UCAC and URAT: optical astrometric catalog observing programs

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Report Documentation Page

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layout of talk

- overview: global astrometry, other projects
- UCAC (all sky, 8 ... 16 mag, 20 mas)
- status of current optical reference frame
- URAT (USNO astrograph + 4-shooter camera)

overview

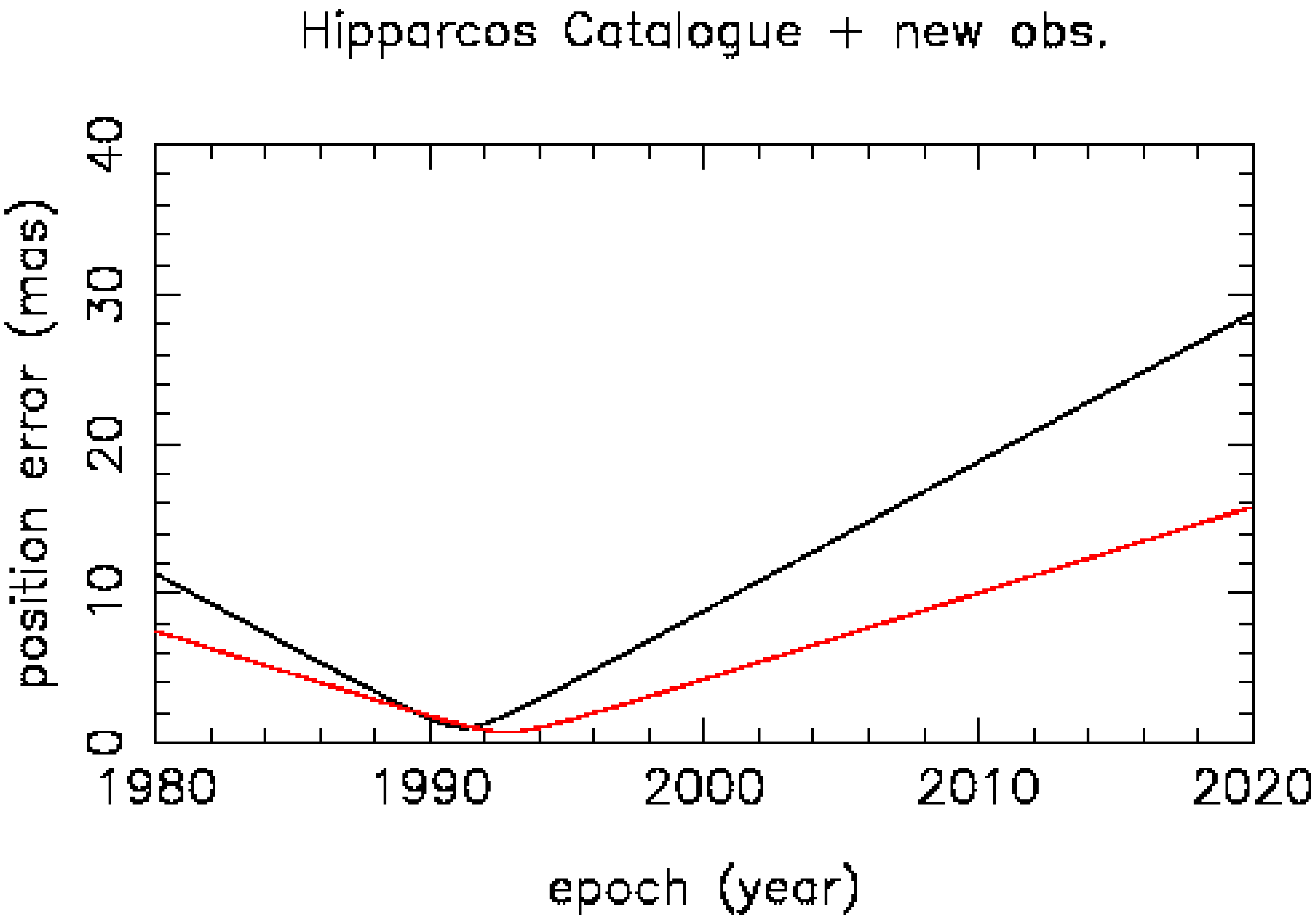
other projects / catalogs

where do UCAC and URAT fit in ?

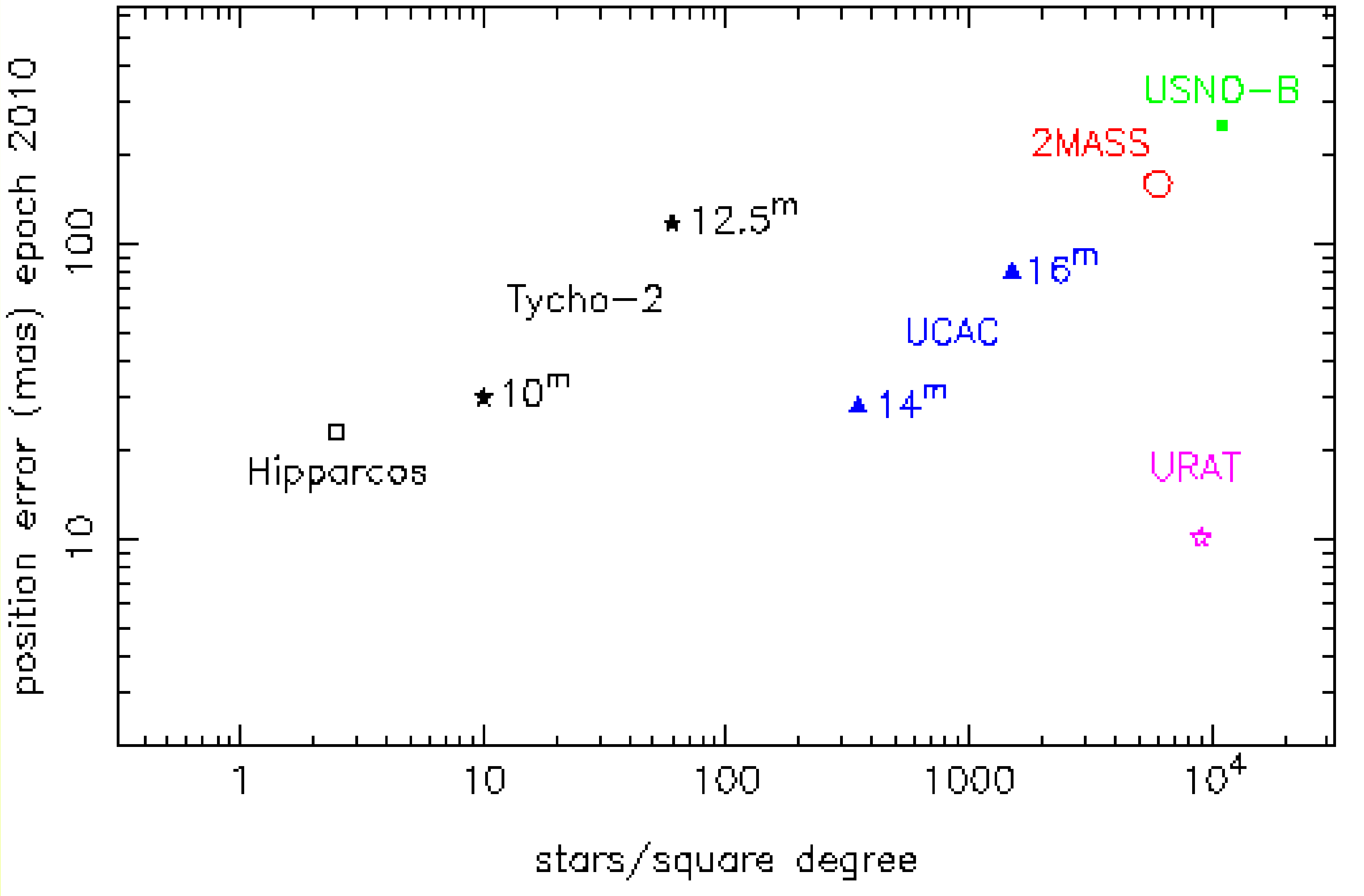
catalogs / projects

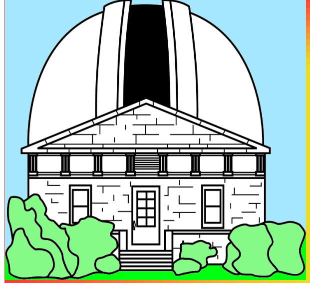
name of catalog	ground space	proper motion	mag range	numb stars	pos.err (mas)	year
ICRF2	G	QSO	radio	3414	0.3	2009
Hip.	S	yes	<= 12	100 K	1.0	1997
Tycho-2	G/S	yes	<= 12	2.5 M	10..100	2000
UCAC	G	yes	8..16	100 M	20.. 70	2004+
2MASS	G	no	IR	500 M	90	2003
USNO-B	G	yes	12..21	1000 M	200	2003
PanSTARRS	G	yes	17..23	2000 M	<30	2010
URAT	G	yes	9..18	500 M	5..30	2011
JASMINE	S	yes	near IR	M	3.0	2011+
JMAPS	S	yes	0..14	30 M	1.0	2013
Gaia	S	yes	6..20	1000 M	0.025	2020
SIM	S	yes	0..20	20,000	0.004	dead

position error increases with time



accuracy of catalogs





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A strograph
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UCAC observing

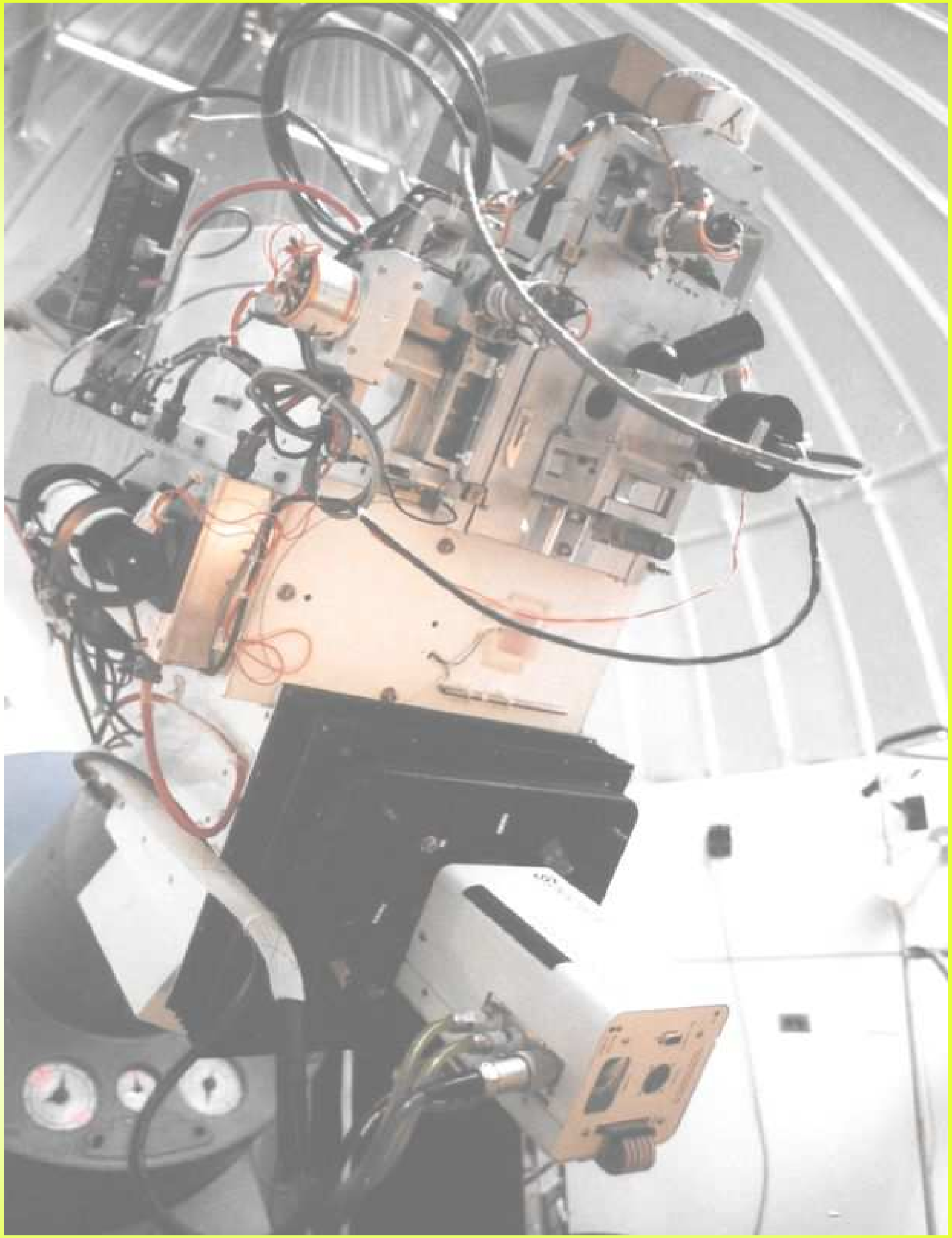
- 1997 – 2004 (all-sky completed)
- 579 – 642 nm bandpass
- R = 8 to 16 mag
- 4k x 4k CCD = 1 sq. degree FOV
- over 278,000 exposures taken (20 – 150 sec)
- positions accurate to 20 mas (10 – 14 mag)
- incl. proper motions (various early catalogs)

observing at CTIO

x-y slide

backend of astrograph

4k camera



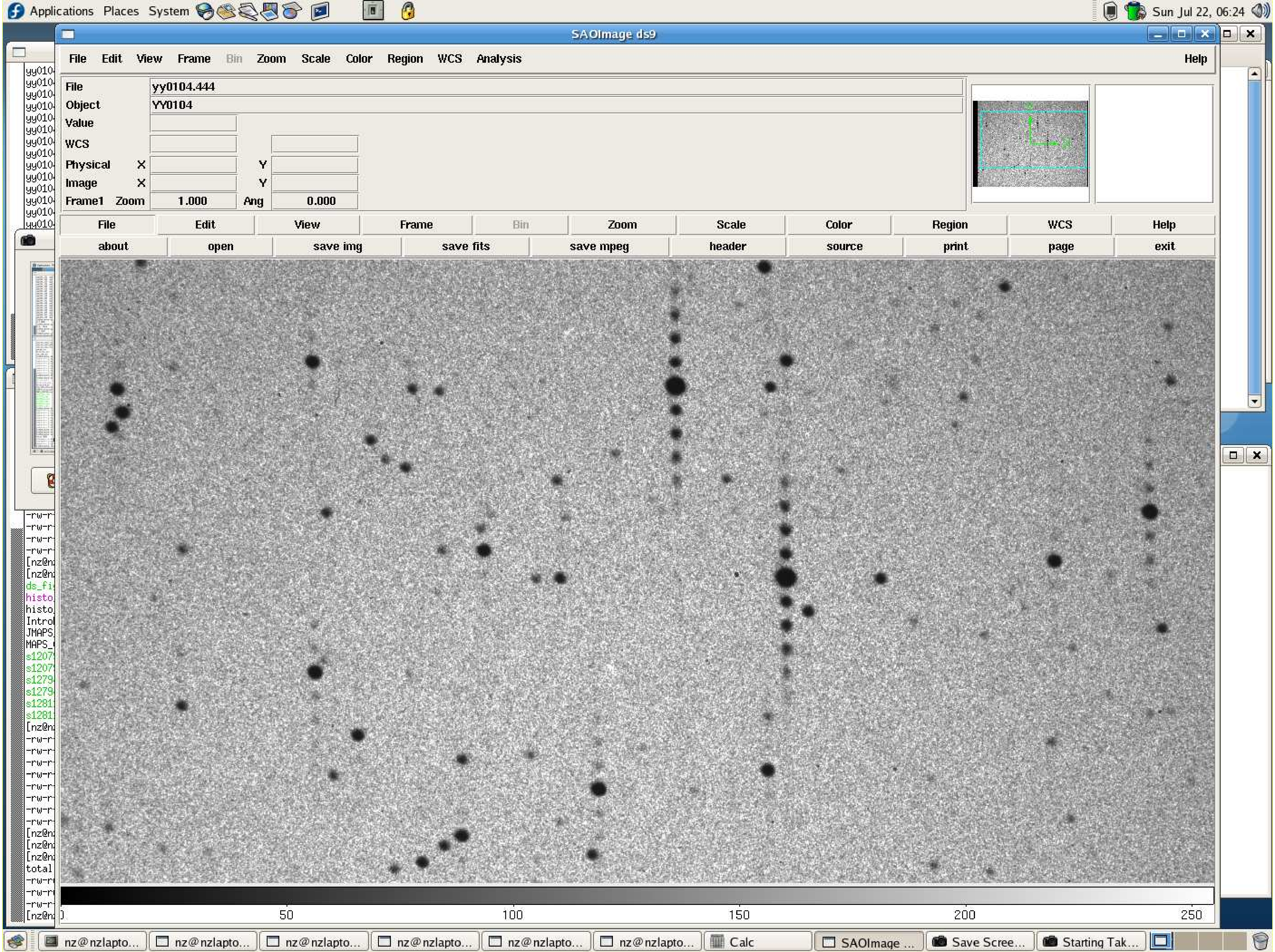
UCAC products

- UCAC1 (2000) : part of Southern Hemisphere
- UCAC2 (2003) : -90 to +50 deg decl.
- UCAC3 (2009) : all-sky, about 100 million stars
  - re-processing all pixel data (4.5 TB compressed)
  - improved completeness (bright stars, doubles, fainter)
  - improved astrometry (empirical profile fits)
  - new data for proper motions
  - improved photometry (1 band)

StarScan plate measure machine
Washington, DC

StarScan plate measuring

- early epoch data for proper motions
- CCD camera, step-stare mode
- accurate to <= 0.5 micrometer absolute
- 1930 AGK2: 1,900 plates done
- 1976..1995 ZA: 2,300 plates: done
- 1983..1990 BB: 900 plates: done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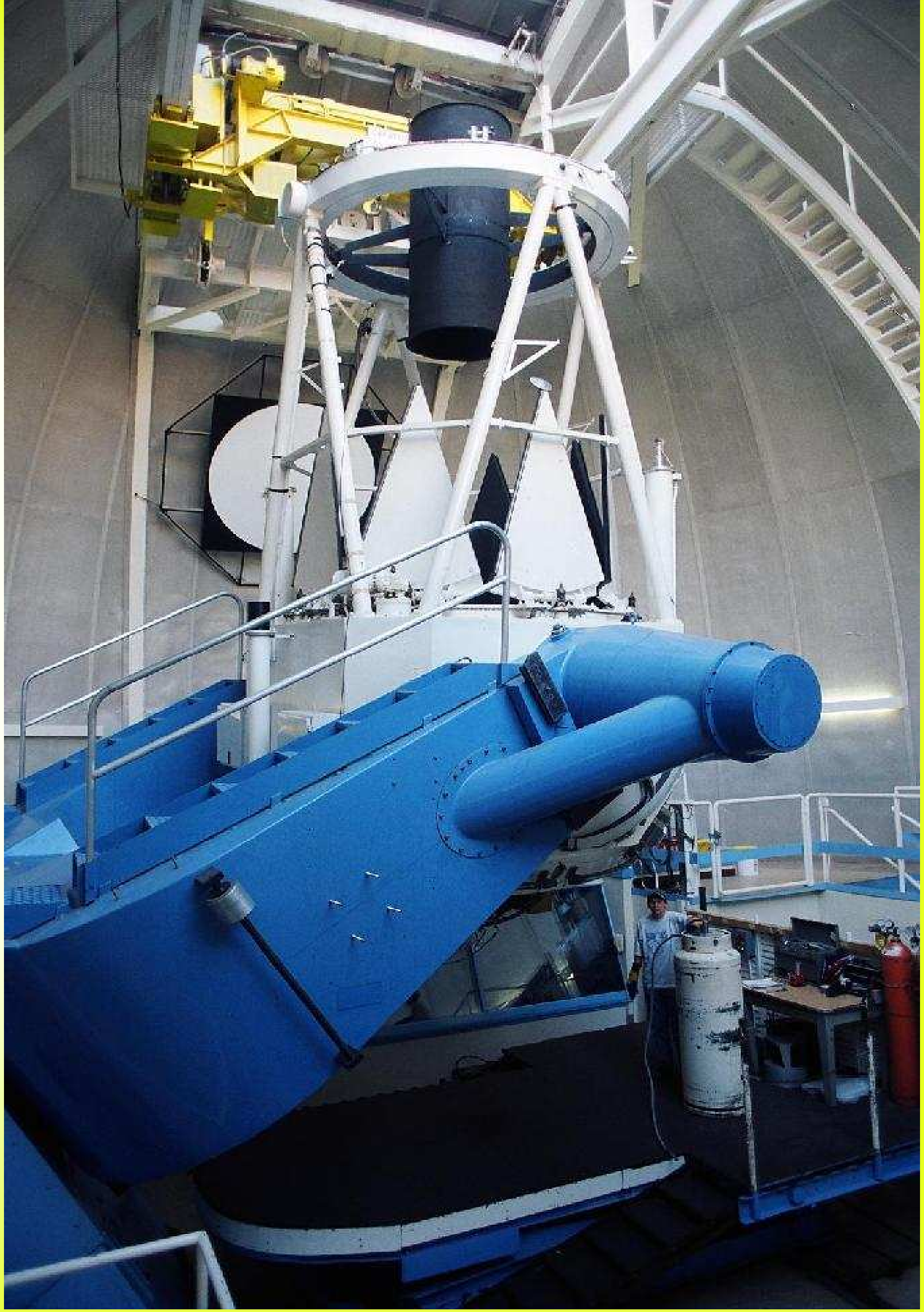
KPNO 2.1 m

CTIO 0.9 m

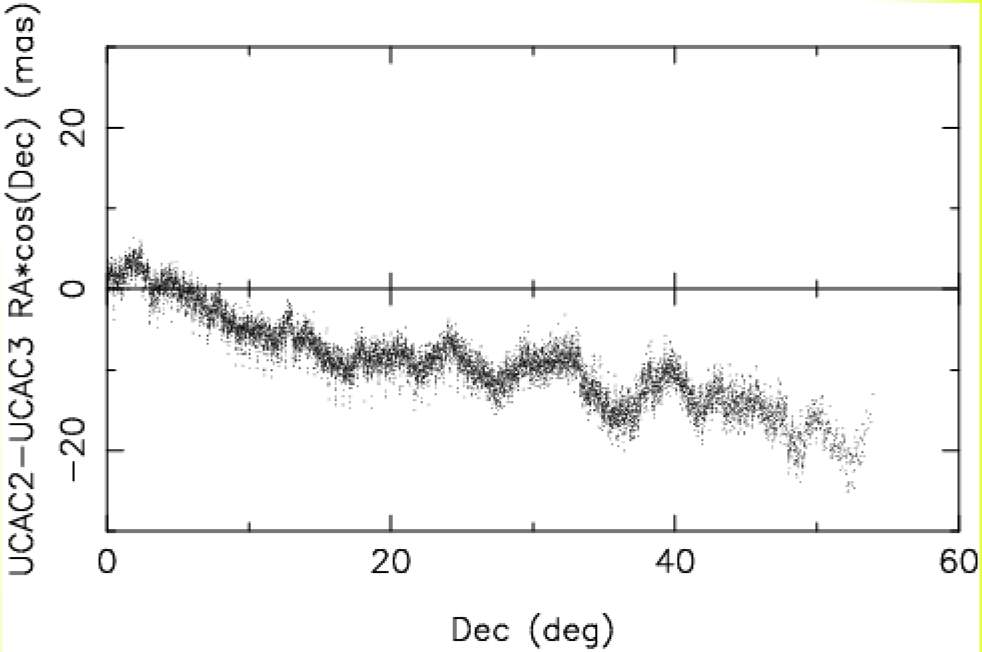
KPNO 0.9 m

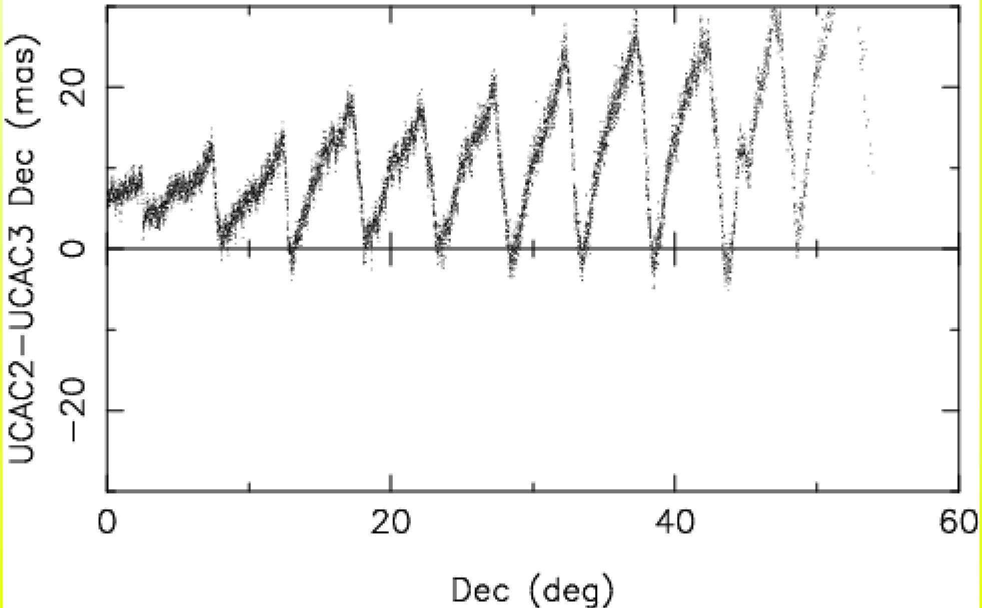
extragalactic reference frame link: observing in parallel with astrograph for > 500 ICRF sources



What's wrong with UCAC3 ?

- rush job (deadline for an all-sky catalog with PM)
- about 1% of stars listed twice, others not at all (bug in code)
- PM faint stars taken from Schmidt survey for Dec > -30 deg (poor quality)
- accept low S/N stars, thus not as clean as UCAC2

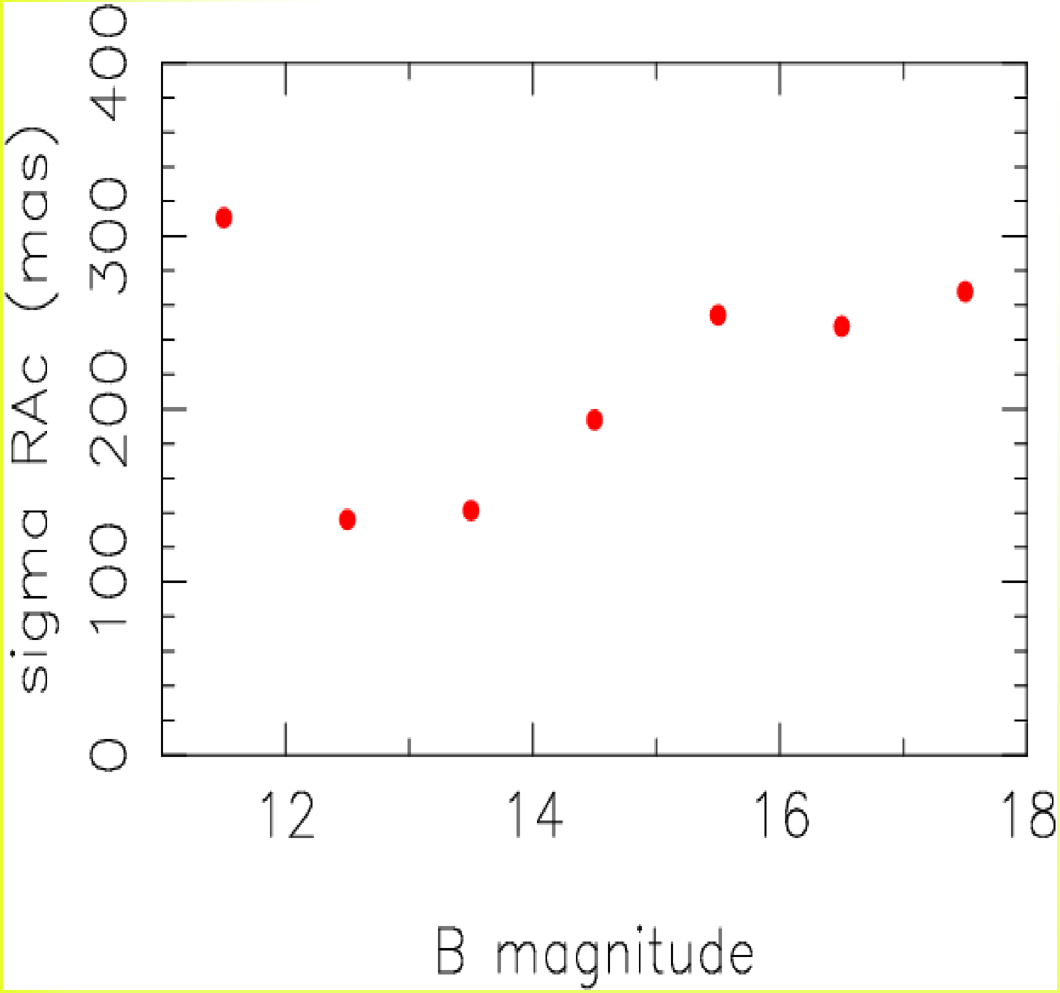


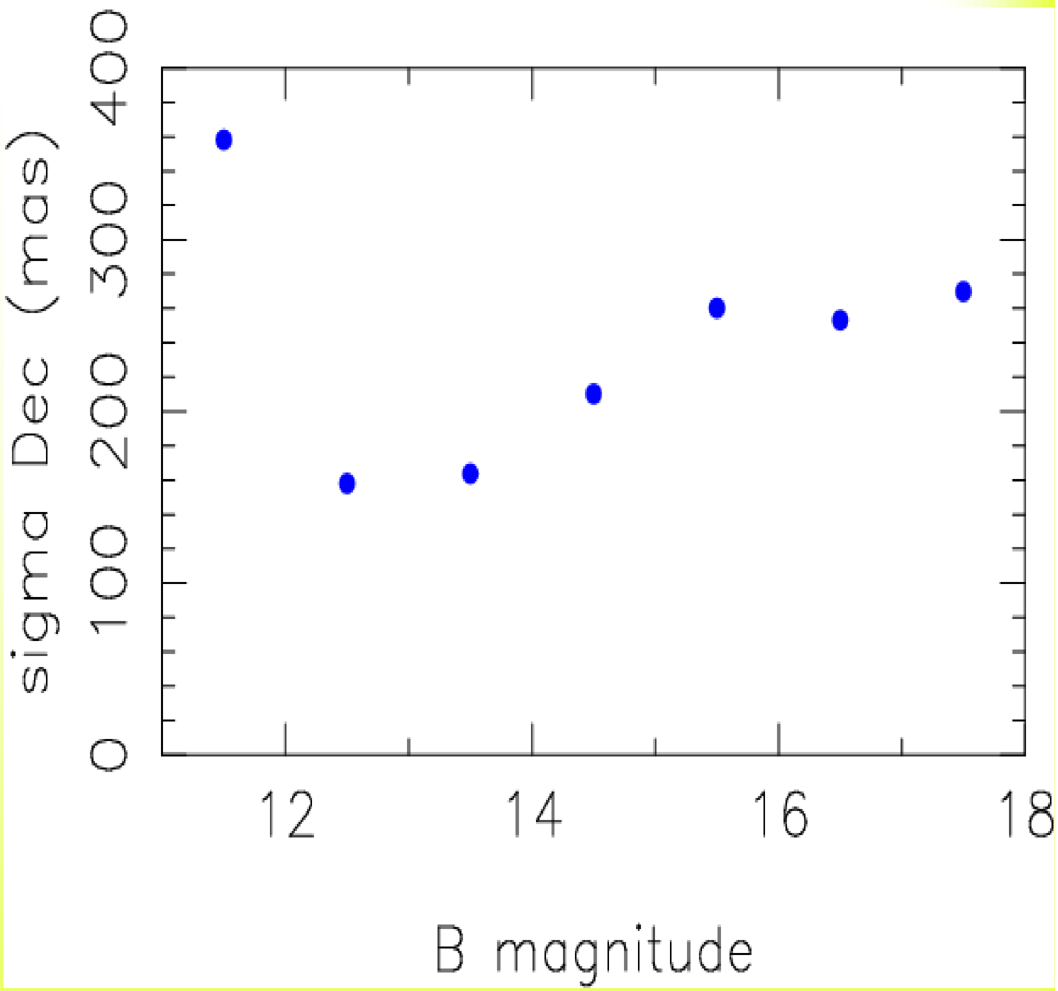


UCAC4 = final release

- PM faint stars Dec > -30 deg:
  - new reductions of NPM 1st epoch blue plates by T.Girard (Yale) and USNO based on PMM scans
  - small systematic errors, random err. 4-5 mas/yr
- analytic CTE solution (mag.eq. errors)
- overlap iteration of CCD frames
- release: spring 2011 after extensive testing
- additional data: individ. positions at epoch ...

NPM 1st epoch blue plates done





Status of current
optical reference frame

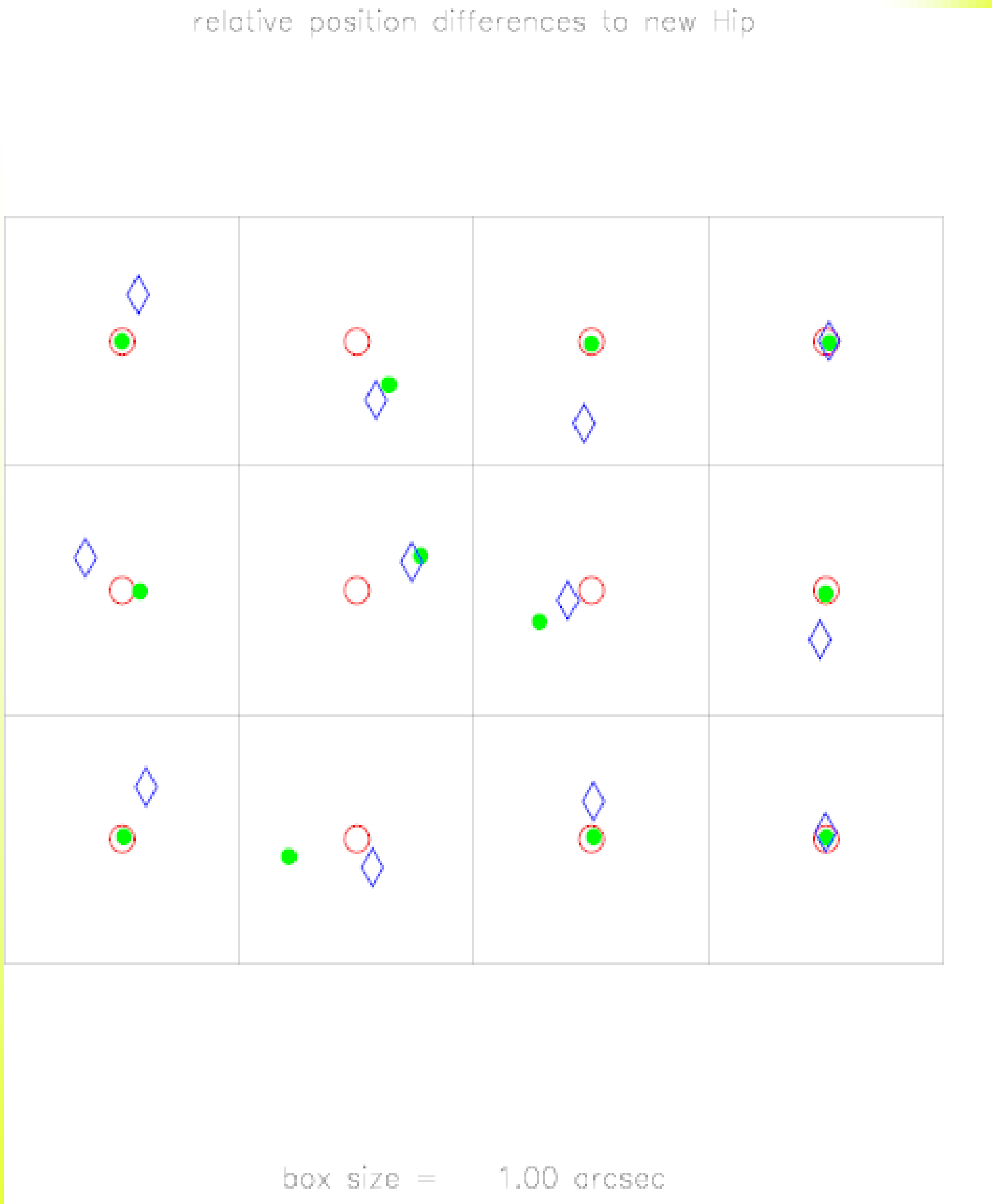
20 years after Hipparcos
5-10 years before Gaia

Limits of primary optical system

- Hipparcos
  - orientation of axes: still good to ~ 1 sigma (2.7 mas) error w.r.t. ICRF, based on 46 radio stars (Boboltz et al. 2007); max.rotation 0.55 +-0.36 mas/yr
  - 1 mas/yr PM error → 20 mas at 2011 epoch
  - some stars much worse (Zacharias et al. 2009)
- Tycho-2
  - begin to see systematic errors, zonal, mag.eq.
  - UCAC3 data shown 1-2 mas/yr level for Tycho stars
  - local system (degree scale) position errors 30 mas ?

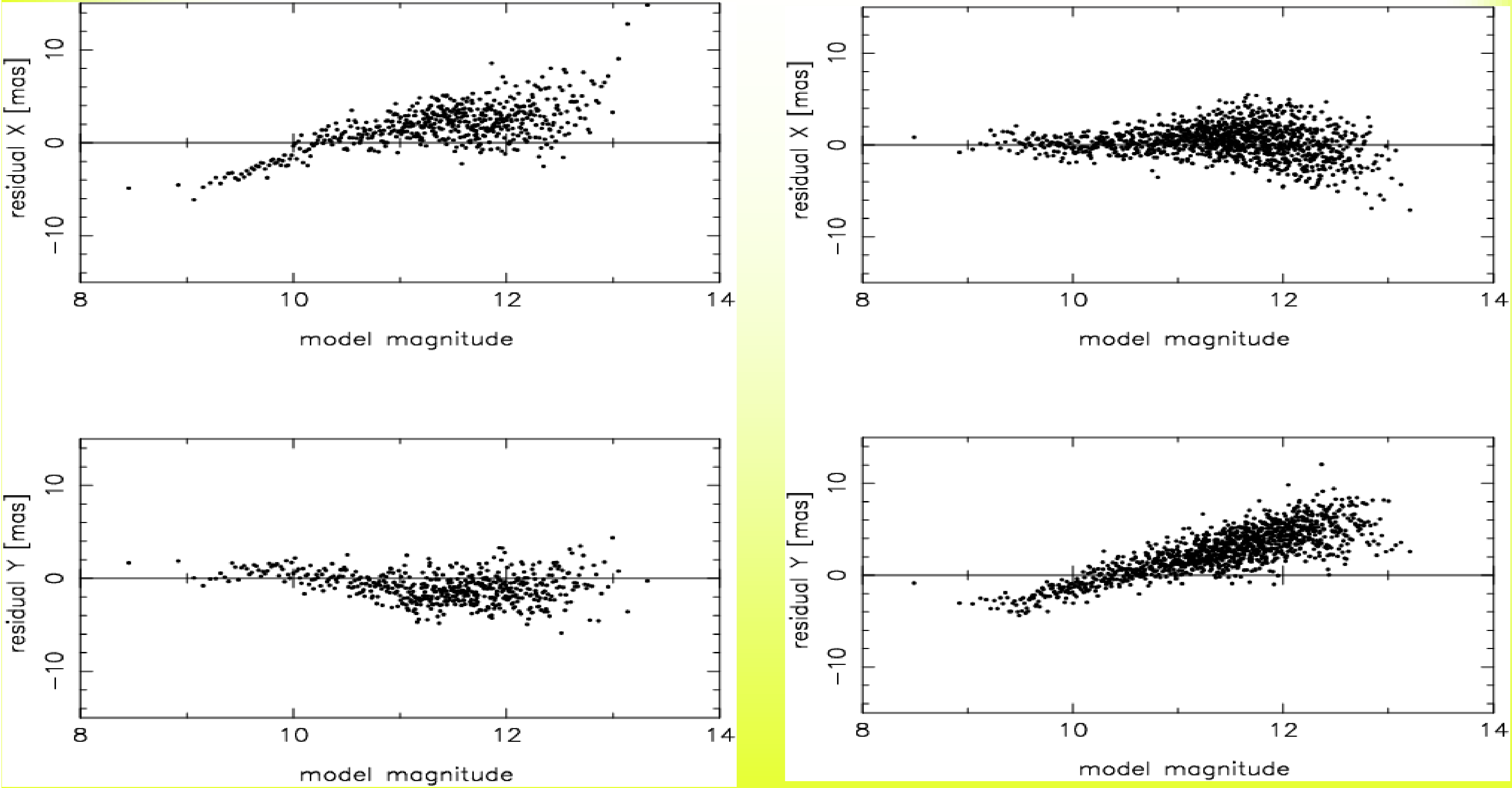
Some discrepant Hipparcos stars

- compare positions at UCAC epoch (~ 2000)
- use Hipp. PM, parallax
- red = new Hipp.red.
- green = orig.Hipp.red.
- blue = UCAC position
- box size = 1000 mas !
- Zacharias et al. 2009, DDA meeting



Zonal mag.eq. Tycho-2 ?

- UCAC3 – Tycho2: north (NOFS), south (CTIO)



ICRF radio-optical offsets real or catalog errors ?

Significant radio-optical reference frame offsets from CTIO data

Marion I. Zacharias (USNO)
Norbert Zacharias (USNO)
IAU XXVII General Assembly
Rio de Janeiro, Brazil
August 03-14, 2009

Abstract

We present results from the first application of UCAC3 data. A re-reduction of optical positions of extragalactic reference frame sources from CTIO 0.9m observing with UCAC3 gave consistent results with earlier reductions based on UCAC2. However, for many of the ICRF sources a significant offset in the order of 30 to 80 mas between the radio and optical positions is seen. Thus either the optical and radio centers of emission of some of these sources do not coincide, or the optical reference frame as represented by Tycho-2 and based on Hipparcos might have local deviations.

Astrograph reference stars

Wide-field images of ICRF source fields were taken with the USNO Twin Astrograph as part of the USNO CCD Astrograph Catalog (UCAC) project. These observations were contemporaneous to the NOAO observing runs. For each observing run an individual reference star catalog was constructed using Astrograph data and UCAC2 reduction procedures with Tycho-2 reference stars. For 1 observing run (runz) the reductions were repeated using the new UCAC3 reduction pipeline with improved systematic error control (runz3).

Deep frame observations

Deep frames were observed with the CTIO 0.9m telescope (Fig. 3). A customized filter was used to match the spectral bandpass of the USNO Twin Astrograph. At least 4 frames were taken per source. The sky distribution of the optical counterparts of ICRF sources of the all southern observing runs can be seen in Figure 2, whereby a faint optical source has a signal/noise ratio of 5 or less. For a potential problem source the (optical-radio) position difference is greater than 3-sigma of the total, estimated errors.

Deep frame reductions

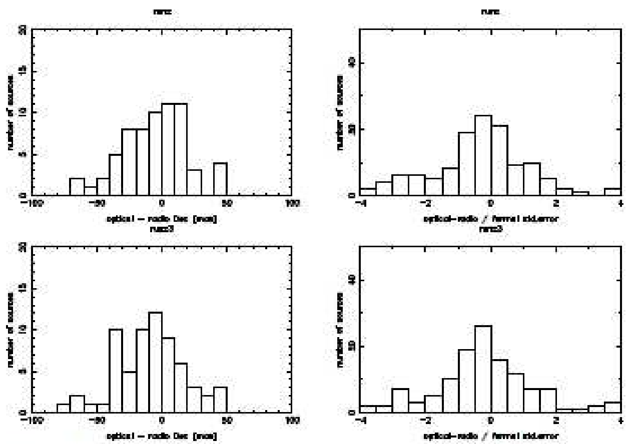
Each deep CCD frame was reduced using a dedicated secondary reference star catalog from astrograph data. A field distortion pattern was derived from residuals and corrections applied. A linear plate model was adopted for the final adjustment. Thus optical positions of reference frame counterparts could be obtained on the HCRF.

Optical–radio results

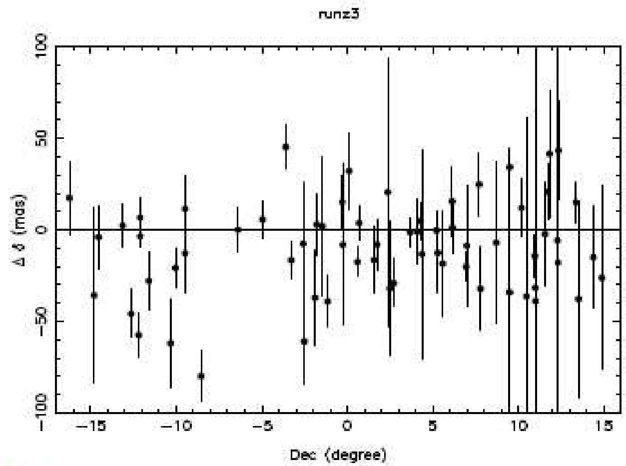
Table 1 shows results of "problem" sources from a single observing

source	Opt-Radio (sigma)		Opt-Radio (mas)		run
0147−076	-3.1	8.1	-53.1	139.8	Sep 1999
	-0.6	3.0	-20.4	107.1	Dec 1999
	-3.0	7.3	-61.2	147.5	Sep 2000
0215+015	-7.2	-3.1	-62.9	-26.9	Dec 1999
	-4.5	-0.5	-59.5	-7.2	Sep 2000
0238−084	3.2	-4.6	62.1	-88.4	Sep 1999
	0.3	-2.4	8.3	-72.8	Dec 1999
	2.2	-6.8	36.6	-113.2	Sep 2000
0405−123	-0.6	-2.7	-9.8	-48.7	Sep 1999
	-1.3	-5.7	-10.0	-42.0	Dec 1999
	-0.4	-3.7	-4.9	-44.5	Sep 2000
2128−123	-4.3	0.4	-39.6	3.8	Jun 1999
	-5.7	1.2	-39.0	8.5	Sep 1999
	-9.4	-0.8	-51.2	-4.3	Sep 2000

The following histograms show the (optical-radio) position difference distribution and the distribution of total optical position errors.



The following plots display the optical–radio position differences in declination as function of declination for the 2 reductions, respectively.



Conclusions

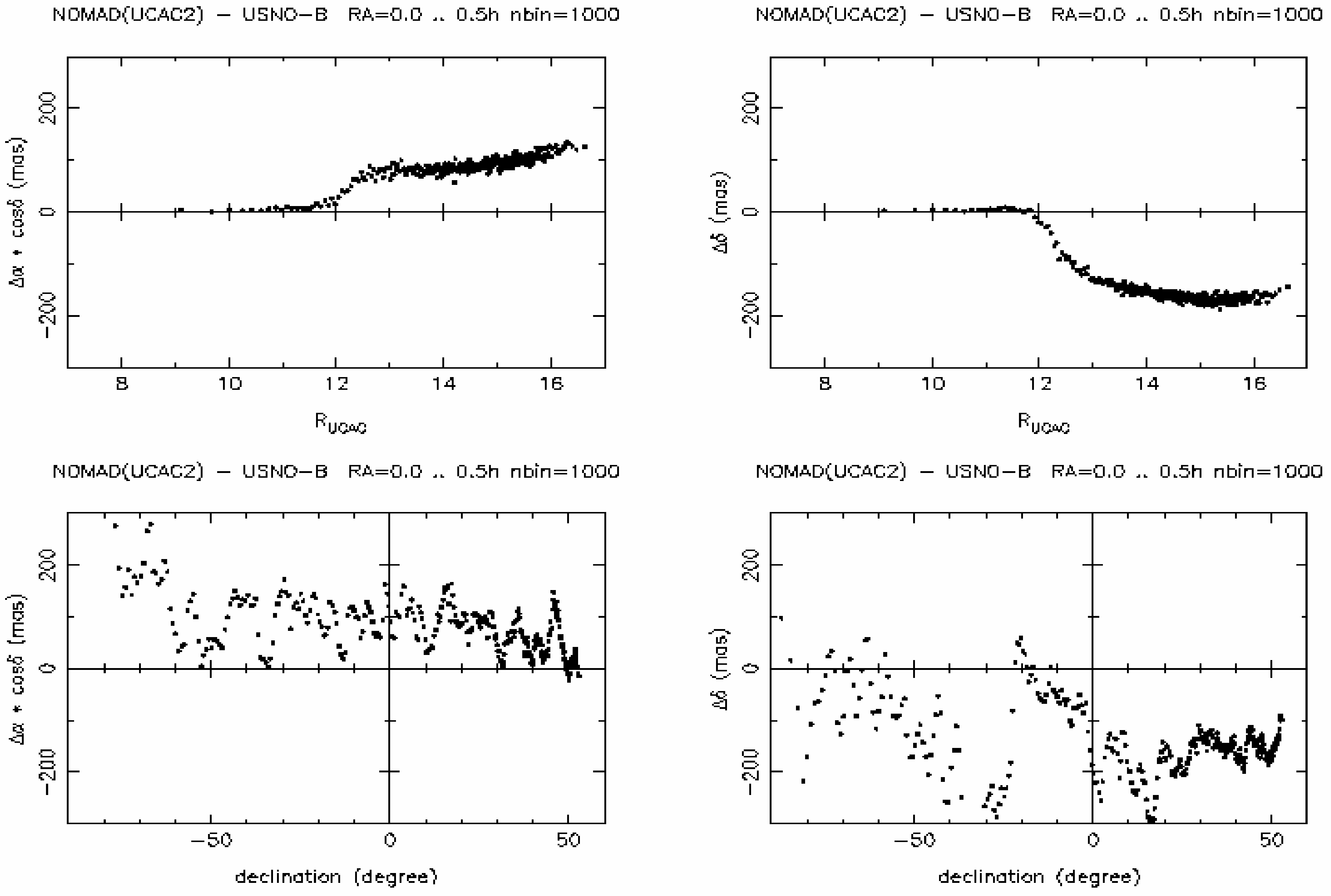
The results from UCAC2 based and UCAC3 based data are very consistent. This indicates that even the old UCAC2 based results likely are correct on the 20 mas level. Optical position results of problem sources are also very consistent between observing runs, sometimes separated by several years.

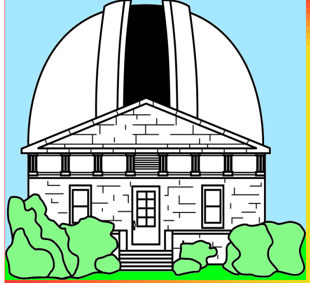
Assuming the UCAC and deep CCD data are correct, the only explanation for the significant offsets between radio and optical position seen for more sources than can be explained by random errors is either a real physical offset between the centers of emission at radio and optical wavelengths, or a problem in the optical reference frame. Maybe we begin to see local, zonal errors in the Tycho-2 catalog.

References and Acronyms

- Zacharias,N., et al. 1999, AJ, 118, 2511-2525, "Accurate Optical Positions of Extragalactic Radio Reference Frame Sources"
- de Vegt,C., et al. 2001, AJ, 121, 2815-2818 "A Catalog of Faint reference Stars in 398 Fields of Extragalactic Radio Reference Frame Sources"
- Assafin,M., et al. 2003, AJ, 125, 2728-2739

Faint stars: Schmidt plate pattern





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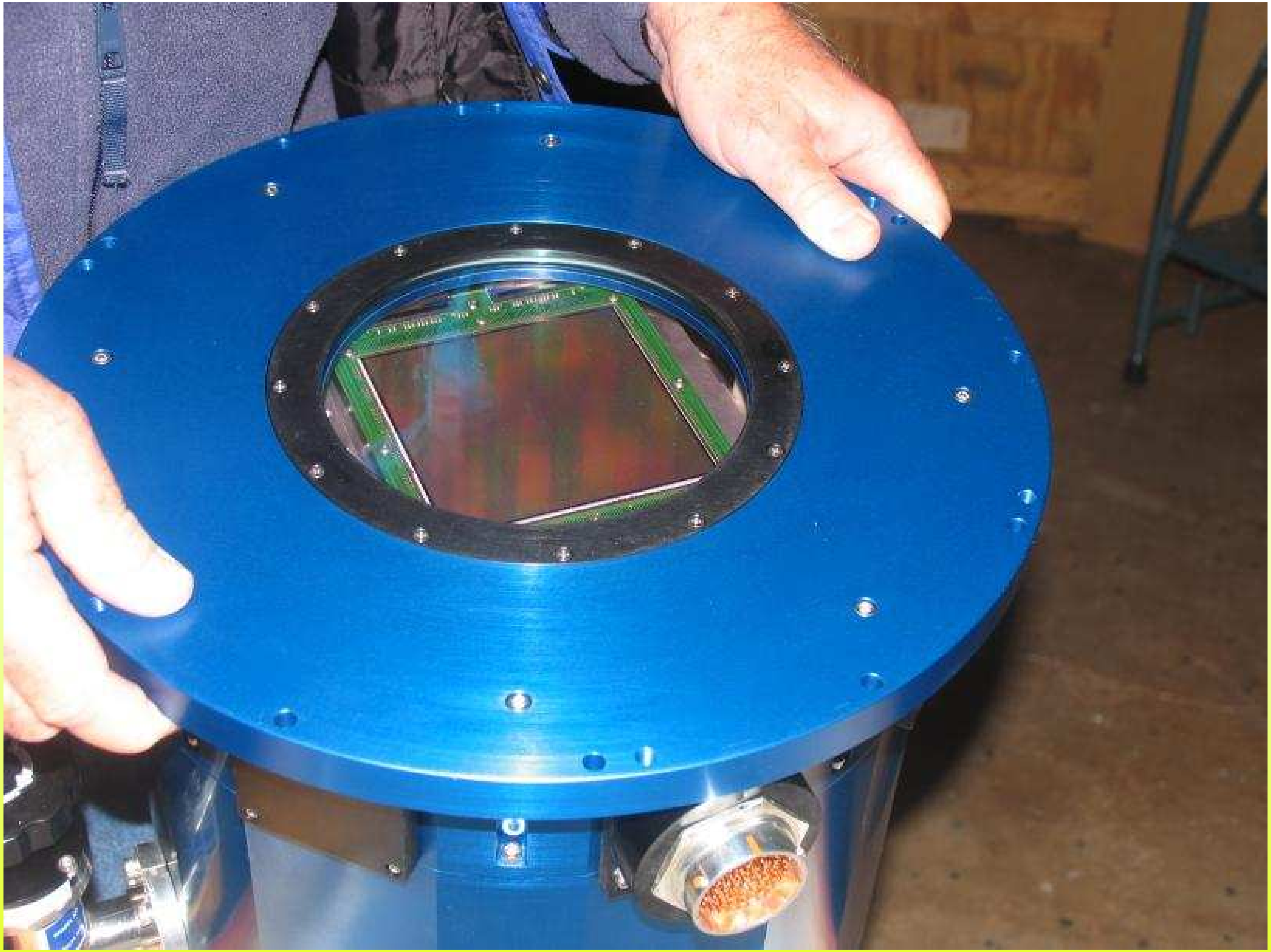
URAT project

- complete re-make of astrograph 2008-2010
- 28 sq. deg. per exposure! (4 detectors)
- single bandpass (670 – 750 nm)
- 10 mas per image (well exposed star)
- multiple sky overlaps / year, 7 - 18 mag
  - clocked anti-blooming: extend dynamic range
  - neutral density spots: option to observe 1-6 mag
- observe 2-3 years each at NOFS, then CTIO
- solve for positions, motions + parallax

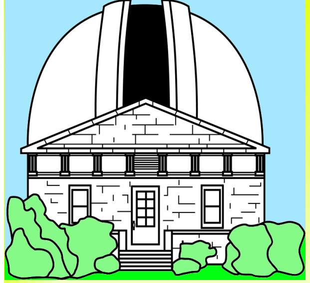
10k camera dewar 2007/2008



astrograph with single10k camera at NOFS 2007/2008

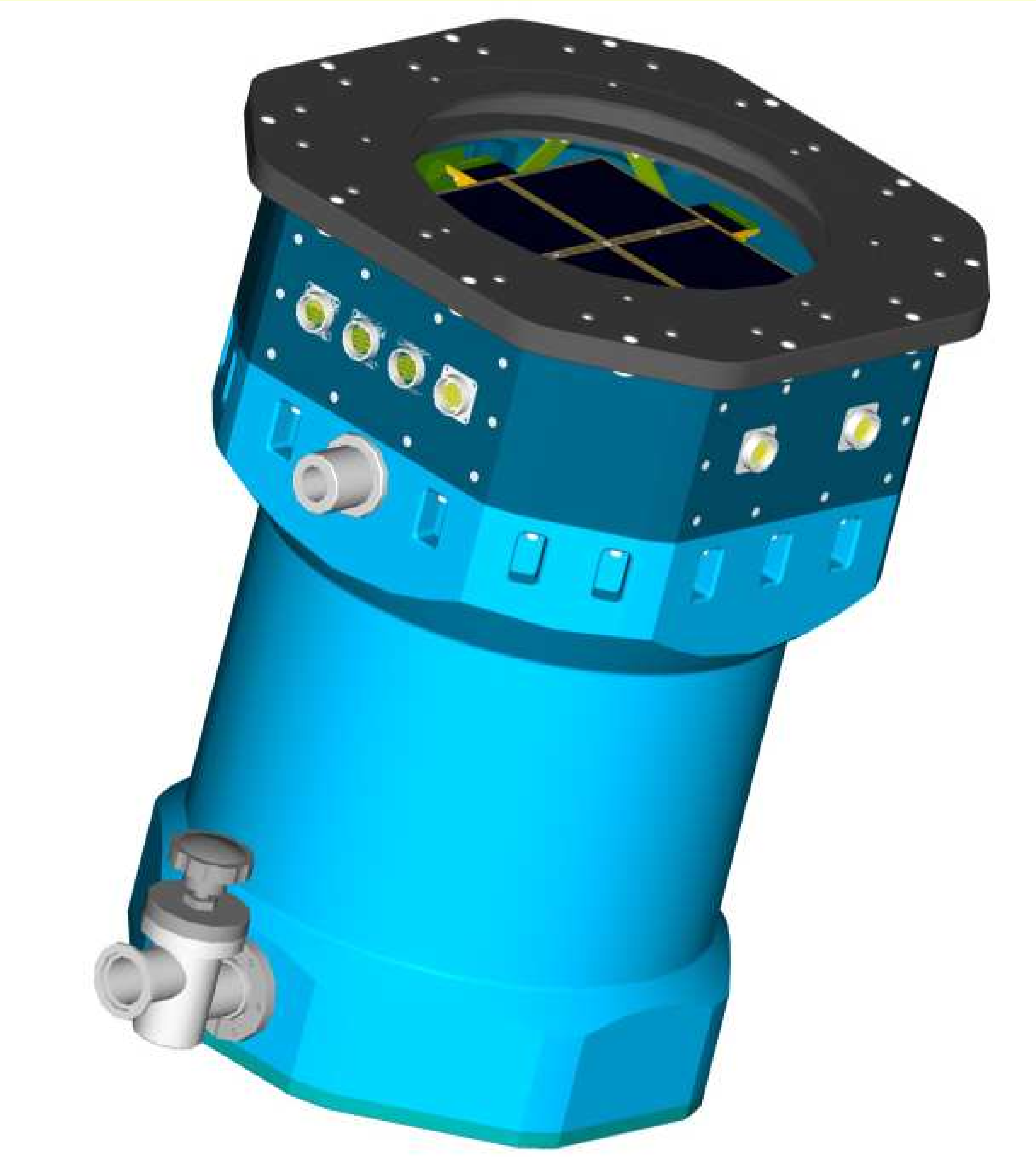
status of URAT project

- use “red lens” of USNO 20 cm astrograph
  - automate 2 mounts (Washington DC, NOFS)
- detector:
  - 10.5k by 10.5k CCD chips produced successfully
  - 10k test camera complete, 1st light October 2007
  - “4-shooter” camera funded fiscal year 2008
  - first successful thinned 10k chip June 2010
- expect first light of URAT Nov 2010

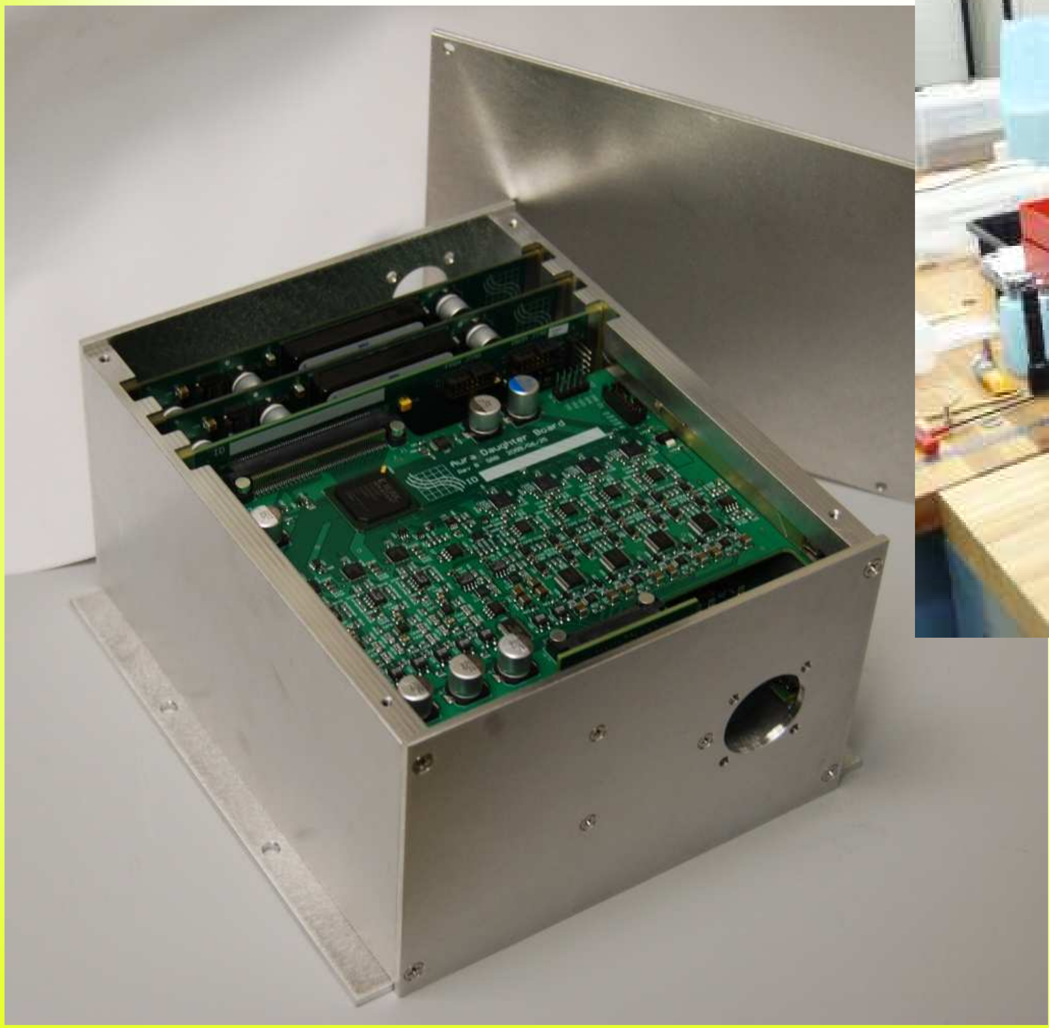


4-shooter camera dewar assembly

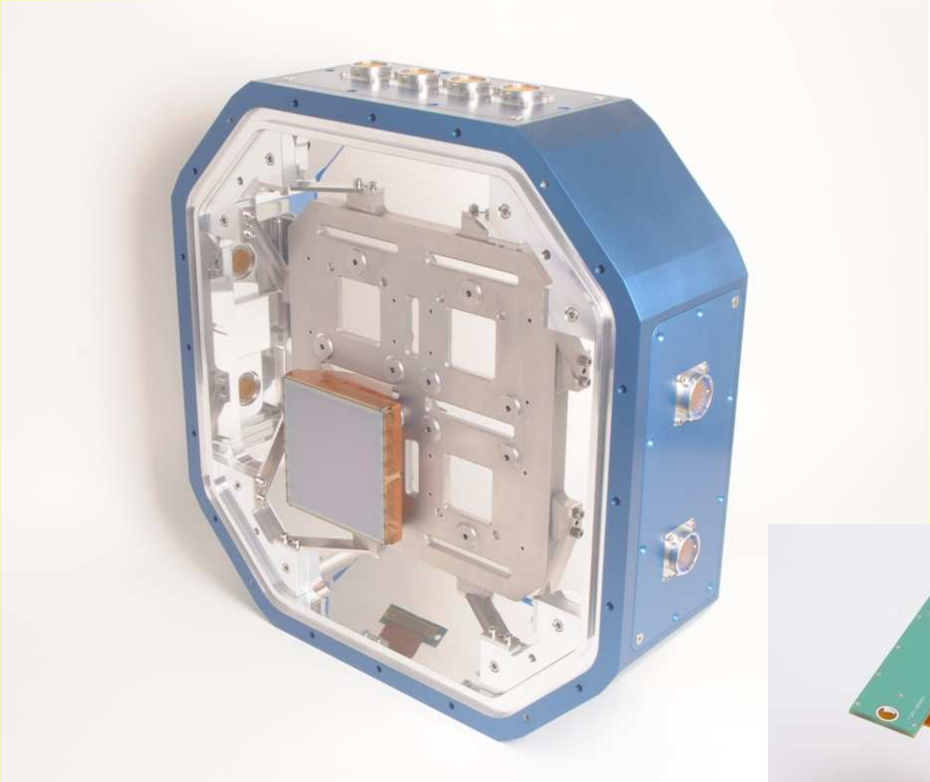
300 mm aperture 140 kg

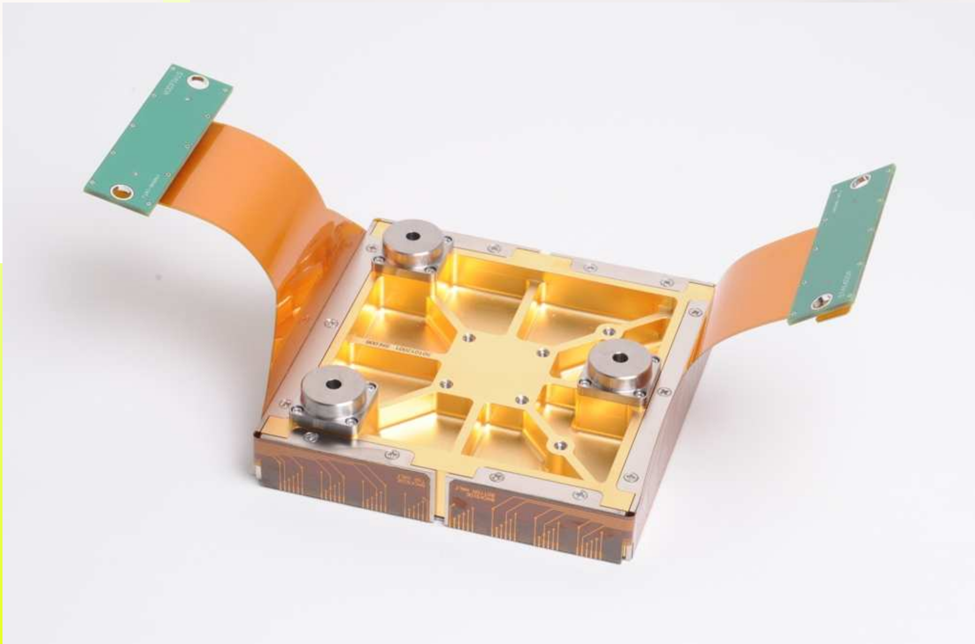


spring 2010, electronics, dewar

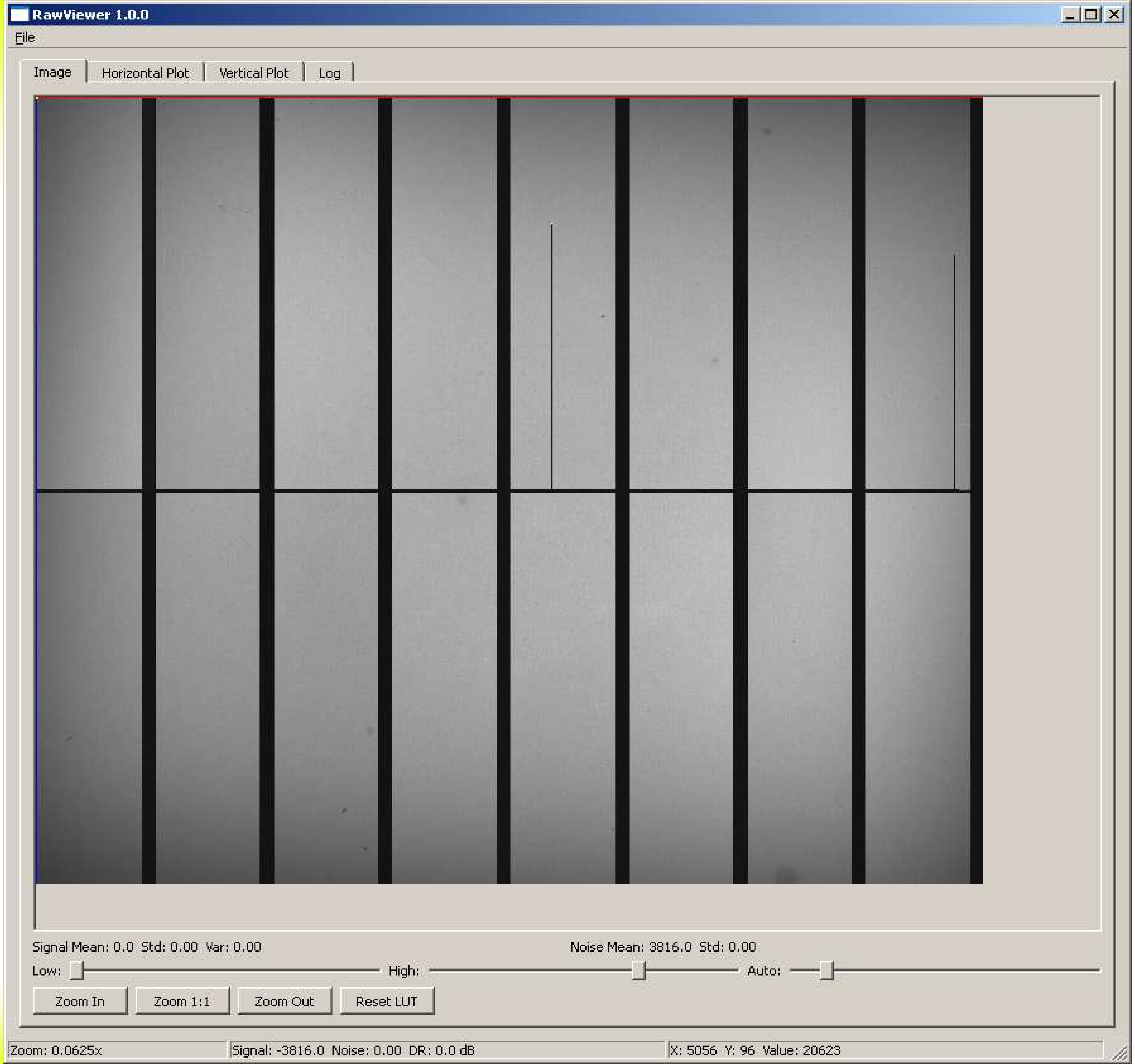


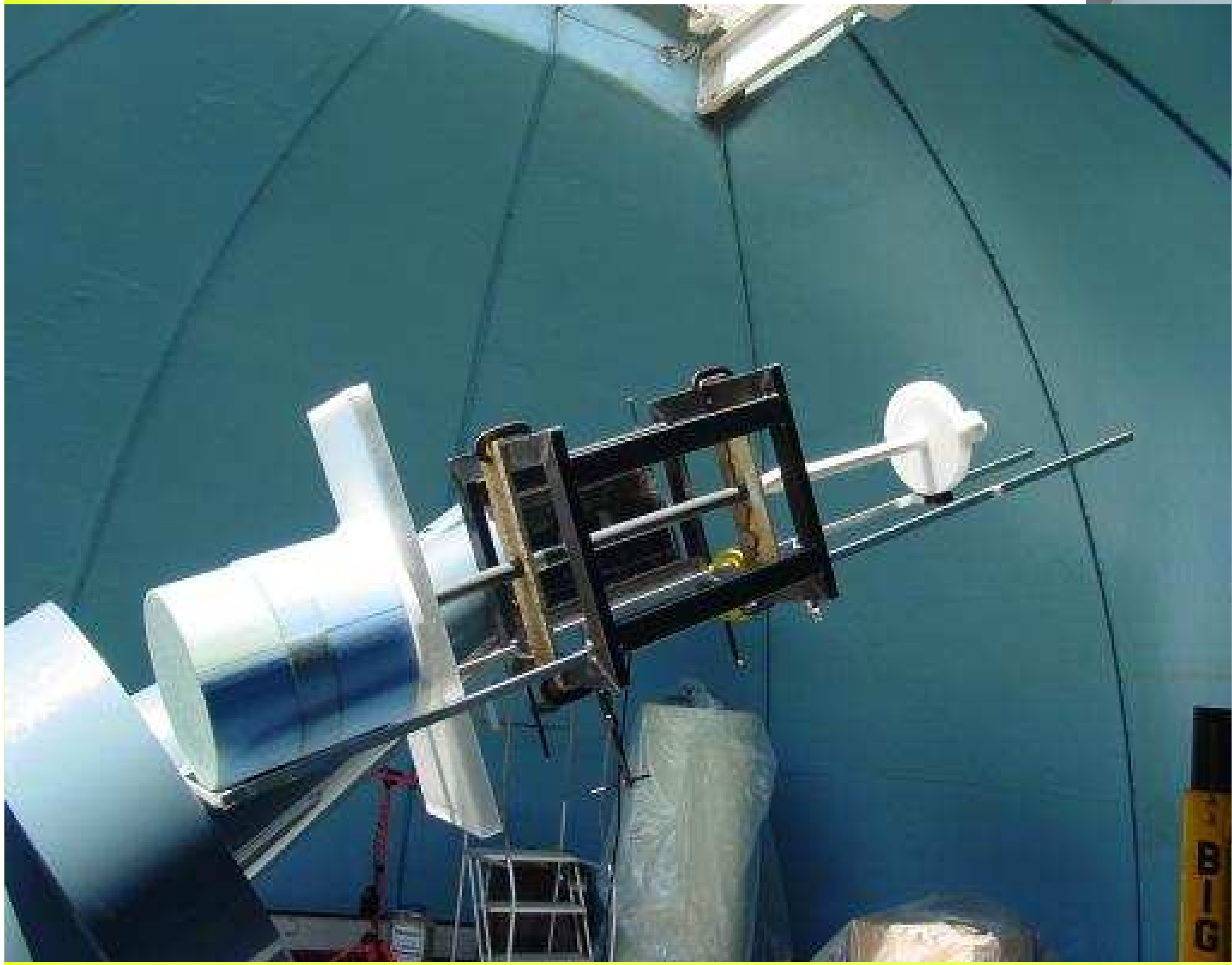
spring 2010, 10k packaging

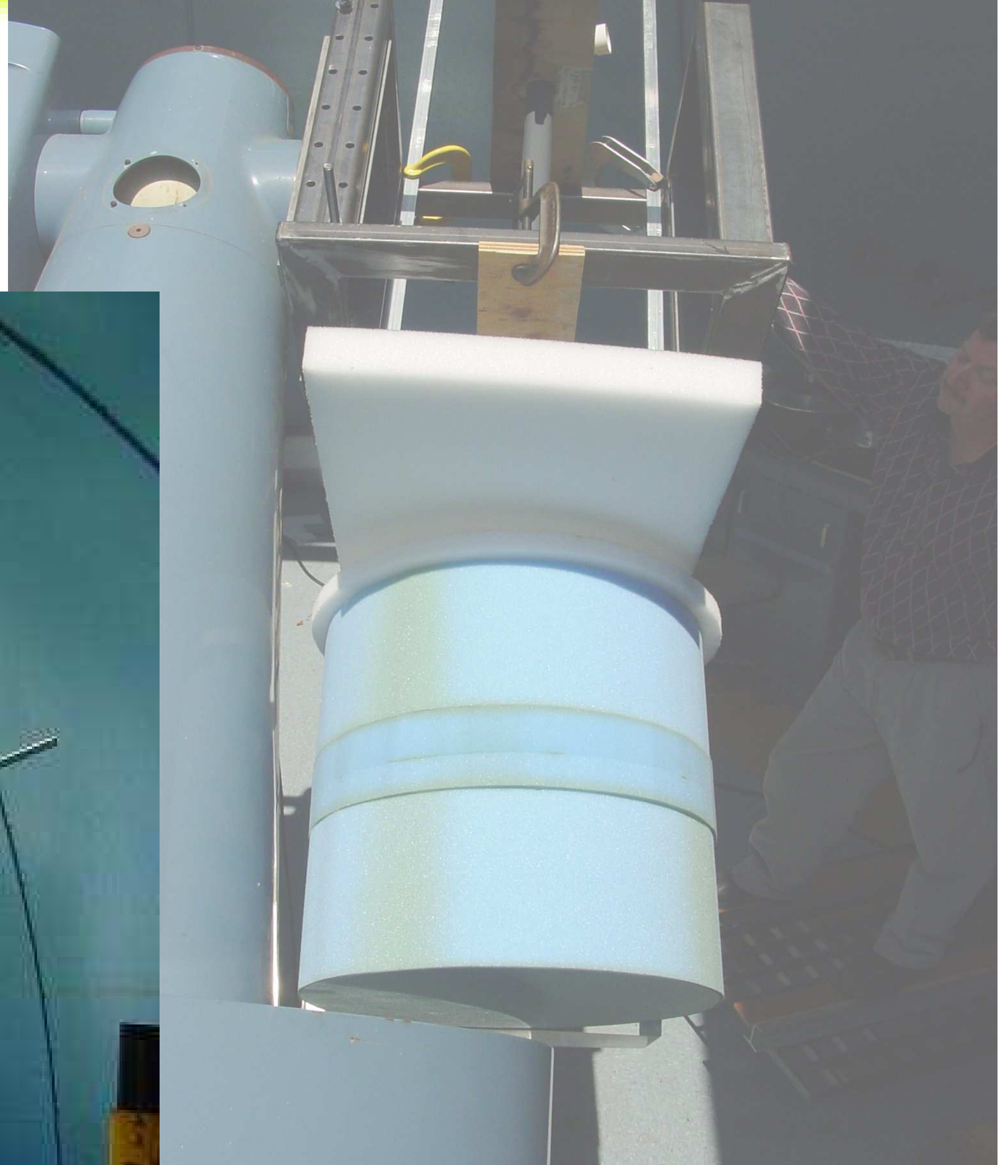




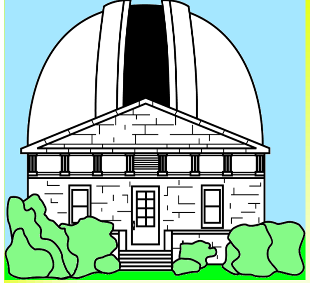
2010, June 29: successful image backside, thinned 10k detector in lab at STA, 16 outputs





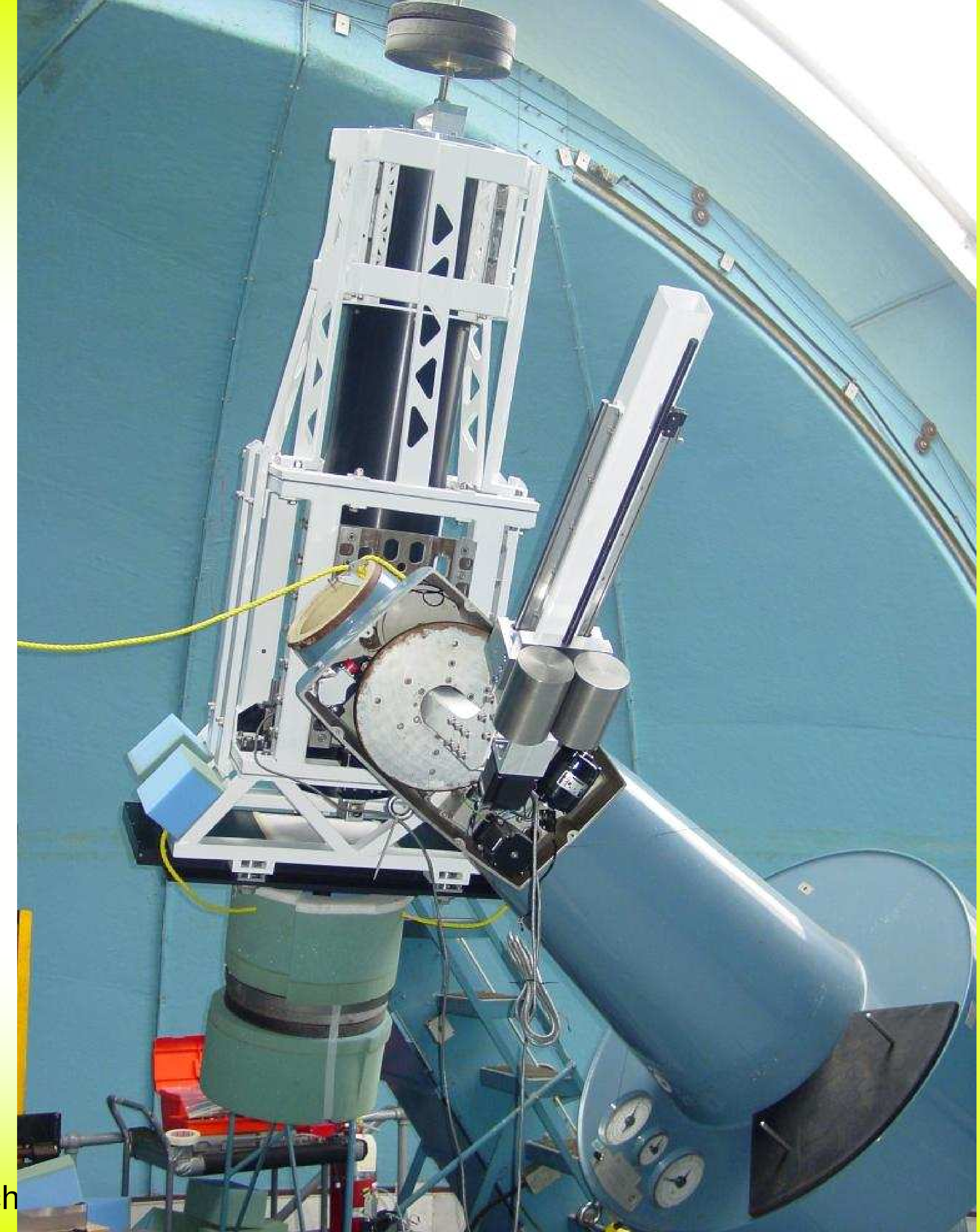


rebuilding astrograph in 24inch dome, 2008



Astrograph mechanical work complete

May 2009 at USNO



summary

- UCAC3: all-sky to 16th mag, 2009 catalog release
- UCAC4: final release 2011, good PM, bug fixes
- URAT: new all-sky astrometric survey
  - use re-furbished astrograph, 7-18 mag, 5-30 mas
  - 111 million pixel CCD detector at astrograph 2007
  - “4-shooter” camera ordered in 2008, delivery 2010
  - 28 sq.degree per exposure, single band (670-750nm)
  - first catalog release scheduled for 2013

UCAC AND URAT: OPTICAL ASTROMETRIC CATALOG OBSERVING PROGRAMS

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ABSTRACT. The third USNO CCD Astrograph Catalog (UCAC3) all-sky catalog was released in August 2009. The final release, UCAC4, is in preparation and will include corrections and improvements to positions and proper motions, as well as publication of intermediate data. Properties of UCAC products are presented.

The USNO Robotic Astrometric Telescope (URAT) project uses the optics of the UCAC telescope with a new, wide-field camera to cover 28 sq.deg per exposure. A new all-sky survey to R $\approx$ 18 mag will begin in 2011 from Arizona and be continued from Chile. Neutral density spots on the single bandpass filter allow observations of bright stars. URAT will be able to directly link Hipparcos stars and extragalactic sources of the International Celestial Reference Frame (ICRF). Multiple sky overlaps per year will give mean positions, proper motions and parallaxes from these CCD observations. An accuracy level of 10 mas is expected for high signal-to-noise stellar observations.

1. INTRODUCTION

The goal of the astrometric observing programs described here is to provide many millions of accurate, all-sky, optical reference stars fainter than Hipparcos and Tycho-2 stars, at current epochs, including positions and proper motions. These star catalogs are aiming at a densification of the optical reference frame on the coordinate system of the defining radio frame (ICRF2, Fey et al. 2009). Due to errors in the proper motions of star catalogs the predicted positions at a future epoch degrade with time. Only new observations can improve the quality of the positions and proper motions.

name of catalog	ground space	proper motion	mag range	numb stars	pos.err (mas)	catalog release	remark
ICRF2	G	QSO	radio	3414	0.3	2009	VLBI
Hip.	S	yes	$\leq$ 12	100 K	1.0	1997	ESA
Tycho-2	G/S	yes	$\leq$12	2.5 M	10..100	2000	ESA,USNO
UCAC3	G	yes	8..16	100 M	20.. 70	2009	first CCD survey
2MASS	G	no	IR	500 M	90	2003	1 epoch
USNO-B	G	yes	12..21	1000 M	200	2003	Schmidt plates
PanSTARRS	G	yes	17..23	2000 M	$\leq$30	$\geq$2011	Hawaii
SkyMapper	G	yes	16..22	1000 M	?	$\geq$2011	Australia
SST	G	yes	17..23	2000 M	?	$\geq$2011	DARPA
URAT1	G	yes	8..18	500 M	10..30	2012	USNO,NOFS,CTIO
LSST	G	yes	18..24	3000 M	?	$\geq$2015	NOAO
nano-JASMINE	S	yes	near IR	2 M	3.0	$\geq$2013	Japan
JMAPS	S	yes	0..14	30 M	1.0	2018	USNO
Gaia	S	yes	6..20	1000 M	0.025	$\geq$2015	ESA
SIM	S	yes	0..20	20,000	0.004	on hold	NASA,JPL

Table 1: Comparison of current and future (nearly) all-sky survey observing projects significant for astrometry.

Table 1 provides an overview about current and future, astrometric, global catalog observing programs from the ground and space. The UCAC program is essentially complete, pending a final data release, while the URAT program is a ground-based follow-up to UCAC to begin in 2011 with improved accuracy and reaching even fainter magnitudes with first results expected to be released in 2012. Contrary to other ground-based sky survey projects, URAT uses a small-aperture, dedicated astrometric telescope for highest positional accuracy of stars in the mid-magnitude range, bridging the gap between the current optical reference frame and deeper surveys.

2. UCAC

The USNO CCD Astrograph Catalog project observations were completed in 2004. Operating in a bandpass between V and R, over 278,000 exposures of 1 sq.deg each were obtained in a 2-fold all-sky overlap pattern with each field having a long (125 sec) and a short (25 sec) exposure. After the UCAC1 early data release (Zacharias et al. 2000), the widely used UCAC2 catalog (Zacharias et al. 2004) was released, covering declinations $-90°$ to about $+50°$ for over 48 million stars.

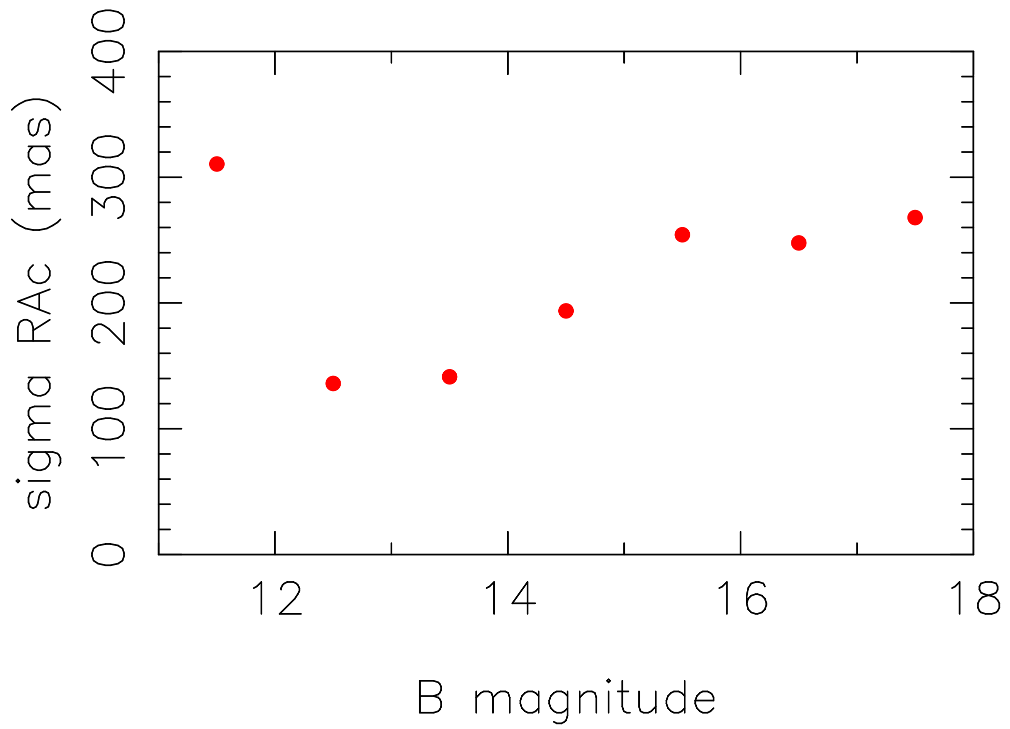

Figure 1: Precision of re-reduced NPM first epoch data. The standard error for the RA*cos(Dec) coordinate is shown as a function of NPM blue magnitude (Girard 2010). Results for the Dec coordinate are similar.

UCAC2 is a relatively “clean” reference star catalog, having cut out all identified “problem” cases (like blended images), while the UCAC3 released in 2009 is the first all-sky catalog in this series (Zacharias et al. 2010), aiming at a high degree of completeness and thus also includes a relatively large number of problem cases and unreliable low S/N sources. Details about the astrometric reductions of UCAC3 can be found elsewhere (Finch et al. 2010).

UCAC3 was put together within a given deadline and lacks high-quality proper motions for faint stars north of declination $-30°$. Uncorrected SuperCosmos data of Schmidt plate scans were widely used. This resulted in systematic errors in UCAC3 proper motions as function of the Schmidt plate pattern of up to about 10 mas/yr in some areas (Zacharias et al. 2010, Röser et al. 2010).

Most stars brighter than about V=12.5 and many others brighter than V=14 have high-quality proper motions in UCAC3 due to the use of early epoch astrograph plates. Over 5000 plates from the AGK2 (epoch close to 1931), as well as from the Hamburg Zone astrograph and USNO Black Birch twin-astrograph programs, have been scanned on the StarScan machine (Zacharias et al. 2008) and reduced for UCAC. All other faint stars to the limit of UCAC and south of $\delta = -30°$ also have high-quality proper motions thanks to the Southern Proper Motion (SPM) program and re-reductions in a joint USNO/Yale effort, which provided SPM 1st epoch data in time for the UCAC3.

The proper motion problems of UCAC3 north of $\delta = -30°$ and software bugs causing for example some stars (about 1% of all stars in the catalog) to be listed twice and others not at all, will be resolved in the upcoming, final, UCAC4 release. In a collaboration between USNO and Yale University, the Northern Proper Motion (NPM) Lick astrograph plates (which were also scanned on the PMM machine at NOFS, like the SPM plates) were re-processed to provide a new, highly accurate star catalog at a mean epoch of about 1950 covering all sky north of the SPM data. Fig. 1 shows the random errors of the NPM 1st epoch data and combined with the $\approx$ 50 year epoch difference to UCAC CCD observing, proper motion errors of 3 to 5 mas/yr are expected with remaining systematic errors estimated to be on the 2 mas/yr level. In addition to a compiled catalog of about 100 million stars, individual CCD observed positions will become available with the UCAC4 release in 2011.

3. OPTICAL REFERENCE FRAME TODAY

About 20 years after the central epoch of observations the positional accuracy of individual Hipparcos stars has degraded to typically 20 mas per coordinate (1 σ). The coordinate axes of the Hipparcos reference frame are still aligned to the ICRF with errors not larger than 2.7 mas and system rotations not larger than 0.55 mas/yr; limits set by a recent investigation of 46 radio stars (Boboltz et al. 2007).

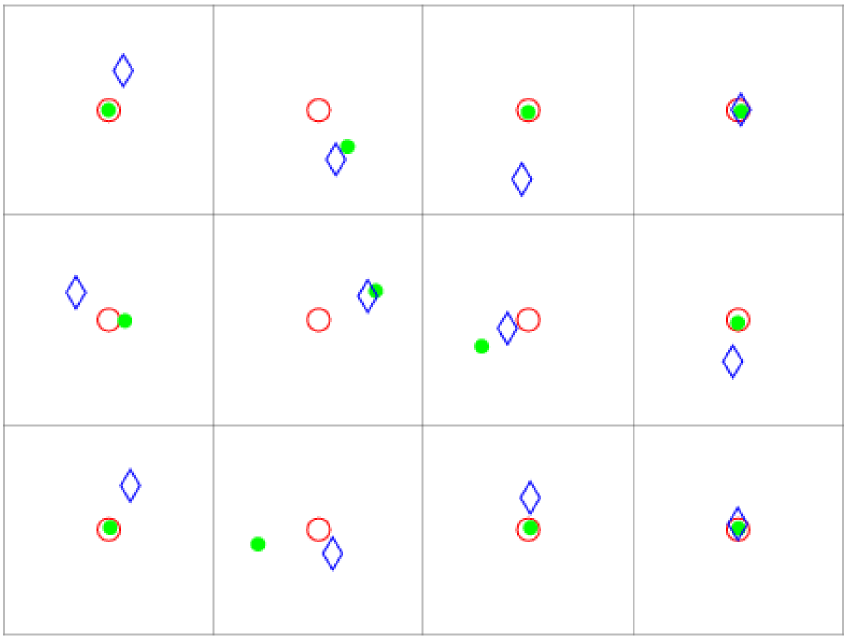

Figure 2: 2-dim (RA,Dec) position discrepancies of selected Hipparcos stars. A red, open circle represents the new Hipparcos reduction position, while a green, filled circle shows the original Hipparcos catalog position relative to that and the blue diamond indicates the location of the UCAC CCD observation as obtained near the 2000 epoch. The respective Hipparcos catalogs position, proper motion and parallax data was used to derive a position at the UCAC epoch for this comparison. The size of the box for each star is 1 arcsec = 1000 mas.

However, some Hipparcos stars can have much larger positional errors at current epochs. During the UCAC3 construction about 1500 stars (random sample) were excluded as reference stars and the observed CCD-based positions (at about epoch 2000) compared with the original (ESA 1997) and re-reduced (van Leeuwen 2007) Hipparcos catalog positions at that epoch. For about 1 to 2 % of the stars large discrepancies were found (Zacharias et al. 2009) up to several 100 mas (Figure 2). Sometimes the CCD data agree with the original but not the new reductions and vice versa, and sometimes all 3 data points are not consistent with estimated errors by large margins.

Limits of the Tycho-2 reference frame begin to become visible as well. Systematic radio-optical extragalactic reference frame source position differences are seen in the 30 mas range for some areas, which may be due to remaining Tycho-2 systematic errors (Zacharias & Zacharias 2009). Small magnitude equations of Tycho-2 positions are seen in UCAC3 data (Zacharias et al. 2010) and in work with the SPM (Girard, private communication) as function of declination zones.

Going to fainter stars, systematic errors of star positions at current epochs are at least 20 mas just from the expected error propagation of proper motion errors in UCAC type catalogs. For Schmidt plate data, these local systematic errors reach 200 to 400 mas, as seen in many external comparisons.

4. URAT

The USNO Robotic Astrometric Telescope (URAT) project uses the same astrograph "red lens" as was used for the UCAC program. A completely new tube assembly has been built in the USNO Instrument Shop and electronic upgrades of its B&C mount are in progress. For the first time, on September 9, 2010, the new mount system was operated under computer control to point at stars and track.

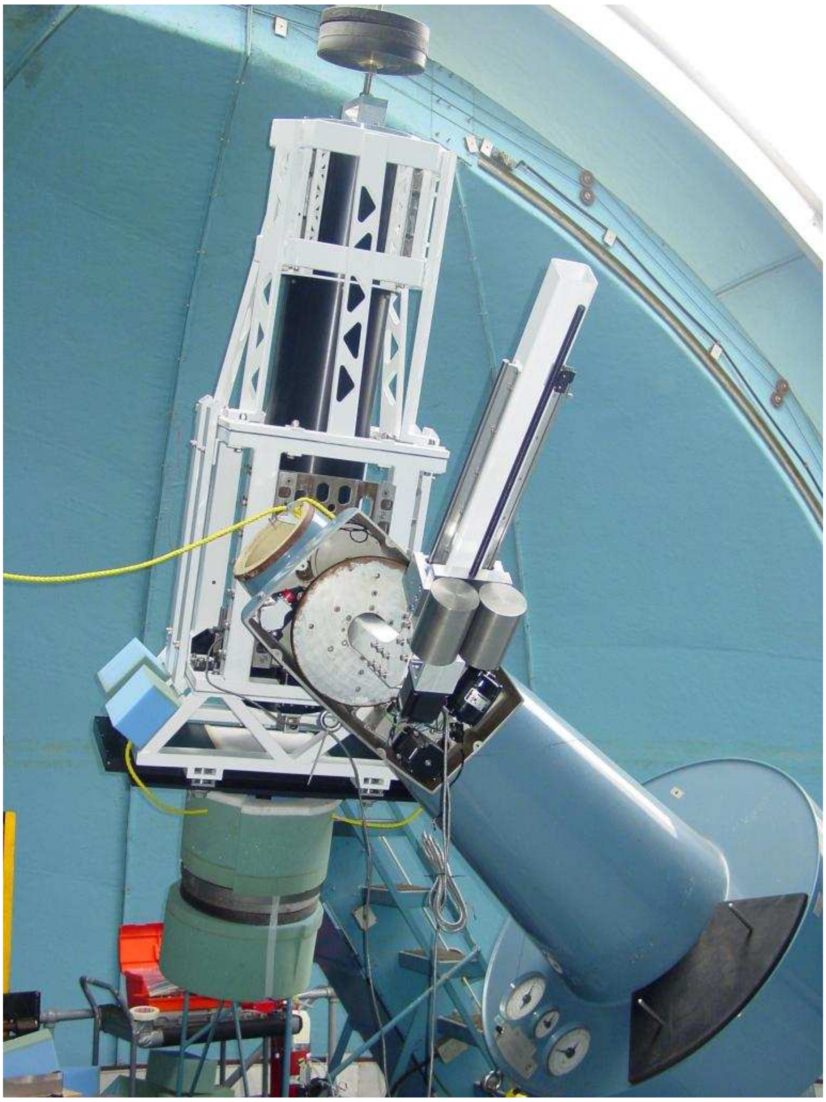

Figure 3: The new tube assembly of the USNO astrograph in 2009 after completion of the mechanical work. The camera dewar has a mass of ≈ 140 kg and the change in mass due to evaporating LN_2 requires a movable counterweight on the opposite side to balance this relatively small telescope on its mount.

telescope aperture	20	cm
bandpass	670–750	nm
pixel scale	0.905	arcsec/pixel
pixel size	9.0	μm
field of single detector	2.65 x 2.65	degree
number of imaging detectors	4	STA1600
number of guide/focus det.	3	2k by 5k each
sky area per exposure	28	sq. degree
survey expos.time	4	min
magnitude range	8 – 18	mag
survey begin at NOFS	2011	

Table 2: Properties of the URAT program.

A summary of the URAT project properties is given in Table 2. The detector design and electronics allow for clocked anti-blooming operations which extend the usable dynamic range for astrometry by about 3 magnitudes at the bright end (beyond saturation). The dewar has a 300 mm clear aperture window which also serves as the filter. It contains also 2 neutral density spots (5 and 7.5 mag attenuation, respectively) to allow stars as bright as about R = 1 be observed relative to surrounding stars of magnitude 8 or fainter in a large area of sky. A prototype camera with a single, front-side illuminated 10k detector was successfully operated in 2007/2008. A "4-shooter" camera for URAT was funded in 2008. The 4 thinned STA16000 detectors of 10,560 by 10,560 pixels each (Figure 3) image 28 square degrees of sky in a single exposure. On 3 sides of the 2 by 2 array of main detectors, there are additional 2k by 5k CCDs with 8 μm pixel size used for guiding and focus control.

Figure 4: Flat field image of a successfully thinned 10k detector for the URAT camera. Pixel data of the 16 outputs are shown with overscans. The cosmetic quality is excellent with only 2 column defects on the entire 111 million pixel area.

After test and commissioning the entire instrument will be moved to the USNO Flagstaff, Arizona station (NOFS) in 2011 to begin a new sky survey. The shipping container also serves as control room.

After 2 to 3 years of operation, the instrument will likely be moved to the Cerro Tololo Interamerican Observatory (CTIO) to observe the southern hemisphere. Due to the large field of view, several complete sky overlaps per year will be obtained of the accessible hemisphere to derive mean positions, proper motions and parallaxes on the 10 to 30 mas level, depending on the brightness of stars.

The URAT survey will be able to directly link many ICRF optical counterparts to the Hipparcos reference frame. A successful Gaia mission of course will supersede most of the URAT data; however, a significant improvement of the optical reference frame and data for galactic dynamics studies are expected from URAT in several releases beginning in 2012. URAT will also provide excellent reference stars for the other ongoing or planned very deep surveys until then.

For the latest update on UCAC and URAT, see
http://www.usno.navy.mil/usno/astrometry/optical-IR-prod .

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