

Gravitational-Wave Lensing in an Active Galactic Nucleus

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Asian Gravitational Wave Astronomy Meeting (AGWAM), the 5th of July 2026
in collaboration with Otto A. Hannuksela, Samson H. W. Leong & Ryan Zhang

see also [arXiv:2408.13144](https://arxiv.org/abs/2408.13144)



Collaborators

Johns Hopkins U.



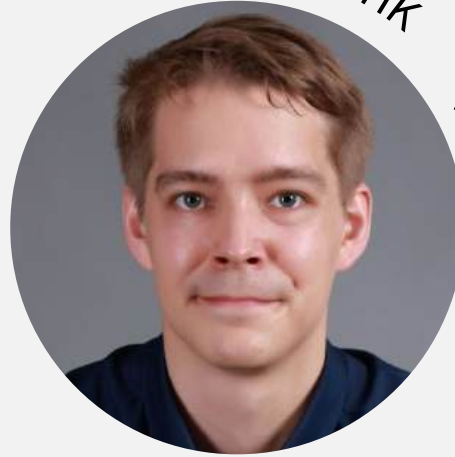
Ryan
Zhang

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Samson H. W.
Leong

CUHK



Otto A.
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Johns Hopkins U.



Mesut
Çalışkan

Johns Hopkins U.



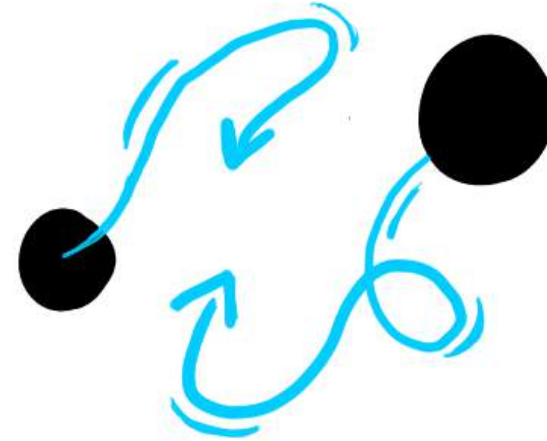
Francesco
Iacovelli

Binary formation channels 1 & 2

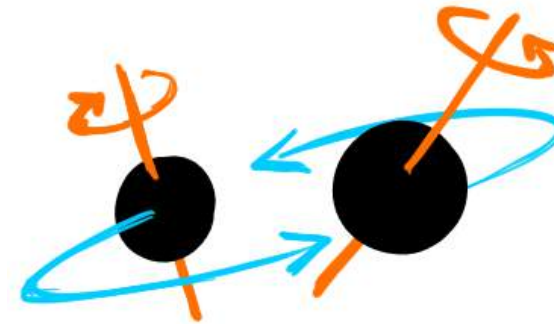
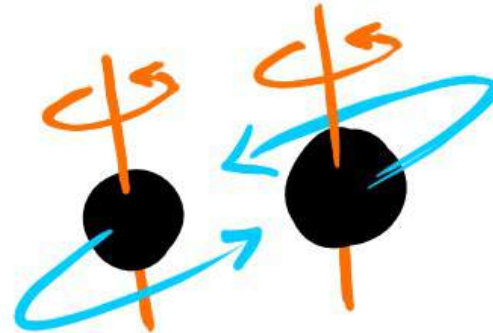
Common envelope

Dynamical capture

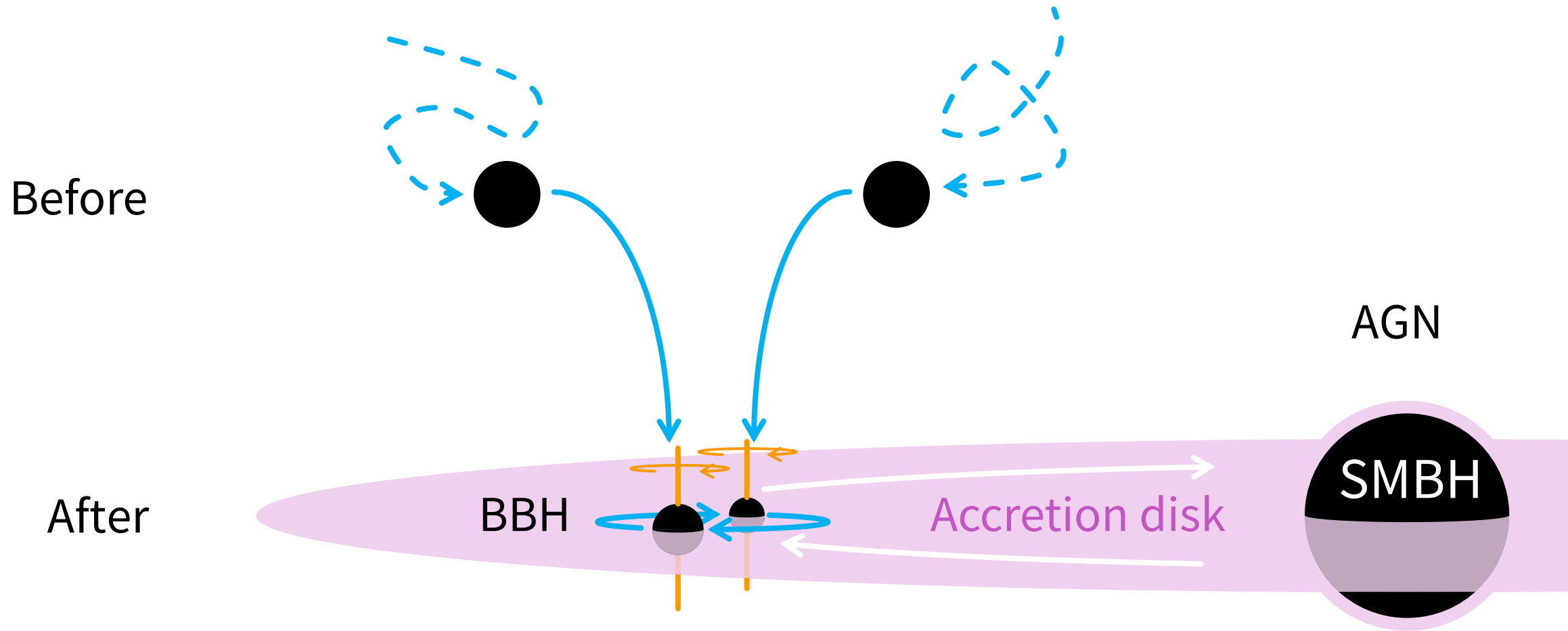
Before



After



Binary formation channel 3

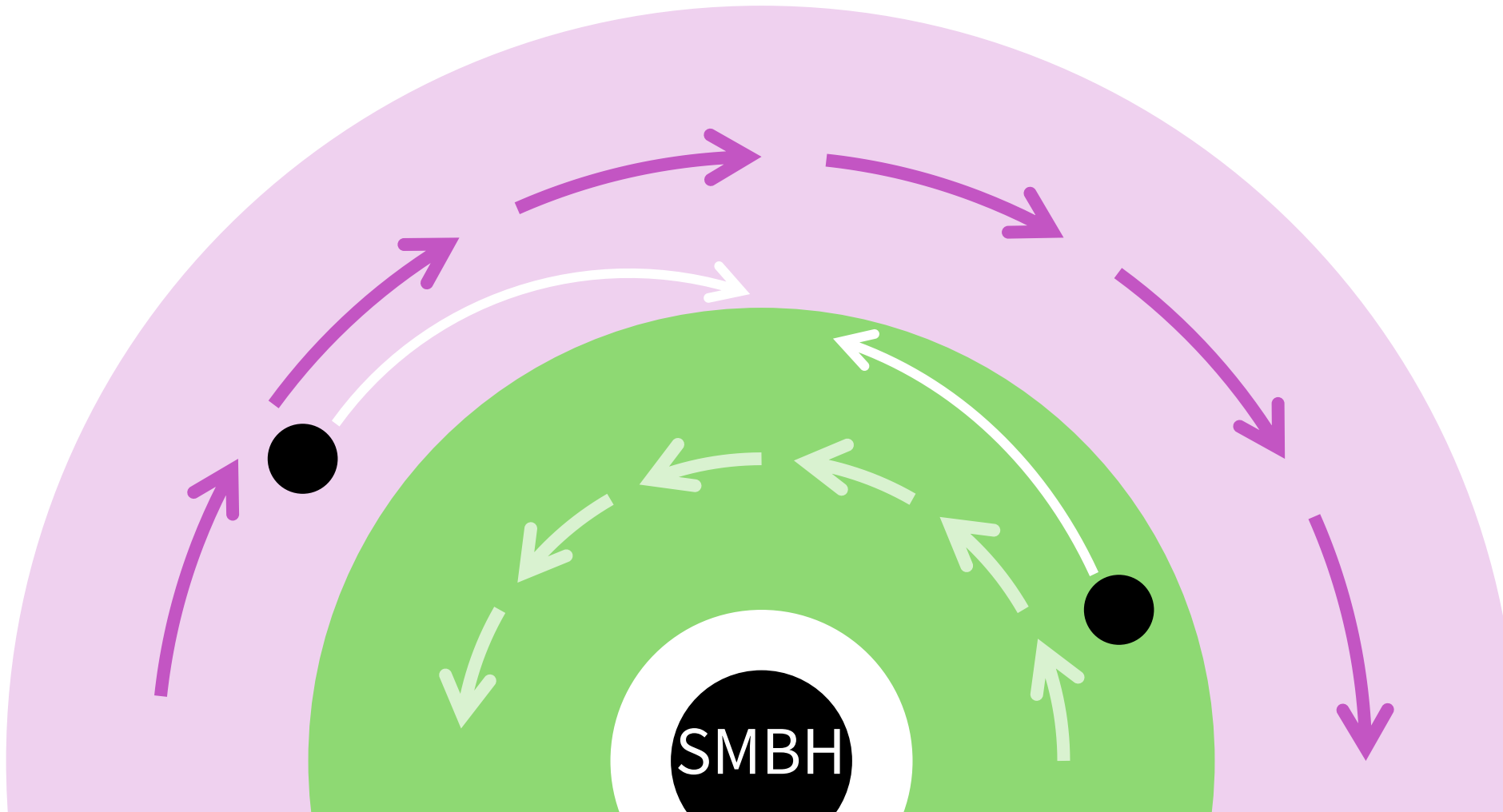


Migration traps

Peng & Chen, 2104.07685

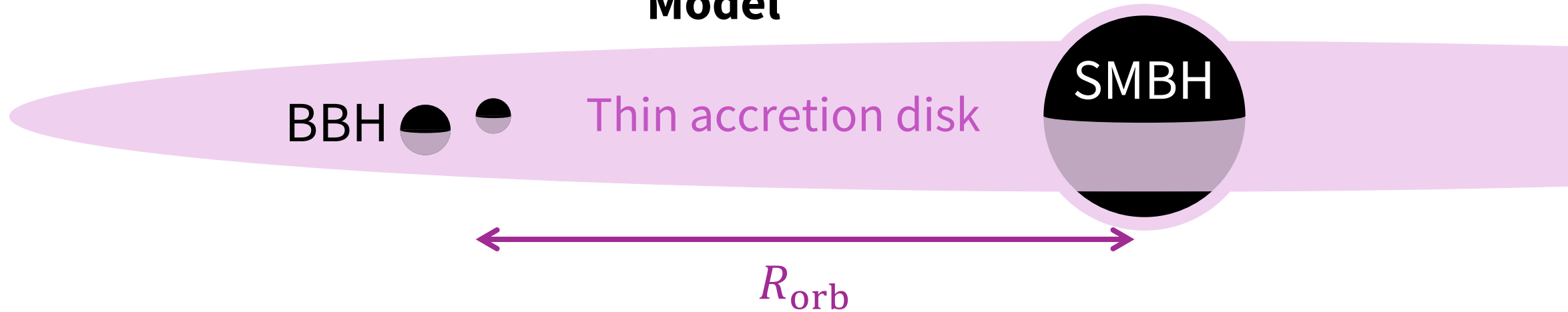
$7 R_{\text{Sch}}$

Bellovary et al., 1511.00005 20 to 300 R_{Sch}



Probability of lensing

Model

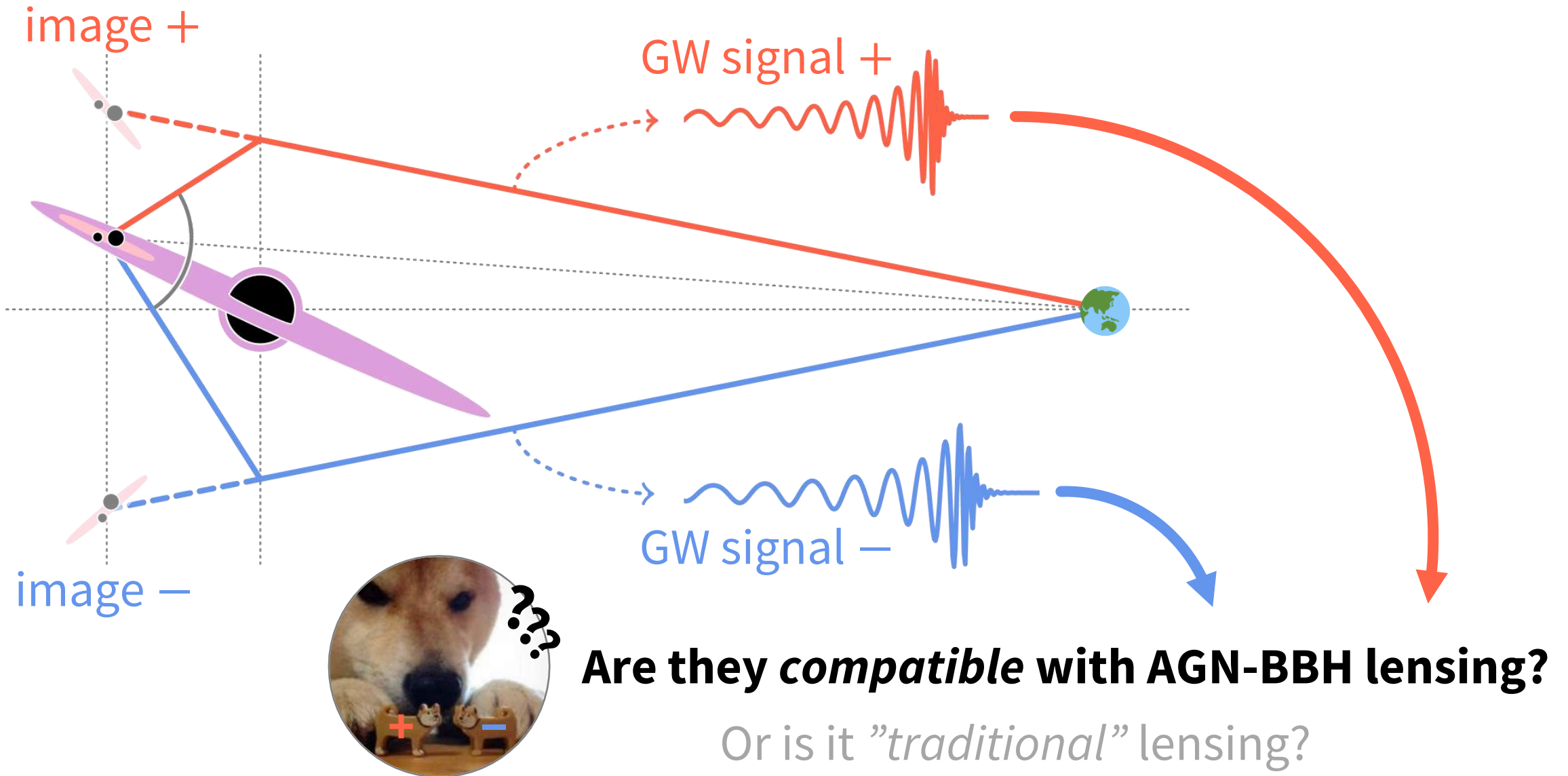


$$\left\{ \begin{array}{l} \text{Prob(Lensed|Model)} \approx \frac{R_{\text{Sch}}}{2 R_{\text{orb}}} \\ > 10^5 \text{ observations of GWs in the future} \end{array} \right. \longrightarrow \begin{array}{l} \text{GW lensing will occur} \\ \text{(if the channel is non-negligible)} \end{array}$$

arXiv:2408.13144

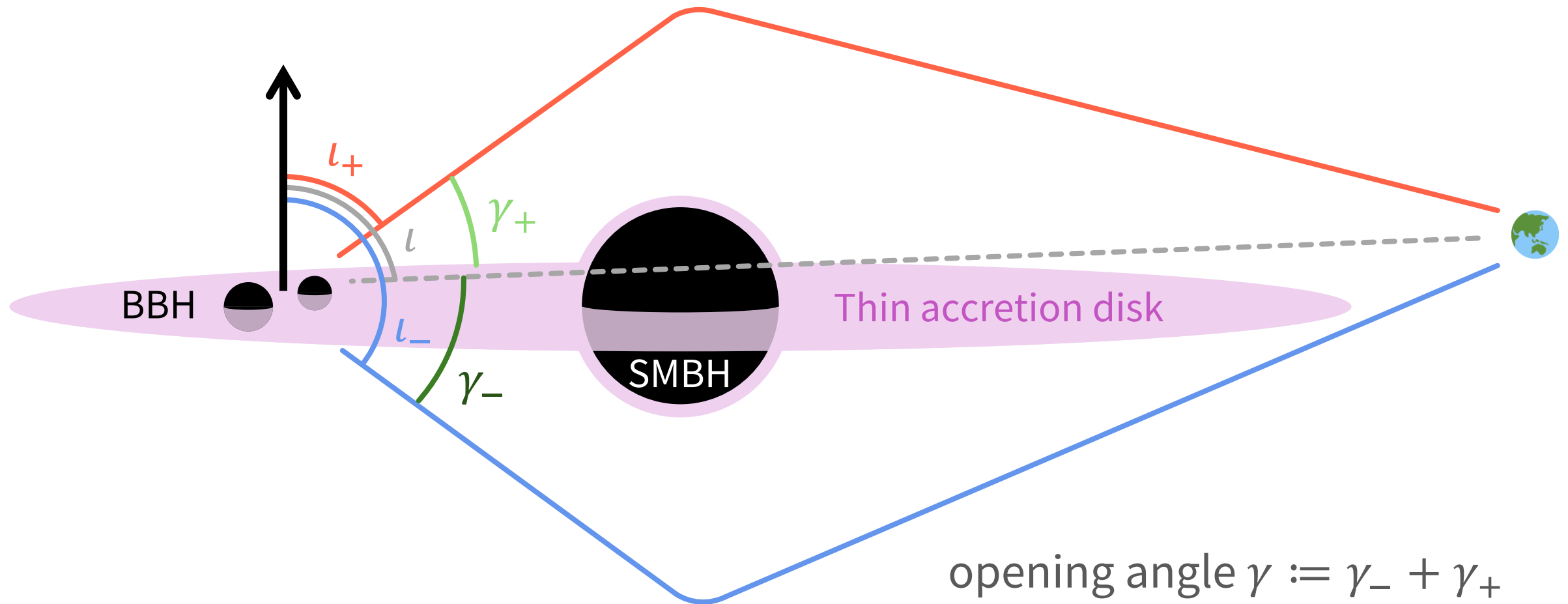
S. H.W. Leong, J. Janquart, A. Kumar Sharma, **P. Martens**, P. Ajith, **O. A. Hannuksela**

Discrimination criteria

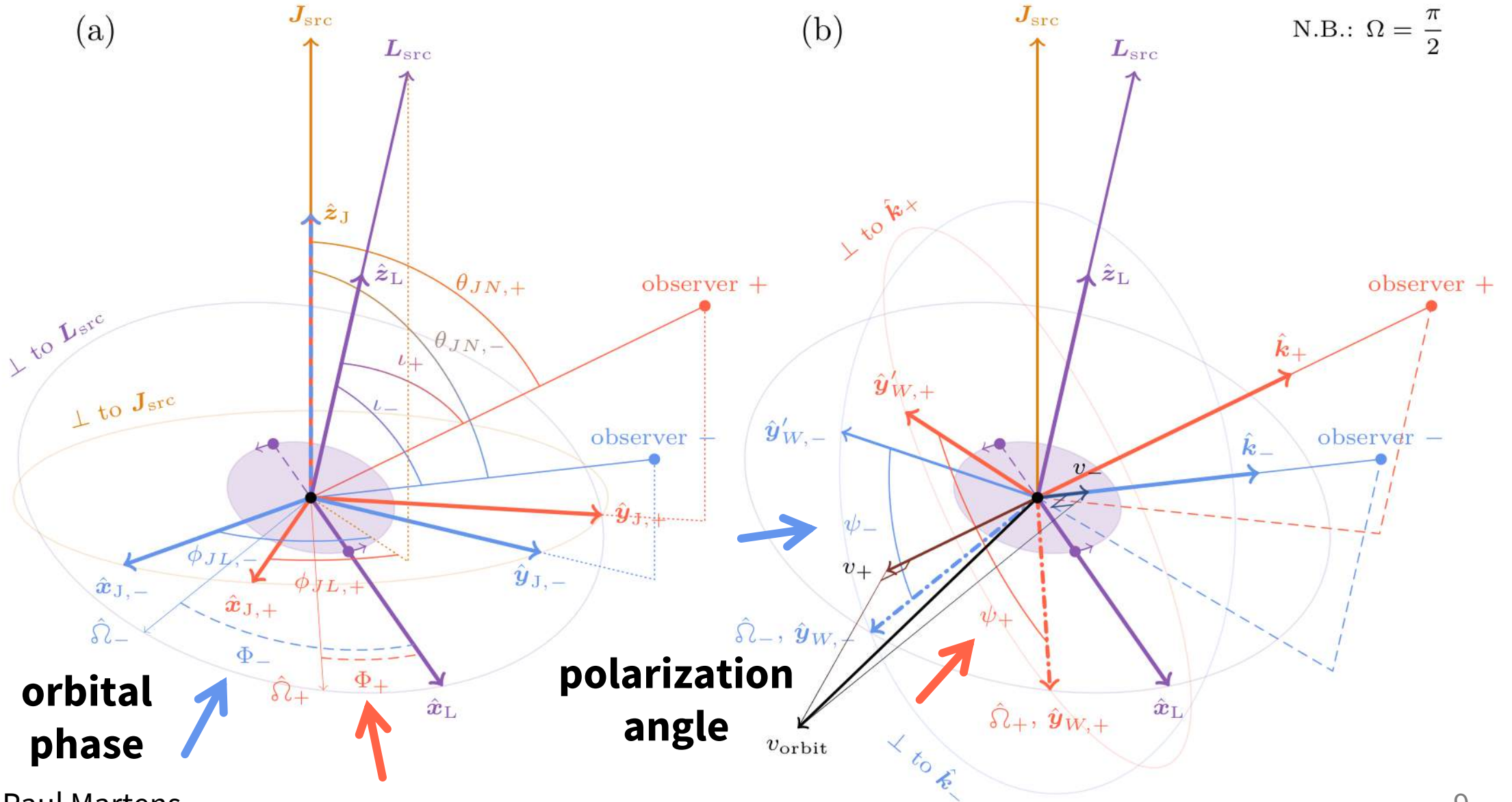


Large angles

Feature 1



BBH parameters & observer position



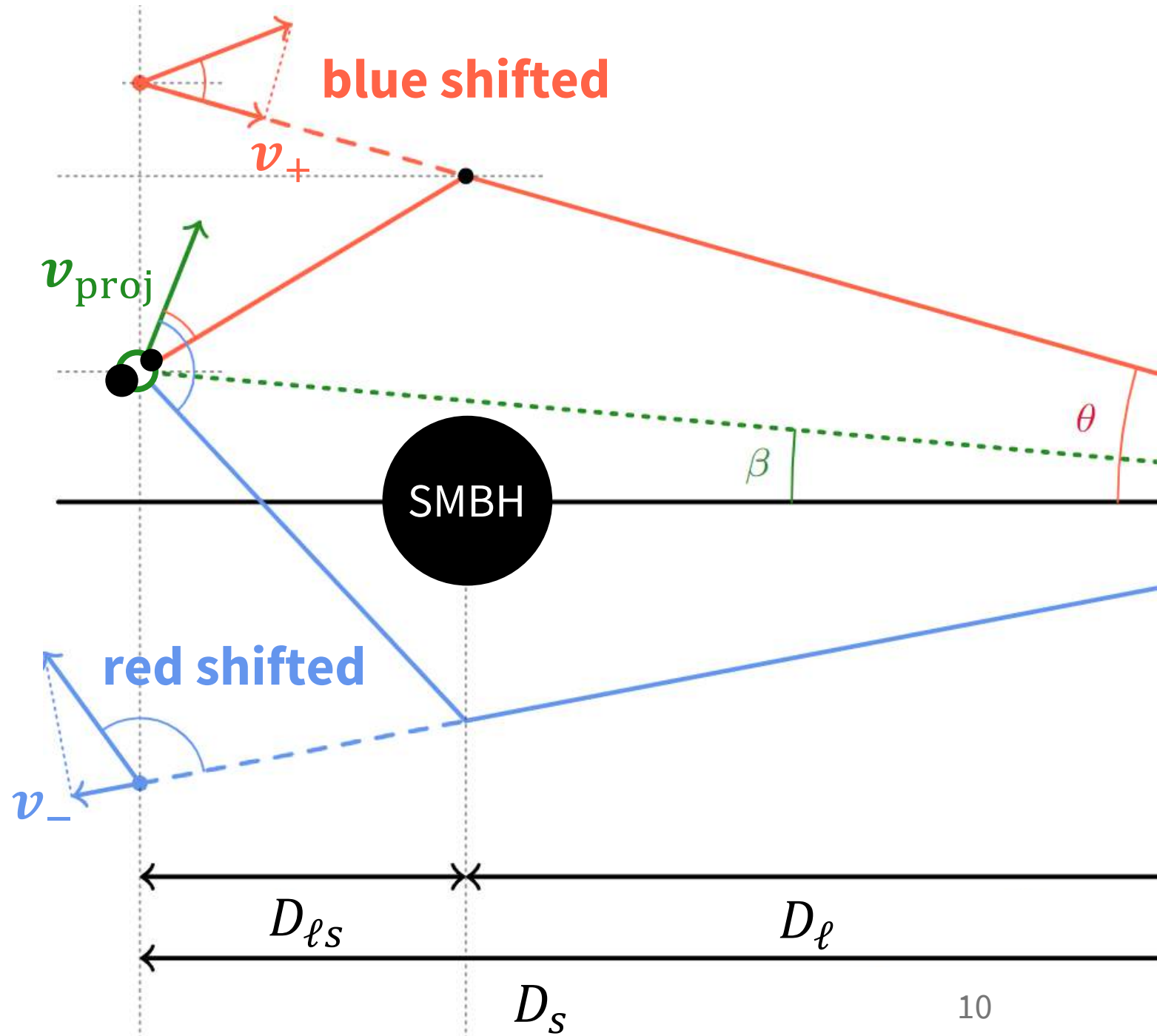
Doppler shift

Feature 2

$$v_{\text{orb}}^2 \propto \frac{M_{\text{AGN}}}{R_{\text{orb}}} \propto \frac{R_{\text{Sch}}}{R_{\text{orb}}}$$

$$\delta z_{\text{bias}} \propto \Delta v_{\pm}$$

$$\Delta v_{\pm} \sim 2 \frac{R_{\text{Sch}}}{R_{\text{orb}}}$$



A gravitational wave signal

GW Signal



PE

15 parameters

- 2 masses
- 6 spin parameters
- 1 source distance
- 2 for sky localization
- 1 time of arrival
- 3 angles
 - Inclination ι
 - Phase of coalescence ϕ_{coal}
 - Polarization ψ

+ lensing parameters...

Parameter estimation

🚧 Preliminary result 🚧

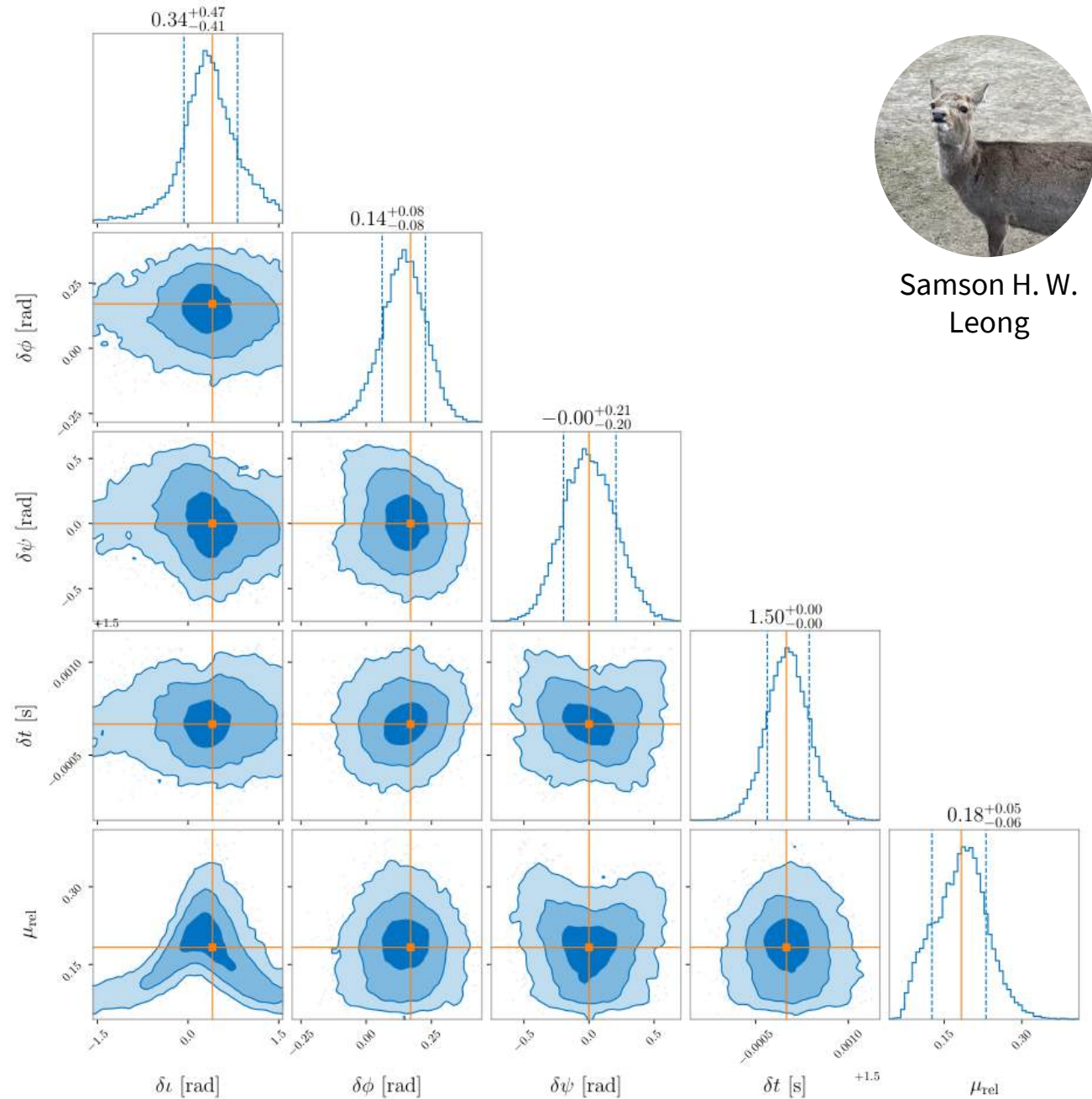
Can we realistically
recover the parameters?

Apparently, yes!



But more ongoing...

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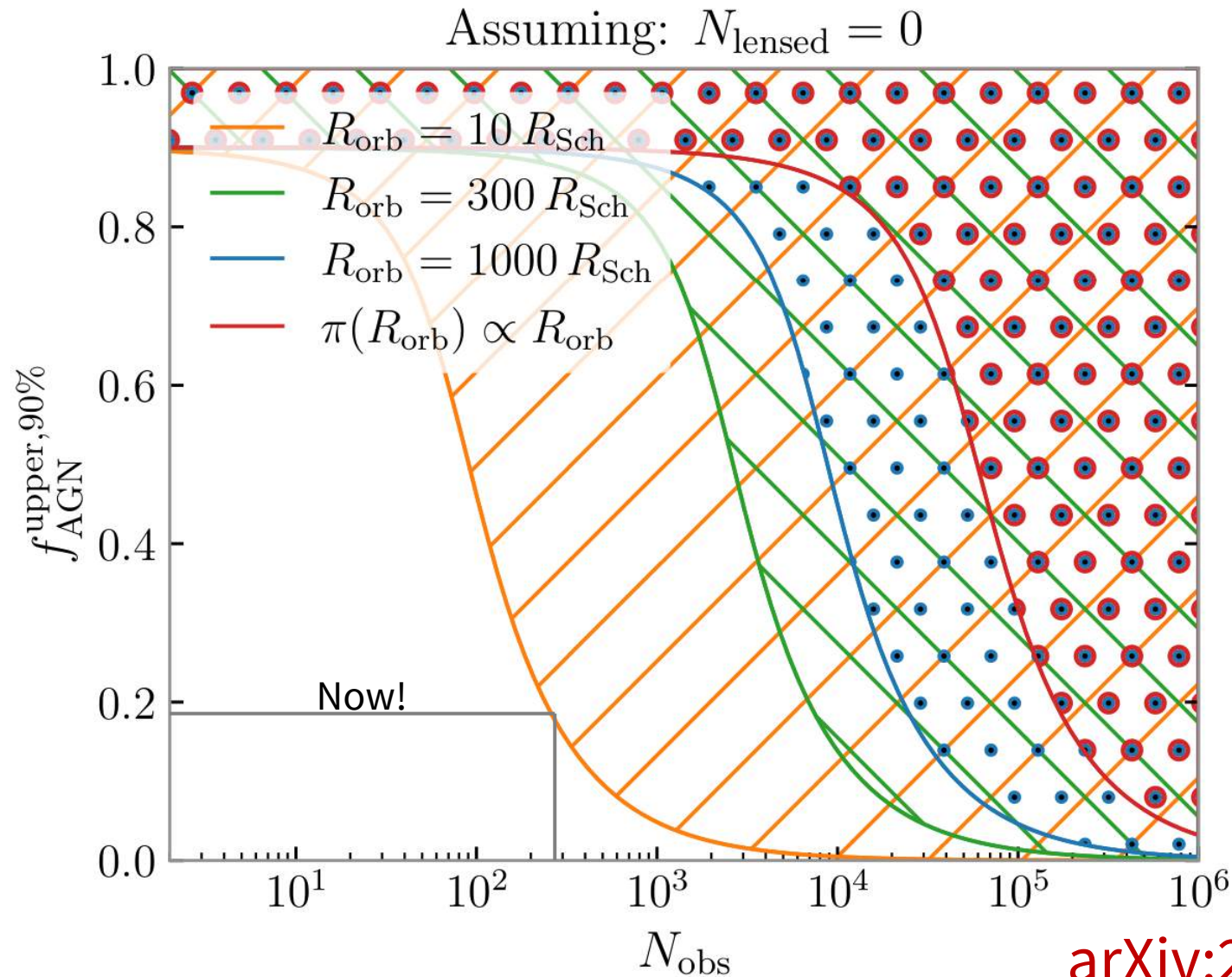


Samson H. W.
Leong

Future developments

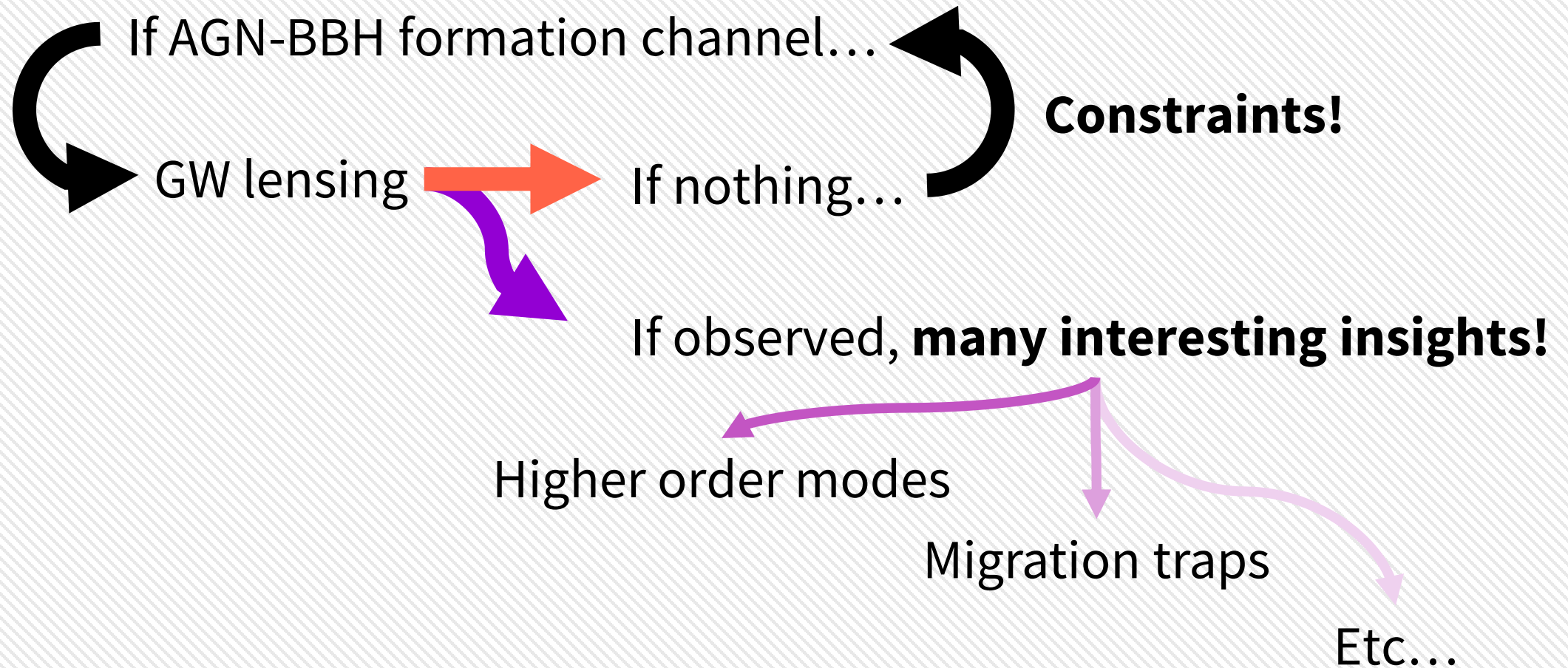
- Constrain the recoverable **parameter space**
 1. In simplified setting first
 2. Using full parameter estimation
 3. Including FAR & co...
- Consider **additional effects**

What if we do not find any AGN-BBH?



arXiv:2408.13144

Summary



Quick mention! 🍾

Testing cosmological isotropy with gravitational waves and gamma-ray bursts

Brian H. Y. Cheng¹, Donniel C. Cruz², Otto A. Hannuksela¹, Davendra S. Hassan³, Christian Heiderijk⁴, Leo Q. Hu⁴, Souvik Jana¹, Jinwon Kim⁵, Albert K. H. Kong^{6,7}, Peony K. K. Lai¹, Samuel C. Lange¹, Samson H. W. Leong¹, Matteo Lulli¹, Li-Ting Ma⁶, Paul Martens^{1*}, Boris H.-L. Ng¹, Thomas C. K. Ng^{8,9,1}, Surojit Saha⁶, Gwangeon Seong¹⁰, Helen Xian¹, and Yanyan Zheng¹¹

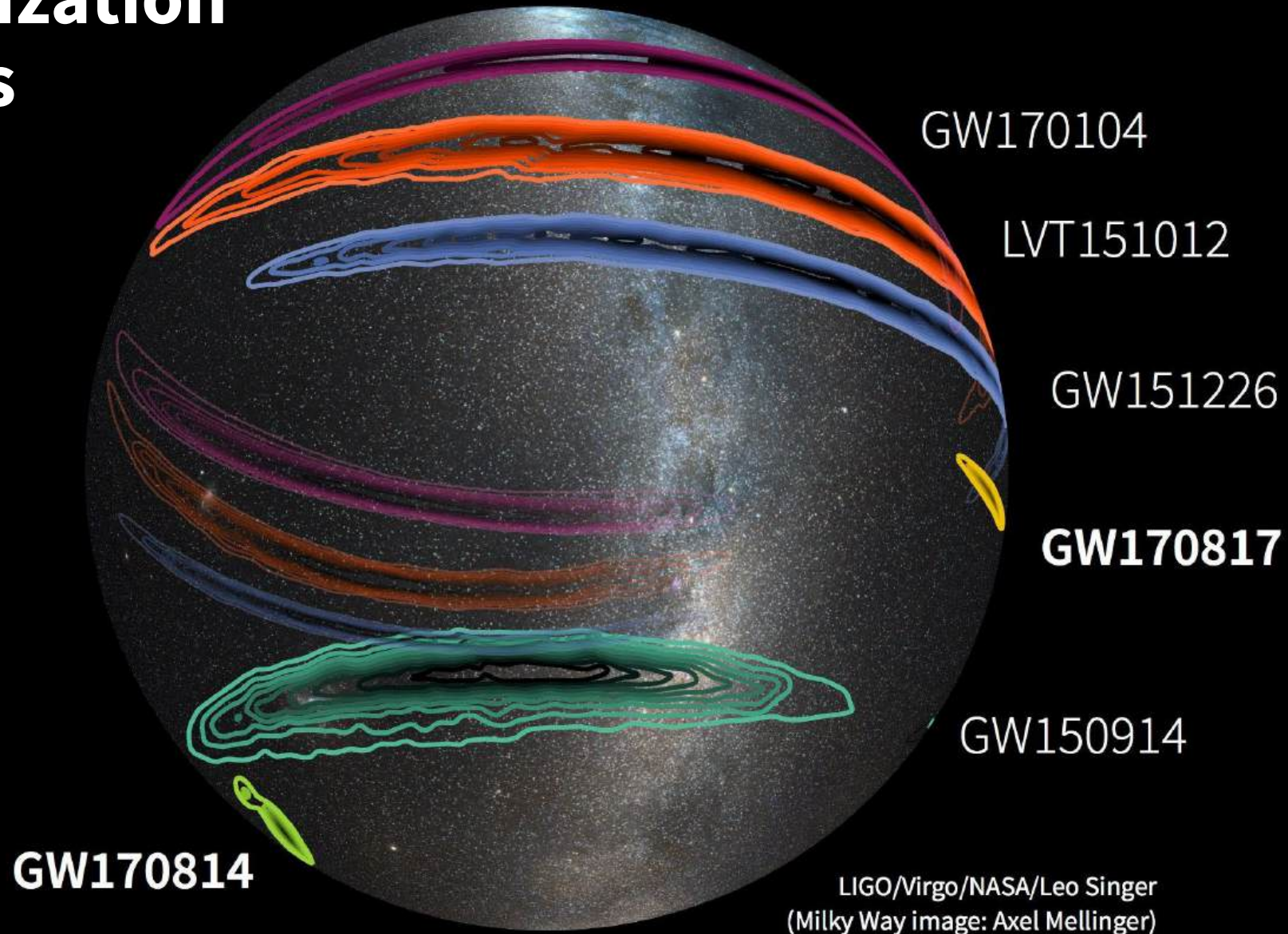


Thank you!

Extra slides



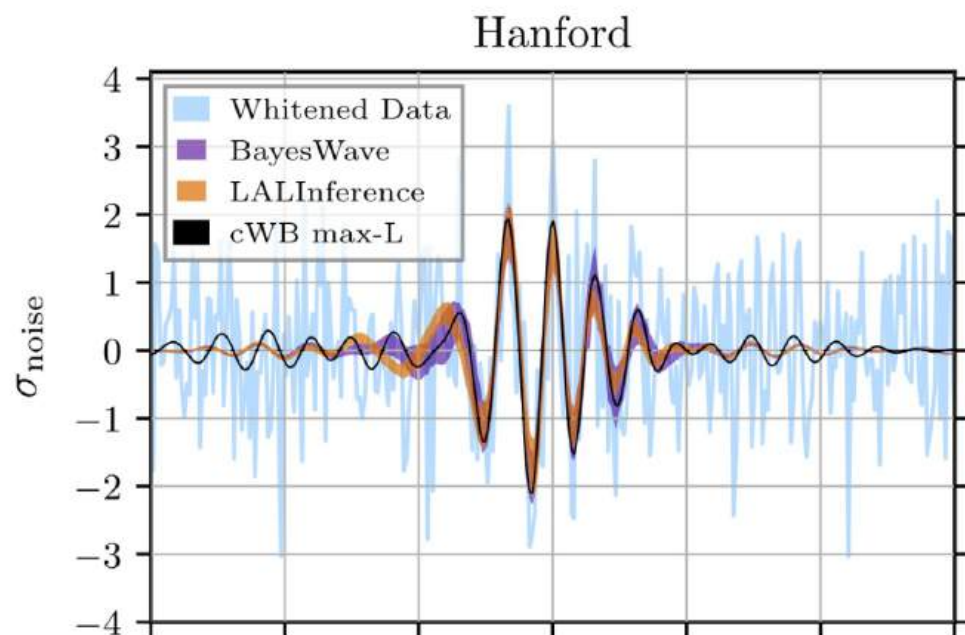
Sky localization examples



GW190521

An illustration

Waveform



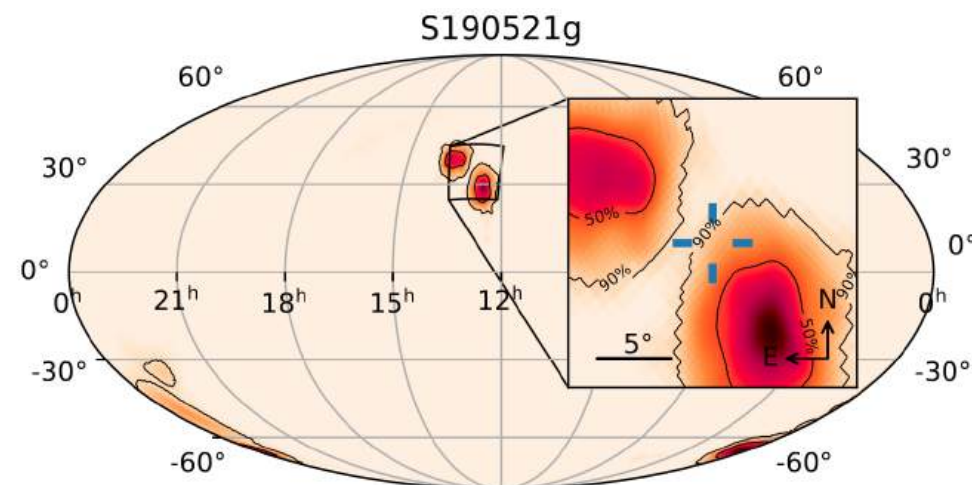
arXiv: 2009.01075

Intermediate
masses

$$\begin{cases} 85^{+21}_{-14} M_{\odot} \\ 66^{+17}_{-18} M_{\odot} \end{cases}$$

but arXiv:2009.12346...

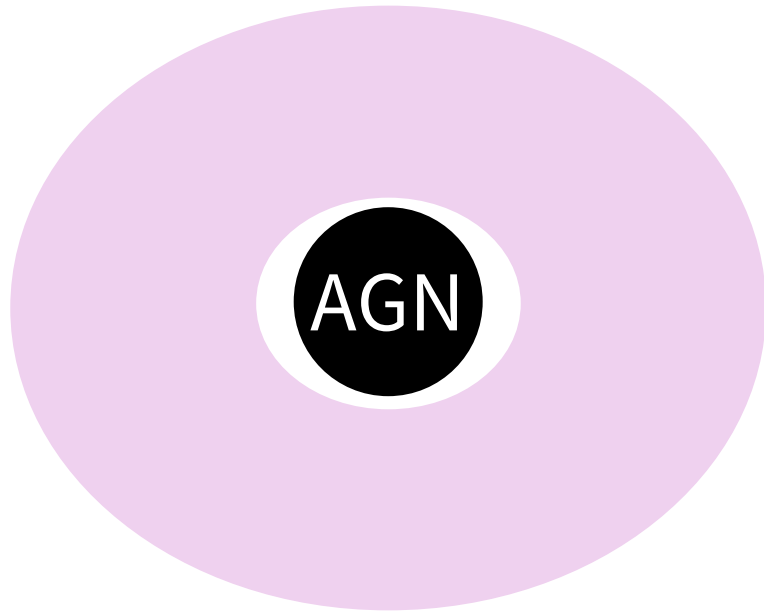
Possible flare



arXiv: 2006.14122

Flare vs lensing

Face-on



Flare

Edge-on



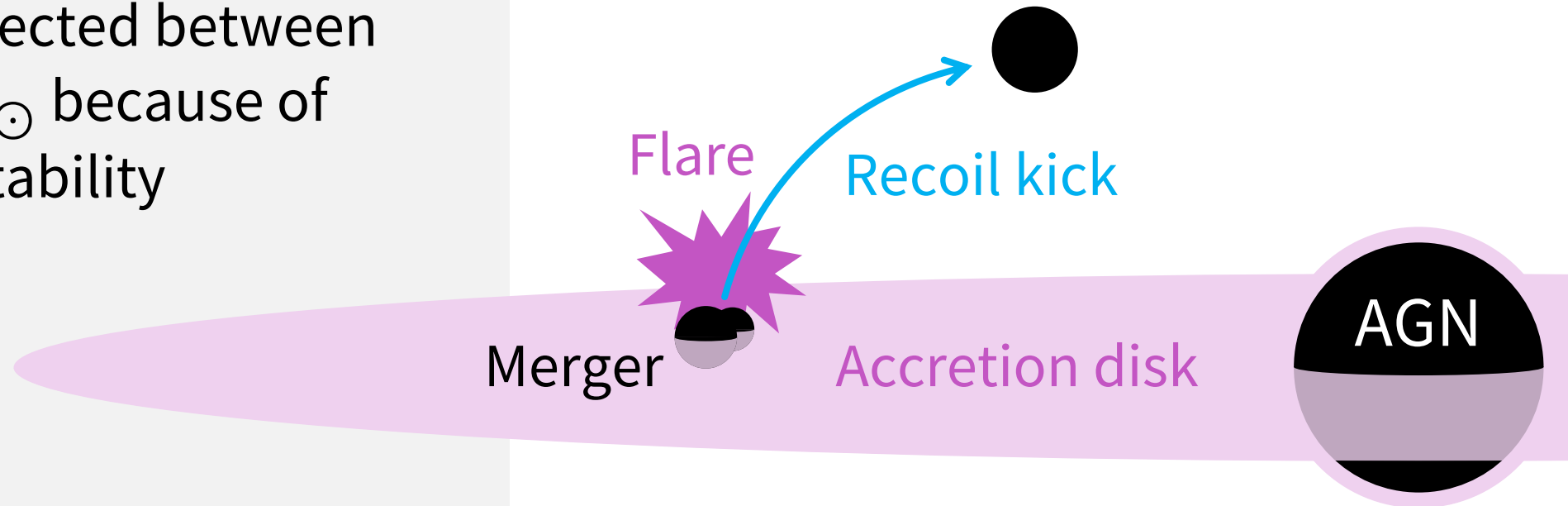
Lensing

IMBH

No remnant expected between
64 and 135 $M_{\odot}$ because of
pair instability

*Intermediate mass from
the accretion disk*

Recoil & flare



*Flare would be from
the accretion disk*

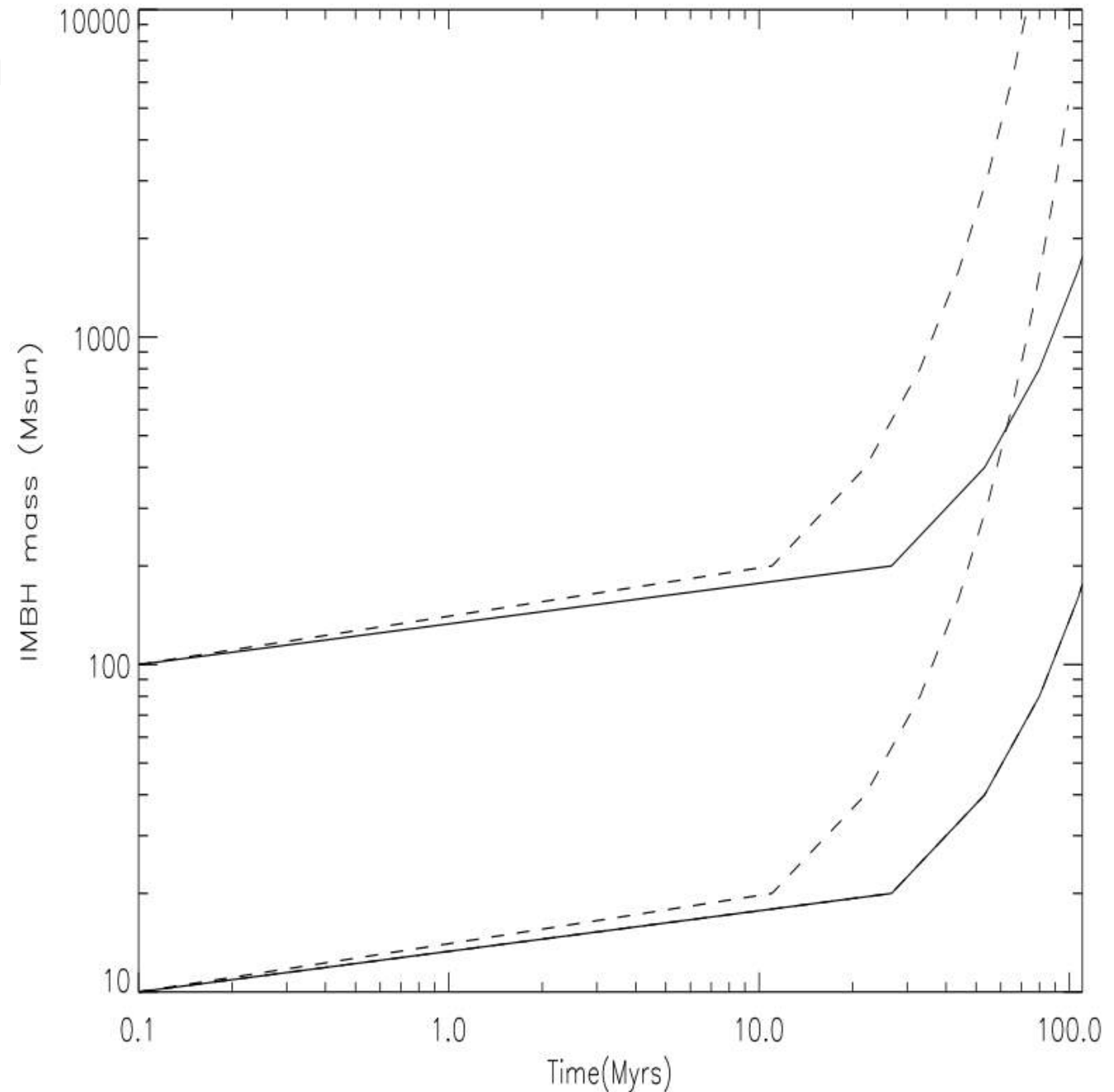
but arXiv:2009.12346...

Mass growth rate in an accretion disk

$$\sim 10^{-7} M_{\odot}/\text{yr}$$

McKernan *et al.*,
arXiv: 1206.2309

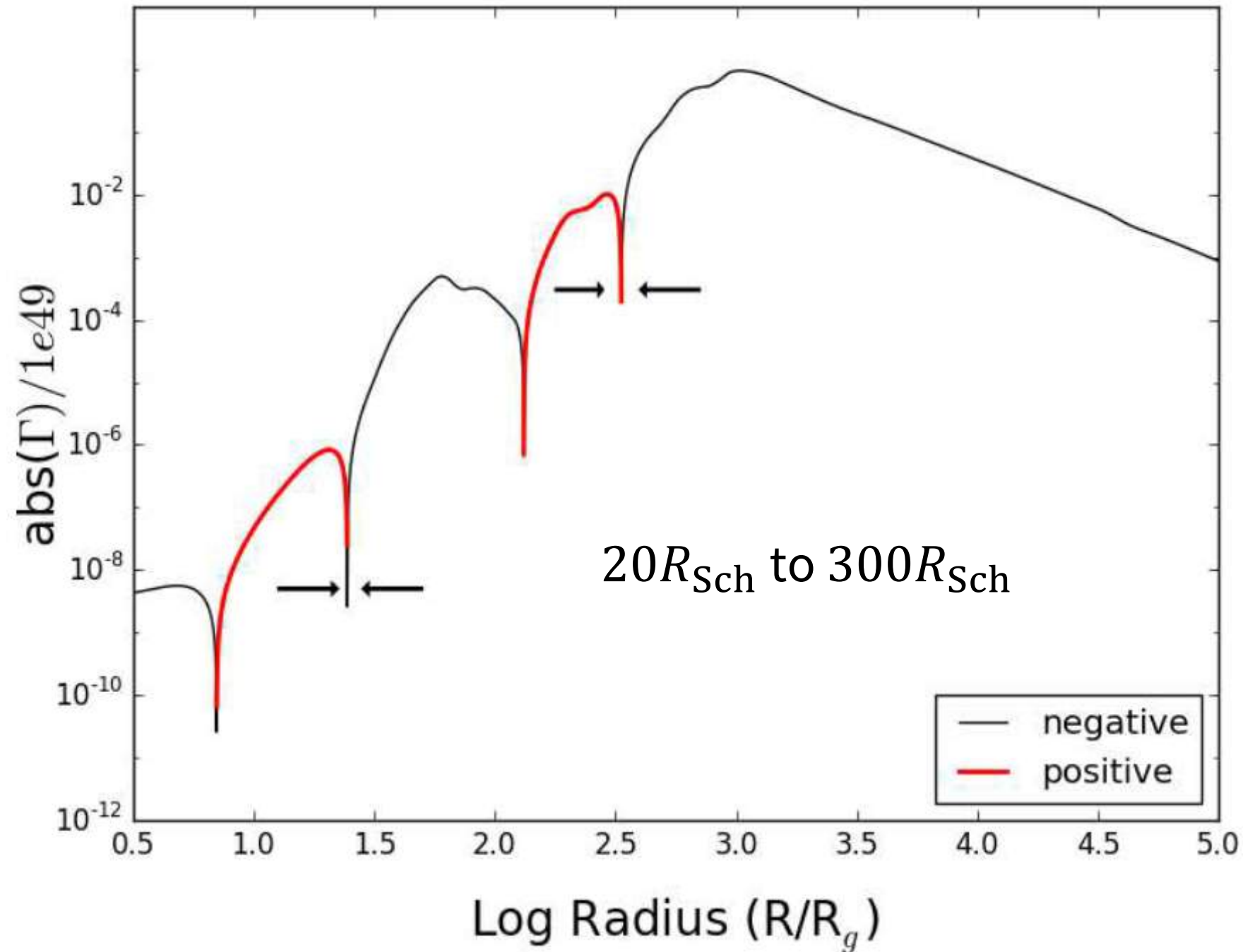
McKernan *et al.*,
arXiv: 1403.6433



Torque and traps

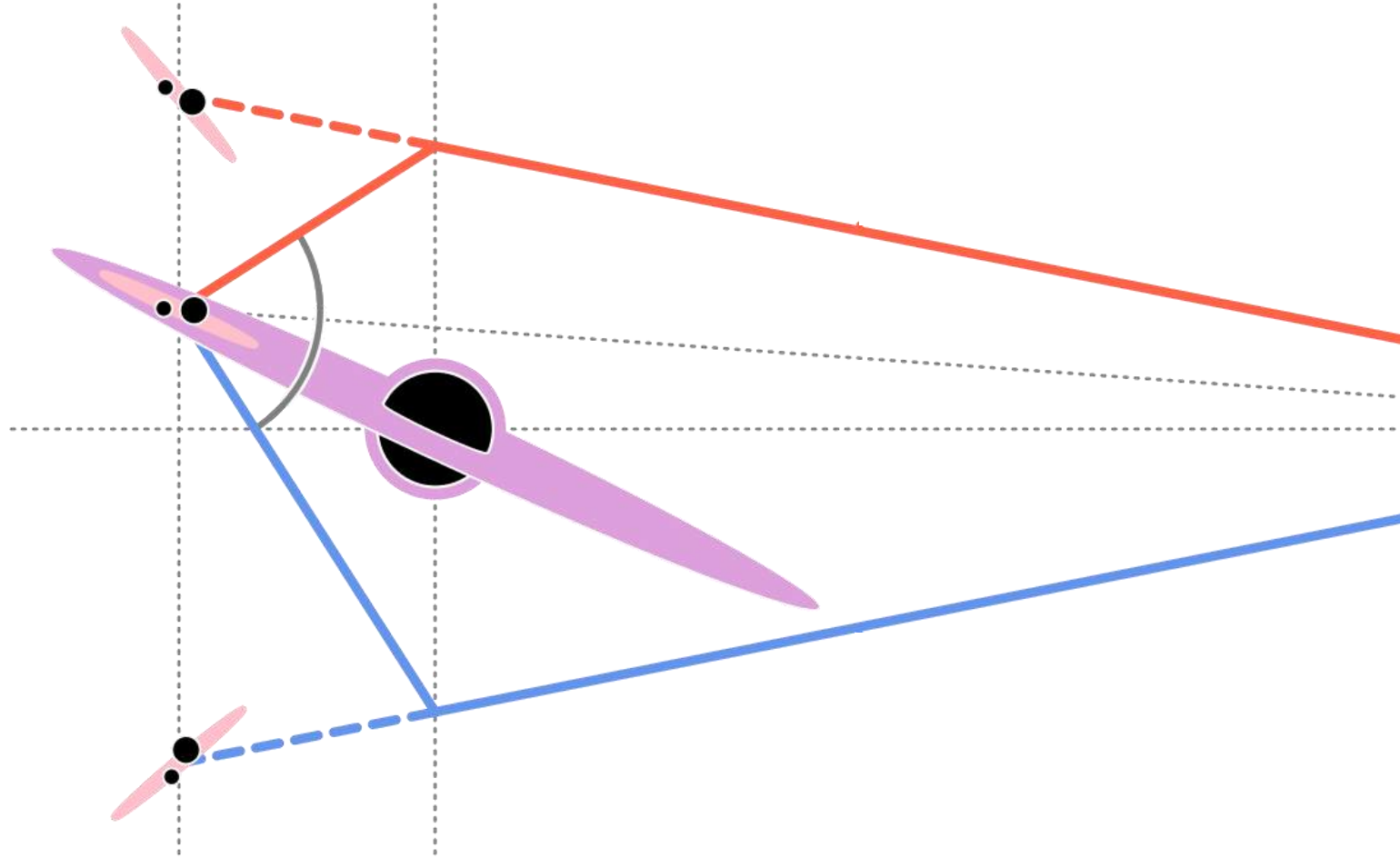
Bellovary et al.,
1511.00005

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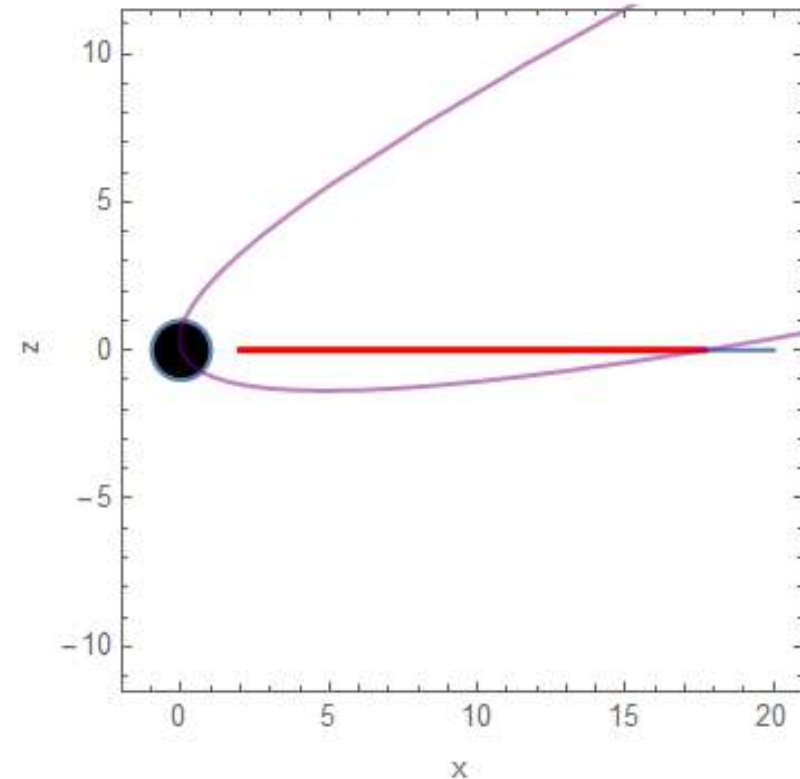
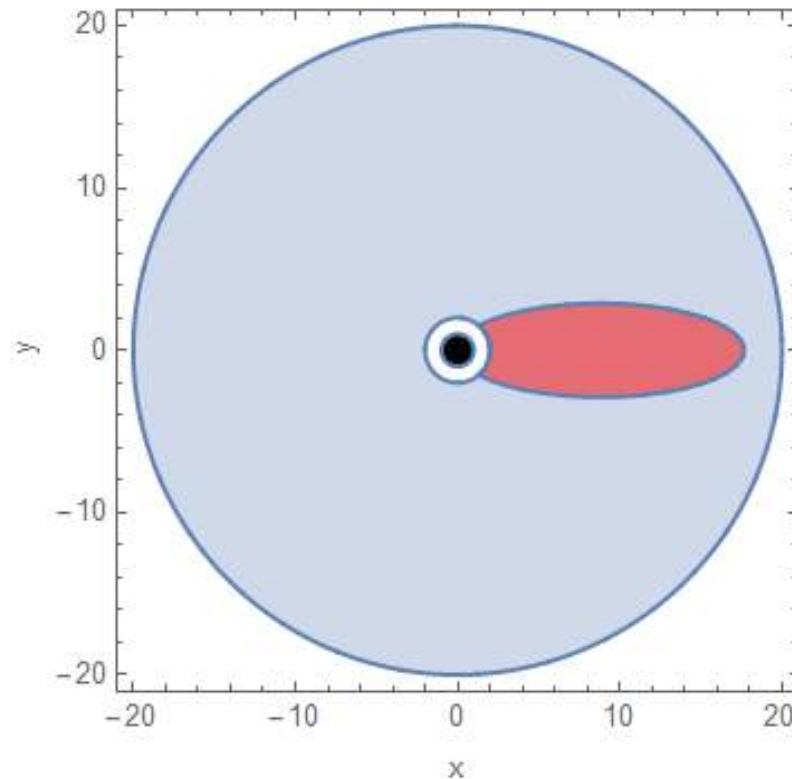
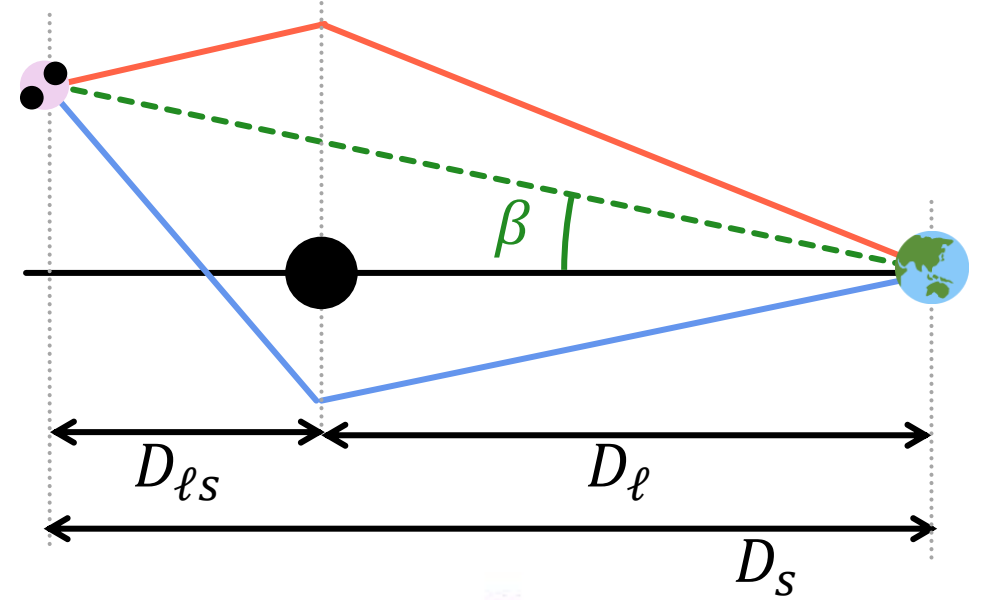
Some assumptions...

- Geometrical optic limit
- Point mass lens
- No additional effect
(for now)

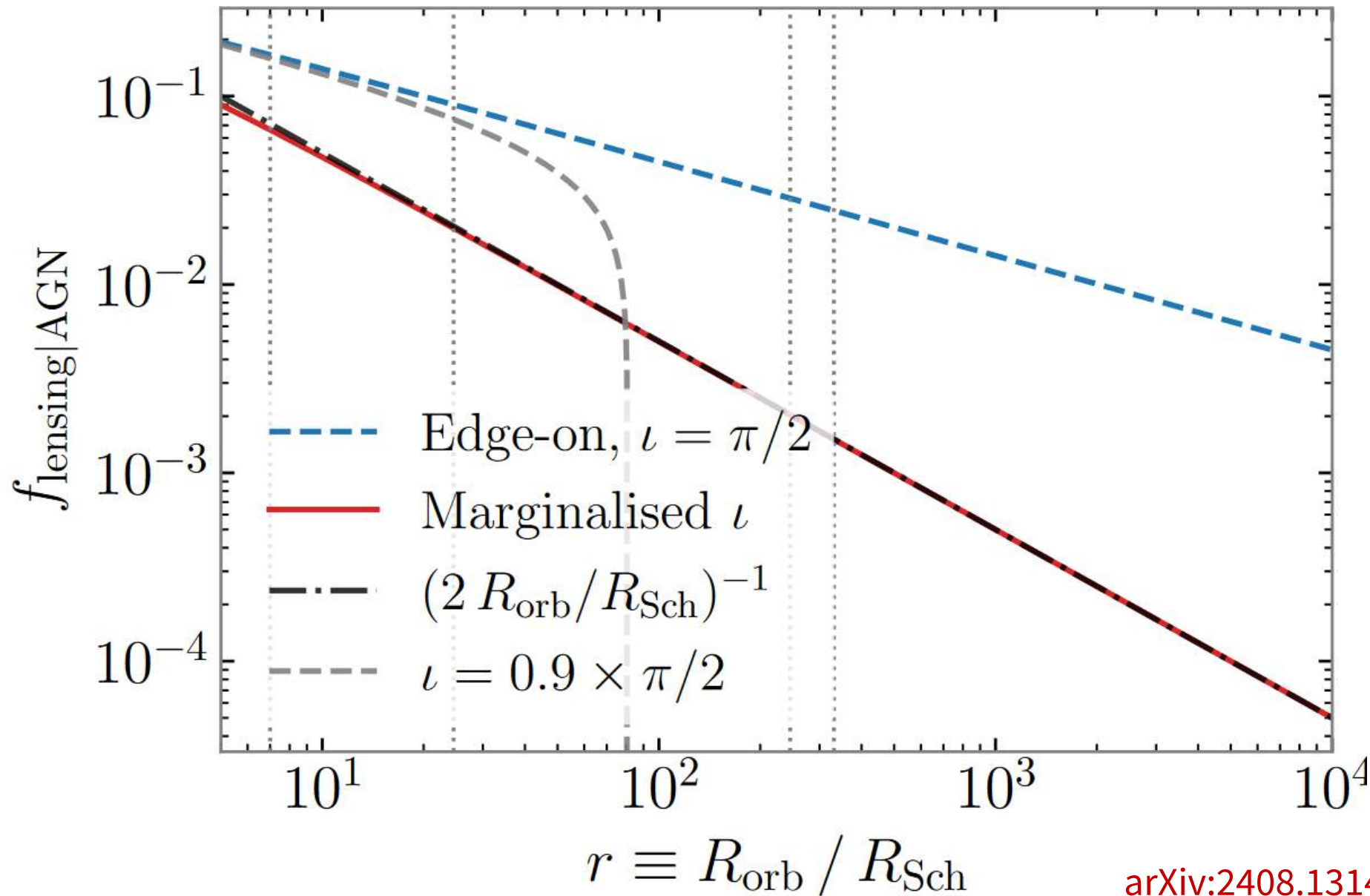


Lensing condition

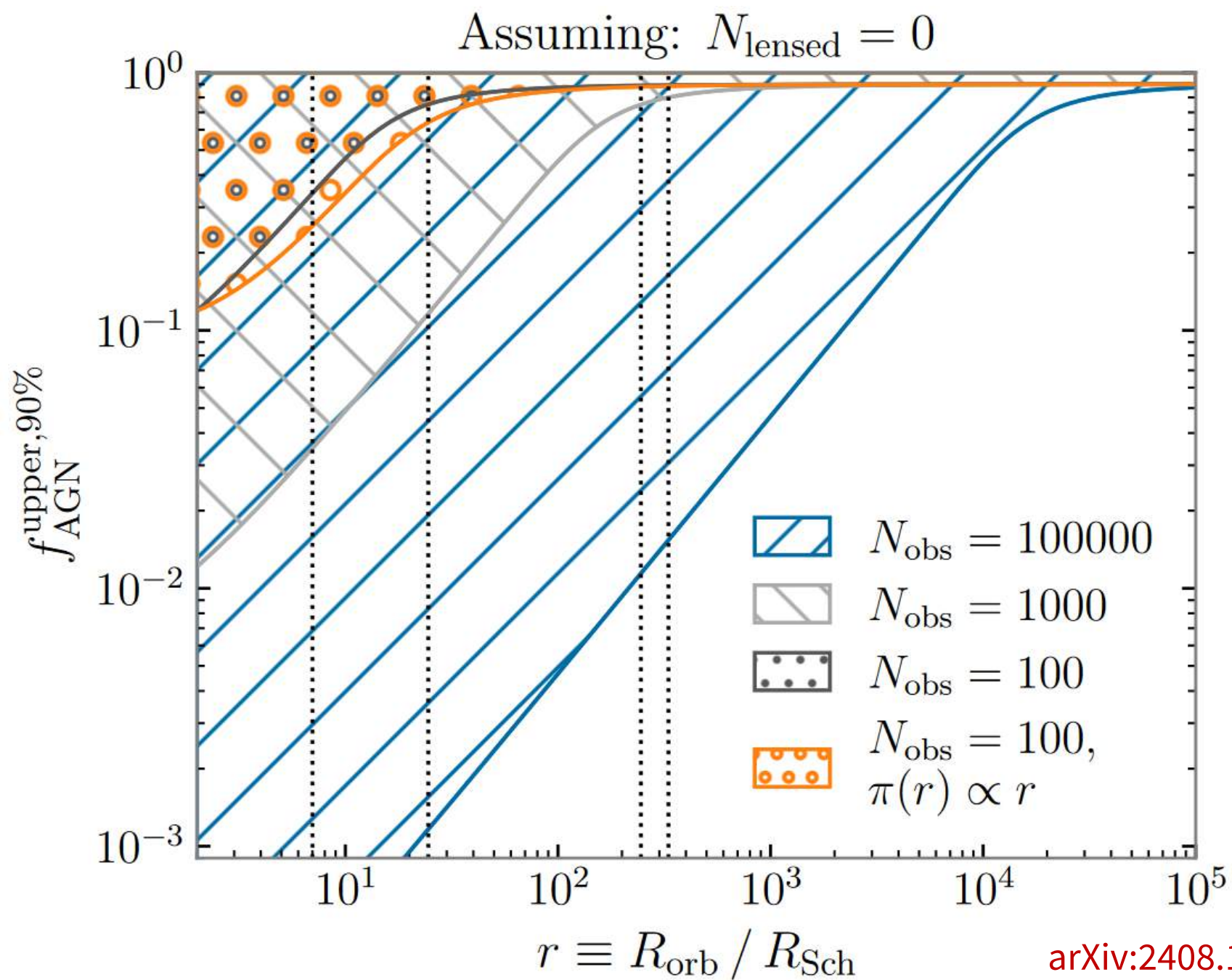
$$\beta \leq \theta_E \text{ where } \theta_E^2 := 2R_{\text{Sch}} \frac{D_{\ell s}}{D_S D_\ell}$$



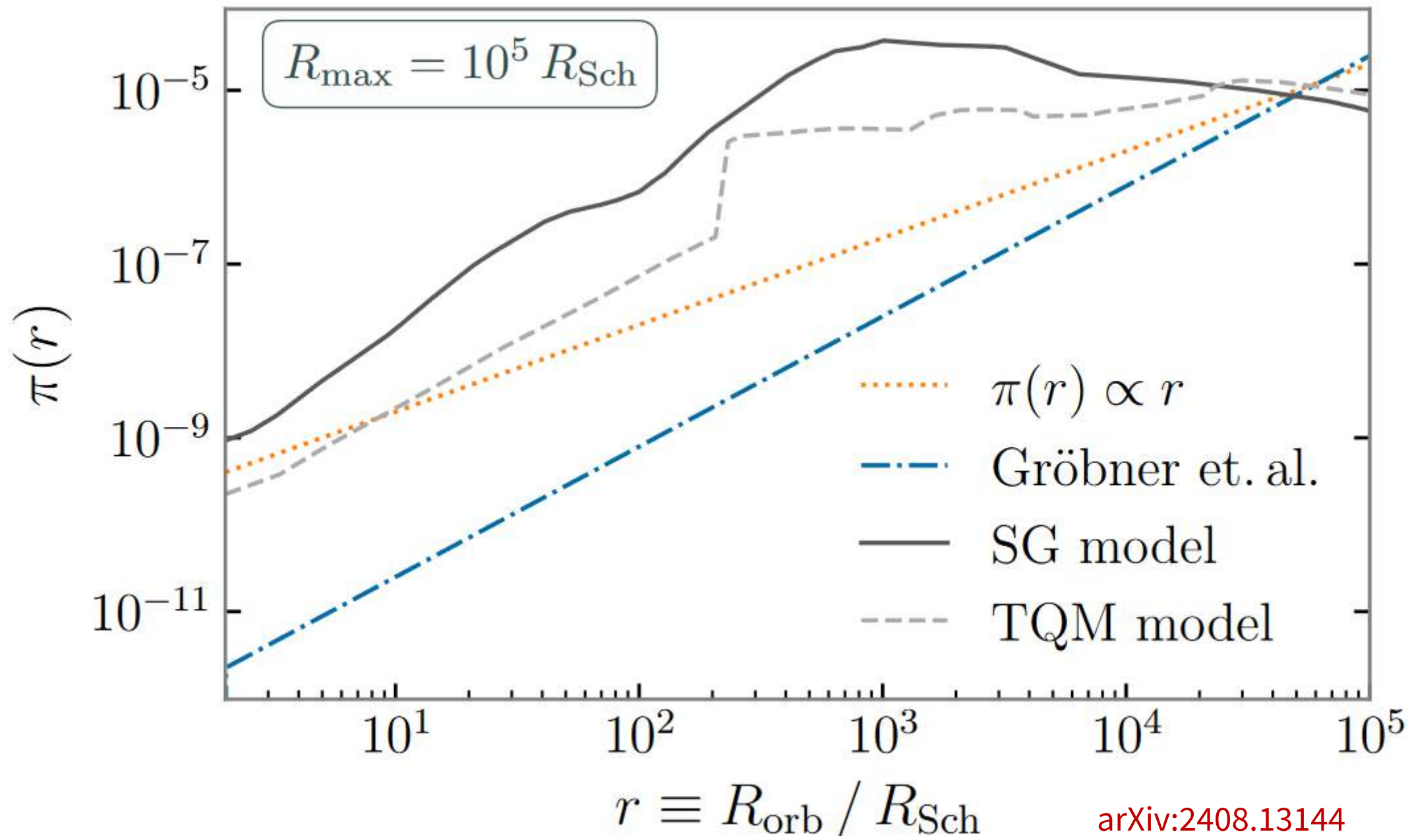
Probability of lensed BBH in an AGN



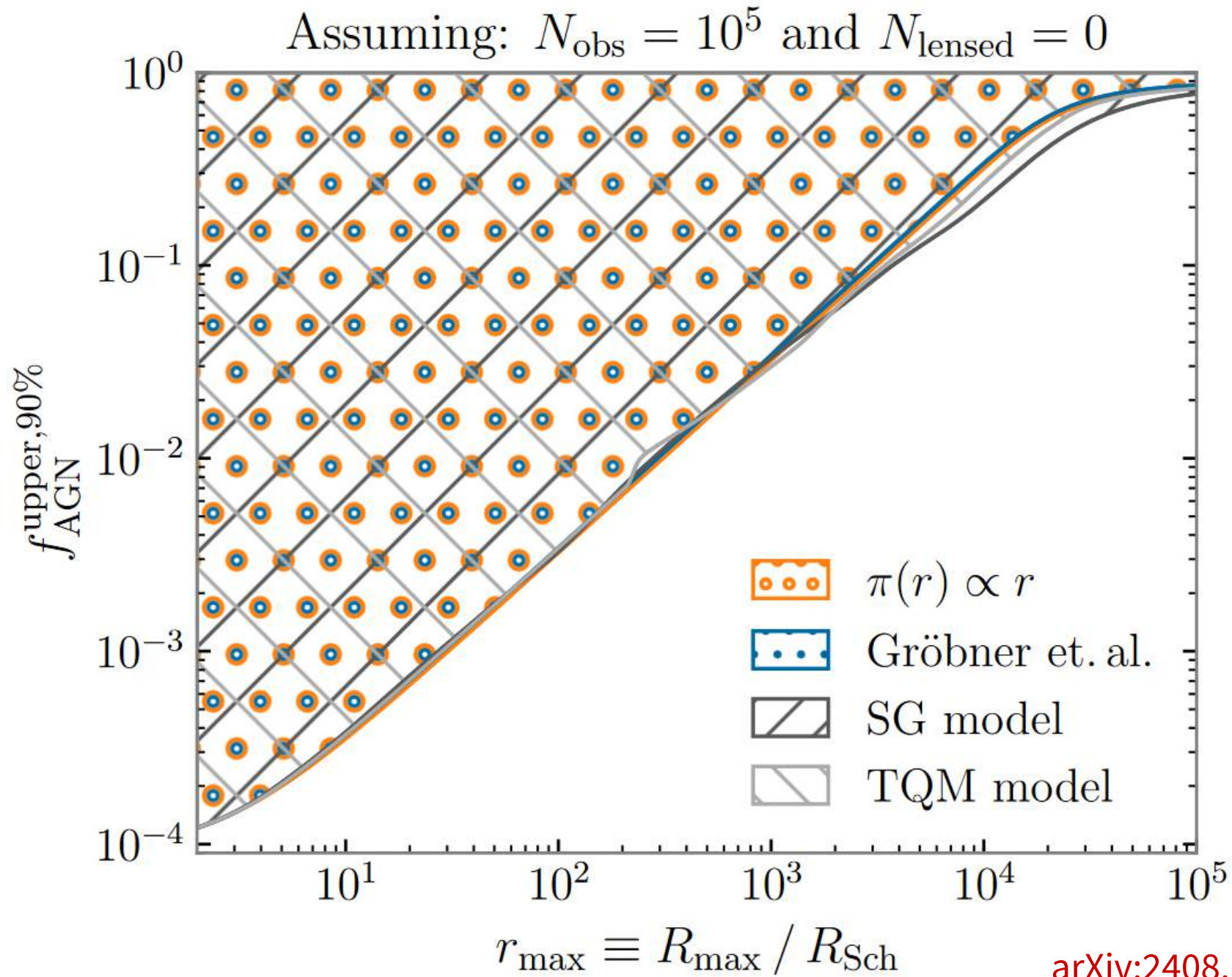
arXiv:2408.13144



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