



ZENTRUM FÜR
ASTRONOMIE



UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Direct Solver Aiming at Elimination of Systematic Errors in 3D Stellar Positions

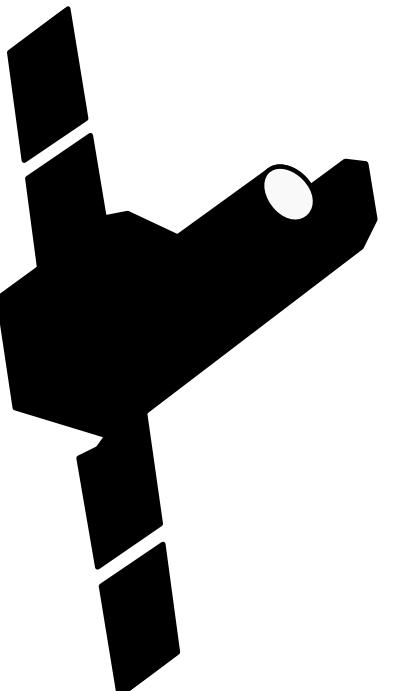
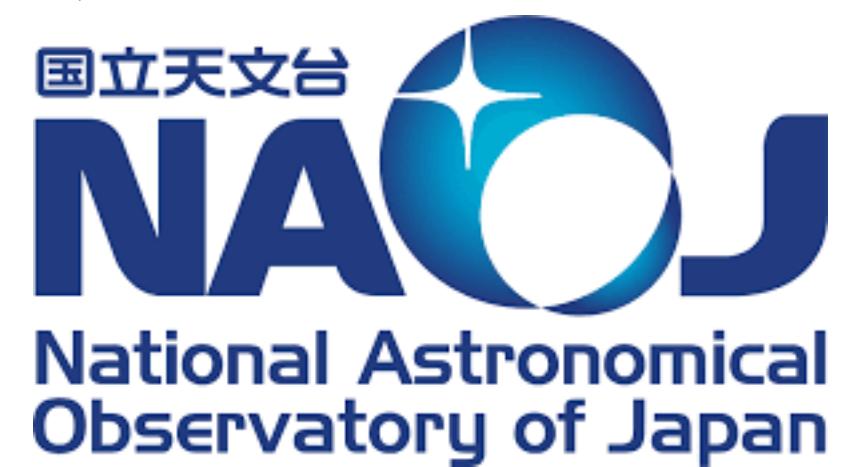
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by the German Aerospace Agency
(Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR)
through grant 50OD2201

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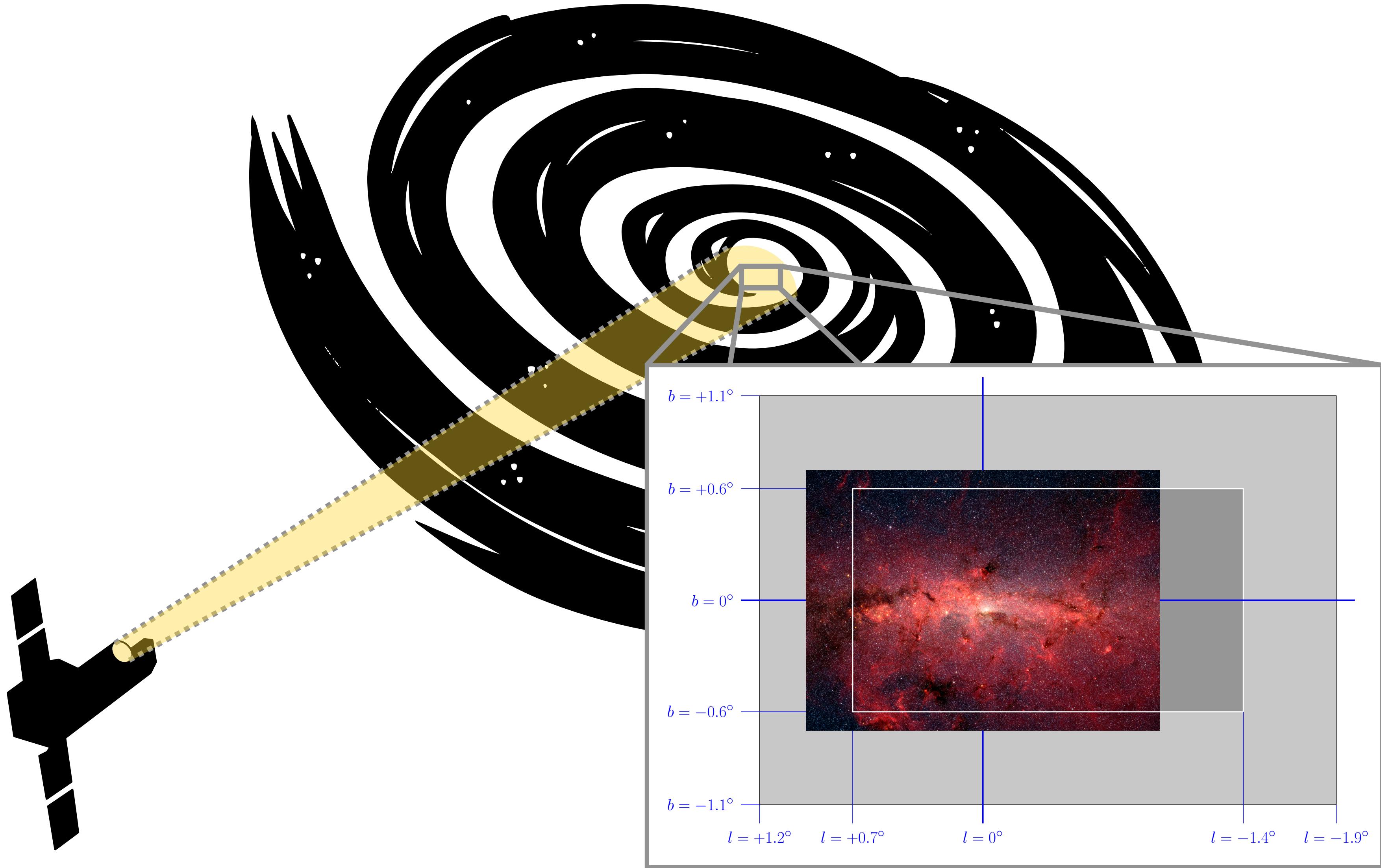
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Japan
Astrometry
Satellite
Mission for
INfrared
Exploration

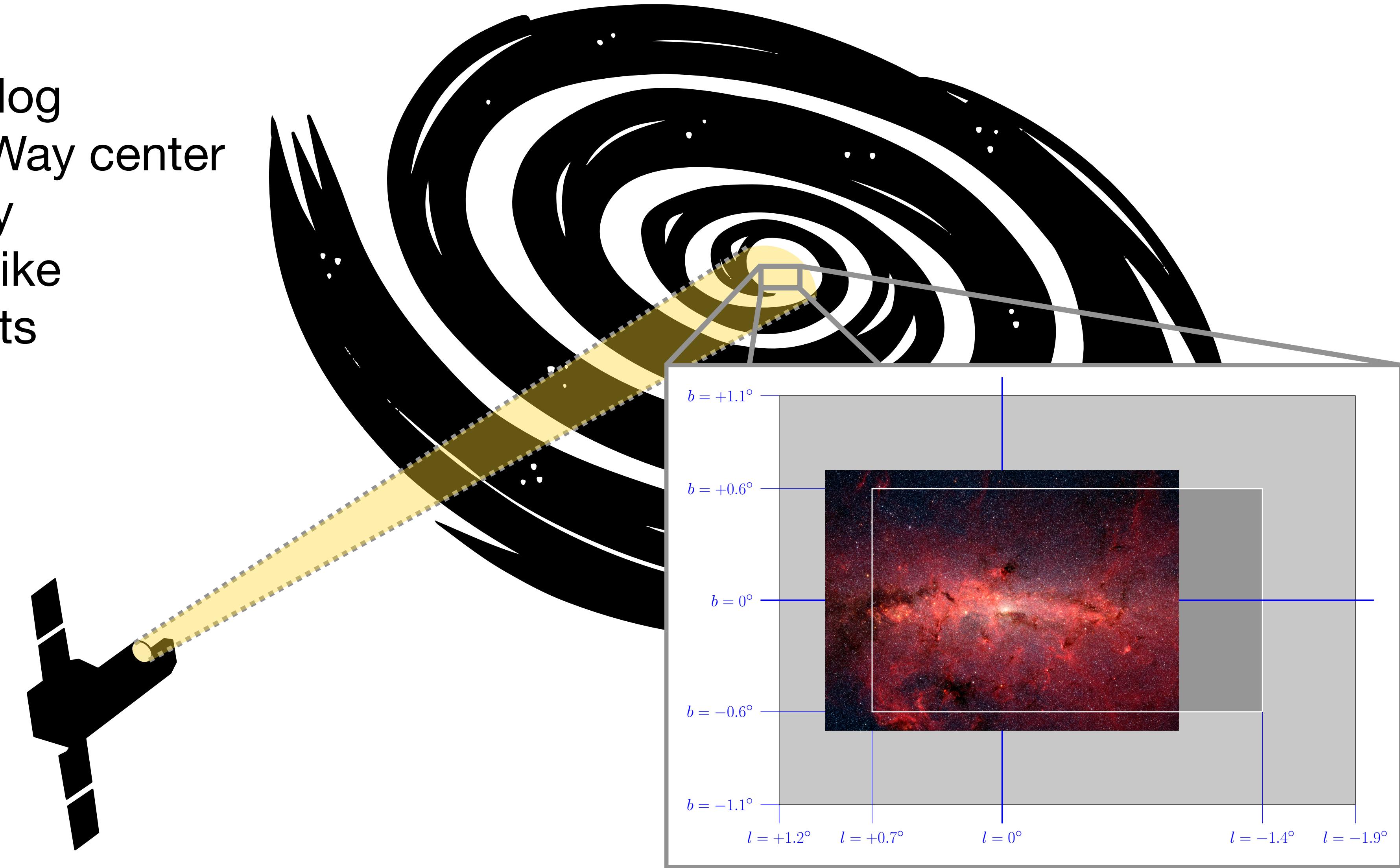


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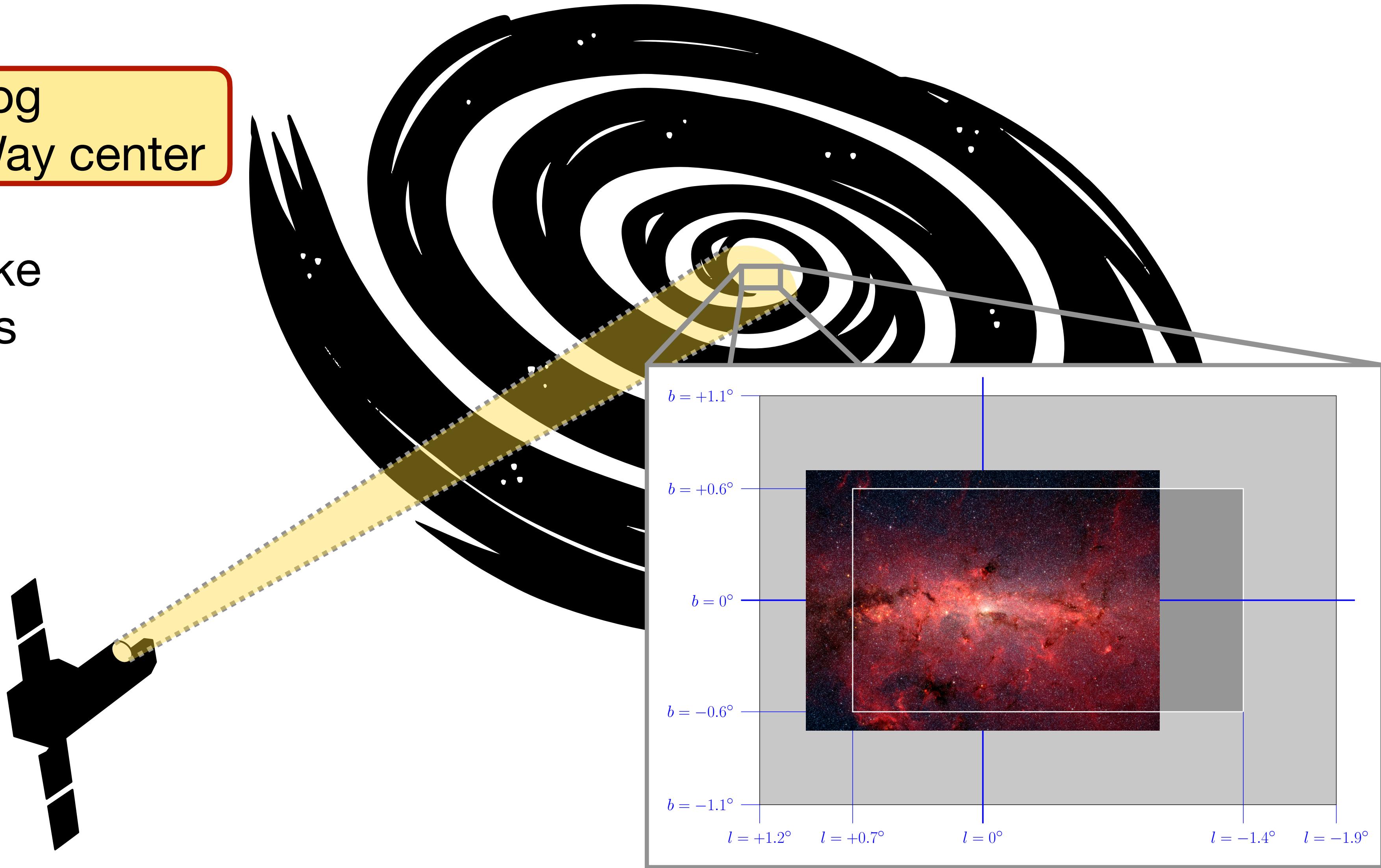
- Goals:
1. Star catalog
of Milky Way center
 2. Discovery
of Earth-like
exoplanets



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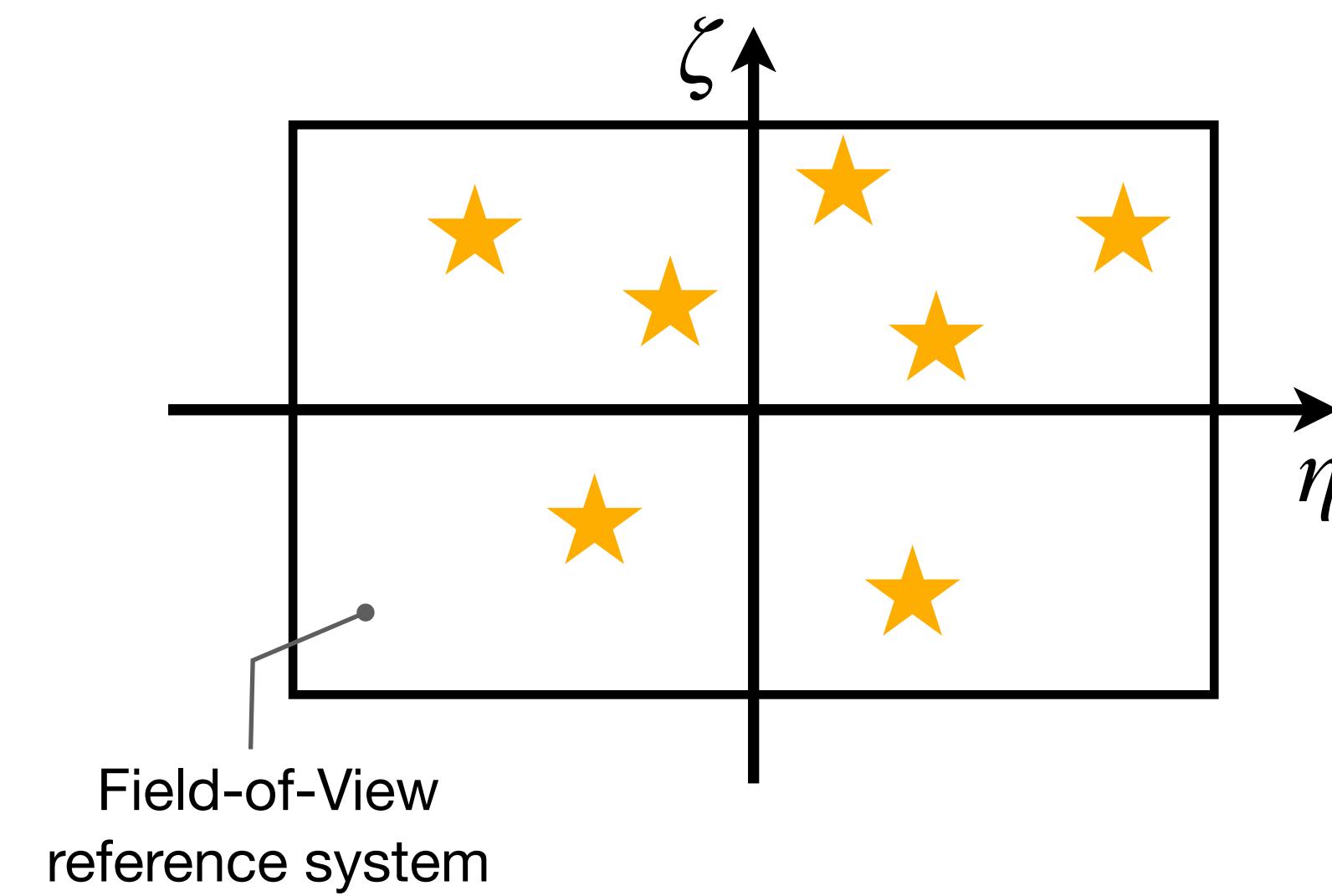
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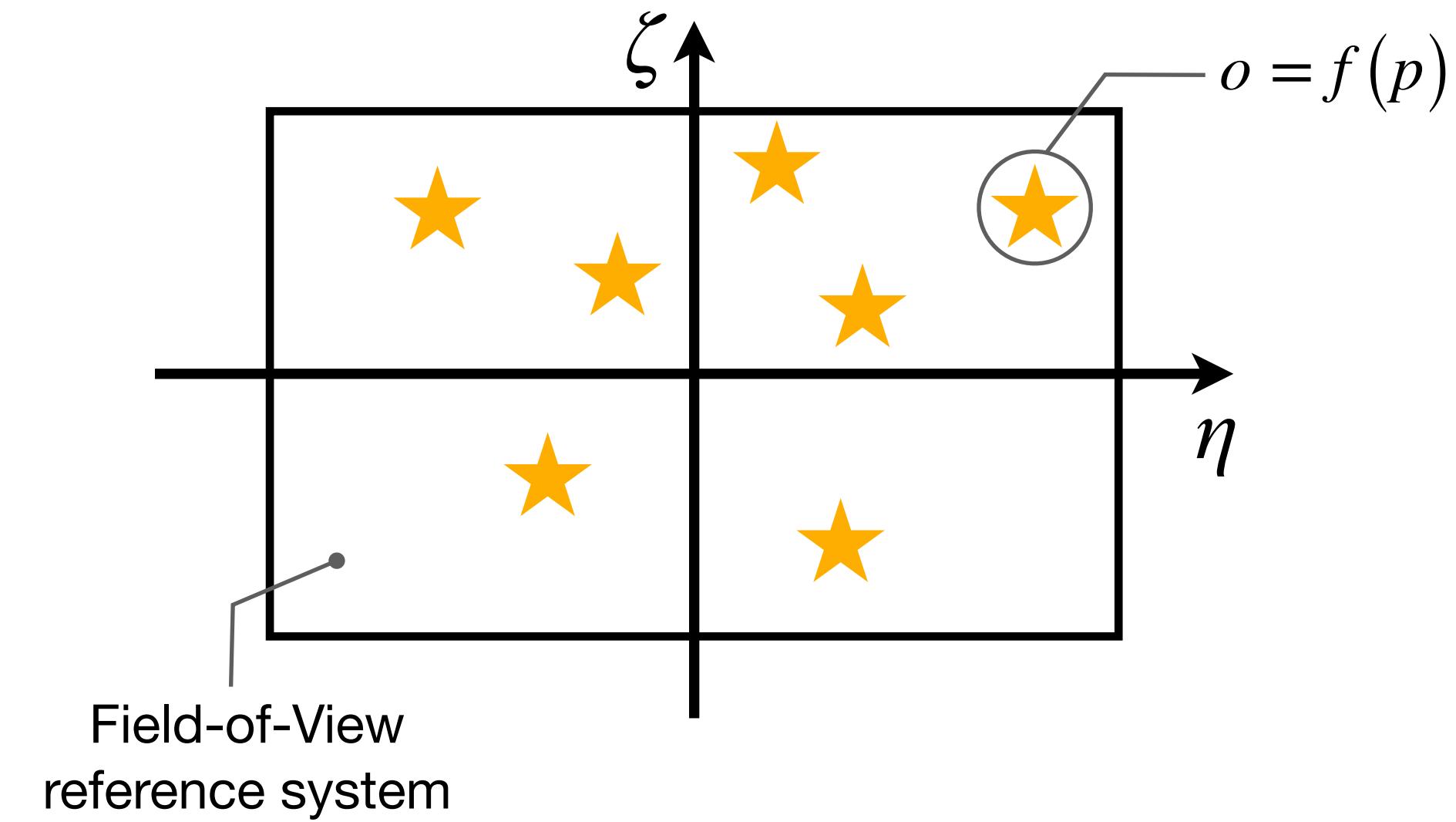
Astrometric Problem

3 / 14



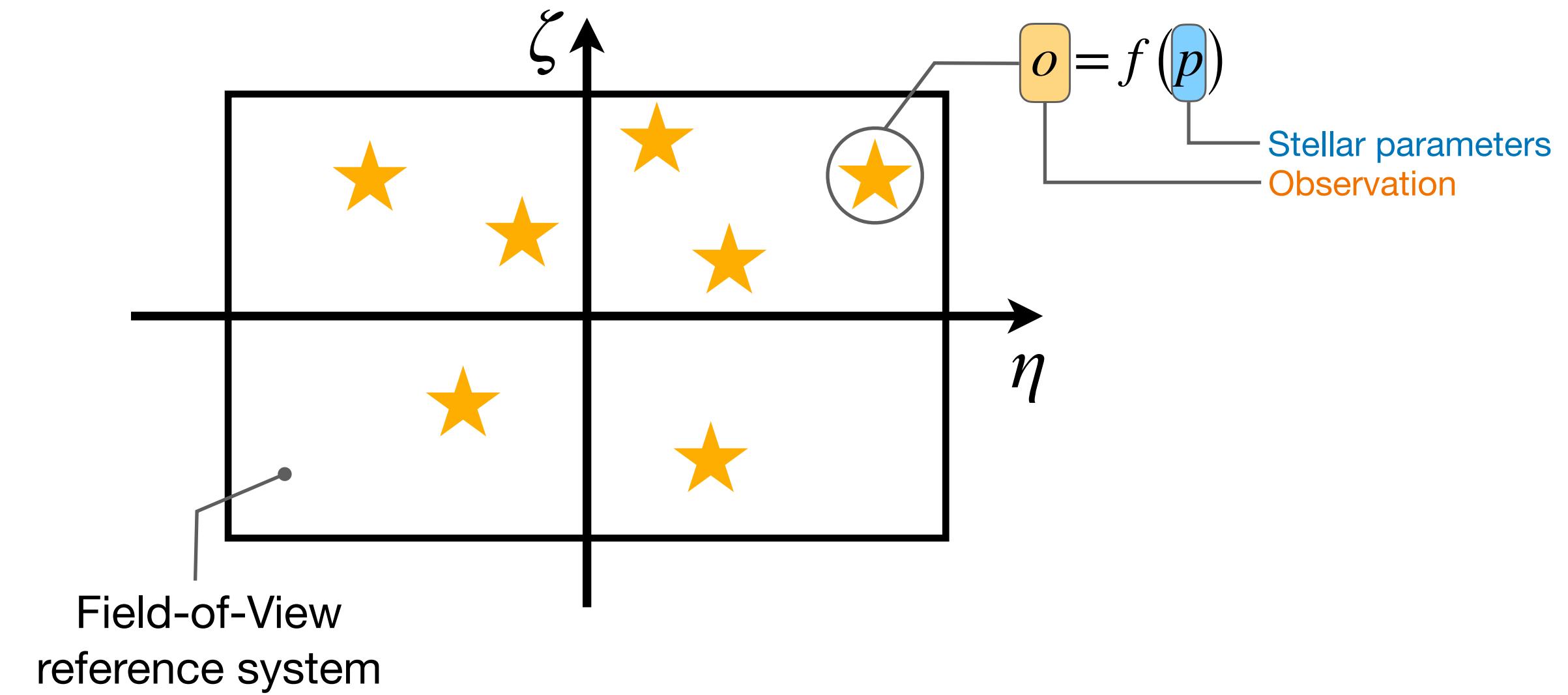
Astrometric Problem

3 / 14

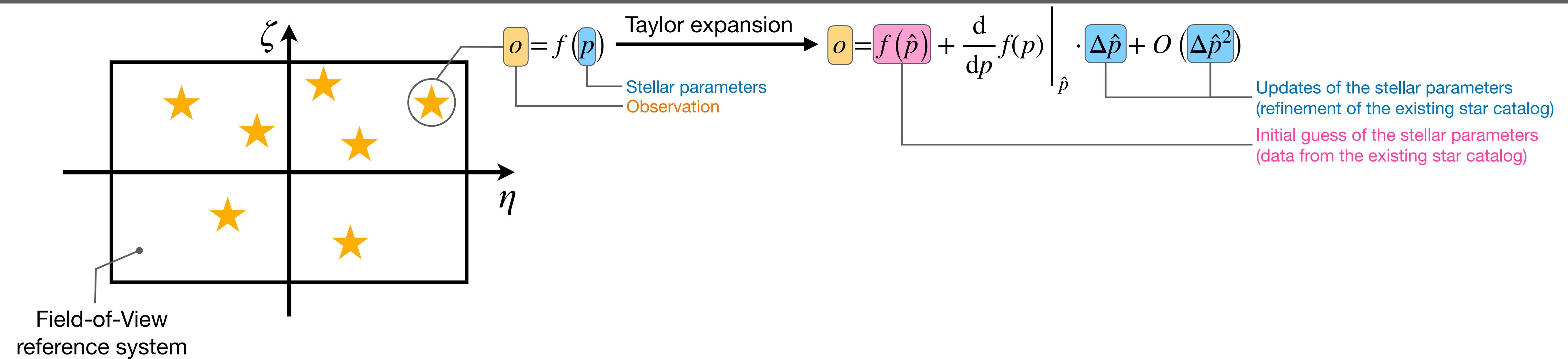


Astrometric Problem

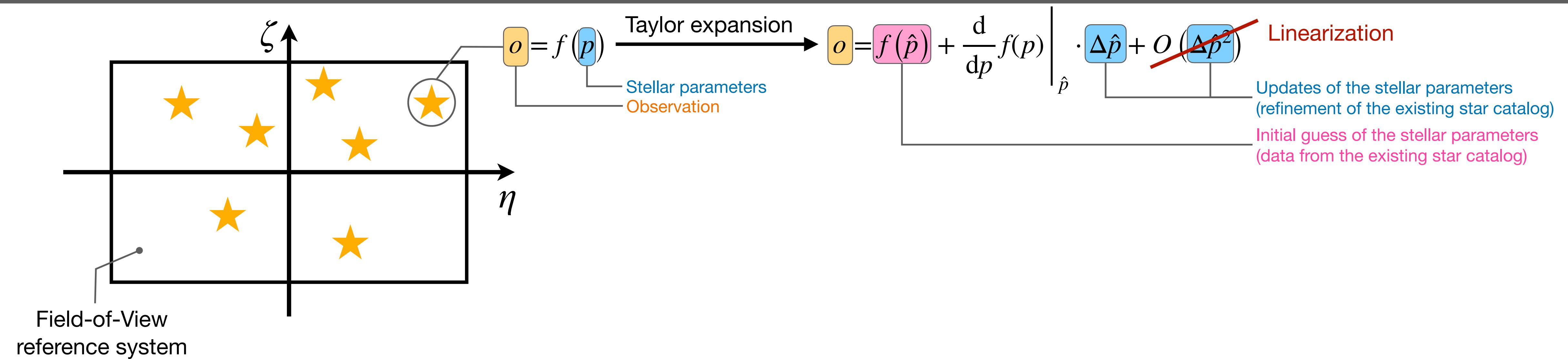
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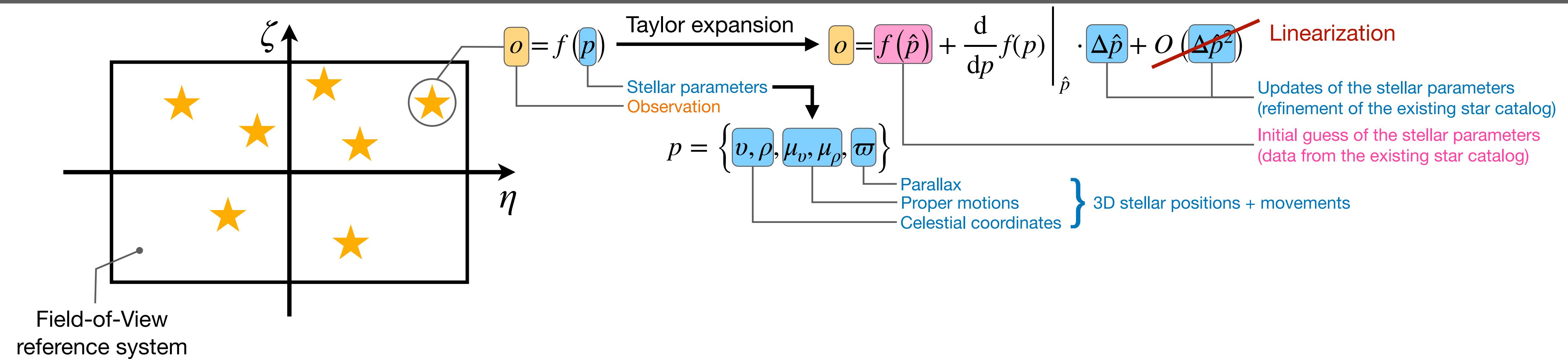
Astrometric Problem



Astrometric Problem

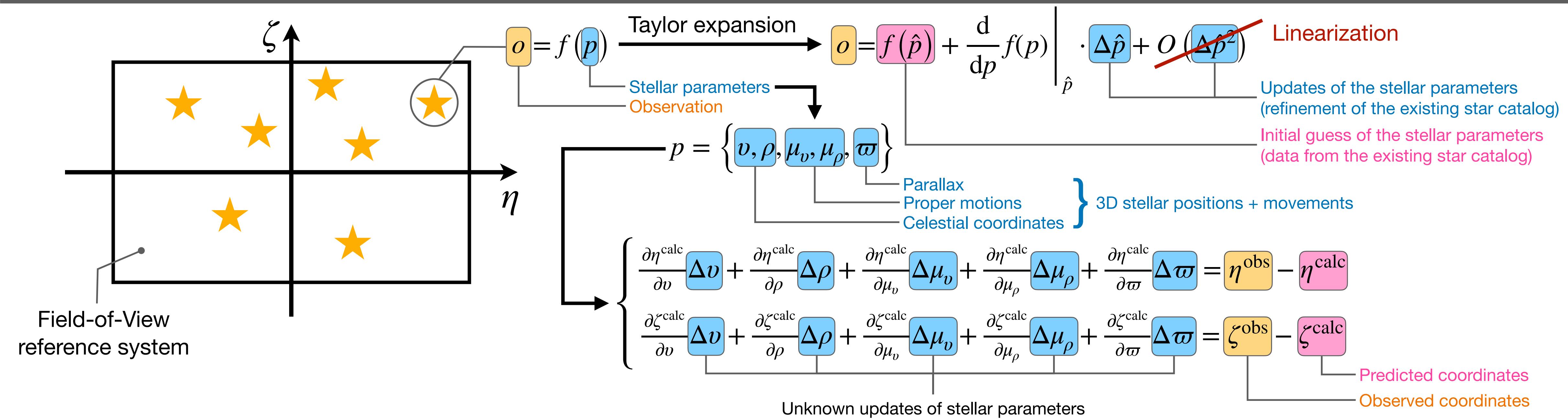


Astrometric Problem



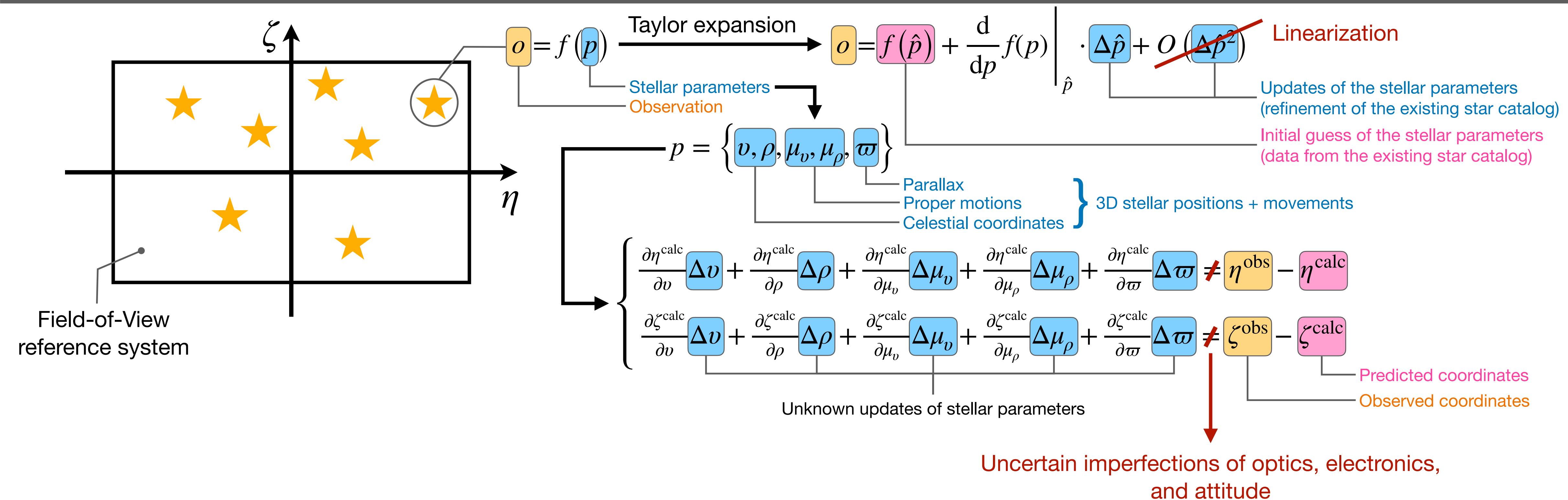
Astrometric Problem

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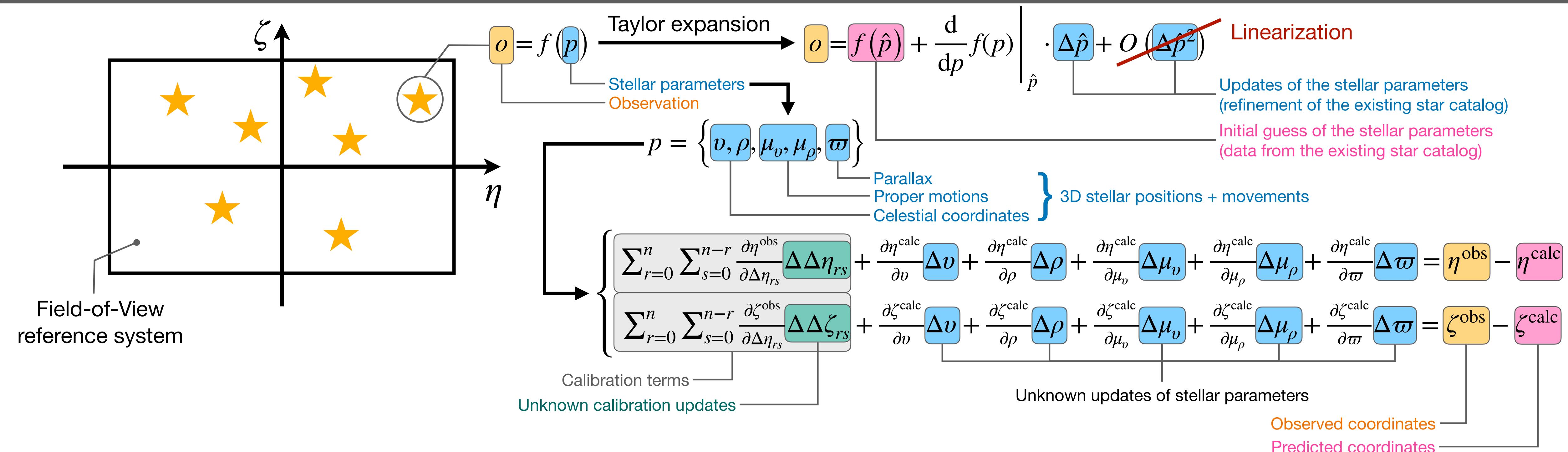
Astrometric Problem

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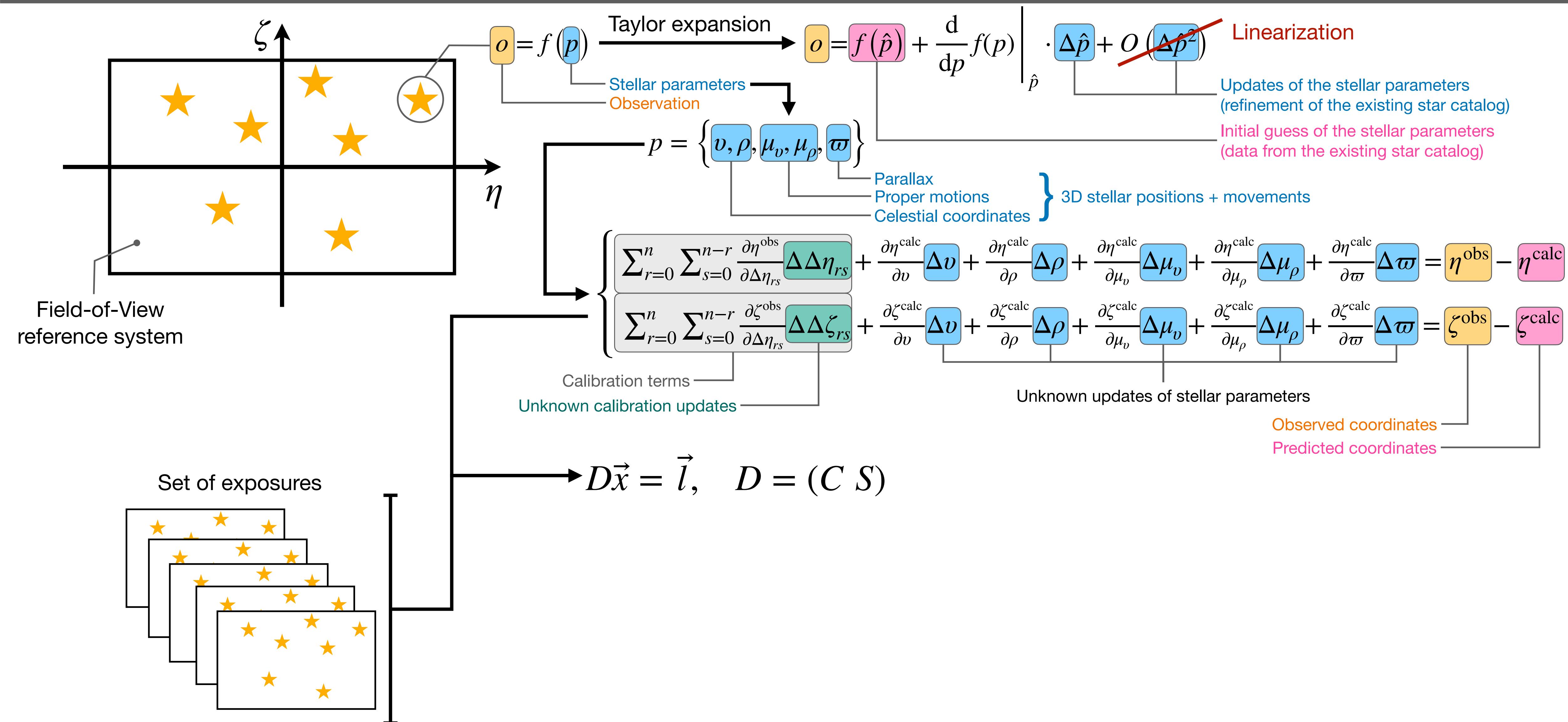
Astrometric Problem

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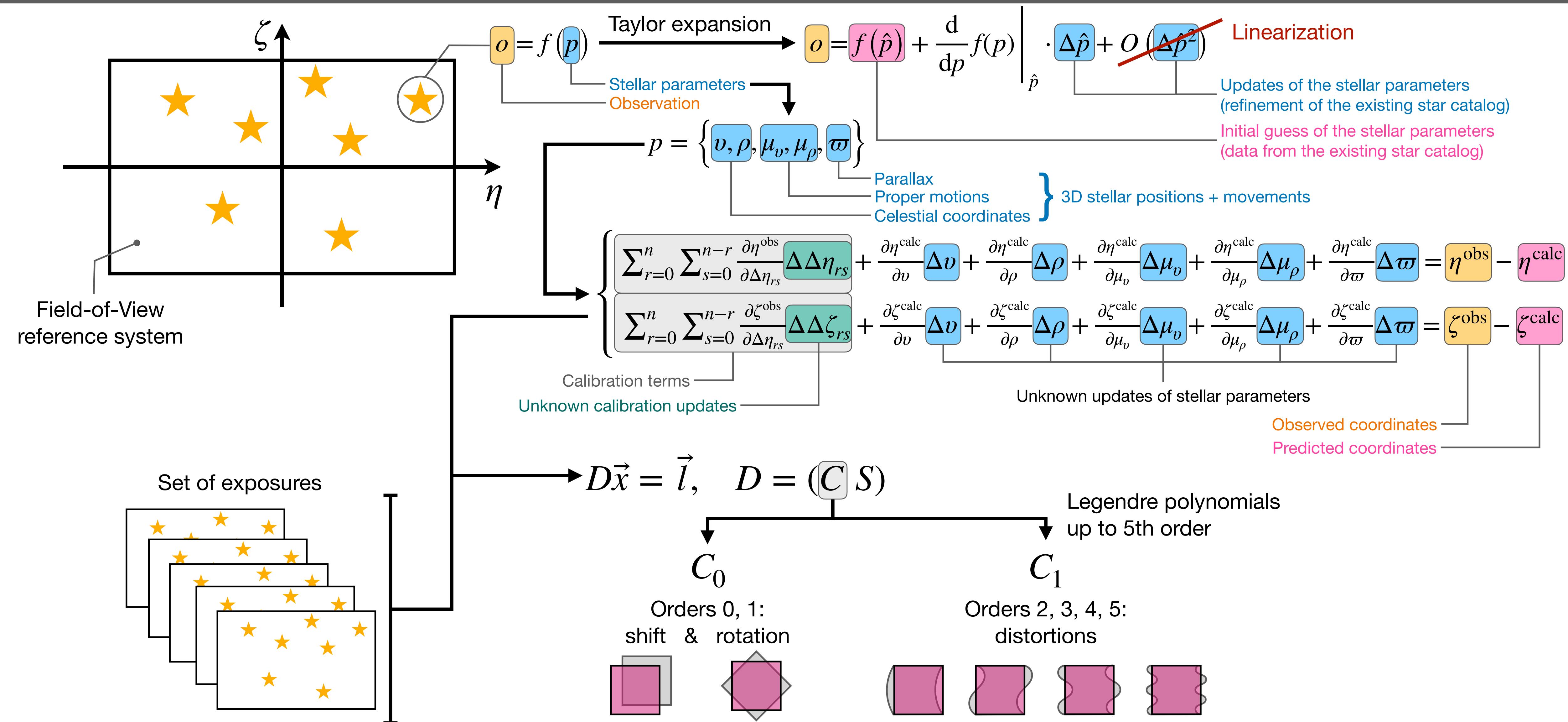
Astrometric Problem

3 / 14



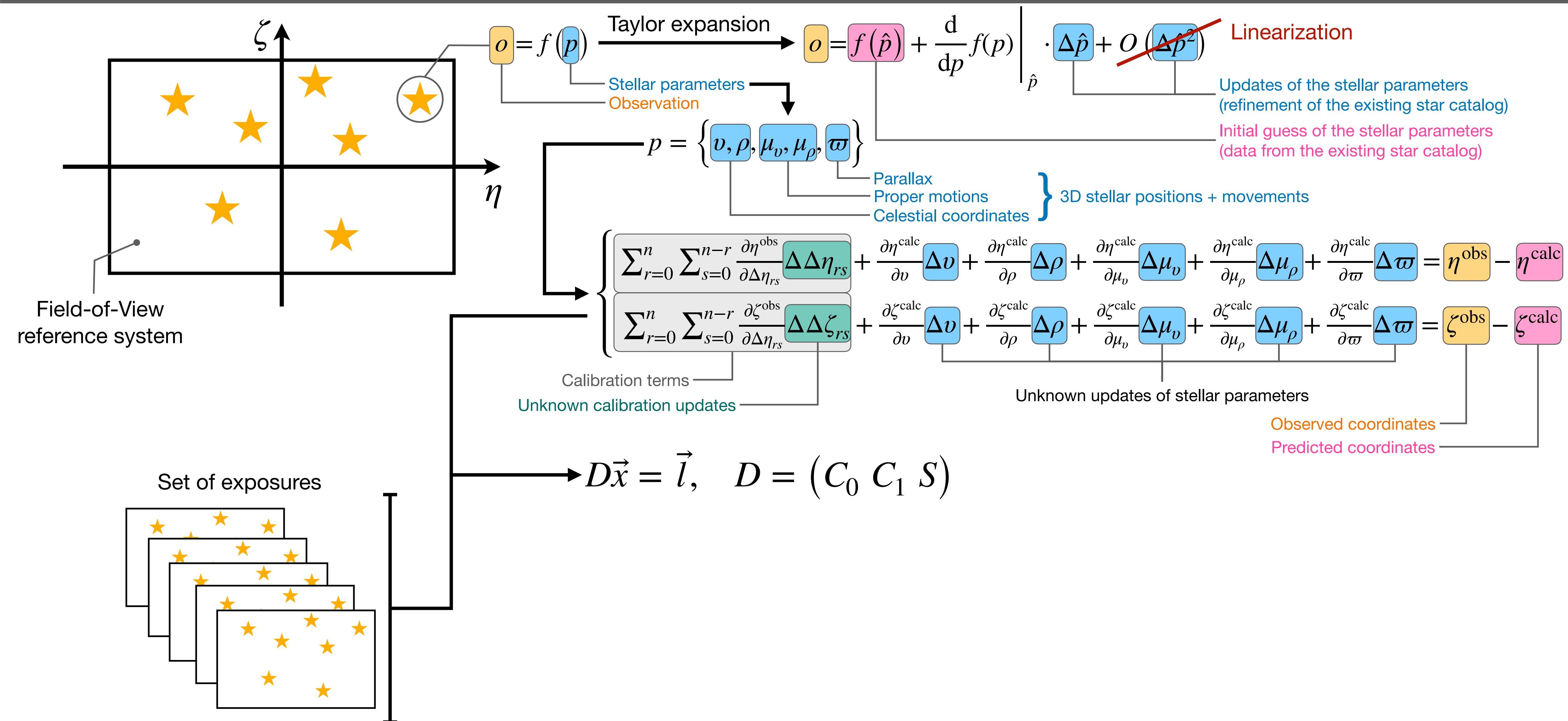
Astrometric Problem

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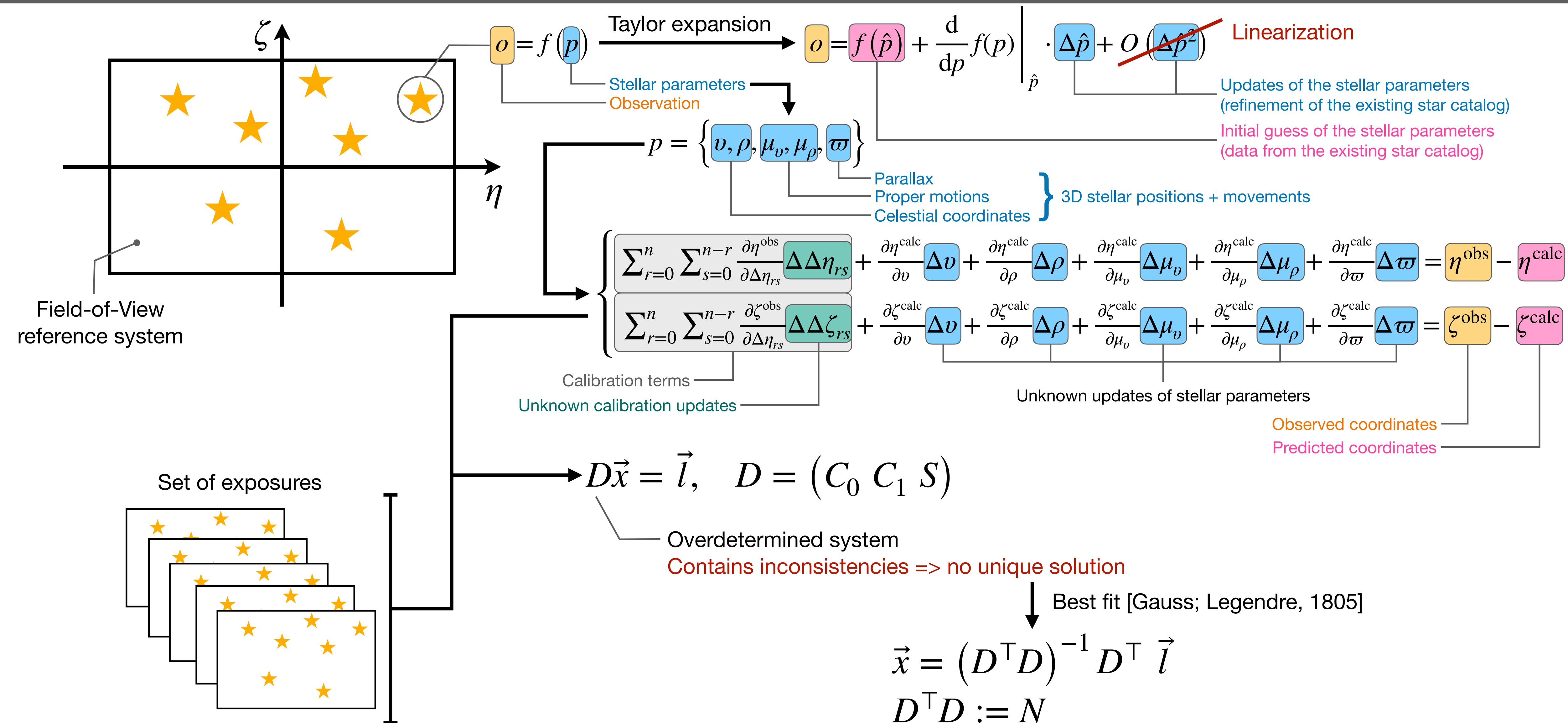
Astrometric Problem

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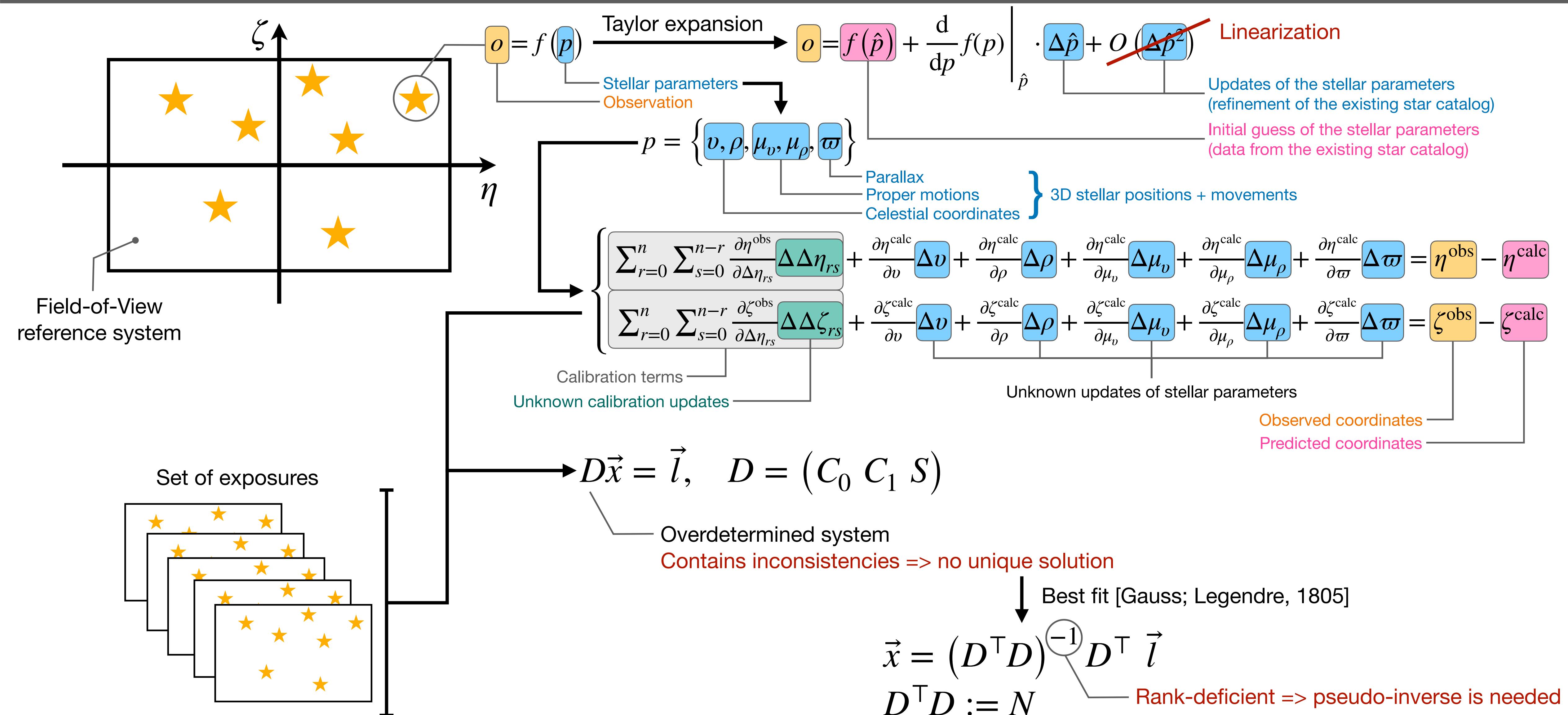
Astrometric Problem

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Astrometric Problem

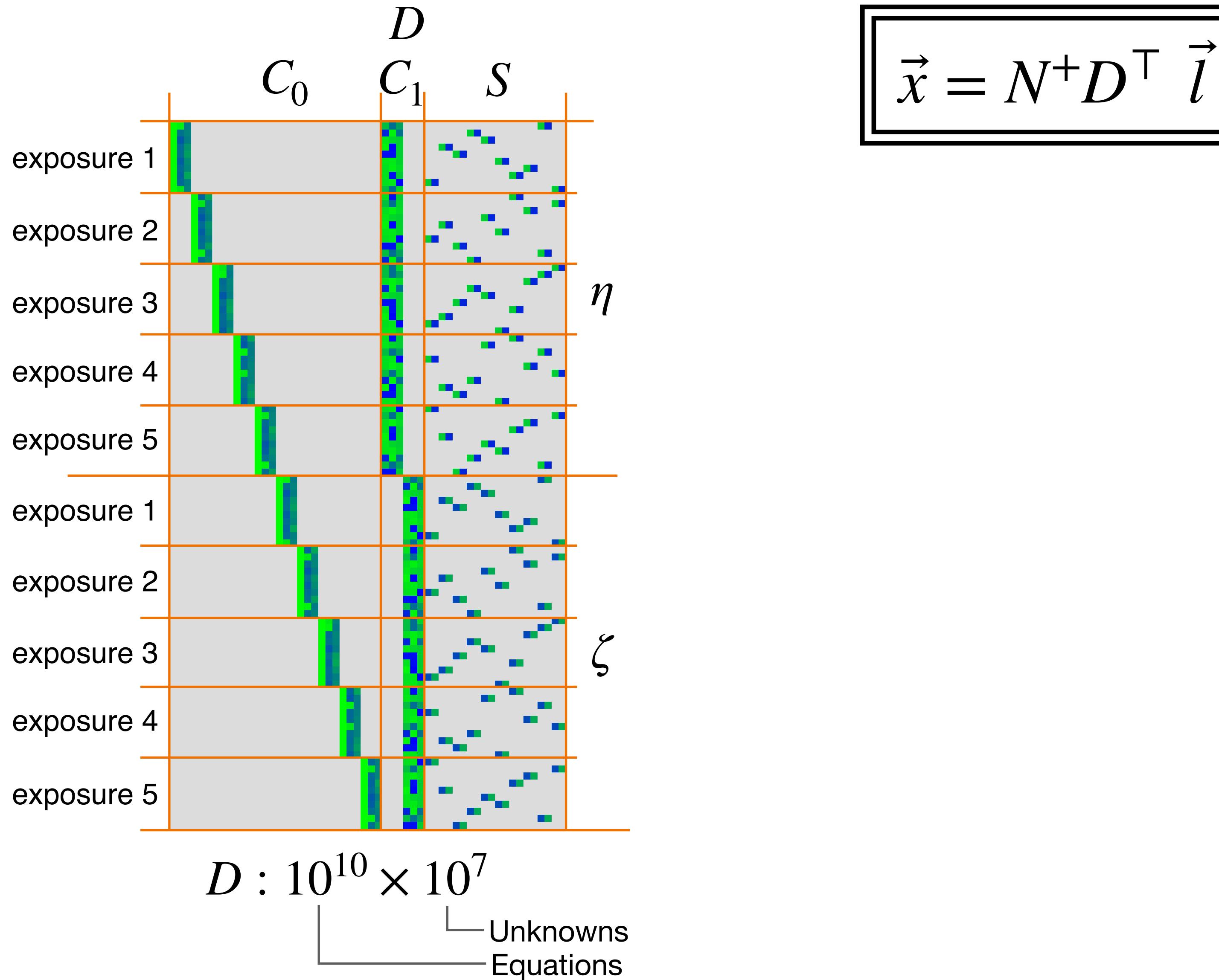
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$$\vec{x} = N^+ D^\top \vec{l}$$

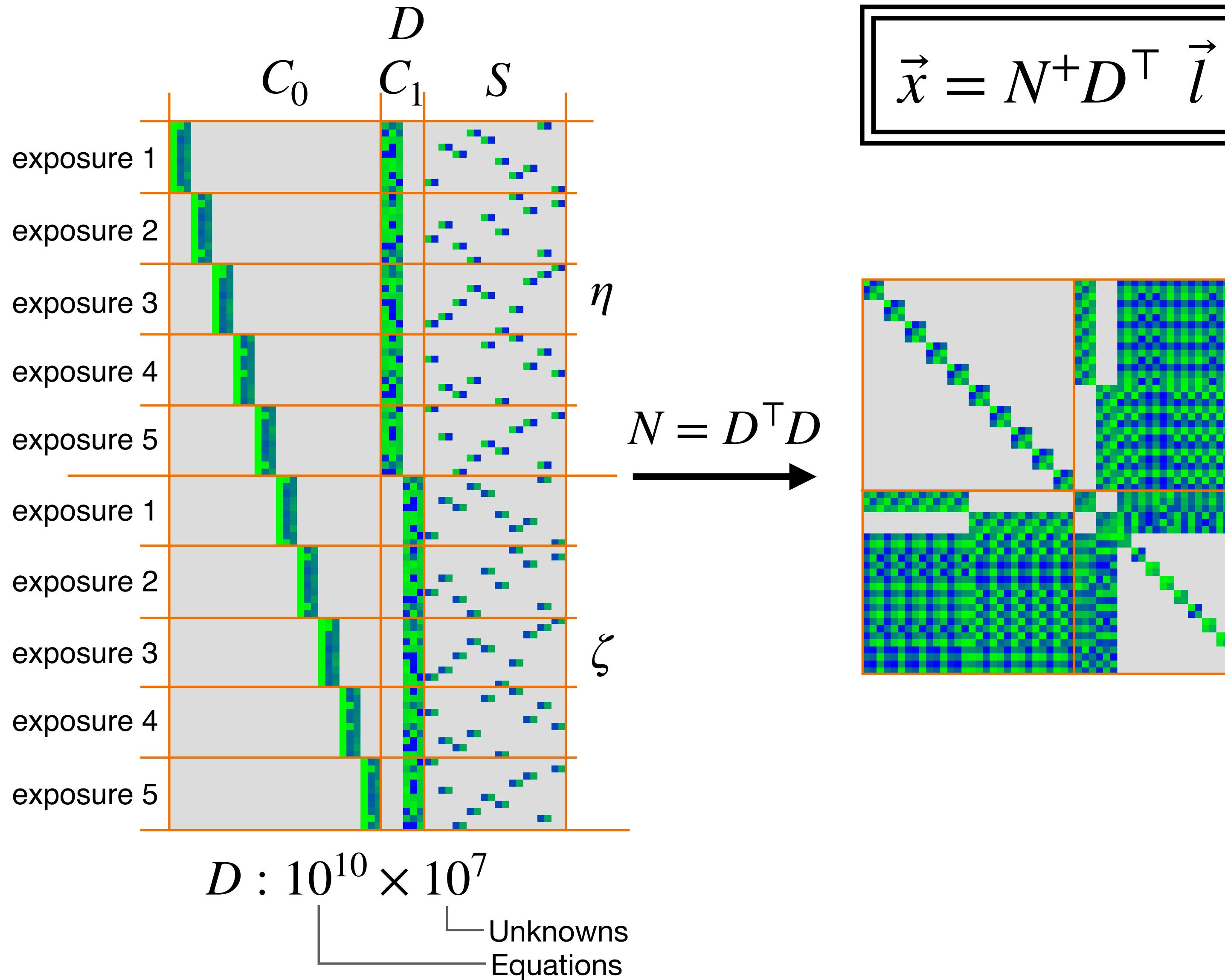
Approach to Solution

4 / 14



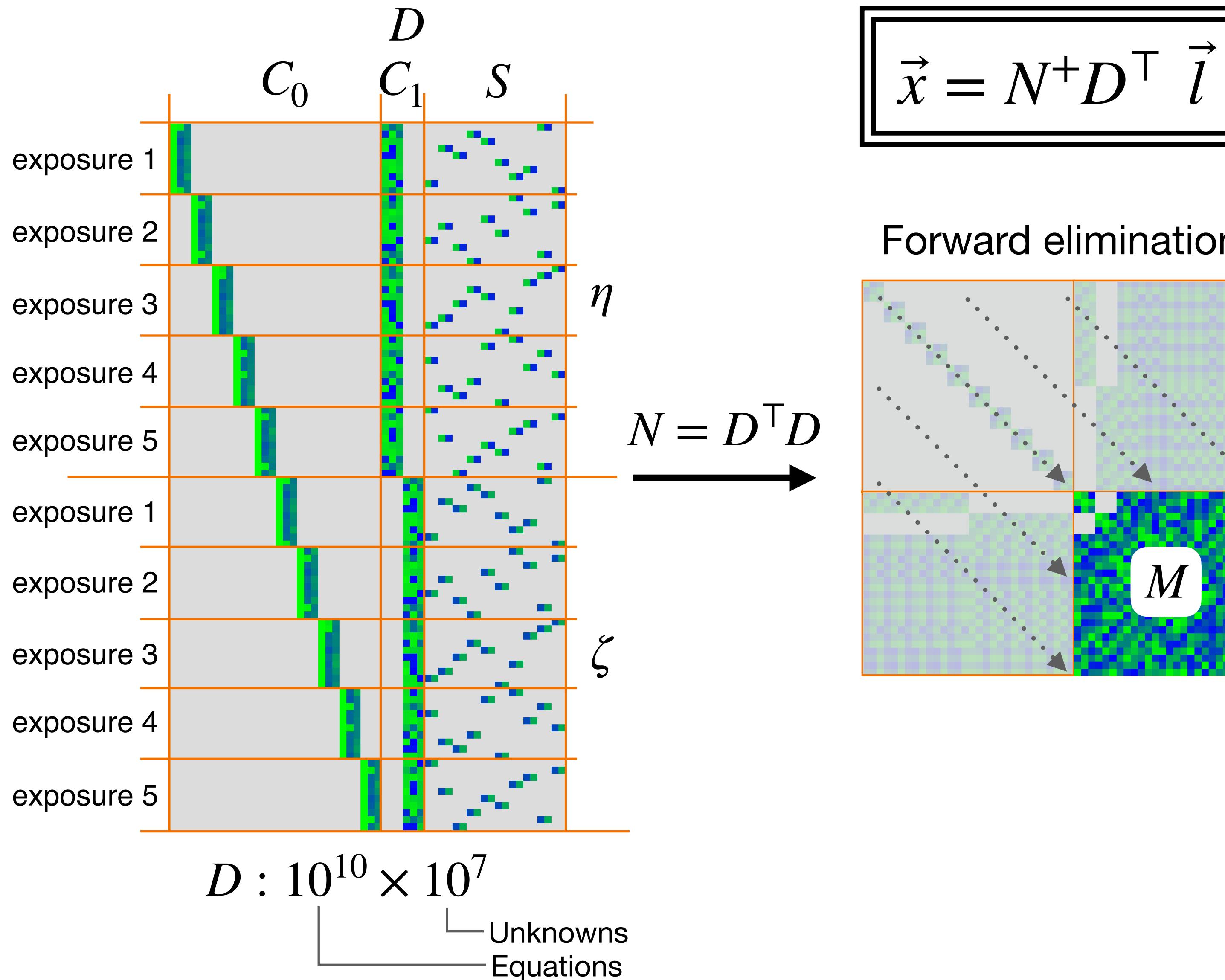
Approach to Solution

4 / 14



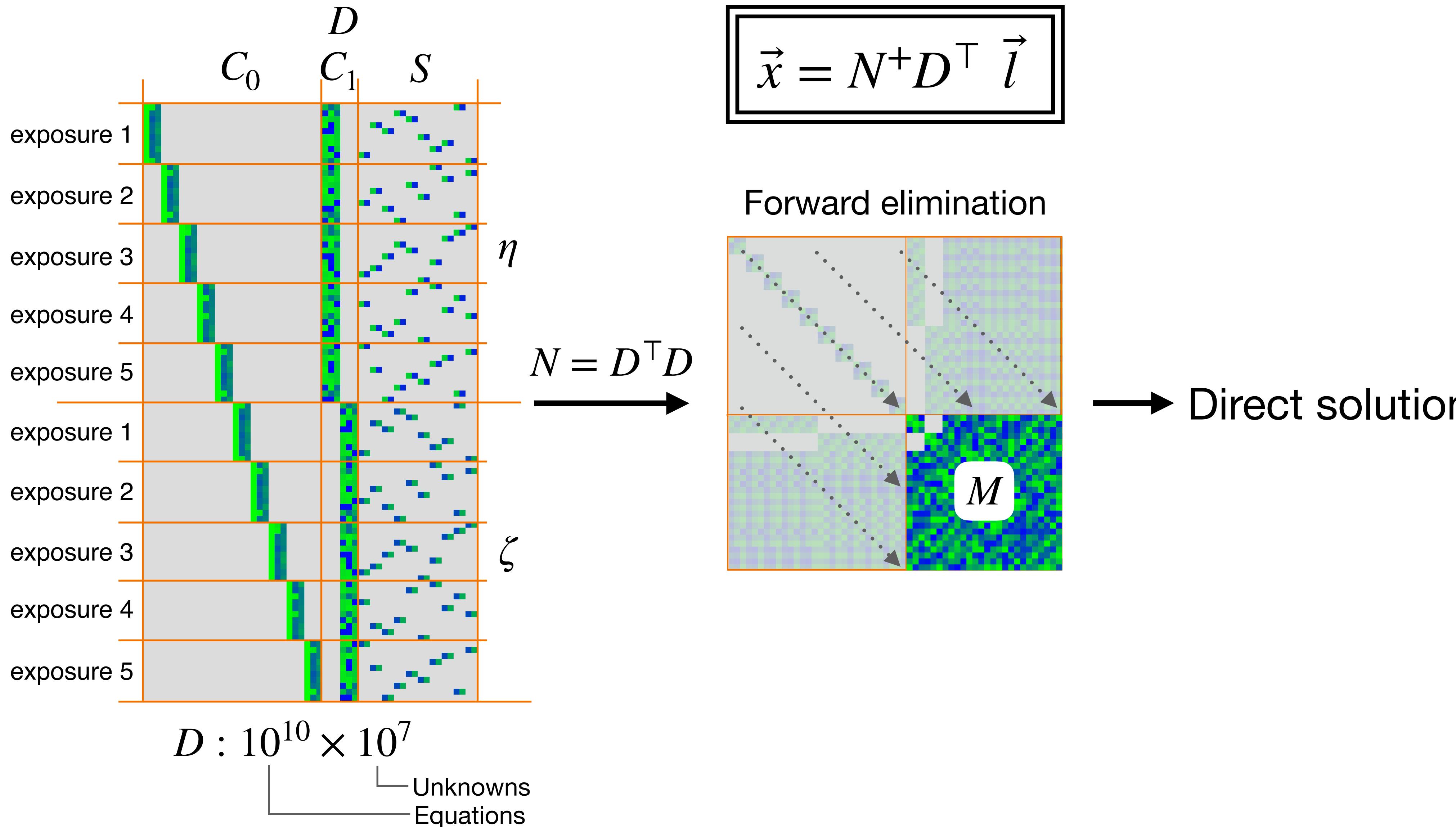
Approach to Solution

4 / 14



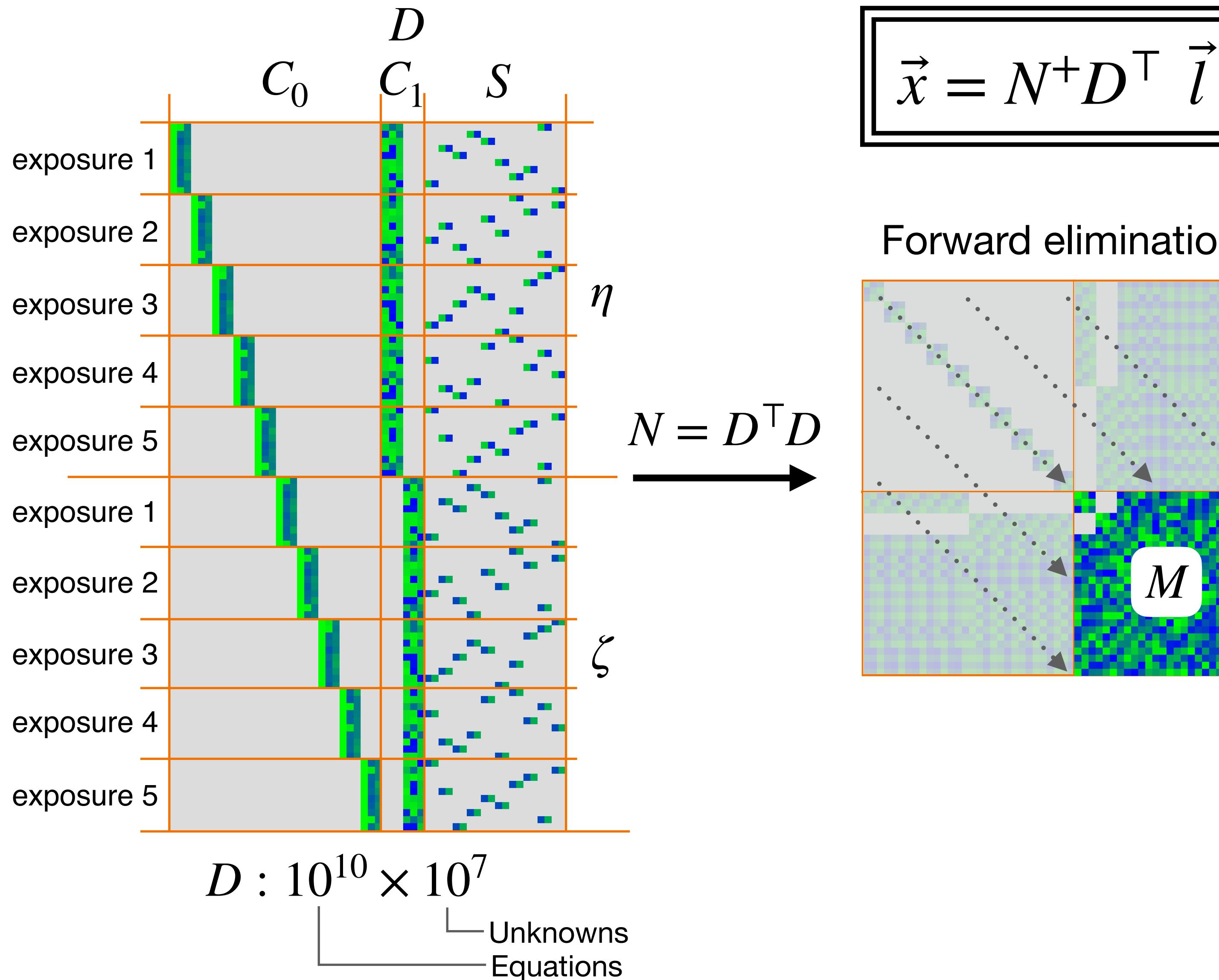
Approach to Solution

4 / 14



Approach to Solution

4 / 14

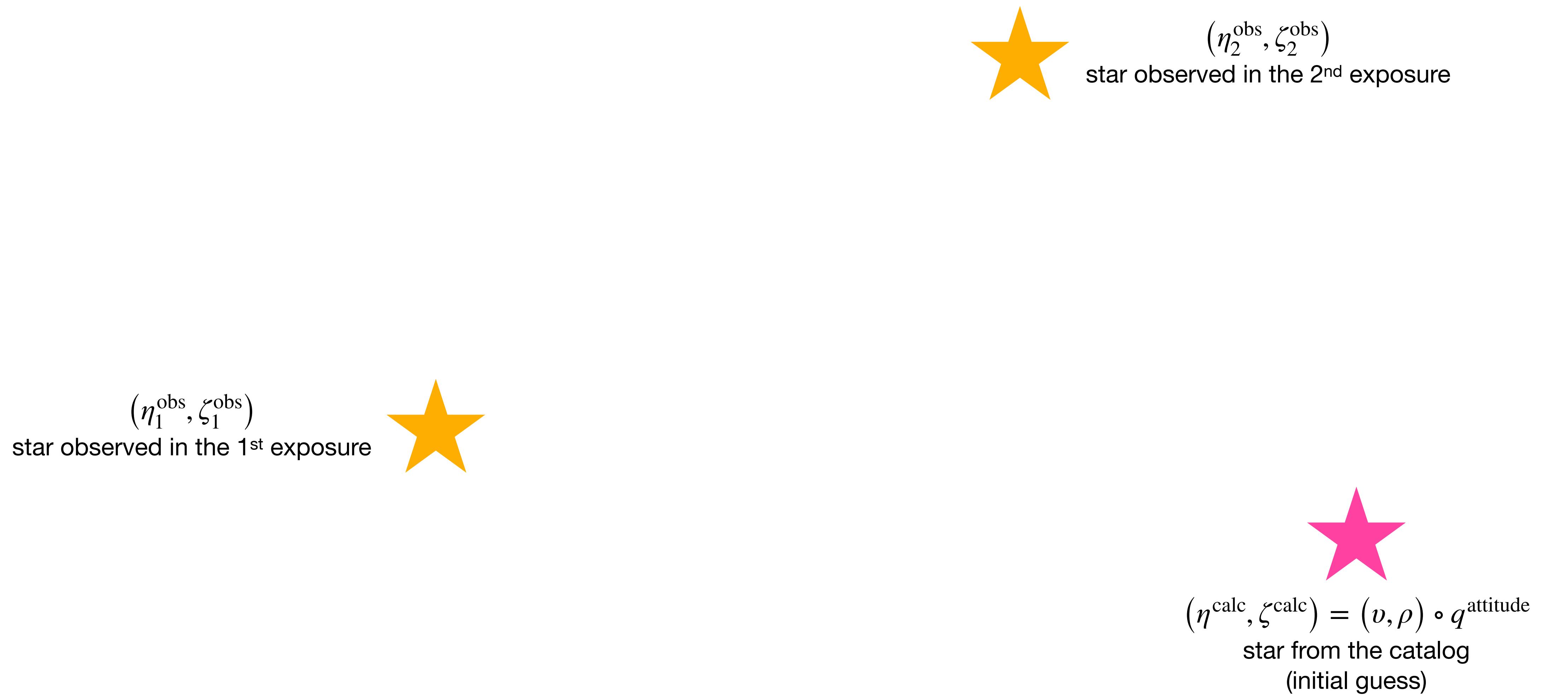


→ Direct solution

- + No convergency issues:
optimal solution is guaranteed
- + Estimation of uncertainties

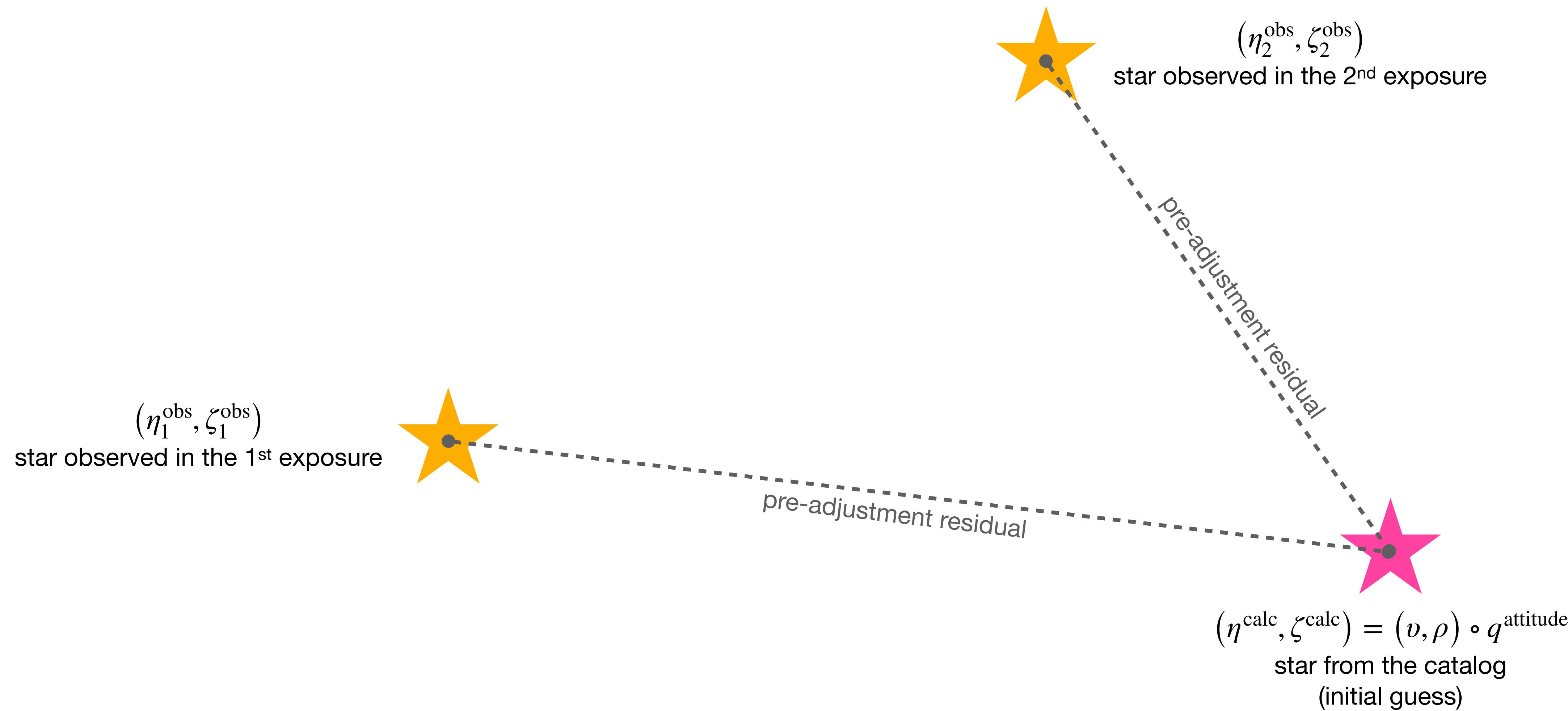
Solution Example

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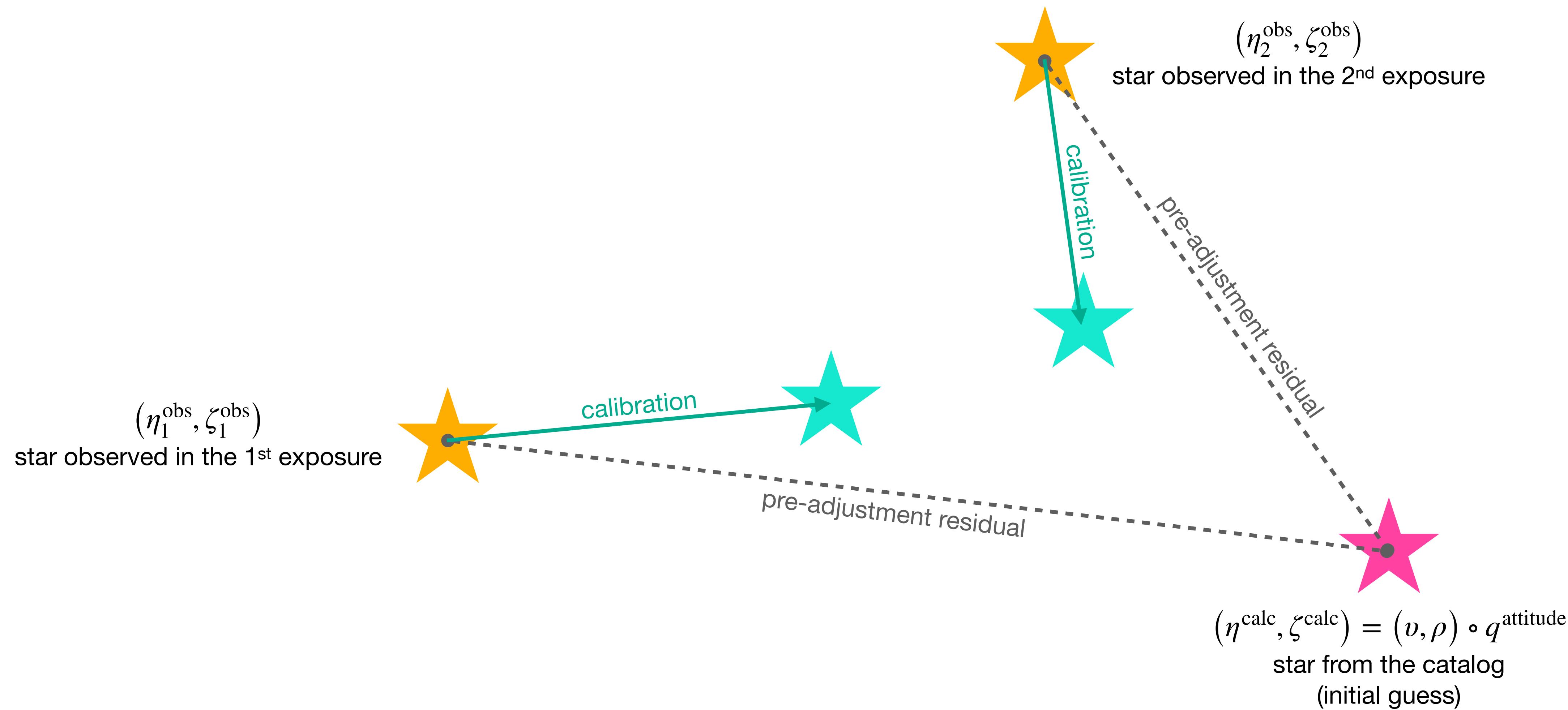
Solution Example

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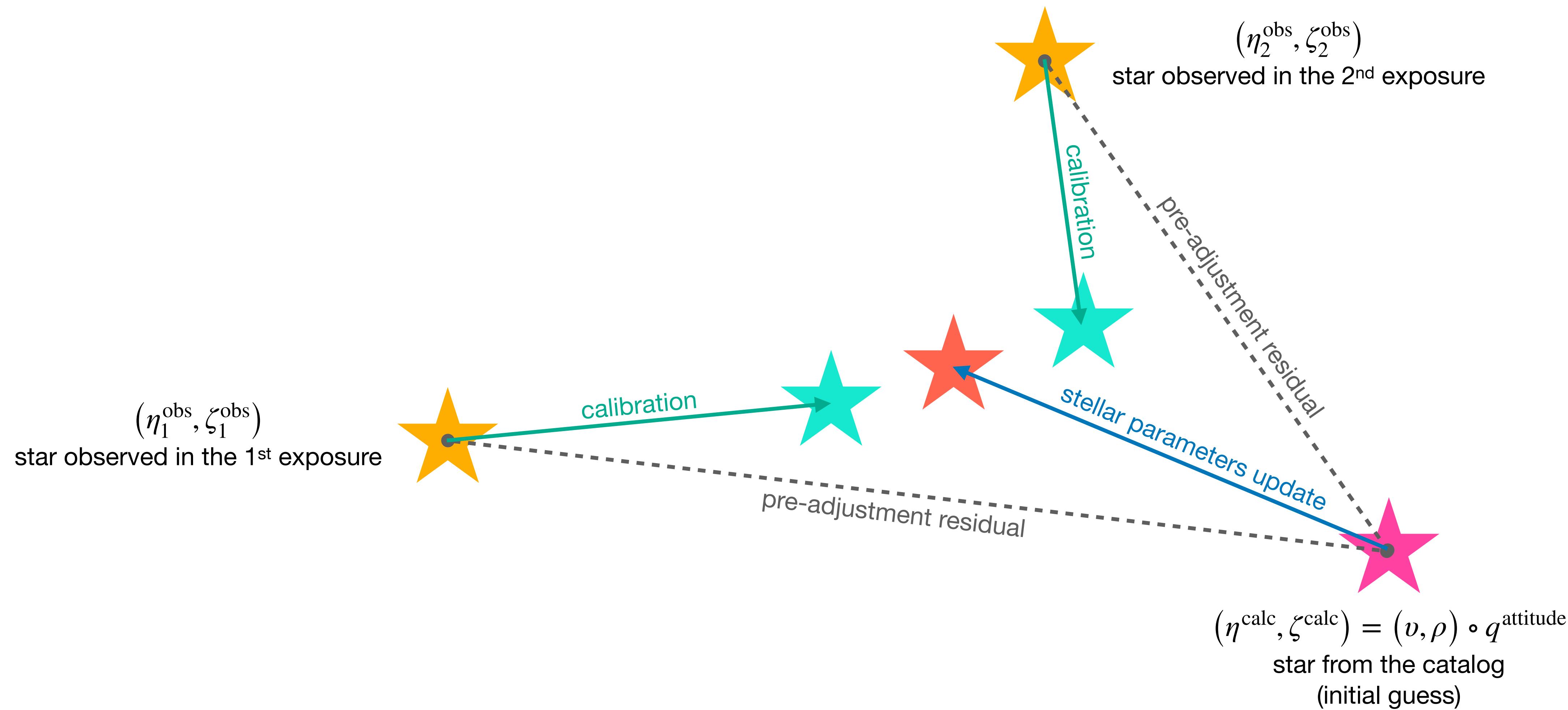
Solution Example

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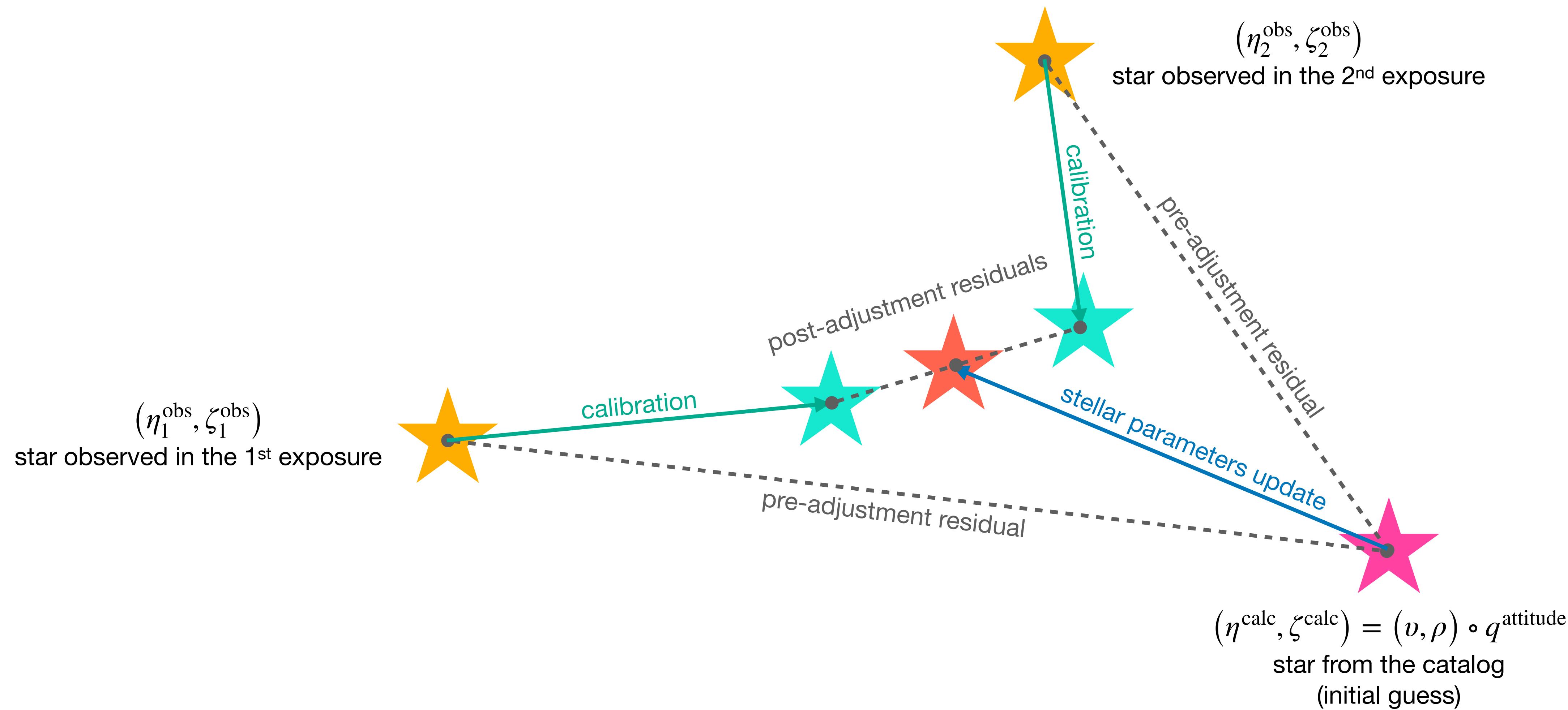
Solution Example

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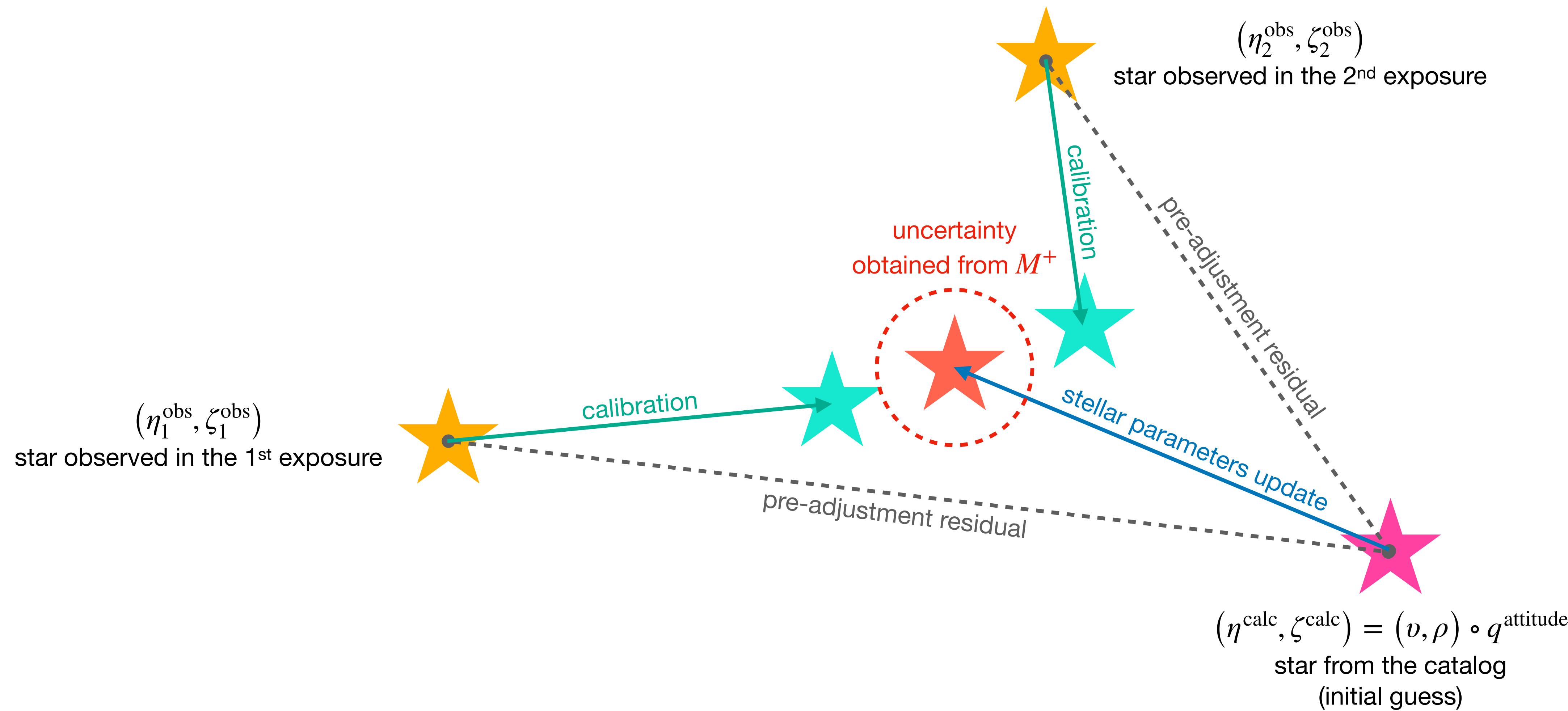
Solution Example

5 / 14



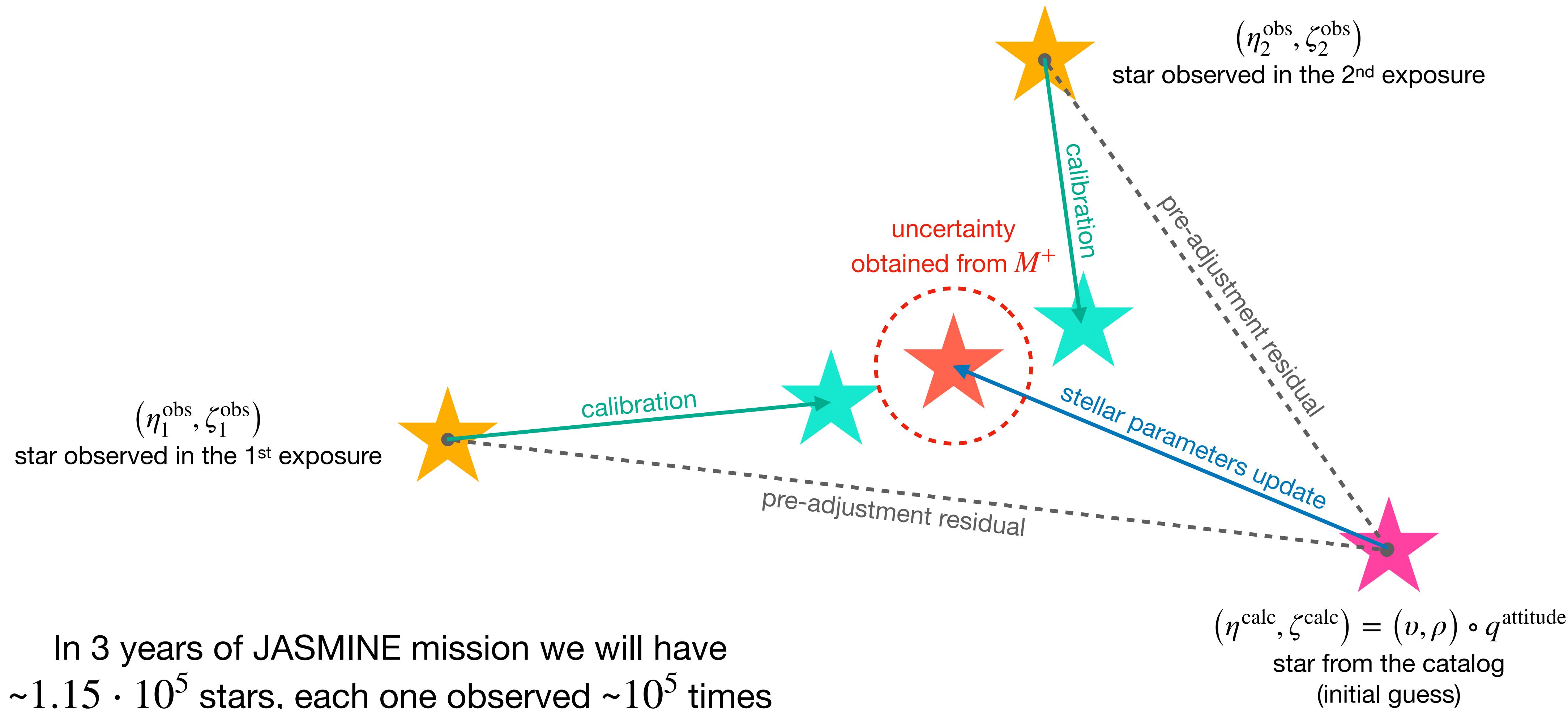
Solution Example

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Solution Example

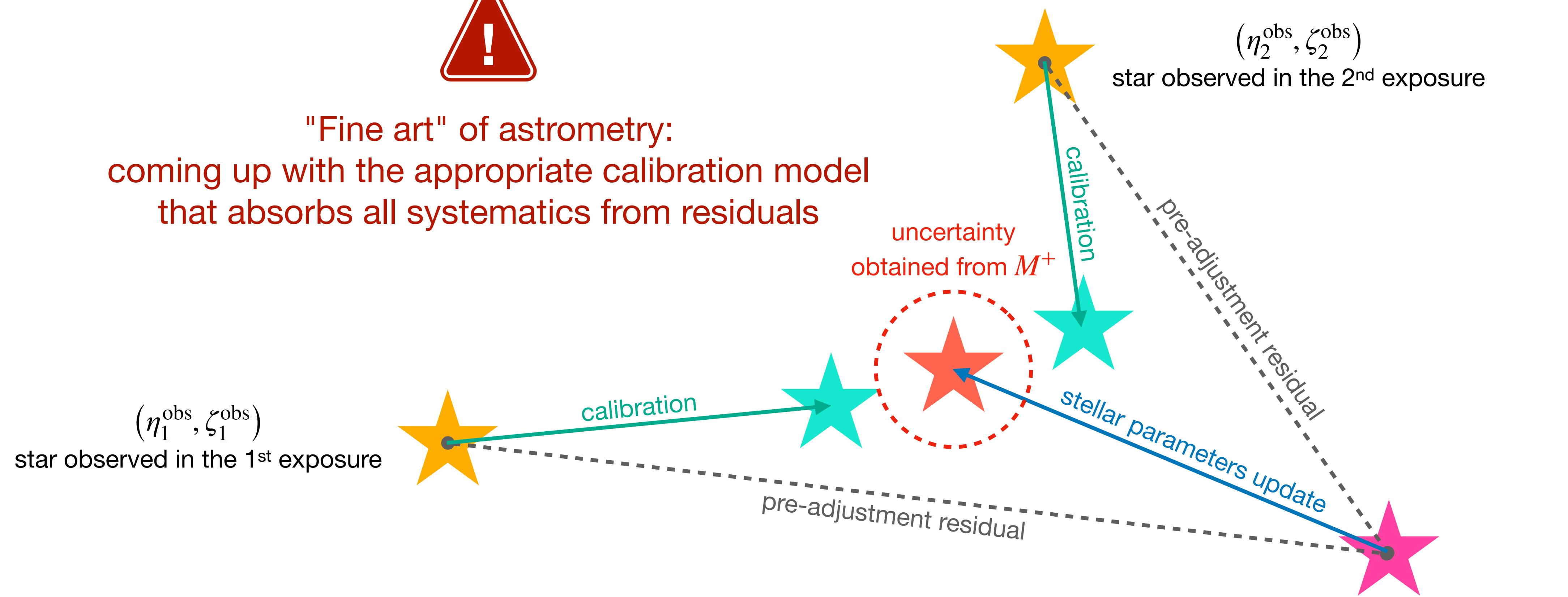
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Solution Example



"Fine art" of astrometry:
coming up with the appropriate calibration model
that absorbs all systematics from residuals



In 3 years of JASMINE mission we will have
 $\sim 1.15 \cdot 10^5$ stars, each one observed $\sim 10^5$ times

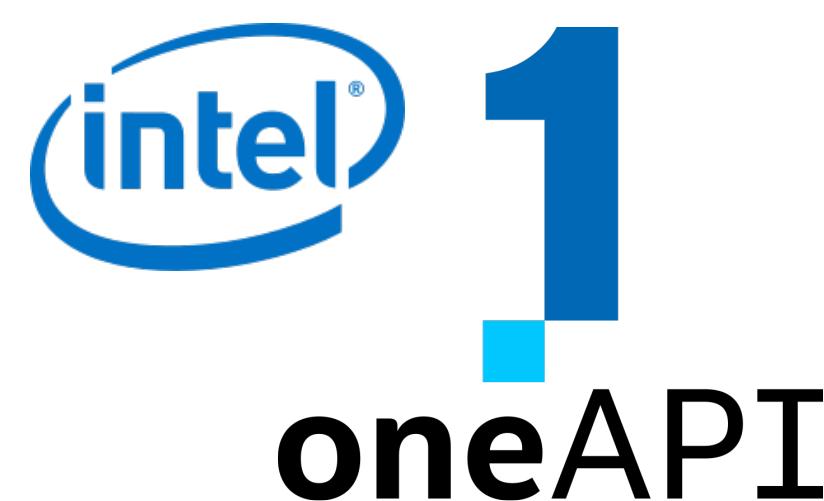
$$(\eta^{\text{calc}}, \zeta^{\text{calc}}) = (v, \rho) \circ q^{\text{attitude}}$$

star from the catalog
(initial guess)

AJAS – ARI JASMINE Astrometric Solution

AJAS Pipeline

Cluster-oriented, multi-process, and multi-threaded



MPI OpenMP MKL

ICX



L A P A C K
L -A P -A C -K
L A P A -C -K
L -A P -A -C K
L A -P -A C K
L -A -P A C -K

ScaLAPACK

[Blackford et al., 1997]

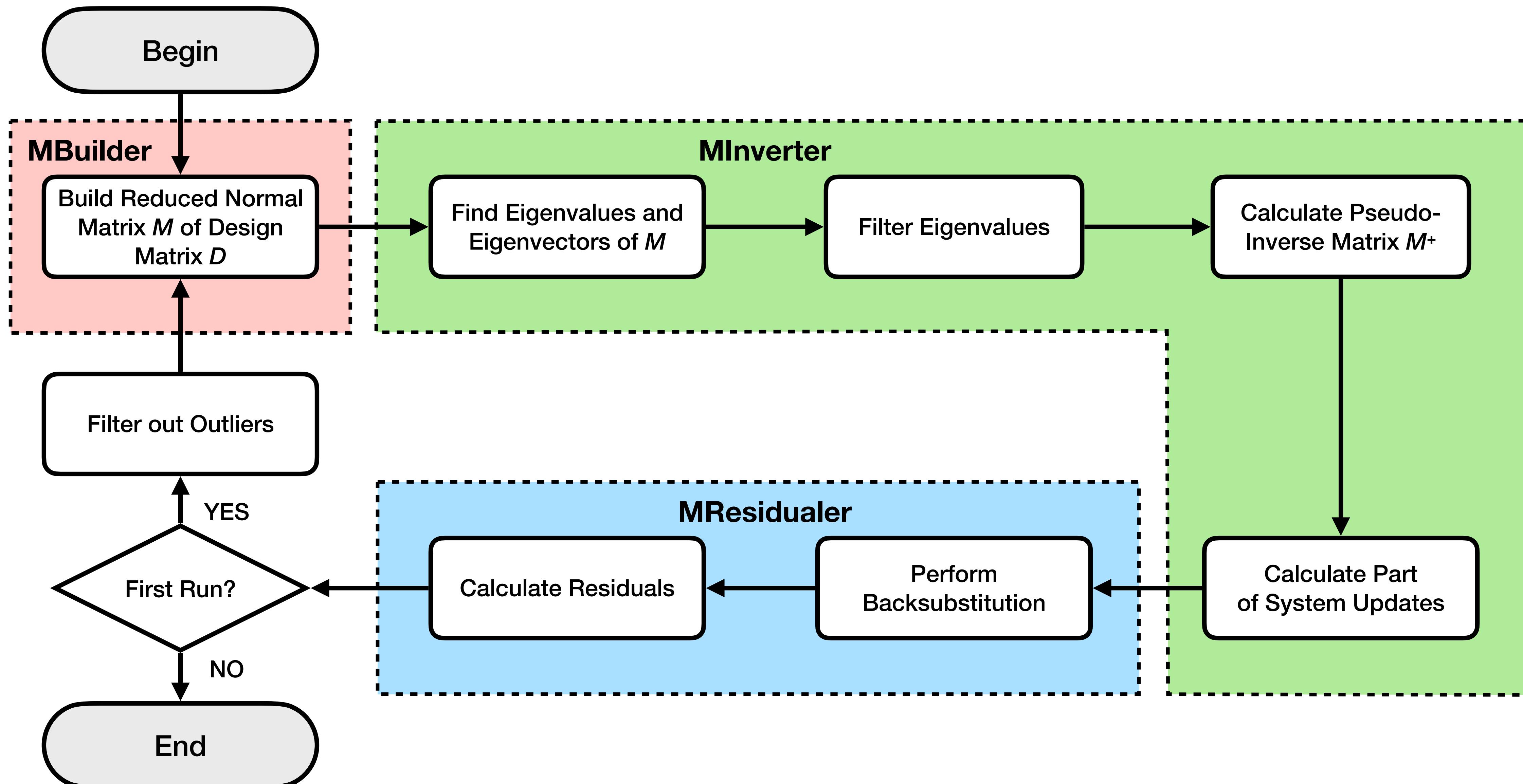


[Sakurai et al., 2019]

AJAS Pipeline Twin

Local-oriented, single-process, and single-threaded





Number of telescope detectors Number of exposures

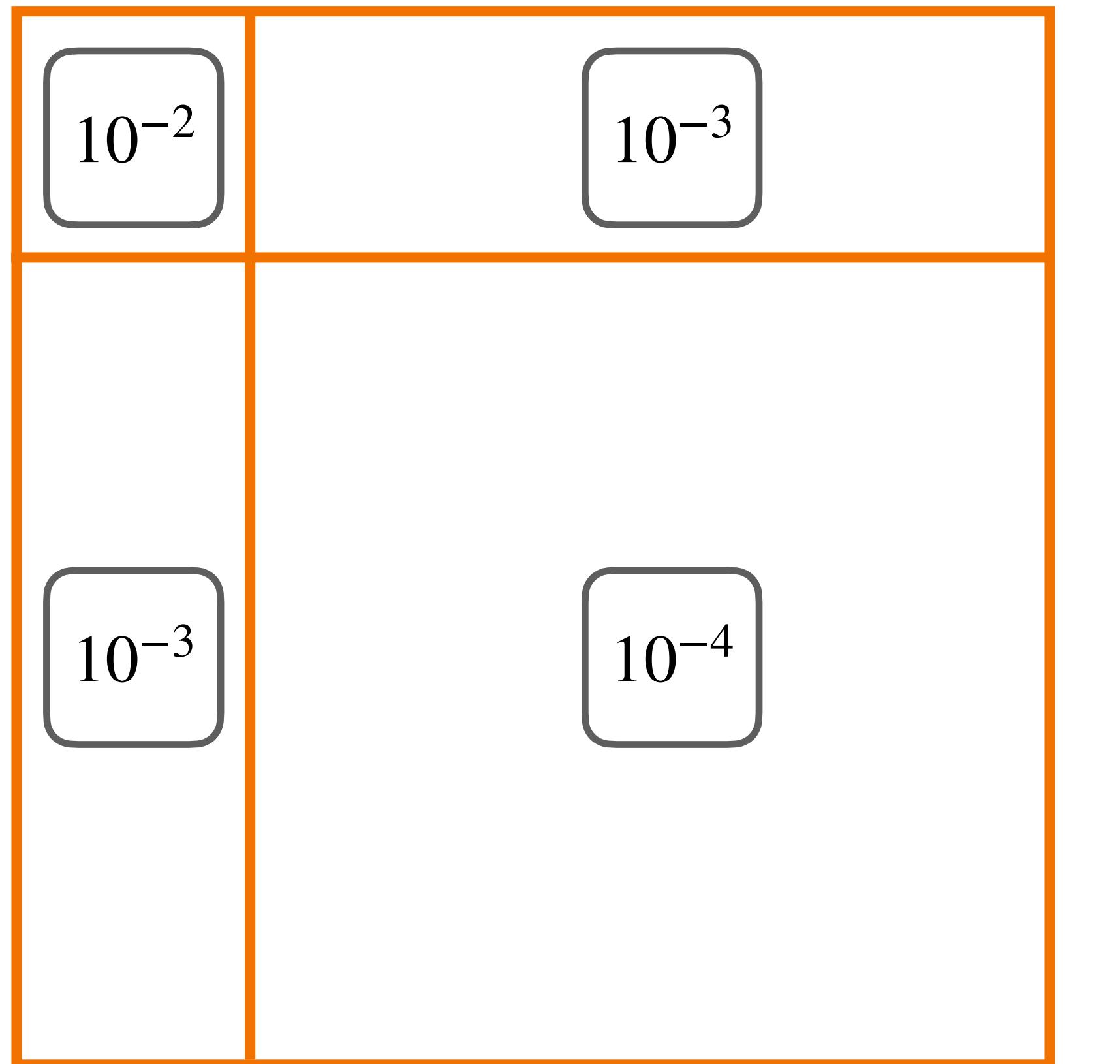
$$M = \sum_{n=1}^N \sum_{\tau=1}^Y \begin{pmatrix} M_{n\tau}^{(1)} & M_{n\tau}^{(2)} \\ M_{n\tau}^{(3)} & M_{n\tau}^{(4)} \end{pmatrix}$$

$$\vec{b} = \sum_{n=1}^N \sum_{\tau=1}^Y \begin{pmatrix} \vec{b}_{n\tau}^{(1)} \\ \vec{b}_{n\tau}^{(2)} \end{pmatrix}$$

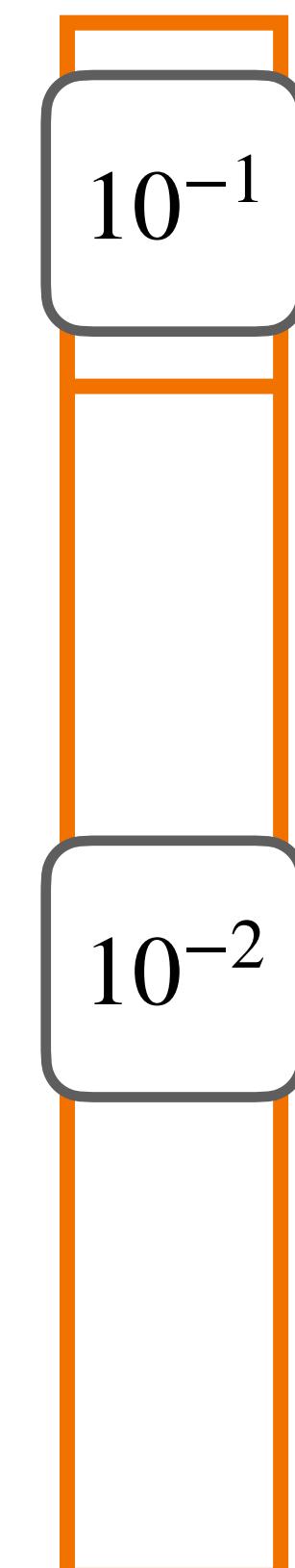
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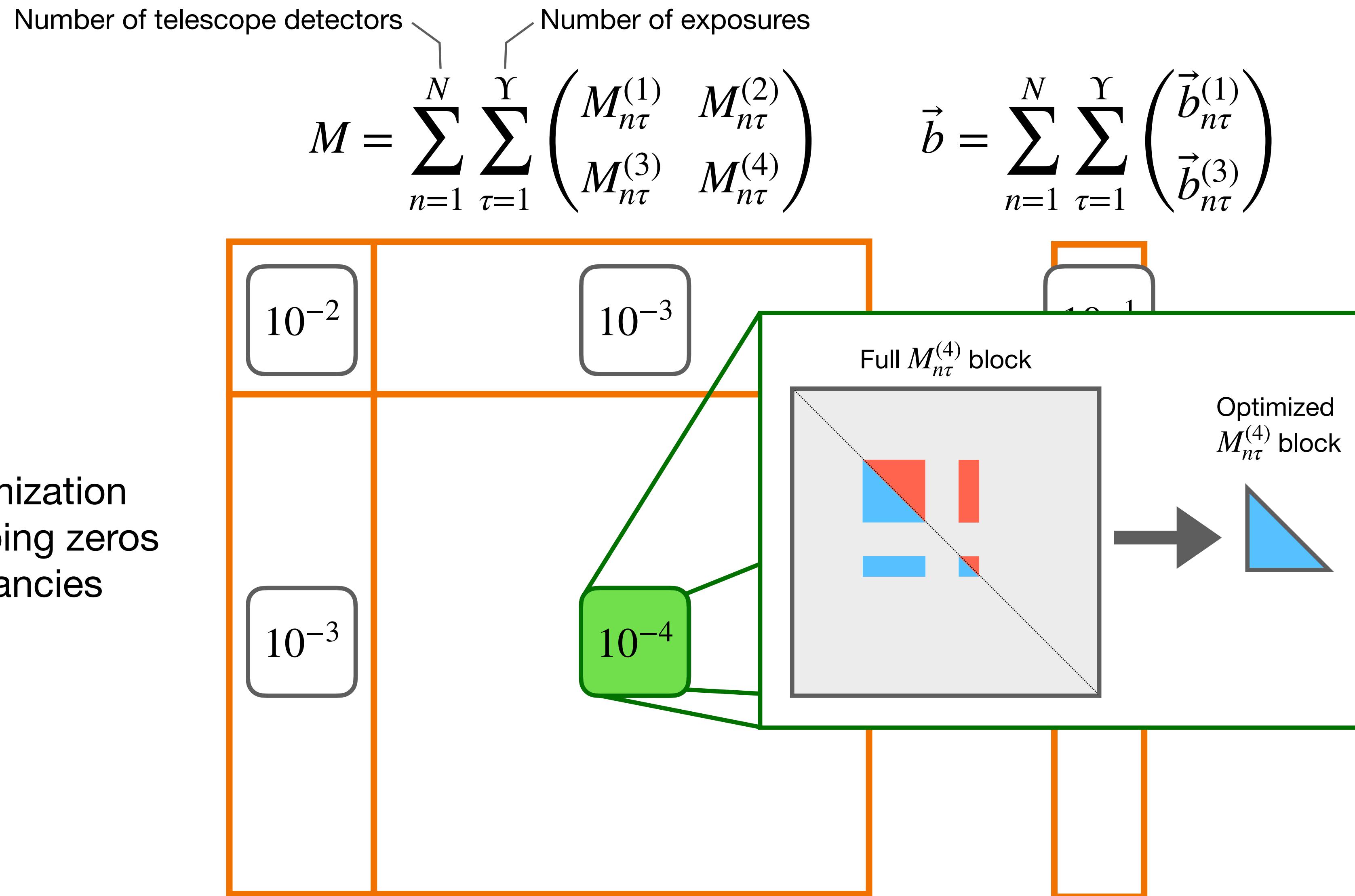
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Storage optimization
based on skipping zeros
and redundancies

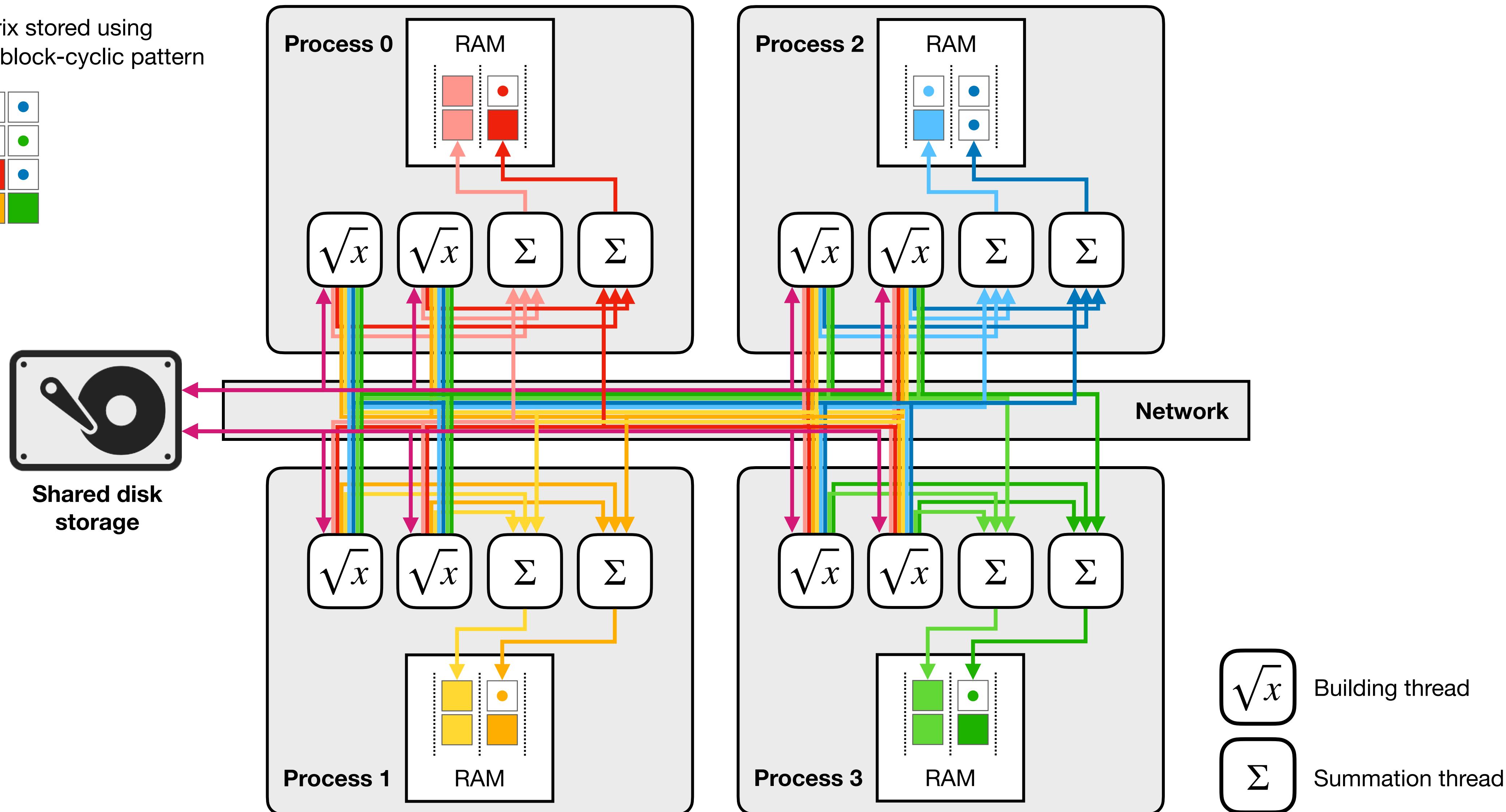
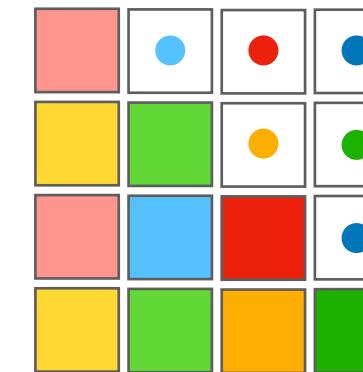




Matrix Building Module: Parallelism

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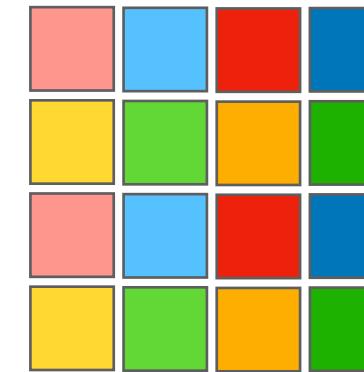
M – symmetric matrix stored using
ScaLAPACK-compatible block-cyclic pattern



Matrix Inversion Module

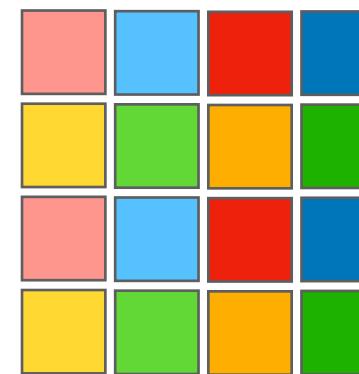
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M – symmetric matrix stored using
ScaLAPACK-compatible block-cyclic pattern



EigenExa
[Sakurai et al., 2019]

Matrix
of eigenvectors



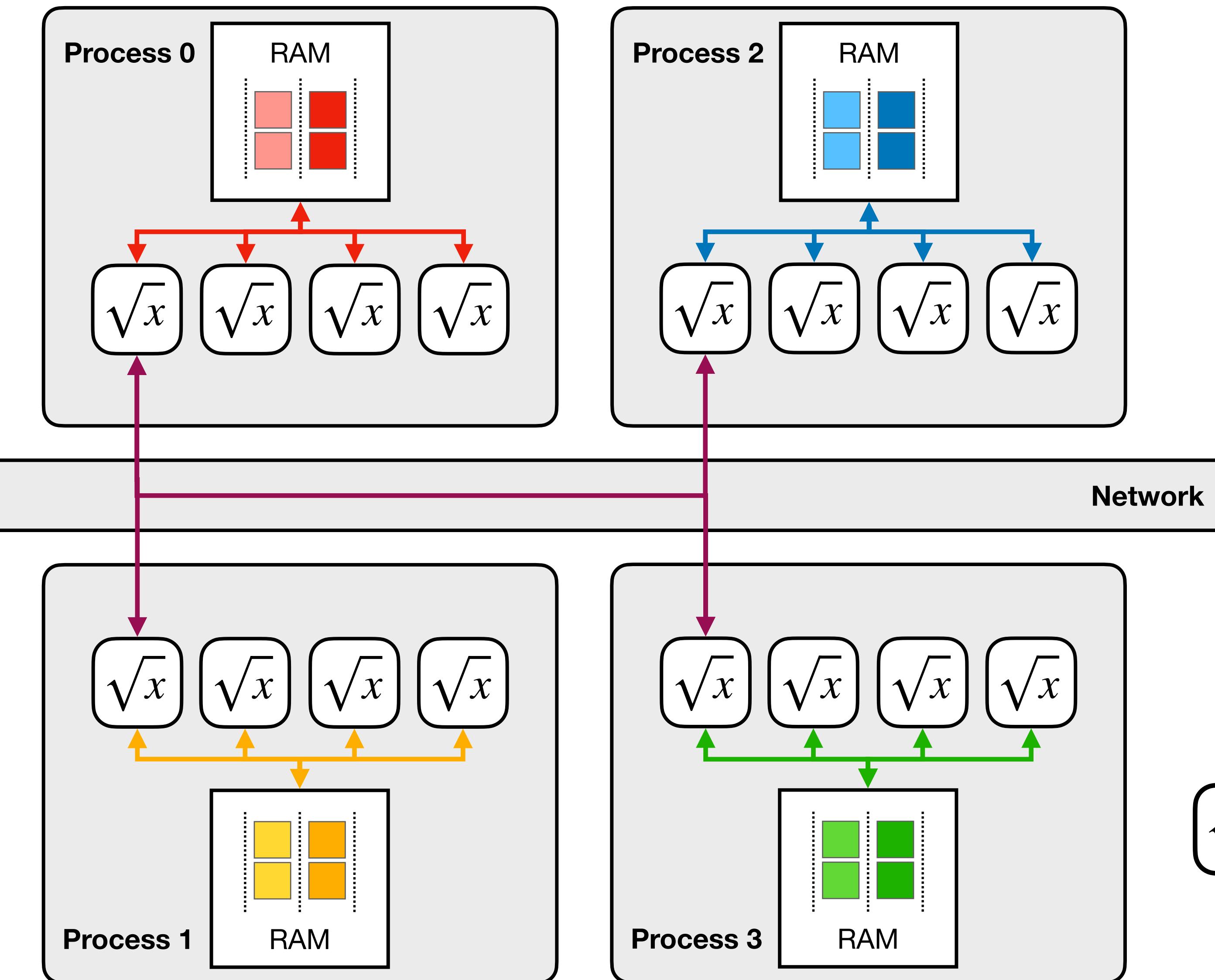
Vector
of eigenvalues



Filtering
of eigenvalues

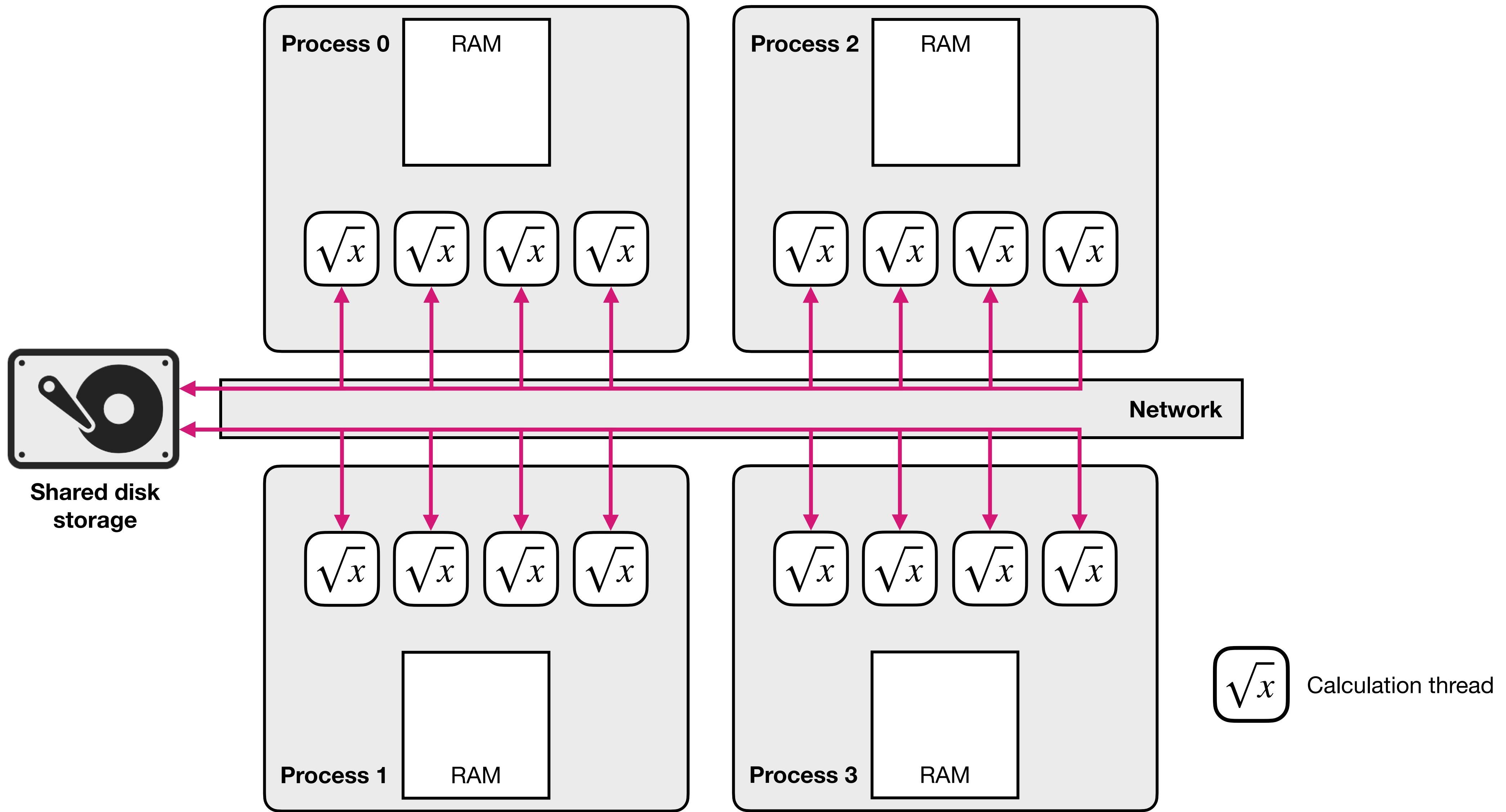
ScalAPACK
[Blackford et al., 1997]

M^+ matrix
and solution



Residuals Calculation Module

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High-Performance Computing
services of the state

Baden-Württemberg, Germany

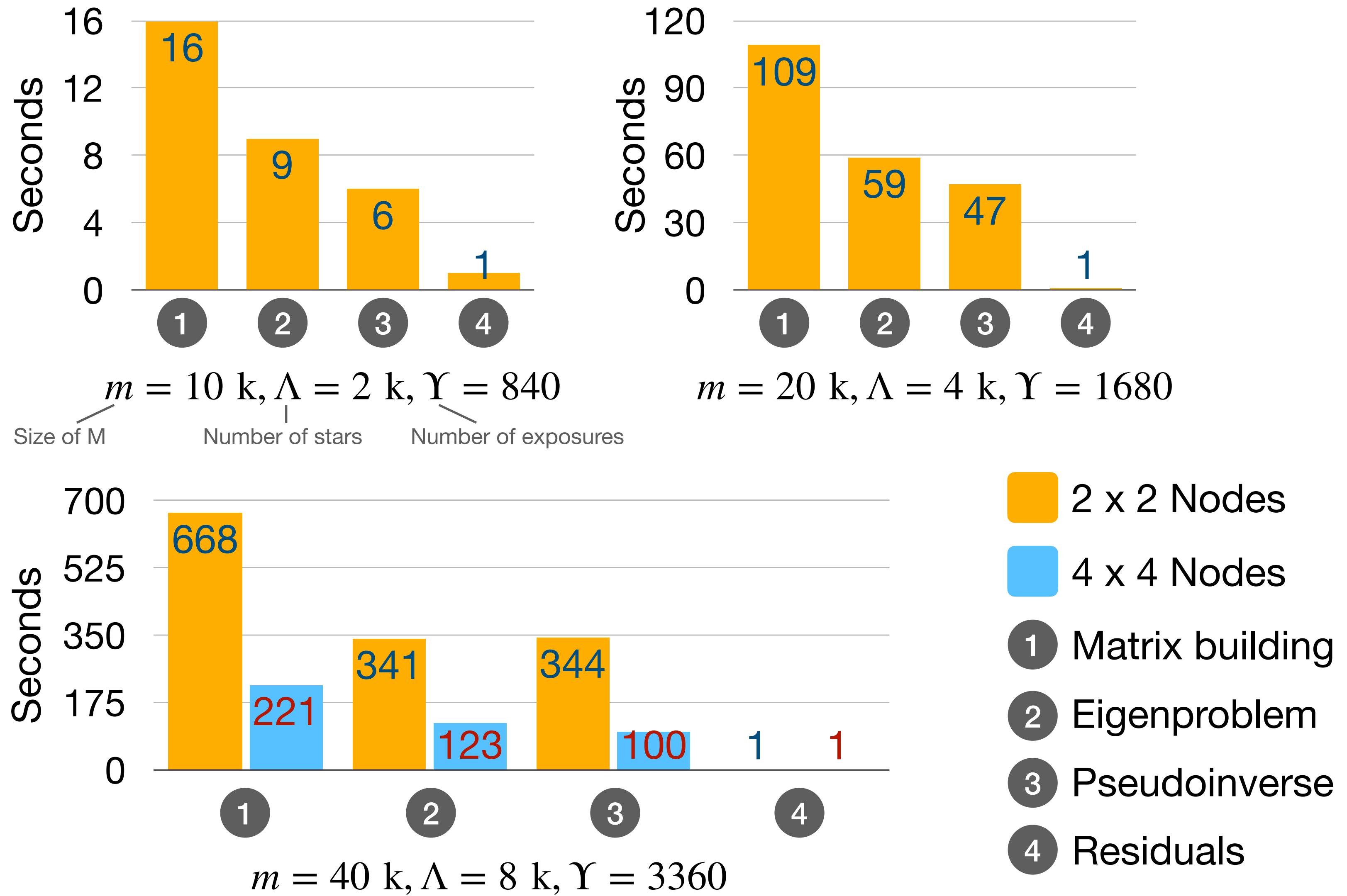
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2.1 GHz, 40 cores

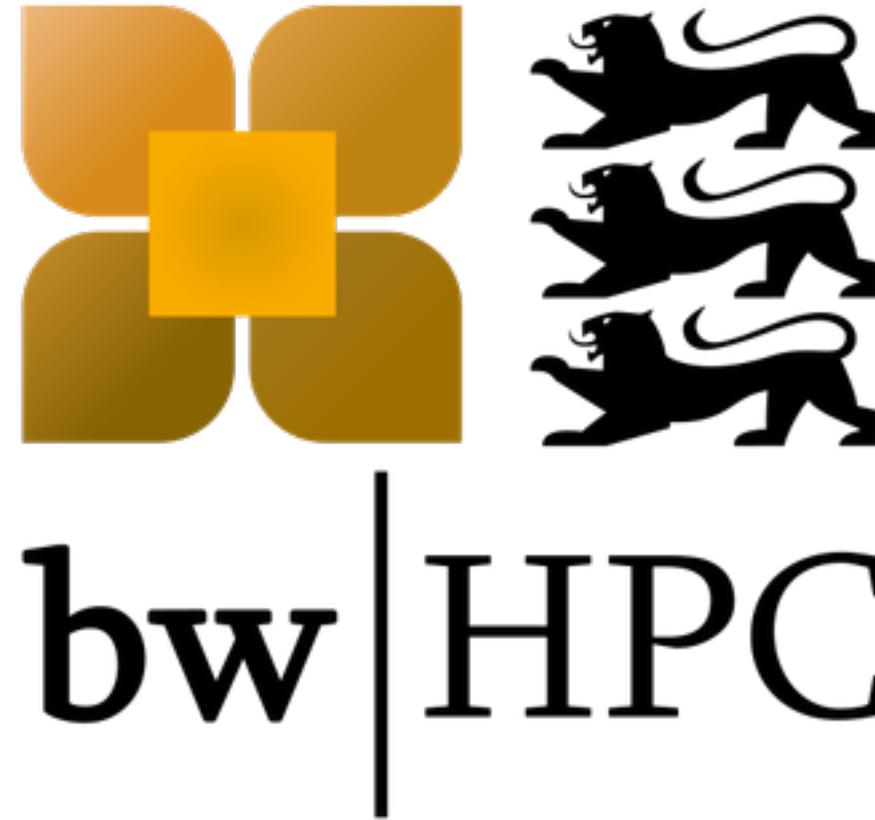
RAM: 90 GB

Nodes: up to 8 x 8

Network: InfiniBand

Shared Disk: 40 Tb





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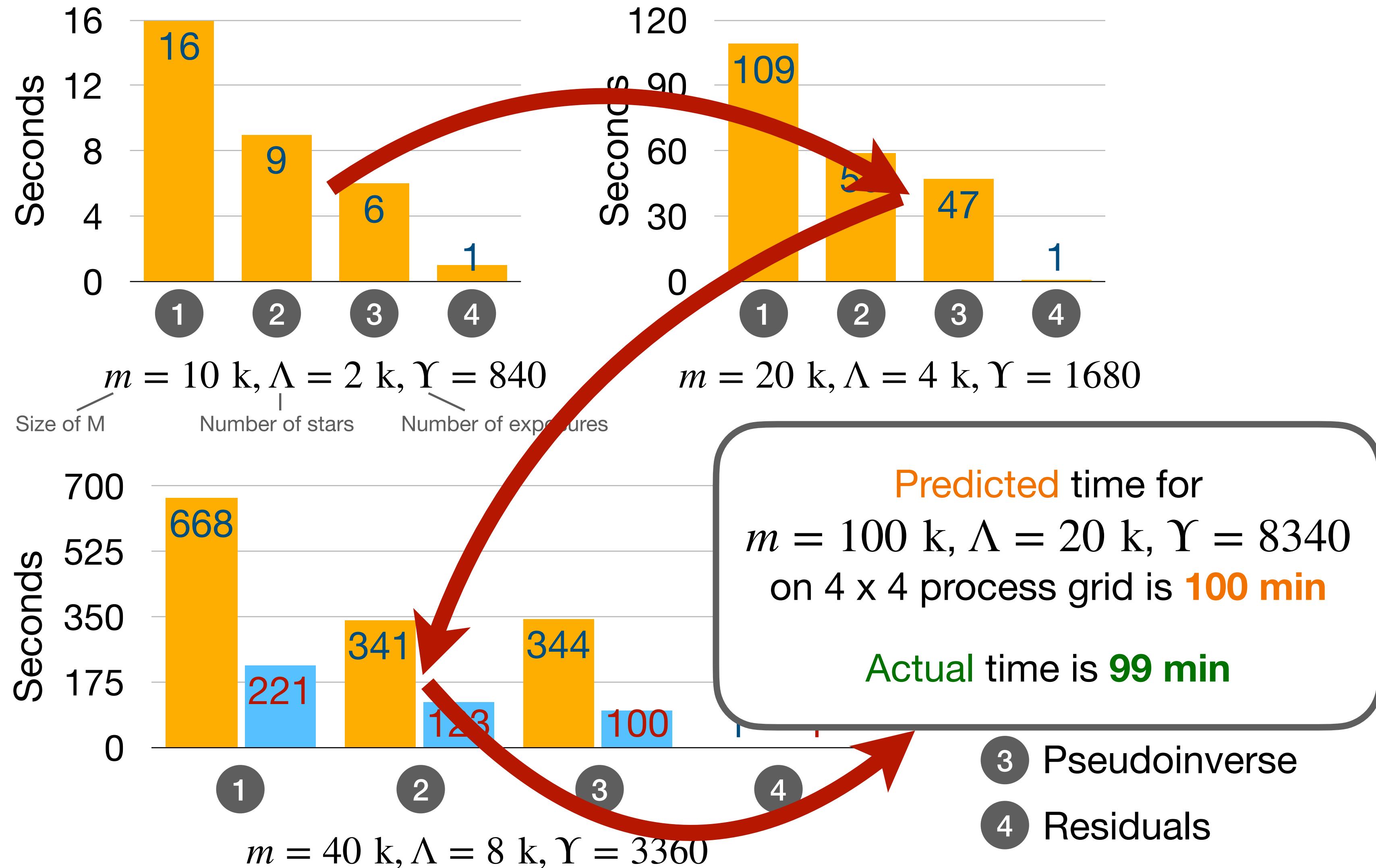
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Achieved:

1. **Validated:** viability of the direct method for solving the JASMINE astrometric problem
2. **Developed:** hybrid parallel software solver for CPU clusters
3. **Tested:** smaller-scale mock science data

Future Work:

1. **To develop:** means of estimating the uncertainties of calibration model and residuals
 - Covariance matrix for C_0 calibration terms and residuals, **computationally tough**
2. **To test:** realistic-size astrometric problems
3. **To optimize:** communication and data access bottlenecks
4. **To research:** data mining on residuals – extracting systematics and moving it to calibration, so the residuals become random



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Thank you for attention!

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