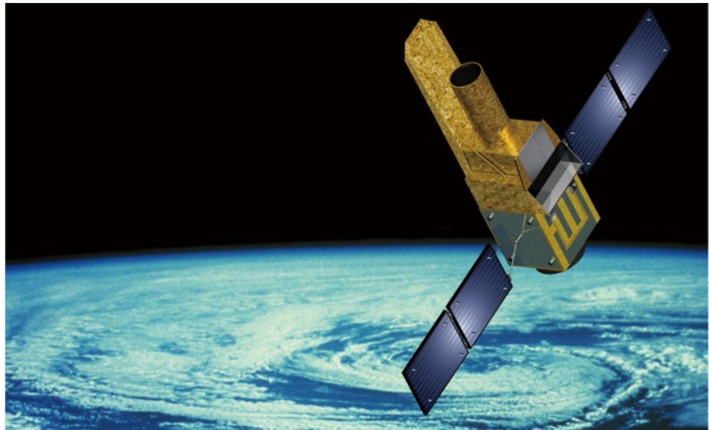
Mullard Space Science Laboratory

The JASMINE mission

(Japan Astrometry Satellite Mission for INfrared Exploration)

Daisuke Kawata (JASMINE Project Scientist,
Mullard Space Science Laboratory, University College London)
Hajime Kawahara (JASMINE Exoplanet Science lead, ISAS/JAXA)
Naoteru Gouda (JASMINE Principal Investigator, NAOJ)
and
JASMINE team



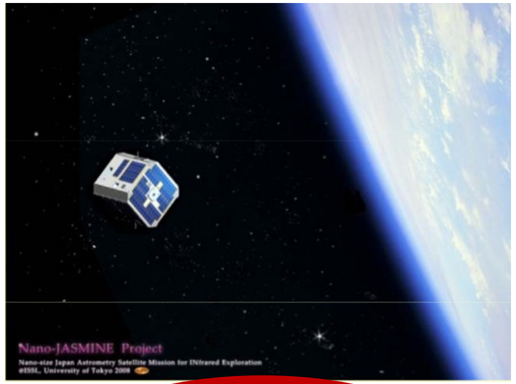
国立天文台 NAOJ National Astronomical Observatory of Japan

ISAS JAXA

In Japan, NIR astrometry mission planning started around 2000.

Challenge: NIR detector cannot scan the sky unlike CCD used by Gaia

Gouda et al. (2009)

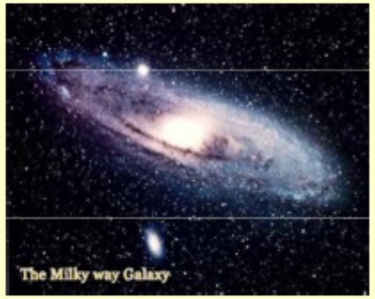


Hop: Nano-JASMINE launch date: July 2010

very small nano-satellite: 25kg, 50^3cm^3

the diameter of a primary mirror: 5cm

the first space astrometry in Japan



Step: Small-JASMINE target launch date : ~2015

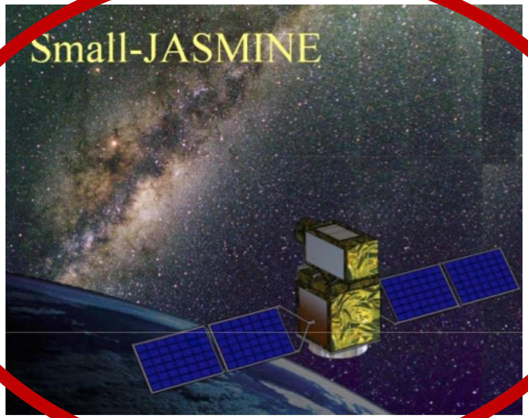
step -by-step approach to JASMINE for both science and techniques

the diameter of a primary mirror: 30cm

weight of a satellite: ~400kg

survey toward the restriced regions of the Galactic bulge

→ **JASMINE**



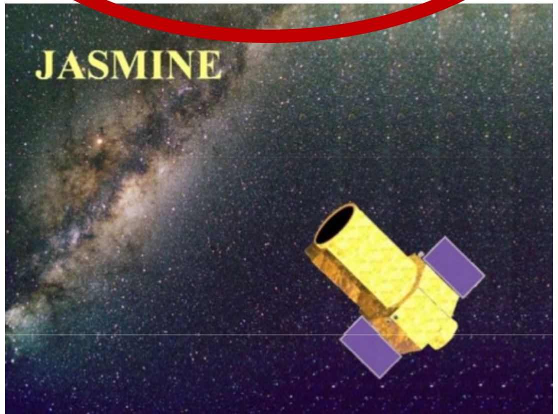
Jump: JASMINE target launch date: the first half of 2020's

the diameter of a primary mirror: 80cm

weight of a satellite: ~1500kg

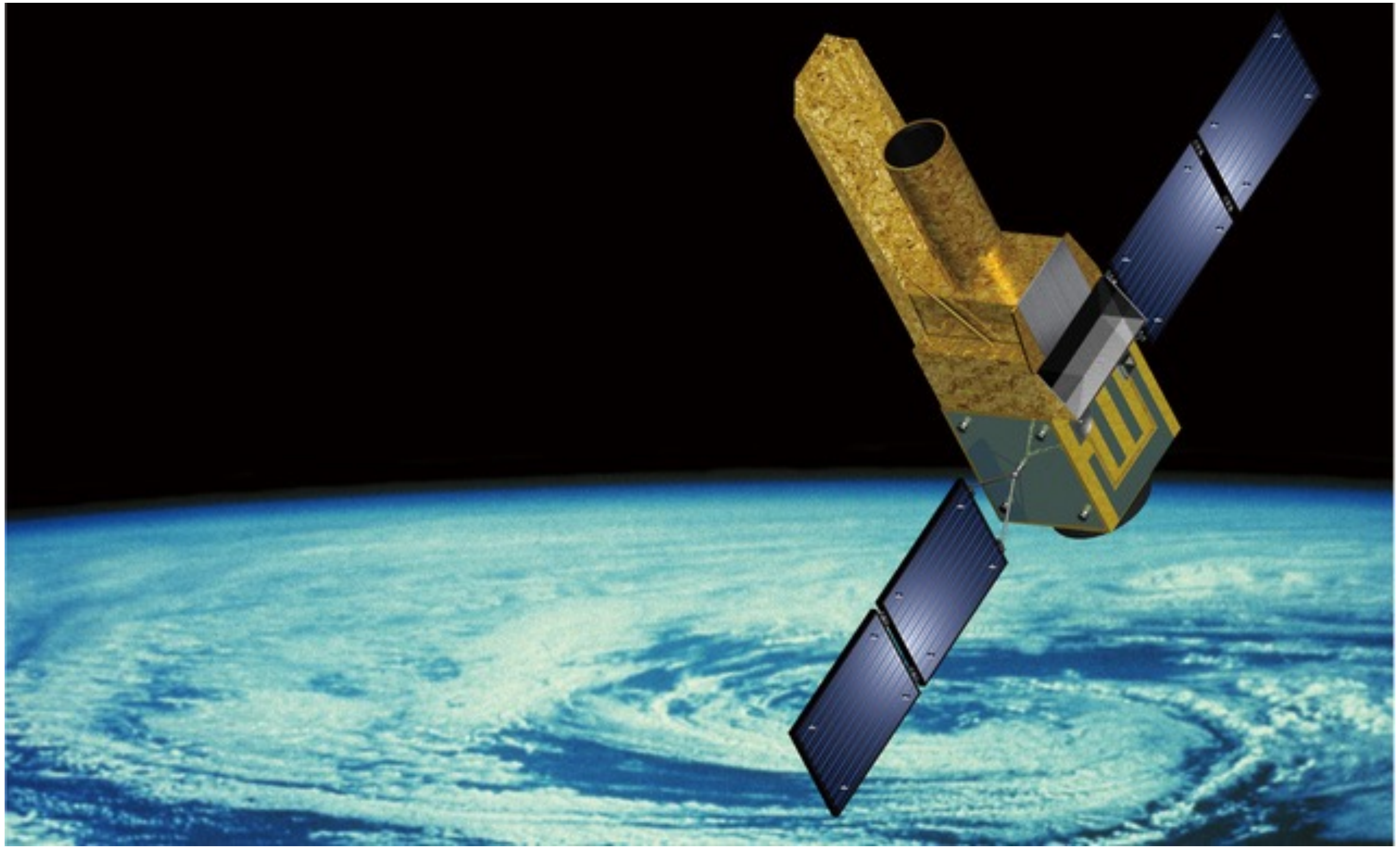
survey toward the whole region of the Galactic bulge

<< **GaiaNIR**



JASMINE (Japan Astrometry Satellite Mission for INfrared Exploration)
selected for JAXA Science Mission M-Class #3 (planned launch in 2028)
NIR astrometry and time-series NIR photometry

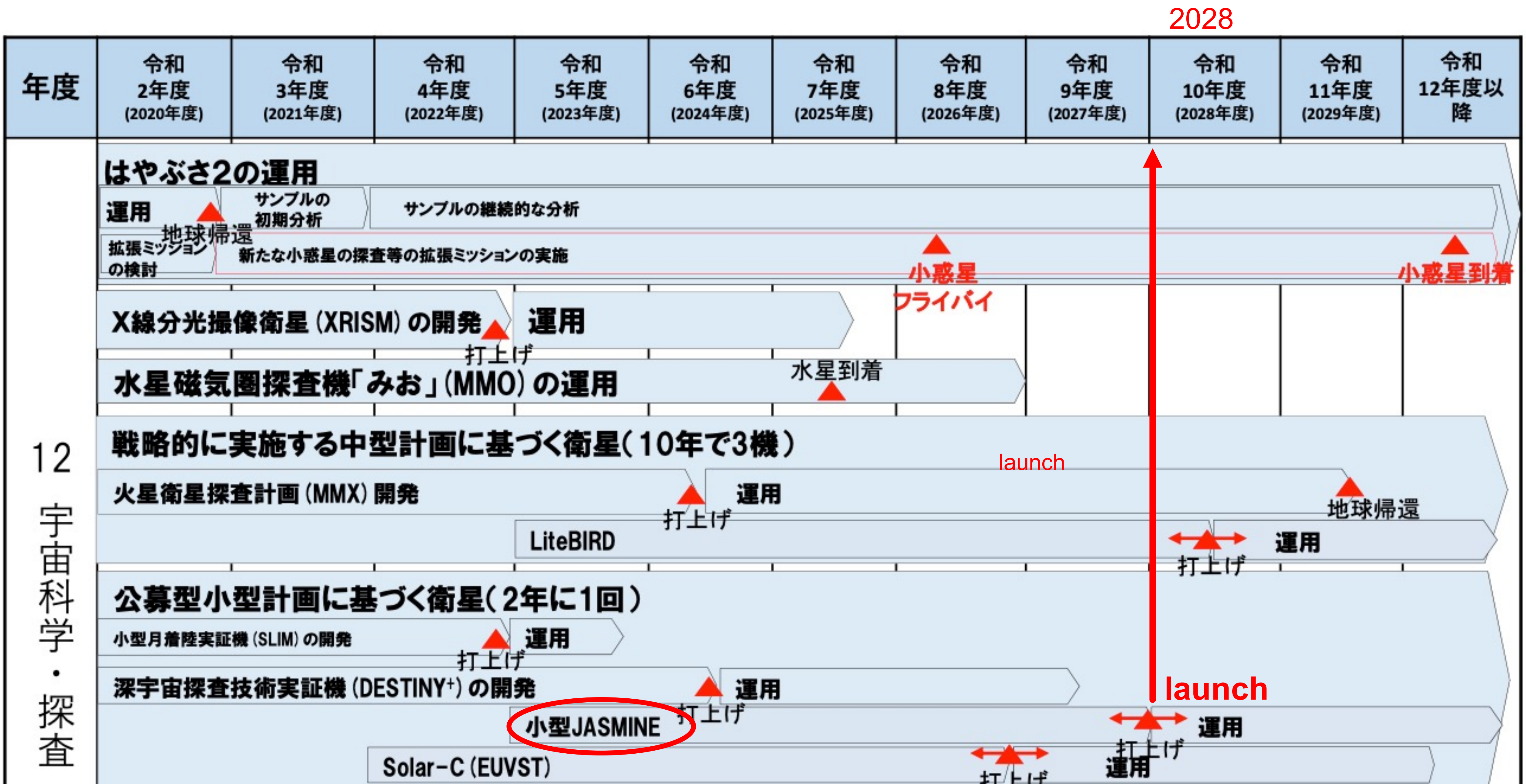
M-mission with Epsilon launcher
every 2 years



36 cm diameter, limiting magnitude: Hw(1.0-1.6 μm)=9-14.5 mag

$$Hw \sim 0.941J+0.059H-0.045(J-H)^2$$

Japan space science programme roadmap (28 Dec. 2021, Cabinet Office website)



Japanese Consortium and International collaboration

ISAS
空へ挑み、宇宙を拓く JAXA 宇宙航空研究開発機構
国立天文台 NAOJ National Astronomical Observatory of Japan
KYOTO UNIVERSITY KYOTO JAPAN FOUNDED 1897
Astrobiology Center
TOHOKU UNIVERSITY 東北大学 TOHOKU UNIVERSITY
統数研
東京大学 THE UNIVERSITY OF TOKYO
むすんで、うみだす。 京都産業大学 KYOTO SANGYO UNIVERSITY
HIROSHIMA 広島大学

真の強さを学ぶ。 新潟大學 NIIGATA UNIVERSITY
お茶の水女子大学 Ochanomizu University
国立大学法人 東京海洋大学 Tokyo University of Marine Science and Technology
宮城教育大学
独立行政法人 国立高等専門学校機構 高知工業高等専門学校 National Institute of Technology, Kochi College
弘前大学 Hirosaki University

愛媛大学 EHIME UNIVERSITY
国立大学法人 鹿児島大学 KAGOSHIMA UNIVERSITY
GUNMA ASTRONOMICAL OBSERVATORY 県立ぐんま天文台
大阪大学 OSAKA UNIVERSITY

USNO
UCL
ZAH
DLR
LIBERTAS PERFUNDET OMNIA LVCE UNIVERSITAT DE BARCELONA
esa

JASMINE two main science goal

- Galactic Centre Archaeology
  - To reveal the Milky Way's central core structure and its formation history
  - To explore the formation history of the Milky Way structures, like the bar, which triggered the radial migration of the Sun

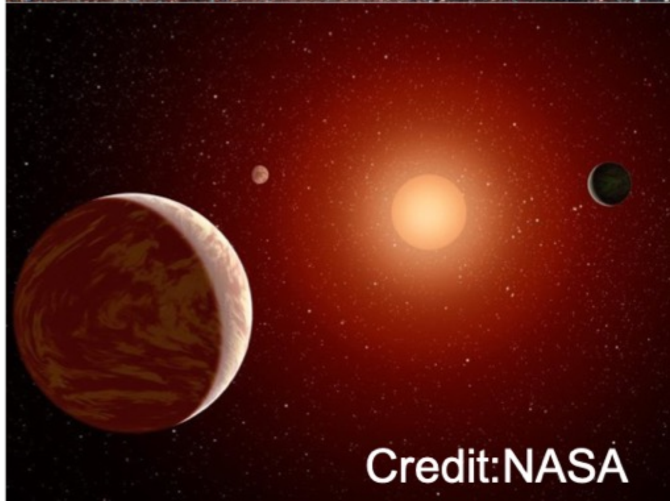
  ⟸ **NIR astrometry of the Galactic centre**

  Unexplored territory of the ESA Gaia mission, but NIR MOS (MOONS, SDSS-V, Subaru/PFS) will provide spec data in late 2020s!

- Exoplanets
  - To discover Earth-like habitable exoplanets

  ⟸ **NIR time-series photometry of M-dwarfs**

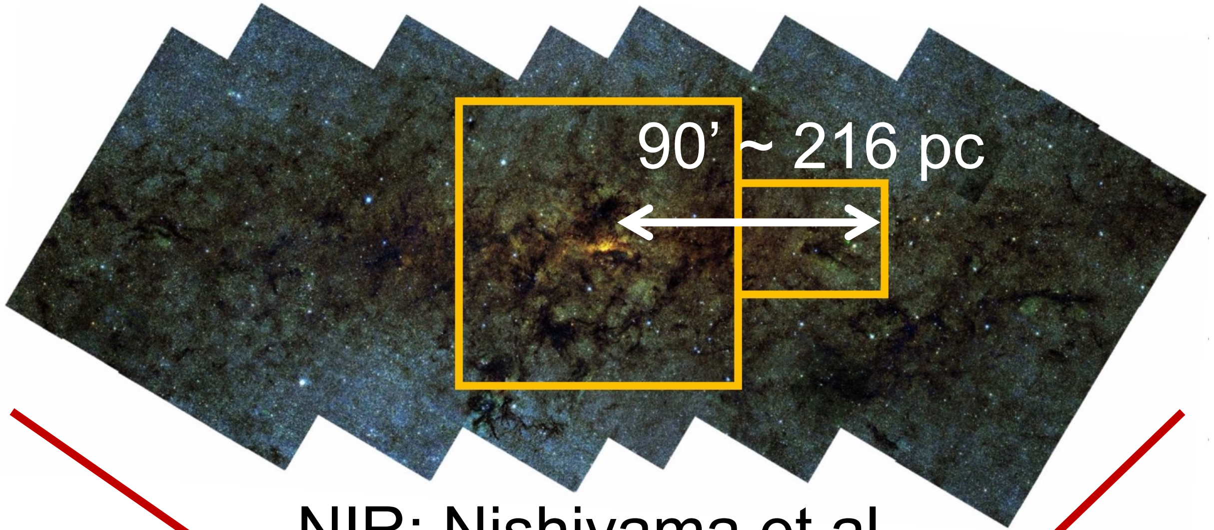
  Target for JWST, ARIEL spec follow-up!



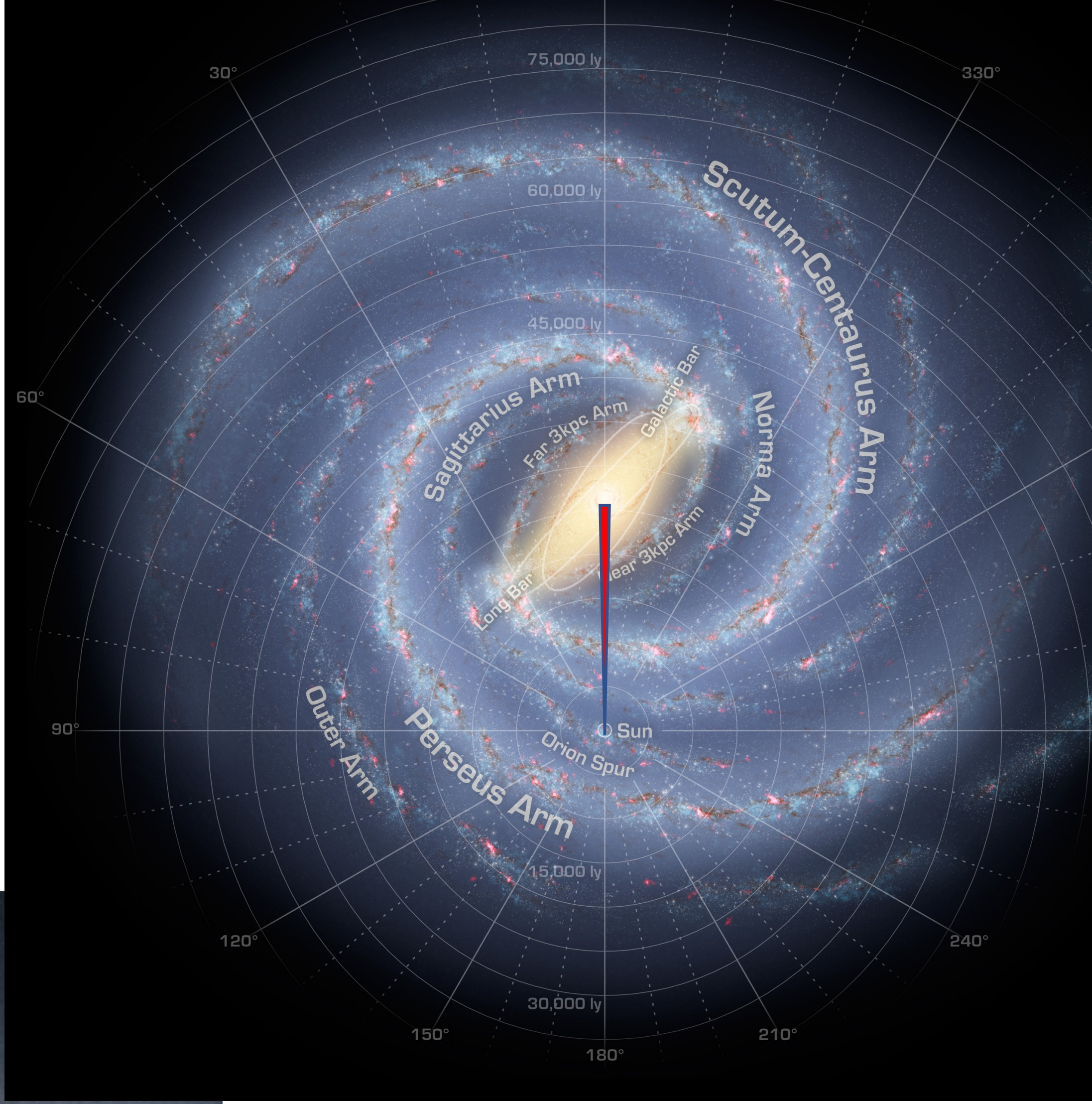
ISAS JAXA 国立天文台 NAOJ National Astronomical Observatory of Japan

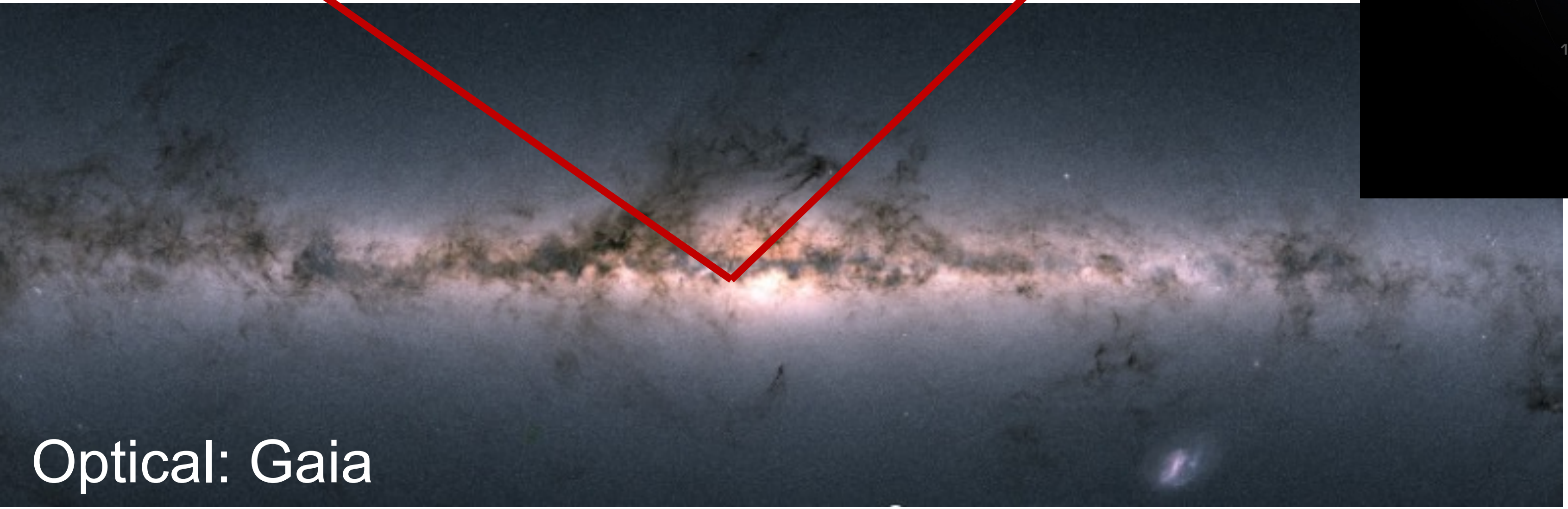
Galactic Centre Survey (Rgc~200 pc)

Near-IR : see through the dust in the disk



NIR: Nishiyama et al.

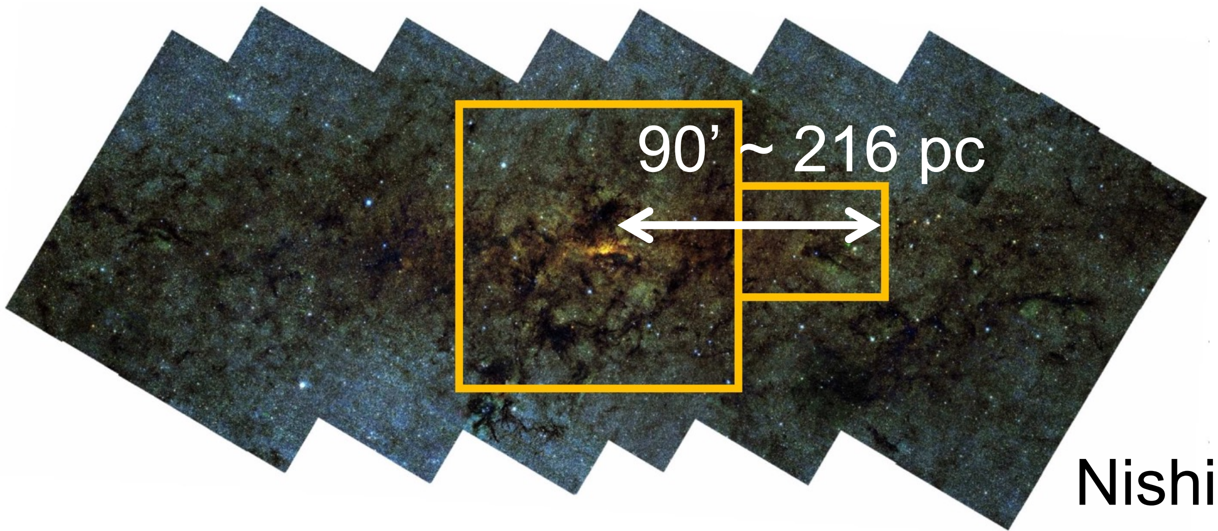


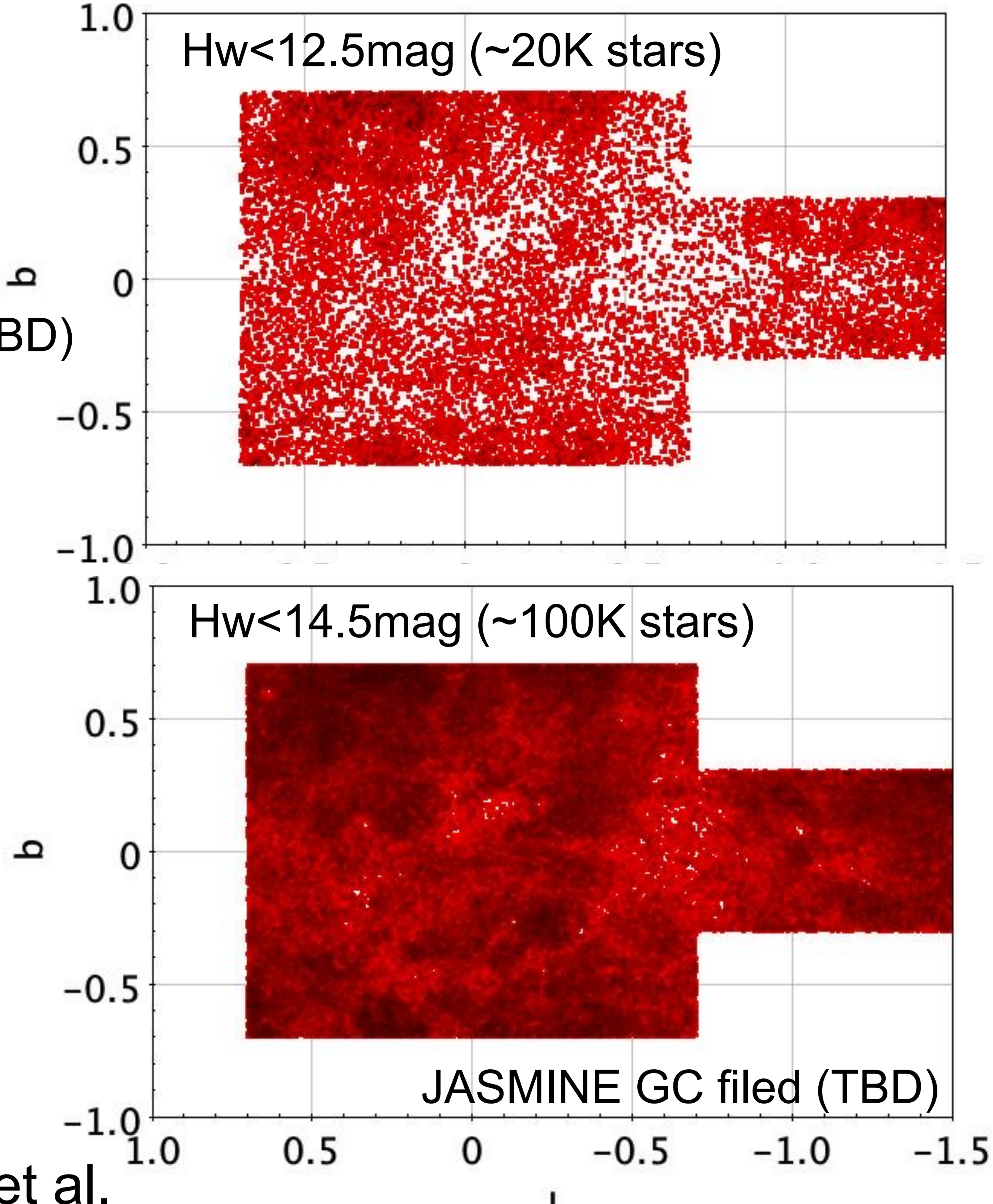


Optical: Gaia

Galactic Centre Survey (Rgc~200 pc)

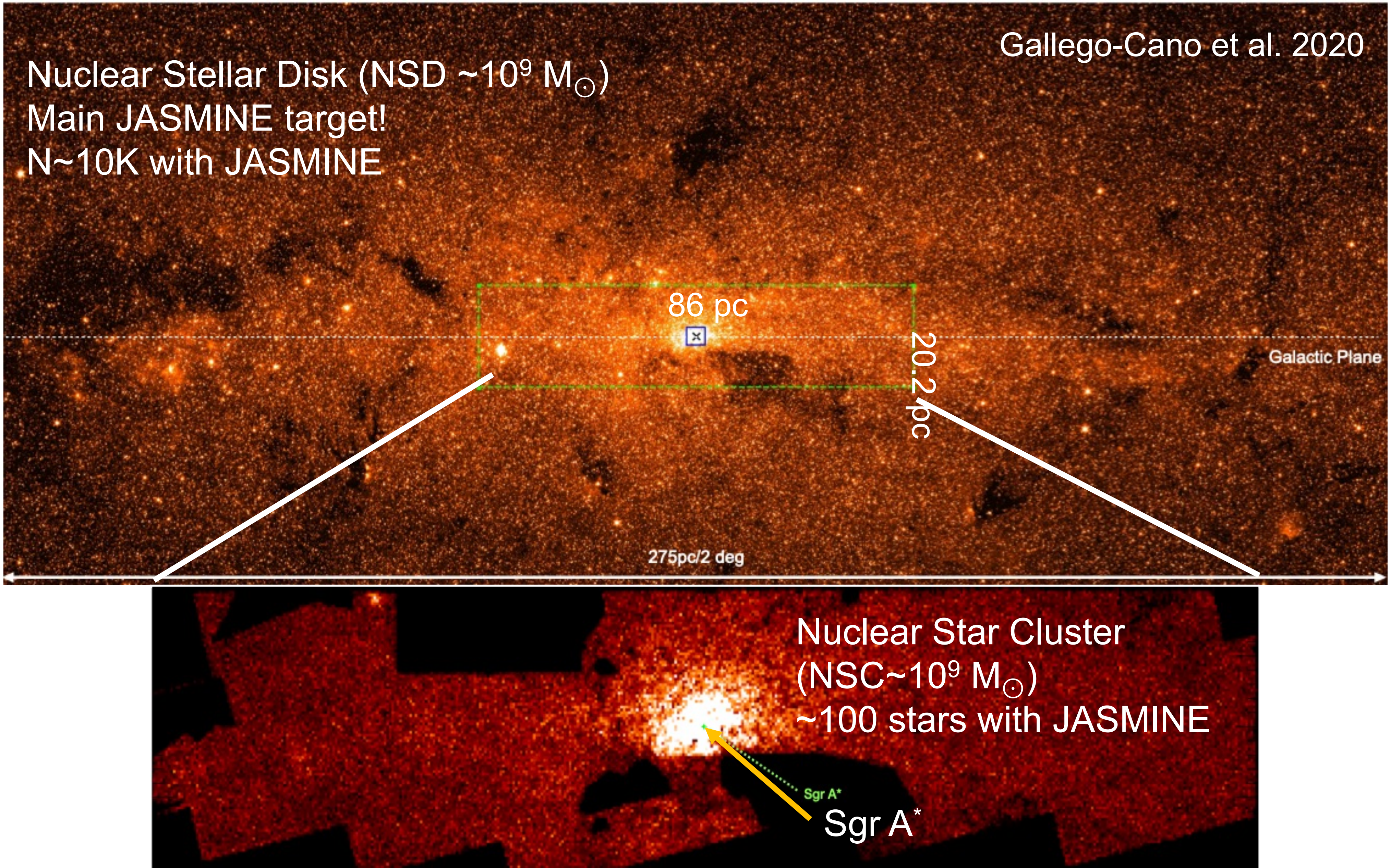
- Main astrometry survey (spring, fall)
- Precise NIR astrometry, with ~100K obs. in 3 years.
  Hw<12.5 (14.5) mag, 25 (125) μas
  (Verr< 5 km/s, N~10^5) ⇒ Galactic centre structure
- 12.5s exp. x 20 every ~100 min cadence photometry (TBD)
- Serendipitous sciences
  - (IM)BHs, microlensing, binary
  - Ultra light DM, soliton core
  - High velocity stars
  - X-ray and radio sources.
  - Solar system objects





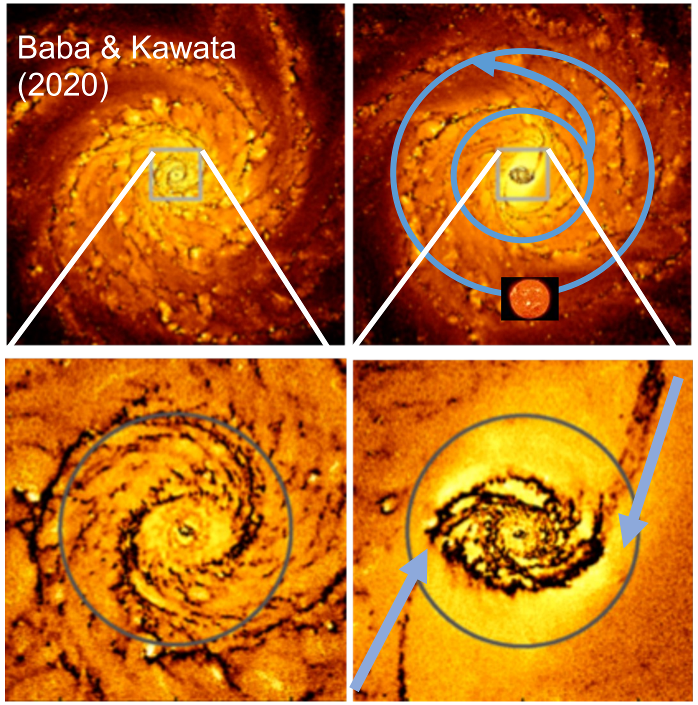
Nishiyama et al.

Galactic Centre Archaeology: Galactic Nucleus



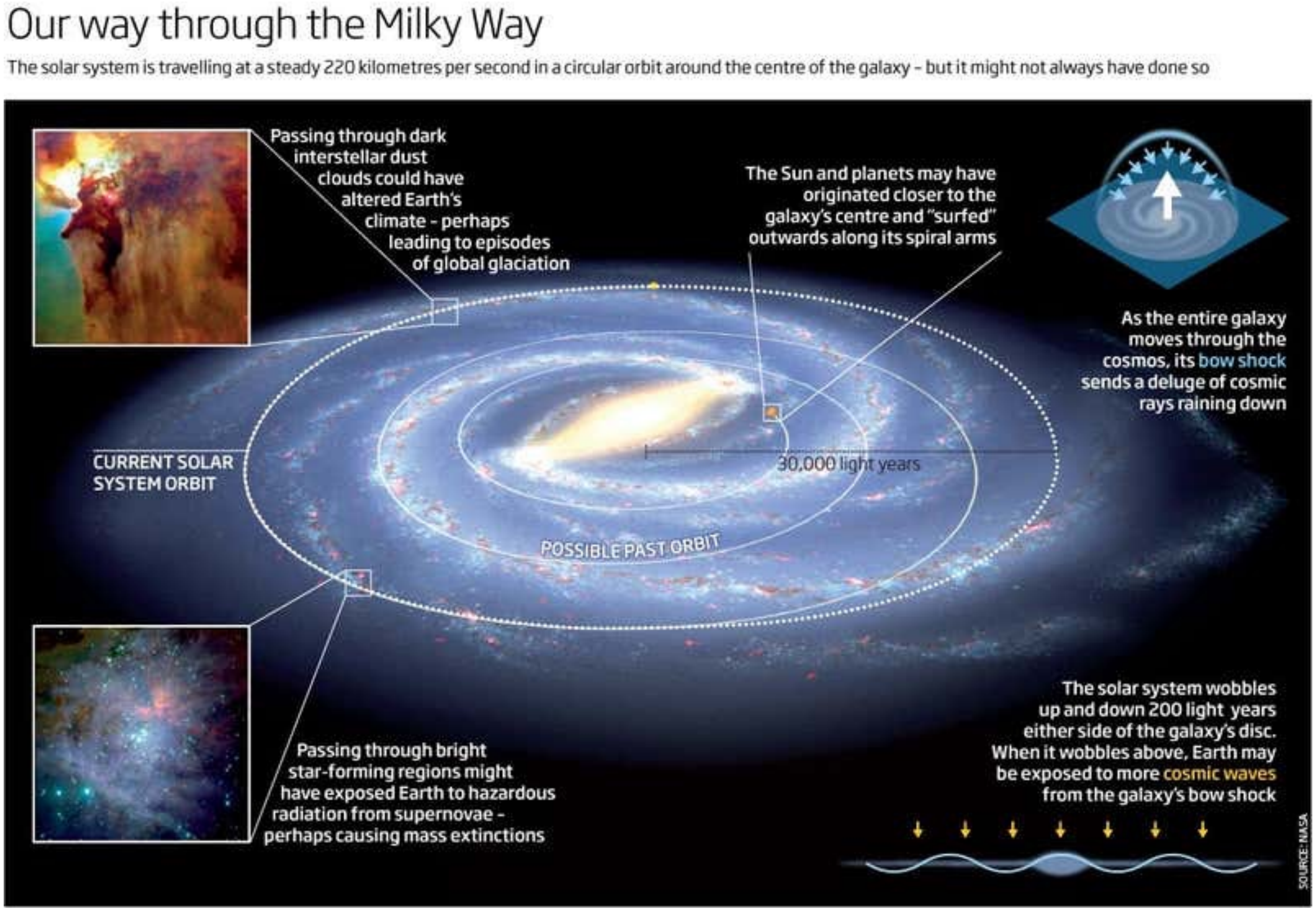
NSD will tell us the epoch of the Galactic bar formation

Hierarchical clustering at the early Universe



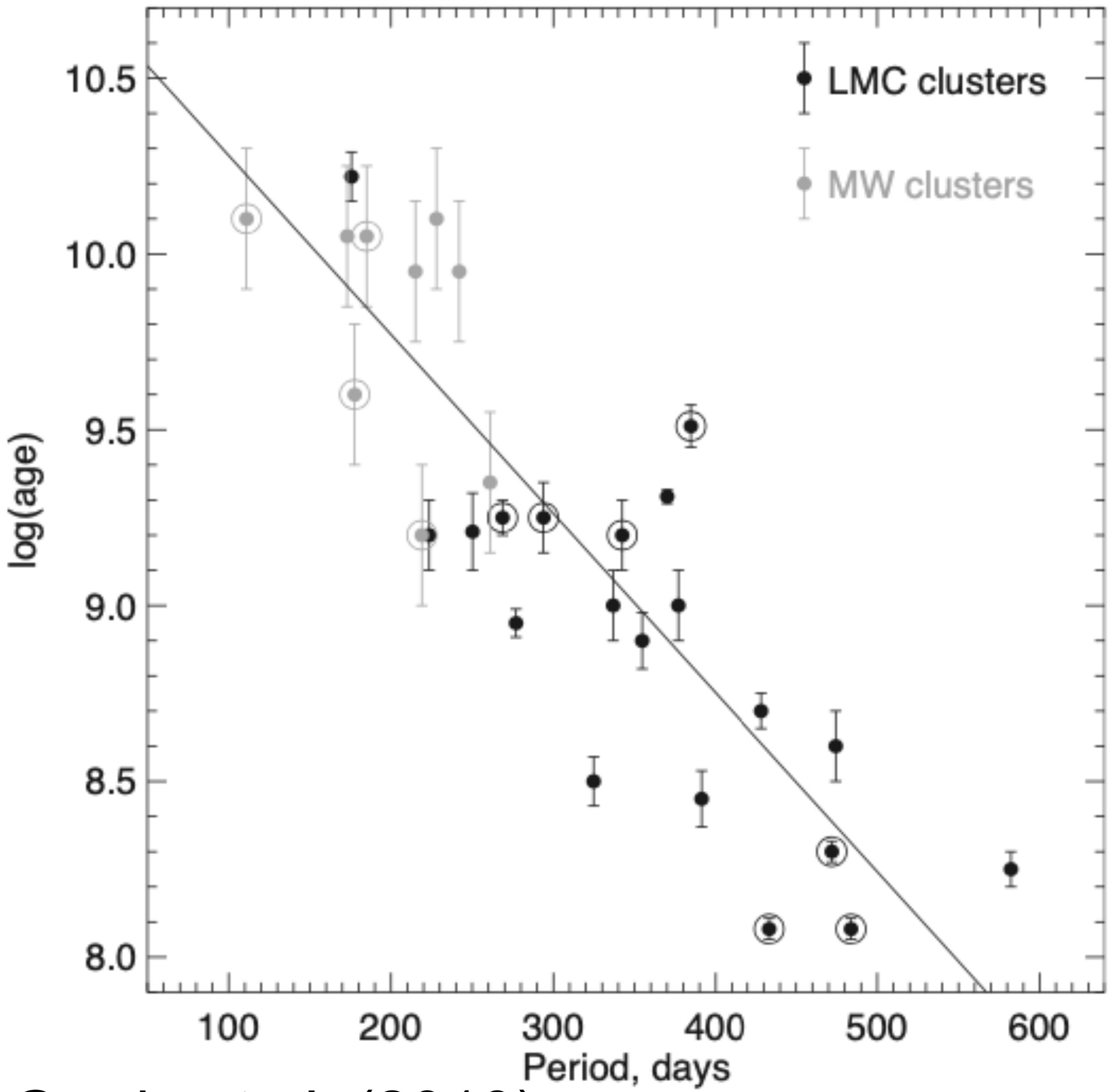
The burst of star formation in the cold nuclear disk (NSD)
= the formation epoch of the Galactic bar
Bar formation epoch ~ formation epoch of NSD
Impact to radial migration of the Sun?

Bar (strong impact on the orbits of stars) or the Sun, which one formed earlier?
key to study the past orbit of the Sun.

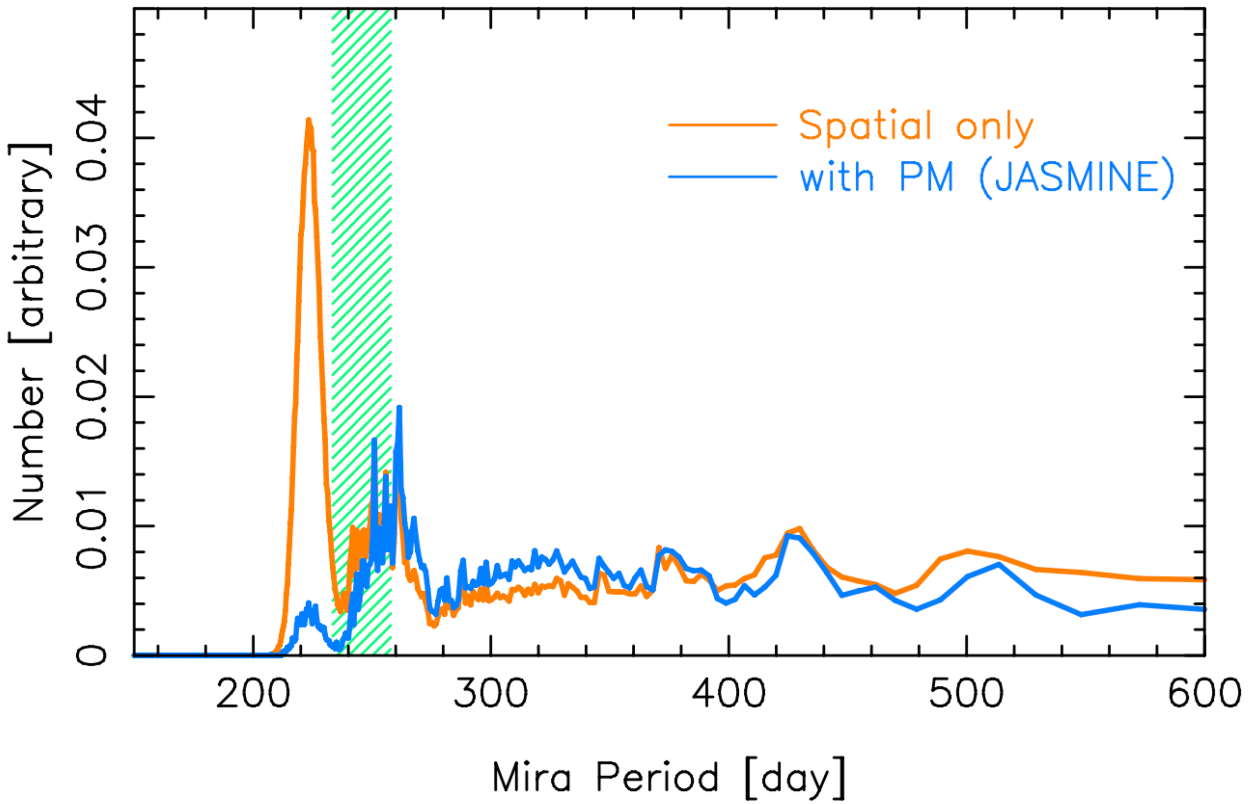


New Scientist

Age tracers: e.g. Mira variables



Grady et al. (2019)

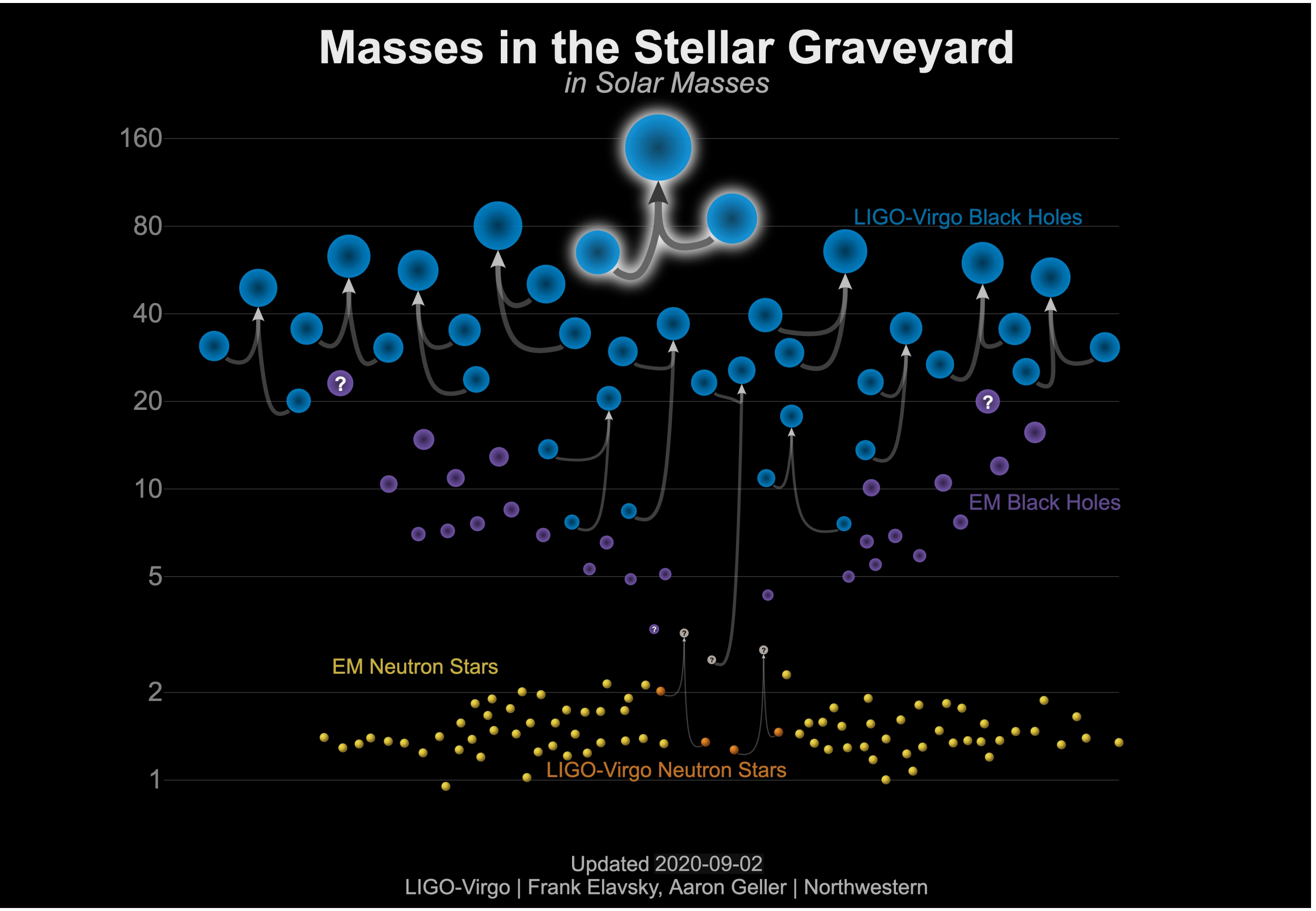


Proper motion from JASMINE will help to select NSD Miras (Baba & Kawata 2020).

Identifying Galactic Centre Miras with
PRIME (NIR bulge microlensing survey telescope
2022- led by Osaka U.)

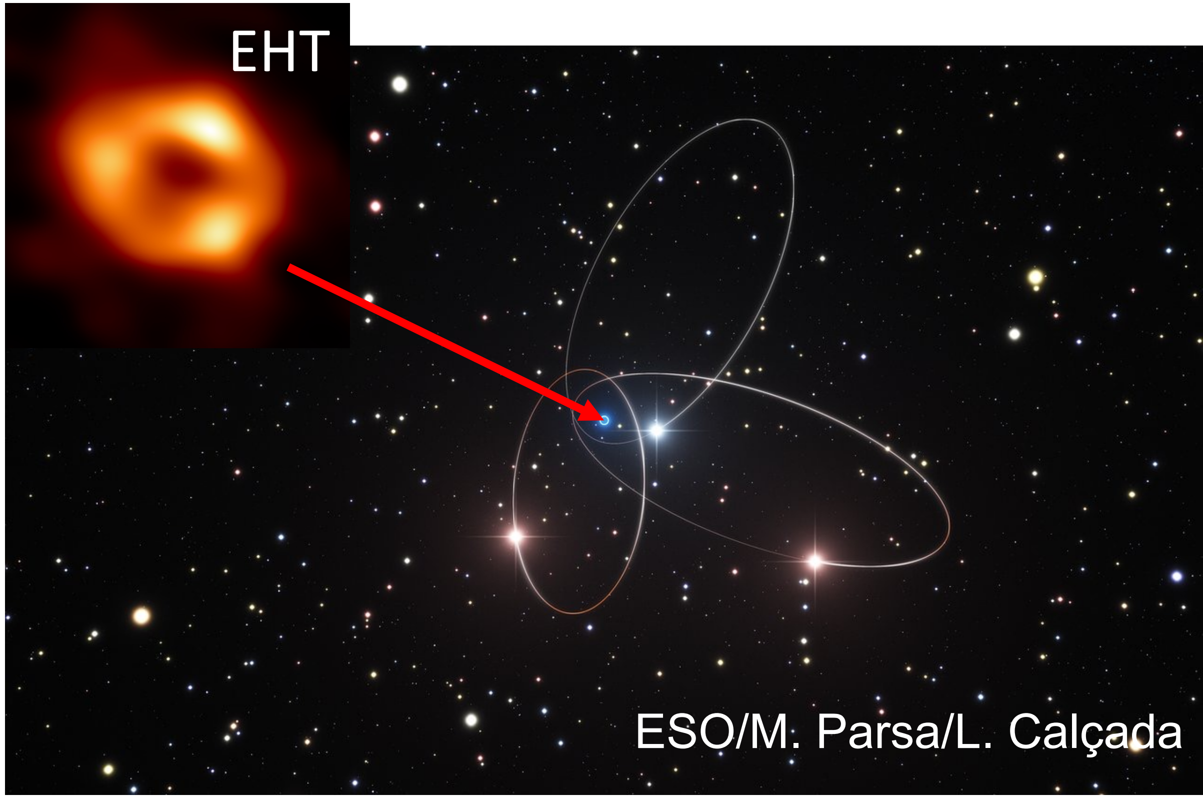
Missing Intermediate mass (100-10^5 $M_\odot$) Black Hole (IMBH)!

Stellar mass BH(<~100 $M_\odot$)



Gravitational Wave detection of BHs (2017 Nobel Prize)

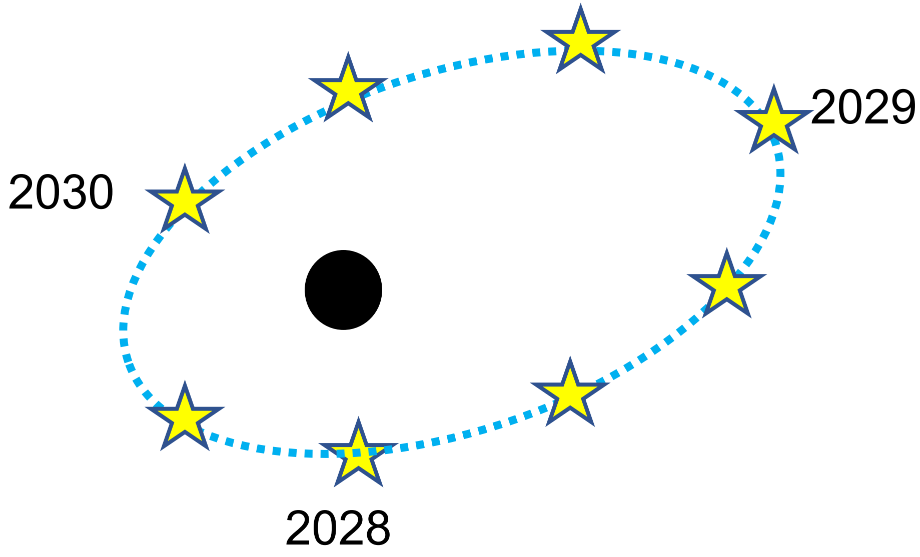
Super-massive BH (e.g. Galactic SMBH, 4×10^6 $M_\odot$)



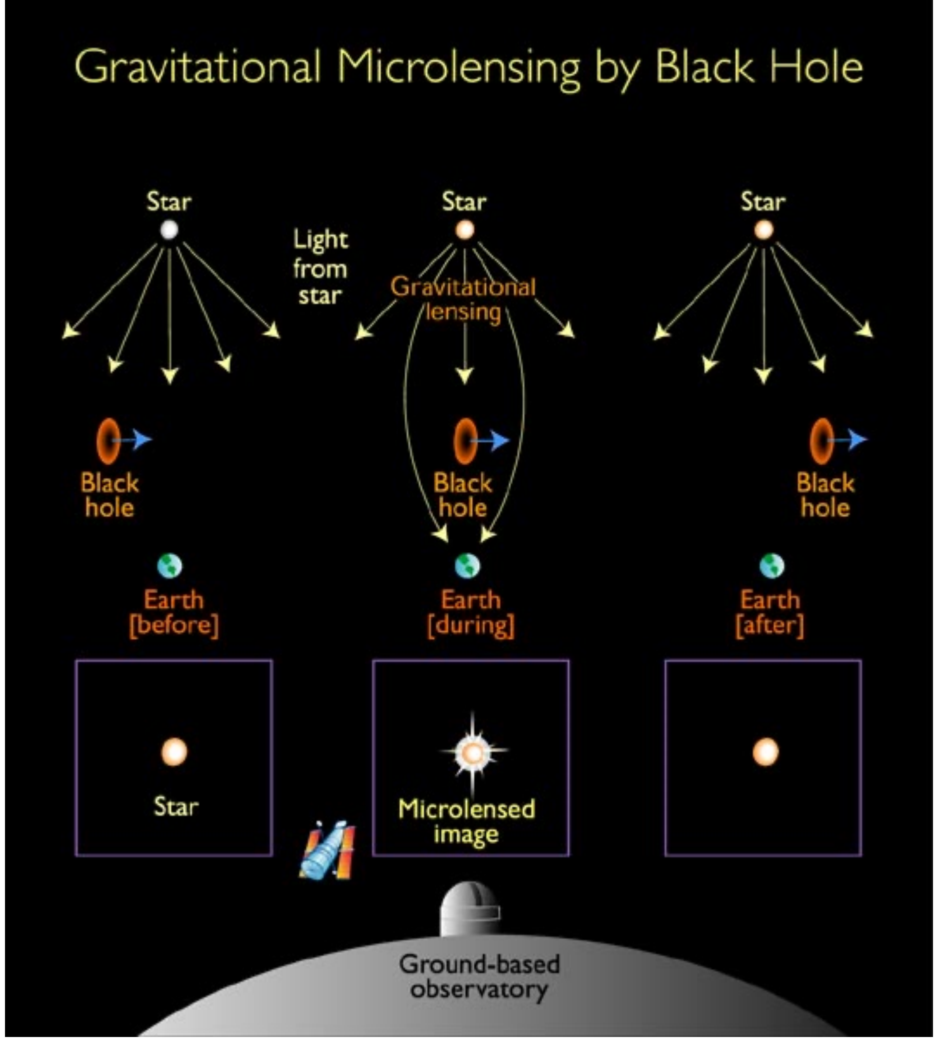
~20 years of motion of stars around the SMBH (2020 Nobel Prize)

Hunting (IM) Black Holes in the Galactic centre?

e.g. Runaway merger IMBH near SMBH
(e.g. Portegies Zwart et al. 2006)
Remnants of dwarf galaxy mergers



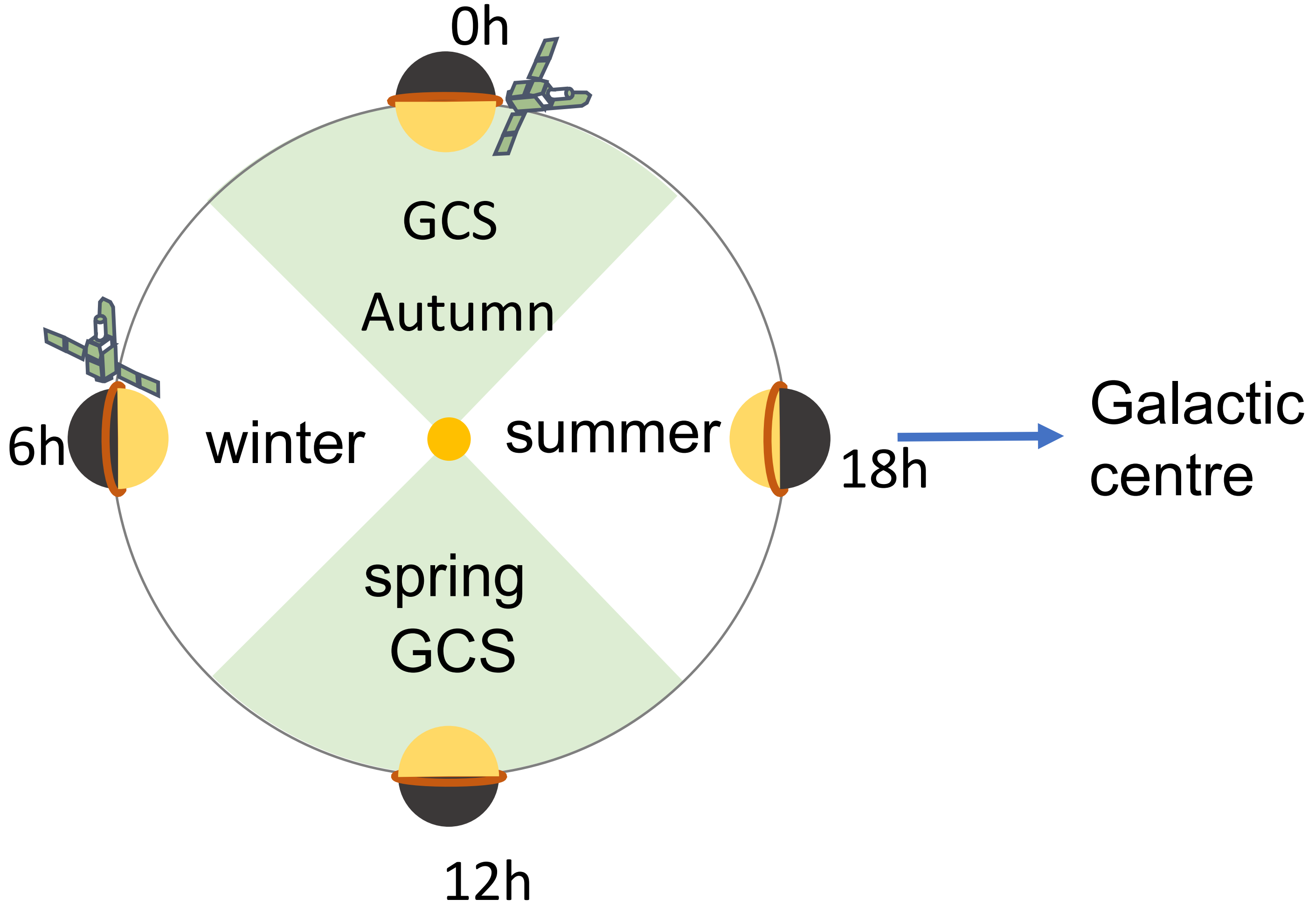
30 non-interacting BH-star binary expected from JASMINE Galactic Centre Survey (Yamaguchi et al. 2018).



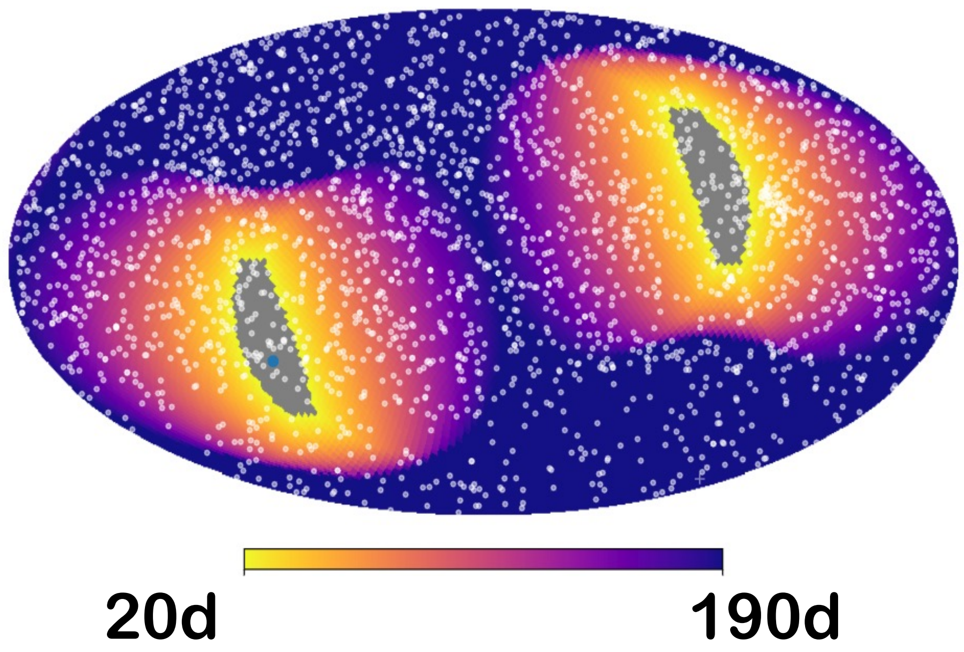
About 10 microlensing event expected. Photometric + Astrometric microlensing 1000 $M_{\odot}$ BH@d=7.5 kpc, ~700 days Θ_E~8.2 mas (Toki & Takada 2022)

Synergy with SUBARU ULTIMATE (NIR wide-field AO, faint stars populations and motion with JASMINE reference frame)

Spring and Autumn: NIR Astrometry Galactic Centre Survey (GCS)
Summer and Winter: Exoplanet survey (EPS): M-dwarf transit



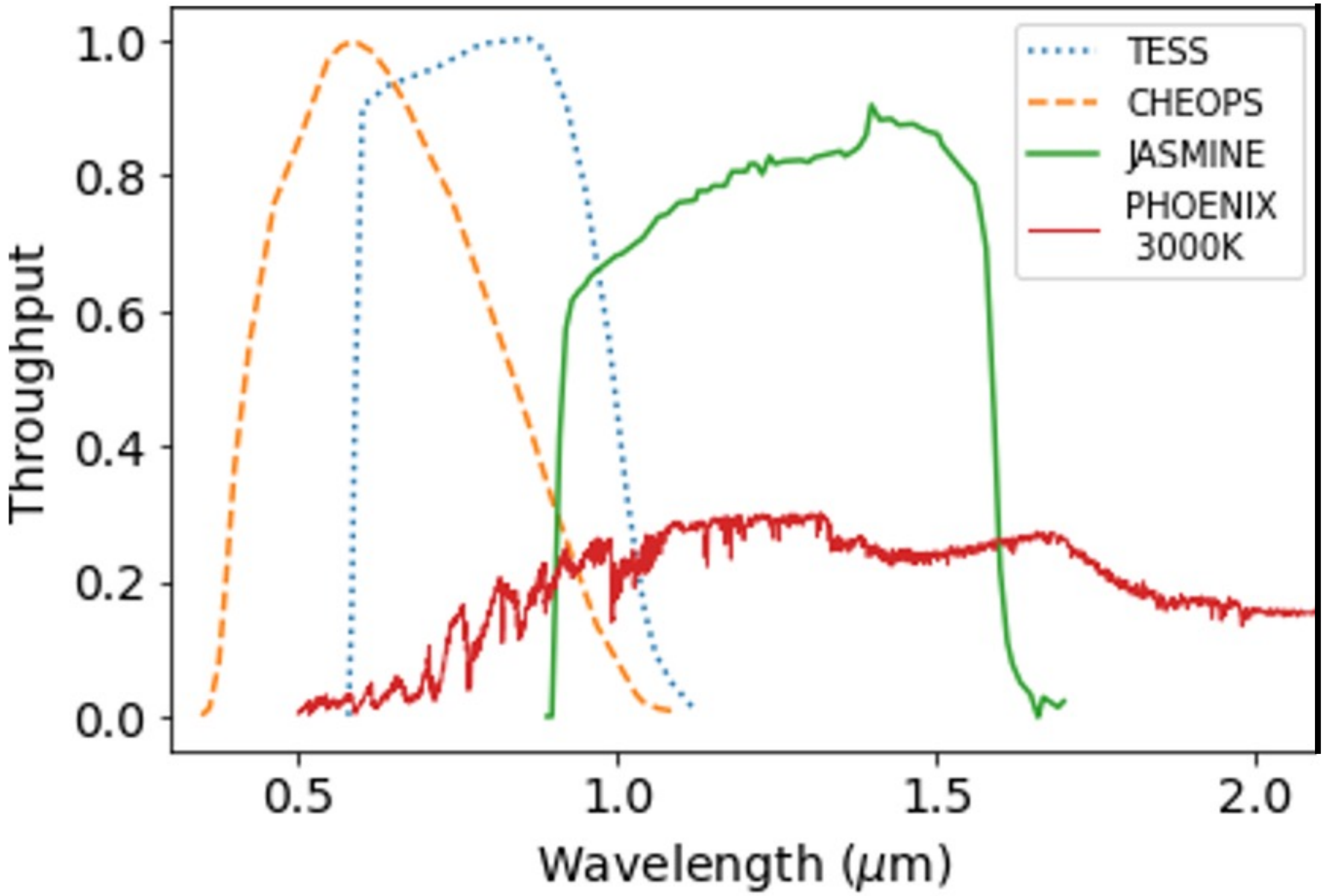
EPS potential target M-dwarf



Observable days in summer and winter

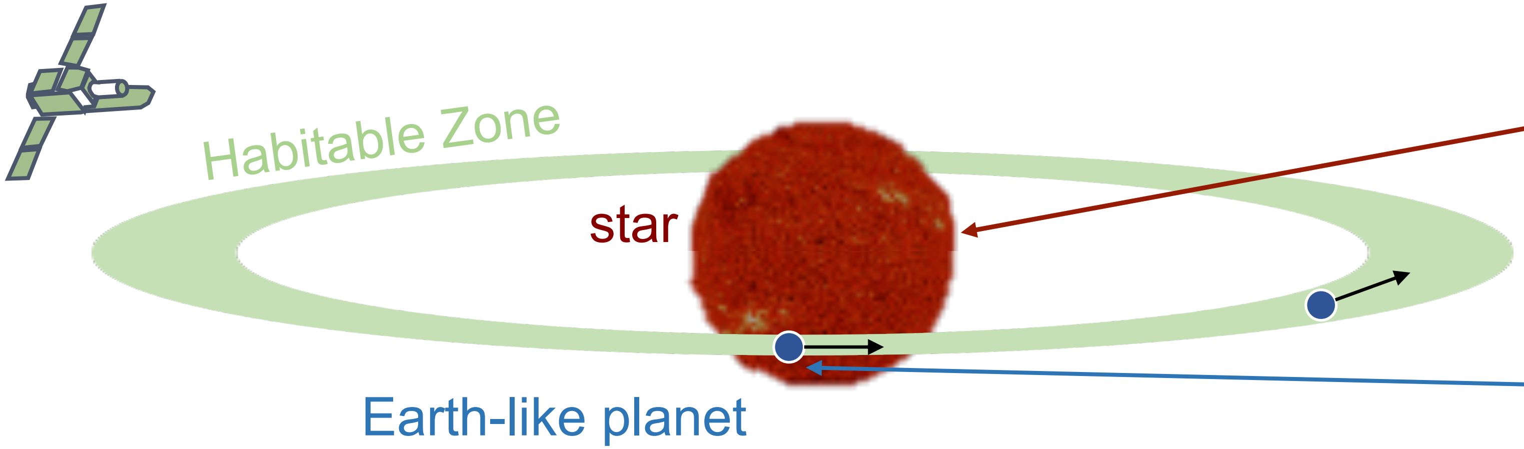
Exoplanet Science Team: **Kawahara**, Masuda, Fukui, Hirano, Kotani, Kodama, Kuzuhara, Omiya, Takahashi, Kasagi, Kawashima, Tada, Miyakawa

M-type cool stars are brighter in NIR



High-precision photometry exploration of Habitable Zone (HZ) Earth-like planets

NIR photometry



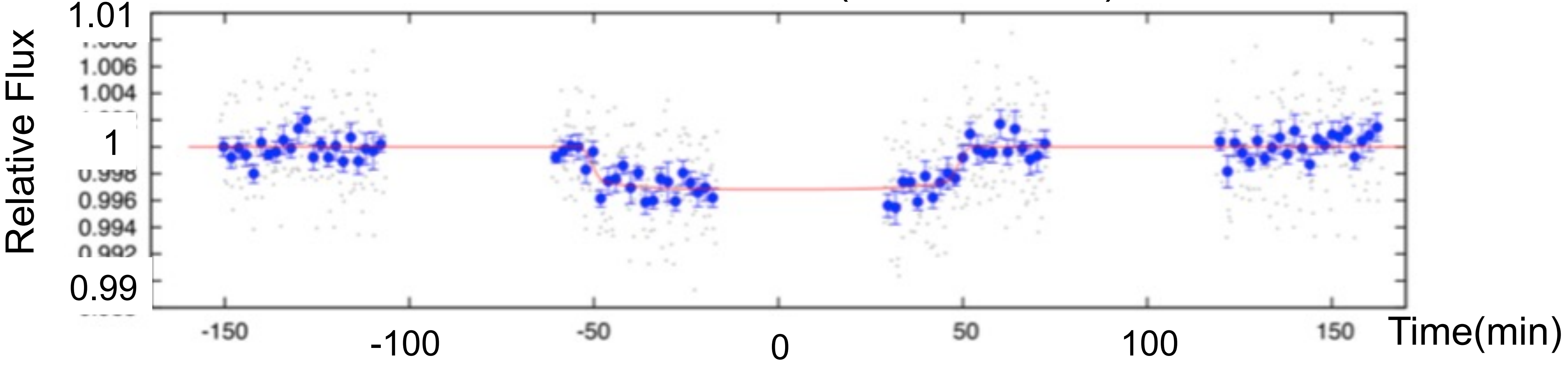
3000K, 0.2 $R_\odot$, 0.2 $M_\odot$

Earth-size transit depth=0.2-0.3%

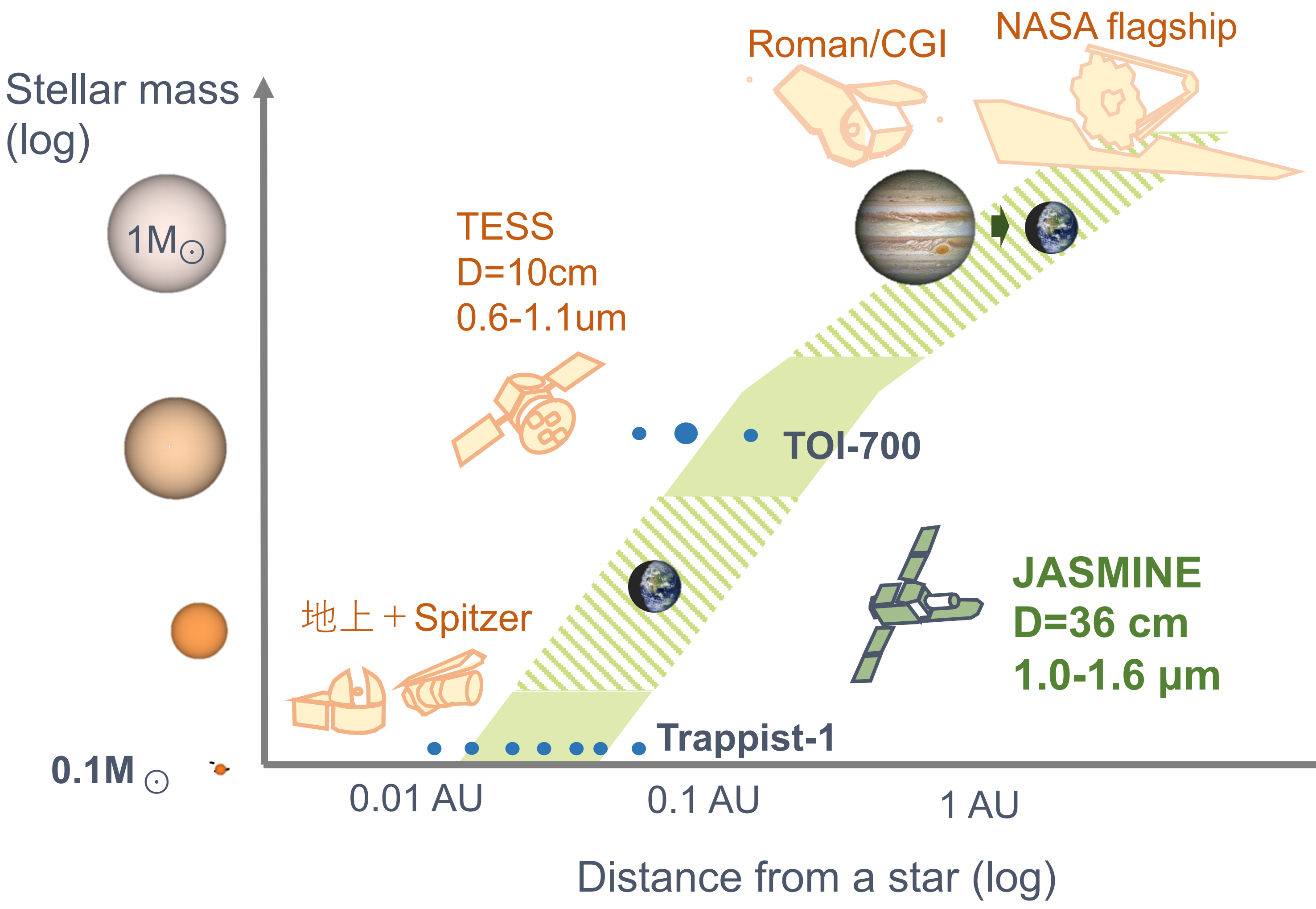
HZ orbits ~ 2 weeks

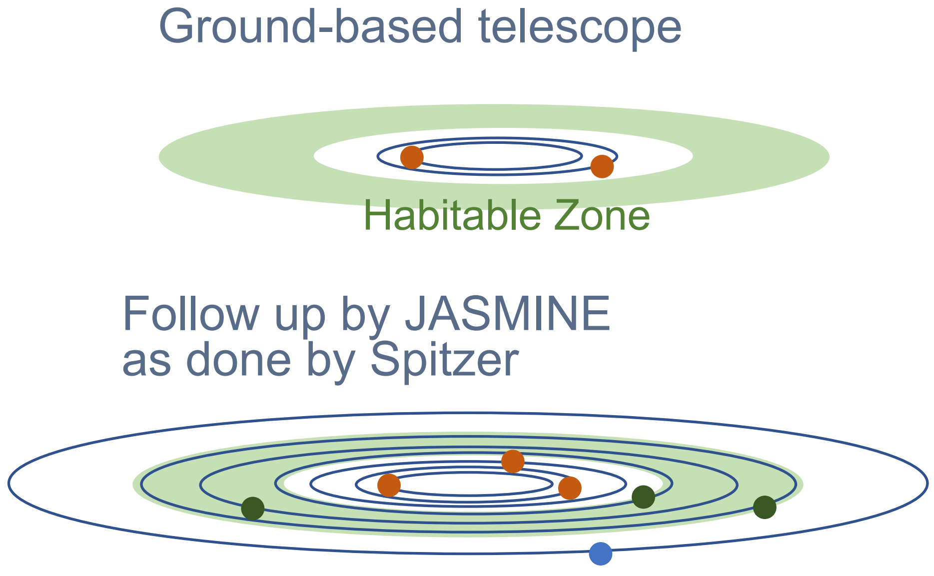
High precision space photometry monitoring

JASMINE Transit Simulation (Hirano et al.)



Niche capability of JASMINE Exoplanet survey





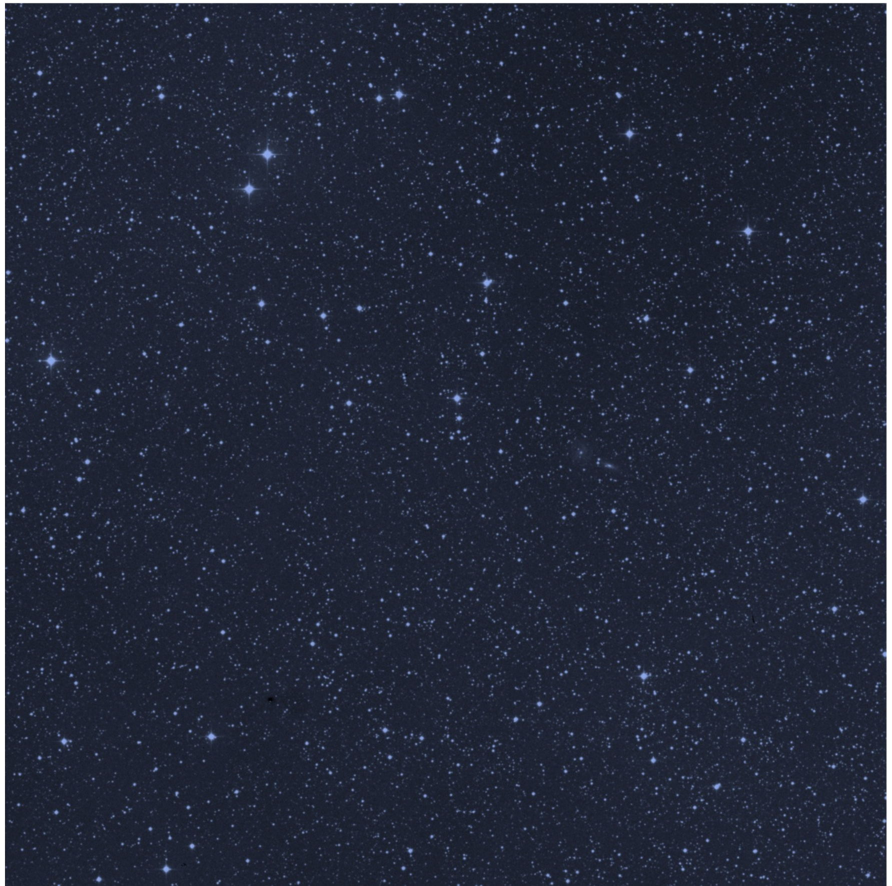
HZ transit detection rate for the system found with inner planet transit ＝ 20-40%

2~5 HZ Earth-like planets from 25 observations

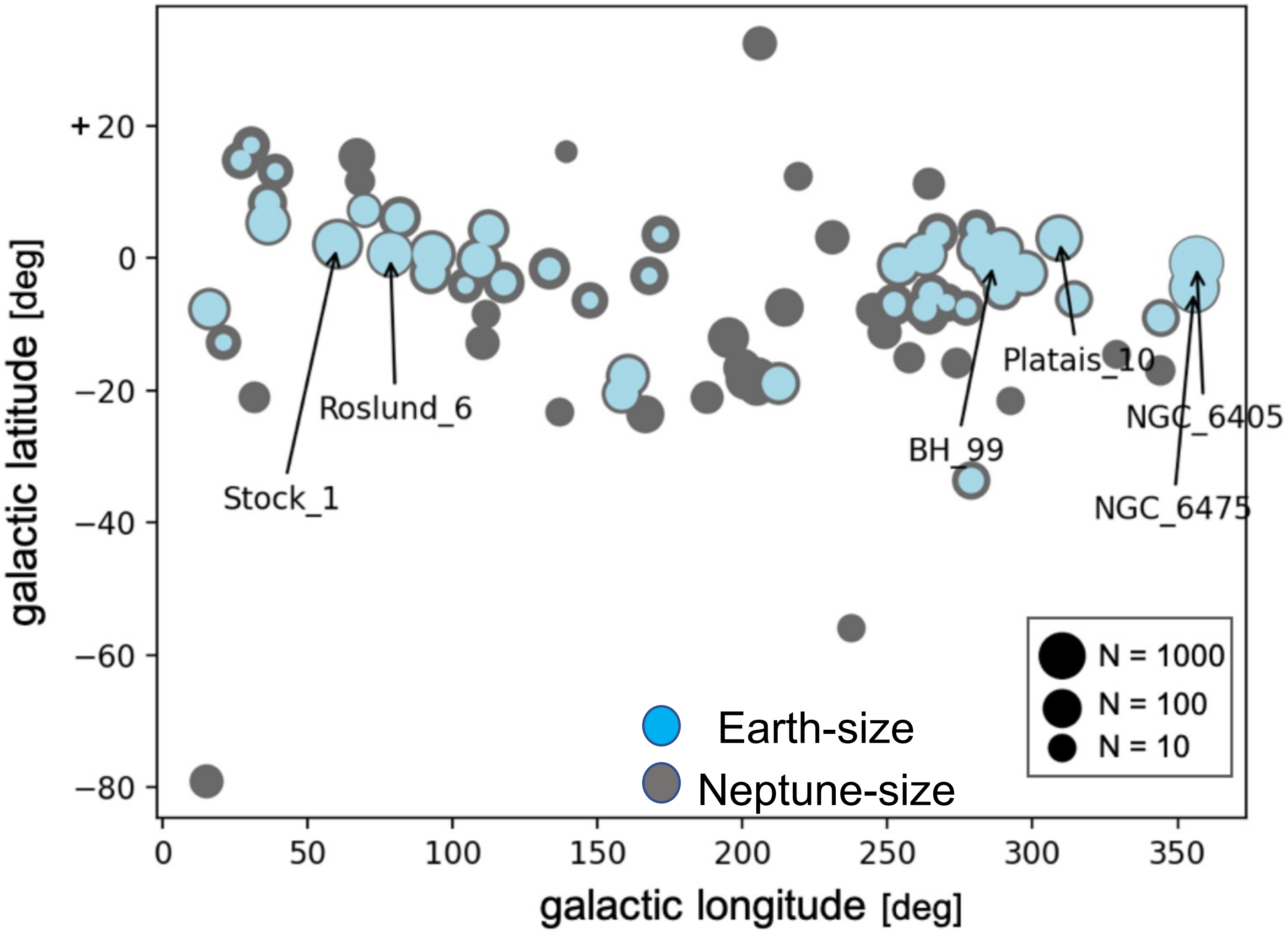
Other potential targets for exoplanet survey I: Young star clusters

- Exoplanets around ~1,000 cool young stars?
- Taking an advantage of FoV 0.55 x 0.55 deg², small pixel size of 0.47 arcsec

M39 (0.6 x 0.6 deg²)

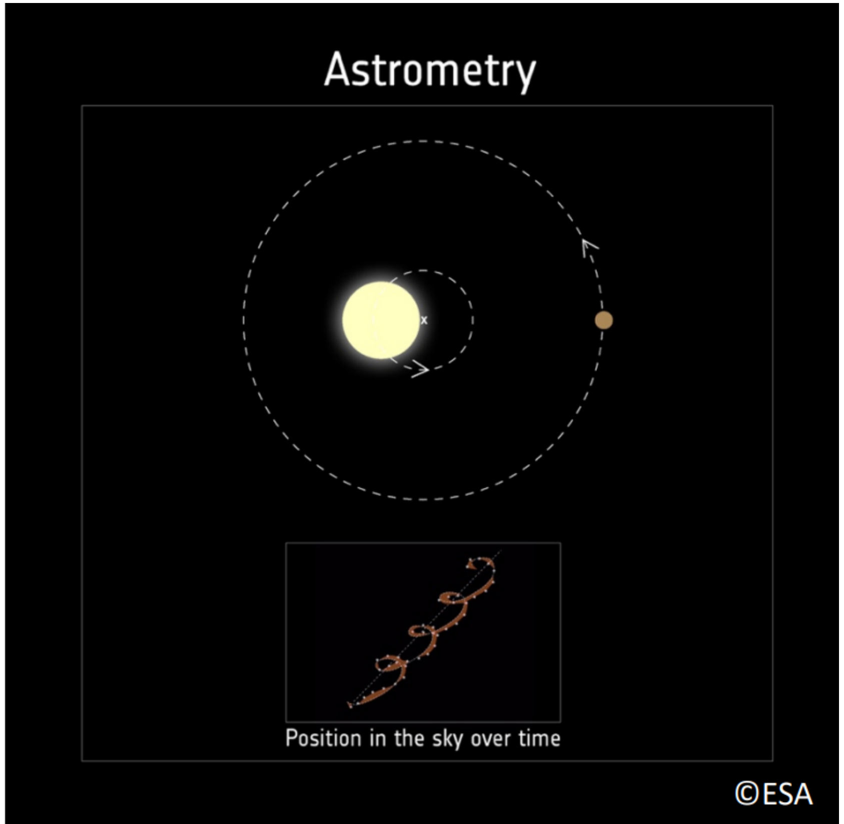


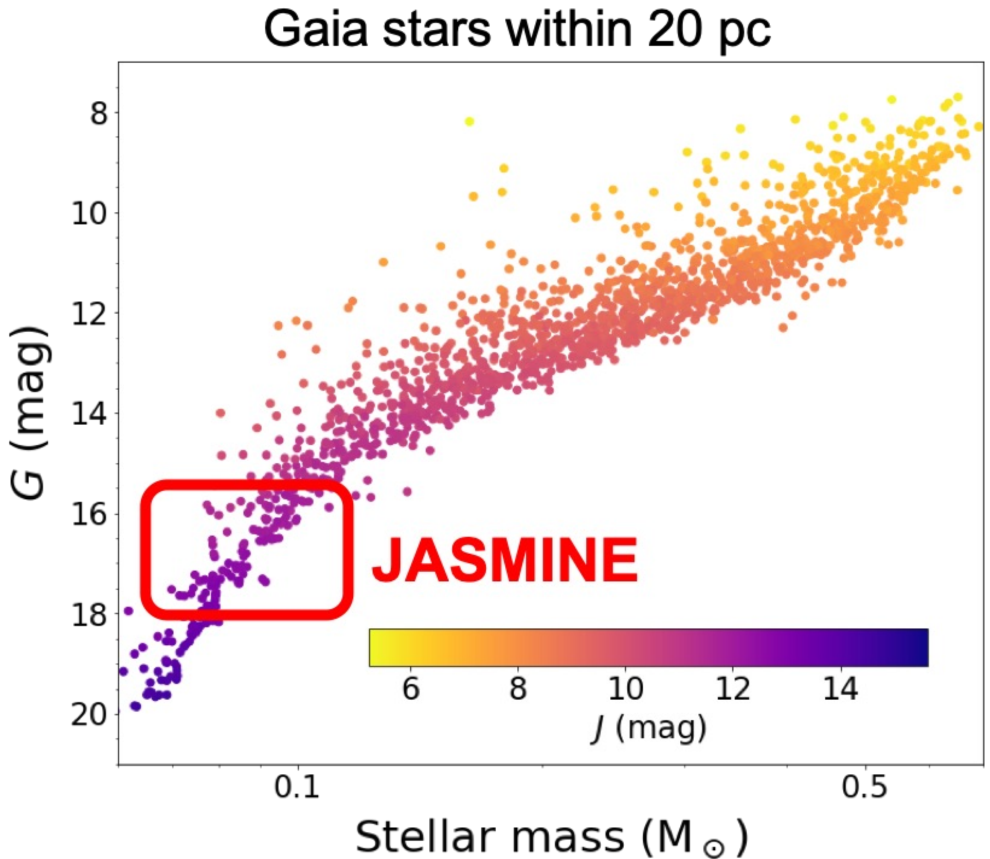
Star clusters < 500 pc



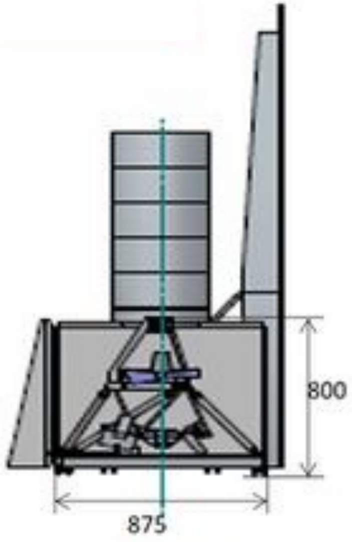
Other potential targets II: Astrometric Planet Survey

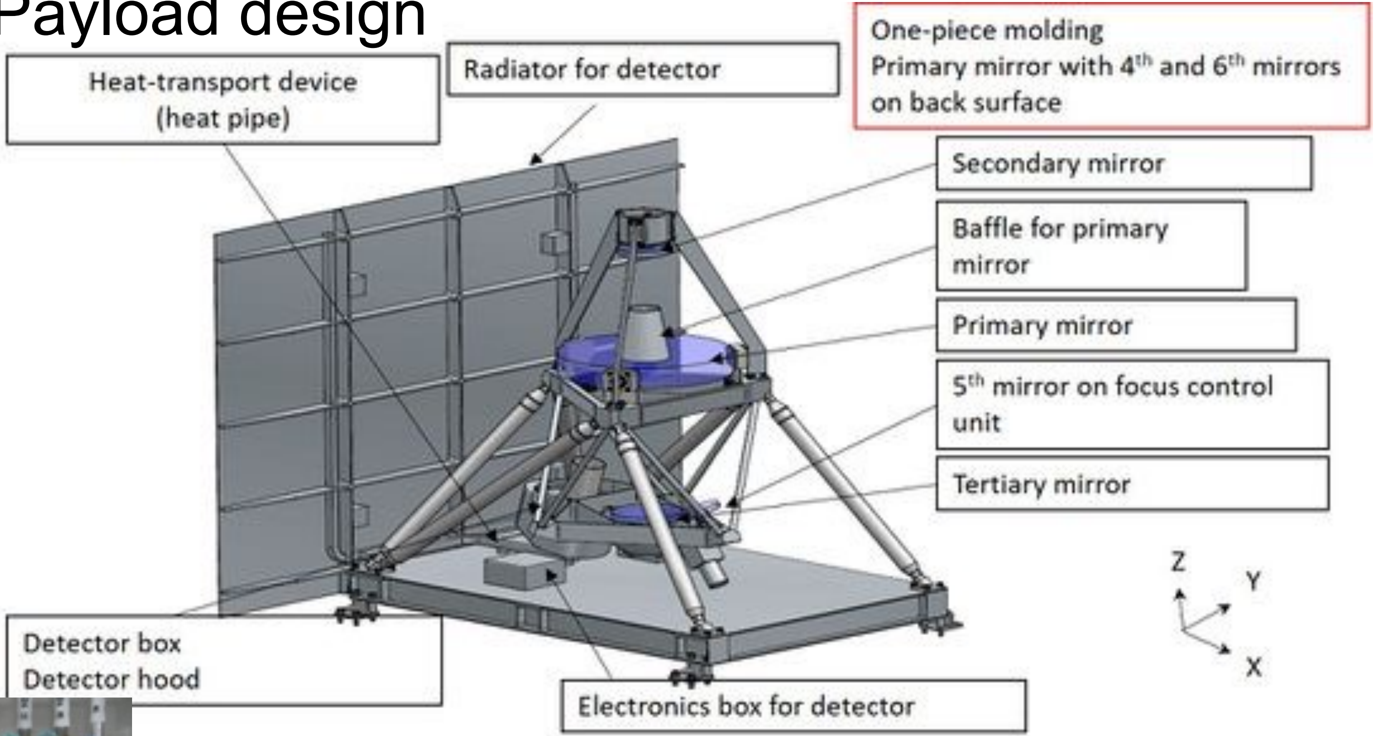
- Ultra cool dwarfs (too red for Gaia): Is there any giant planets?
- Known RV lor DI long-P system, combined with Gaia, ~20 years baseline
- Astrometric microlensing for nearby (<500 pc, very rare) microlensing sources
- **3 years of Galactic centre survey: astrometric and transit**

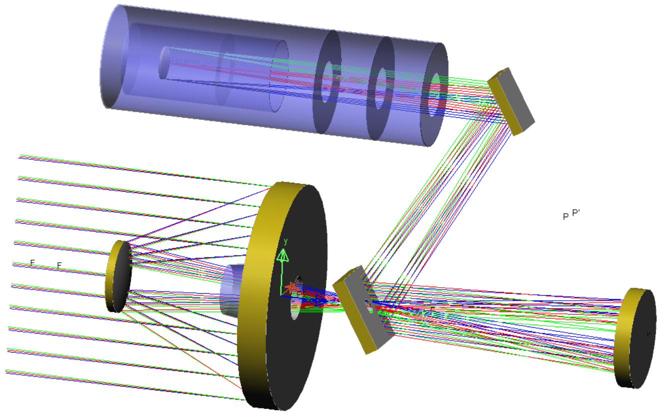




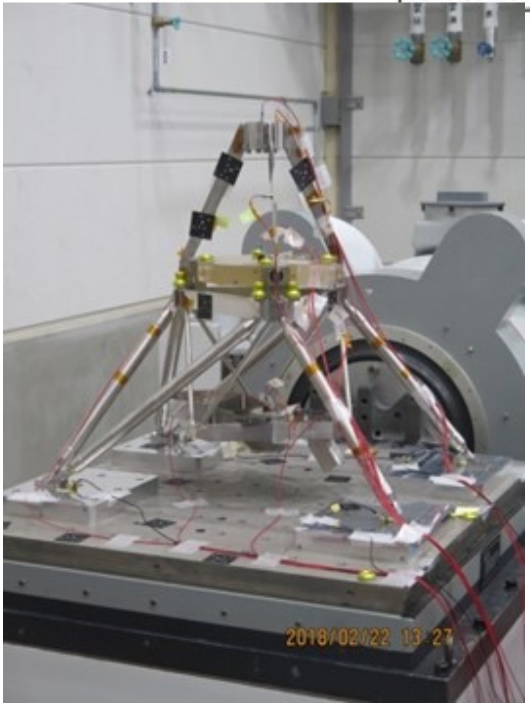
Preliminary Payload design

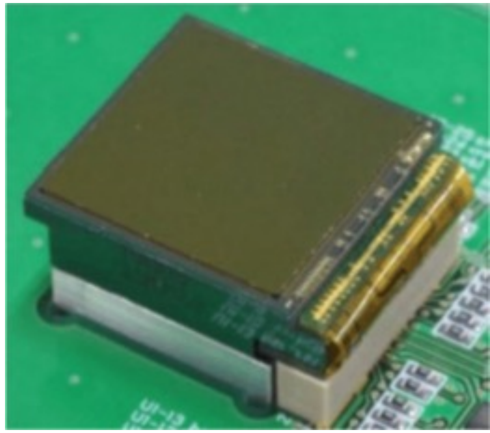






Prelim. Optical design by S. Kashima



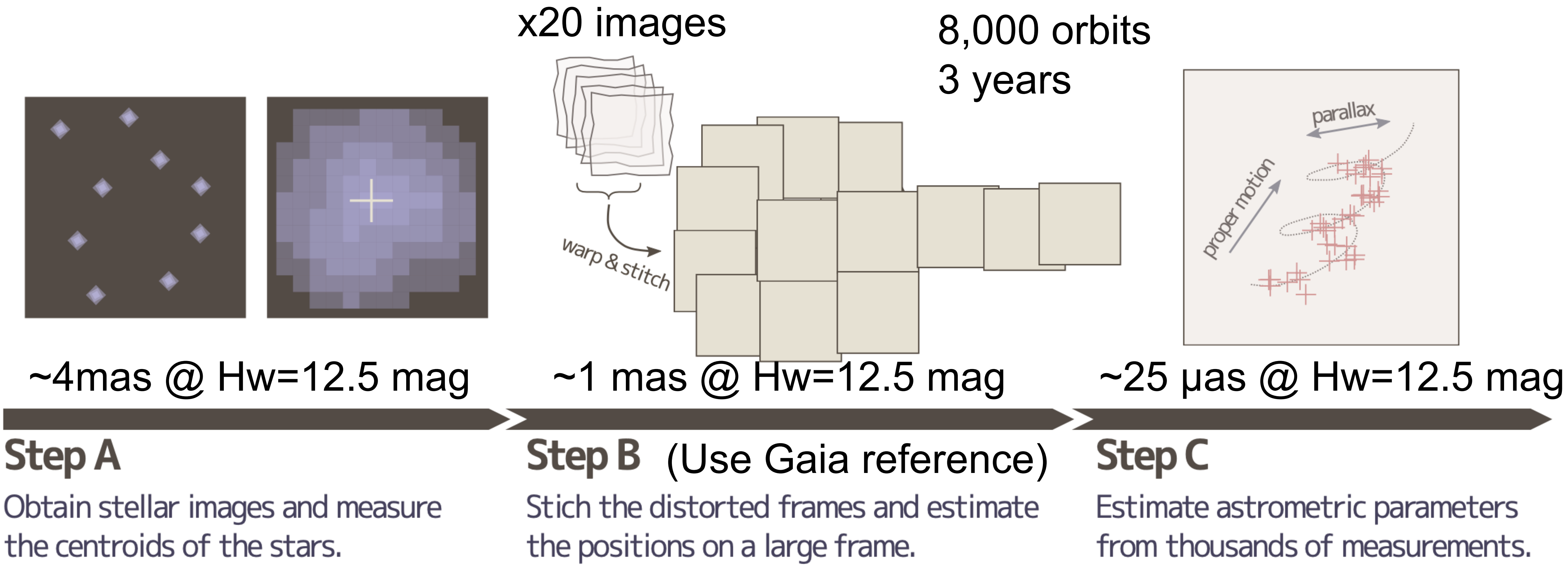


Thermal stability is crucial
Super-Super Invar alloy (coefficient of thermal expansion) $0\pm5\times10^{-8}$ /K
Mirrors of CLEARCERAM®-Z EX (CTE: $0\pm1\times10^{-8}$ /K)
Telescope temperature control within 278±0.1 K for 50 min.

2x2 New InGaAs NIR detector (1920x1920 pix, NAOJ)

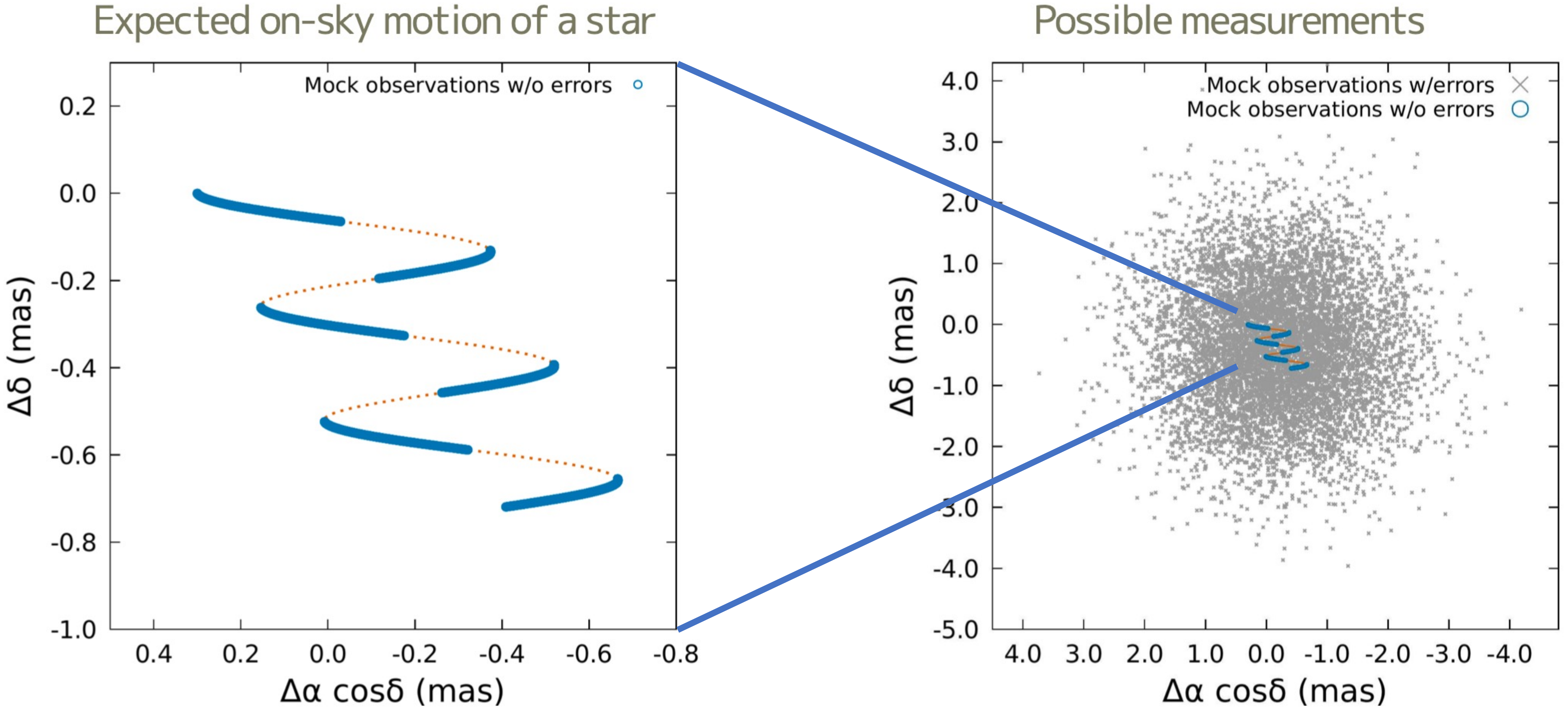
Flat calibration for inter- and intra-pixel uniformity is crucial.
Flat light source on board (Kotani et al.)

Galactic Centre programme: Nobs ~ 20 images x 8,000 orbits
Astrometric accuracy improved by sqrt(Nobs), i.e. ~1/400



Credit: R. Ohsawa

In more realistic mock data

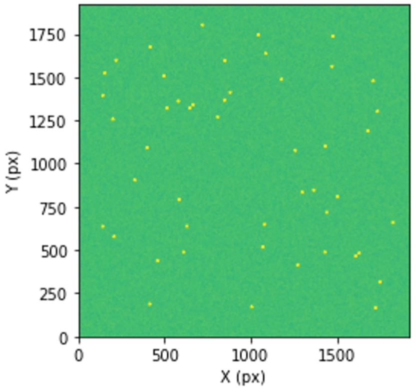


ω=0.3 mas, μ=0.3 mas/yr, σ=1 mas

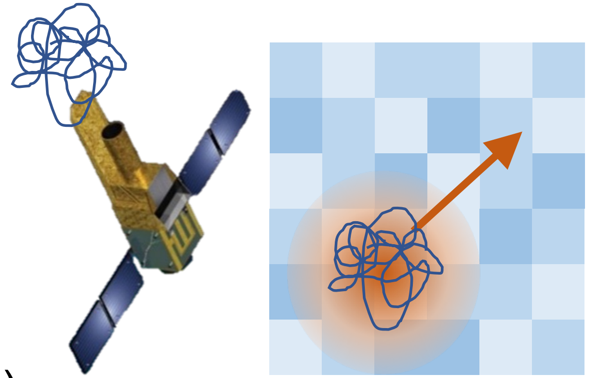
Credit: R. Ohsawa

Astrometric and photometric accuracy with many images
end-2-end simulation Team:
Ohsawa, Kamizuka, Kawahara, Hirano, Aizawa, Miyakawa, Yamada, Kataza et al.
ARI-Heidelberg: Michael Bierman, Wolfgang Löffler et al.

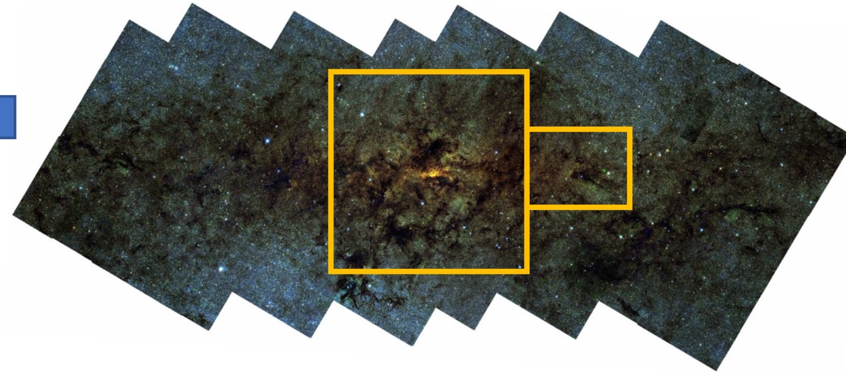
JASMINE Image Simulator (JIS)



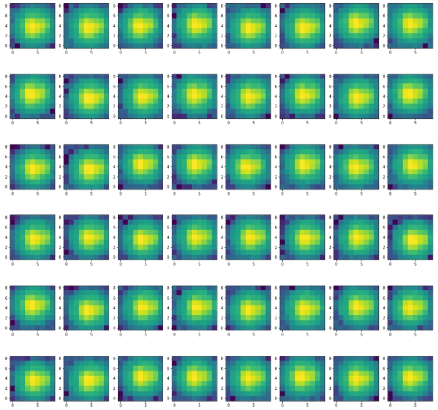
Wave Front Error (PSF, optical distortion chromatic aberration)
Detector (inter/intra pixel sensitivity, pixel distortion, noise),
Attitude Control Error, Aberration



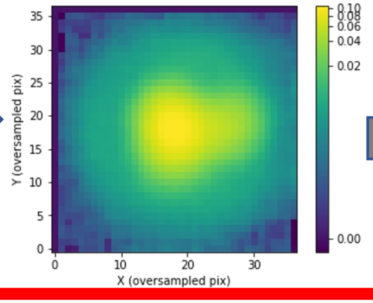
in point source catalogue ($\alpha,\delta,\pi,\mu_\alpha,\mu_\delta$),
From catalogue, (2MASS, Sirius, VVV),
incl. background stars
+ binary, variables, microlensing…



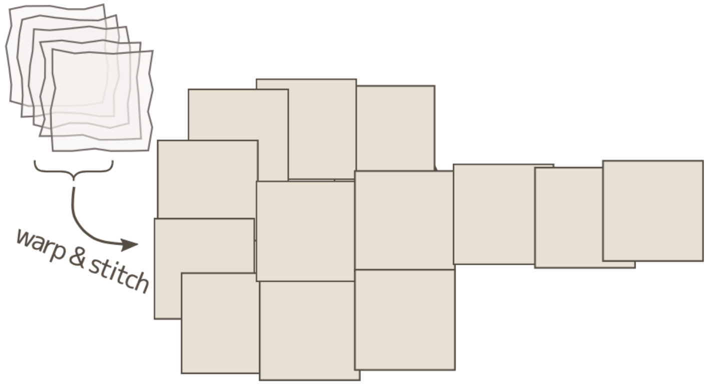
JASMINE Astrometry Data Analysis (JADA)



Background subtraction
Star image extraction

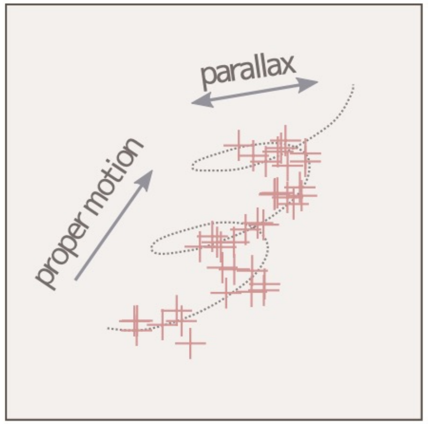


Build ePSF
Centroid estimates
~4 mas @Hw~12.5



Distortion correction, using stars in the overlapped frames. **Thermal stability!**
~1 mas

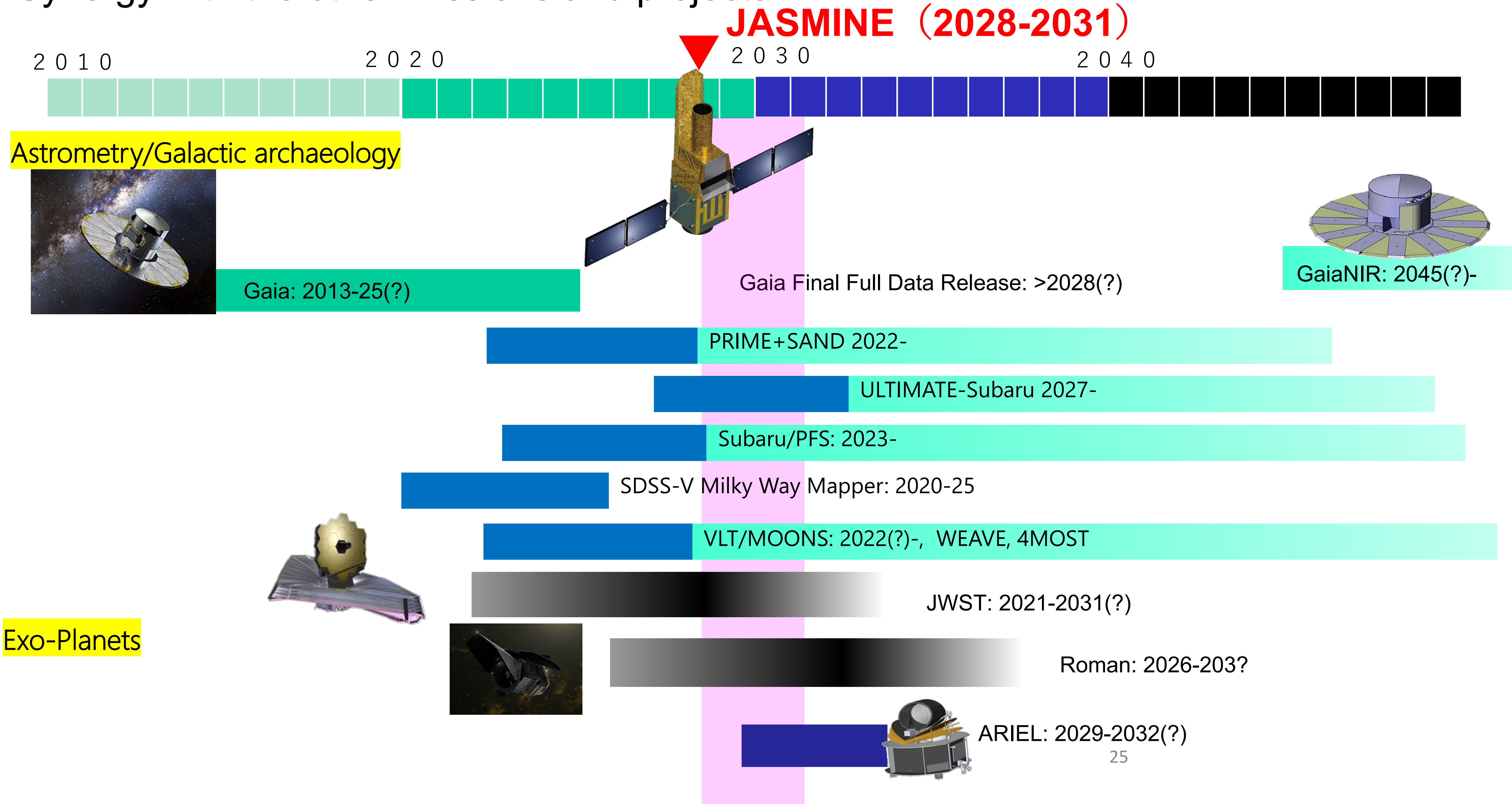
3yrs data
8,000 frames



Astrometry Parameter
($\alpha,\delta,\pi,\mu_\alpha,\mu_\delta$)
~25 μas @Hw~12.5 mag

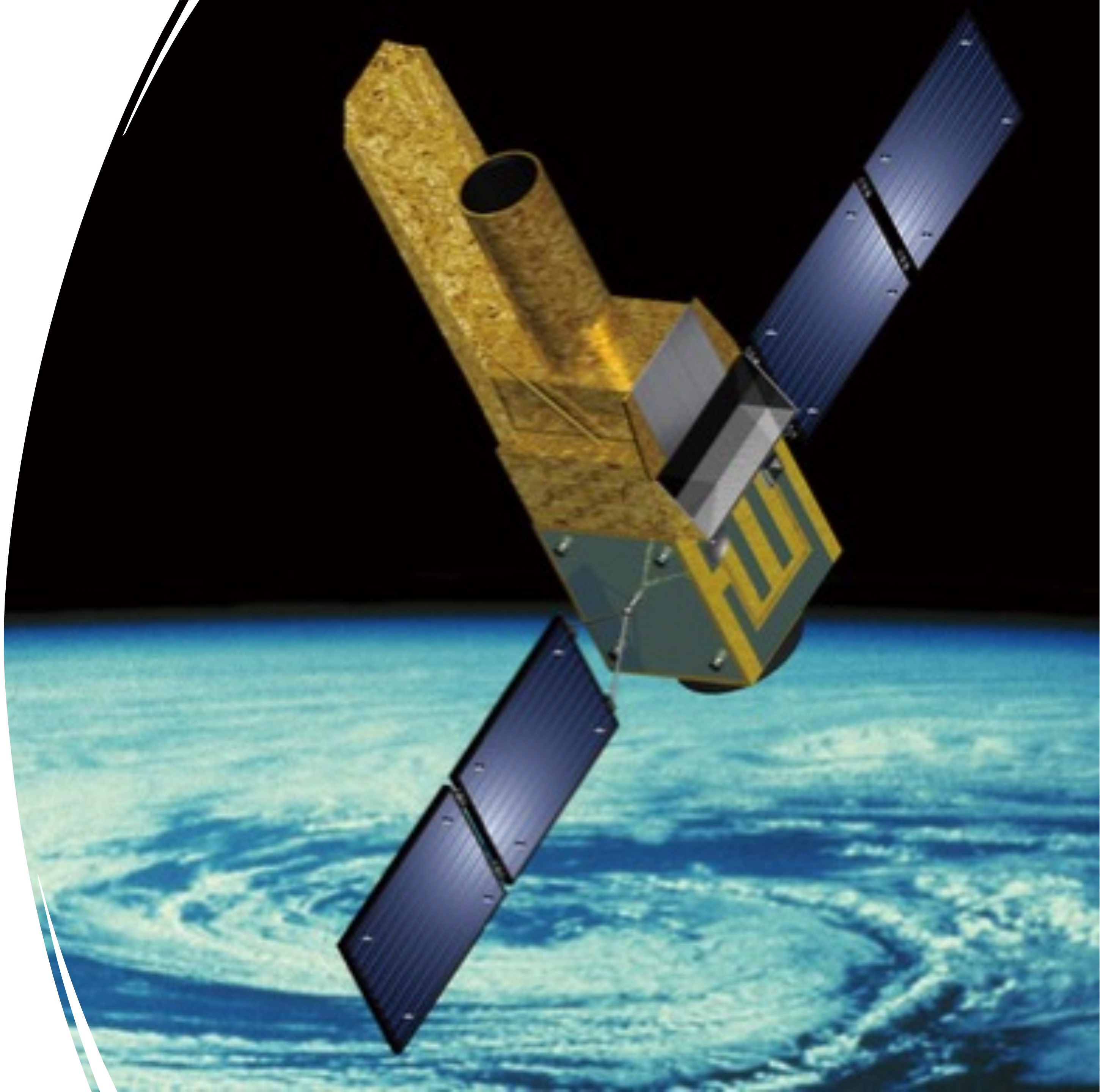
1 orbit

Synergy with the other missions and projects



Summary

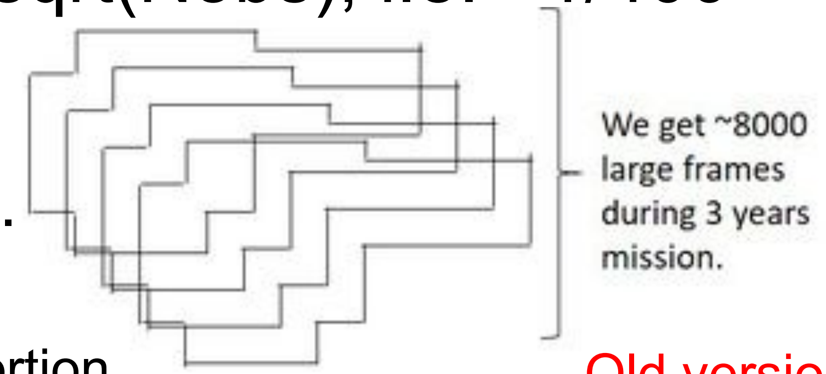
- JASMINE will be the first NIR space astrometry mission with planned launch in 2028,
  a pioneer for GaiaNIR.
- Two goals of Galactic centre archaeology and exoplanet science.
- As seen in Gaia, the astrometry mission provides the new dimension of data: the JASMINE data will be valuable for wide-range of sciences, including targeted and serendipitous targeted discovery of diverse exoplanet populations.
- You are welcome to join!



Galactic Centre programme: Nobs ~ 20 images x 8,000 orbits
Astrometric accuracy improved by sqrt(Nobs), i.e. ~1/400

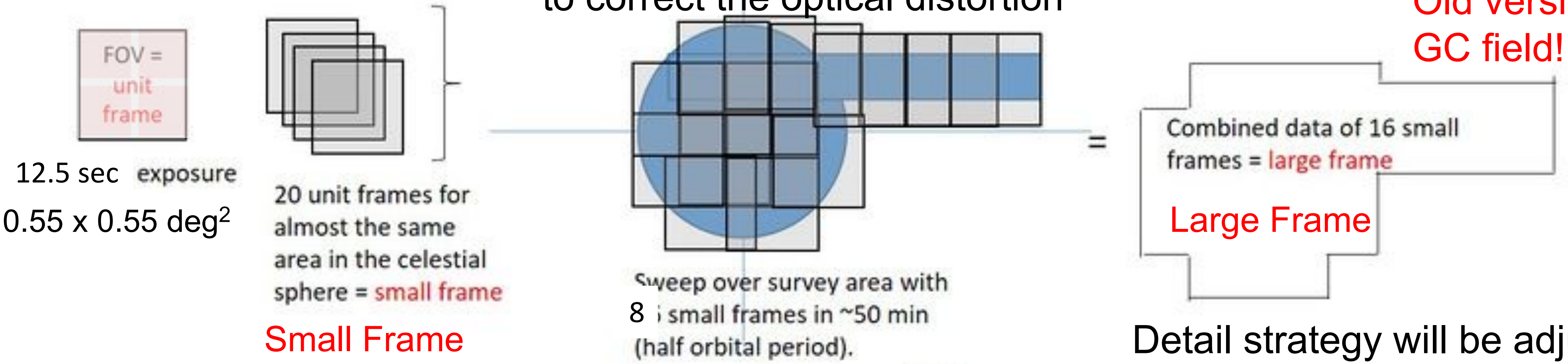
Sun Synchronous orbit with LTAN 6:00 or 18:00

One orbit ~ 100 min, and GC is observable ~50 min.

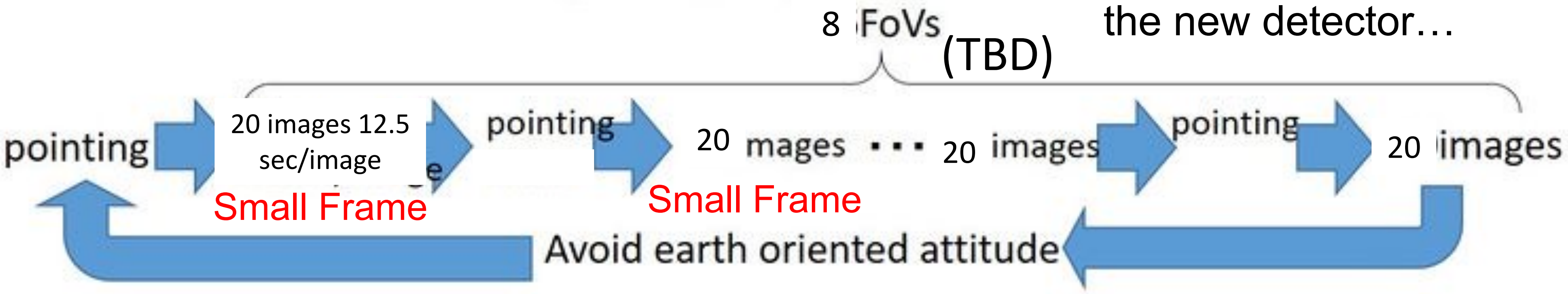


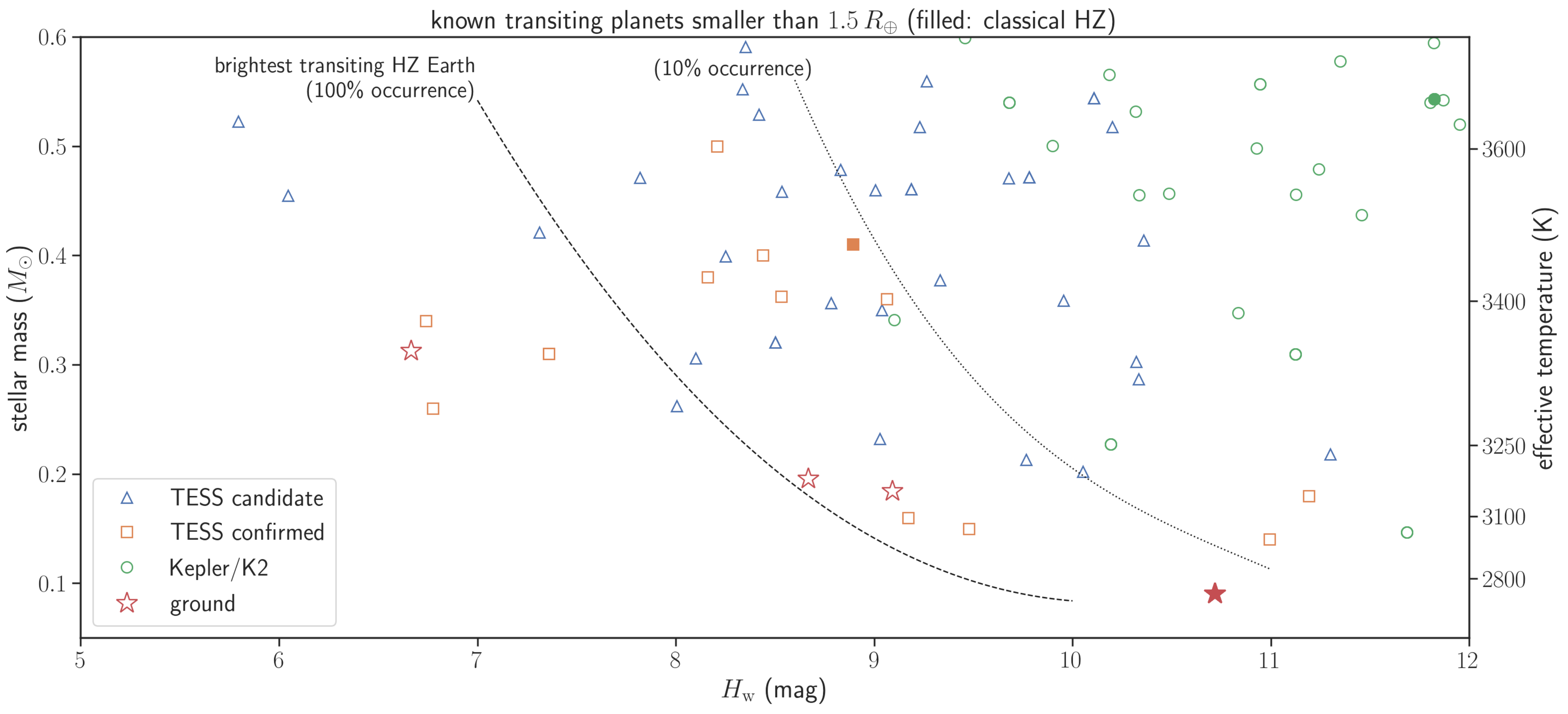
Old version of GC field!

Overlap of small fields
to correct the optical distortion



Detail strategy will be adjusted for the new detector…

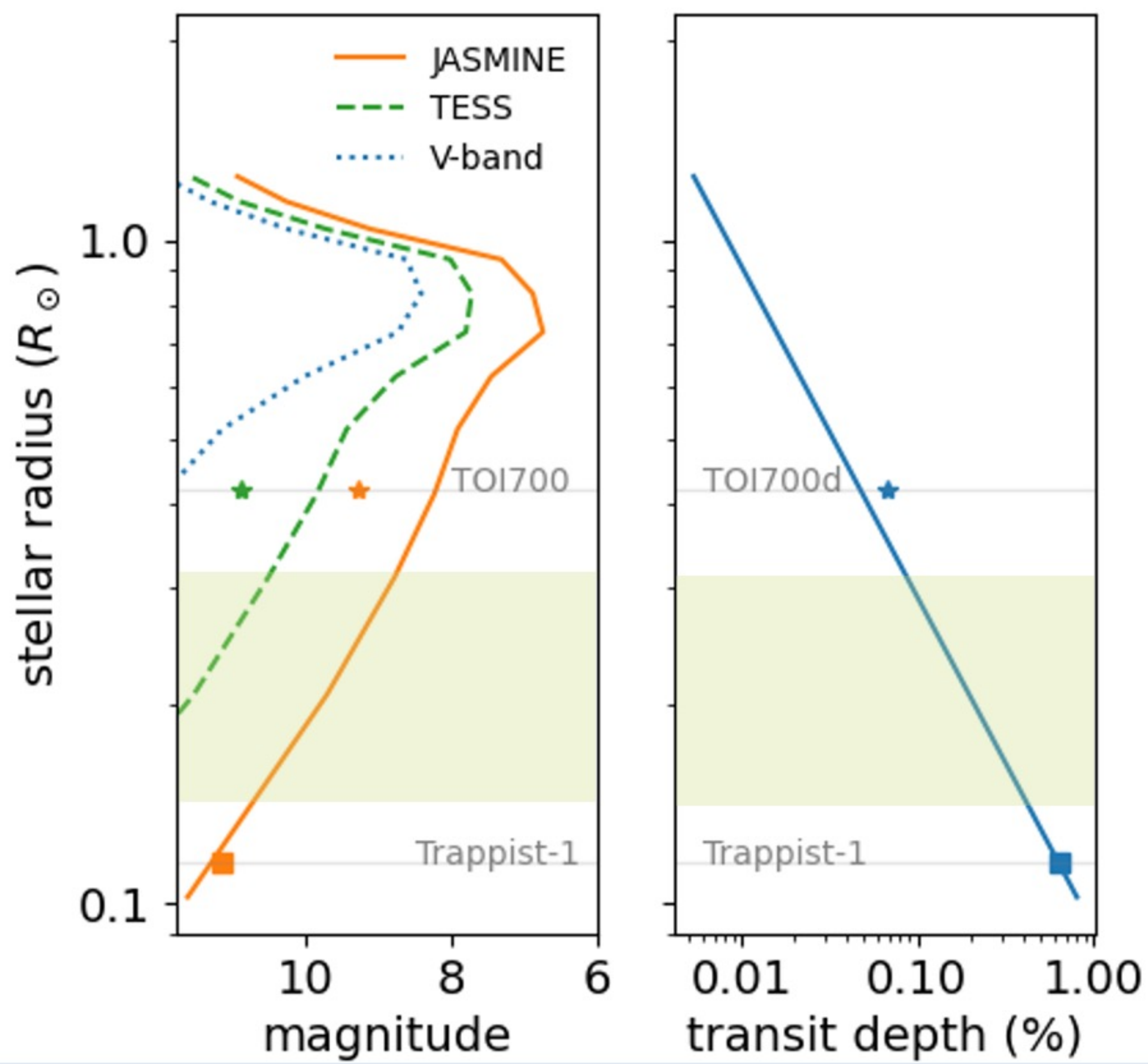


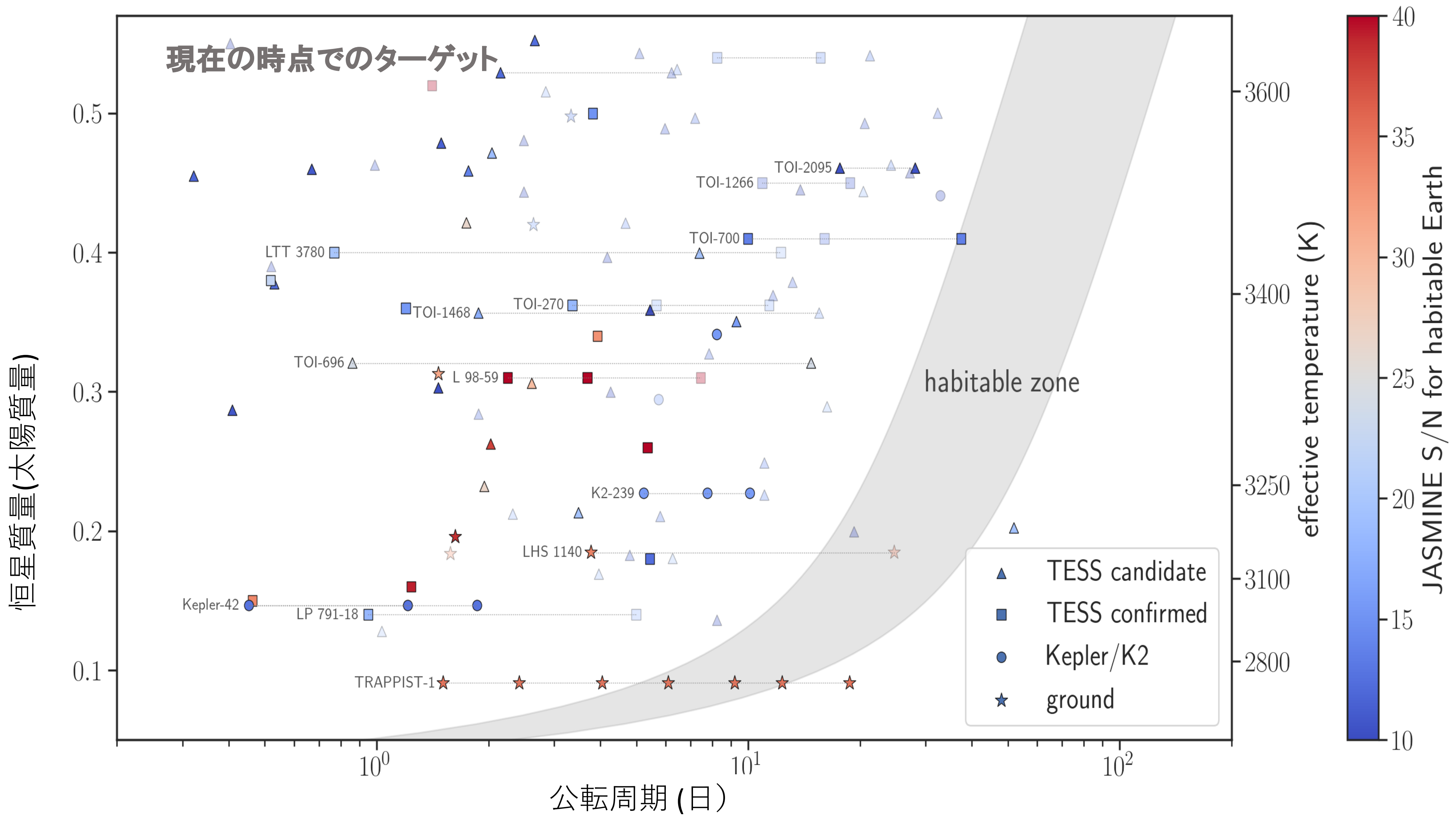


Credit: K. Masuda

Magnitude of 250th brightest star in the sample of dR = 0.1 $R_\odot$ bin

Transit depth of Earth-size planet





加えて、褐色矮星変動、若い惑星探査など赤外精密測光を活かした独自性の高い探査も検討中