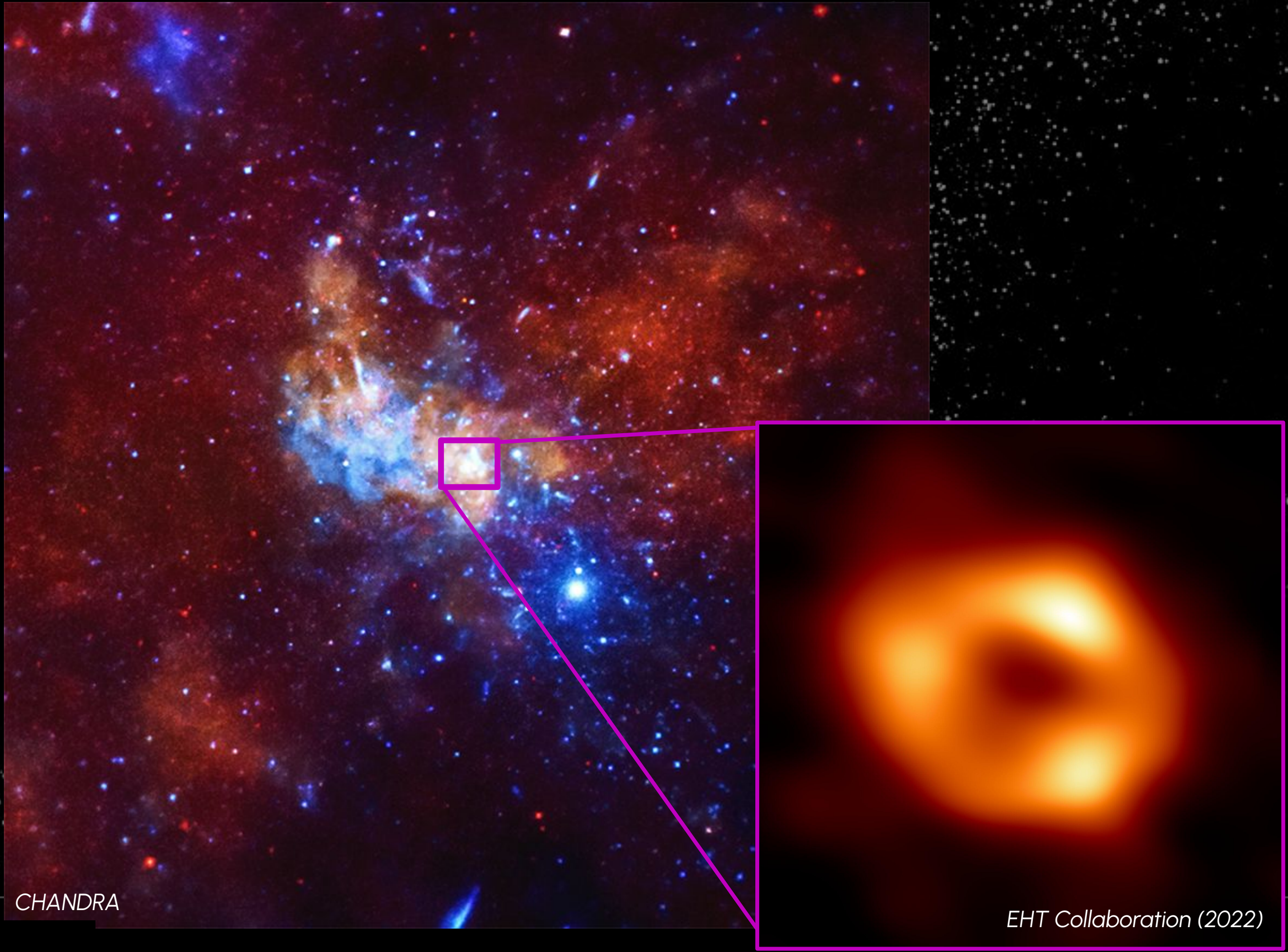
Investigating Magnetic Reconnection as a Flaring Mechanism in Sgr A* Using Local Plasma Properties

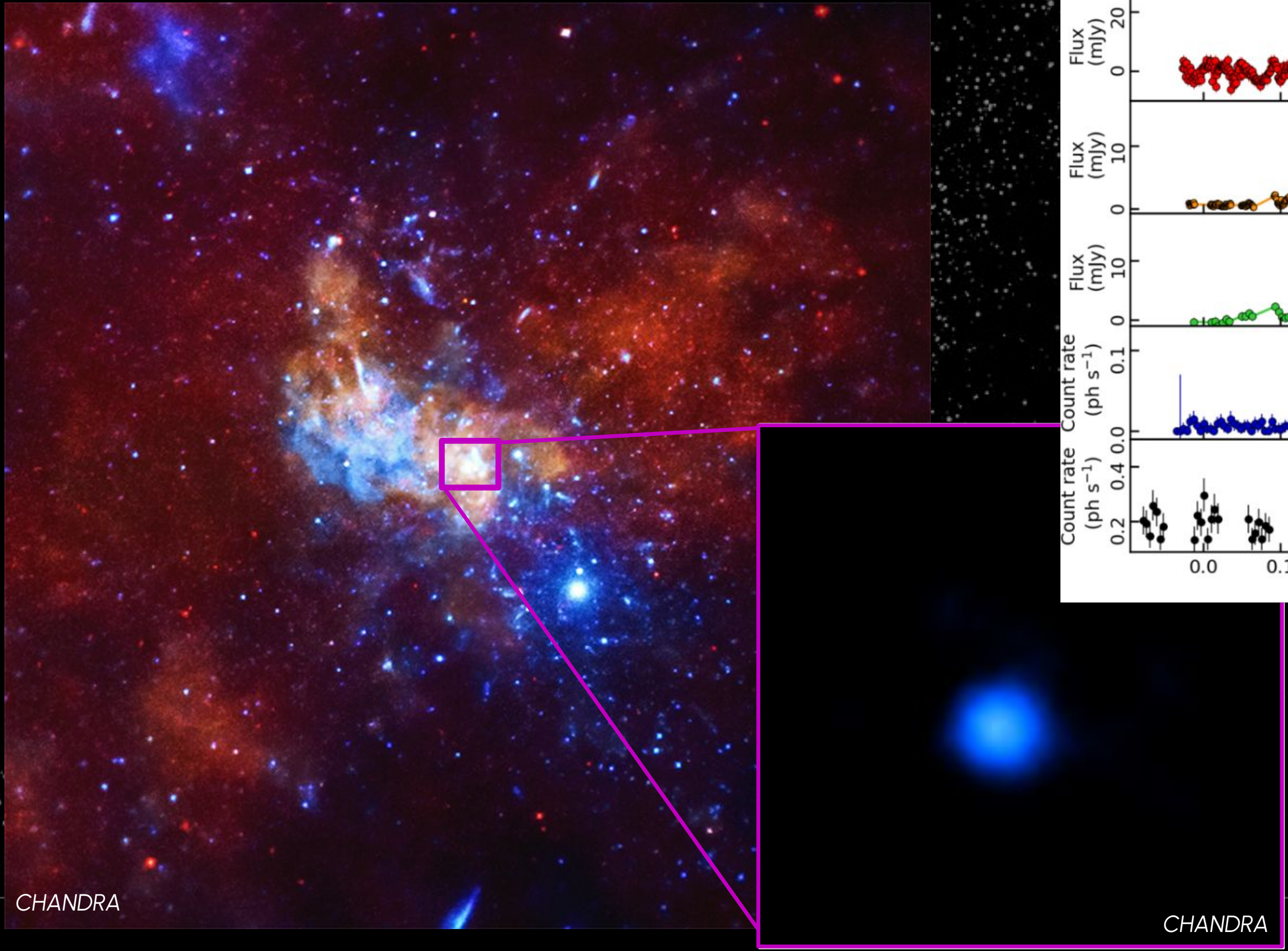
Aylecia Lattimer

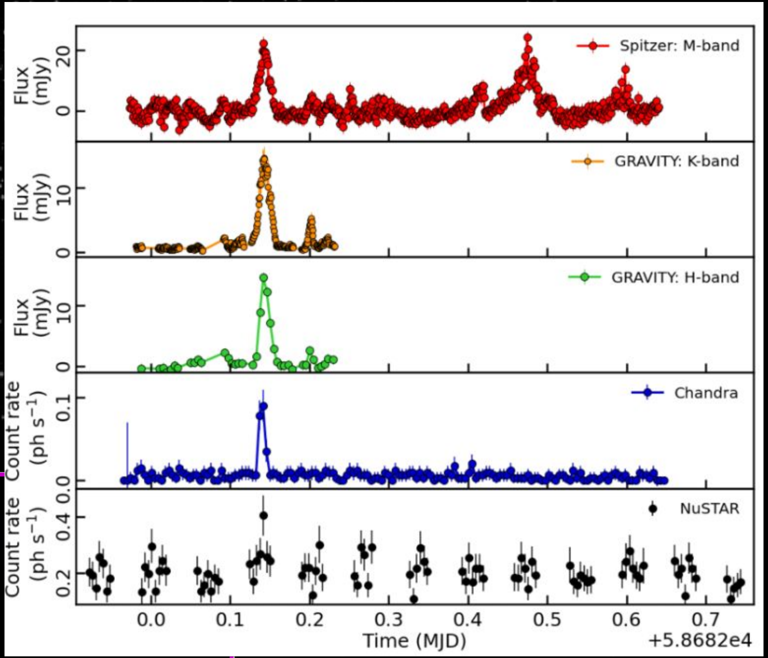
with Subhrat Praharaj, Rittick Roy, Paul Tiede, & Sera Markoff

Event Horizon Telescope

ANTON PANNEKOEK INSTITUUT


CHANDRA
EHT Collaboration (2022)





GRAVITY Collaboration (2021)

Flaring in IR & X-ray → powered by reconnection?

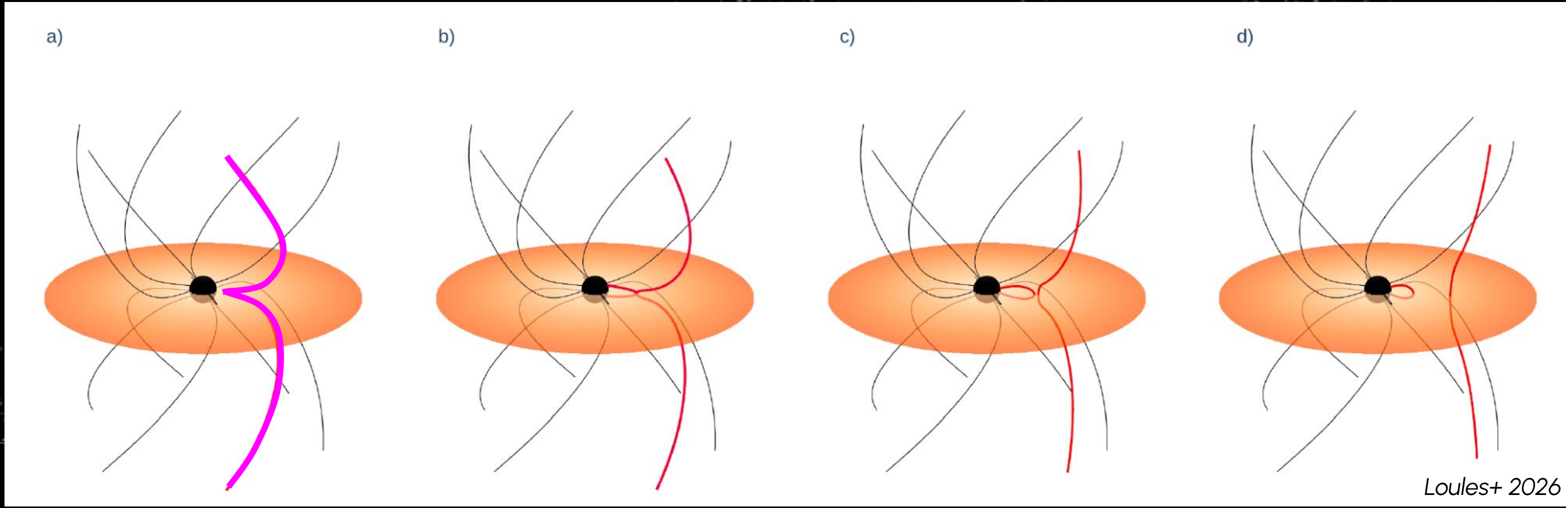
Recap: Reconnection in Magnetically Arrested Disks

magnetic fields thread accreting material, advected inward

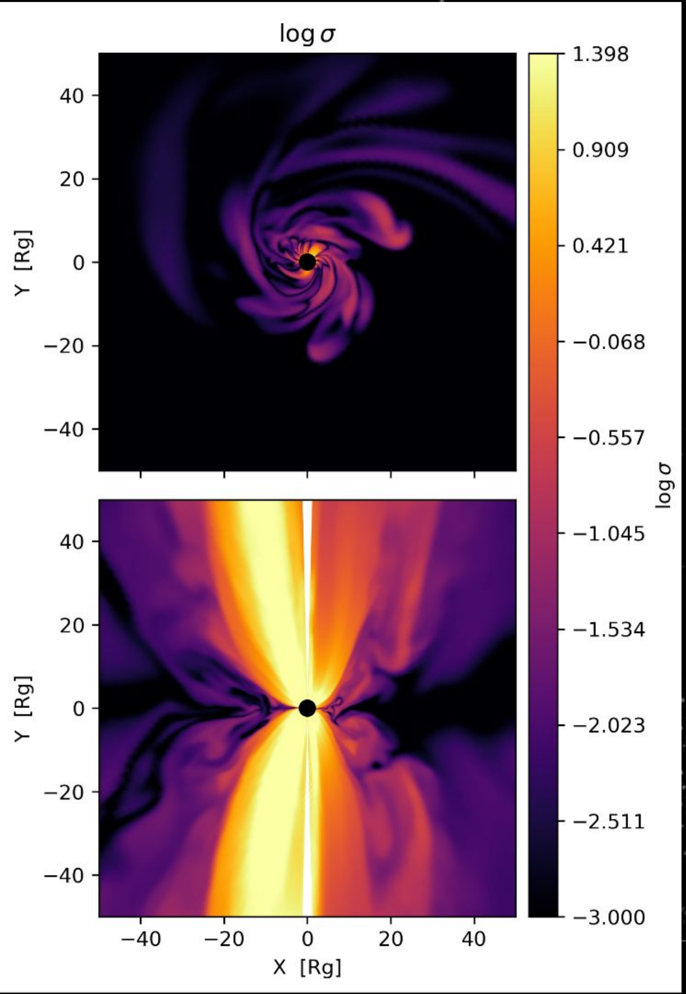
Magnetic flux builds up at horizon, suppresses accretion

field lines reconnect

magnetic flux is expelled from inner regions

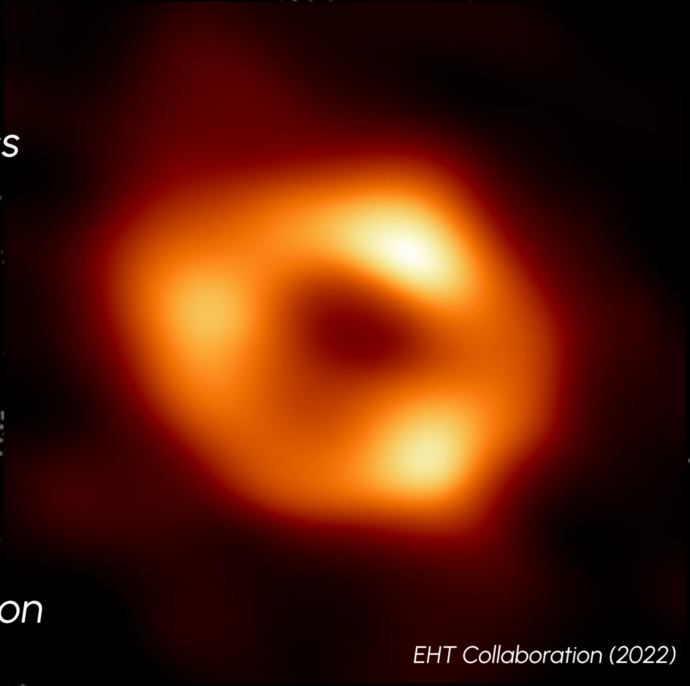


Loules+ 2026



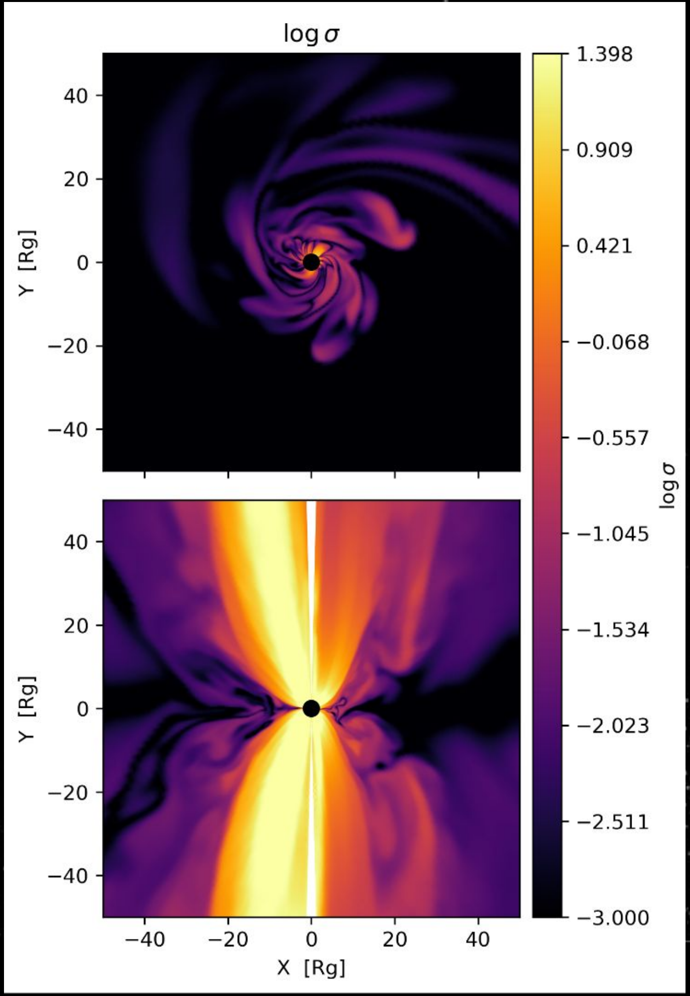
general relativistic magnetohydrodynamics (GRMHD) simulation

observation

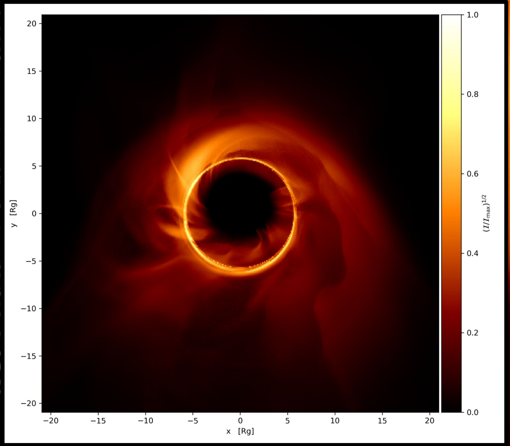


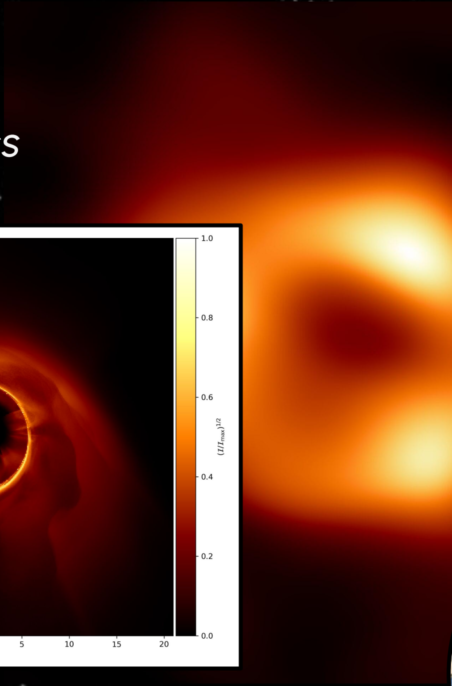
EHT Collaboration (2022)

General relativistic ray-tracing bridges the gap...



general relativistic magnetohydrodynamics (GRMHD) simulation



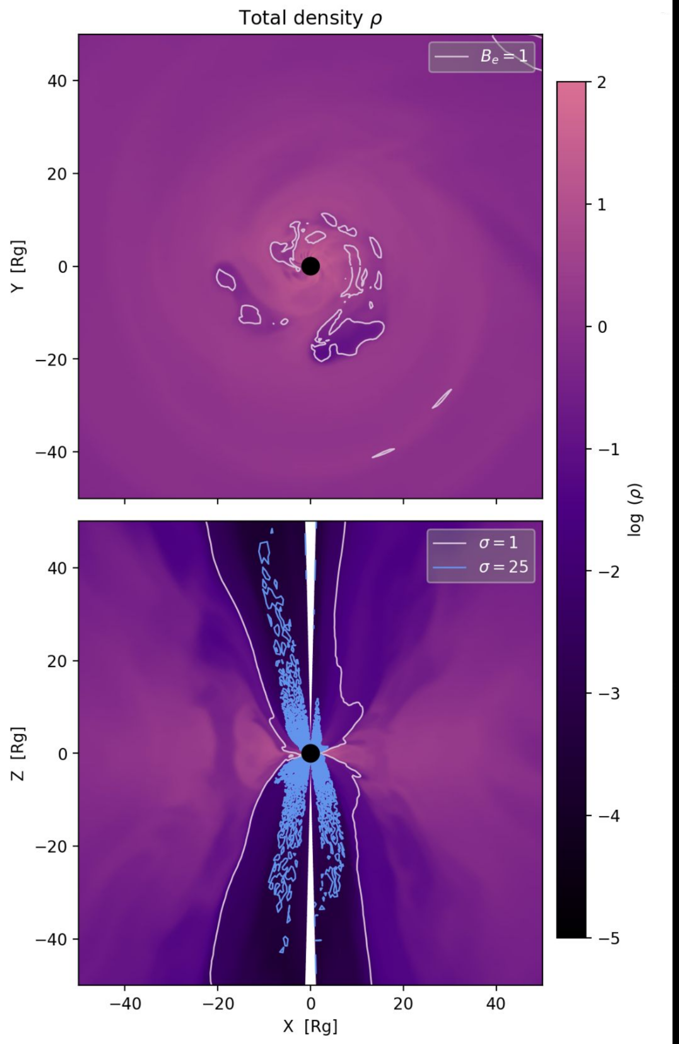


Picasso

Roy, Tiede, Lattimer++ 2026, in prep.

Current GRMHD* Caveats

1. only evolves protons → electrons added in post-processing



Current GRMHD* Caveats

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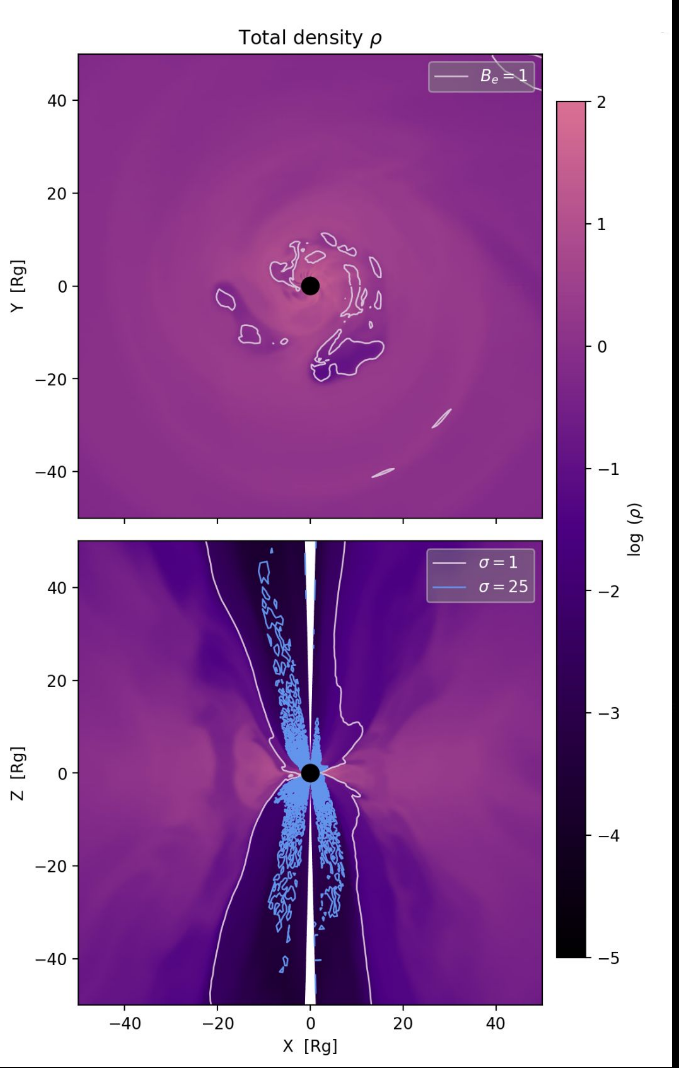
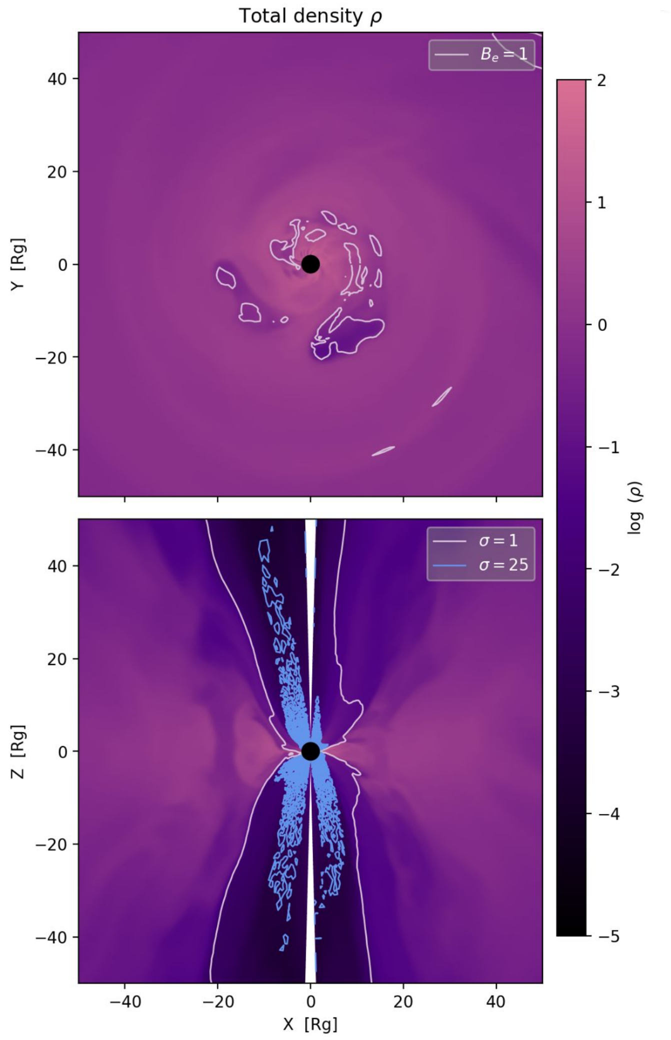
    a. Added electrons are thermally distributed

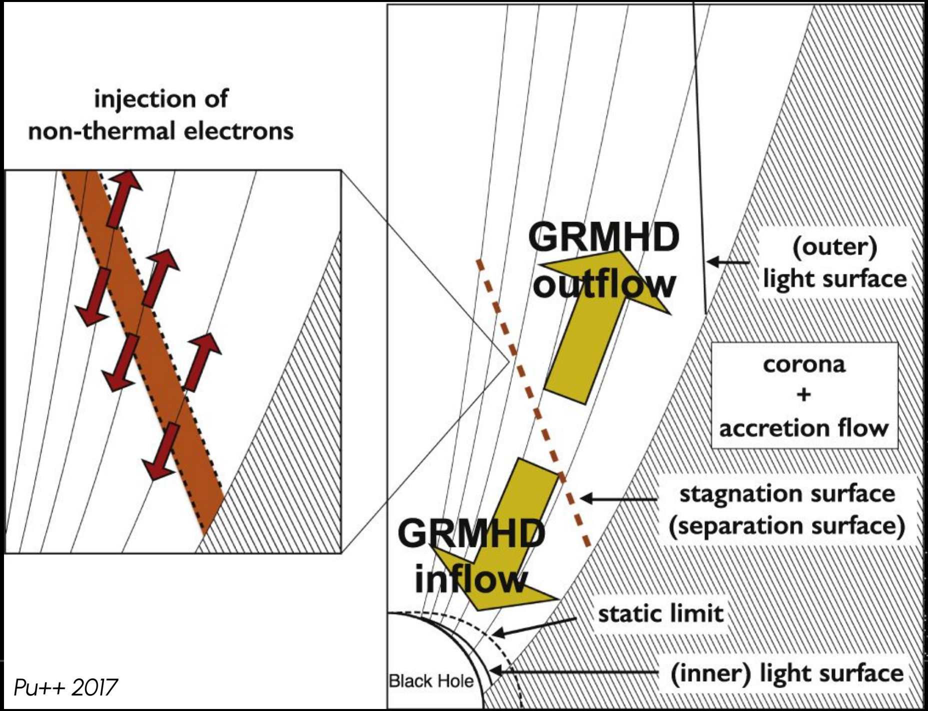


Current GRMHD* Caveats

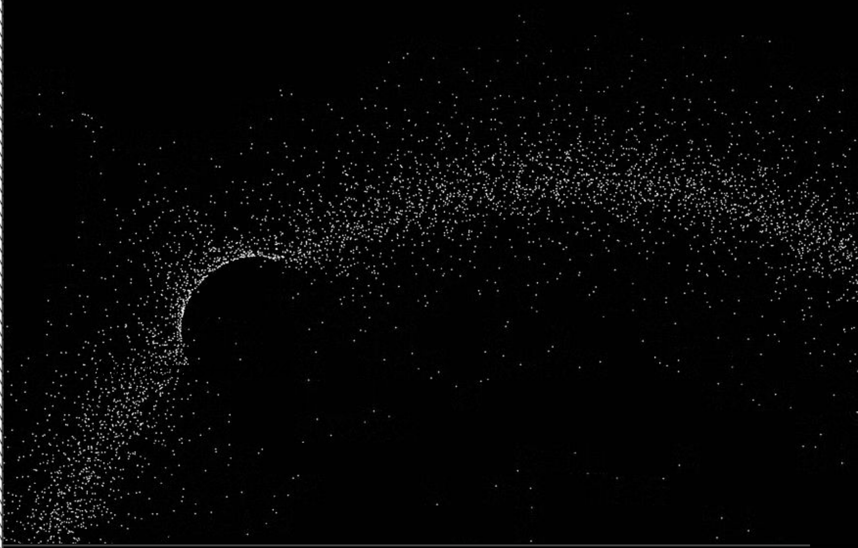
1. only evolves protons → electrons added in post-processing
    a. Added electrons are thermally distributed
2. "Floor" plasma injected for numerical stability at regions of high magnetization (low density)



magnetically dominated, strong electric fields,
and charge separation
→ pair production (electron-positron pairs)



Pu++ 2017



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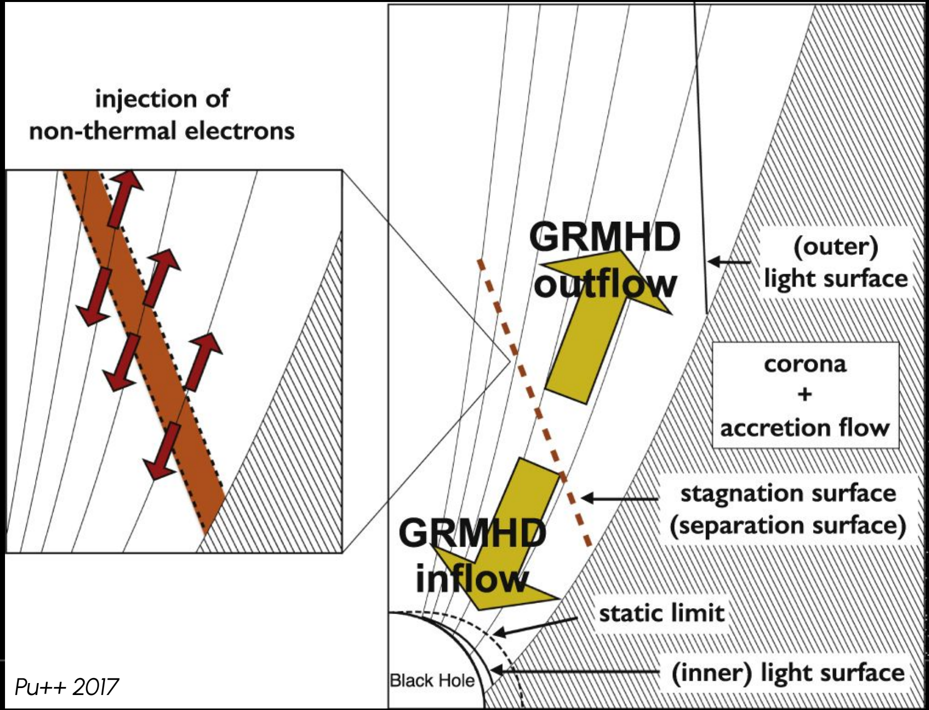

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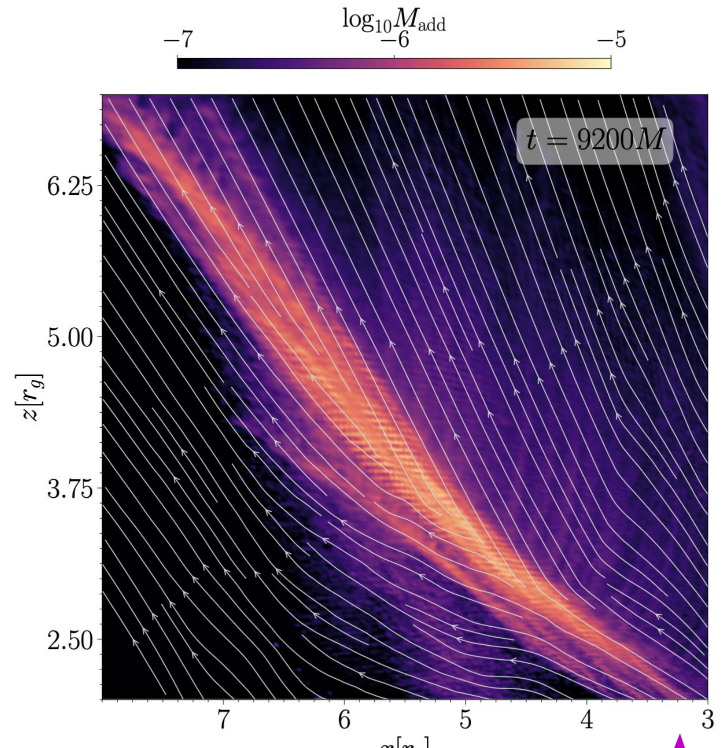


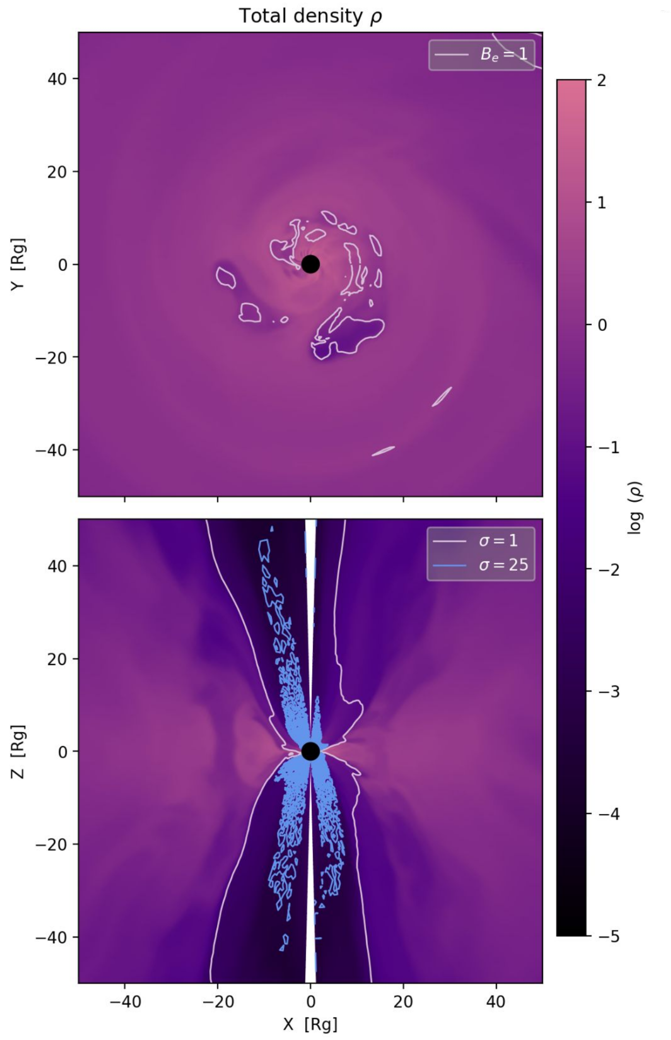
Mpisketzis++ 2024

correlated with "floor" injection

Current GRMHD* Caveats

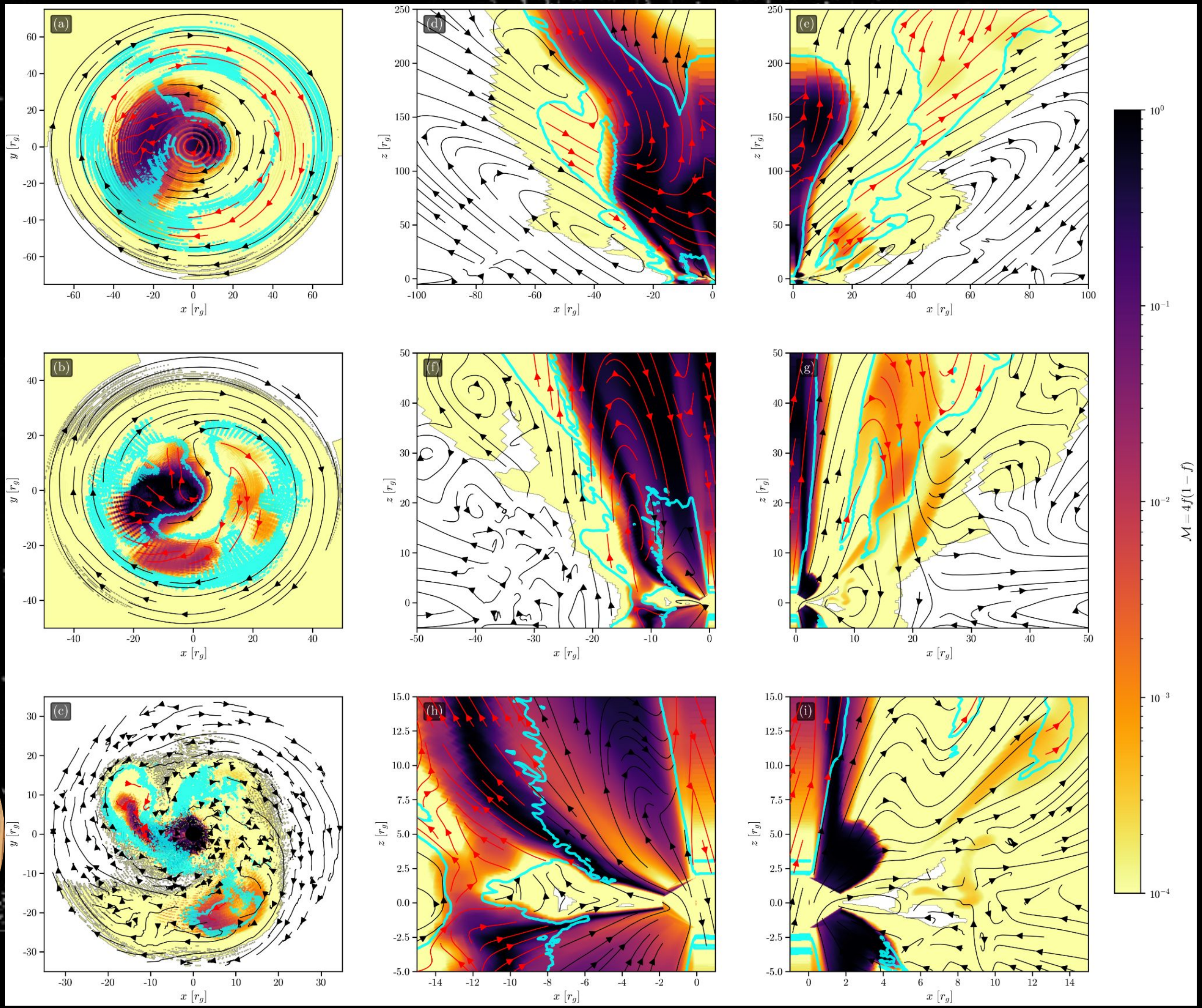
1. only evolves protons → electrons added in post-processing
    a. Added electrons are thermally distributed
2. "Pair" plasma proxy injected at regions of high magnetization

How would this pair plasma affect our simulated images?



GRMHD + tracers!

- dynamic refinement to resolve:
    - jet funnel, sheath
    - magnetic instabilities
- maximum resolution: $N r \times N\theta \times N\phi = 6224 \times 2208 \times 2496$



Praharaj+ 2026, in prep.

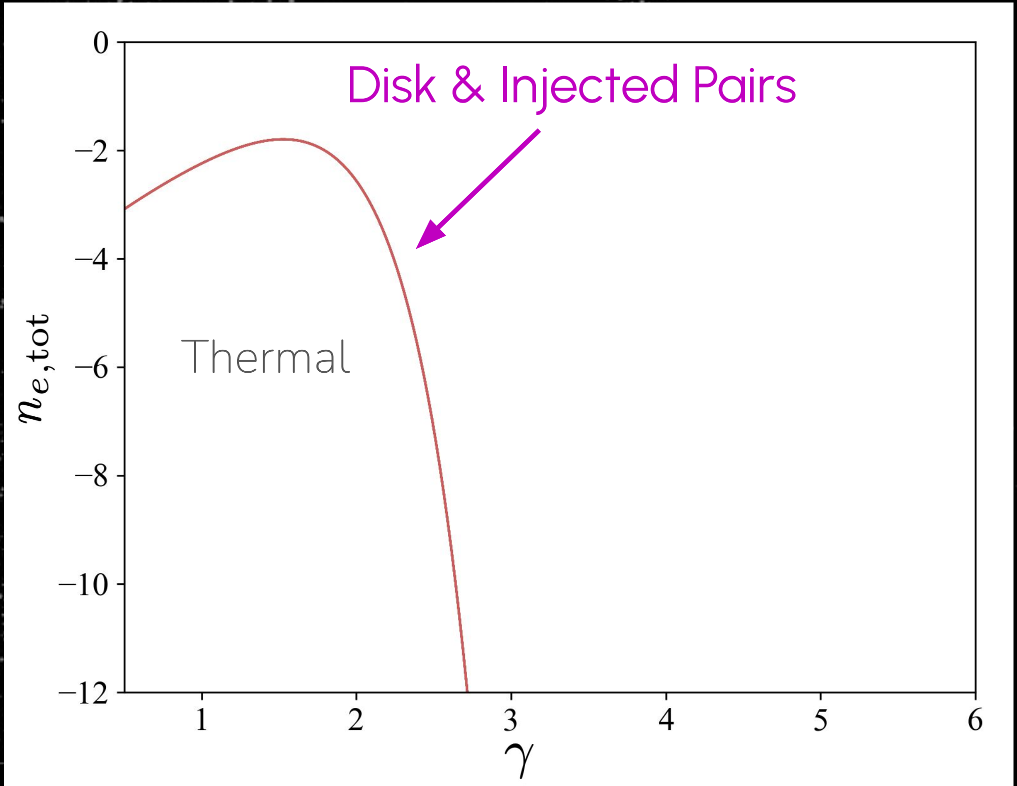
Modifying our Standard* Parameters

Pair Injection

1. Inject pairs with thermal distribution
2. Inject pairs with power-law distribution

Ray-tracing Regions

1. Standard magnetization region → σ ≤ 1
2. Extended region → σ ≤ 20



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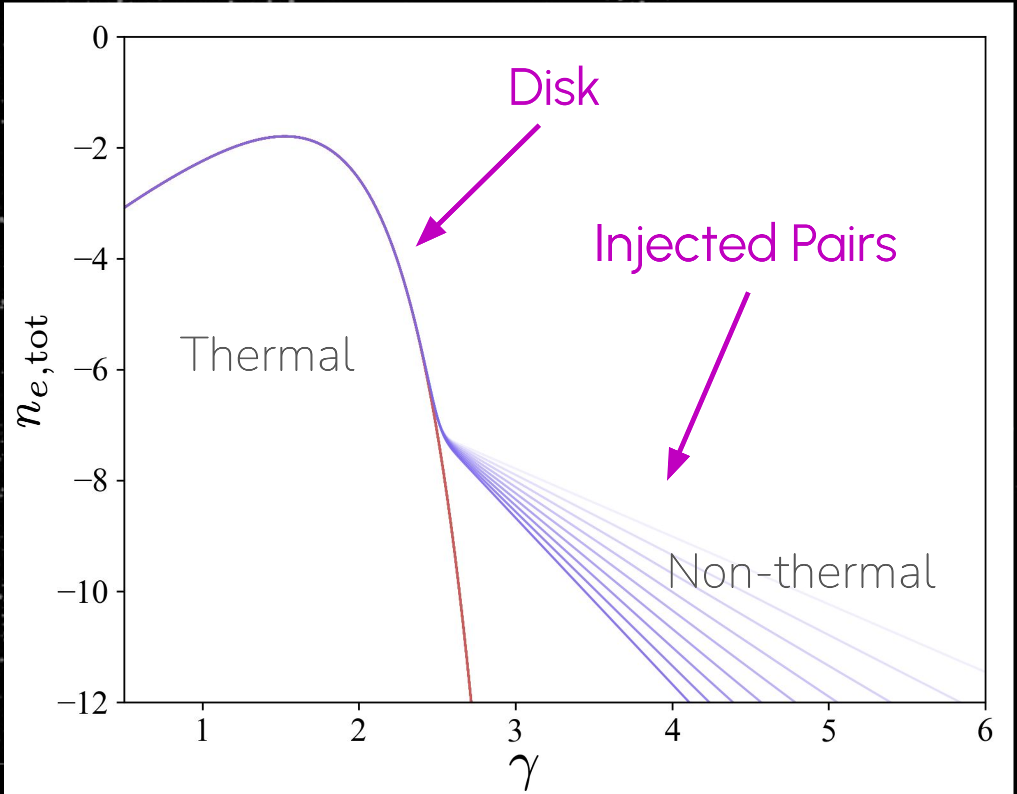

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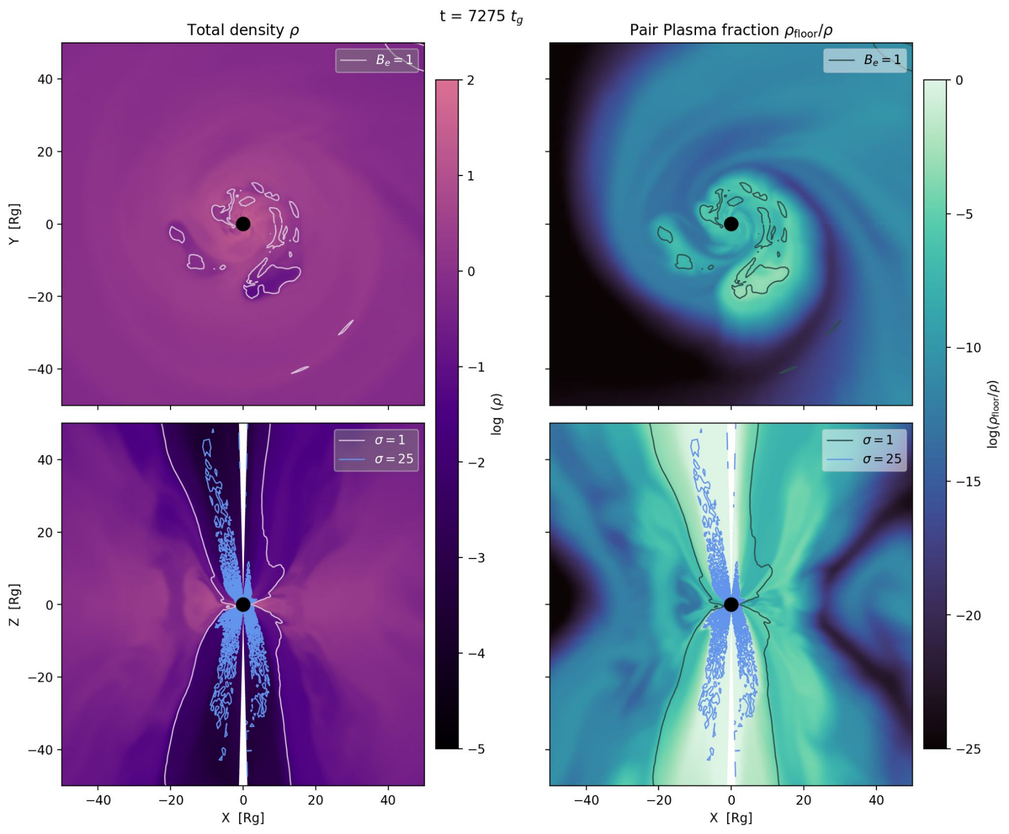

Lattimer++ 2026, in prep.

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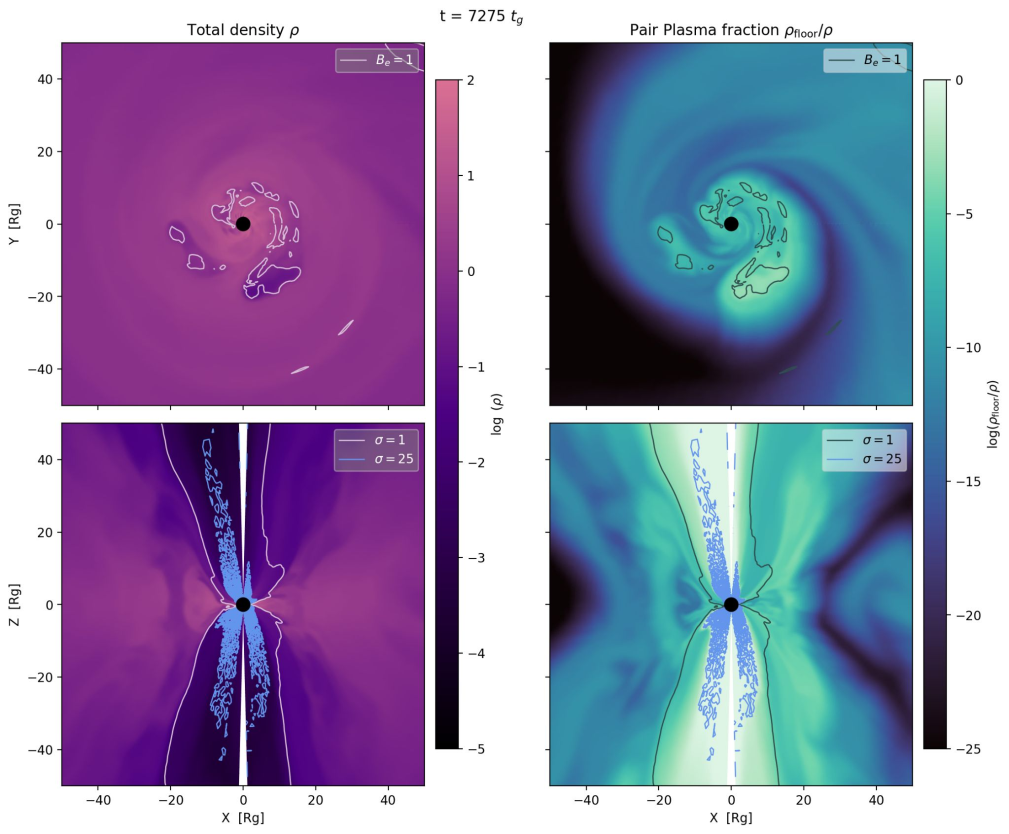

Lattimer++ 2026, in prep.

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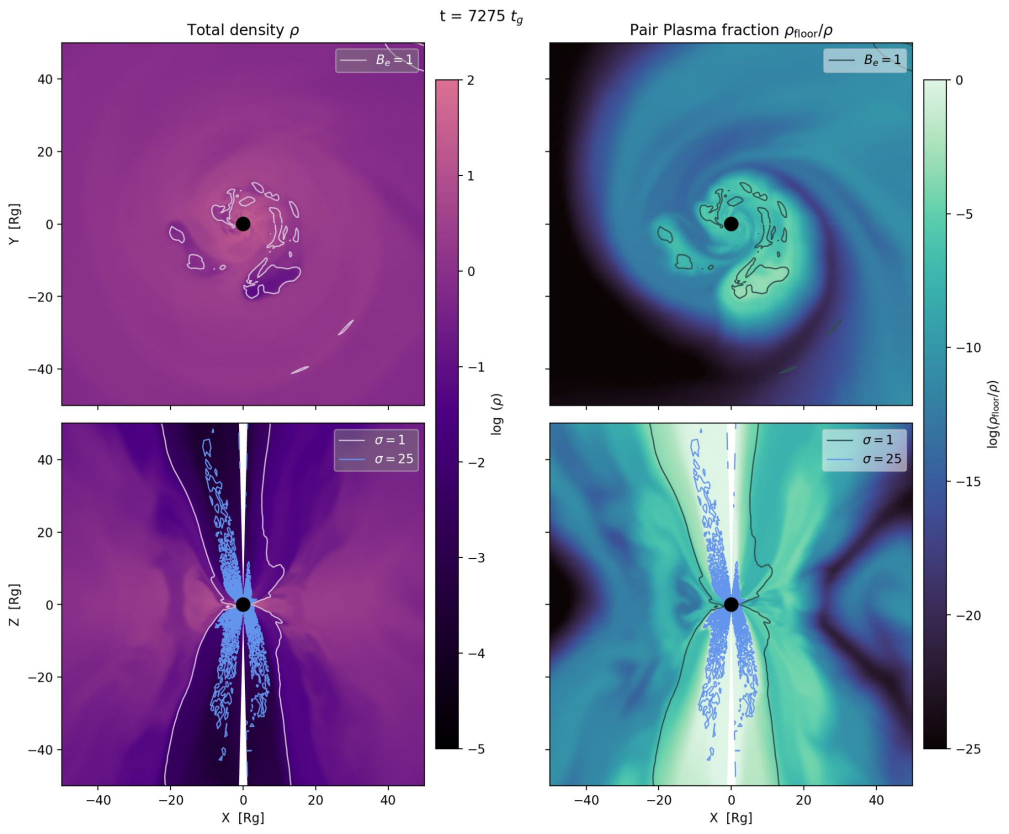
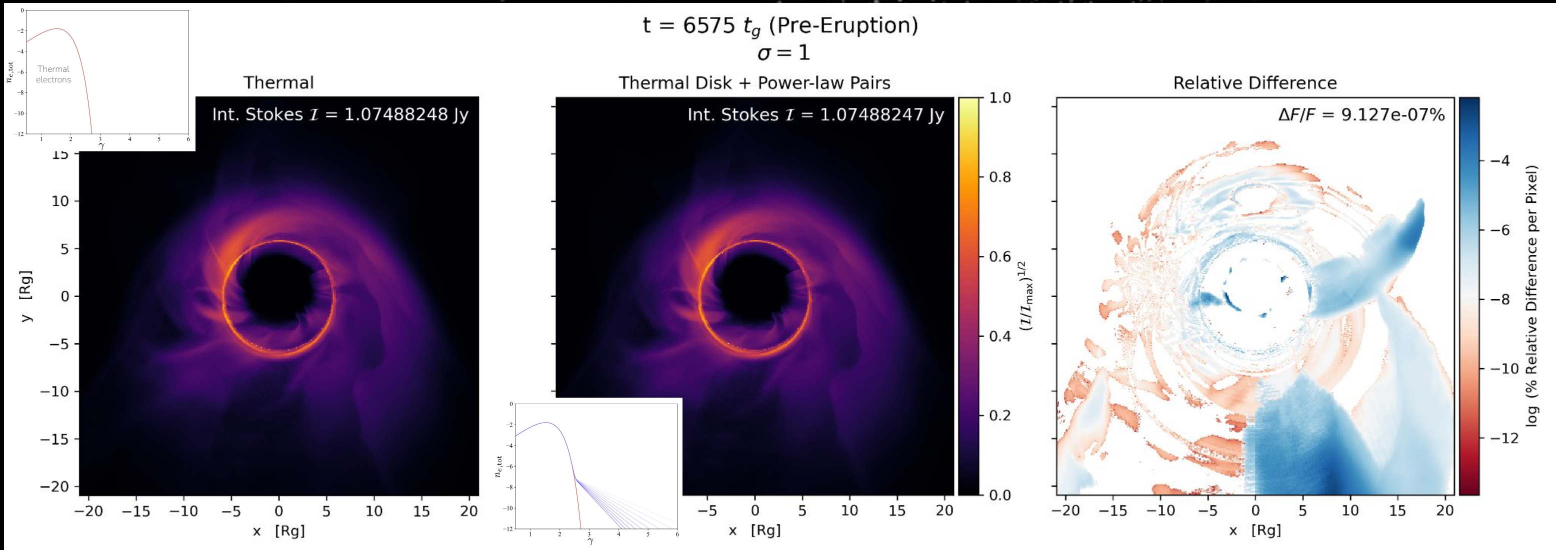
...and now we ray-trace!

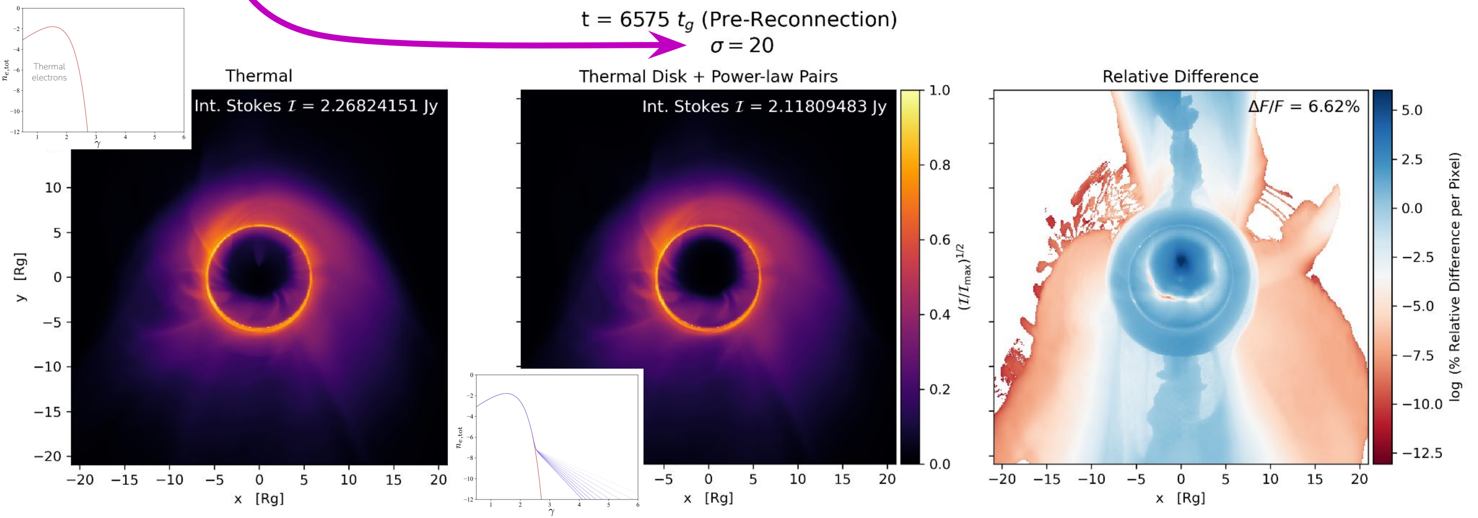


Lattimer++ 2026, in prep.

Outside Eruption

Includes more of polar region





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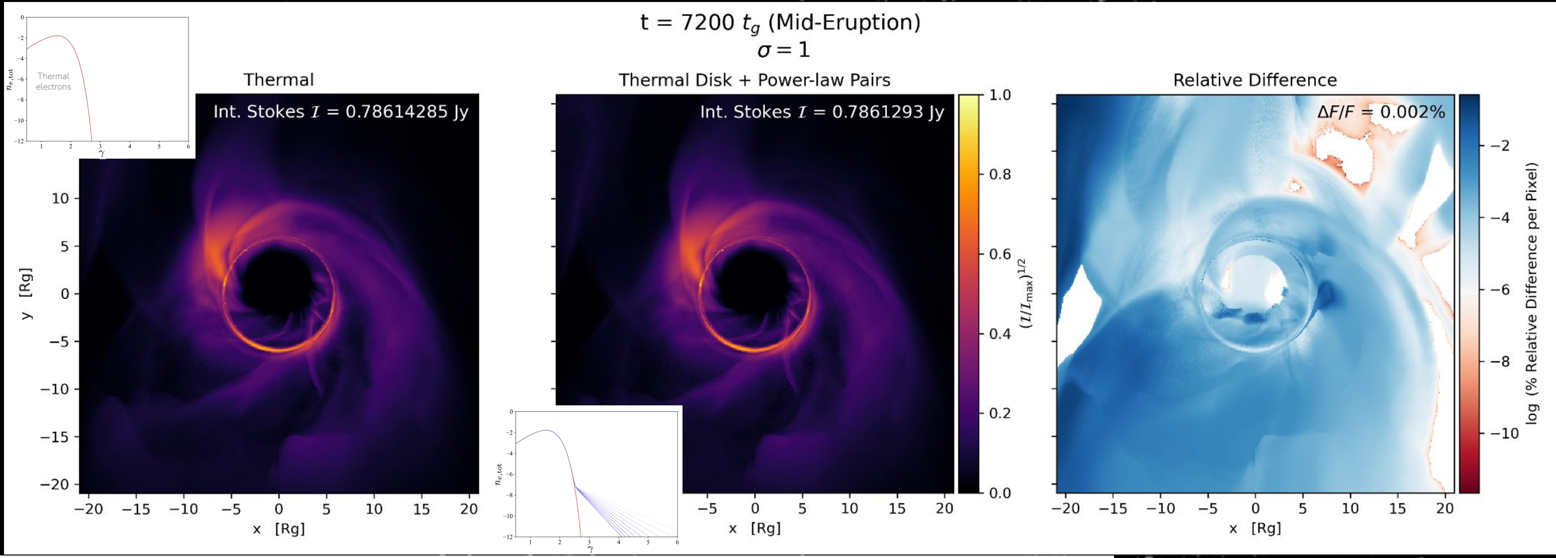

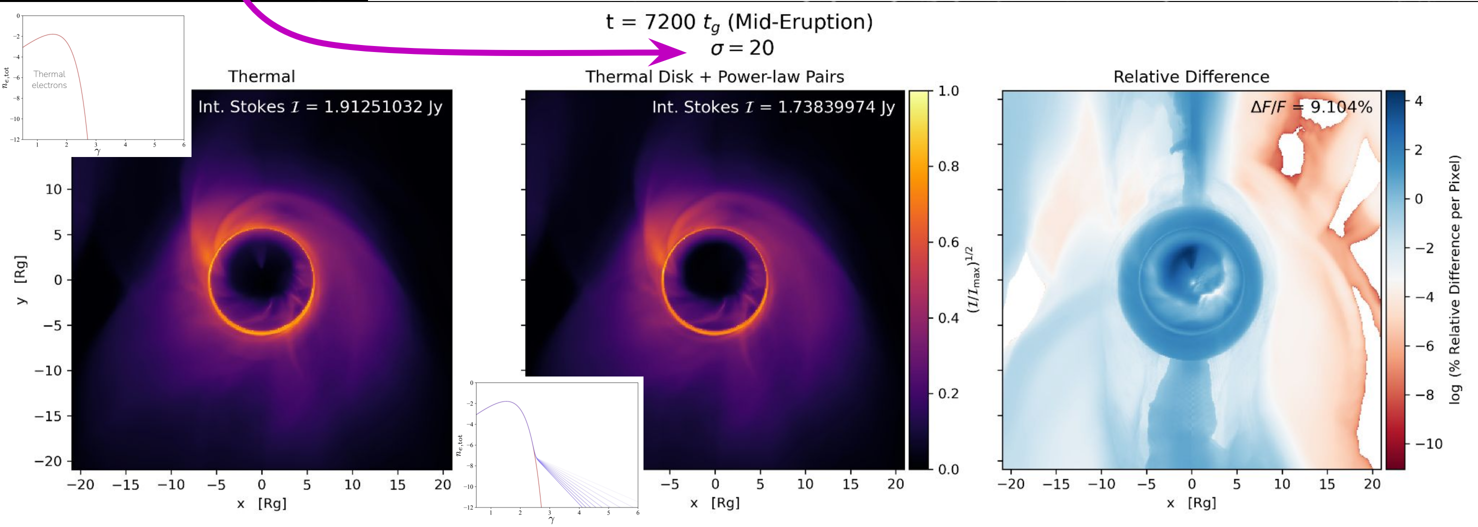

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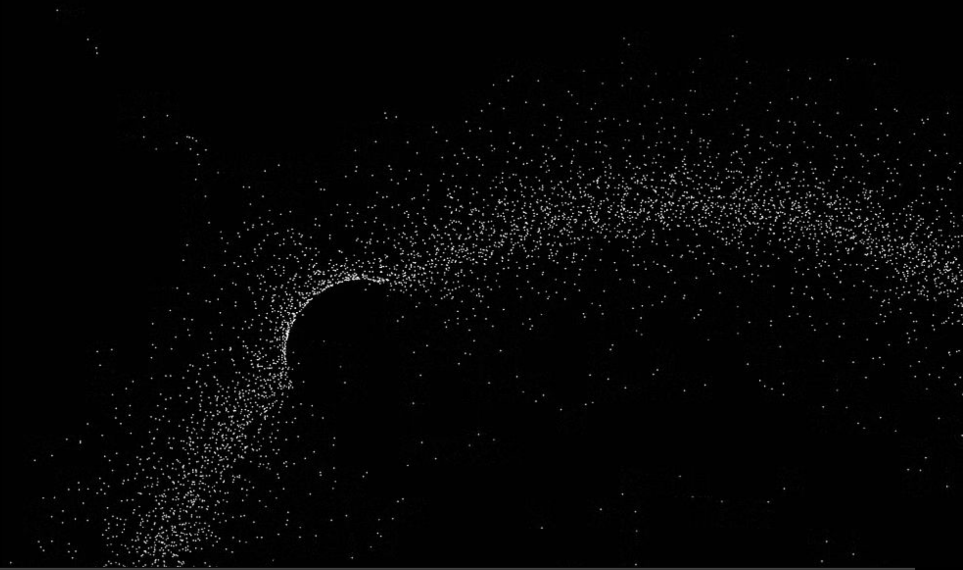
Conclusions

How can the injection of "floor" plasma affect simulated images?



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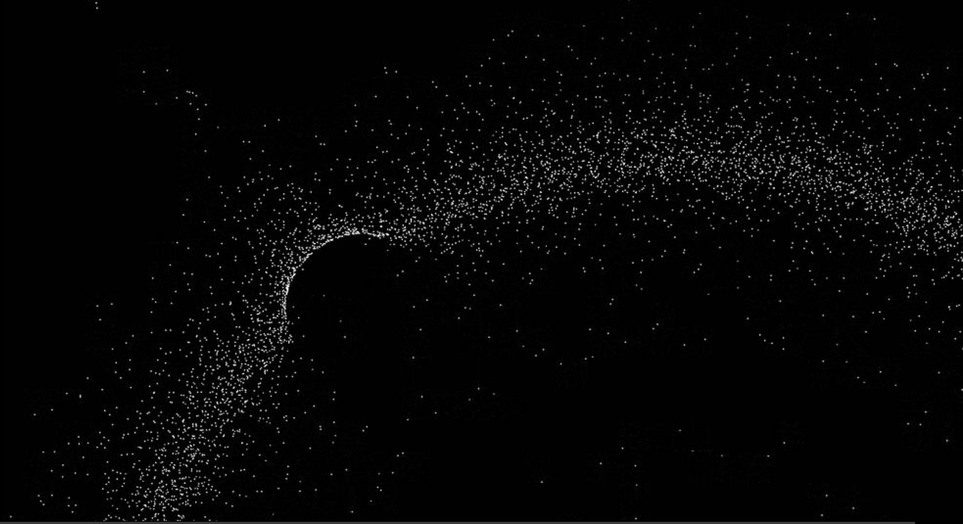
How can the injection of "floor" plasma affect simulated images?

1. treating injected material as non-thermal (power-law) has a negligible effect on resulting image for standard ray-tracing regions both during and outside flux eruption/reconnection events



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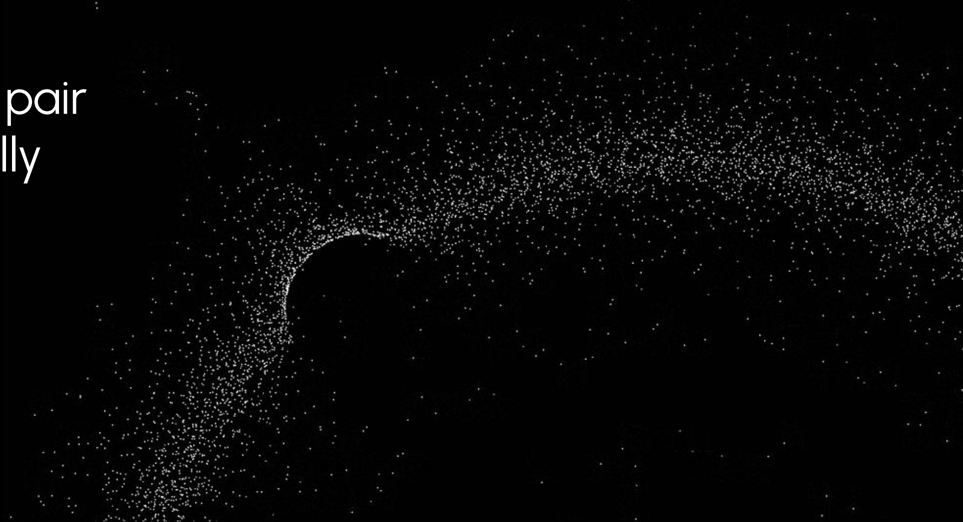
2. Inclusion of high-σ regions may make pair plasma effect non-negligible, especially mid-eruption events



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**For this set of parameters!*

Conclusions & Upcoming

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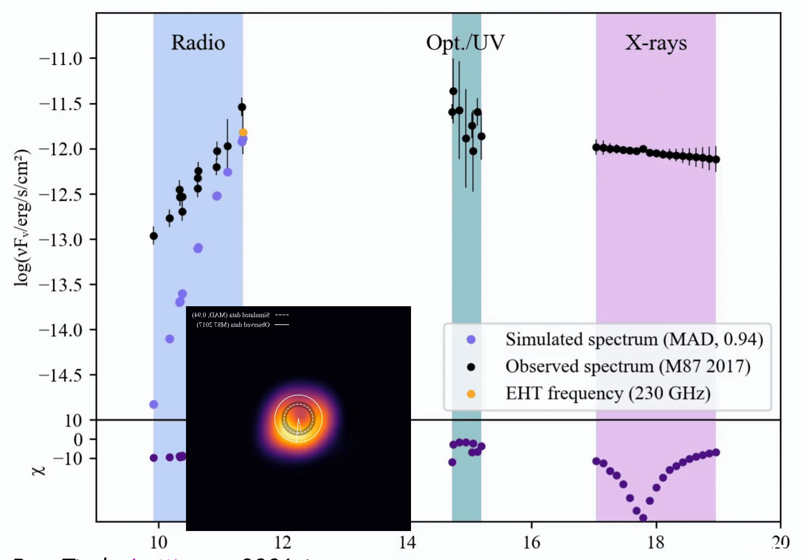
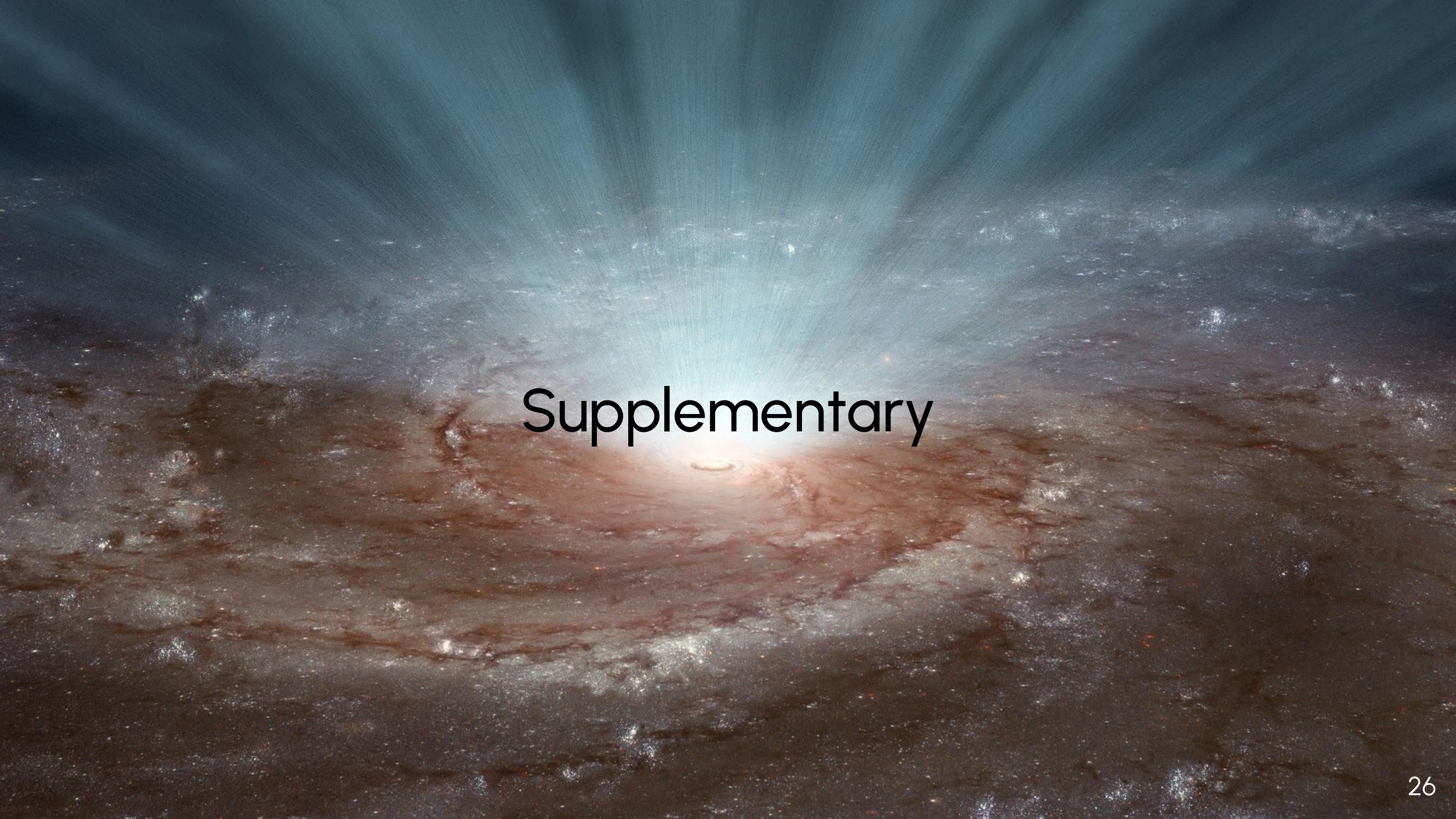
For the future: get electron distribution from plasma properties by fitting to spectra, image, & polarization constraints → do we recover variability?



Roy, Tiede, Lattimer+ 2026, in prep.

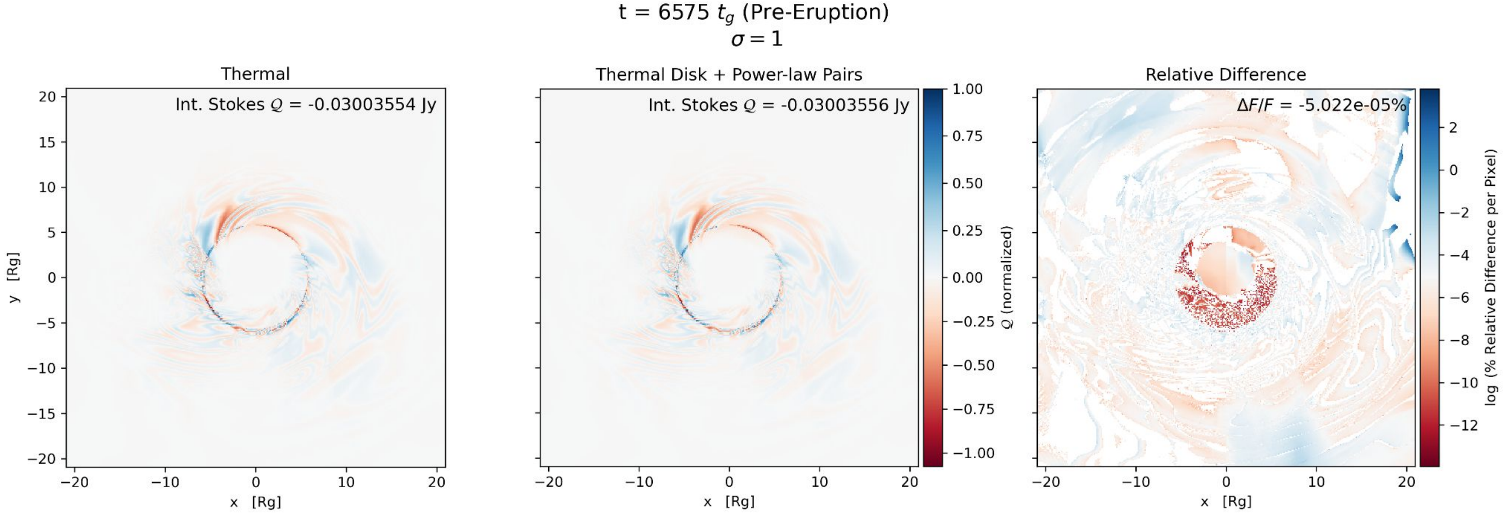
Supplementary



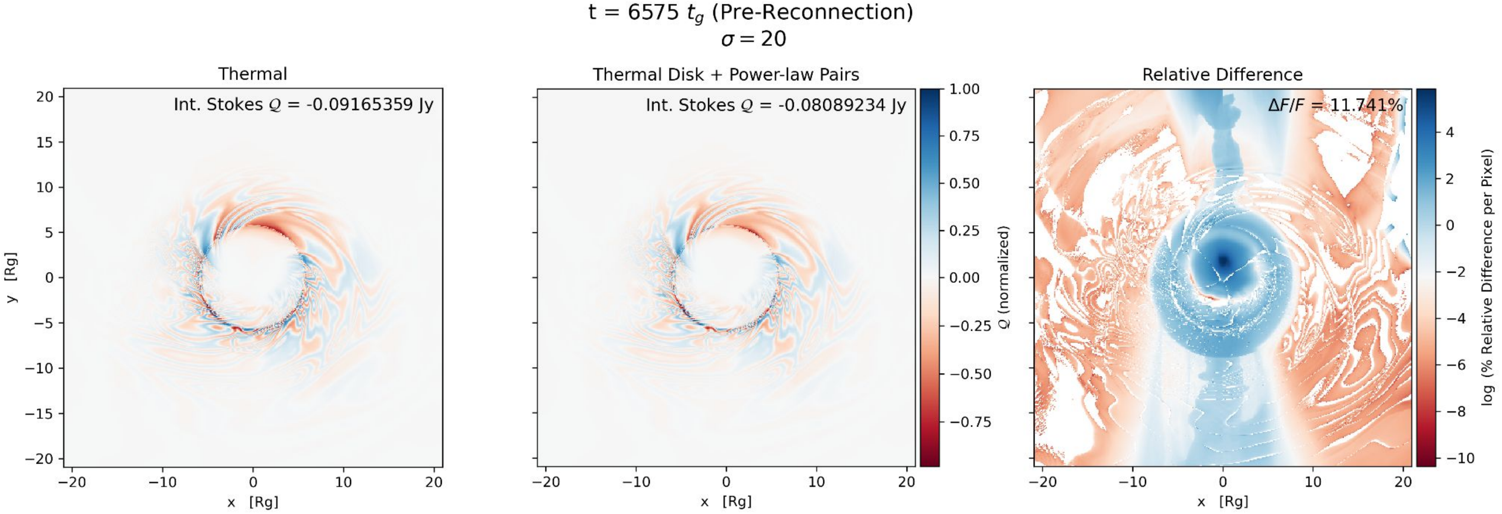
GRMHD Simulation Setup

- initial base grid: logarithmic radial spacing with $N_r \times N_\theta \times N_\phi$ = 778 x 276 x 312
  - Minimum 10 cells per MRI length
- dynamic AMR to resolve:
  - jet funnel
  - jet sheath
  - magnetic instabilities
- maximum effective resolution: $N_r \times N_\theta \times N_\phi = 6224 \times 2208 \times 2496$
- Fishbone-Moncrief torus: inner edge at $R_{in} = 20r_g$ and pressure maximum at $R_{max} = 41r_g$

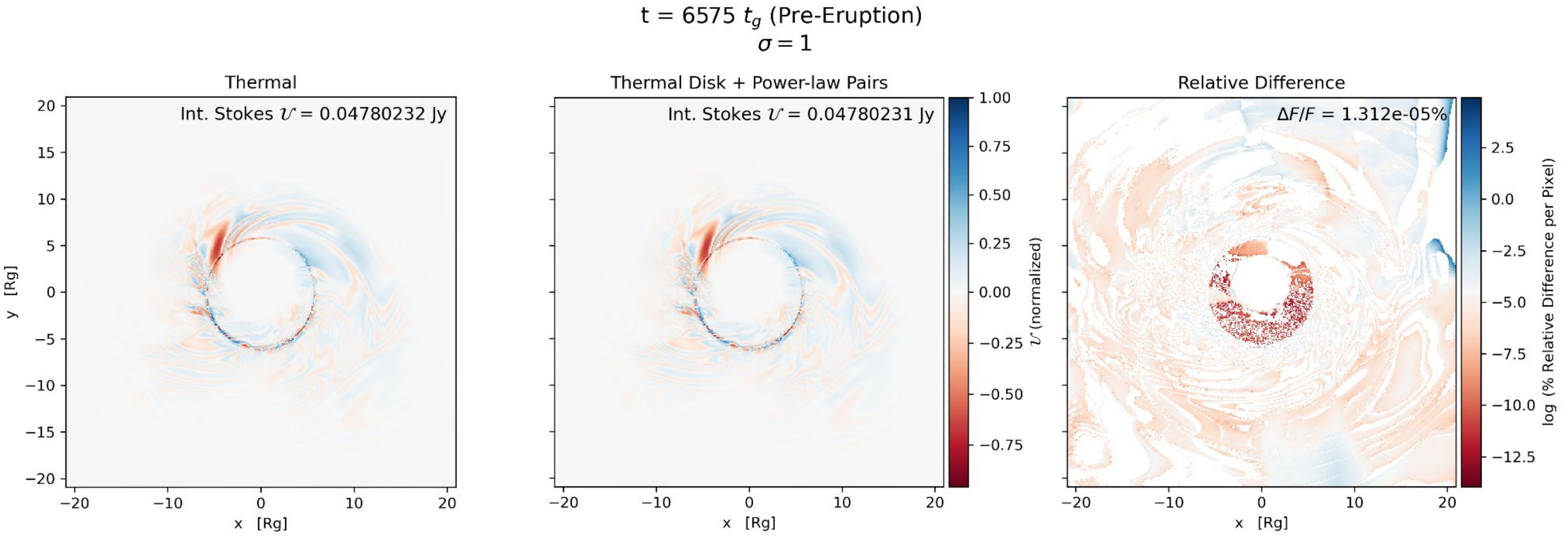
Stokes Q



t = 6575 t_g (Pre-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{Q}$ = -0.03003554 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{Q}$ = -0.03003556 Jy
$\mathcal{Q}$ (normalized)
Relative Difference
$\Delta F/F$ = -5.022e-05%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]

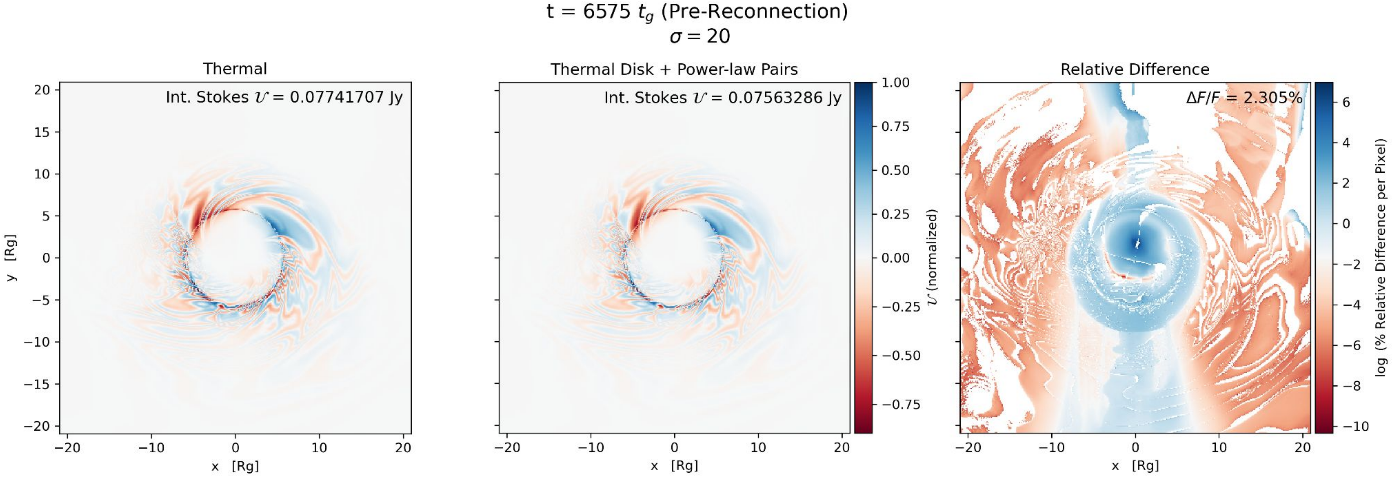


t = 6575 t_g (Pre-Reconnection)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{Q}$ = -0.09165359 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{Q}$ = -0.08089234 Jy
$\mathcal{Q}$ (normalized)
Relative Difference
$\Delta F/F$ = 11.741%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]



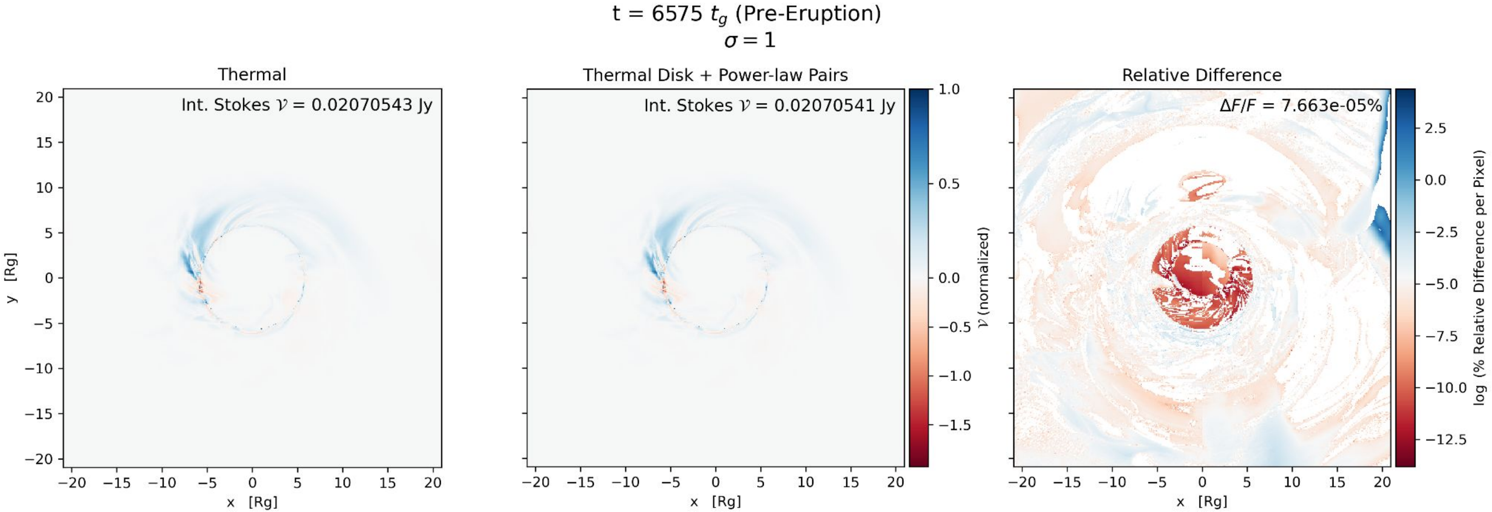
t = 6575 t_g (Pre-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{U}$ = 0.04780232 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{U}$ = 0.04780231 Jy
Relative Difference
$\Delta F/F$ = 1.312e-05%
$\mathcal{U}$ (normalized)
log (% Relative Difference per Pixel)
y [Rg]
x [Rg]

Stokes U

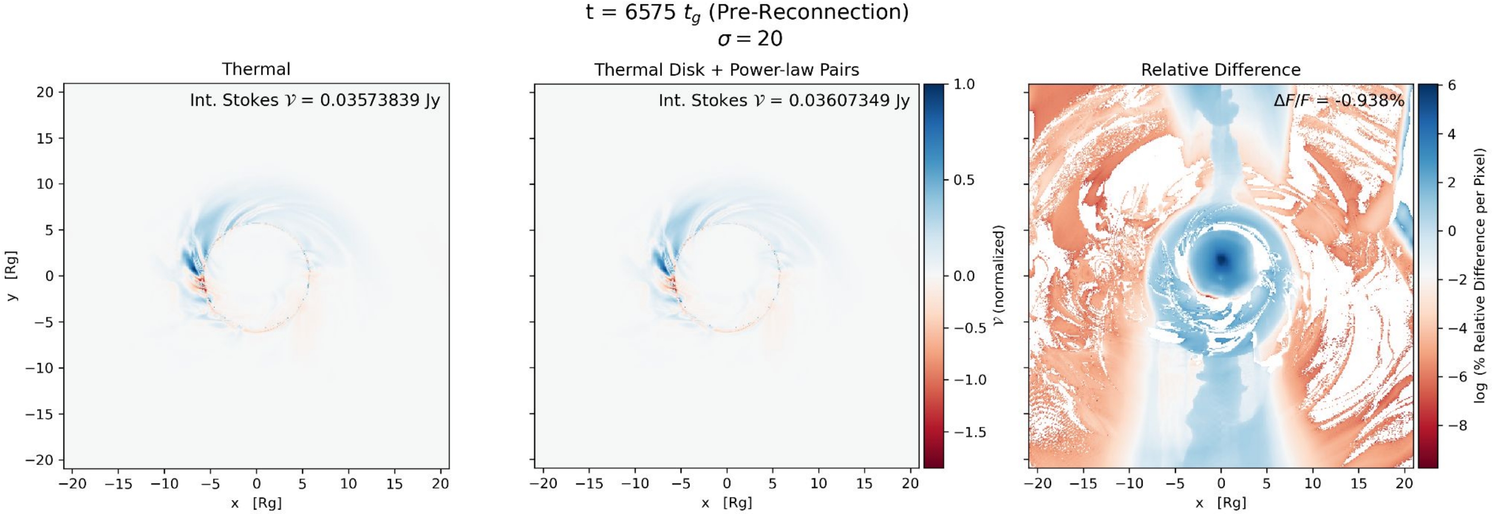


t = 6575 t_g (Pre-Reconnection)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{U}$ = 0.07741707 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{U}$ = 0.07563286 Jy
Relative Difference
$\Delta F/F$ = 2.305%
$\mathcal{U}$ (normalized)
log (% Relative Difference per Pixel)
y [Rg]
x [Rg]

Stokes V

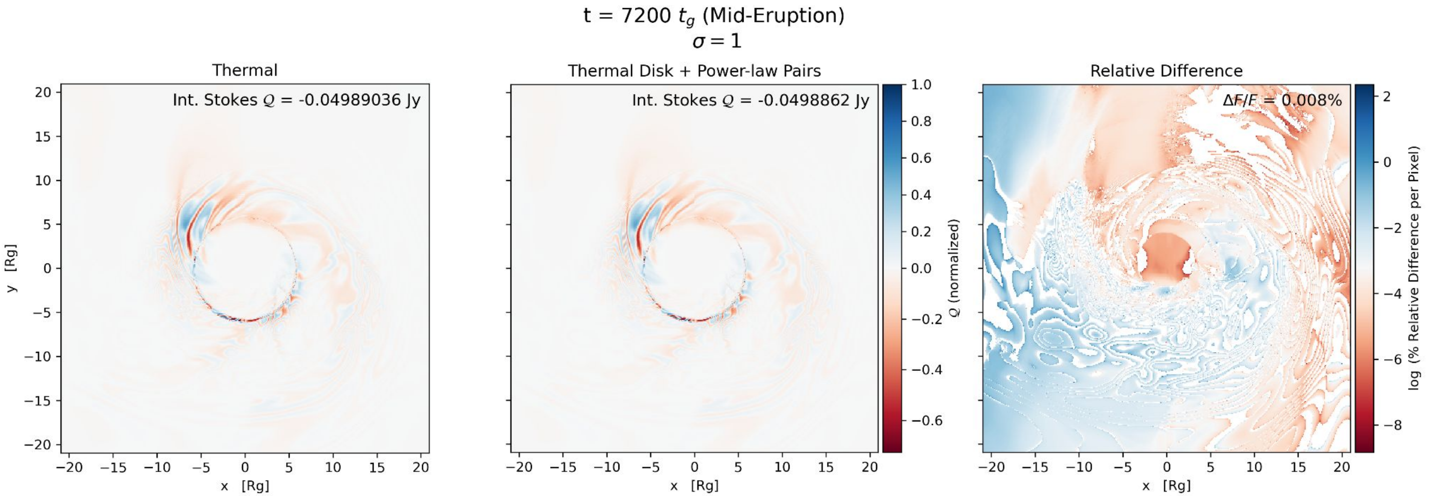


t = 6575 t_g (Pre-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{V}$ = 0.02070543 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{V}$ = 0.02070541 Jy
$\mathcal{V}$ (normalized)
Relative Difference
$\Delta F/F$ = 7.663e-05%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]

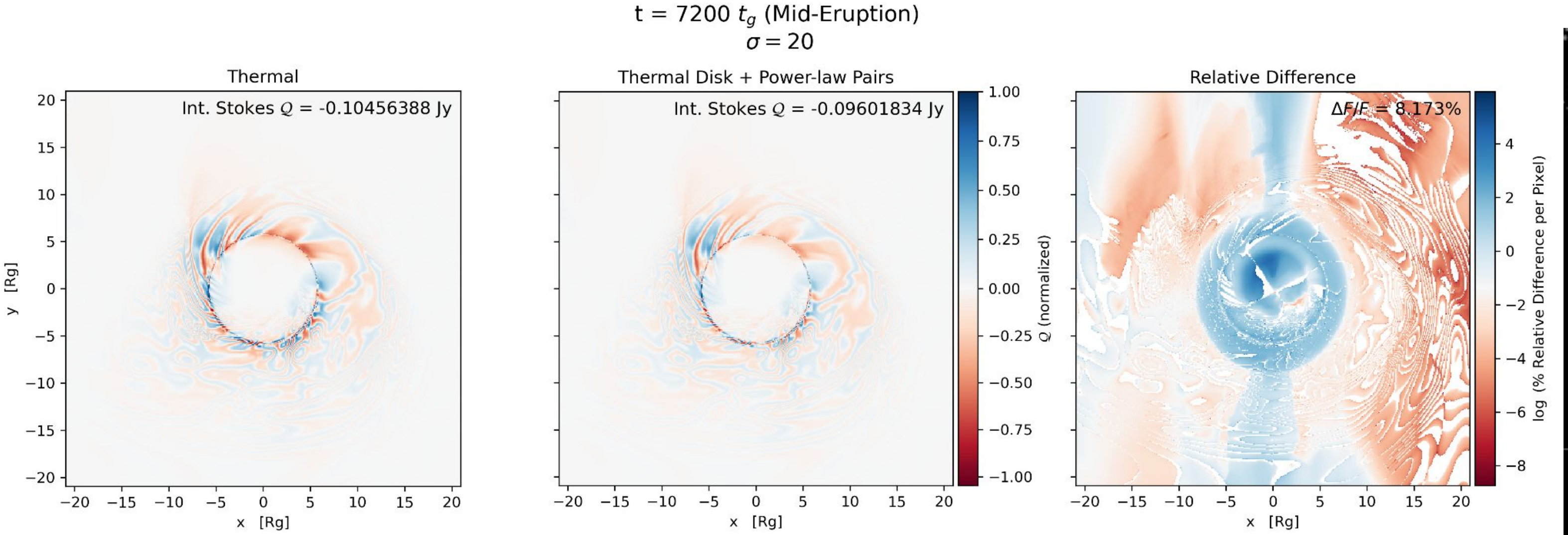


t = 6575 t_g (Pre-Reconnection)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{V}$ = 0.03573839 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{V}$ = 0.03607349 Jy
$\mathcal{V}$ (normalized)
Relative Difference
$\Delta F/F$ = -0.938%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]

Stokes Q

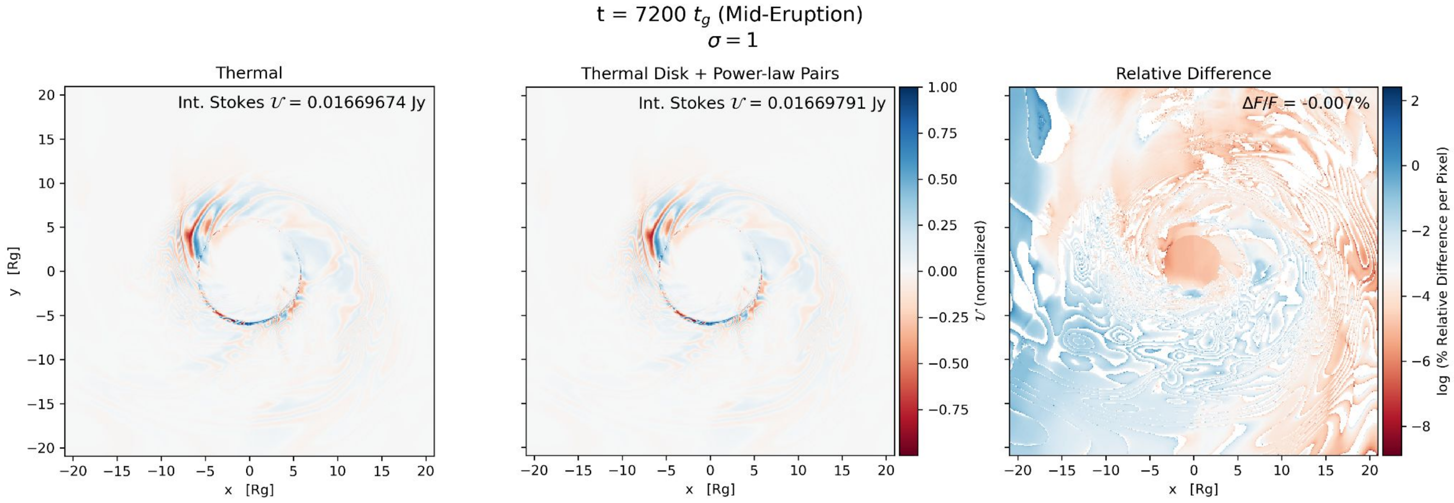


t = 7200 t_g (Mid-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{Q}$ = -0.04989036 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{Q}$ = -0.0498862 Jy
$\mathcal{Q}$ (normalized)
Relative Difference
$\Delta F/F$ = 0.008%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]

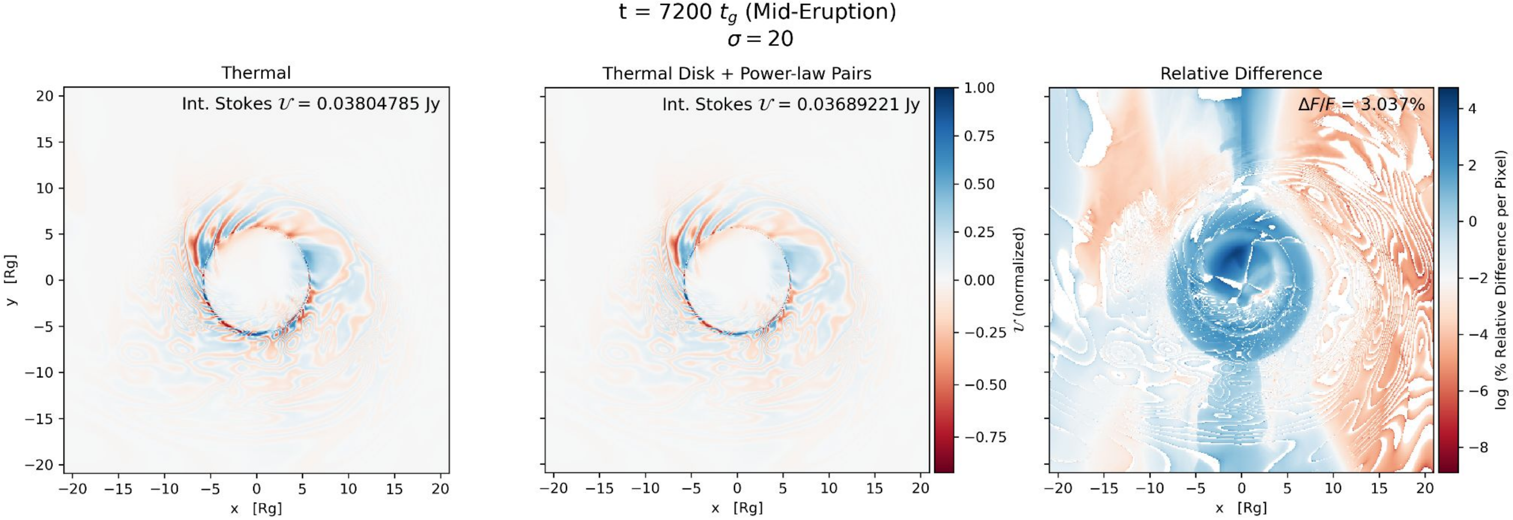


t = 7200 t_g (Mid-Eruption)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{Q}$ = -0.10456388 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{Q}$ = -0.09601834 Jy
$\mathcal{Q}$ (normalized)
Relative Difference
$\Delta F/F$ = 8.173%
log (% Relative Difference per Pixel)
x [Rg]
y [Rg]

Stokes *U*

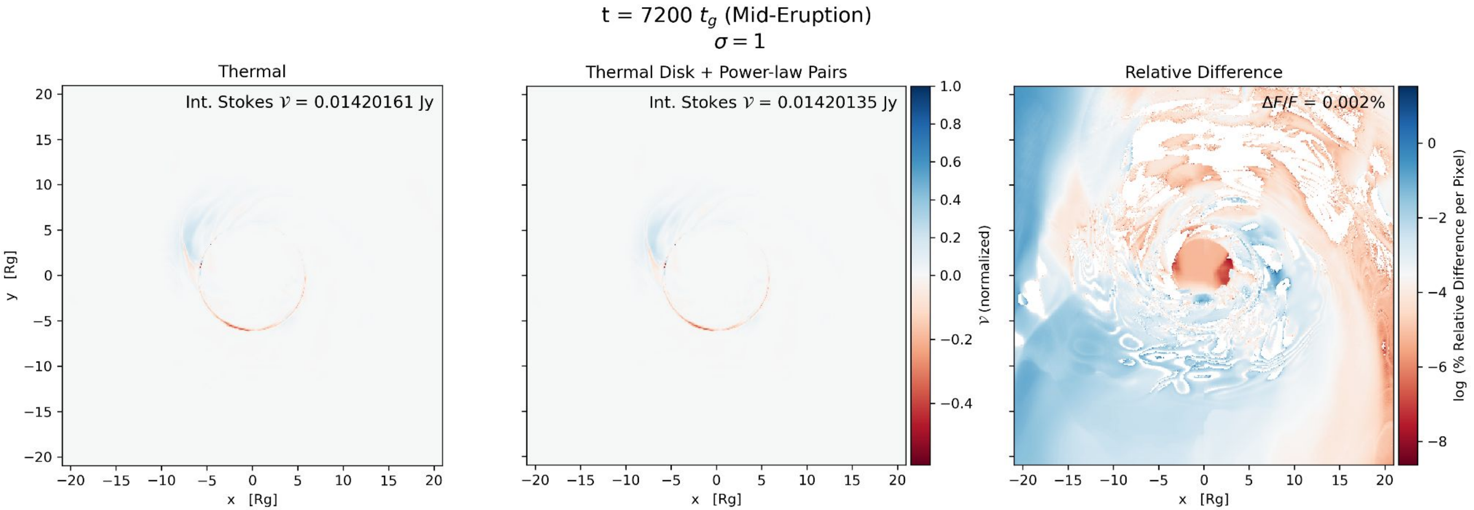


t = 7200 t_g (Mid-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{U}$ = 0.01669674 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{U}$ = 0.01669791 Jy
Relative Difference
$\Delta F/F$ = -0.007%
y [Rg]
x [Rg]
$\mathcal{U}$ (normalized)
log (% Relative Difference per Pixel)

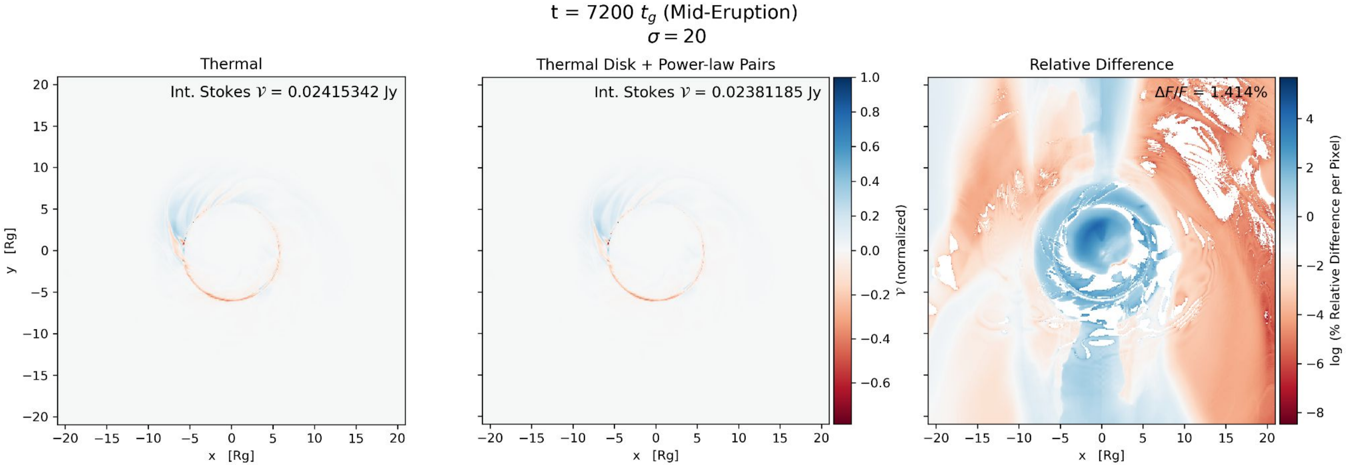


t = 7200 t_g (Mid-Eruption)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{U}$ = 0.03804785 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{U}$ = 0.03689221 Jy
Relative Difference
$\Delta F/F$ = 3.037%
y [Rg]
x [Rg]
$\mathcal{U}$ (normalized)
log (% Relative Difference per Pixel)

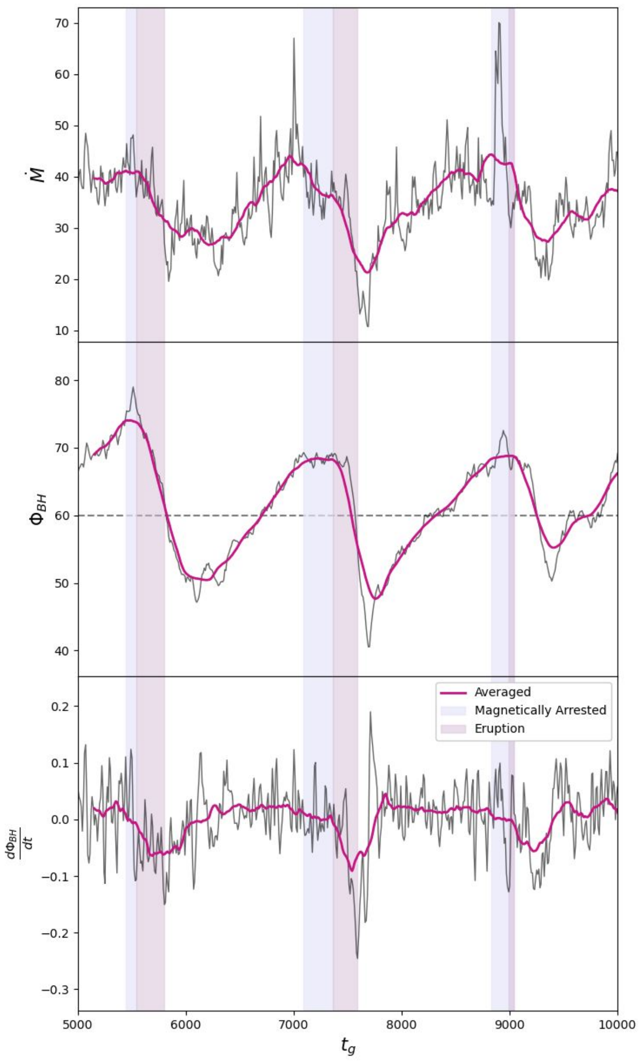
Stokes *V*



t = 7200 t_g (Mid-Eruption)
$\sigma = 1$
Thermal
Int. Stokes $\mathcal{V}$ = 0.01420161 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{V}$ = 0.01420135 Jy
Relative Difference
$\Delta F/F$ = 0.002%
y [Rg]
x [Rg]
$\mathcal{V}$ (normalized)
log (% Relative Difference per Pixel)



t = 7200 t_g (Mid-Eruption)
$\sigma = 20$
Thermal
Int. Stokes $\mathcal{V}$ = 0.02415342 Jy
Thermal Disk + Power-law Pairs
Int. Stokes $\mathcal{V}$ = 0.02381185 Jy
Relative Difference
$\Delta F/F$ = 1.414%
y [Rg]
x [Rg]
$\mathcal{V}$ (normalized)
log (% Relative Difference per Pixel)


$\dot{M}$
Φ_{BH}
$\frac{d\Phi_{BH}}{dt}$
Averaged
Magnetically Arrested
Eruption
t_g