

# Preparation for Gaia DR4: simulations of epoch astrometry for non-single stars

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Katia Sivkova

Advisors: Pierre Kervella & Alexandre Gallet



Observatoire  
de Paris

| PSL 

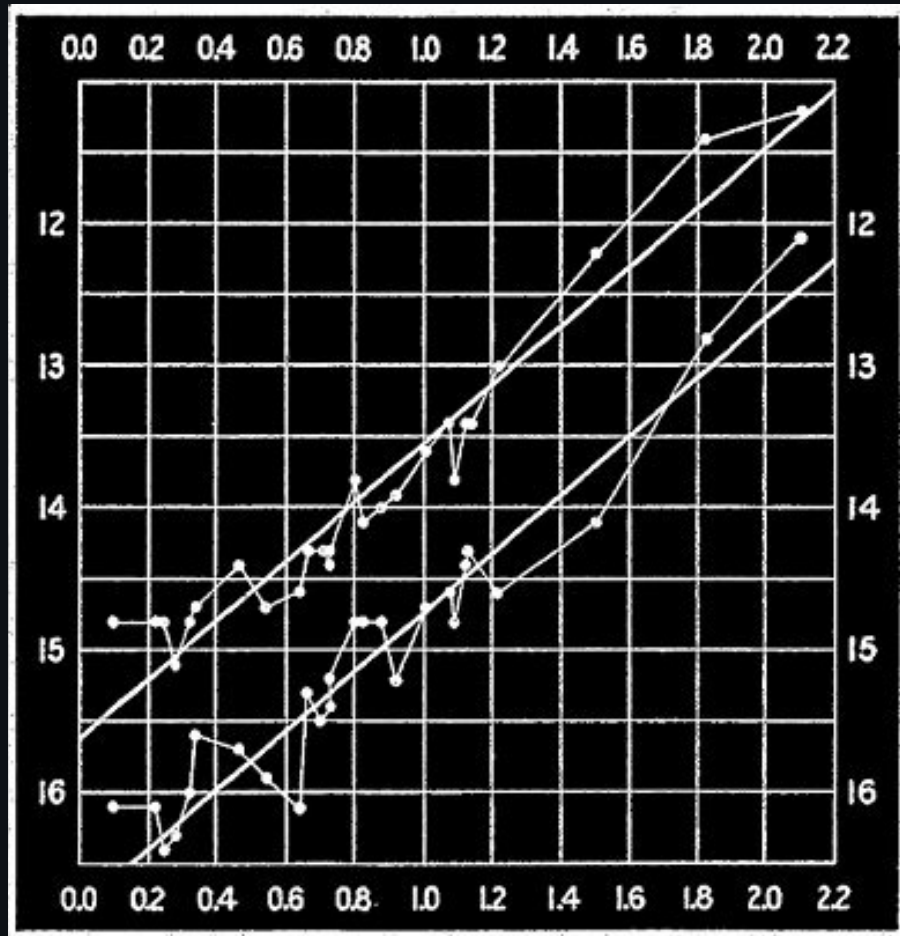


# My focus

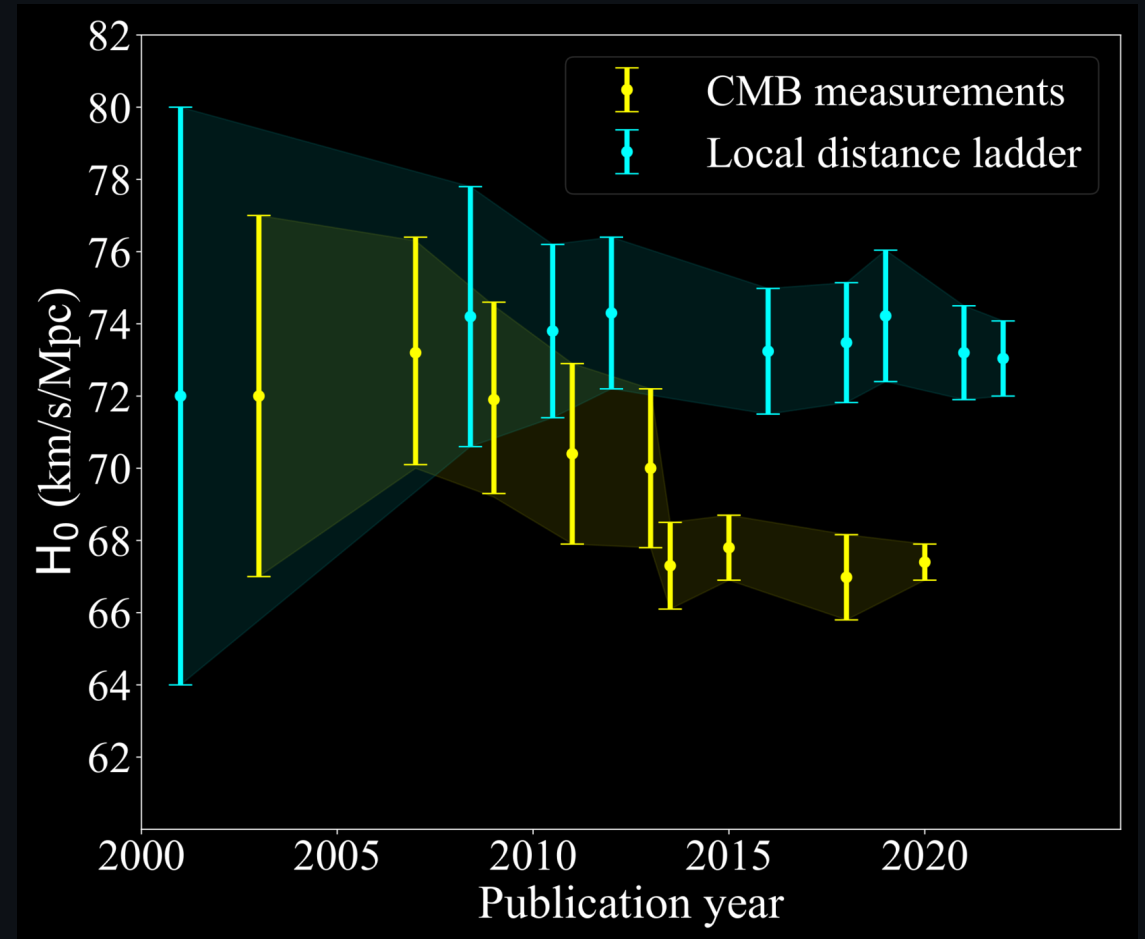
Accurate distances of binary  
Cepheids with Gaia epoch  
astrometry and optical  
interferometry



# Cepheid Period-Luminosity relation



Leavitt+ 1912



Perivolaropoulos & Skara 2022

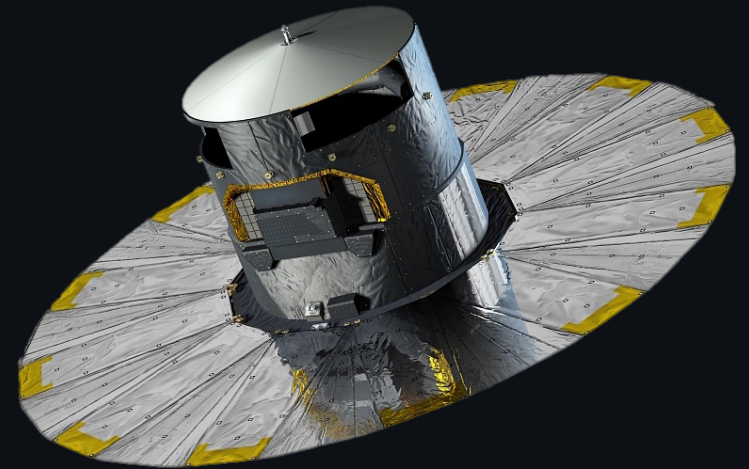
# Gaia parallaxes

## DR3:

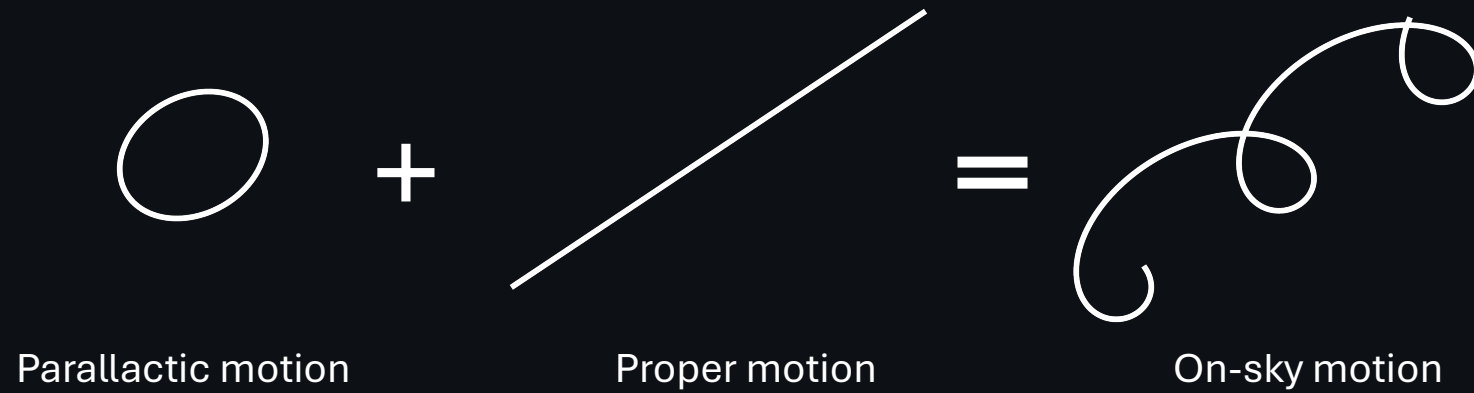
- Full astrometric solution: 1.46 billion sources
- Binary sources: ~800 000 sources
- Variable binaries: 869 sources

Only RX Cam with full orbital solution + 3 with partial solutions

V1334 Cyg:  $4.1\sigma$  deviation compare to interferometry+RV method



# Gaia epoch astrometry

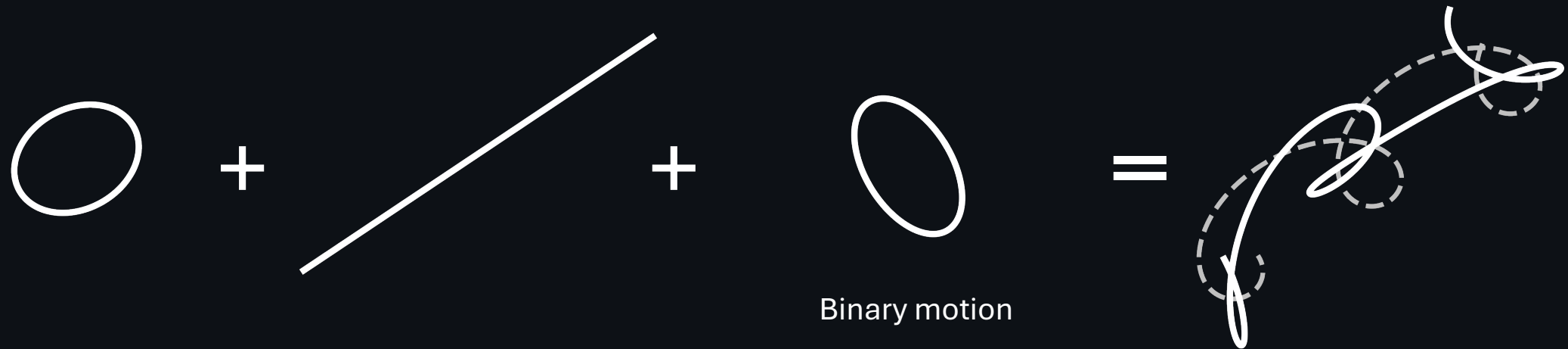


# Gaia epoch astrometry

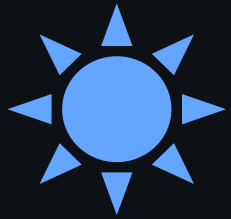


New in DR4

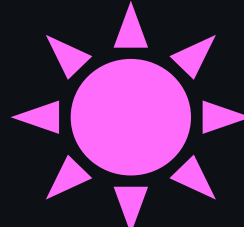
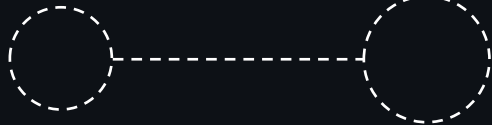
# Gaia: unresolved binaries



# Cepheid case: variable-induced mover (VIM)



Companion



Cepheid

$$x_{phot}(t) = \frac{F_{comp}}{F_{comp} + F_{ceph}(t)} x_{comp} + \frac{F_{ceph}(t)}{F_{comp} + F_{ceph}(t)} x_{ceph}$$



# Python tool: simbinary

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## Introduction

`simbinary` is a Python package to simulate Gaia epoch astrometry for binary systems, with a particular focus on Variable-Induced Mover (VIM) sources.

The package contains two main modules:

- `SimBinary` : simulation of Gaia epoch astrometric data
- `fitGaia` : a shortcut to fit data using [kepmodel](#)

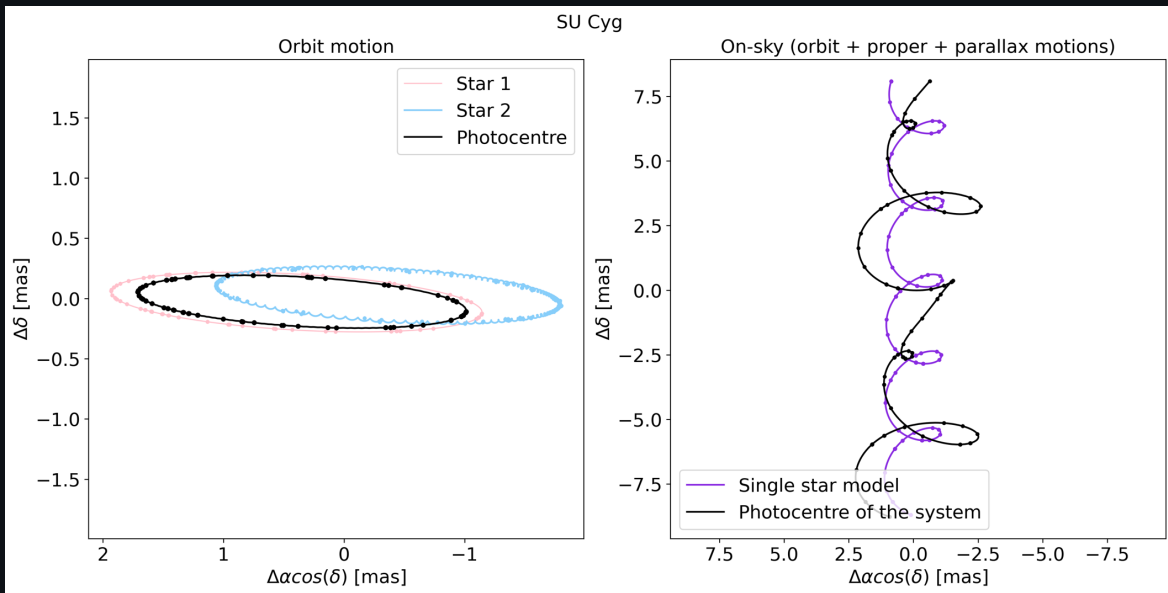
[github.com/katsivkova/simbinary](https://github.com/katsivkova/simbinary)

Sivkova+ in prep.

## Simulation parameters:

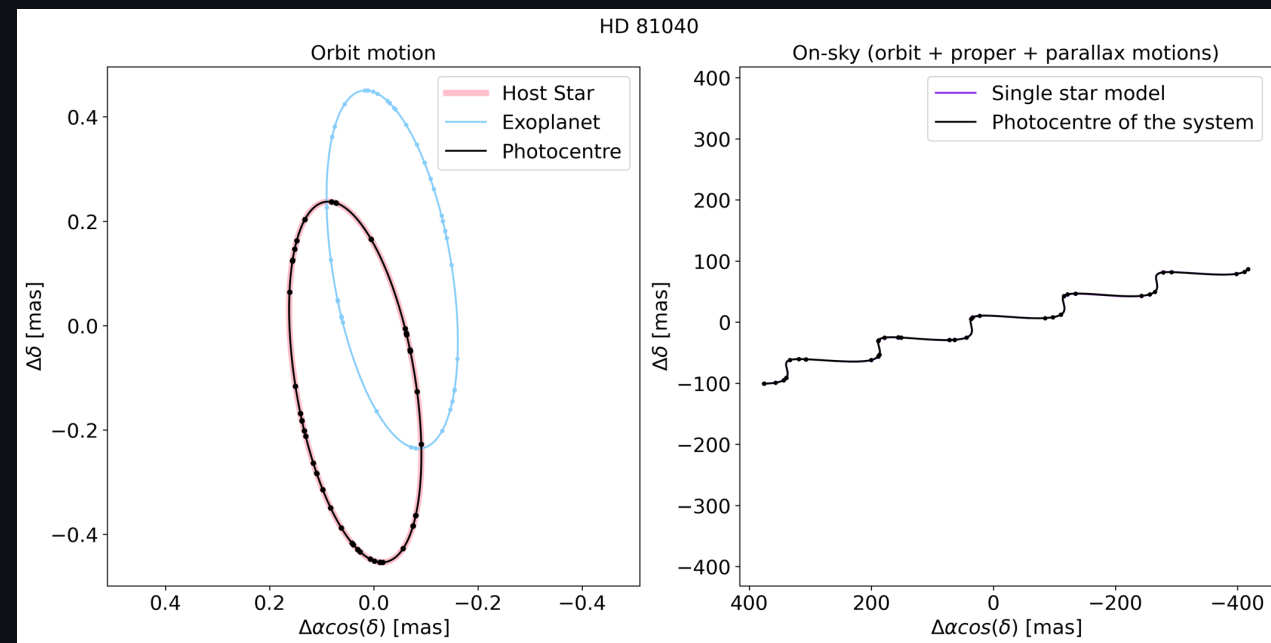
- ★ Orbital ( $P, a, e, i, \Omega, \omega, T_0, q$ )
- ★ Parallax
- ★ Proper motion
- ★ Pulsation ( $P_{\text{puls}}, T_{0,\text{puls}}$  etc)

# Python tool: simbinary



Hierarchical triples

Dark companions (BHs or exoplanets)



# Proper motion effect



# Proper motion effect

Photocentre displacement along  $\delta$ :

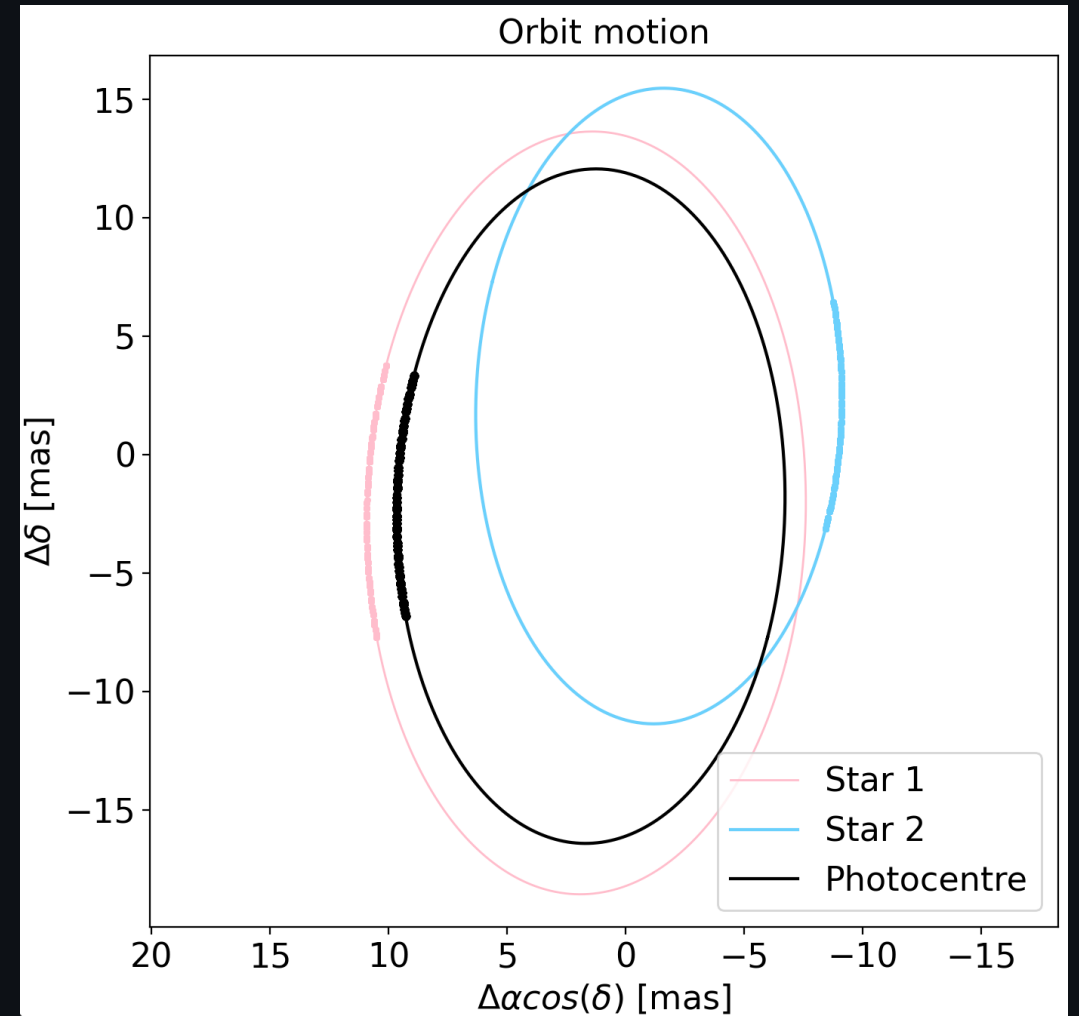
$\sim 10$  mas

or

$\sim 1.8$  mas/year

Proper motion:

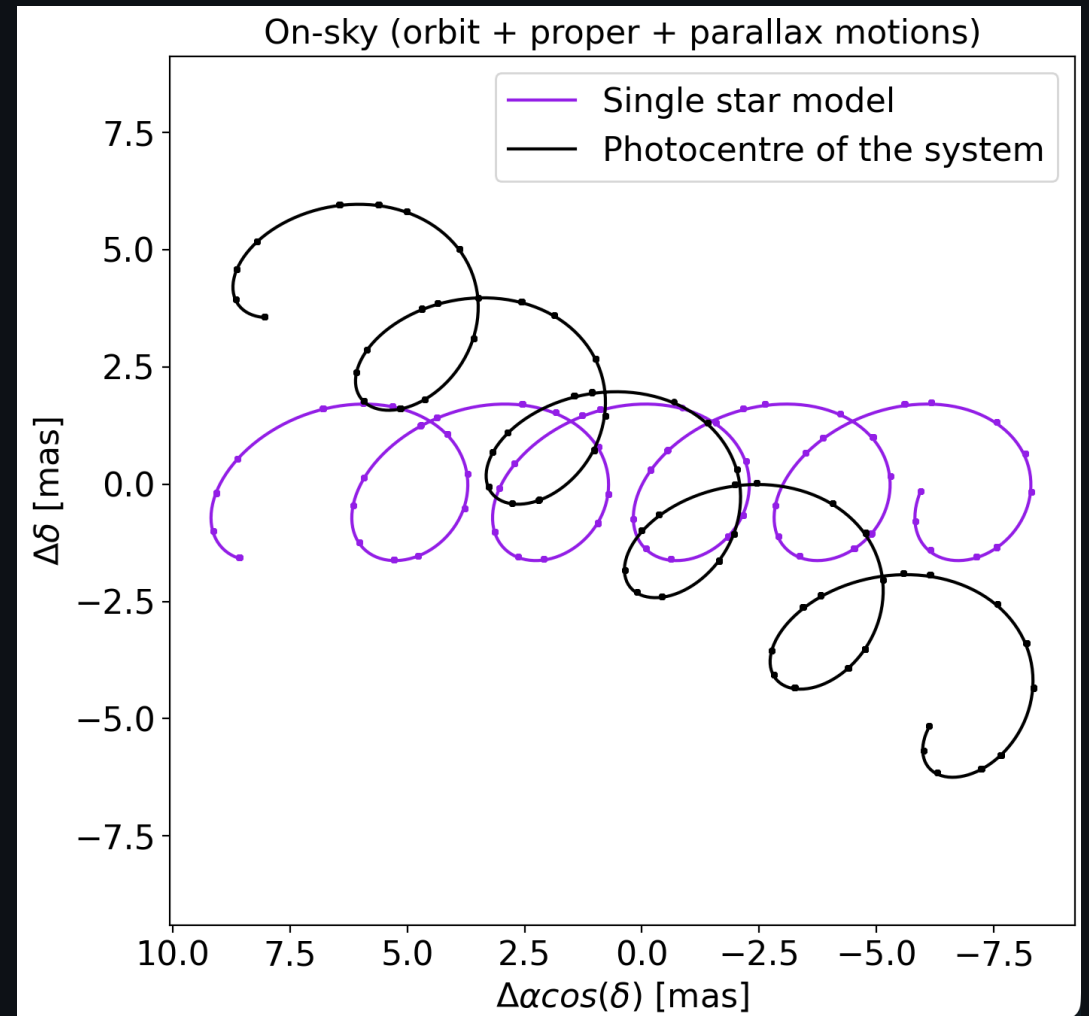
3 and 0 mas/year



# Proper motion effect

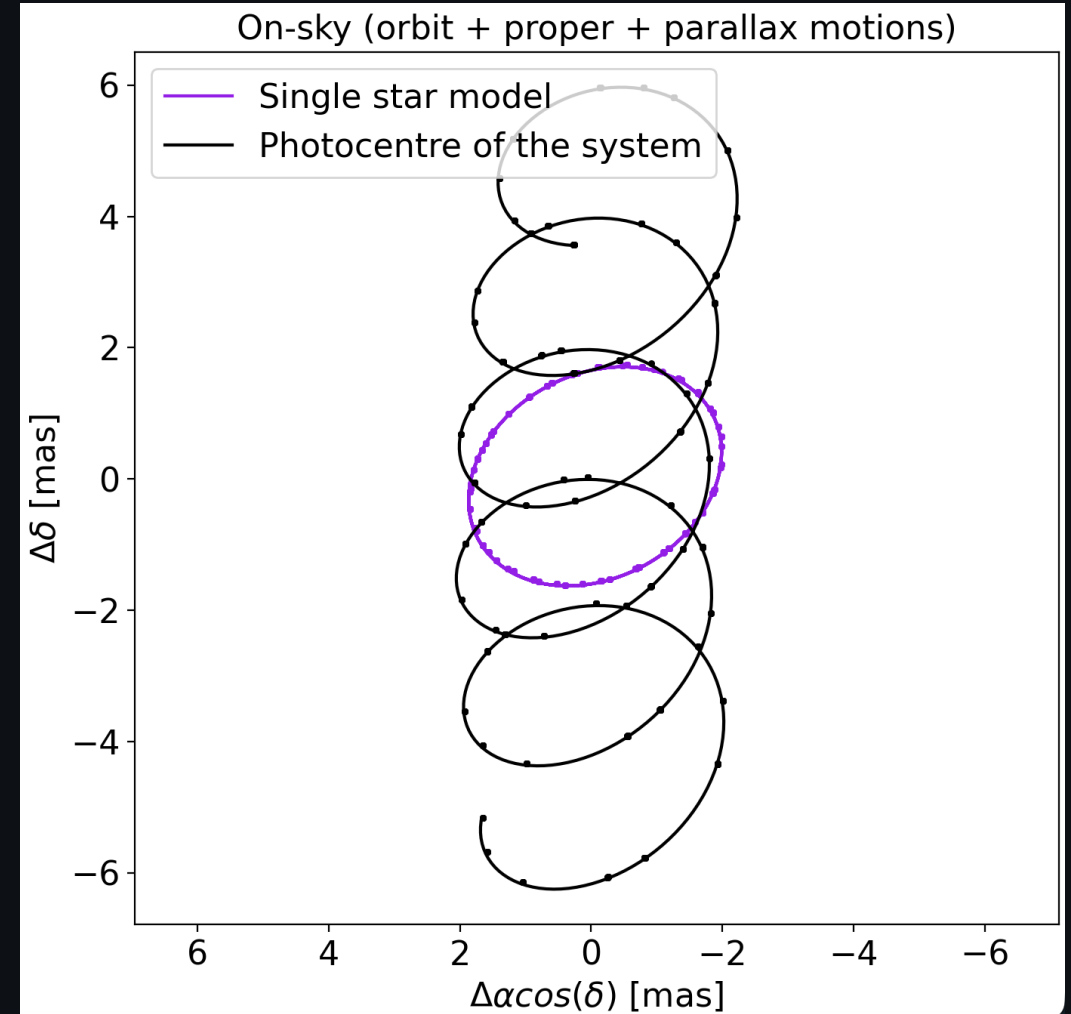
Proper motion:  
3 and 0 mas/year

But Gaia will detect:  
3 and 1.8 mas/year

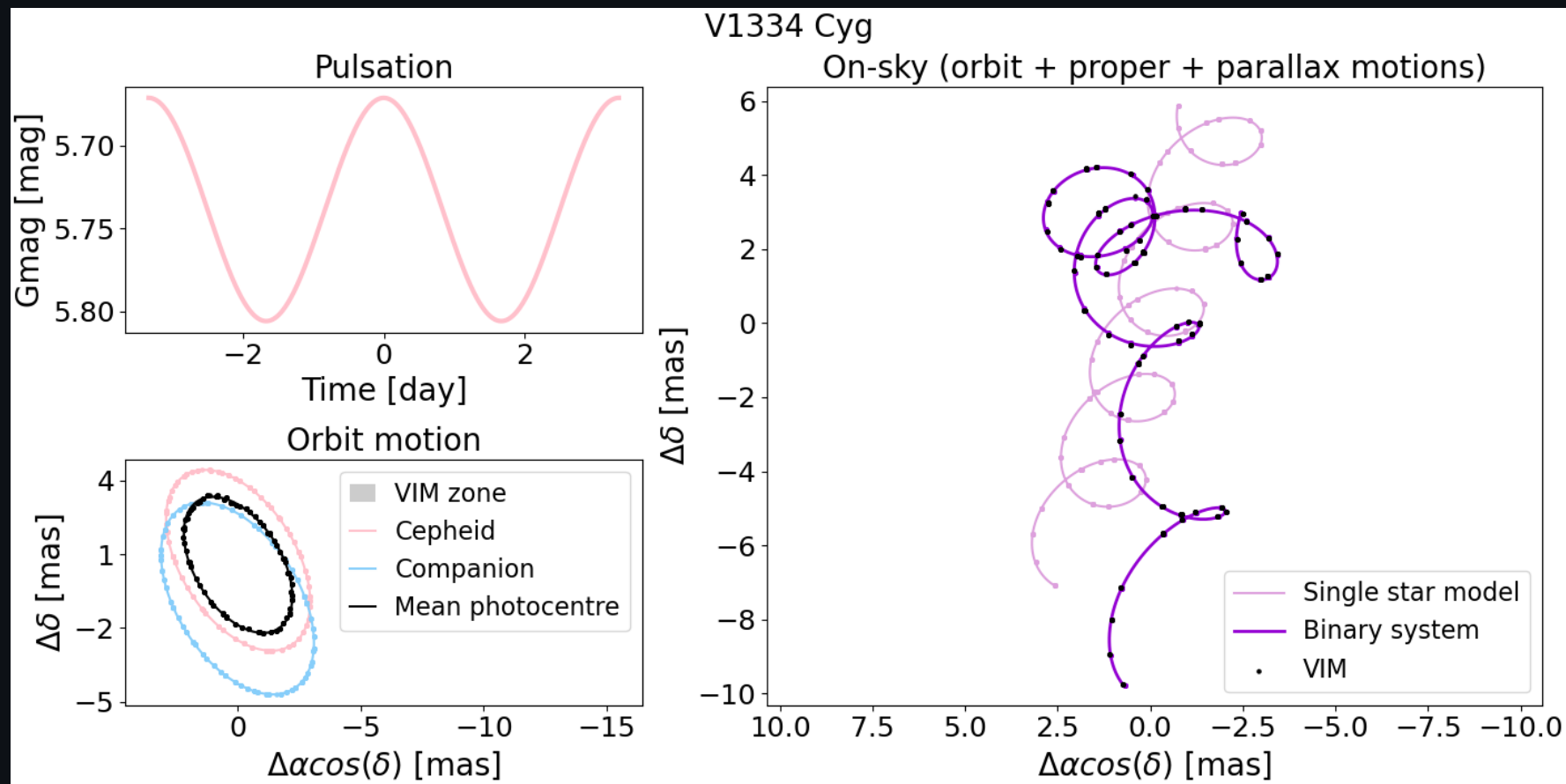


# Proper motion effect

1. Simulate the object with PM = (0,0) at DR3 lifespan
2. Fit SS model
3. Use the resulting PM as correction



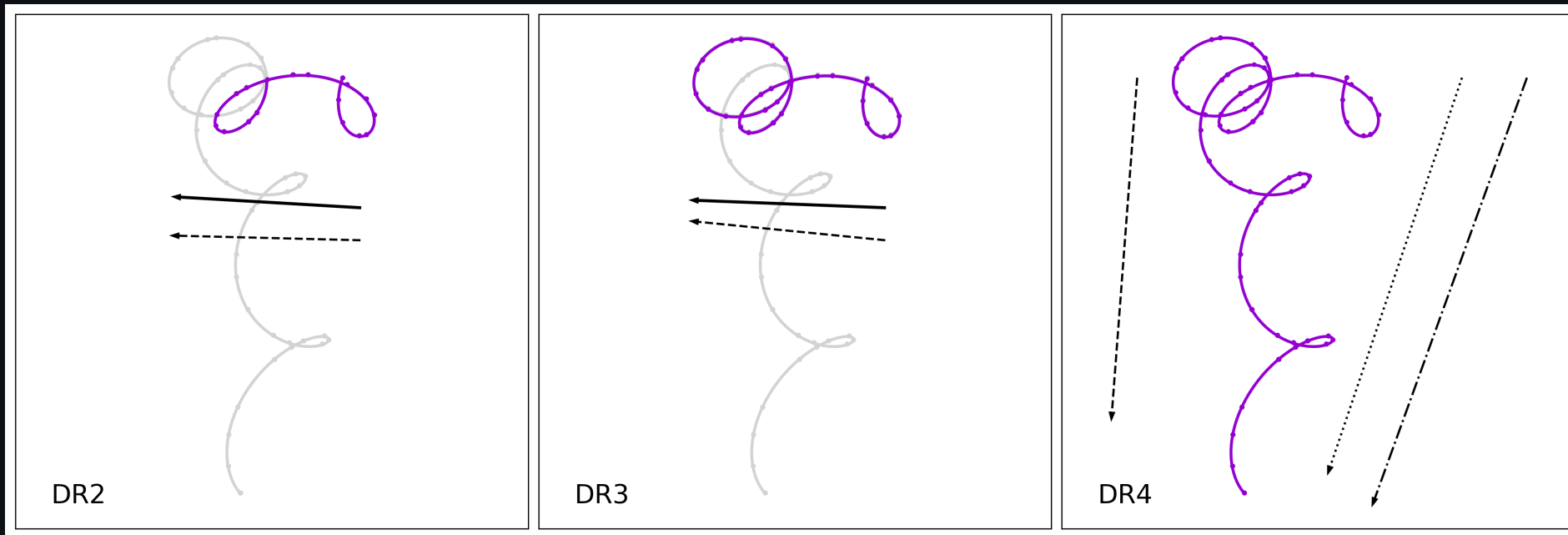
# Binary Cepheid: V1334 Cyg



- $4\sigma$  difference in parallax
- ruwe of 2.8

Orbital parameters from **Gallenne+ 2018**

# Cepheids: V1334 Cyg



← Gaia measurement

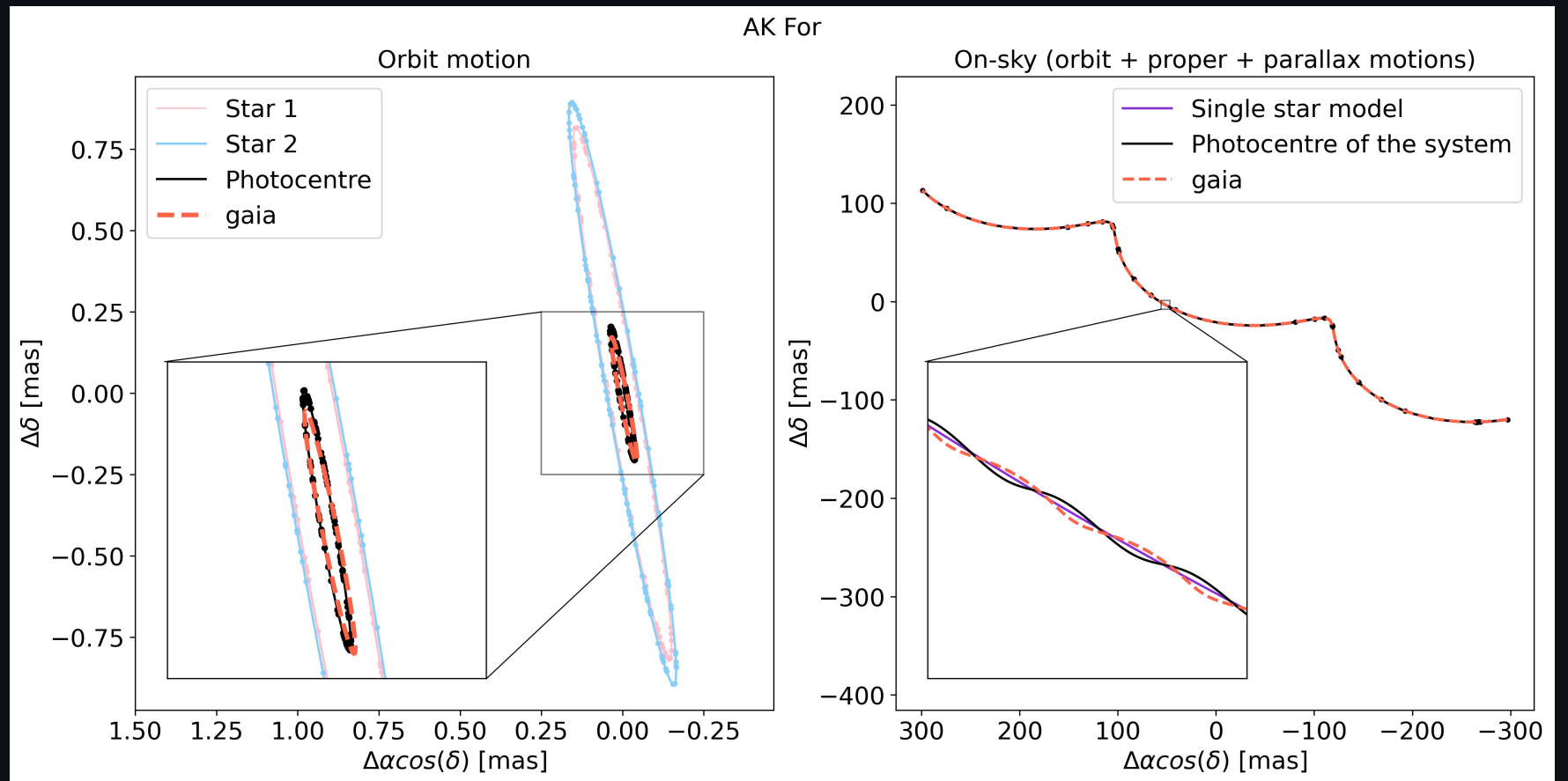
←····· Corrected PM

← - - - - - Our SS fit

← · - · - · - - Gaia-Hipparcos PM from Kervella+ 2022

# Agreement with Gaia: AK For

- Orbital targeted search in Non-Single Star DR3
- Imprecisions in  $e$  and  $\Omega$
- $T_0$  shifted by  $P/2$
- Visual match of photocentric orbit



Orbital parameters from [Gallenne+ 2023](#)

# Thank you for your attention

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## Introduction

`simbinary` is a Python package to simulate Gaia epoch astrometry for binary systems, with a particular focus on Variable-Induced Mover (VIM) sources.

The package contains two main modules:

- `SimBinary` : simulation of Gaia epoch astrometric data
- `fitGaia` : a shortcut to fit data using [kepmodel](#)

## Installation

### Install directly from GitHub

```
pip install git+https://github.com/katsivkova/simbinary
```



### Install in editable mode (for development)

```
git clone https://github.com/katsivkova/simbinary
cd simbinary
pip install -e .
```



[github.com/katsivkova/simbinary](https://github.com/katsivkova/simbinary)

Sivkova+ in prep.

[ekaterina.sivkova@obspm.fr](mailto:ekaterina.sivkova@obspm.fr)



## Gaia orbital parameters

Only photometric orbit

## Interferometry + RV

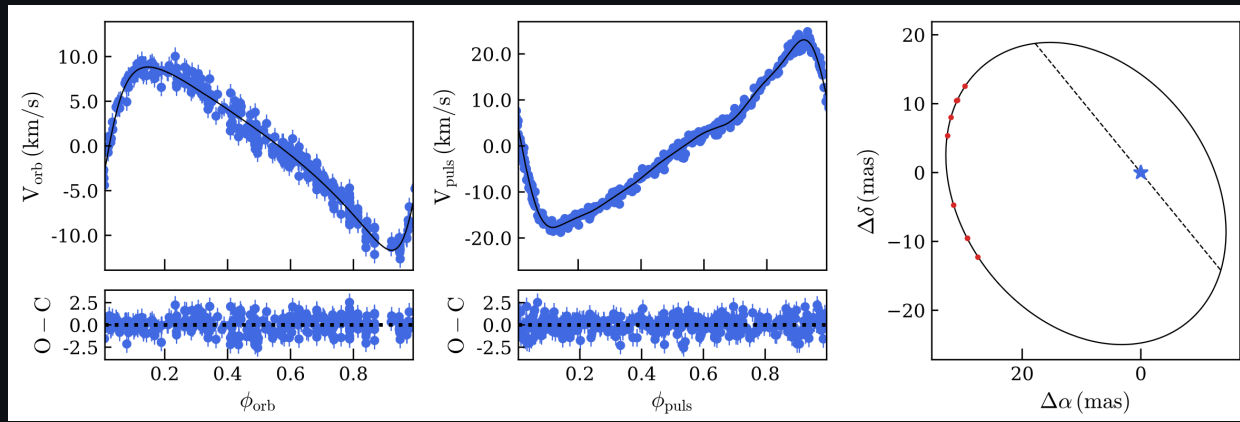
Time consuming observations

## Combined fit

Precise orbital parameters and  
parallaxes for a large sample

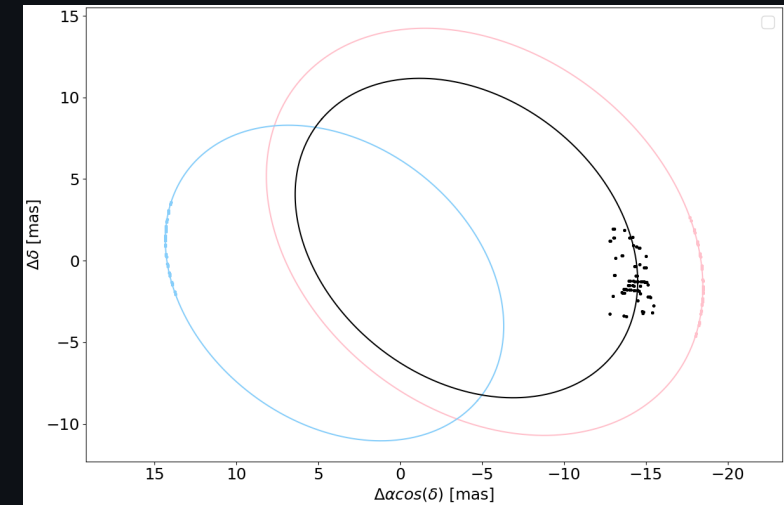
- 2 runs with GRAVITY/VLT
- Observations with M&M/CHARA
- DR4 publication: December 2026

# Cepheid AW Per



Evans+ 2024

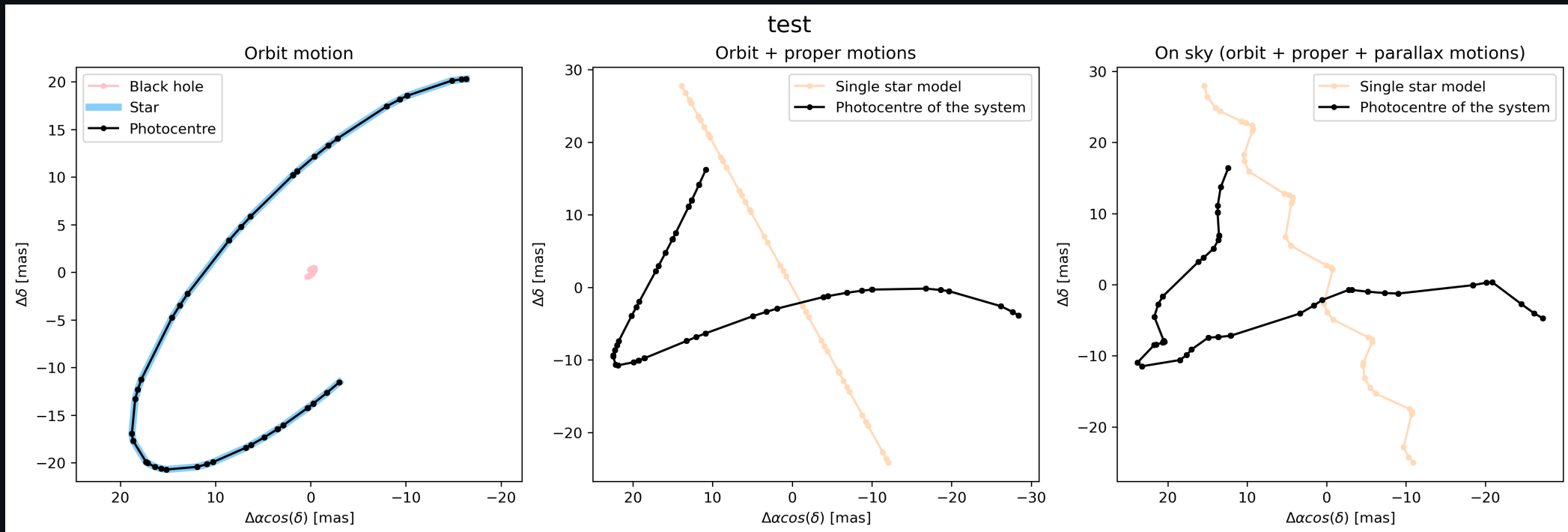
Orbit  
But no distance



No orbit  
But distance

# Proper motion effect

Object's motion = orbital + proper + parallax

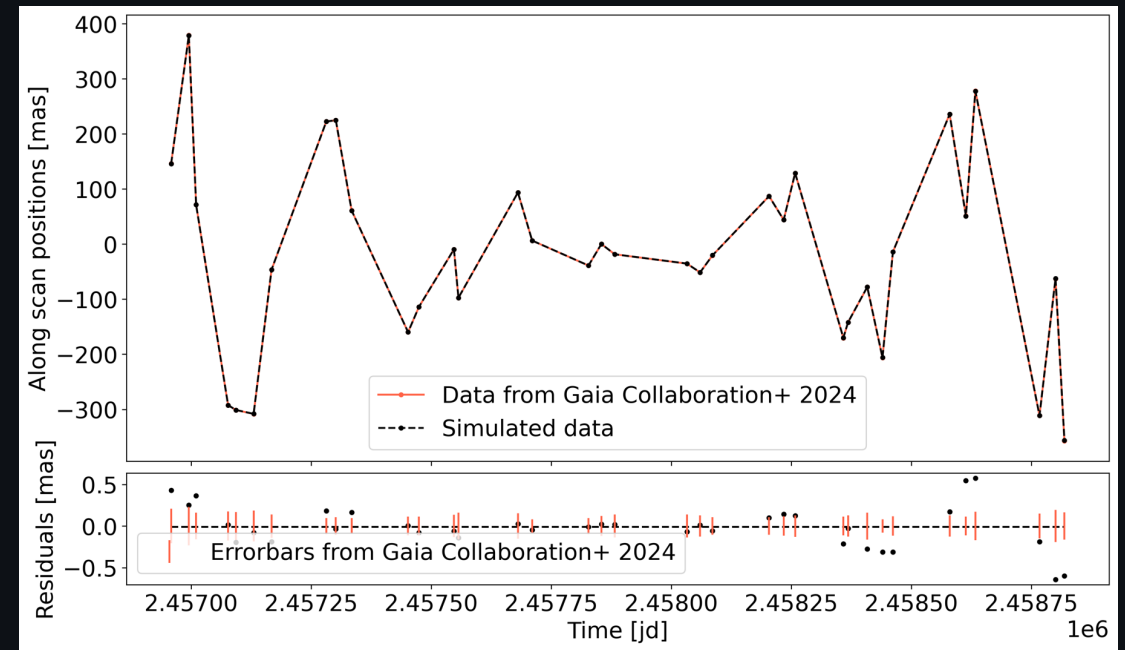
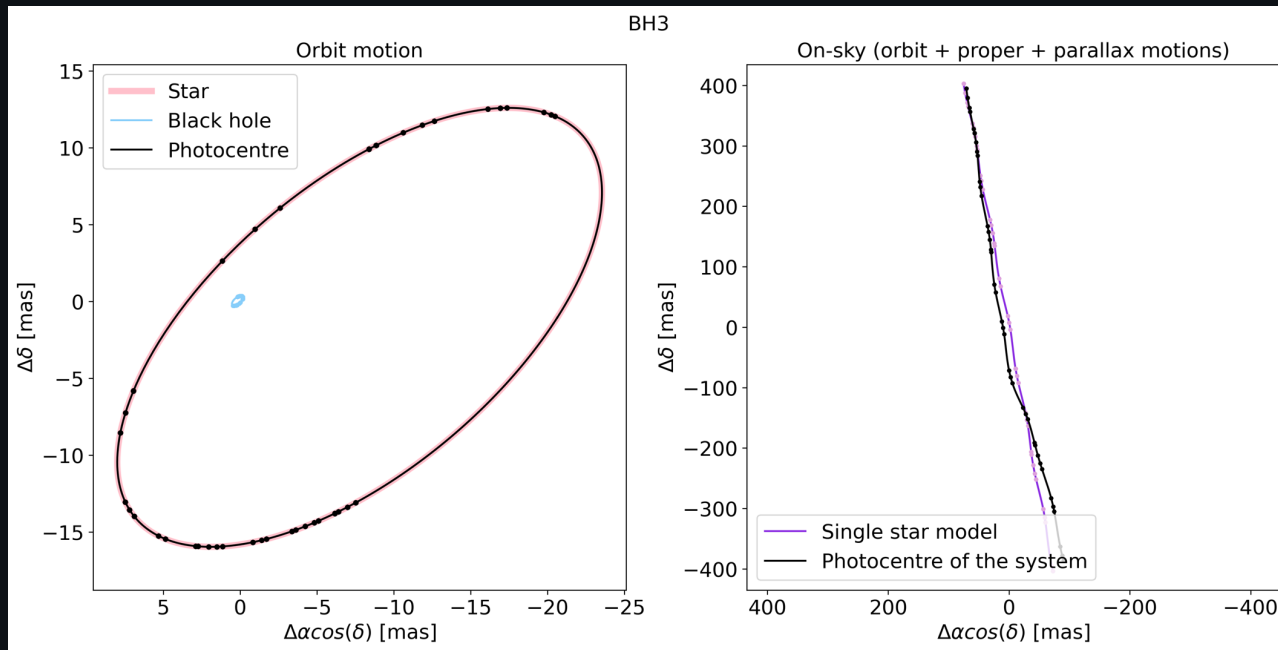


BH3's model with  $P=3000$  days,  $pmra = -5$  mas/year,  $pmdec = -10$  mas/year

Single star fit:  $-6.53, -2.85$  mas/year

This happened for BSs considered as SS in DR3

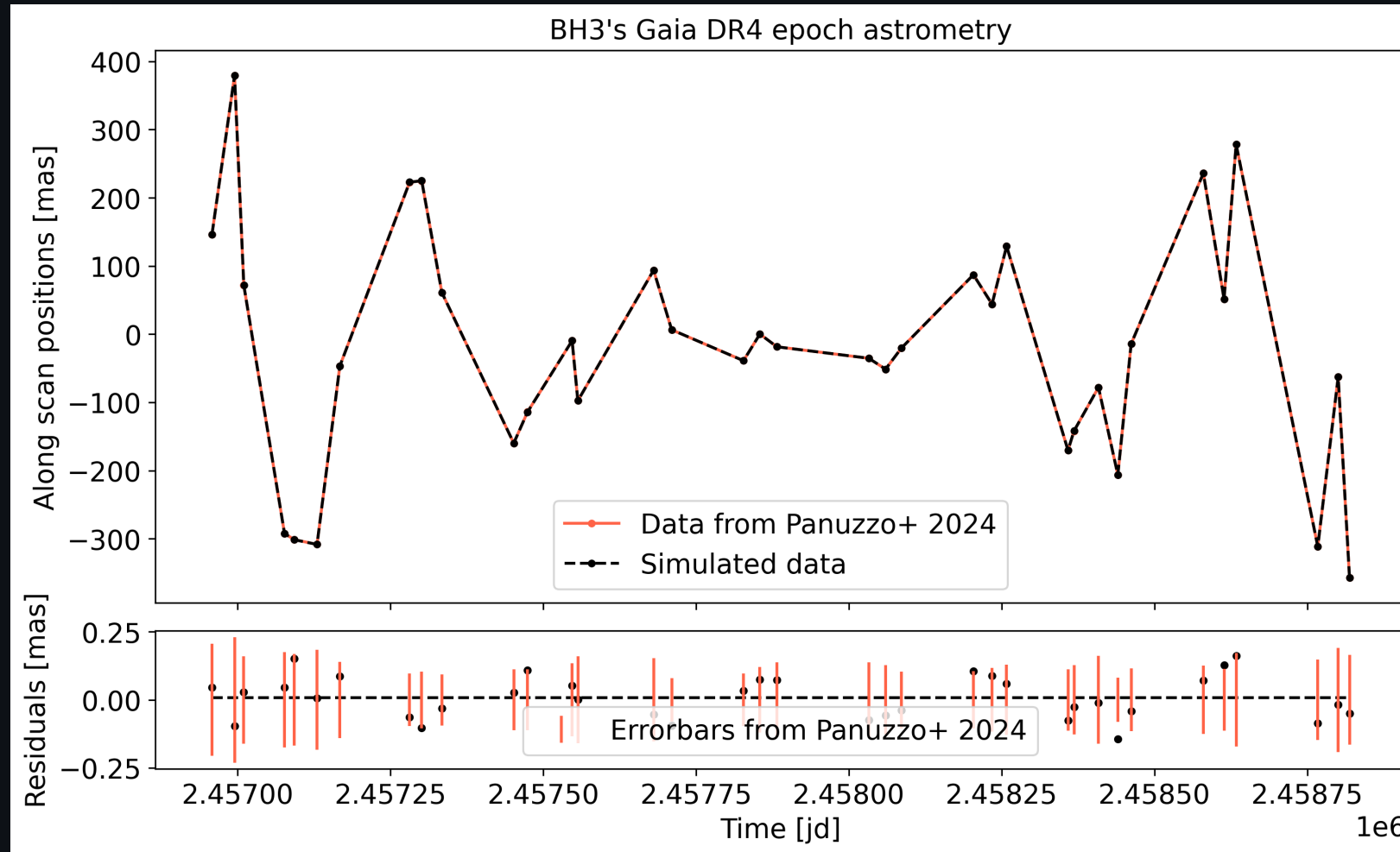
# Gaia black hole 3 (BH3)



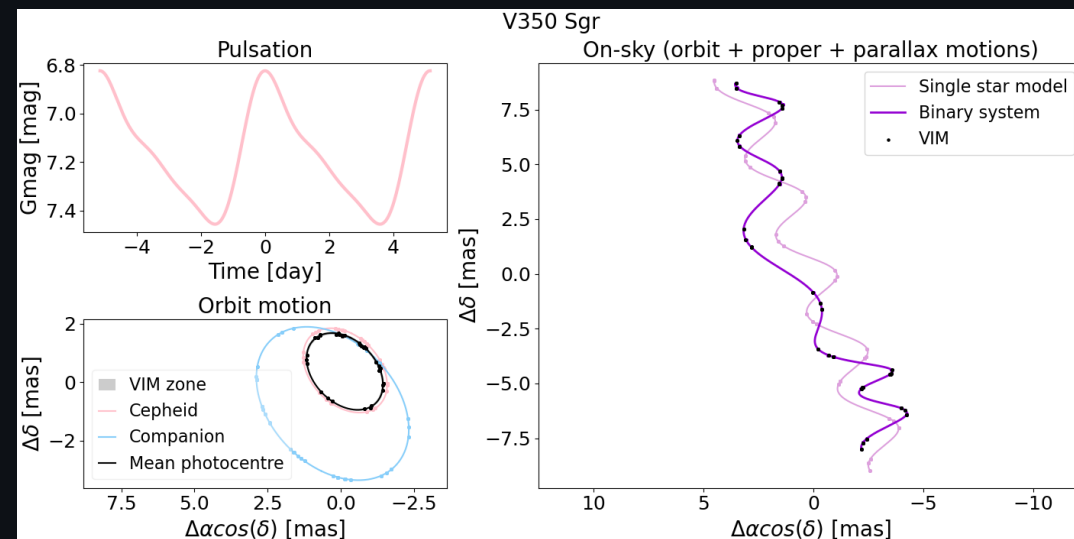
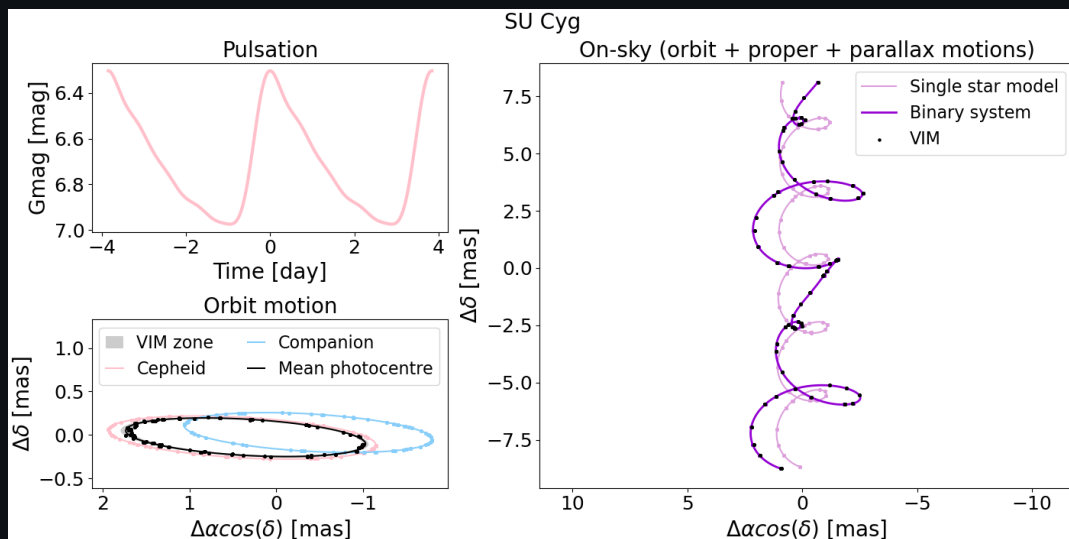
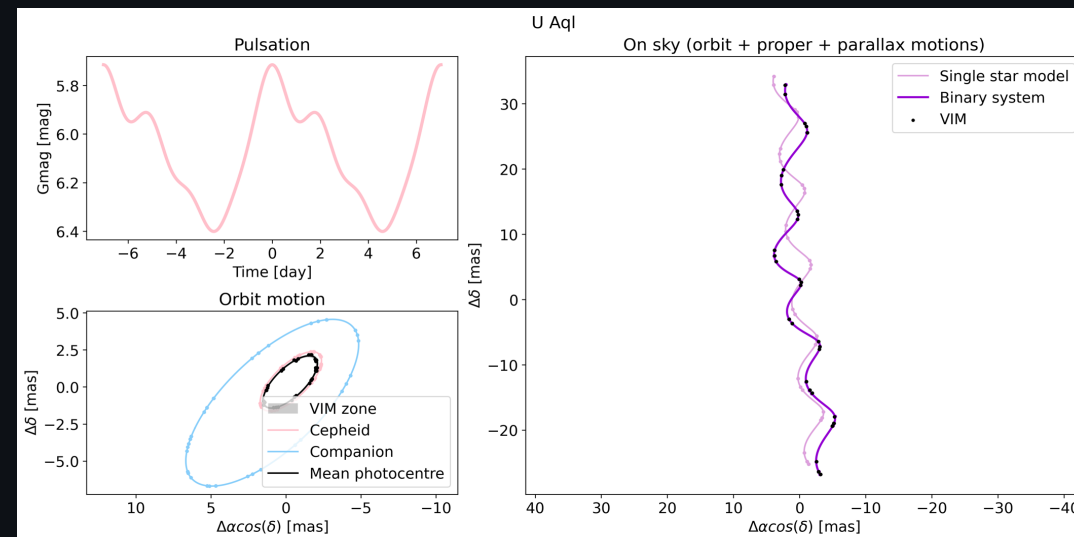
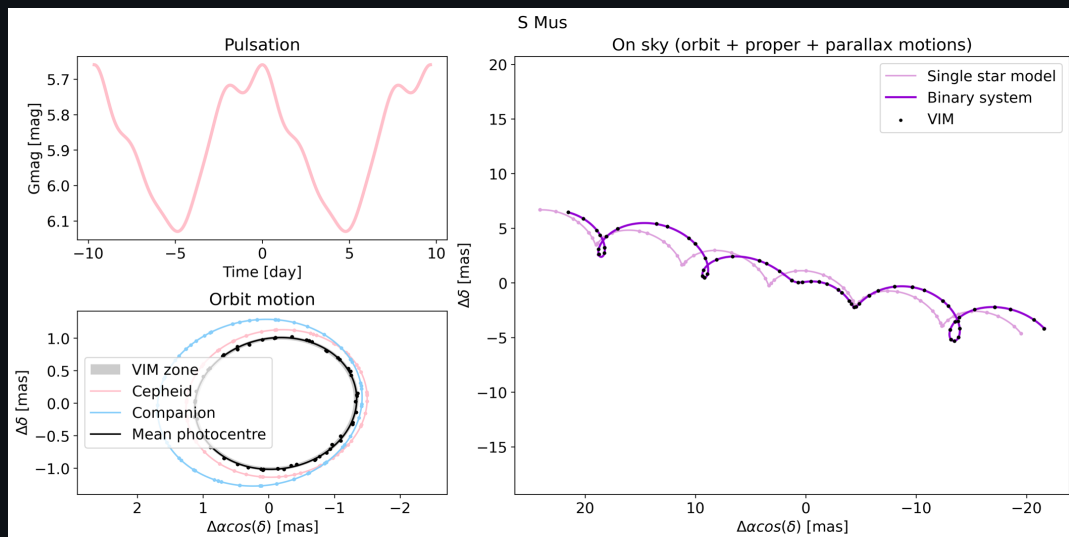
Orbital parameters from

Gaia Collaboration+ 2024

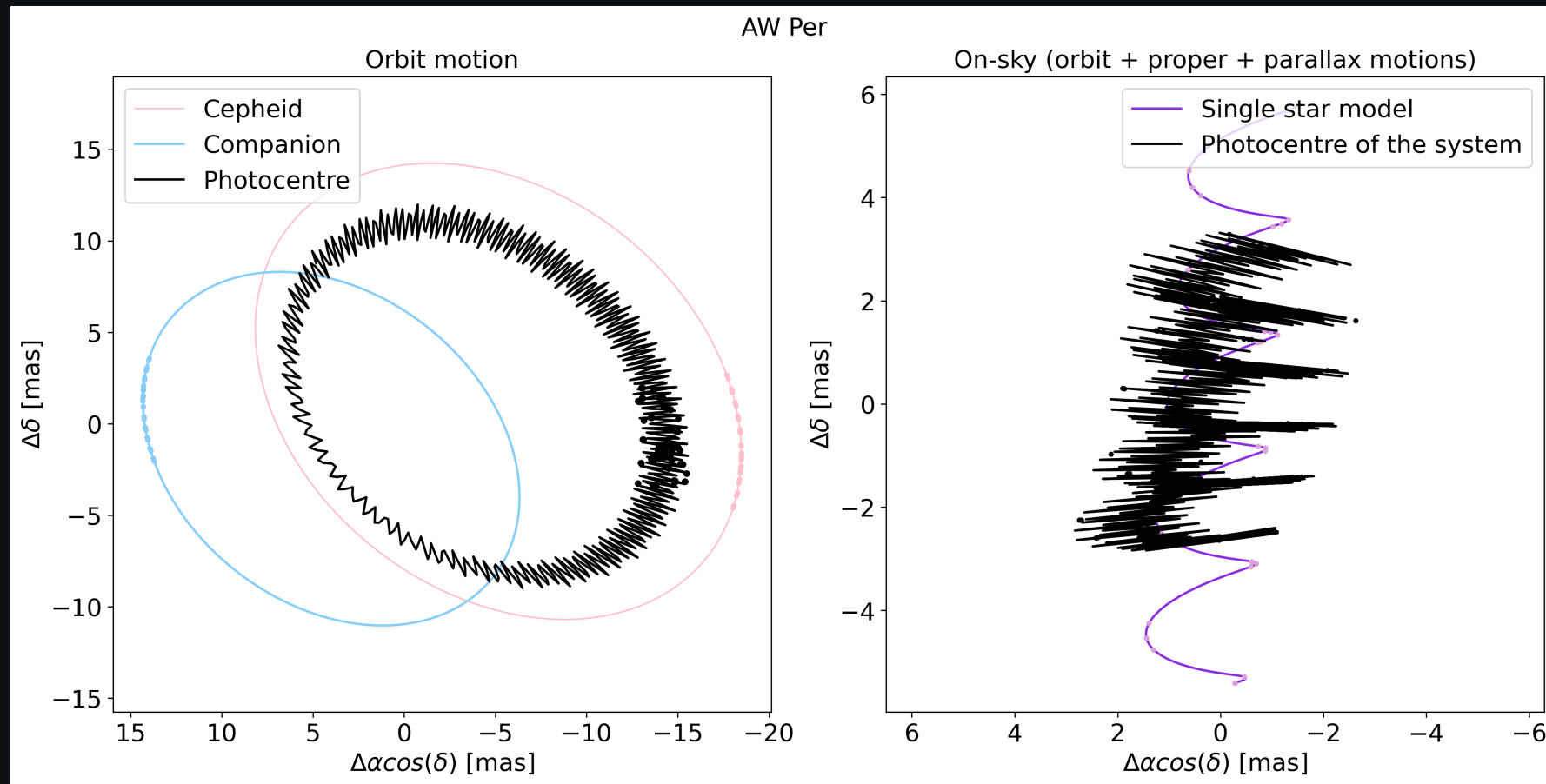
# Gaia black hole 3 (BH3)



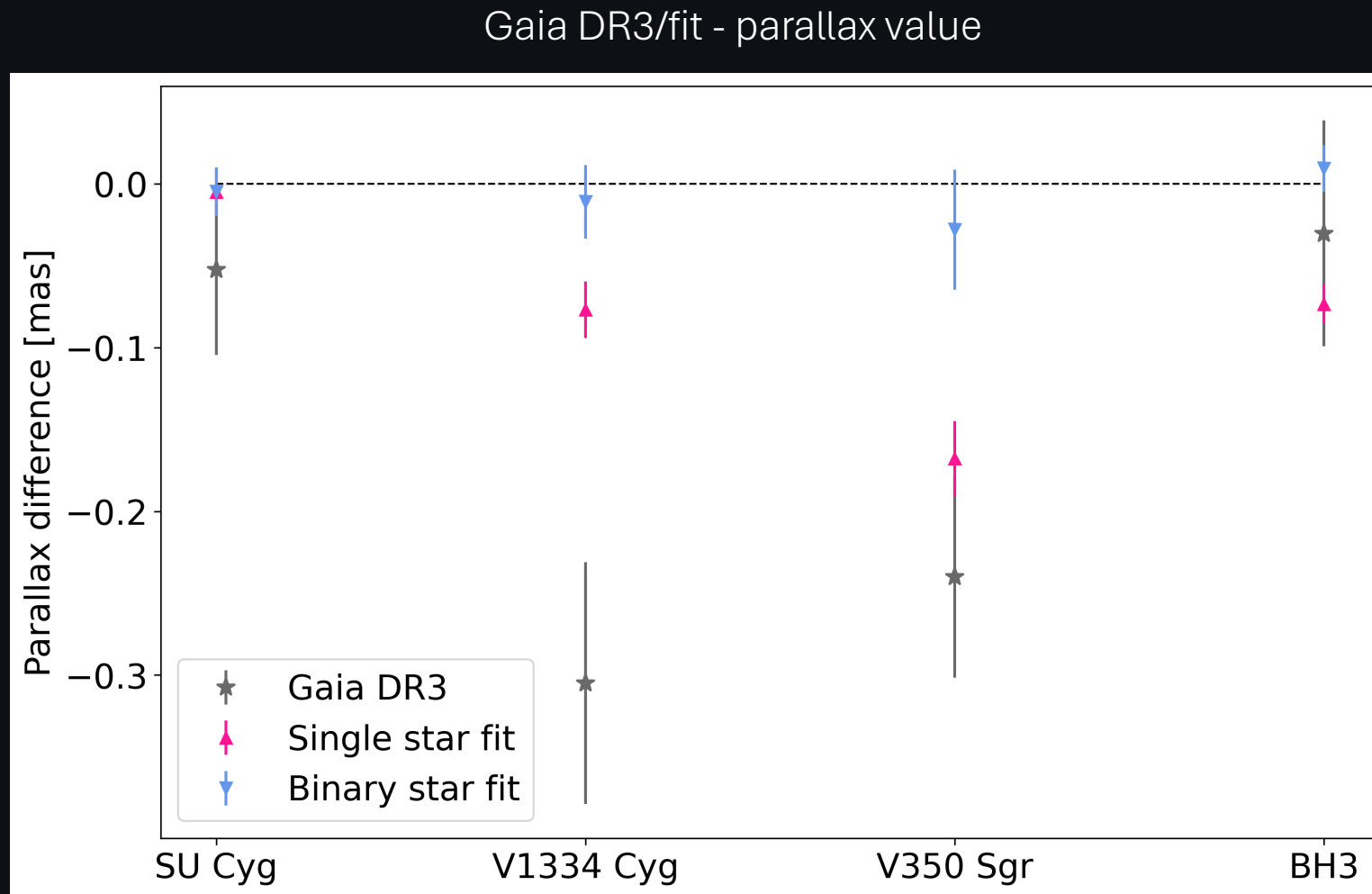
# Other Cepheids



# AW Per



# Parallax accuracy



Gallenne+ 2025

Gallenne+ 2018

Evans+ 2025

Gaia Collaboration+ 2024

# Binary: effect on parallax

