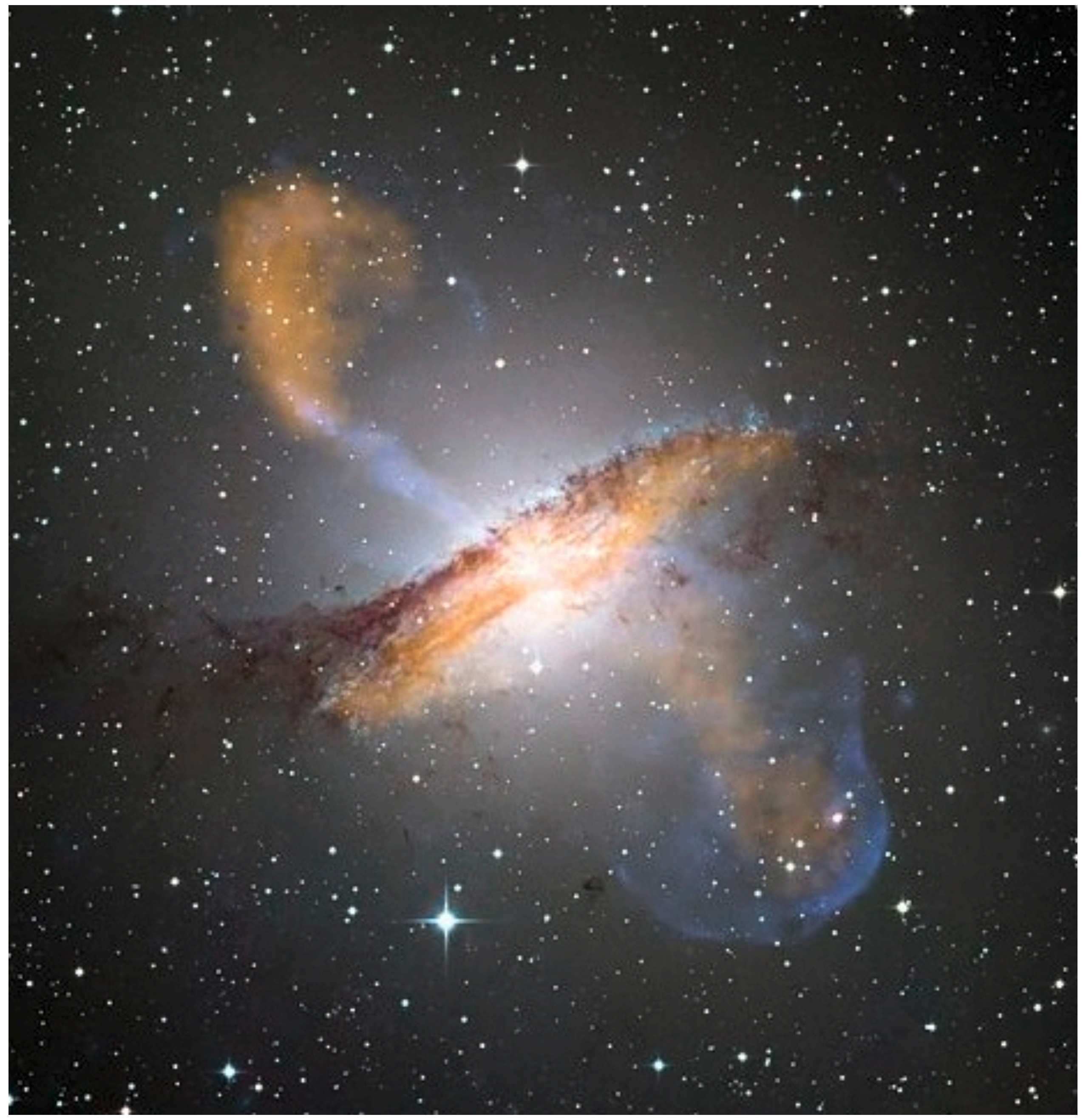
Probing H_0 and resolving AGN disks with ultrafast photon counters

Marios Galanis
Stanford University

Based on **Phys. Rev. D 109, 123029/arXiv:2403.15903**
with Neal Dalal (PI),
Charles Gammie (UIUC), Sam Gralla (University of Arizona), Norm Murray (CITA)

Stellar intensity interferometry workshop 2025 - Waischenfeld - October 14, 2025

Active Galactic Nuclei



Centaurus A

Supermassive Black Holes accreting gas

Composite image credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)]

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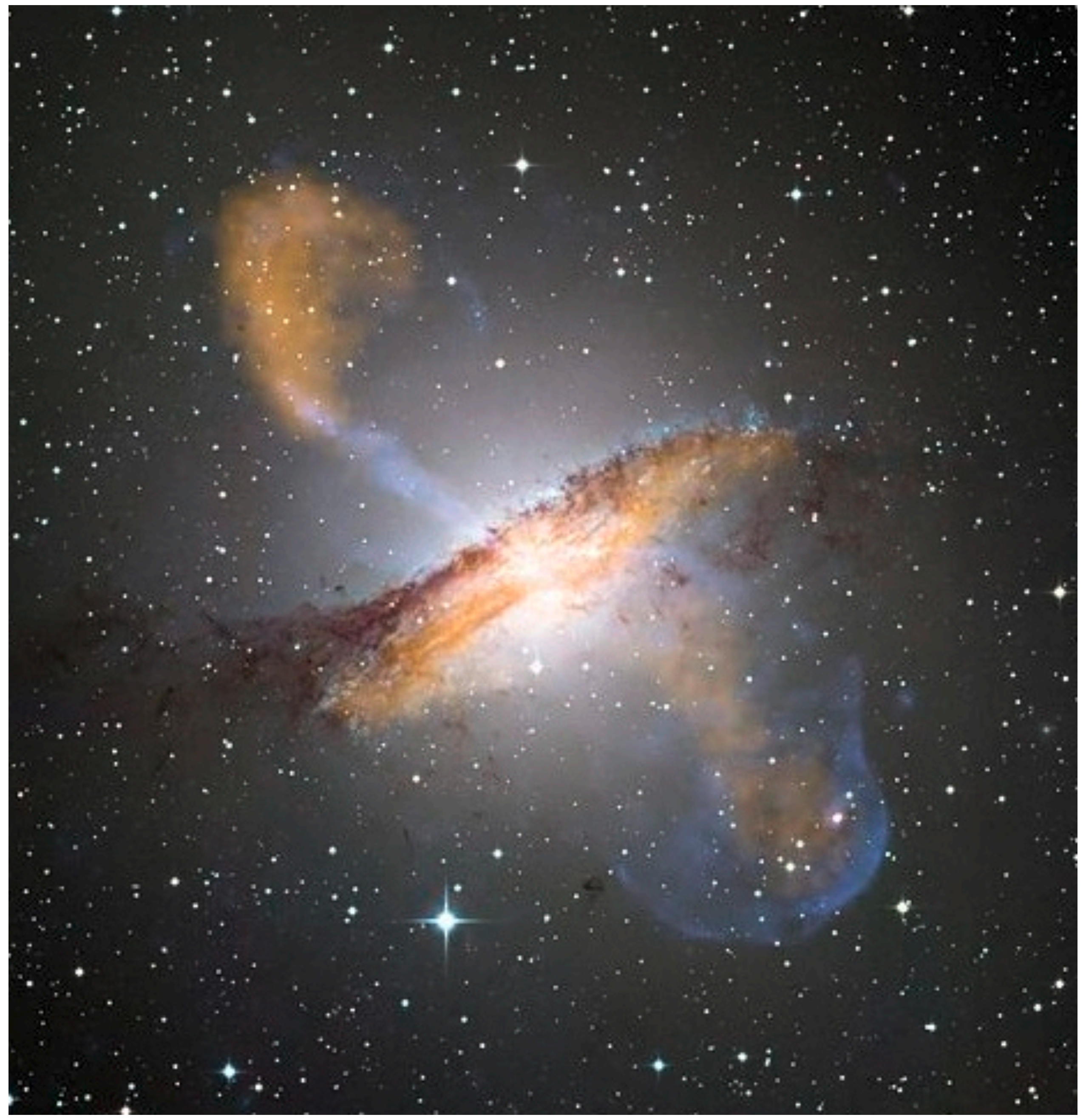

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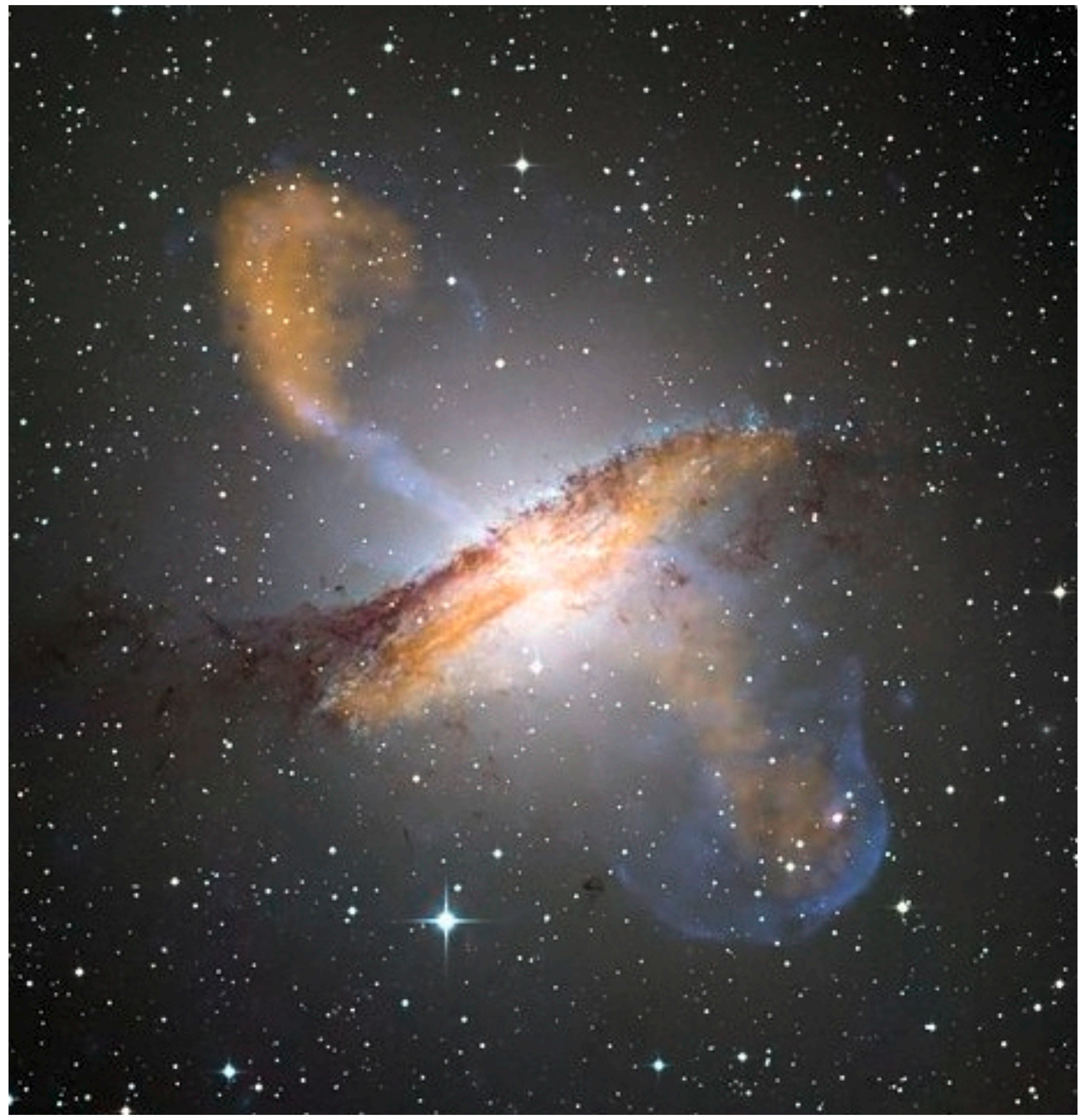

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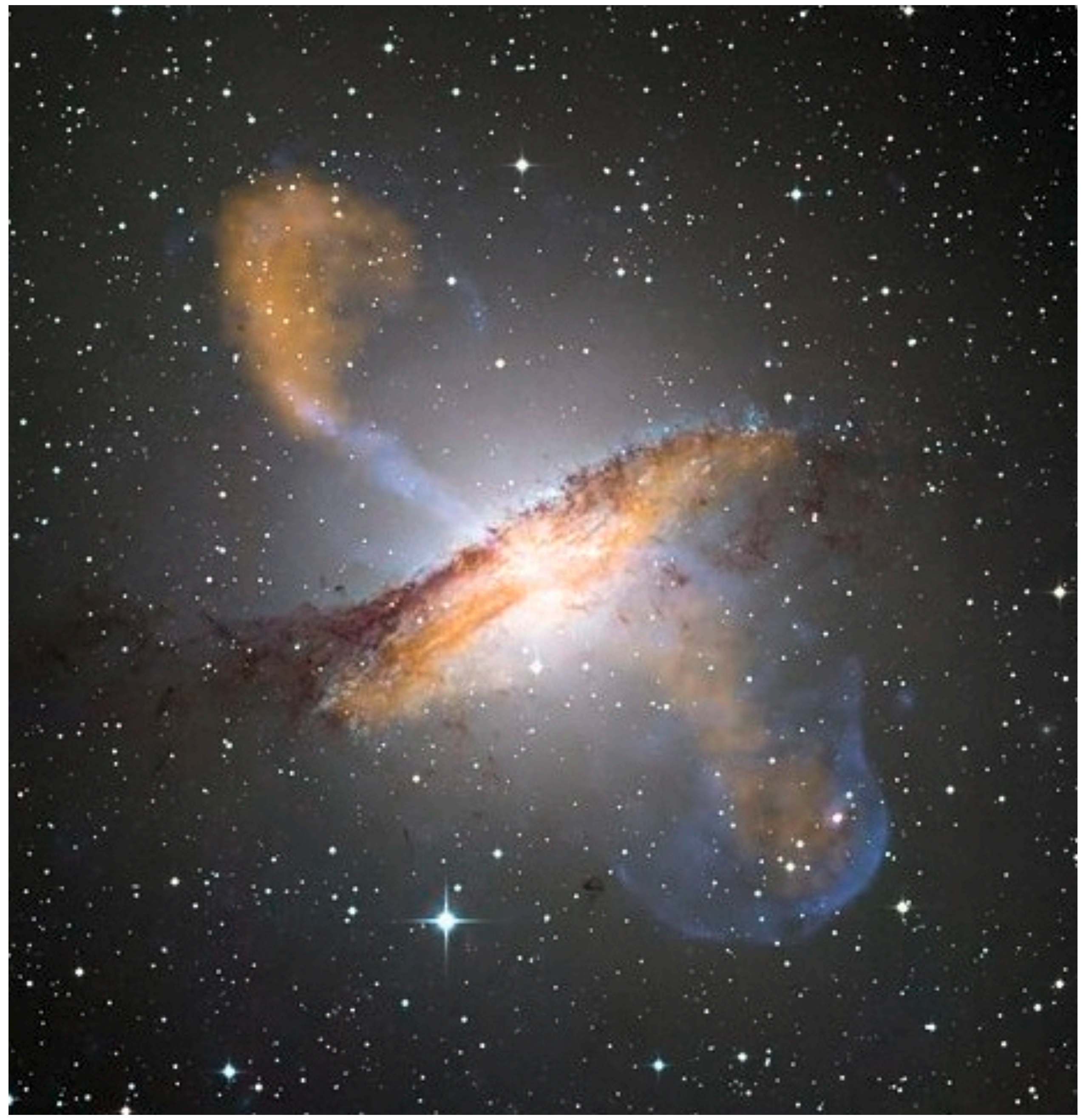

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$\theta_{\mathrm{ISCO}} \sim 0.02 - 0.2\mu\mathrm{as}$ Baseline ~ 460 - 4000km

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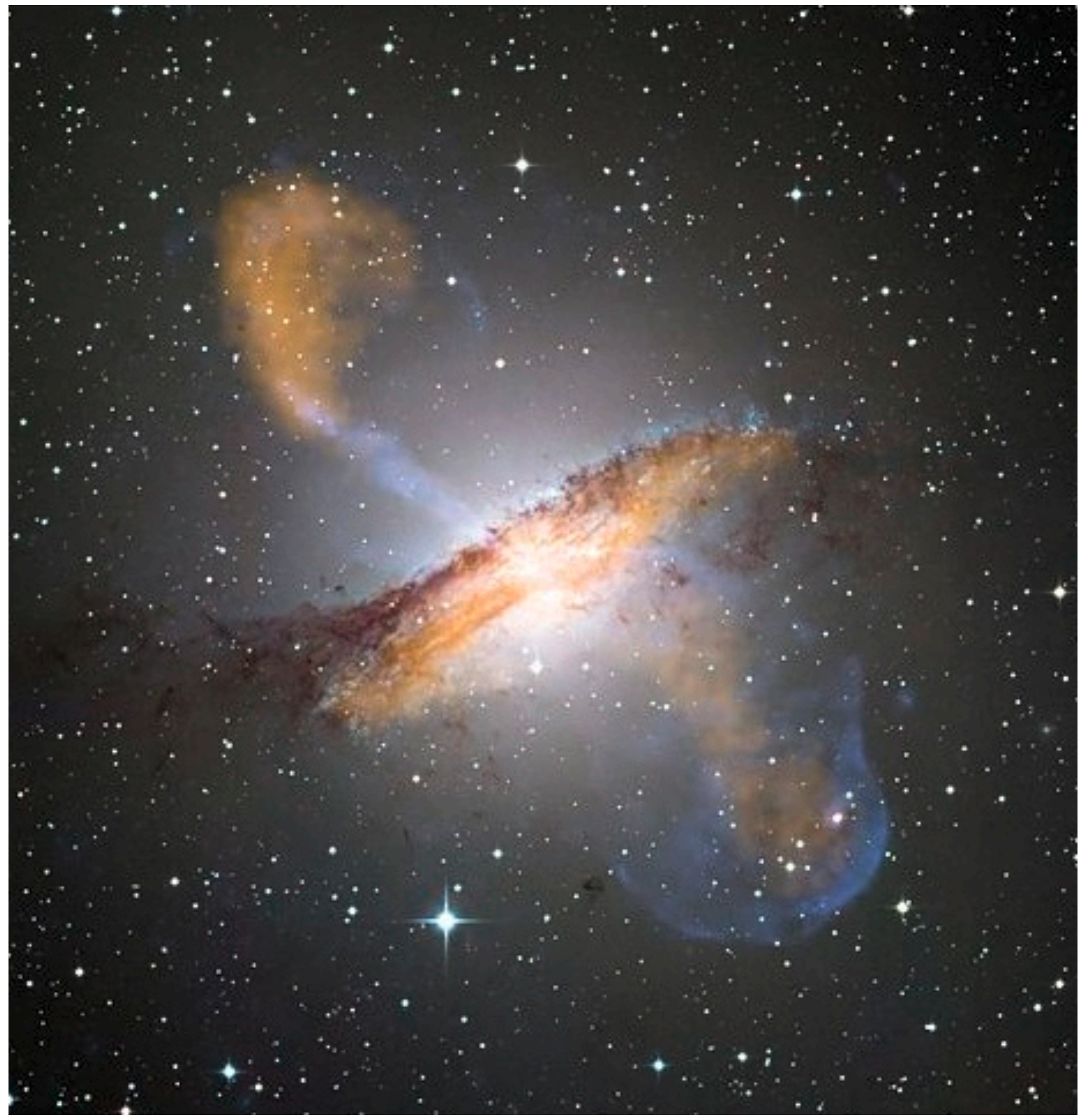

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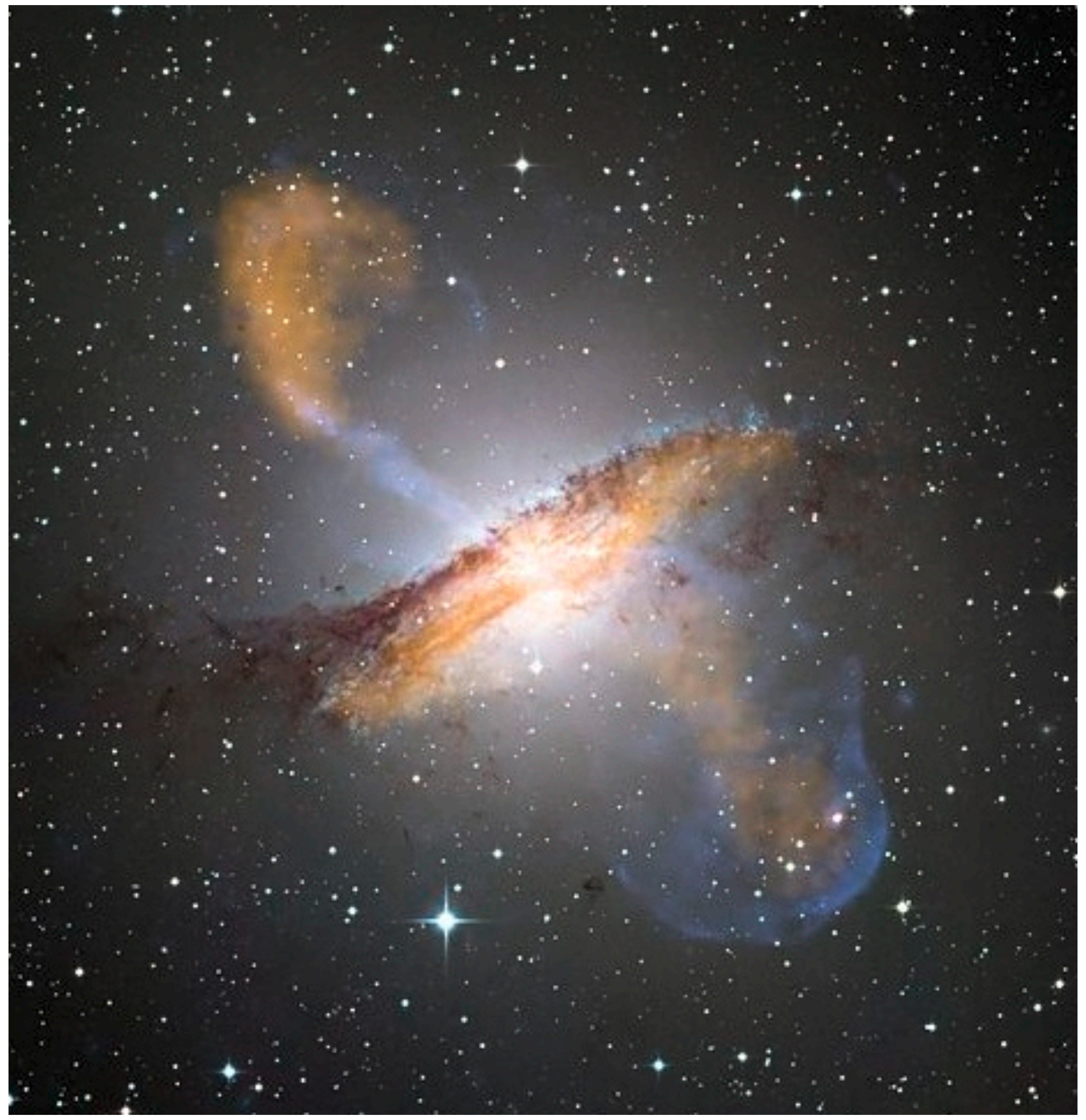

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Two applications:

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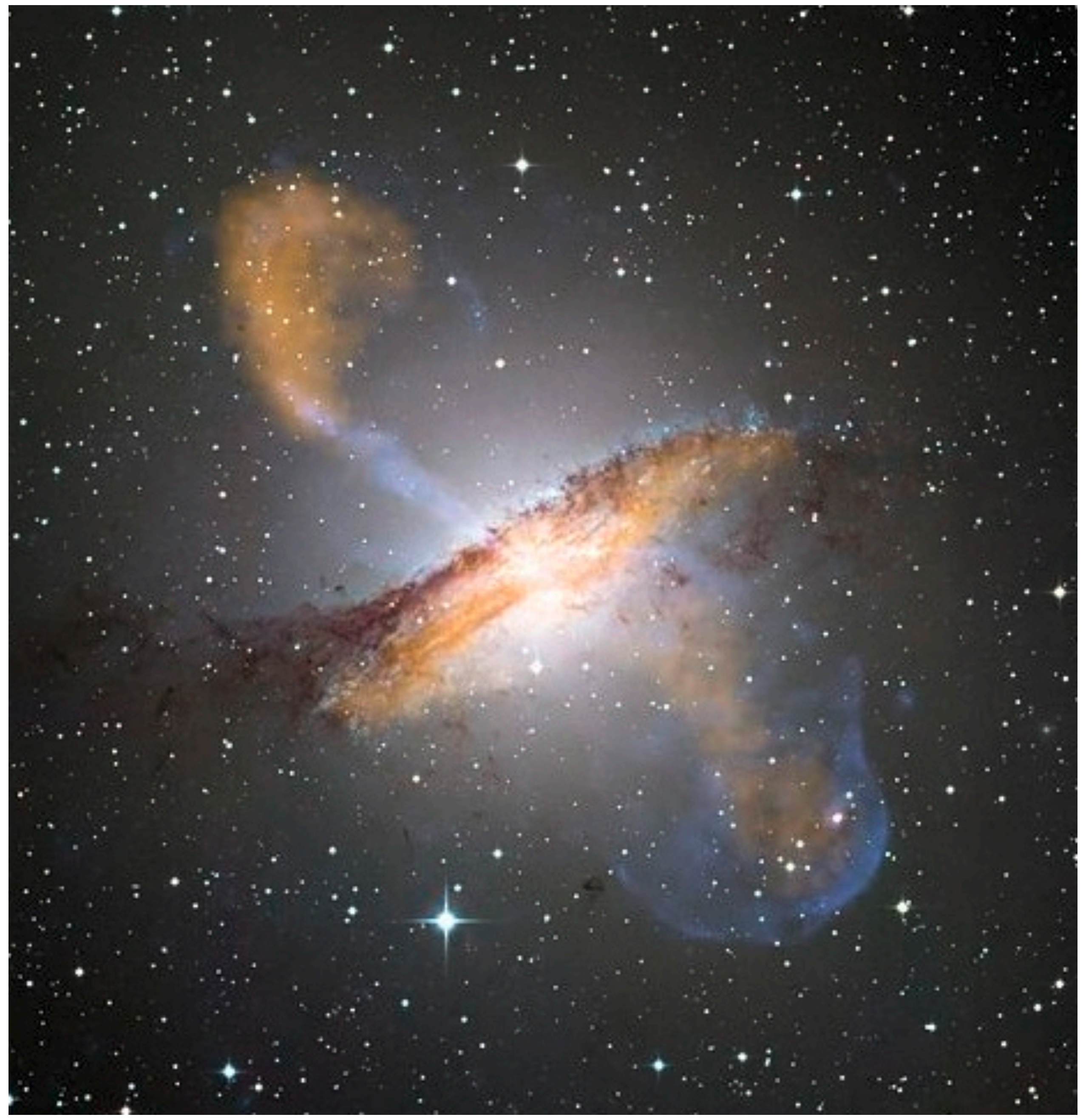

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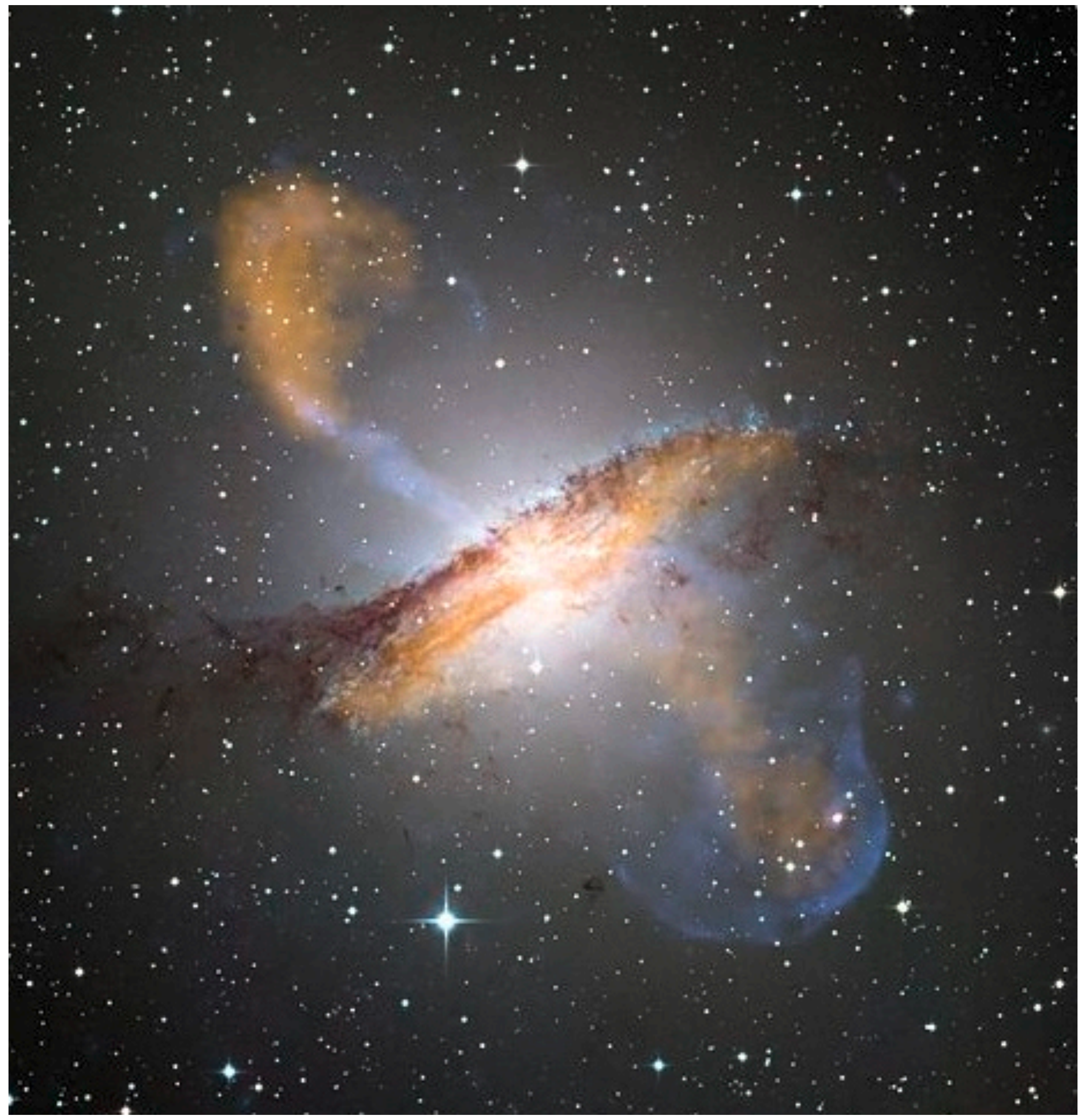
Two applications:

1. Resolve accretion disks of **nearby** AGNs and study their physics

Composite image credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)]

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Active Galactic Nuclei



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Two applications:

1. Resolve accretion disks of **nearby** AGNs and study their physics

2. Resolve the Broad Line Region of **distant** AGN and probe H_0

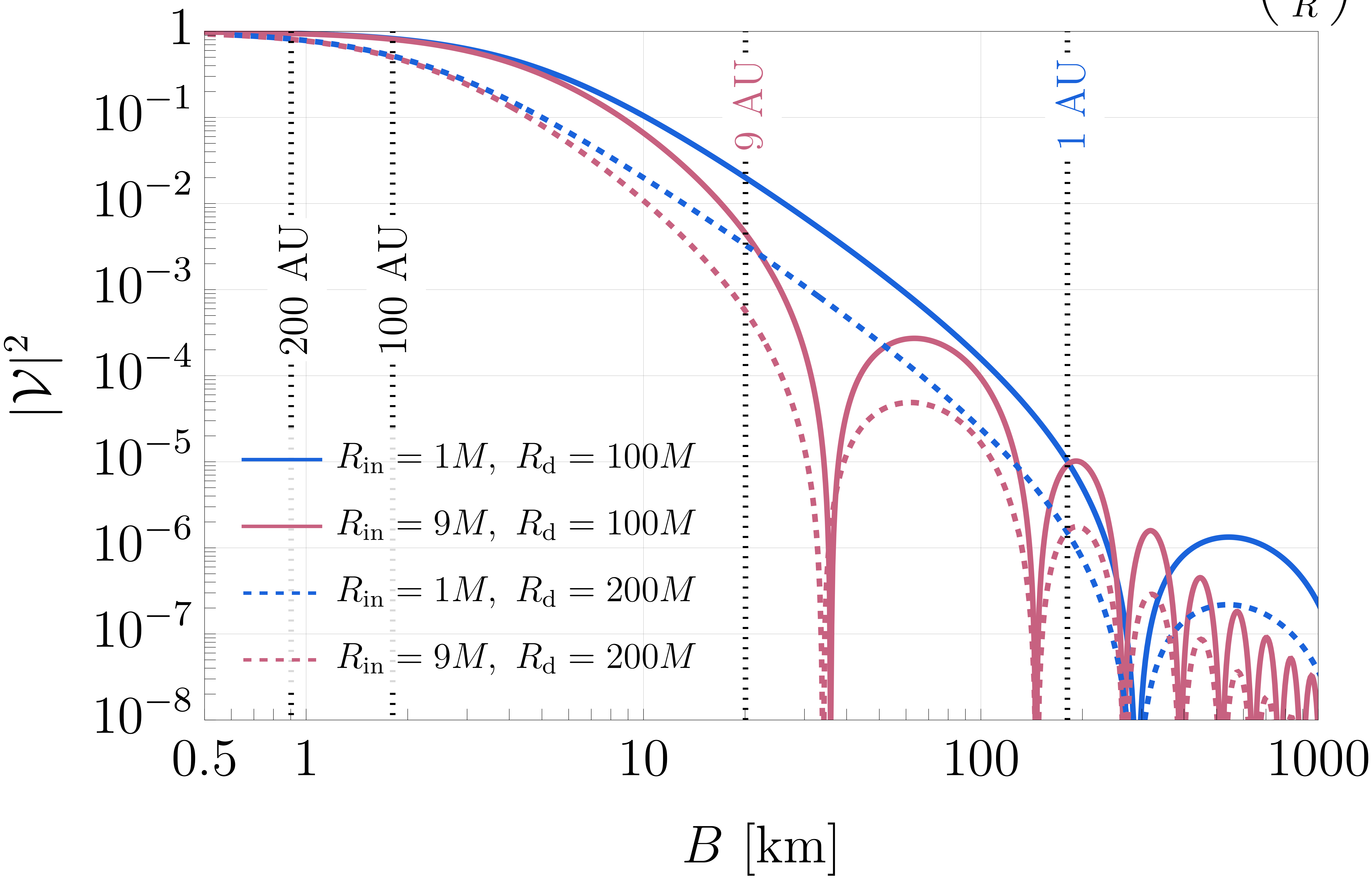
Composite image credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)]

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Application 1: AGN disks

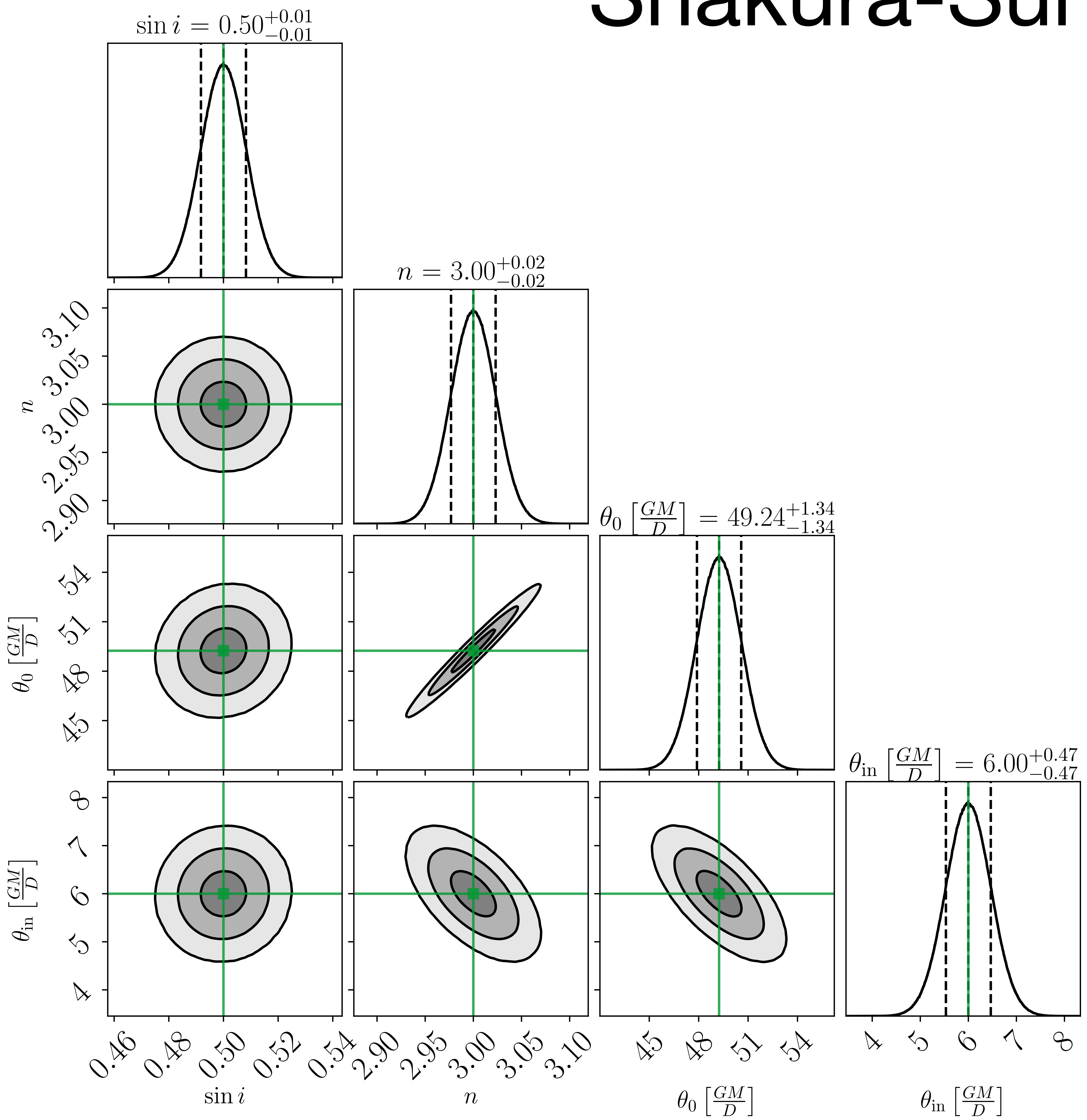
Toy example: Shakura-Sunyaev

$$T \sim T_0 \left(\frac{R_0}{R}\right)^{\frac{3}{4}} \left[1 - \left(\frac{R_{\rm ISCO}}{R}\right)^{\frac{1}{2}}\right]^{\frac{1}{4}}$$



[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Shakura-Sunyaev Fisher



CTA array
30ps time-jitter
5000 spectral channels
24 hrs
SNR=2000

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

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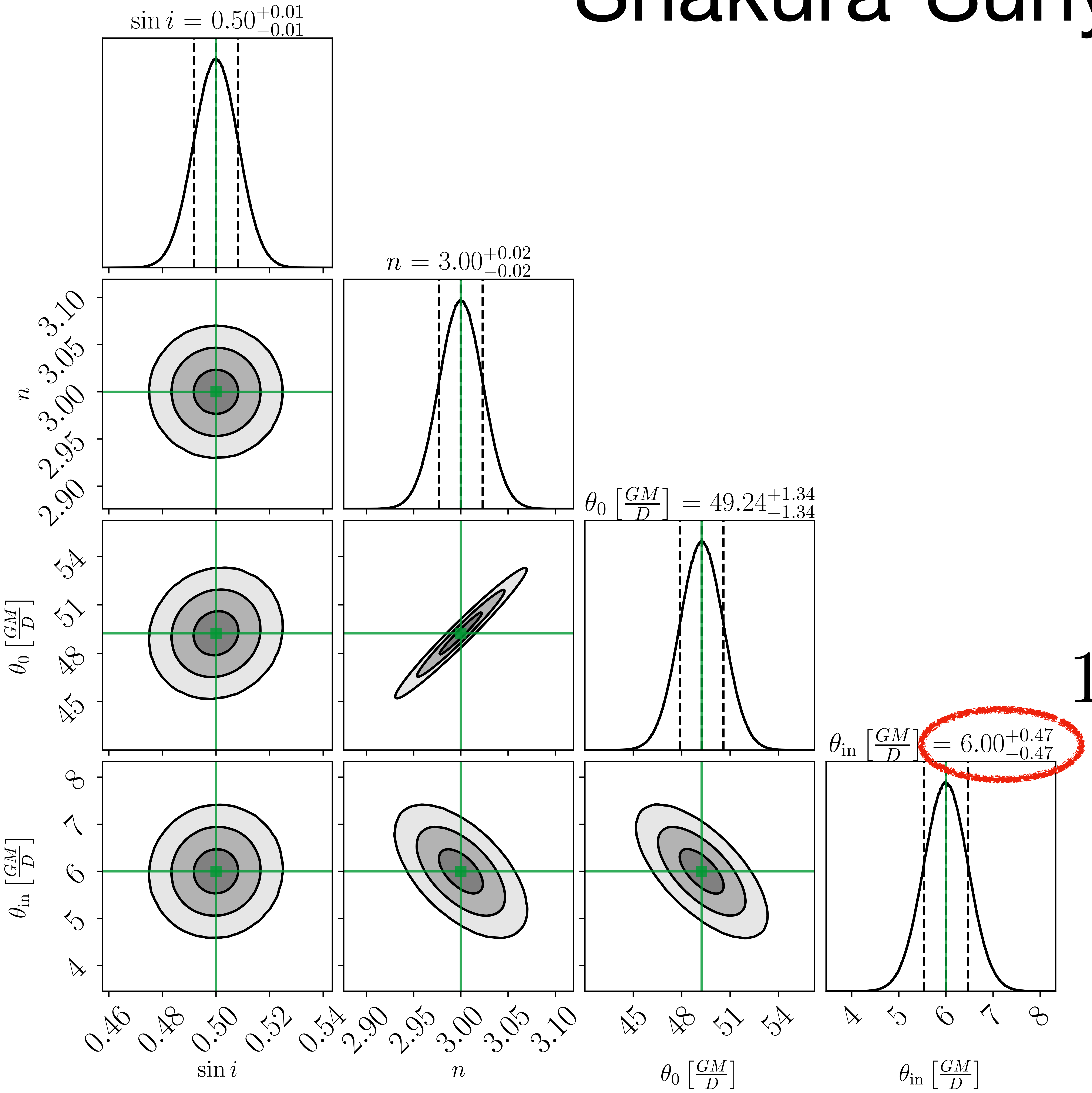

13σ

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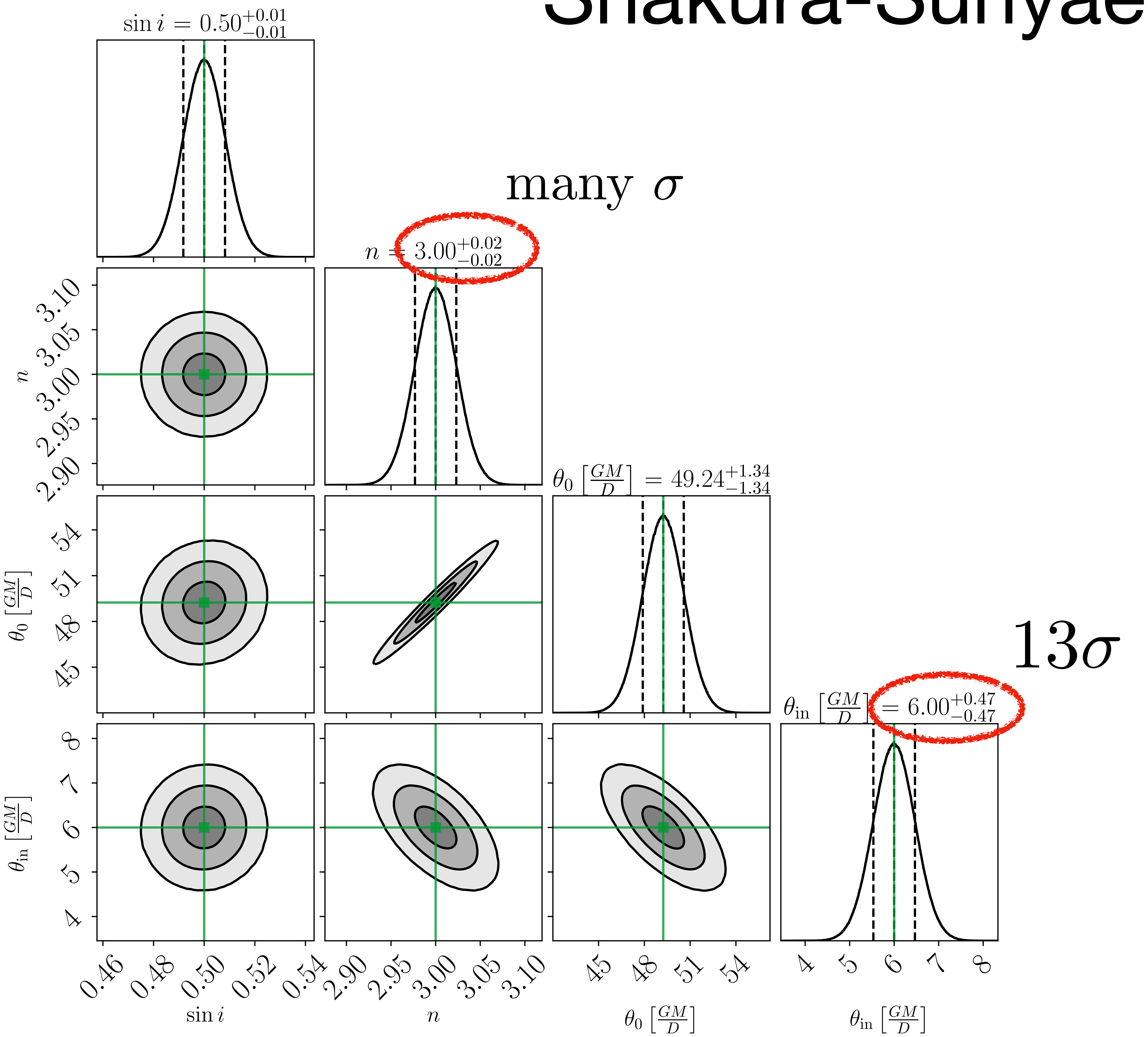

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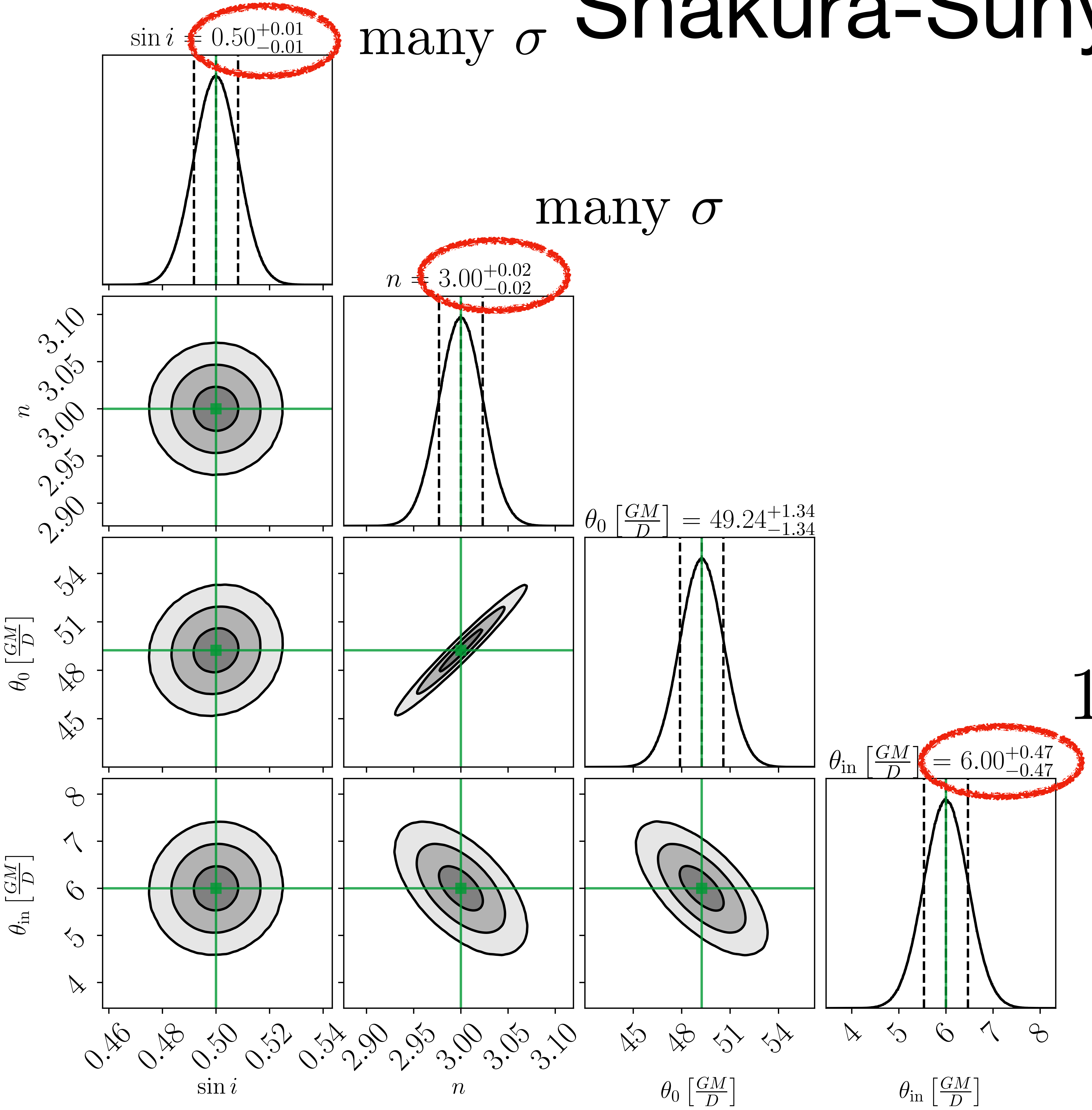
Shakura-Sunyaev Fisher

many σ

many σ

13σ



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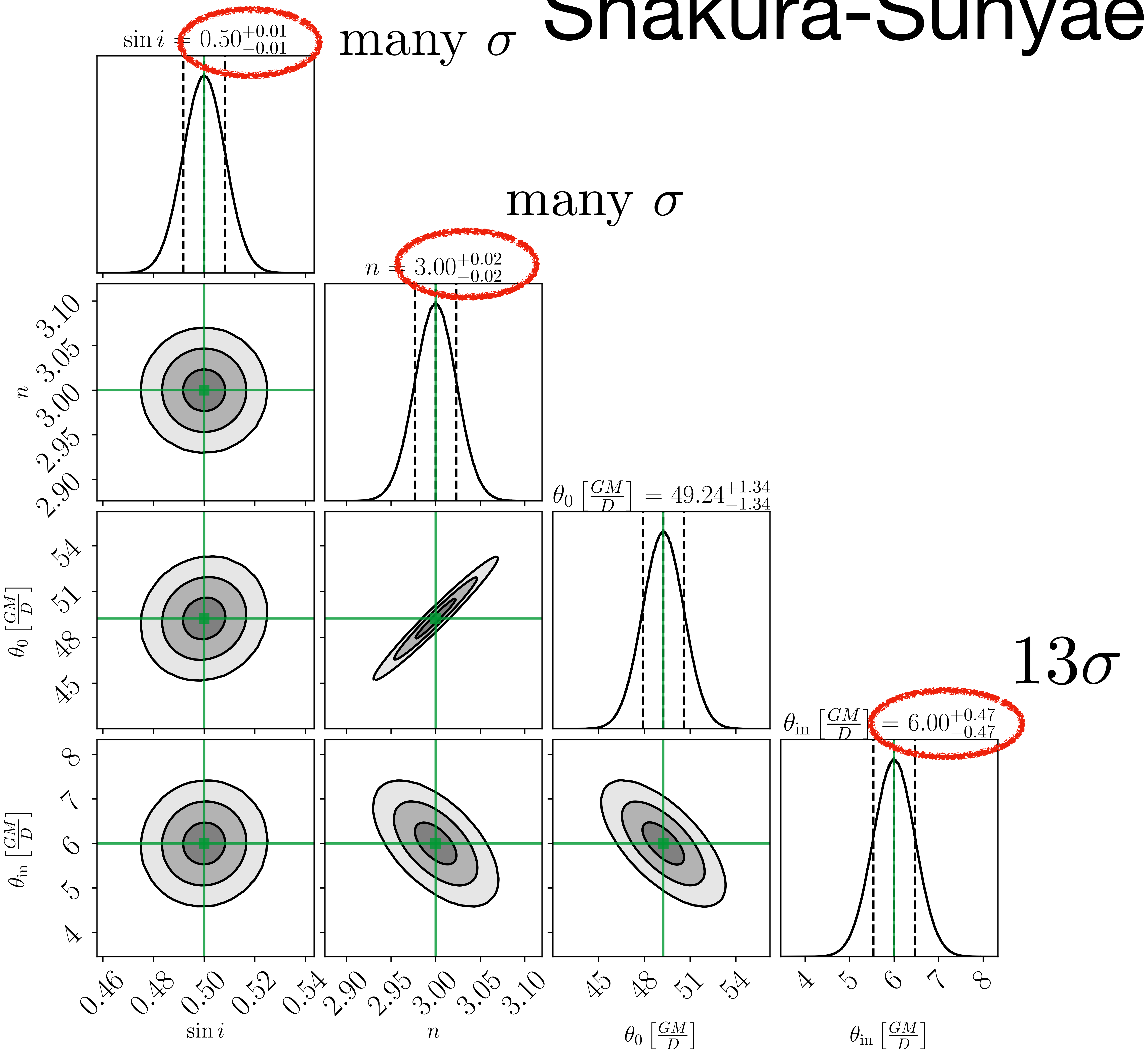
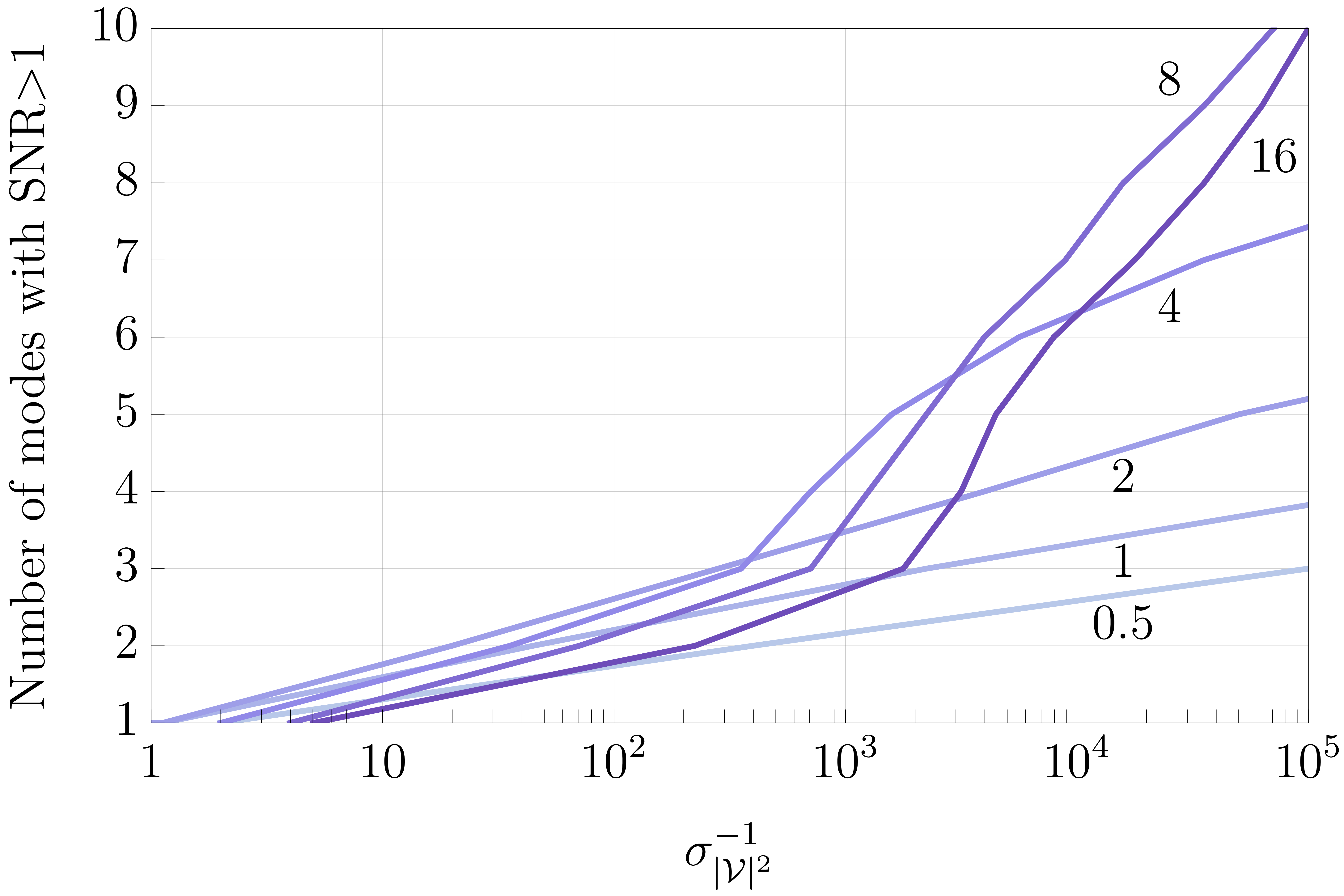


CTA array
30ps time-jitter
5000 spectral channels
24 hrs
SNR=2000

2 x 10m telescopes
30ps time-jitter
16 spectral channels
24 hrs
SNR=7

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Principal component analysis



[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Why is this useful?

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<u>Inner structure:</u> Can measure environment at the BH, spin?

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No other way to do this!

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Application 2: Hubble constant

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[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

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Reverberation Mapping

Video credit: Wikipedia

[Blandford, McKee ’82]

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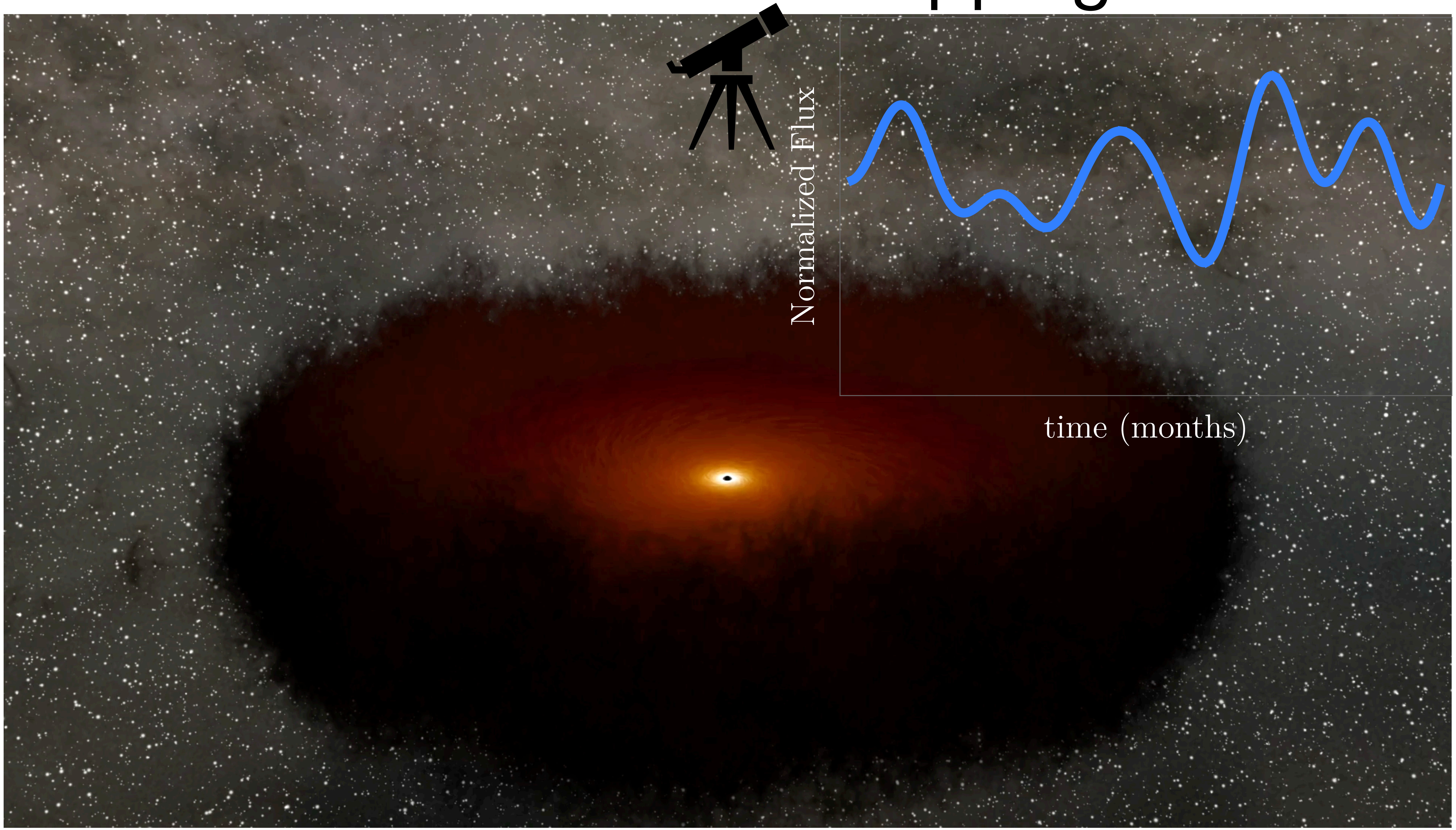

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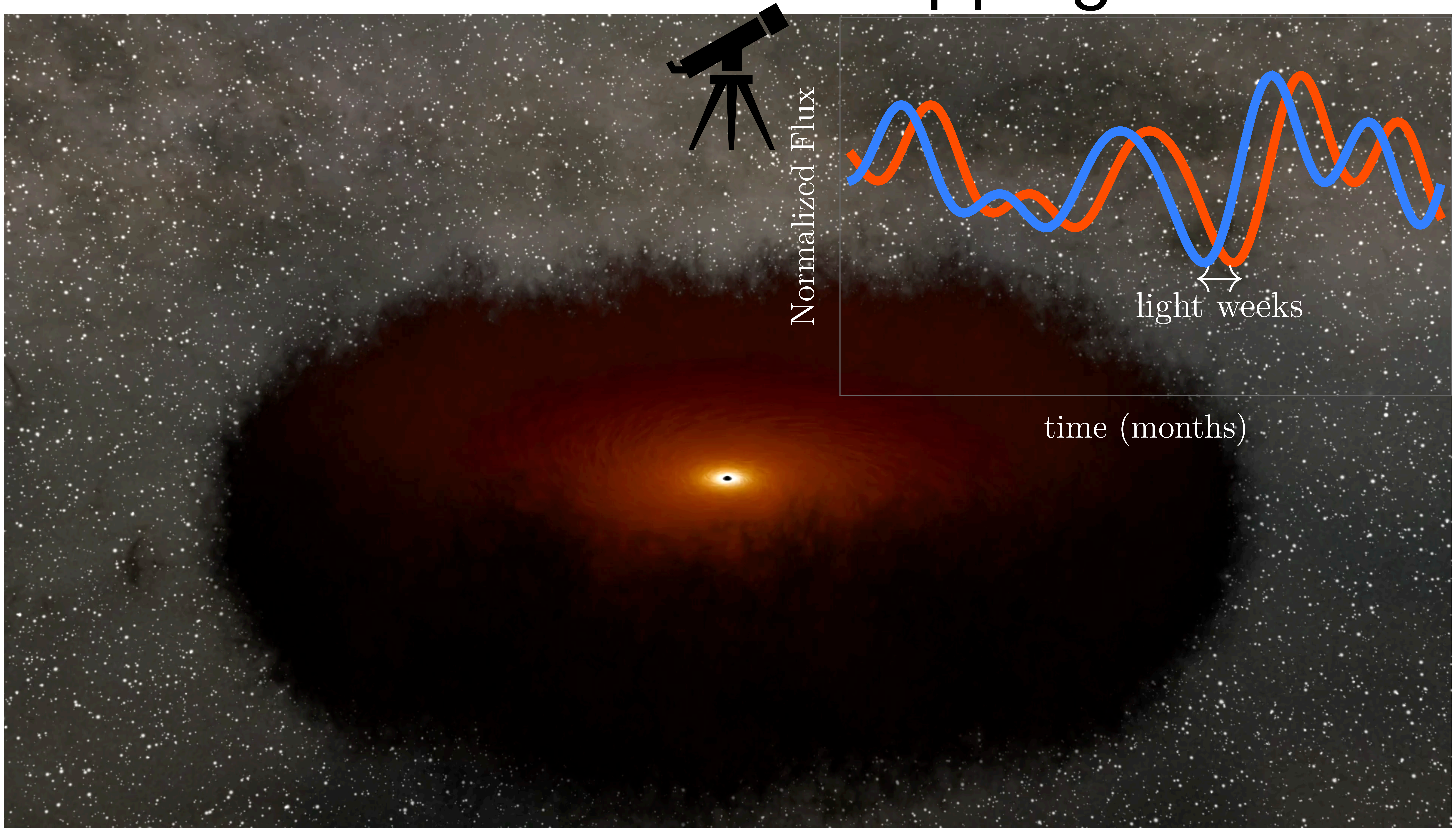

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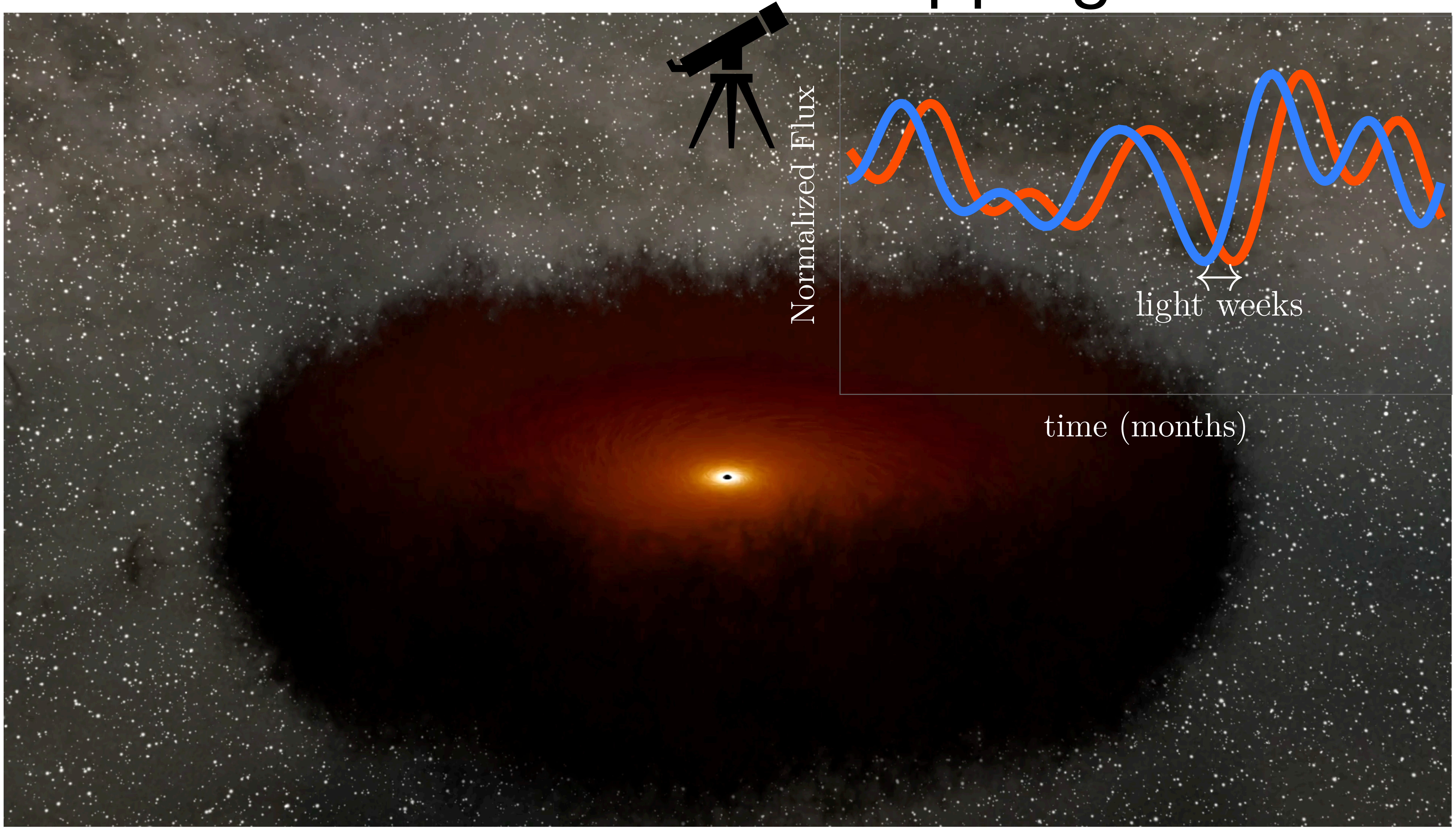
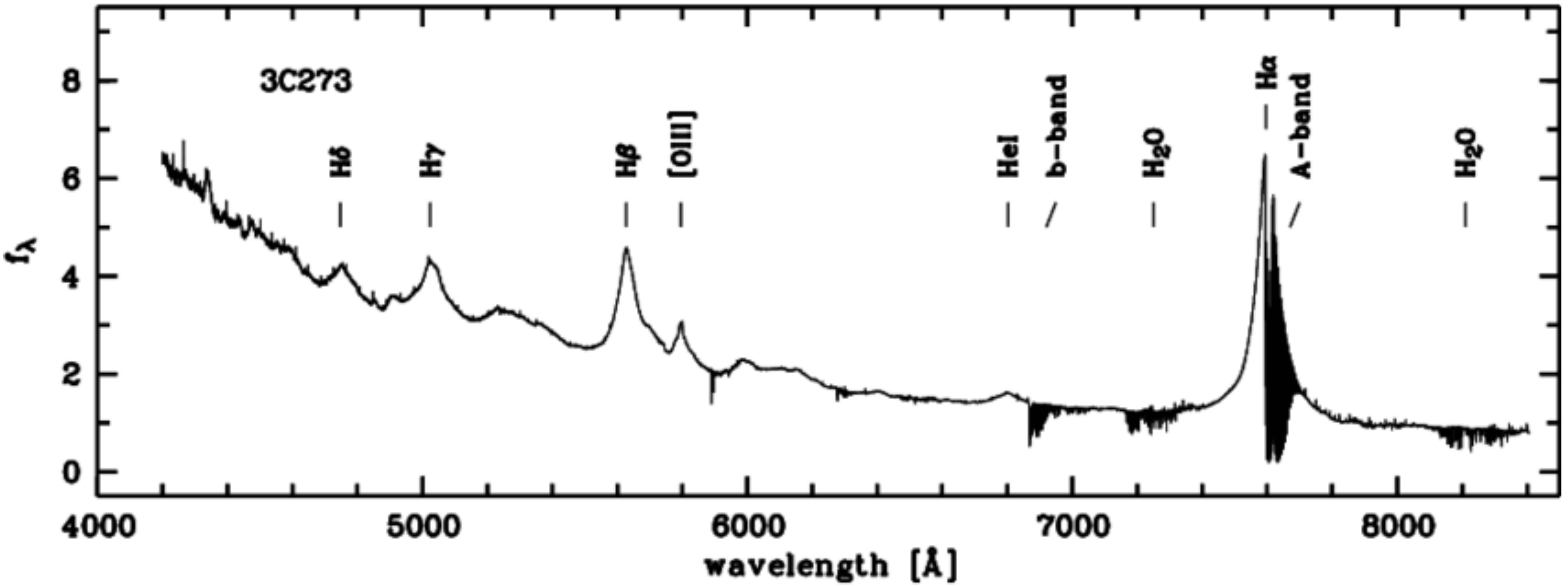


Time-delay gives physical size

Video credit: Wikipedia

[Blandford, McKee ’82]

Broad Line Region



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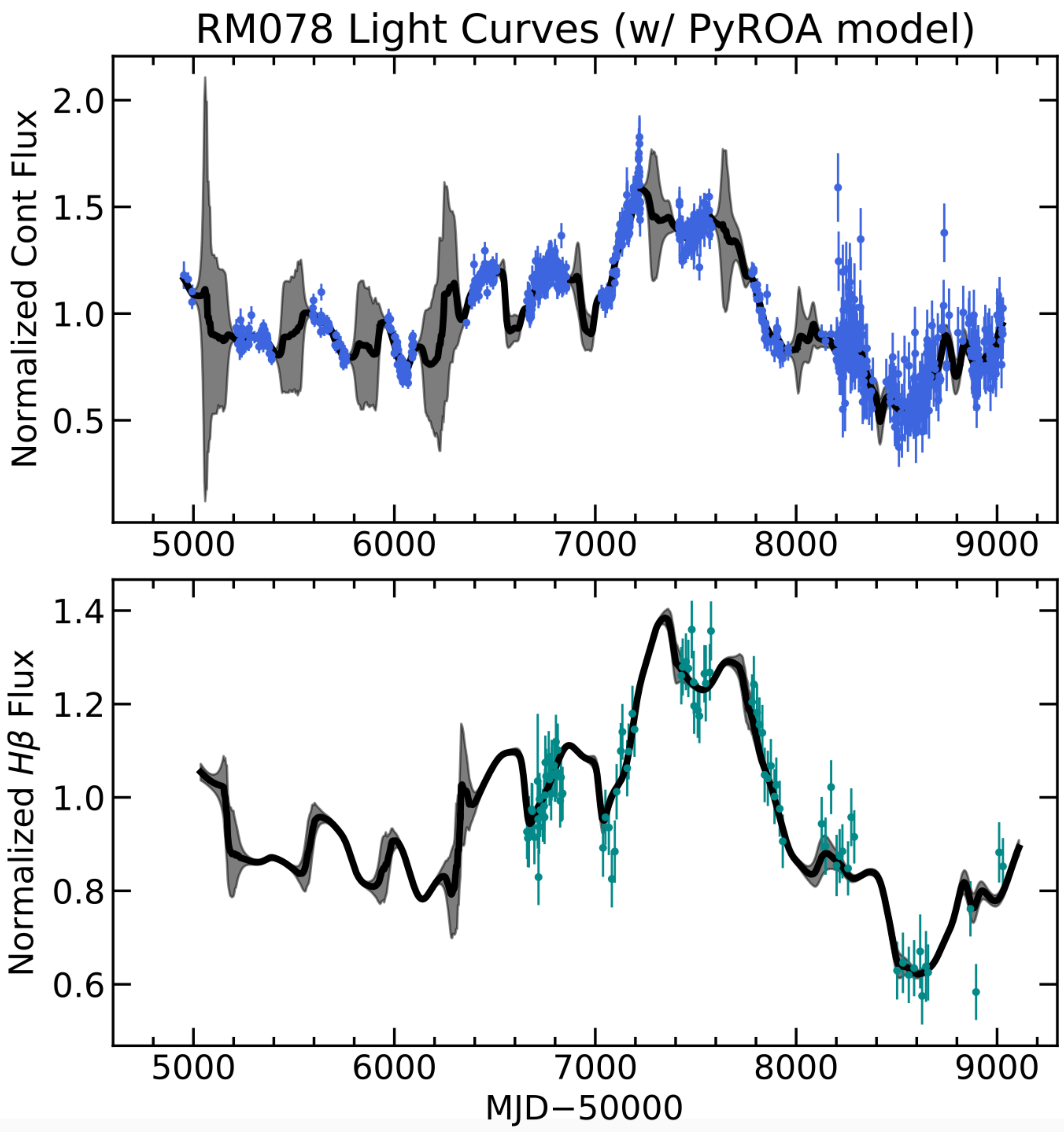

[SDSS RM Project, arXiv:2305.0101]

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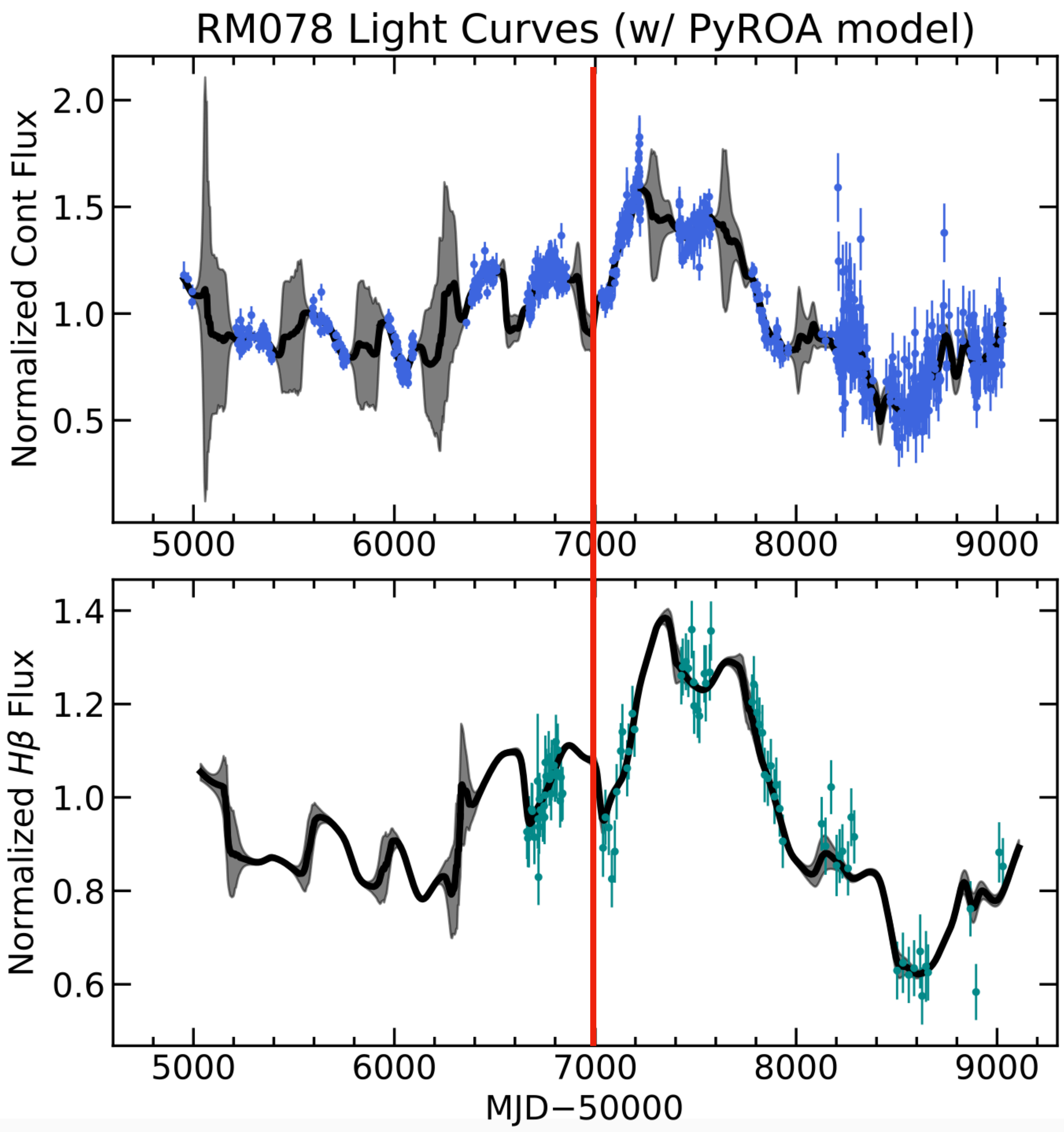

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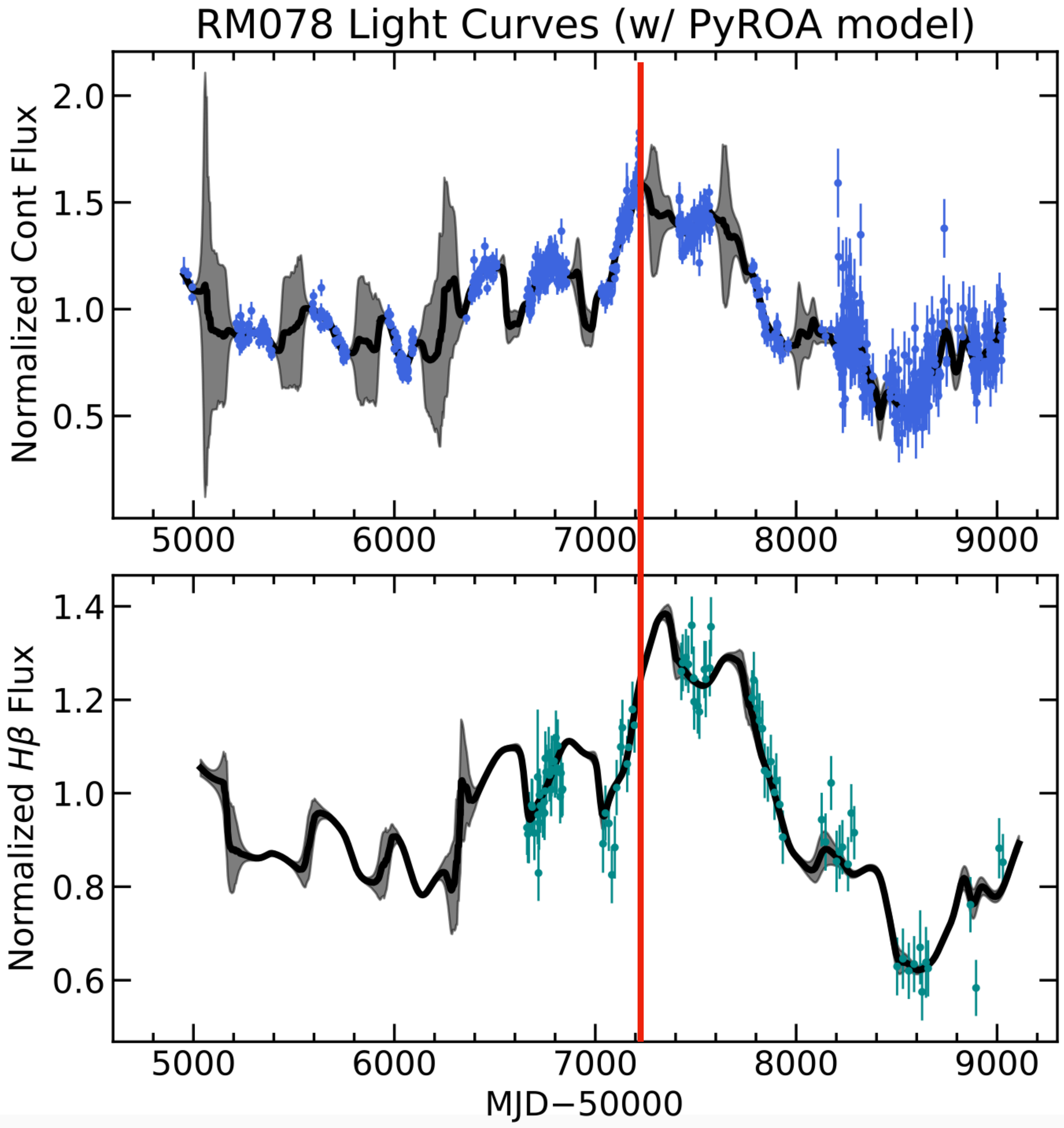

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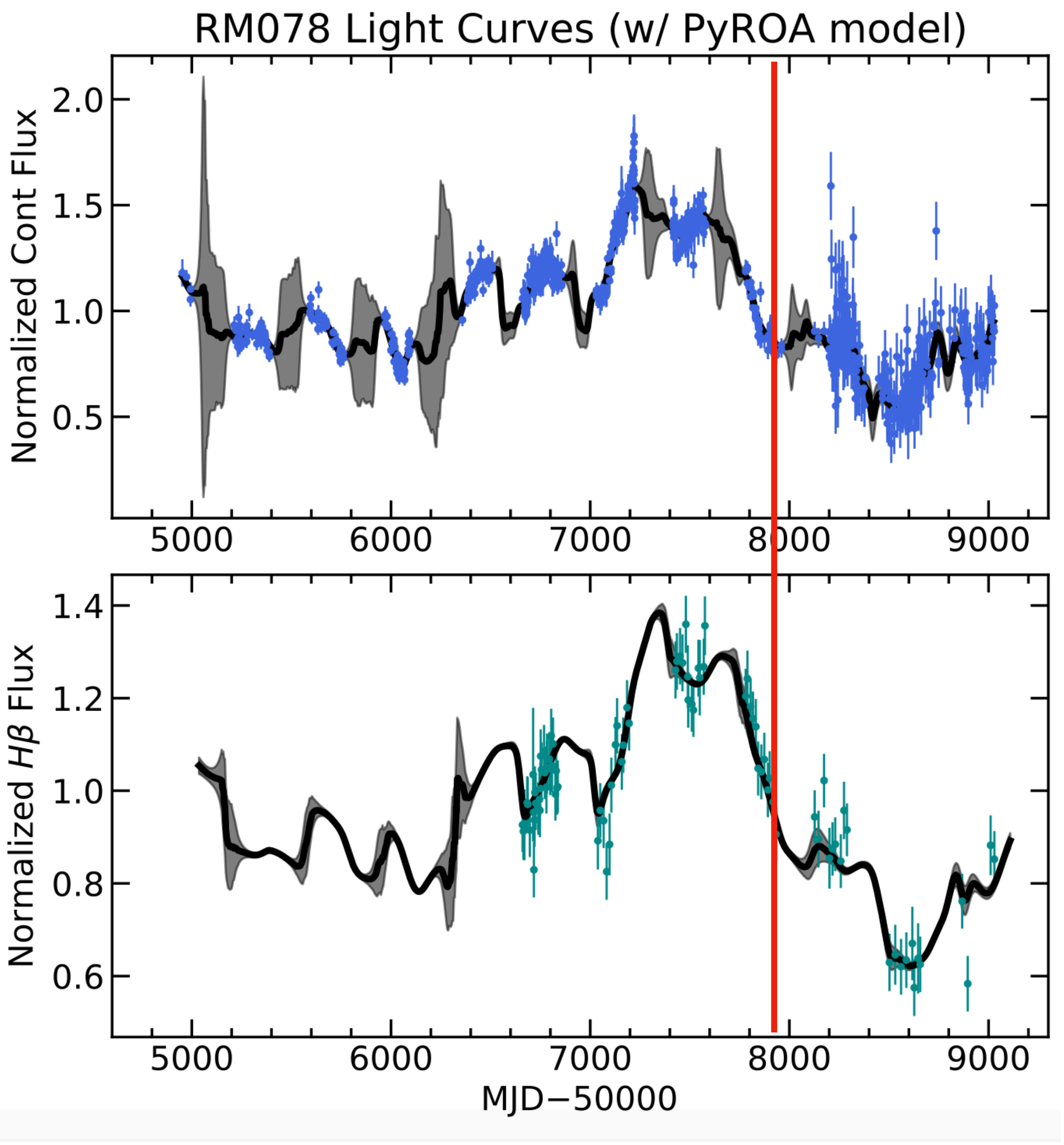

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[N. Dalal, **MG**, C. Gammie, S. Gralla, N. Murray, arXiv:2403.15903]

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Video credit: Wikipedia

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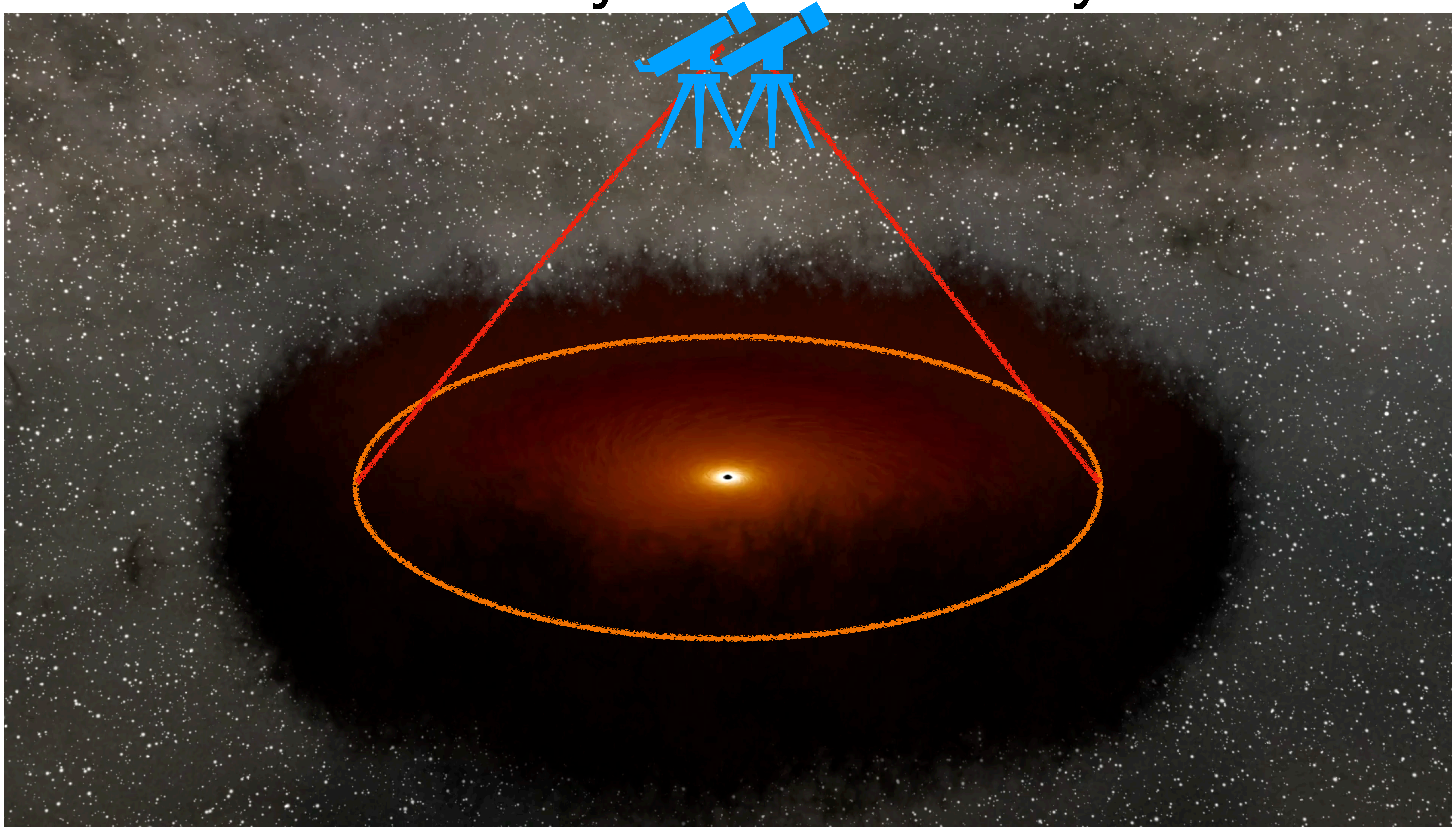

Intensity Interferometry gives angular size

Video credit: Wikipedia

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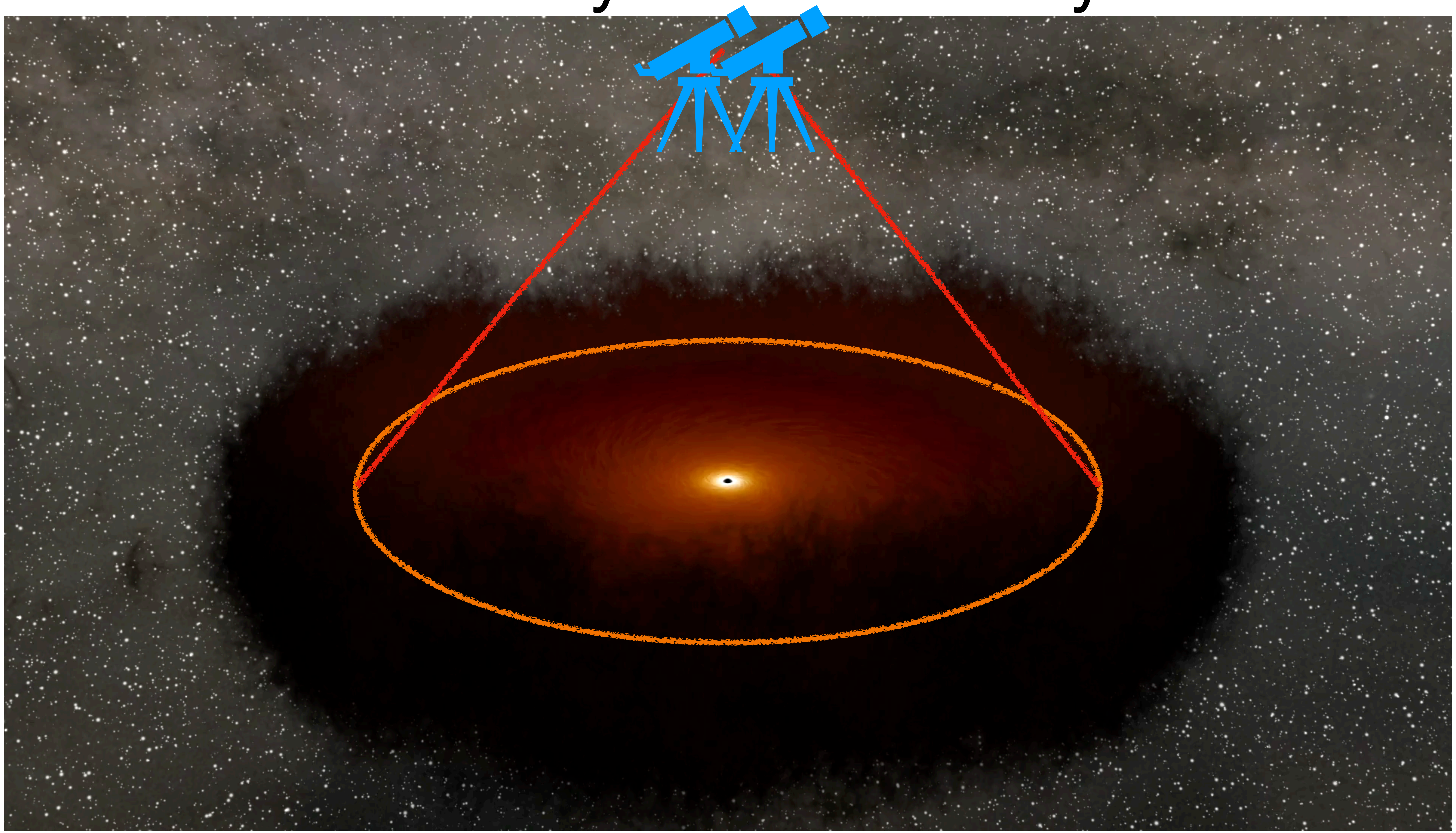

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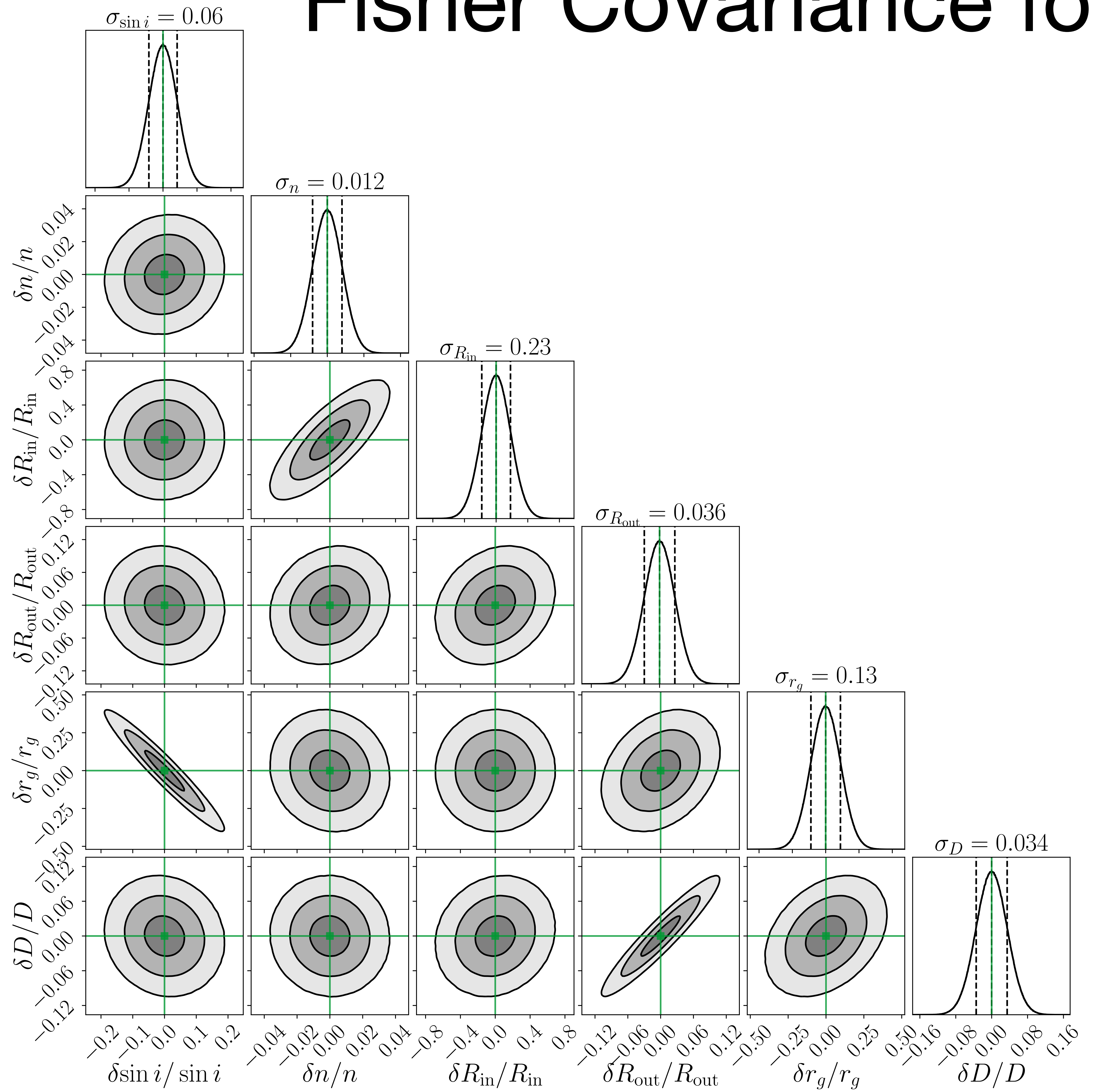
Fisher Covariance for IRAS 09149-6206



CTA-like array

$v/c \sim 0.01$

30ps time-jitter

$T_{\rm obs} = 24{\rm hrs}$

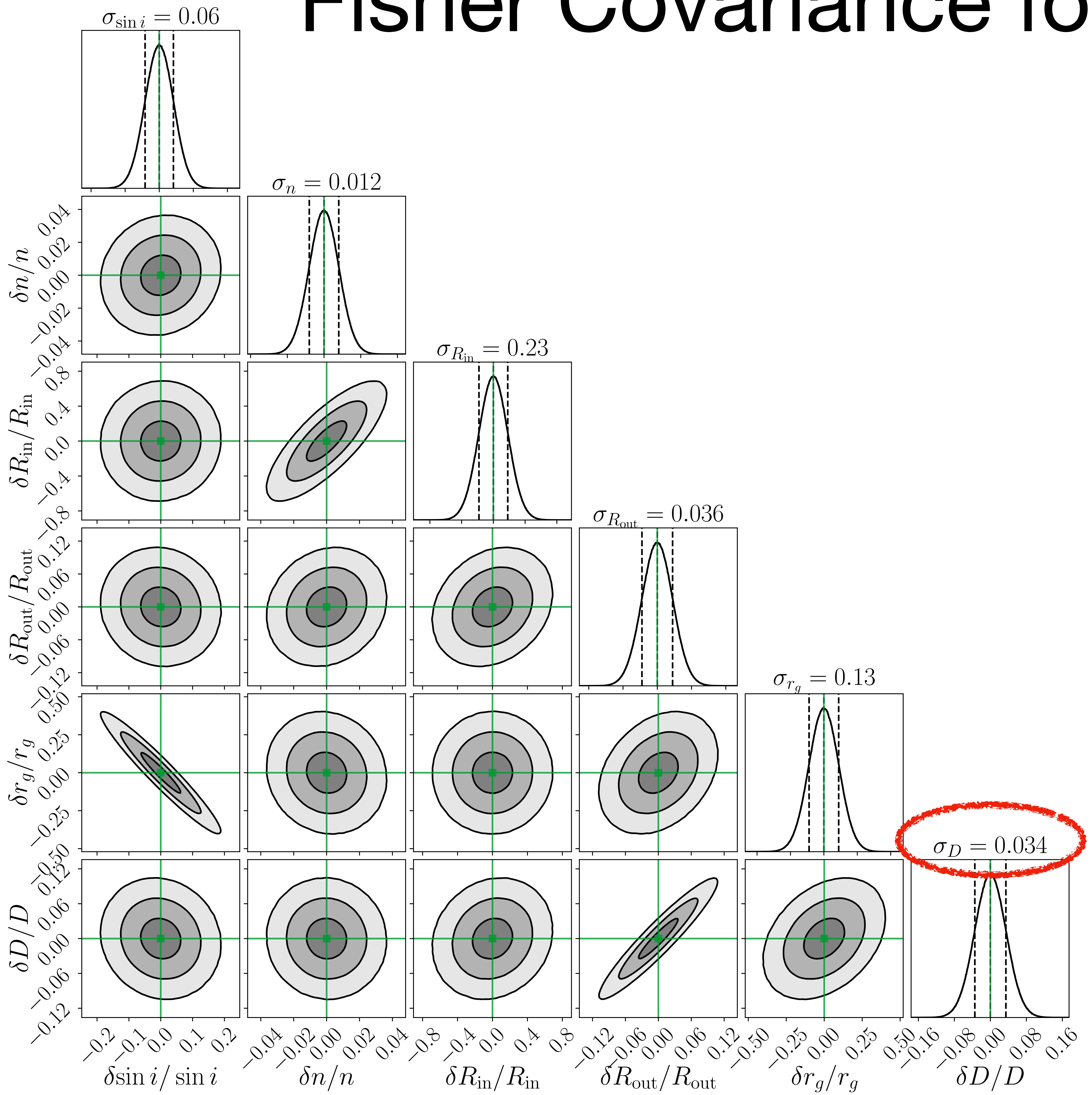
$\mathcal{R} = 5000, \quad 50$ channels

SNR ≈ 73 per channel

IRAS 09149-6206, z=0.057

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Fisher Covariance for IRAS 09149-6206



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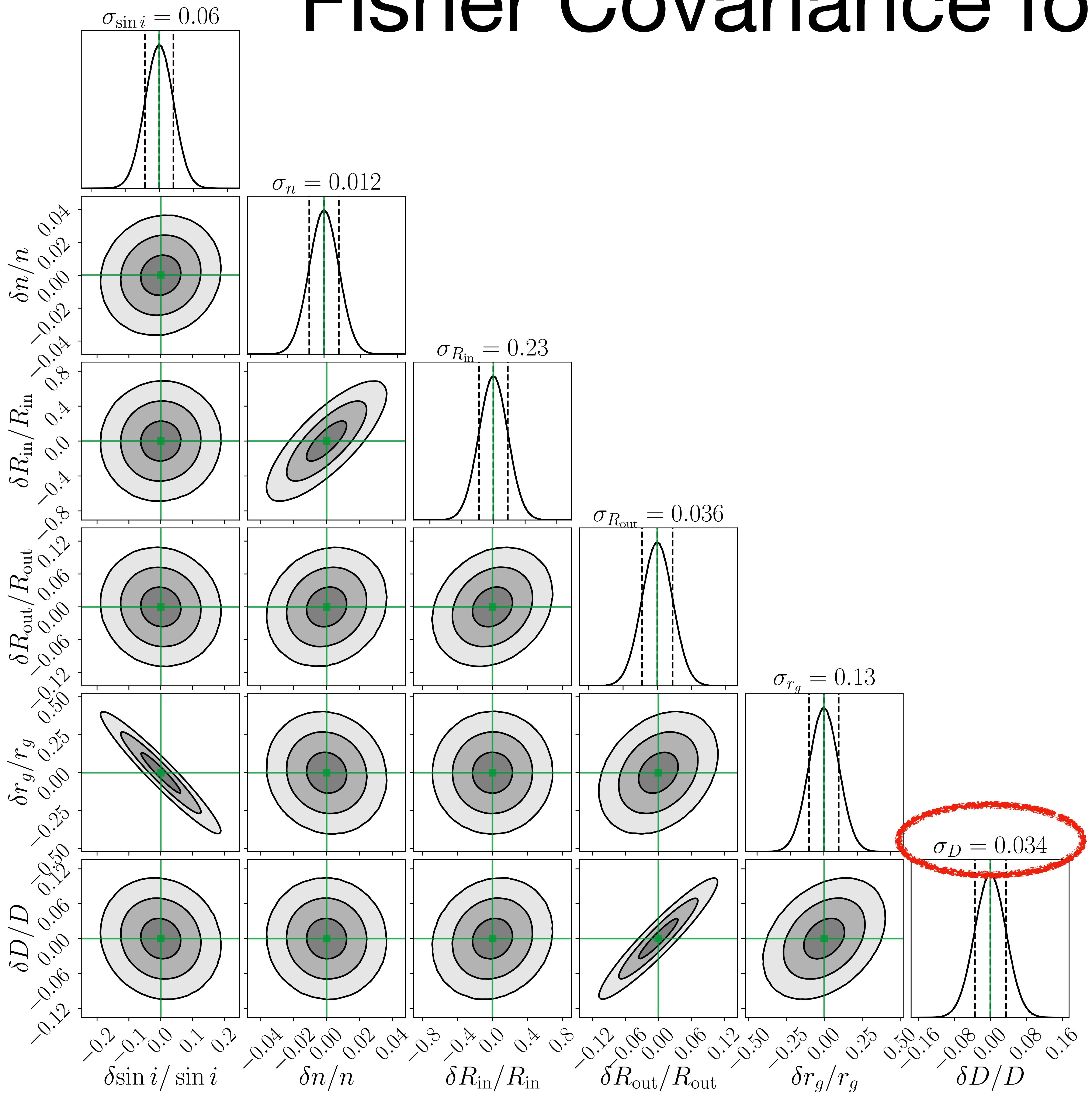
Fisher Covariance for IRAS 09149-6206



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IRAS 09149-6206, z=0.057

3.4%
Distance error!

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Distance error *per* AGN - spectroscopy

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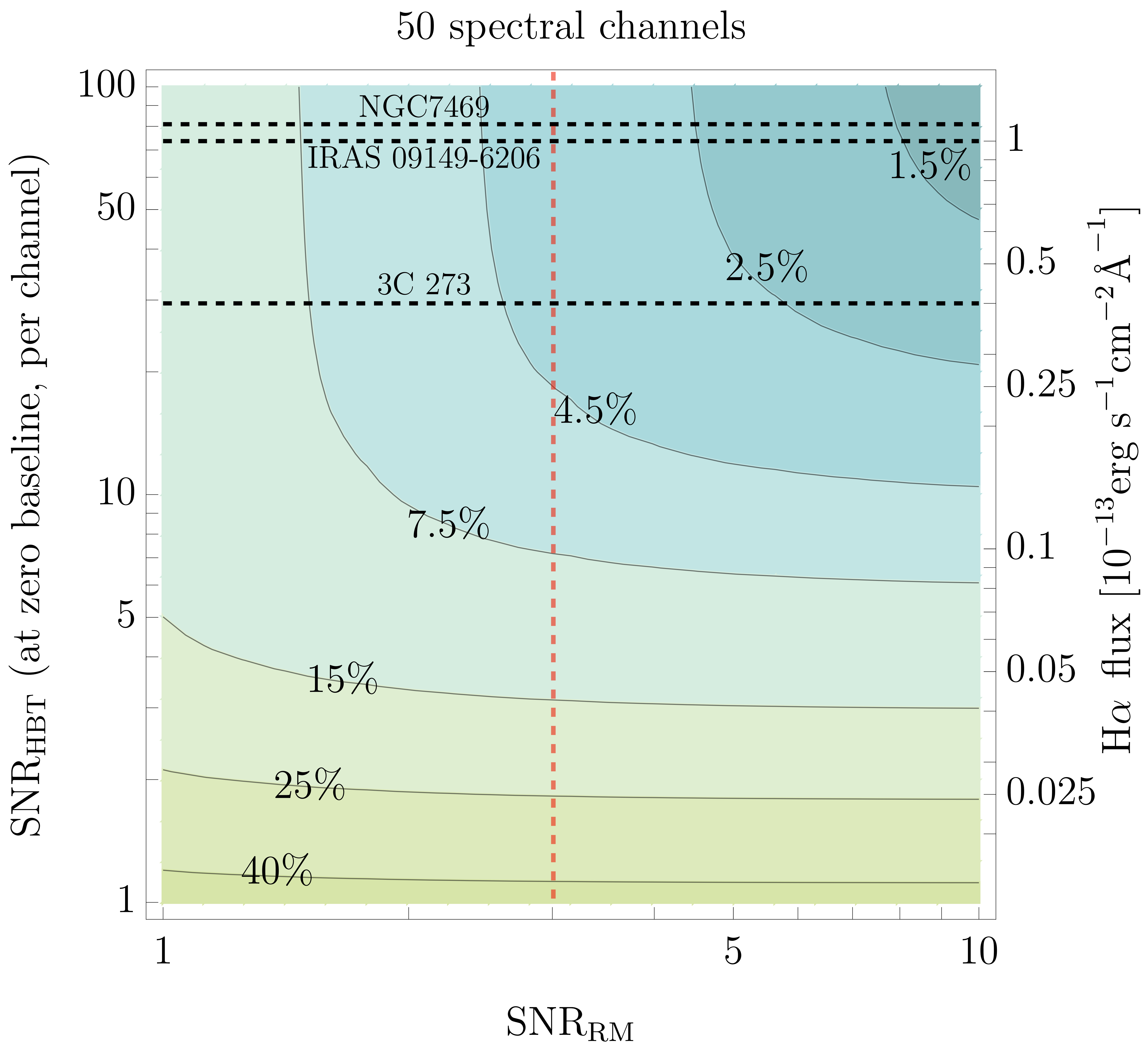
IRAS 09149-6206, z=0.057
NGC 7469, z=0.016
3C 273, z=0.158



[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Distance error *per* AGN - one pixel

CTA-like array

$v/c \sim 0.01$

30ps time-jitter

$T_{\mathrm{obs}} = 24\mathrm{hrs}$

IRAS 09149-6206, z=0.057
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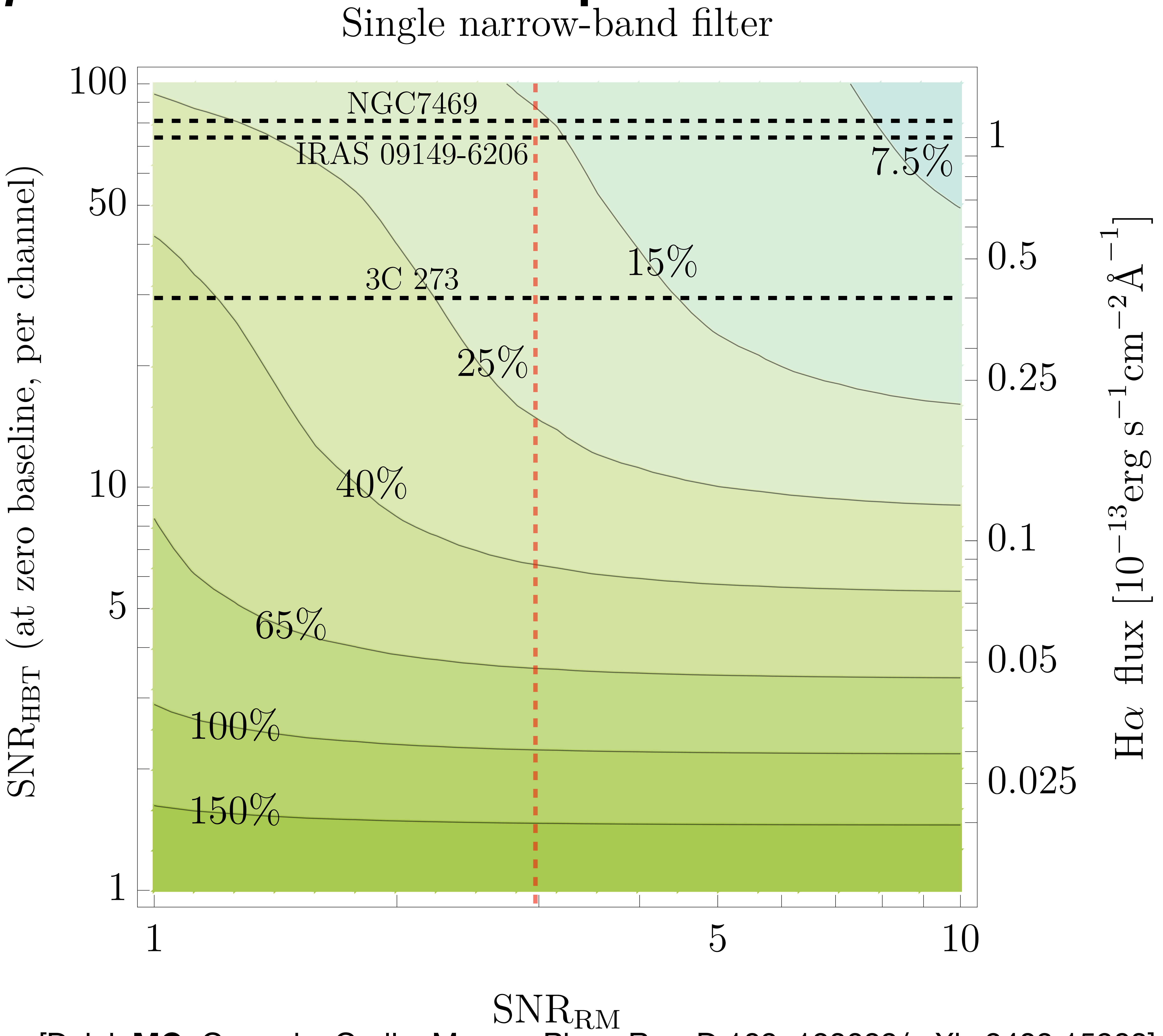

[Dalal, **MG**, Gammie, Gralla, Murray, Phys. Rev. D 109, 123029/arXiv:2403.15903]

Conclusions

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Study close-by AGNs in great detail

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Start with small arrays and short baselines and expand outwards

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- Reverberation mapping → Hubble constant

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Thank you!

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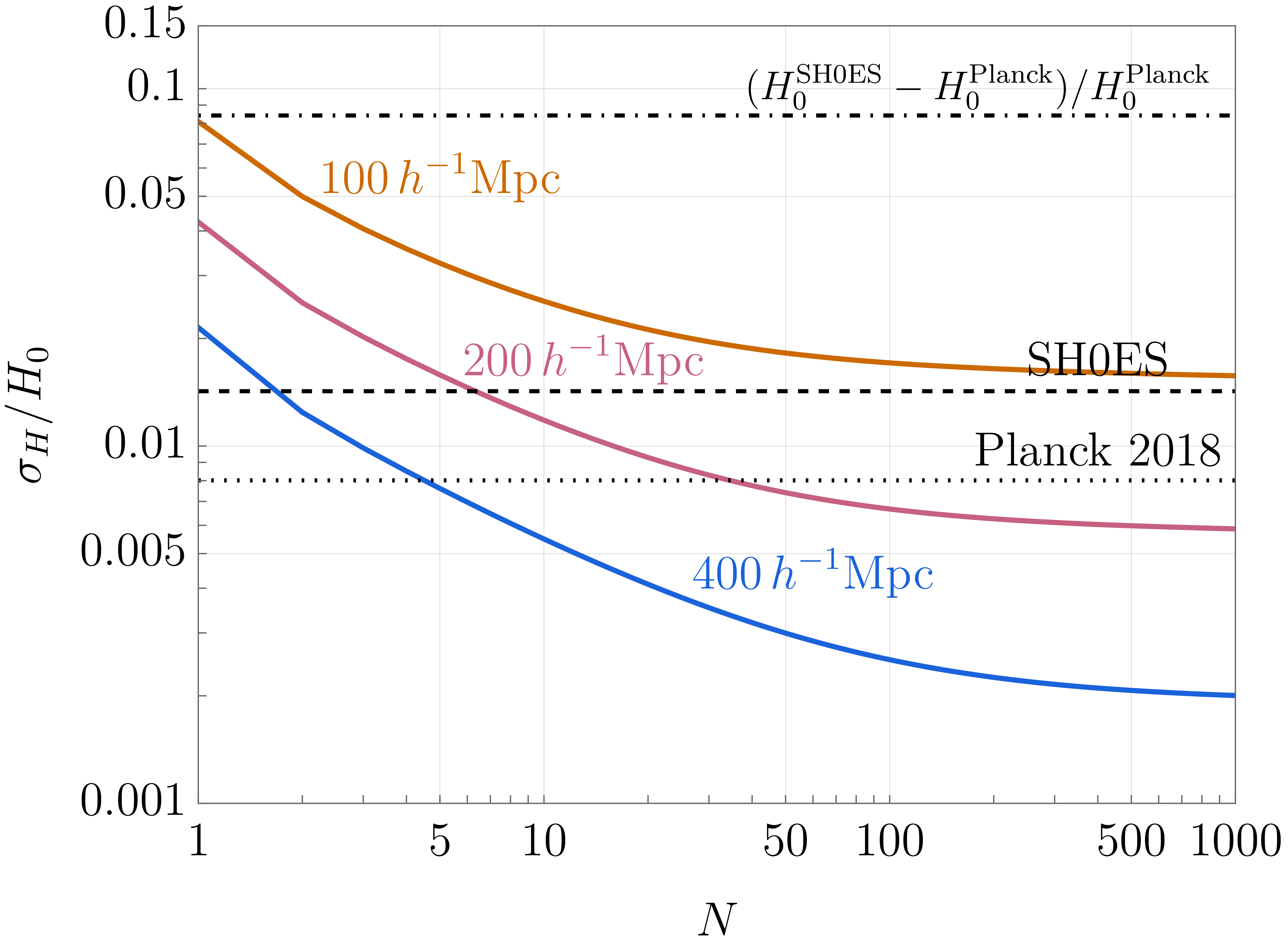
AGN Extras

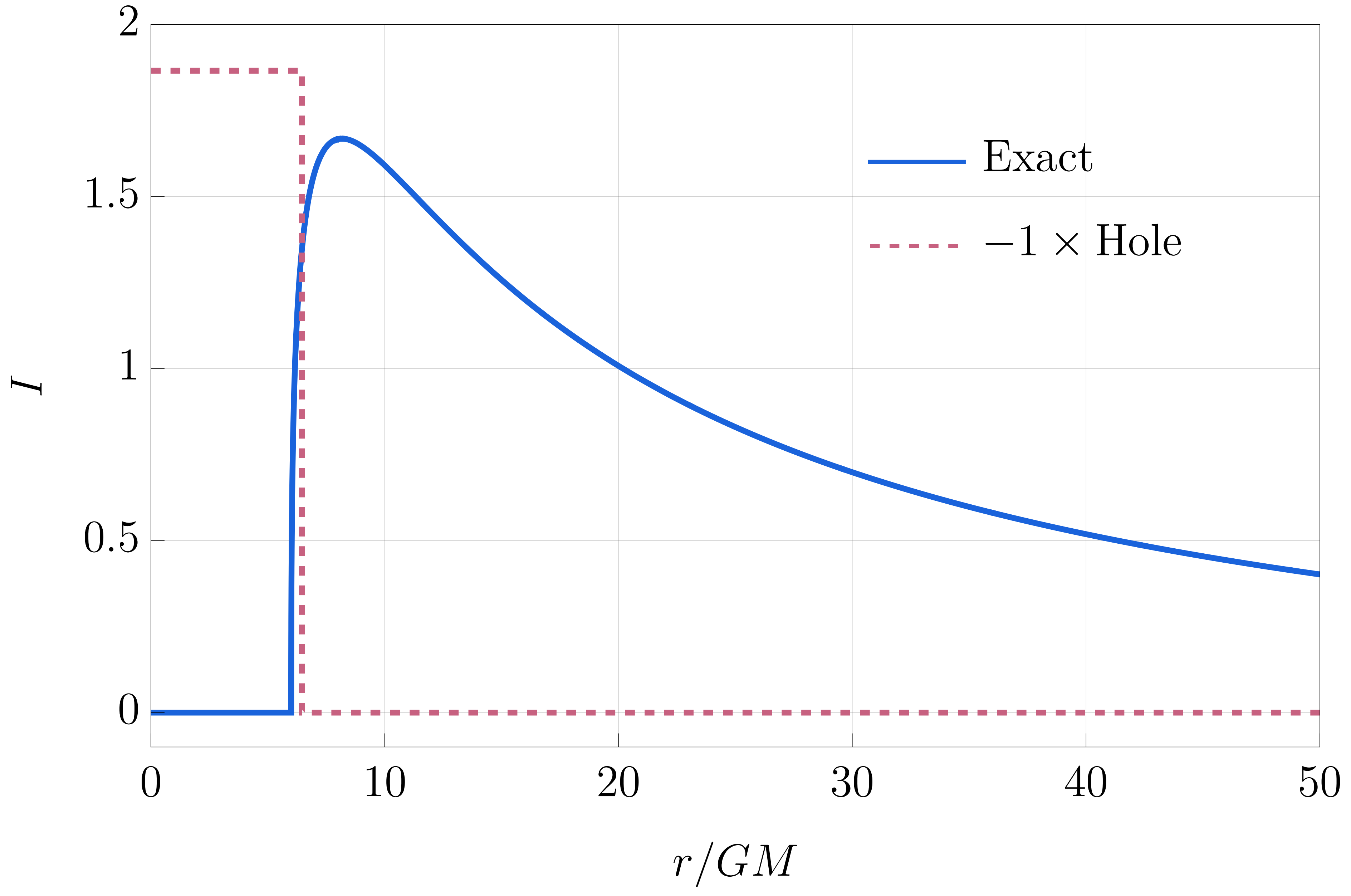
Sample variance on H0

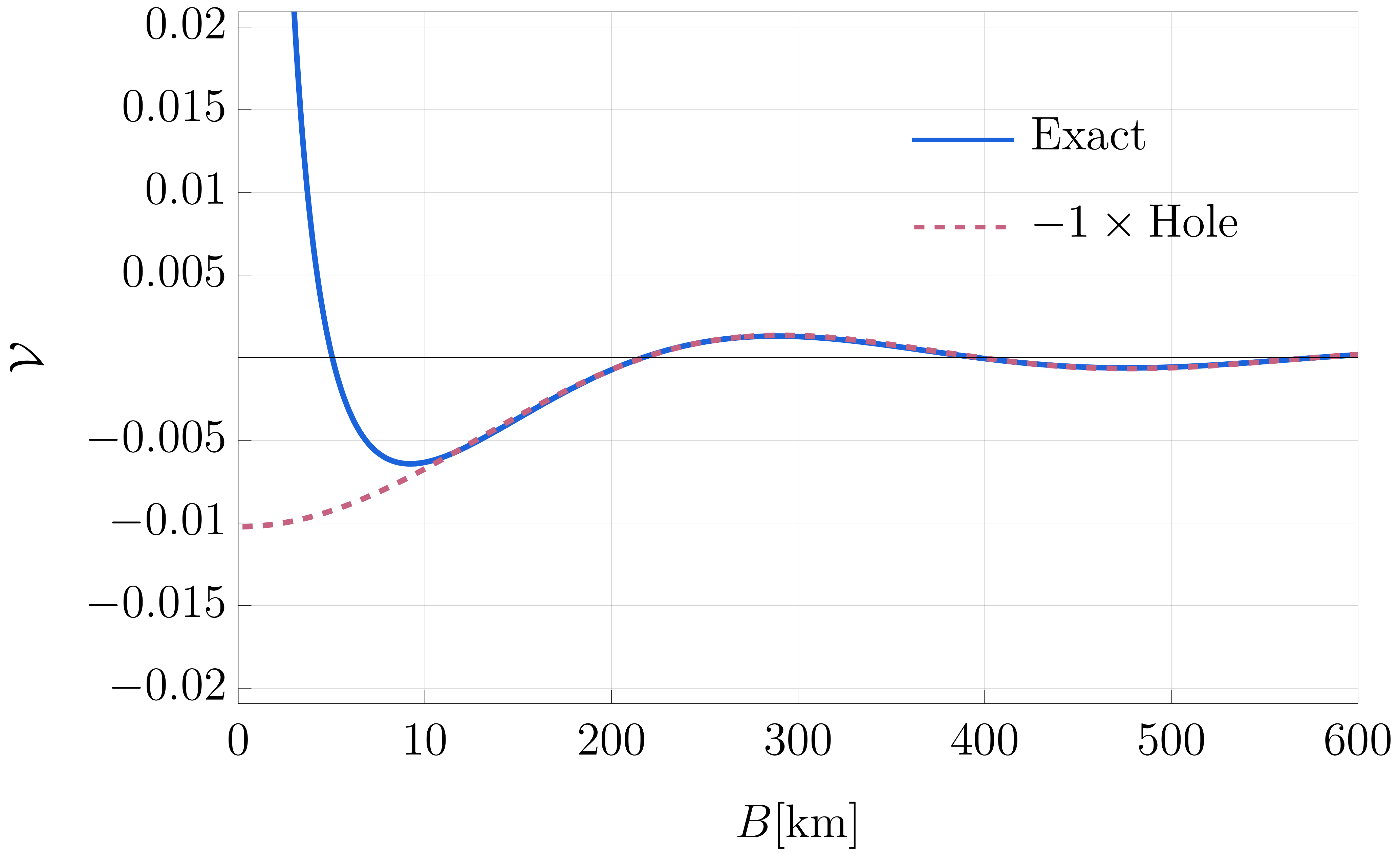


$$\sigma_H^2 = \sigma_{\rm CV}^2 + \frac{v^2}{R_{\rm max}^2}\frac{1}{N_{\rm obj}}, \quad v \approx 630 \text{ km/s}$$

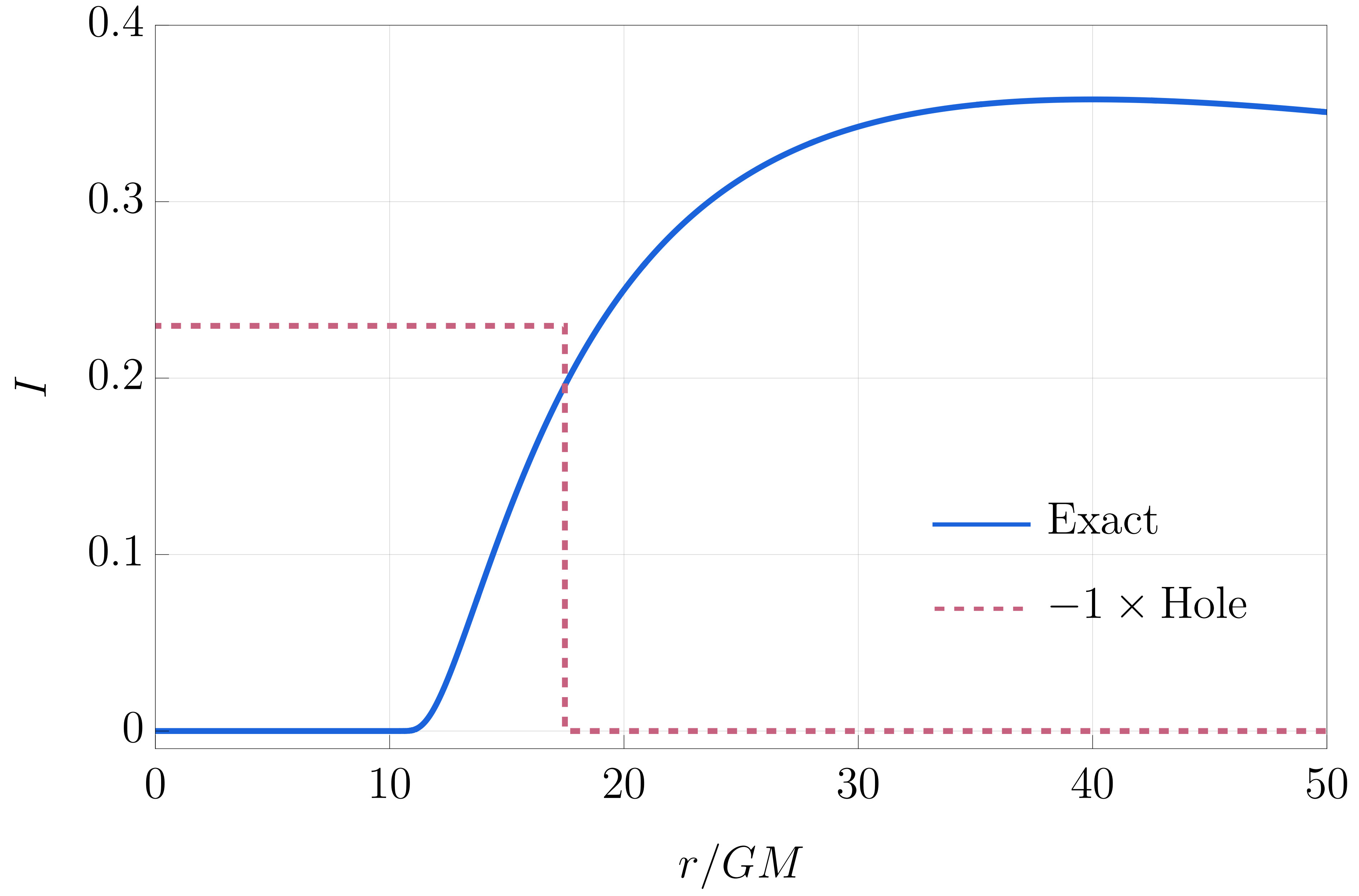
[Riess et al. 2022]
[*Planck* 2018]

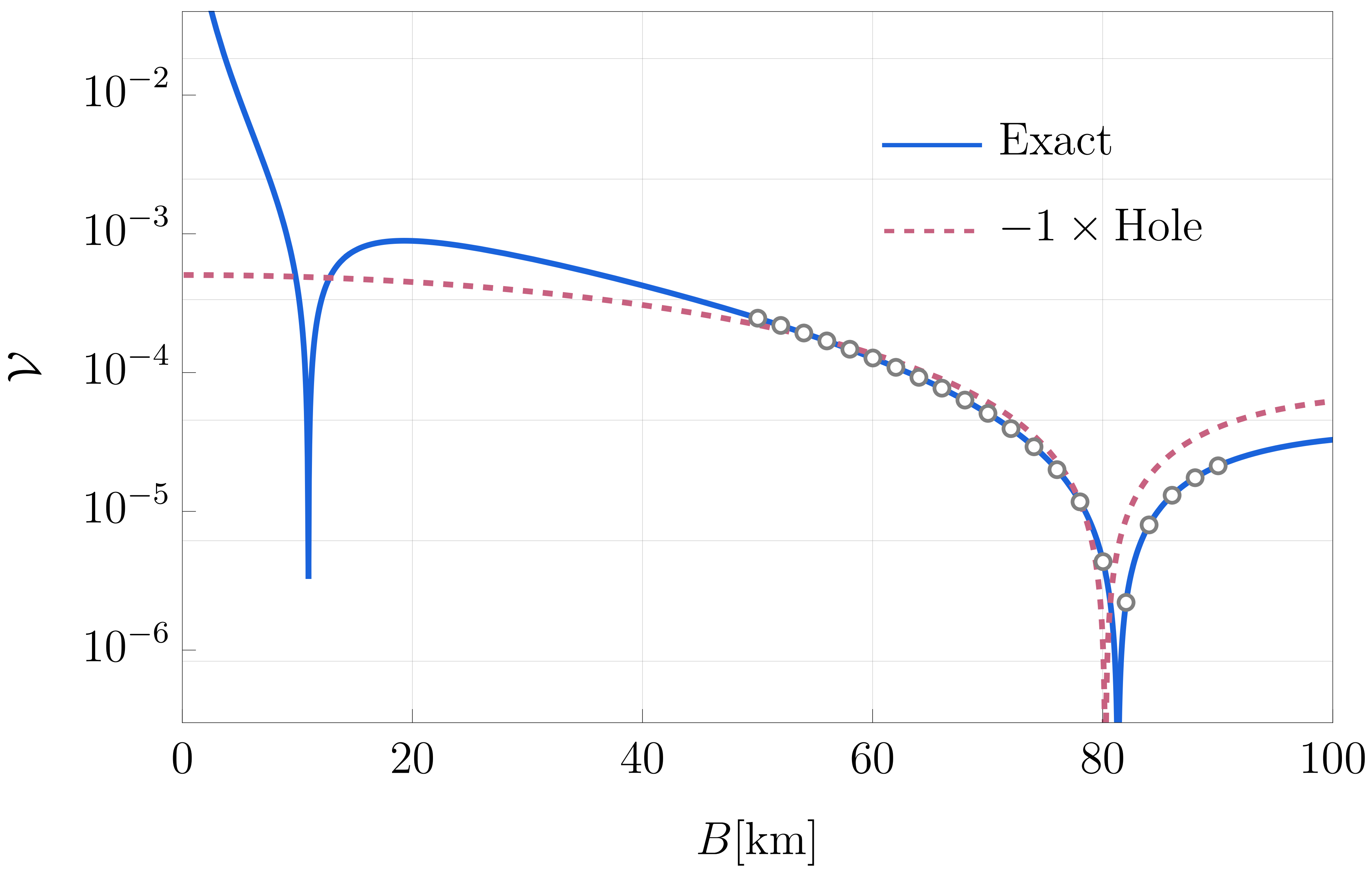
Sharp hole profile





Wide hole profile





H0 redshifts

SNe Ia Riess: $0.023 < z < 0.15$

Just Cepheids, $z<0.011$

H0LiCOW: $z=0.41$, HE 0435-1223