

Chapter 6

Internet Telescopes

Capabilities and Benchmarks

Kelly Graves¹ and Glen Mackie²

1. Swinburne University, Australia

2. Centre for Astrophysics & Supercomputing, Swinburne University

Introduction

In this golden age of small-telescope astronomy, the term “armchair astronomer” has an entirely new significance. High-quality, low-cost optics have combined with advances in imaging-array technologies and sophisticated, electronic servomotor mounts to place instruments of exceptional power and effectiveness in the hands of amateurs. Some of these instruments are well-configured and well-sited; many represent hundreds of thousands of dollars in investment and even larger commitments in owner/operator time. Open standards such as those in the ASCOM initiative (Web: ASCOM) have enabled automation components from many different manufacturers to work together in a more-or-less integrated fashion. The results are fully-automated, serious-amateur telescopes quite capable of variable star work, supernovae searches, and even detecting extrasolar planets. In the past few years, the control software and interfaces to these automated telescopes have become exceptionally sophisticated, surpassing professional control software at least in beauty and design, if not in raw functionality. Most of these interfaces can function through the Internet. Armchair astronomy, indeed!

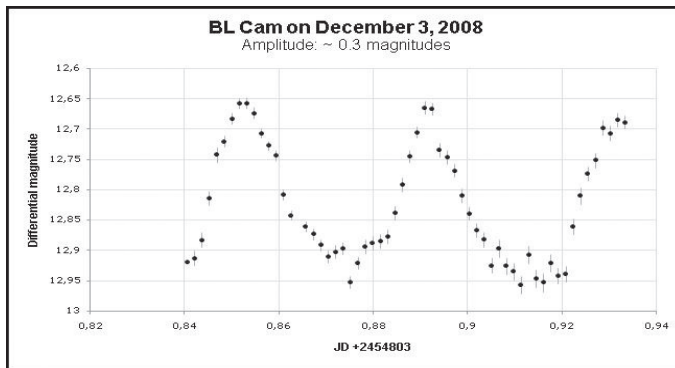


Figure 1: Automatically-generated light curves for the AAVSO by Geir Klingenberg, using Photometrica on GRAS G1.

At the same time, automation of mid-sized institutional telescopes has improved. Instruments in the one-meter range are now routinely capable of autonomous operation. Often referred to as “robotic” telescopes, they can also be operated remotely. Many of these instruments are owned by universities, foundations, and consortia. Sometimes, an unassociated professional, senior student, or serious amateur can gain access to the control software (usually through a proposal-submission process) and can operate the instrument nearly as effectively as though he or she were in the observatory control room.

An industry has emerged at the juncture of these two trends in automation and remote-instrument control. Private owners of small observatories have established facilities with optical, imaging, and computational capabilities that were the exclusive province of institutions only a decade ago. Instruments in these observatories are available to anyone with a browser, a reasonable Internet connection, and some idea of what to do with a telescope. Finance isn’t even a barrier: use of some of the observatories is free, funded by science grants or astronomy clubs.

Scope and goals

This paper concentrates on Internet telescopes outside the community of institutional observatories. The goal is to answer two main questions about these telescopes:

How useful are these new observatories for observations by serious amateurs, undergraduate or graduate students, and professional astronomers?

Which telescopes are the most appropriate choices for particular observations?

Definitions

Many publications use *robotic telescope*, *remote telescope*, and *Internet telescope* interchangeably, yet they mean quite different things. For this paper we define in these ways:

Robotic telescope: a telescope capable of autonomous, untended operation;

Remote telescope: a telescope that can be controlled without physical operator contact;

Internet telescope: a telescope operated by a computer that is accessed via the Internet.

See www.internetscopes.org/definitions (Web: Graves) for expanded definitions of these three types of telescopes and for definitions of other terms used here.

Methodology

We applied an eight-step methodology as follows:

1. Search for Internet telescopes, robotic telescopes, and browser telescopes.
2. Collect these items together in an online database.
3. Create preliminary criteria to apply to the database with the goal of highlighting telescopes that might be of interest to serious amateurs, students, and professional astronomers.

4. Provide some simple calculations in the database to help users identify telescopes that meet their criteria.
5. Define some benchmarks and measurements that might be helpful to an observer who wants to perform scientific research through an Internet telescope.
6. Apply these benchmarks to a small sample of Internet telescopes to ascertain how well the benchmarks—if applied over a long period of time—might work.
7. Evaluate the utility of these benchmarks in particular and benchmarks in general.
8. Suggest a path forward for long-term benchmarking.

The Search

Hessman (Web: Hessman) maintains a table of “Robotic Telescope Projects”, and although his list is evidently based on a definition more broadly inclusive than the definition of a robotic telescope suggested in www.internet-scopes.org/definitions, only a few of the 107 autonomous telescopes it lists are publicly controllable through the Web. Querci and Querci (2000) maintain a similar list with a similar focus, but their list pre-dates most of the technologies used in today’s Internet telescopes.

Astronomy-related Web forums reveal that beneath the notice of Hessman’s list are an extremely large number of telescopes of professional or near-professional quality. Google searches of intuitive terms were surprisingly unrevealing, but some experimentation yielded an effective search technique:

- Construct a list of known Internet telescopes.
- Examine the HTML source of the Web pages at their access points to construct a keyword list.
- Construct Google searches based on these keywords to yield Web pages in the same functional and competitive domains.
- Repeat steps 1, 2 and 3 until the list of telescopes stops growing.
- Post messages in several online discussion forums, asking people to point out observatories.
- Repeat steps 1, 2 and 3 until the list of telescopes stops growing.
- Search arXiv, ADS, Google Scholar, Scopus, Web of Science, Math SciNet, and the glossy astronomy magazines using the accumulated keyword list.

This search yielded over eighty different instruments that are:

- Controllable through a browser or a private client application.
- Available to the public or to open groups (where a membership is required but easy to obtain).

- In an open queue where anyone can use a free instrument or use a simple booking system to reserve a time.
- Operated wholly or partially at the discretion of the observer.

At the time of publication, only four of these instruments were included in Hessman's table. For example, the Bradford Telescope (Web: Bradford) is truly a robotic telescope (as opposed to one with Internet control), but interested people can register and request images. While the telescopes at Bradford may be research-capable instruments, Bradford's organizers do not offer research-level access to the general public.

The Database

This inventory of Internet telescopes continues to grow. It is collected in an online database at: www.internetscopes.org/database (Web: Graves). Guest access (for browsing only) is open, without any password. Observatory managers who have requested it have been given editor access and invited to view and correct the entries pertaining to their particular instruments.

The database is fully searchable. One could, for example, find instruments of 300 mm or greater, faster than $f/10$, in the southern hemisphere in regions between UT +4 and UT +8, where stock calibration libraries are available, where the camera has a large-format, non-blooming CCD array, and where a "V" filter is available.

A periodically-updated static listing is at: www.internetscopes.org/list (Web: Graves).

Internet Telescopes: A Brief Characterization

What does an examination of the database reveal? Simple rental telescopes are quite easy to find and quantify. The database catalogs roughly 36 of these (with some uncertainty driven by ever-shifting observatory policies). Open institutional telescopes that qualify as Internet telescopes are harder to find and sometimes impossible to characterize or to specify. Although these telescopes may or may not have autonomous robotic capabilities, they are included in the database because they are in one way or another available to the public. The database lists about 45 of these.

Private Internet telescopes are nearly impossible to locate, and only a few are in the database. Like dark matter, this group of telescopes is hidden and probably numerically the most-populated! You can lease some or all of the time on them in blocks of years or months. Oddly, tabulation of these telescopes is made even more difficult by the contrarian fact that some of these private telescopes are also marketed as rental telescopes, and by the fact that the integrators are also often the firms who assemble the institutional instruments.

Observatories as Consumer Industries

The quality of the “observing product” in the inventory database is widely variable, as are the knowledge and attention to detail of the owners. For example, some owners of virtual observatories regard the need for an attendant’s physical visit to a remote site as evidence of a design flaw, while others strongly maintain that near-constant human attention at the host site is necessary for smooth remote operation.

Some Internet telescopes are configured for “layperson” exploration. Among the most-notable are SLOOH (Web: SLOOH), which operates several telescopes on Mount Tiede in the Canary Islands, and the “Seeing in the Dark” (Web: Seeing in the Dark) telescope, which is in New Mexico, USA. While the instruments employed by casual-use browser observatories can be of very high quality, the lack of control through their particular interfaces usually makes them unsuitable for most research work. For example, on some sites of this type, a request for an image of a portion of the sky might return a new image ... but it might instead return an image taken a week ago. Other sites of this type only allow observers to target common, named objects: the spaces “in between” are inaccessible. As well, new images are usually posted in public areas of the site: this not only may not be in the best interests of researchers, but could undermine appeal to the target audiences who come to the sites to see as many visually-stunning images as possible.

Affiliate Marketing and Client Confusion

Affiliate marketing of Internet telescopes is common and growing. For example, New Mexico Skies (NMS) (Web: New Mexico Skies), which operates roughly 30 telescopes, but only markets three of them directly as iBisque (Web: iBisque), acts as an affiliate source. iSkies (Web: iSkies), an Australian-based company that sells telescope time for schools, re-markets NMS time. This is a classic example of affiliate marketing. Google searches originating in Australia do not return a well-placed link to New Mexico Skies, but a Google Australia search returns iSkies in the first page of links. iSkies uses the physical location of its IP address to reach an audience in Australia that NMS would normally find very hard to tap and is outside the NMS core audience. Further, iSkies makes good use of the time-zone difference, emphasizing the fact that Australian schools can do night-time imaging during school hours.

More importantly, a researcher and potential customer can be confused by the relationships between the different host sites, affiliates, and affiliate sources. For example, the GRAS telescopes in North America are sited at New Mexico Skies, where they are physically attended to by NMS; because of this, parts of the NMS branding extend into some of the GRAS web pages. In the past, GRAS has re-branded and re-sold connections from Bareket Ob-

servatory in Israel, now part of the Space Grant Internet Telescope Network (SGITN) (Web: SGITN).

Consumer Observatories as Research Tools

A small number of observatory owners — operating roughly a third of the telescopes in the inventory — are very enthused about attracting researchers. These owners want to keep costs down, degree of instrument control high, and technology as well-tuned as possible. At least three services — Cherry Mountain Observatory, Global Rent-a-Scope (GRAS), and LightBuckets — combine a very serious regard for researchers, substantial expertise, and aggressively-maintained inventories. They each take a different approach: Cherry Mountain's smooth peer-to-peer interface confers absolute control to the observer. GRAS has a superbly-effective "express mode" suitable for economical high-volume work, what amounts to a "scientist in residence", and a built-in photometric tool. LightBuckets has a proprietary interface that rapidly builds professional observing plans, coupled with large, high-quality instruments.

Observatory managers are quite willing to make operational and physical changes to accommodate the needs of individual researchers, since that may well draw still other researchers to the facilities. For example, only one of the over 80 Internet telescopes listed offered pipelining capabilities (a common technique to optimize data processing); yet 10 of 12 observatory managers questioned were very open to exploring how to include it if it would be of use to professional researchers.

Cross-Vendor Transportability

A researcher could attempt to take an image with the iBisque 355 mm SCT in New Mexico, USA ... only to discover cloudy conditions. She could then default to Cherry Mountain Observatory's 368 mm RCOS in Texas, USA and, failing that, could try the GRAS 317 mm RCOS in Moorook, Australia a few hours later. Further failure there could be countered with the LightBuckets' 368 mm RCOS in Pingelly on Australia's western coast, and, finally with Bareket's 380 mm Astrograph in Israel.

Internet telescopes are particularly useful because the queues are phenomenally short, and because many owners and operators approach requests for assistance with the customer-service values of businesses who need to expand their markets. This can be important when astronomers want to deal with transient phenomena, or when timing is critical, as it was for Tim Puckett and Robert Gagliano of the Puckett Observatory Supernova Search, who needed a confirming image for an IAU submission. See Figure 2.

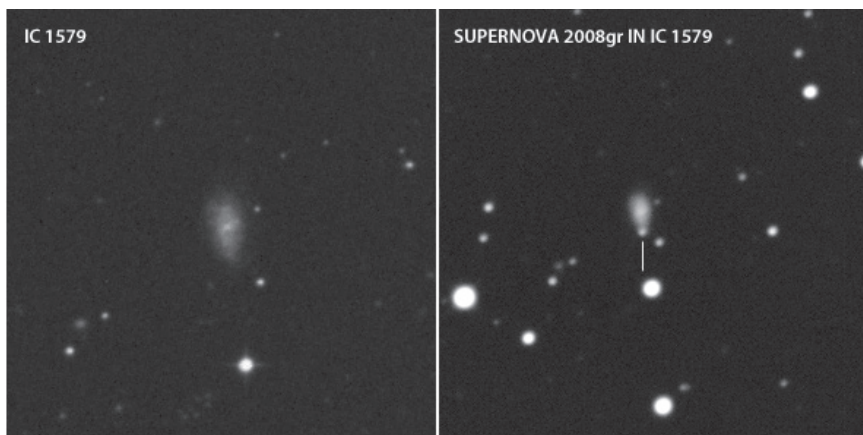


Figure 2: On October 29th, 2008, Puckett and Gagliano observed a possible supernova at R.A. = 0h45m32s.28, Decl. = $-26^{\circ}34'20''.2$ in IC 1579 (image at left), but needed confirmation. They turned to Steve Cullen, whose image of SN 2008gr, taken the next night, is at the right.

This sounds wonderful, but the reality is quite different. At the moment, while the popular observatories all use ASCOM protocols for inter-device control, and while almost all accept some form of scripted commands (DC3's ACP Planner scripts are quite common), an observer cannot prepare a single observing plan and use it on several telescopes from different vendors. To allow researchers to capitalize on the advantages of ad-hoc global access, vendors should consider some method to allow an observing plan from one observatory to be used at another. Typically, vendors bear the cost of purchase and integration, so commercially-available software like ACP does not significantly increase researcher costs.

True transportability of observing plans may wait on a widespread open standard. RTS2 (Web: Kubanek), for example, is an open-standard-software control package in fairly-widespread use on autonomous robotic telescopes; it provides more than enough power to be useful across the emerging Internet telescope market and has the capability to migrate "downwards" into smaller observatories. While RTS2's C-like syntax allows it to be extremely powerful, Internet observatory managers consulted observed its very power and the associated learning curve might limit customer access and hence market adoption rates of those observatories operated as for-profit businesses. This is a small problem, however: once an open standard is broadly adopted, its library calls can easily be invoked by one or more higher-level interpreted symbolic languages.

The Most-Useful Telescopes

What constitutes a minimal set of functionality that any researcher would need? The inventory database has a built-in function to help answer this question: a red “Research Ready” tag that displays “YES” if a telescope has been adequately surveyed and the critical fields “Autoguide”, “Filter Control”, “Exposure Control”, “Image Storage”, and “Time Control” are all flagged as “Y”. For the purposes of this study, these fields together are taken to define a telescope that offers sufficient control to be broadly useful to researchers: an observer can pick an object, select a filter, control the length of the exposure and the time at which it is made, elect to have the image stored for later retrieval, and choose to use or ignore autoguiding.

Different research applications may require yet more-complete control of binning, plate-solving, dithering, reference frames, and much more. However, experience with the database shows that the minimal set of criteria attached to the “Research Ready” tag always points to the telescopes that offer full control.

Benchmarks

“Benchmarking” can mean several different things. Ultimately it has to be practical and the reward-to-effort ratio must be very favorable to encourage long-term application.

We examined some simple benchmarks and recommend a small number that give a basic notion of the condition and usefulness of a telescope.

CCD MTBF and NDC

CCDs seem to be the most reliable components of Internet telescopes. SBIG (Web: SBIG) and other prominent suppliers of CCD cameras cite impressive Mean Time Between Failure (MTBF) figures for their equipment, in the range of 10^6 hours. CCD performance can in part be monitored by their noise and dark current (NDC). This can be easily done with two bias frames, two flat-field frames, and one dark frame. It is particularly simple to do, since the AIP4WIN image processing software (Berry and Burnell 2006) will perform some of the calculations automatically. However, the long MTBF compared to the moderate effort required for the calculation suggests that the return-to-effort would make this a better spot-check than a benchmark. To confirm this, 12 of the 24 telescopes flagged as “research ready” were spot-checked in November, 2008. None were operating outside the acceptable ranges suggested by Berry and Burnell (2006).

Stock Calibration Libraries

Most Internet telescopes have a stock calibration library (minimally, a set of dark files or a master dark file, and one or more flat and luminance files)

and most are kept updated. For many purposes and for some researchers, this library may be sufficient. Is a benchmark to assess the usefulness of stock calibration libraries worth the effort?

A few simple trial images of objects were taken, and then attempts were made to calibrate the images using the off-the-shelf algorithm in MaximDL's calibration wizard. In most cases, however, the stock calibration libraries have a limited usefulness. In the first instance, most research work requires many more calibration files than could reasonably be maintained by the observatory owner; in the second instance, the possible range of requirements makes a full, current library quite difficult to maintain.

While a benchmark to point to those calibration libraries that might be useful to research is not practical, observatory owners are very happy to have researcher business, and more than one expressed a willingness to modify the stock libraries to aid in particular work. This suggests that the use of stock libraries is a matter for collaboration but not one to be benchmarked yet.

Image Quality

A simple way to check optical performance of a telescope is to perform a full-width at half-maximum (FWHM) calculation on a set of sample images in the center of a telescope's field of view (Berry and Burnell 2006). Poor FWHM performance will most likely come from focus and collimation failures or from bad seeing.

Documented ability of a particular instrument to return good FWHM results over time is certain to attract researchers. With proper statistically-governed sampling, long-term FWHM measurements can be an excellent predictor of the results from a particular instrument, observatory owner, host operator, or host site.

A trial sampling of FWHM measurements in good to excellent seeing conditions on 12 Internet telescopes over 6 weeks revealed a substantial range: from 1.53 to 7.76 arc sec. Procedurally, a star-field should be used that has some arbitrarily large number of stellar images (at least ten) near the center of the field of view; they should be measured and averaged to generate a result. This eliminates edge-effects and compensates for errors in judgment (for example, where an operator may select what appears to be a single, off-shape star but is in fact two stars in the line of sight). The return-to-effort ratio is quite good, since a benchmarker can measure ten stars in a few minutes.

Mount alignment and tracking

Most (but not all) Internet telescopes do autoguiding well. On telescopes where unguided operation is rare, the presence of an auto-guider can "cloak" a misalignment, which will only show up during unguided operations. Two of

the 12 telescopes studied carefully had autoguiders that could not be turned off through the automated interface; the observatory owners were surprised, and took steps to rectify the problem.

A metric to determine upper practical limits for unguided photometry would be extremely useful. A moderately-long exposure (perhaps 900 seconds) of suitable stellar objects can be used to measure the elongation per-unit-time of the resulting image. AIP4WIN is useful again, since its “Star Image” tool will calculate the elongation of a star’s image. Unlike the FWHM benchmark, though, the mount-alignment benchmark is relatively (although not completely) insensitive to seeing, and objects further from the center of the field-of-view can be used.

A trial sampling of mount-alignment measurements in all seeing conditions on 12 Internet telescopes over 6 weeks revealed that most are well-aligned. Again, the return-to-effort ratio is high.

Costs by Specification and Performance

A few Internet telescopes can be used at no charge, but most are operated commercially. When a scope is not free, the inventory database records prices, although this raw price may not be enough to allow observers to gauge potential cost-effectiveness. To help address this issue, the database includes a supplementary metric: cost per objective millimeter per hour (CPMMH). For example, LightBuckets’ combination of a 609 mm RCOS refractor and a high quantum-efficiency camera is a superb buy at \$0.149/mm/hr, whereas the GRAS 106 mm Petzval Apochromat Astrograph is less of a bargain at \$0.849/mm/hour (while correct, this comparison is made by way of illustration; both GRAS and LightBuckets offer a wide range of pricing options, and GRAS has several instruments in the same value range as the LightBuckets’ 609 mm RCOS).

In addition, within a standardized benchmark suite, actual run costs for the benchmark actions can be tabulated over a number of trials to provide an operations-based costing estimate on a typical set of tasks. This same costing information can be obtained dynamically in the database. This figure is unquestionably worth tracking. Of the telescopes that show per-hour costs, 28% had CPMMH changes as this paper was being written, suggesting active price-monitoring is well worthwhile. All the price changes were downwards: we expect this trend to continue indefinitely.

The cost of target acquisition is a concern with a remote telescope, particularly when autoguiding or plate-solving, which can dramatically increase billed time. The simple cost benchmark suggested above could be made more sophisticated if it were extended to track actual cost of acquisition, which could be calculated by subtracting the cost of imaging minutes from the total cost of a run.

In trials, no consistent and fair method of making this cost calculation in a way that would be meaningful to researchers was developed, largely because the manner in which control software operates imaging plans and reports against them varies wildly. An industry conversation is probably necessary to find a global cost benchmark.

A Database of Benchmarks

As a suggestion for development, a sample benchmarks database has been attached to the main inventory database. It can be accessed by clicking on the "See Benchmarks" button on the right-hand side. Extended discussion with observatory owners revealed they were extremely reticent to consent to publication of short-term collections of data. This quite-understandable position is consistent with proper benchmarking practice: in a complex instrument installation partially dependent on environmental conditions, accurate comparisons can only be made by repeated testing over a long period of time. The benchmarks database is populated with a few records containing actual data, but the data is not directly linked to particular telescopes, so as to respect the wishes of the owners.

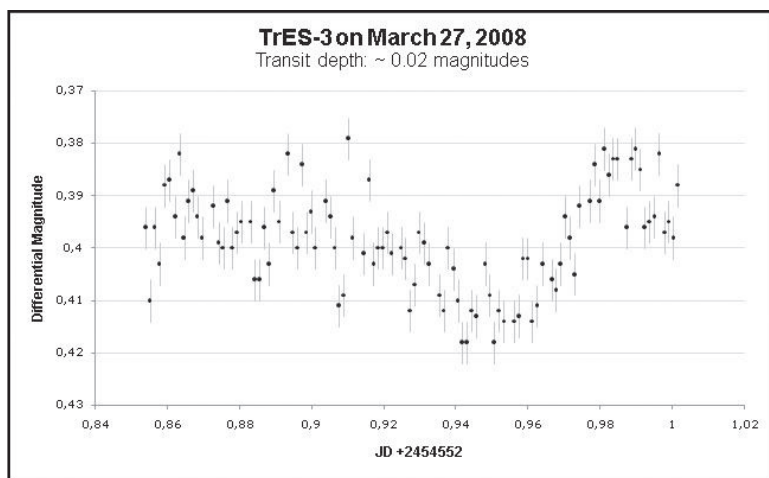


Figure 3: Extrasolar planet transit light curve by Geir Klingenberg, using Photometrica on GRAS G2.

Conclusion

This work catalogs over 80 Internet telescopes that can be accessed remotely by the general public. Operators were willing to disclose detailed information on configurations and costs on 24 instruments, and a similar level of information can probably be collected on at least another 40 telescopes. The

searchable inventory database is a rapid and convenient way for researchers to locate an instrument of a particular configuration and capability at a particular location. The upper end of this range of instruments is certainly very capable of being useful to serious amateurs, graduate students, and professionals. While some equipment limitations certainly exist, this class of instruments is well-operated and is a source of innovation that the general astronomical community will find useful. The competitive customer-service attitude and willingness to cooperate of many observatory operators extends the practical capabilities of the telescopes.

At the moment, no cross-service benchmarking program exists. The simple benchmarks examined here and perhaps a small number of more sophisticated benchmarks are certainly justified. Obviously, an industry conversation is the mechanism through which this must begin to happen. Observatory owners are enthused about long-term benchmarks. As a result of this work, a small group of observatory operators have tentatively agreed to begin a long-term benchmarking collaboration, with the results to be published on the Web site and database associated with this work, which will be supplemented with a Wiki and kept as current as possible during the International Year of Astronomy. As is often the case in physics, the act of observing changes that which is observed.

Authors' Note: Contact Information

Kelly Graves: 1150 Manulife Place, 10180-101 Street, Edmonton, Alberta, Canada T2N 4N4. klg@ideasfirst.com.

Glen Mackie: Centre for Astrophysics and Supercomputing, Swinburne University of Technology, P.O. Box 218, Hawthorn, Victoria 3122, Australia. gmackie@swin.edu.au.

References

- Berry, R. and Burnell, J. 2006. *The Handbook of Astronomical Image Processing*. Richmond VA: Willman-Bell, Inc.
- Querci, F. R. and Querci, M. 2000. Robotic telescopes and networks: New tools for education and science. *Astrophys. Space Sci.* 273, 257-272.
- Web: ASCOM. Internet <http://ascom-standards.org>, accessed 26 Jan. 2009.
- Web: Bradford. Internet <http://www.telescope.org/>, accessed 26 Jan. 2009.
- Web: Graves. Internet www.internetscopes.org/definitions, accessed 11 Apr. 2009.
- Web: Graves. Internet www.internetscopes.org/database, accessed 11 Apr. 2009.
- Web: Graves. Internet www.internetscopes.org/list, accessed 11 Apr. 2009.
- Web: Hessman. Internet <http://www.astro.physik.uni-goettingen.de/~hessman/MONET/links.html>, accessed 27 Jan. 2009.
- Web: iBisque. Internet <http://www.bisque.com/ibisque/telescopenetwork.asp>, accessed 27 Jan. 2009.

- Web: iSkies. Internet <http://www.iskies.com/>, accessed 27 Jan. 2009.
- Web: Kubanek. Internet <http://rts2.org/>, accessed 05 Feb. 2009.
- Web: New Mexico Skies. Internet <http://www.nmskies.com/index.php>, accessed 26 Jan. 2009.
- Web: SBIG. Internet <http://www.sbig.com/>, accessed 26 Jan. 2009.
- Web: Seeing in the Dark. Internet <http://www.pbs.org/seeinginthedark/explore-the-sky/internet-telescope.html>, accessed 26 Jan. 2009.
- Web: SGITN. Internet <http://sgitn.space.edu/intro/index.php>, accessed 27 Jan. 2009.
- Web: SLOOH. Internet http://www.slooh.com/lp_sched_teide.php, accessed 26 Jan. 2009.

