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THE UCSB REMOTE ACCESS ASTRONOMY PROJECT

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ABSTRACT The remote access astronomy project is a computerized telescope and data distribution system that has the potential to substantively change the way astronomical concepts are taught to undergraduate students, and to improve the teaching of astronomy, earth science, and physics at the high school and undergraduate levels. In addition, particularly at the secondary school level, it can serve as a forum for the distribution of curriculum materials and data among teachers, and as an educational network between high schools, universities, and professional astronomers. The system is undergoing testing at the undergraduate level, with several high schools, and a local museum.

INTRODUCTION

The UCSB Remote Access Astronomy Project (RAAP) grew out of experiences in teaching undergraduate astronomy several years ago. It quickly became clear that most students were less than impressed with the usual roof top observation sessions with small telescopes. In addition to having to come back to campus when it is cold and dark, the students could see very little more (qualitatively) in the eyepiece than with the unaided eye. This is particularly disappointing when compared to the beautiful pictures presented in the textbook. Clearly, for them, astronomy should be done from the textbook and not with a telescope! With the current need for vast improvements in science education at all levels of pre-university and university teaching, it seemed desirable to extend the use of high quality astronomical images to high school and undergraduate physics and astronomy students and teachers through the use of a dial-in data distribution system connected to the local area network. In this way, images from our telescope, as well as images from other sources, could be made available for high school students and teachers as well as to UCSB students.

From a modern perspective of photon counting devices, some comparisons of the eye, emulsions and photon integrators (CCD, etc.) are very instructive. The major difficulty with the eye as a light detector is not "read noise", "dark current" or quantum efficiency, but rather integration time. The eye has an effective integration time of only about 50 ms. Though near single photon sensitivity is possible, typical dark-adapted sensitivity is 10-100 photons on a receptor in an integration time. Emulsion grain sensitivities are typically of order 100 photons per grain.

Film has excellent spatial resolution, but suffers from low quantum efficiency and dynamic range. The UCSB Remote Access Telescope (RAT) uses a cooled CCD as the photoreceptor. It has an average quantum efficiency of 40% and read noise of 12 electrons and a dark current of about 1 electron per second. Pixel capacity (well depth) is about 150,000 electrons. For a comparison, the UCSB RAT, which has a 14-inch aperture with its CCD camera is roughly as sensitive as the Lick 120 inch was with film 40 years ago. A large amount of astronomy was done then, and can still be done now at this sensitivity, which corresponds to a detection of a 20th magnitude point source in a few minutes.

LIMITING BACKGROUNDS AND SENSITIVITY

A number of issues enter the calculation of a signal to noise ratio. These include background flux from airglow, back-scattered terrestrial light, zodiacal light and diffuse galactic and extragalactic light as well as optical throughput and detector noise (read noise and dark current). The fundamental limiting backgrounds from the sky are summarized in Table I.

TABLE I Signal to Noise Considerations

Fundamental Limiting Backgrounds

Source	S_{10} Equivalent # 10th Mag Obj per sq deg
Airglow	50
zodiacal light(away from ecliptic)	150
Starlight (mean)	100
Galaxies	1
Total	~ 300

The total is equivalent to 10^{-2} photons/$cm^2 - sec$ per sq arc second.

$$1\ (\text{deg})^2 = 10^{7.113}\ (\text{arc sec})^2\ (= 3600^2)$$

$$1\ S_{10} = 6.86 \times 10^{-6}\ \text{erg} - cm^{-2} - s^{-1} - st_2^{-1}$$

$$1\ S_{10} = 1\ 10^{th}\ \text{mag obj}/(\text{deg})^2 = 10^{-7.113}\ 10^{th}\ \text{mag obj}/(\text{arc sec})^2$$

$$= 27.78\ \text{mag}/(\text{arc sec})^2$$

$$300\ S_{10} = 21.59\ \text{mag}/(\text{arc sec})^2$$

N_R - readout noise e^-

i_{DC} - dark current e^-/s

Q_e - Quantum eff

F - point source signal flux on telescope $\gamma/\mathrm{s} - \mathrm{cm}^2$

F_β - background from sky $\gamma/\mathrm{s} - \mathrm{cm}^2 - \mathrm{arcsec}^2$

Ω - pixel size arcsec^2 (assume > seeing)

ϵ - telescope optical efficiency

τ - integration time sec

A - effective telescope area cm^2

$$\text{Signal} \quad S = F\tau A\epsilon Q_e \quad e^-$$

$$\text{Noise} \quad N = \left(N_R^2 + \tau(FA\epsilon Q_e + i_{DC} + F_\beta A\epsilon Q_e\Omega)\right)^{\frac{1}{2}}$$

$$\text{let } A_\epsilon = A\epsilon Q_e \equiv \text{Effective area}$$

$$\text{let } N_T = FA_\epsilon + i_{DC} + F_\beta A_\epsilon\Omega$$

$$S/N = FA_\epsilon\sqrt{\tau}/\left[\tfrac{N_R^2}{\tau} + FA_\epsilon + i_{DC} + F_\beta A_\epsilon\Omega\right]^{\frac{1}{2}}$$

$$= FA_\epsilon\sqrt{\tau}/\left[\tfrac{N_R^2}{\tau} + N_T\right]^{\frac{1}{2}} = FA_\epsilon\tau/\left[N_R^2 + \tau N_T\right]^{\frac{1}{2}}$$

I. for small τ S/N $\sim \tau$ N_R Limited

II. for large τ S/N $\sim \sqrt{\tau}$ N_T Limited

Time to measure a given S/N:

$$S_N = S/N = FA_\epsilon\tau/\left[N_R^2 + \tau N_T\right]^{\frac{1}{2}}$$

$$\tau = \frac{S_N^2 N_T \pm \sqrt{S_N^4 N_T^2 + 4F^2A_\epsilon^2 S_N^2 N_R^2}}{2F^2A_\epsilon^2}$$

$$= \frac{S_N^2 N_T}{2F^2A_\epsilon^2}\left[1 + \sqrt{1 + \frac{4F^2A_\epsilon^2N_R^2}{S_N^2N_T^2}}\right]$$

As can be seen, this ideally is about 21.6 magnitudes per square arc second equivalent. Most easily accessible ground-based sites are worse that this. Given the background flux, we can compute the signal to noise ratio (S/N) given the object flux (magnitude), detector (CCD) characteristics and optical throughput.

Figure 1 shows the results of this calculation for objects of magnitude m=15, 17.5 and 20 given our system characteristics with 1× and 10× ideal dark sky conditions. A couple of caveats are in order here. First, we have assumed all the light is dumped on one pixel (2" pixels) i.e., this is for point sources. Second, we have assumed perfect guiding during integration. This is not trivial for the longer integrations. In any case, it is an instructive calculation.

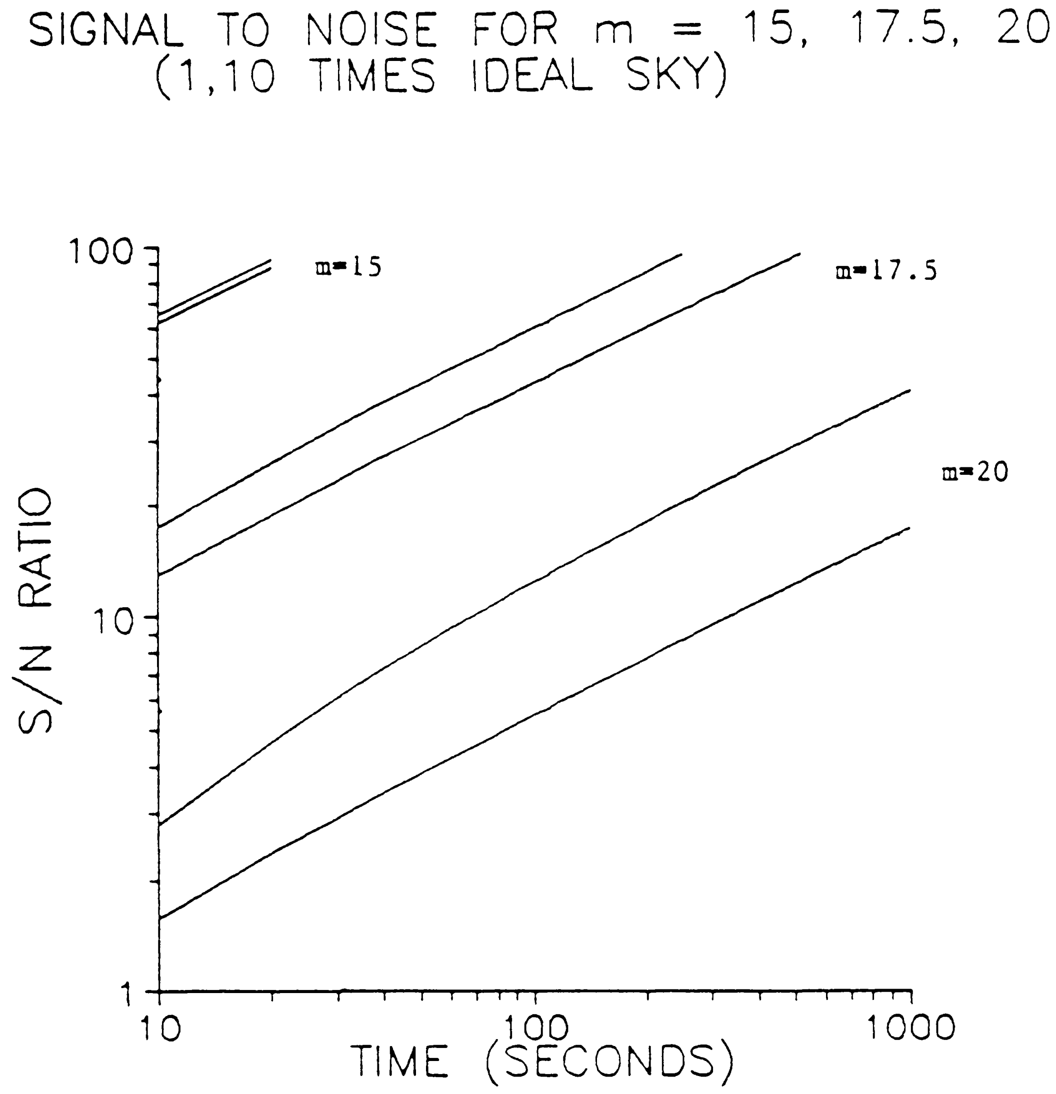

Figure 1: Signal to Noise Ratio vs. Integration Time

CURRENT SYSTEM

The system consists of a 14-inch diameter aperture telescope, computer controlled with micro step-driven stepper motors, a thermoelectrically-cooled CCD camera, 16-position filter wheel (dual 8-position wheels), and a servoed focus. The telescope is housed in a computer-controlled, weatherized enclosure. A computerized weather station and infrared sky monitor determine meteorological conditions before opening the "dome". This part of the system communicates via a microwave link to the base of the system, which consists of an ethernet-connected network of workstations for local undergraduate use and a high speed modem interface for remote users (high schools and other colleges). The dial-in interface uses V.32/V.42 modem technology for effective throughput of 1-1.5 KBs (Kilo Bytes per second) for compressed image files, 2 KBs for binary executable files and 3-4 KBs for ASCII text files. Our current Thompson CCD has a format of 576×384 pixels, and after image compression yields image sizes of 90-300 KB, depending on the image complexity. Typical image transfer times over the dial in link are 1-4 minutes per image at 9600 baud. Figure 2 shows the current system.

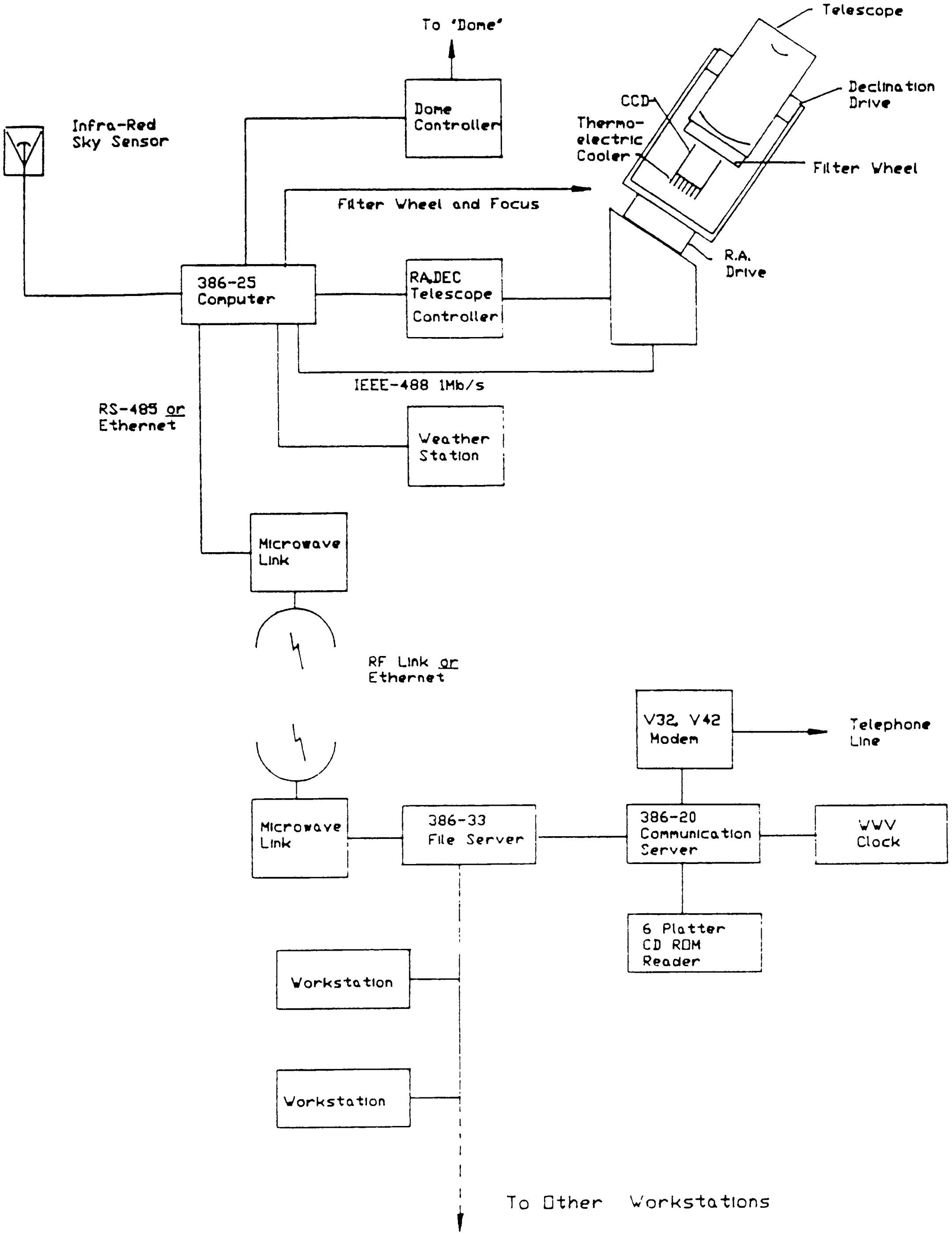

Figure 2: System Diagram

Undergraduate and high school users can submit target requests to the system during the day, or have their computer automatically call in at night when costs are lower. The next day they can download their images and analyze them during normal class hours. This eliminates the need for evening classes which, for the majority of students and teachers, is not practical on a daily basis.

Typical costs for night-time image transfer over the phone lines are 10-40 cents per image (for long distance calls). Eventually, the system may be put on one of the university networks (internet, etc.), but at present, very few high schools have access to such a network. We are currently operating on a commercial telephone number, but may go to an 800 number to centralize costs.

The workstation for image analysis can vary considerably, though at present we are targeting 32-bit IBM-PC class machines (80386 or 80486 CPU). This class of machine currently has from 1.5 MIPS (16 MHz 386SX) to 20 MIPS (33 MHz 486) and has enough power to handle the image manipulation. Cost for our current minimum-recommended workstation is about $2000, including the Super VGA display. A V.32/V.42 modem adds about $500. As all these costs are constantly dropping, it is anticipated that within a few years costs will drop again by a factor of 2. Other computers and image processing programs (e.g., Apple-MacIntosh) can also be used with our data, as all our images are stored in standard "FITS" (Flexible Image Transport) format.

In addition to the telescope, we have an extensive library of images on CD-ROM and magnetic disks which include NASA images of Jupiter and Saturn and their satellites, Uranus, Neptune, Mars, Venus, Earth and the Moon. We also have radio and infrared sky maps, x-ray survey maps, images from the Keck Telescope and Hubble Space Telescope, and daily solar images. We currently have about 50,000 images available comprising over 20 GB of data.

These images are an excellent aid for teaching high school astronomy, physics, and earth science courses. Teachers and students can call our bulletin board and request any of these images to be loaded into their directories for use in class assignments or individual research projects. We are also developing activities and teaching units to accompany some of the images, which will be available for distribution beginning in the fall of 1991.

Some of the units that we are developing are: demonstrating Kepler's Laws by plotting the orbits of some of the Jovian and Saturnian satellites; comparing craters on our moon, the Saturnian moons Dione, Callisto, and Mimas, and known or suspected craters on Earth to study history of the solar system, erosion processes on different planets; estimating the masses of bodies that caused observed craters; observing sun spots using daily solar images; calculating trajectories of volcanic debris from the images of volcanic eruptions on the Jovian moon Io; using the radio, infrared, and x-ray maps of the sky to learn about how the universe might "look" if we could "see" at wavelengths other than the visible.

Our bulletin board (The "Astro-RAAP") is designed to serve as a forum for the exchange of information between high schools, colleges, and universities. We have a variety of programs available for downloading, which include educational software for the IBM-compatible PC, image processing programs, general utilities, and text files. E-mail can be exchanged between schools in different parts of the country, and between high schools and the university. As already demonstrated in two California high schools, student response is extremely positive, and students are excited about coming to class and looking for their e-mail messages!

In the longer term we may be able to support one hundred or more schools on our system. It is hoped that participating schools will work towards developing common curricula, thus allowing a larger number of teachers to participate, and making it easier for new teachers to implement this technology in their classrooms. Our system provides a very natural way to distribute curricula and images together.

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