

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: October 2009

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

$$10^{15} = 1\,000\,000\,000\,000\,000$$

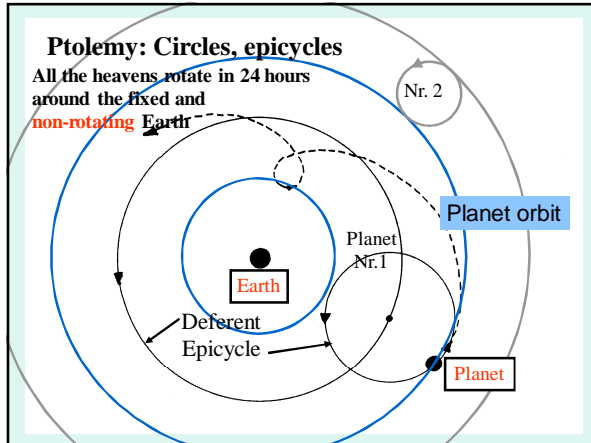
= 1 million billion times larger



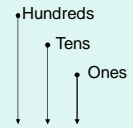
Tycho Brahe
ca. 1590

Ptolemy
ca. 150 A.D.

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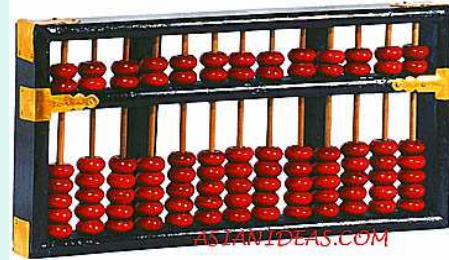


Numerals: Roman Arabic
XX = 20
CCCXV = 315



abacus

Oldest find in Europe ca. 400 BC



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The Arabs:

Translation of Greek texts and science



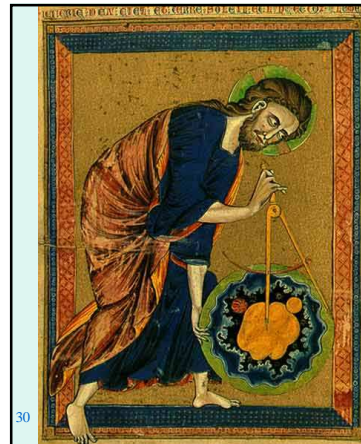
Harun al Rashid
766 - 809

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

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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

30

6 30

11 Nov. 1572
Nova Stella

R.A. 0.5 h
Dec. 63 deg

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**

Tycho Brahe's new instruments

Fig. 5. Den store Kvadrant fra Augsburg, benyttet af Tycho Brahe fra år inden Uraniborg grundlagges. Den kunne kun male henfor igjort astronomiae modernae mechanica.

Fig. 6. Tycho Brahes sigtende.

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Sextans Astronomicus Trigonicus
PRO DISTANTIIS REMANDIS.

Tycho Brahe on Hven 1576-97
A barrel of gold

Sextant 1580

Høg 9

Kepler 1596
Mysterium Cosmographicum

Figur 15 Keplers polyederuniverset. Mellem Saturn-sfæren og Jupiter-sfæren er der indstaaet en terning, mellem Jupiter og Mars et tetraeder, og derefter igen et dobbeltkugle, et dobbeltkugle og et dobbelt mellem de øvrige planetsfærer. (Illustration fra Mysterium Cosmographicum, 1596.)

Kepler 1619 *Harmonices Mundi*

HARMONICIS LIB. V. 207

omnia (infinita in potentia) permeantes actu : id quod aliter à me non potuit exprimi, quam per continuam seriem Notarum intermedia.

Figur 17 Planetskalaer fra Harmonices mundi. En skalas længde er et direkte udtryk for den pågældende planets excentricitet. Jorden og Venus er her ikke medtaget.

Kepler found ~70 laws for the motion of planets
But we usually mention only 3 of these...

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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

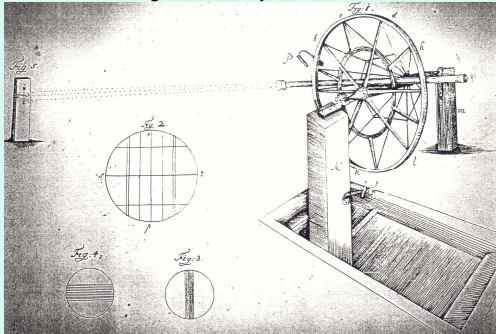
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Ole Rømer's meridian circle 1705

Accuracy ~4 arcsec per star from 3 observations

MCs took over only after 1800

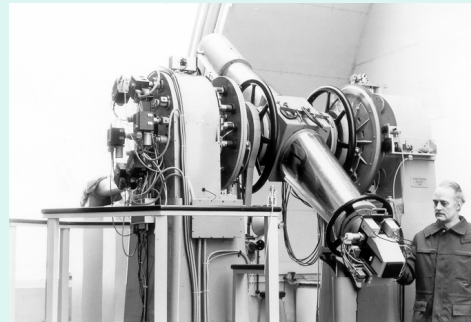
Quadrants were good: Bradley 1760-> 1.1 arcsec!!!



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Brorfelde meridian circle – Feb. 1979

Accuracy ~0.1 arcsec per star with 4 obs.



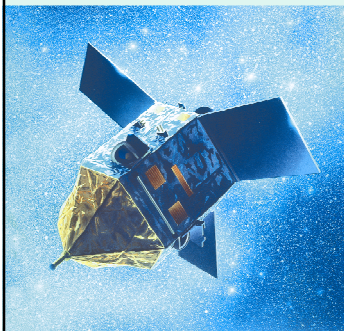
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14 15

Hipparcos satellite

Measured 2.5 million stars in 1989-93

Distances, positions, motions and magnitudes



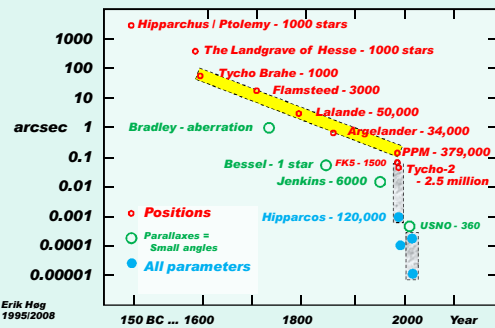
The Tycho-2 Catalogue

Medal 1999 from ESA's Director of Science:

For outstanding contribution to the science programme

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Astrometric Accuracy versus Time



Erik Høg 1995/2008

1946:
Erik Høg – 14 years

Goes to school
Reads astronomy

Builds telescopes
Observes the stars

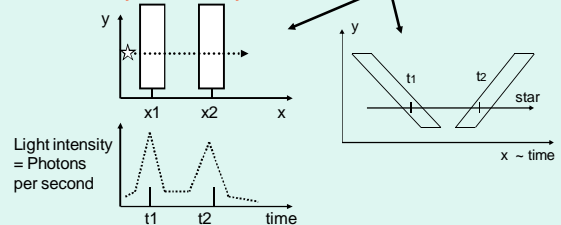


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Slits + Photon counting vs. Time => Astrometry + Photometry

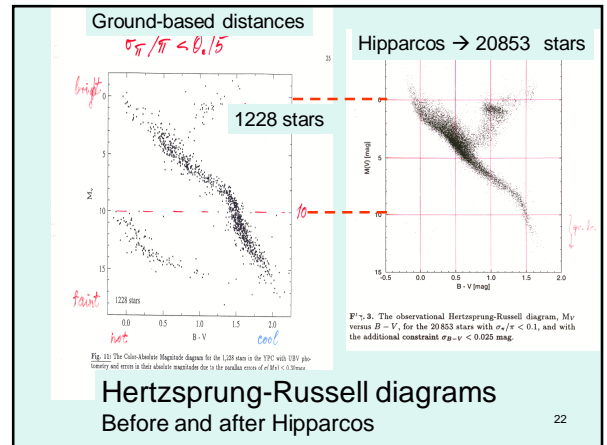
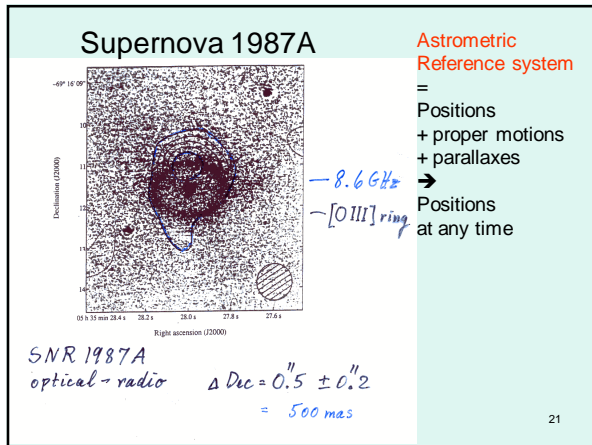
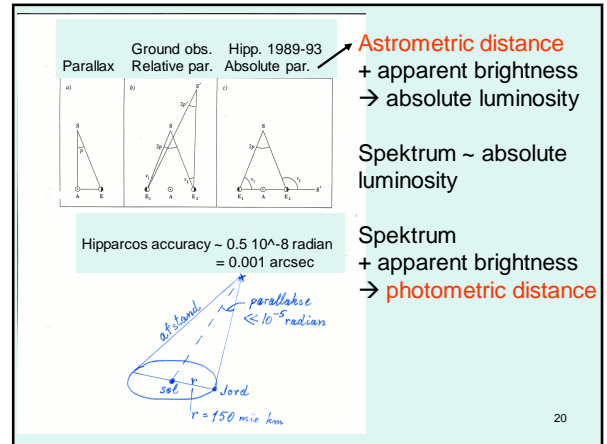
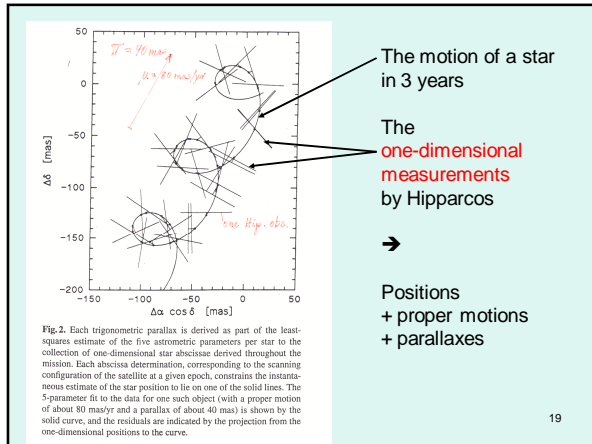
Ideas 1960



B. Strömgen 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 1997:
16 volumes + 6 CD ROMs



The age paradox

An old problem solved by Hipparcos in 1997

The oldest stars in globular clusters are older than the Universe

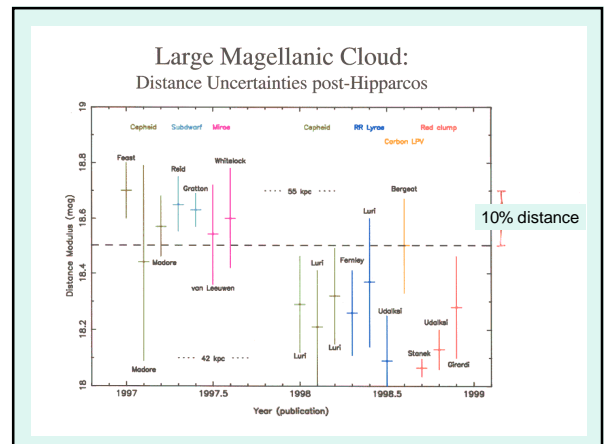
Hipparcos distances are $\sim 10\%$ larger

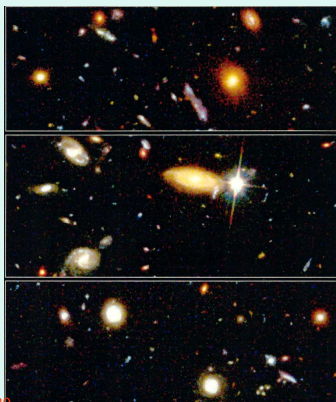
- \Rightarrow surface of star $\sim 20\%$ larger
- \Rightarrow faster energy consumption
- \Rightarrow stars in globular clusters are younger age ~ 13 billion years

Expansion of the Universe

Hipparcos distances are $\sim 10\%$ larger

- \Rightarrow larger expansion age ~ 14 billion years





Big Bang
14 billion years ago

Many galaxies formed
1 billion years after

Dark matter
+ dark energy
= 95 % of total mass

30 Hubble Deep Field Details HST - WFPC2
PRC96-01b - ST ScI OPO - January 15, 1996 - R. Williams (ST ScI), NASA

25 30

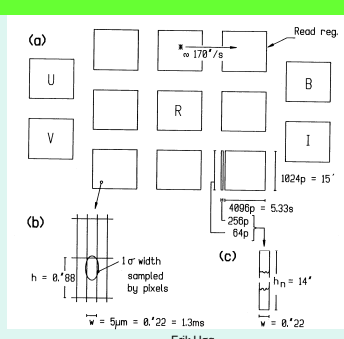
From the Roemer mission to Gaia

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



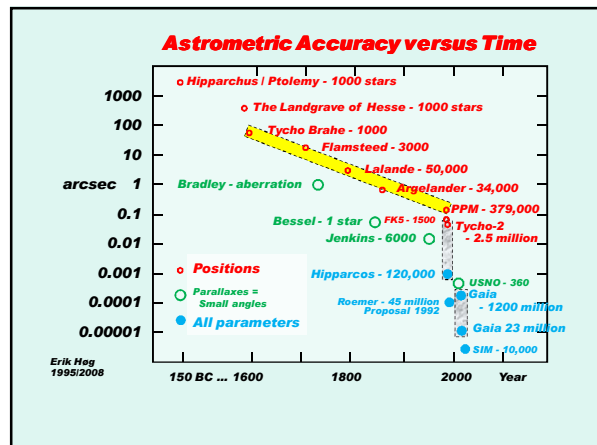


(a) Read reg. 170°/s

(b) $h = 0.198$
 $w = 5 \mu\text{m} = 0.122 = 1.3\text{ms}$

(c) $4896p = 5.33s$
 $256p = 64p$
 $h_n = 14'$
 $w' = 0.122$

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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>

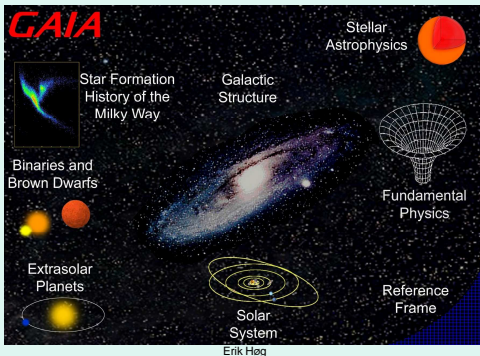
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Gaia: Complete, Faint, Accurate

	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 μarcsec 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

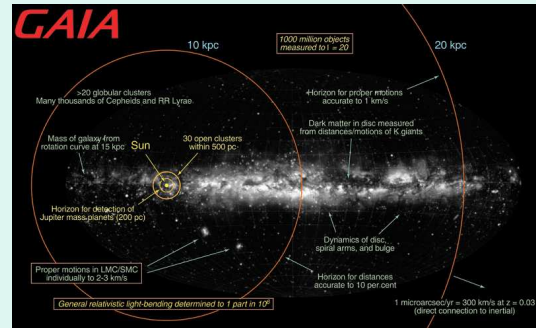
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Areas of science touched on by Gaia



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Gaia accuracies in the Galaxy and beyond

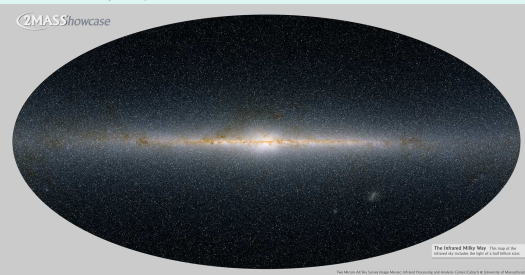


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The Milky Way in near-IR (2MASS)

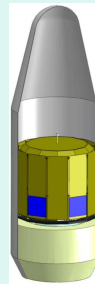
470 million objects
Accuracy of positions 0.08 arcsec



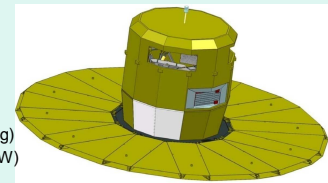
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Gaia Satellite and System



- ESA-only mission
- Launch date: 2012
- Lifetime: 5 years
- Launcher: Soyuz-Fregat from CSG
- Orbit: L2
- Ground station: New Norcia and/or Cebreros
- Downlink rate: 4-8 Mbps

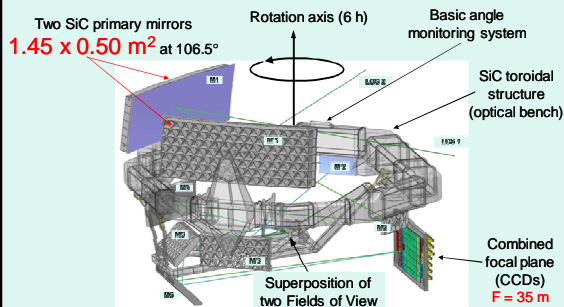


- Mass: 2030 kg (payload 690 kg)
- Power: 1720 W (payload 830 W)

Figures courtesy EADS-Astrium

Telescope and payload of Gaia

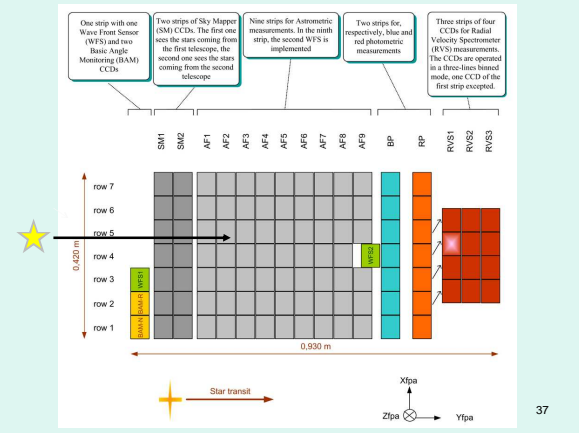
Launch 2012



Two anastigmatic off-axis telescopes

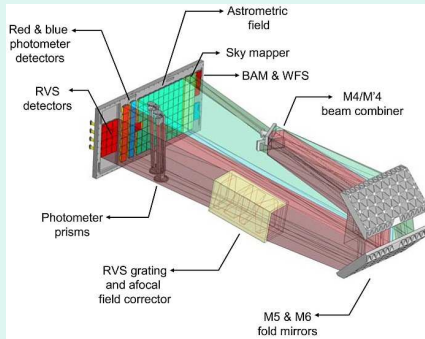
Figure courtesy EADS-Astrium

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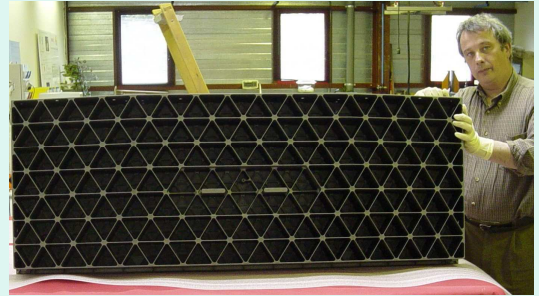
Photometric instrument, the RVS, and the Gaia focal plane



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38 40

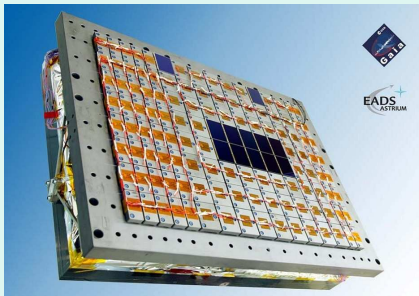
Main mirror - model



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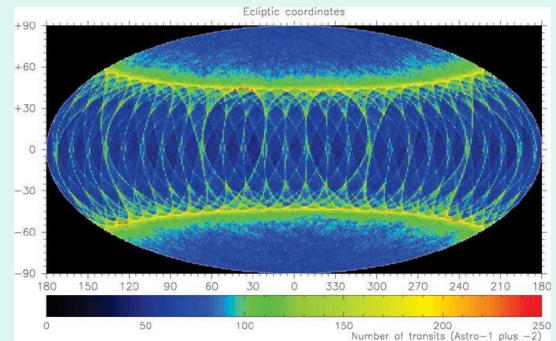
Thermo-Mechanical Focal Plane Demonstrator Model



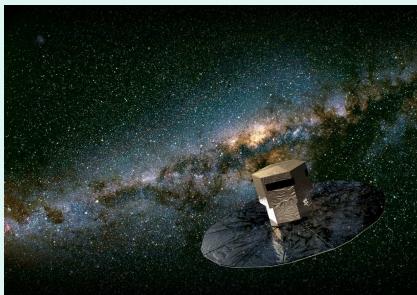
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Predicted astrometric transits



Gaia - with the Milky Way



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The Gaia astrometric survey of 1000 million stars can not be surpassed in completeness and accuracy within the next 30-40 years



Website: www.astro.ku.dk/~erik

Read e.g.:

- *The age of the world from the highest authorities*
- *Astrometry and optics during the past 2000 years*