Astrometric surveys in the Gaia era

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layout of talk

- Gaia DR1: summary astrometric properties
- Gaia DR1: use with other surveys, new proper motions
- UCAC5: example of improved astrometry
- Gaia: astrometric properties of DR2 (April 2018)
- current + future astrometric surveys: what is left to do?
- summary

Gaia DR1:

summary of astrometric properties (Lindegren et al. 2016)

primary sources (TGAS)

- 2,057,050 sources total (Tycho-2 subset)
  - position error: 0.14 - 0.60 mas (10%, 90%)
  - proper motion error: 0.44 – 2.67 mas/yr
  - parallax error: 0.24 – 0.64 mas
- 93,635 Hipparcos stars subset:
  - position error: 0.150 – 0.39 mas (10%, 90%)
  - proper motion error: 0.031 – 0.129 mas/yr
  - parallax error: 0.23 – 0.50 mas

secondary sources

- 1.14 billion objects
  - position error: 0.26 – 12.9 mas
  - depending on brightness, observing history
- missing:
  - proper motions
  - parallaxes
- results in short-term, ground-based astrometric catalog updates until Gaia DR2

Gaia DR1:

use with other surveys,

new proper motions,

new parallaxes

Gaia DR1 = 2nd epoch

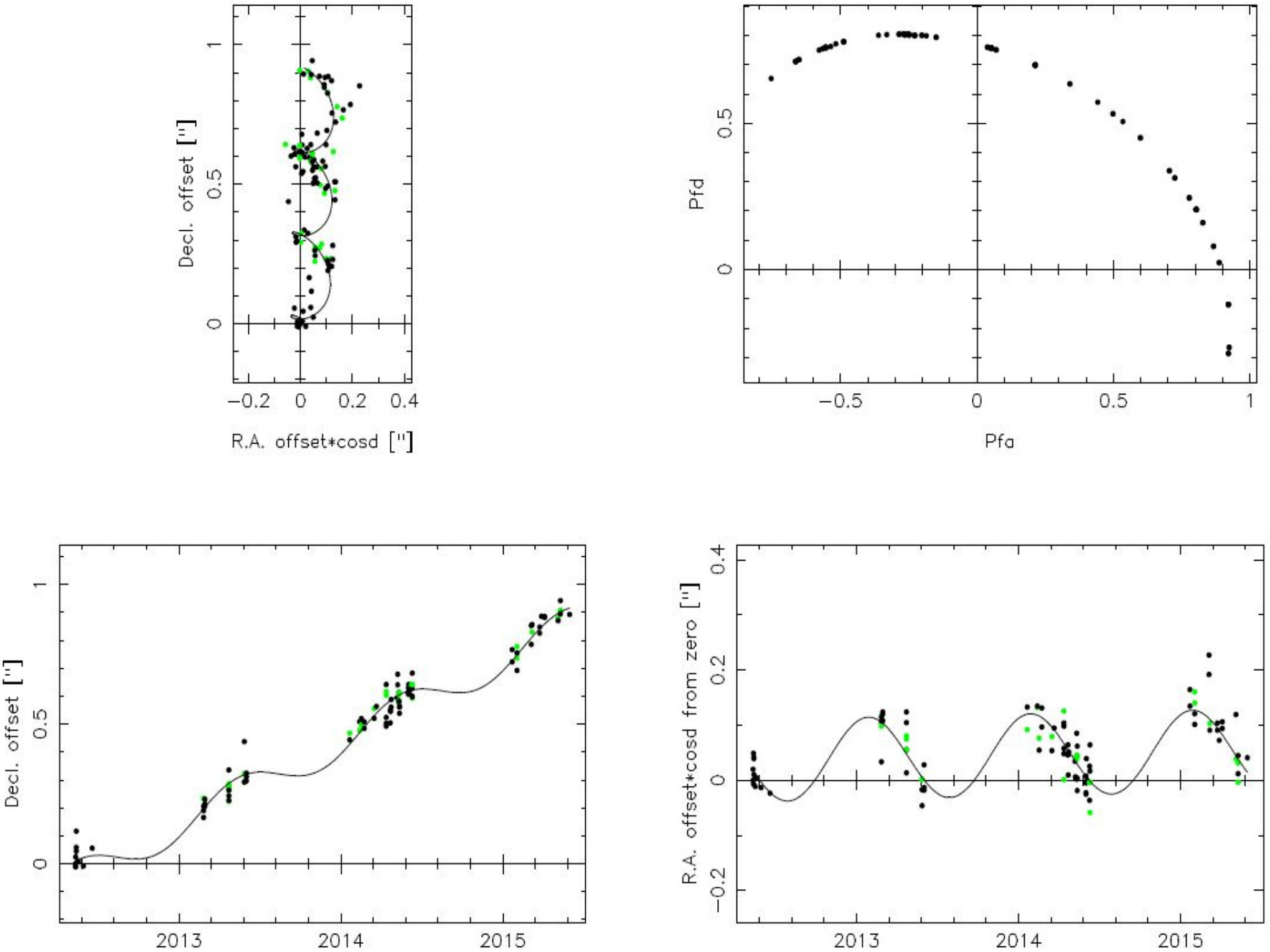
- HSOY (Hot Stuff for One Year)
  - Altmann et al. Jan 2017 (arXiv:1701.02629)
  - 583 million objects (about 1 to 5 mas/yr)
  - PPMXL update (Schmidt plate survey data)
- UCAC5 (USNO CCD Astrograph Catalog)
  - Zacharias, Finch, Frouard, Feb. 2017 (1702.05621)
  - 107 million (1-2 mas/yr R=11-15, 5 mas/yr R=16)
  - UCAC4 update (CCD data = 1st epoch)

… continued

- Gaia-PS1-SDSS, 2MASS (GPS1) PM catalog
  - H-J Tian et al. March 2017 (arXiv: 1703.06278)
  - 350 million objects, ¾ of sky covered
  - multi-epoch proper motion update
  - 1.5 – 2 mas/yr typical precision
  - although check with QSO: 2 – 3 mas/yr
  - system.errors claimed <= 0.3 mas/yr
- PMA = absolute proper motions (with 2MASS)
  - 421 million obj, error PM = 2..5 mas/yr
  - Akhmetov+ 2017 MN submitted

new parallaxes

- URAT Parallax Catalog (UPC), Finch+2016
- total over 112,000 nearby stars
- over 53000: prev. no published trig.parallax
- similar product for southern hemisphere in preparation
- short lifetime: Gaia DR2 will be much more comprehensive and accurate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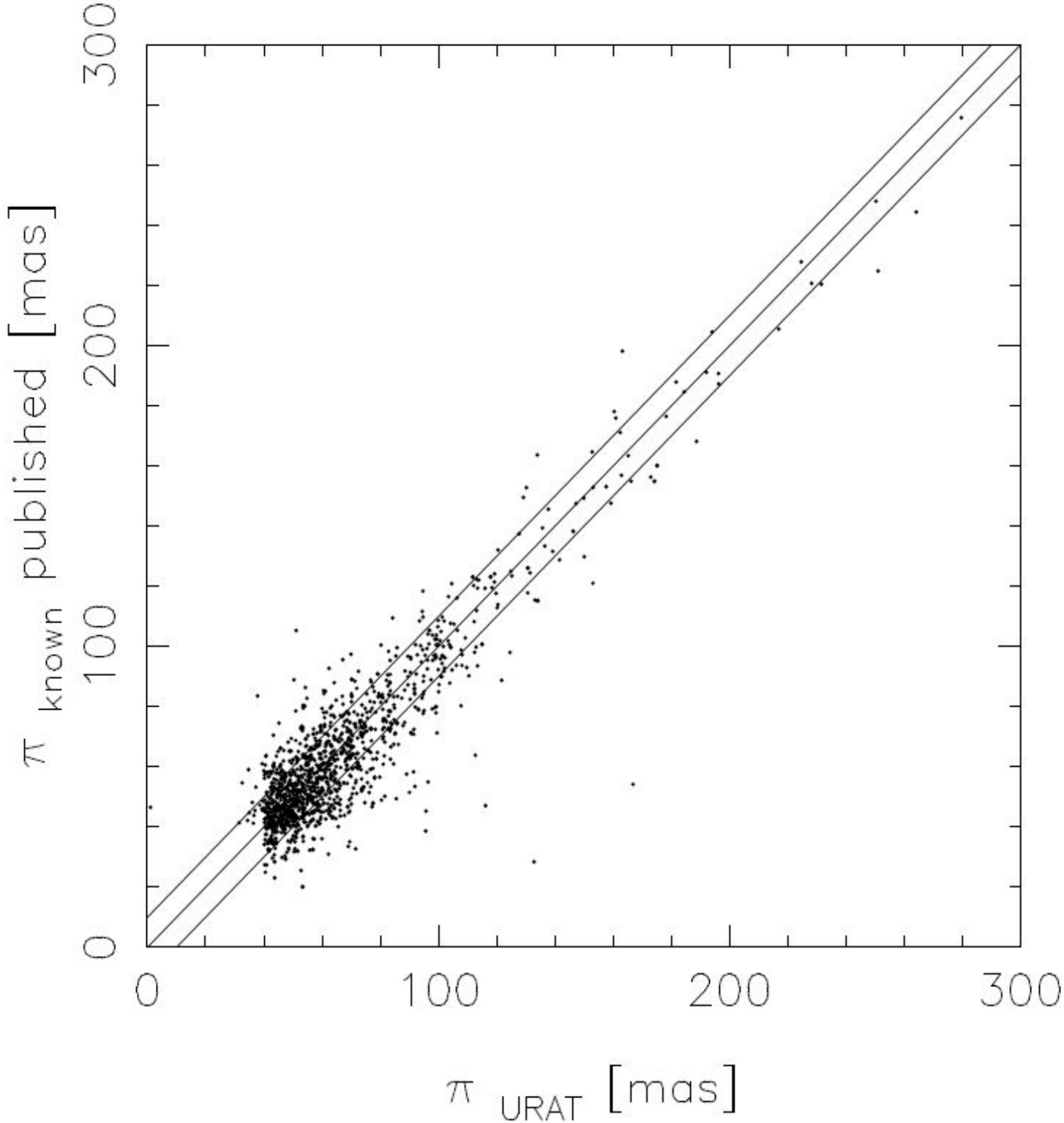


UPC = URAT Parallax Catalog (2016) 112,177 stars

UCAC5:

example of improved astrometry

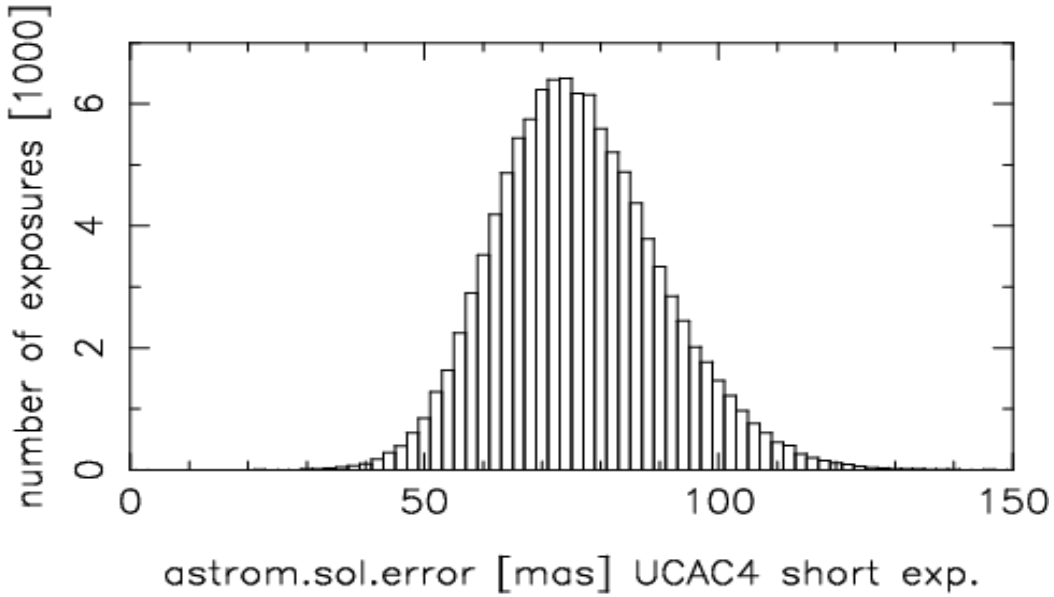

“UCAC dome” at CTIO

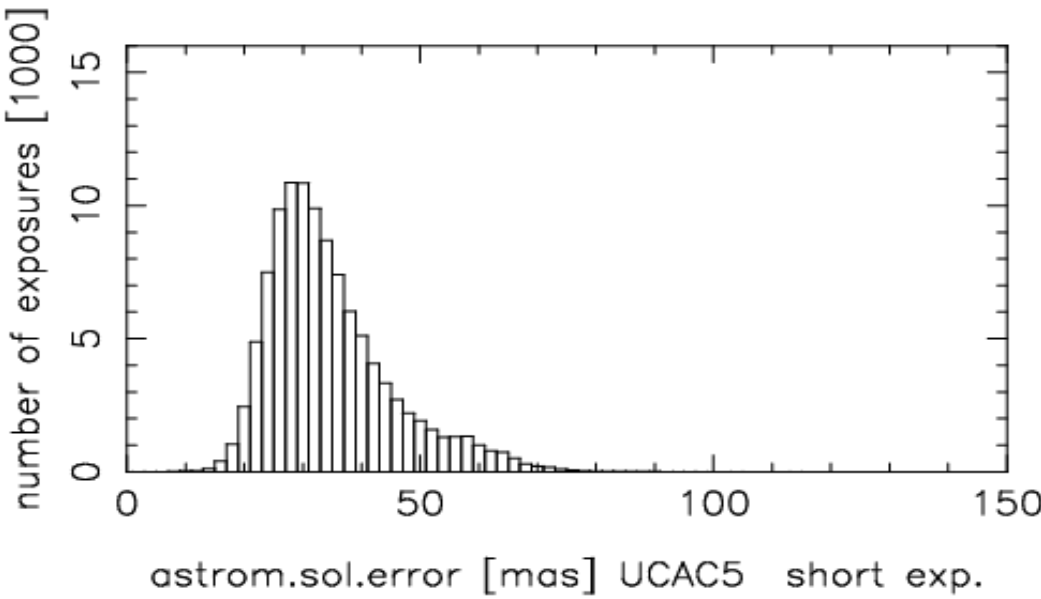
UCAC project

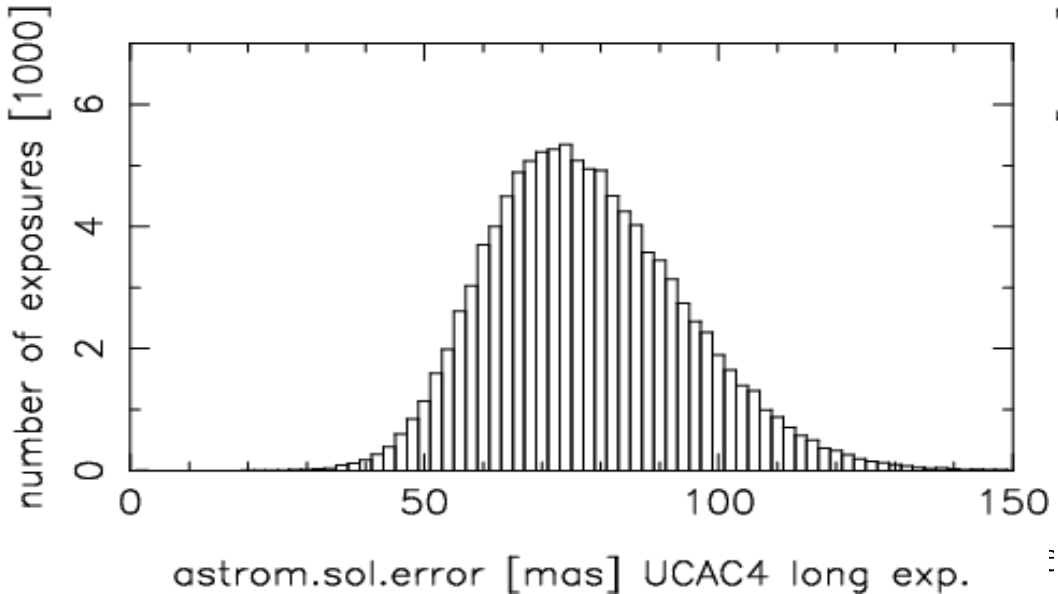
- USNO astrograph (redlens) + 4k CCD (1 sq.deg)
- 1997 – 2004 (all-sky, CTIO + NOFS locations)
- 579 – 642 nm bandpass, R = 8 to 16 mag stars
- 2-fold overlap pattern, long + short expos./field
- linear "plate solution" + system. error corrections
- positions accurate to 20 mas (10 – 14 mag)
- UCAC4 release (2012) uses Tycho-2 ref.stars
- new reductions now with Gaia DR1 as ref.star cat.

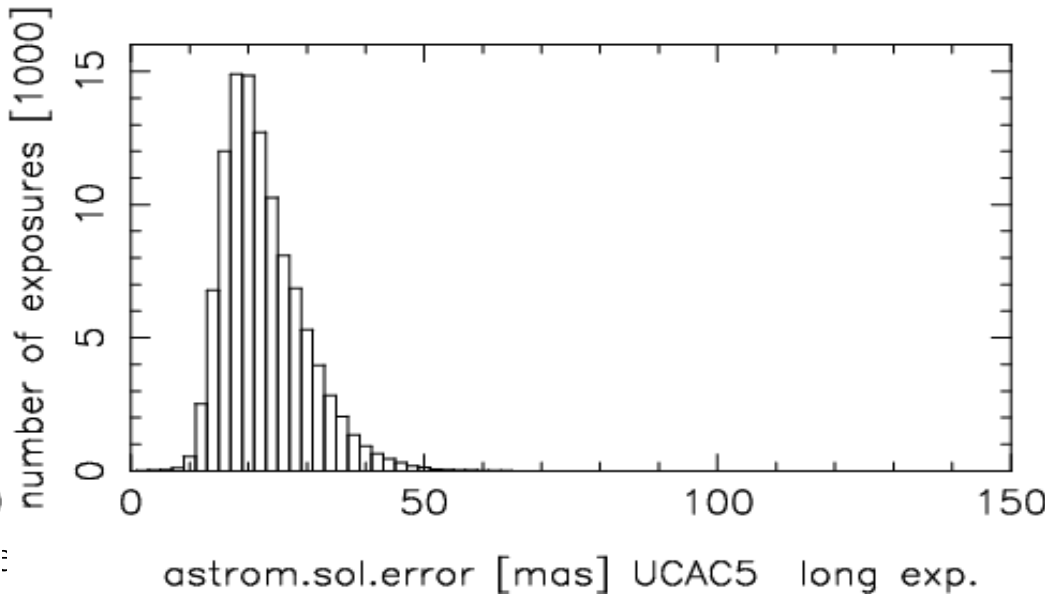
UCAC4: use Tycho2 ref.stars

UCAC5: use TGAS ref.stars









error propagation of astrometric "plate" solution (x,y to RA,Dec)

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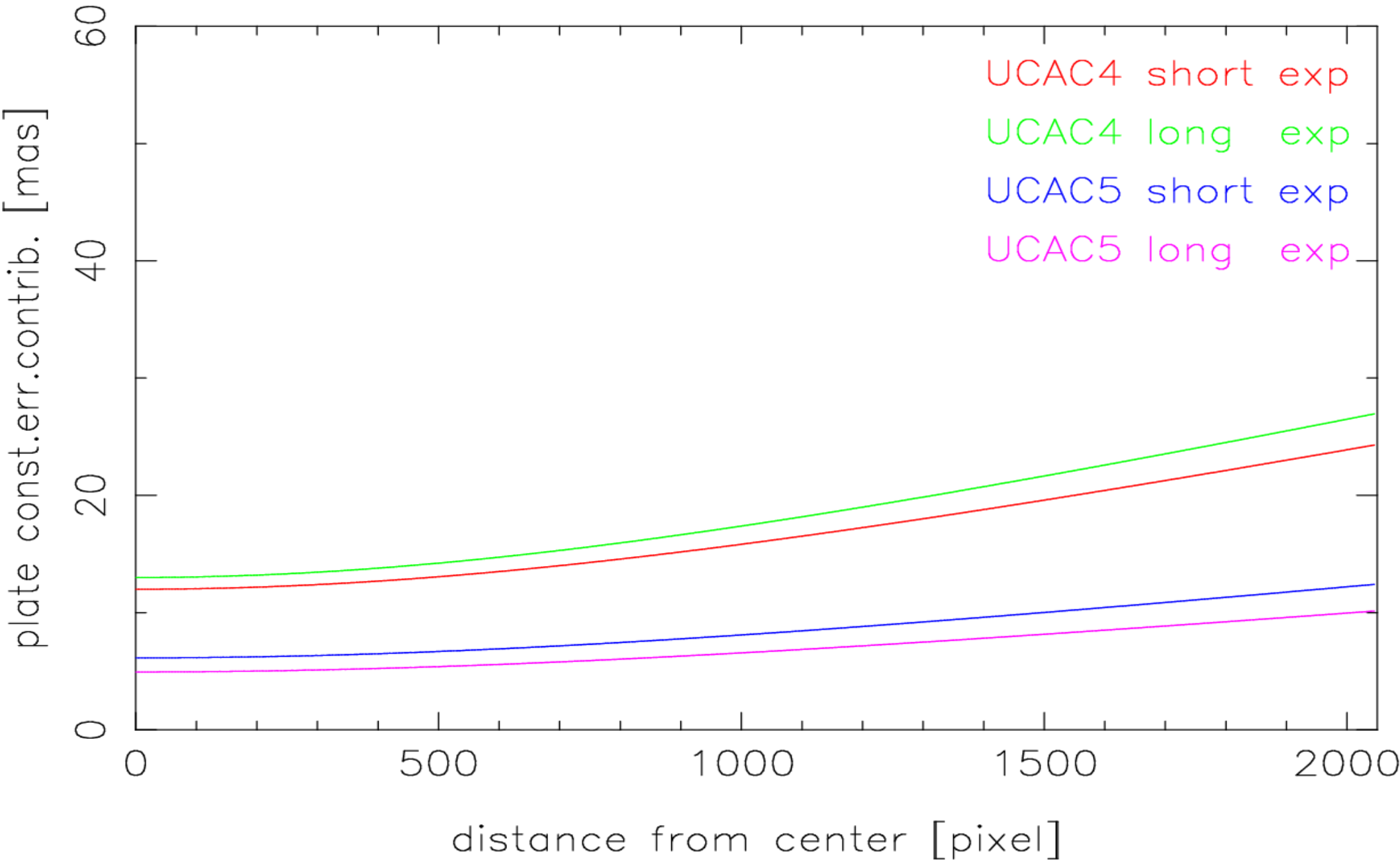
On the Systematic Accuracy of Photographic Astrometric Data

HEINRICH EICHHORN AND CAROL ANN WILLIAMS*
Van Vleck Observatory, Wesleyan University, Middletown, Connecticut
(Received 21 February 1963)

For several models for the relationship between measured and standard coordinates, formulas are established which give the systematic error in a photographic star position (due to the inaccuracy of the plate constants) as a function of the coordinates of the star and the number of stars on the frame (plate or film). These formulas are derived by approximating the covariance matrix of the plate constants assuming a uniform star density and replacing the product sums in the inverse covariance matrix (i.e., the matrix of the normal equations of the plate constants) by definite integrals. For several special cases, these covariance matrices are established and diagrams given which illustrate the formulas. A criterion is given which indicates which of several possible formulas for the transformation of measured to standard coordinates will give the most accurate results. The results hold— *mutatis mutandis*—for proper motions as well as for positions.

“plate constant” error contrib.

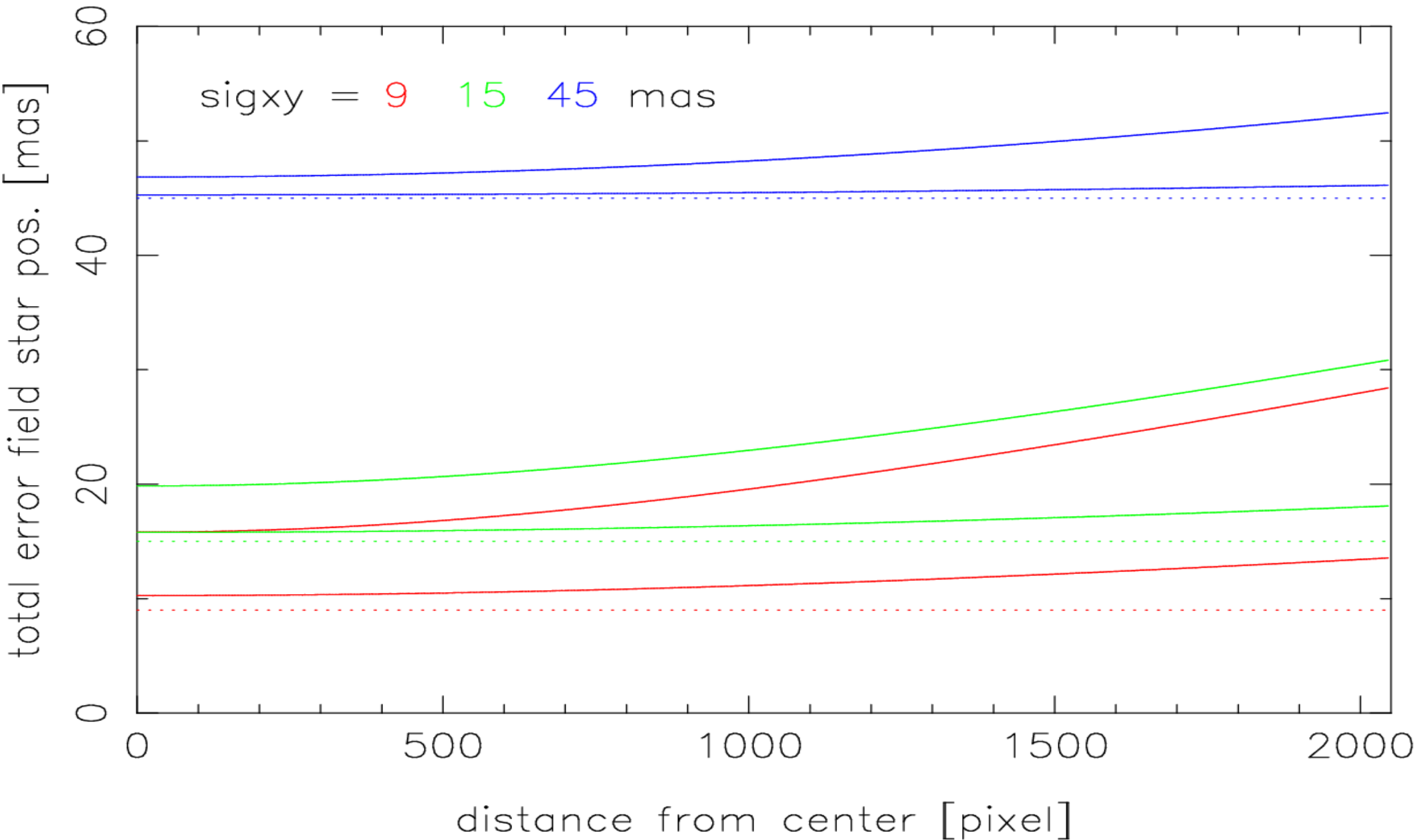


total pos.error of field stars (sigxy + pl.const.err.propag.)

top line = UCAC4 result

bottom line = UCAC5 result

dashed line = limit from object fit precision (sigxy)



what does this mean?

- random errors:
  - improvement of field star positions not as large as suggested from “plate solution errors” improvement
  - if simple “plate model” and sufficient number of reference stars (Tycho-2) are available (even at substantially lower precision than Gaia data)
  - at faint end (= most stars): total error dominated by object center error (x,y position): nearly no help from better reference stars
- systematic errors: Gaia is of course a big help

Gaia:

astrometric properties of DR2 (April 2018)

DR2 = big step for astrometry

- accurate proper motions and parallaxes for over 1 billion objects (sub-mas level)
- superior astrometry to ground-based surveys, most between about G = 4 to 20.7 “done” for mean position + simple motion
- era of traditional astrometric sky surveys will be over very soon (position and proper motion catalogs like GSC, PPM, PPMXL, NPM, SPM, UCAC, URAT, USNO-B ...)

Current + future astrometric surveys:

what is left to do?

Or: is there life after Gaia?

astrometric research not fully covered by Gaia

(1) very bright stars (G <= 3.x), until near final Gaia DR, likely after 2020

(2) faint objects (G >= 20.7) = main open area

(3) other than optical bandpass (like near-IR)

(4) complex motion or variable centroid objects, i.e. "time domain astronomy" require observations at multiple, specific epochs or long time-line observations:

(a) orbital motions of natural satellites (USNO + Paris Observatory)

(b) asteroid mass determination (close encounters)

(c) many double and multiple star systems, companions, exo-planets

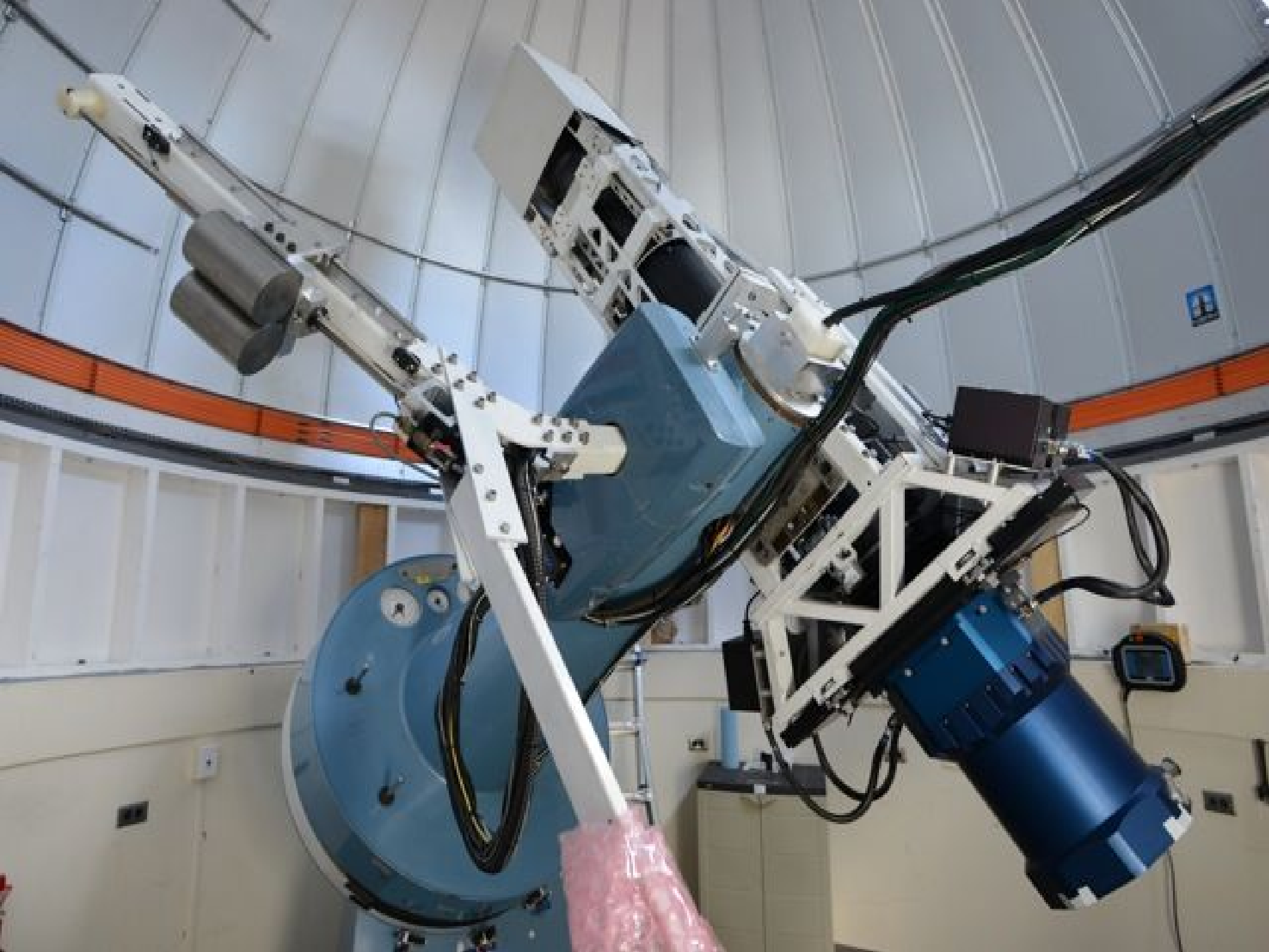
(d) some AGN, extragalactic reference frame objects (variability induced center motion)

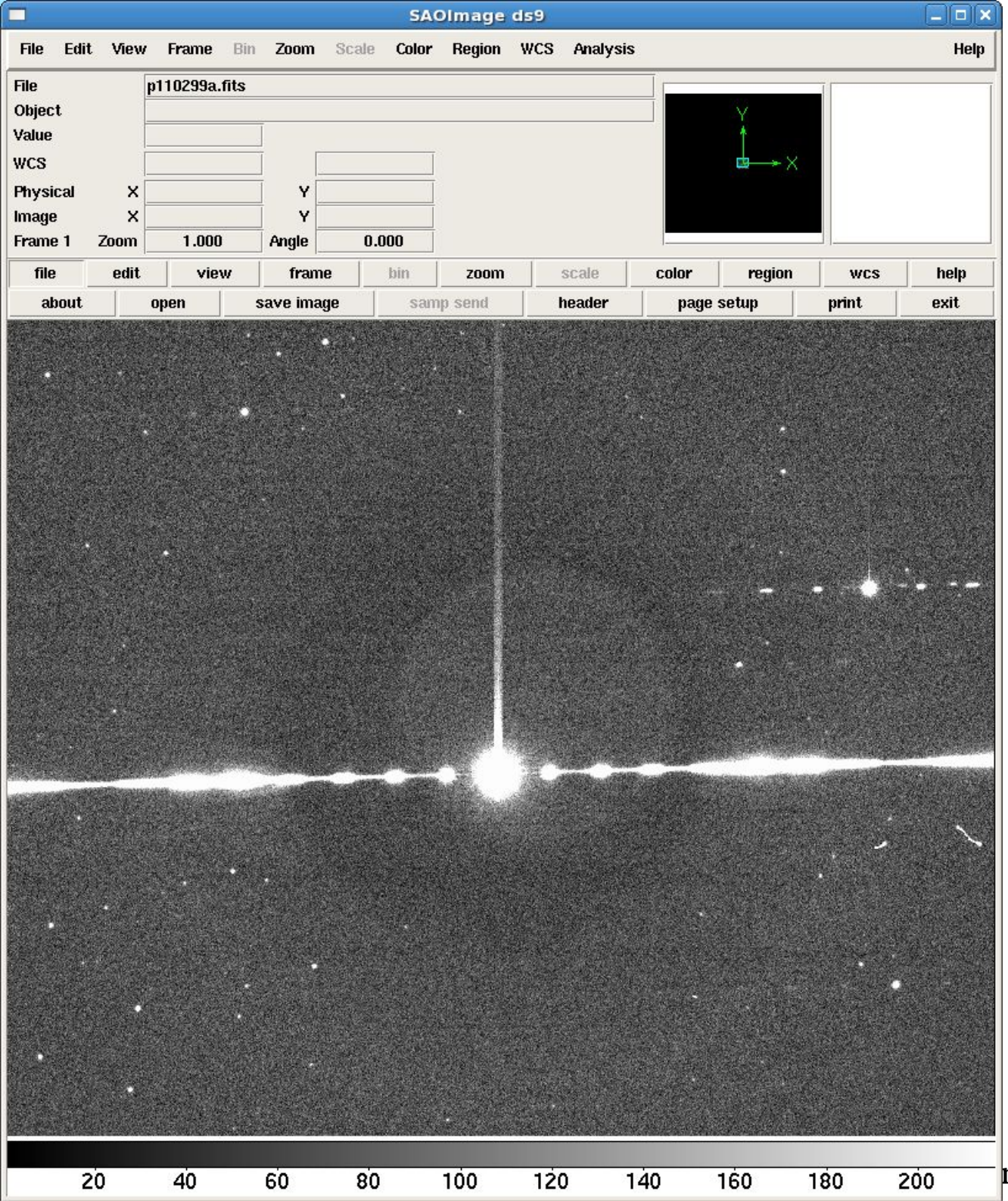
current + near future surveys

- most of the following have also photometric justification besides astrometry (see prev.slide)
- LSST : (2) and (4) (future 6.5 m tel.)
- VISTA: (2) and (3) (near IR, ESO 4m)
- ZTF : mainly photometric + (4) (Palomar 48in)
- PanSTARRS, SkyMapper, SDSS: some (2) (4) (Hawaii, Australia, New Mexico)
- URAT-south: (1)

URAT operations south

- USNO Robotic Astrometric Telescope
- at CTIO, Chile since Oct 2015, ongoing
  - targeted bright star observations with neutral density spot + objective grating
  - R = -1.5 to 4.5 mag
  - about 10 mas precision per nightly mean position
  - multiple epochs per year
  - use UCAC5 reference stars = Gaia DR1 + UCAC





5 sec exposure of Sirius with ND spot filter and grating

summary

(1) Gaia DR1: TGAS (2 million stars) = new optical reference frame

(2) short-term ground-based astrometric surveys use Gaia DR1:

- (a) reduce earlier epoch data
- (b) combine with 1.14 billion Gaia positions only → new proper motions
- (c) use several years of ground-based observ.: new trigon. parallaxes

(3) Gaia DR2 will "put an end to this" : positions, proper motions and parallaxes for stars in about 4 to 20.7 mag: all done

(4) current and future ground-based surveys for astrometry:

- (a) very bright star observations (URAT-south).
- (b) go deeper than Gaia limit (LSST, ...)
- (c) many epochs, long-term programs for complex motions
- (d) other than optical bandpass (VISTA), positions depending on color