UCAC and URAT: optical astrometric catalog observing programs

Norbert Zacharias
Ralph Gaume

U.S. Naval Observatory
Astrometry Department

nz@usno.navy.mil
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?
<table>
<thead>
<tr>
<th>name of ground proper mag</th>
<th>numb</th>
<th>pos.err</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td>catalog space</td>
<td></td>
<td>stars</td>
<td></td>
</tr>
<tr>
<td>motion</td>
<td></td>
<td>(mas)</td>
<td></td>
</tr>
<tr>
<td>range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stars</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICRF2</td>
<td>G</td>
<td>QSO</td>
<td>radio</td>
</tr>
<tr>
<td>Hip.</td>
<td>S</td>
<td>yes</td>
<td>&lt;= 12</td>
</tr>
<tr>
<td>Tycho-2</td>
<td>G/S</td>
<td>yes</td>
<td>&lt;= 12</td>
</tr>
<tr>
<td>UCAC</td>
<td>G</td>
<td>yes</td>
<td>8..16</td>
</tr>
<tr>
<td>2MASS</td>
<td>G</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>USNO-B</td>
<td>G</td>
<td>yes</td>
<td>12..21</td>
</tr>
<tr>
<td>PanSTARRS</td>
<td>G</td>
<td>yes</td>
<td>17..23</td>
</tr>
<tr>
<td>URAT</td>
<td>G</td>
<td>yes</td>
<td>9..18</td>
</tr>
<tr>
<td>JASMINE</td>
<td>S</td>
<td>yes</td>
<td>near IR</td>
</tr>
<tr>
<td>JMAPS</td>
<td>S</td>
<td>yes</td>
<td>0..14</td>
</tr>
<tr>
<td>Gaia</td>
<td>S</td>
<td>yes</td>
<td>6..20</td>
</tr>
<tr>
<td>SIM</td>
<td>S</td>
<td>yes</td>
<td>0..20</td>
</tr>
</tbody>
</table>

2010 Sep 21
Zacharias & Gaume: UCAC and URAT; Journees, Paris
position error increases with time

Hipparcos Catalogue + new obs.

![Graph showing position error increasing with time](image-url)
accuracy of catalogs
USNO CCD Astromgraph Catalog

PI: Norbert Zacharias
Astrometry Department
U.S. Naval Observatory
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
- 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
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

sigma RAc (mas) vs. B magnitude

sigma Dec (mas) vs. B magnitude
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 or radio center 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 (run1) the reductions were repeated using the new UCAC3 reduction pipeline with improved systematic error control (run3).

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

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

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
Faint stars: Schmidt plate pattern

\[
\Delta \alpha \quad \Delta \delta
\]

-200 200

-50 0 50

RA=0.0 .. 0.5h nbins=1000

NOMAD(UCAC2) - USNO-B
USNO Robotic Astrometric Telescope

PI: Norbert Zacharias
Astrometry Department
U.S. Naval Observatory
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 16\textsuperscript{th} 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.degrees per exposure, single band (670-750nm)
  - first catalog release scheduled for 2013