Astrometry in Information Systems

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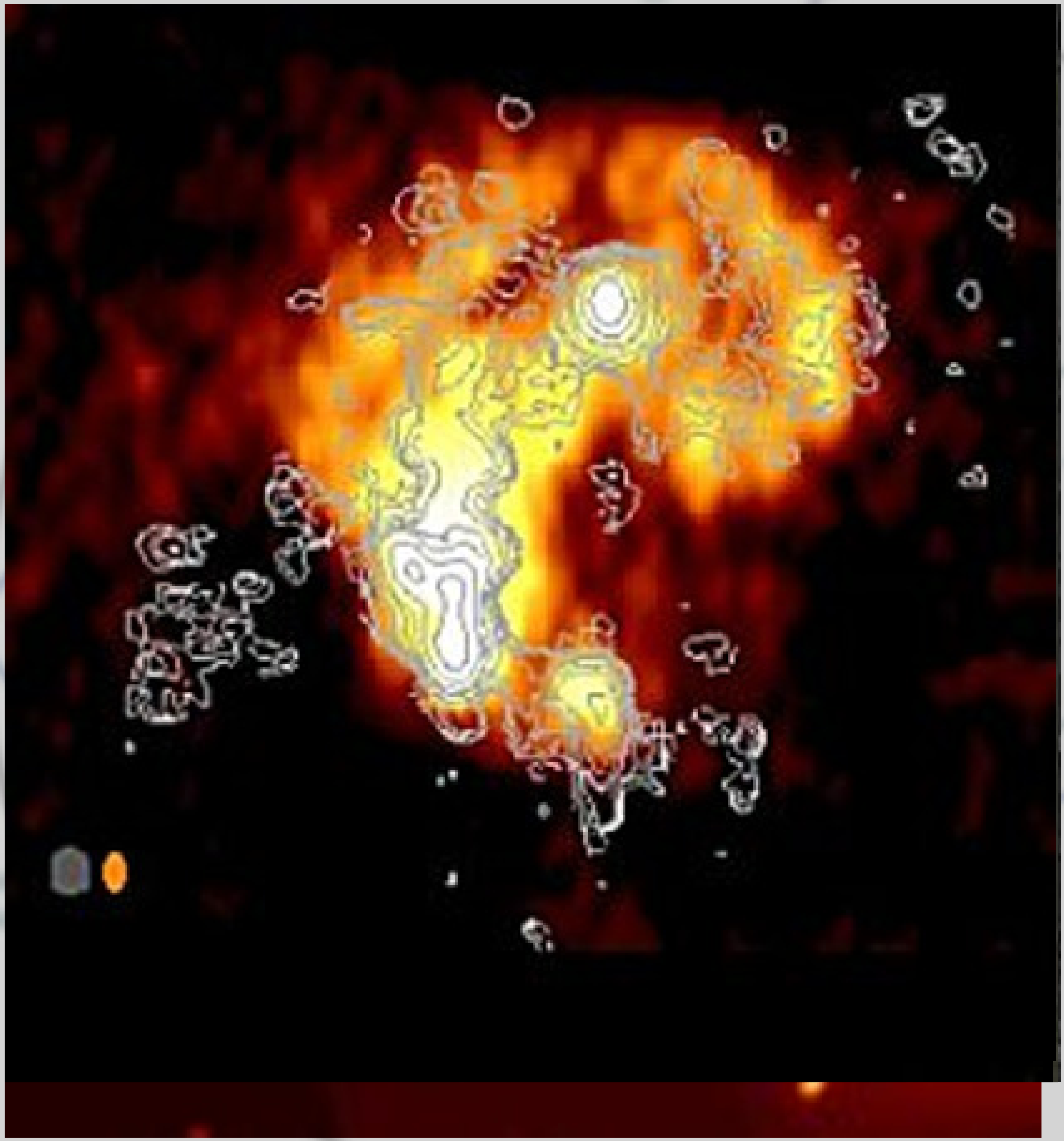
Lecture Overview

- Why
- Astrometric reference frames
- Calibration astrometry
- Astrometry & information systems
  - The total is more than the sum of its parts

NGC 4038 and NGC 4039. The Antennae galaxies



Why Astrometry: multi-λ

X-Ray

Visible DSS

Optical AAO

Optical color

Infrared

Spitzer

IRAS

Radio

Why Astrometry: large scale structure

Two-point correlation function :

"excess probability" above what would be expected for a random distribution of equivalent density.

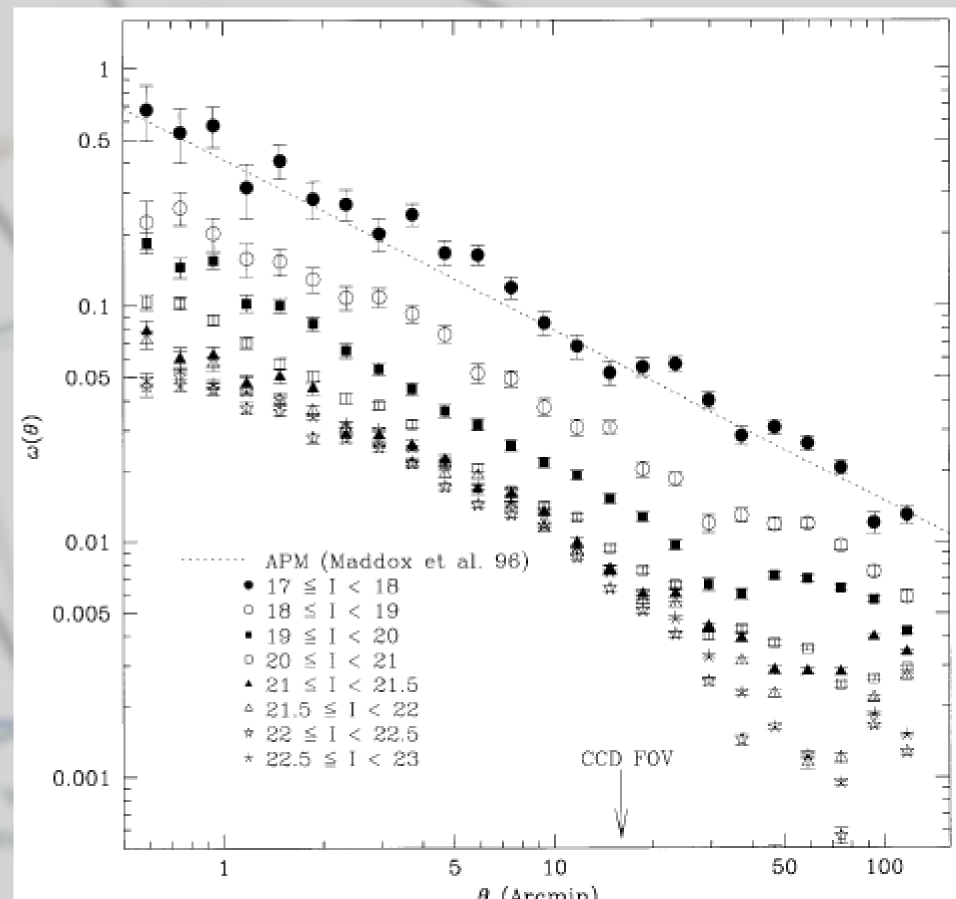
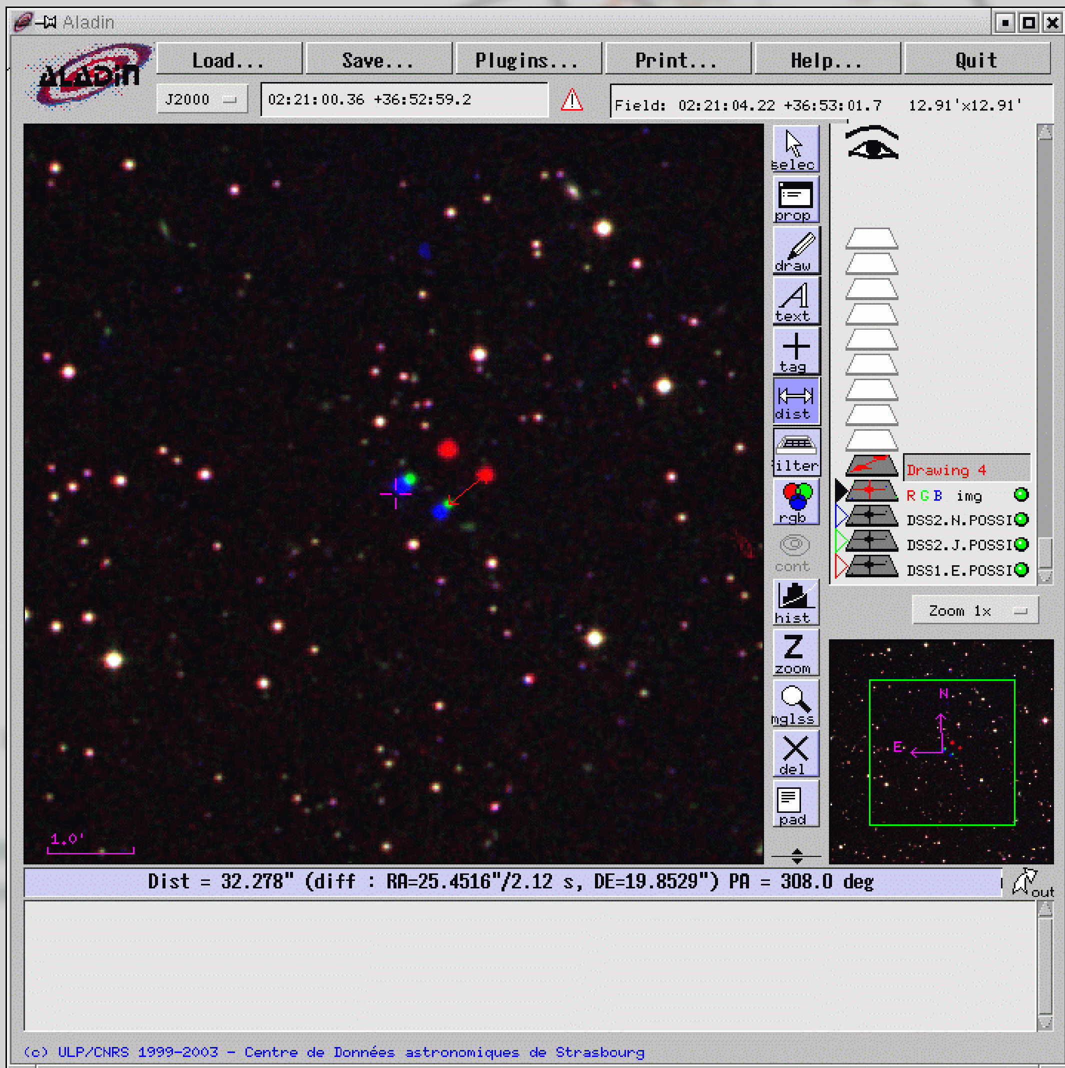


Figure 2: The angular correlation functions of survey galaxies are shown as function of galaxy luminosity. (Postman et al 1997)

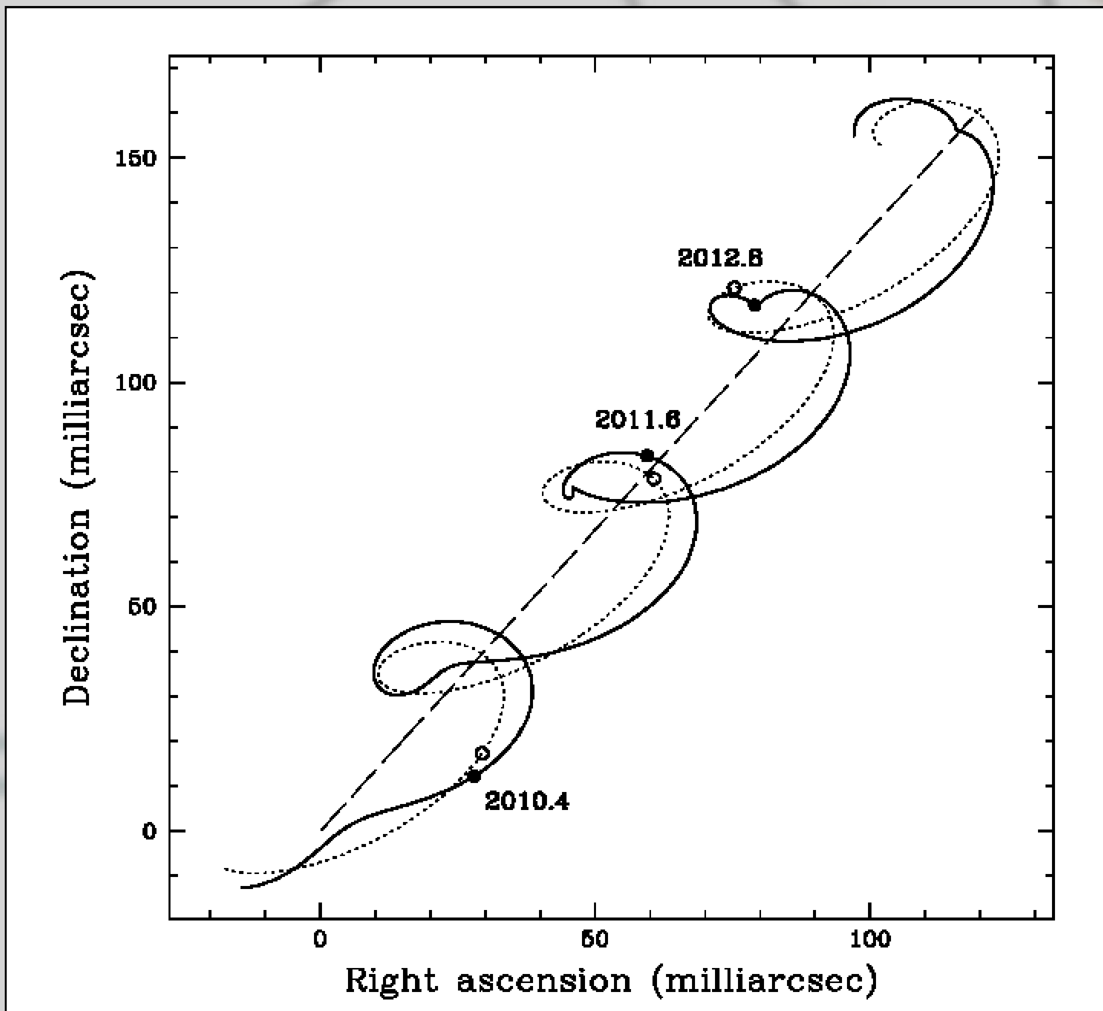
Why Astrometry: stellar motion



Estimation of the proper motion of ** WNO7:
32 .278''/(1987.751-1951.839)
=**0.9''/yr**

Galactic Center
Relative astrometry
2010: state-of-the-art = mas
2020: MICADO – E-ELT :40 µas

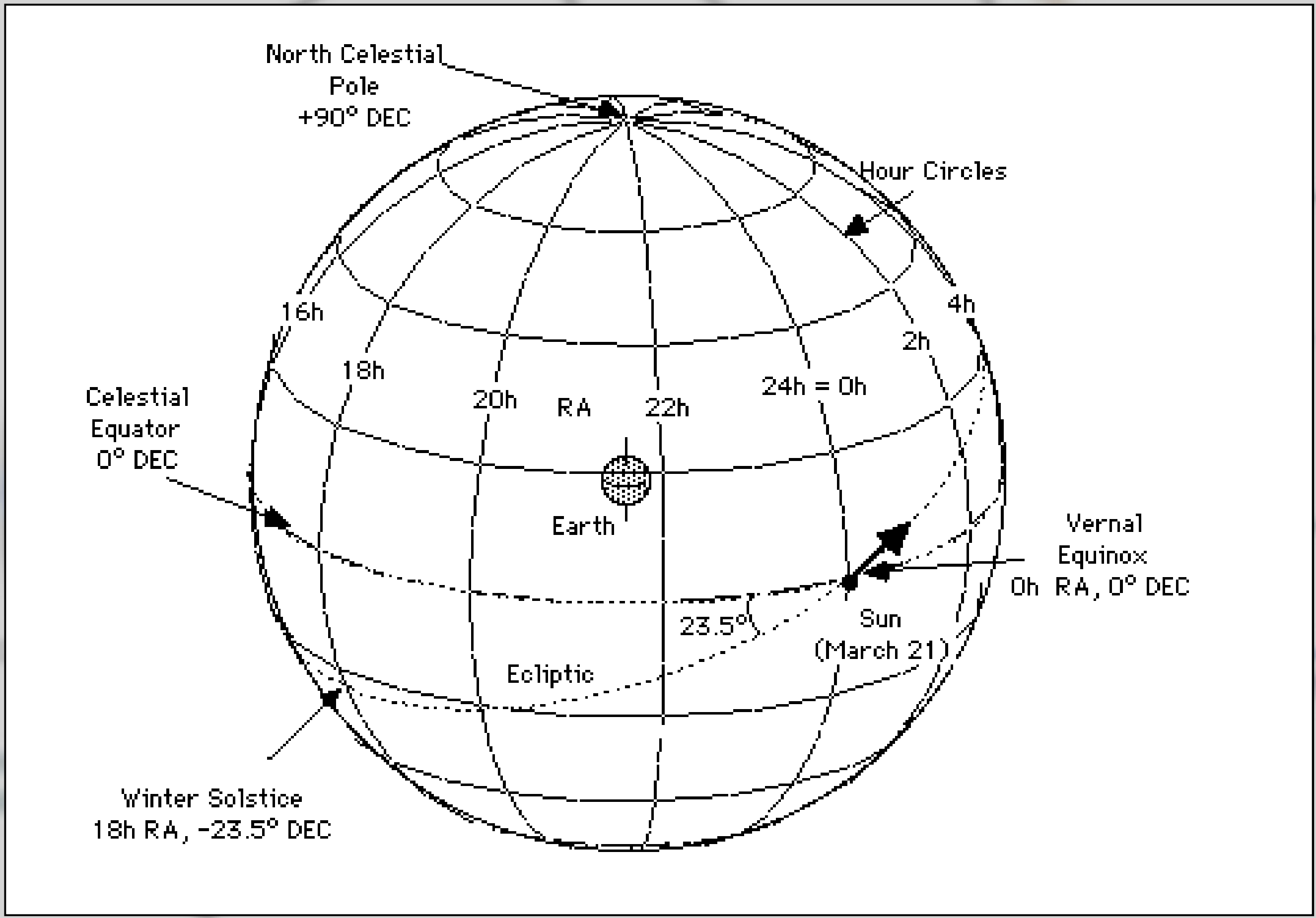
Why Astrometry: low-mass / planetary companions



Required precision (order of magnitude):
Yearly motion Sun at 10 pc ~ 1 mas

Example research program:
Stellar Planet Survey (STEPS)
30 M stars

Astrometric Reference Frames



The Earth precesses, or wobbles on its axis, once every 26,000 years. Unfortunately, this means that the Sun crosses the celestial equator at a slightly different point every year, so that our "fixed" starting point changes slowly - about 40 arc-seconds per year.

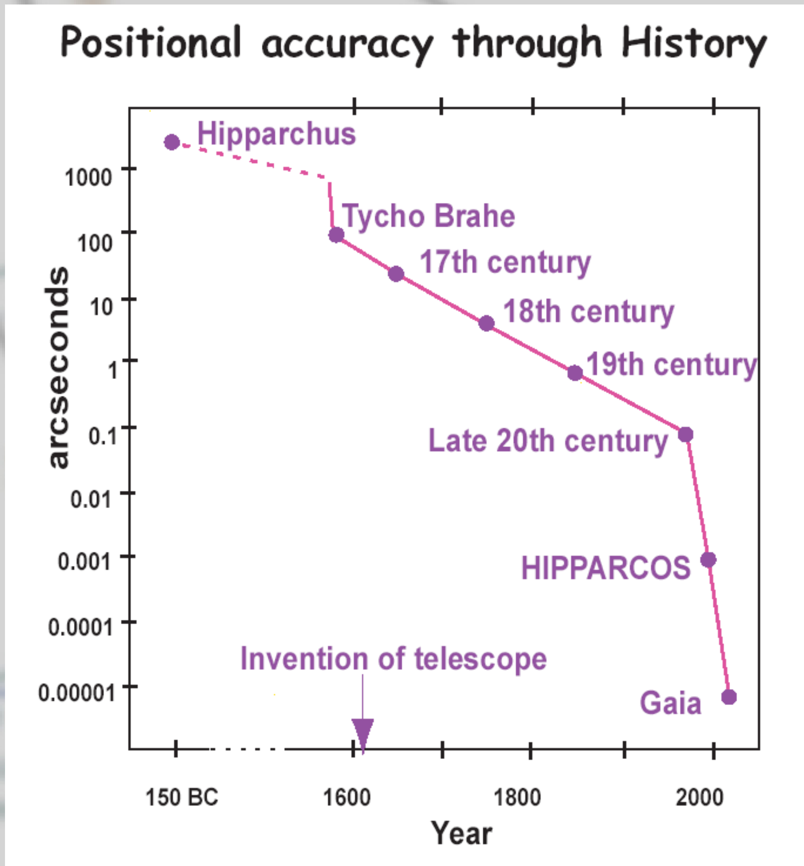
Ecliptic and equatorial coordinates

Coordinate systems

Name	center	Reference plane	Reference point
Horizontal azimuth Altitude	observer	Horizon	Clockwise from south (most often)
Equatorial Right ascension (α, ra) declination (δ, dec)	Earth	Equator	Counterclockwise from vernal equinox (=intersection equator./ecliptic)
Ecliptic Ecliptic longitude (λ) Ecliptic latitude (β)	Earth or Sun	Ecliptic	Counterclockwise from vernal equinox
Galactic Galactic longitude (l) Galactic latitude (b)	Sun	Milky Way disk	Counterclockwise from Milky Way Center
Supergalactic Supergal. longitude (SGL) Supergal. Latitude (SGB)	?	Supergalactic plane	Counterclockwise from intersection milky way plane, supergalactic plane

Astrometry Reference Catalogs

ASTROMETRIC DATA: currently recommended
2MASS
Hipparcos
TYCHO-2
UCAC2: USNO CCD Astrograph Catalog, 2nd release
UCAC2 Bright Star Supplement
USNO B1.0
ASTROMETRIC DATA: superseded or not recommended
FK4,5
IRS: International Reference Stars
ACRS
PPM
TYCHO-1
ACT Reference Catalog
Tycho Reference Catalogue
AC: Astrographic Catalogue
UCAC1: USNO CCD Astrograph Catalog, 1st release
GSC 1.2: Guide Star Catalog version 1.2
USNO A2.0
USNO SA2.0
GSC 2.2: Guide Star Catalog version 2.2



Fifth Fundamental Catalog (FK5)

FK5 Part II:

- mean positions and proper motions at equinox and epoch J2000.0 for 3117 fundamental stars
- to about magnitude 9.5
- terms of elliptic aberration are eliminated from the mean positions,
- More than 200 catalogs providing star positions obtained from throughout the world have been used in the compilation of the FK5 Extension.

Calibration challenge: everything moves in empty space

- Motion of coordinate system
  - Earth's precession, nutation
  - Epoch of equinox
- Motion of reference points:
  - Stellar proper motion:

Solution: extragalactic sources:

International Celestial Reference System (ICRS)

ICRS/ICRF

- Current standard celestial reference system adopted by IAU.
- Origin is barycenter of the solar system, axes that are intended to be "fixed" with respect to space.
- ICRS co-ordinates are witihin 100mas of equatorial co-ordinates.
- Distinction between ICRS and FK5 (J2000) becomes important when accuracies < 50 milli-arcseconds.
- The **International Celestial Reference Frame** (ICRF) is realization of ICRS defined by the measured positions of 212 extragalactic sources (mainly quasars).
- Agrees with the orientation of the Fifth Fundamental Catalog (FK5) "J2000.0" frame to within the (lower) precision of the latter.

Also from wikipedia

2MASS

- Hipparcos – 120,000 stars, incomplete
- Tycho-2 – complete till 11 V(Tycho)
- -> we need much deeper all-sky reference catalog for most of present-day observations
- -> put a deep catalog on Hipparcos and use it as second-order reference catalog

2MASS

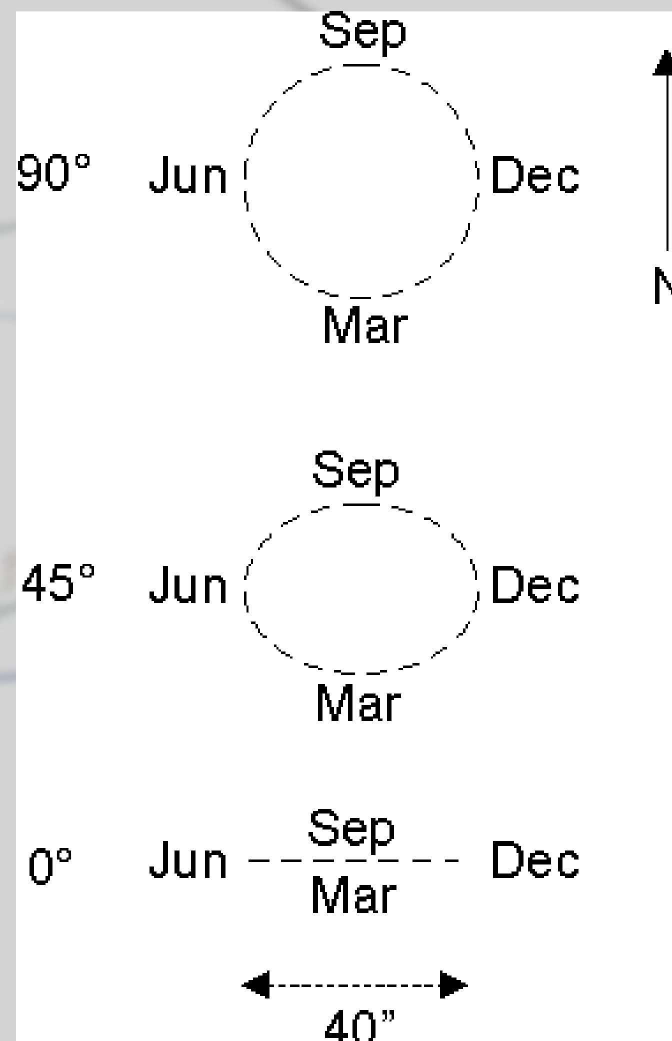
- Two micron all sky survey (2MASS)
- J,H,Ks – all in 2MASS photometric system (close to Johnson)
- Observations in 1997-2001
- Completeness 16-16.5 in J
- ~470 mln stars in PSC
- ~ 1.5 mln objects in XSC
- Coordinate system - ICRS: Hipparcos->Tycho-2->ACT->2MASS
- typical error reference source: 0.1”

Astrometric Calibration

- Atmospheric Refraction
  - The deviation of light or other electromagnetic wave from a straight line as it passes through the atmosphere due to the variation in air density as a function of altitude
  - The atmospheric refraction is zero in the zenith, is less than 1' (one arcminute) at 45° altitude, still only 5' at 10° altitude

Astrometric Calibration

- Aberration
  - Due to finite light speed: $\theta - \varphi \approx v/c \sin\theta$
  - Annual aberration is due to the revolution of the Earth around the Sun.
  - Planetary aberration is the combination of aberration and light-time correction.
  - Diurnal aberration is due to the rotation of the Earth about its own axis.
  - Secular aberration is due to the motion of the Sun and solar system relative to other stars in the galaxy



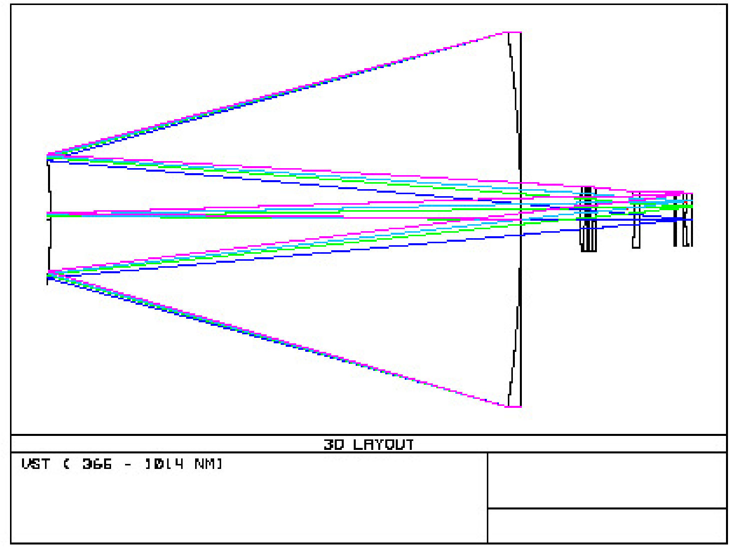


Fig. 1 - VST complete optical layout of telescope with one lens and the ADC, with a curve dewar window

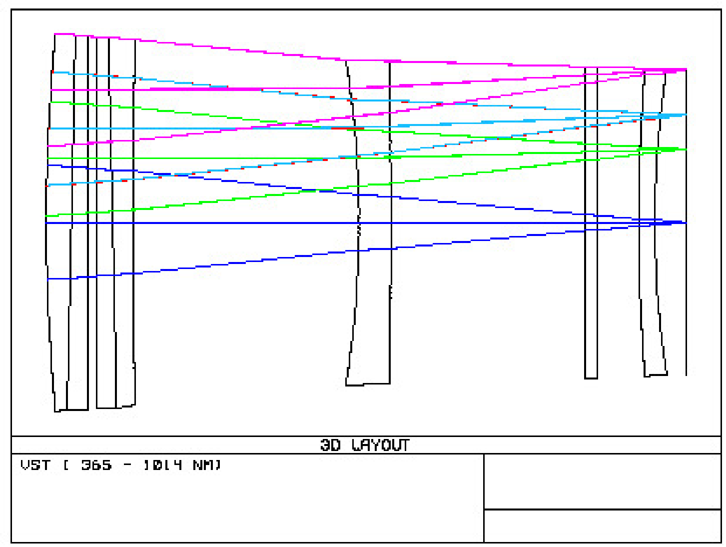
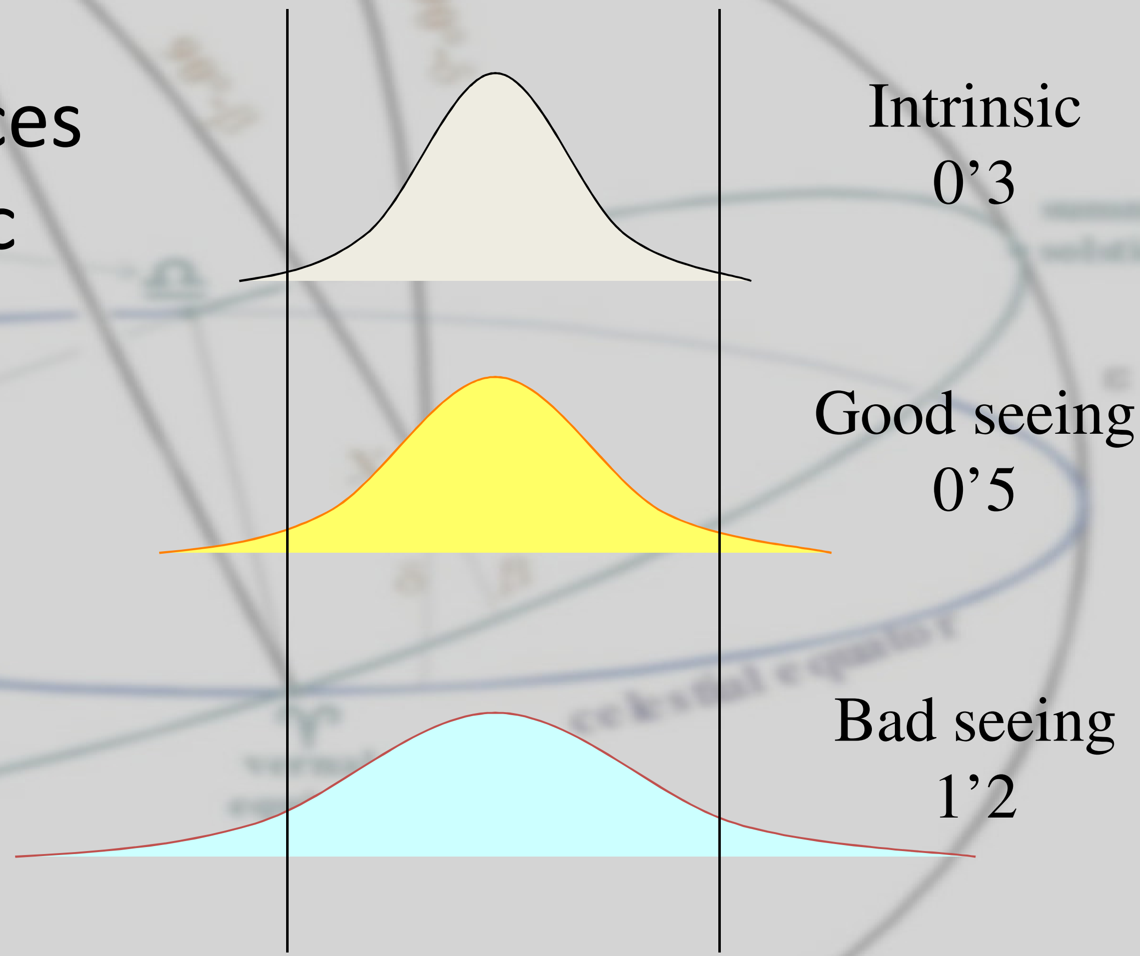


Fig. 2 - VST zoom of the optical layout of the corrector with one lens and the ADC, with a curve dewar window

Intrinsic Positional Accuracy

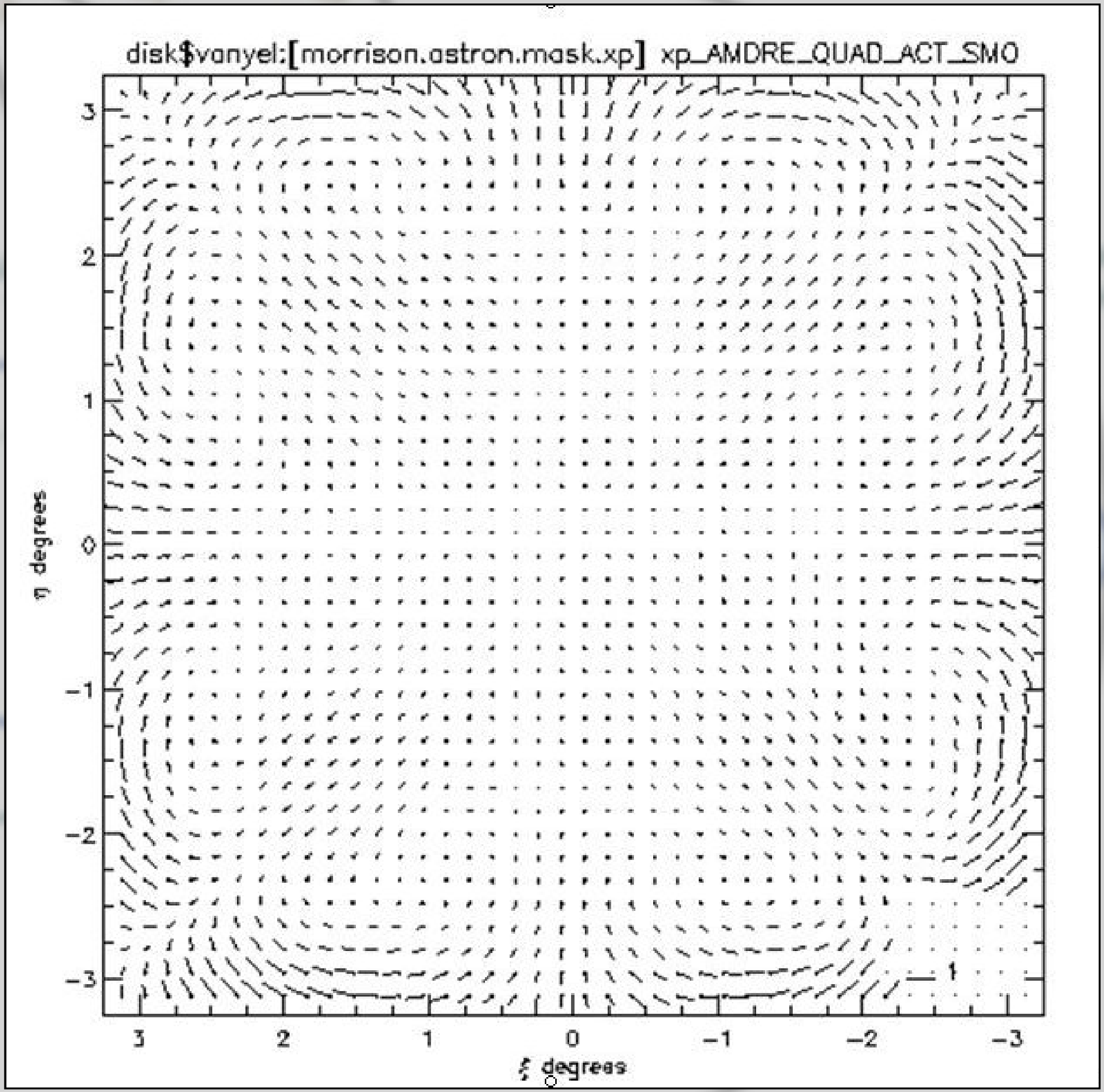
- Seeing influences the astrometric accuracy



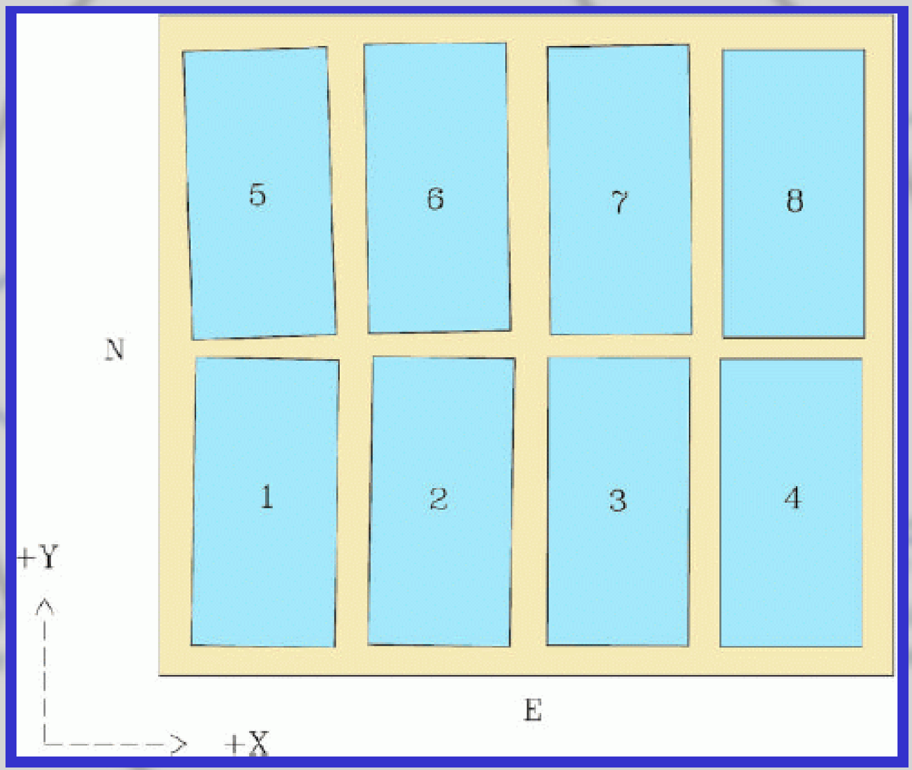
Astrometric Calibration

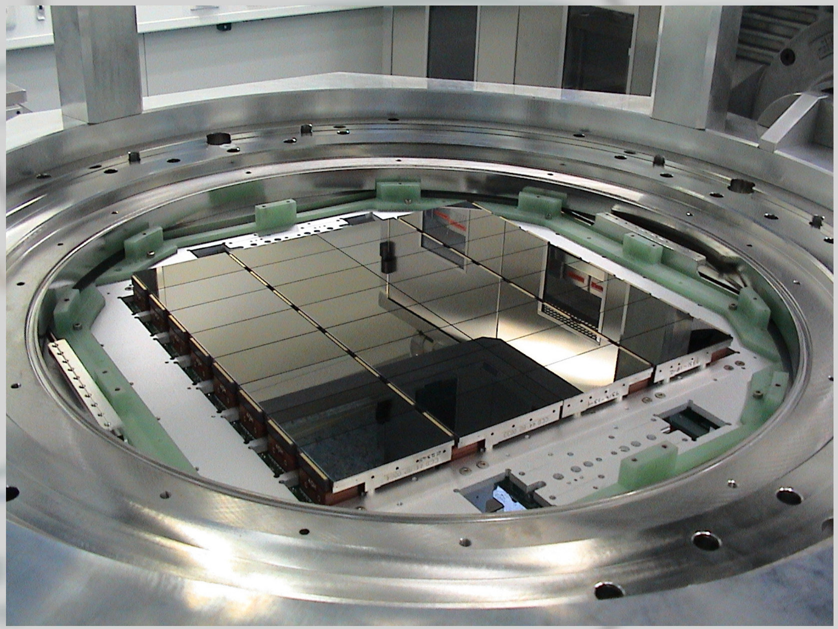
Palomar Sky Survey Plate

Optical distortion map

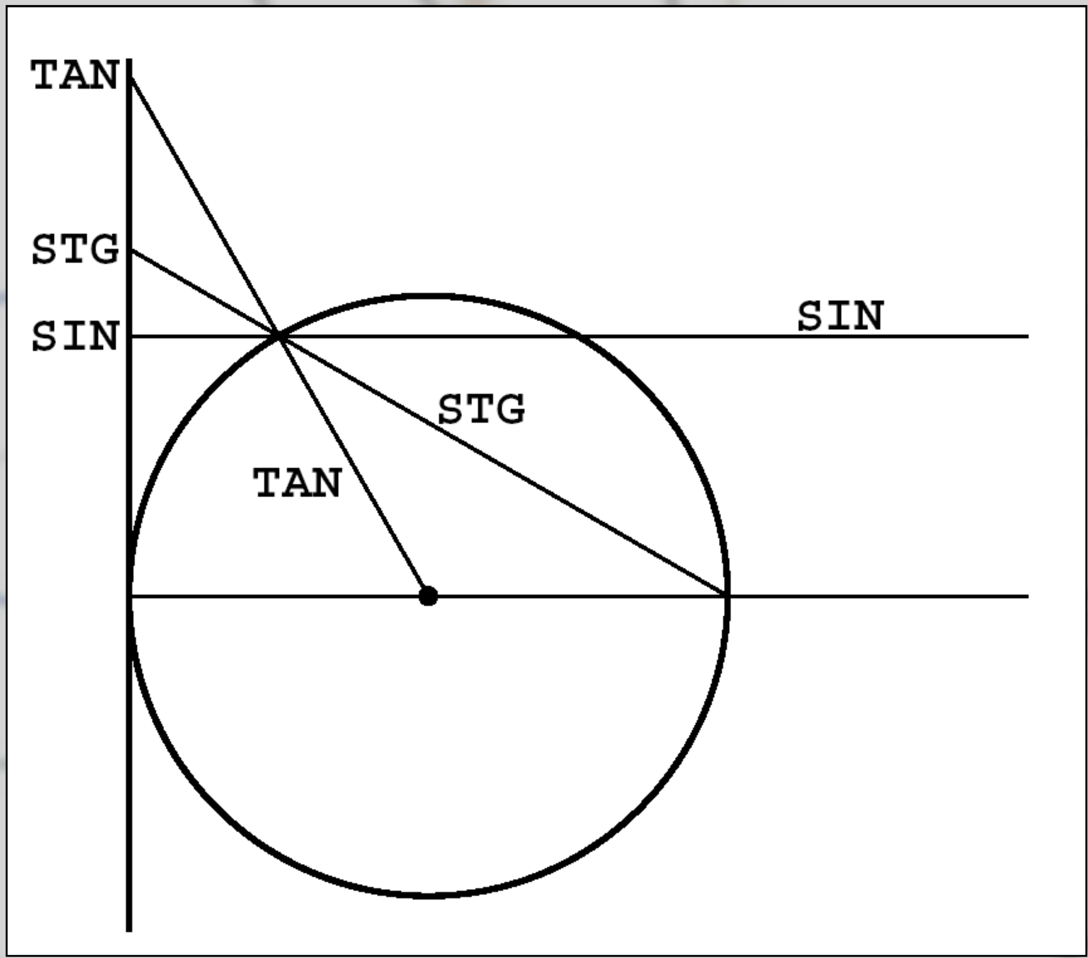


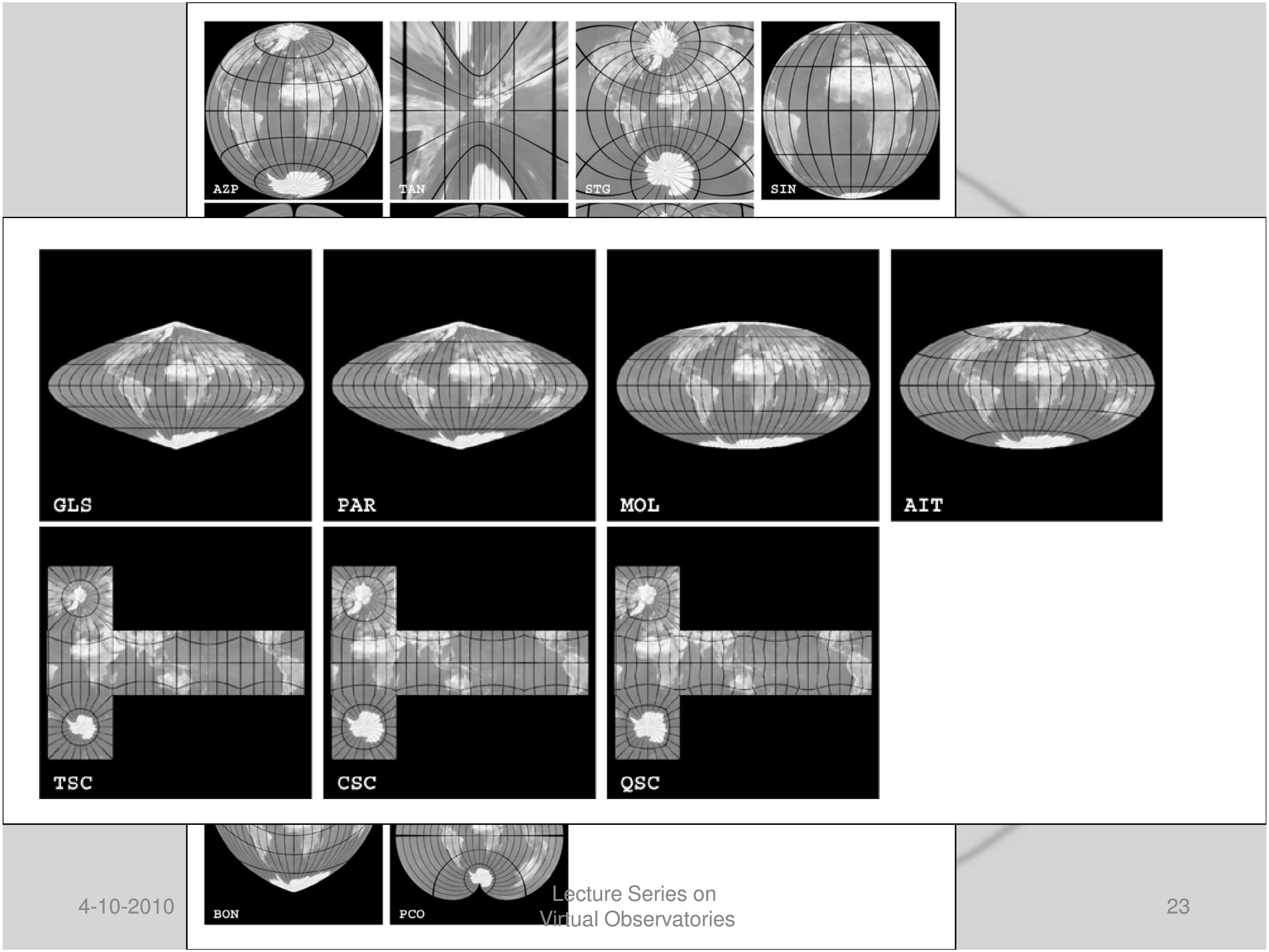
Astrometry: wide field images



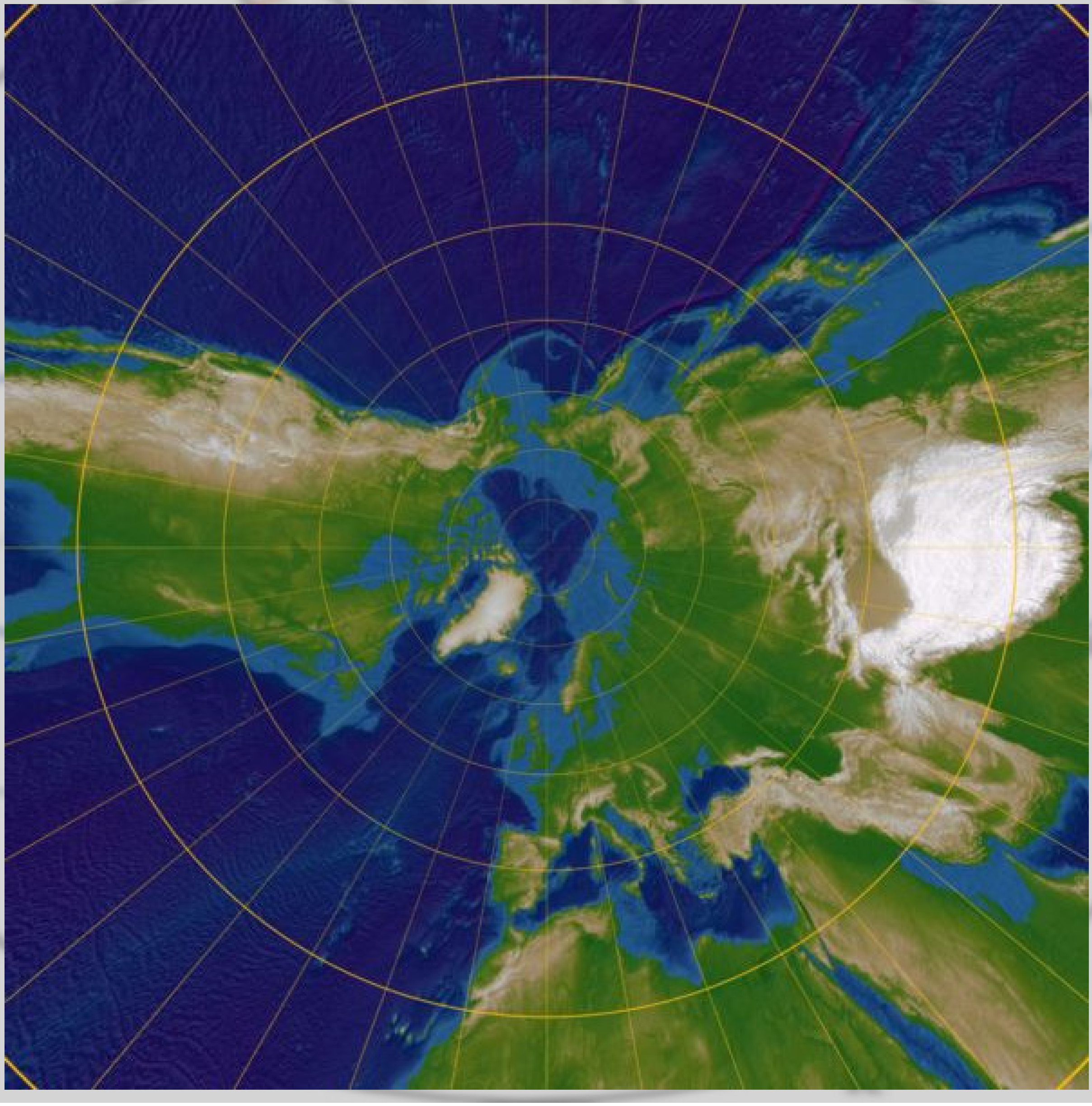


3D→2D
Astrometric Projections




AZP
TAN
STG
SIN
GLS
PAR
MOL
AIT
TSC
CSC
QSC
BON
PCO

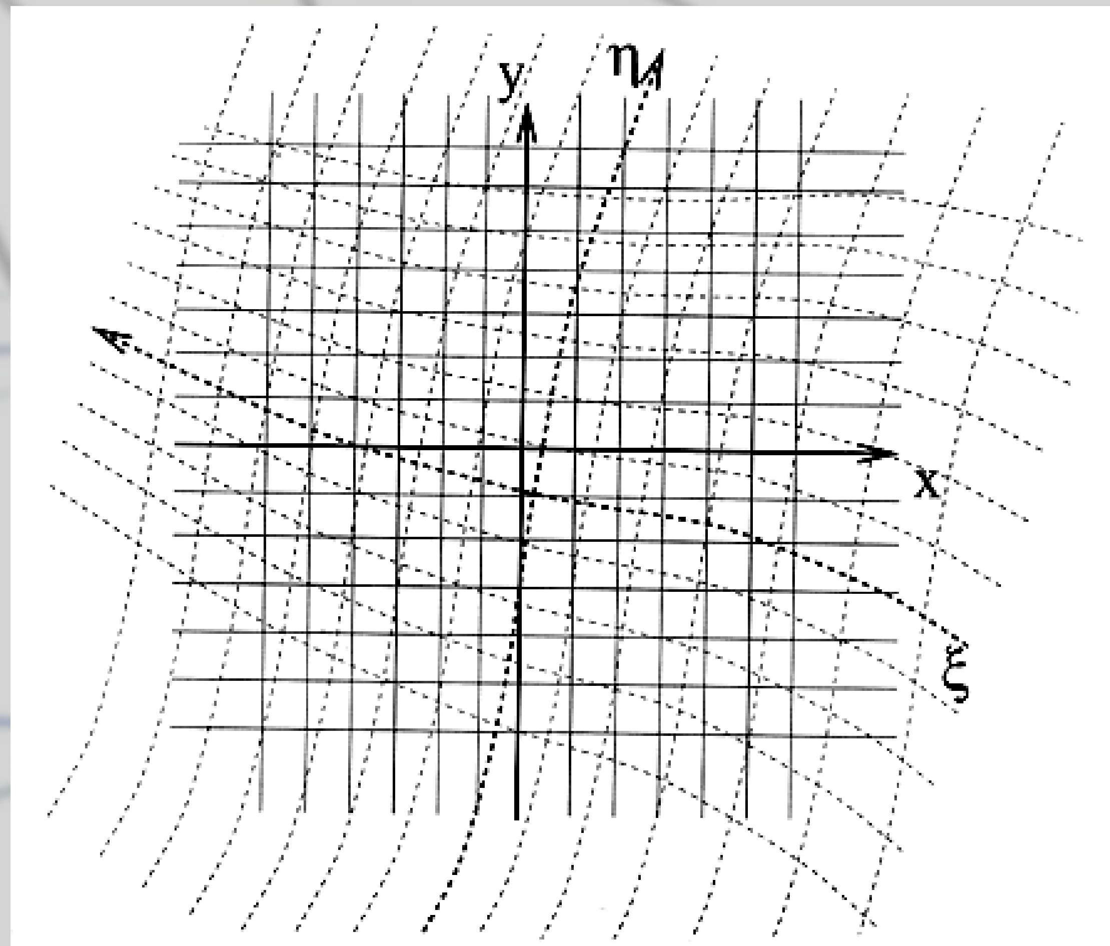
Gnomonic projection



Astrometric Calibration

- Single field
  - Polynomial description

$$\xi(x,y) = a + \Sigma\, b_{ij}\, x^i\, y^j$$
$$\eta(x,y) = c + \Sigma\, d_{ij}\, x^i\, y^j$$



Astrometric Calibration

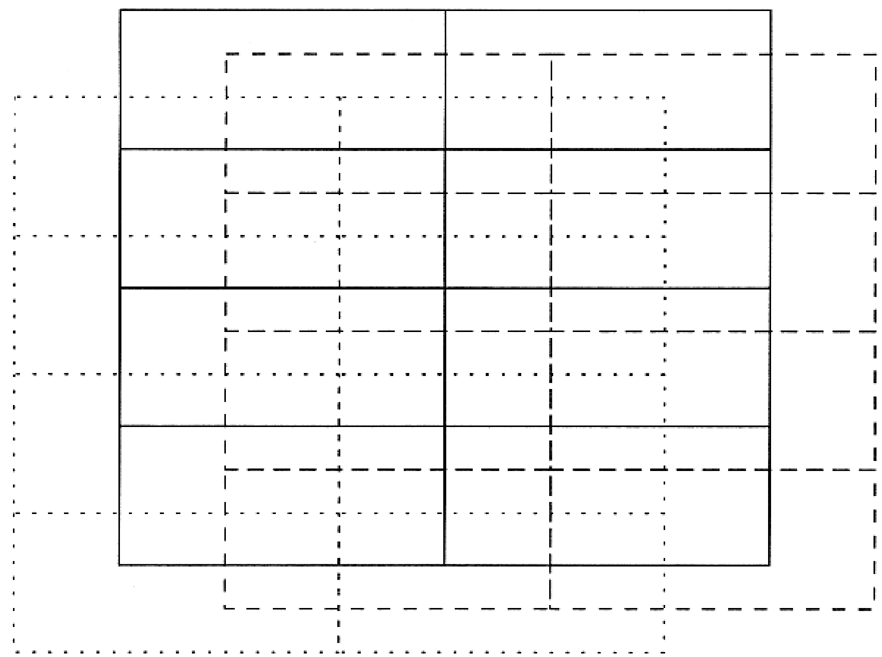
- Overlap fields
  - Independent set of params/field
  - Dependence of b and d with field

$$\xi(x,y) = a + \Sigma\Sigma\, b_{ijk}\, x^i\, y^j f^{\,k}$$

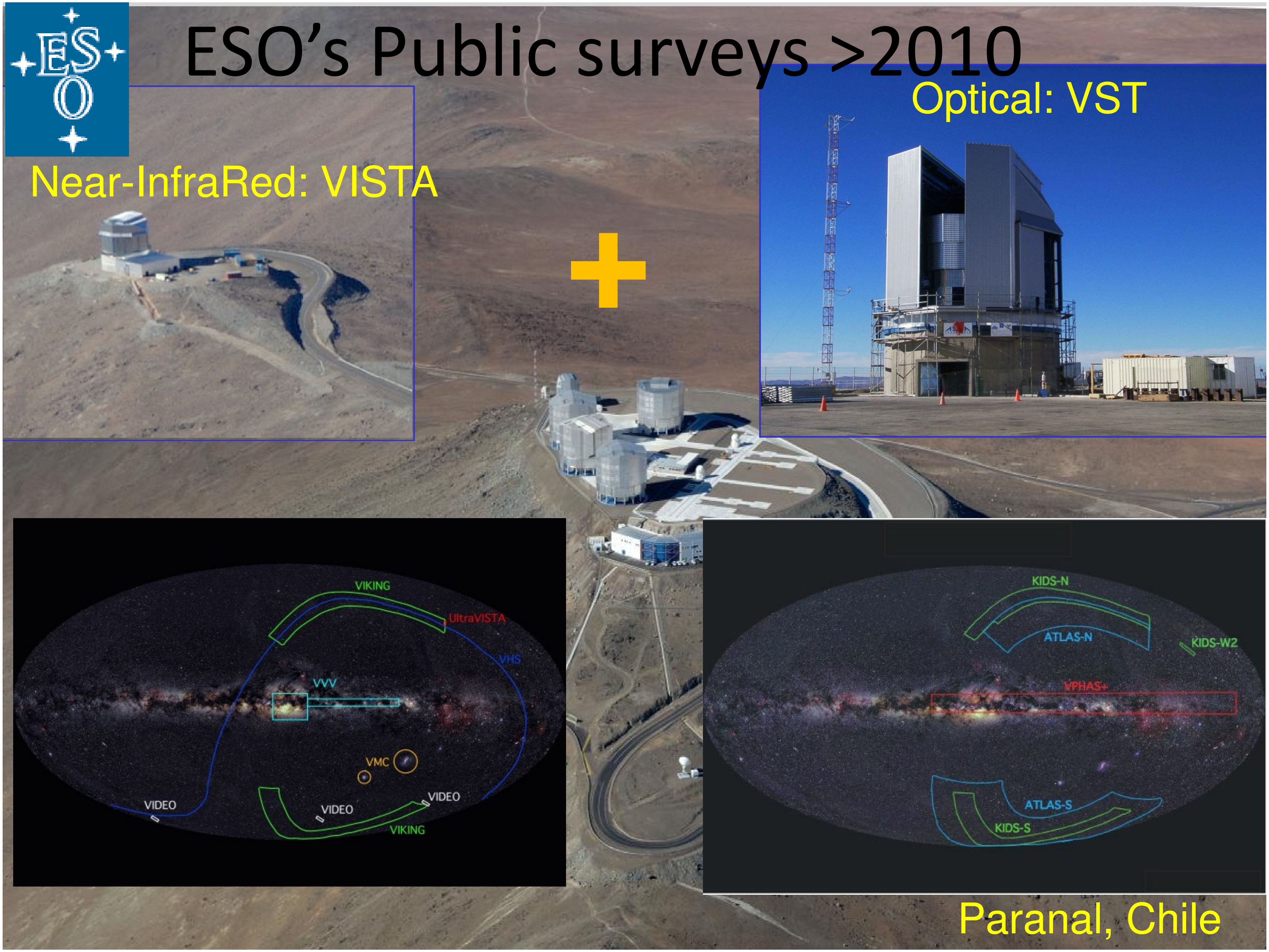
$$\eta(x,y) = c + \Sigma\Sigma\, e_{ij}\, x^i\, y^j f^{\,k}$$

  - Spatial terms Chebychev polynomes

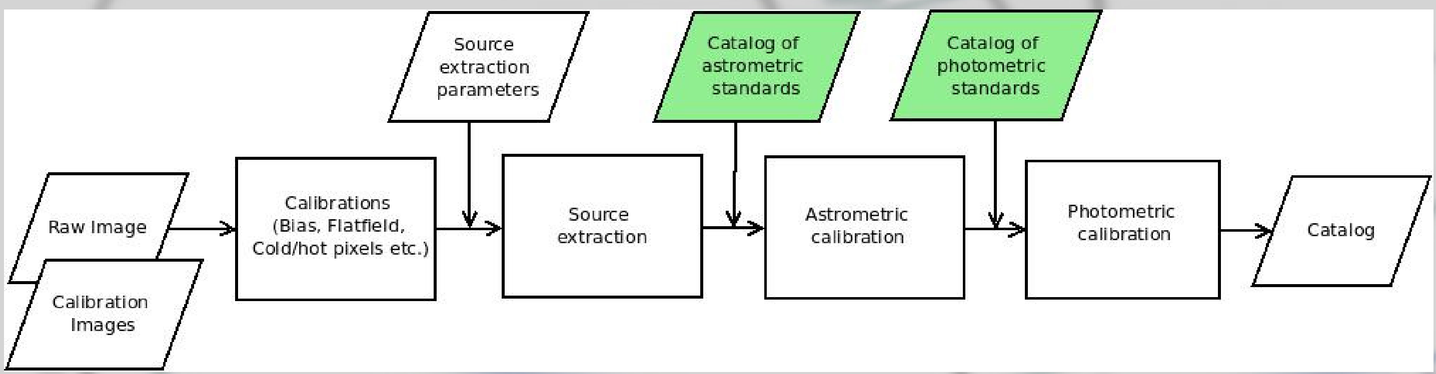
$$P_{n+1} - f\, R_n(f) + P_{n-1}(f) = 0$$

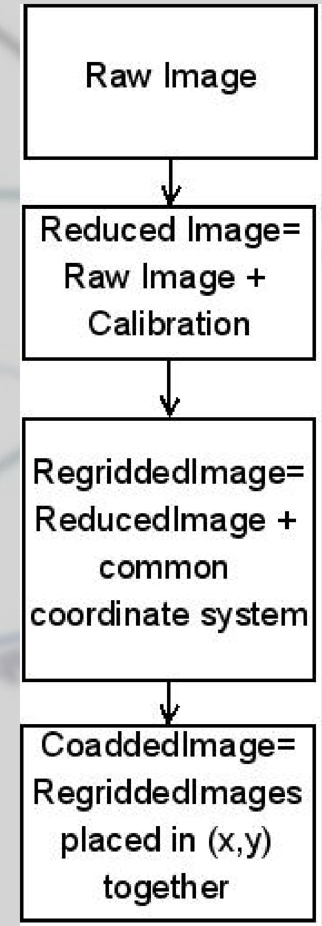


ESO's Public surveys >2010



Astrometry: wide field images





Astrometry & Virtual Observations: standardization

1. "**tiling the sky**"
   - Common choice of the field centers of observations
2. **Common reference positions**
   - choice of coordinates when projecting the coordinate system of re-gridded images
3. "**pixelating the sky**"
   - choice of pixel positions (pixel-grid) with respect to the reference positions

Benefits

- Continuity of sky coverage:
  - When observations of different projects enter the archives,
- Direct analysis
  - When observations of different projects enter the archives taken at either different filters or at different epochs of the same area of the sky
- No excess interpolation of data
  - The tedious interpolation of images is done only once
- After many years of operation, the co-ordination will build up a much more complete and smooth archive which will provide a valuable survey in itself, beyond the goals of the individual projects.

Standardization (sociological) challenges

- Which coordinate system
- Which projection
- …….

END

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