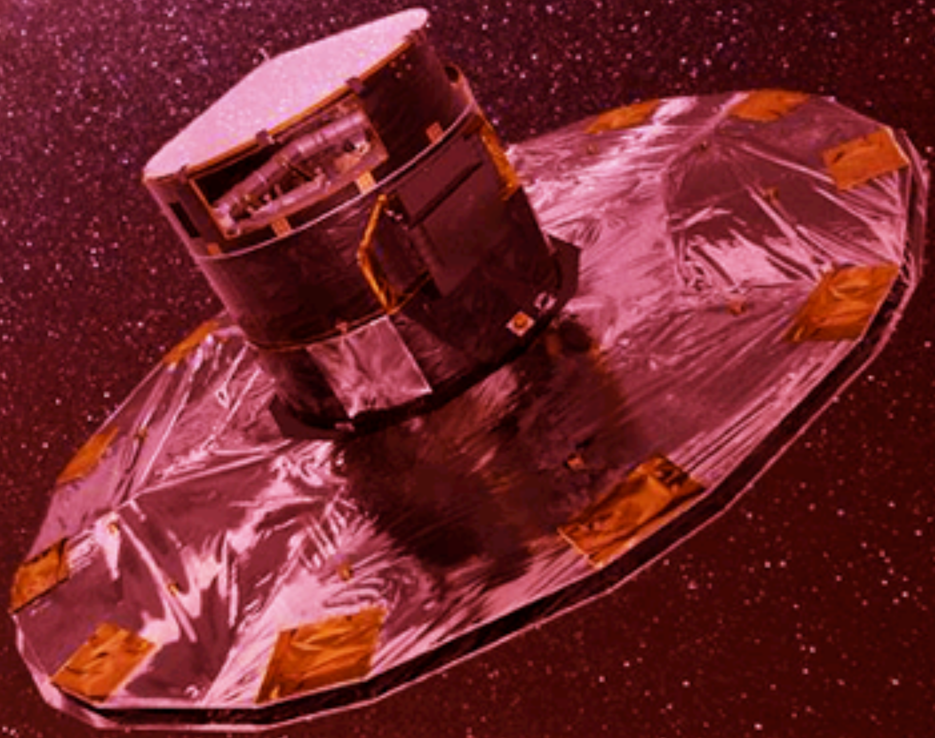
GaiaNIR

A Future All Sky Astrometry Mission



DAVID HOBBS
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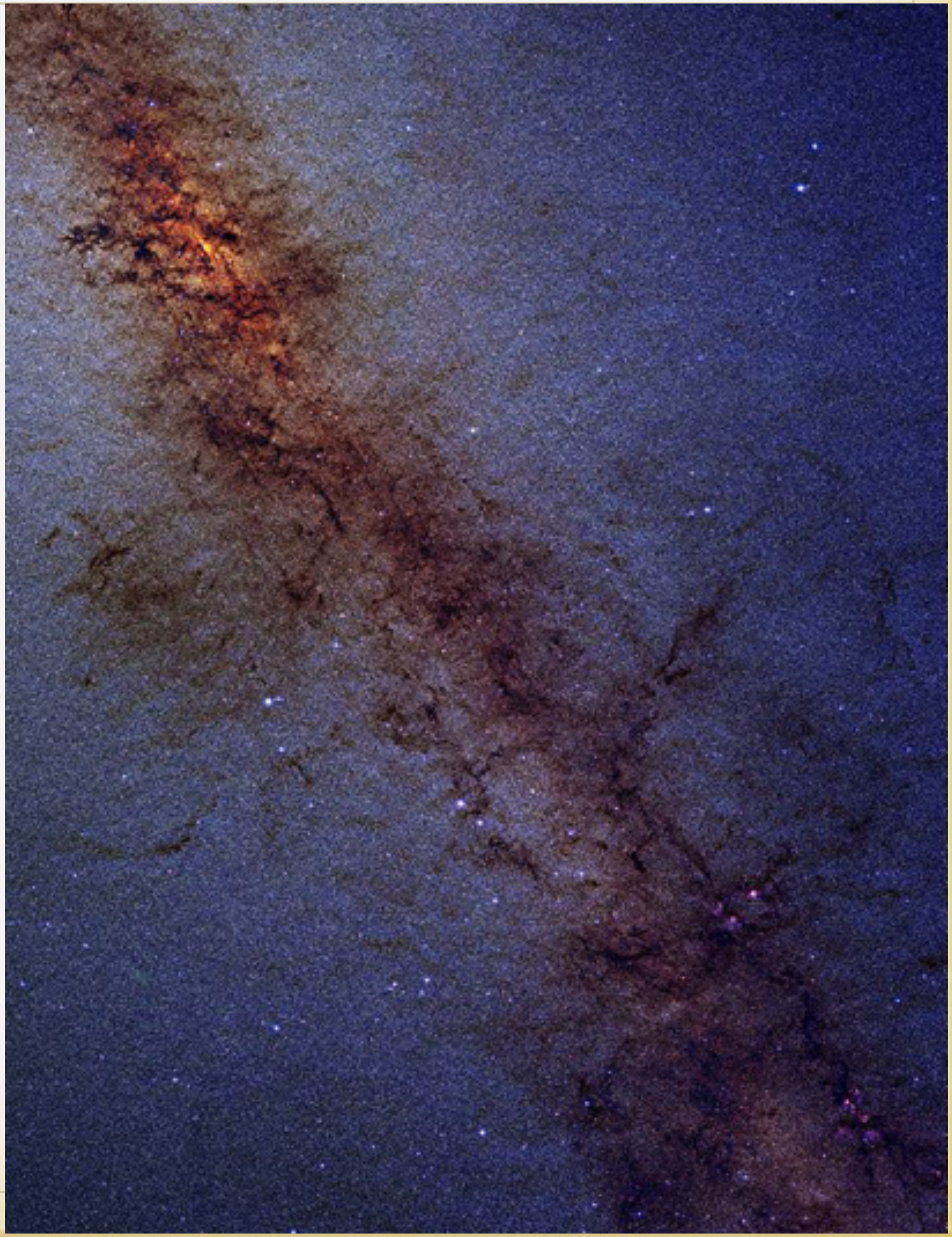
Motivation For GaiaNIR

IR image from the Two Micron All-Sky Survey (image G. Kopan, R. Hurt)



- Gaia is that it only operates at optical wavelengths but the GC and spiral arms are obscured by interstellar extinction.
- We need to switch to the NIR but this is not possible with CCDs ⇒ new NIR detectors.
- To scan the entire sky we need rotation ⇒ detectors correct for rotation - use Time Delayed Integration (TDI).

Improved PMs

$$\sigma_{\mu_{\alpha *}} = \frac{\sqrt{\sigma^2_{\alpha^*_{\rm N}} + \sigma^2_{\alpha^*_{\rm G}}}}{t_{\rm N} - t_{\rm G}} = \frac{\sqrt{25^2 + 25^2}}{20} \sim 1.77\ \mu\text{as yr}^{-1}, \quad \sigma_{\mu_\delta} = \frac{\sqrt{\sigma^2_{\delta_{\rm N}} + \sigma^2_{\delta_{\rm G}}}}{t_{\rm N} - t_{\rm G}} = \frac{\sqrt{25^2 + 25^2}}{20} \sim 1.77\ \mu\text{as yr}^{-1}$$

Second Epoch
GaiaNIR 5yr
(2035-40)

Stars only seen in NIR will not benefit from this improvement

A separation of 20 years will allow for very accurate PMs. An improvement by a factor of 14 in PM's for two 5 yr missions or a factor of 20 for two 10 yr missions when compared to Gaia's nominal 25 μas yr^{-1}.

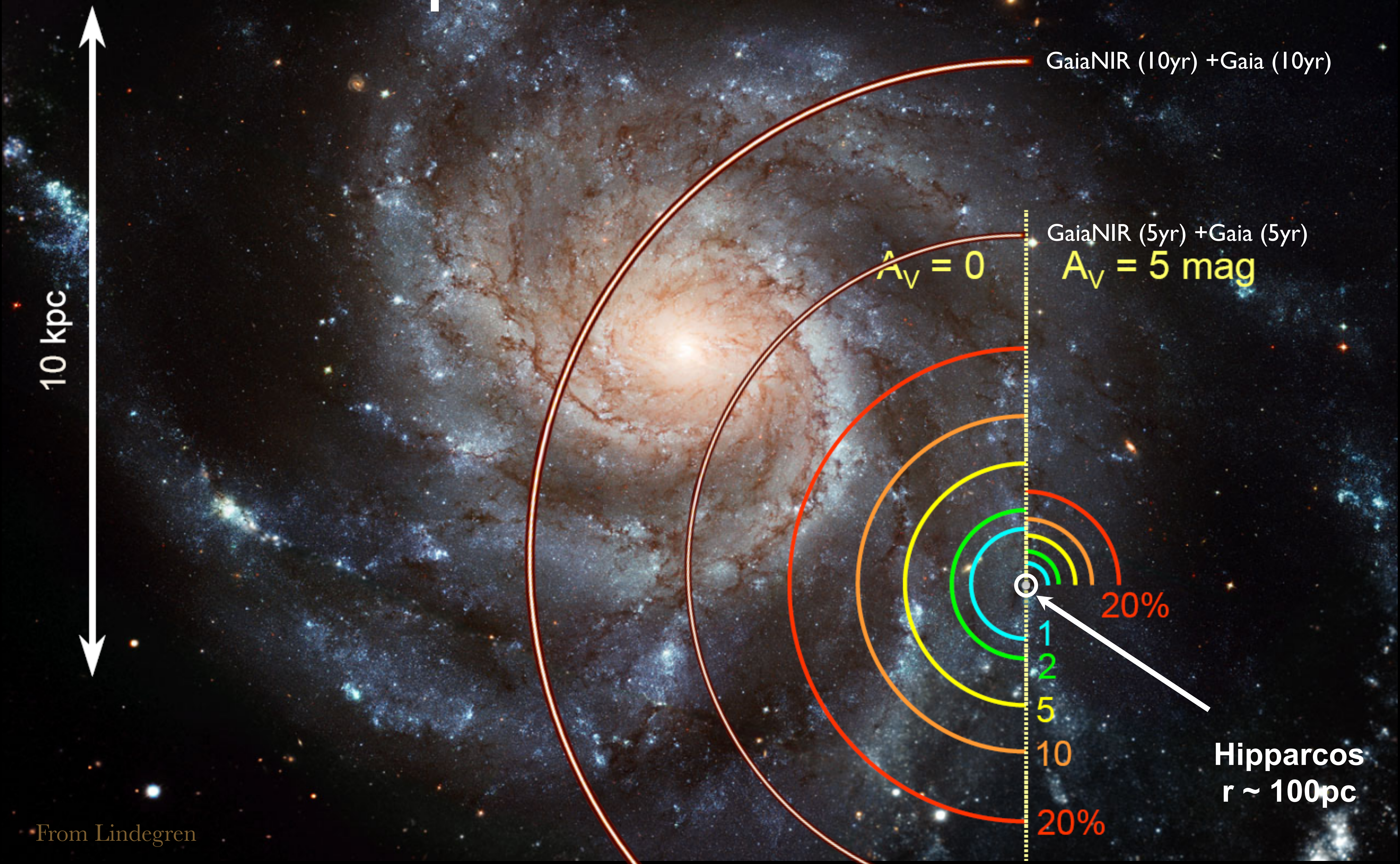
20 yr
separation

First Epoch
Gaia 5yr
(2015-20)

$\sigma_{\mu_{\alpha *}} = 25\ \mu\text{as yr}^{-1}$ $G = 15$

Parallax horizon for G0V stars

Improved Parallaxes



Science Cases

Three main scientific topics for a new Gaia-like mission:

Astrometry Science Cases:

1. **Use NIR astrometry and photometry to probe obscured regions of the Galaxy and allow us to observe intrinsically red objects.**
2. A new mission 20 years after Gaia would give combined PMs 14-20 times better & parallaxes √2 times better - opening many new science cases.
3. The slowly degrading accuracy of the Gaia optical reference frame and the Gaia catalogue needs to be reversed.

Proposal title: GaiaNIR
Combining optical and Near-Infra-Red (NIR) capabilities with Time-Delay-Integration (TDI) sensors for a future Gaia-like mission.

PI: Dr. David Hobbs,
Lund Observatory, Box 43, SE-221 00 Lund, Sweden.
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Core team members:	The following minimum team is needed to initiate the project.
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A. Brown	Leiden Observatory, Holland.
A. Mora	Aurora Technology B.V., Spain.
C. Crowley	HE Space Operations B.V., Spain.
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Proposal writers:	See Appendix A.
Other supporting scientists:	See Appendix B.
Senior science advisor's:	
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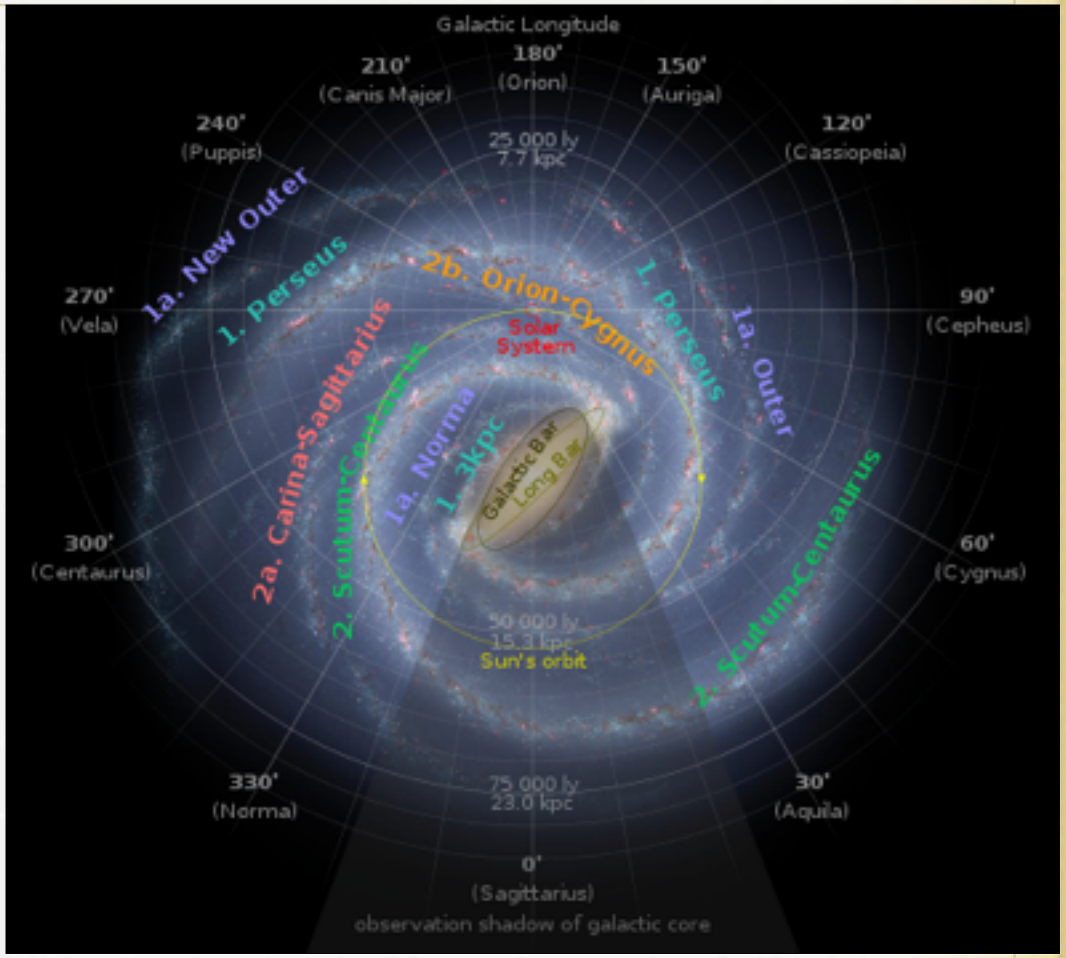
Fig. 1: *Left is an IR image from the Two Micron All-Sky Survey (image G. Kopan, R. Hart) while on the right an artist's concept of the Gaia mission superimposed on an optical image, (Image ESA). Images not to scale.*

1. NIR Astrometry

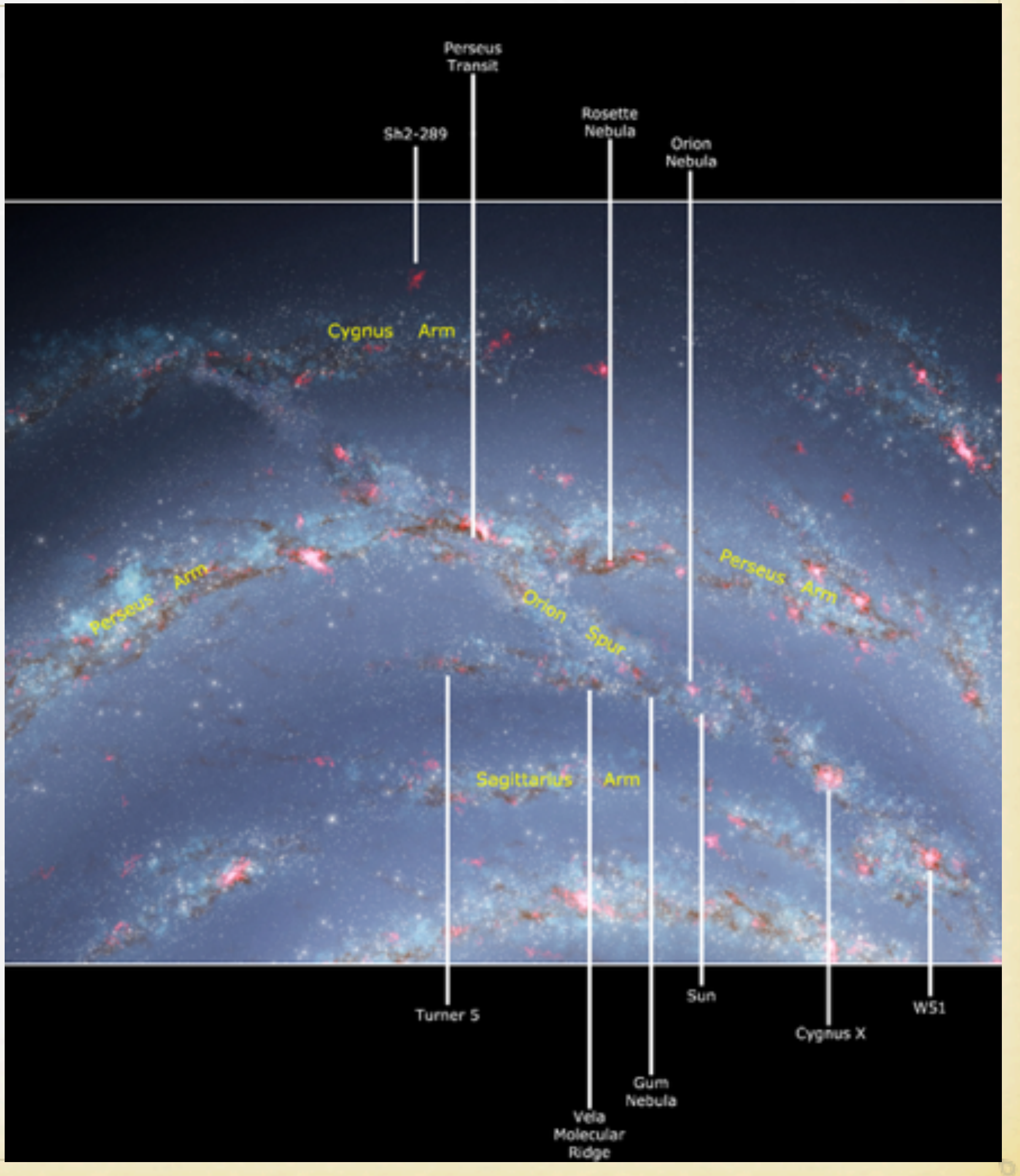
- The bulge/bar region needs NIR:
  - Radial migration at the bulge/bar IF is hidden.
  - Did the bar create a peanut-shaped pseudo-bulge?
  - Star formation in the bar - DM density in the GC.
  - Bar may perturb the Halo DM profile.



- Galactic rotation curve and dark matter:
  - The inner disk is not well known.
  - Does the thin disc or the spiral arms have DM components.
  - VLBI measurements of 100's of masers exist but GaiaNIR would vastly improve this.

1. NIR Astrometry

- Central black hole region.
  - Other surveys (e.g. JASMIN, GRAVITY, WFIRST) may give first epoch measurements in small regions.
- For the spiral arms GaiaNIR:
  - Reveal the internal & the bulk dynamics of young clusters.
  - Allow the dusty star forming regions to be globally surveyed for the 1st time.



Many other science cases: brown dwarfs, cool white dwarfs, free floating planets, PL relations of red Mira's, etc.

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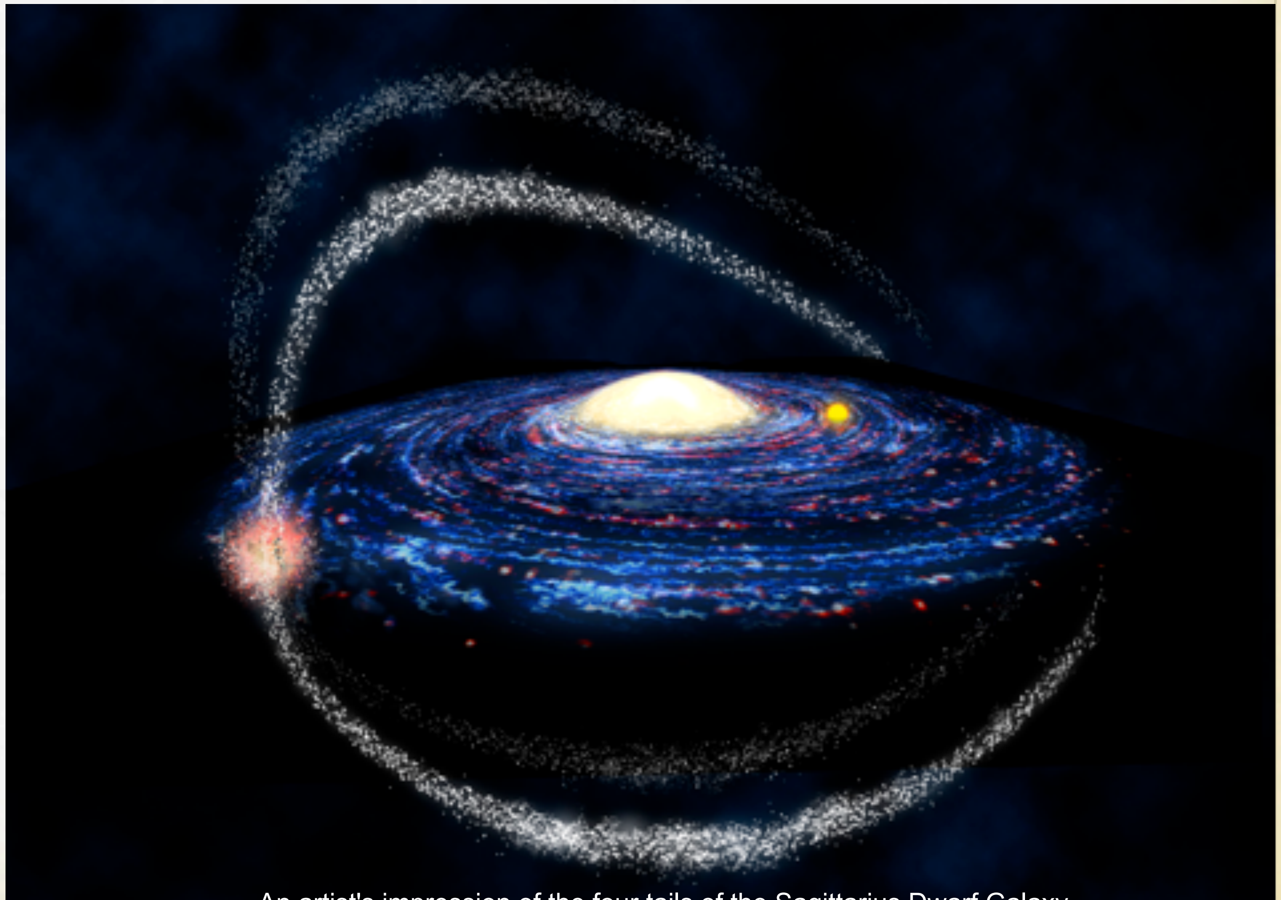
2. Improved PM & Parallax

- Improved PMs would give tangential velocities of >1 km/s at 100 kpc allowing structure in streams and dwarf galaxies in the Halo to be resolved.

$$v = \frac{K\mu}{p} \quad \text{or}$$
$$v = K * 0.00177\ [\text{mas/yr}] * 100\ \text{kpc} \sim 0.85\ [\text{km/s}]$$

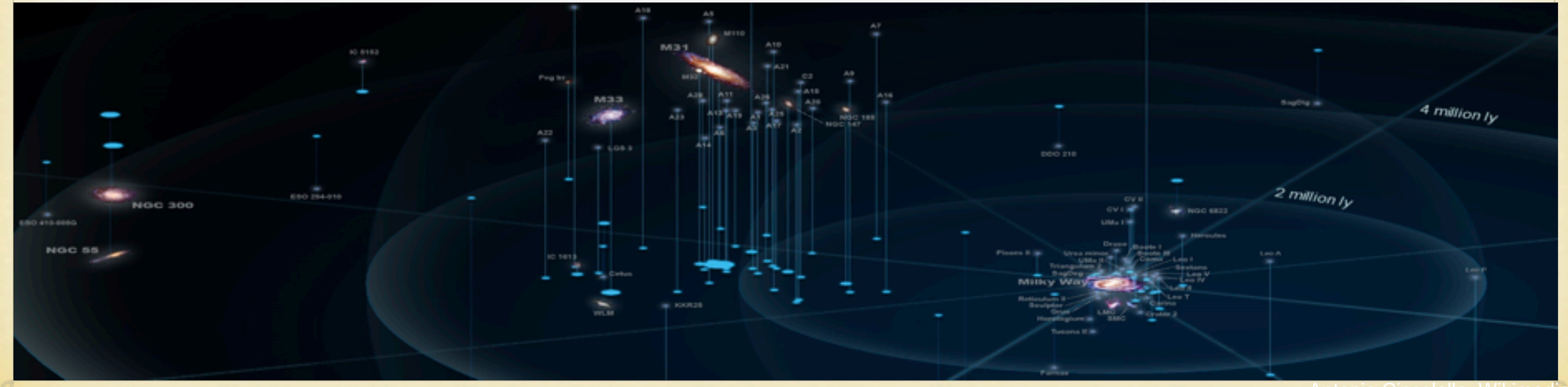
- Gaps in streams can reveal DM sub-halo structure.
- Outer Halo PMs - the mass of the Galaxy.
- PMs - cusped or a flat dark matter (core) Halo problem?
- Improved PMs will reveal detail structure in every part of the Galaxy.



An artist's impression of the four tails of the Sagittarius Dwarf Galaxy
Figure credit: Amanda Smith, Institute of Astronomy, University of Cambridge

2. Improved PM & Parallax

- Internal dynamics of local group galaxies (e.g. M31), dwarf spheroids, globular clusters, LMC & SMC improved.
- Map the DM sub-structure in the local group.
- HVSs - trace their origin to GC or Magellanic clouds. Constraints on axis ratios & orientation in models of the Galaxy.
- Exoplanet & binary periods of 30 - 40 yr (Saturn P=29 yr).
- SS orbits for >100,000 objects with 2 missions.



Antonio Ciccolella, Wikimedia

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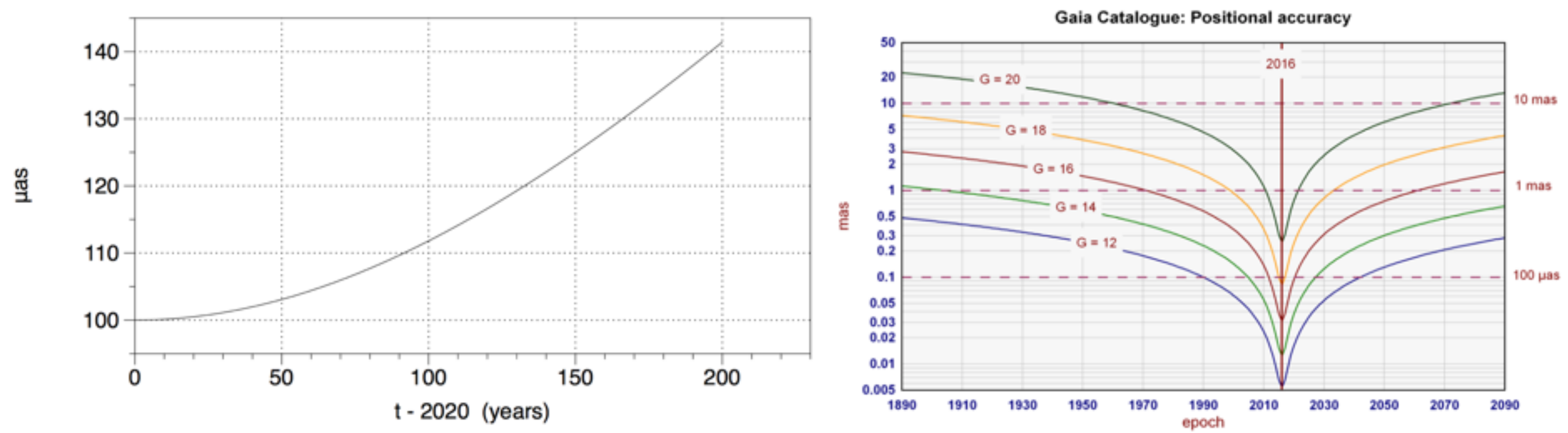
3. RF & Catalogue Ageing

- The RF will degrade with time. E.g. if individual primary sources are accurate to 100 µas and RF spin accurate to < 0.5 µas yr^{-1}.
- The positional accuracy of the catalogue degrades due to PM errors .
- Expand the Gaia optical RF to the NIR increasing its density in obscured regions.
- This is a strong science case on its own for future observational astronomy.

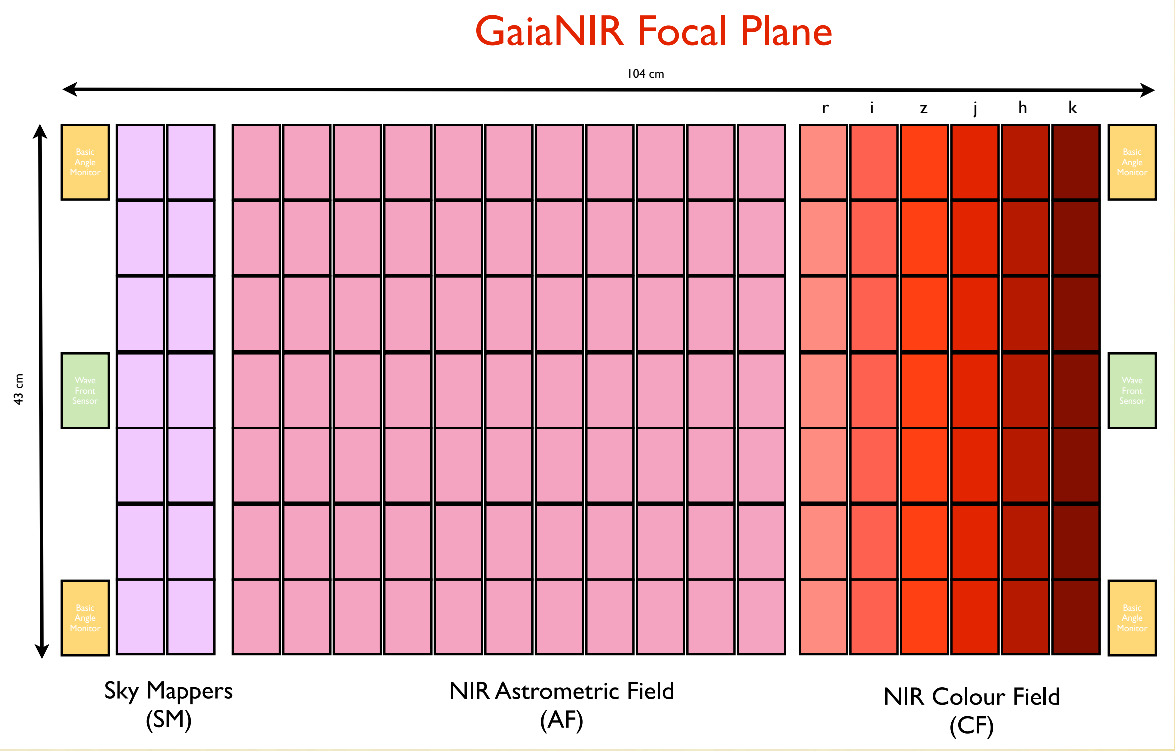


The positional accuracy of the Gaia reference frame and catalogue over time. (Image F. Mignard).

Detectors & Filters

- HgCdTe (MCT) materials are most promising for NIR sensors with TDI mode.
  - Readout noise is too large.
  - Charge generation in MCT layer - charge accumulation & transfer in a silicon substrate.
  - Readout only occurs once at the end of pixel transfers.
- Use one NIR detector - wavelength overlap with Gaia is needed.
- Cooling strategy must be passive (~80K).

A maximum focal plane composed of NIR only detectors



- Filter photometry 4 to 6-bands similar to Sloan and 2MASS e.g. r, i, z, j, h, k.
- No Spectrograph !

Star Counts

Average	25 000 stars deg^{-2}
Typical	150 000 stars deg^{-2}
Design	600 000 stars deg^{-2}
Maximum	**3 000 000** stars deg^{-2}

Gaia star count requirements

Band (nm)	**Pole stars deg^{-2} (f)**	**Anti-GC stars deg^{-2} (f)**	**GC stars deg^{-2} (f)**
600-1000 (G band)	2 529 (1.0)	63 118 (1.0)	234 701 (1.0)
600-1800	4 302 (1.70)	156 714 (2.48)	**4 077 687** (17.4)
600-2400	4 643 (1.84)	186 774 (2.96)	**9 273 894** (39.5)

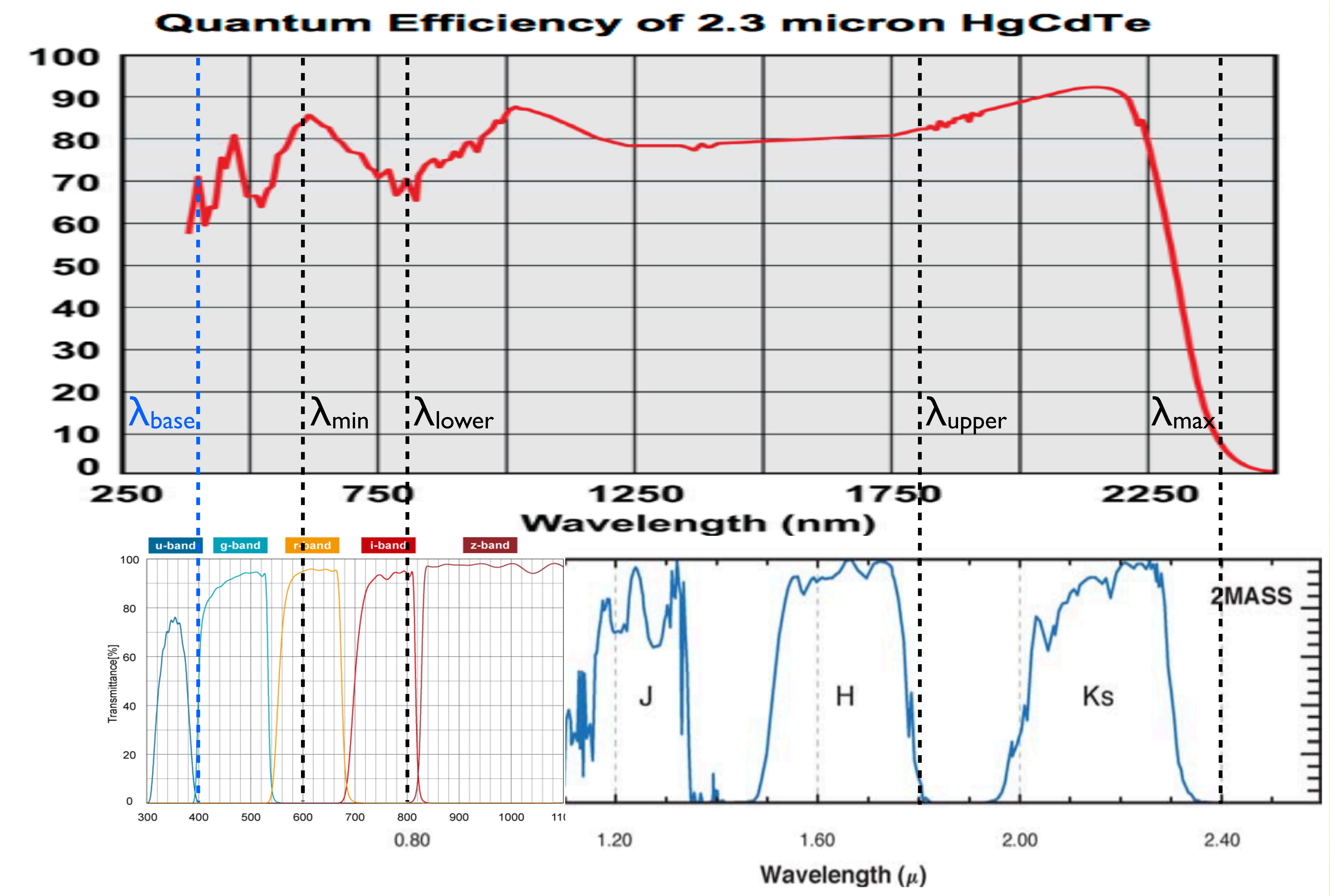
Estimated values for GaiaNIR based on Galaxy model. The factor **f** is the ratio of counts to those in the Gaia G-band and numbers are complete to equivalent of G=21 (Carme Jordi et al. 2017).

- Limiting the waveband to 1800 nm would reduce the star counts by a factor of 2 - not enough!
- Can onboard VPU and TM bandwidth handle these numbers plus a margin (TBD)?

Wavelength Range

Patched together illustration of possible filter bands (Sloan and 2MASS) and quantum efficiency (Teledyne) and the various cut-off wavelengths.

Going to as low a wavelength as possible would give more overlap with Gaia.



A Cheaper Mission?

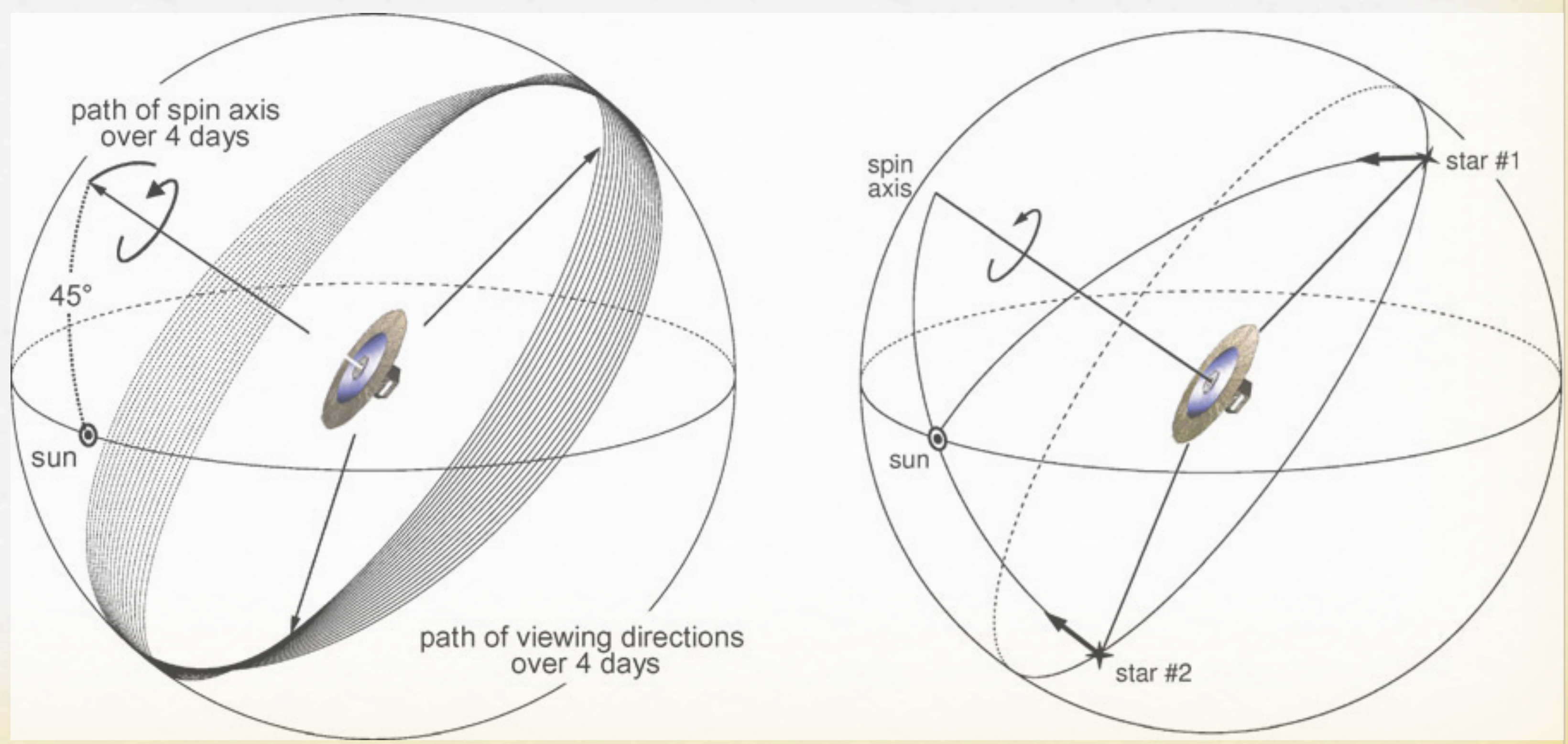
GaiaNIR cost ~700M€ (L-class) but there are no more L-class missions before 2035.

We must fit in an M-class mission (600 M€).

We have to tweak the parameters to reduce costs significantly!

A radical rethink of the concept and design is needed - e.g.'s

- Use relative astrometry and only 1 FoV.
- A step-and-stare mission or a de-scan mechanism to avoid TDI mode?
- A beam combiner to remove one set of optical components?
- International collaboration?



What Happens Next?

- Mission science requirements specified over the summer - scientific Expert Group.
- In Sept.-Oct. ESA will use the requirements at their Concurrent Design Facility (CDF) to make a preliminary evaluation of the concept resulting is a satellite design.
- The CDF will focus on:
    - To tradeoff different architectures to achieve the science objectives within an M-class mission.
    - To re-design the Payload Module (optics) and the Focal Plane to host NIR detectors.
    - To provide technical specifications and development plan for TDI-NIR detectors.
    - To assess the step-and-stare vs spin.
    - To assess a de-scan mechanism to allow the use of conventional NIR detectors.
    - To preliminary design the SC and provide the associated mission costs.

- We have interest and momentum now! Hopefully we can proceed to an M-class global astrometry mission proposal - M7/8?