How I Found My Place in the Universe
(and helped everybody else find theirs)

By
Jessica Mink
Smithsonian Astrophysical Observatory

American Museum of Natural History, April 13, 2015

Outline

Planet Surfaces: 1973-4 Mars Observations

Stars and Planets: 1976-1990 Occultations

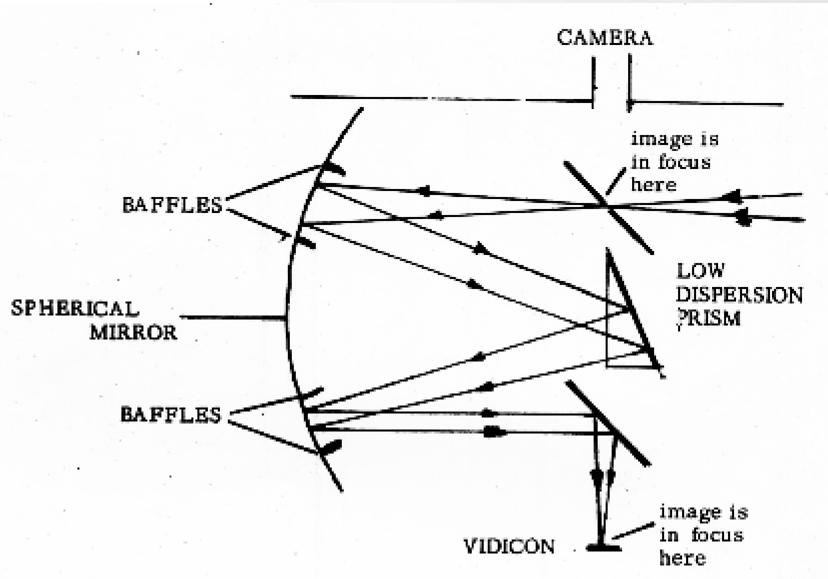
Milky Way: 1985-1990 IRAS and Spacelab 2 IRT

The Universe: 1990-2015 WCS, Plates, and Spectroscopy

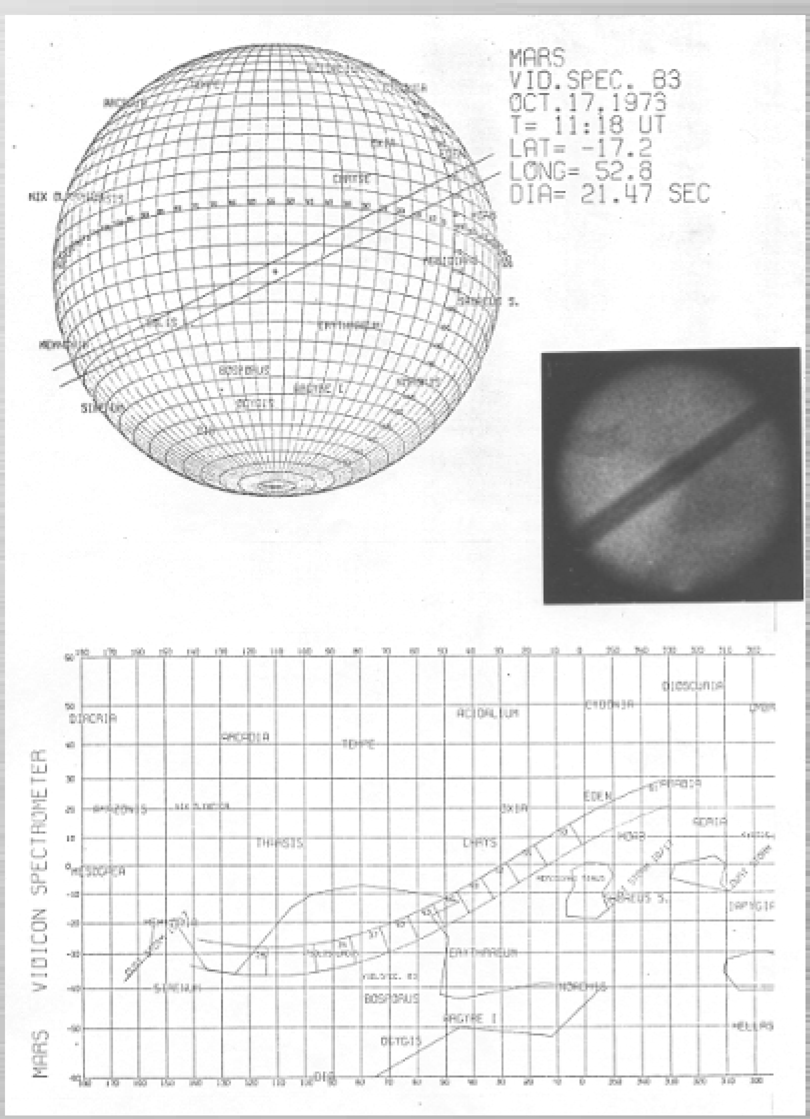
Projections

Orthographic: Face-on planet in sky
Mercator: Map of entire planet surface

It All Started With Mars

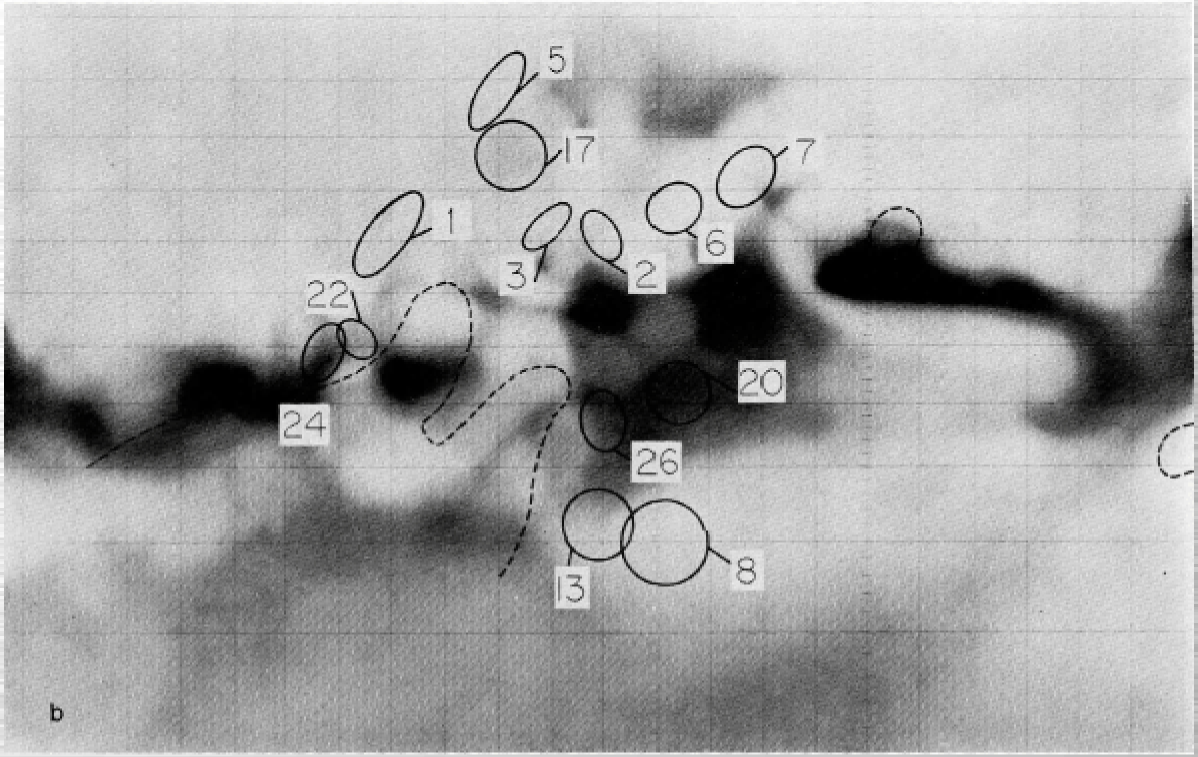


MIT Vidicon Spectrometer with camera monitoring slit in mirror



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

It All Started With Mars



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

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

Then Came Uranus

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
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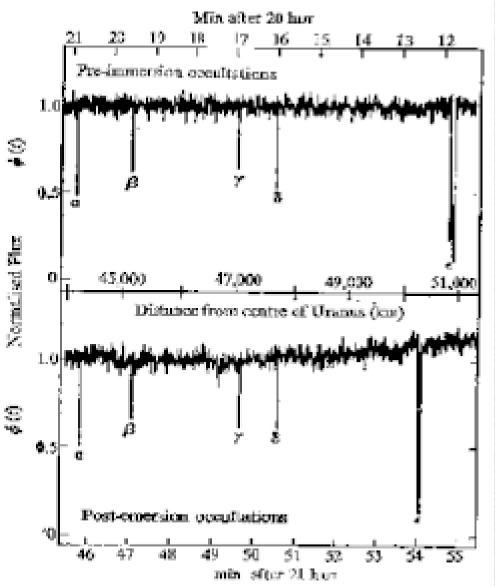
OCCULTATIONS BY URANUS AND (6) HEBE

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.



Circular No. 3048

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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. 10 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 21h06m 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 Kuppuswamy 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."

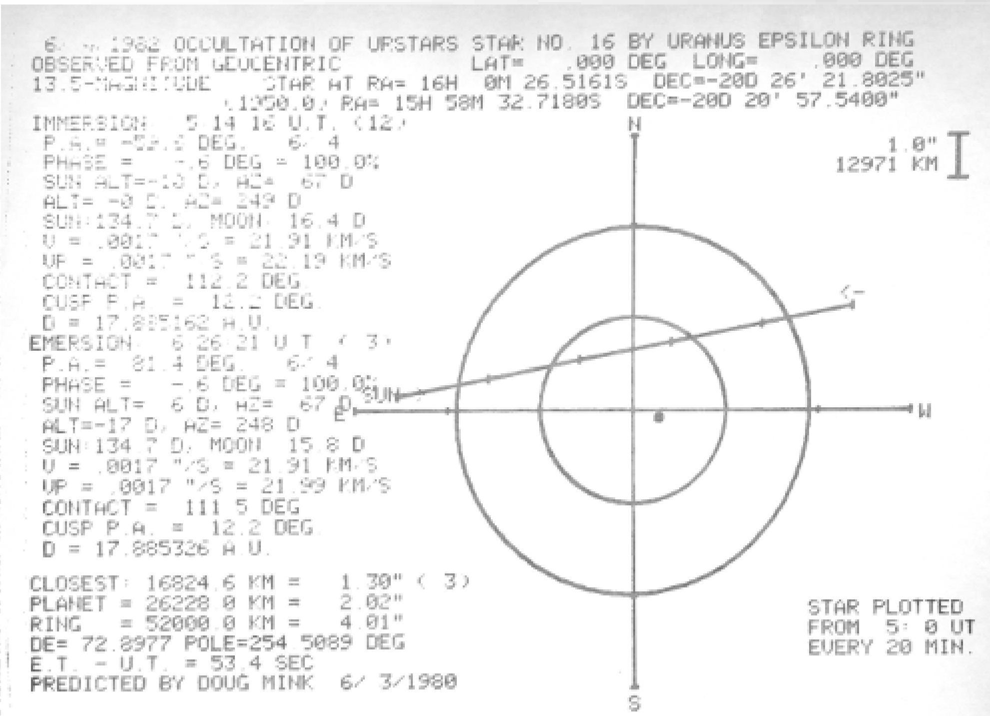
Computations by the undersigned show that the asymmetry in the times of the satellite occultations about the main occultation (as observed at the Airborne Observatory) is consistent with the existence of a circular belt in the plane of Uranus' equator. Allowance for foreshortening yields the radii of 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 opposition 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

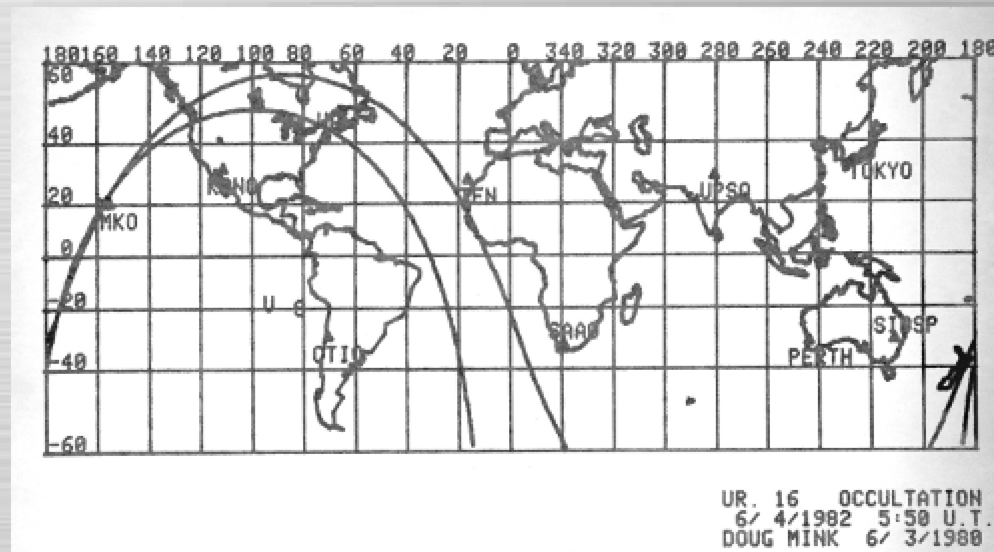
Occultation of SAO 158687 by Uranus and Its Rings

(Eliot, Dunham, and Mink, Nature 261, 328, May 26 1977)

Mapping observability

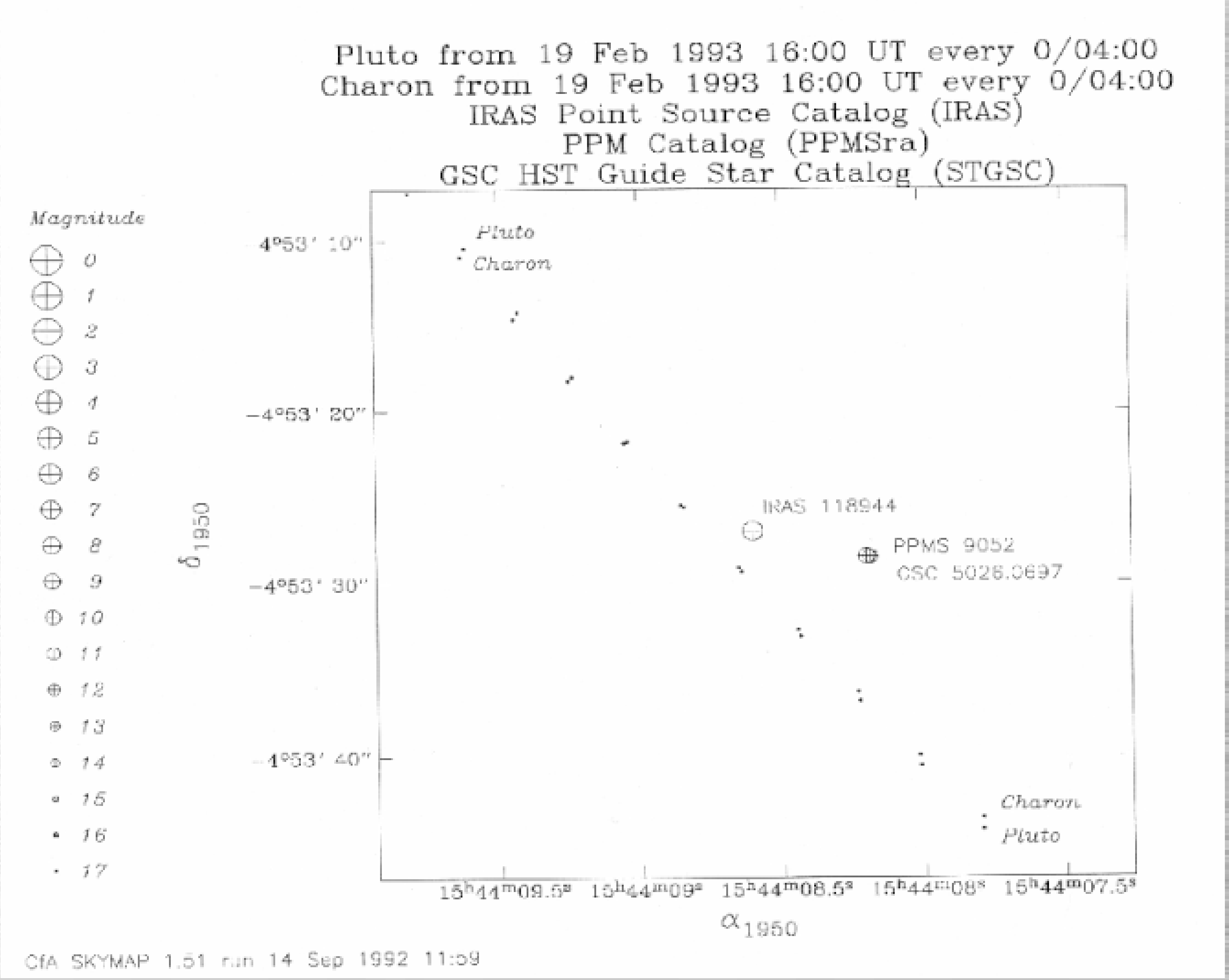


Geocentric prediction of Uranus 16



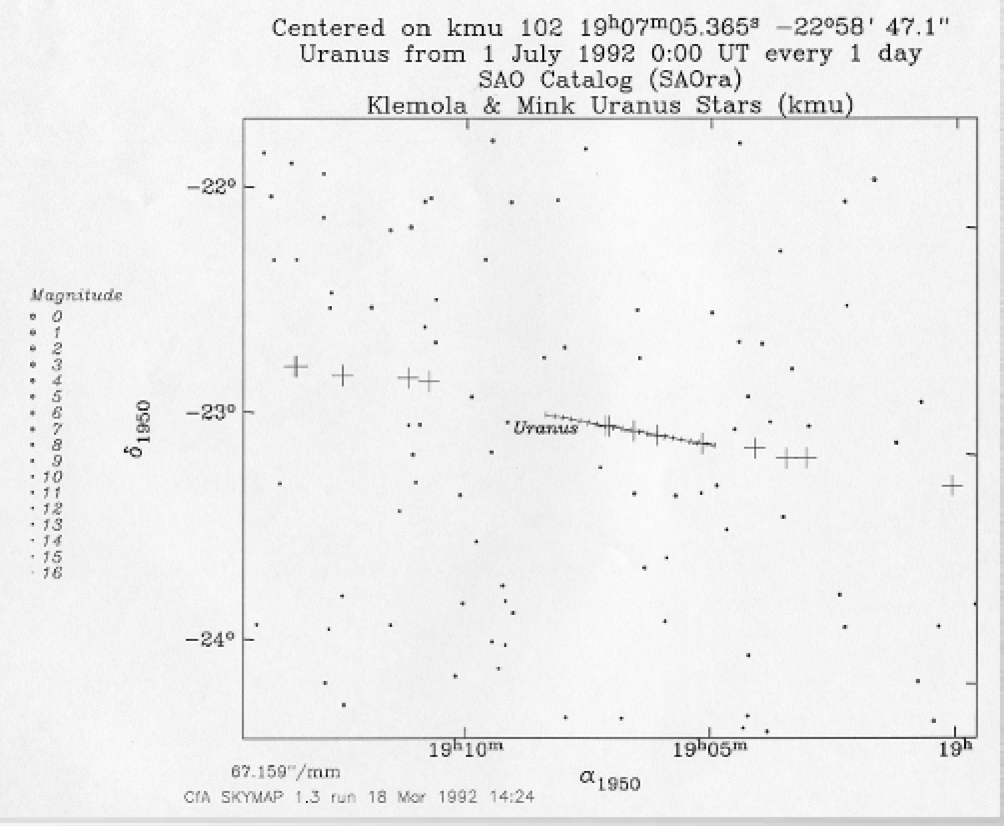
Sun down, Uranus up for Uranus 16

Finding Stars to be Occulted

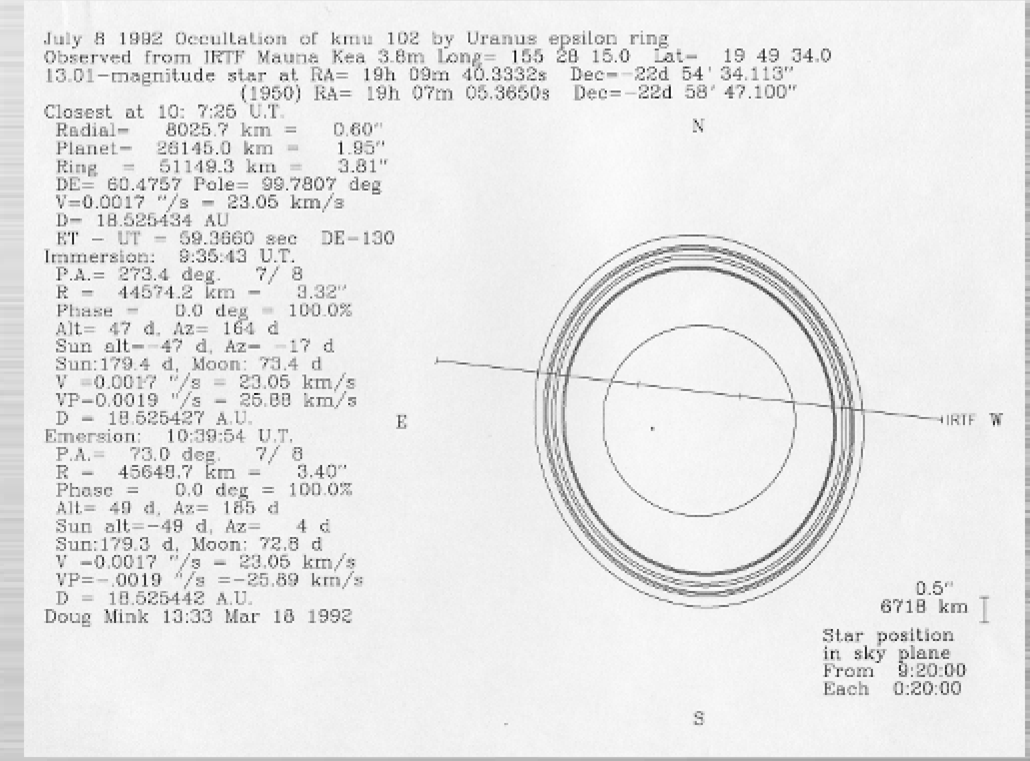


Map showing appulse of the Pluto/Charon system to a star
Note rotation of Charon around Pluto and variations in star position

Predicting Occultations



Palomar Sky Survey overlay for stars occulted by Uranus



Sky plane map of Uranus ring occultation of KMU102

Predicting Occultations

Venus Occultation of SAO 160149 on January 21, 2003

Click here for predictions for various cities

Catalog positions at 2003-01-21 11:00 UT

The arcsec column gives the distance from the SAO position

SAO_number	RA2000	Dec2000	Mag	Type
160149	16:53:54.416	-19:18:50.17	8.20	G0

PPM_number	RA2000	Dec2000	Mag	Type	Arcsec
232288	16:53:54.583	-19:18:48.54	8.60	G0	2.87

Tycho2_num	RA2000	Dec2000	MagB	MagV	Arcsec
6226.02681	16:53:54.550	-19:18:51.04	9.14	8.57	2.08

The following positions are at the catalog epochs

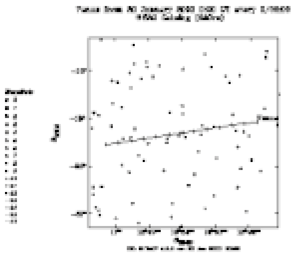
GSC_number	RA2000	Dec2000	Mag	Class	Band	N	Arcsec
6226.0268	16:53:54.509	-19:18:50.44	8.51	0	8	1	1.28

GSC-ACTnum	RA2000	Dec2000	Mag	Class	Band	N	Arcsec
6226.0268	16:53:54.552	-19:18:50.15	8.51	0	8	1	1.84

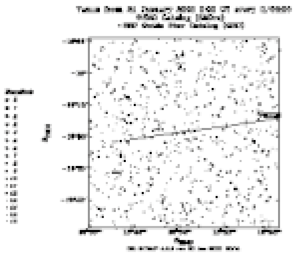
2MASS_num.	RA2000	Dec2000	MagJ	MagH	MagK	Arcsec
25.2772036	16:53:54.544	-19:18:50.92	7.399	7.151	7.067	1.93

USNO_A2_number	RA2000	Dec2000	MagB	MagR	Plate	Arcsec
0675.16930485	16:53:54.562	-19:18:48.34	9.2	9.9	808	2.62

Finding Charts

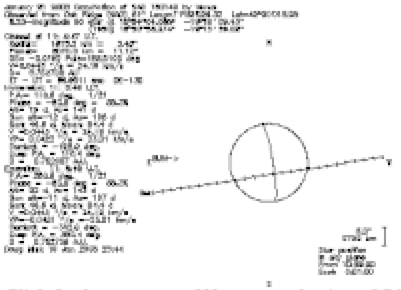


Click for larger map of 5° field around star

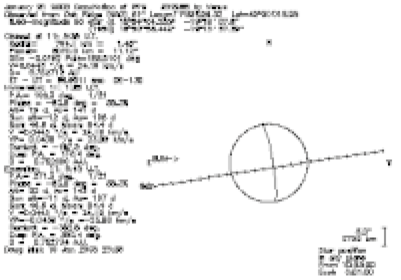


Click for larger map of 1° field around star

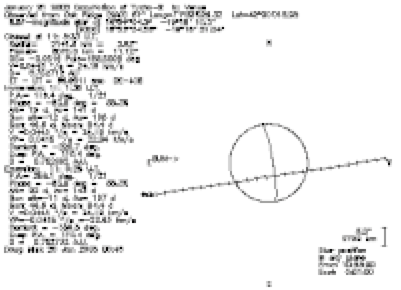
Predictions for Different Catalog Positions



Click for larger map of Venus occultation of SAO position



Click for larger map of Venus occultation of PPM position



Click for larger map of Venus occultation of Tycho-2 position

IRAS Projections

Infrared Astronomical Satellite (IRAS) Explanatory Supplement (1988)
Edited by C.A. Beichman, G. Neugebauer, H.J. Habing, P.E. Clegg, T.J. Chester
X. The Formats of the IRAS Catalogs and Atlases, D. Extended Emission

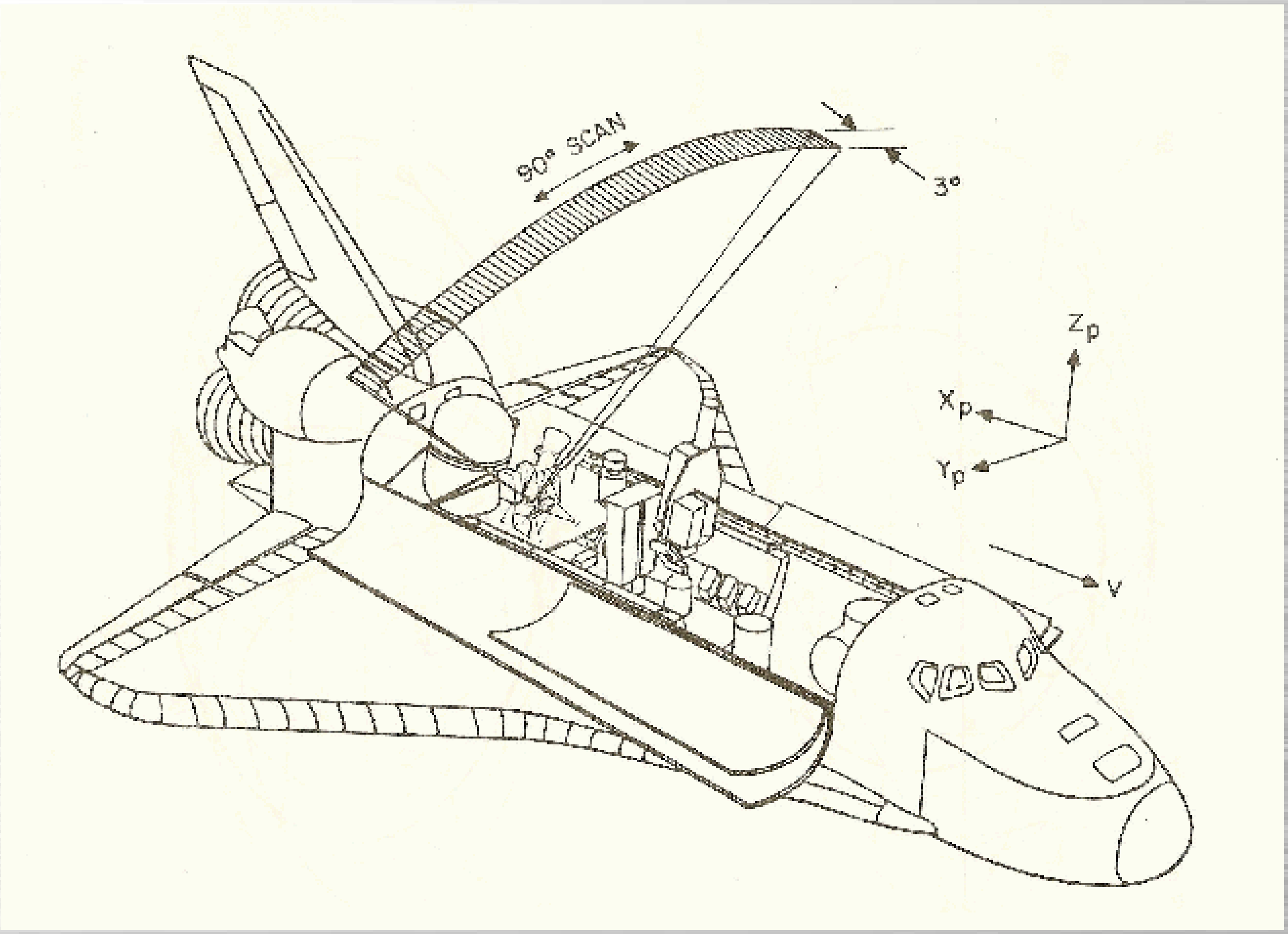
Polar: Maps of sky around North and South Poles

Aitoff: Map of entire sky

Sinusoidal: Maps of galactic plane

Gnomonic: Maps of regions of sky

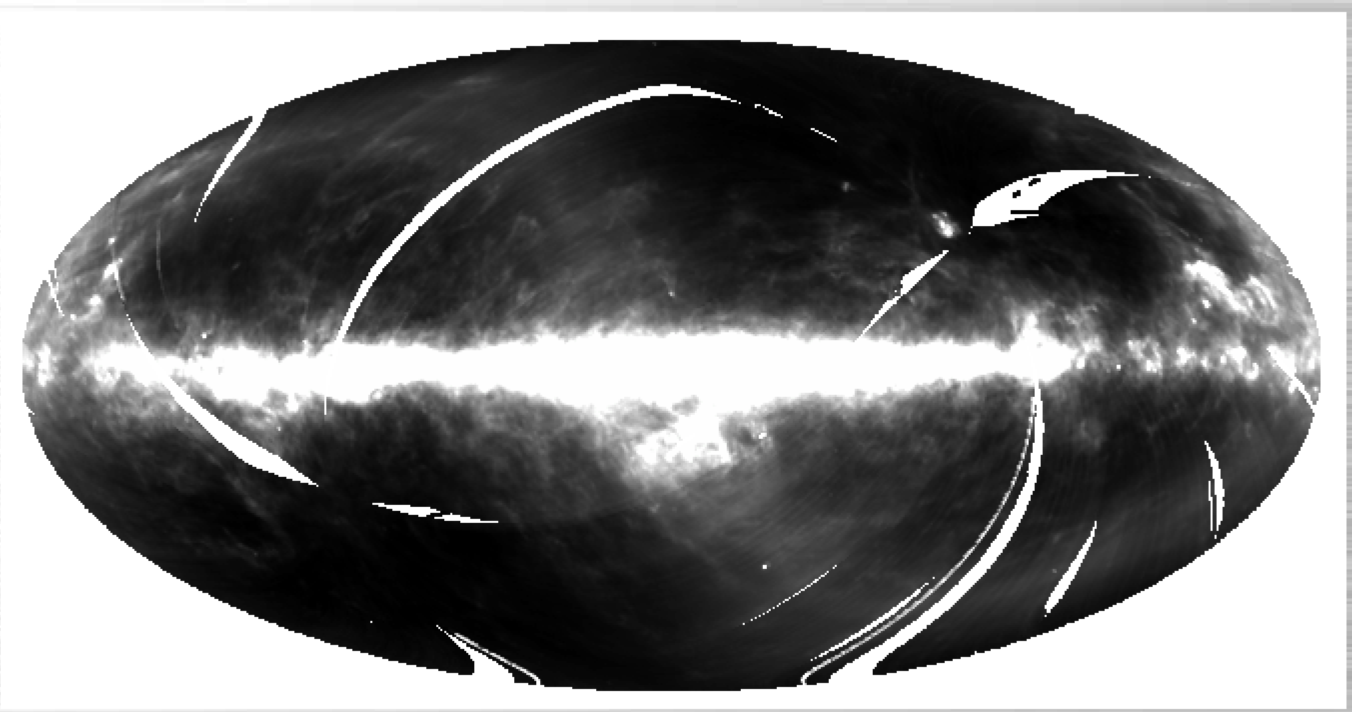
All-Sky IR Mapping from Space



Spacelab 2 Infrared Telescope

(Space Shuttle Challenger, July 1985)

All Sky IR Mapping from Space



IRAS 120 μm
Aitoff All-Sky Projection
1984 Data Release HCON 1

All Sky IR Mapping from Space

```
COMMENT   PROJECTION FORMULAE:
COMMENT    FORWARD FORMULA; XLON0 IS THE CENTER LONGITUDE OF THE
COMMENT        MAP.  ARC-SINE AND ARC-COSINE FUNCTIONS ARE REQUIRED.
COMMENT     R2D = 45. / ATAN(1.)
COMMENT     PIX = 2.
COMMENT     RHO = ACOS( COS(XLAT) * COS((XLON-XLON0)/2.) )
COMMENT     THETA = ASIN( COS(XLAT) * SIN((XLON-XLON0)/2.) / SIN(RHO) )
COMMENT     F = 2. * PIX * R2D * SIN(RHO/2.)
COMMENT     SAMPLE = -2. * F * SIN(THETA)
COMMENT     XLINE = -F * COS(THETA)
COMMENT     IF(XLAT .LT. 0.)  XLINE = -XLINE
COMMENT
COMMENT    REVERSE FORMULA; XLON0 IS THE CENTER LONGITUDE OF THE MAP.
COMMENT         ARC-SINE AND ARC-COSINE FUNCTIONS NEEDED.
COMMENT     R2D = 45. / ATAN(1.)
COMMENT     PIX = 2.
COMMENT     Y = -XLINE / (PIX * 2. * R2D)
COMMENT     X = -SAMPLE / (PIX * 2. * R2D)
COMMENT     A = SQRT(4.-X*X-4.*Y*Y)
COMMENT     XLAT = R2D * ASIN(A*Y)
COMMENT     XLON = XLON0 + 2. * R2D * ASIN(A*X/(2.*COS(XLAT)))
COMMENT
COMMENT   REFERENCES:
COMMENT    IRAS SDAS SOFTWARE INTERFACE SPECIFICATION(SIS)  #623-94/NO. SF05
COMMENT    ASTRON. ASTROPHYS. SUPPL. SER. 44,(1981) 363-370 (RE:FITS)
COMMENT   RECONCILIATION OF FITS PARMS W/ SIS SF05 PARMS:
COMMENT    NAXIS1 = (ES - SS + 1); NAXIS2 = (EL - SL + 1);
COMMENT    CRPIX1 = (1 - SS);      CRPIX2 = (1 - SL)
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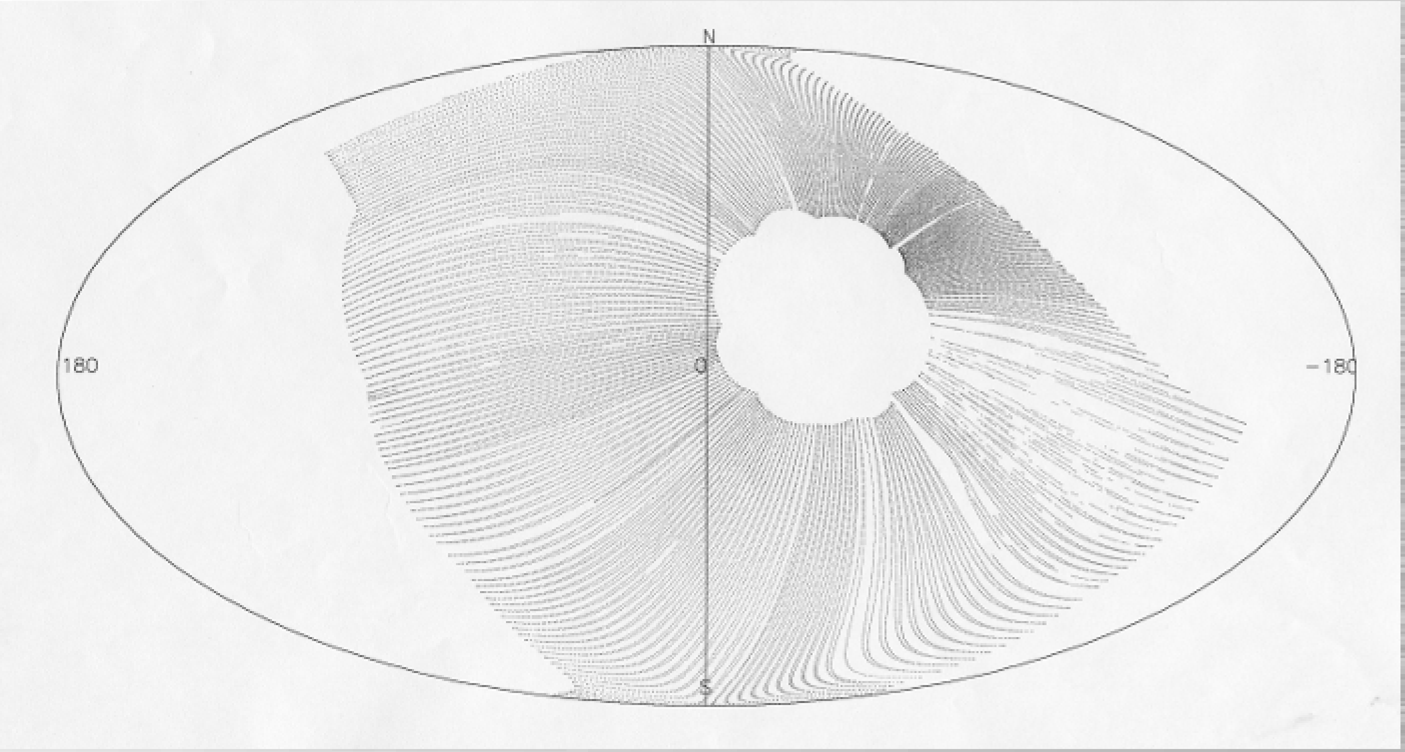
IRAS Aitoff All-Sky Projection Fortran Code in FITS Header

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)

Galactic Center from Spacelab 2

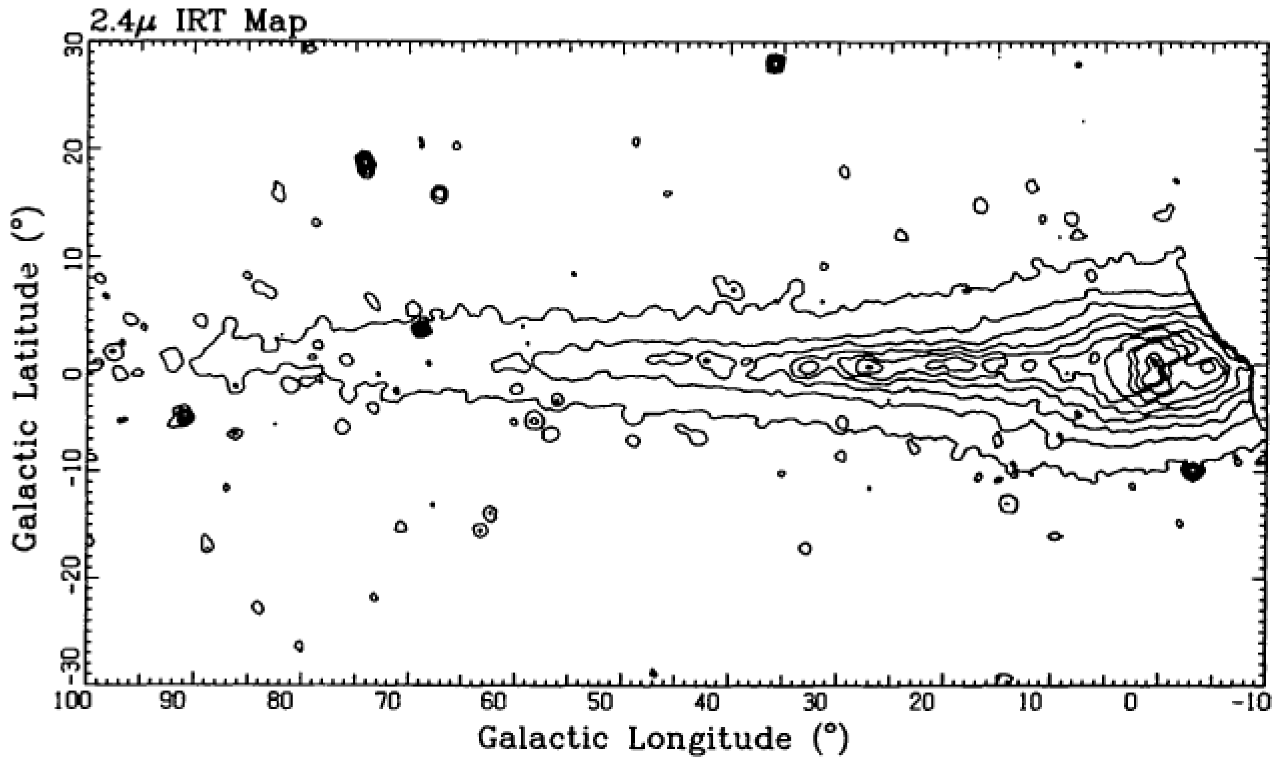
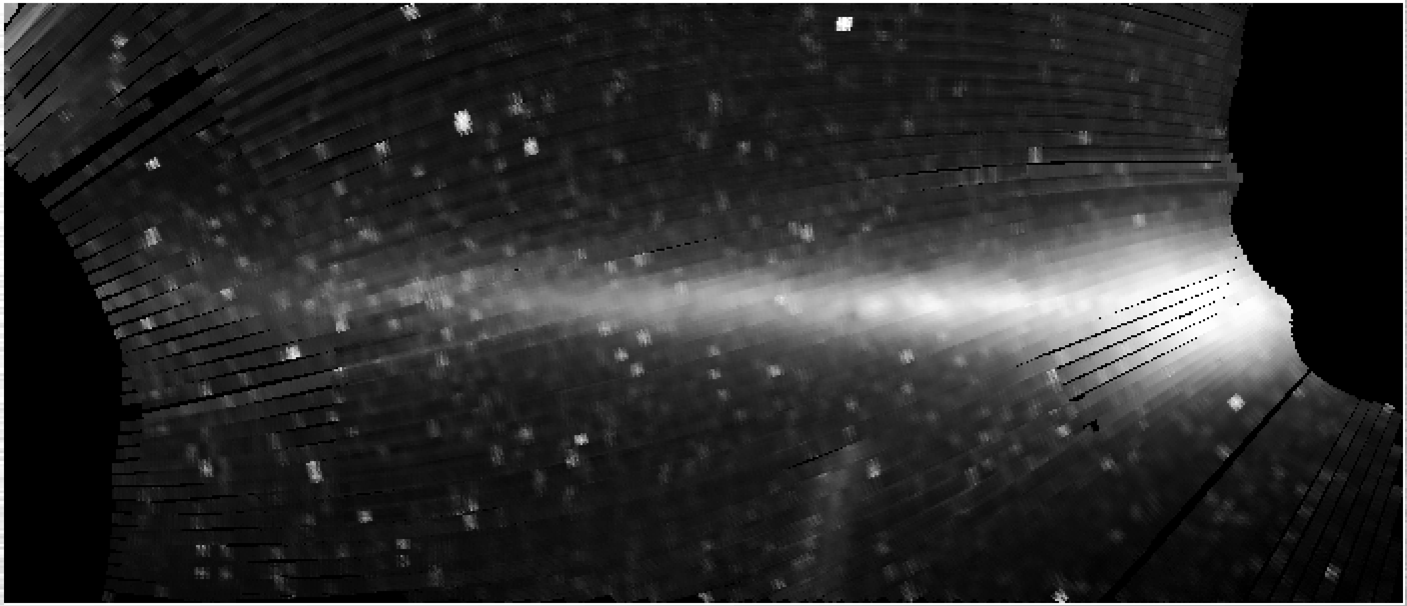


FIG. 5.—Contour map of the 2.4 μm emission from the Galactic plane region. The contours are spaced logarithmically in 10 steps between 0.67×10^{-10} and 16×10^{-10} W cm^{-2} μm^{-1} sr^{-1}.

Linear Projection in Galactic Coordinates

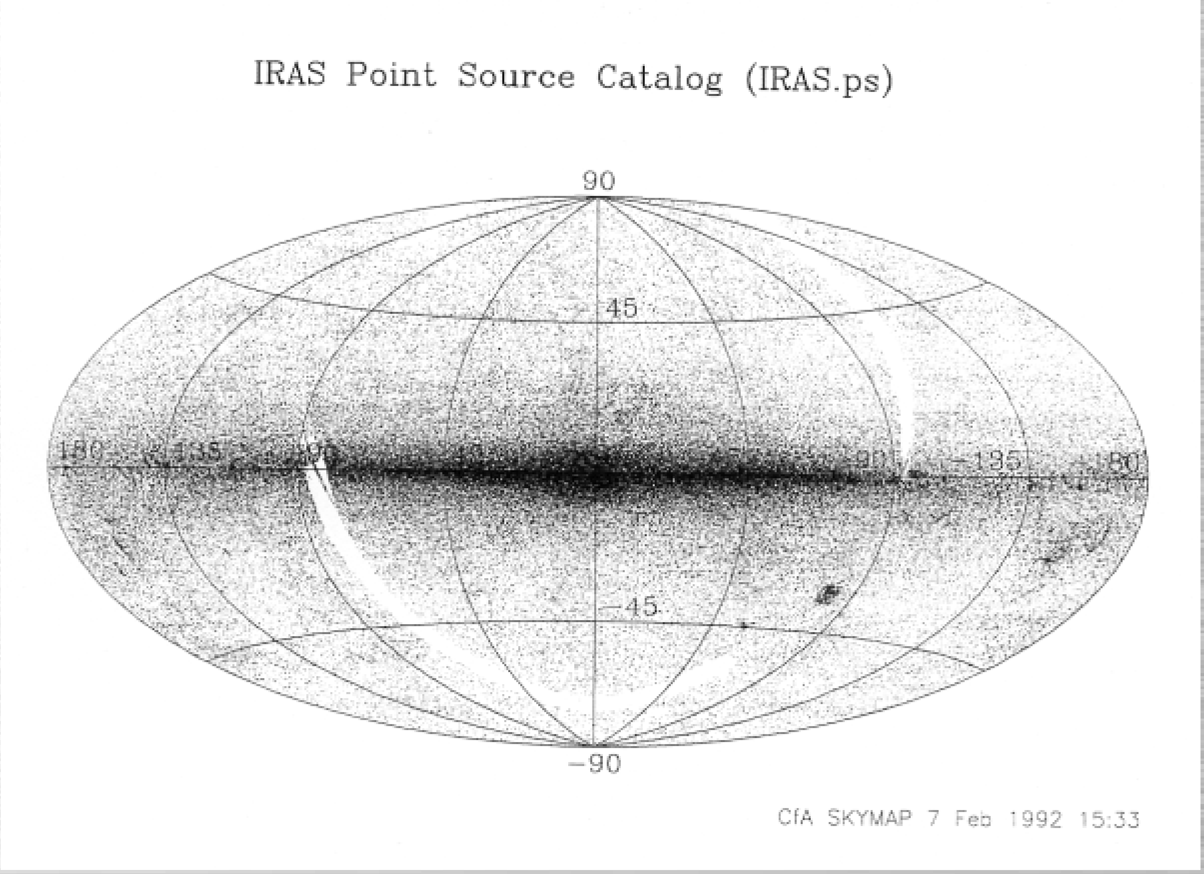
(Kent, Mink, Fazio, Koch, Melnick, Tardiff, Maxson, ApJS 78:403-408, 1992)

Galactic Center from Spacelab 2

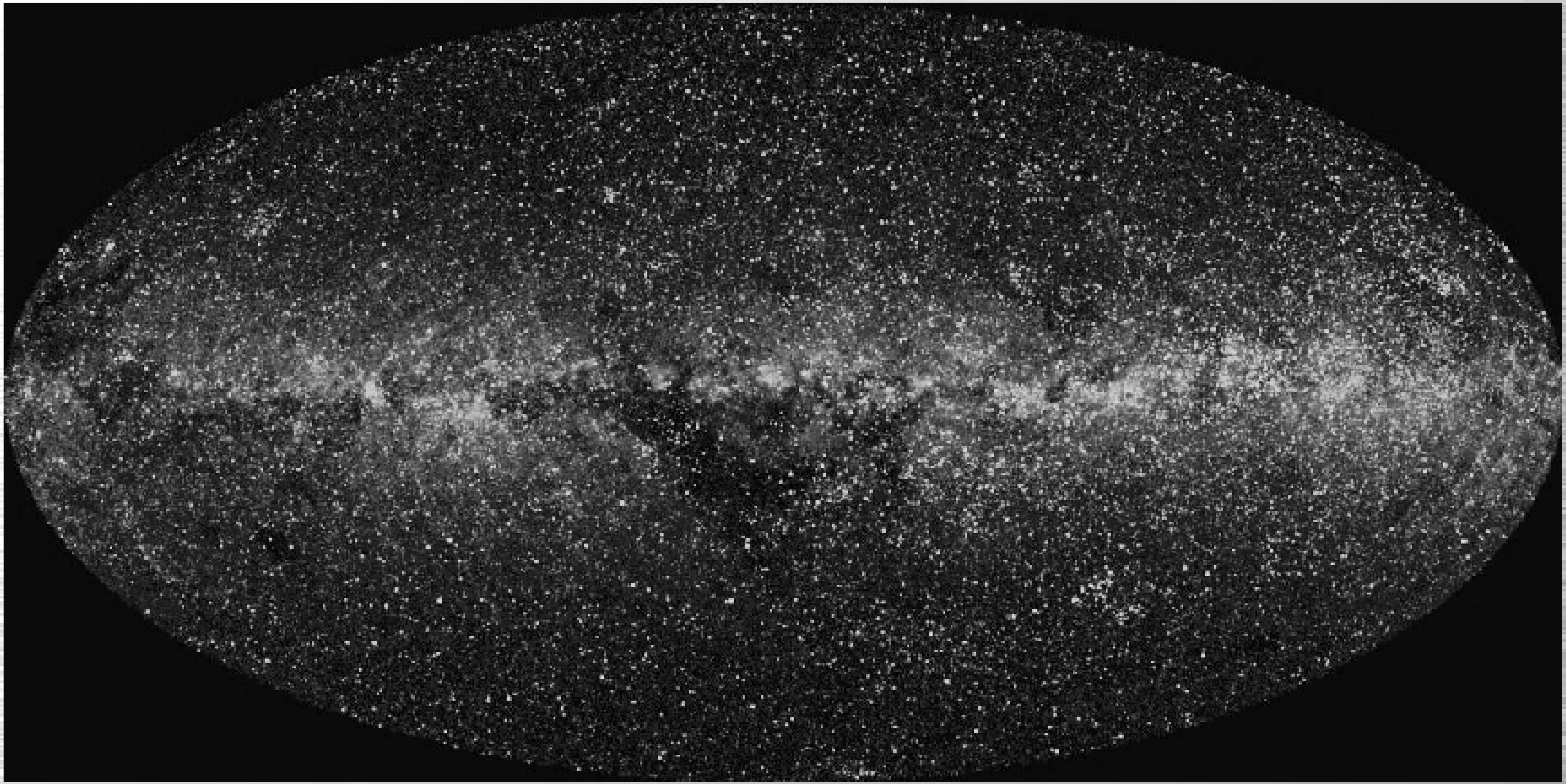


Linear Projection in Galactic Coordinates
(Mink, August 1990, unpublished)

All-Sky Maps meet Catalogs



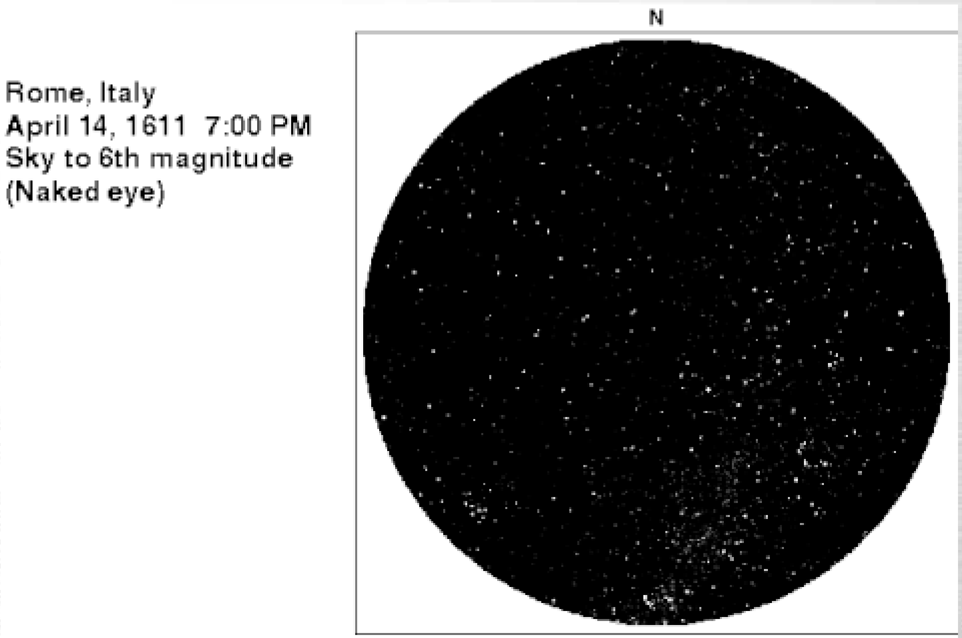
All-Sky Maps meet Catalogs

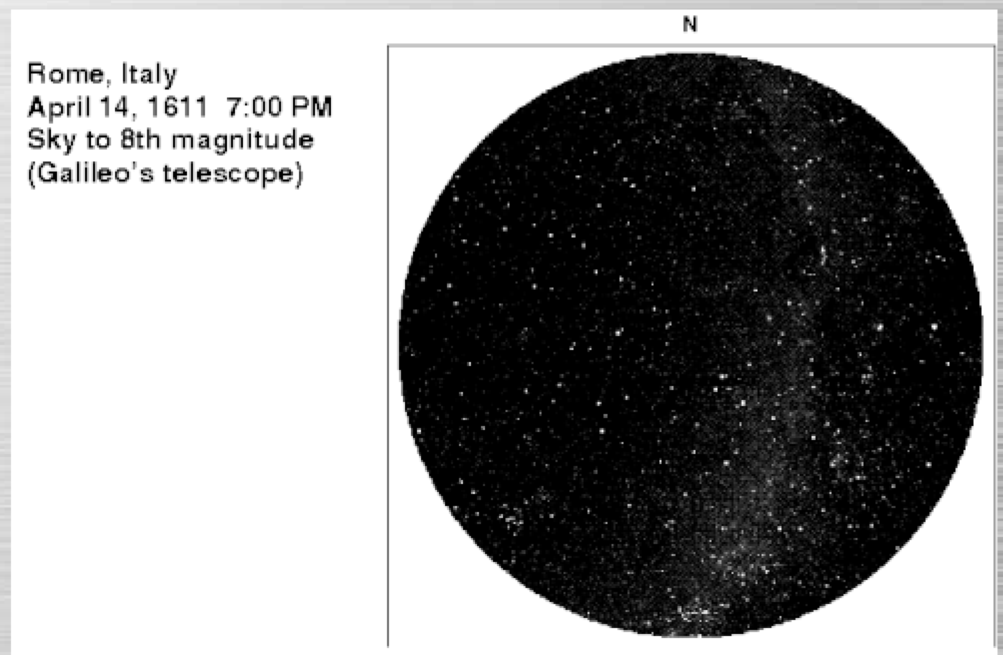


Space Telescope Guide Star Catalog, Galactic Plane, Aitoff Projection

(Mink, D.J. 1994. In Astronomical Data Analysis Software and Systems III, A.S.P. Conference Series, Vol. 61, 1994, Dennis R. Crabtree, R.J. Hanisch, and Jeannette Barnes, eds., p. 191)

Galileo's Telescope Expands the Sky



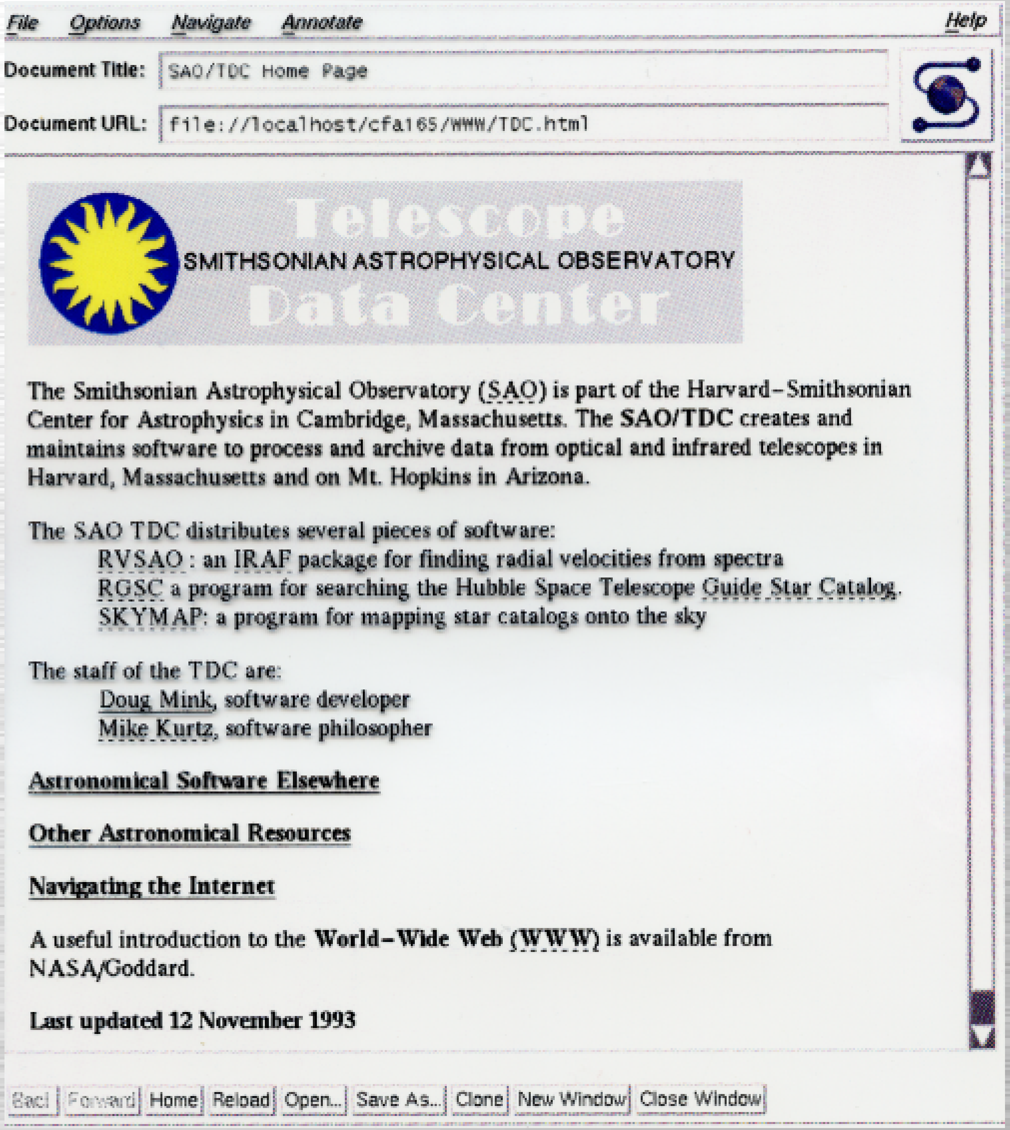


Polar projections centered on local apex in Rome

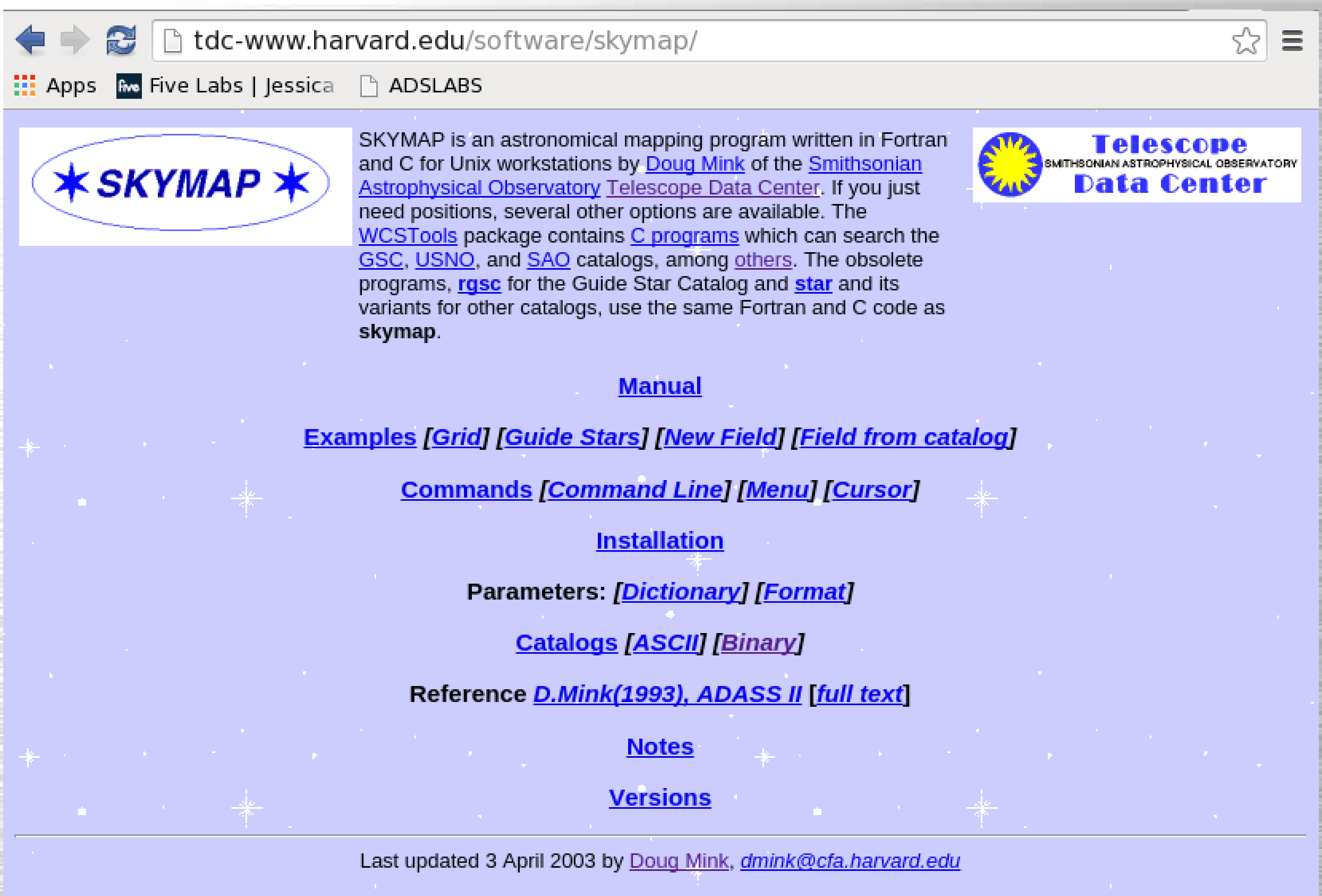
Owen Gingerich will present a keynote address at a conference sponsored by the American Academy of Rome celebrating the moment in 1611 when Galileo Galliei proudly presented the "telescope" to the intelligentsia of Rome... the Academy asked Paine Professor of Astronomy and director of the Harvard-Smithsonian Center for Astrophysics Irwin Shapiro and his Center colleague Douglas Mink to produce a map of the stars as they appeared over Rome on the night of April 14, 1611. For their efforts, Shapiro and Mink received a Jeroboam of champagne; Gingerich, however, got a trip to Rome.

(Harvard Gazette, April 10, 1997)

Onto the World Wide Web



Documentation on the World Wide Web


tdc-www.harvard.edu/software/skymap/

Apps Five Labs | Jessica ADSLABS

SKYMAP

SKYMAP is an astronomical mapping program written in Fortran and C for Unix workstations by Doug Mink of the Smithsonian Astrophysical Observatory Telescope Data Center. If you just need positions, several other options are available. The WCSTools package contains C programs which can search the GSC, USNO, and SAO catalogs, among others. The obsolete programs, **rgsc** for the Guide Star Catalog and **star** and its variants for other catalogs, use the same Fortran and C code as **skymap**.

Telescope Data Center — Smithsonian Astrophysical Observatory

Manual

Examples [*Grid*] [*Guide Stars*] [*New Field*] [*Field from catalog*]

Commands [*Command Line*] [*Menu*] [*Cursor*]

Installation

Parameters: [*Dictionary*] [*Format*]

Catalogs [*ASCII*] [*Binary*]

Reference *D.Mink(1993), ADASS II* [*full text*]

Notes

Versions

Last updated 3 April 2003 by Doug Mink, *dmink@cfa.harvard.edu*

Digitized Sky Survey Projection

AURA (1993-1994), "The Digitized Sky Survey" CDROM Manual
Doggett, J. (1997), http://gsss.stsci.edu/Software/GetImage/GetImage.htm
Mink, Jessica (1999), "WCSTools: Image Astrometry Toolkit", http://tdc-www.harvard.edu/software/wcstools/

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PLTLABEL= 'E1356            ' /Observatory plate label
PLATEID = '08MC             ' /GSSS Plate ID
REGION  = 'XE429            ' /GSSS Region Name
DATE-OBS= '23/03/55         ' /UT date of Observation
UT      = '06:02:00.00      ' /UT time of observation
EPOCH   =  1.9552226562500E+03 /Epoch of plate
PLTRAH  =                   10 /Plate center RA
PLTRAM  =                    7 /
PLTRAS  =  5.5528480000000E+01 /
PLTDECSN= '+                ' /Plate center Dec
PLTDECD =                   17 /
PLTDECM =                   17 /
PLTDECS =  3.8380860000000E+01 /
EQUINOX =  2.0000000000000E+03 /Julian Reference frame equinox
EXPOSURE=  5.0000000000000E+01 /Exposure time minutes
BANDPASS=                    8 /GSSS Bandpass code
PLTGRADE=                    1 /Plate grade
PLTSCALE=  6.7200000000000E+01 /Plate Scale arcsec per mm
SITELAT = '+33:24:24.00     ' /Latitude of Observatory
SITELONG= '-116:51:48.00    ' /Longitude of Observatory
TELESCOP= 'Palomar 48-inch Schmidt'/Telescope where plate taken
CNPIX1  =                10748 /X corner  (pixels)
CNPIX2  =                 2023 /Y corner
DATATYPE= 'INTEGER*2        ' /Type of Data
XPIXELSZ=  2.5284450000000E+01 /X pixel size microns
YPIXELSZ=  2.5284450000000E+01 /Y pixel size microns
```

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PPO1    =  0.0000000000000E+00 /Orientation Coefficients
PPO2    =  0.0000000000000E+00 /
PPO3    =  1.7747471555000E+05 /
PPO4    =  0.0000000000000E+00 /
PPO5    =  0.0000000000000E+00 /
PPO6    =  1.7747471555000E+05 /
AMDX1   =  6.7241844402360E+01 /Plate solution x coefficients
AMDX2   =  3.9757845495110E-01 /
AMDX3   = -2.0498717200880E+02 /
AMDX4   = -1.3607216767070E-05 /
AMDX5   = -2.2201873529570E-05 /
AMDX6   =  7.4284599162830E-07 /
AMDX7   =  0.0000000000000E+00 /
AMDX8   =  1.9162087720540E-06 /
AMDX9   = -9.2146076767620E-10 /
AMDX10  =  2.1089546241680E-06 /
AMDX11  = -9.3945135632070E-08 /
AMDY1   =  6.7256622034650E+01 /Plate solution y coefficients
AMDY2   = -3.9844579471320E-01 /
AMDY3   = -6.8591056129270E+01 /
AMDY4   = -1.3176449798960E-05 /
AMDY5   = -7.8391468151820E-06 /
AMDY6   = -7.4802178840710E-07 /
AMDY7   =  0.0000000000000E+00 /
AMDY8   =  1.8834016180180E-06 /
AMDY9   = -1.9452422448560E-07 /
AMDY10  =  2.1574073462190E-06 /
AMDY11  = -1.6009508926300E-08 /
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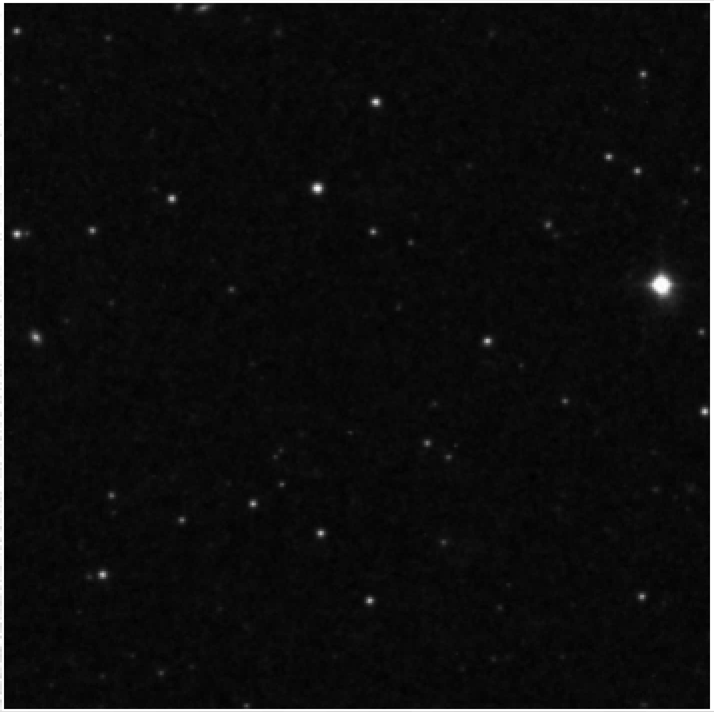
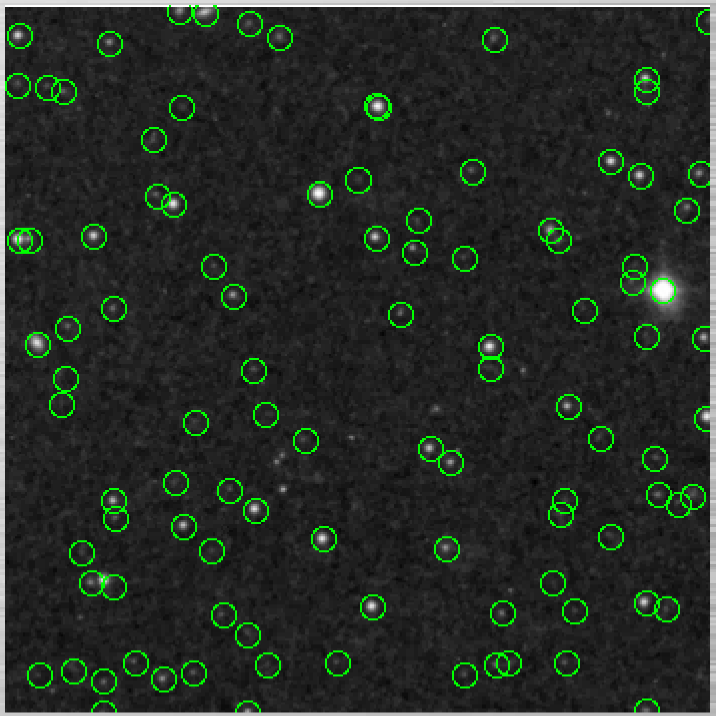
Digitized Sky Survey Projection

Mink, Jessica (1999), "WCSTools: Image Astrometry Toolkit" , http://tdc-www.harvard.edu/software/wcstools/



DS9 display of DSS image with previous header



DS9 display of same DSS image with regions generated by WCSTools imcat program which remotely accessed the GSC2 catalog

AIPS Projections

The eight most commonly-used projections of classic AIPS may be computed using the *worldpos* and *worldpix* subroutines written by Bill Cotton and Eric Greisen of NRAO:

SIN: Orthographic projection
TAN: Tangent plane projection
ARC: Zenithal equidistant projection
NCP: North celestial pole projection
GLS: Sanson-Flemsteed sinusoidal projection
MER: Mercator projection
AIT: Hammer-Aitoff equal area all-sky projection
STG: Stereographic projection
(zenithal orthomorphic)

in Mink, Jessica, "WCSTools: Image Astrometry Toolkit", http://tdc-www.harvard.edu/software/wcstools/

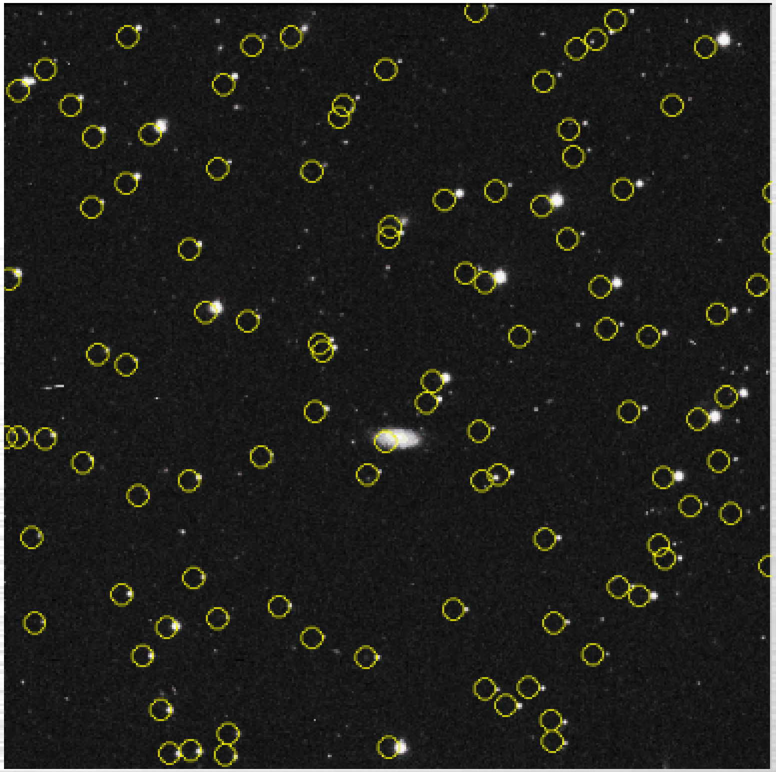
FITS-WCS Projections

Calabretta, M.R., & Greisen, E.W., (2002),"Representations of celestial coordinates in FITS", Astronomy & Astrophysics, 395, 1077-1122.

AZP: Zenithal (Azimuthal) Perspective
SZP: Slant Zenithal Perspective
TAN: Gnomonic = Tangent Plane
SIN: Orthographic/synthesis
STG: Stereographic
ARC: Zenithal/azimuthal equidistant
ZPN: Zenithal/azimuthal PolyNomial
ZEA: Zenithal/azimuthal Equal Area
AIR: Airy
CYP: CYlindrical Perspective
CAR: Cartesian
MER: Mercator
CEA: Cylindrical Equal Area
COP: COnic Perspective

COD: COnic equiDistant
COE: COnic Equal area
COO: COnic Orthomorphic
BON: Bonne
PCO: Polyconic
SFL: Sanson-Flamsteed
PAR: Parabolic
AIT: Hammer-Aitoff equal area all-sky
MOL: Mollweide
CSC: COBE quadrilateralized Spherical Cube
QSC: Quadrilateralized Spherical Cube
TSC: Tangential Spherical Cube
NCP: North celestial pole (special case of SIN)
GLS: GLobal Sinusoidal (Similar to SFL)

Fitting a WCS using WCSTools

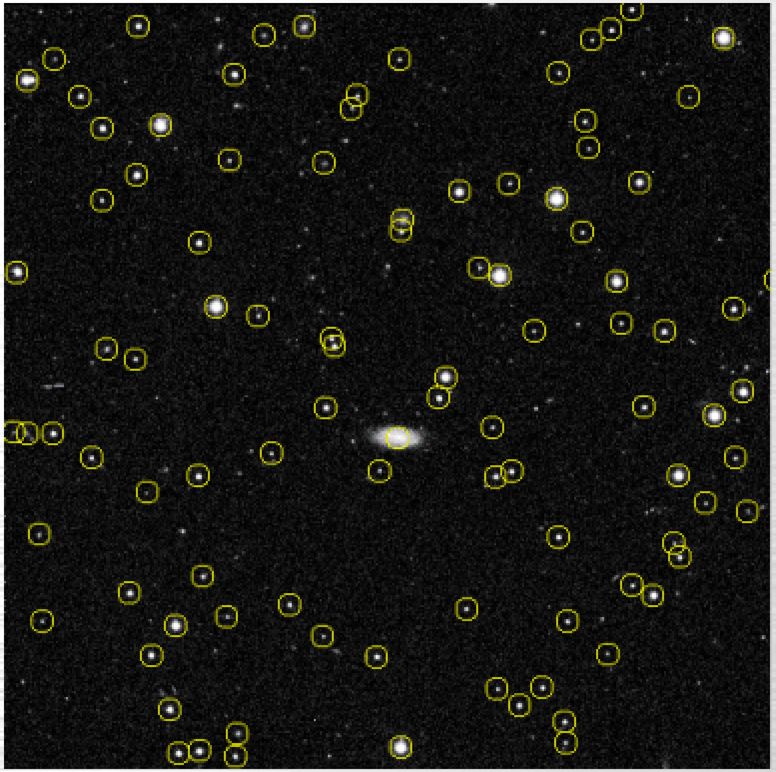


```
NAXIS   =                    2 /  NUMBER OF AXES
NAXIS1  =                 1024
NAXIS2  =                 1024
RA      = '16:15:56'            /MEAN RA
DEC     = '31:25:10'            /MEAN DEC
EPOCH   =                 2000  /MEAN EPOCH
DATE-OBS= '1995-03-06T10:04:50'           /UT DD/MM/YY AT END OF EXPOSURE
EXPTIME =               240.00 /INTEGRATION TIME, SECONDS
HJDN    =        2449871.91686 /HELIOCENTRIC JULIAN DAY AT MIDDLE OF EXPOSURE
SECPIX  =                0.652 /SEC OF ARC SPATIAL PIXEL , SET BY PARAMETERS
```

USNO-B1.0 Catalog plotted over image using telescope pointing

FITS header with limited WCS keywords from telescope

Fitting a WCS using WCSTools



```
NAXIS    =                    2 /  NUMBER OF AXES
NAXIS1   =                 1024
NAXIS2   =                 1024
RA       = '16:15:56.591'
DEC      = '+31:25:07.35'
EPOCH    =                 2000
RADECSYS= 'FK5      '
EQUINOX =                  2000
CRPIX1   =             516.9970
CRPIX2   =             513.4151
CD1_1    =      -0.000178936537
CD1_2    =       0.000000555651
CD2_1    =       0.000000278868
CD2_2    =       0.000178740421
WCSRFCAT= 'ub1      '
WCSIMCAT= 'testx90m.sex'
WCSMATCH=                   147
WCSNREF =                   217
WCSTOL   =               2.5000
CTYPE1   = 'RA---TAN'
CTYPE2   = 'DEC--TAN'
CRVAL1   =        243.985795481
CRVAL2   =         31.418709691
SECPIX1 =                0.6442
SECPIX2 =                0.6435
WCSSEP   =                0.257
```

USNO-B1.0 Catalog plotted over image after imwcs WCS fit

FITS header with WCS keywords after WCS fit using imwcs

Finding Stars for WCSTools

WCSTools supports several ways to find
the star-like objects in an image

- WCSTools IMSTAR task (also built into IMWCS)

- IRAF DAOFIND task
 (its X,Y,Magnitude is WCSTools standard position format)

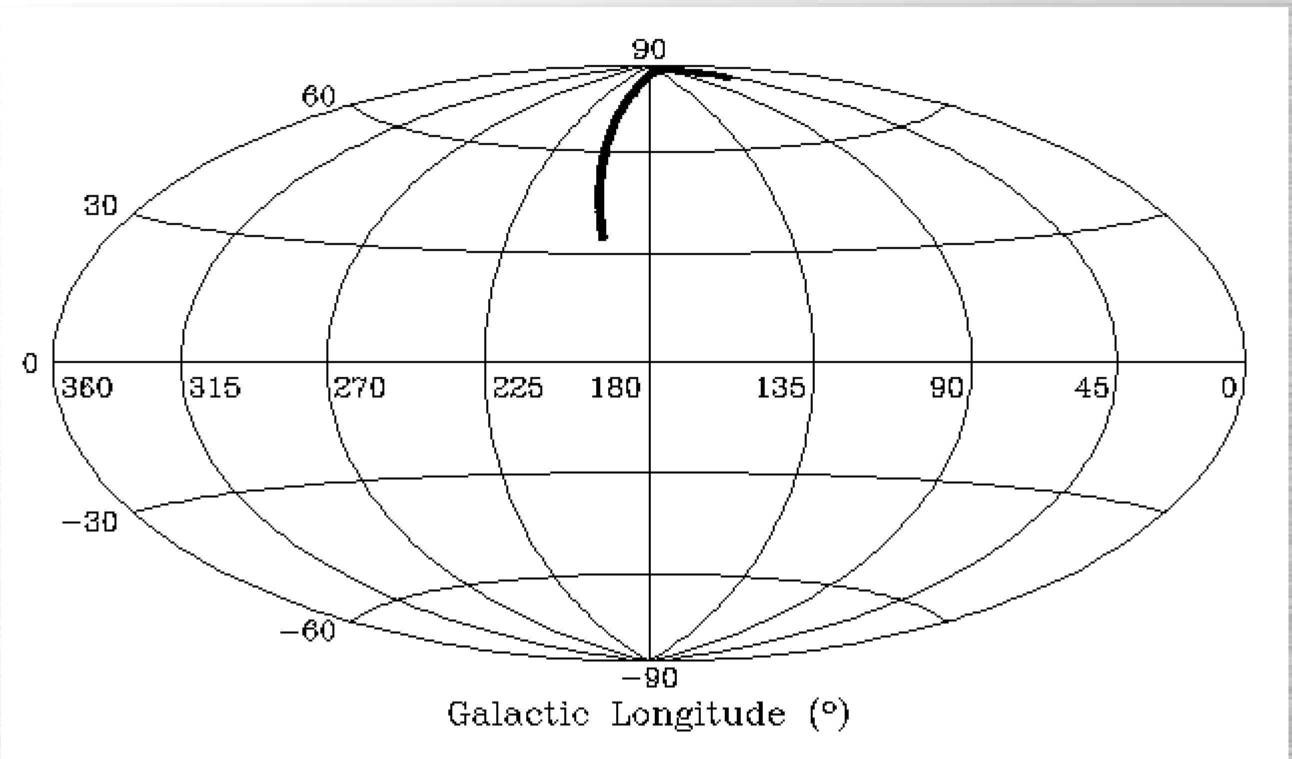
- Sextractor
(output formattable to WCSTools standard)

More Catalogs

These catalogs are available and supported by SAO/TDC search and mapping software.

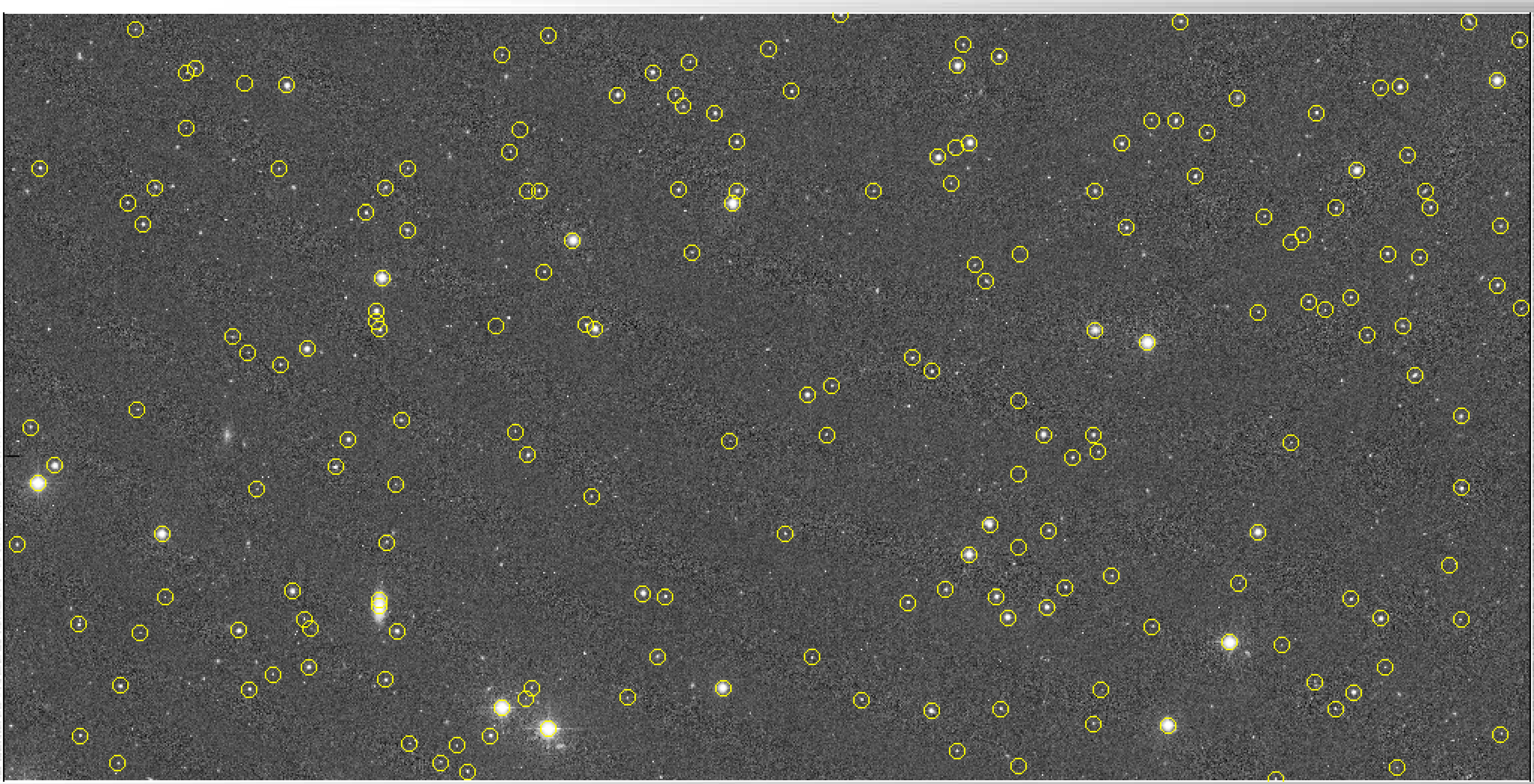
Catalog or Format	No. Stars	Bytes	Region Search	Image Search	Mapping
USNO-B1.0 Catalog	1,036,366,767	83,614,060,960	sub1 (scat)	imub1 (imcat)	
GSC II Catalog (2.2.01)	998,402,801	>80,000,000,000	sgsc2 (scat)	imgsc2 (imcat)	
2MASS Point Source Catalog	470,992,970	31,775,592,000	stmc (scat)	imtmc (imcat)	
2MASS Extended Source Catalog	1,647,599	11,533,193	stmx (scat)	imtmx (imcat)	
USNO UCAC3 Catalog	100,766,420	8,536,270,559	sucac3 (scat),	imucac3 (imcat)	
USNO UCAC2 Catalog	48,366,996	2,128,147,841	sucac2 (scat),	imucac2 (imcat)	
GSC-ACT Catalog	25,541,952	1,231,787,520	sgsca (scat)	imgsca (imcat)	
SDSS Photometry Catalog	53 million (DR1)	??	ssdss (scat)	imsdss (imcat)	
HST Guide Star Catalog	25,541,952	1,231,787,520	sgsc (scat)	imgsc (imcat)	skymap
Tycho-2 Catalog	2,539,913	528,721,576	sty2 (scat)	imty2 (imcat)	
USNO/Hipparcos ACT Catalog	988,758	318,380,076	sact (scat)	imact (imcat)	
SKY2000 Catalog	299,167	11,368,374	ssky2k (scat)	imsky2k (imcat)	skymap
PPM Catalog	378,910	22,734,656	sppm (scat)	imppm (imcat)	skymap
SAO Catalog	258,996	15,539,876	ssao (scat)	imsao (imcat)	skymap
IRAS Point Source Catalog	245,889	7,376,698	siras (scat)	imiras (imcat)	skymap
Hipparcos Catalog	118218	4492312	ship (scat)	imhip (imcat)	skymap
Yale Bright Star Catalog	3256	291548	sbsc (scat)	imbsc (imcat)	skymap
Starbase tab-delimited ASCII	varies	varies	scat	imcat	
TDC Space-Delimited ASCII	varies	varies	scat	imcat	skymap
TDC Binary	varies	varies	scat	imcat	skymap
USNO-A2.0 Catalog	526,280,881	6,315,370,572	sua2 (scat)	imua2 (imcat)	skymap
USNO-SA2.0 Catalog	55,368,239	664,418,868	susa2 (scat),	imusa2 (imcat)	
USNO-A1.0 Catalog	488,006,860	5,856,082,320	sua1 (scat)	imua1 (imcat)	skymap
USNO-SA1.0 Catalog	54,787,624	657,451,488	susa1 (scat)	imusa1 (imcat)	skymap
USNO J-1.0 Catalog	19,911,514	238,938,168	sujc (scat)	imujc (imcat)	

Testing Catalog Accuracy



216 1x1 degree fields from the 8K array on the KPNO 36-inch telescope cover half of the CfA Century survey, 50 degrees across the sky

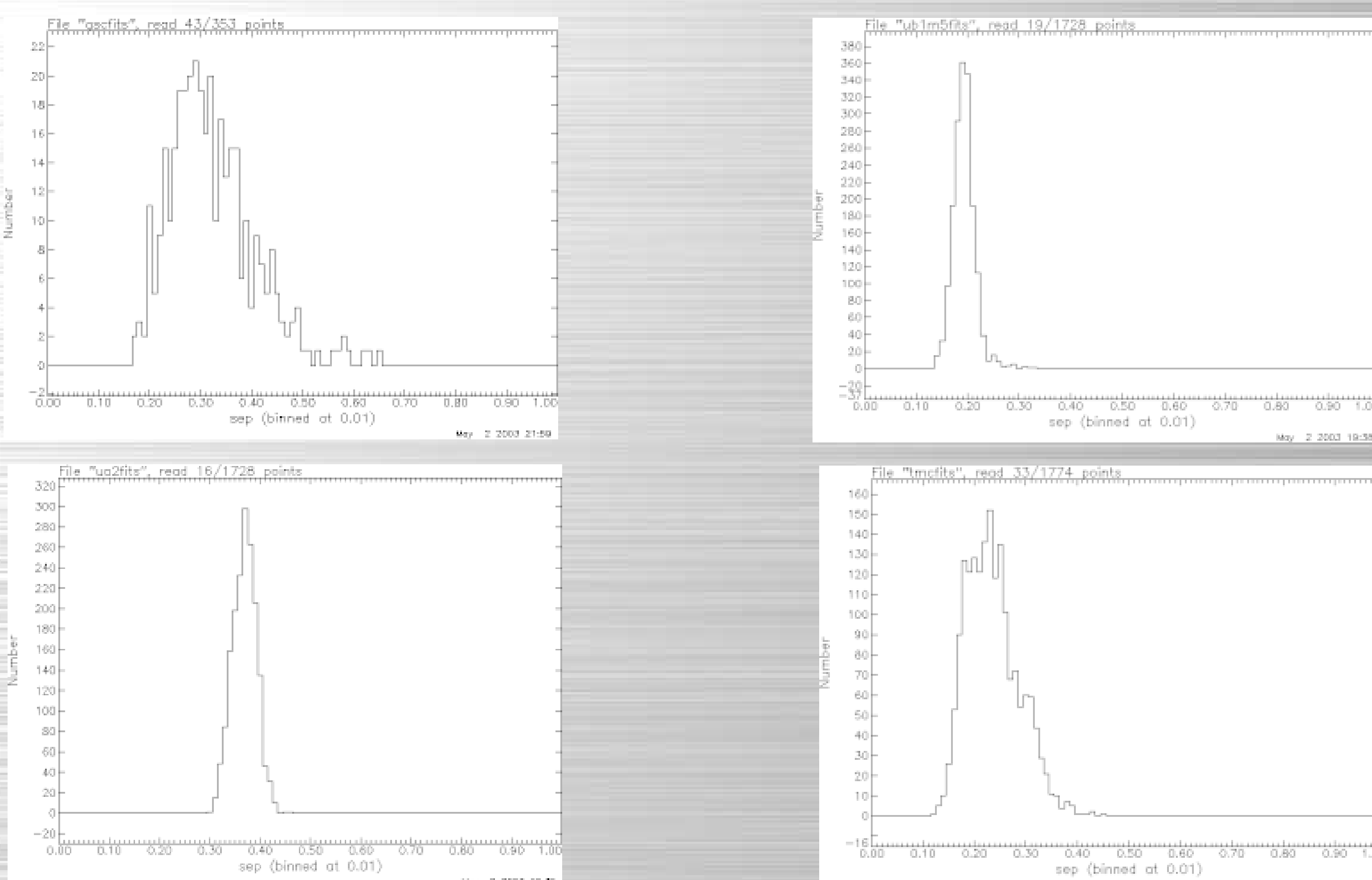
Testing Catalog Accuracy



The 2MASS Point Source Catalog plotted over one of the 1728 test images

Testing Catalog Accuracy

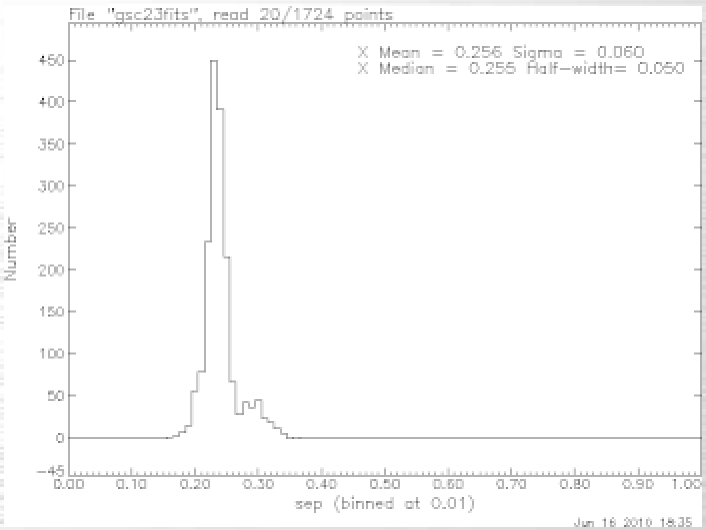
D. J. Mink, W. R. Brown, M. J. Kurtz (2004) A Comparison of Large All-Sky Catalogs Astronomical Data Analysis Software and Systems XIII, F. Ochsenbein, M. Allen, and D. Egret, eds. ASP Conference Series, Vol. 314, p. 141

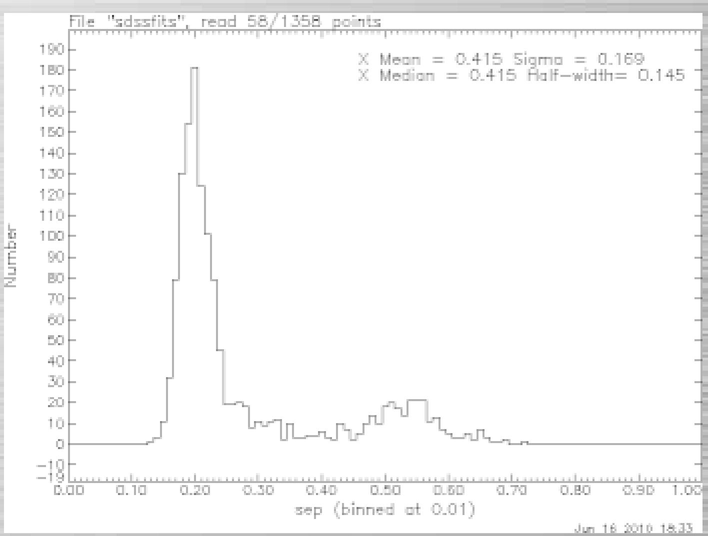


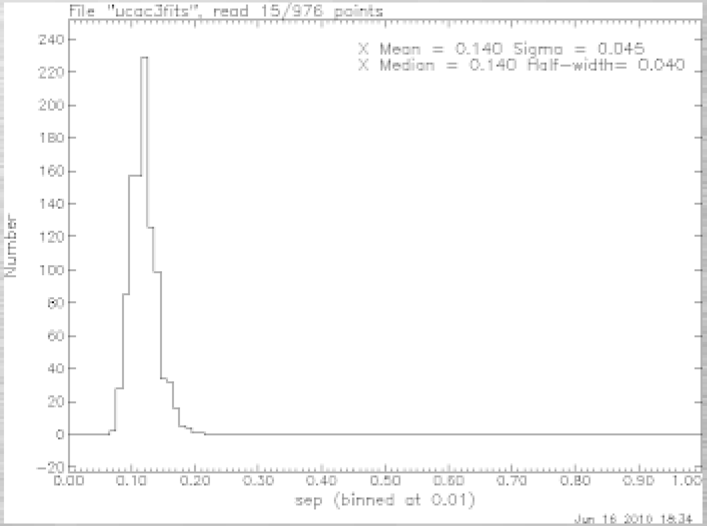
Differences between catalogs and WCS fits to 1726 images

Testing Catalog Accuracy

D. J. Mink (2010) Unpublished







Differences between catalogs and WCS fits to 1726 images

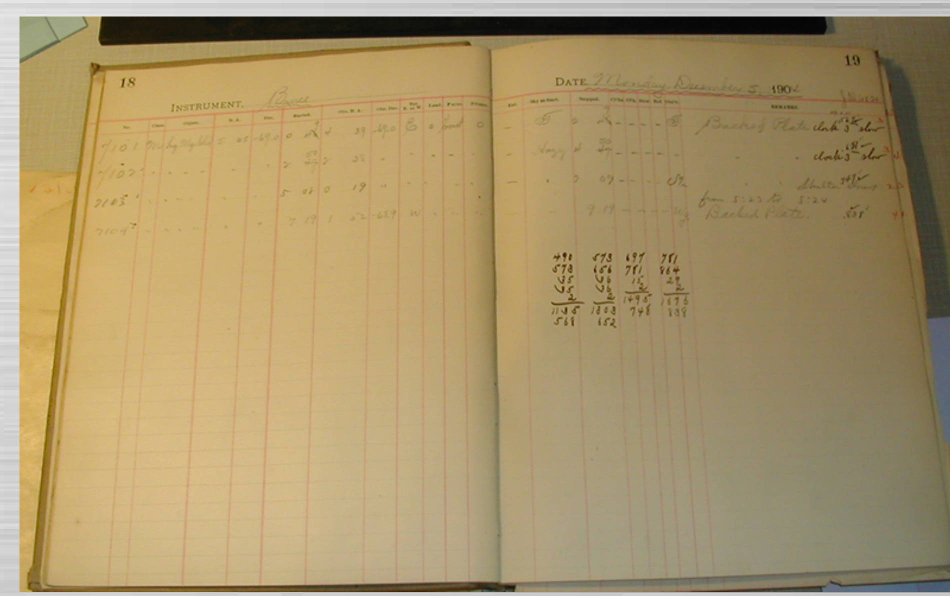
Accommodating image distortions in WCSTools

WCSTools supports several methods of fitting distiortions to images as this seems not to be standardizable

- **Digitized Sky Survey Plate Model**
- **IRAF TNX and ZPX projections with polynomial distortion**
- **Spitzer/STScI polynomial distortion model**
- **SWARP polynomial distortion model**

Putting Positions on Harvard's Plates

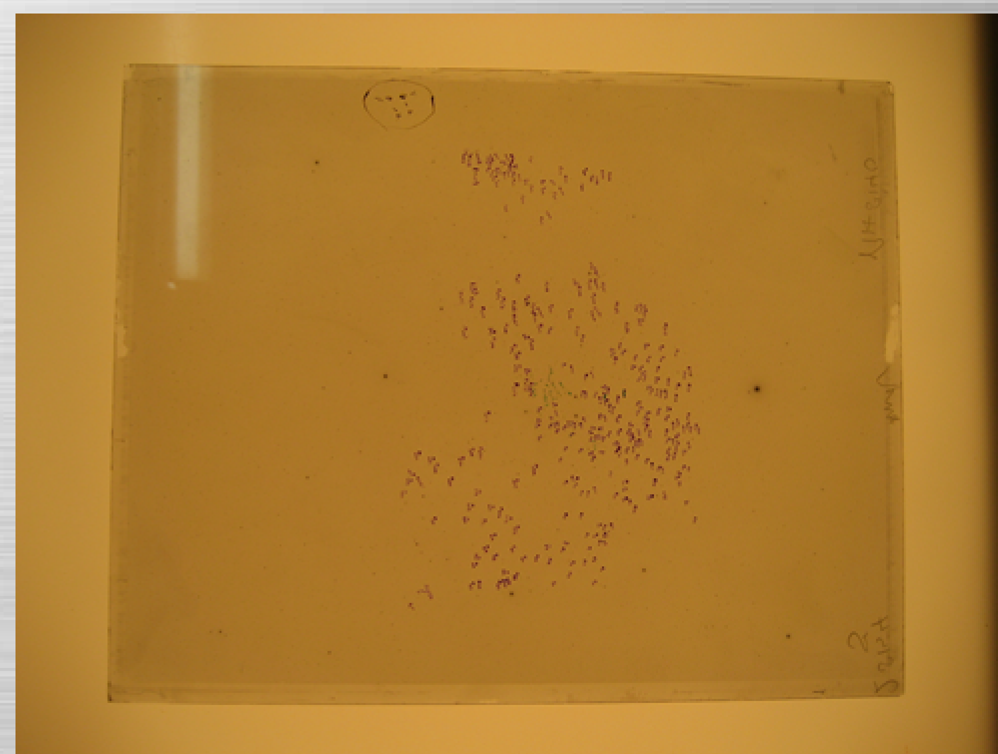
Mink, D.; Doane, A.; Simcoe, R.; Los, E.; Grindlay, J. (2006). "The Harvard Plate Scanning Project" in Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing, iAstro workshop, Sofia, Bulgaria, 2005 proceedings, Sophia: Heron Press Ltd.



From hand-written cards and logbooks

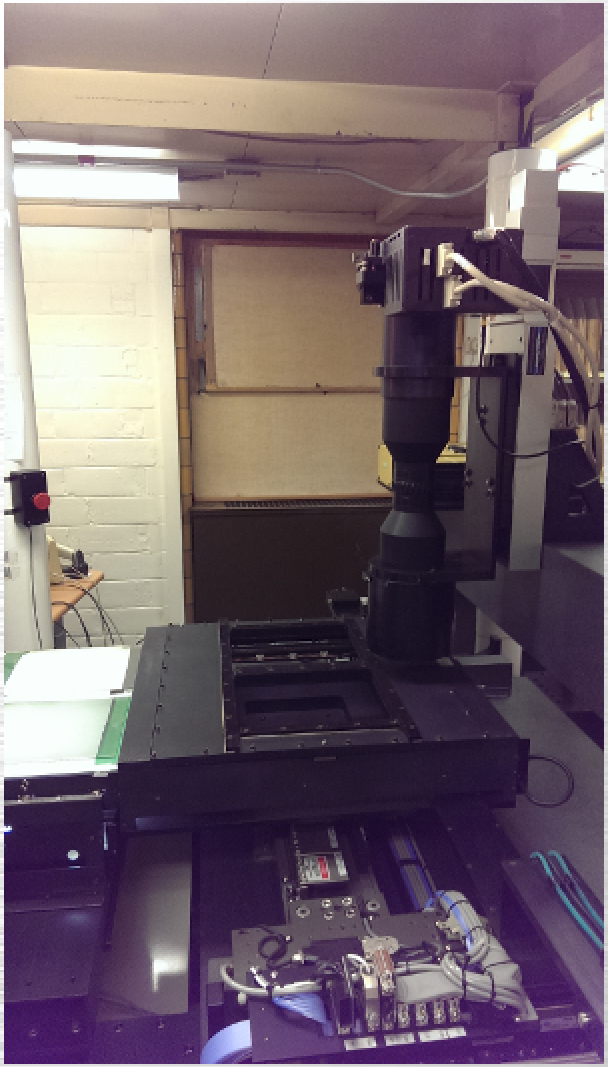
Putting Positions on Harvard's Plates

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

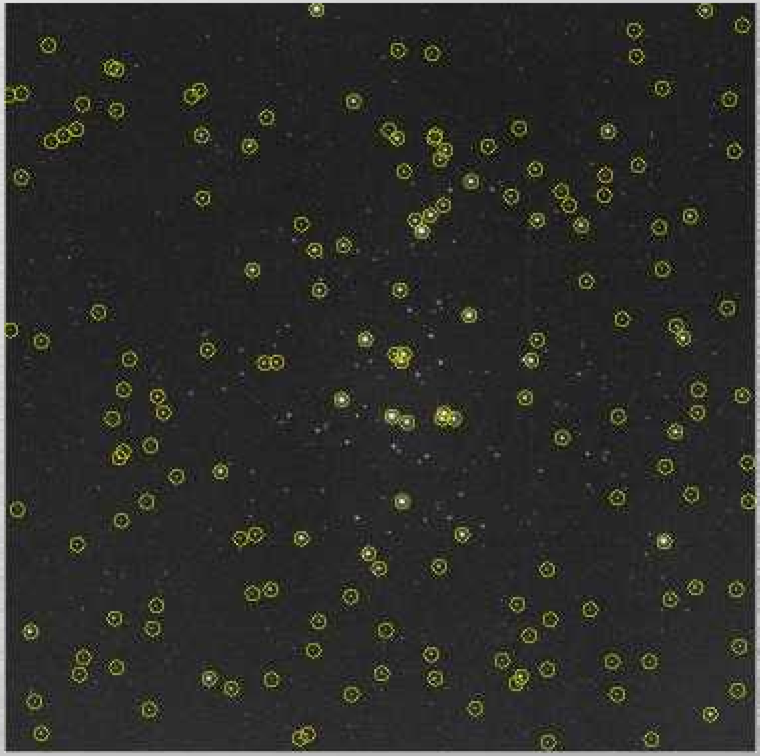
Putting Positions on Harvard's Plates



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

100,000th Plate Scanned, April 7, 2015

sethead sets values of keywords in FITS Headers

Each keyword should be followed by an equal sign and the value to which it is to be set

Values which are all numeric are assumed to be numbers and are aligned as such within the header.

A list of filenames may be used by prefacing the name of the file containing the list with a @.

Multiple FITS extension headers may be changed at once using -x [range of extension numbers]

Change the right ascension and declination of a FITS image to a different epoch.

```
Before:
RA      = '9:51:19.45'        /MEAN RA
DEC     = '69:15:26.42'       /MEAN DEC
EPOCH   = 1950                /MEAN EPOCH

$ sethead -nvkr X ra='09:55:25.177' dec='+69:01:13.72' epoch=J2000 test.fts
SETHEAD WCSTools  3.9.1, 24 March 2015, Jessica Mink (jmink@cfa.harvard.edu)
Set Header Parameter Values in FITS image file test.fts
RA = 09:55:25.177
DEC = +69:01:13.72
EPOCH = 2000
teste.fts: rewritten successfully.

After:
XRA     = '9:51:19.45'        /MEAN RA
XDEC    = '69:15:26.42'       /MEAN DEC
XEPOCH  = 1950                /MEAN EPOCH
...
RA      = '09:55:25.177'
DEC     = '+69:01:13.72'
EPOCH   =            2000
SETHEAD = 'SETHEAD 2.5 1998-09-01 13:31 RA, DEC, EPOCH updated'
```

gethead extracts information from FITS headers

Keyword names may be entered in either upper or lower case

Tab-separated table output, with column headers, is an option

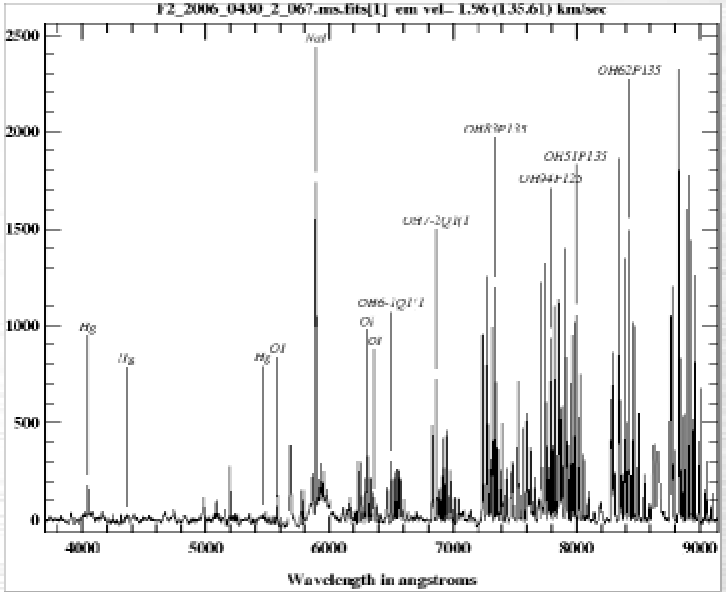
Afile containing a list of filenames may be used by prefacing it with a @.

Multiple parameters from list of FITS files

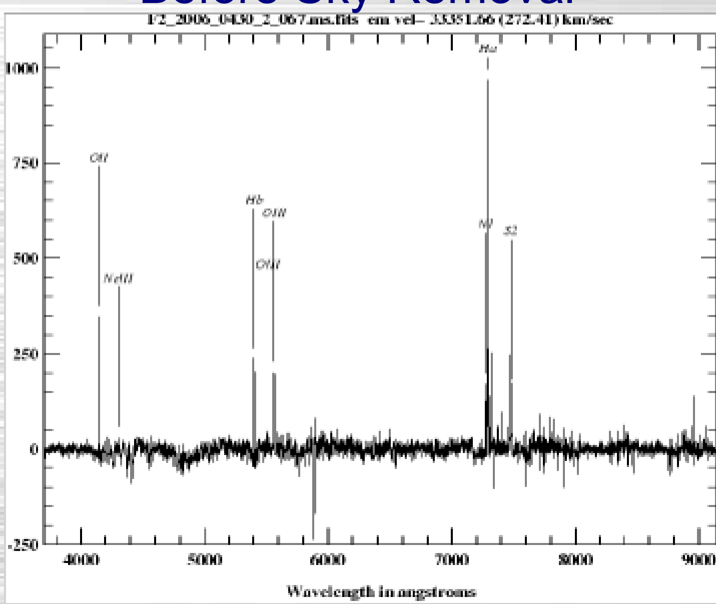
Get the image sizes from the NAXIS, NAXIS1, and NAXIS2 header keywords from a list of FITS and IRAF files, printing the output in tab table format:

```
$ gethead -th @fits.list naxis naxis1 naxis2
FILENAME        NAXIS   NAXIS1  NAXIS2
--------        -----   ------  ------
0083.19083010-0706459.fits      2       2720    161
hiptest.fits    2       600     600
test.fits       2       2720    161
test_fabien.fits        2       2080    2048
testbin.fits    2       765     510
testbinf.fits   2       680     450
testbinfg10x10.fits     2       765     510
testbinfg20x20.fits     2       765     510
testbinfg40x40.fits     2       680     450
webccd-1.fits   2       680     450
webccd-2.fits   2       765     510
```

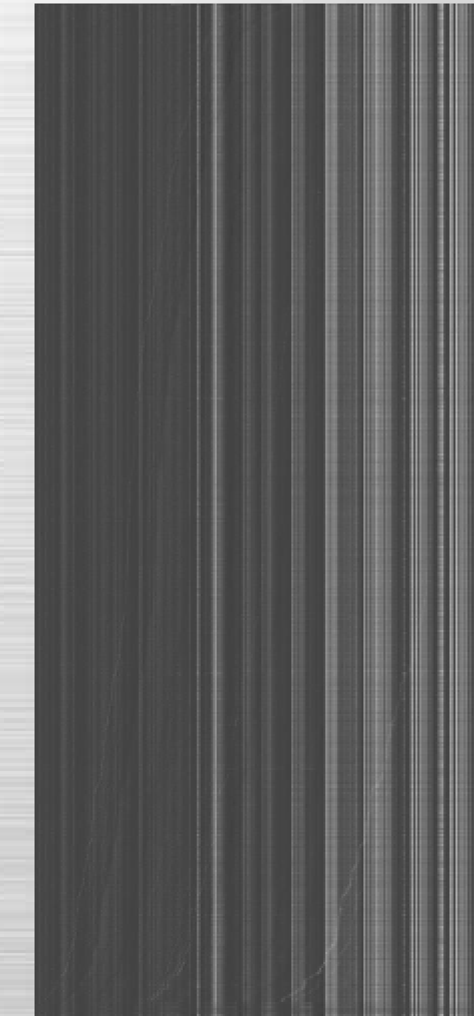
Redshifting Into the Universe



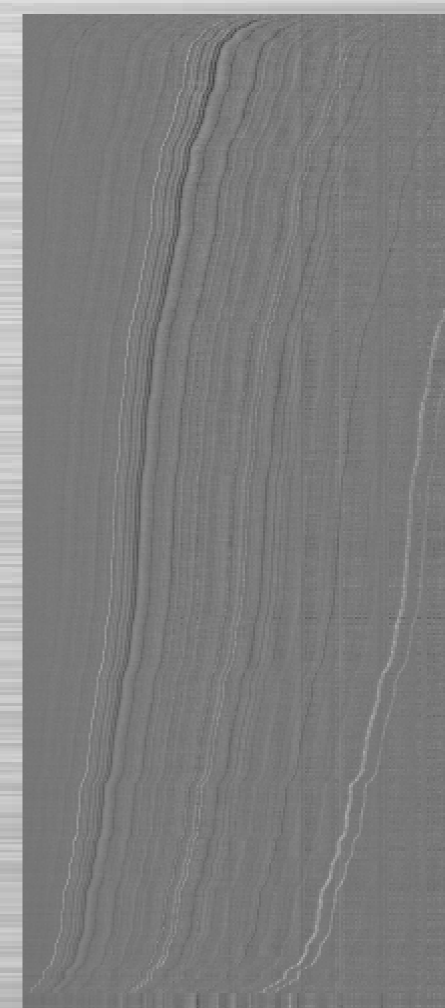
Before Sky Removal



After Sky Removal



Before Sky Removal



After Sky Removal

12,553 Spectra from the Hectospec SHELS survey