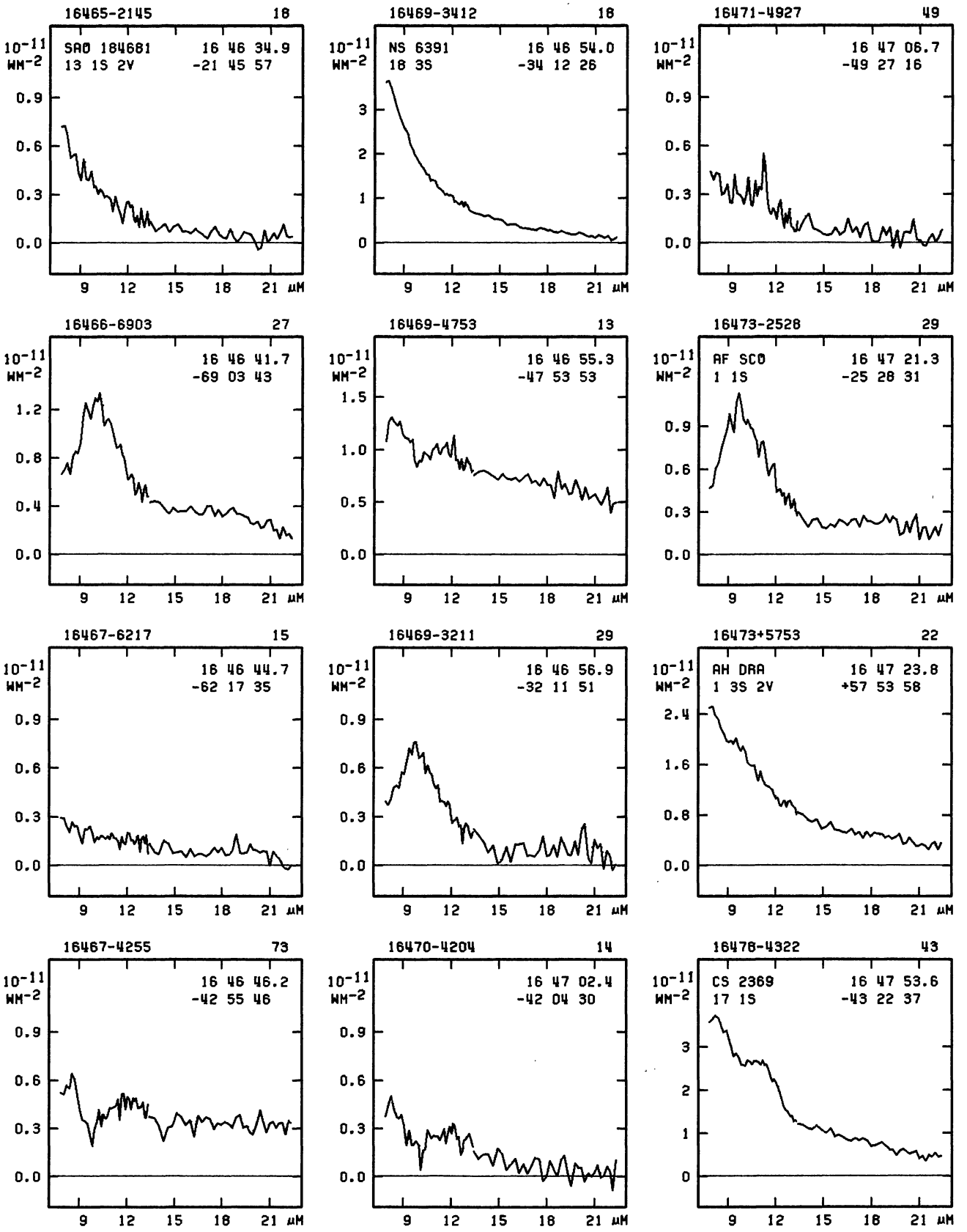

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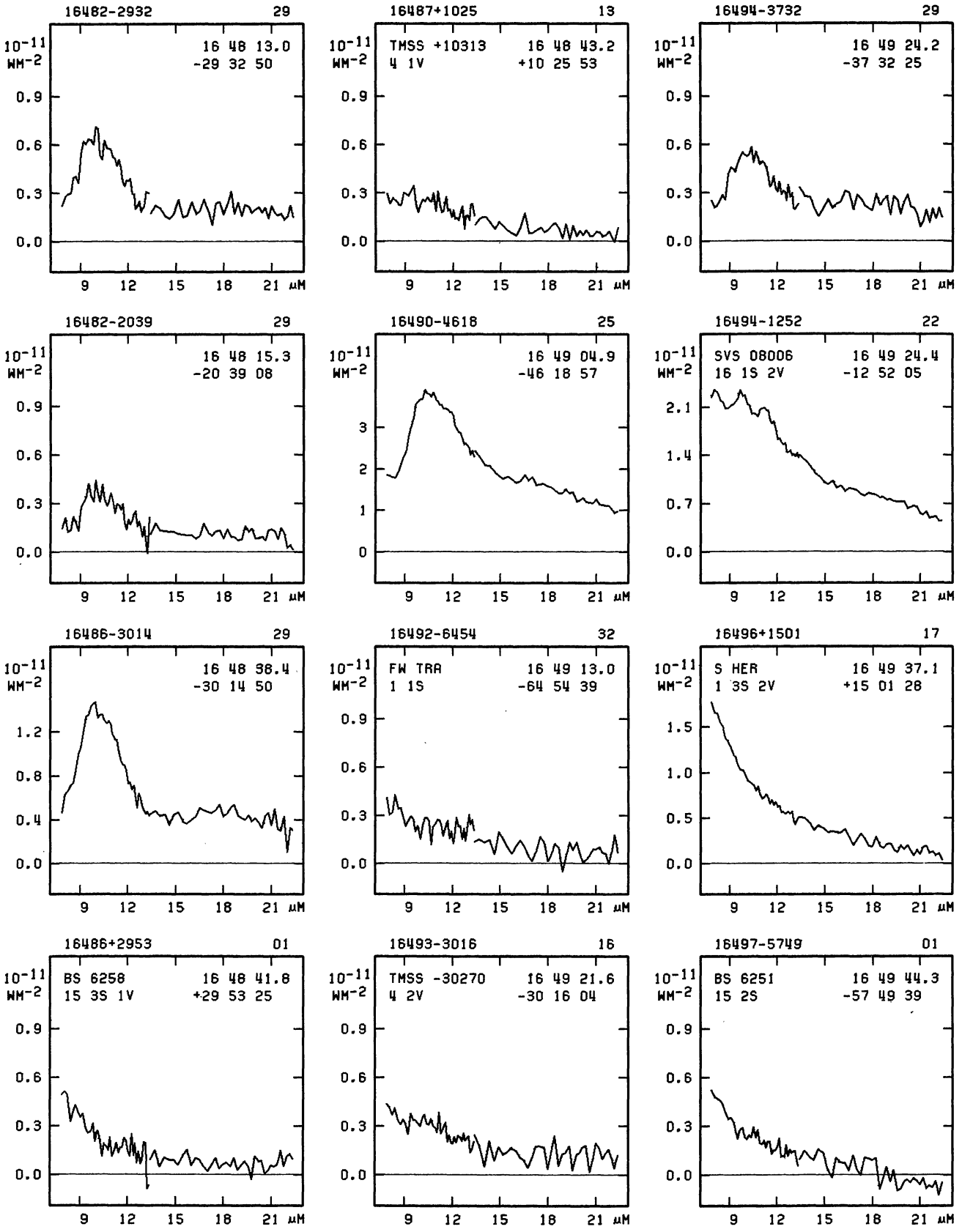

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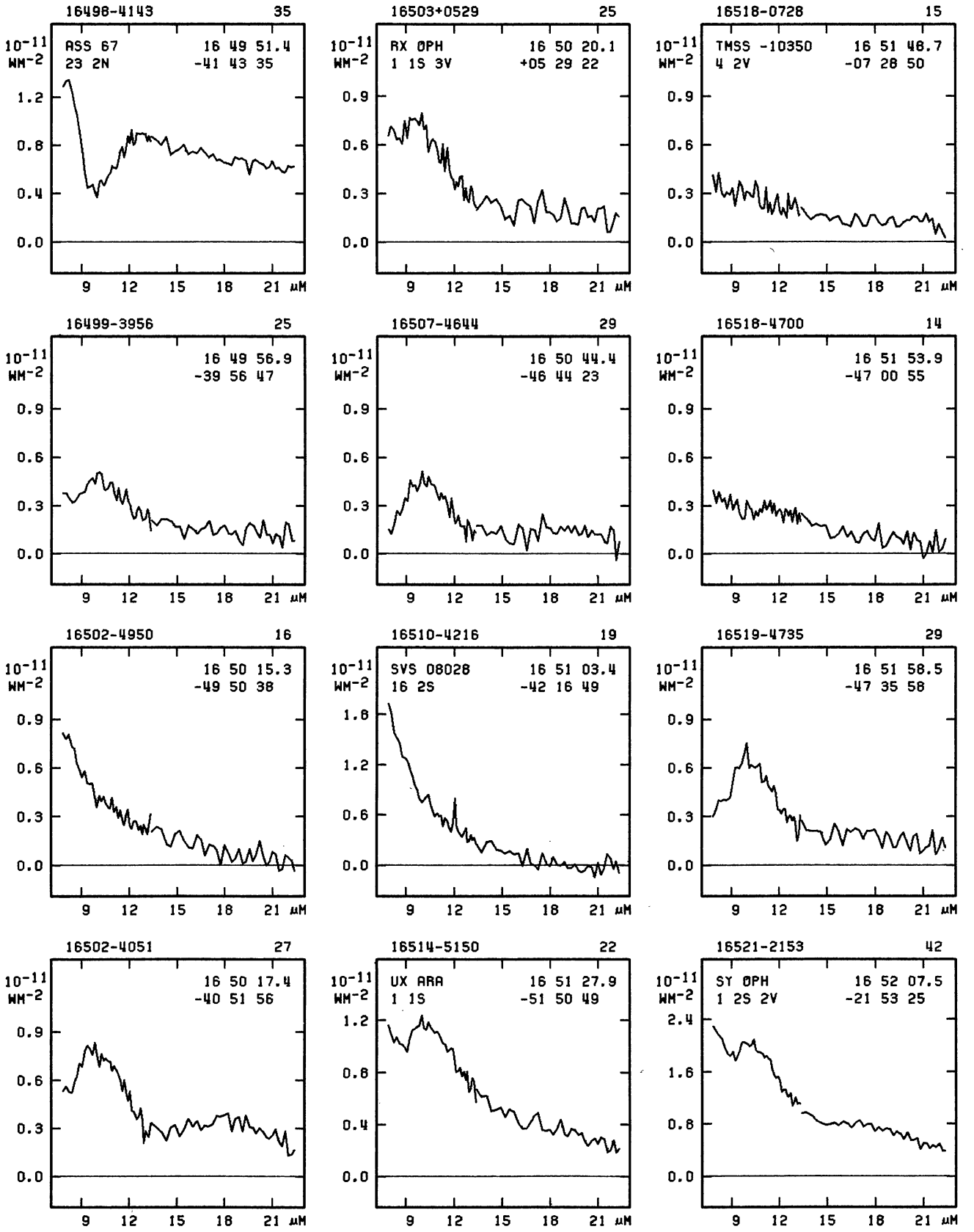

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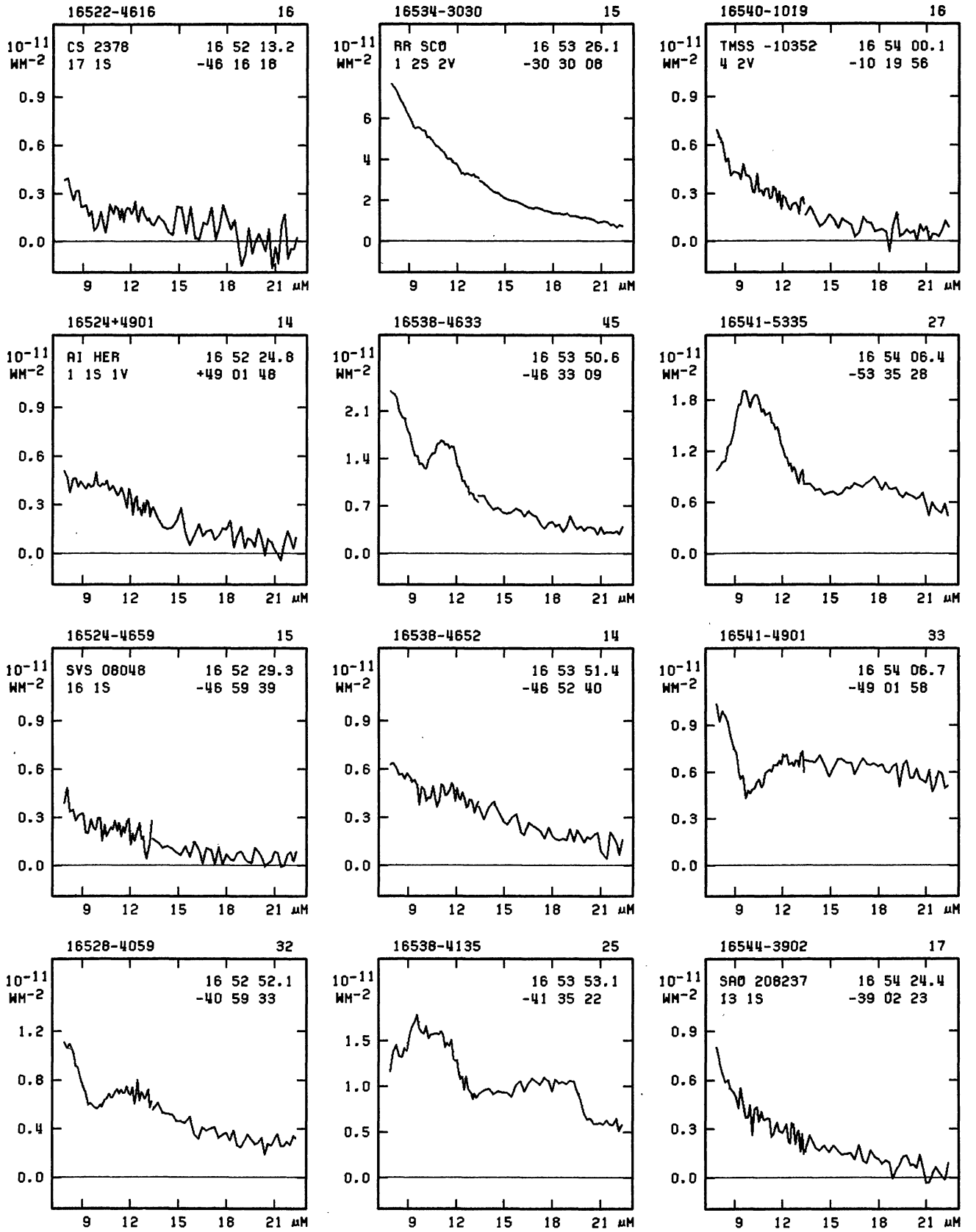

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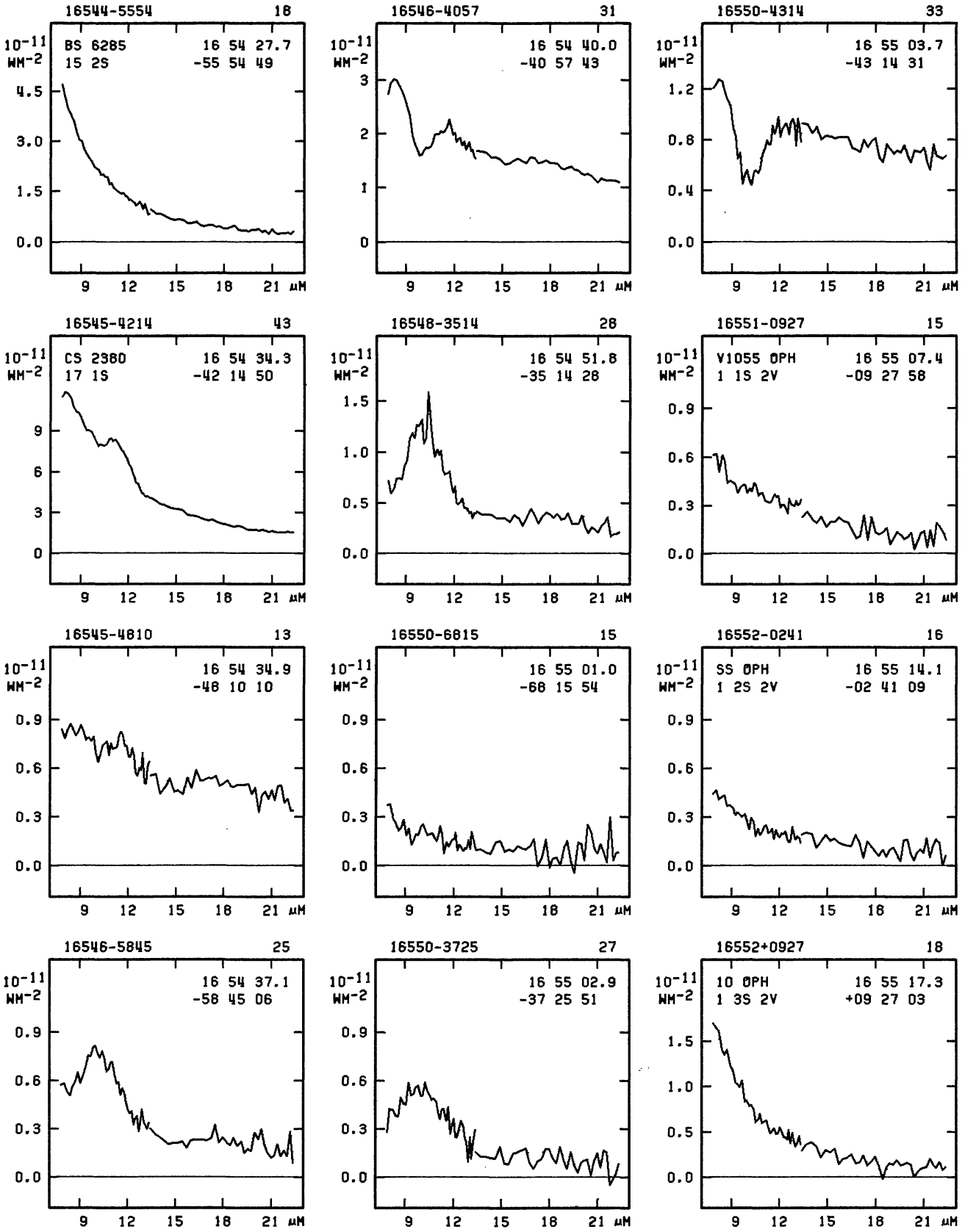

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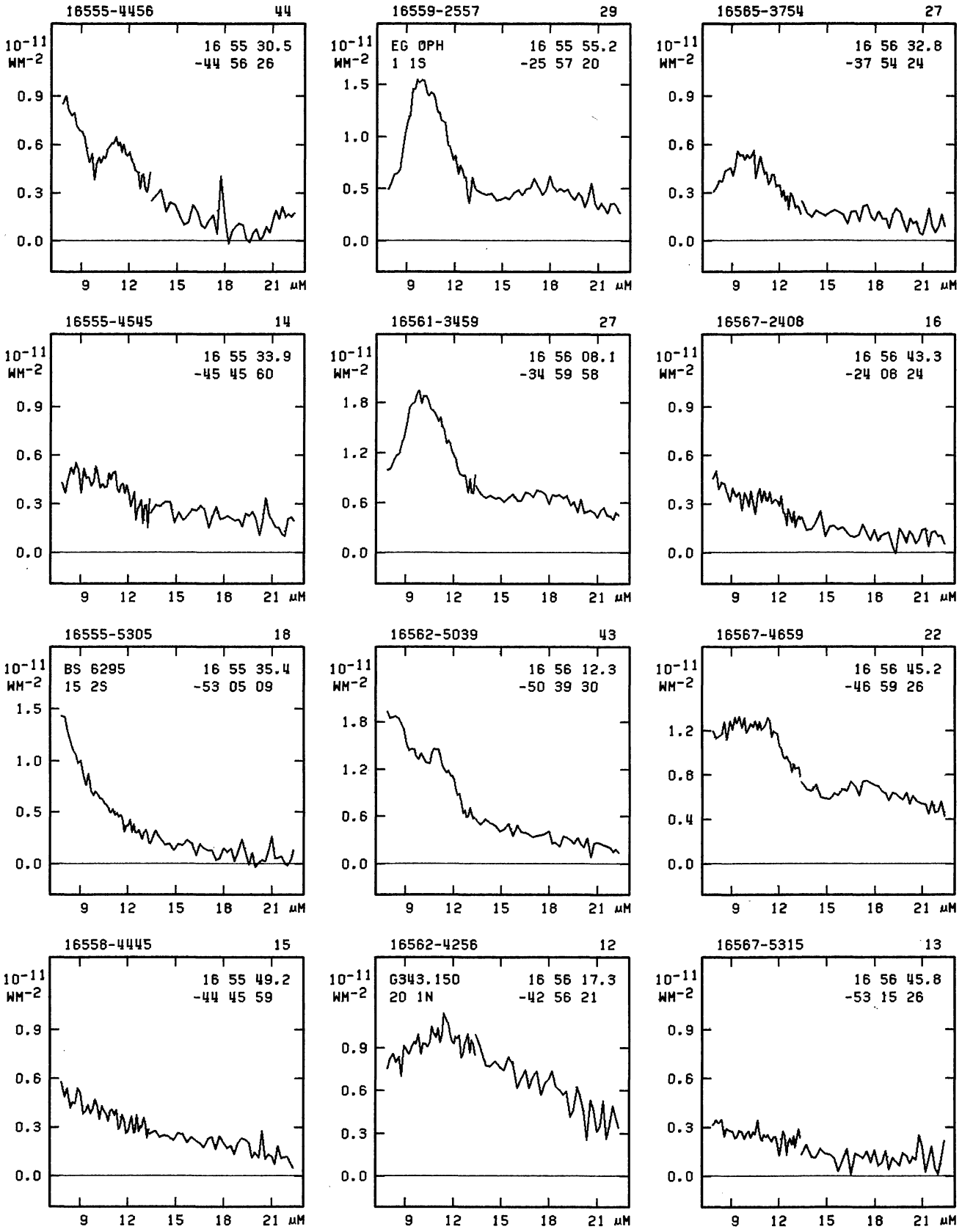

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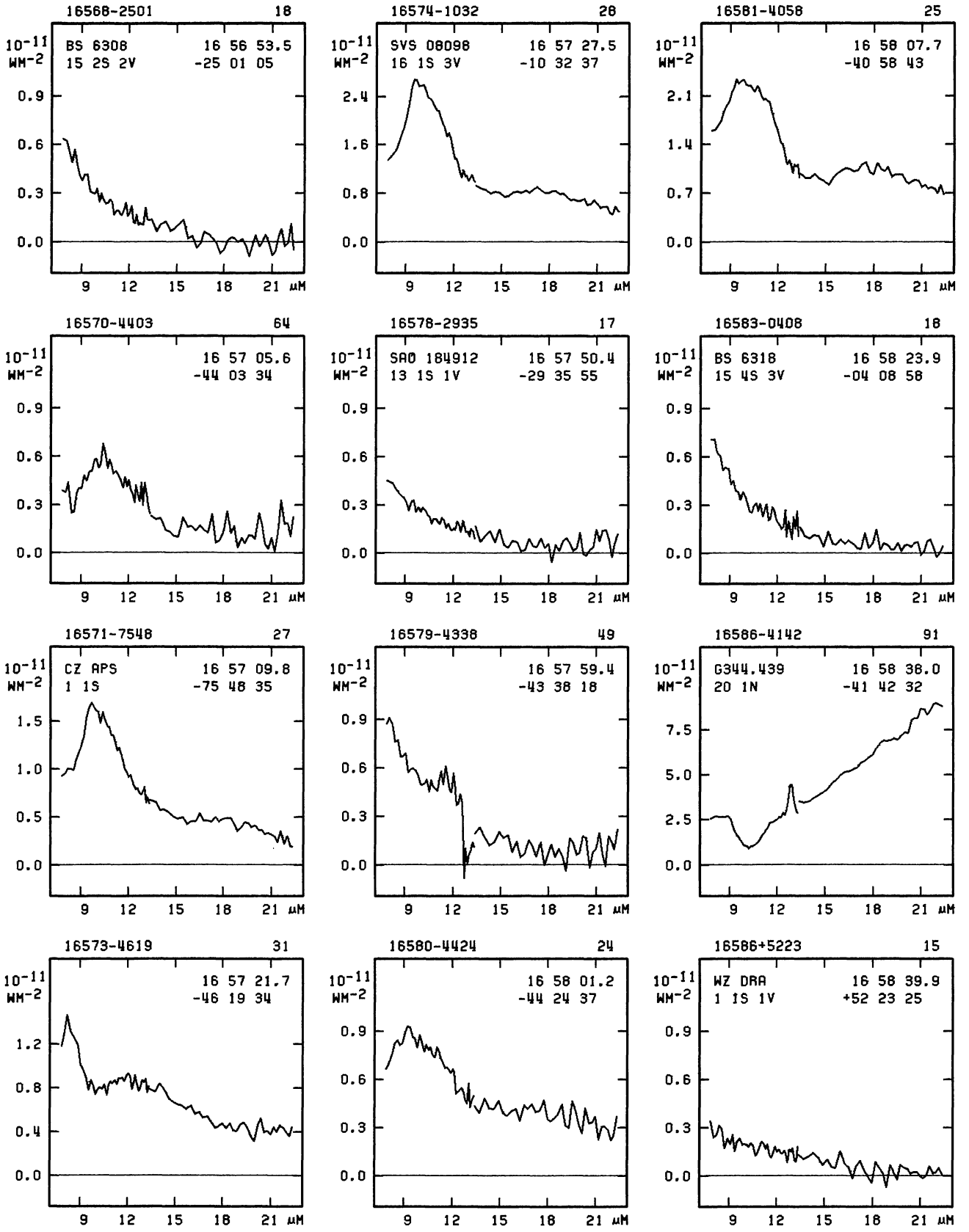

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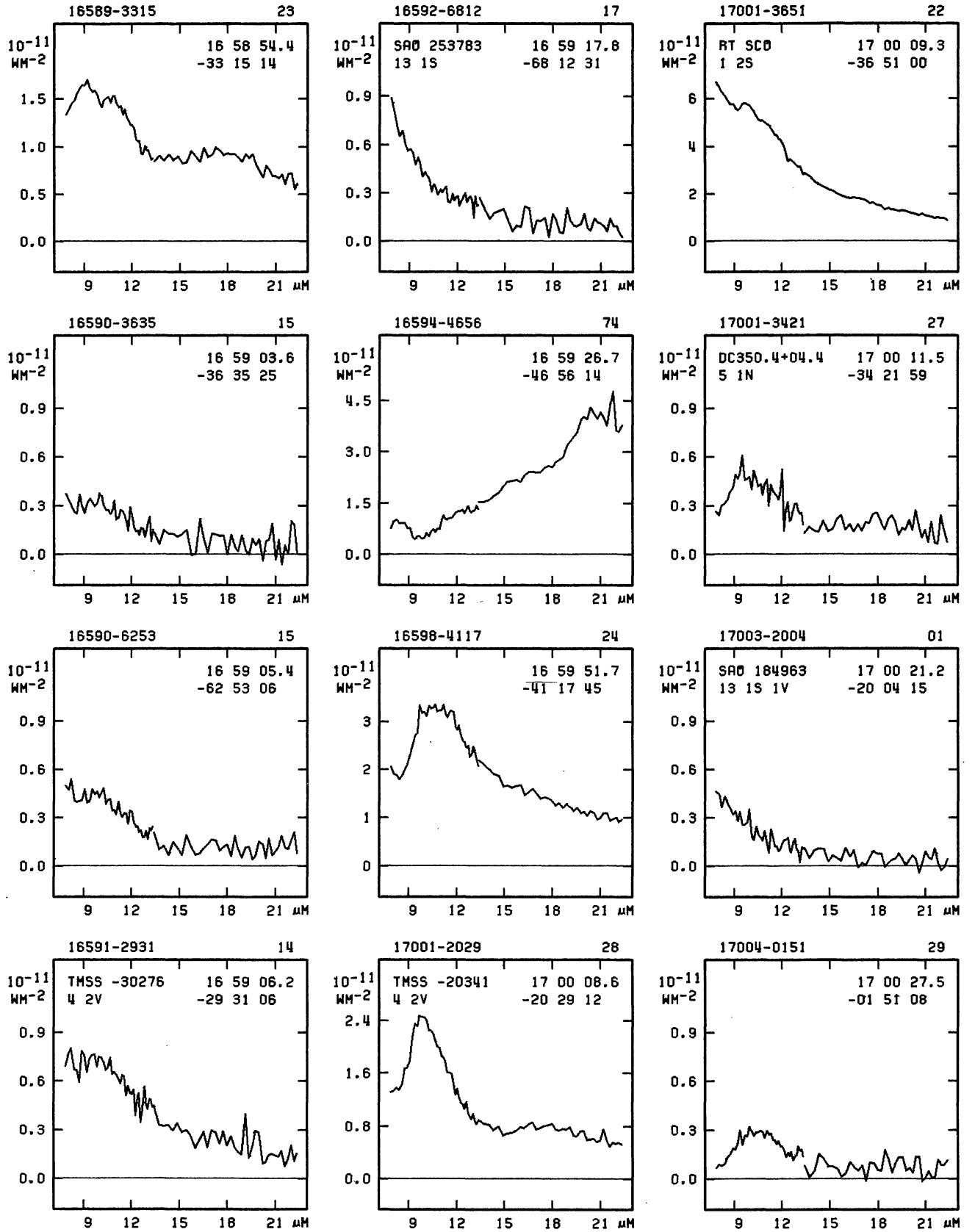

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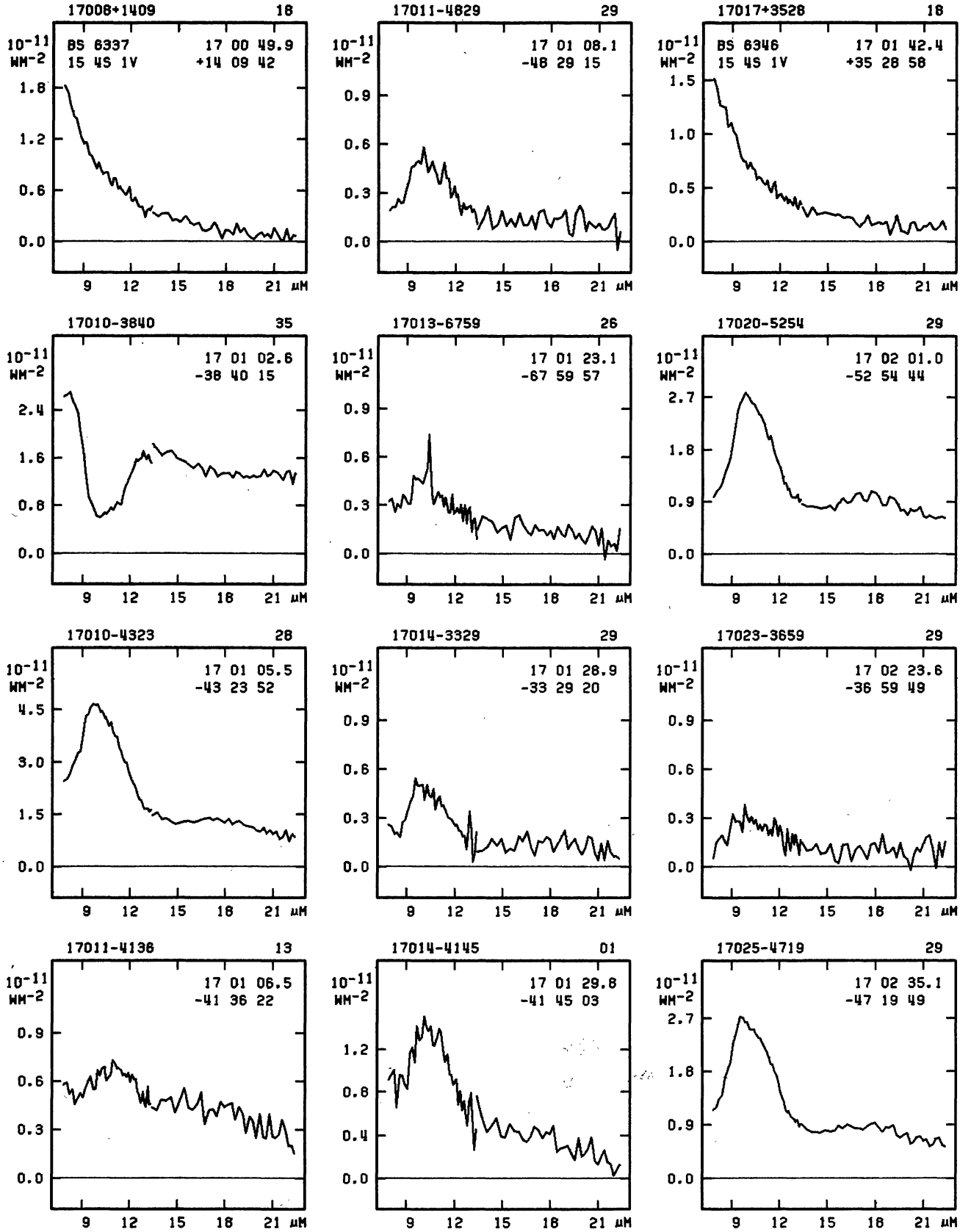

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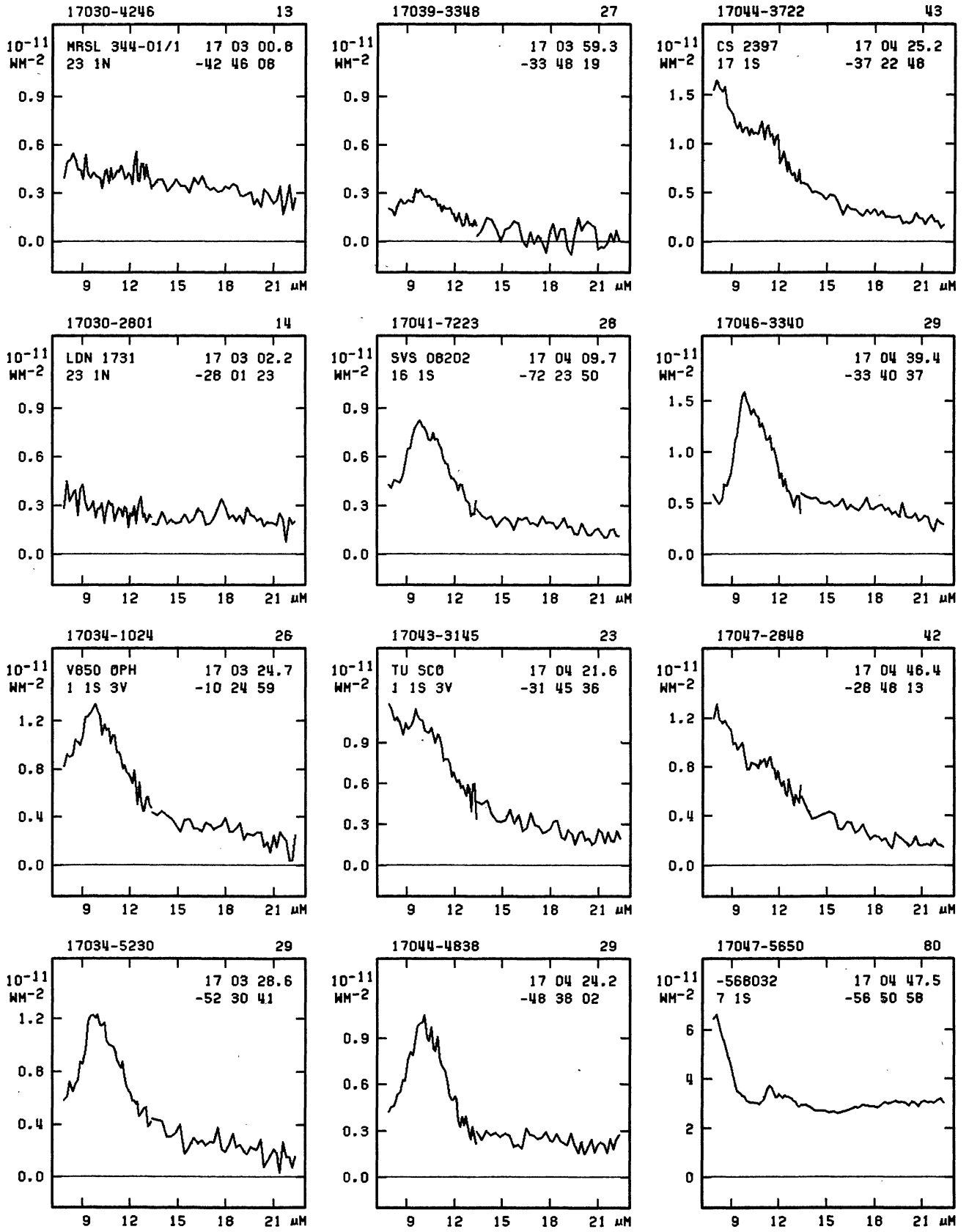

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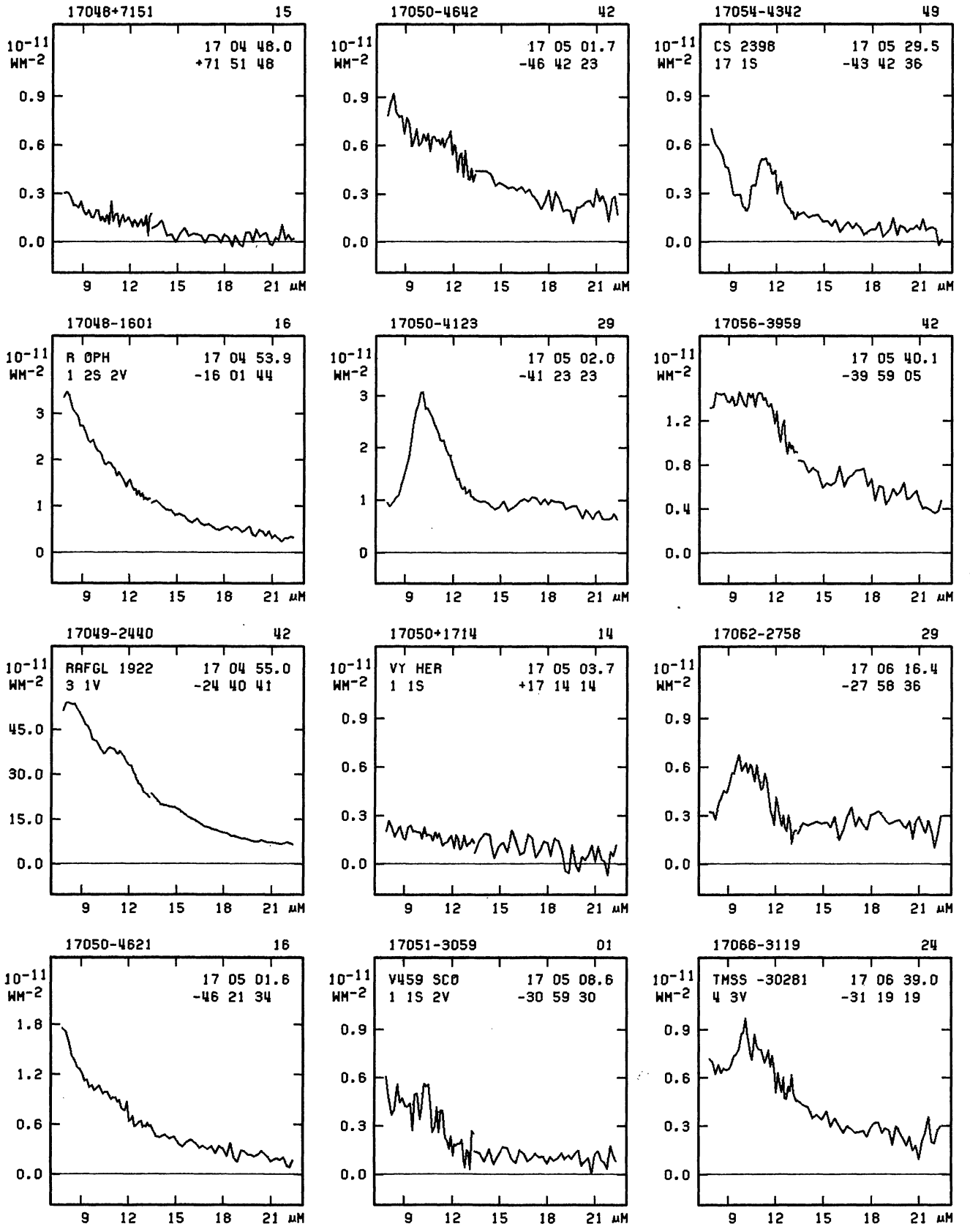

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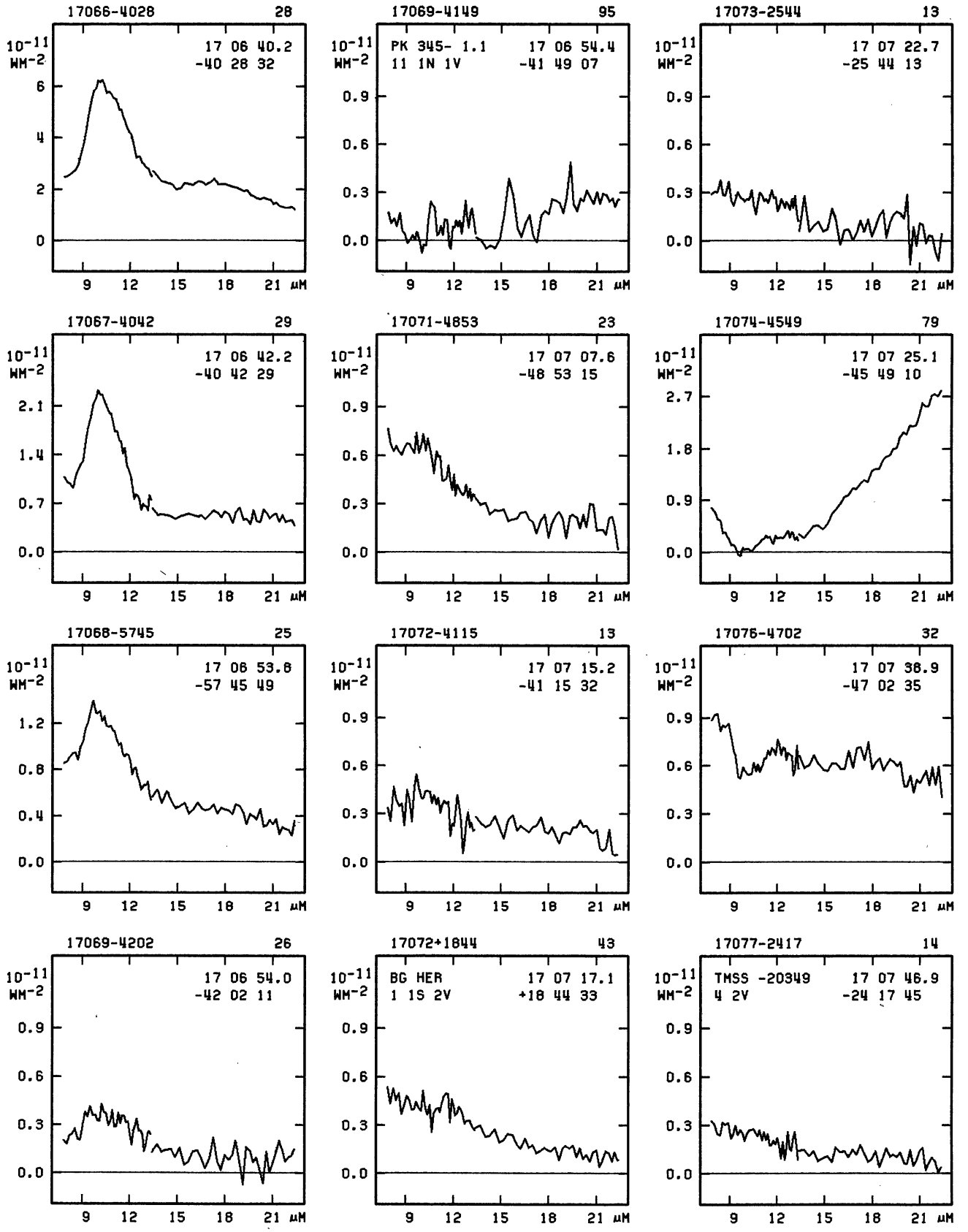

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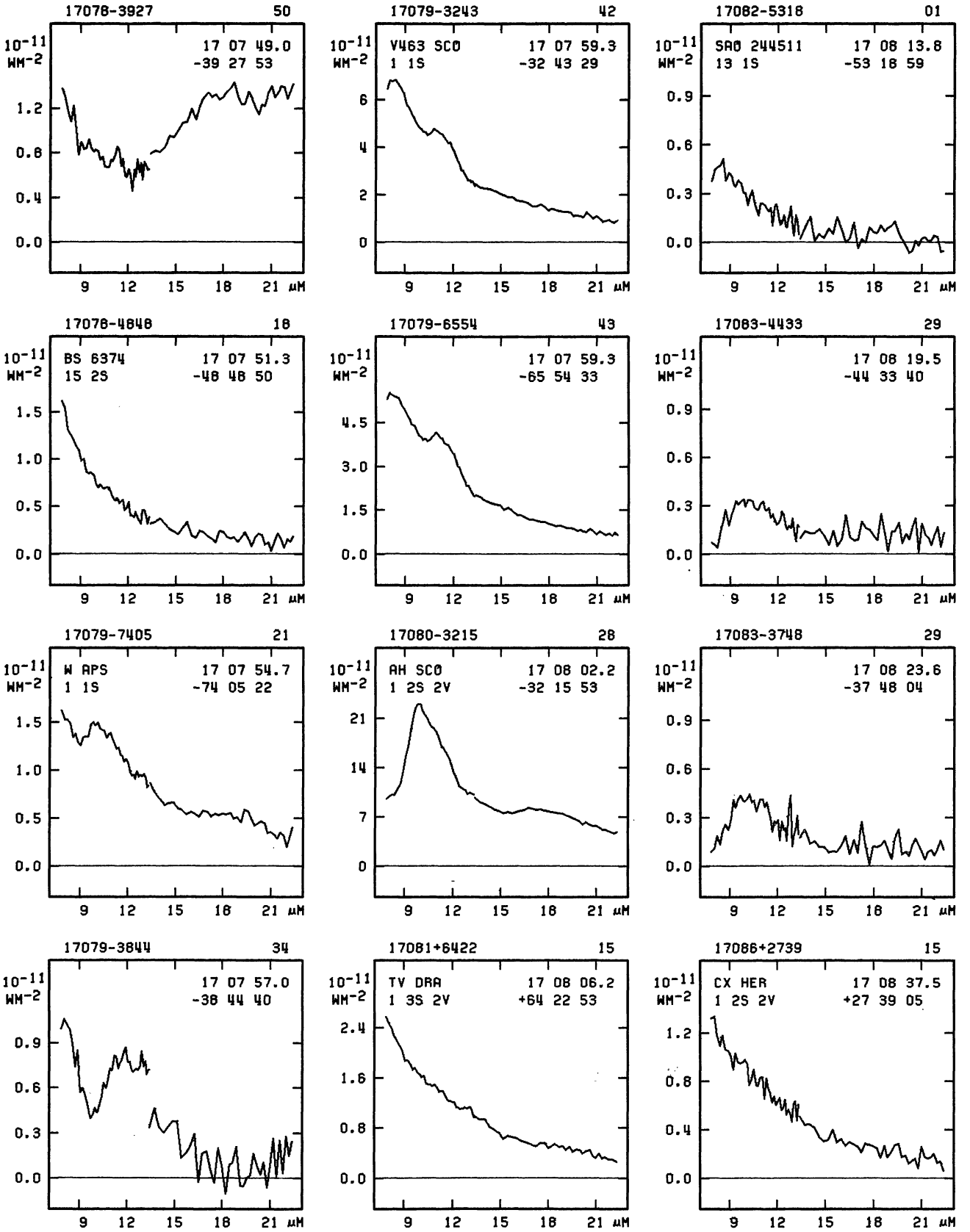

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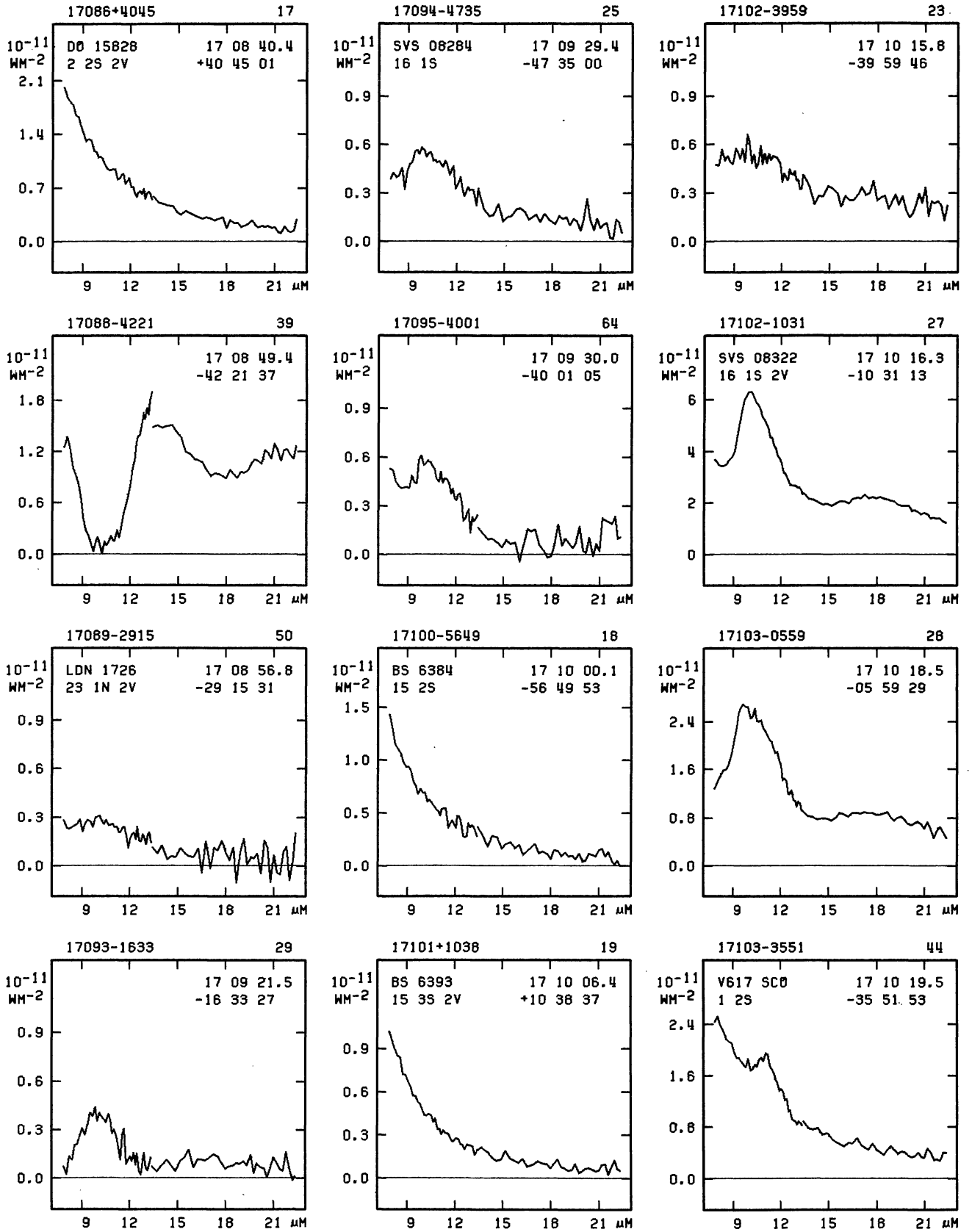

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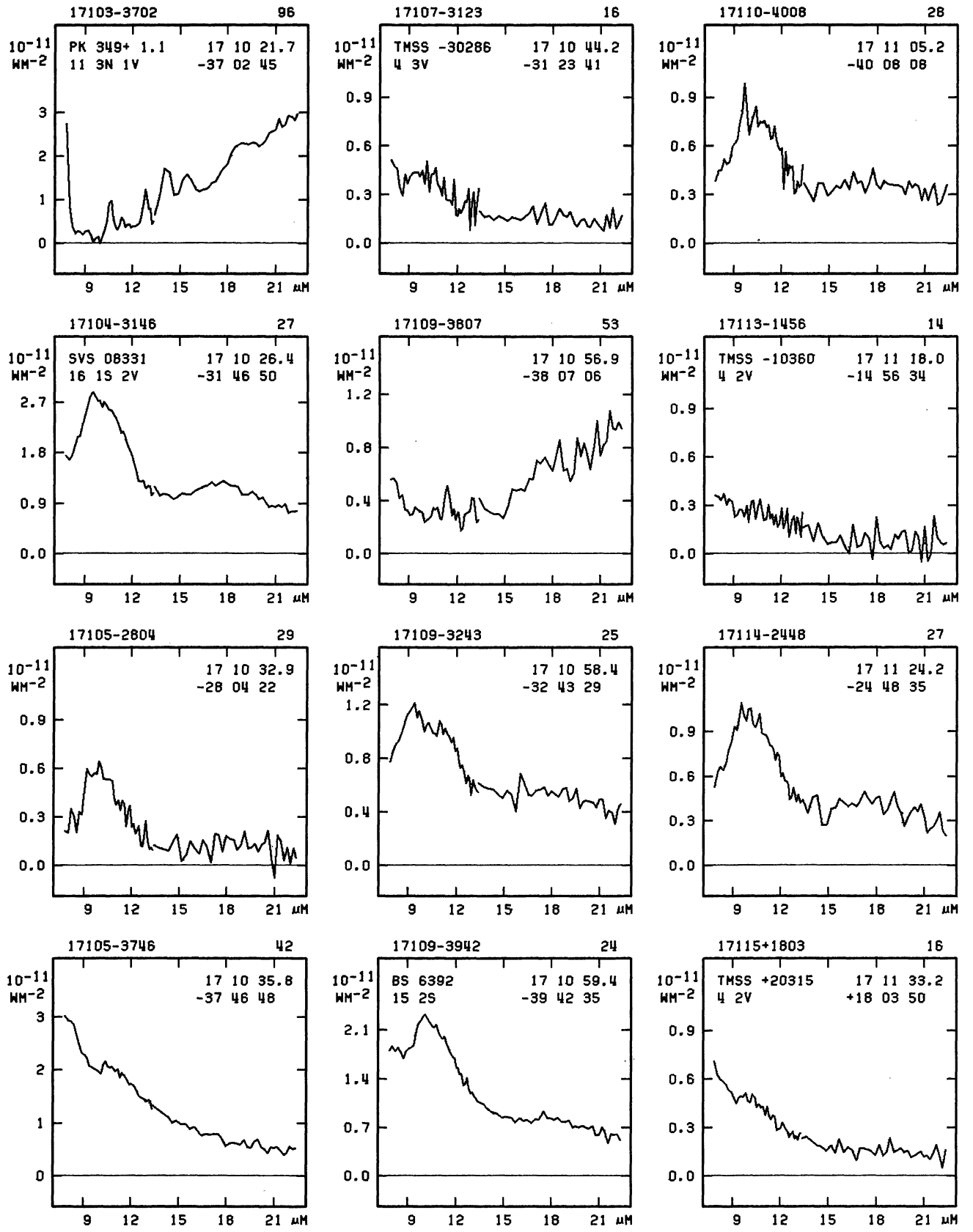

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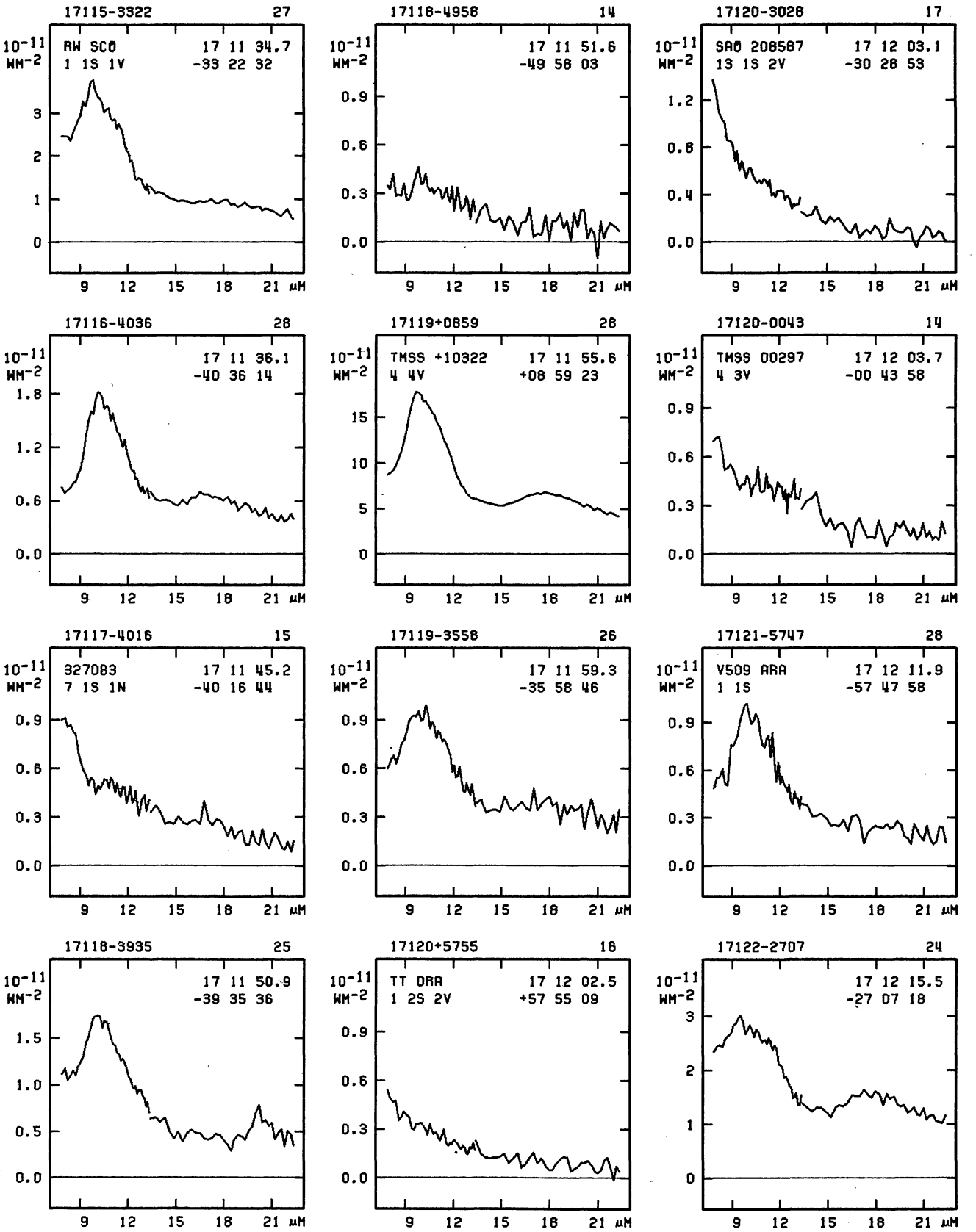

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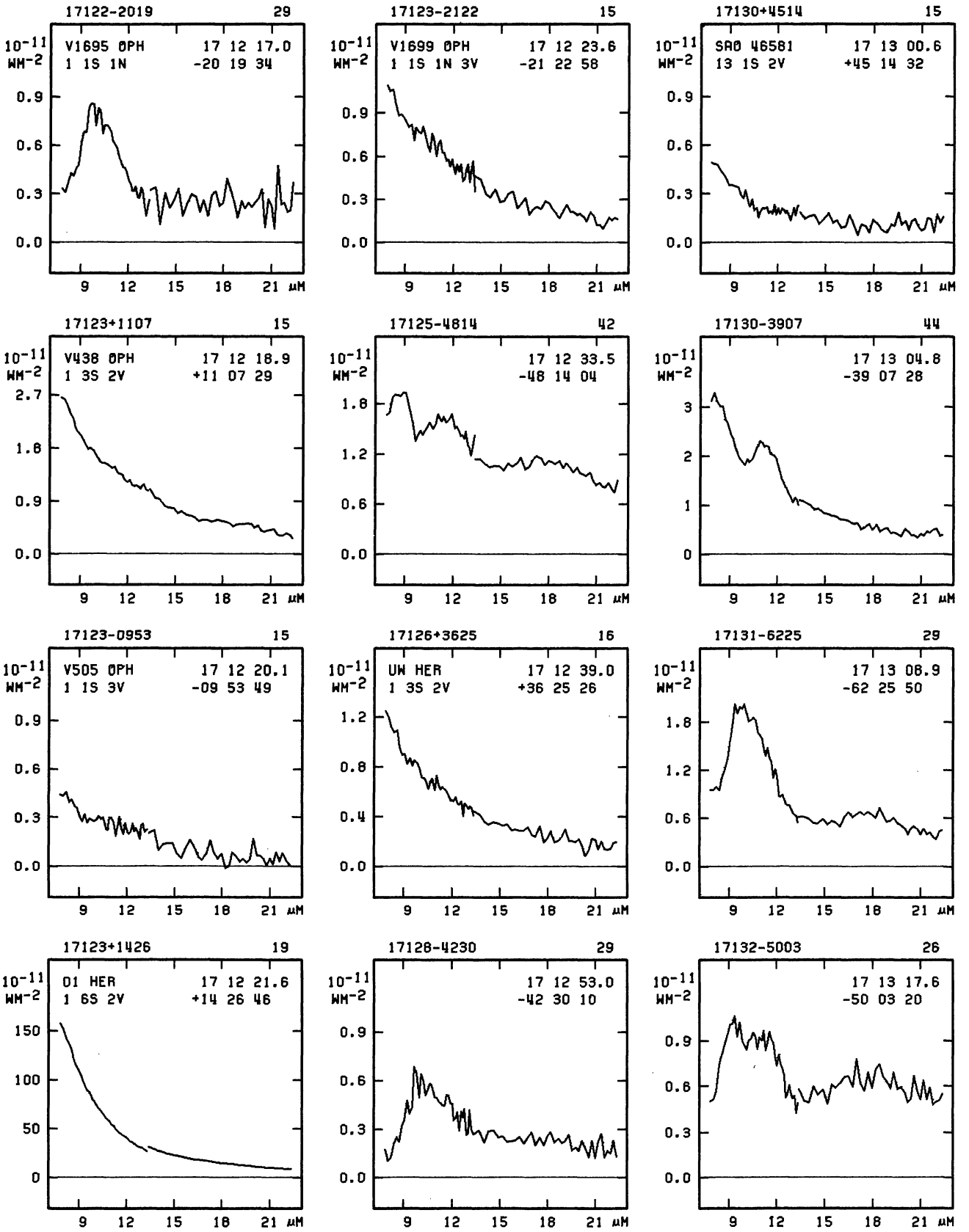

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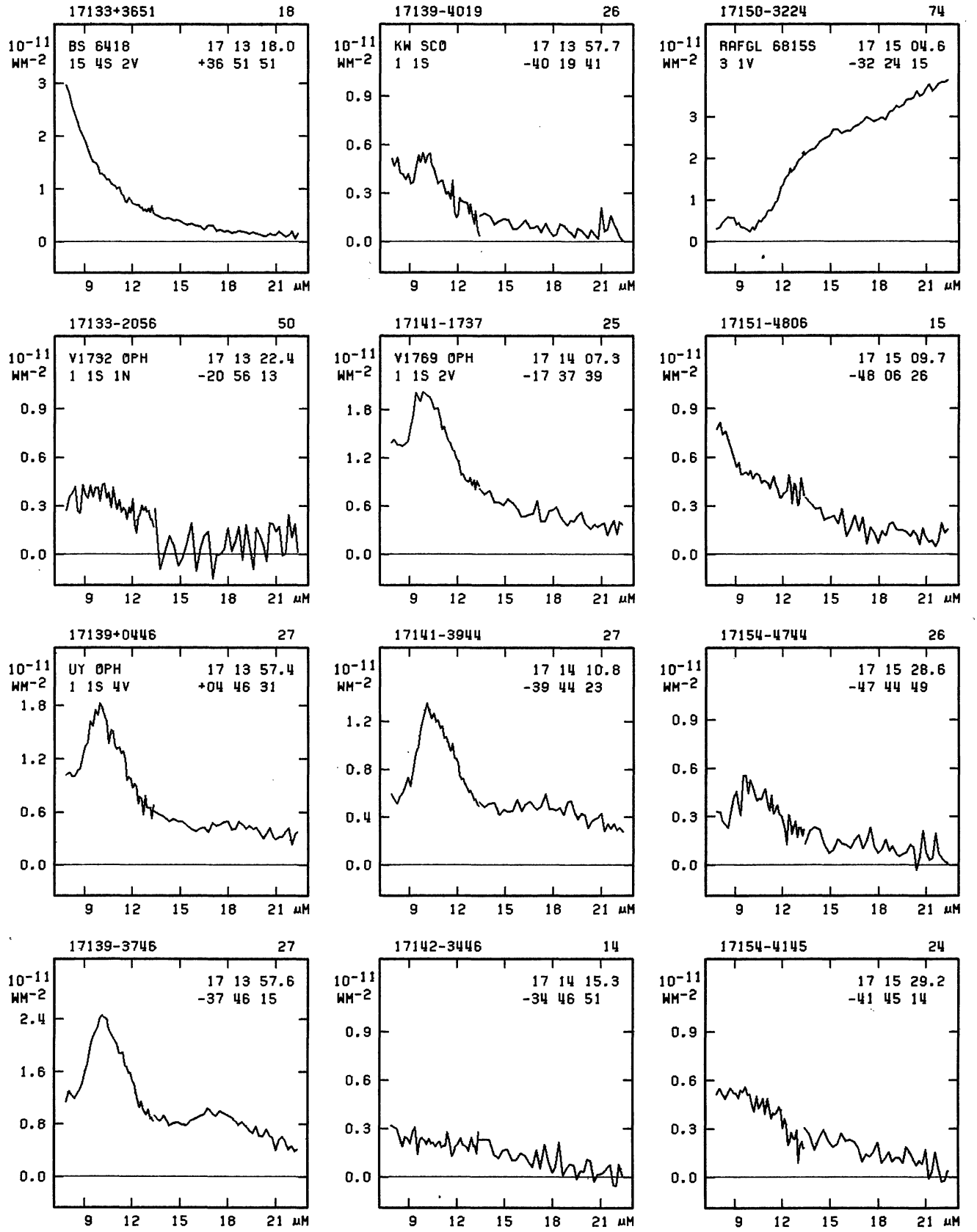

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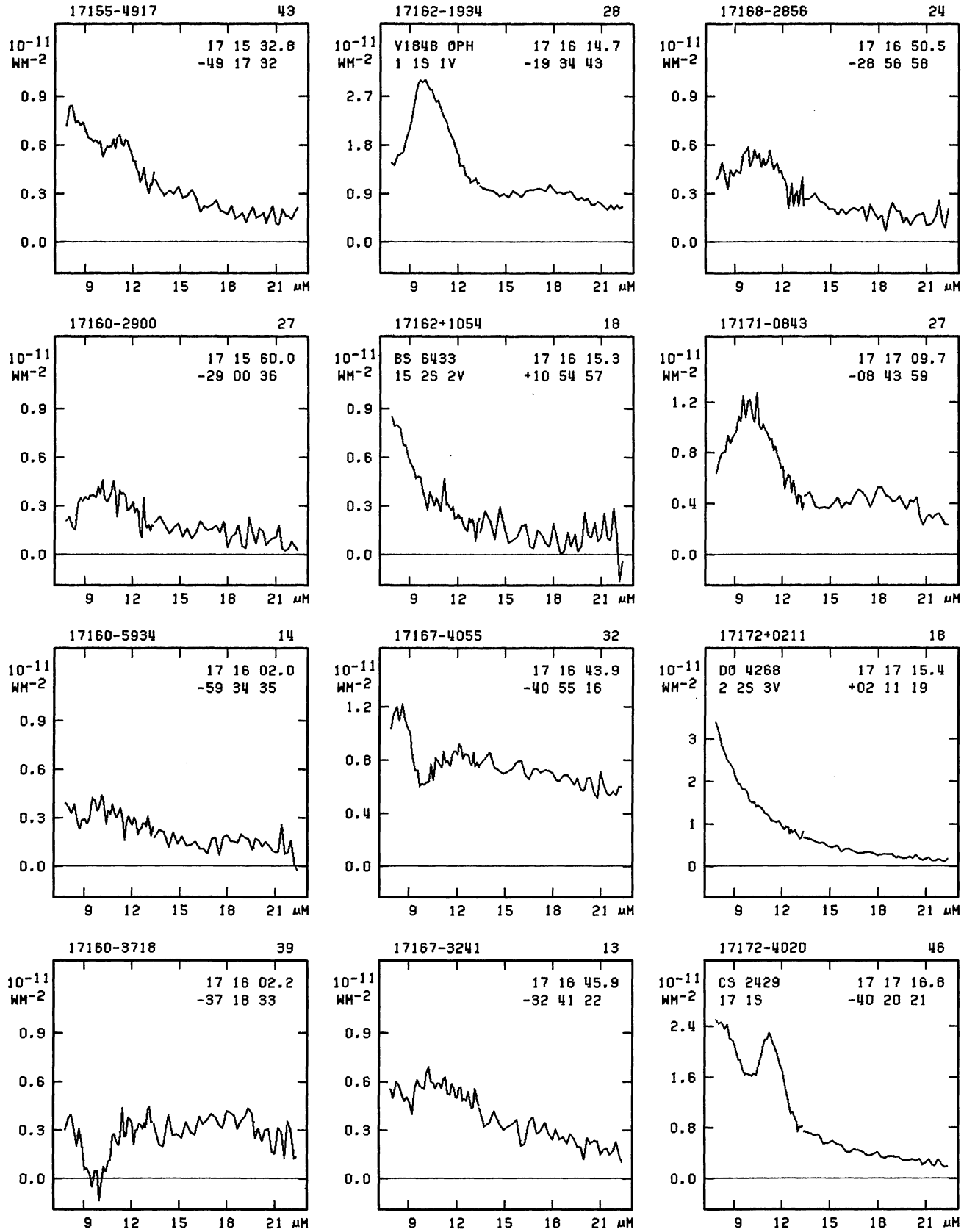

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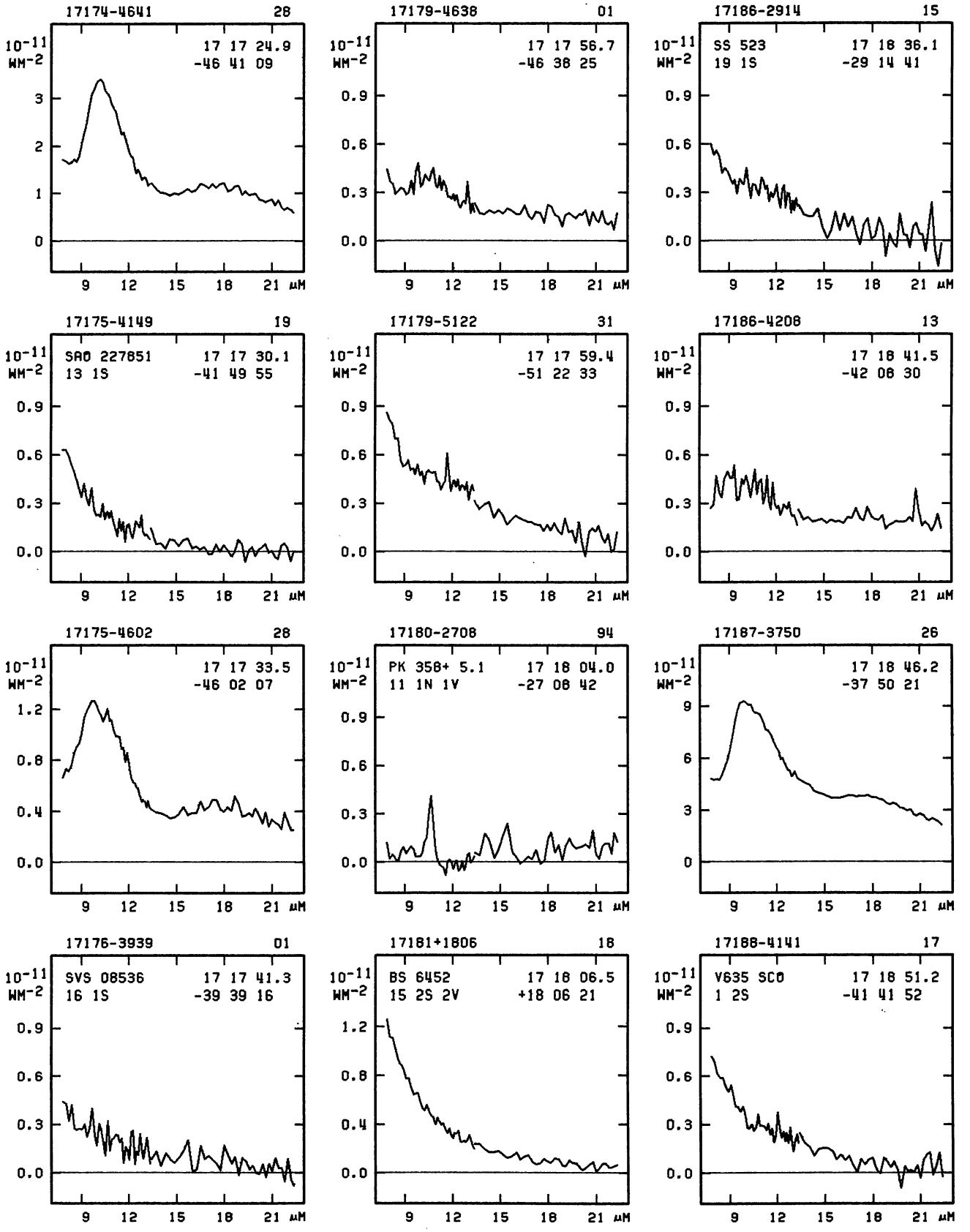

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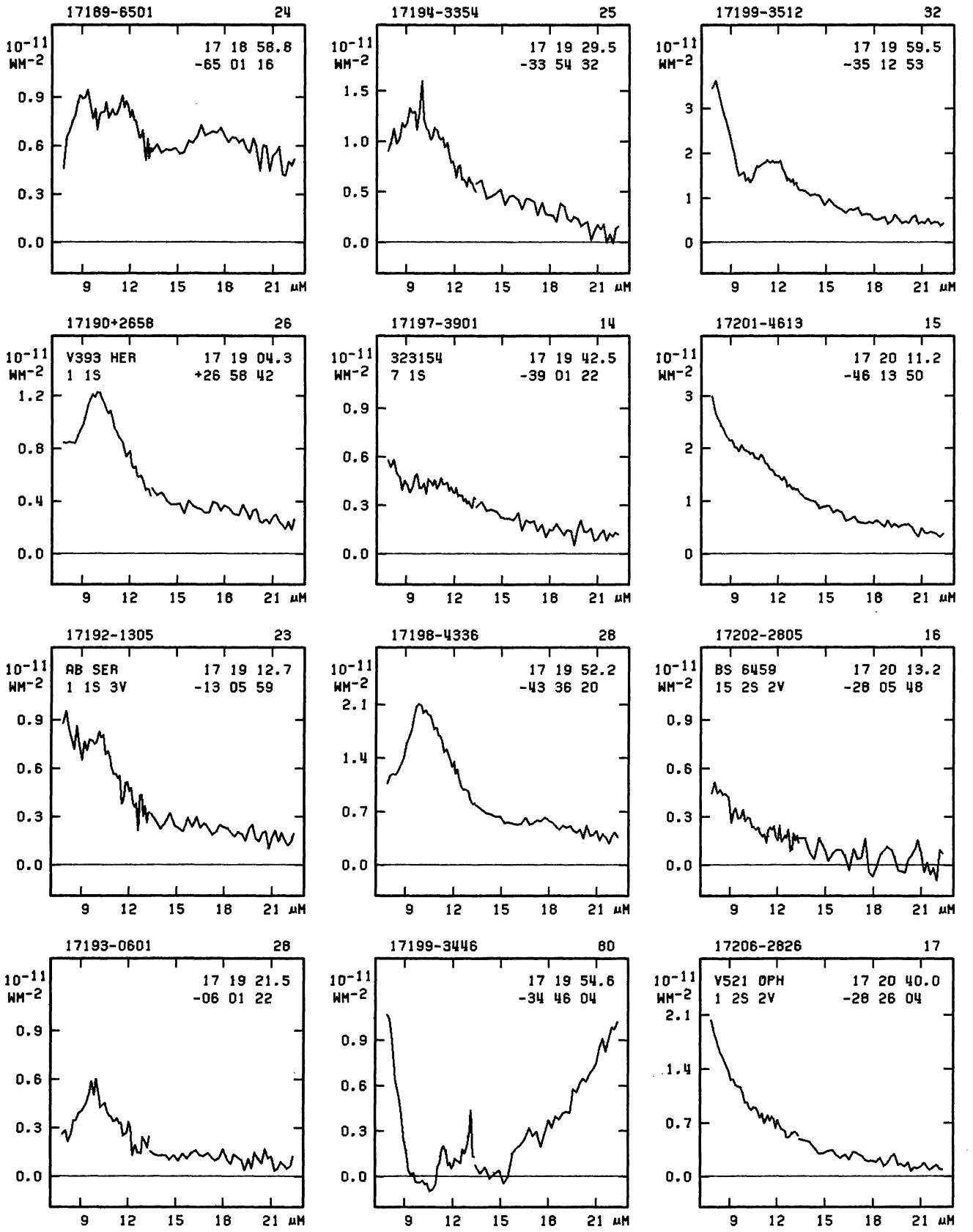

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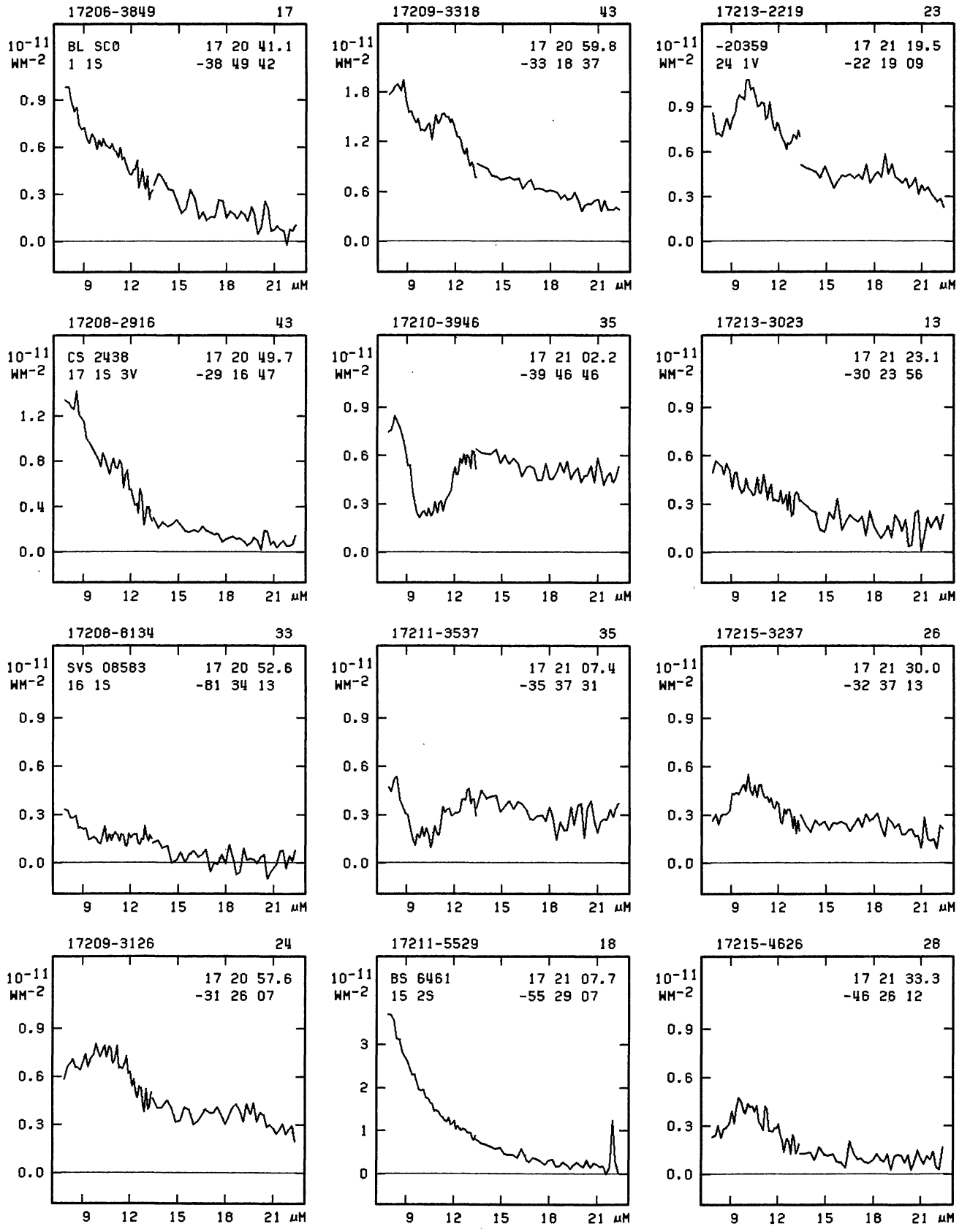

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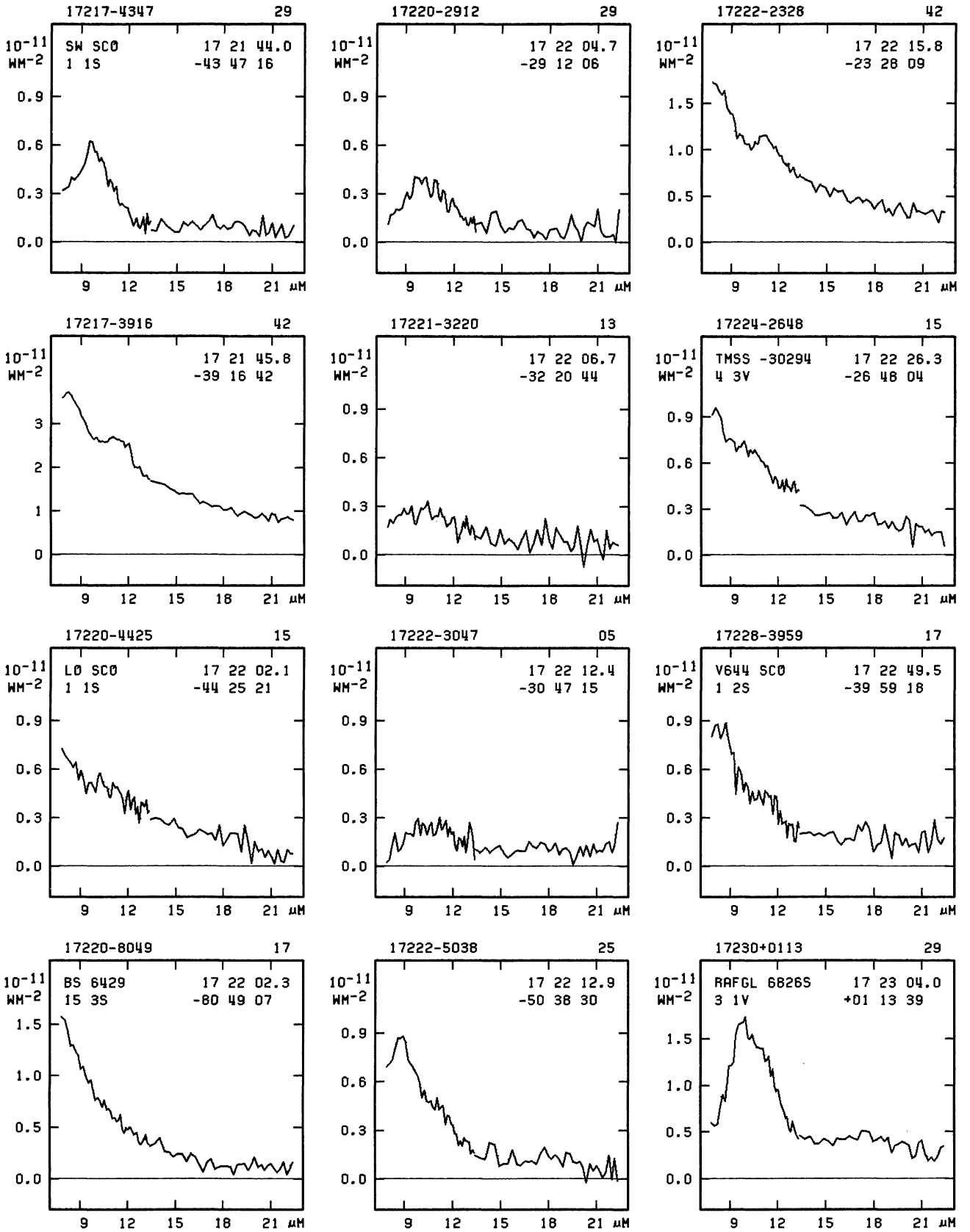

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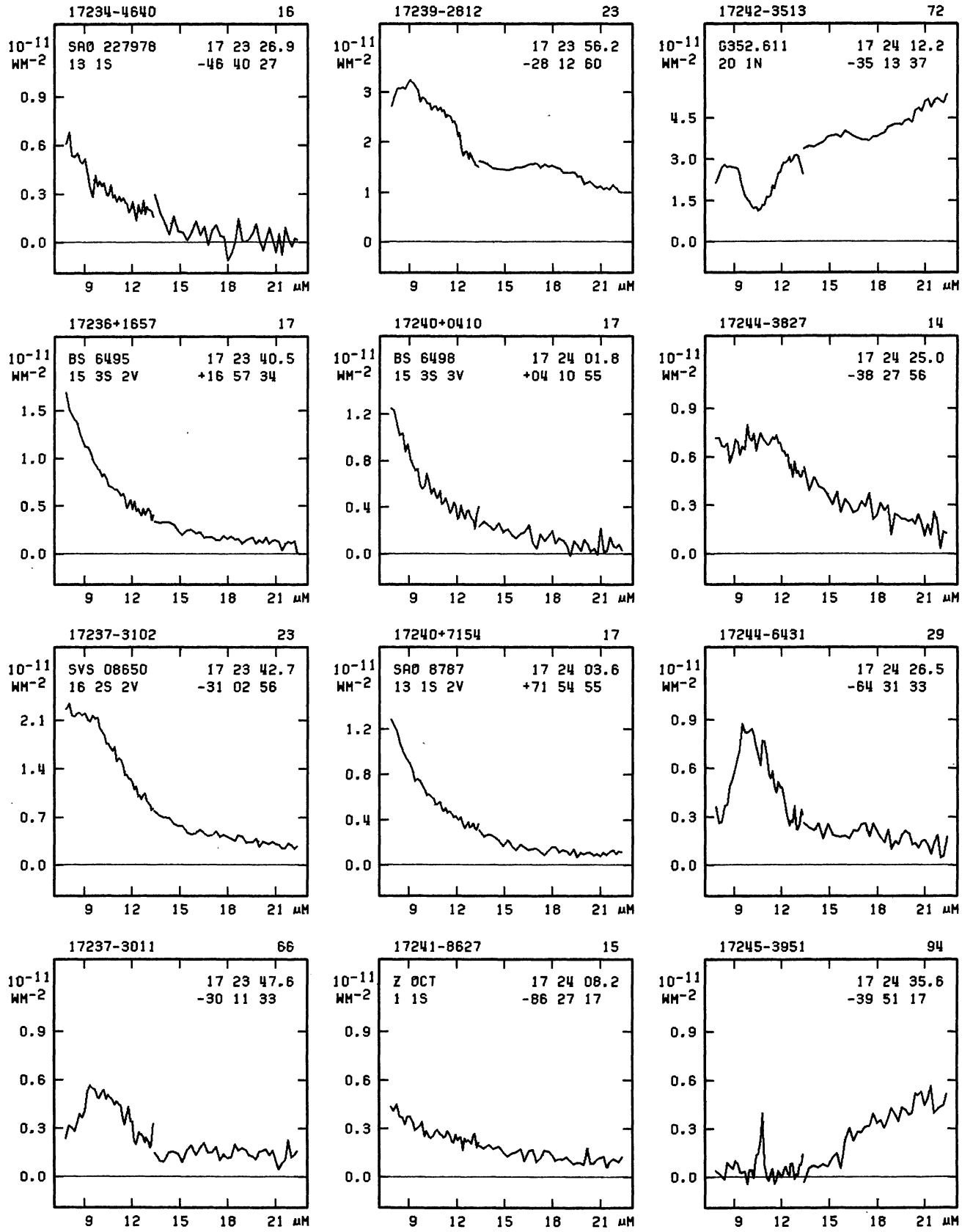

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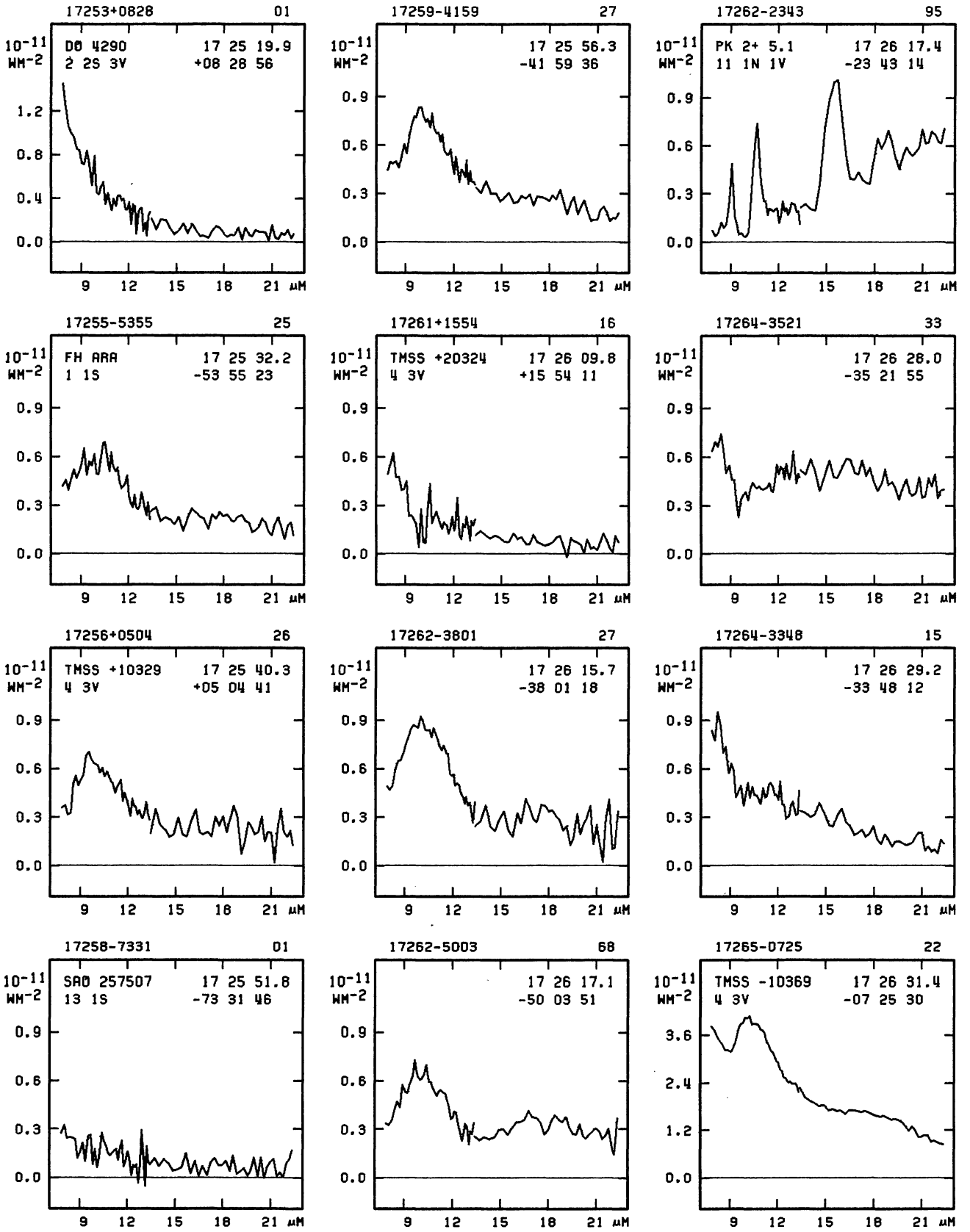

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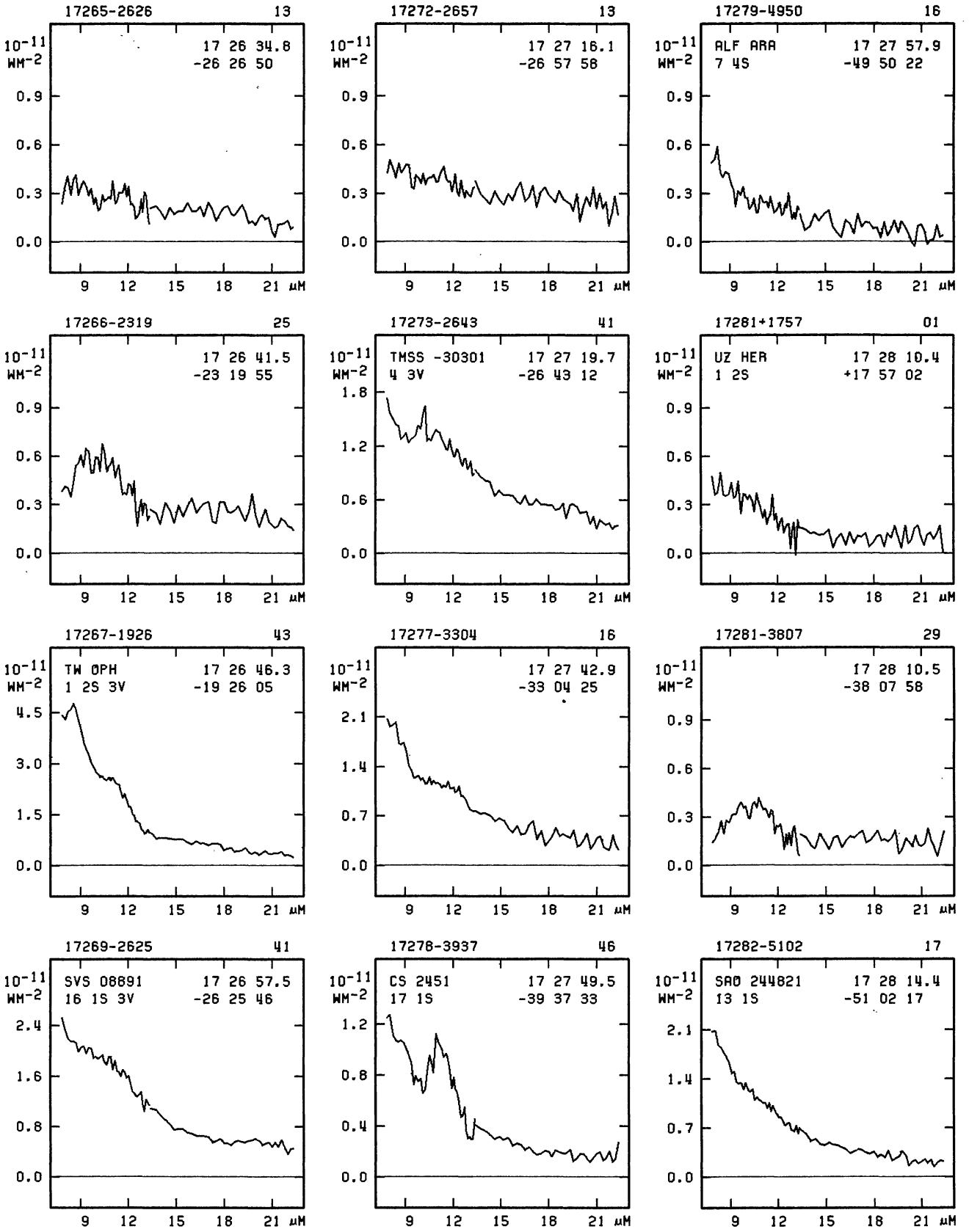

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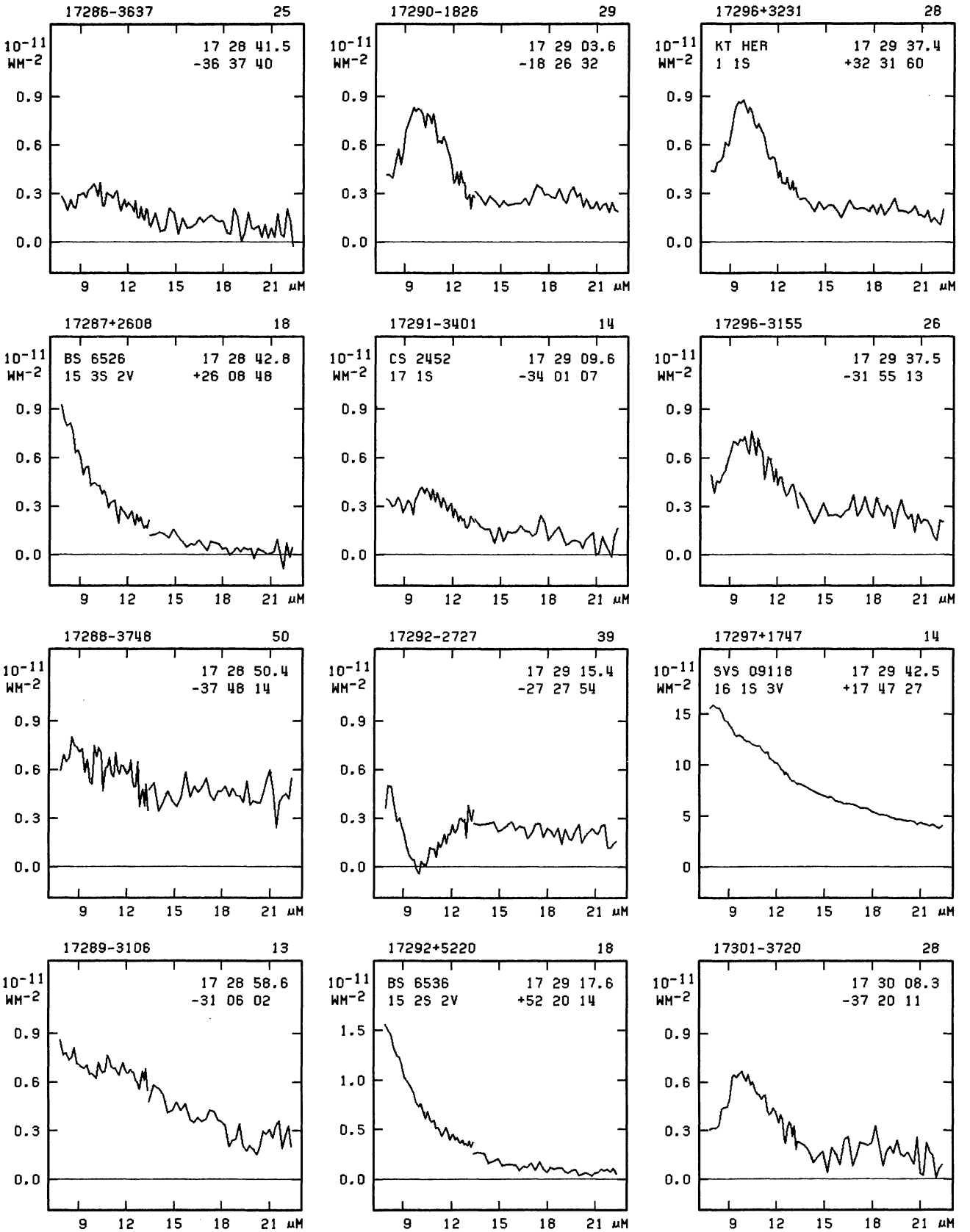

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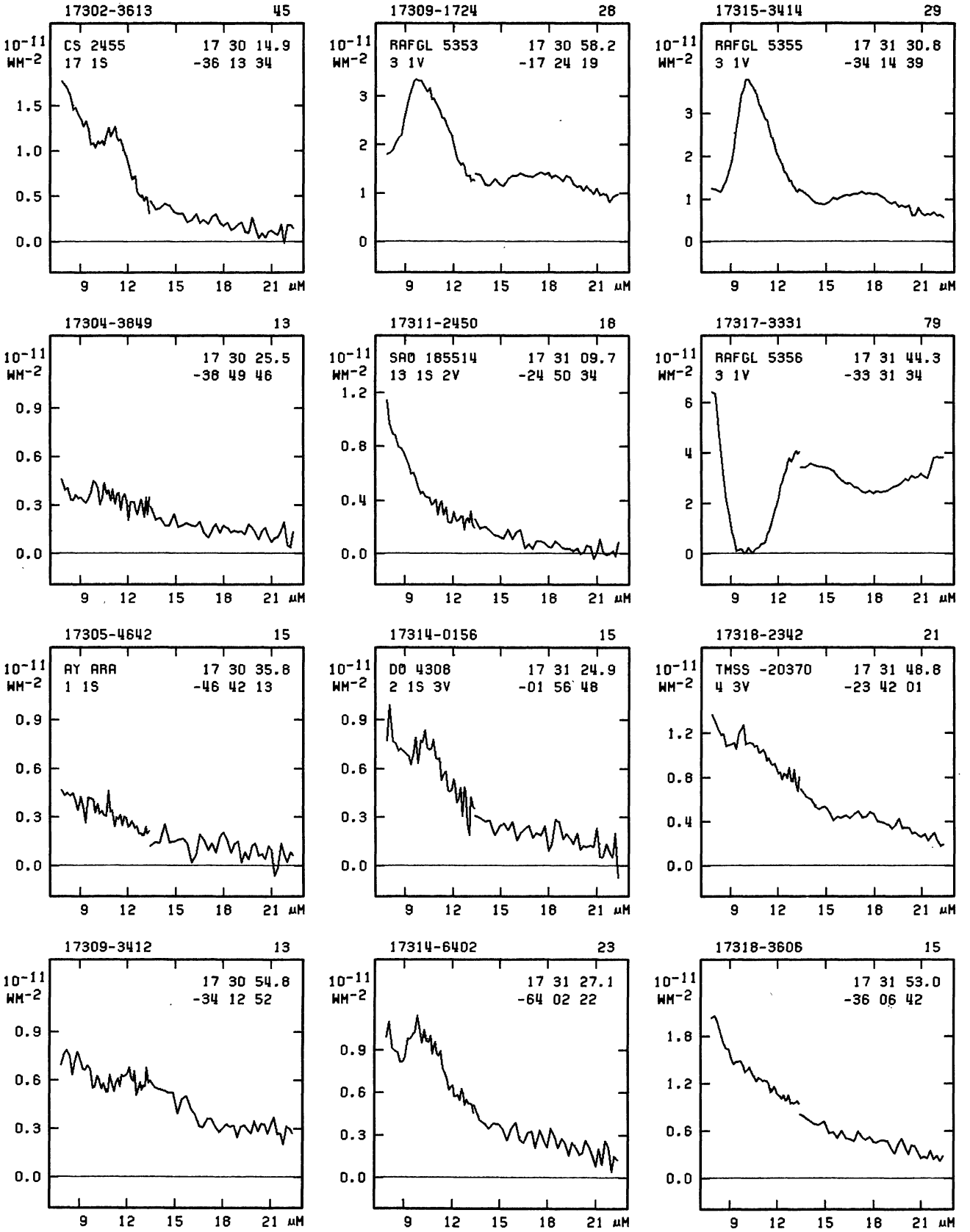

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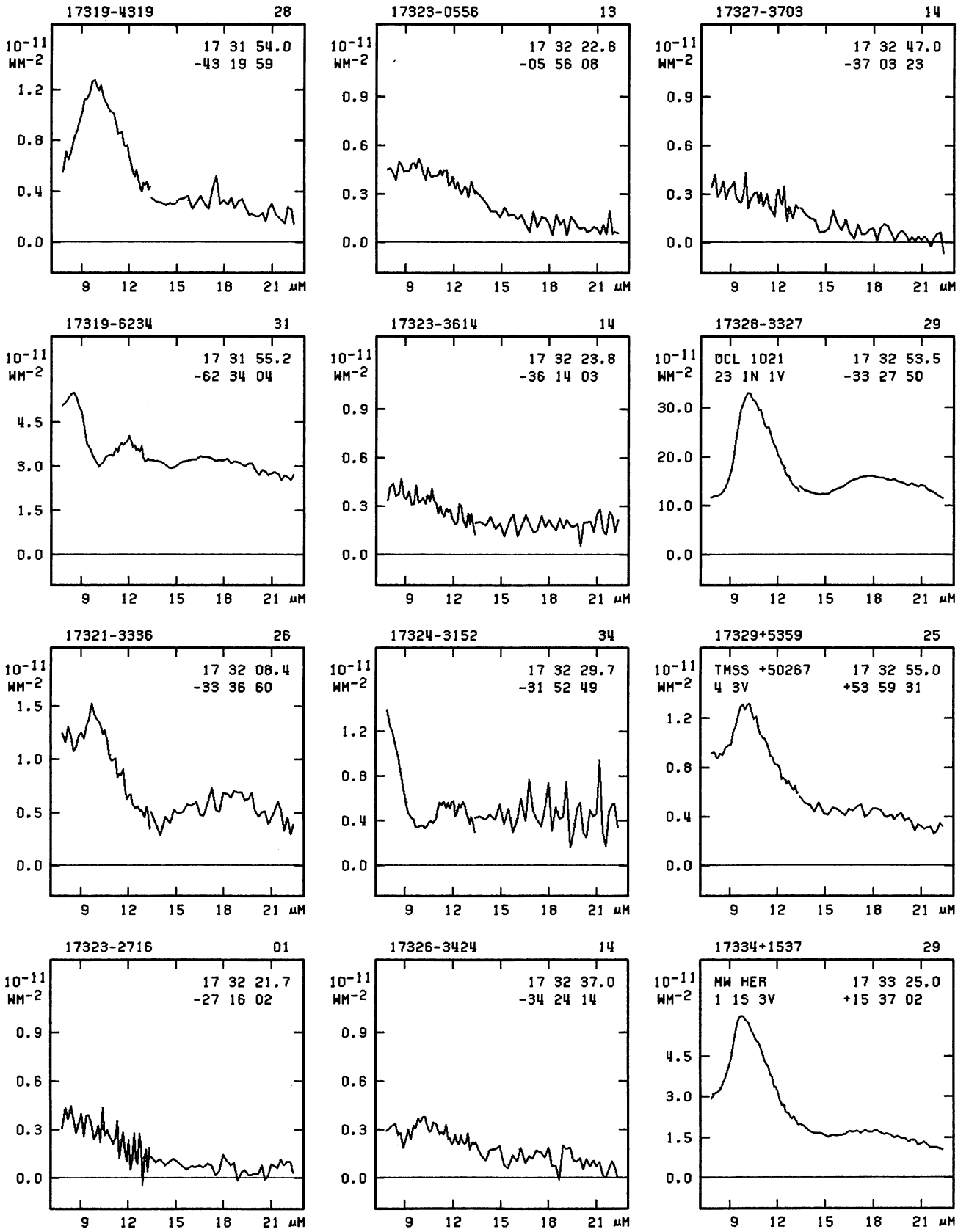

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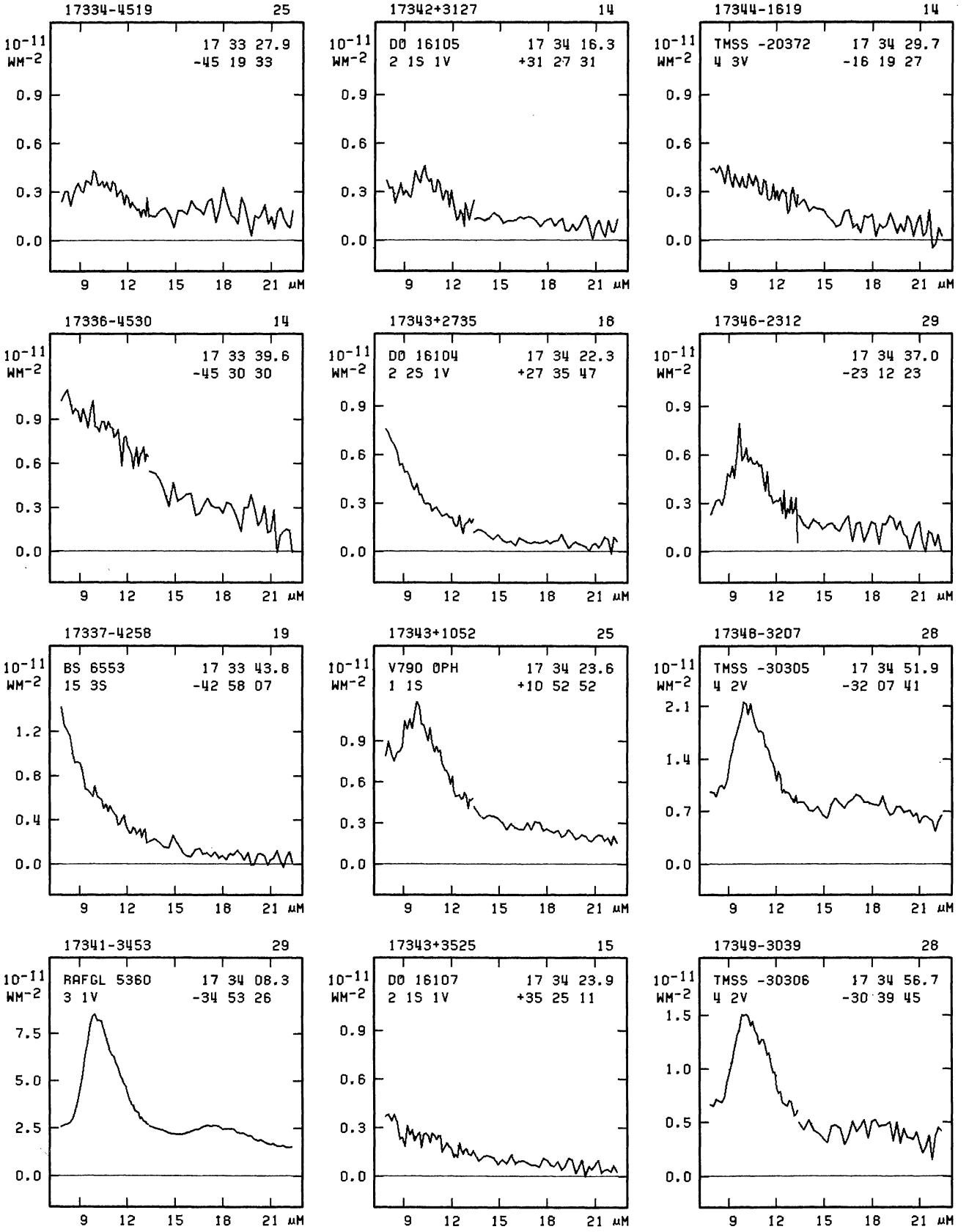

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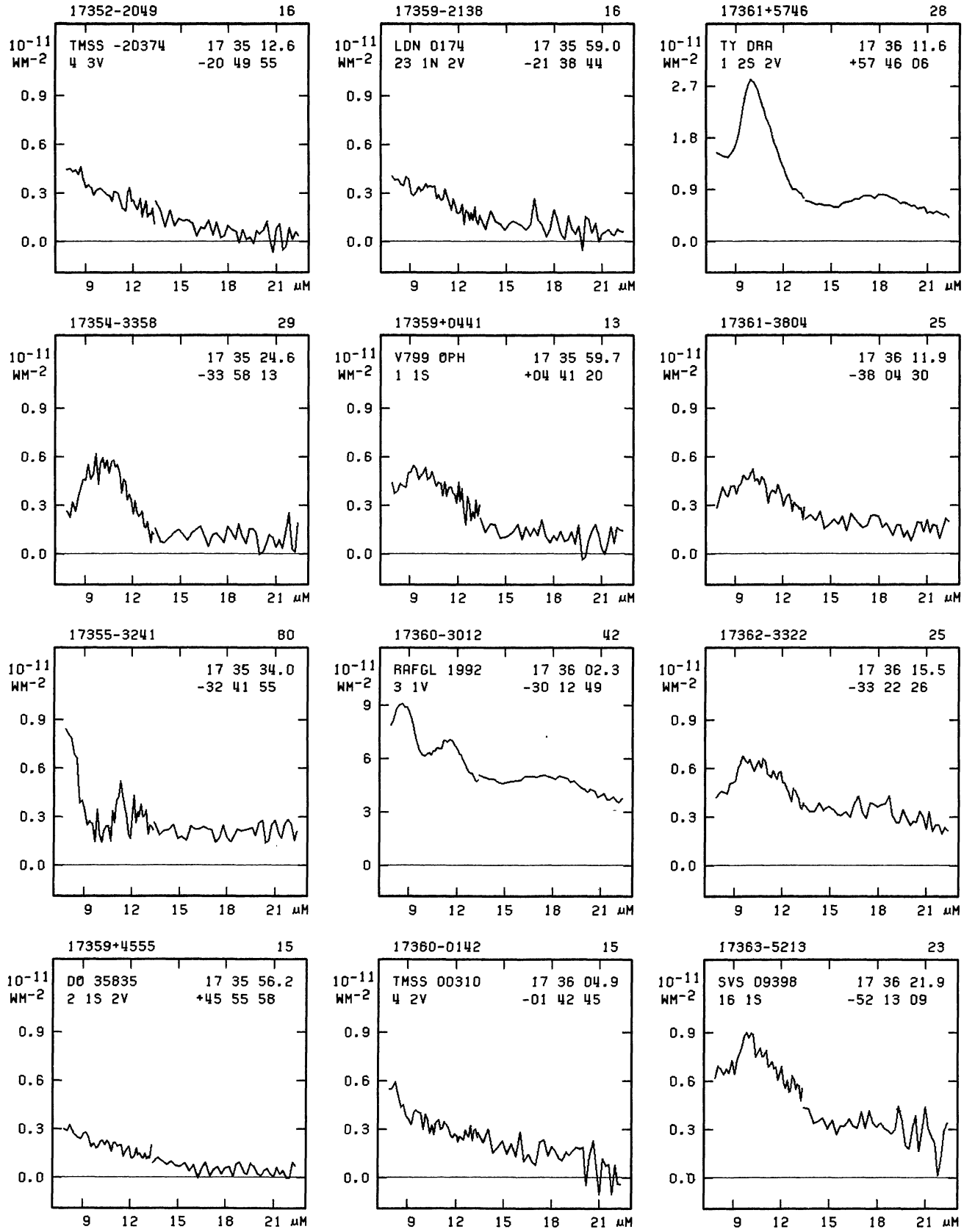

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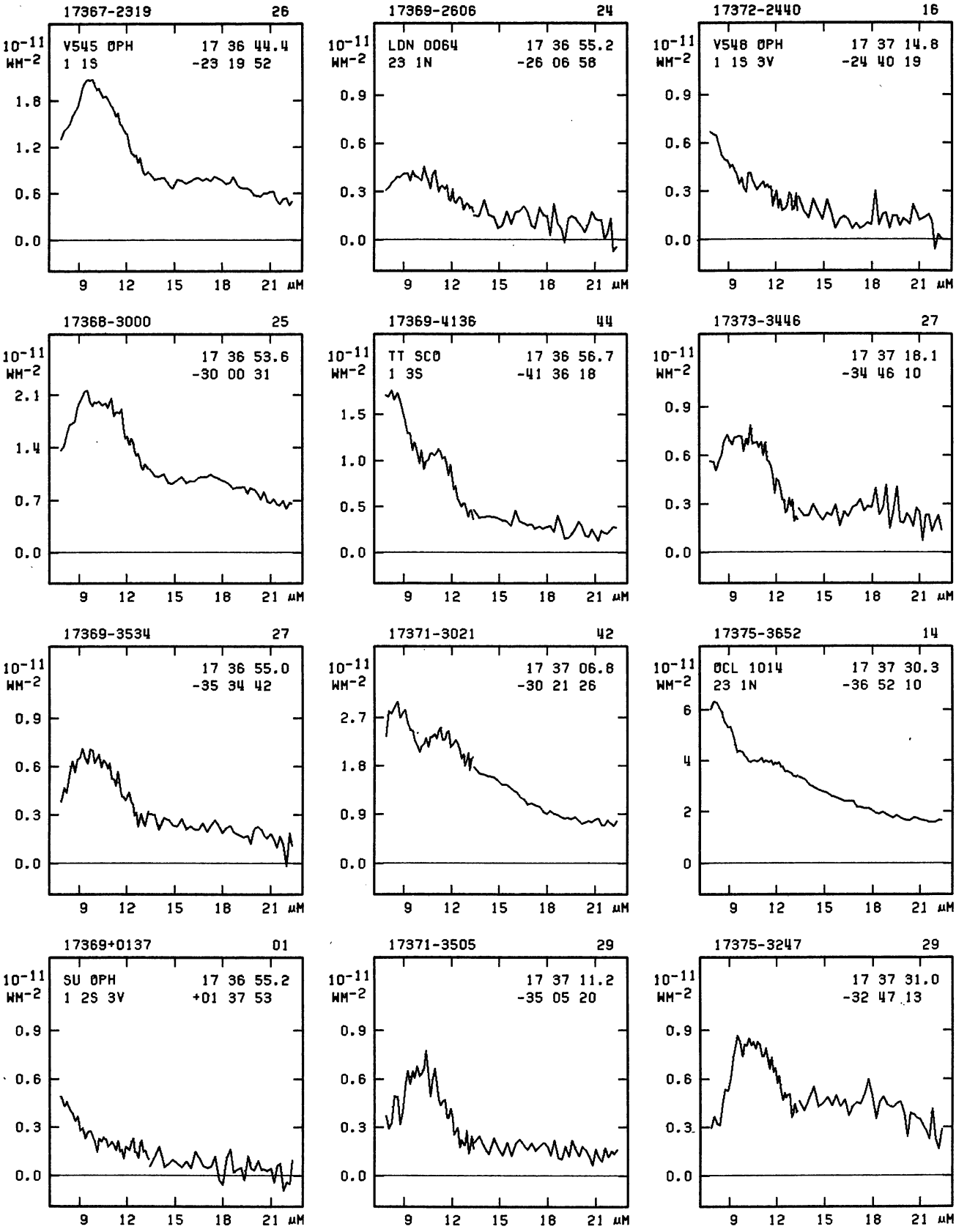

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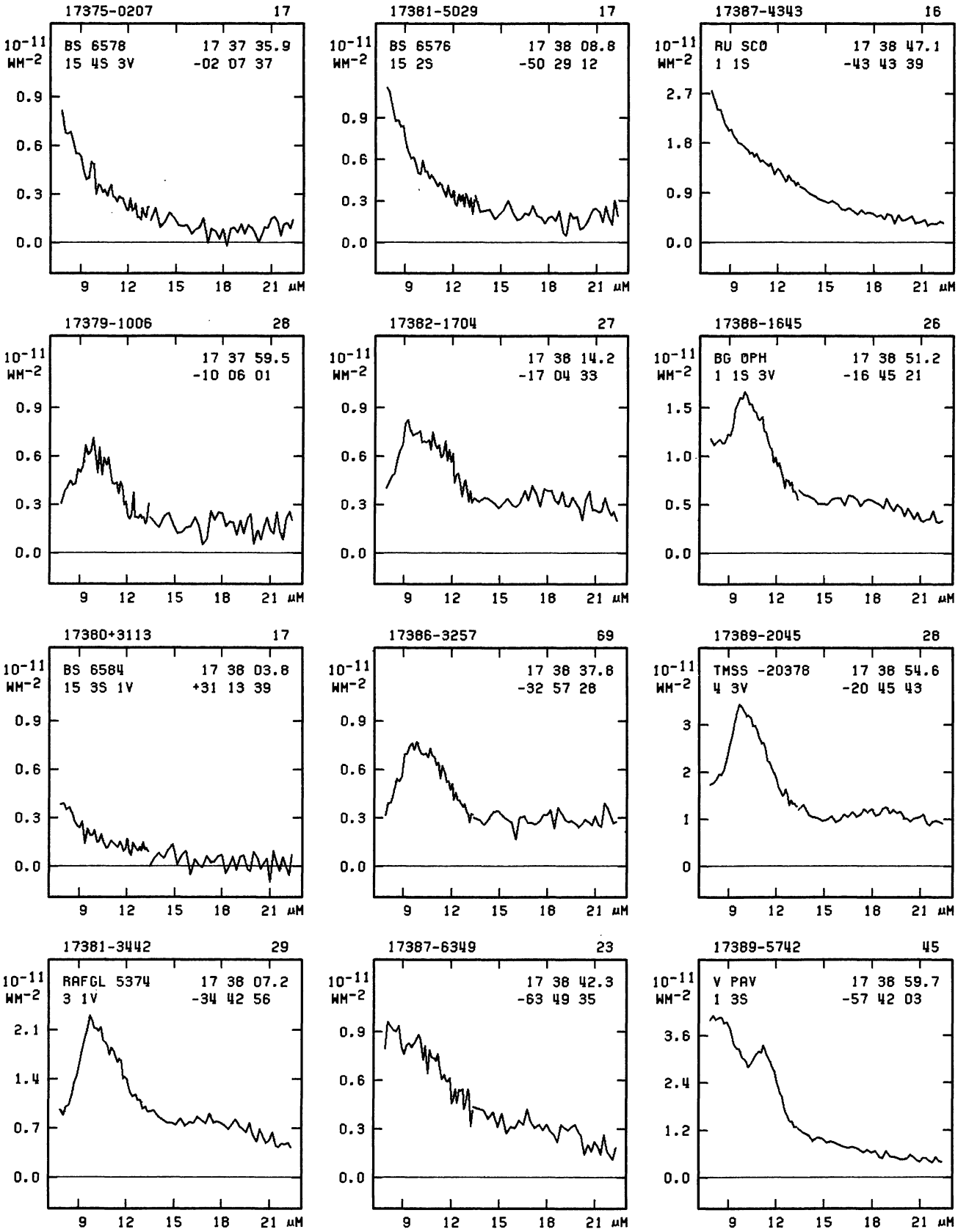

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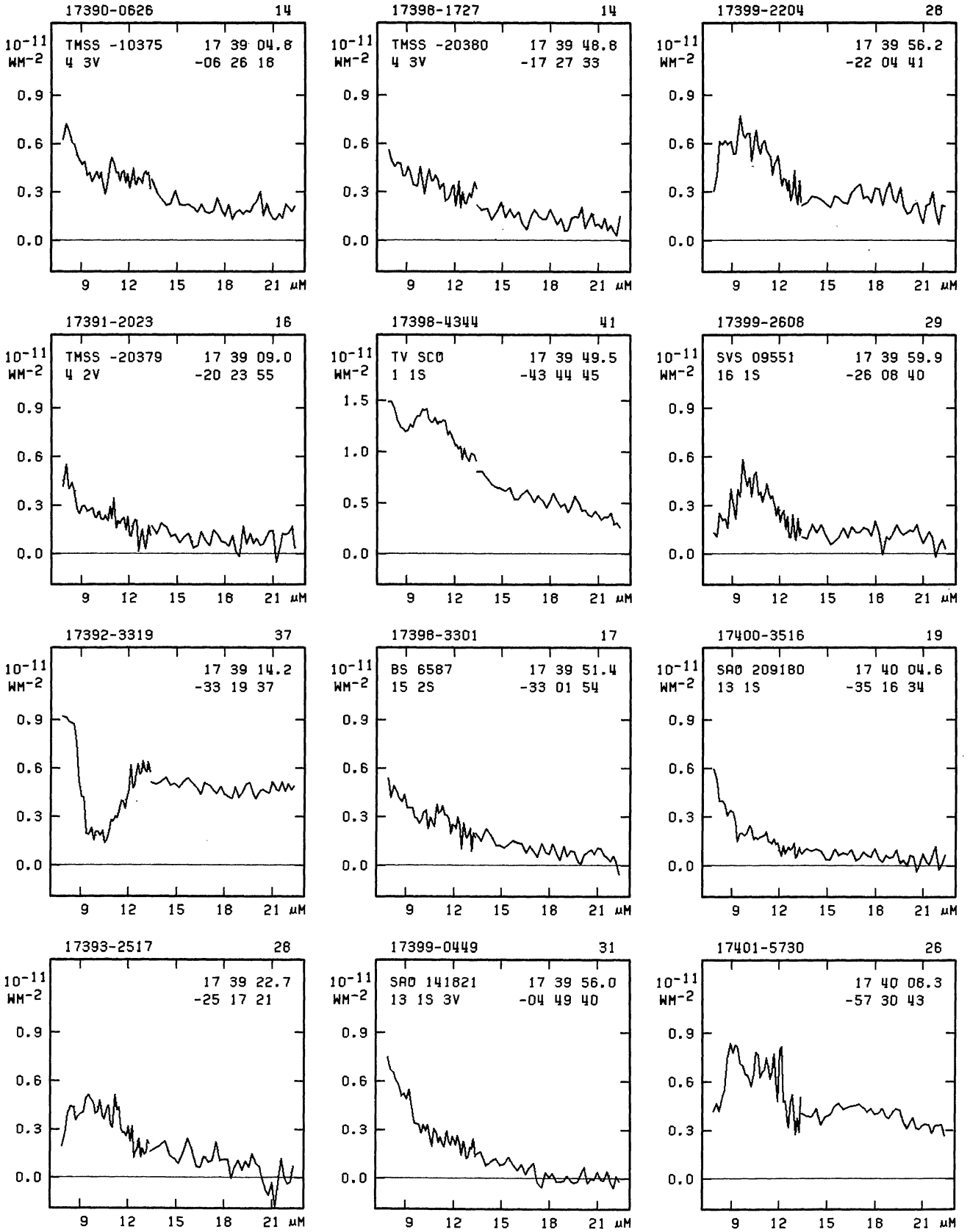

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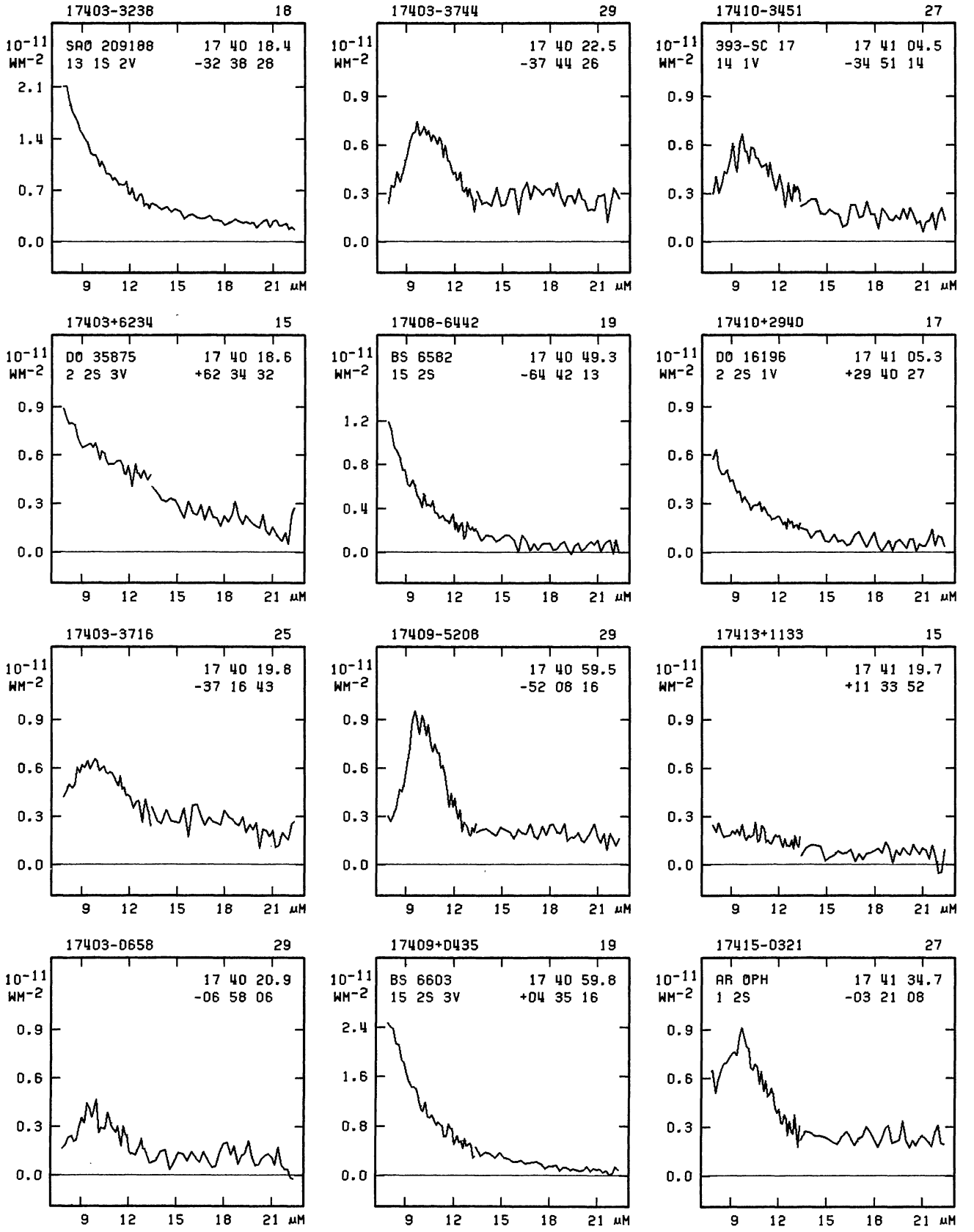

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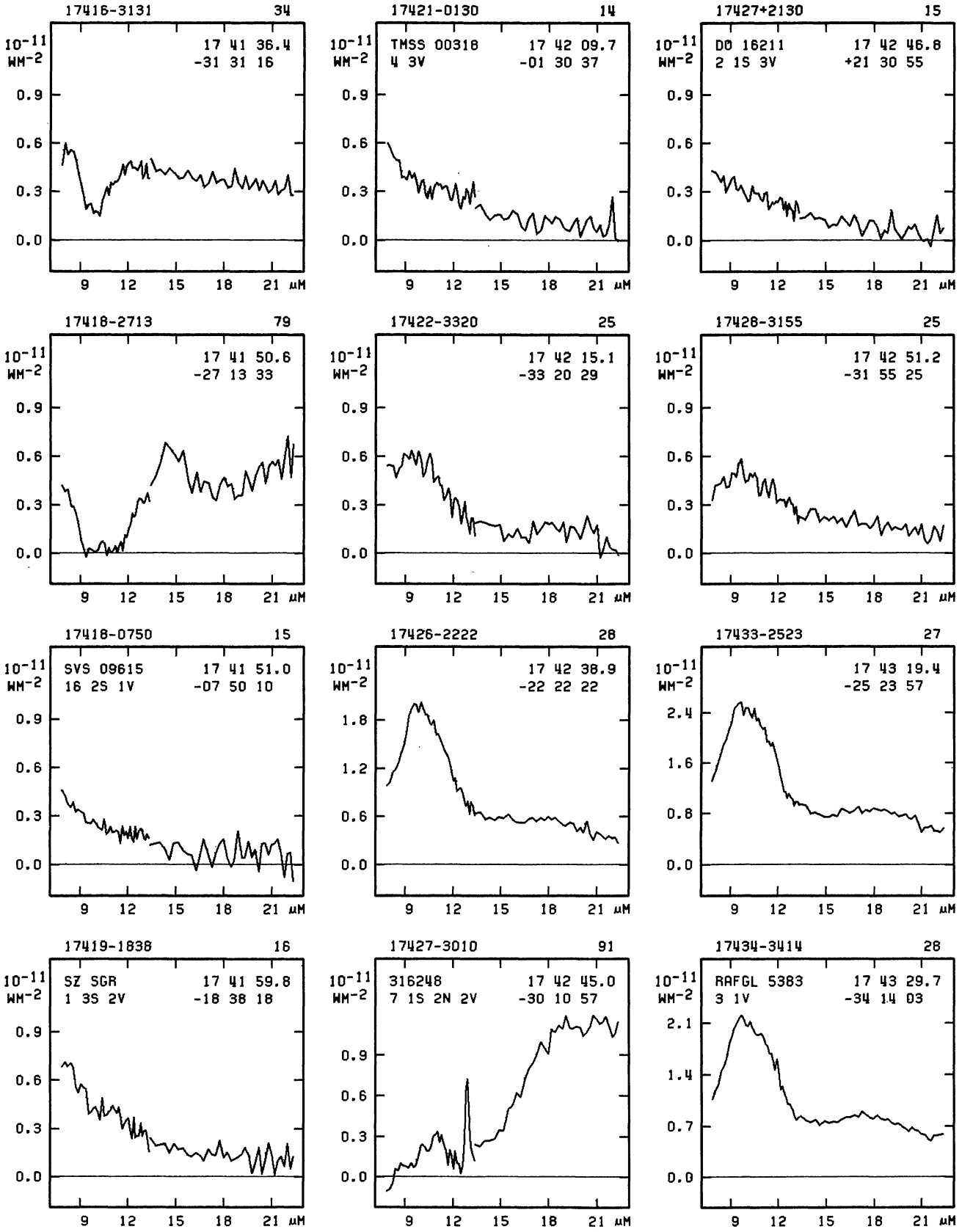

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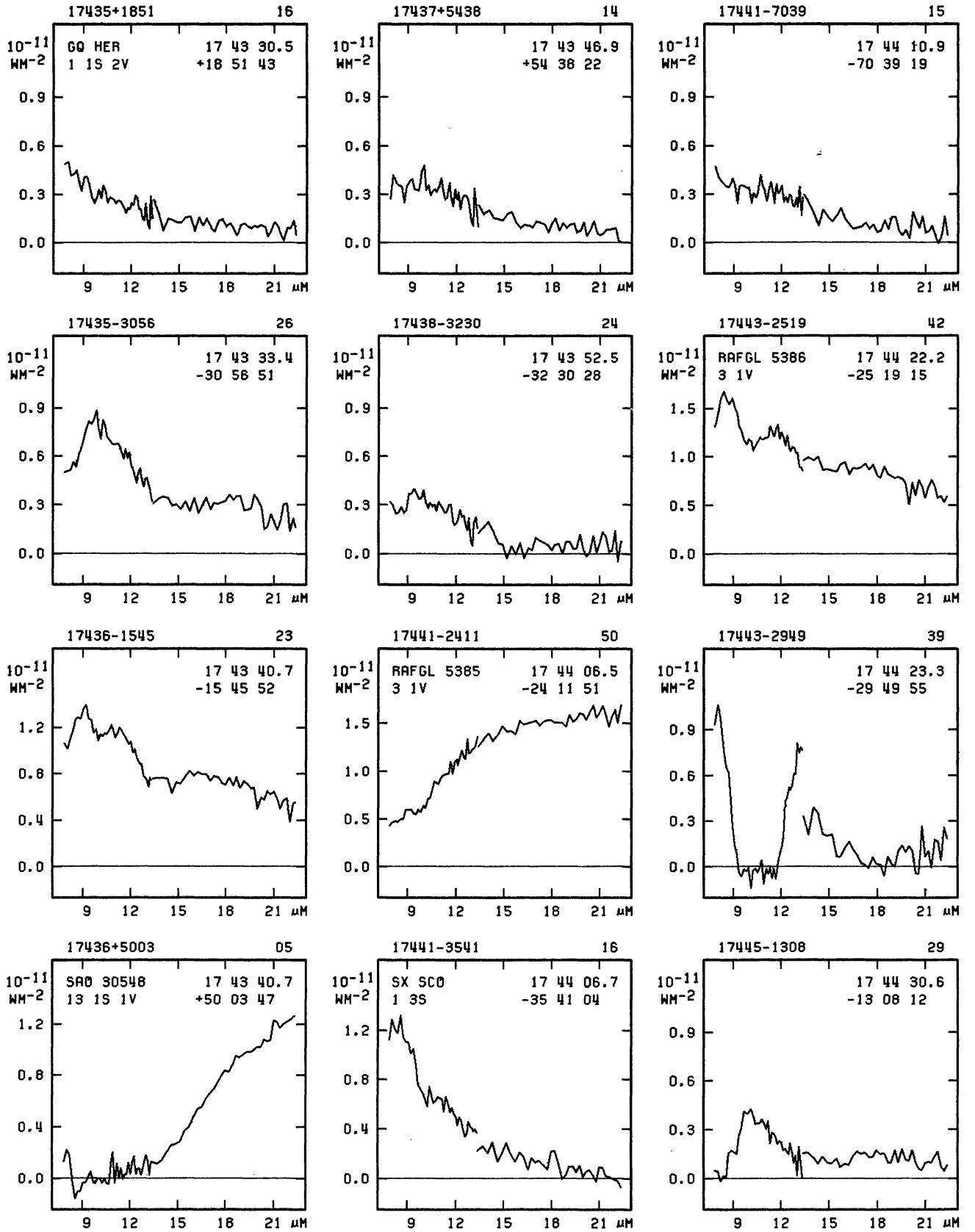

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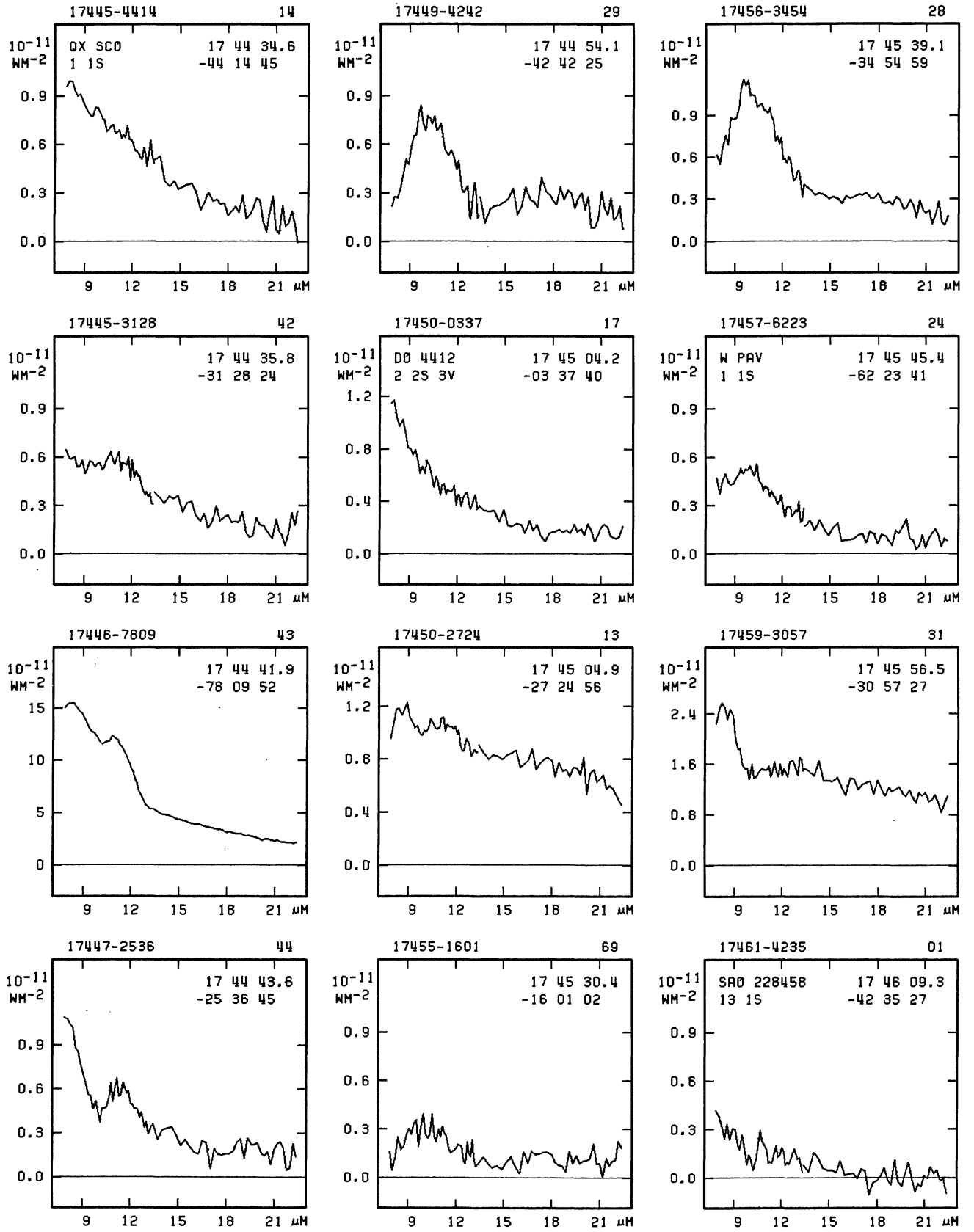

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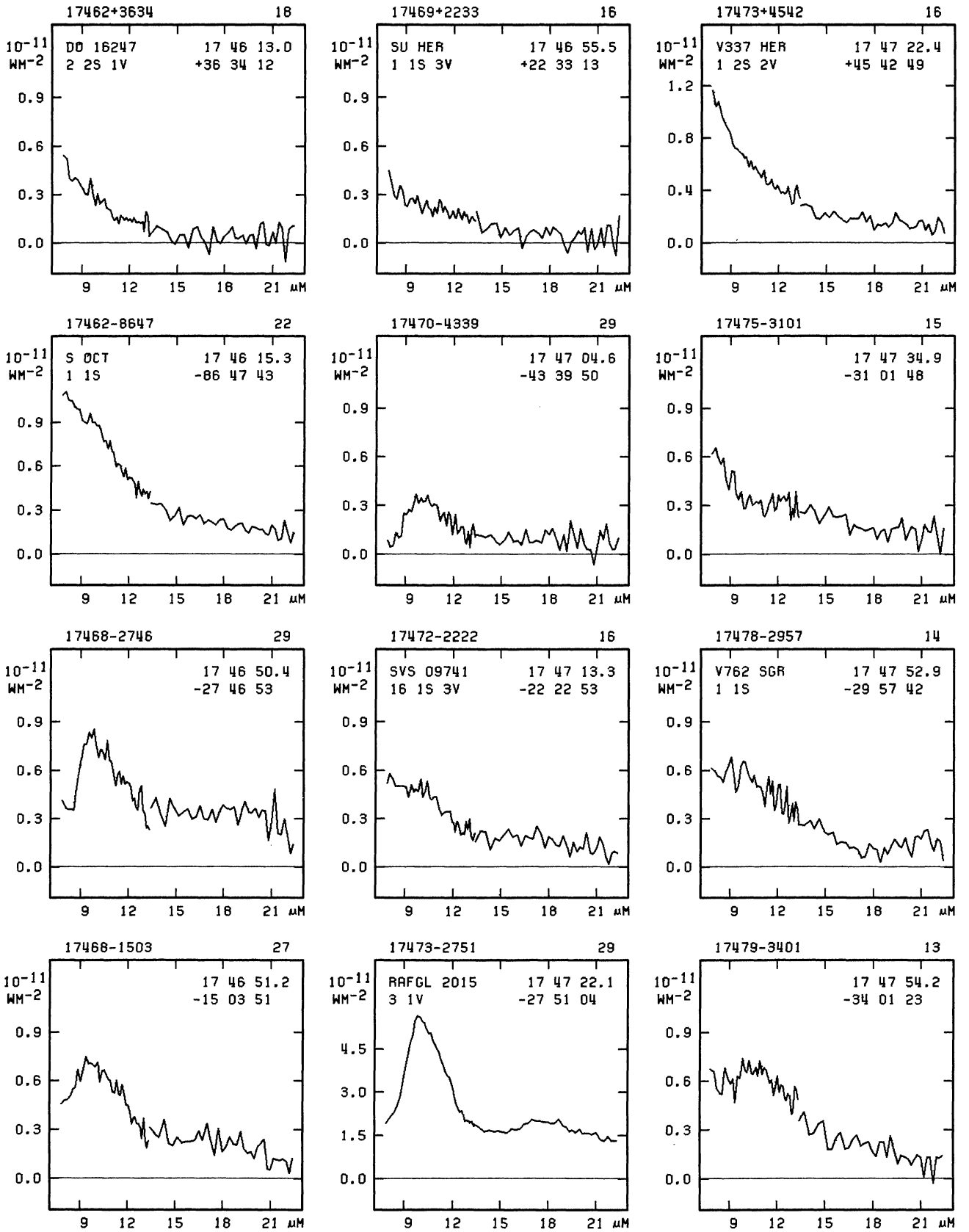

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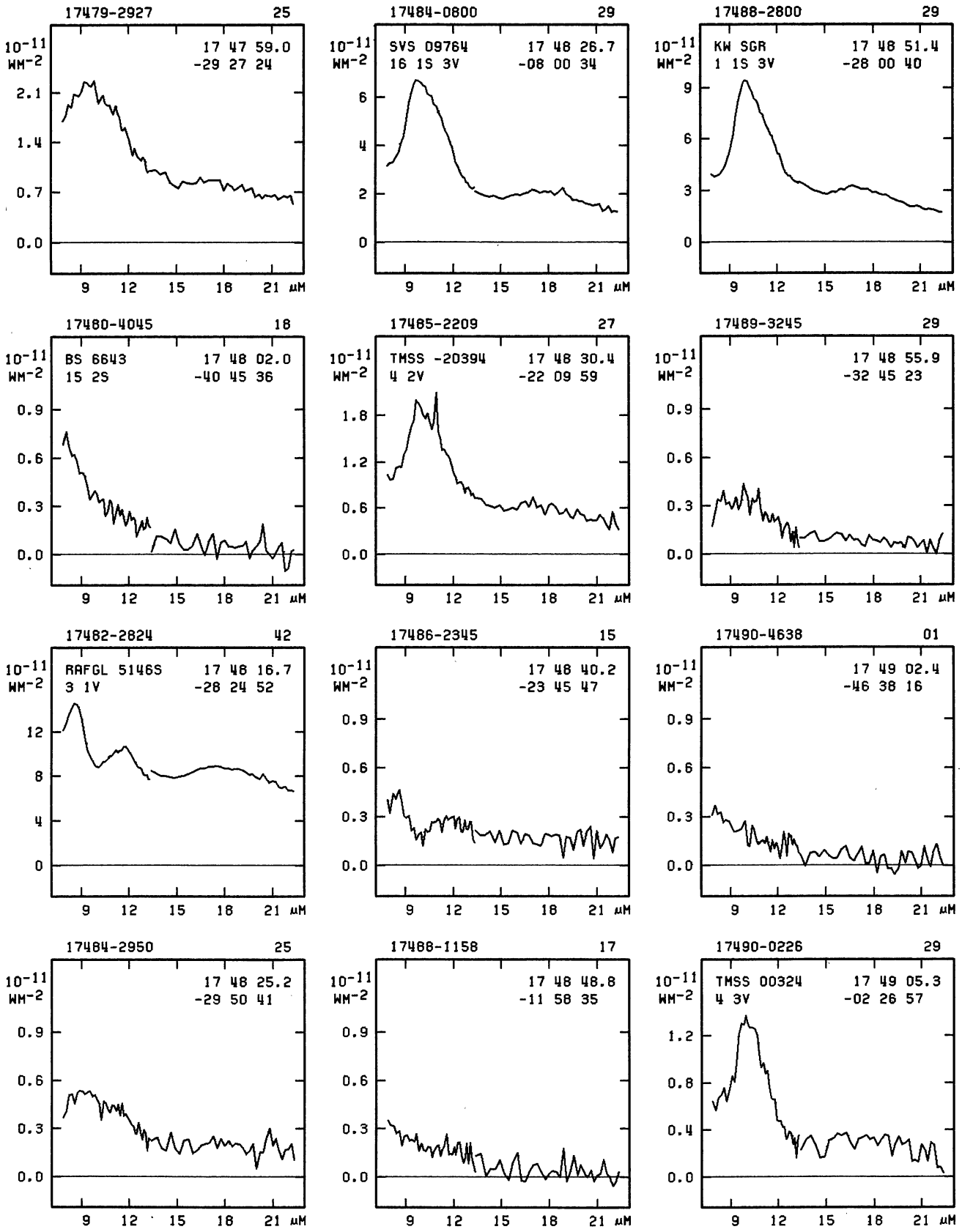

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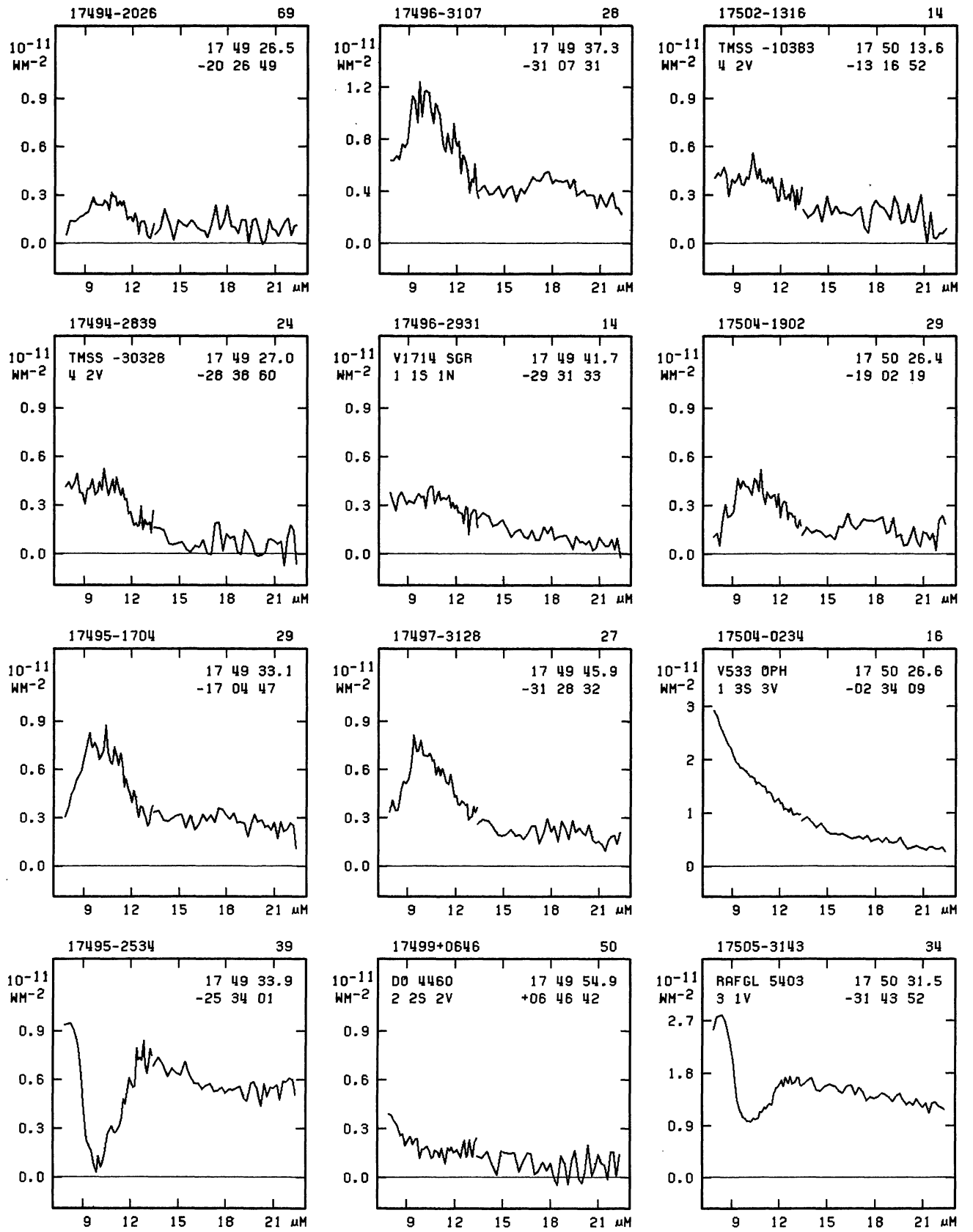

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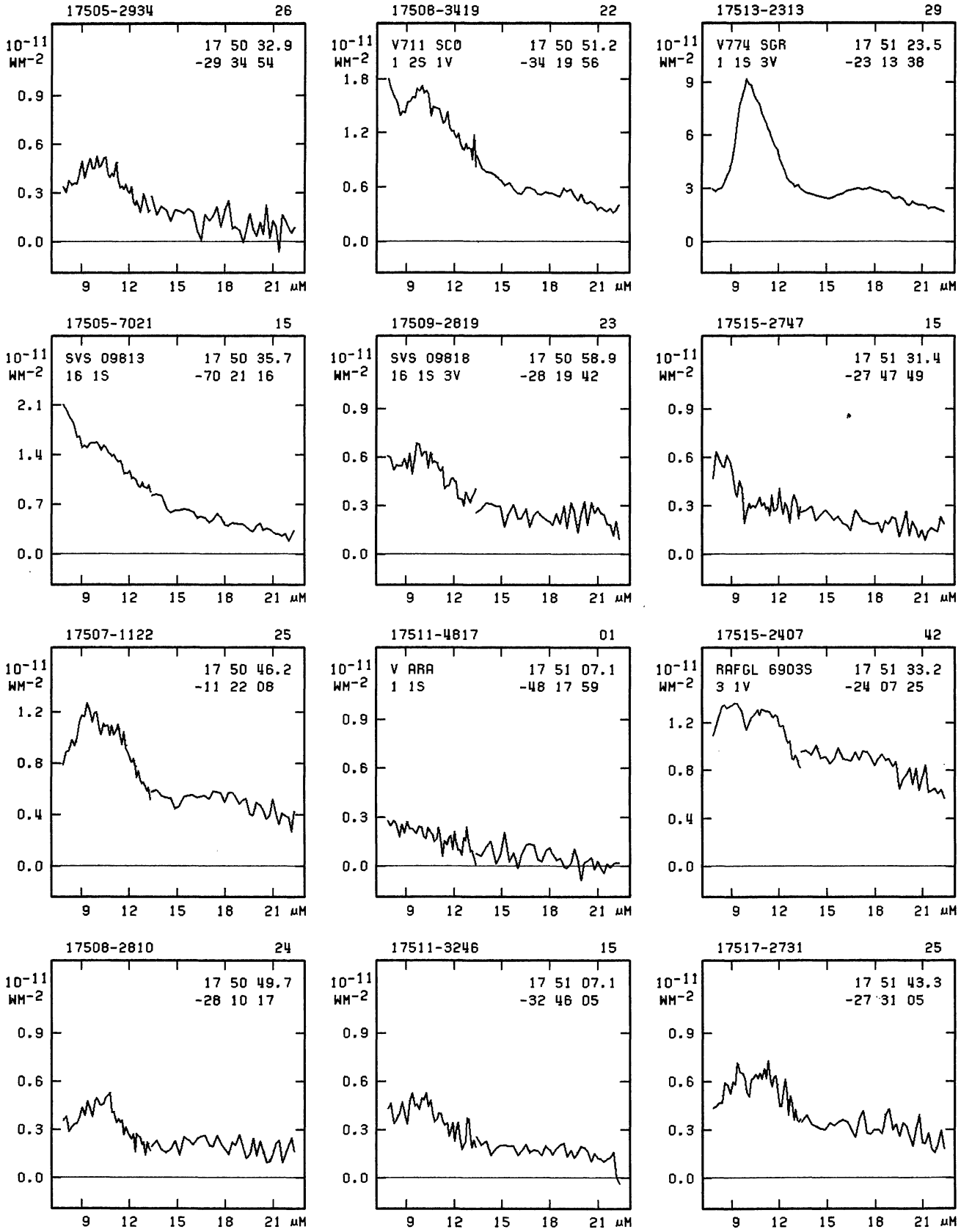

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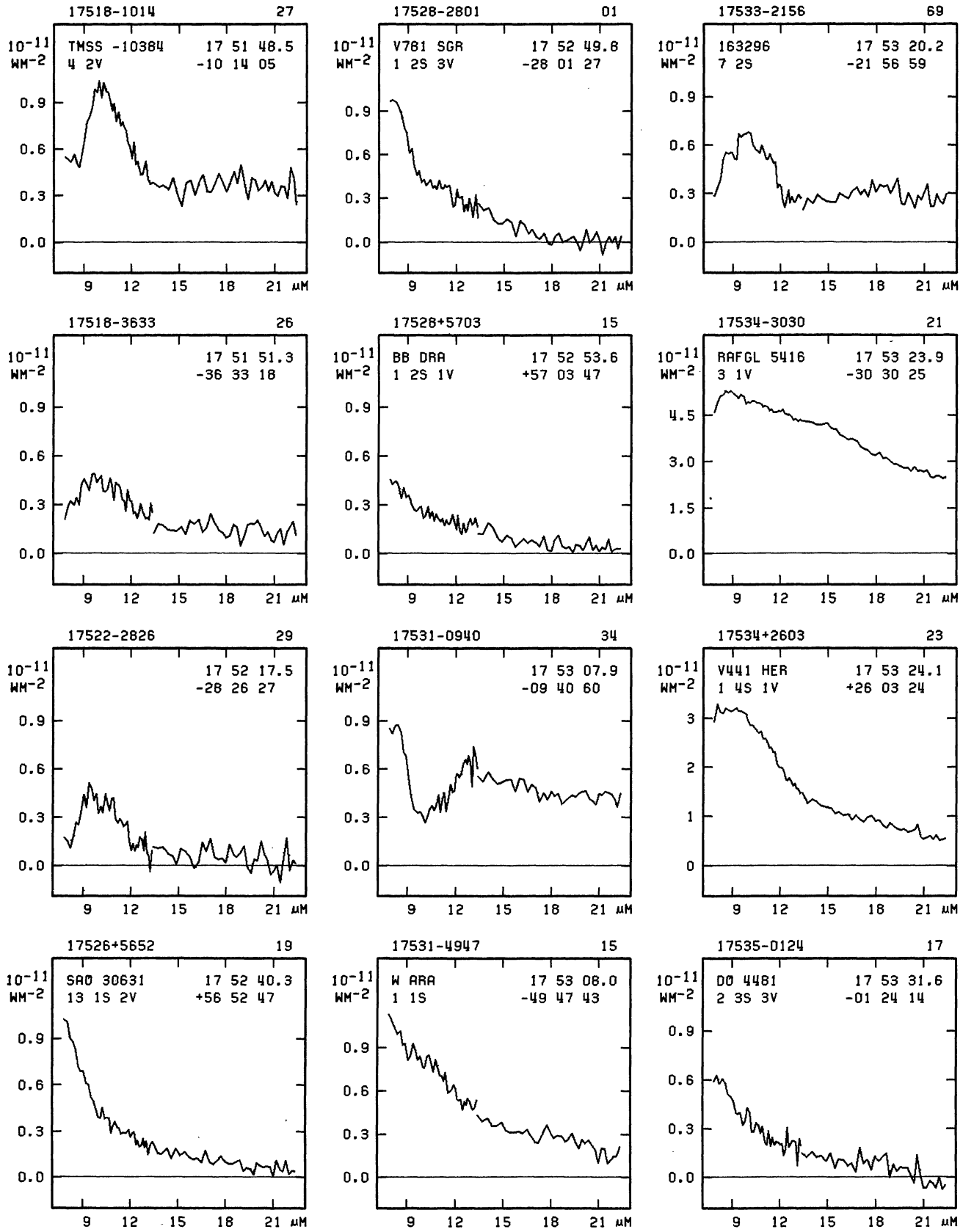

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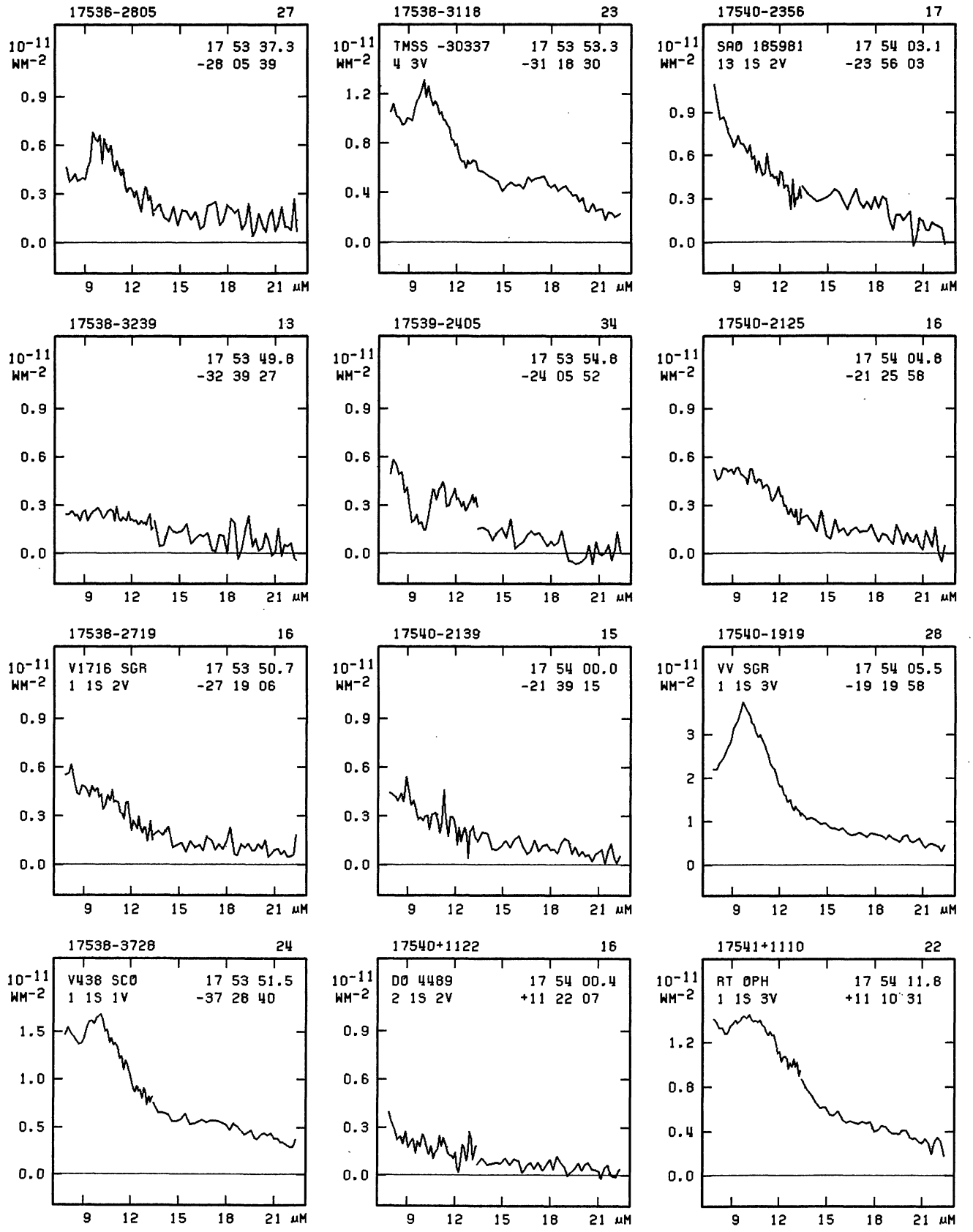

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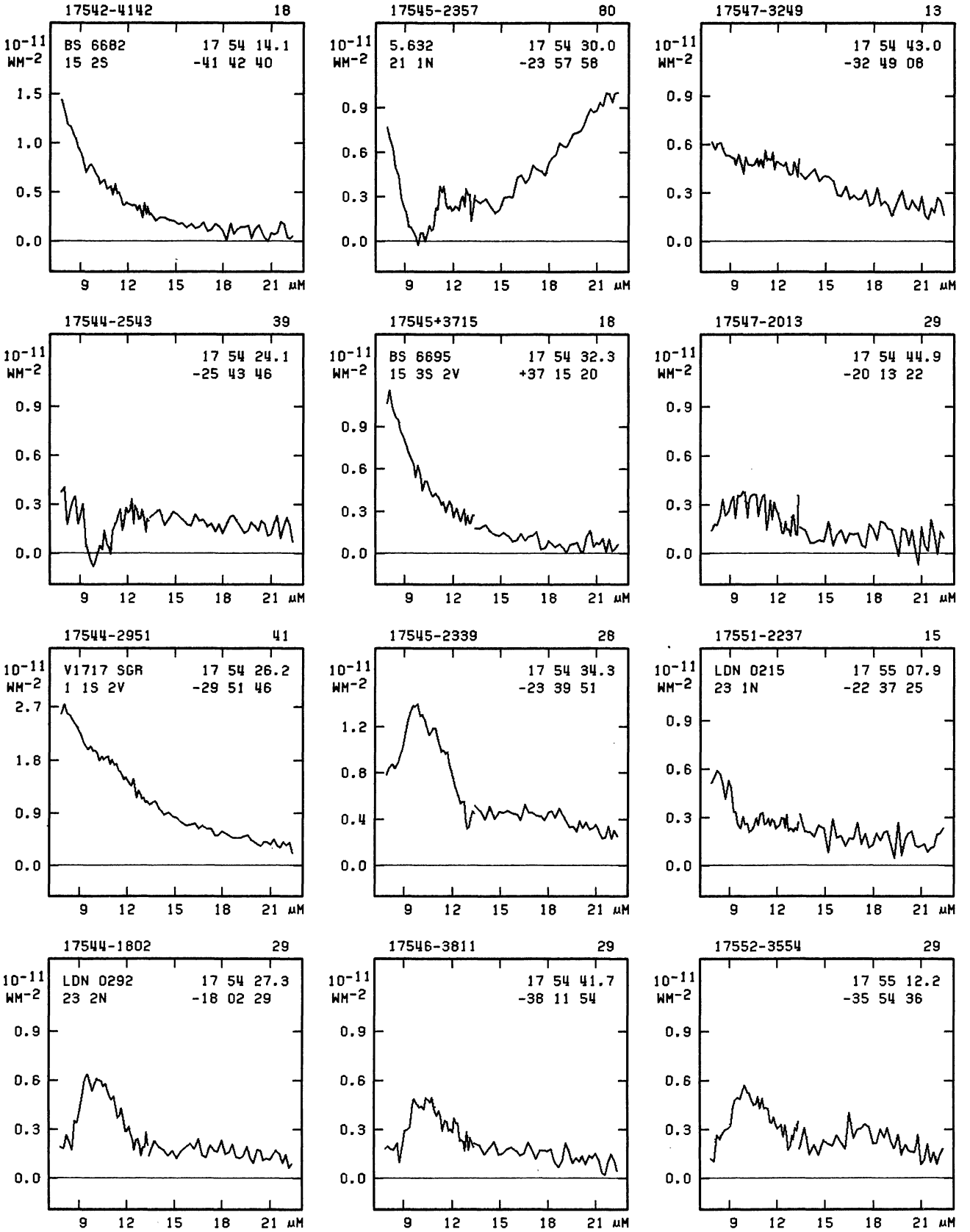

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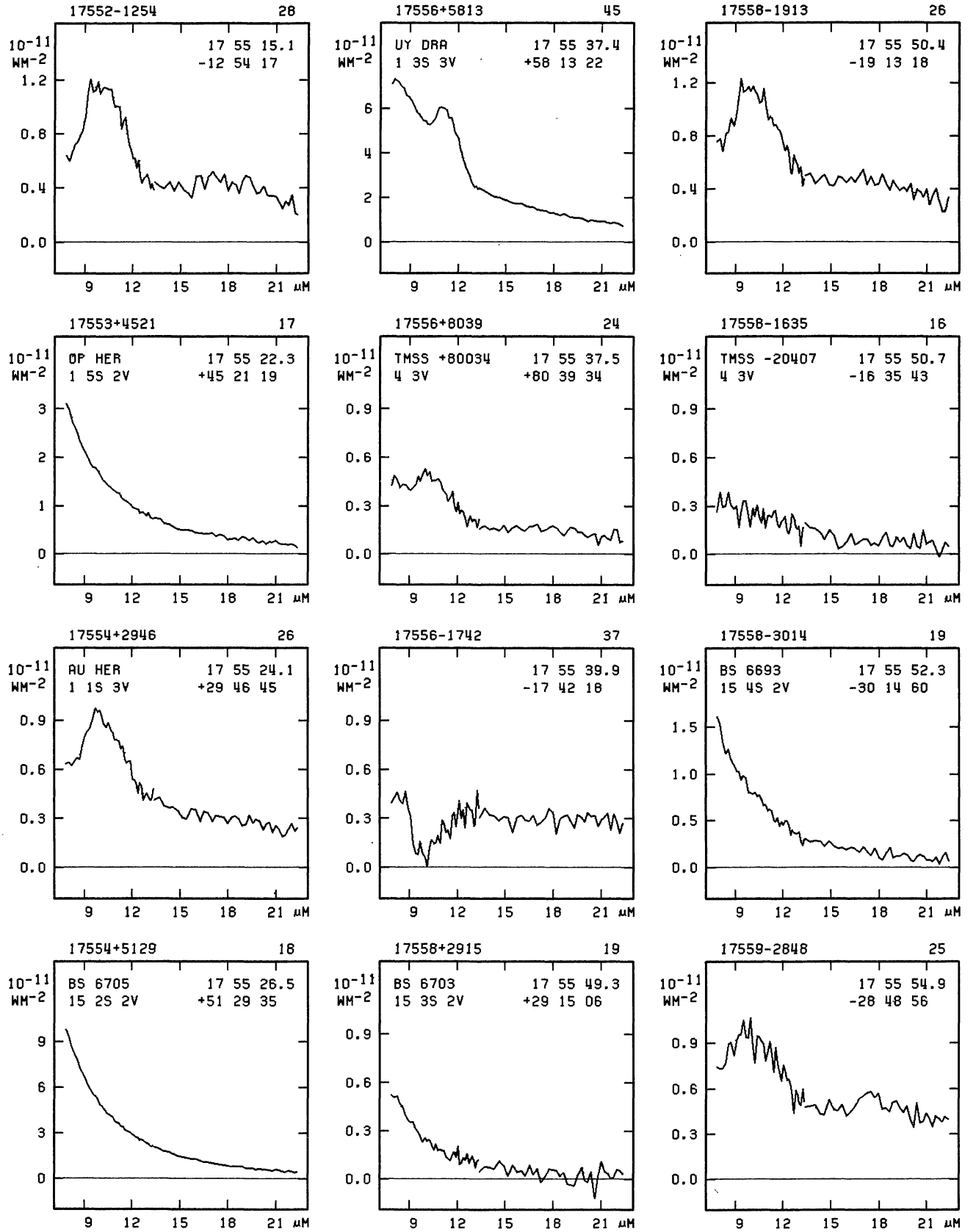

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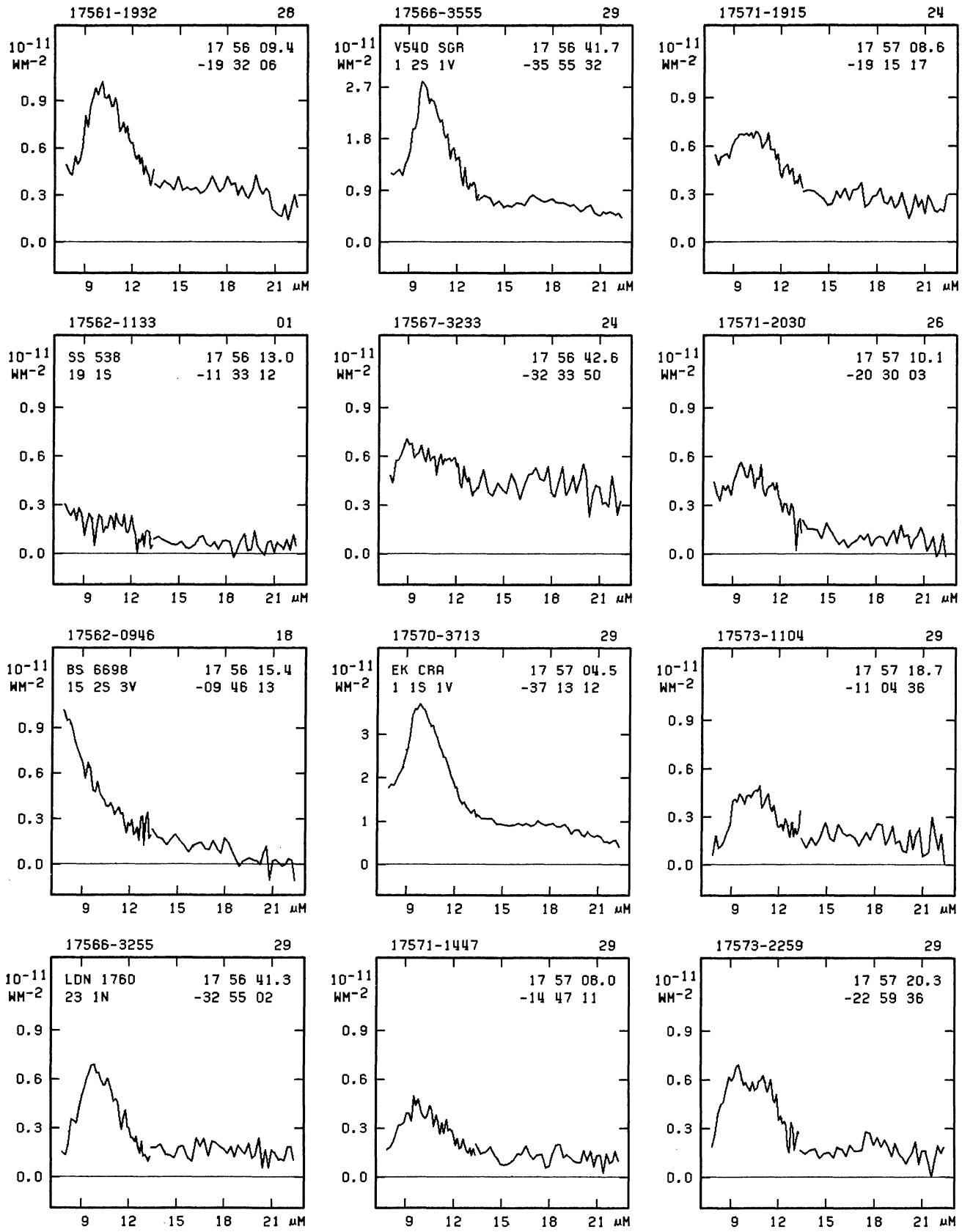

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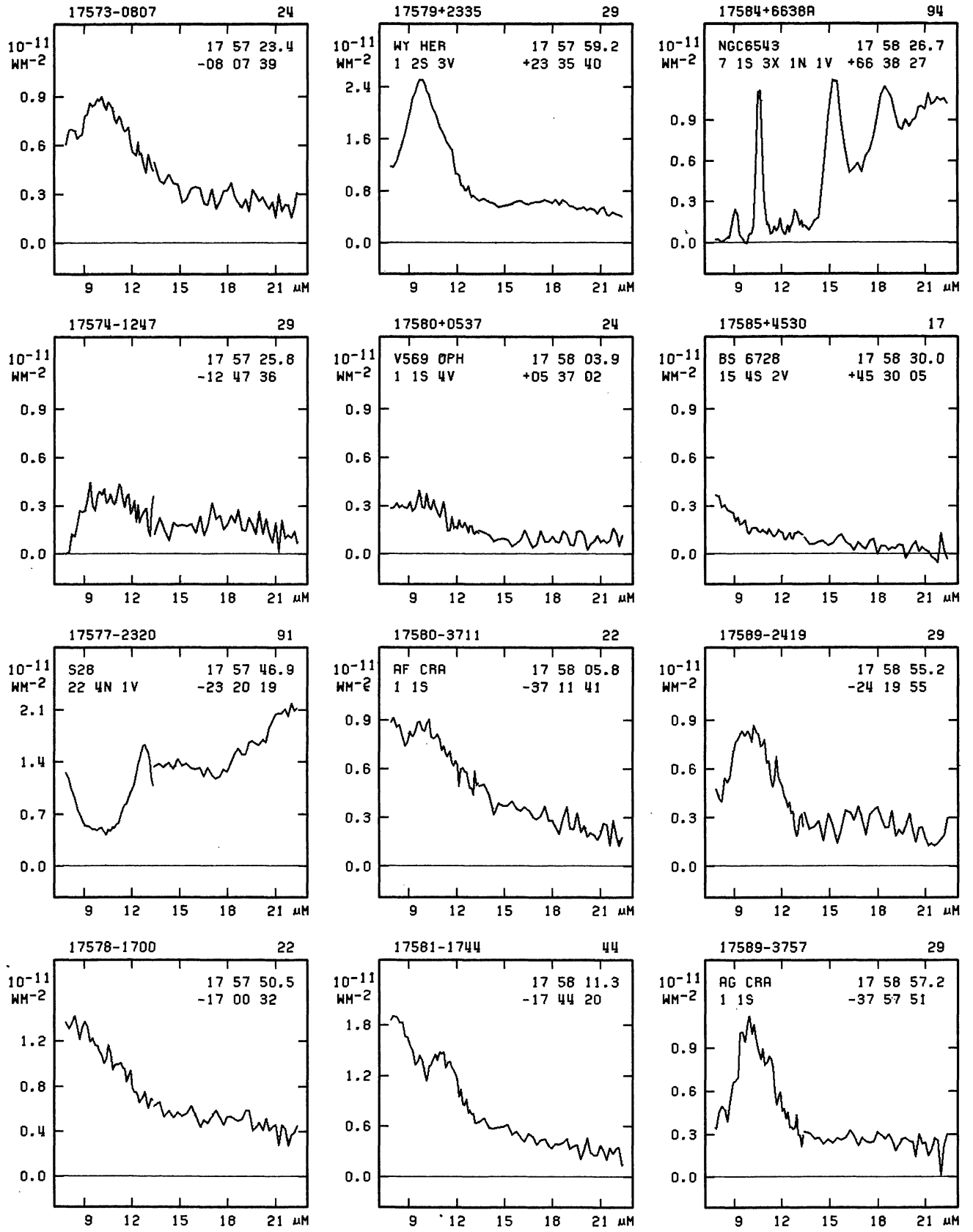

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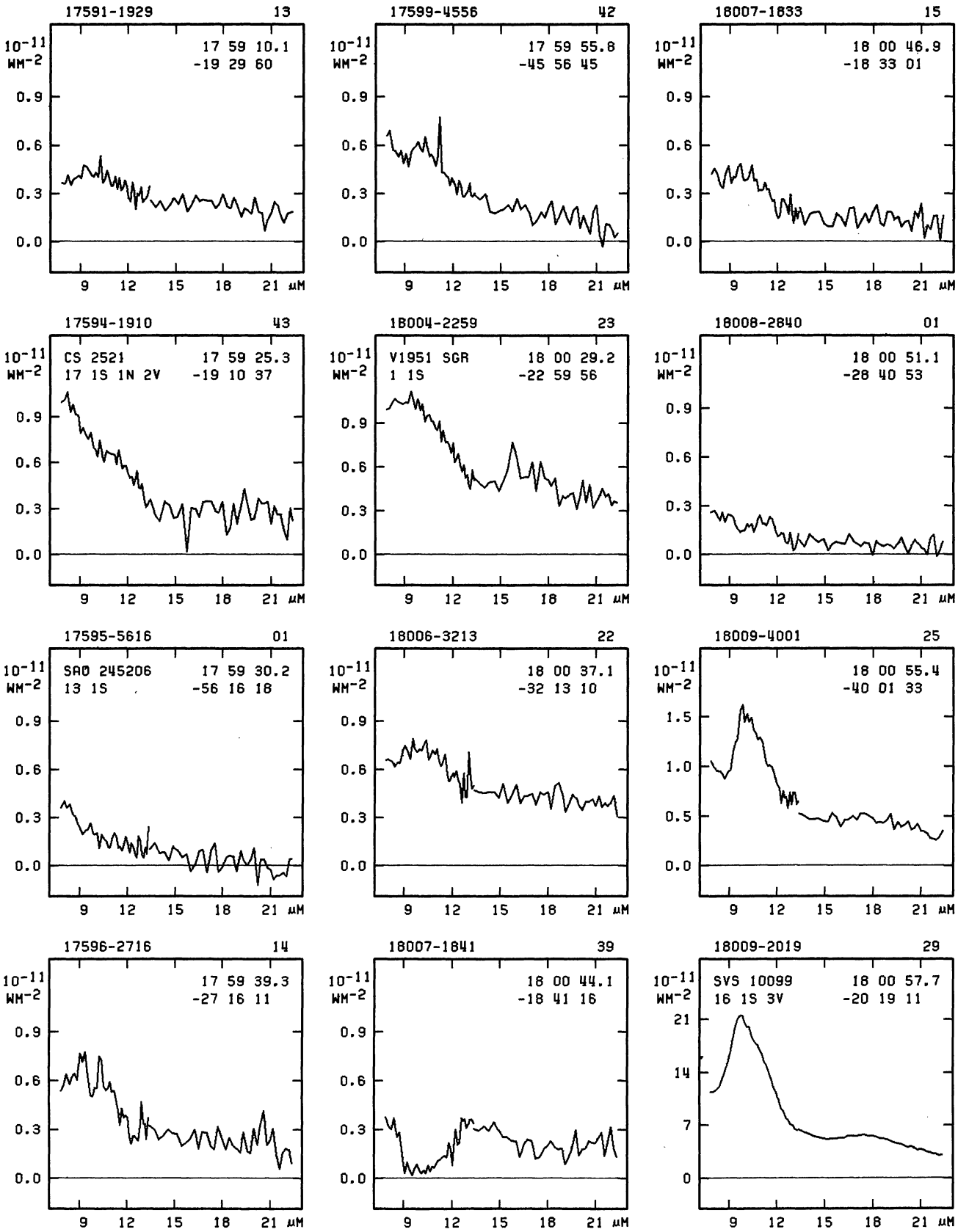

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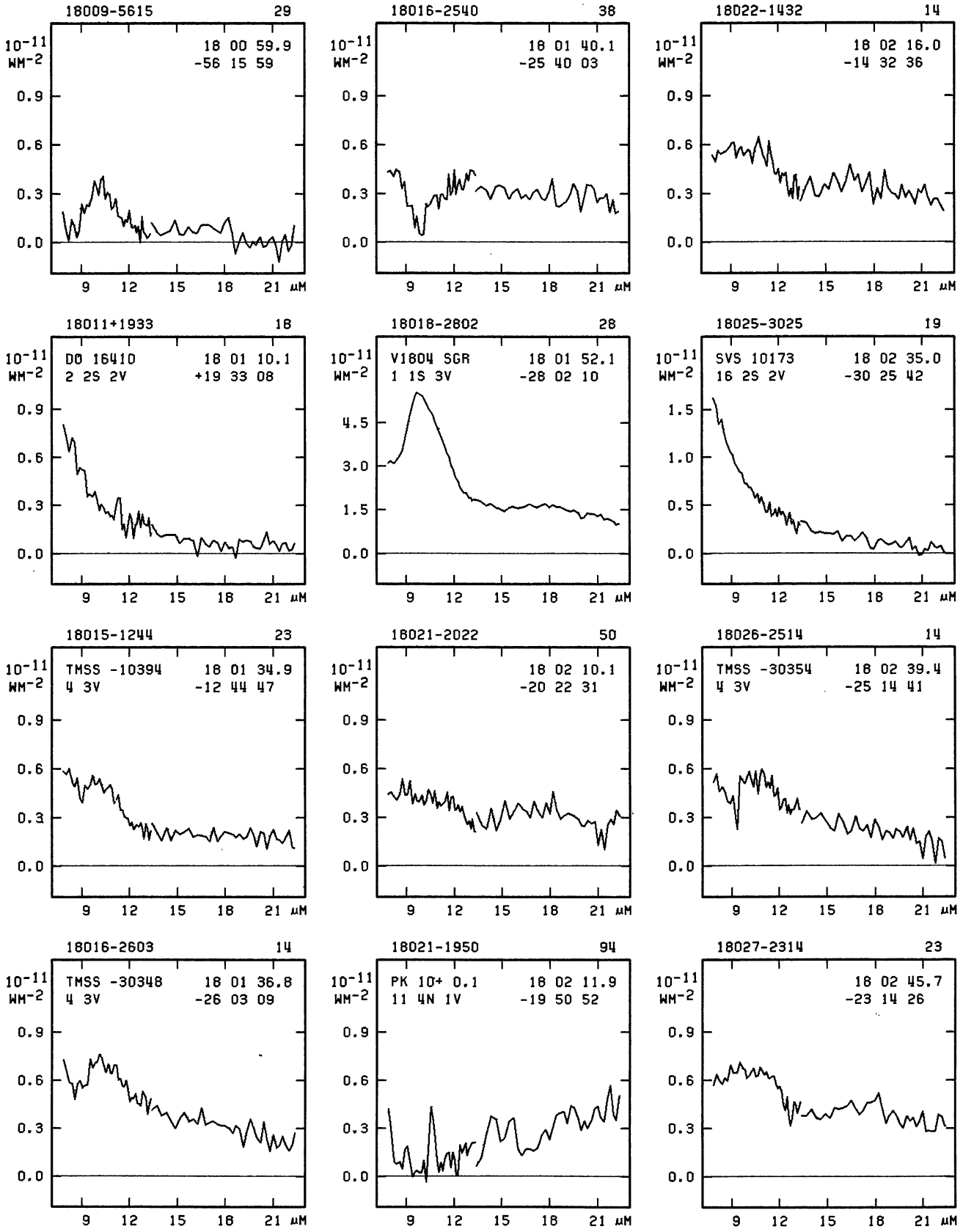

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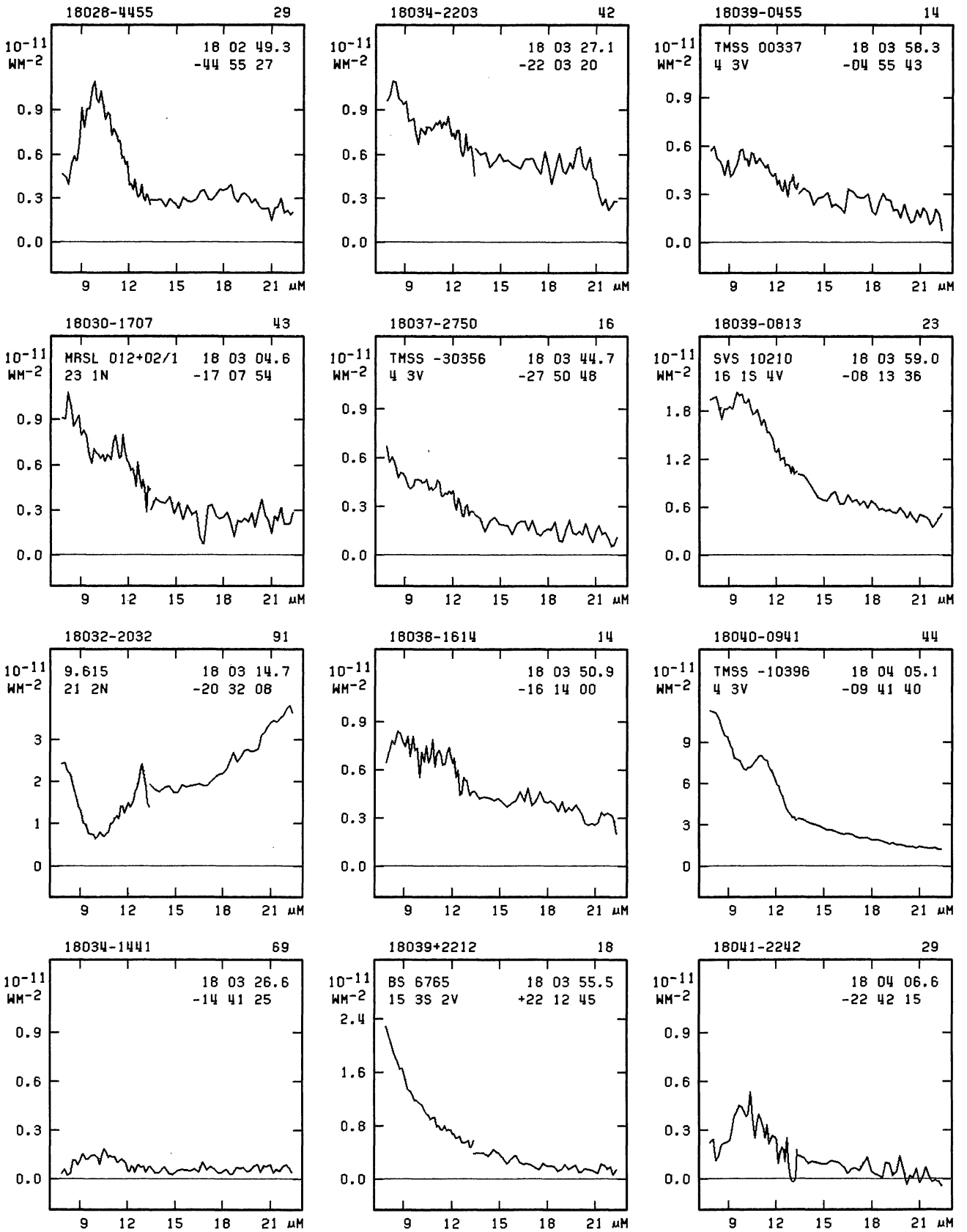

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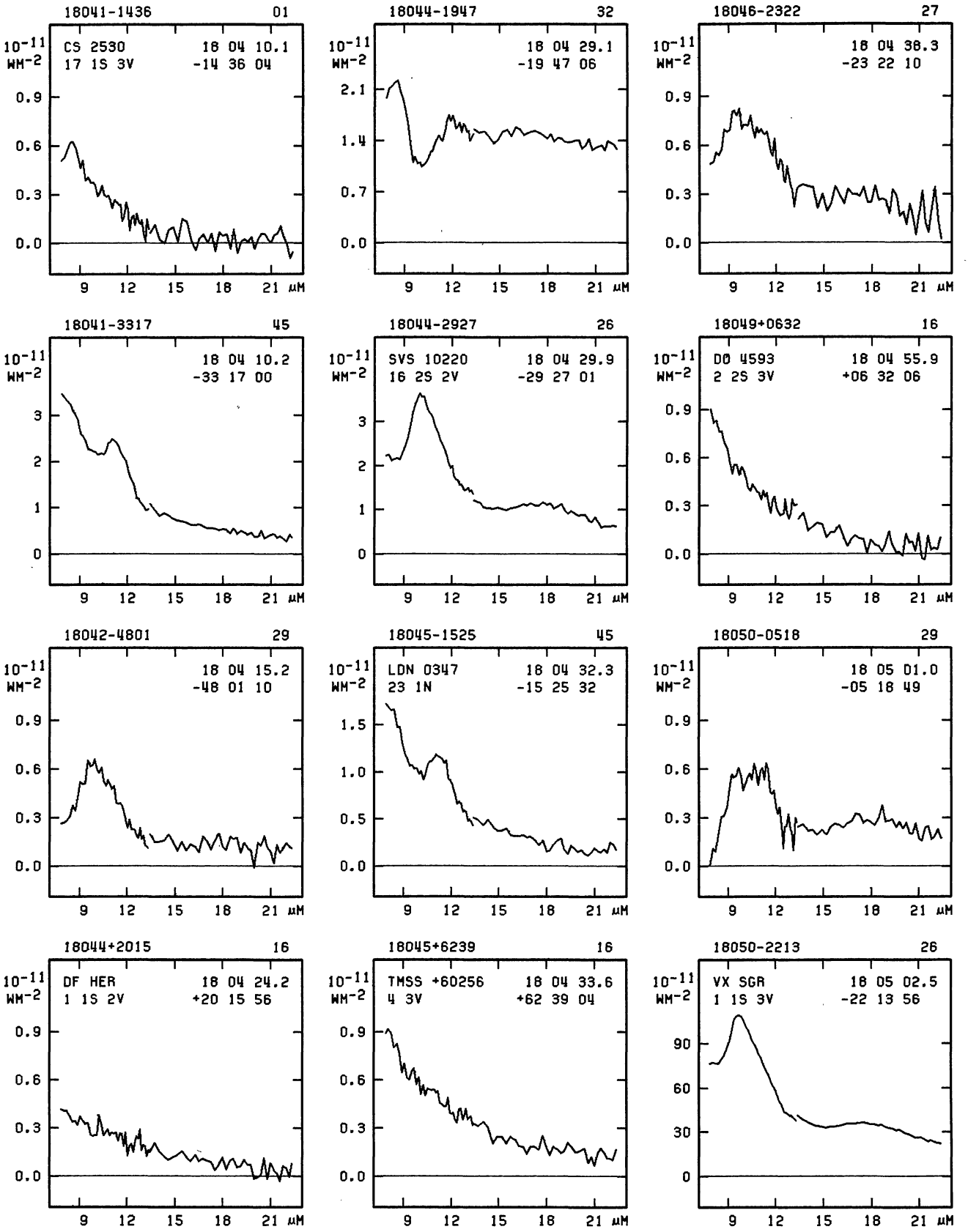

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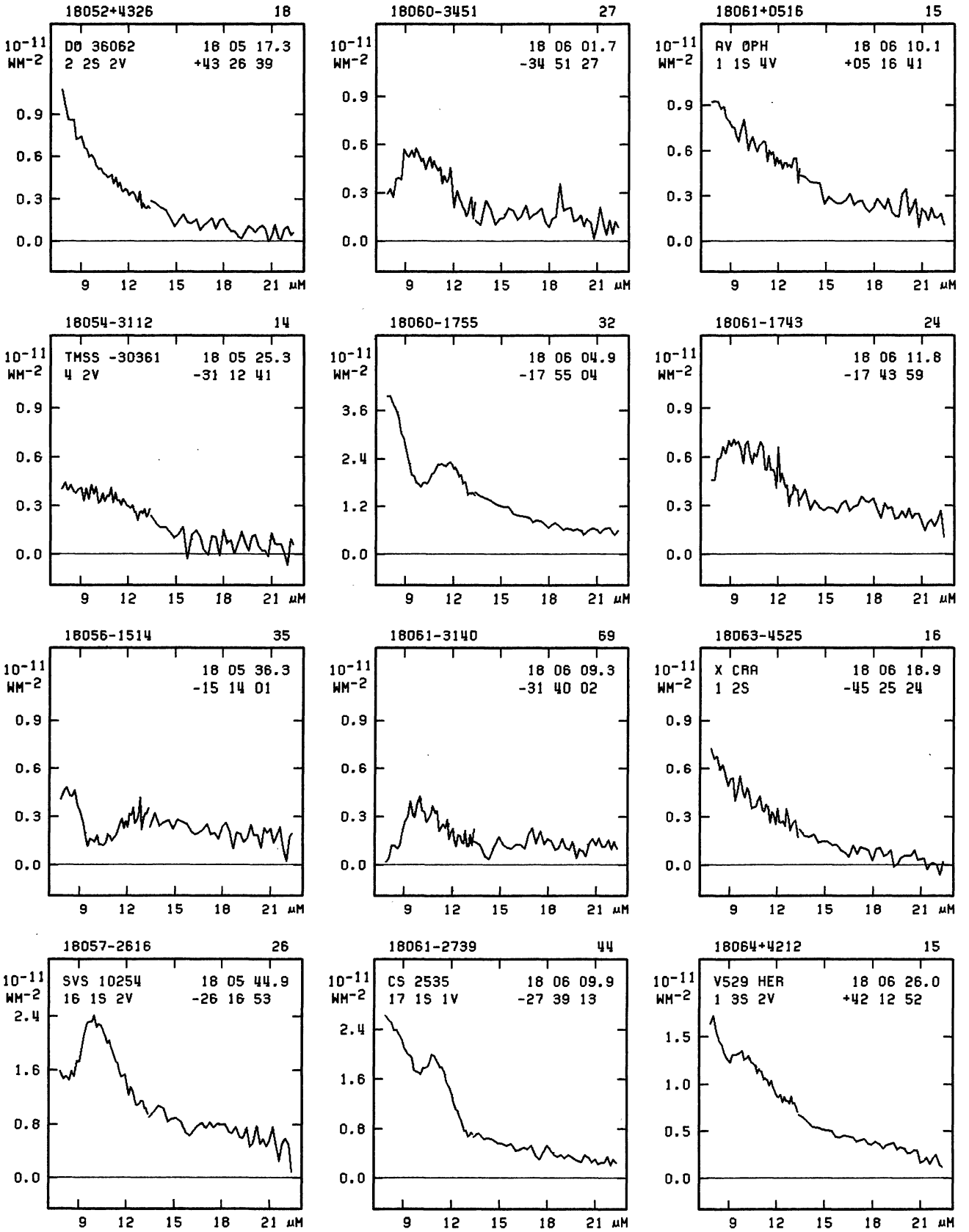

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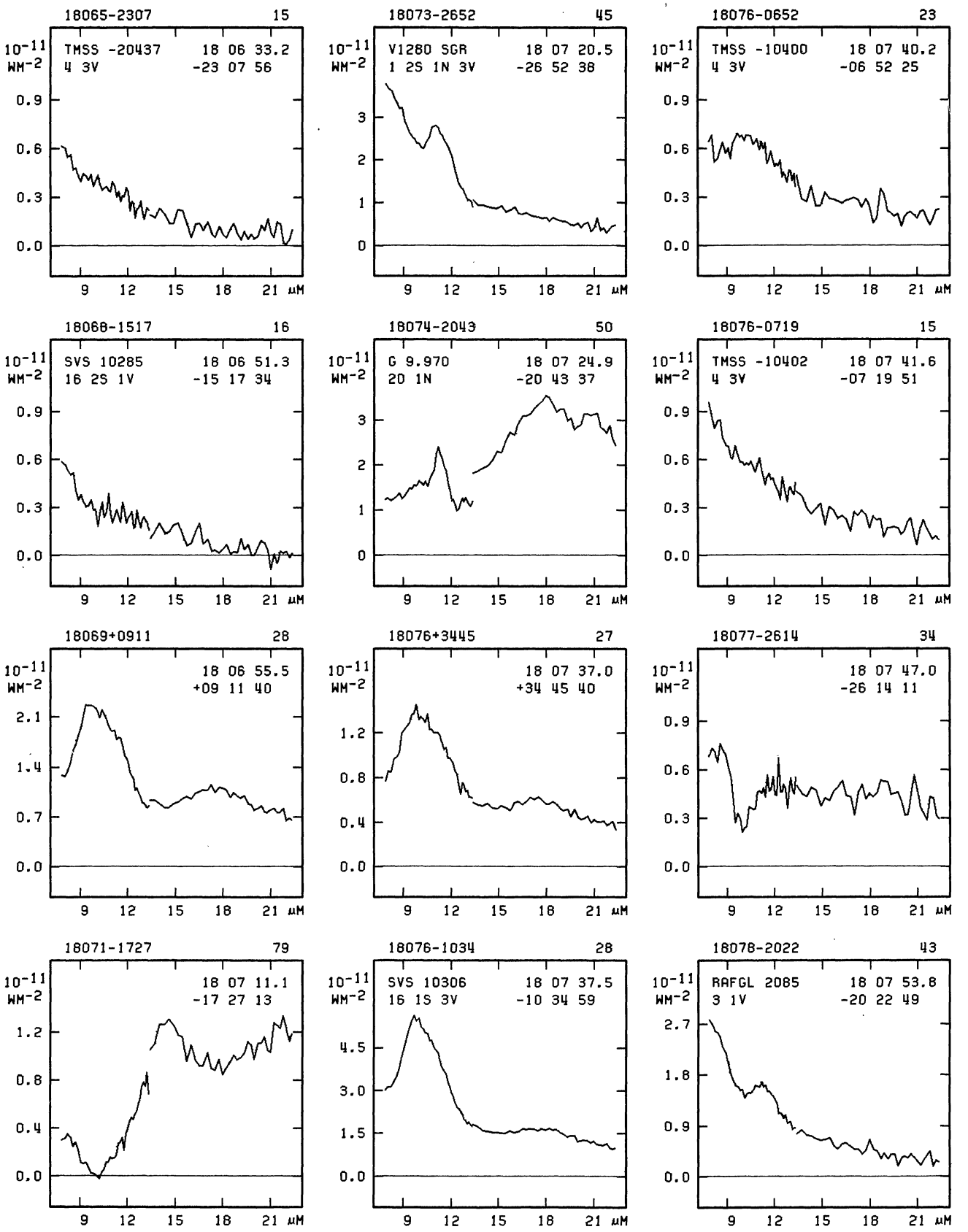

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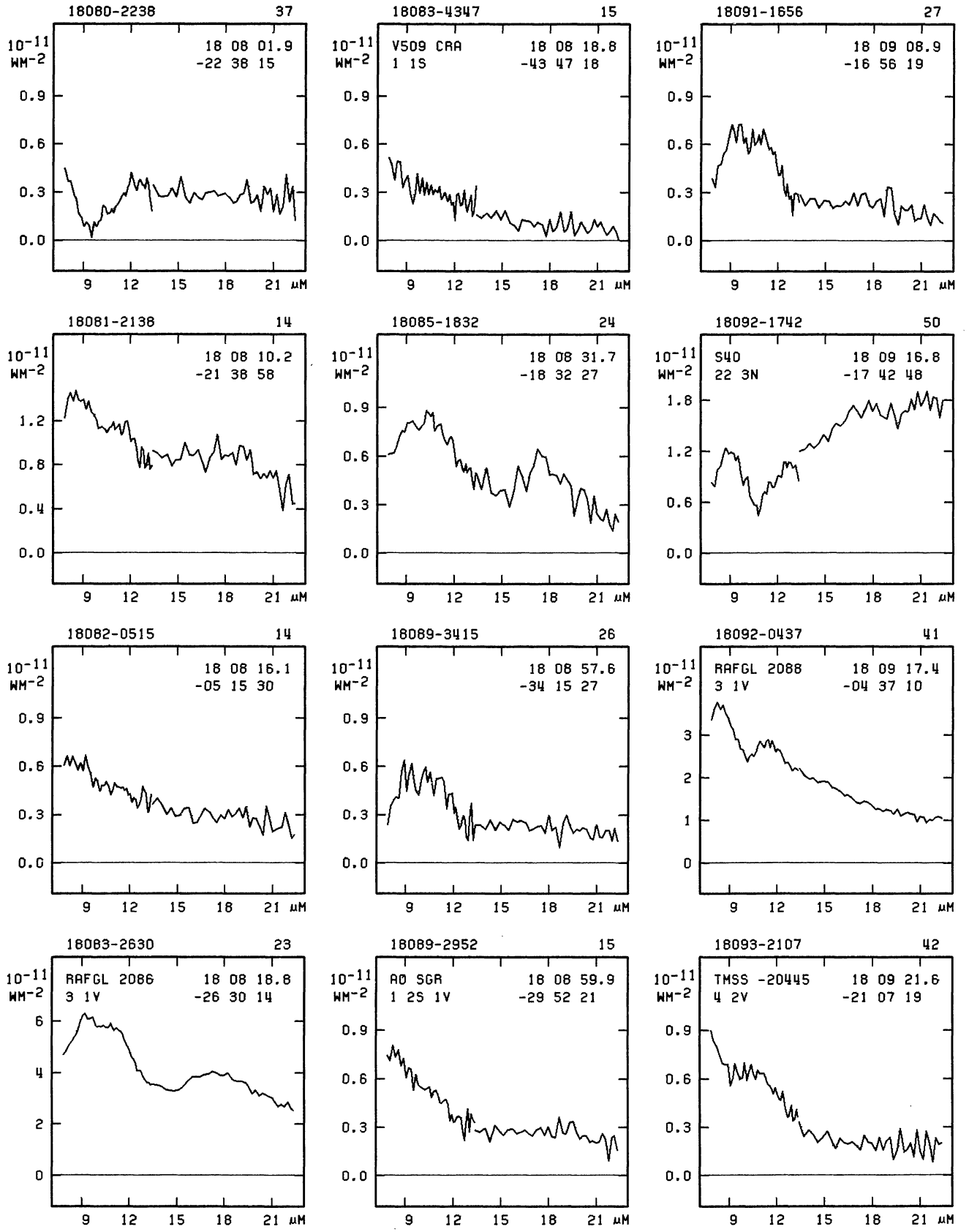

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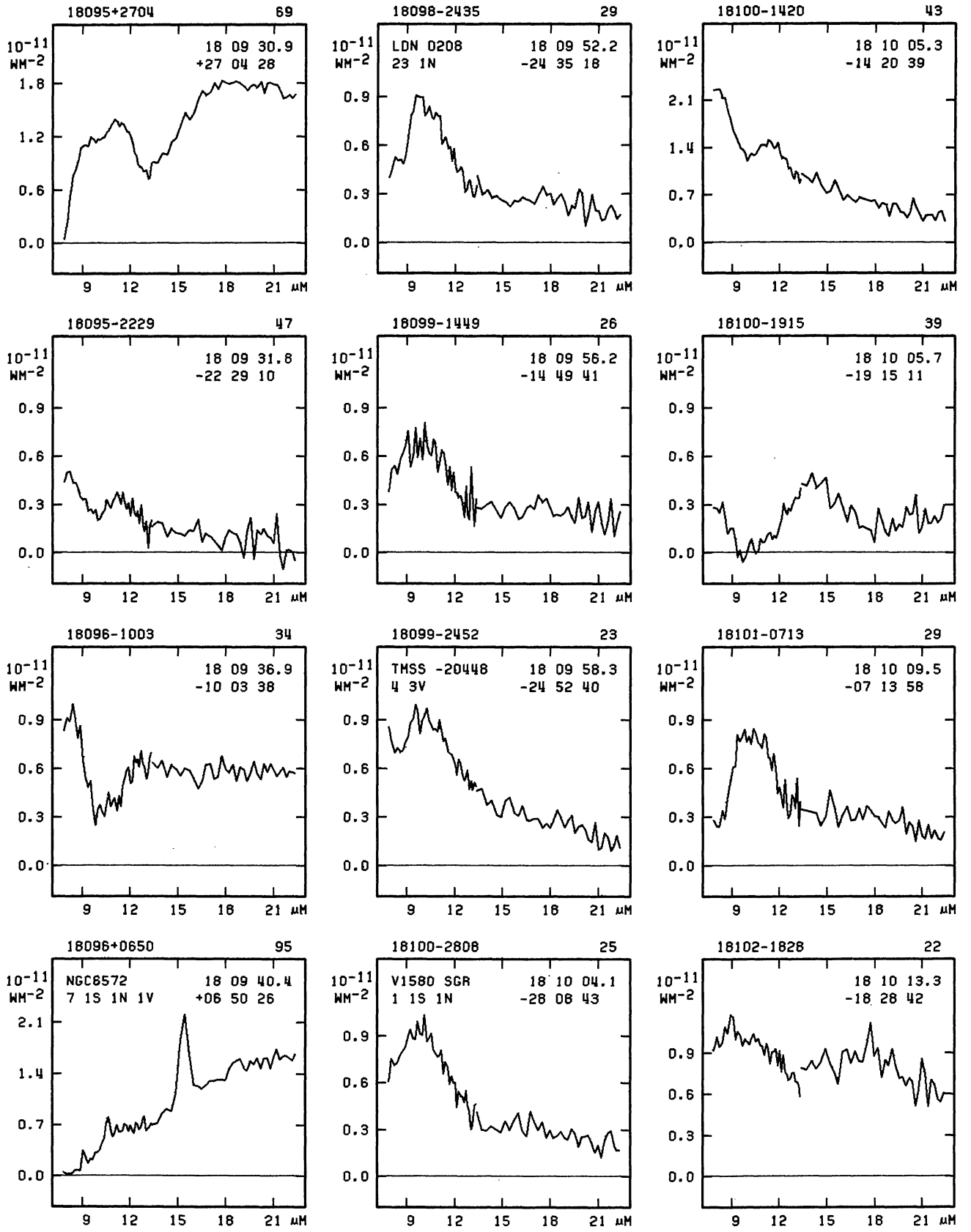

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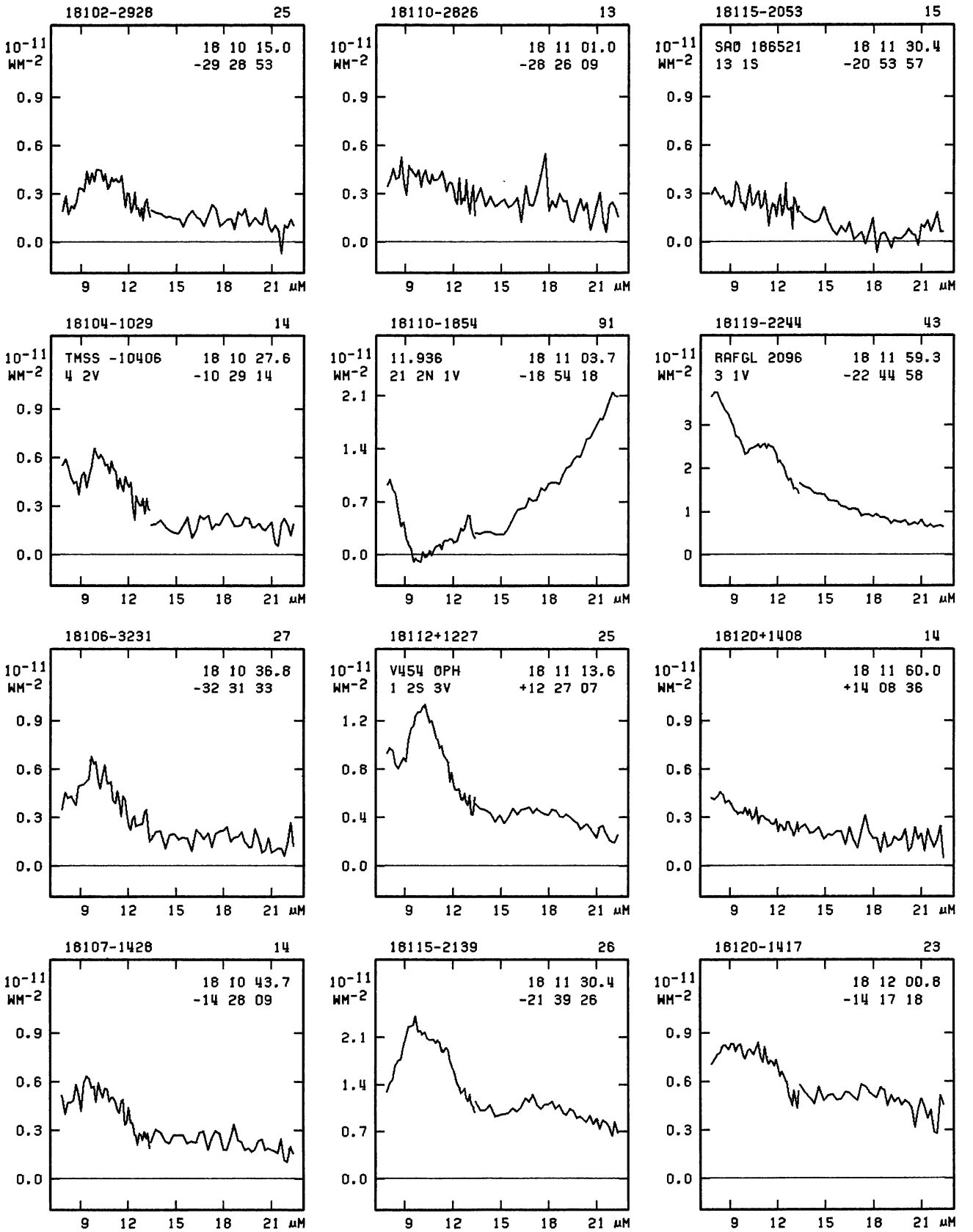

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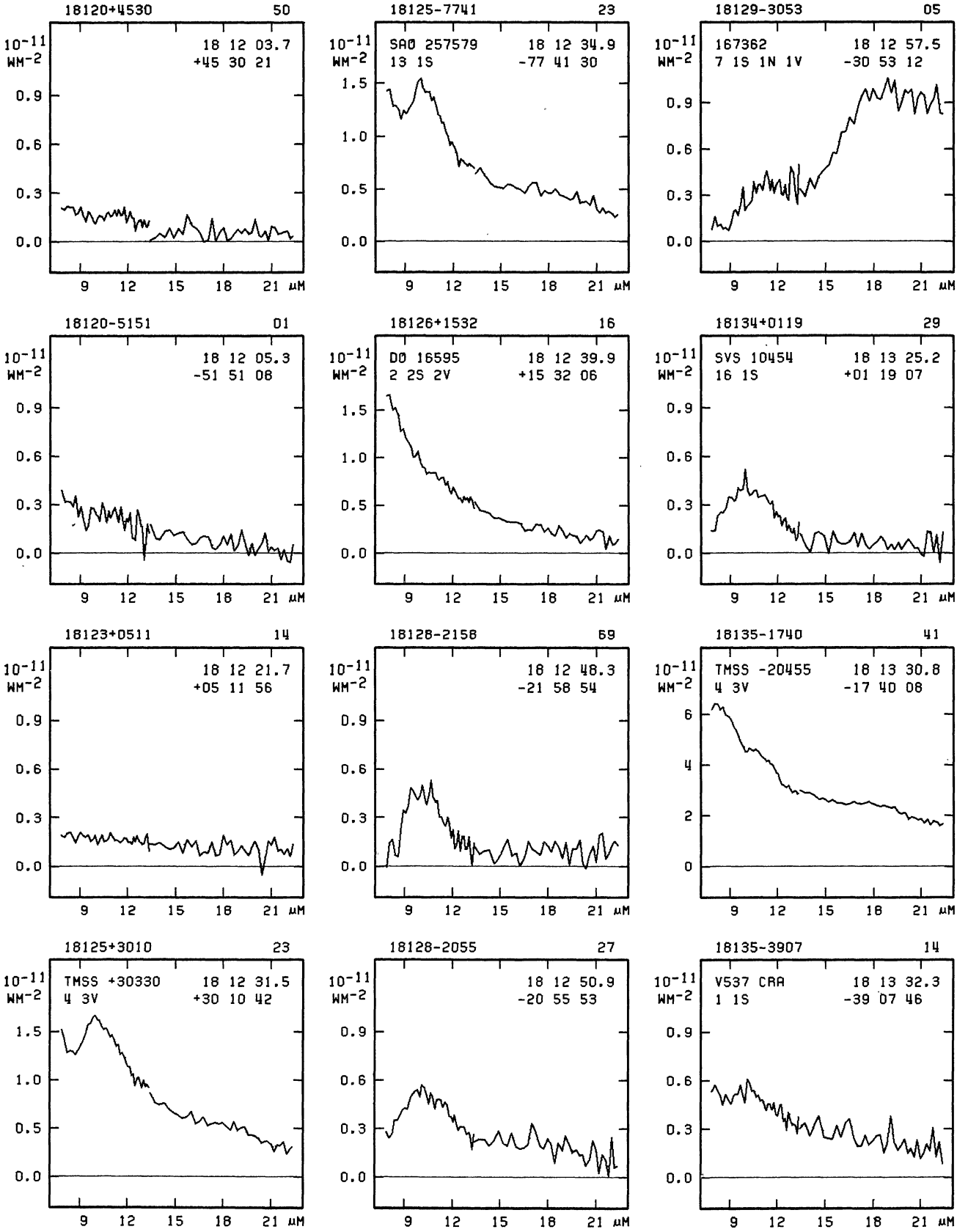

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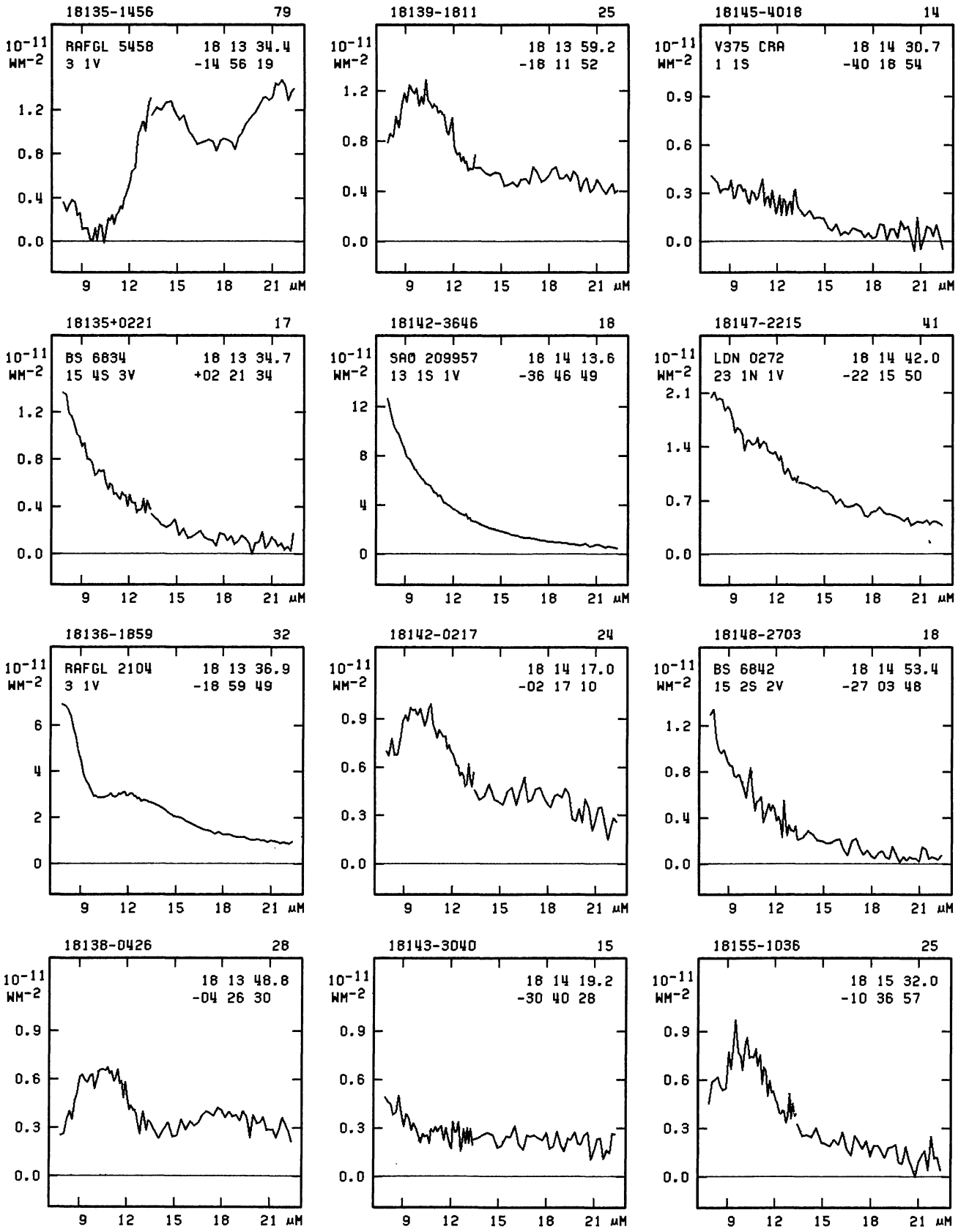

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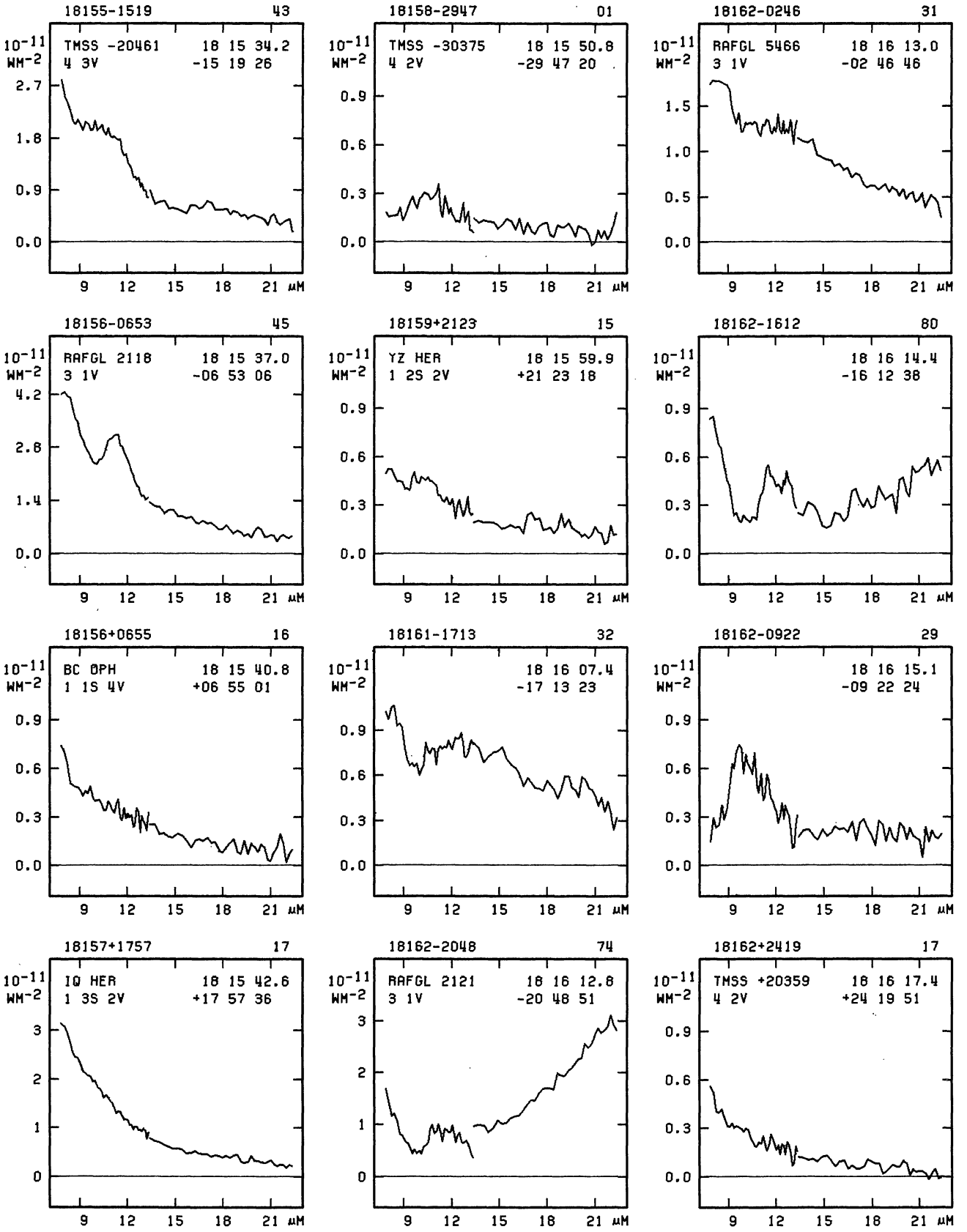

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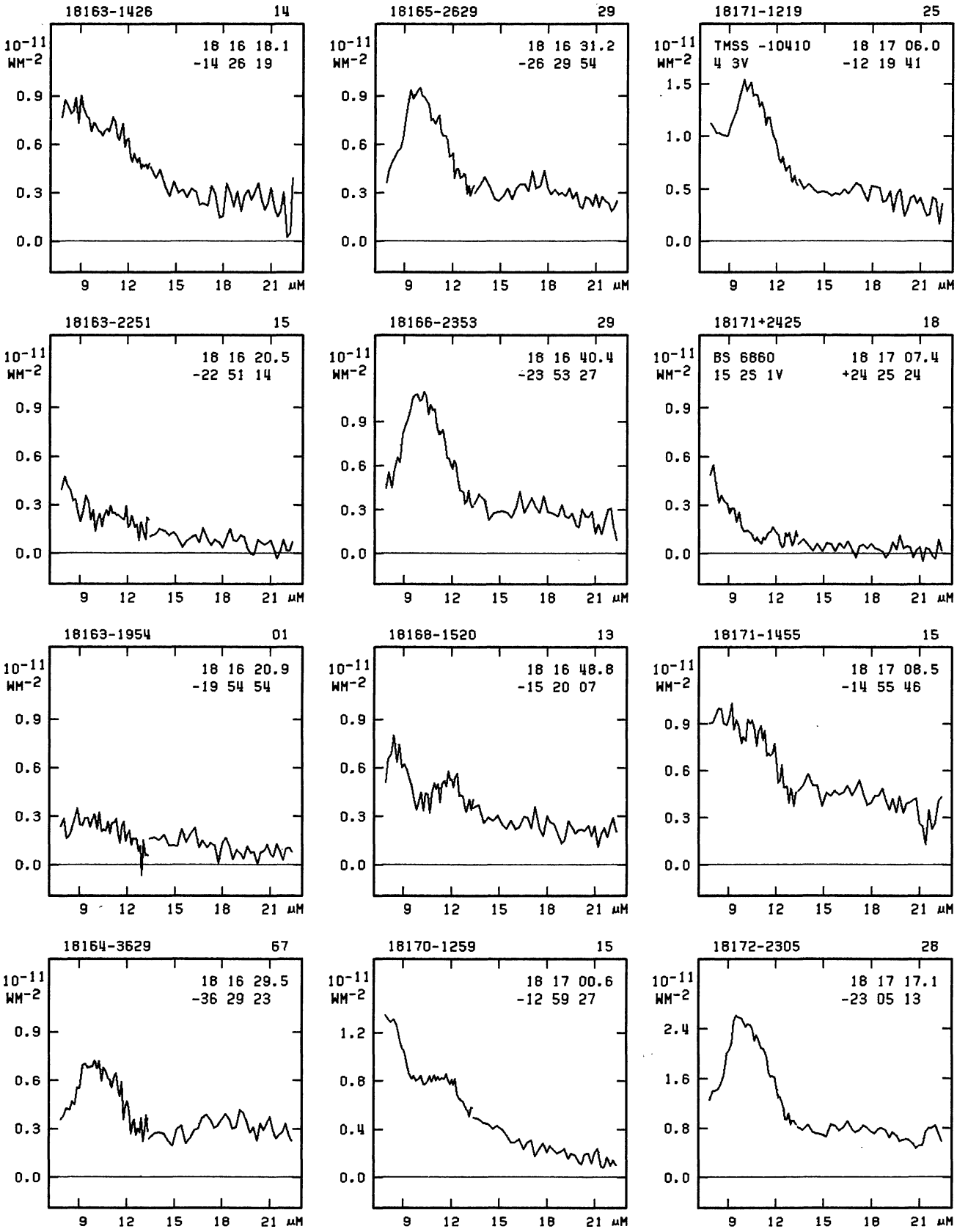

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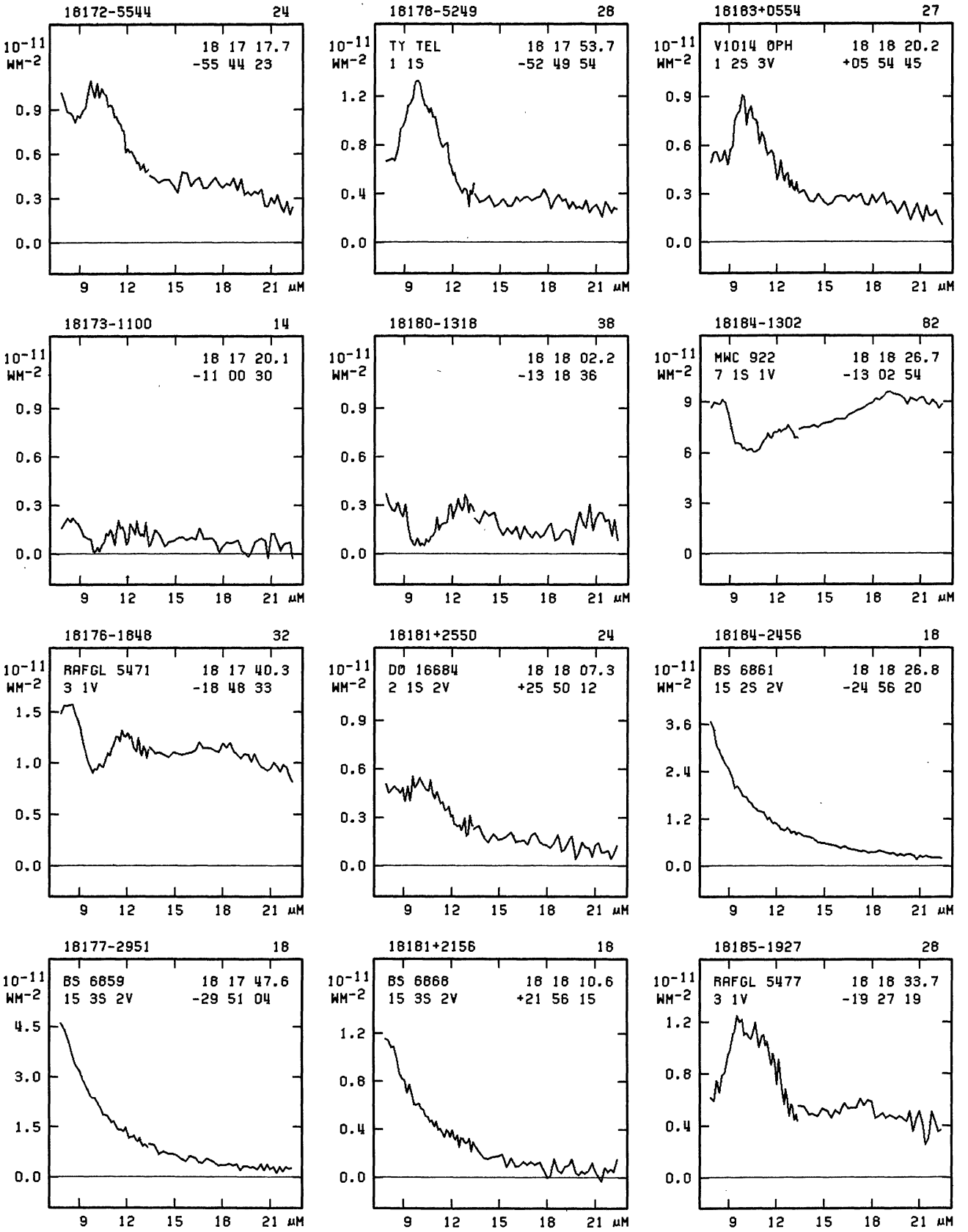

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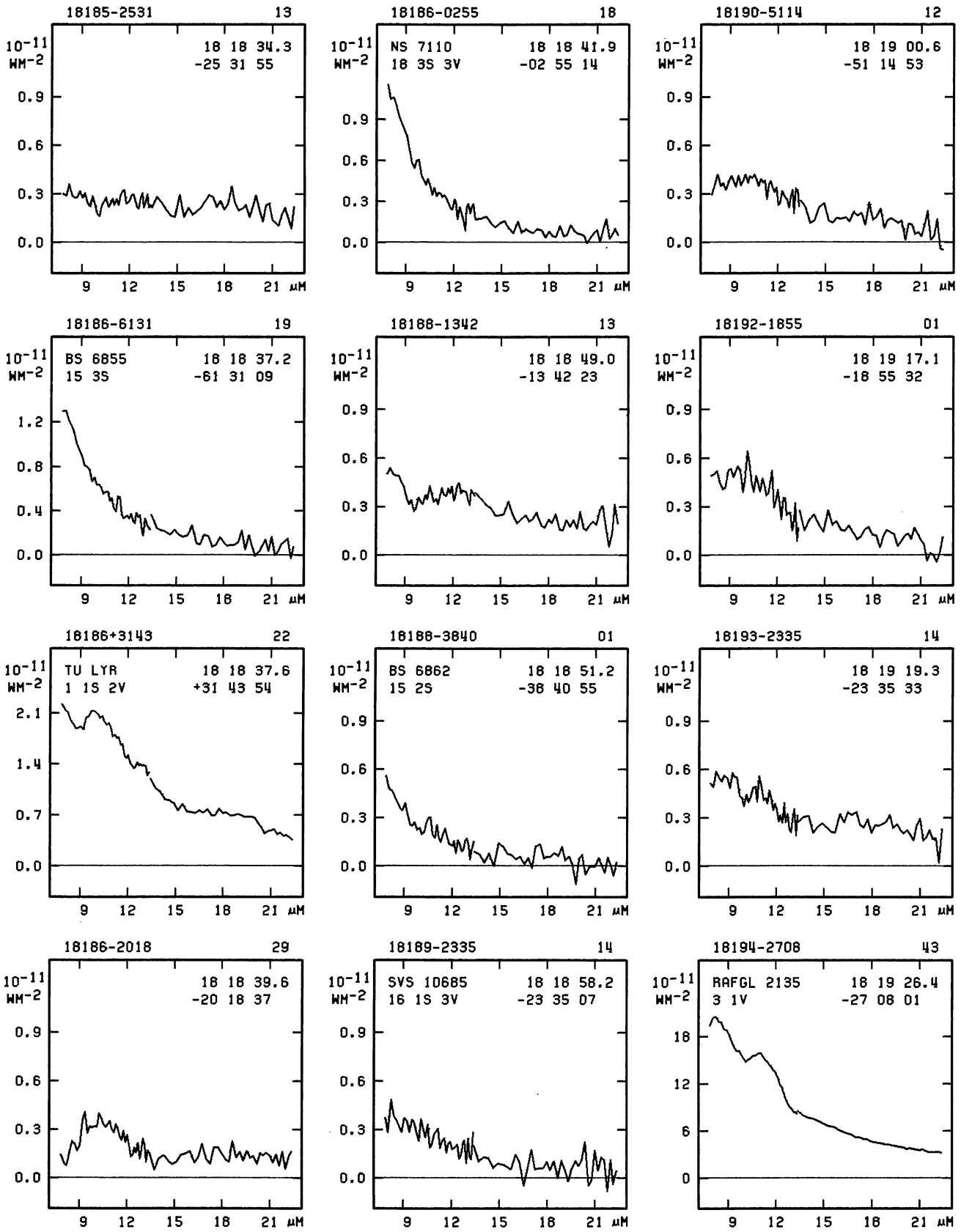

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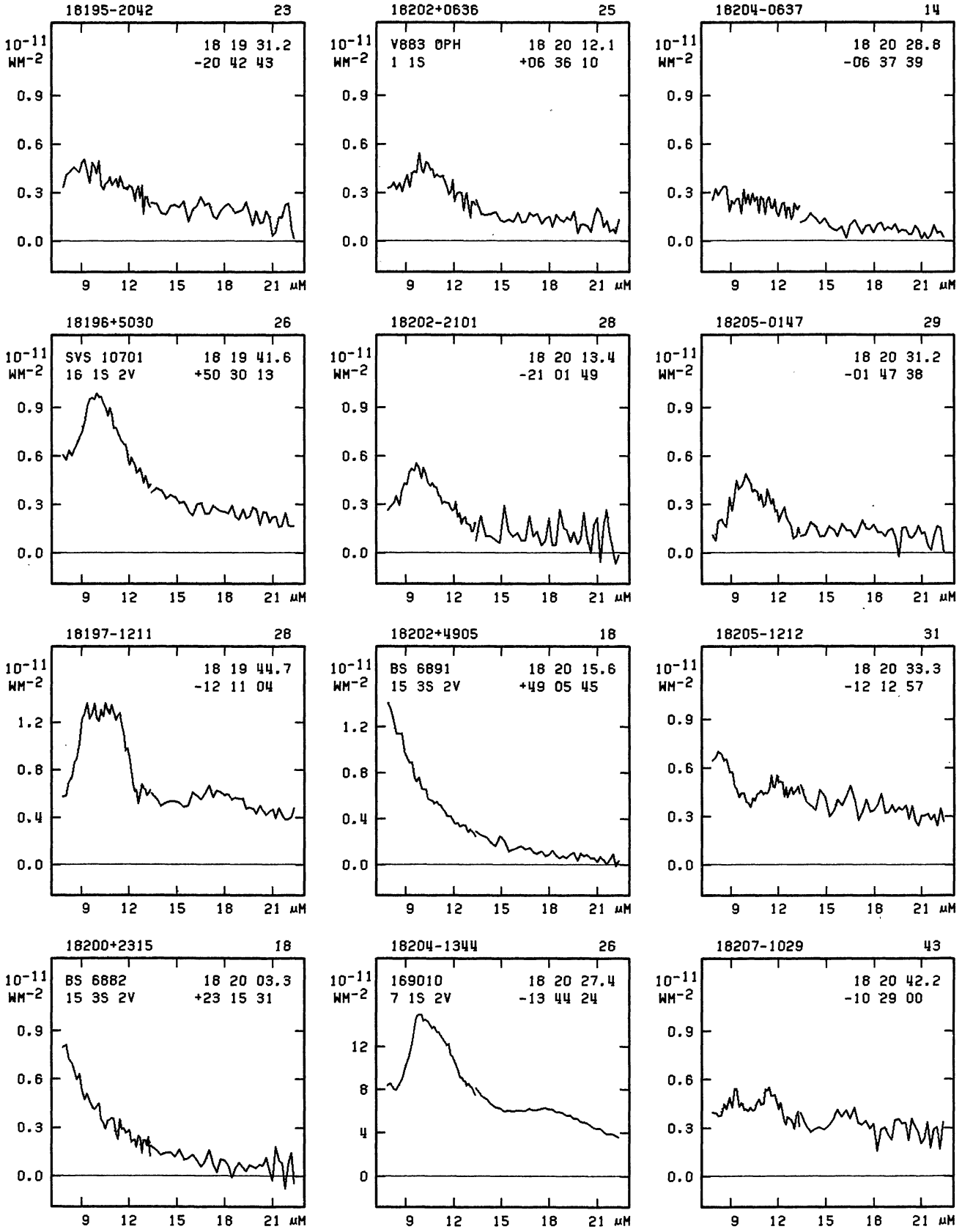

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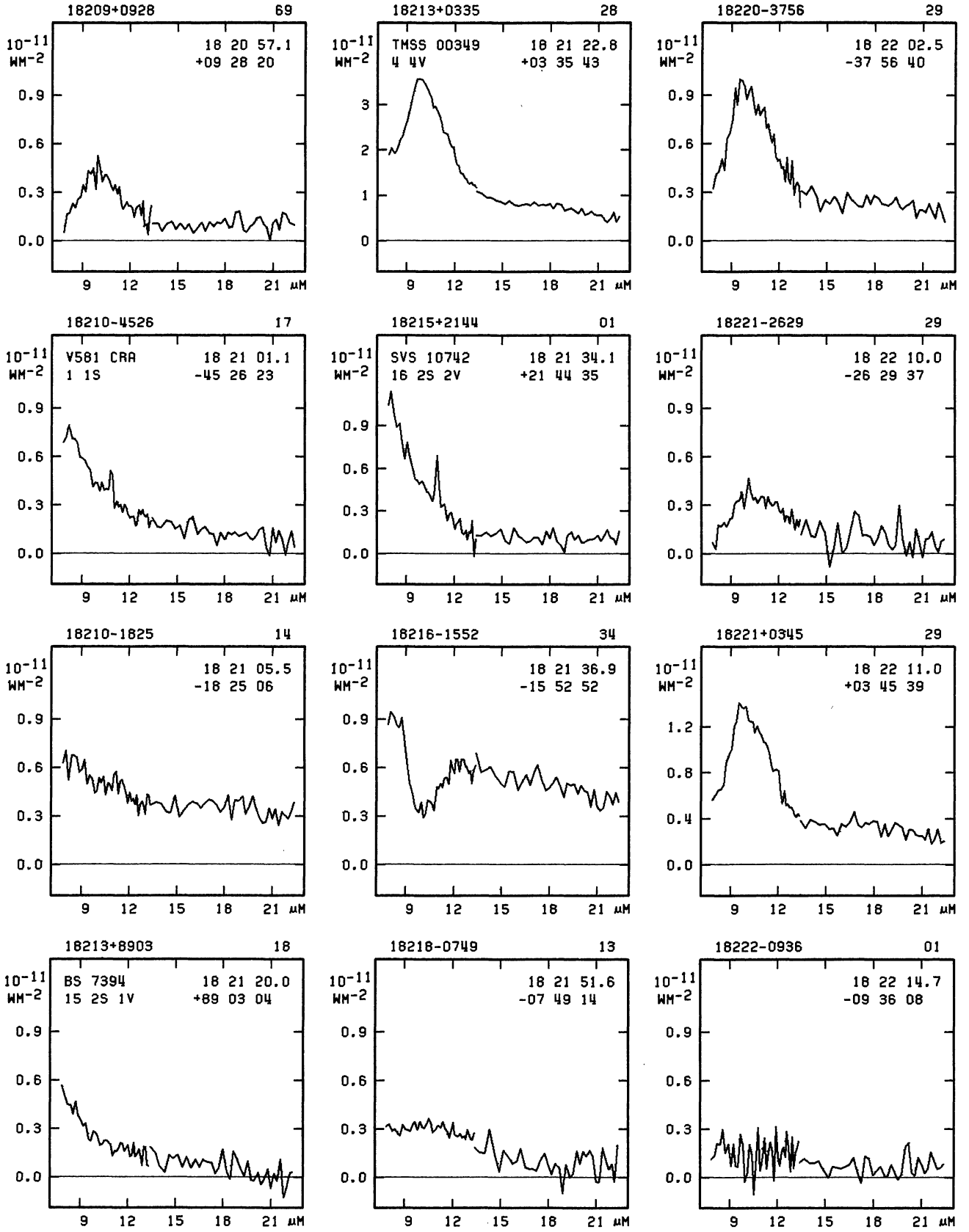

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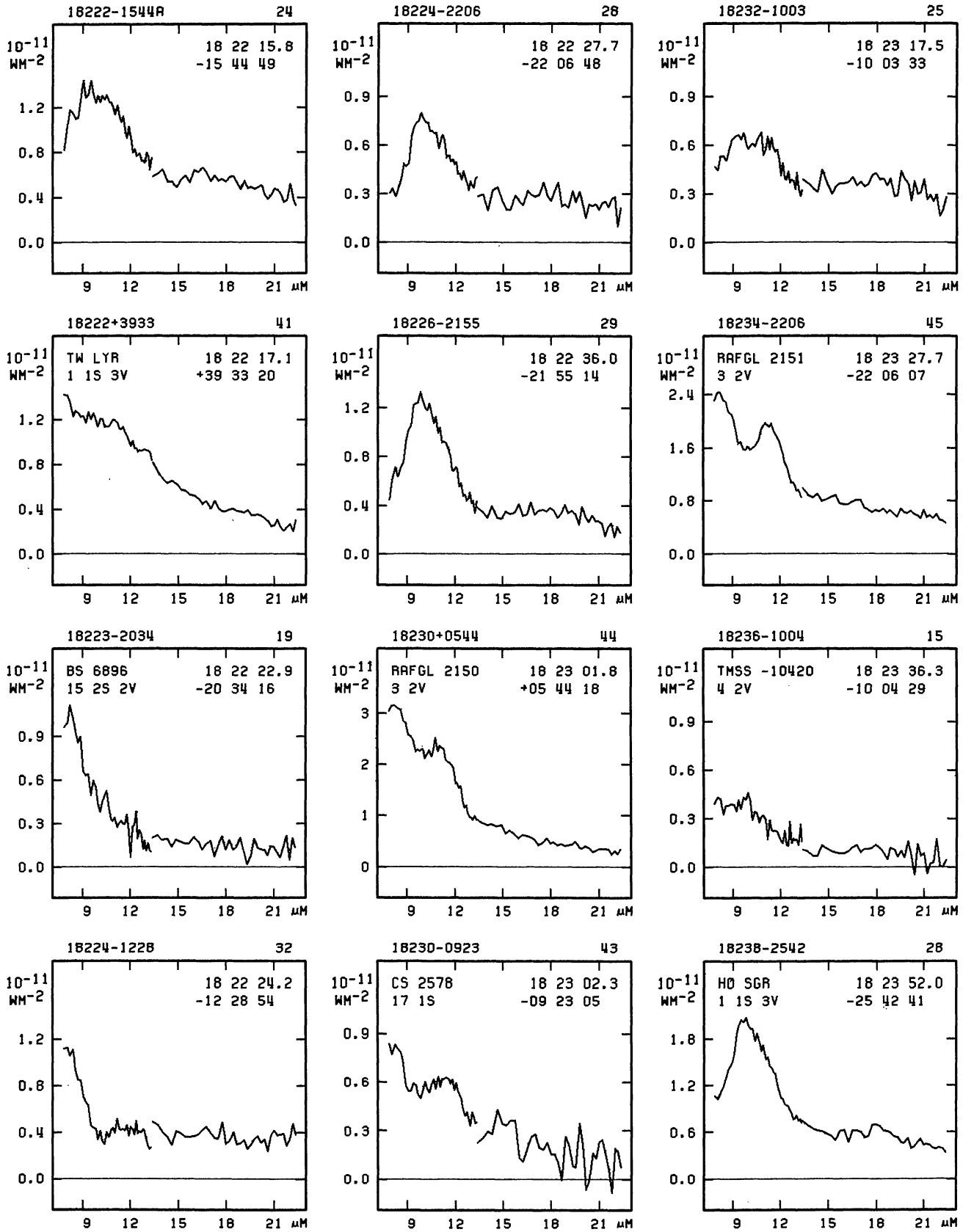

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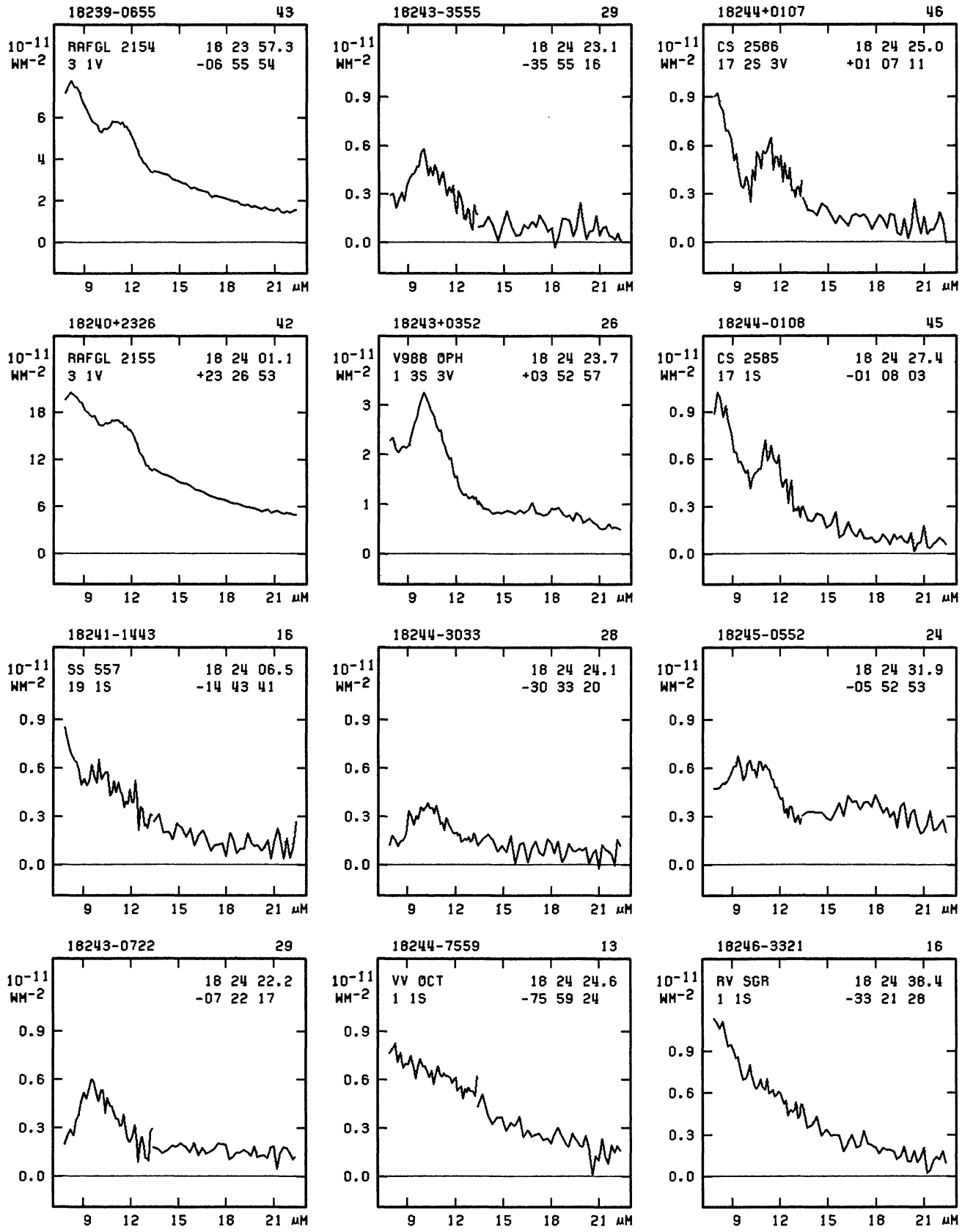

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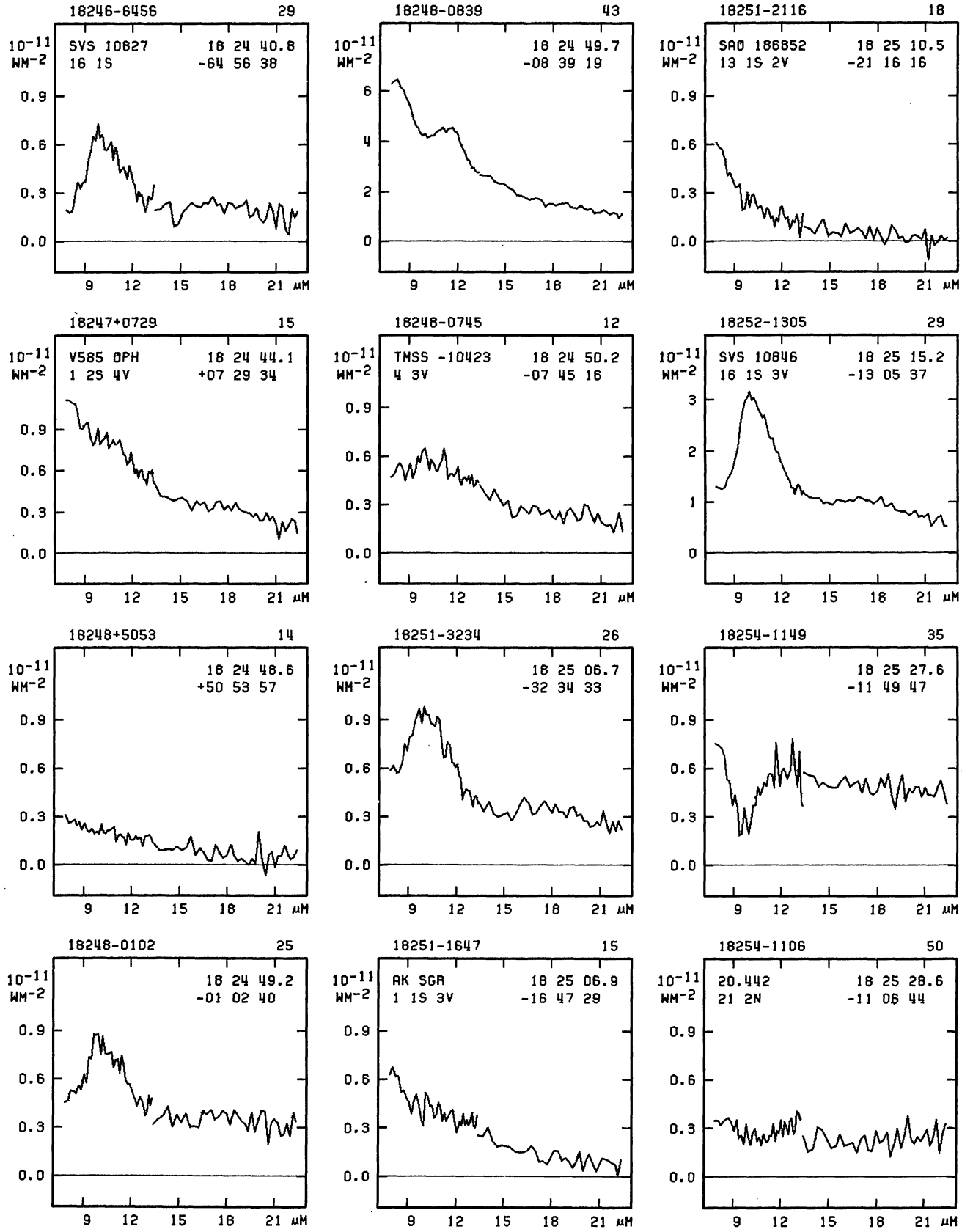

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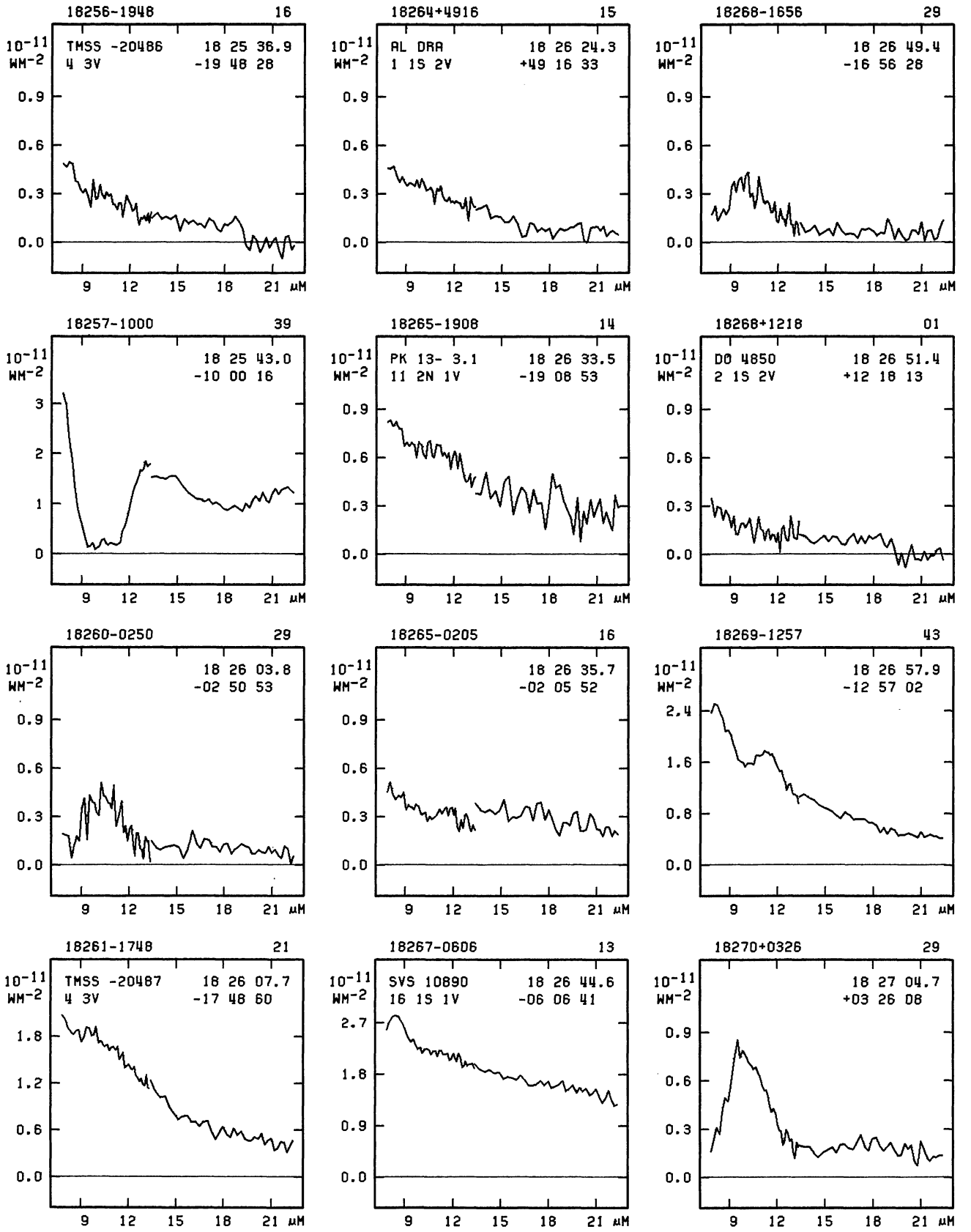

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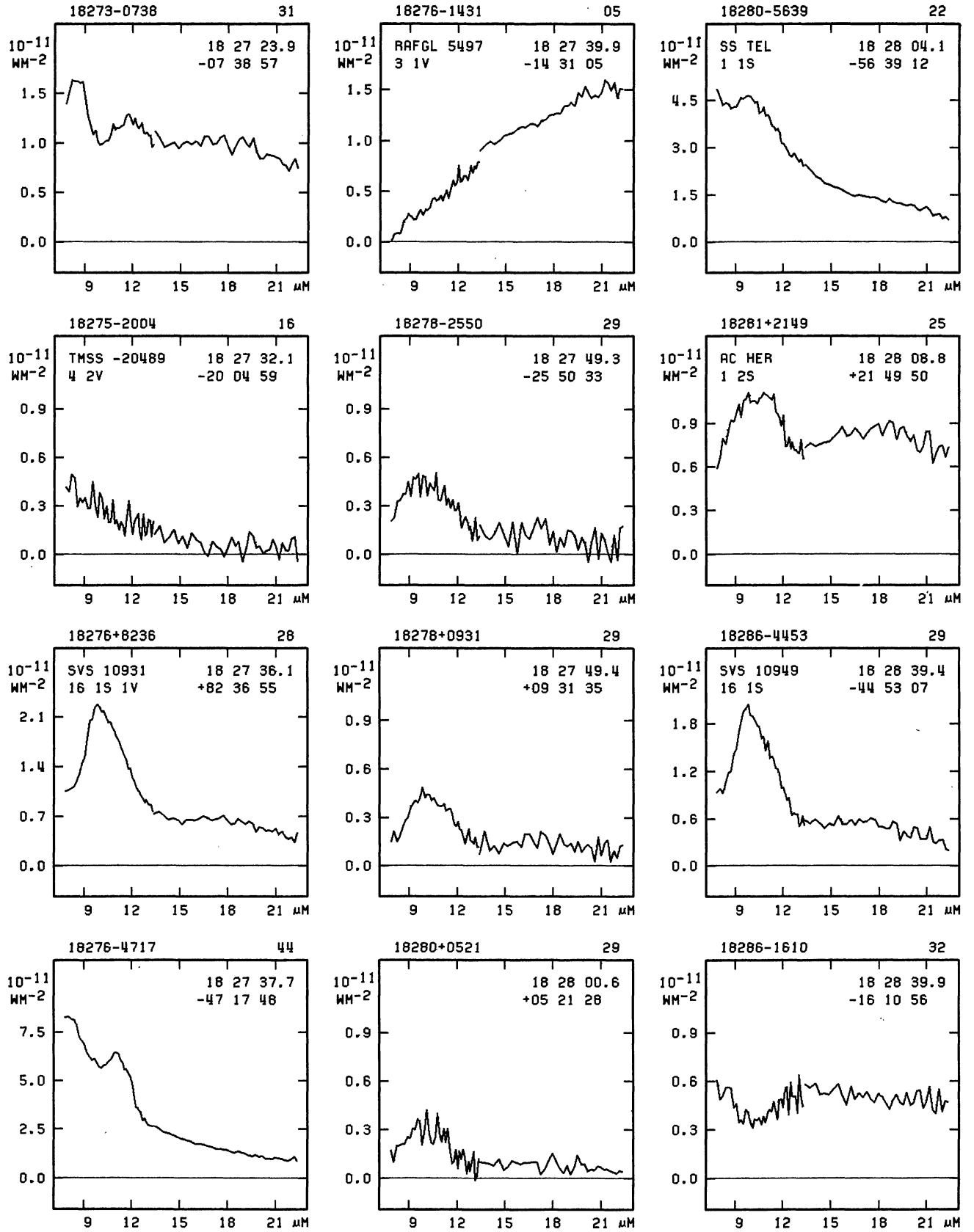

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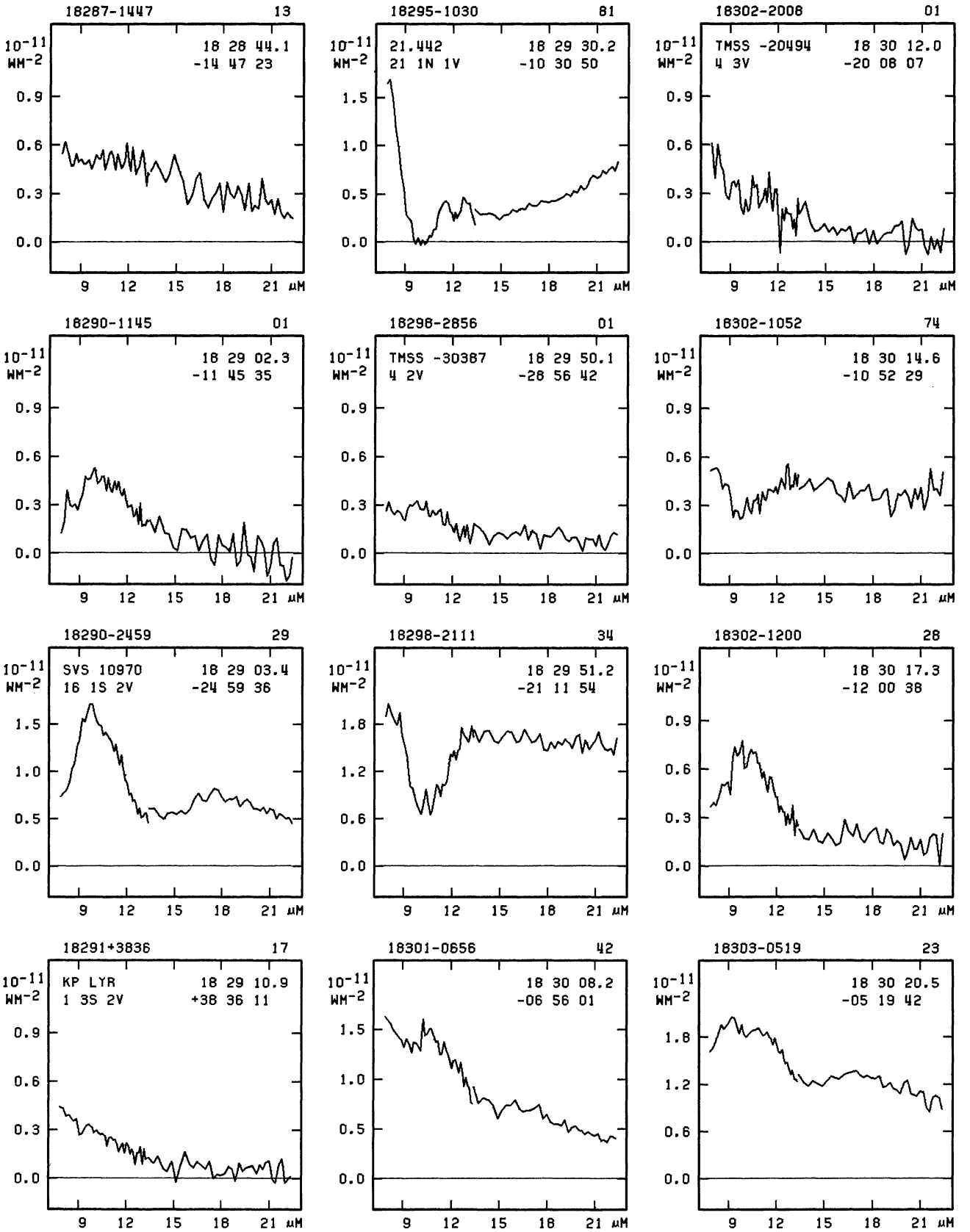

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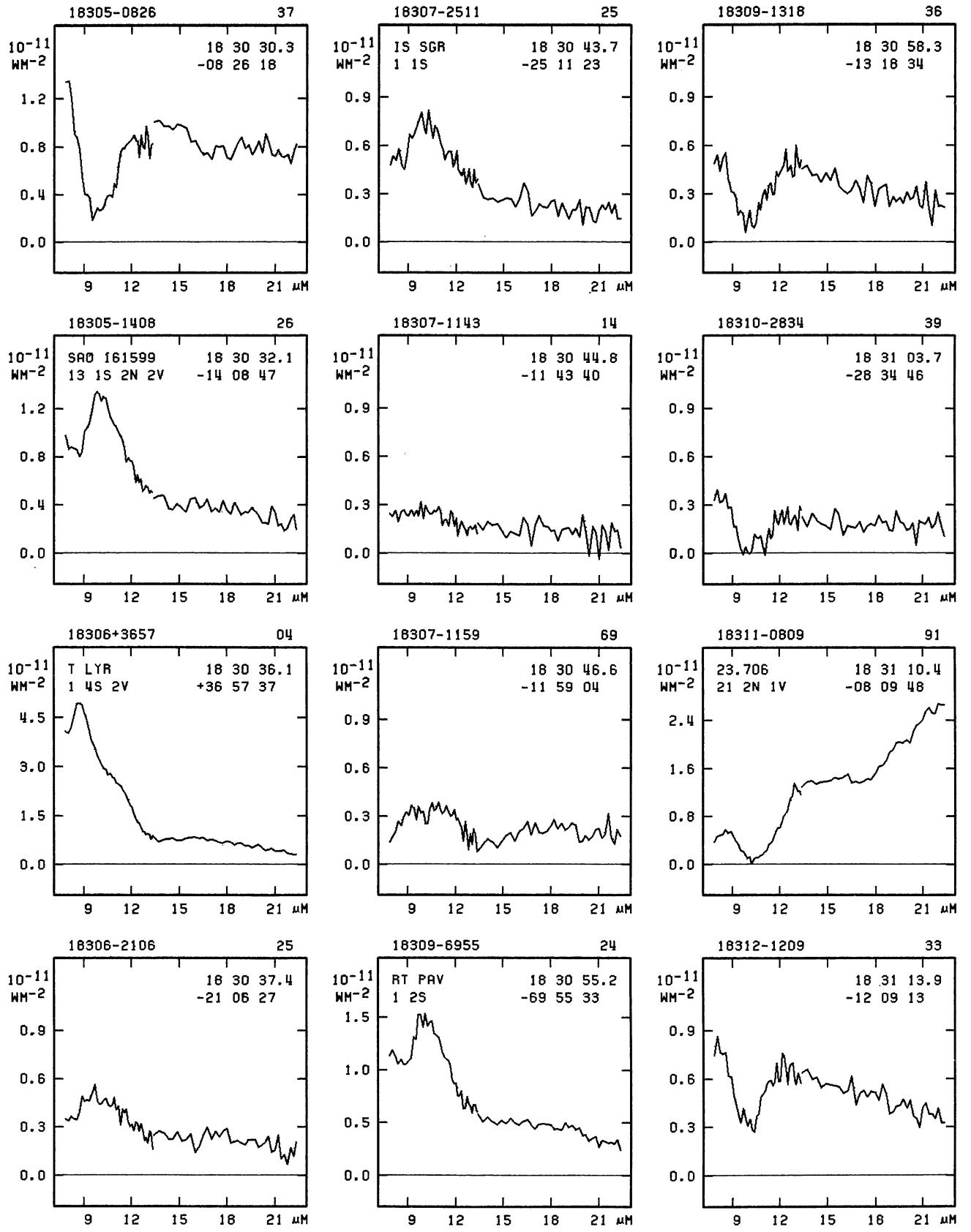

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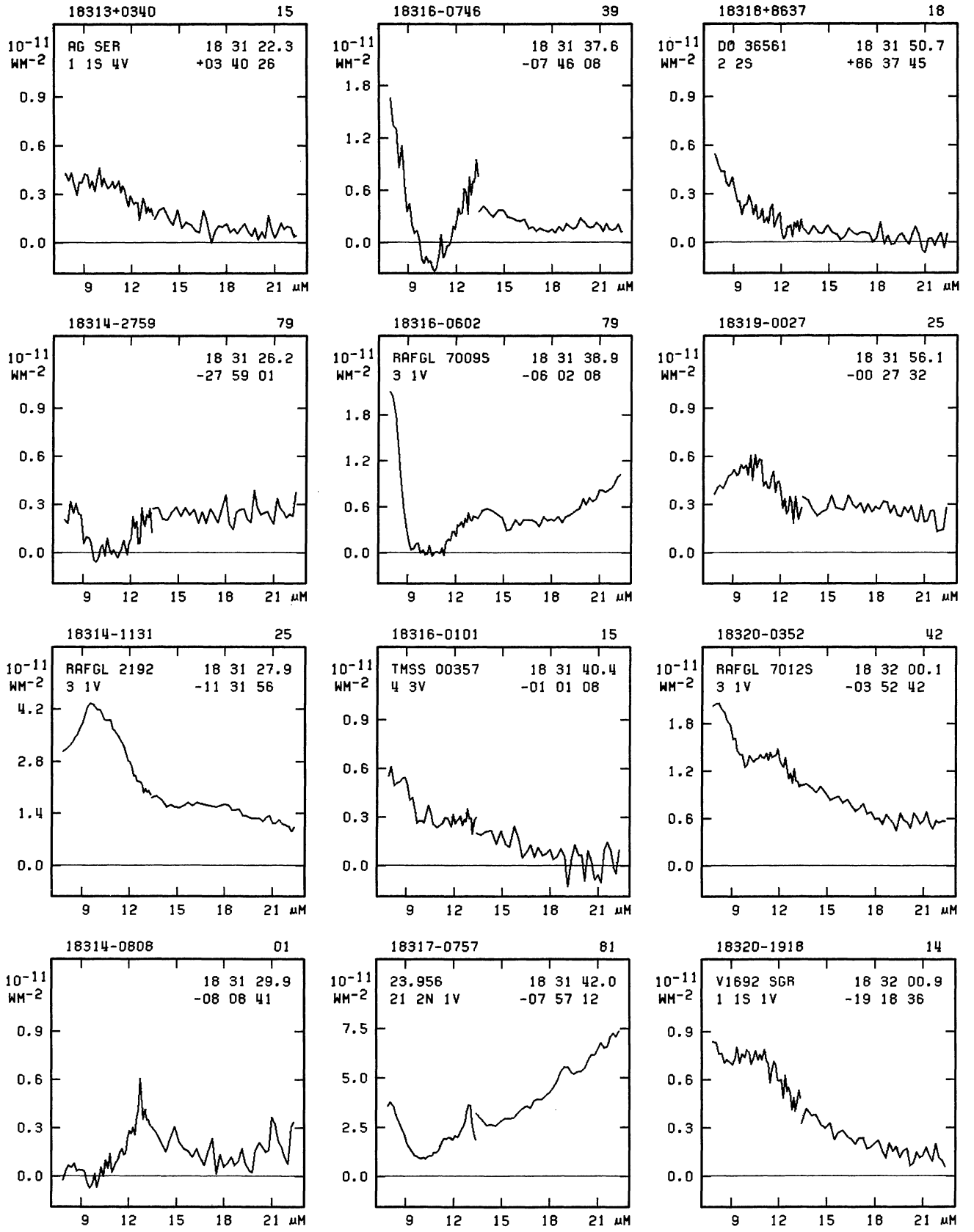

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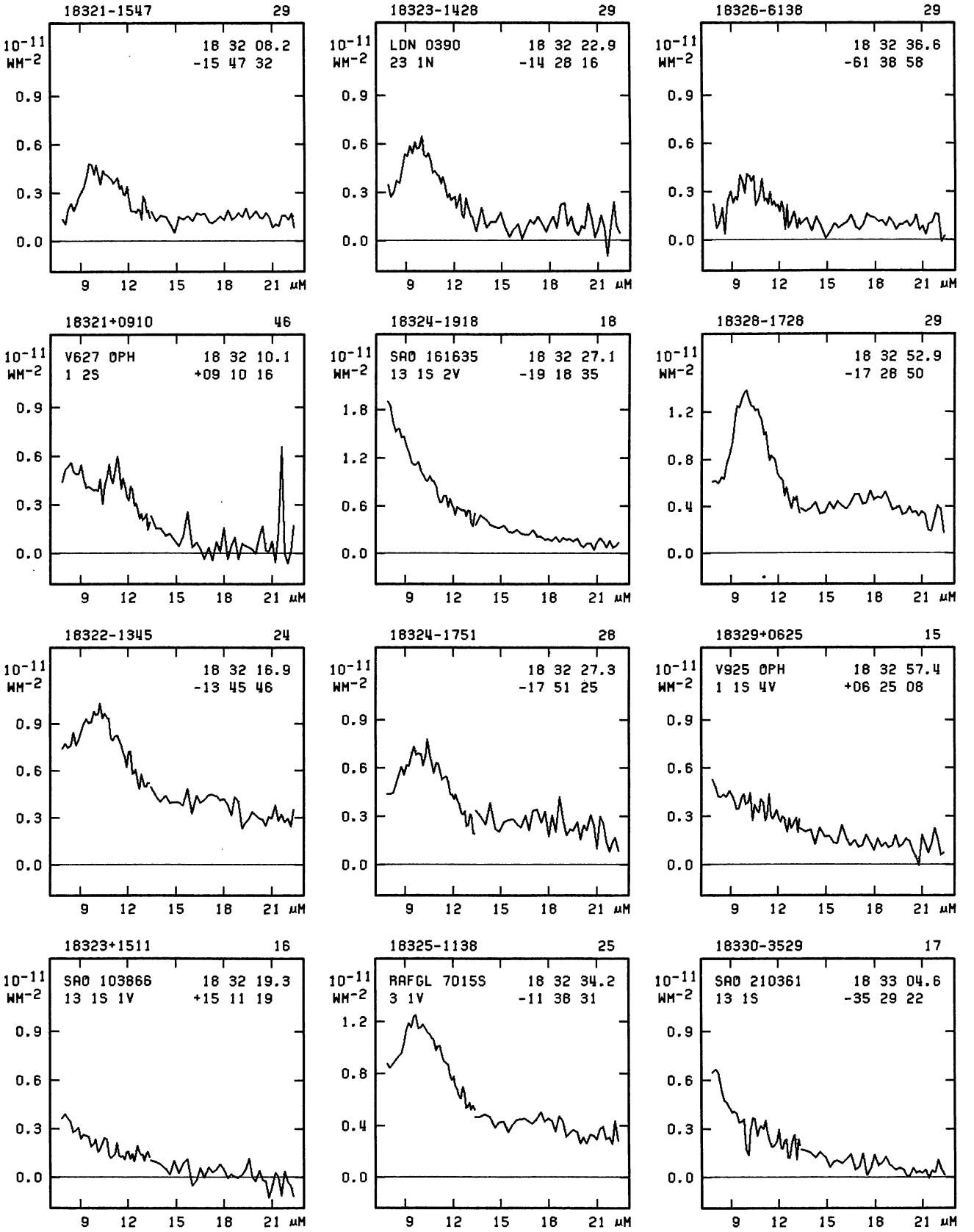

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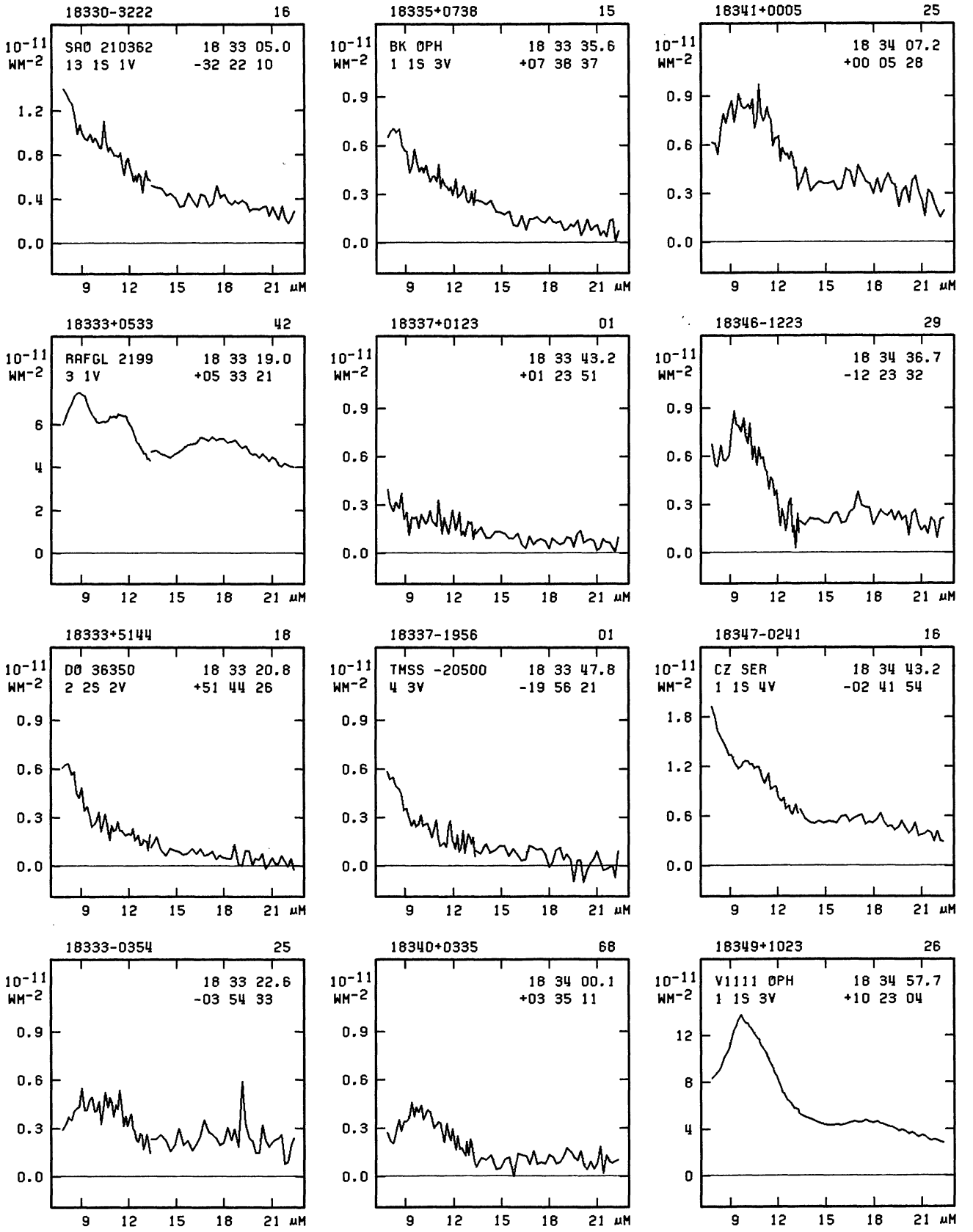

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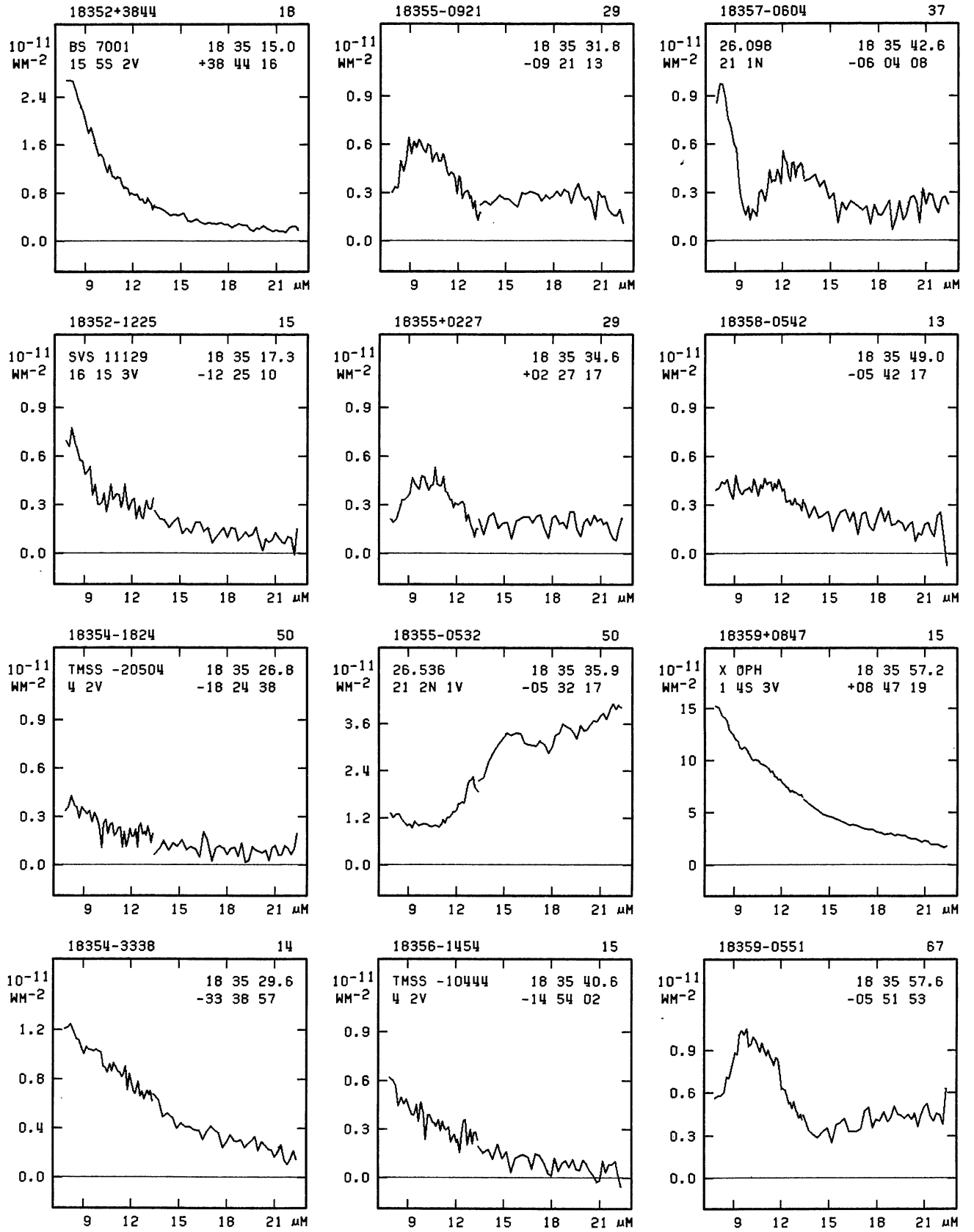

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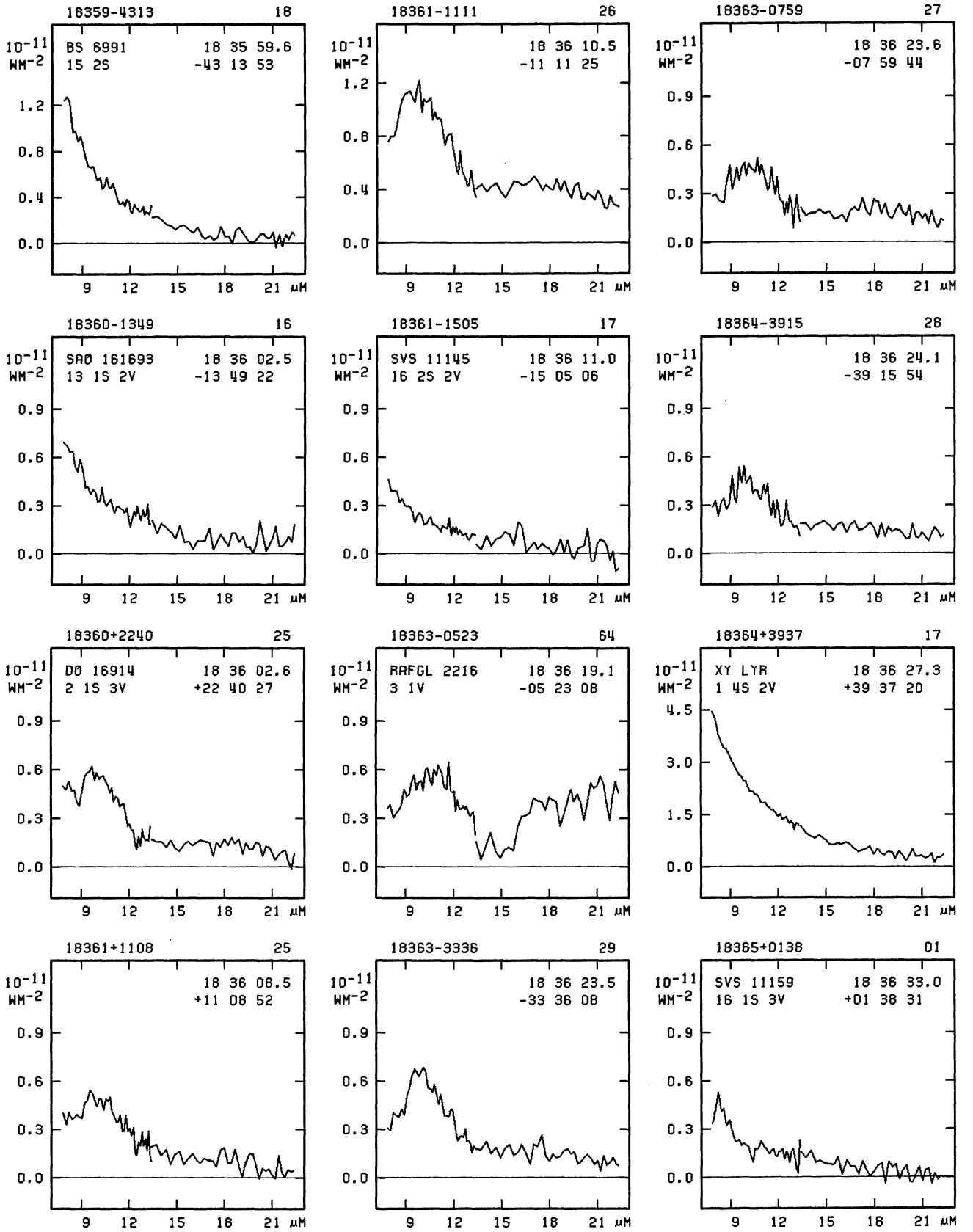

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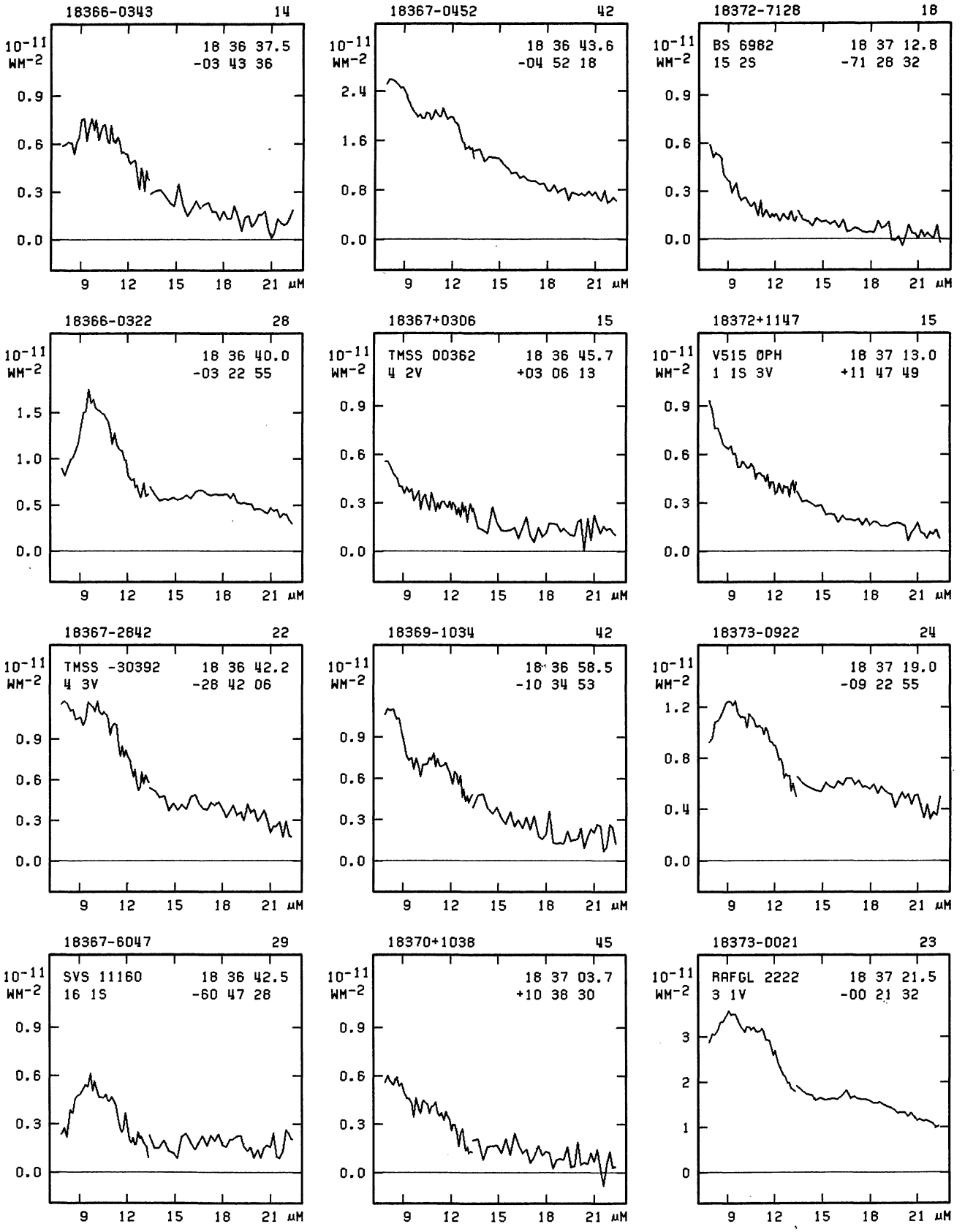

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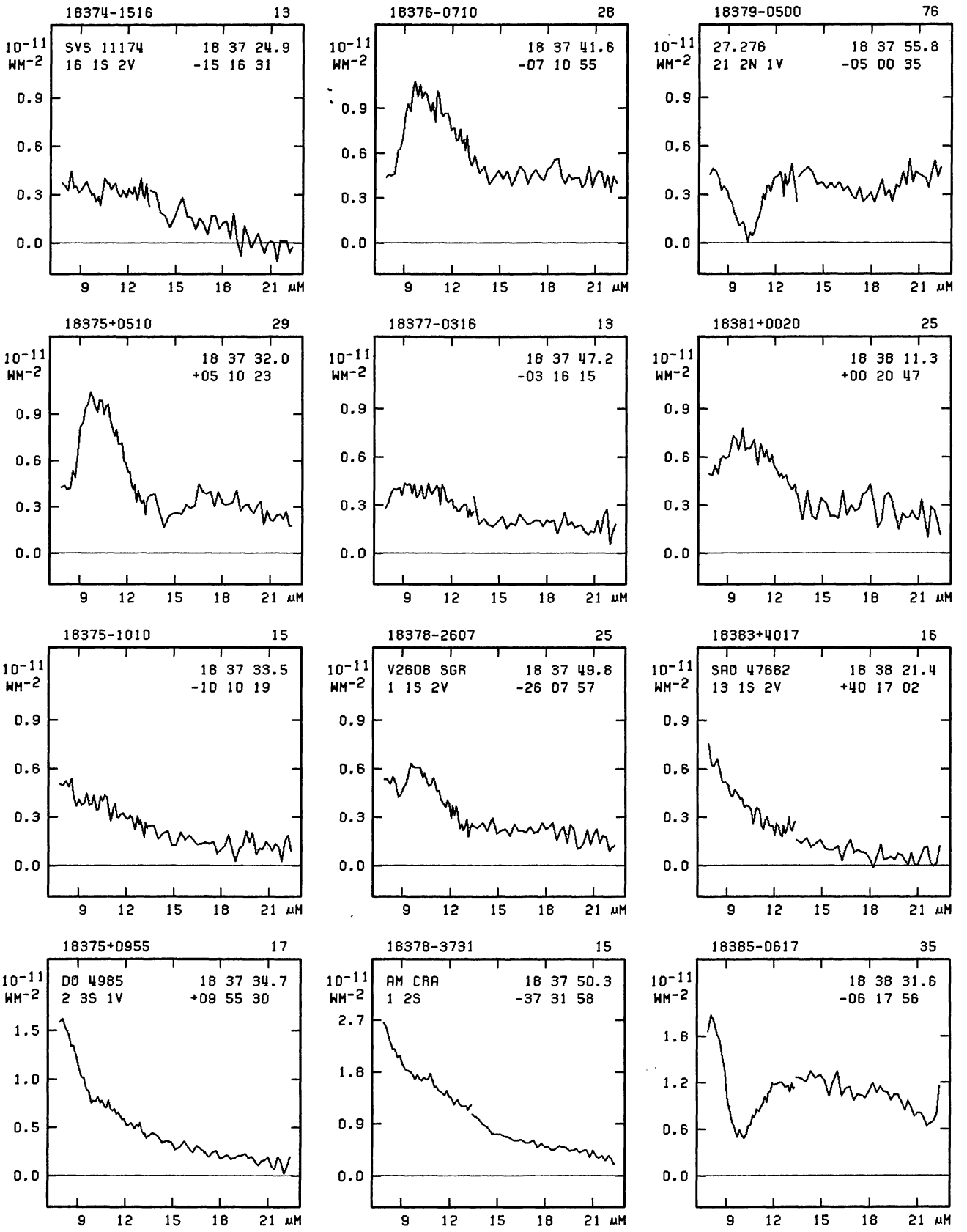

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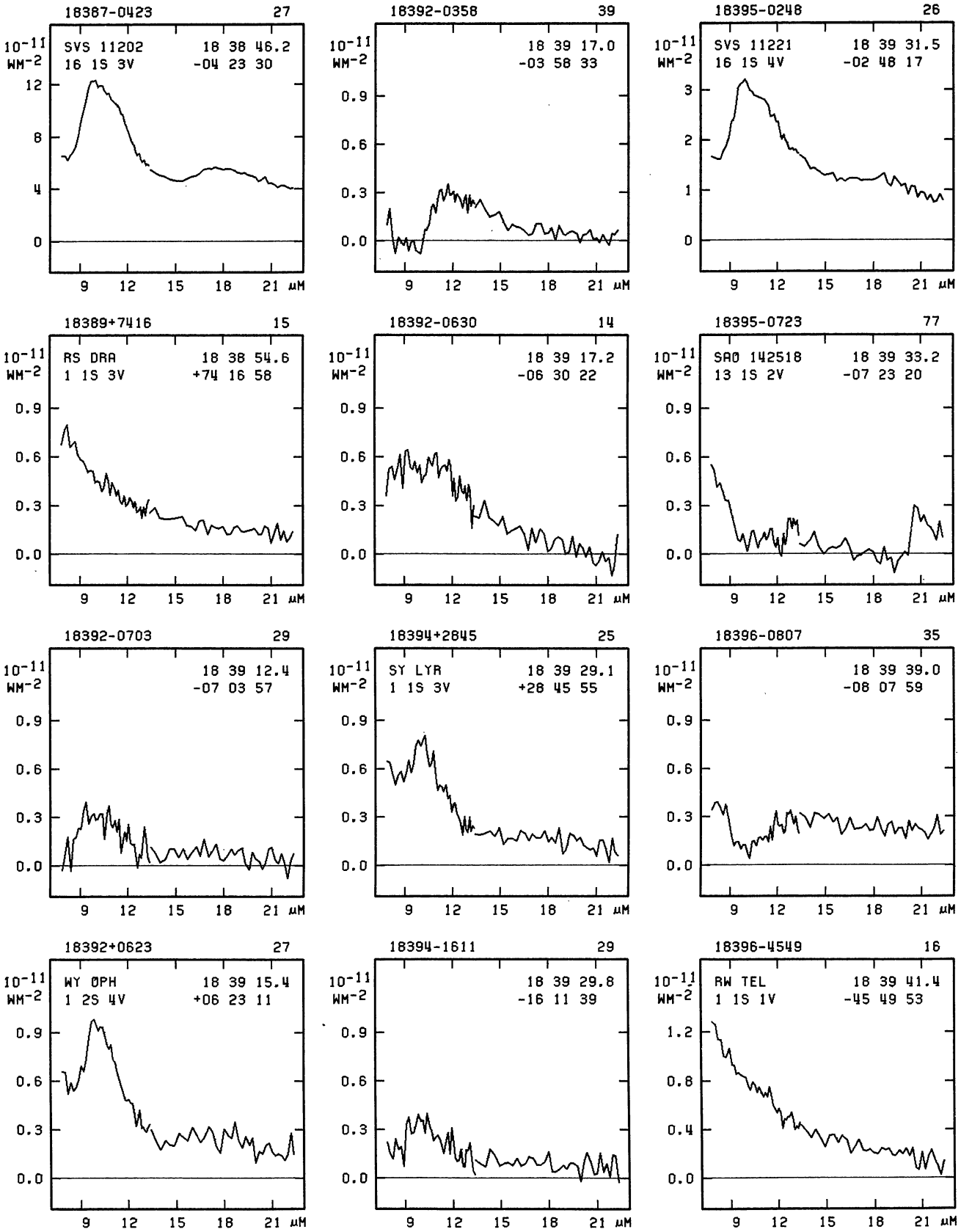

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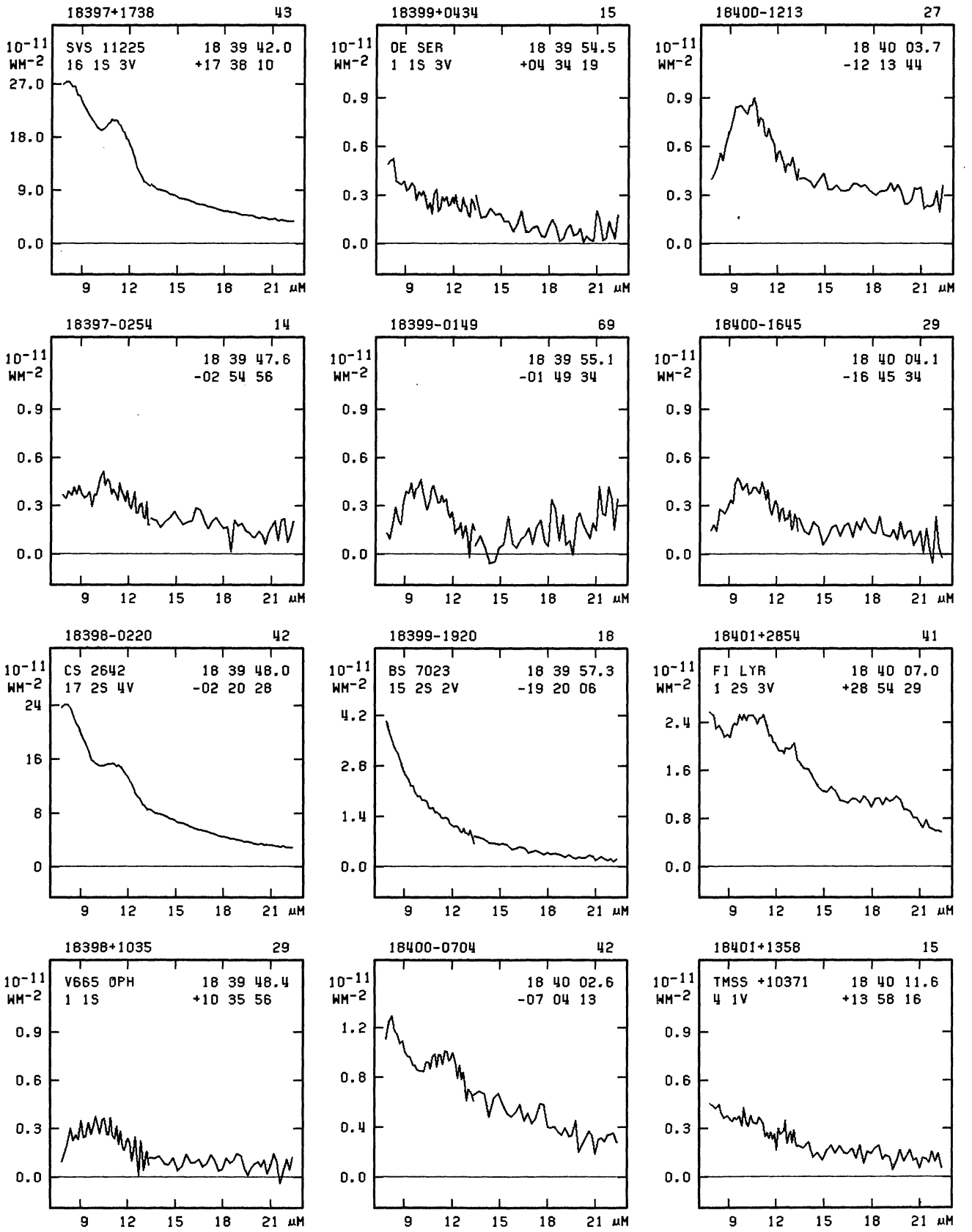

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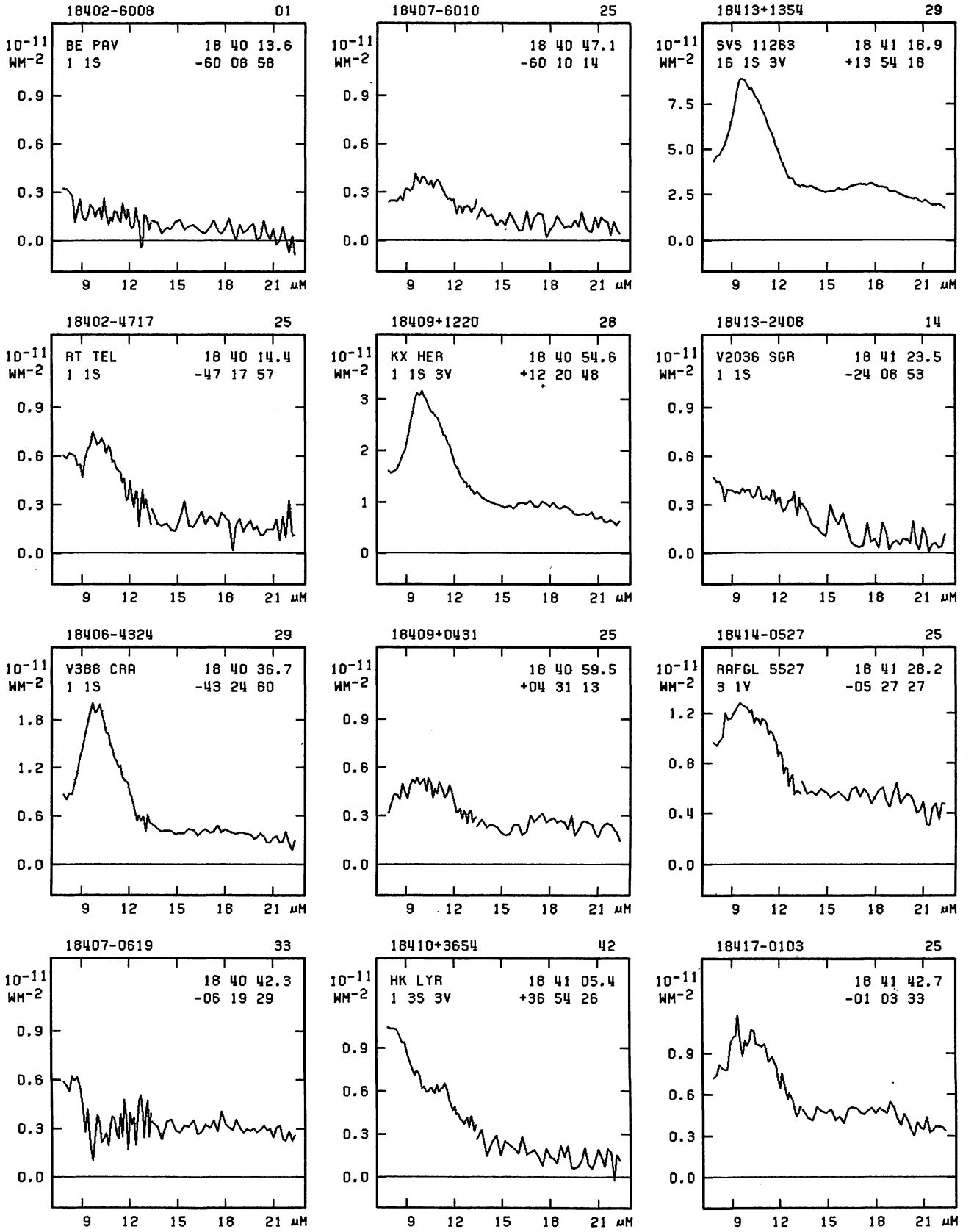

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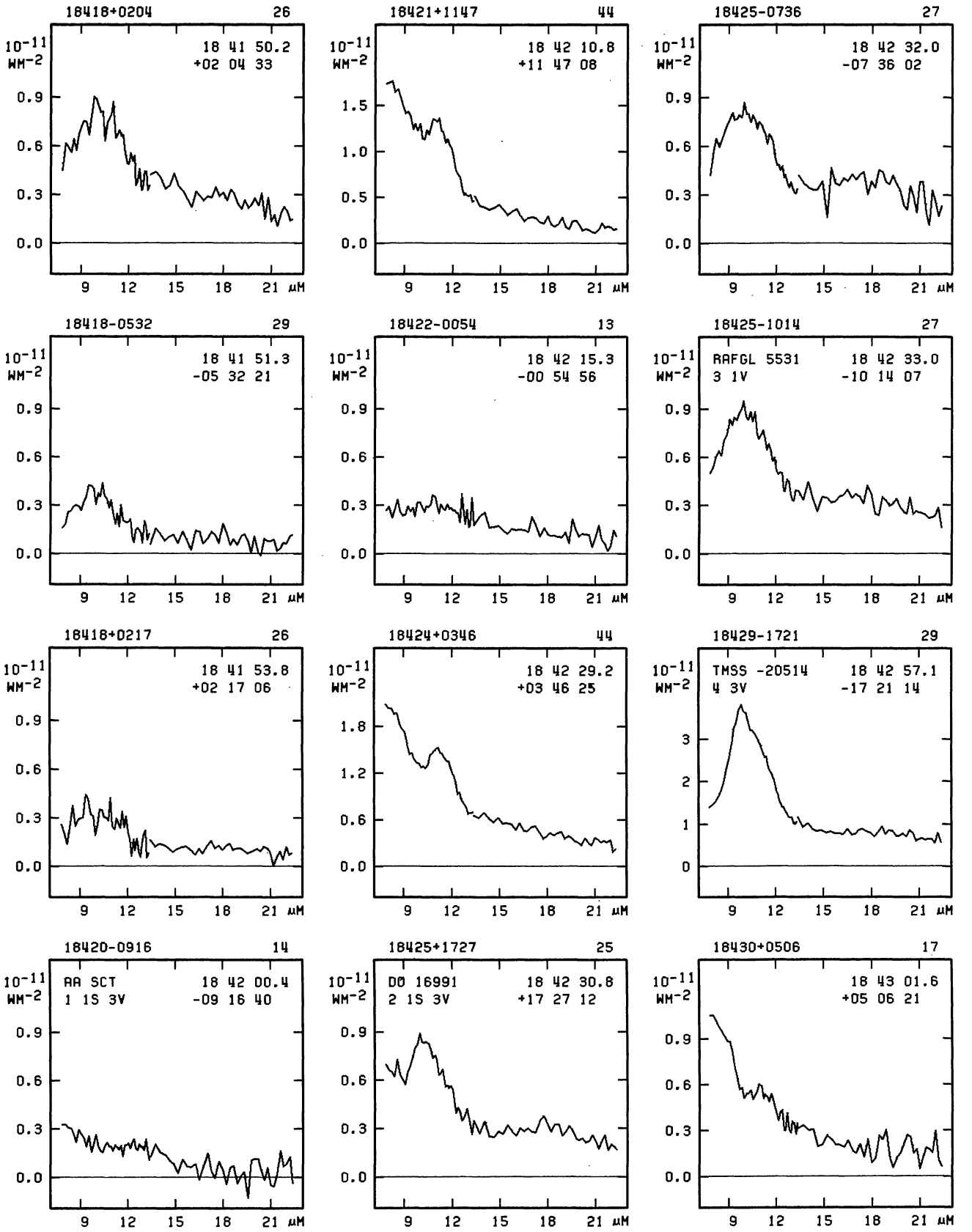

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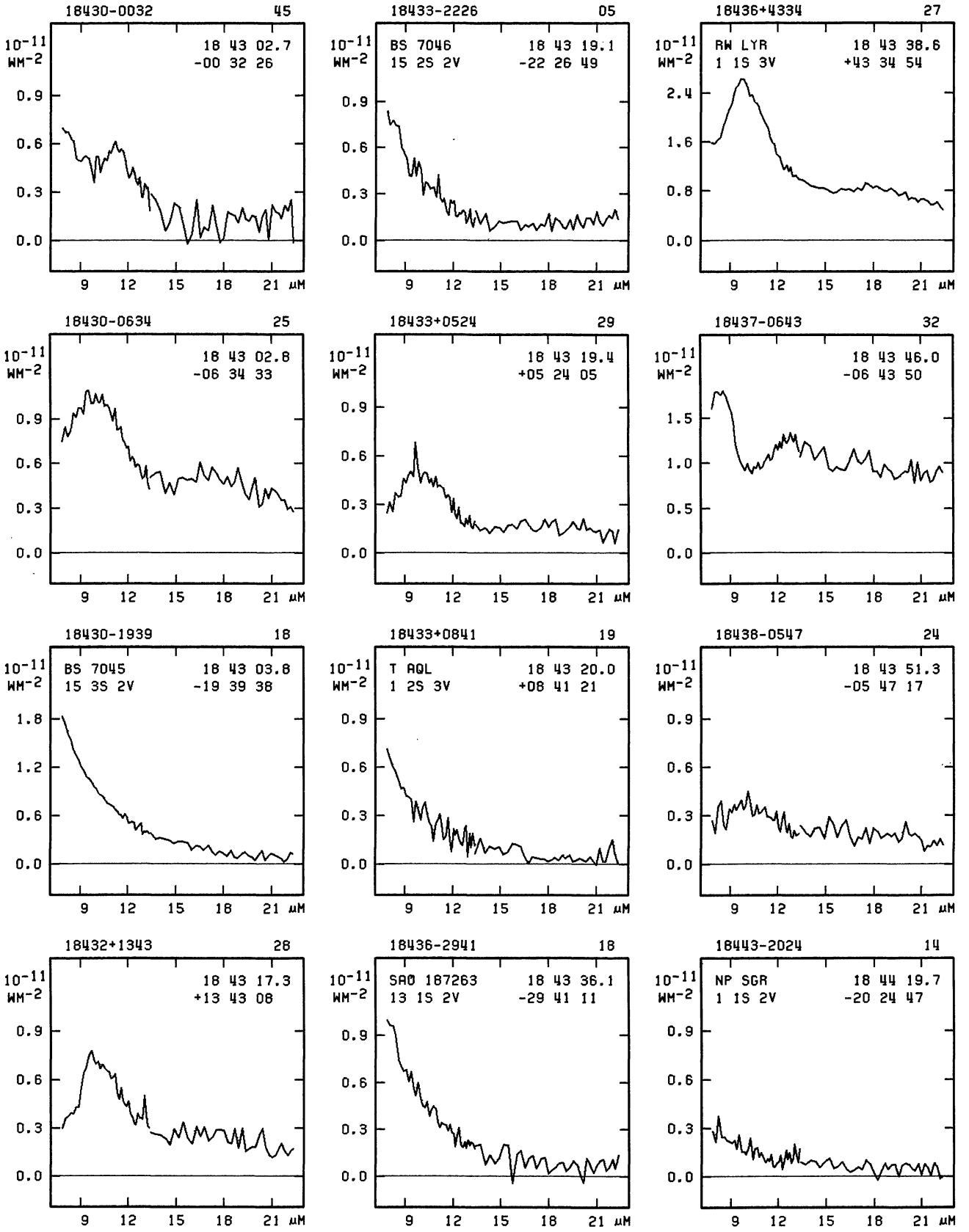

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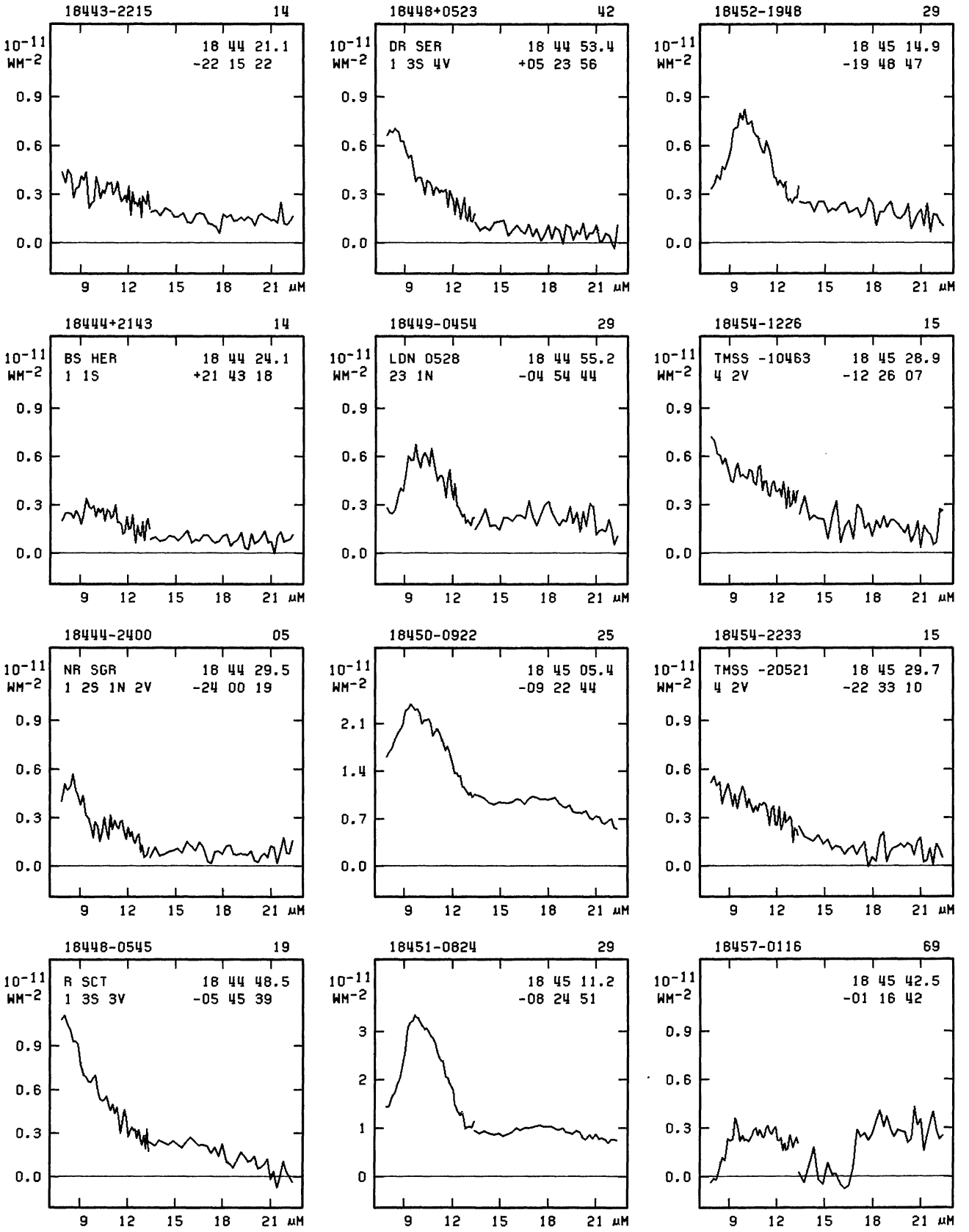

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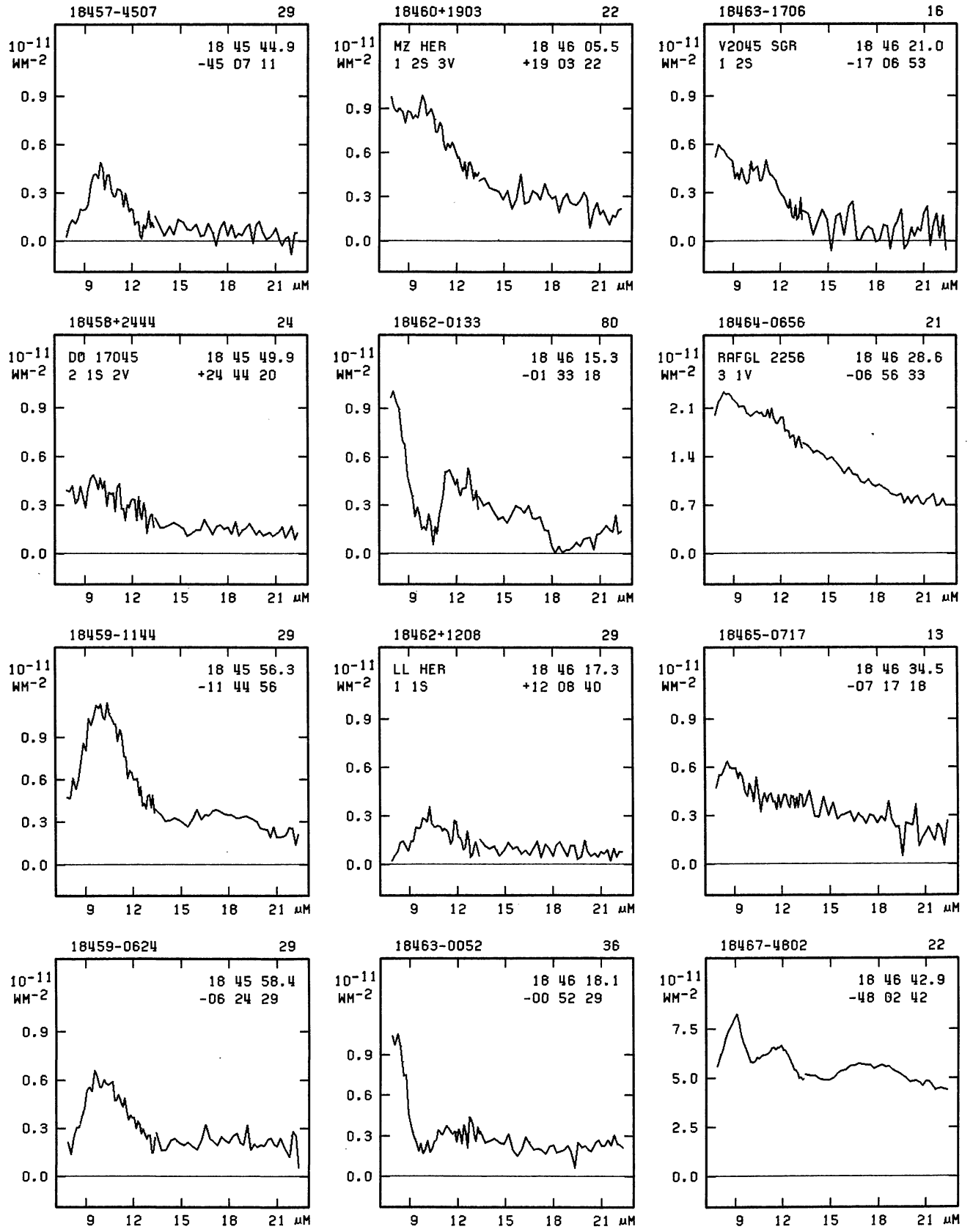

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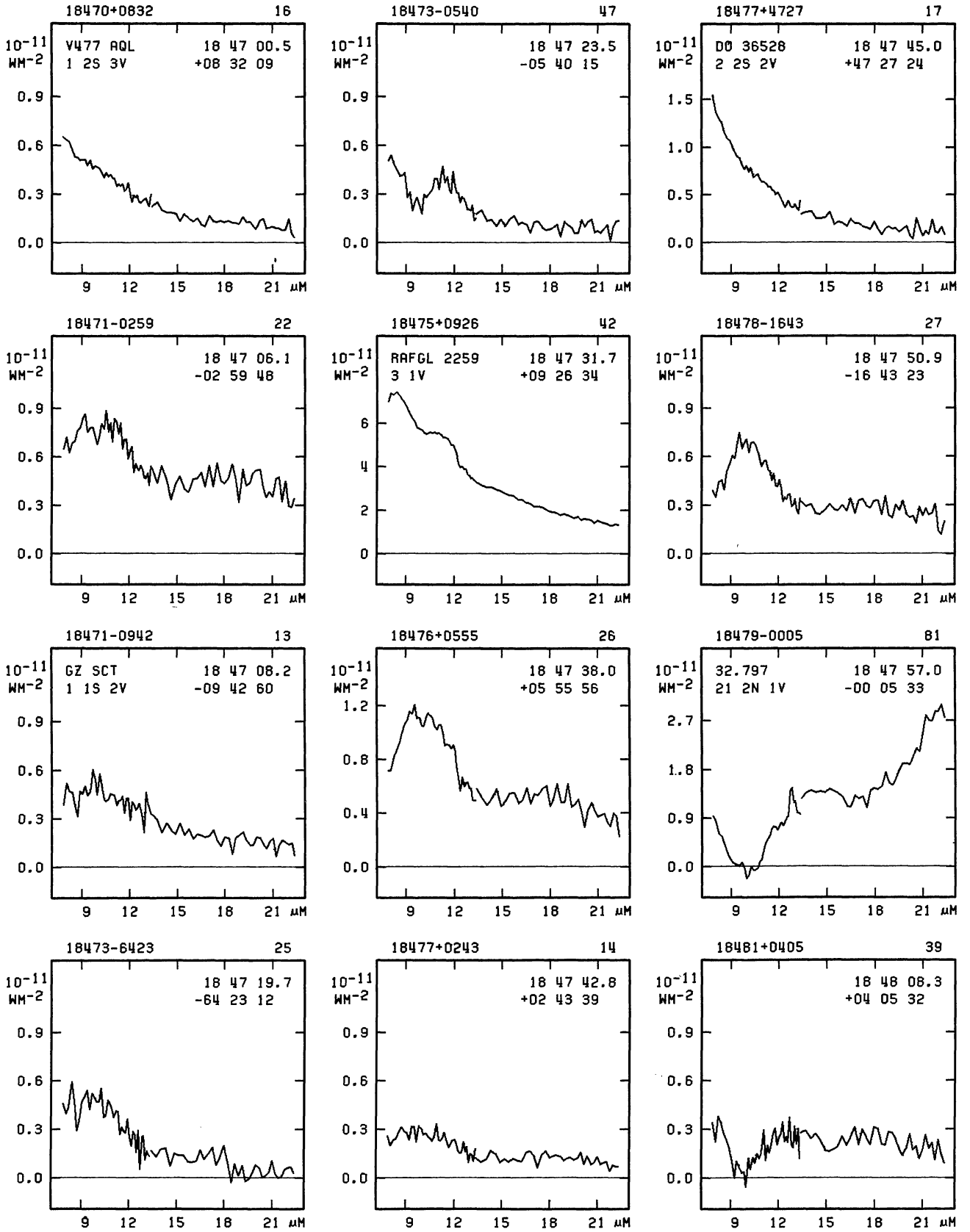

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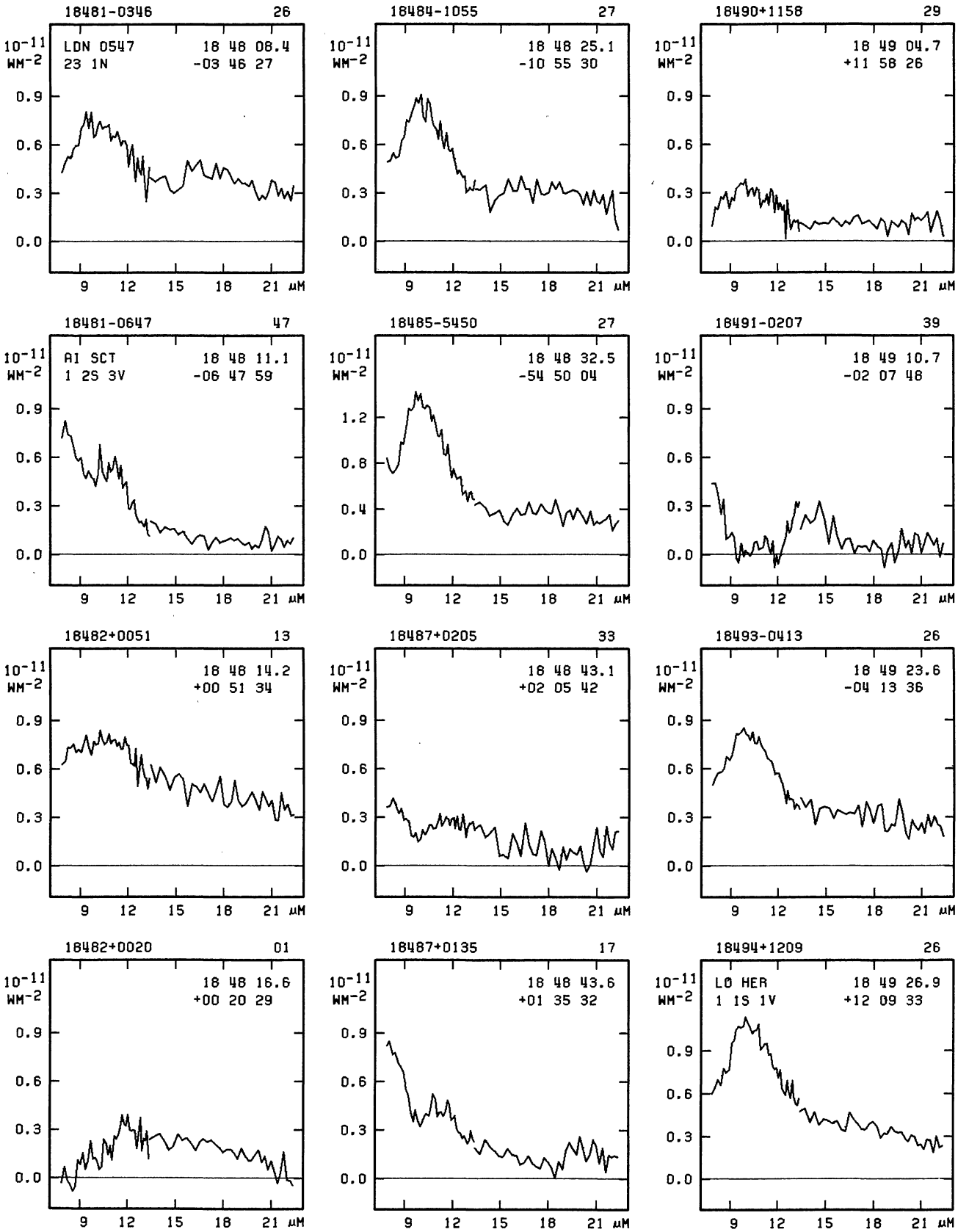

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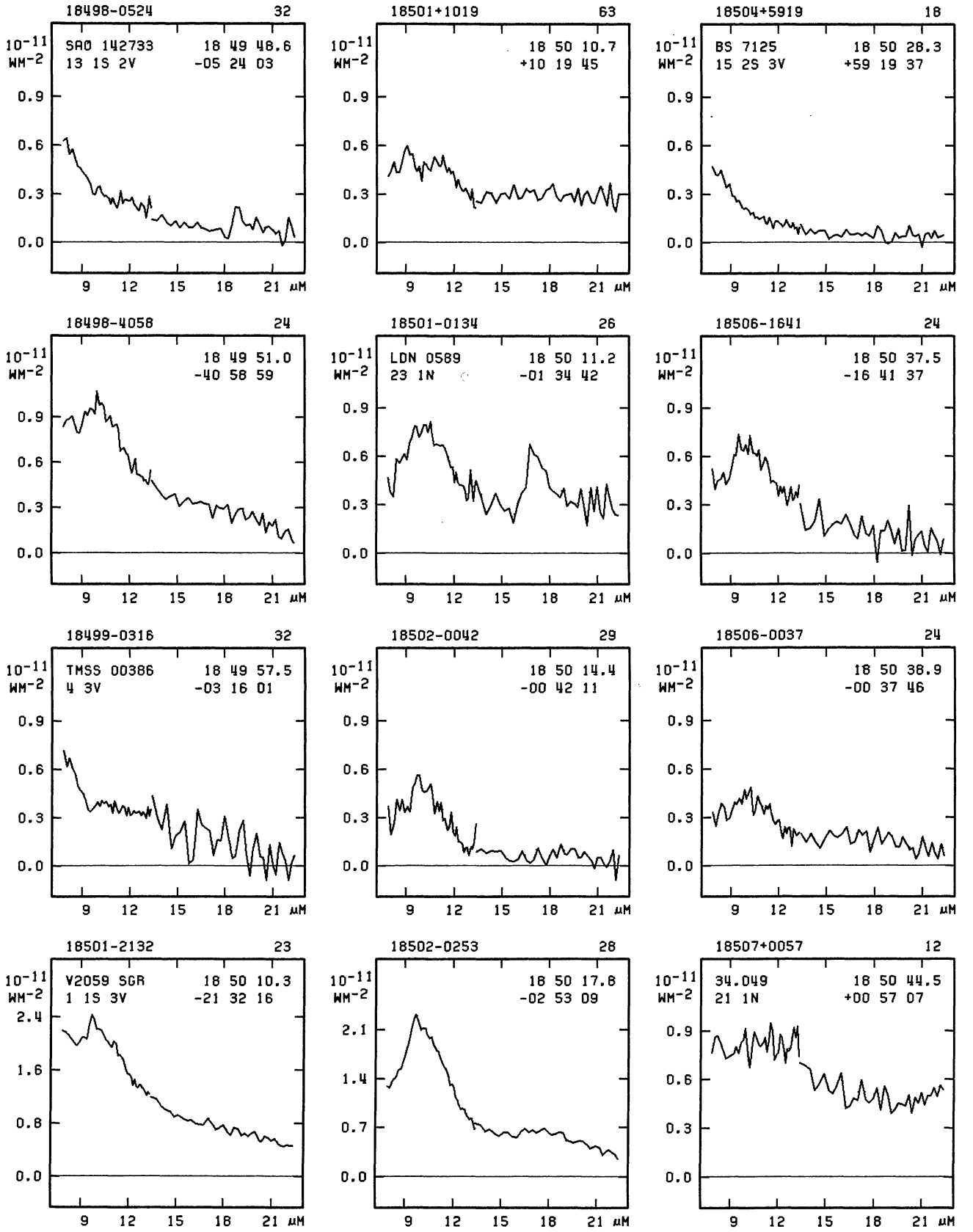

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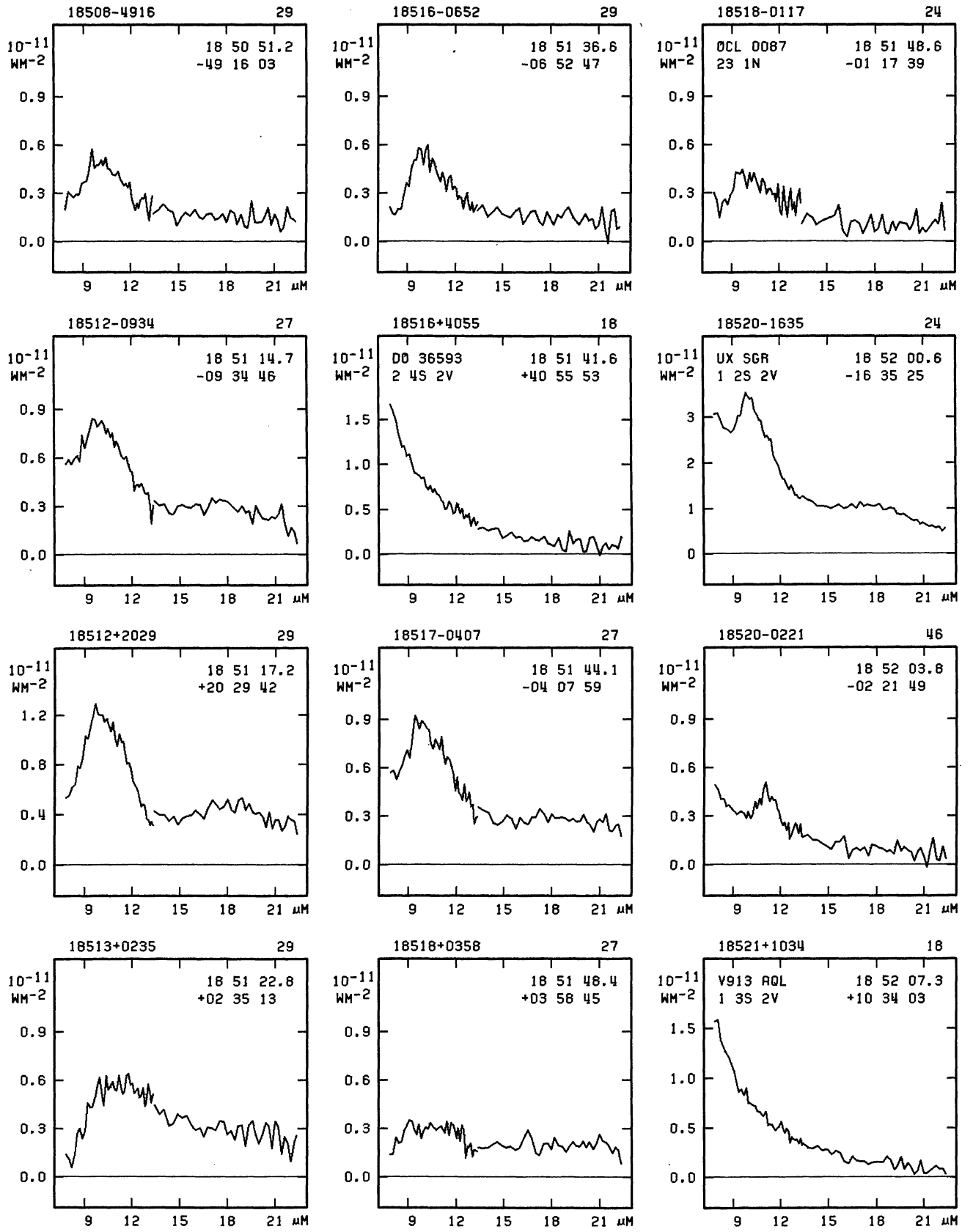

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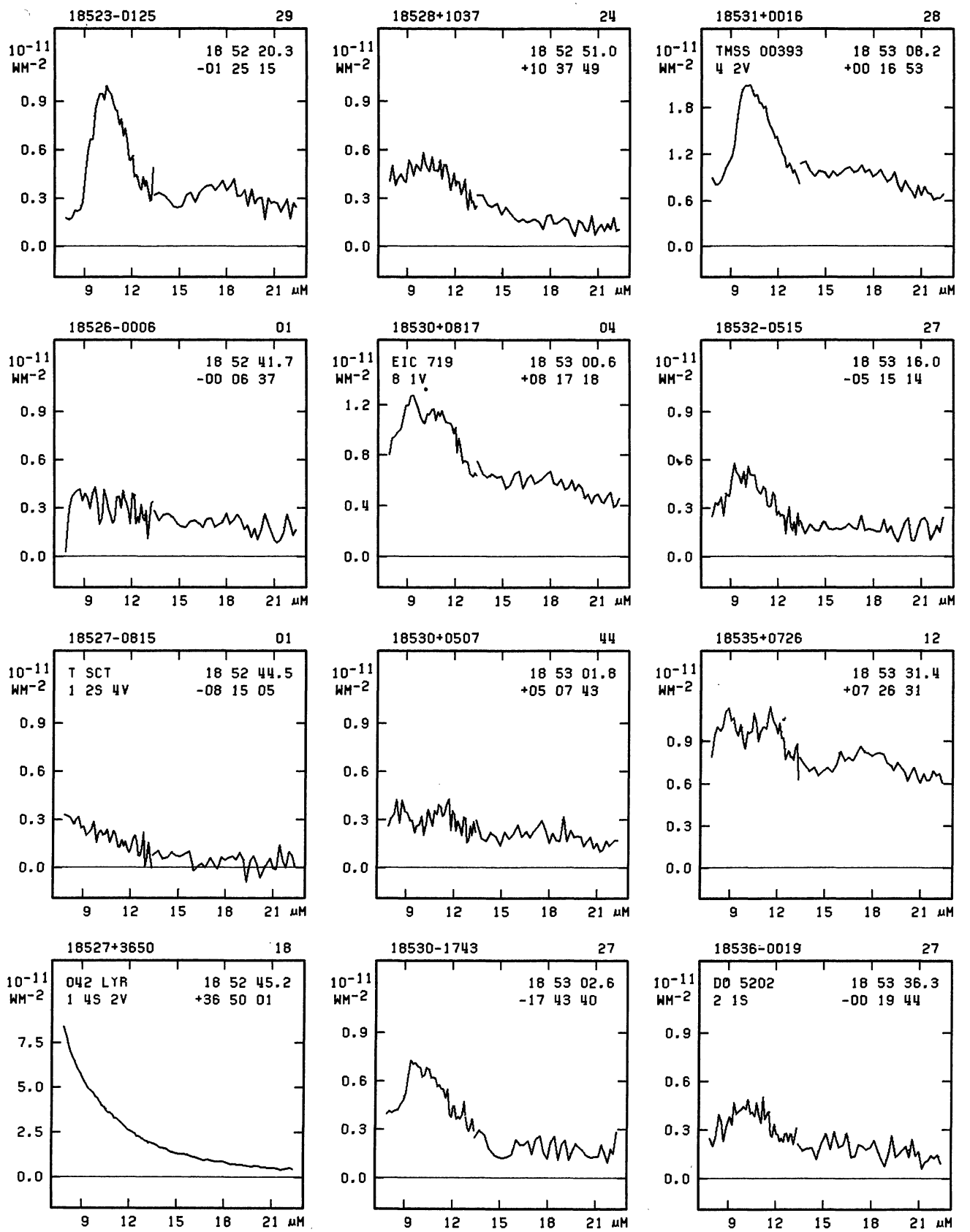

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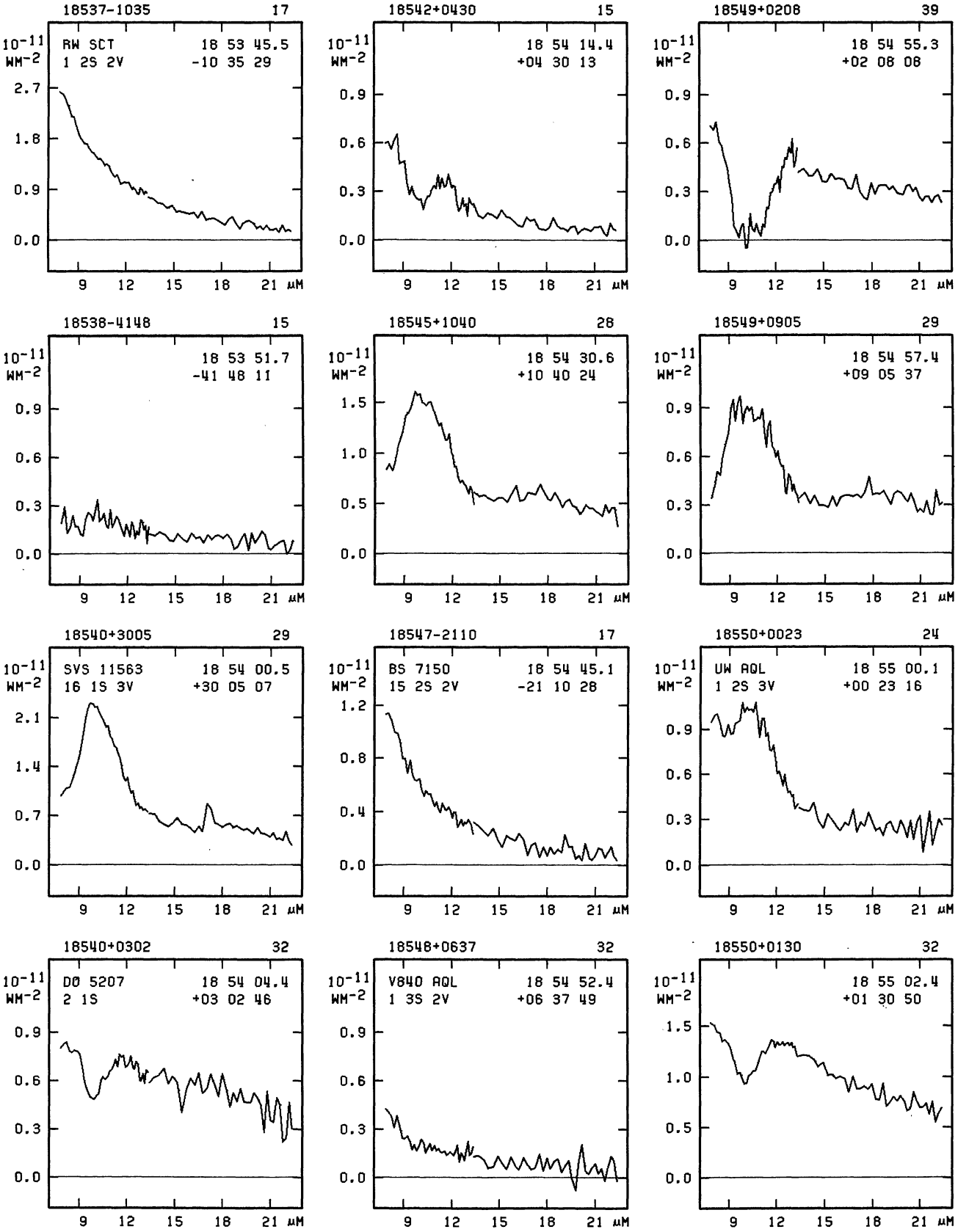

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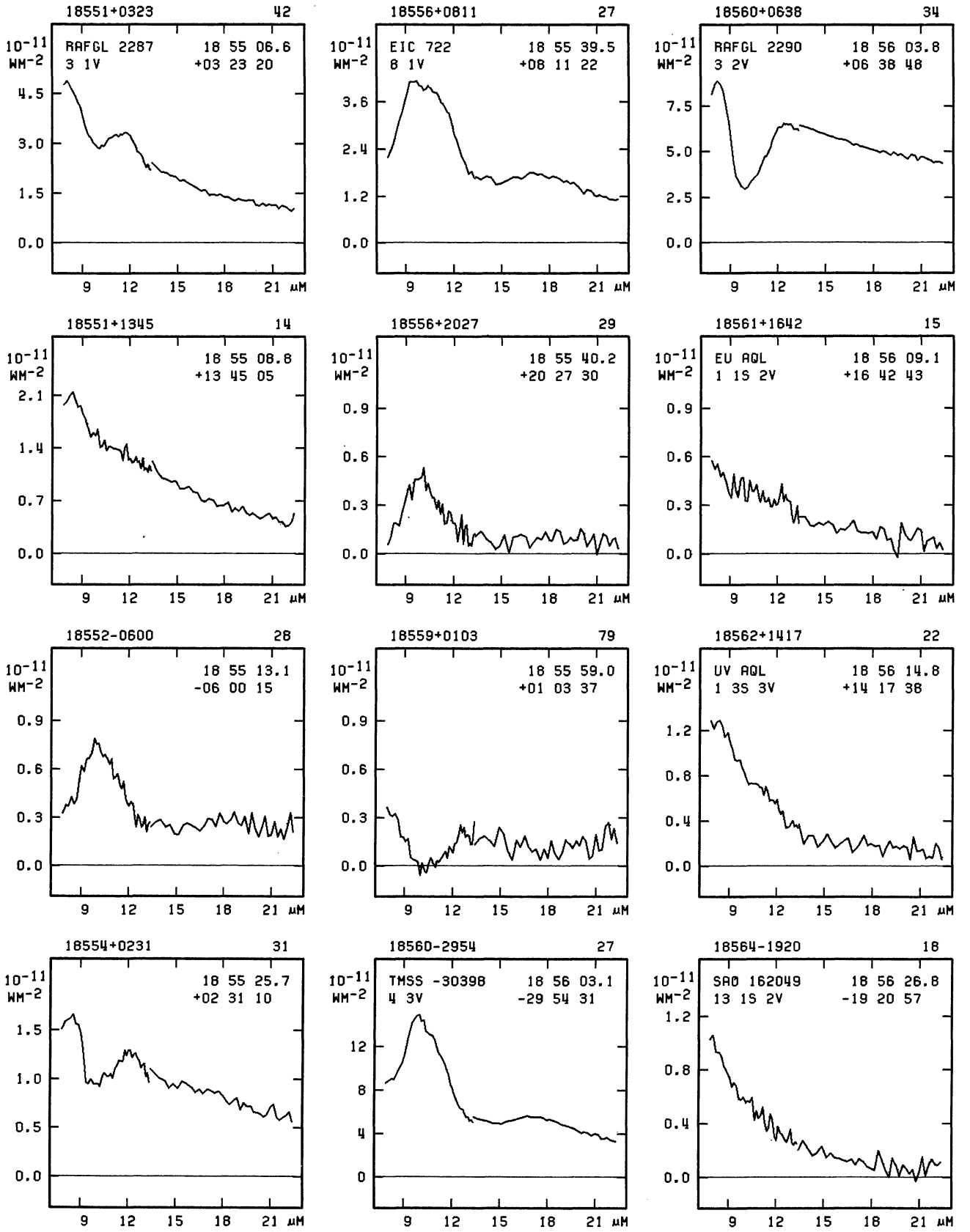

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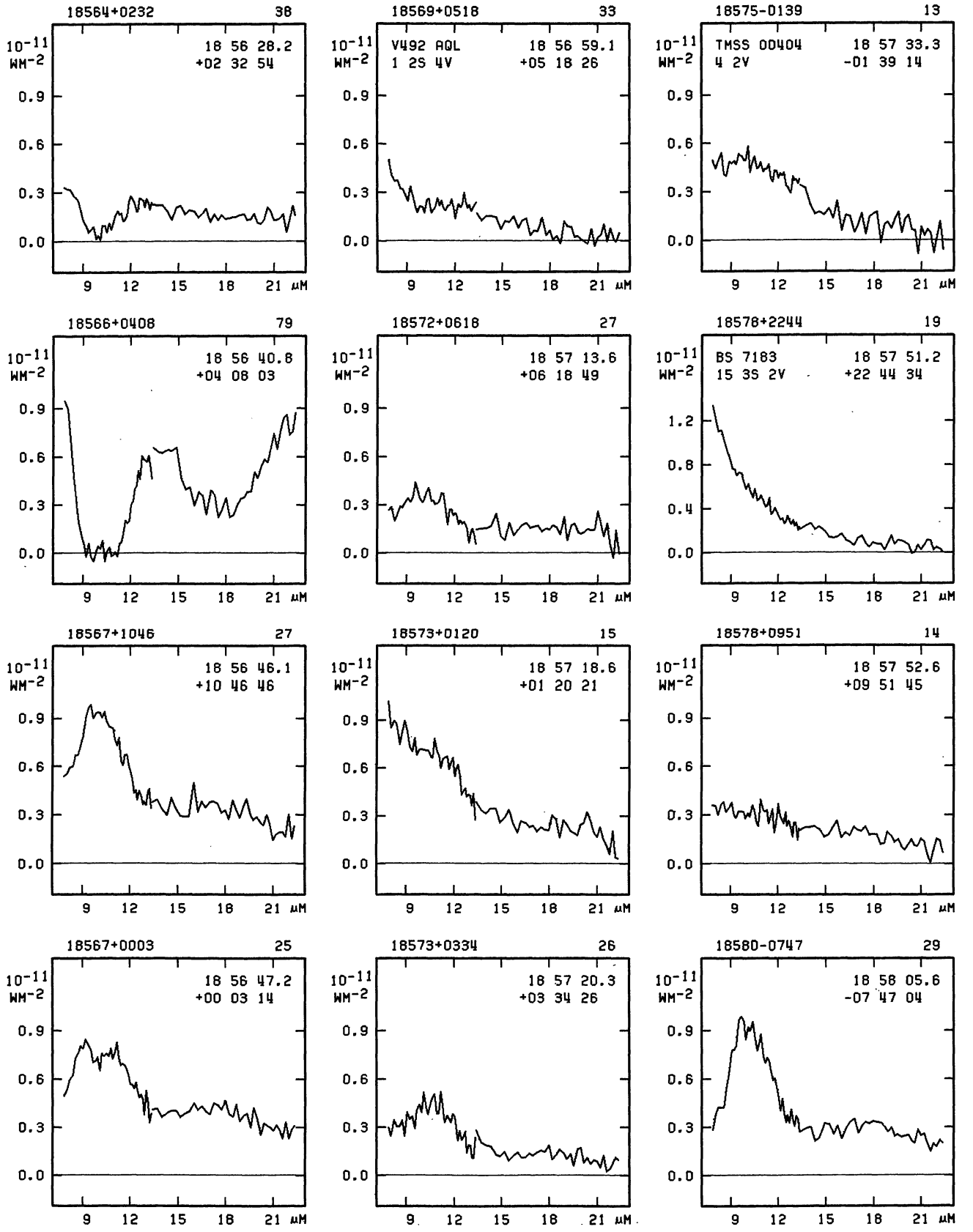

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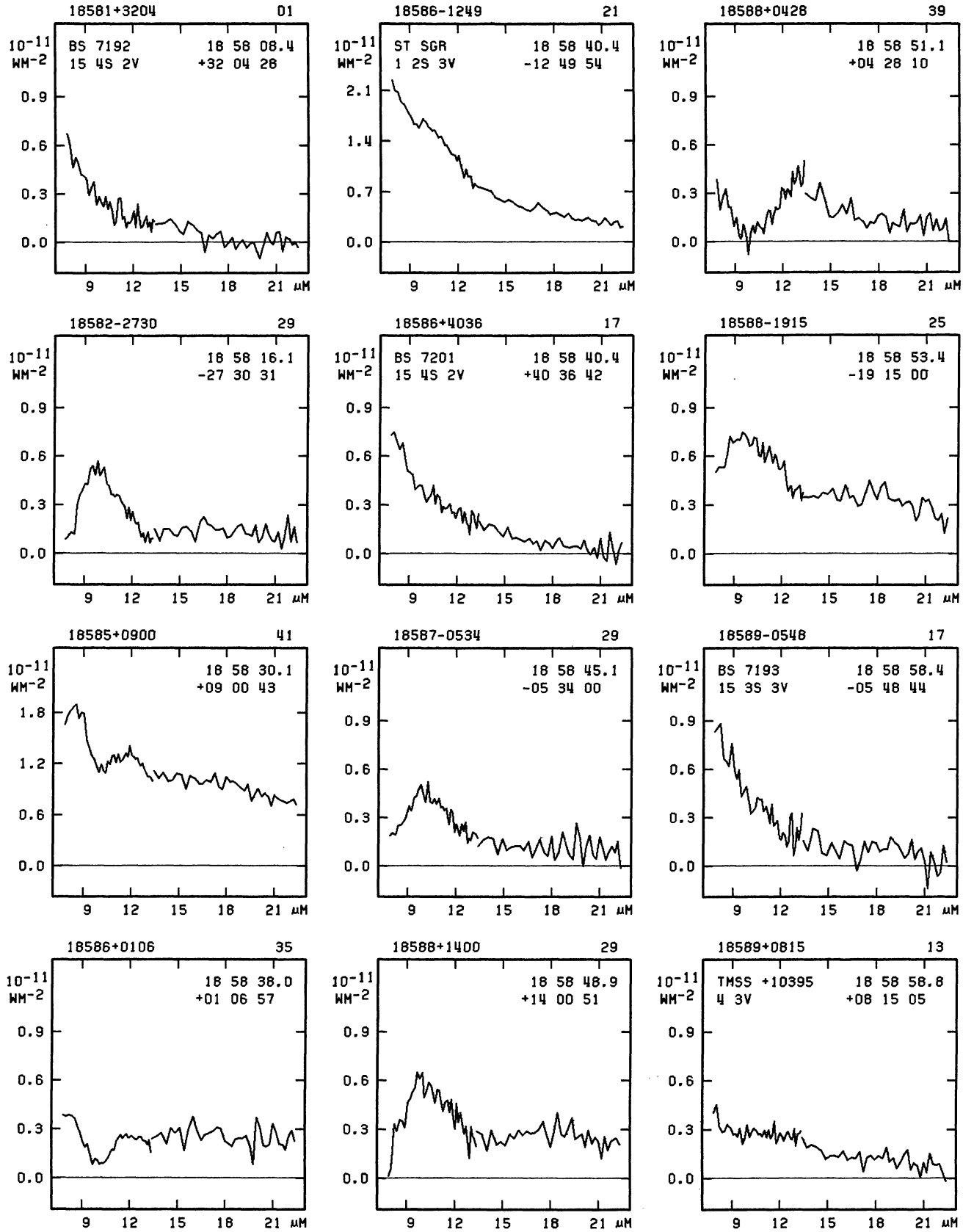

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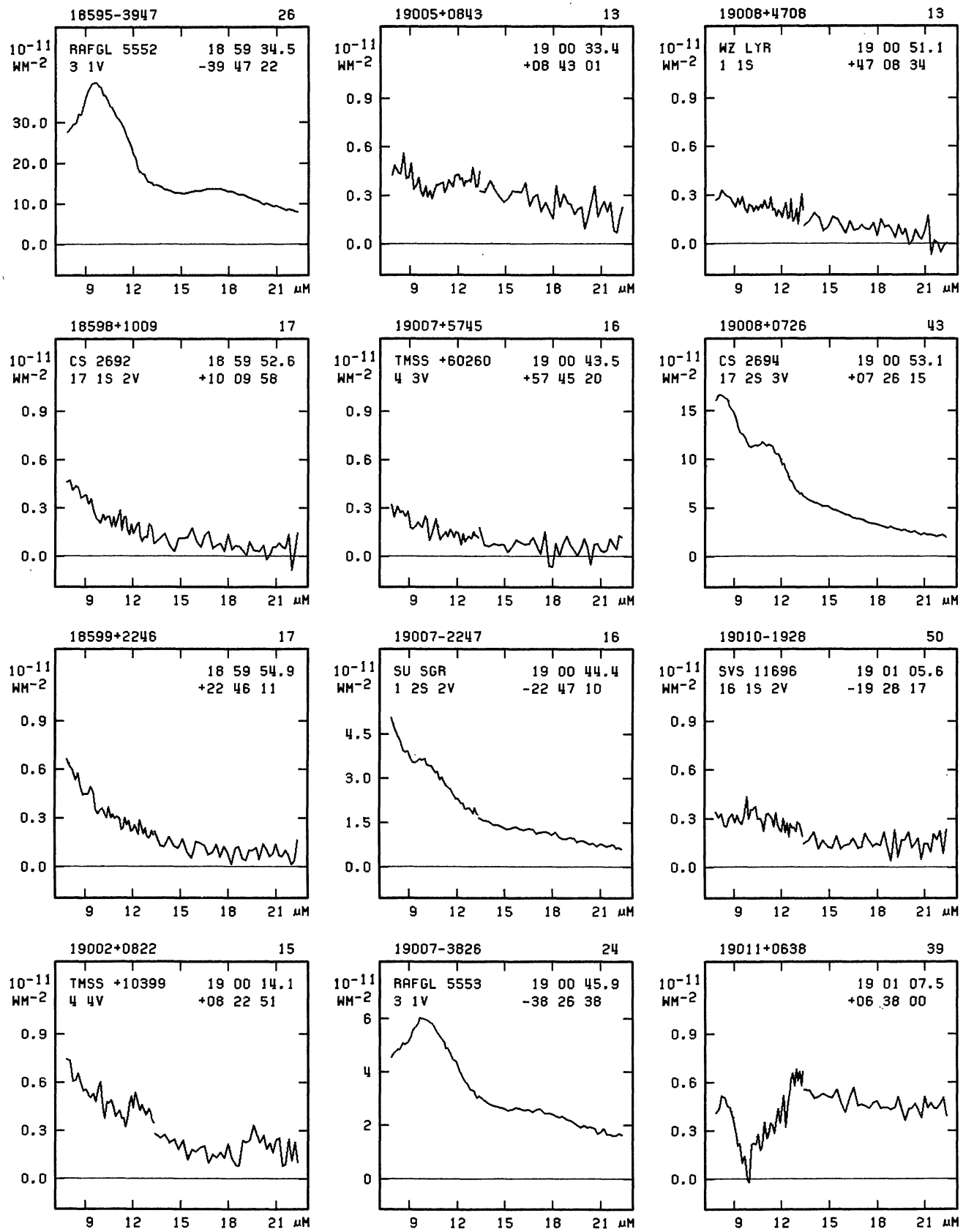

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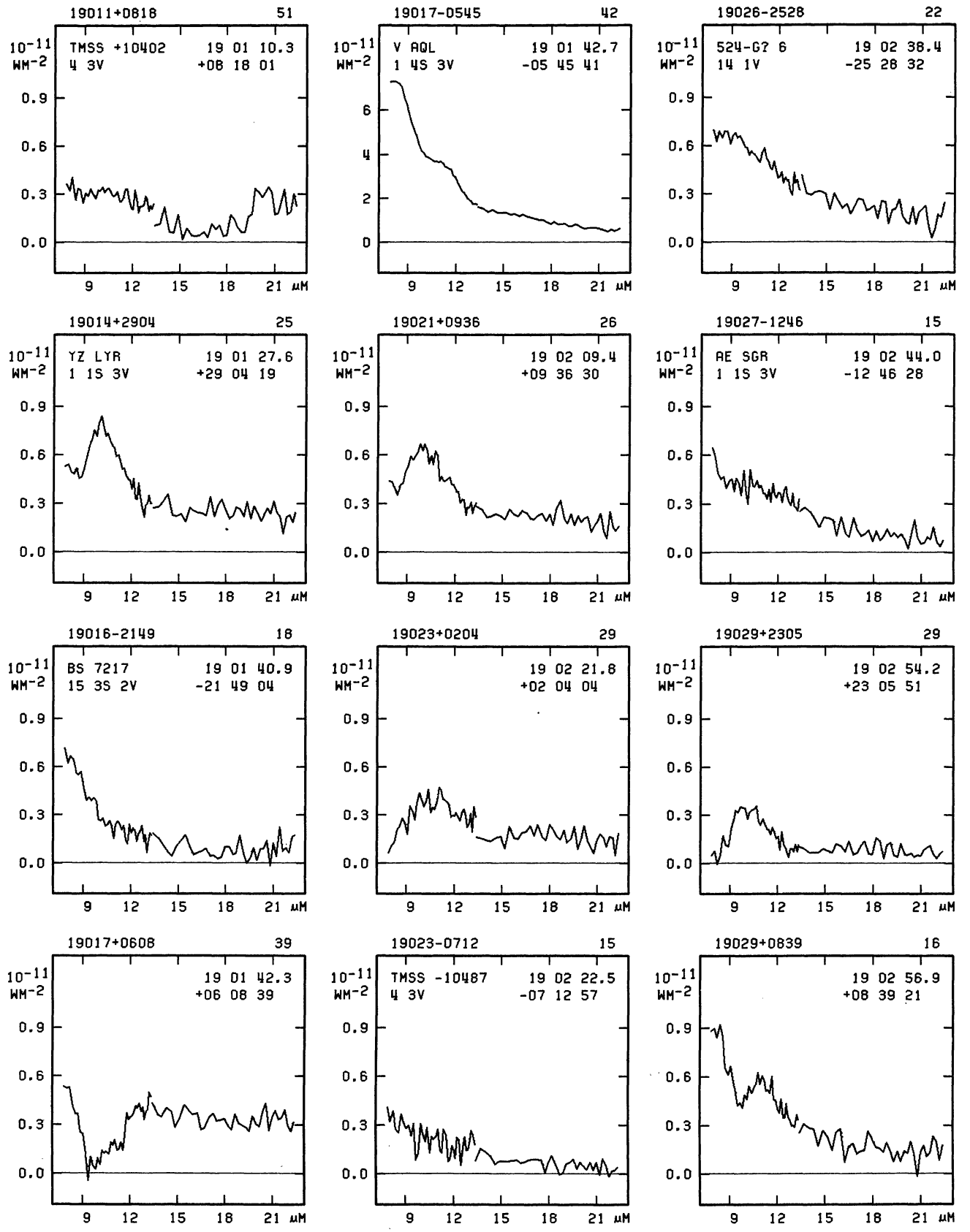

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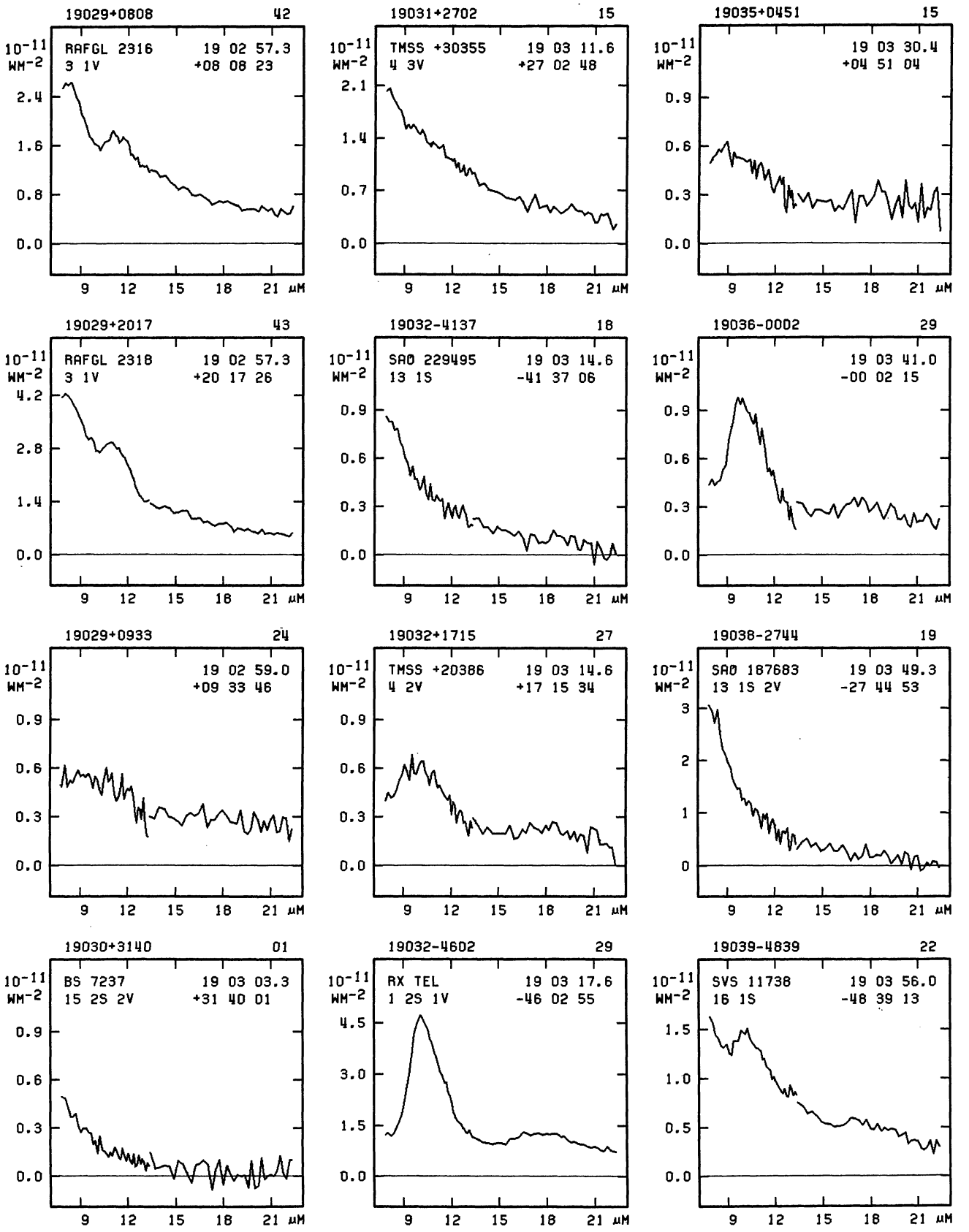

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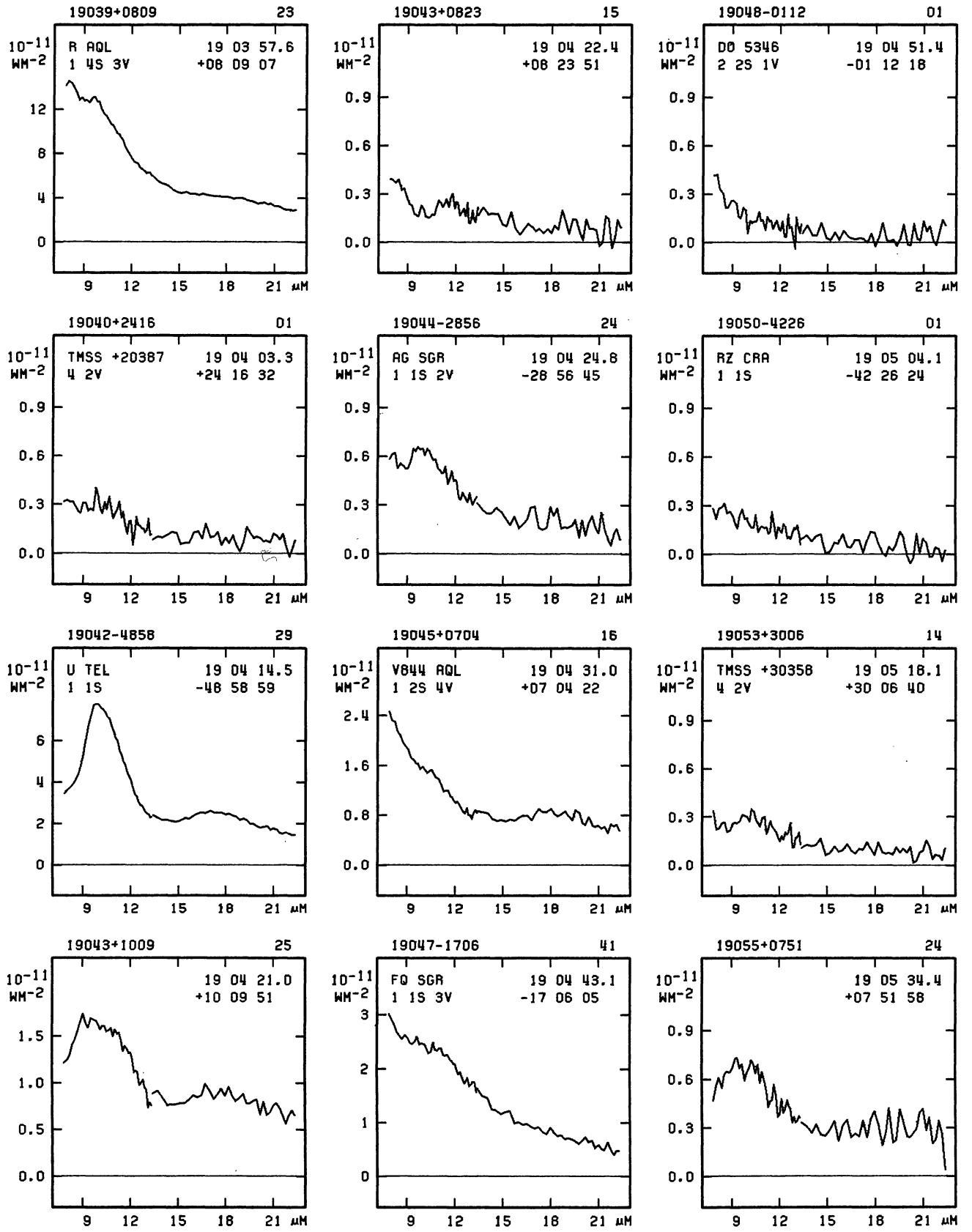

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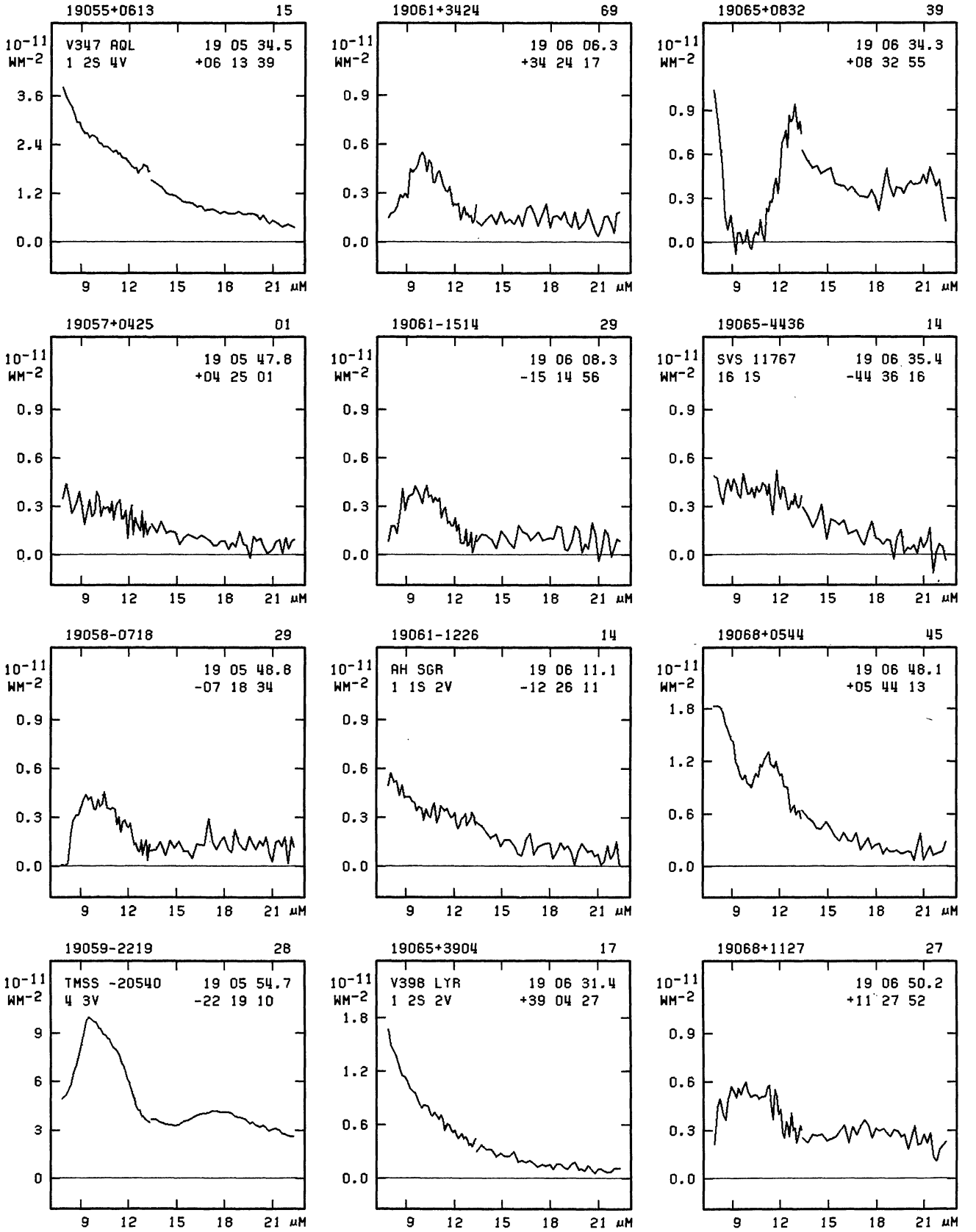

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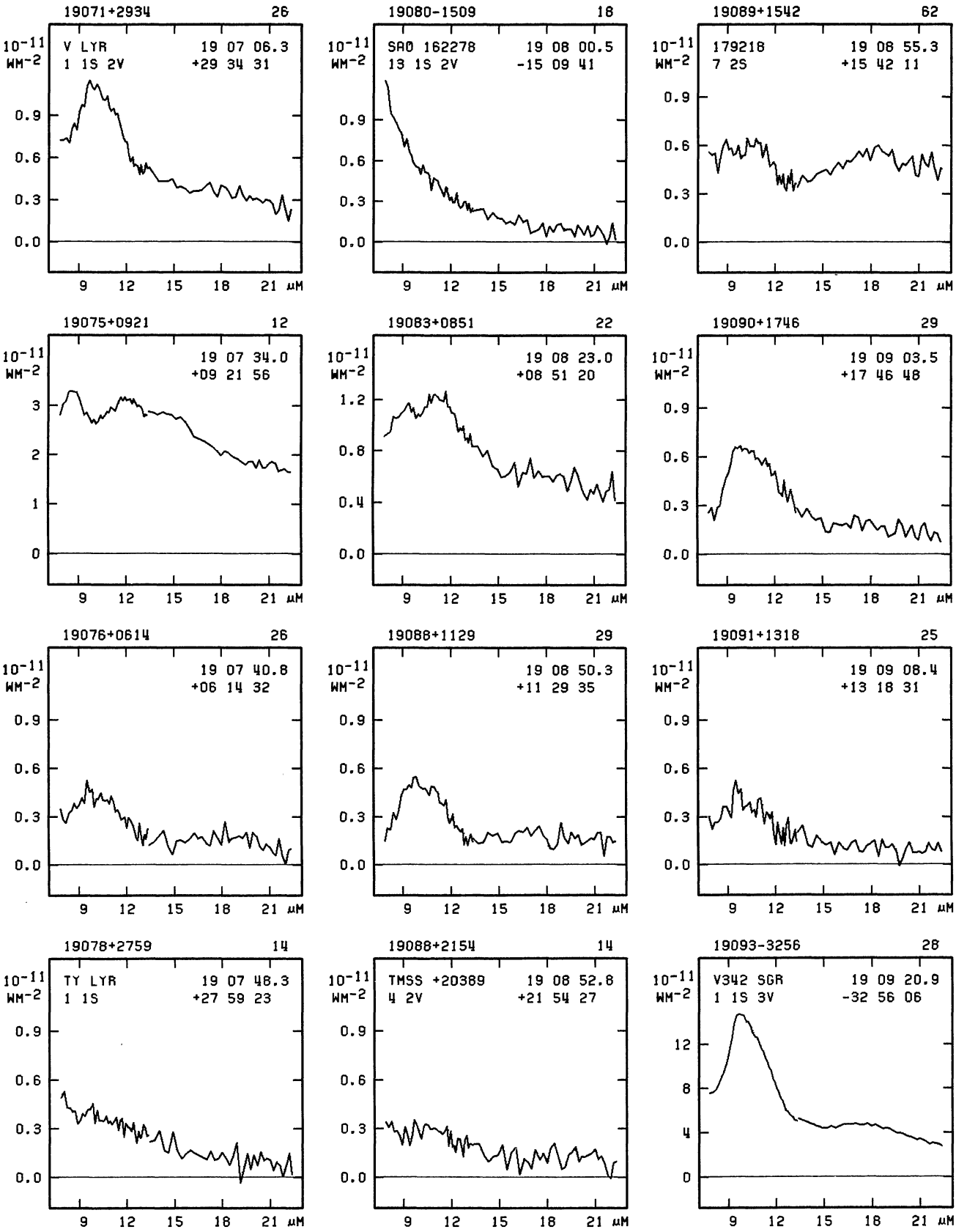

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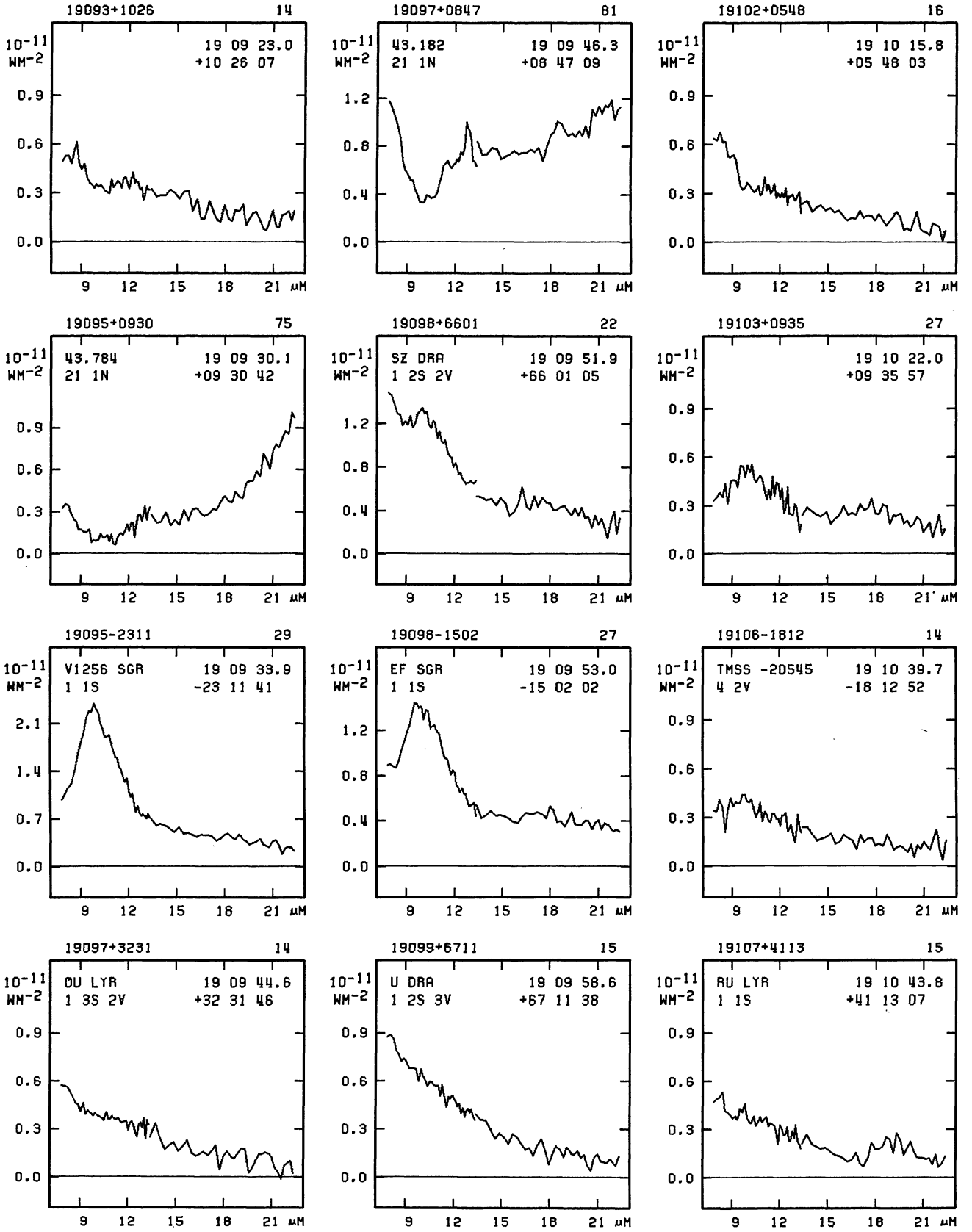

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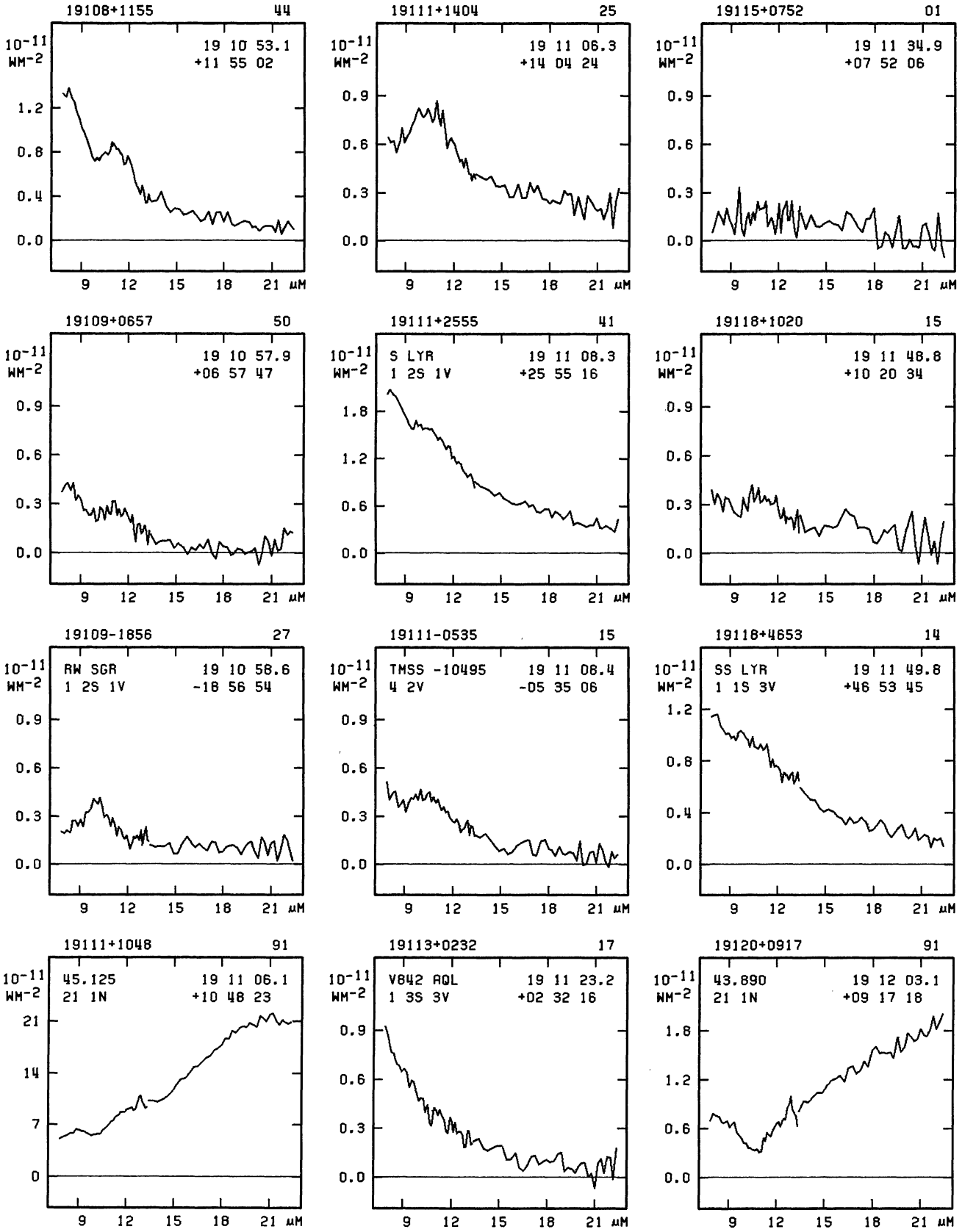

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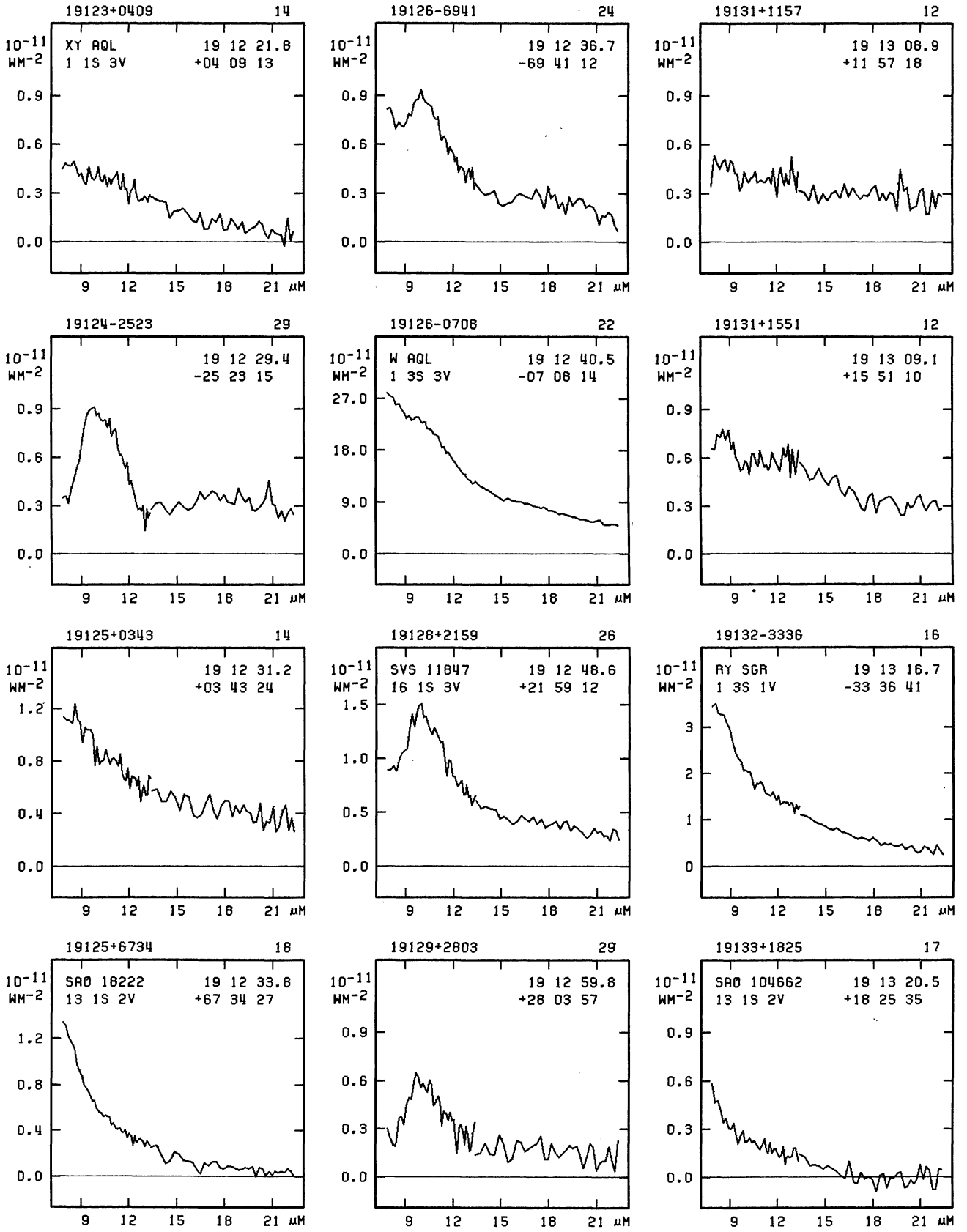

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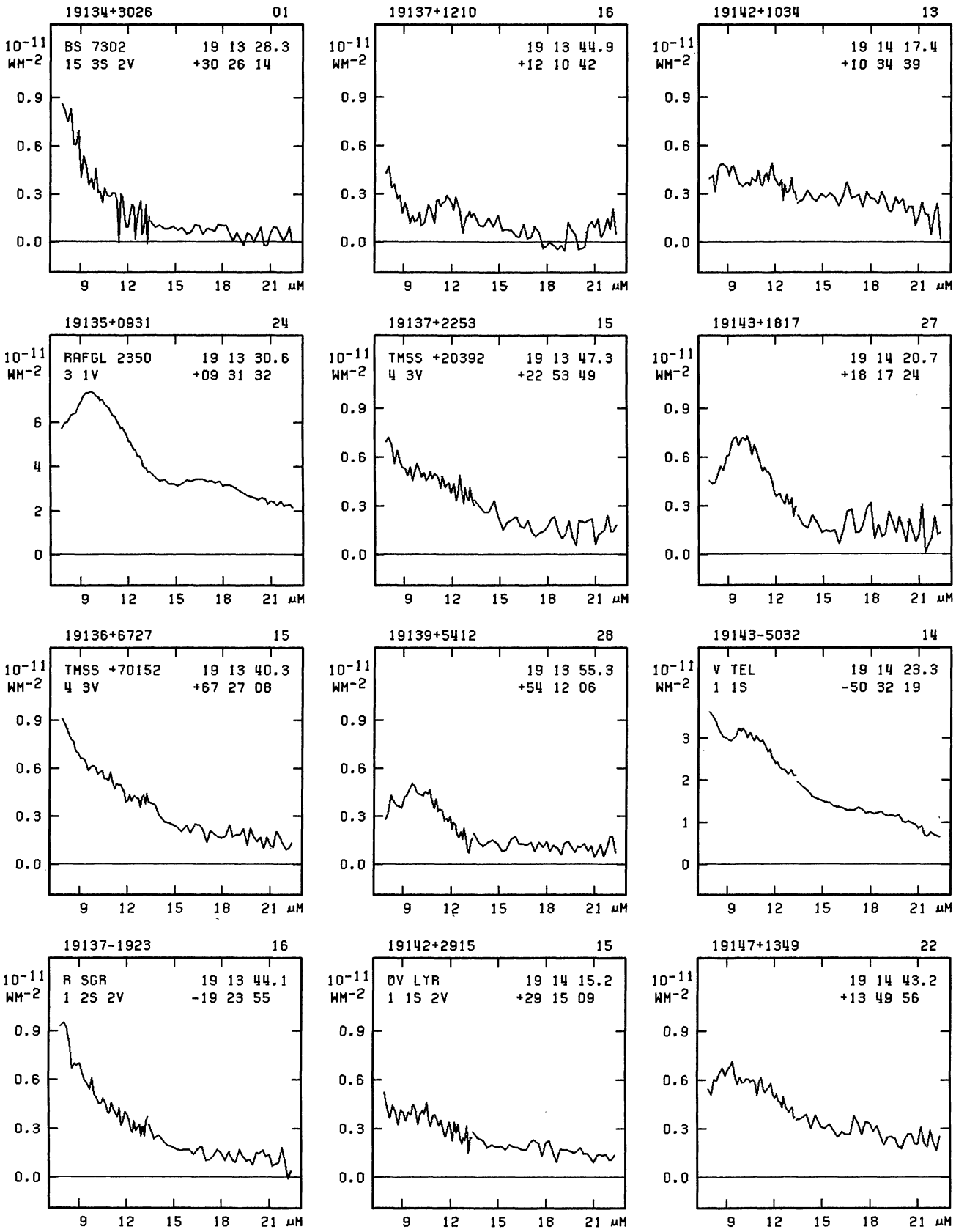

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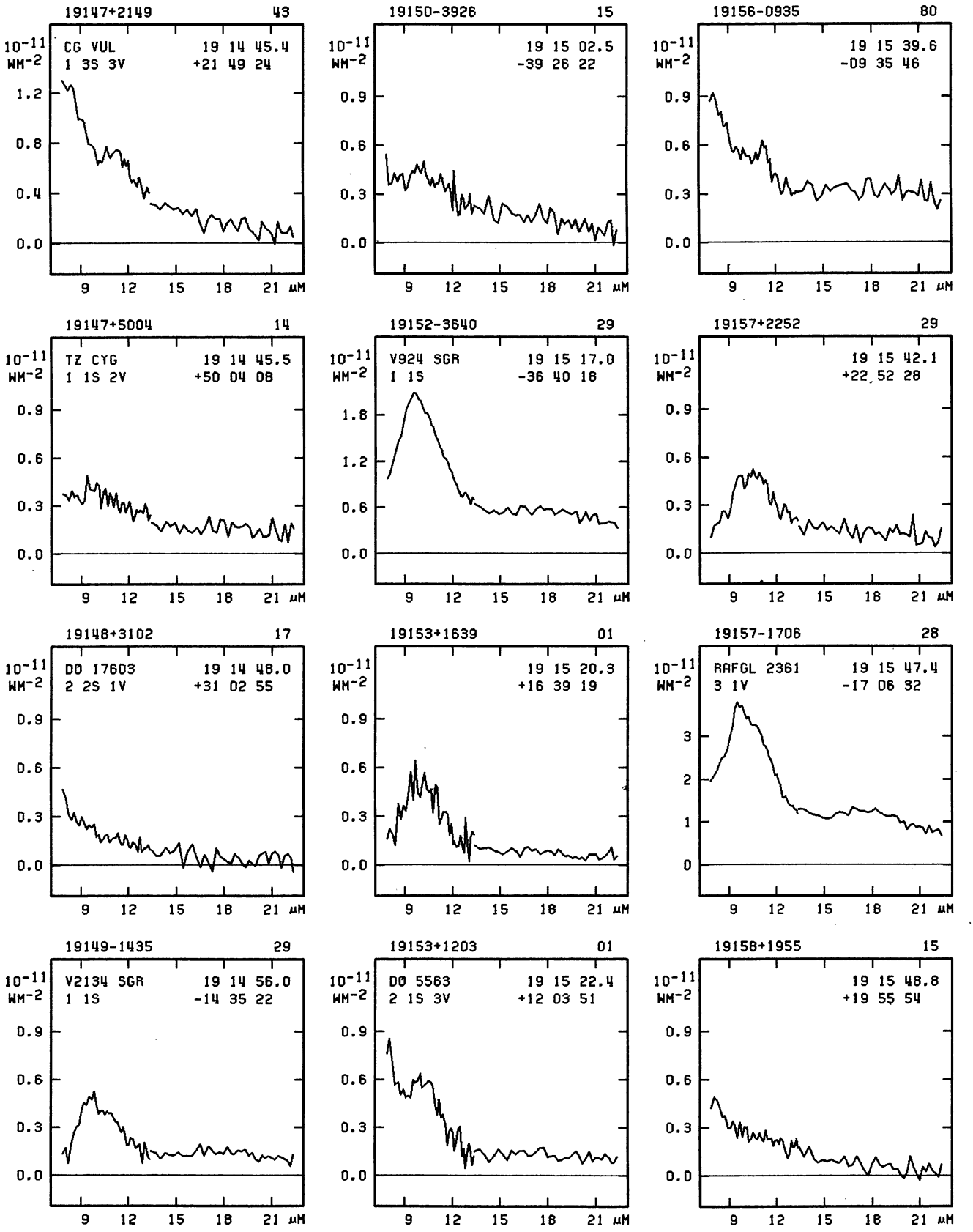

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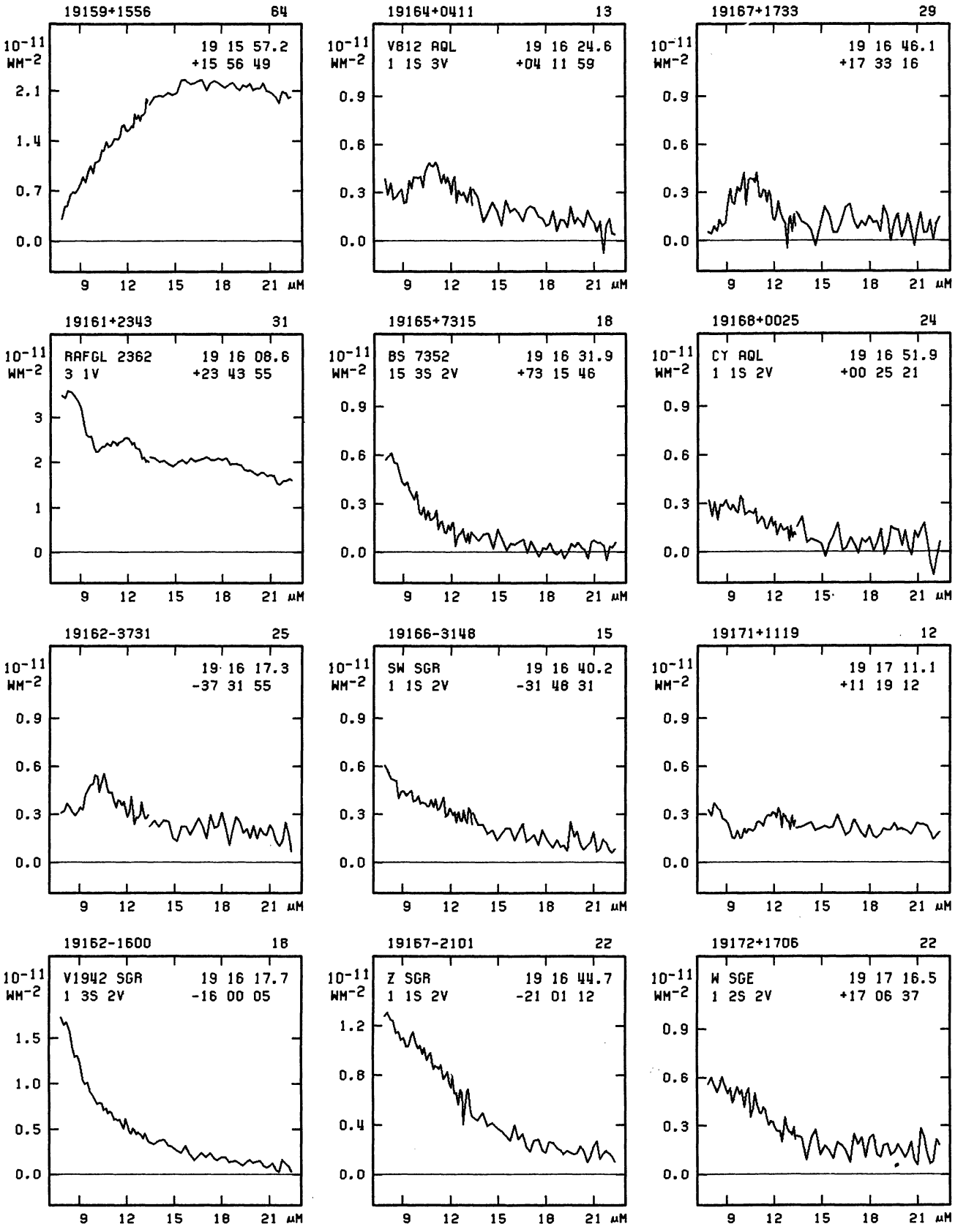

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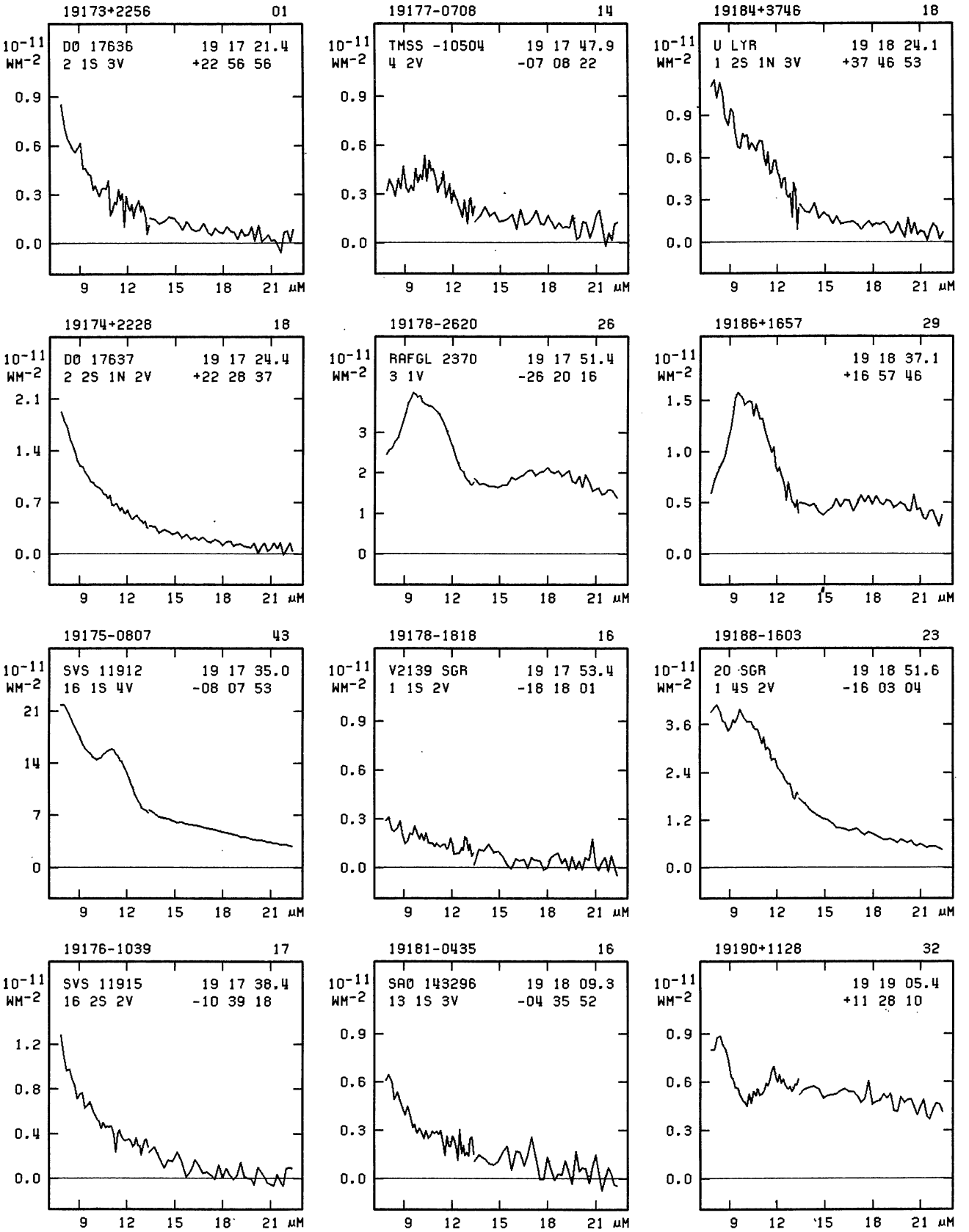

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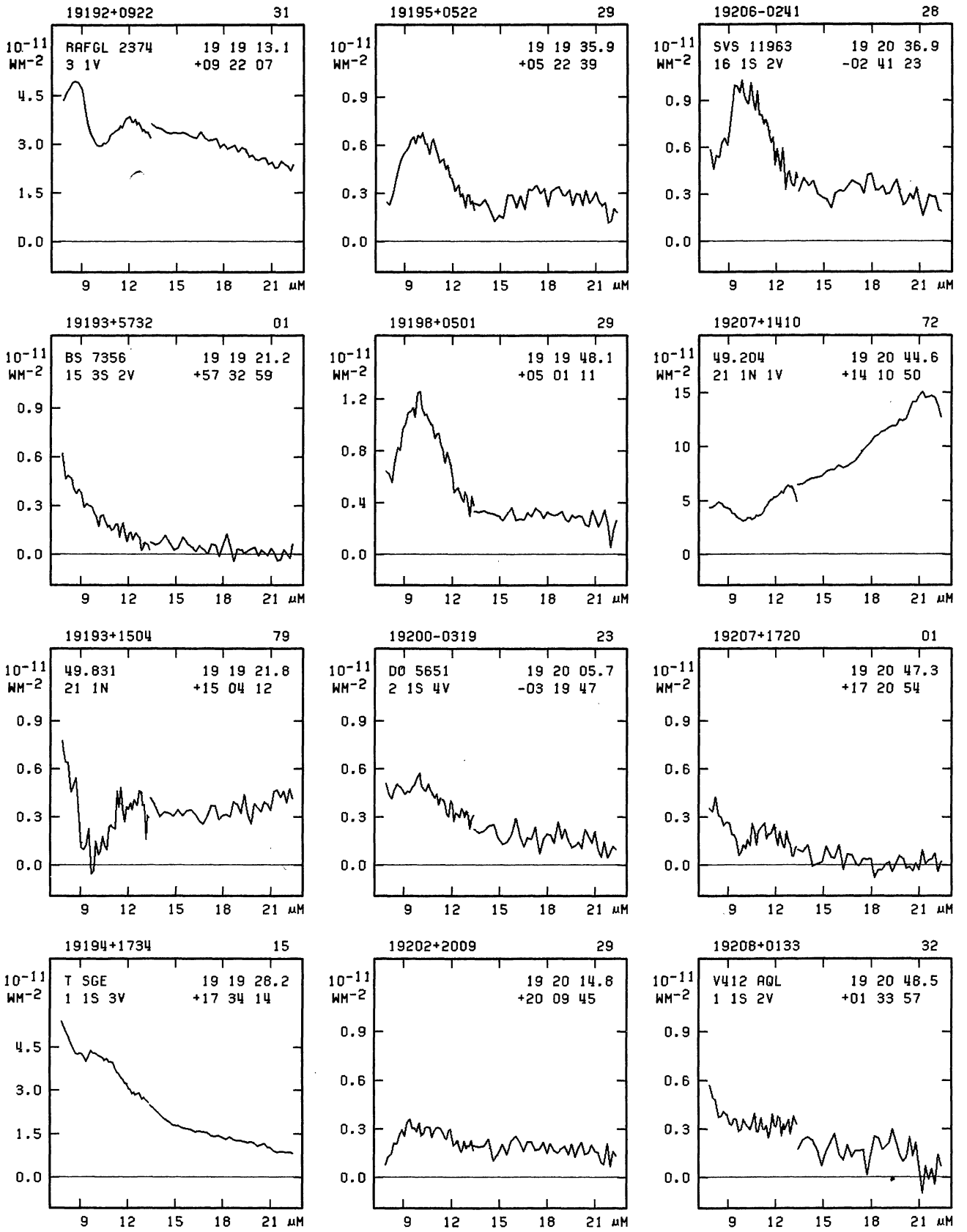

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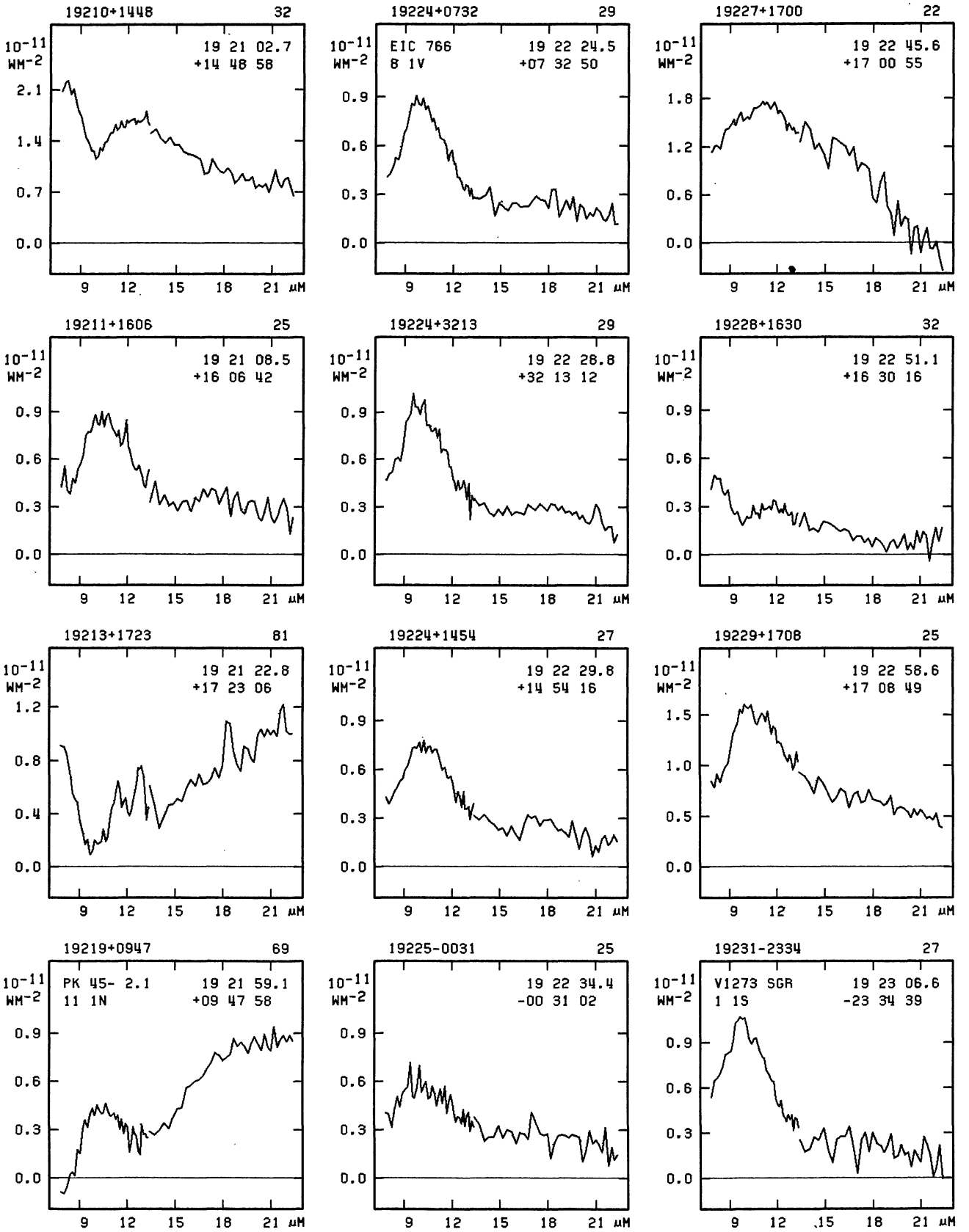

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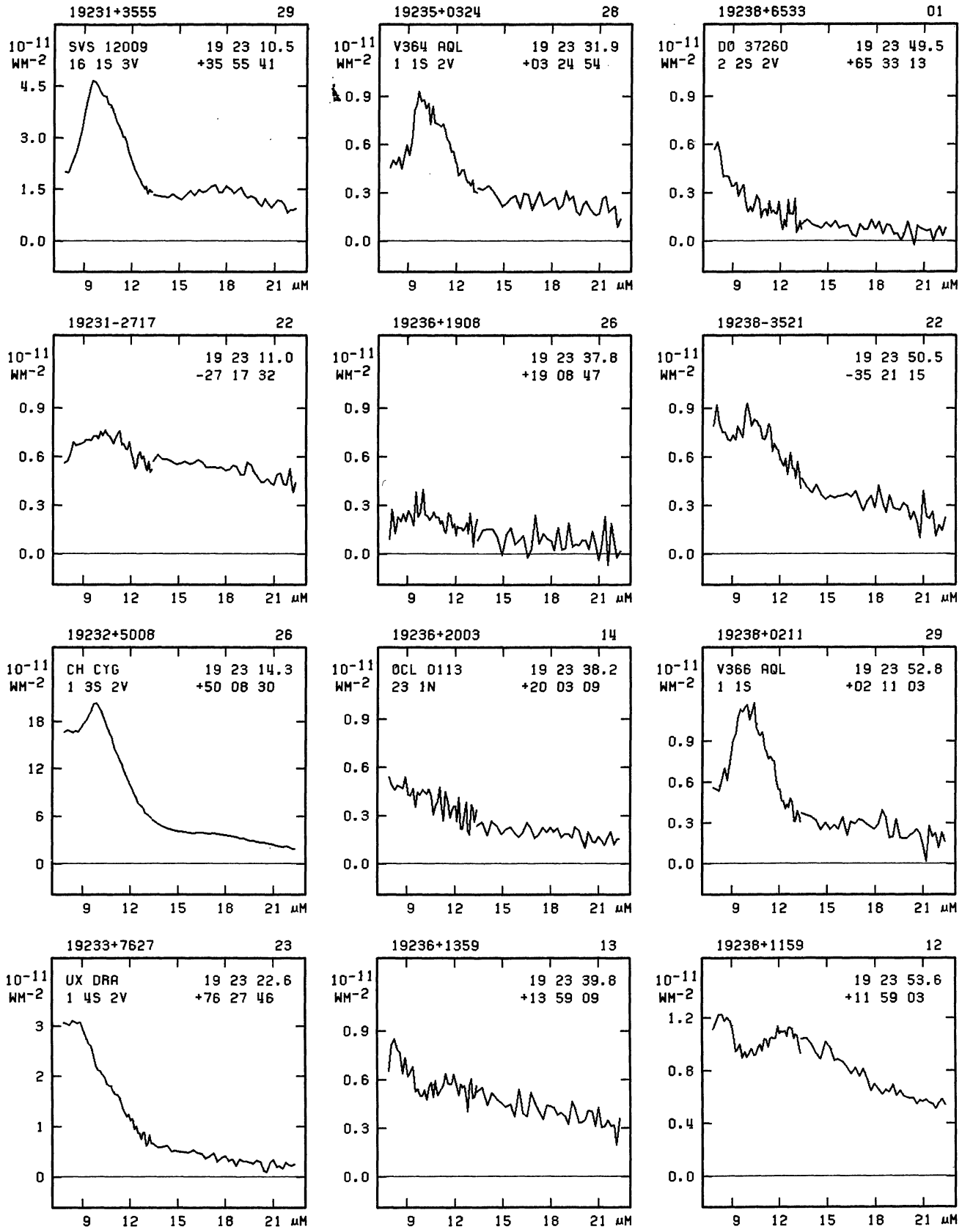

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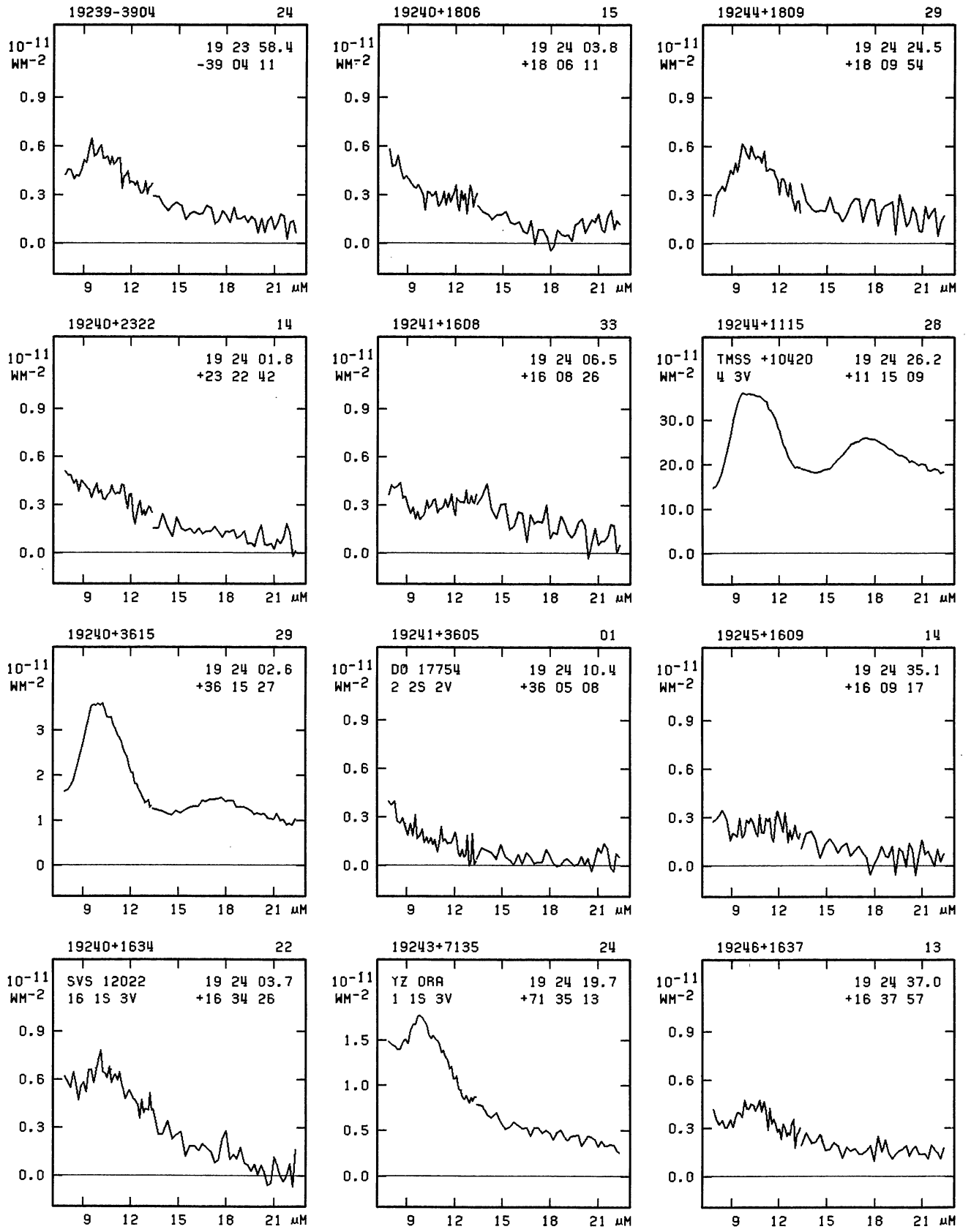

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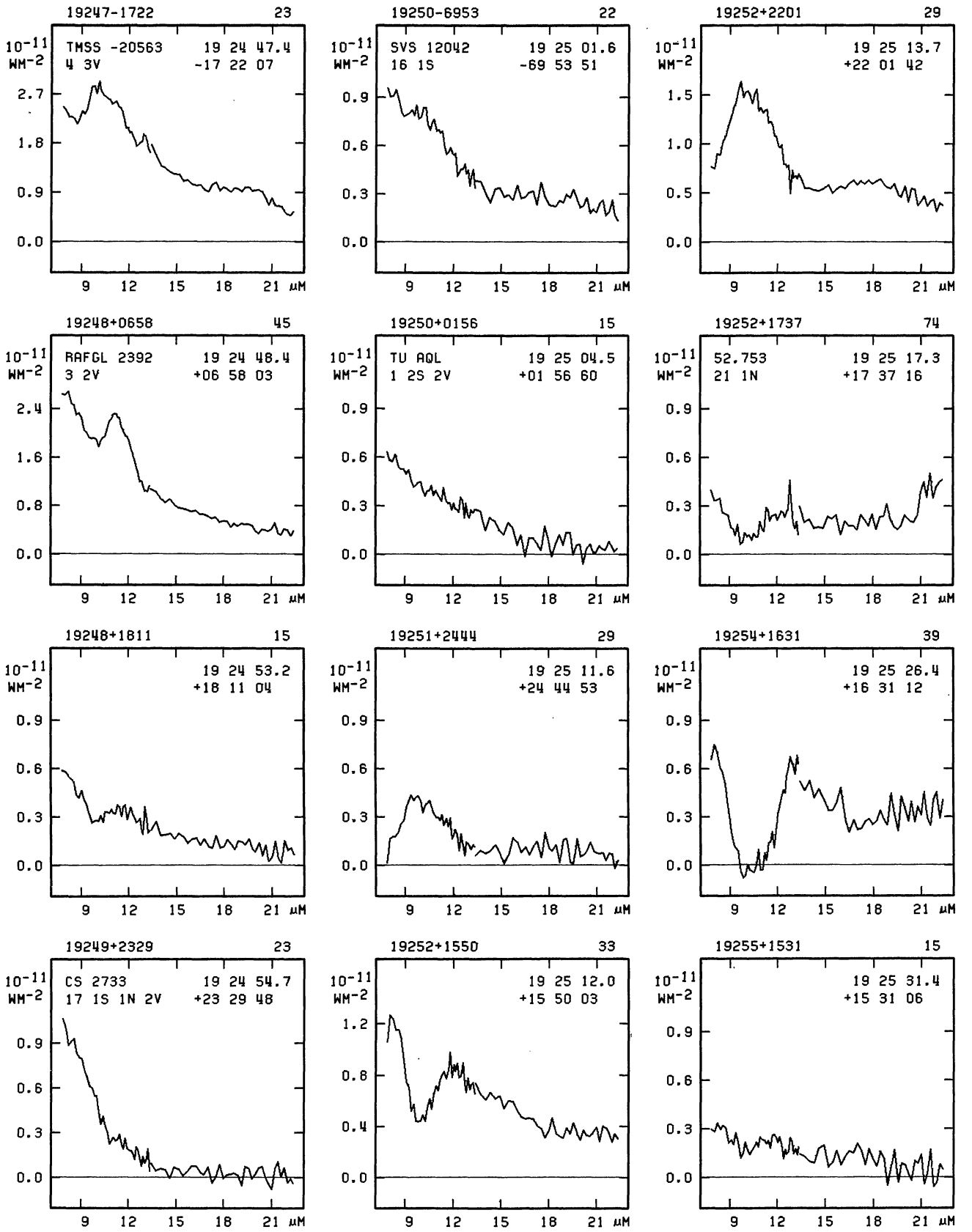

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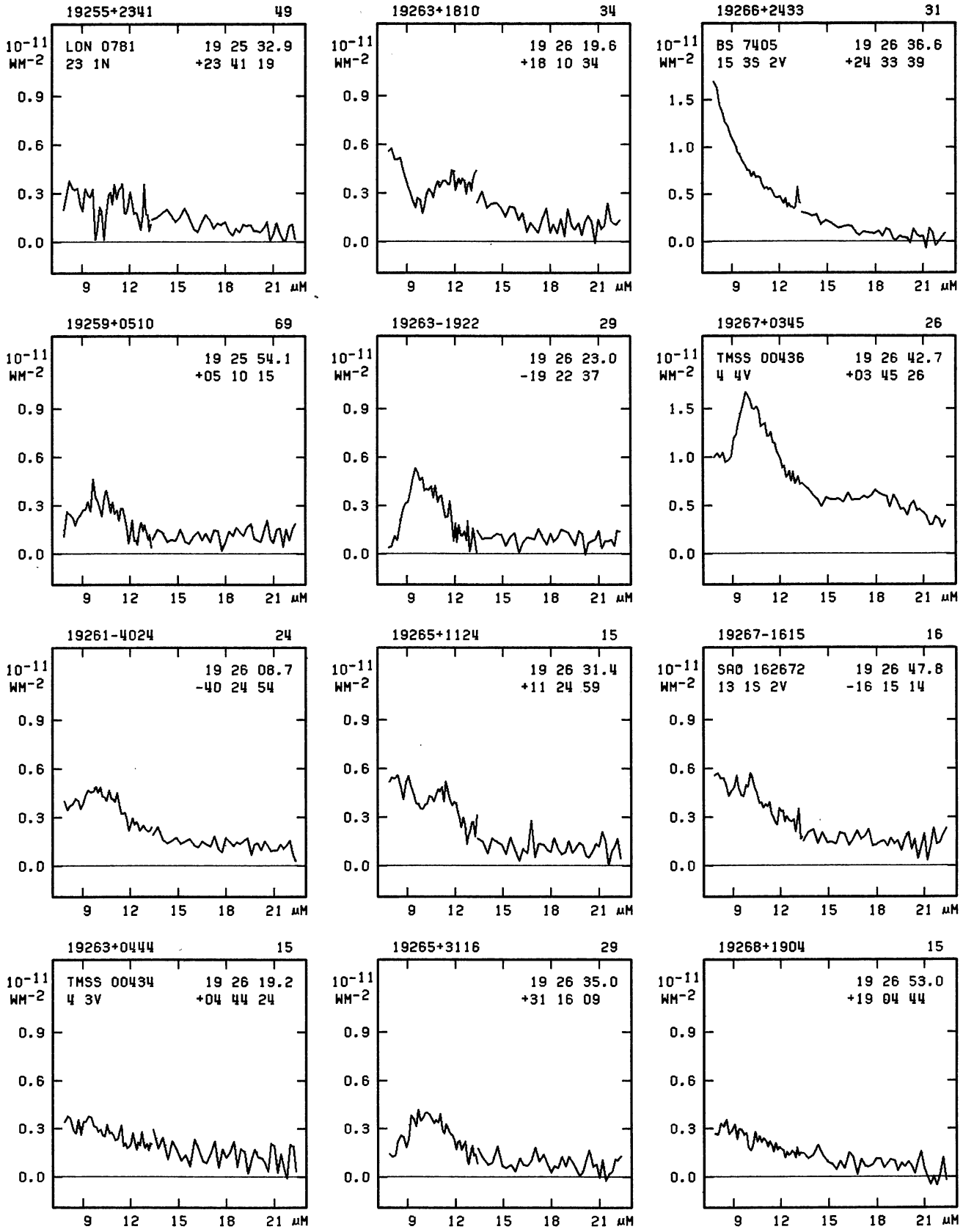

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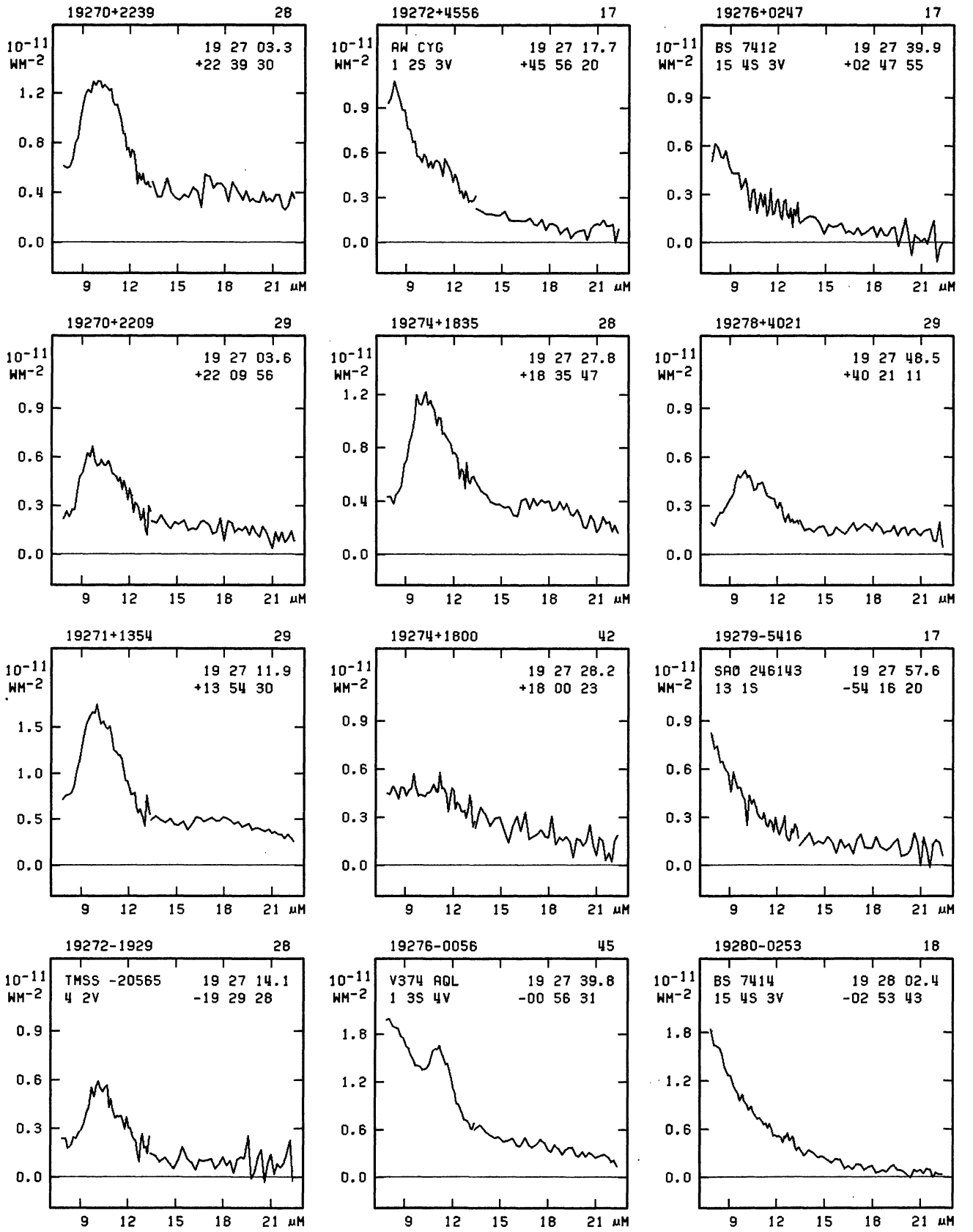

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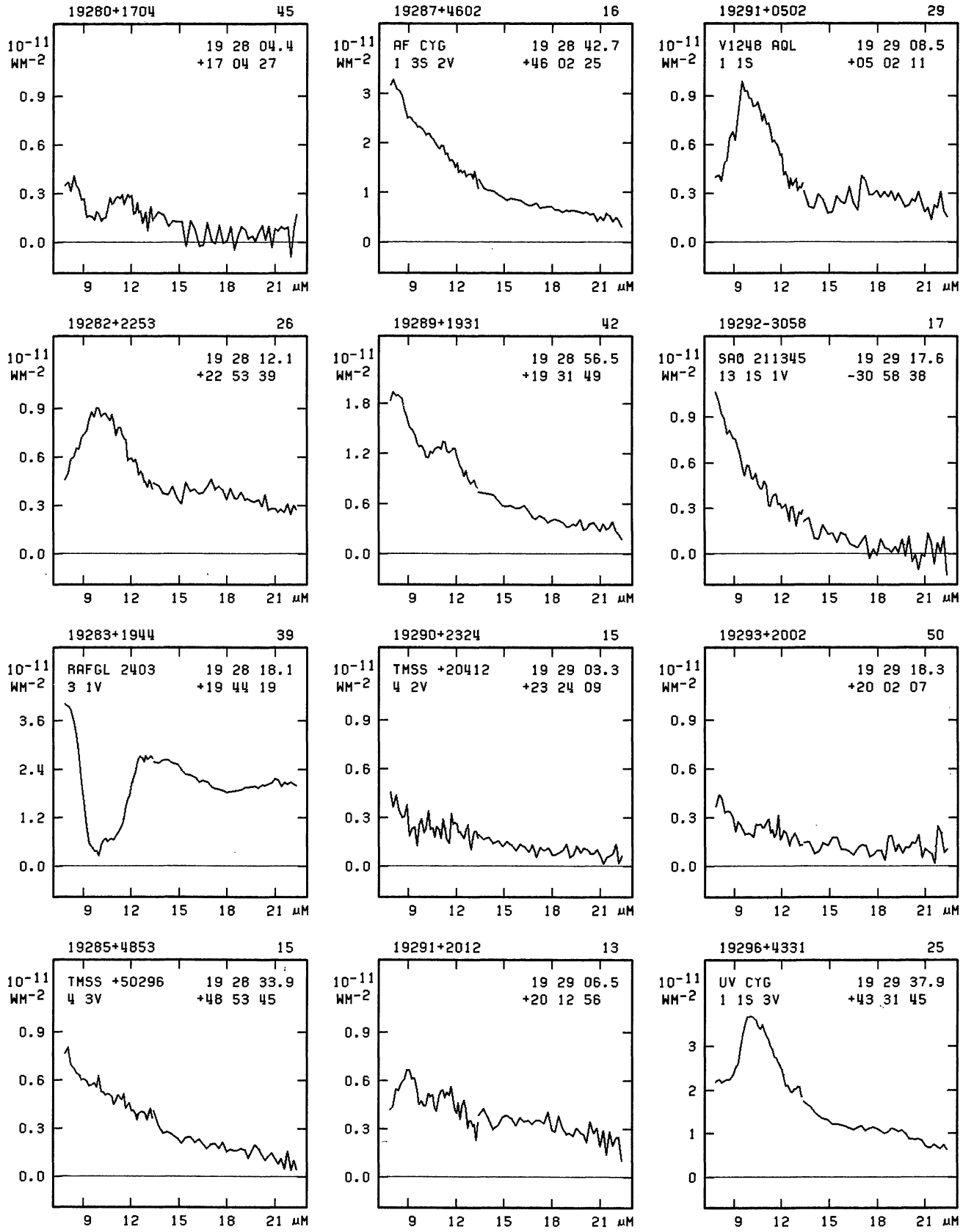

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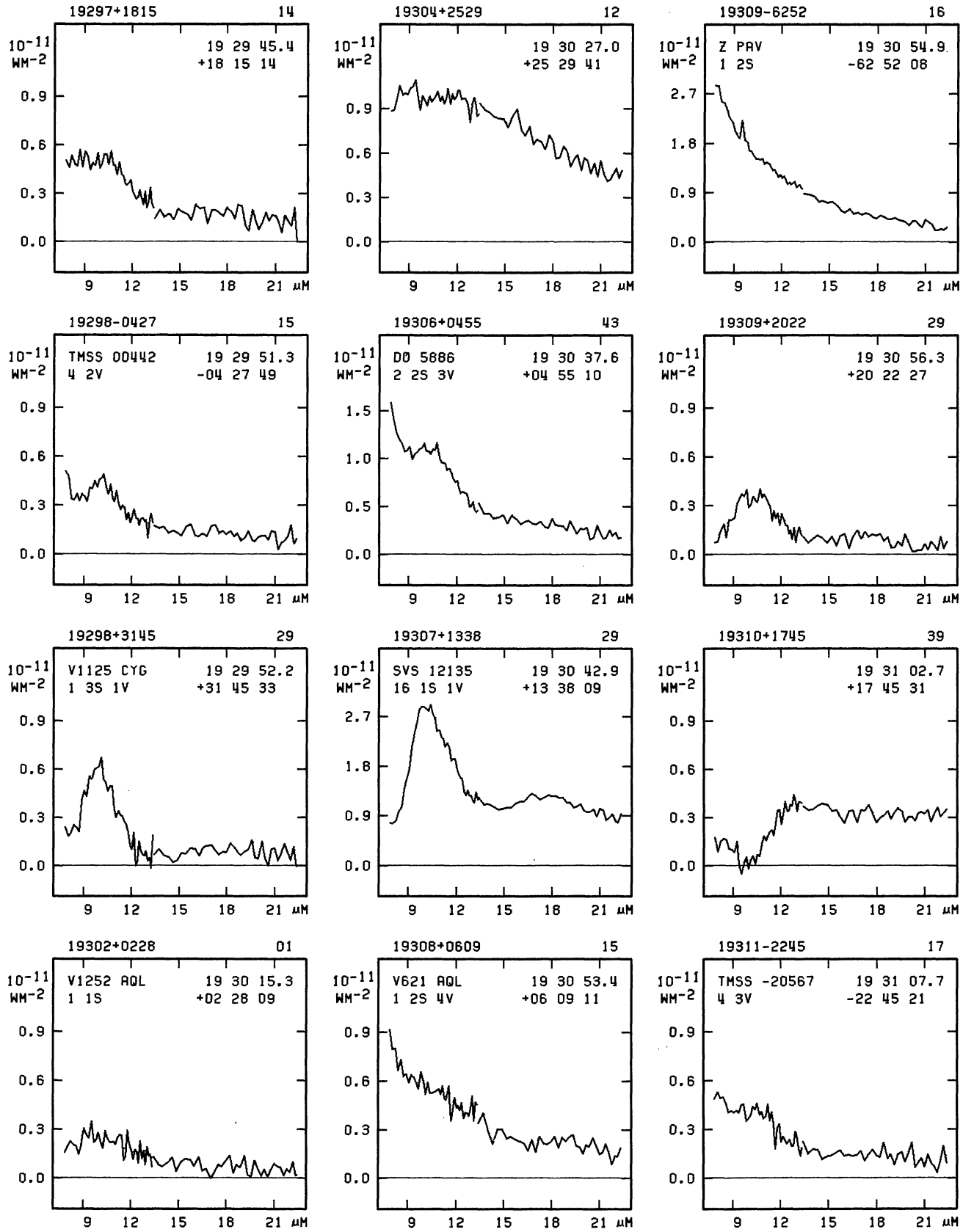

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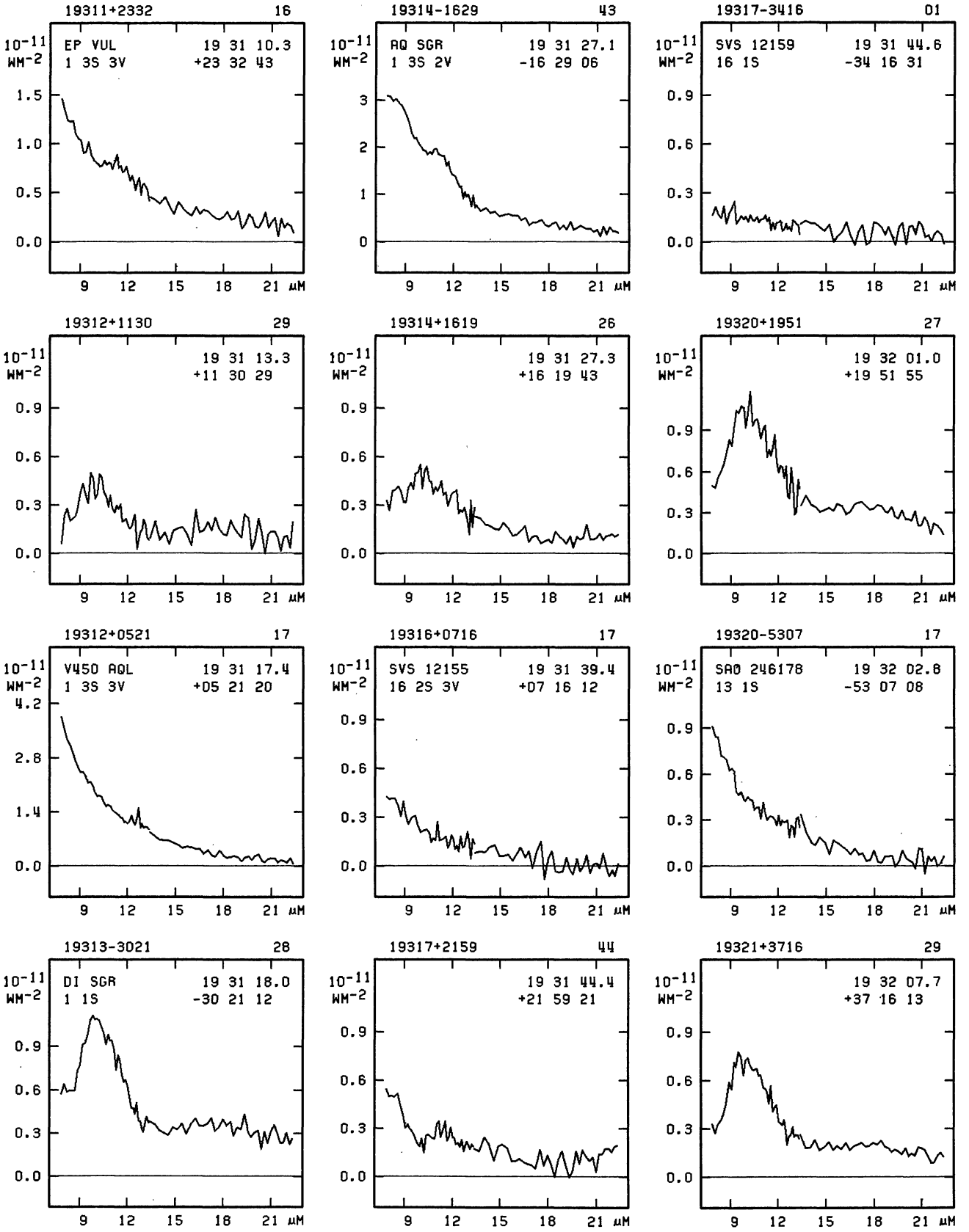

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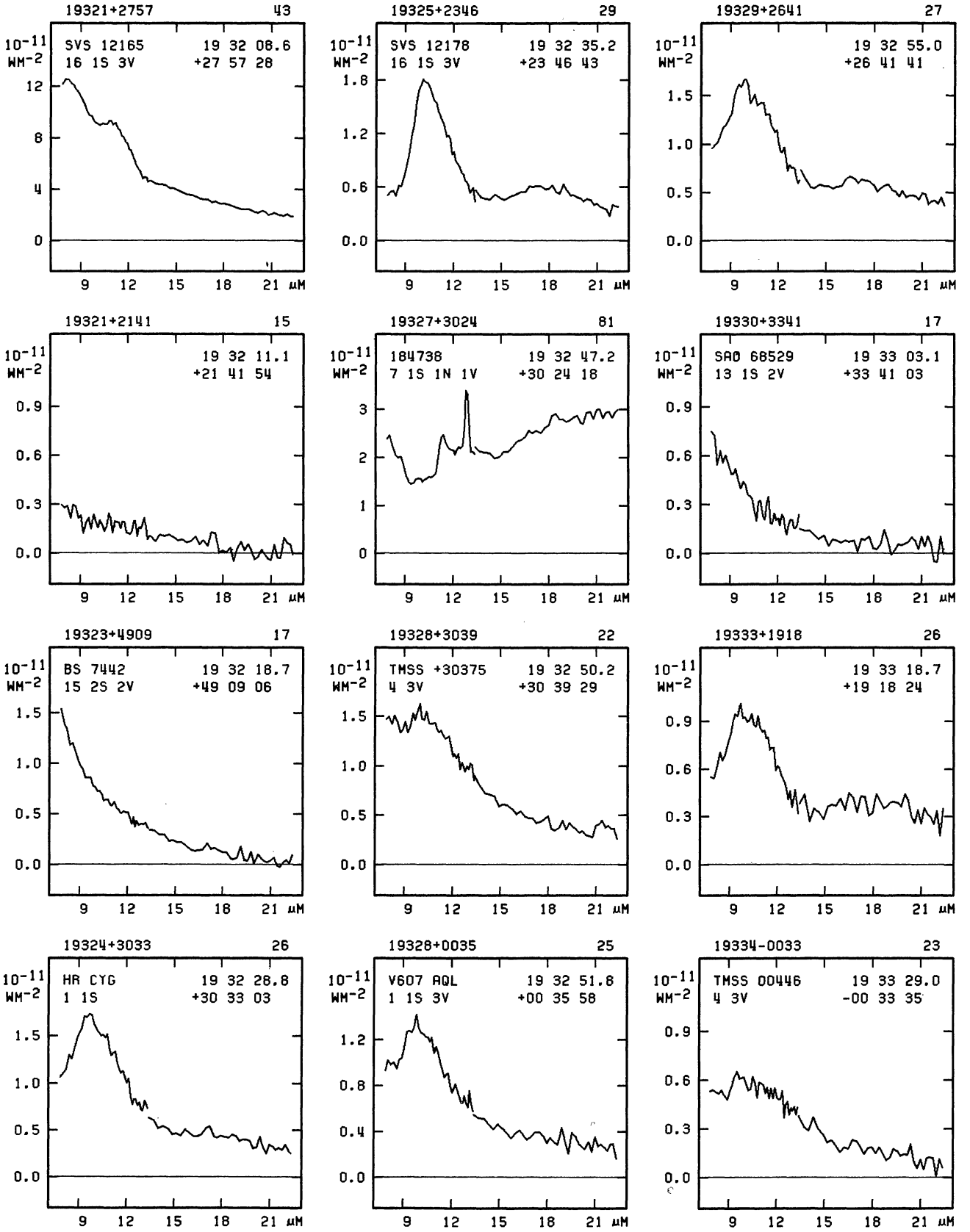

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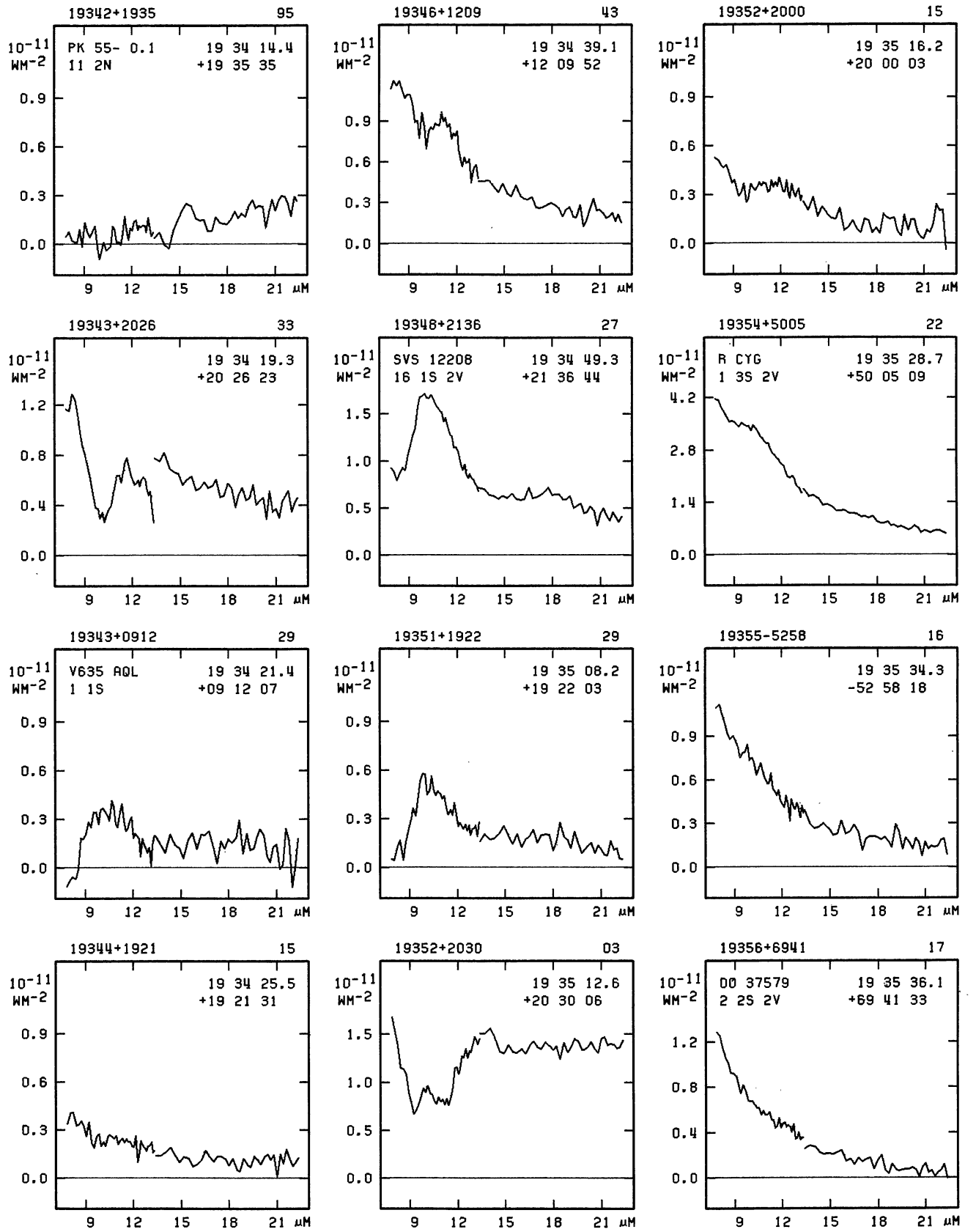

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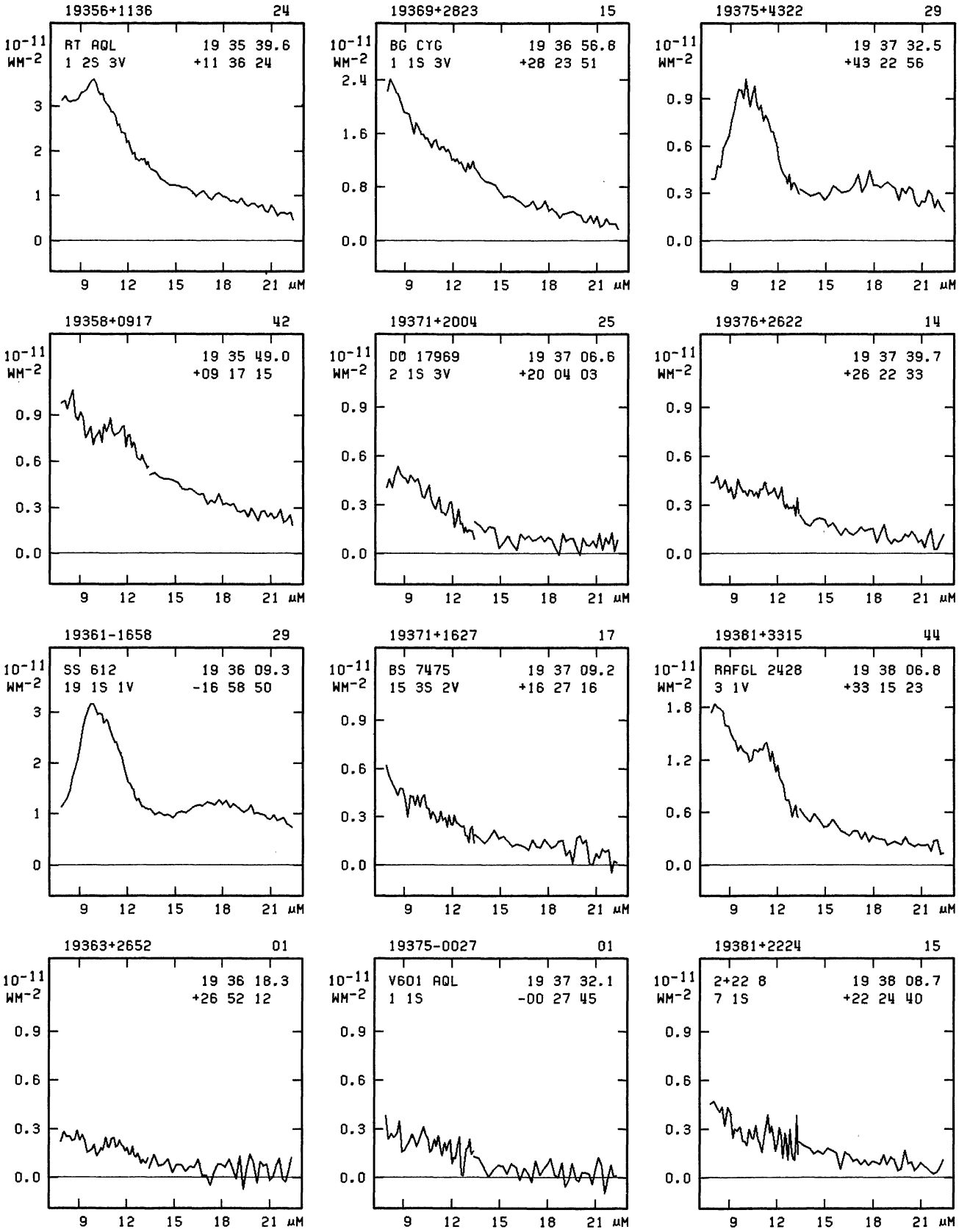

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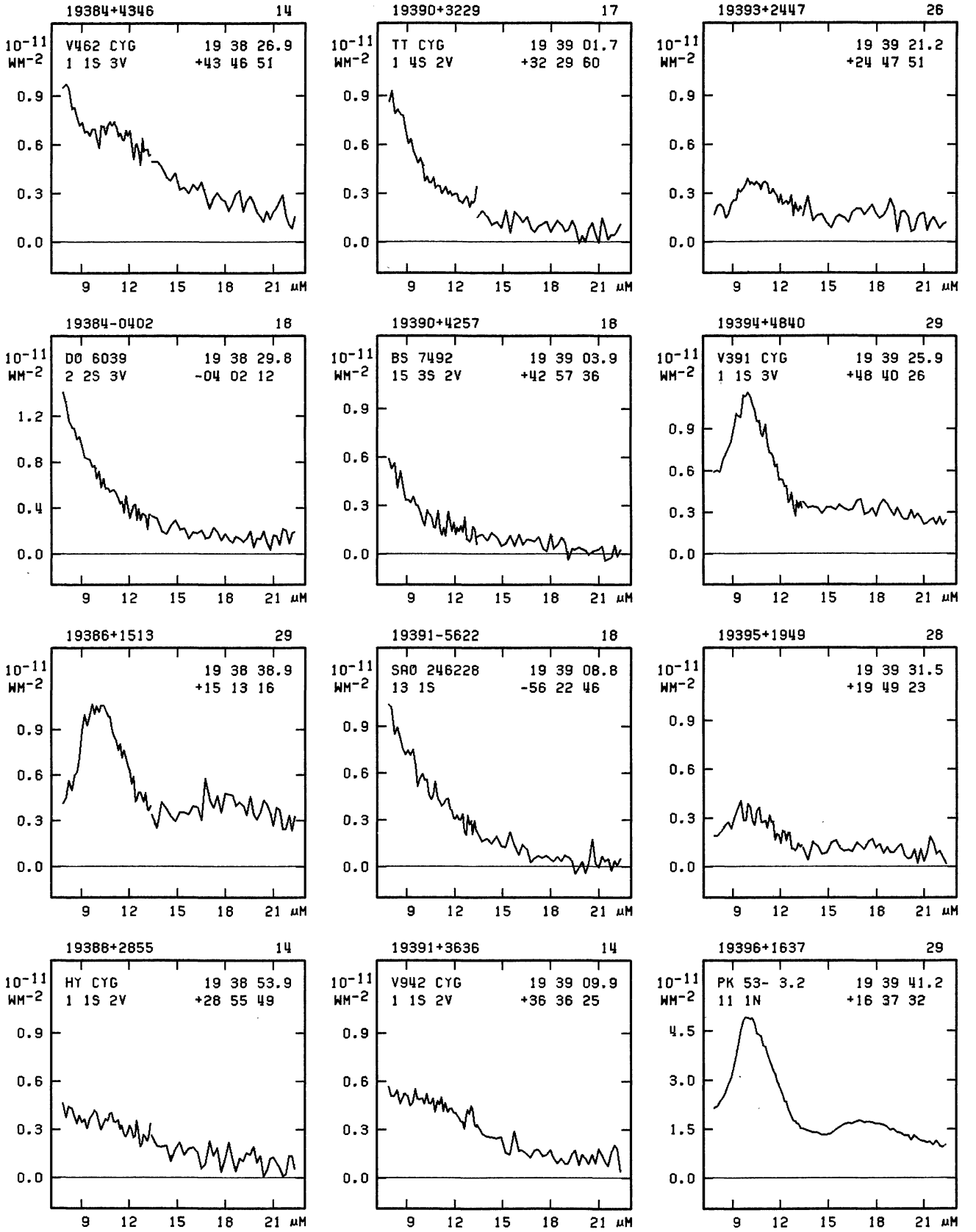

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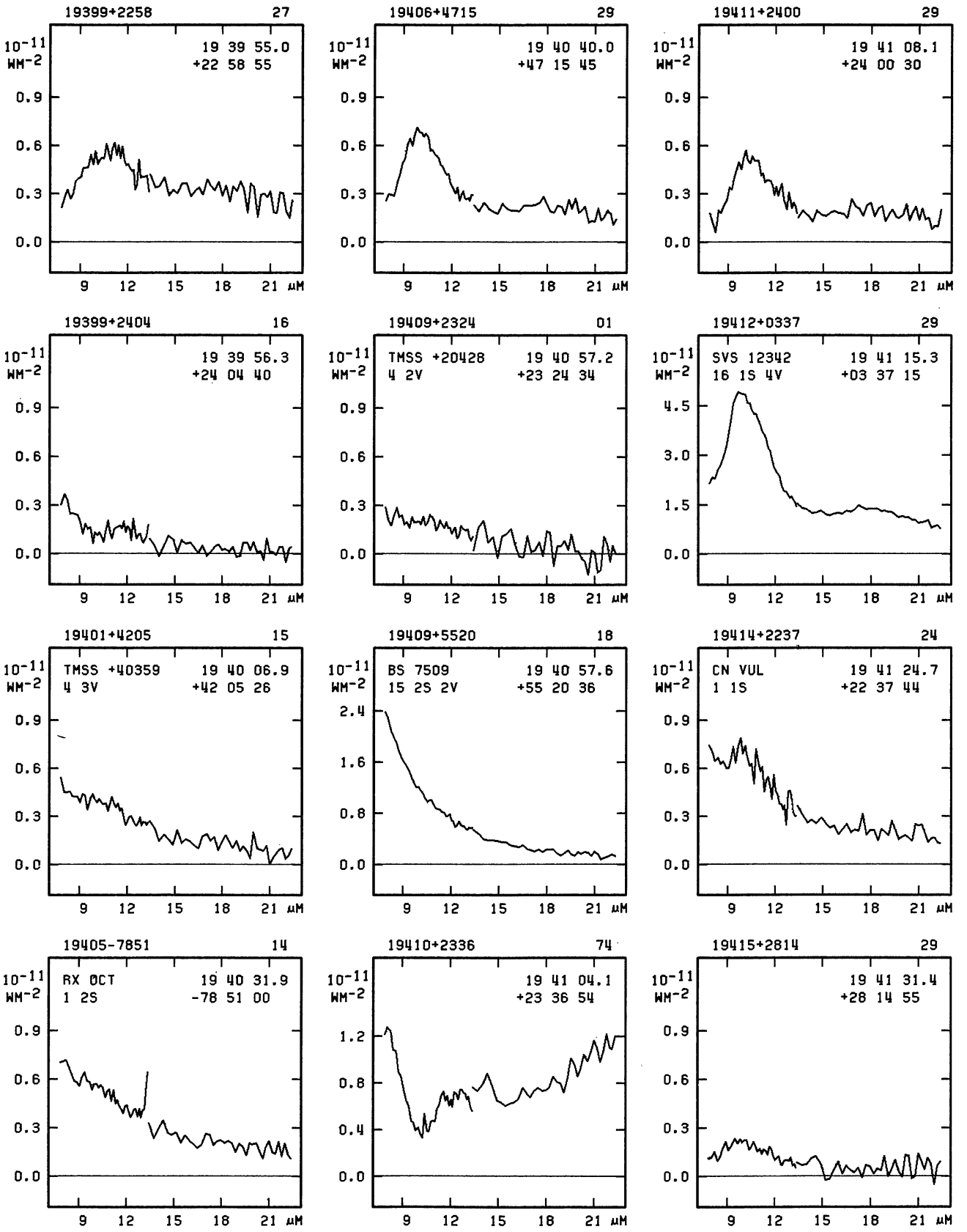

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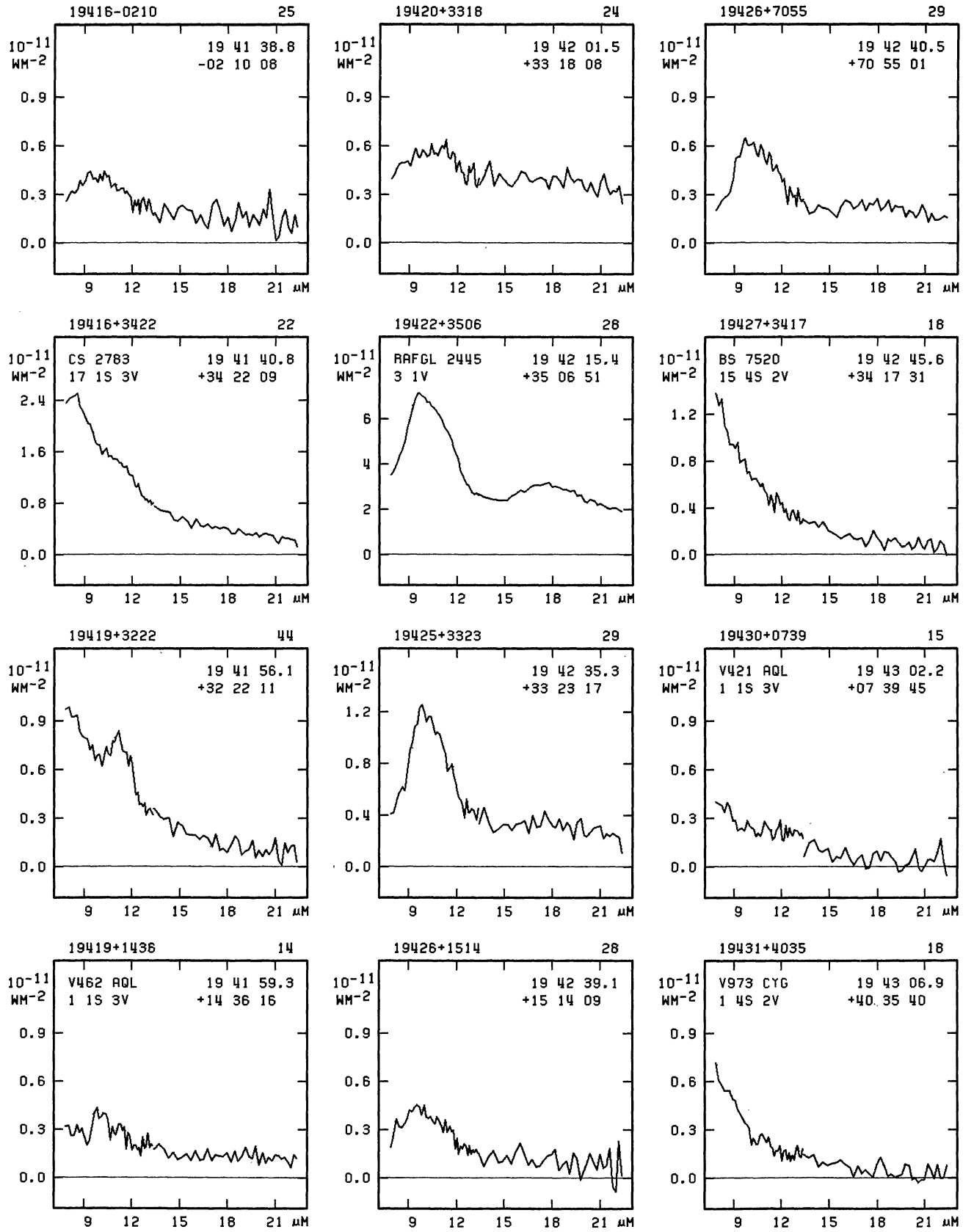

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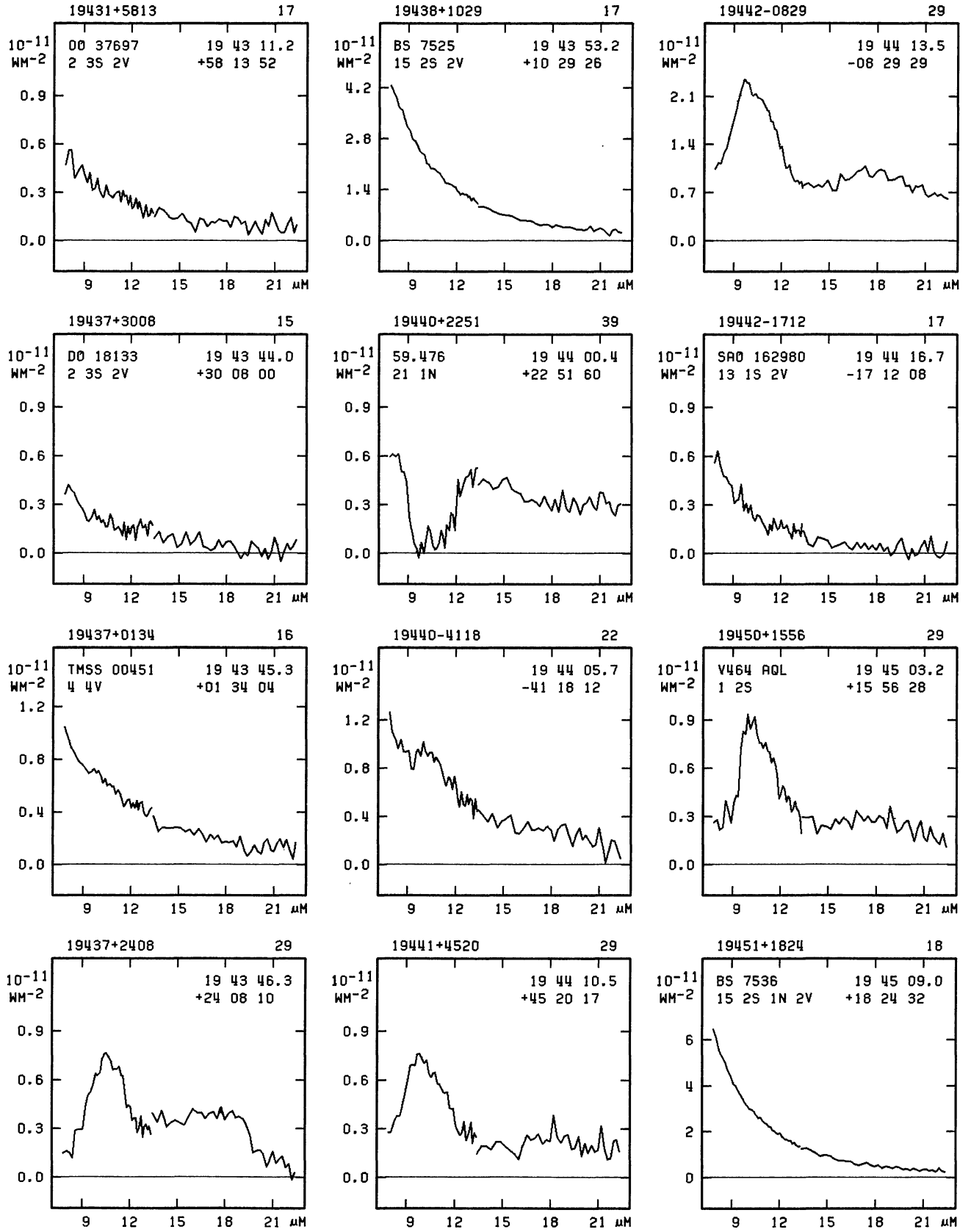

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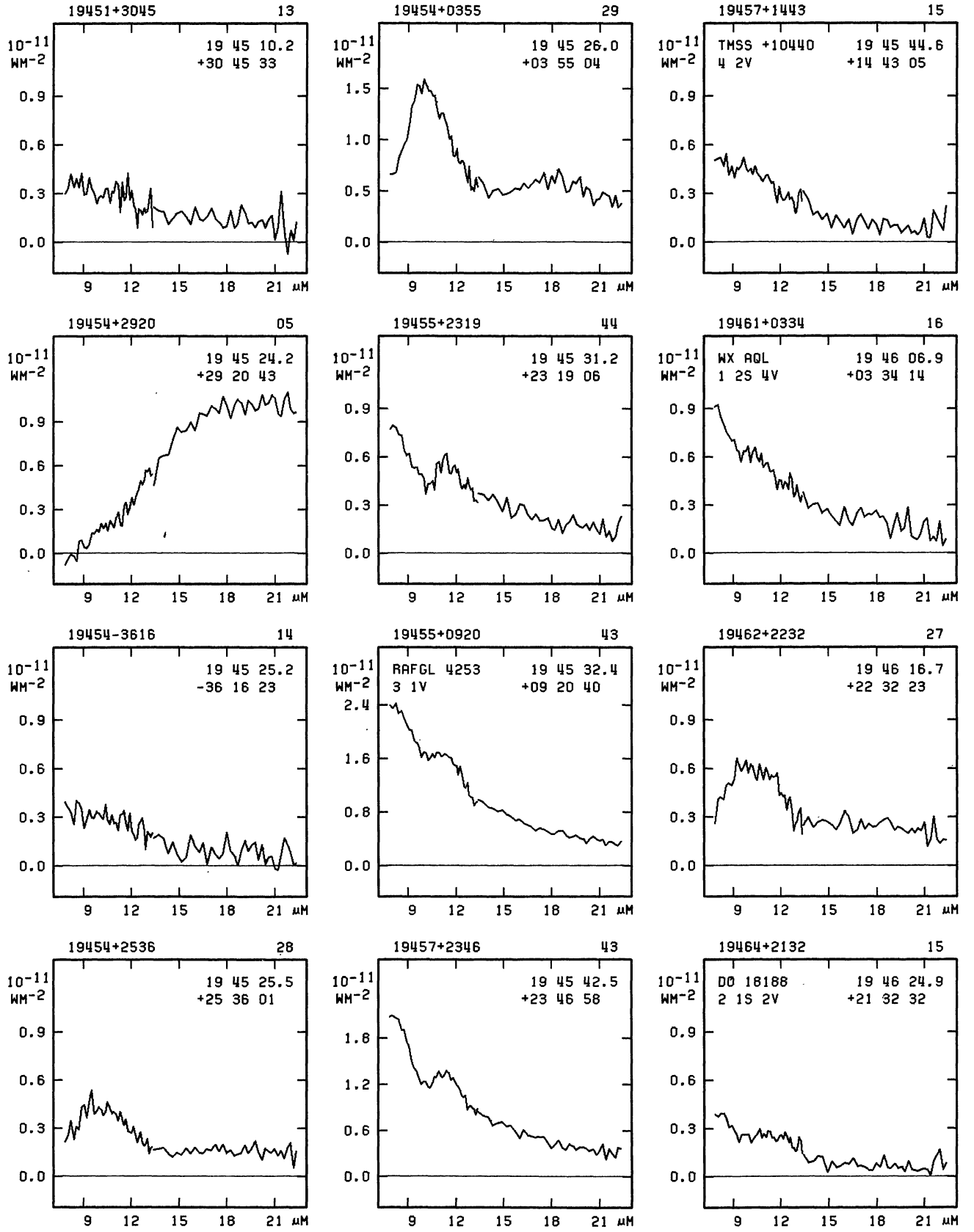

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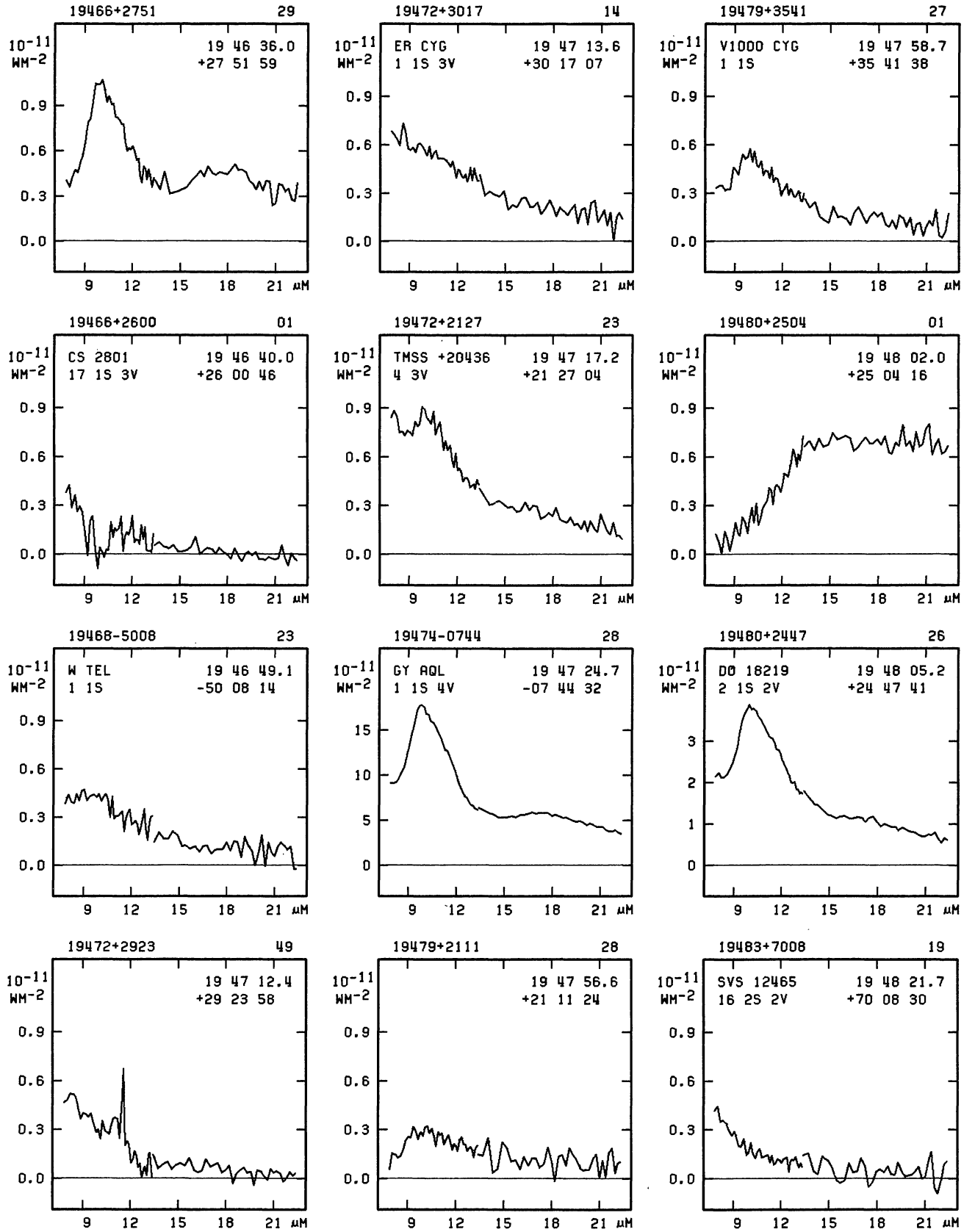

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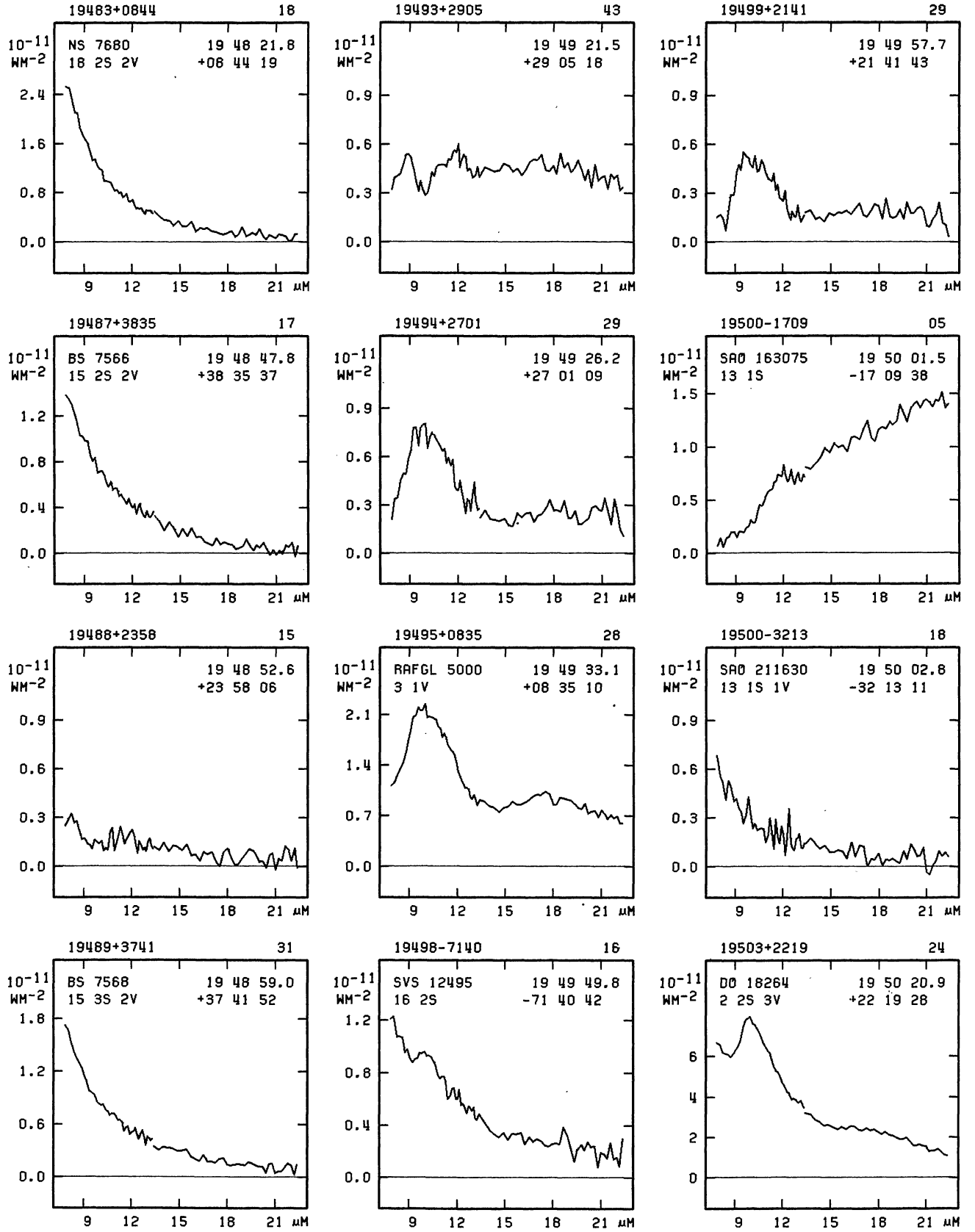

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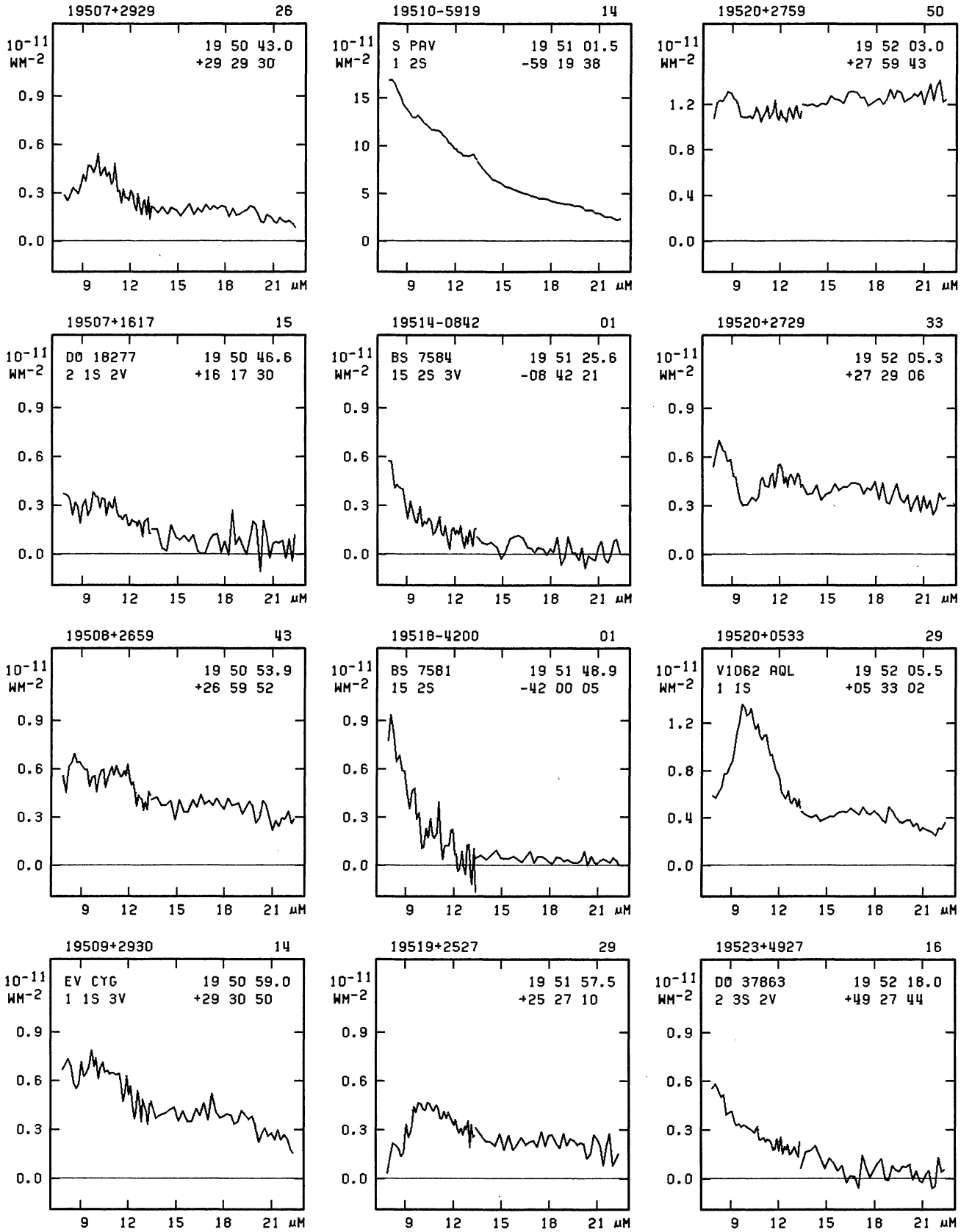

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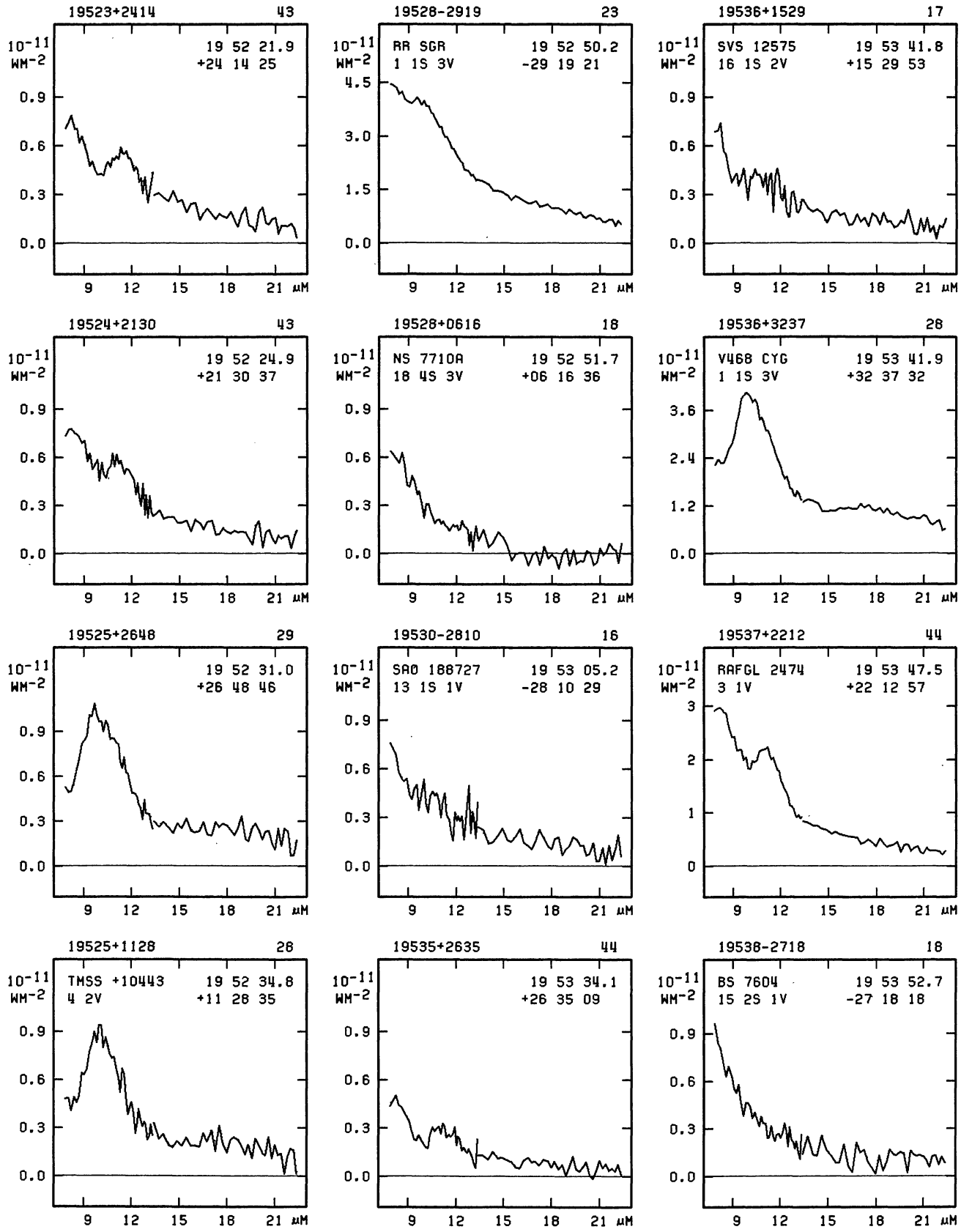

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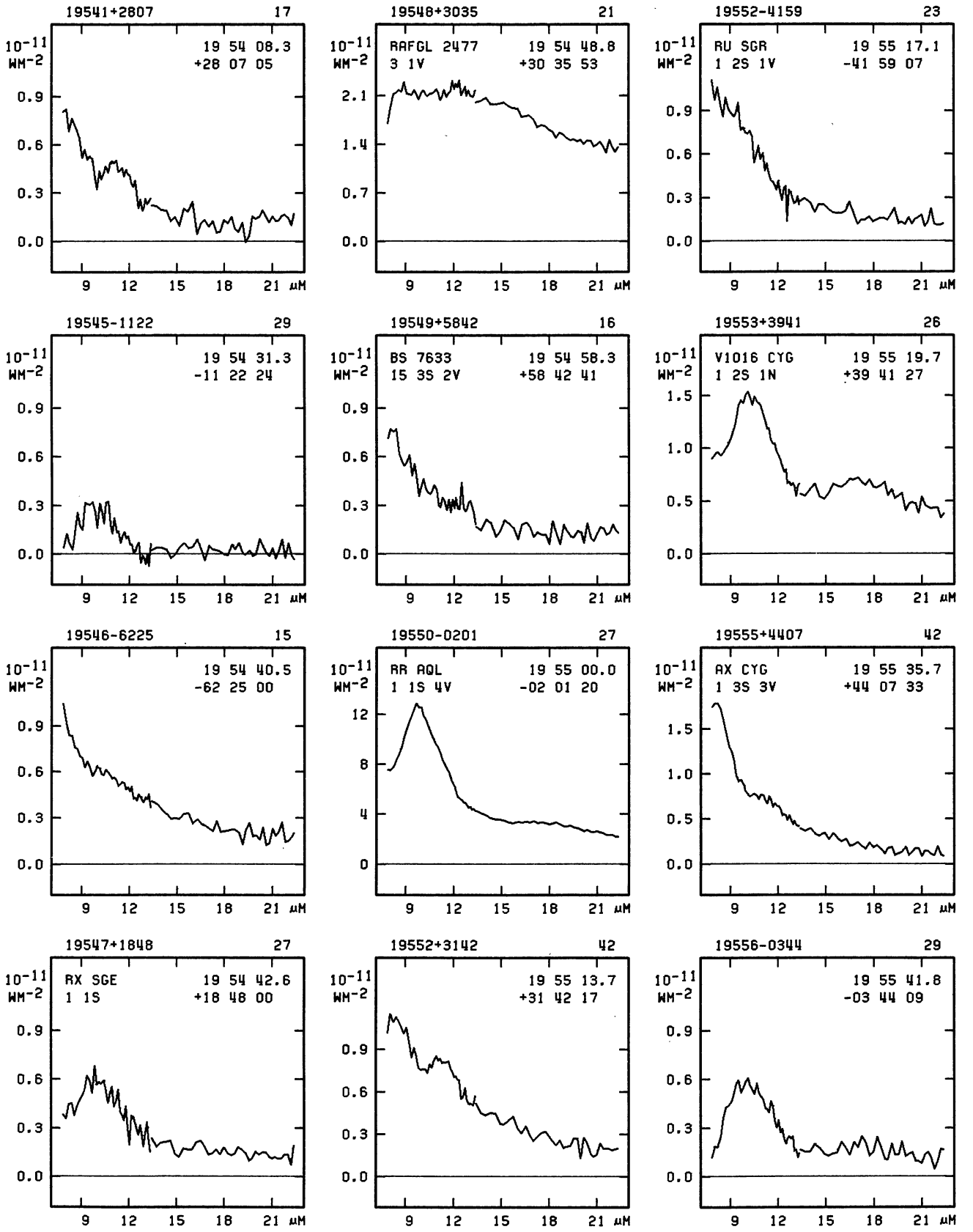

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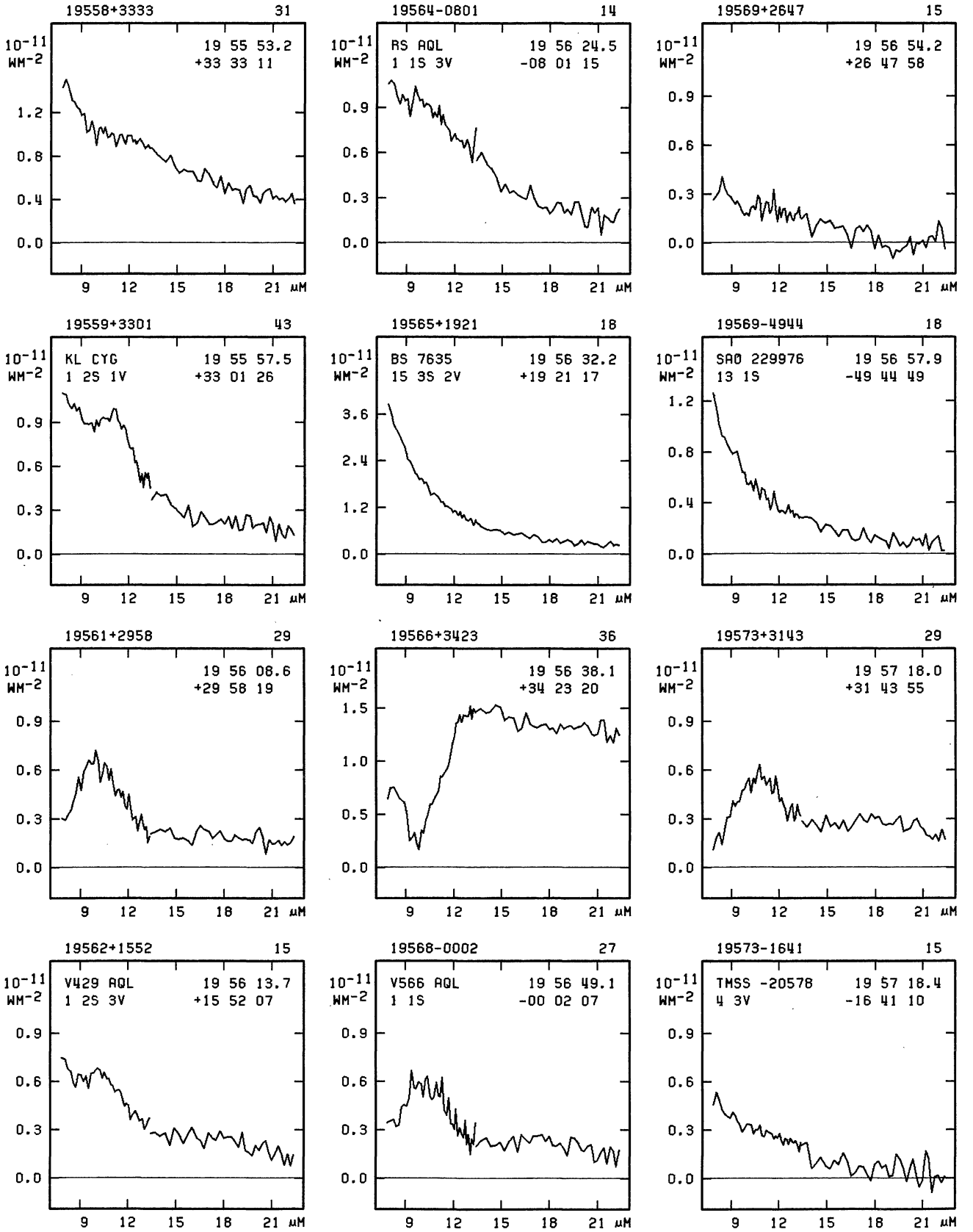

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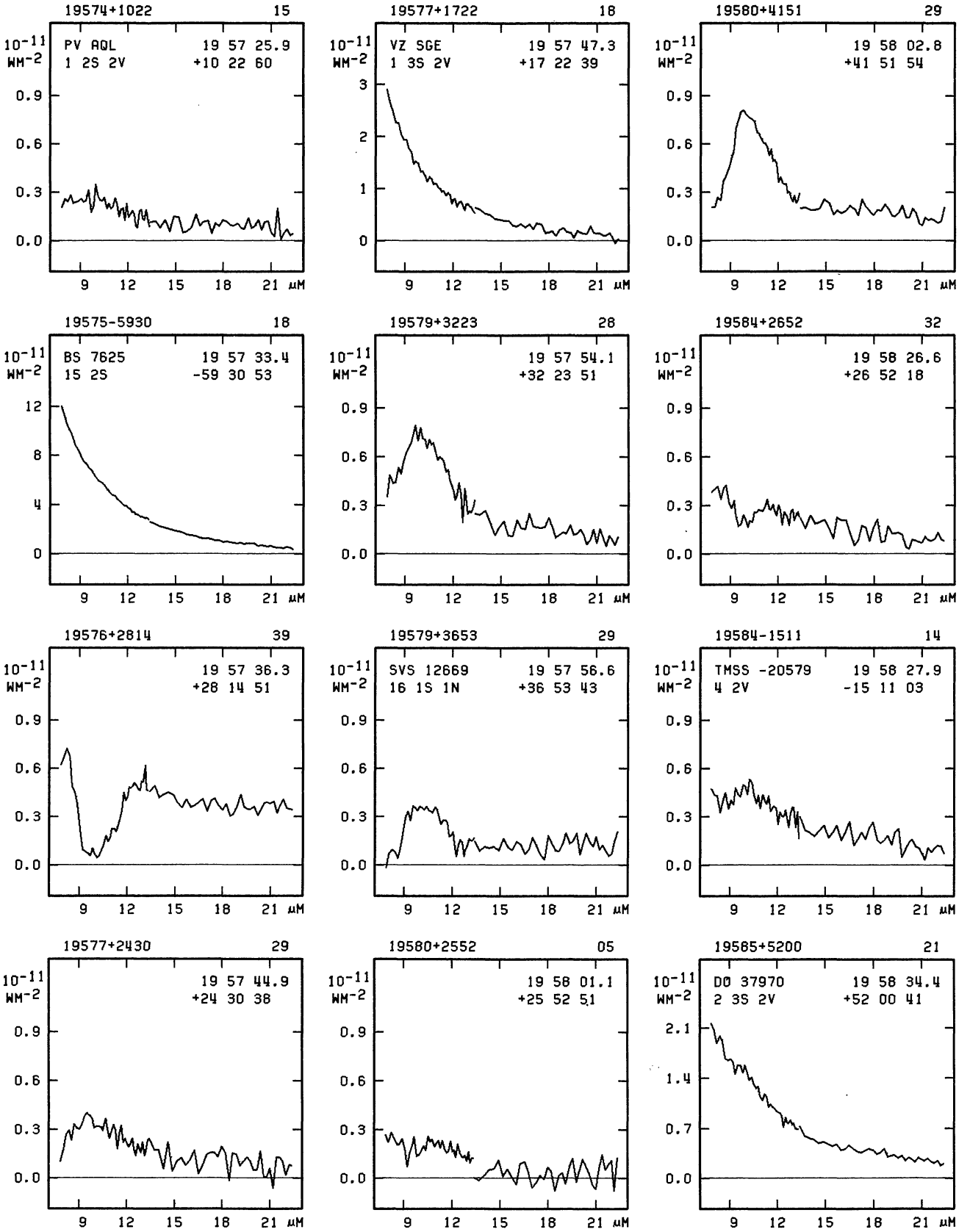

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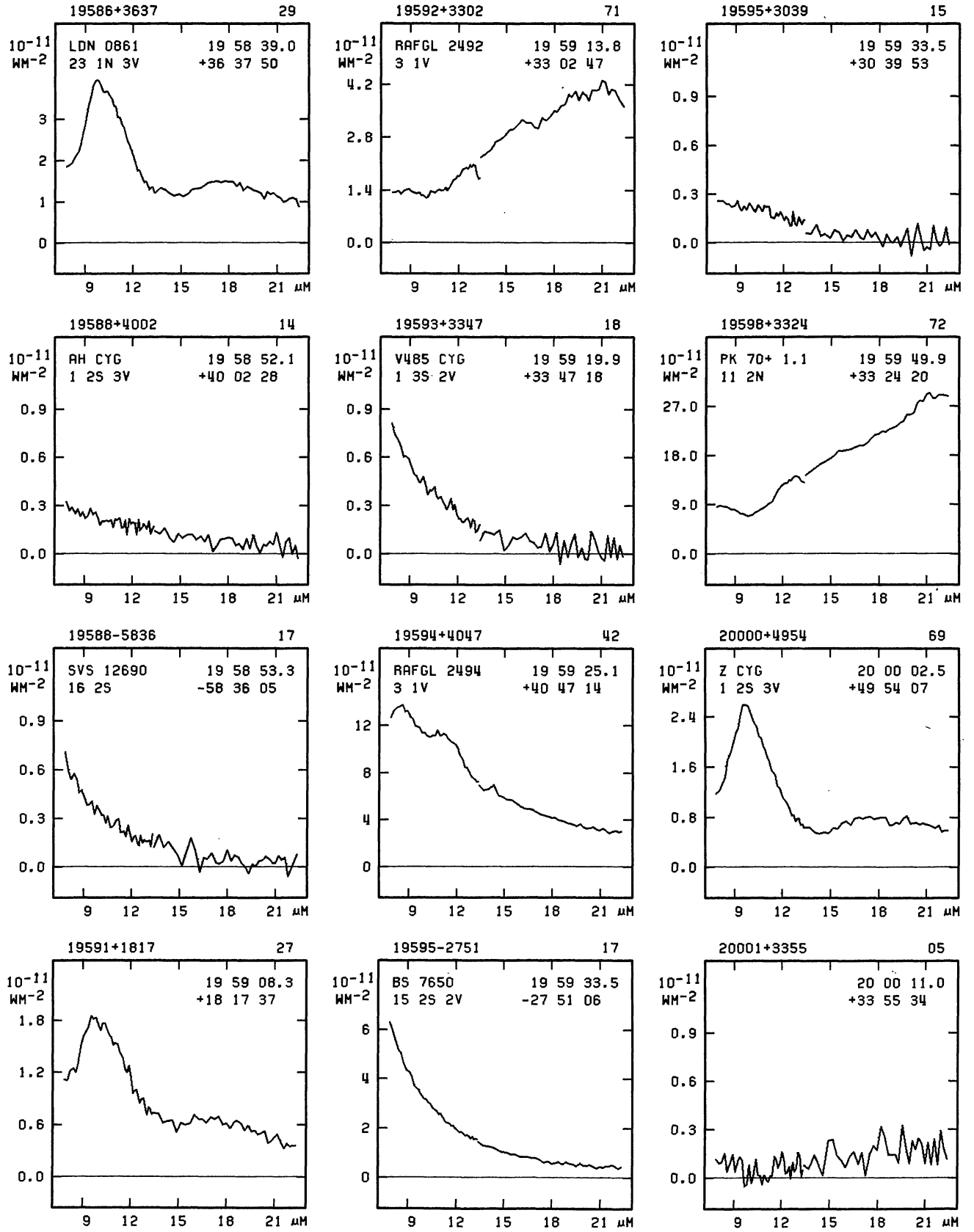

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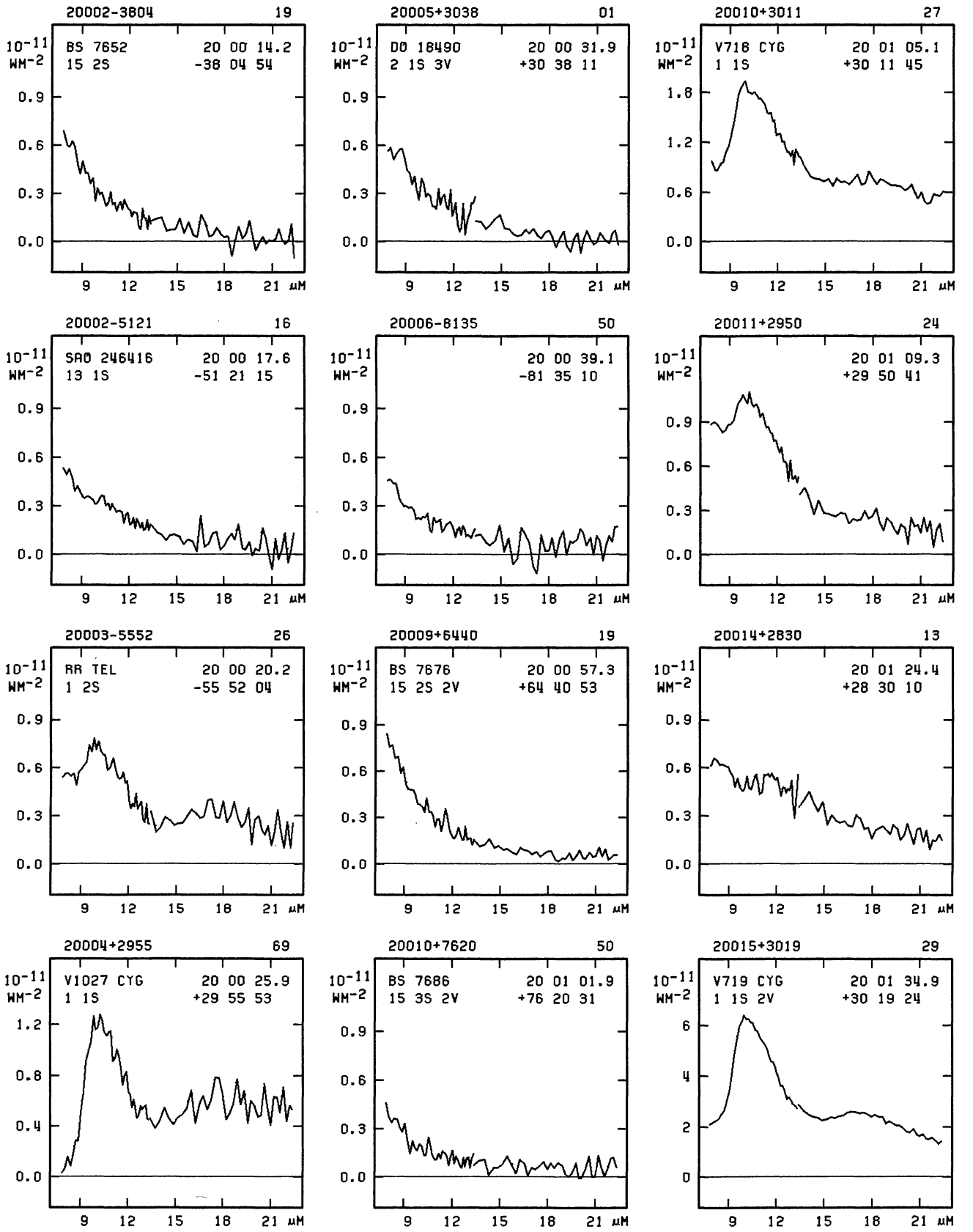

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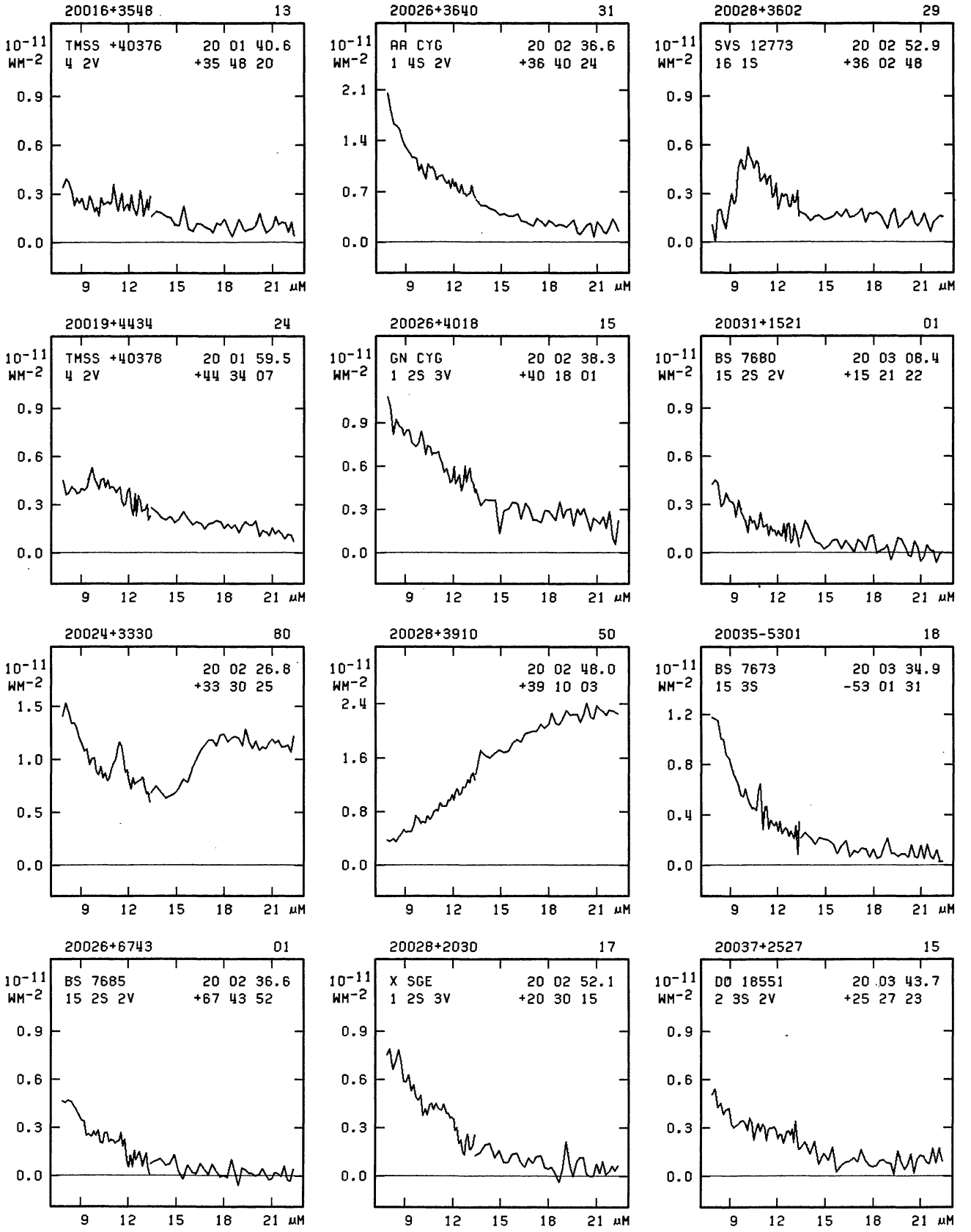

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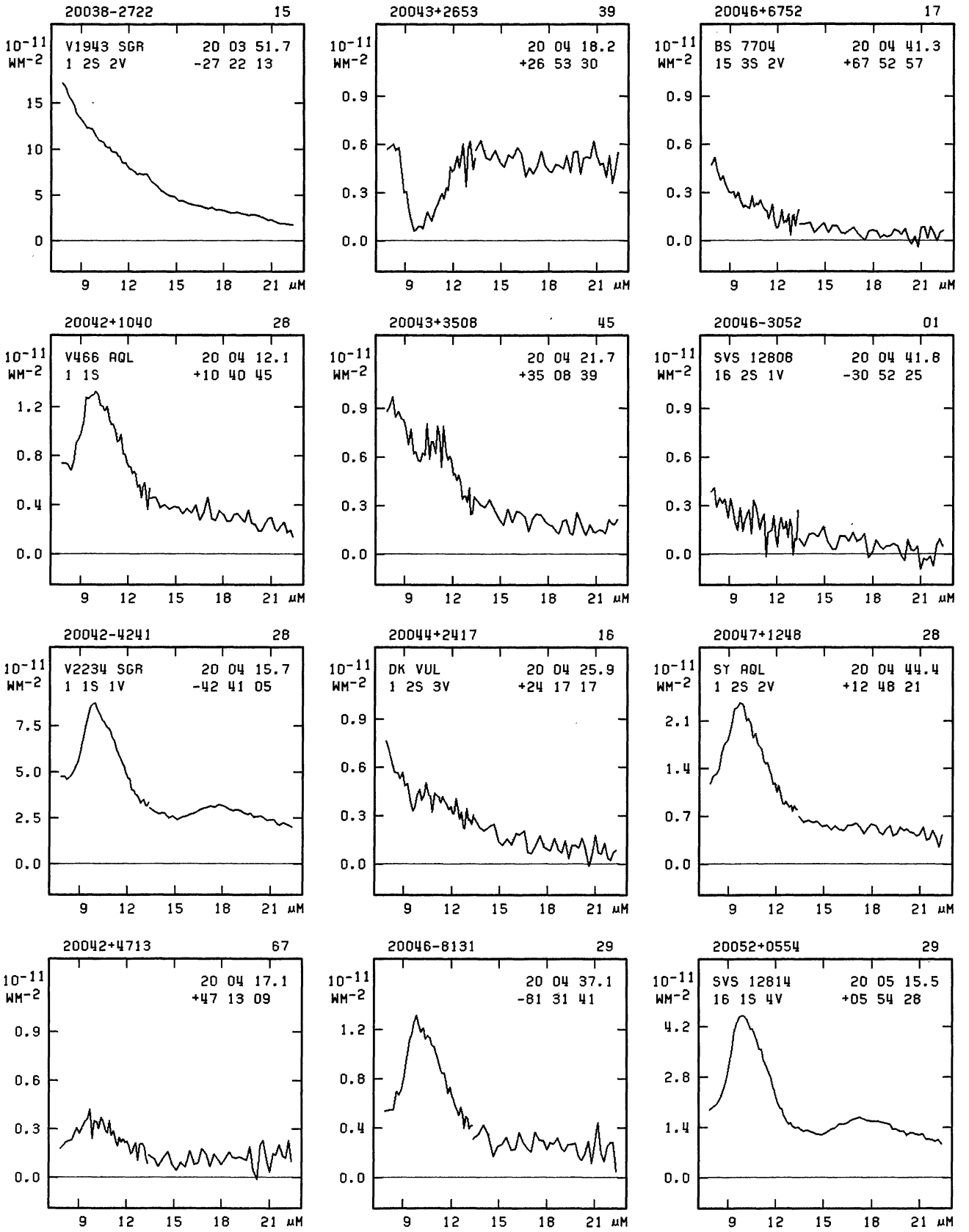

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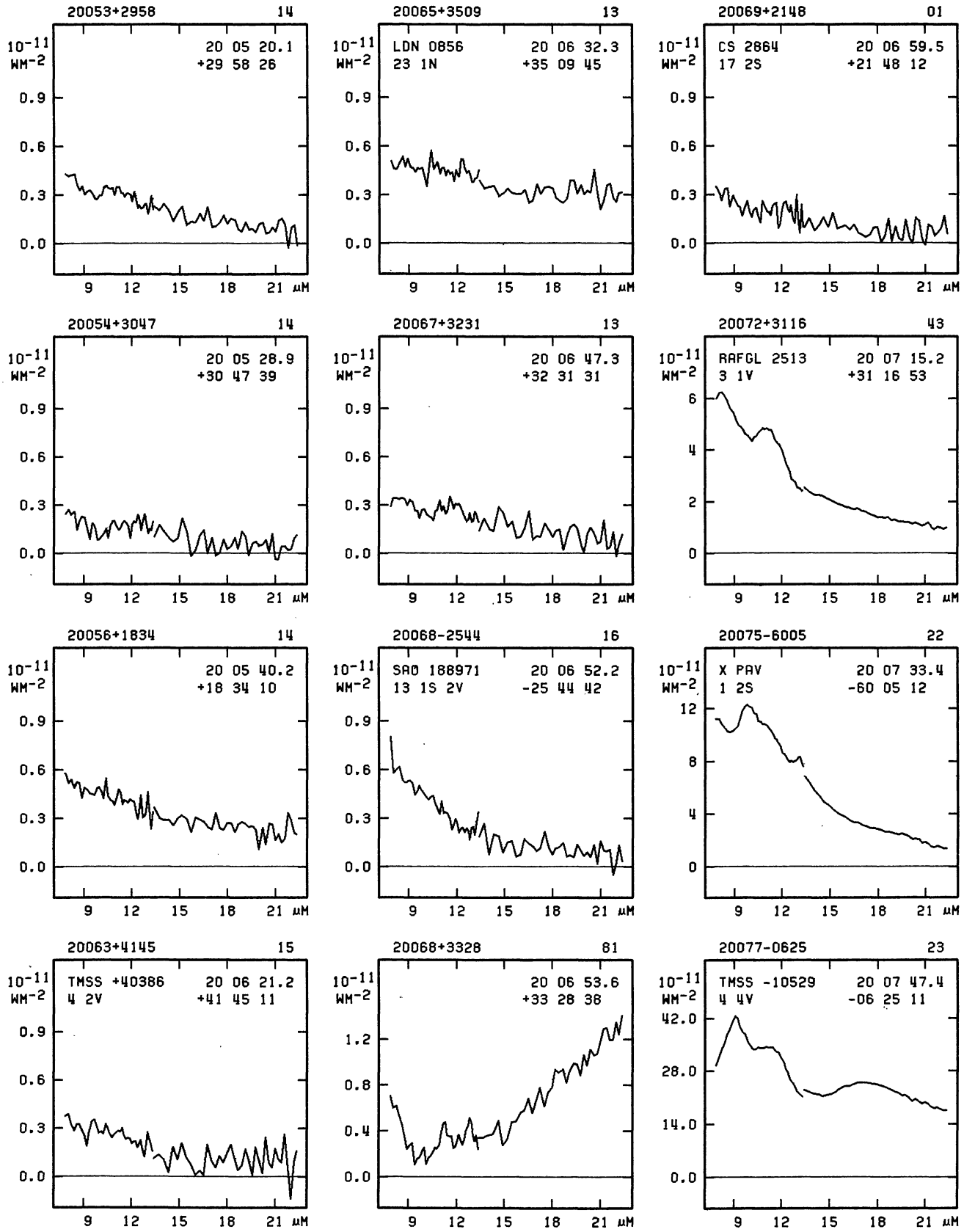

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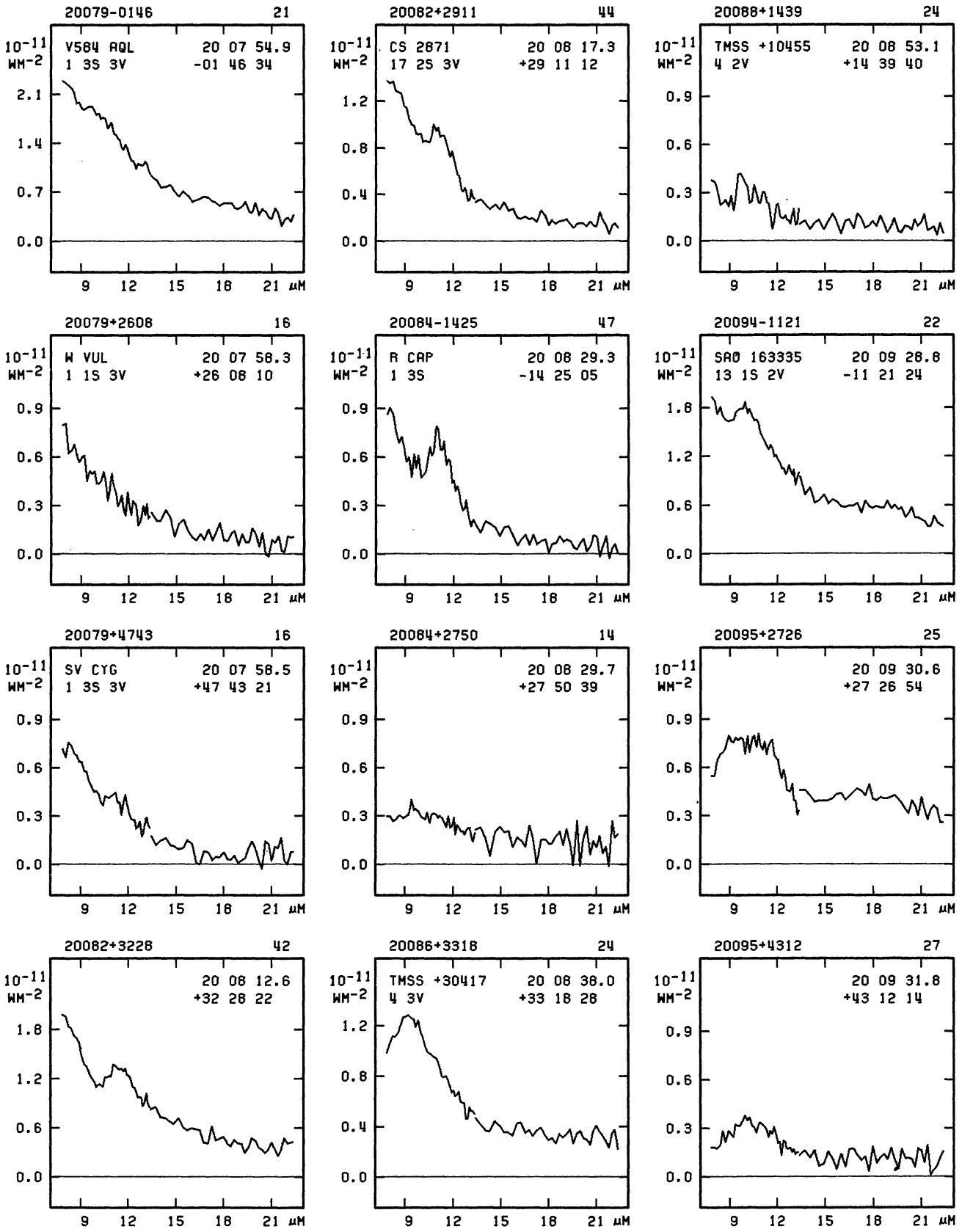

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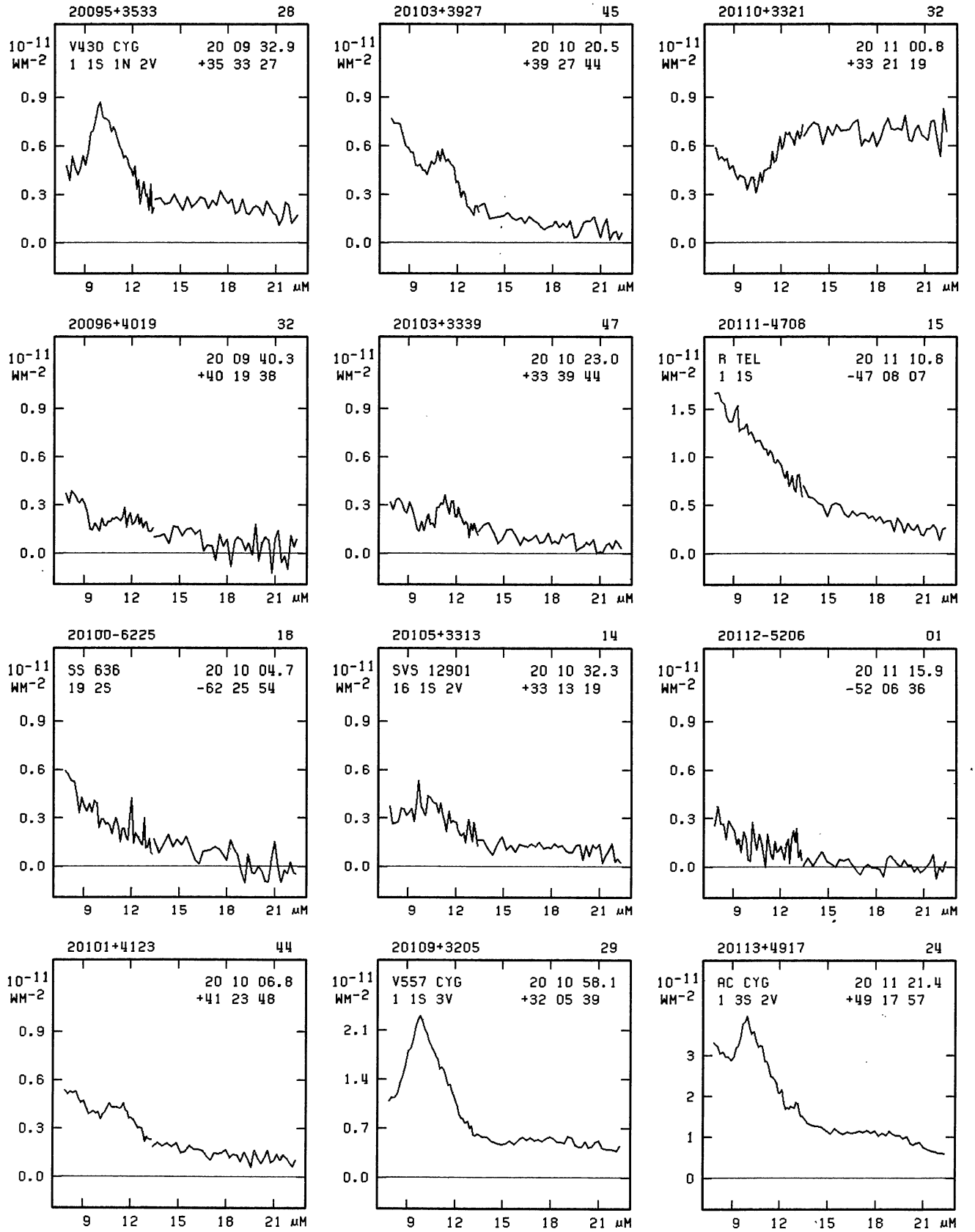

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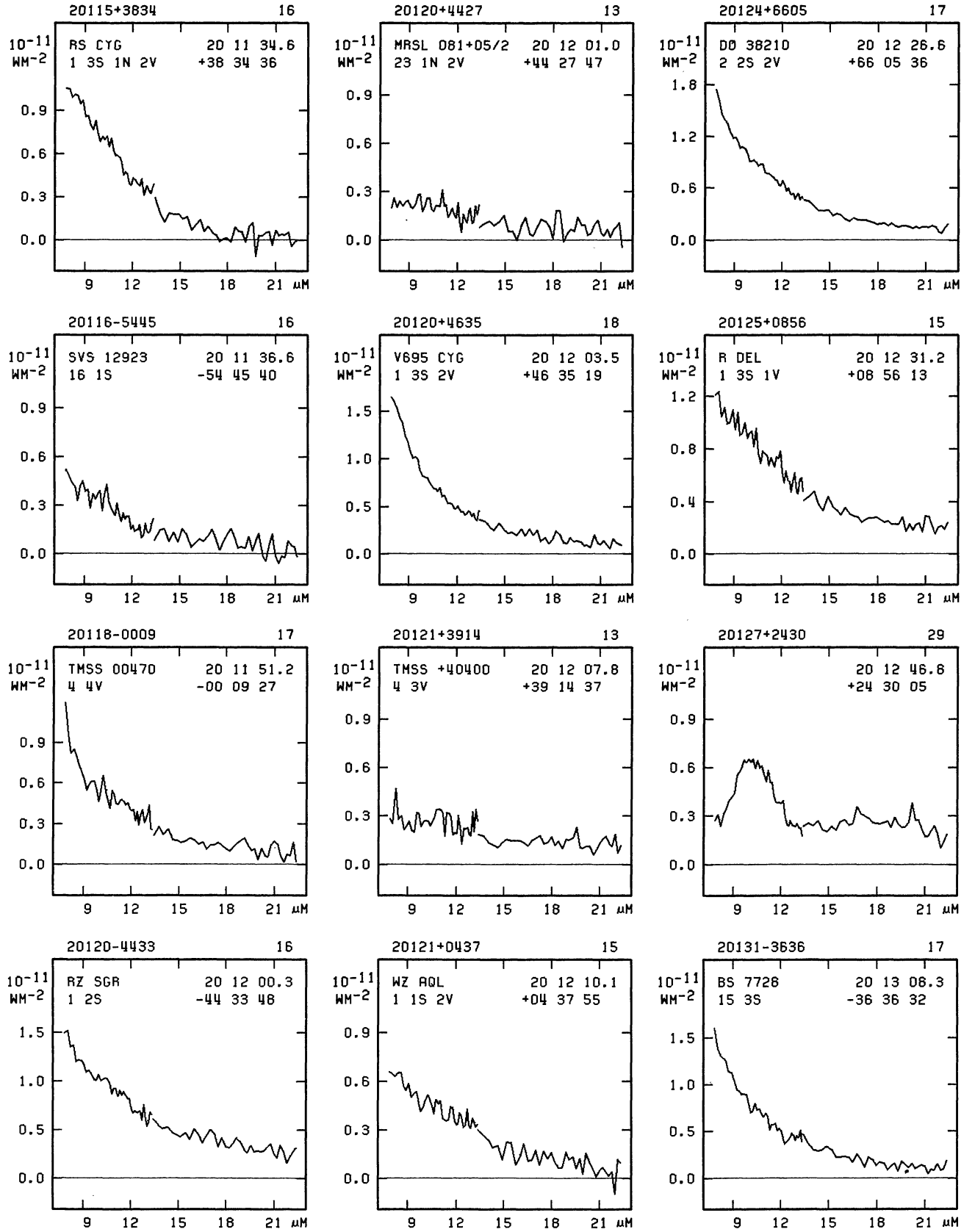

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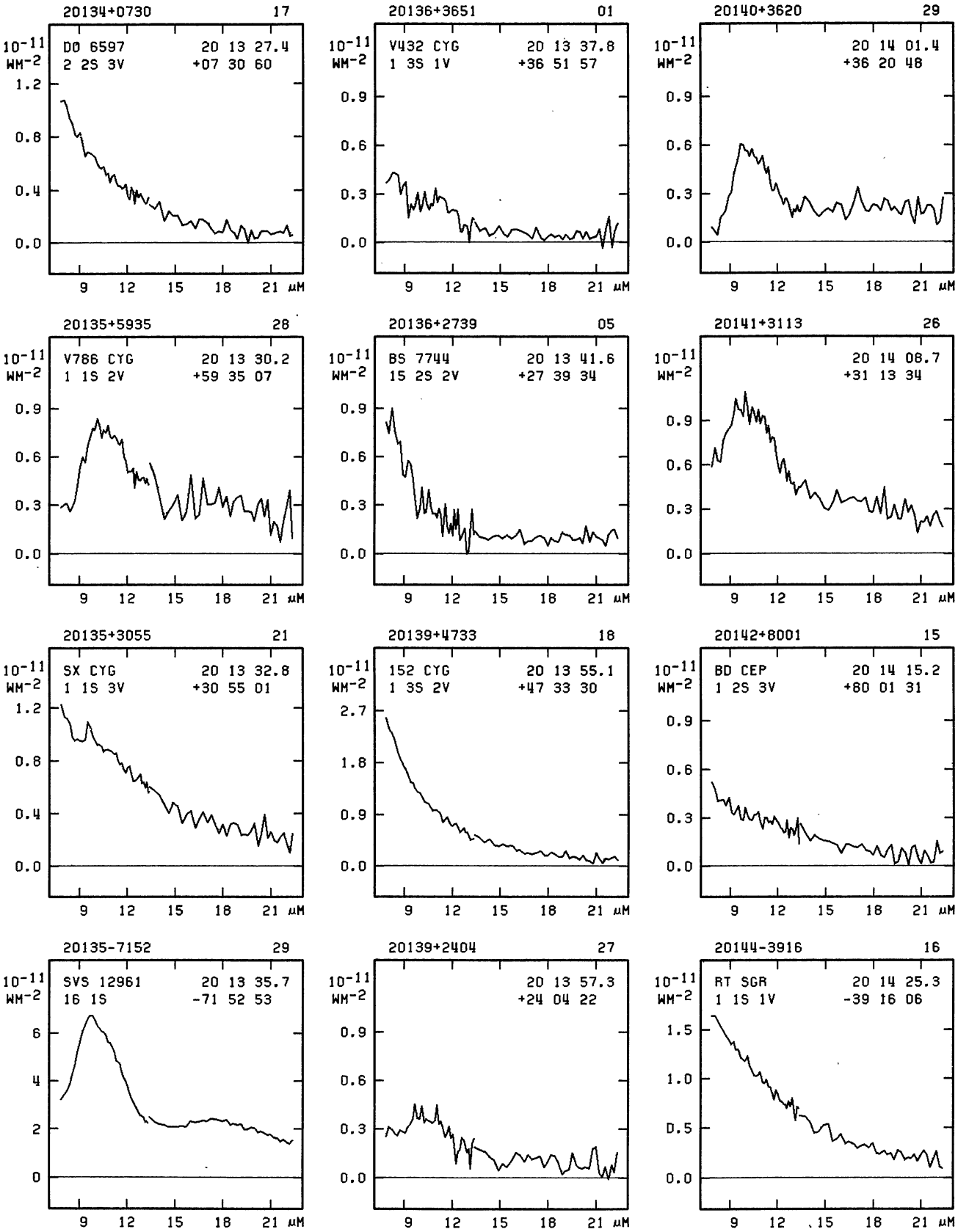

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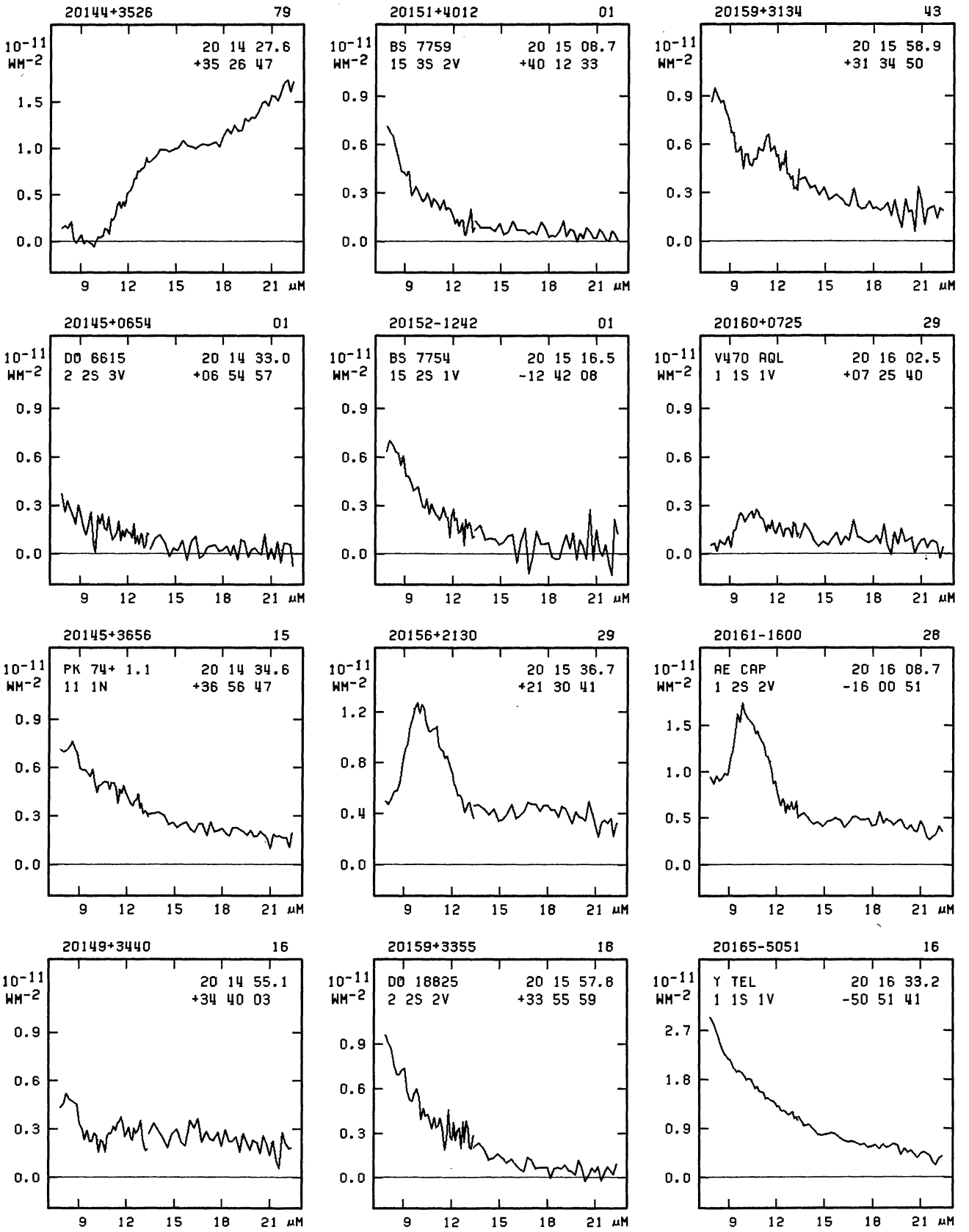

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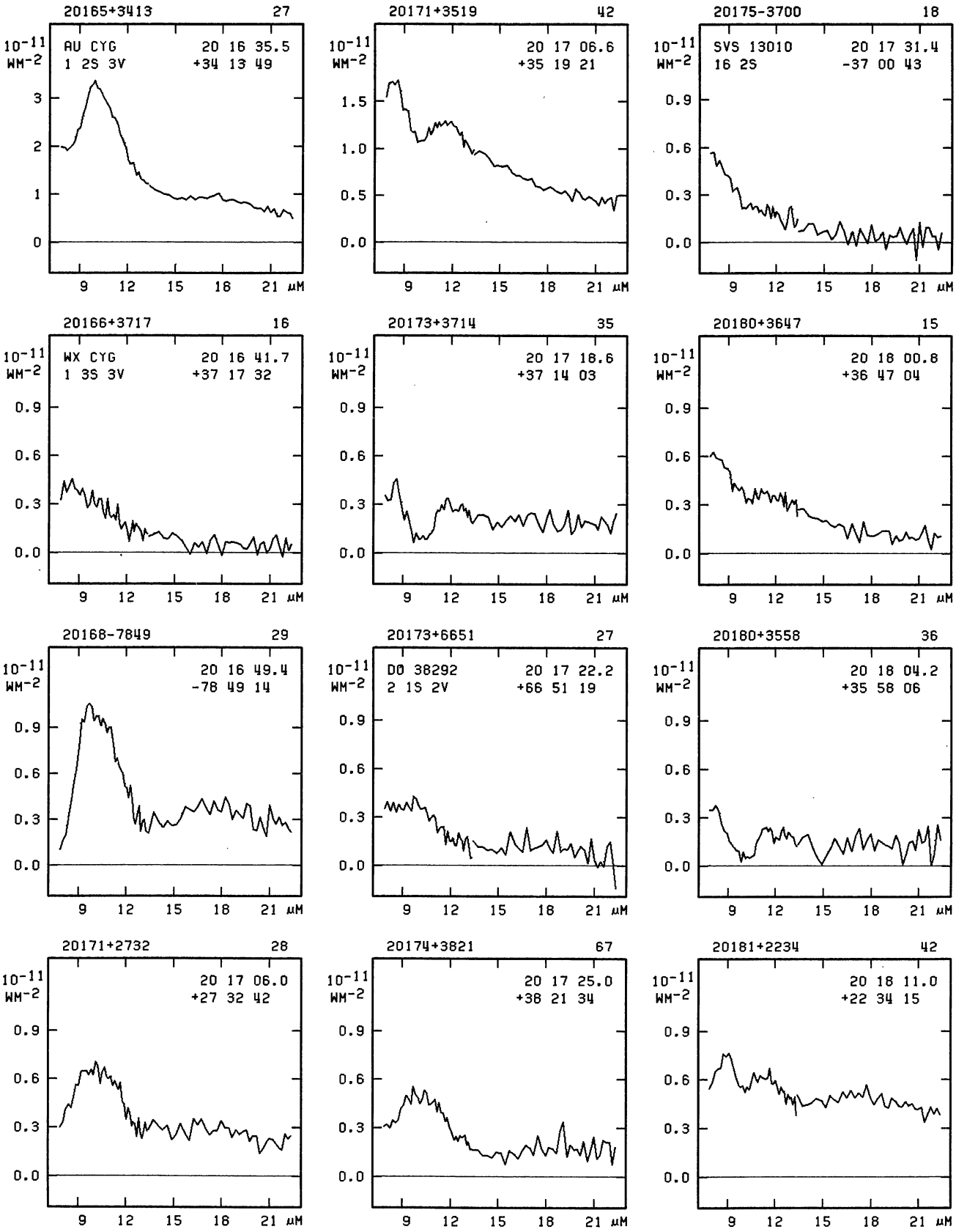

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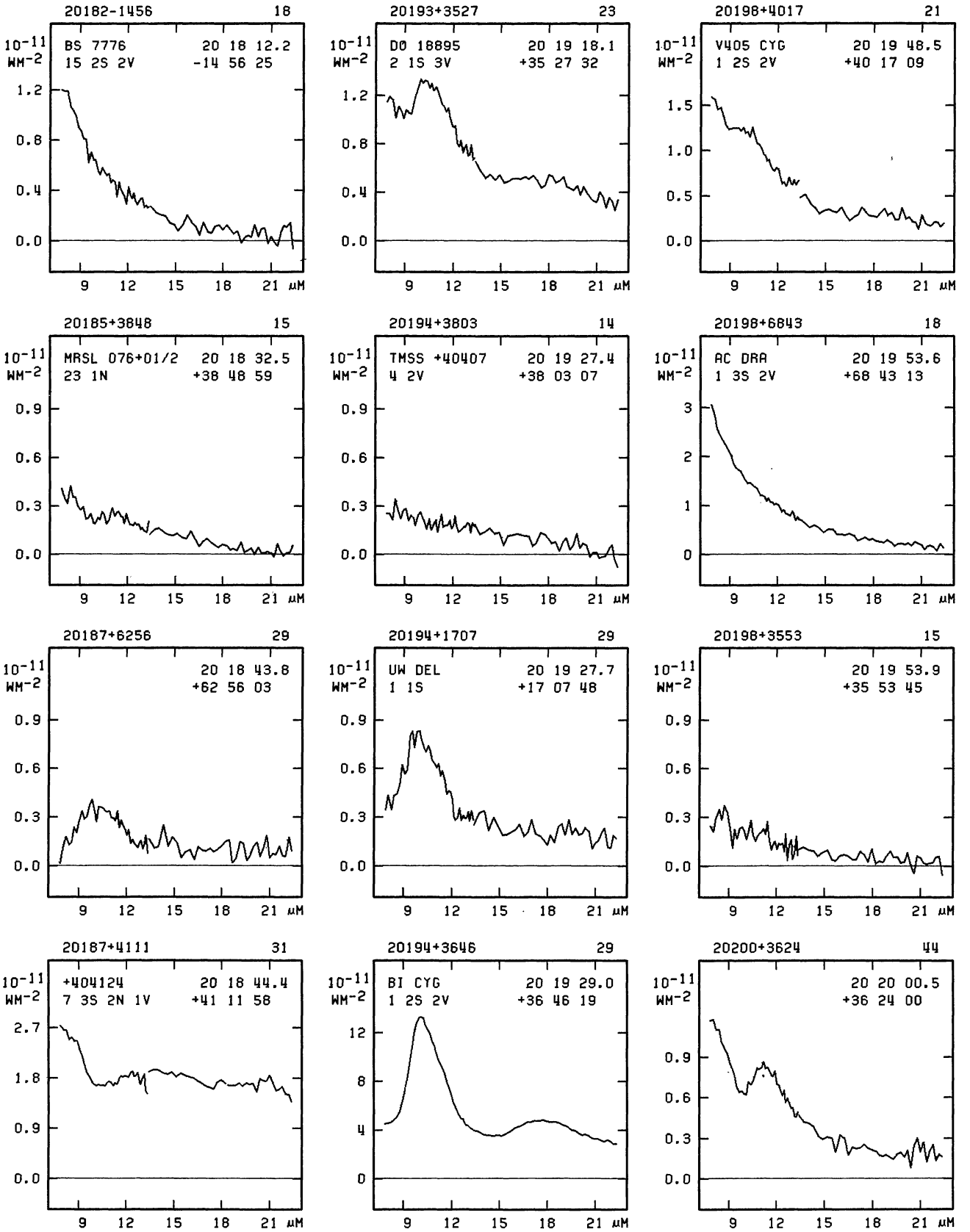

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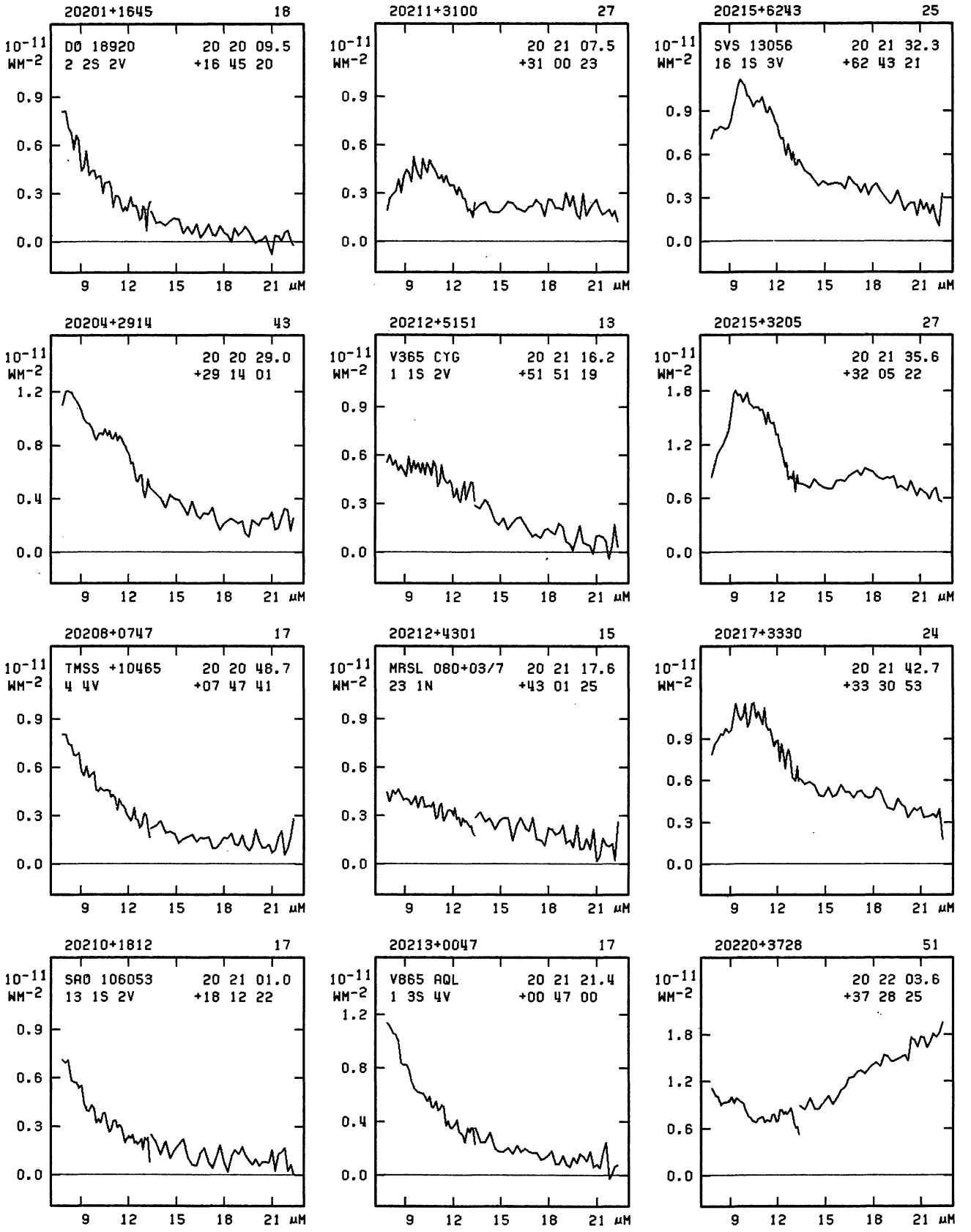

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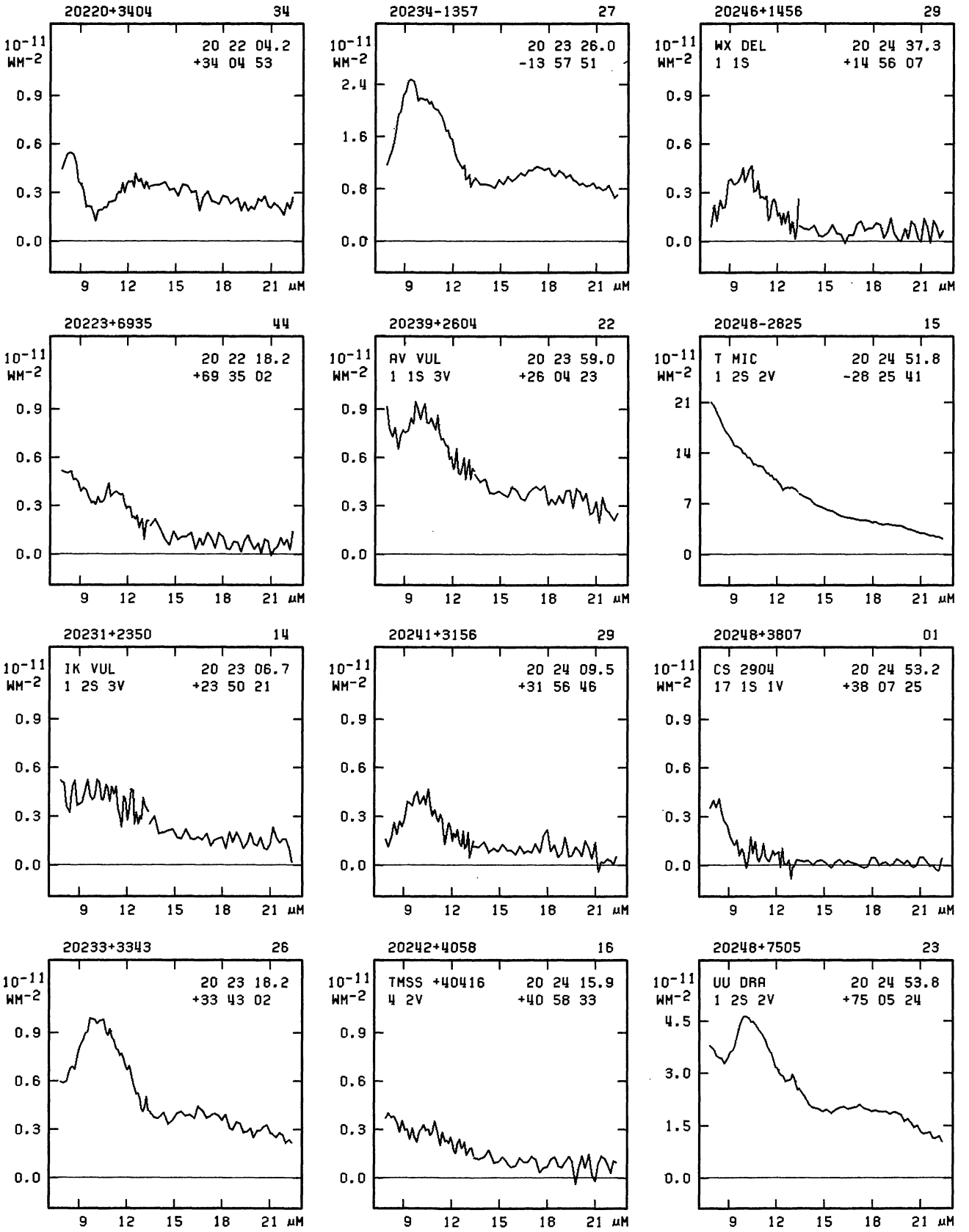

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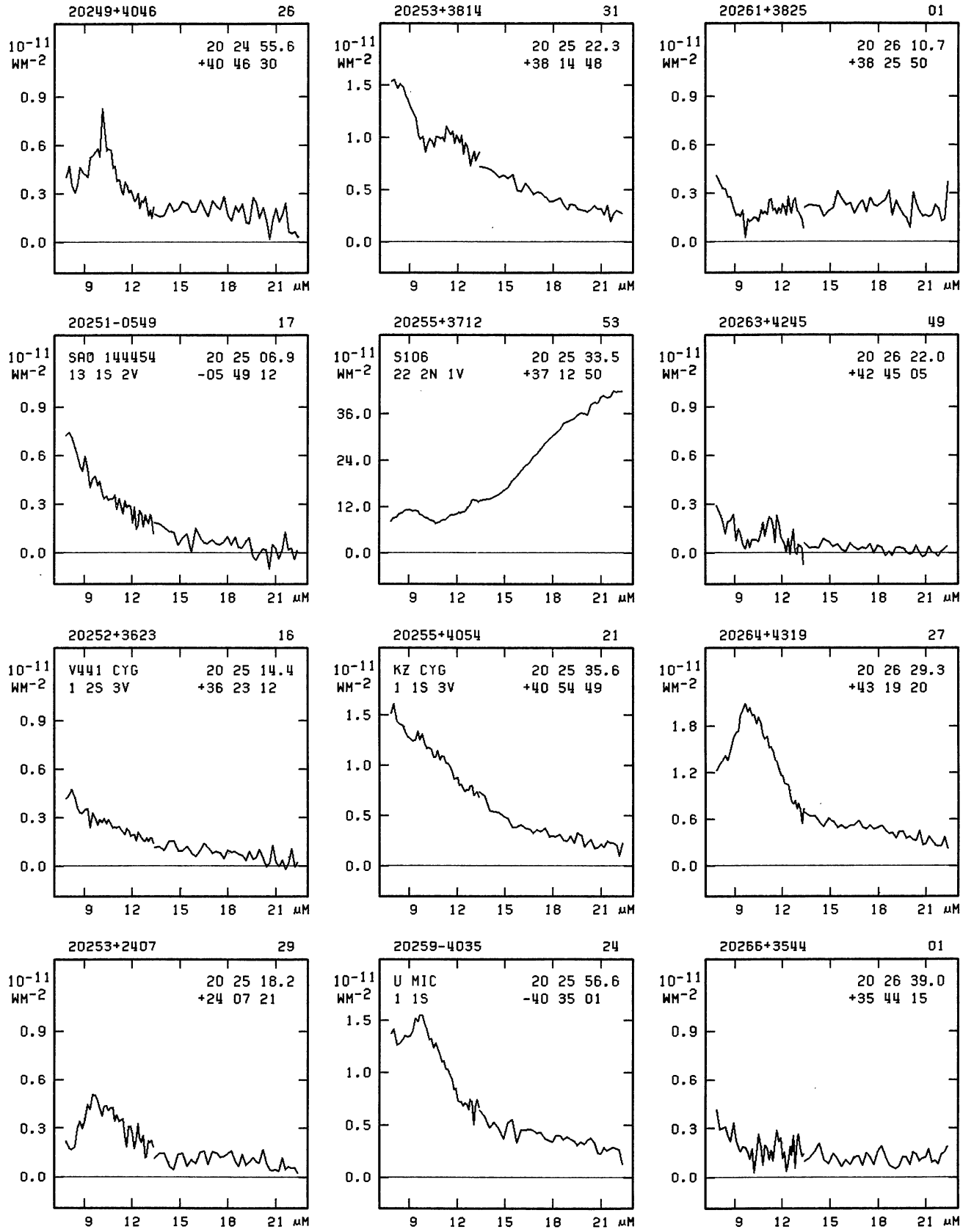

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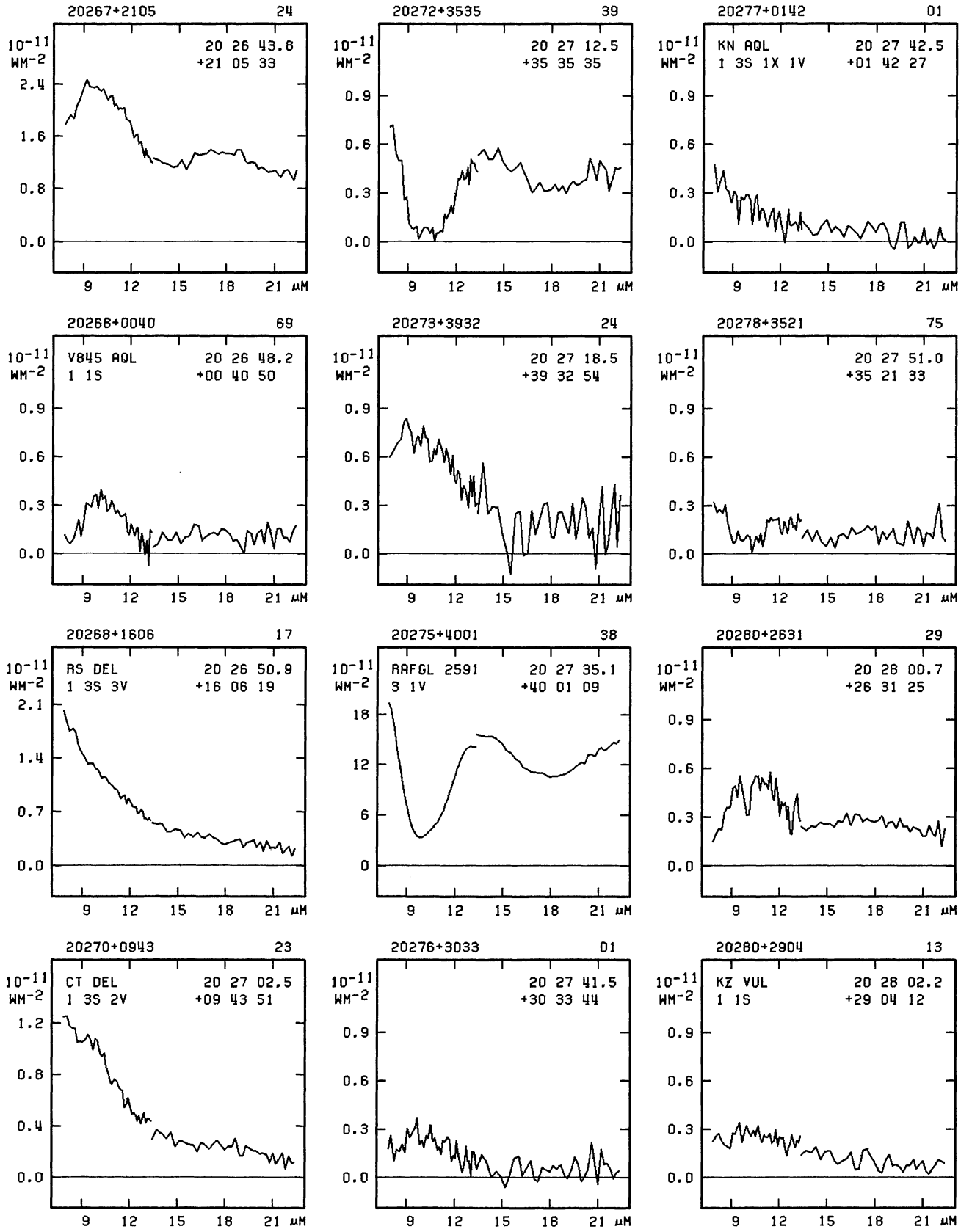

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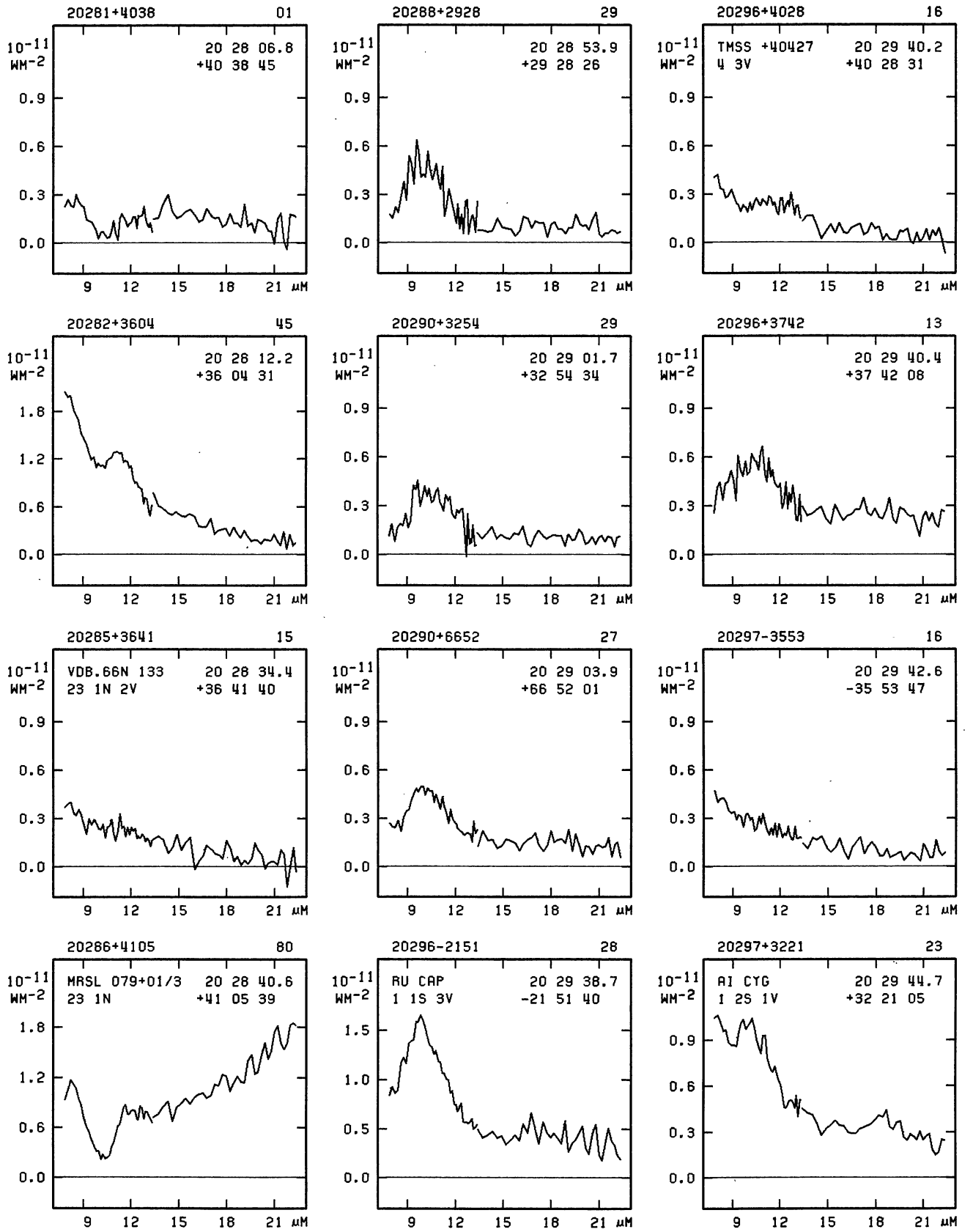

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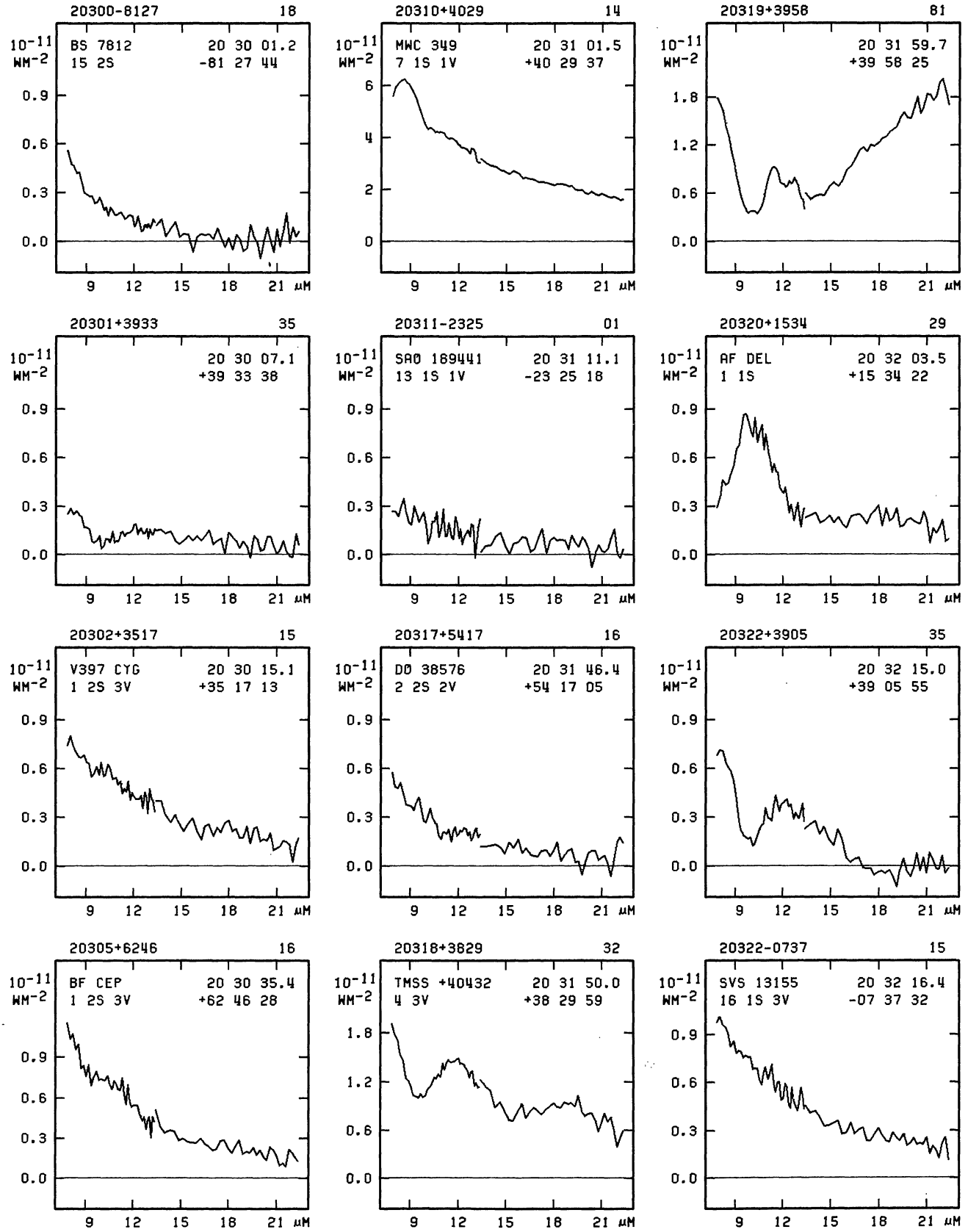

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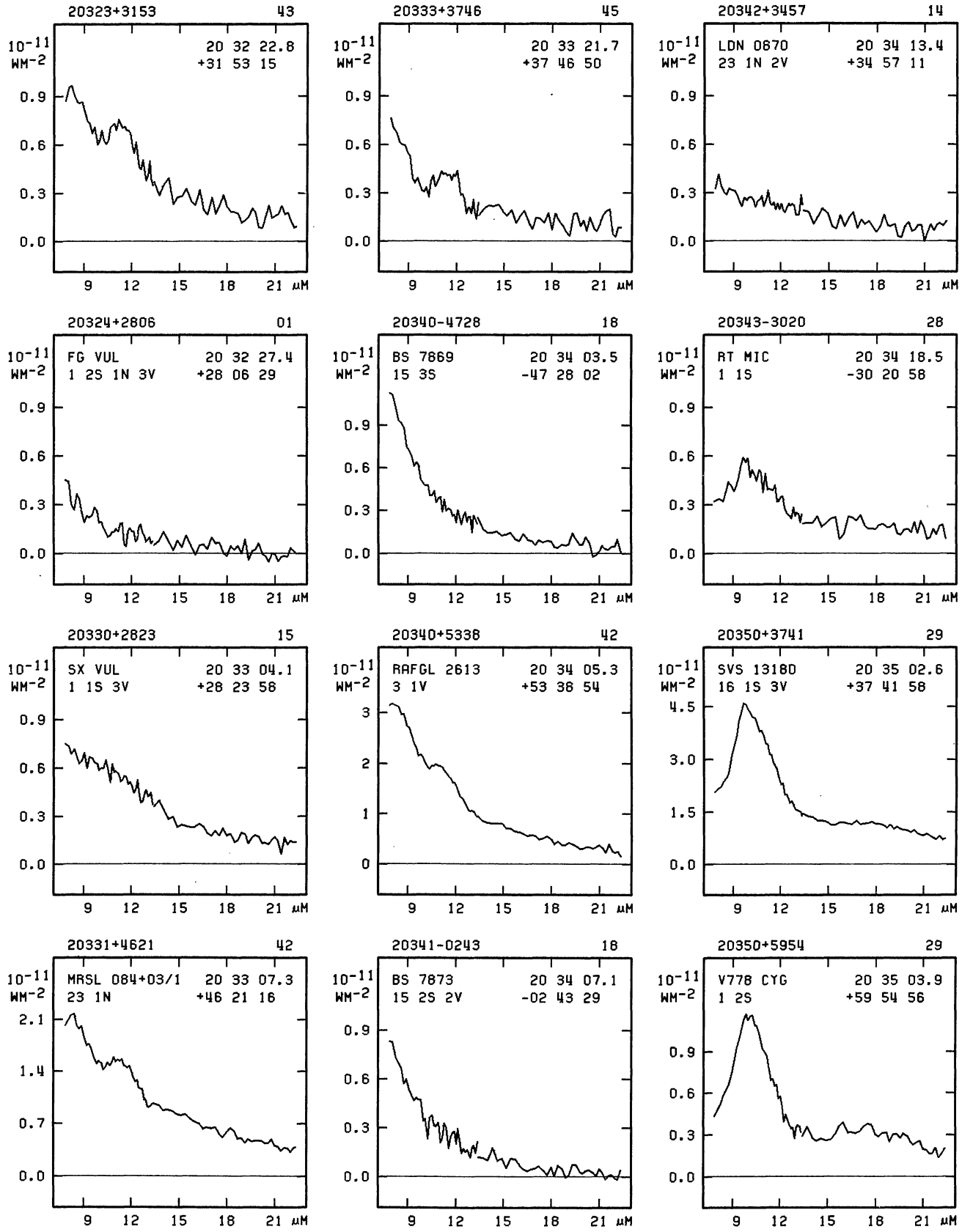

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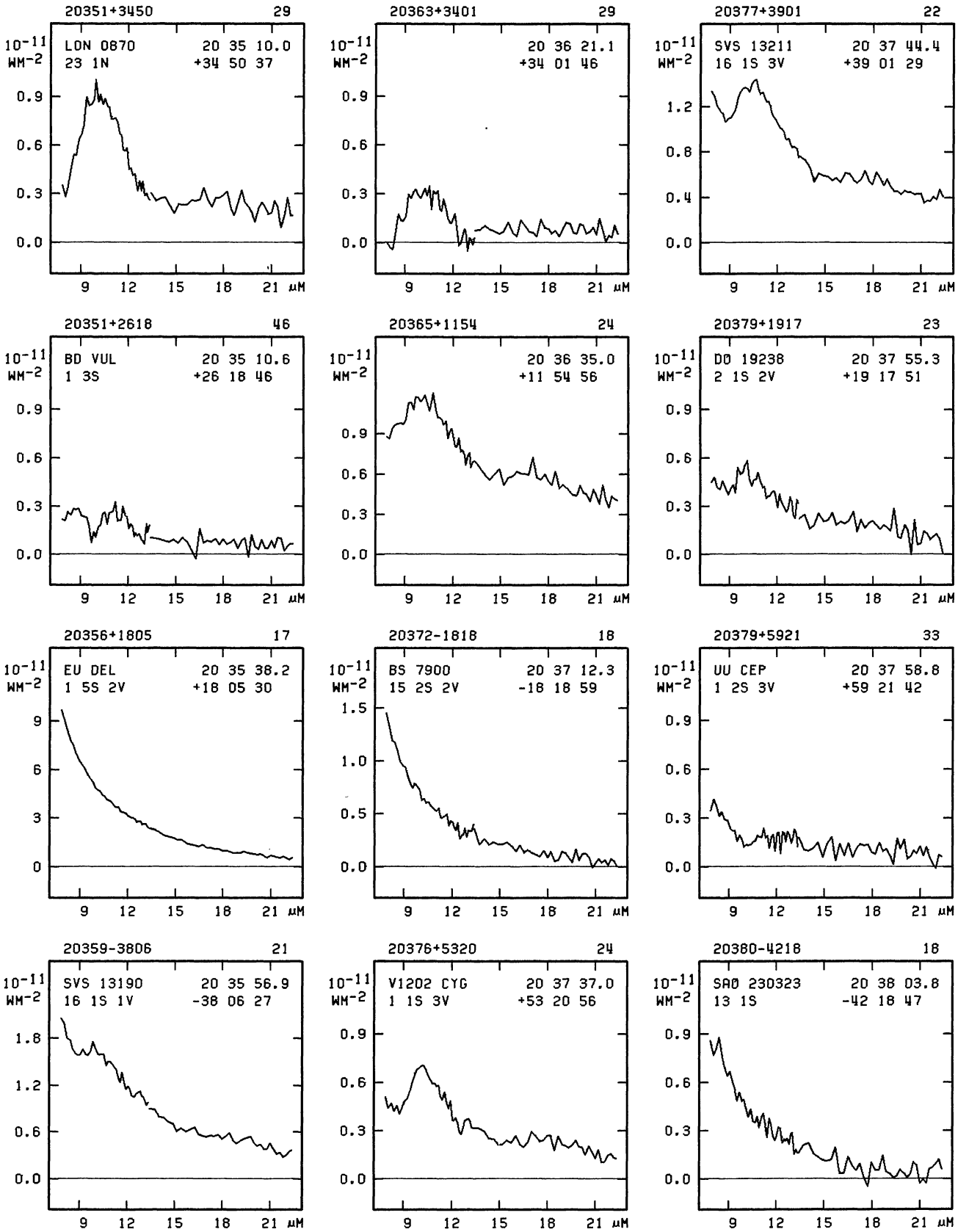

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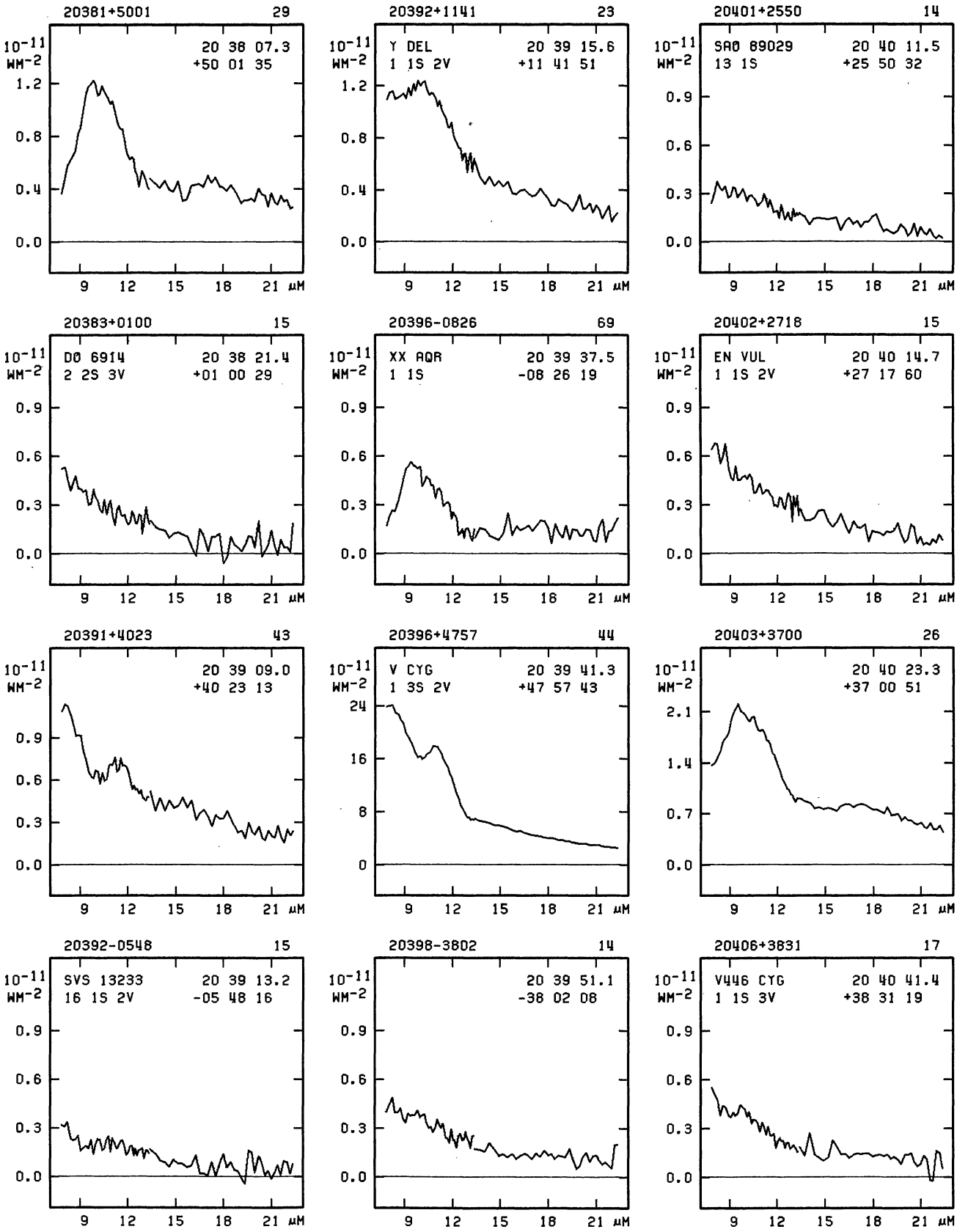

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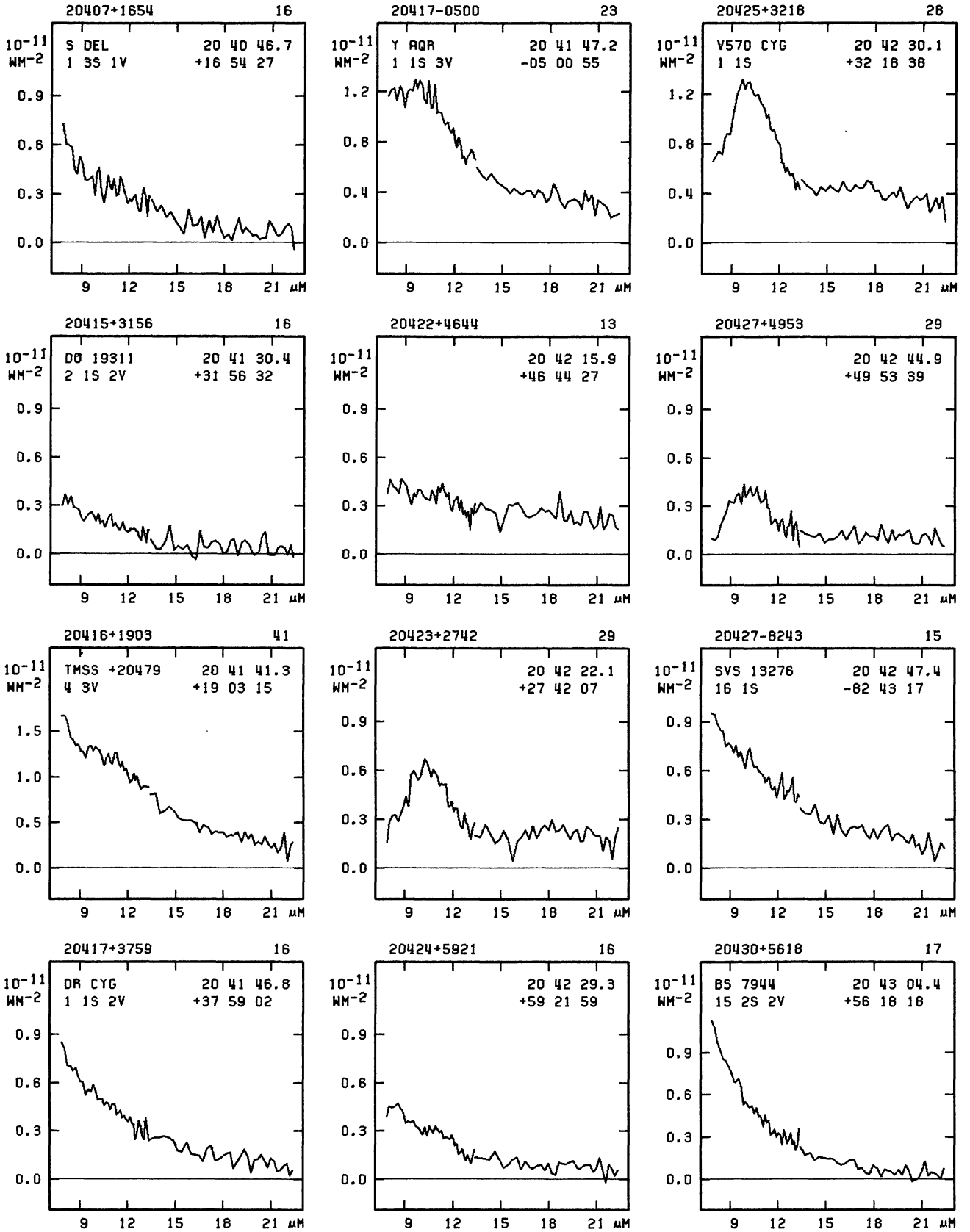

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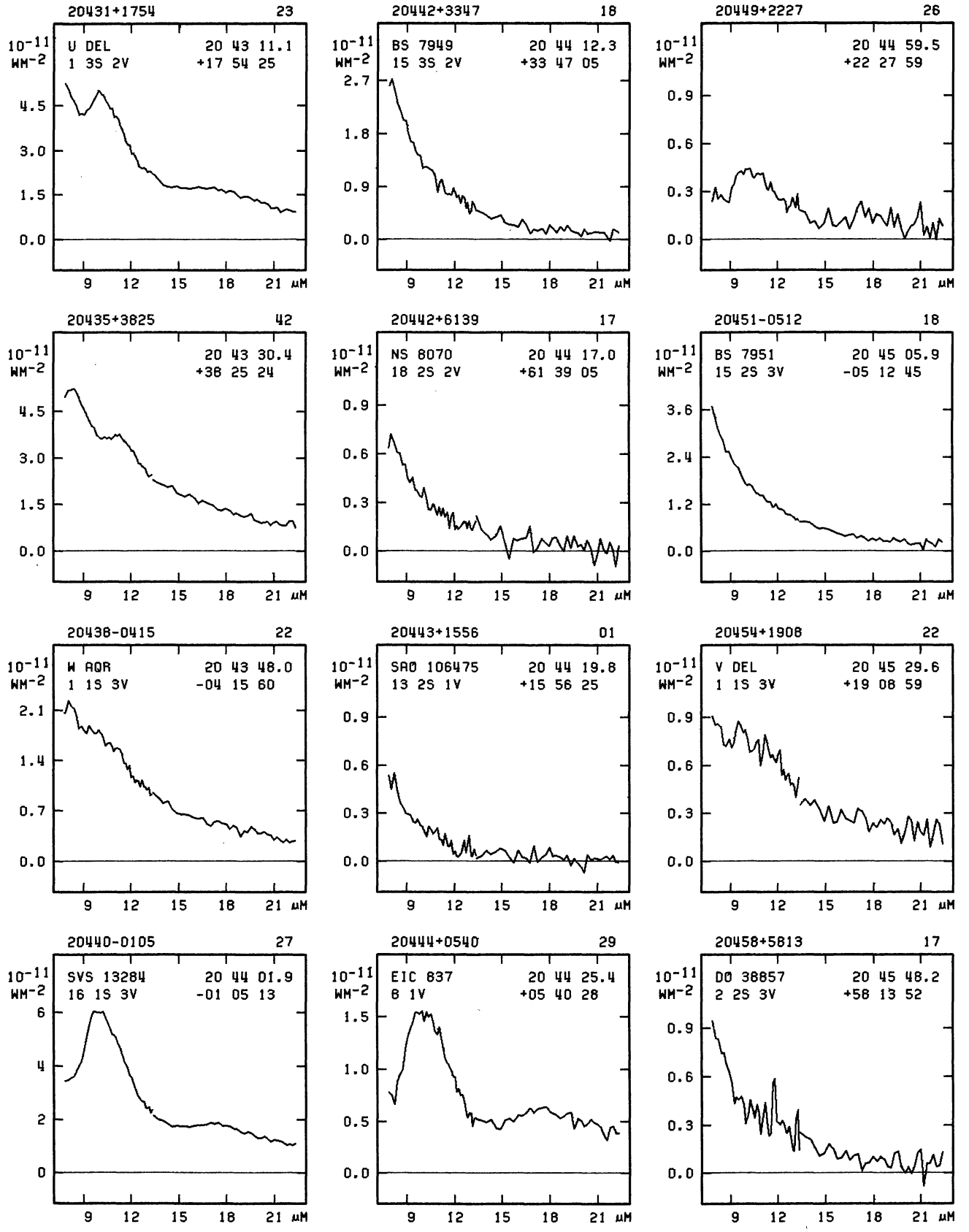

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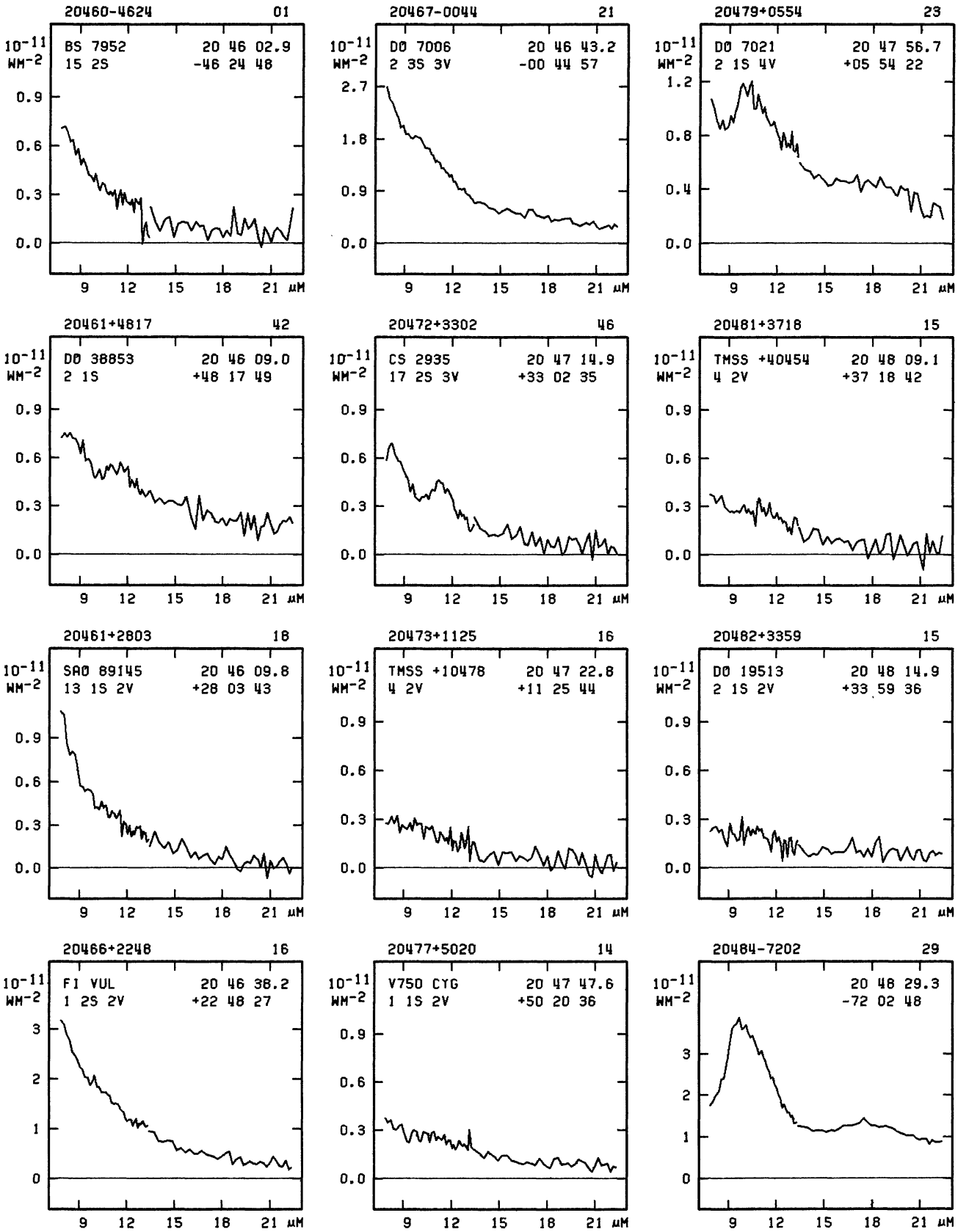

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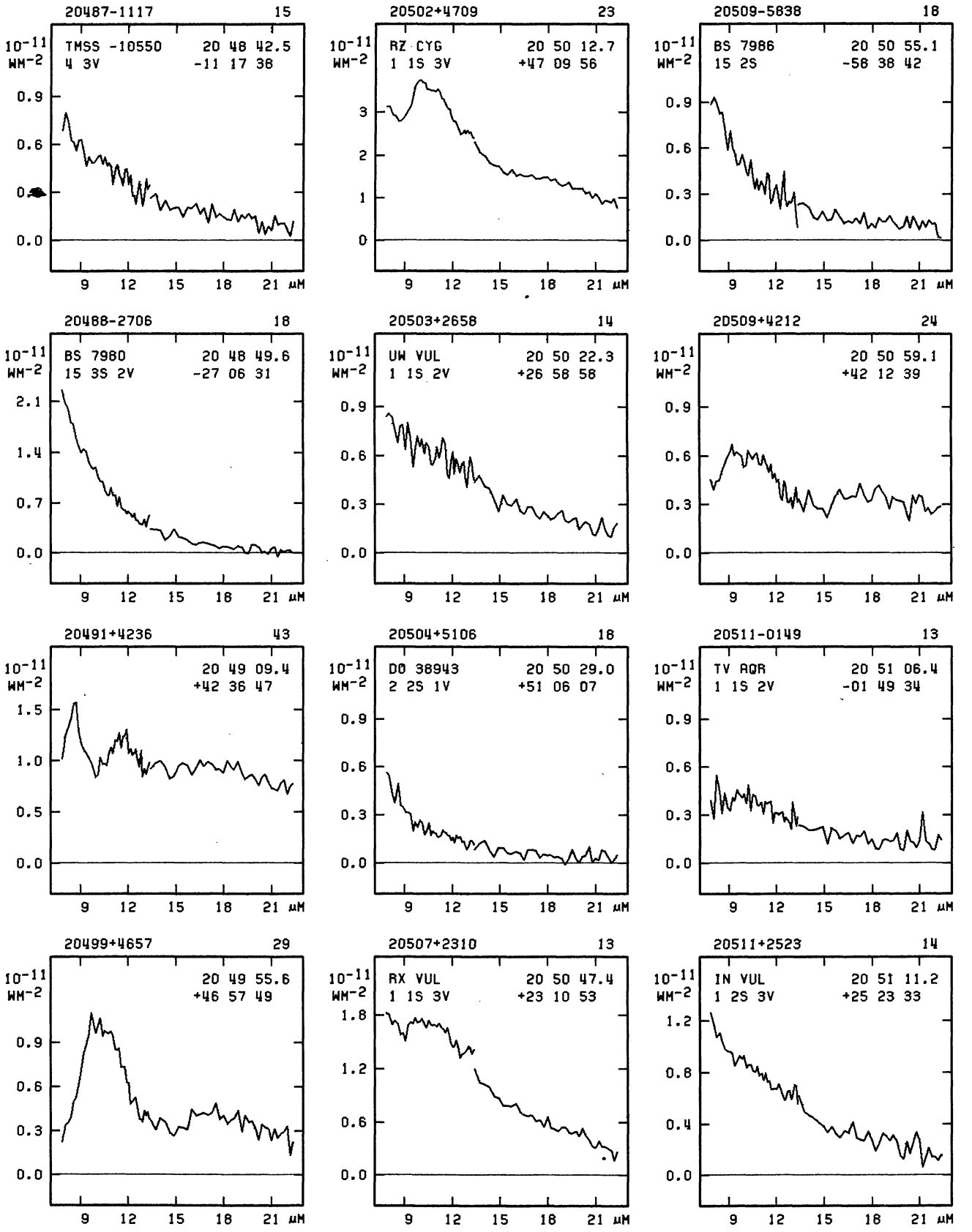

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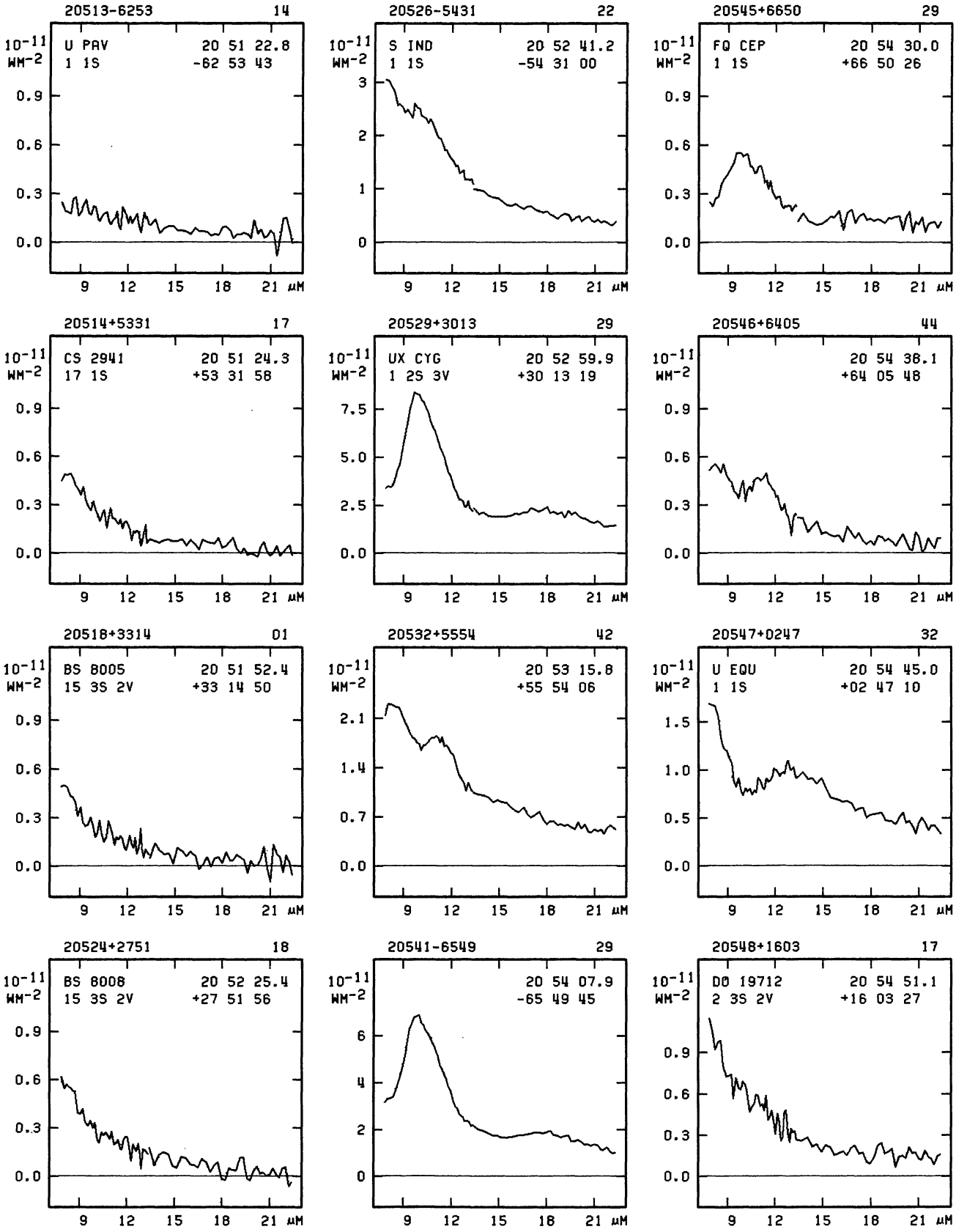

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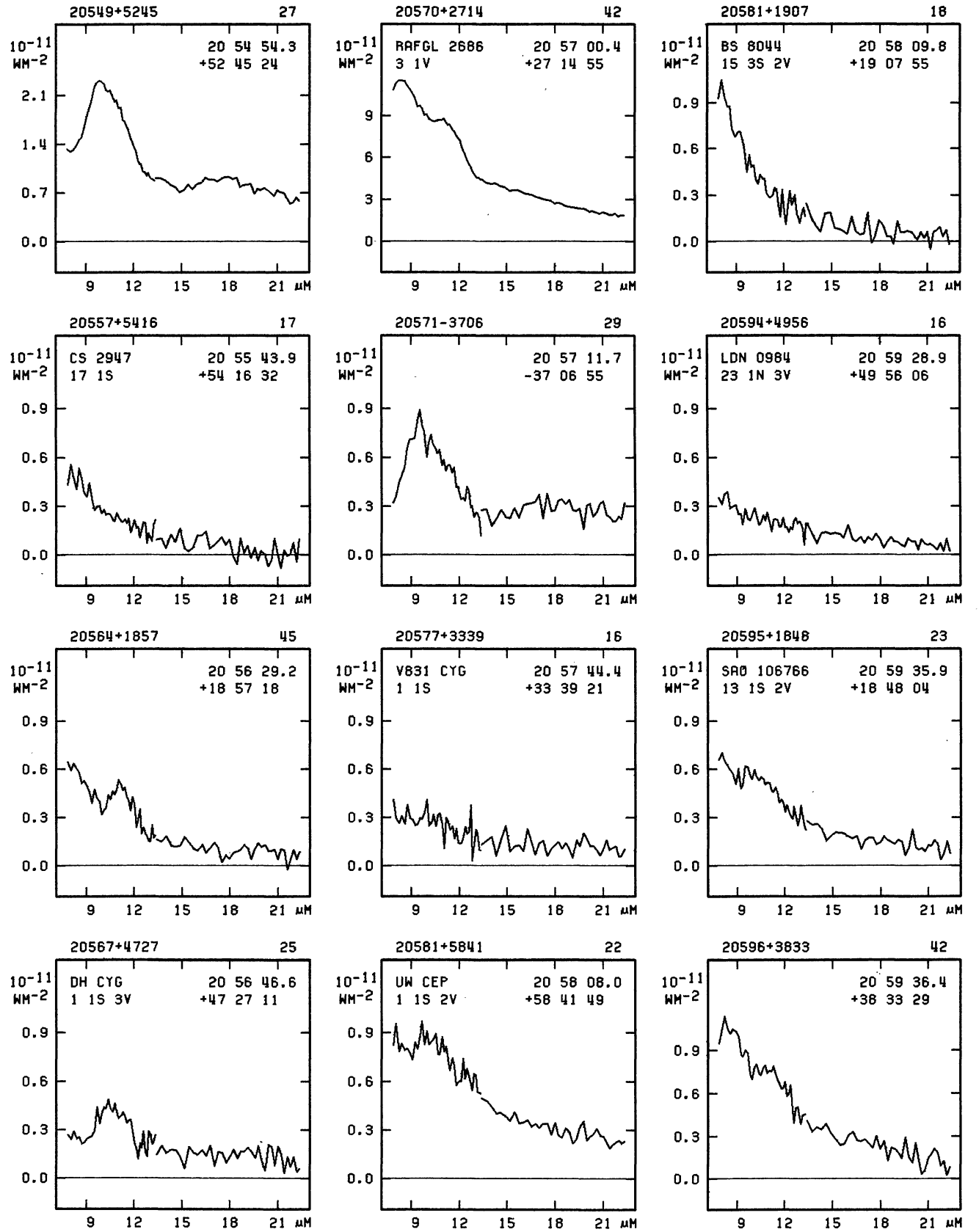

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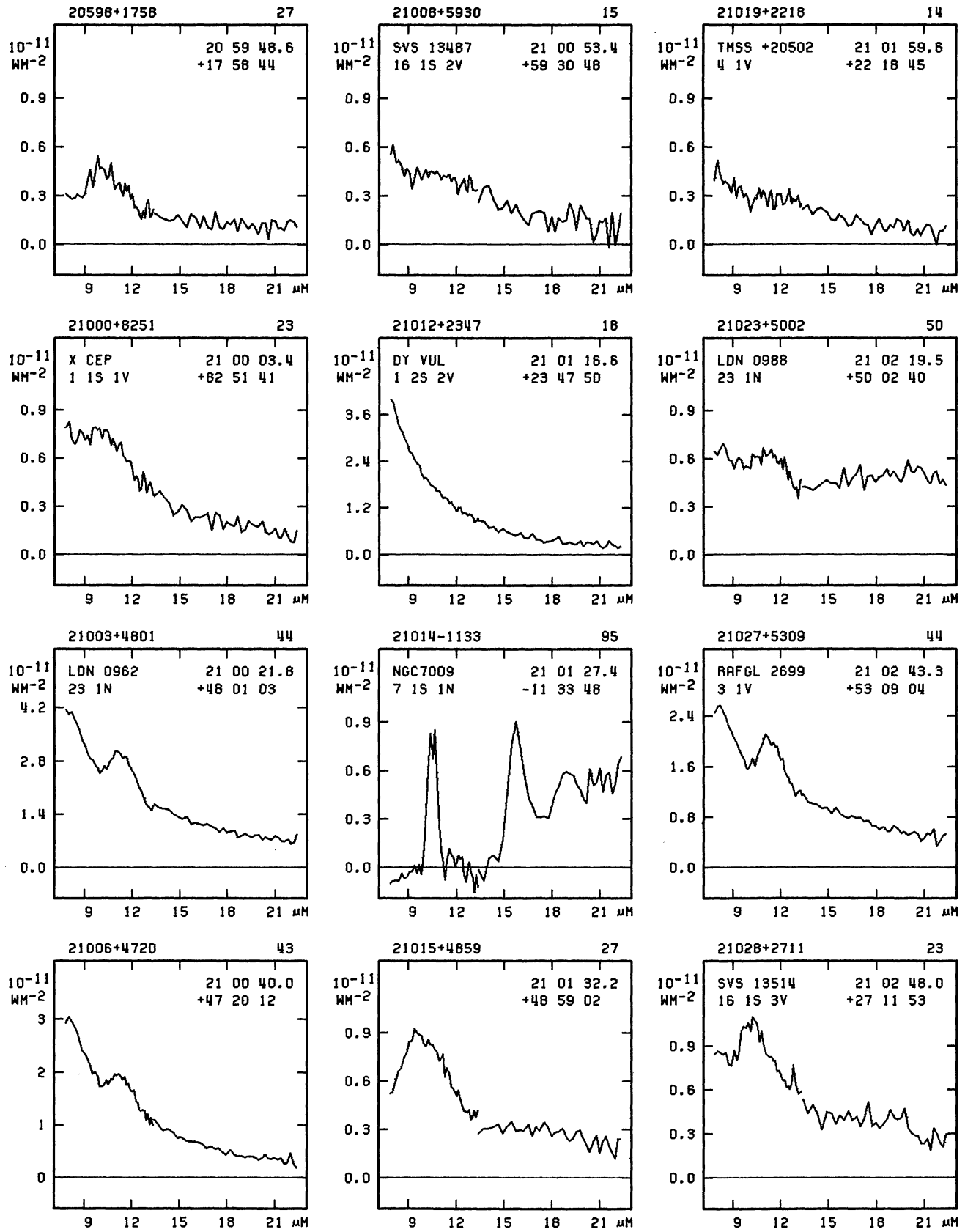

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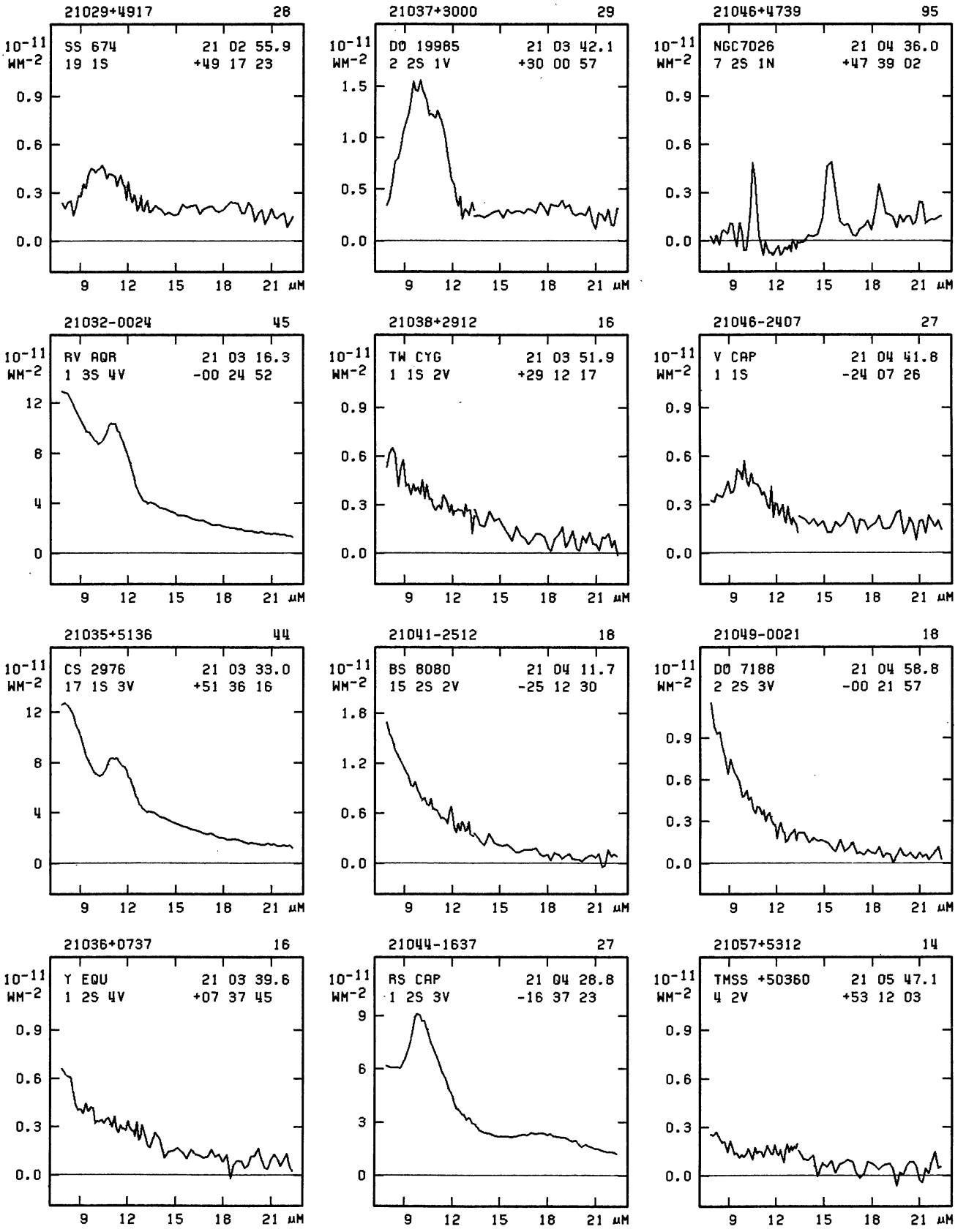

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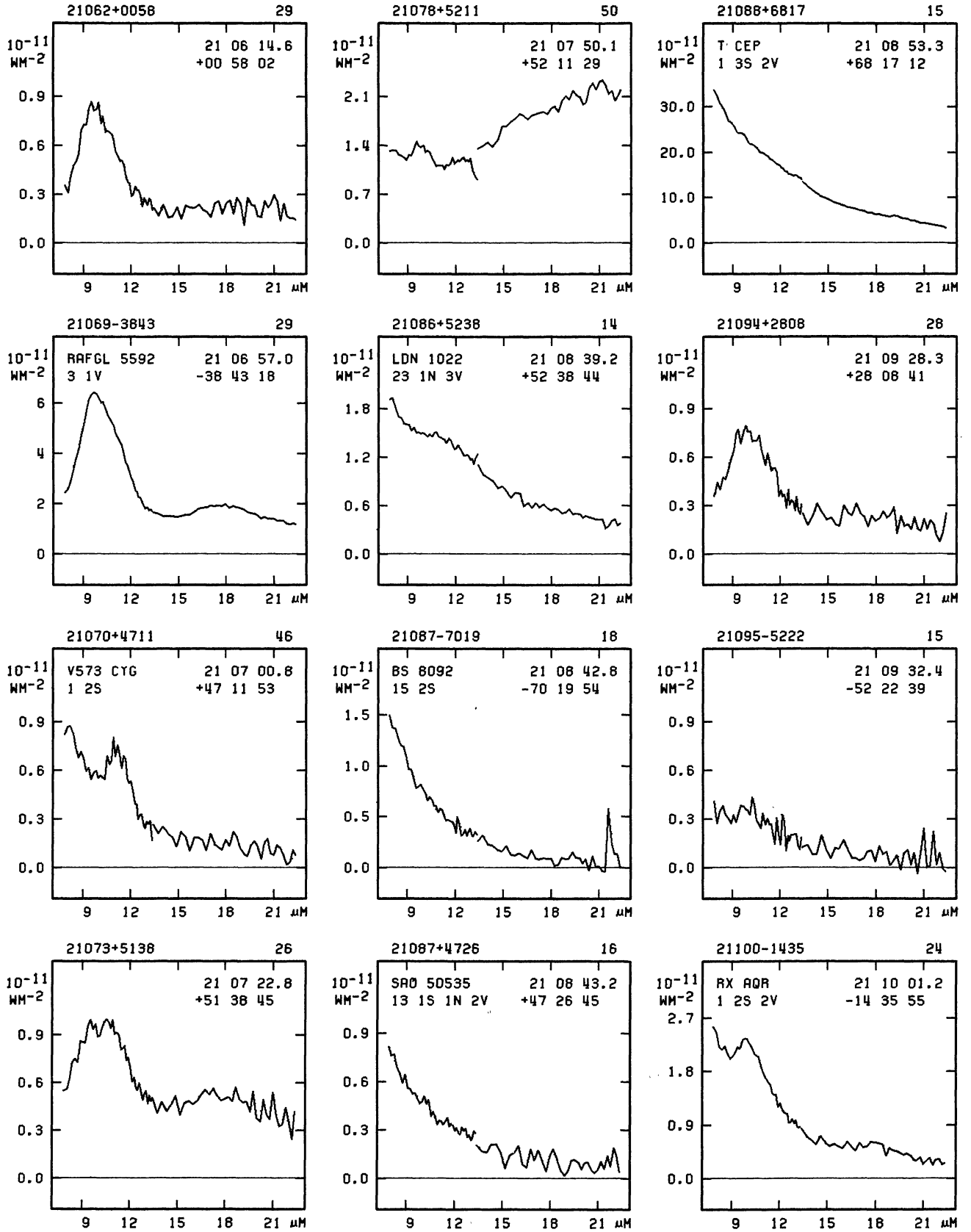

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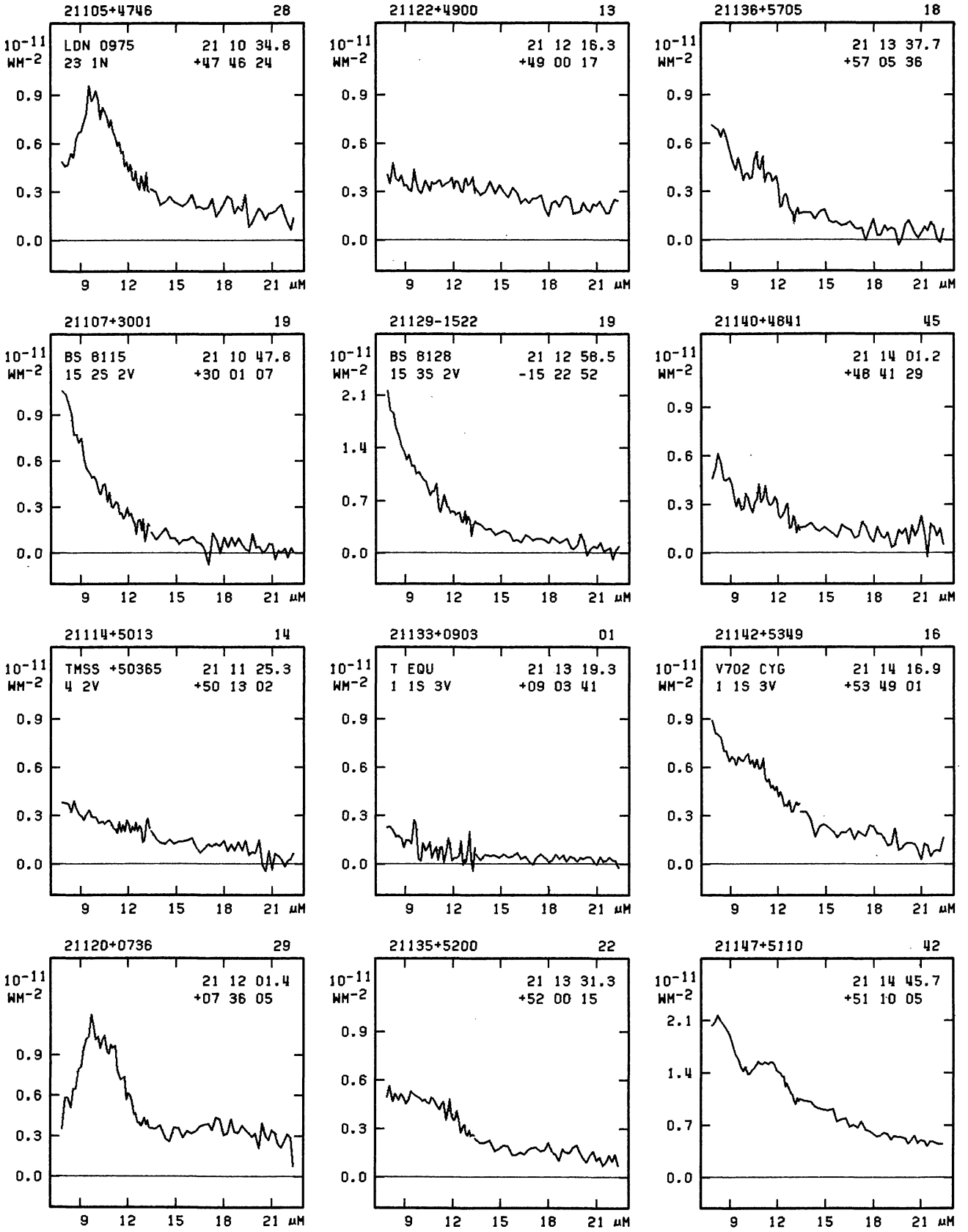

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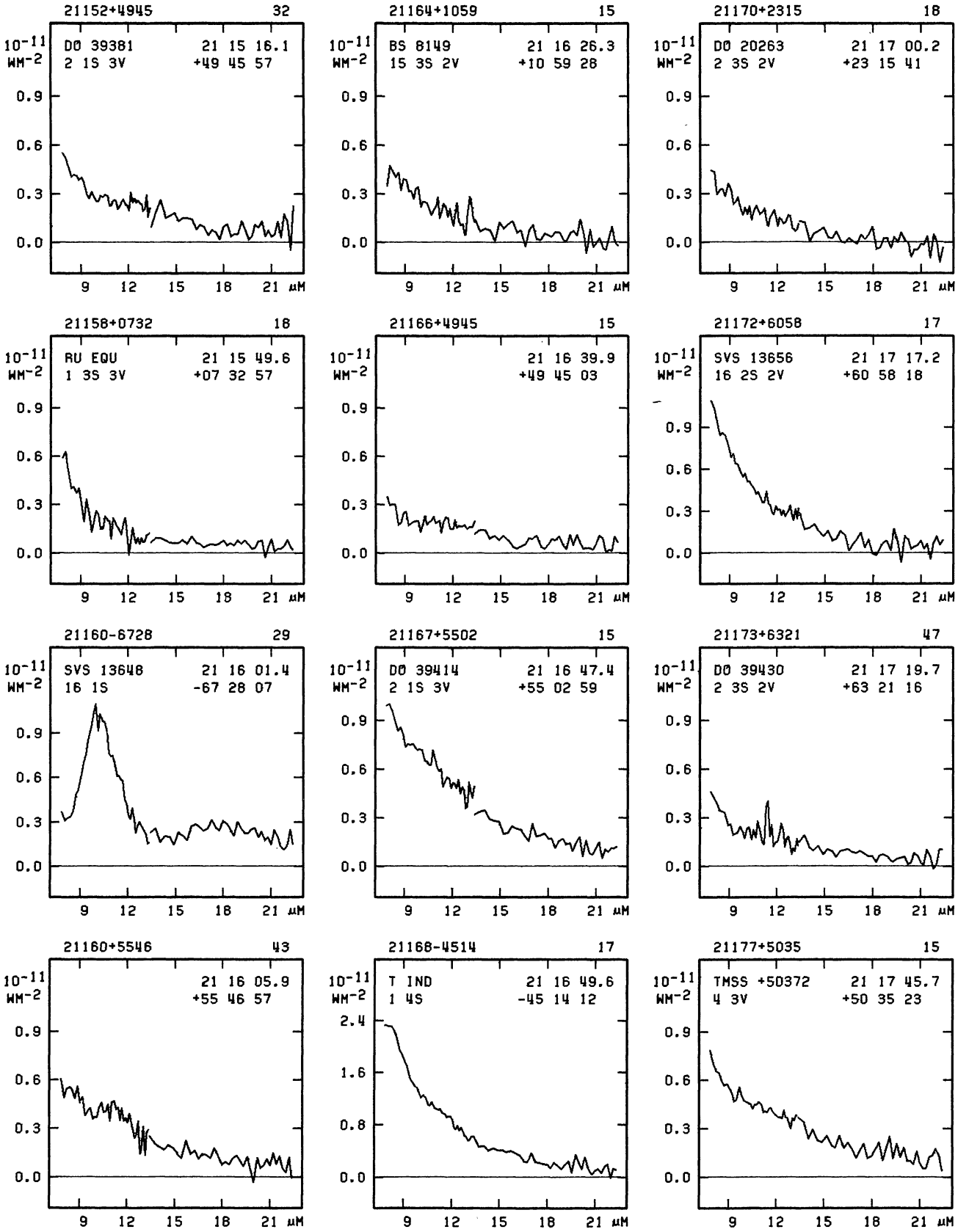

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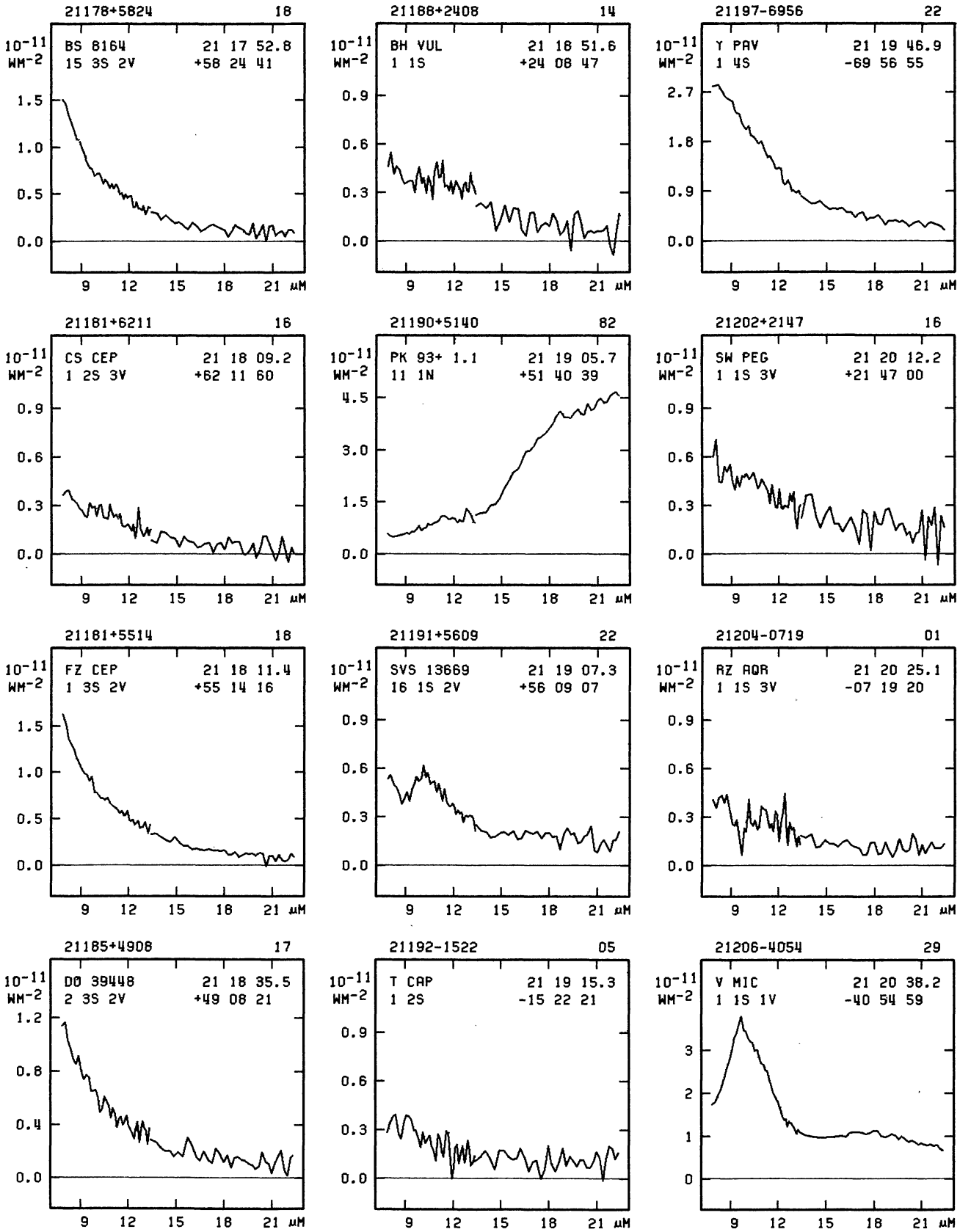

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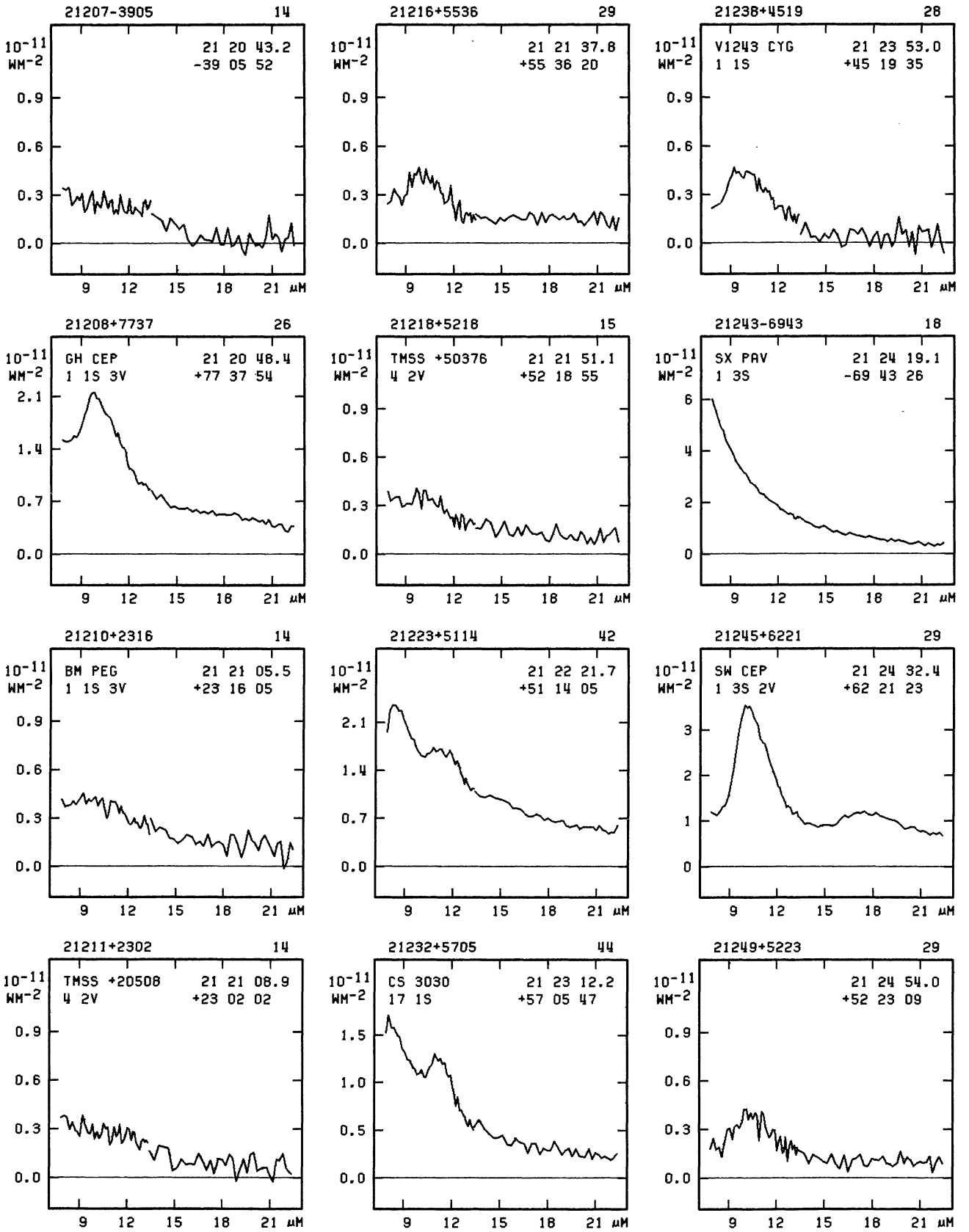

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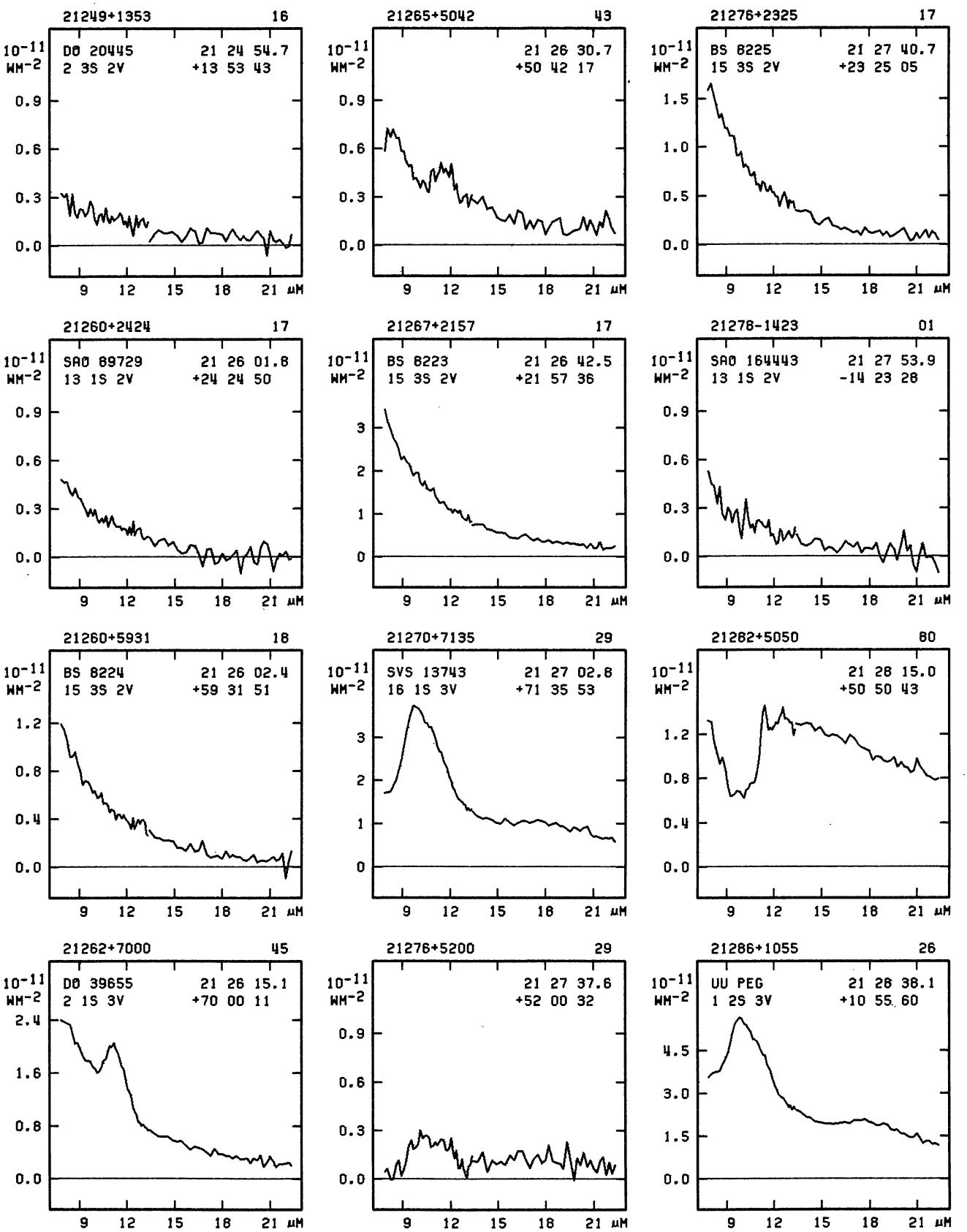

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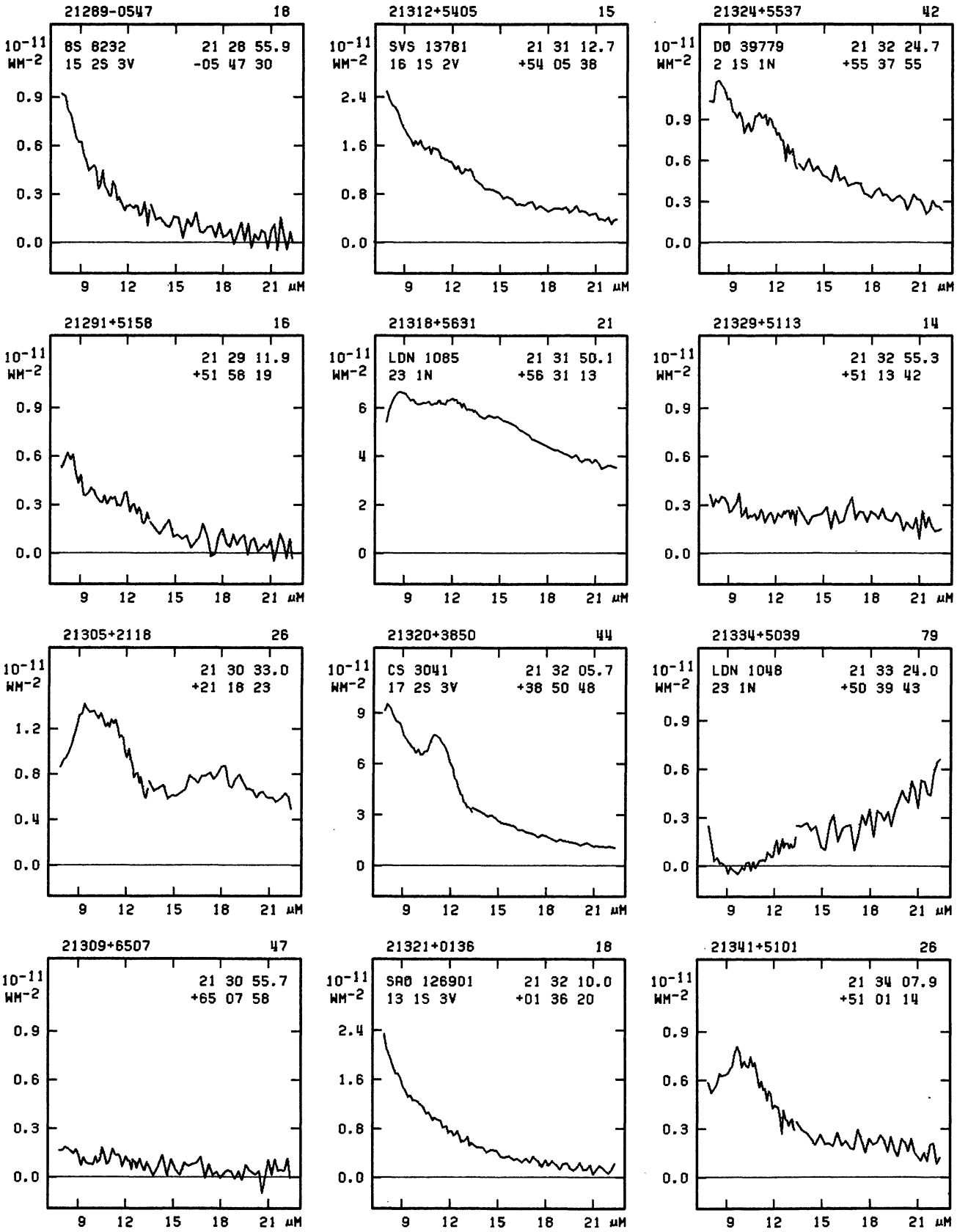

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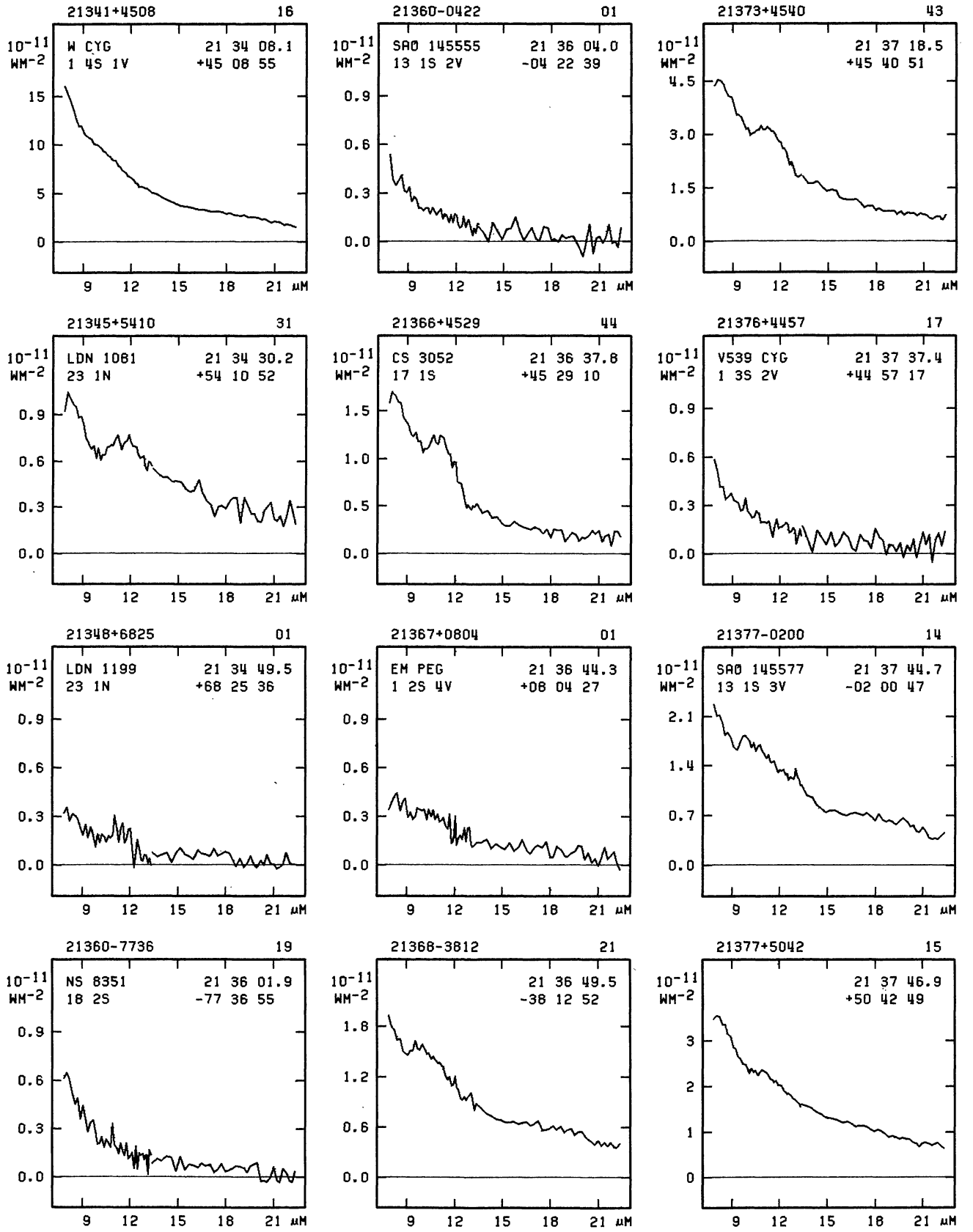

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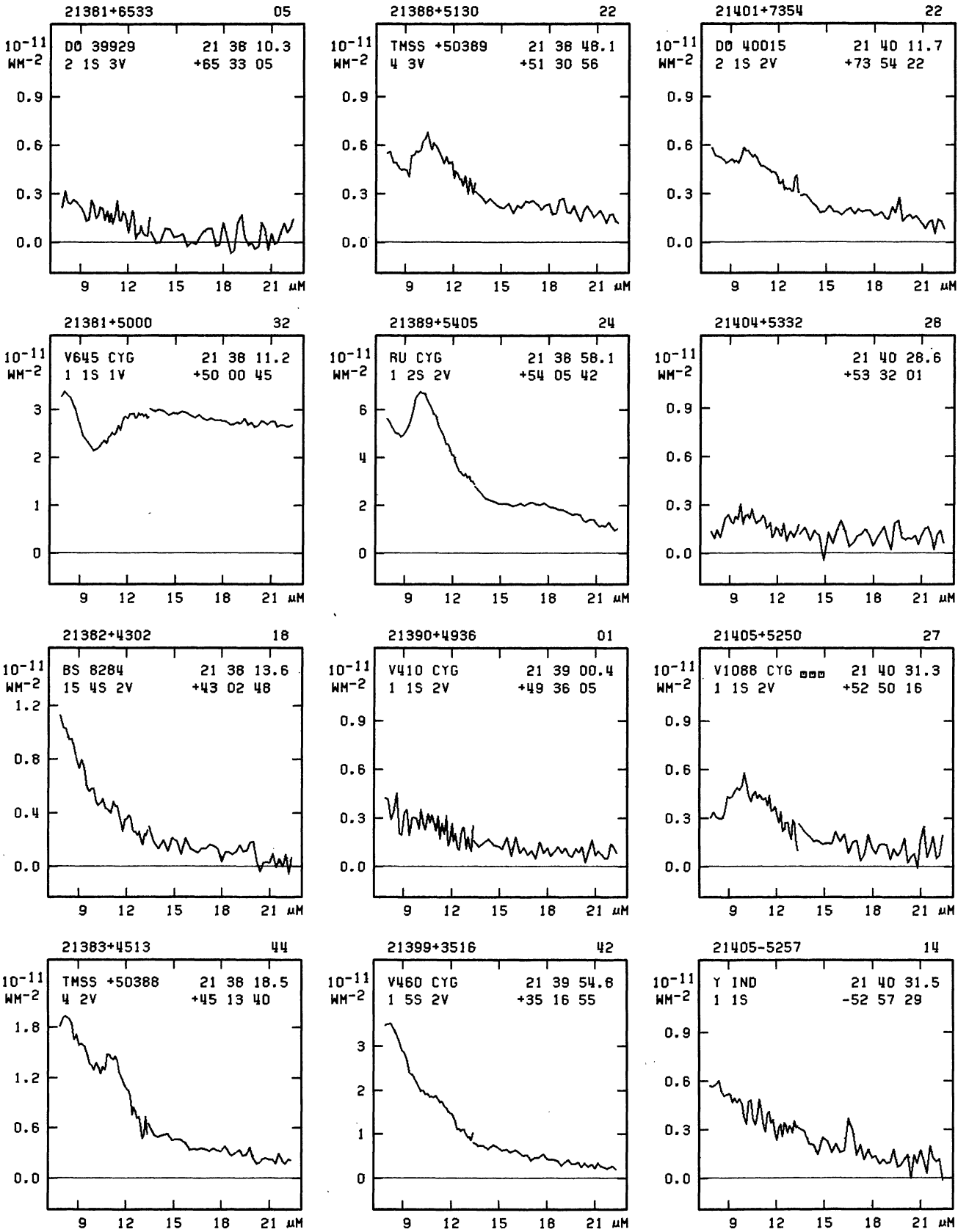

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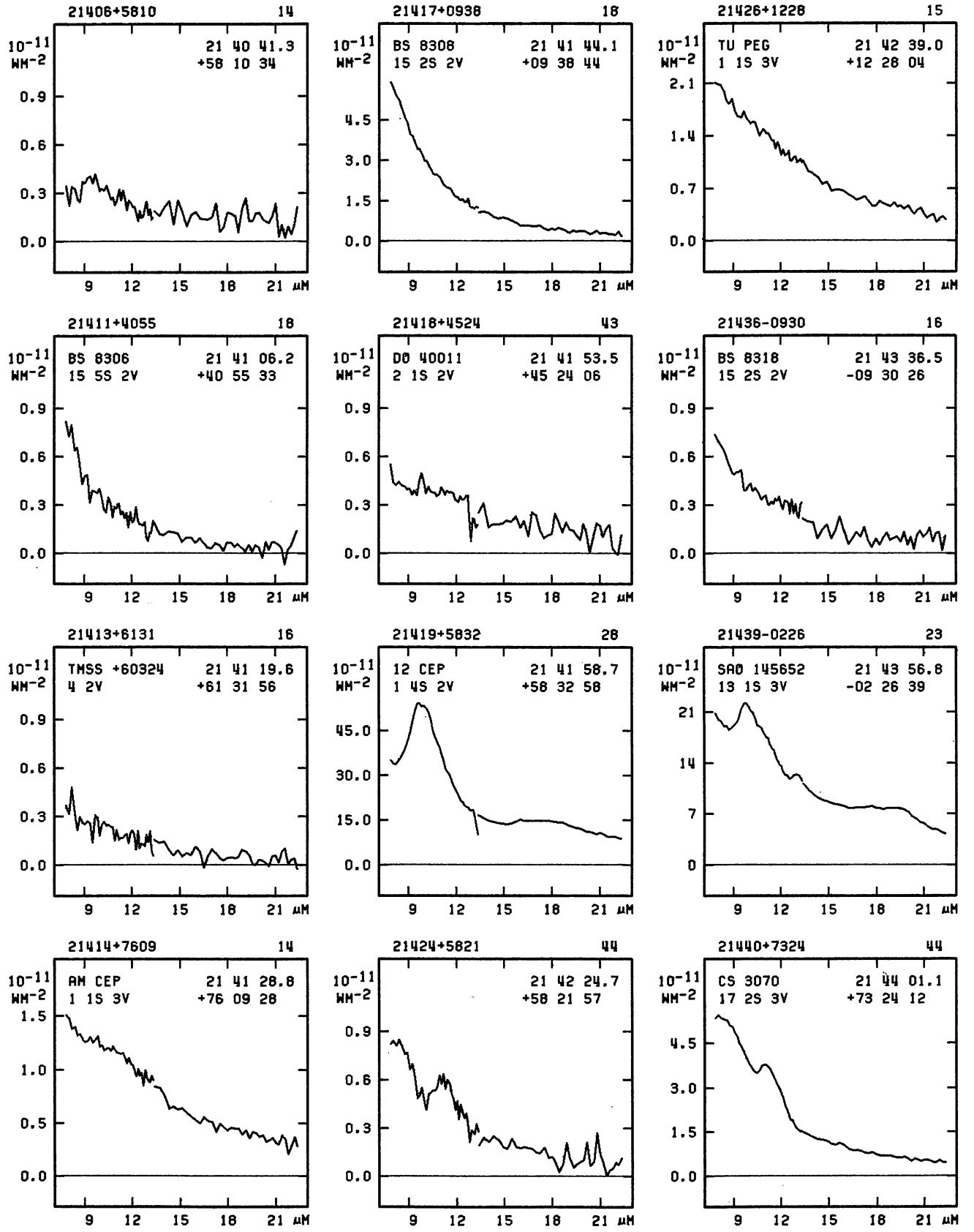

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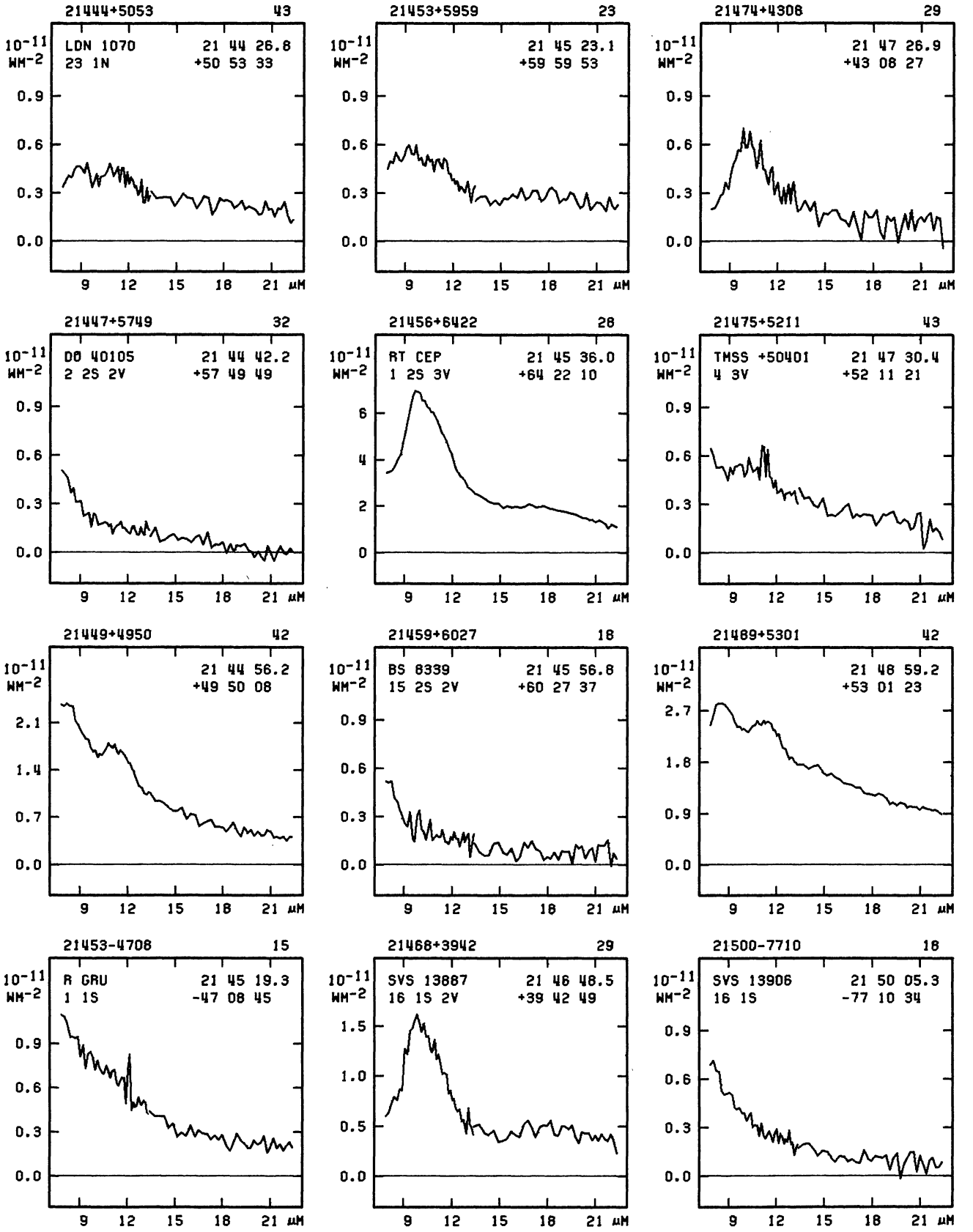

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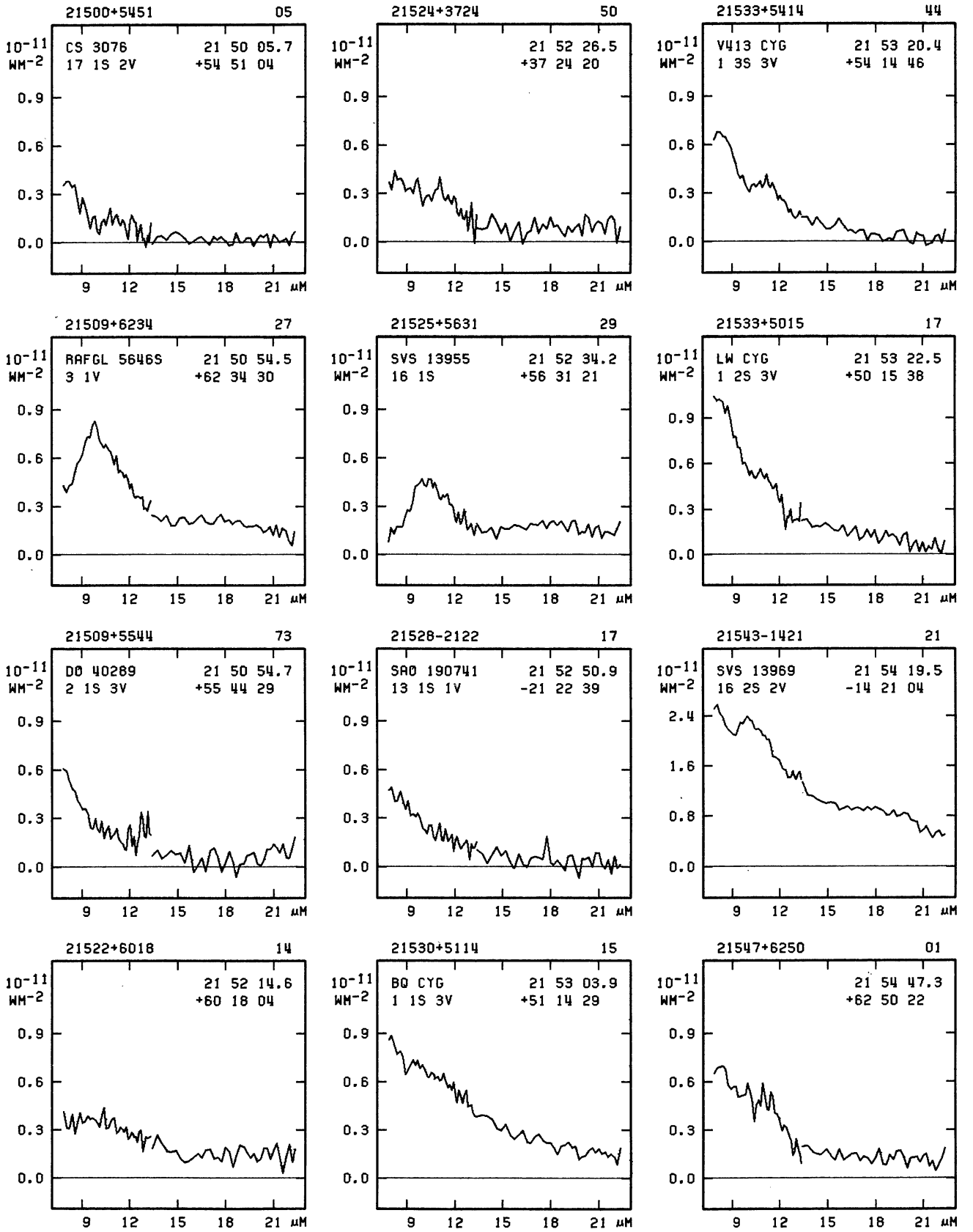

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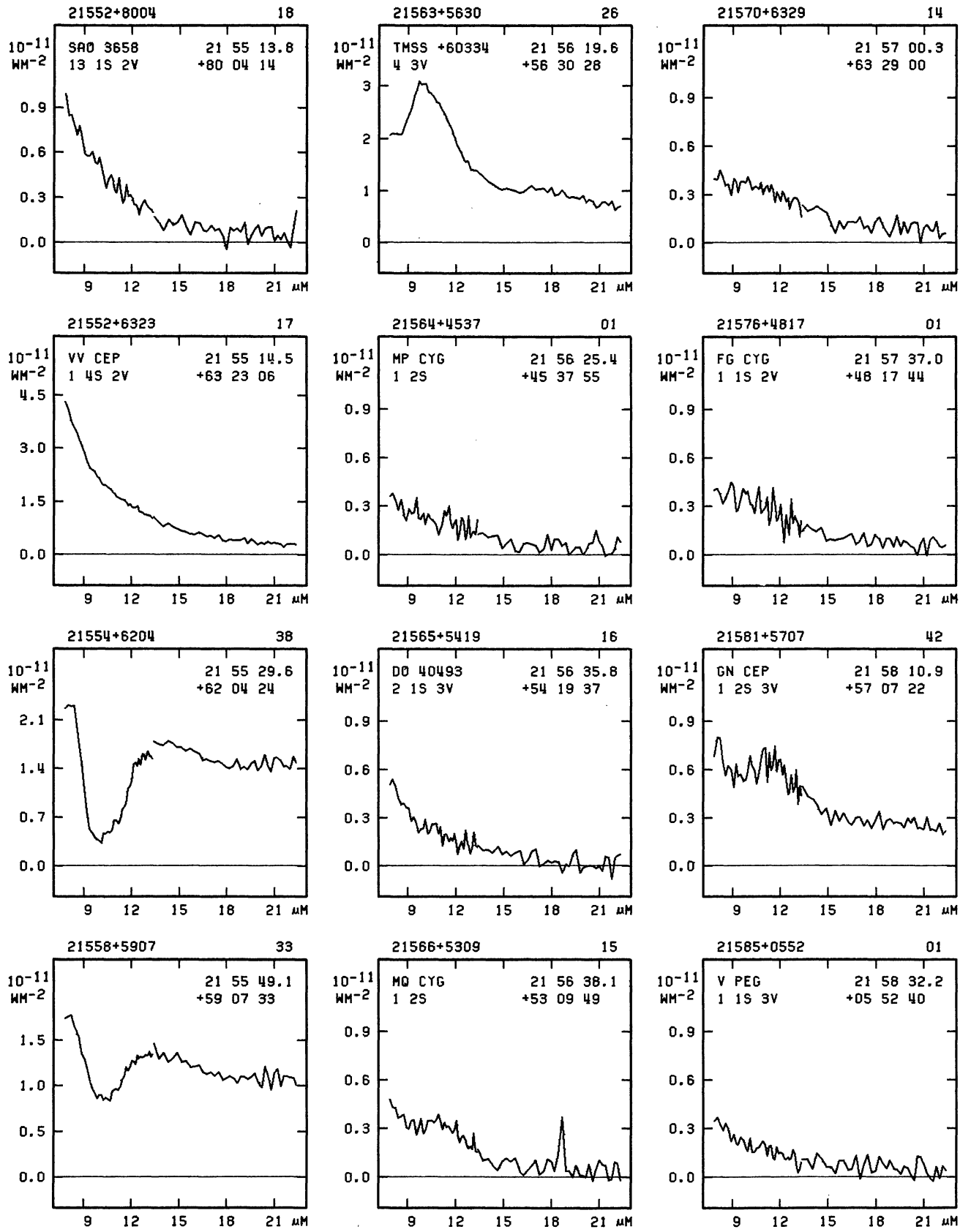

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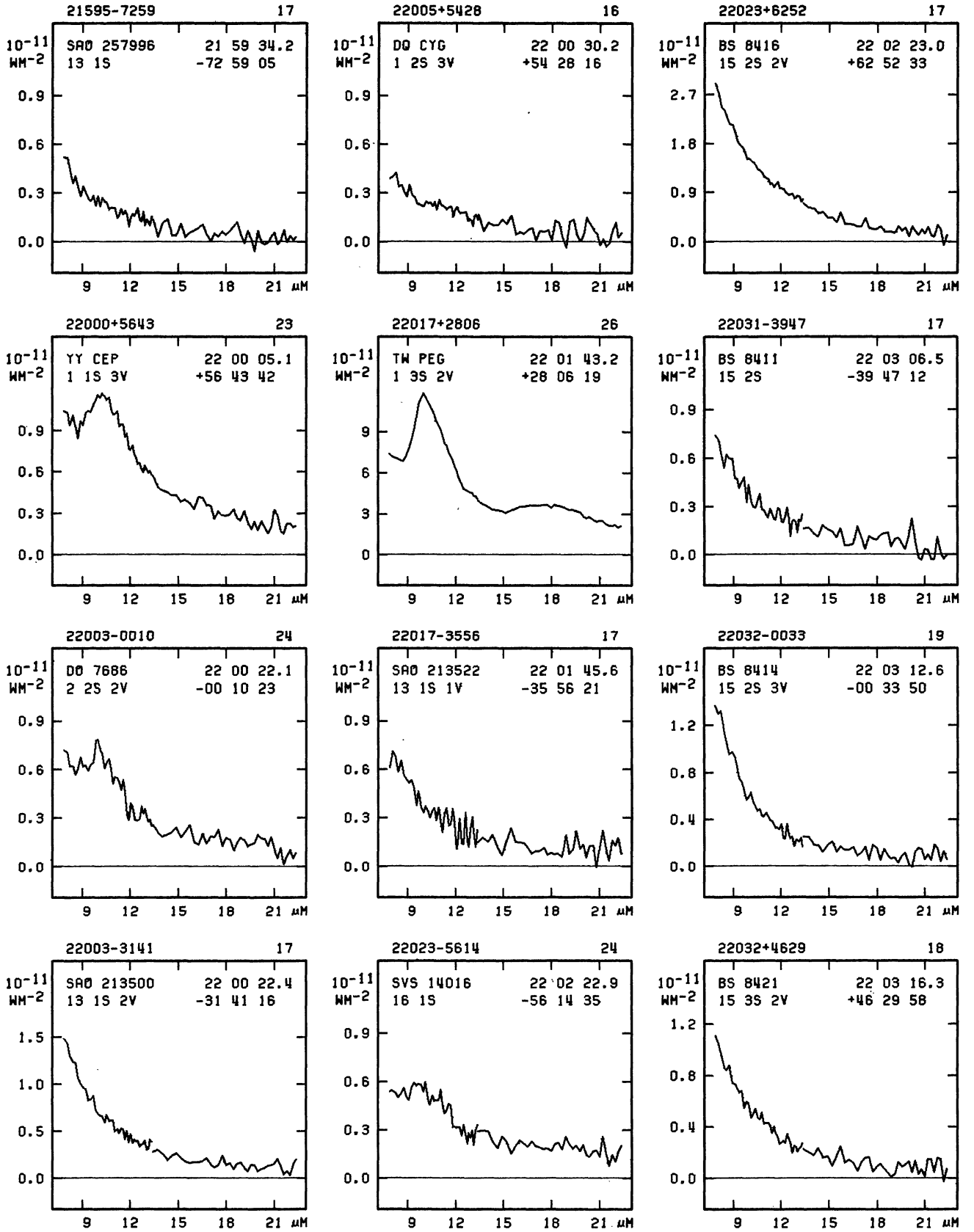

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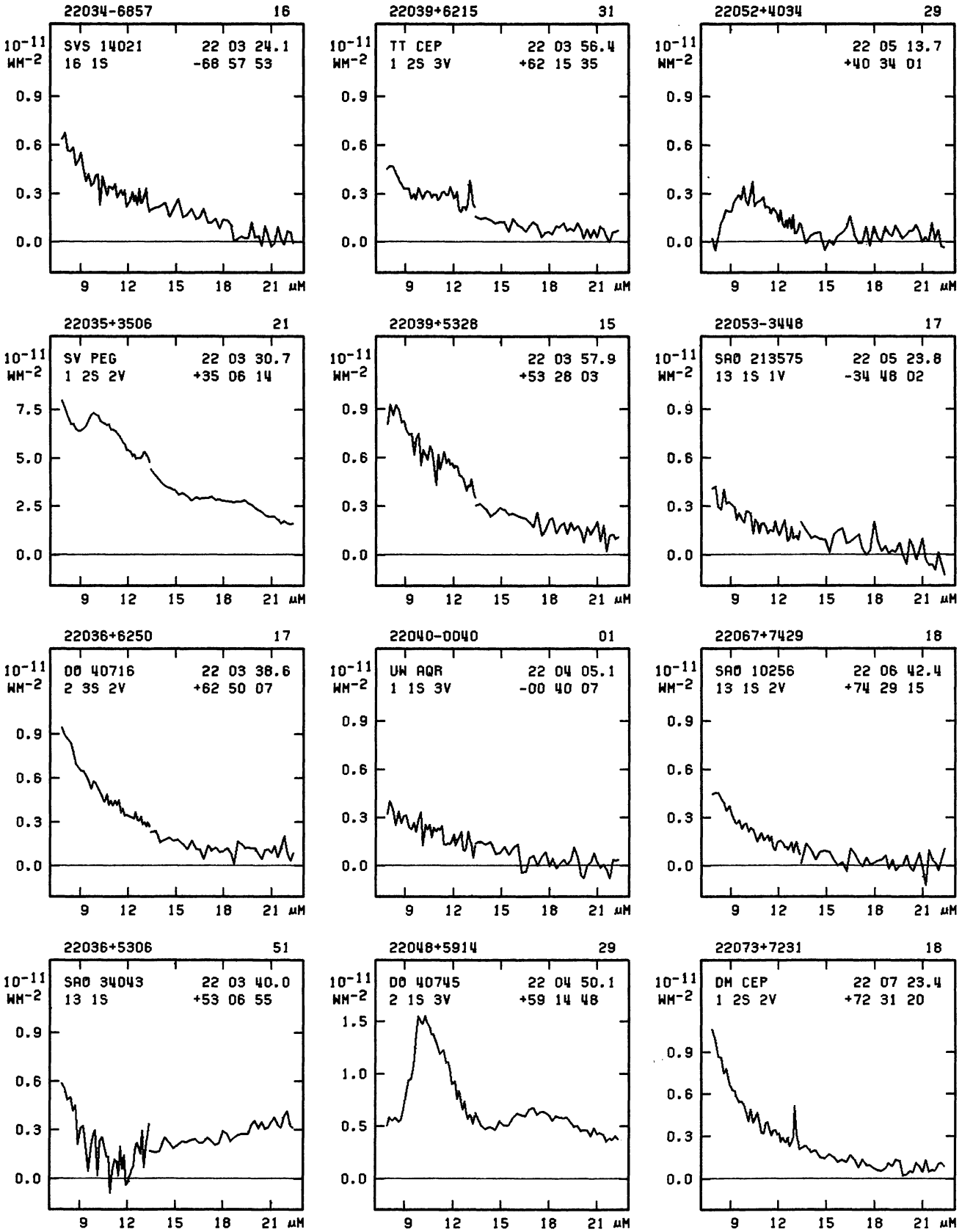

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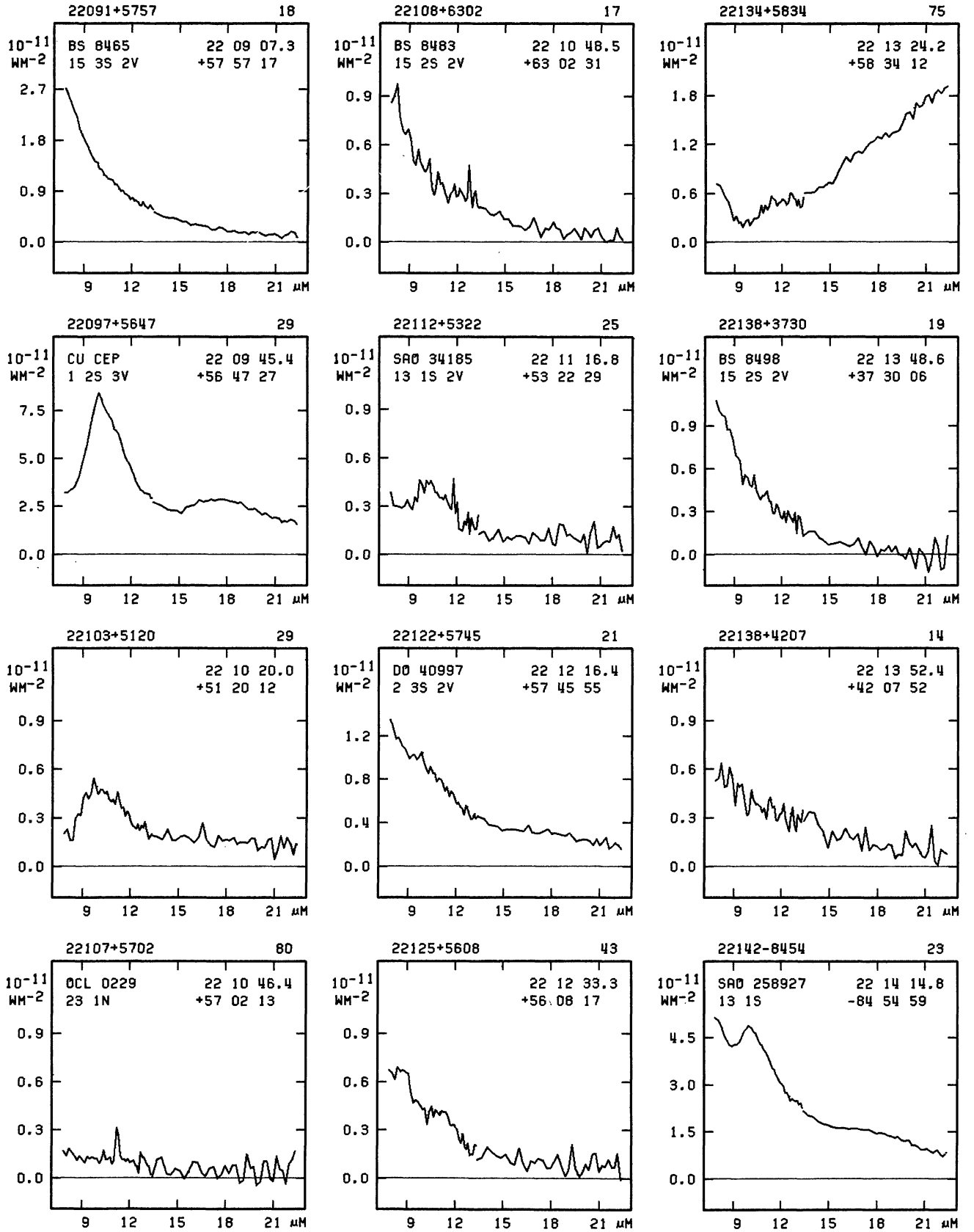

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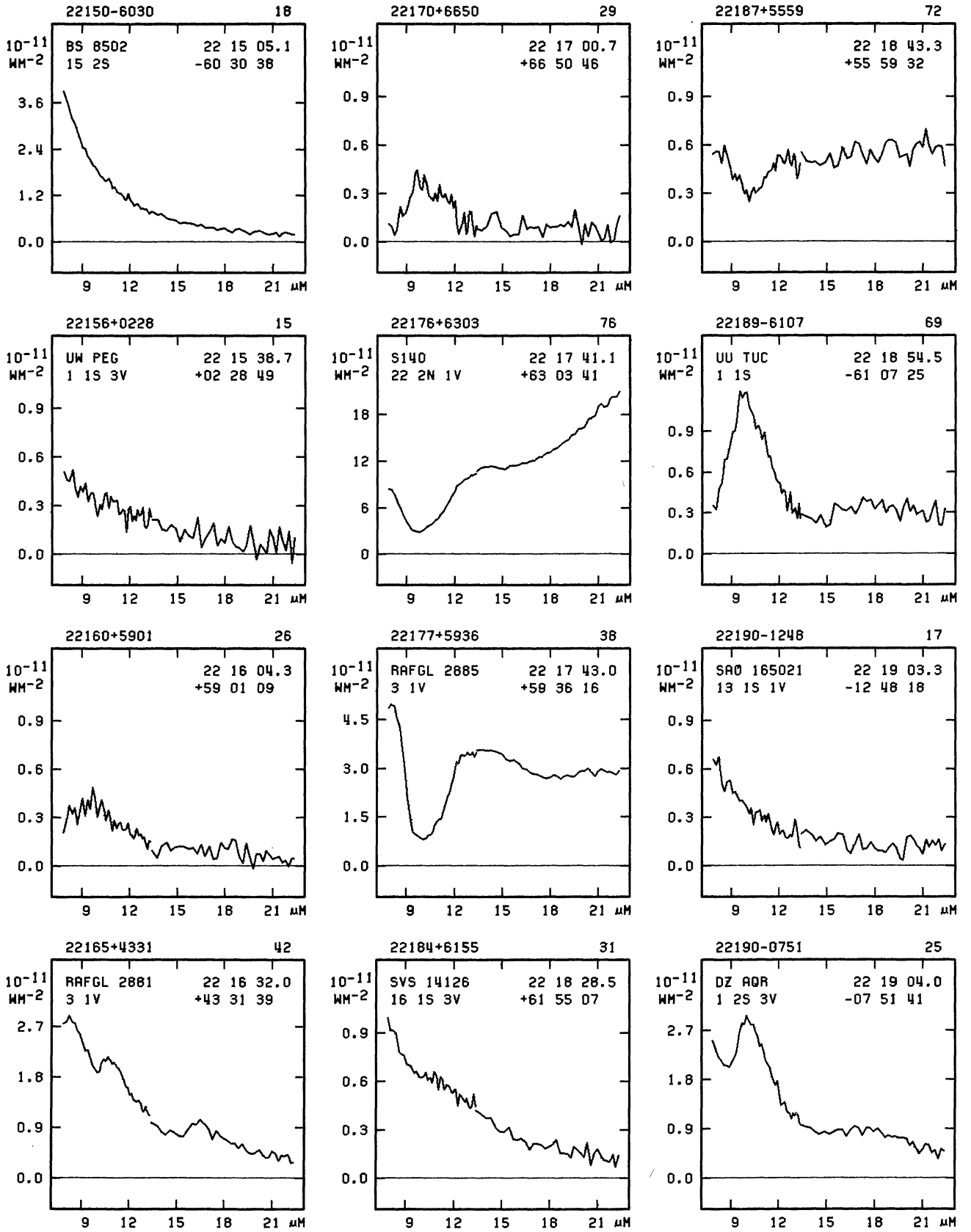

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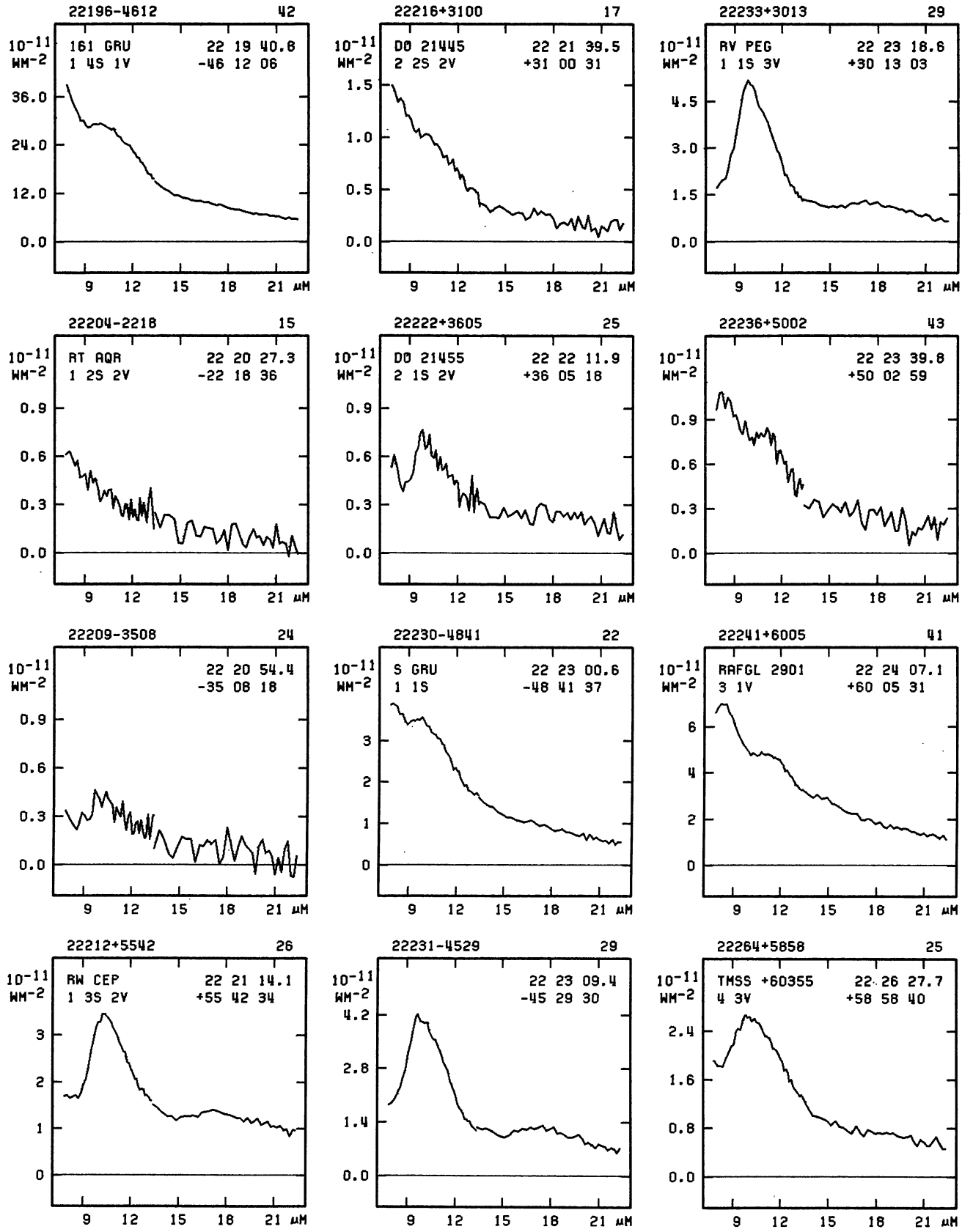

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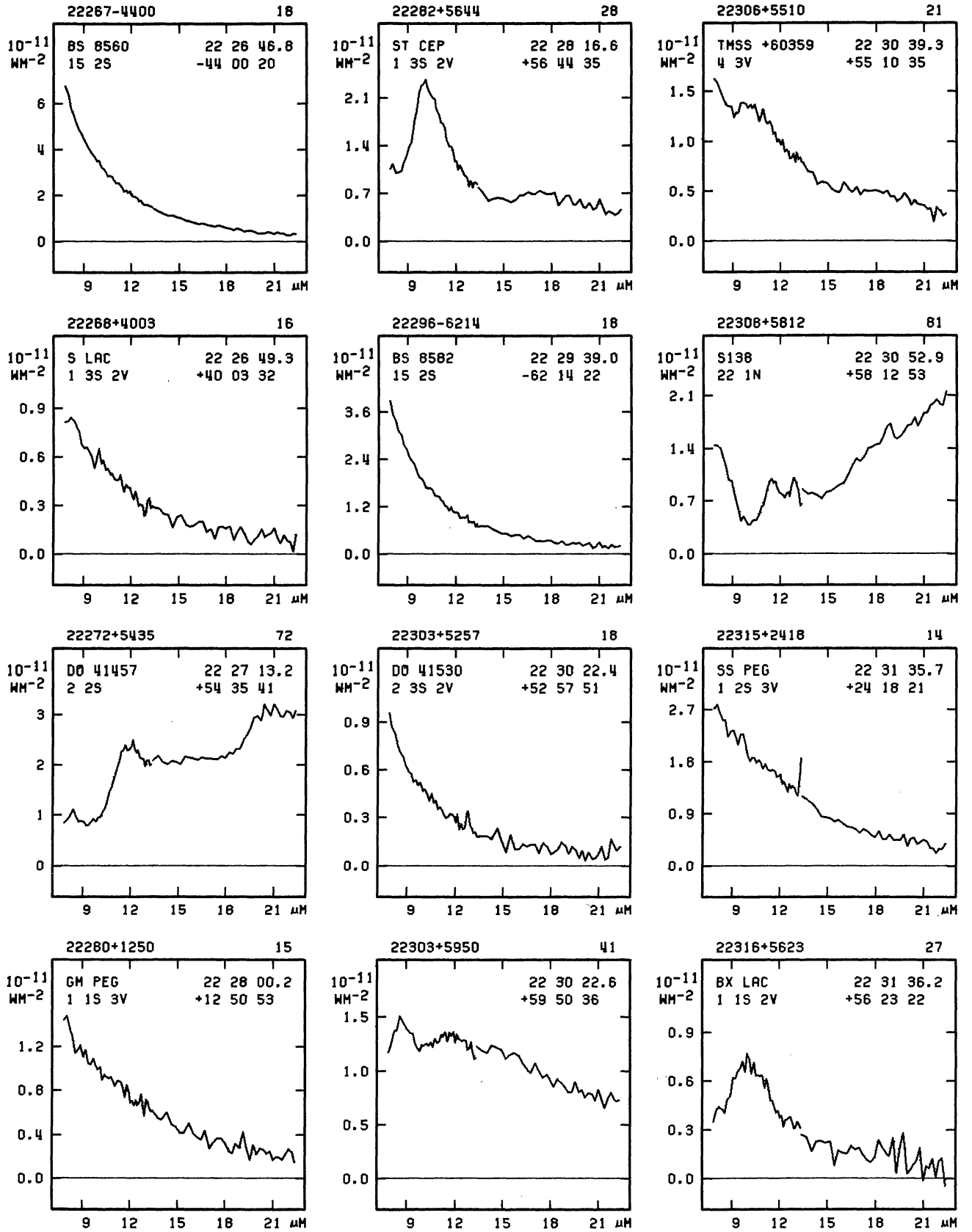

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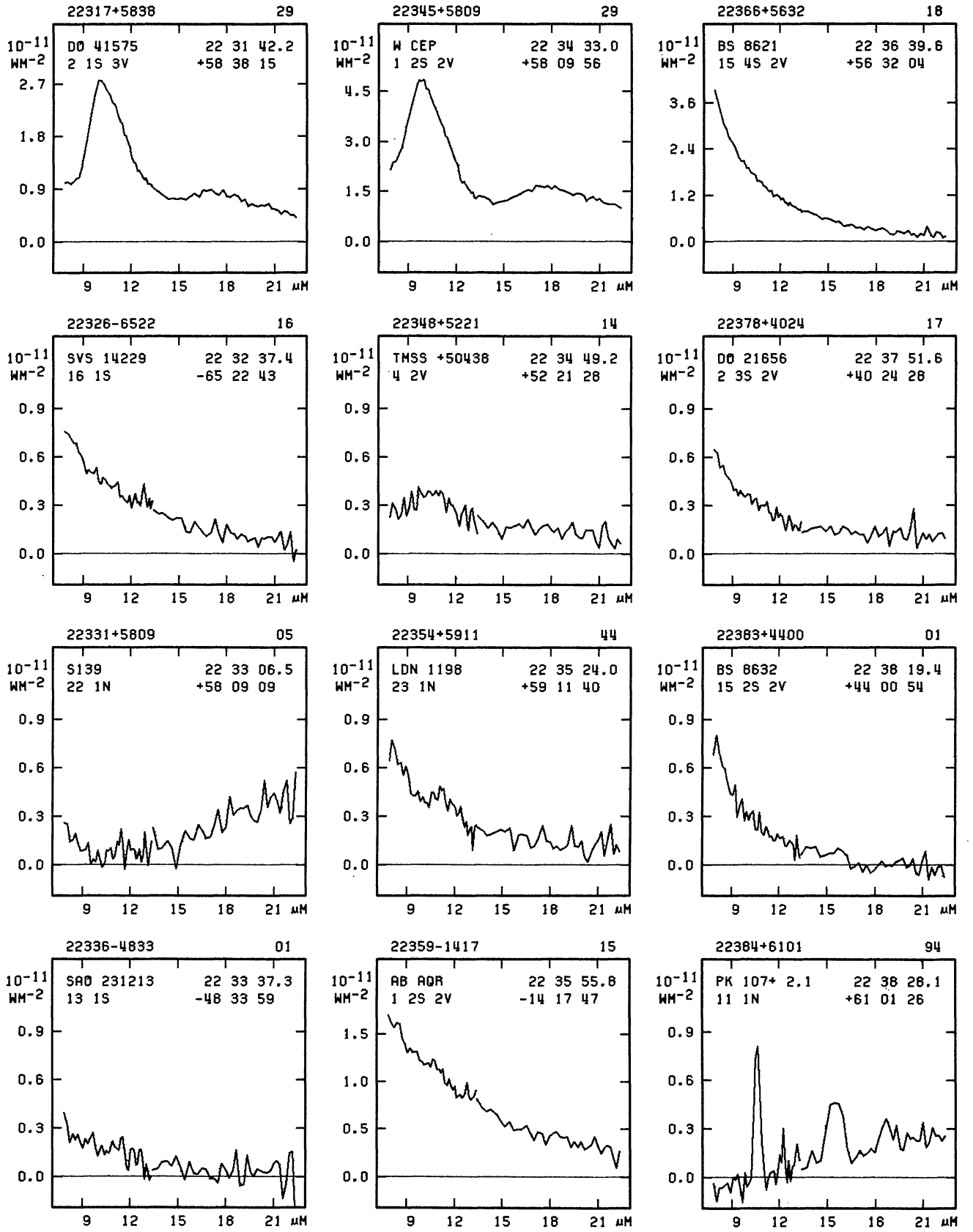

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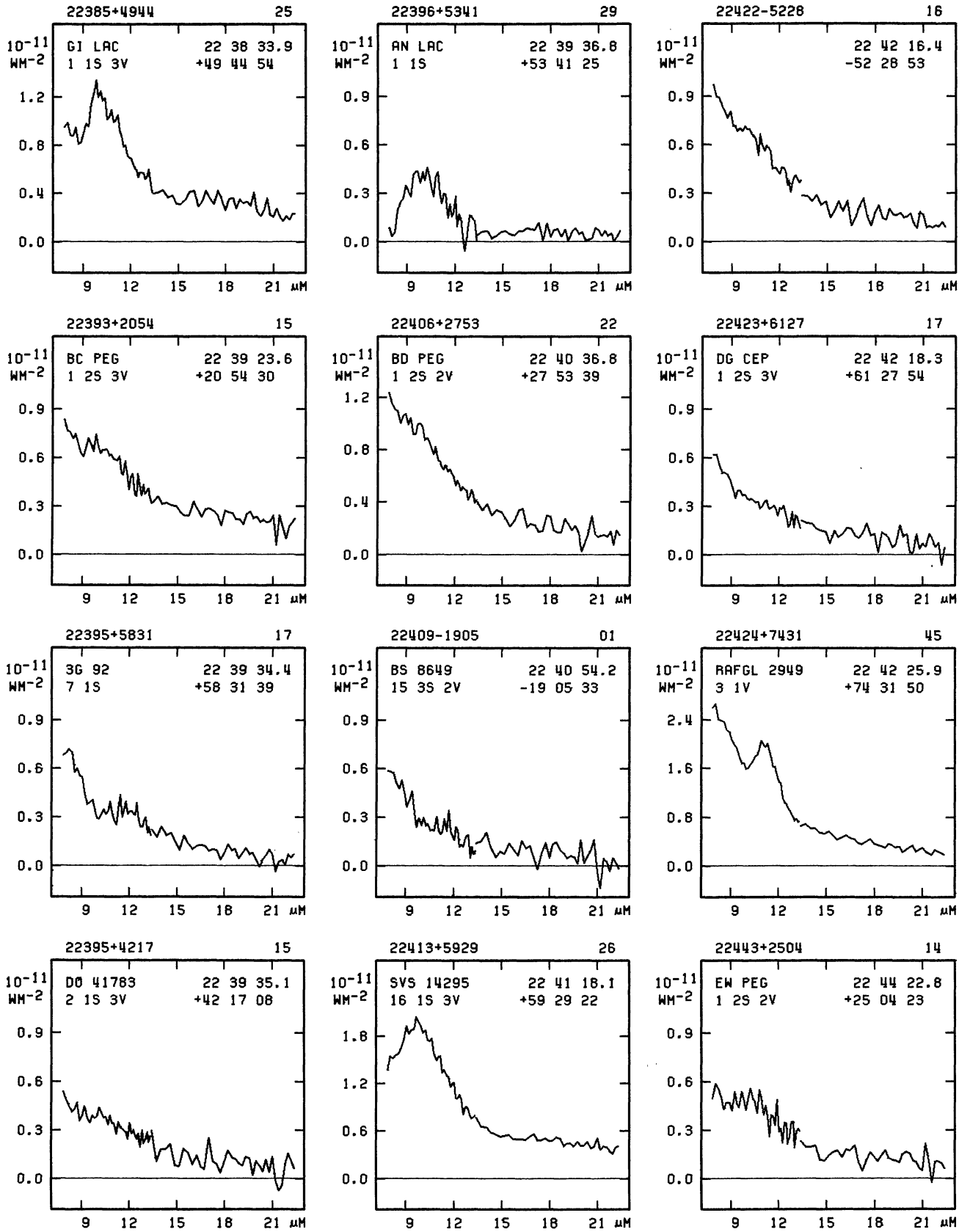

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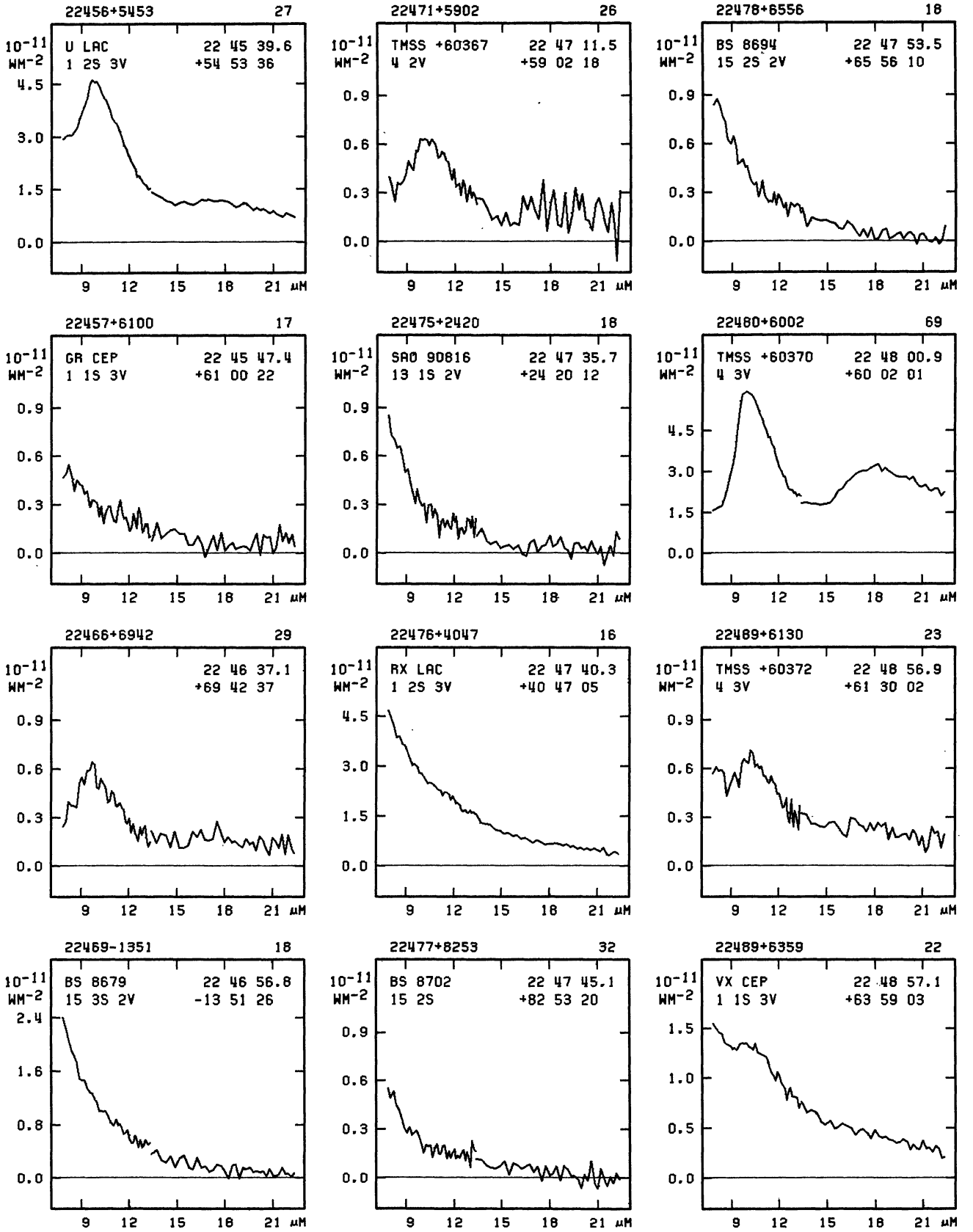

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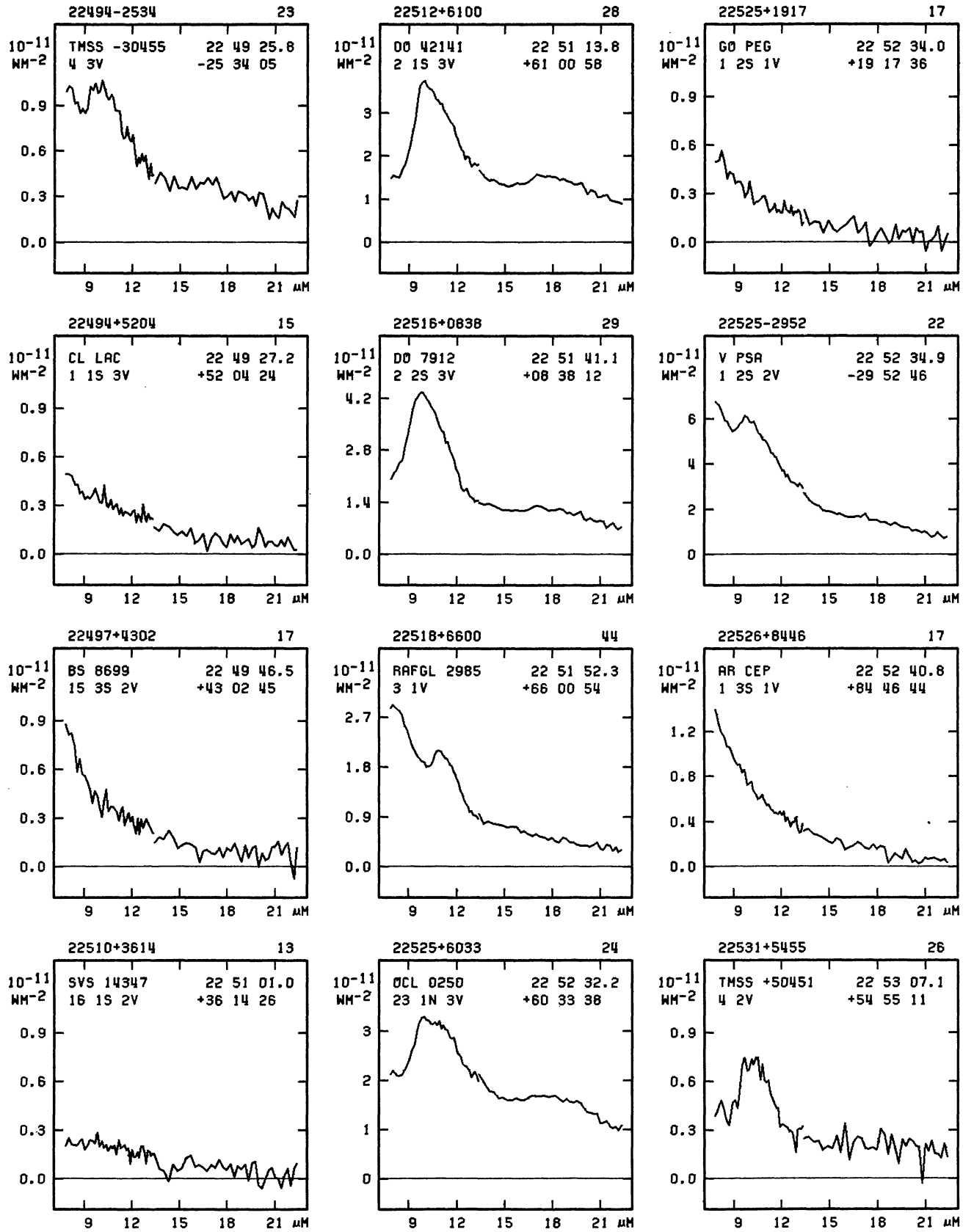

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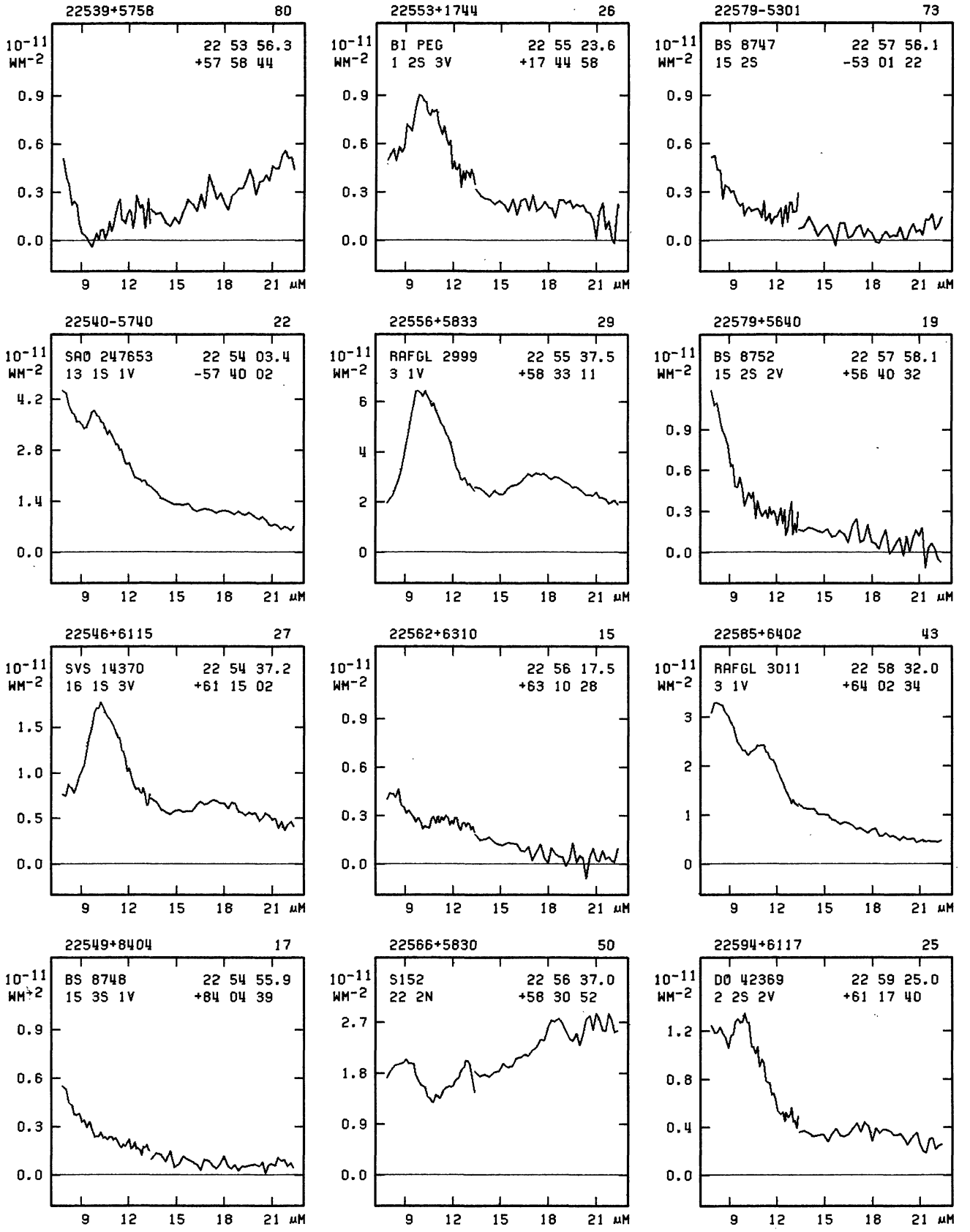

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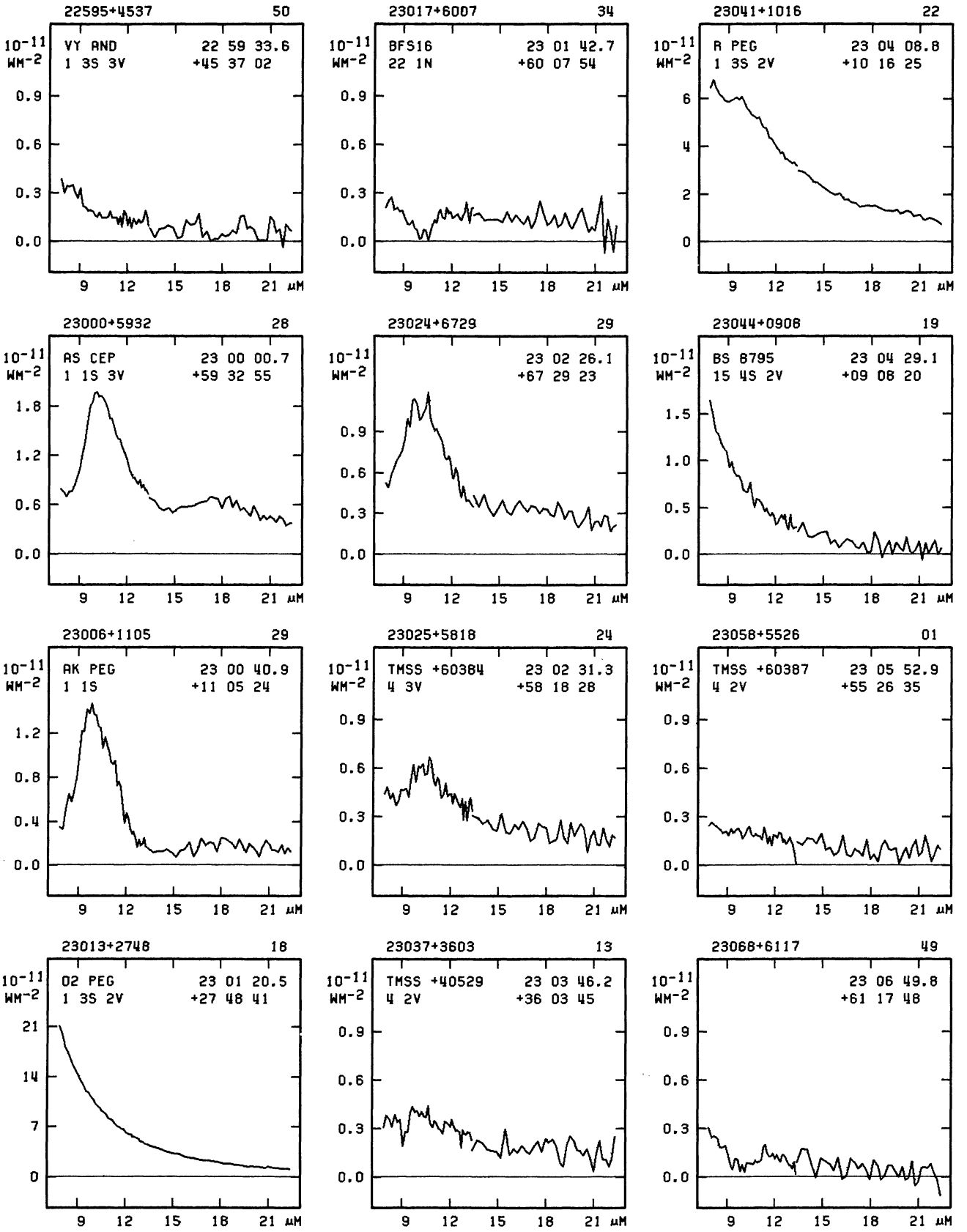

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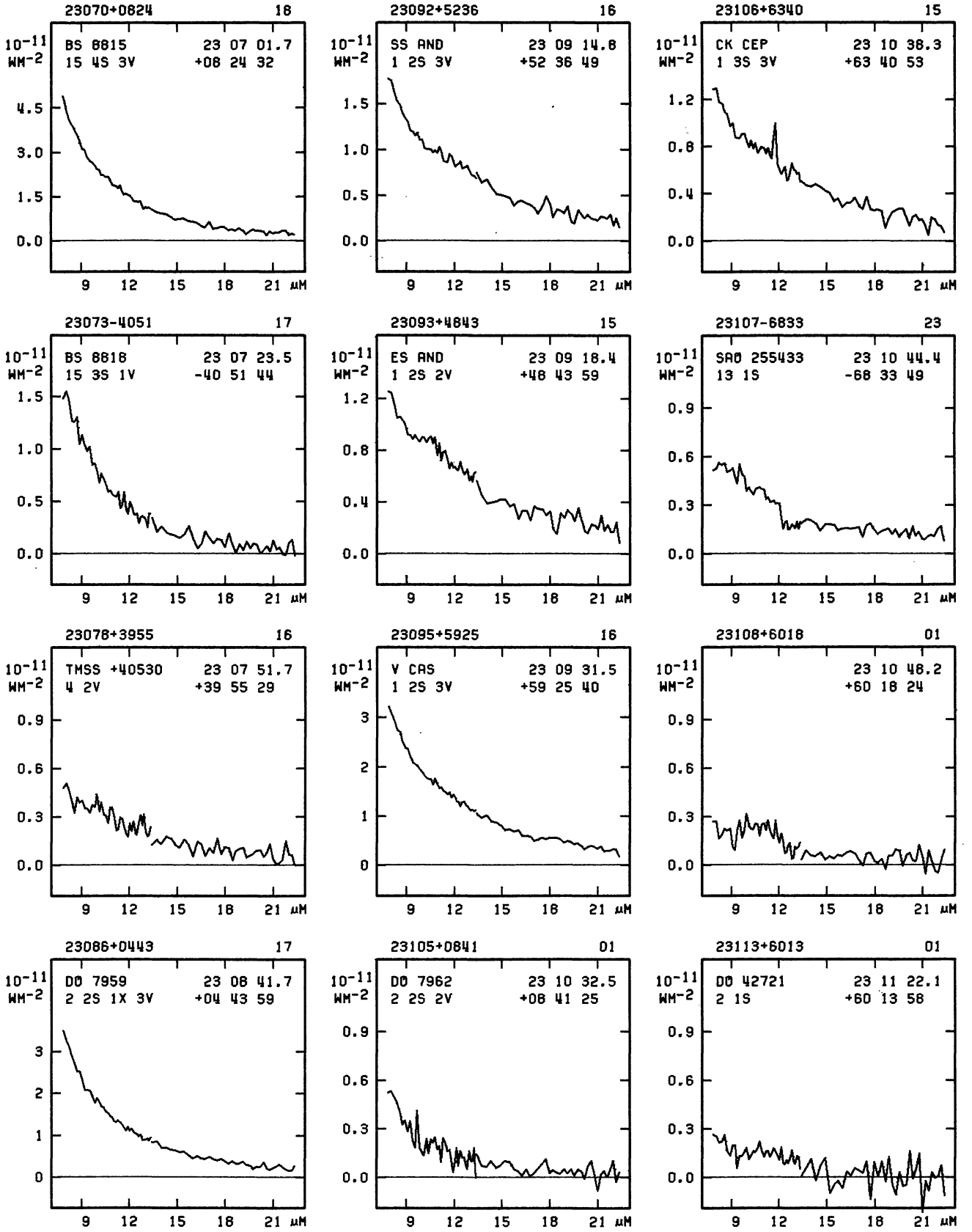

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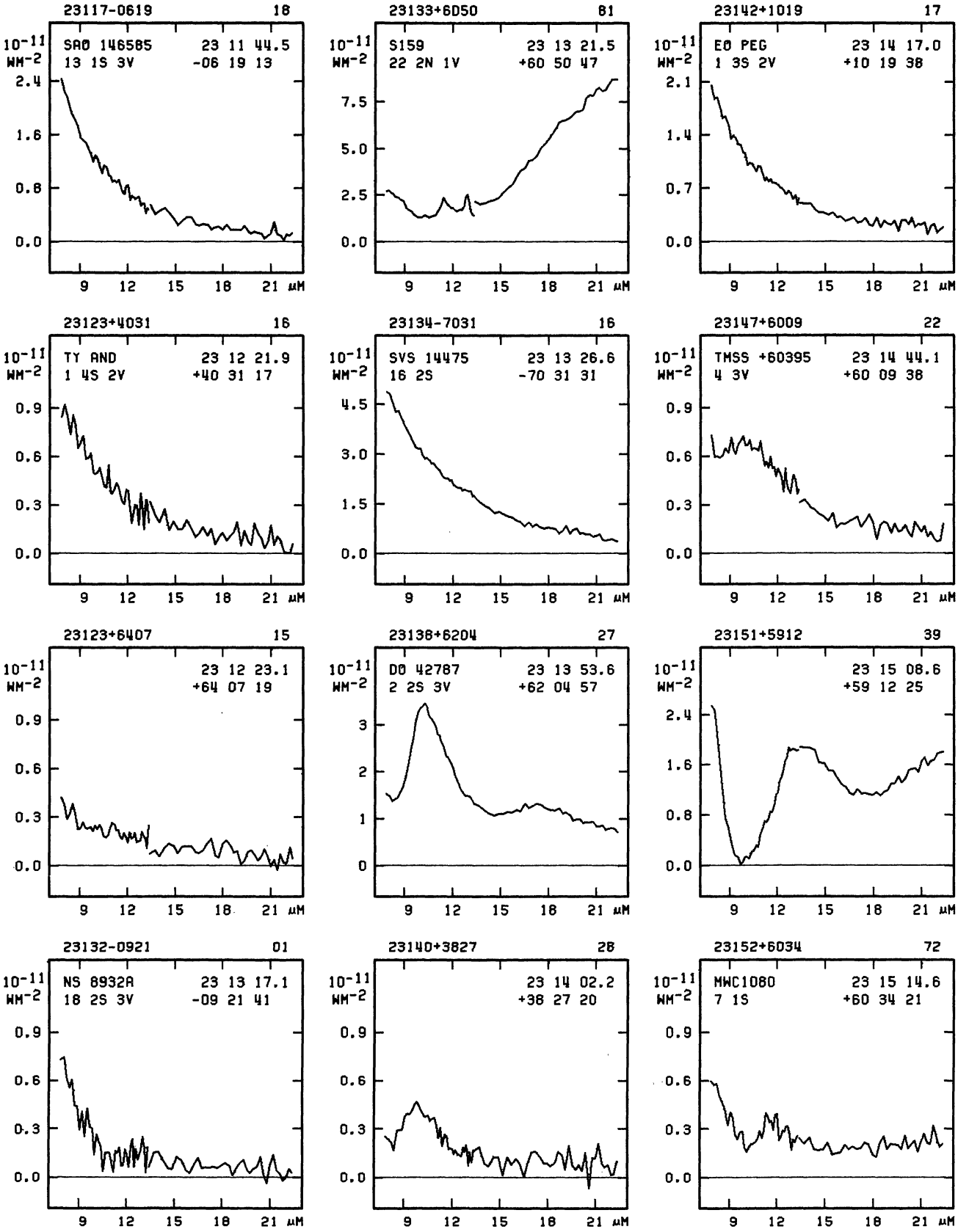

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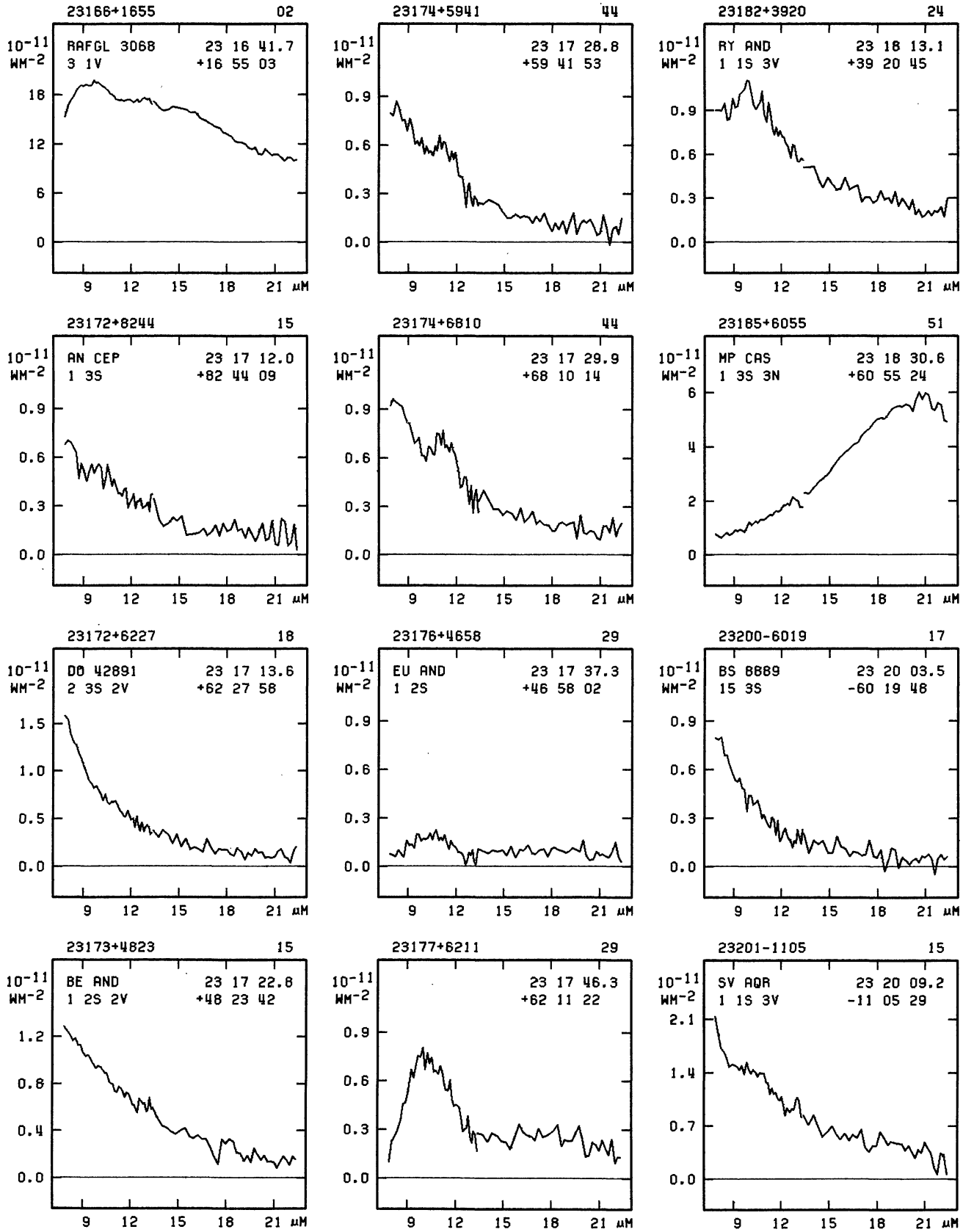

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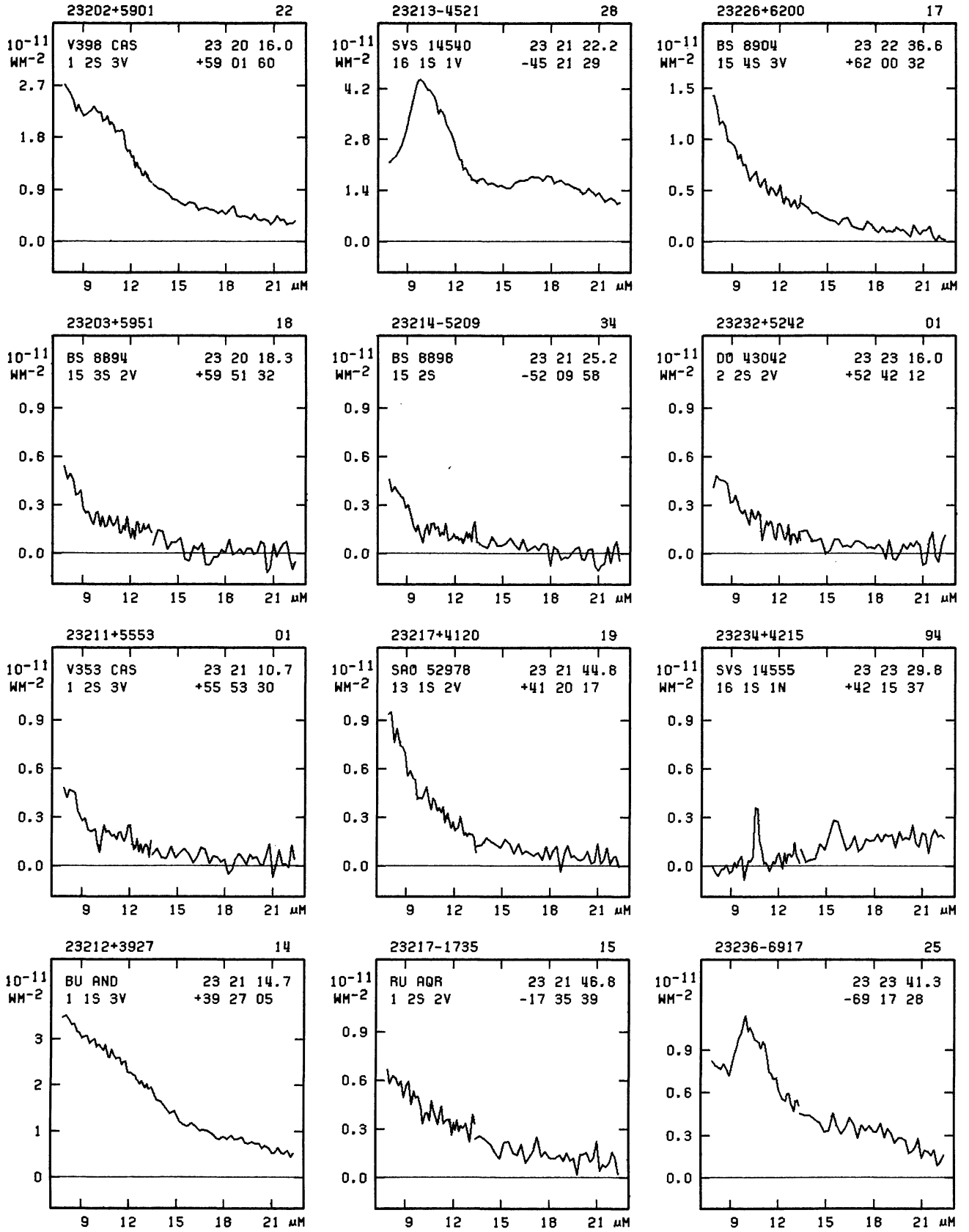

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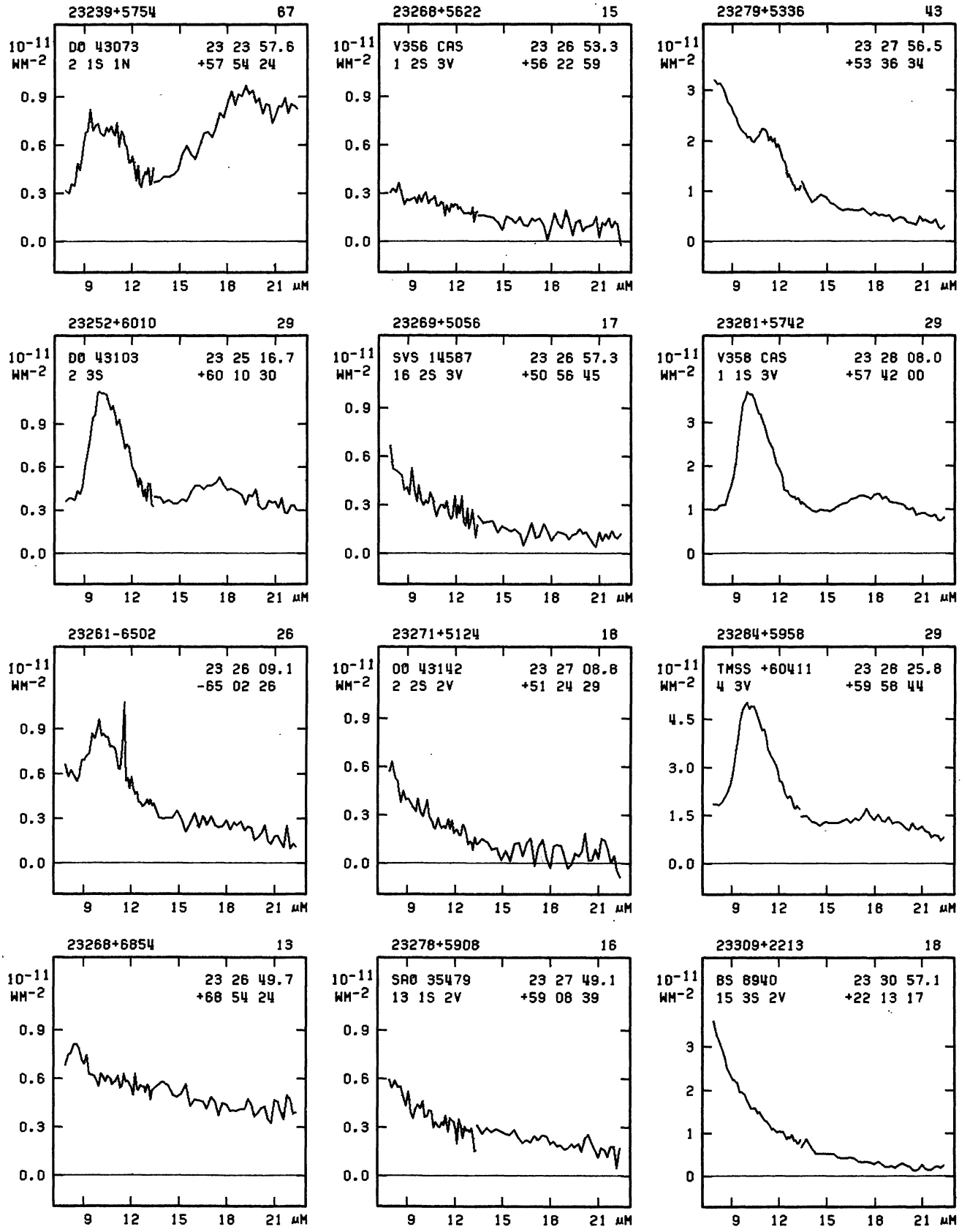

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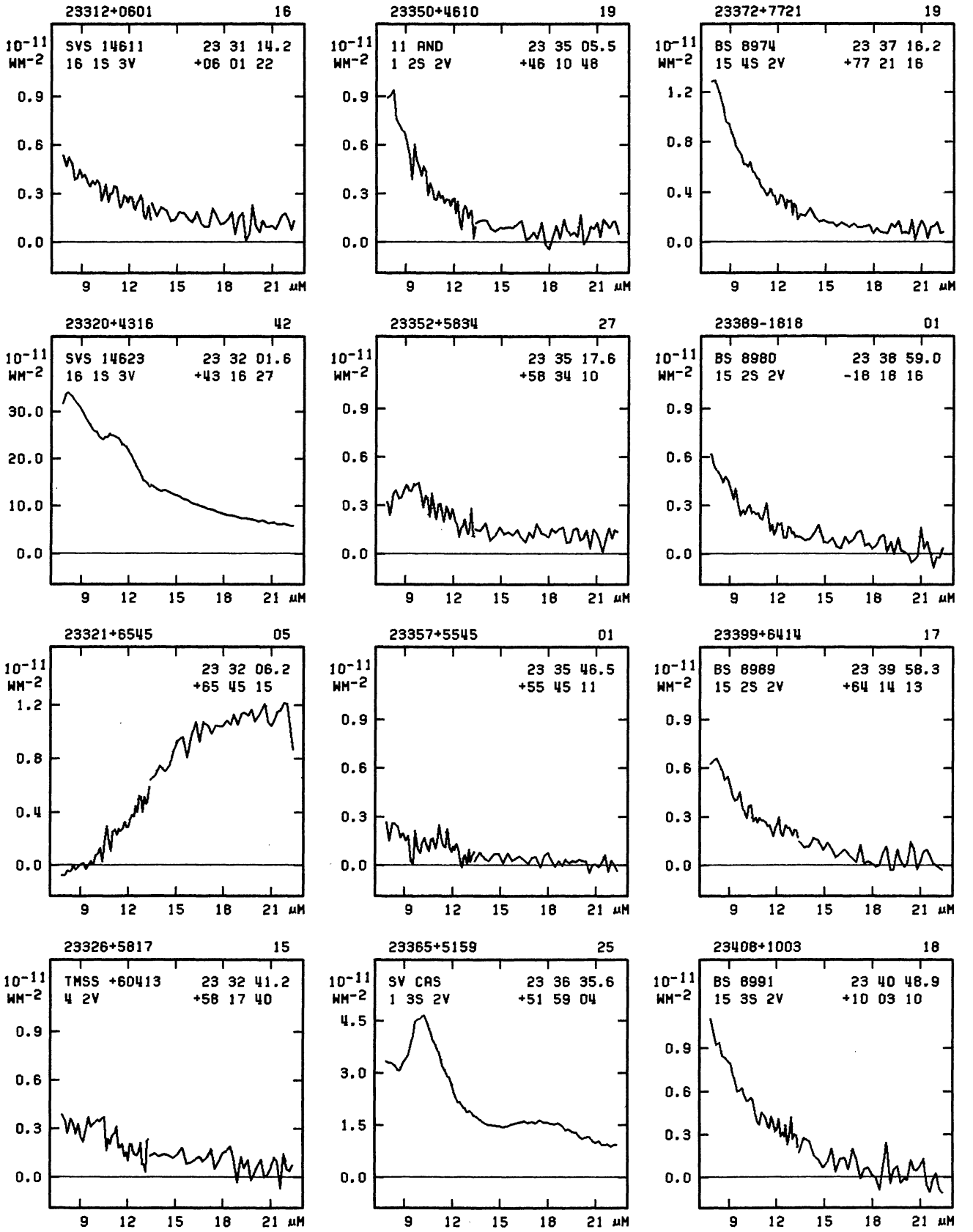

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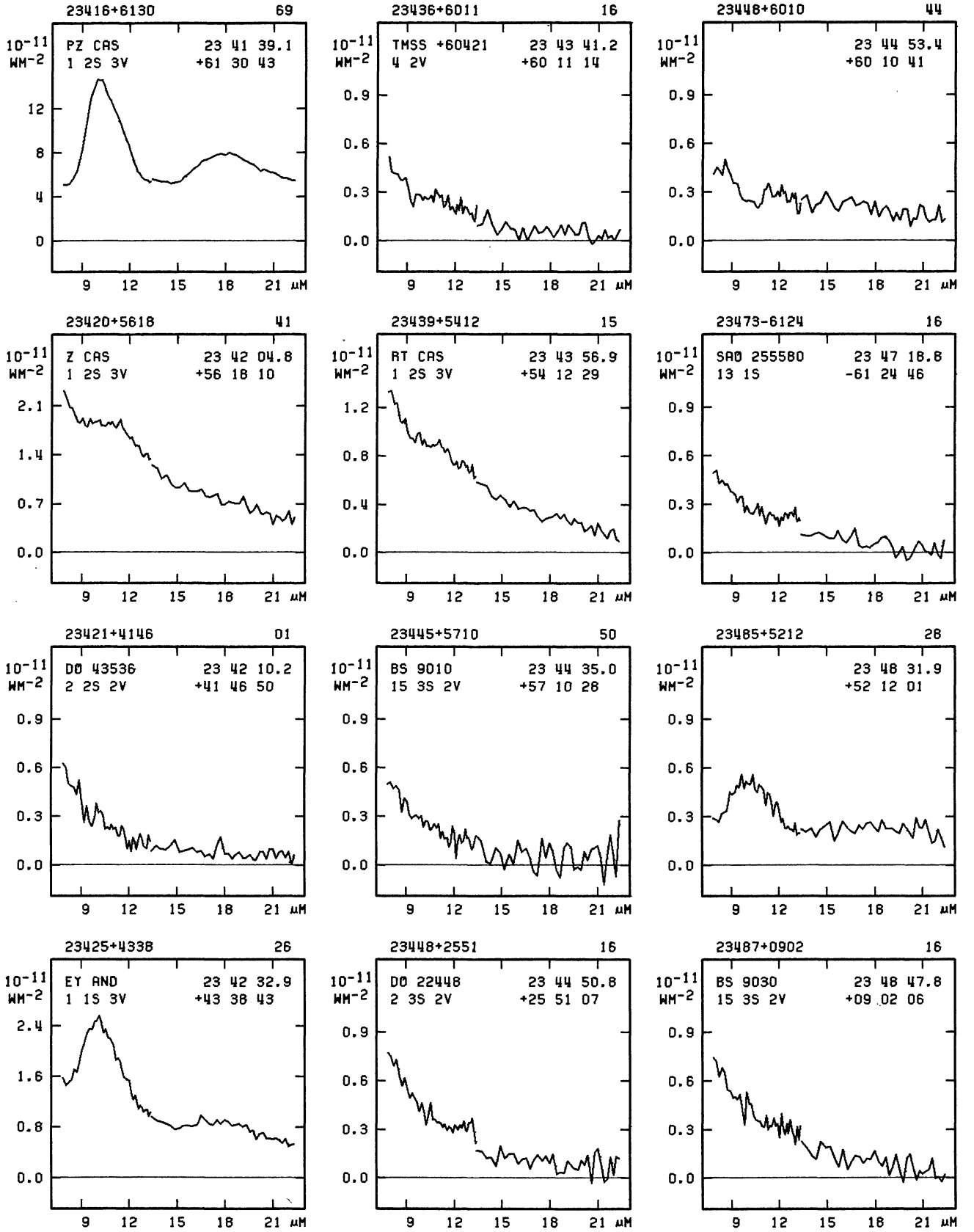

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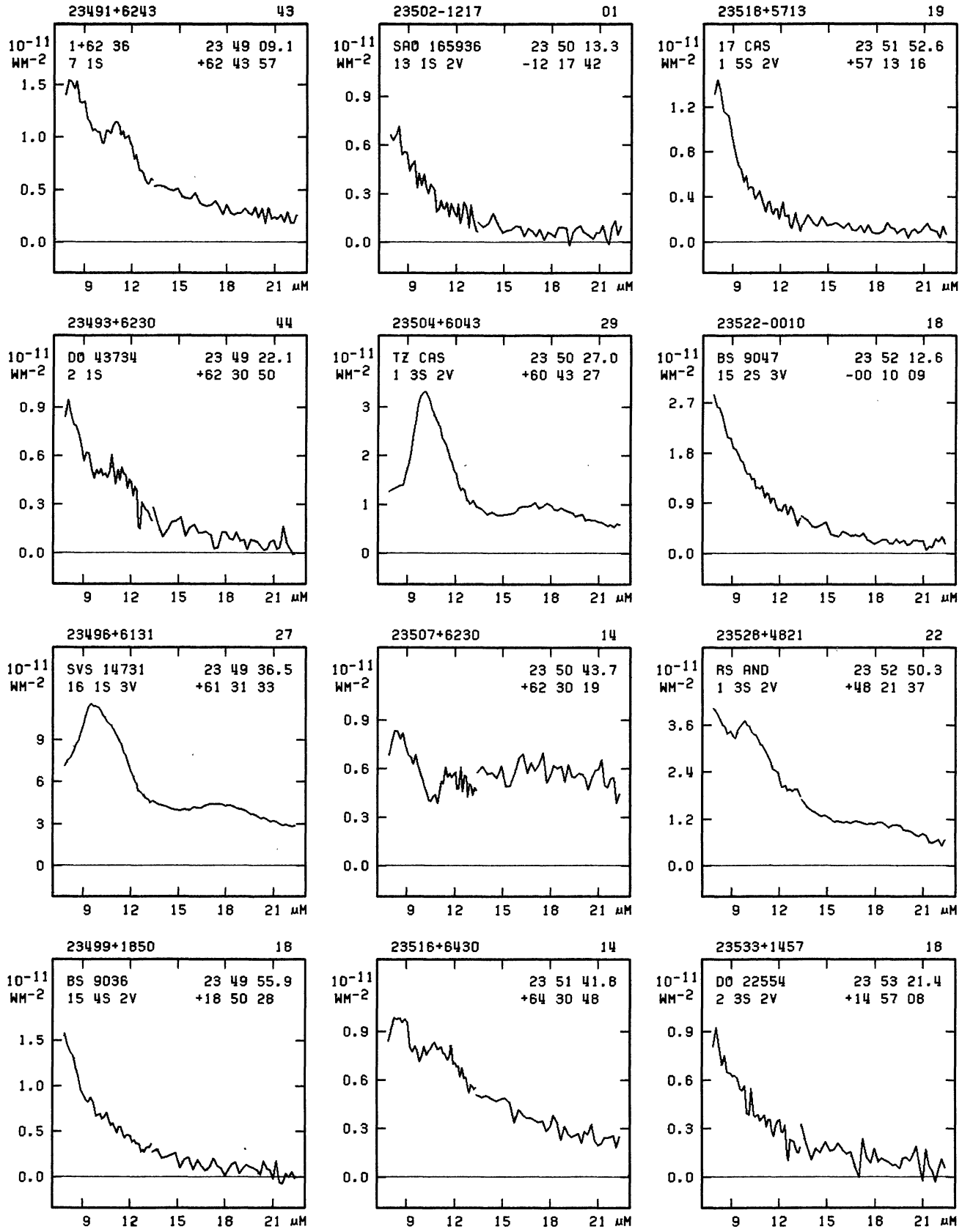

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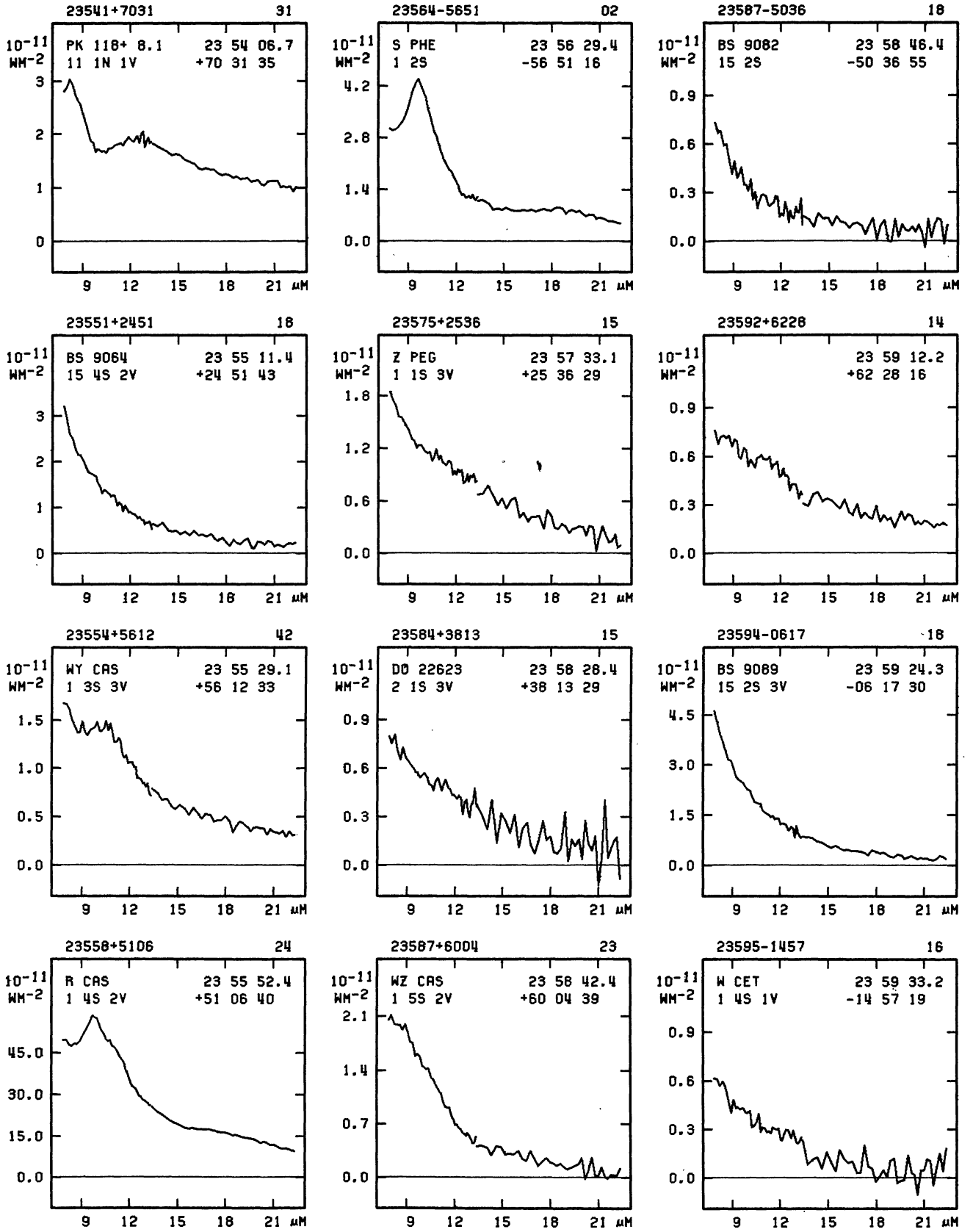

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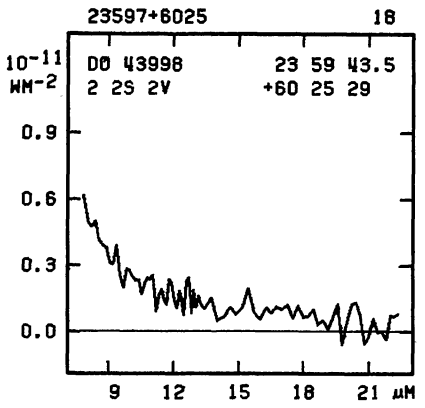

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