GaiaNIR
A Future All Sky Astrometry Mission

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### Motivation For GaiaNIR

- 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

\[
\sigma_{\mu_\alpha} = \frac{\sqrt{\sigma_{\alpha_N}^2 + \sigma_{\alpha_G}^2}}{t_N - t_G} = \frac{\sqrt{25^2 + 25^2}}{20} \approx 1.77 \, \mu\text{as yr}^{-1}, \quad \sigma_{\mu_N} = \frac{\sqrt{\sigma_{\delta_N}^2 + \sigma_{\delta_G}^2}}{t_N - t_G} = \frac{\sqrt{25^2 + 25^2}}{20} \approx 1.77 \, \mu\text{as yr}^{-1}
\]

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 \( \mu\text{as yr}^{-1} \).

Stars only seen in NIR will not benefit from this improvement.
Parallax horizon for G0V stars

Improved Parallaxes

GaiaNIR (10yr) + Gaia (10yr)
GaiaNIR (5yr) + Gaia (5yr)

$A_V = 0$
$A_V = 5$ mag

From Lindegren
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 $\sqrt{2}$ 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.
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.

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

- 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.
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.
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Fig. 1: Left is an IR image from the Two Micron All-Sky Survey (image G. Koru, 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.
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.
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).

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

A maximum focal plane composed of NIR only detectors
### Star Counts

<table>
<thead>
<tr>
<th><strong>Average</strong></th>
<th>25 000 stars deg$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical</strong></td>
<td>150 000 stars deg$^{-2}$</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>600 000 stars deg$^{-2}$</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>3 000 000 stars deg$^{-2}$</td>
</tr>
</tbody>
</table>

Gaia star count requirements

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

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?