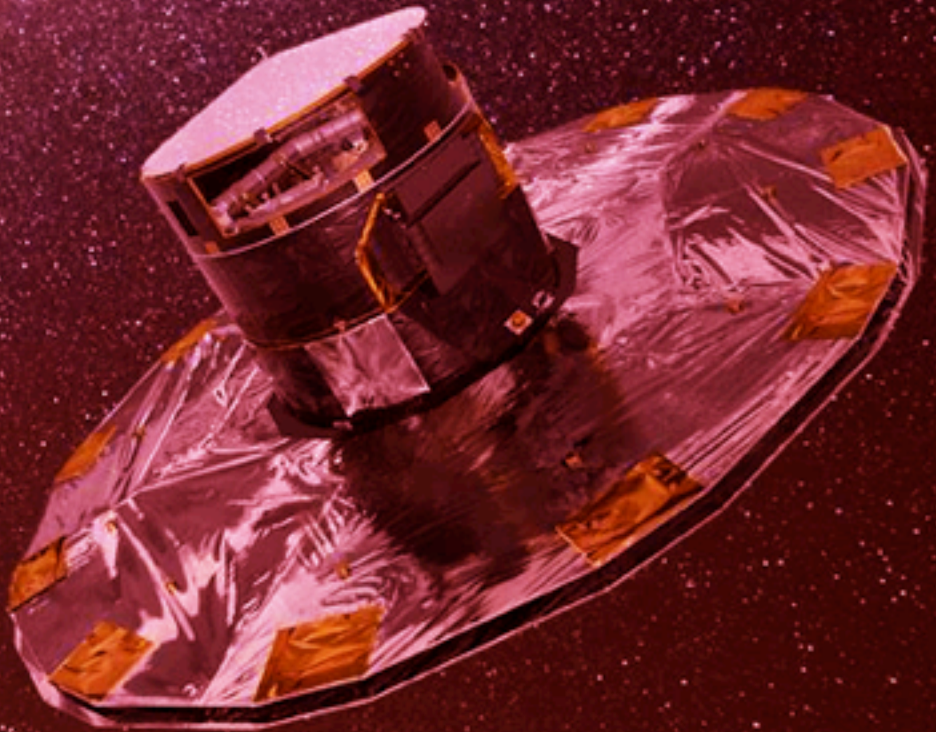
GaiaNIR

A Future All Sky Astrometry Mission



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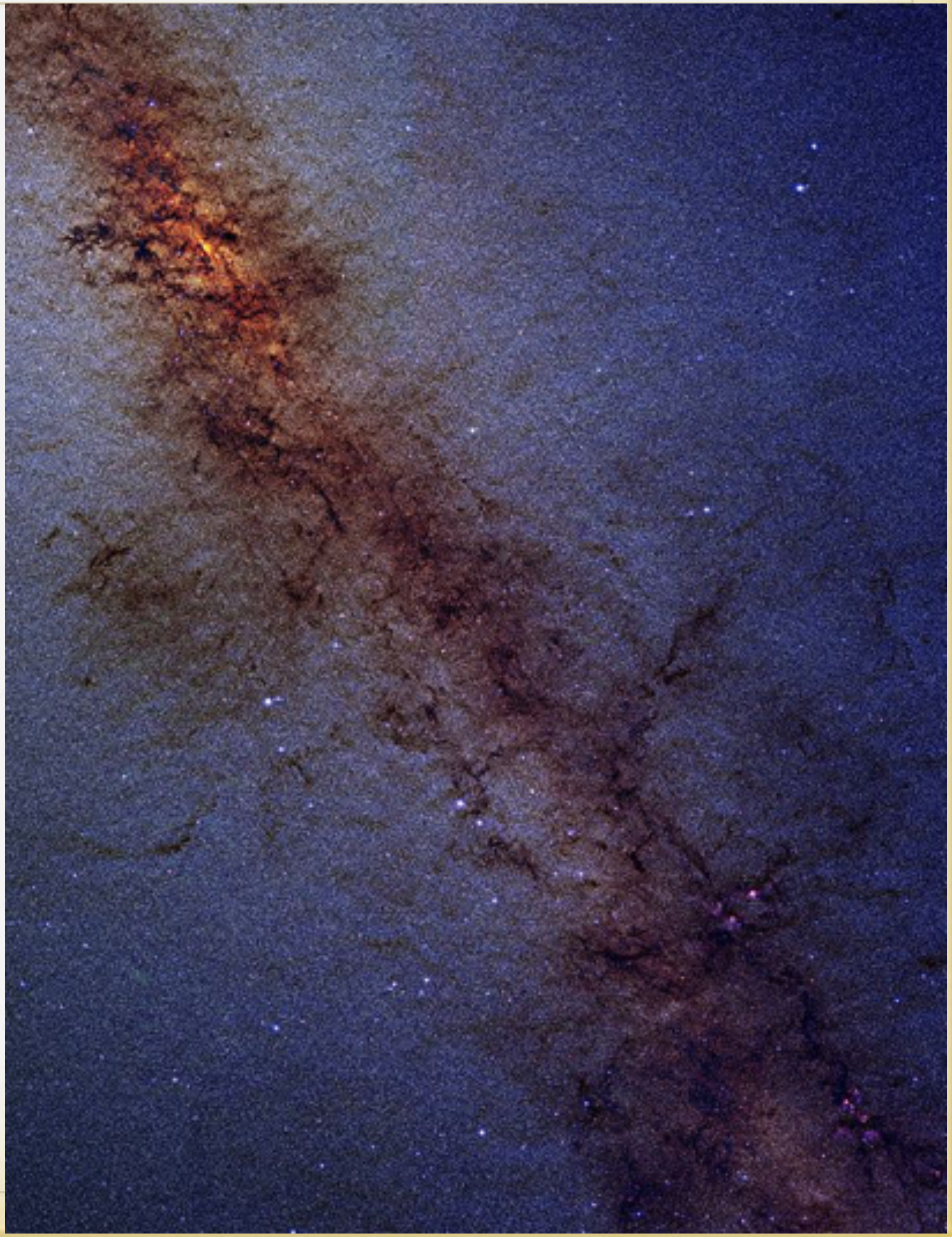
Motivation For GaiaNIR

- A weakness of Gaia is that it only operates at optical wavelengths.
- The Galactic centre and spiral arm regions are obscured by interstellar extinction.
- Can overcome this switching to the NIR but this was not possible with CCDs ⇒ new detectors.
- To scan the entire sky & measure global absolute parallaxes we need rotation ⇒ detectors correct for rotation.

Technological challenge:

- Optical and Near-Infra-Red (NIR).
- A scanning mission needs Time Delayed Integration (TDI) mode or similar to compensate for rotation - does not exist in NIR !
- Detector read out noise must be low.

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



Science Cases

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

Astrometry:

1. Adding NIR astrometry and photometry to probe obscured regions of the Galaxy and allow us to observe intrinsically red objects.
2. A new mission at a 20 yr time interval would give 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 catalogue needs to be maintained.

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

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Core team members:	The following minimum team is needed to initiate the project.
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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. Hurt) while on the right an artist's concept of the Gaia mission superimposed on an optical image, (Image ESA). Images not to scale.*

Measurement Concept

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

GaiaNIR - will do all sky global astrometry in the **visible** and **NIR**.

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 compared to Gaia's nominal 25 μas yr^{-1}.

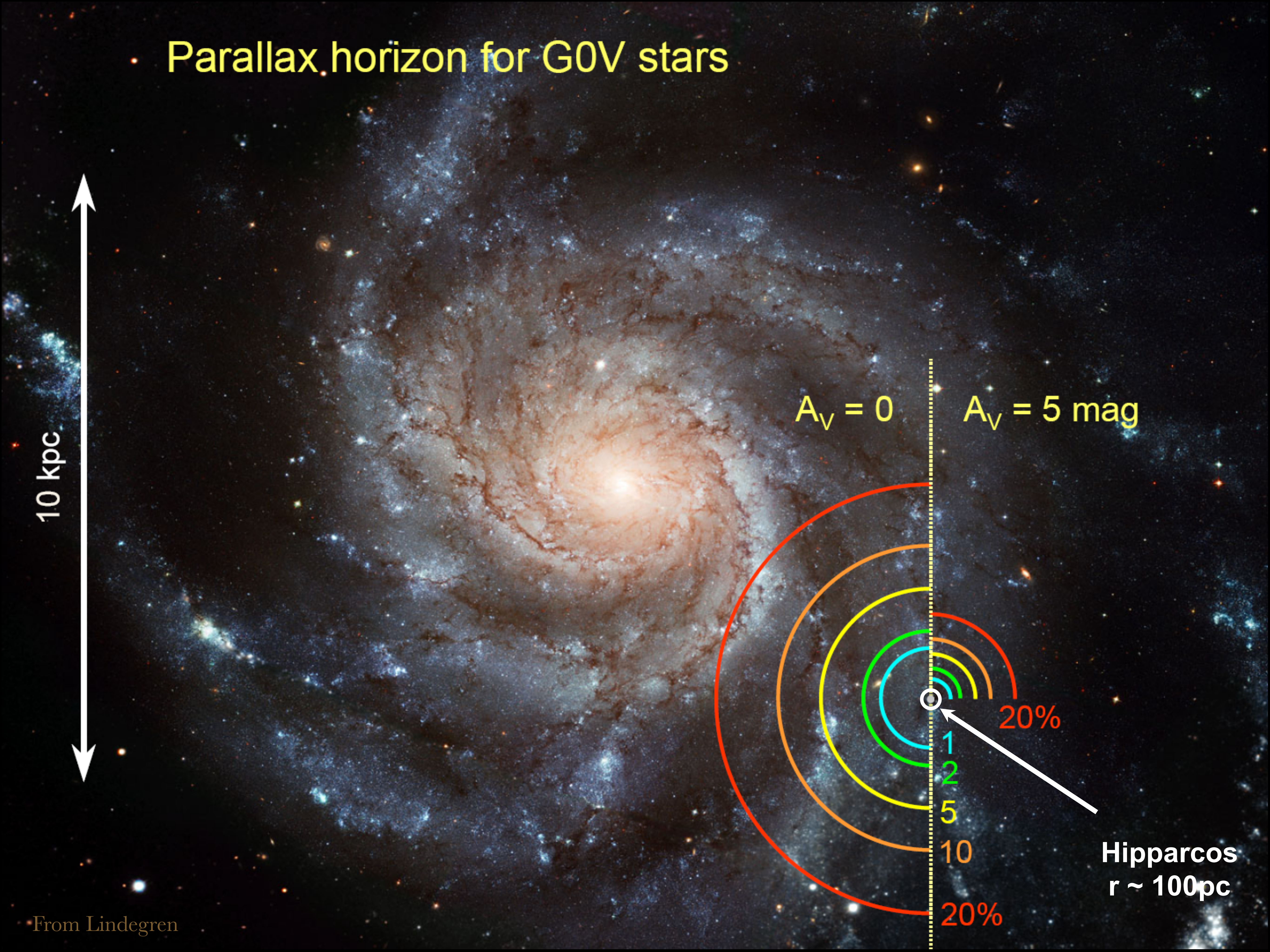
Second Epoch
GaiaNIR 5yr
(2035-40)

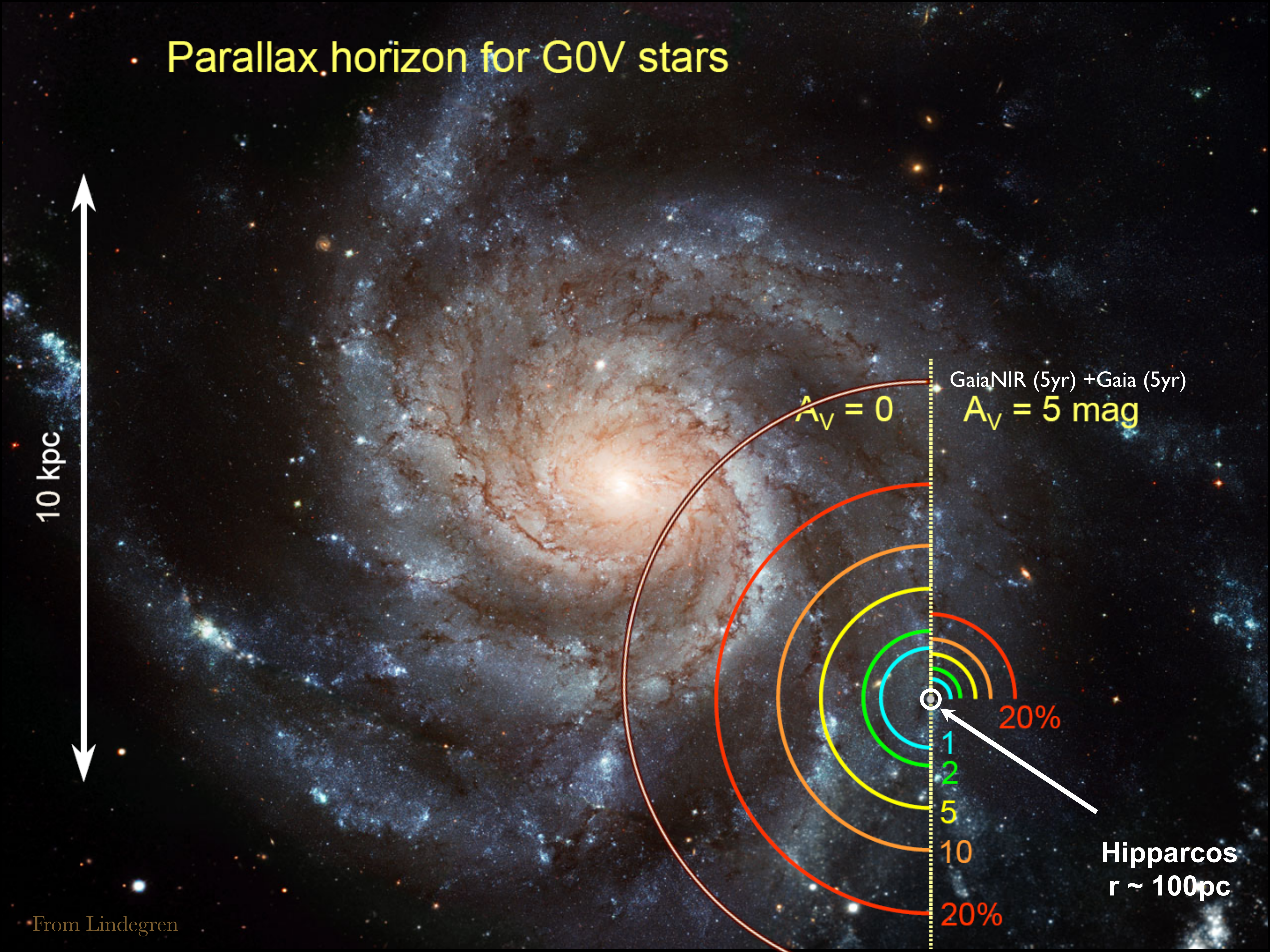
Stars only seen in NIR will not benefit from this improvement

20 yr separation

First Epoch
Gaia 5yr
(2015-20)

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


Parallax horizon for G0V stars
10 kpc
$A_V = 0$
$A_V = 5$ mag
20%
1
2
5
10
20%
Hipparcos
r ~ 100pc
From Lindegren


Parallax horizon for G0V stars
10 kpc
GaiaNIR (5yr) +Gaia (5yr)
A_V = 0
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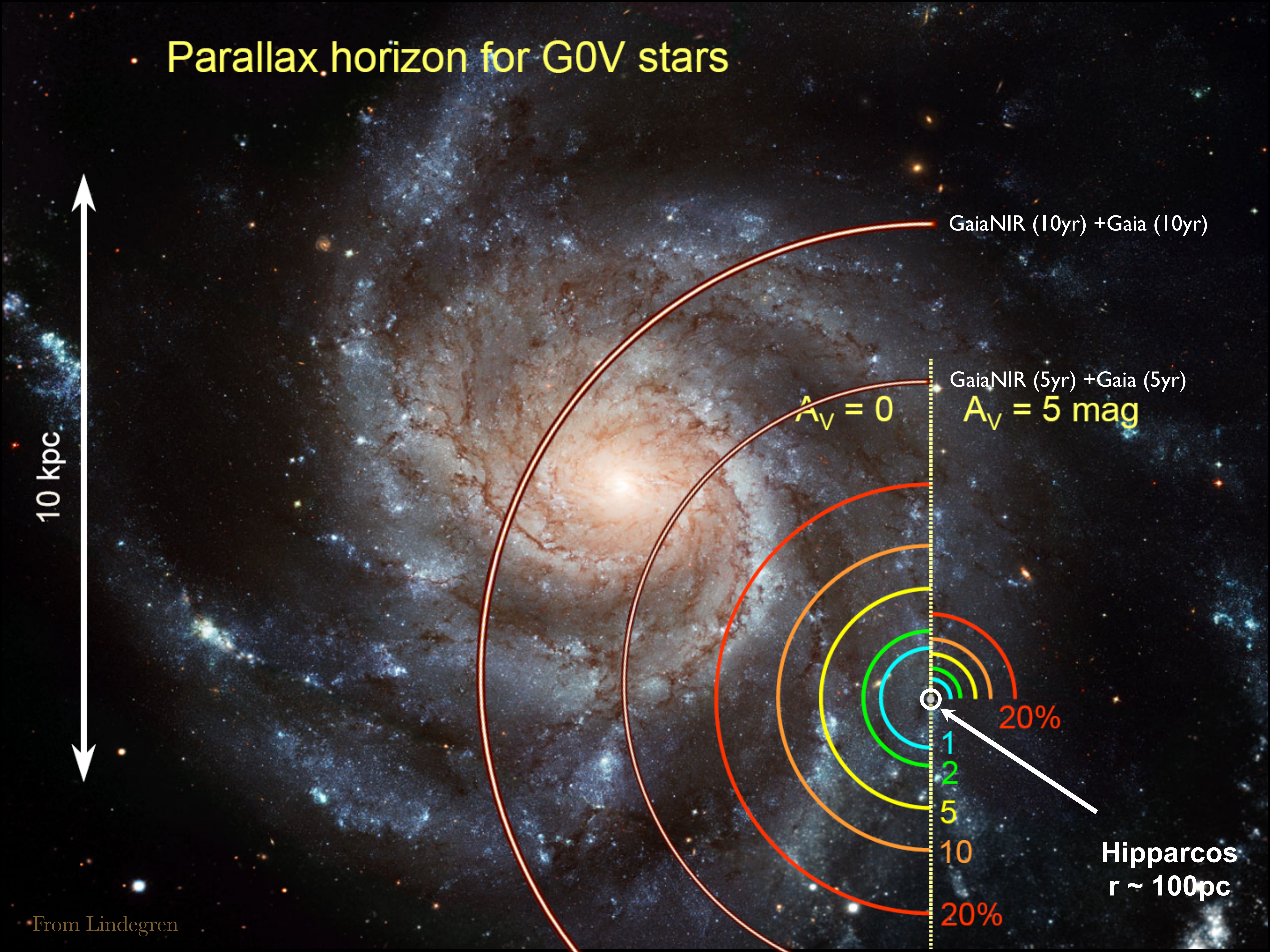
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20%
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Hipparcos
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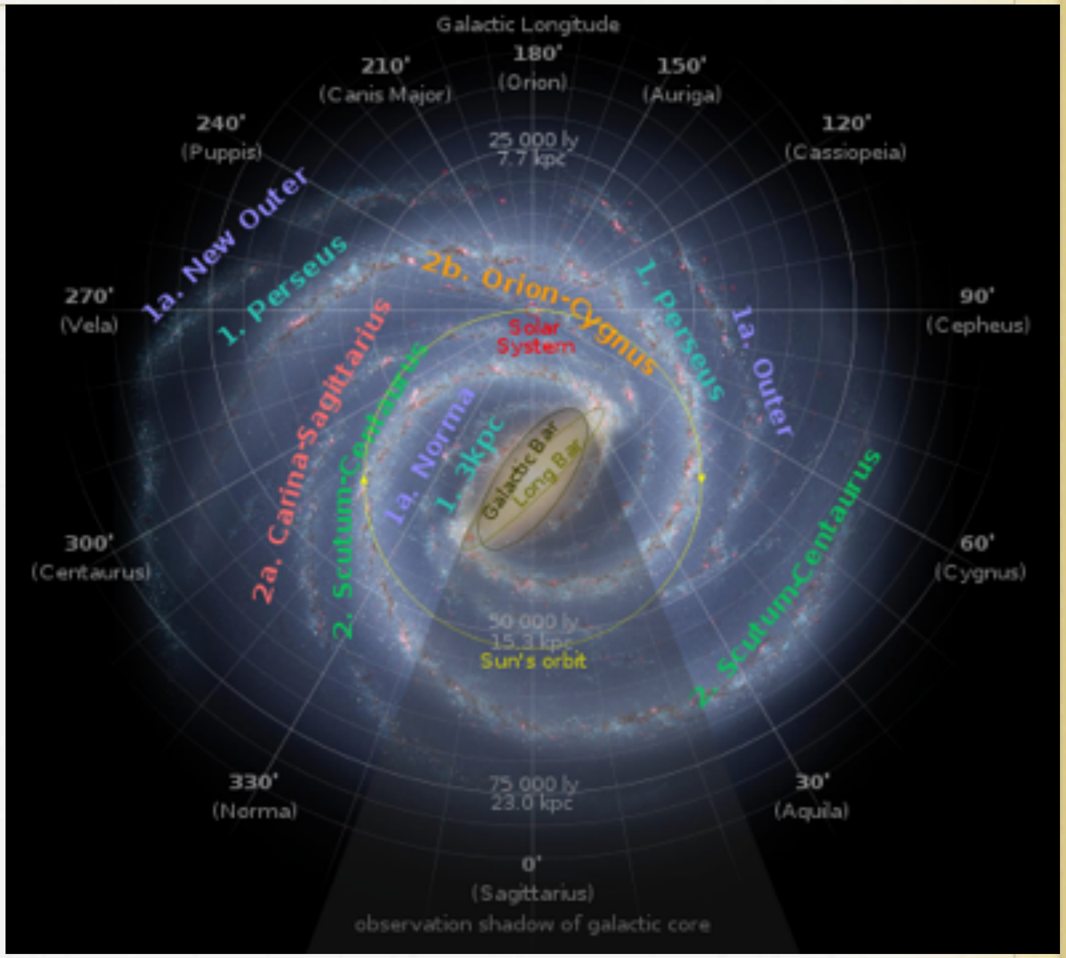
From Lindegren

1. NIR Astrometry

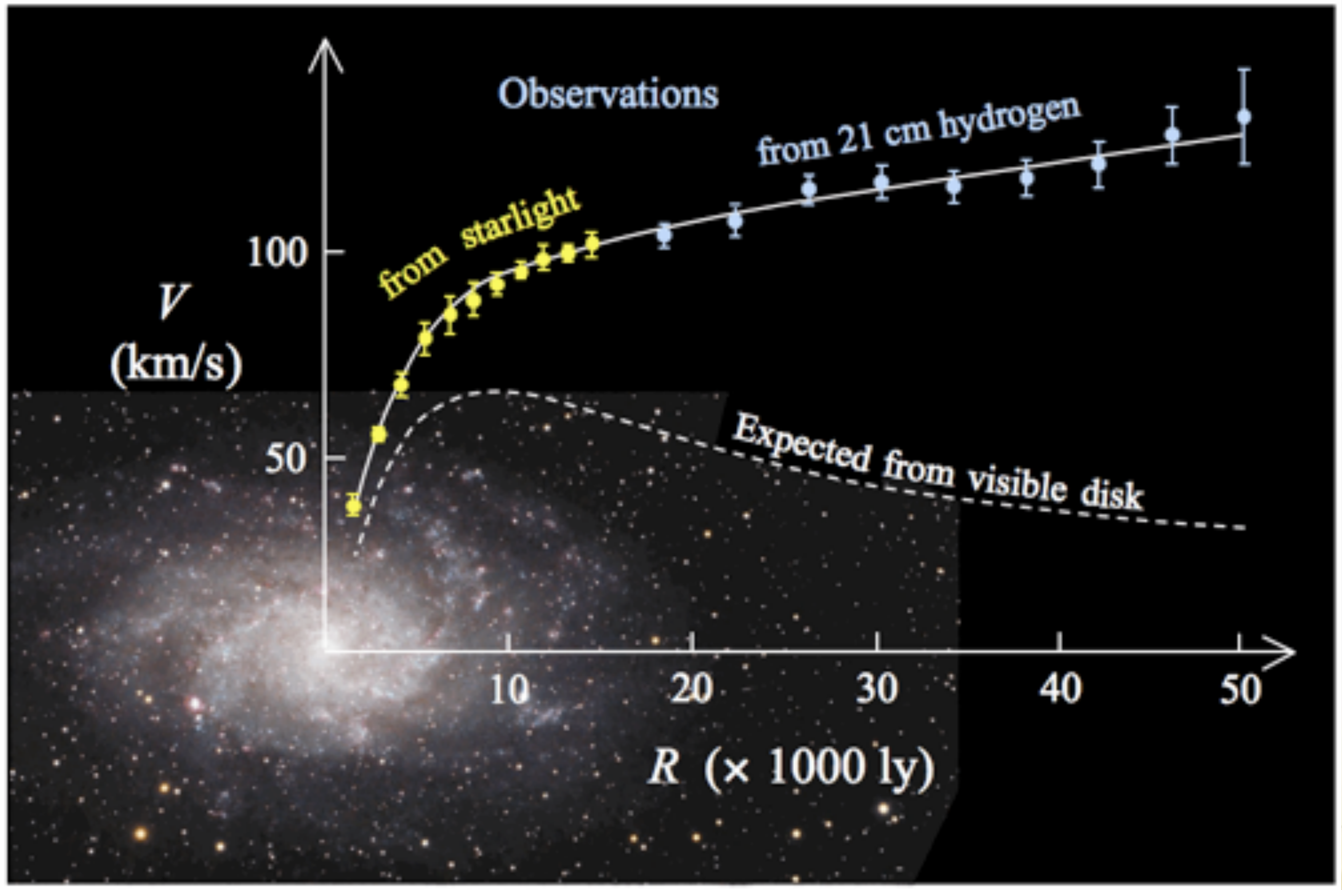
- The bulge and bar regions need NIR.
  - Radial migration at the interface is hidden by dust
  - Stellar bar may have created a peanut-shaped pseudo-bulge - PMs and parallaxes are needed.
  - Star formation in the bar affects DM density profile in the Galactic Centre.
  - Bar may interact with the Halo to perturb the Halo DM profile.



- Central black hole region
  - Other surveys (e.g. JASMIN, GRAVITY) may supply first epoch measurements but only in small regions.

1. NIR Astrometry

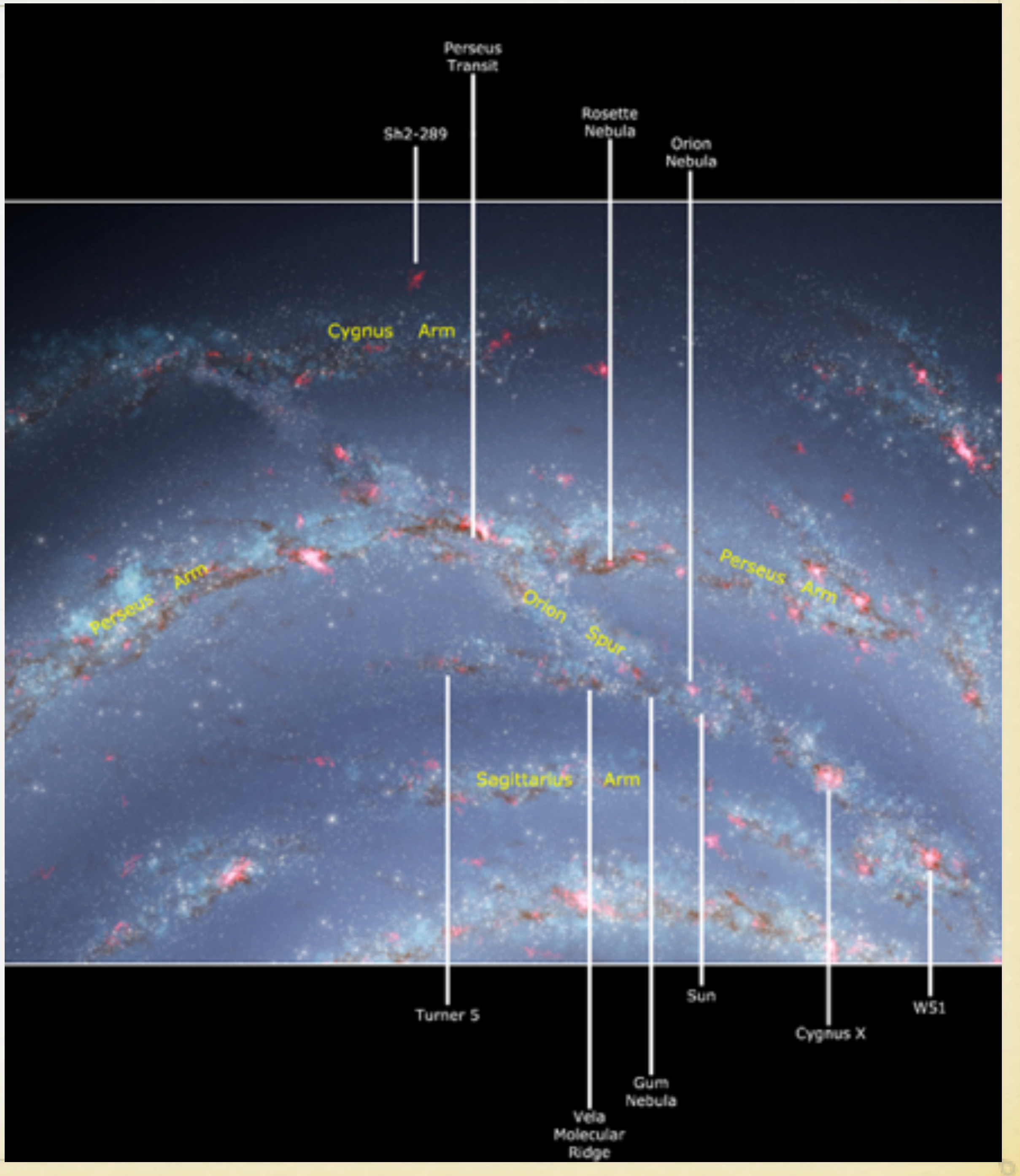
- Galactic rotation curve and dark matter.
  - GaiaNIR is needed to unveil the inner disk which is not well known.
  - Does the thin disc have DM components.
  - Have spiral arms their own DM components.
  - VLBI measurements of 100's of masers probe the rotation curve but GaiaNIR would vastly improve this.



1. NIR Astrometry

- For the spiral arms GaiaNIR:
  - could map them in detail - astrometry for 100's of millions of objects.
  - could reveal the internal dynamics & bulk dynamics of young clusters.
  - allow these dusty star forming regions to be globally surveyed for the 1st time.

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

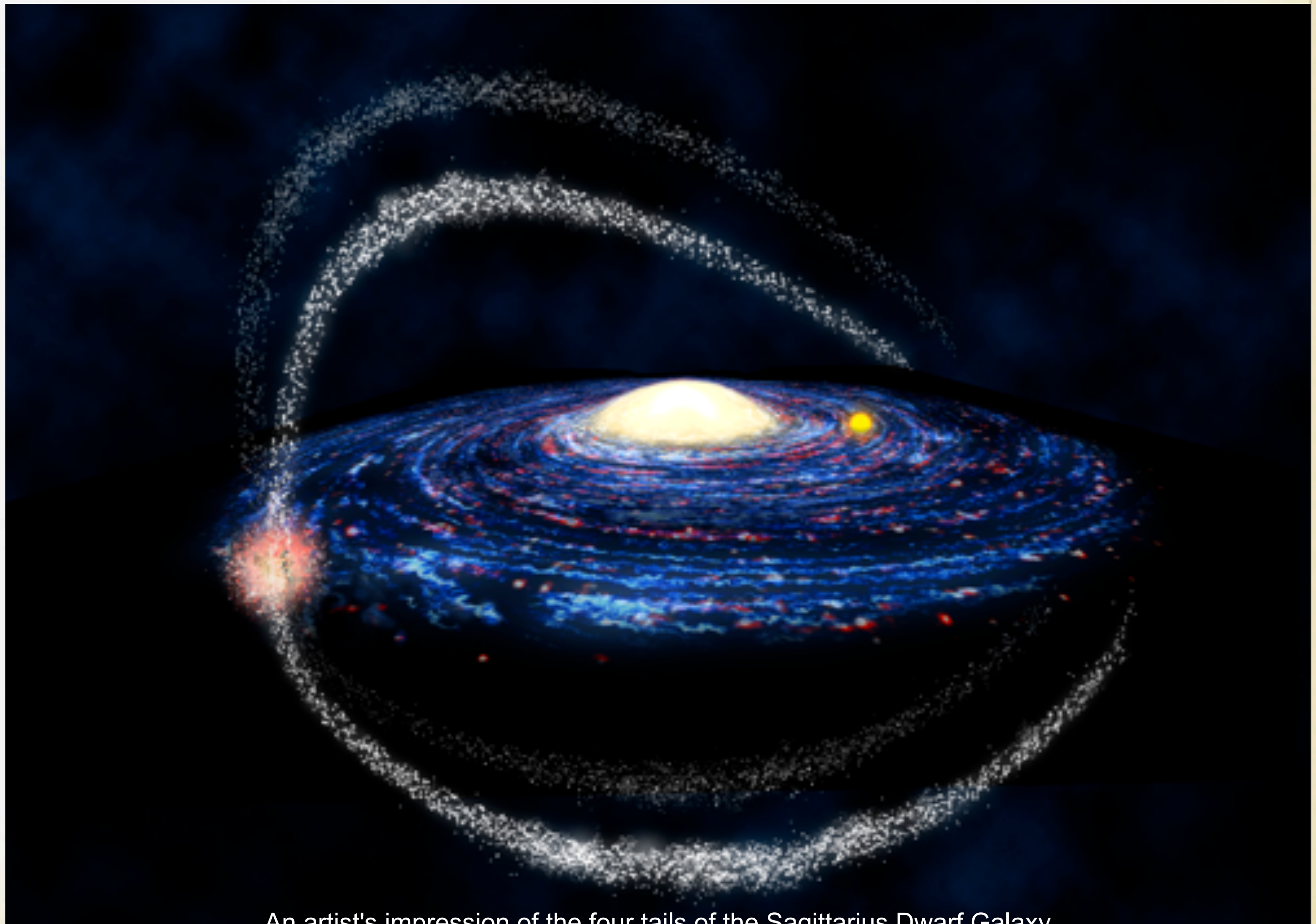


2. Improved PM & Parallax

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

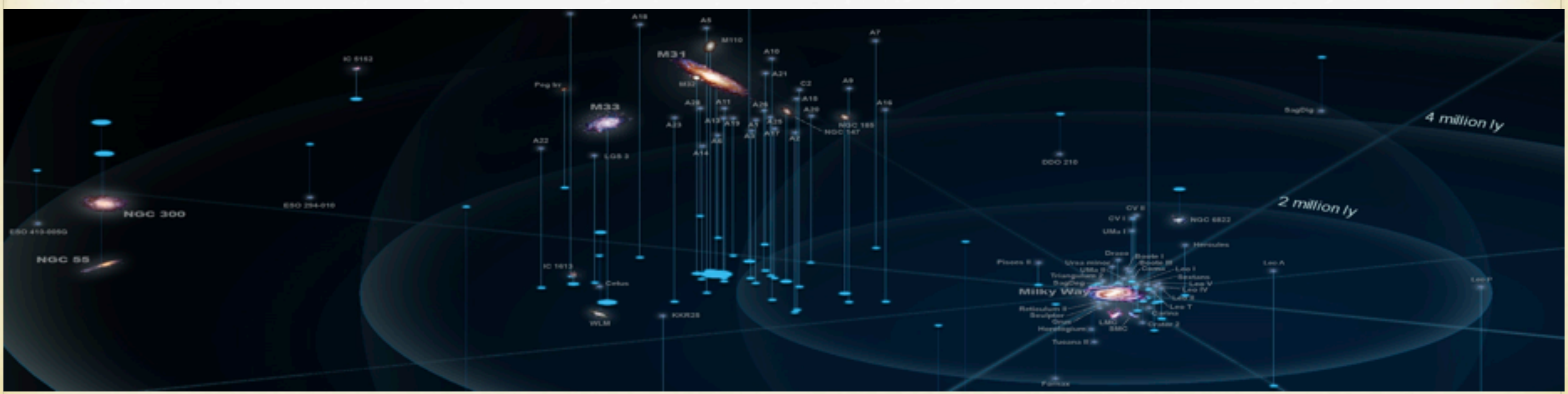
$$v = \frac{K\mu}{p} \quad \text{or}$$
$$v = K * 0.00177 \text{ [mas/yr]} * 100 \text{ kpc} \sim 0.85 \text{ [km/s]}$$

- PMs may be used to detect gaps in streams revealing DM sub-halo structure.
- PMs in outer Halo could better estimate the mass of the Galaxy.
- Finally, can PMs shed more light on the cusped or a flat dark matter Halo problem?


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.
- Examples of dynamics within the local group:
  - Using PMs to determine rotational parallaxes to M31, M33 and other local galaxies.
  - Dynamical measurements of the mass distribution of M31.
  - Probe the internal kinematics of classical dwarf spheroids (dSph's).



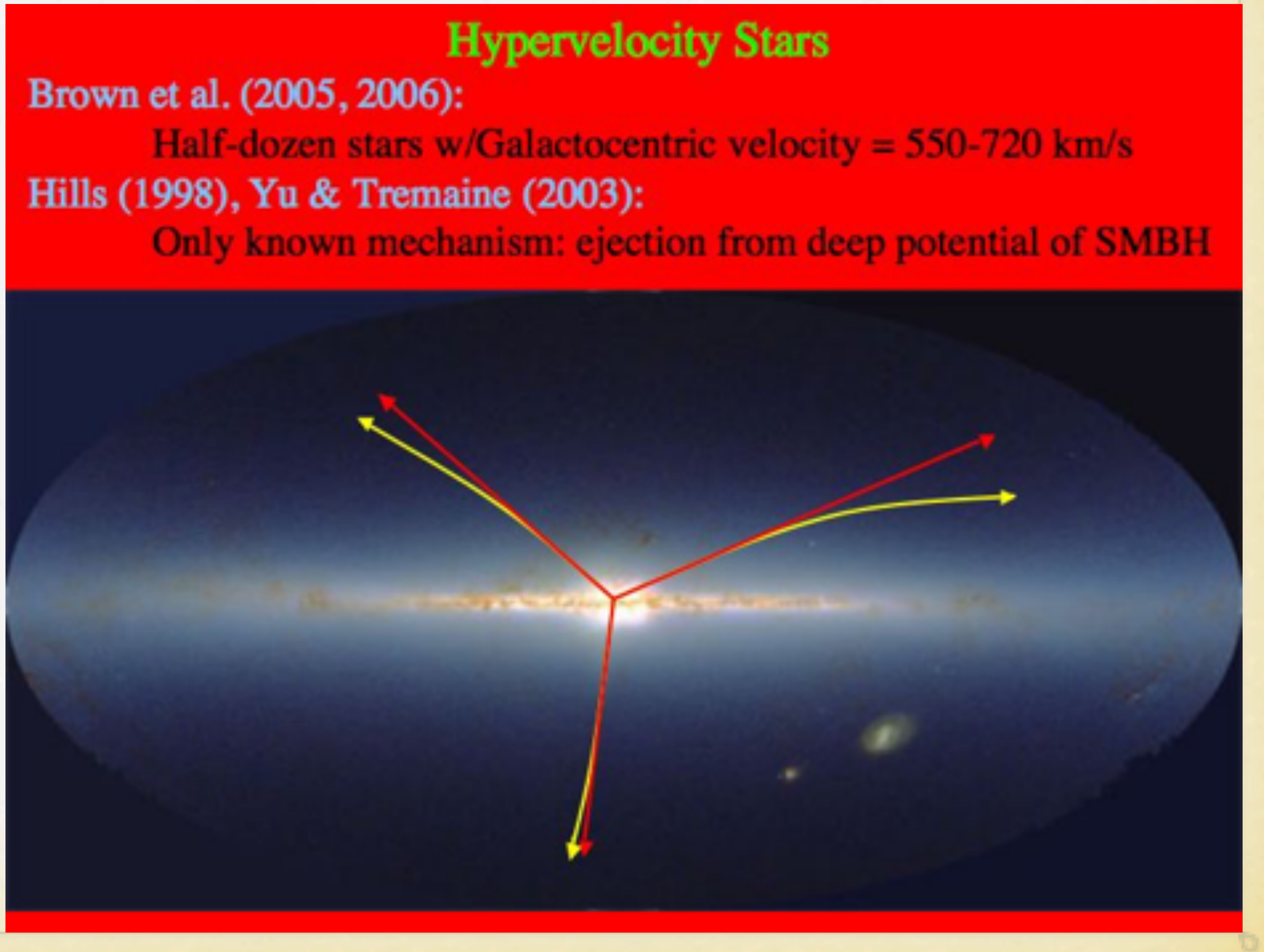
Antonio Ciccolella, Wikimedia

2. Improved PM & Parallax

- Hyper-velocity stars need accurate PMs and V_R to trace their origin (GC or Magellanic clouds). Constraints on axis ratios & orientation of triaxial models of Galactic potential.

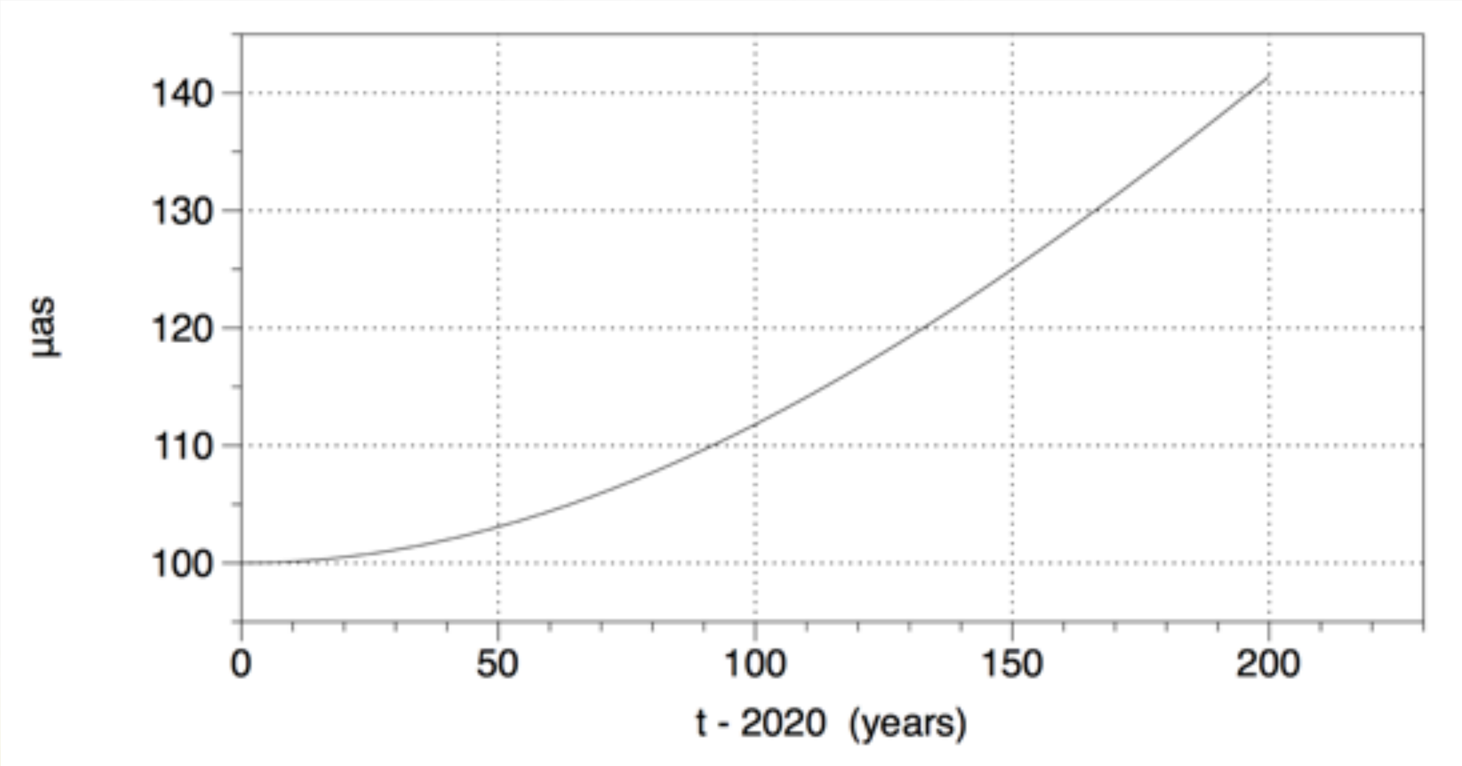
- Exoplanet & binary detectable period is 30 - 40 yr with GaiaNIR + Gaia (Saturn P=29 yr).

- Solar System orbits for >100,000 objects - greatly improved if based on 2 missions.



3. RF & Catalogue Ageing

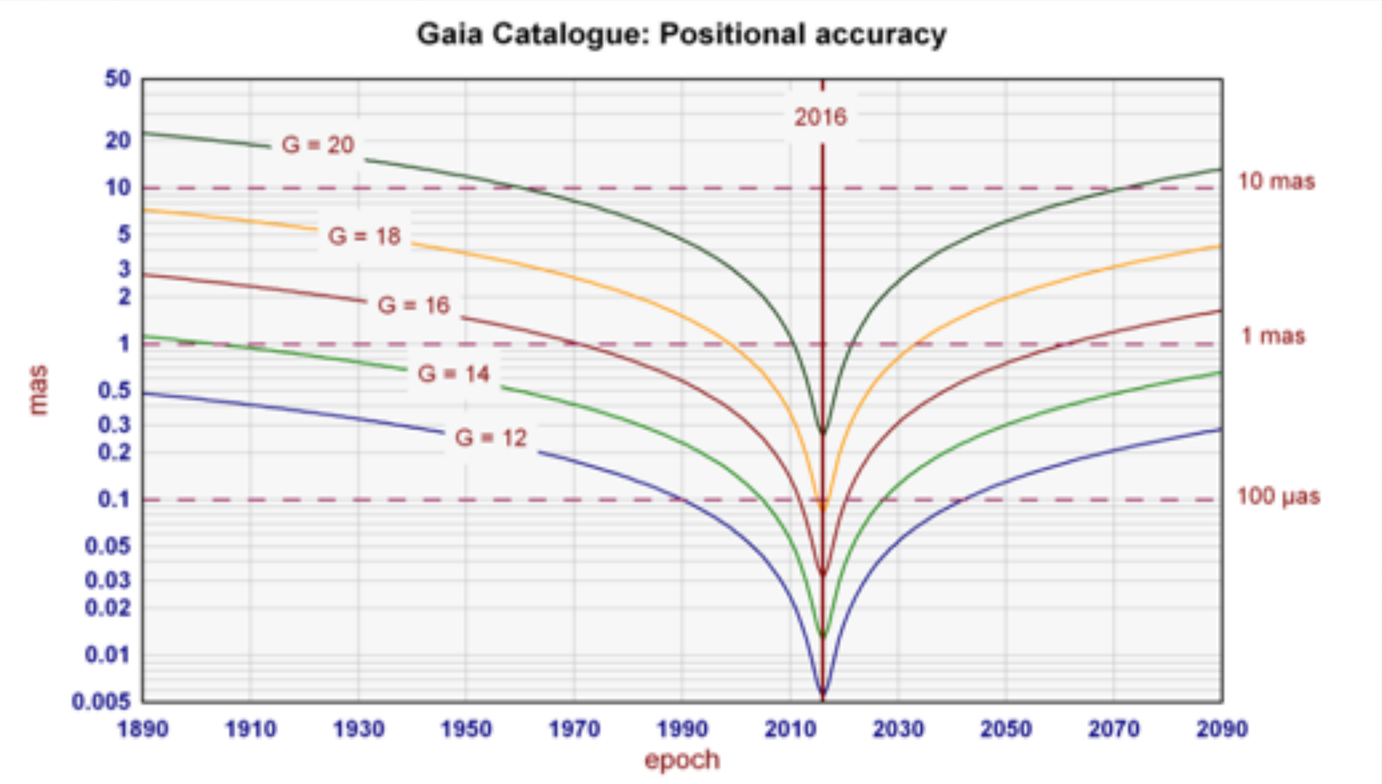
- The RF will degrade with time. Eg. Individual primary sources are accurate to 100 µas and RF spin accurate to < 0.5 µas yr^{-1}.
- This very small drift is not a problem but over time other systematic PMs patterns will show up.
- The largest is the Galactic-centric acceleration of ~4.3 µas yr^{-1} which can be (largely) accounted for but others also exist.



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

3. RF & Catalogue Ageing

- The positional accuracy of the catalogue will degrade over time due to PM errors - which will eventually require a new Gaia-like mission to maintain the catalogue.
- Expand the Gaia optical RF to the NIR increasing its density in obscured regions and linking this to the ICRF.
- This on its own is a strong science case due to the need to maintain dense and accurate reference grids in both optical & NIR for future observational astronomy.

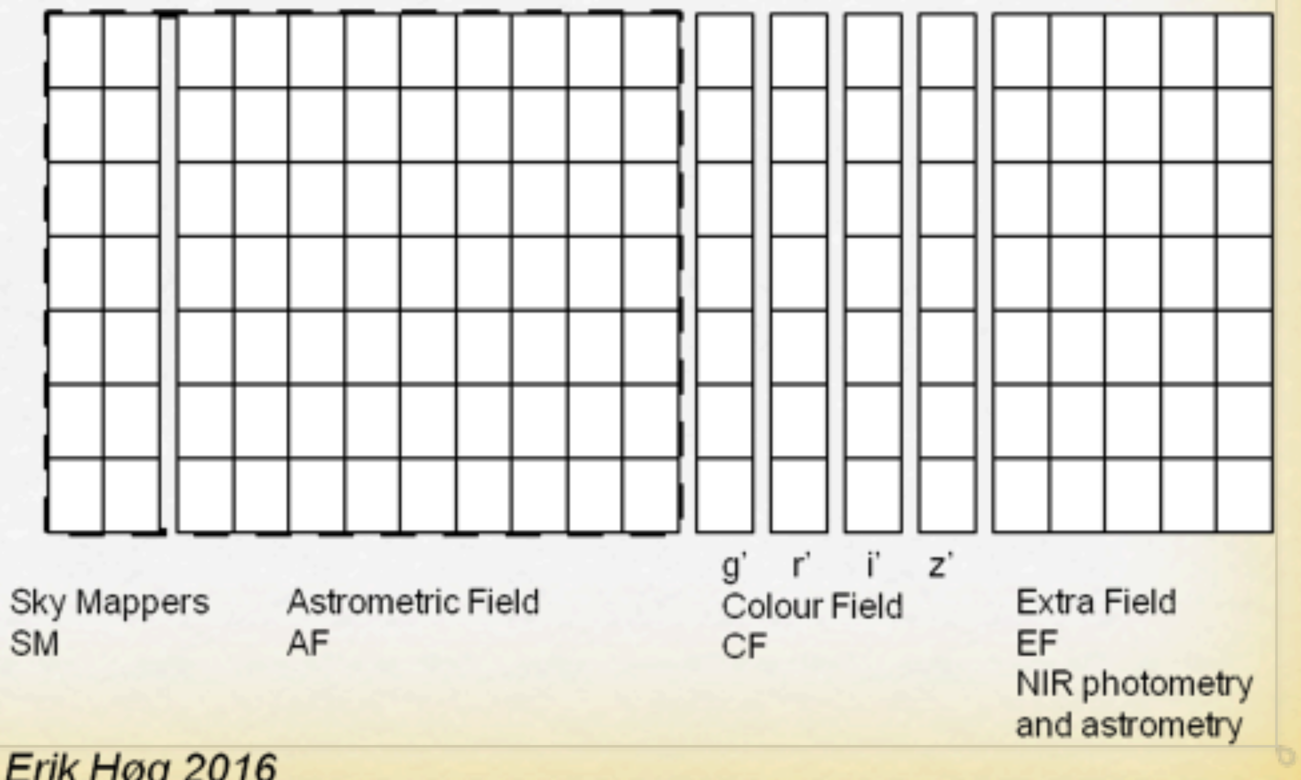


The positional accuracy of the Gaia catalogue over time. (Image F. Mignard).

Detectors & Filters

- ESA study of NIR sensors (400–2000 nm) with TDI mode.
  - HgCdTe (MCT) materials are most promising for NIR sensors.
    - Readout noise (off-chip summing of each pixel) is too large.
    - Charge generation in MCT - silicon substrate for charge accumulation and transfer to next pixel - readout only occurs once at the end of pixel transfers.
  - Achievable astrometric accuracy ?
  - Cooling strategy must be passive and needs to be assessed (100K).
  - Can the focal plane consist of just one type of detector or (CCDs + NIR sensors).
- Filter photometry 4-band (7-band ?) similar to Sloan bands, g´, r´, i´, z´ (j´, h, k).
- No Spectrograph !

A focal plane composed of optical and NIR detectors



What Happens Next?

- Mission science requirements are being specified over the summer - scientific Expert Group.
- In the Autumn 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 most important challenges of the mission will be identified for further technical study:
  - Detector type for Optical-NIR (together or separate).
  - TDI detectors for NIR.
  - De-scan mechanisms ?
  - Step-stare mission concept (with 2 or 3 FoVs) ?
  - BA variations and BA monitors.
  - Can we get better accuracy then Gaia ?

- Hopefully we proceed to an M-class mission proposal - M7 ?