Gaia in the ELTs era

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gaia

One great goal…

Understand the chemical and dynamical history of our Galaxy

"Understanding the details of the Galaxy in which we live is one of the **great intellectual challenges** embraced by **modern science**."

Perryman *et al.*
"GAIA: Composition, formation and evolution of the Galaxy"
Astronomy and Astrophysics (2001)

Perryman is the scientific leader of ESA's Hipparcos mission, and a founding father of its successor mission, Gaia.

What Gaia will give us?

Gaia will give us <u>one billion</u> of object..!

("un miliardo")

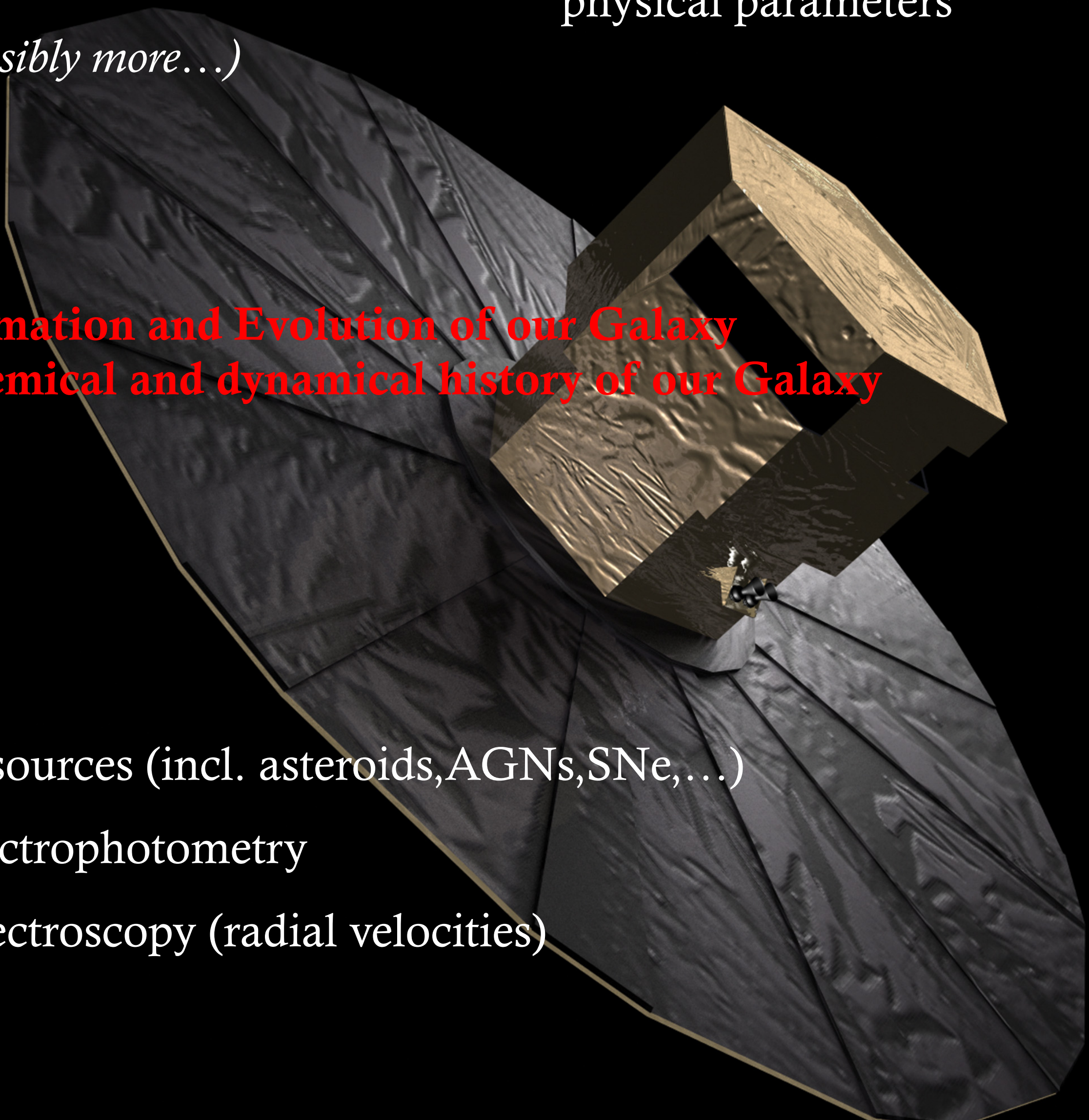
(From the "ancient" italian comic "Il signor Bonaventura")

All-sky survey

Launch May 2013

5 years activity *(possibly more…)*

Based on Hipparcos principle to obtain **α, δ, π, μ_α, μ_δ** + complementary radial velocities ⇨ 6D phase space survey **+** physical parameters



Composition, Formation and Evolution of our Galaxy
Unraveling the chemical and dynamical history of our Galaxy

10^9 stars

20 μas at V=15

V_{lim} = 20 all point sources (incl. asteroids,AGNs,SNe,…)

Low resolution spectrophotometry

High resolution spectroscopy (radial velocities)

“Madamina il catalogo è questo”
(“My dear lady, this is the list…”)
Don Giovanni (Da Ponte, Mozart)

The expected 3D distribution in the Milky Way of the contents of the Gaia catalogue will cover a **significant portion** of our Galaxy

Credits: X. Luri & the DPAC-CU2. Simulations based on an adaptation for Gaia of the Besançon galaxy model (A. Robin et al.)

Gaia scanning principle

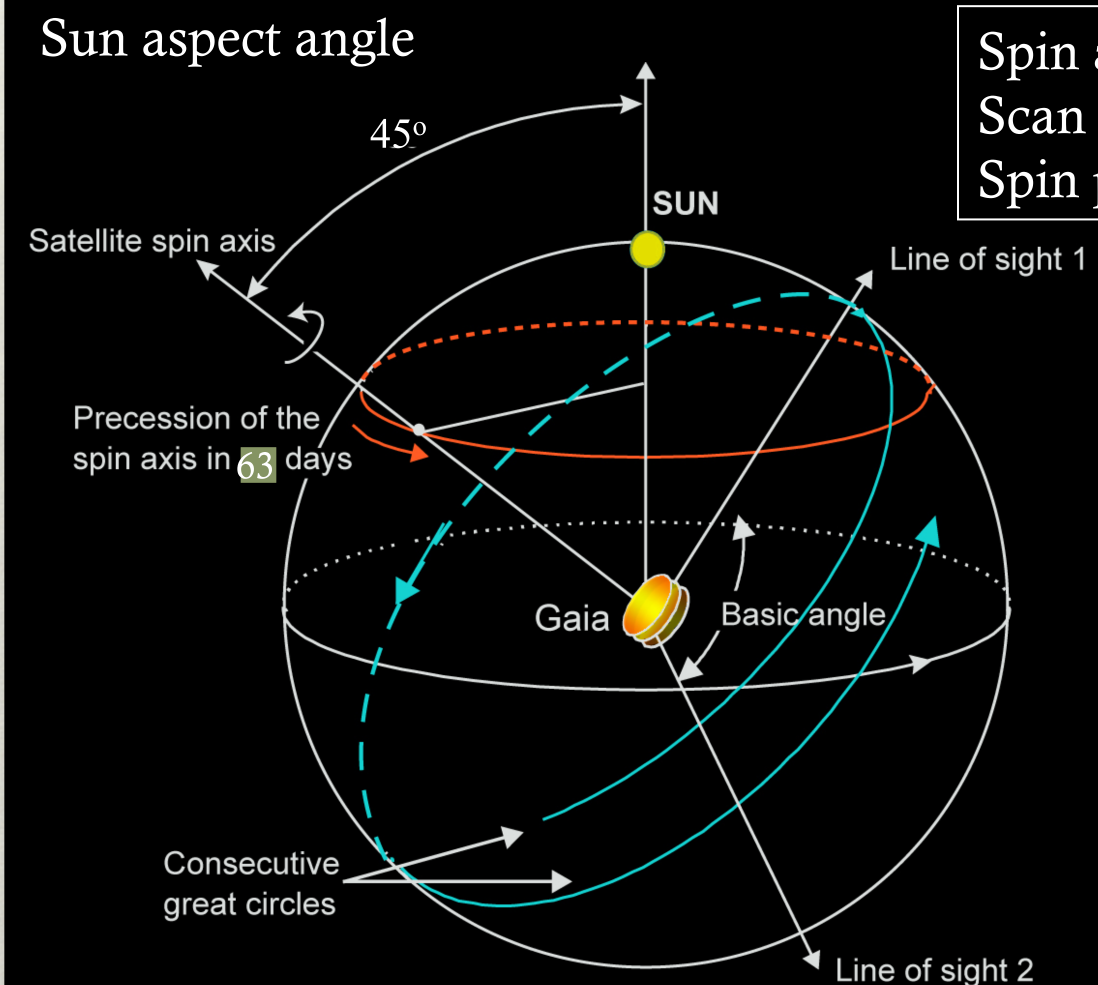


Figure courtesy Karen O'Flaherty

Spin axis	45º to Sun
Scan rate:	60 arcsec/s
Spin period:	6 hours

↓

Great circle scan

What Gaia will do

Astrometry (V < 20):

– completeness to 20 mag (on-board detection) ⇒ **10^9 stars**
– accuracy: 10–25 μarcsec at 15 mag (Hipparcos: 1 milliarcsec at 9 mag)
– scanning satellite, two viewing directions

Photometry (V < 20):

– astrophysical diagnostics (low-dispersion photometry)
  ⇒T_{eff} , log g, [Fe/H], extinction

Radial velocity (V < 17):

– application:
  • third component of space motion
  • dynamics, population studies, binaries
  • spectra for V < 14: chemistry, rotation
– principle: slitless spectroscopy in Ca triplet (847–874 nm)

Gaia: Complete, Faint, Accurate

	Hipparcos	Gaia
Magnitude limit	12 mag	20 mag
Completeness	7.3 – 9.0 mag	20 mag
Bright limit	0 mag	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	1 (3C 273)	500,000
Galaxies	None	1,000,000
Accuracy	1 milliarcsec	7 µarcsec at V = 10
		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^{-1} to V = 17
Observing sample	Pre-selected	**Complete and unbiased**

One Billion Stars in 3-D will provide …

- in our Galaxy …
  - the distance and velocity distributions of all stellar populations
  - the spatial and dynamic structure of the disk and halo
  - its formation history
  - a detailed mapping of the Galactic dark-matter distribution
  - a rigorous framework for stellar-structure and evolution theories
  - a large-scale survey of extra-solar planets (~7,000)
  - a large-scale survey of Solar-system bodies (~250,000)

- … and beyond
  - definitive distance for standard candles out to the LMC/SMC
  - quasar detection, redshifts, microlensing structure (~500,000)
  - fundamental quantities to unprecedented accuracy

Our Galaxy

Gaia is the first survey providing **6D phase space** (***r***, ***v***) data combined with **spectro-photometry** for very large, magnitude-limited samples of stars

- **Distances + magnitudes & colours + kinematics**
  - age-metallicity-kinematics relation
  - substructure in disk and halo (mergers, accretion)
  - age of Galactic components
  - star formation history, evolution of the IMF
  - Chemical enrichment

- **Mass distribution**
  - determine gravitational potential from stellar motions
  - dark matter

- **Formation of the Milky Way**
  - monolithic collapse or via accretion of satellites?
  - is there a smooth age-metallicity-kinematic relation?
  - look for substructures…
  - age from WD luminosity function (200,000, precise to <0.5 Gyr)
  - Disk dynamics (bars, spirals)

Stellar Astrophysics with Gaia

- Comprehensive luminosity calibration, for example:
  - distances to 1% for ~10 million stars to 2.5 kpc
  - distances to 10% for ~100 million stars to 25 kpc
  - Peculiar stellar types and rapid evolutionary phases in large numbers
  - calibration of fundamental distance indicators

    e.g., Cepheids and RR Lyrae

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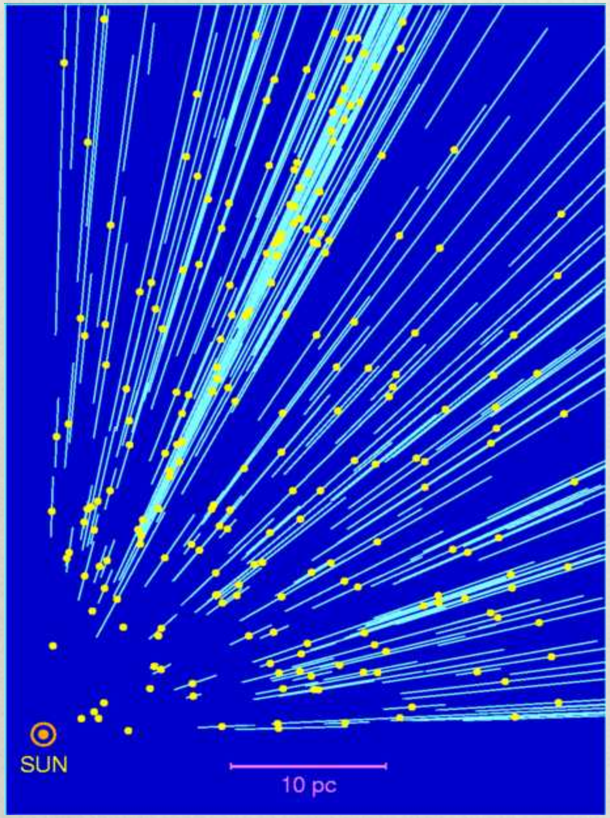
- Physical properties, for example:
  - clean Hertzsprung–Russell diagrams throughout the Galaxy
  - Solar-neighbourhood mass and luminosity function

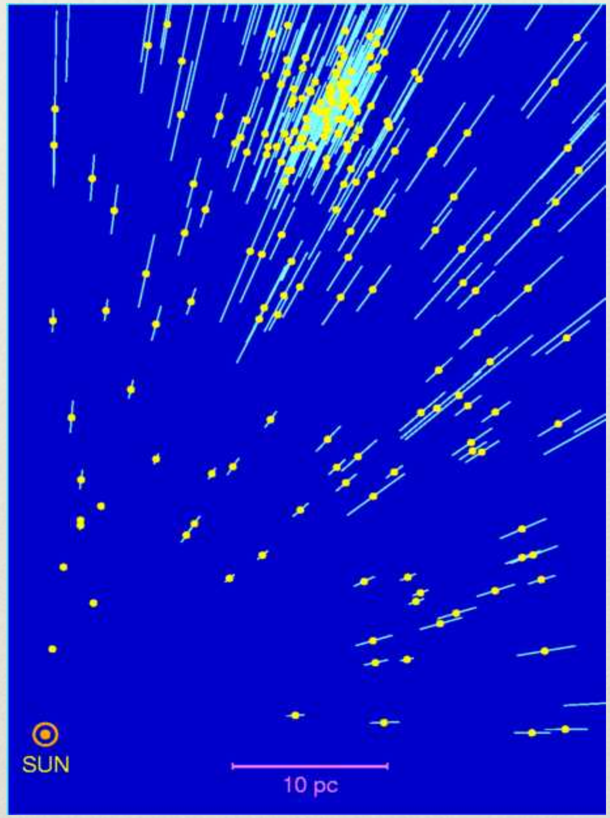
    e.g., white dwarfs (~400,000) and brown dwarfs (~50,000)
  - initial mass and luminosity functions in star-forming regions
  - luminosity function for pre-main-sequence stars
  - detection and dating of all spectral types and Galactic populations
  - detection and characterisation of variability for all spectral types

Distance accuracy to nearby stars

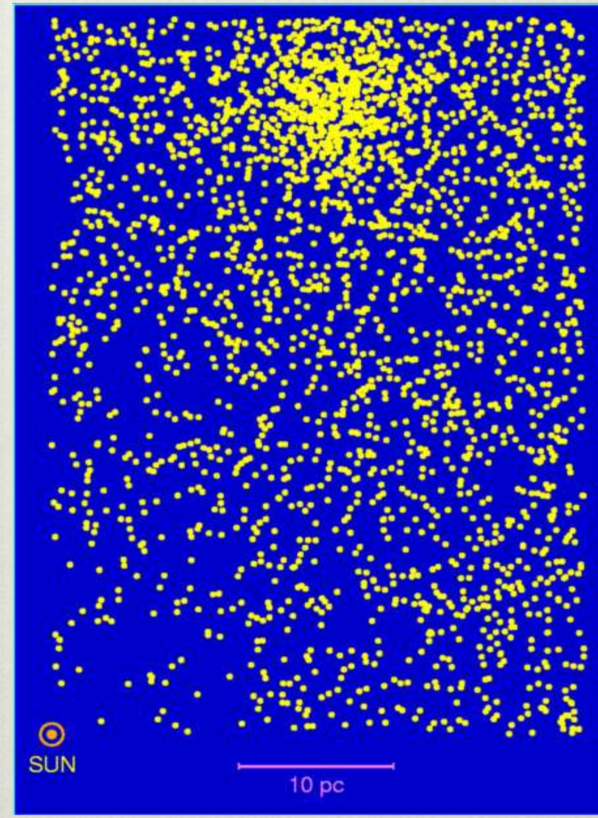
Courtesy Paola Marrese



Ground



Hipparcos



Gaia

Studies of the Solar System

- Asteroids etc.:
  - deep and uniform (20 mag) detection of all moving objects
  - ~250,000 objects observed, mainly main-belt asteroids
  - orbits: 30 times better than present
  - spin-axis direction, rotation period, shape parameters for majority
  - composition versus heliocentric distance
  - diameters for ~1000 to 20%, masses for ~150 to 10%
  - Trojan companions of Mars, Earth, and Venus
  - Kuiper-Belt objects: ~50 objects to 20 mag (binarity, Plutinos)

- Near-Earth Objects:
  - Amors, Apollos and Atens (3070, 3675, 610 known today)
  - A lot of *new* small object expected
  - detection limit: 260–590 m at 1 AU, depending on albedo

A short flashback…

(Just to convince you that GAIA will have a great impact on astronomy…)

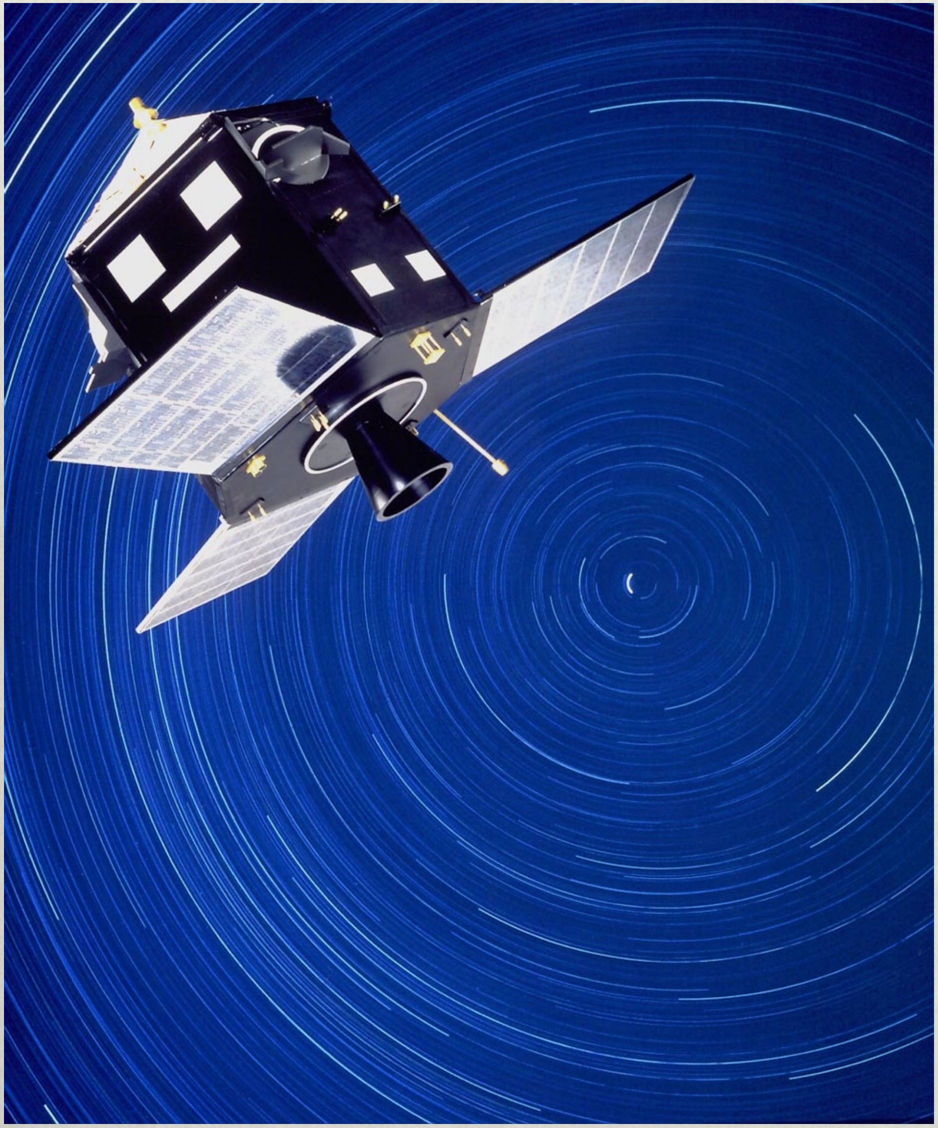
On-Board Object Detection

- Requirements:
  - unbiased sky sampling (magnitude, colour, resolution)
  - all-sky catalogue at Gaia resolution (0.1 arcsec) to V~20 mag does not exist

- Solution is on-board detection:
  - no input catalogue or observing programme
  - good detection efficiency to V~21 mag
  - low false-detection rate, even at high star densities

- Gaia will therefore detect:
  - variable stars (eclipsing binaries, Cepheids, etc.)
  - supernovae: ~20,000
  - gravitational-lensing events: ~1000 photometric and ~100 astrometric
  - Solar-system objects, including near-Earth asteroids and Kuiper-Belt objects

Hipparcos HIgh Precision PARallax COllecting Satellite

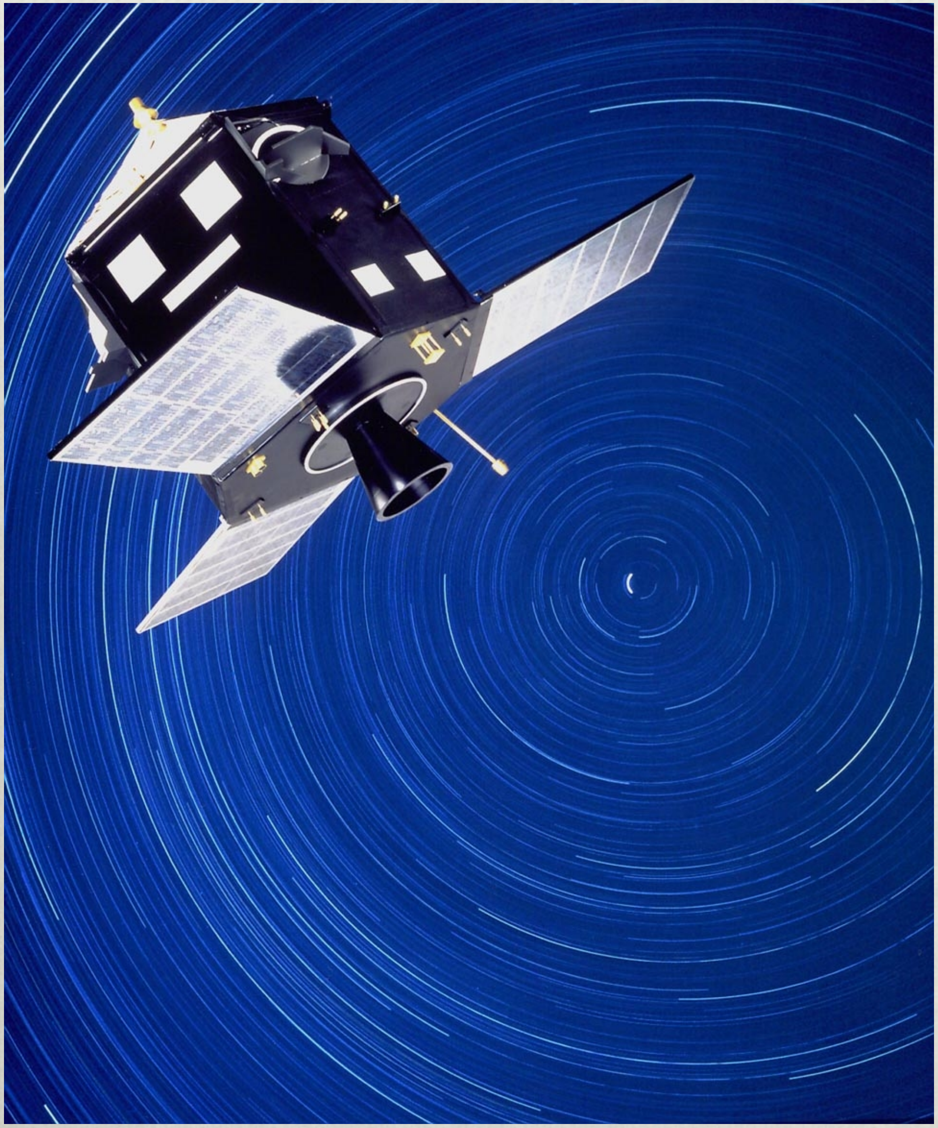


General principle of HIPPARCOS:
global astrometry instrument conceived to measure large angles on the sky

ESA mission
Launch: August 8, 1989.

Catalog:
- Around 120.000 objects
- **NO** radial velocities!

Hipparcos HIgh Precision PARallax COllecting Satellite



The principle of HIPPARCOS was invented by Lacroute in 1966 . More than 10 years elapsed before space technology allowed serious consideration of its development.

General principle of HIPPARCOS:
global astrometry instrument conceived to measure large angles on the sky

ESA mission
Launch: August 8, 1989.
Orbit: a very elongated orbit instead of the “expected” geostationary one.
Perigee **500** km high and an apogee close to **36500** km.
Period = 10h 40min.
Last observation: March 1993.

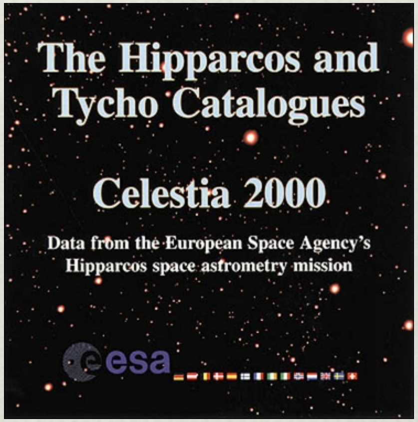
Hipparcos catalogue

Two catalogues were produced independently. The most detailed and updated reduction is presented in Vol. 1 & 3 of the published catalogue (ESA, 1997)

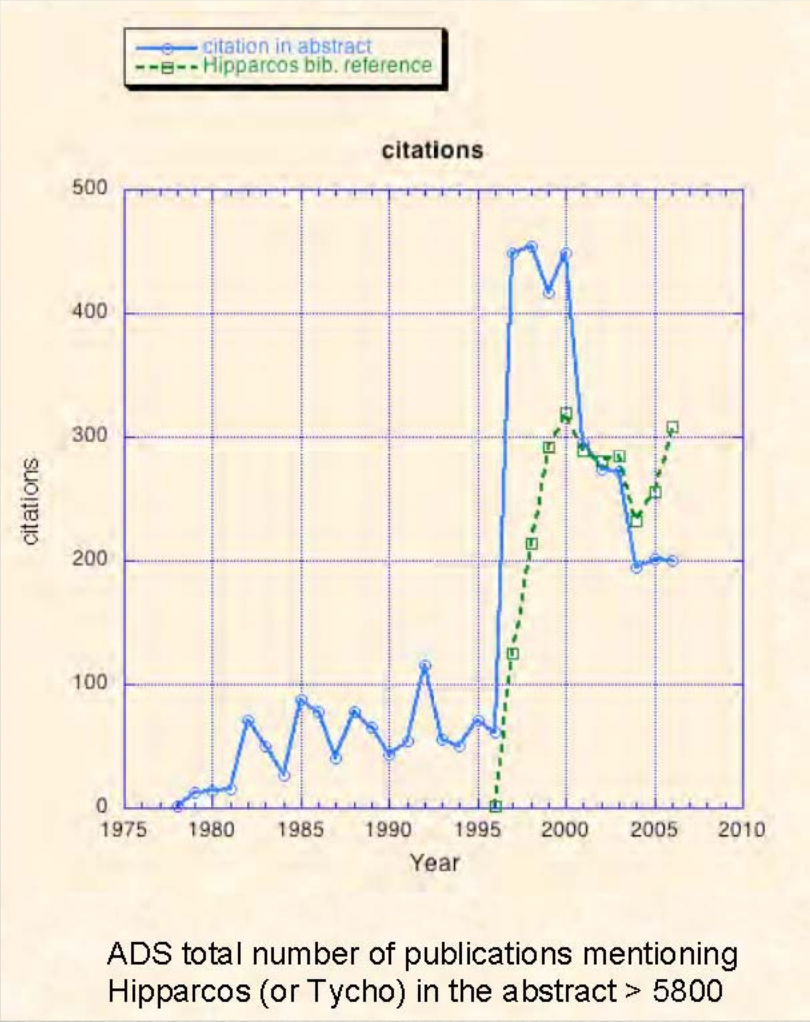
117,955 entries for astrometry &
118,204 for the photometric results

Distance <10%: 21 000
Distance <20%: 50 000

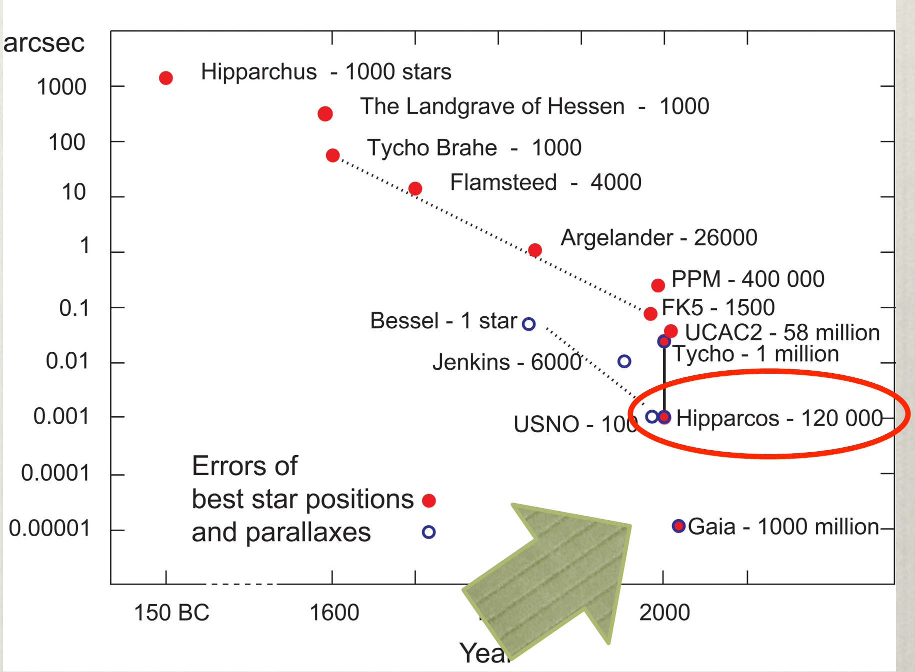
limiting magnitude: V=12.4 &
complete to V=7.3 to 9.0



Hipparcos was highly successful mission and had a lasting impact on astrophysics



Courtesy: C.Turon



Courtesy: Erik Høg

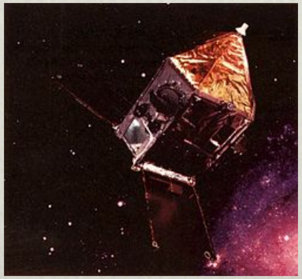
Back to the future …

From Hipparcos to Gaia …

- Massive leap:
  - accuracy: 2 orders of magnitude (1 milliarcsec to 7 microarcsec)
  - limiting sensitivity: 4 orders of magnitude (~10 mag to 20 mag)
  - number of stars: 4 orders of magnitude (10^5 to 10^9)

- Measurement principles identical:
  - two viewing directions (absolute parallaxes)
  - sky scanning over 5 years $\Rightarrow$ parallaxes and proper motions

- Instrument improvement:
  - larger primary mirror: $0.3 \times 0.3\ m^2 \rightarrow 1.45 \times 0.50\ m^2$, $\sigma \propto D^{-(3/2)}$
  - improved detector (PMT $\rightarrow$ CCD)



What GAIA can provide to ELT

Just a few examples…

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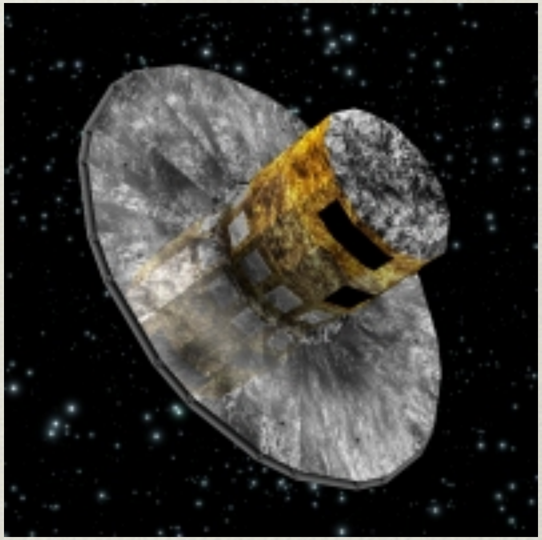
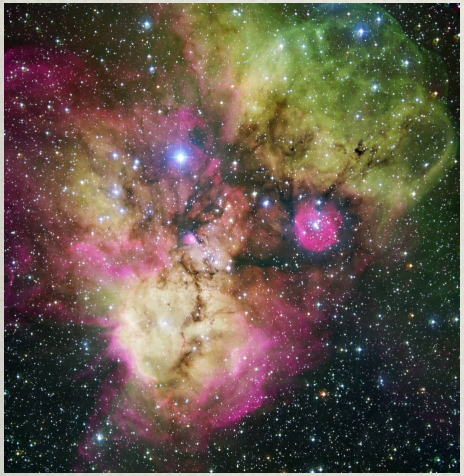


Gaia will give us an extremely detailed knowledge of the stellar populations in the Milky Way (largest and more precise three dimensional chart of our Galaxy, unprecedented positional and radial velocity measurement.



ELTs will revolutionise our view of stellar population in the local Universe, from observations of heavily obscured star-formation/stellar clusters in the Milky Way, out to spectroscopy of evolved galaxies beyond 10 Mpc

Comparing and contrasting external galaxies with the Milky Way will give **us a way to constrain crucial aspects of galaxy formation and evolution.**

Gaia will provide the ELTs with an **exquisite astrometric reference frame** with sub-milliarcsec quality **out to magnitude 20** (very useful in precise targeting for ELTs)

Gaia will screen *all stars* within 200 pc for **Jupiter size planets**, delivering **an extensive target list** for the ambitious to image nearby planetary systems

With an expected harvest of about **11 million parallaxes accurate to 1%** for stars within about 2.5 kpc, Gaia will provide the most accurate calibration to data across **almost all spectral types and luminosity classes.**

And, what about metallicity?

In combination with the structural and dynamical informations, GAIA will give us an unprecedented picture of the distribution of metals in the Milky Way.

How the metallicity distribution relates to the formation and evolution of our Galaxy

Investigation about the **radial migration** of stars

…Briefly, gaia will give us **candidate first stars** which can be followed up with ELT to do *nucleocosmochronometry*

Short version:

Great leap in our knowledge of **stellar astrophysics**

↳ Great leap in our knowledge of **stellar populations**

↳ Great leap in out knowledge of **galaxies**

"You cannot understand galaxies if you cannot understand stars"
(John R. Percy)

That's all …
… Thanks for you time !

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*For **many** slides and figure, credits are to be given to a number of people in the GAIA team (apologize for not citing their names…)*

Useful links

- http://gaia.esa.int
- http://www.eso.org/sci/facilities/eelt/science/

Curiosities…

Professor Michael Perryman, the scientific leader of ESA's Hipparcos mission, and a founding father of its successor mission, Gaia, has been awarded the 2011 Tycho Brahe Prize from the European Astronomical Society. The prize recognises the extraordinary work accomplished by Perryman in shepherding the field of astrometry to its successful leap into space-based observations and demonstrating the importance of measuring stellar positions for a plethora of astronomical applications.