# ASTROMETRIC, PHOTOMETRIC, AND SPECTROSCOPIC OBSERVATIONS OF TRUMPLER 37 in the 1980's and early 1990's

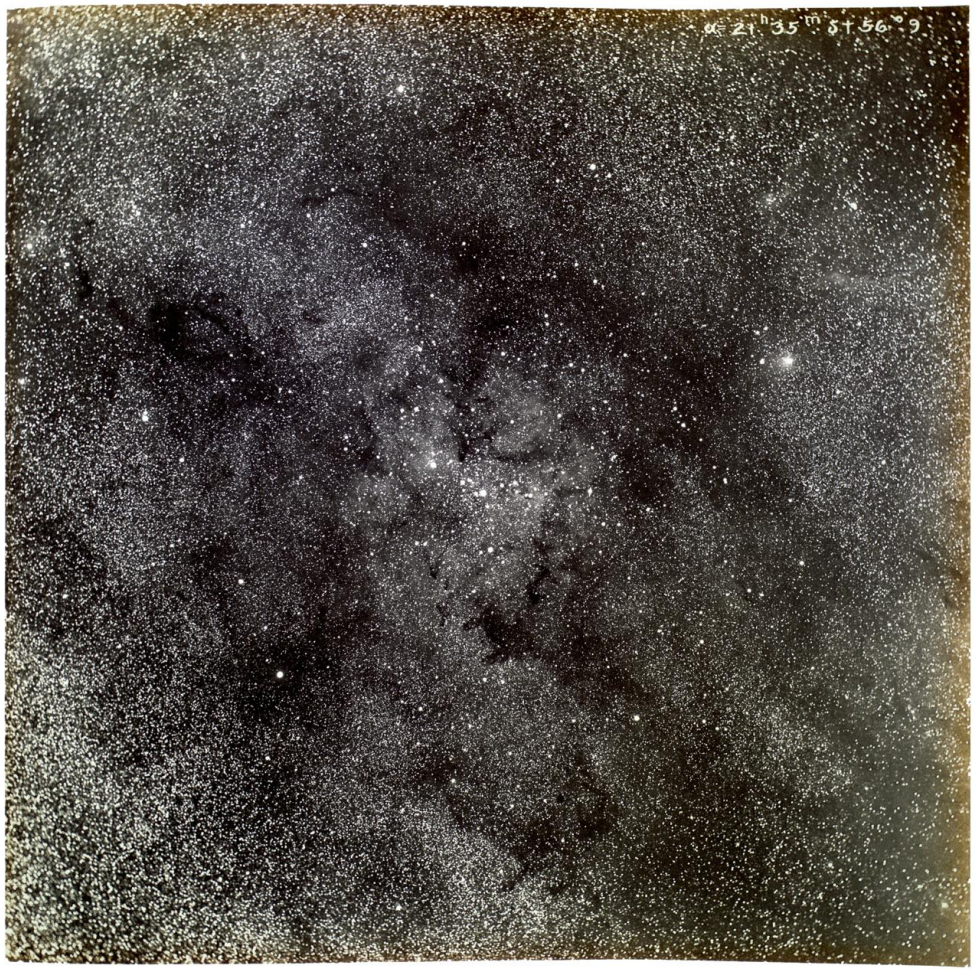
## . . .with a coda on the Gettysburg College Observatory

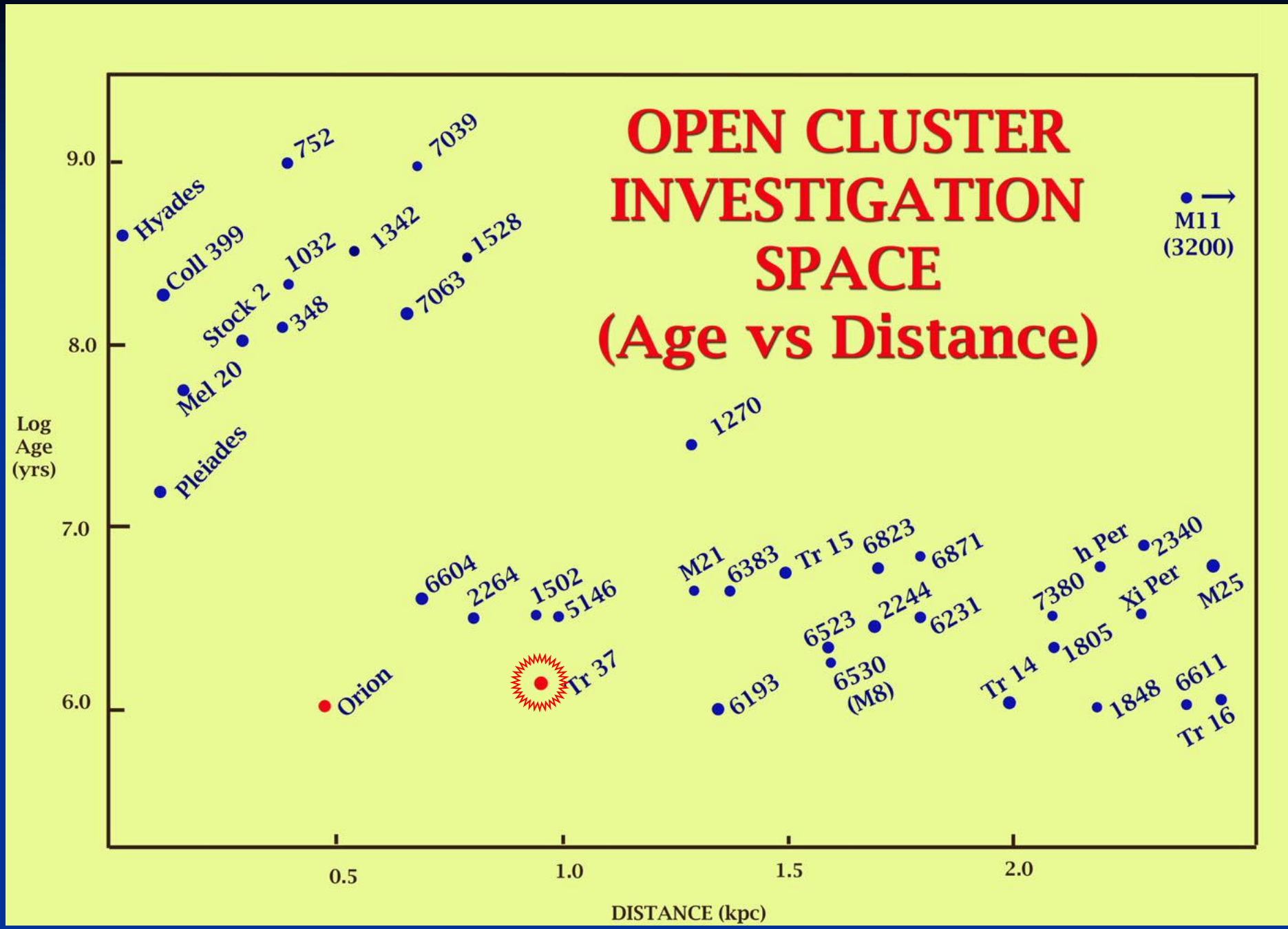
Larry Marschall, Gettysburg College
Gettysburg, Pennsylvania, 17325 USA

# WHY STUDY TR37?

- Possibly the nearest youngest clusters next to Orion
- Similar in size, age, and structure to the Rosette Nebula, NGC 2244
- Central star HD206267 is "Trapezium-like"
- Central cluster of HII region IC 1396 at heart of Ceph OB 2 Association

" The very center of these nebulous masses is gritty with small stars which are entirely free of nebulosity. All around this stars for some distance are veiled in nebulosity"---Barnard Milky Way Atlas, plate 49 [1927]




OPEN CLUSTER INVESTIGATION SPACE (Age vs Distance)
Log Age (yrs)
9.0
8.0
7.0
6.0
0.5
1.0
1.5
2.0
DISTANCE (kpc)
Hyades
752
7039
Coll 399
1342
Stock 2
1032
1528
348
7063
Mel 20
Pleiades
1270
M11 (3200)
6604
2264
1502
5146
M21
6383
Tr 15
6823
6871
h Per
2340
7380
Xi Per
M25
6523
2244
6231
1805
Tr 14
Orion
Tr 37
6193
6530 (M8)
1848
6611
Tr 16

# FIRST ASTROMETRIC STUDY 1987

- Data from 7 overlapping fields covering roughly 1.5° total
- Plates taken at Yerkes Observatory, 1937 and 1973
- Positions for 1385 Stars
- Proper motions and cluster membership probabilities for 1187 Stars

THE ASTRONOMICAL JOURNAL VOLUME 94, NUMBER 1 JULY 1987

## MEMBERSHIP IN THE YOUNG CLUSTER TRUMPLER 37

LAURENCE A. MARSCHALL
Department of Physics, Gettysburg College, Gettysburg, Pennsylvania 17325

WILLIAM F. VAN ALTENA
Yale University Observatory, New Haven, Connecticut 06511

*Received 5 March 1987; revised 3 April 1987*

ABSTRACT

Astrometric positions for 1387 stars and proper motions for a subset of 1135 stars brighter than $V = 15$ in a 1.5° field surrounding the young open cluster Trumpler 37 are presented. Membership probabilities are presented for those stars with measured proper motions, and 486 stars with probabilities of $> 80\%$ are identified.

### I. INTRODUCTION

The open cluster Trumpler 37 (Co 2137 + 572, $l = 99.3°$, $b = 3.73°$), identified as the nucleus of the Cepheus OB 2 association (Simonson 1968), is one of the very youngest clusters ($\log \tau < 6.5$), and its distance of less than 1 kpc makes it also one of the nearest of its age group. Yet it has received little attention in studies of stellar evolution compared to other clusters of comparable ages such as IC 1805, NGC 2244, NGC 2264, and NGC 6530 (Lynga 1985). Of these, it most nearly resembles NGC 2244, which is embedded in the central "hole" of the Rosette Nebula. Tr 37 similarly lies in a region of reduced emission surrounded by the H II region IC 1396. Barnard's Milky Way atlas (1927) describes it thus: "The very center of these nebulous masses is gritty with small stars which are entirely free of nebulosity. All around this stars for some distance are veiled in nebulosity." On the Palomar Sky Survey red photograph, the nebula appears exceedingly Rosette-like, and though it is larger in angular size, this is primarily due to the greater distance of the Rosette. Actually, both the nebula and the cluster are quite comparable to the Rosette in physical extent. A number of recent radio studies of IC 1396 have noted this similarity (Wendker and Baars 1980; Heske and Wendker 1986).

As listed in Lynga's cluster catalog, both NGC 2244 and Tr 37 show similar amounts of visual absorption, about 1.5 mag. The relative neglect of Tr 37 by astronomers to date may be due in part to its general lack of concentration, accentuated by its larger angular extent on the sky. Lynga classifies Tr 37 as a Trumpler class IV object, less distinct from the background than NGC 2244, which he assigns a Trumpler class II. In his original survey of clusters, Trumpler (1930) assigned them both to class IV, and noted that Tr 37 seems to be a more populous grouping of stars.

The central star of the cluster, HD 206267, was included in a recent study of "Trapezium-like" systems by Abt (1986). It is one of the youngest examples of these multiple-star systems, which Abt likens to the Trapezium ($\theta^1$ Orionis) in having components of nearly identical separation. Though not quite as complex and active a region as Orion, the interaction between stars and gas is still quite evident in the vicinity of the cluster (Wendker and Baars 1980). That, together with the relative youth and proximity of Trumpler 37, promises interesting results for studies of the early evolution of stars. However, fundamental observational data is spotty.

Alksinis (1958) has published an extensive set of magnitudes ($m_{pg}$) and approximate spectral types (no luminosity classes are given) for stars in the Cepheus region, including about a hundred members of the cluster, but these have not been tied to photoelectric *UBV* sequences or modern MK spectral types. Only a few of the brighter stars in the cluster were included in a spectroscopic and photometric study of the Cepheus association by Simonson (1968). The only focused scrutiny of the cluster remains the paper of Garrison and Kormendy (1976), who published MK classifications for 51 stars and photoelectric *UBV* photometry for 37 stars brighter than $V = 10.1$ in a region about 3° (48 pc) in diameter surrounding Tr 37. They derive a distance modulus of 9.9 for the cluster, and their earliest main-sequence spectral type of O6 indicates that the cluster is comparable in age ($2–4 \times 10^6$ yr) to the very youngest open clusters, such as NGC 2244 (Marschall *et al.* 1982) and NGC 6530 (van Altena and Jones 1972). The Garrison and Kormendy photometry has been supplemented by photoelectric *UBVRI* magnitudes of 26 fainter cluster stars $10.5 < V < 15.75$ by Cardon de Lichtbuer (1982). Most recently, Kun (1986) has identified 155 H$\alpha$ emission stars fainter than $V = 13$ in a 19.5 square degree field centered on Tr 37 (approximately the same coverage as Garrison and Kormendy), and has presented photographic *UBVR* magnitudes for them.

No comprehensive membership studies of the cluster have been undertaken previously. This study presents measurements of astrometric positions of 1387 stars along with proper motions for 1135 stars brighter than $V = 15$ within approximately 0.75° (12.5 pc) of the cluster center. The astrometric positions and membership probabilities for Tr 37 should establish a foundation for further photometric and spectroscopic studies of its member stars, adding to the roster of nearby young clusters suitable for studies of stellar evolution.

### II. PLATE MEASUREMENT AND REDUCTION

The plate material for this study consisted of 17 Yerkes plates covering seven overlapping fields centered on the star HD 206267 (R.A.(1950) = $21^h37^m24^s$, Dec. (1950) = 57°15′45″). Table I lists pertinent data for the plates, and Fig. 1 [Plate 5] shows the coverage of the overlapping fields. We refer to these as the center field, east field, northeast field, etc. All star images on the plates, a region roughly 1.5° in diameter, were measured using the PDS microdensitometer at Yale University Observatory. Positions and magnitudes for each image were reduced using a two-dimensional Gaussian fitting program written by Jin-Fuw Lee for the PDP 11/60 computer at Yale.

 0004-6256/87/010071-13$00.90  

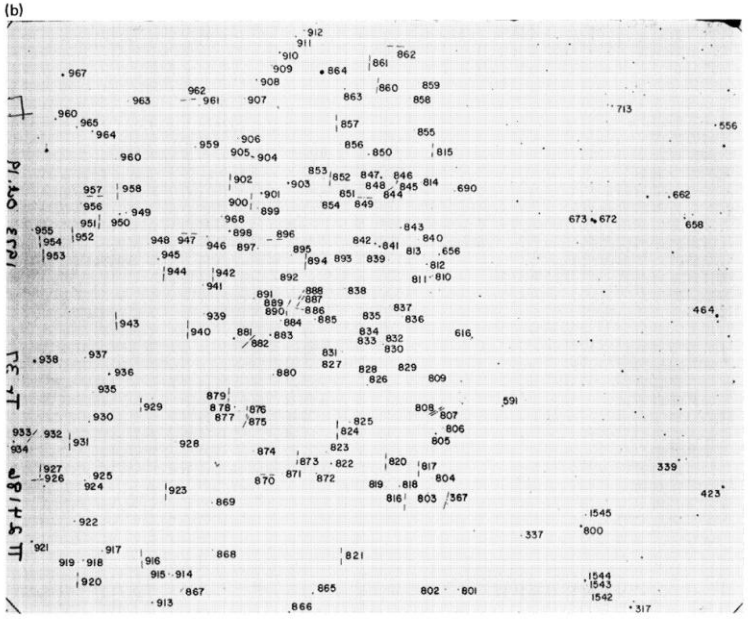
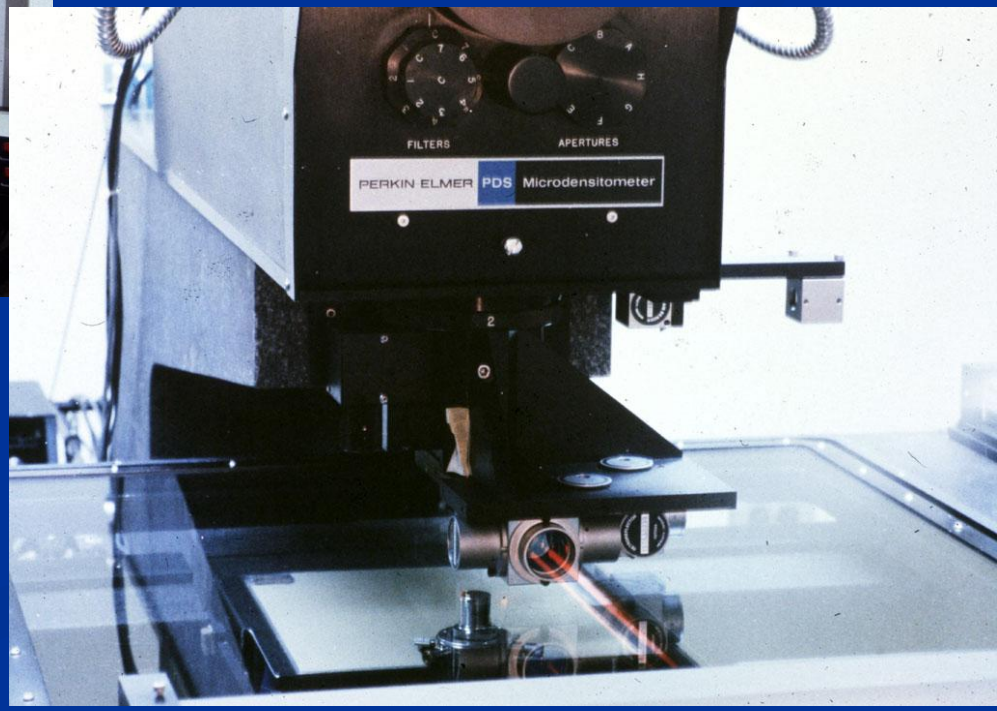


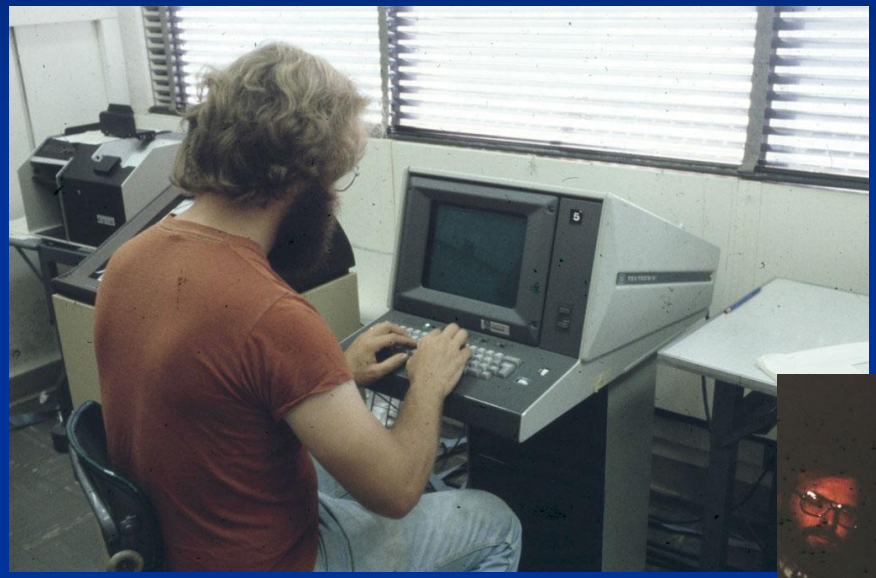

FIG. 4. (b) East field.

L. Marschall and W. van Altena (see page 73)

# MEASURING THE PLATES, 1980's
# THE YALE PDS MEASURING MACHINE

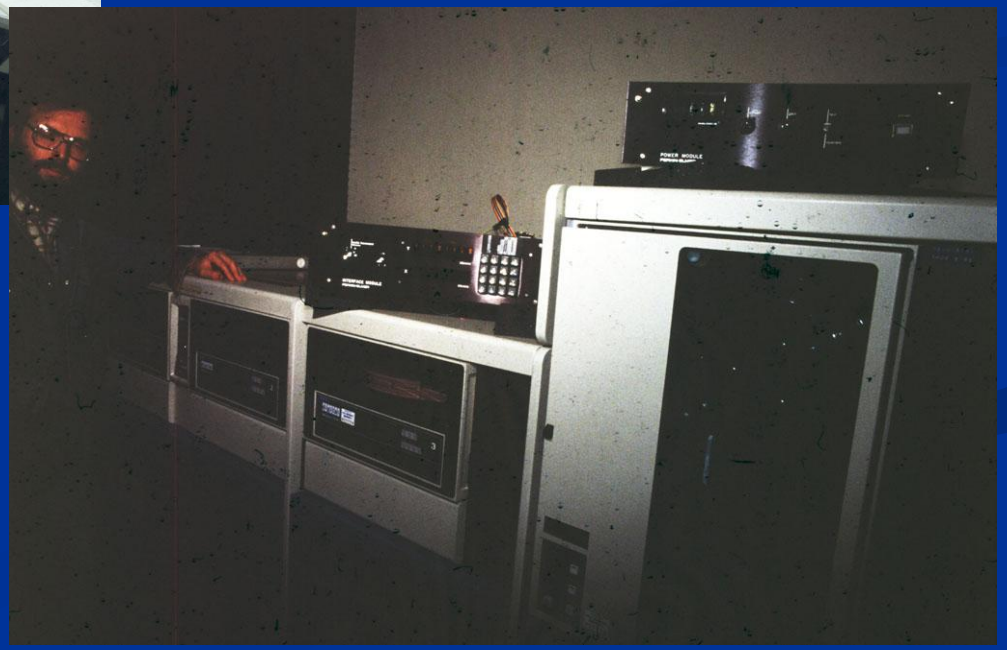


# MEASURING THE PLATES, 1980's
# THE YALE PDS MEASURING MACHINE



*THE TEK 4010 TERMINAL*

*THE VAX COMPUTER*



# PHOTOMETRIC STUDY 1990

THE ASTRONOMICAL JOURNAL VOLUME 99, NUMBER 5 MAY 1990

## PHOTOMETRY OF THE YOUNG OPEN CLUSTER TRUMPLER 37

LAURENCE A. MARSCHALL[a)]
Gettysburg College, Gettysburg, Pennsylvania 17325

NEIL F. COMINS[a)]
University of Maine, Orono, Maine 04469

GARY B. KARSHNER[a)]
Gettysburg College, Gettysburg, Pennsylvania 17325
*Received 2 October 1989; revised 19 January 1990*

ABSTRACT

Photoelectric *UBV* observations of 120 stars in the young open cluster Trumpler 37 are presented, primarily in the magnitude range $10.0 < V < 13.5$. An analysis of the color–magnitude diagram of the cluster yields an age of $6.7 \times 10^6$ yr and reveals the presence of a number of possible pre-main-sequence stars in the cluster.

### INTRODUCTION

Trumpler 37 (Co 2137 + 572, $l = 99.3°$, $b = 3.73°$), an open cluster associated with the H II region IC 1396, has been identified with the nucleus of the Cep OB2 Association (Simonson 1968). It is one of the very youngest of the open clusters in the Milky Way ($\log t < 7.0$), comparable in age NGC 2264, NGC 2244, IC 1805, and NGC 6530. Its hottest star, HD 206267, which excites the surrounding nebula, is classified as O6.5 V ((f)) by Walborn (Walborn and Panek 1984). This star, along with its nearby companions, has often been noted as a multiple system bearing a striking resemblance to the O stars in the Orion Trapezium (Abt 1986). Also like the Trapezium region, Tr 37 is embedded in a region of active star formation. It has long been identified as a T association, and Kun (1986), has identified a large number of faint emission stars in the vicinity, many of which may be low-mass, pre-main-sequence cluster members.

With a distance modulus of approximately 10.0 (Garrison and Kormendy 1976), Tr 37 would seem an inviting target for studies of early stellar evolution; but it has not yet drawn as much attention as NGC 2264 and the Orion Trapezium. Because Tr 37 is more diffuse than these clusters, as well as more distant, there is more confusion with other stars along the line of sight, and identification of bona fide members of Tr 37 has been difficult. Moreover, unlike the Trapezium, it has no dark absorbing cloud behind it to reduce confusion with background stars. In a recent proper-motion study of the cluster, Marschall and Van Altena (1987) identified 486 stars with kinematic membership probabilities greater than 80% within a 30 arcmin radius of HD 206267. These stars form a preliminary sample for studies of the physical characteristics of the cluster population.

Previous photometric and spectroscopic studies of the cluster are limited in number and depth. Garrison and Kormendy (1976) presented photoelectric UBV photometry for 37 stars and MK spectral classifications for 51 stars, all brighter than $V = 10.1$, in a region about 3' in diameter surrounding the cluster. Eleven of these stars were identified as members by Marschall and Van Altena. Cardon de Lichtbuer (1982) supplemented this photometry with photoelectric *UBVRI* magnitudes of 26 fainter cluster stars in the magnitude range $10.5 < V < 15.75$. More recently, Kun (1986) has conducted an objective prism search for emission stars in the region covered by Garrison and Kormendy, along with photographic photometry of 155 stars fainter than approximately $V = 13.5$. Only 15 of these were common to Marschall and Van Altena's study, seven of which appear to be cluster members. Most recently Clayton and Fitzpatrick (1987) obtained *IUE* spectra of 17 stars from the list of Garrison and Kormendy and derived ultraviolet extinction curves from their data.

In Kun's color–magnitude diagram of the Tr 37 stars (which includes the data of Garrison and Kormendy), there is a conspicuous gap in the sampling between $V = 10.0$ and $V = 13.5$. The present paper reports on UBV photometry of 120 stars, selected from Marschall and Van Altena's probable members, and lying primarily in this magnitude range. These data, combined with the previous photometric data, enable us to construct a more complete color–magnitude diagram for Tr 37, permitting an estimate of the cluster age and revealing the presence of a population of stars above the lower end of the main sequence which may be possible pre-main-sequence cluster members.

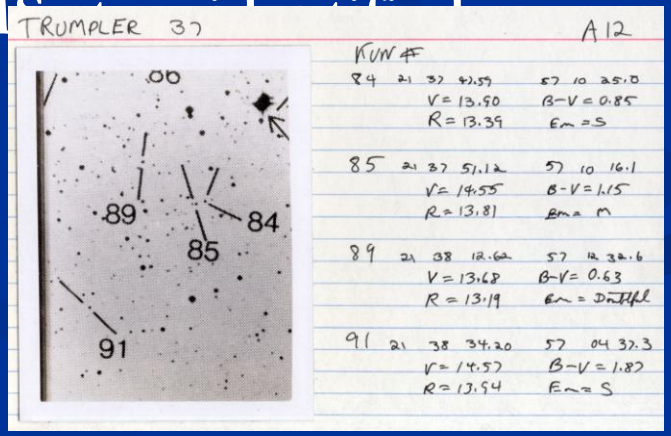
### OBSERVATIONS

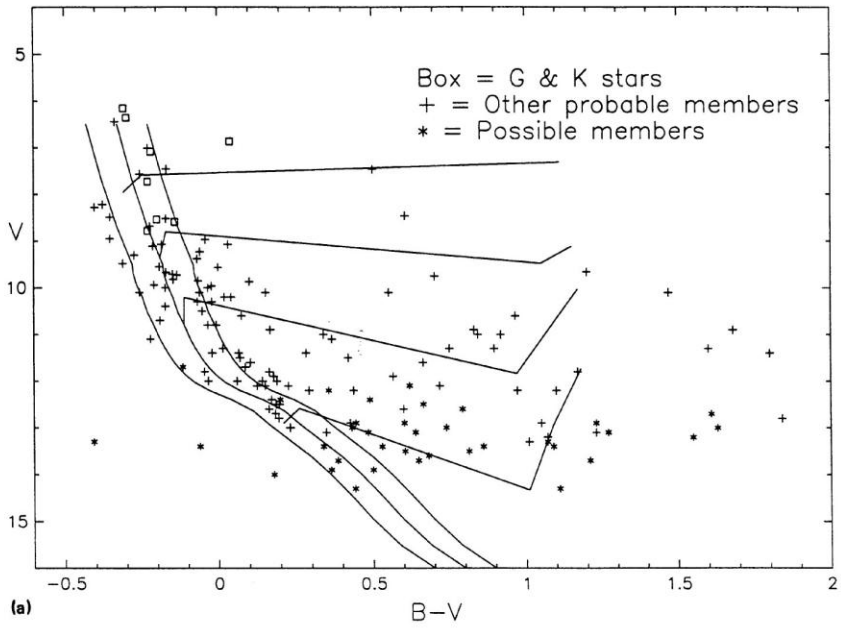
Photoelectric photometry was carried out on the Kitt Peak 1.3 m telescope equipped with the Mark III automated photometer on 29, 30, and 31 October 1986, and on the Kitt Peak No. 2 0.9 m telescope equipped with the Automated Filter Photometer on 11 October 1985. Additional observations of about 20 stars were obtained using the 1.3 m on 22 December 1987 and the No. 2 0.9 m on 4 and 6 November 1988. Standard *UBVRI* filters were used. Between one and two dozen stars from Landolt's lists of equatorial standards (Landolt 1973, 1983) were observed every night, covering a range of colors and at a range of airmasses sufficient to derive both extinction and transformation equations simultaneously for each night's observations using standard least-squares techniques. Only during the 1987 and 1988 observing runs were standard stars chosen specifically from Landolt's second list, which includes *R* and *I* measurements as well as

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by AURA, Inc., under contract with the National Science Foundation.

 0004-6256/90/051536-12$00.90  

- Observations using Mark II Aperture Photometer of the KPNO 50" telescope
- Absolute UBV photometry of 120 Stars
- Population of possible PM





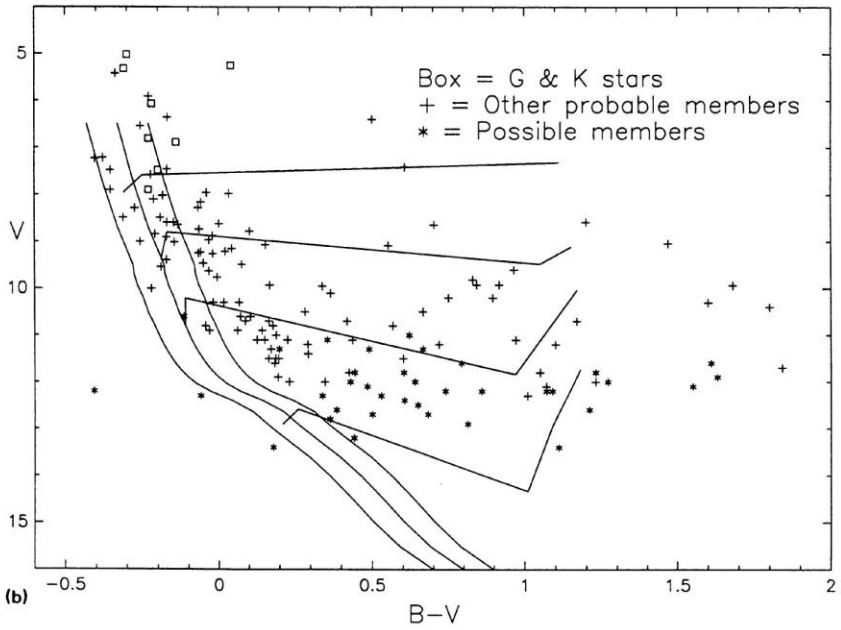




FIG. 4.(a) Color–magnitude diagram for Trumpler 37 dereddened using color excesses interpolated from the isoreddening contours of Fig. 3 with a ratio of total to selective absorption $R = 3.0$. The ZAMS (flanked by lines showing offsets from the ZAMS of $\pm 0.1$ in $B - V$) and pre-main-sequence contraction tracks used to calculate the age of the cluster are shown. (b) Color–magnitude diagram for Trumpler 37 dereddened using color excesses interpolated from the isoreddening contours of Fig. 3 with a ratio of total to selective absorption $R = 5.0$. As in (a), the ZAMS and pre-main-sequence contraction tracks used to calculate the age of the cluster are shown.

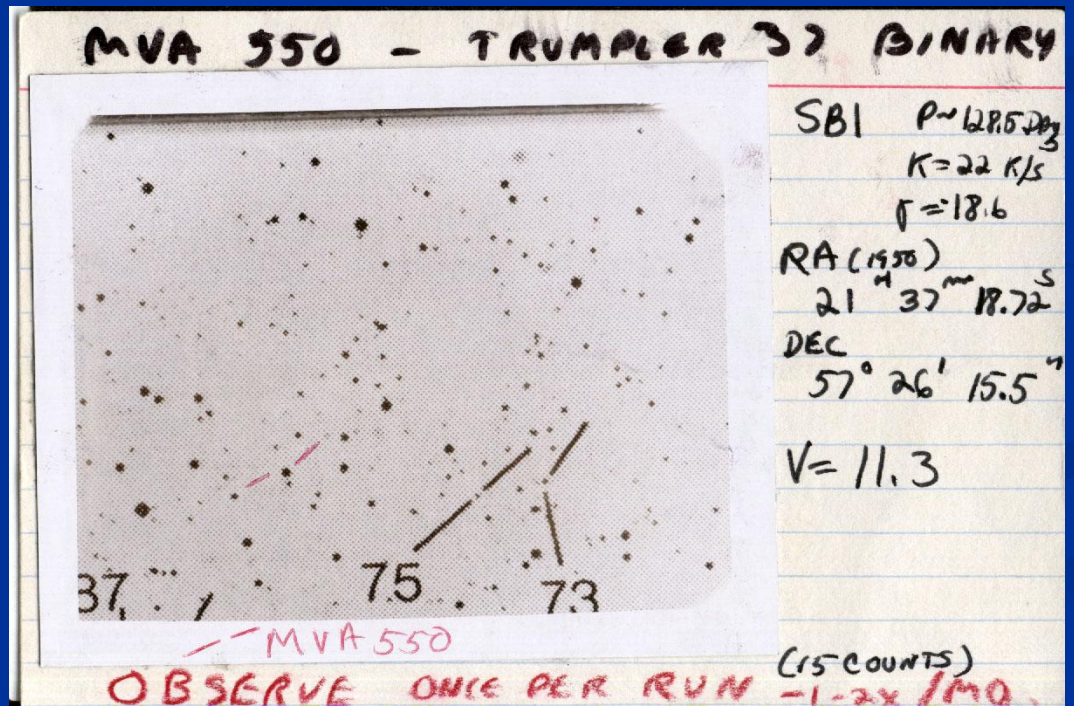
# PHOTOMETRIC STUDY 1990

- HR Diagram Fitting Age of $6.7 \times 10^6$ years.

# RADIAL VELOCITY MEASUREMENTS OF Tr 37

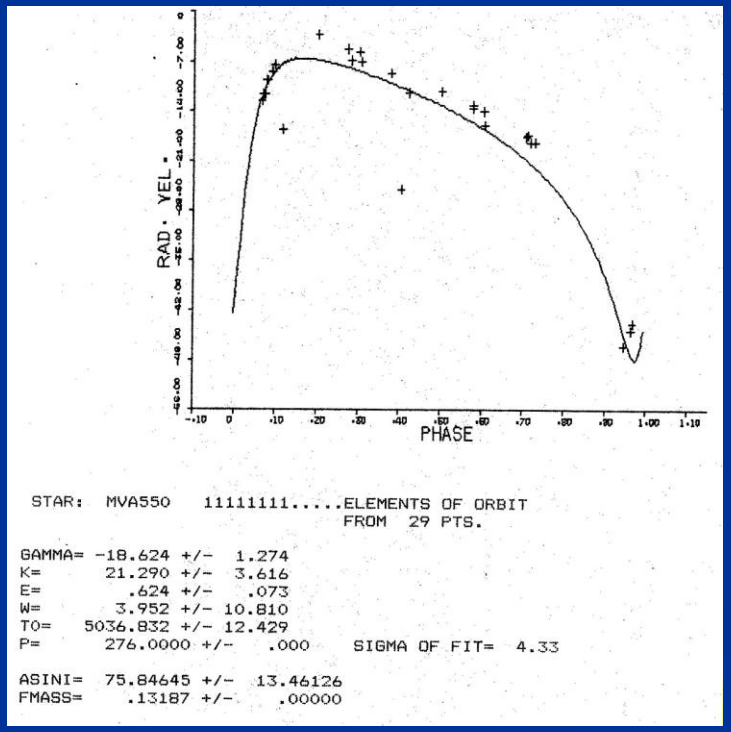
## (Preliminary RV Survey in 1987 by L. Marschall)

- Using the 1.5m Tillinghast Telescope on Mt. Hopkins, AZ; Echelle Spectrograph---L. Marschall, D. Latham, R. Mathieu
- Mean Heliocentric RV of cluster members ~ -16 k/s
- 2 Binary Candidates discovered: MVA 234 and MVA 550



# SPECTROSCOPIC BINARIES IN Tr 37 (Preliminary solns 1987 by L. Marschall)

- Using the 1.5m Tillinghast Telescope on Mt. Hopkins, AZ; Echelle Spectrograph---L. Marschall, D. Latham, R. Mathieu
- Mean Heliocentric RV of members ~ -16 k/s

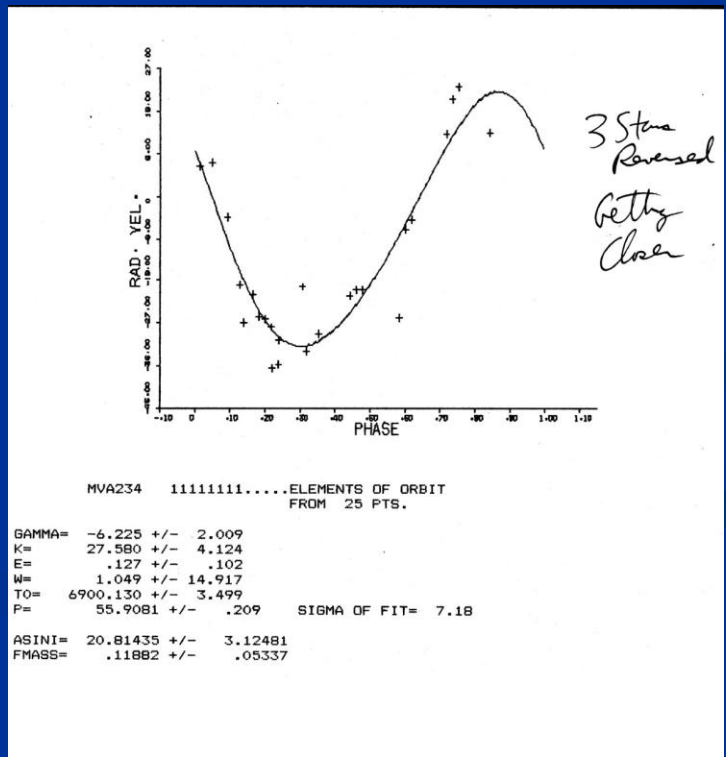



STAR: MVA550 11111111.....ELEMENTS OF ORBIT
FROM 29 PTS.

| | | | |
|---|---|---|---|
| GAMMA= | -18.624 | +/- | 1.274 |
| K= | 21.290 | +/- | 3.616 |
| E= | .624 | +/- | .073 |
| W= | 3.952 | +/- | 10.810 |
| T0= | 5036.832 | +/- | 12.429 |
| P= | 276.0000 | +/- | .000 |

SIGMA OF FIT= 4.33

| | | | |
|---|---|---|---|
| ASINI= | 75.84645 | +/- | 13.46126 |
| FMASS= | .13187 | +/- | .00000 |




MVA234 11111111.....ELEMENTS OF ORBIT
FROM 25 PTS.

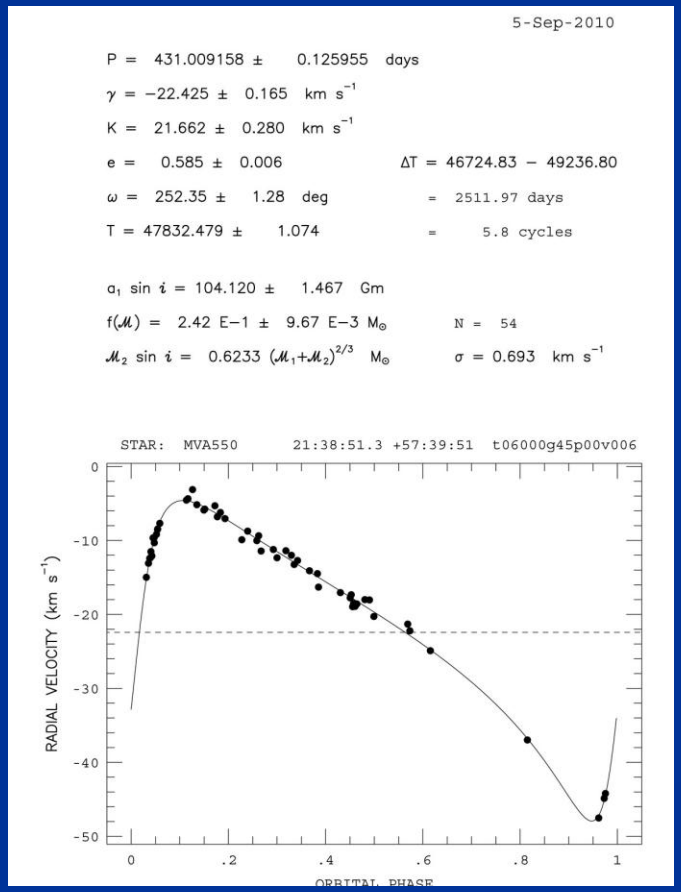
| | | | |
|---|---|---|---|
| GAMMA= | -6.225 | +/- | 2.009 |
| K= | 27.580 | +/- | 4.124 |
| E= | .127 | +/- | .102 |
| W= | 1.049 | +/- | 14.917 |
| T0= | 6900.130 | +/- | 3.499 |
| P= | 55.9081 | +/- | .209 |

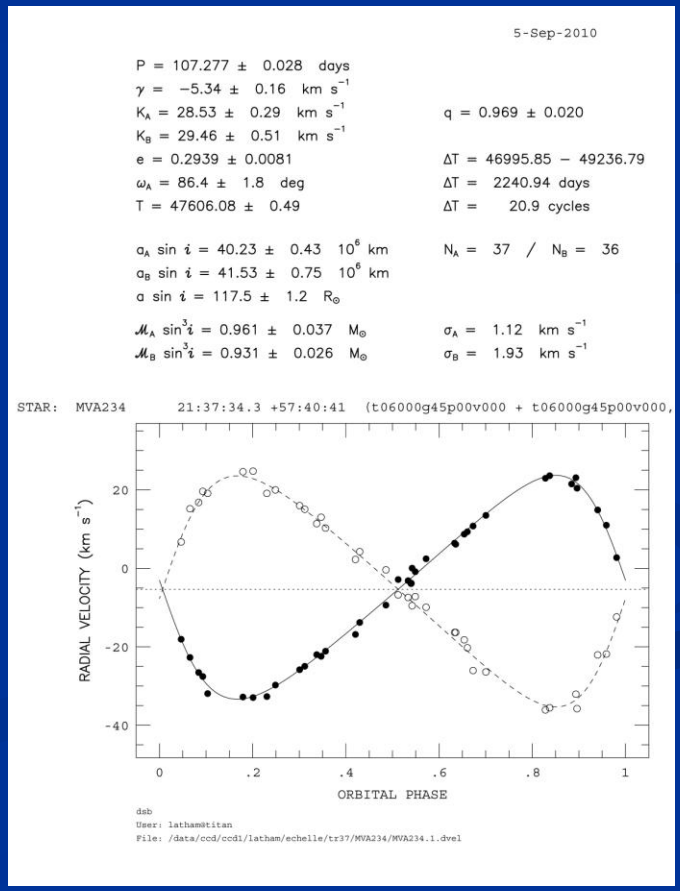
SIGMA OF FIT= 7.18

| | | | |
|---|---|---|---|
| ASINI= | 20.81435 | +/- | 3.12481 |
| FMASS= | .11882 | +/- | .05337 |

# RADIAL VELOCITY OBSERVATIONS OF BINARIES IN TR 37….2010 Update

- **Preliminary Solutions by Dave Latham**
- **More observations, improved crosscorrelation and fitting software (Todcor, synthetic spectrum library, etc).**



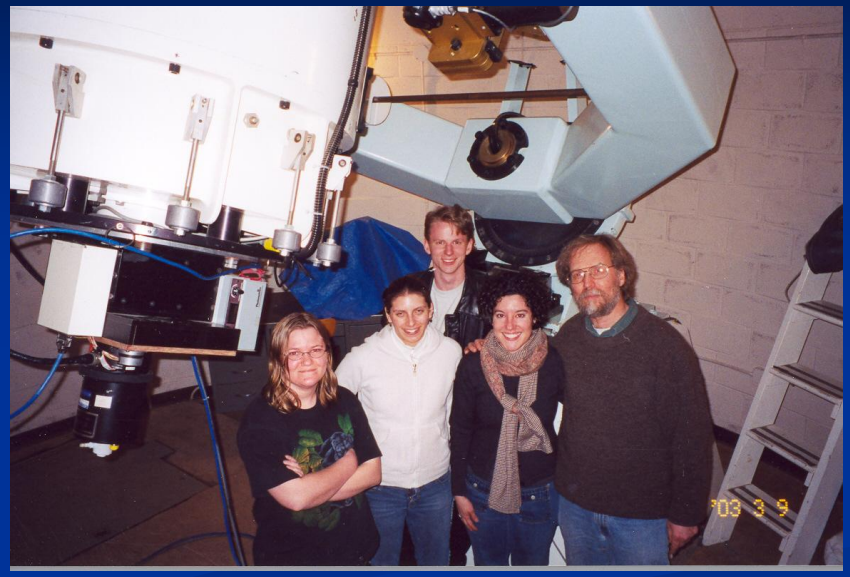
# OBSERVING FACILITIES USED BY GETTYSBURG COLLEGE

- The Gettysburg College Observatory
  - 0.4m Reflector on Campus
  - Available every clear night
- The National Undergraduate Research Observatory
  - 0.9m Reflector on Anderson Mesa, Flagstaff, AZ, owned by Lowell Observatory.
  - Guaranteed 2 weeks time, either on site or service observing as member of NURO consortium.

# The Lowell 32-inch Telescope On Anderson Mesa, Flagstaff, Arizona

National Undergraduate Research Observatory

# Gettysburg Students And Faculty at the NURO 0.9 m



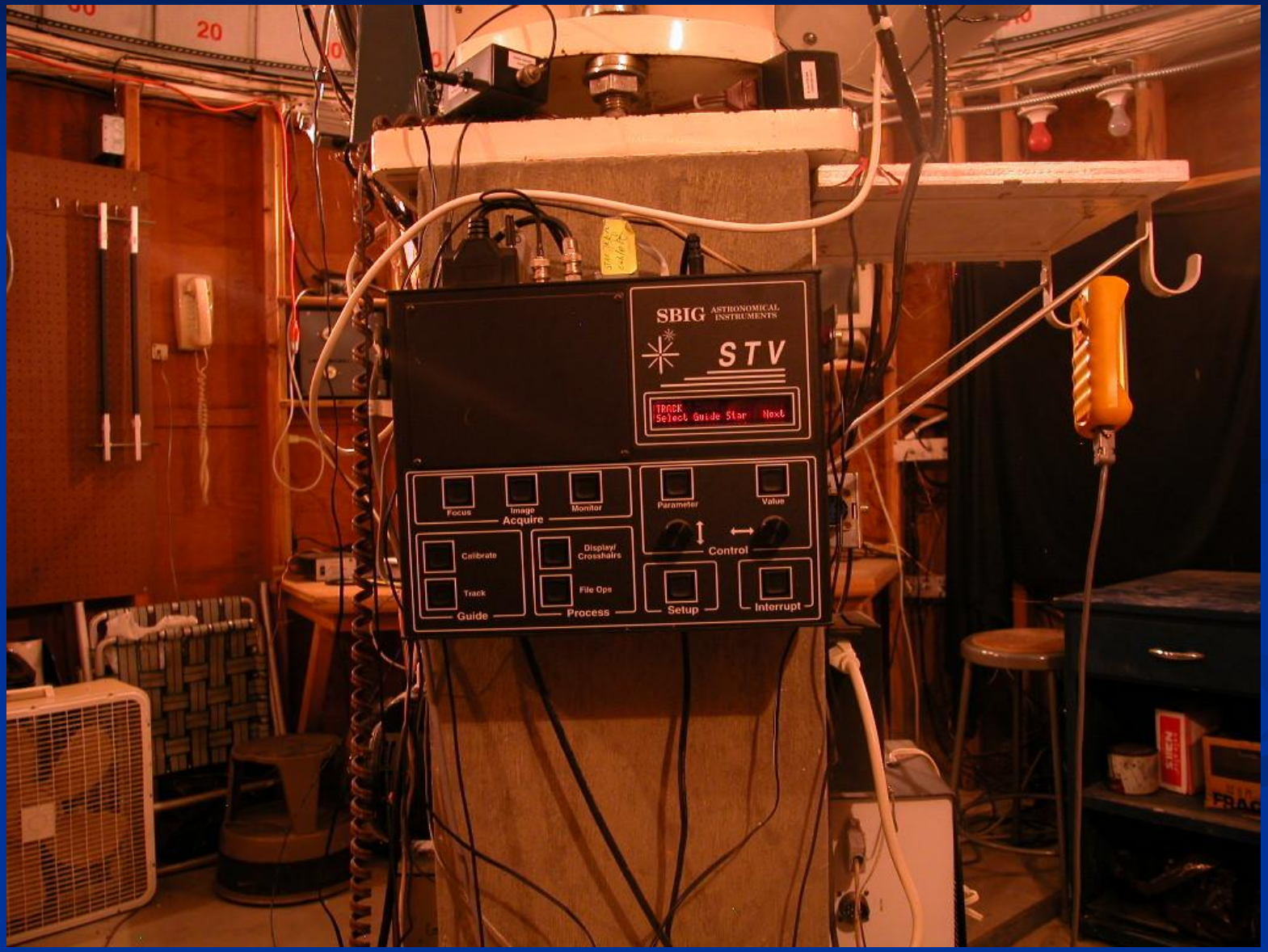

# Gettysburg College Observatory view from the southeast

# THE GCO 16” REFLECTOR

- F/11 0.4 m
- Mfr. Ealing, 1968
- Upgrade by ACE, Tucson, 1996, 2010
- Camera: Photometrics 350; TE Cooled; High Speed readout
- Chip: SiTE 003B 1024 x 1024 pixels
- ACE 2-wheel filter box; 16 slots
- STV-Offset Guider

# Camera and Filter Box

# SBIG STV Automatic Guider

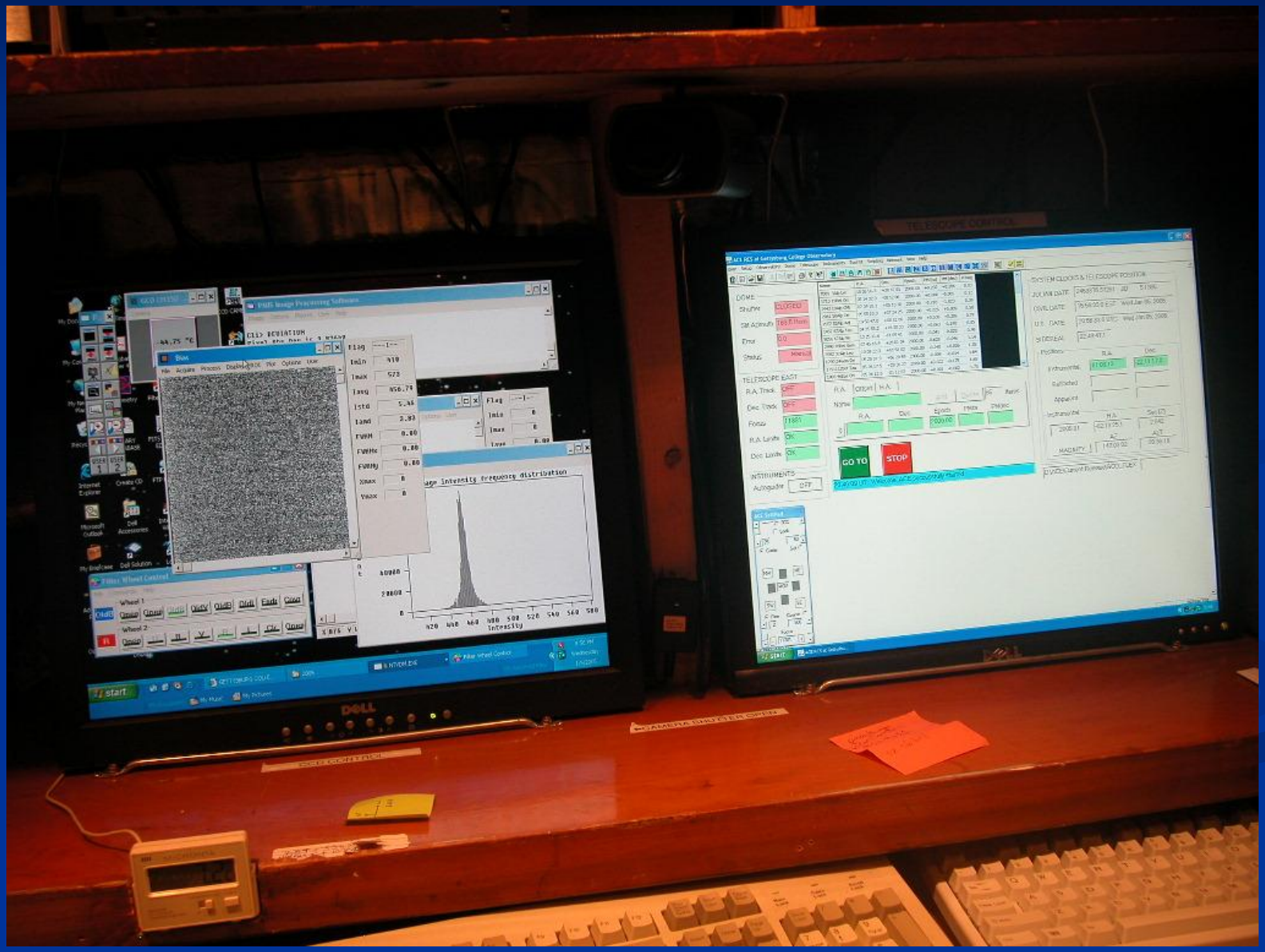


# Warm Room Controls and Hardware

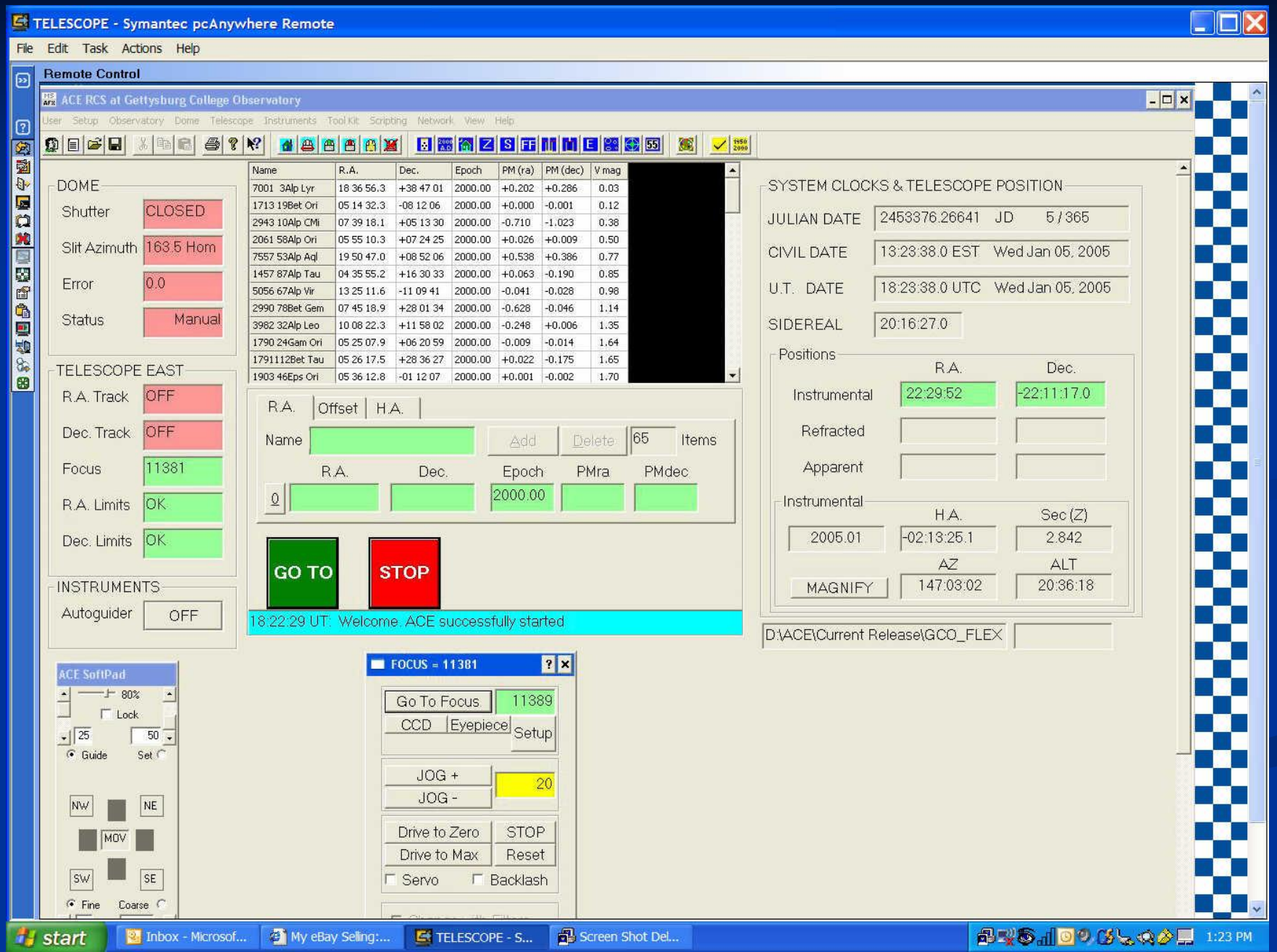
# Astronomer's View of the Controls

# Guider and CCD controls

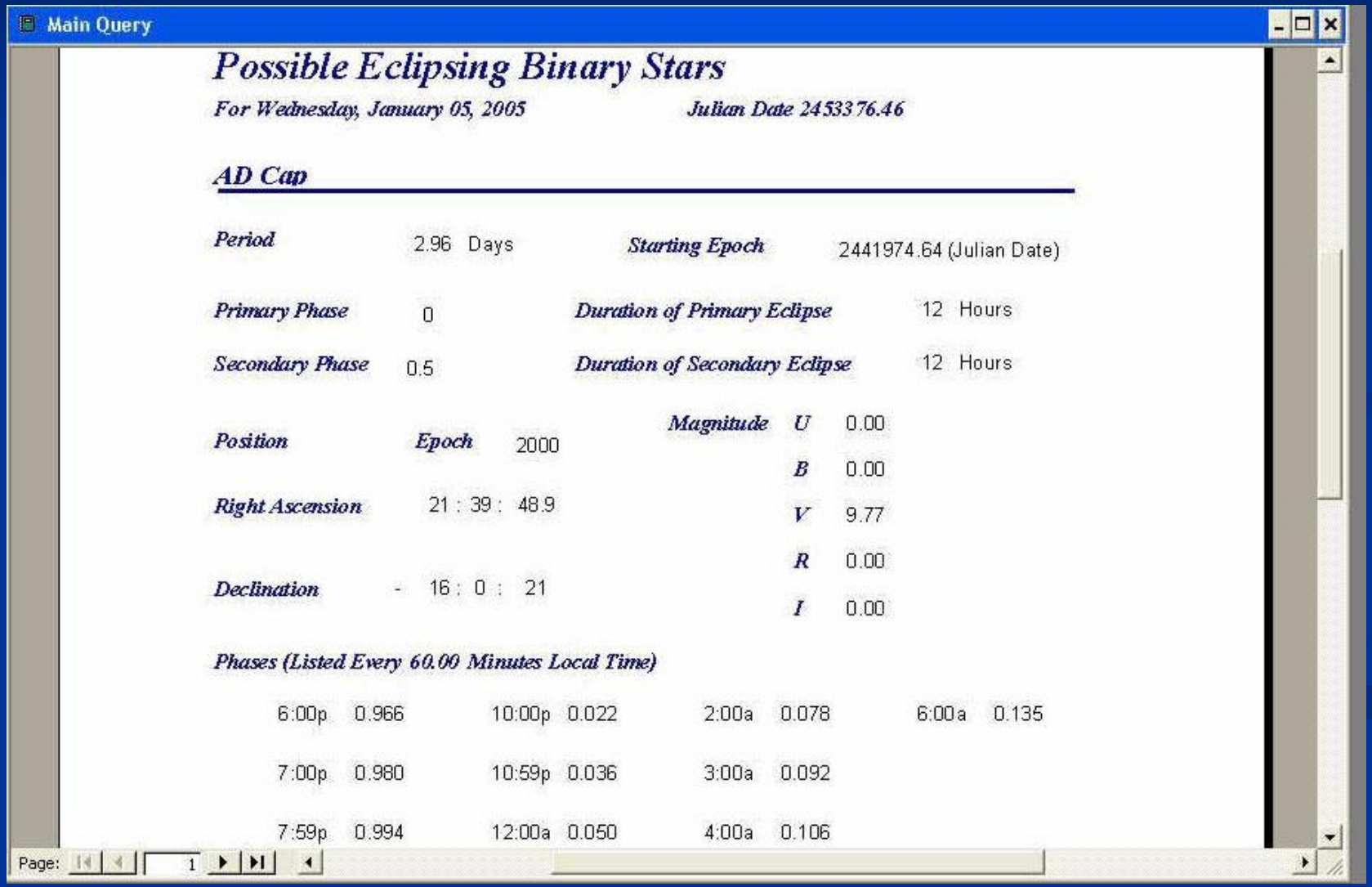
# CCD and Telescope Controls



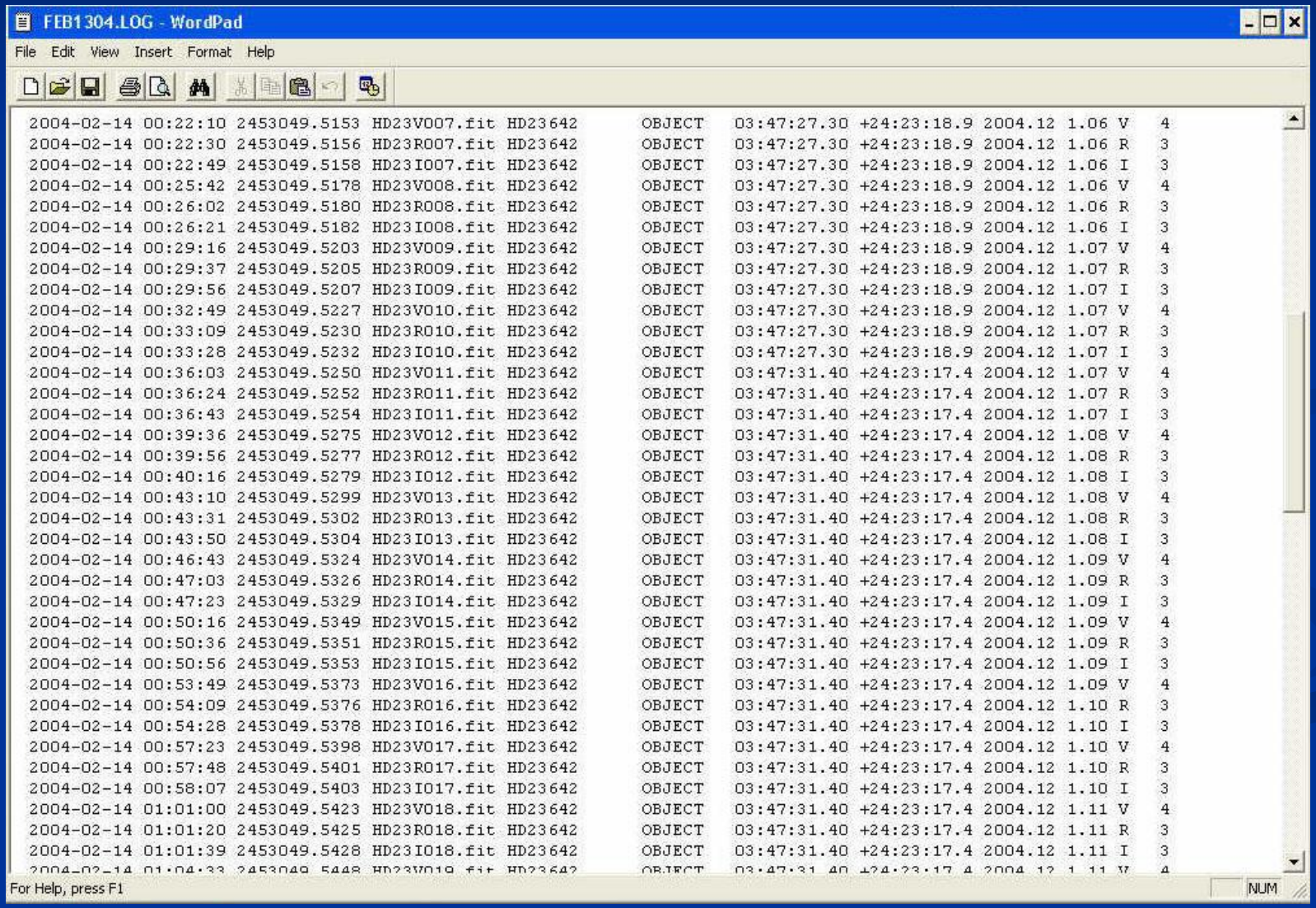
# The ACE Telescope Control Screen



# Observing Aids: Phase predictor for eclipsing Binary Stars



# Automatic Image Data Logging



FEB1304.LOG - WordPad

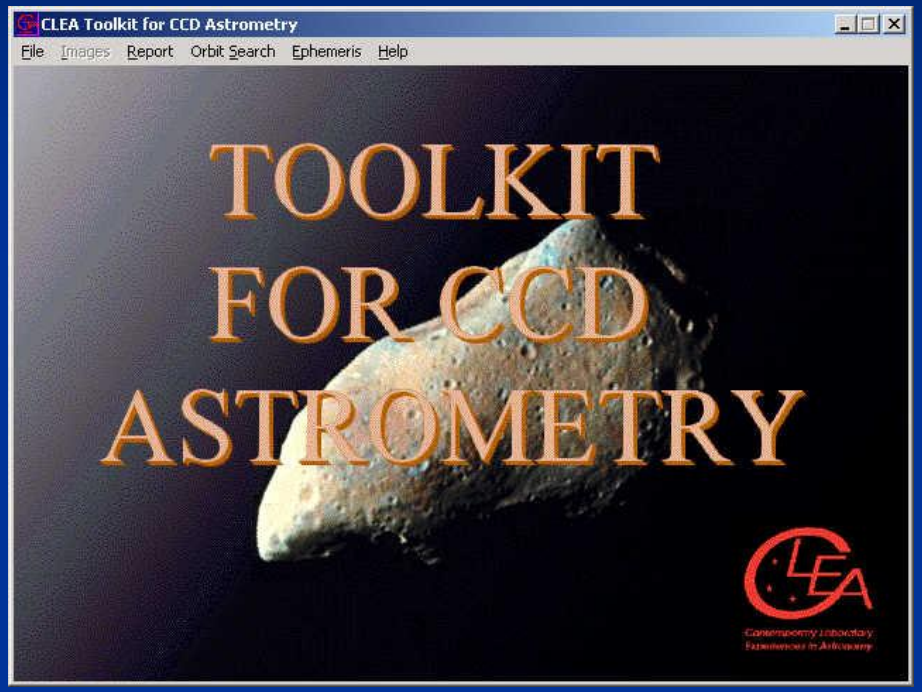
File Edit View Insert Format Help

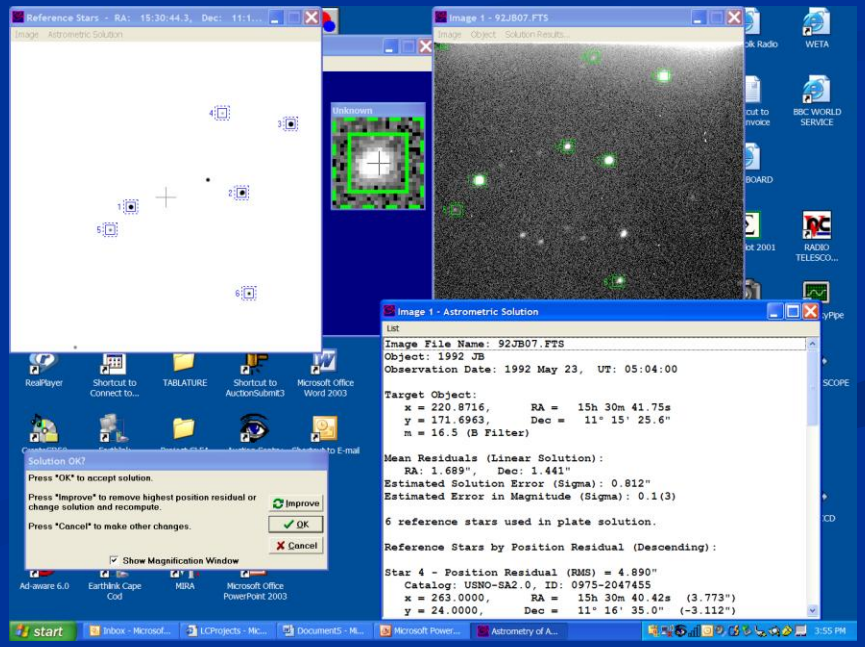
```
2004-02-14 00:22:10 2453049.5153 HD23V007.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 V   4
2004-02-14 00:22:30 2453049.5156 HD23R007.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 R   3
2004-02-14 00:22:49 2453049.5158 HD23I007.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 I   3
2004-02-14 00:25:42 2453049.5178 HD23V008.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 V   4
2004-02-14 00:26:02 2453049.5180 HD23R008.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 R   3
2004-02-14 00:26:21 2453049.5182 HD23I008.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.06 I   3
2004-02-14 00:29:16 2453049.5203 HD23V009.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 V   4
2004-02-14 00:29:37 2453049.5205 HD23R009.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 R   3
2004-02-14 00:29:56 2453049.5207 HD23I009.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 I   3
2004-02-14 00:32:49 2453049.5227 HD23V010.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 V   4
2004-02-14 00:33:09 2453049.5230 HD23R010.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 R   3
2004-02-14 00:33:28 2453049.5232 HD23I010.fit HD23642      OBJECT   03:47:27.30 +24:23:18.9 2004.12 1.07 I   3
2004-02-14 00:36:03 2453049.5250 HD23V011.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.07 V   4
2004-02-14 00:36:24 2453049.5252 HD23R011.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.07 R   3
2004-02-14 00:36:43 2453049.5254 HD23I011.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.07 I   3
2004-02-14 00:39:36 2453049.5275 HD23V012.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 V   4
2004-02-14 00:39:56 2453049.5277 HD23R012.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 R   3
2004-02-14 00:40:16 2453049.5279 HD23I012.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 I   3
2004-02-14 00:43:10 2453049.5299 HD23V013.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 V   4
2004-02-14 00:43:31 2453049.5302 HD23R013.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 R   3
2004-02-14 00:43:50 2453049.5304 HD23I013.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.08 I   3
2004-02-14 00:46:43 2453049.5324 HD23V014.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 V   4
2004-02-14 00:47:03 2453049.5326 HD23R014.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 R   3
2004-02-14 00:47:23 2453049.5329 HD23I014.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 I   3
2004-02-14 00:50:16 2453049.5349 HD23V015.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 V   4
2004-02-14 00:50:36 2453049.5351 HD23R015.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 R   3
2004-02-14 00:50:56 2453049.5353 HD23I015.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 I   3
2004-02-14 00:53:49 2453049.5373 HD23V016.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.09 V   4
2004-02-14 00:54:09 2453049.5376 HD23R016.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.10 R   3
2004-02-14 00:54:28 2453049.5378 HD23I016.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.10 I   3
2004-02-14 00:57:23 2453049.5398 HD23V017.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.10 V   4
2004-02-14 00:57:48 2453049.5401 HD23R017.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.10 R   3
2004-02-14 00:58:07 2453049.5403 HD23I017.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.10 I   3
2004-02-14 01:01:00 2453049.5423 HD23V018.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.11 V   4
2004-02-14 01:01:20 2453049.5425 HD23R018.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.11 R   3
2004-02-14 01:01:39 2453049.5428 HD23I018.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.11 I   3
2004-02-14 01:04:33 2453049.5448 HD23V019.fit HD23642      OBJECT   03:47:31.40 +24:23:17.4 2004.12 1.11 V   4
```

For Help, press F1

NUM

# Software to Blink and Measure Asteroids

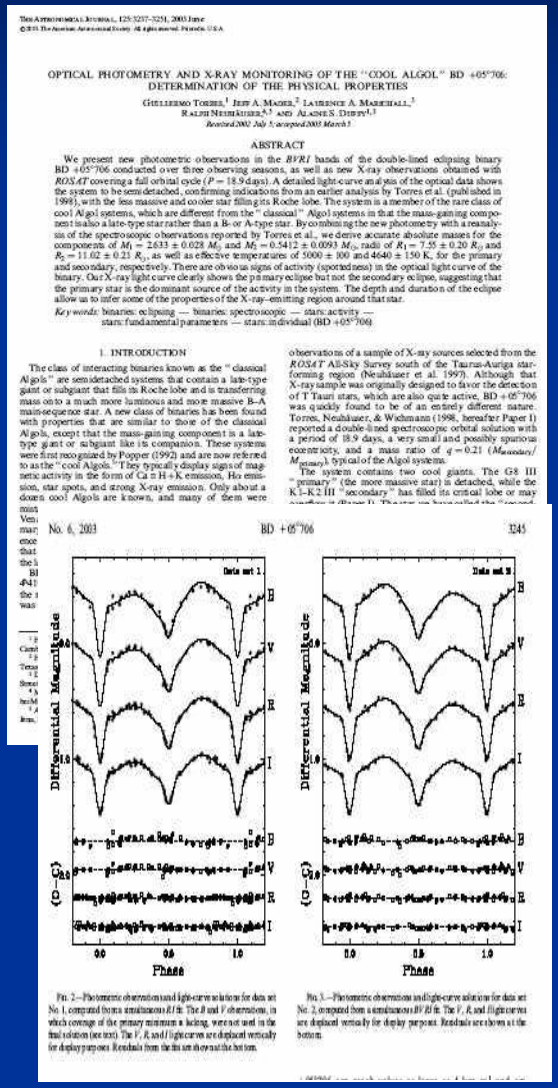


# OBSERVING PROJECTS

- **FACULTY-STUDENT RESEARCH**
  - **Astrometry of critical list asteroids**
  - **Photometry of Eclipsing Binary Stars --- collaboration with G. Torres, et al, CFA**
  - **Target of Opportunity Light curves of bright supernova**
  - **Transits of Extrasolar Planets**
- **ADVANCED PHYSICS LAB EXERCISES**
  - **CCD photometry of short period variables (δ Scuti, SX Phe)**
  - **Astrometry of bright asteroids**

# Photometry of Eclipsing Binaries and Bright Supernovas



OPTICAL PHOTOMETRY AND X-RAY MONITORING OF THE "COOL ALGOL" BD +05°706: DETERMINATION OF THE PHYSICAL PROPERTIES

GUILLERMO TORRES,[1] JEFF A. MADER,[2] LAURENCE A. MARSCHALL,[3] RALPH NEUHÄUSER,[4,5] AND ALAINE S. DEMPSEY[1,3]

*Received 2002 July 5; accepted 2003 March 5*

ABSTRACT

We present new photometric observations in the *BVRI* bands of the double-lined eclipsing binary BD +05°706 conducted over three observing seasons, as well as new X-ray observations obtained with *ROSAT* covering a full orbital cycle ($P = 18.9$ days). A detailed light-curve analysis of the optical data shows the system to be semi-detached, confirming indications from an earlier analysis by Torres et al. (published in 1998), with the less massive and cooler star filling its Roche lobe. The system is a member of the rare class of cool Algol systems, which are different from the "classical" Algol systems in that the mass-gaining component is also a late-type star rather than a B- or A-type star. By combining the new photometry with a reanalysis of the spectroscopic observations reported by Torres et al., we derive accurate absolute masses for the components of $M_1 = 2.633 \pm 0.028\ M_\odot$ and $M_2 = 0.5412 \pm 0.0093\ M_\odot$, radii of $R_1 = 7.55 \pm 0.20\ R_\odot$ and $R_2 = 11.02 \pm 0.21\ R_\odot$, as well as effective temperatures of $5000 \pm 100$ and $4640 \pm 150$ K, for the primary and secondary, respectively. There are no obvious signs of activity (spottedness) in the optical light curve of the binary. Our X-ray light curve clearly shows the primary eclipse but not the secondary eclipse, suggesting that the primary star is the dominant source of the activity in the system. The depth and duration of the eclipse allow us to infer some of the properties of the X-ray–emitting region around that star.

*Key words:* binaries: eclipsing — binaries: spectroscopic — stars: activity — stars: fundamental parameters — stars: individual (BD +05°706)

1. INTRODUCTION

The class of interacting binaries known as the "classical Algols" are semidetached systems that contain a late-type giant or subgiant that fills its Roche lobe and is transferring mass onto a much more luminous and more massive B–A main-sequence star. A new class of binaries has been found with properties that are similar to those of the classical Algols, except that the mass-gaining component is a late-type giant or subgiant like its companion. These systems were first recognized by Popper (1992) and are now referred to as the "cool Algols." They typically display signs of magnetic activity in the form of Ca II H+K emission, H$\alpha$ emission, star spots, and strong X-ray emission. Only about a dozen cool Algols are known, and many of them were

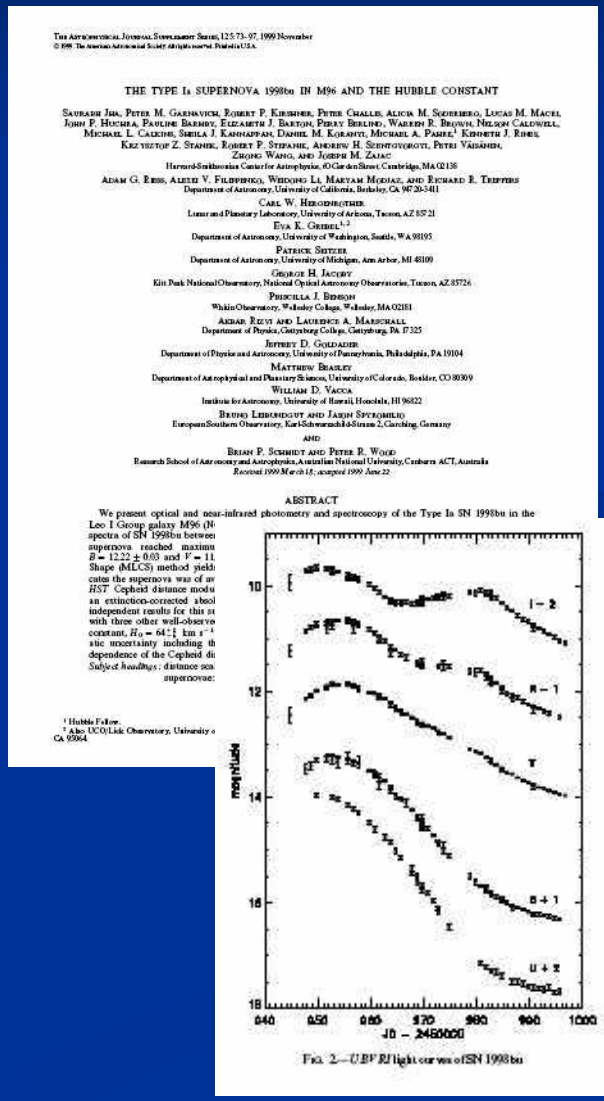
observations of a sample of X-ray sources selected from the *ROSAT* All-Sky Survey south of the Taurus-Auriga star-forming region (Neuhäuser et al. 1997). Although that X-ray sample was originally designed to favor the detection of T Tauri stars, which are also quite active, BD +05°706 was quickly found to be of an entirely different nature. Torres, Neuhäuser, & Wichmann (1998, hereafter Paper I) reported a double-lined spectroscopic orbital solution with a period of 18.9 days, a very small and possibly spurious eccentricity, and a mass ratio of $q = 0.21$ ($M_{secondary}/M_{primary}$), typical of the Algol systems.

The system contains two cool giants. The G8 III "primary" (the more massive star) is detached, while the K1–K2 III "secondary" has filled its critical lobe or may




FIG. 2.—Photometric observations and light-curve solutions for data set No. 1, computed from a simultaneous *BVRI* fit. The *B* and *V* observations, in which coverage of the primary minimum is lacking, were not used in the final solution (see text). The *V*, *R*, and *I* light curves are displaced vertically for display purposes. Residuals from the fits are shown at the bottom.

FIG. 3.—Photometric observations and light-curve solutions for data set No. 2, computed from a simultaneous *BVRI* fit. The *V*, *R*, and *I* light curves are displaced vertically for display purposes. Residuals are shown at the bottom.



THE TYPE Ia SUPERNOVA 1998bu IN M96 AND THE HUBBLE CONSTANT

SAURABH JHA, PETER M. GARNAVICH, ROBERT P. KIRSHNER, PETER CHALLIS, ALICIA M. SODERBERG, LUCAS M. MACRI, JOHN P. HUCHRA, PAULINE BARMBY, ELIZABETH J. BARTON, PERRY BERLIND, WARREN R. BROWN, NELSON CALDWELL, MICHAEL L. CALKINS, SHEILA J. KANNAPPAN, DANIEL M. KORANYI, MICHAEL A. PAHRE,[1] KENNETH J. RINES, KRZYSZTOF Z. STANEK, ROBERT P. STEFANIK, ANDREW H. SZENTGYORGYI, PETRI VÄISÄNEN, ZHONG WANG, AND JOSEPH M. ZAJAC
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

ADAM G. RIESS, ALEXEI V. FILIPPENKO, WEIDONG LI, MAEYAM MODJAZ, AND RICHARD R. TREFFERS
Department of Astronomy, University of California, Berkeley, CA 94720-3411

CARL W. HERGENROTHER
Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

EVA K. GREBEL[1,2]
Department of Astronomy, University of Washington, Seattle, WA 98195

PATRICK SMITH
Department of Astronomy, University of Michigan, Ann Arbor, MI 48109

GEORGE H. JACOBY
Kitt Peak National Observatory, National Optical Astronomy Observatories, Tucson, AZ 85726

PRISCILLA J. BENSON
Whitin Observatory, Wellesley College, Wellesley, MA 02181

AKBAR REZVI AND LAURENCE A. MARSCHALL
Department of Physics, Gettysburg College, Gettysburg, PA 17325

JEFFREY D. GOLDADER
Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19104

MATTHEW BRADLEY
Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309

WILLIAM D. VACCA
Institute for Astronomy, University of Hawaii, Honolulu, HI 96822

BRUNO LEIBUNDGUT AND JARKO SVERGUN[3]
European Southern Observatory, Karl-Schwarzschild-Strasse 2, Garching, Germany

AND

BRIAN P. SCHMIDT AND PETER R. WOOD
Research School of Astronomy and Astrophysics, Australian National University, Canberra ACT, Australia

*Received 1999 March 15; accepted 1999 June 22*

ABSTRACT

We present optical and near-infrared photometry and spectroscopy of the Type Ia SN 1998bu in the Leo I Group galaxy M96 (N
spectra of SN 1998bu betwee
supernova reached maximu
$B = 12.22 \pm 0.03$ and $V = 11$.
Shape (MLCS) method yield
cates the supernova was of av
*HST* Cepheid distance modu
an extinction-corrected absol
independent results for this s
with three other well-observe
constant, $H_0 = 64^{+4}_{-3}$ km s$^{-1}$
atic uncertainty including th
dependence of the Cepheid di

*Subject headings:* distance sca
supernovae:

[1] Hubble Fellow.
[2] Also, UCO/Lick Observatory, University o
Ca 95064.




FIG. 2.—*UBVRI* light curves of SN 1998bu

Optical Photometry and Spectroscopy of the "Cool Algol" AV Delphinus: Determination of the Physical Properties

Jeff A. Mader[1], Guillermo Torres[2], Laurence A. Marschall[3]

ABSTRACT

We present new spectroscopic and *BVRI* photometric observations of the double-lined eclipsing binary AV Del (Period = 3.85 days) conducted over six observing seasons. A detailed radial velocity and light-curve analysis of the optical data shows the system to be most likely semi-detached, with the less massive and cooler star filling its Roche lobe. The system is a member of the rare class of "cool Algol" systems, which are distinguished from the "classical" Algol systems in that the mass-gaining component is also a late-type star rather than a B- or A-type star. By combining the spectroscopic and photometric analyses we derive accurate absolute masses for the components of $M_1 = 1.453 \pm 0.028\ M_\odot$ and $M_2 = 0.705 \pm 0.014\ M_\odot$, radii of $R_1 = 2.632 \pm 0.030\ R_\odot$ and $R_2 = 4.233 \pm 0.060\ R_\odot$, as well as effective temperatures of $6000 \pm 200$ K and $4275 \pm 150$ K for the primary and secondary, respectively. There are no obvious signs of activity (spottedness) in the optical light curve of the binary.

*Subject headings:* binaries: eclipsing–binaries: spectroscopic–stars: fundamental parameters–stars: individual (AV Del)

1. INTRODUCTION



The class o
tems that contai
mass onto a m
continues our st

[1] W. M. Keck C
[2] Harvard-Smit
gtorres@cfa.har
[3] Department o
marschal@gettys

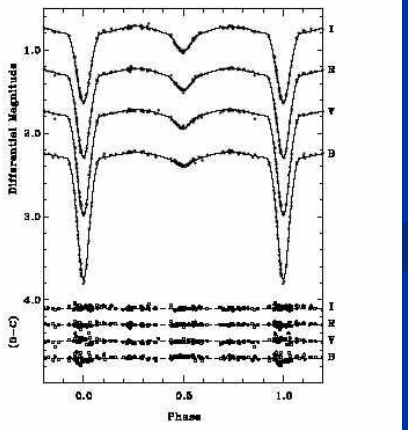
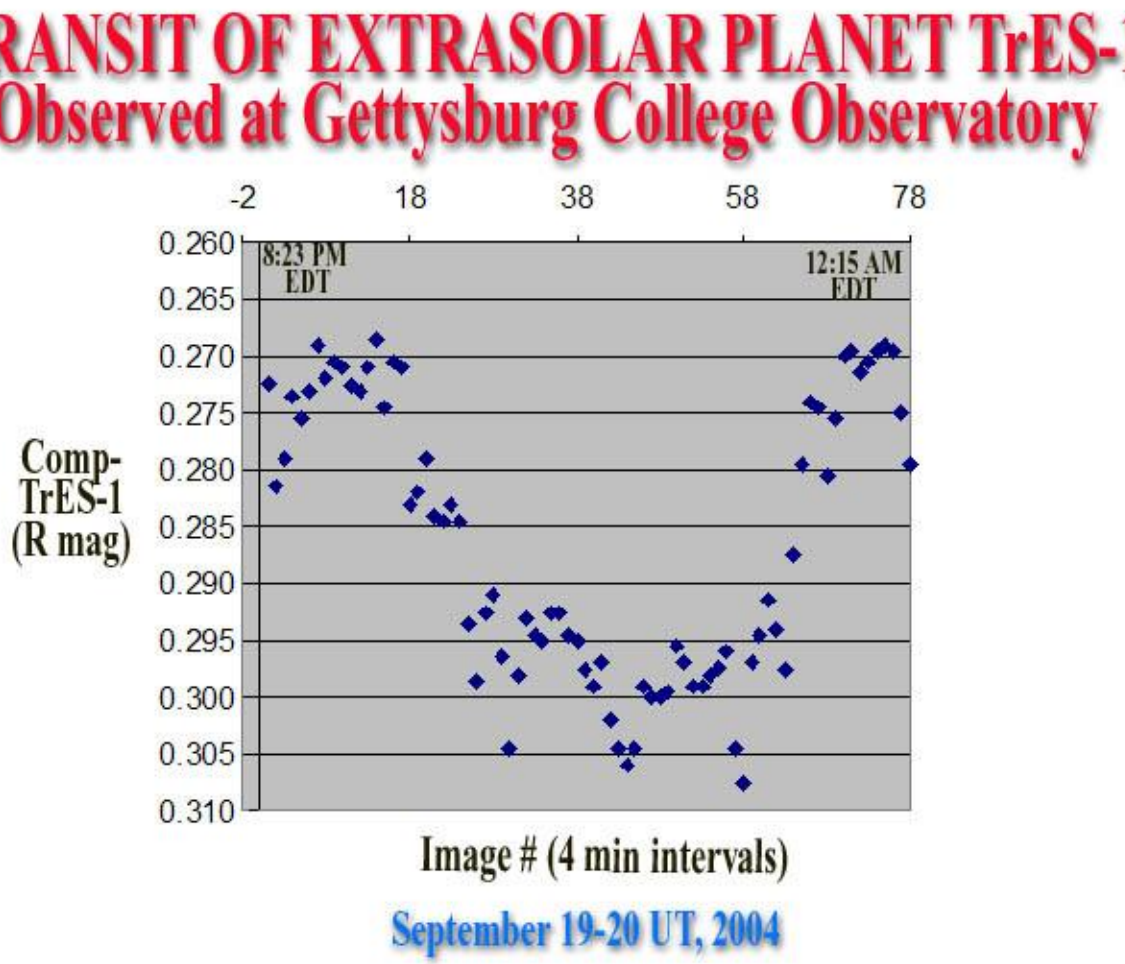
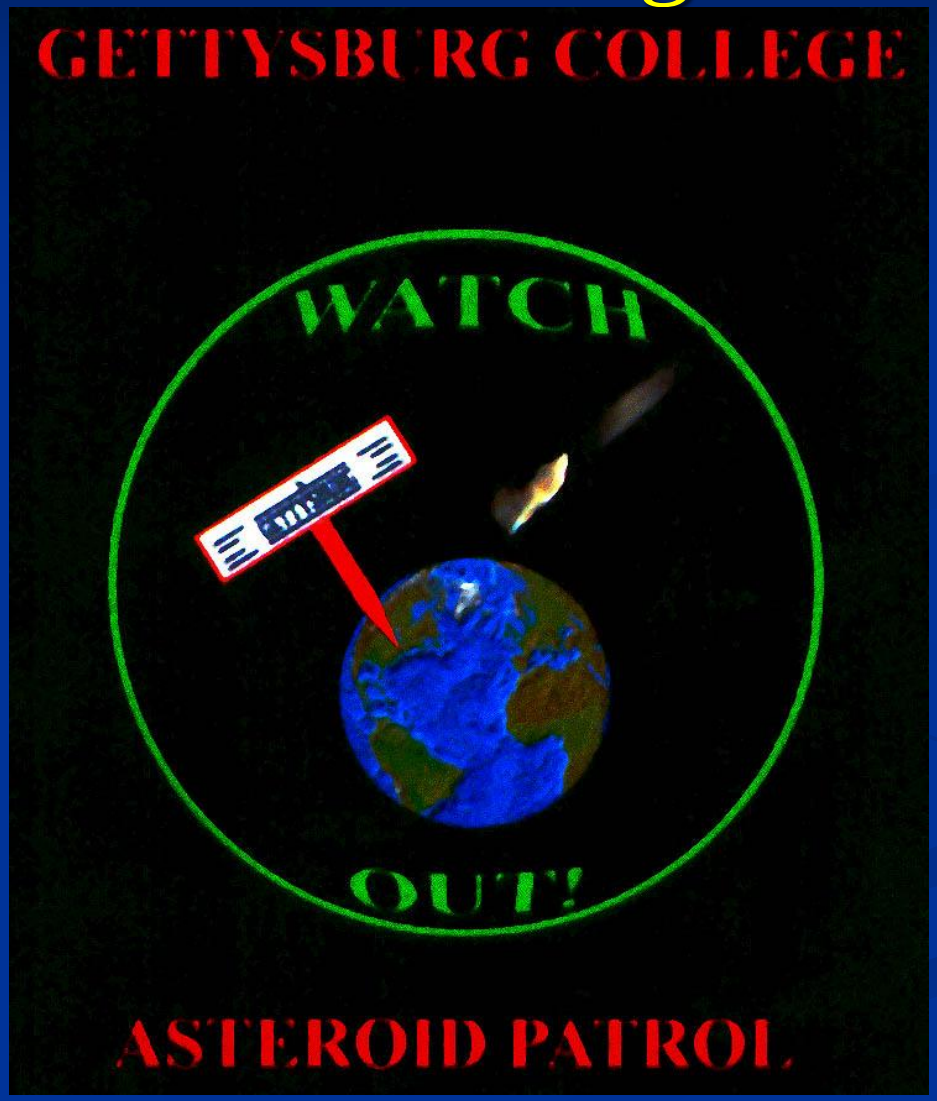



FIG. 2.— Light curves in *BVRI* for AV Del (displaced vertically for display purposes) along with our best fits for the semi-detached case. Residuals are shown at the bottom.

# Extrasolar Planet Photometry



# The Gettysburg Asteroid Patrol T-Shirt Logo



# TRUMPLER 37 Mosaic made of 4 18’ square images from Gettysburg College Observatory