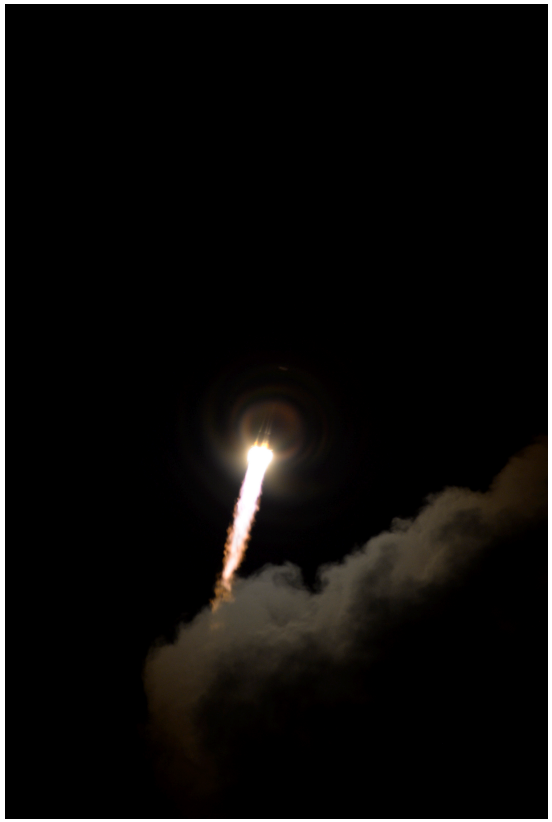
Gaia: A billion-star 3D map of the Milky Way

Paul McMillan

Lund Observatory, Gaia Data Processing & Analysis Consortium

gaia

Launched Dec 2013



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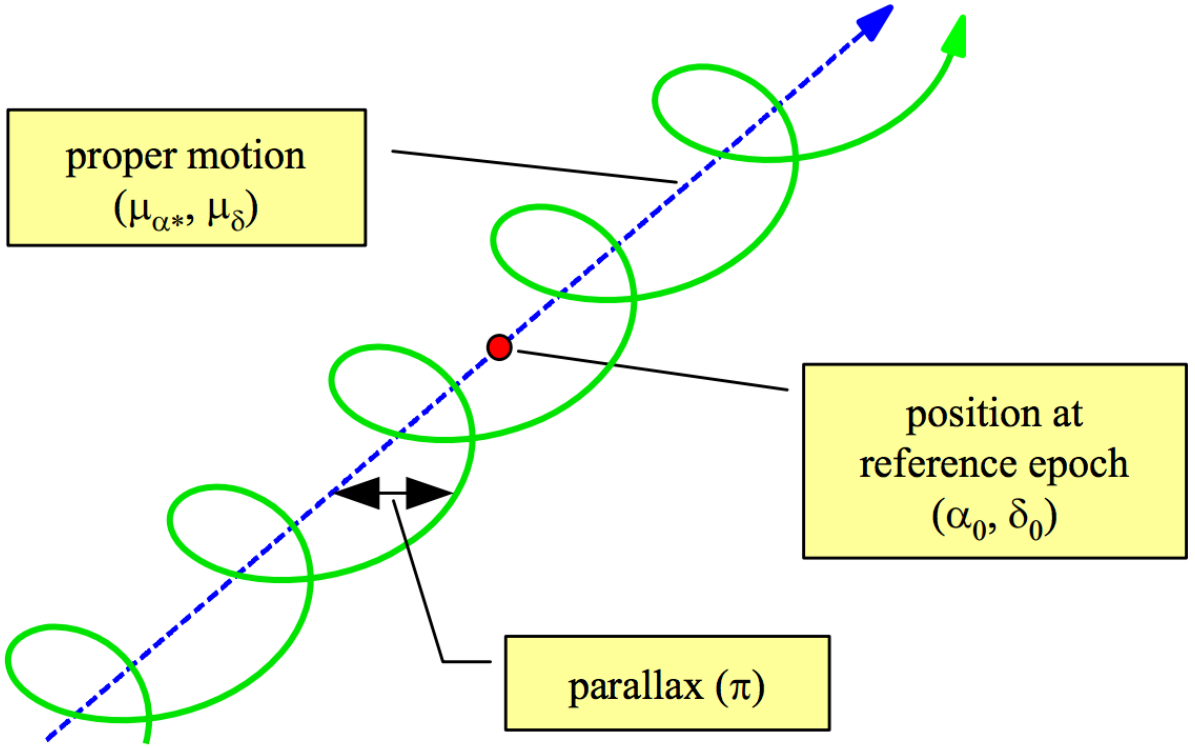
How are things going with Gaia?

Everything is going fine.

Key feature: Astrometry



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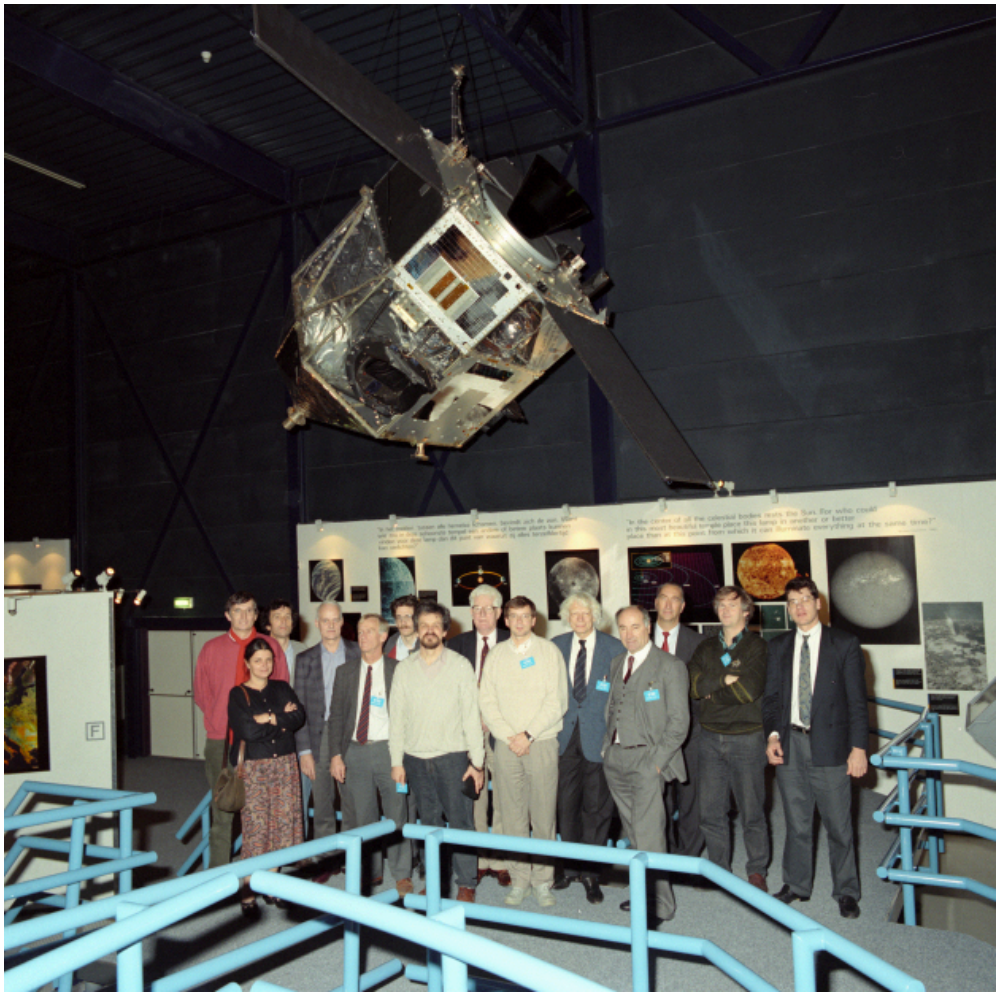
Successor to Hipparcos



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The reason Lund is relevant to this discussion

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Why astrometry?

Parallax = only direct way to measure distance

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For scale:

Proxima centuri – 1arcsec (hair's width 20 m away)

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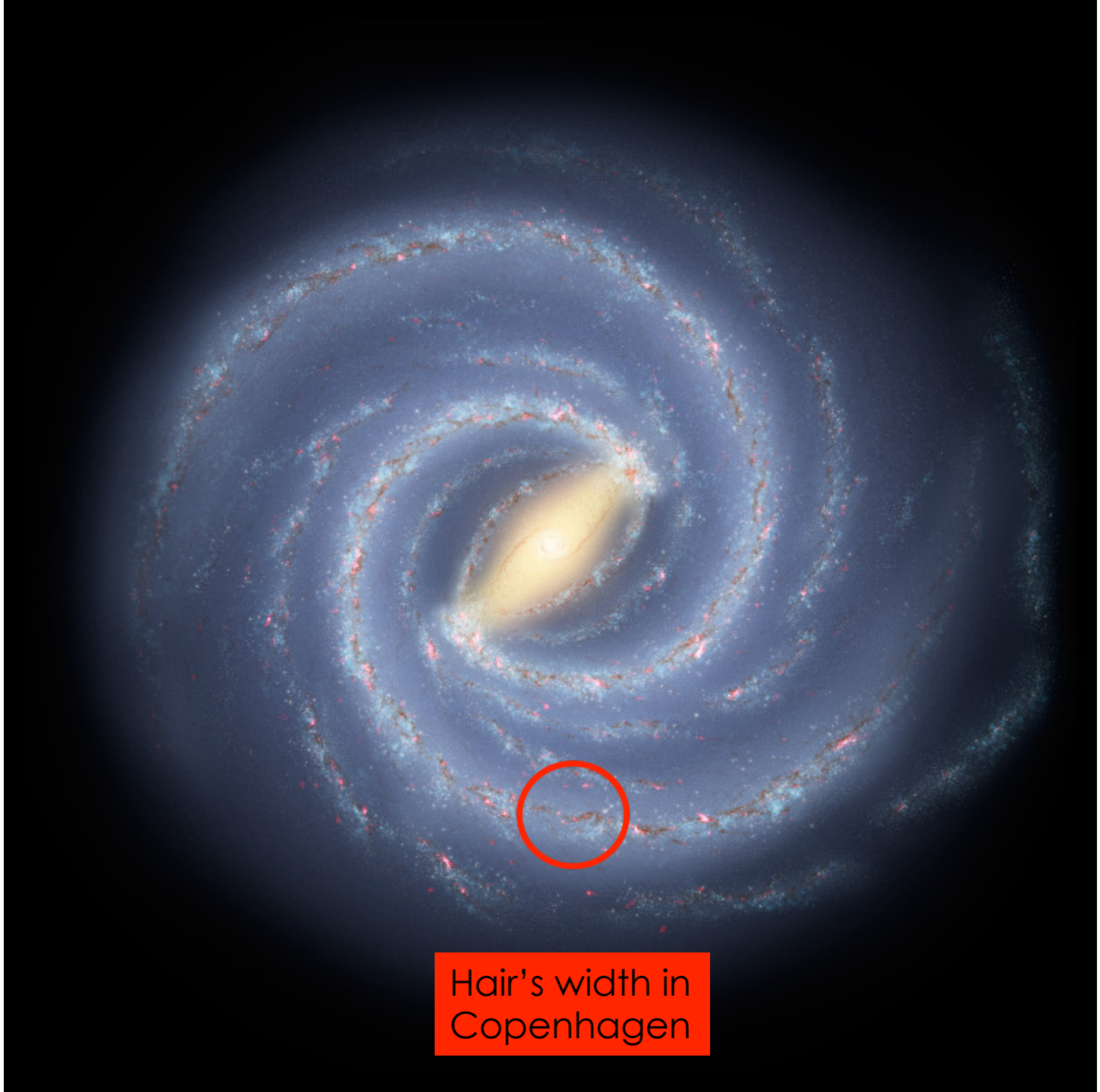

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Gaia's measurement accuracy

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How do we achieve this accuracy?

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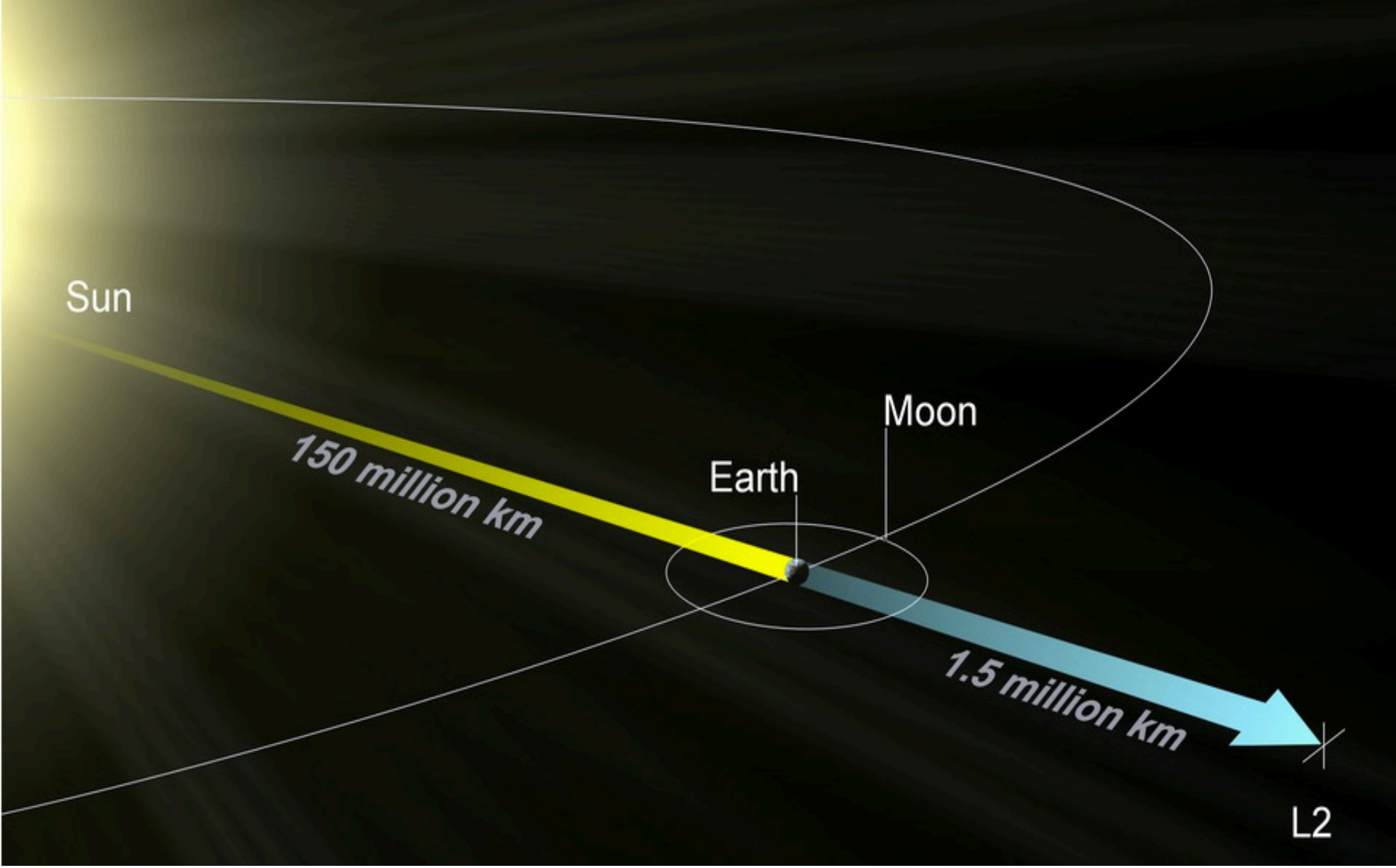

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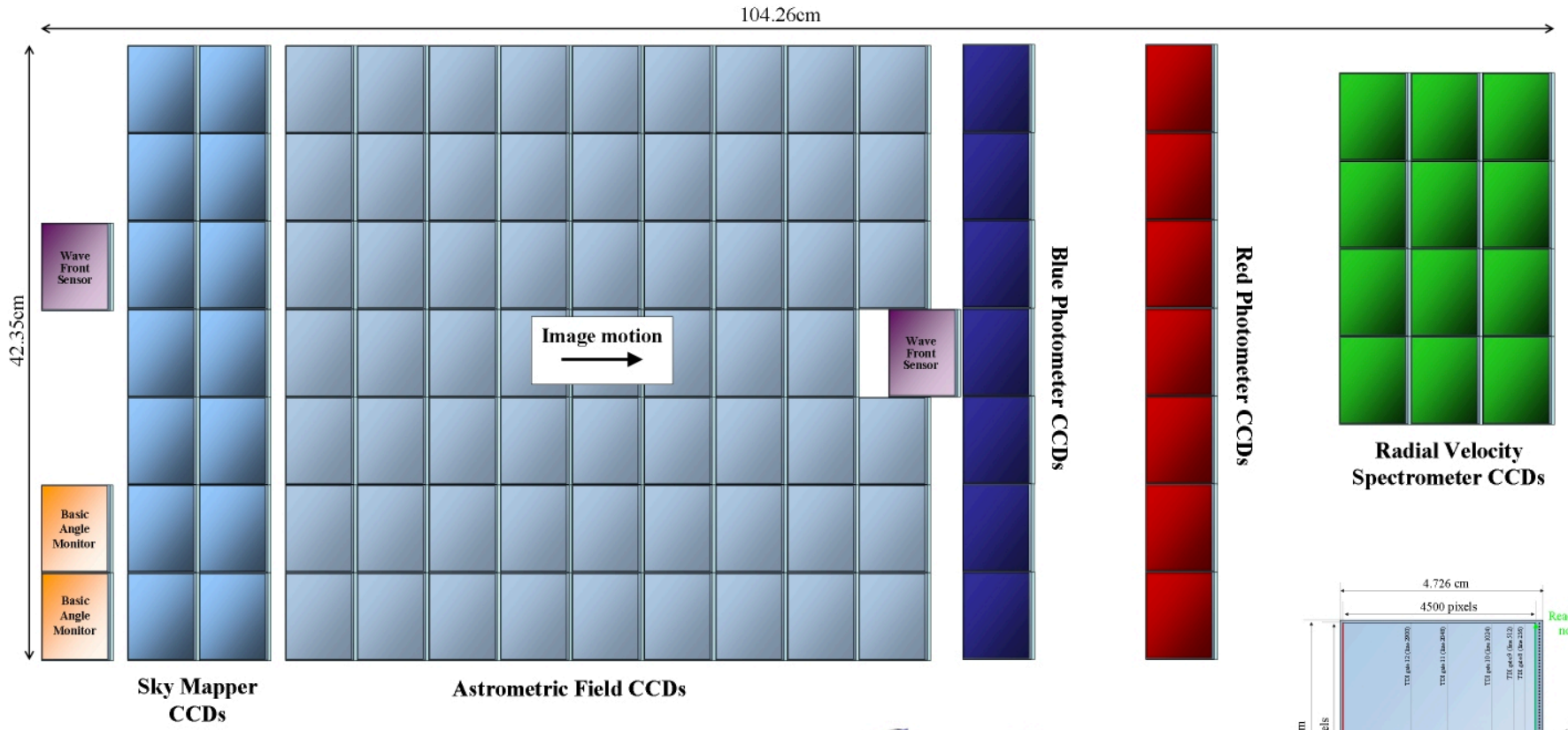
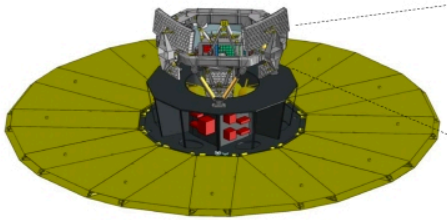
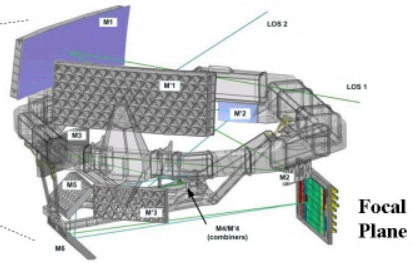
Gaia Focal Plane

106 CCDs ≈ 938 million pixels ≈ 2800 cm²



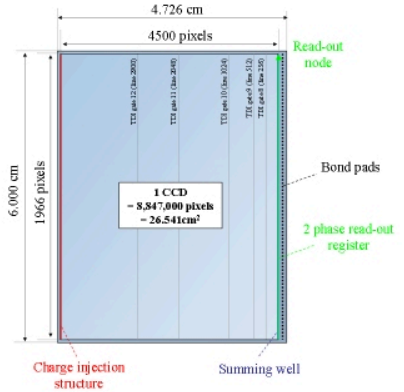


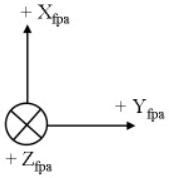
Gaia (MLI removed)



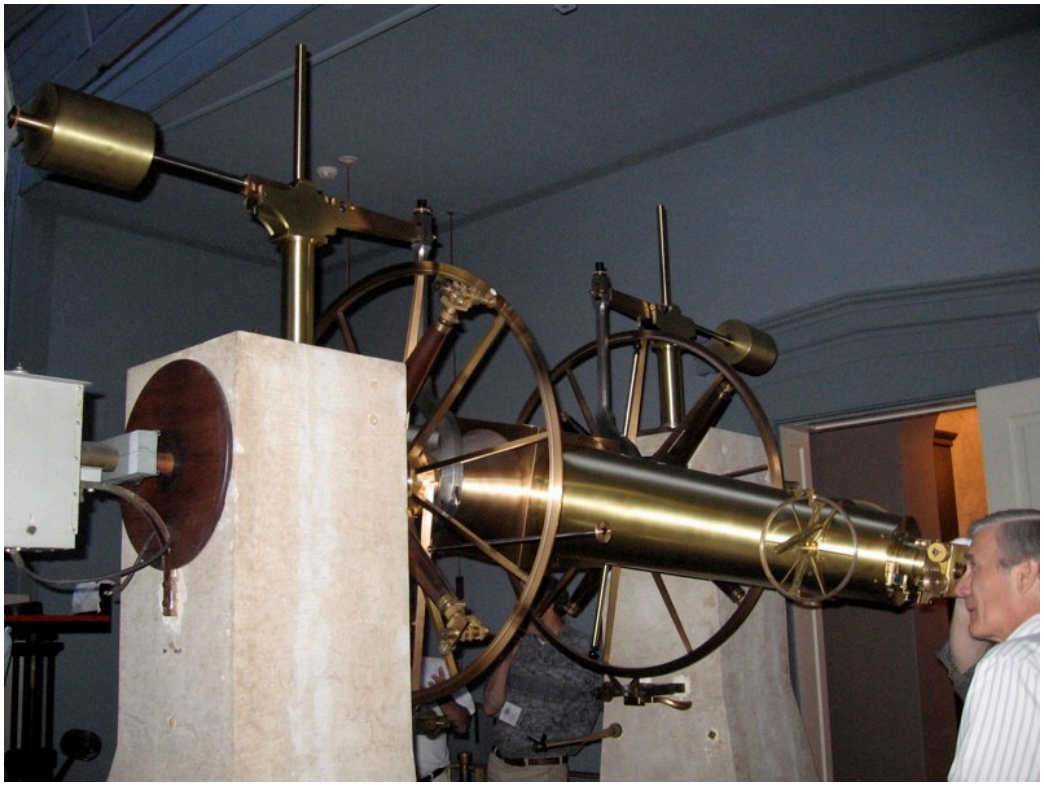
Payload Module (telescopes)

Focal Plane





Updating an old idea



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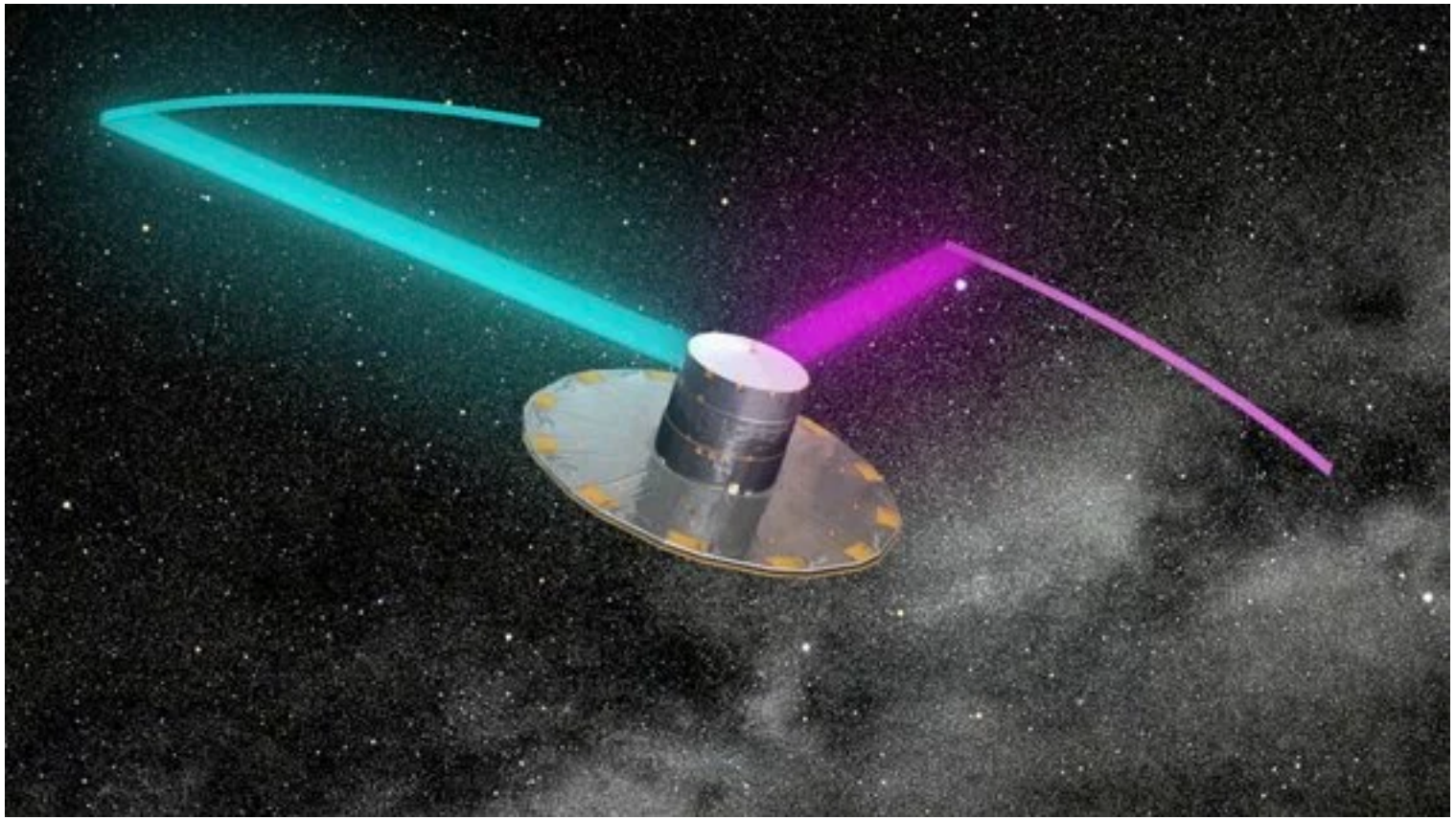

Add some lightsabers (?)

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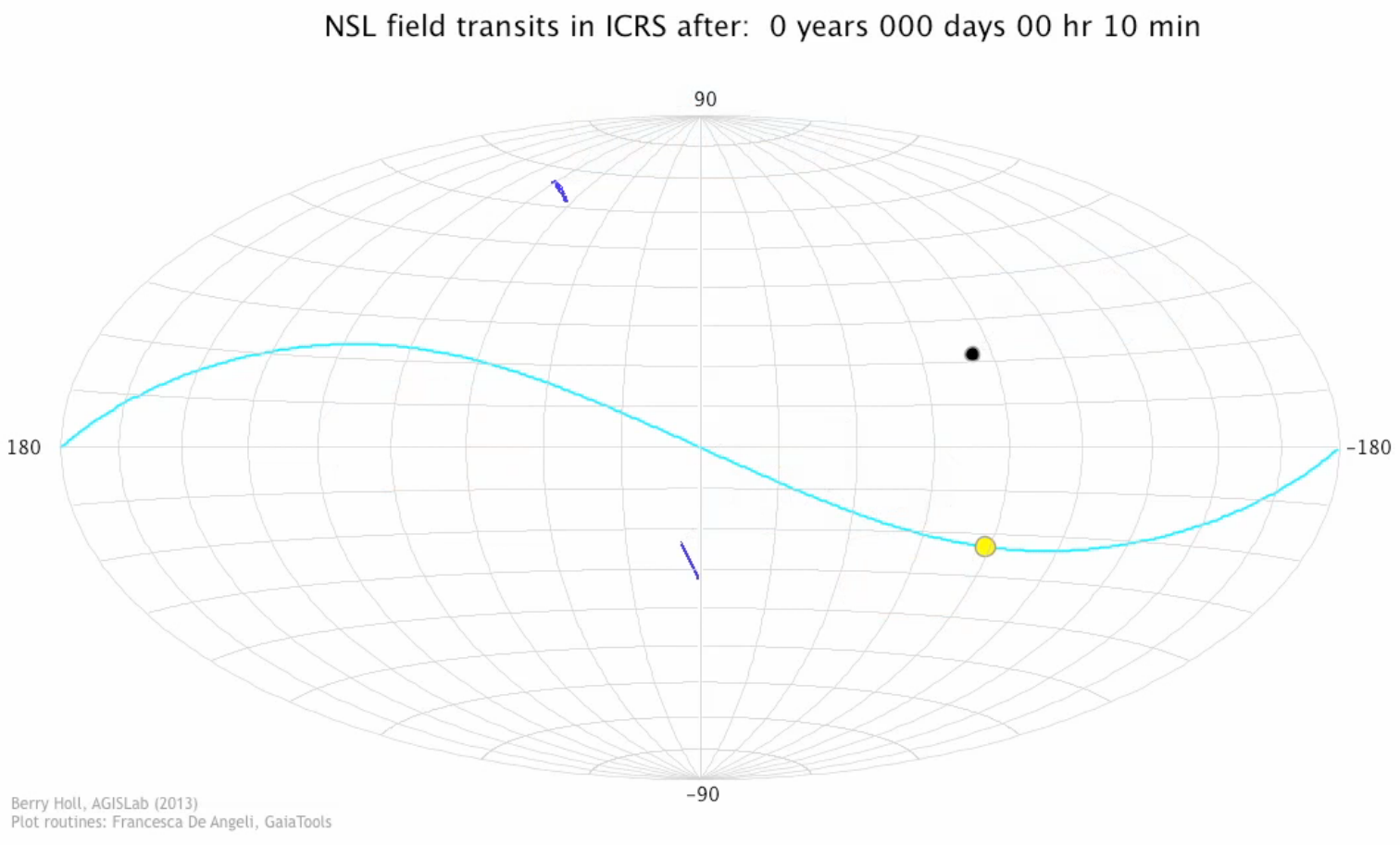
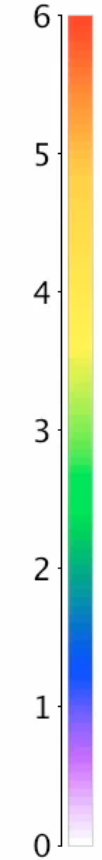
Scan the sky


NSL field transits in ICRS after: 0 years 000 days 00 hr 10 min
90
180
-180
-90
Berry Holl, AGISLab (2013)
Plot routines: Francesca De Angeli, GaiaTools


6
5
4
3
2
1
0

Big upgrade on Hipparcos

50-100 x more accurate

20,000 x more sources!

No predetermined selection

Additional data

3D in velocity as well as position (for some stars)

Optical colors for all stars

Astrophysical parameters for most/all stars

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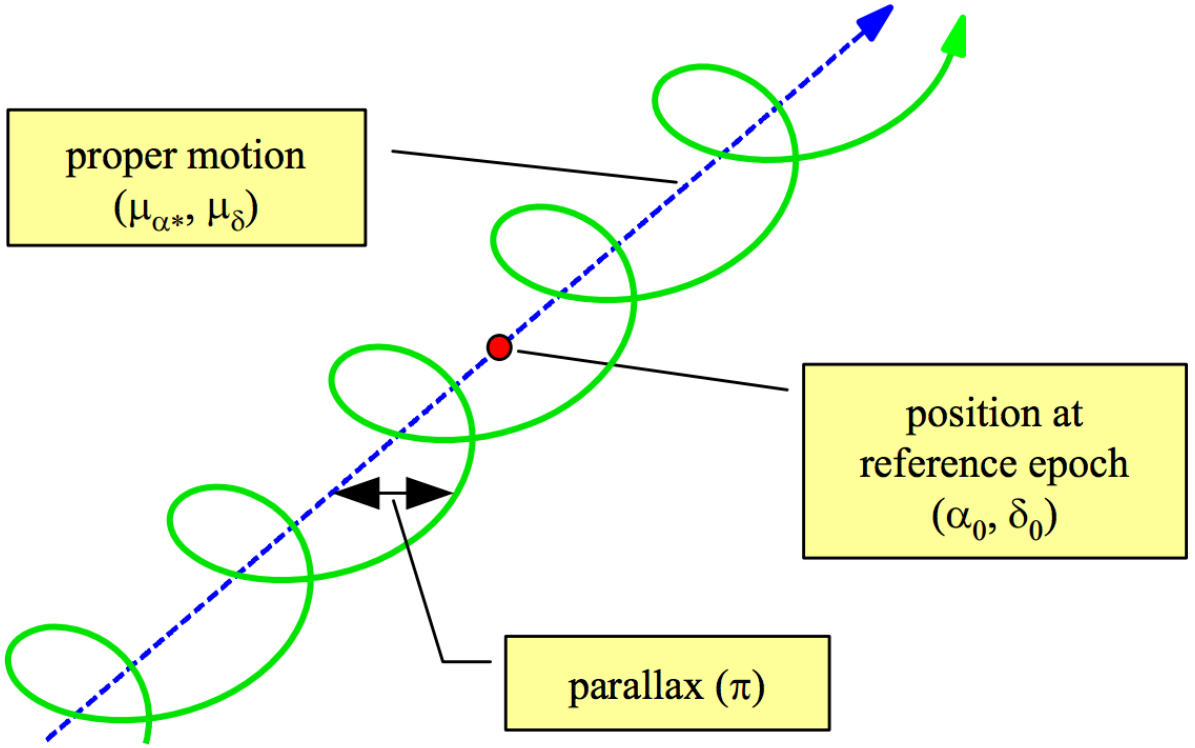
This is in the absence of e.g. a binary companion



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Additional data

3D in velocity as well as position (for some stars)

Optical colors for all stars

Astrophysical parameters for most/all stars

Ability to find orbit solutions for binaries/exoplanets

Solar system objects

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Big upgrade on Hipparcos

	Hipparcos	**Gaia**
Magnitude limit	12 mag	20.7 mag
Completeness	7.3 – 9.0 mag	20.7 mag
Bright limit	0 mag	?
Number of objects	120,000	47 million to G = 15 mag 360 million to G = 18 mag ~2000 million to G = 20 mag
Effective distance limit	1 kpc	50 kpc
Quasars	1 (3C 273)	500,000
Galaxies	None	1,000,000
Accuracy	1 milliarcsec	7 μarcsec at G = 10 mag 26 μarcsec at G = 15 mag 600 μarcsec at G = 20 mag
Photometry	2-colour (B and V)	Low-res. spectra to G = 20 mag
Radial velocity	None	15 km s^{-1} to G_{RVS} = 15.5 mag
Observing	Pre-selected	Complete and unbiased

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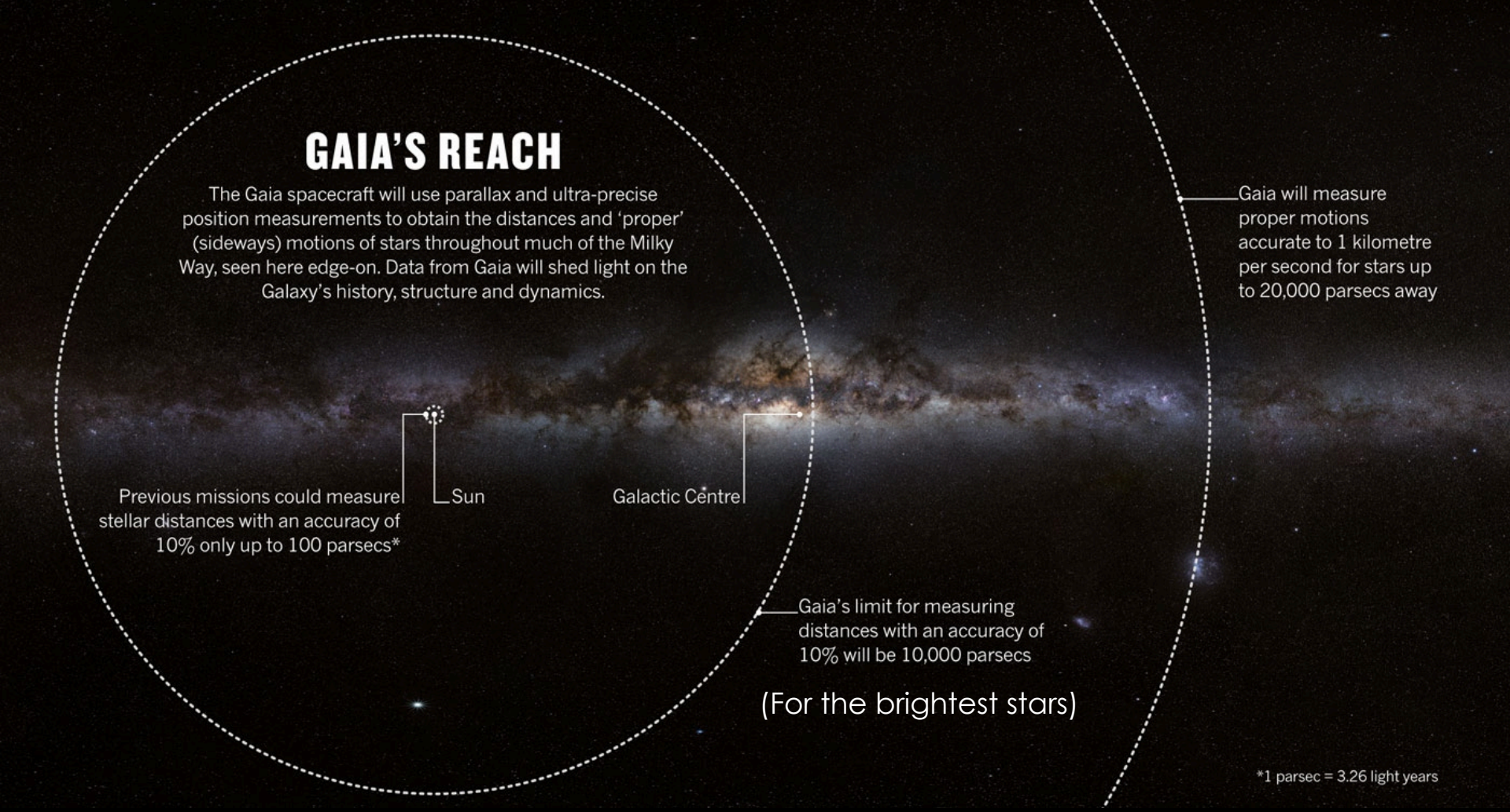
GAIA'S REACH
The Gaia spacecraft will use parallax and ultra-precise position measurements to obtain the distances and 'proper' (sideways) motions of stars throughout much of the Milky Way, seen here edge-on. Data from Gaia will shed light on the Galaxy's history, structure and dynamics.
Gaia will measure proper motions accurate to 1 kilometre per second for stars up to 20,000 parsecs away
Previous missions could measure stellar distances with an accuracy of 10% only up to 100 parsecs*
Sun
Galactic Centre
Gaia's limit for measuring distances with an accuracy of 10% will be 10,000 parsecs
(For the brightest stars)
*1 parsec = 3.26 light years

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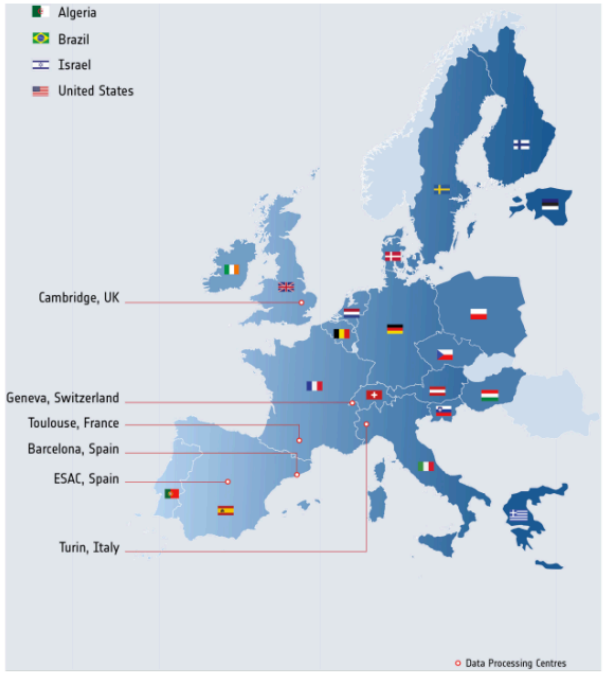
Teamwork to deliver the promise of Gaia

- 10+ years of effort
- 450 scientists and engineers
- 160 institutes
- 24 countries and ESA
- Six data processing centres



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0 1 0 0 0 0 0 1 1 0 0 1 0 0 1 1 0 0 1 1 0 1 1 0 0 1 0 1 0

Gaia DPAC Data Processing & Analysis Consortium

α δ ϖ $\mu_{\alpha*}$ μ_δ G ...

(Slide from A. Brown)

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Data release 1: September 2016

Astronomers celebrate

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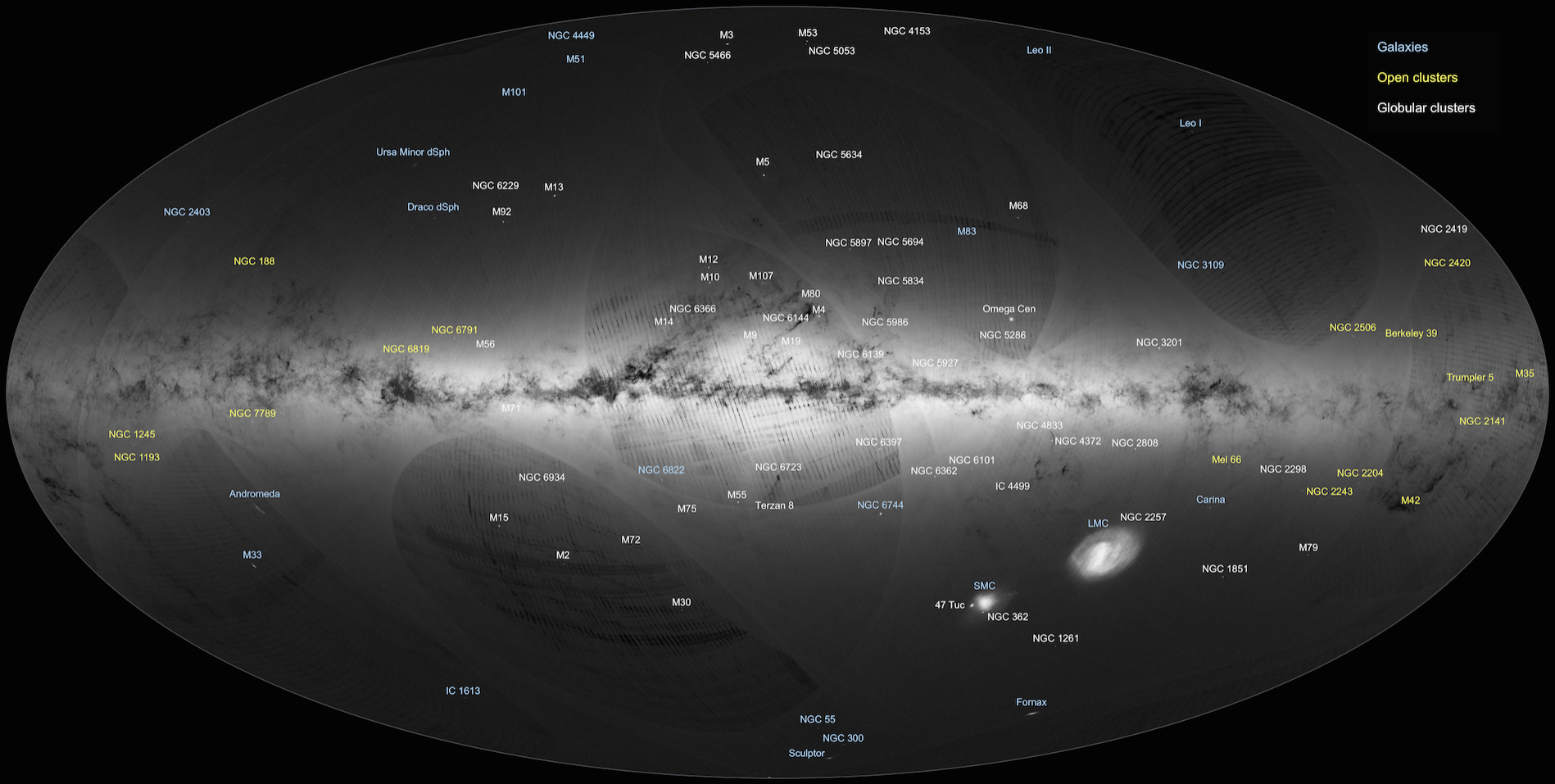
→ GAIA'S FIRST SKY MAP



Galaxies

Open clusters

Globular clusters

www.esa.int

Credit: ESA/Gaia/DPAC

European Space Agency

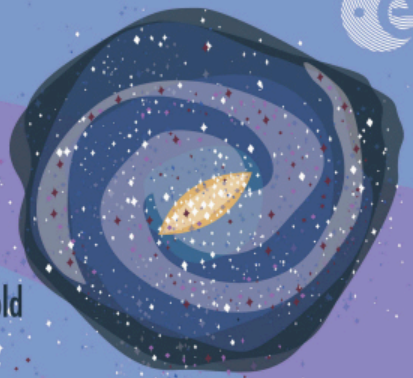
→ GAIA DATA RELEASE 1

esa

14
September 2016

1000 days since launch

1 spacecraft
2 telescopes
10 mirrors
1 camera
106 CCDs
937,782,000 pixels



1 Milky Way
>100,000,000,000 stars
~13,000,000,000 years old

Content of the release

Total number of sources in primary astrometric data set:
2,057,050
with position, magnitude, parallax & proper motion

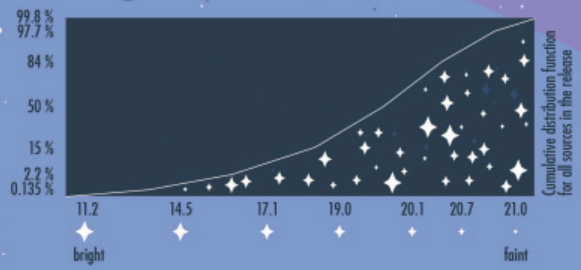
Total number of sources in secondary astrometric data set:
1,140,622,719
with position & magnitude

3194 Variable stars
- 599 Cepheids (43 new discoveries)
- 2595 RR Lyrae (343 new discoveries)

2152 Quasars
with position & magnitude

Data collected over 14 months

Magnitude distribution



Data challenge so far

>50 billion focal plane transits
>110 billion photometric observations
>9.4 billion spectroscopic observations
~120,000 hours of computing time to identify stars
6 data processing centres

1 day on Gaia

637,000,000 astrometric measurements
155,000,000 photometric measurements
13,000,000 spectrometric measurements
70,000,000 celestial objects
40 GB of data downlinked to Earth

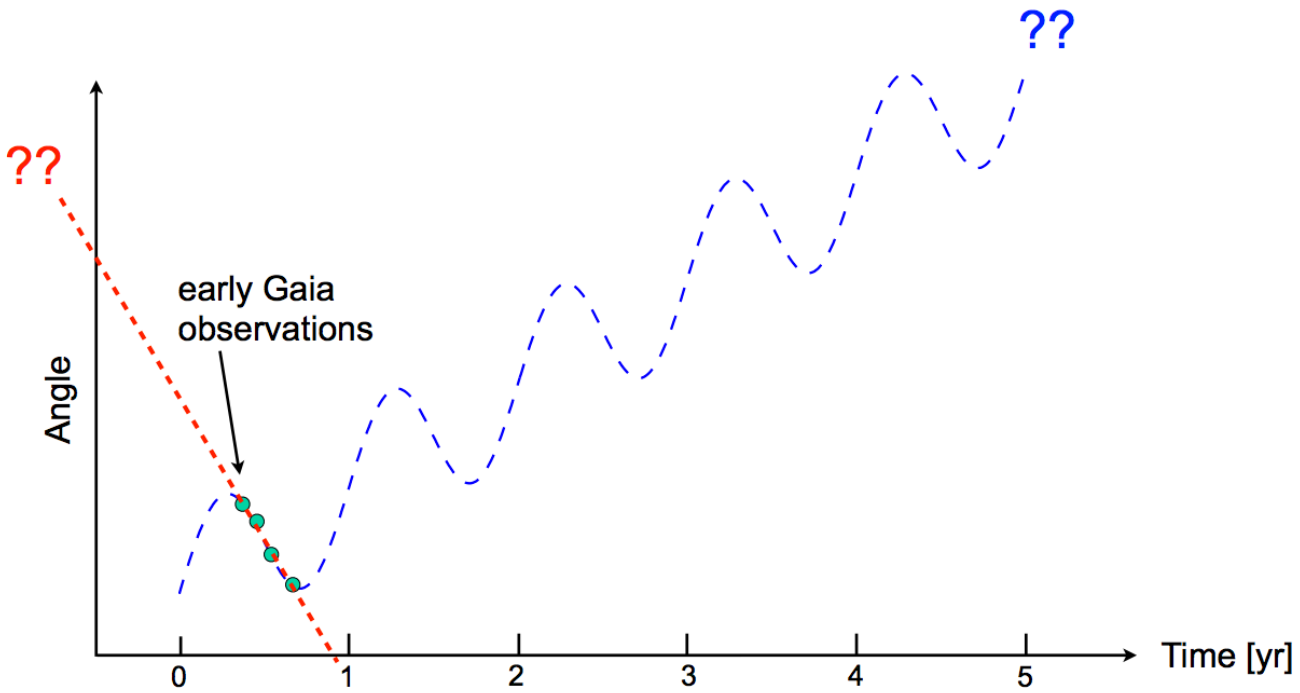
DR1 in summary

1 billion positions & magnitudes

2 million parallaxes & proper motions

Getting parallaxes early

Degeneracy for <1 yr of observations



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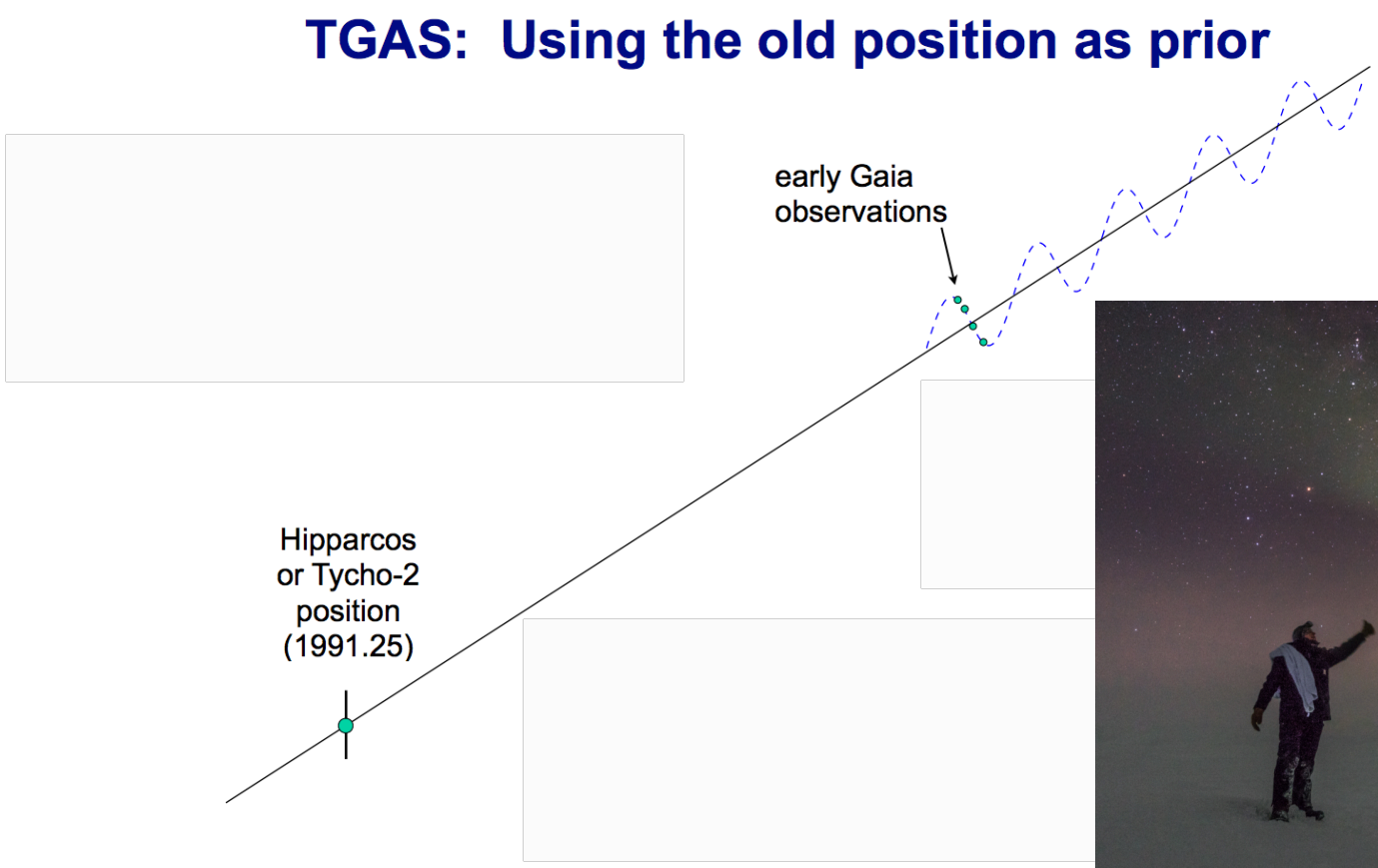
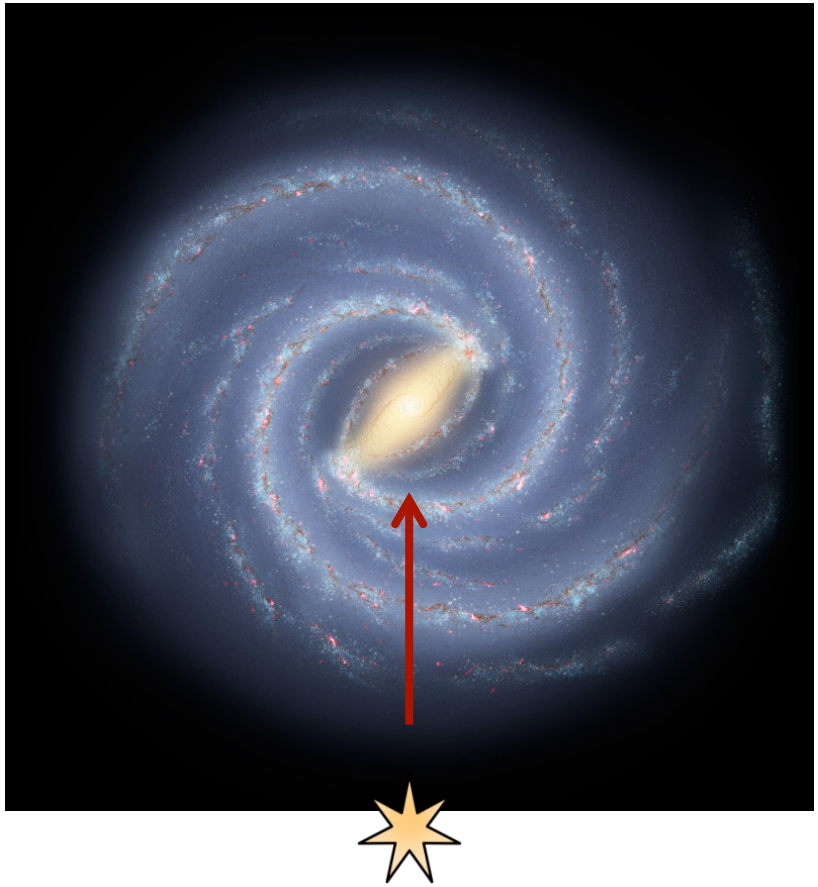
Getting parallaxes early

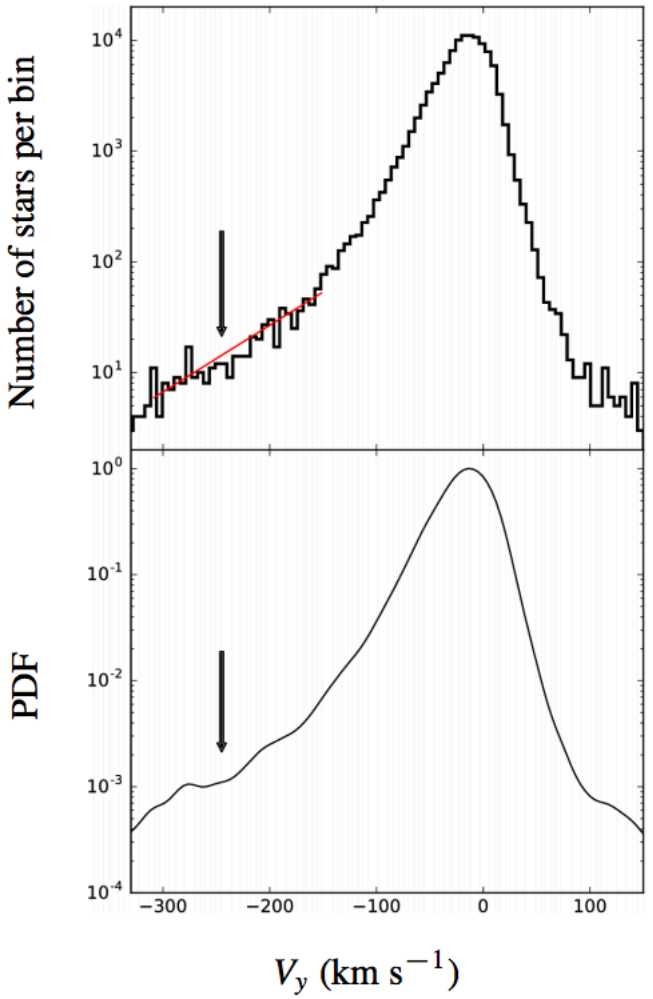


Slides from
L. Lindegren

Science with DR1

Deflection of stars?





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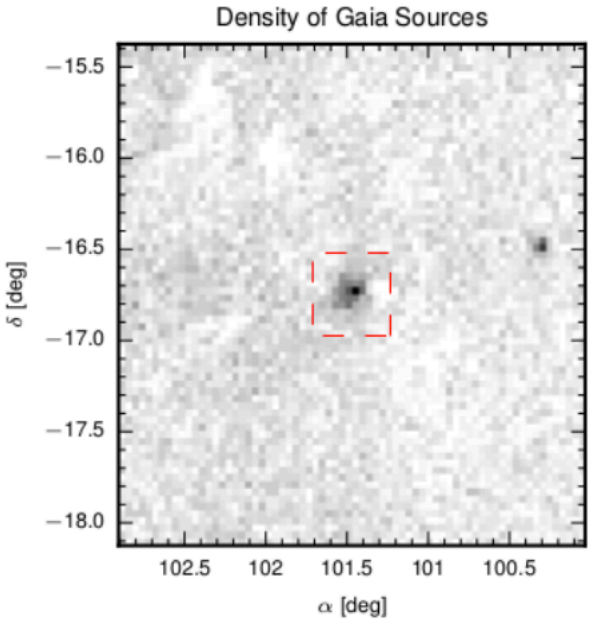
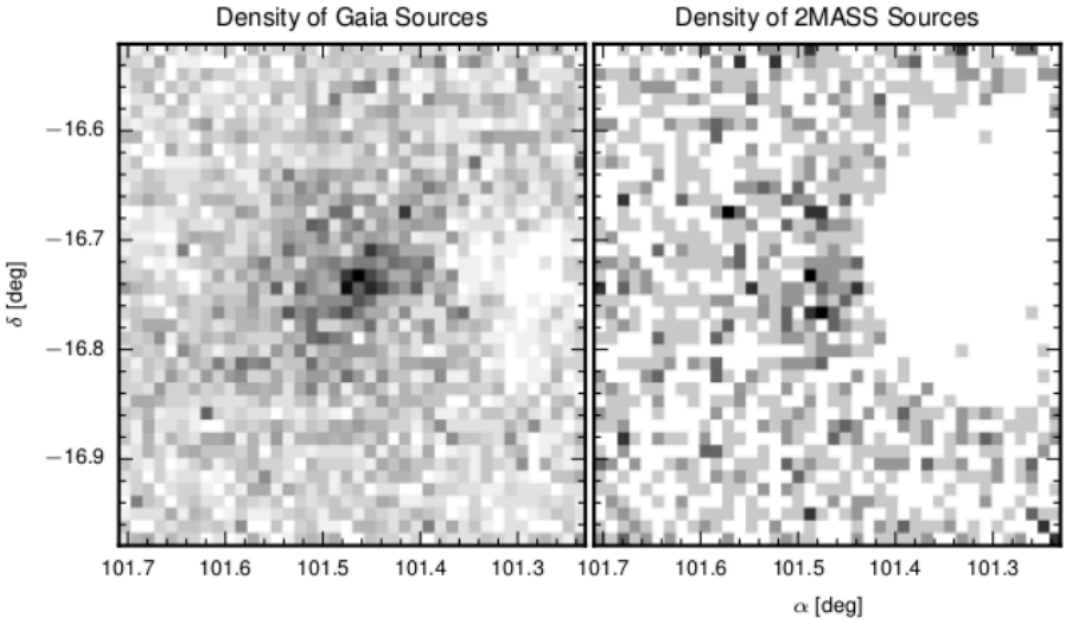
Discovery of clusters

Gaia 1





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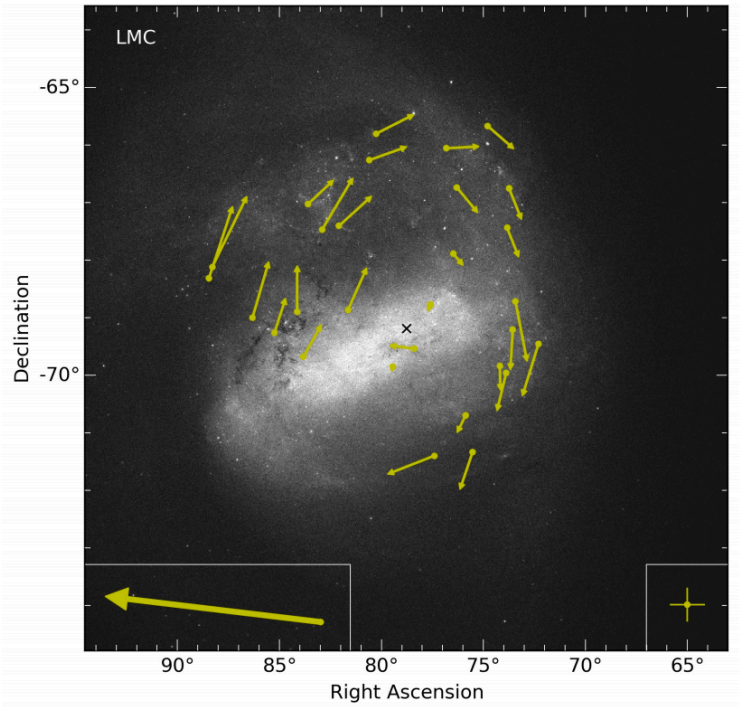
Rotation of the Large Magellanic Cloud



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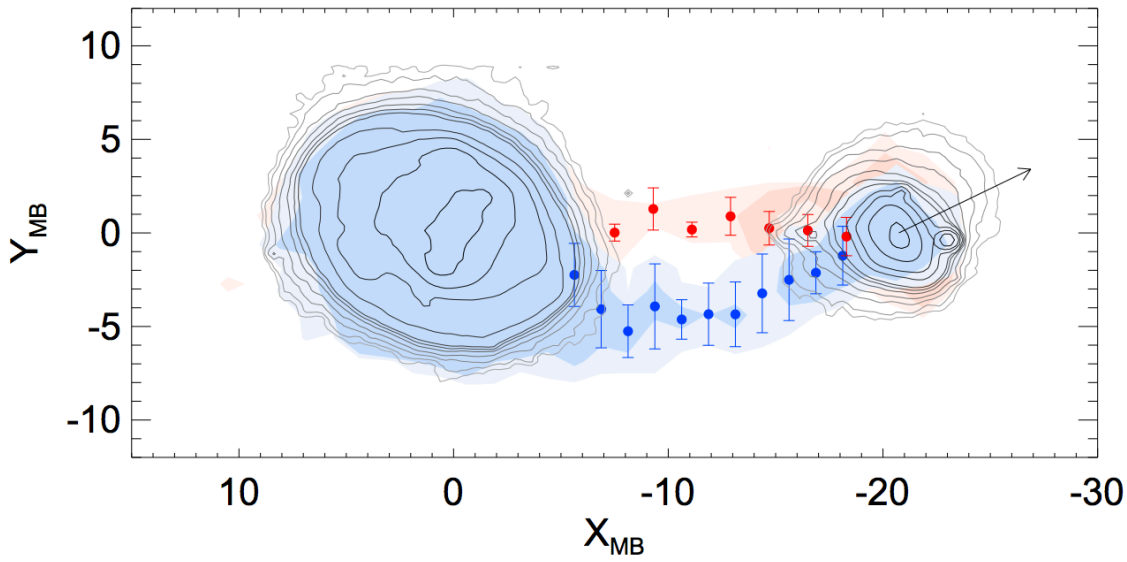
Bridge between the clouds



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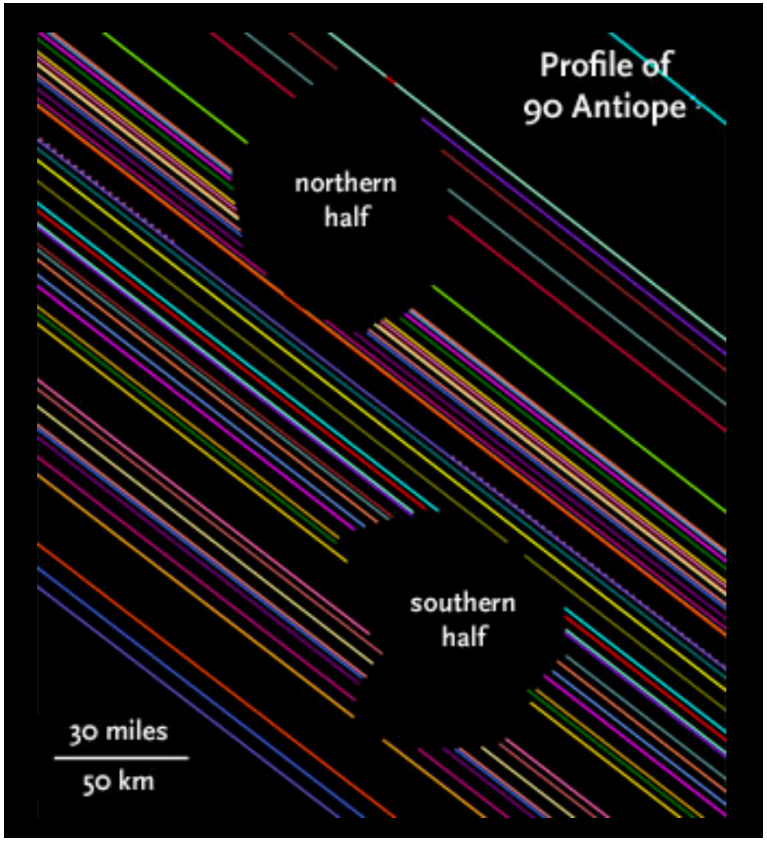
Occultation

As a planet/asteroid passes in front of a star, the shadow falls at different points on the Earth at different times.

Can reconstruct the shapes, rings, atmospheres of the solar system body



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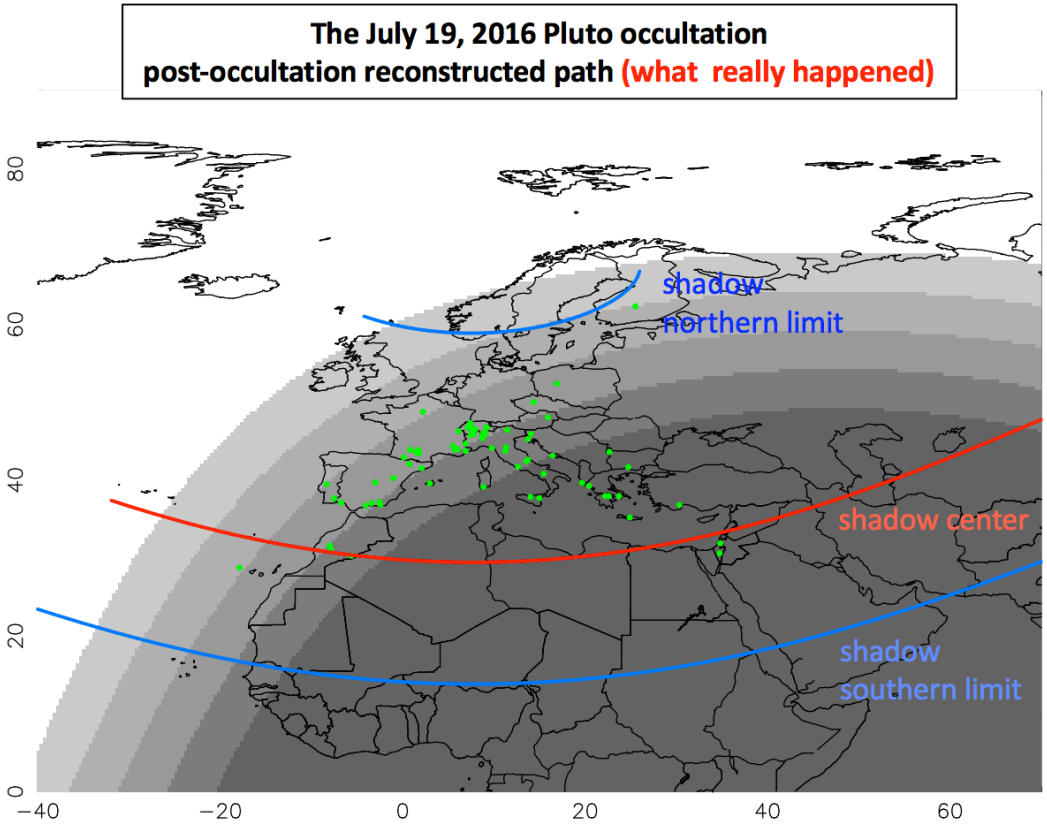
Occultation



green dots: sites involved in the campaign (not all got data!)

Images from
B. Sicardy

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Data release 2 – April 2018

Parallaxes and proper motions for a billion stars (brighter than 21st mag)

Colours for all those stars

Radial velocities for around 5 million (brighter than 12th mag)

Epoch astrometry for more than 10000 asteroids

Everything treated as a single star

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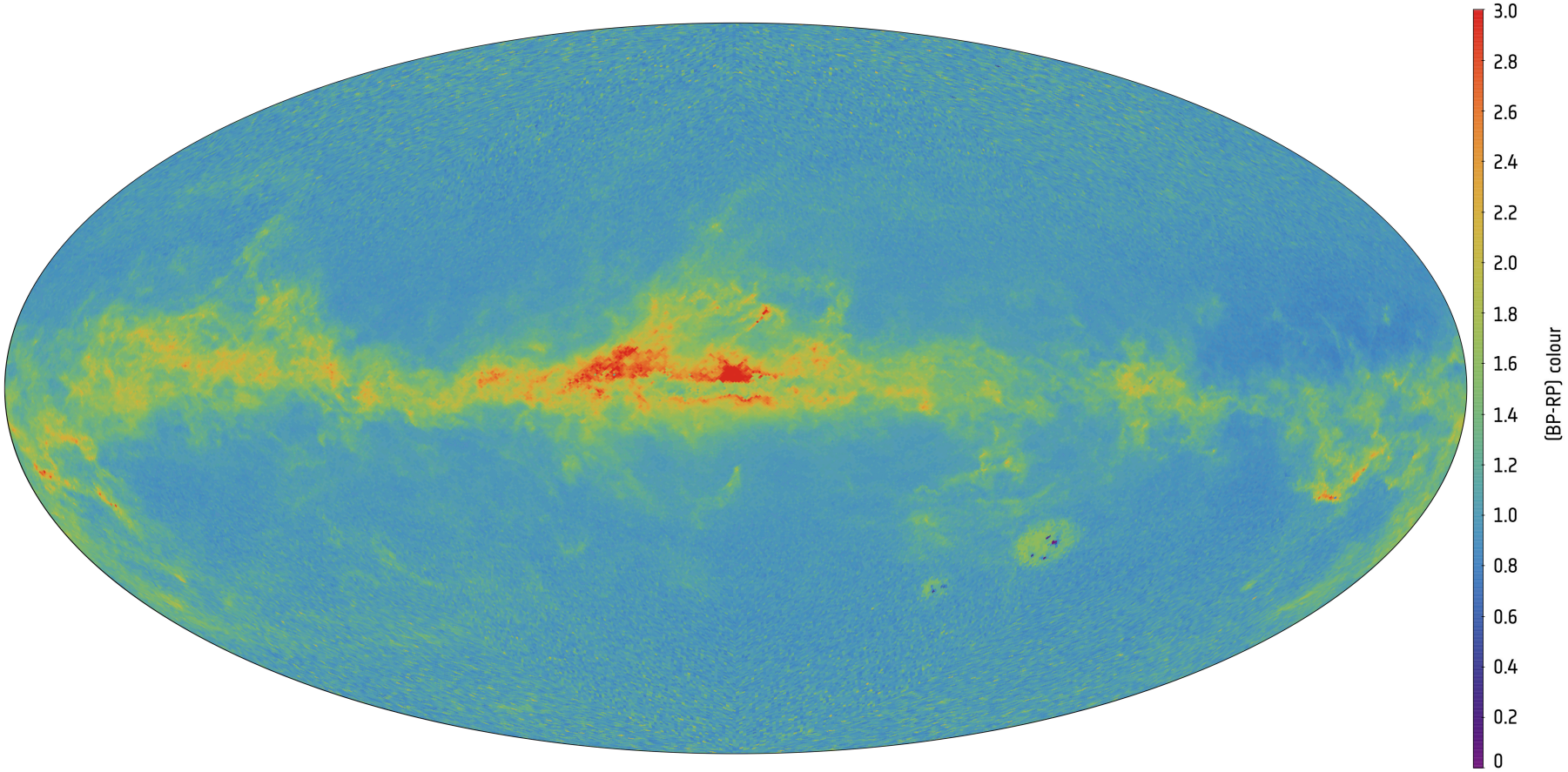
The Galaxy in colour



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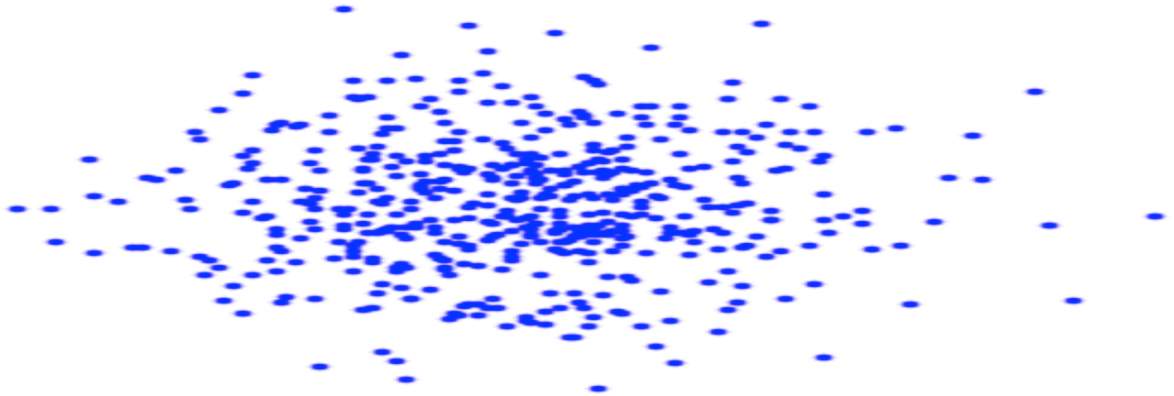
Clusters in 3D?



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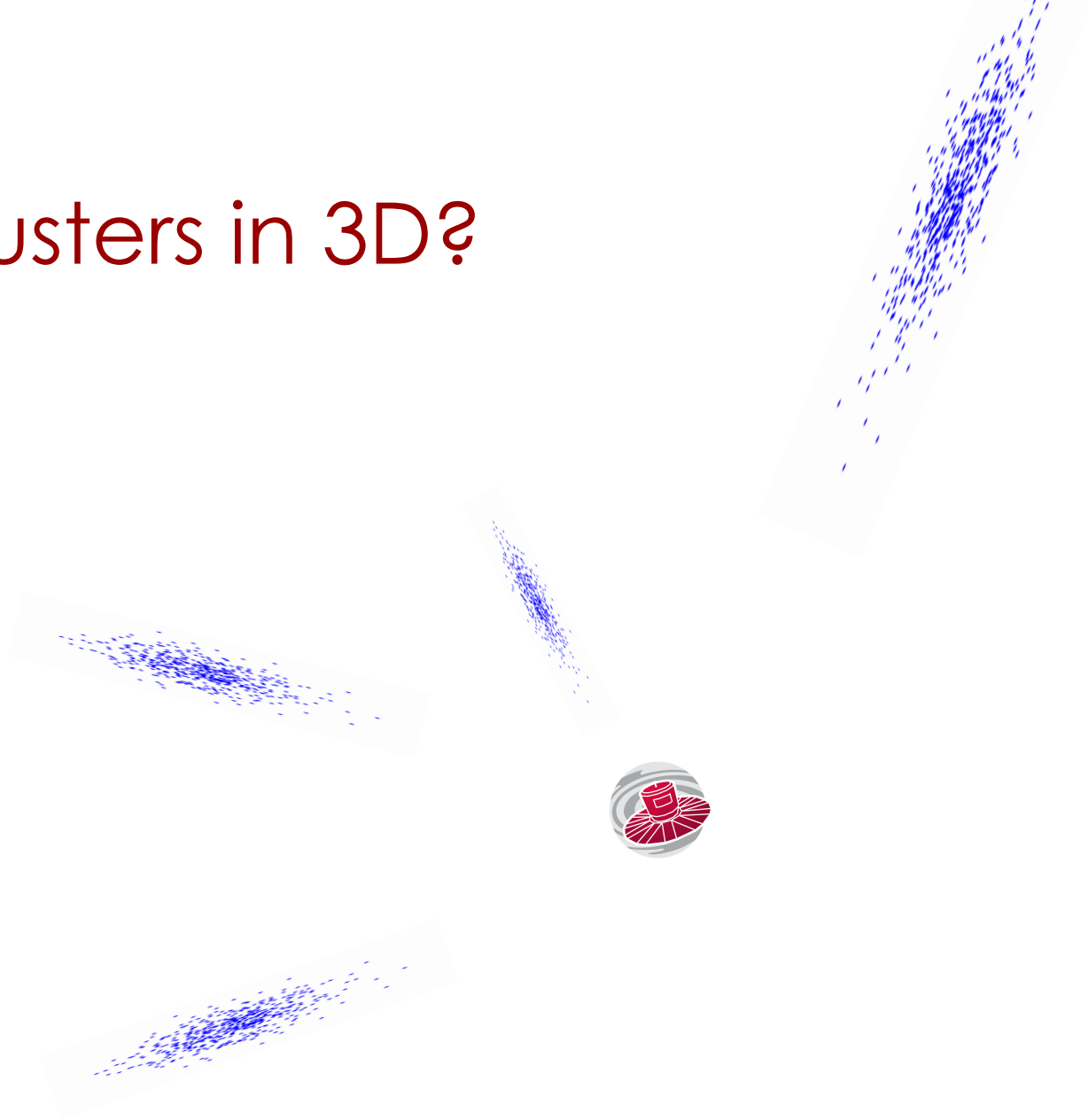

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Clusters in 3D?

For example, the Hyades:

~50 pc away (20mas)

Core radius of 2 pc (±0.8mas)

(Compare to ~0.02mas precision)

So we'll have a real 3D map of the cluster without fingers of god

(Image from wikipedia)

Probably pretty good out to ~200pc, but getting worse as you go further. Cleverer approaches needed.

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DR3

Due in 2020

Radial velocities for ~100 million stars

More detailed photometry

Non-single star catalogues

Solar system results (incl orbit solutions)

Improved everything else

gaia

DR4

Due 2022

Full catalogues, include epoch data

Source classification

Exo-planet list (~20000 planets, mostly ~Jupiter mass+, periods < 5yr)

Further…

Gaia mission was planned for 5 years

10 years is entirely possible.

We're very optimistic about funding

Improves parallaxes by factor ~1.5, proper motions by factor ~3, binary/exoplanet characterisation by factor ~20!

Thank you!