National Astronomical Observatory of Japan

ZENTRUM FÜR ASTRONOMIE

The JASMINE astrometric solvers

or how to obtain high-precision astrometry of the Nuclear Stellar Disc

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How does Gaia produce such good astrometry?

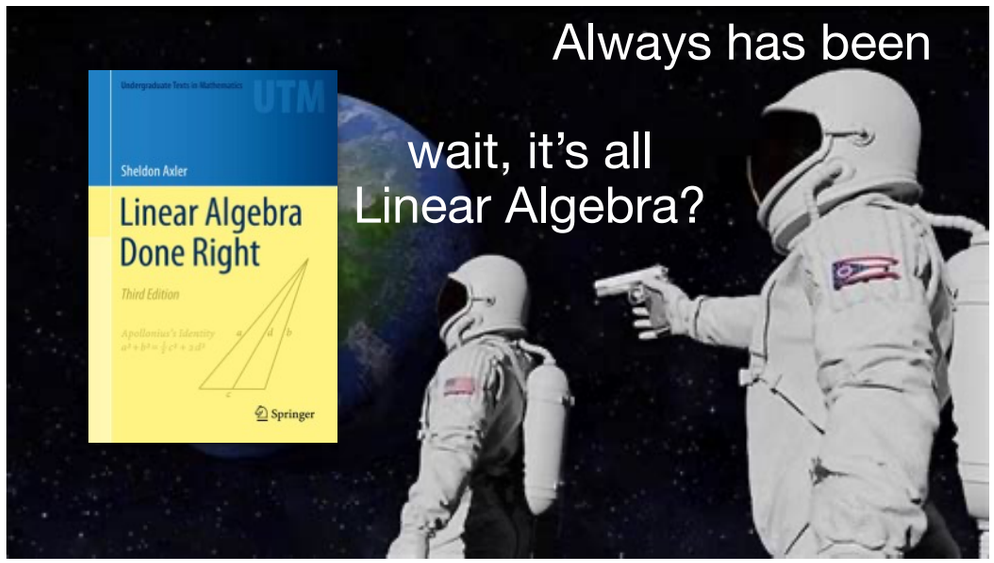
Gaia DR4

62 detectors

66 months worth of exposures

~2.5 Trillion observations

Astrometry for Billions of stars



How does Gaia produce such good astrometry?

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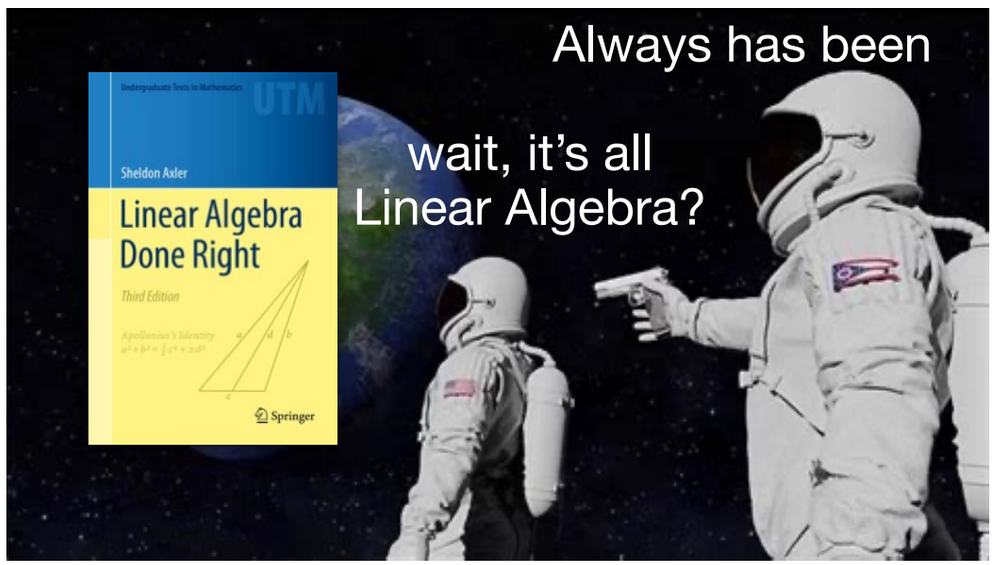
LINEAR ALGEBRA

~2.5 Trillion observations



Linear algebra you say?

Modes of the instrument

(Jacobian)

Observations

$$\mathbf{A}\mathbf{x} \simeq \mathbf{b}$$

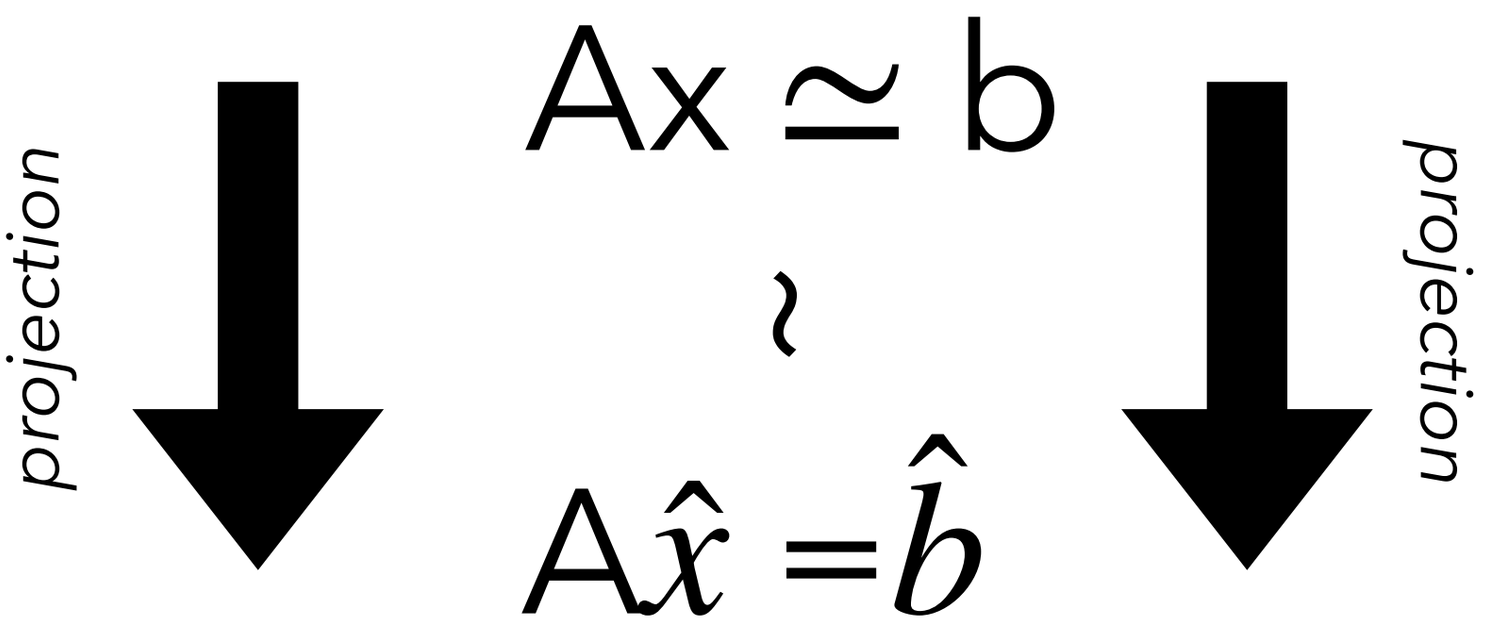
Model Parameters

- Astrometry: $\alpha_0, \delta_0, \varpi, \mu_{\alpha*}, \mu_\delta$
- Colour factors
- Attitude
- Calibration

Key idea

Express the observations as the linear combination of the modes of your instrument ***(according to a given model)***.

Linear algebra you say?

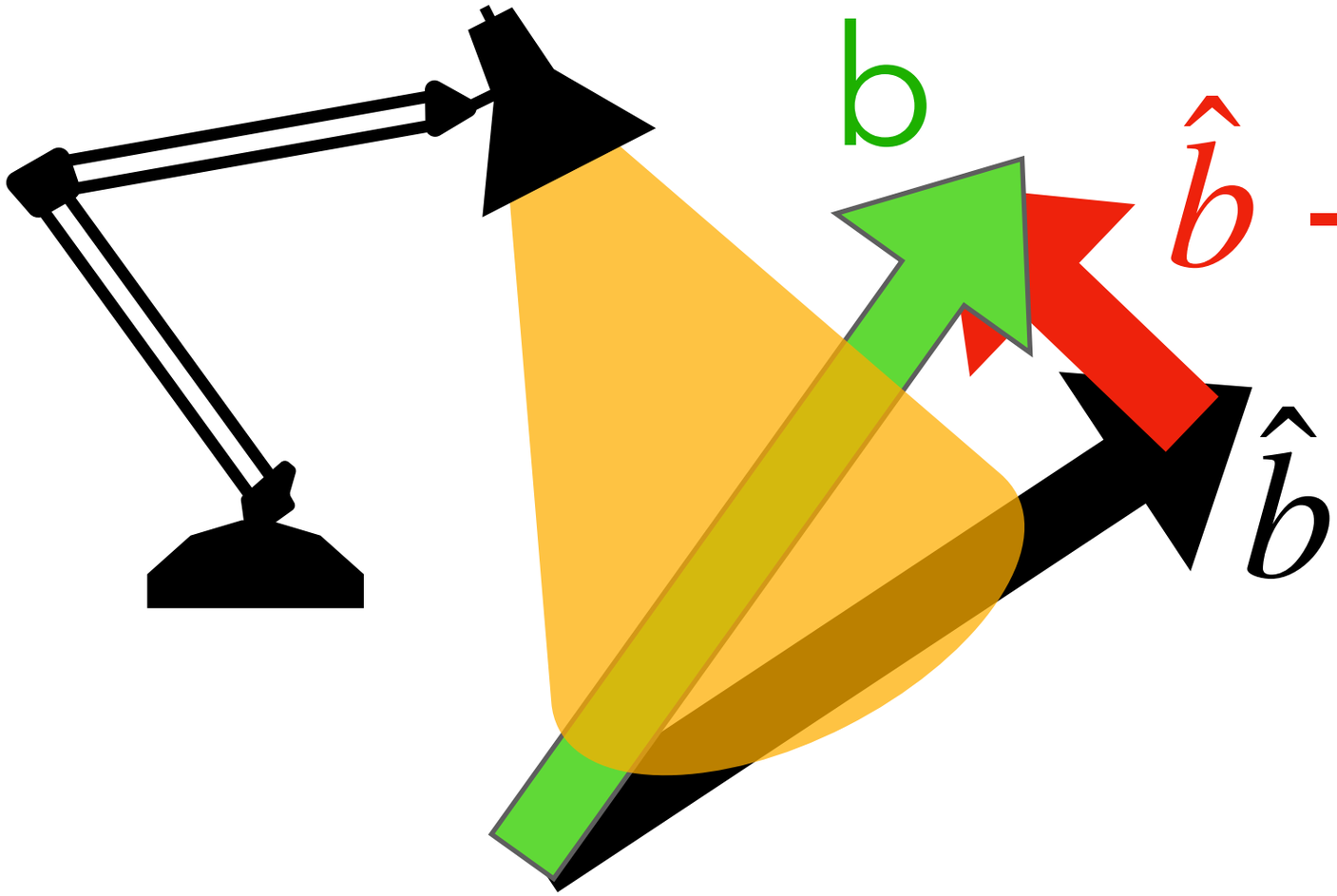


Key idea

Solve by Least Squares Minimisation

First project the observations into the subspace spanned by the modes of the instrument and then find the linear combination

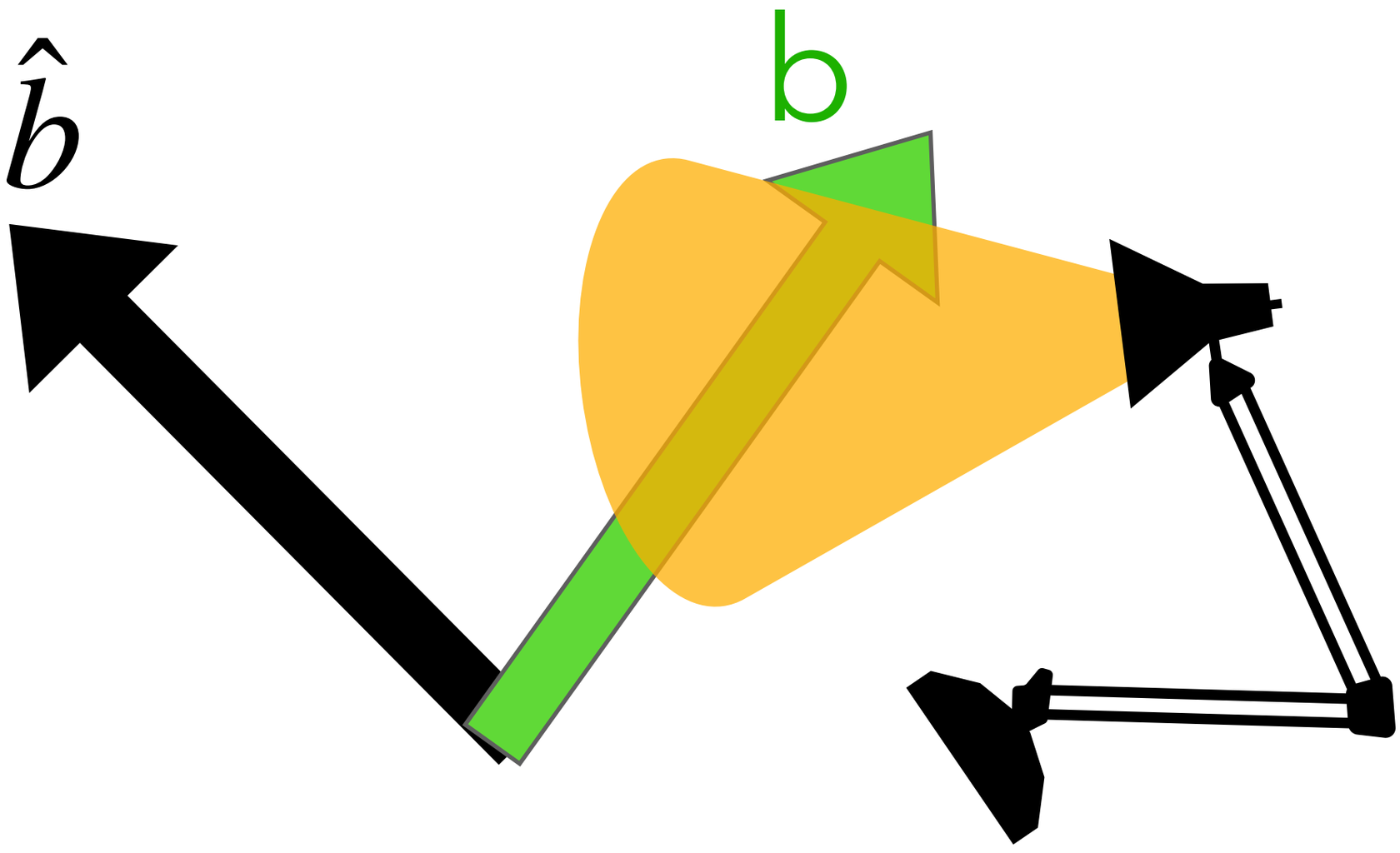
Linear algebra you say?



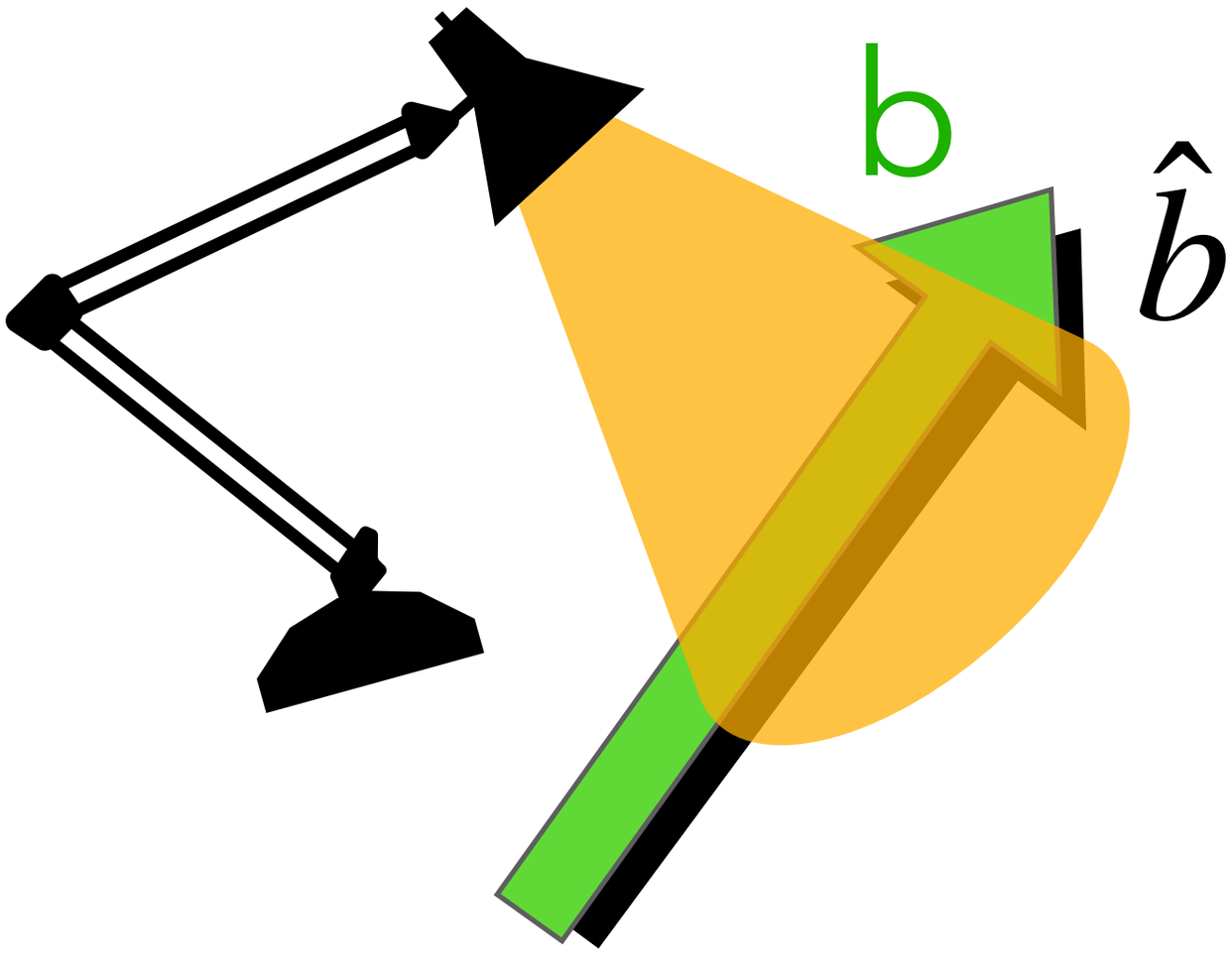
Key idea

Gaia is looking for the combination of model parameters that minimises the residuals ***(given a model of the instrument)***

Linear algebra you say?



Linear algebra you say?

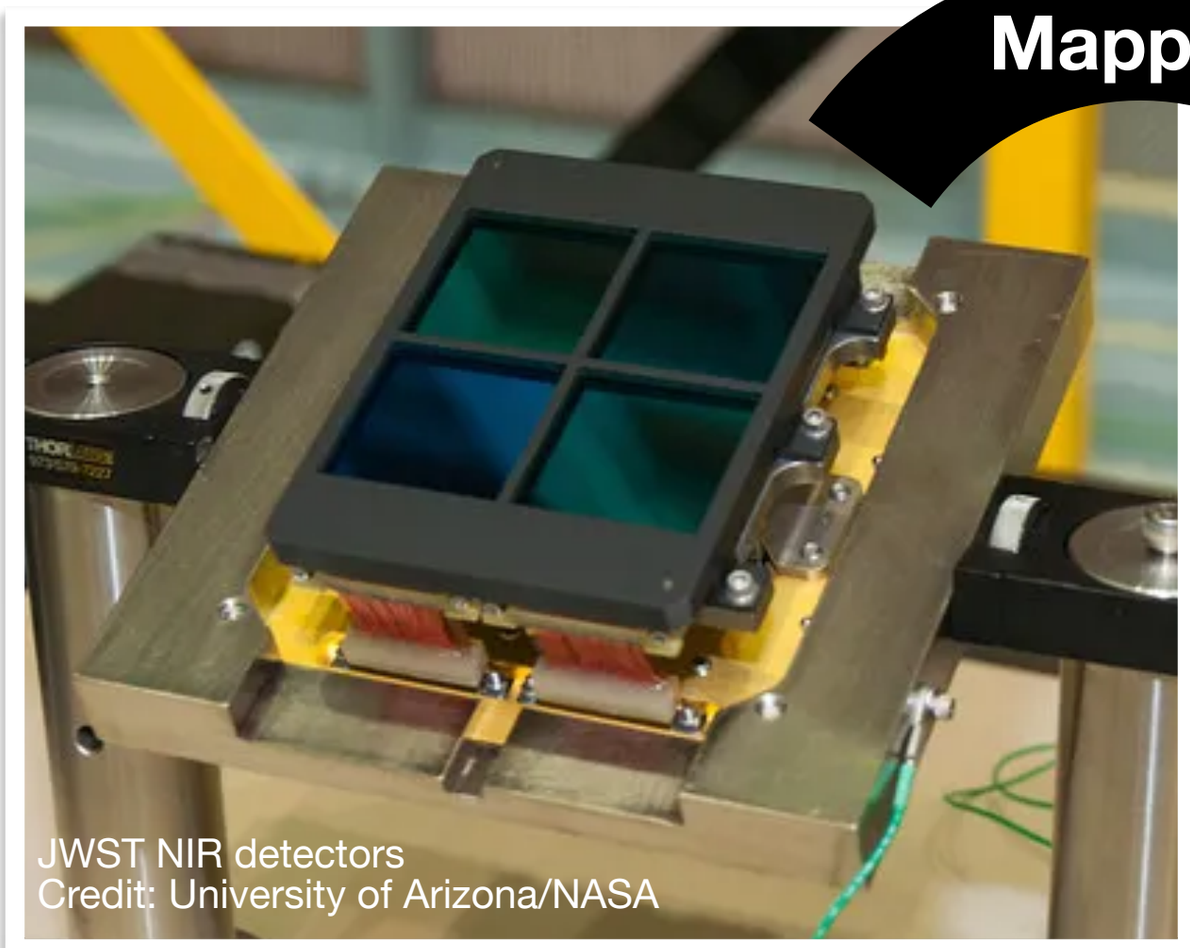


Key idea

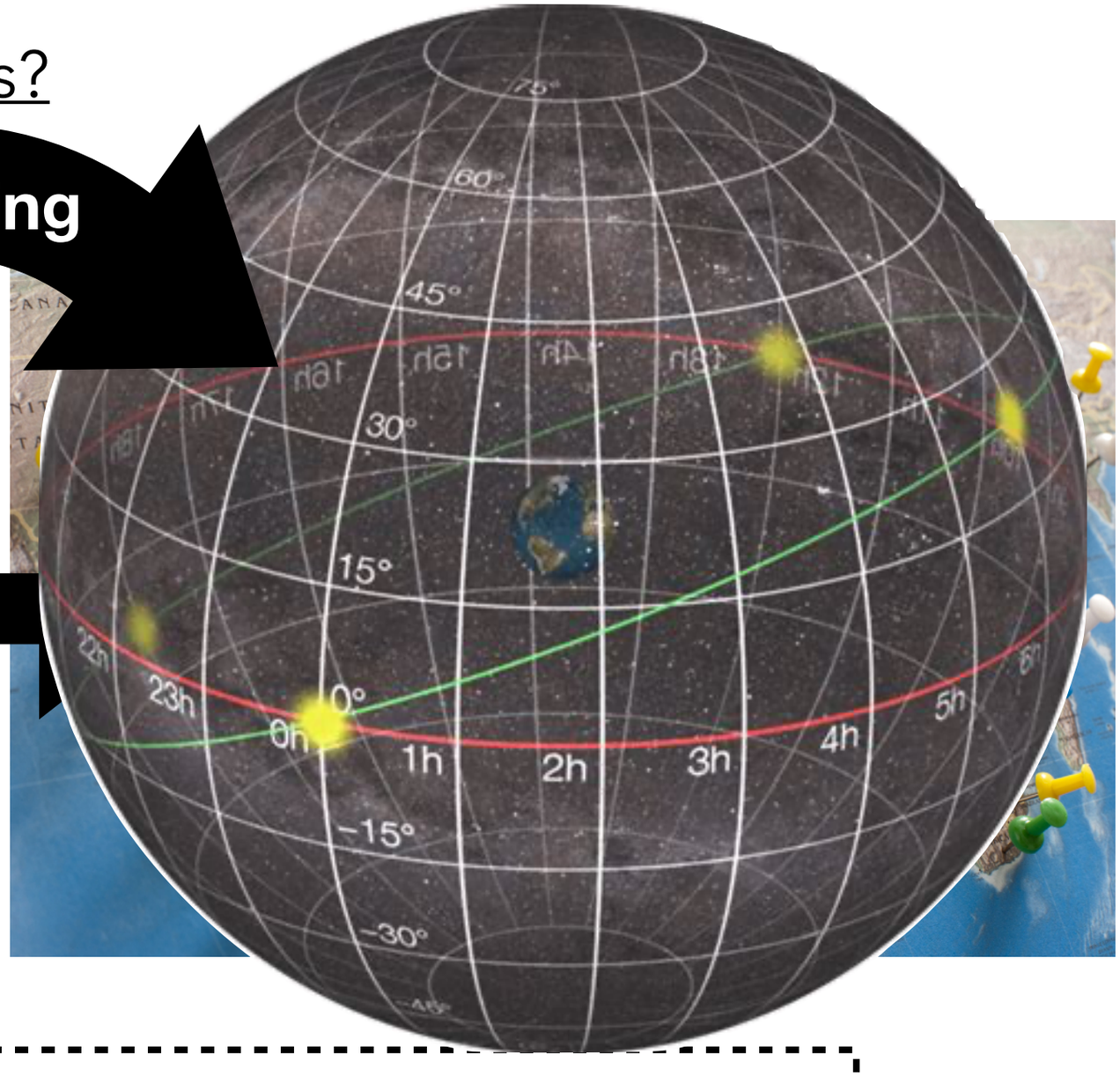
There is a model such that the projection (shadow) is as close as possible to the observations **but we do not know it in advance!**

If the method is not special… what is?

How to calibrate the observations?



Mapping

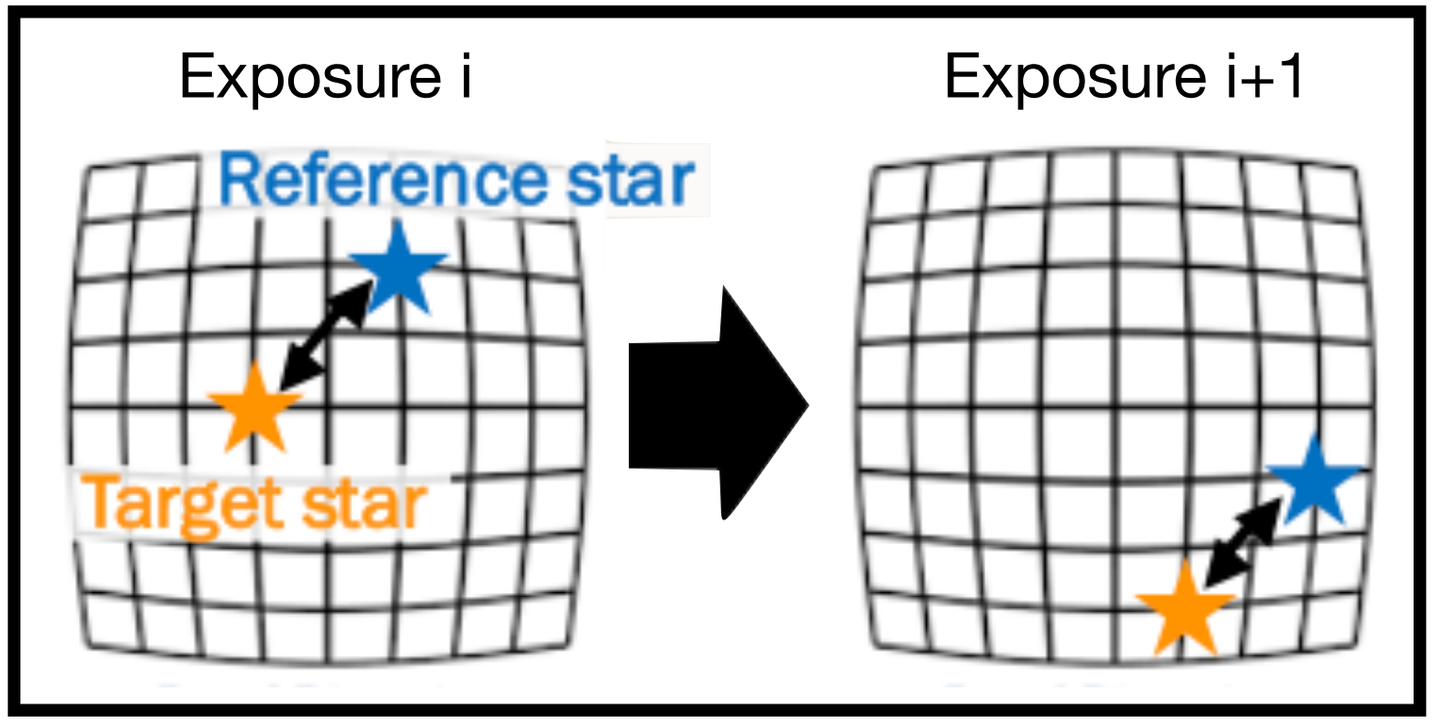


Key idea

We use reference sources to **undistort** the images

If the method is not special… what is?

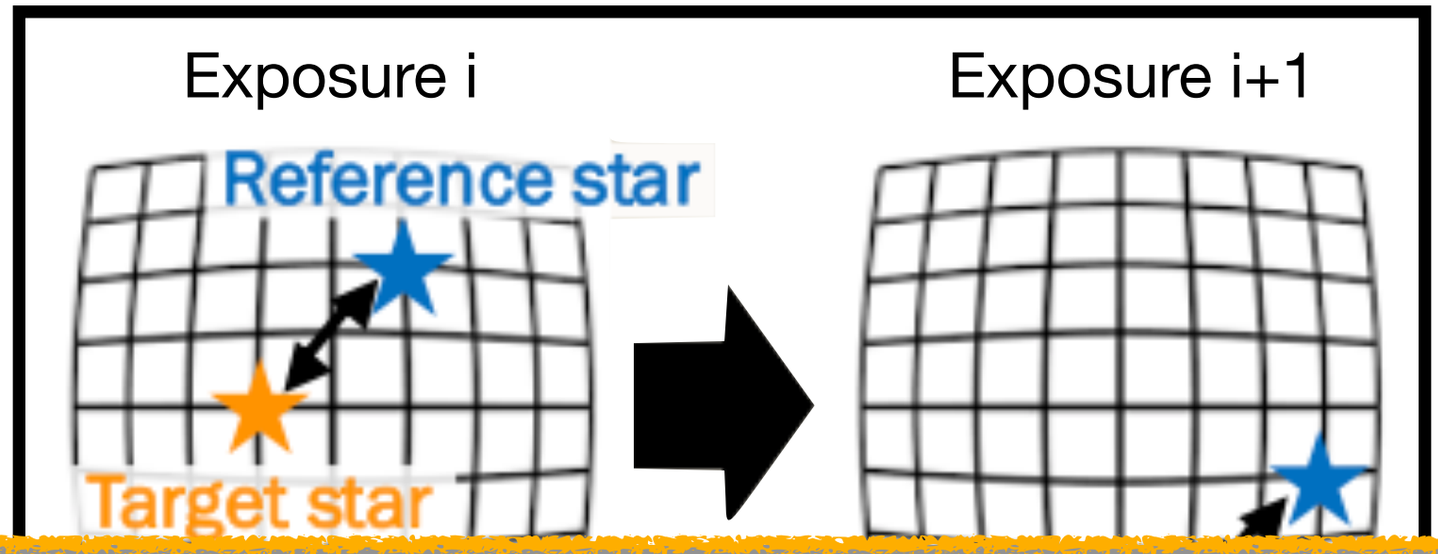
The simplest approach



We model each exposure independently to obtain the epoch astrometry

If the method is not special… what is?

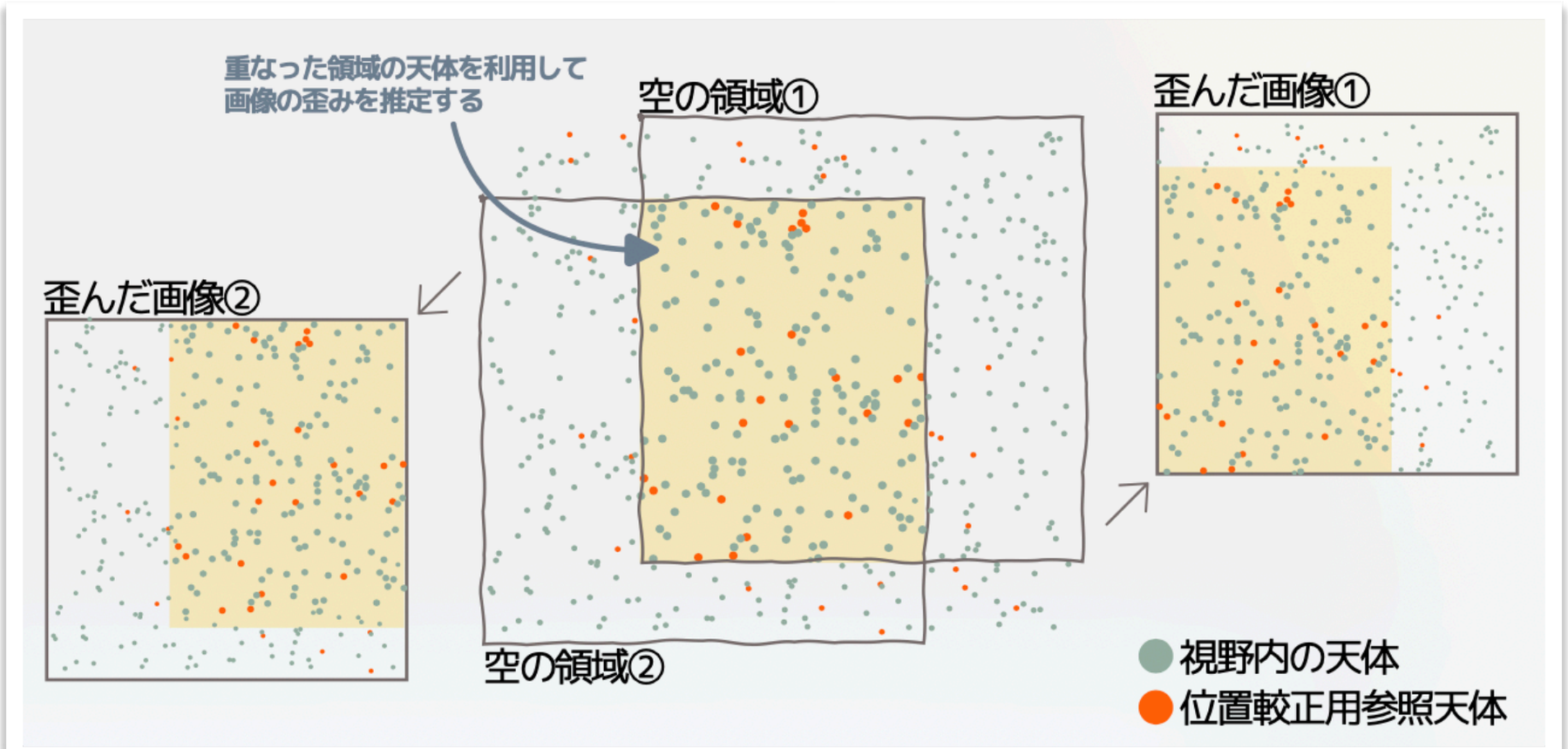
The simplest approach



+ Easy to implement
+ Embarrassingly parallelazable
- The calibration is poorly constrained and, as a result, the precision of the astrometry is also low

If the method is not special… what is?

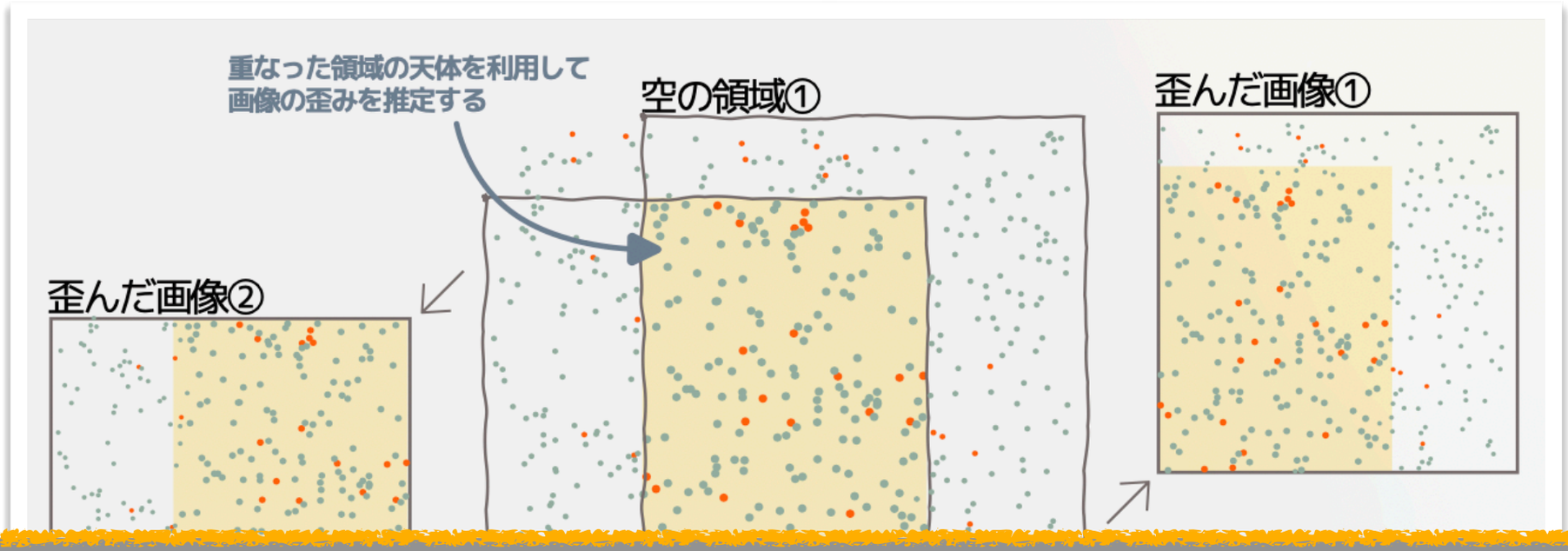
A more interesting approach



We observe some of stars at two different locations within the focal plane at consecutive exposures and impose that parts of the calibrations **must** be conserved

If the method is not special… what is?

A more interesting approach



+ The calibration is more robust
+ The astrometry gets a bigger share of the precision budget
- Harder to implement and parallelise
- If we make the wrong assumptions, we could end up trading accuracy for precision

If the method is not special… what is?

The trade off

If the method is not special… what is?

The trade off

So… how does Gaia do it?

The secret sauce

Key idea

Use a calibration model of your instrument that, simultaneously, contains the fewest possible parameters but explains the observations with the least possible biases!

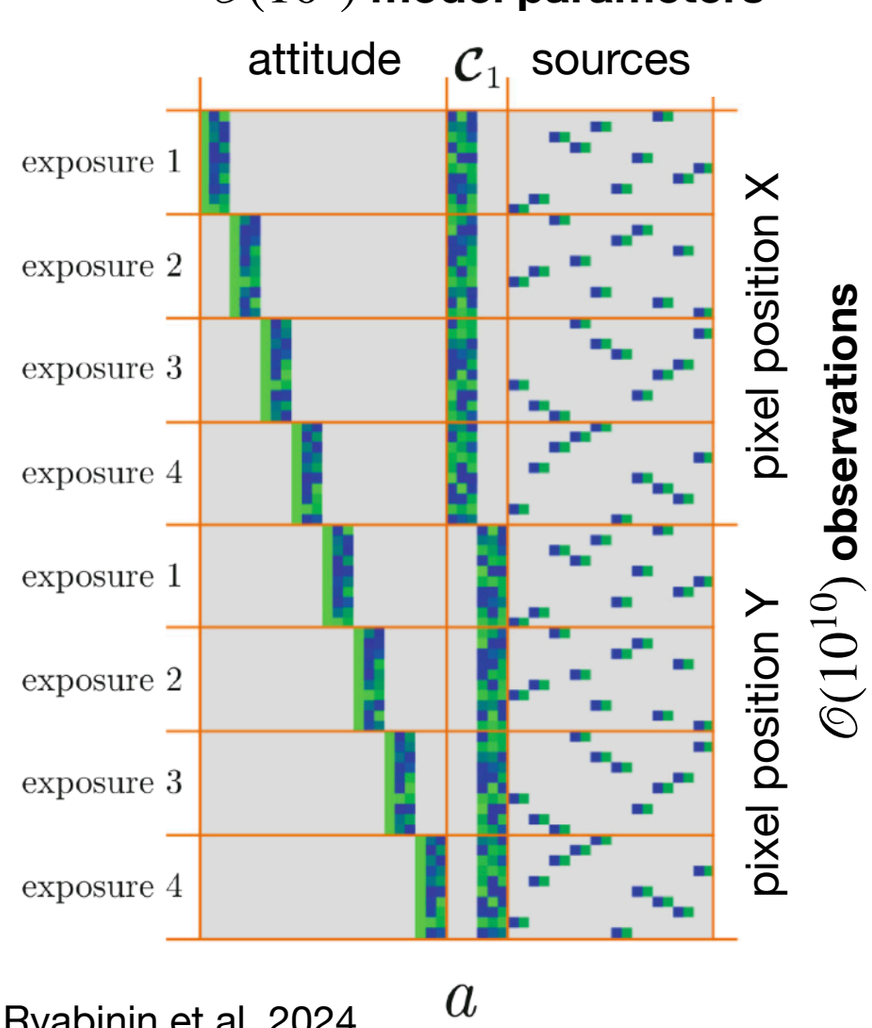
(*in other words, expand the validity of your cal. parameters to as many observations as possible!)*

How to do it then?

Design matrix of JASMINE

$$Ax \simeq b$$

$\mathcal{O}(10^7)$ **model parameters**



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Key idea

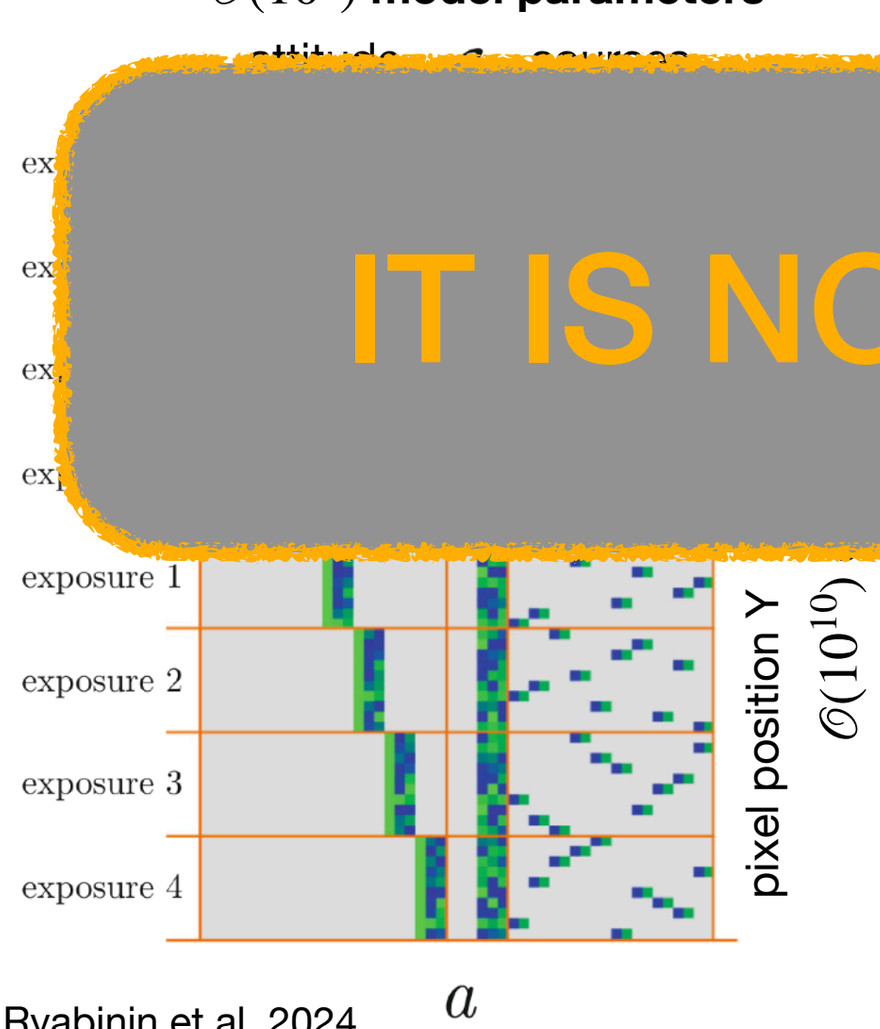
The Design matrix is so **huge** that it becomes a serious technical challenge to find x

How to do it then?

Design matrix of JASMINE

$$Ax \simeq b$$

$\mathcal{O}(10^7)$ **model parameters**



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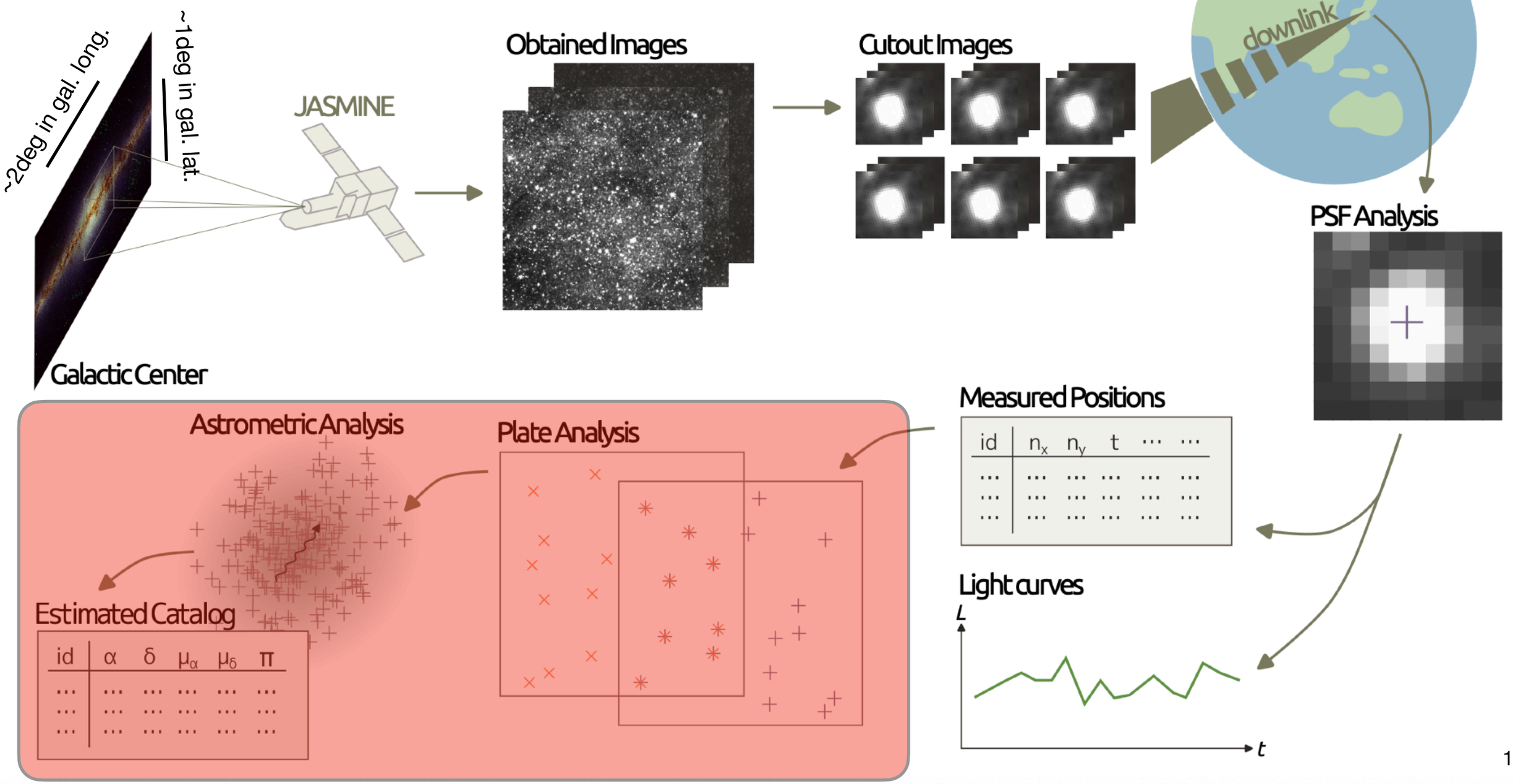
IT IS NOT EASY!

ea

atrix is so
huge that it becomes a serious technical challenge to find x

The astrometric challenge of JASMINE

How to obtain high precision, consistent global astrometry for the JASMINE targets?



***NOTE:** being developed by ARI team @Heidelberg University*

The astrometric solution

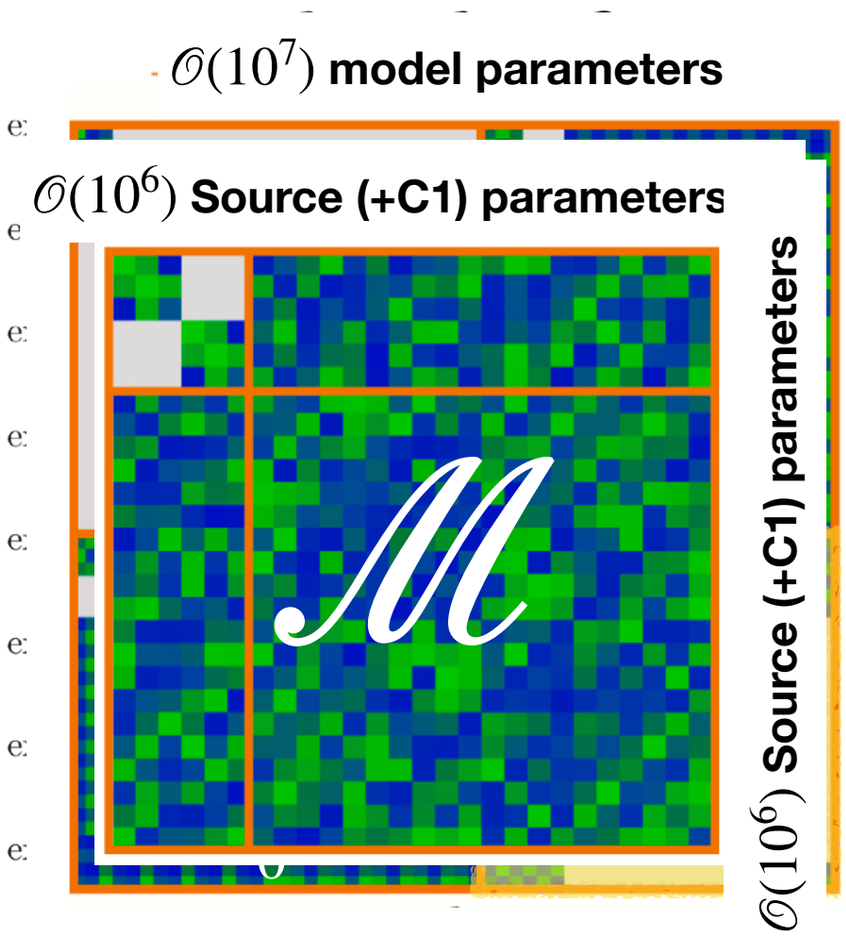
Direct: AJAS* solver

Pseudo-inverse

$$A\hat{x} = \hat{b} \blacktriangleright \mathscr{M}\hat{x}_S = \hat{b}_S \blacktriangleright \hat{x}_S = \mathscr{M}^{+}\hat{b}_S$$

Reduced normal matrix

$\mathcal{O}(10^7)$ **model parameters**



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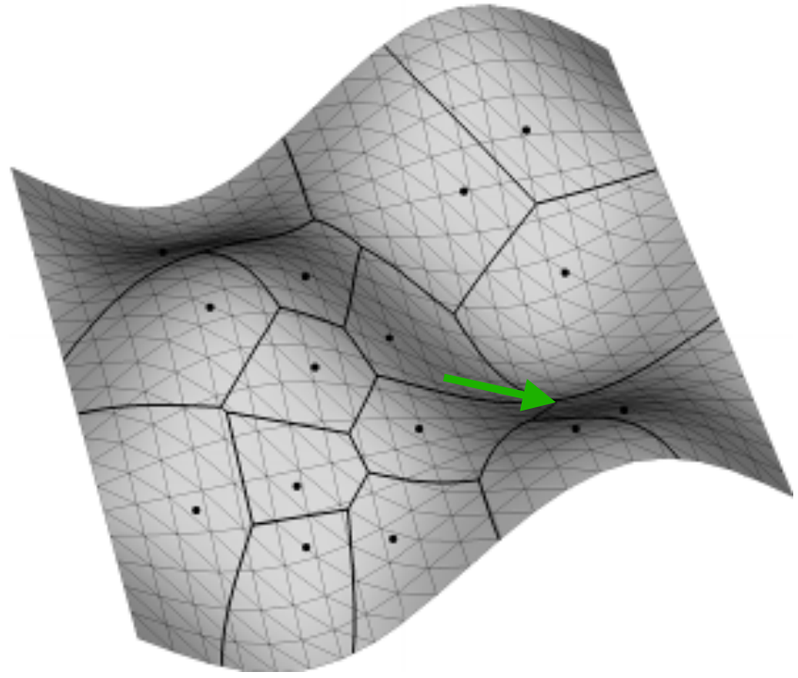
N-dimensional manifold of parameters

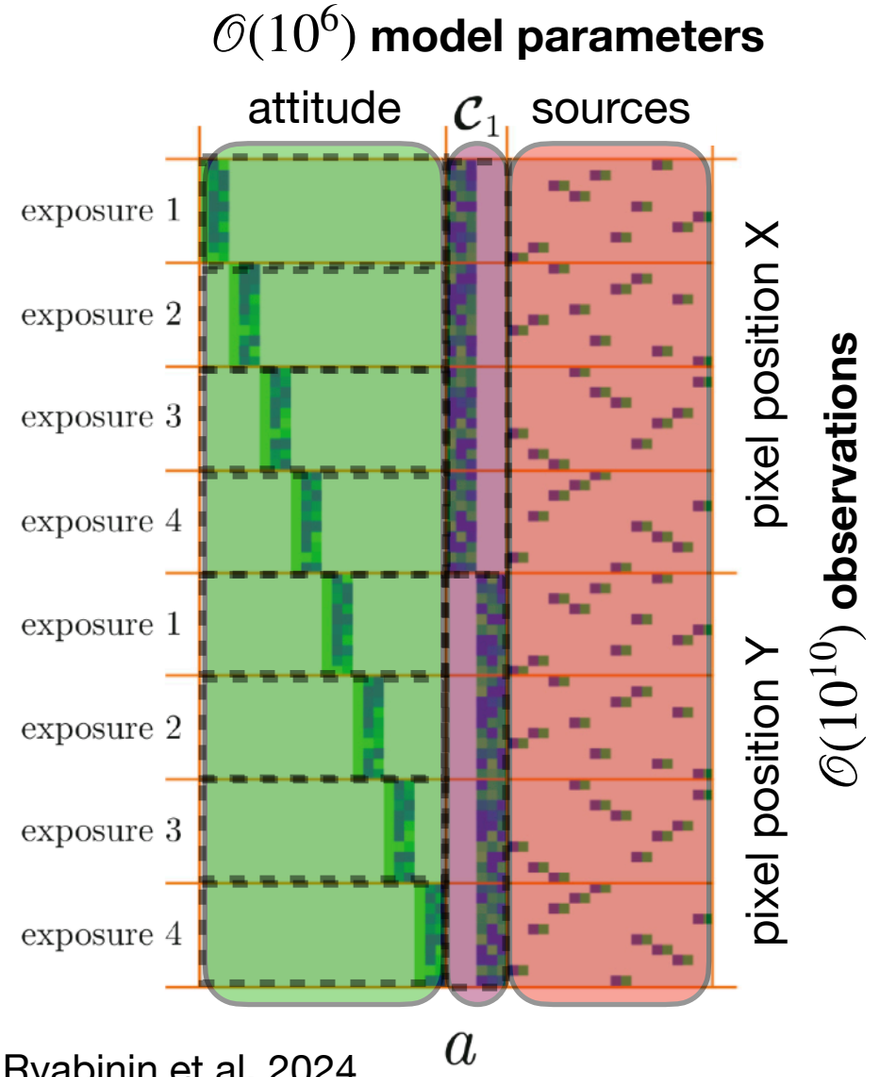


+ Takes into account the (local) shape of the whole manifold
- Only works if the initial guess is close enough to the truth
+ Provides the full correlation matrix and eigenvalues
- The size of the problem is huge
+ Requires only 1 step

The astrometric solution

Iterative: JAXBIS solver

$$A\hat{x} = \hat{b} \;\blacktriangleright\; A_i\hat{x}_i = \hat{b}_i$$



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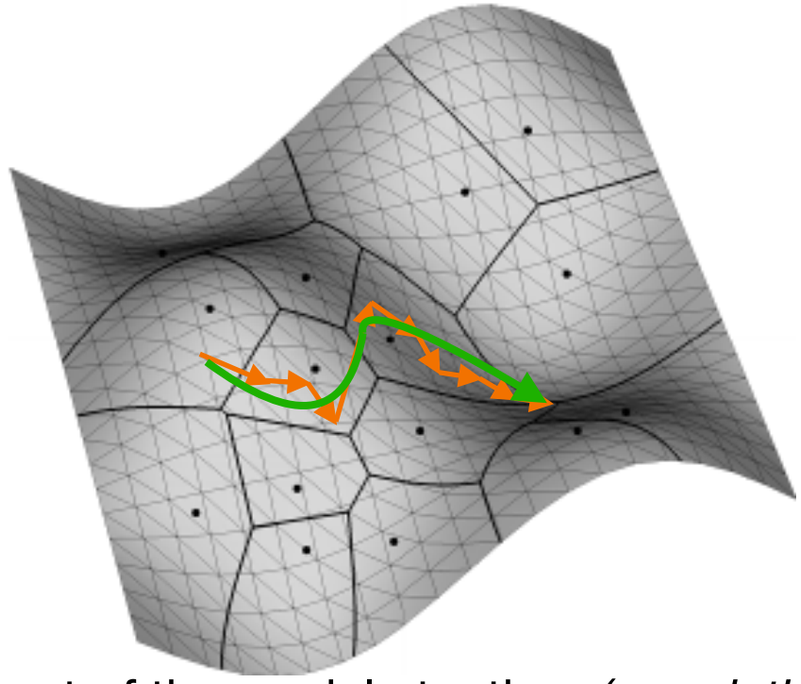
Many k-dimensional manifolds of parameters



- Solves one part of the model at a time *(correlations are indirect)*
- Approaches the global minima *slowly*
+ Can start relatively far from the truth
+ Each LS problem is relatively small
+ Self-corrects mistakes

The astrometric solution

Iterative: JAXBIS solver

$$A\hat{x} = \hat{b} \;\blacktriangleright\; A_i\hat{x}_i = \hat{b}_i$$

How to reach optimal solution?

$\mathcal{O}(10^6)$ **model parameters**

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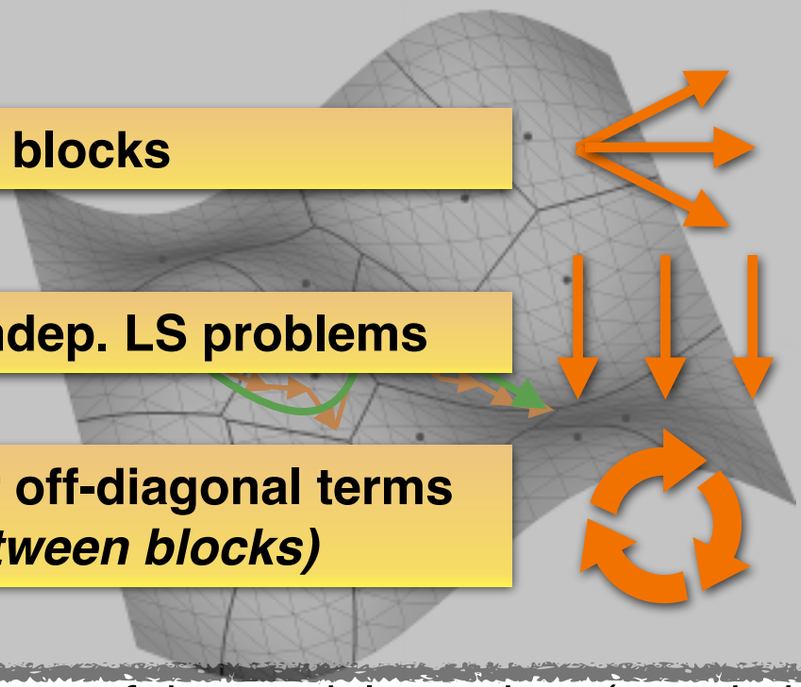
Many k-dimensional manifolds of parameters



Split into blocks

Solve many small indep. LS problems

Iterate to account for off-diagonal terms
(correlation between blocks)

- Solves one part of the model at a time *(correlations are indirect)*
- Approaches the global minima *slowly*
+ Can start relatively far from the truth
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Current state of JASMINE solvers

AJAS

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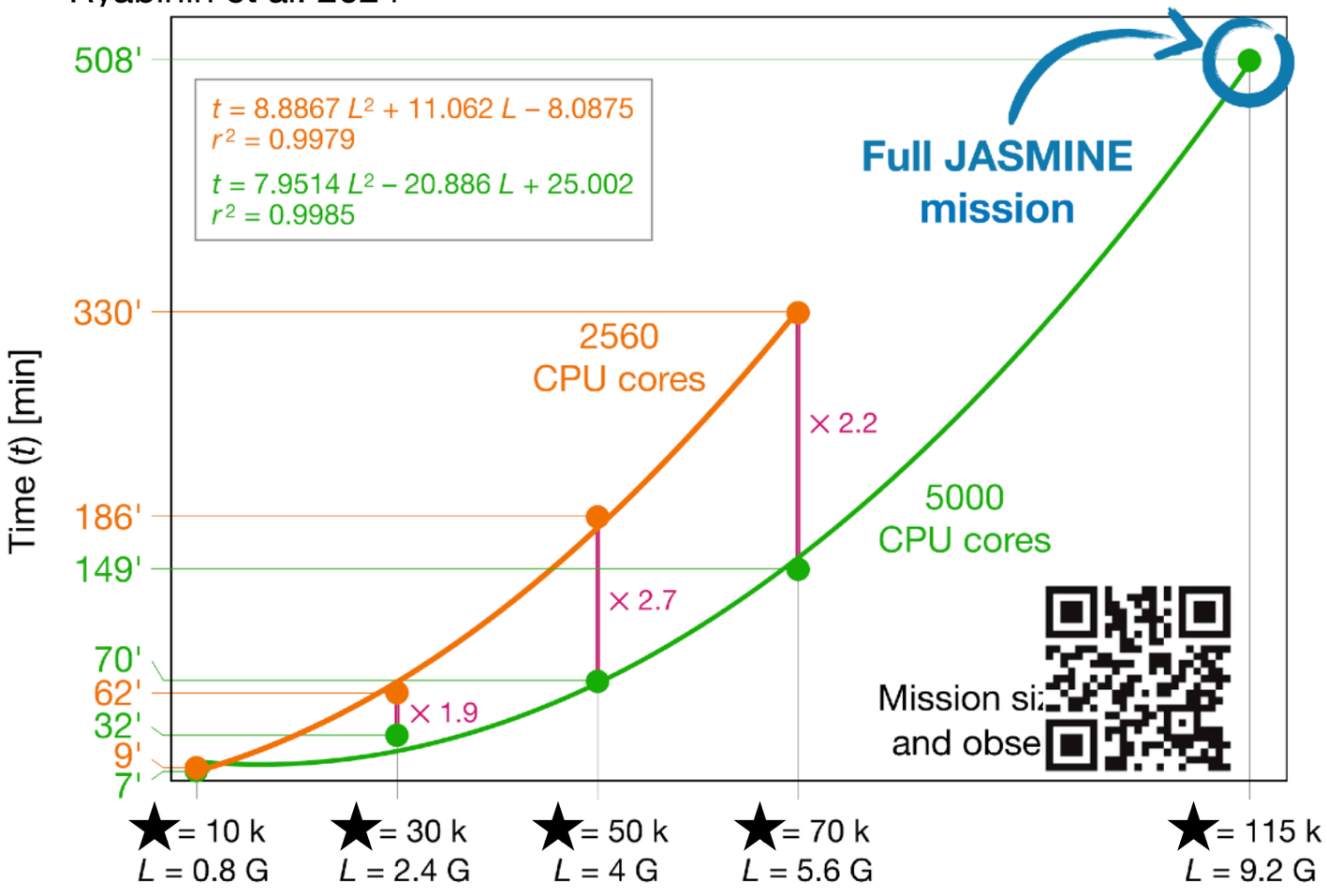
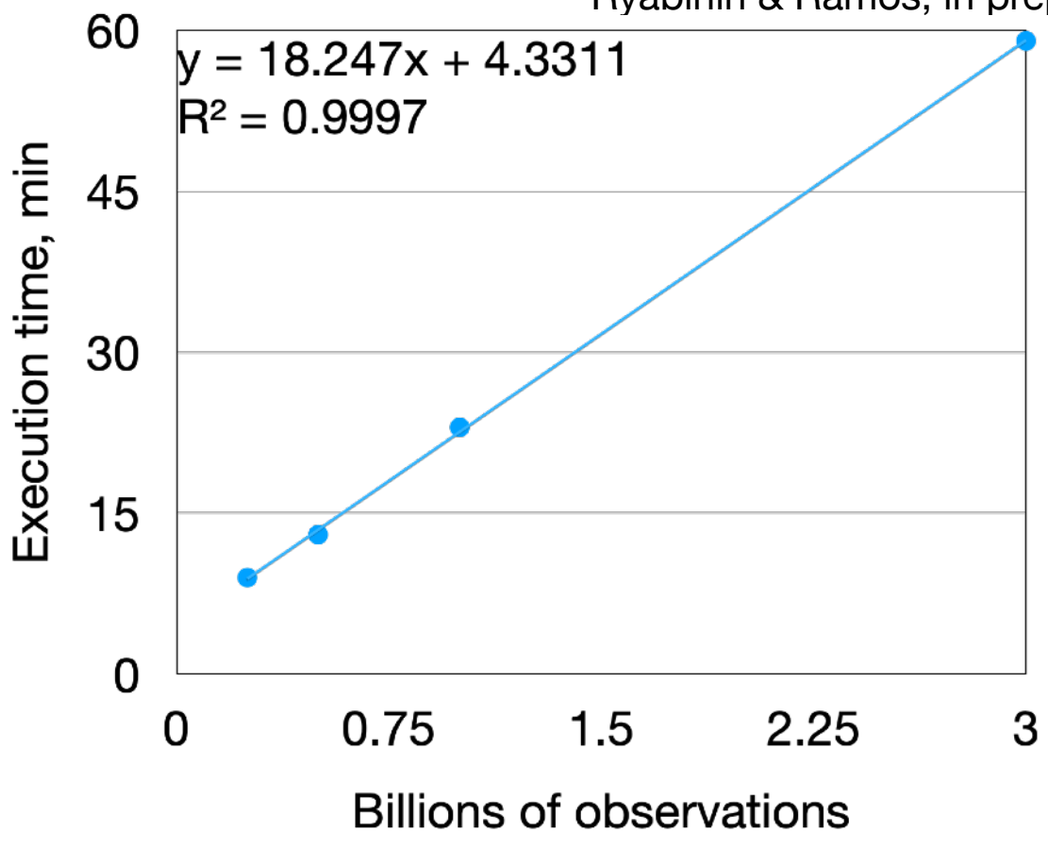


JAXBIS

Ryabinin & Ramos, in prep.



Key idea

AJAS scales as n_{obs}^3 but gives more information

JAXBIS scales as n_{obs} but makes it harder to interpret the results

Conclusions

➡ JAXBIS and AJAS are almost ready to be applied to real surveys

➡ The use of JAX in JAXBIS allows us to bypass the difficulty of deriving the analytical derivatives of non-linear models without sacrificing performance

➡ Thanks to that, we can easily and efficiently test the effect of different calibration models on the astrometric solutions

➡Both softwares are capable of processing the whole JASMINE mission in ~10 hours using HPC.

➡JAXBIS can be used for any survey aiming for precise astrometry (**Gaia NIR**, *VVVX-GalCen, PRIME, ROMAN and others)*

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THANK YOU!

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