The Establishment of Astrometric Calibration Regions

And the determination of positions for objects much fainter than existing reference stars

- T. M. Girard *(Yale Univ.)*

A Typical Astrometric Reduction (Redux)

The goal is the determination of celestial coordinates (α,δ) for a star or stars of interest on a plate or other detector.

1. Extract reference stars from a suitable reference catalog.
2. Identify and measure target stars and reference stars on the plate.
3. Transform reference-star coordinates to standard coordinates.
4. Determine the plate model (*e.g.,* polynomial coefficients) that transforms the measured *x,y's* to standard coordinates. Use the reference stars, knowing their measures and catalog coordinates, to determine the model.
5. Apply the model to the target stars.
6. Transform the newly-determined standard coordinates into celestial coordinates.

Reference-catalog considerations...

Density: Is there a sufficient number of (measurable) reference stars on the target plate/frame?

Magnitude range: Is the magnitude coverage also adequate? *(Beware of magnitude equation!)*

Precision: Does the combination of the reference catalog precision and the number of reference stars produce a modeling error that is acceptable?

Accuracy: Is the uncertainty in the absolute system of the reference catalog acceptable?

Primary reference catalogs...

ICRS (Ma *et al*. 1998): defined by VLBI positions of 212 compact extragalactic radio sources

Hipparcos (ESA 1997): defines ICRS in the optical

- 120,000 objects → ~3 /deg^2, $V < 7.5$
- @1991 typical ε_{pos} = 1 mas; @2005 ε_{pos} = 15 mas

Tycho-2 (Høg *et al*. 2000): Hipparcos satellite starmapper & 1st-epoch ground-based positions

- 2.5x10^6 objects → 25 to 150 /deg^2, $V < 11.5$
- @2005 typical ε_{pos} = 25 to 100 mas, depending on magnitude

UCAC2 (Zacharias *et al*. 2004): USNO CCD Astrograph Catalog & 1st-epoch astrograph data

- 48x10^6 objects, -90°< δ <+40° to +52°, (soon to be all-sky, ?UCAC3?)
- $R_{UCAC} < 16$, ~85% complete, (soon to be more, ?UCAC3?)
- ε_{pos} = 30 to 70 mas

Secondary reference catalogs...

2MASS (http://www.ipac.caltech.edu/2mass/): 2-Micron All-Sky Survey

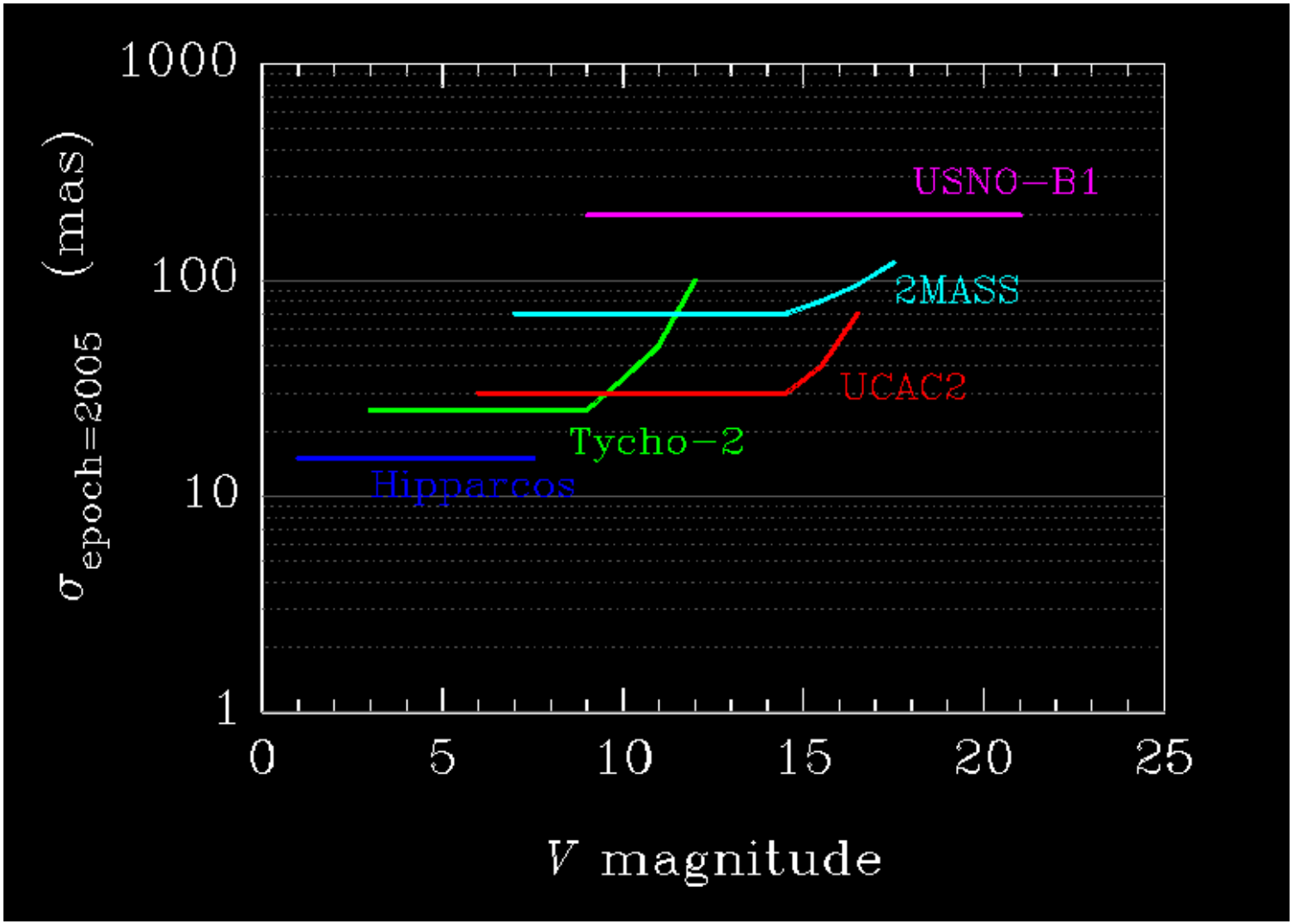
- 470×10^6 objects → $J \leq 16$
- @2000 ε_{pos} = 70 to 120 mas, (systematics?)
- no proper motions

USNO-B1 (Monet *et al*. 2003): PMM measures of several Schmidt surveys

- 1×10^9 objects → $V \leq 21$
- calibrates using "Yellow Sky" catalog based on NPM & SPM plates
- @2000 typical $\varepsilon_{pos} \approx 200$ mas
- proper motions: yes, but...

NOMAD (http://www.nofs.navy.mil/nomad/): merge of Hipparcos, Tycho-2, UCAC2, and USNO-B1.

Current astrometric catalogs...



The assignment...

Good afternoon, Mr. Phelps.

A puzzling new radio source has been detected – the signal from which, oddly enough, varies irregularly in frequency in a manner that mimics exactly the Ventures' 1960 instrumental classic "Walk Don't Run." Regardless, the radio position of the source is well-determined on the ICRF reference frame. A deep *V*-band CCD exposure has been obtained with an unspecified orbiting telescope, in an attempt to identify the optical counterpart.

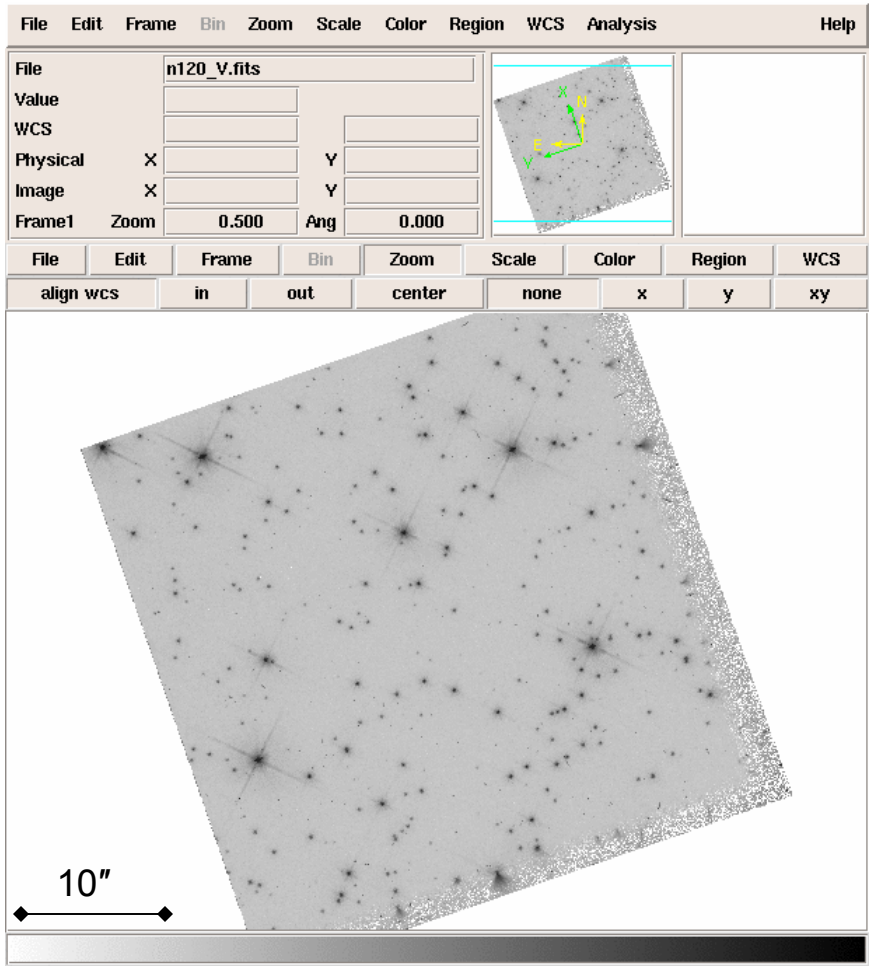
Your mission Jim, should you decide to accept it, is to determine accurate celestial coordinates for all objects in the CCD frame to allow for this cross-identification.

As always, should you or any members of your team be captured, this funding agency will disavow any knowledge of you and your mission.

Good luck, Jim.

(This message will self-destruct in five seconds.)

The target...

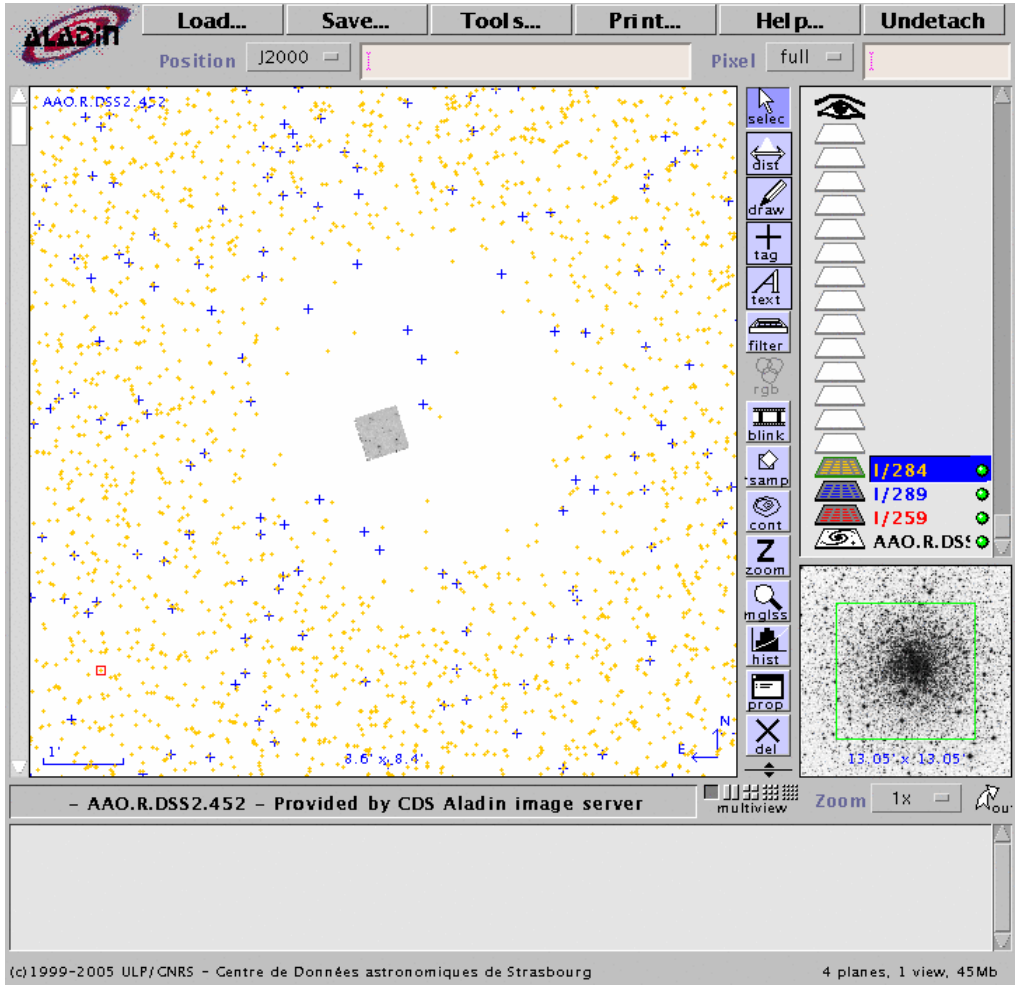


Target frame:

800x800 CCD frame
(36”x36”)
120-sec *V* exposure
centered on target position

$\alpha_{2000} = 16^h23^m38.22^s$
$\delta_{2000} = -26°31'53.7''$

Existing catalogs & the target frame...

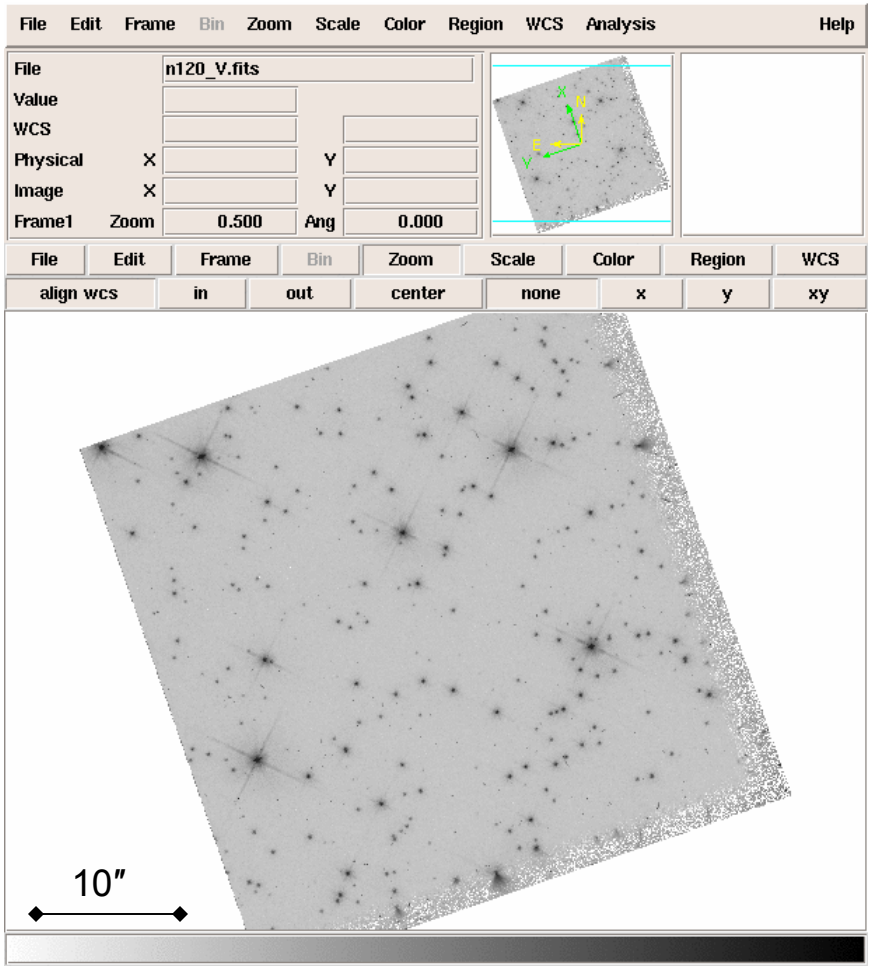


Yikes! It's in M4!

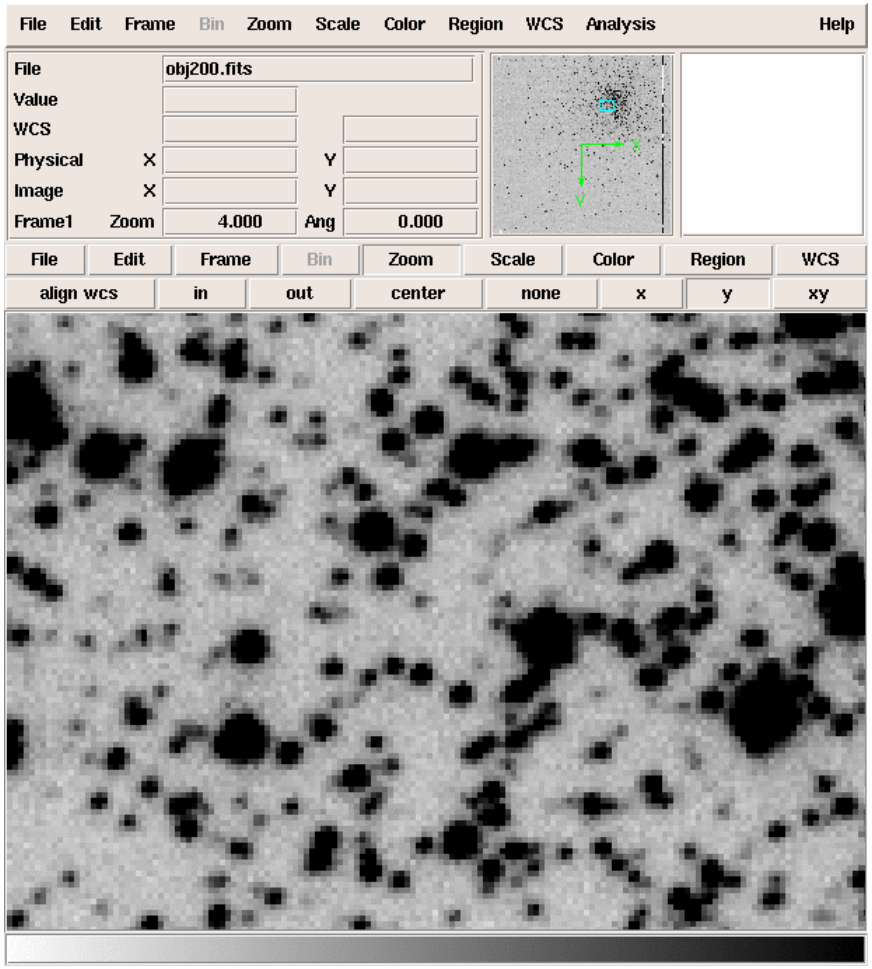
(DSS2 background image)

Tycho-2
UCAC2
USNO-B1

The missing link...



Target frame



→ Ground-based CCD, good seeing

The linking procedure...

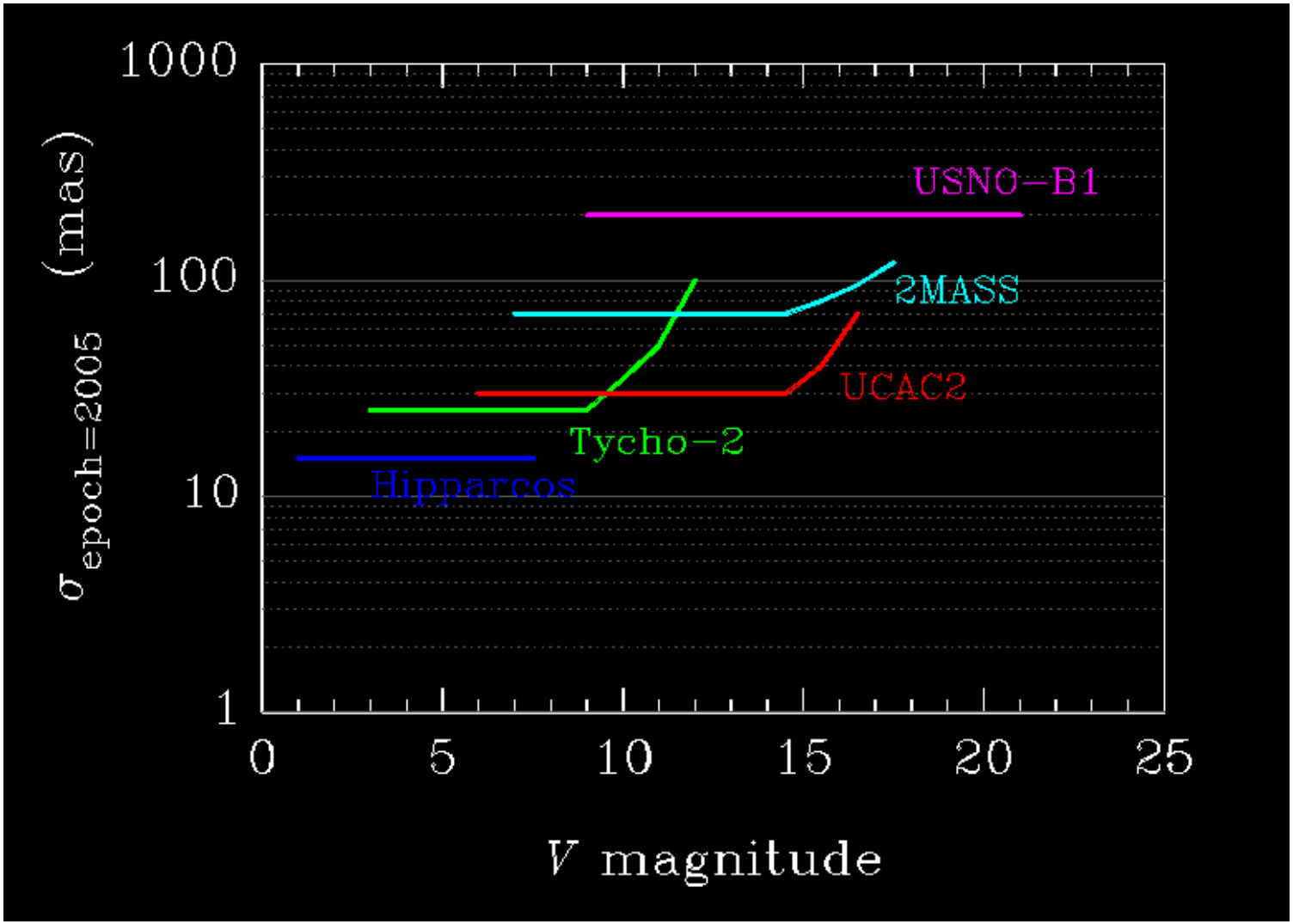
1. Identify and measure in the linking frame all reference stars and linking stars
2. Perform an astrometric solution for the linking frame, thereby generating (α,δ)'s for the linking stars → a "link" catalog
3. Identify and measure in the target frame all linking stars
4. Perform an astrometric solution for the target frame, using the (α,δ)'s from the link catalog
   - If there is a target image, apply the solution to its (*x,y*), or
   - If there is only a target (α,δ) to study, invert the solution to determine the corresponding (*x,y*) in the target frame; (*if need be, guess and iterate)*

* See Bailyn *et al.* 1994 for an example of how this *used* to be done.

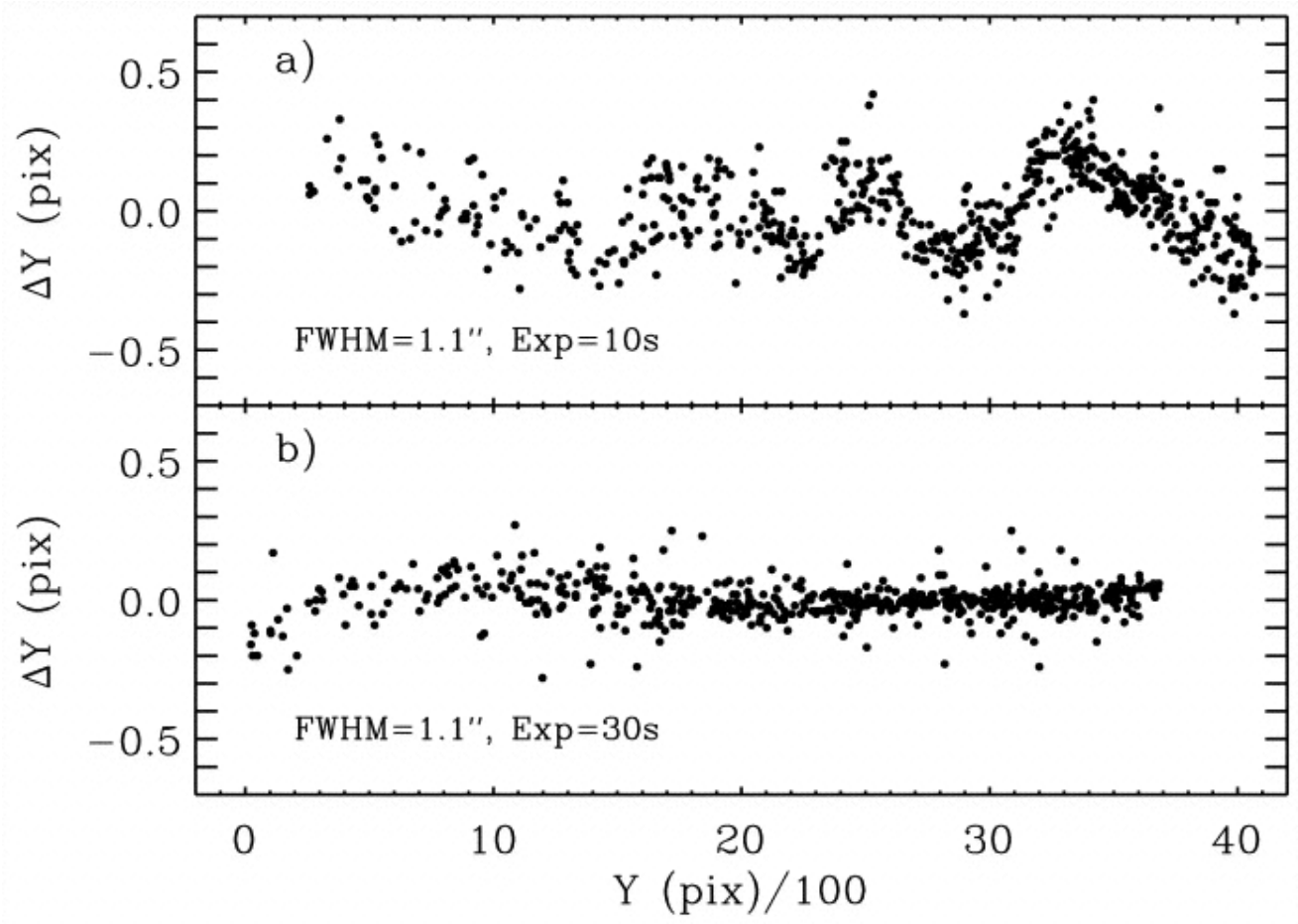
Instrument-calibration standard regions...

- SDSS - Stone *et al.* 1999
  - 16 (7.6°x3.2°) regions along the Celestial Equator, using
  - FASTT (Flagstaff Astrometric Scanning Transit Telescope)
  - density = 800 to 11,000 stars/deg^2
  - 9.5<*R*<17.8 (10.0<*V*<18.3); complete to *R*=17.2 (*V*=17.7)
  - accurate to 26 mas (12 mas precision), σ_μ≈6 mas/yr
  - ...then along came UCAC →
    - SDSS astrometry: σ=45/100 mas (σ_{sys}=30 mas) @ *r*≈20/22
- NOAO Mosaic Imager @KPNO 4-m – Platais *et al.* 2002, 2003
  - standard region around NGC 188, using
  - Lick astrograph plates as linking material and Tycho-2 reference frame→
  - derivation of Mosaic chip geometry + 4-m 1st-epoch plates →
    - new astrometric standard region: 0.75 deg^2, 7800 stars, *V*<21
    - for well-measured stars, σ=2 mas, σ_μ=0.2 mas/yr

Current astrometric catalogs...



A cautionary note, the air we breathe...



1 pixel = 0.26″

Repeated KPNO 4-m Mosaic exposures. (Platais *et al.* 2002)

References...

Bailyn, C. D. *et al.* 1994, ApJ Lett. 433, L89.

ESA 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noordwijk:ESA).

Høg, E., *et al.* 2000, A&A 355, L27.

Ma C. *et al.* 1998, AJ 116, 516.

Monet, D. G., *et al.* 2003, AJ 125, 984.

Platais, I. *et al.* 2002, AJ 124, 601.

Platais, I. *et al.* 2003, AJ 126, 2922.

Stone, R. C. *et al.* 1999, AJ 118, 2488.

Zacharias, N., *et al.* 2004, AJ 127, 3034.