Building the largest mock catalogue of the Milky Way centre in the Near Infrared

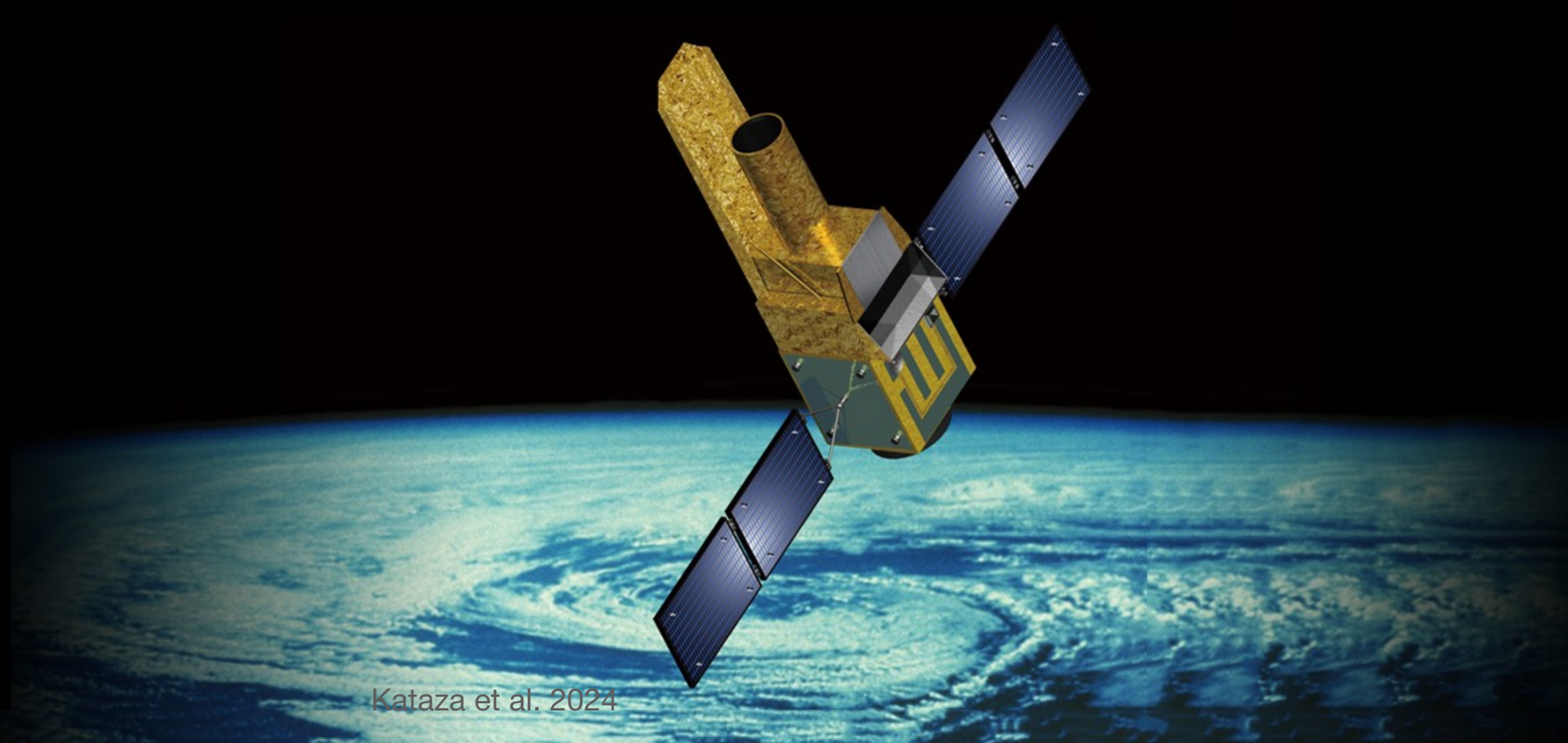
Pau Ramos

17 March 2025

The Galactic Centre Survey

JASMINE mission

The upcoming Japanese Near Infrared high-precision astrometric mission



Kataza et al. 2024

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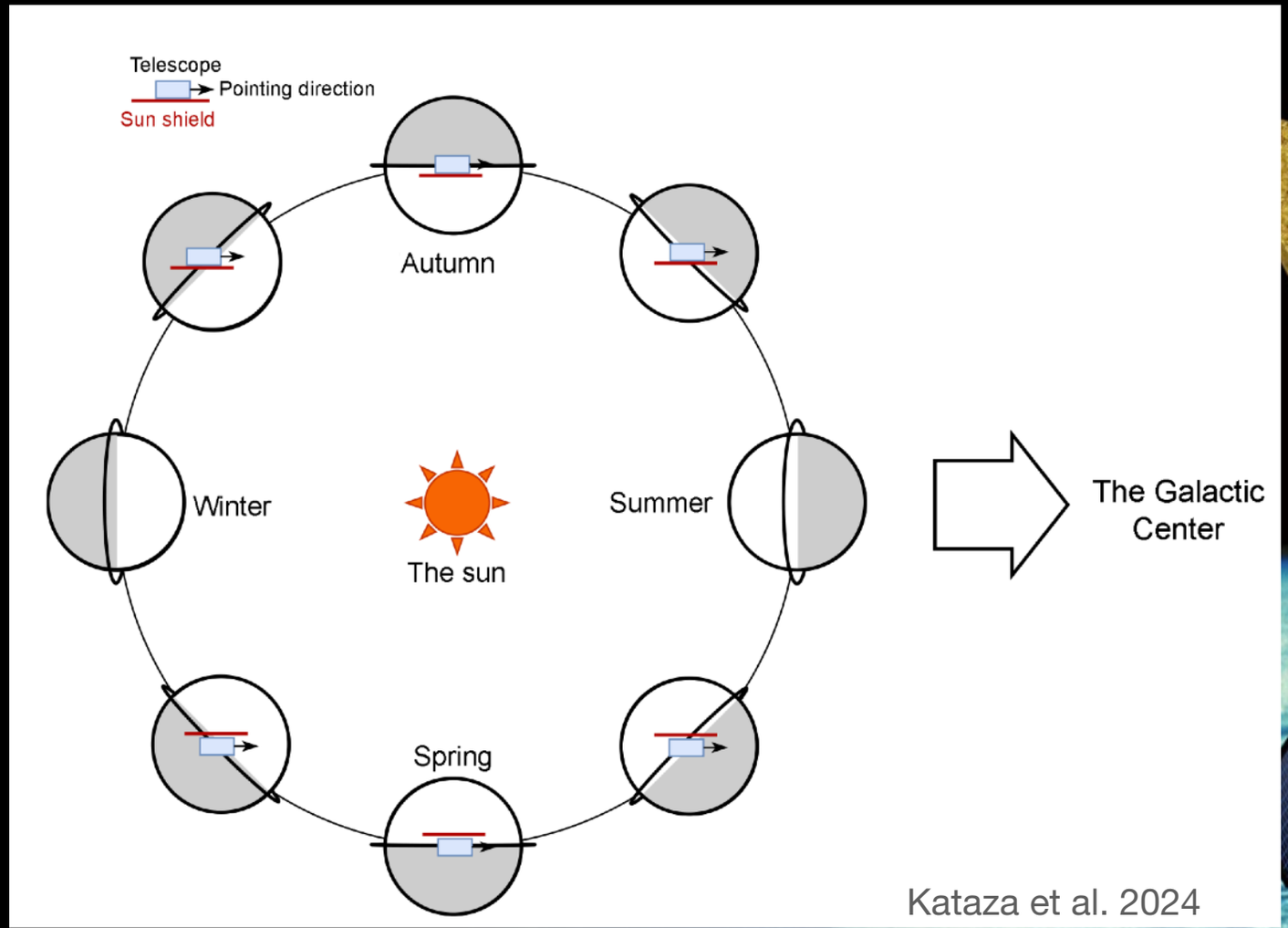
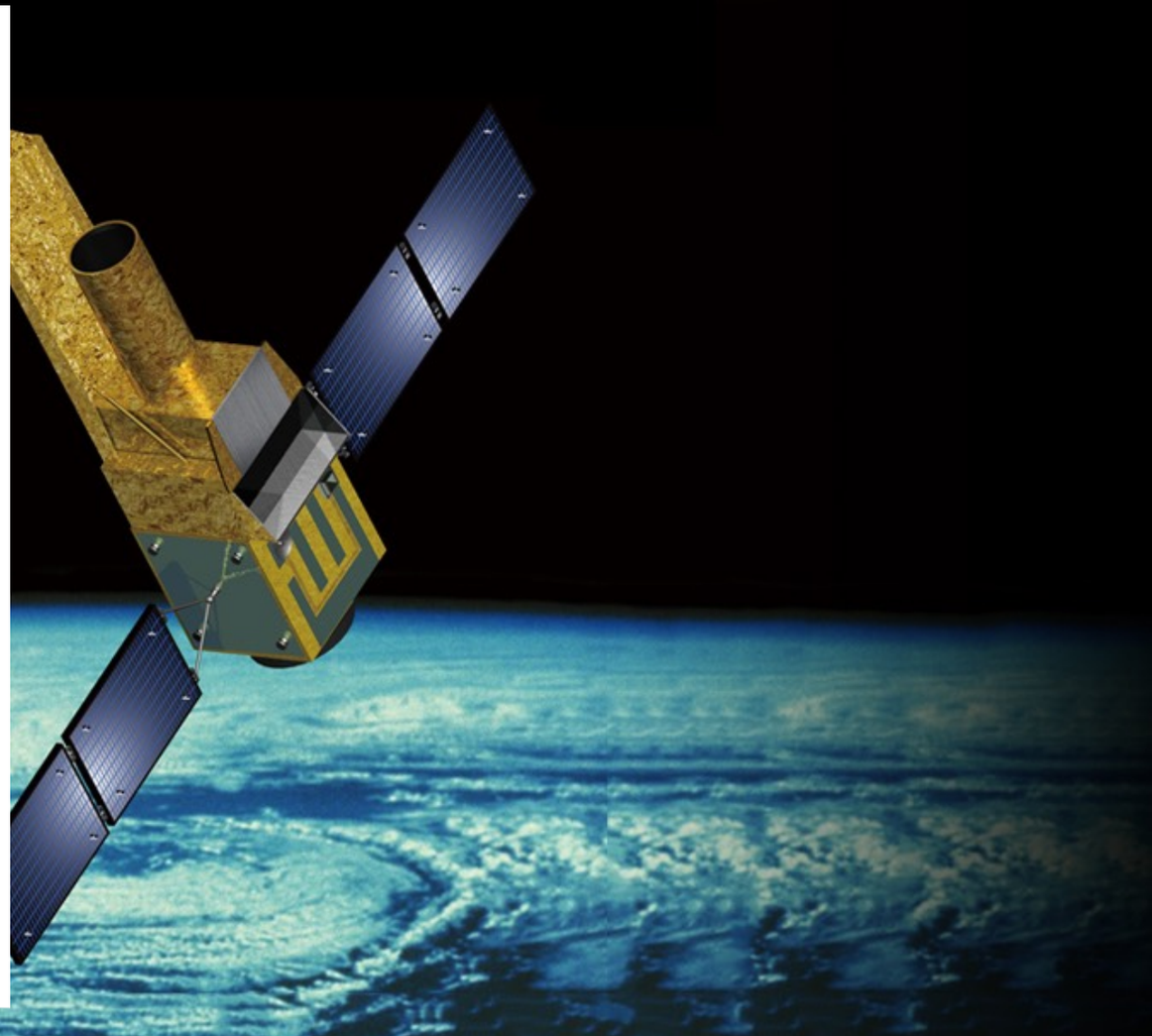


Kataza et al. 2024



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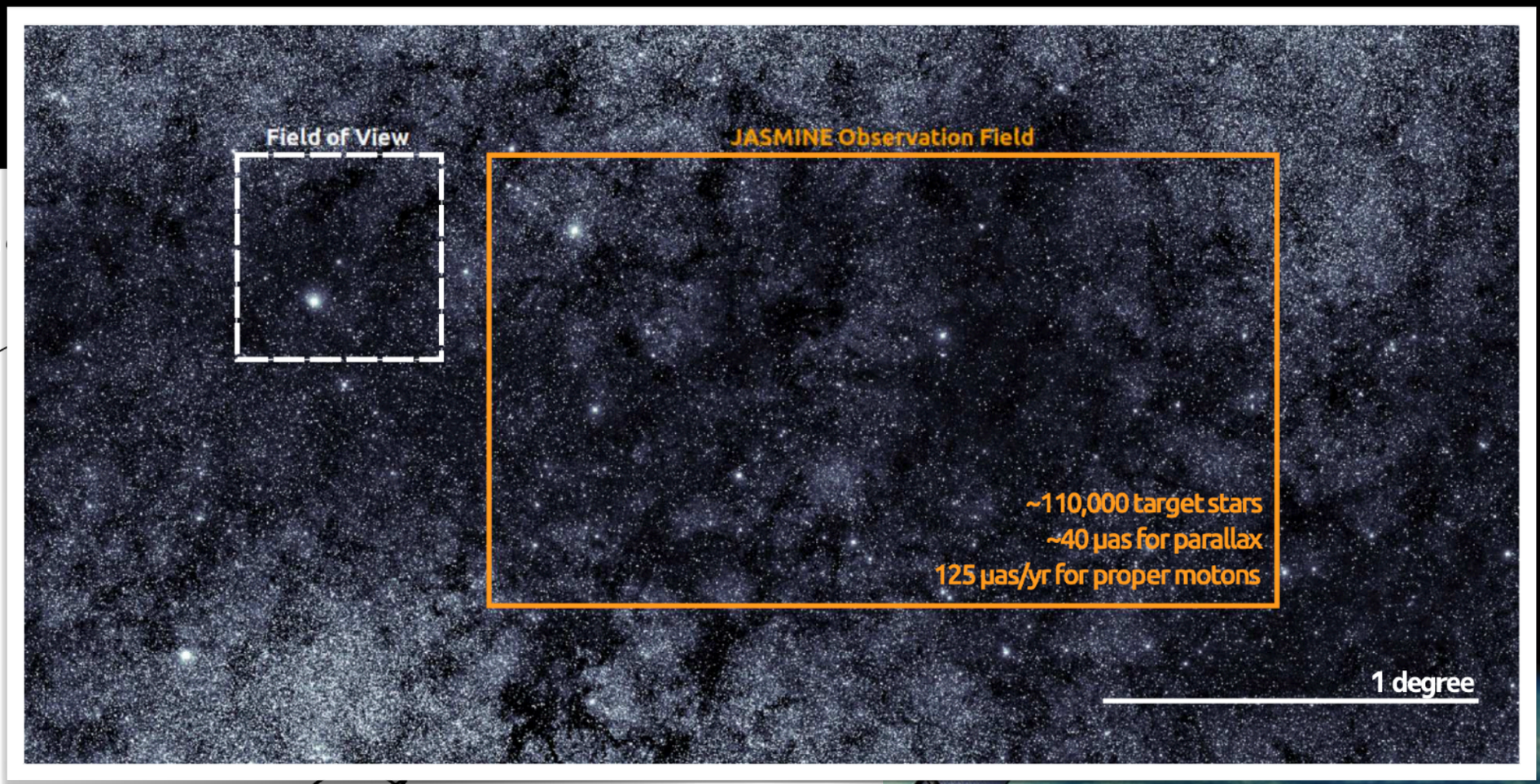
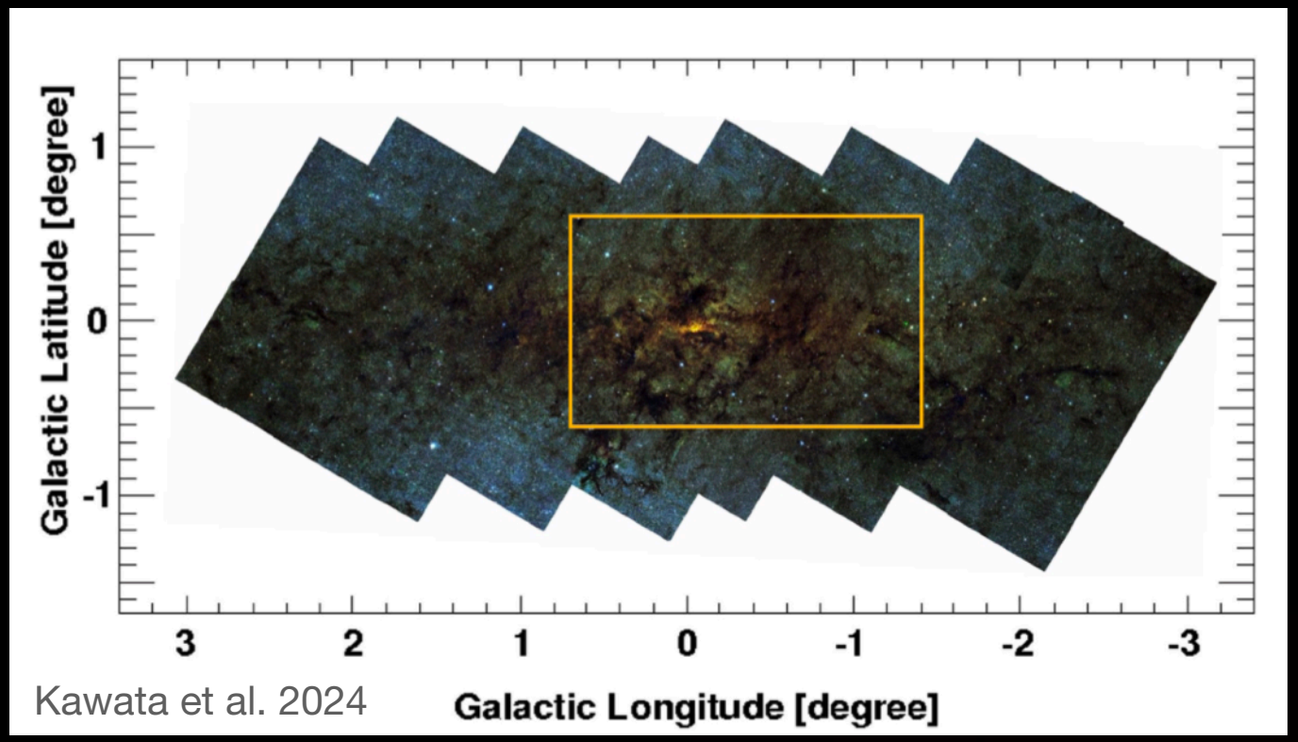


Kataza et al. 2024

The Galactic Centre Survey



Kawata et al. 2024

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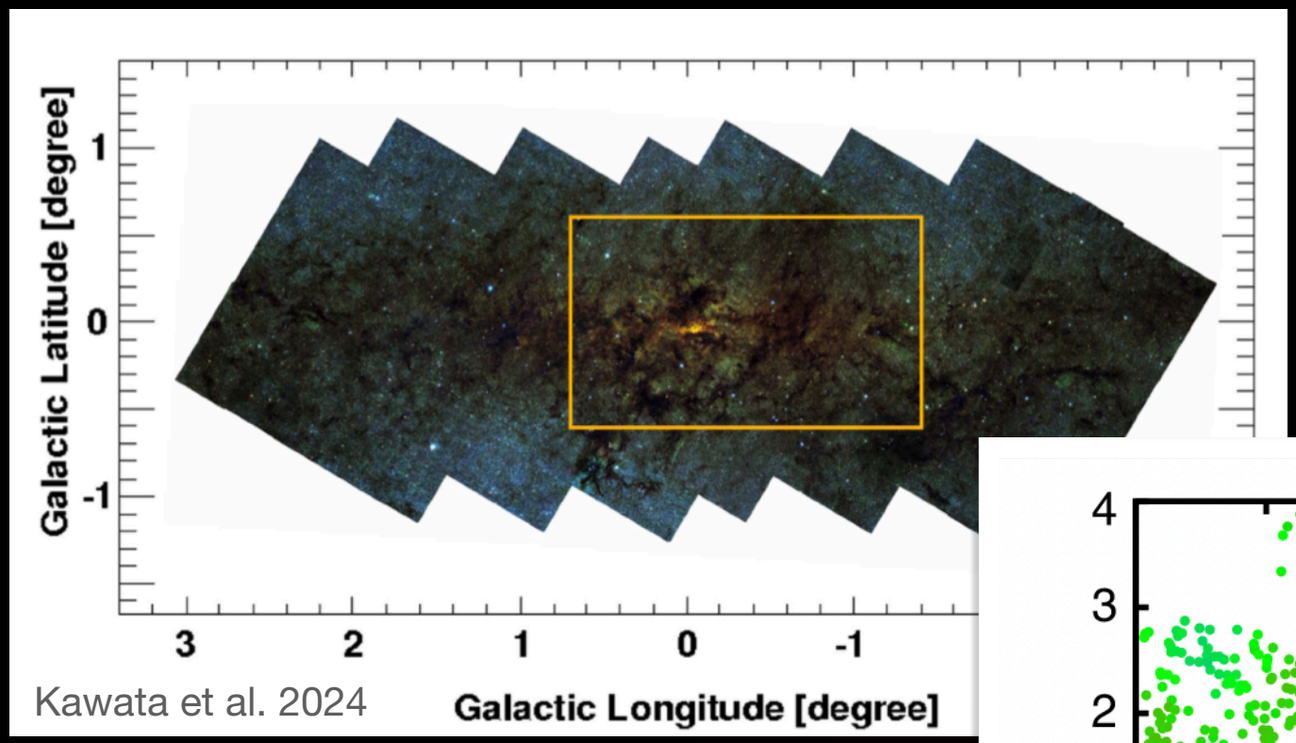

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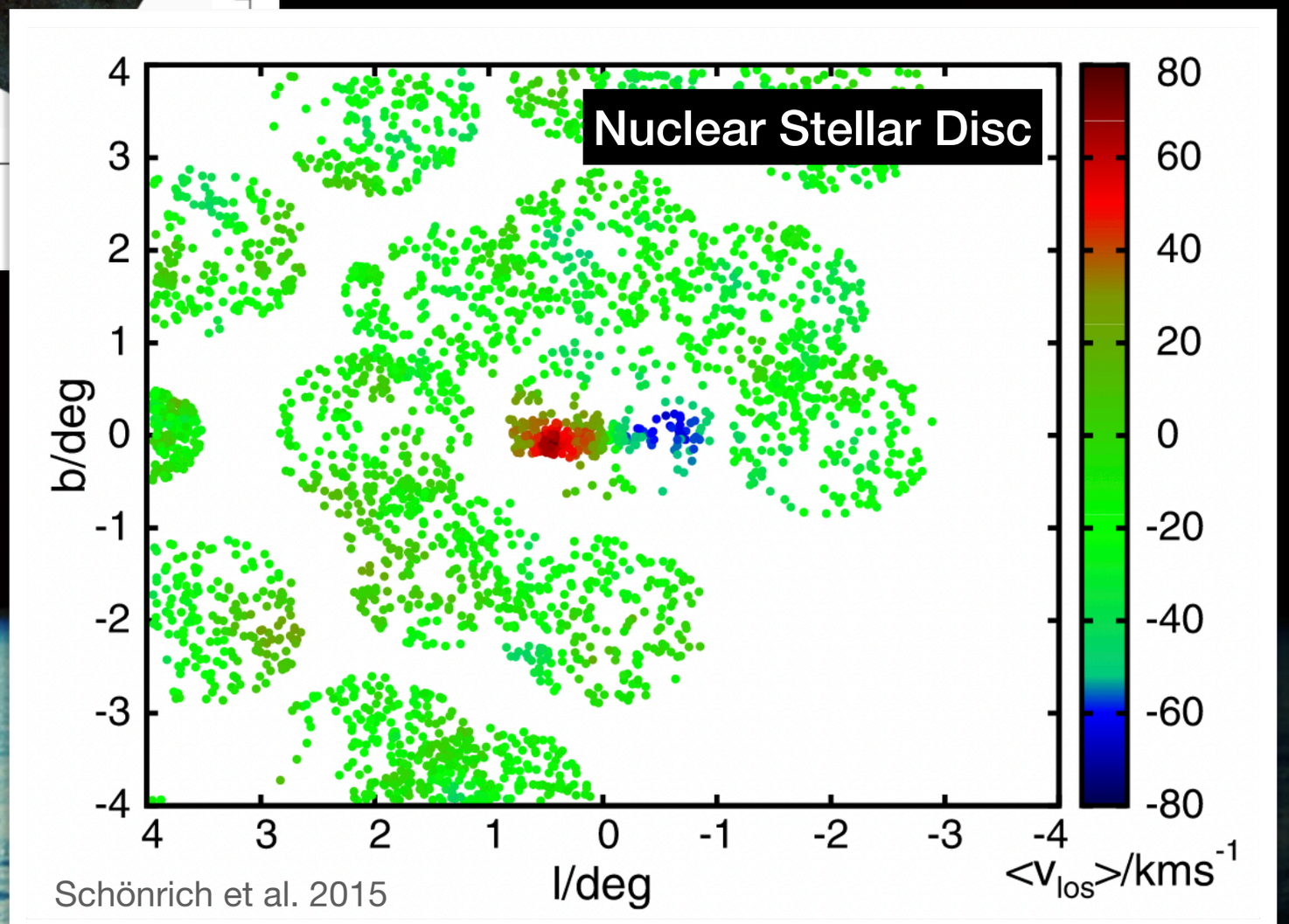

Schönrich et al. 2015

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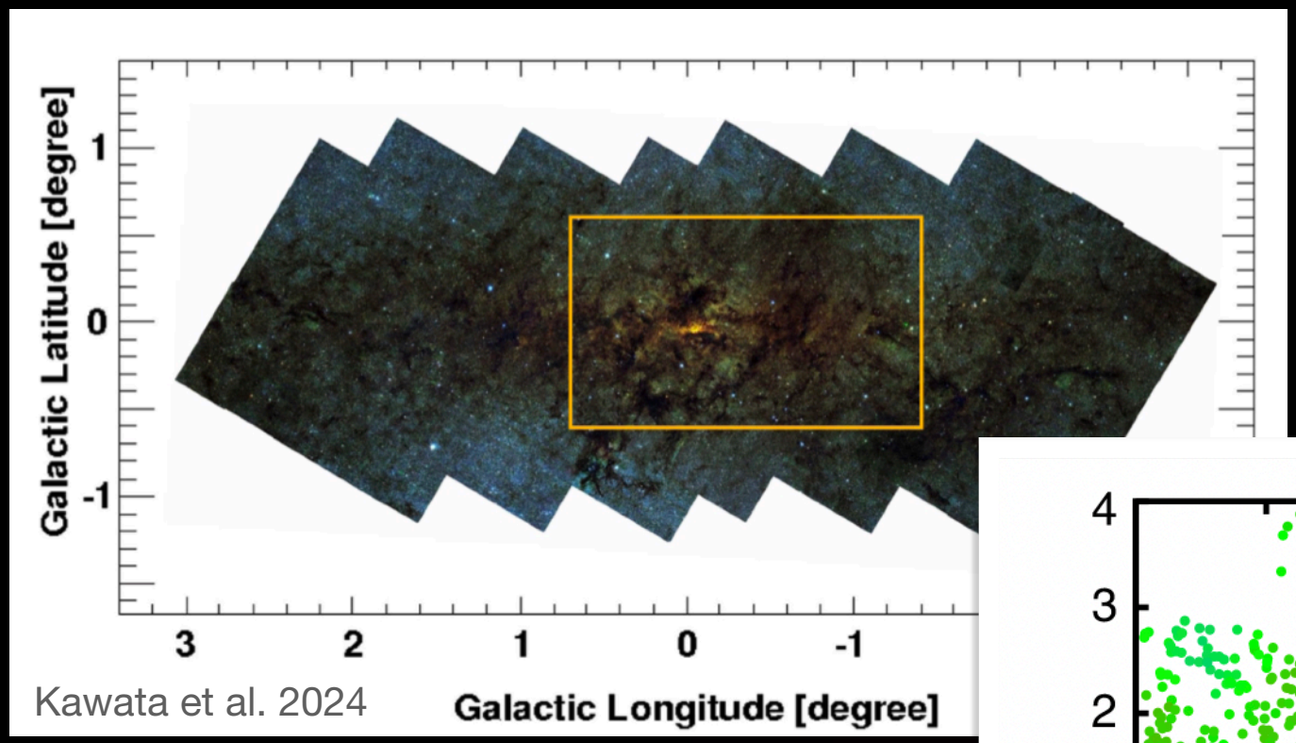

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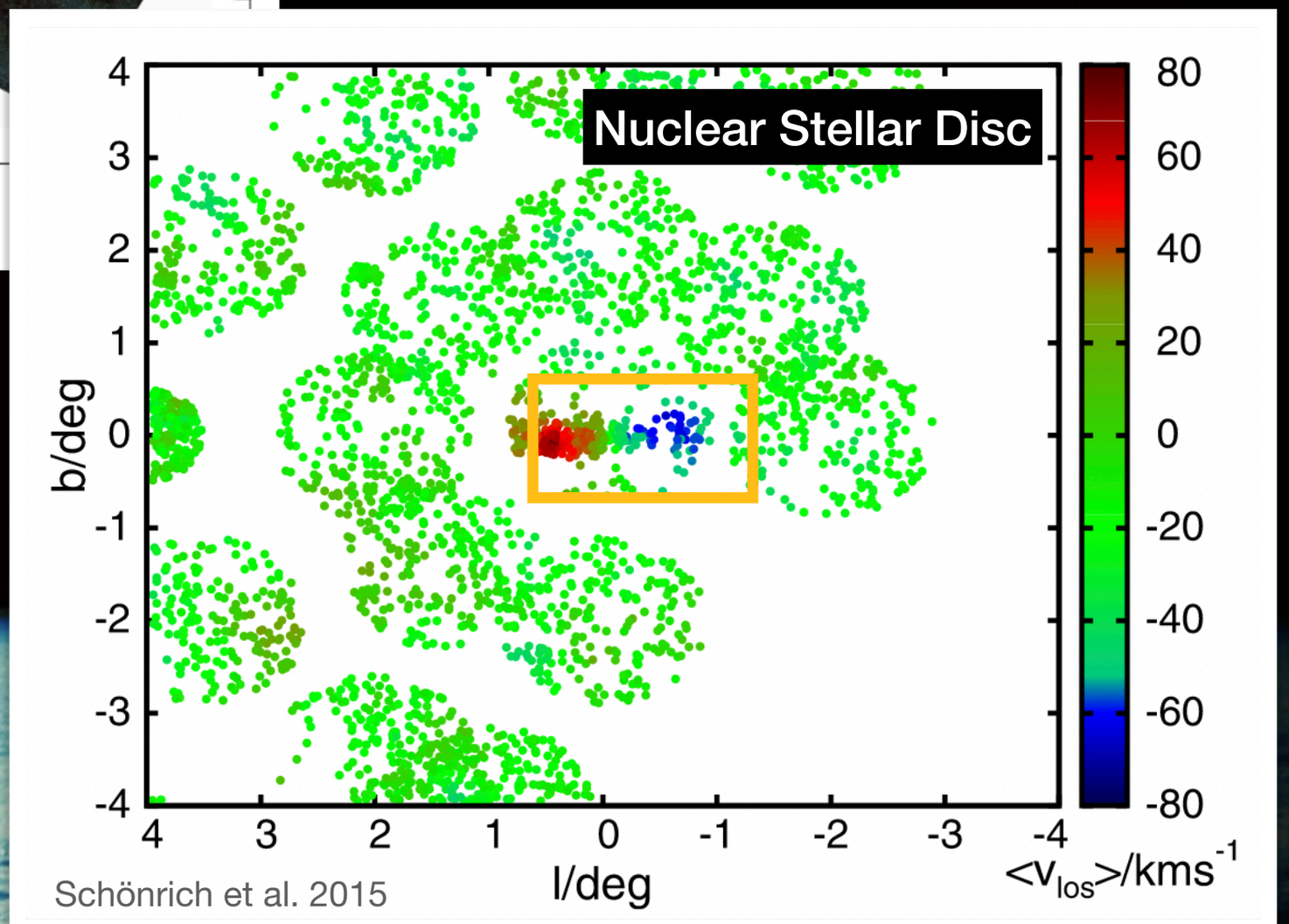

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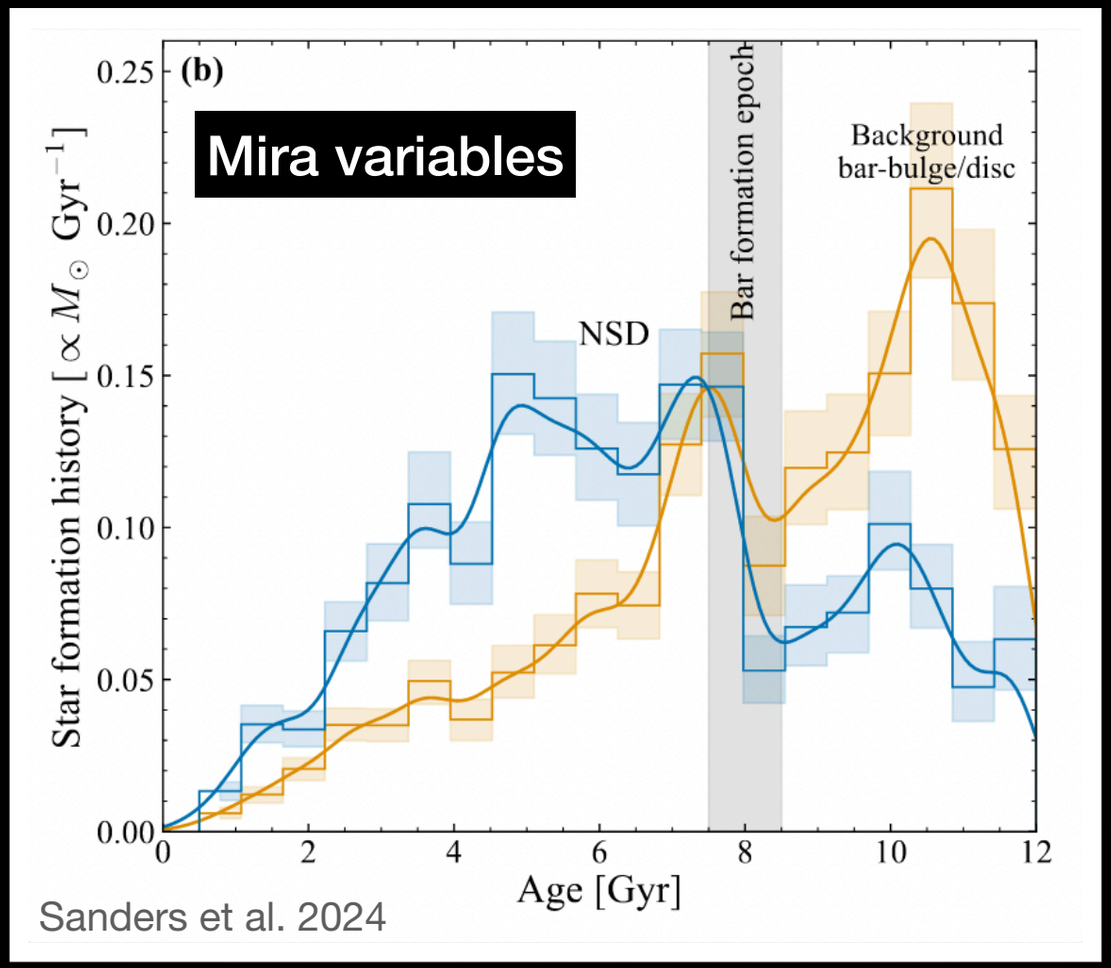

Sanders et al. 2024

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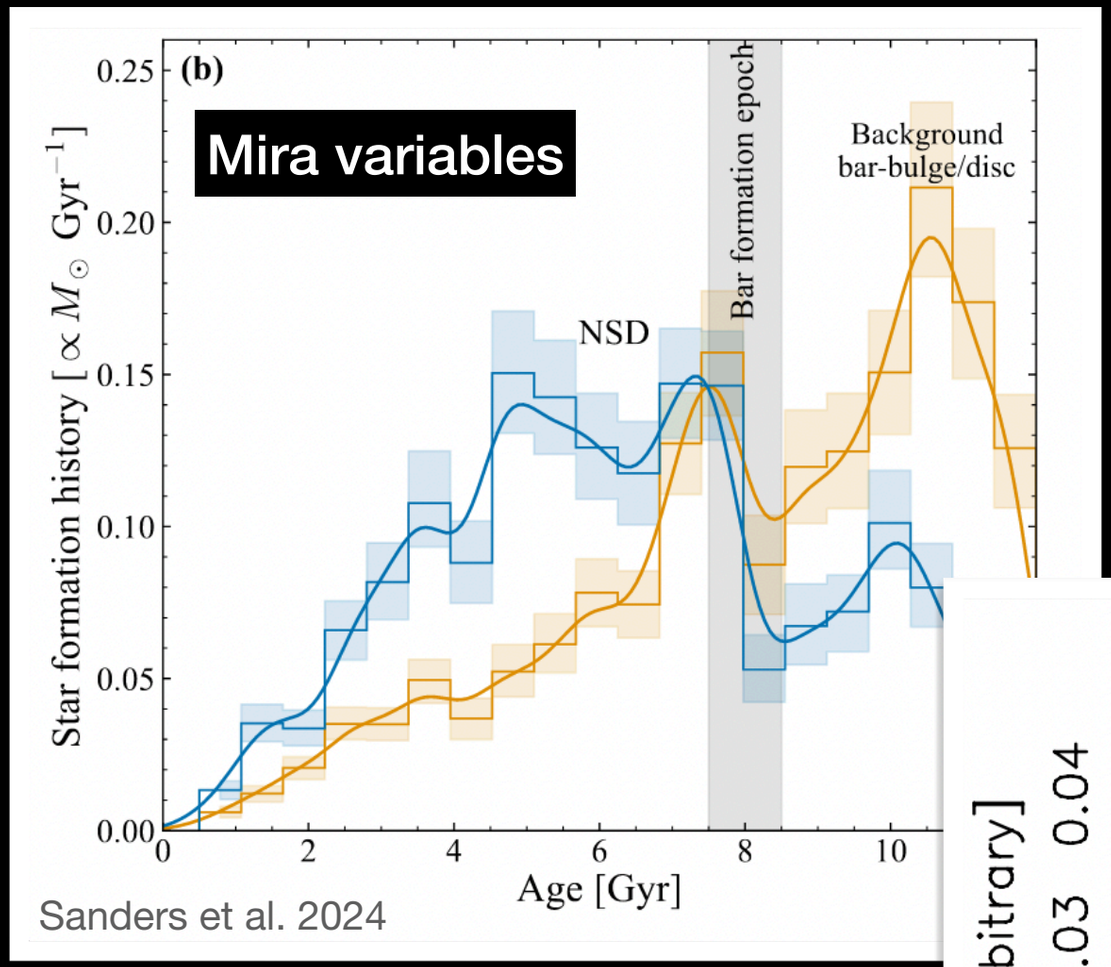
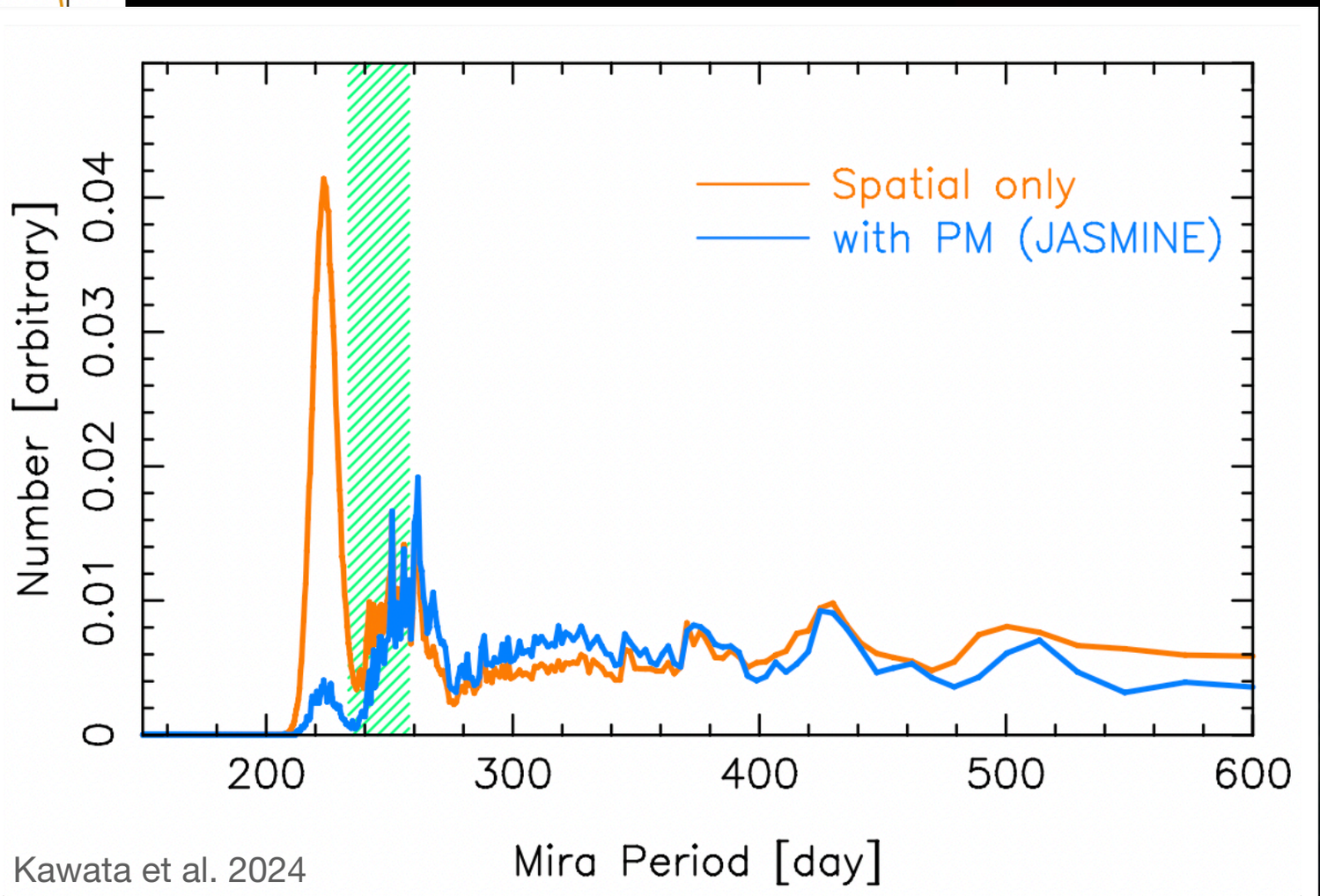


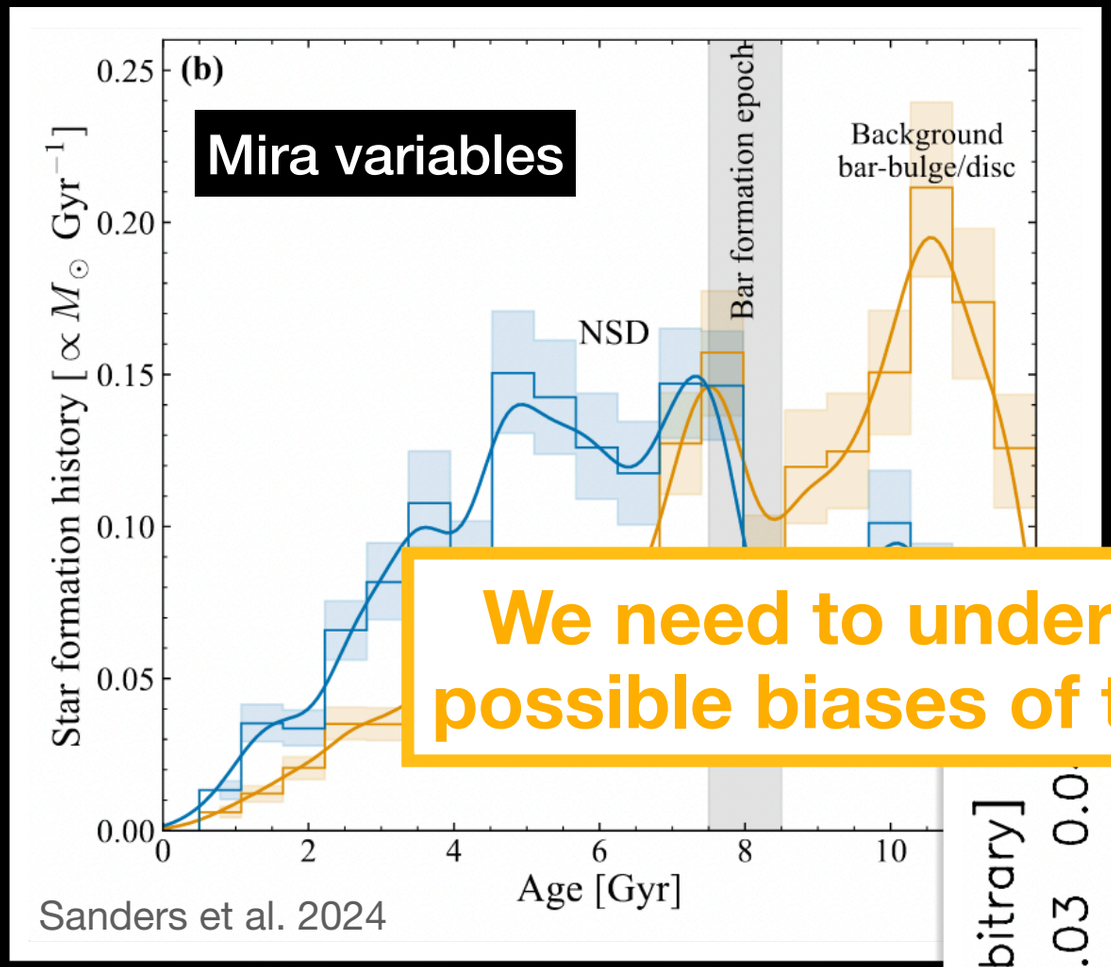
Sanders et al. 2024

The NSD teaches us about the formation of the bar!



Kawata et al. 2024

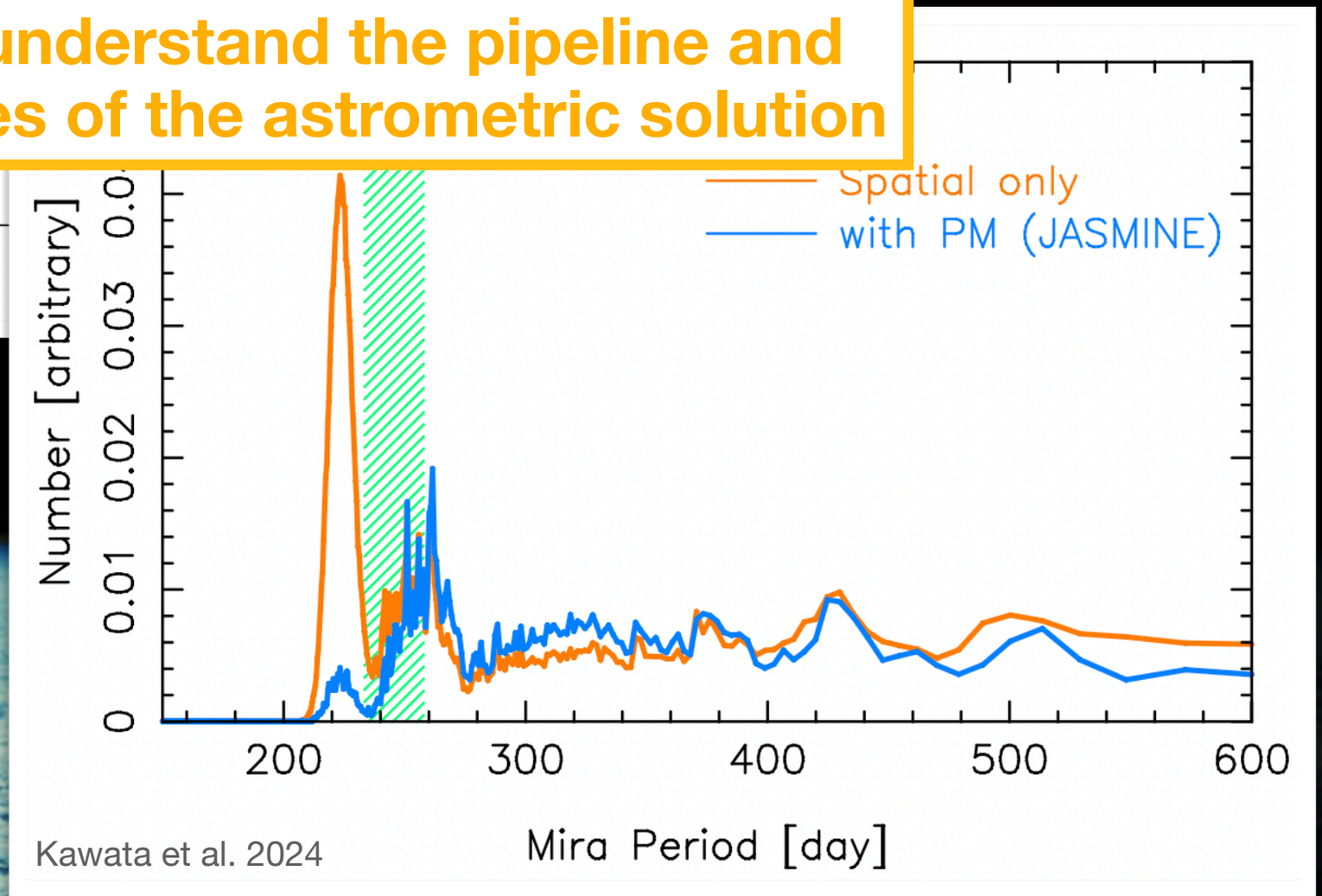
The Galactic Centre Survey



Sanders et al. 2024

The NSD teaches us about the formation of the bar!

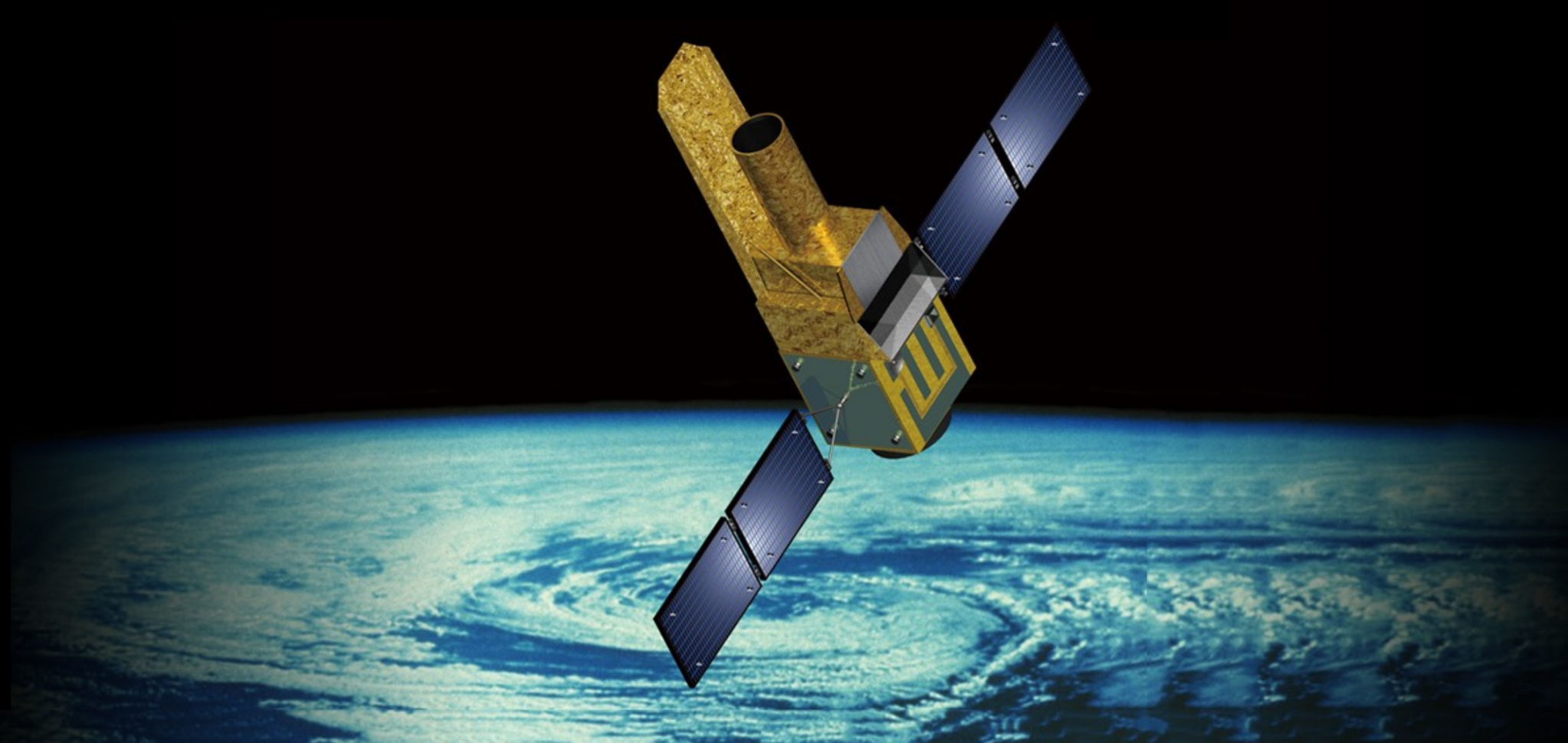
We need to understand the pipeline and possible biases of the astrometric solution



Kawata et al. 2024

Testing the astrometric solution

In order to test and develop our Solvers we need a Ground Truth to generate mock observations and use as reference



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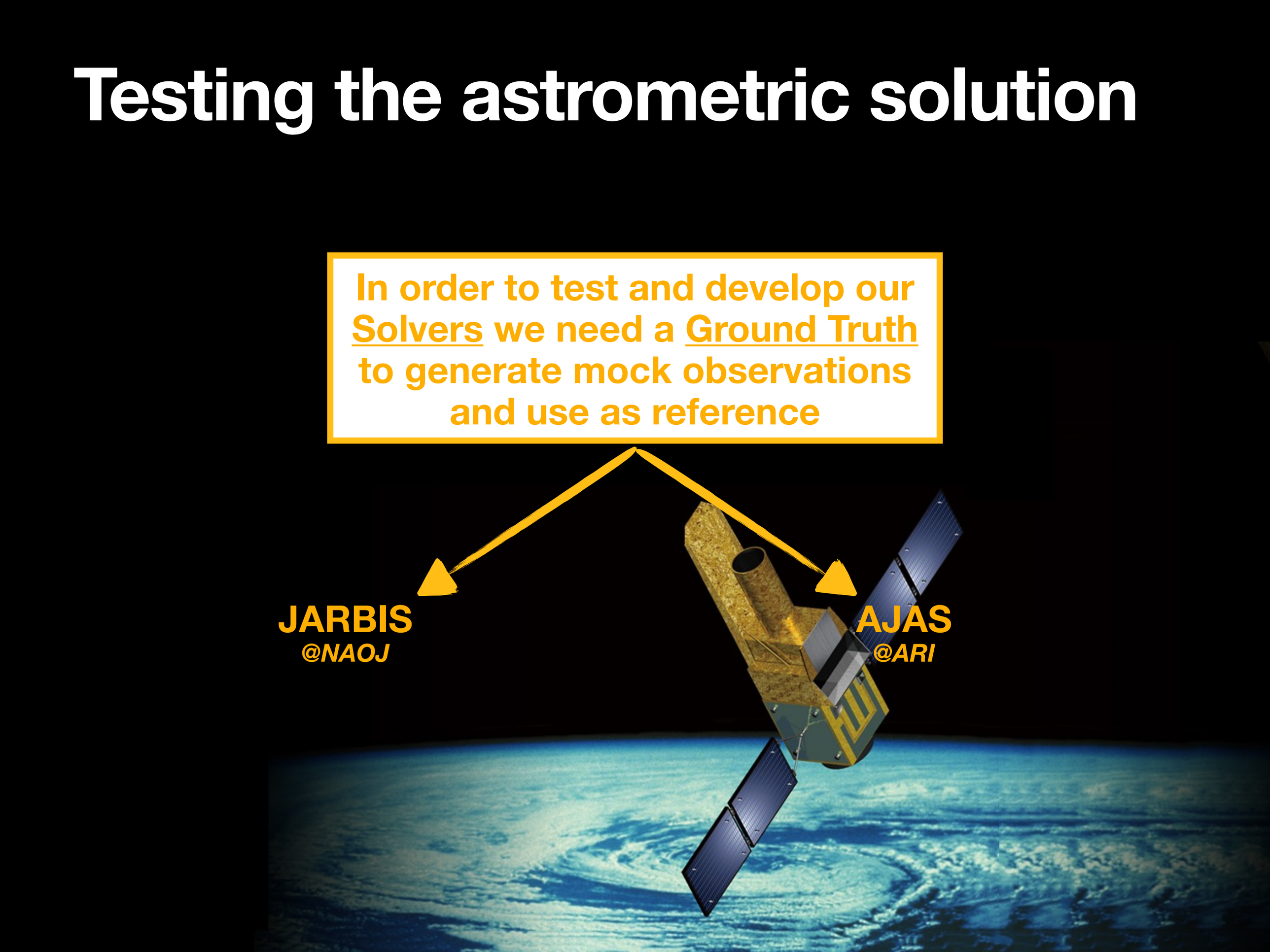

Testing the astrometric solution

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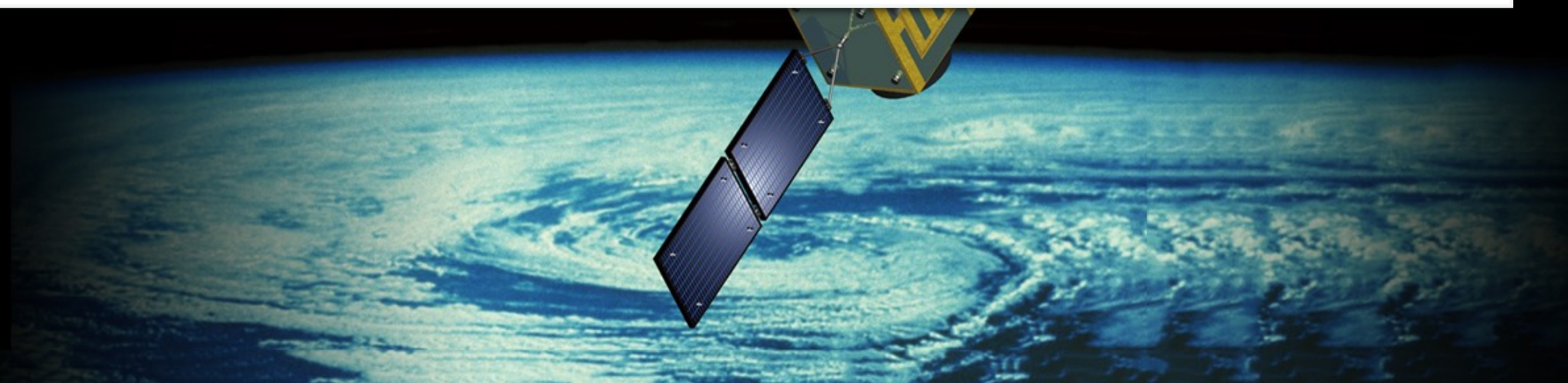
journal homepage: www.elsevier.com/locate/jocs

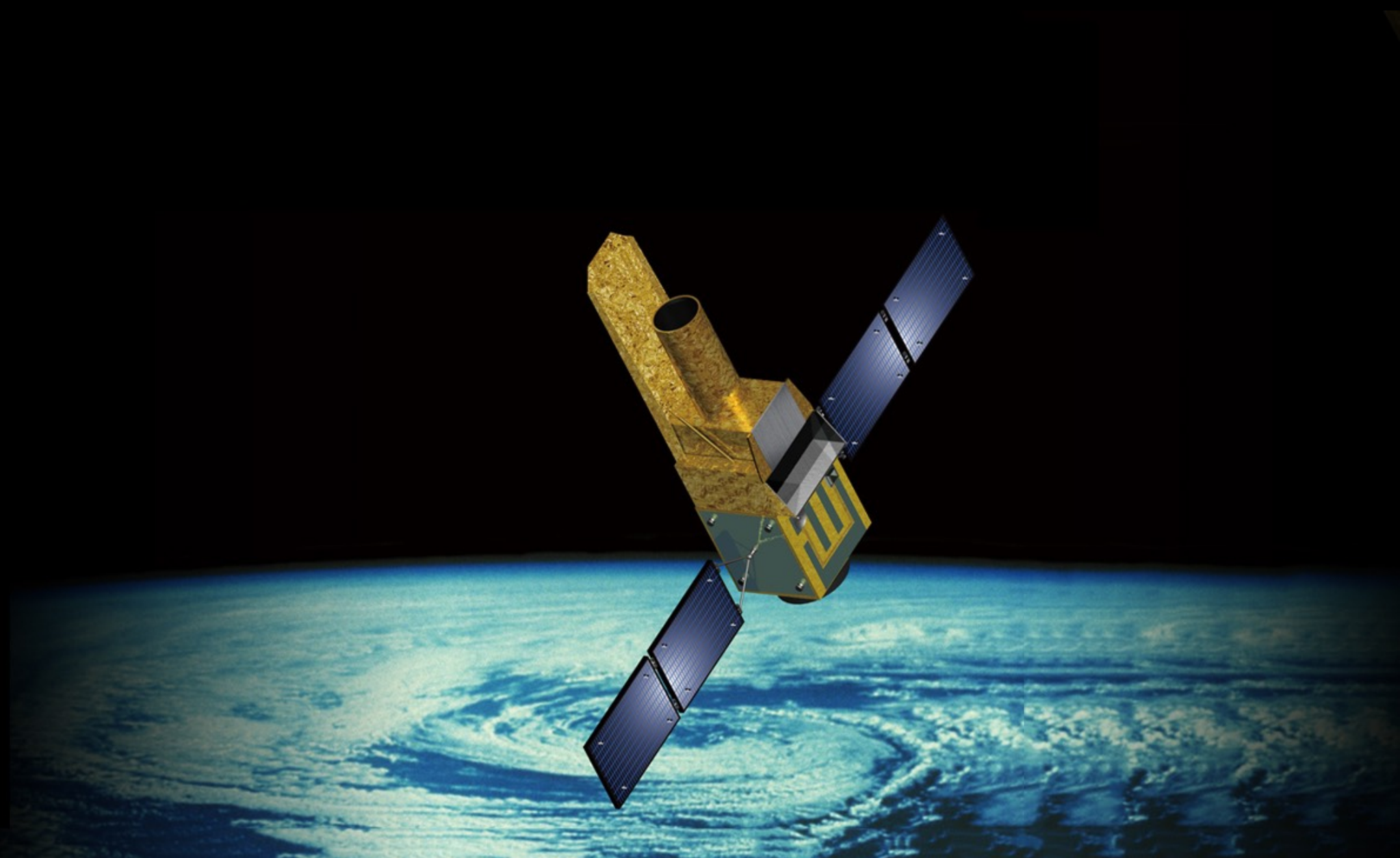
AJAS: A high performance direct solver for advancing high precision astrometry

Konstantin Ryabinin *, Gerasimos Sarras, Wolfgang Löffler, Olga Erokhina, Michael Biermann

Astronomisches Rechen-Institut, Center for Astronomy of Heidelberg University, Mönchhofstr. 12–14, Heidelberg, 69120, Germany

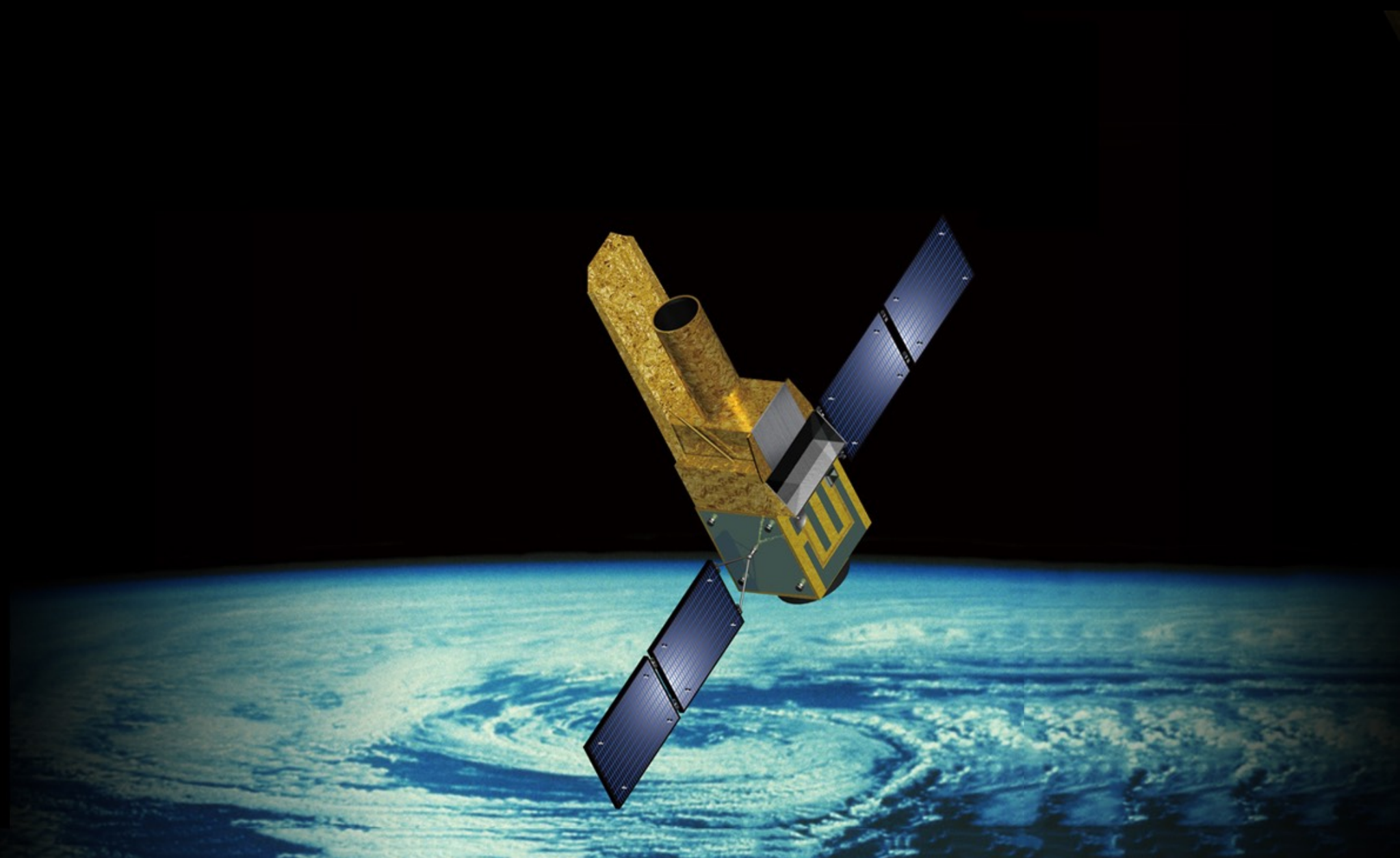


Which Ground Truth to use?



Which Ground Truth to use?

Off-the-shelf models



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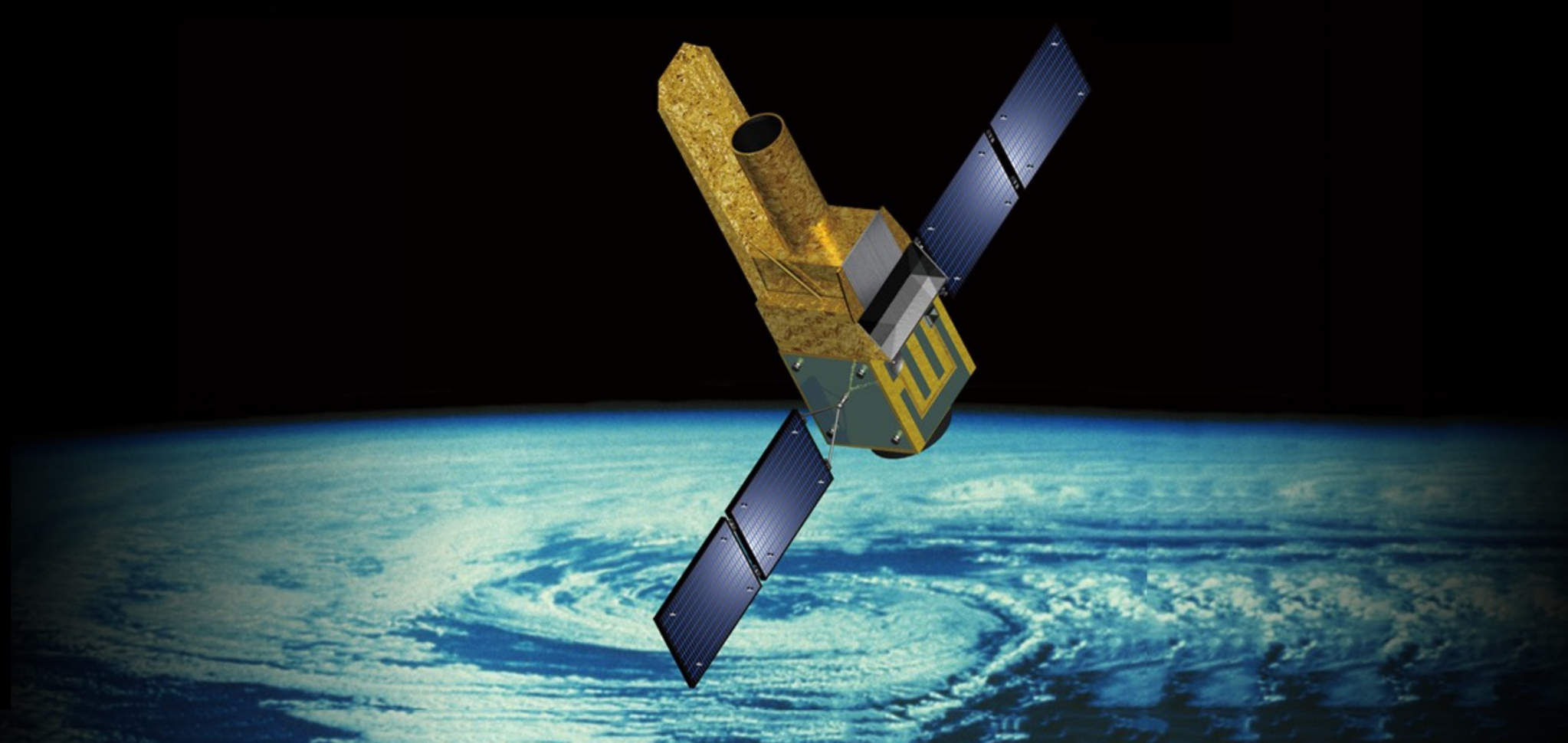

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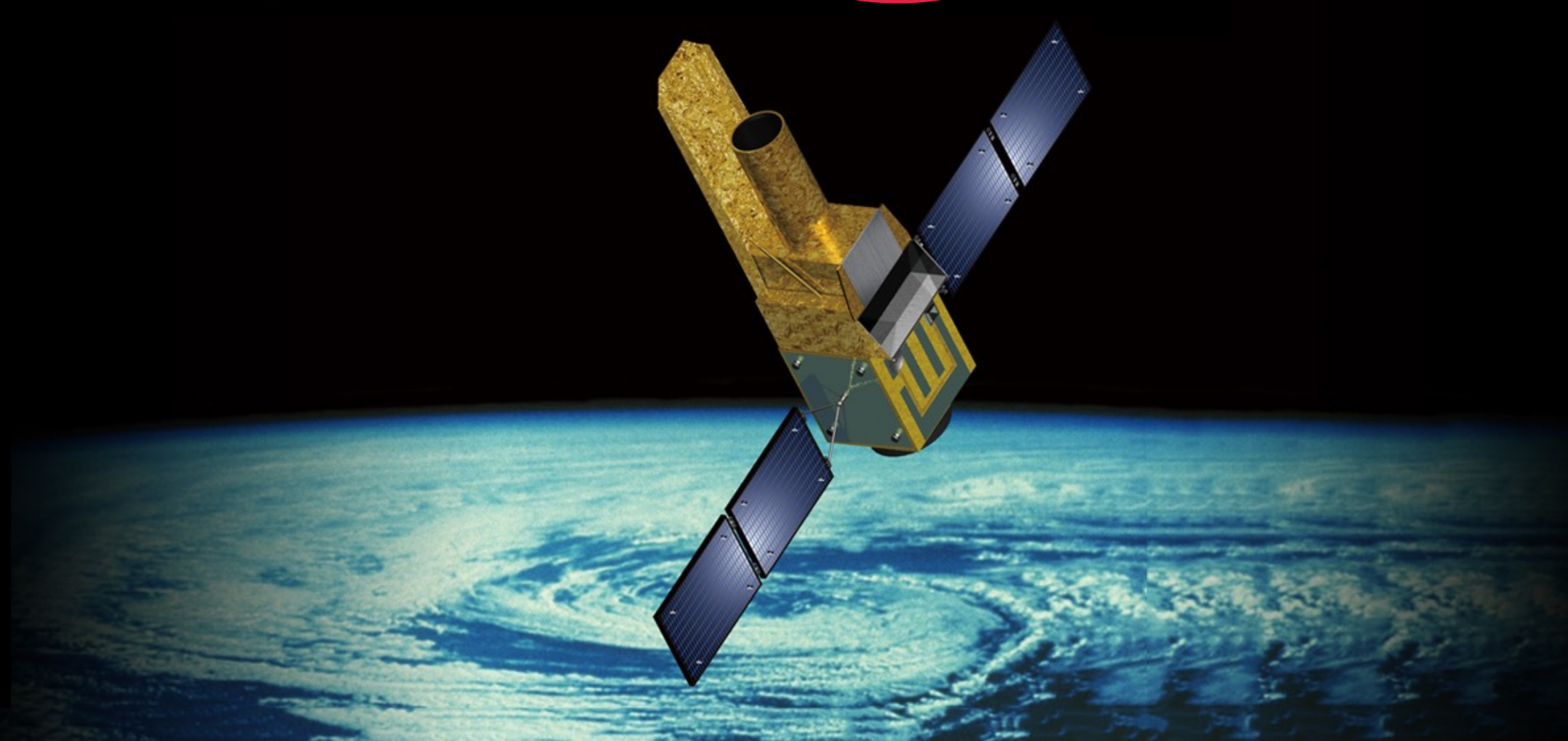
Off-the-shelf models

Koshimoto+21 model



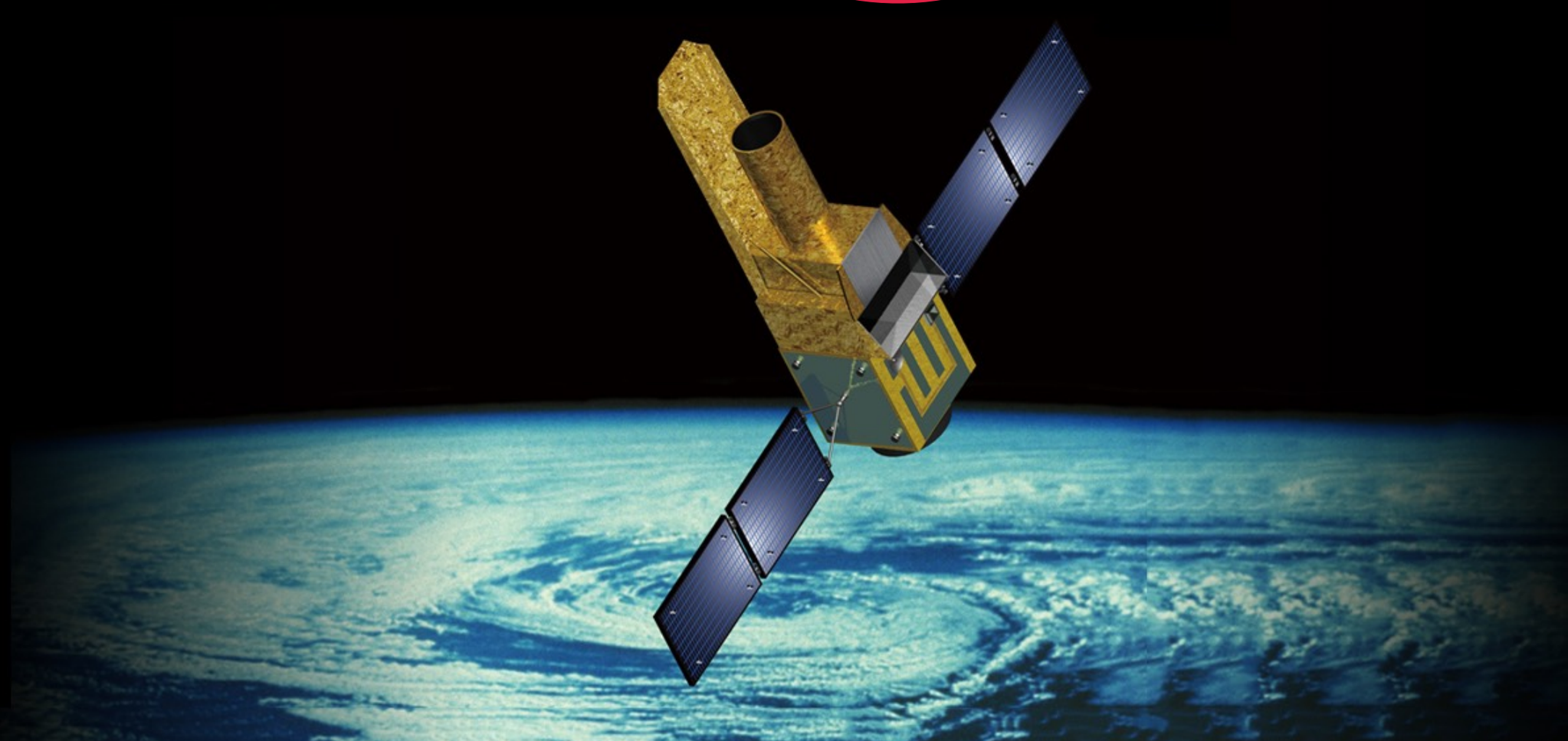
Which Ground Truth to use?

Off-the-shelf models

BGM

Koshimoto+21 model

Bar



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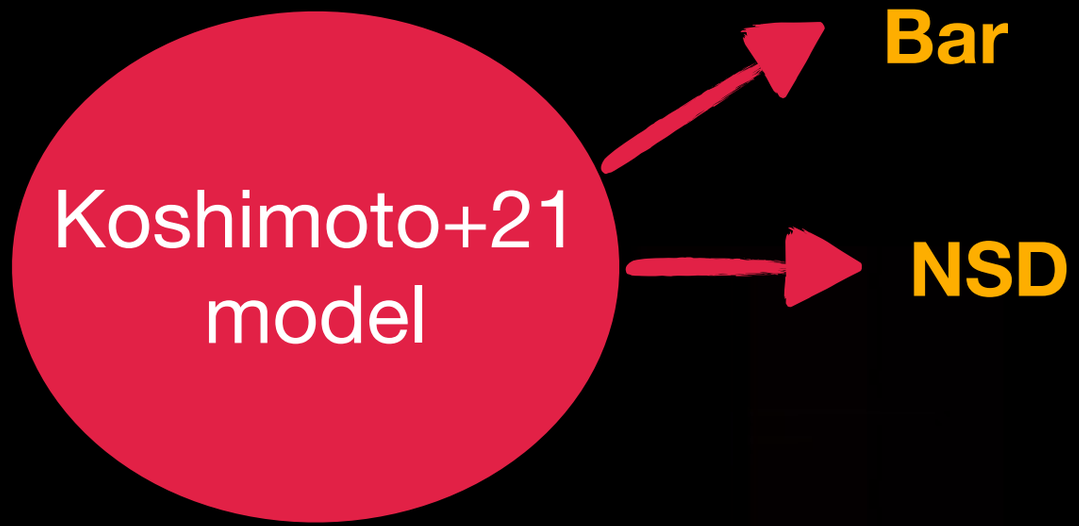

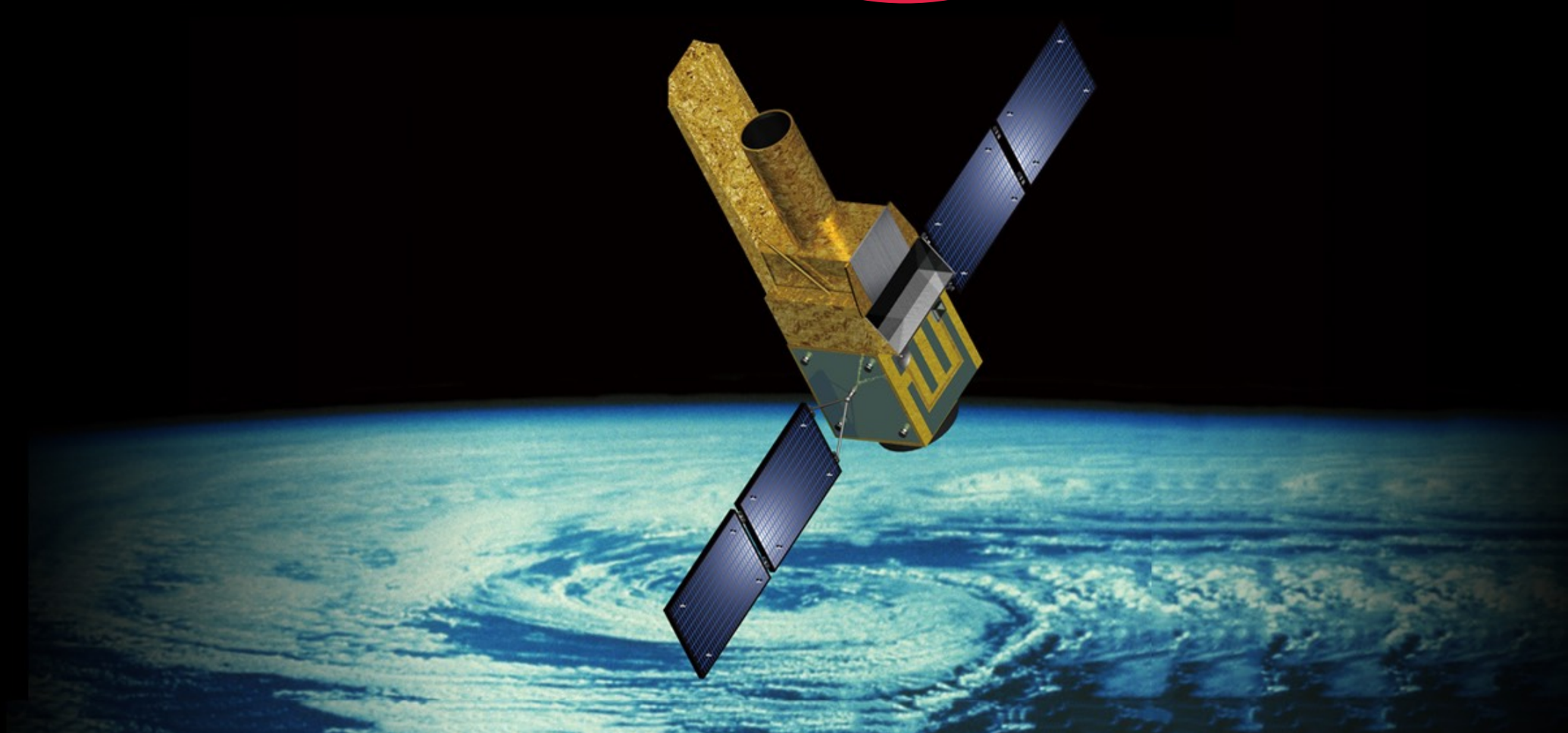

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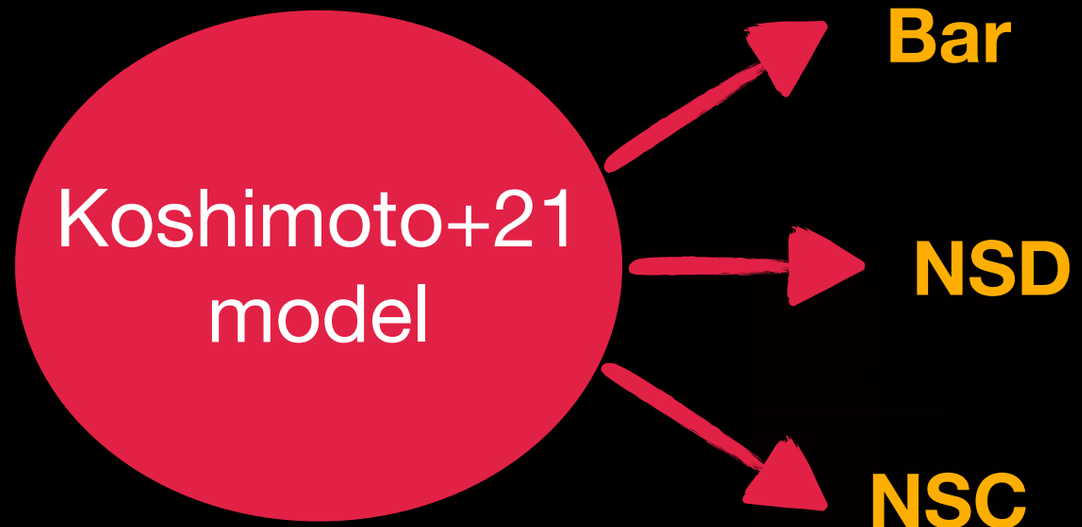

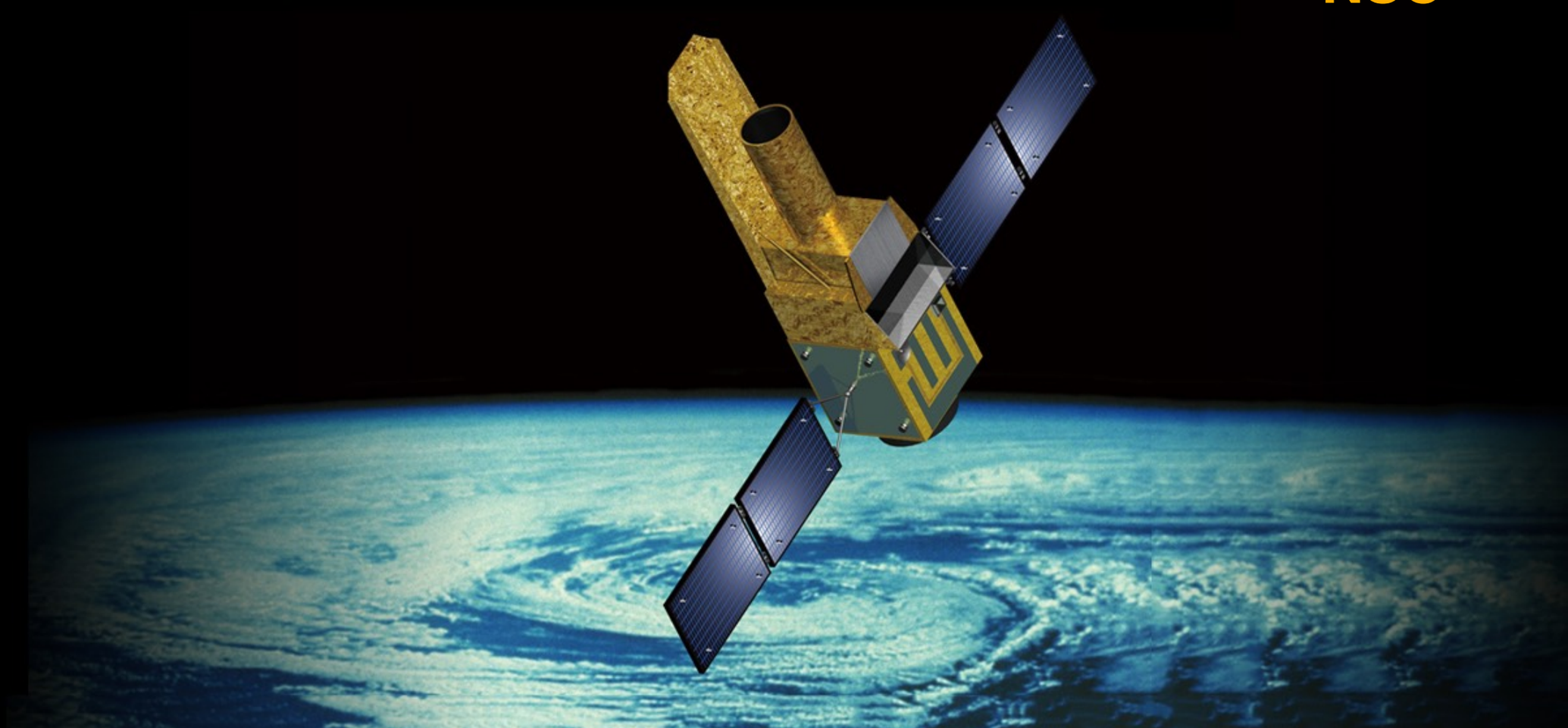

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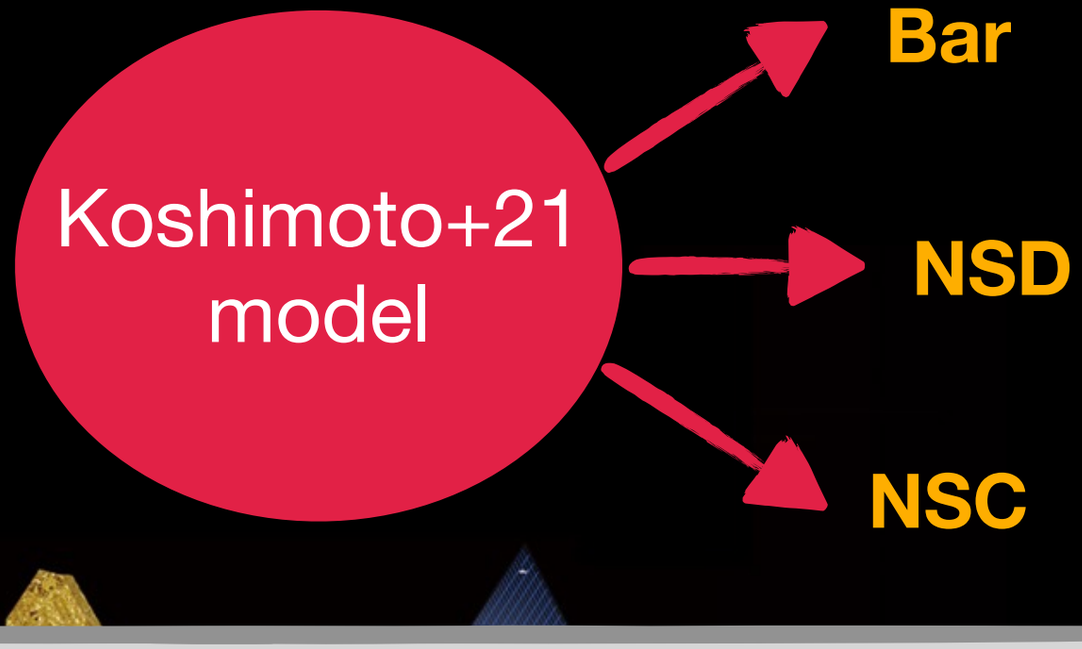

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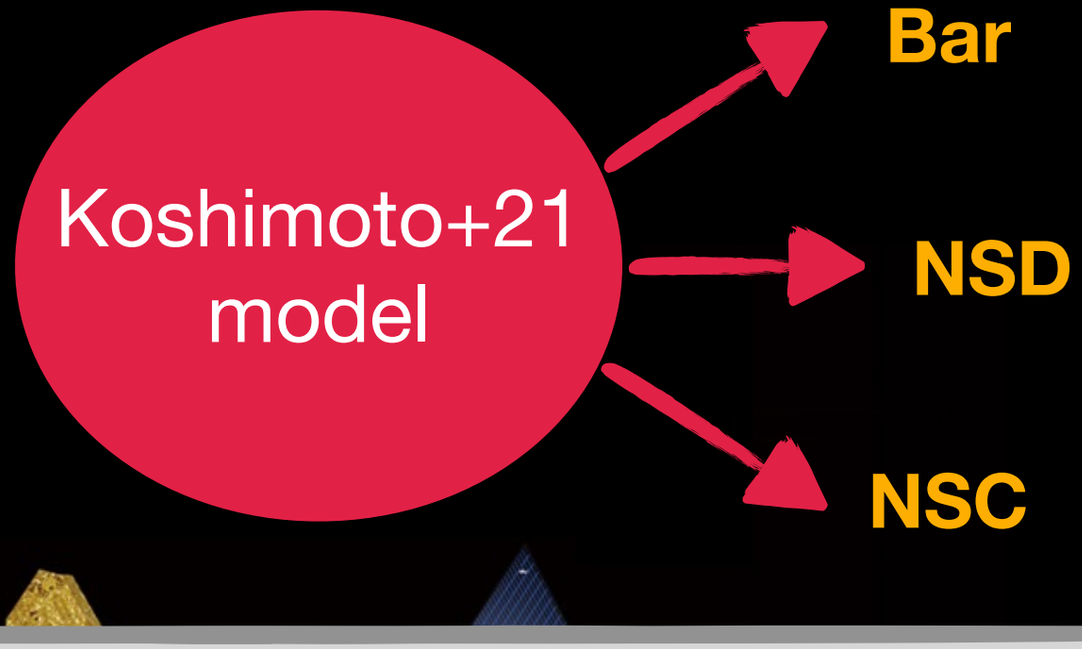
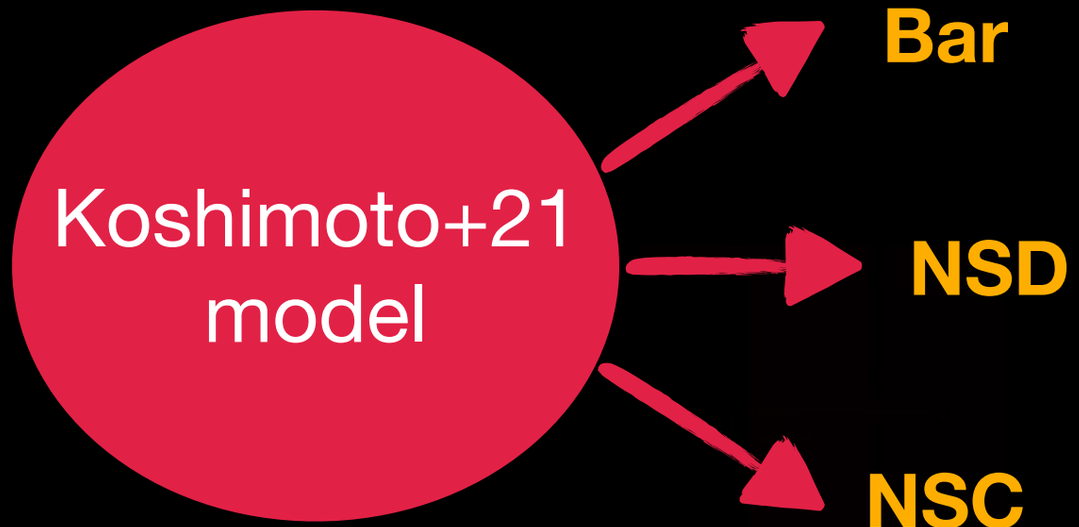


Data driven

Which Ground Truth to use?

Off-the-shelf models



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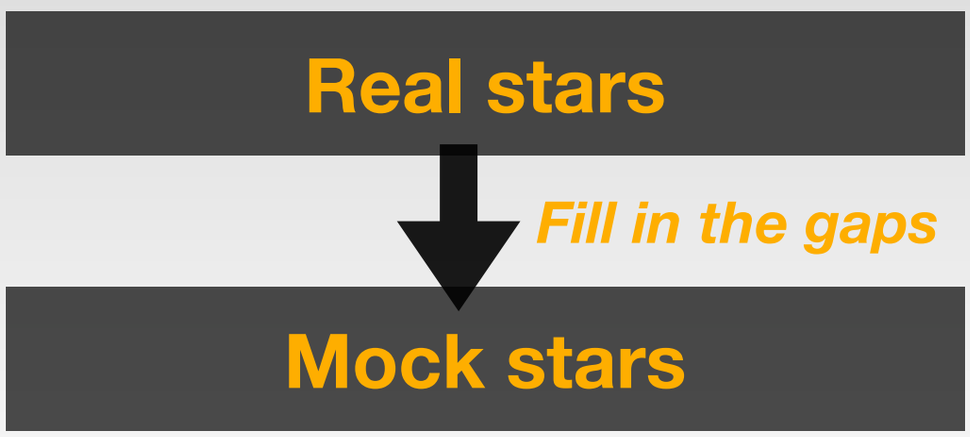

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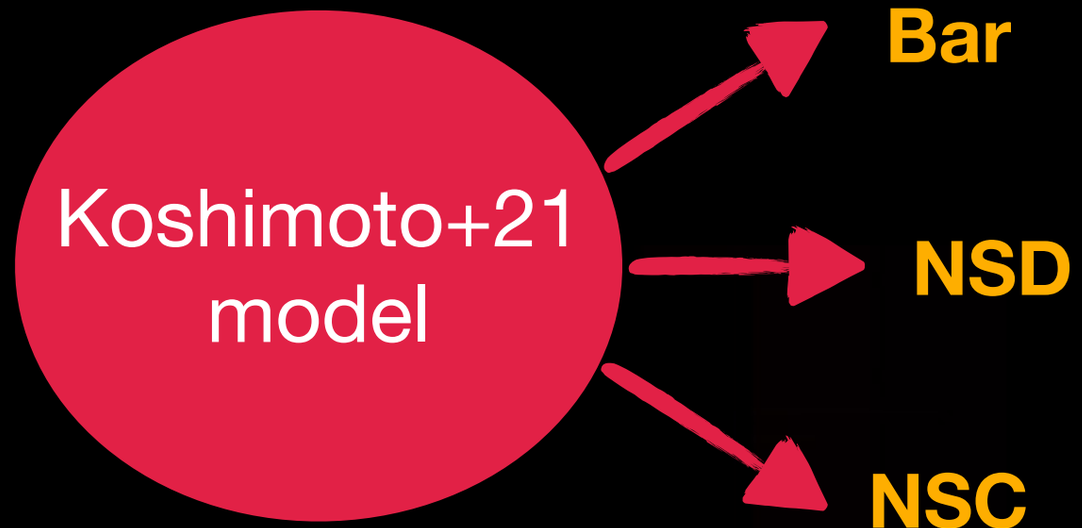

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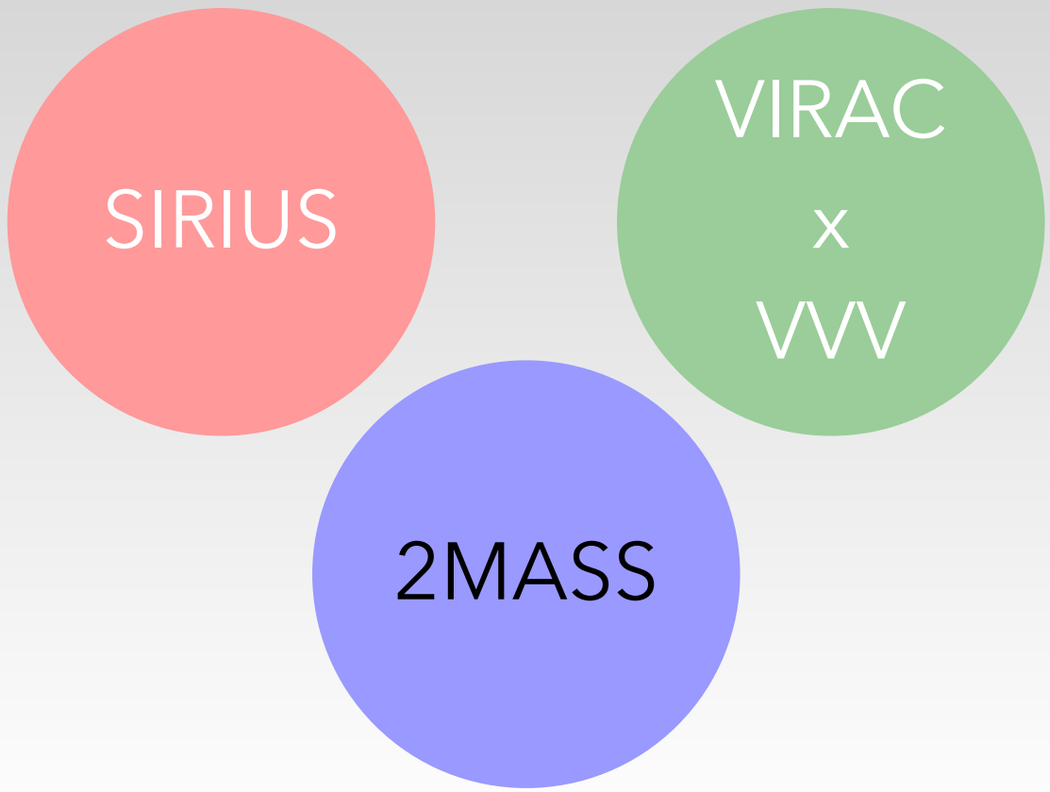

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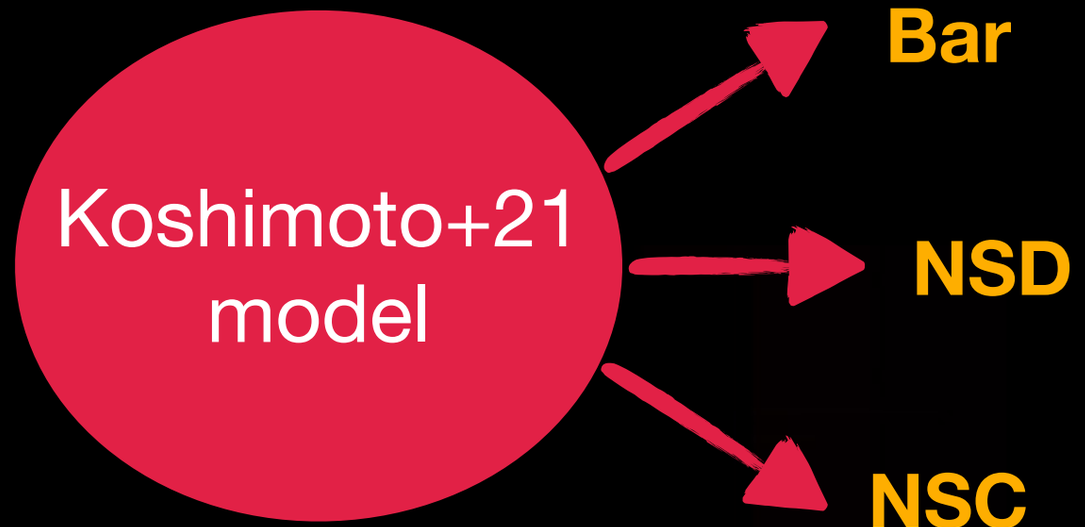

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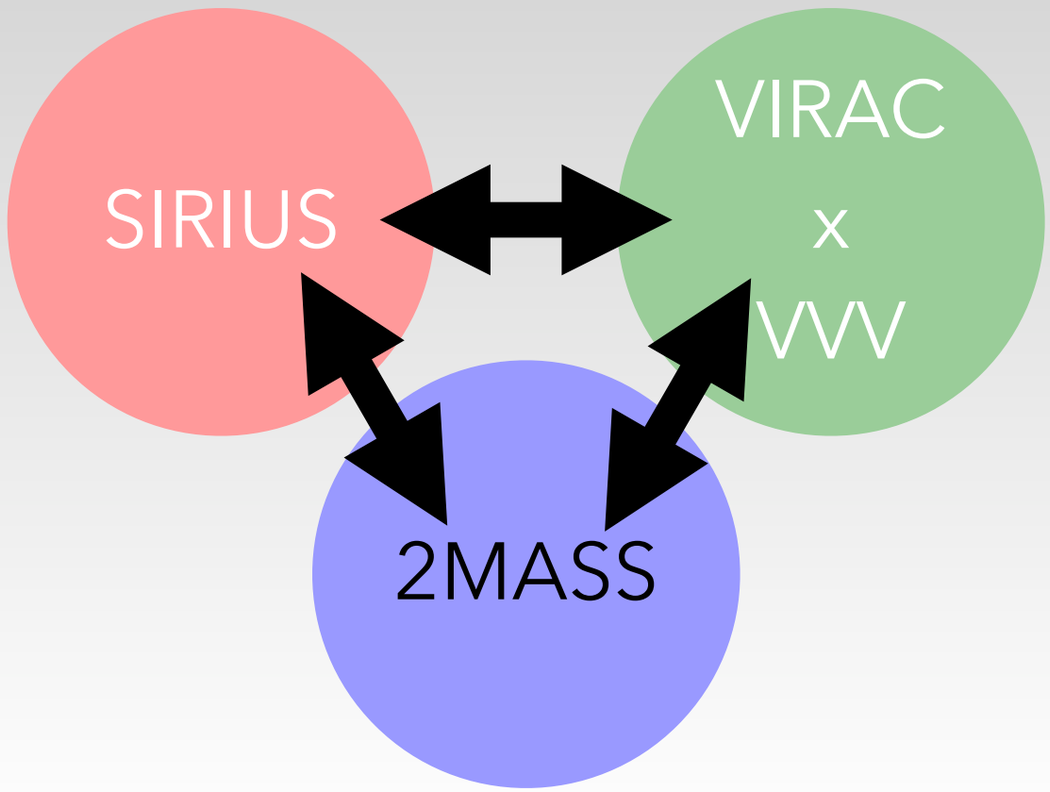

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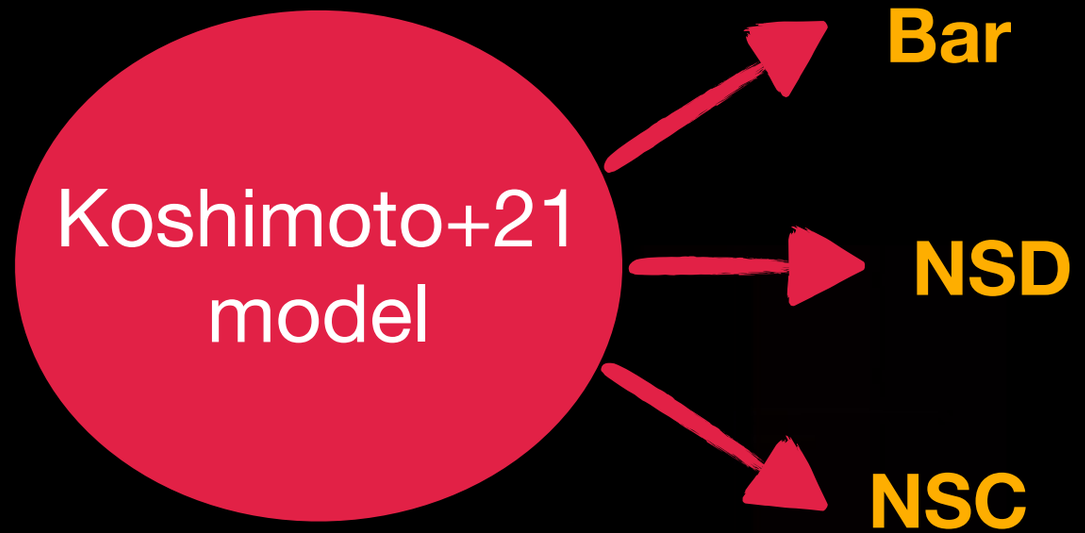

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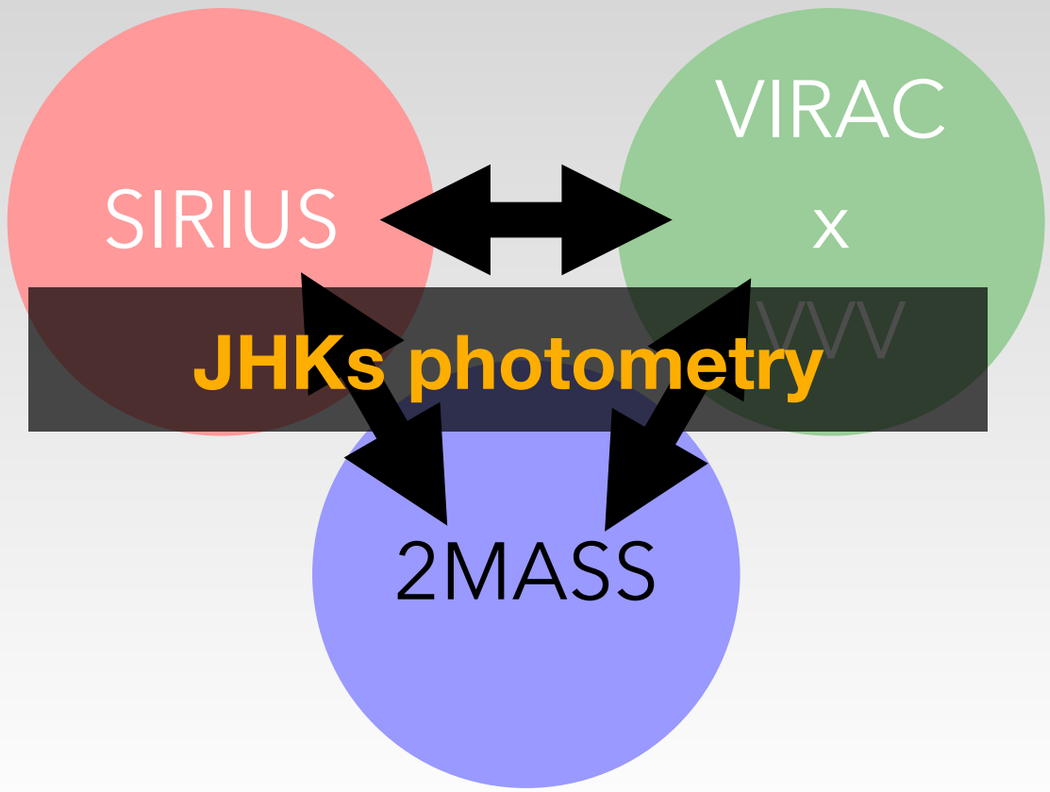
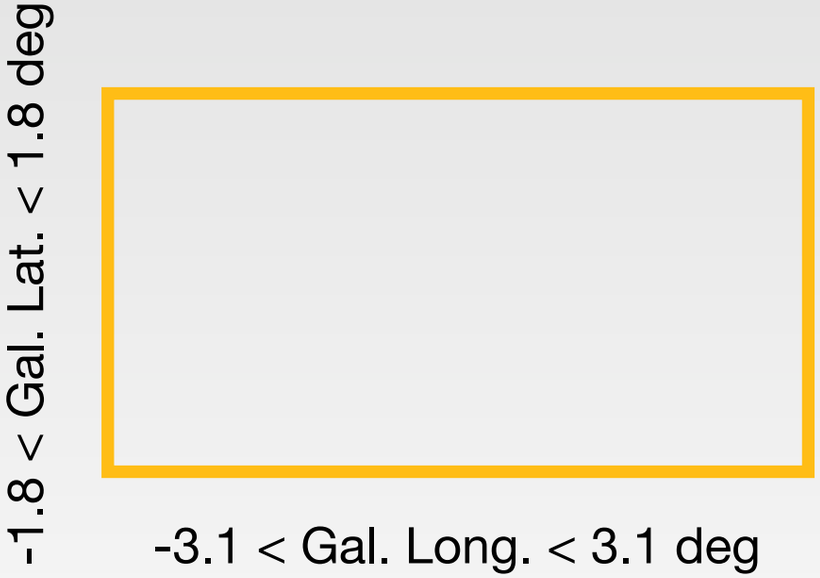


Which Ground Truth to use?

Data driven

Real stars



2MASS

- 3,005,695 Point sources
- mp_flg == 0
- Mostly “bright” stars

Skrutskie et al., 2006

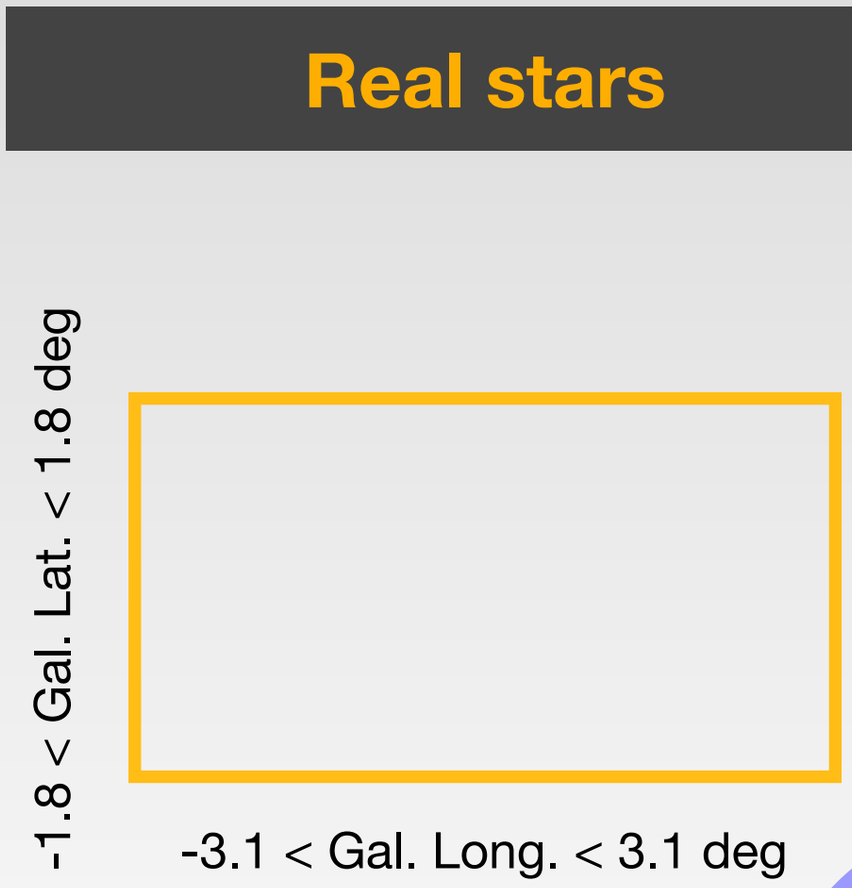
SIRIUS

VIRAC
x
VVV

Which Ground Truth to use?

Data driven

Real stars



SIRIUS

- 12,019,778 Point sources
- Very good completeness
- Deep
- **Does not** cover the whole window of interest

Nishiyama et al., 2006

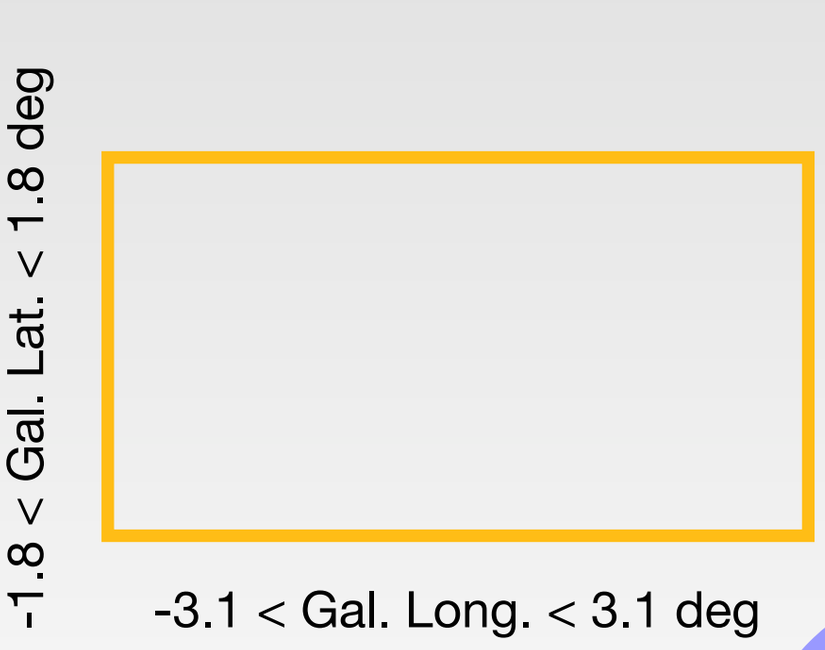
2MASS

VIRAC
x
VVV

Which Ground Truth to use?

Data driven

Real stars



VIRAC (Ks<16)
x
VVV

- 20,897,004 stellar sources
- Good completeness
- Deep
- Provides low-precision proper motions and parallax for most sources
- **Complex surveys with many spurious sources**

Leigh et al., 2025,
Minniti et al. 2010

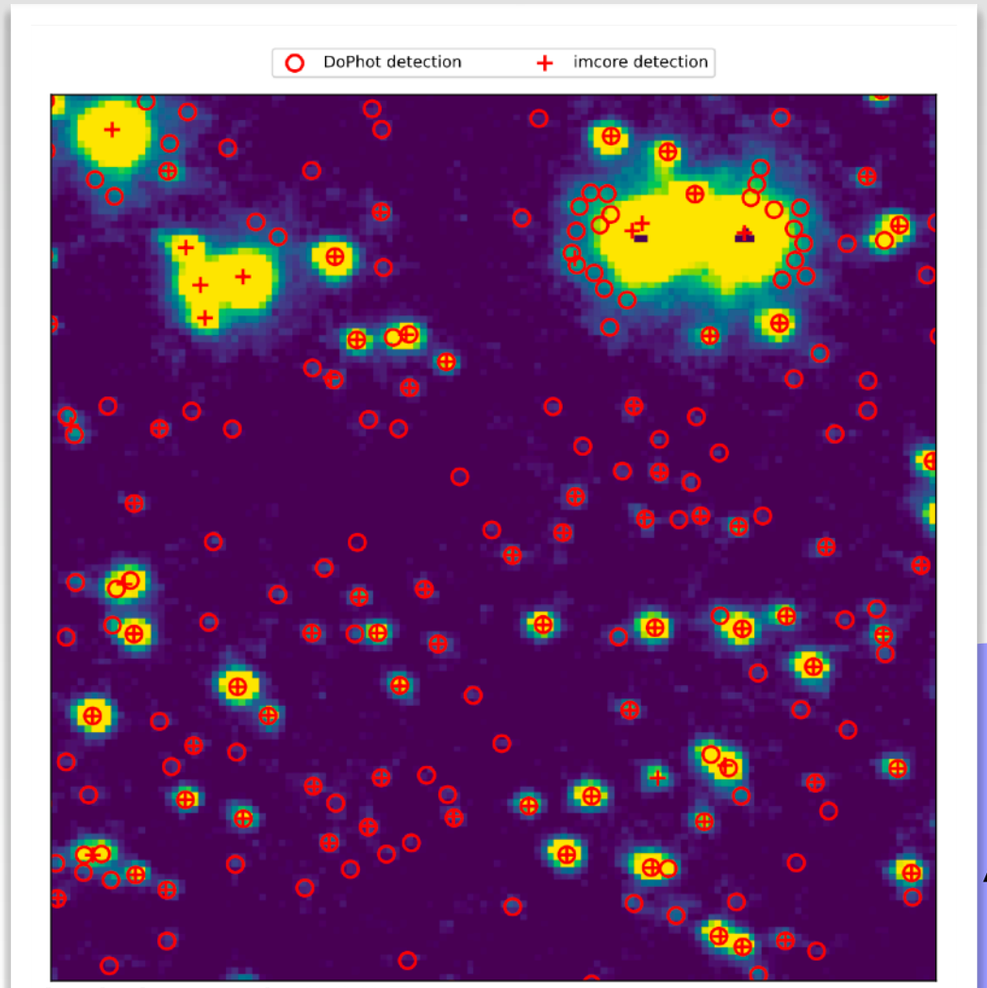
2MASS

SIRIUS

Which Ground Truth to use?

Data driven

Real stars



Leigh et al. 2025

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SIRIUS

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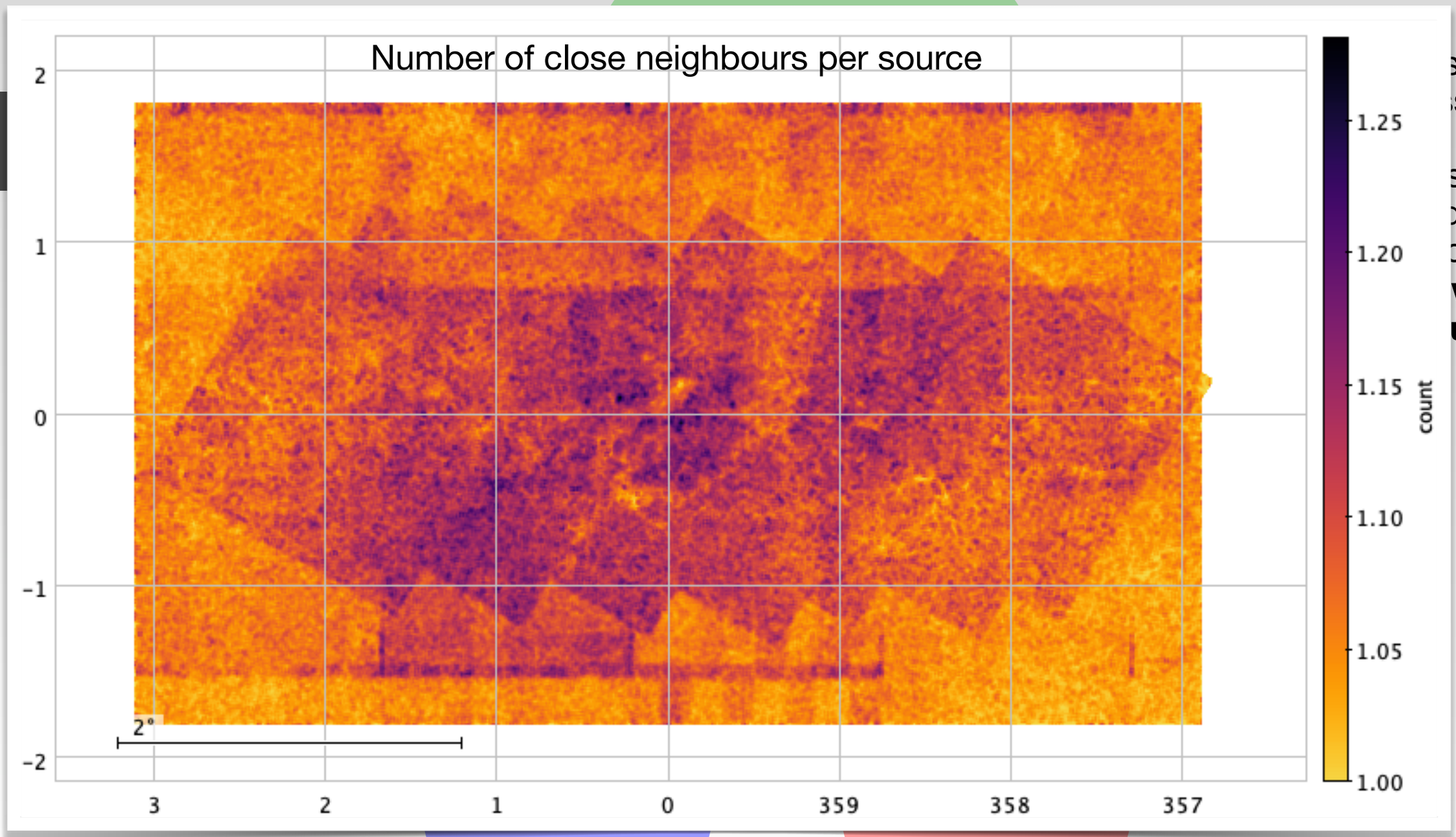

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Which Ground Truth to use?

Data driven

Real stars

-1.8 < Gal. Lat. < 1.8 deg

-3.1 < Gal. Long. < 3.1 deg

Gaia DR3

- 4,478,401 xmatched sources
- Provides high-precision proper motions and parallax for nearby sources
- **Survey in the optical, so it misses most sources of interest (extinction)**

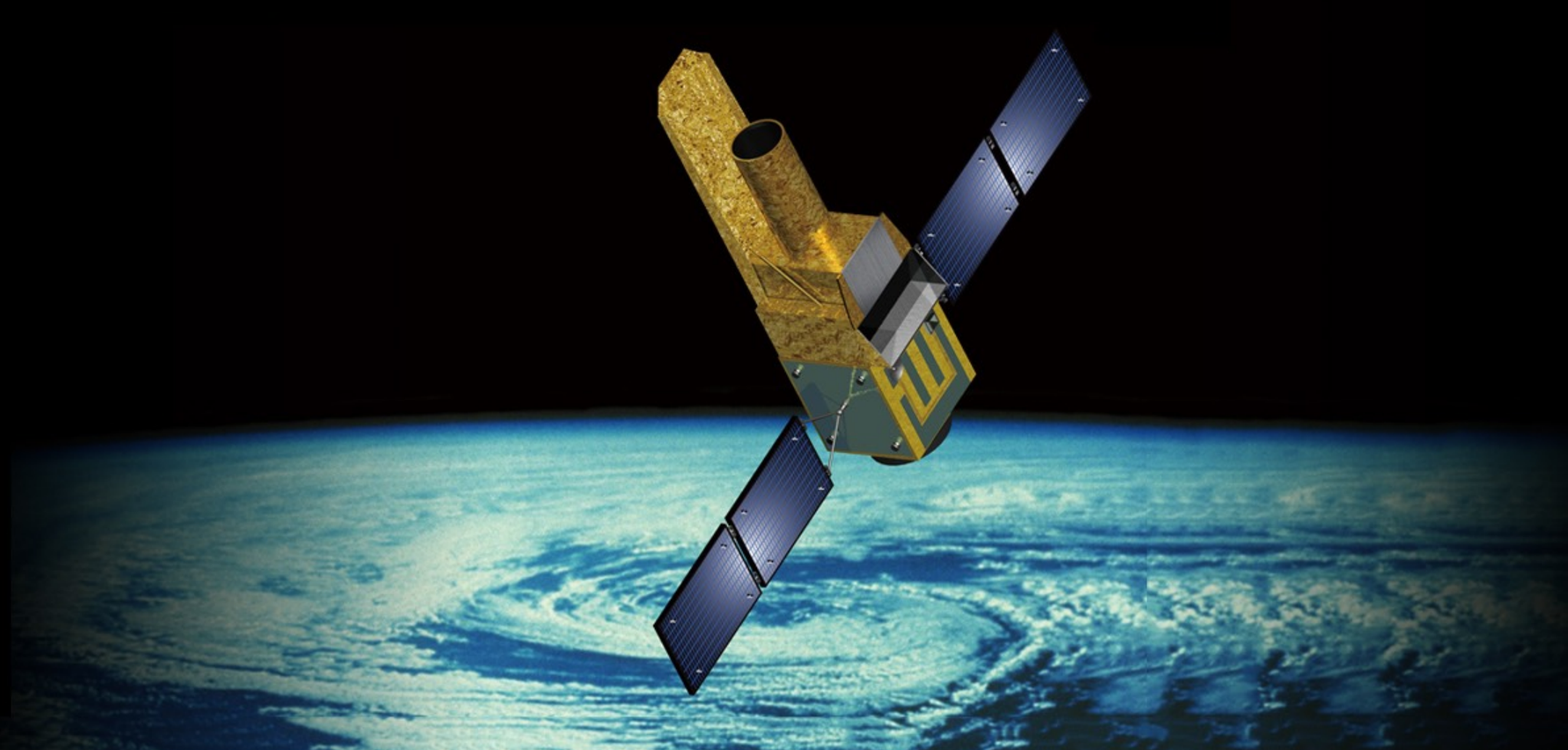
Gaia Collaboration+21,23

2MASS

SIRIUS

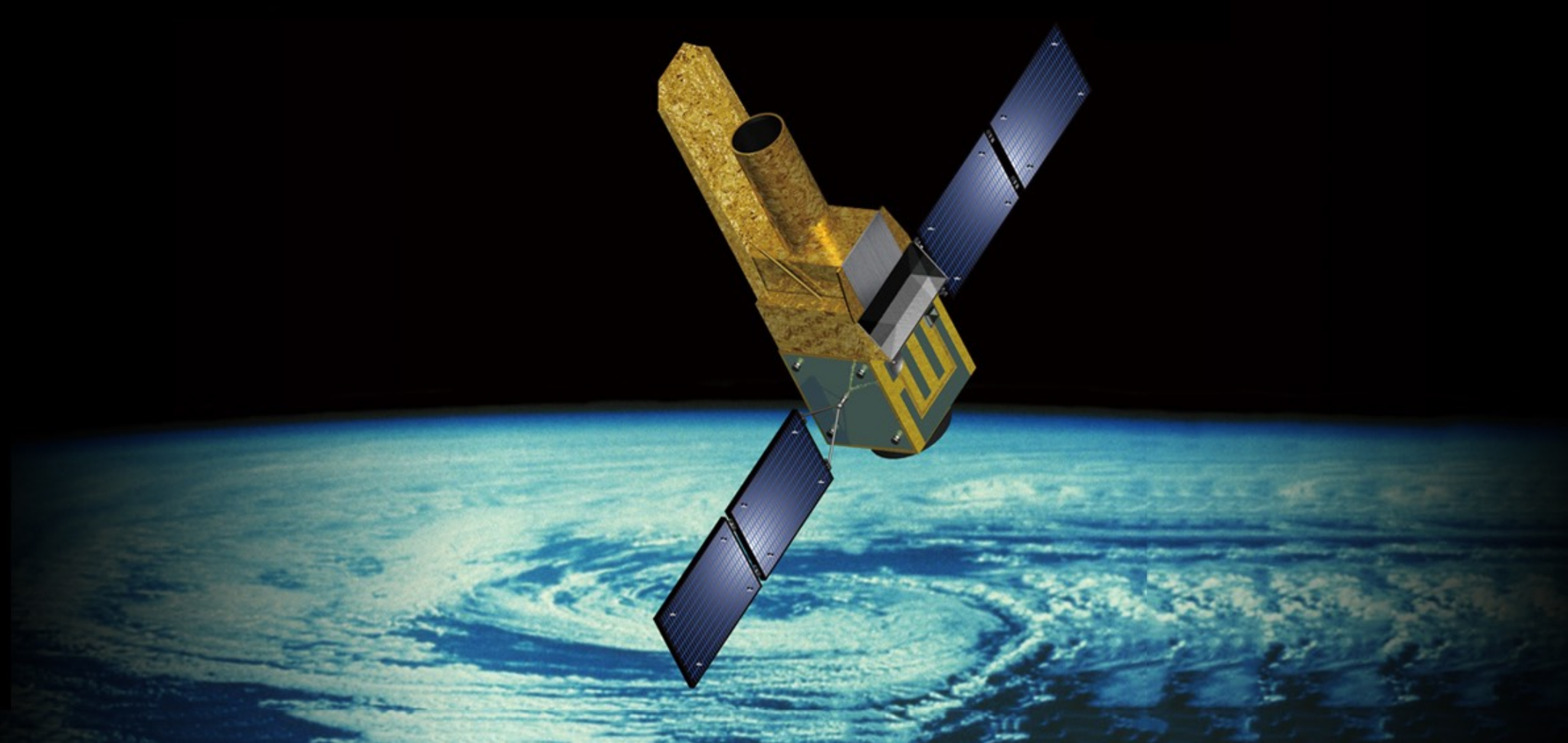
VIRAC x VVV

Steps to building the mock catalogue



Steps to building the mock catalogue

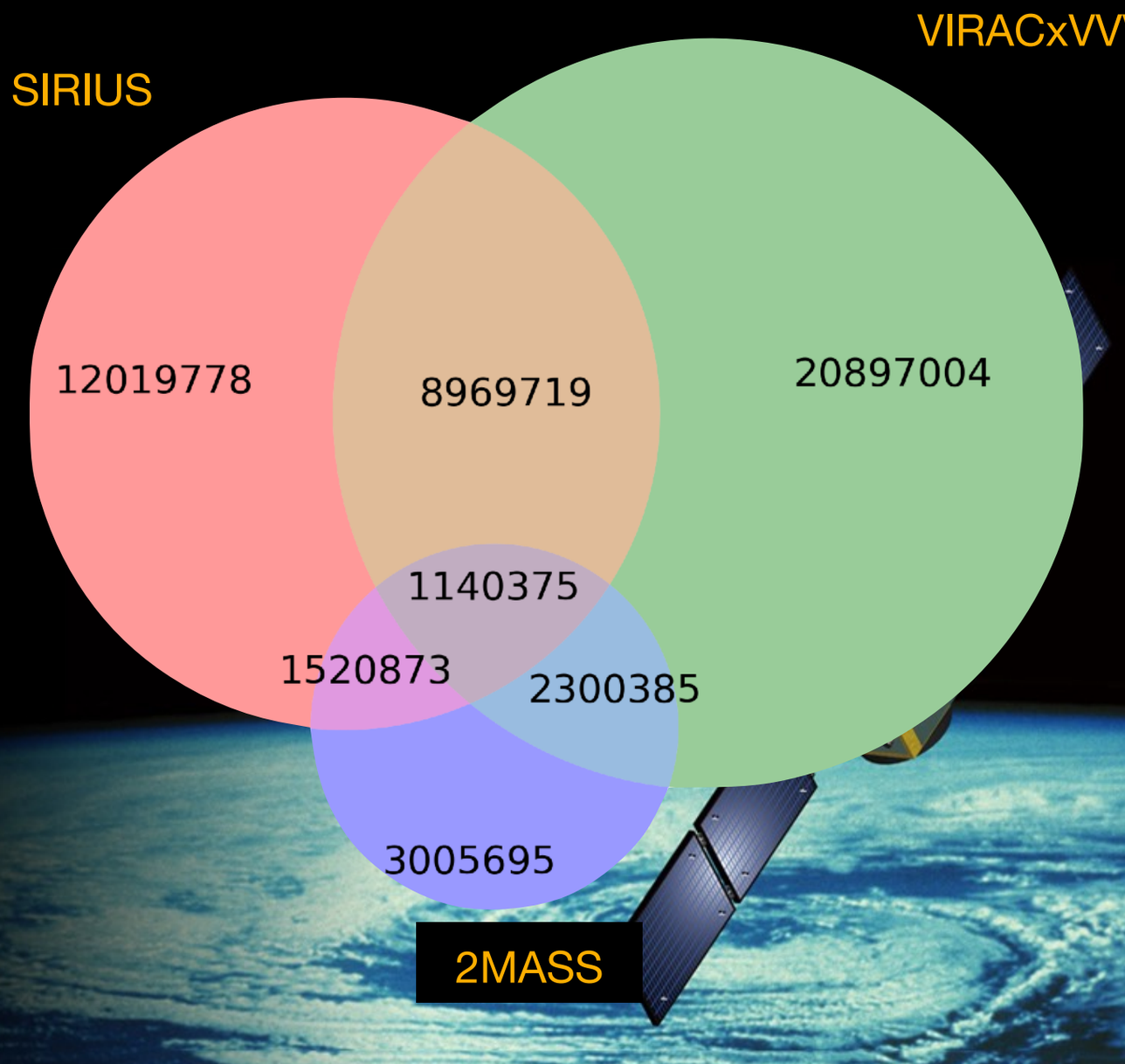
- **Step 1: create a complete catalogue of the Galactic centre**



Steps to building the mock catalogue

- **Step 1: create a complete catalogue of the Galactic centre**

24,585,042 unique sources



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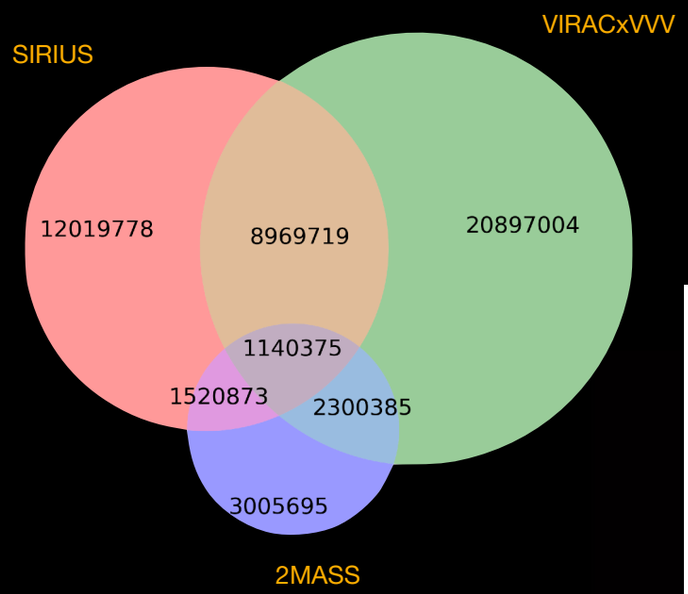
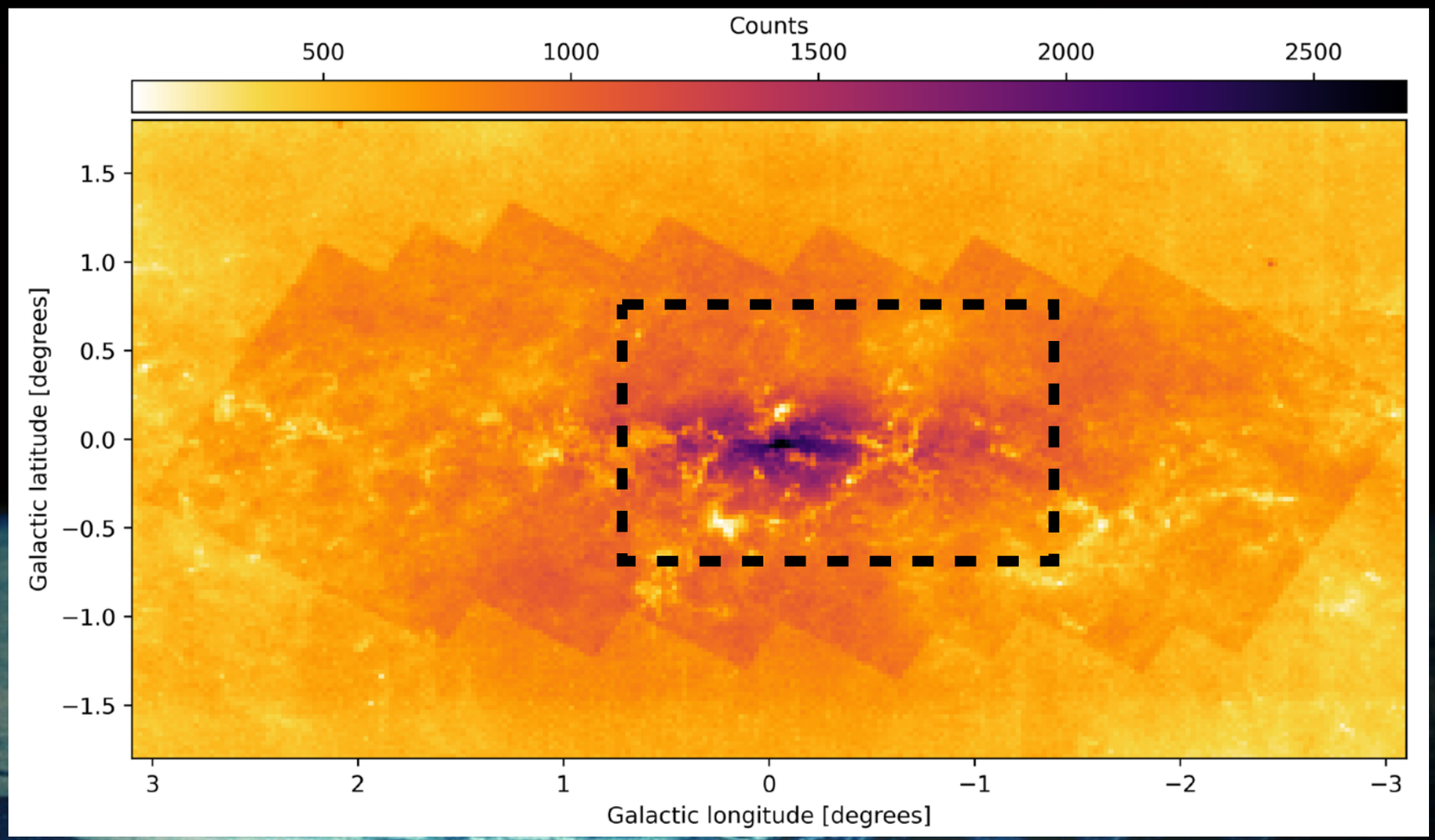
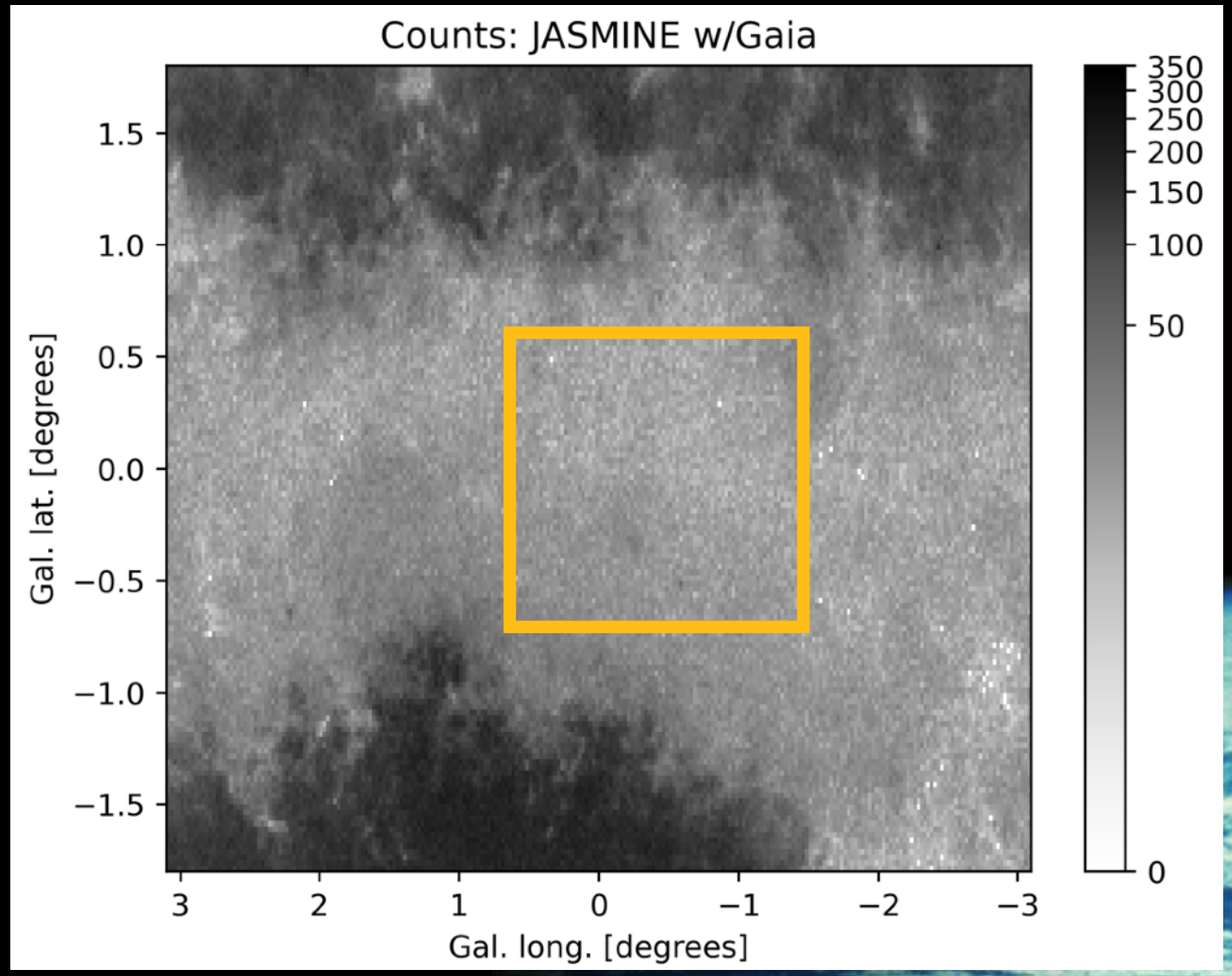
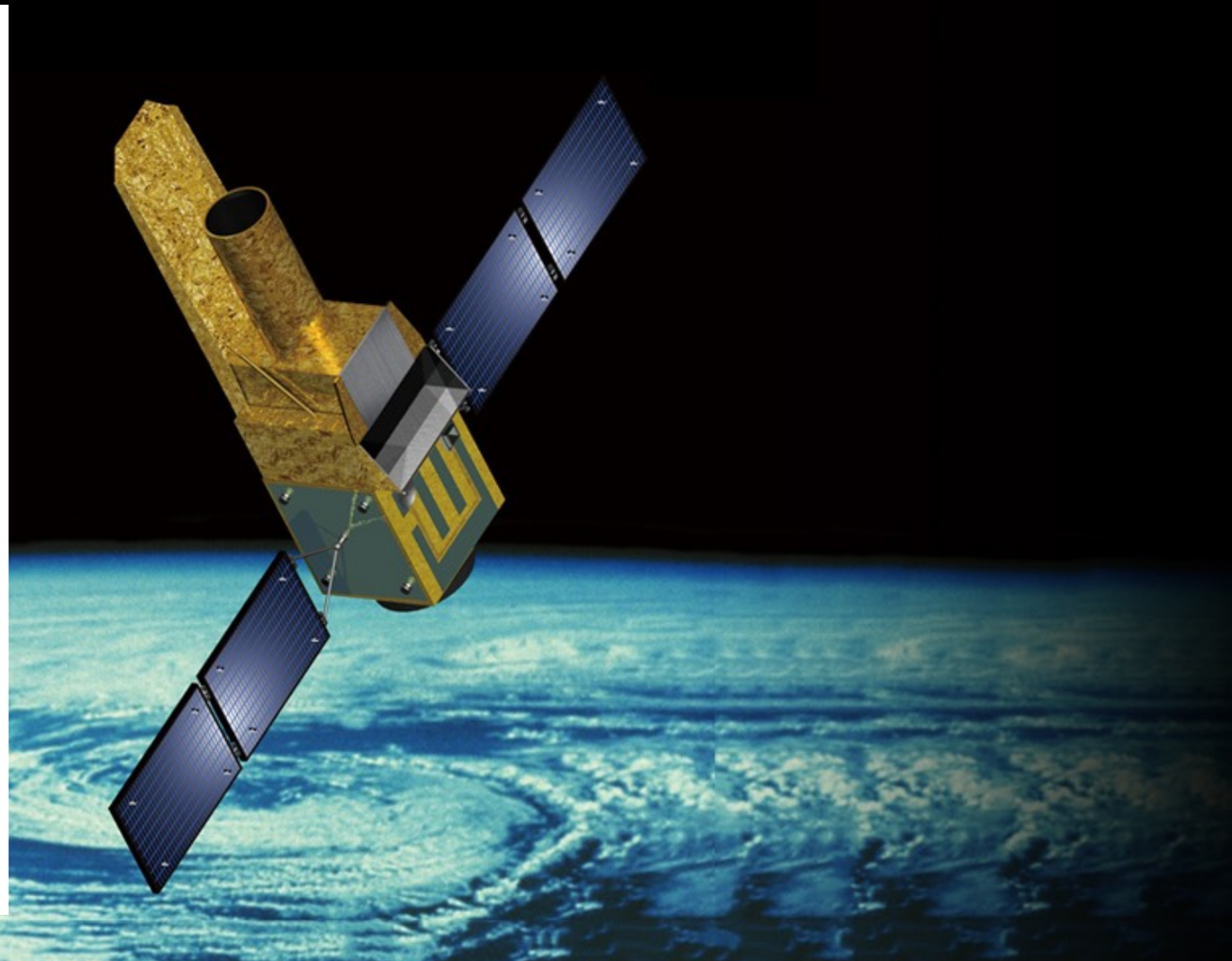




Steps to building the mock catalogue

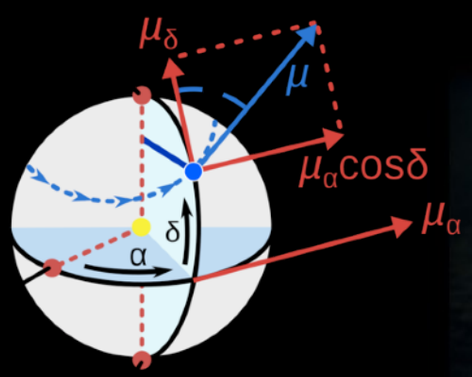
# stars in JASMINE GCS	With Gaia astrometry	$\varpi/\sigma_\varpi \geq 3$
~200k	~55k	~43k





Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**



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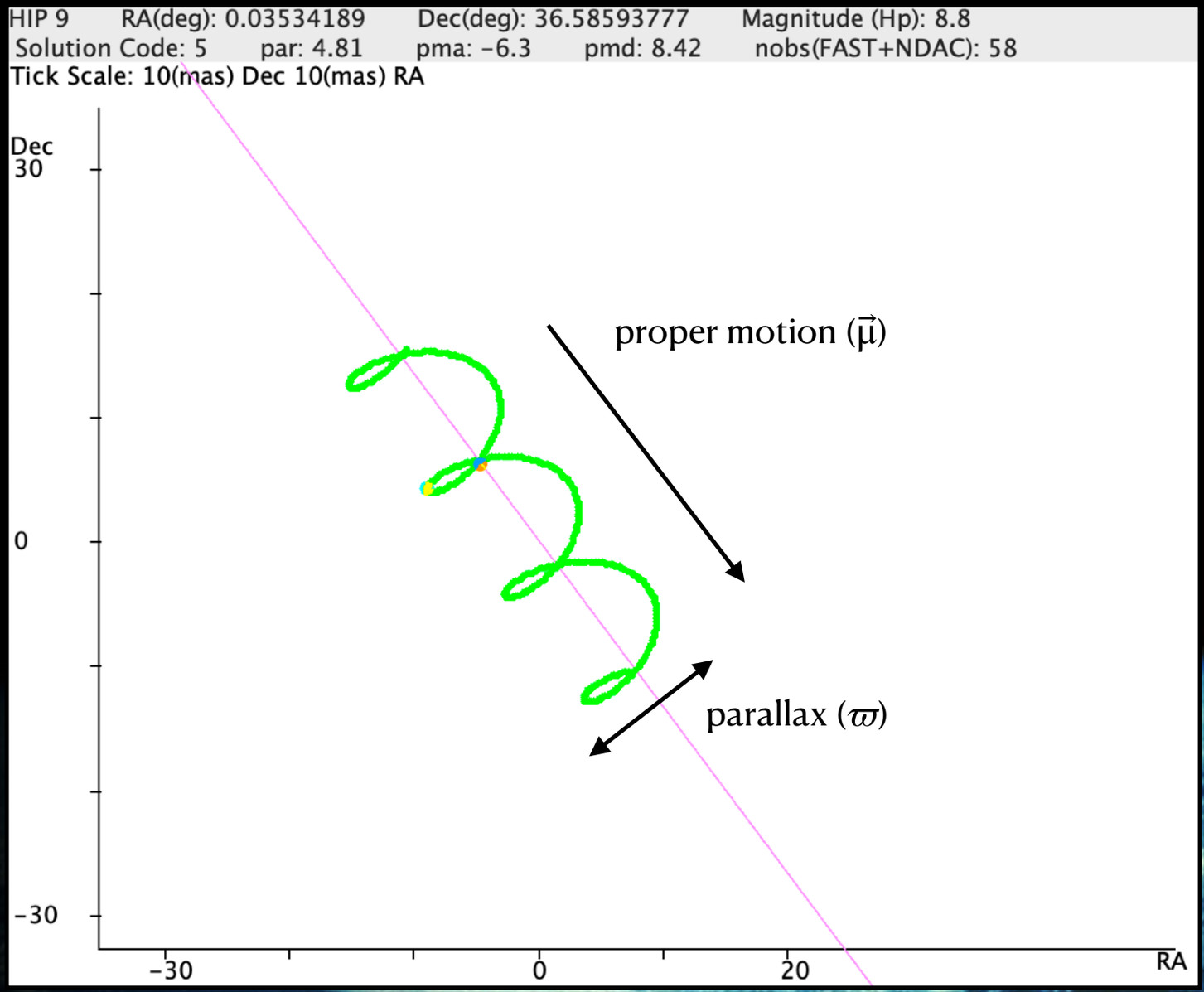
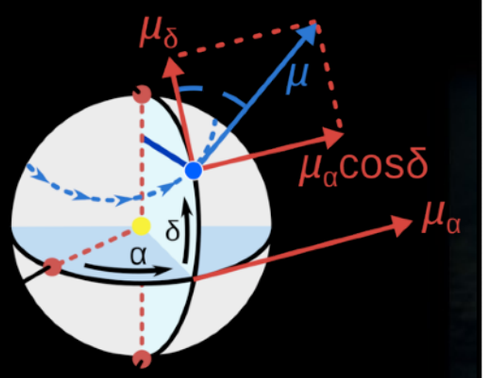




Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**

We need		We have
Hw *(at least J&H, ideally, Ks too)*	→	We have it!
l	→	We have it!
b	→	We have it!
parallax	→	Only for some
pmra	→	Only for some
pmdec	→	Only for some
radial velocity	→	*Not really needed*

Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**

We need		We have
parallax	→	Only for some

We can get parallaxes by inverting the distance

We need a probability distribution of distances for each star

Steps to building the mock catalogue

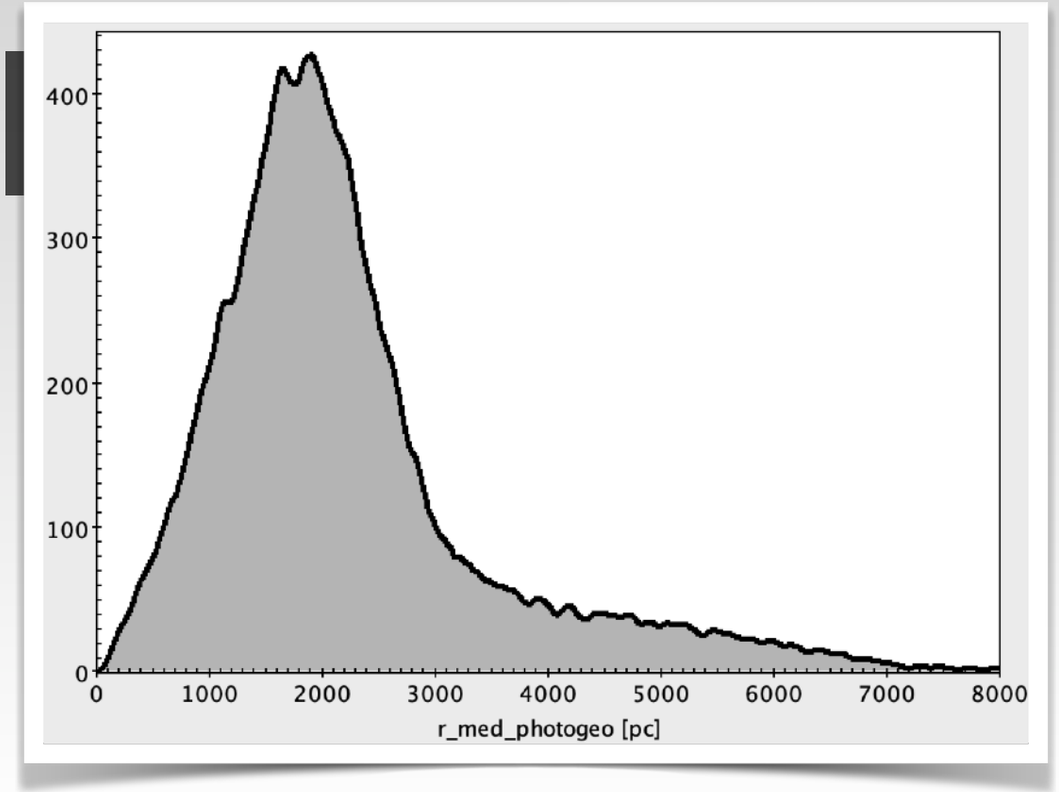
- **Step 2: obtain the true values necessary to propagate positions into the future**

We need

parallax

Gaia DR3

Most Gaia stars are close-by and have a photogeometric distance from CBJ2021



Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**

We need		We have
parallax	→	Only for some

For the rest, we need to infer it from photometry and parallaxes

(proper motions are not helpful)

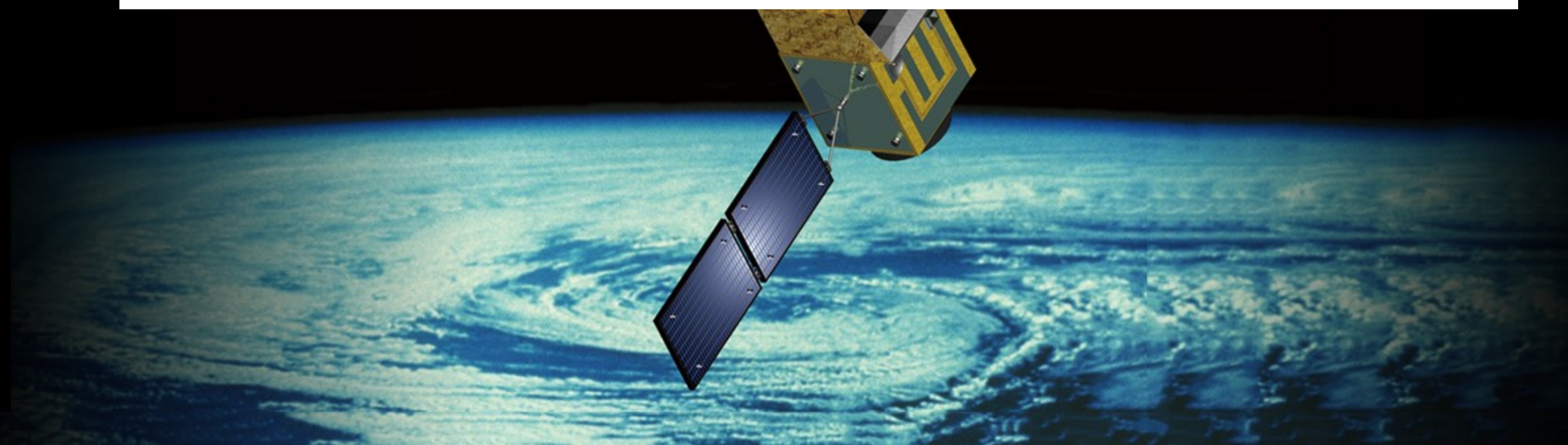
Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**
  - **Step 2.1: obtain the Distance and age-bin posterior P.D.F.**

Koshimoto et al. 2021

Table 1
Scale Lengths, Scale Heights, and Local Densities for Thin and Thick Disks

	Age T (Gyr)	R_d (pc)	$z_{d,\odot}$ (pc)	$z_{d,4.5}$ [a] (pc)	$\rho^{MS}_{d,\odot}$ [b] ($M_\odot$ pc^{-3})	$\rho^{WD}_{d,\odot}$ [b] ($M_\odot$ pc^{-3})	$n^{RG}_{d,\odot}$ [b] (pc^{-3})
Thin disk	0–0.15	5000	61	36	5.1×10^{-3}	5.5×10^{-5}	6.9×10^{-6}
	0.15–1	2600	141	85	5.0×10^{-3}	2.2×10^{-4}	3.3×10^{-5}
	1–2	2600	224	134	3.8×10^{-3}	2.9×10^{-4}	4.2×10^{-5}
	2–3	2600	292	175	3.2×10^{-3}	3.3×10^{-4}	2.1×10^{-5}
	3-5	2600	372	223	5.9×10^{-3}	7.8×10^{-4}	6.5×10^{-5}
	5–7	2600	440	264	6.3×10^{-3}	1.0×10^{-3}	6.1×10^{-5}
	7–10	2600	445	267	1.3×10^{-2}	2.4×10^{-3}	1.3×10^{-4}
Sum/Mean			329	197	4.2×10^{-2}	5.1×10^{-3}	3.6×10^{-4}
Thick disk	12	2200	903		1.7×10^{-3}	4.4×10^{-4}	9.1×10^{-6}



Steps to building the mock catalogue

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Koshimoto et al. 2021

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11 components
thin disc (7), thick disc, bar/bulge, NSD and NSC

Steps to building the mock catalogue

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Koshimoto et al. 2021

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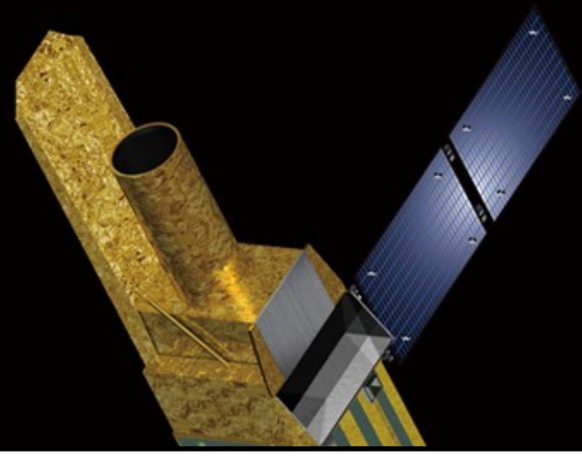
$$P_i(D|J,H,Ks,\varpi) \propto P_i(J,H,Ks,\varpi|D)P_i(D) = P_i(J,H,Ks|D)P_i(\varpi|D)P_i(D)$$

Steps to building the mock catalogue

- **Step 2: obtain the true values necessary to propagate positions into the future**
  - **Step 2.1: obtain the Distance and age-bin posterior P.D.F.**



$$P_i(D|J,H,Ks,\varpi) \propto P_i(J,H,Ks,\varpi|D)P_i(D) = P_i(J,H,Ks|D)P_i(\varpi|D)P_i(D)$$

Density

Steps to building the mock catalogue

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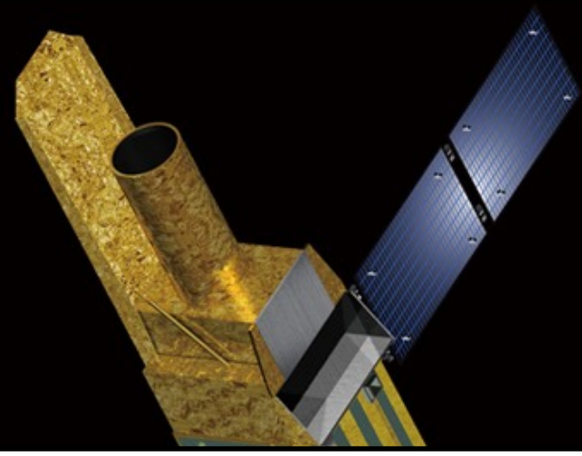

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~N(1/D, parallax_error)

Steps to building the mock catalogue

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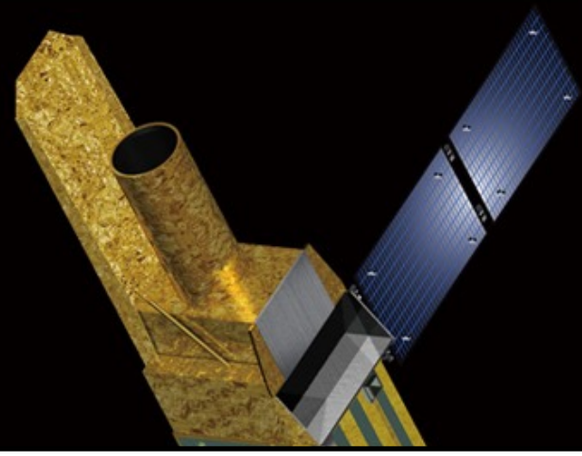

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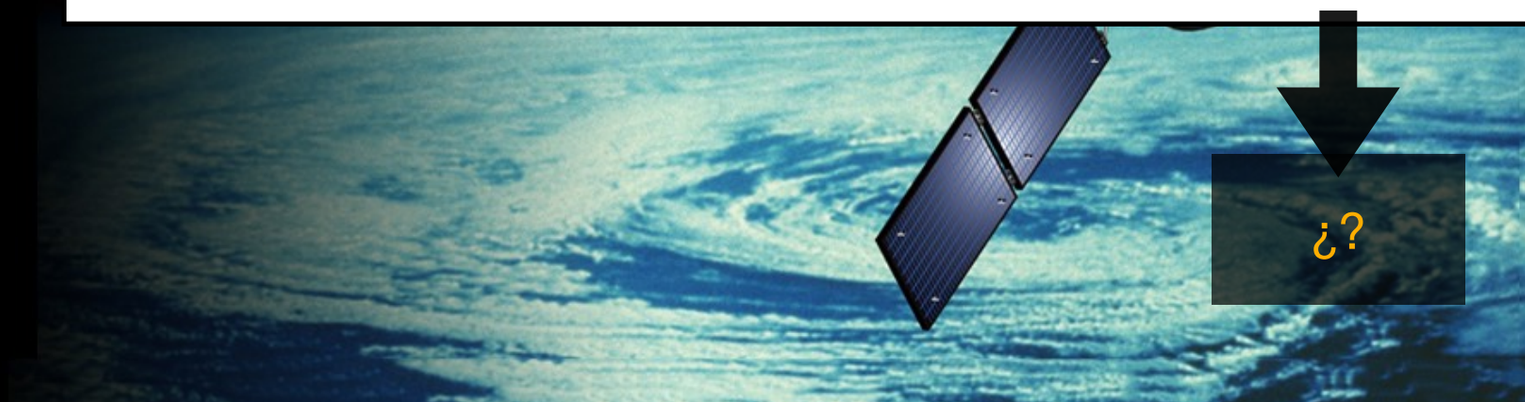

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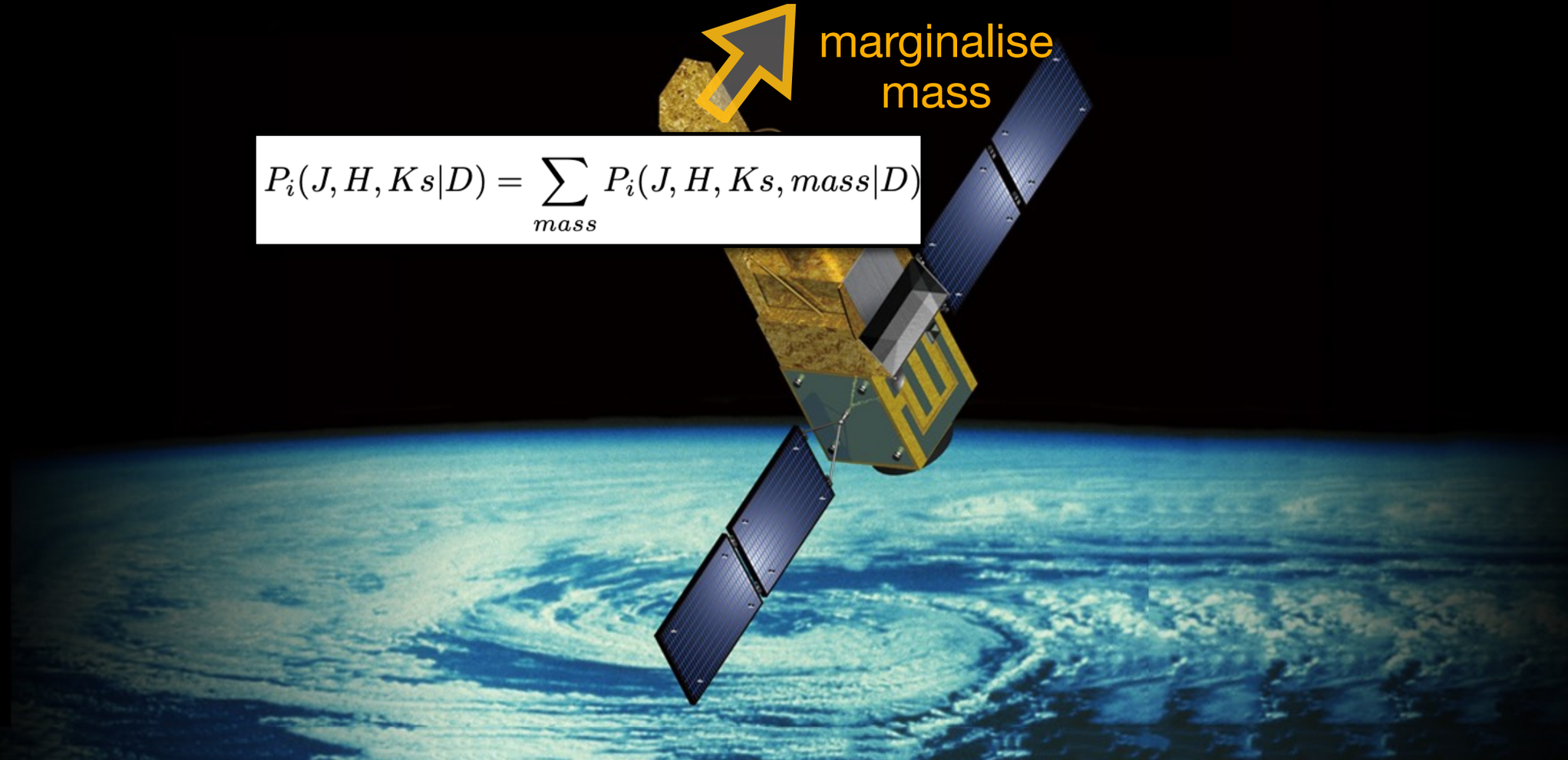
marginalise mass

$$P_i(J,H,Ks|D) = \sum_{mass} P_i(J,H,Ks,mass|D)$$



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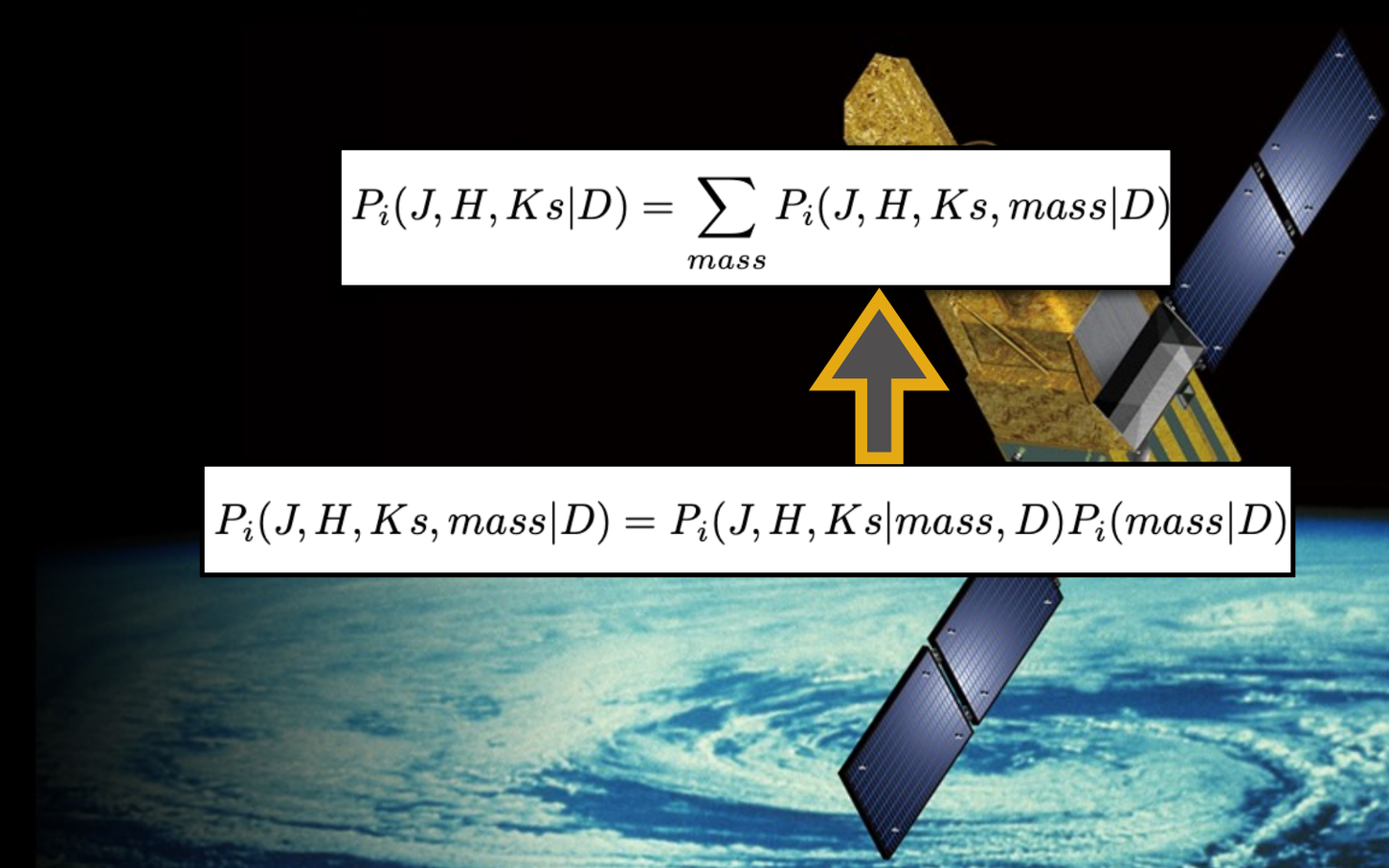

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$$P_i(J,H,Ks,mass|D) = P_i(J,H,Ks|mass,D)P_i(mass|D)$$

Normal distribution

IMF

Steps to building the mock catalogue

- **Step 2: obtain the true values neces into the future**
  - **Step 2.1: obtain the Distance and age-**

$$P_i(D|J,H,Ks,\varpi) \propto P_i(J,H,Ks,\varpi|D)P_i(D)$$

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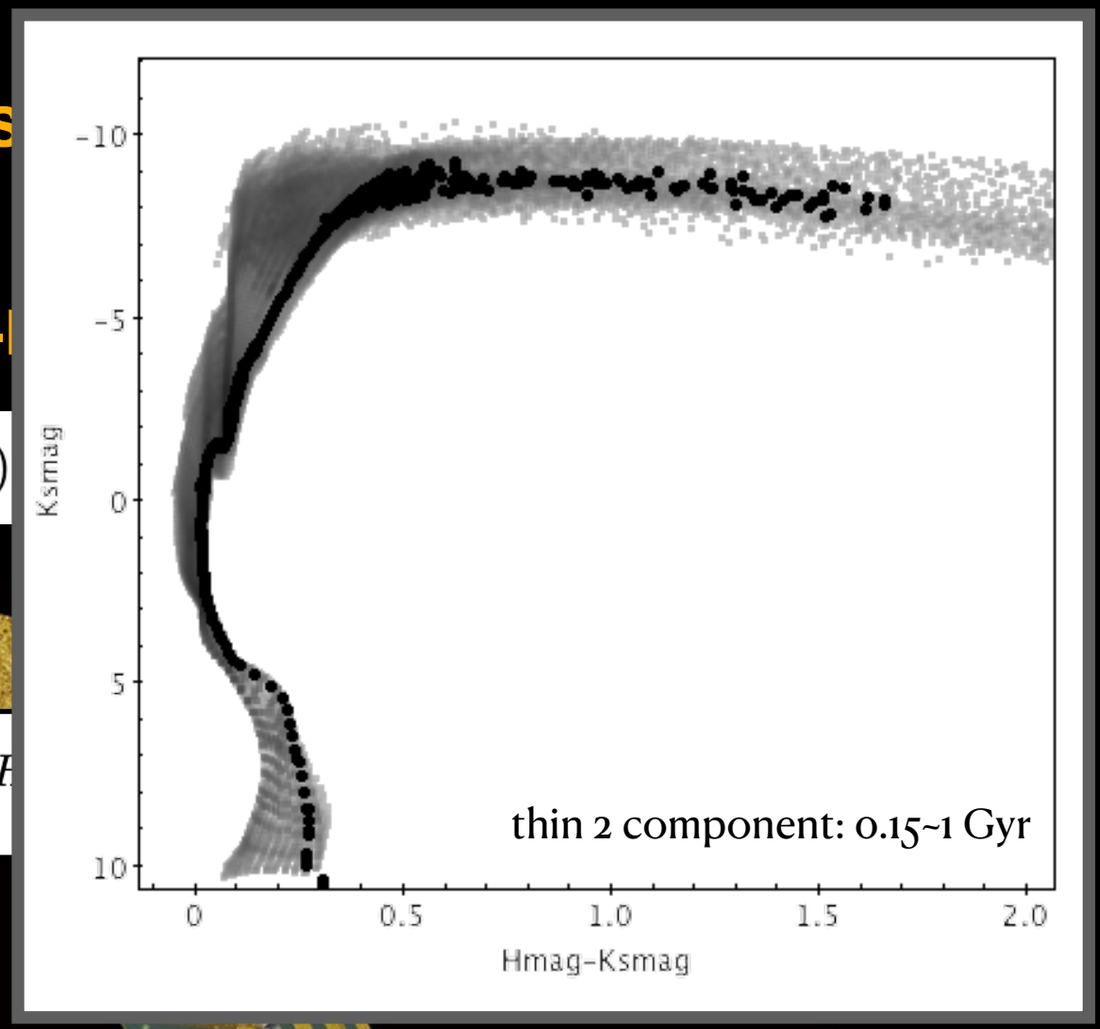
Normal distribution

IMF



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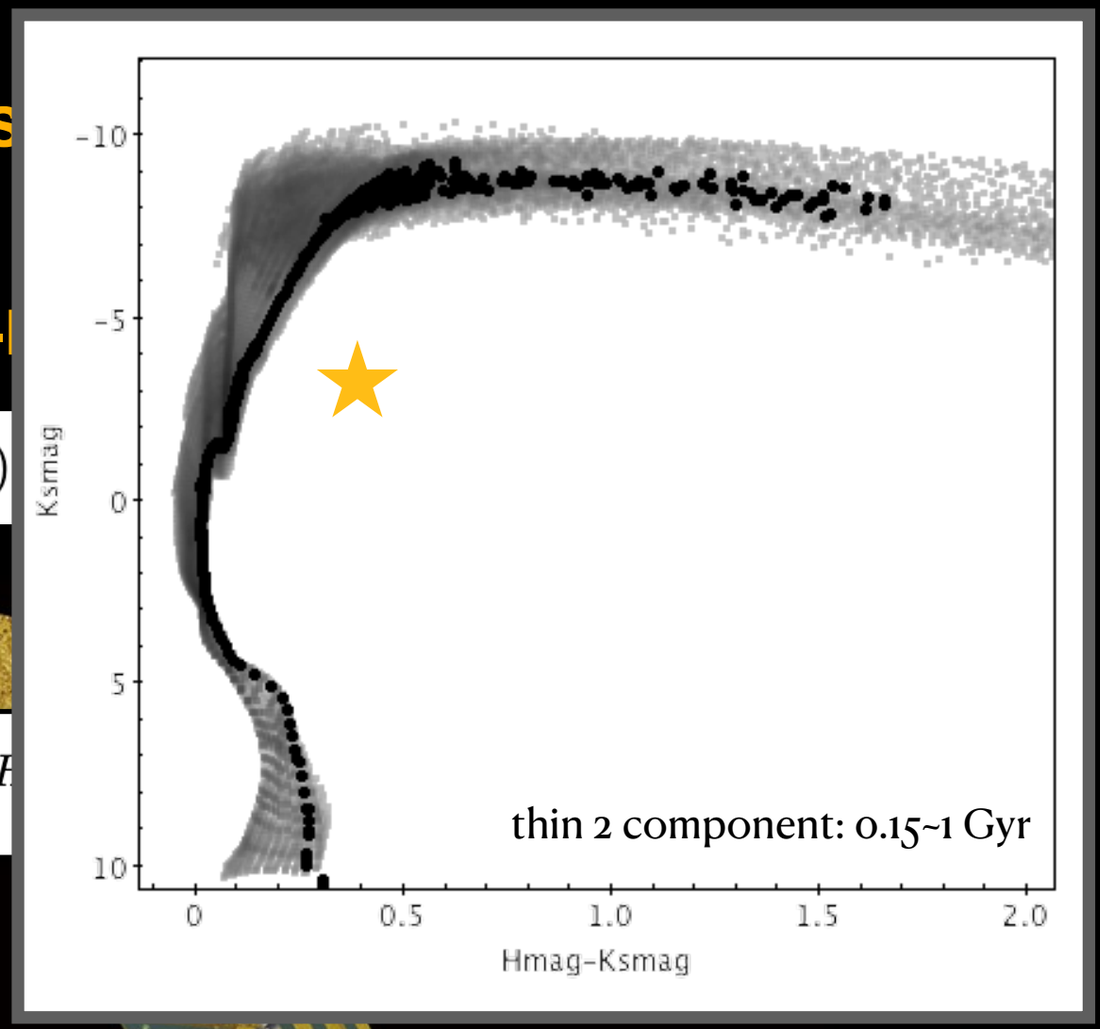

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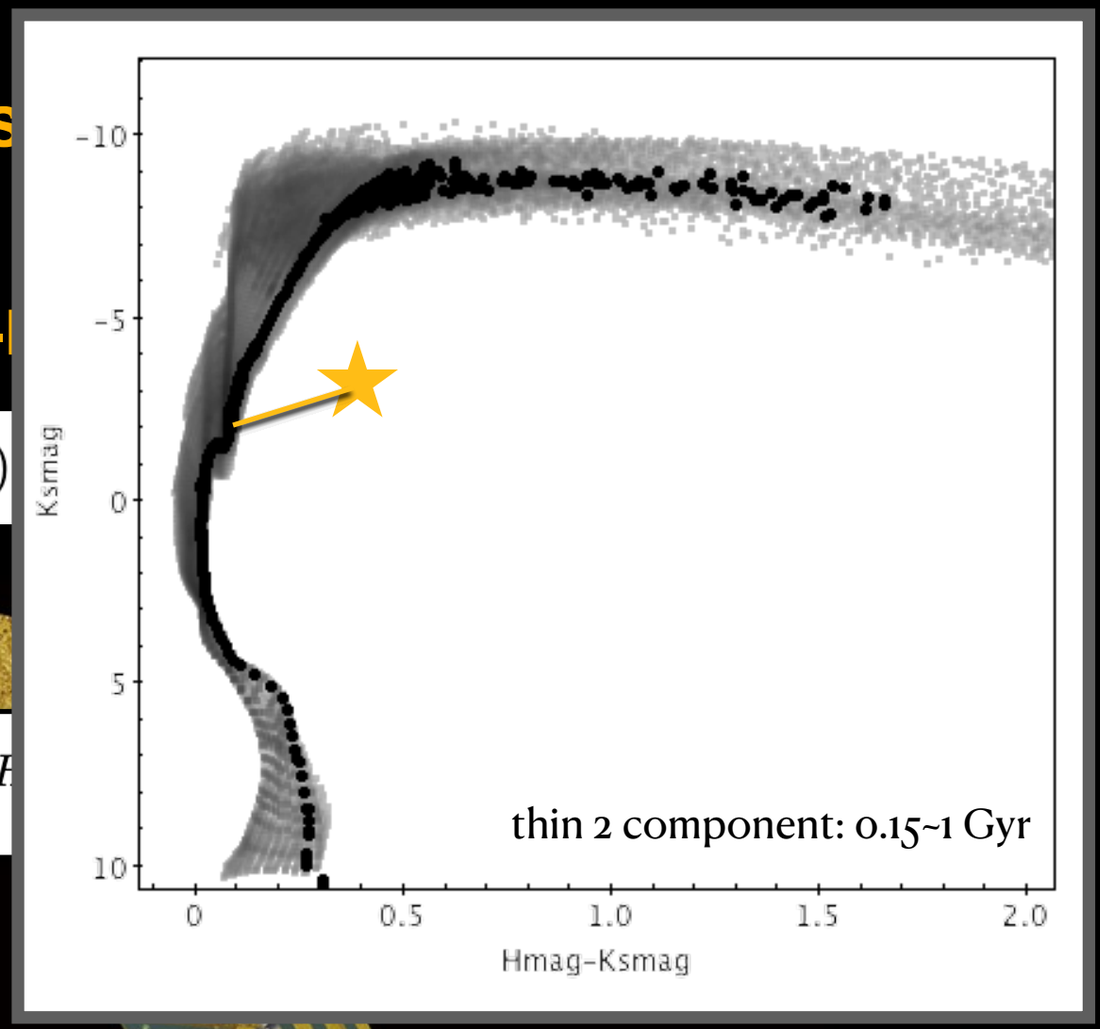

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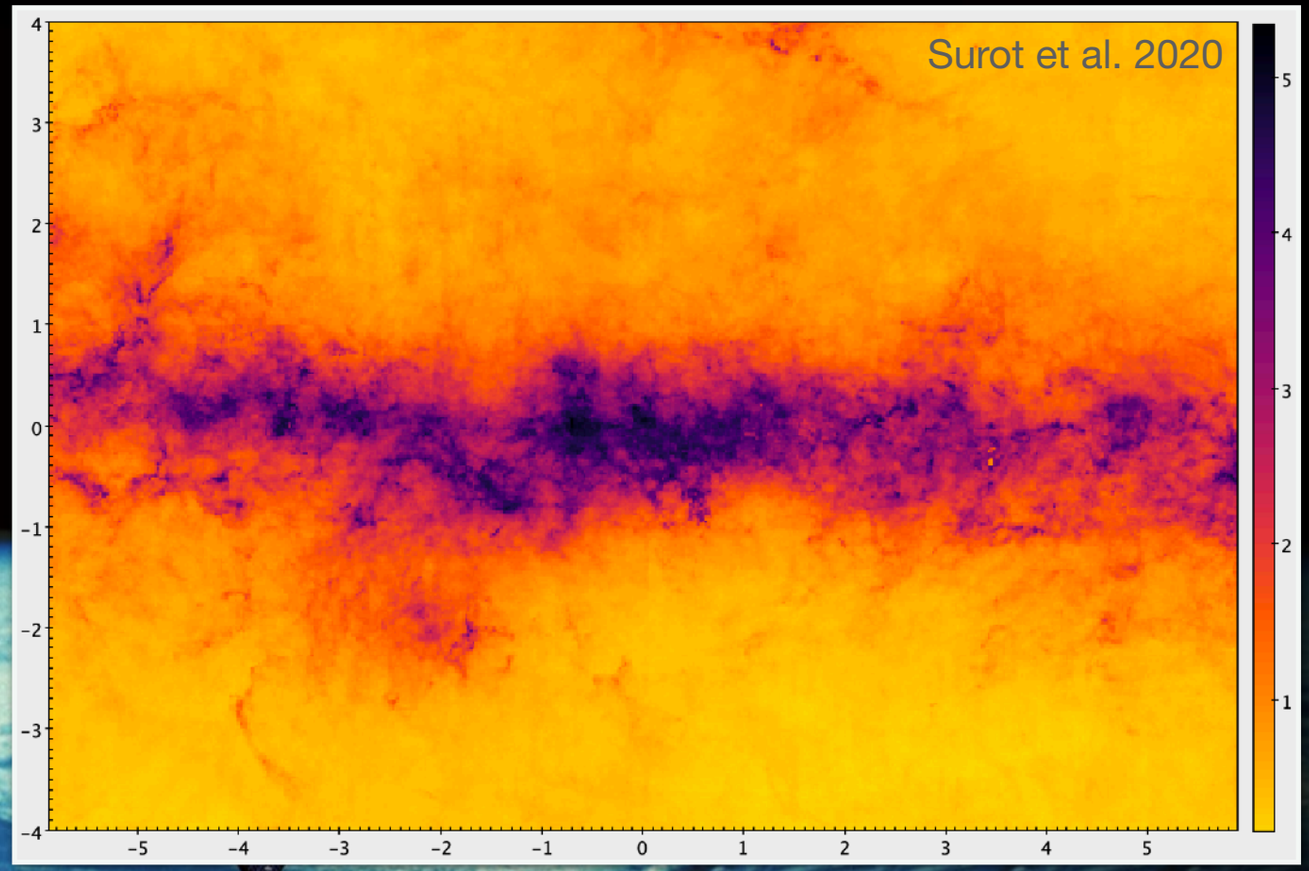
  - **Step 2.2: repeat (2.1) for all sources in each bin of the extinction map**



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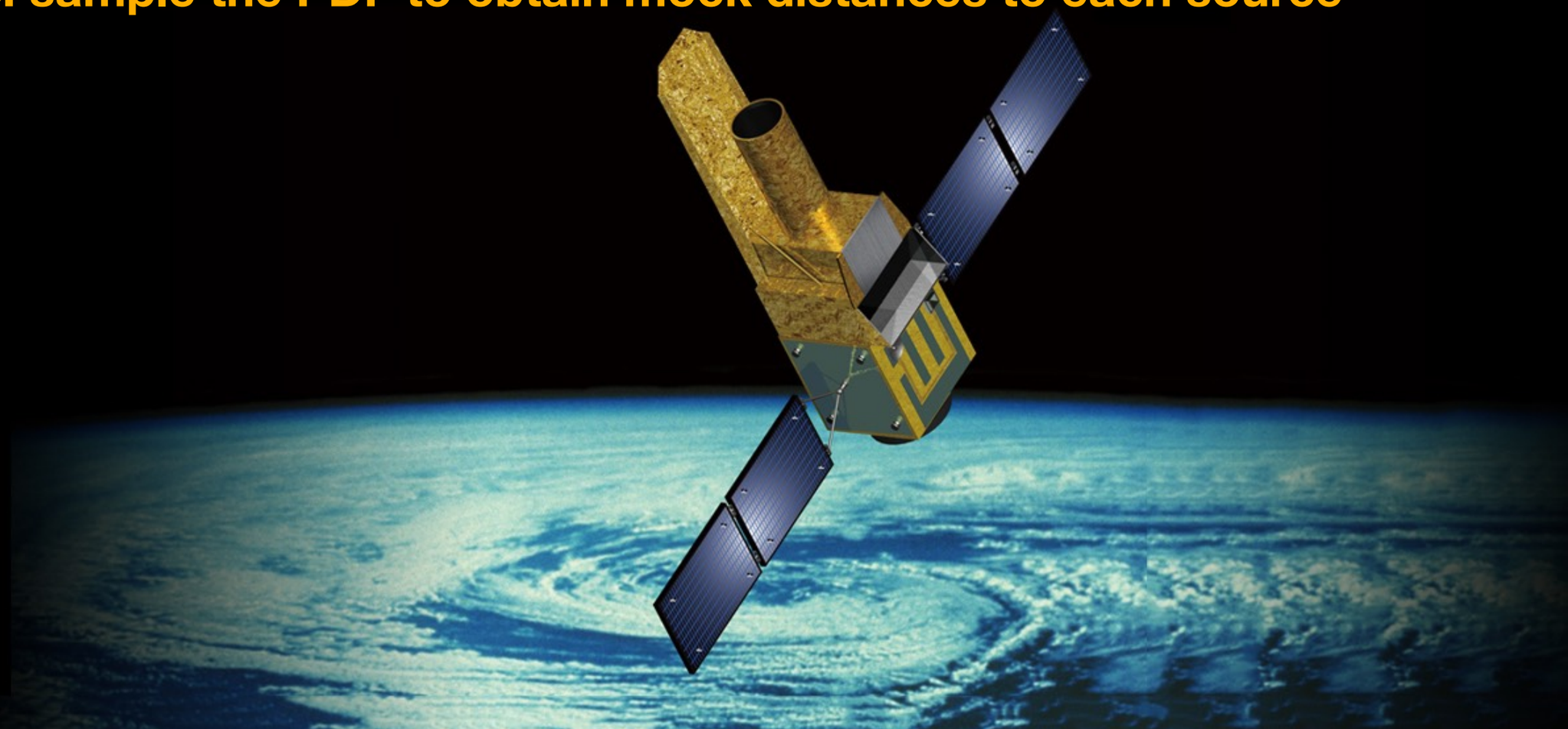
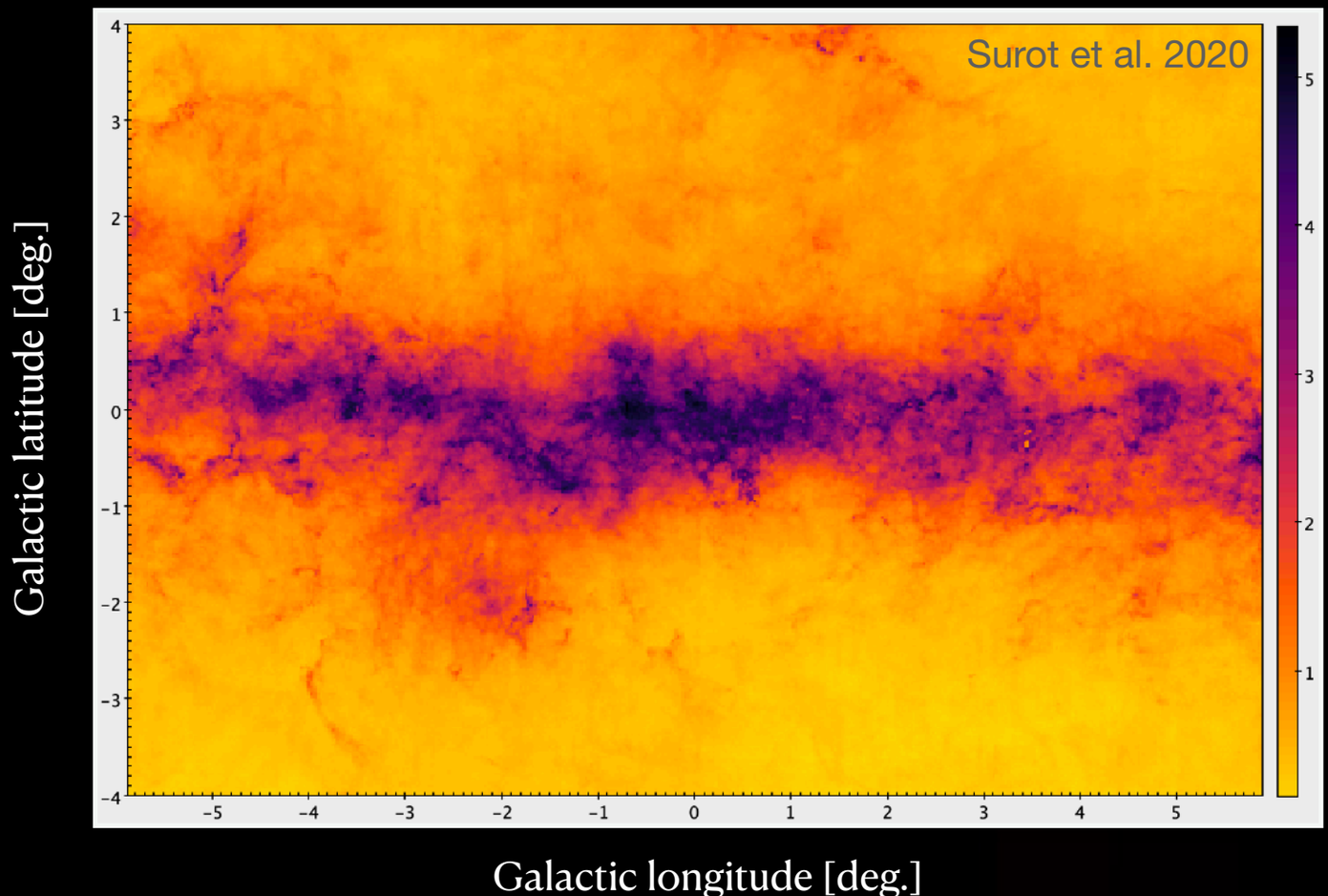
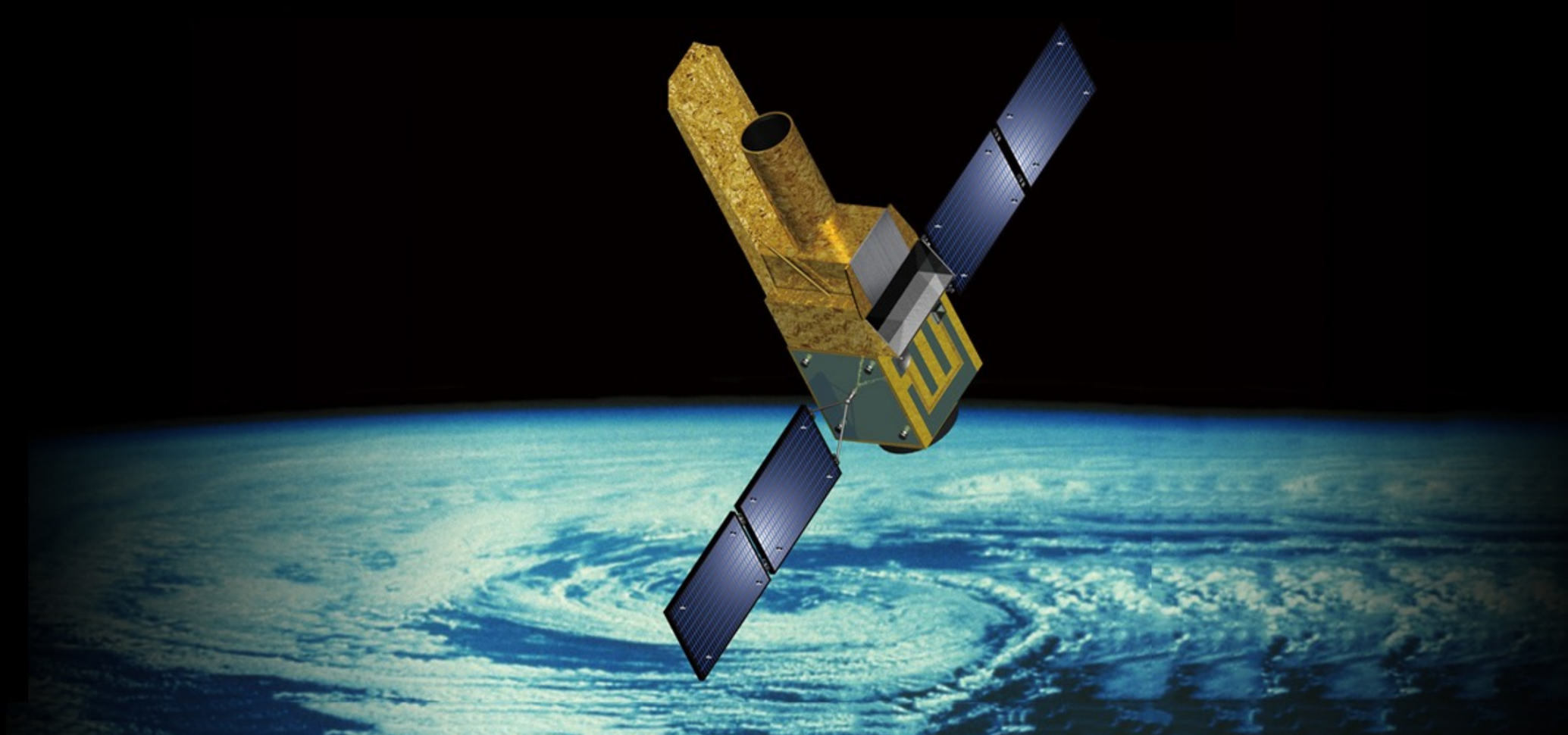
  - **Step 2.3: sample the PDF to obtain mock distances to each source**

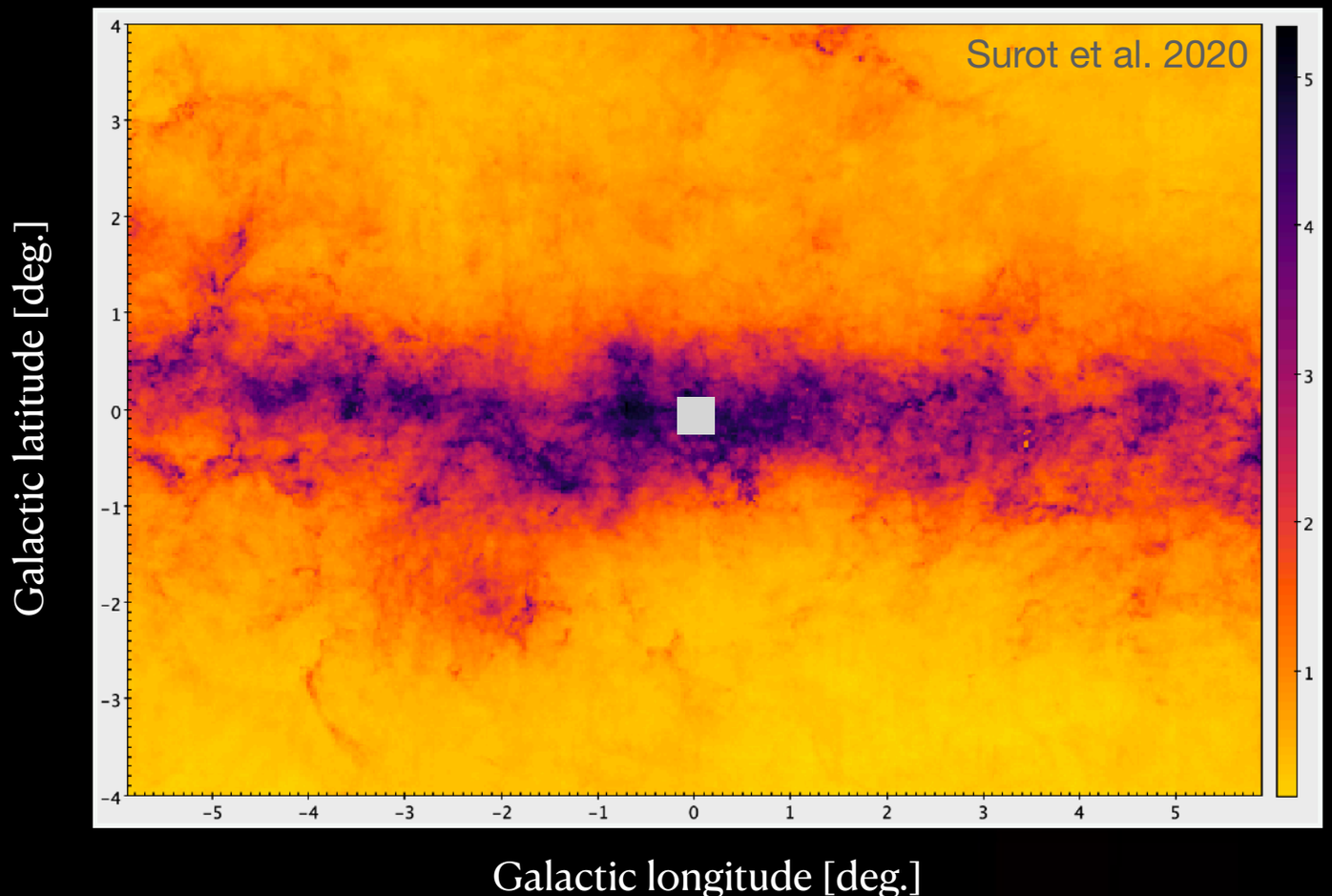


Examples


Surot et al. 2020
Galactic latitude [deg.]
Galactic longitude [deg.]
E(J-Ks)



Examples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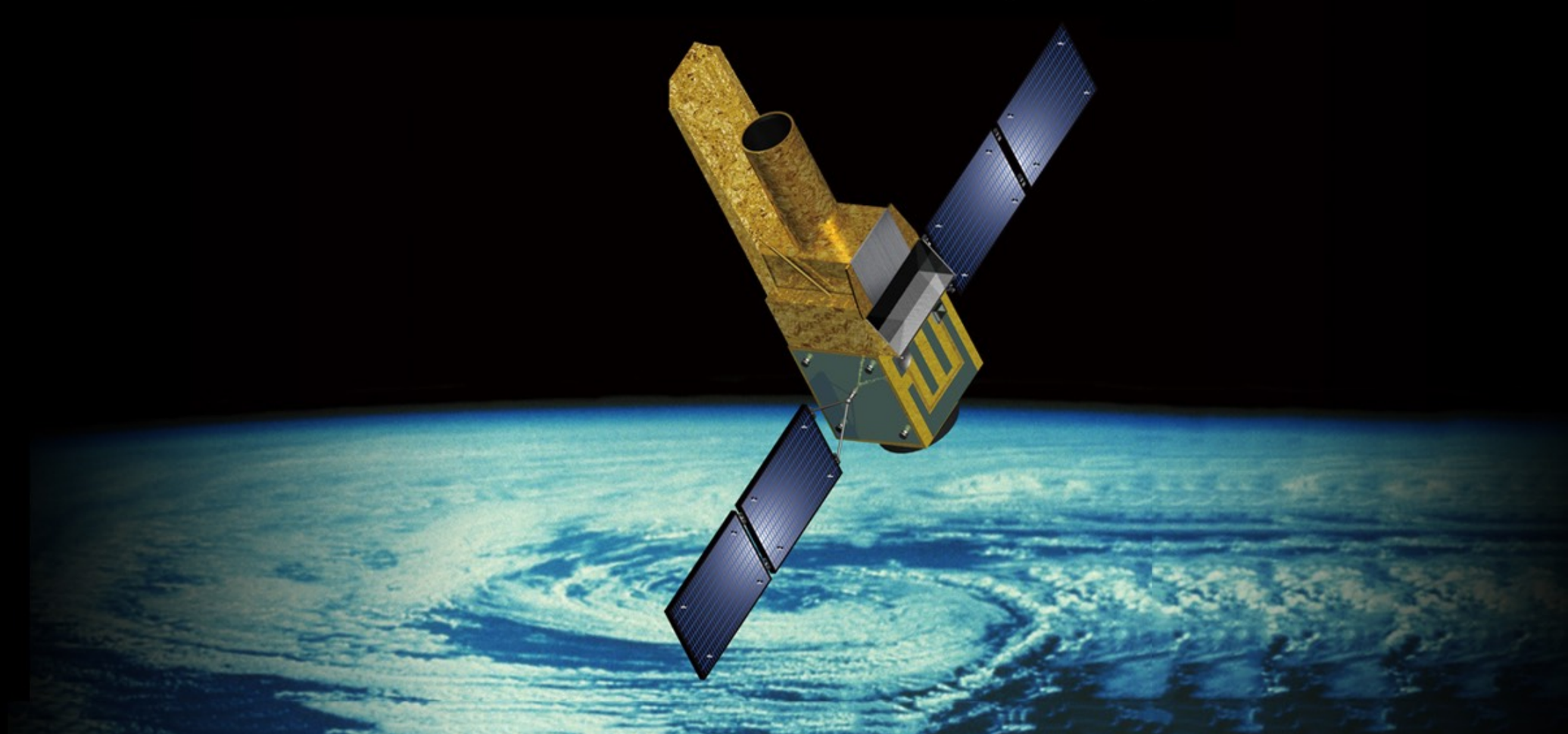
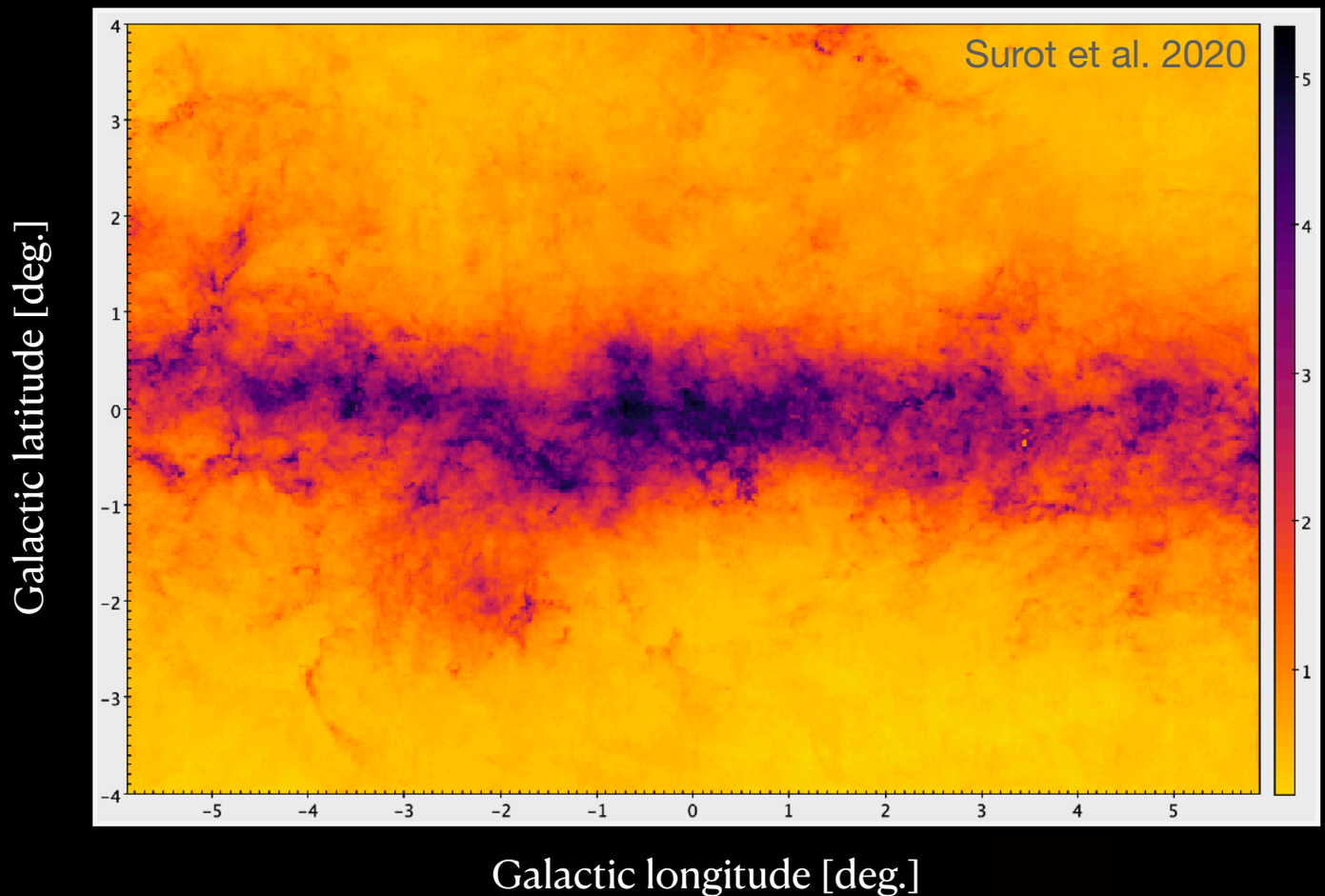
Galactic longitude [deg.]
E(J-Ks)



Examples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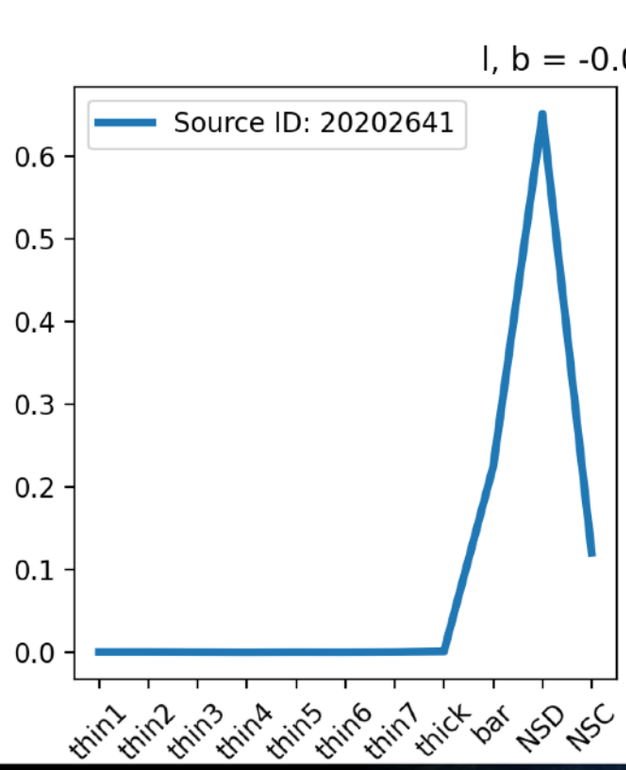
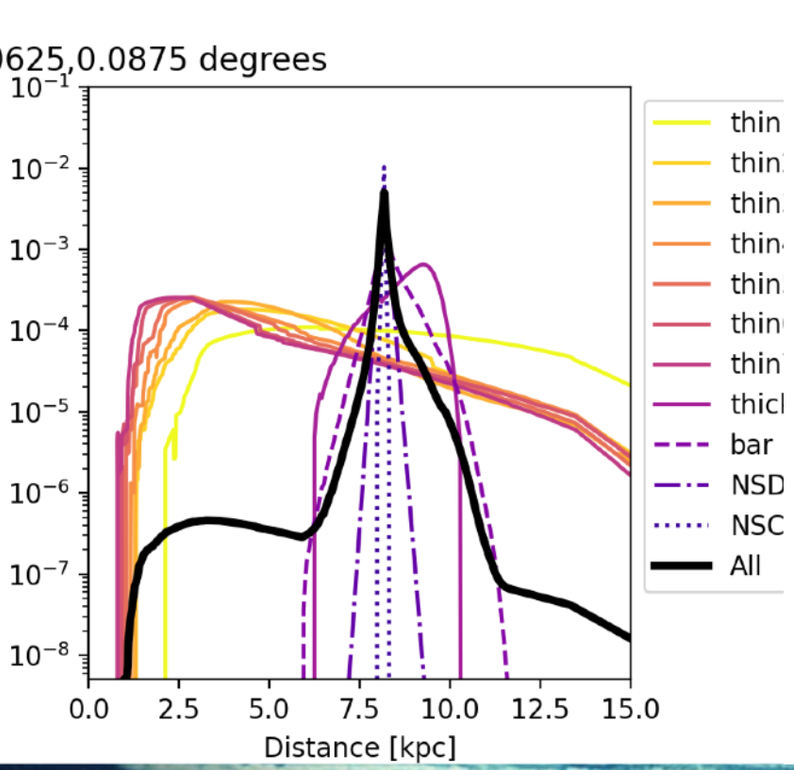
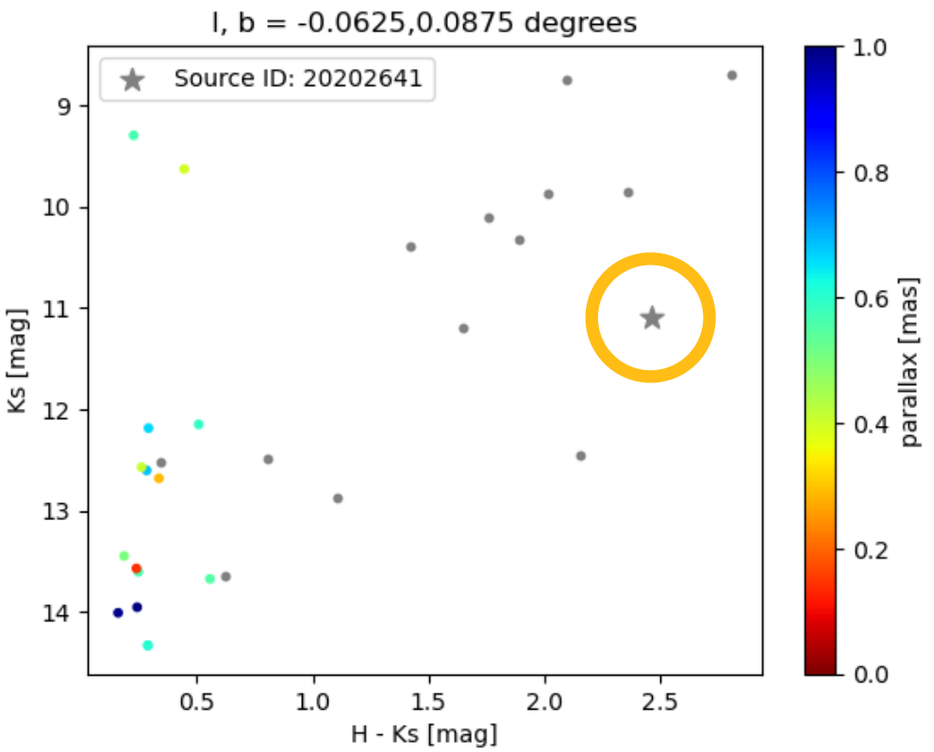
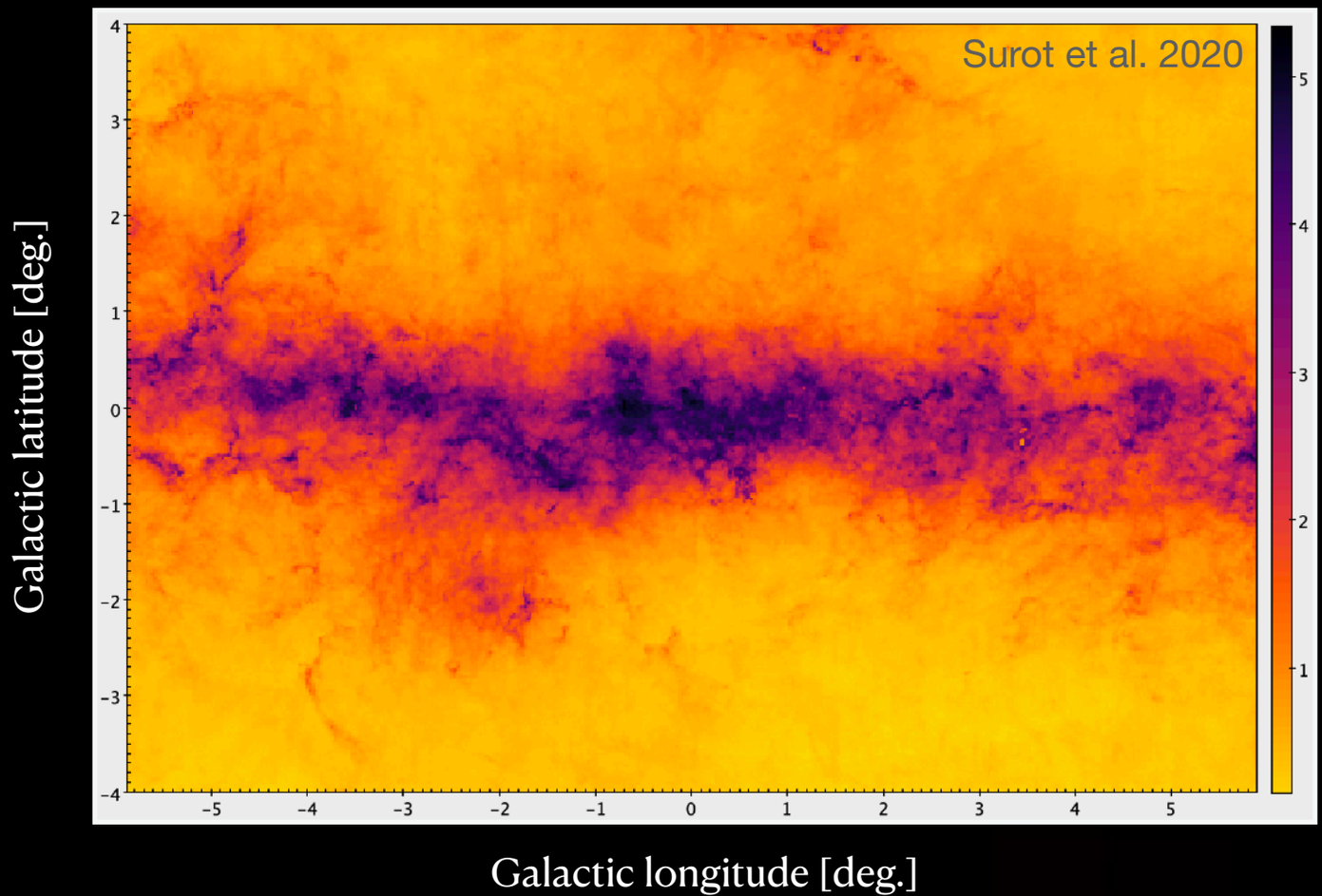
E(J-Ks)

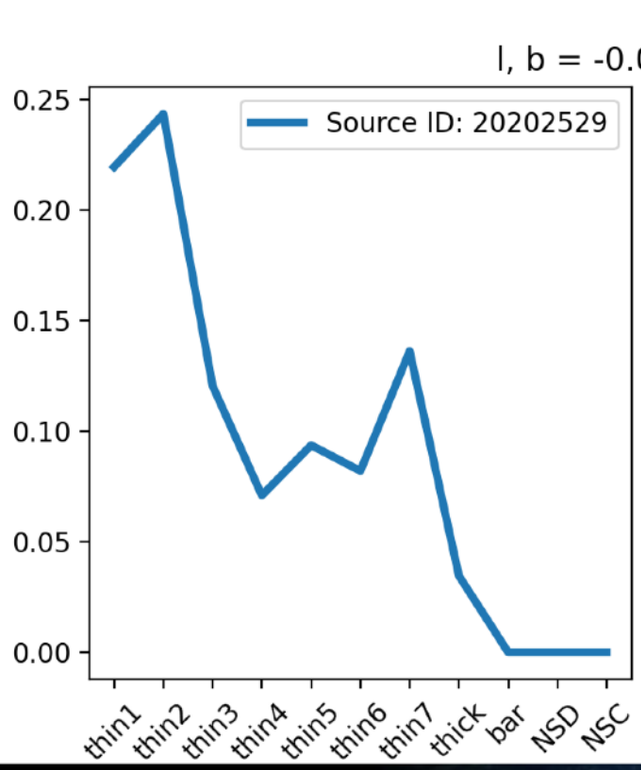

Source ID: 20202641
thin1
thin2
thin3
thin4
thin5
thin6
thin7
thick
bar
NSD
NSC

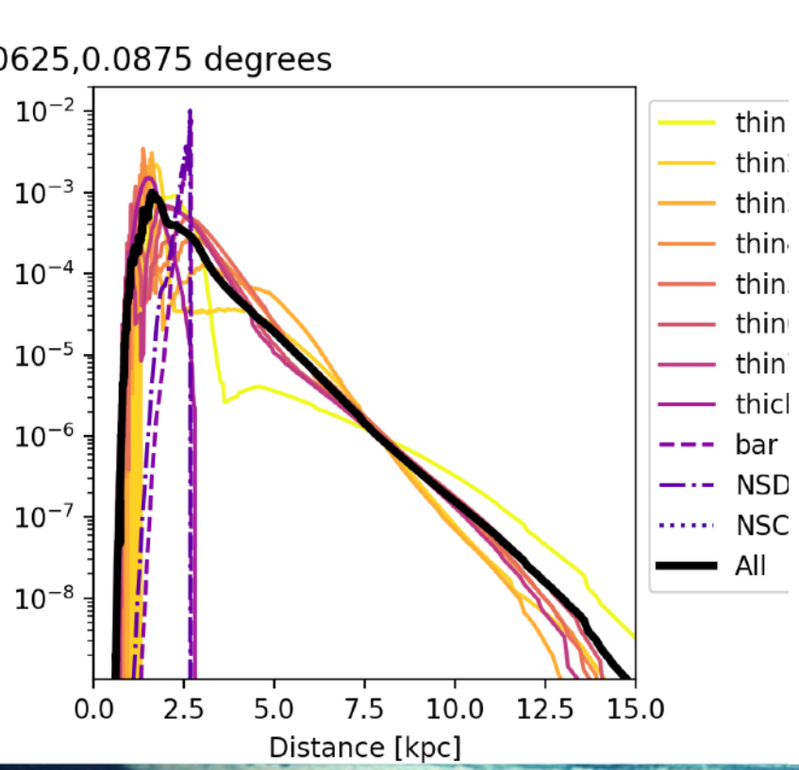

l, b = -0.0625,0.0875 degrees
Distance [kpc]
thin
bar
NSD
NSC
All

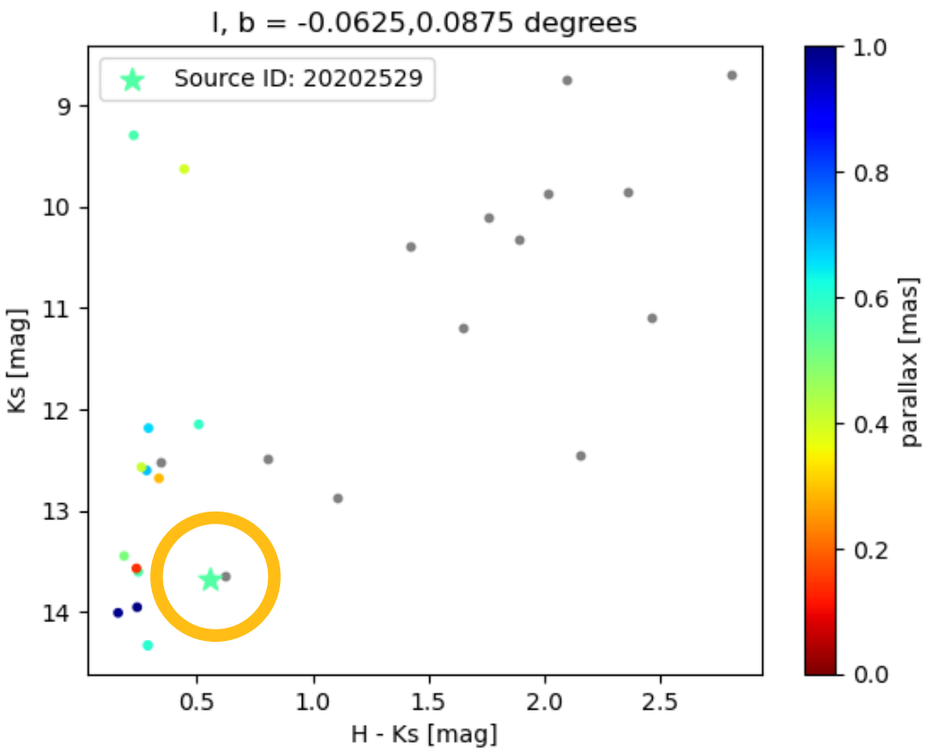

l, b = -0.0625,0.0875 degrees
Source ID: 20202641
Ks [mag]
H - Ks [mag]
parallax [mas]

Examples


Surot et al. 2020
Galactic latitude [deg.]
Galactic longitude [deg.]
E(J-Ks)


Source ID: 20202529
thin1
thin2
thin3
thin4
thin5
thin6
thin7
thick
bar
NSD
NSC

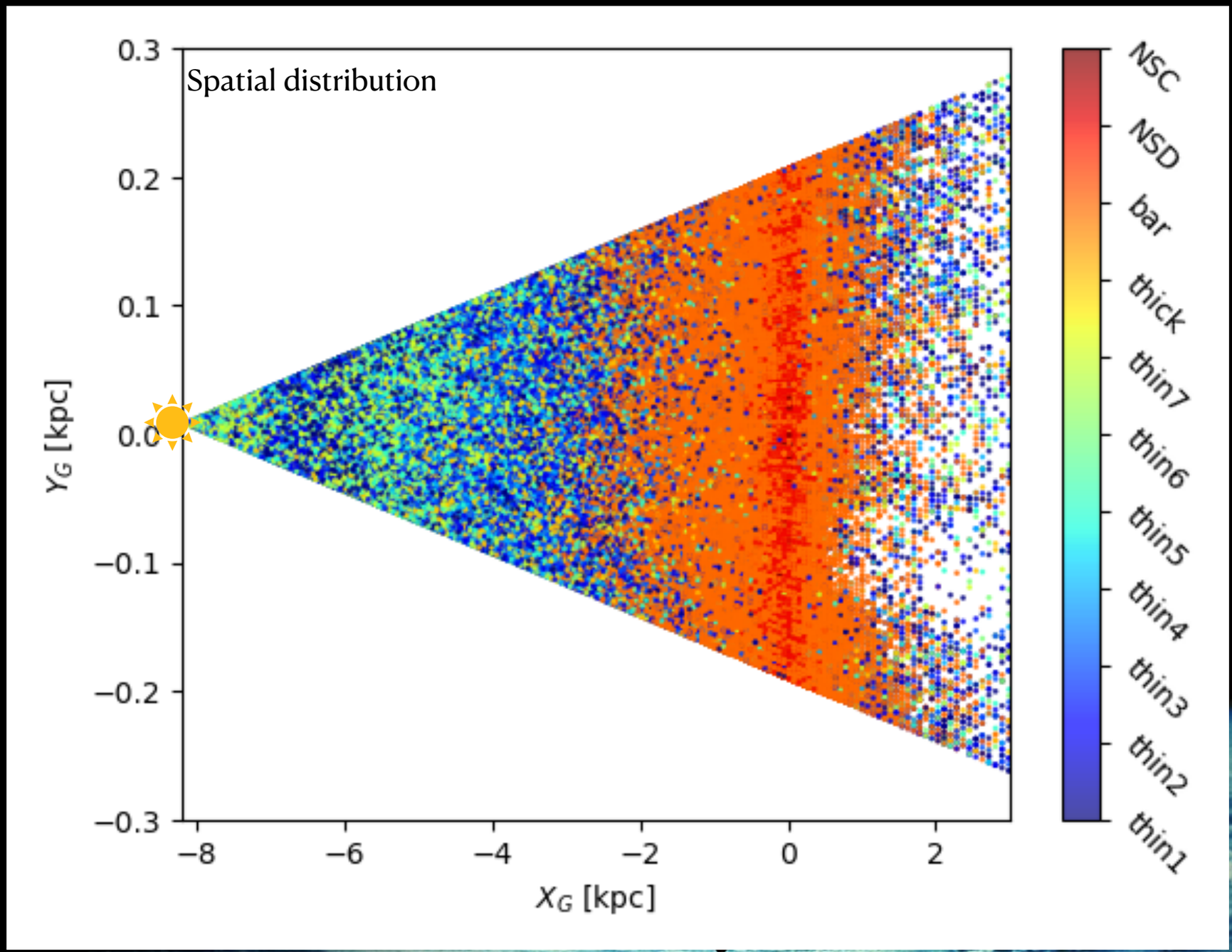

l, b = -0.0625,0.0875 degrees
Distance [kpc]
All


l, b = -0.0625,0.0875 degrees
Source ID: 20202529
Ks [mag]
H - Ks [mag]
parallax [mas]

Results

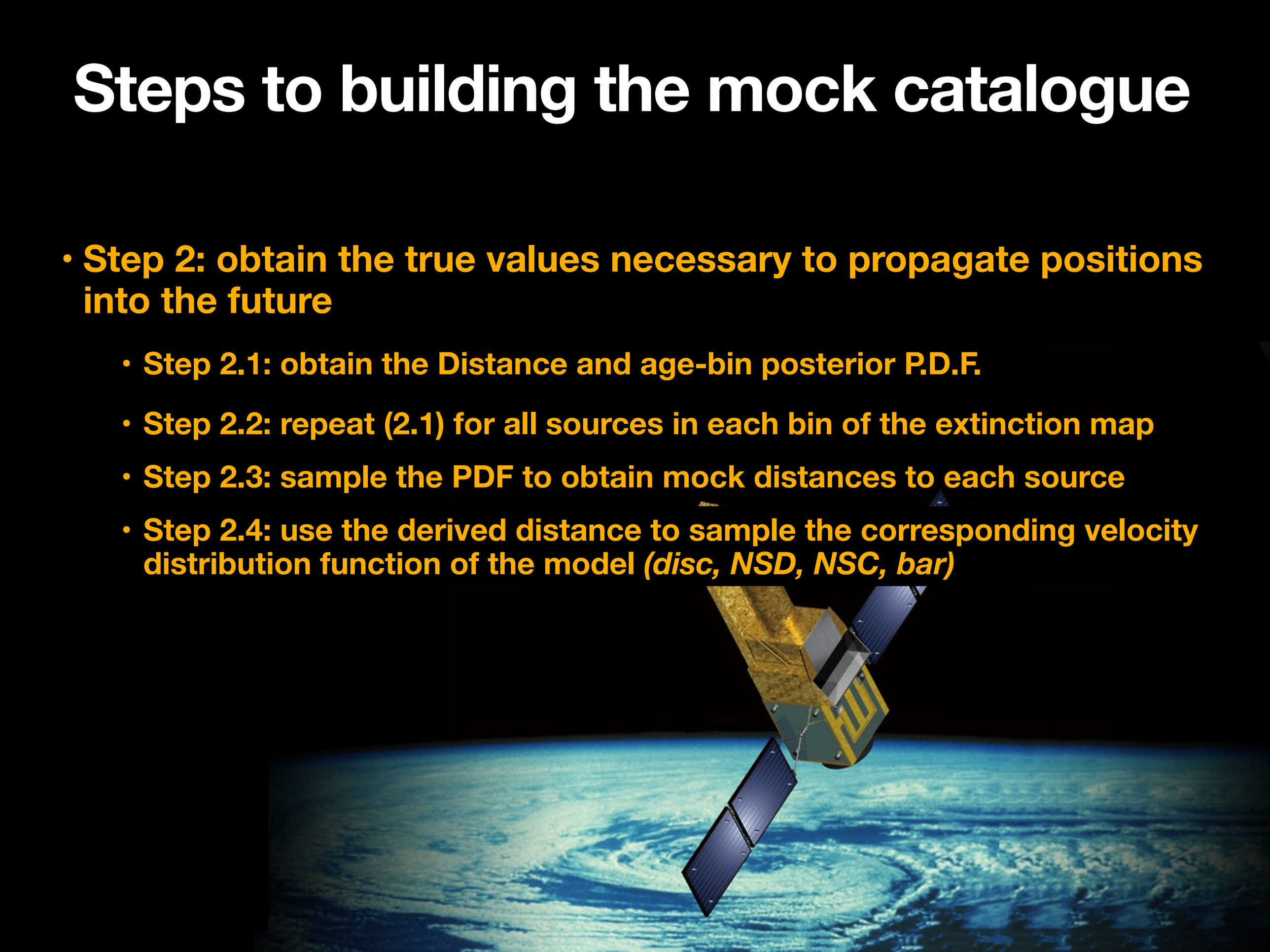
preliminary

Mock catalogue of the JASMINE window v1.0



Steps to building the mock catalogue

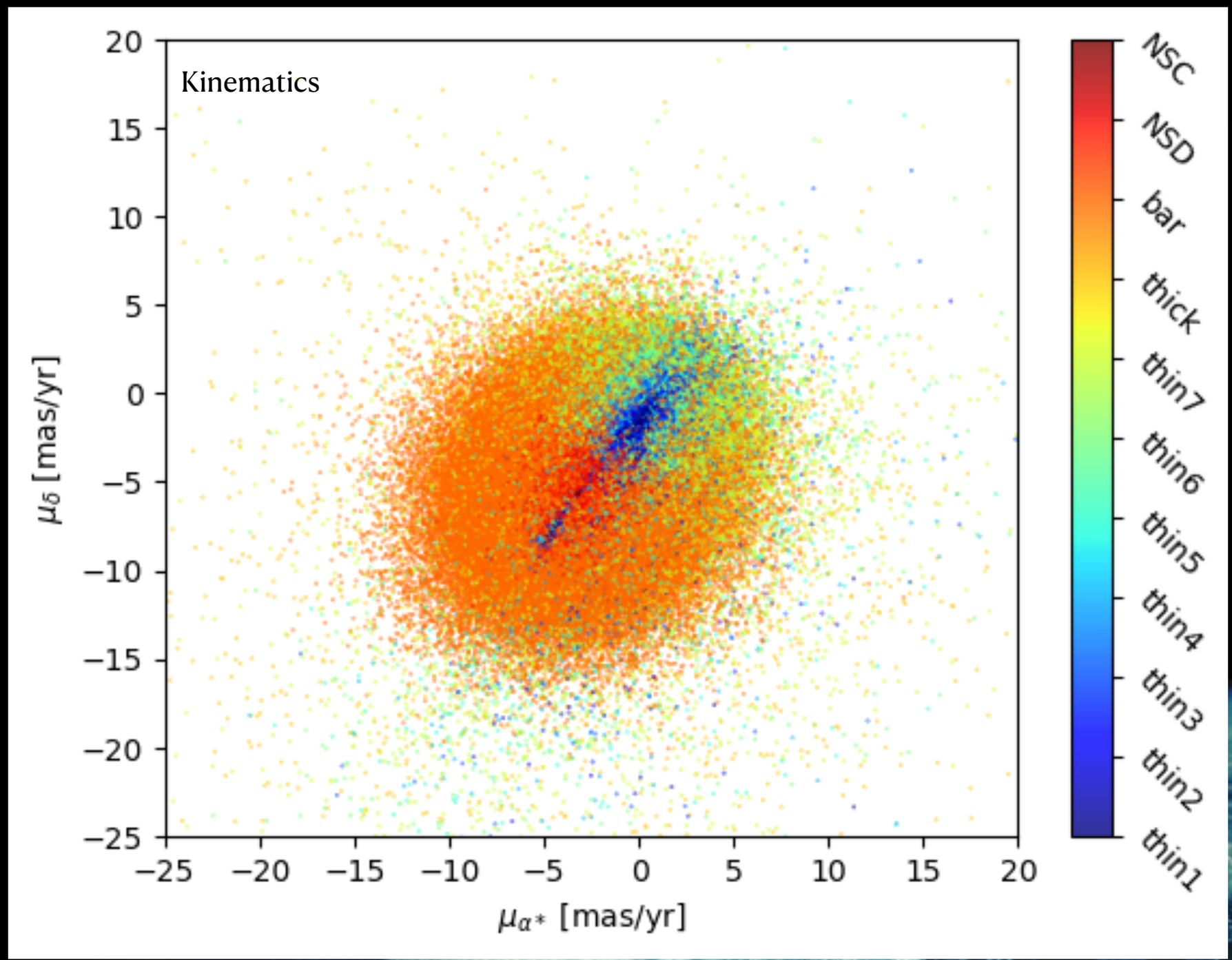
- **Step 2: obtain the true values necessary to propagate positions into the future**
  - **Step 2.1: obtain the Distance and age-bin posterior P.D.F.**
  - **Step 2.2: repeat (2.1) for all sources in each bin of the extinction map**
  - **Step 2.3: sample the PDF to obtain mock distances to each source**
  - **Step 2.4: use the derived distance to sample the corresponding velocity distribution function of the model *(disc, NSD, NSC, bar)***



Results

preliminary

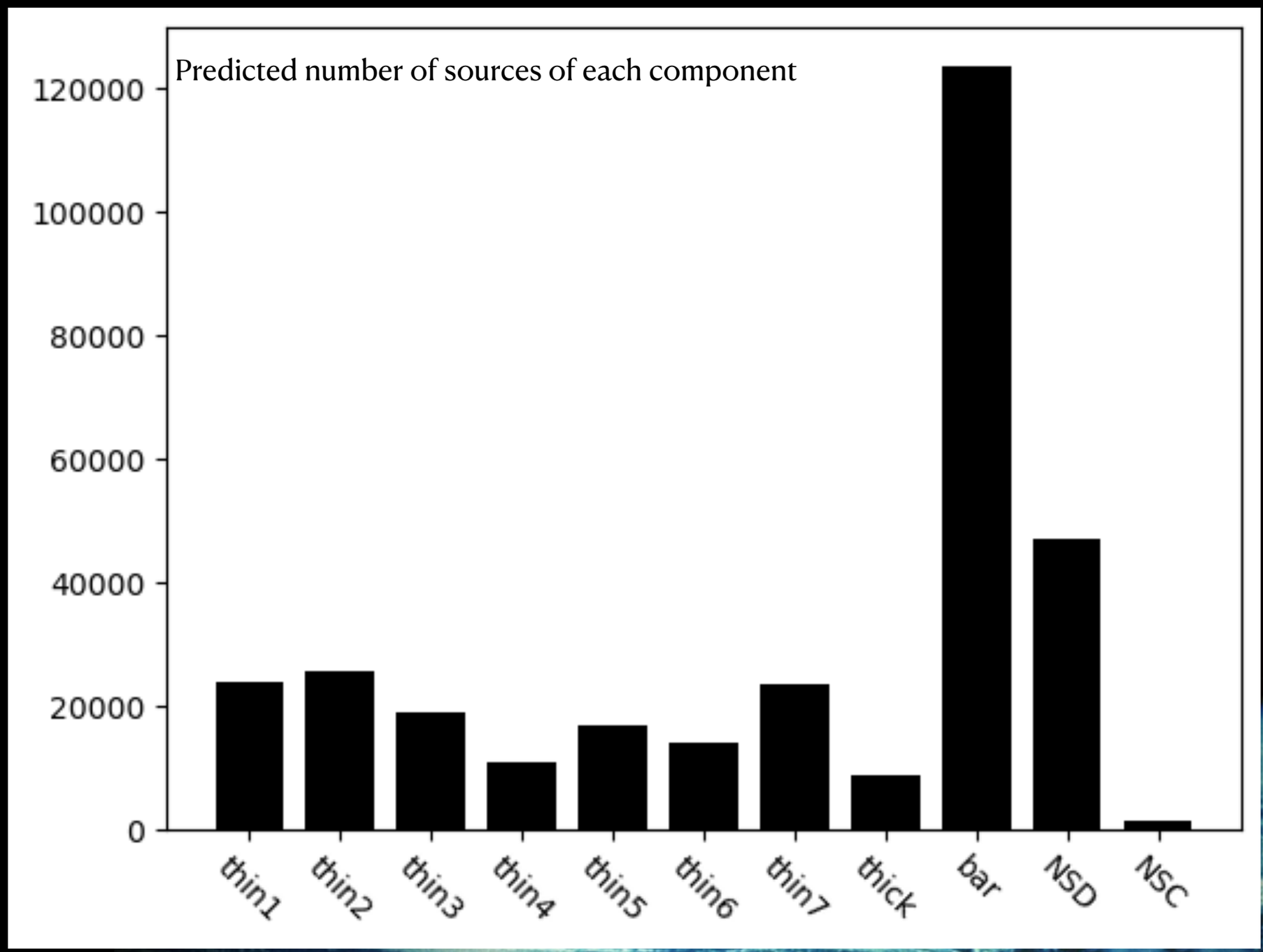
Mock catalogue of the JASMINE window v1.0



Results

preliminary

Mock catalogue of the JASMINE window v1.0



Conclusions

- Most complete catalogue of NIR stars in the MW centre
- Realistic mock catalogue of the central region
- Probabilistic classification of NSD stars

- Upcoming:
  - Running the method for a wider window and deeper
  - Photo-astrometric distances soon available for ~20M ★

- This mock catalogue will be very useful for JASMINE but also for other missions like ROMAN or even Gaia NIR

Thank you!

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@brugalada.bsky.social

Pau Ramos

5 August 2024

Steps to building the mock catalogue

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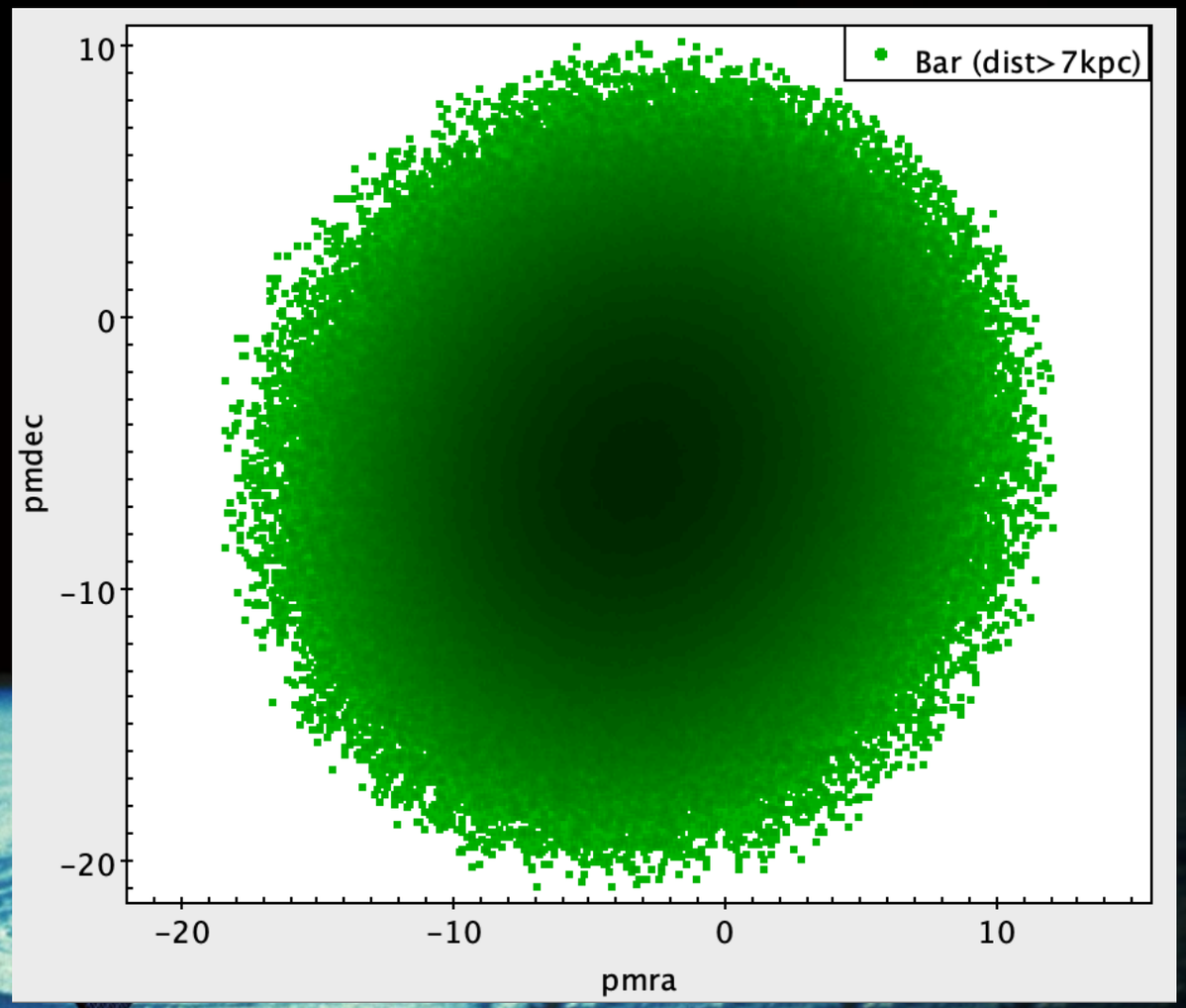

The proper motions of the stars that are so far away are not precise enough to help constrain the distance!

Steps to building the mock catalogue

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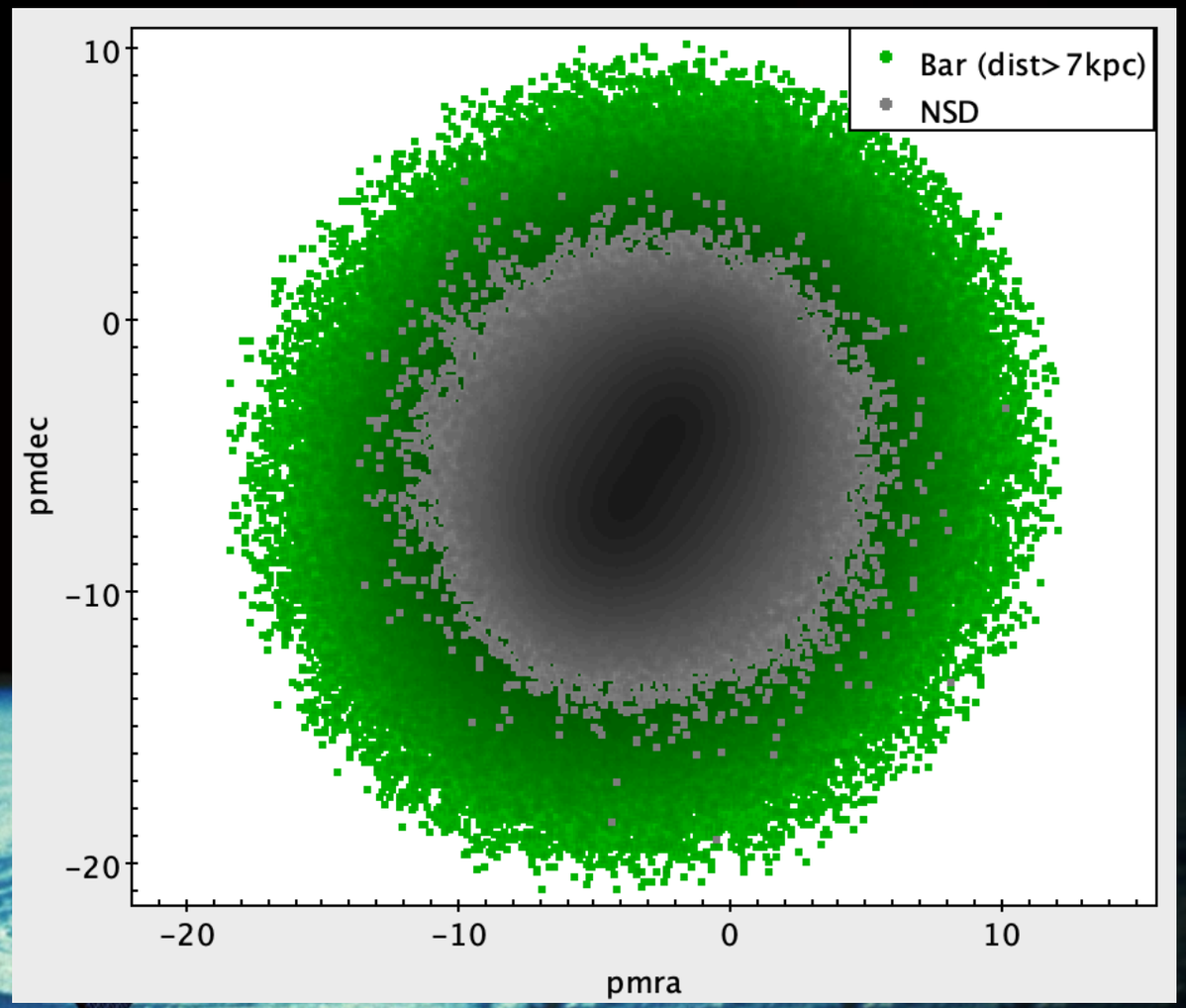

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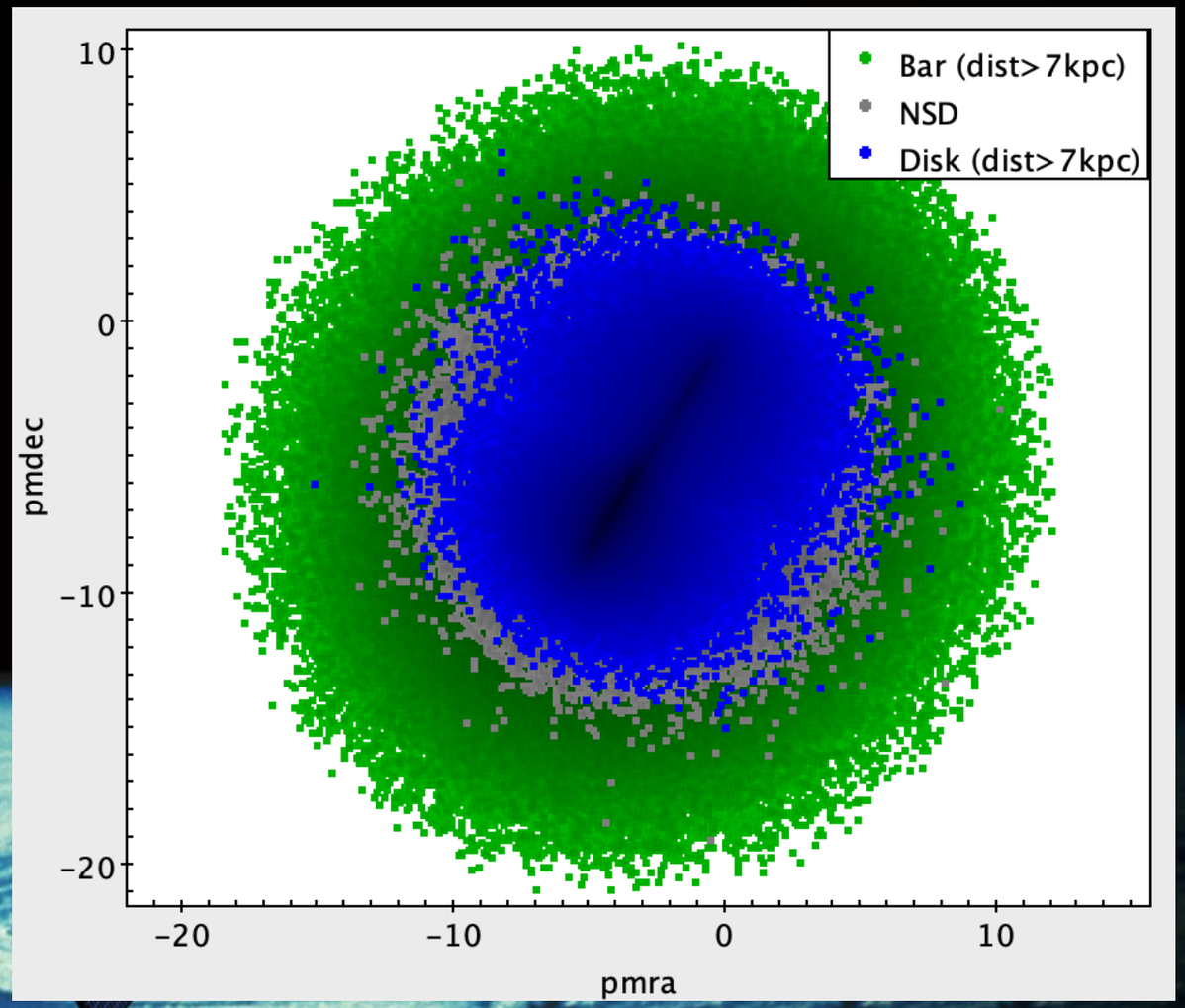

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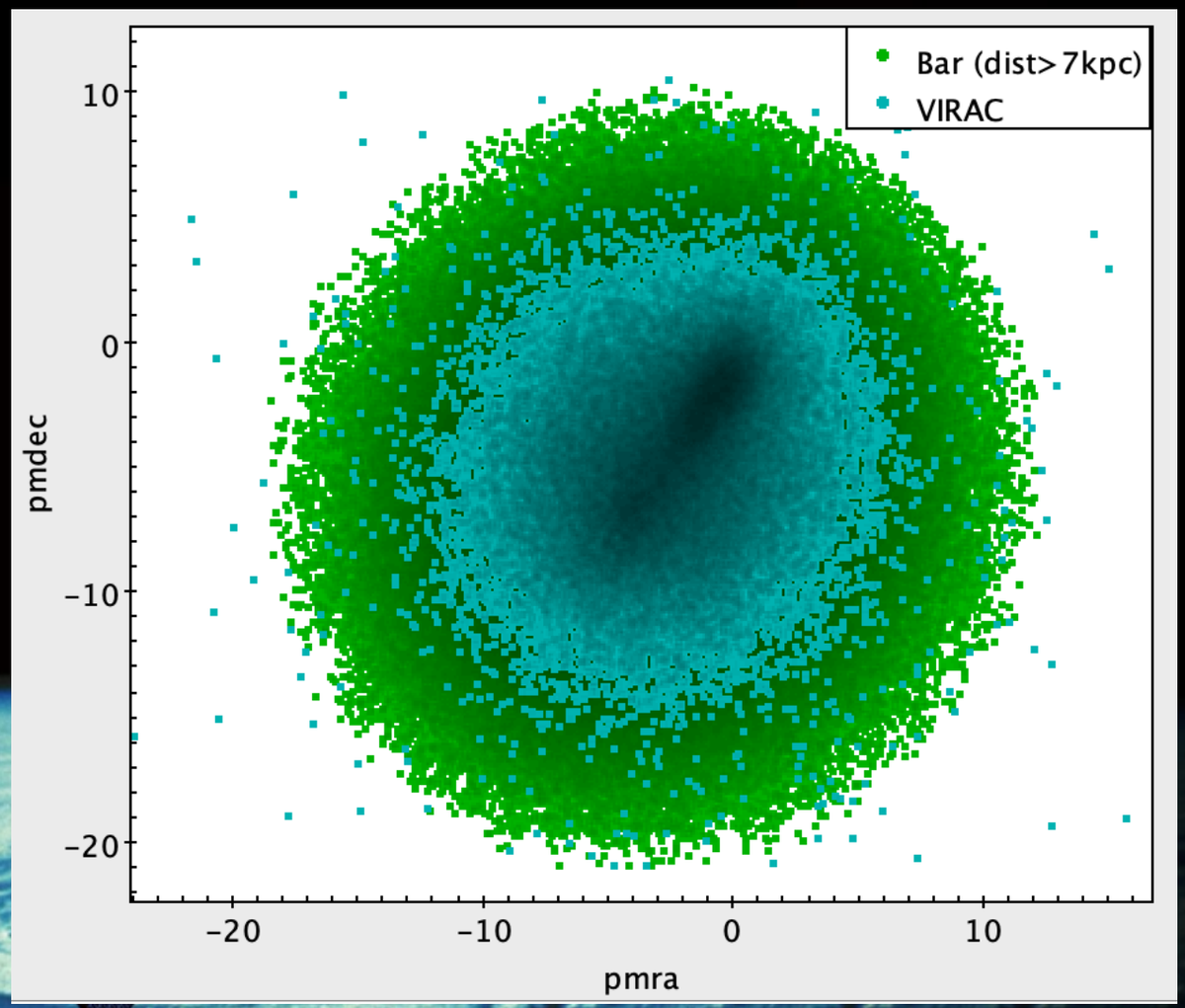

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