Astrometry and photometry from space: Hipparcos, Tycho, Gaia

With an historical introduction

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Content:

- *Ptolemy, Tycho Brahe, meridian circles*
- *Hipparcos mission including the Tycho experiment*
- *Gaia mission*

2007: Rome, Monteporzio and University Tor Vergata, and Catania. 2008: USA, USNO in Wash., NRAO in Charlottesville.
– Version: November 2008

The visible universe

is 10^{15} times larger than Tycho Brahe believed

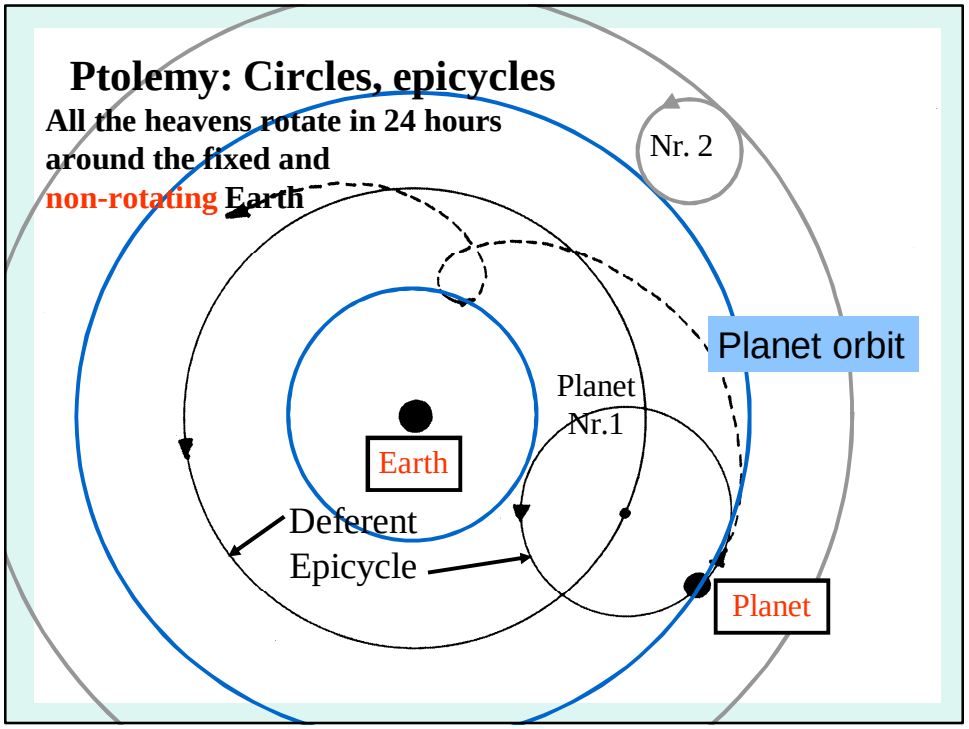
10^{15} = 1 000 000 000 000 000
= 1 million billion times larger

Ptolemy
ca. 150 A.D.

Tycho Brahe
ca. 1590

Ptolemy: Circles, epicycles

All the heavens rotate in 24 hours around the fixed and non-rotating Earth



Numerals: Roman Arabic

XX = 20

CCCXV = 315

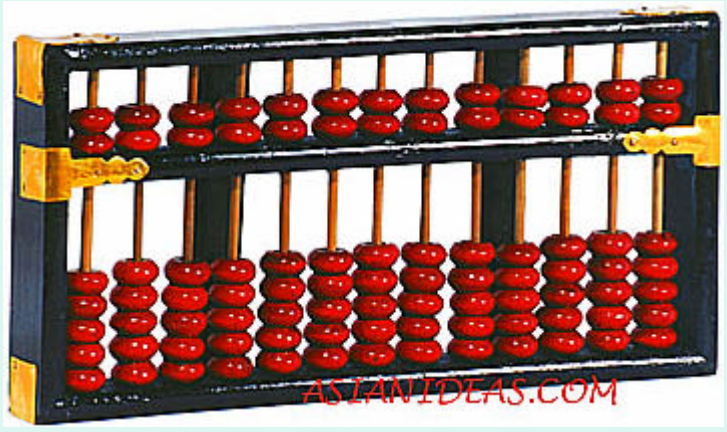
Hundreds

Tens

Ones

abacus

Oldest find in Europe ca. 400 BC



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The Arabs:

Translation of Greek texts and Science

Harun al Rashid
766 - 809

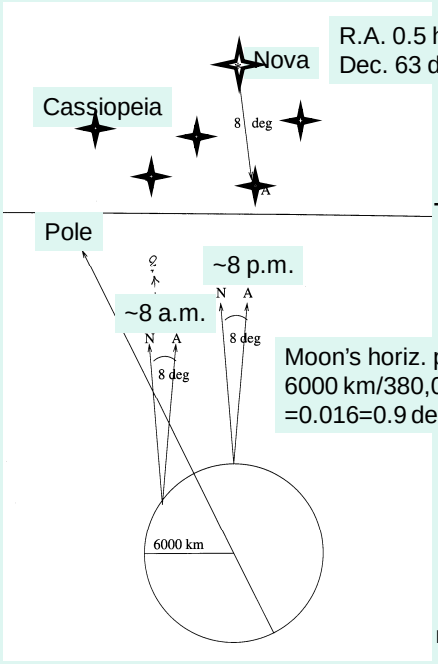
Our arabic numerals: from India to Europe:

500 In India: ”Position” numerals: e.g. 0, 10, 203
820 Al-Khwarizmi: Algorithm; astronomy
1021 Alhazen: Book on light and optics
1085 Toledo taken by Christians: large Arab library
1120 In Europe:
Al-Khwarizmi’s book on algebra is translated

God as the architect of the world

from a Middle Age Bible
ca. 1250
Codex Vindobonensis

Men of the church had time to think and to teach



11 Nov. 1572 Nova Stella

Tycho Brahe measured the nova:
Larger distance than the Moon

***He* concluded in 1572**:
This is a miracle
a sign from God

***We* say**:
He tipped the
antique picture of the world

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Quadrant 1570 Sighting the star

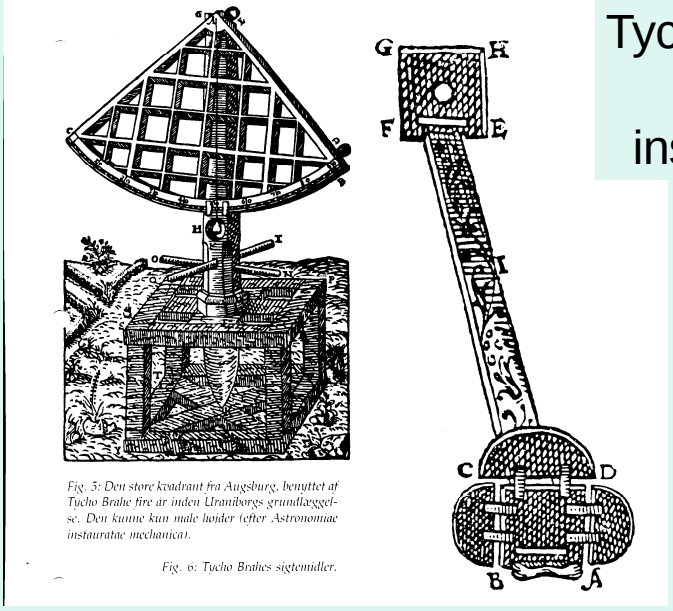

Fig. 5: Den store kvadrant fra Augsburg, benyttet af Tycho Brahe fire år inden Uraniborgs grundlæggelse. Den kunne kun måle højder (efter Astronomiae instauratae mechanica).

Fig. 6: Tycho Brahes sigtemidler.

Tycho Brahe's *new* instruments

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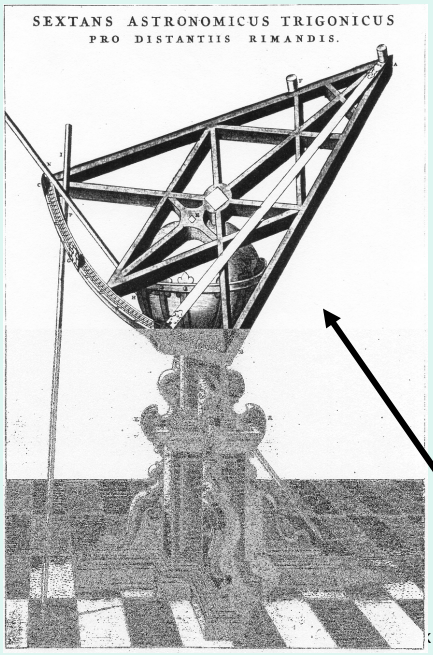
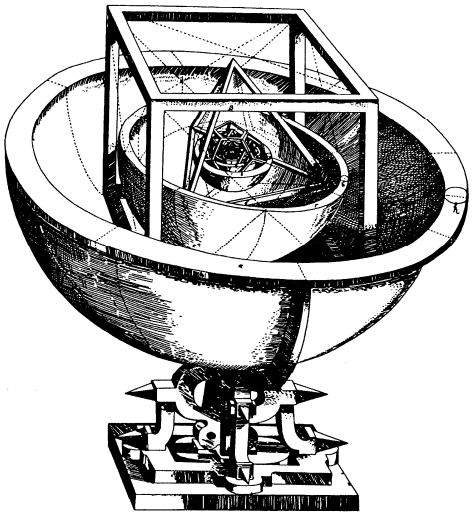


Tycho Brahe
on Hven
1576-97
A barrel of gold

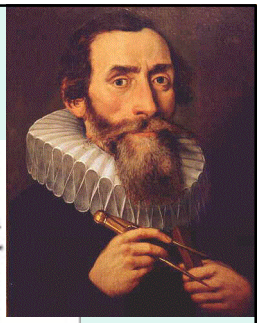
Sextant 1580

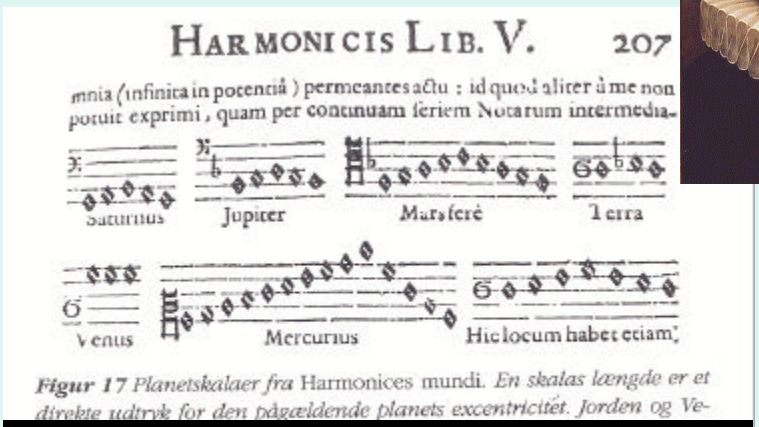


Figur 15 *Keplers polyederunivers. Mellem Saturn-sfæren og Jupiter-sfæren er der indskudt en terning, mellem Jupiter og Mars et tetraeder, og derefter hhv. et dodekaeder, et ikosaeder og et oktaeder mellem de øvrige planetsfærer. (Illustration fra* Mysterium Cosmographicum, *1596.)*

Kepler 1596
Mysterium
Cosmographicum

Kepler 1619 *Harmonices Mundi*





Figur 17 Planetskalaer fra Harmonices mundi. *En skalas længde er et direkte udtryk for den pågældende planets excentricitet. Jorden og Ve-*

Kepler found ~70 laws for the motion of planets

But we usually mention only **3** of these…

Isaac Newton 1687:

Philosophiæ Naturalis Principia Mathematica

Mathematics 1665-66:

Differential- and integral calculus

+ Clear concepts 1687:

Gravity, force, acceleration, absolute time, velocity

>>> Laws of motion:

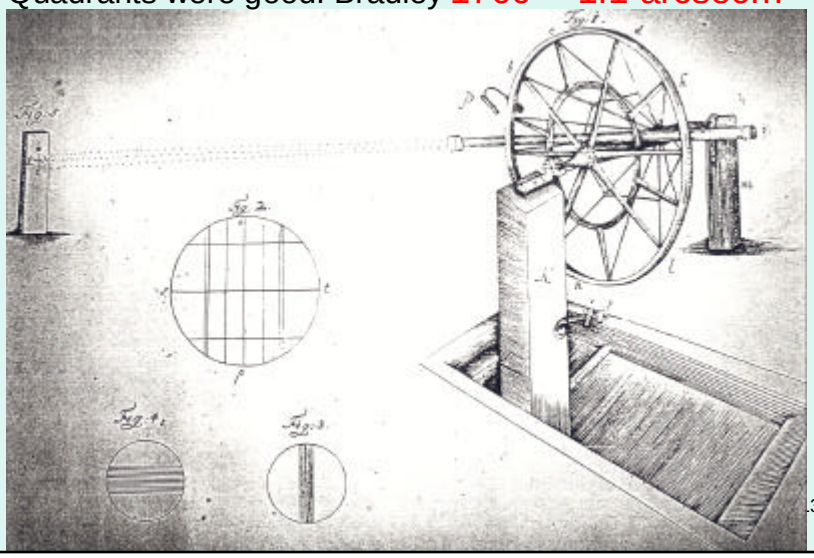
Kepler's 3 laws;

motions in the heavens and on Earth….

>>> The technical revolution

Ole Rømer's meridian circle 1705

Accuracy ~4 arcsec per star from 3 observations
MCs took over only after 1800
Quadrants were good: Bradley 1760-> 1.1 arcsec!!!



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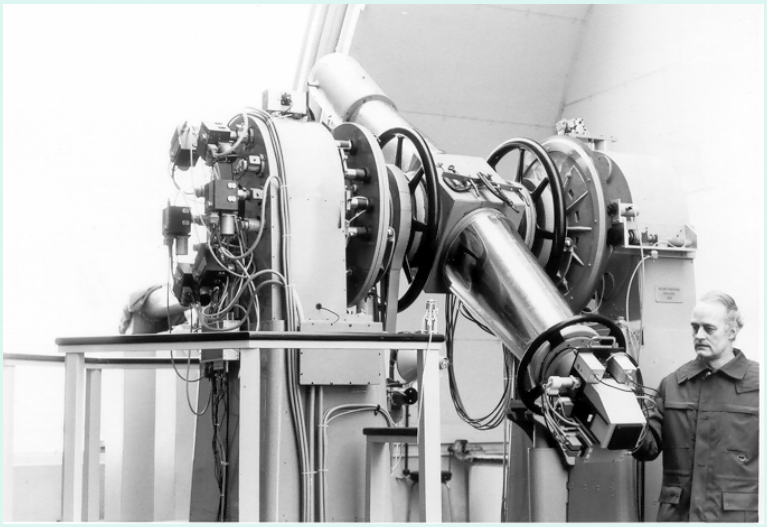
Brorfelde meridian circle – Feb. 1979

Accuracy ~0.1 arcsec per star with 4 obs.



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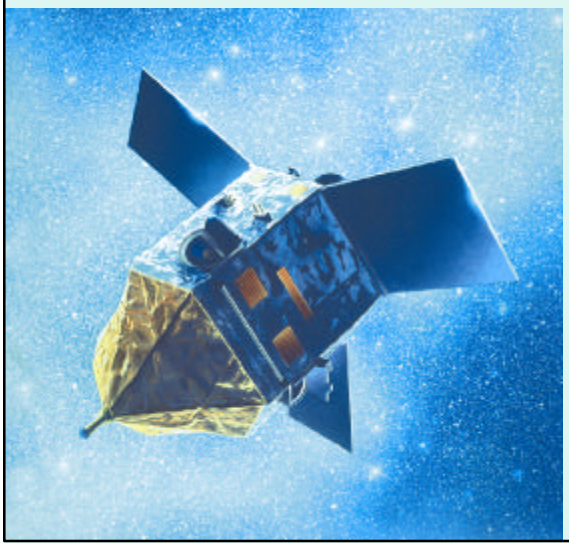
Hipparcos satellite

Measured 2.5 million stars in 1989-93

Distances, positions, motions and magnitudes



The Tycho-2 Catalogue

Medal 1999 from ESA's Director of Science:

For outstanding contribution to the science programme

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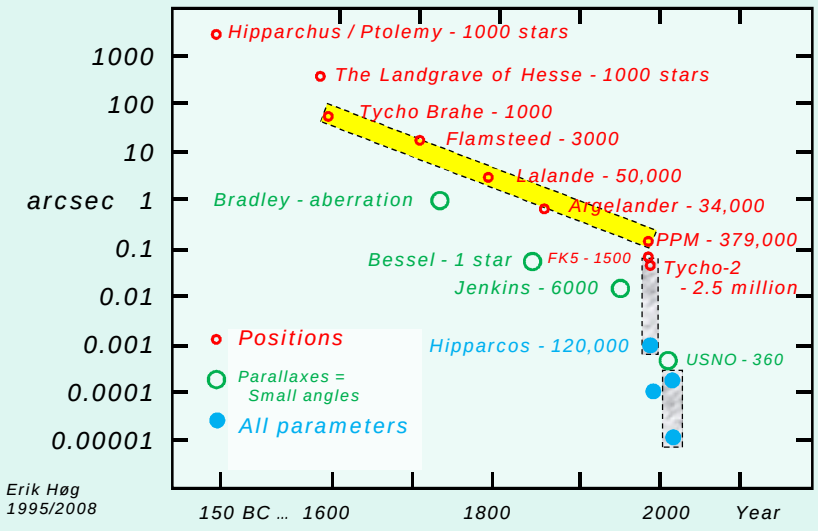
Astrometric Accuracy versus Time



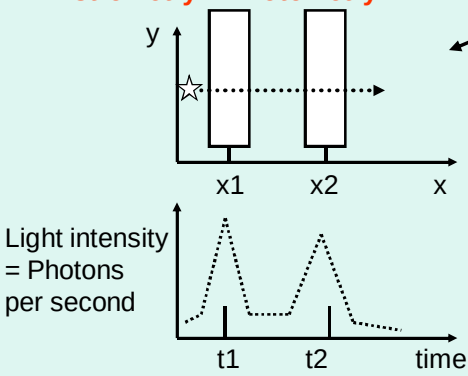
1946:

Erik Høg – 14 years

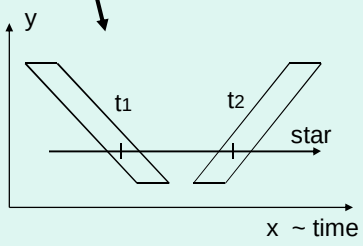
Goes to school
Reads astronomy

Builds telescopes
Observes the stars

Slits + Photon counting vs. Time
=> Astrometry + Photometry



Ideas 1960



B. Strömgren 1932: slits + switching mirror
Atomic bombs 1957 : Counting techniques
E. Høg 1960 : Slits + counting

P. Lacroute 1967: Go to space!
E. Høg 1975: Design of Hipparcos

Hipparcos mission : 1989-93
Final results 1996:
16 volumes + 6 CD ROMs

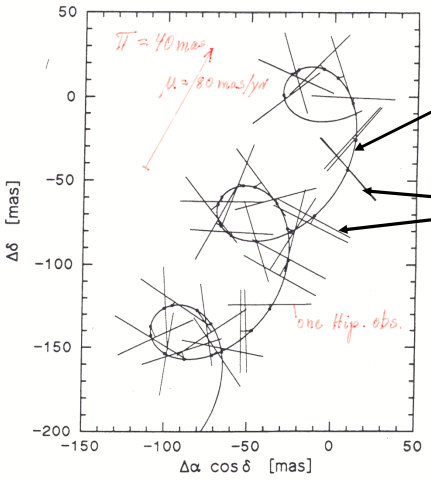


Fig. 2. Each trigonometric parallax is derived as per the least-squares estimate of the five astrometric parameters per star to the collection of one-dimensional star abscissae derived throughout the mission. Each abscissa determination, corresponding to the scanning configuration of the satellite at a given epoch, constrains the instantaneous estimate of the star position to lie on one of the solid lines. The 5-parameter fit to the data for one such object (with a proper motion of about 80 mas/yr and a parallax of about 40 mas) is shown by the solid curve, and the residuals are indicated by the projection from the one-dimensional positions to the curve.

The motion of a star in 3 years

The one-dimensional measurements by Hipparcos

✍

Positions
+ proper motions
+ parallaxes

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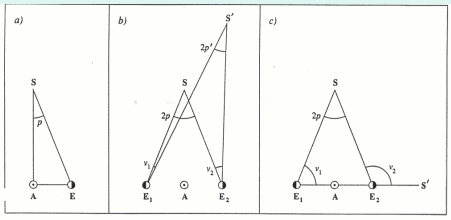
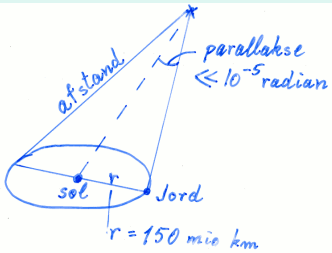
Ground obs. Hipp. 1989-93
Parallax Relative par. Absolute par.



Hipparcos accuracy ~ 0.5 10^-8 radian
= 0.001 arcsec



Astrometric distance
+ apparent brightness
✍ absolute luminosity

Spektrum ~ absolute luminosity

Spektrum
+ apparent brightness
✍ photometric distance

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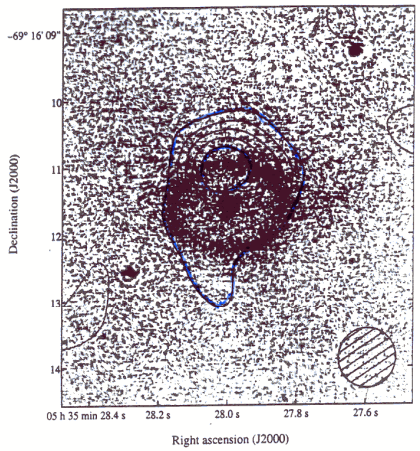
Supernova 1987A



— 8.6 GHz

— [O III] ring

SNR 1987A

optical – radio Δ Dec = 0.″5 ± 0.″2

= 500 mas

Astrometric Reference system

=

Positions

+ proper motions

+ parallaxes

✍

Positions at any time

Ground-based distances

$\sigma_\pi/\pi < 0.15$

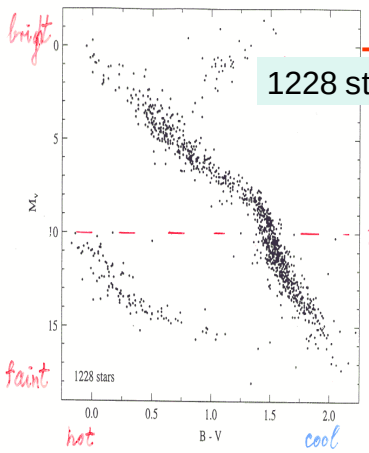
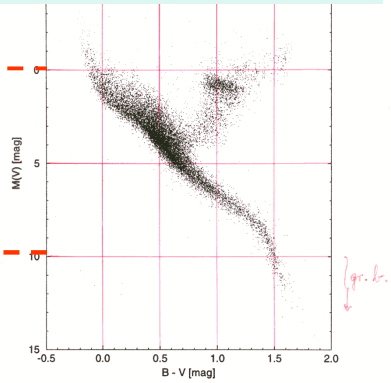


Fig. 11: The Color-Absolute Magnitude diagram for the 1,228 stars in the YPC with UBV photometry and errors in their absolute magnitudes due to the parallax errors of $\sigma(M_V) < 0.30$mag

1228 stars

Hipparcos ✍ 20853 stars



F'γ. 3. The observational Hertzsprung-Russell diagram, M_V versus $B-V$, for the 20 853 stars with $\sigma_\pi/\pi < 0.1$, and with the additional constraint $\sigma_{B-V} < 0.025$ mag.

Hertzsprung-Russell diagrams

Before and after Hipparcos

An old problem solved by Hipparcos in 1997

The age paradox

The oldest stars in globular clusters are older than the Universe

Hipparcos distances are ~ 10% larger

⇒ surface of star ~ 20% larger

⇒ faster energy consumption

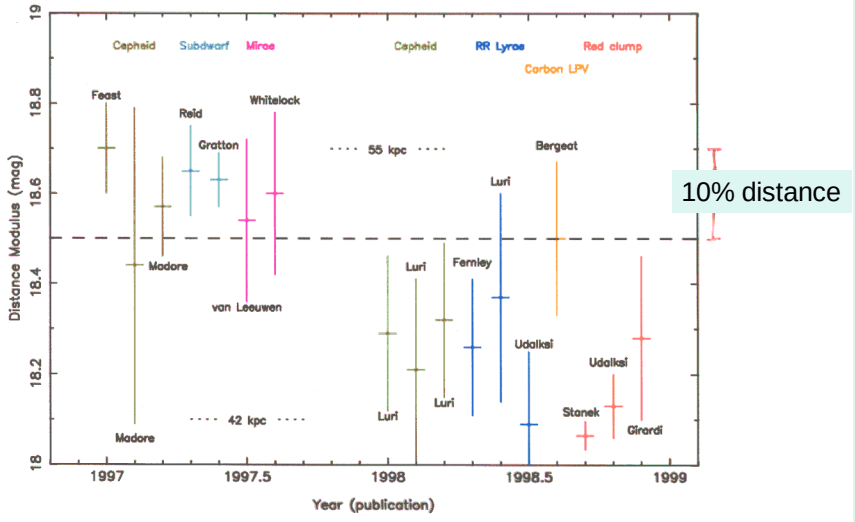
⇒ stars in globular clusters are younger
age ~ 13 billion years

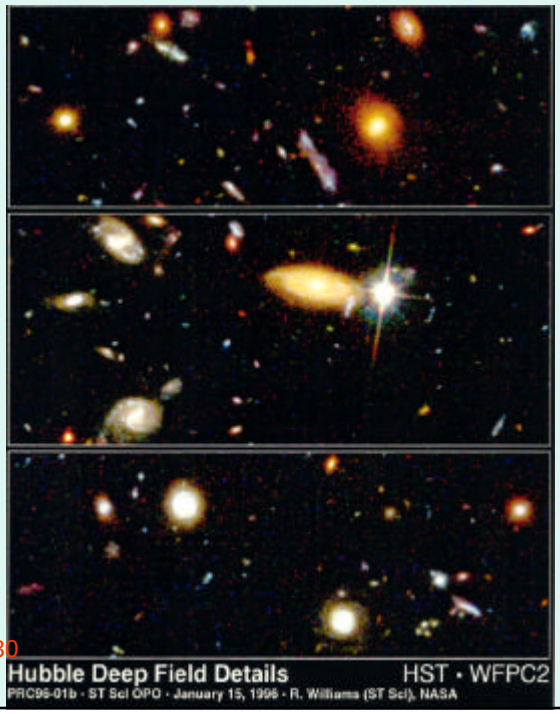
Expansion of the Universe

Hipparcos distances are ~ 10% larger

⇒ larger expansion age ~ 14 billion years

Large Magellanic Cloud:
Distance Uncertainties post-Hipparcos





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Big Bang
14 billion years ago

Many galaxies formed
1 billion years after

Dark matter
+ dark energy
= 95 % of total mass

25 30

From the Roemer mission to Gaia

by Erik Høg, Copenhagen

- *August 1989: Hipparcos launched*
- 1990-91 dialogue with Russian colleagues
- *Proposal 1992 at IAU Symposium in Shanghai:*
  - Satellite in scanning mode with CCDs
  - Direct imaging for astrometry and photometry
  - 0.1 mas at 12 mag from a 5 year mission
- Roemer proposal for ESA M3 mission in 1993
- Later enhancements: *0.01 mas mission goal; Input catalogue dropped; Interferometry studied and dropped; Radial velocities added; Prism photometry instead of filters.*
- *Other missions: SIM, DIVA, FAME*
- *Get the 6-page poster at www.astro.ku.dk/~erik in the section Gaia*

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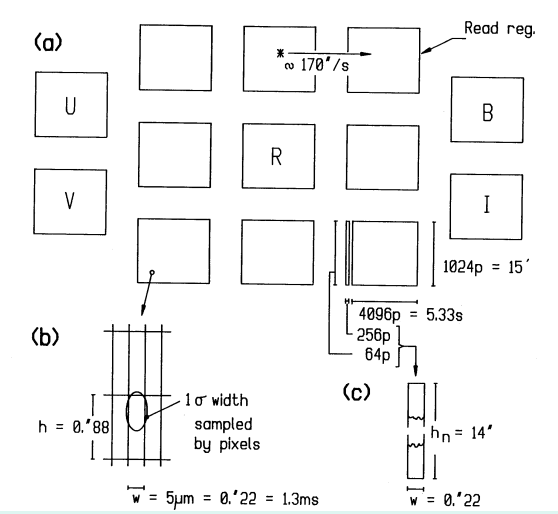
Fig. 1. Focal plane of Roemer - 1992



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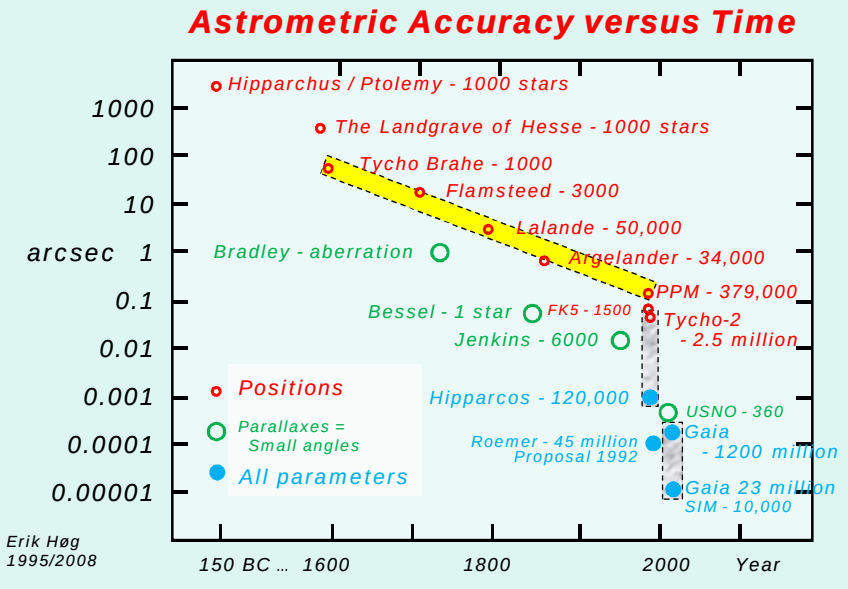


Gaia

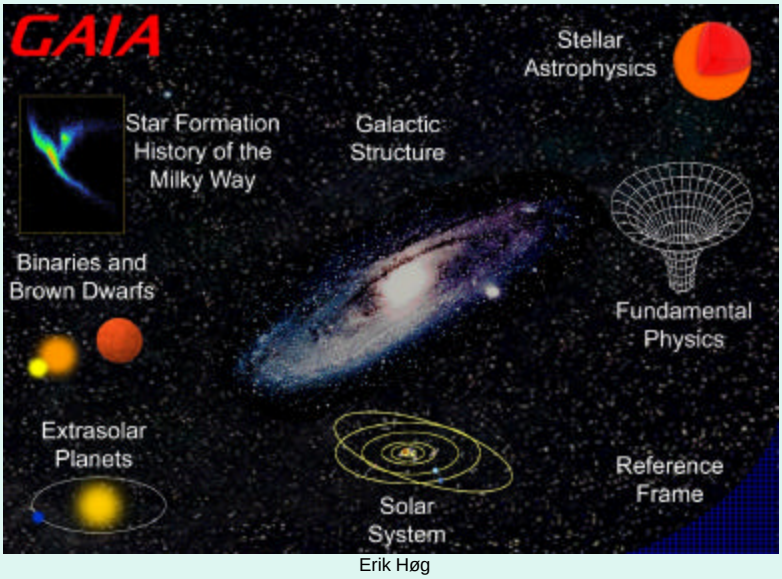
A Stereoscopic Census of our Galaxy

A selection of slides
by Erik Høg in September 2007 from
http://www.rssd.esa.int/Gaia

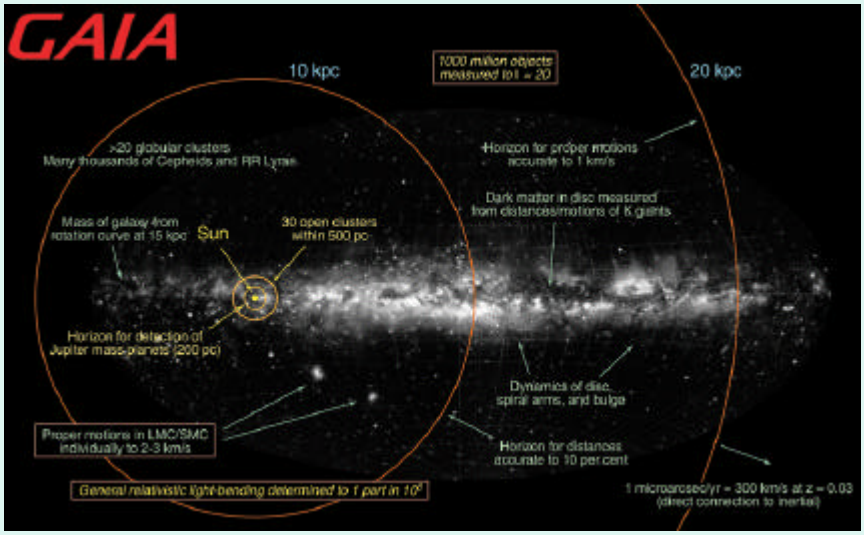
Gaia: Complete, Faint, Accurate

	Hipparcos	Gaia
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	20 mag
Bright limit	0	6 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	50 kpc
Quasars	None	5×10^5
Galaxies	None	$10^6 – 10^7$
Accuracy	1 milliarcsec	7 uarcsec at V = 10 25 µarcsec at V = 15 300 µarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km/s to V = 16-17
Observing	Pre-selected	Complete and unbiased

Areas of science touched on by Gaia

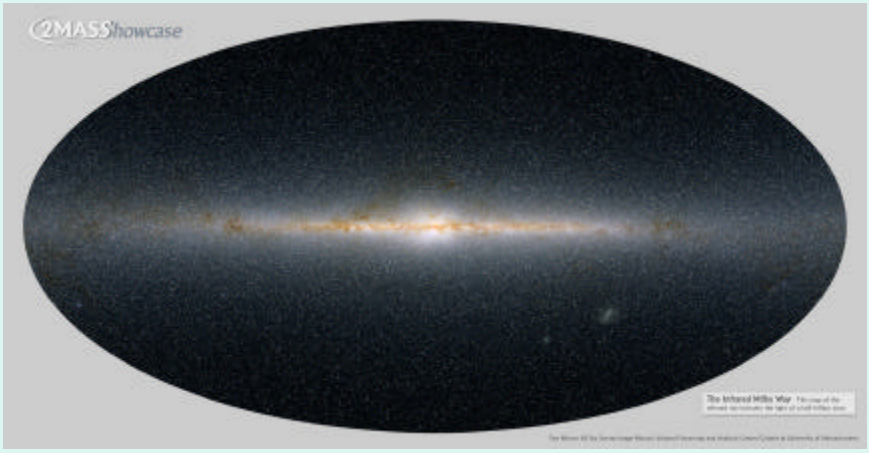


Gaia accuracies in the Galaxy and beyond

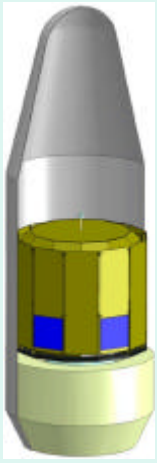


The Milky Way in near-IR (2MASS)

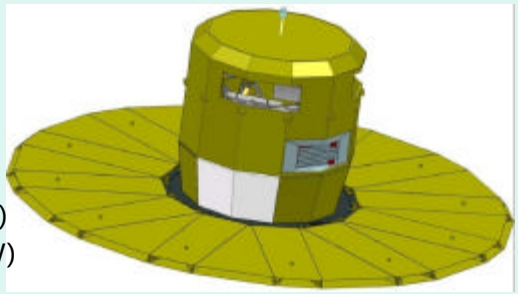
500 million objects
Accuracy of positions 0.08 arcsec



Gaia Satellite and System



- ESA-only mission
- Launch date: 2011
- Lifetime: 5 years
- Launcher: Soyuz–Fregat from CSG
- Orbit: L2
- Ground station: New Norcia and/or Cebreros
- Downlink rate: 4–8 Mbps



- Mass: 2030 kg (payload 690 kg)
- Power: 1720 W (payload 830 W)

Figures courtesy EADS-Astrium

Telescope and payload of Gaia

Launch 2011

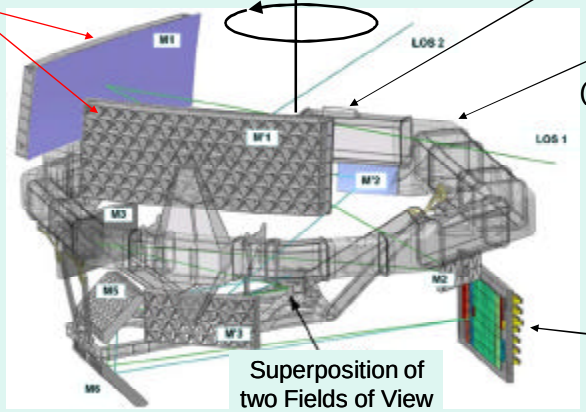
Two SiC primary mirrors

1.45 x 0.50 m^2 at 106.5?

Rotation axis (6 h)

Basic angle monitoring system

SiC toroidal structure (optical bench)



Combined focal plane (CCDs)

F = 35 m

Superposition of two Fields of View

Two anastigmatic off-axis telescopes

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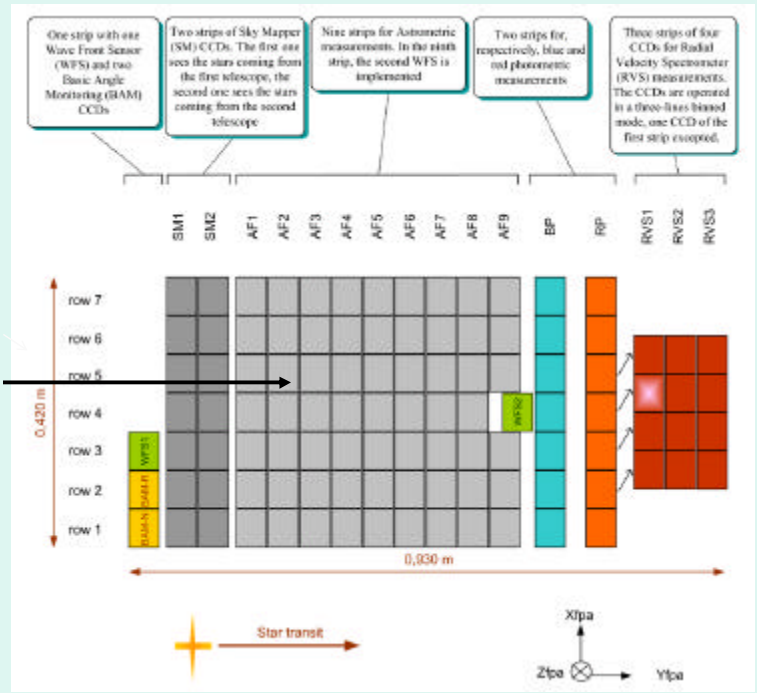
Figure courtesy EADS-Astrium



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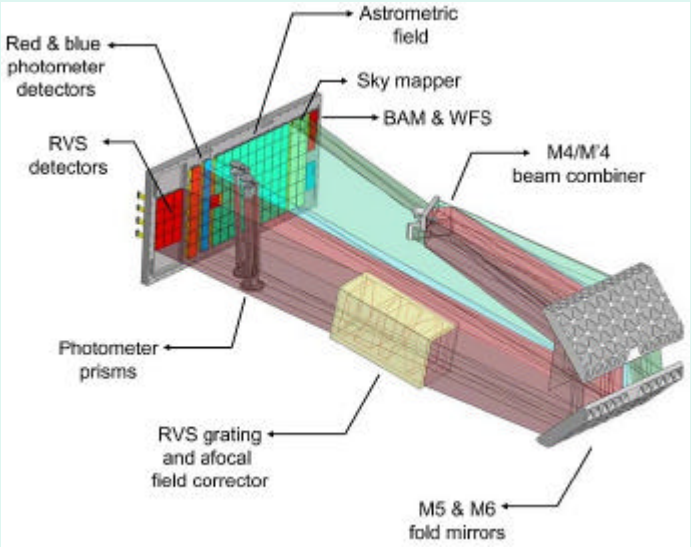
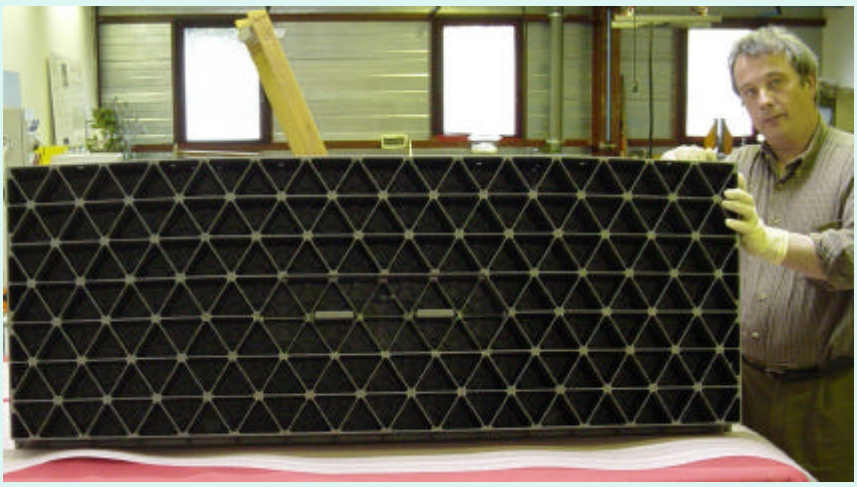
Photometric instrument, the RVS, and the Gaia focal plane



40 38 40

Main mirror - model



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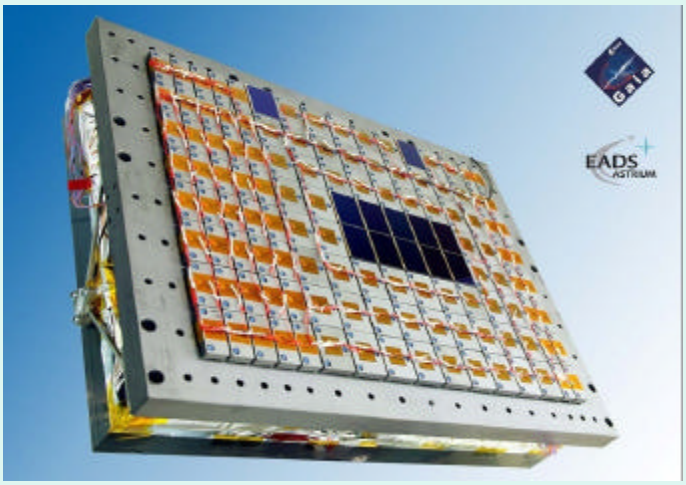
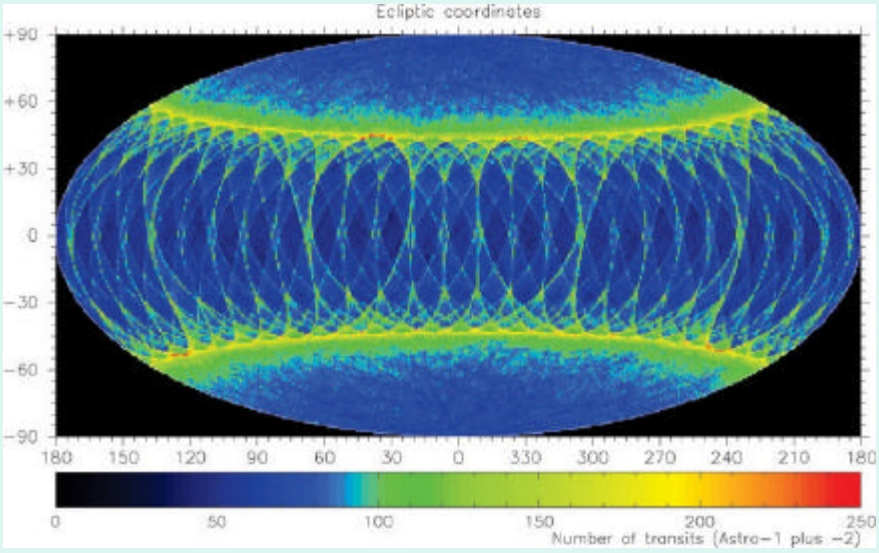
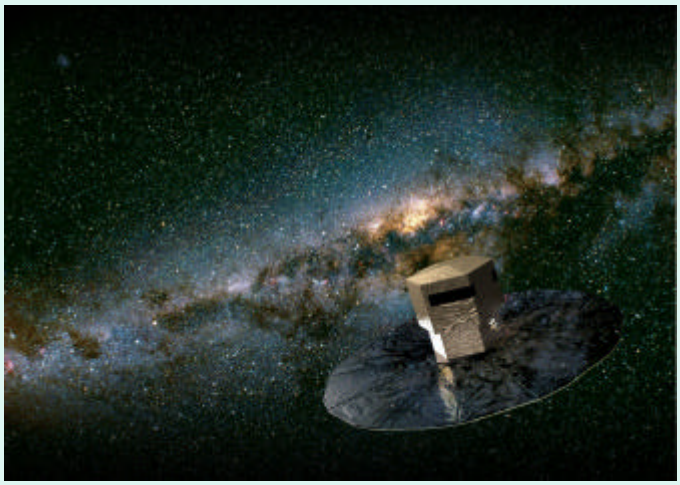
Thermo-Mechanical Focal Plane Demonstrator Model



Predicted astrometric transits



Gaia - with the Milky Way



The Gaia astrometric survey of 1000 million stars can not be surpassed in completeness and accuracy within the **next 40-50 years**

Website: www.astro.ku.dk/~erik Read e.g.:

- ***The age of the world*** *from to the highest authorities*
- *Contributions to the history of astrometry*