Michael Perryman

Cavendish Laboratory, Cambridge (1977−79)

European Space Agency, NL (1980−2009)

(Hipparcos 1981−1997; Gaia 1995−2009)

[Leiden University, NL,1993−2009]

Max-Planck Institute for Astronomy & Heidelberg University (2010)

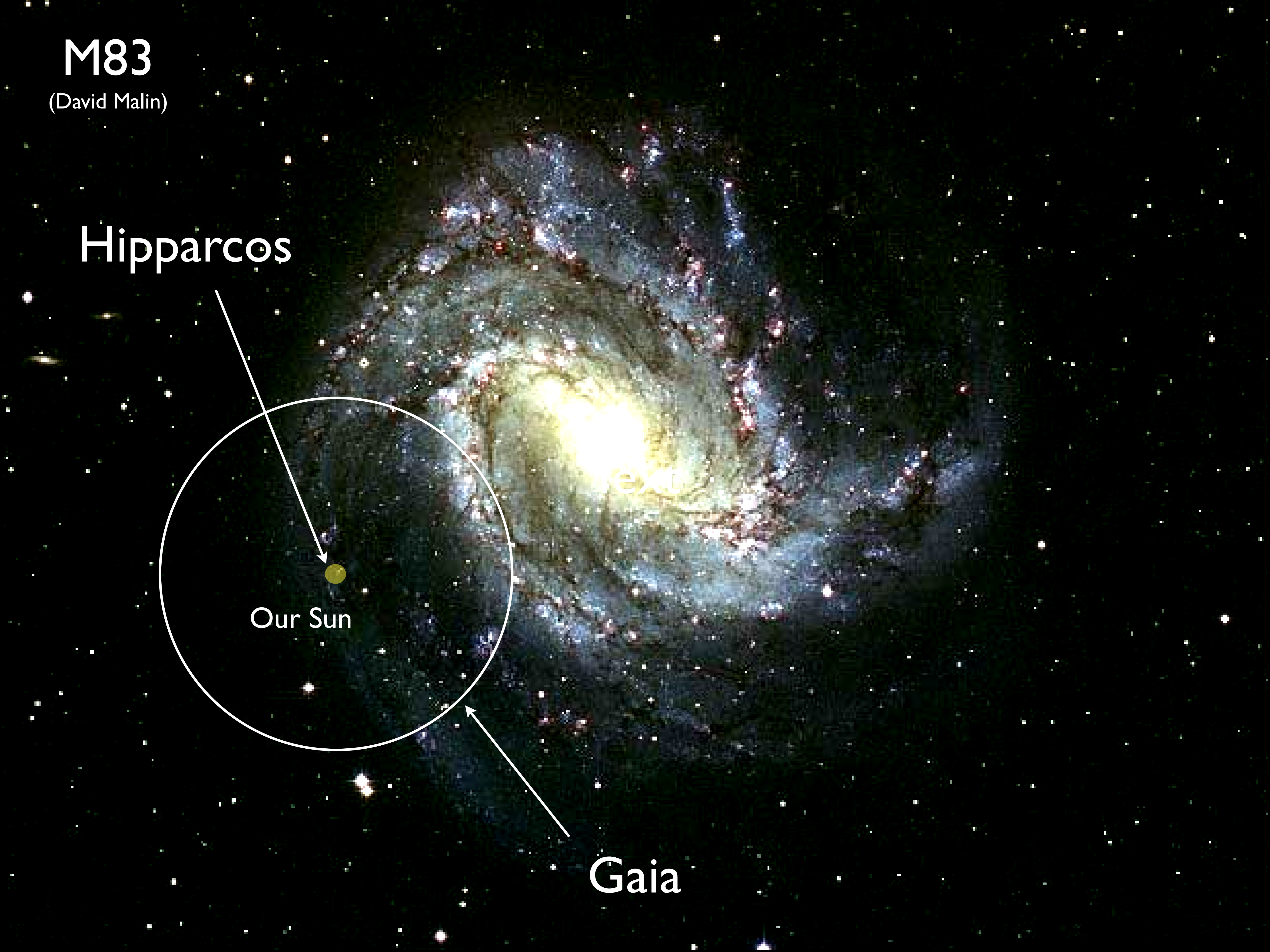
Visiting Professor:

University of Bristol (2011−12)

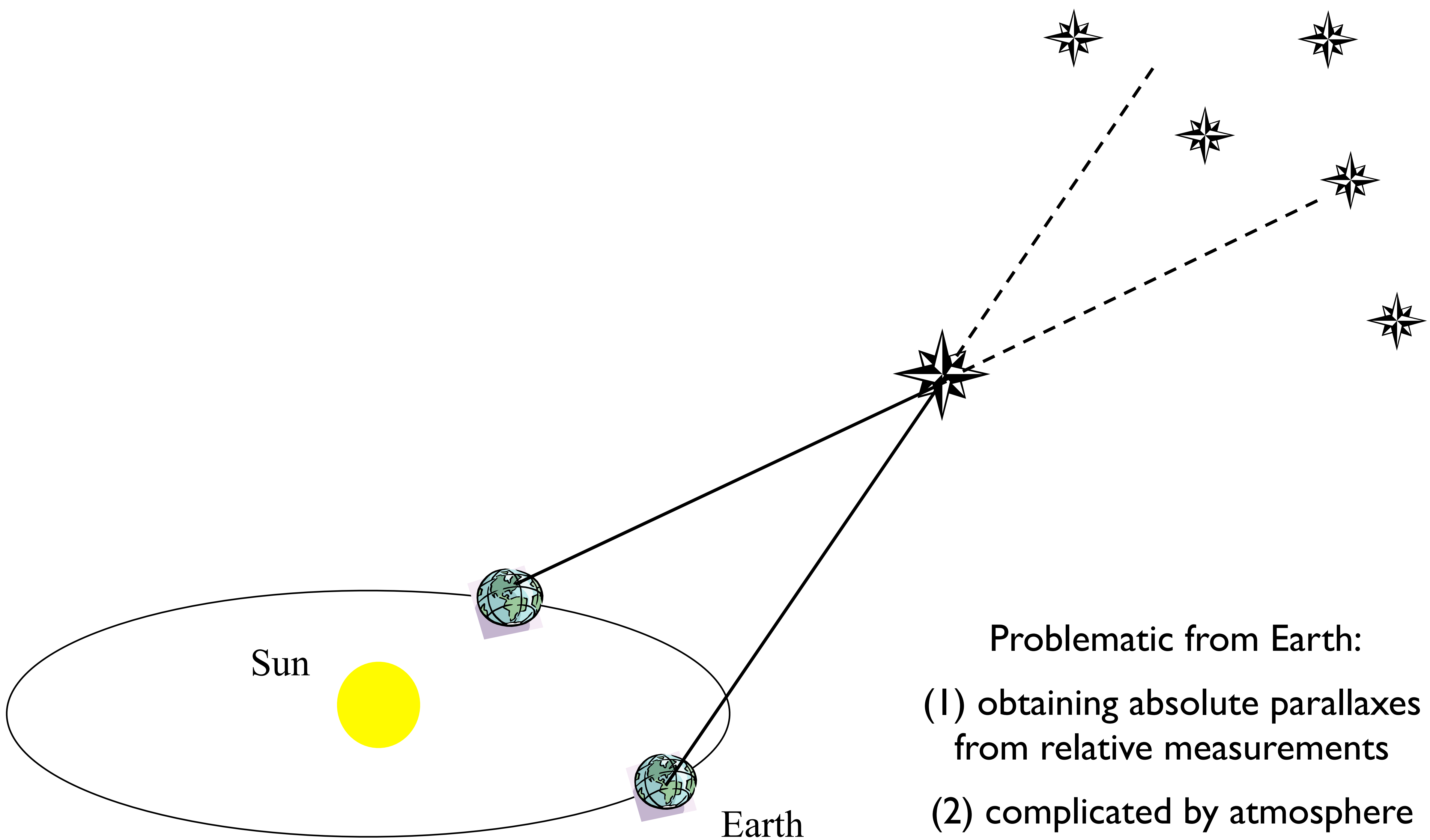
University College Dublin (2012−13)

Lecture program

1. Space Astrometry 1/3: History, rationale, and Hipparcos
2. Space Astrometry 2/3: Hipparcos science results (Tue 5 Nov)
3. Space Astrometry 3/3: Gaia (Thu 7 Nov)
4. Exoplanets: prospects for Gaia (Thu 14 Nov)
5. Some aspects of optical photon detection (Tue 19 Nov)


M83
(David Malin)
Hipparcos
Our Sun
Gaia

Parallax measurement principle…



Problematic from Earth:

(1) obtaining absolute parallaxes from relative measurements

(2) complicated by atmosphere [+ thermal/gravitational flexure]

(3) no all-sky visibility

Some history: the first 2000 years

- 200 BC (ancient Greeks):
  - size and distance of Sun and Moon; motion of the planets
- 900–1200: developing Islamic culture
- 1500–1700: resurgence of scientific enquiry:
  - Earth moves around the Sun (Copernicus), better observations (Tycho)
  - motion of the planets (Kepler); laws of gravity and motion (Newton)
  - navigation at sea; understanding the Earth's motion through space
- 1718: Edmond Halley
  - first to measure the movement of the stars through space
- 1725: James Bradley measured stellar aberration
  - Earth's motion; finite speed of light; immensity of stellar distances
- 1783: Herschel inferred Sun's motion through space
- 1838–39: Bessell/Henderson/Struve − the first parallaxes
- 1880–1990: photographic and meridian circle catalogues

The History of Astrometry, Perryman 2012: European Physical Journal H37, 745-792

The first star distances...

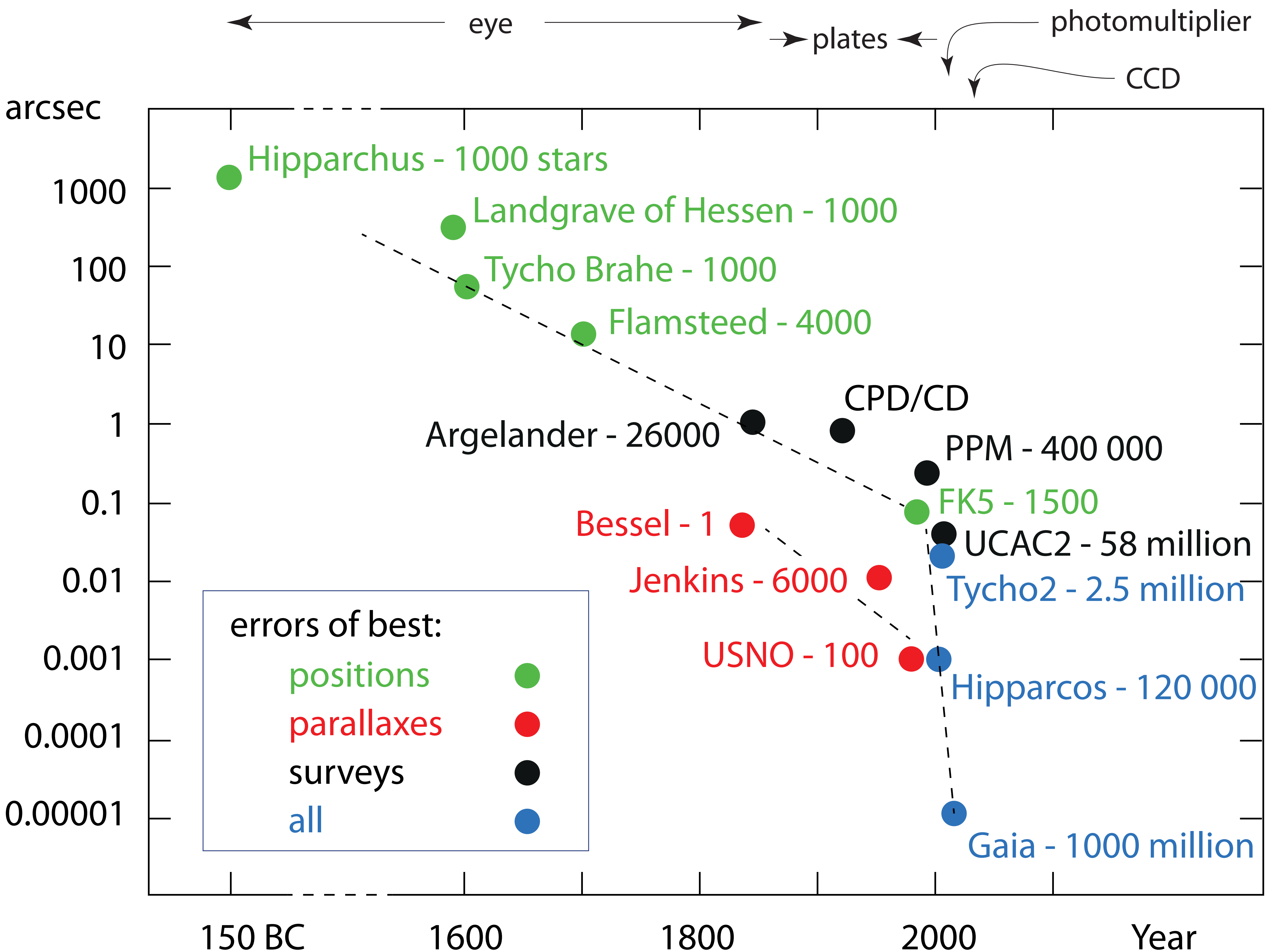
After a 250 year marathon journey, Friedrich Bessel, Thomas Henderson, and Wilhelm Struve measured the first star distances around 1838–39

John Herschel:
"the sounding line in the Universe of stars has at last touched bottom"

Bessel was awarded the Royal Astronomical Society's Gold Medal, for
"*the greatest and most glorious triumph which practical astronomy has ever witnessed*"

Struve's refractor, Tartu

Accuracy over time



Over the last 100 years, bigger telescopes measure:

- fainter stars (billions)
- more star motions (millions)
- more star distances (few thousand)

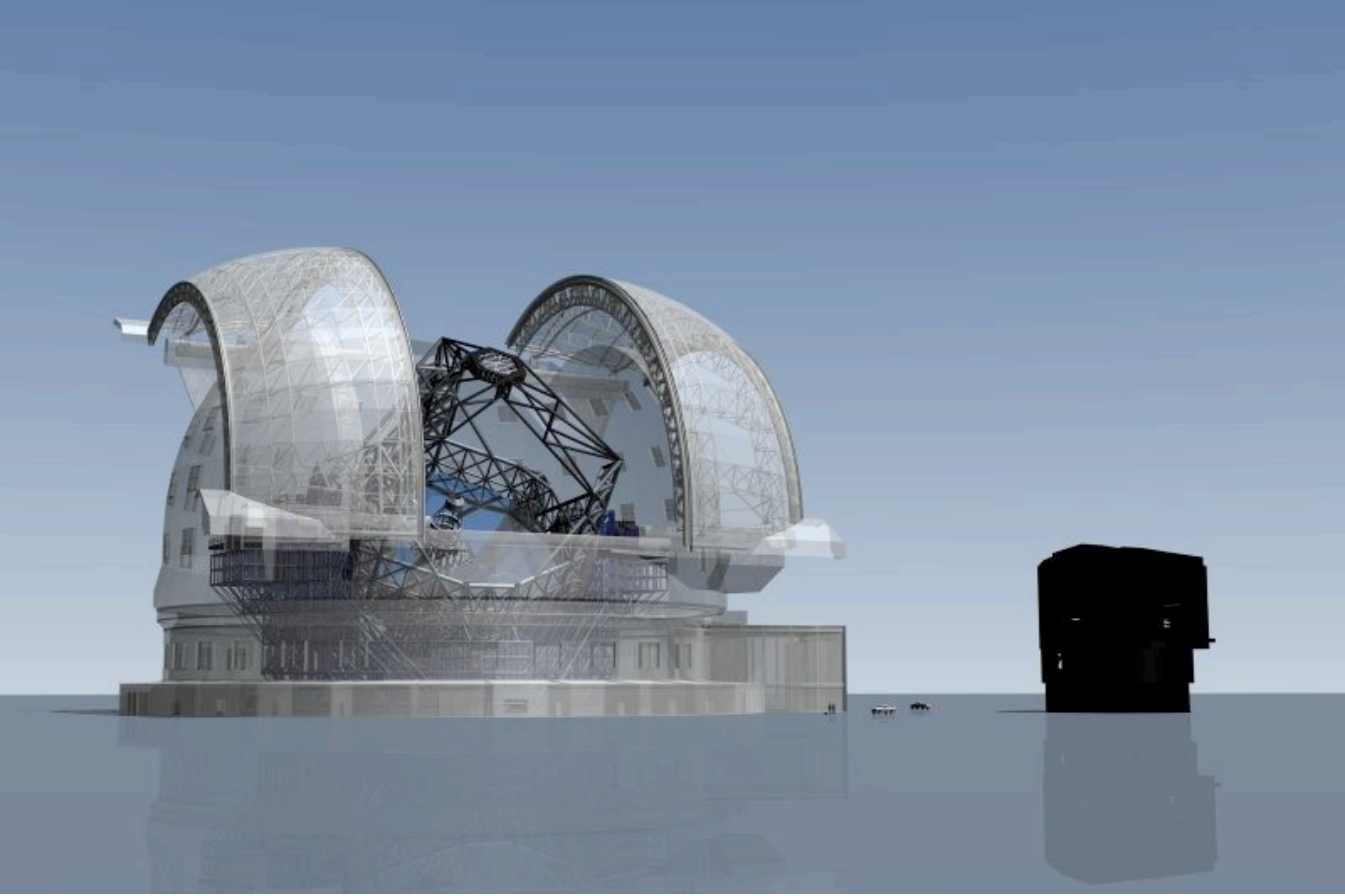
The Astrographic Catalogue 1887 – 1930/1964

...measurements made and recorded by hand!

Yerkes refractor
~ 1900

Schmidt telescopes ~1950–1980

European Southern Observatory, Chile ~2000



European ELT (Extremely Large Telescope) ~ 2020

...but it remains all but impossible to measure star distances from Earth, beneath its phase-perturbing atmosphere...

Stellar Distances and Motions: principles and numbers

- star distances are determined trigonometrically, using Earth's annual orbit around the Sun as baseline
  (INPOP06: 149 597 870 691 m, recently defined by IAU as 149 597 870 700 m)
- star distance of 1 pc gives a parallax of 1 arcsec
- nearest star is ~1 pc ≈ 3.26 light years = 3×10^{16} m
- Galactic centre ≈ 8 kpc ≈ 30,000 light years; requires 10 μas at 10% accuracy
- stars move through space at ~30 km/s, equivalent to ~0.1 arcsec/yr at a distance of 100 pc

Accuracy of positions from the ground (1/4)

Comment: accuracies are not limited by diffraction (Rayleigh criterion):

$\sin\theta = 1.22\ \lambda/D$ for $D=0.3$m, $\lambda = 600$ nm $\Rightarrow$ 0.5 arcsec

The theoretical photon-noise limited positional error for a monolithic telescope is:

$$\sigma_{\rm ph} = \frac{\lambda}{4\pi D}\frac{1}{\rm S/N}$$

... Lindegren (1978)

... for $V=15$ mag, $\lambda=600$ nm, $D=10$ m, $\varepsilon=0.4$, $t=1$ hr $\Rightarrow$ $\sigma \sim 30$ μas

Even the best astrometric accuracies from ground fall far short of this due to <u>atmospheric turbulence</u>, usually further degraded by <u>differential chromatic refraction</u>

Understanding the fundamental accuracy limits has evolved greatly over past 30−40 years:

- 1970s: long-focus telescopes + photographic plates gave ~ 20−30 mas (Harrington & Dahn 1980)
- 1980s: CCDs eliminated the plate-specific error sources (but not atmospheric turbulence)

For small separations near the zenith (≲1 arcmin) errors on the time-averaged separation between stars (θ) are consistent with atmospheric (Kolmogorov-like) turbulence models:

$$\sigma_\delta \simeq 540\, D^{-\frac{2}{3}}\, \theta\, t^{-\frac{1}{2}}\ \text{arcsec}$$

... Lindegren (1980)

... values of $\theta = 1$ arcmin, $D=1$ m, $t=1$ hr $\Rightarrow$ $\sigma_\delta \sim 3$ mas (Gatewood 1987, Han 1989, Monet et al 1992)

Accuracy of positions from the ground (2/4)

With several reference stars, theoretical estimates give a further improvement, e.g.:

$$\sigma_\delta \propto D^{-1}\theta^{\frac{4}{3}}\, t^{-\frac{1}{2}} \qquad \text{Lindegren (1980)}$$

$$\sigma_\delta \propto D^{-\frac{3}{2}}\theta^{\frac{11}{6}}\, t^{-\frac{1}{2}} \qquad \text{Lazorenko (2002)}$$

... substantially confirmed experimentally (e.g. Pravdo & Shaklan 1996)

Aperture apodisation + improved treatment of reference star symmetry gives:

$$\sigma_\delta \propto D^{-\frac{k}{2}+\frac{1}{3}}\theta^{\frac{k\mu}{2}}\, t^{-\frac{1}{2}} \qquad \text{Lazorenko \& Lazorenko (2004)}$$

where (k,μ) depend on the number of reference stars and their magnitudes.

... for 10-m telescopes, very good seeing, and t~600 s ⇒ $\lesssim$ 100 μas

observational results:

- narrow-field AO on Palomar and VLT ⇒ 100−300 μas (Neuhauser 2007, Roll 2008, Cameron 2009)
- VLT-FORS2 (R=16 mag, t=17s, seeing=0.55 arcsec) ⇒ 300 μas (Lazorenko 2006)

Note: these promising positional results refer to narrow-angle measurements, typically at zenith, and not to an all-sky reference system

Accuracy of positions from the ground (3/4)

Interferometers:

For larger separations, $\theta \sim 0.5^\circ$, theory and data had suggested a turbulent-limited accuracy $\propto \theta^{1/3}$, and (to first-order) independent of *D* (Lindegren 1980). Therefore interferometers were not immediately considered as particularly advantageous for relative positional measurements. But: when baselines exceed the beam separation at the top of the (turbulent) atmosphere, a qualitative change in atmospheric behaviour occurs, and:

$$\sigma_\delta^2 \simeq 5.25\, B^{-4/3} \theta^2 \int h^2 C_n^2(h) (V t)^{-1}\, \mathrm{d}h$$

Shao & Colavita (1992), eqn 2

... baseline *B*, star separation θ (arcmin), wind speed versus height $V(h)$, and integration time *t*. $C_n(h)$ is complicated function describing the atmospheric refractivity power spectrum with height, which determines the seeing

For Mauna Kea, Shao & Colavita (1992, eqn 4) found:

$$\sigma_\delta \simeq 300\, B^{-\frac{2}{3}}\, \theta\, t^{-\frac{1}{2}} \text{ arcsec}$$

... equivalent to the single aperture form, with *B* replacing *D* (and a smaller numerical factor)

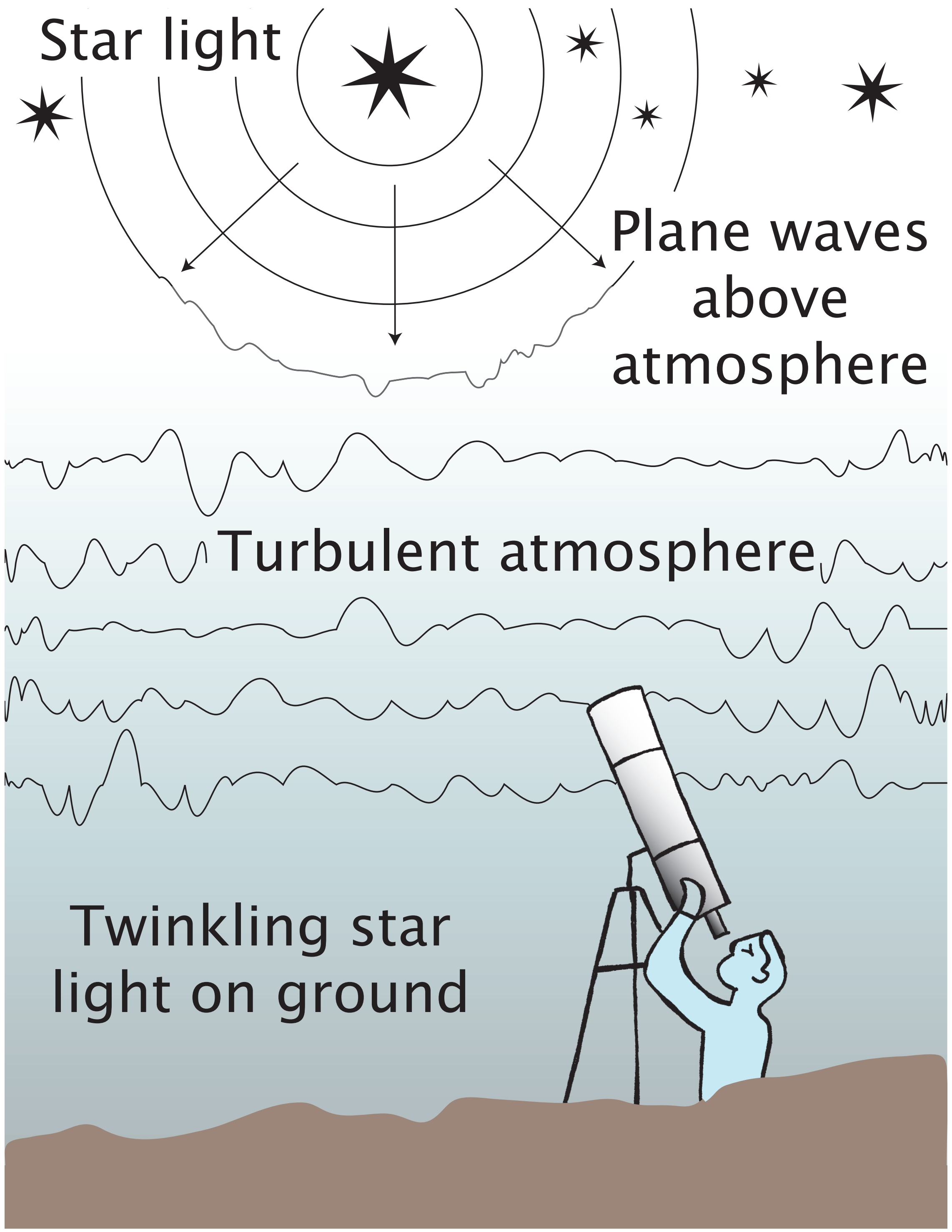
Accordingly, interferometric accuracy depends linearly on star separation, and improves with increasing baseline. For θ = 20 arcsec, *B* = 200 m, t =1 hr $\Rightarrow$ $\sigma \simeq$ 10 μas

... as targeted (but still to be demonstrated) by VLTI−PRIMA (Phase-Referenced Imaging and Microarcsec Astrometry) and VLTI−Gravity (stellar motions in the Galactic centre)

Accuracy of positions from the ground (4/4)

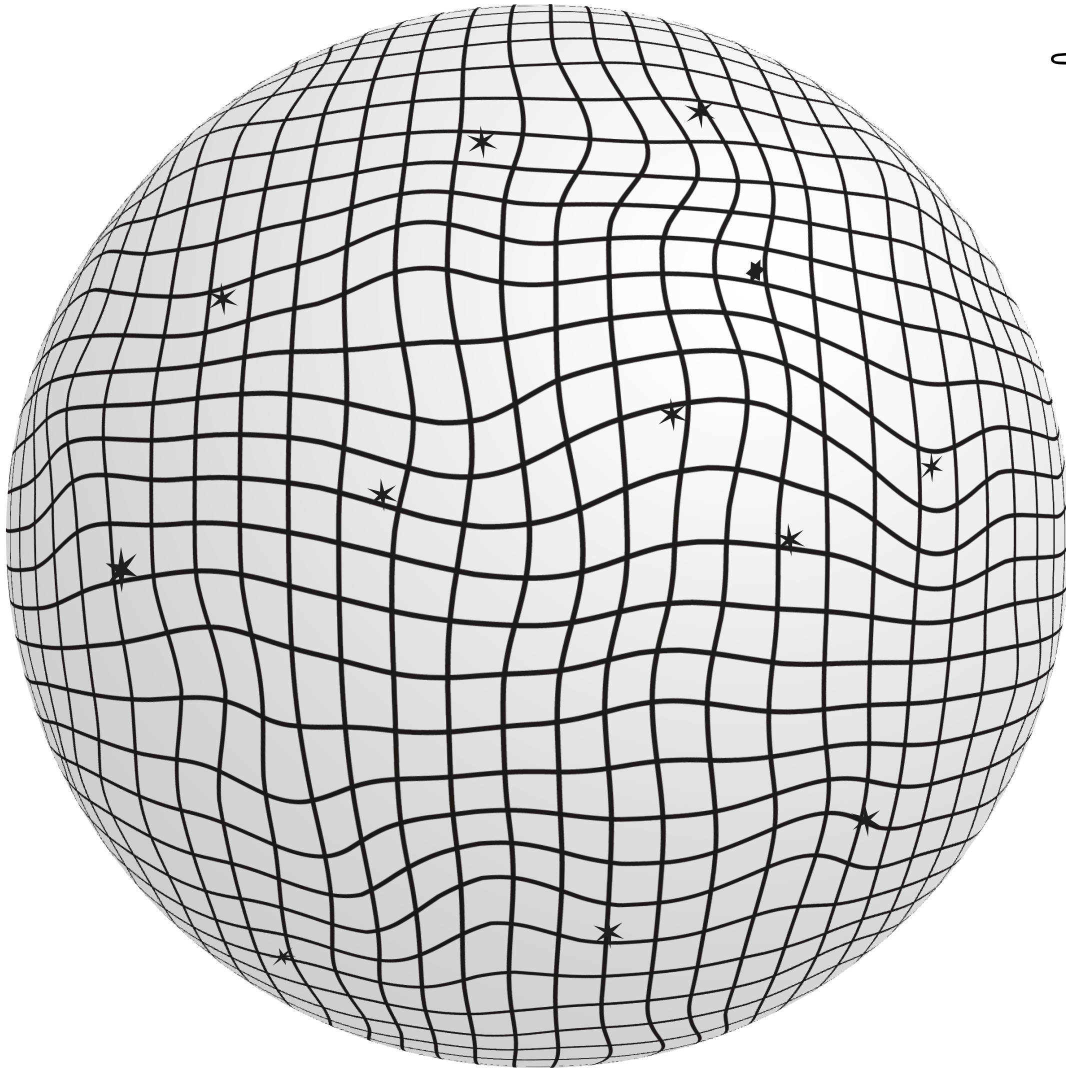
Antarctic:

- the integrated amplitude of $C_n^2(h)$ determines the 'seeing', usually quantified through the Fried parameter r_0. At optical wavelengths, Antarctic seeing is not exceptional, at $\sim 1-3$ arcsec
- but the determining factor for interferometric astrometry is 'tilt isoplanatism', the second moment of the $C_n^2(h)$ profile in the previous equation. The h^2 factor means that the accuracy is dominated by high-altitude turbulence
- at the south pole, this high-altitude profile is less affected by the jet streams, trade winds, and high-altitude wind shear that govern the behaviour at mid-latitude
- measurements from Dome C confirm long atmospheric coherent times, and large isoplanatic angles (~30 arcsec) over which the paths are temporally coherent... Lloyd et al (2002) even reported seeing Jupiter scintillate (angular diameter 30−50 arcsec)
- their studies suggest that a 100m interferometer at Dome C could reach 100 μas differential astrometry 300 times faster than a comparable interferometer at a good mid-latitude site

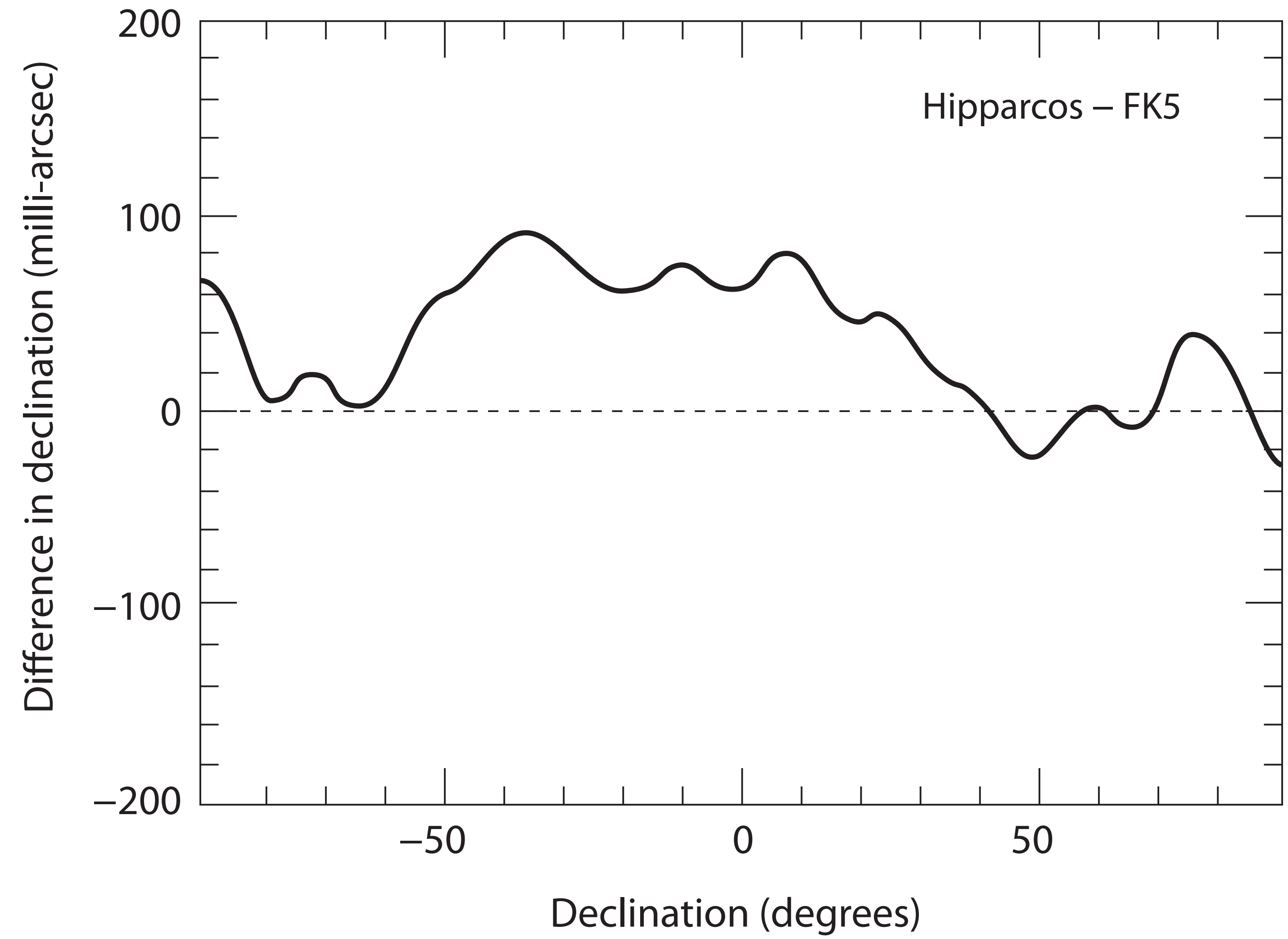


This is the problem...

These are the angles...



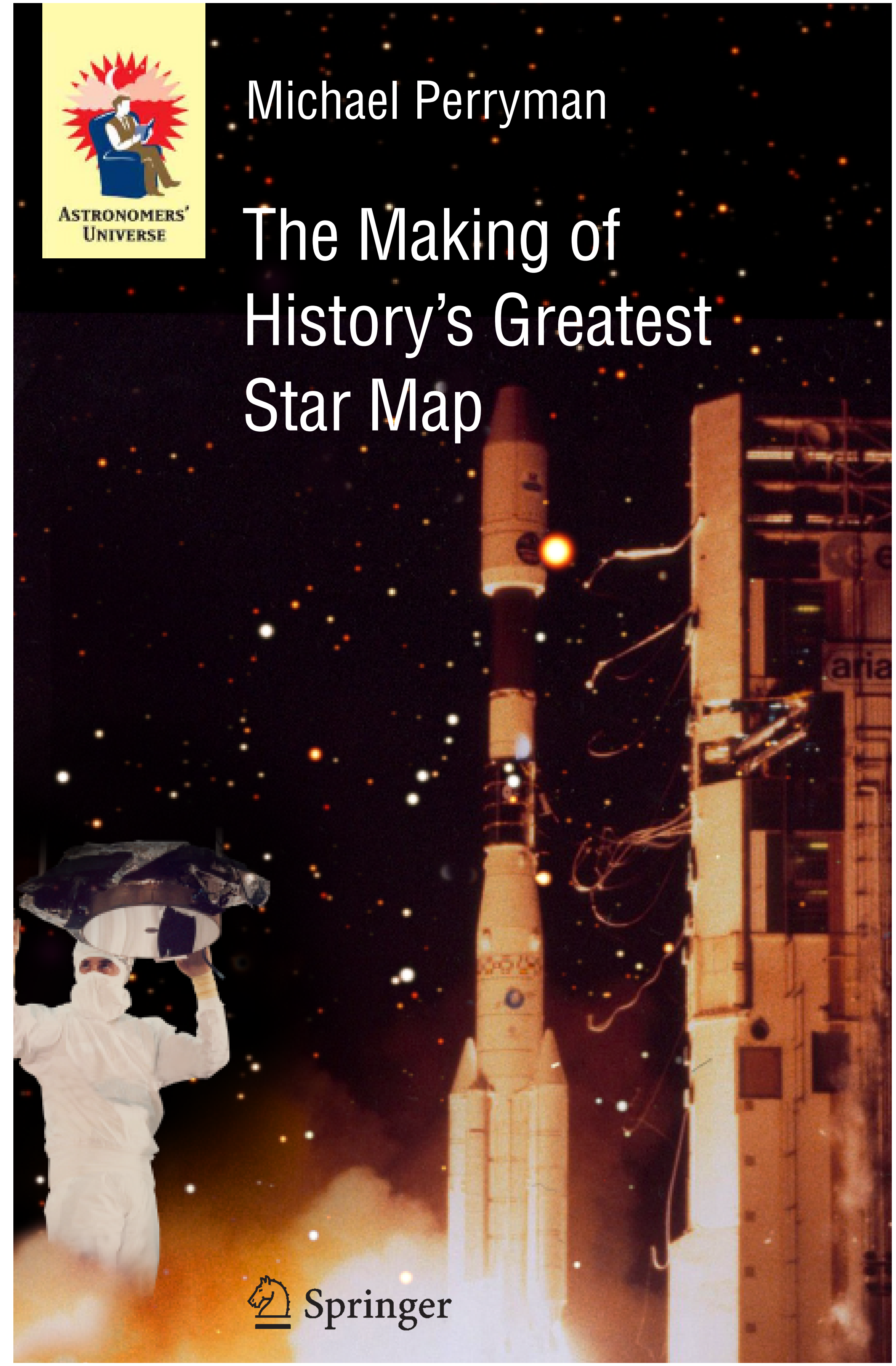
☞ schematic of a distorted reference frame



...it has proven impossible to eliminate these local distortions from small field observations (photographic plate or CCD), even using the method of 'block adjustment' (Eichhorn 1988)

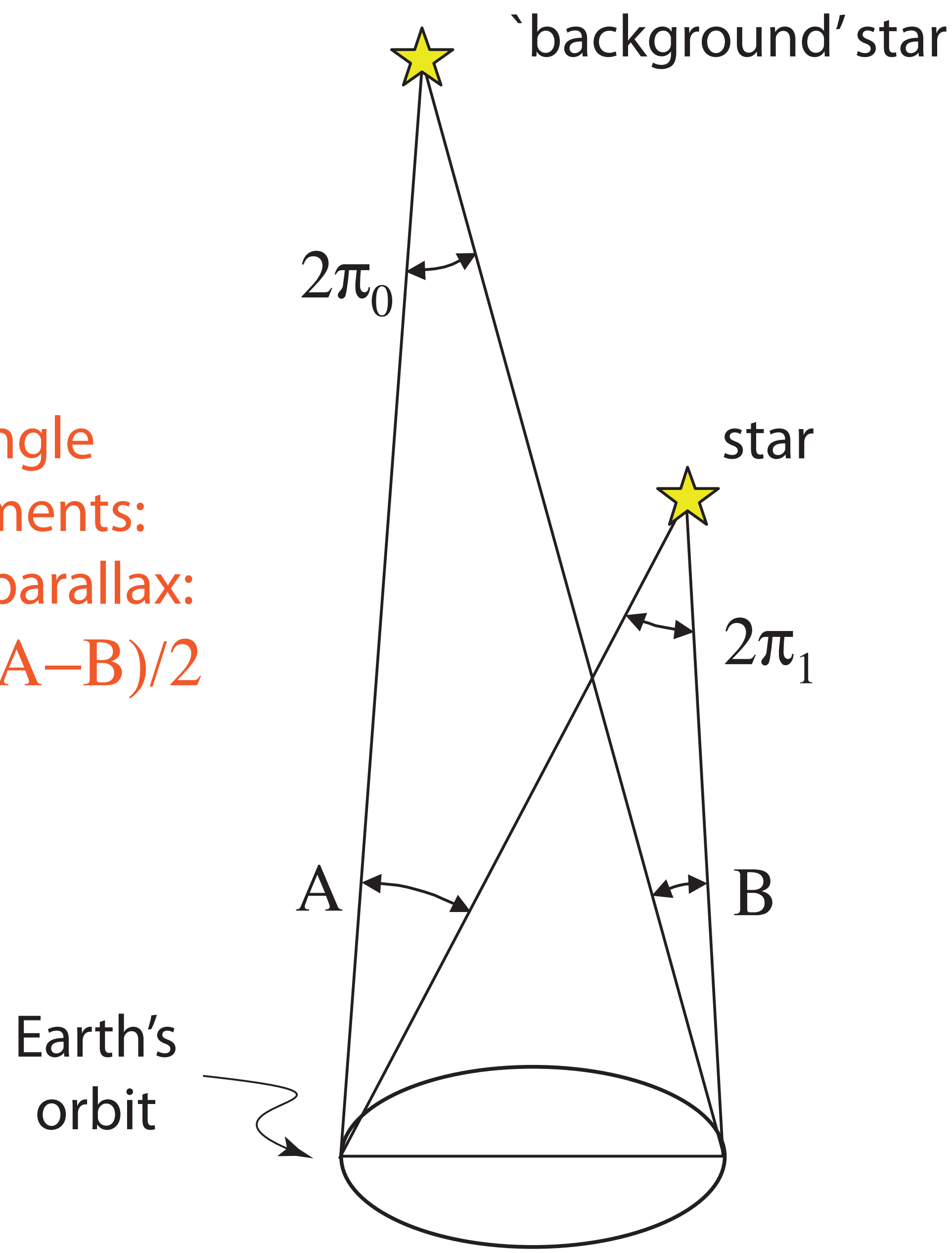
Hipparcos − ground-based (FK5) systematic errors (Schwan 2002)

- the original science case was to calibrate the upper part of the main sequence
- numerous political hurdles in getting the mission accepted by ESA (1978-1981)
- the work of 100 scientists, and 1000 engineers in 20 European industries
- two data analysis teams
- all conducted in an era when correspondence was by mail (telex if urgent) and data transferred on magnetic tape by post



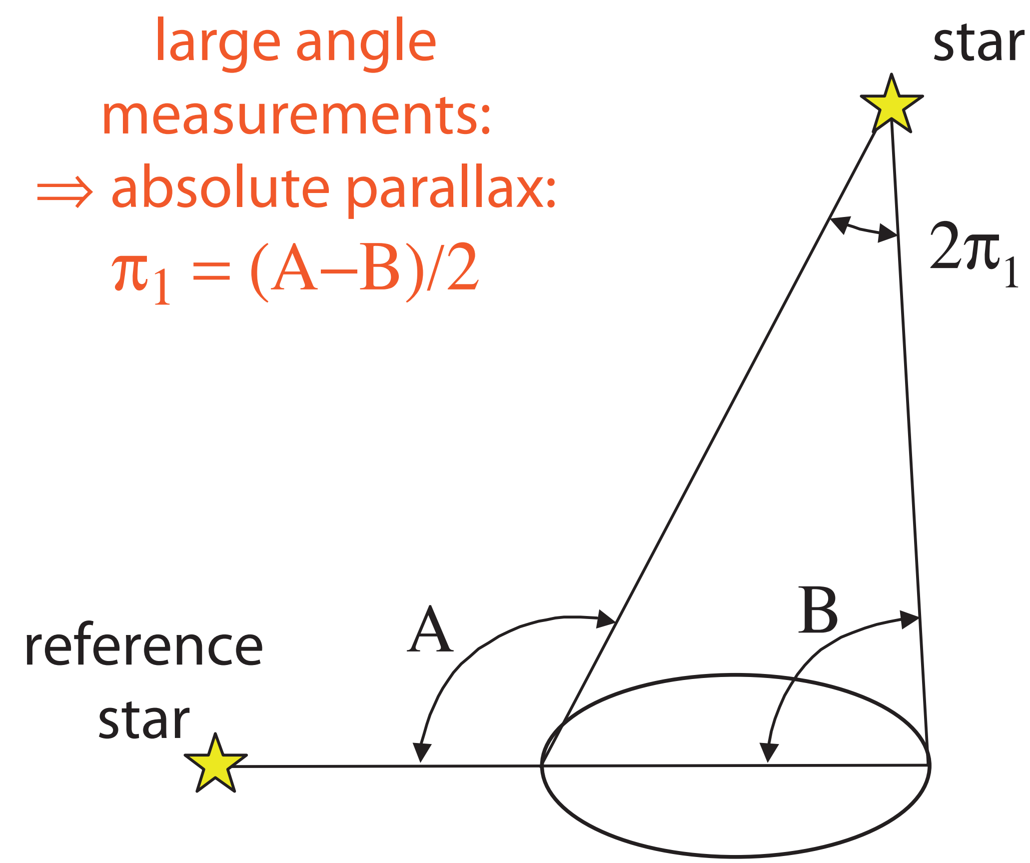
Measurement principle

small angle measurements:
$\Rightarrow$ relative parallax:
$\pi_1 - \pi_0 = (A-B)/2$



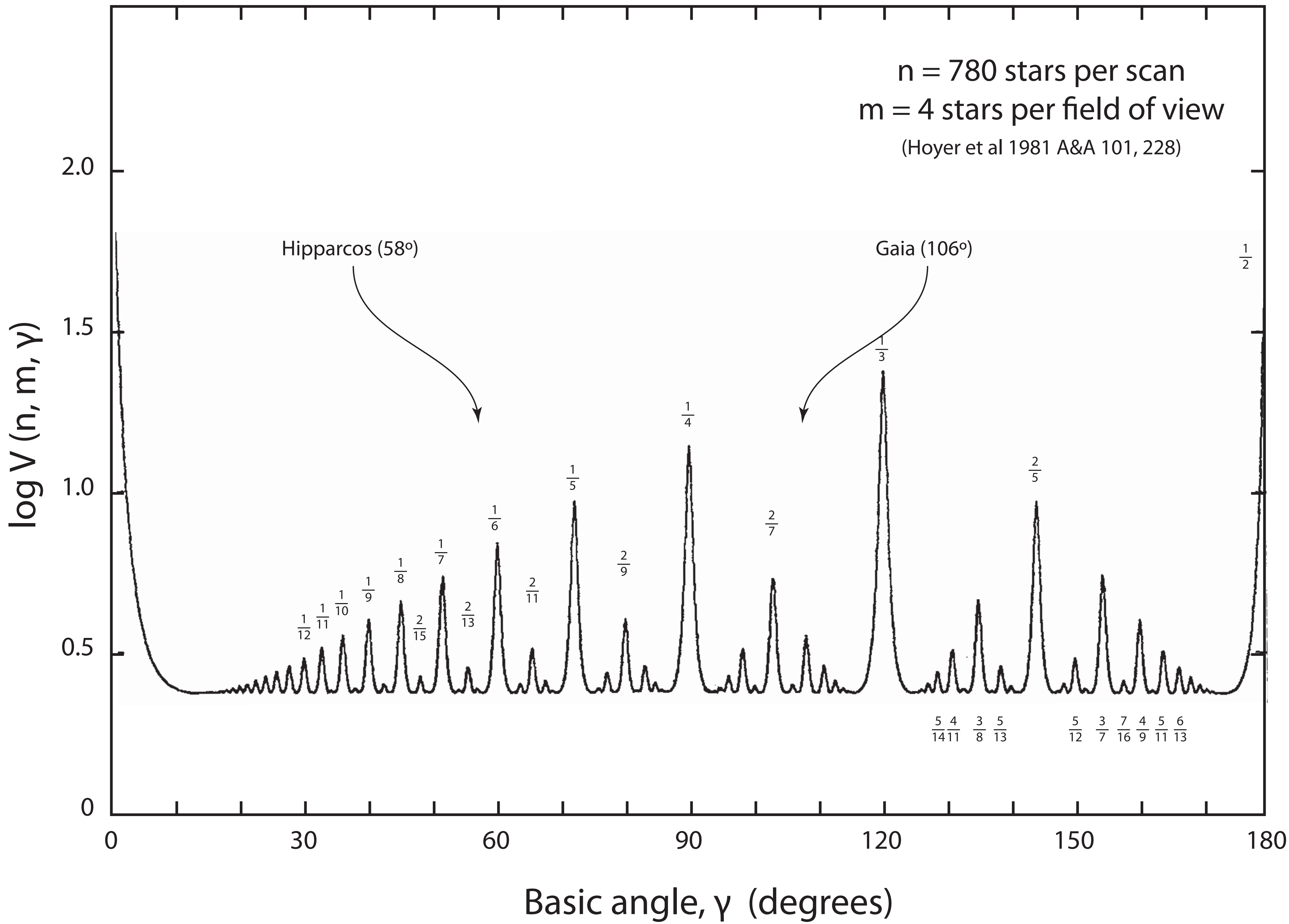
ground, or HST−FGS etc

large angle measurements:
$\Rightarrow$ absolute parallax:
$\pi_1 = (A-B)/2$



Hipparcos, Gaia

The basic angle follows from the great-circle rigidity...

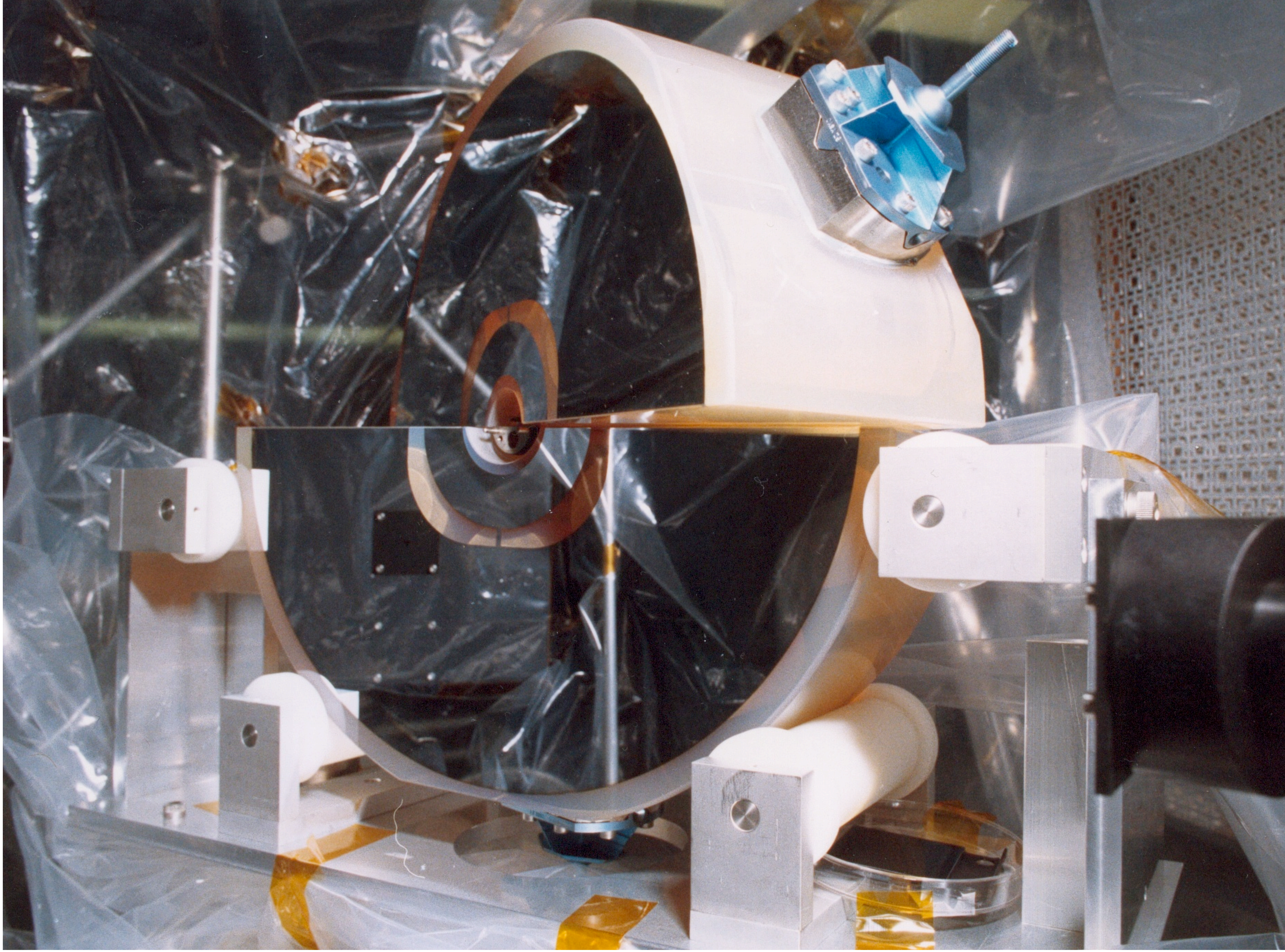


- Physics underpinning positional measurements:
  - the stellar distances (parallaxes): used to convert apparent quantities (notably magnitude) to absolute values (luminosities)
  - the space motions (angular, eg mas/yr), converted to linear space velocities (km/s) for kinematics and dynamics (absence of V_{rad})

- Main problems in making these measurements from ground:
  - the Earth's atmosphere (+ gravitational flexure +thermal variations)
  - determining an all-sky reference star grid such that:
    - the proper motions are (largely) free of systematics
    - the parallaxes are <u>absolute</u> (rather than relative)

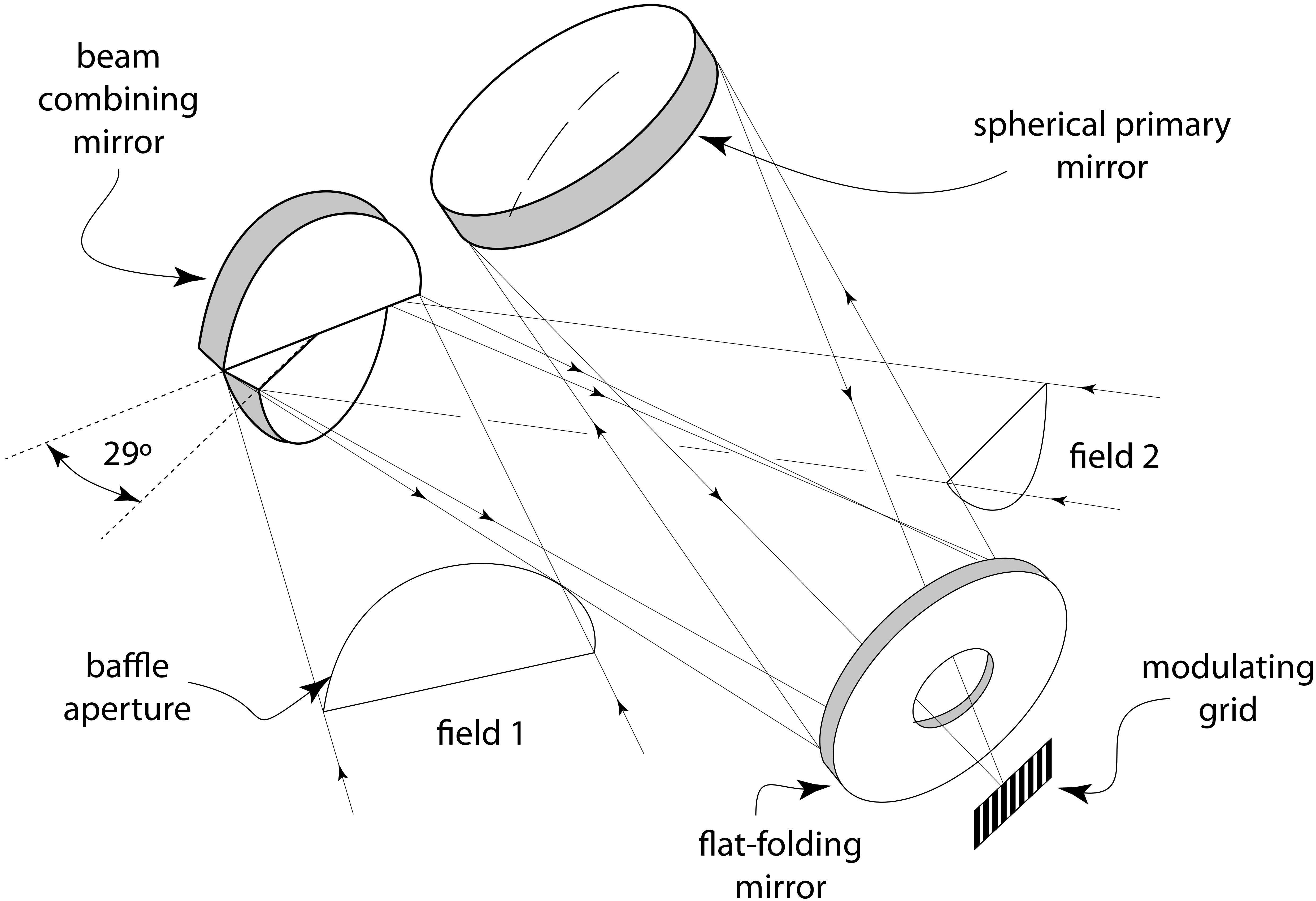
- Justification for making these measurements from space:
  - measurements <u>above</u> the atmosphere
  - the consequent ability to make <u>large-angle</u> measurements
  - the resulting provision of <u>absolute</u> parallaxes

Early discussions, Bordeaux 1965

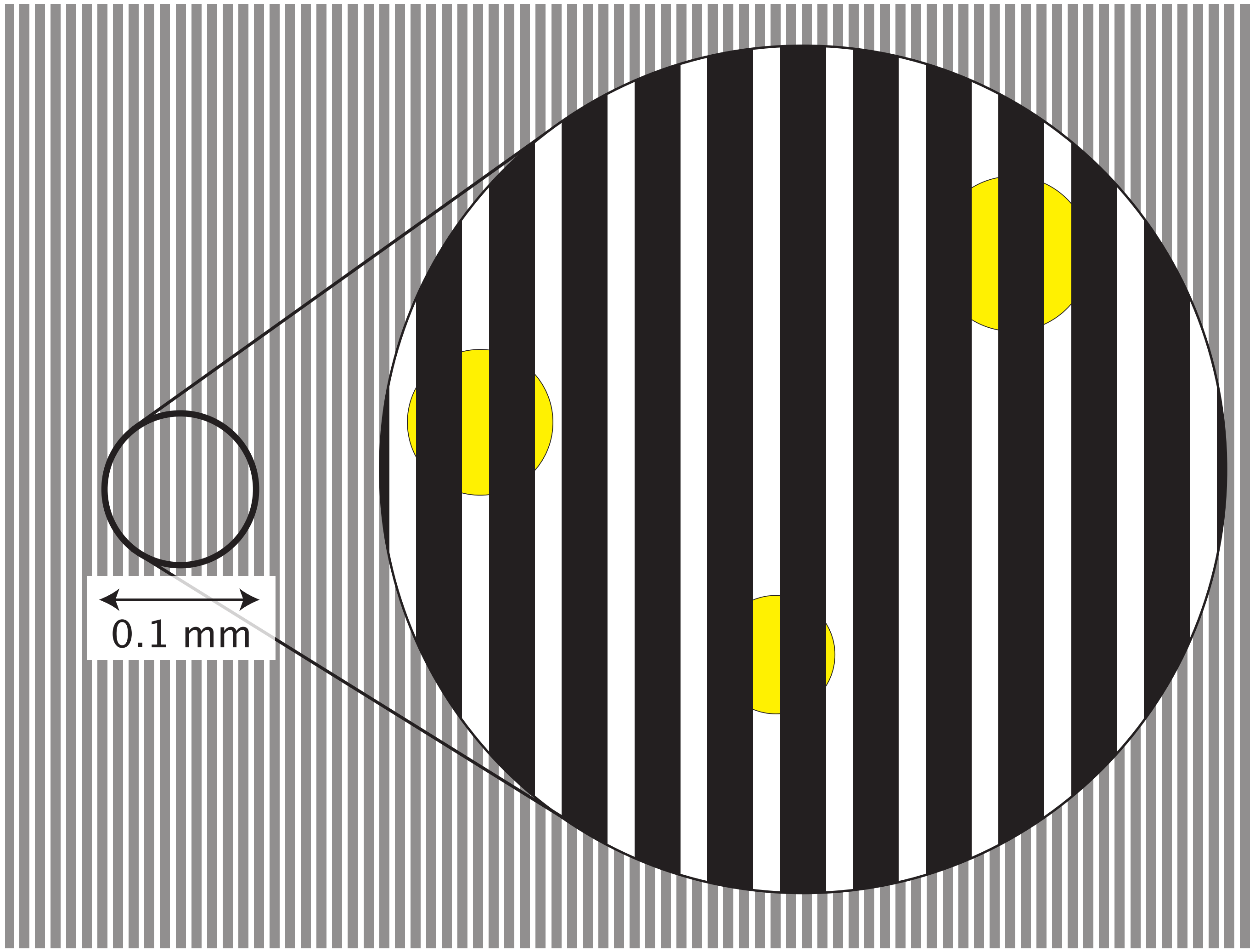


The 30 cm diameter beam combining mirror (now in National Maritime Museum, London)

Hipparcos optical design



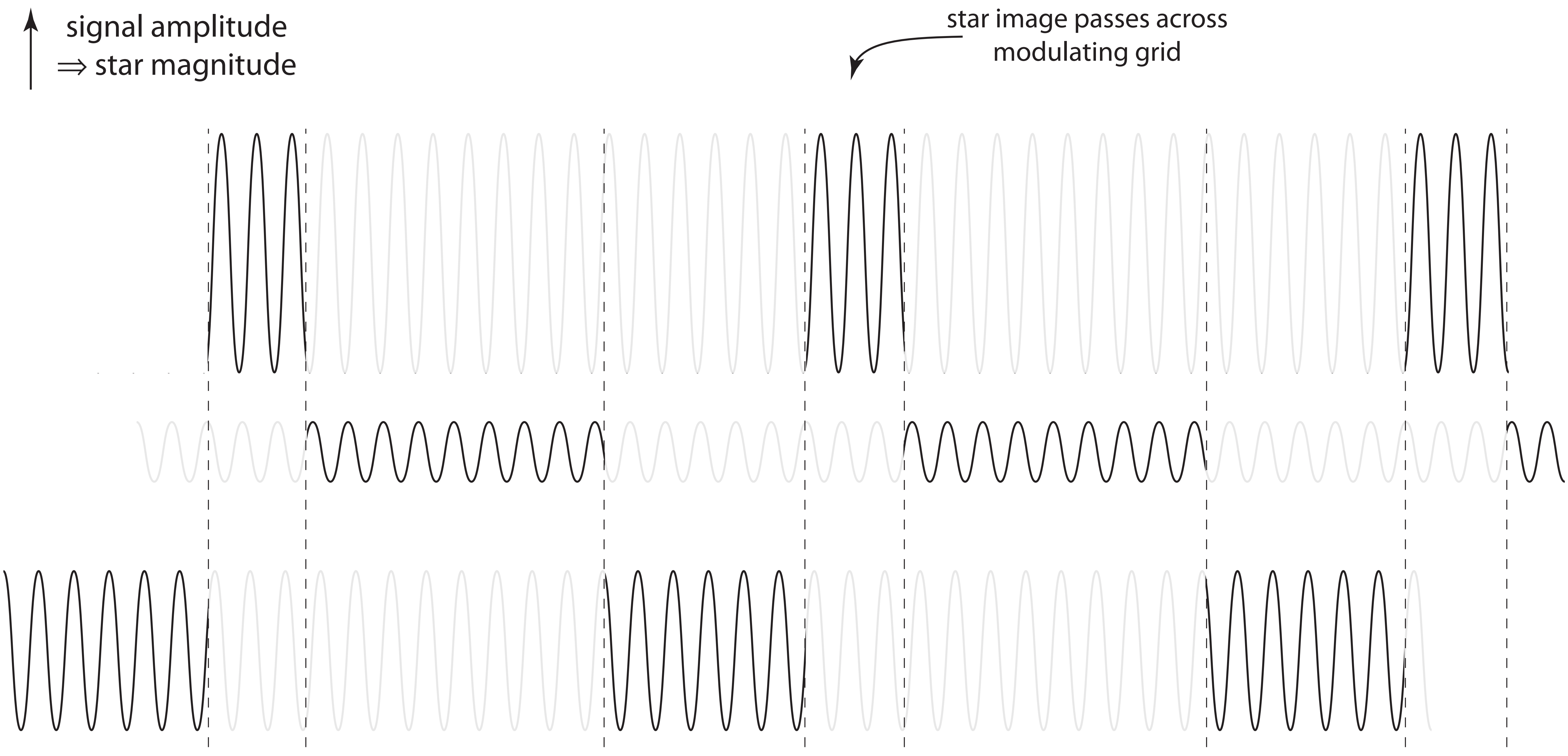
Hipparcos: measurements at the focal plane



- a high fidelity modulating grid
- 2688 grid lines
- about 2.5 cm x 2.5 cm
- grid period = 1.208 arcsec on sky

- star images pass behind grid
- detector with piloted field of view sampled the modulated signal by switching rapidly between star images several times per sec
- both fields of view are sampled
- modulation intensity → star magnitude
- relative signal phase → along-scan separation (modulo grid period and γ)
- star positions established to ~1 arcsec *a priori*, to allow detector piloting, and to resolve the grid period ambiguity in the relative separation
- signal digitised at 1200 Hz, sent to ground

Image dissector tube piloting

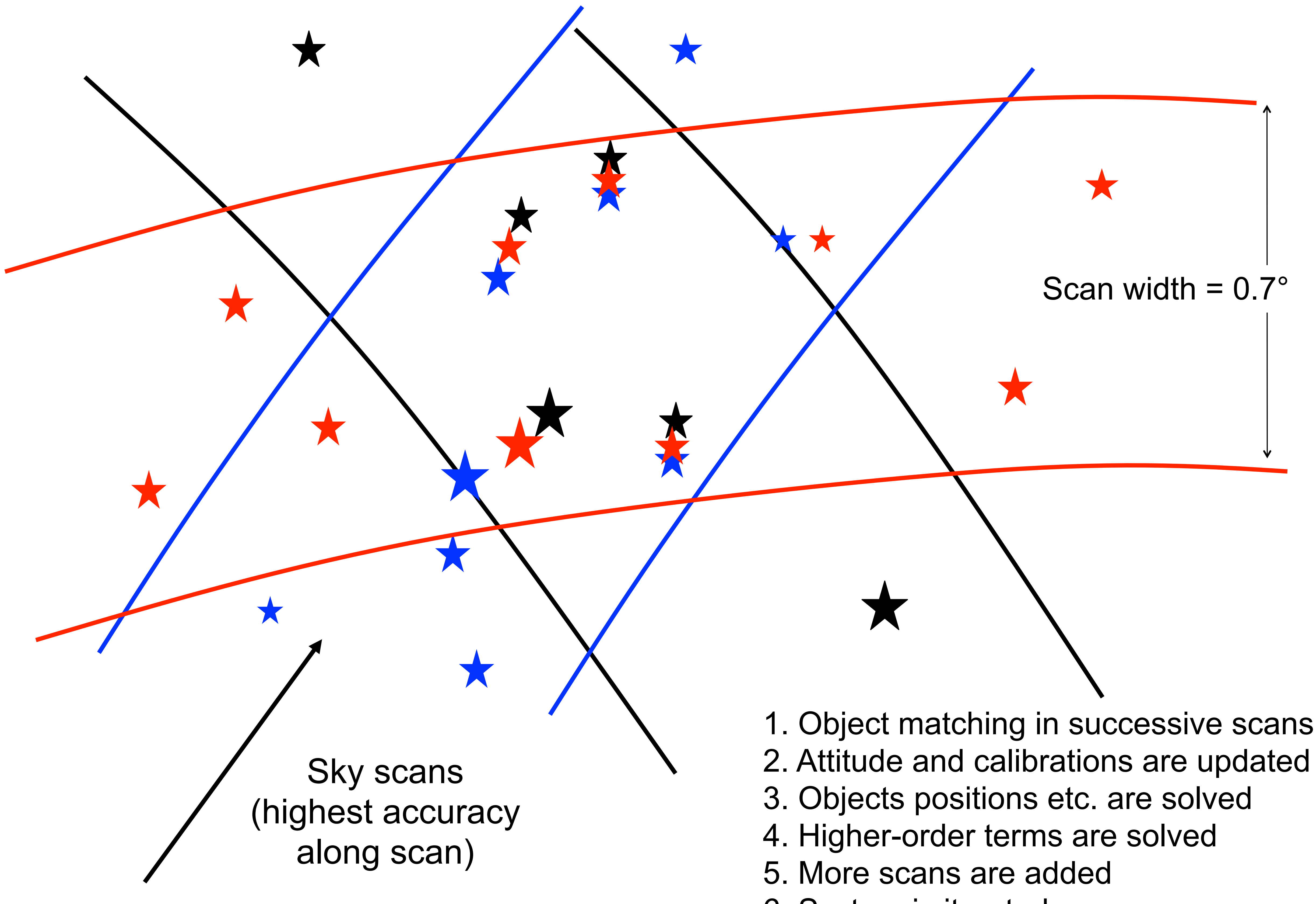


* requires star positions a priori
* dwell period ∝ star magnitude
* switching frequency = f(structural modes)

phase difference ⇒ along-scan separation,
modulo grid period (~1.2 arcsec) and basic angle (γ ~58°)

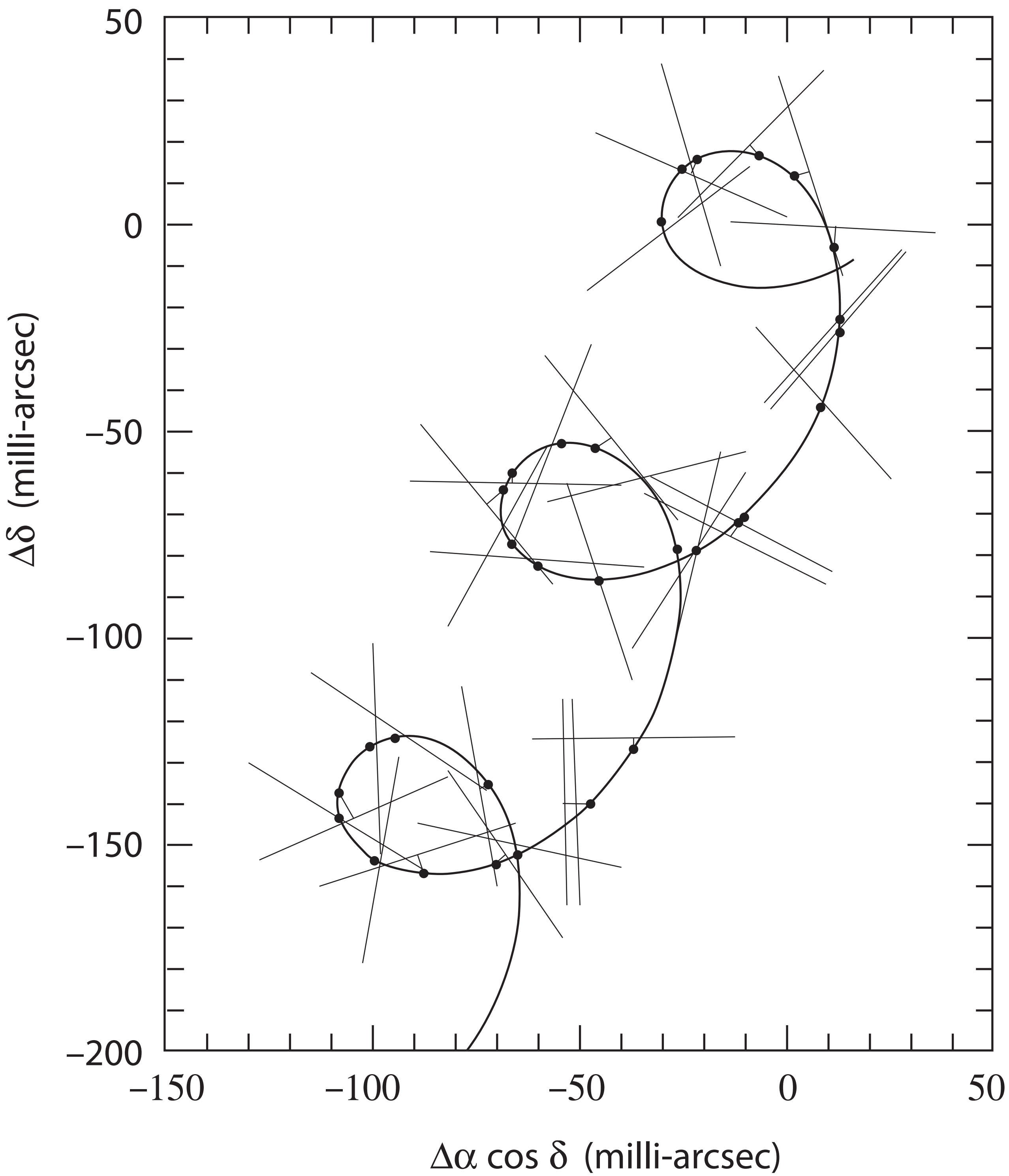
second harmonic (A,ϕ) ⇒ binary star (Δm, $\Delta\theta$)

Star Observing Principles: Hipparcos & Gaia



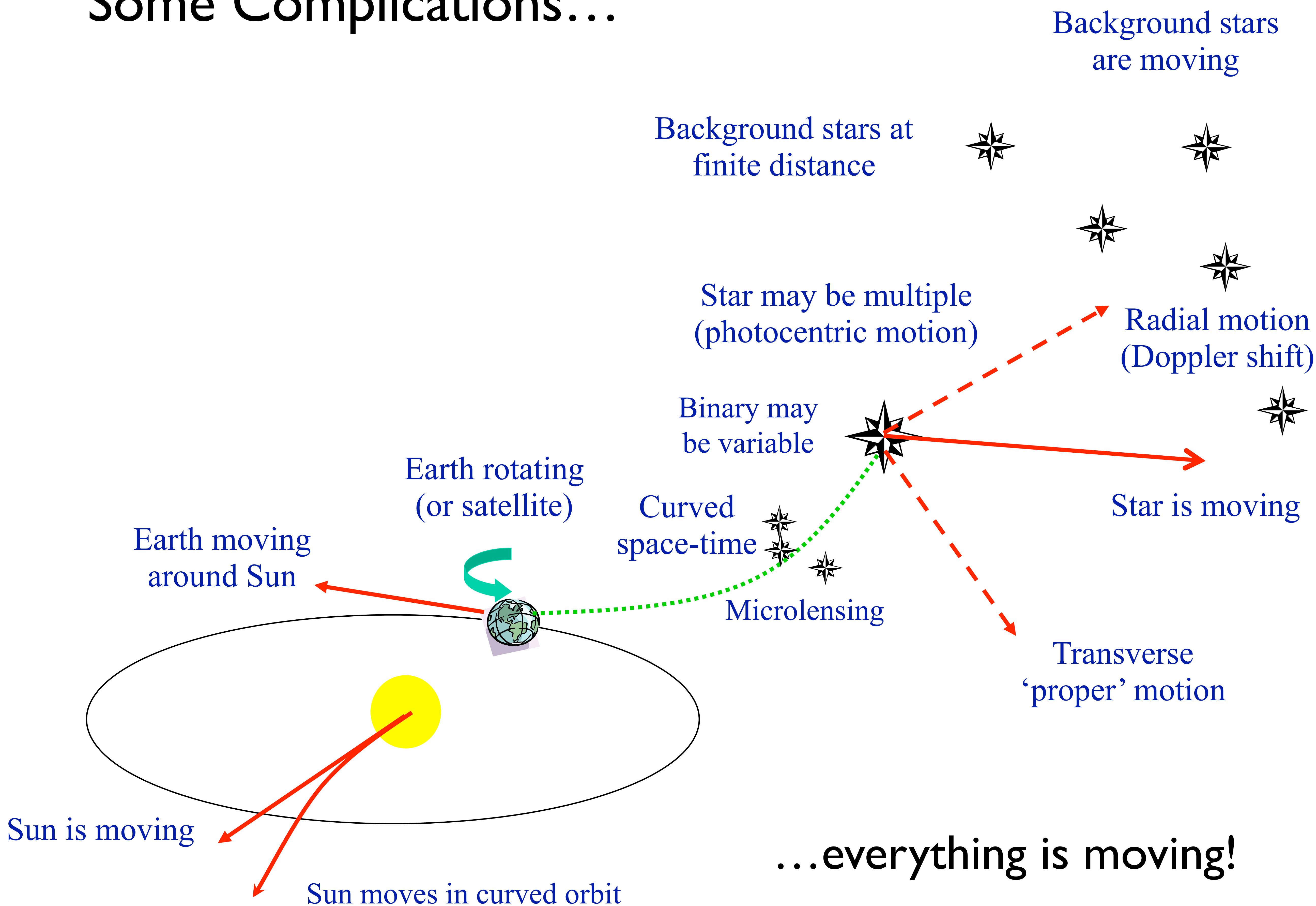
1. Object matching in successive scans
2. Attitude and calibrations are updated
3. Objects positions etc. are solved
4. Higher-order terms are solved
5. More scans are added
6. System is iterated

Data Analysis: Principles



- as the satellite traces out a series of great circles on the sky, each star is (effectively) instantaneously stationary
- each star has a 2d position (abscissa and ordinate) projected onto that great circle
- in principle one should solve for both coordinates
- in practice, only the projection along the great circle (abscissa) dominates the 'great-circle solution'
- least-squares adjustment gives the along-scan position of each star at that epoch
- all great circles (12 hr duration) over the entire 3-year mission are then 'assembled'
- a star's position at any time *t* is represented by just <u>five</u> parameters: position (*xy*), proper motion components (μ_x, μ_y), parallax (π)

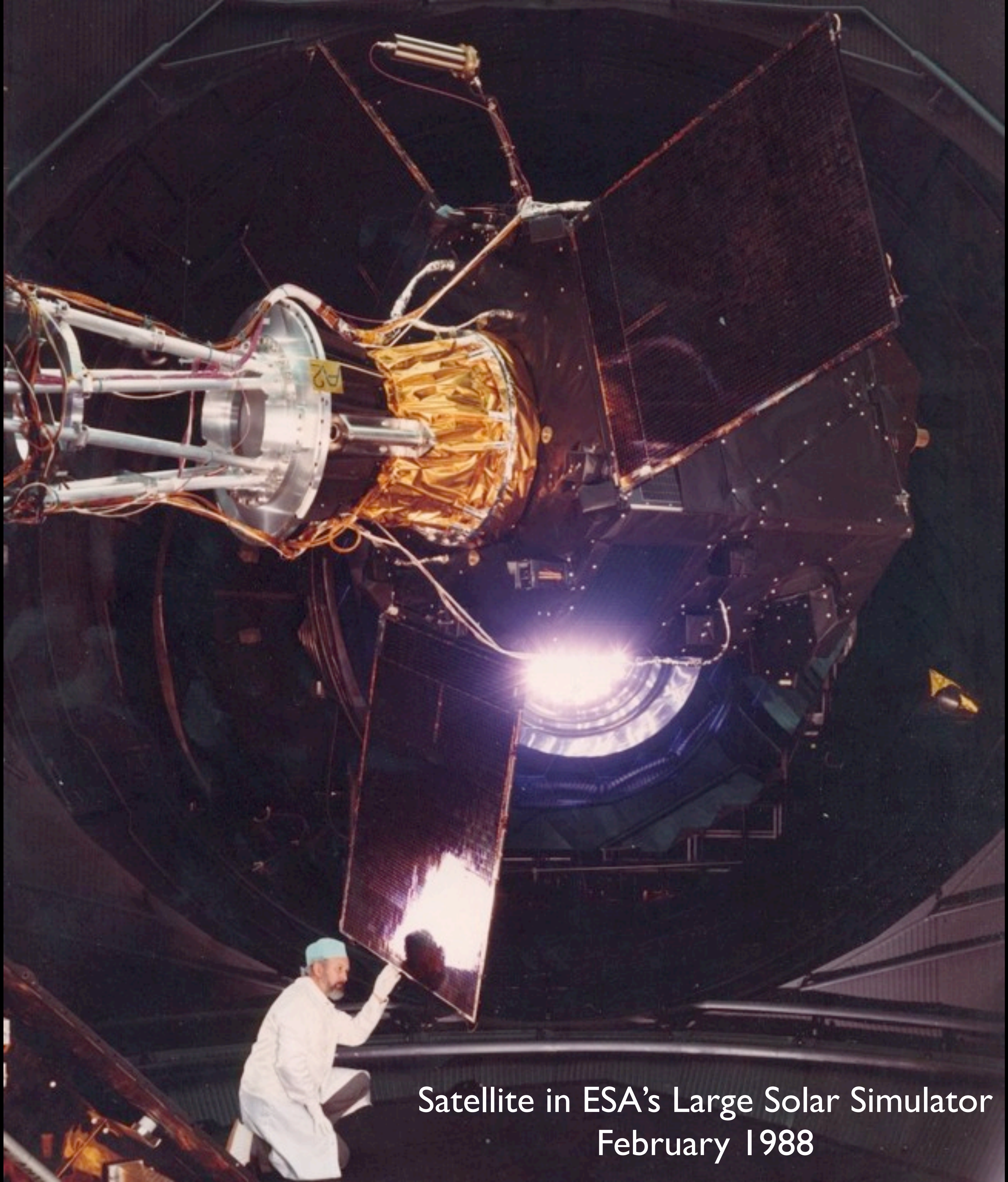
Some Complications…



…everything is moving!

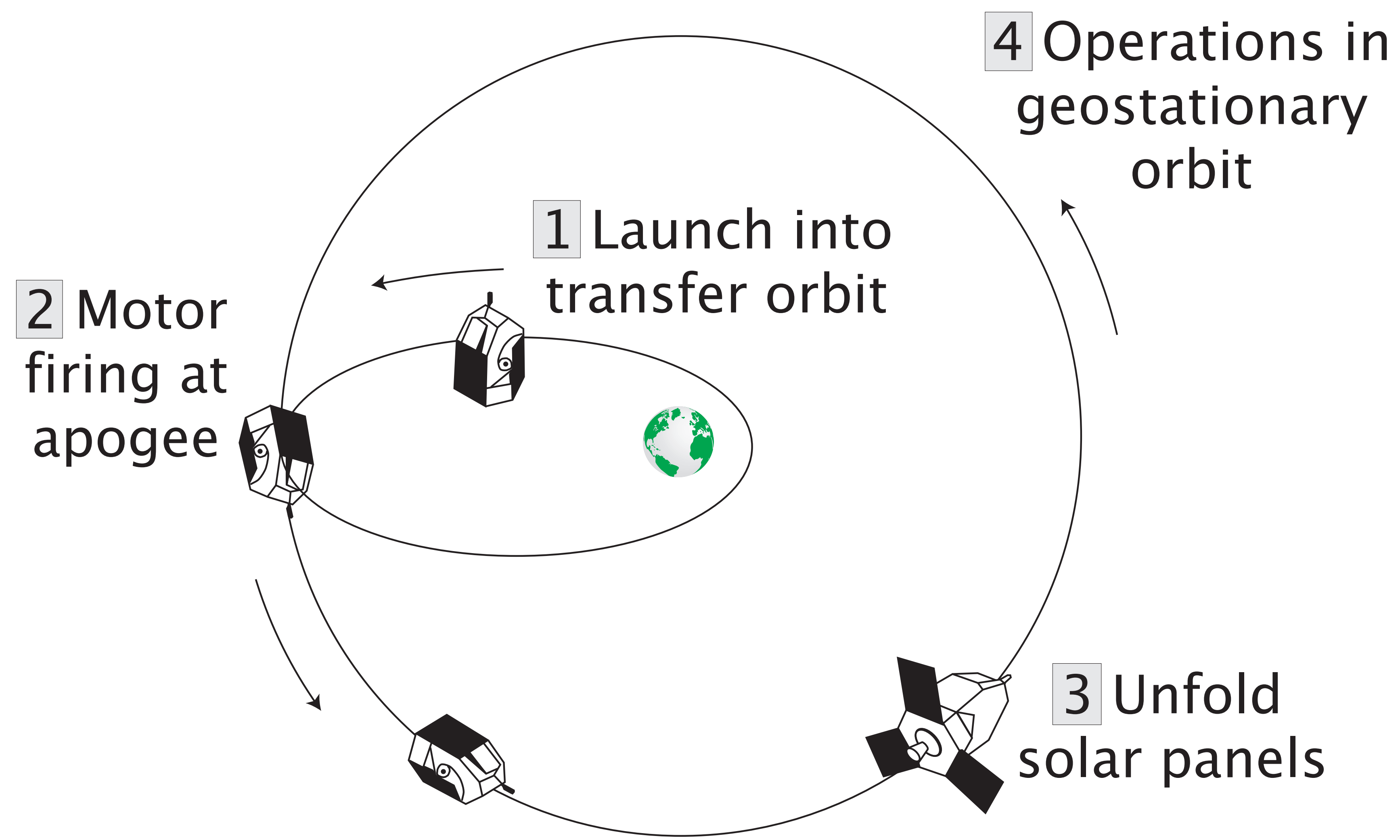
Hipparcos: many detailed technical issues

- uplink of star catalogue to be observed over next hours
- gas jet thrusters to:
  - keep satellite spinning uniformly
  - follow the pre-determined sky-scanning law
- rigorous thermal control, including fixed angle of solar illumination (defined by the scanning law)
- on-board data handling
- downlink: telemetry stream with star identification
- 3-year observation lifetime to give separability positions, parallaxes, and proper motions



Satellite in ESA’s Large Solar Simulator
February 1988

Launch - transfer orbit - geostationary orbit



Scientists losing hope for satellite trapped in orbit

By Mary Fagan
Technology Correspondent

SCIENTISTS are losing hope that they can save the Hipparcos satellite, which was to be one of the most important science projects of the century, from being trapped forever in the wrong

ground station at Perth in Australia, but even then the satellite

Independent, 15 August 1989

Hi-Shear Part Blamed For Hipparcos Failure

By PETER B. de SELDING
Space News Staff Writer

PARIS — A faulty component supplied by a California company was the principal

There remains a possibility that the explosive transfer lines connected to the initiators might themselves have delivered a weak charge which, when combined with

Space News, 16 July 1990

HIPPARCOS

Bad day for astronomers

Kourou, French Guiana

AFTER a perfect launch in French Guiana on 8 August, the European astronomy satellite Hipparcos ran into trouble when the apogee motor failed three times to respond to commands to fire. The motor is responsible for lifting the satellite into

carrying a West German direct broadcasting television satellite, TV-SAT 2, as well as Hipparcos. The first launch attempt was stopped seven seconds short of ignition by an overzealous computer. But then the mission got off to a good start with the perfect positioning of Hipparcos

Nature, 17 August 1989

Scientists battle to revive star satellite

By Steve Connor, Technology Correspondent

SCIENTISTS will try to revive a satellite today which is orbiting aimlessly around the Earth after its booster rocket twice failed to respond

The booster rocket, called the apogee engine, yesterday failed to respond to a command to fire which should have moved the satellite into a much bigger

Daily Telegraph, 12 August 1989

Space partners fall out over British cuts to star map project

Robin McKie and Nicholas Booth

A BITTER conflict has broken out between Britain and its European space partners over plans to halt UK funding for a unique star-mapping probe that is circling the Earth.

cussions beyond the country's involvement in the project. Analysis of three years' data is required to improve our knowledge of star positions. Any disruption would curtail the project indefinitely.

The threatened cut infuriated Esa delegates when they were

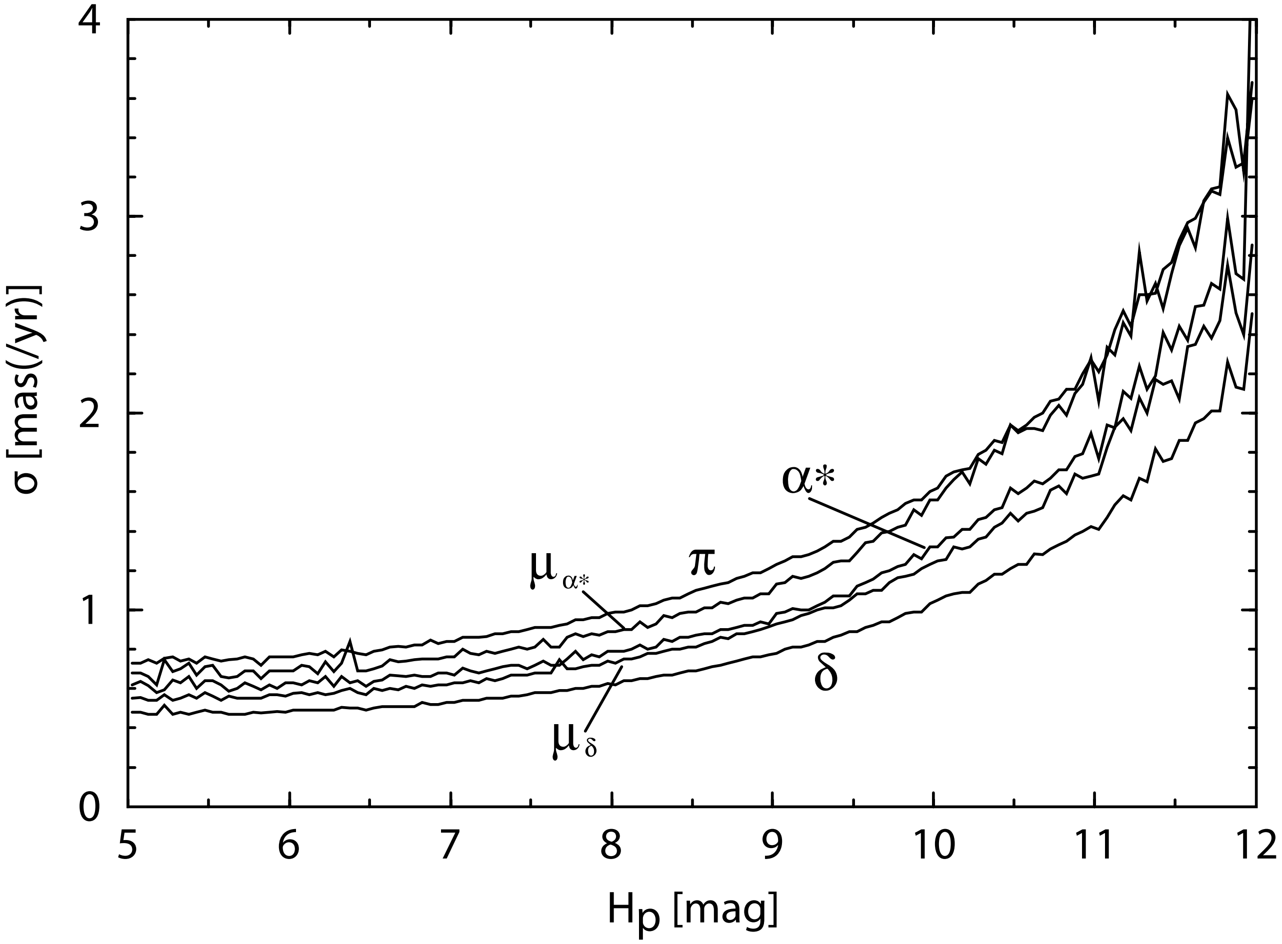
The Observer, 24 March 1991

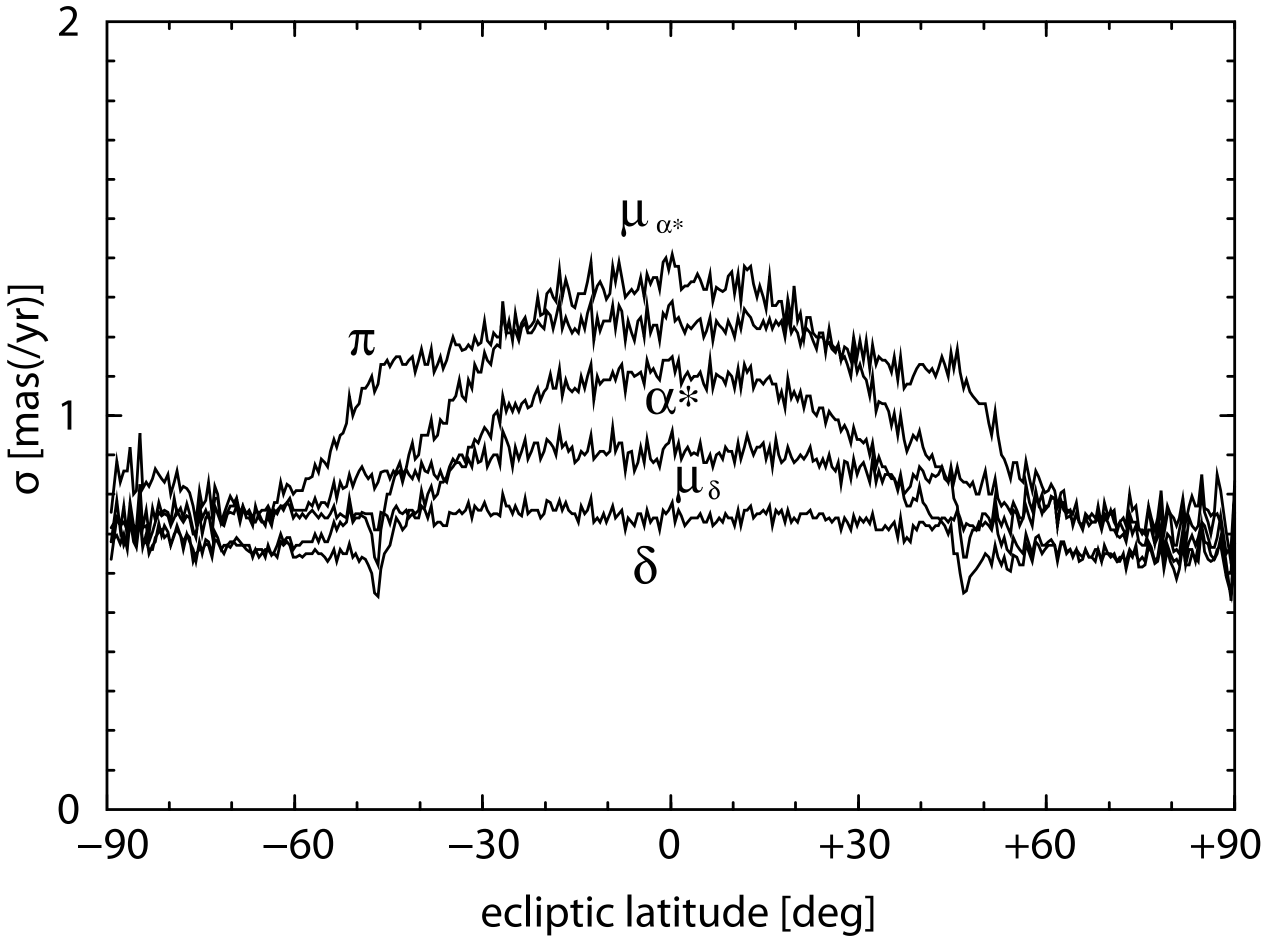
Retrospective of major milestones

- 1968: first proposals for space astrometry
- 1980: acceptance by ESA's Science Programme Committee
- 1981: start of Phase B
- 1989: launch by Ariane 4, flight 33 (Kourou)
- 1993: end of satellite operations
- 1996: completion of data analysis (NDAC/FAST, TDAC)
- 1997: release of the Hipparcos Catalogue (118,000 stars)
  release of the Tycho Catalogue (1 million stars)
- 2000: release of Tycho 2 Catalogue (2.5 million stars)

Numerical results

A catalogue of 118,000 stars (published 1997):
each of the 5 parameters determined to ~1 milliarcsec





The printed catalogue...

Number HIP 1	2	Descriptor: epoch J1991.25 RA h m s 3	Dec ° ′ ″ 4	V mag 5	6 7	Position: epoch J1991.25 α (ICRS) deg 8	δ deg 9	10	Par. π mas 11	Proper Motion μα* mas/yr 12	μδ 13	Standard Errors α* mas 14	δ 15	π 16	μα* mas/yr 17	μδ 18	Astrometric Correlations (%) δ/α* π/α* π/δ μα*/α* μα*/δ μα*/π μδ/α* μδ/δ μδ/π μδ/μα* 19–28	Soln F1 % 29	F2 30
32301		06 44 37.45	−38 26 12.3	8.80	H	101.156 050 02	−38.436 752 52		−0.45	5.30	−0.21	0.75	0.76	0.91	0.97	1.19	− 3 +17 − 9 +12 + 0 − 4 + 2 −13 +13 − 3	0	−2.25
32302		06 44 38.52	+19 59 15.4	8.68	G	101.160 515 05	+19.987 620 00		2.28	−0.89	−2.08	1.17	0.69	1.34	1.45	1.02	+12 +27 −32 −12 −29 +31 − 3 −63 +40 +41	6	3.43
32303		06 44 39.94	−14 43 42.4	8.83	H	101.166 427 36	−14.728 444 16		8.48	−18.80	−31.95	0.94	0.82	1.07	1.26	1.07	− 4 +32 + 2 −25 + 2 − 8 + 4 −30 +10 −36	0	−1.53
32304		06 44 41.19	+38 46 41.4	9.56	H	101.171 613 91	+38.778 176 56		5.72	−1.90	−24.34	1.33	0.85	1.47	1.69	1.08	+ 7 +29 − 1 −17 −19 + 9 −16 −53 − 4 +15	0	−2.67
32305		06 44 42.19	+59 38 26.0	9.69	G	101.175 777 63	+59.640 564 09		2.61	−0.75	−5.55	1.22	1.13	1.58	1.60	1.15	− 2 +25 −26 + 6 +29 + 8 +28 − 4 + 5 +23	0	−0.40
*32306		06 44 42.94	+26 07 48.7	9.20	H	101.178 897 28	+26.130 197 74		2.23	5.54	−22.38	1.55	0.84	1.51	2.08	1.30	−20 +16 + 8 +23 +20 +16 +45 −53 − 6 +18	0	0.08
*32307		06 44 42.89	−57 26 25.6	8.55	G	101.178 694 46	−57.440 432 20		10.93	−52.24	56.74	1.21	1.18	1.29	1.37	1.27	− 6 +12 + 3 + 4 − 6 − 6 −11 −21 − 3 −28	0	
32308		06 44 42.97	+14 54 37.4	10.73	H	101.179 036 65	+14.910 388 44		18.07	12.45	−168.02	2.21	1.27	2.26	2.40	1.72	−10 +43 −12 −17 + 4 − 7 +11 −64 + 5 + 7	0	−0.06
32309		06 44 44.22	−61 13 27.3	6.95	H	101.184 250 53	−61.224 248 79		3.31	−8.59	8.03	0.55	0.49	0.54	0.61	0.58	− 2 +11 +10 + 8 − 7 − 7 − 8 + 5 − 5 −16	0	−0.79
32310		06 44 44.35	−19 03 10.7	7.32	H	101.184 780 68	−19.052 981 12		3.00	−6.54	1.13	0.42	0.48	0.74	0.51	0.60	+ 5 − 2 − 2 +15 +11 −10 + 7 − 5 − 1 −13	0	−0.87
32311		06 44 45.46	+28 58 15.6	5.42	H	101.189 436 33	+28.970 989 12		5.72	−8.75	−23.65	0.79	0.43	0.84	0.96	0.64	+19 +33 − 7 + 3 −13 + 2 − 4 −42 +22 +24	0	0.31
32312	H	06 44 45.63	−04 23 36.8	8.55	1 G	101.190 105 63	−04.393 555 80	A	4.10	−5.45	−1.18	2.03	2.00	1.92	1.62	1.42	−25 +20 −11 −27 + 1 −32 − 8 −17 −26 +14	0	1.33
32313		06 44 45.92	+71 53 20.3	10.92	H	101.191 327 78	+71.888 964 31		44.43	−118.98	−549.44	2.67	3.56	4.88	2.94	4.18	+ 4 +11 + 2 − 5 + 3 + 9 + 3 −13 + 6 + 7	1	
32314	H	06 44 46.27	−52 25 25.0	8.29	H	101.192 792 15	−52.423 618 21	A	4.98	−6.12	12.63	1.24	1.23	1.18	1.25	1.33	− 6 − 4 − 1 −21 − 9 +19 − 9 −18 − 1 −22	1	−0.36
32315		06 44 46.60	+44 30 20.0	6.64	H	101.194 150 53	+44.505 542 19		2.53	1.32	−16.23	0.68	0.51	0.79	0.89	0.61	− 9 +11 − 2 + 2 −16 + 8 −14 −25 −10 −11	0	1.72
32316		06 44 46.66	−09 23 38.7	7.79	H	101.194 436 11	−09.394 078 52		4.88	11.76	−4.50	0.86	0.68	0.96	0.93	0.80	−26 +36 −14 −39 + 8 − 4 +12 −50 + 7 + 0	0	−0.04
32317		06 44 48.95	−28 23 39.8	9.97	H	101.203 976 55	−28.394 400 35		2.64	−13.78	6.92	0.94	1.14	1.56	1.15	1.34	− 6 + 8 +14 + 6 − 8 +17 −10 − 3 − 4 − 4	0	2.81
32318		06 44 49.57	+03 40 47.7	7.63	H	101.206 552 04	+03.679 903 28		0.65	−1.82	−0.29	0.89	0.54	1.05	0.87	0.68	− 5 +45 − 4 − 9 − 6 −24 −11 −45 −11 + 1	0	0.52
32319		06 44 50.94	−18 34 13.6	7.07	H	101.212 241 21	−18.570 445 70		11.21	−16.00	−18.46	0.43	0.48	0.79	0.52	0.59	+ 1 + 5 −13 +22 +24 − 9 +20 −12 + 2 −12	0	−1.39
32320	H	06 44 51.63	+59 26 57.3	7.07	H	101.215 130 15	+59.449 252 74	A	9.43	−2.67	11.42	1.10	0.89	1.24	1.30	0.81	−22 +51 −30 +12 + 5 +29 +16 −19 +13 − 1	2	1.54
32321		06 44 51.80	+49 20 37.1	7.99	G	101.215 818 18	+49.343 650 45		7.42	−41.40	−14.85	0.78	0.64	1.04	1.02	0.73	−13 +31 −37 − 1 −18 +15 + 1 −33 +25 +26	0	1.58
32322		06 44 51.96	−27 20 32.6	6.43	H	101.216 483 45	−27.342 380 72		37.60	−6.18	293.89	0.41	0.50	0.65	0.50	0.55	− 5 + 2 + 3 + 7 −19 − 8 −17 + 3 + 8 −10	2	0.91
32323		06 44 52.08	−59 18 13.9	9.53	H	101.216 982 02	−59.303 872 91		1.30	−2.14	7.28	0.72	0.77	0.80	0.79	0.93	− 3 − 4 + 2 + 7 + 0 −23 + 1 +12 − 2 − 5	0	0.46
32324		06 44 52.52	+19 31 39.5	8.12	H	101.218 853 55	+19.527 631 57		3.61	−4.73	1.98	1.82	1.13	1.79	2.11	1.54	+19 − 8 −18 −41 −19 +14 −22 −66 +18 +15	2	
32325		06 44 53.37	+23 13 40.2	8.85	H	101.222 362 82	+23.227 843 36		1.73	−23.86	1.91	1.61	0.70	1.77	1.79	1.11	+16 +56 − 2 + 2 − 5 − 6 +17 −52 +37 +17	6	0.57
32326		06 44 53.45	−66 51 56.4	8.71	1 H	101.222 705 66	−66.865 662 50		16.46	−38.05	−48.55	0.69	0.66	0.72	0.49	0.70	− 2 +27 +17 −68 − 1 −19 + 0 −19 − 5 −10	2	−0.22
32327		06 44 53.81	+00 37 12.6	9.24	G	101.224 228 42	+00.620 163 64		1.82	1.57	0.72	1.30	0.92	1.33	1.42	1.17	−53 +19 + 1 −56 +35 − 7 +34 −69 − 6 −43	0	−0.11
32328		06 44 54.55	−48 42 28.7	9.18	H	101.227 271 29	−48.707 964 14		6.84	8.98	64.34	0.76	0.72	0.81	0.85	1.01	− 9 +11 − 1 −17 − 1 + 9 − 2 −14 − 7 − 9	1	−1.03
32329		06 44 54.86	+20 51 38.2	7.20	H	101.228 599 62	+20.860 622 25		21.77	93.72	12.86	1.02	0.45	1.07	0.98	0.61	+ 6 +62 + 2 − 2 + 0 −15 +16 −45 + 7 +29	0	−0.20
32330		06 44 55.61	−50 34 20.1	9.09	G	101.231 692 88	−50.572 243 64		1.94	−7.26	10.08	0.71	0.66	0.75	0.84	0.85	− 8 +22 −13 + 9 − 8 + 4 − 9 + 3 − 5 − 9	3	2.03
32331		06 44 55.62	+22 02 01.4	8.63	2 H	101.231 768 59	+22.033 728 98		2.44	0.54	−1.99	1.10	0.52	1.18	1.12	0.69	+ 3 +51 − 1 + 8 − 2 −10 +14 −43 +15 +17	0	−0.17
32332		06 44 55.67	−70 26 01.6	6.10	H	101.231 974 46	−70.433 772 84		5.18	−15.57	5.94	0.50	0.45	0.49	0.53	0.51	− 6 +14 − 3 −48 +14 + 2 −16 −27 +13 − 4	0	0.59
32333		06 44 56.36	+22 50 14.6	6.76	H	101.234 828 69	+22.837 382 14		8.42	−15.80	−0.18	1.04	0.45	1.04	1.18	0.64	+13 +43 + 4 +29 + 9 − 7 +25 −36 +18 +24	0	−0.29
32334		06 44 57.88	−35 07 18.1	8.04	G	101.241 164 23	−35.121 702 79		3.55	−2.34	10.74	0.52	0.58	0.69	0.61	0.75	+ 2 +10 −14 + 6 − 7 + 1 −10 +23 − 5 +11	0	1.35
32335		06 44 59.04	−27 15 59.2	8.90	1 H	101.246 015 57	−27.266 453 67		2.07	−3.67	4.17	0.68	0.88	1.15	0.83	1.02	−16 − 1 + 0 + 7 −14 −14 −14 + 4 + 5 −18	1	0.35
*32336		06 44 59.18	−67 49 33.6	8.57	H	101.246 577 18	−67.825 994 92		1.44	−12.38	2.71	0.69	0.67	0.72	0.68	0.77	− 2 +29 − 6 +20 − 4 − 6 + 0 − 7 + 7 −18	0	−1.00
*32337	H	06 44 59.14	+10 45 09.6	8.00	H	101.246 430 63	+10.752 673 67	*	3.05	2.71	−12.71	1.64	1.05	1.16	1.40	1.05	−32 +22 − 1 −24 +14 + 2 +17 −67 + 5 −25	2	−0.67
32338		06 44 59.76	−05 56 33.6	8.06	H	101.249 010 03	−05.942 678 53		2.13	−0.91	−0.40	0.81	0.59	1.02	1.05	0.85	+ 3 +38 −12 −15 −24 −11 −14 −32 +13 +33	0	1.04
32339	H	06 45 02.56	−30 35 11.1	6.53	G	101.260 675 92	−30.586 414 96	A	3.51	−7.96	4.44	0.55	0.64	0.73	0.57	0.73	+ 0 + 1 − 3 +16 − 5 + 8 − 7 + 4 + 1 − 7	7	−0.33
32340		06 45 03.08	+09 34 18.9	10.64	H														
32341		06 45 03.65	+45 58 15.3	8.35	H	101.265 223 36	+45.976 477 62		2.02	3.59	−4.57	0.94	0.71	1.16	1.31	0.98	− 2 +24 −18 + 5 −16 +15 − 8 −30 +17 + 7	0	1.06
*32342		06 45 05.57	−46 56 09.1	7.78	H	101.273 190 10	−46.935 862 90		3.72	−6.28	10.99	0.57	0.60	0.66	0.74	0.77	− 4 − 3 − 6 −10 + 7 +13 + 4 −34 +25 −14	0	1.07
*32343		06 45 05.54	−52 21 44.7	7.84	H	101.273 062 89	−52.362 430 36		5.02	−6.03	39.23	0.64	0.55	0.64	0.71	0.63	+ 7 + 6 − 7 − 9 −10 + 5 −10 −19 +21 − 9	0	−1.78
32344		06 45 06.32	−11 24 47.8	8.92	H	101.276 321 13	−11.413 269 09		9.32	17.23	−17.13	1.12	0.92	1.26	1.58	1.18	−35 +29 −13 −22 +11 − 4 +16 −27 +18 −47	5	0.72
32345		06 45 06.70	−01 01 15.5	7.45	H	101.277 919 88	−01.020 985 94		2.20	−1.14	−1.91	0.77	0.50	0.98	0.87	0.68	−21 +45 −34 −27 −11 − 9 − 5 −39 + 5 +36	0	−1.99
32346		06 45 06.79	+13 45 10.8	8.56	H	101.278 307 25	+13.752 999 45		3.77	−3.68	−8.37	0.94	0.59	1.10	1.06	0.77	−17 +32 − 7 − 6 +18 −37 +15 −47 − 1 −18	0	−0.80
32347		06 45 07.20	−13 12 28.1	9.31	H	101.279 995 54	−13.207 795 33		6.29	−27.11	−3.21	1.20	0.90	1.38	1.44	1.08	+ 3 +24 − 7 − 3 −27 − 9 −20 −17 +25 −10	0	−0.41
32348		06 45 07.23	−31 39 15.6	7.61	H	101.280 136 83	−31.654 326 31		1.67	−7.30	5.13	0.48	0.52	0.66	0.57	0.57	− 3 +10 + 5 +22 −20 + 2 −18 +18 + 1 − 7	0	−1.22
32349		06 45 09.25	−16 42 47.3	−1.44	2 G	101.288 541 05	−16.713 143 06	+	379.21	−546.01	−1223.08	1.21	1.04	1.58	1.33	1.24	+ 5 +22 −30 −50 +13 −31 +12 −54 +32 − 5	0	
32350		06 45 09.73	+39 22 06.5	6.93	H	101.290 561 19	+39.368 467 56		18.38	−13.15	−135.45	0.79	0.50	0.86	0.99	0.68	+ 2 +32 + 9 − 6 − 2 − 8 − 5 −35 − 3 − 8	0	−0.69
32351		06 45 09.93	−82 53 45.1	7.60	G	101.291 373 91	−82.895 866 43		12.43	−32.71	9.80	0.55	0.56	0.60	0.62	0.63	− 6 +20 + 7 +14 + 5 +13 + 0 −24 + 7 −22	1	1.45
32352		06 45 10.01	−18 16 05.7	6.90	H	101.291 721 67	−18.268 244 82		7.65	0.27	−27.46	0.48	0.51	0.87	0.60	0.68	+ 0 +11 − 7 +29 +38 − 6 +37 −14 +10 − 8	0	−0.98
32353	H	06 45 10.02	+30 49 33.5	7.27	H	101.291 754 57	+30.825 973 01	A	14.41	−10.34	−15.49	1.46	0.81	1.37	1.66	0.98	+15 +25 −27 + 0 −19 +18 − 8 −48 +40 +24	3	1.23
32354		06 45 10.49	−47 13 21.8	7.22	2 H	101.293 703 55	−47.222 733 54		2.69	−1.53	6.55	0.54	0.57	0.62	0.77	0.76	+ 3 − 4 + 1 − 9 + 7 +23 + 2 −34 +17 − 7	0	−0.38
32355		06 45 11.21	−00 02 35.4	7.02	G	101.296 706 32	−00.043 173 63		1.90	0.40	−1.71	0.71	0.48	0.87	0.80	0.61	−32 +25 −29 −41 − 1 + 8 + 6 −51 +19 + 2	0	−0.70
32356		06 45 13.35	−46 51 12.1	7.49	G	101.305 614 09	−46.853 371 41		3.29	−6.27	11.64	0.55	0.57	0.62	0.72	0.73	− 5 + 5 − 6 −10 +12 +12 + 9 −37 +16 −18	0	1.61
32357		06 45 13.85	+05 12 47.7	7.53	H	101.307 707 36	+05.213 263 81		4.58	−11.77	3.57	0.99	0.62	1.03	0.98	0.78	−17 +24 + 2 −43 + 4 −14 +10 −66 −24 +14	0	−1.11
32358		06 45 14.46	+53 05 11.6	7.04	1 H	101.310 233 15	+53.086 115 14		2.58	−14.49	−21.48	0.67	0.48	0.74	0.74	0.53	−12 +31 − 3 +24 +34 + 2 +30 −14 +12 −26	0	0.13
32359		06 45 14.58	+13 20 09.4	7.28	1 H	101.310 748 60	+13.335 933 34		1.44	−0.51	−0.57	0.81	0.45	0.89	0.85	0.60	− 6 +49 − 8 − 4 + 1 −21 + 9 −48 + 6 +10	0	−3.02
32360		06 45 14.66	−25 38 24.5	8.40	H	101.311 082 82	−25.640 144 89		0.03	−3.31	3.43	0.52	0.66	0.95	0.61	0.79	+ 8 +11 + 2 +13 +14 −16 +14 −32 − 1 + 9	2	−1.44
32361		06 45 17.17	+46 51 52.8	8.81	H	101.321 540 91	+46.864 654 84		6.97	−24.86	0.83	1.03	0.71	1.09	1.46	0.90	+12 +25 + 2 − 7 −13 + 5 −12 −31 + 4 +16	0	−0.20
32362		06 45 17.43	+12 53 45.8	3.35	H	101.322 639 80	+12.896 055 13		57.02	−115.16	−190.91	0.74	0.43	0.83	0.67	0.50	−10 +54 −10 −15 + 7 −31 + 4 −43 − 7 + 8	0	−1.42
32363		06 45 17.51	+82 25 01.4	8.63	H	101.322 968 28	+82.417 042 07		1.71	0.59	−6.14	0.70	0.74	0.92	0.74	0.90	+20 +31 +12 −15 + 0 +15 − 2 + 1 + 5 +30	1	−0.63
32364		06 45 21.89	+35 32 06.3	8.82	H	101.341 217 10	+35.535 086 55		18.76	84.57	−210.32	1.59	1.07	1.44	1.88	1.28	+39 +13 −26 −60 −40 +26 −32 −83 +28 +32	0	−0.64
32365		06 45 22.68	−34 37 41.2	9.06	H	101.344 505 61	−34.628 118 31		3.47	−3.77	3.47	0.67	0.83	0.96	0.78	1.16	− 4 +10 −23 +12 − 4 +17 − 2 +21 + 4 +10	1	2.39
32366		06 45 23.08	−31 47 34.5	5.92	G	101.346 167 95	−31.792 921 74		41.20	−204.91	−304.13	0.40	0.43	0.56	0.48	0.48	+ 9 +18 + 9 +14 −11 + 7 −11 +14 − 1 + 7	0	0.06
32367		06 45 23.28	+23 38 46.4	7.16	H	101.346 991 57	+23.646 229 46		4.02	24.18	0.04	1.03	0.50	1.05	1.21	0.70	+22 +37 + 1 +19 − 3 − 4 +11 −36 +19 +33	2	−0.22
32368		06 45 23.38	−23 27 45.0	6.04	H	101.347 405 23	−23.462 488 65		2.63	−19.70	23.38	0.34	0.42	0.64	0.37	0.45	+ 4 +10 − 7 +41 −32 +14 −22 −10 +18 +22	1	−0.61
32369		06 45 23.51	+24 40 20.9	6.95	1 H	101.347 942 30	+24.672 478 08		0.62	−0.01	−3.17	1.00	0.54	1.02	1.06	0.64	+21 +41 +10 + 9 −10 + 9 + 1 −40 + 9 +35	0	1.95
32370		06 45 24.28	−09 58 48.9	8.45	G	101.351 154 38	−09.980 251 56		3.90	−0.41	−4.41	0.94	0.72	1.02	1.09	0.87	−20 +16 + 4 −37 + 9 +10 −48 + 0 −14	2	1.05
32371		06 45 24.50	−26 09 21.0	9.12	H	101.352 066 94	−26.155 823 35		3.83	−14.42	−3.68	0.71	0.86	1.17	0.87	1.08	−12 −10 + 3 + 5 −11 + 8 −10 − 2 − 3 + 0	0	0.49
32372		06 45 24.58	−28 26 16.0	9.53	H	101.352 419 43	−28.437 789 13		4.16	10.58	3.69	0.96	1.13	1.56	1.20	1.38	− 4 + 0 +11 −10 −10 + 2 − 8 − 8 −12 + 6	0	1.49
32373		06 45 25.15	+47 04 01.5	8.28	1 G	101.354 797 39	+47.067 091 47		3.32	8.94	−11.53	1.77	1.28	1.96	2.32	1.44	− 4 +21 −13 −12 − 7 + 4 − 3 −41 + 0 + 9	0	
32374		06 45 25.28	−65 02 39.2	7.18	2 H	101.355 345 60	−65.044 225 38		2.83	−8.38	−5.80	0.50	0.50	0.52	0.56	0.56	+ 2 + 3 + 9 + 5 −13 + 6 −14 + 2 +12 − 4	0	0.55
32375		06 45 26.05	−52 12 03.4	6.56	1 G	101.358 555 46	−52.200 931 17		1.49	2.19	2.71	0.50	0.46	0.52	0.58	0.60	+ 8 +13 + 8 − 1 −14 − 6 −13 − 8 +13 − 9	1	−0.64
32376		06 45 26.51	+09 45 56.9	6.65	H	101.360 465 17	+09.765 812 72		11.03	41.55	−32.30	0.81	0.50	0.89	0.98	0.72	+ 7 +27 +18 − 9 −12 −23 − 3 −65 −28 +27	0	1.44
*32377		06 45 27.04	−17 50 31.1	9.56	H	101.362 669 21	−17.841 965 95		2.65	4.15	5.50	0.92	1.09	1.76	1.20	1.40	−15 +12 −31 +13 +40 −33 +32 −38 +30 −30	0	0.67
*32378	H	06 45 27.02	+29 21 59.8	8.22	G	101.362 577 08	+29.366 618 61	A	11.07	−32.30	−74.61	3.70	2.58	3.74	3.29	2.70	−18 +22 − 6 −28 +47 − 1 +55 −57 +20 −58	0	−0.75
32379		06 45 27.67	+38 22 57.6	8.02	1 H	101.365 309 89	+38.382 664 07		2.58	−13.76	−32.74	0.93	0.61	1.09	1.20	0.75	− 9 +27 −28 − 7 −22 +24 − 3 −52 +22 +23	0	−0.52
32380		06 45 27.86	−07 08 10.2	8.44	H	101.366 081 97	−07.136 180 22		1.63	−4.89	8.19	0.92	0.69	1.13	0.97	0.81	− 9 +41 −34 −33 −23 −11 −18 −37 +23 + 7	0	−1.97
32381		06 45 28.78	−36 50 57.9	7.98	H	101.369 899 88	−36.849 420 81		6.04	−4.44	−7.71	0.56	0.62	0.73	0.63	0.76	+15 + 3 + 5 +16 + 5 +21 + 4 +27 + 2 +15	1	0.67
32382		06 45 28.86	+44 14 01.8	7.47	G	101.370 257 83	+44.233 847 16		22.09	143.37	−189.41	0.74	0.56	0.86	0.97	0.67	− 4 + 3 − 4 + 2 −24 − 2 −22 −13 − 9	0	−0.43
32383		06 45 30.50	+15 28 48.0	8.43	H	101.377 068 44	+15.479 993 86		2.75	0.47	−10.37	1.10	0.55	1.18	1.10	0.70	−11 +52 −25 + 7 − 7 − 1 −16 −46 +23	0	1.61
32384		06 45 30.94	−01 27 45.9	7.82	H	101.378 909 23	−01.429 984 20		1.99	−1.47	−2.74	0.74	0.53	0.87	0.79	0.61	+ 1 +18 −21 −31 −17 − 1 −16 −44 + 7 +14	0	0.97
32385	H	06 45 31.19	−30 56 56.4	5.62	2 H	101.379 961 61	−30.948 990 76	A	2.06	−3.11	4.20	0.70	0.78	0.90	0.78	0.87	+ 7 −23 −26 −14 − 9 +16 −14 −37 +25 + 8	17	0.54
32386		06 45 32.30	−14 57 26.5	8.95	H	101.384 574 03	−14.957 373 37		4.04	−6.43	3.06	1.09	1.01	1.41	1.65	1.38	−16 +28 −34 − 7 −10 − 1 − 1 −24 +31 −31	0	1.43
32387		06 45 33.10	+04 35 38.9	7.04	H	101.387 903 70	+04.594 130 93		2.66	−12.57	−4.64	0.78	0.51	0.86	0.86	0.64	+ 7 +22 + 2 +11 − 9 −10 − 1 −46 −13 +35	0	0.10
32388	H	06 45 33.95	−31 30 03.0	8.93	H	101.391 452 39	−31.500 840 45	A	6.22	1.23	−8.39	1.06	1.10	1.29	1.19	1.23	− 7 + 4 +11 +31 − 2 −10 − 6 + 7 +12 −21	4	0.46
32389		06 45 35.10	+27 40 23.7	6.70	H	101.396 247 38	+27.673 248 53		3.59	−5.28	−0.89	0.88	0.52	0.96	1.17	0.80	− 6 +19 − 9 + 6 +16 + 5 +19 −50 +16 − 6	0	0.08
32390		06 45 35.52	−20 40 51.4	8.39	G	101.397 982 20	−20.680 934 26		0.38	−5.36	−0.38	0.65	0.74	1.08	0.90	0.94	+ 2 +12 −10 +19 +12 − 2 +11 −31 + 6 + 3	1	−0.19
32391		06 45 37.69	−24 11 01.2	8.82	H	101.407 059 35	−24.183 665 04		3.98	6.89	10.83	0.55	0.71	1.05	0.66	0.74	+ 7 + 7 + 0 +19 −28 +13 −23 −12 +18 +11	0	−0.64
32392		06 45 42.52	−66 20 33.4	8.87	H	101.427 174 48	−66.342 603 95		2.13	−3.29	16.33	0.76	0.72	0.79	0.61	0.80	− 1 +16 +13 −56 − 4 − 9 + 1 − 3 − 5 −14	0	0.08
32393		06 45 43.01	−20 51 09.6	7.44	H	101.429 227 74	−20.852 664 23		2.18	−4.73	0.77	0.59	0.65	0.97	0.79	0.82	− 3 +15 − 7 + 9 +14 + 3 −13 −33 +10 − 6	0	0.09
32394		06 45 46.40	+37 46 41.4	8.02	H	101.443 336 50	+37.778 180 12		0.61	3.21	−11.71	0.94	0.60	1.09	1.16	0.73	− 9 +26 −12 −10 + 5 + 8 − 3 −53 + 5 +15	0	−0.04
32395		06 45 48.46	−45 59 51.9	9.00	H	101.451 929 91	−45.997 737 14		11.89	77.31	−1.18	0.66	0.73	0.76	0.86	0.98	−11 + 0 + 0 − 4 +20 − 6 +14 −29 + 7 −37	0	−0.87
32396		06 45 49.04	−70 31 21.6	7.60	H	101.457 231 97	−70.522 652 79		5.91	18.35	−10.66	0.64	0.56	0.62	0.66	0.65	+ 0 +19 − 2 −51 + 9 + 1 +13 −27 +19 + 3	0	0.27
32397		06 45 49.98	+02 29 57.4	7.22	2 H	101.458 241 96	+02.499 282 46		1.11	−1.77	−2.51	0.82	0.54	0.88	0.86	0.69	+12 +30 −15 −43 −22 −20 −24 −56 − 6 +33	0	−1.09
32398		06 45 50.06	−00 42 59.2	6.78	H	101.458 571 45	−00.716 448 83		4.96	−5.90	−4.20	0.73	0.46	0.88	0.80	0.63	−14 +40 −19 −32 − 7 −11 − 2 −43 + 2 +32	0	0.50
32399		06 45 50.91	+62 38 58.5	7.56	H	101.462 145 42	+62.649 572 38		4.23	−0.87	3.41	0.62	0.59	0.94	0.92	0.81	+30 +13 − 5 +13 +12 + 8 − 4 + 5 +34 +19	0	−0.84
32400	H	06 45 51.85	+03 24 02.5	8.86	H	101.466 025 74	+03.400 696 07	A	−0.74	−2.70	1.82	3.70	2.44	3.29	4.40	3.30	−27 +19 + 7 −25 − 5 −33 − 8 −51 − 8 − 5	2	0.79

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No. HIP 31	Tycho Magnitudes B_T mag 32	σ mag 33	V_T mag 34	σ mag 35	36	Colour Indices B−V mag 37	σ mag 38	39	V−I mag 40	σ mag 41	42-3	Magnitude (Hp) Hp mag 44	σ mag 45	s mag 46	N 47	48	Variability (Hp) Max mag 49	Min mag 50	P days 51	52-4	Multiplicity Data CCDM 55	56-7	Flags 58-61	AB 62	θ ° 63	ρ ″ 64	$σ_ρ$ ″ 65	ΔHp mag 66	σ mag 67	Misc Flags 68-70
32301	10.740	0.043	8.977	0.017		1.469	0.037	T	1.48	0.06	L	8.9357	0.0023	0.017	109		8.90	8.96					1							
32302	8.578	0.013	8.641	0.017		−0.080	0.015	G	−0.06	0.02	H	8.6647	0.0018	0.019	90		8.62	8.70					1							
32303	9.428	0.022	8.919	0.021		0.489	0.023	T	0.56	0.02	L	8.9418	0.0018	0.017	87		8.91	8.98		C			1							
32304	10.085	0.028	9.581	0.028		0.474	0.036	T	0.55	0.04	L	9.6686	0.0028	0.021	85		9.64	9.71		C			1							
32305	10.121	0.044	9.676	0.046		0.370	0.015	G	0.43	0.02	H	9.7810	0.0046	0.032	80		9.71	9.84					1 S							
32306	10.463	0.043	9.279	0.025		1.015	0.039	T	0.99	0.03	L	9.3625	0.0018	0.016	75		9.34	9.39		C			1							
32307	9.113	0.013	8.603	0.013		0.506	0.015	G	0.58	0.02	H	8.6639	0.0017	0.014	98		8.64	8.69		C			1 X S							
32308	11.700	0.106	10.794	0.079		0.804	0.098	T	0.83	0.07	L	10.8879	0.0039	0.033	86		10.78	10.95					1 S							G
32309	8.820	0.011	7.144	0.006		1.427	0.010	T	1.41	0.02	L	7.0835	0.0011	0.011	107		7.07	7.10					1							S
32310	7.207	0.005	7.296	0.005		−0.076	0.006	T	−0.06	0.01	L	7.3007	0.0008	0.010	201		7.28	7.32		C			1							S
32311	7.321	0.006	5.588	0.003		1.445	0.006	G	1.34	0.04	E	5.5643	0.0012	0.007	78		5.55	5.58					1							S
32312	8.871	0.013	8.575	0.014	*	0.310	0.015	G	0.36	0.02	H *	8.5680	0.0034	0.024	91	*	8.53	8.61		U	06448−0424	H 1	2 C D	AB	343	0.490	0.053	3.68	0.20	D
32313						1.364	0.133	G	1.60	0.25	I	11.0176	0.0041	0.047	192		10.93	11.10		C			1							G
32314	8.485	0.010	8.340	0.012	*	0.140	0.015	T	0.15	0.01	L *	8.3396	0.0015	0.013	103	*	8.32	8.36		D	06447−5225	I 1	2 C A	AB	338	0.662	0.003	0.99	0.02	S
32315	8.236	0.011	6.784	0.006		1.224	0.010	T	1.18	0.01	L	6.8062	0.0008	0.008	83		6.79	6.82		C			1							S
32316	9.232	0.020	7.904	0.012		1.127	0.018	T	1.09	0.02	L	7.9630	0.0013	0.010	72		7.95	7.98		C			1							S
32317	11.100	0.045	10.072	0.029		0.884	0.042	T	0.89	0.03	L	10.1130	0.0033	0.035	161		10.06	10.18		C			1							G
32318	7.755	0.008	7.641	0.009		0.111	0.011	T	0.12	0.01	L	7.6682	0.0013	0.012	79		7.65	7.69			06448+0341	I 1	1 S							S
32319	7.363	0.005	7.098	0.006		0.249	0.008	T	0.28	0.01	L	7.1416	0.0009	0.009	168		7.13	7.16		C			1							S
32320	7.476	0.015	7.067	0.018	*	0.387	0.021	T	0.45	0.02	L *	7.1573	0.0019	0.010	67	*	7.14	7.18		D	06449+5927	I 1	2 C A	AB	130	4.019	0.006	1.88	0.03	S
32321	8.519	0.011	8.032	0.010		0.461	0.015	G	0.53	0.02	H	8.0945	0.0013	0.011	81		8.07	8.11		C			1							S
32322	7.067	0.004	6.499	0.004		0.550	0.021	G	0.64	0.02	A	6.5522	0.0007	0.008	159		6.54	6.56		C			1							S
32323	9.507	0.016	9.483	0.021		0.022	0.023	T	0.04	0.02	L	9.5439	0.0026	0.028	113		9.50	9.60		C			1							
32324	8.368	0.009	8.162	0.010		0.196	0.001	G	0.21	0.00	H	8.1886	0.0013	0.012	94		8.16	8.21		C			1 X							
32325	10.421	0.038	8.983	0.019		1.213	0.033	T	1.17	0.03	L	9.0170	0.0017	0.014	83		9.00	9.04		C			1							
32326	9.435	0.016	8.765	0.014		0.610	0.016	T	0.68	0.01	L	8.8365	0.0015	0.016	108		8.80	8.86		U			1							
32327	9.727	0.017	9.317	0.018		0.441	0.007	G	0.51	0.01	H	9.3444	0.0020	0.020	115		9.31	9.38		C			1							G
32328	9.821	0.024	9.292	0.023		0.505	0.025	T	0.58	0.03	L	9.2872	0.0019	0.018	107		9.26	9.32					1							
32329	7.881	0.008	7.260	0.006		0.562	0.022	G	0.64	0.02	H	7.3212	0.0008	0.006	100		7.31	7.33		C			1							S
32330	9.005	0.013	9.013	0.017		−0.054	0.002	G	−0.03	0.00	H	9.0824	0.0019	0.018	113		9.06	9.11		C			1							
32331	8.517	0.010	8.628	0.013		−0.110	0.015	G	−0.09	0.02	H	8.5997	0.0031	0.026	107		8.55	8.64		U 2			1							
32332	7.838	0.008	6.253	0.004		1.335	0.003	G	1.23	0.04	E	6.2604	0.0010	0.006	108		6.25	6.27					1							S
32333	6.989	0.005	6.783	0.006		0.197	0.007	T	0.22	0.01	L	6.8187	0.0007	0.006	94		6.81	6.83		C			1							S
32334	8.036	0.008	8.041	0.009		−0.013	0.006	G	0.01	0.01	H	8.0478	0.0015	0.016	132		8.03	8.08					1							S
32335	11.147	0.054	9.085	0.016		1.745	0.046	T	1.90	0.12	O	8.9956	0.0030	0.026	153		8.95	9.04		U			1							
32336	9.697	0.020	8.667	0.014		0.897	0.018	T	0.90	0.01	L	8.7263	0.0018	0.013	107		8.70	8.75		C			1							
32337	8.899	0.013	8.100	0.011	*	0.724	0.013	T	0.78	0.01	L *	8.1479	0.0012	0.010	101	*	8.13	8.16		D	06450+1045	I 1	2 C A	AS	182	0.219	0.002	0.22	0.06	S
32338	7.969	0.008	8.039	0.010		−0.059	0.012	T	−0.04	0.01	L	8.0519	0.0011	0.010	87		8.03	8.07		C			1							
32339	6.368	0.003	6.483	0.005	*	−0.111	0.003	G	−0.10	0.00	H *	6.4933	0.0010	0.009	142	*	6.48	6.51		D	06450−3035	I 1	2 C A	AB	224	4.545	0.020	3.66	0.12	S
32340											T	10.7798	0.0039	0.037	97		10.71	10.84		C			S							G G
32341	8.417	0.015	8.333	0.018		0.083	0.022	T	0.10	0.02	L	8.3870	0.0019	0.014	69		8.36	8.42		C			1							
32342	7.590	0.007	7.752	0.011		−0.134	0.007	G	−0.13	0.01	H	7.7308	0.0011	0.011	101		7.71	7.75					1							S
32343	9.414	0.017	7.968	0.010		1.219	0.015	T	1.18	0.01	L	8.0027	0.0012	0.010	106		7.98	8.02		C			1							
32344	10.206	0.032	9.051	0.021		0.992	0.030	T	0.97	0.02	L	9.0899	0.0020	0.020	84		9.07	9.15		C			1							
32345	7.356	0.005	7.444	0.007		−0.075	0.008	T	−0.05	0.01	L	7.4325	0.0008	0.009	117		7.42	7.45		C			1							
32346	8.633	0.011	8.542	0.013		0.089	0.016	T	0.10	0.02	L	8.5932	0.0014	0.013	101		8.57	8.62					1							
32347	9.788	0.028	9.341	0.028		0.435	0.032	T	0.50	0.03	L	9.4055	0.0025	0.022	67		9.37	9.44		C			1							
32348	7.480	0.006	7.591	0.007		−0.095	0.008	T	−0.08	0.01	L	7.5792	0.0012	0.012	151		7.56	7.60		C			1							
32349						0.009	0.007	G	−0.02	0.00	A	−1.0876	0.0024	0.040	159		−1.17	−0.98		U	06451−1643	I 1	1 O							S X
32350	7.337	0.006	6.966	0.006		0.351	0.008	T	0.41	0.01	L	7.0124	0.0010	0.009	90		7.00	7.03		C			1							
32351	8.014	0.008	7.626	0.009		0.401	0.015	G	0.47	0.02	H	7.6828	0.0012	0.012	109		7.66	7.70		C			1							
32352	8.154	0.008	7.003	0.005		0.989	0.007	T	0.97	0.01	L	7.0649	0.0010	0.011	173		7.05	7.08					1							
32353	7.578	0.011	7.249	0.014	*	0.312	0.017	T	0.36	0.02	L *	7.3539	0.0013	0.012	81	*	7.33	7.38		D	06452+3050	I 1	2 C A	AB	90	3.739	0.011	2.16	0.04	S
32354	7.015	0.006	7.200	0.009		−0.157	0.006	G	−0.14	0.02	A	7.1679	0.0010	0.010	100		7.15	7.24		U 2			1							
32355			7.146	0.005		0.208	0.004	G	0.23	0.01	H	7.0870	0.0010	0.009	139		7.07	7.10					1							
32356	7.300	0.006	7.459	0.009		−0.138	0.001	G	−0.13	0.00	H	7.4423	0.0013	0.011	104		7.43	7.47					1							S
32357	7.503	0.007	7.519	0.008		−0.010	0.010	T	0.01	0.01	L	7.5320	0.0014	0.009	87		7.52	7.54					1							S
32358	9.125	0.014	7.209	0.006		1.591	0.012	T	1.61	0.01	L	7.1506	0.0020	0.014	105		7.13	7.18		M			1							S
32359	7.636	0.007	7.307	0.007		0.312	0.009	T	0.36	0.01	L	7.3564	0.0016	0.012	97		7.34	7.38		M			1							
32360	8.212	0.006	8.354	0.009		−0.124	0.010	T	−0.11	0.01	L	8.3614	0.0015	0.019	190		8.33	8.40					1							
32361	9.177	0.017	8.836	0.018		0.318	0.040	G	0.37	0.05	H	8.8845	0.0019	0.015	75		8.84	8.91		C			1							
32362	3.879	0.003	3.393	0.002		0.443	0.008	G	0.48	0.03	C	3.4417	0.0005	0.004	86		3.44	3.45					1							S
32363	10.223	0.025	8.749	0.013		1.241	0.022	T	1.20	0.02	L	8.7921	0.0016	0.019	133		8.76	8.82					1							
32364	9.639	0.018	8.876	0.015		0.670	0.015	G	0.73	0.01	H	8.9584	0.0018	0.015	112		8.93	8.98					1 G							
32365	10.668	0.034	9.166	0.016		1.263	0.030	T	1.22	0.03	L	9.2222	0.0014	0.018	128		9.20	9.26		C			1							
32366	6.500	0.003	5.977	0.003		0.491	0.015	G	0.57	0.02	A	6.0286	0.0006	0.006	147		6.02	6.04		C			1							S
32367	8.853	0.014	7.306	0.008		1.299	0.013	T	1.26	0.01	L	7.3185	0.0008	0.008	82		7.30	7.33		C			1							S
32368	7.593	0.005	6.170	0.003		1.205	0.003	G	1.12	0.04	E	6.2078	0.0005	0.007	246		6.20	6.22		C			1							S
32369	9.128	0.017	7.137	0.008		1.650	0.015	T	1.67	0.01	L	7.0543	0.0025	0.019	80		7.02	7.08		U 2 C	06454+2440	I 1	1 S							S
32370	8.459	0.011	8.450	0.014		0.008	0.015	G	0.03	0.01	H	8.4622	0.0018	0.013	72		8.45	8.49		C			1							
32371	10.303	0.024	9.206	0.015		0.939	0.022	T	0.93	0.02	L	9.2614	0.0024	0.025	170		9.21	9.31					1							
32372	10.862	0.035	9.650	0.020		1.036	0.031	T	1.01	0.03	L	9.7023	0.0027	0.029	151		9.66	9.75		C			1 S							
32373	8.867	0.013	8.347	0.012		0.505	0.015	G	0.58	0.02	H	8.3575	0.0034	0.020	81		8.33	8.39		U			1 X S							
32374	9.312	0.015	7.383	0.007		1.635	0.014	T	2.12	0.04	O	7.2466	0.0035	0.030	121		7.20	7.29		U 2			1							S P
32375	7.921	0.008	6.663	0.005		1.075	0.009	G	1.03	0.04	E	6.7274	0.0010	0.010	113		6.71	6.75		M			1							S
32376	7.039	0.004	6.688	0.004		0.333	0.005	T	0.39	0.01	L	6.7303	0.0007	0.007	102		6.72	6.74		C			1							S
32377	11.170	0.052	9.729	0.023		1.216	0.045	T	1.18	0.04	L	9.7249	0.0027	0.028	149		9.67	9.79					1 S							
32378	8.939	0.016	8.286	0.014	*	0.560	0.015	G	0.63	0.01	H *	8.3590	0.0019	0.011	77	*	8.34	8.38		D	06455+2922	I 1	2 C A	AB	42	0.320	0.004	0.49	0.03	S
32379	8.381	0.010	8.058	0.010		0.307	0.013	T	0.35	0.02	L	8.0998	0.0021	0.019	89		8.07	8.13		C			1							
32380	9.545	0.021	8.550	0.015		0.870	0.019	T	0.88	0.01	L	8.5999	0.0017	0.012	85		8.58	8.63		C			1							
32381	8.055	0.009	7.978	0.011		0.069	0.013	T	0.08	0.01	L	8.0064	0.0011	0.012	117		7.98	8.03		C			1							
32382	8.198	0.008	7.554	0.009		0.614	0.015	G	0.68	0.01	H	7.5987	0.0011	0.010	85		7.58	7.62		C			1							
32383	8.543	0.010	8.427	0.012		0.112	0.015	T	0.13	0.01	L	8.4709	0.0016	0.011	90		8.45	8.49		C			1							
32384	7.802	0.007	7.828	0.008		−0.004	0.015	G	0.02	0.01	H	7.8311	0.0014	0.013	112		7.81	7.85		C			1							
32385	5.415	0.010	5.573	0.014	*	−0.138	0.015	T	−0.13	0.02	L *	5.5752	0.0140	0.134	146	*	5.33	5.68		U 2 C	06455−3057	I 1	2 C B	AB	223	4.982	0.012	2.62	0.07	S P
32386	10.518	0.052	9.118	0.026		1.183	0.046	T	1.14	0.04	L	9.1180	0.0032	0.023	87		9.08	9.16		C			1							
32387	7.092	0.006	7.049	0.007		0.044	0.009	T	0.06	0.01	L	7.0563	0.0012	0.010	91		7.04	7.08			06456+0436	I 1	1 S							S
32388	9.444	0.015	8.998	0.015	A	0.400	0.495	G	0.50	0.04	L *	9.0247	0.0018	0.018	144	*	8.99	9.07		D	06456−3130	I 1	2 C D	AB	16	6.133	0.058	3.77	0.25	D
32389	8.445	0.012	6.847	0.006		1.339	0.011	T	1.30	0.01	L	6.8521	0.0008	0.008	76		6.84	6.86					1							S
32390	8.310	0.012	8.360	0.016		−0.043	0.011	G	−0.02	0.01	H	8.3857	0.0015	0.015	132		8.36	8.42		C			1							
32391	8.895	0.008	8.813	0.010		0.074	0.012	T	0.09	0.01	L	8.8509	0.0015	0.020	225		8.81	8.89					1							
32392	10.930	0.046	9.082	0.017		1.569	0.040	T	2.22	0.09	O	8.9268	0.0031	0.022	105		8.89	8.96					1							
32393	9.072	0.015	7.561	0.008		1.271	0.013	T	1.18	0.06	F	7.6027	0.0015	0.016	130		7.58	7.63		C			1							S
32394	10.058	0.027	8.182	0.011		1.559	0.023	T	1.58	0.02	L	8.1396	0.0010	0.012	97		8.12	8.16		D			1							
32395	9.662	0.019	9.067	0.018		0.575	0.009	G	0.64	0.02	A	9.1214	0.0019	0.012	101		9.10	9.15		C			1							
32396	9.189	0.014	7.730	0.008		1.230	0.013	T	1.19	0.01	L	7.7591	0.0012	0.011	103		7.74	7.78					1							
32397	7.142	0.009	7.216	0.010		−0.063	0.012	T	−0.04	0.01	L	7.2075	0.0042	0.046	91		7.16	7.44		P 1 A			1							
32398	6.735	0.004	6.767	0.004		−0.025	0.005	T	0.00	0.01	L	6.7768	0.0007	0.005	113		6.77	6.79					1							
32399	7.690	0.008	7.576	0.008		0.111	0.011	T	0.12	0.01	L	7.5996	0.0010	0.010	100		7.58	7.61		C			1							
32400	9.111	0.035	8.619	0.029	*	0.463	0.041	T	0.53	0.04	L *	8.9554	0.0021	0.016	78	*	8.92	8.99		R	06459+0324	I 1	2 C A	AB	159	1.531	0.006	0.04	0.02	

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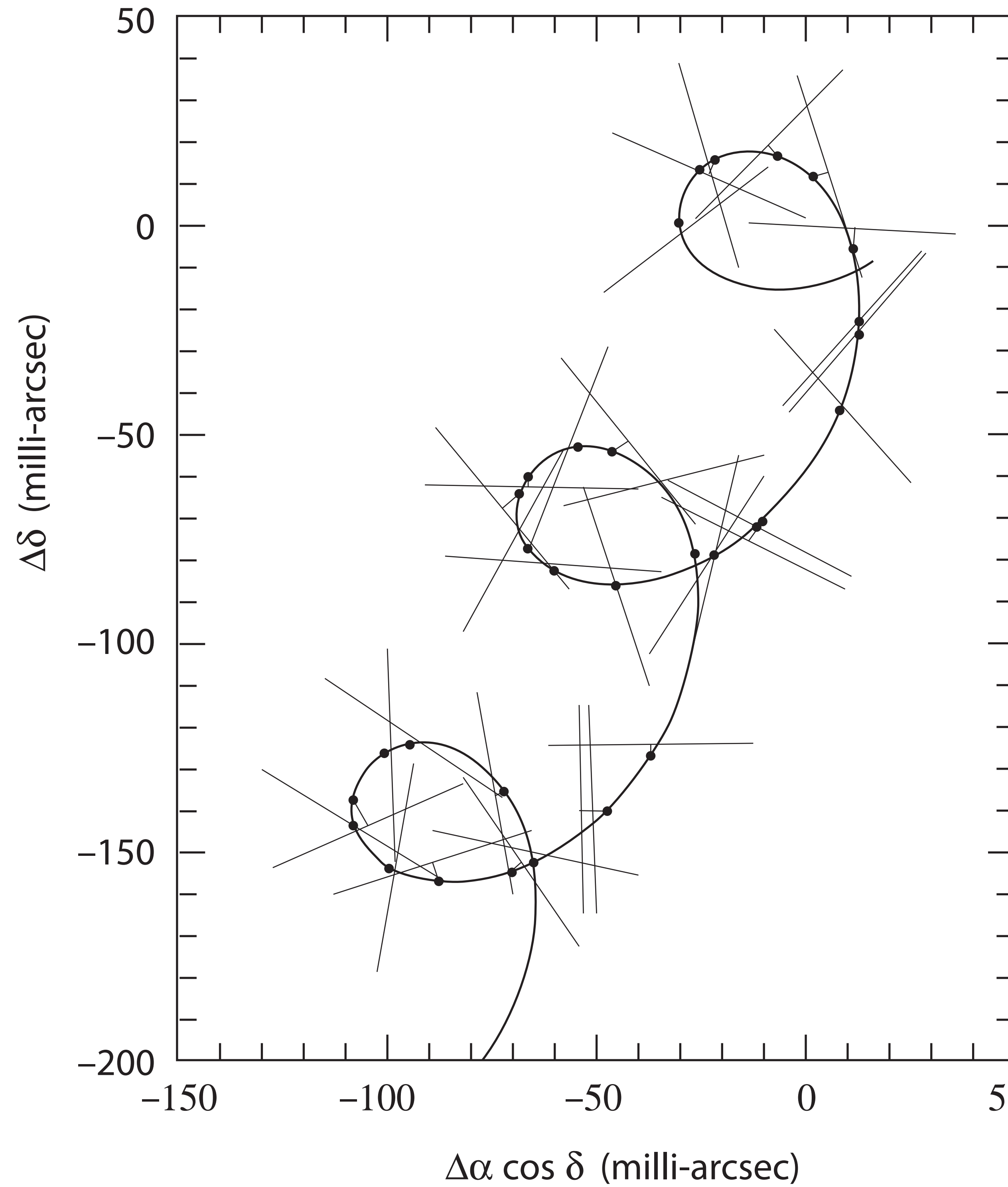
What's in the catalogue

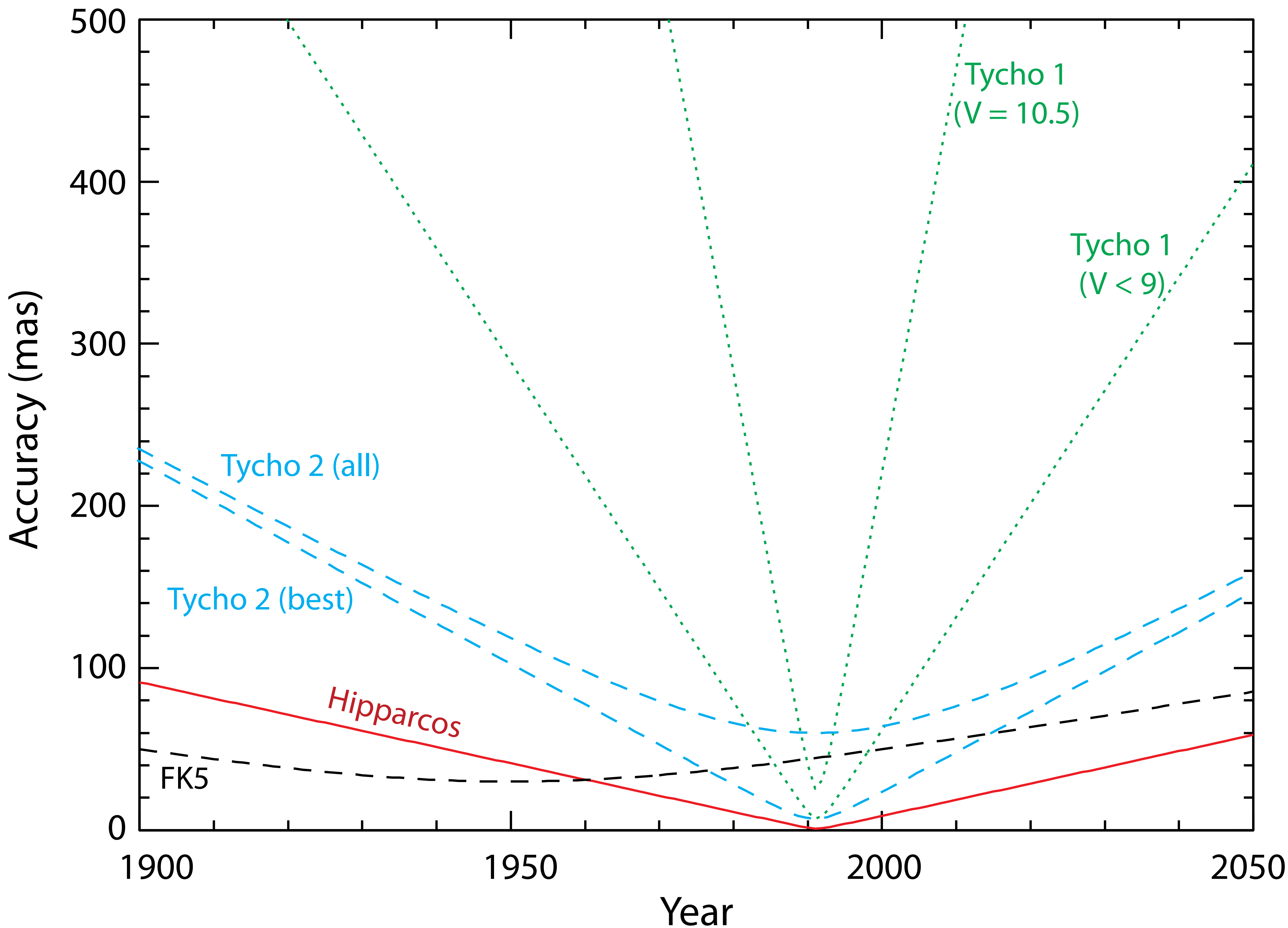
- position (2) at mid-epoch (~1990)
- proper motion (2)
- parallax (1)
- covariance matrix (5x5)
  - formulae for propagation
- flags indicating fits
- photometry (B,V)
- variability indicators
- multiplicity
  - 7-parameter fits (acceleration)
  - full orbital solutions (235)
- intermediate astrometry



Internal (formal) standard error versus external (or true) error

- estimating true parallax accuracies is a classical problem in fundamental positional astronomy with, typically, $\sigma_{int} << \sigma_{ext}$
- true uncertainties have historically been assessed by:
  - analysis/modelling of all identified error sources
  - comparison with independent measurements of the same stars
  - use of spectrophotometric, kinematic, or dynamical data
  - statistical interpretation of the distribution of observed parallaxes
- Lindegren (1995) analysed the negative parallax distribution, assuming:
  - parallaxes are non-negative
  - observation error and true parallax are statistically independent
- result: $\sigma_{ext} / \sigma_{int} \sim 0.99 \pm 0.02$
- combined with other assessments, the final catalogue claims:
  - $\sigma_{ext} / \sigma_{int} < 1.2$
- difficult to consider this not applying to positions and proper motions

Degradation of the reference frame with time



Some limitations of Hipparcos

- a modest telescope aperture (30cm)
- modulating grid leading to ~30% light loss
- a low-efficiency photocathode detector (~10%)
- sequential (non-multiplexed) star observations

These shortcomings are addressed by Gaia,
which uses the same principles as Hipparcos
to improve accuracies by x50

A retrospective...

Looking back, you might ask *'what was the big deal?'*

but Hipparcos pushed many simultaneous technology limits;
it provided the biggest improvement factor in history;
no other experiments have bettered it in 25 years;
and perhaps...
Bohdan Paczynski would have admired its small size!

"Hipparcos is the first time since Sputnik in 1957 that a major new development in space science has come from outside the United States"

Freeman Dyson (Infinite in All Directions)1988