Impact of Internal Faraday Rotation on Black Hole Spin Signatures in Sgr A* Polarimetry

EHTC+24

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

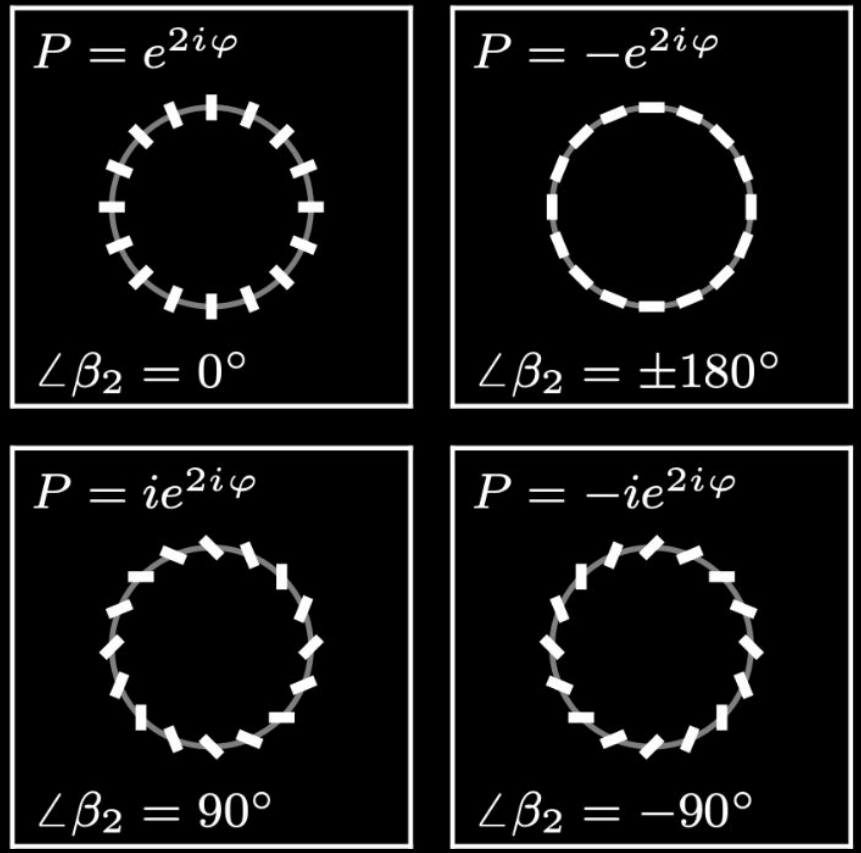
Tintin Nguyen (Harvard University)

Sep 22, 2026

BLACK HOLE INITIATIVE

Collaborators: Michael D. Johnson (CfA), Angelo Ricarte (CfA), Daniel Palumbo (CfA), Charles Gammie (UIUC), Eliot Quataert (Princeton)

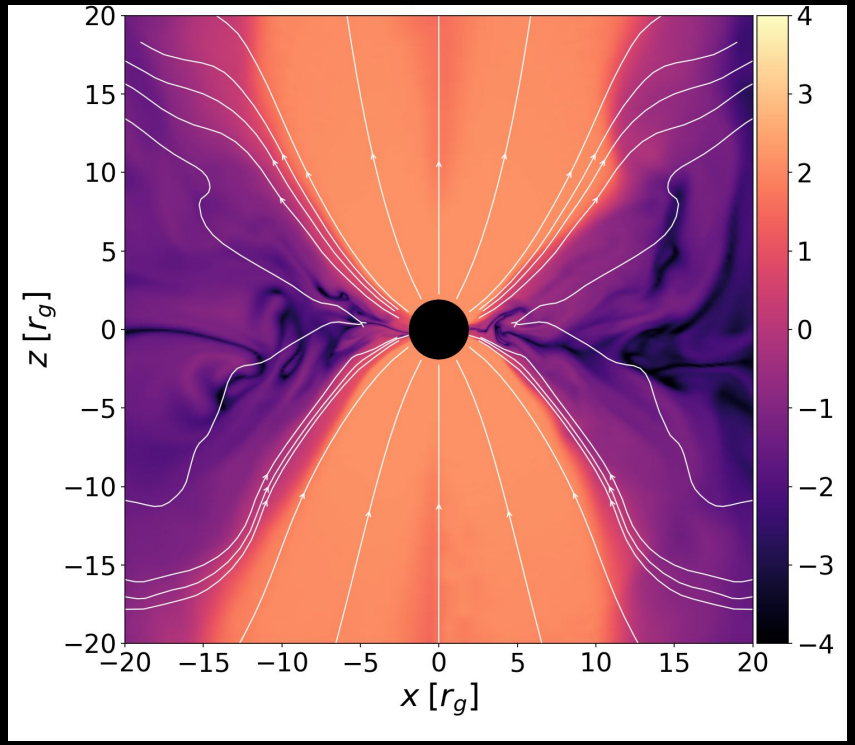
Rotational Symmetry of Linear Polarization



- Linear polarization can be decomposed into azimuthal modes (Palumbo+20)
- The second mode β_2 correlates with magnetization state (Palumbo+20) and energy flow (Chael+23)
- $\arg(\beta_2)$ measures the linear polarization pitch angle, which is a potential black hole spin tracer (Qiu+23, Emami+23, Ricarte+23, Palumbo 24, Wong+26)

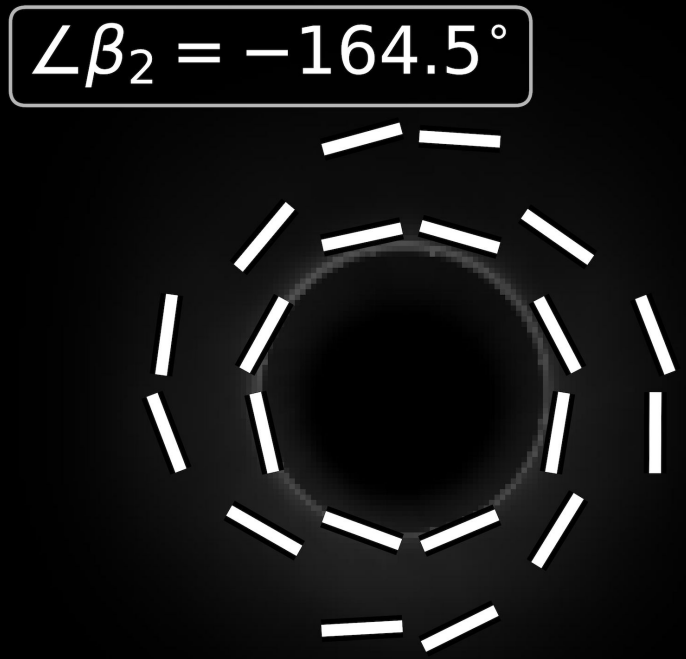
Magnetically Arrested Disk (MAD)

$\log(B^2/\rho)$



- Strong poloidal magnetic fields choking accretion inflow, launching highly efficient relativistic jets (Narayan+03, Igumenshchev 08, McKinney+12)
- Modeled by ideal GRMHD simulations generated by KHARMA code (Prather+24), ray traced with ipole (Mościbrodzka & Gammie 2018)

Polarization Twistiness Traces Spin



Simulated GRMHD MAD images

See also: Emami+23, Chael+23, Qiu+23, Wong+26, EHTC Sgr A* VIII

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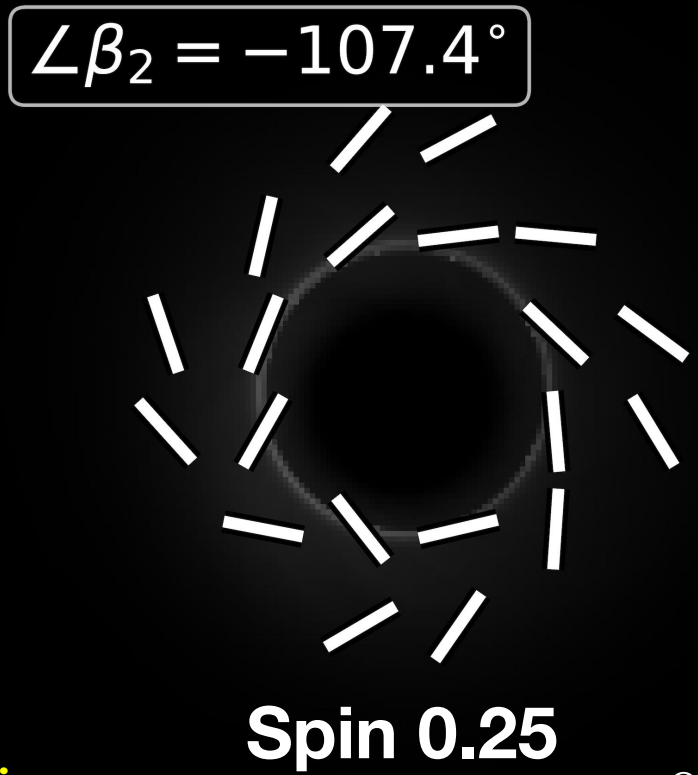

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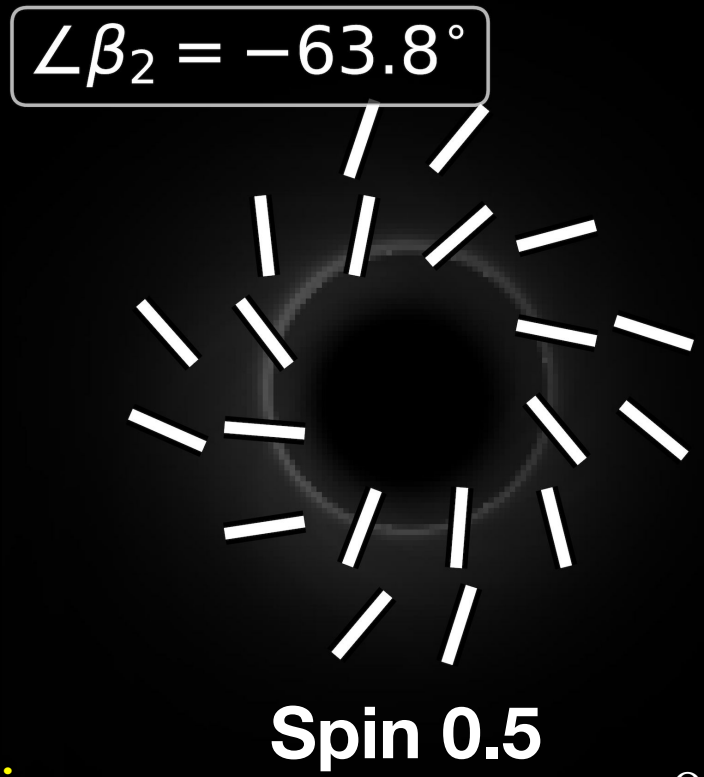

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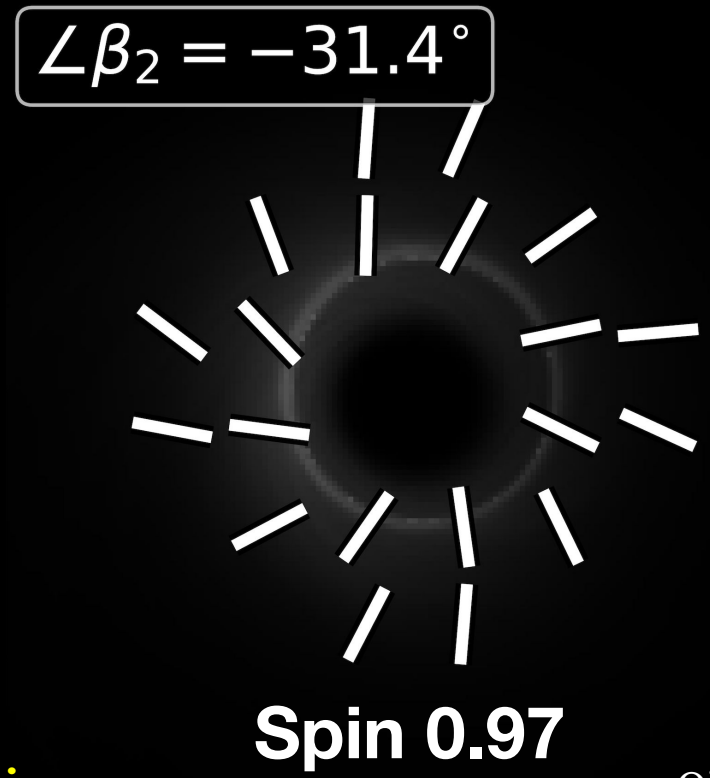

Simulated GRMHD MAD images

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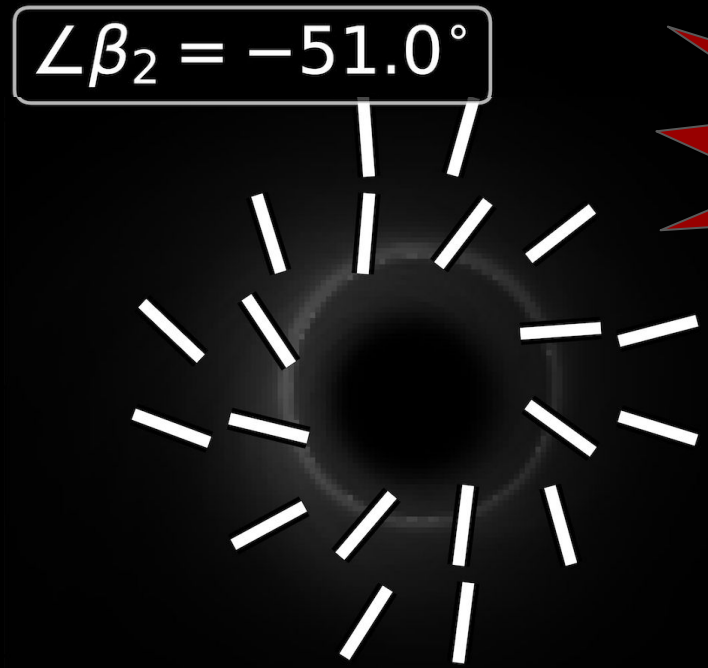
Polarization Twistiness Traces Spin



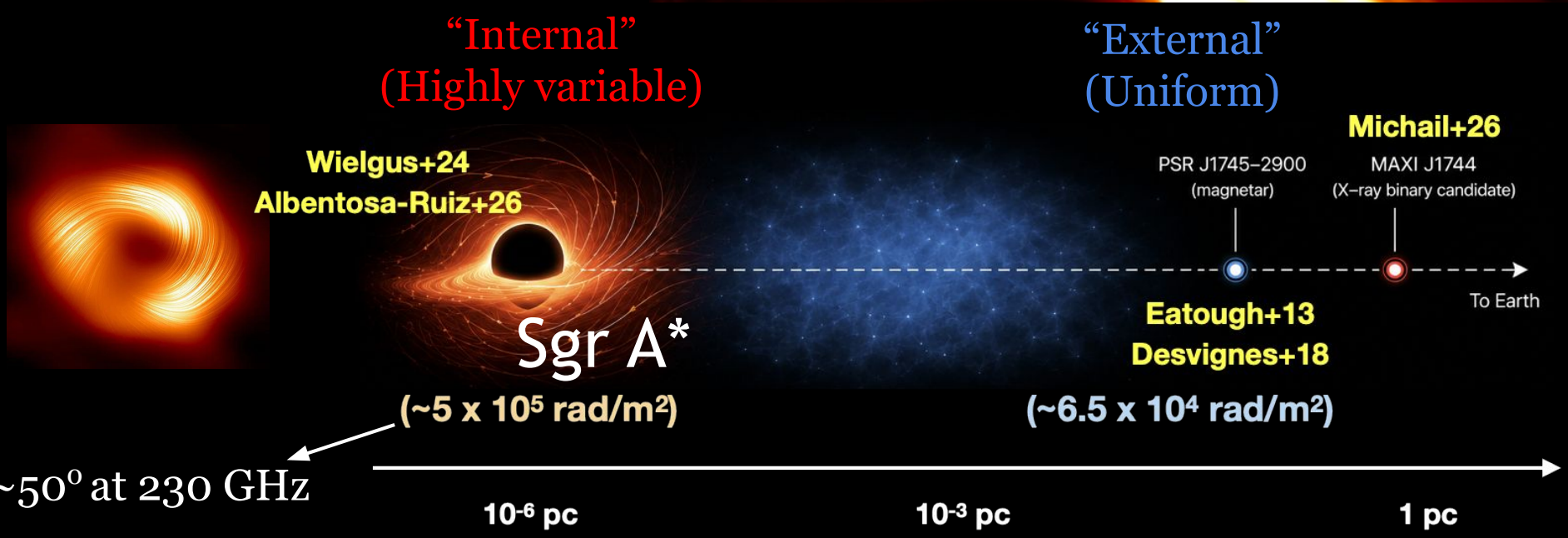
I cheated!!!
I turned off
Faraday rotation!

Spin 0.97

Simulated GRMHD MAD images

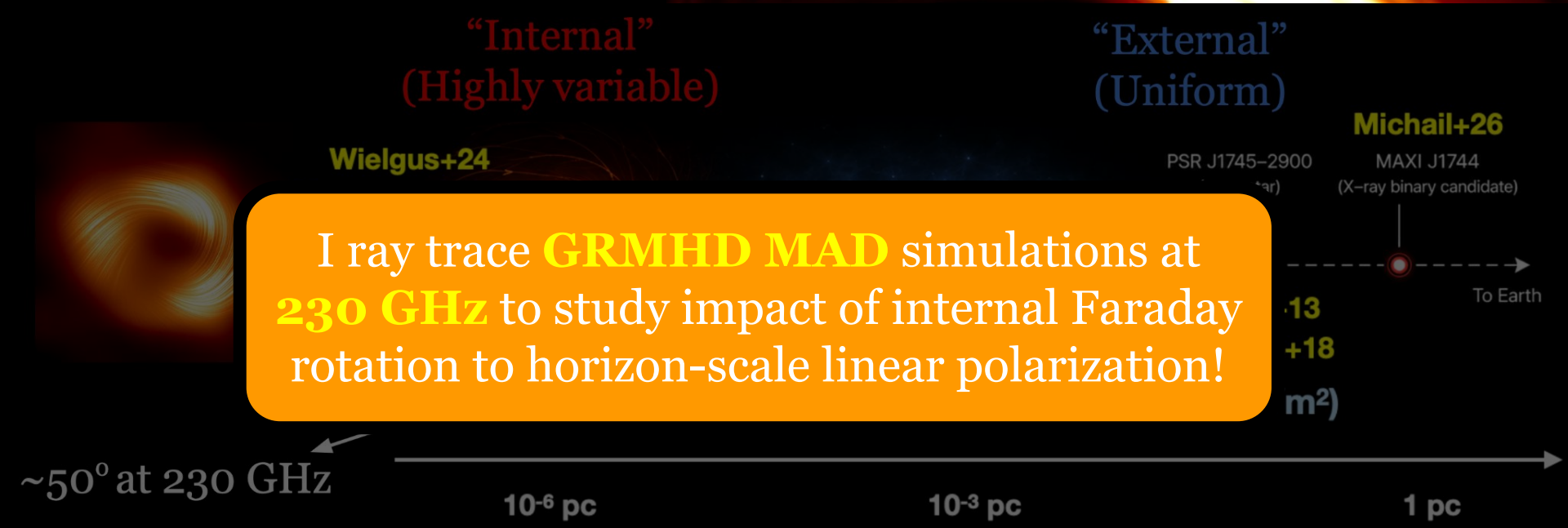
See also: Emami+23, Chael+23, Qiu+23, Wong+26, EHTC Sgr A* VIII

Sgr A* Faraday Rotation Measure



Sgr A* **rotation measure** can **vary by an order of magnitude** both **spatially** across the image (Ricarte+20) and **temporally** on intra-hour scale (Wielgus+24)!

Sgr A* Faraday Rotation Measure



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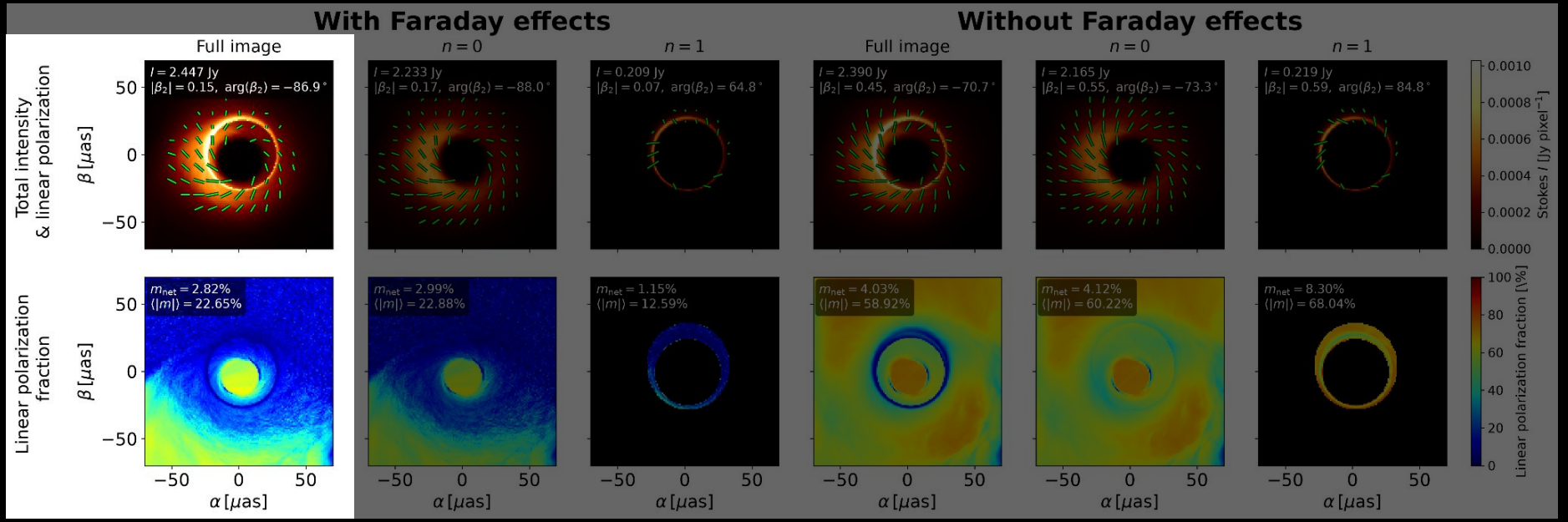
Ray Traced Images

Time-averaged Sgr A* best bet model: spin = 0.5, inclination = 150°, R_{low} = 1, R_{high} = 160



Ray Traced Images

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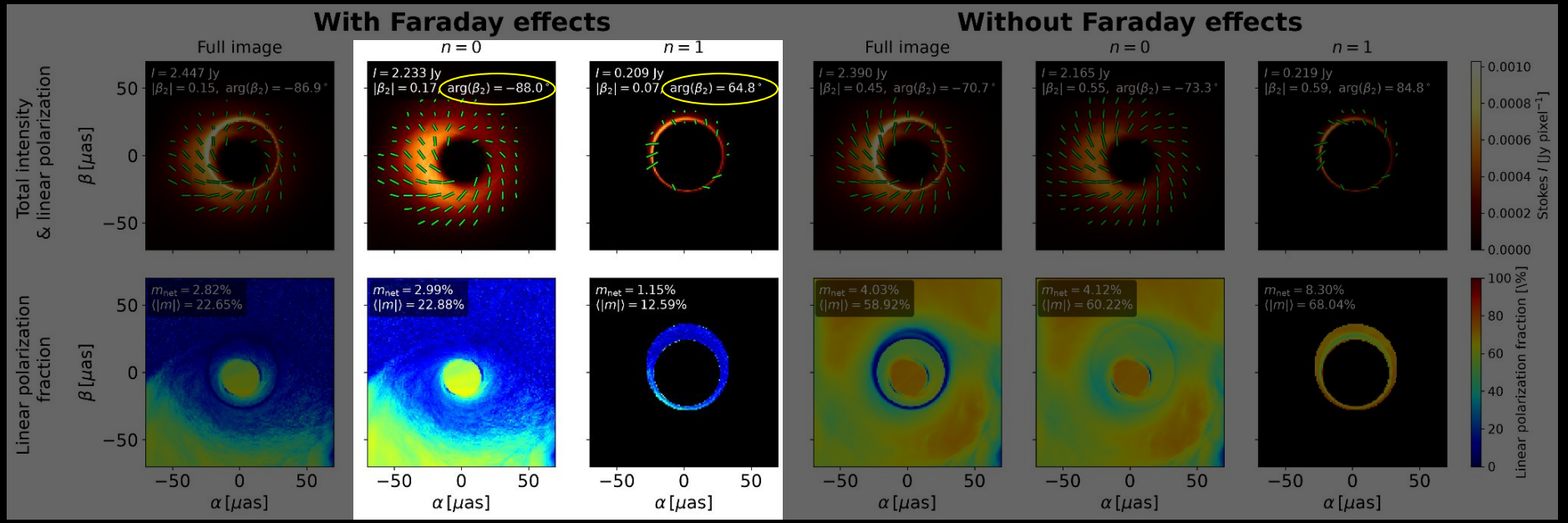

Direct image **Lensed image**

Ray Traced Images

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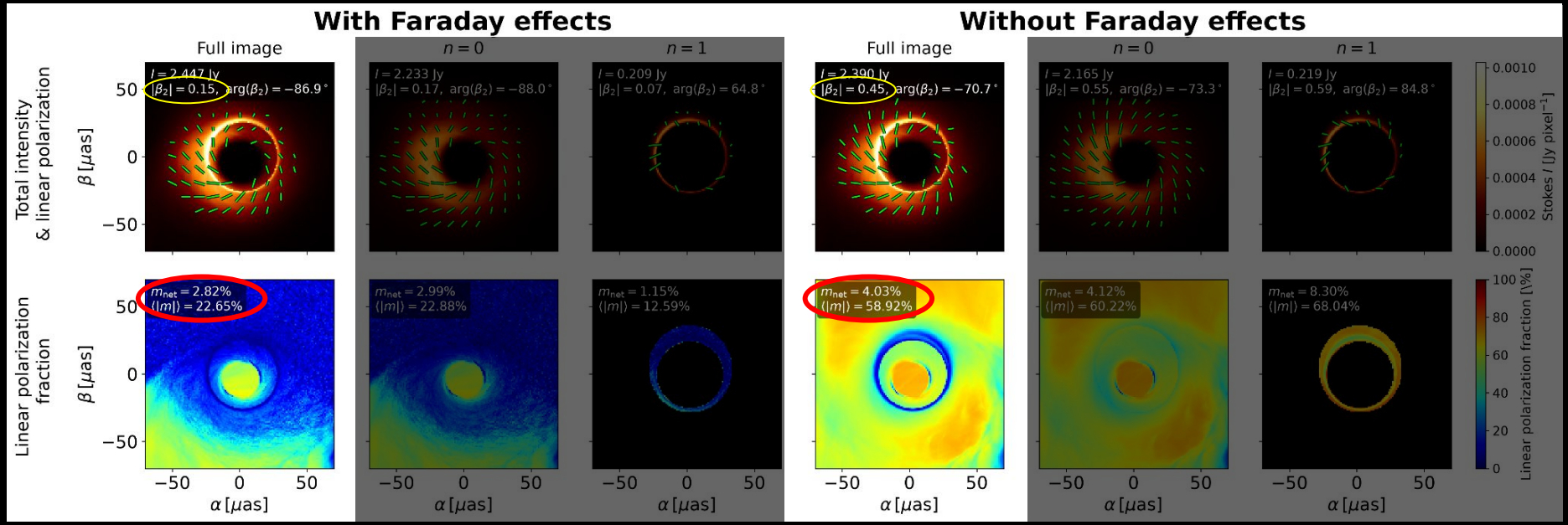
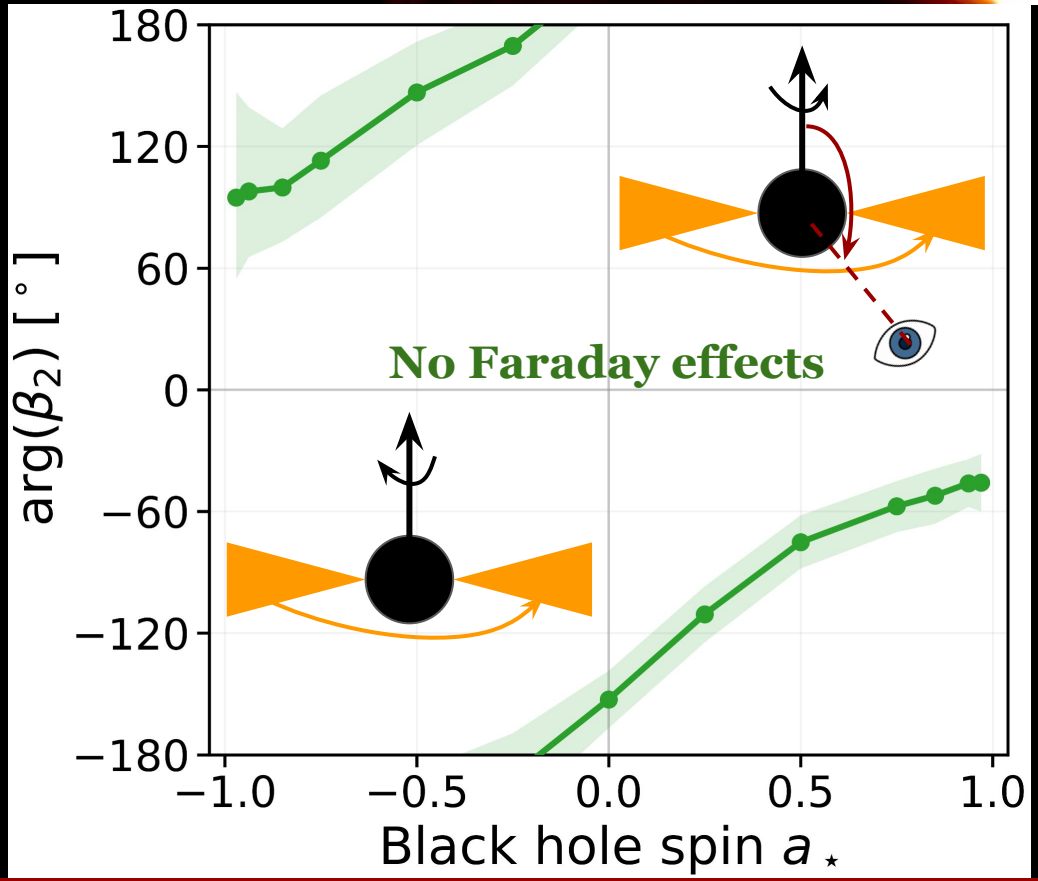


Faraday rotation depolarizes and scrambles the resulting polarized image

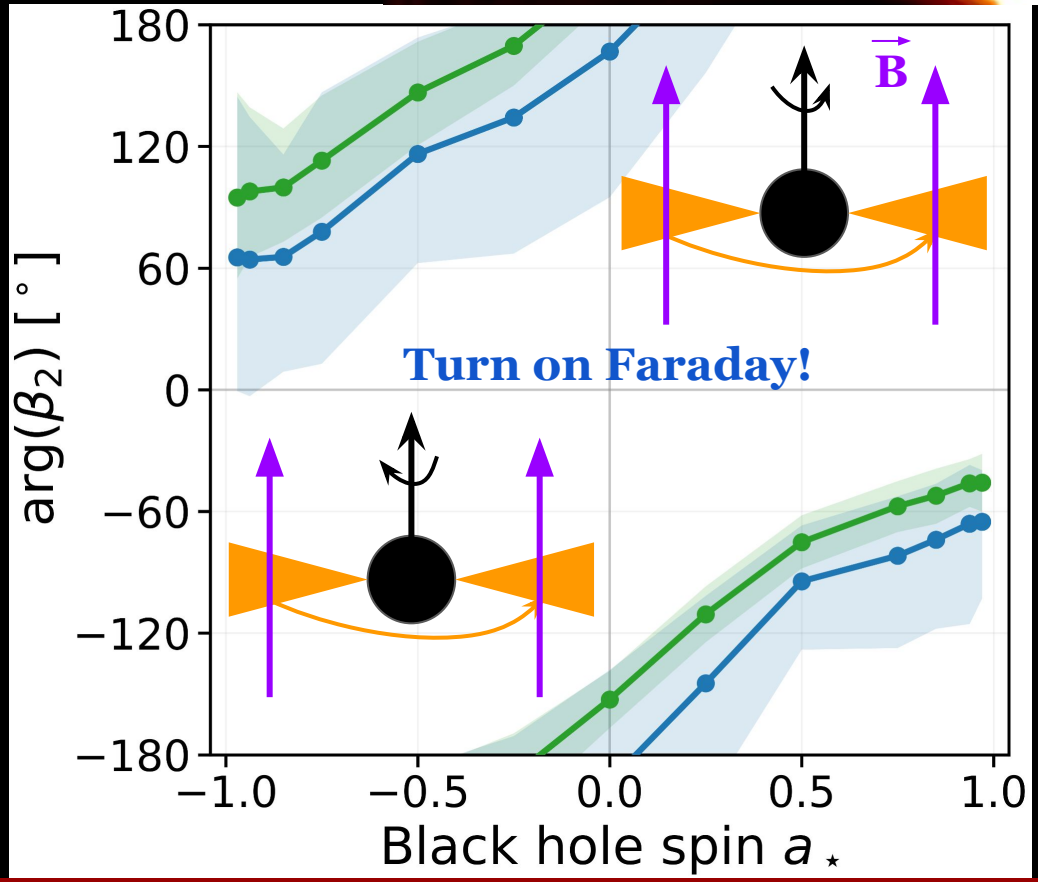
Impact of Faraday Rotation on Spin Signature



Simulated GRMHD MAD images

Circularly averaged over 100 snapshots, 3 inclinations, and 10 R_{low}-R_{high} combos

Impact of Faraday Rotation on Spin Signature



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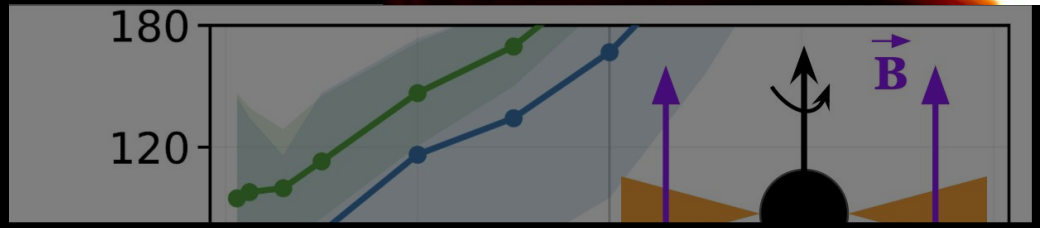
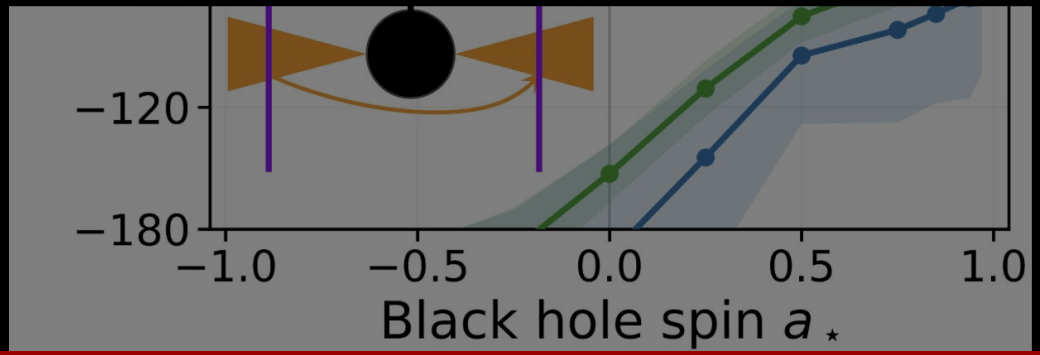
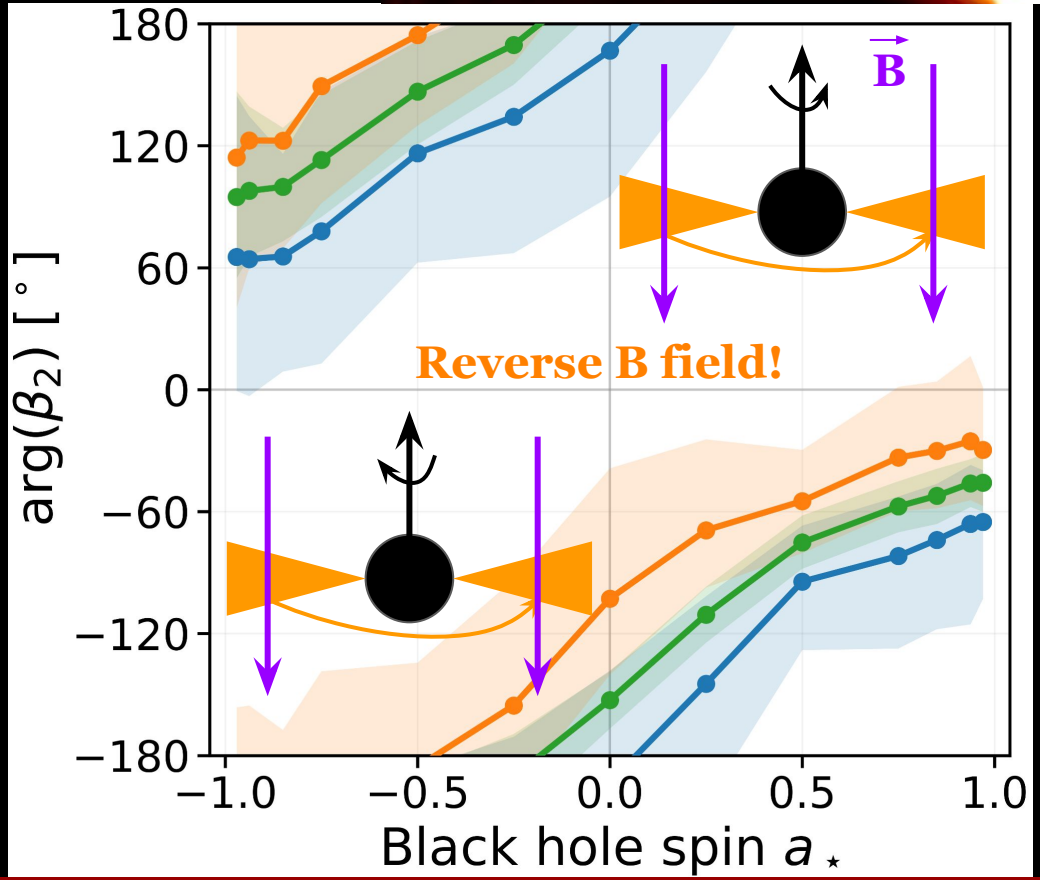


Internal Faraday rotation introduces a ~30° bias offset to the $\angle\beta_2$-spin relation

Simulated GRMHD MAD images
Circularly averaged over 100 snapshots, 3 inclinations, and 10 R_{low}-R_{high} combos

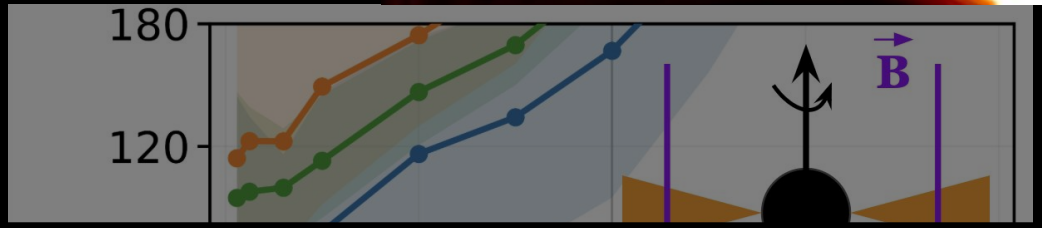


Impact of Faraday Rotation on Spin Signature



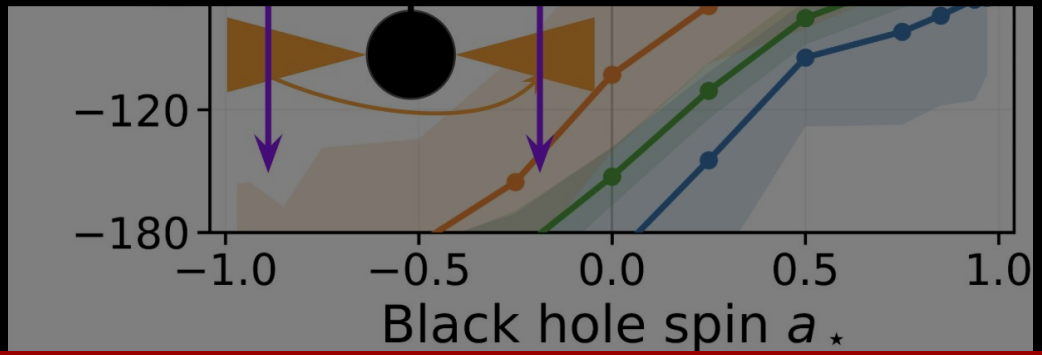
Simulated GRMHD MAD images
Circularly averaged over 100 snapshots, 3 inclinations, and 10 R_{low}-R_{high} combos

Impact of Faraday Rotation on Spin Signature

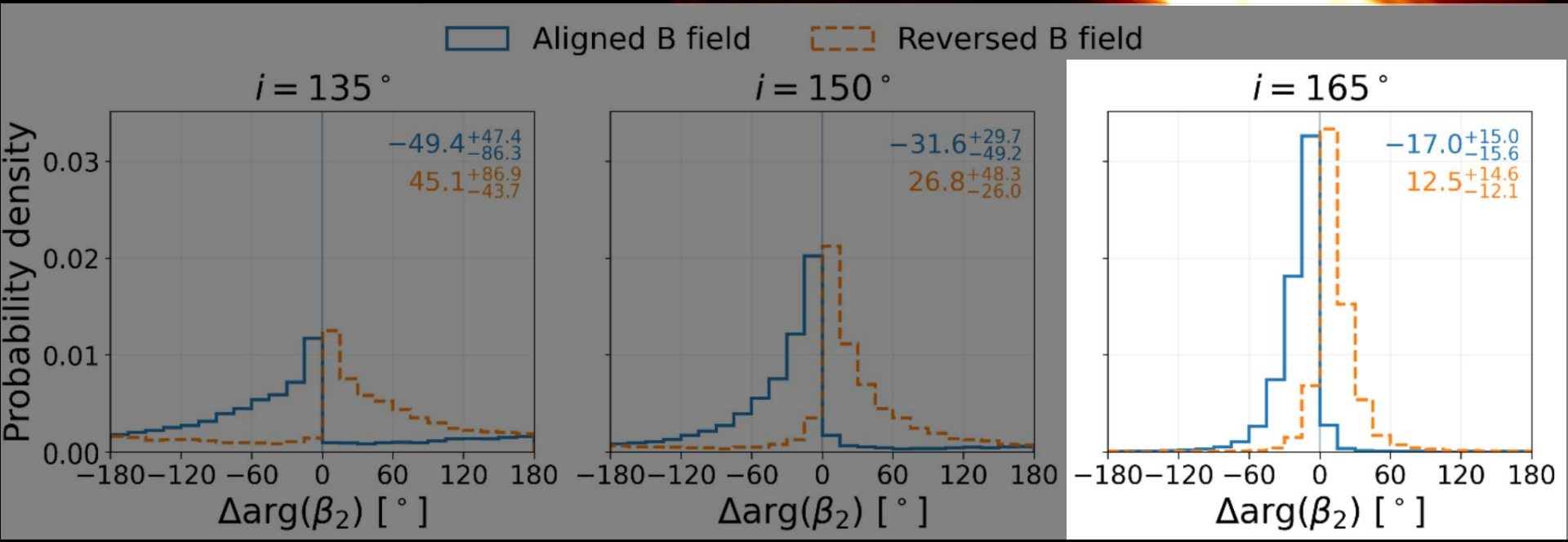


If we can correct for Faraday rotation, the $\angle\beta_2$-spin relation is much tighter, with a 1σ scatter of ~10°-20°!

Simulated GRMHD MAD images
Circularly averaged over 100 snapshots, 3 inclinations, and 10 R_{low}-R_{high} combos



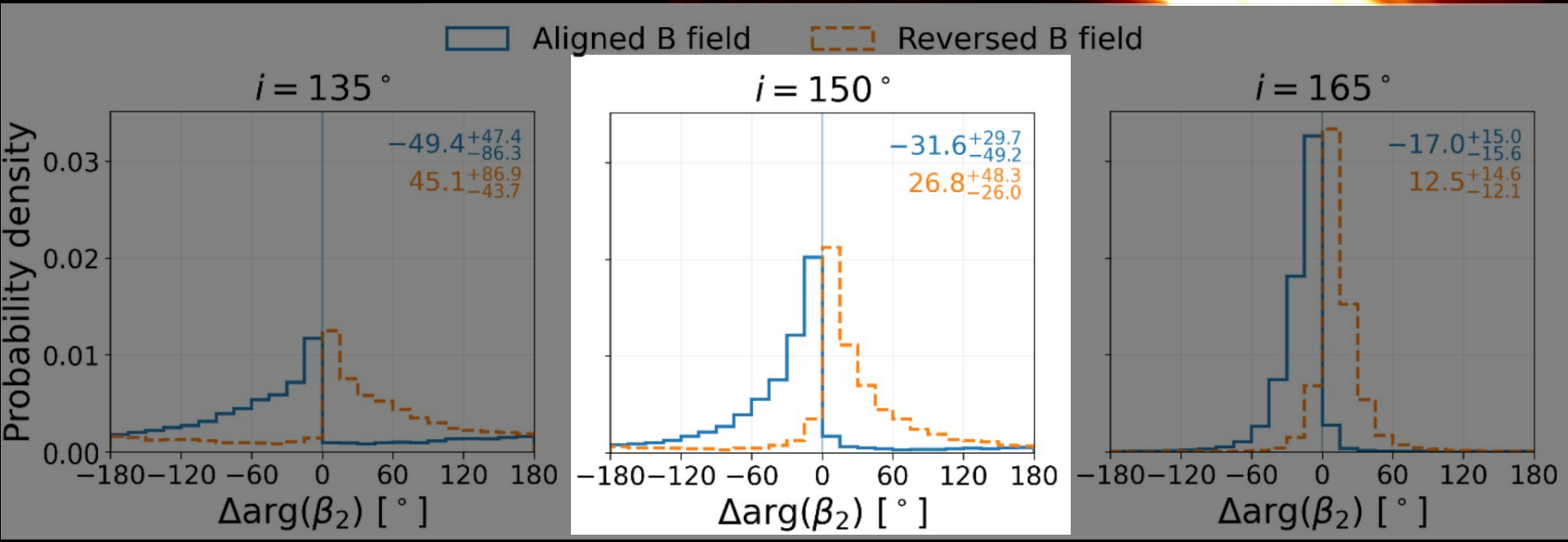
Impact of Faraday Rotation on $\angle\beta_2$



Enhanced Faraday depth

Edge-on ← → Face-on

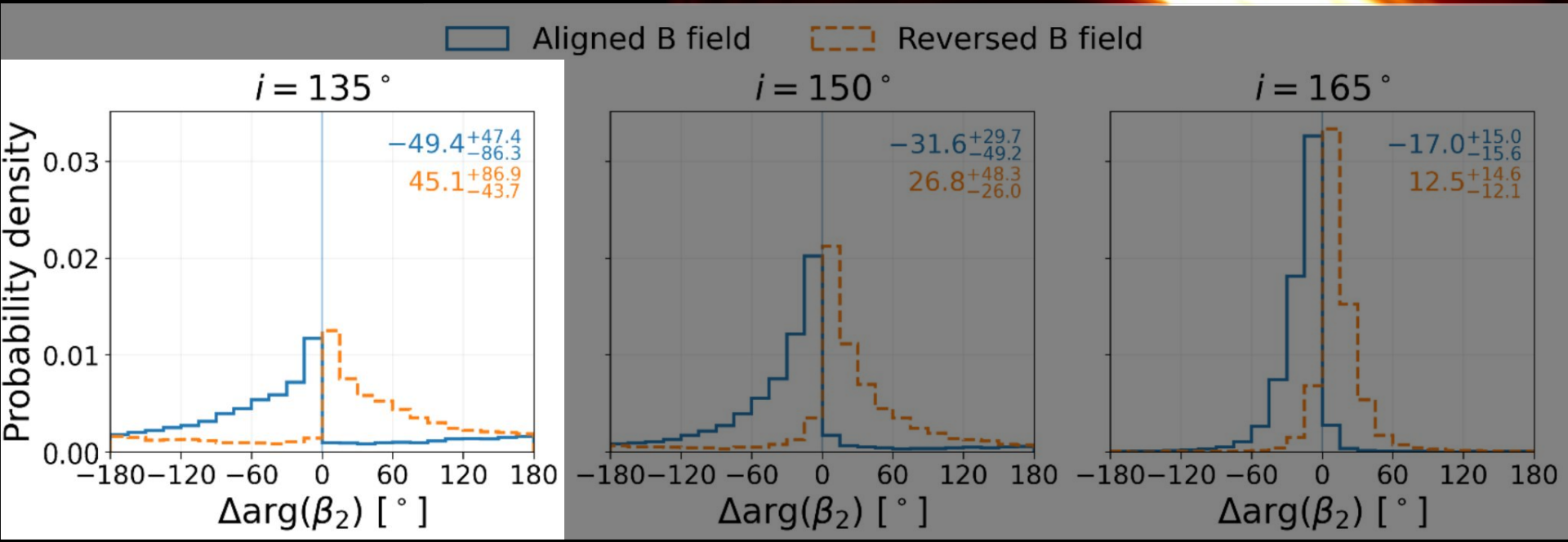
Impact of Faraday Rotation on $\angle\beta_2$



Enhanced Faraday depth

Edge-on ← → Face-on

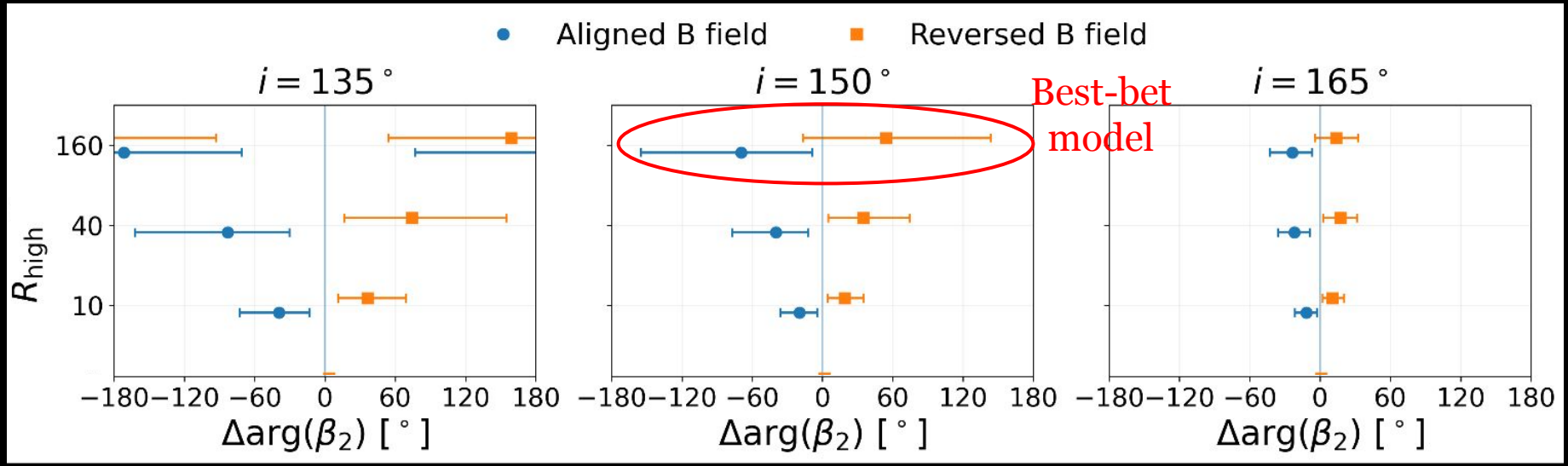
Impact of Faraday Rotation on $\angle\beta_2$



Enhanced Faraday depth

Edge-on ← → Face-on

Impact of R_{high} Parameter on $\angle\beta_2$

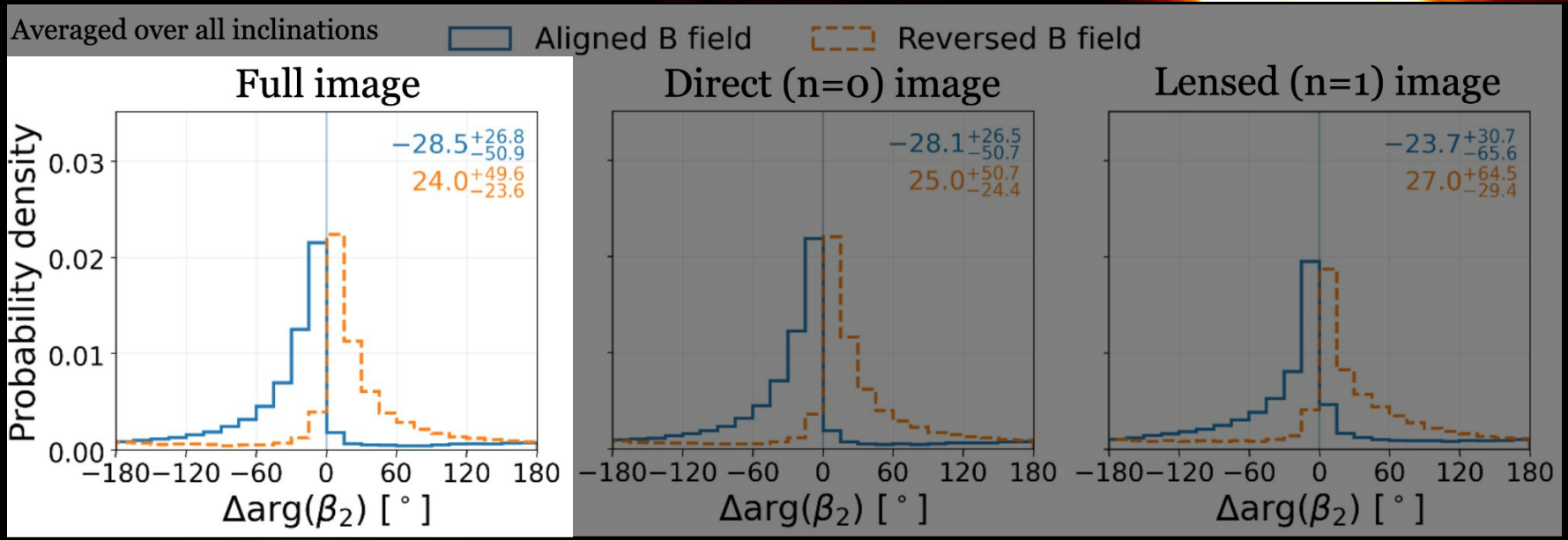


Enhanced Faraday depth

Edge-on

Face-on

Image Decomposition



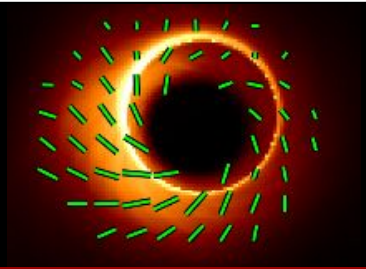
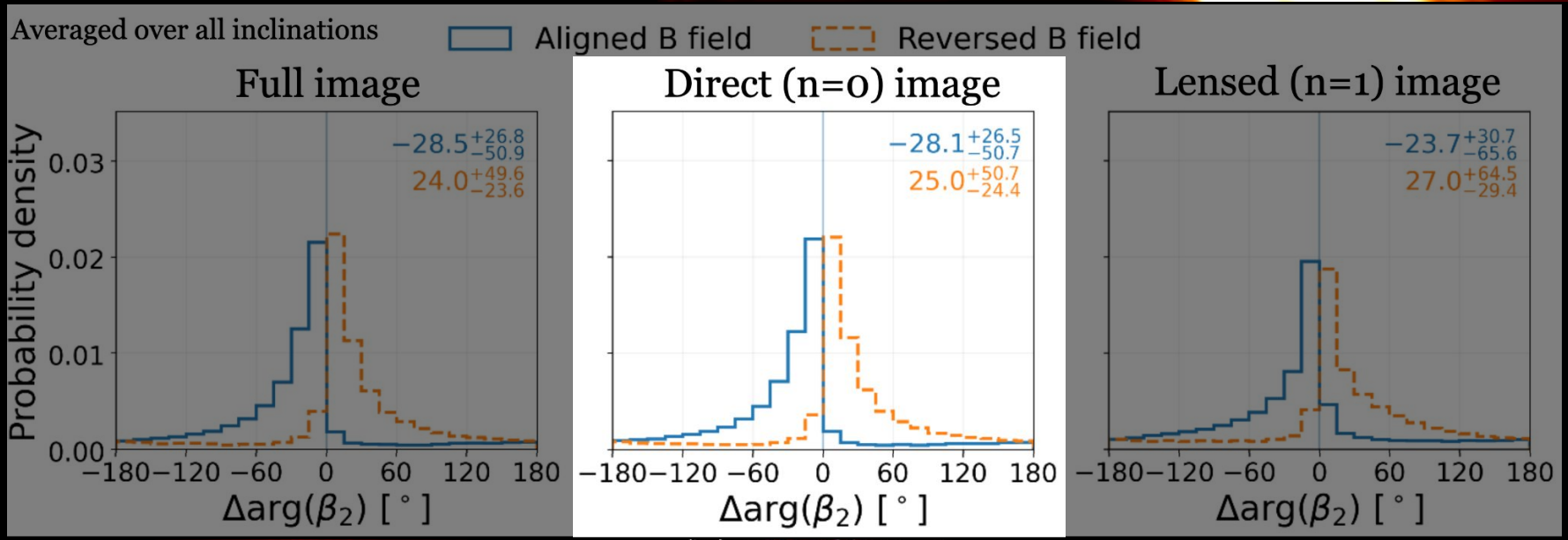
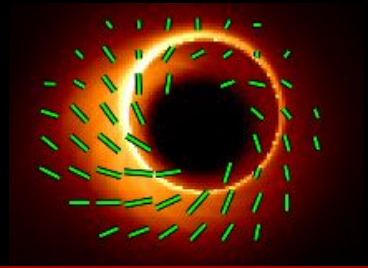


Image Decomposition





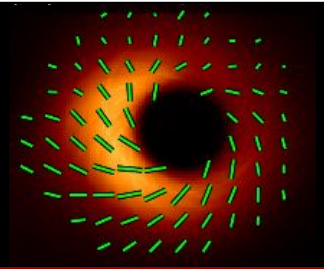
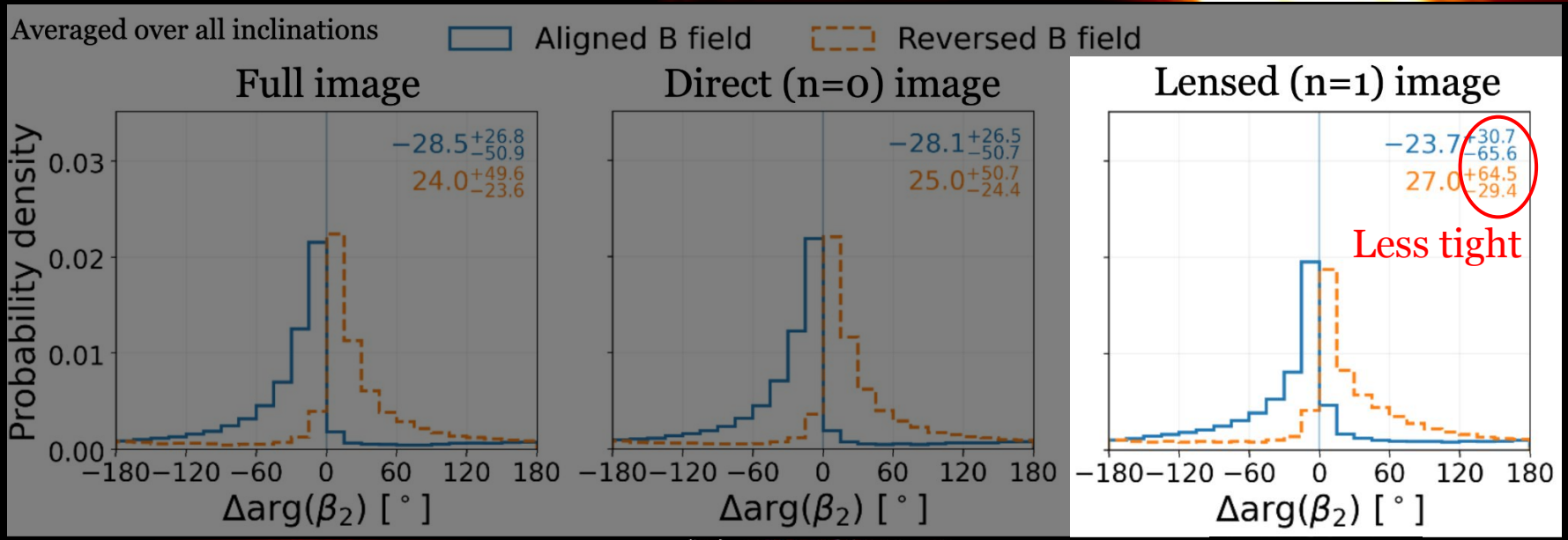
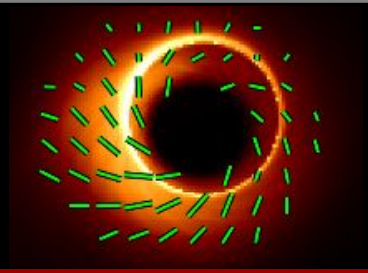
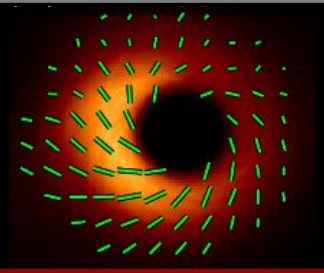
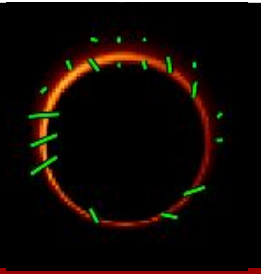


Image Decomposition





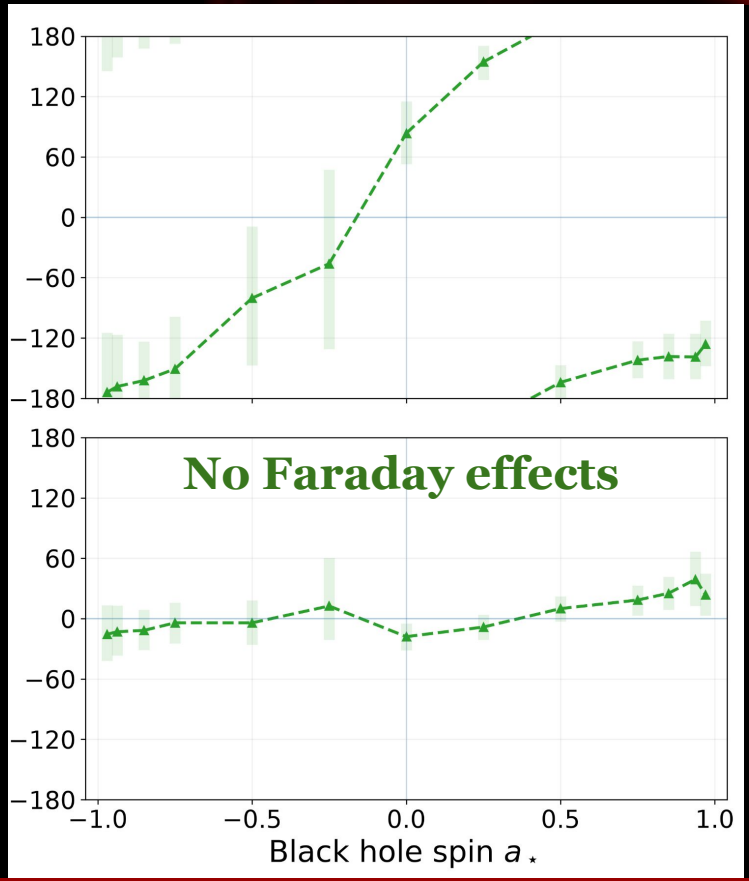




Combining n=0 and n=1 images

$$\angle\beta_{2,n=0} - \angle\beta_{2,n=1}$$

$$\angle\beta_{2,n=0} + \angle\beta_{2,n=1}$$



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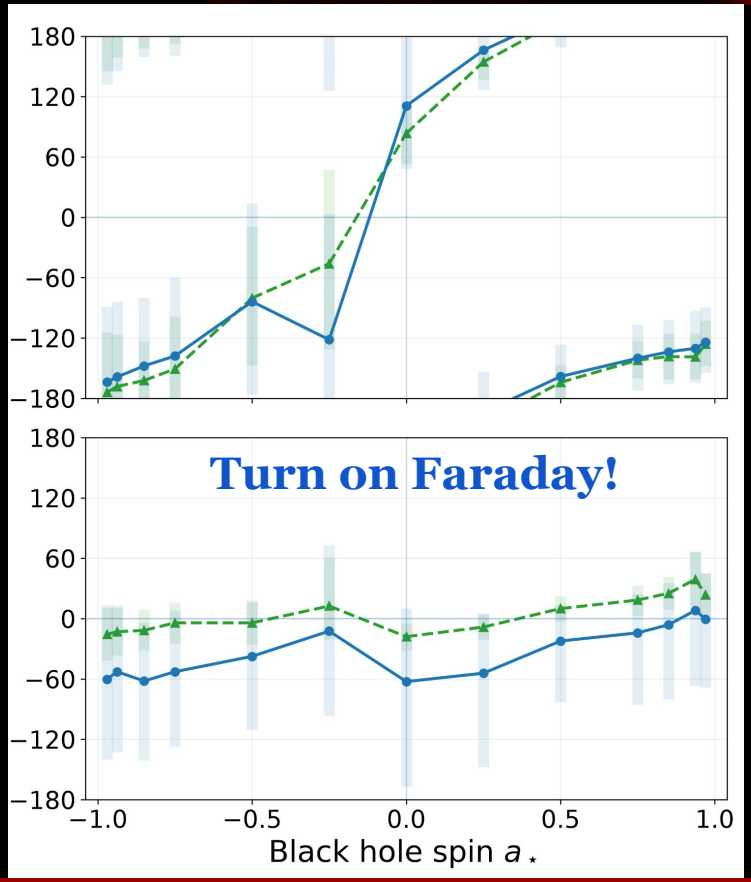
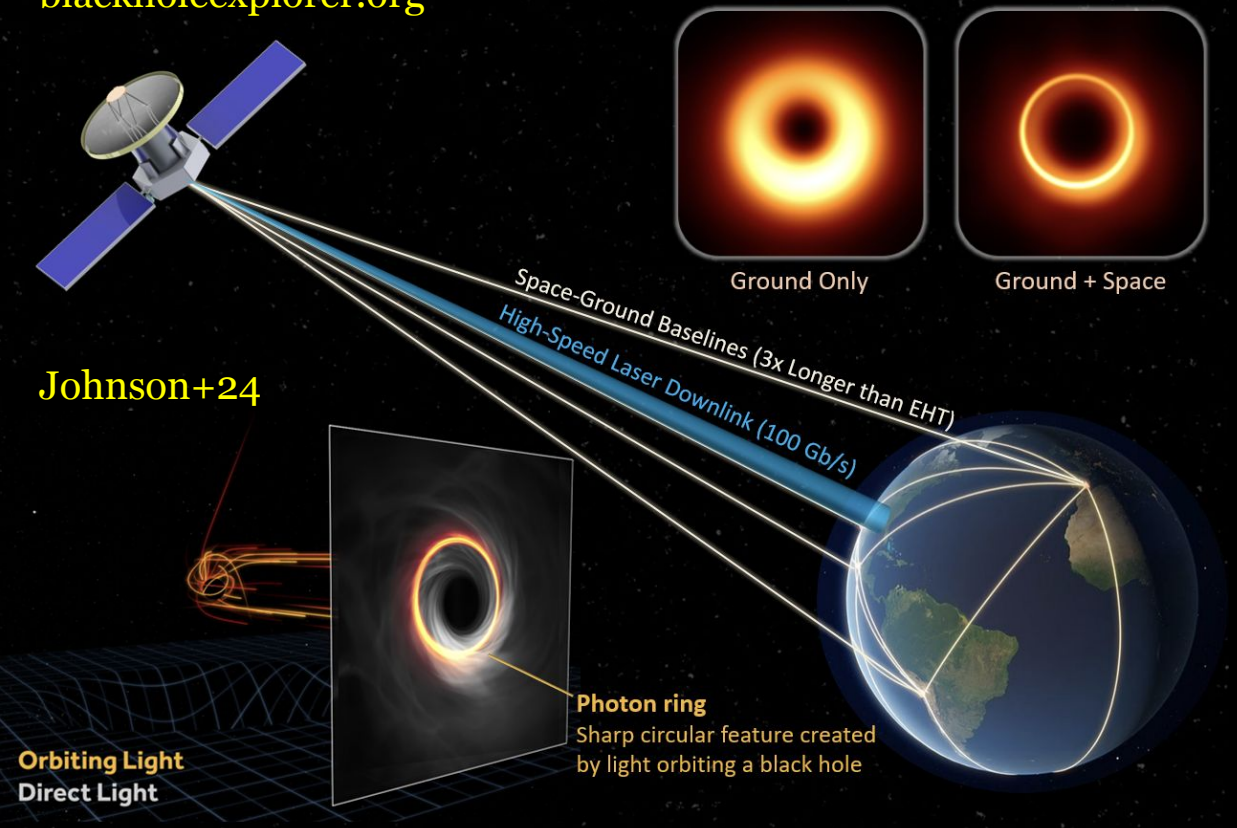
$$\angle\beta_{2,n=0} - \angle\beta_{2,n=1}$$

$$\angle\beta_{2,n=0} + \angle\beta_{2,n=1}$$



Black Hole Explorer

blackholeexplorer.org



Johnson+24

Extending the Event Horizon Telescope into space can resolve **photon rings** of M87* and Sgr A* for the first time

Conclusion

- Internal Faraday rotation shifts $\angle\beta_2$ by ~30° with greater impact toward edge-on viewing inclination. The shift direction depends on B field polarity.
- The $\angle\beta_2$-spin relation is less tight for n=1 image. However, combining n=0 and n=1 polarimetry can provide a more Faraday insensitive observable.
- If we can correct for Faraday rotation, the $\angle\beta_2$-spin relation is significantly tighter. This motivates future derotation with resolved rotation measure maps.

THANK YOU FOR LISTENING!

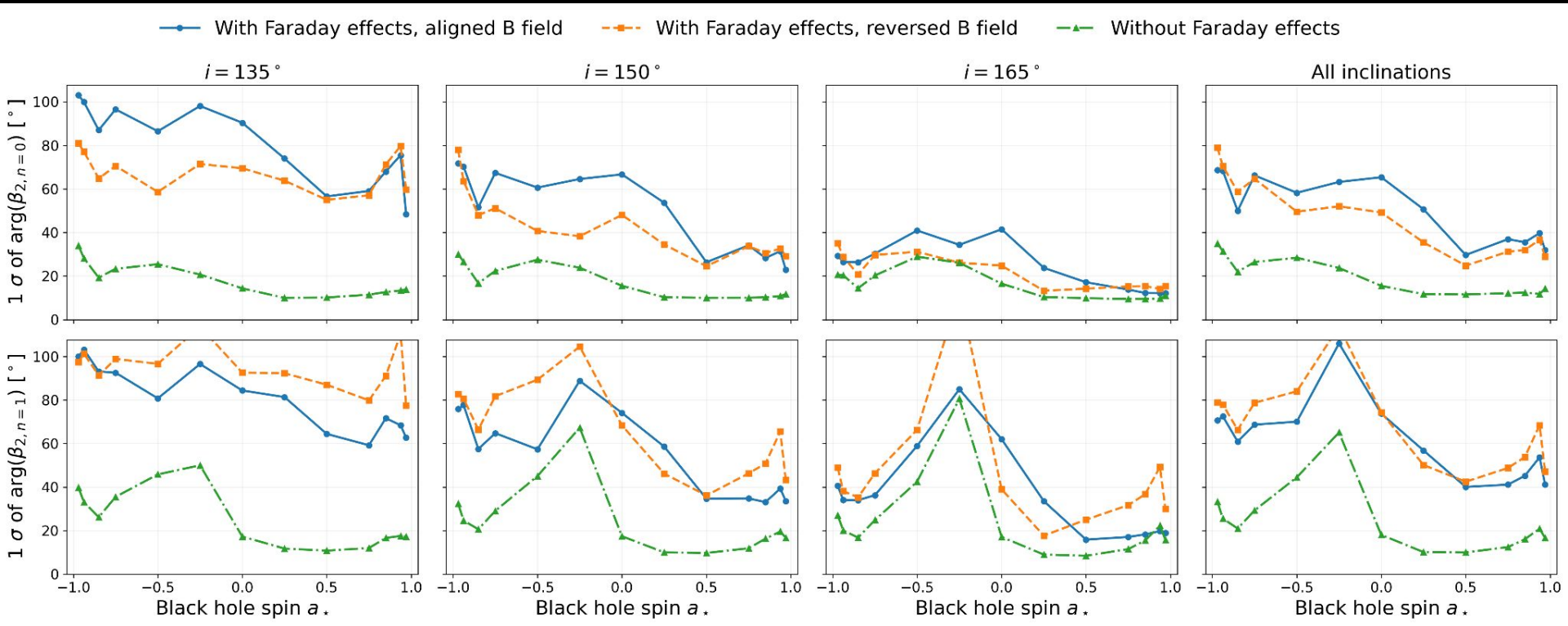
Tintin Nguyen
tintin.nguyen@cfa.harvard.edu

Stay tuned for the paper!

Appendix

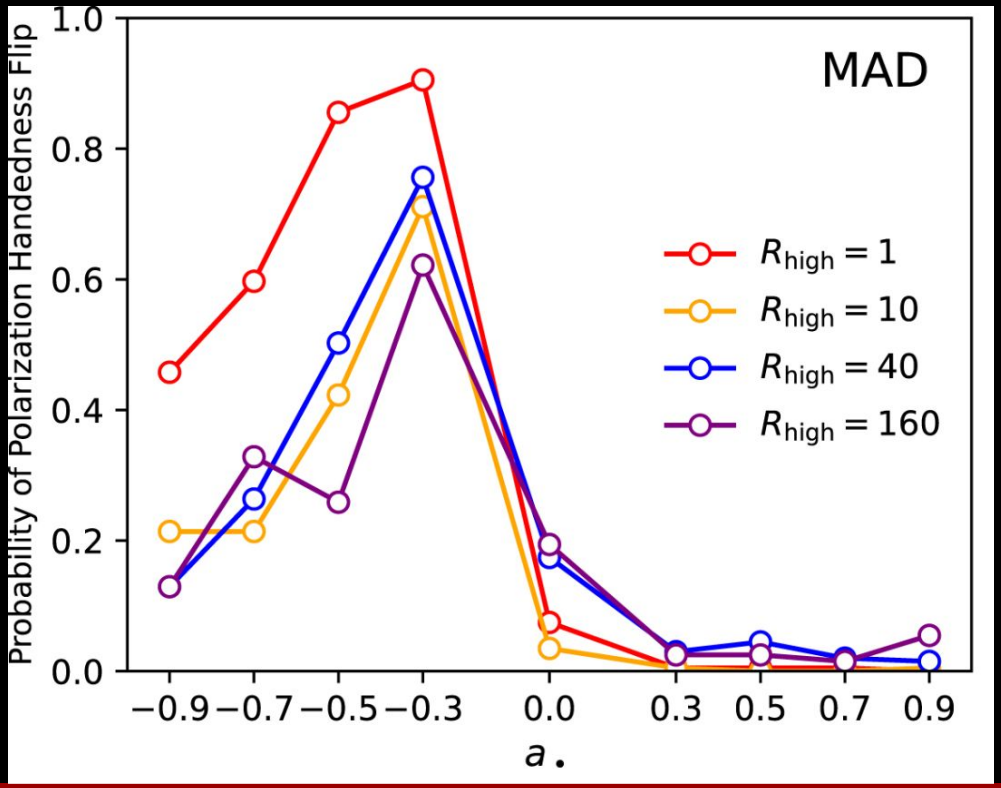
GRMHD parameters	Accretion state	Magnetically arrested disk (MAD)
	Snapshot	$20,000 - 25,000\, t_g, 50\, t_g$ cadence (100 snapshots)
	Black hole spin	$a_\star = 0, \pm 0.25, \pm 0.5, \pm 0.75, \pm 0.85, \pm 0.9375, \pm 0.97$
Ray tracing parameters	Frequency	230 GHz
	Viewing inclination	$i = 135°, 150°, 165°$
	$R_{\rm low}$	1, 5, 10
	$R_{\rm high}$	1, 10, 40, 160 ($R_{\rm high} \geq R_{\rm low}$)
	Image decomposition	Full image, $n = 0$ (direct image), $n = 1$ (lensed image)
	Faraday modes	With Faraday effects, without Faraday effects
	Magnetic field polarity	Aligned, reversed

Appendix


With Faraday effects, aligned B field
With Faraday effects, reversed B field
Without Faraday effects
$i = 135^\circ$
$i = 150^\circ$
$i = 165^\circ$
All inclinations
1 σ of arg($\beta_{2,n=0}$) [°]
1 σ of arg($\beta_{2,n=1}$) [°]
Black hole spin $a_\star$

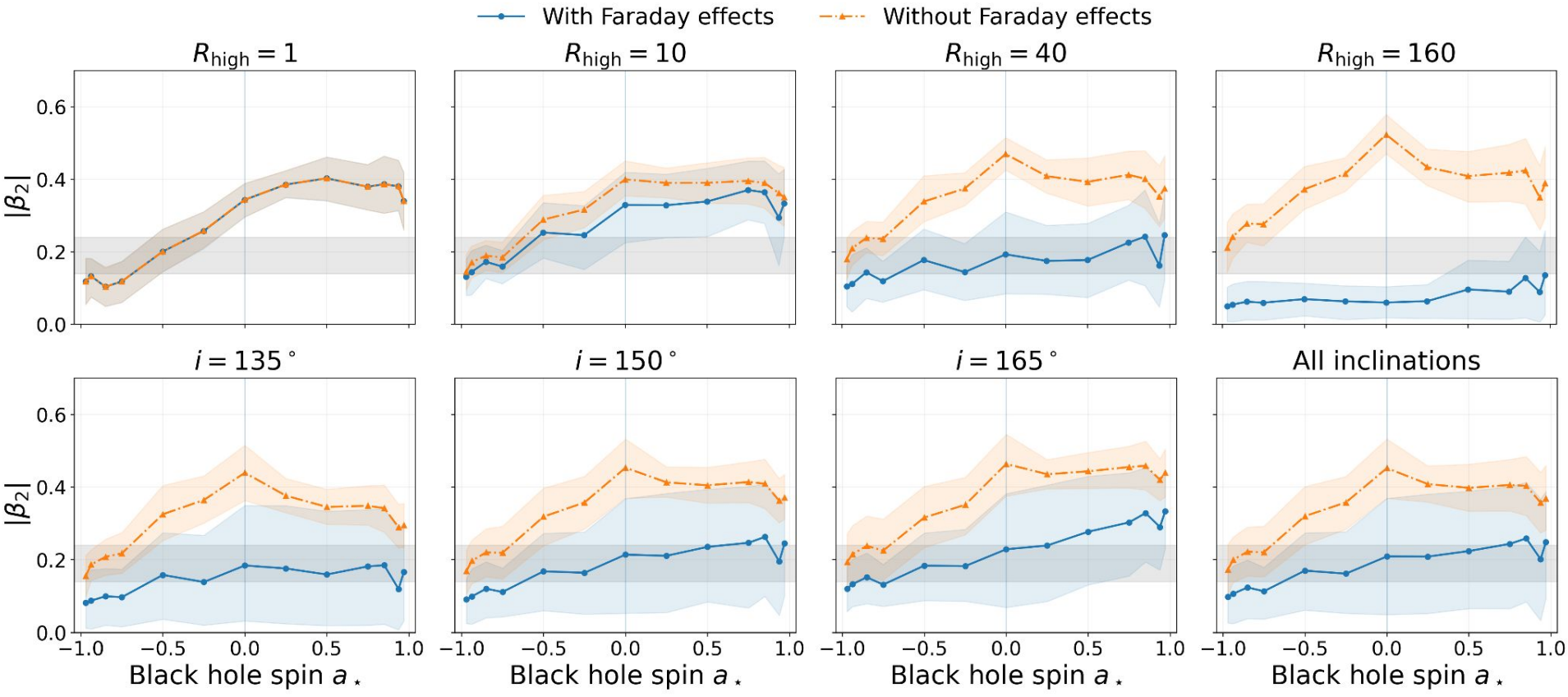
Appendix

Probability of polarization handedness flip

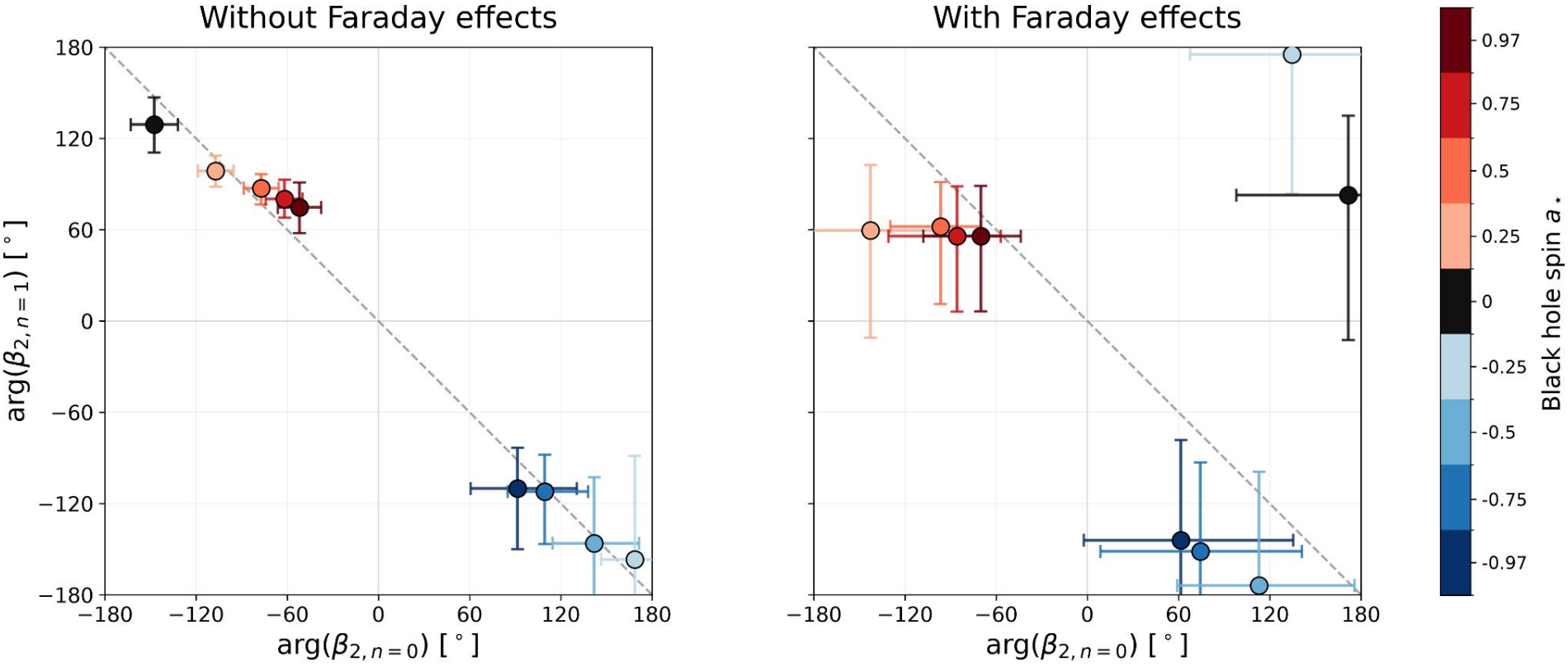


Ricarte+22

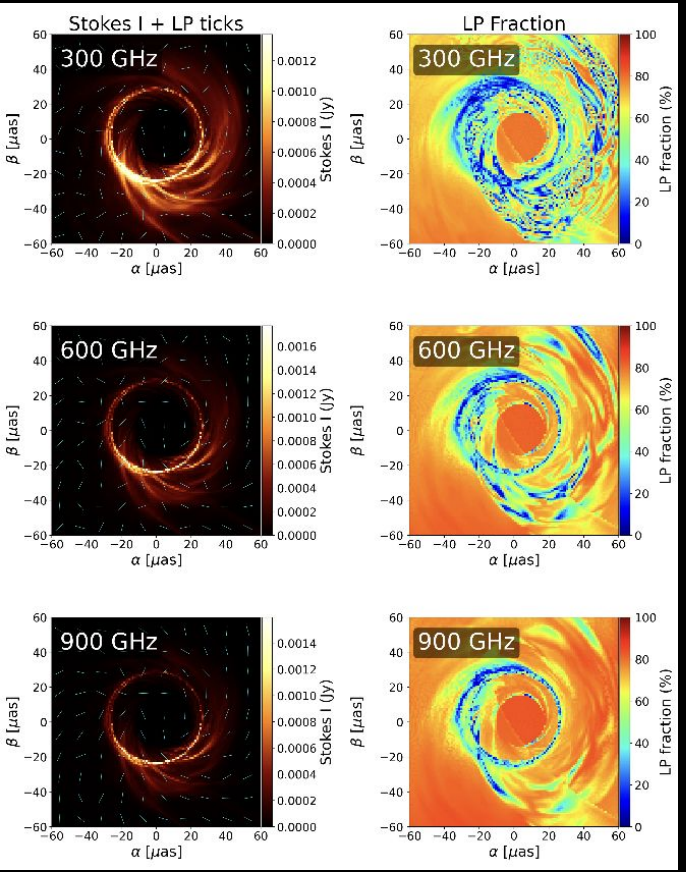
Appendix

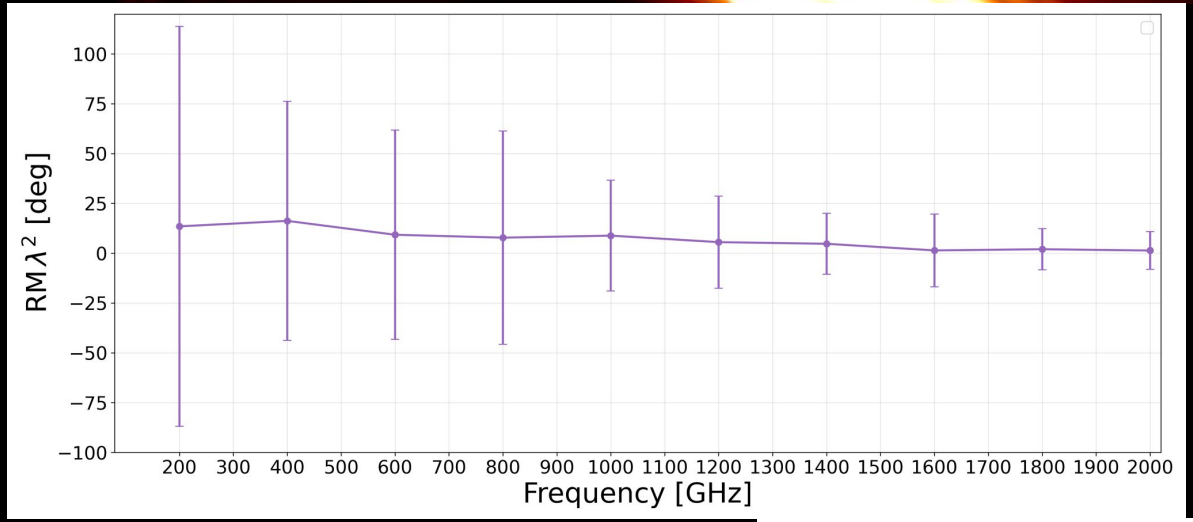

With Faraday effects
Without Faraday effects
$R_{\rm high} = 1$
$R_{\rm high} = 10$
$R_{\rm high} = 40$
$R_{\rm high} = 160$
$i = 135^\circ$
$i = 150^\circ$
$i = 165^\circ$
All inclinations
$|\beta_2|$
0.0
0.2
0.4
0.6
−1.0
−0.5
0.0
0.5
1.0
Black hole spin $a_\star$

Appendix


Without Faraday effects
With Faraday effects
$\arg(\beta_{2,n=1})$ [°]
$\arg(\beta_{2,n=0})$ [°]
180
120
60
0
−60
−120
−180
Black hole spin a_*
0.97
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-0.97

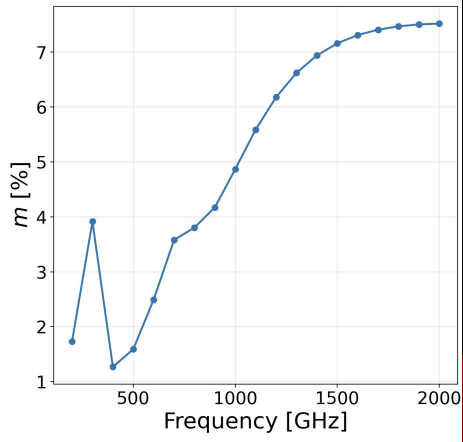
Higher Frequencies Mitigate Faraday Rotation





Probe more compact (photon ring) and less depolarized emission

Reduce Faraday rotation and reveal more intrinsic polarized pattern



Combining n=0 and n=1

$$\angle\beta_{2,n=0} - \angle\beta_{2,n=1}$$

$$\angle\beta_{2,n=0} + \angle\beta_{2,n=1}$$