GaiaNIR
ESA-led NIR all-sky astrometry mission

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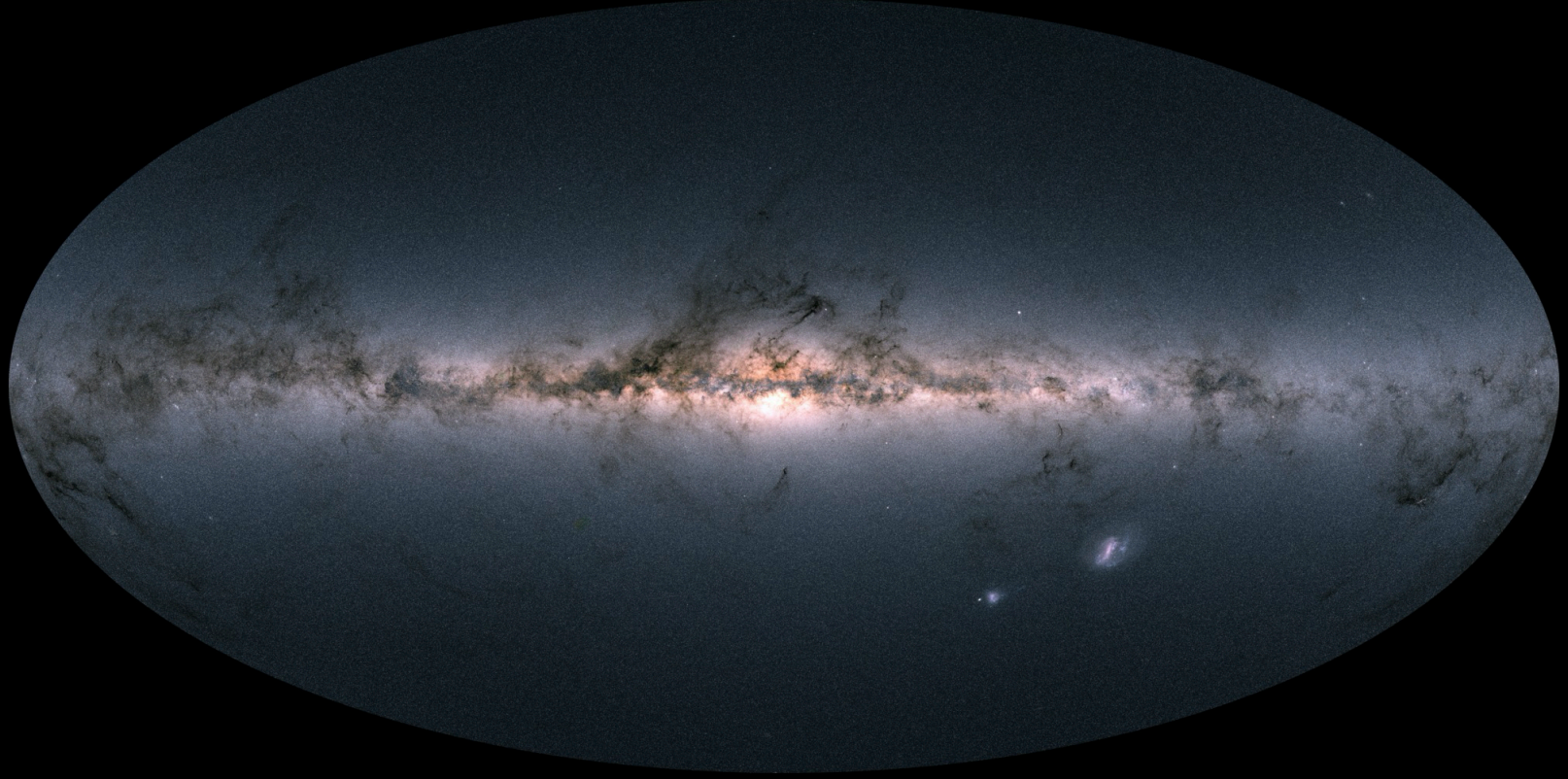
ESA Gaia mission (2013-2022)
Optical All-Sky Astrometry mission



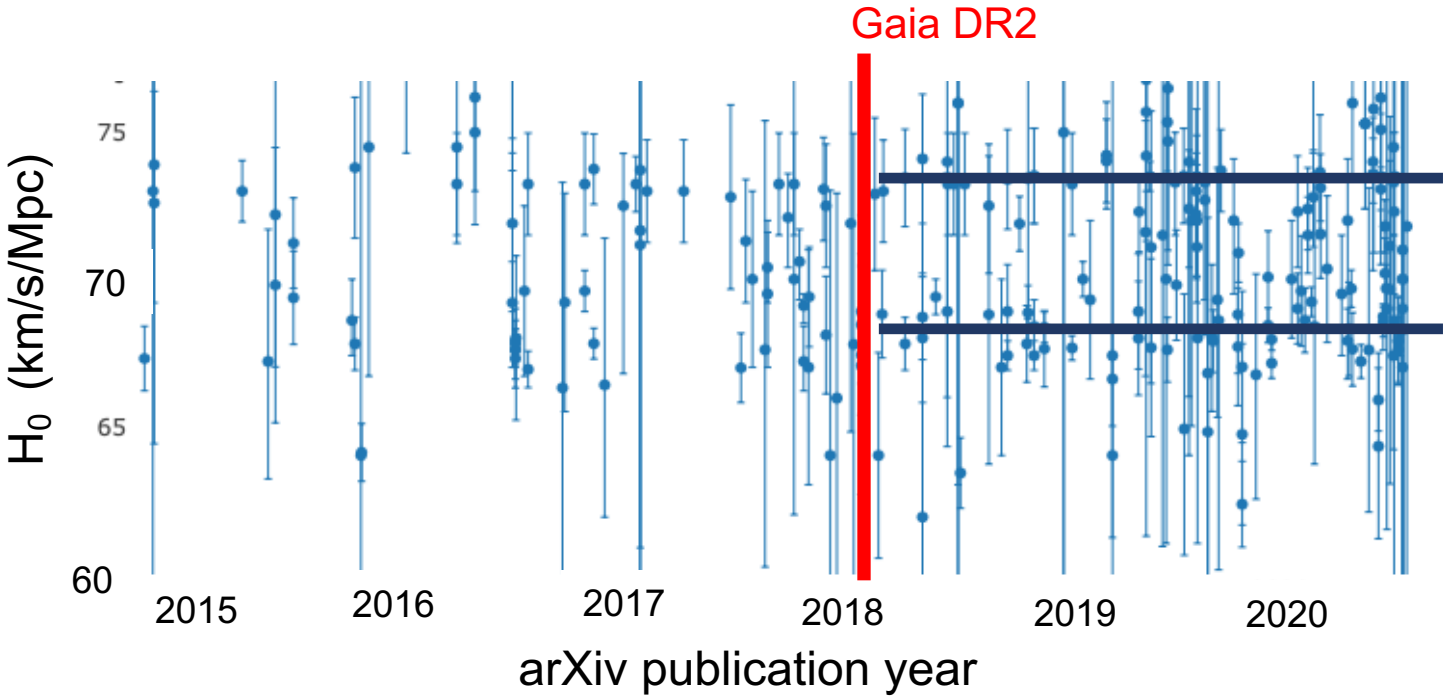
Gaia DR2 (April 2018, preliminary data), >~3,500 citations
already made huge impacts on from solar system, exoplanet to Galaxy, Cosmology!

Gaia-Enceladus: relic of the last significant merger of our Galaxy at ~10 Gyr ago

Helmi et al. (2018, Nature)
See also
Belokurov et al. (2018) for a DR1 feature known as Gaia Sausage

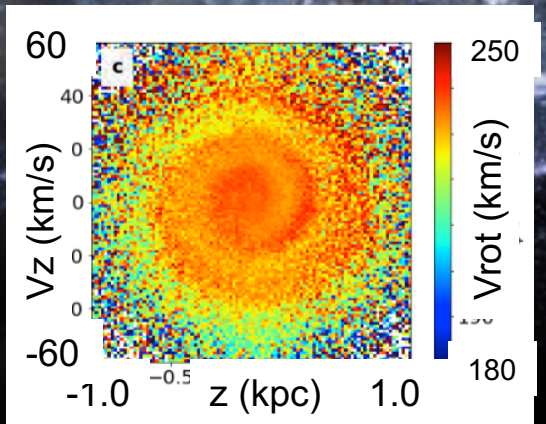
Credit: ESA, NASA, Koppelman, Villalobos and Helmi,

The Hubble Constant Tension:
Planck CMB : $H_0 = 67.4 \pm 0.5$ km/s/Mpc
Gaia calibrated Cepheids : $H_0 = 73.5 \pm 1.4$ km/s/Mpc (SH0ES project)
4.2 σ tension! (Riess 2019, Nature review)



Machine-Learning assisted meta-analysis http://numericalatlas.cs.ucl.ac.uk (Crossland+Kawata et al.)

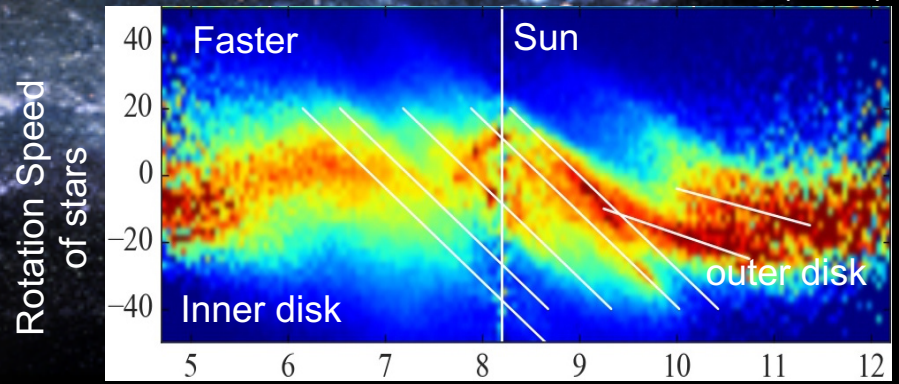
Gaia DR2 revealed the ripples in the Milky Way disk!



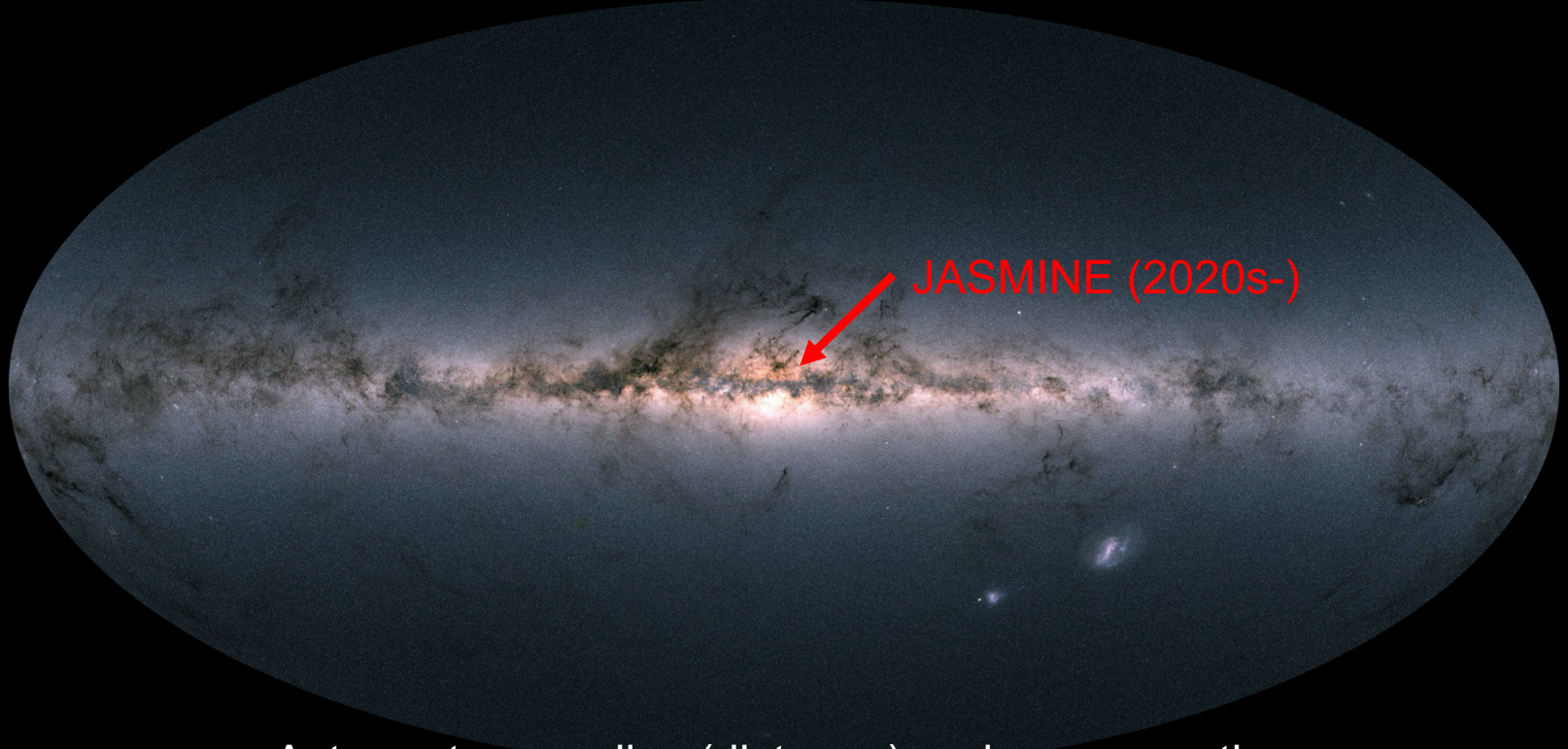
Phase spiral

Antoja et al. (2018, Nature)

Kawata et al. (2018)



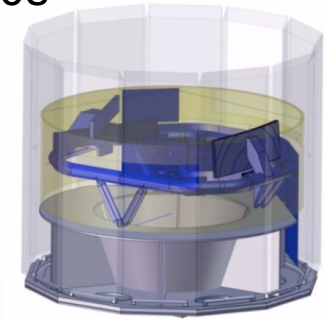
ESA Gaia mission (2013-2022)
Revolutionising Astronomy!

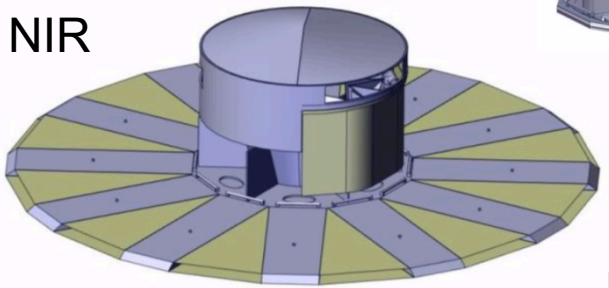


Astrometry, parallax (distance) and proper motion
providing new dimensions of information
… but in the Gaia data, many disk and bulge stars are hidden in the dust.

GaiaNIR (~Ultimate JASMINE): All-sky NIR astrometry in 2040s

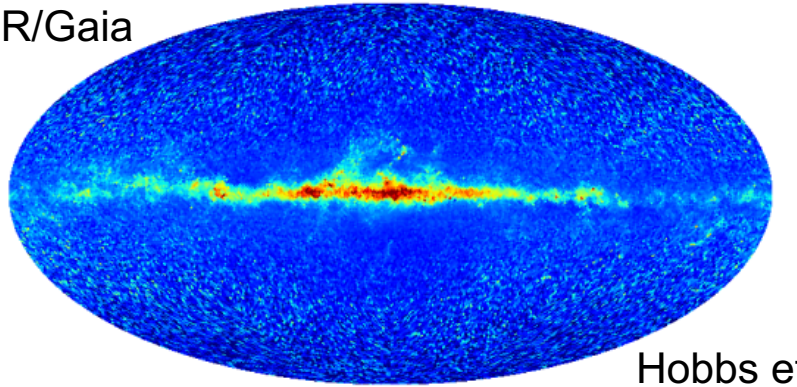
- NIR (λ=0.8-1.8 μm, G_{NIR}< 20 mag)
- 14 times better proper motion, ~1.8 μas/yr
- Update Gaia Celestial Reference Frame in NIR



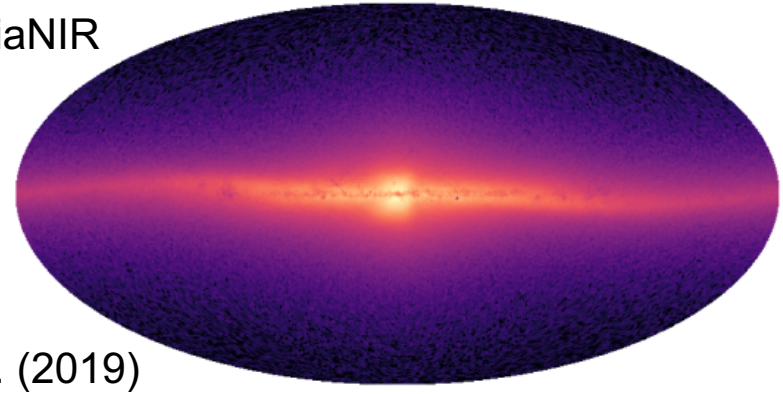


ESA CDF report (2017)

GaiaNIR/Gaia



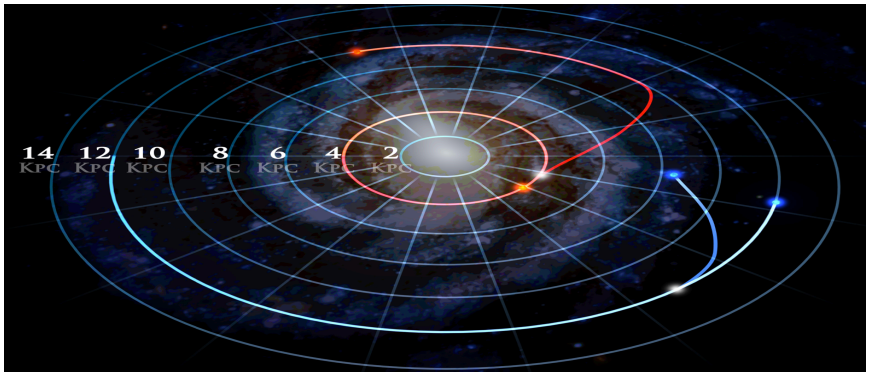
GaiaNIR



Hobbs et al. (2019)

NIR (λ=0.8-1.8 μm, G_{NIR}< 20 mag)
Gaia-level astrometry (~10 μas, derr~10%, Verr~1 km/s at the Galactic centre)
⇒ 5x more stars (~8B stars) than Gaia, seeing through the dust!

- Galactoseismology … origin of the bar and spiral arms, dark and baryon matter distribution
- Radial migration … Where are we from? The Sun's past orbit.

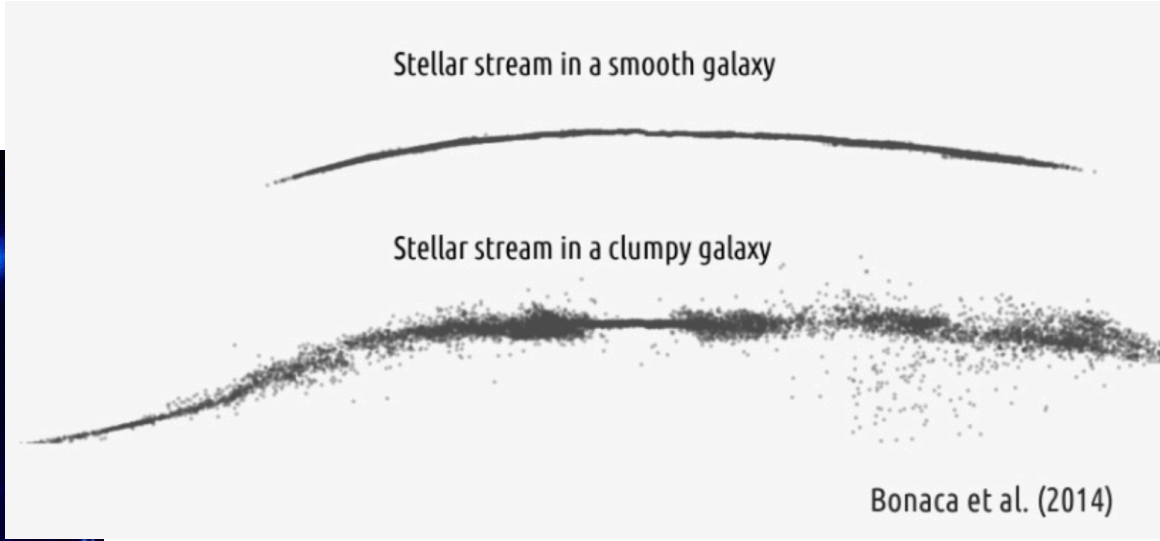


Credit: SDSS

- Plus more … star forming regions, the distance to the gravitational wave sources, stellar mass BHs and IMBH (via binary, astrometric microlensing), primordial BHs as DM, Mira variable distance calibration for cosmology, exoplanet in dusty young stars

~20 yrs time separation since Gaia and JASMINE
⇒ 14 times better proper motion ~1.8 μas/yr ~ 10 km/s at 1 Mpc!

- Proper motion and internal stellar motion of Local Group galaxies, incl. LMC, SMC, M31, M33, dwarf galaxies.
- Gaps in stellar streams, wide binary populations
  ⇒ distribution of sub-DM halos, nature of DM

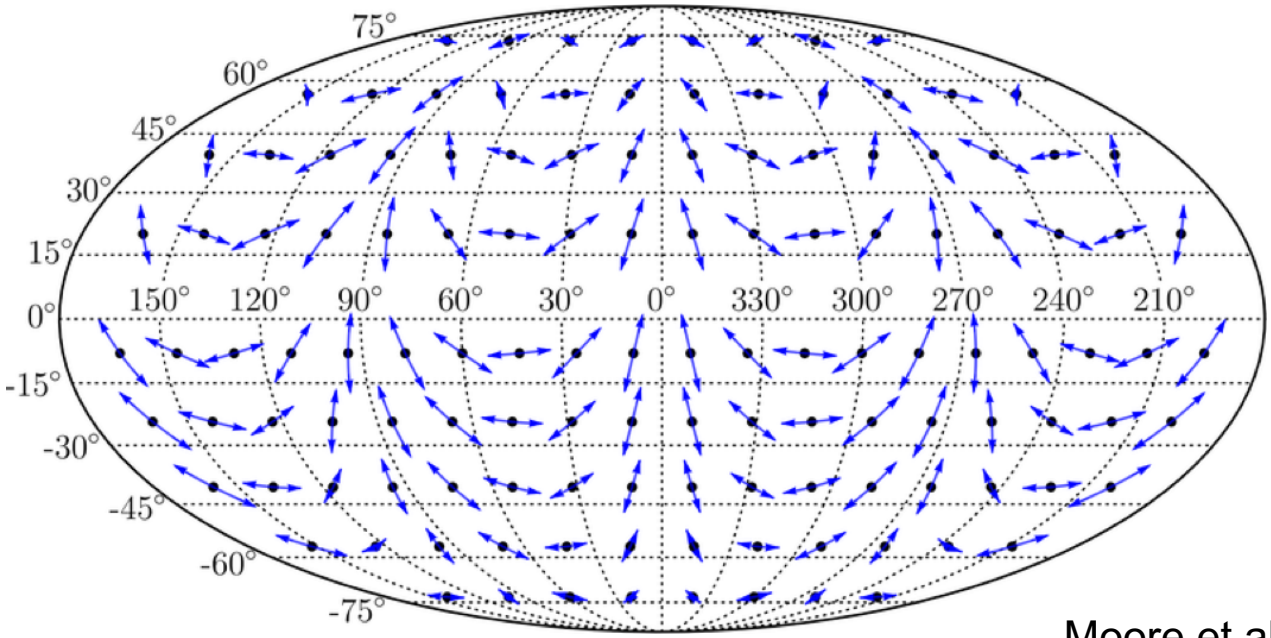


Improved proper motion

- Long period exo-planet
- Solar system:
  - acceleration of asteroids in the main asteroid belt,
  - the origin of Near Earth Objects.

NIR Celestial Reference Frame (CRF) in 2040s, when Gaia CRF degraded

- Reference frame for future (NIR) observation
- Astrometric gravitational waves (~nHz)



Moore et al. (2017)

2030 年代将来計画検討 White Paper 評価 総評

欧州 GAIA 衛星、小型 JASMINE の延長線上にあり、国際プロジェクトパートナーとして日本の貢献が期待されます。日本のコミュニティーも小型 JASMINE のメンバーをはじめ、大きく育ちつつあるのはとても高く評価できます。また、赤外領域での観測により、GAIA衛星では見えかったハローを含む銀河系構造、銀河中心、ブラックホール、ローカルグループ等のサイエンスだけでなく、太陽系や系外惑星のサイエンスも大いに期待できます。下記に示す評価者の方々に共通して、日本独自の貢献は何か、日本が主体となって開発する技術は何かについてより具体的な記述が求められています。また実現可能性についても懸念が示されています。さらなる検討を期待します。

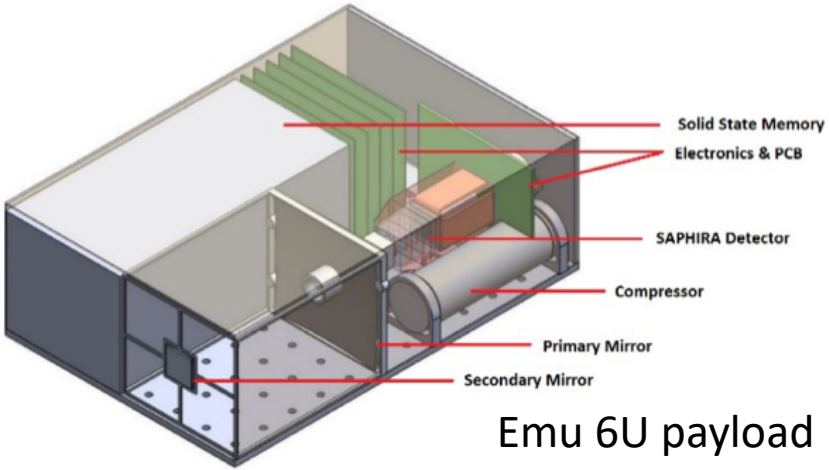
GAIA と GaiaNIR に関しては、長期のベースラインによる Synergy について記述されて います が、小型 JASMINE との Science Synergy についてもより具体的な例があるとわかりやすいと思われます。より遠方に、より精密に観測するという目標はすべてのミッションに共通する課題であり、競合するプロジェクトにも書かれています。本提案では総花的で　評価者の指摘にもあるように期待されるサイエンスの定量的な議論の記述がありませんで した。GAIA-JASMINE-GaiaNIRではじめて可能となるキーサイエンスについて、焦点を絞って具体例をいくつか挙げ、その実現のために日本がどのような役割を果たしていくかが書かれているとより説得力のあるプロジェクトに成長していくと思います。2040 年代を 目指すプロジェクトということで、小型 JASMINE の成功を含め、今後の発展に期待しま す。

日本独自の貢献は何か、日本が主体となって開発する技術は何か？

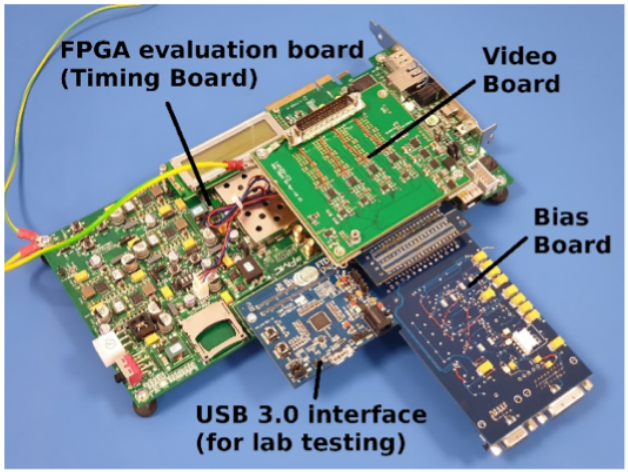
- Science contribution
  - Japanese on-going legacy in Astrometry, e.g. VERA, JASMINE
  - (N)IR astronomy: Subaru, PRIME, TAO, SPICA, TMT
  - Gravitational Wave: KAGRA, LiteBIRD
- Potential technical contribution from Japan
  - Launcher
  - Super-Super Invar (low expansion allow, data from JASMINE)
  - Data analysis heritage from JASMINE NIR astrometry experience
  - Subaru PFS spec (pre-mission) follow up, or on-board spectrograph?
- Ongoing tight connection with the ESA Gaia/GaiaNIR community
  - Member of Gaia DPAC (Gouda, Yamada)
  - Contributing to Voyage 2050 proposal as co-authors (Kawata (5^{th} author), Gouda), which was limited to 30.

実現可能性、特に NIR TDI detector

- To use the same survey/calibration strategy with Gaia, GaiaNIR requires NIR detector with TDI to scan the all-sky. However, there is no such detector.
- Current most promising candidate … Leonardo, SAPHIRA LmAPD array “Linear-mode avalanche photodiode (LmAPD) arrays for low-noise near-infrared imaging **in space**” Gilbert et al. (arXiv:1911.04684)
- Australian (ANU) Emu mission (ISS in 2021), NIR TDI imaging ⇒ increase TRL
- Currently 1k x 1k, a larger format array development is supported by ESA



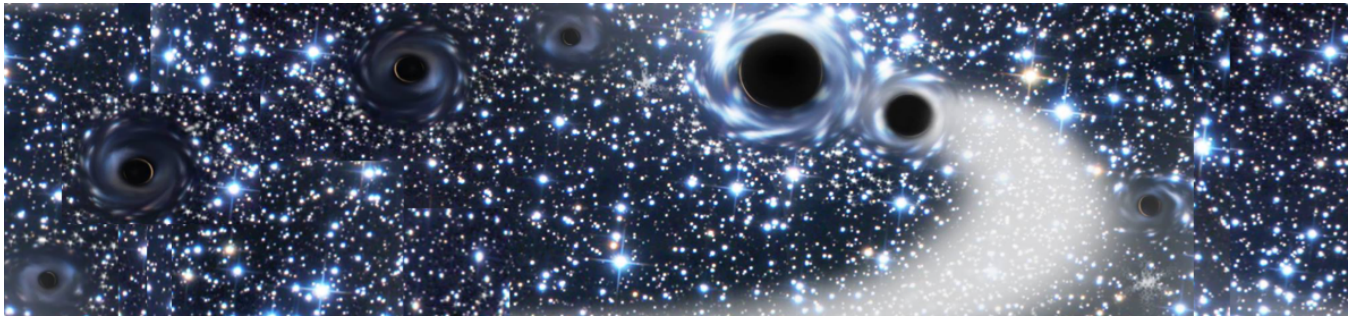
Emu 6U payload



Prototype of Emu detector readout electronics.

サイエンスの定量的な議論、Gaia-JASMINE-GaiaNIRキーサイエンス

- New NIR astrometry will provide Gaia-level astrometry (~10 μas) for 5x more stars (~8B stars) than Gaia. More disk stars hidden in the dust.
  ⇒ kinematics of stars around the spirals and the bar, radial migration
  Verr<1 km/s … enough to detect the expected motion of ~10 km/s level.
- ~20 yrs time separation since Gaia and JASMINE will enable 14 times better proper motion, i.e. ~1.8 μas/yr ~ 10 km/s at 1 Mpc, and also allow to measure **acceleration** of solar system objects and potentially some stars.
- JASMINE-GaiaNIR … ~ 20 yrs time separation for the stars in the Galactic centre direction. ⇒ long-period BH-star non-interacting binary, **massive BHs in the Galactic centre?**
- **Serendipitous discovery factor is ∞.**



Credit:
M. Sedda