

# The no-hair theorems at work in M87\*

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Società Italiana di Fisica. 111° Congresso Nazionale, Palermo,  
22-26 Settembre 2025



# Outline

- 1 Motivations
- 2 The spin and orbital configuration
- 3 The Lense-Thirring and quadrupolar orbital precessions
- 4 Confrontation with the observations
- 5 Conclusions

# The observed jet precession in M87\*

- Recently, VLBI allowed to *measure* the *precession* of the *jet* from the *supermassive black hole*—or *megapyknon* [lorio 2025a]—M87\* [Cui et al. 2023, Cui and Lin. 2025] at a rate

$$|\Omega_p^{\text{exp}}| = 0.56 \pm 0.02 \text{ rad yr}^{-1} = 32 \pm 1.1^\circ \text{ yr}^{-1}. \quad (1)$$

- The *jet* and the *orbital angular momentum*  $\hat{h}$  of the *accretion disk* existing around M87\* are assumed *tightly coupled* [Cui and Lin. 2025].
- The *measured* features of the *jet precession* can be *reproduced*, both *qualitatively* and *quantitatively*, by a simple analytical model of the 1pN *Lense-Thirring* and *quadrupolar orbital precessions* of a *fictitious test particle* mimicking the accretion disk assumed circular [lorio 2025b, lorio 2025c].

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# The spin-orbit geometry of M87\*

- The SMBH's **spin axis** is [Cui et al. 2023]

$$\hat{\mathbf{k}} = \{ \sin \theta \sin \eta_p, -\sin \theta \cos \eta_p, \cos \theta \}, \quad (2)$$

$$\theta = 17.21^\circ, \eta_p = 288.47^\circ. \quad (3)$$

- The particle/disk's **orbital angular momentum** is [Cui et al. 2023]

$$\hat{\mathbf{h}} = \{ \sin \phi \cos \eta, \sin \phi \sin \eta, \cos \phi \}, \quad (4)$$

$$\phi_0 = 17.85^\circ, \eta_0 = 291.7^\circ. \quad (5)$$

The angles  $\eta$  and  $\phi$  are called **position angle** and **viewing angle**, respectively [Cui et al. 2023].

- The **measured angle** between the **jet** and the **SMBH's spin axis** is [Cui et al. 2023]

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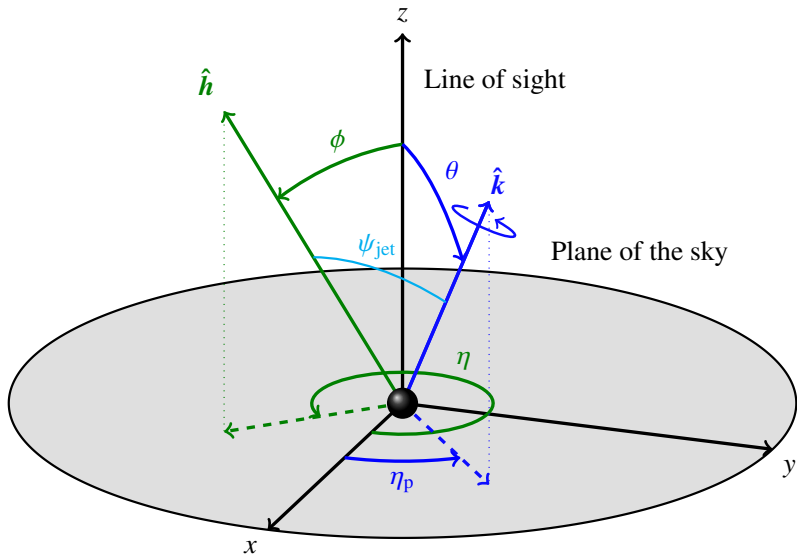
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# The no-hair orbital precession

The **Lense-Thirring** and **quadrupolar** orbital precessions of the **orbital angular momentum** of a test particle are

$$\frac{d\hat{\mathbf{h}}}{dt} = \boldsymbol{\Omega}^{\text{LT}} \times \hat{\mathbf{h}}, \quad (7)$$

$$\boldsymbol{\Omega}^{\text{LT}} = \frac{2GJ}{c^2 r_0^3} \hat{\mathbf{k}}. \quad (8)$$

$$\frac{d\hat{\mathbf{h}}}{dt} = \boldsymbol{\Omega}^{Q_2} \times \hat{\mathbf{h}}, \quad (9)$$

$$\boldsymbol{\Omega}^{Q_2} = \frac{3n_{\text{K}} Q_2}{2Mr_0^2} (\hat{\mathbf{k}} \cdot \hat{\mathbf{h}}) \hat{\mathbf{k}}. \quad (10)$$

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- In eq. (8) and eq. (10),  $G$  is the Newtonian constant of gravitation,  $c$  is the speed of light,  $r_0$  is the radius of the effective circular orbit representing the accretion disk,  $M$  is the mass of the black hole—or *pyknon* [lorio 2025a],  $n_K := \sqrt{GM/r_0^3}$  is the Keplerian mean motion, and  $J$  and  $Q_2$  are the spin angular momentum and the quadrupole mass moment of the SMBH, respectively.
- According to the no-hair theorems, the spin angular momentum and the quadrupole mass moment of a Kerr black hole are given by

$$J = a^* \frac{M^2 G}{c}, \quad |a^*| \leq 1, \quad (11)$$

$$Q_2 = -\frac{J^2}{c^2 M} = -a^{*2} \frac{M^3 G^2}{c^4}. \quad (12)$$

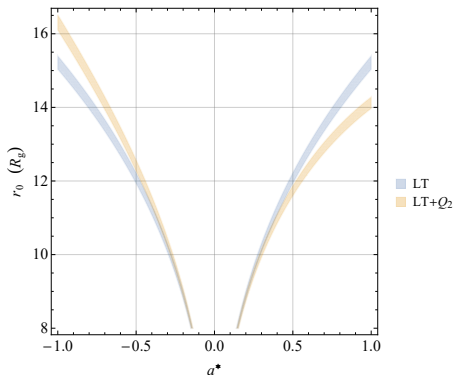
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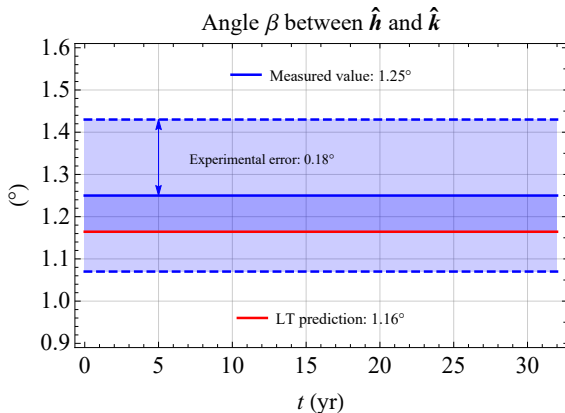
# Constraints on the hole's spin and the disk radius

By **imposing** that the *theoretically* predicted no-hair jet precessions  $\Omega^{\text{LT}}$  or  $\Omega^{\text{LT}} + \Omega^{\text{Q}_2}$  lie within the *measured bounds* set by eq. (1), one gets the following **allowed regions** in the  $\{a^*, r_0\}$  plane, where  $R_g = GM/c^2$  is the hole's gravitational radius.



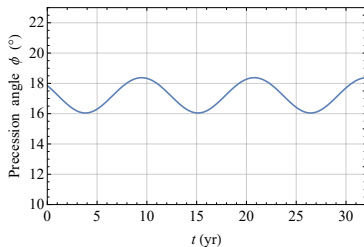
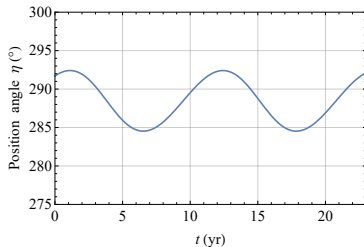
# The spin-orbit angle

The angle  $\beta$  between  $\hat{\mathbf{k}}$  and  $\hat{\mathbf{h}}$ , *theoretically calculated* from the Lense-Thirring precession for  $a^* = 0.9375$ ,  $r_0 = 14.9R_g$ , agrees well with the *measured* value of eq. (6)



# The precession of the jet's axis

The *theoretically* produced Lense-Thirring time series for  $\eta$  and  $\phi$ , calculated by simultaneously integrating eqs. (7)–(8) with the initial conditions of eq. (5) and  $a^* = 0.9375$ ,  $r_0 = 14.9R_g$ , agree both *qualitatively* and *quantitatively* with the corresponding *measured* signals in [Cui et al. 2023]



# Summary and overview (I)

- By assuming a *tight disk-jet coupling* in M87\*, a simple 1pN *analytical* model of the *orbital precessions* of a fictitious test particle due to the black hole's *Lense-Thirring* and *quadrupole* fields is able to *reproduce* the recently *measured* features of the *jet precession*.
- By considering the spin parameter  $a^*$  and the effective disk radius  $r_0$  as independent variables of the *theoretical* disk precession rate  $\Omega^{\text{theo}}$ , *allowed regions* in the  $\{a^*, r_0\}$  plane can be obtained by imposing that  $\Omega^{\text{theo}}$  is constrained by its *measured* counterpart  $\Omega_p^{\text{exp}}$ .

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## Summary and overview (II)

- The inclusion of the hole's **quadrupole  $Q_2$**  removes the **degeneration** of the two allowed branches in the  $\{a^*, r_0\}$  plane occurring for the **negative** and **positive** values of  $a^*$  when only the **Lense-Thirring** effect is considered. The resulting allowed regions tend to become **indistinguishable** from the **purely gravitomagnetic ones** for  $|a^*| \lesssim 0.5$ .
- The **spin-orbit angle**, *calculated* only with the **Lense-Thirring** effect, **agrees** with the **measured angle** between the **jet** and the **hole's spin**.
- The **measured** time series of the **position** and **viewing angles** are **well reproduced** by the corresponding **theoretically calculated** signals obtained from the **Lense-Thirring** effect






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