# Ray-Tracing in Relativistic Jet Simulations

## Circular Polarization

Joana Kramer

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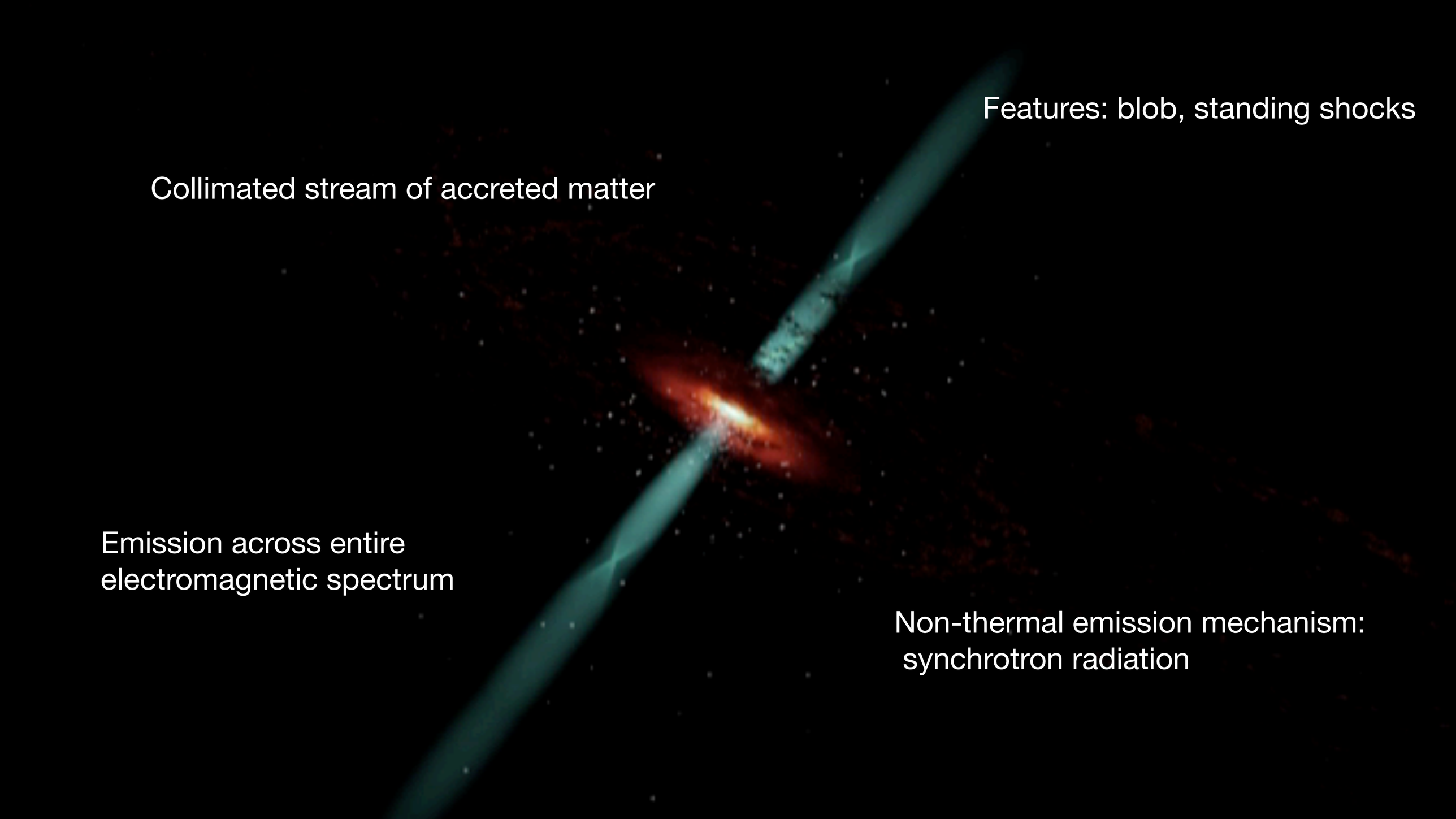
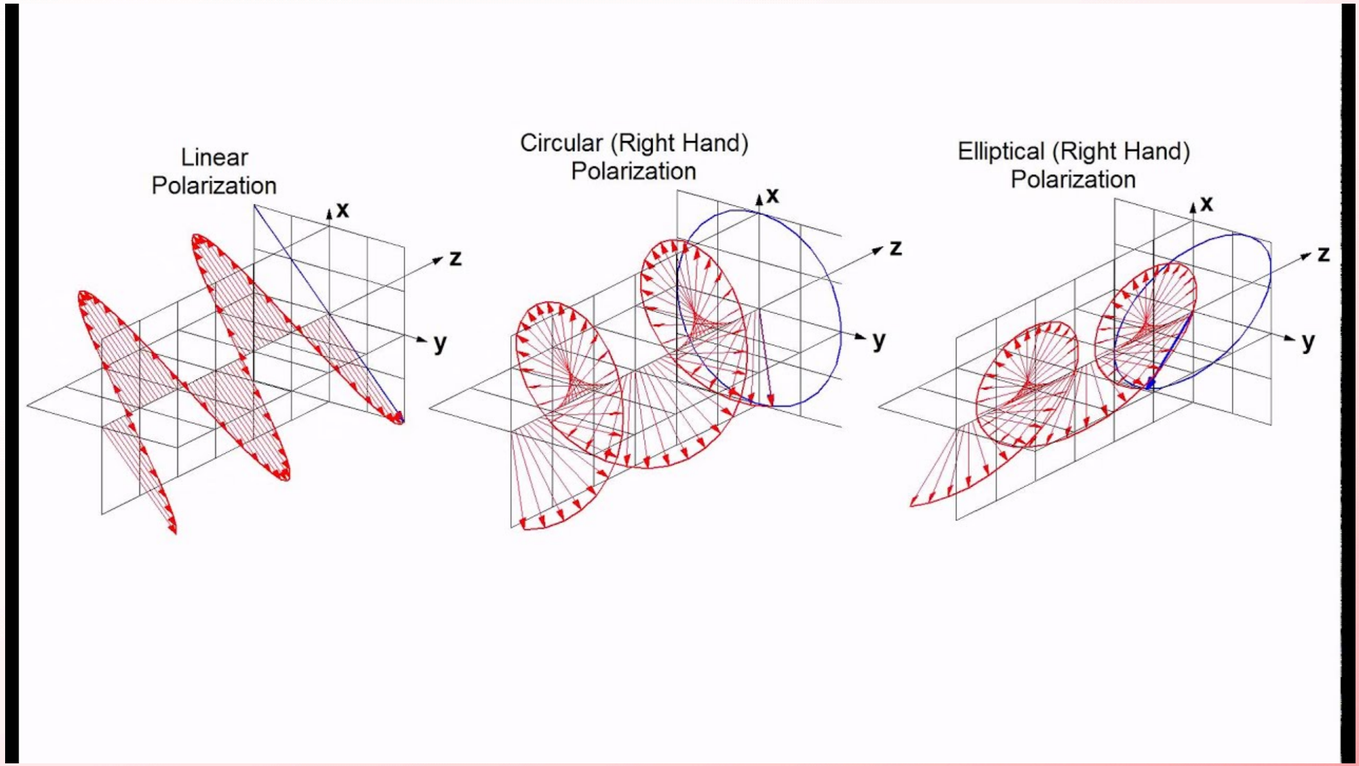
*15th EVN Symposium & Users Meeting:*
*Providing the Sharpest View of the Universe*
*University College Cork, Ireland*
*July 11-15, 2022*


Features: blob, standing shocks
Collimated stream of accreted matter
Emission across entire
electromagnetic spectrum
Non-thermal emission mechanism:
synchrotron radiation

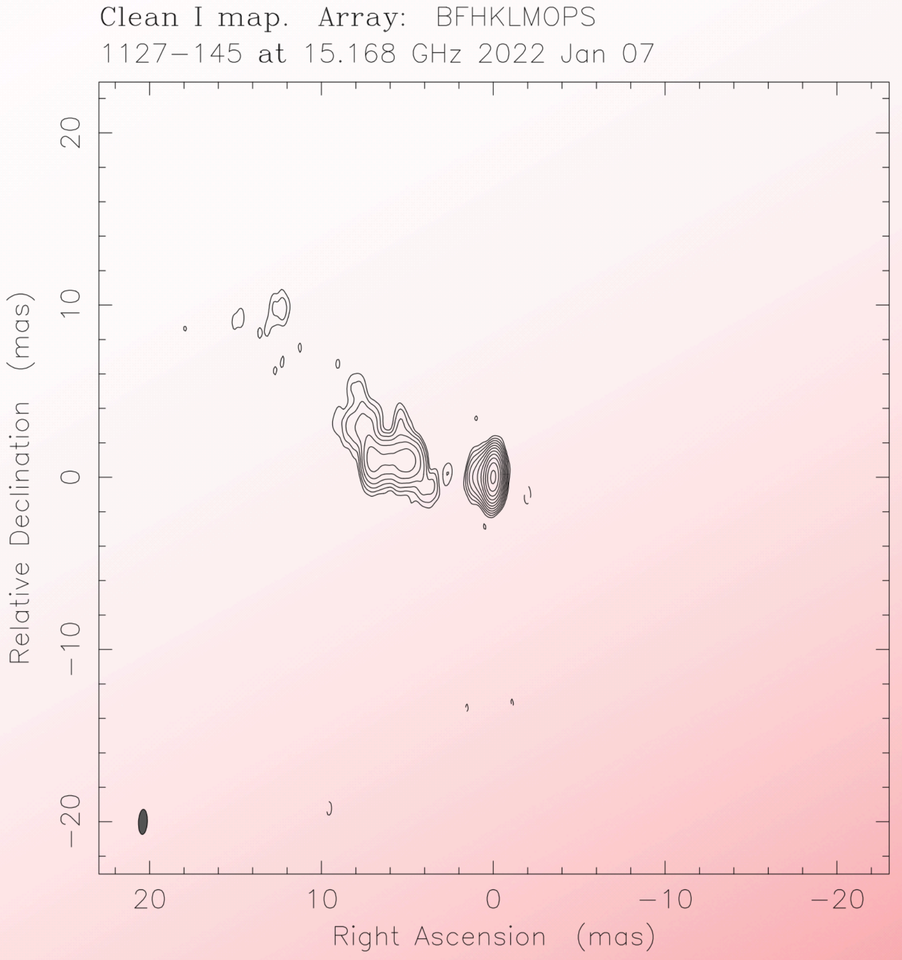
# Polarization



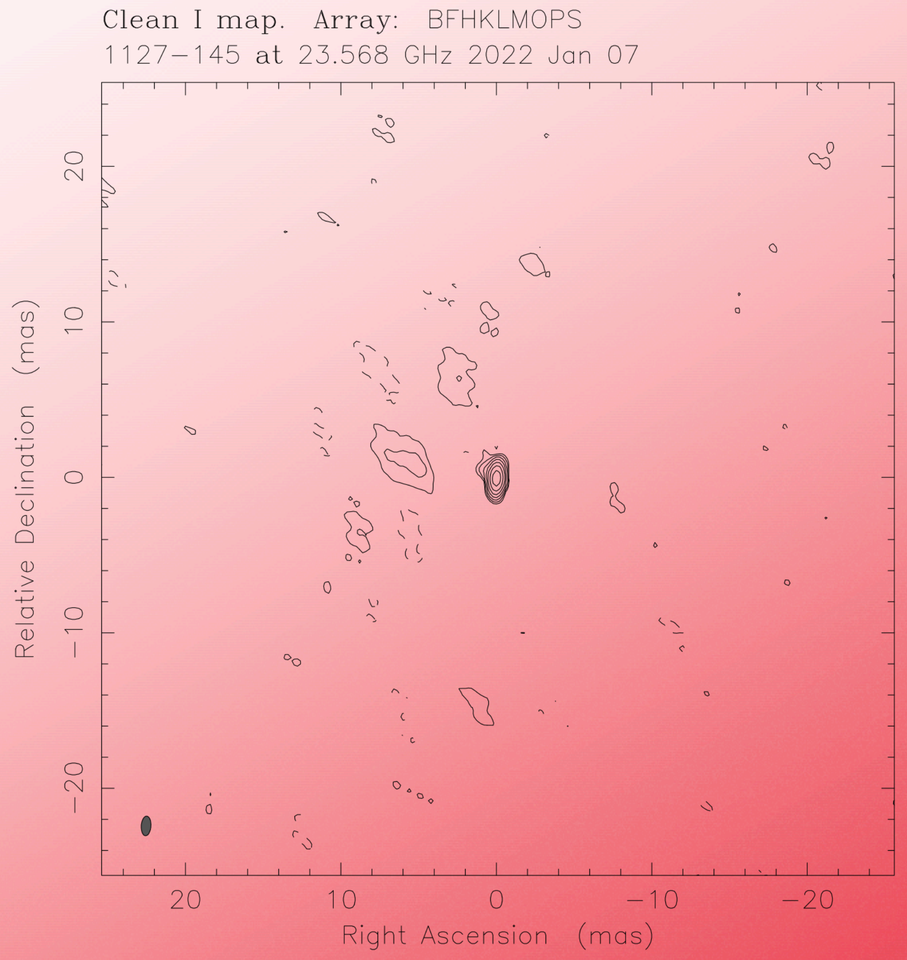

- Circular polarization
  - Insights on Magnetic field orientation in blazer jets
  - Nature of jet's plasma composition

$$m_c = -\frac{V}{I}$$

# The beginning: Stokes I



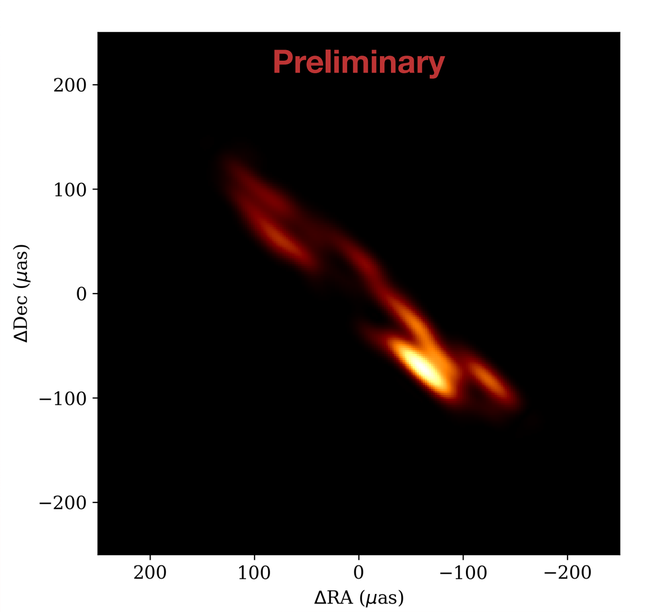

Map center: RA: 11 30 07.053, Dec: −14 49 27.388 (2000.0)
Map peak: 1.49 Jy/beam
Contours %: −0.08 0.08 0.16 0.32 0.64 1.28 2.56
Contours %: 5.12 10.2 20.5 41 81.9
Beam FWHM: 1.46 x 0.515 (mas) at −2.89°




Map center: RA: 11 30 07.053, Dec: −14 49 27.388 (2000.0)
Map peak: 1.27 Jy/beam
Contours %: −1 1 2 4 8 16 32 64
Beam FWHM: 1.26 x 0.625 (mas) at −3.82°

# Stokes I overplotted with EVPAs

Polarized image of Cen A

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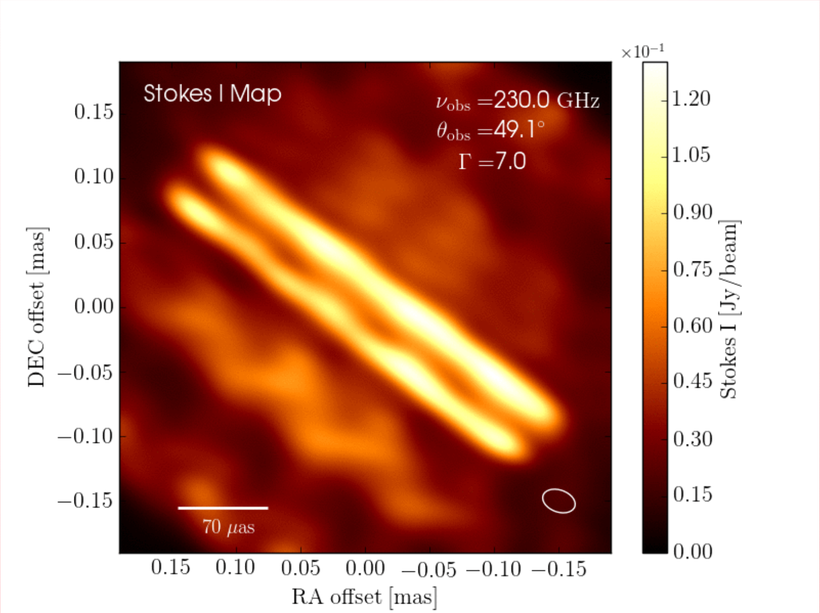


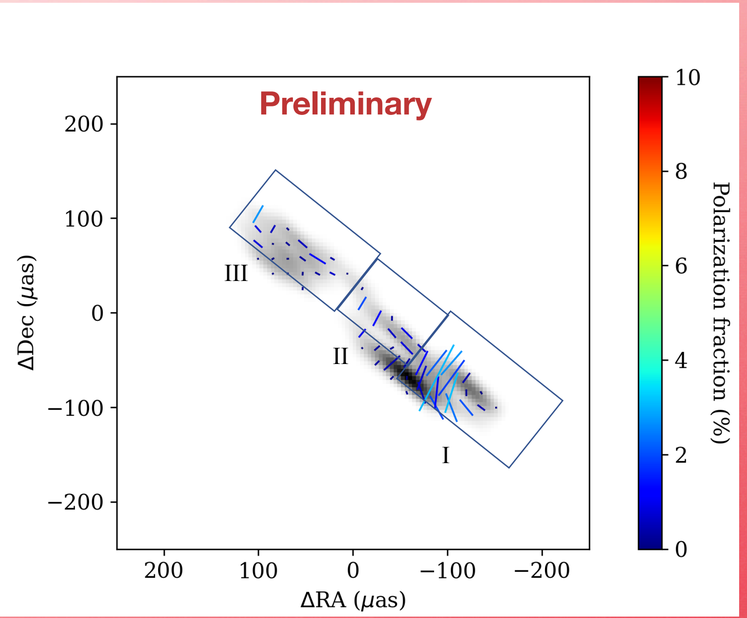


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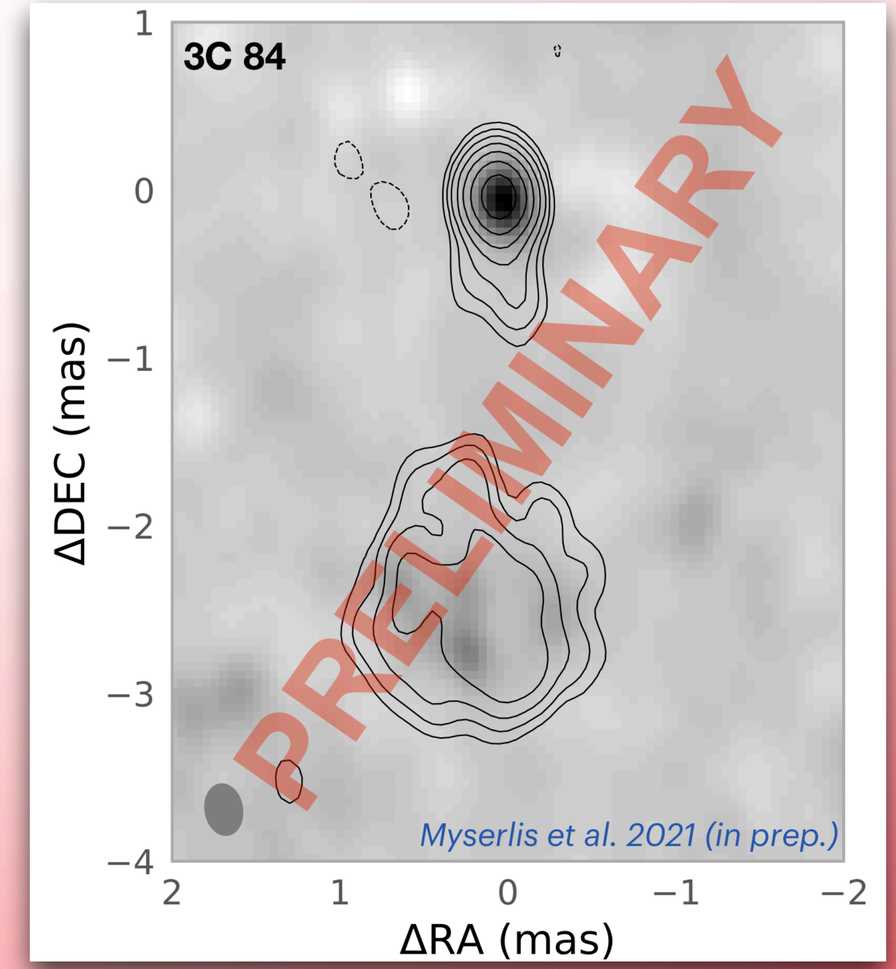
# Final Step: Stokes V



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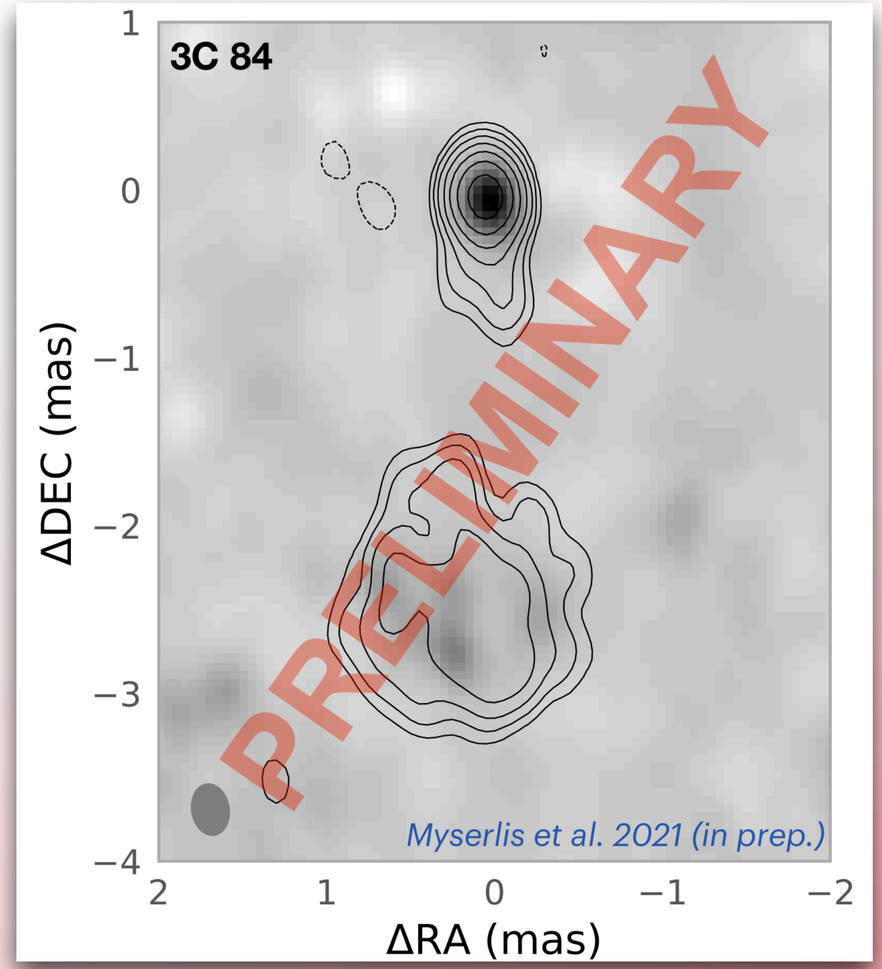
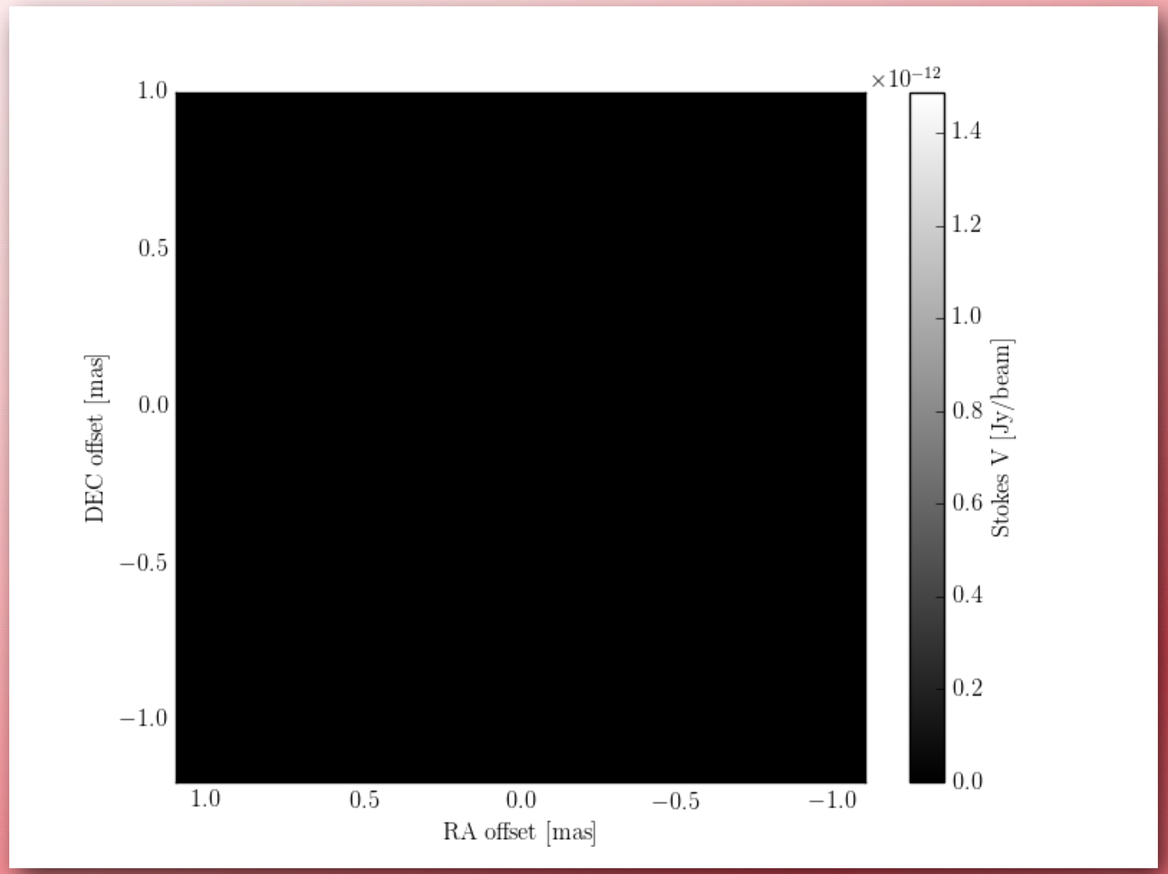
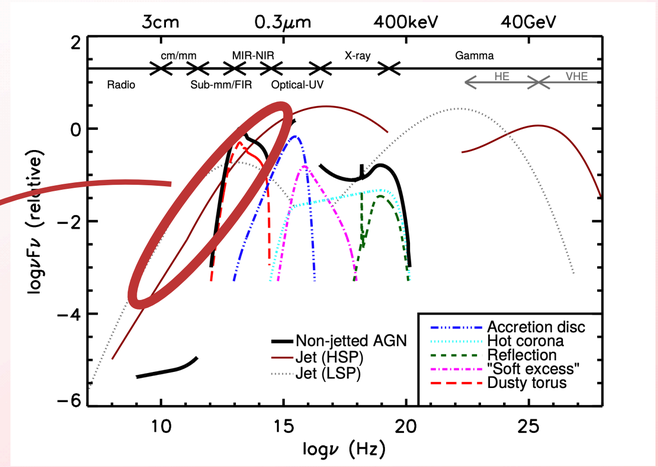


# Ray-Tracing in Relativistic Jet Simulations



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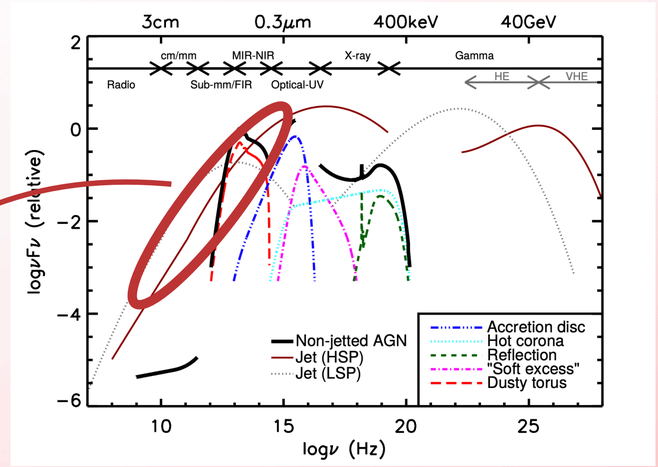


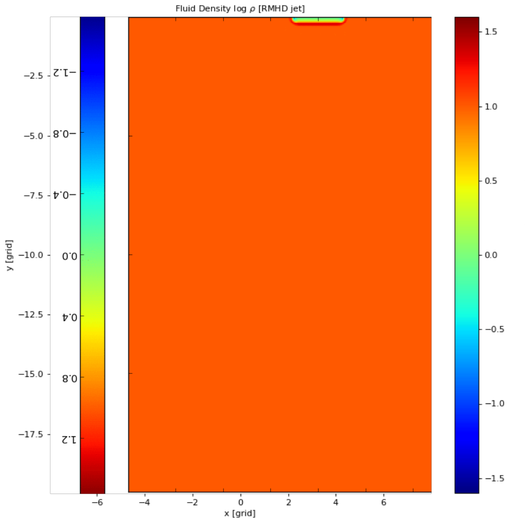


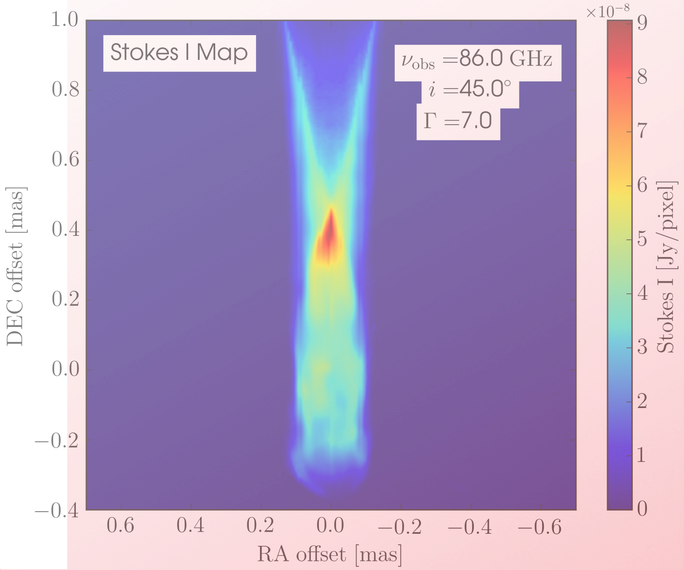


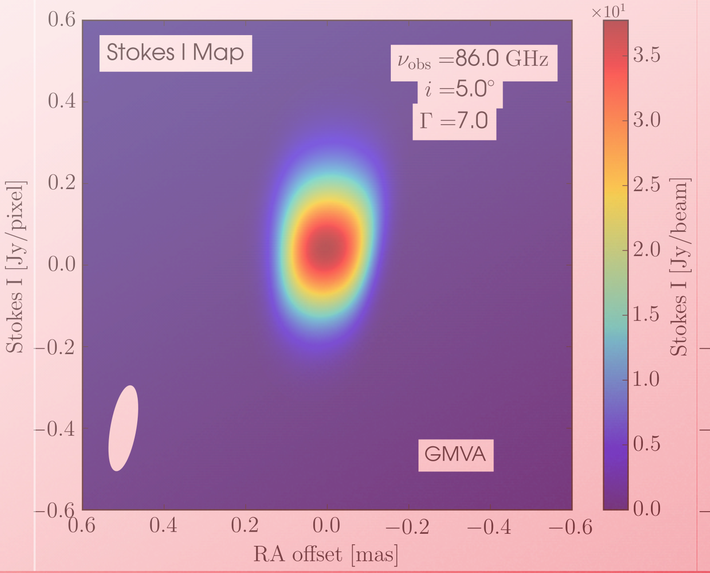


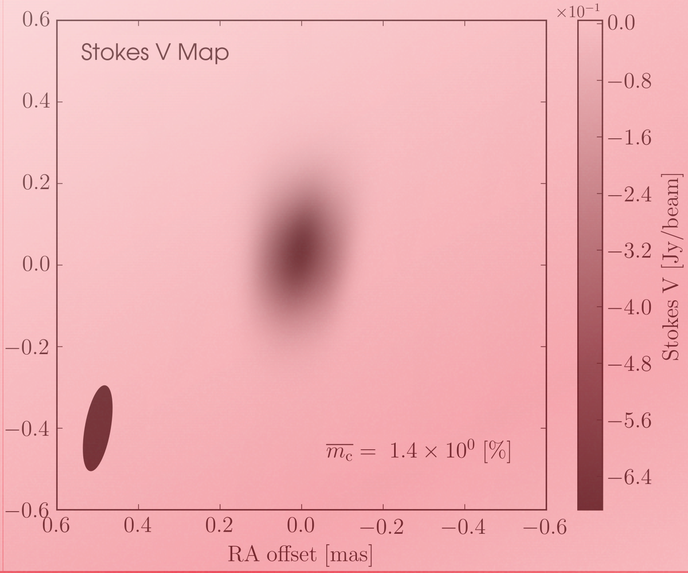




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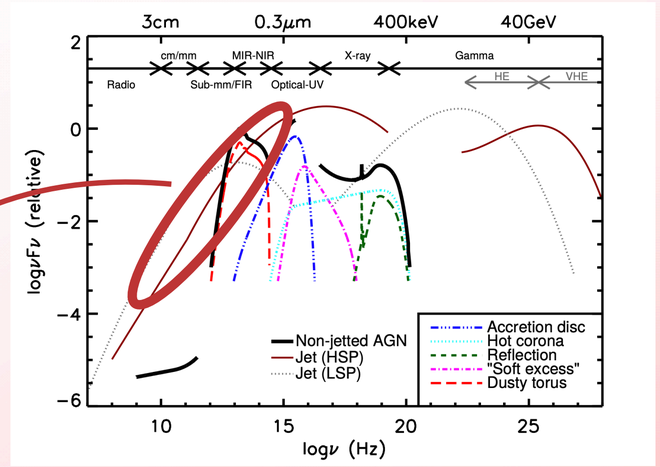


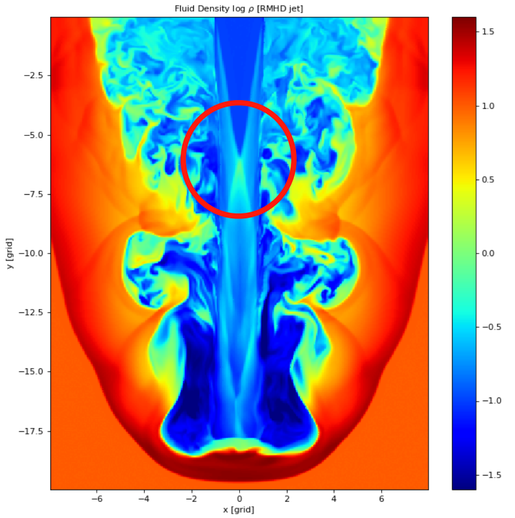


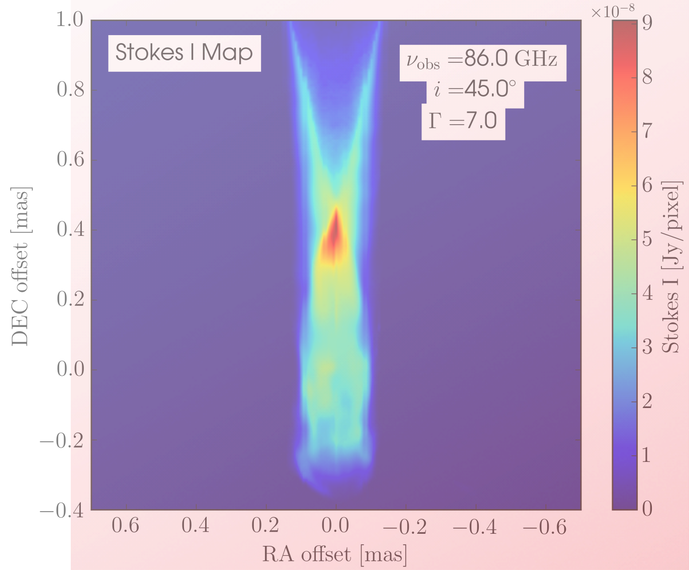


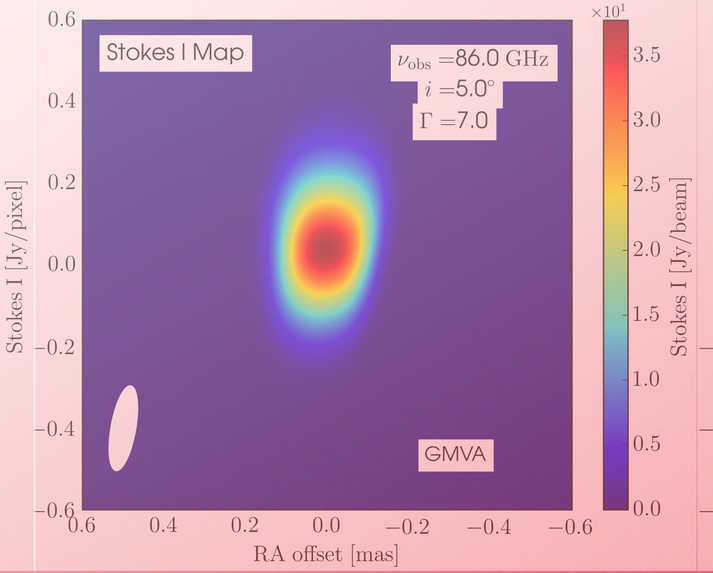


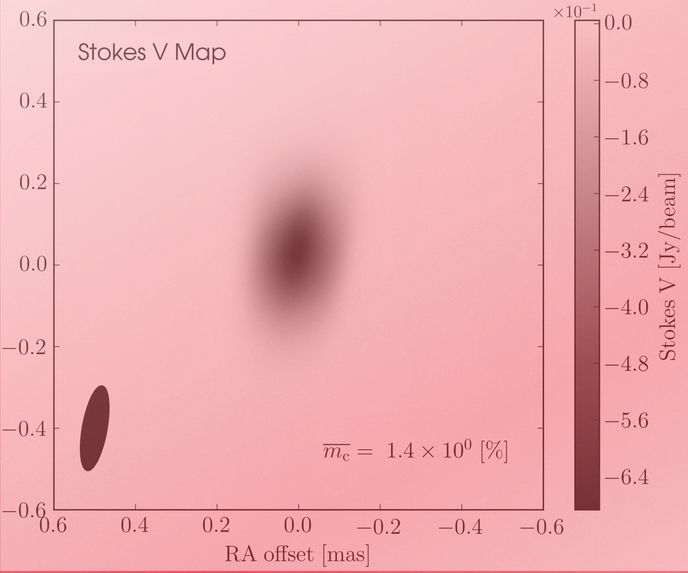




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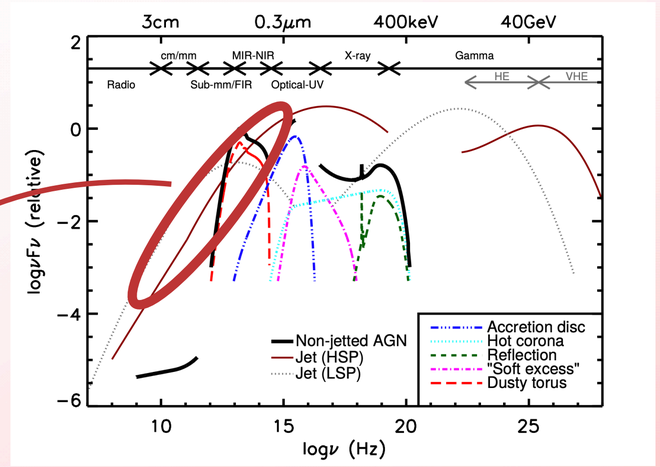
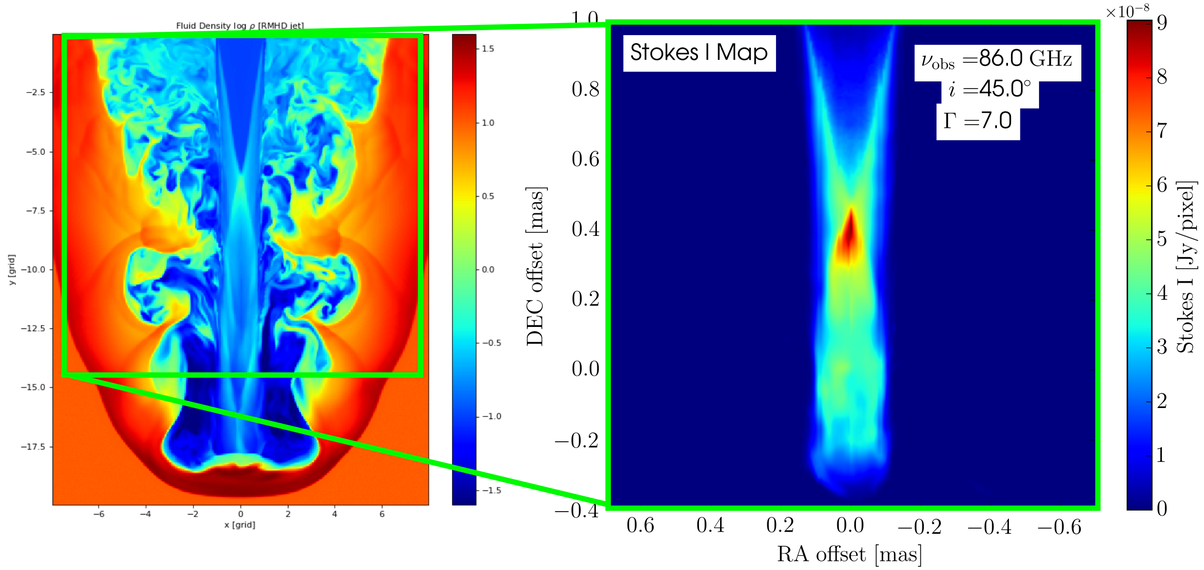
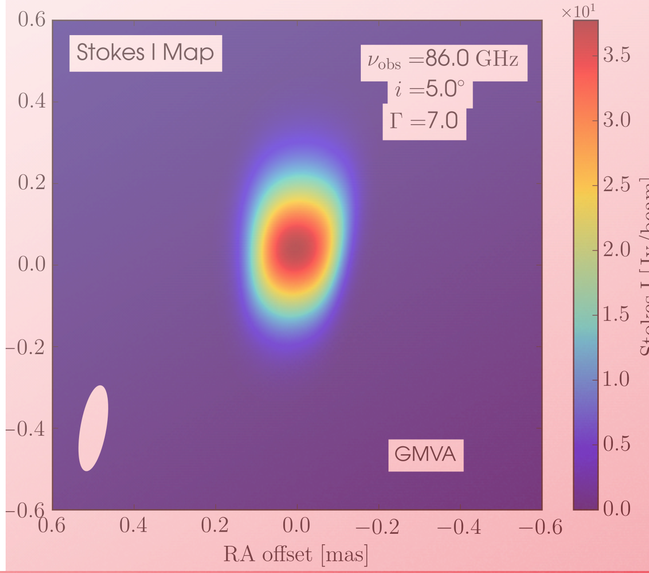
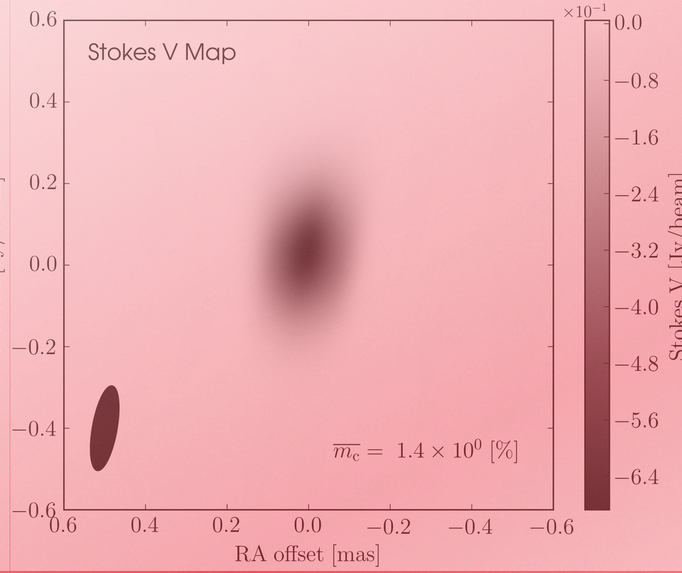
# Ray-Tracing in Relativistic Jet Simulations

$$n_e(\gamma) = n_0 \left( \frac{\gamma}{\gamma_{\min}} \right)^{-s}$$




plasma density, pressure, & magnetic energy density (PLUTO) ⟷ Electron number density & power-law cut-off (RADMC-3D)



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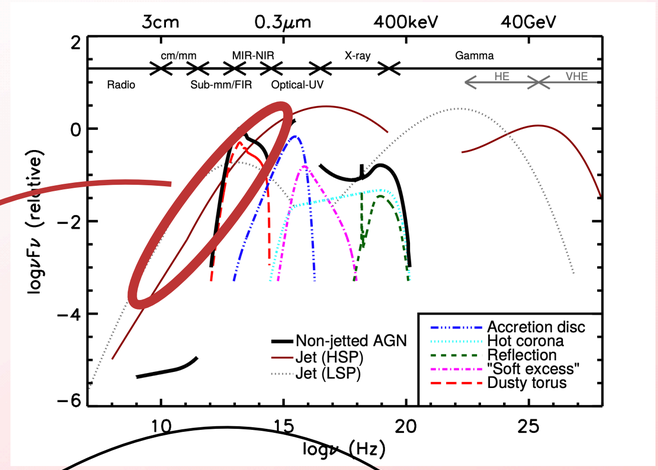


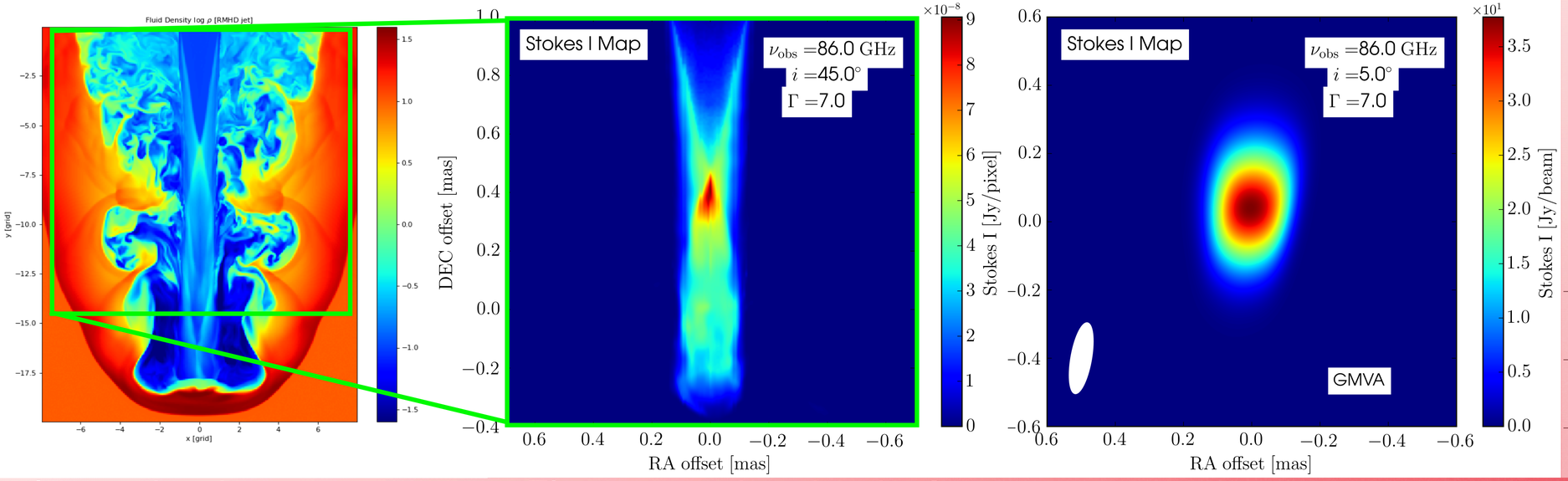


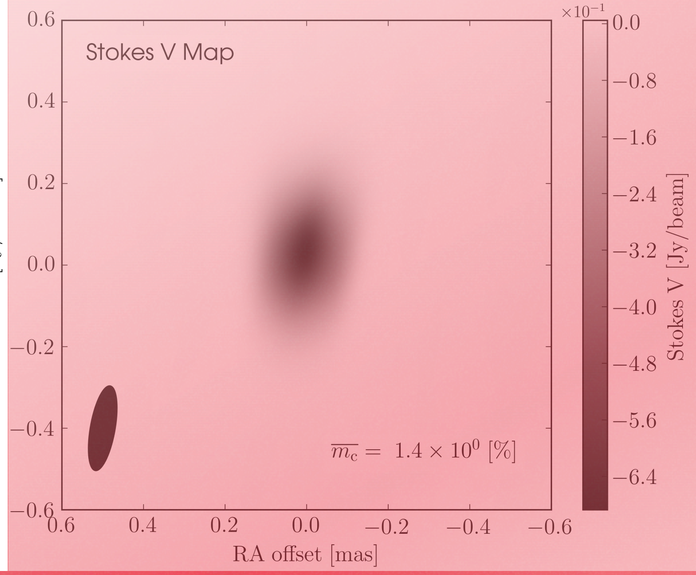


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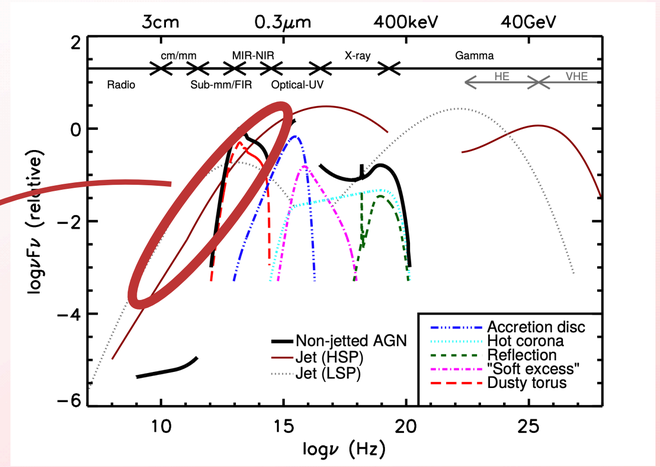


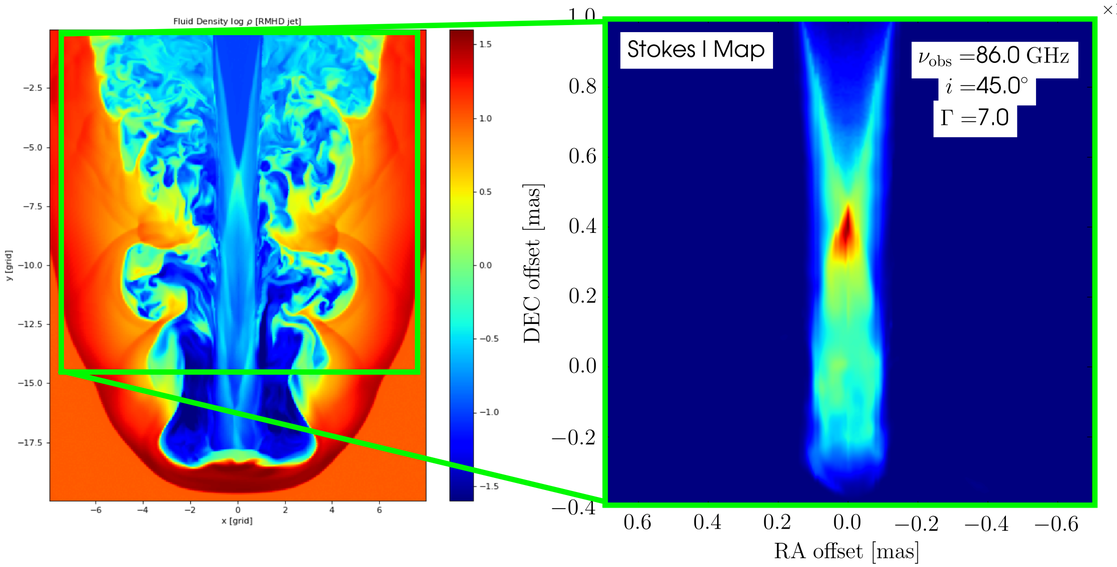





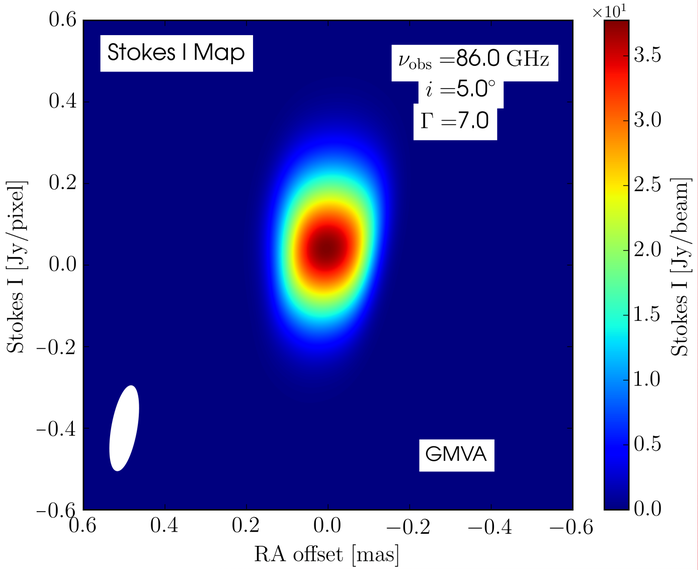


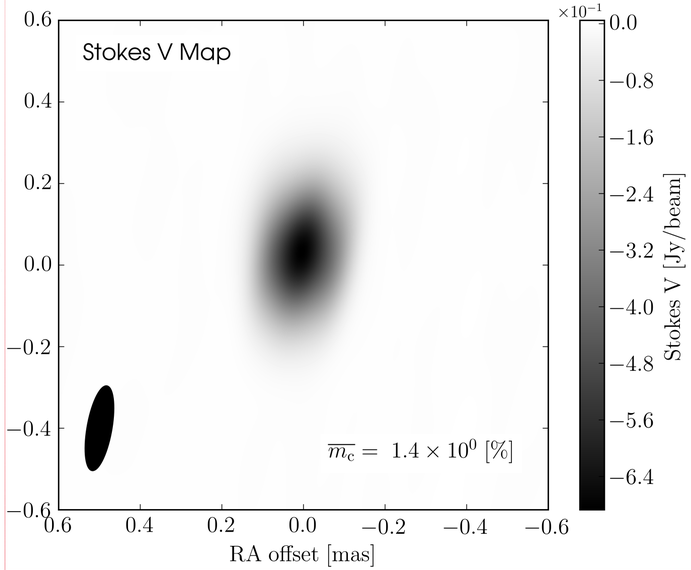


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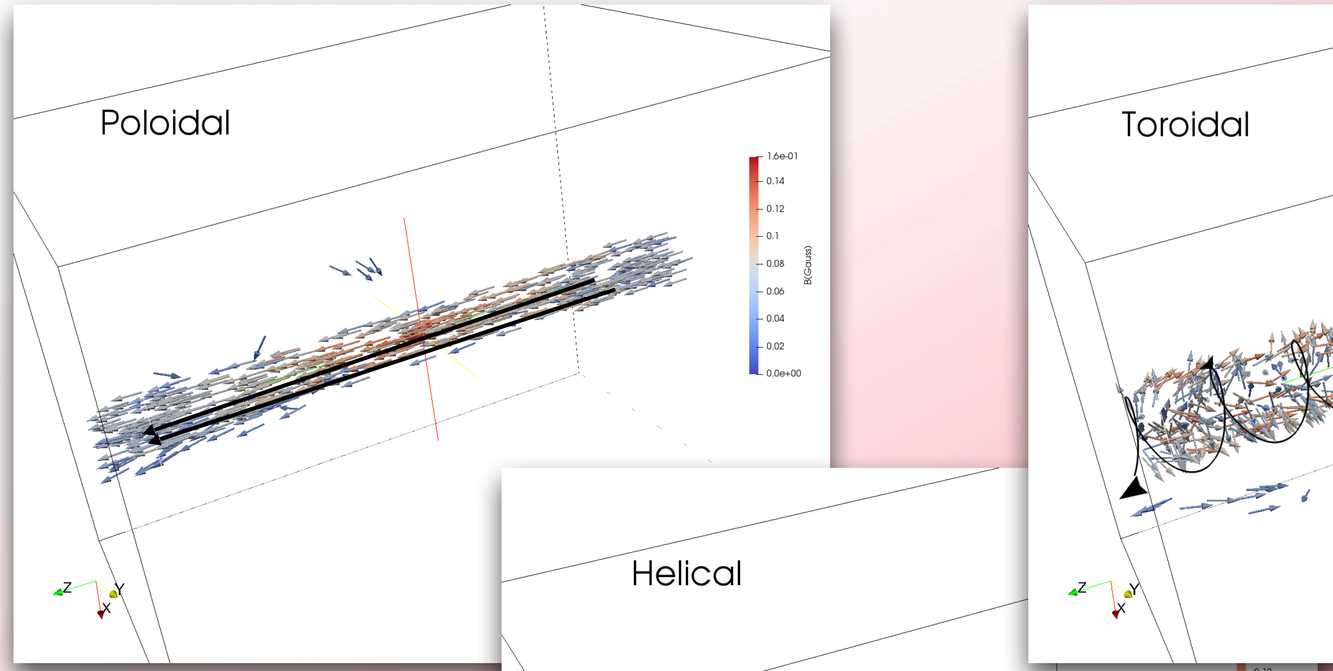
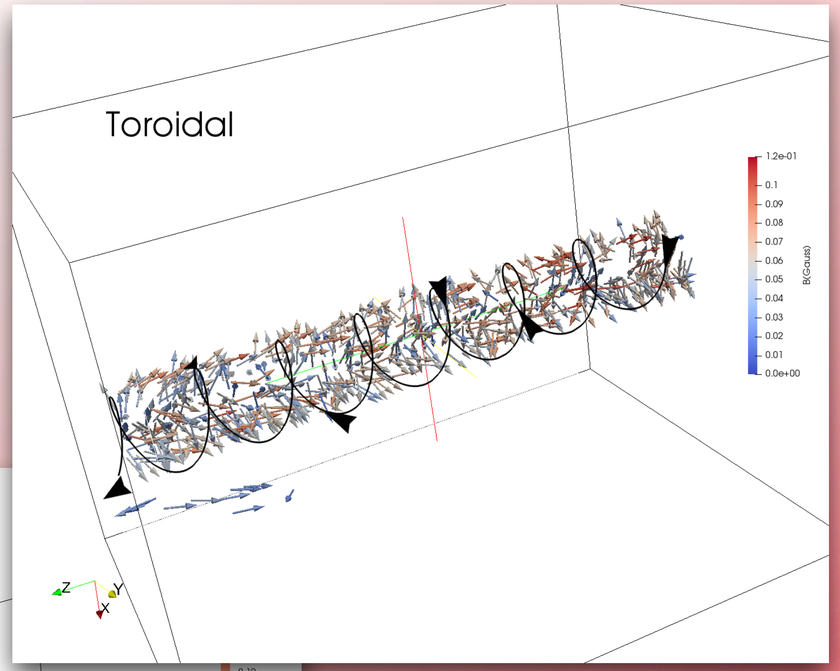
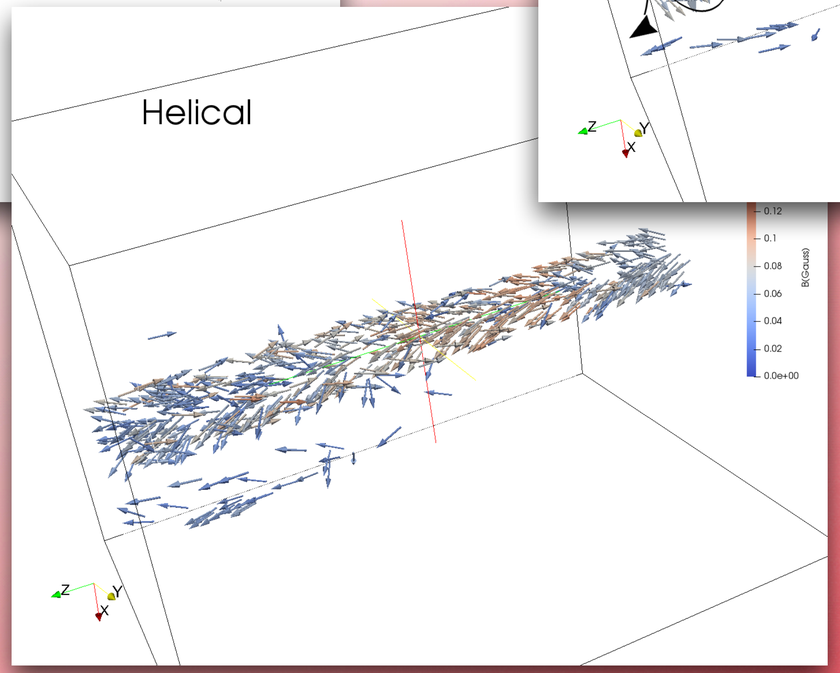
# Magnetic Field Morphology Study




Kramer, J. A. and MacDonald, N. R.,
“Ray-tracing in relativistic jet simulations: A polarimetric study of magnetic field morphology and electron scaling relations”,
Astronomy and Astrophysics, vol. 656, 2021. doi:10.1051/0004-6361/202141454.

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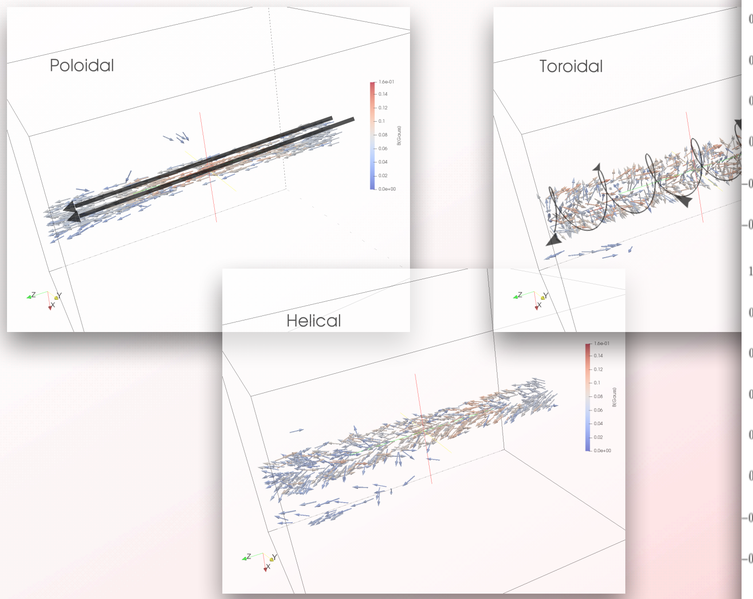


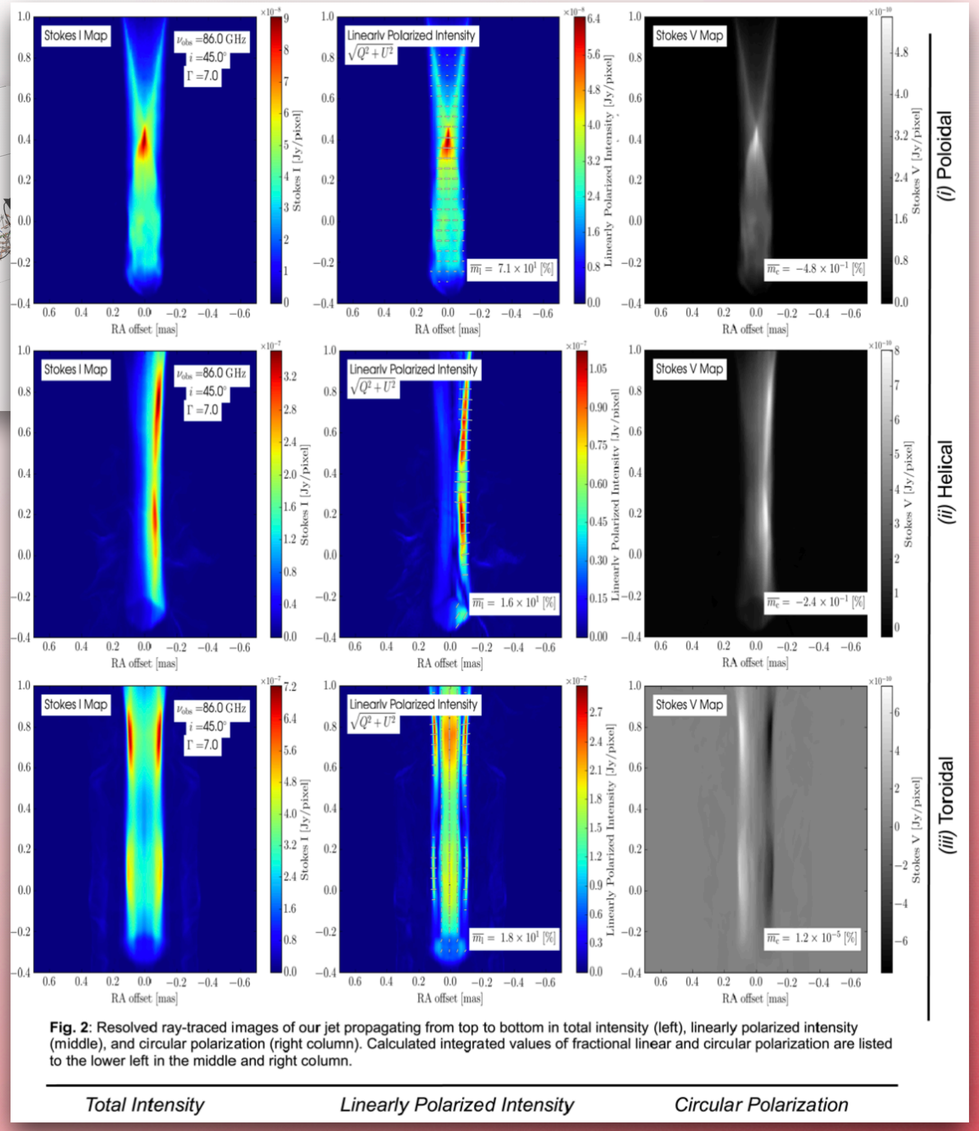


**Fig. 2**: Resolved ray-traced images of our jet propagating from top to bottom in total intensity (left), linearly polarized intensity (middle), and circular polarization (right column). Calculated integrated values of fractional linear and circular polarization are listed to the lower left in the middle and right column.

$$n_e(\gamma) = n_0 \left(\frac{\gamma}{\gamma_{\min}}\right)^{-s}$$

$$\int_{\gamma_{\min}}^{\gamma_{\max}} d\gamma n_e(\gamma) = \frac{\rho}{m_p}$$

$$\int_{\gamma_{\min}}^{\gamma_{\max}} d\gamma n_e(\gamma)\gamma m_e c^2 = \frac{p}{\left(\hat{\gamma} - 1\right)}$$

$$\int_{\gamma_{\min}}^{\gamma_{\max}} d\gamma n_e(\gamma)\gamma m_e c^2 = \epsilon_B \frac{B^2}{8\pi\left(\hat{\gamma} - 1\right)}$$



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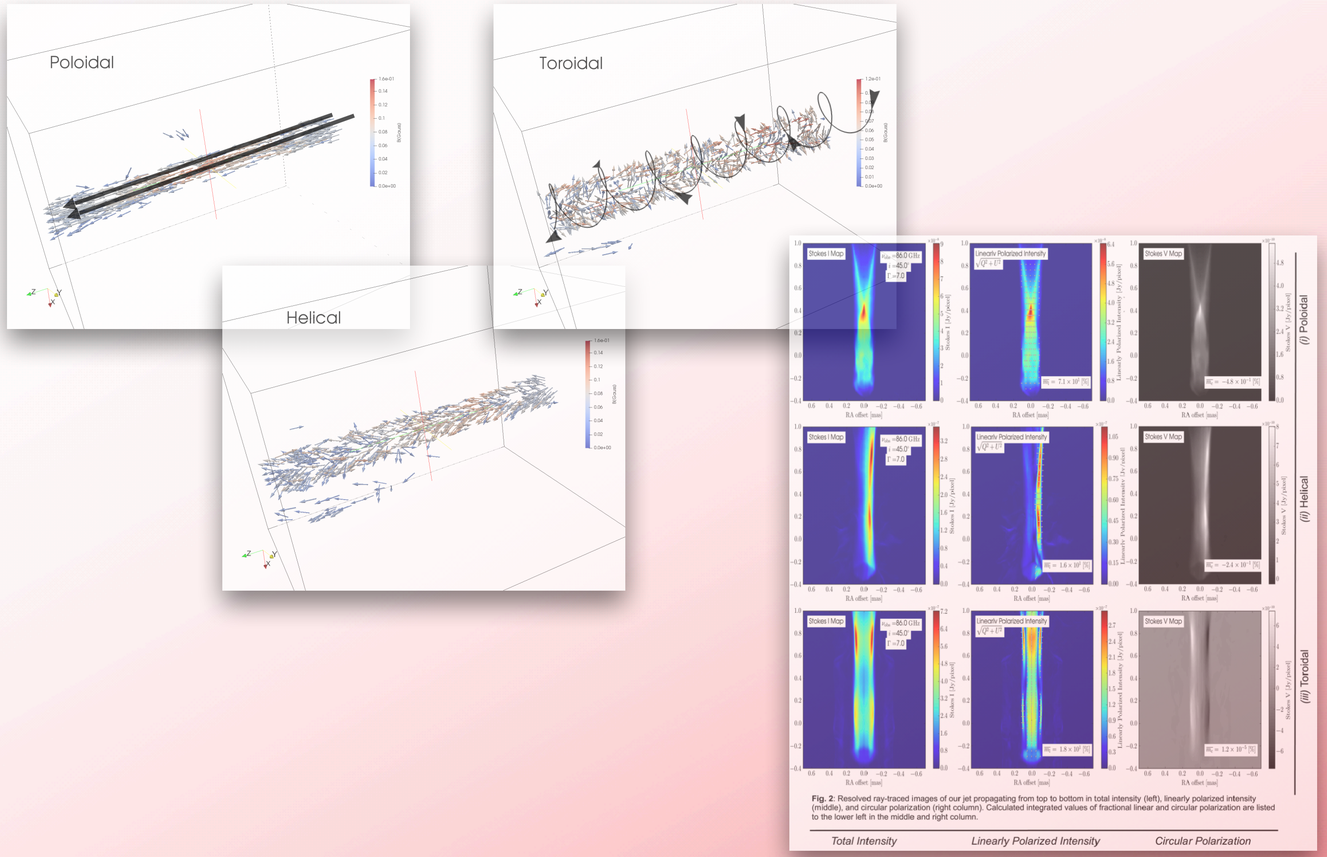





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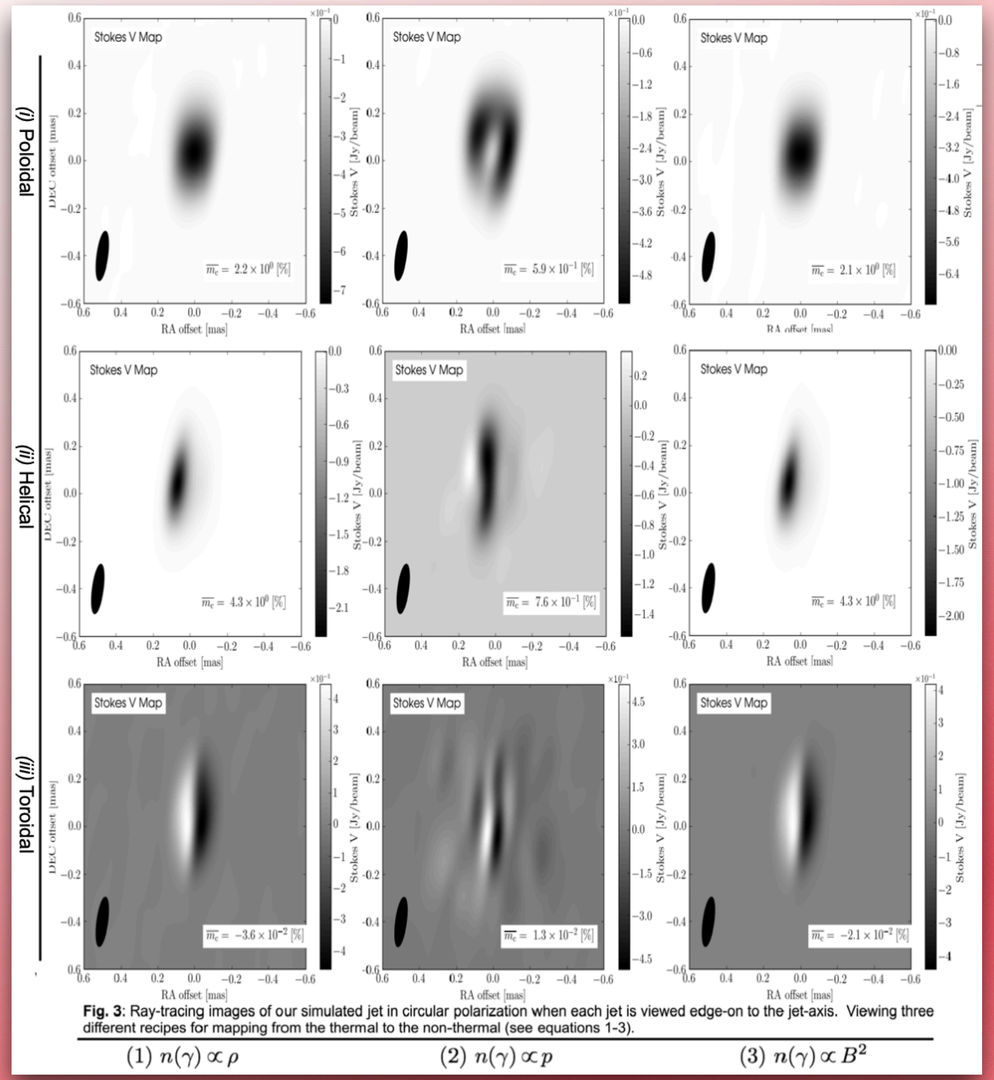


Fig. 3: Ray-tracing images of our simulated jet in circular polarization when each jet is viewed edge-on to the jet-axis. Viewing three different recipes for mapping from the thermal to the non-thermal (see equations 1-3).

(1) $n(\gamma) \propto \rho$ (2) $n(\gamma) \propto p$ (3) $n(\gamma) \propto B^2$

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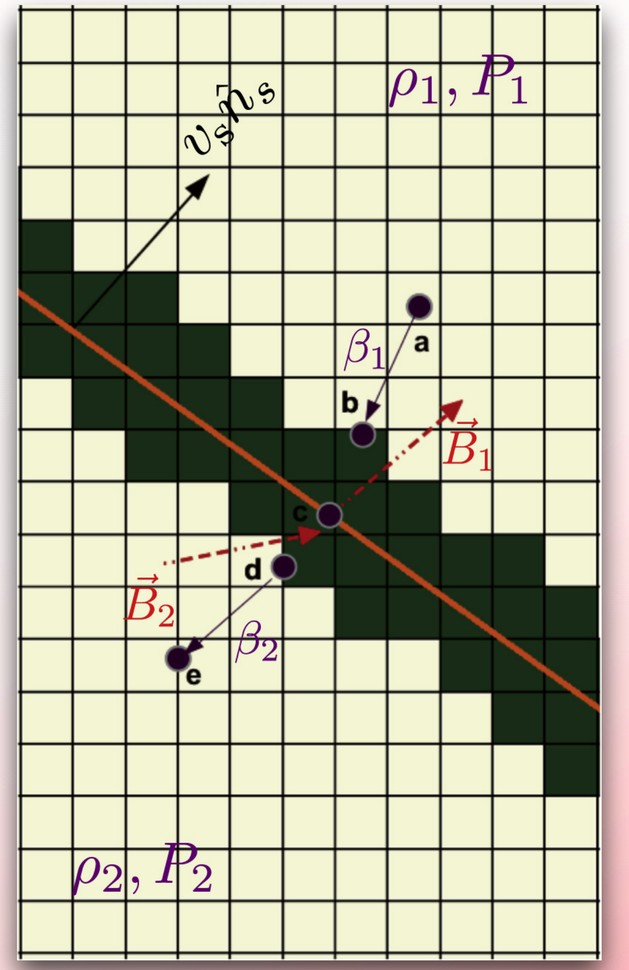
# Hybrid Fluid-Particle Jet Study




Vaidya et al. 2018

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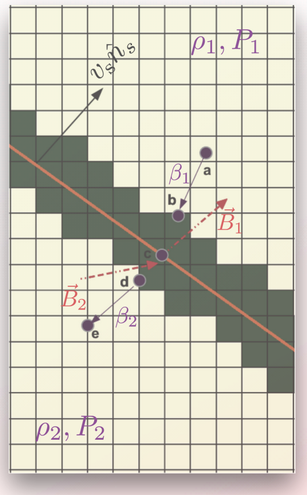


Vaidya et al. 2018

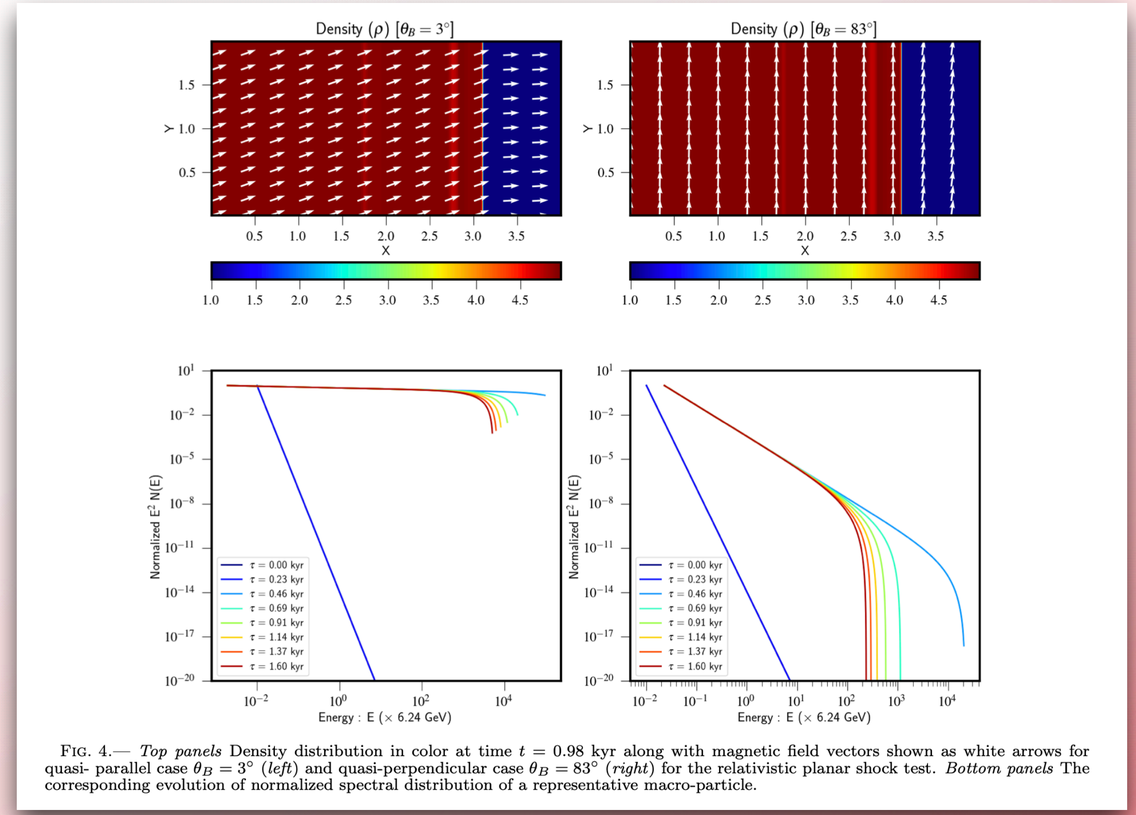


FIG. 4.— *Top panels* Density distribution in color at time $t = 0.98$ kyr along with magnetic field vectors shown as white arrows for quasi- parallel case $\theta_B = 3°$ (*left*) and quasi-perpendicular case $\theta_B = 83°$ (*right*) for the relativistic planar shock test. *Bottom panels* The corresponding evolution of normalized spectral distribution of a representative macro-particle.

Vaidya et al. 2018

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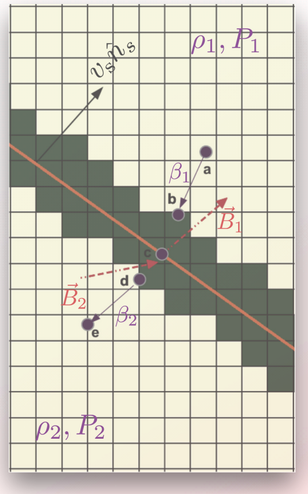


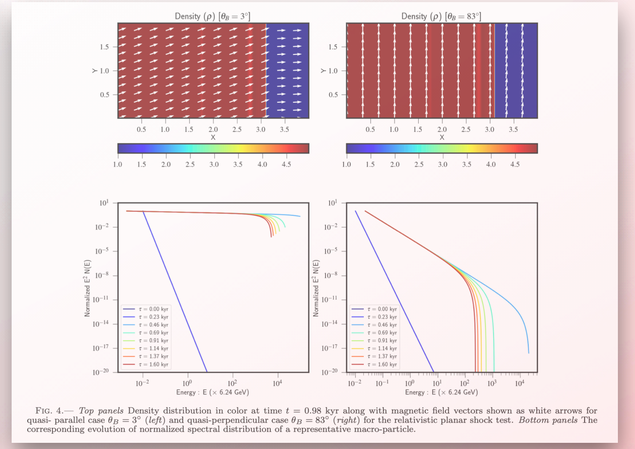


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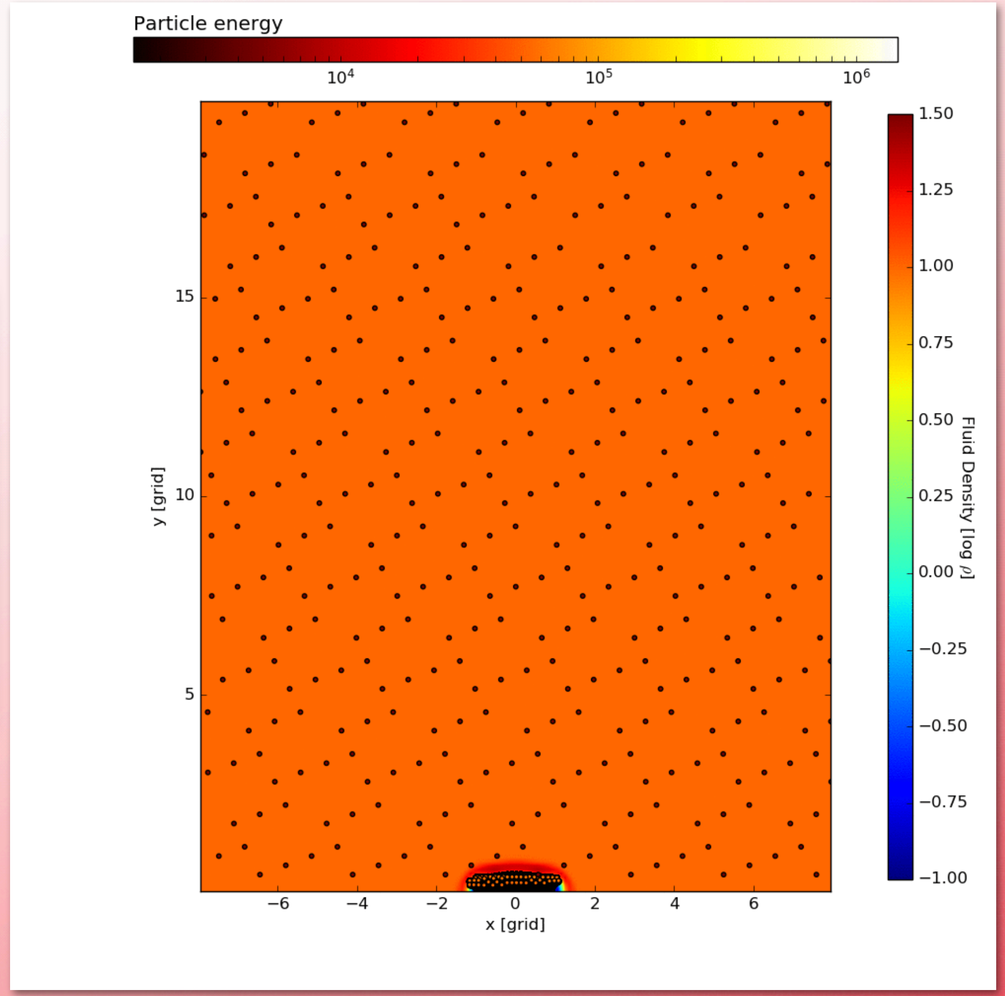

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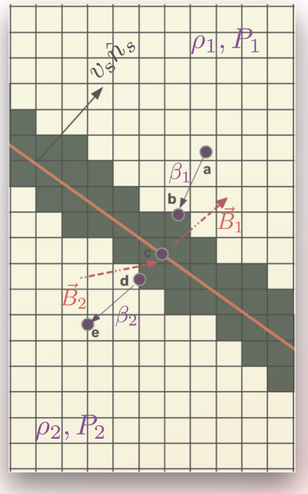
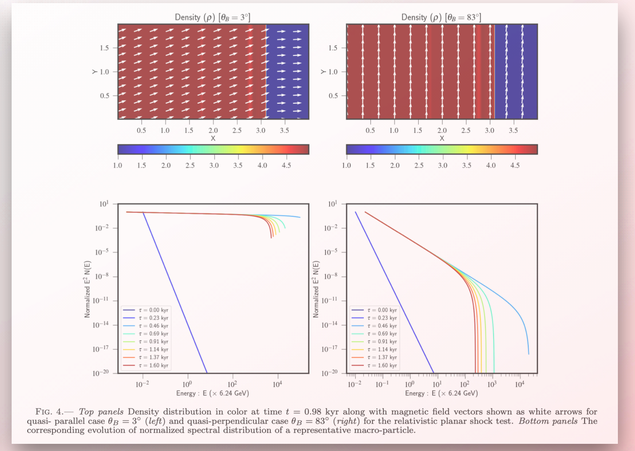



Vaidya et al. 2018

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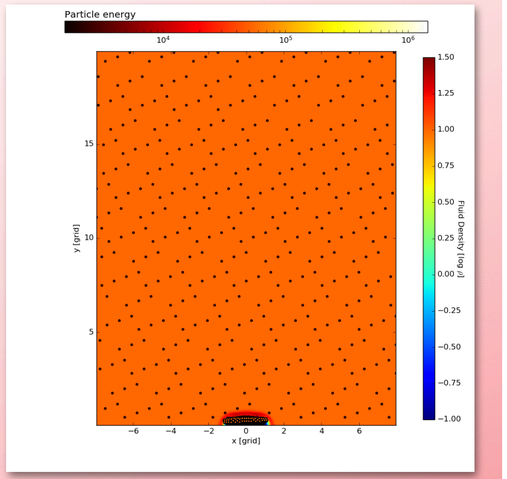
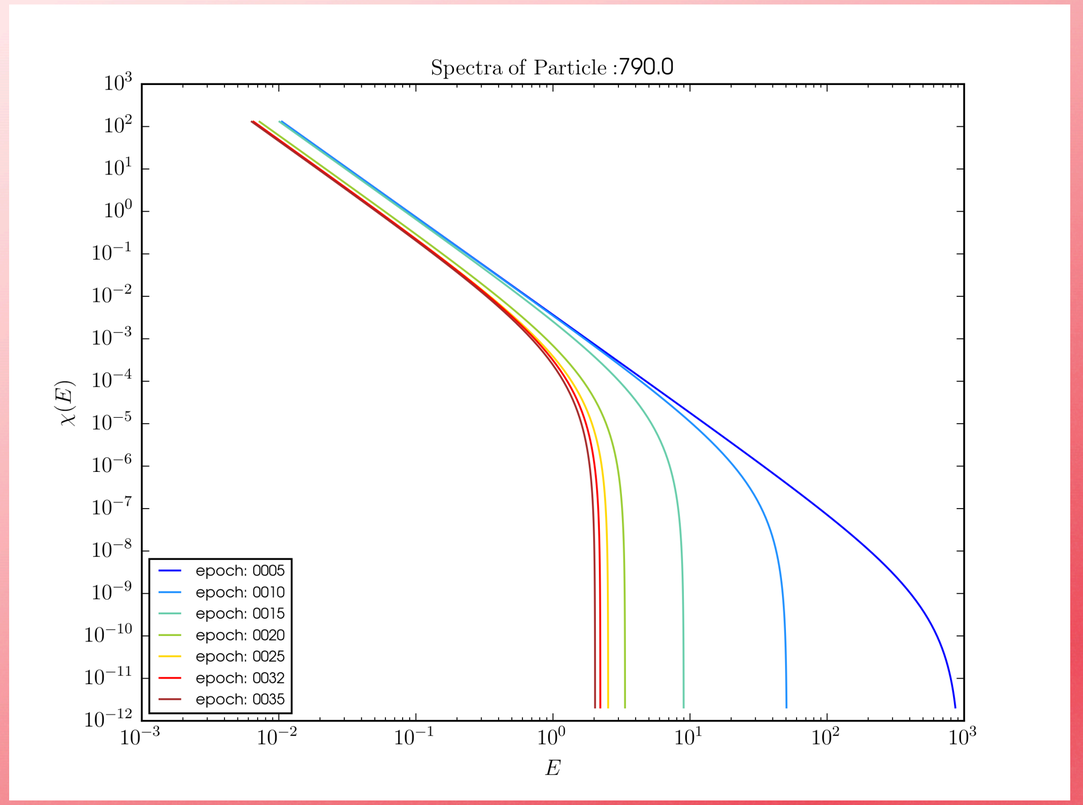
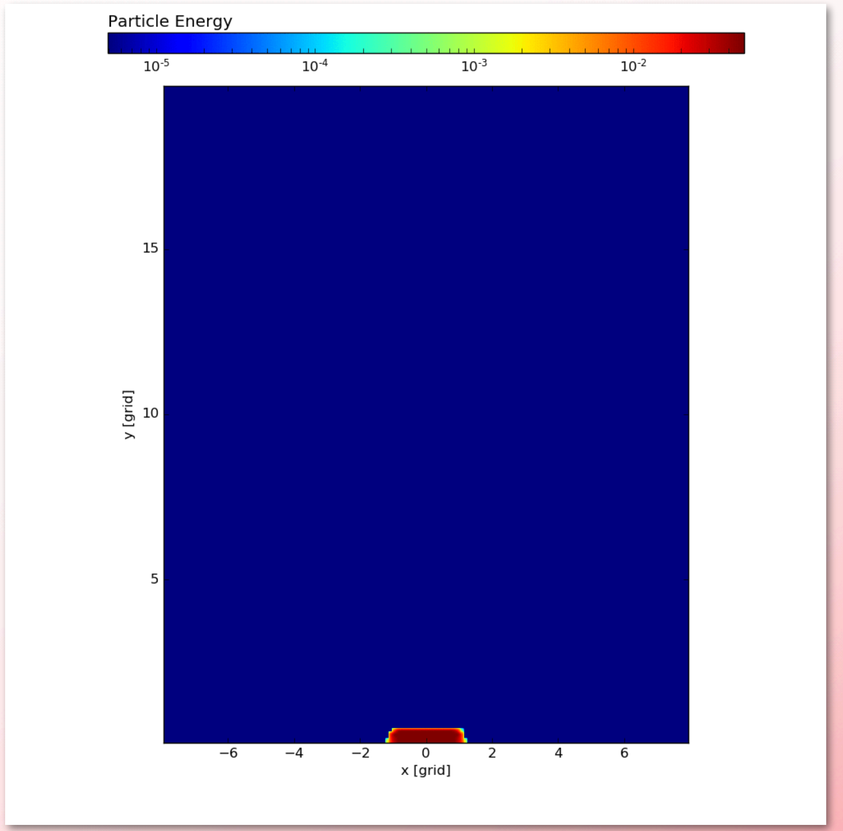
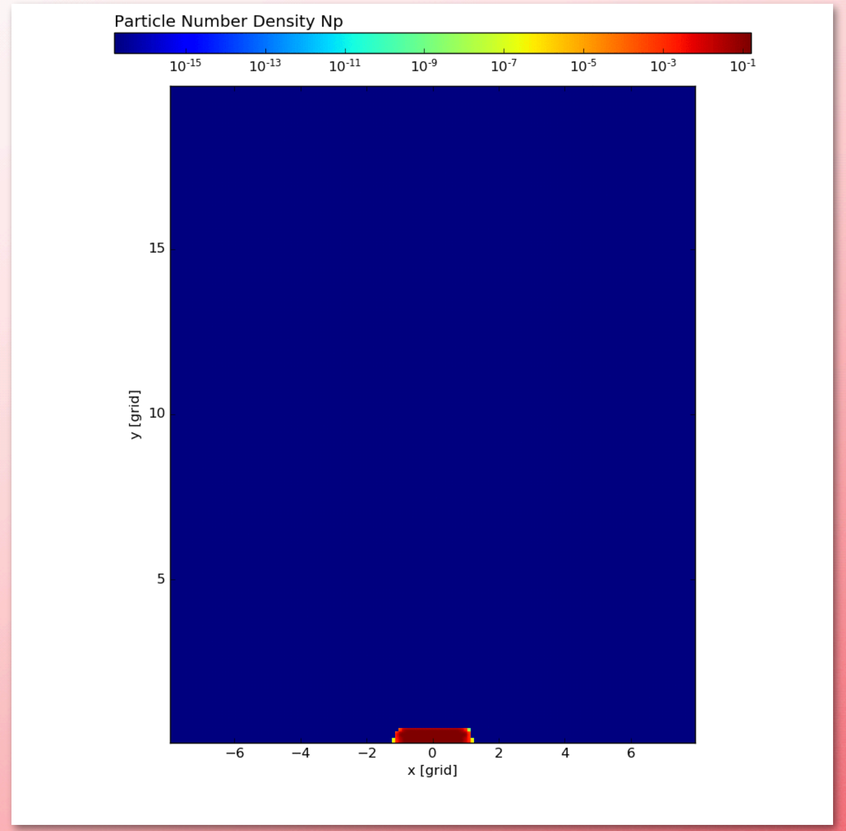


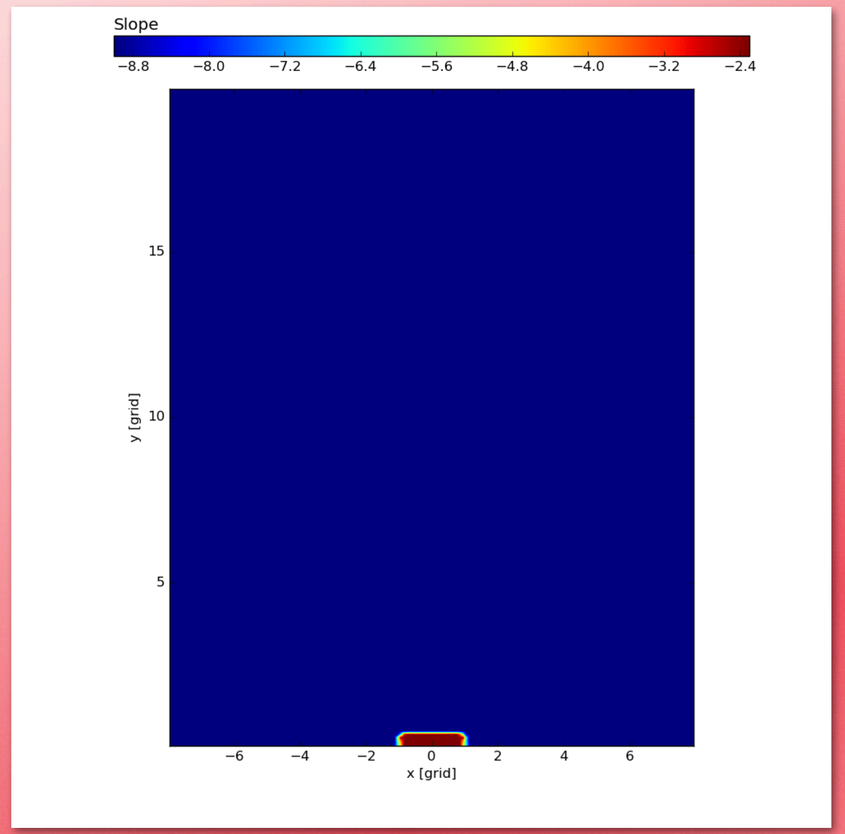

Vaidya et al. 2018



# Hybrid Fluid-Particle Jet Study



# Ray-Tracing in Relativistic Jet Simulations

## - Takeaway -

- We ♥ Circular polarization
  - Clear distinction in a purely poloidal vs. purely toroidal magnetic field

    How so?
  - Spine brightening vs. sheath brightening
  - Signs in CP
  - Bi-modal EVPA scattering

**Kramer & MacDonald 2021**
**Ray-tracing in relativistic jet simulations: A polarimetric study of magnetic field morphology and electron scaling relations**
**A&A 656, A143 (2021)**