Astrometric surveys 2000 to 2020

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An overview of optical astrometric all-sky surveys with multi-colour photometry.

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ABSTRACT: ***An overview of optical astrometric all-sky surveys with multi-colour photometry***. Hipparcos and Tycho-2 provide the preferred frame of bright astrometric reference stars. This frame is connected to the zero proper motions in the International Celestial Reference System (ICRS) defined by 212 quasars. Connection to fainter stars will by 2015 reach R=18 mag with 400 million stars in the all-sky survey, URAT. The surveys Pan-STARRS and LSST from Hawaii and Chile will cover the entire sky to 24 mag very frequently, including astrometry and multi-colour photometry. About 2013 the entire sky should have obtained five- or six-colour photometry to 23 mag by Pan-STARRS or SkyMapper. The Gaia mission covers all stars to 20 mag with high-accuracy astrometry and low-resolution spectra for photometry with high angular resolution.

With 6, 2 or 1 slide per page: www.astro.ku.dk/~erik/AstrometricSurveys6pp.pdf
...Surveys2pp.pdf, ...Surveys.pdf

Radio- and Space Astrometry

★ 1970 --- : Radio astrometry : accurate absolute positions, reference system by quasars, Earth rotation

★ 1997 : 212 selected quasars define the ICRS to 0.020 mas

Hipparcos frame agrees herewith +/- 0.6 mas, +/- 0.25 mas/a

Space astrometry surveys:

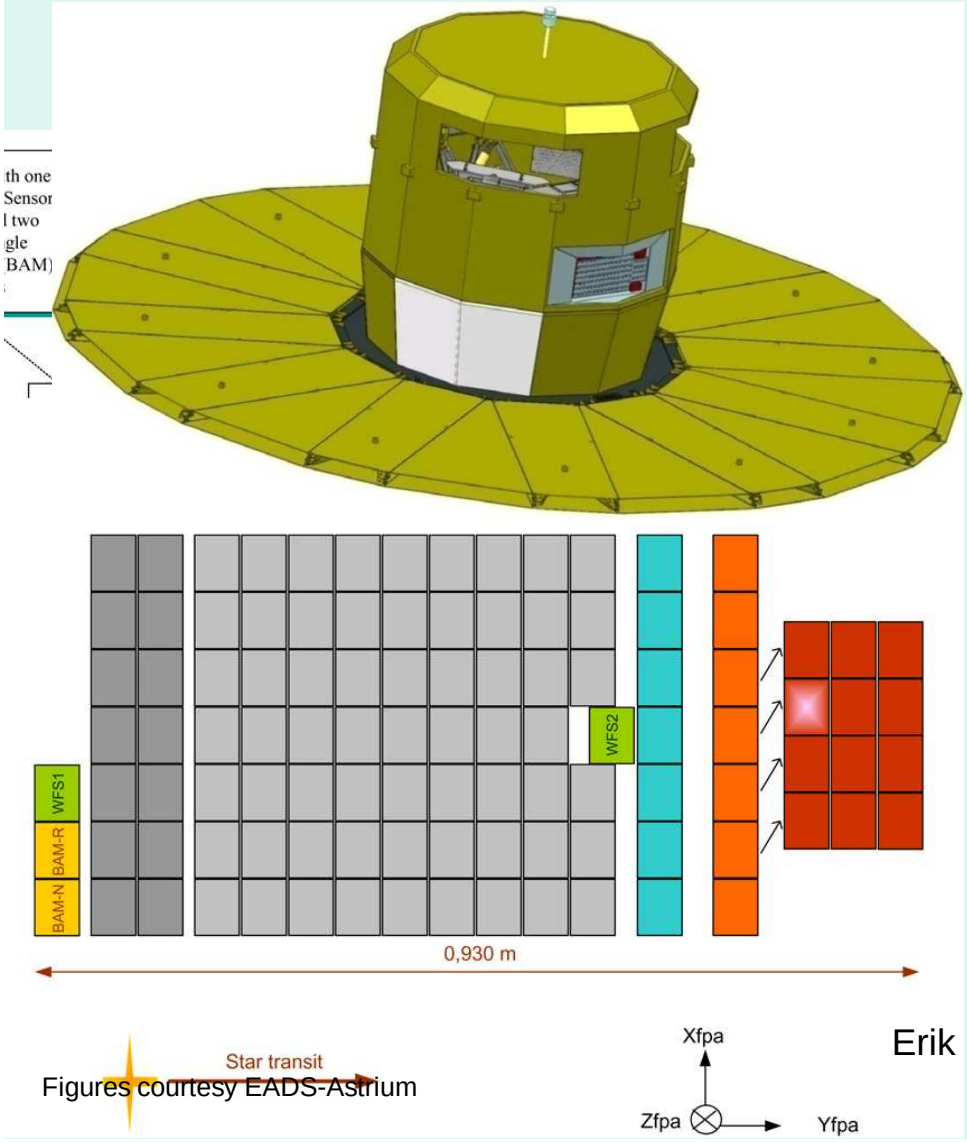
- 1997 : Hipparcos : accurate large & small angles
  120,000 stars 1 mas/a motions (N & S)
  120,000 stars 1 mas absolute parallaxes
  21,000 stars with <10% error on distances
  2007 : 30,000 stars with <10% error on distances
- 2000 : Tycho-2 : 2.500,000 stars 2.5 mas/a motions

www.astro.ku.dk/~erik/Tycho-2/

- 2017… : Gaia : 1000 million stars 0.3 mas at limit 20 mag

www.rssd.esa.int/GAIA/ more on Gaia follows

Gaia mission:
Astrometry, photometry, spectra



Figures courtesy EADS-Astrium

Two telesc. 1.45 x 0.5 m, F=35 m
2 x 0.8 sq.deg field
2012- 2017… : 1000 million stars
Complete to 20 mag
- 0.3 mas at limit V=20 mag
- 0.025 mas at V=15
- 0.007 mas at V=10

Low resolution spectra to V=20
Radial veloc. +/-15 km/s to V=16-17

Expected science, astrom.+photom.:
p.m.+ parallaxes ->HRs, brown dwarfs
500,000 quasars
10-100 million galaxies
10-20,000 exo-planets
Asteroid masses and diameters
Variables, Double stars

Ground-based surveys

Comprehensive lists of surveys, current and future, in the optical and near IR are given by N. Zacharias, including many links:

www.astro.yale.edu/astrom/dens_wg/astrom-survey-index.html

Ground-based surveys from these lists to 20 mag or deeper follow here:

Mosaic, DAS, VISTA, VST observe fields < 1 sq.deg and cover only selected parts of the sky. SDSS scans ¼ of the sky.

USNO-B1.0, 2MASS, SkyMapper, PanSTARRS, LSST : ½ sky and more

2001: 2MASS : 470,000,000 near IR sources, 80 mas pos., no p.m., all sky

SkyMapper : Siding Spring Observatories, Australia. D=1.3 m,
5.7 sq.deg field, 32 CCDs 4k x 2k, *u, v, g, r, i, z* filters, 300-950 nm
2008-2013? all south covered 6 times, 22-23 mag, < 50 mas

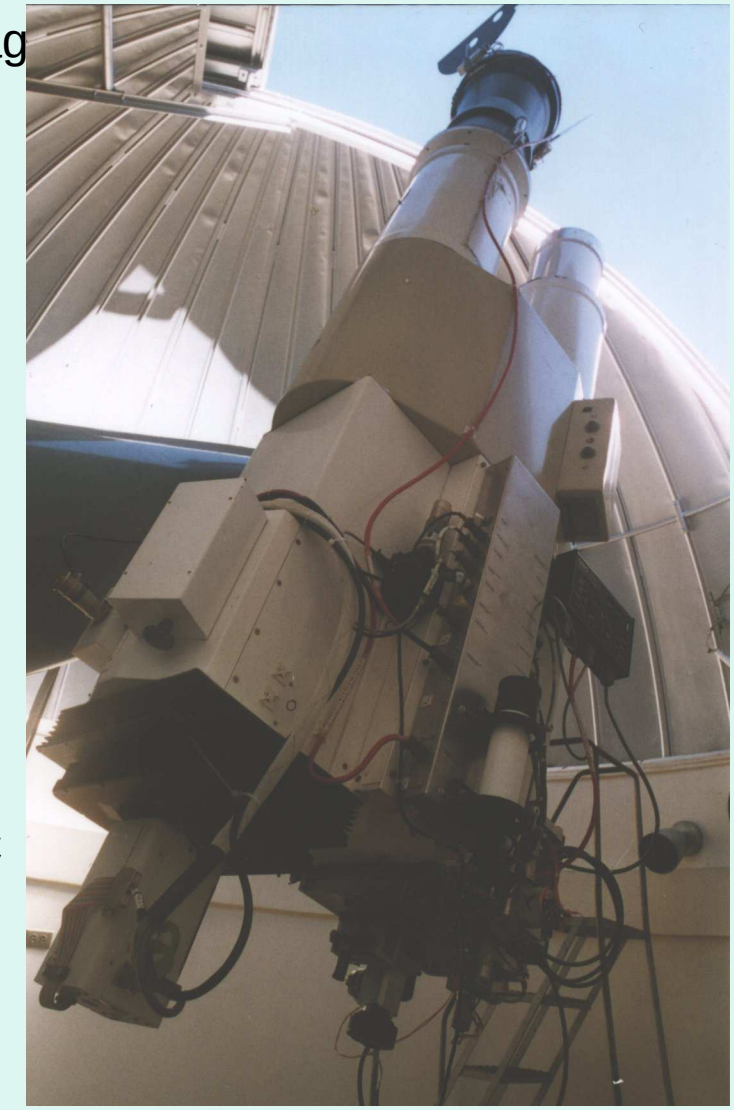
USNO – US Naval Observatory

USNO-B1.0 : 2002: 1,000,000,000 stars to 20th mag
200 mas positions, also p.m., all sky

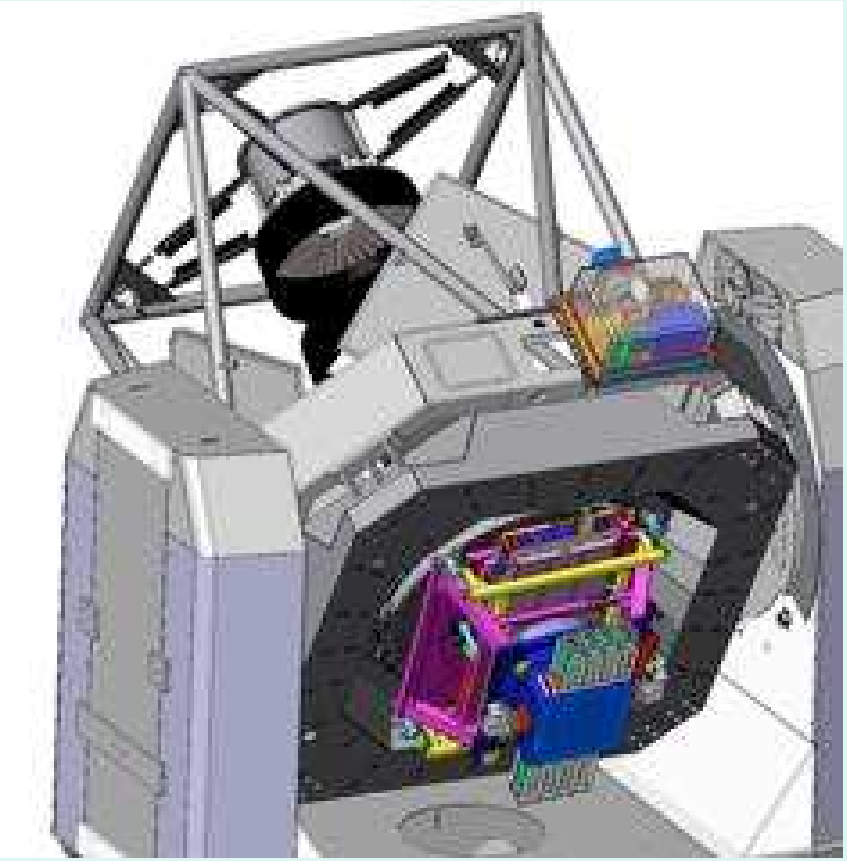
UCAC: CCD Astrograph Catalog
4 k x 4 k pixels CCD 1 sq.deg
2000: UCAC2: 48 million stars
70 mas at limit R=16 mag
20 mas 10-14 mag

2009: UCAC3: 100 million stars, all sky
70 mas at limit R=16 mag
15 mas 10-14 mag

URAT: 20 cm, f= 2m Astrograph, same as UCAC
10 k x 10 k CCD 4x = 28 sq.deg
2009-2015: 400 million stars, all sky
30 mas at R=18 mag
5 mas 10-15 mag



Pan-STARRS – Panoramic Survey Telescope

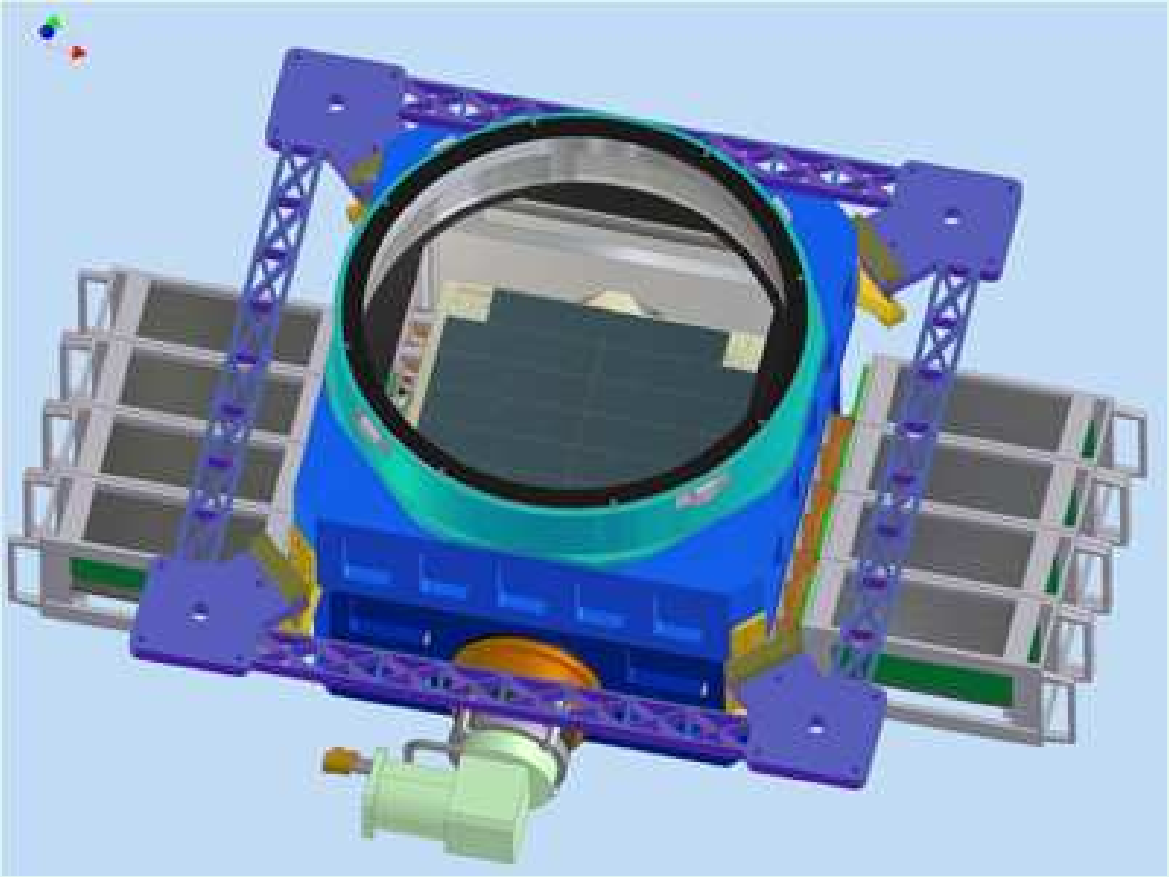


Four 1.8 m telescopes on Hawaii
Funding provided for four
Prototype 'PS1' first light in 2007
3 deg diameter field, Sloan filters
24 mag in 30-60 s exposure

Processing on-line
6000 sq.deg every night
¾ sky 20 times per year with PS1

Expected science, astrom.+photom:
100,000 Jupiter Trojans (2900 now)
20,000 Kuiper belt objects (800)
Interstellar debris, NEOs
Variables, new dwarf galaxies
Type Ia supernovae
p.m.+ parallaxes -> brown dwarfs

Pan-STARRS – Panoramic Survey Telescope



3 deg diameter field
60 CCDs 1.4 Gpixel

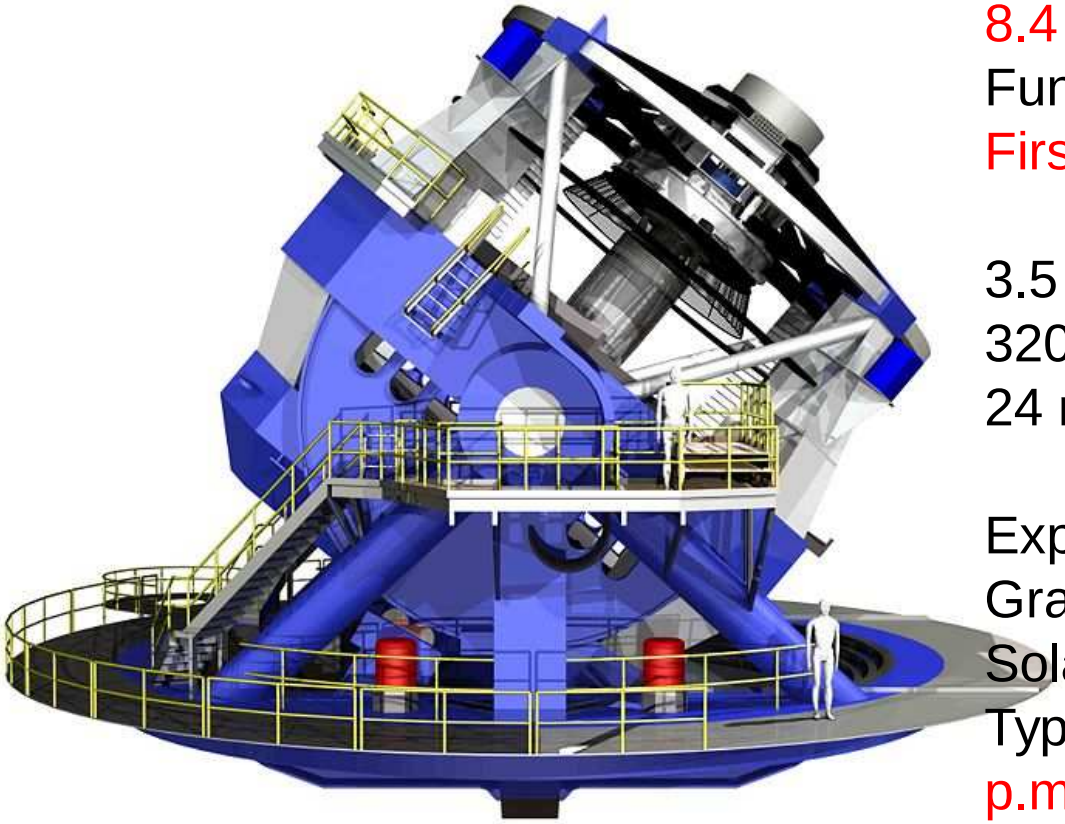
5 Sloan filters or none
g-, *r*-, *i*-, and *z*-band filters
Primarily visible 0.5-0.8 mu
But also *Y*-band at 1.0 mu
Not UV

24 mag in 30-60 s exposure

Processing on-line
6000 sq.deg every night
¾ sky 20 times/year w. PS1

Orthogonal Transfer Charge Coupled Device (OTCCD)
allowing image motion compensation on each CCD, and bright star management

LSST – Large Synoptic Survey Telescope

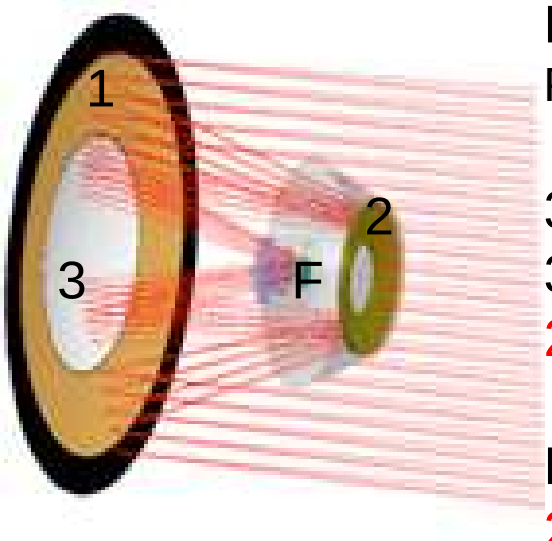


8.4 m telescope, El Penon in Chile
Funded partly: 30 of 400M$
First light in 2015

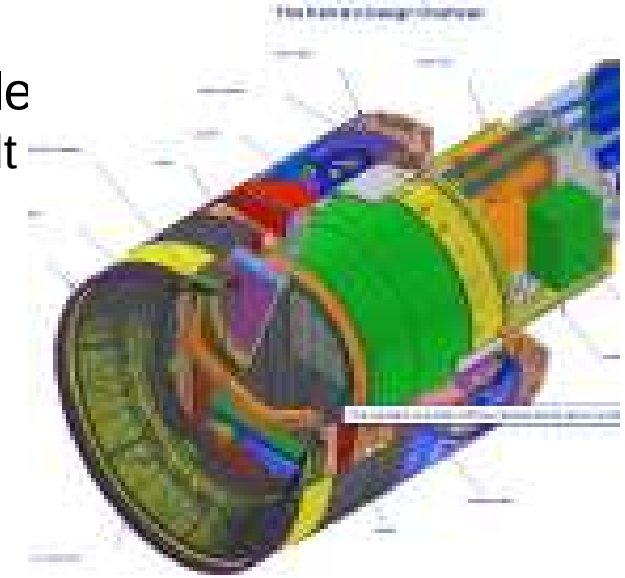
3.5 deg diameter field
320-1060 nm, Sloan filters
24 mag in 15 s exposure

Expected science, astrom.+photom. :
Grav. lensing -> dark energy/matter
Solar system objects
Type Ia supernovae
p.m.+ parallaxes -> brown dwarfs
Mapping the Milky Way

LSST – Large Synoptic Survey Telescope

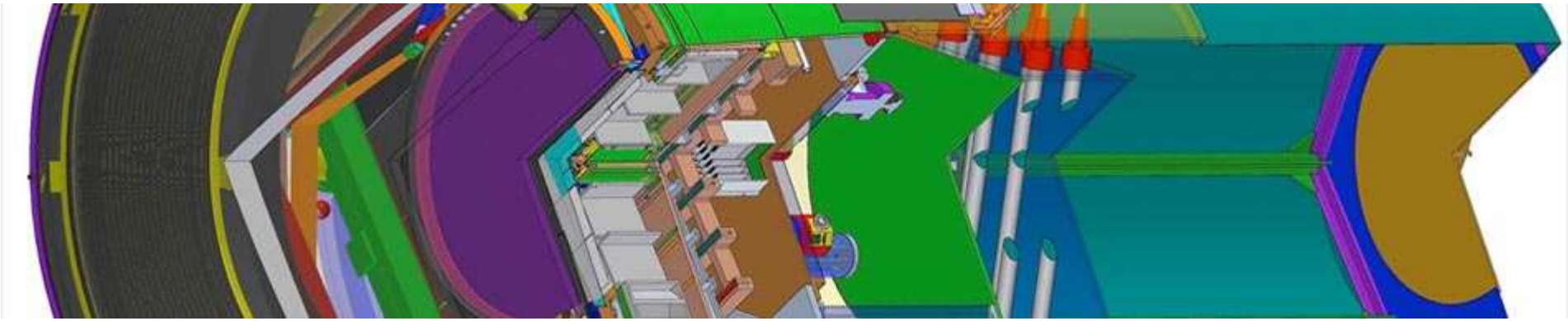


D=8.4 m F=9.9m wide angle
Paul-Baker/Mersenne Schmidt



3.5 deg diameter field
320-1060 nm, Sloan filters
24 mag in 15 s exposure

Processing on-line
200,000 pictures per year
0.7” median seeing, 0.2” pixel



Astrometric surveys 2000 to 2020

Survey	Year compl.	Stars million	Limit mag	Pos. acc. at limit mag mas	Notes
Hipparcos	1997	0.12	V=12	1	+par. All sky
Tycho-2	2000	2.5	V=12	60	All sky
USNO-B1.0	2002	1000	V=20	200?	All sky
UCAC3	2009	100	R=16	70	All sky
SkyMapper	***2013?***	***3000***	***V=23***	***100 ****	***All south***
URAT	***2015?***	***400***	***R=18***	***30***	***+par. +/- 5 mas All sky***
Pan-ST, PS1	***2010…***	***4000***	***V=24***	***63 ****	***+par. ¾ sky from N***
LSST	***2015…***	***4000***	***V=24***	***9 ****	***+par. All south***
Gaia	***2016***	***1000***	***V=20***	***0.3***	***+par. All sky***
SIM ?	*2020?*	*0.01*	*V=20*	*0.02*	*+par.*

Only optical astrometric surveys of ½ sky or more, with positions and p.m.
The Hipparcos and Gaia annual p.m. and par. have same accuracy as the positions.
* Appr. precision of relative astrometry from a 3-year survey. No systematic error is included since we assume that a *preliminary* Gaia reference catalogue will be used.

Three deep surveys

Survey	Year compl.	Stars million	Limit mag	Pos. acc. at limit mag mas	Notes
SkyMapper	***2013?***	***3000***	***V=23***	***100 ****	***All south***
Pan-ST, PS1	***2010…***	***4000***	***V=24***	***63 ****	***+par. ¾sky from N***
LSST	***2015…***	***4000***	***V=24***	***9 ****	***+par. All south***

Only optical astrometric ground-based surveys of ½ sky or more are included, all with positions and p.m.

* Appr. precision of relative astrometry from a 3-year survey. No systematic error is included since we assume that a *preliminary* Gaia reference catalogue will be used and will be sufficiently accurate to put all ground-based astrometry on an absolute system.

The above precision values were kindly provided by Dave Monet, who notes that they are probably pessimistic and quite uncertain. I have made an independent simple minded estimate which gave the smaller values 46, 35, and 5 mas, respectively. I believe that Monet's values should be more trusted. -- I began with LSST based on Z. Ivezic et al. astro-ph/0805.2366, Table 3, scaled to 5.3 mas for 3 years of observations instead of 10. SkyMapper, PS1 and LSST have telescopes with D=1.3, 1.8, 8.4 m and the precisions were scaled according to the smaller number of photons. The different seeing was taken into account with FWHM = 1.5, 1.0, 0.7 arcsec, thus for the three $5.3*8.4/1.3*10^{-0.2}$ **1.5/0.7=46 and 5.3*8.4/1.8*1.0/0.7=35, and 5 mas. respectively. This assumed almost the same ratios of field size to sky area for the three.*

LSST – 2015 to 2025
Astrometry and photometry

TABLE 3 from Z. Ivezic et al. astro-ph/0805.2366
The expected proper motion, parallax and accuracy
for a 10-year long baseline survey with LSST.

r mag	$\sigma_{xy}{}^{a}$ mas	$\sigma_{\pi}{}^{b}$ mas	$\sigma_{\mu}{}^{c}$ mas/yr	$\sigma_{1}{}^{d}$ mag	$\sigma_{C}{}^{e}$ mag
21	11	0.6	0.2	0.01	0.005
22	15	0.8	0.3	0.02	0.005
23	31	1.3	0.5	0.04	0.006
24	74	2.9	1.0	0.10	0.009

a Typical astrometric accuracy (rms per coordinate per visit);
b Parallax accuracy for 10-year long survey;
c Proper motion accuracy for 10-year long survey;
d Photometric error for a single visit (two 15-second exposures);
e Photometric error for coadded observations (see Table 1).