JASMINE series

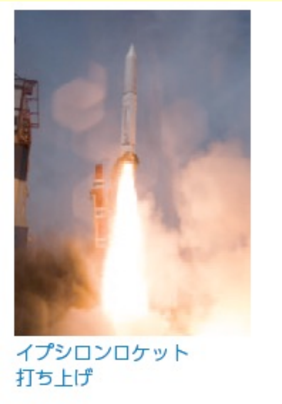
★JASMINE

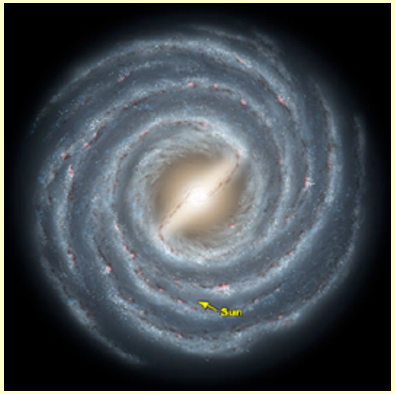
—Japan Astrometry Satellite Mission for INfrared Exploration—

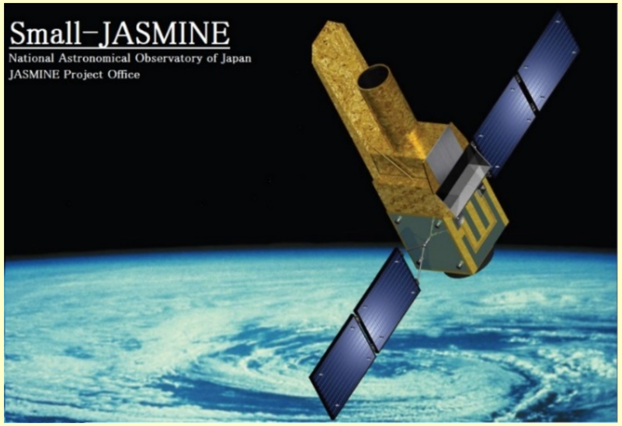
~Today I focus on the Small-JASMINE mission~

Naoteru Gouda

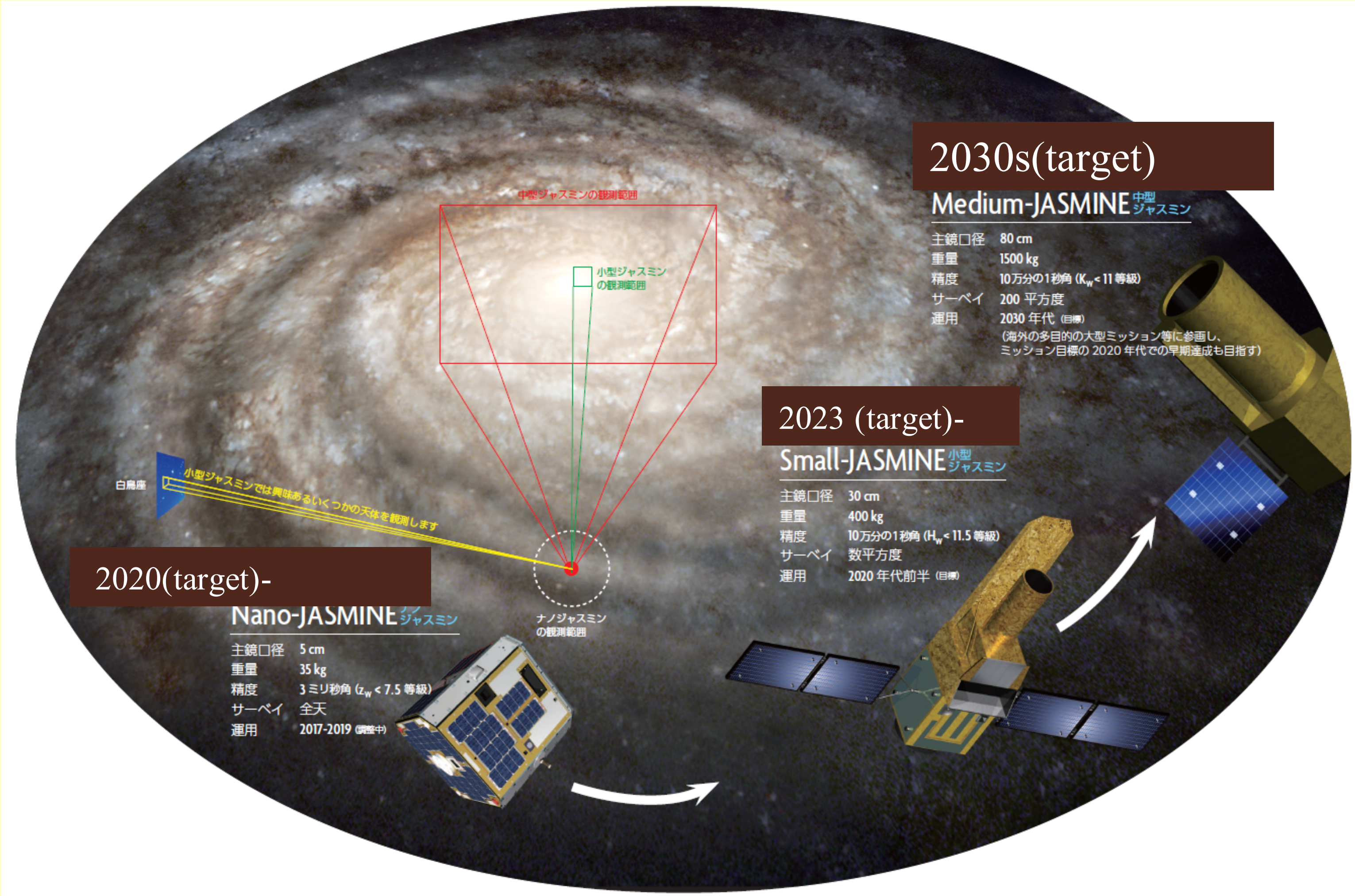
Director of JASMINE Project Office, NAOJ



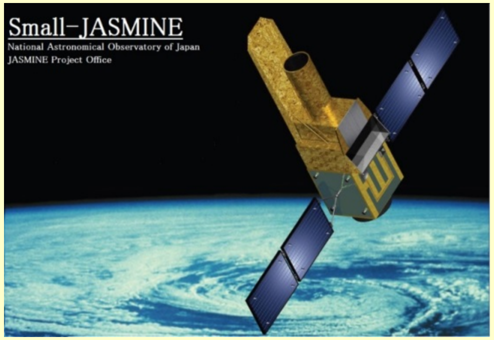




◎Japanese group is promoting space astrometry missions, JASMINE projects series, in international collaboration with Gaia DPAC team. JASMINE missions are complementary to Gaia mission.



1. Outline of Small-JASMINE



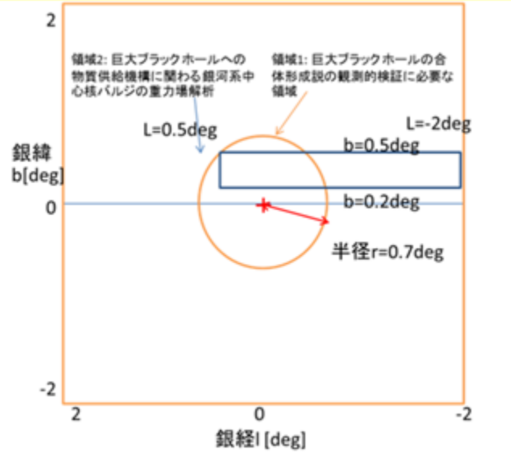
We have been aiming at the realization of the Small-JASMINE mission as a mission of the small science satellite program executed by JAXA.

Astrometric Measurement in Hw-band (1.1μm~1.7μm)

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**



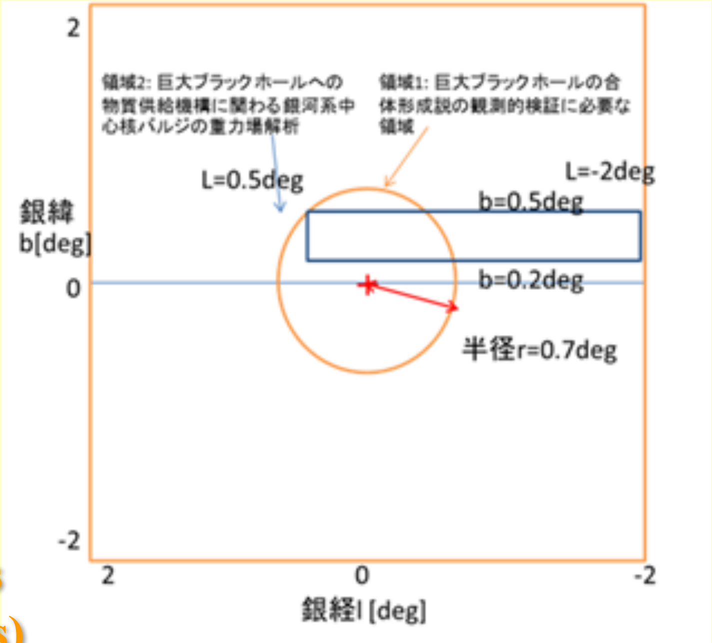
2. survey for **open use** in **summer and winter** → **some directions toward interesting target objects**

(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

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



Survey region 1:

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

・the number of observable stars

bulge stars: ~**4900(Hw<12.5mag)** **<=high precisions of parallax(20μas)**

(**disk stars in front of the bulge:～3500(Hw<12.5) common with stars measured by Gaia**)

➡ This survey region makes it possible to determine whether or not relatively small supermassive black holes merge to form the supermassive black hole at the Galactic center. Please refer to the scientific objective A-1.

Survey region 2:

Survey region: Galactic longitude **-2.0～0.5 degree**

Galactic latitude **0.2～0.5 degree**

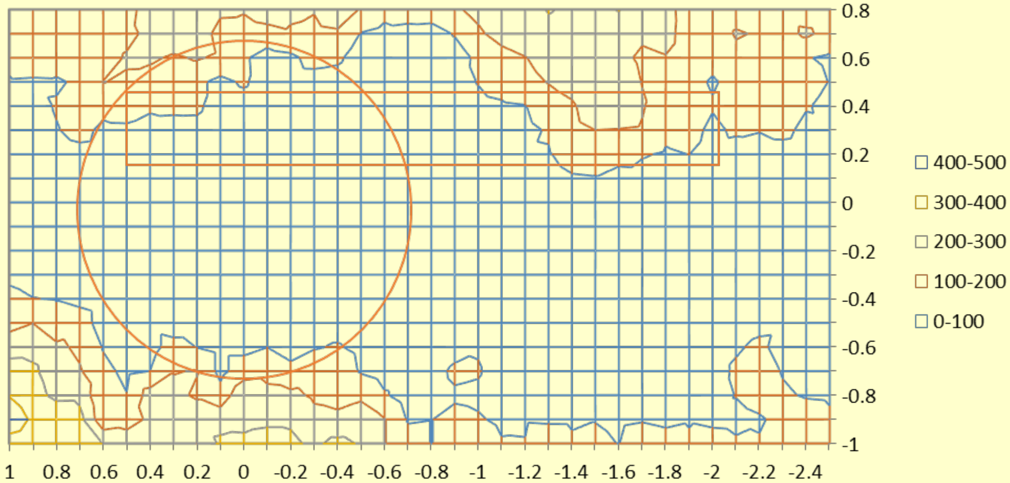
・the number of observable stars

bulge stars: ~**5000 (Hw<12.5mag)** **<=high precisions of parallax(20μas)**

(**disk stars in front of the bulge: ～1600 (Hw<12.5)**)

➡ This survey region makes it possible to determine whether an inner bar exists. Please refer to the scientific objective A-2

The number density of observable stars(Hw<12.5)



estimated by the use of the combination of 2MASS and the Guide Star Catalogue(GSC)

Galactic longitude

The number of stars /(1dgree × 1 degree)

Galactic latitude

	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	−0.1	−0.2	−0.3	−0.4	−0.5	−0.6	−0.7	−0.8	−0.9	−1	−1.1	−1.2	−1.3	−1.4	−1.5	−1.6	−1.7	−1.8	−1.9	−2	−2.1	−2.2	−2.3	−2.4	2.5
0.8	173	179	198	198	177	136	282	298	248	221	218	283	231	208	273	190	133	158	166	190	219	231	265	305	287	276	304	259	231	157	153	170	136	167	155	152
0.7	143	148	182	150	120	157	241	264	263	162	122	146	181	168	182	95	71	58	49	108	188	229	241	276	267	249	239	217	226	162	153	207	193	171	215	168
0.6	126	165	141	121	126	216	215	187	209	184	111	67	80	133	120	43	40	17	23	47	125	172	197	231	258	278	226	183	196	160	131	179	143	120	106	84
0.5	91	86	89	114	203	183	162	139	121	73	114	46	59	61	53	15	27	31	29	56	104	139	175	204	220	206	256	197	160	133	89	132	147	120	134	97
0.4	60	61	108	111	128	146	128	124	122	43	59	35	31	45	45	27	22	21	27	59	75	87	96	158	193	230	252	209	133	125	109	128	111	117	108	74
0.3	42	56	94	129	80	82	35	60	64	24	29	41	29	61	60	28	31	22	29	47	68	48	75	110	185	200	197	191	120	135	77	118	105	128	71	82
0.2	39	47	59	73	66	46	59	58	68	25	35	17	30	60	61	31	19	23	38	49	79	38	89	93	137	127	142	108	90	101	63	47	55	57	47	42
0.1	51	47	42	36	34	49	48	43	67	21	16	27	36	52	41	21	10	19	23	23	35	38	70	63	91	96	59	65	51	53	34	37	44	39	42	39
0	45	55	43	36	54	59	53	28	29	27	19	21	31	32	28	21	19	16	14	18	49	34	24	51	80	57	41	46	58	31	34	35	17	47	49	36
−0.1	43	46	29	50	61	47	28	34	28	33	23	31	34	43	35	15	19	23	28	32	32	37	38	47	63	80	53	54	63	22	39	30	25	26	35	73
−0.2	63	59	52	55	45	36	42	32	35	23	36	44	69	38	25	36	28	26	31	32	29	46	68	87	72	92	92	76	36	31	27	45	40	20	33	61
−0.3	80	63	70	58	47	38	32	52	39	52	40	42	71	62	28	42	42	37	35	68	59	47	36	63	41	50	42	49	35	54	39	29	27	45	36	51
−0.4	125	102	96	71	47	76	51	35	46	49	36	59	38	42	43	31	45	35	28	55	67	34	50	53	35	32	50	39	28	39	32	41	72	67	47	46
−0.5	170	199	123	154	51	79	64	37	40	50	37	45	61	66	63	51	51	55	36	61	70	41	52	49	33	34	34	25	35	23	31	57	74	80	79	52
−0.6	250	256	222	181	94	47	65	141	97	70	70	99	57	93	108	76	46	53	33	67	90	49	33	35	33	37	28	34	38	42	58	88	120	66	50	54
−0.7	356	325	225	209	123	80	101	196	204	70	154	170	130	152	165	89	58	52	65	117	109	45	40	45	42	22	52	30	20	46	56	116	140	94	56	84
−0.8	397	347	270	273	110	103	245	222	188	138	276	227	222	187	173	190	111	55	59	88	81	46	38	36	39	38	62	59	57	86	63	103	128	112	92	87
−0.9	455	386	396	333	127	151	220	260	252	263	280	286	286	224	218	229	204	92	98	123	109	83	86	79	78	97	83	93	80	93	81	77	92	121	149	116
−1	362	339	374	366	295	264	283	239	198	319	316	329	319	281	328	290	204	136	98	131	153	107	105	189	126	117	98	151	136	112	136	112	106	119	157	140

Astrometric Precisions in the key survey mode:

parallax and position:

< ~20 μas for Hw<12.5mag

proper motion:

< ~20 μas/yr for Hw<12.5mag

(photometry(Hw-band): ＜0.01 mag)

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

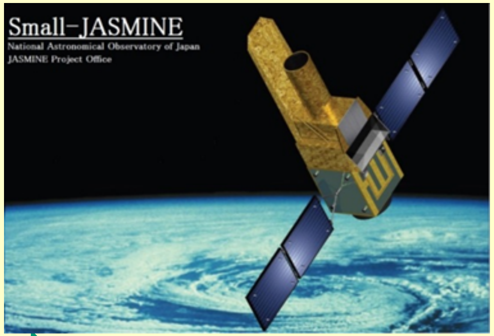
★Survey mode for open use in summer and winter seasons

We will accept mission proposals for open call to scientific communities in the world and the time allocation committee will select targets and their priority.

Examples of candidates of scientific targets:
X-ray binaries (e.g. CygX-1), γ-ray binaries, planetary systems of brown dwarfs, star-forming regions besides the area near the center, etc.

*the precisions of astrometric parameters of target objects depend on each target while the precisions are restricted by the designed system of the satellite.

★Complement of the Gaia mission in Small-JASMINE



* Gaia can measure only about ～80 bulge stars with high precisions(<20μas 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) => ～8900 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

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

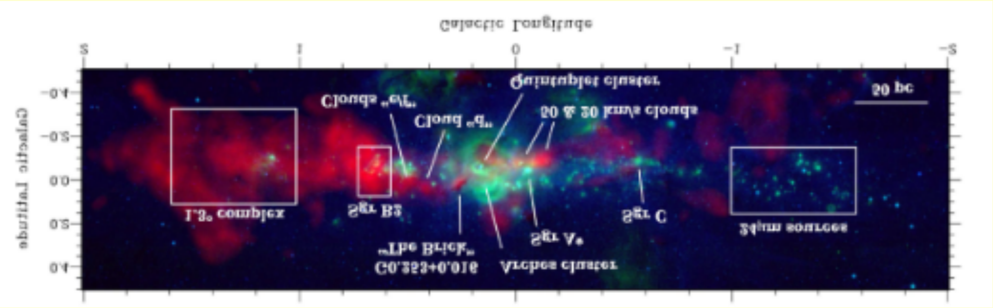
8

２. Scientific Objectives

SJ will provide scientific outputs over the widely spread fields of astronomy and astrophysics.

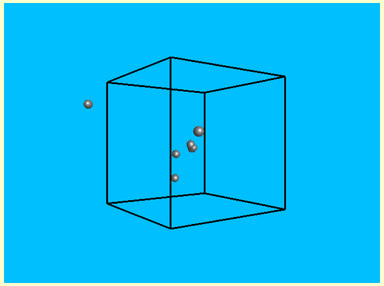
★Examples of scientific objective of Small-JASMINE

A. Astrophysics around the Galactic center



Scientific Objectives

A-1. Formation of the supermassive black hole at the Galactic center



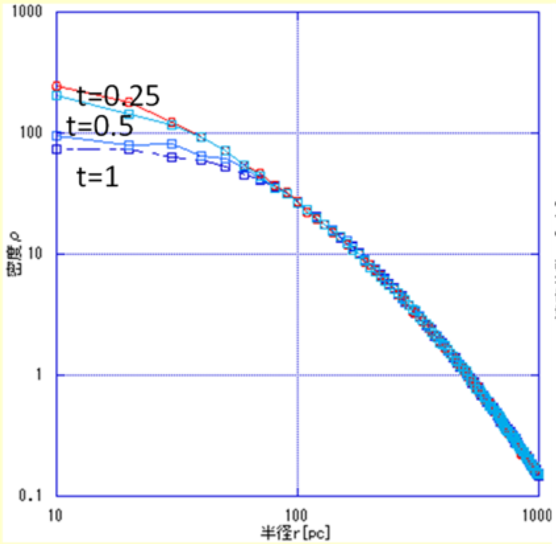
Merging of black holes and/or Accretion of gas?

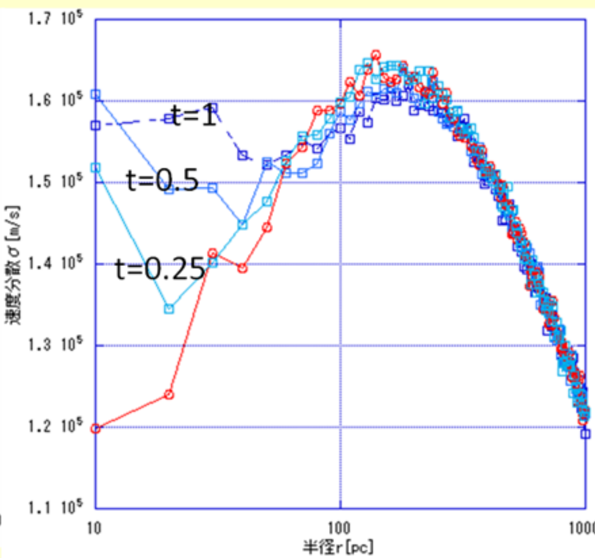
Small-JASMINE=>Proof of merging of intermediate BHs

1. If intermediate mass BHs(above 100,000 solar mass: the total mass is 4 million solar mass) exit and they have fallen into the Galactic center(<100pc) by the dynamical friction,
   ➔the effect of the dynamical friction (and the release of the gravitational energy of BH binaries) "heat up" the stars around the center area(<100pc).
2. The heated up density profile and the distribution of the velocity dispersion:
   the universal function independent of mass distribution and the number of BHs
   (core radius〜100pc:independent of the initial density profile of the bulge)
   ＊**Self-similar evolution to the universal functions**

(Merritt et al. 2004,
Tanikawa & Umemura 2014)

For example, SJ's data will determine whether the stellar distribution within 100pc from the Galactic center corresponds to the universal function with more than 99.7% confidence level.



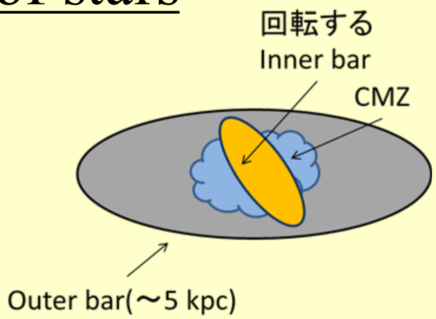


Scientific Objectives

A-2. Gravitational potential at the Galactic nuclear bulge

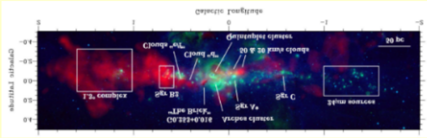
Small-JASMINE's data will constrain models of the gravitational potential in the Galactic nuclear bulge region (within ~300pc away from the Galactic center) with the phase space density of stars

***Gas accretion to the Galactic center**



Gas fueling is very important for the growth of SMBH,
activities of galactic nuclei, nuclear star bursts and
the formation of super star clusters in the Galactic central region.

*need to clarify transport mechanism of gas to the Galactic center



◎ candidate of key processes for transportation of gas :

rotating bar=>Losing angular momentum and energy of gas

➡ Existence of an inner bar? <=suggestion of existence by the spatial distribution of stars

Gas transportation from CMZ=>within 10pc

SJ will suggest the existence of the inner bar by the difference of the pattern speed.

For example, SJ will determine whether the pattern speed of the inner bar is much different from that of the outer bar with more than 99.7% confidence level.

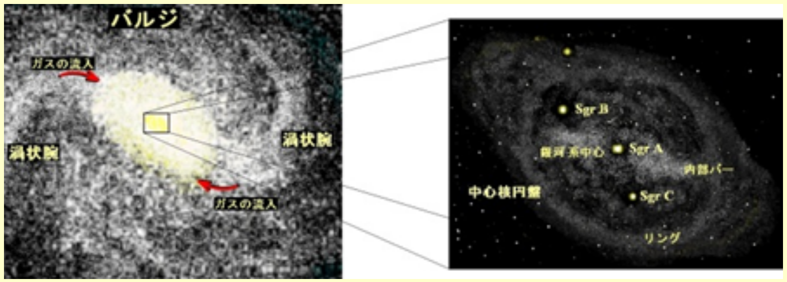
***the pattern speed of the outer bar: 35～50km/s/kpc**

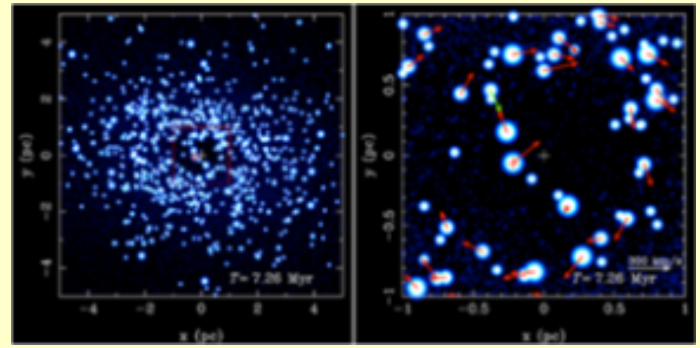
***the pattern speed of the inner bar if it exit:stability condition=>more than170km/s/kpc**

Scientific Objectives

A-3. Motion of star clusters around the Galactic center

➔ the birth places of star clusters





A-4. Discovery of unknown stellar clusters in the nuclear bulge by detection of parallel movement of the stellar proper motions

➔ clarification of star formation rates

A-5. Discovery of Hyper Velocity Stars(HVS) in the nuclear bulge

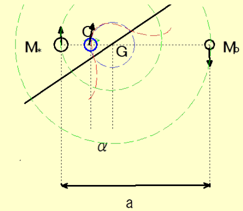
➔ clarification of the origins of HVS and S-stars

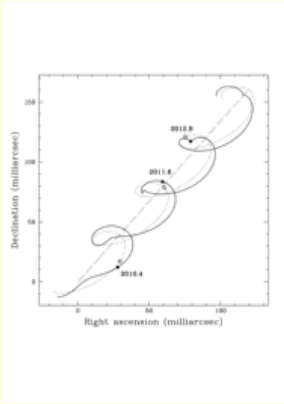
* Stellar binary+ SMBH or single star + IMBH-SgrA* binary

A-6. Analysis of symbiotic X-ray binaries

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

Scientific Objectives





A-7. 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

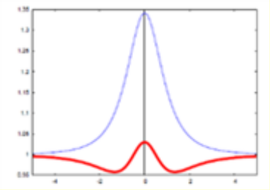
ref: the first detection of the astrometric microlensing effect due to celestial objects outside the solar system* *(HST: Sahu, et al., 2017)***

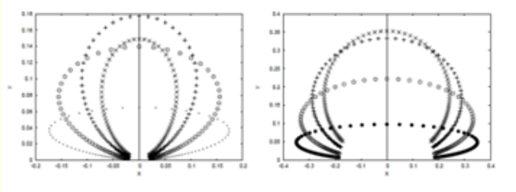
➔ **Determination of the mass of the white drawf Stein2015B!**

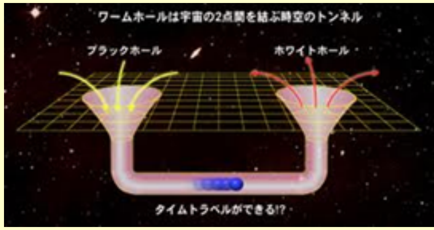
A-8. Discovery of exoplanets by the use of astrometric microlensing:

A-9. Discovery of unknown objects

e.g. Wormholes?!







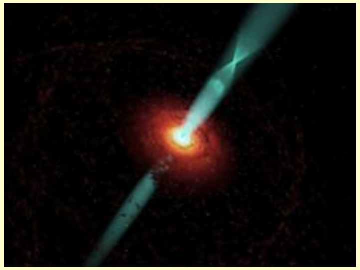
A-10. Stellar physics, Star formation

＊3-Ddistribution of inter -stellar dust

＊annual parallax and proper motions of Mira-type variable stars in the bulge

Scientific Objectives

B: Astrophysics besides the direction toward the Galactic nuclear bulge



Open use time (in summer and winter seasons): less than 50% of the total observation time

Good candidates: phenomena with short periods, bright objects in infrared bands

B-1. Compact celestial objects

Determination of the orbit elements of X-ray binaries and γ-ray binaries

➔ Big revolution! ➔physics of accretion disk and jets, etc.

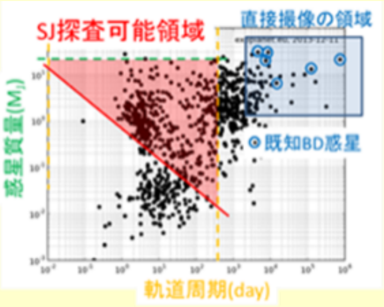
*a good candidate of X-ray binary : Cyg X-1:(l=71°, b=+3°)

period:5.6 days(unmeasurable by Gaia) companion star: mv~9mag , change of the position:

40~50μas measurable by Small-JASMINE

➔identification of compact objects

*γCas: WD or NS=>1s degree of confidence, HESS J0632: NS or BH (2s)



B-2. Extra-planets

detection of planets by astrometric method

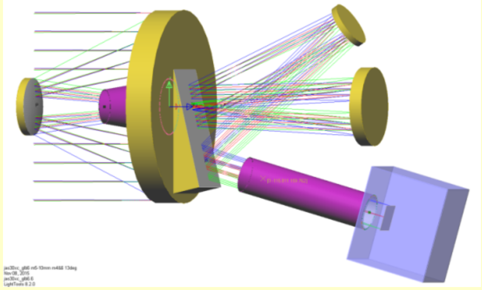
*determination of mass with precisions of <20% for stars measured by radial velocities

*primary star: low-mass star(late M-dwarf, brawn dwarf): H=10mag,V=16-18mag

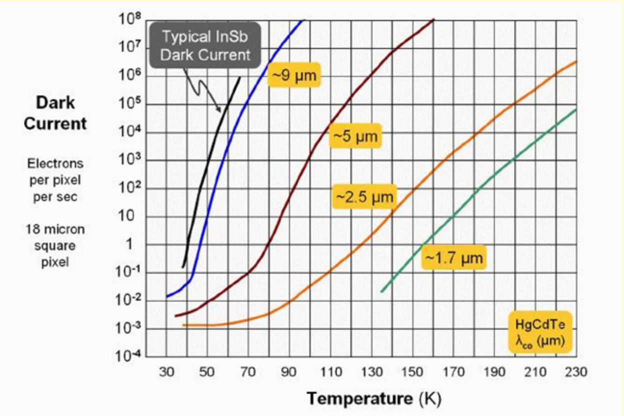
B-3. Analysis of stellar hot spots

Design of Small-JASMINE instrument

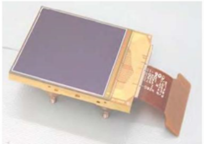
- Optics design: Modified Korsch System (3mirrors)



- 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



pixel size:10μm Band:1.1～1.7μm

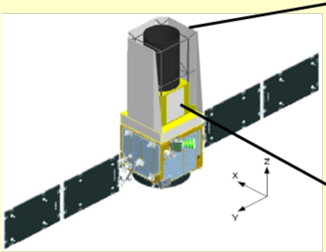
the number of pixels:4096✕4096

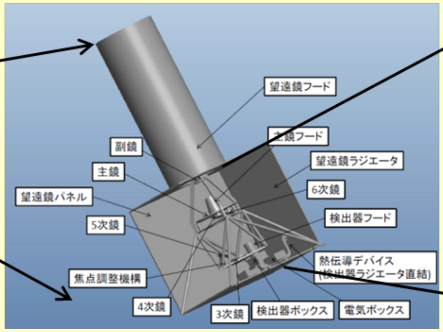
potential well:100,000

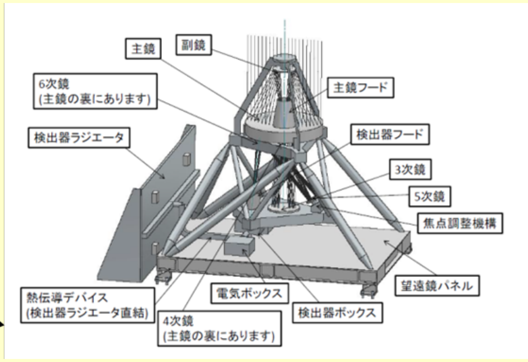
read-out noise :30e

J, H-bands for photometry

H1RG, Number of detectors: 2







Structure model of the mission system

The target launch date is around ~2023-2024

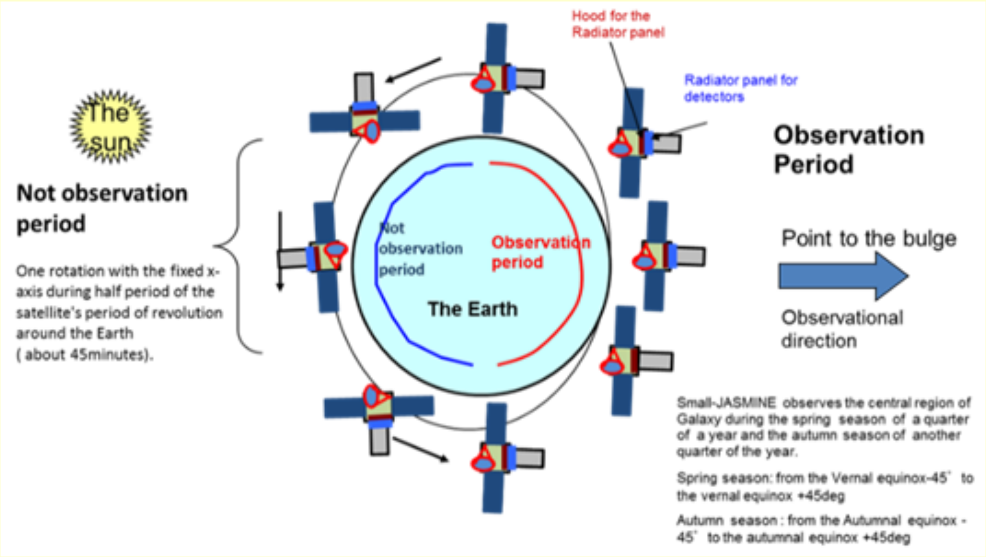
Mission life: ~3 years

Orbits: Sun synchronized orbit ~550km

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

イプシロンロケット
打ち上げ

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



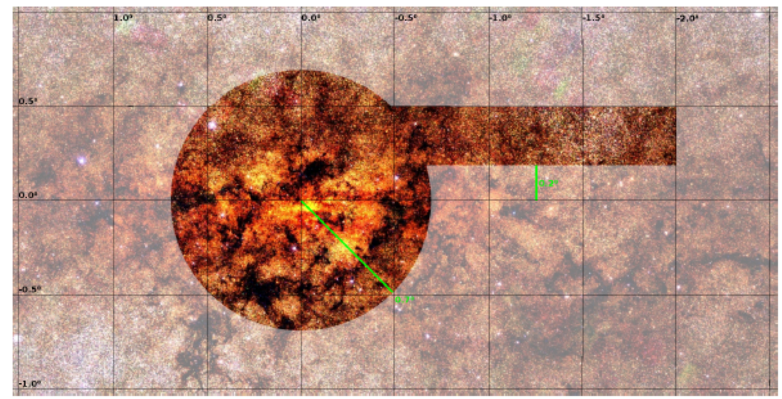


Figure 1: *The two Small-JASMINE target regions near the Galactic centre: a centred circular target with a radius of 0.7° and a rectangular off-centre target with 0.3°×2.5°. Coloured 2MASS image.*

Small JASMINE

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

and universities.

★ Observing strategy

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

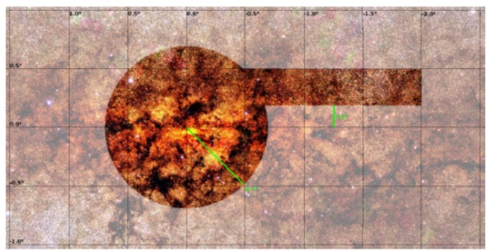
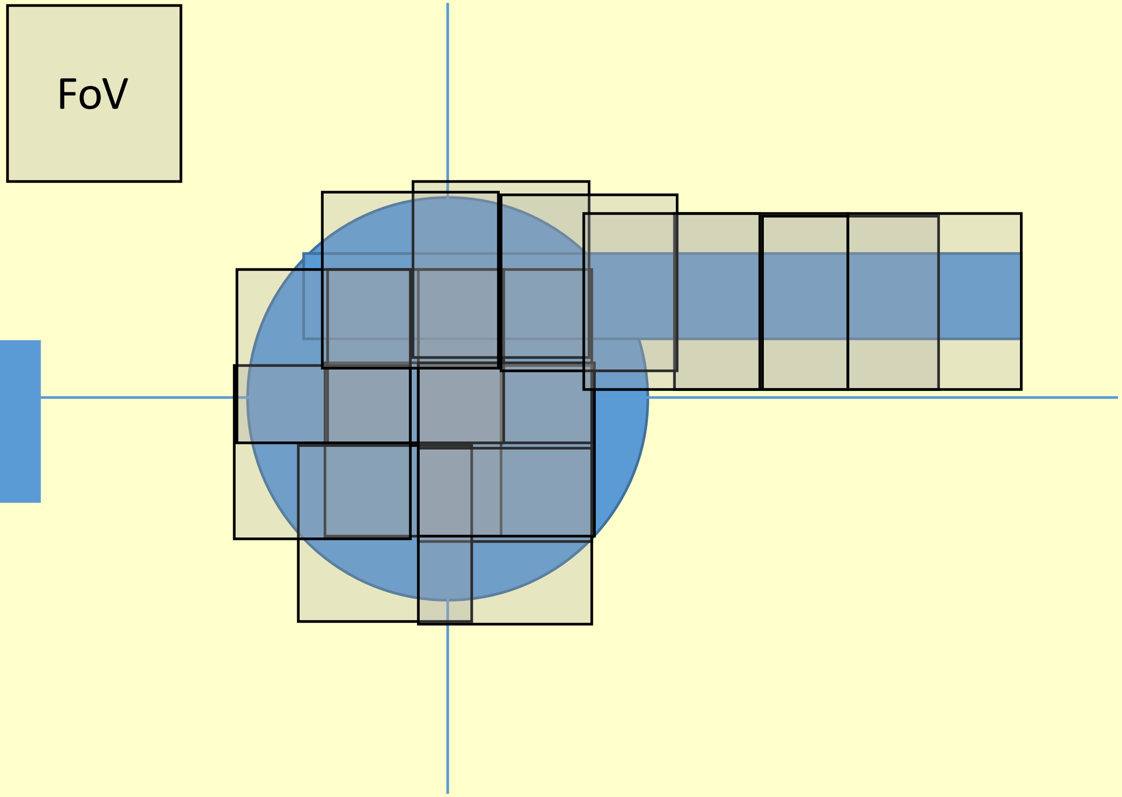
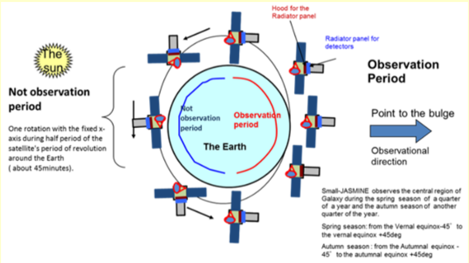


Figure 1: *The two Small-JASMINE target regions near the Galactic centre: a centred circular target with a radius of 0.7° and a rectangular off-centre target with 0.3°×2.5°. Coloured 2MASS image.*



The whole survey region
=Large Frame



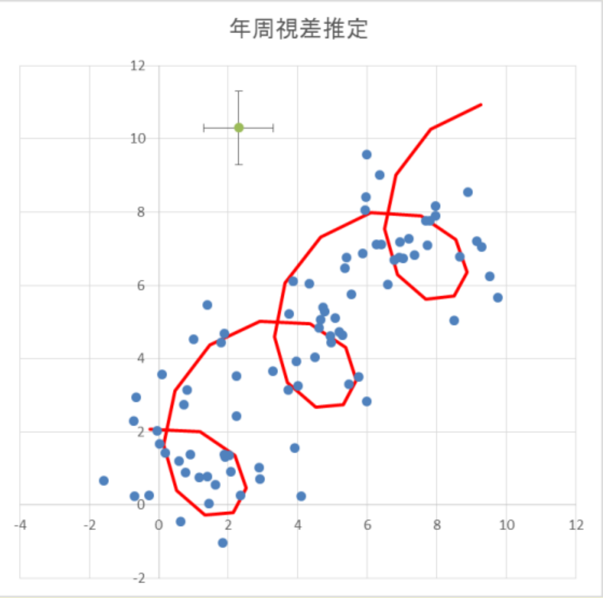
16FoVs (every 50 minutes)

pointing → 20images 7.1sec/image → pointing 30sec → 20images ・・・ 20images → pointing → 20images

Avoid earth oriented attitude

Overview of data analysis

***Mission requirement of SJ**
=>precision of parallaxes should be equal to or less than 20μas



Multiple measurements of stellar positions on the trace of the star

Precision of estimation of the parallax is reduced to be much less than that of the single measurements of the stellar position

Case of Small JASMINE

- **0.15 M – 0.6M measurements of each star**
- **Single observation precision ≈ 4mas**
- **parallax precision (requirement): 20 μas ≈ 4mas / 200**

★Statistical error(random error)

reduction according to 1/√N-raw

★Systematic error ⇨ estimation, control , removal, calibration

Estimation is important process for astrometry to reduce systematic errors

★Self-Calibration

○Modelization of systematic errors

It is possible to model the systematic errors by the use of the fact that we can presume that relative stellar positions on the celestial sphere do not move in short periods and/or the trace of a single star with negligible effects of planets, gravitational lens and/or hot spots has a definitive shape, that is, helical motion!

Then, in principle, systematic components of time variations of relative angular distances between stars are systematic errors.

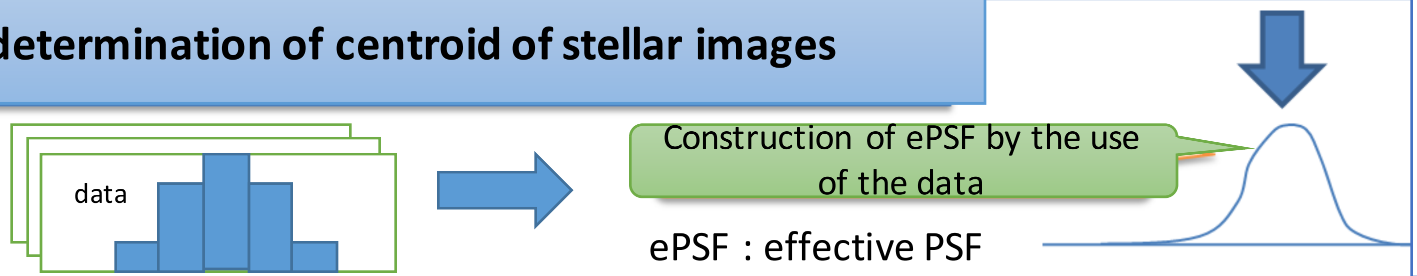
*Even if we do not know in advance the physical causes of the systematic errors, we can model the errors by the use of fitting functions such as polynomial expression, Fourier series, Basian spline-type smoothing etc.

*avoidance of overfitting problem=>the use of Akaike's Information Criterion

*systematic errors with annual motions and/or linear motions have degeneracy with stellar motions

➔calibration by known annual parallaxes and proper motions of stars measured by other missions, such as Gaia.

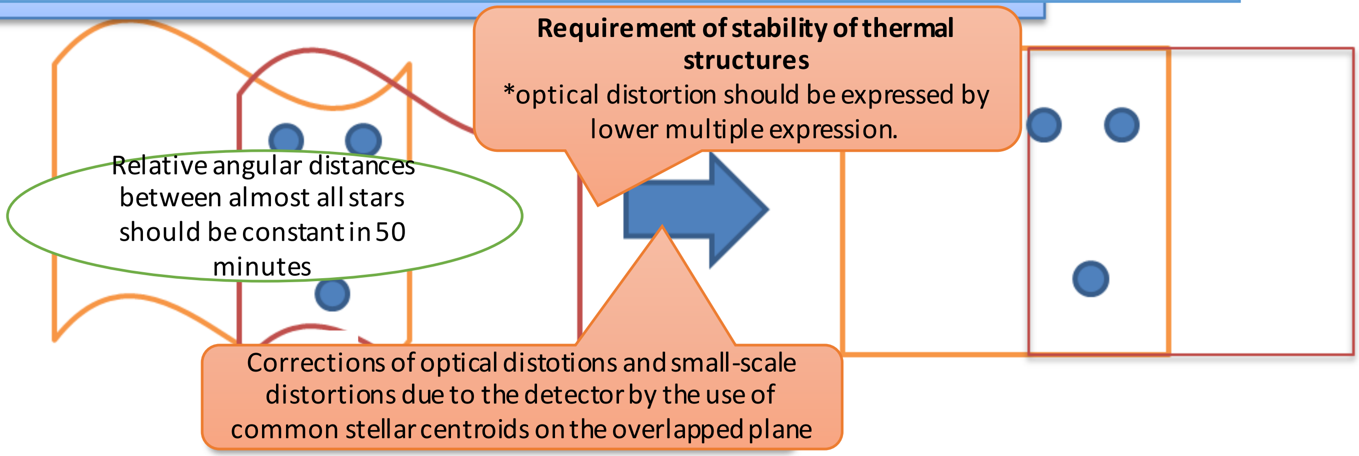
A　determination of centroid of stellar images



Target precision

relative stellar positions
1/130 pixels
(～4mas)

B Construction of a large-frame by correcting distortions

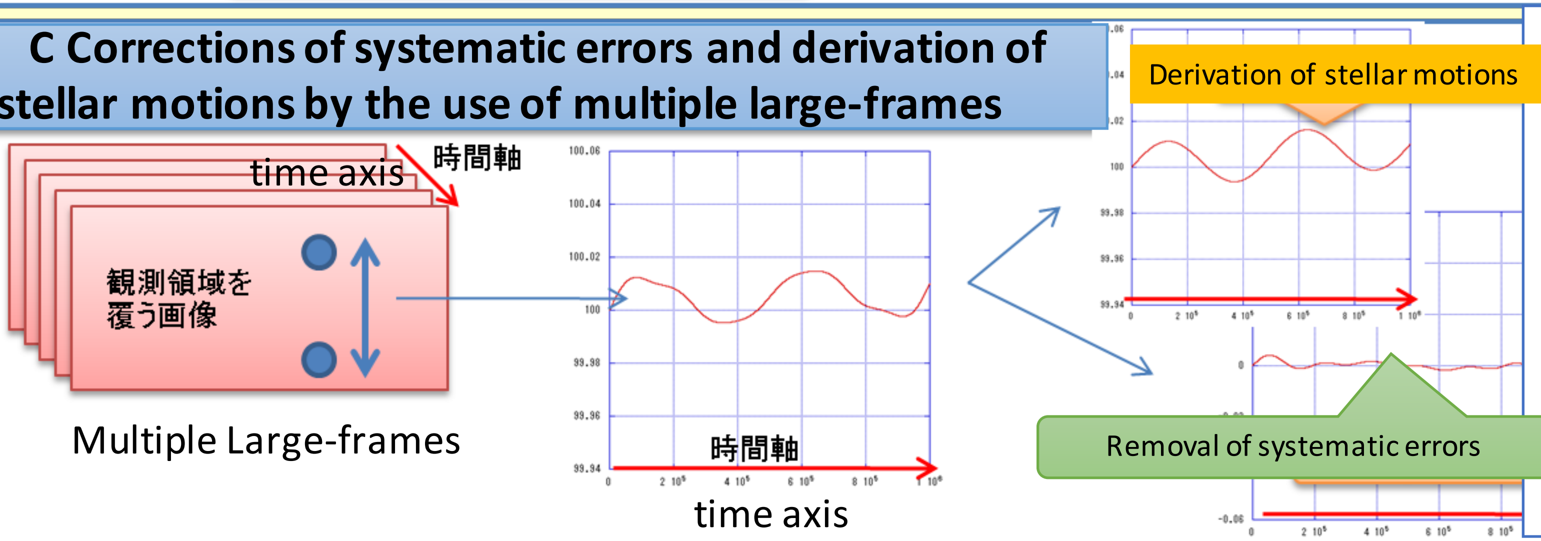


Target precision

Relative stellar position
0.001 pixels
(～0.5mas)

（up to 80 measurements of each star）

C Corrections of systematic errors and derivation of stellar motions by the use of multiple large-frames



Target precisions
Annual parallaxes of stars
～20μas

Modelization of systematic errors

↓

Requirement: simple functions as much as possible

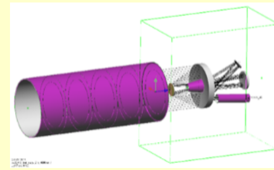
* Ex. a small number of parameters in the models

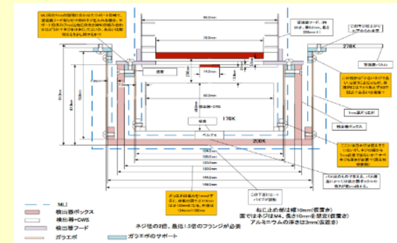
↓

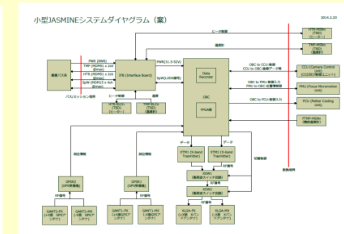
Requirements to the satellite system

★We have accomplished the concept studies of the satellite system in which the mission requirements and system requirements are satisfied.

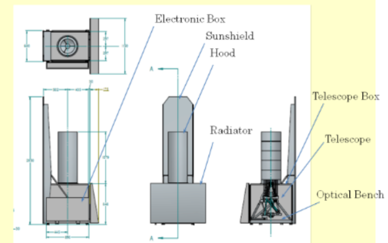
- ○capability of the mission instrument
  - ＊decrease in the stray light
  - ＊decrease in contamination and outgas
  - ＊thermal environment around the telescope(278K) and detector(<180K).
  - ＊the stability of the thermal structure
  - ＊pointing stability of the telescope

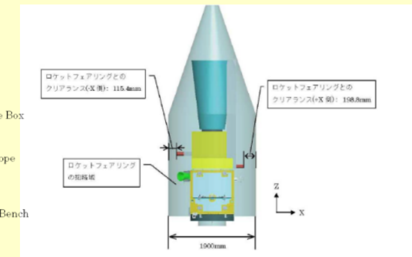






- ○telemetry : X-band for downlink of scientific data
- ○command & data Handling : no big issues
- ○attitude control : no big issues
- ○electric power : enough margin
- ○data analysis:
- ○cost(including the budget for risk management): within the upper limit(8.5 billion JPN) for the small science satellite program executed by JAXA.

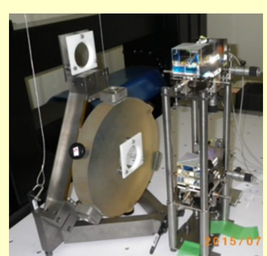


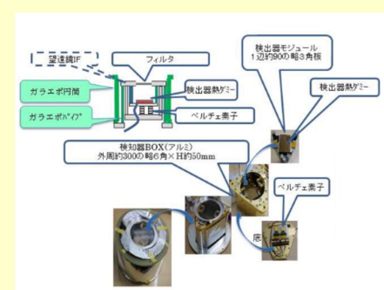


Critical technics: thermal stable structure, optics(stray light etc.), thermal control, radiation effects to the detector

We will perform multiple steps to verify the feasibility of the critical techniques by constructing various manufacturing models (BBM, EM, PFM and FM)

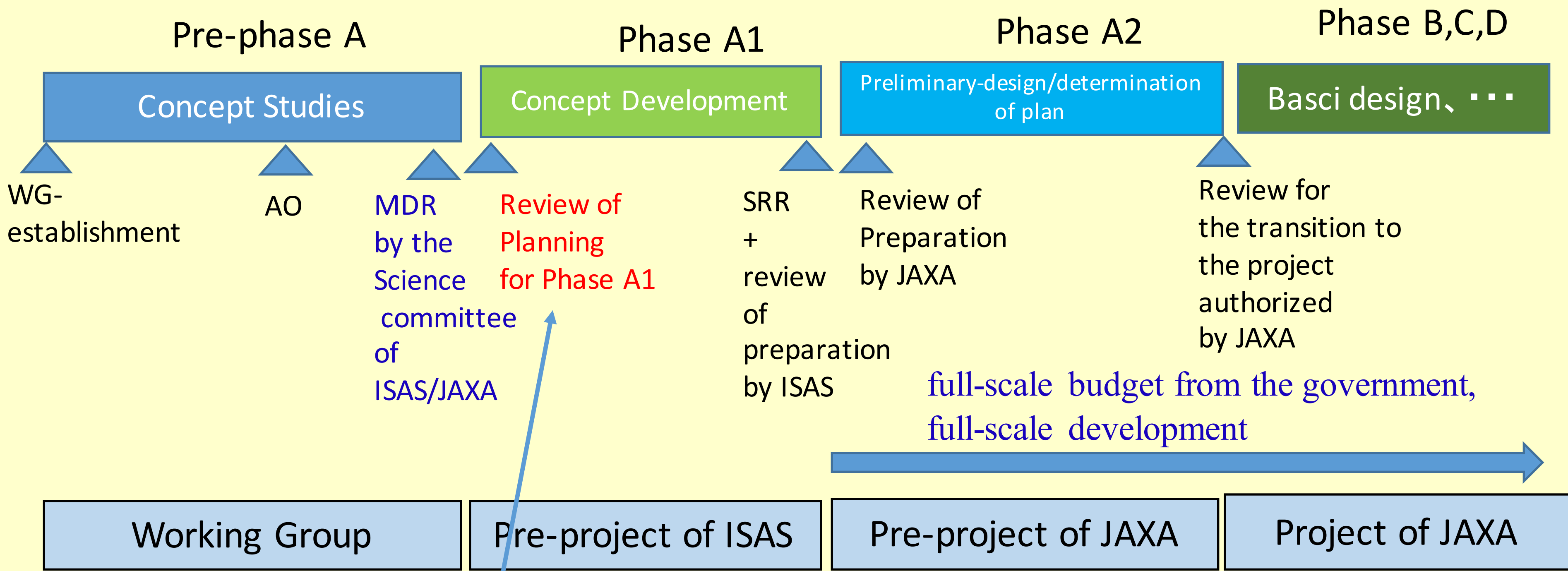
Ex. Athermal telescope structure made of super-super invar* of zero thermal expansion newly developed alloy, coefficient of thermal expansion;0 ±5x10^{-8}/K,





★Present status of Small-JASMINE

～Multiple steps of reviews by JAXA(up to the present time)～



Small-JASME has successfully passed the MDR (Mission Design Review) !!

We will have this review of planning by HQ of ISAS soon later.

As part of this review, we will have the international review around this October.

The purpose of this review: clarification of action items and their priorities for Phase A1

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

★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 Nano-JASMINE and Small-JASMINE

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.

Furthermore, we have possibility that DLR will contribute to Small-JASMINE for funding in the context of the general agreement on collaboration between DLR and JAXA if Small-JASMINE will successfully pass the review process.

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

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

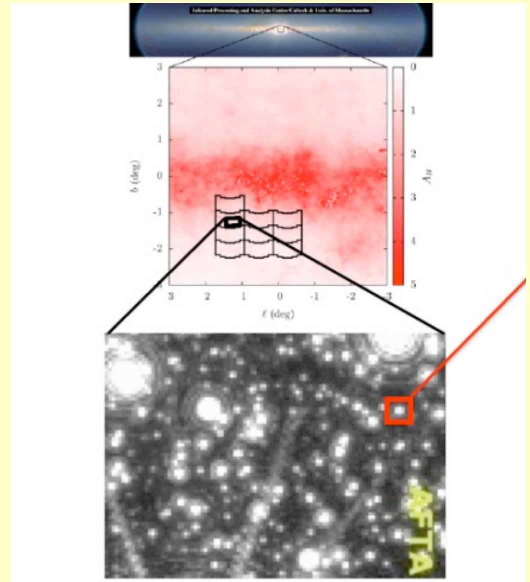
Information of radial velocities , chemical composition and photometry (in other bands) is complementary to Small-JASMINE for the scientific targets in the Galaxy.

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

○Synergy with WFIRST
Microlensing survey

Properties.

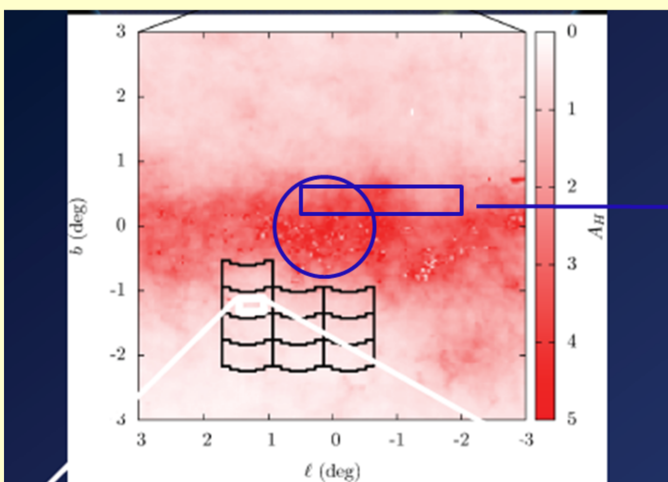
- ~3 sq. deg (10 fields).
- ~432 days (6 seasons of 72 days each).
- ~15 minute cadence, 52s in W149.
- ~12 hour cadence, 290s for Z087.
- ~85% of the area will have ~40,000 measurements per star ($N^{-1/2}$ = 1/200).
- ~60 million stars down to H_{AB}<21.6.
- 2 million seconds of integration time.
- ~2.5 billion photons detected for a H_{AB}=19.6 star



If 10 μas –level precisions of astrometric parameters can be realized by WFIRST, then we will have strong synergy of scientific collaboration between WFIRST and Small-JASMINE

Survey regions of both missions are complementary to each other

Microlensing Fields of WFIRST



Survey region of Small-JASMINE

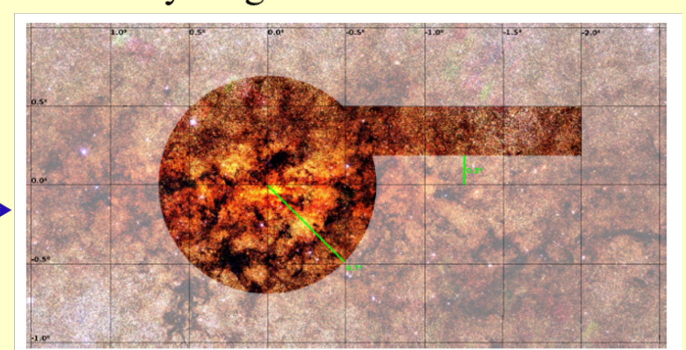


Figure 1: *The two Small-JASMINE target regions near the Galactic centre: a centred circular target with a radius of 0.7° and a rectangular off-centre target with 0.3°×2.5°. Coloured 2MASS image.*

○ Collaboration with Post-Gaia missions

Theia and GaiaNIR

JASMINE team is very happy to contribute to both missions in aspects of synergies for scientific outputs and the development of technologies which include the data analysis software.

***We are now preparing the conclusion of the MOU for scientific and technical collaboration between Theia and Small-JASMINE.**

***Small-JASMINE would like to play a role of a precursor to GaiaNIR as an infrared space astrometry mission.**

Jasmine

Thank you for your support!