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THE NATURE OF HOAG'S OBJECT*

ROBERT W. O'CONNELL† AND JEFFREY D. SCARGLE
Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz
AND
W. L. W. SARGENT
Hale Observatories, California Institute of Technology, and Carnegie Institution of Washington
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ABSTRACT

Hoag's object is found to be a distant compact galaxy, 5 kpc in diameter, surrounded by a luminous blue ring with outer diameter 37 kpc. The absolute magnitudes of the core and ring are $M_V = -20.1$ and $M_V \sim -21$, respectively. Absorption by a dust band surrounding the core is not responsible for the appearance of the ring, which is an independent structural component of the galaxy. Several interpretations are considered, including the possibility that the system is a gravitational lens.

Subject headings: galactic structure — galaxies

Some time ago, Hoag (1950) discovered a remarkable object at $\alpha = 15^h15^m.0$, $\delta = +21°46'$ (1950) which he described as a "perfect halo" surrounding a diffuse nucleus. At first glance, it appeared to be a planetary nebula; however, its galactic coordinates ($l^{II} = 30°$, $b^{II} = +56°$) and color were not typical of that class of object. Therefore, Hoag suggested "as a most conservative alternative" that it was a "pathological" galaxy. Curiously, although plainly visible on the Palomar *Sky Survey*, Hoag's object is not included in the *Morphological Catalogue of Galaxies* (Vorontsov-Velyaminov and Arhipova 1963), the *Catalogue of Galaxies and Clusters of Galaxies* (Zwicky and Herzog 1963), or the *Catalogue of Galactic Planetary Nebulae* (Perek and Kohoutek 1967). It does not lie within the boundary of a recognized cluster of galaxies.

A print of Hoag's object taken with the 36-inch Crossley telescope of Lick Observatory is reproduced in figure 1 (plate 10). The object consists of a slightly diffuse circular core 6″ in diameter surrounded by a symmetric annulus with inner and outer diameters of 28″ and 45″, respectively, and an axial ratio of 0.93 ± 0.05. No luminous material is visible between the core and the inner edge of the ring, and little structure is apparent in the ring.

We have obtained several spectrograms of the object with the Cassegrain image-tube spectrograph on the 200-inch (5-m) telescope of Hale Observatories and the prime-focus spectrograph on the Lick 120-inch (3-m) telescope. The core exhibits the Ca II H and K lines and the G band in absorption at a redshift of 12,740 ± 50 km s^{-1}. The [O II] λ3727 line is not visible. Adopting a Hubble constant of 75 km s^{-1} Mpc^{-1}, we find the distance to Hoag's object to be 170 Mpc. Hence, the core of the object is 5 kpc in diameter, and the annulus has inner and outer diameters of 23 kpc and 37 kpc, respectively. Therefore, Hoag's object is indeed a pathological galaxy.

With the 120-inch prime-focus scanner, we have photometered the core of Hoag's object at 10 points between 3450 and 7450 Å rest wavelength, using intermediate bandwidths (65–130 Å). After a small correction for a foreground galactic reddening of $E(B - V) = 0.03$, we find that the intrinsic energy distribution of the core is identical within the observational uncertainty (0.07 mag) with that of the inner 30″ of M31. The monochromatic magnitude at 5500 Å is 16.2; hence, the mean surface brightness of the core is $\sigma_V = 19.8$ mag per square arc sec, and its corrected absolute magnitude is $M_v = -20.1$. The diameter, surface brightness, colors, and absolute magnitude of the core of Hoag's object are similar to those of the compact galaxies exhibiting late-type absorption spectra discussed by Sargent (1970).

The ring of Hoag's object is unfortunately quite faint. A trace of continuum at the position of the ring is detectable on an untrailed IIa-O spectrogram exposed for 2 hours at the 120-inch prime focus. However, no emission lines are visible. Direct photography with the 120-inch and Crossley telescopes with filter-plate combinations designed to isolate the Hα–[N II] region suggests that emission here is also minimal. Hence, the ring appears to contain little ionized gas.

From the *Sky Survey* plates we estimate that the surface brightness of the ring is roughly 22–23 mag per square arc second. Thus, its integrated magnitude is approximately 15 and its absolute magnitude is about −21; i.e., the ring is significantly more luminous than the core of Hoag's object. The color of the ring, again judged from the *Sky Survey*, is $B - V \sim 0.5 \pm 0.2$; it is, therefore, considerably bluer than the exteriors of normal elliptical and S0 galaxies, for which $B - V \sim 0.95$ (Tifft 1969).

The dark annulus interior to the ring may in part be produced by dust absorption of the type often observed

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† Present address: University of Virginia, Charlottesville.

in S0 galaxies (Sandage 1961). However, the large differential in surface brightness between the ring and the dark annulus ($\gtrsim 2$ mag) as well as the ring's blueness clearly indicate that the ring is an independent structural component of the galaxy and not simply the unobscured rim of a normal S0 disk.

If the ring is composed of stars, a crude upper limit to its age is set by the fact that only improbably special initial conditions could prevent its disintegration due to internal motions for a time longer than $\sim 10^9$ years. Furthermore, if star formation in the ring terminated shortly after the ring's creation and occurred with an initial luminosity function similar to that in the solar neighborhood, then its color implies that the age of the ring is $\sim 10^9$ years (Searle, Sargent, and Bagnuolo 1973).

Although Hoag's object is probably the best example, a number of other systems with external rings apparently unconnected to the inner structure are known. Among them are NGC 6028 (Vorontsov-Velyaminov 1960), NGC 2859 (Sandage 1961), and IC 5285 (Sargent 1970). As in Hoag's object, many of the rings exhibit little internal structure and are blue-to-neutral in color on the *Sky Survey*. NGC 3081 represents a good transitional case between annular and normal spiral structure. In this object, the prominent ring is quite blue and contains knots. There is luminous connecting material between the nucleus and ring, which Sandage (1961) describes as two tightly wound spiral arms.

Given the available data, there is no reason to suppose that radiation from the rings in these systems is predominantly anything other than direct starlight. One possible alternative—that we are seeing light scattered from the core by an annulus of dust—is made implausible in Hoag's object by the fact that the ring is at least as luminous as the core.

The above systems are to be distinguished from the "extragalactic rings" discussed by Theys, Spiegel, and Toomre (1972), which consist of *isolated* ringlike H II regions usually near a companion galaxy and exhibiting conspicuous internal structure. Although some of the galaxies with external annuli could be "extragalactic ring" systems fortuitously viewed such that the companion is projected against the ring, the number of isolated rings is apparently too small to account for all of them.

It is not clear that external ringlike structure should be considered a product of the normal mechanism of spiral arm formation. Hodge (1968), for instance, notes that extensive outer annular envelopes are present in a number of Seyfert and nearby radio galaxies and are perhaps related to nuclear activity. Gravitational encounters between galaxies are another possibility. The "isolated" H II rings are presumably produced by a direct collision between their companions and another object. Less catastrophic interaction can possibly initiate star formation in "trapped" rings as well. In the case of Hoag's object, a pair of 17–18 mag galaxies is nearby. If these are at the same distance as Hoag's object, then their projected separation from the object is 220 kpc, and the three could well have undergone a close encounter 10^8–10^9 years ago.

One of the more exotic possible interpretations of Hoag's object—namely, that the ring is the image of a background galaxy produced by the gravitational focusing of the core—is also worth considering. This was originally proposed by Hoag (1950) and can be explored using Liebes's (1964) analysis of gravitational lenses. We find that the properties of the hypothetical background source inferred from our observations of the ring are consistent with those of the most luminous Sc galaxies. However, the inordinately high mass for the core of Hoag's object, $\mathfrak{M} = 1.4 \times 10^{13}\,\mathfrak{M}_\odot$, required in this interpretation appears to be ruled out by the absorption line widths on our spectrograms, which suggest $\mathfrak{M} < 10^{12}\,\mathfrak{M}_\odot$. Even in the absence of this observation, the model is rendered implausible by the extremely high mass-to-light ratio, $\mathfrak{M}/L_v \sim 1500\,(\mathfrak{M}/L_v)_\odot$, implied for the core coupled with the improbability of the necessary 8″ alignment of centers of two relatively rare objects and the existence of a number of other systems with similar features.

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ROBERT W. O'CONNELL
Box 3818, University Station, Charlottesville, Virginia 22903

JEFFREY D. SCARGLE
Lick Observatory, University of California, Santa Cruz, California 95064

W. L. W. SARGENT
Robinson Laboratory, California Institute of Technology, Pasadena, California 91109

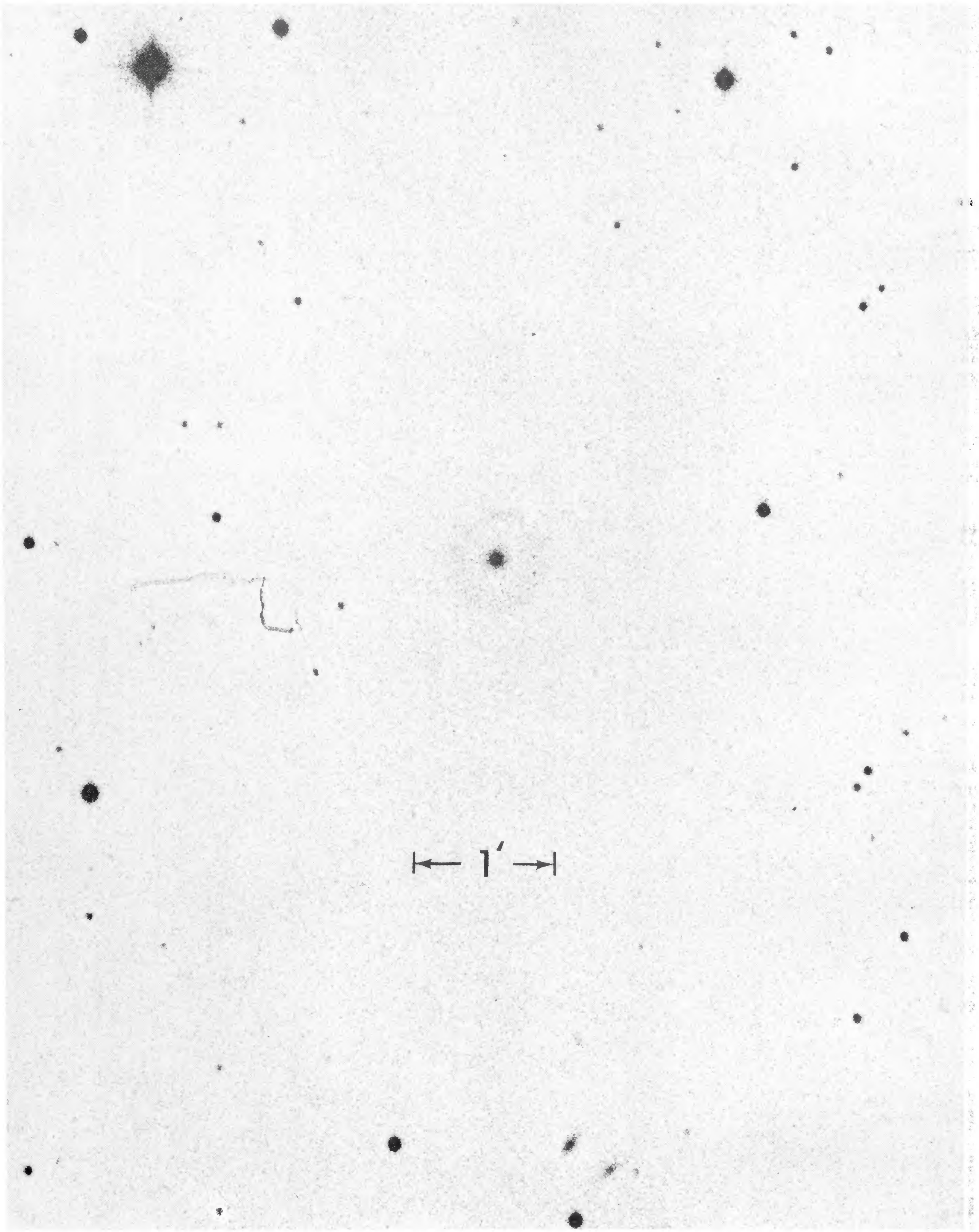

FIG. 1.—A composite print of two Crossley 36-inch plates of Hoag's object (103a-F + GG14, 75-minute exposure; and pre-flashed 098-02 + GG14, 100-minute exposure). North is at the left, and East is down. The ring is best viewed if the print is held at a distance of several feet. The irregular streak to the left of Hoag's object is a plate flaw. Near the bottom of the print are the two possible companions to the object mentioned in the text. One minute of arc corresponds to 49.5 kpc.

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