

THE DARK MASS SIGNATURE IN THE ORBIT OF S2

JOURNÉES DU PNHE 12/09/2021

GERNOT HEIBEL,

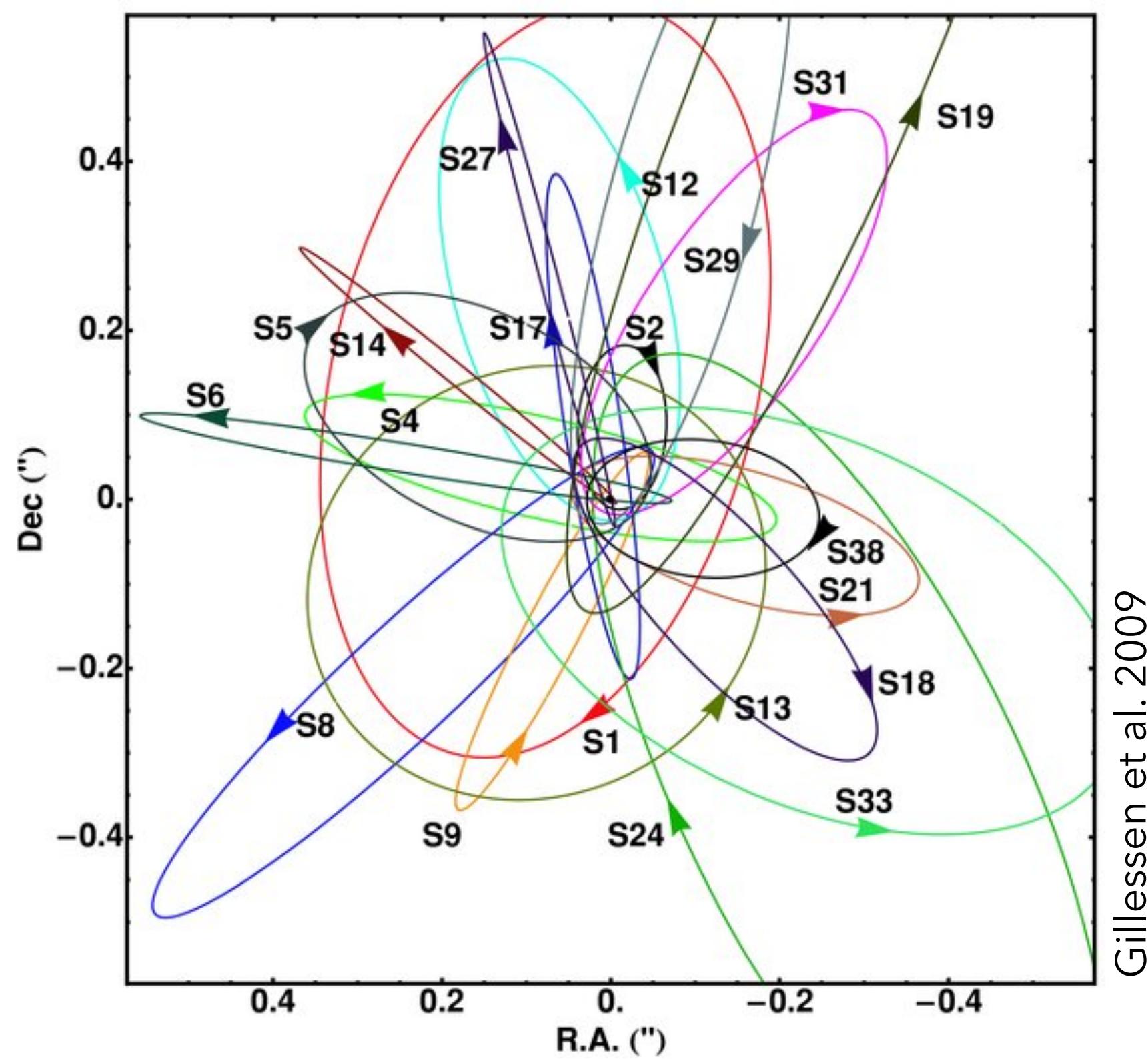
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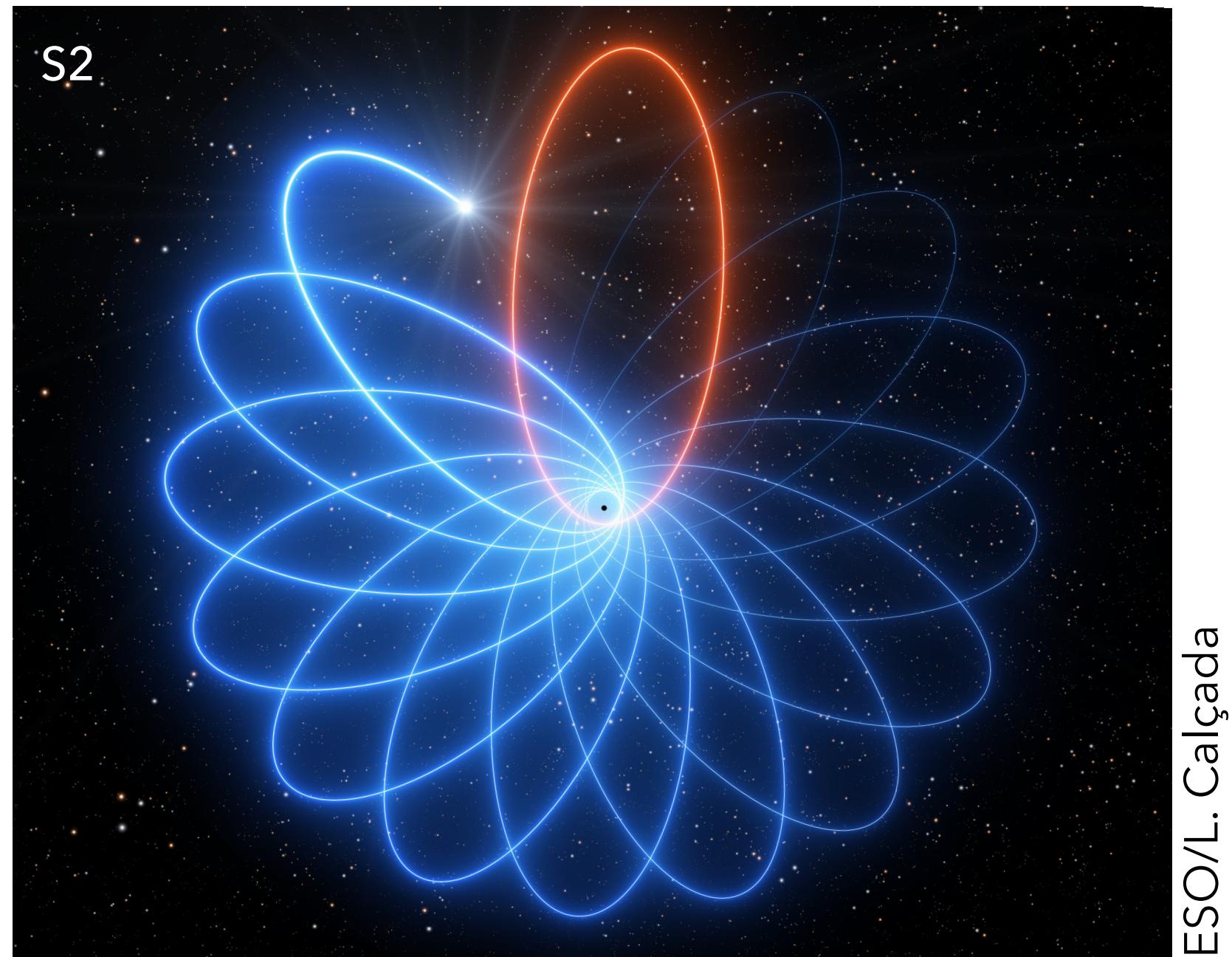
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1. Context

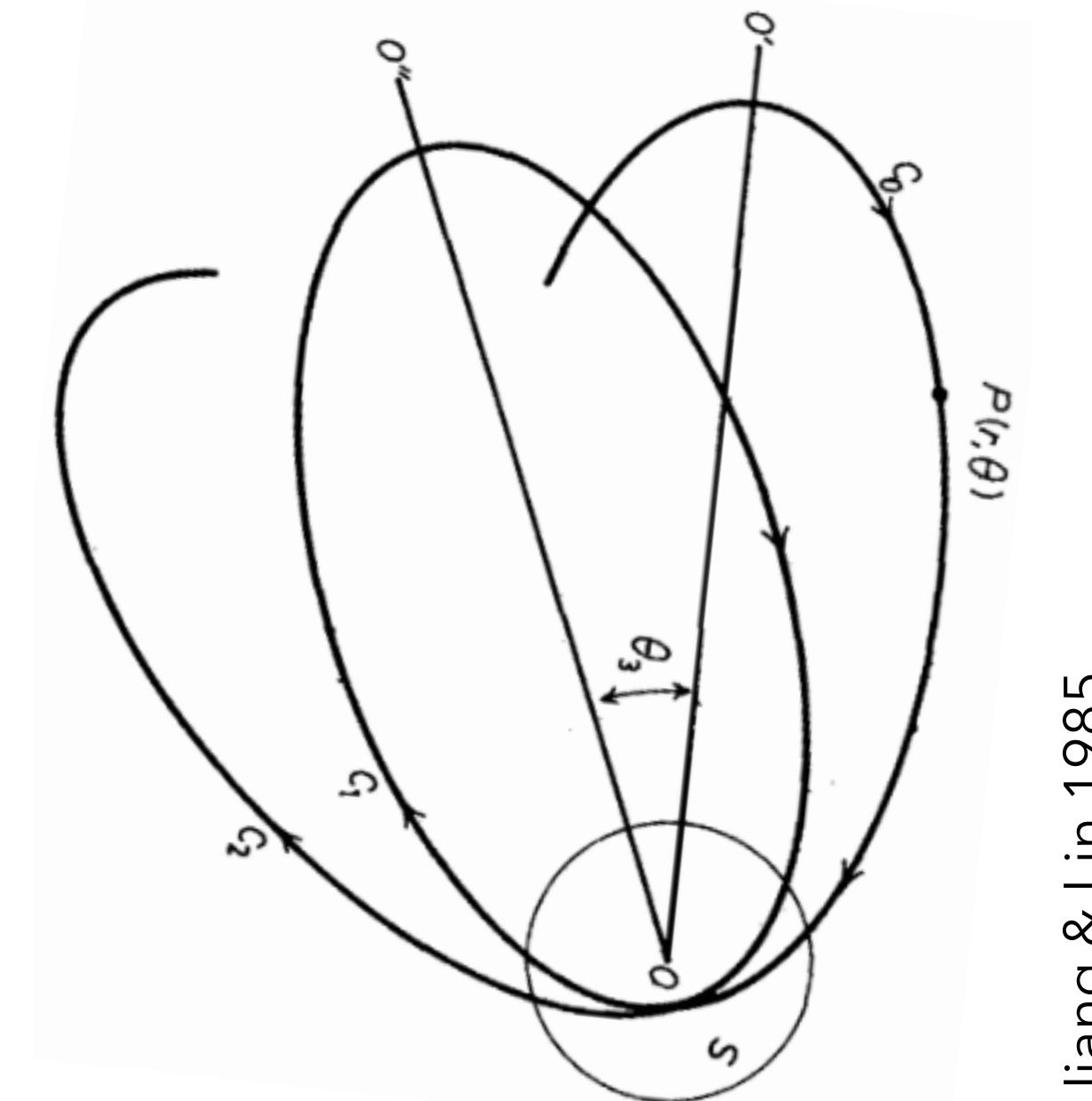
- Infrared observation of stars in the GC
 - \exists massive compact object / black hole
 $\sim 4.2 \times 10^6 M_\odot$ → Nobel prize 2020



- Focus shifted towards testing GR
 - Gravitational redshift + transverse doppler shift; GRAVITY Collab. (2018)
 - Schwarzschild precession ; GRAVITY Collab. (2020)

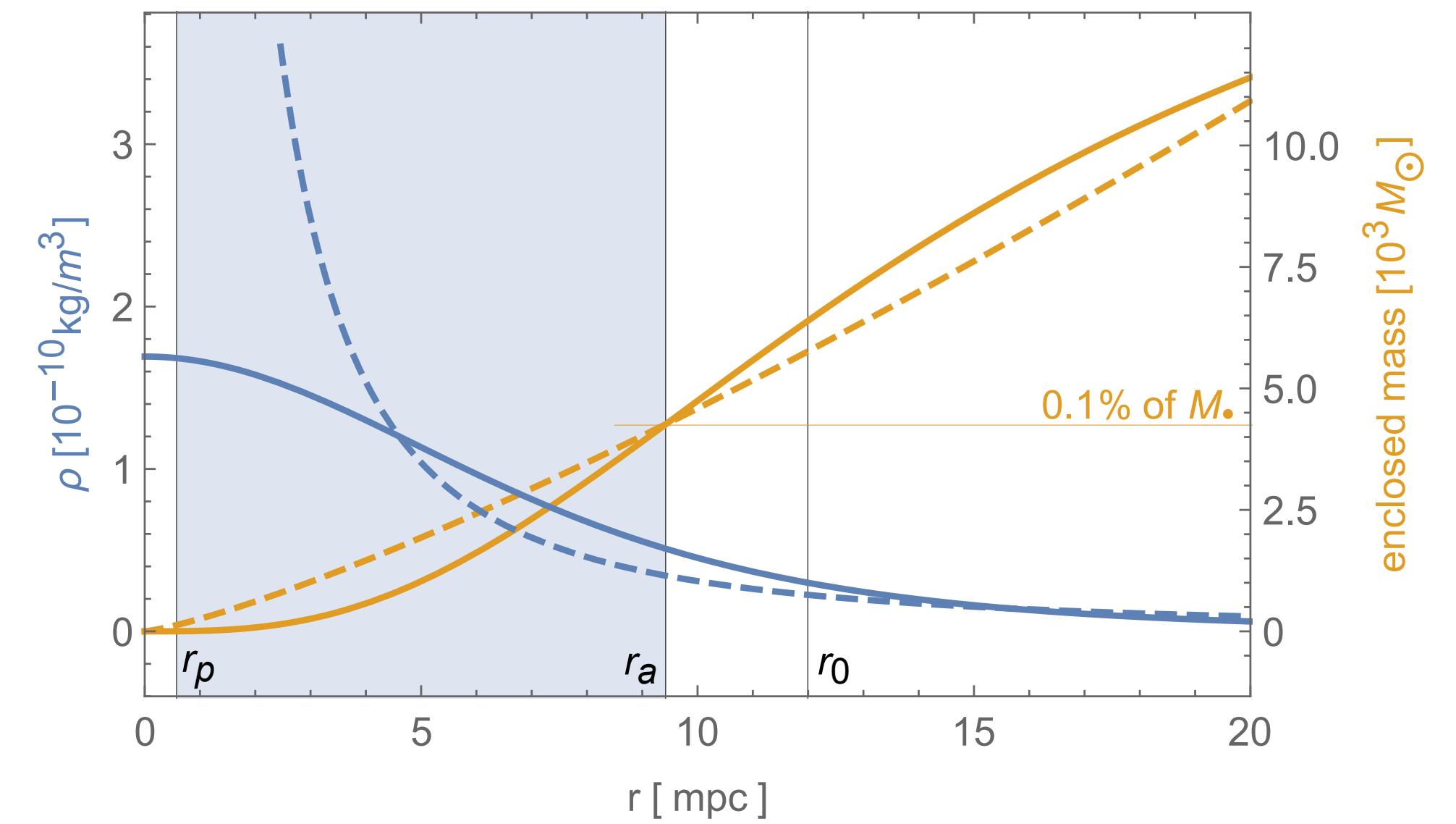


- Perturbations from 2-body problem
 - E.g. dark extended continuous mass distribution → **dark mass/extended mass**
 - E.g. faint stars, stellar remnants, black holes, (exotic) dark matter
 - Net effect onto a star's orbit: retrograde precession → **mass precession**



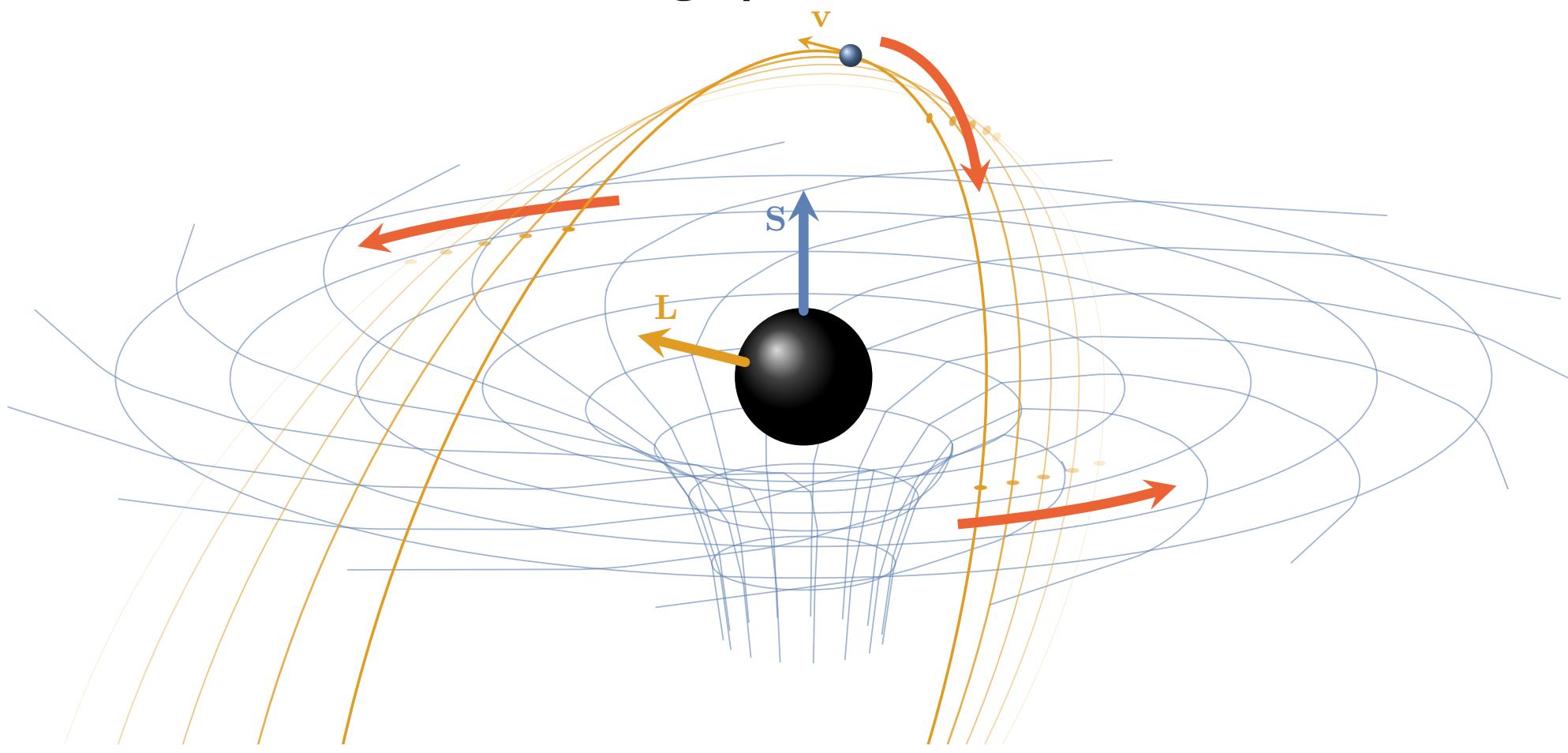
Jiang & Lin 1985

- Counteracts Schwarzschild precession ⇒ has to be modelled
- Upper bound by GRAVITY et al. (2020)
 - $< 0.1\%$ of M_\bullet , or $4200 M_\odot$ inside S2's apocentre
 - Assuming Plummer & cusp distributions with scale parameter $0.3'' \approx 0.012 \text{ pc} \approx 2500 \text{ AU}$
 - innermost GC



2. Motivation

- Studying dark mass in its own right.
 - Is there any yet undetected matter content between S2 and Sgr A*? Distribution? Nature?
- Studying dark mass as perturber for measuring relativistic effects.
 - Schwarzschild precession → MBH mass
 - Lense-Thirring precession → MBH spin



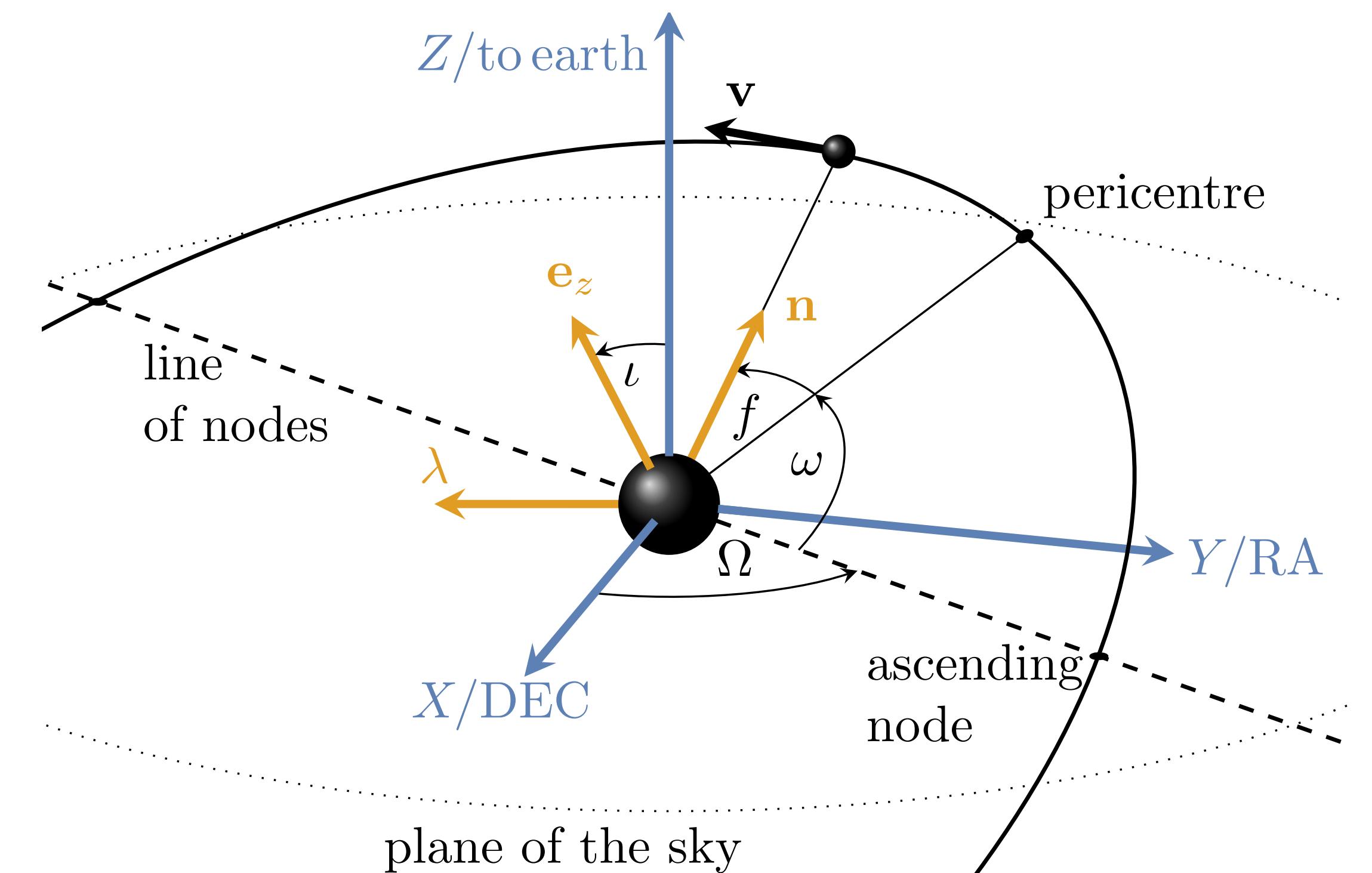
3. Aims

- Deepen understanding of extended mass
 - from a theoretical angle
 - gain information useful to observation (detection threshold predictions)
- Scope: S2, Plummer & cusp of 0.012 pc scale (→ faint stars, stellar remnants, black holes)
- focus on astrometry (cf. Takamori et al. (2020) for radial velocity)
- disentangle mass precession from Schwarzschild precession (→ blueprint for spin)

4. Methods

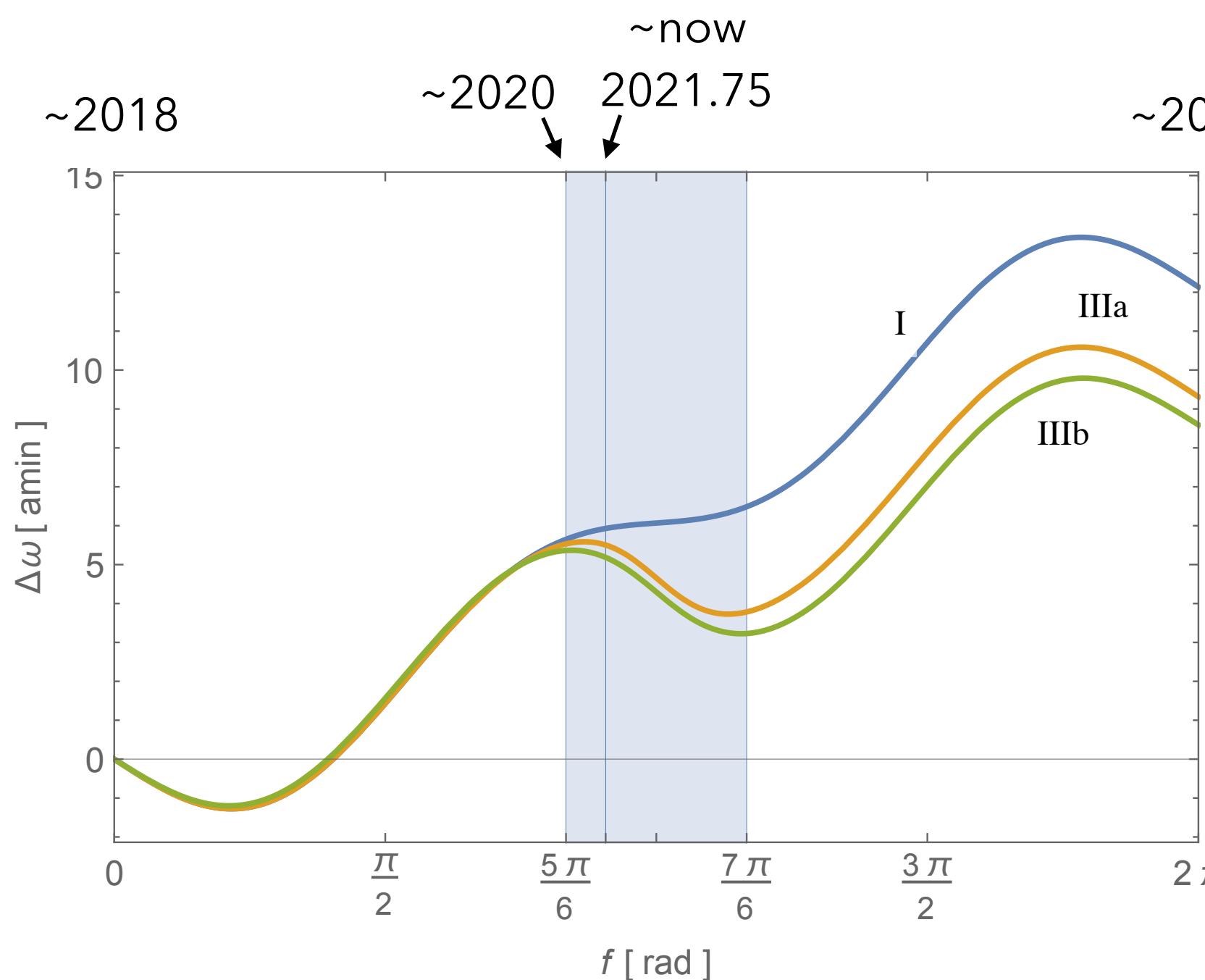
- 3 layers of analysis
 - A. theoretical analysis at the hand of the **osculating orbital elements**
 - B. theoretical analysis at the hand of the **observables** (RA, DEC, RV)
 - C. mock-data analysis – fitting model orbits

- to A.
 - Kepler orbit fully described by
 - 6 elements, e.g. $\vec{\mu} = (a, e, i, \Omega, \underline{\omega}, f)$
 - perturbed Kepler orbit fully described by
 - initial osculating Kepler orbit $\vec{\mu}_0 = \vec{\mu}(t_0)$
 - evolution equations $\dot{\vec{\mu}}(t) = \underbrace{(\text{perturbations})}_{\text{GR, dark mass}}$

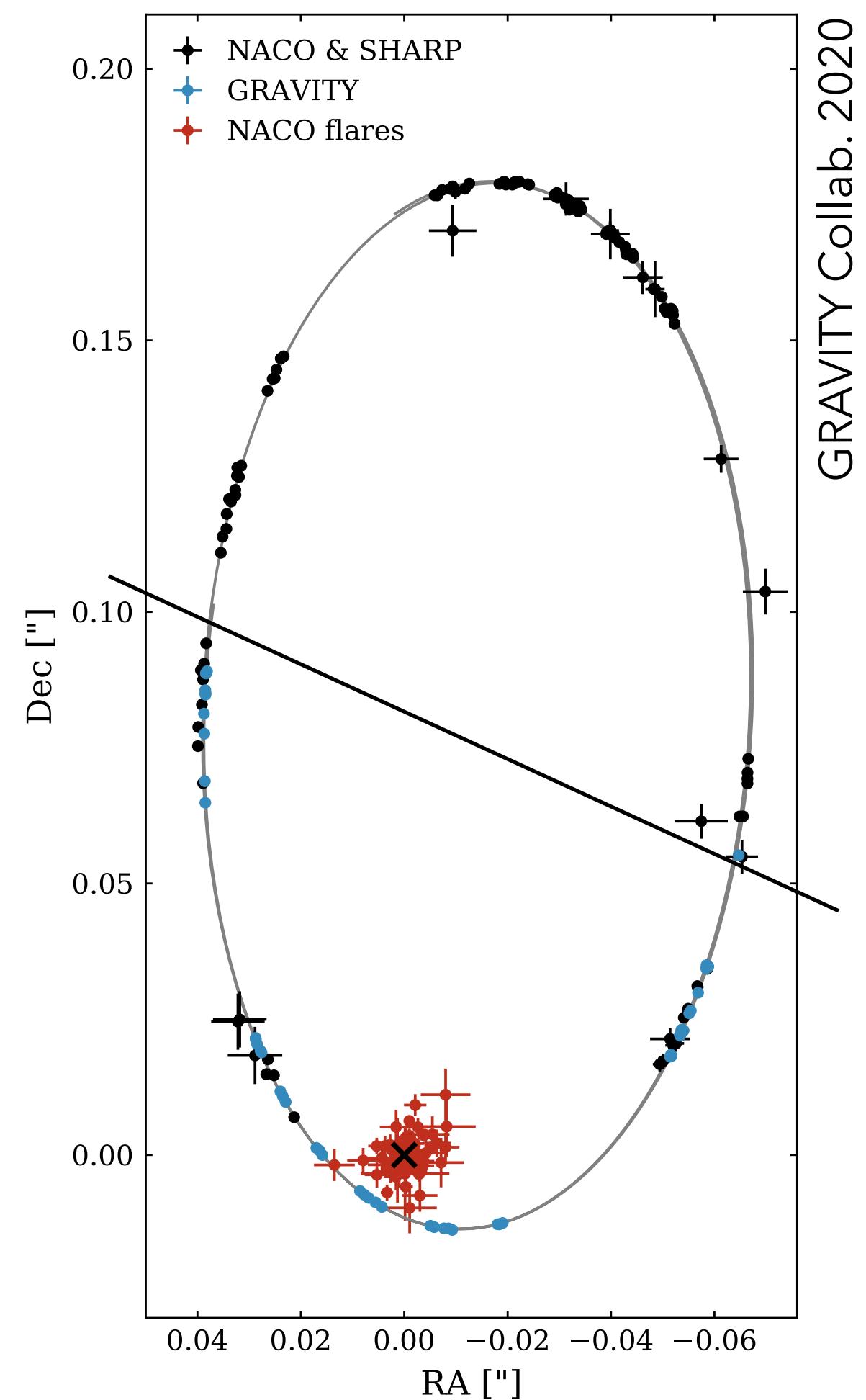
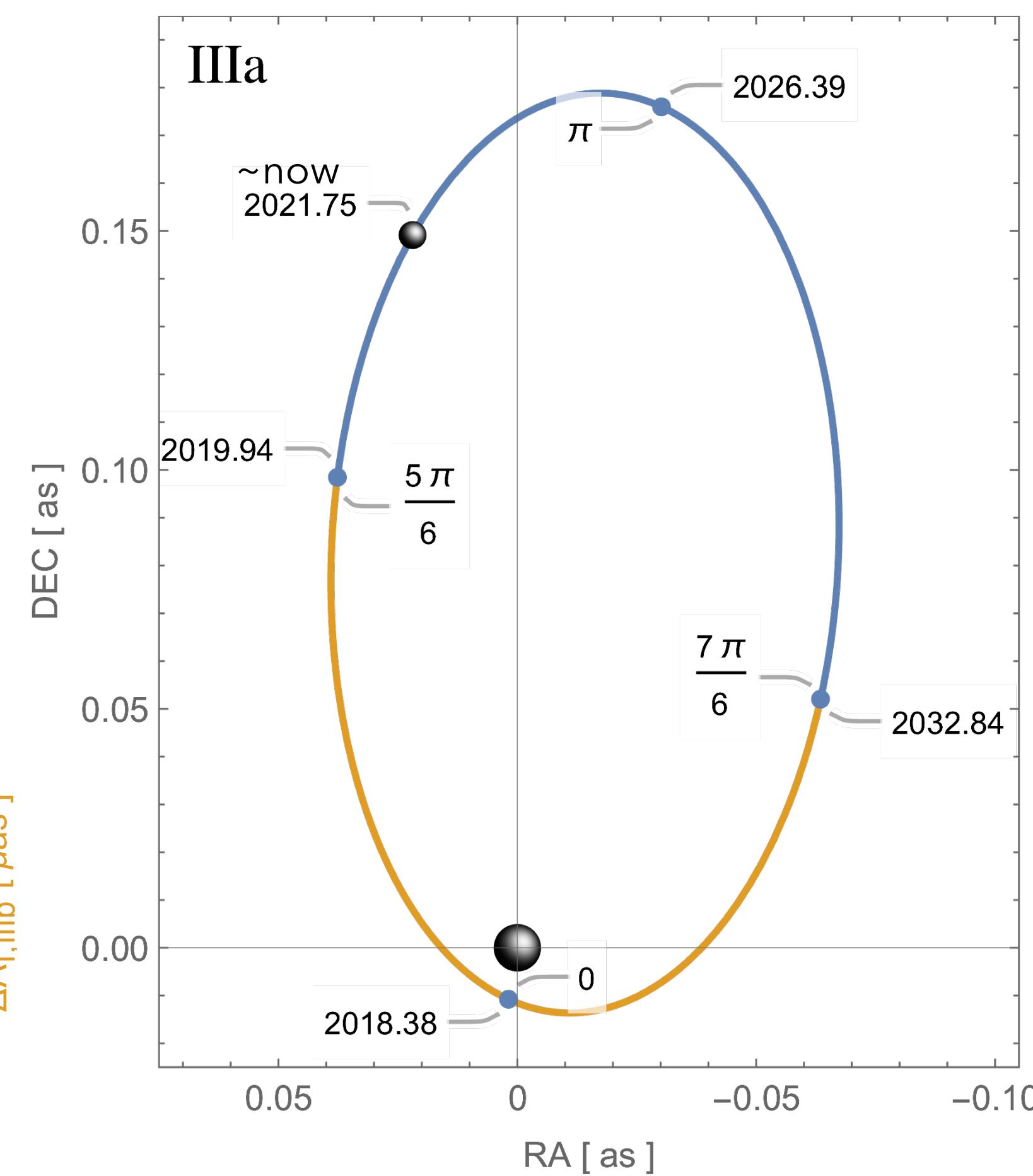
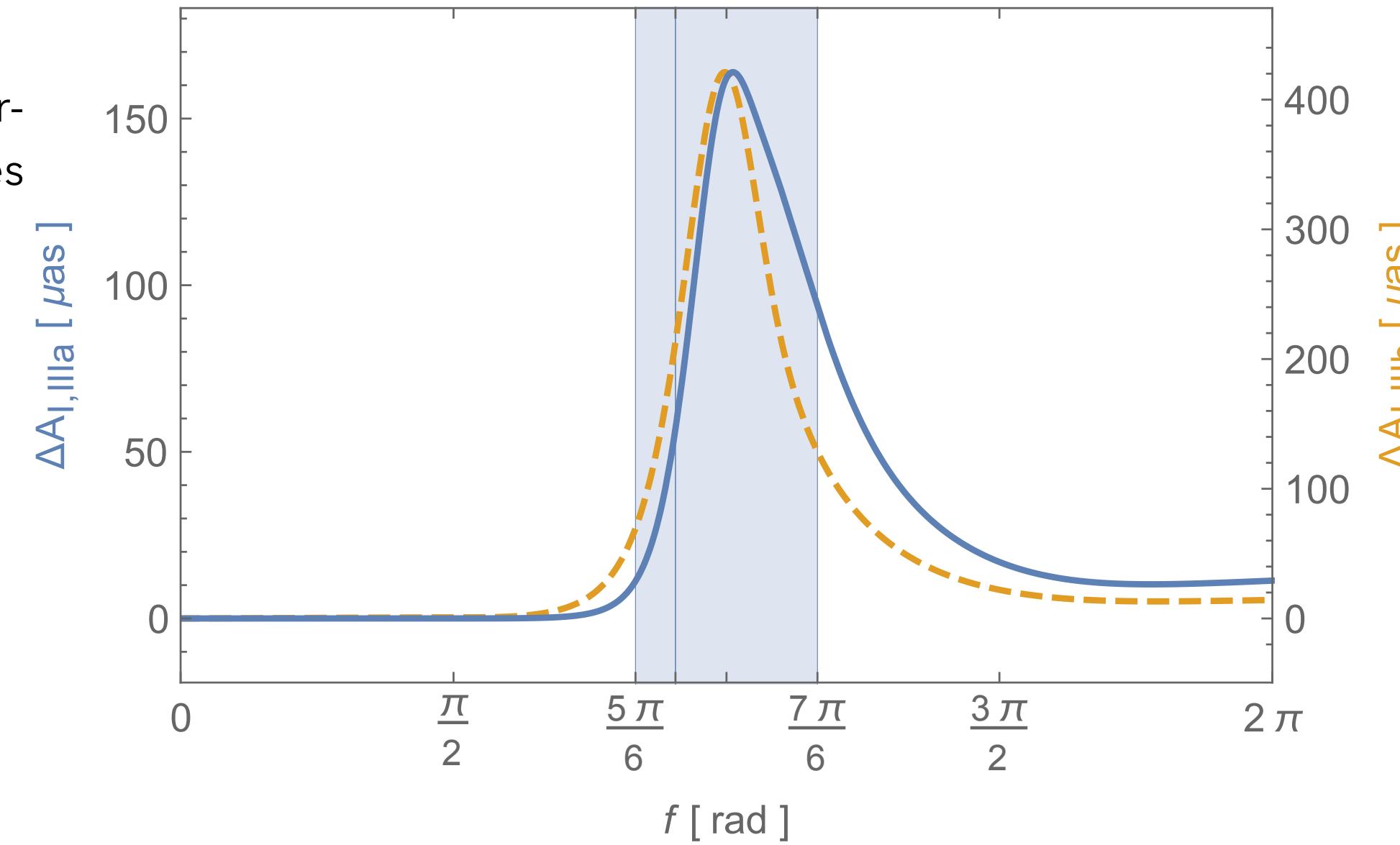


5. Results

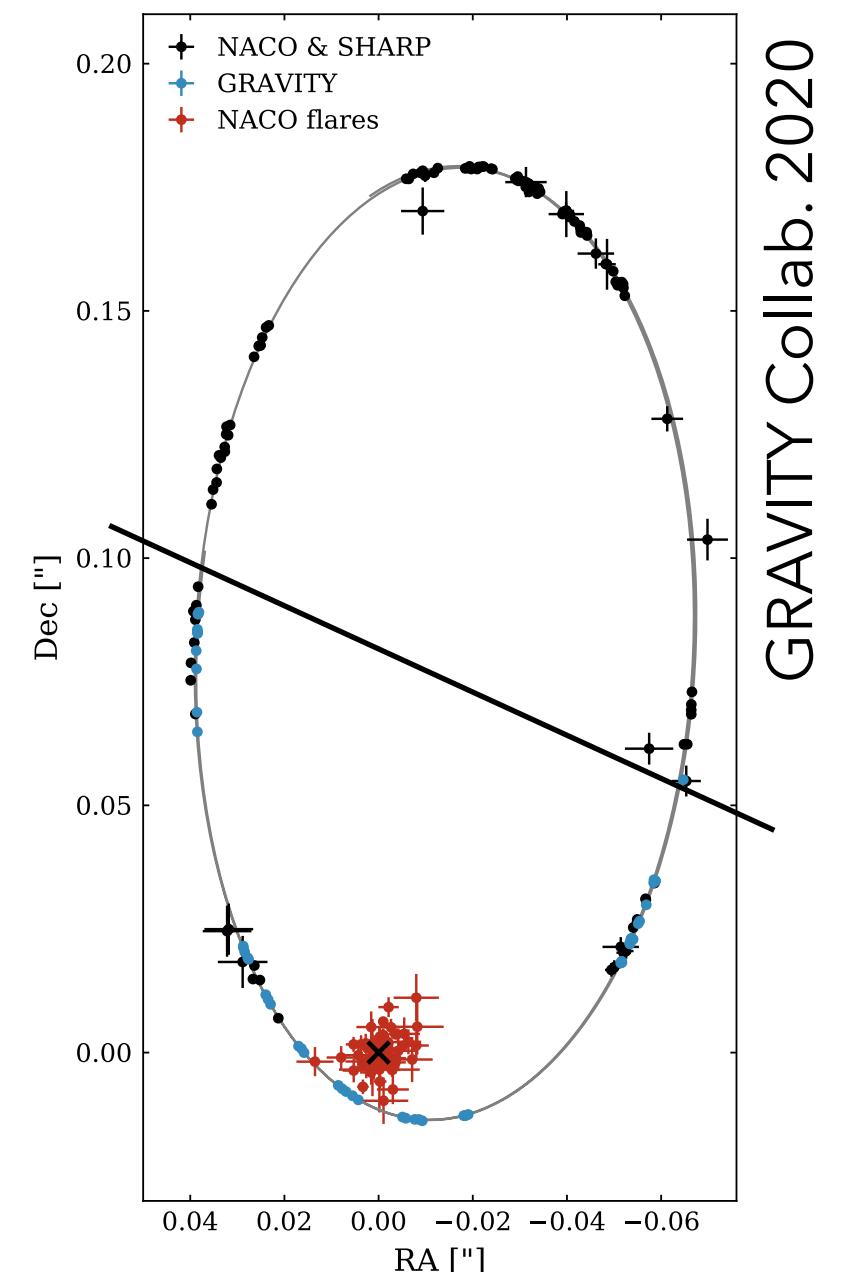
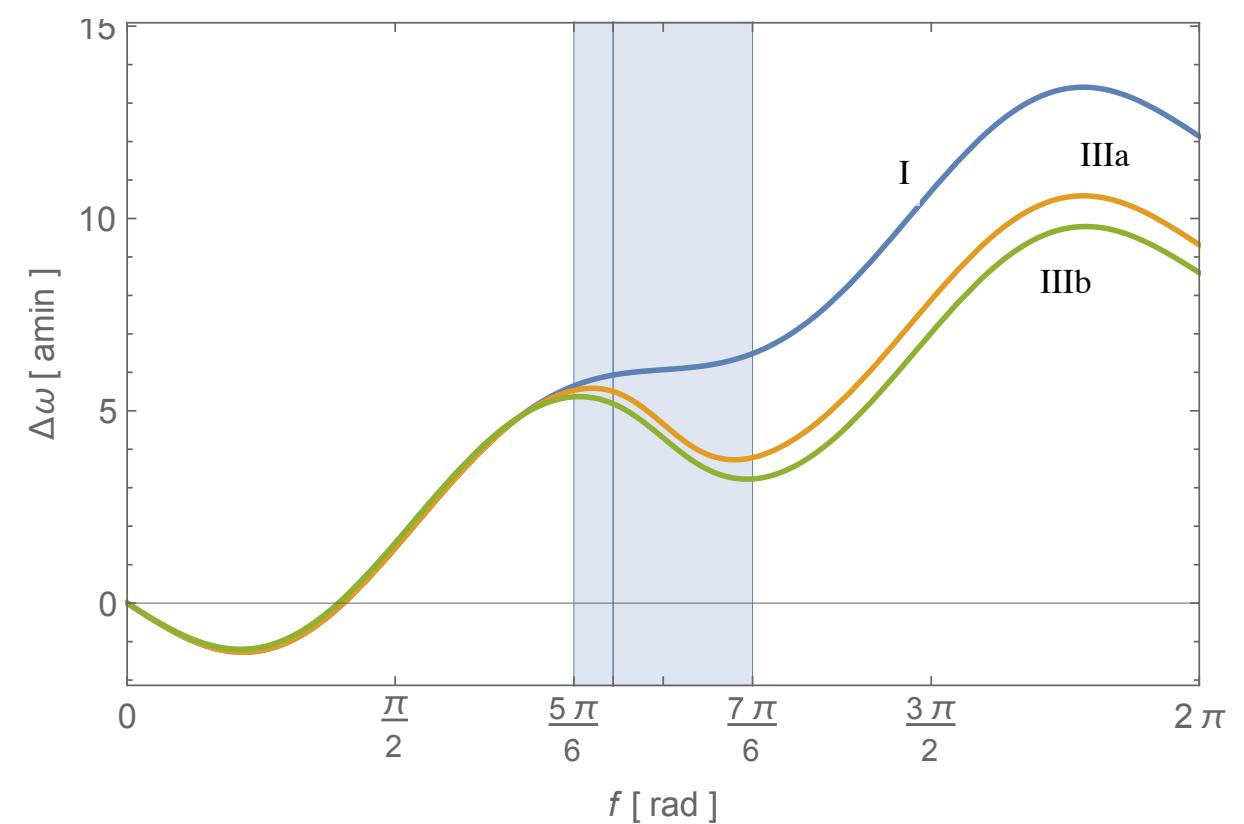
A.
osc. orb.
elements



B.
observables



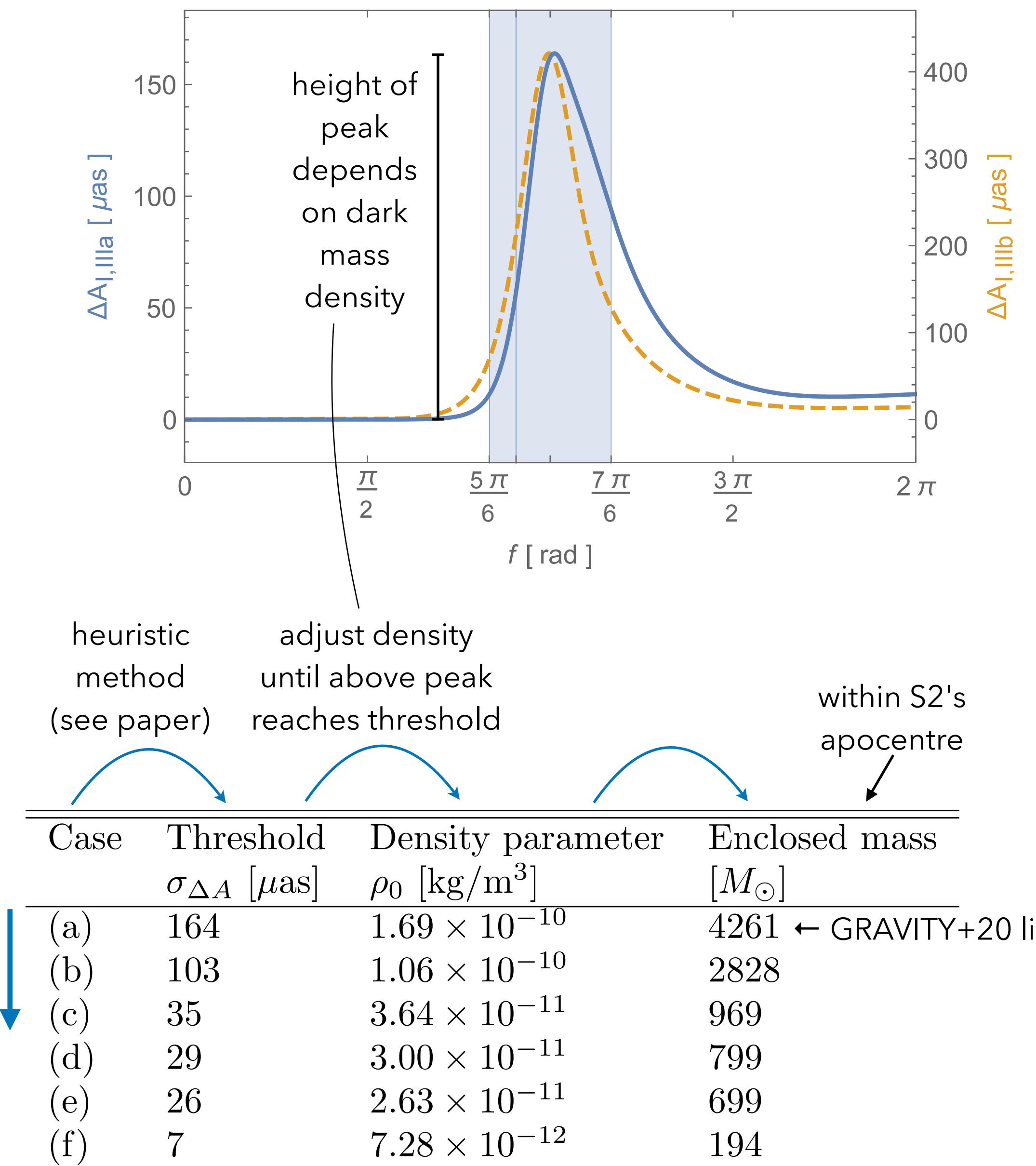
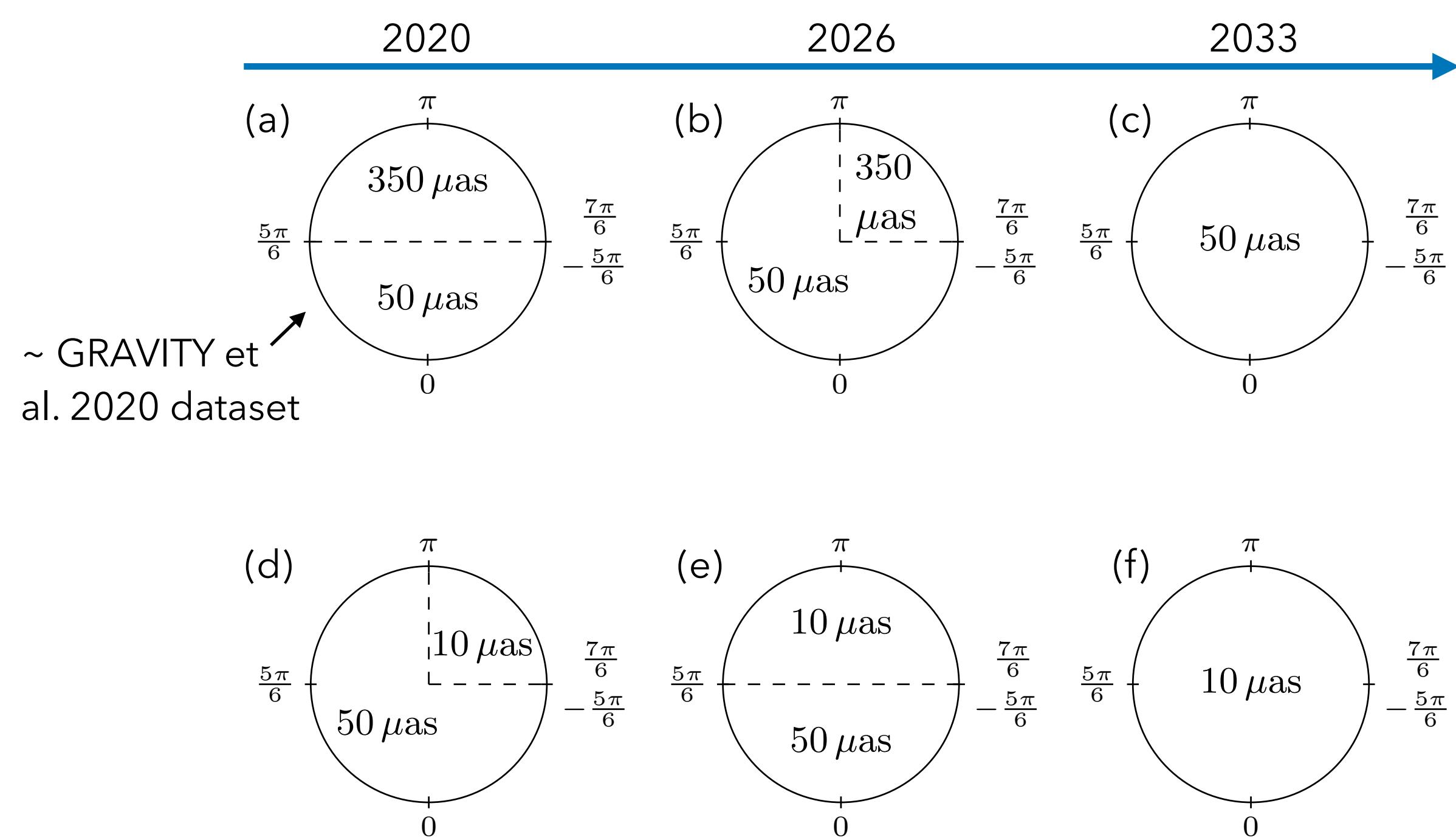
- Main result 1
 - Mass precession: almost exclusively in apocentre half.
 - Schwarzschild precession: --- || --- in pericentre half.
 - Clear cut separation of both effects.
- Main result 2
 - Data limited to the pericentre half is not sensitive to a dark mass.
 - Data --- || --- apocentre half is sensitive.
- Implication for observation
 - Much to gain by sampling apocentre half with VLTI/ GRAVITY.
 - How much?



- Detection threshold estimates from theory

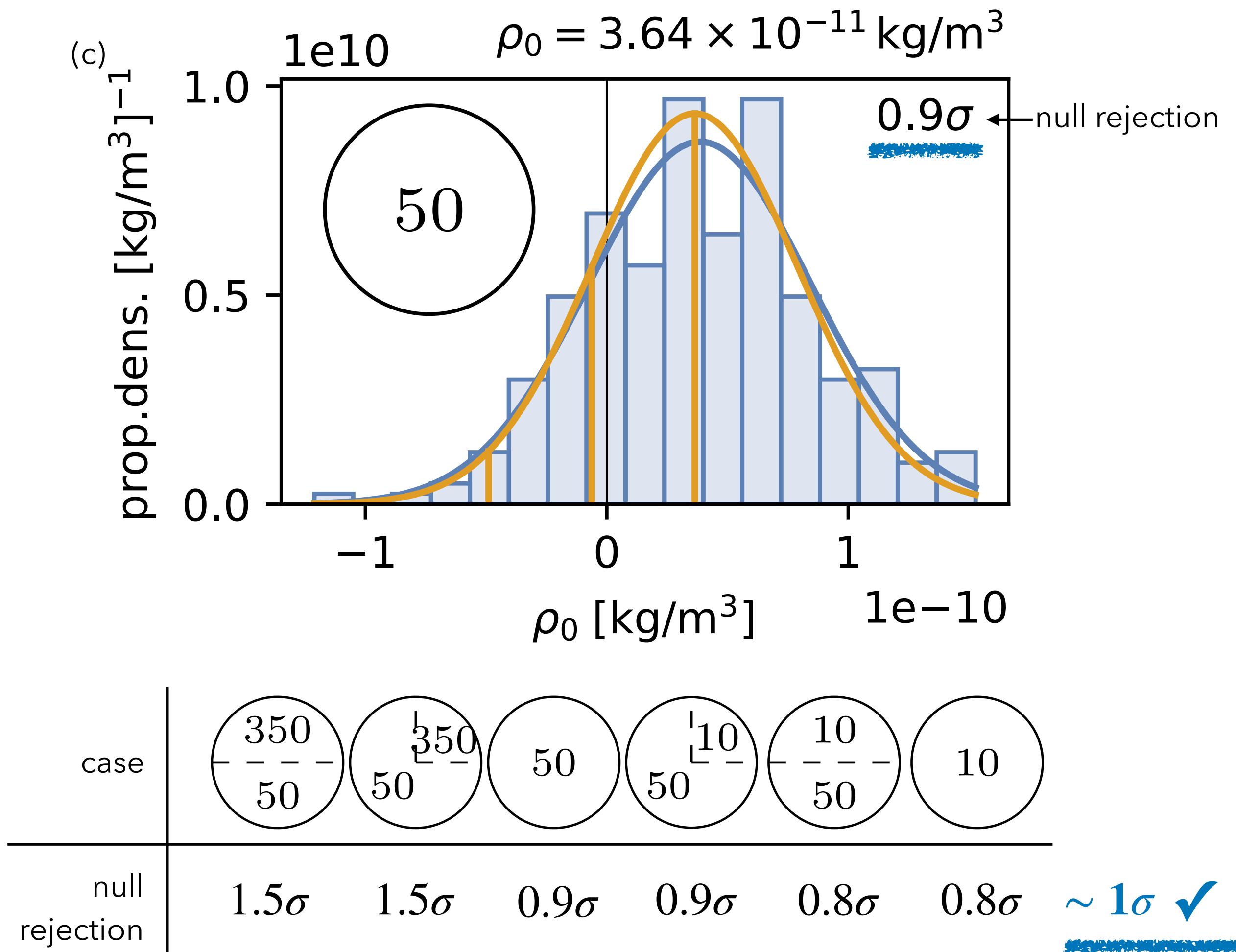
→ What is the maximal extended mass, detectable with 1σ given a data set of certain (astrometric) accuracies?

→ 6 cases



C. Mock data analysis

- Each case: 250 mock-data sets, 114 astrometric, and 114 spectroscopic data points each
- Full orbit of data
- Data limited to orbital section



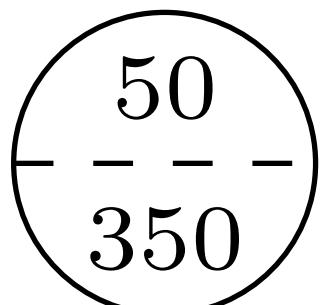
- ⇒ no convergence
- ⇒ (weakly) sensitive
- Main result 1 & 2 ✓
- Main result 3
 - A full orbit of data is required to substantially constrain a dark mass.

- Main result 4

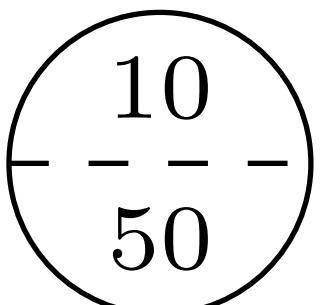
→ Given a **full orbit** of astrometric and spectroscopic data, then the astrometric component on the **pericentre half** plays the **stronger role** in constraining the dark mass than the astro-metric component on the apocentre half.

Mirrored cases

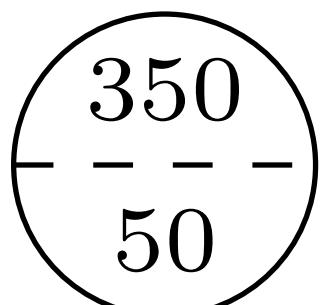
better astrometric accuracy on apocentre half



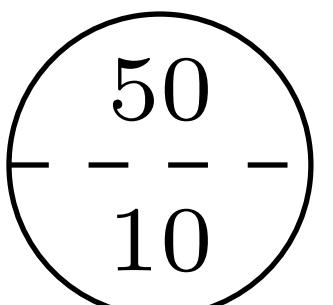
1.2σ



5.2σ



1.5σ



8.9σ

better astrometric accuracy on pericentre half

Summary

- Main result 1
 - Mass precession → apocentre half
 - Schwarzschild precession → pericentre half
- Main result 2. Data limited to...
 - ... pericentre half → not dark mass sensitive
 - ... apocentre half → (weakly) sensitive
- + provided observation with 1σ detection threshold estimates.
- Main result 3
 - Full orbit of data required to substantially constrain a dark mass.
- Main result 4. Full orbit of data...
 - astrometric peri-half component more important than astrometric apo-half component

Takeaway message

- Despite secular interference, different precession effects distinguishable by their distinct signatures which they inscribe within one orbit.
- Should be particularly useful facing the future goal of detecting the spin of Sgr A* via the Lense-Thirring precession.