

Sagittarius A* and its environment: a review on GRAVITY(+) results

2nd New Horizons for Psi workshop @ Beijing, China
27/08/2026

Arianna Foschi
on behalf of the GRAVITY Collaboration

Aim of the talk

- Show current constraints on matter distributions at the Galactic Center (GC), using the motion of S-stars around Sagittarius A* (SgrA*).
 - Dark matter (DM) models that are (mostly) **spherically symmetric: standard DM models and superradiant boson clouds.**
(arXiv [2112.07478](#) / [2409.12261](#) / [2306.17215](#) / [2312.02653](#))
- **Going beyond spherical symmetry:** update on newly discovered S301 and degeneracy with a Newtonian disk-like structure (arXiv [2607.12664](#) / [2607.26713](#))

Introduction

Sagittarius A* and the Galactic Center are the **perfect** environment to test DM models.

For standard models: matter accreted by SMBH can create DM spikes around them

(Gondolo & Silk 1999, Sadeghian *et al.* 2013)

Introduction

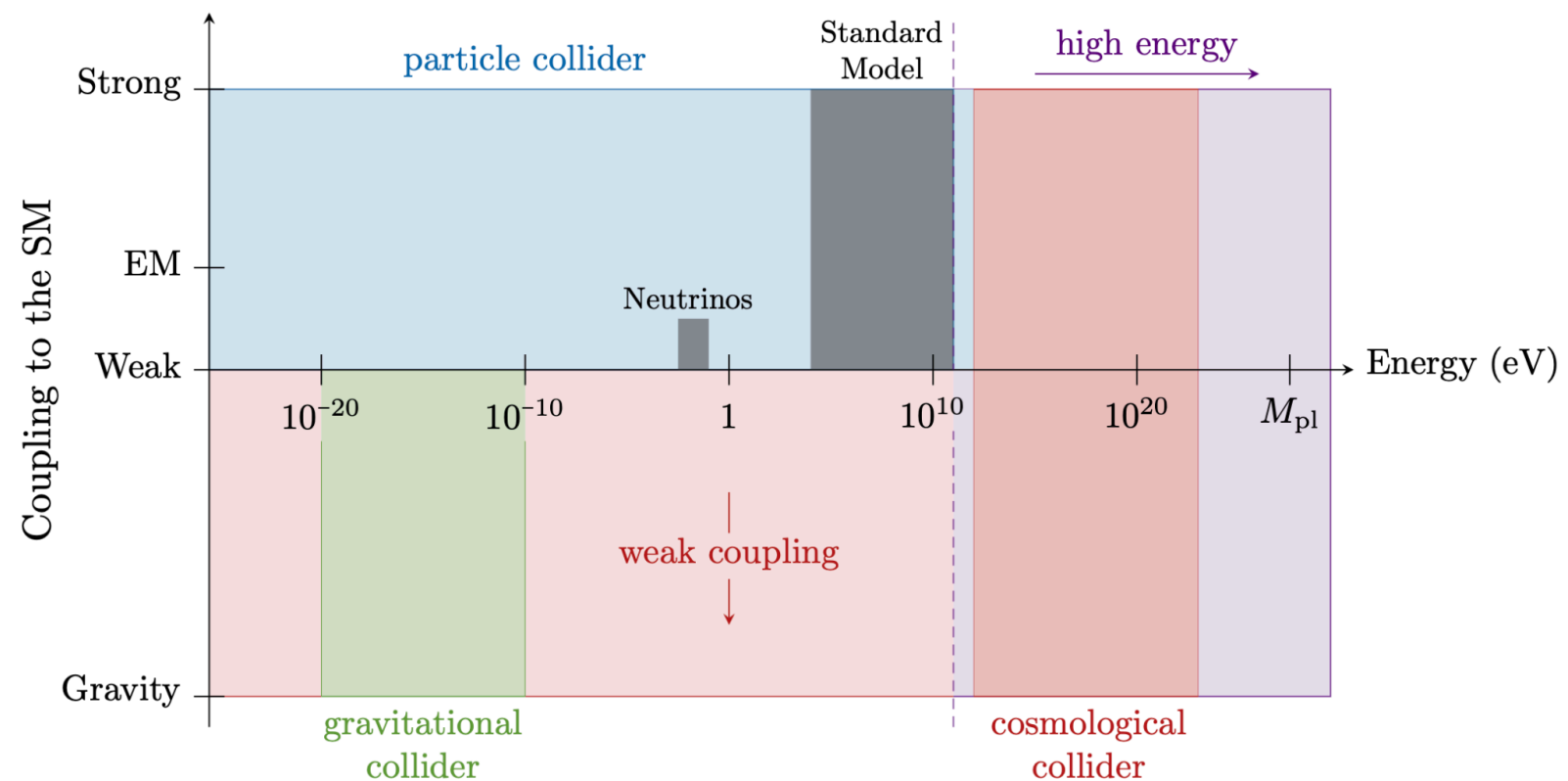
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(Gondolo & Silk 1999, Sadeghian *et al.* 2013)

For superradiant clouds: SgrA*'s mass allows us to test boson masses as small as 10^{-19} eV

(Kodama & Yoshino 2011, Brito *et al.* 2015, Baumann *et al.* 2020)



Data

Results obtained using S2 motion

1. Gravitational redshift measurement (GRAVITY Coll. 2018);
2. Schwarzschild precession (GRAVITY Coll. 2020);
3. Retrograde precession due to extended matter (GRAVITY Coll. 2021, 2024);
4. SgrA* mass:
 $M_{\bullet} = (4.29 \pm 0.01) \cdot 10^6 M_{\odot}$
(GRAVITY Coll. 2024).

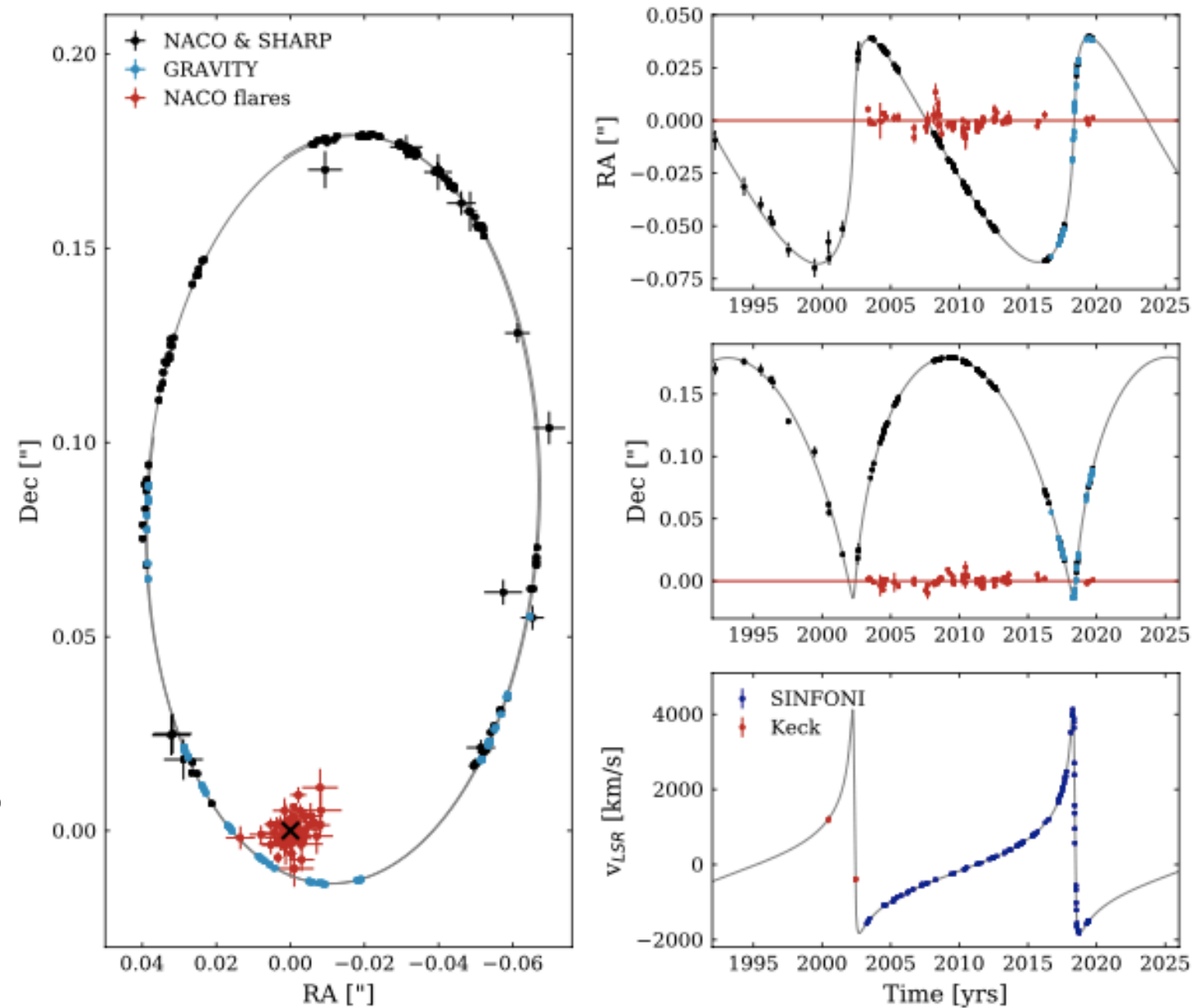


Figure from GRAVITY Coll. *et al.* 2020

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Astrometric data

(GRAVITY precision $\approx 50 \mu\text{as}$)

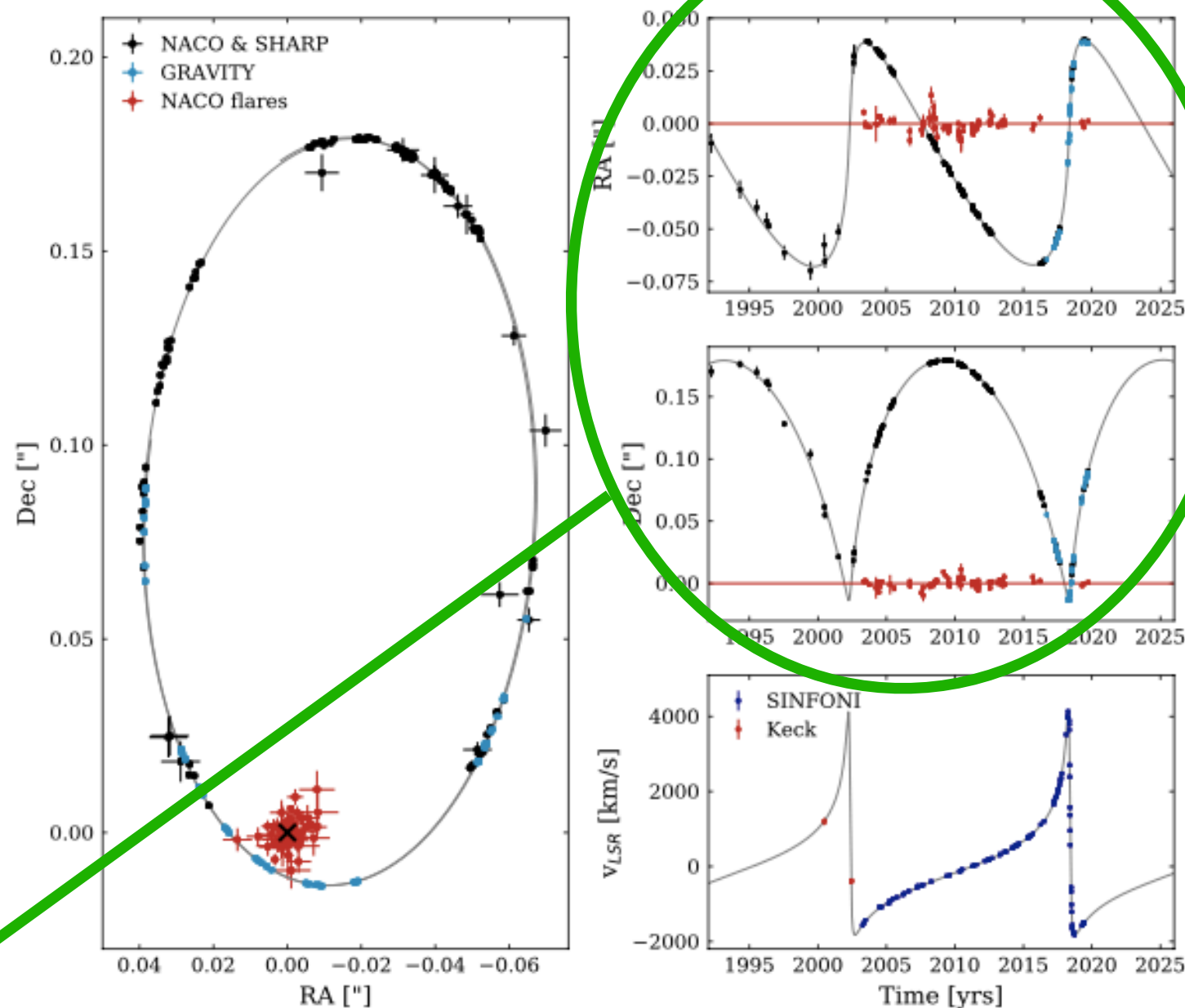


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Spectroscopic data

(SINFONI, ERIS from 2023)

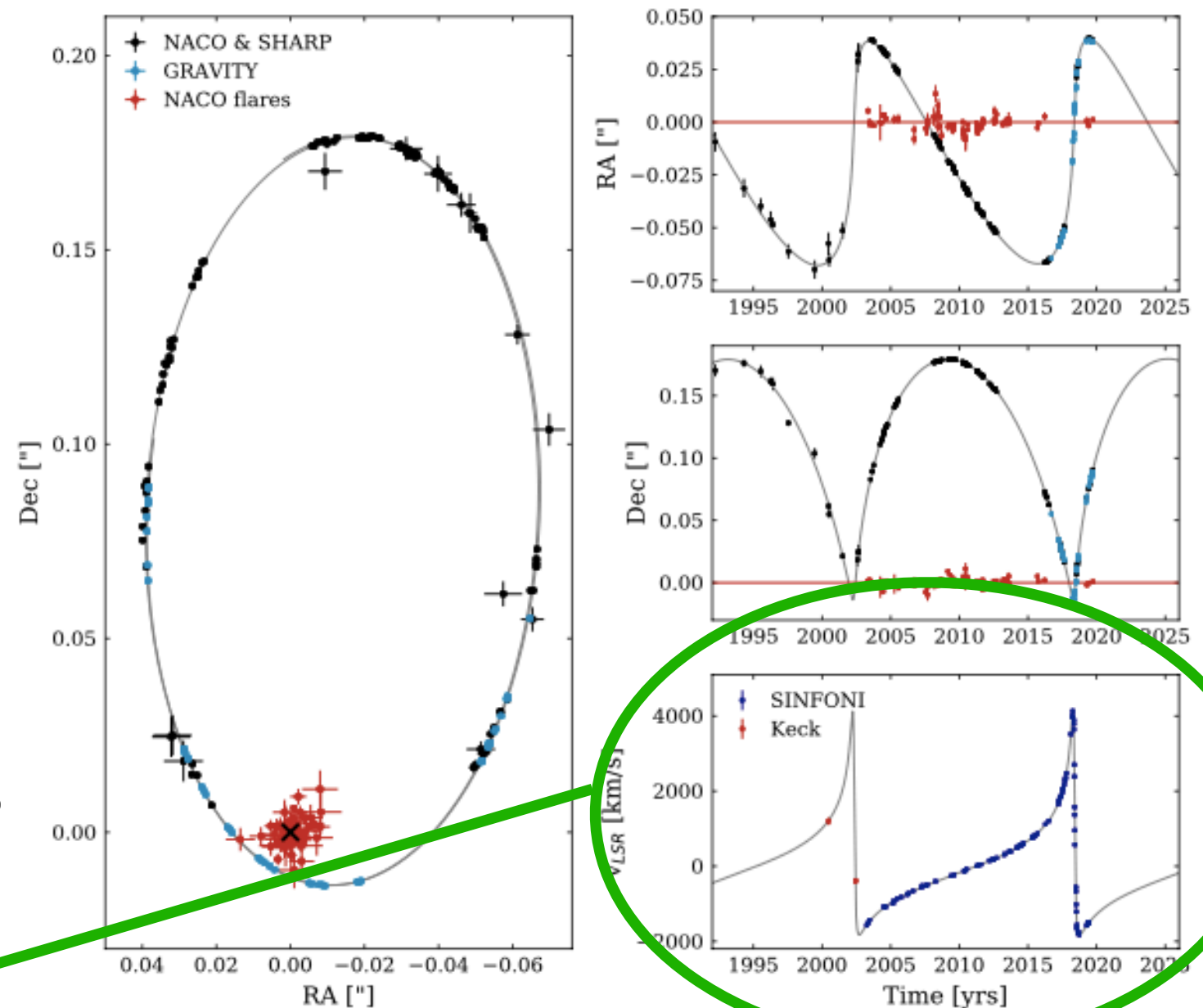


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Standard models for DM

① Power law: $\rho(r) = \rho_0 \left(\frac{r}{r_0} \right)^s$ $-2.75 \lesssim s \lesssim -1.5$ for stellar cusp
($r_0 = 40$ mpc) (Alexander & Hopman 2009, Preto & Amaro-Seoane 2010)

$-2.5 \lesssim s \lesssim -2.25$ for DM spike
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② Plummer profile: $\rho(r) = \rho_0 \left[1 + \left(\frac{r}{a} \right)^2 \right]^{-5/2}$ $0 < a \leq 40 \text{ mpc}$

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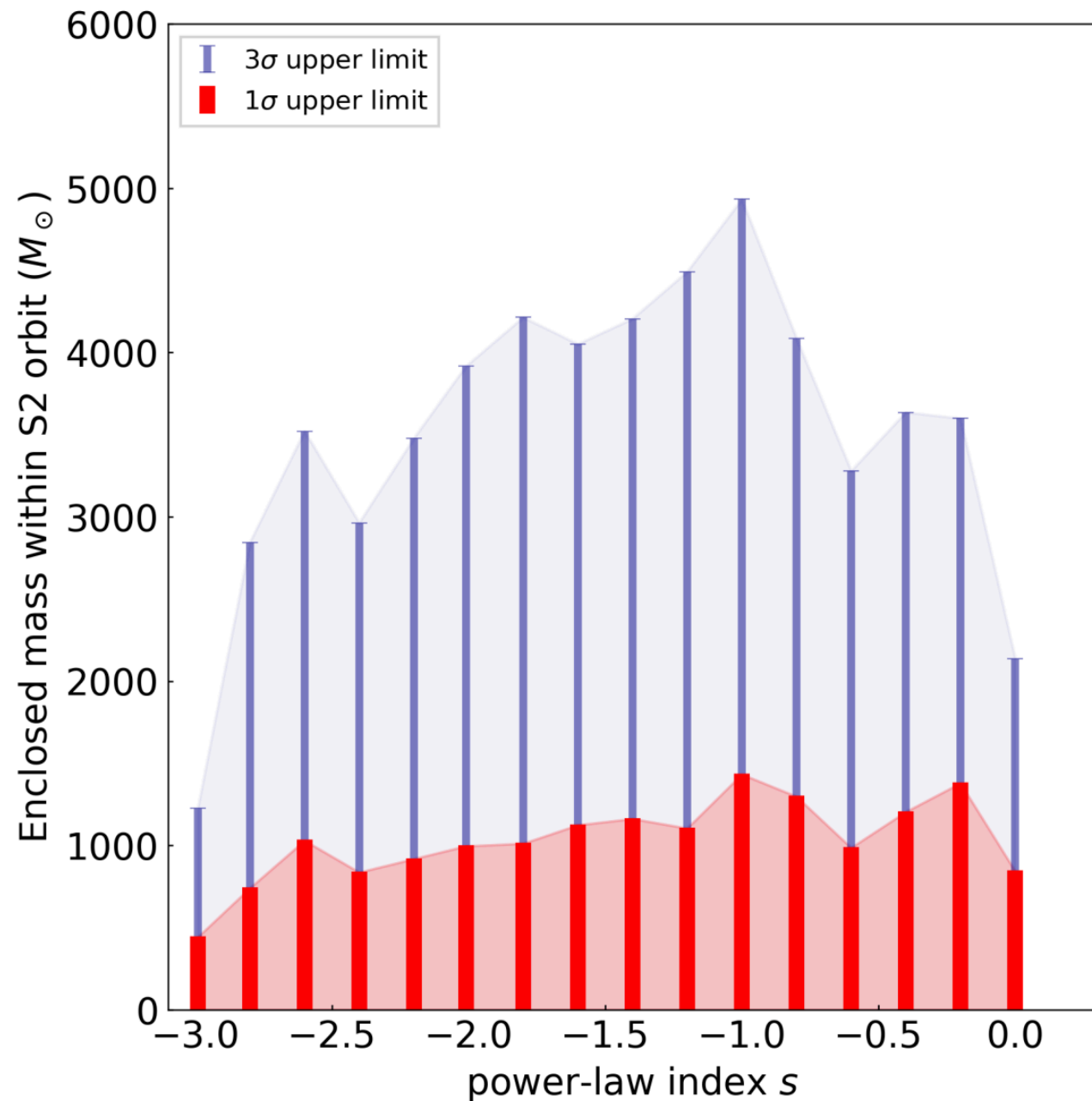
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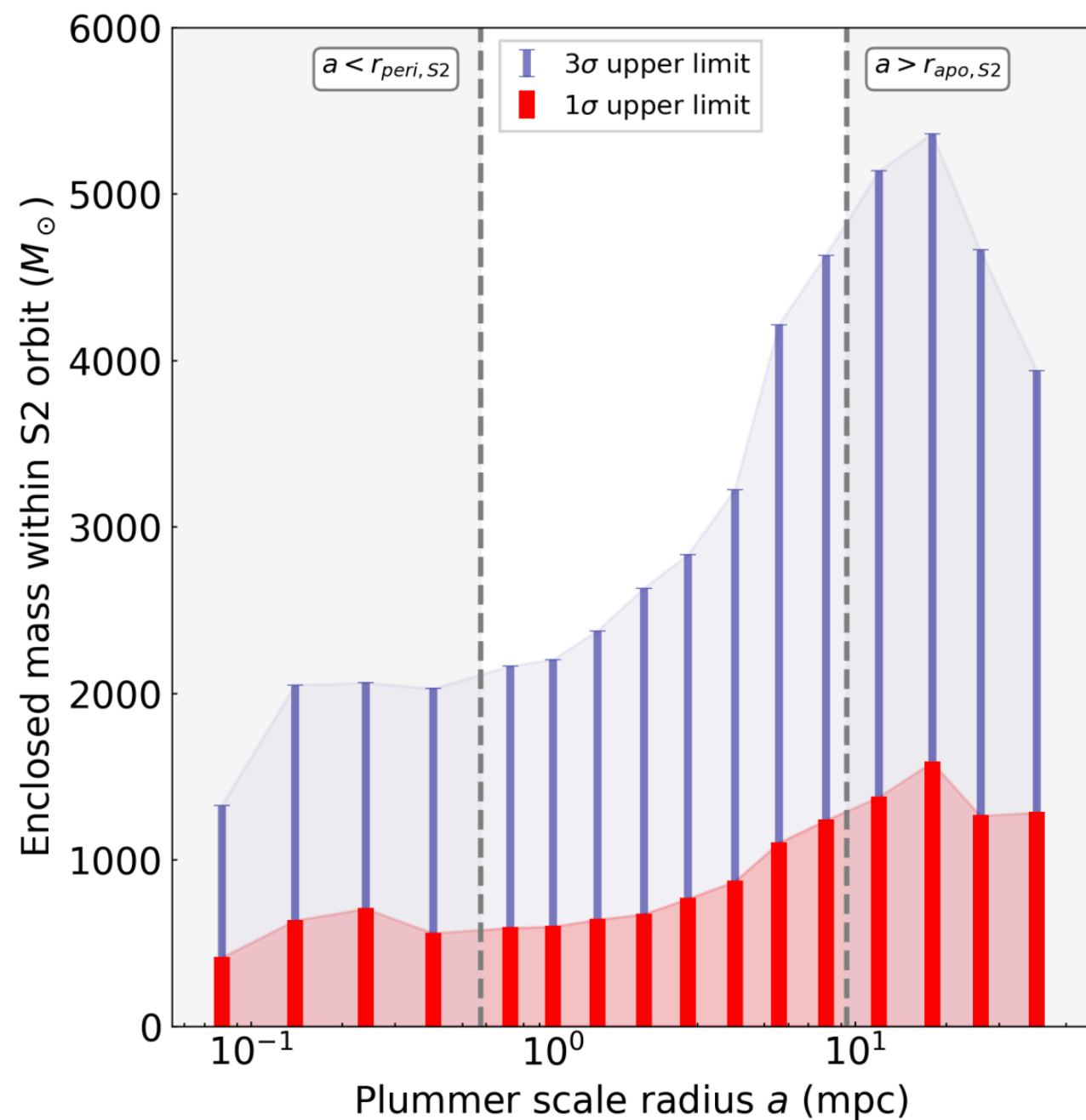
Spherical symmetry $\longrightarrow$ Orbits of **S2, S29, S55, S38** used

Standard models for DM

Power law profile



Plummer profile



Extended mass within $r_0 \sim 0.01$ pc (S2's apocenter) $M_{\text{ext}} < 1200 M_\odot$
 or 0.03 % $M_\bullet$, independently of density profile

Superradiant boson clouds

A monochromatic **massive** field with frequency ω interacts with a **rotating** BH, whose angular frequency at the horizon is Ω_H .

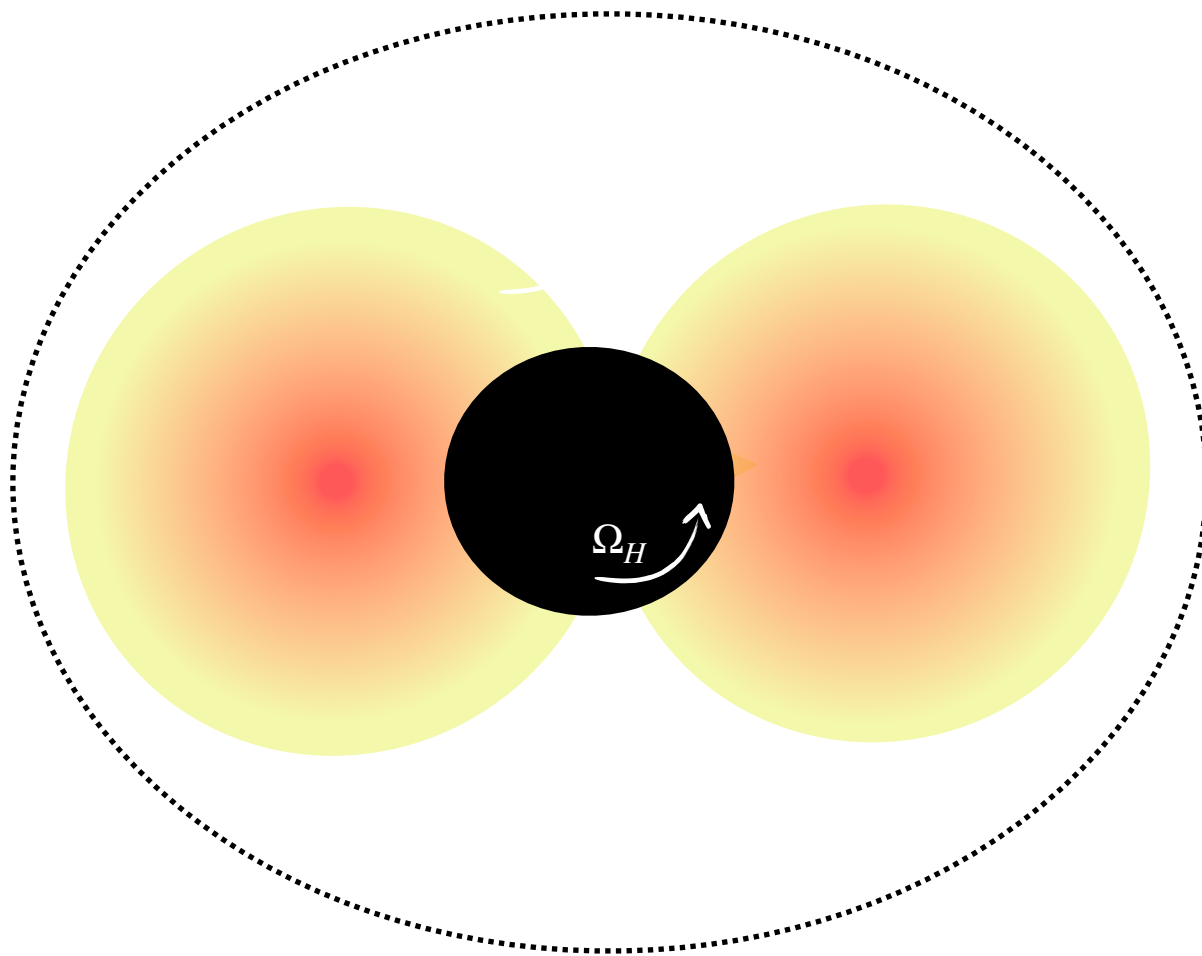
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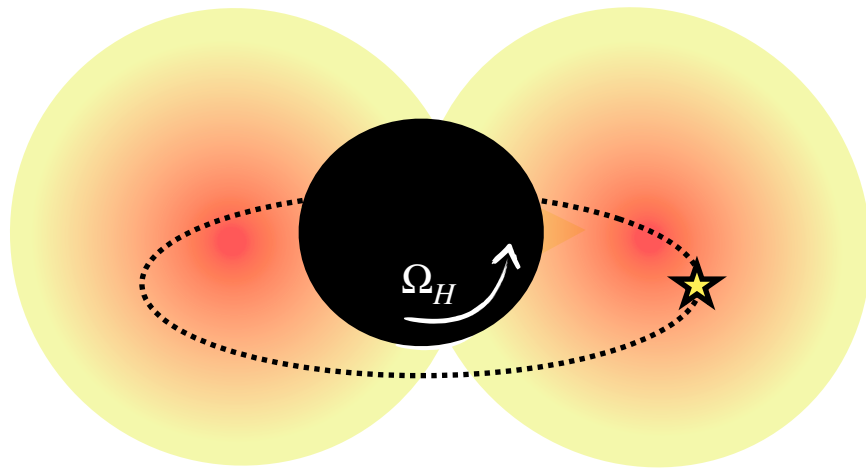
(Press & Teukolsky 1972, Cardoso et al. 2004, Brito et al. 2015)

Superradiance condition: $\omega < m\Omega_H$

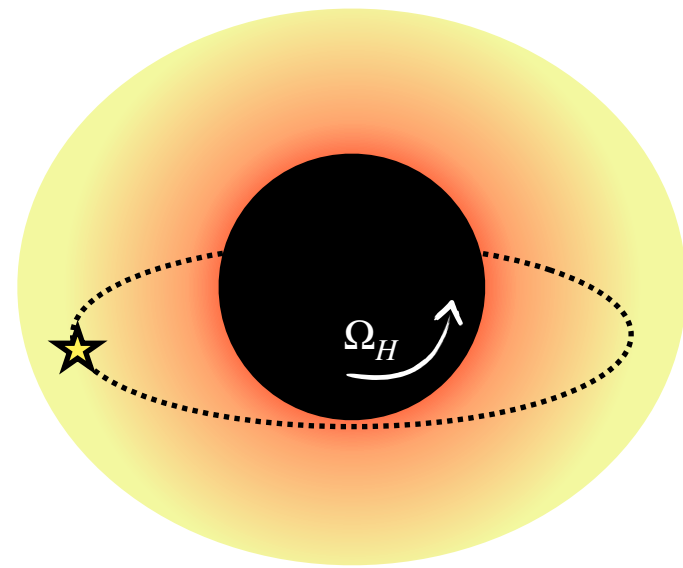


The field's mass μ acts as a **potential barrier** and the amplitude of the field **grows** in time, creating **condensed** states, the *boson clouds*.

Superradiant boson clouds



Scalar cloud

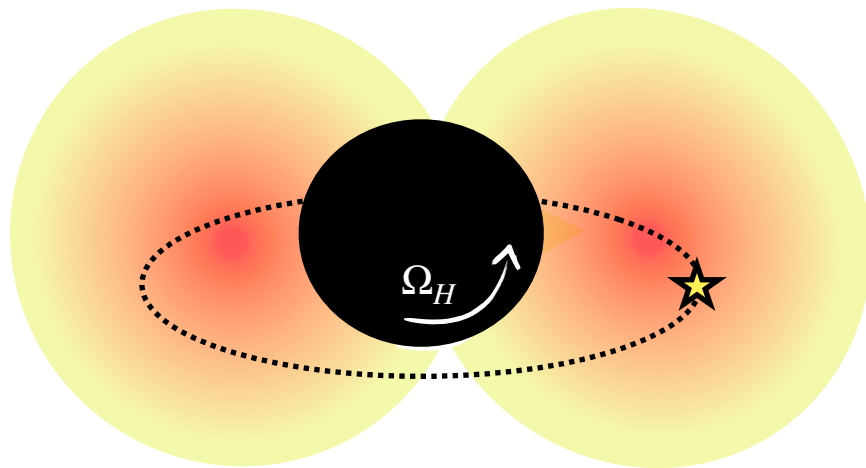


Vector cloud

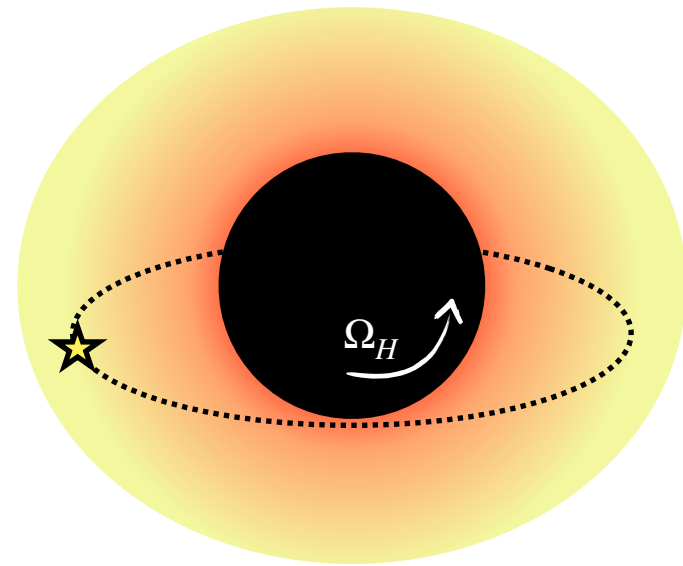
Mass coupling

$$\alpha = R_S \mu = \left[\frac{GM_\bullet}{c^2} \right] \left[\frac{m_s c}{\hbar} \right]$$

Superradiant boson clouds



Scalar cloud



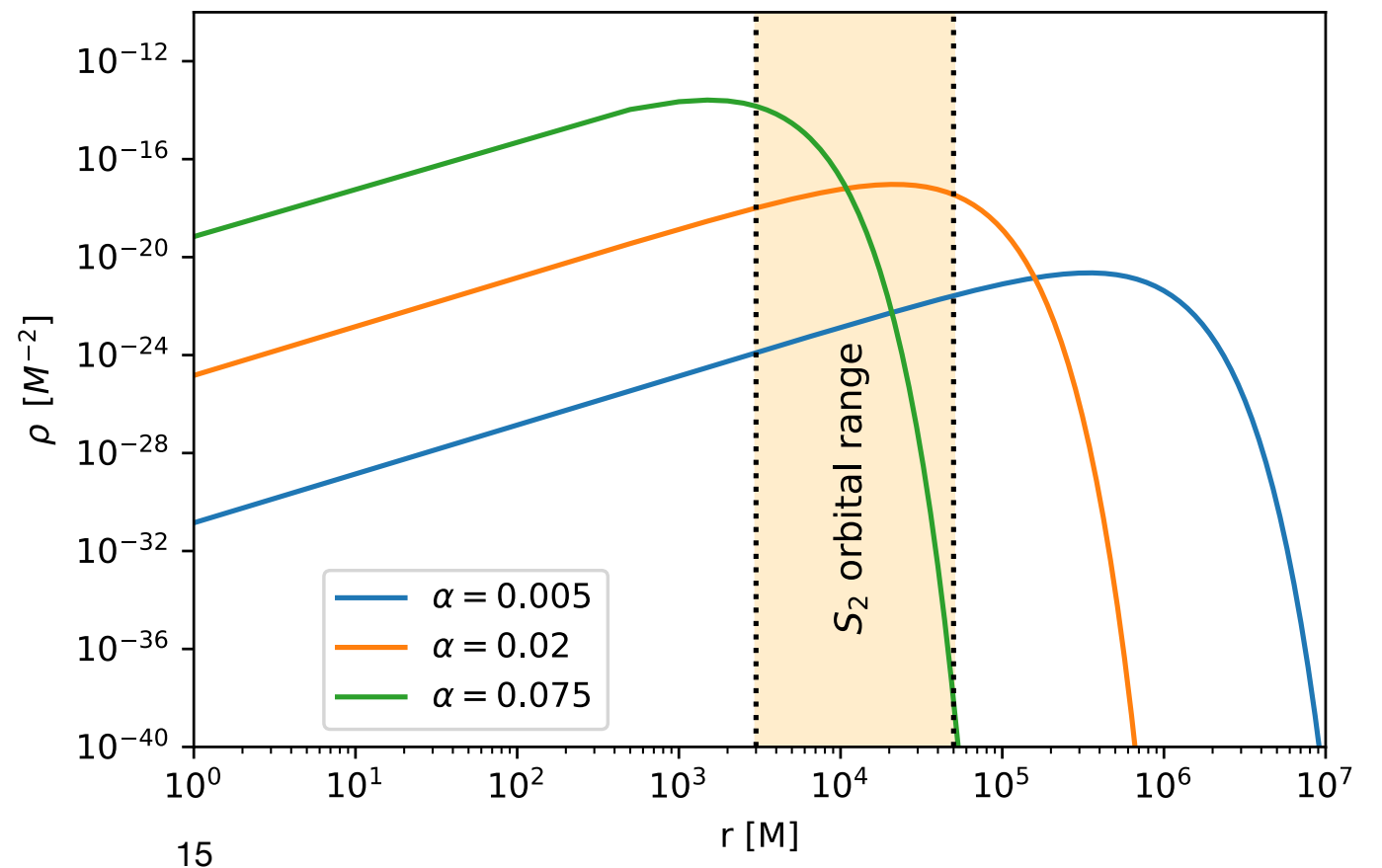
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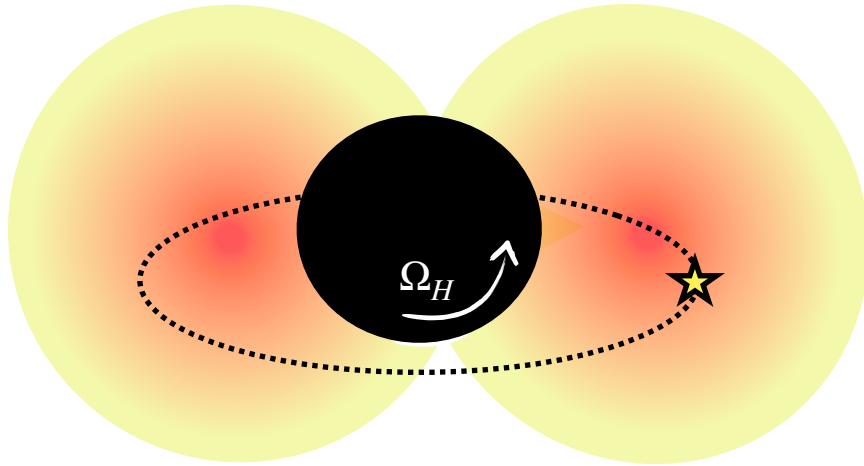
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$$R_{\text{peak}} = \frac{\int_0^\infty \rho \bar{r} d\bar{r}}{\int_0^\infty \rho d\bar{r}} = \frac{3M_\bullet}{\alpha^2}$$

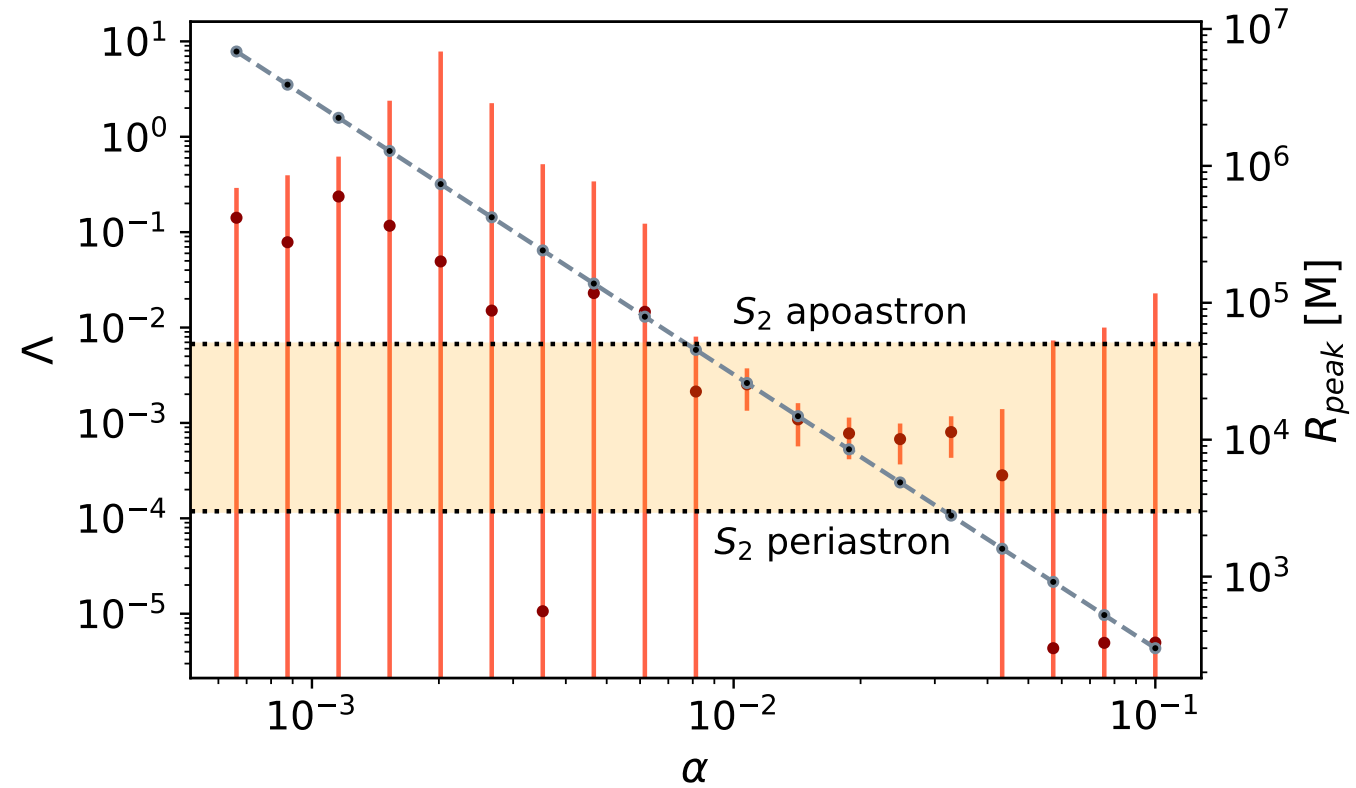
(Scalar cloud)



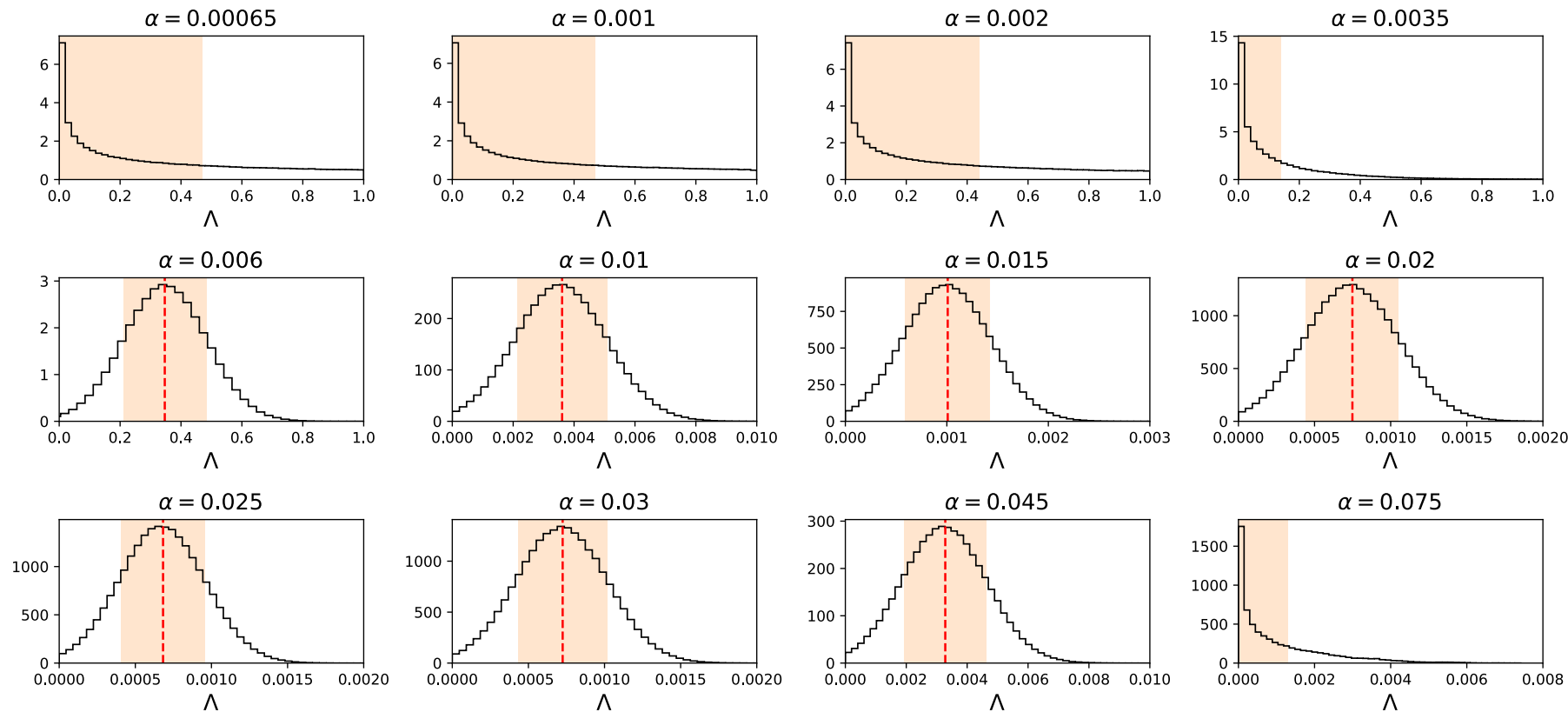
Superradiant boson clouds



Scalar cloud



Probability density $p(\Lambda_\alpha|D)$

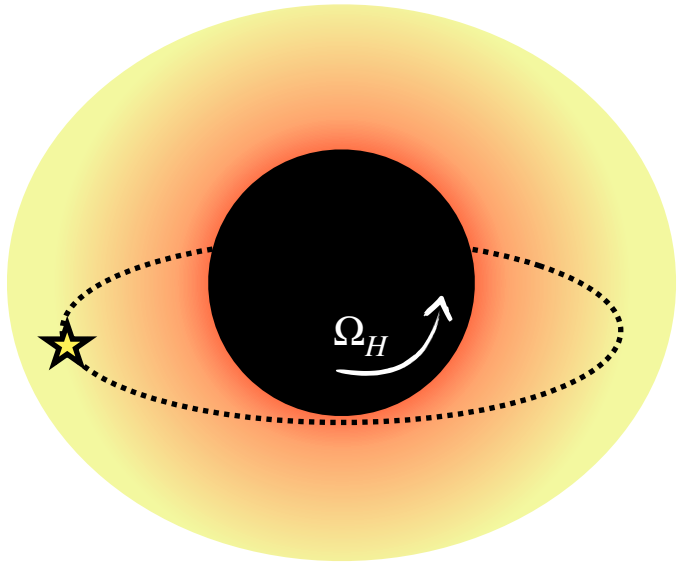


$$0.01 \lesssim \alpha \lesssim 0.04$$

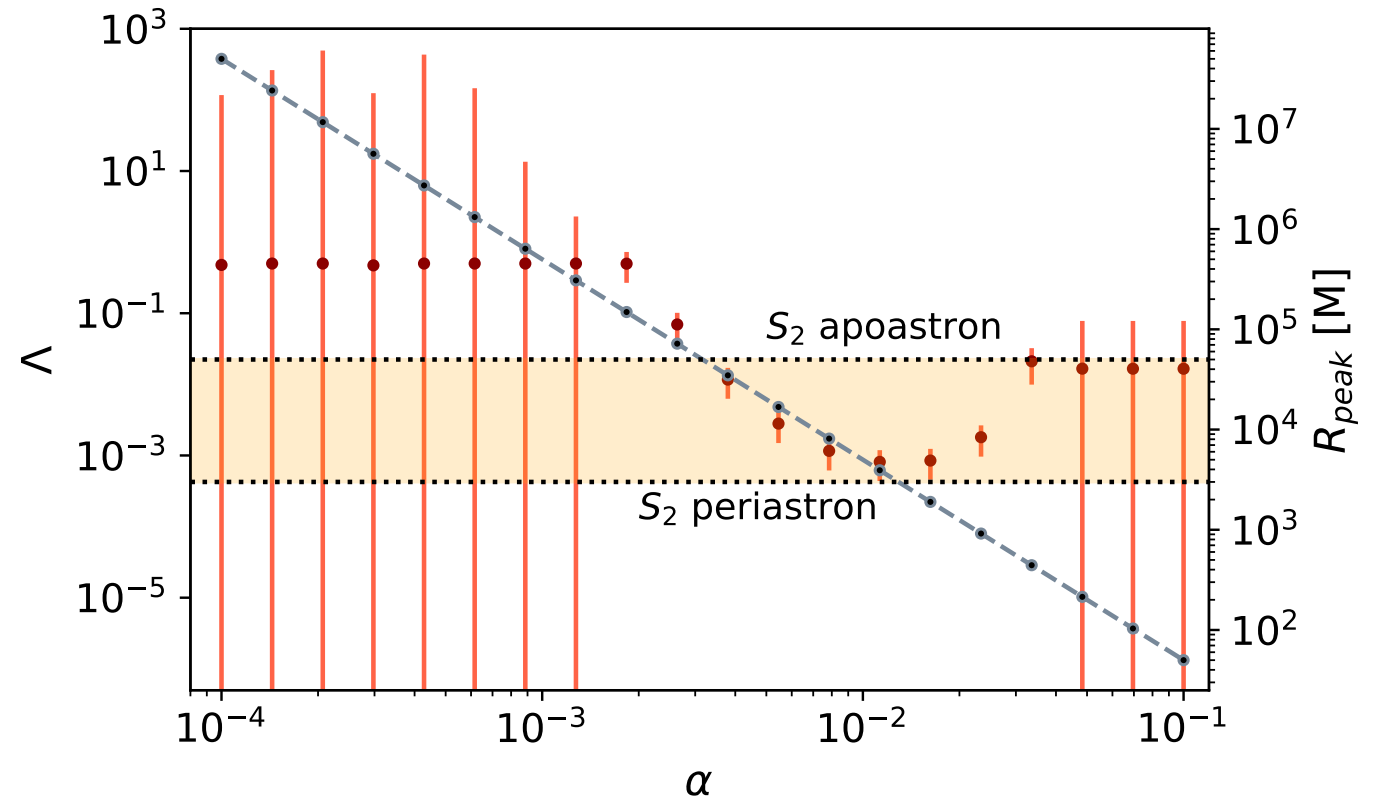
$$(10^{-19} \text{ eV} \lesssim m_s \lesssim 10^{-18} \text{ eV})$$

$$\Lambda = \frac{M_{\text{cloud}}}{M_{\bullet}}$$

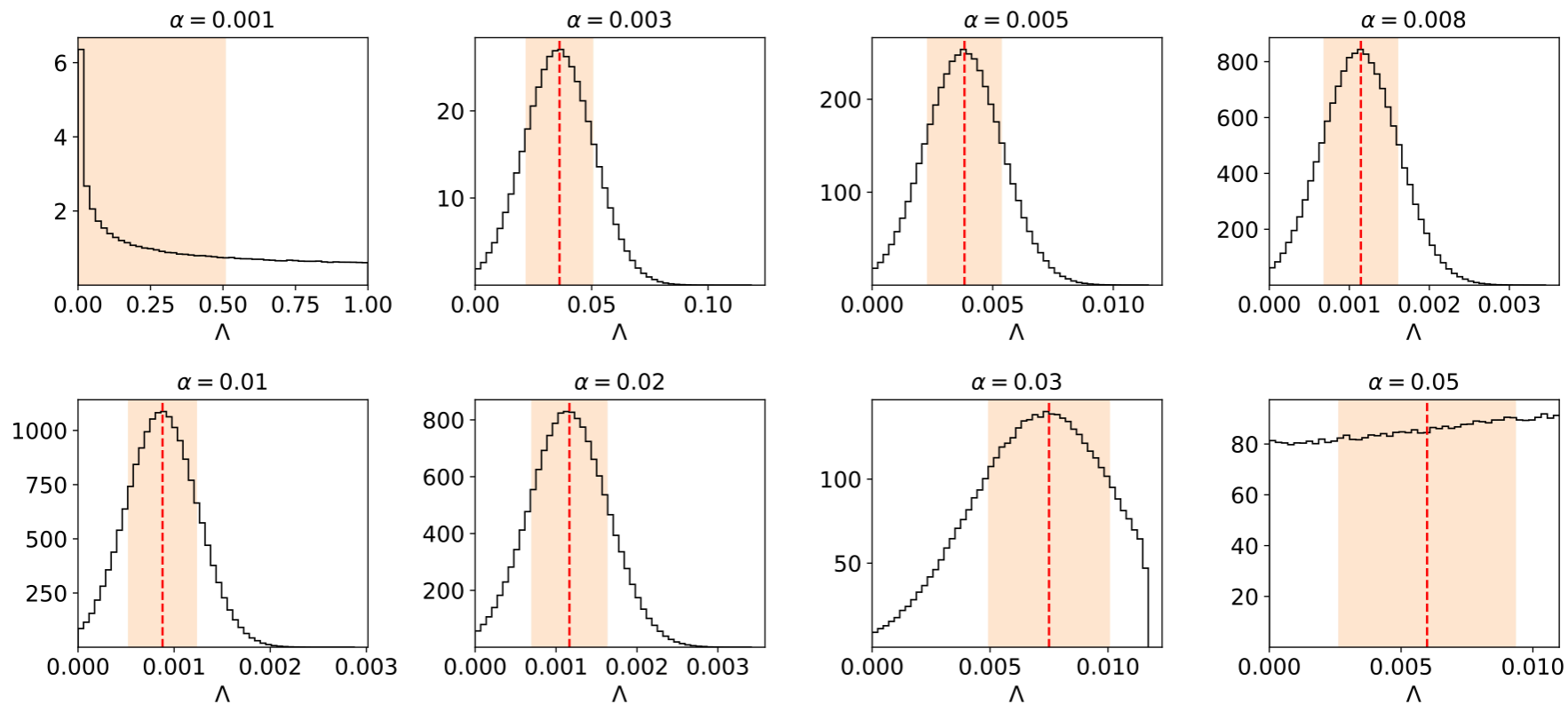
Superradiant boson clouds



Vector cloud



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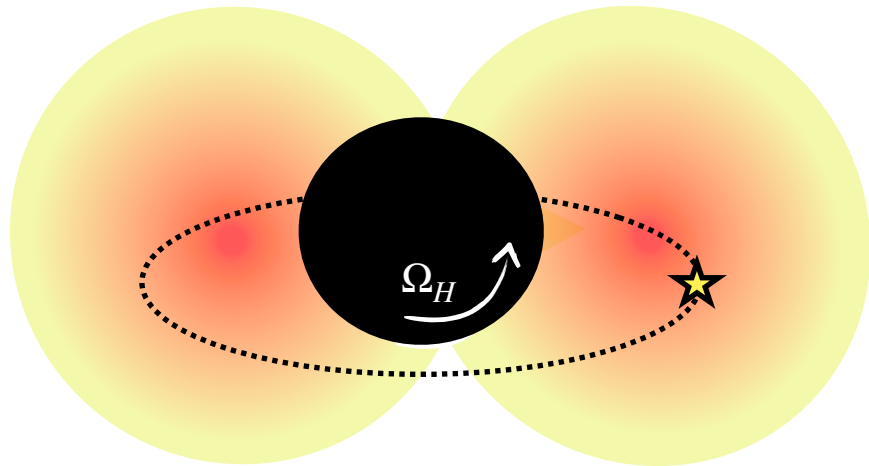


$$0.003 \lesssim \alpha \lesssim 0.03$$

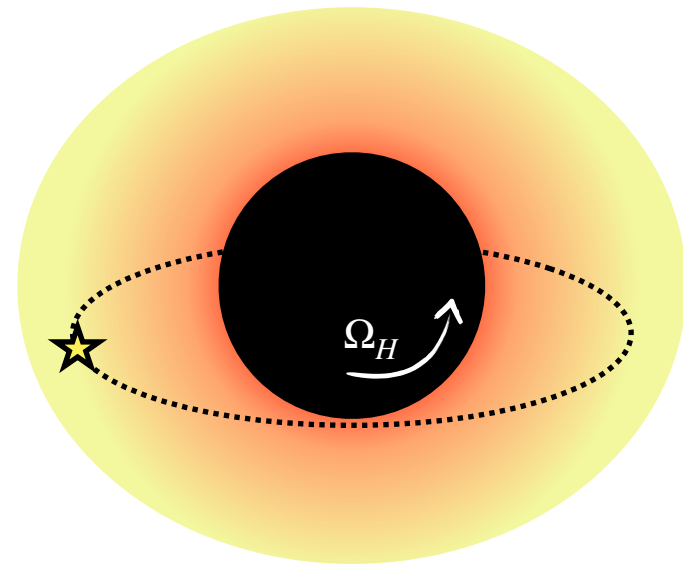
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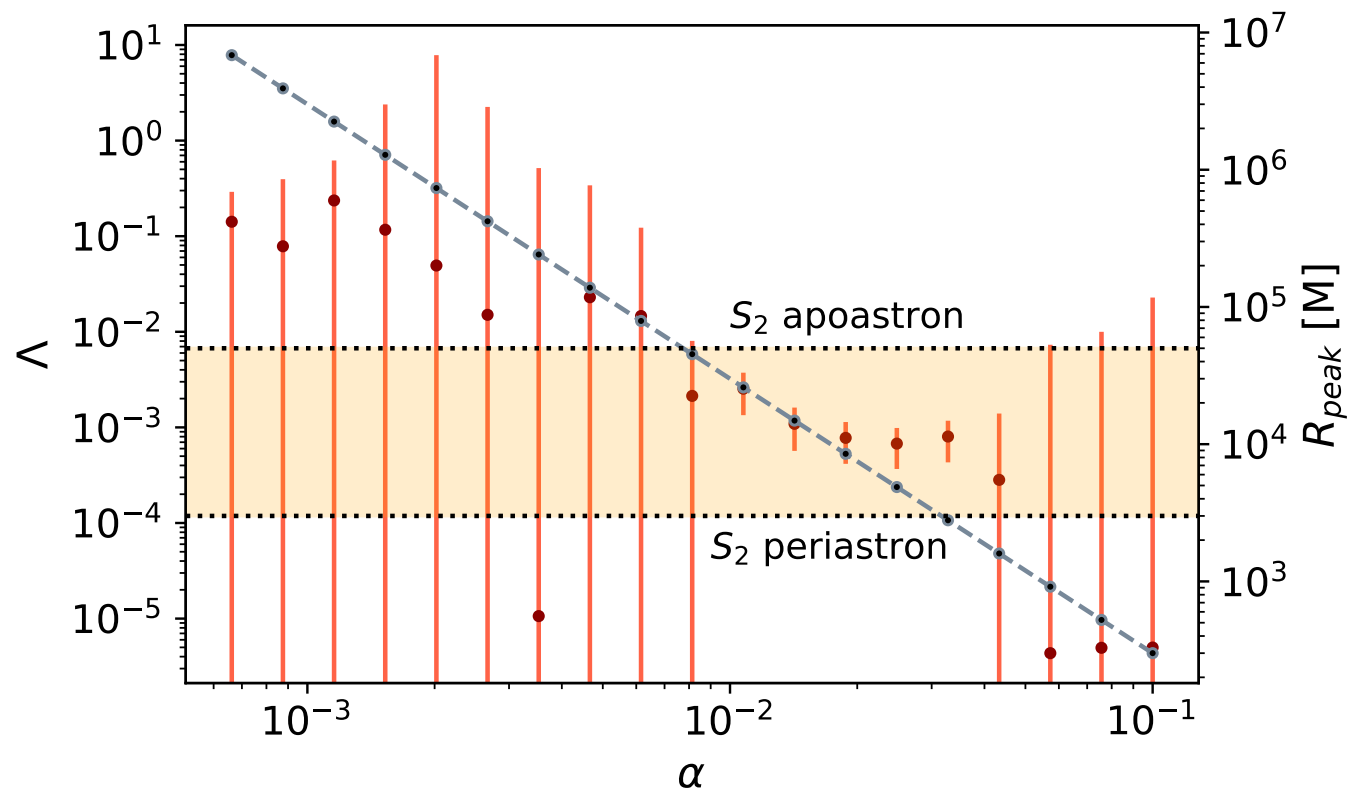
Superradiant boson clouds



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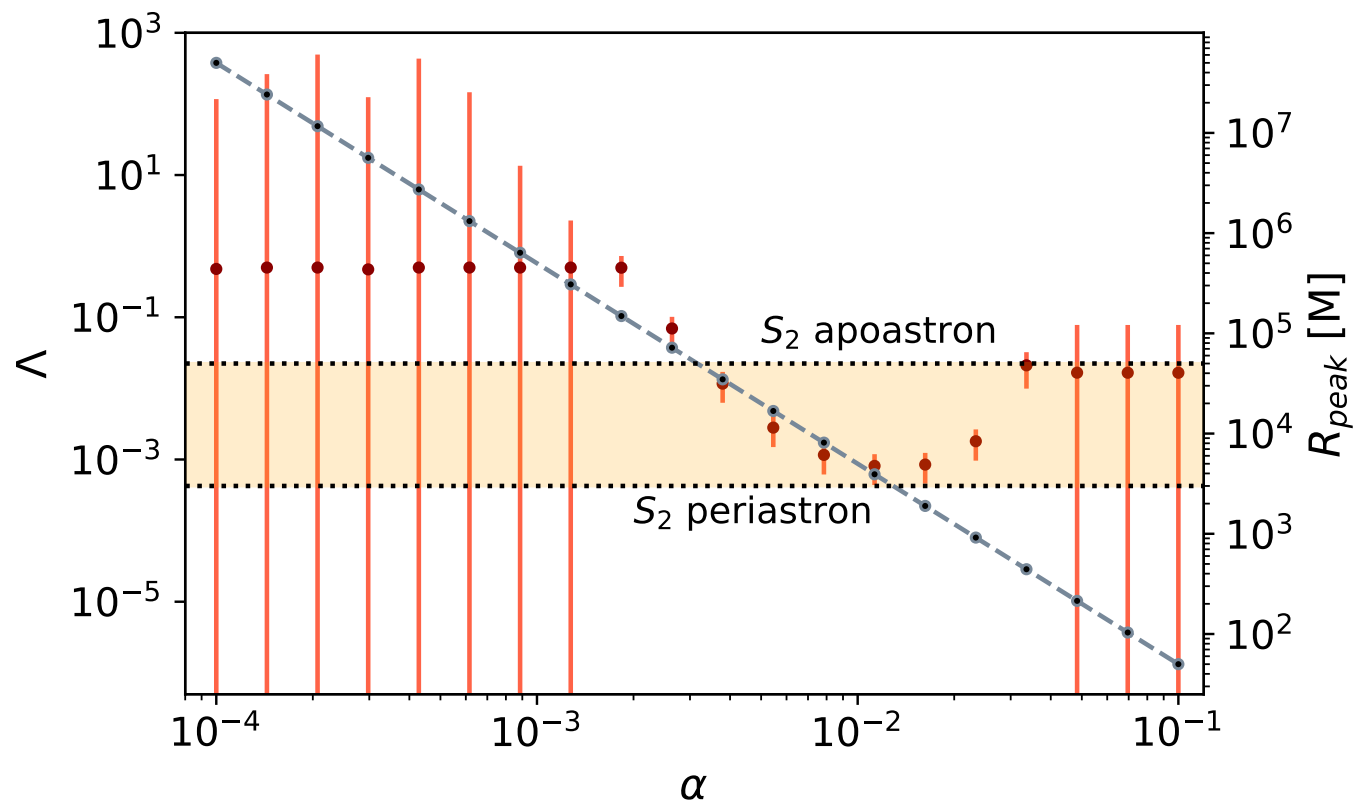
Vector cloud



$$0.01 \lesssim \alpha \lesssim 0.04$$

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$$M_{\text{cloud}} \lesssim_{18} 10^{-3} M.$$



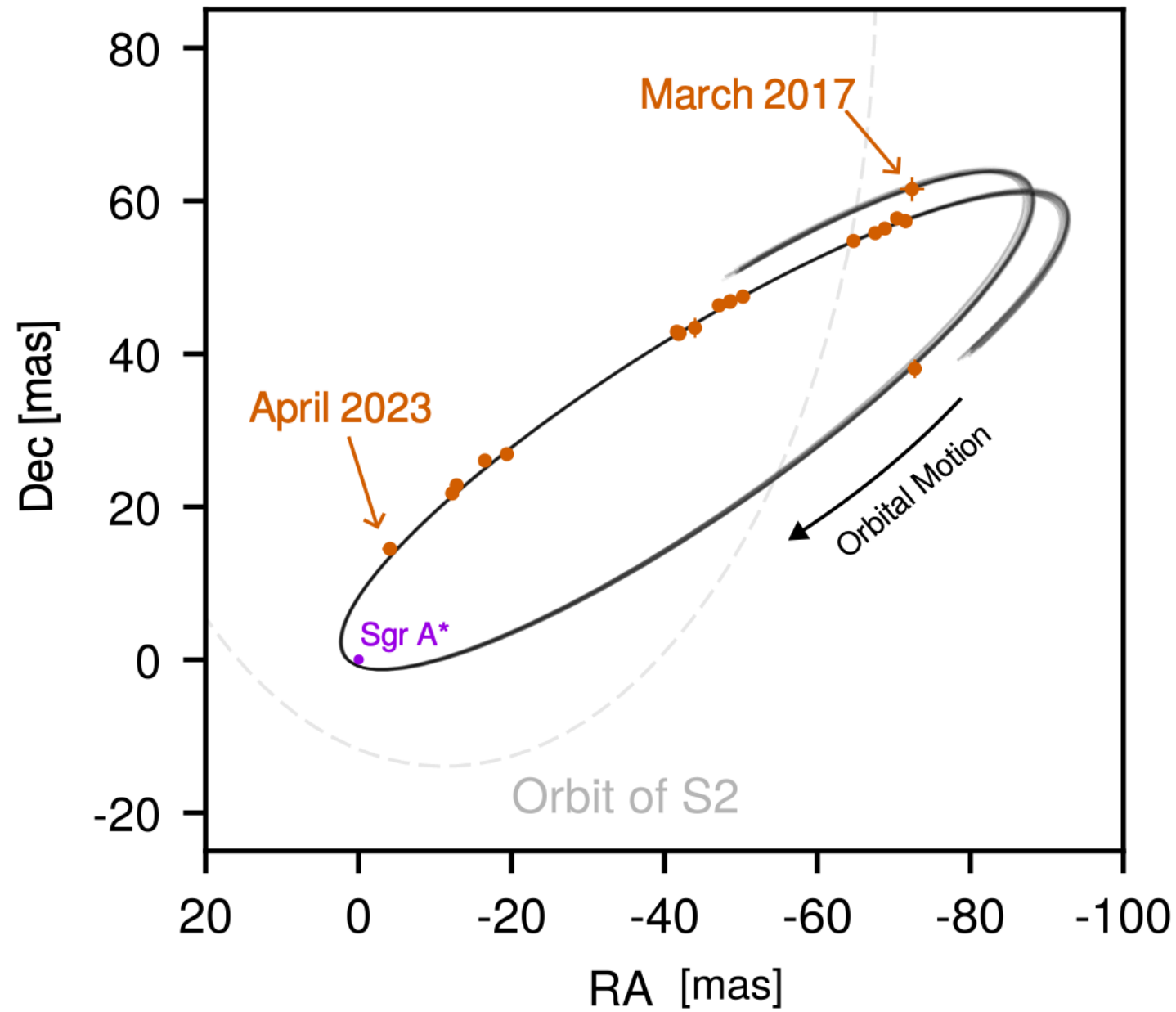
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The discovery of S301

(GRAVITY+ Coll. 2026)

$$r_p \sim 140 R_S$$
$$e \sim 0.98$$
$$P \sim 8.7 \text{ years}$$



The discovery of S301

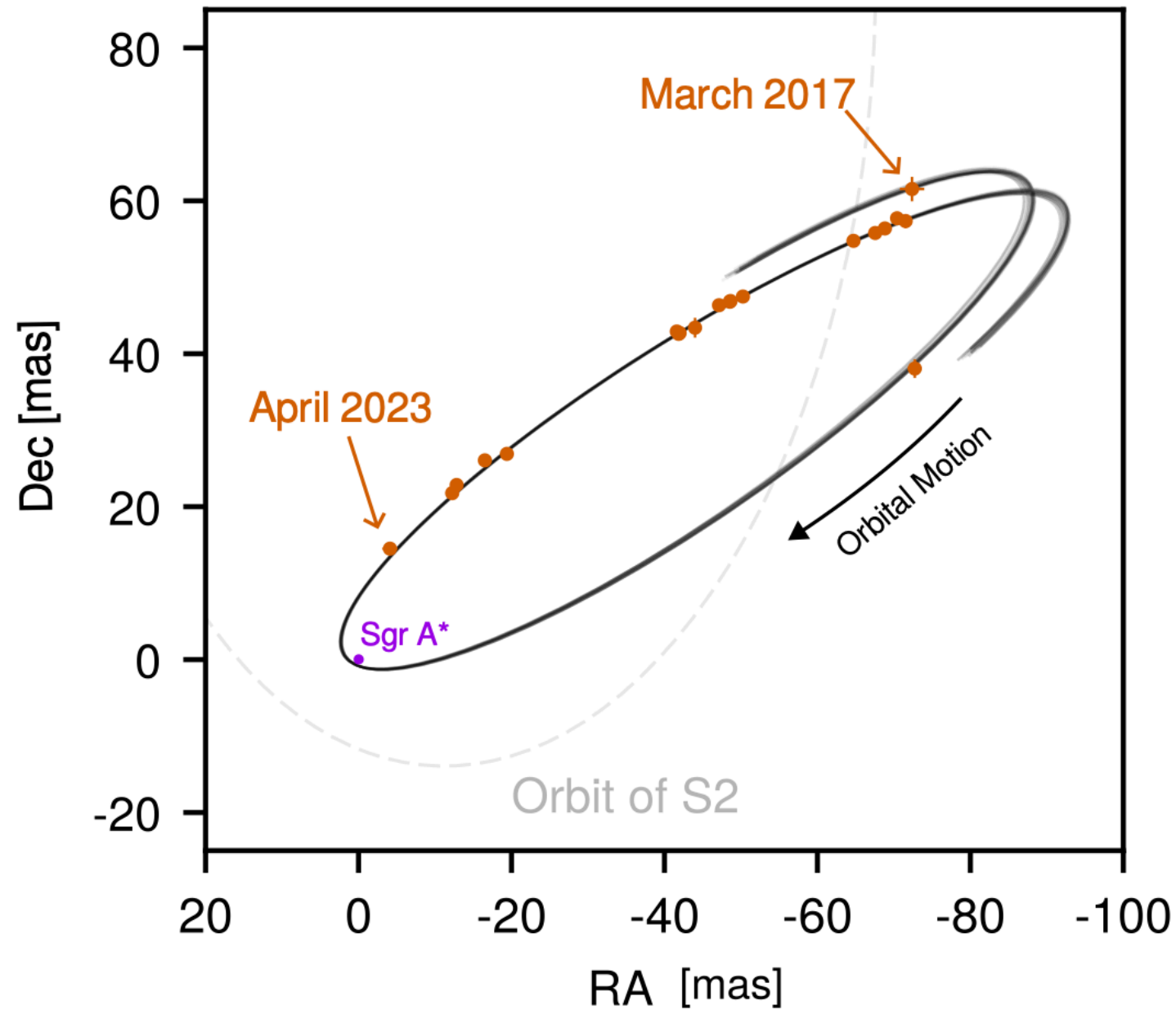
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precession becomes
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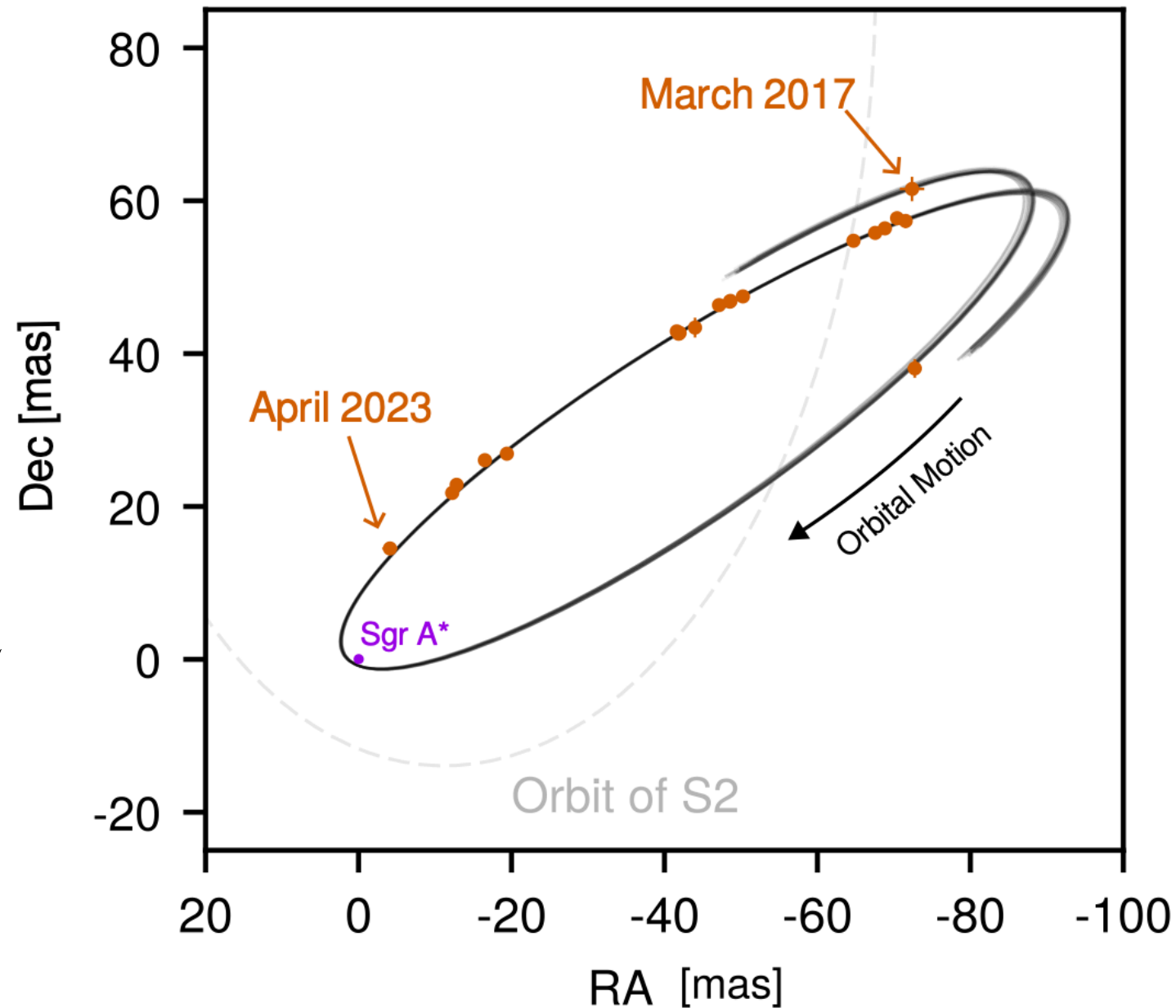
→ **Lense-Thirring
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measurable**

$$\Delta \varpi_{\text{LT}} = -8\pi\chi \cos \theta \left(\frac{GM_\bullet}{a(1-e^2)c^2} \right)^{3/2}$$

$\sim 0.11^\circ \chi \cos \theta$

$$\Delta \Theta_{\text{LT}} = -4\pi\chi \sin \theta \sin \lambda \left(\frac{GM_\bullet}{a(1-e^2)c^2} \right)^{3/2}$$

$\sim 0.05^\circ \chi \sin \theta \sin \lambda$



The effect of a disk-like structure

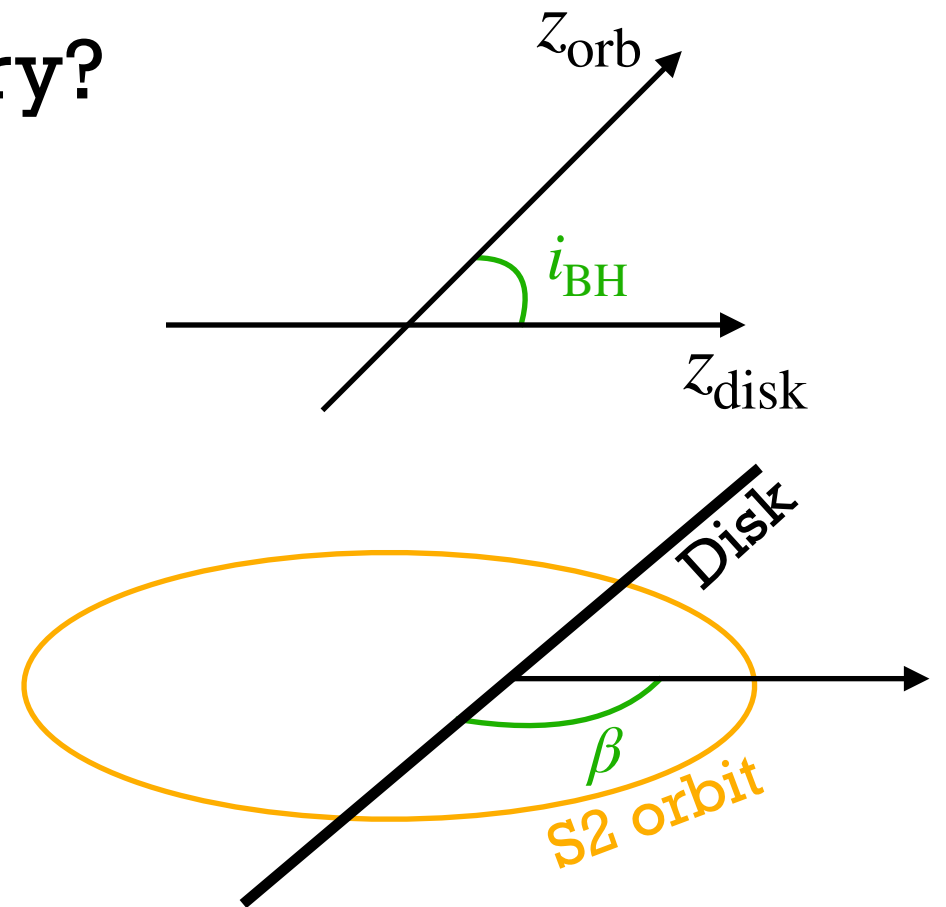
(Foschi et al. 2026)

What if we go beyond spherical symmetry?

i_{BH} = inclination between orbit and disk

β = angle between the line of nodes ℓ_{obs} and $z_{\text{BH//orb}}$

$$\Sigma_{\text{disk}} \propto r^{-\gamma}$$



The effect of a disk-like structure

(Foschi et al. 2026)

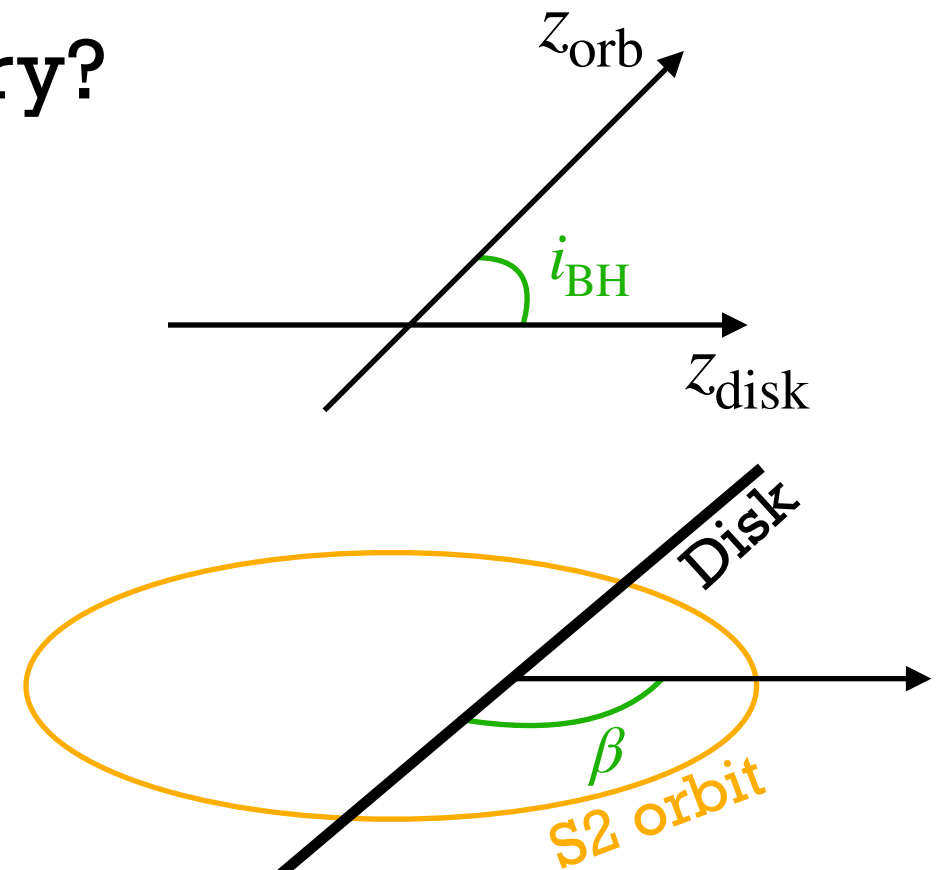
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→ It also generates an out-of-plane precession $\Delta\Theta$!



The effect of a disk-like structure

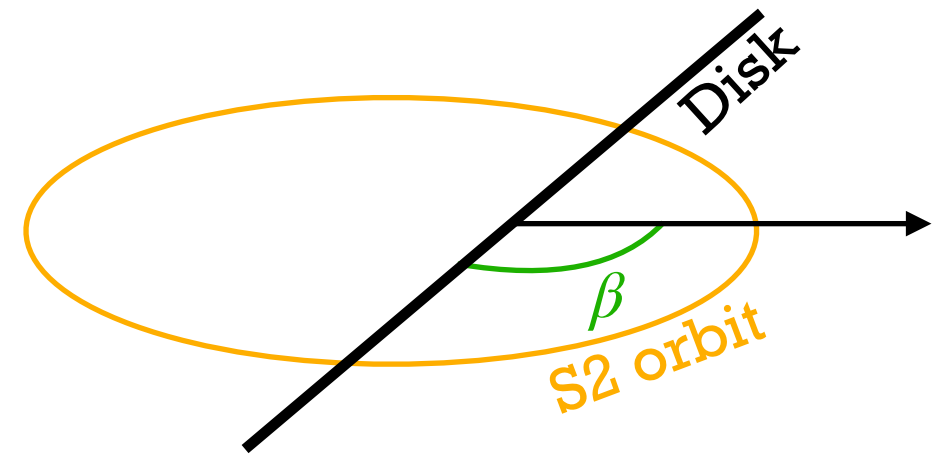
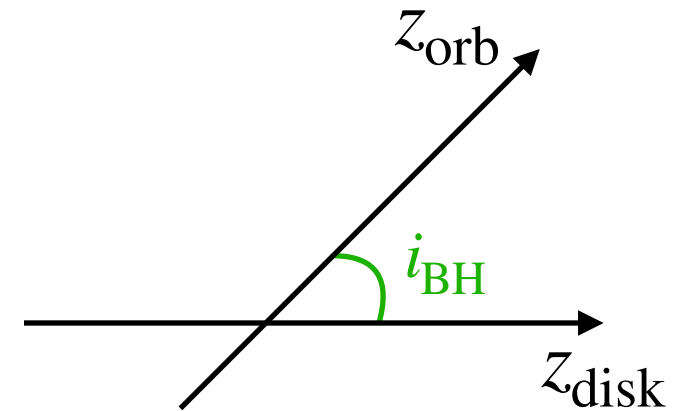
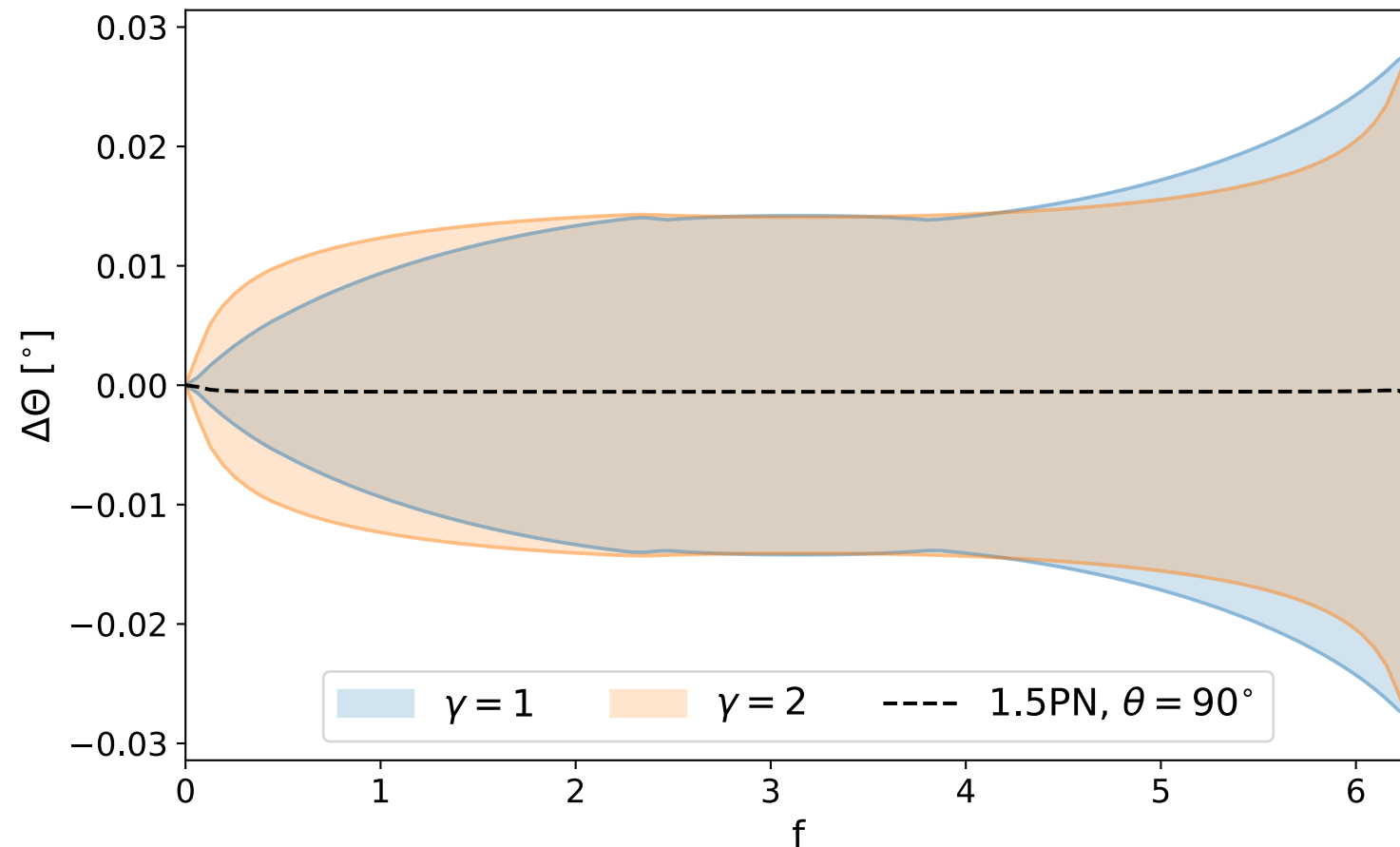
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S2



$$M_{\text{disk}} = 10^3 M_{\odot}$$

$i_{\text{BH}} = 1^\circ$ is fixed

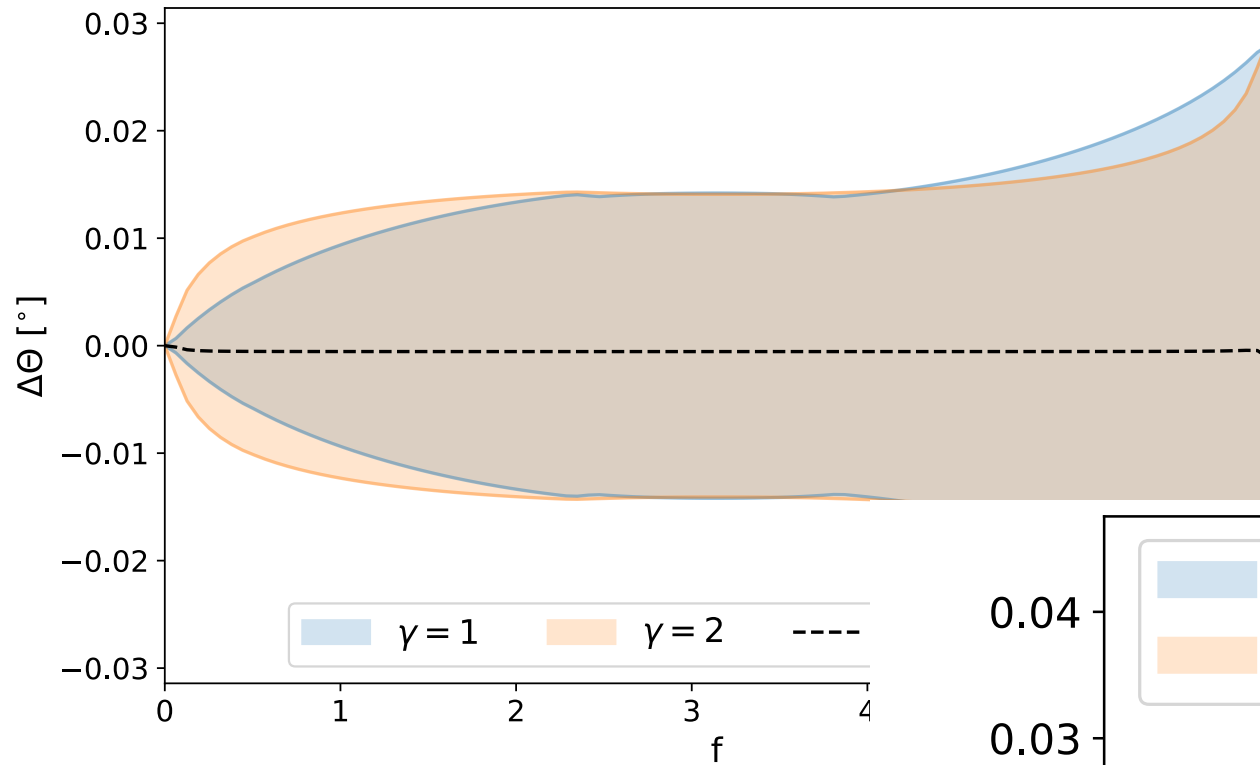
$$\beta \in [0, 2\pi)$$

$$\chi = 1$$

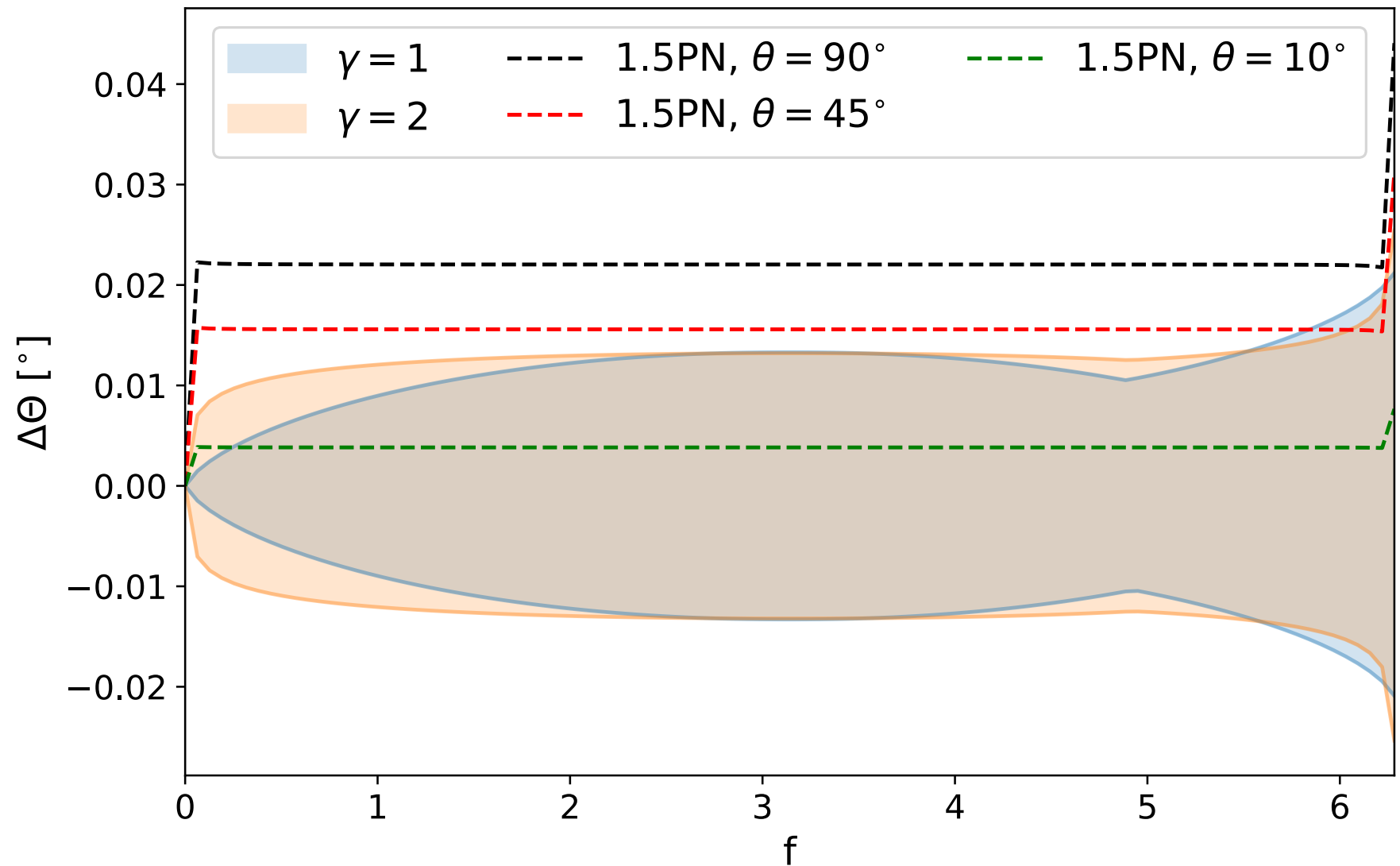
Degeneracy between disk and spin

(Foschi et al. 2026)

S2



S301



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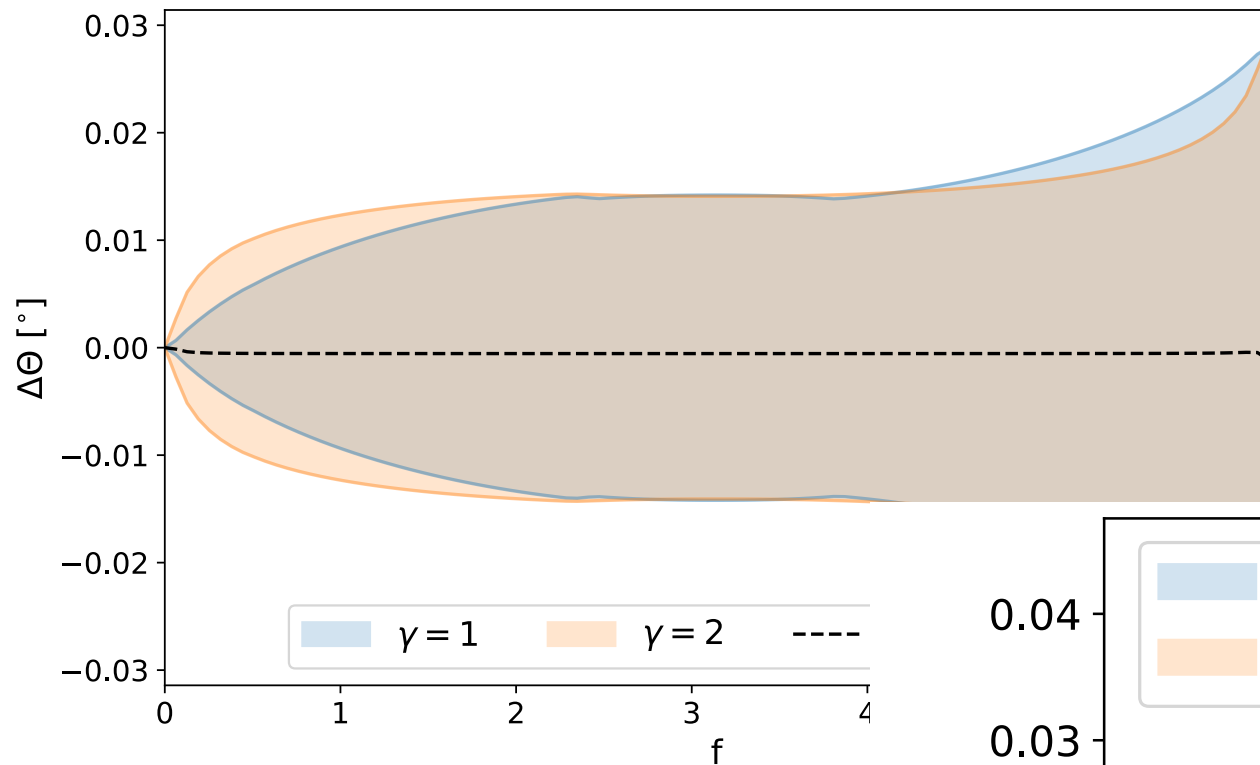
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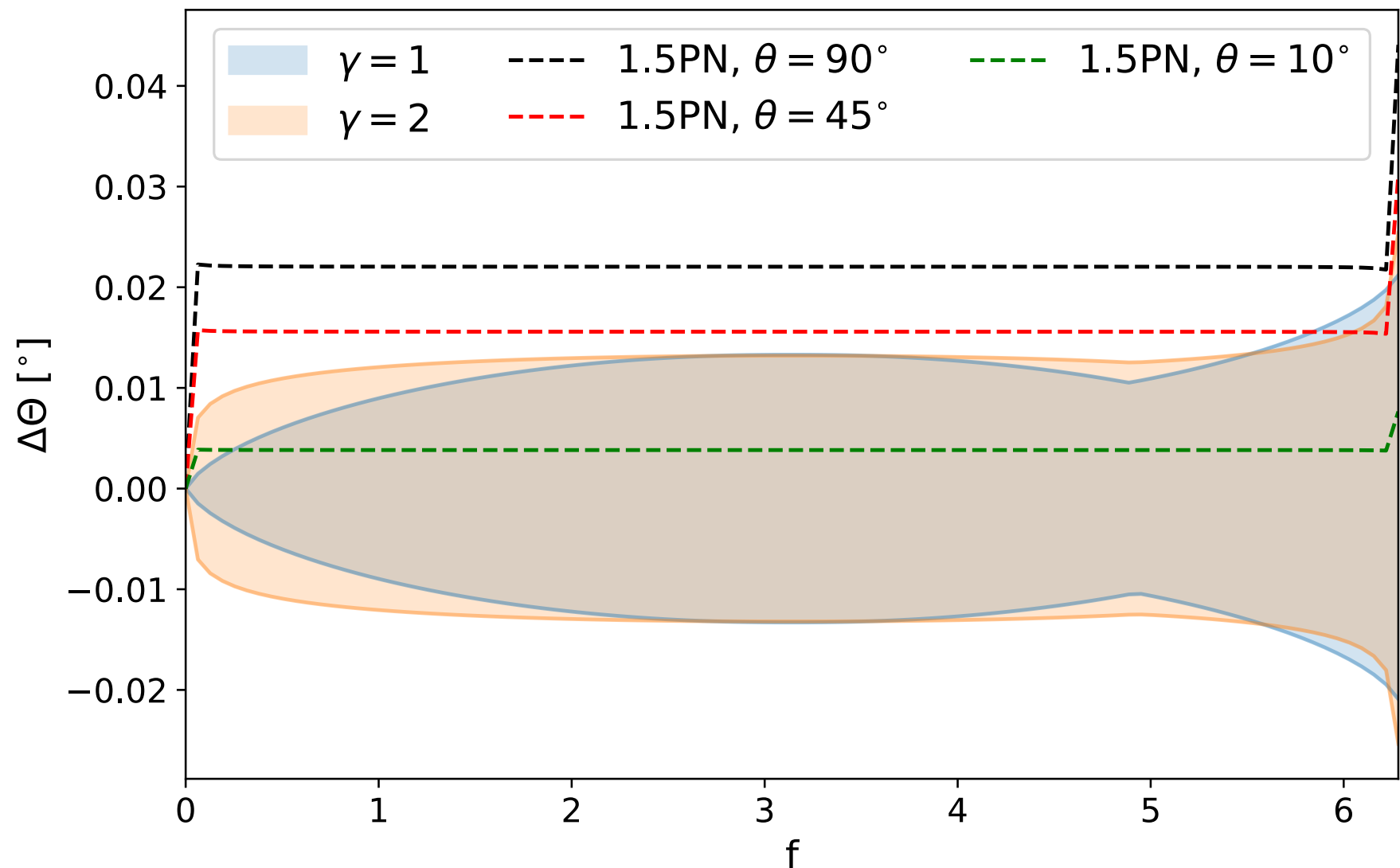
Degeneracy between disk and spin

(Foschi et al. 2026)

S2



S301



**Possible
degeneracy
between spin and
Newtonian effect of
a disk-like
structure**

Conclusions & future steps

- **Spherically symmetric distributions** around SgrA* within S2 orbital range have a mass upper limit of

$$M_{\text{ext}} \sim 10^{-3} M_{\bullet} \sim 10^3 M_{\odot}$$

regardless of the model tested.

- These limits will be improved with GRAVITY+ and more stars.
- Test **axisymmetric disk-like structures** of matter → new (different) upper limits on mass. (Foschi et al. 2026)
- Study the degeneracy with the Lense-Thirring precession in order to have a clean measurement of SgrA* spin.

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Stay tuned and thank you very much for you attention!

谢谢关注！