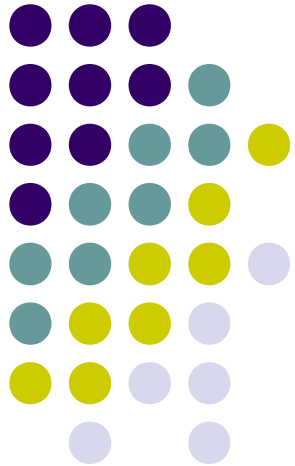
Current star catalogs

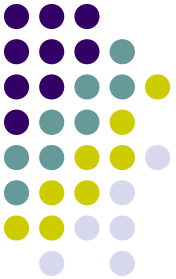
Comparison and their application to occultation work

Mike Kretlow – ESOP 34

2015, Hannover, Germany



TOC and Introduction



- Basic terms and properties of star catalogs
- Brief history about the past ~ 45 yrs
- Current (common) star catalogs used in (asteroidal and planetary) occultation work
- Some future prospects

Basics on star catalogs

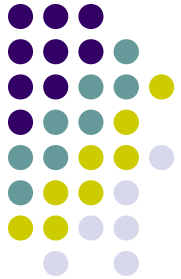
Astrometric star catalogs are usually created by

- Observing the sky or parts of it (astrometry)
- Compiling and reducing from other observational programs and / or catalogs
- and often both (e.g. PMs)
- Supplemented by other data (e.g. photometry)

- Completely merged datasets (e.g. NOMAD)

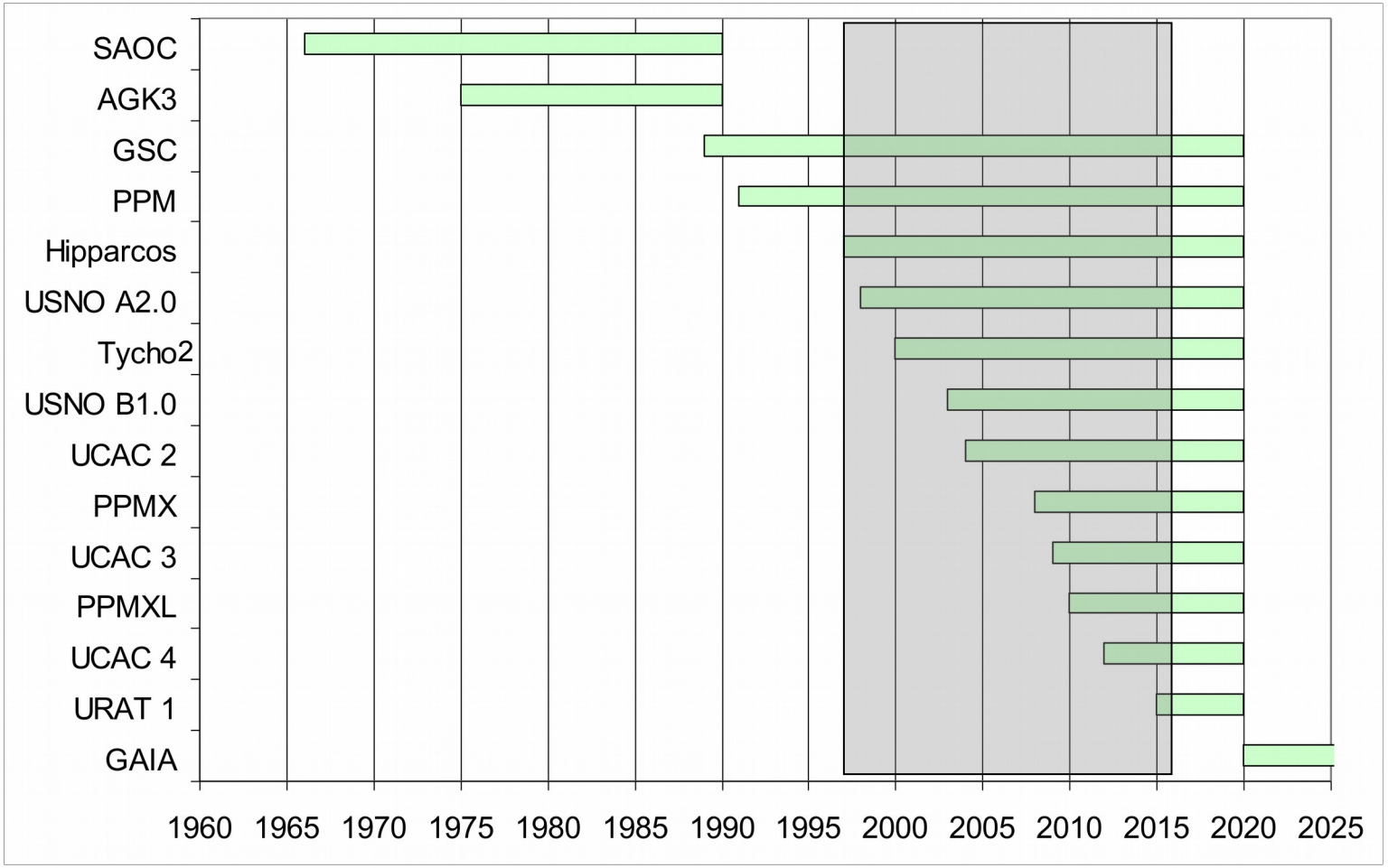
- Coordinates (positions) and proper motions belong to a reference system: FK4, FK5, FK6, ICRF, HCRF, etc.

Basics on astrometry and orbits of asteroids



- Different kinds of astrometric observations : ground based optical (relative, absolute), radio observations and space based.
- Vast majority is photographic and CCD astrometry.
- Typical MB asteroid :
  - 10^2 – 10^3 observations
  - Yrs up to many decades of observational time span
  - => heterogeneous data set (method, star catalog, reference system etc.).
- Orbit determination: LSQ fit to the observations.
  - => complex biasing behaviour depending on this heterogeneous data set, orbit improving algorithms (weighting, rejecting) and planetary model (e.g. JPL DE xxx).

The past ~45 yrs of astrometric catalogs (incomplete)



The past ~45 yrs of astrometric catalogs (incomplete)

- 1970-1990 : AGK3, SAOC, others (e.g. Perth 70)
  - AGK3: ~250000 * , ~9-10 mag, PMs, B1950 / FK4, DE > -2°
  - SAOC: ~260000 *, ~9-10 mag, PMs, B1950 / FK4, full sky

- 1989-1991: GSC I and PPM
- 1997, 2000: Hipparcos and Tycho-2
- 2001: ARIHIP
- 1998: USNO A2.0
- 2003: USNO B1.0
- 2004: UCAC 2
- 2008: PPMX
- 2009: UCAC 3
- 2010: PPMXL
- 2012: UCAC 4
- 2015: URAT 1

Catalogs used in minor planet astrometric observations

- UCAC 2 – 4
- USNO A2.0
- USNO B1.0
- GSC 1+2 / GSC-ACT
- CMC (…,14,15)
- PPMX und PPMXL
- URAT 1

Catalog	MPC flags	Count	%
USNO A2.0	c, d	30,786,427	53.0
UCAC	e, q, r, t, u	12,559,000	21.6
USNO B1.0	o, s	6,800,387	11.7
Unknown	–	4,171,601	7.2
USNO A1.0	a, b	2,205,452	3.8
GSC 1	h, i, j, z	543,037	0.9
GSC ACT	m	364,575	0.6
CMC	w	337,053	0.6
Tycho	f, g	299,648	0.5
ACT	l	13,866	0.0
NOMAD	v	2,763	0.0
GSC 2	k	180	0.0
Total	–	58,083,989	–

Obs. code	Time frame	Catalog
704	Before 2000-January-01	USNO A1.0
704	After 2000-January-01	USNO A2.0
691	1991-August-31–1999-September-28	GSC 1
691	1999-September-29–2000-December-21	USNO A1.0
691	2000-December-22–2006-December-26	USNO A2.0
703	Before 2005-January-01	USNO A2.0

Systematic errors and bias between catalogs

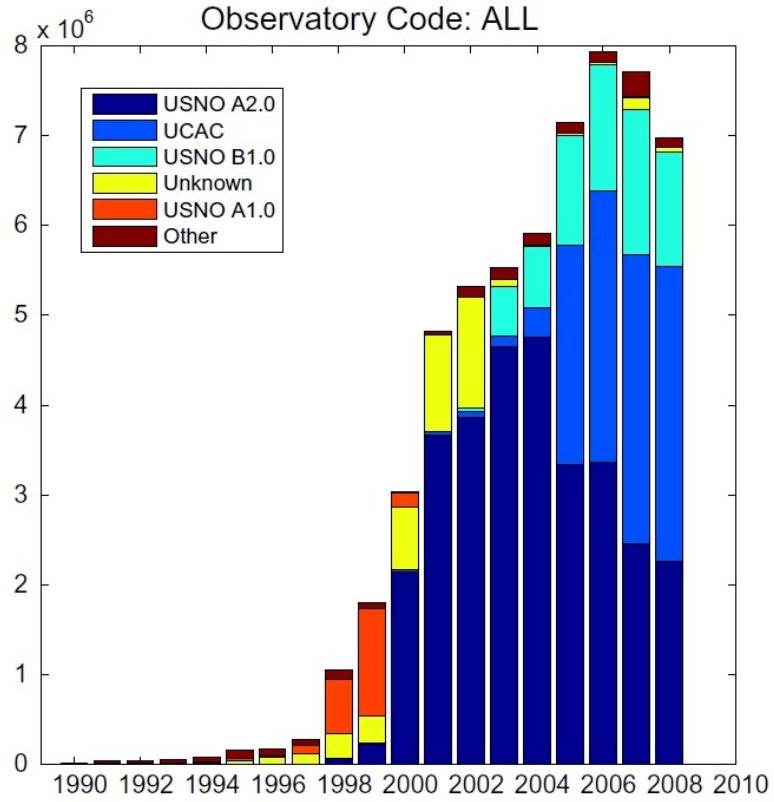


Fig. 3. Year-by-year counts of star catalog usage for CCD astrometry.

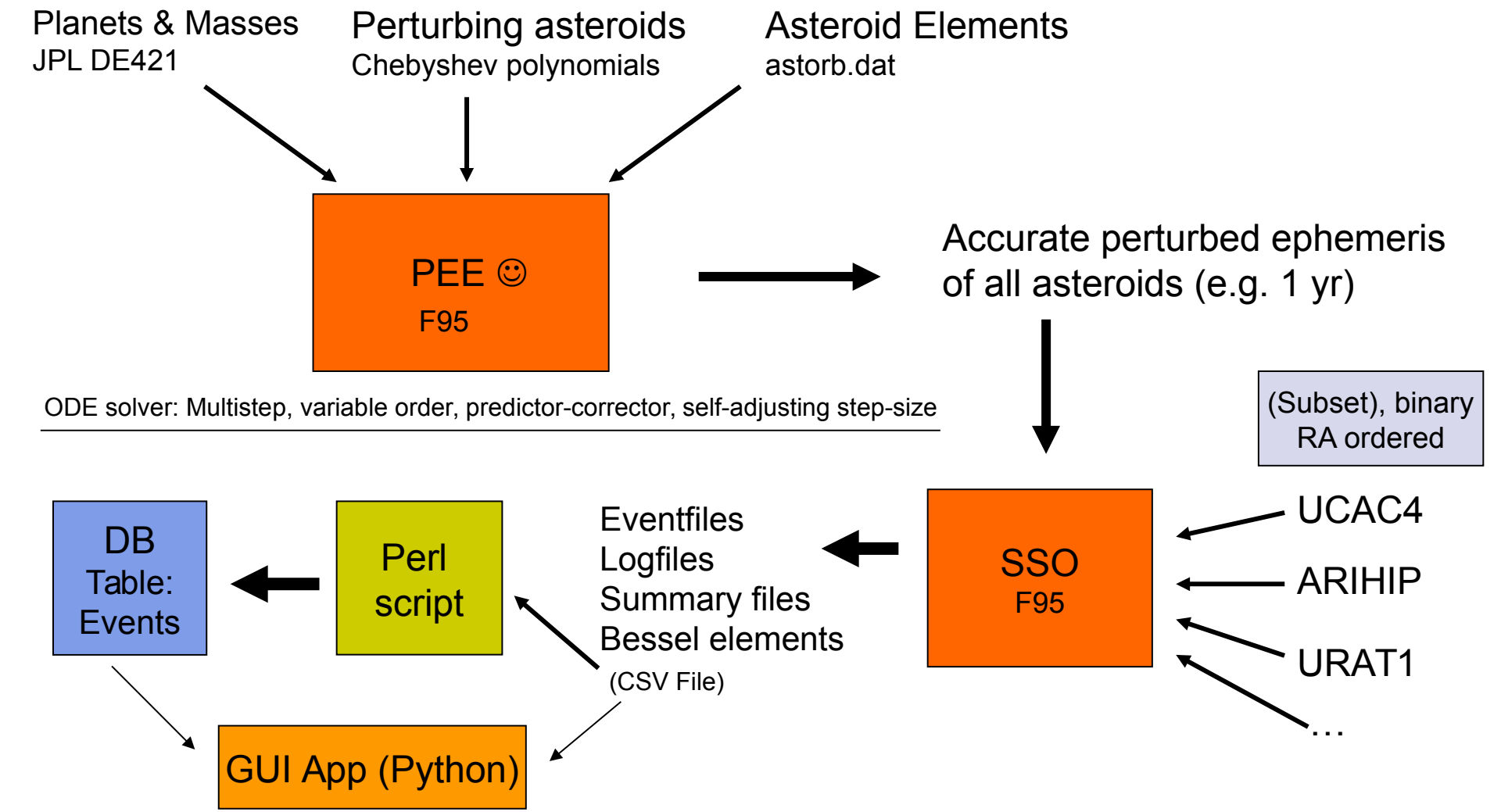
Inter-catalog systematic errors, with respect to 2MASS.

Catalog	Mean ± std. dev.	
	RA (mas)	DEC (mas)
Tycho-2	−1 ± 28	−12 ± 24
UCAC2	2 ± 23	−7 ± 20
USNO B1.0	−16 ± 123	126 ± 123
USNO A2.0	63 ± 180	142 ± 189
USNO A1.0	−41 ± 419	−34 ± 352

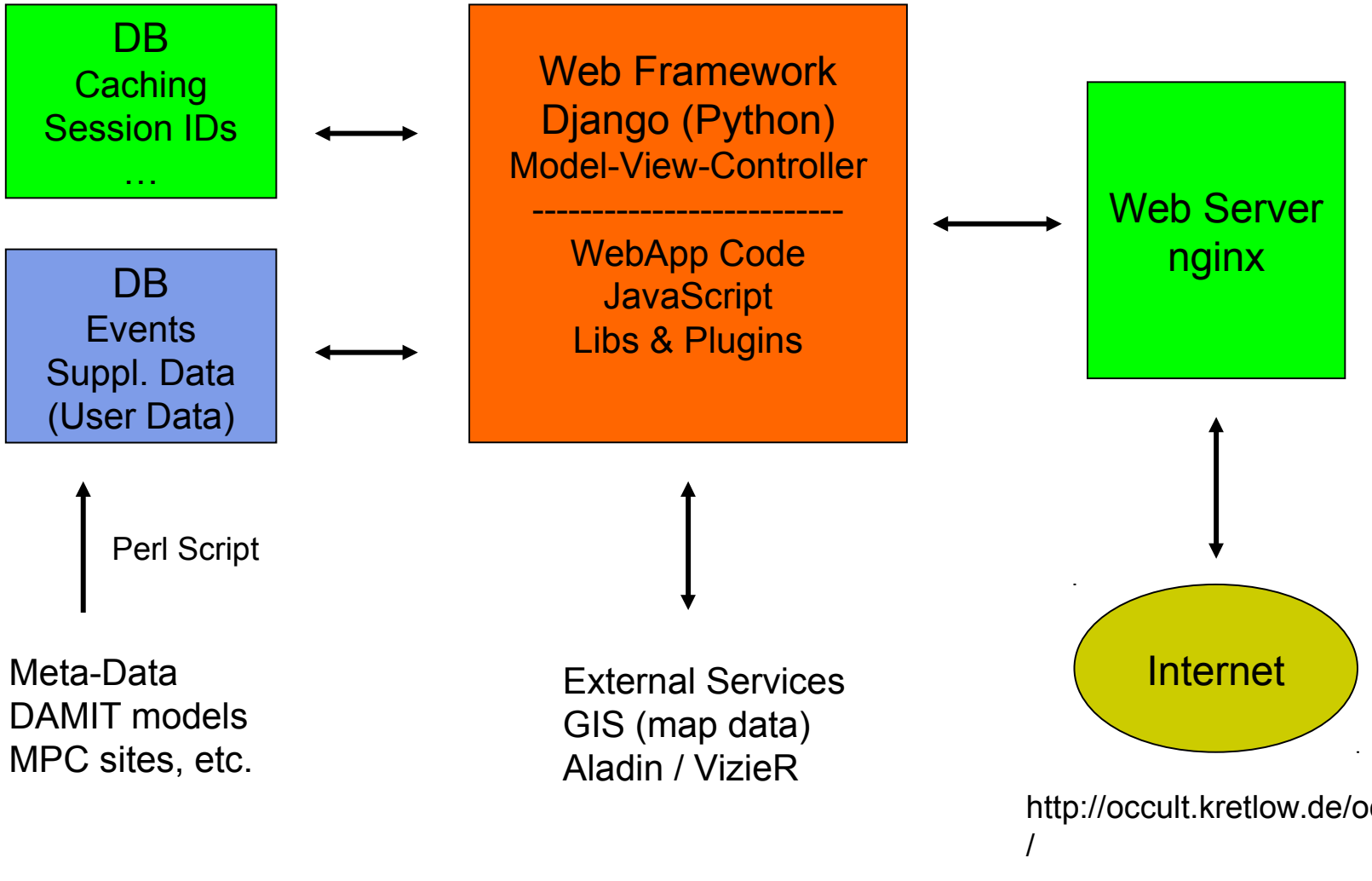
Producers of occultation predictions

- Win-App OCCULT by Dave Herald (AU).
  - Steve Preston (USA).
  - Other contributors and (local) coordinators, preparing and selecting events, web presentation etc.
- Edwin Goffin (BE / EAON). Non-public software. Access: PDF.
- Mike Kretlow (DE / IOTA-ES). Non-public software. Access: WebApp.
- Andrey Plekhanov (RUS), LinOccult. Access: Mail?

Workflow and tool chain (1)



Workflow (2) and WebApp



European asteroidal occultation reports 1997-

Asteroidal Occultation Reports Database

Home (Observations) | Results and Lists | Informations and Credits | Home (Predictions) | Top (Mike Kretlow)

Results | Incomplete Reports | LC Candidates | Observers Activity Report | Annual Statistics | Star Catalog Statistics | Top-20 List

Star Catalog Statistics

Catalog	Reported OCC	Positive OCC (O+)	SR
2UC	762	165	22%
3UC	314	11	4%
4UC	460	38	8%
GSC	49	3	6%
HIP	334	73	22%
TYC	2100	410	20%
PPM	124	18	15%
PPMX(L)	5	0	0%
TAC	52	6	12%

SR: Success Rate = OCC(O+) / OCC(total)

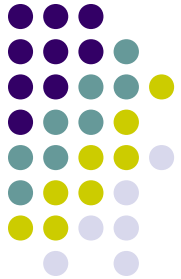
http://occult.kretlow.de/occrep/reports/6/

Post-Hipparcos era

- Hipparcos catalog is the primary realisation of the ICRF at optical wavelengths.
- Since then many (star catalog) projects aimed to extend the Hipparcos system to higher star density and limiting magnitudes.
- Tycho-2, UCAC, PPMX(L), etc.

2MASS

Two-Micron All-Sky Survey



- Full-sky near-IR (J,H,K) survey (1997-2000).
- About 470 mio. point sources with coordinates near epoch 2000 on ICRF.
- Not an astrometric catalog but errors in positions at mean epoch about 60-100 mas (not so bad).
- No proper motions.

Hipparcos and Tycho-2

Hipparcos (1997):

- ~ 118 thousend stars
- Complete up to V ~ 7-9 mag, Limit ~ 12.4
- ~ 3 stars per square degree
- M.e. positions 1-3 mas and PMs 1-2mas /yr (1991.25)

Tycho-2 (2000):

- ~ 2.5 mio. stars
- Complete up to V ~ 11.0, Limit ~ 11.5
- ~ 25…150 stars per square degree
- M.e. positions 10-100 mas, PMs 1-3 mas / yr

ARIHIP

- Combination of Hipparcos data (HIP and TYC2) with ground based observations (FK5, GC).
  - HIP + FK5 (= FK6)
  - HIP + GC
  - HIP + TYC2
- ARIHIP construced by selecting ´best data´ from these three combined catalogs.
- 90842 stars, m.e. in PM 0.89 mas/yr

PPMX

- PPM-Extended (PPMX) is a catalog of 18,088,919 stars on the ICRF down to about 15 mag in the GSC photometric system.
- PPMX was built by LSQ fit to individual observations (AC, ARIHIP, GSC, Tyc-2, 2MASS, CMC14, UCAC2,…) spread over more than a century.
- The typical error of the proper motions is 2 mas/yr for 66 percent of the survey stars and the high-precision stars, and about 10 mas/yr for all other stars.
- ARIHIP is a subset of PPMX (data just copied)

PPMXL

- PPMXL contains about 900 million objects, some 410 million with 2MASS photometry, aiming to be complete down to about V ~ 20 full-sky .
- PPMXL is th result of a re-reduction of USNO-B1 (only relative PMs) together with 2MASS (no PMs) to the ICRS (PPMX as representative).
- The mean errors of positions at epoch 2000.0 are 80 to 120 mas, if 2MASS astrometry could be used, 150 to 300 mas else.
- The resulting typical individual mean errors of the proper motions range from 4 mas/y to more than 10 mas/y depending on observational history.
- PPMXL also gives correction tables to convert USNO-B1.0 observations of e.g. minor planets to the ICRS system.

UCAC2

- CCD observations 1997-2004 with 20cm astrograph.
- About 48 mio. stars -90° … ~ +45° (+52°) down to R ~ 16mag => high star density compared to TYC-2 etc.
- Early-epoch transit and photographic data (AGK2, SPM, NPM plate scans) were used to derive PMs.
- Positions and PMs linked to ICRF.
- Typical astrometric error 20 mas (R ~ 10-14 mag) at observational epoch.

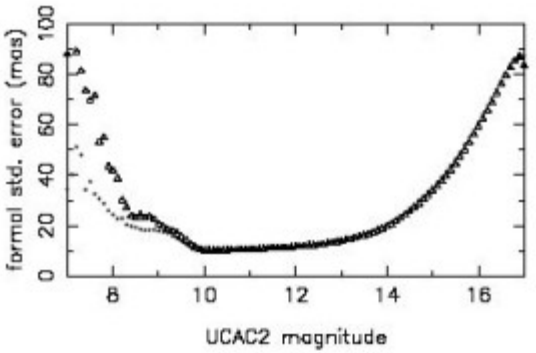


Fig. 8.— Precision of the CCD astrograph positions at their observational epoch. The filled dots and open triangles represent the RA and Dec component, respectively.

UCAC 3 vs UCAC 2

- Sky coverage completed (UCAC 2: -90° …~45°).
- Double star problems resolved.
- Goes deeper / higher star density (R ~ 8-16).
- The early epoch data for UCAC3 proper motions come from over 140 ground- and space-based catalogs, as well as Schmidt plate data from the Southern Proper Motion (SPM) program and the SuperCOSMOS project.
- The proper motions of stars in the northern hemisphere did not take the NPM data into consideration (leaved to next generation UCAC4).
- Because of plate dependent and field-to-field errors in the UCAC3 catalog, it is suggested that positions and proper motions of UCAC3 stars in the northern hemisphere ($\delta > -20^\circ$) should be used with caution.

Position difference PPMX-UCAC3

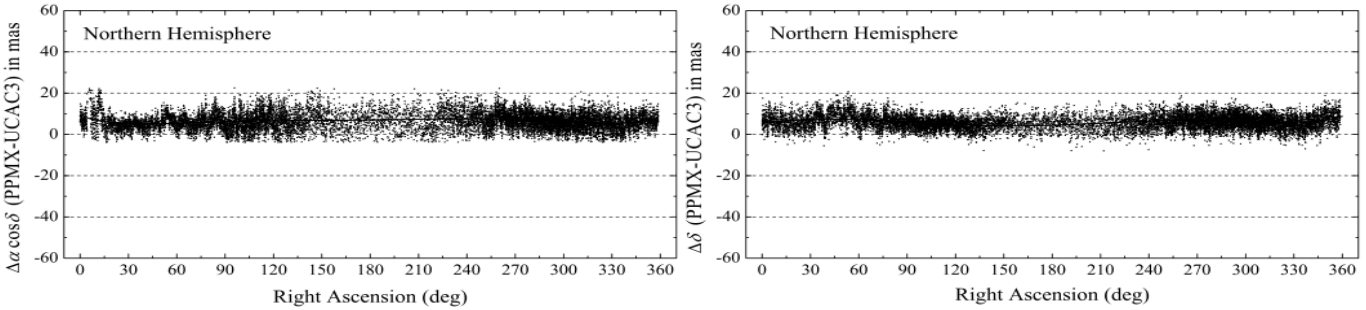


Fig. 2 Position difference [PPMX-UCAC3] at epoch J2000.0 as a function of right ascension for stars in the northern hemisphere $\delta > -20°$. Each dot represents the mean calculated over 500 stars.

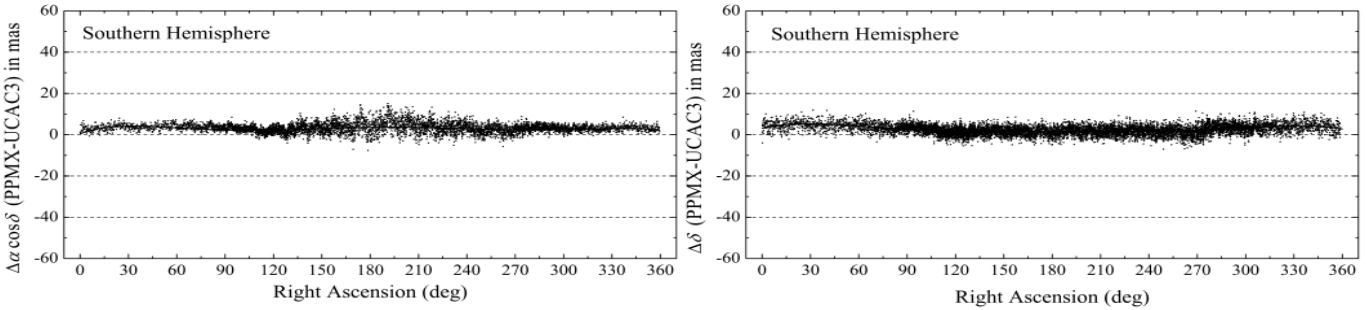


Fig. 3 Position difference [PPMX-UCAC3] at epoch J2000.0 as a function of right ascension for stars in the southern hemisphere $\delta < -20°$. Each dot represents the mean calculated over 500 stars.

Distorsions in proper motion

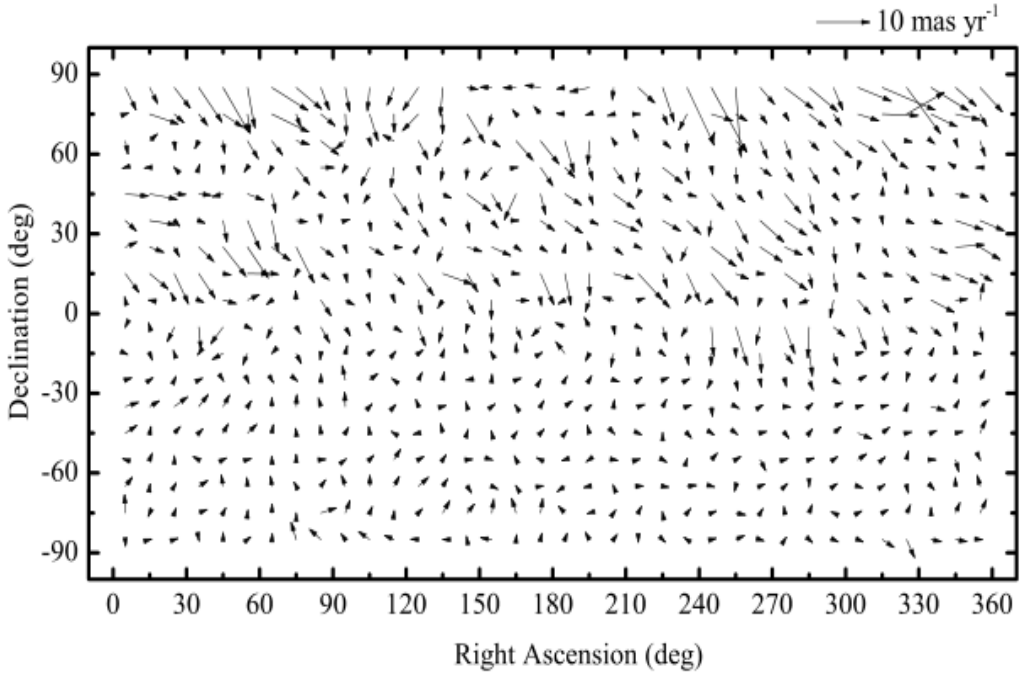


Fig. 7 Regional difference of proper motions between PPMX and UCAC3 in the sense [PPMX-UCAC3] in the equatorial coordinates.

UCAC 4

- Over 113 million objects; over 105 million of them with proper motions (PMs).
- Astrograph observations have been supplemented for bright stars by FK6, Hipparcos, and Tycho-2 data to compile the UCAC4 star catalog complete from the brightest stars to about magnitude R ~ 16.
- Mean positions and PMs are derived by combining these observations with over 140 ground- and space-based catalogs, as well as unpublished measures of over 5000 plates from other astrographs.
- For most of the faint stars in the southern hemisphere, the first epoch plates from the Southern Proper Motion (SPM) program form the basis for PMs, while the Northern Proper Motion (NPM) first epoch plates serve the same purpose for the rest of the sky.
- These data are supplemented by 2MASS and APASS data.
- The positional accuracy of stars in UCAC4 at mean epoch is about 15-100 mas per coordinate (depending on magnitude), while the formal errors in PMs range from about 1 to 10 mas yr–1 depending on magnitude and observing history.
- Systematic errors in PMs are estimated to be about 1-4 mas yr–1.

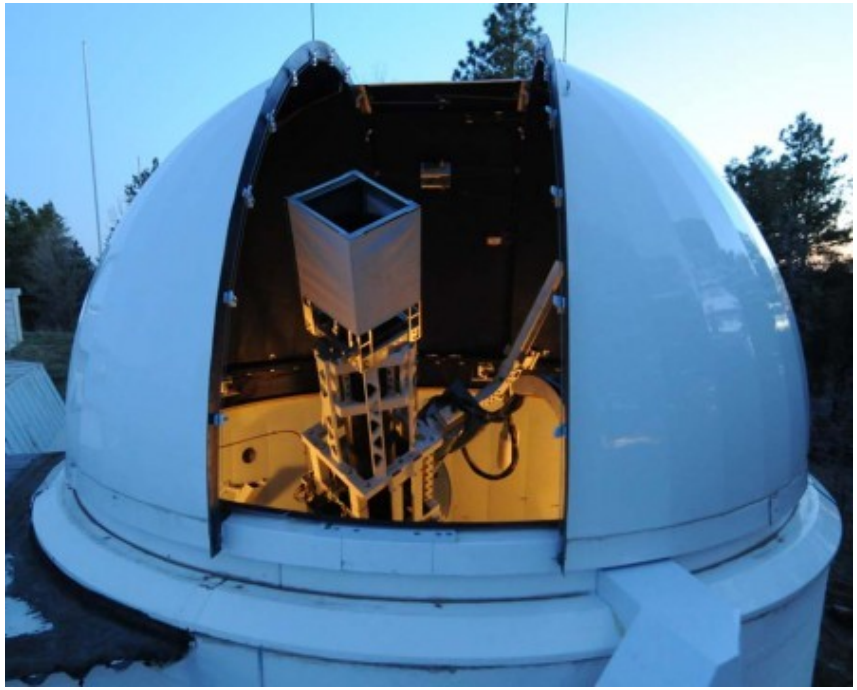
SPM 4

- The Southern Proper Motion Catalog 4 contains absolute proper motions, positions, and B,V photometry for over 100 million stars and galaxies, down to a magnitude of V=17.5.
- Sky coverage is from declination -20 degrees to the south celestial pole. Cross references to the 2MASS near-infrared catalog are also included, as is the 2MASS JHK photometry.
- The absolute proper motions are tied to the ICRS at the bright end, via Hipparcos stars, and to external galaxies at the faint end.
- The final precision of the SPM positions and absolute proper motions is approximately 30 to 150 mas and 2 to 10 mas/yr, respectively. Systematic errors in the proper motions are still being evaluated but are estimated to be on the order of 1 mas/yr.

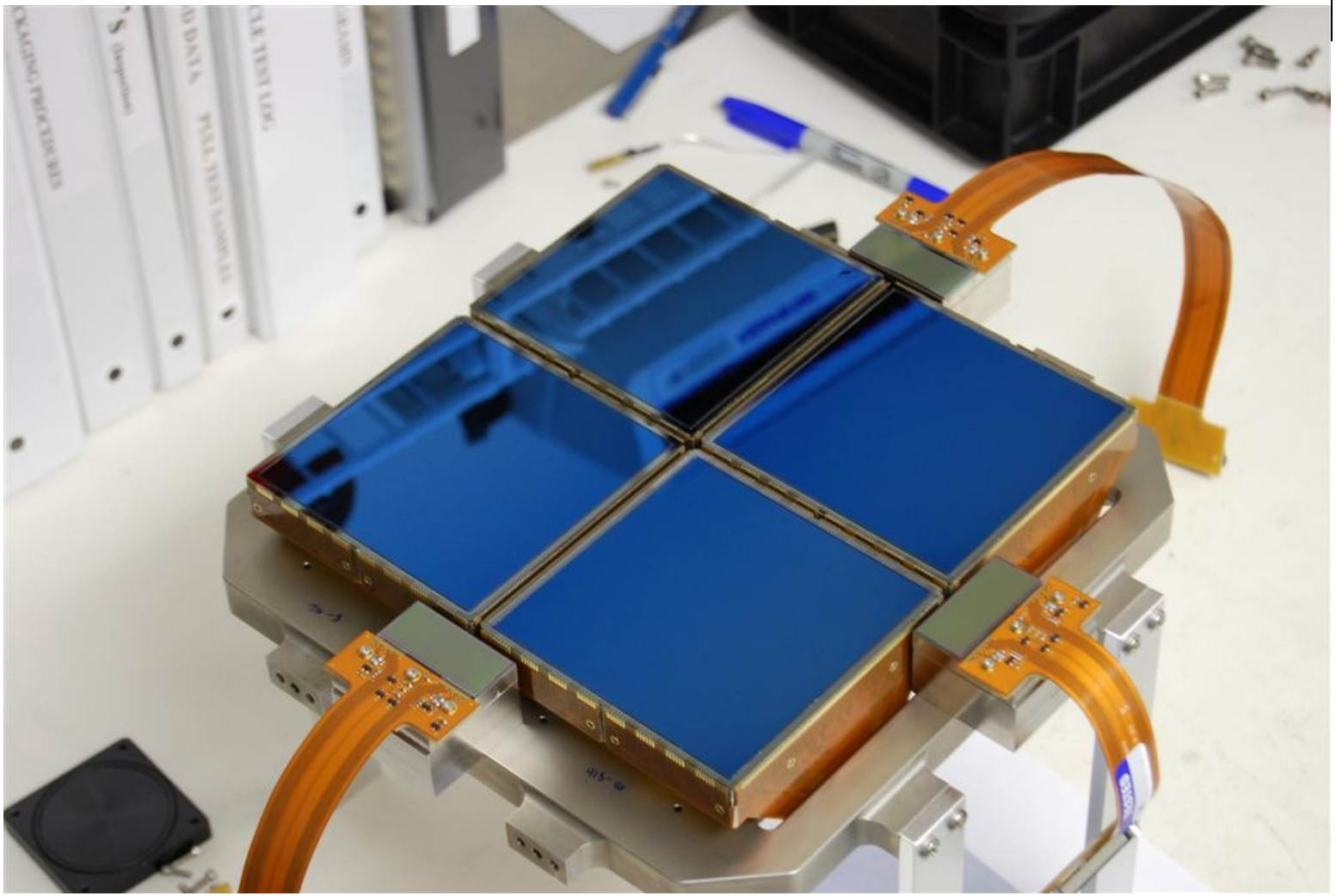
USNO Robotic Astrometric Telescope Catalog (URAT)

- Successor to the well-known UCAC (2 - 4) projects.
- Same astrograph, but larger and more sensitive CCD camera und etwas weiter im roten Bereich (680-750 nm, d.h. zwischen R und I).
- 2006 / 2007: Project start.
- March / April 2012: Survey start.
- March 2015: URAT1 public available. ~ 18 GB binary data.
- Astrometrica: Beta version.

http://www.astrometrica.at/Beta/Astrometrica.zip



2 x 2 chip CCD Array



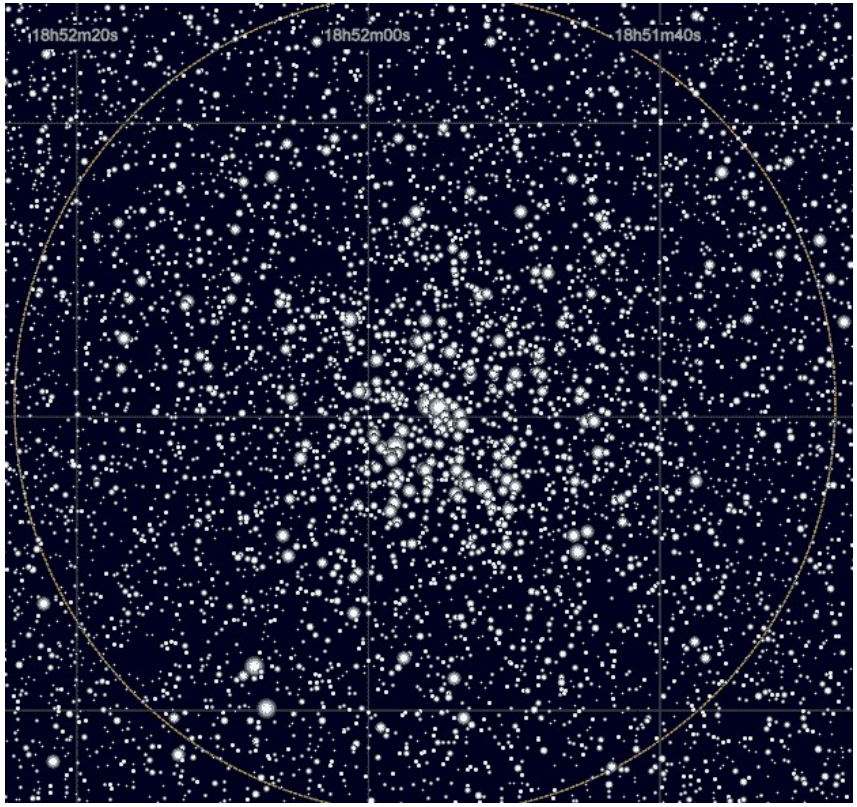
10k x10k CCD (9mu) ST1600B

Properties of URAT1

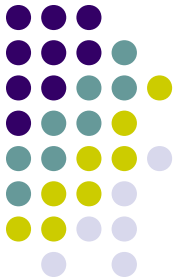
- Observational catalog (2012.3 - 2014.6, largely end of 2013) tied to the ICRS.
- 228 mio. objects (3 - 18.5 mag).
- 4x higher star density as for UCAC4.
- Position accuracy ~ 5 - 40 mas. Systematic error 5 - 10 mas.
- PMs dervived from URAT1 vs 2MASS (2MASS mean EP ~ 2000).

Err (PM) ~ 5 - 8 mas/yr (PPMX ~ 2 mas/yr).

=> PMs in URAT1 not of high quality.



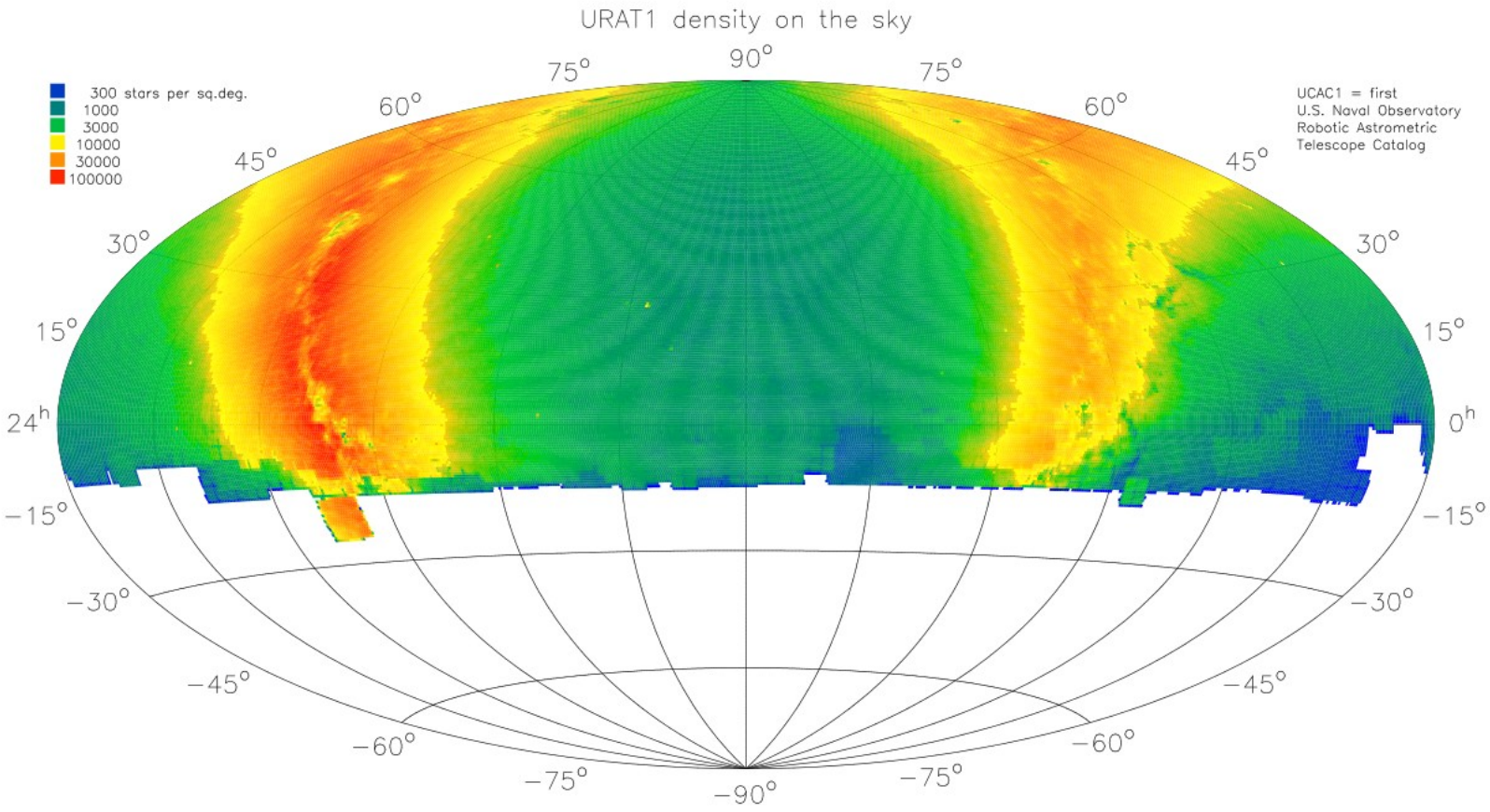
Properties of URAT1



- 37 mio. with APASS photometriy (B,V,g,r,i).
  188 mio. with 2MASS photometry (J,H,K).

- Problematic cases like double stars rejected, but non-stellar objects (asteroids, galaxies, quasars, etc.) not => Caution with occultations !

- Covers mainly the northern sky (down to DE -15°) + Pluto field (down to DE -25°).


URAT1 density on the sky
300 stars per sq.deg.
1000
3000
10000
30000
100000
UCAC1 = first
U.S. Naval Observatory
Robotic Astrometric
Telescope Catalog
90°
75°
75°
60°
60°
45°
45°
30°
30°
15°
15°
24h
0h
−15°
−15°
−30°
−30°
−45°
−45°
−60°
−60°
−75°
−75°
−90°

URAT: application to astrometric observations and occultations

- At present URAT1 provides the best astrometric accuracy because of the very recent observation epoch and a apparently small internal error.
- Goes deep enough for asteroidal and planetary occltation work.
- Good link to the ICRS (e.g. compared to USNO B1.0, relative PMs)
- Accessibility (18GB, VizieR)
- Supported by Astrometrica.

=> All in all probably first-choice catalog for both astrometric CCD observations of asteroids and for occultation work.

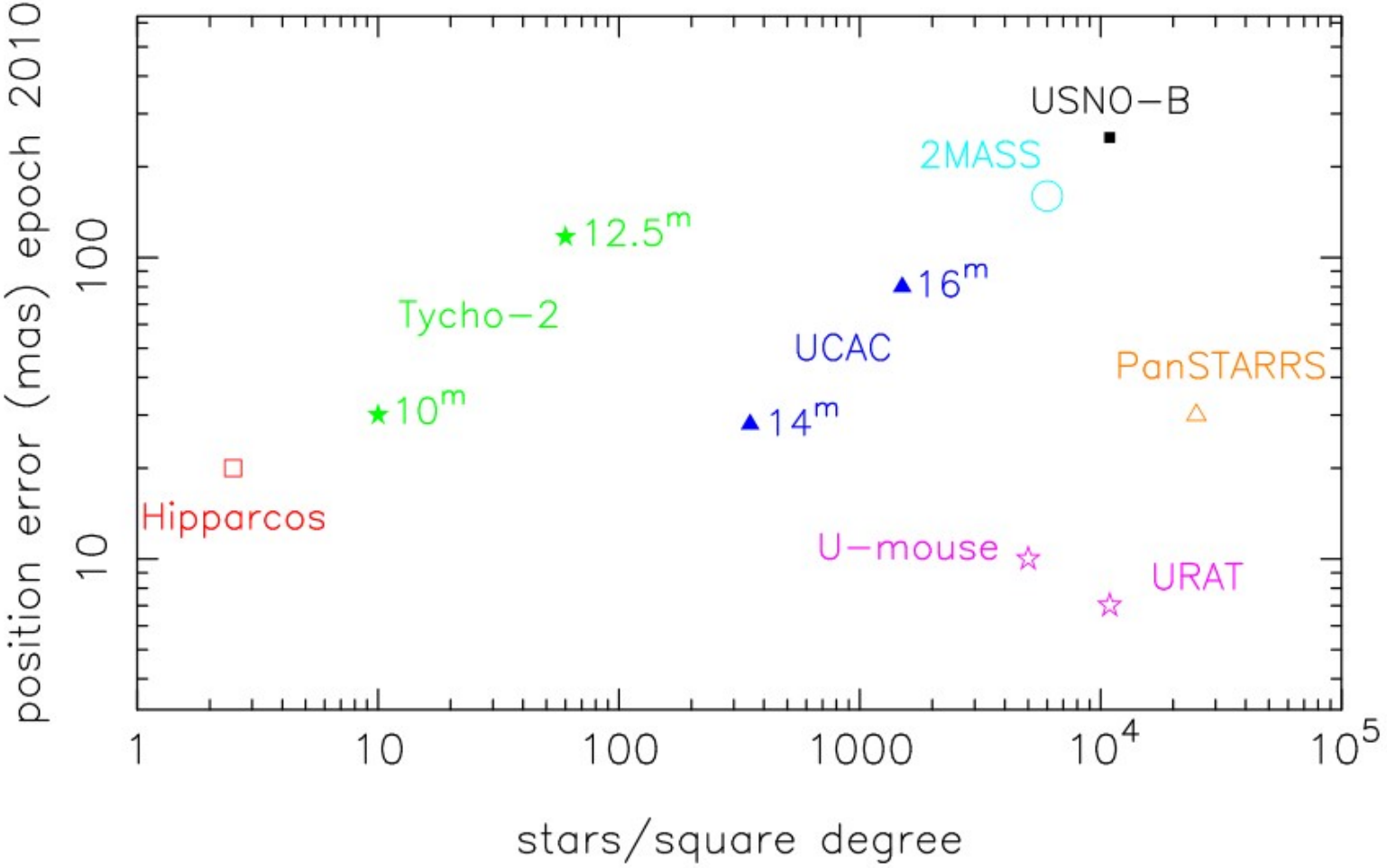


Figure 1. The global positional accuracies of some optical reference star catalogs are plotted as a function of the density (number of stars per square degree). For Tycho-2 and UCAC a range is given for positional errors depending on magnitude as indicated. See text for further explanation.

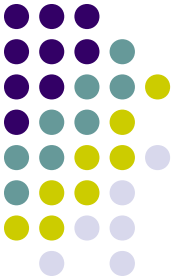
The currently ´best´ catalog (IMHO) !?

- URAT1 or ARIHIP >
  PPMX or UCAC4 >
  PPMXL >
  UCAC2

- Consider (also) SPM4 for southern hemisphere.

Do NOT use: NOMAD, USNO B1.0, UCAC3, 2MASS

Future prospects



- ~2018: URAT1 ≈ UCAC4 (because of URAT1 PMs).
- URAT2 = URAT1 + better PMs.
- URAT2 expected within the next ~ 1-2 yrs.
- Switch latest in ~2018 to URAT2.
- Investigations into systematic differences to other catalogs (especially to USNO A2.0, B1.0 and PPMX(L)) would be useful (e.g. debiasing of astrometric observations of asteroids).
- GAIA star catalog: different releases mid-2016…2020 (?).
  Kind of data access for occultation work TBD.
  Impact on occultation work => second presentation.