Observation of highly obscured star formation regions by Small JASMINE

西亮一 （新潟大学）

JASMINE検討室の郷田直輝教授による資料を中心に

(Small-)JASMINE

★JASMINE

―Japan Astrometry Satellite Mission for INfrared Exploration―

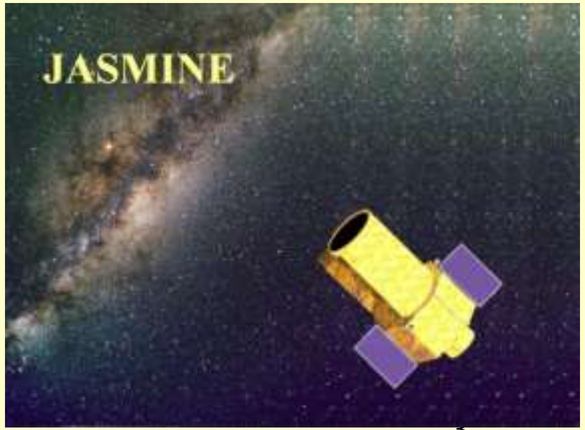
Naoteru Gouda(NAOJ), JASMINE team

JASMINE
（赤外線位置天文観測衛星）
計画シリーズ

---Japan Astrometry Satellite Mission for INfrared Exploration---

国立天文台JASMINE検討室を中心に推進

Nano-JASMINE　小型 JASMINE　中型JASMINE



ISAS/JAXA has selected Small-JASMINE as the unique candidate for the 3rd M-class science satellite mission !!

Launch date is mid 2020s

1.Astrometry

◎ Positions on the celestial sphere

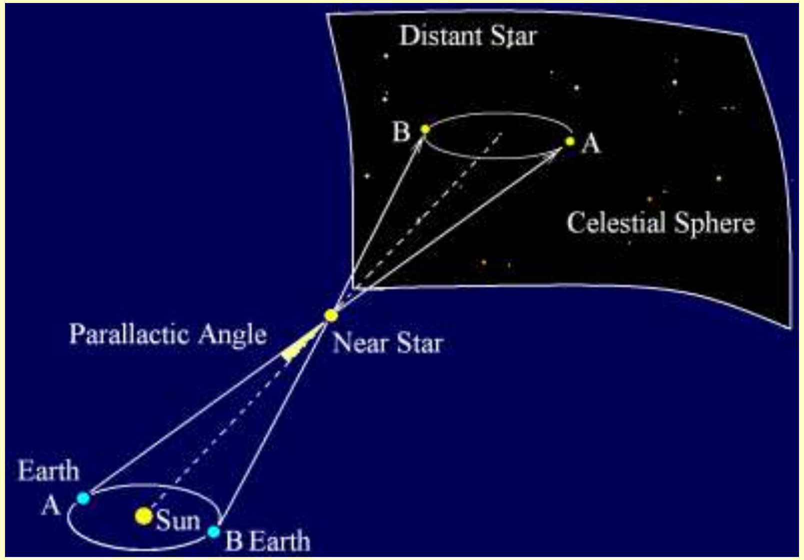
➡ 2-dimensional coordinate of stars

◎ Motions of stars

1. Apparent annual elliptical motion

*Parallactic Ellipse (annual parallax)

➡ Distances of stars(1-dim.coordinate)

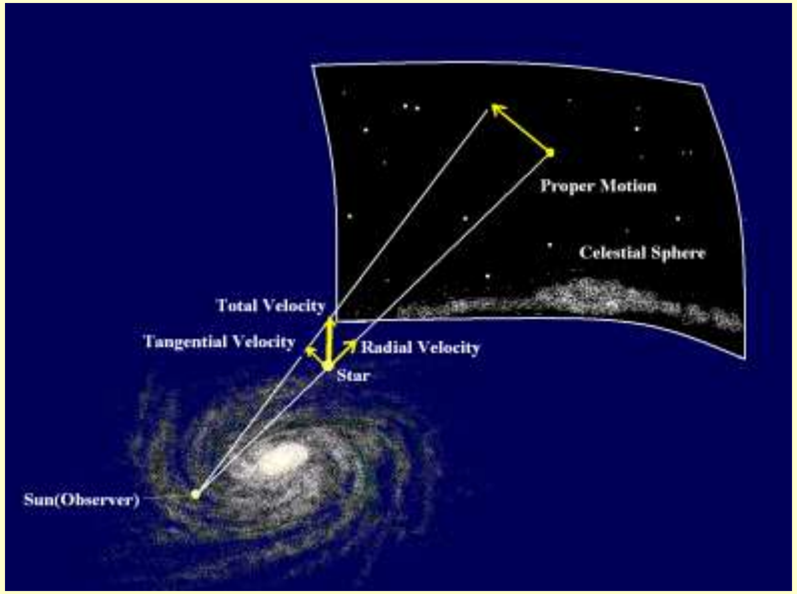


2. Systematic displacement of stellar positions

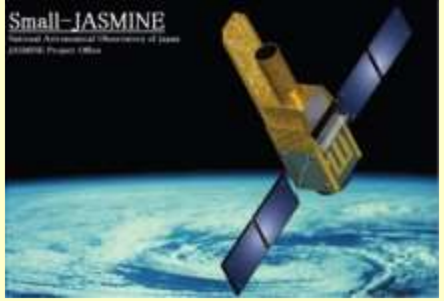
Proper motion

*Proper motion + Distance

➡ Tangential velocities of stars



2. Outline of Mission



We have been aiming at the realization of the Small-JASMINE mission as a mission of the small science satellite program (M-class mission) executed by JAXA (Japanese Space Agency).

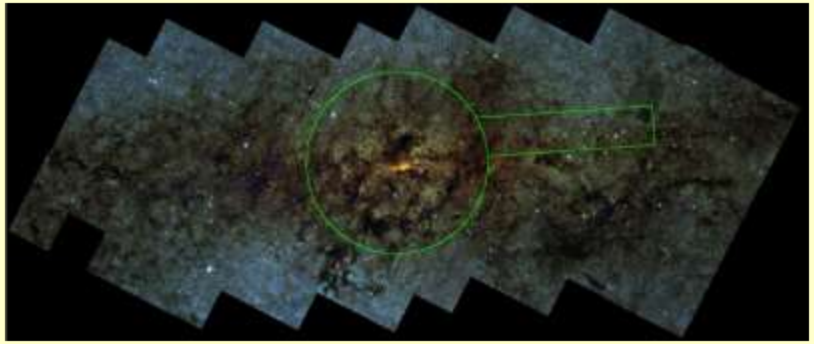
Astrometric Measurement in Hw-band(1.1μm~1.7μm) ***Hw~0.7J+0.3H**

Infrared astrometry missions have advantage in surveying the Galactic nuclear bulge, hidden by interstellar dust in optical bands!

Two survey modes

1. survey for **the key project** in **spring and autumn**

Nuclear bulge around the Galactic center



J, H, K tricolor composite image of the Galactic center area(imaged by SIRIUS on the Nagoya University IRSF 1.4m telescope: Nishiyama et al., 2004 Spring Astronomical Society Press Release).
The survey area of Small-JASMINE is written with the green line.

2. survey for **secondary objectives** in **non-bulge observations**

some directions toward interesting target objects

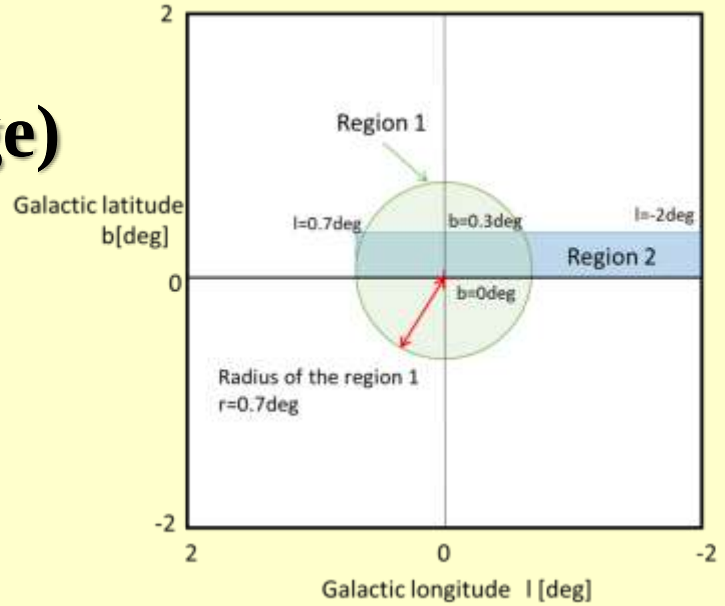
(e.g CygX-1, planetary systems of brown dwarfs, star-forming regions besides the area near the center)

Advantage of Small-JASMINE: every 100 minutes!
High frequent measurements of the same target

Phenomena with short periods

Good monitoring of photometric and astrometric time-variable phenomena!!

2. The details of the survey mode for the key project（toward the Galactic nuclear bulge)



★ **Small-JASMINE will measure totally**

about 67,000 bulge stars＋31,000 disk stars for Hw<~15 mag. (at minimum)

Survey region 1:

the circle with **the radius of 0.7 degree** (～100pc)
around the Galactic center

・the number of observable stars

bulge stars: **~5000(Hw<12.5mag),** **<=precisions of parallax(<~25μas) and proper motion(<~25μas/yr)**

~45000(12.5mag<Hw<15mag) **<=precisions of proper motion(<~125μas/yr)**

(**disk stars:～4000(Hw<12.5) , ～21000(12.5mag<Hw<15) common with stars measured by Gaia**)

Survey region 2:

Survey region: Galactic longitude：**-2.0～0.7 degree** Galactic latitude： **0.0～0.3 degree**

・the number of observable stars

bulge stars: **~3000 (Hw<12.5mag)** **<=precisions of parallax(<~25μas) and proper motion(<~25μas/yr)**

~26000(12.5mag<Hw<15mag) **<=precisions of proper motion(<~125μas/yr)**

(**disk stars: ～1500 (Hw<12.5), ～9500(12.5mag<Hw<15) common with stars measured by Gaia)**

Small-JASMINE will provide and open to science communities in the world the data of parallaxes, proper motions and time sequences of stellar positions on the celestial sphere in the survey region of the key project.

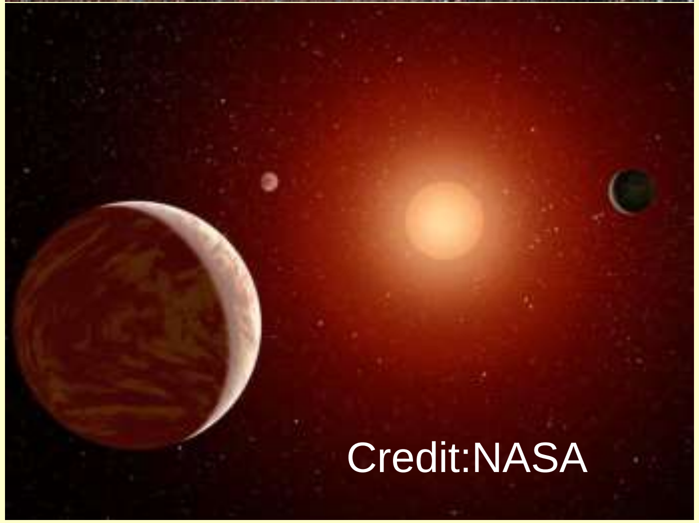
3. Science Goal and scientific objectives

JASMINE science goal:

To investigate from the origin of our Galaxy to the formation of habitable planets

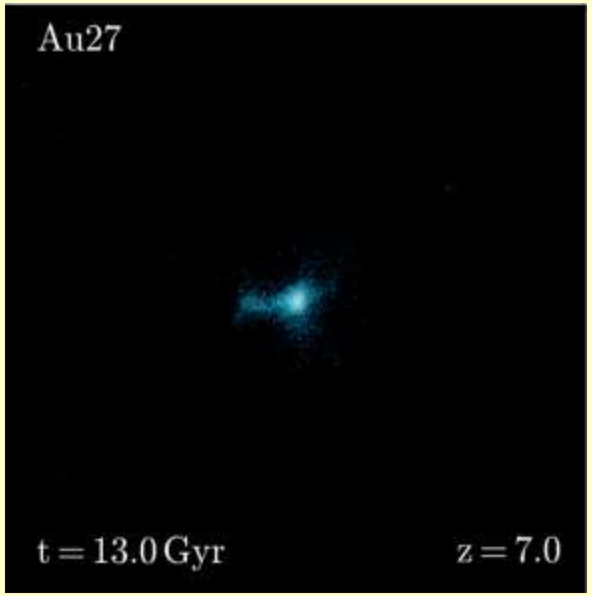
3 main objectives:

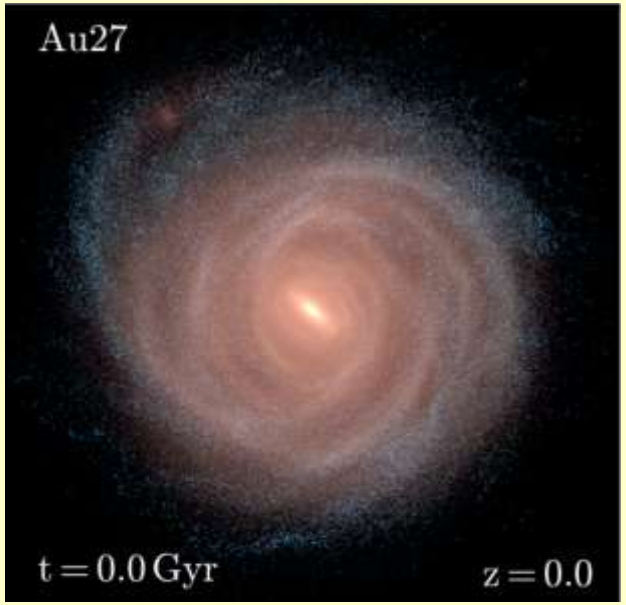
- Galactic center archaeology
- Exploration of habitable planets around M-dwarfs
- Cultivating international-level future leaders through the international space mission led by Japan!



3.1 Galactic Center Archaeology

Galactic center contains the stellar population history
from the first star formation to the present





Auriga 27 (Grand et al. 2017)

Precise measurements of the motions of stars with different ages and metallicities will tell us the formation epochs of halo, bulge, bar and disk as well as the BH formation process.

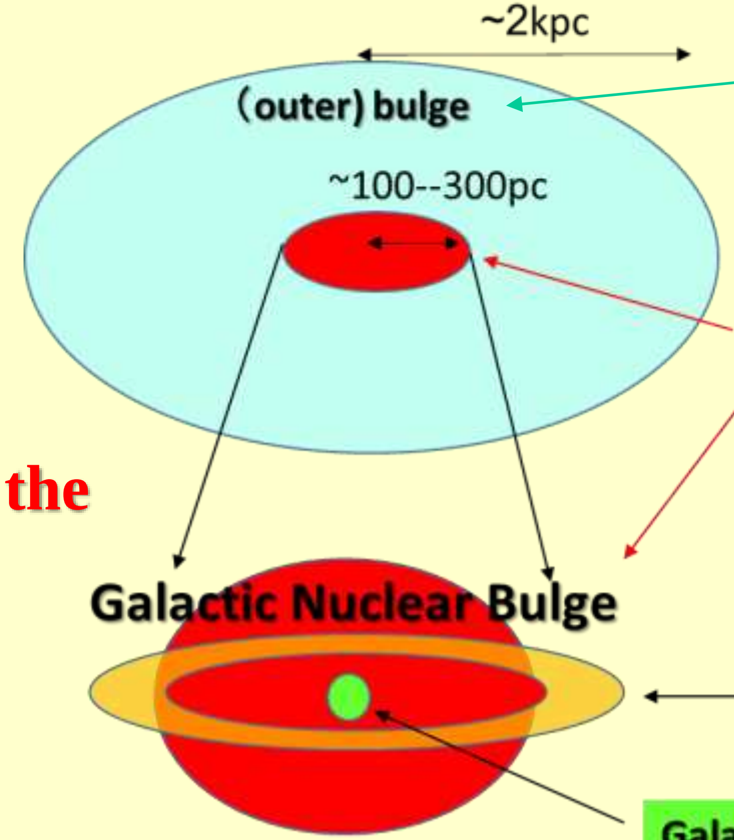
*: astrometry missions with high precisions (~ a few tens micro-arcseconds level)

JASMINE➔

Galactic Center Archaeology through the exploration of the Galactic nuclear bulge (in spring and autumn)

The Galactic nuclear bulge has strange unresolved astronomical phenomena and celestial objects

The Galactic nuclear bulge is very interesting and important target because of the treasure of the hidden history of the Galaxy and SMBH.



Gaia*(optical), (WFIRST*) BRAVA, etc (radial velocity, chemical components, type and age of stars)

Galactic nuclear bulge

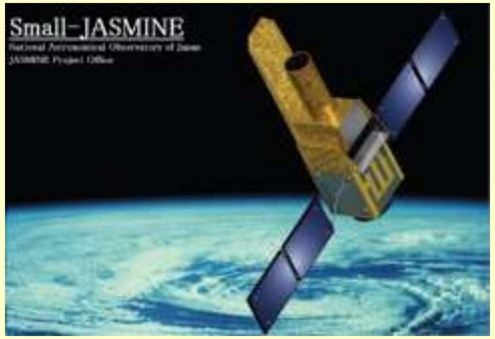
Small-JASMINE*🡐unique in the world!
APOGEE, VVV, MOONS
GALACTICNUCLEUS,etc.
(radial velocity, chemical components, type and age of stars)

Central Molecular Zone(CMZ)

Galactic central region (<10pc)

GRAVITY*(VLTI), TMT* etc.
(very narrow field of view)
APOGEE, GALACTCNUCLEUS, etc.

★Complement to the Gaia mission in Small-JASMINE



＊ Gaia can measure only about ～70 bulge stars with high precisions(<25μas precision of the parallax) which are located in the same region as the whole survey region of Small-JASMINE around the Galactic center due to the effect of absorption by the interstellar dust.

SJ (Small-JASMINE) => ～7000 bulge stars

＊ Gaia can measure the same target every 40 days. So Gaia cannot resolve the astrophysical phenomena with much shorter periods than around 40 days.

SJ=> every 100 minutes although the survey regions are restricted.

→ Small-JASMINE

Scientific objectives of Small-JASMINE

—Research Issues which Small-JASMINE can clarify for the Galactic nuclear bulge first in the world—

SO-2 Characterize the gravitational potential (of a bar structure)

What is the transport mechanism of gas from CMZ to the central region (radius of <~10pc)?

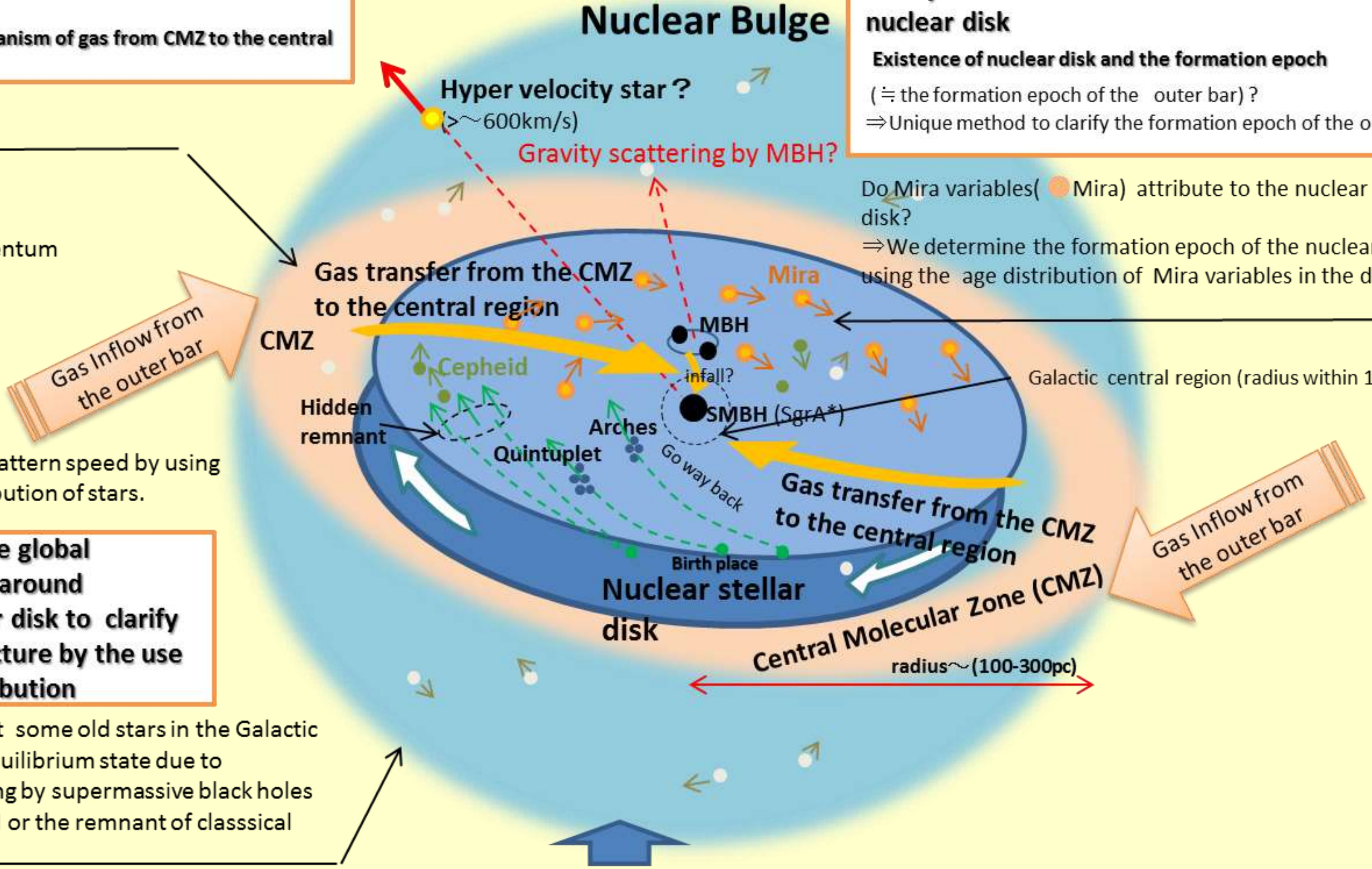
Collision of gas and shock-wave formation
⇒loss of angular momentum and energy of gas
⇒ inflow of the gas
Effect of the shock
⇒ it depends on the pattern speed of the nuclear stellar disk.
⇒ We investigate the pattern speed by using the phase space distribution of stars.

SO-1 Characterize the Galactic nuclear bulge to clarify the formation and evolution of the nuclear disk

Existence of nuclear disk and the formation epoch

(≒ the formation epoch of the outer bar) ?
⇒Unique method to clarify the formation epoch of the outer bar

Do Mira variables(Mira) attribute to the nuclear stellar disk?
⇒We determine the formation epoch of the nuclear disk using the age distribution of Mira variables in the disk.



SO-3 Characterize the global dynamical structure around the Galactic nuclear disk to clarify the origin of its structure by the use of phase space distribution

We verify whether or not some old stars in the Galactic nuclear are now in the equilibrium state due to the gravitational scattering by supermassive black holes
⇒Evolution of the SMBH or the remnant of classsical bulge?

***** Clarification of the formations of stars and stellar clusters in the nuclear bulge , and exploration of various kinds of celestial objects *****

Identify hidden remnants of stellar clusters
➔verification of Secular evolution

Clarifiy the birth places of stellar clusters, such as Arches, Quintuplet

Calrifiy whether Cepheids attribute the nuclear disk

What is the reason why hyper velocity stars (HVS)exit?

Exploration of various kinds of celestial objects
gravitational lens objects, compact objects, stellar physics, interstellar medium, etc.

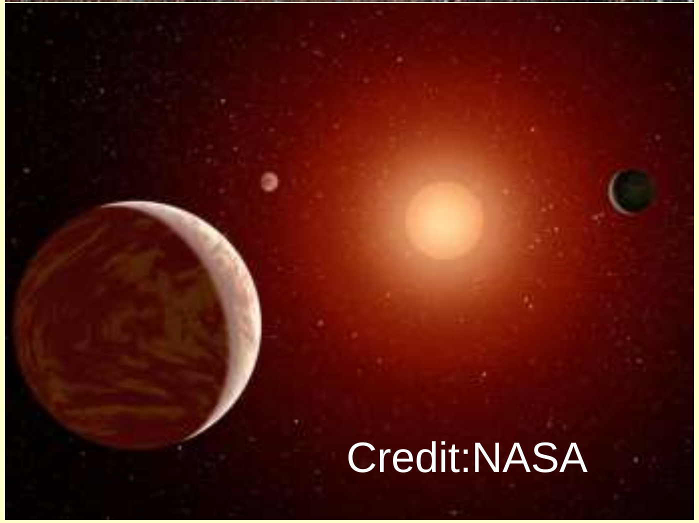
3. Science Goal and scientific objectives

JASMINE science goal:

To investigate from the origin of our Galaxy to the formation of habitable planets

3 main objectives:

- Galactic center archaeology
- Exploration of habitable planets around M-dwarfs (Transit method)
- Cultivating international-level future leaders through the international space mission led by Japan!



TRAPPIST-1の惑星系 Gillon et al. (2017)

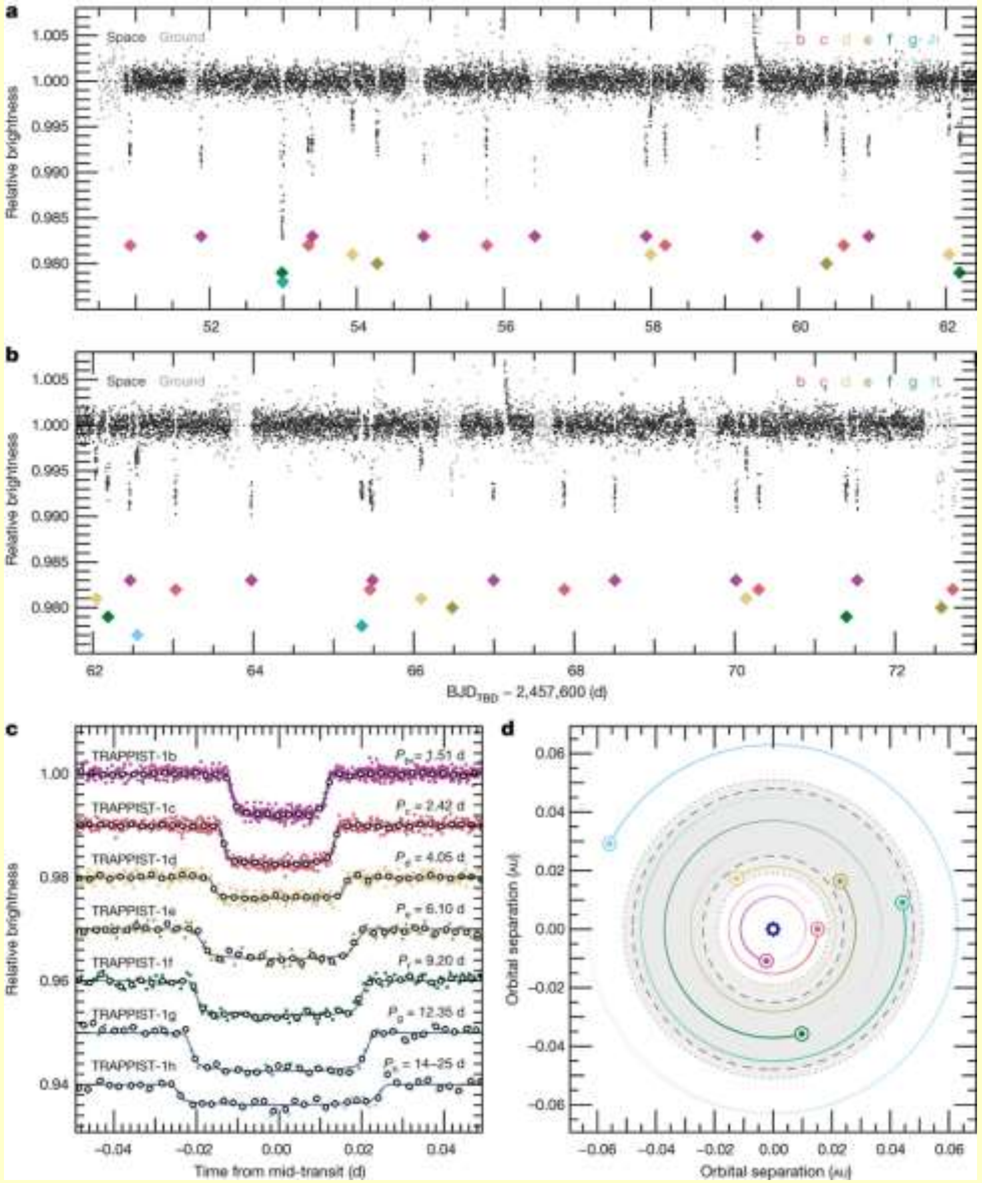


Figure 1: The TRAPPIST-1 system as seen by Spitzer

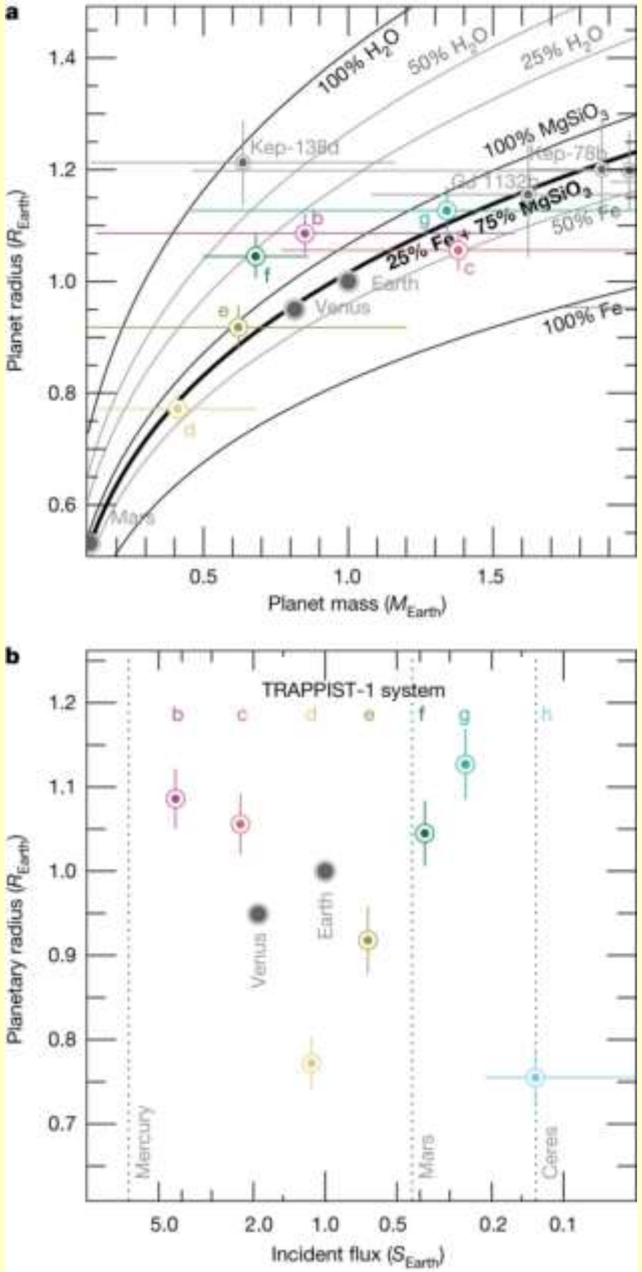


Figure 2: Mass–radius and incident-flux–radius diagrams for terrestrial planets

TRAPPIST1主星

Parameter	Value
Star	**TRAPPIST-1 = 2MASS J23062928−0502285**
Magnitudes[1]	$V = 18.8$, $R = 16.6$, $I = 14.0$, $J = 11.4$, $K = 10.3$
Distance (pc)[1]	12.1 ± 0.4
Mass, $M_{\square}$ ($M_{\odot}$)[†]	0.0802 ± 0.0073
Radius, $R_{\square}$ ($R_{\odot}$)[†]	0.117 ± 0.0036
Density, $\rho_{\square}$ ($\rho_{\odot}$)	$50.7^{+1.2}_{-2.2}$
Luminosity, $L_{\square}$ ($L_{\odot}$)[†]	0.000524 ± 0.000034
Effective temperature, T_{eff} (K)[†]	2,559 ± 50
Metallicity, [Fe/H][†] (dex)	+0.04 ± 0.08

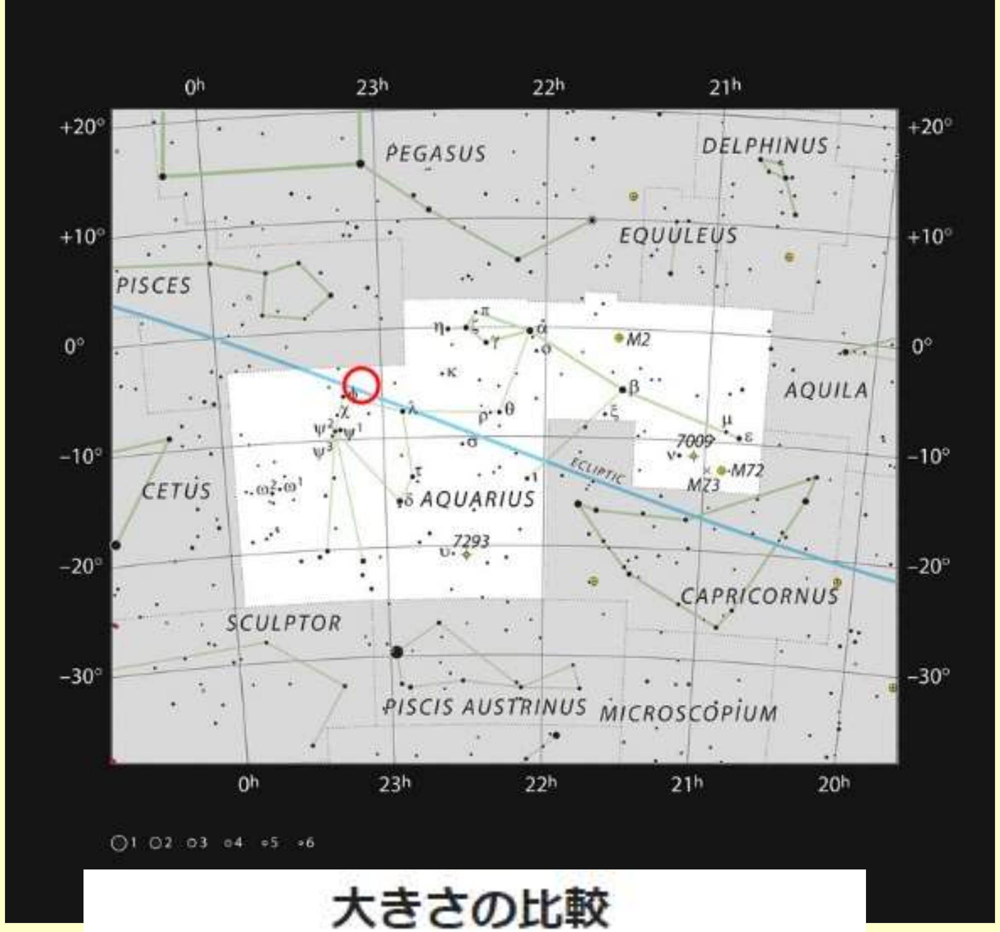
TRAPPIST1惑星

Planets	b	c	d	e	f	g	h
Number of unique transits observed	37	29	9	7	4	5	1
Period, P (days)	1.51087081 ± 0.60 × 10^{-6}	2.4218233 ± 0.17 × 10^{-5}	4.049610 ± 0.63 × 10^{-4}	6.099615 ± 0.11 × 10^{-4}	9.206690 ± 0.15 × 10^{-4}	12.35294 ± 0.12 × 10^{-3}	20^{+15}_{-6}
Mid-transit time, T_0 − 2,450,000 (BJD_{TDB})	7,322.51736 ± 0.00010	7,282.80728 ± 0.00019	7,670.14165 ± 0.00035	7,660.37859 ± 0.00038	7,671.39767 ± 0.00023	7,665.34937 ± 0.00021	7,662.55463 ± 0.00056
Transit depth, $(R_p/R_{\square})^2$ (%)	0.7266 ± 0.0088	0.687 ± 0.010	0.367 ± 0.017	0.519 ± 0.026	0.673 ± 0.023	0.782 ± 0.027	0.352 ± 0.0326
Transit impact parameter, b ($R_{\square}$)	$0.126^{+0.092}_{-0.078}$	$0.161^{+0.076}_{-0.084}$	0.17 ± 0.11	$0.12^{+0.11}_{-0.09}$	0.382 ± 0.035	0.421 ± 0.031	$0.45^{+0.22}_{-0.29}$
Transit duration, W (min)	36.40 ± 0.17	42.37 ± 0.22	49.13 ± 0.65	57.21 ± 0.71	62.60 ± 0.60	68.40 ± 0.66	$76.7^{+2.7}_{-2.0}$
Inclination, i (°)	$89.65^{+0.22}_{-0.27}$	89.67 ± 0.17	89.75 ± 0.16	$89.86^{+0.10}_{-0.12}$	89.680 ± 0.034	89.710 ± 0.025	$89.80^{+0.10}_{-0.05}$
Eccentricity, e (2σ upper limit from TTVs)	<0.081	<0.083	<0.070	<0.085	<0.063	<0.061	-
Semi-major axis, a (10^{-3} AU)	11.11 ± 0.34	15.21 ± 0.47	$21.44^{+0.66}_{-0.63}$	$28.17^{+0.83}_{-0.87}$	37.1 ± 1.1	45.1 ± 1.4	63^{+27}_{-13}
Scale parameter, $a/R_{\square}$	$20.50^{+0.16}_{-0.31}$	$28.08^{+0.22}_{-0.42}$	$39.55^{+0.30}_{-0.59}$	$51.97^{+0.40}_{-0.77}$	$68.4^{+0.5}_{-1.0}$	$83.2^{+0.6}_{-1.2}$	117^{+50}_{-26}
Irradiation, S_p (S_{Earth})	4.25 ± 0.33	2.27 ± 0.18	1.143 ± 0.088	0.662 ± 0.051	0.382 ± 0.030	0.258 ± 0.020	$0.131^{+0.081}_{-0.067}$
Equilibrium temperature (K)[†]	400.1 ± 7.7	341.9 ± 6.6	288.0 ± 5.6	251.3 ± 4.9	219.0 ± 4.2	198.6 ± 3.8	168^{+21}_{-28}
Radius, R_p (R_{Earth})	1.086 ± 0.035	1.056 ± 0.035	0.772 ± 0.030	0.918 ± 0.039	1.045 ± 0.038	1.127 ± 0.041	0.755 ± 0.034
Mass, M_p (M_{Earth}) (from TTVs)	0.85 ± 0.72	1.38 ± 0.61	0.41 ± 0.27	0.62 ± 0.58	0.68 ± 0.18	1.34 ± 0.88	-
Density, ρ_p (ρ_{Earth})	0.66 ± 0.56	1.17 ± 0.53	0.89 ± 0.60	0.80 ± 0.76	0.60 ± 0.17	0.94 ± 0.63	-

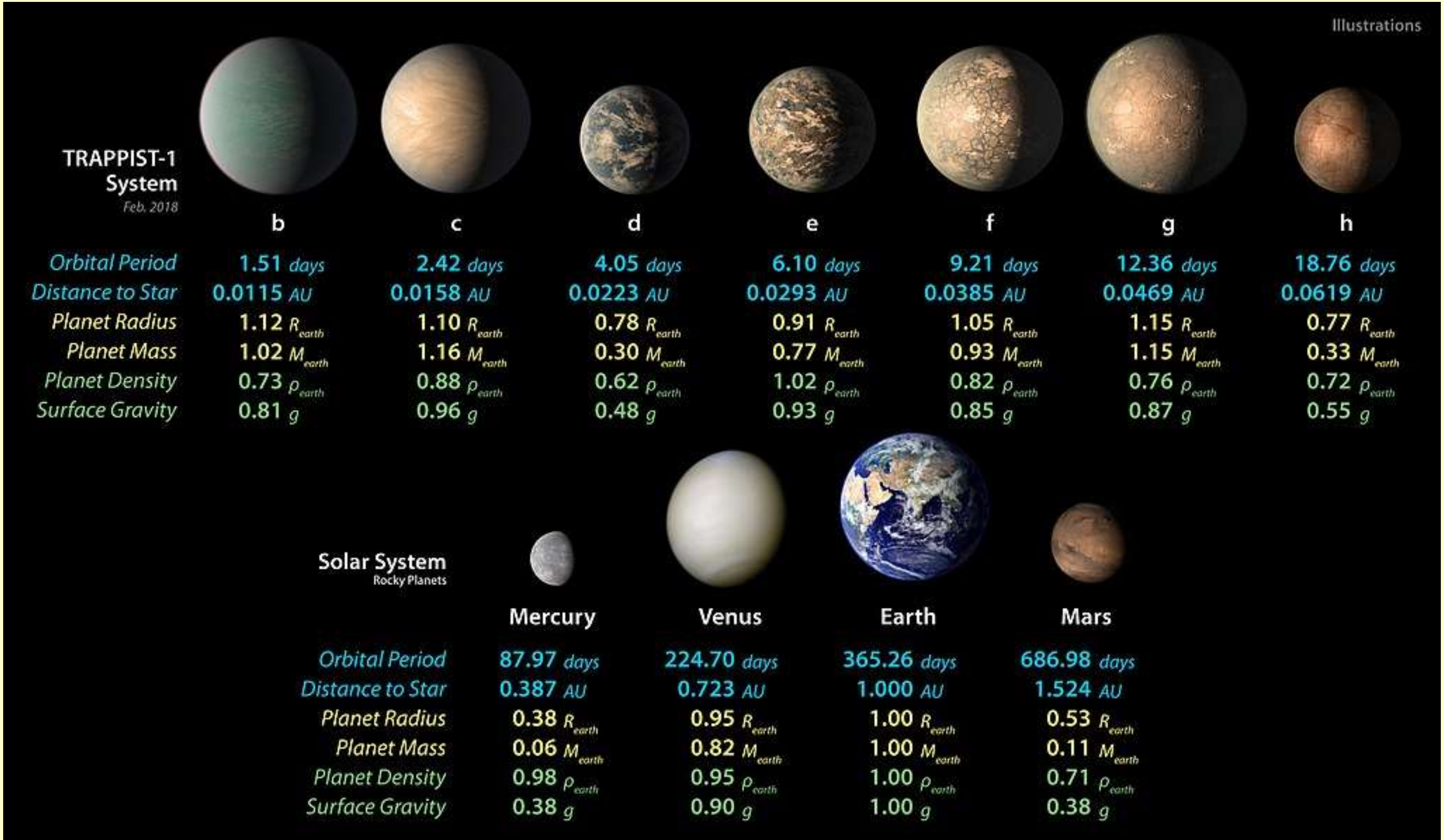
TRAPPIST-1の惑星系

TRAPPIST-1の主星:

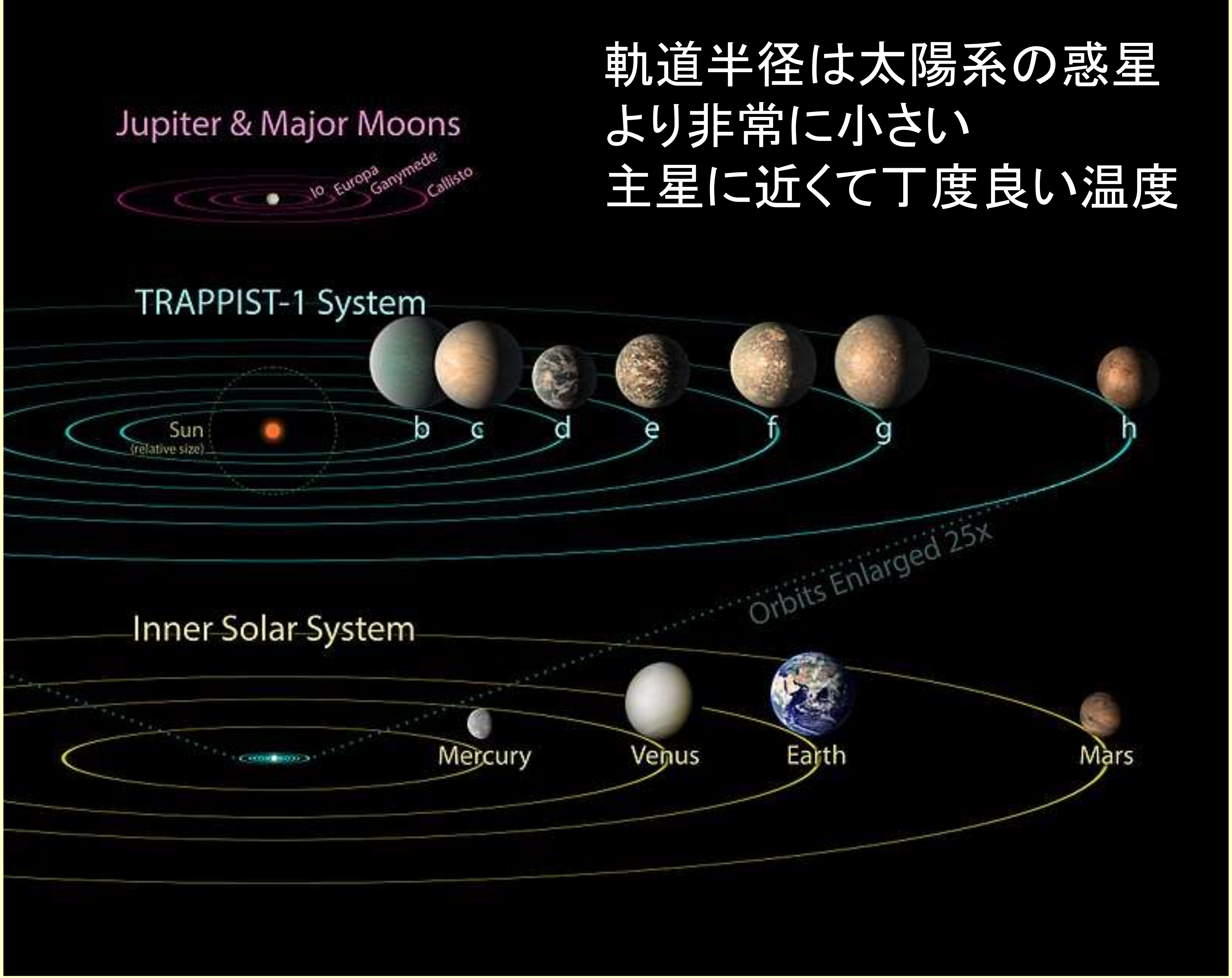
- 天球面での位置:　みずがめ座
- 明るさ:　19等級
- 距離:　約40光年
- 質量:　太陽の約0.09倍
- 半径:　太陽の約0.12倍
- 年齢:　約80億歳
- 表面温度:　約2500K



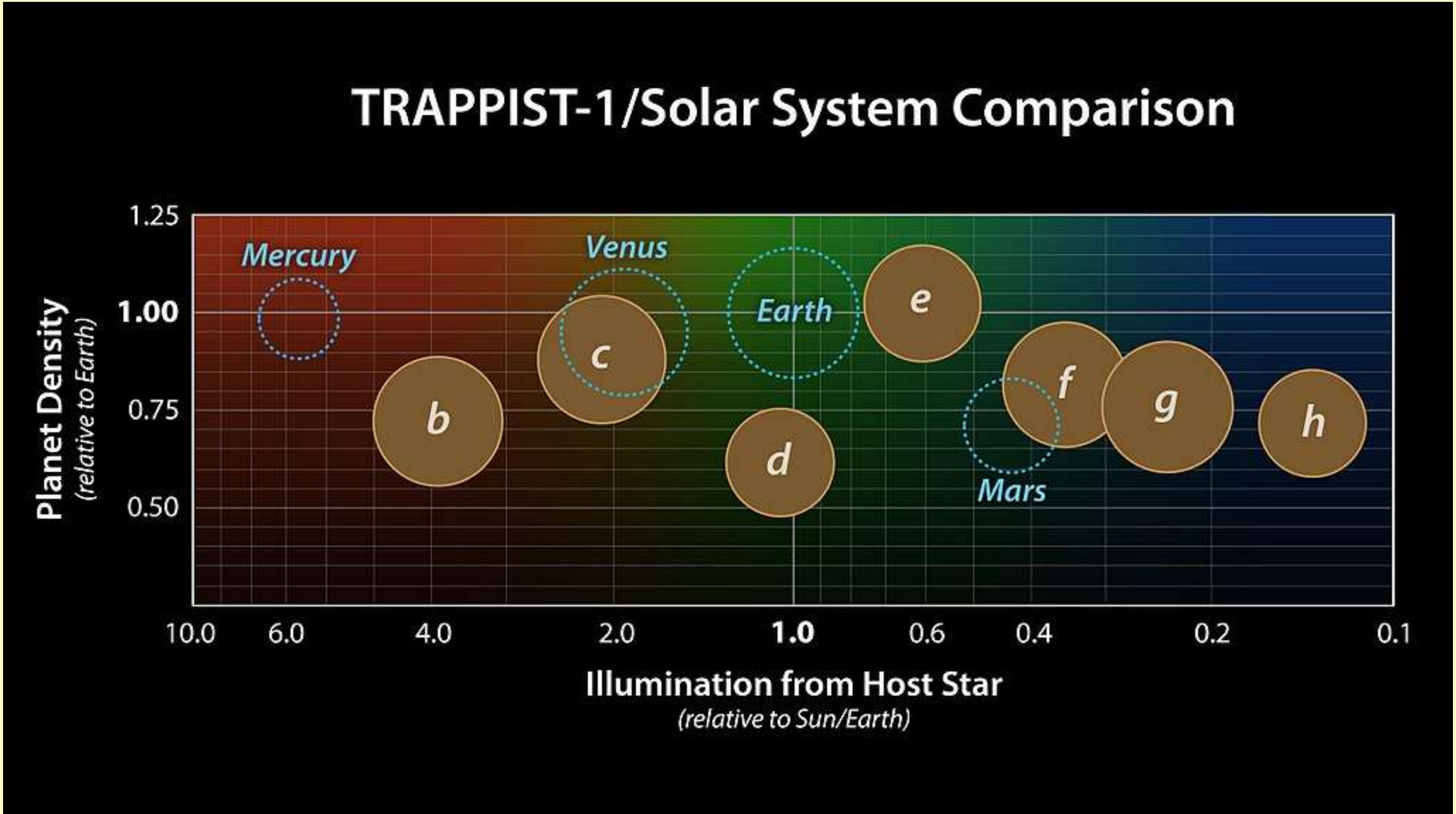
トランジット法によって7個の惑星が発見された



軌道半径は太陽系の惑星
より非常に小さい
主星に近くて丁度良い温度

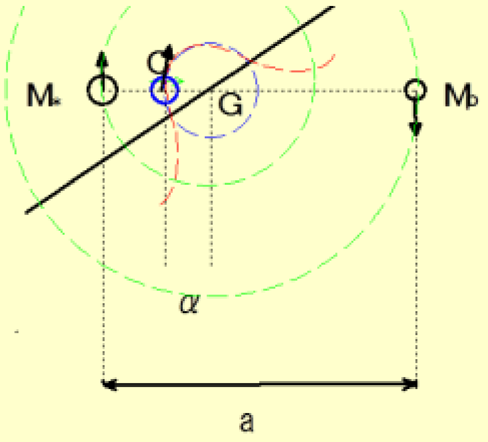


惑星系の比較： 主星からのエネルギー，大きさ，密度



Other Scientific objectives in the key Projects

(a) Discovery of unknown BHs



(i) Residual from a helical motion ➔ discovery of BH-star binaries

➔ analysis of orbit element ➔ clarification of BH mass

(ii) Astrometric microlensing

➔ *discovery of BH, clarification of BH mass*

****ref: the first detection of the astrometric microlensing effect due to celestial objects outside the solar system (HST: Sahu, et al., 2017)***

➔ Determination of the mass of the white drawf Stein2015B!

(b) Discovery of Hyper Velocity Stars(HVS) in the nuclear bulge

➔clarification of the origins of HVS and S-stars

*** Stellar binary+ SMBH or single star + IMBH-SgrA* binary**

(c) Analysis of symbiotic X-ray binaries

➔ the origin of X-ray emission spread along the galactic plane(!?).

Other Scientific objectives in the key project

(d) Motion of star clusters around the Galactic center

➔ the birth places of star clusters

(e) Discovery of unknown stellar clusters in the nuclear bulge

by detection of parallel movement of the stellar proper motions

➔ clarification of star formation rates

(f) Discovery of exoplanets by the use of astrometric method:

(g) Discovery of unknown objects

e.g. Wormholes?!

(h) Stellar physics, Star formation

* 3-Ddistribution of inter -stellar dust
* annual parallax and proper motions of Mira-type variable stars in the bulge

★Enlargement of scientific objectives of Small-JASMINE

Small-JASMINE=> proper motion of 70,000 bulge stars

＋spectroscopic measurements（radial velocities, type of stars, age of stars, etc.）,
multi-photometric measurements（type and age of stars）

Enlargement of information of physical characters of stars
=>
Enlargement of scientific objectives of Small-JASMINE by scientific collaborations with other projects and collaborative research with other researchers in the world

＊Increase of great scientific outputs by the use of the Gaia data in many fields
➔Enlargement of scientific communities which use astrometric data.
Progress of analysis tools for the investigation of the Galactic dynamical structures and open use of these tools to the public.
＝＞Lead to great scientific outputs by the use of data provided by Small-JASMINE

Project Scientist: Prof.Kawata(UCL)➔Production of White Paper

3.2 Operation mode in non-bulge observations

Option1: Transit observation of mid/late M-type stars (~3000K) to find terrestrial planets in the habitable zone

Establishment of science team independently of JASMINE team (exo JASMINE team)

PI.:Kawahara (Univ. of Tokyo),

Kotani(ABC), D.Suzuki, T.Yamada(ISAS), Masuda(Princeton Univ.), etc.

Option2: Clarification of very interesting and important target objective suggested by science communities.

Option3: Calibrations for the data analysis

Observation of highly obscured star formation region

1. Bulge young stars
2. Nearby clustering star forming regions (molecular clouds)

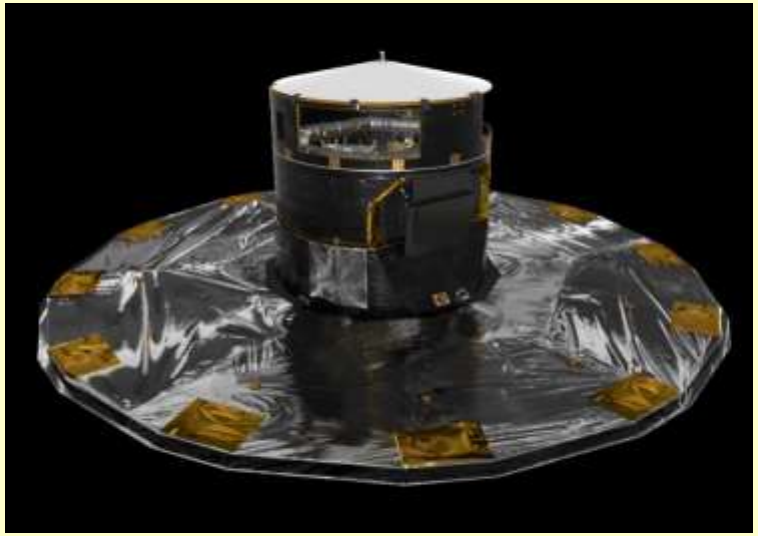
Gaia

★Gaia: astrometric satellite of ESA

・2013: launch

・2014: observation start

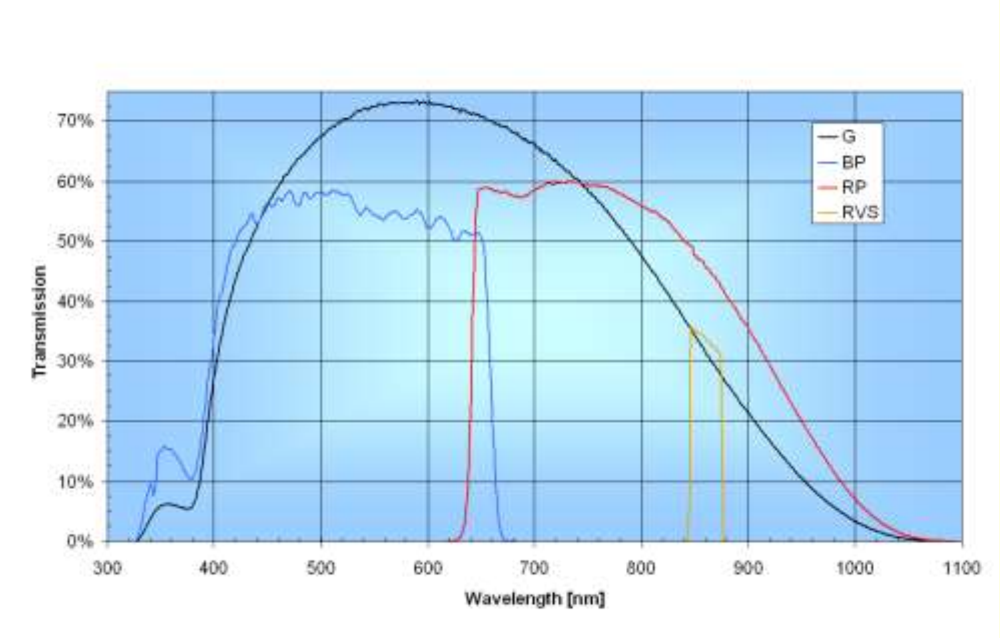
・2018: Data Release 2



All sky survey

G band（0.33 - 1.0μ）,

6 mag < G < 20 mag



stellar position,

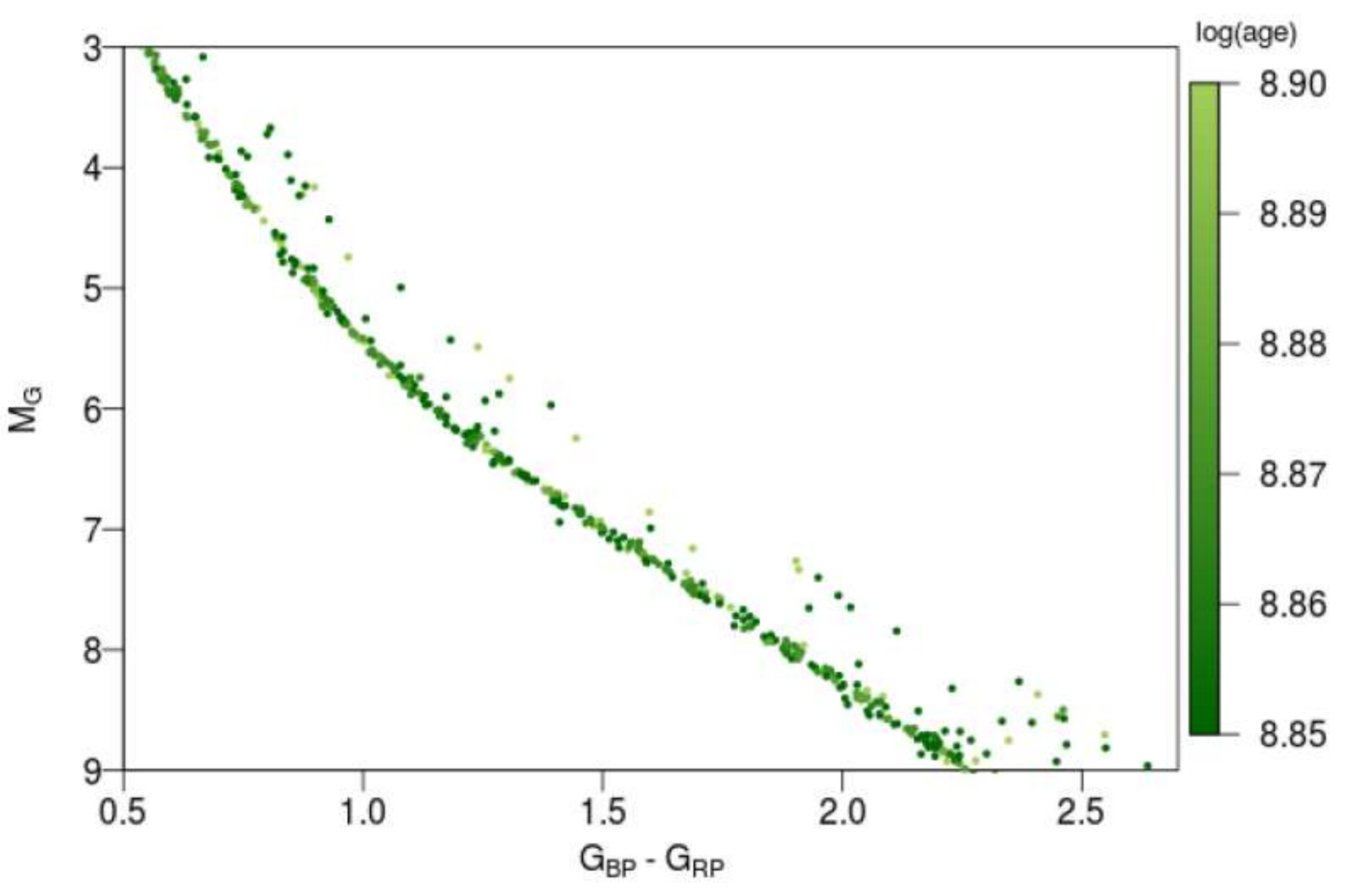
parallax（distance）,

proper motion, magnitude,

color, （radial velocity）

->accurate H-Rdiagram

H-R diagram Hyades＋Praesepe（Gaia Collaboration）



Orion region

Nearby active star formation region

Orion giant molecular cloud A

Orion giant molecular cloud B

Massive star

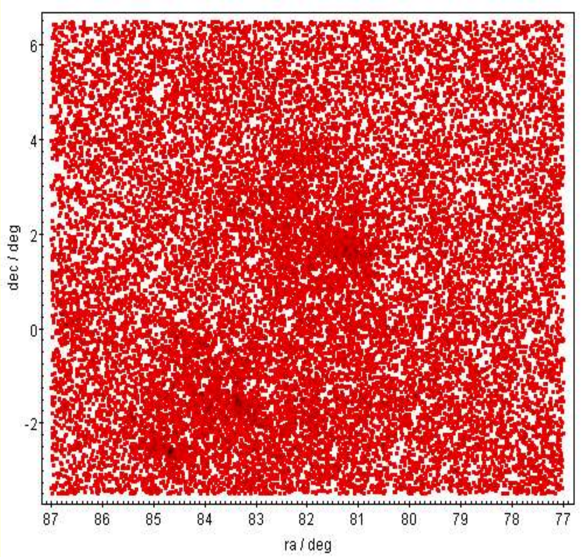
Orion OB1 association

Orion Nebula Cluster

Barnard’s loop（Supernova remnant）

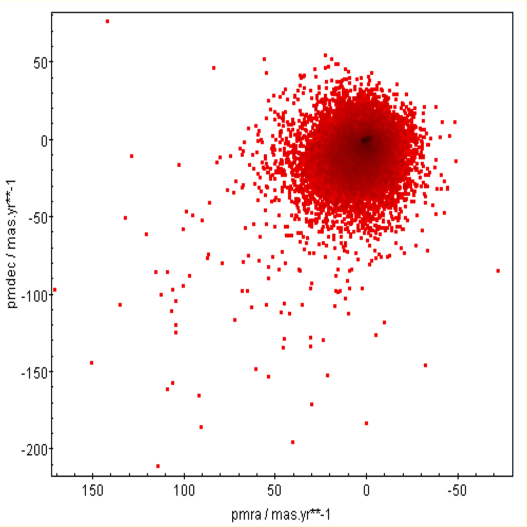
Sequential star formation?

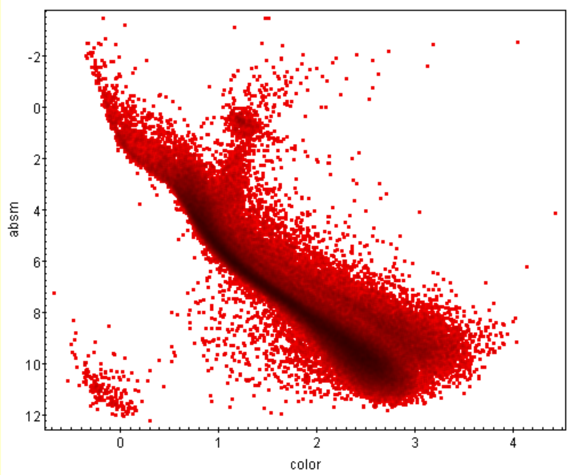
North area（Orion B and Ori OB association）
10 degree × 10 degree, 2 mas ≦ pi ≦ 3.5 mas



← Celestial plane

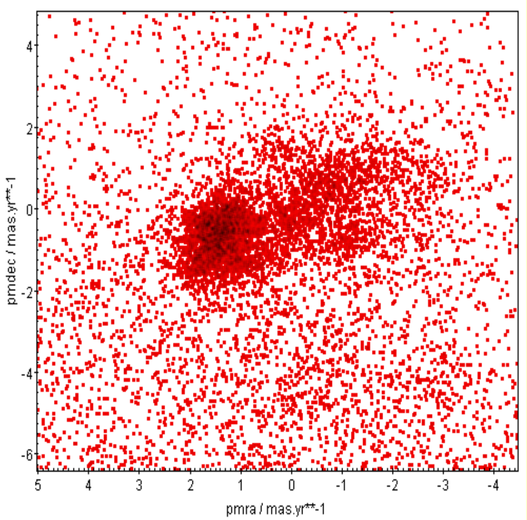
→ Proper motion



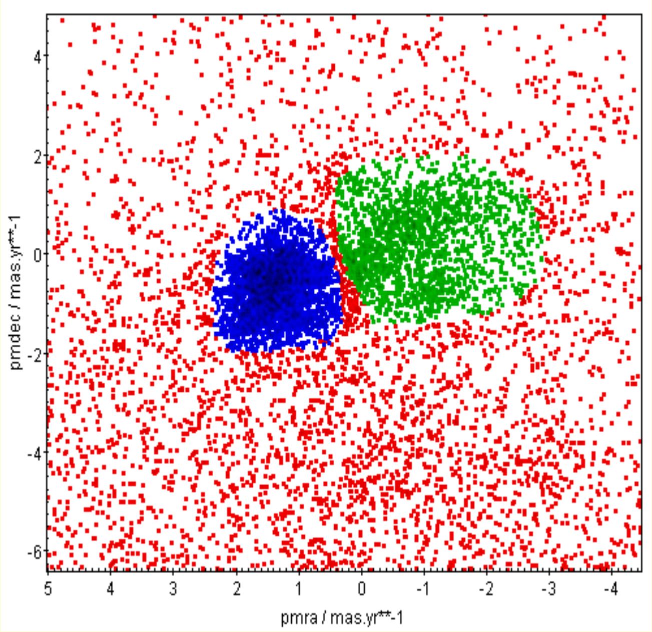


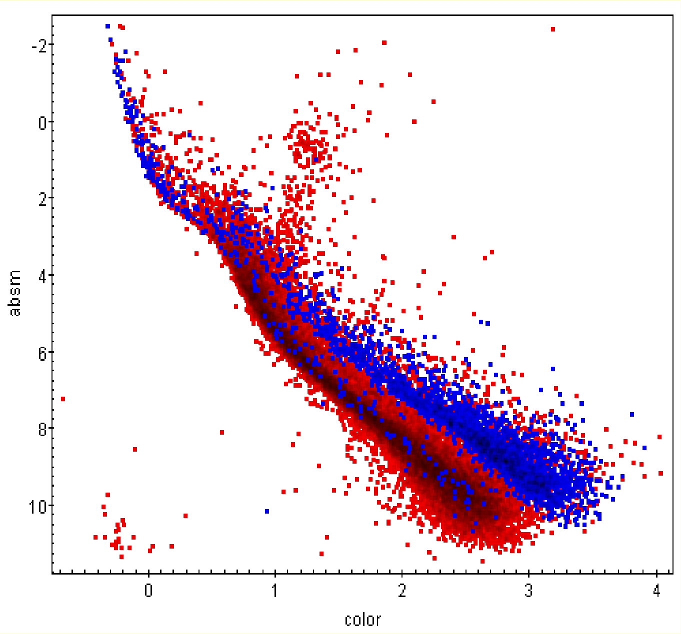
← H-R diagaram

→ Proper motion Scale up

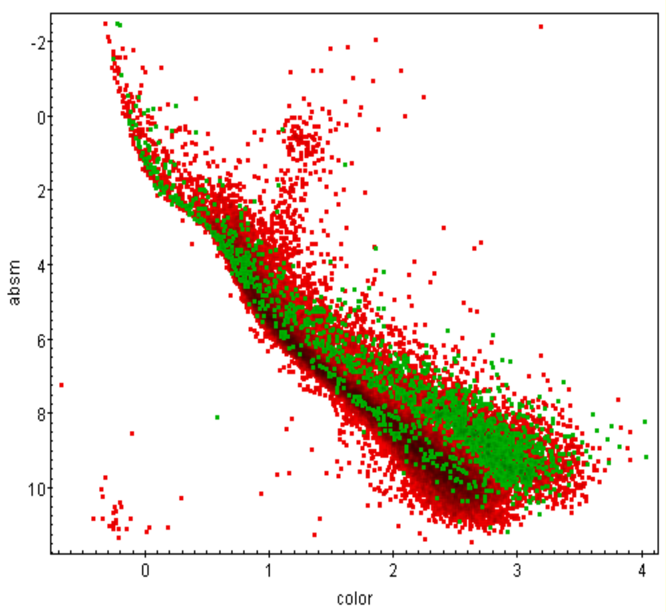


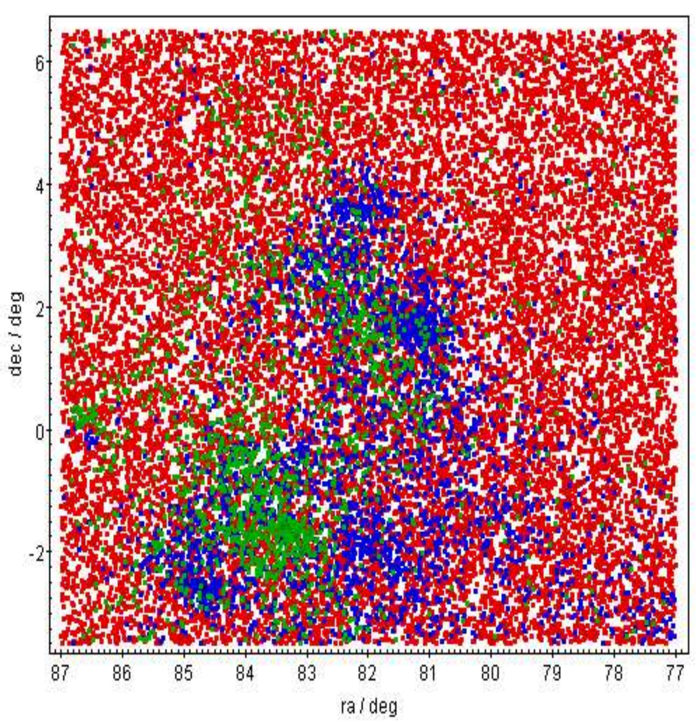
Select block stars on the PM plane

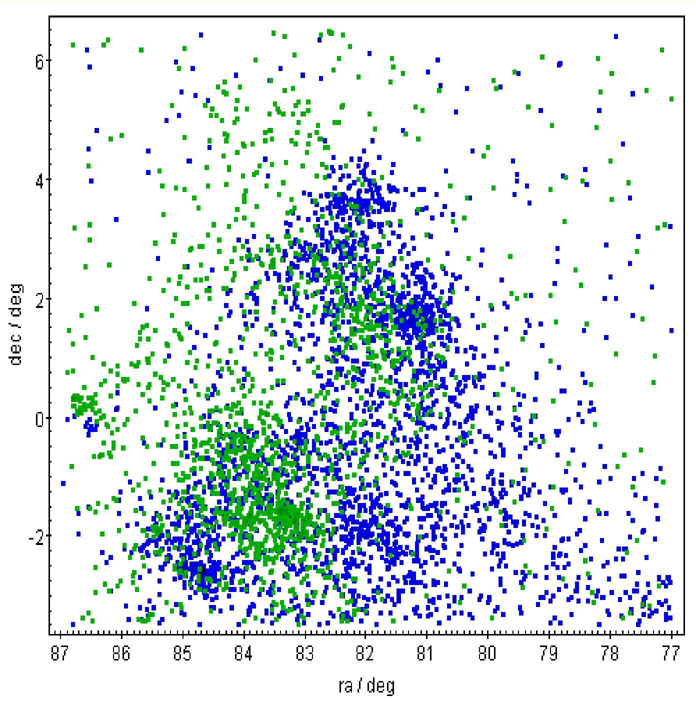




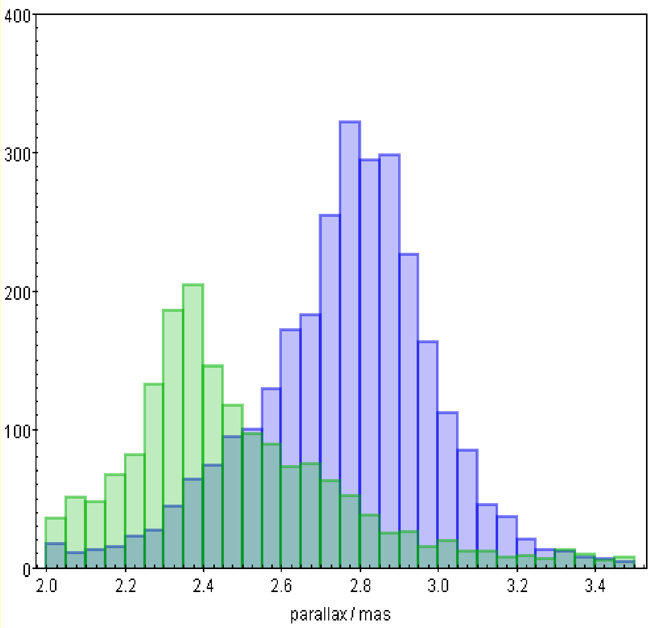
blue： younger stars
green： a little older stars



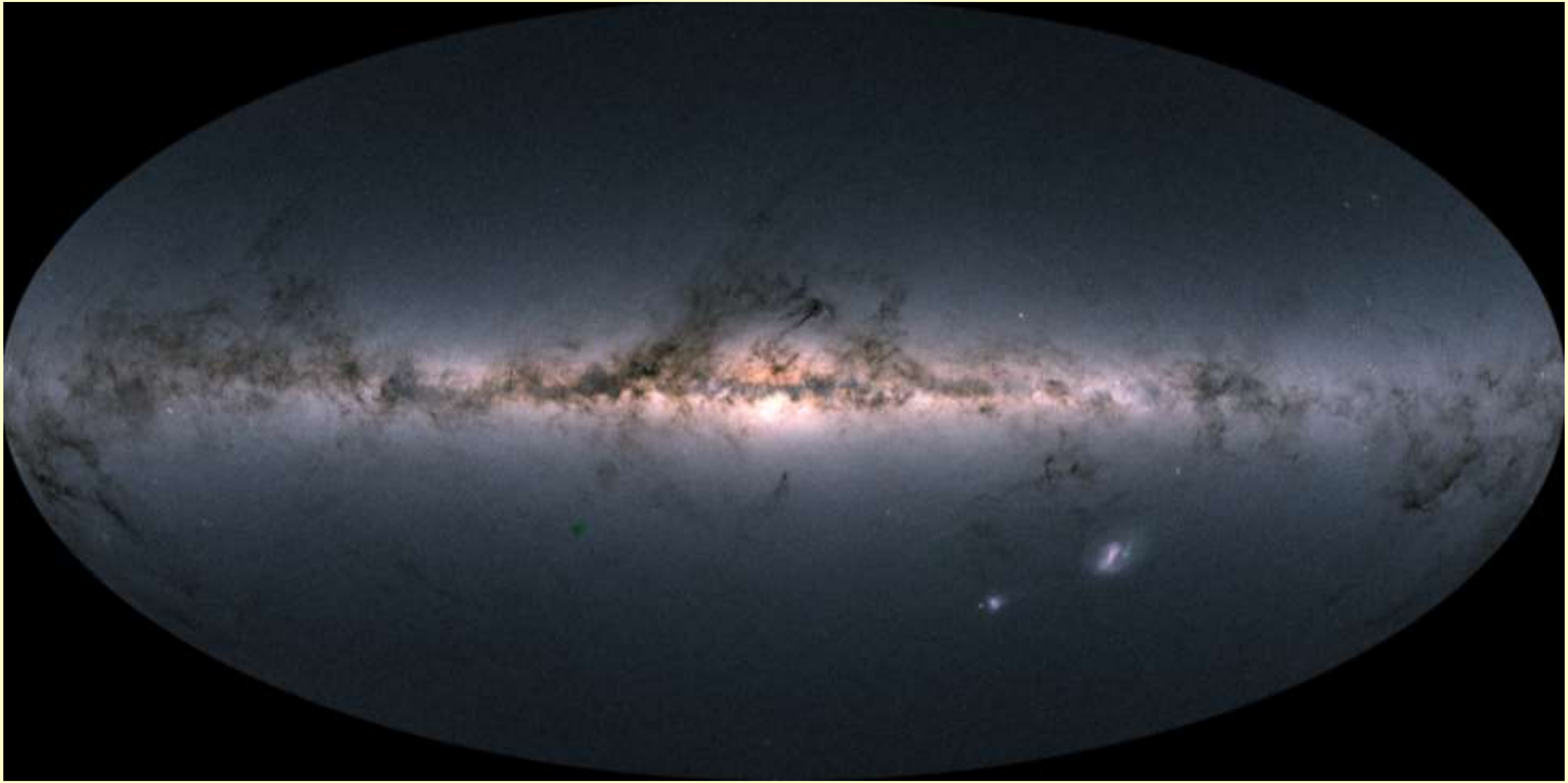




Distribution
on the
celestial plane



Parallax distribution

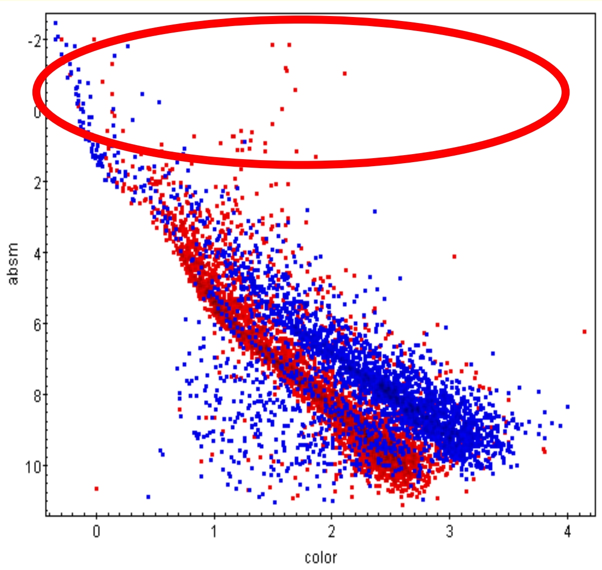


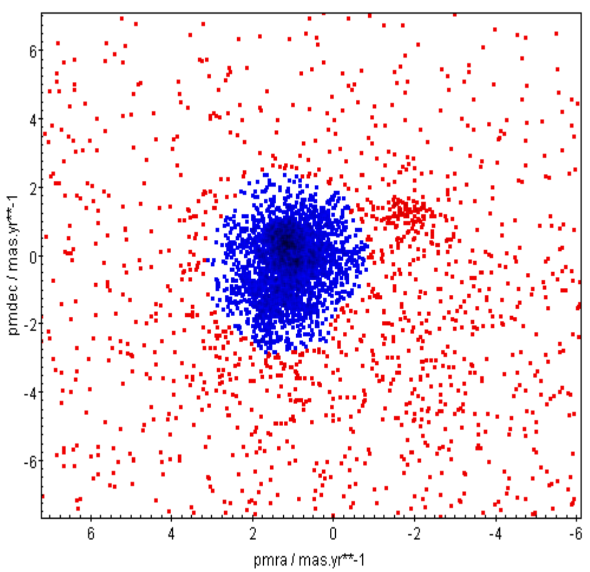
Gaia DR2

Search bulge young stellar groups by Small JASMINE

- Orion region: young stars can be selected
  as block stars on the PM diagram
  1mas / y velocity dispersion
  ▪low mass and middle mass young stars
  ▪possible for clouded region
- Bulge: about 20 times distant
  50 μas / y accuracy is necessary
- It is better, if radial velocities are available.
  But it is not absolutely necessary.

Small ASMINE：15 mag 125 μas / y (5 km / s)
(2.5 mas / y for Orion)





Orion A region

Pick up by parallax
proper motion distribution

→ Small JASMINE

Nearby clustering star forming regions

- Almost of stars are formed via clustering star formation.
- But almost of these stars will spread out and become field stars.
- These processes are very important to understand the evolution of galaxies.

Spread out process: Gaia

Initial condition: Small JASMINE

Nearby clustering star forming regions

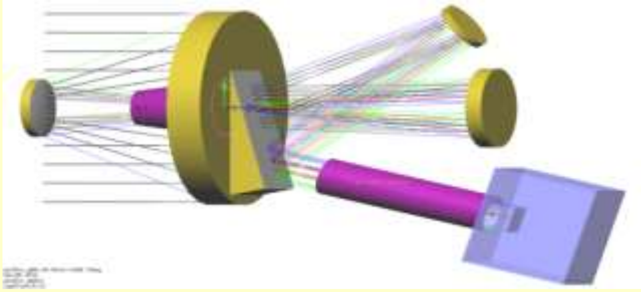
- Rho-Oph (150pc, 250 YSOs)
- Perseus (250 pc, 350 YSOs)
- Orion (400 pc, 3400 YSOs)
- Serpens (400 pc, 200 YSOs)
- others (NA Neb, Cep OB3, Mon R2,,,)

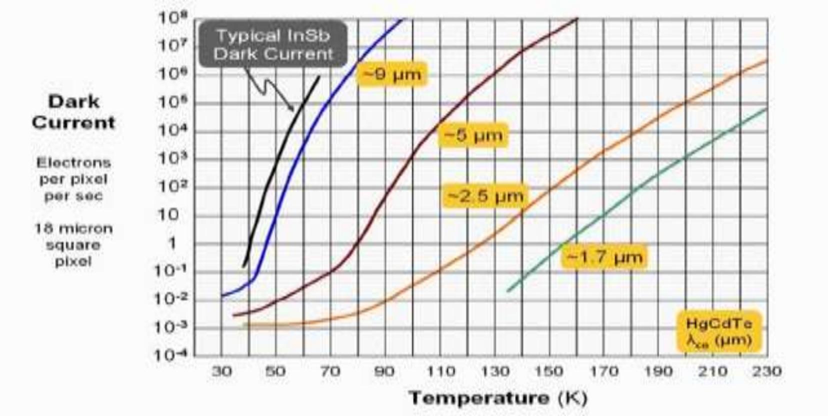
Spread out process: Gaia

Initial condition: Small JASMINE

4. Satellite System Overview

- Optics design: Modified Korsch System (3mirrors)
- Material: CLEARCERAM　　T～278K
  (Ultra－Low Expansion Glass－Ceramics)
- Aperture size: 0.3m
- Focal length: 3.9m
- Field of view: 0.6 degree ×0.6 degree
- Detector: T<180K





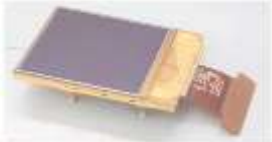
Hw-band: HgCdTe(H4RG), Number of detectors: 1
Band:1.1～1.7μm

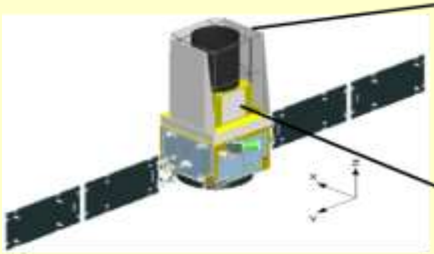
pixel size:10μm

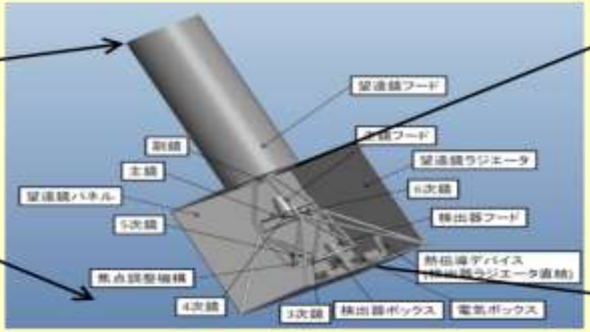
the number of pixels:4096×4096

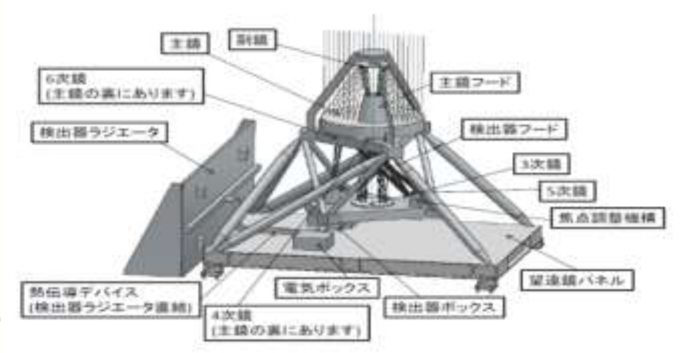
potential well:100,000

read-out noise :30e





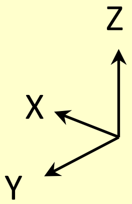




Structure model of the mission system

Bus System

• Semi-custom-made bus module* which has been developed for JAXA small scientific satellite series is adopted. * the Standard Bus for Small Scientific Satellites by NEC
• Saving of both, development time and cost is expected.



Artist concept of
Small-JASMINE satellite

Bus module specification

Bus weight		200~250kg
Bus Size		1000x1000x1000 mm
Mission	weight	< 200kg
	power	< 300W
	size	1000x1000xheight
Attitude control		Three axis control
	Accuracy	< 1 arcmin
	Stability	< 0.1mas/10msec
	Maneuvering	180deg/10min
Propulsion system		Option → RCS*
Duration of life		> 1 year → 3 year*

* Small-JASMINE adaption

(RCS = Reaction Control System)

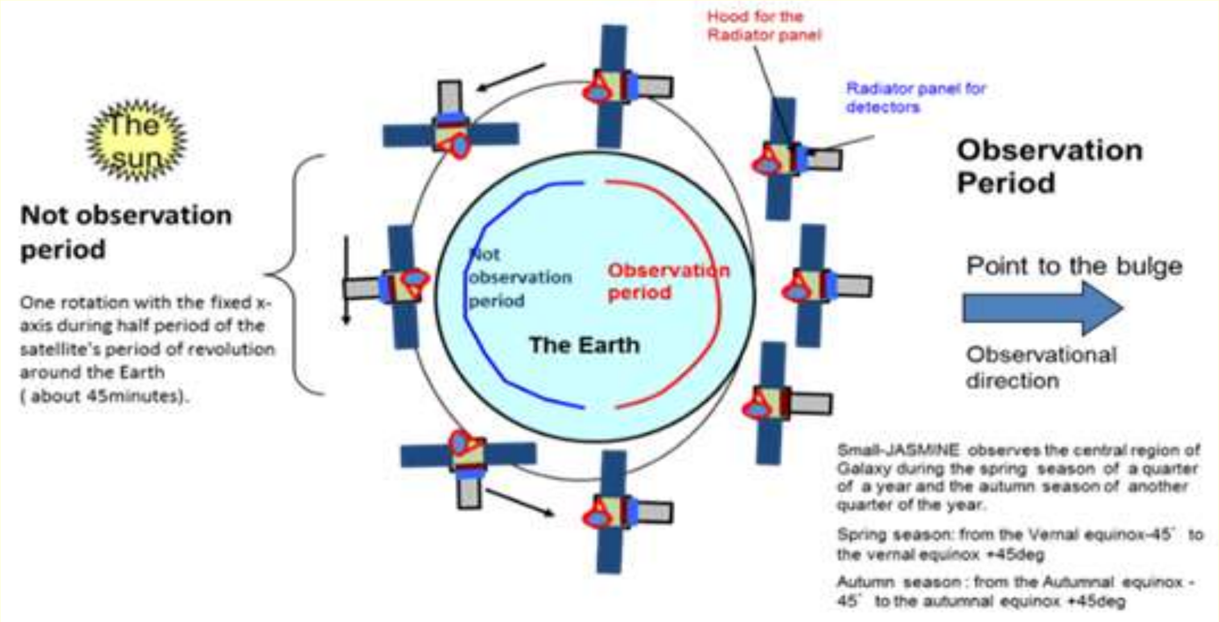
The target launch date is mid 2020s

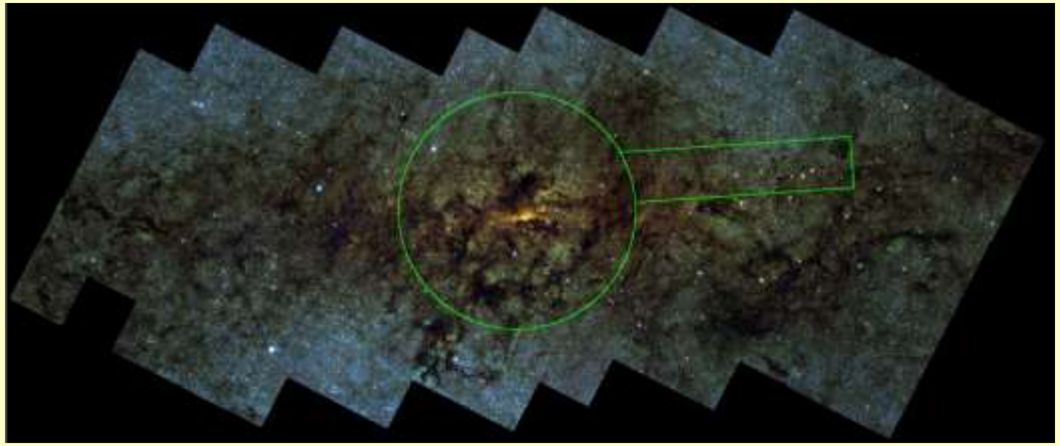
Mission life: ~3 years (at minimum)

Orbits: Sun synchronized orbit ~550km

Launcher: Epsilon launch vehicle(solid rocket) provided by JAXA

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





J, H, K tricolor composite image of the Galactic center area(imaged by SIRIUS on the Nagoya University IRSF 1.4m telescope: Nishiyama et al., 2004 Spring Astronomical Society Press Release).
The survey area of Small-JASMINE is written with the green line.

Small JASMINE

Development effort of NAOJ with JAXA (Japan Aerospace eXploration Agency) and universities.

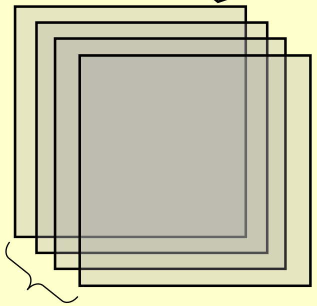
5 Observing strategy

We adopt "the point and stare" strategy and flames-link method(block-adjustment).

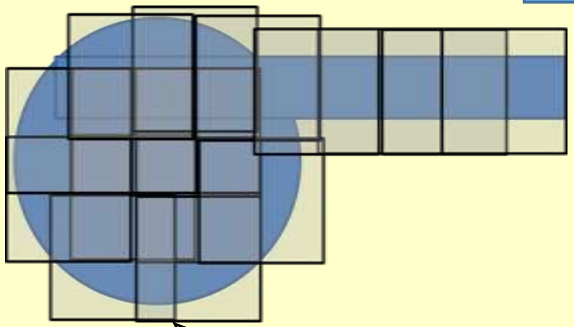
Frames-Link method

The whole survey region is composed by combining the small fields by using many stars in an overlap region between two consecutively observed adjacent small-fields. This method is suitable for surveys of the Galactic bulge because there is a sufficient number of stars to link small-fields with good accuracy.

Unit frame (image of FOV size taken in 7.1 seconds exposure):
(A) Estimate center of image position

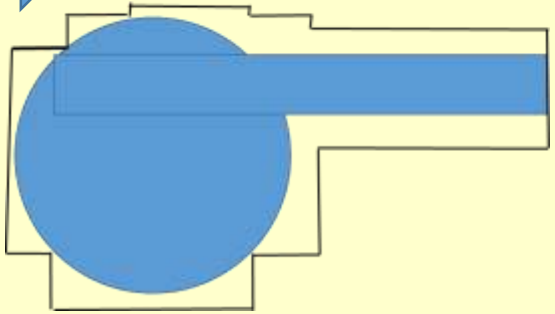


(almost same position) 20 unit frames
= small flame



Small frame (FOV size)

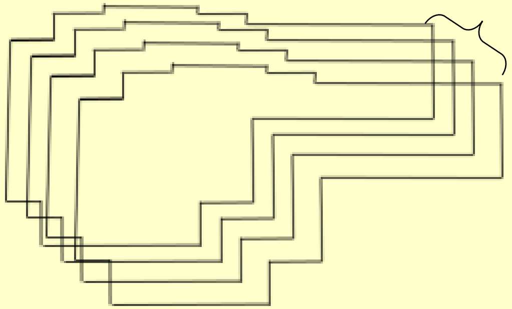
(B):16 small frames ⇒ large frame
(50min ≈ half of orbital period)
Correct optical distortion and image distortion



Large frame
(whole observational area of bulge direction)

3 years operation
(3 months in autumn and 3 months in spring in every year)

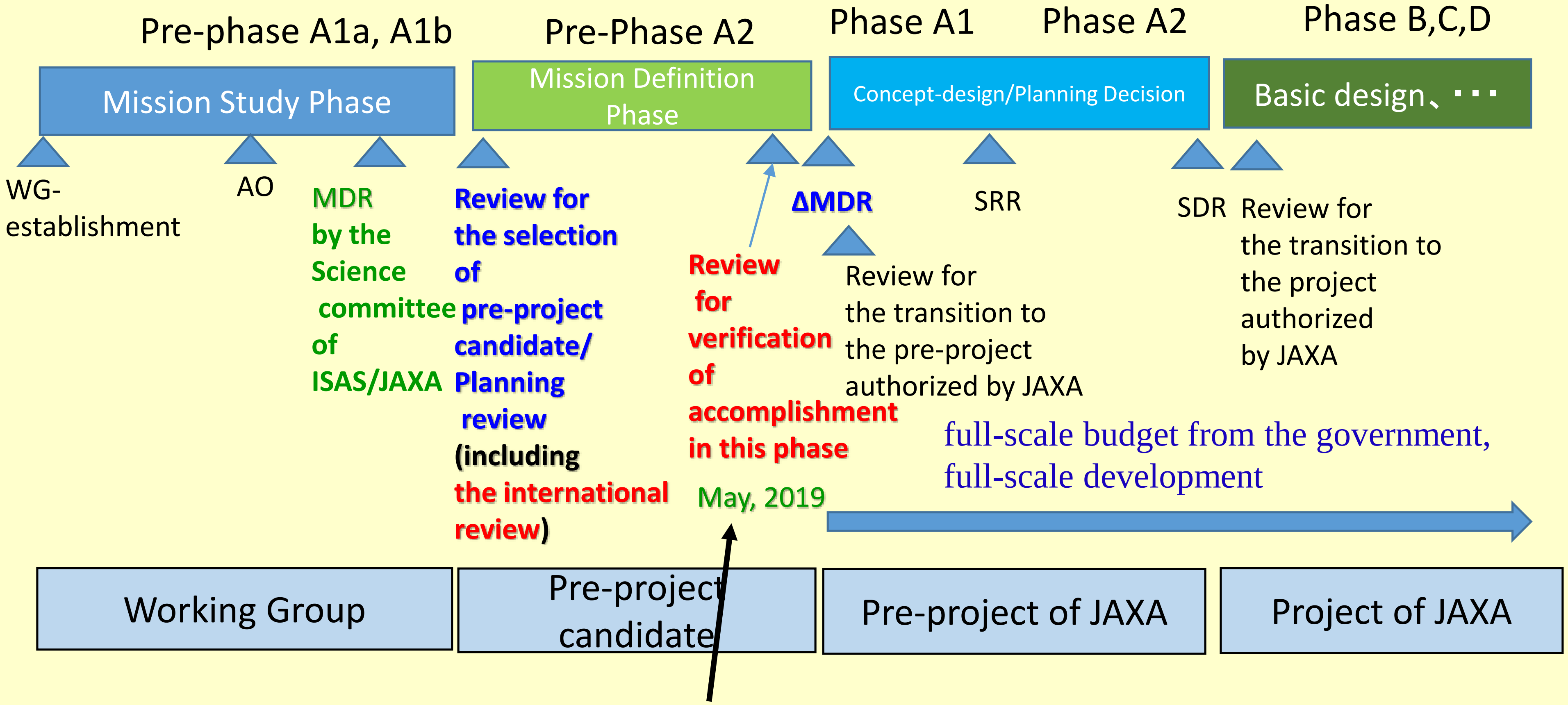
8000 large frames



(C):
Correct systematic error
Estimate parallax and proper motion

6 Present status of Small-JASMINE

～Multiple steps of reviews by JAXA～



Small-JASME successfully passed the review for verification of accomplishment of issues which should be solved in Pre-Phase A2 on 10th May 2019.

*ISAS: Institute of Space and Astronautical Institute (a branch of JAXA)

7. International Collaboration

○IAU Commission A1 (astrometry) recommends Small-JASMINE for its unique infrared space astrometry mission!

○Close collaboration between Gaia and Small-JASMINE

∗ Gaia DPAC members are supporting the development of data analysis for Small-JASMINE

∗ We had the Gaia-JASMINE joint meeting in Mitaka, Tokyo in Dec. ,2016

In particular, the ZAH-ARI Gaia team and the astrometry group of Lohrmann Observatory, Technische Universität Dresden, has sent us the Letter of Interest for the data processing for Small-JASMINE

○Cooperation with APOGEE-2(S) and BRAVA is very strong synergy for studies of the Galactic bulge.

Information of radial velocities , chemical composition and photometry (in other bands) is complementary to Small-JASMINE for the scientific targets in the Galaxy.

In particular, MOU for powerful scientific collaboration between APOGEE-2(S), SDSS-IV collaboration and Small-JASMINE has been concluded.

○ Collaboration with US team (USNO, SDL(Utah State Univ.), MIT, Virginia Univ. etc.)

*US team is now considering the support of development and tests
of the detector box unit including H4RG

We applied to MO of NASA.

Science researchers are included in the US team.
This science team in US is happy to collaborate with Japanese science team
through the (Small-)JASMINE consortium

○ Collaboration with ESA

***ESA is now considering the support of ground stations for the down link of scientific data provided by Small-JASMINE.**

ISAS/JAXA has started to negotiate with ESA.
ESA is very positive for the support due to Gaia teams' strong support of Small-JASMINE.

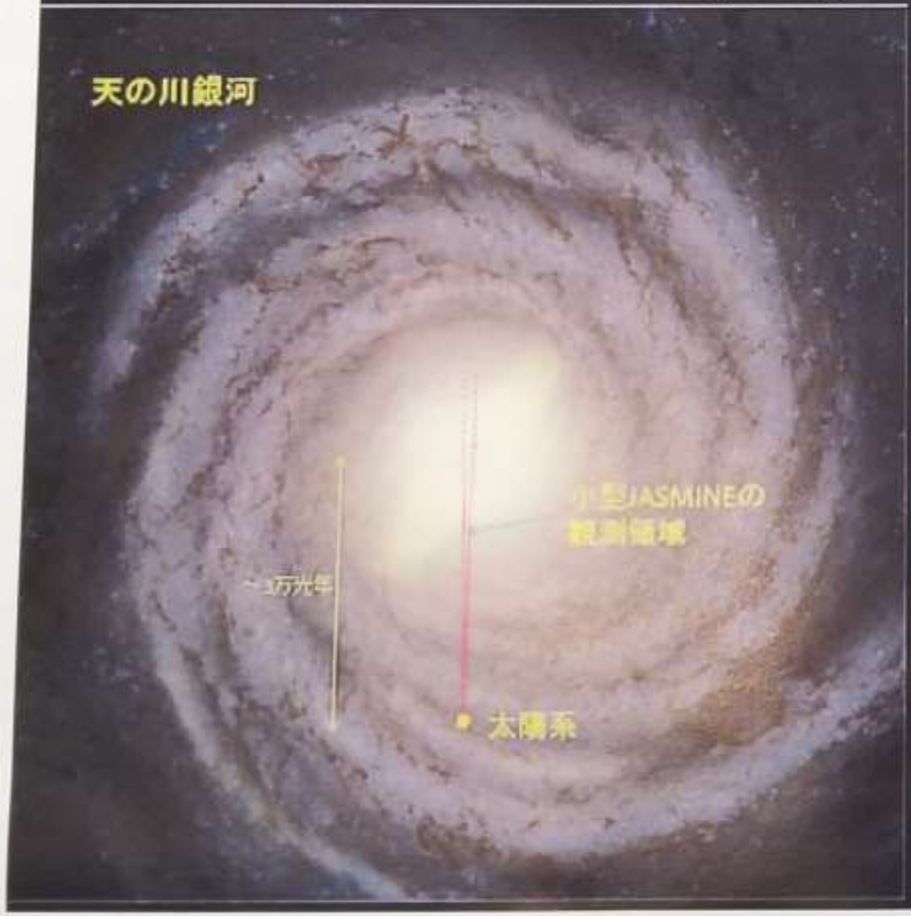
JASMINE Consortium (JC)

Japan Astrometry Satellite Mission for INfrared Exploration

(赤外線位置天文観測衛星)

"Kick-off Meeting"

Aug. 26 (Mon) 2018　AM10:00～PM6:00



SOC/LOC:

Daisuke Kawata (MSSL/UCL, chair)
Junichi Baba (NAOJ)
Yoshiyuki Yamada (Kyoto U.)
Naoteru Gouda (NAOJ)
JASMINE Project, NAOJ

Jasmine

Thank you for your support!