UNC-Chapel Hill's Gamma-Ray Burst Follow-up Programs

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Abstract

UNC-Chapel Hill is currently building and organizing both small (half-meter-class) robotic telescopes and large human-controlled telescopes to observe GRBs localized by NASA's Swift spacecraft. We summarize our Swift era plans for the new, robotic 6×0.41-meter (1.0-meter effective diameter) PROMPT telescopes at CTIO in Chile, the new 4.1-meter SOAR telescope also at CTIO, the 8.1-meter Gemini telescopes at CTIO and Mauna Kea in Hawaii, the 9.2-meter (effective diameter) SALT telescope at SAAO in South Africa, HST, and our newest effort, the Skynet Robotic Telescope Network, which already spans both South and North America and is growing rapidly.

1. Introduction

Observations of GRBs and GRB environments over the past nine years strongly indicate that the long-duration/soft-spectrum GRBs are the death cries of massive stars and the birth cries of black holes. Redshifts have been measured for about seventy of these GRBs and their implied isotropic-equivalent luminosities show them to be the biggest bangs since the Big Bang itself, beating supernovae by six to nine orders of magnitude. Given the sometimes extreme brightness of their optical/NIR afterglows in the first few seconds to minutes after the burst – in one case the afterglow was bright enough to see with binoculars despite a redshift that placed it three-quarters of the way across the observable universe – and a high expected rate of occurrence at and beyond the highest redshifts that have been measured for any astrophysical object, GRBs are widely expected to be the next great probe of the early universe, allowing astronomers to reach back in time roughly three times closer to the Big Bang than has been achieved to date.

NASA's Swift spacecraft is now making this possible (e.g., Haislip et al. 2006; see below). Swift's impact on the field has been revolutionary: Compared to previous GRB spacecraft, it is localizing GRBs an order of magnitude more often, and doing so an order of magnitude more accurately and an order of magnitude more quickly. In addition to observing GRBs at gamma-ray wavelengths, Swift observes their afterglows at X-ray, UV, and blue optical wavelengths beginning only ≈20 – 70 seconds after each burst.

Arguably, Swift's highest profile mission objective is to use GRBs as probes to study the early universe in new and powerful ways, as originally fleshed out by Lamb & Reichart (2000) in support of Swift's Phase A study[1]. However, there is a problem: although the number of Swift GRBs with redshifts greater than, say, $z = 5$, is expected to be large – ~20 per year – careful consideration of ground-based observing constraints (field up, sun down, weather acceptable) reduces this number to ~1 per year per site for which an early-time NIR spectrum can be obtained. This assumes near-100% access to both telescope and instrument. Consequently large numbers of efficient observing facilities are required, preferably with ready access to NIR spectroscopy or at least multi-band imaging. Between high-z events, such facilities can be turned on equally important problems in GRB physics, environments, and diversity[2].

To these ends, UNC-Chapel Hill is currently building and organizing both small (half-meter-class) robotic telescopes and large human-controlled telescopes that will – in many cases uniquely – meet these new challenges and opportunities. In this paper, we summarize our Swift era plans for the new, robotic 6×0.41-meter (1.0-meter effective diameter) PROMPT telescopes at CTIO in Chile, the new 4.1-meter SOAR telescope also at CTIO, the 8.1-meter Gemini telescopes at CTIO and Mauna Kea in Hawaii, the 9.2-meter (effective diameter) SALT telescope at SAAO in South Africa, HST, and our newest effort, the Skynet Robotic Telescope Network, which

[1] See http://www.physics.unc.edu/~reichart/early.html for a brief summary.

[2] See http://www.physics.unc.edu/~reichart/late.html for a brief summary.

already spans both South and North America and is growing rapidly.

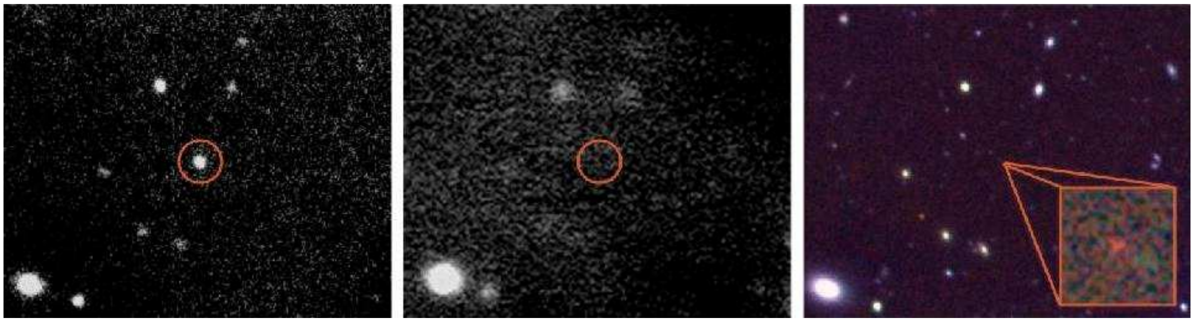

Figure 1. Left panel: NIR discovery image of the bright (J = 17.36 $\pm$ 0.04 mag) afterglow of GRB 050904 from 4.1-m SOAR atop Cerro Pachon in Chile. Middle panel: Near-simultaneous non-detection of the afterglow at optical wavelengths, implying $z > 6$, from one of the six PROMPT telescopes atop Cerro Tololo, only 10 km away. Right panel: Color composite image of the very red afterglow 3.2 days after the burst from 8.1-m Gemini South, also atop Cerro Pachon. From Haislip et al. 2006, Nature, 440, 181.

Indeed, our multi-telescope, multi-wavelength approach has already met with early success: On September 4th, 2005, UNC-Chapel Hill undergraduate Josh Haislip and I discovered and identified the most distant explosion in the universe yet known, a GRB at $z = 6.3$, using both SOAR and PROMPT (Haislip et al. 2006). For the WMAP cosmology, this corresponds to 12.8 billion years ago, when the universe was only 6% of its current age.

Between the SOAR, Gemini, and SALT telescopes, the robotic PROMPT and Skynet telescopes, and the Follow-Up Network for Gamma-Ray Bursts (FUN GRB), a collaboration of about thirty telescopes that I organized in anticipation of the Swift era, we expect to acquire well sampled light curves and spectra at both early and intermediate times, and spanning both optical and NIR wavelengths, for most rapidly, well localized GRBs, and polarization histories for the brightest GRBs. Public Swift UVOT, XRT, and BAT data will complement these observations at shorter wavelengths and public VLA data (see Kulkarni, Berger & Frail 2002) will complement these observations at longer wavelengths. In addition to early-universe science (e.g., Lamb & Reichart 2000), we expect to make significant headway in the areas of GRB physics, environments, and diversity. Specifically, these results will feed the FUN GRB Collaboration's UNC-Chapel Hill-based modeling effort, which focuses on GRB physics, environments, and the role of dust/extinction in these environments (e.g., Reichart 2001a,b; Reichart & Price 2002; Moran & Reichart 2005; Nysewander et al. 2005; Haislip et al. 2006; see also Lee et al. 2001; Galama et al. 2003).

2. UNC-Chapel Hill's Follow-up Programs

Just as BeppoSAX and IPN created a discovery space for ground-based telescopes that could respond on their notification timescales – typically hours to days – the new generation of GRB spacecraft are creating a discovery space for ground-based telescopes that can respond on their notification timescales: seconds to minutes. This relegates much of the new science that will be done in the GRB field to smaller, robotic telescopes and to the most flexible and most efficient of the larger, human-controlled telescopes. UNC-Chapel Hill is currently building and organizing both small (half-meter-class) robotic telescopes and large human-controlled telescopes that will – in many cases uniquely – meet these new challenges and opportunities:

2. 1. PROMPT

UNC-Chapel Hill is currently building PROMPT, which stands for Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes, on Cerro Tololo, on the ridge between the GONG and 1.3-m telescopes. PROMPT's primary objective is rapid and simultaneous multi-wavelength observations of GRB afterglows, some when they are only tens of seconds old. In addition to measuring redshifts by dropout, and early-time SFDs and extinction curves of sufficiently bright afterglows in unprecedented detail, PROMPT is already facilitating quick response observations at 4.1-m SOAR and 8.1-m Gemini South. When not chasing GRBs, PROMPT carries out non-GRB programs, including exoplanet transit searches (e.g., Fischer et al. 2006) and a survey of RR Lyraes in support of NASA's SIM mission, and serves as a platform for undergraduate and high school education throughout the state of North Carolina (see §4).

Figure 2 Three of the six PROMPT telescopes at CTIO in Chile.[3]

When completed in late 2006, PROMPT will consist of six 0.41-m Ritchey-Chrétien telescopes by RC Optical Systems on rapidly slewing (9°/sec) Paramount ME mounts by Software Bisque, each under a clamshell dome by Astro Haven. Five of these telescopes have been outfitted with rapid-readout (<1 sec) Alta U47+ cameras by Apogee, which make use of professional-quality E2V CCDs. The sixth is being outfitted with an LN2-cooled Micro-Cam by Rockwell Scientific for NIR imaging. Each mirror and camera coating combination has been optimized for a different wavelength range, including a u′-band optimized telescope. Although other filters are available, PROMPT will automatically observe GRB localizations in u′g′r′Ri′z′YJH, six of them simultaneously. The R-band telescope will additionally measure polarizations. The polarimeter is being designed and built at UNC-Chapel Hill's Goodman Laboratory for Astronomical Instrumentation.

PROMPT is being built in two phases: Phase I, which was funded by $130,000 from UNC-Chapel Hill and a $100,000 gift from alumnus Leonard Goodman, began in September 2004 and is now complete. Phase I consisted of enclosure construction and the assembly of temporary 0.36-m Schmidt-Cassegrain telescopes by Celestron, with the goal of establishing reliable and robust operations, and to test software. Phase II, which is funded by $912,000 from NSF's MRI and PREST programs, is now underway and consists of upgrading to final optics, the NIR camera, and the polarimeter.

The five optical telescopes are now complete, except for the polarimeter, which will be deployed in mid-2006. The NIR camera, sporting an improved version of HST's NICMOS3 FPA, has just arrived at UNC-Chapel Hill, but will require considerable integration with PROMPT's control software, called Skynet (see §3), before it can be deployed in late 2006.

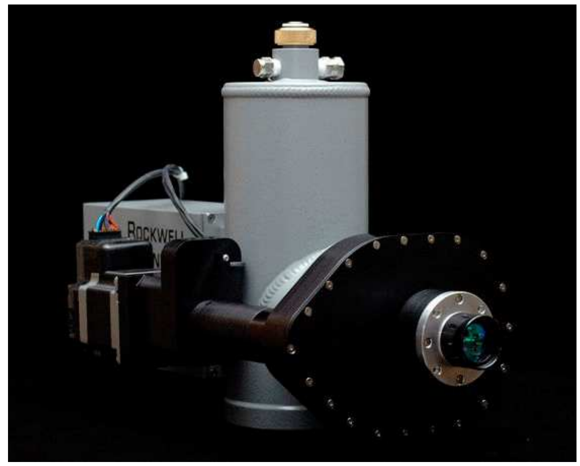

Figure 3. PROMPT's NIR Camera

Between HETE-2, Integral, and now Swift, PROMPT is observing GRB localizations on the rapid timescale about once every three months (we observed GRB 050908 within 25 seconds, GRB 051109 within 75 seconds, and 060306 within 25 seconds of spacecraft notification; Kirschbrown et al. 2005; Haislip et al. 2005; Nysewander et al. 2006), and on longer timescales about once every week. Given our best guesstimates about the star-formation rate at high redshifts, we might observe $z > 5$ GRBs on the rapid timescale as often as once per year, and $z > 7$ GRBs on the rapid timescale perhaps once every two to three years. PROMPT's ability to observe afterglows simultaneously in many filters, including NIR filters, and to do so quickly before the afterglow fades away will allow it to "promptly" pick out record breakers (e.g., Haislip et al. 2006).

2. 2. SOAR & Gemini

Record breaker or not, we are using PROMPT photometry and astrometry to inform our quick response programs on 4.1-m SOAR and 8.1-m Gemini South, which are only one mountaintop away and consequently subject to the same observing constraints. UNC-Chapel Hill is a 17% partner in SOAR, which was dedicated in April 2004 and is now well into commissioning and beginning early science. Furthermore, UNC-Chapel Hill has a three-year commitment from the SOAR Board to interrupt on the rapid timescale. Additionally, UNC-Chapel Hill and the FUN GRB Collaboration, in coalition with

[3] See http://www.physics.unc.edu/~reichart/promptpics.html for more pictures.

the US/UK Gemini GRB Collaboration, were awarded 21 hours of quick response time on Gemini South in Semester 2005B and we expect to be awarded time on both Gemini telescopes in future semesters. All three telescopes are capable of NIR and optical spectroscopy and imaging, as well as able to switch instruments within minutes. Our primary goal is broad spectral coverage for redshift determination, metallicity and re-ionization studies, and spectrophotometry for modeling, unless the afterglow will be too faint by the time that observations can commence, in which case deep, multi-band imaging is the goal. We coordinate PROMPT, SOAR, Gemini, SALT, and FUN GRB Collaboration efforts from UNC-Chapel Hill's new Henry Cox Remote Observing Center.

Figure 4. The SOAR telescope at CTIO in Chile.

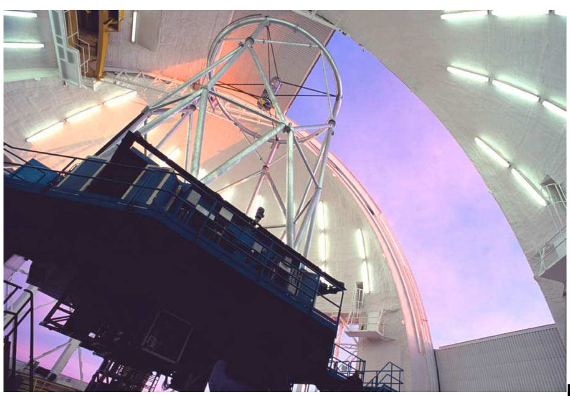

Figure 5. The Gemini South telescope at CTIO in Chile.

2. 3. SALT & HST

UNC-Chapel Hill is a 3% partner in the 9.2-meter (effective diameter) SALT telescope at SAAO in South Africa, which was dedicated in November 2005 and is also now well into commissioning and beginning early science. UNC-Chapel Hill has been awarded SALT's Performance Verification Phase GRB program, and we have already used SALT to observe a handful of GRBs. Although SALT's fixed-altitude design is generally not ideal for rapid follow-up observations of GRBs, we intend to use a good fraction of our time for follow-up spectroscopy and deep, multi-band imaging of GRB afterglows that we observe with PROMPT, SOAR, and Gemini South on the rapid timescale, about a half-day earlier. Additionally, UNC-Chapel Hill in collaboration with Tanvir et al. has been awarded 21 orbits on HST in Cycle 15, to study high-redshift afterglows and host galaxies at later times.

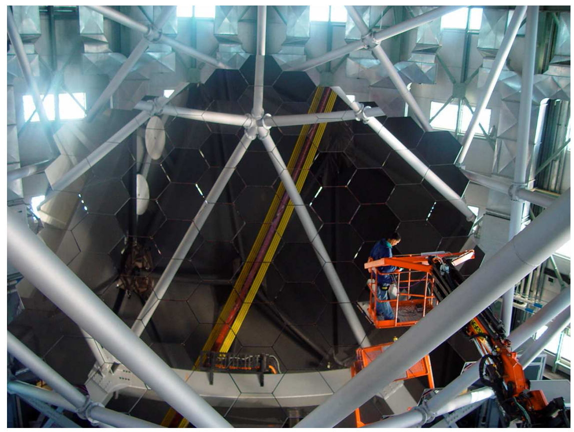

Figure 6. The SALT telescope at SAAO in South Africa.

Figure 7. HST.

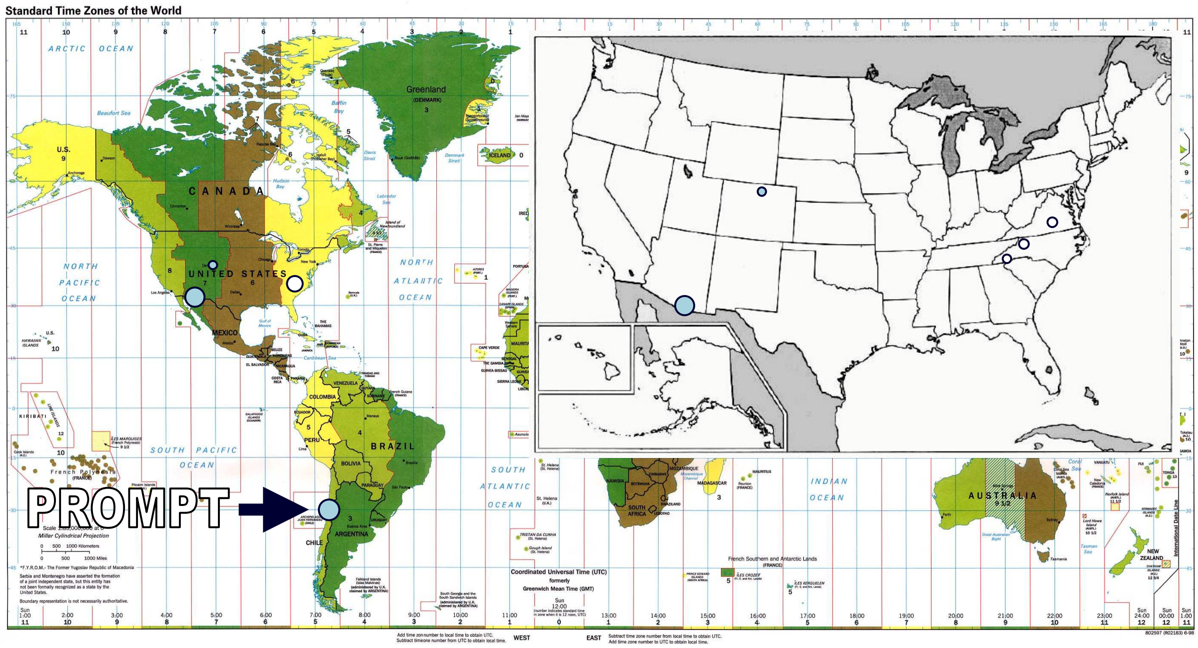

Figure 8. The current state of the Skynet Robotic Telescope Network. Carolina blue circles represent telescopes or clusters of telescopes that have already been integrated into Skynet. White circles represent telescopes or clusters of telescopes that are scheduled for integration this summer.

3. The Skynet Robotic Telescope Network

PROMPT is under the control of "Skynet", a prioritized queue scheduling system that we are developing at UNC-Chapel Hill. Skynet is written in LabView and runs on a computer at UNC-Chapel Hill's Morehead Observatory. Skynet interacts with MySQL databases and commands dumb-by-design "Terminator" programs at each telescope, which control the hardware. Images are automatically transferred back to a 1.1 terabyte RAID 5 with tape backup at Morehead Observatory, making use of communication libraries that we wrote for remote use of SOAR. Users can submit jobs and retrieve data from any location via a PHP-enabled web server that interacts with the MySQL databases.[4] However, GRBs receive top priority and are automatically added to the queue via a socket connection.

Furthermore, we have written Terminator very generally, such that any mount that can be controlled by "TheSky" and any camera that can be controlled by "MaxIm DL", or mounts and cameras that are ASCOM compliant, can easily be integrated into Skynet. We have already integrated a 32-inch robotic telescope in Arizona and a 14.5-inch robotic telescope in Colorado, and have been contacted by owners of telescopes in California, Illinois, New Mexico, North Carolina, Tennessee, Virginia, and Wyoming. Three more telescopes, two in North Carolina and one in Virginia, are scheduled for integration this summer, and the two North Carolina sites (Dark Sky Observatory and Pisgah Astronomical Research Institute) have additional and larger telescopes (two 16-inches, a 24-inch, and a 32-inch) that will be integrated if this summer's efforts prove successful.

Skynet then synchronizes GRB observations across telescopes, even if continents apart, which makes interpreting SFDs much easier, especially if the afterglow is not fading as a power law at early times. When not chasing GRBs, which is most of the time, users are able to queue jobs on each other's telescopes, including PROMPT, at a guest priority level, giving them access to additional facilities and instrumentation, not to mention sky coverage and weather flexibility.

This and the ability to queue schedule one's own telescope, without requiring students to stay awake night after night, has already generated a great deal of interest, so far all by word of mouth. Given the level of interest, we feel that we will be able to grow the network by about ≈1 square meter per year. By the end of the decade, Skynet should have the same total area as a 2 – 3 meter diameter telescope.

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[4] https://fungrb.physics.unc.edu/skynet/

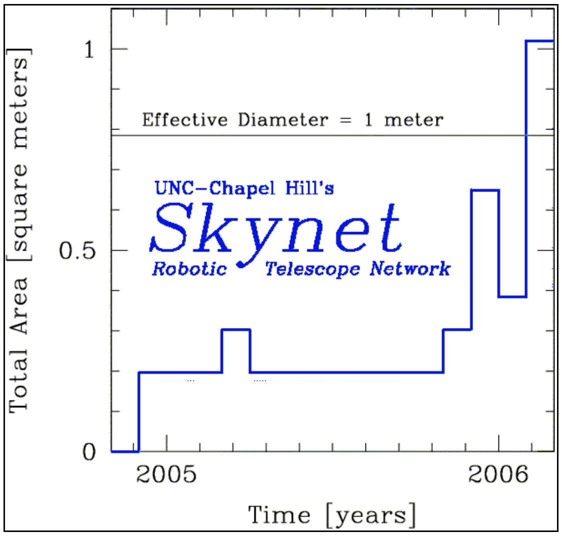

Figure 9. The emergence of Skynet.

4. Education and Public Outreach

When not chasing GRBs, PROMPT is being used by undergraduate and high school students across the state of North Carolina for a wide variety of projects. In addition to UNC-Chapel Hill, PROMPT Collaboration institutions include Appalachian State University, Elon University, Fayetteville State University, Guilford College, Guilford Technical Community College, North Carolina Agricultural and Technical State University, UNC-Asheville, UNC-Charlotte, UNC-Greensboro, UNC-Pembroke, Western Carolina University, and Hampden-Sydney College just across the border in southern Virginia.[5] Each of these institutions has about 400 hours per year of observing time between the six PROMPT telescopes, giving them guaranteed access to a professional observatory and the southern sky. PROMPT Collaboration access began February 1st, 2006.

Furthermore, since PROMPT is fully robotic, none of these institutions have to raise additional money to send students to Chile to use the telescopes – a very expensive proposition. Instead, students simply submit observing requests to Skynet using the web interface. PROMPT automatically observes each target, usually that night, and then Skynet returns the collected images to the students for analysis.

UNC-Chapel Hill's Morehead Planetarium and Science Center (MPSC) has about 2,300 hours per year of observing time for K-12 education and public outreach. MPSC hopes to bring PROMPT into every high school in the state of North Carolina. Funded by a $50,000 NASA/STScI IDEAS grant, MPSC is developing a curriculum for high school science classes that will allow them to submit observing requests to Skynet using the same web interface. This curriculum will also satisfy new statewide graduation requirements.

Finally, funded by an NSF CAREER grant, we have established two programs to bring PROMPT Collaboration students together. The first is the PROMPT Summer Fellowship Program, in which two undergraduates from PROMPT Collaboration institutions other than UNC-Chapel Hill spend 12 weeks with my group in Chapel Hill, where they will chase GRBs with us, help with our commissioning of PROMPT and Skynet, gain experience with large telescopes such as SOAR and possibly SALT, and learn IRAF.[6] Additionally, this year's PROMPT Fellows will help to complete 16-inch robotic telescopes that their home institutions are building for Skynet (§3).

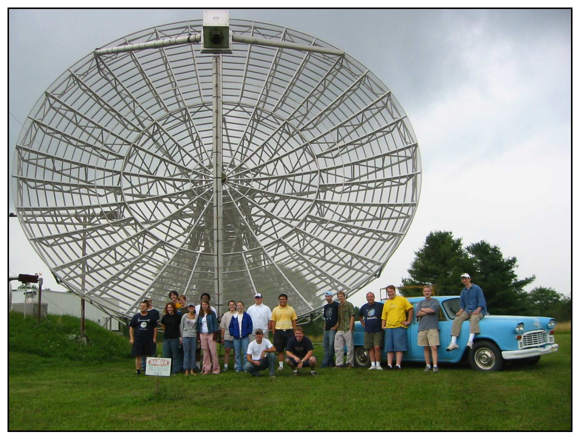

Figure 10. NRAO-Green Bank's 40-foot telescope and participants and coordinators of ERIRA 2005.

Between Swift and UNC-Chapel Hill's follow-up programs, PROMPT Collaboration students will directly experience NIR, optical, UV, X-ray and gamma-ray astronomy – but not radio astronomy. Consequently, our second program supports five PROMPT Collaboration undergraduates, including at least one non-UNC-Chapel Hill student, to attend *Educational Research in Radio Astronomy (ERIRA)* at NRAO, Green Bank, a week-long summer program that I established in 1992 and have coordinated each year since.[7] Other coordinators include Dr. Andrew Stephens (Gemini Observatory) and Mr. Walter Glogowski (Ridgewood High School, Norridge, IL). Fifteen participants are selected from a national pool

[5] See http://physics.unc.edu/~reichart/prompt_documents.html for letters of support.

[6] See http://physics.unc.edu/~reichart/prompt_summer_fellowship_program.html for more information.

[7] See http://physics.unc.edu/~reichart/erira.html for more information.

on the basis of enthusiasm first and background in astronomy second. This makes for a diverse and highly motivated group.

The participants spend one week training to operate a 40-foot diameter radio telescope, which they then use to map the invisible universe and carry out small research projects. Observations are carried out day and night, and what little time remains is spent attending a crash course on radio astronomy, research talks, workshops, and tours, in addition to processing the collected data and completing the small research projects. Naturally, the participants find very little time for sleep, but I select only the most enthusiastic applicants who would not have it any other way.

5. Acknowledgements

DER very gratefully acknowledges support from NSF's MRI, CAREER, PREST, and REU programs, NASA's APRA, Swift GI and IDEAS programs, Dudley Observatory's Ernest F. Fullam Award, UNC's Junior Faculty Development Award, and especially Leonard Goodman and Henry Cox.

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