

# **Forty-Five Years of Turning Data Into Science 1973-2018**

**By  
Jessica Mink  
Smithsonian Astrophysical Observatory**

**MITPAL 50<sup>th</sup> Anniversary, April 17, 2018**

# Outline

**First Data: 1971 MIT 12.143**

**Vidicon Spectrometer: 1973-4 Mars Observations**

**High-Speed Photometry: 1976-1990 Occultations**

**Spacelab 2 IRT: 1985-1990 IRAS and Spacelab 2 IRT**

**Long-slit Spectroscopy: 1990-2018 Z-Machine, FAST**

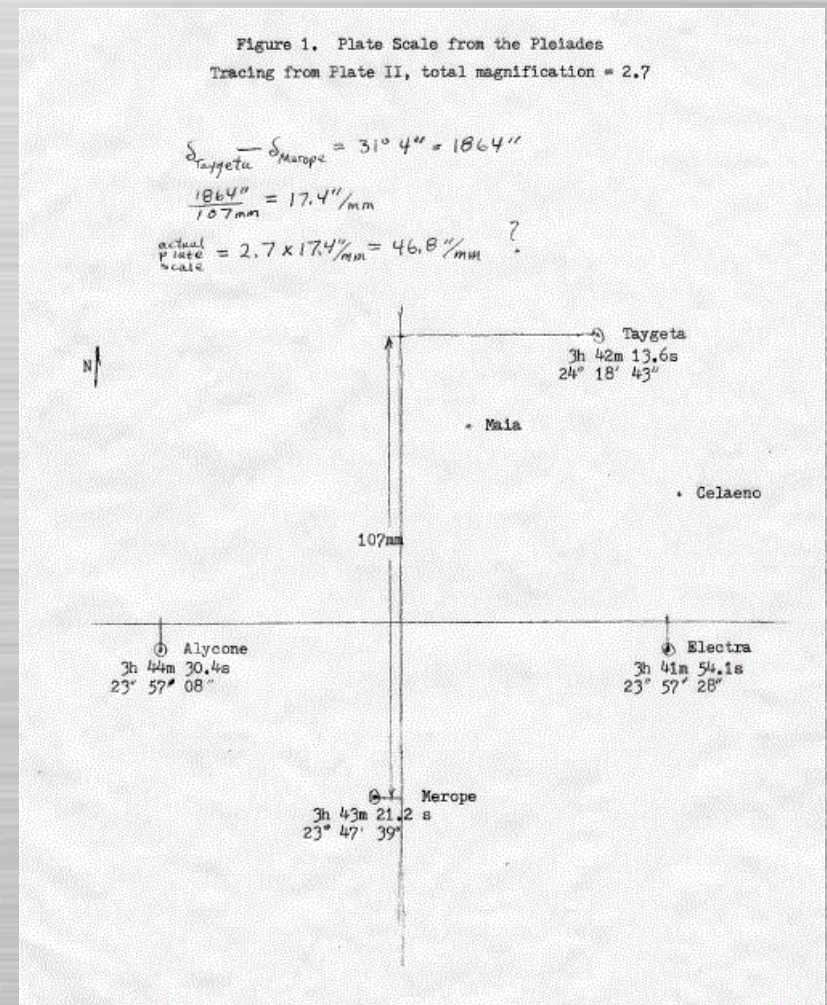
**Digitizing Images: 2002-2018 Harvard Photographic Plates**

**Multi-Fiber Spectroscopy: 2003-2018 Hectospec and Hectochelle**

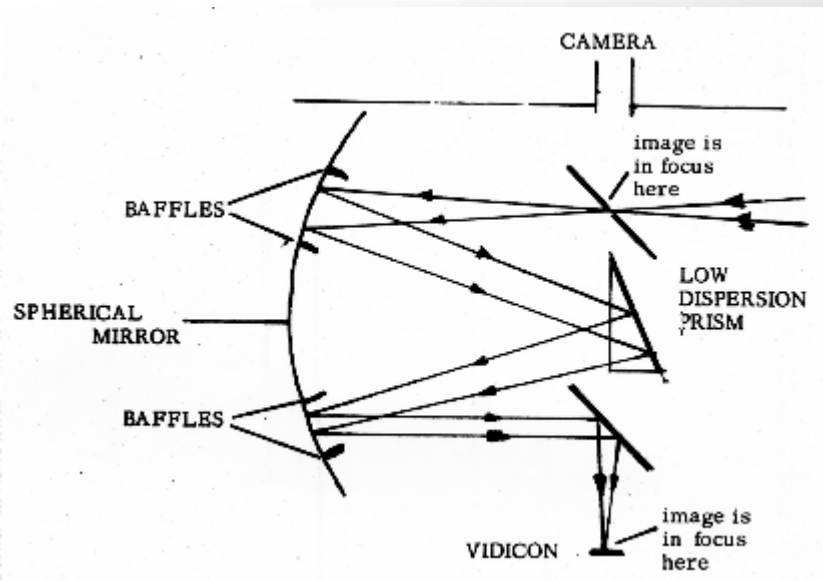
**Echelle Spectroscopy: 2009-2018 TRES**

# MIT 12.143: Plate Scale and Tracking Accuracy of the MIT Wallace Observatory 16 inch Telescope

December 15, 1971

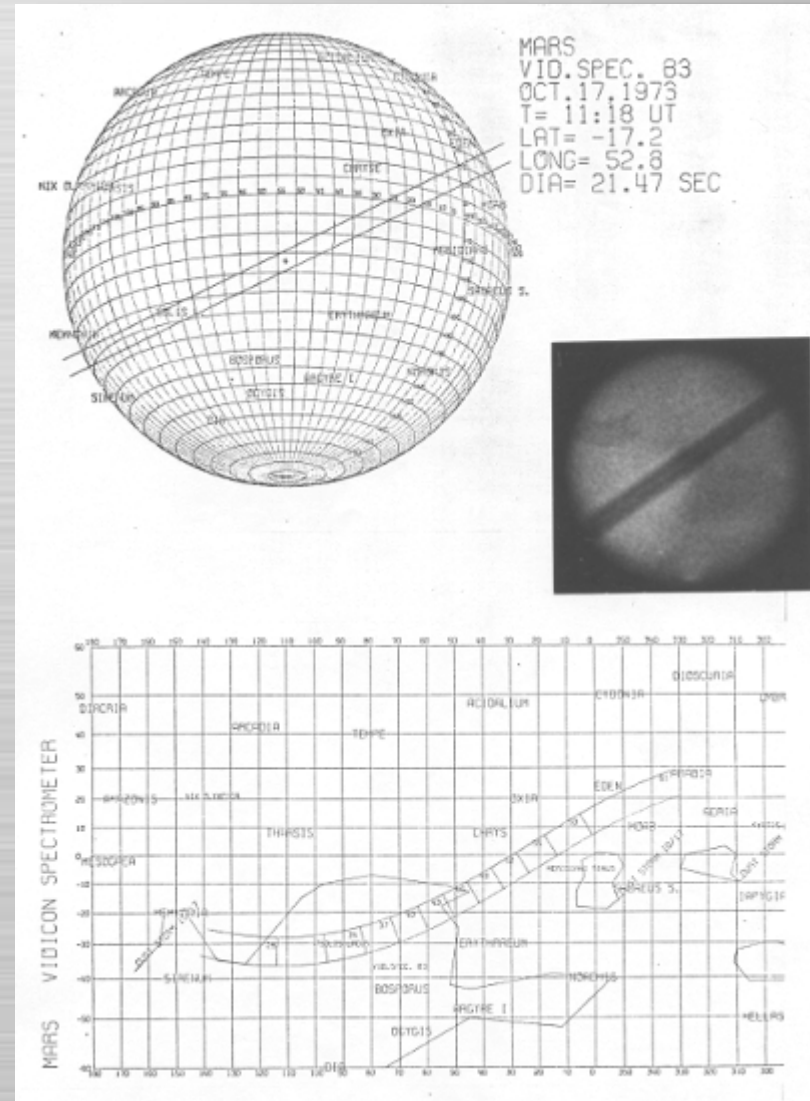


# MIT Vidicon Spectrometer 1973 Mars Opposition

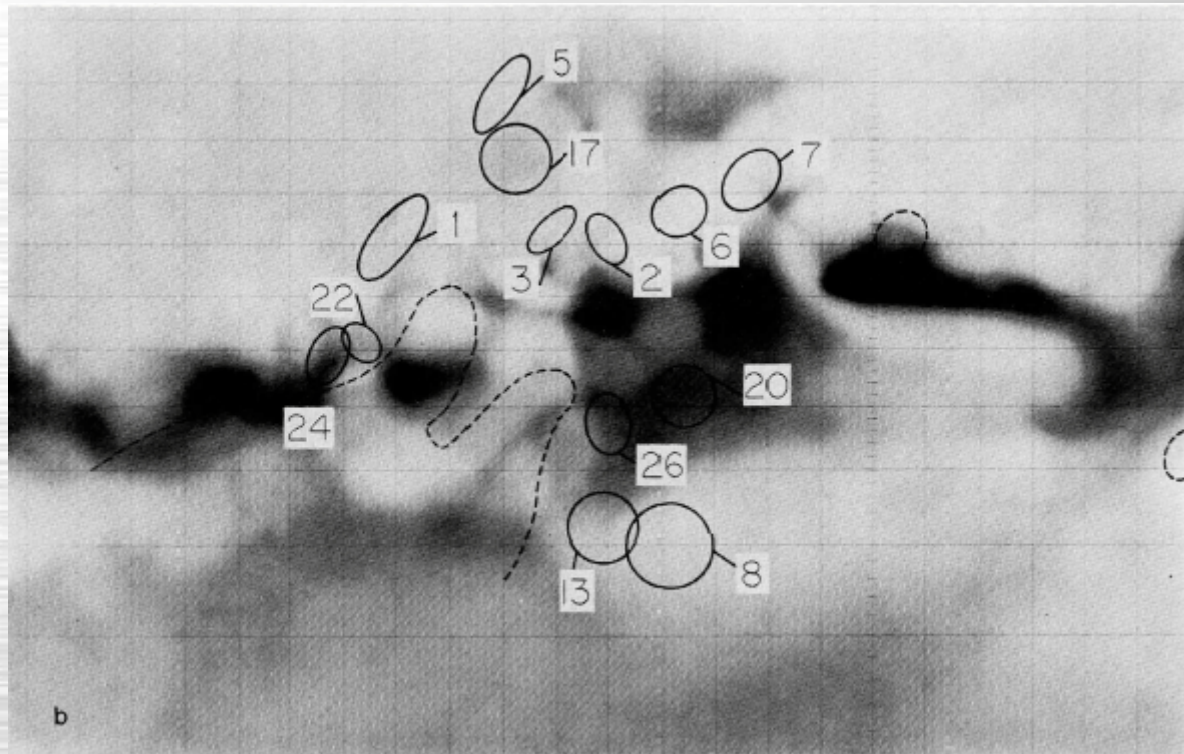


MIT Vidicon Spectrometer with camera monitoring slit in mirror

Spectrometer slit reprojected across Mercator projection of Mars surface  
(Mink, MIT S.M. Thesis 1974)



# Mars Opposition Photometry



**Aperture photos projected on observed planet disk  
and reprojected onto Mercator projection of Mars**

*(Mccord, Huguenin, Mink, and Pieters, Icarus 31, 1977)*

# Not Grad School, But ...

**CORNELL UNIVERSITY**  
*Center for Radiophysics and Space Research*

SPACE SCIENCES BUILDING  
Ithaca, New York 14853

Telephone (607) 256-4971

Laboratory for Planetary Studies

March 17, 1976

Mr. Douglas Mink  
1055 Beacon Street  
Apt. #2  
Brookline, MA 02146

Dear Doug:

Thanks for your recent letter. I was glad to hear that your wife, Missy, has been accepted in Ecology and Evolutionary Biology here. Unfortunately, because of a deluge of first rate applicants and a still constricted budget for the support of graduate students, we have not been able to admit you as a graduate student. I am sorry to have to report this, but the competition was simply too tough. On the other hand, if by any chance you will be here, we would certainly be happy to have you work in our laboratory and -- if a little money can be found -- try to pay you at least part time.

With all good wishes,

Cordially,



Carl Sagan

CS/csk  
cc: Y. Terzian

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Ithaca, New York 14853

Telephone (607) 256-4971

Laboratory for Planetary Studies

June 3, 1976

Mr. Douglas Mink  
1055 Beacon Street #2  
Brookline, Mass. 02146

Dear Doug:

Thanks for your recent letter which, for several different reasons, I was delighted with. I think it certainly is true that once you are here we will have an excellent chance to better assess your skills and abilities and I'm sure it will increase your chance of being admitted to this department. But also we have an extremely interesting job opening up involving data processing and analysis in a set of quite exciting contexts. We are not yet sure that we will have money to support this position, but I would say that the prospects are at least moderately good. Let me urge you to contact -- certainly by the time you are out here but preferably even before -- Dr. James Elliot of this Laboratory to whom I'm sending a copy of this letter. It would probably be a good idea for you to lay out your previous computer and instrumentation experience to Dr. Elliot. I very much hope things will work out well for you.

With all good wishes,

Cordially,



Carl Sagan

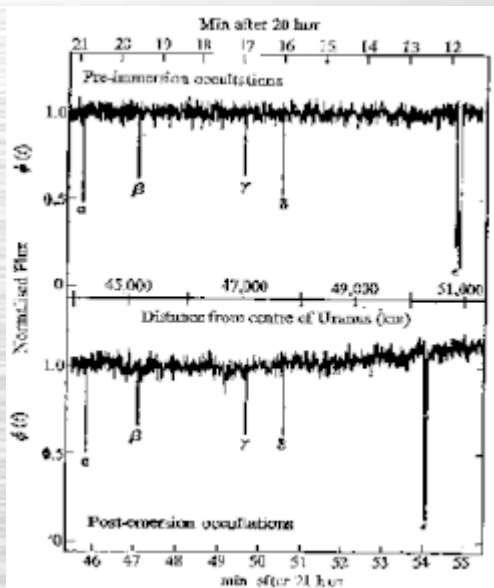
# Discovery of Uranian Rings

Circular No. 3047  
 Central Bureau for Astronomical Telegrams  
 INTERNATIONAL ASTRONOMICAL UNION  
 Postal Address: Central Bureau for Astronomical Telegrams  
 Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.  
 Cable Address: SATELLITES, NEWYORK Telex: 921428  
 Telephone: (617) 864-5758

## OCCULTATIONS BY URANUS AND (6) HEBE

R. Barrow, Gerard P. Kuiper Airborne Observatory, has relayed word from Perth of successful observations by J. L. Elliot in the southern Indian Ocean of last night's occultation of SAO 158687 by Uranus. A secondary occultation was also observed, this presumably being caused by a small body (not Miranda) in orbit about Uranus. J. Hers reports that heavy rain prevented observations in the vicinity of Johannesburg.

Preliminary reports reaching D. Dunham, Computer Sciences Corporation, suggest that the central line of the occultation of gamma Cet by (6) Hebe passed between 50 and 90 km north of Mexico City. Near the latter point the event lasted 55, beginning on Mar. 5d02h34m54s UT. A 2.5s-duration occultation was observed in Mexico City itself.



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## OCCULTATION OF SAO 158687 BY URANUS AND SATELLITE BELT

Amplifying the brief announcement on [IAUC 3047](#), J. L. Elliot reports that several secondary occultations of SAO 158687 on Mar. 19 were observed by E. Dunham, D. Mink and himself from the Kuiper Airborne Observatory and also by R. L. Millis, P. Birch and D. Trout at the Perth Observatory. Both groups independently concluded that these occultations were caused by bodies that are apparently part of a satellite belt about 40 000 km distant from the center of Uranus. The diameters of the satellites range from 100 km to much smaller values. The occultation by Uranus itself was successfully observed from the Airborne Observatory (located at Long. = -90o, Lat. = -50o) and lasted ~ 25 min centered on 21h00m UT. The Uranus occultation did not occur at the Perth Observatory. The secondary occultations took place during an 8-9 min interval around 20h16m UT and during a similar interval around 21h50m UT (although dawn prevented observations of the latter events in Perth).

M. K. V. Bappu, Indian Institute of Astrophysics, cables: "Using the 102-cm reflector at Kavalur (Long. = -5h15m19s.6, Lat. = +12o34'32"), Bhattacharyya and Kuppaswamy found the diminution of SAO 158687 during the occultation by the atmosphere of Uranus to be 0.046 magnitude at an effective wavelength of 7500 A. Visually and photoelectrically they observed the complete disappearance of the star for 8s.9 beginning at 20h19m15s UT and ascribe this to obscuration by a hitherto unknown satellite of the planet."

Computations by the undersigned show that the asymmetry in the times of the satellite occultations about the main occultation (as observed at the Airborne Observatory) is consistent with the existence of a circular belt in the plane of Uranus' equator. Allowance for foreshortening yields the radii of the inner and outer edges of the belt as 44 000 and 51 000 km, respectively. The Kavalur observation suggests occultation by a 100-km-sized body near the outer edge of the belt. Other observers are urged to examine their records for further evidence of this belt. At Sutherland, times of mid-occultation by the belt would have been 20h22m and 21h59m UT; at Mauritius, 20h23m and 21h54m; at Lembang, 20h20m and 21h46m; at Kyoto, 20h22m; at Helwan, 21h56m. Those wishing to attempt to detect the satellite belt directly are advised that at the present position it should be located from 3".5 to 4".0 to the north and south of the center of Uranus and from 2".7 to 3".1 to the east and west; the brightest bodies in it are expected to have mv ~ 19.

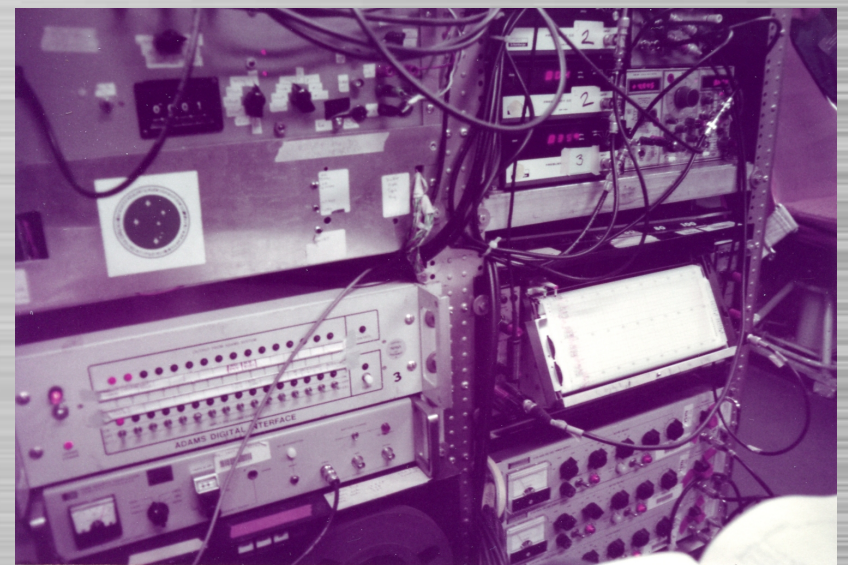
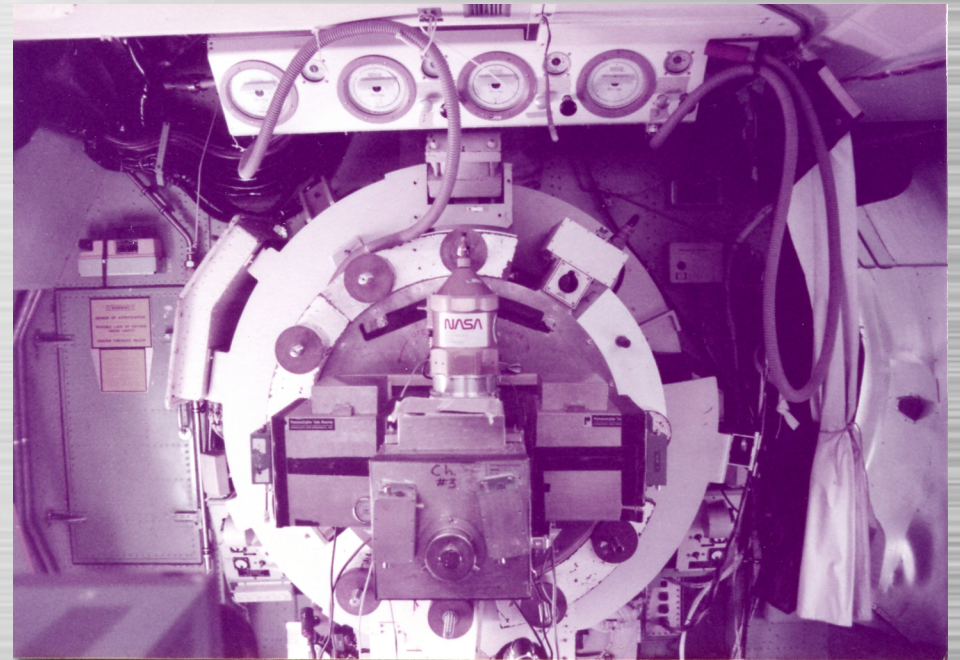
1977 March 14

(3048)

Brian G. Marsden

## Occultation of SAO 158687 by Uranus and Its Rings (Eliot, Dunham, and Mink, Nature 261, 328, May 26 1977)

# 3-Channel Photometer on KAO



Faith Vilas on Guam, 1983



# Occultation Prediction Pipeline

## Existing Star Catalog

Compute Search Boxes  
Search Star Catalog  
Merge resulting regions

## Photographic Plates

Compute planetary ephemeris  
Take plates on astrograph  
Measure plates  
Merge plates

## Make candidate catalog

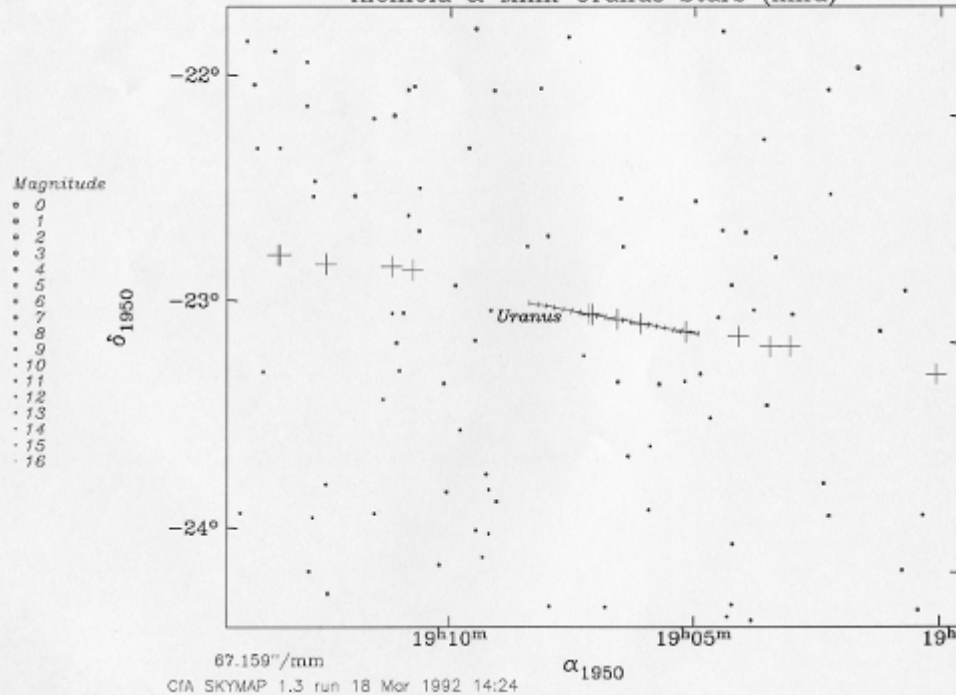
Sort by RA  
Remove duplicate entries  
Renummer  
Make binary file  
Find close stars in 10" boxes  
Run predictions

**Publish close event predictions in AJ article**

# Predicting Occultations

Centered on kmu 102  $19^{\text{h}}07^{\text{m}}05.365^{\text{s}}$   $-22^{\circ}58'47.1''$   
 Uranus from 1 July 1992 0:00 UT every 1 day  
 SAO Catalog (SAOra)

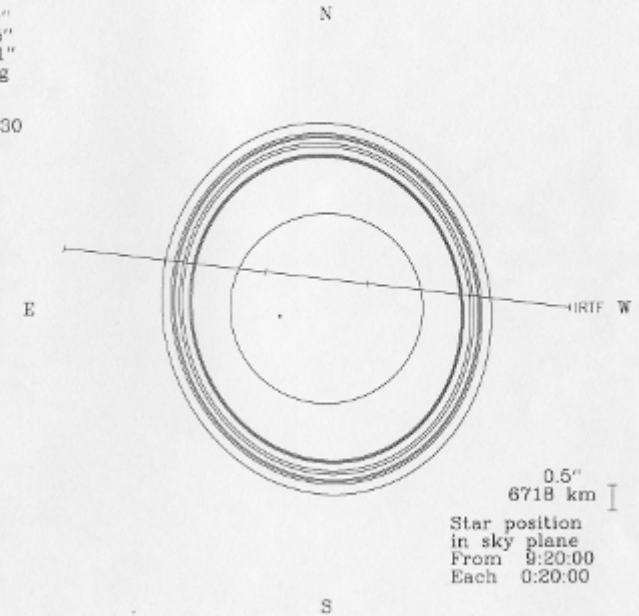
Klemola & Mink Uranus Stars (kmu)



**Palomar Sky Survey overlay  
 for stars occulted by Uranus**

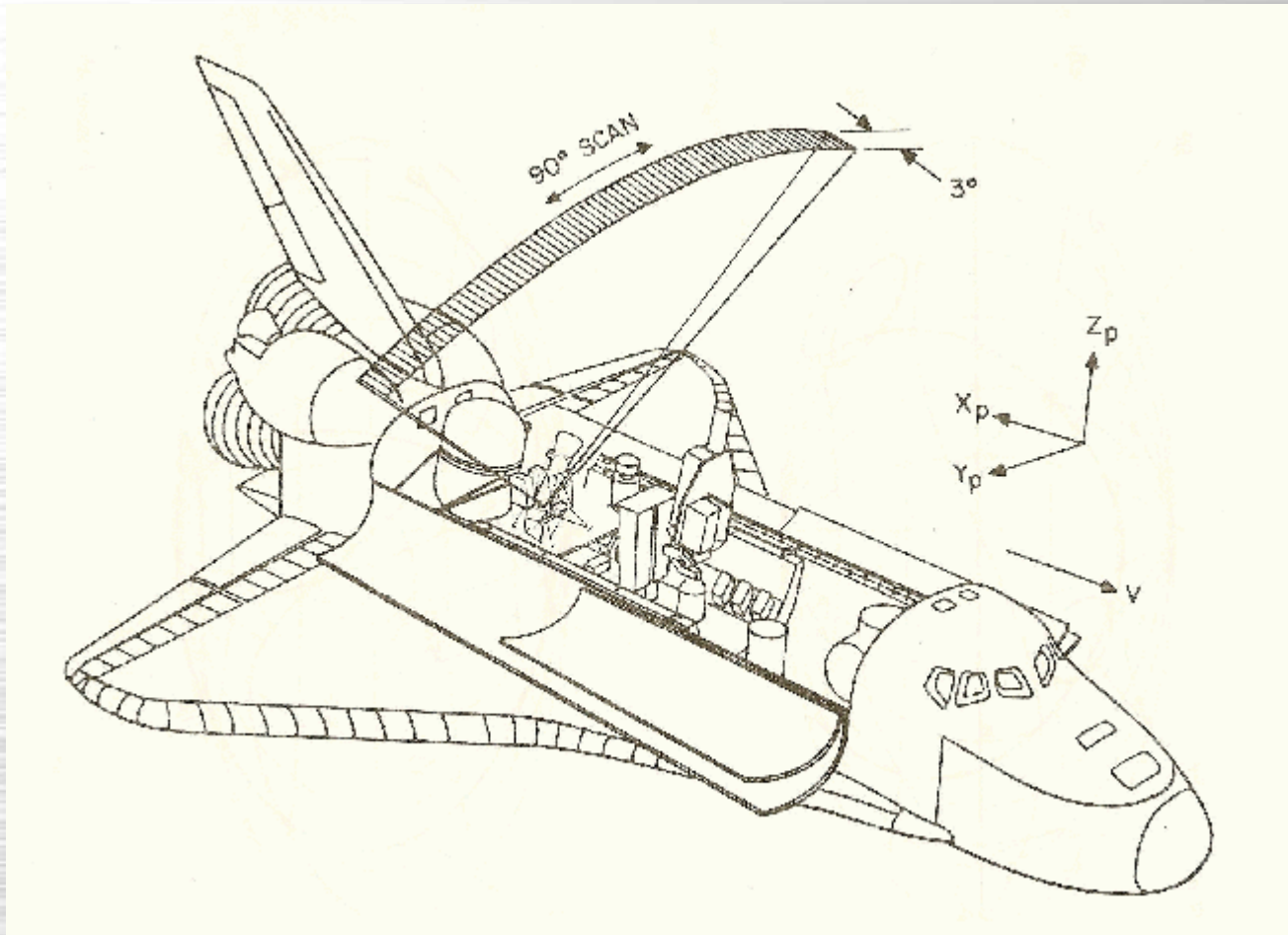
July 8 1992 Occultation of kmu 102 by Uranus epsilon ring  
 Observed from IRTF Mauna Kea 3.8m Long= 155 28 15.0 Lat= 19 49 34.0  
 13.01-magnitude star at RA= 19h 09m 40.3332s Dec=-22d 54' 34.113"  
 (1950) RA= 19h 07m 05.3650s Dec=-22d 58' 47.100"

Closest at 10: 7:25 U.T.  
 Radial= 8025.7 km = 0.60"  
 Planet= 28145.0 km = 1.95"  
 Ring = 51149.3 km = 3.81"  
 DE= 60.4757 Pole= 99.7807 deg  
 V=0.0017 "/s = 23.05 km/s  
 D= 18.525434 AU  
 ET - UT = 59.3660 sec DE-130  
 Immersion: 9:35:43 U.T.  
 P.A.= 273.4 deg. 7/ 8  
 R = 44574.2 km = 3.32"  
 Phase = 0.0 deg = 100.0%  
 Alt= 47 d, Az= 164 d  
 Sun alt=-47 d, Az= -17 d  
 Sun:179.4 d, Moon: 73.4 d  
 V =0.0017 "/s = 23.05 km/s  
 VP=0.0019 "/s = 25.88 km/s  
 D = 18.525427 A.U.  
 Emersion: 10:39:54 U.T.  
 P.A.= 73.0 deg 7/ 8  
 R = 45648.7 km = 3.40"  
 Phase = 0.0 deg = 100.0%  
 Alt= 49 d, Az= 165 d  
 Sun alt=-49 d, Az= 4 d  
 Sun:179.3 d, Moon: 72.8 d  
 V =0.0017 "/s = 23.05 km/s  
 VP=-0.0019 "/s = -25.89 km/s  
 D = 18.525442 A.U.  
 Doug Mink 13:33 Mar 18 1992



**Sky plane map of Uranus  
 ring occultation of KMU102**

# All-Sky IR Mapping from Space



**Spacelab 2 Infrared Telescope**  
(Space Shuttle Challenger, July 1985)

# For Maps, Write a Graphics Terminal

XTERM(1) X window System XTERM(1)

**NAME**  
xterm - terminal emulator for X

**SYNOPSIS**  
xterm [-toolkitoption ...] [-option ...] [shell]

**DESCRIPTION**  
The xterm program is a terminal emulator for the X window system. It provides DEC VT102/VT220 and selected features from higher-level terminals such as VT320/VT420/VT520 (VTxxx). It also provides Tektronix 4014 emulation for programs that cannot use the window system directly. If the underlying operating system supports terminal resizing capabilities (for example, the SIGWINCH signal in systems derived from 4.3BSD), xterm will use the facilities to notify programs running in the window whenever it is resized.

The VTxxx and Tektronix 4014 terminals each have their own window so that you can edit text in one and look at graphics in the other at the same time. To maintain the correct aspect ratio (height/width),

**SEE ALSO**  
resize(1),luit(1),uxterm(1),X(7),pty(4),tty(4)

xterm Control Sequences (this is the file ctlseqs.ms).

<http://invisible-island.net/xterm/xterm.html>  
<http://invisible-island.net/xterm/ctlseqs/ctlseqs.html>  
<http://invisible-island.net/xterm/xterm.faq.html>

**AUTHORS**  
Far too many people, including:

Loretta Guarino Reid (DEC-UEG-WSL), Joel McCormack (DEC-UEG-WSL), Terry Weissman (DEC-UEG-WSL), Edward Moy (Berkeley), Ralph R. Swick (MIT-Athena), Mark Vandevoorde (MIT-Athena), Bob McNamara (DEC-MAD), Jim Gettys (MIT-Athena), Bob Scheifler (MIT X Consortium), Doug Mink (SAO), Steve Pitschke (Stellar), Ron Newman (MIT-Athena), Jim Fulton (MIT X Consortium), Dave Serisky (HP), Jonathan Kamens (MIT-Athena), Jason Bacon, Jens Schweikhardt, Ross Combs, Stephen P. Wall, David Wexelblat, and Thomas Dickey (invisible-island.net).

Patch #330 2017-06-20 XTERM(1)

# IRT Data Pipeline

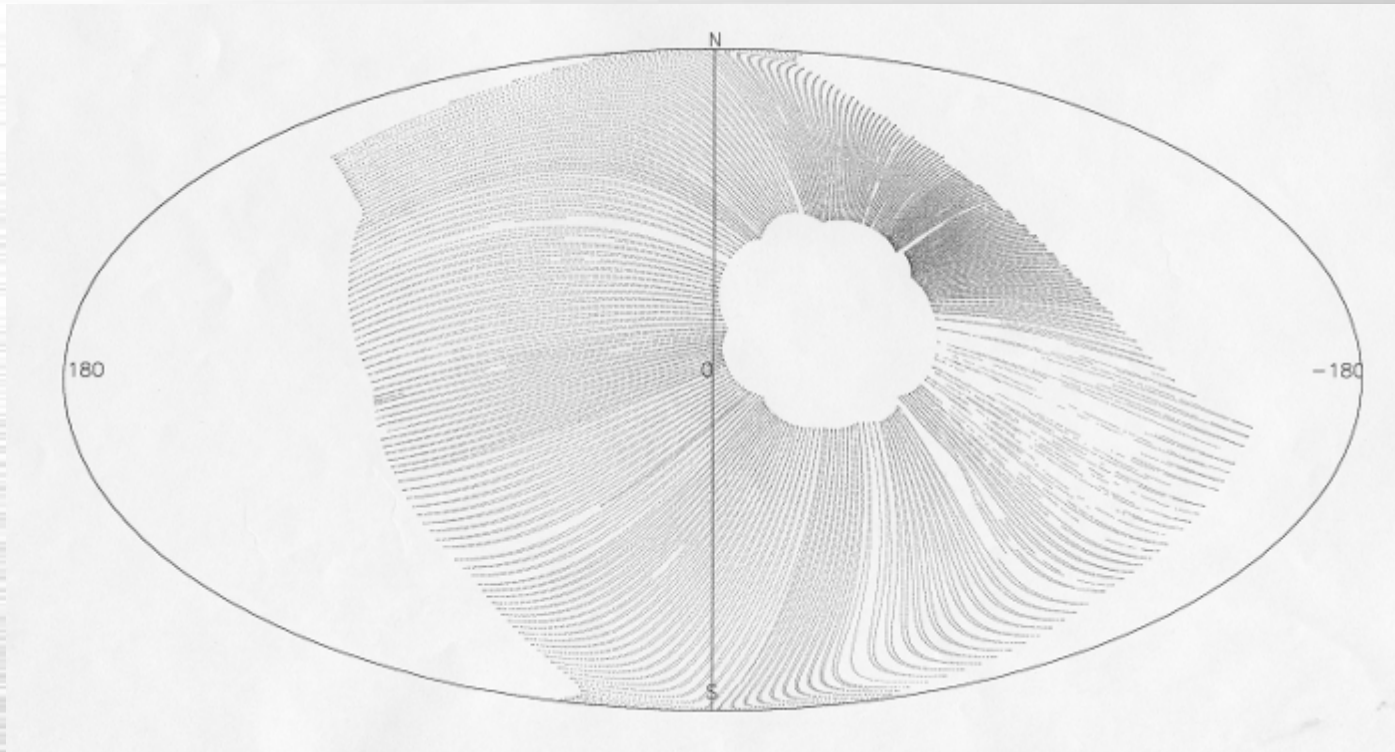
## Telemetry from Space Shuttle:

Position of Space Shuttle  
Scan Position of Telescope in Payload Bay  
Counts from 4 He-chilled masked photometers

## In Computer Room at Johnson Space Center:

Convert each sample to sky position and intensity  
Record scan positions in graphic Aitoff all-sky map  
Record in image mapped to Aitoff all-sky projection using mask shape

# All Sky IR Mapping from IRT



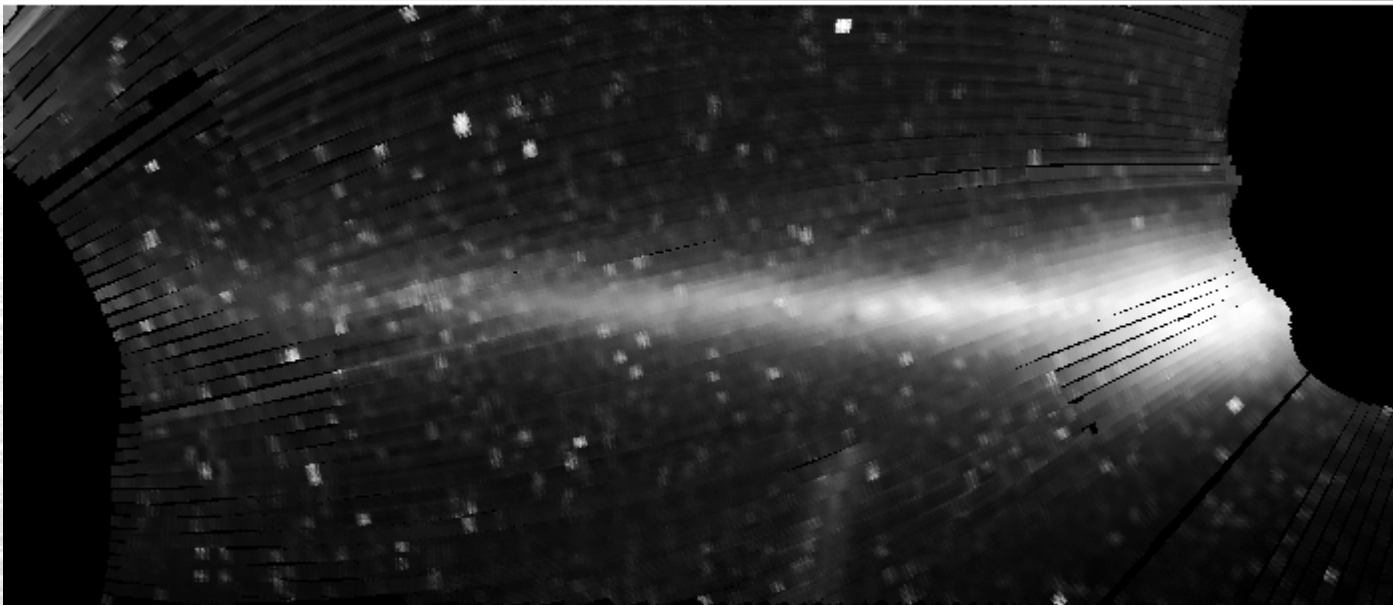
**1985 Day 213, Orbit 4, 50,964 0.1-sec frames**

**Spacelab 2 Infrared Telescope**

*(Space Shuttle Challenger, July 1985)*

MITPAL 50<sup>th</sup>, April 17, 2018

# Galactic Center from Spacelab 2



**Linear Projection in Galactic Coordinates**  
*(Mink, August 1990, unpublished)*

# Galactic Center from Spacelab 2

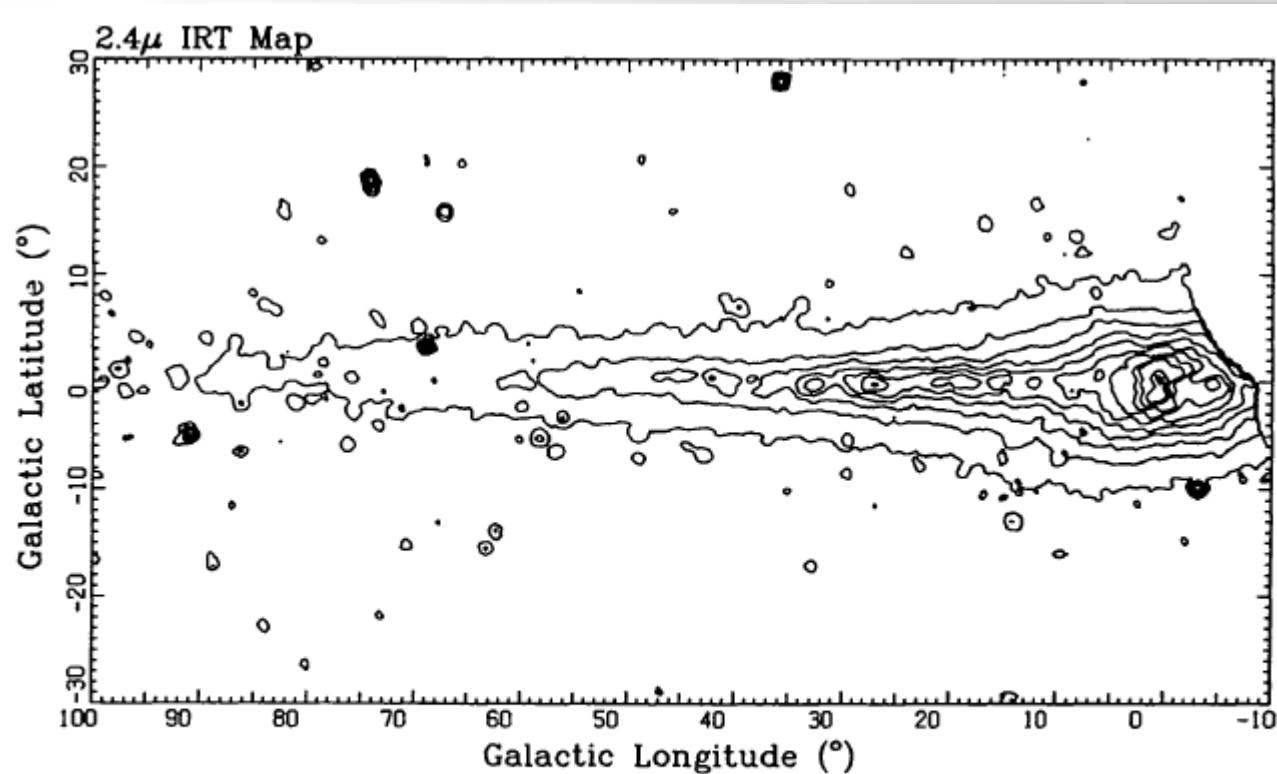


FIG. 5.—Contour map of the  $2.4 \mu\text{m}$  emission from the Galactic plane region. The contours are spaced logarithmically in 10 steps between  $0.67 \times 10^{-10}$  and  $16 \times 10^{-10} \text{ W cm}^{-2} \mu\text{m}^{-1} \text{ sr}^{-1}$ .

## Linear Projection in Galactic Coordinates

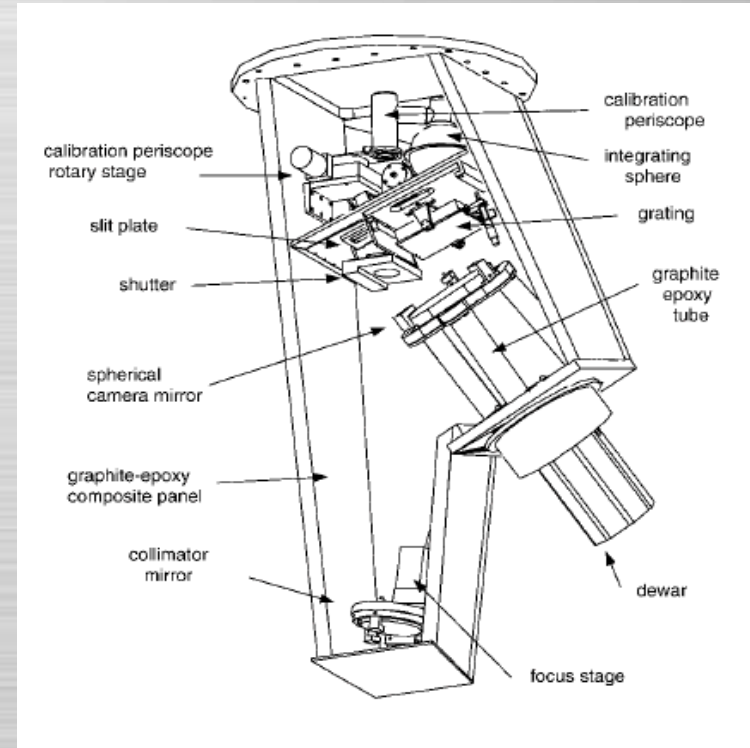
(Kent, Mink, Fazio, Koch, Melnick, Tardiff, Maxson, *ApJS* 78:403-408, 1992)



# FAST Single Slit Spectrograph



**FAST mounted on the 1.5-meter Reflector**



**FAST Spectrograph**

# FAST Spectrograph Pipeline

## For Each Night:

Transfer data from Mt. Hopkins, AZ to Cambridge, MA

Create a digital log for the night

Copy raw data to configuration directories

Catalog raw data

## For Each Configuration:

Process spectrum images

Fit wavelength solutions to all HeNeAr calibration spectra

Apply wavelength solution to entire object spectra images

Find the objects on the slits

Extract 1D sky-subtracted spectrum images

Find a velocity using cross-correlation to templates

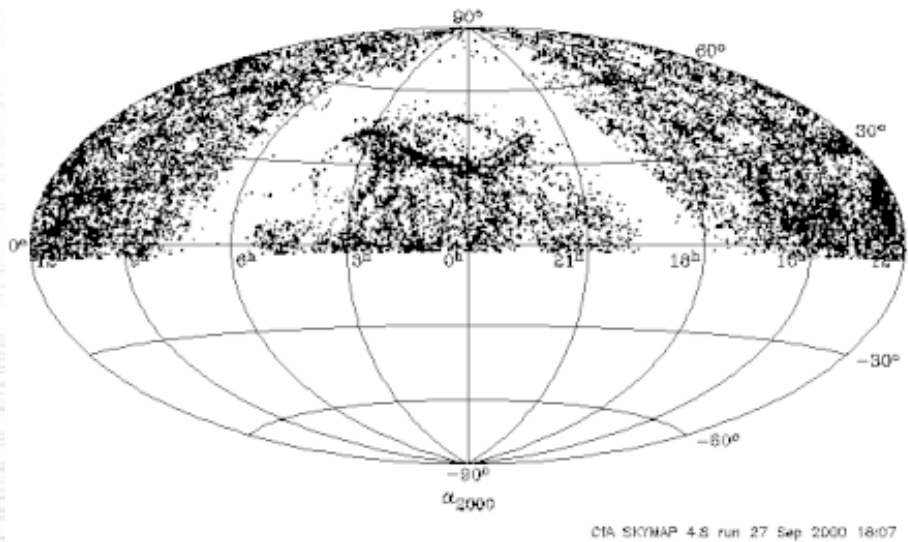
Check results, assign a quality (Q,?,X)

Catalog spectrum metadata

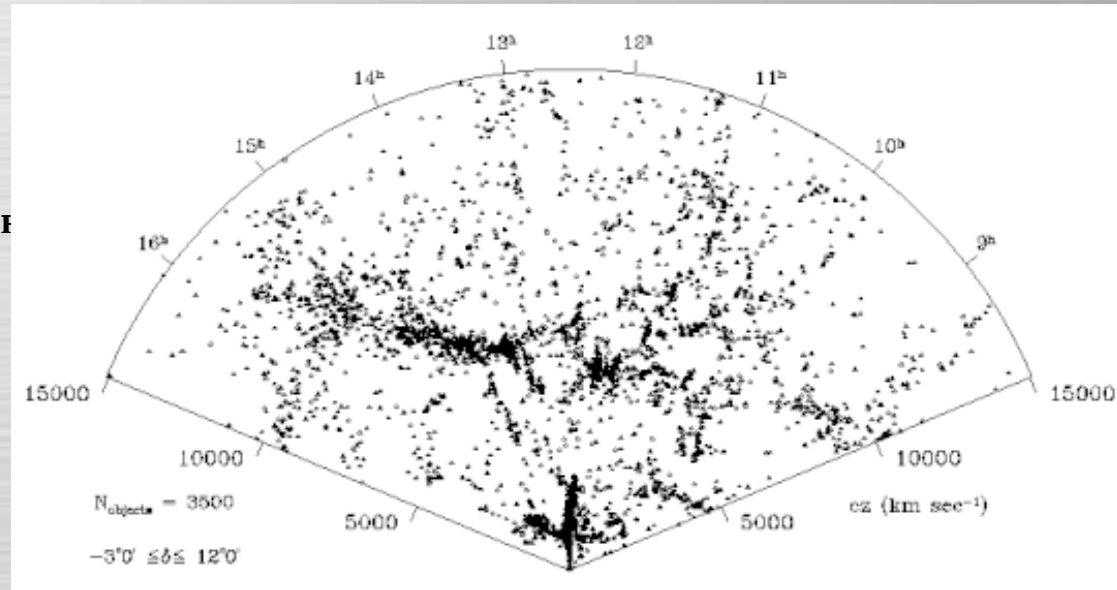
Copy spectra to archive

# Update Zwicky Catalog Galaxies with Redshifts

• Updated Zwicky Catalog (uzcj)



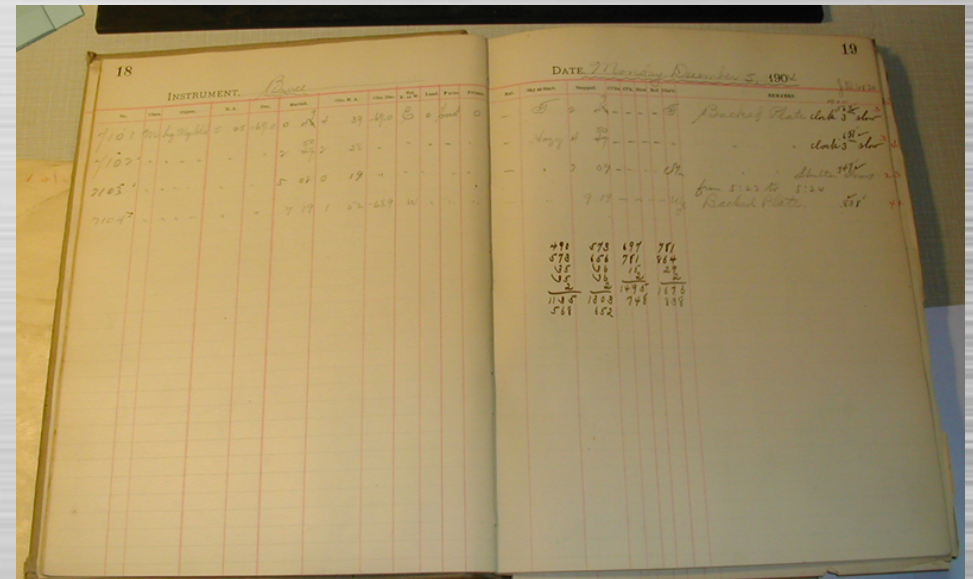
Updated Zwicky Catalog galaxies displayed on an Aitoff-Hammer all-sky projection



Galaxies RA 8h - 17h, Dec -3° - +12°, cz < 15,000 km/sec

# Putting Positions on Harvard's Plates

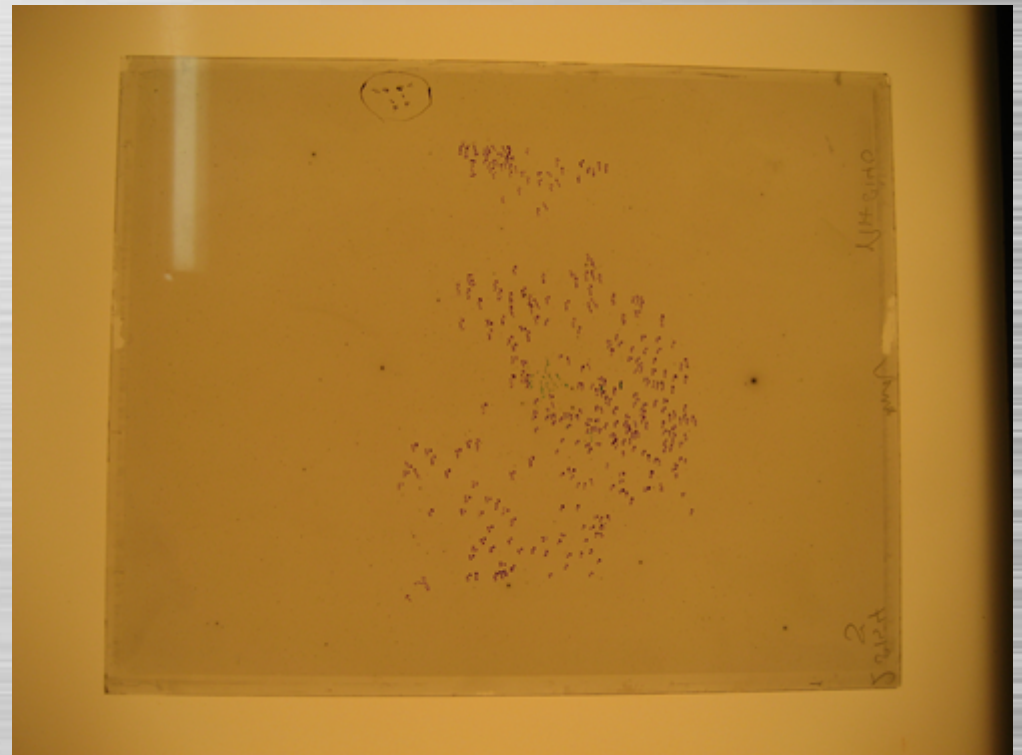
Mink, D.; Doane, A.; Simcoe, R.; Los, E.; Grindlay, J. (2006). "The Harvard Plate Scanning Project" in Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing, iAstro workshop, Sofia, Bulgaria, 2005 proceedings, Sophia: Heron Press Ltd.



From hand-written cards and logbooks

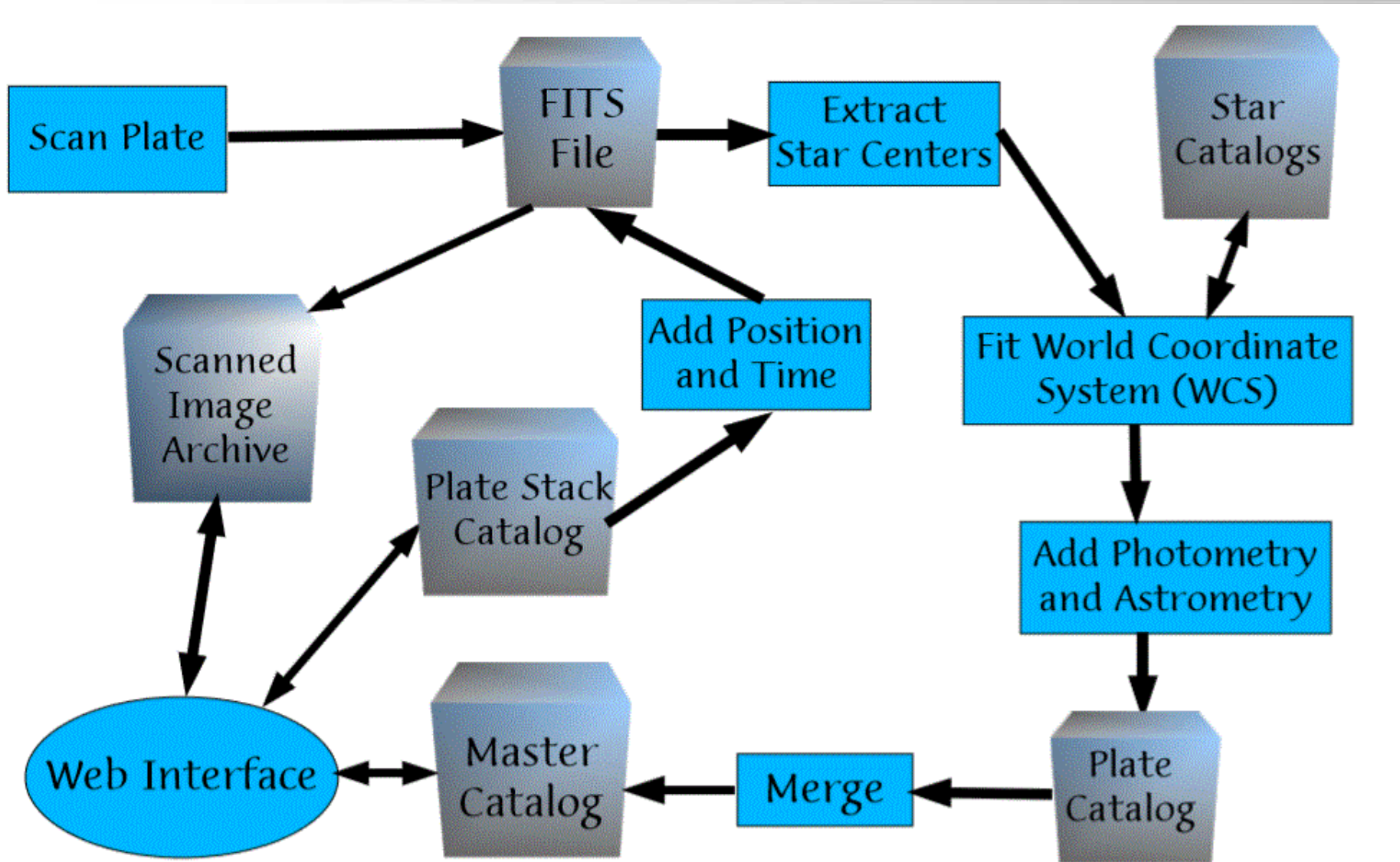
# Putting Positions on Harvard's Plates

Mink, D.; Doane, A.; Simcoe, R.; Los, E.; Grindlay, J. (2006). "The Harvard Plate Scanning Project" in Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing, iAstro workshop, Sofia, Bulgaria, 2005 proceedings, Sophia: Heron Press Ltd.

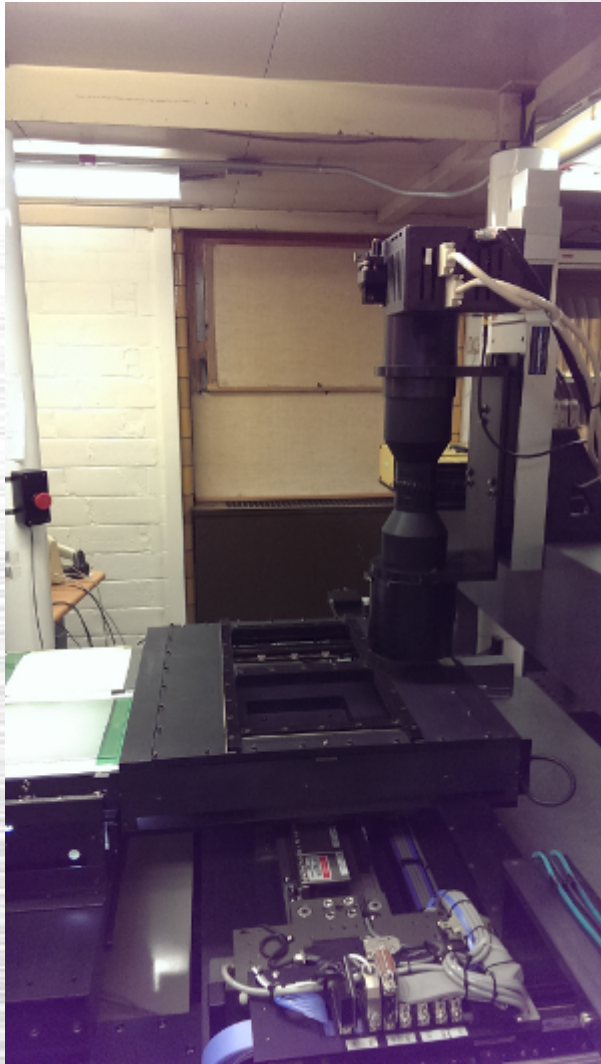


**From three floors of cabinets of glass plates**

# Harvard Plate Pipeline



# Putting Positions on Harvard's Plates



File Edit View History Bookmarks Tools Help  
edu/cgi-bin/plates/mcplate?rfn=21475&dx=1  
python h... Full Text ... Pipes (Pr... Perl File L... MC Serie... MC ... x mcpart (...)

**Telescope Data Center**  
SMITHSONIAN ASTROPHYSICAL OBSERVATORY

[Click here for 1/32nd scale FITS image with WCS](#)  
[Click here for 1/16th scale FITS image with WCS](#)  
[Click on image for 1000 x 1000 JPEG image.](#)

**Harvard Plate Stacks**  
**MC Series Plate**  
**MC21475**

[A Series \(about\)](#)  
[MC Series \(about\)](#)  
[MF Series \(about\)](#)

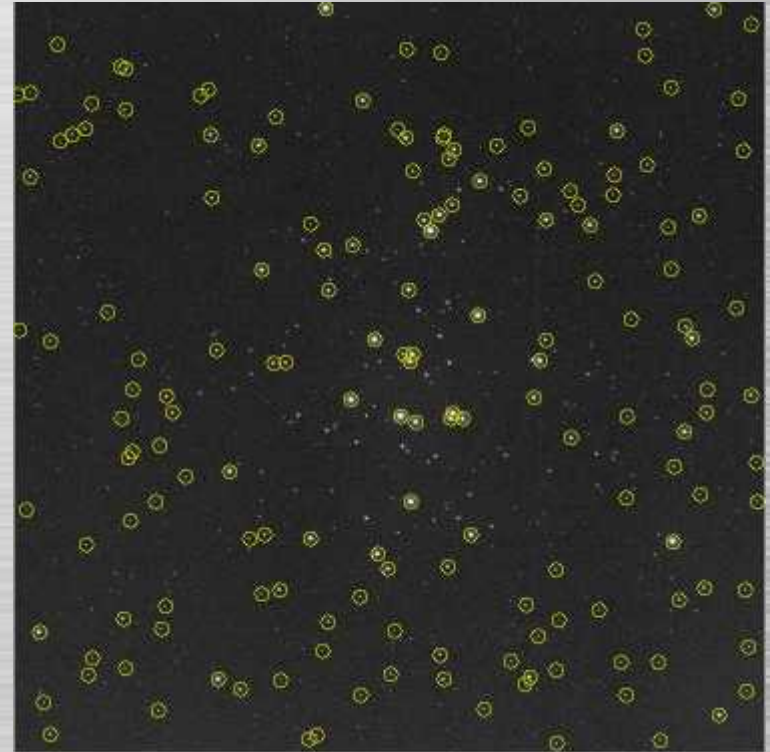
Plate	RA2000	Dec2000	Exp	Epoch	Note
21475	08:39:44.900	+19:44:52.60	25.00	1925-05-22T00:00	RY_Cancri

From glass to bytes on home-built scanner

# Putting Positions on Harvard's Plates



M44 in Plate MC21438



M44 in Plate MC21438  
with Tycho 2 Catalog stars marked

**Zoom in and overplot stars using WCS**



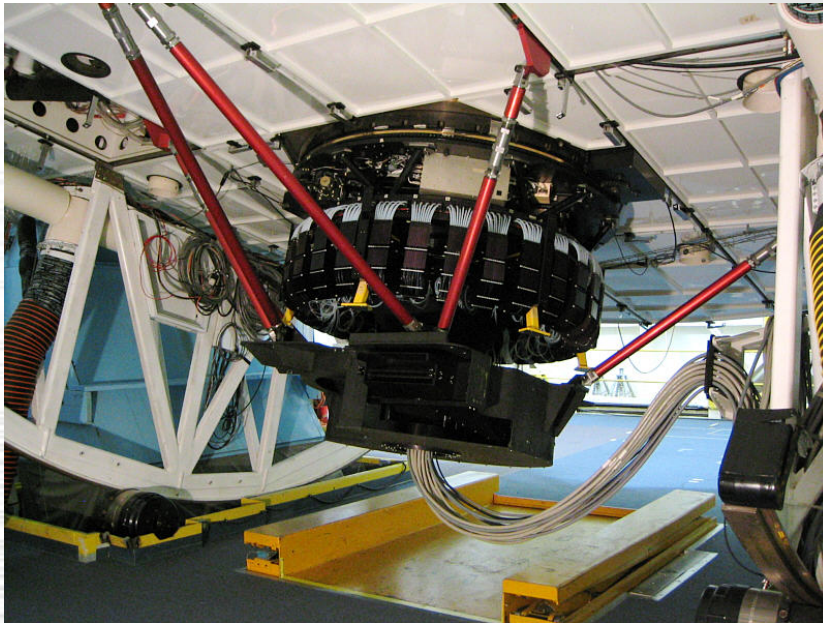
# Putting Positions on Harvard's Plates



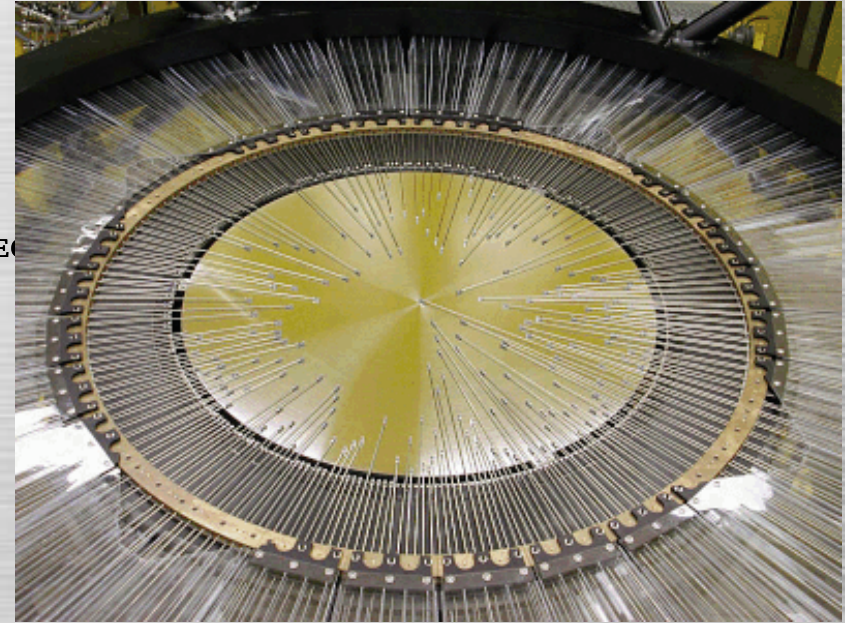
**100,000<sup>th</sup> Plate Scanned, April 7, 2015**

MITPAL 50<sup>th</sup>, April 17, 2018

# Hectospec 300-Fiber Spectrograph



HCTOSPEC



**Hectospec mounted on the 6.5-meter MMT**

**Hectospec Focal Plane with Fibers Positioned**

# Hectospec Data Pipeline

## SPECROAD

1. hscreen
  - \* Sorts files
2. mapcheck
  - \* Makes sure that sky->fiber->aperture maps are present and properly formatted
3. hcalibproc
  - \* Processes bias and dark field image files using HPROC (per amplifier files)
4. multihproc
  - \* Runs HPROC on all calibration lamp (comp), sky flat, and dome flat images.
5. multihmerge
  - \* Runs HMERGE to merge the 4 amps into 1 image for all calibration files
6. multicomcombine
  - \* Combines dome flats -> domeflat.fits, sky flats -> sflat.fits, comps -> comp.fits

## SPECROADCAL

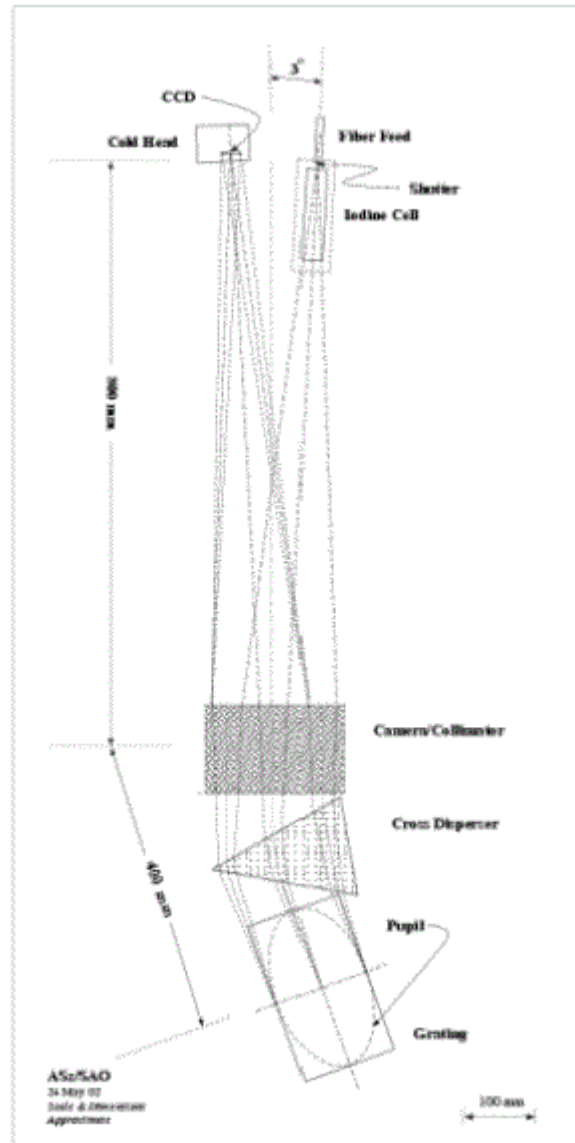
1. apflatten
  - \* creates aperture mask, flat.fits
2. multihflat
  - \* Runs HFLAT to flatten all dome, comp, sflat calibrations
3. multihextract
  - \* Run HEXTRACT to extract spectra from domes, comps, sflats; makes \*.ms files
4. hcal
  - \* create dispersion function
5. hlin
  - \* linearize the skyflat in wavelength
6. maketran
  - \* make throughput correction file tpc\_sflat.ms.fits

## SPECROADOBJ

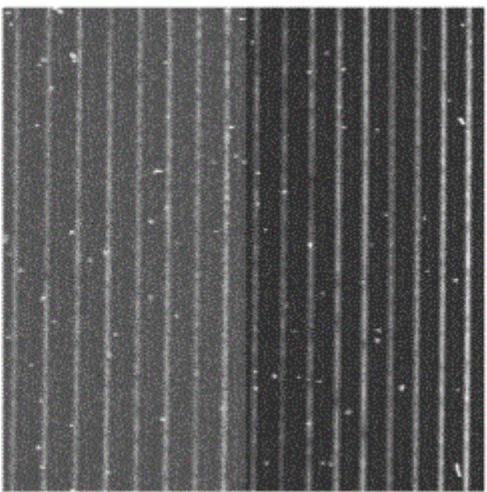
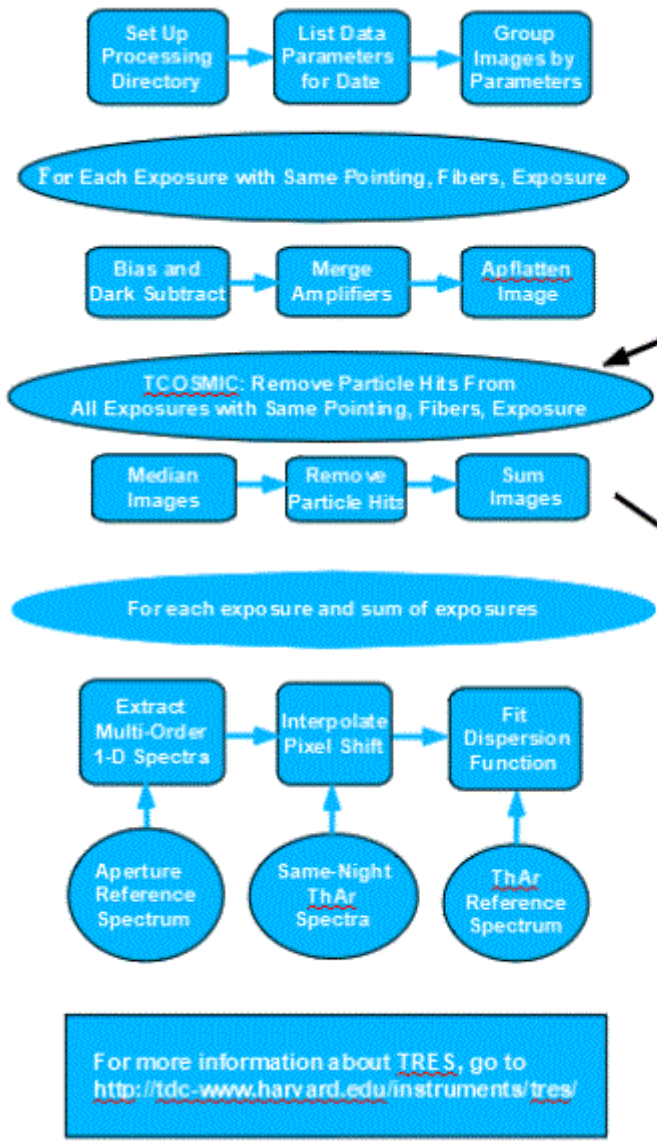
1. multihproc
  - \* Runs HPROC on all object files
2. multihmerge
  - \* Runs HMERGE to merge 4 amplifier extensions for all object images
3. multihflat
  - \* Flattens all object files
4. multihextract
  - \* Uses HEXTRACT to extract object exposures to IRAF multispec .ms.fits files
5. multihlin
  - \* Linearizes object multispec files to same wavelength range and resolution
6. multihscombine
  - \* Combines each field's multispec files to a single one
7. multihtran
  - \* Does throughput correction on each field's combined .ms file
  - \* Removes selected sky absorption features
  - \* Fits and removes "red leak" from all spectra
8. multihsplit
  - \* Splits the \_r.ms files to 300 spectra, into 1d\_pointing directories
9. multiskyproc
  - \* Runs SKYPROC on each 1d\_\* subdirectory, saves in skysub\_\* directories
10. multixcsao
  - \* Use XCSAO to run cross-correlations on skysub\_\* directories



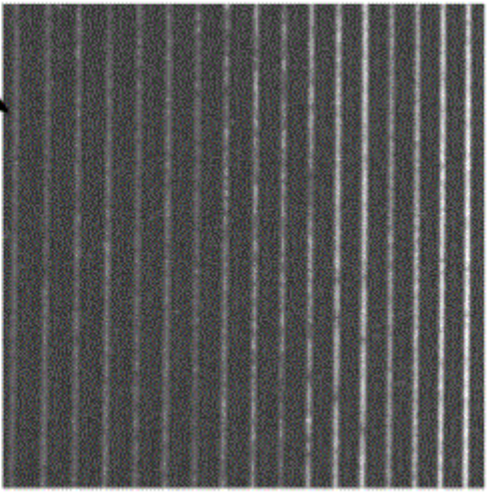
# TRES 51-order Echelle Spectrograph



# TRES Spectrograph Pipeline



Typical raw object spectrum with many particle hits



Same spectrum after TCOSMIC run on multiple exposures