Polarized emission from astrophysical jets: theory

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and BHC collaboration (ERC)

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Outline

- General Relativistic MHD models
- Modeling polarized radiation in GR
- Appearance of accreting black holes in polarized light
  - Linear (circular) polarization
  - Faraday rotation
- Other types of jets
- Summary

Class of sources discussed: Low Luminosity AGN

Ichimaru 1977
Narayan et al. 1994 **RIAF**

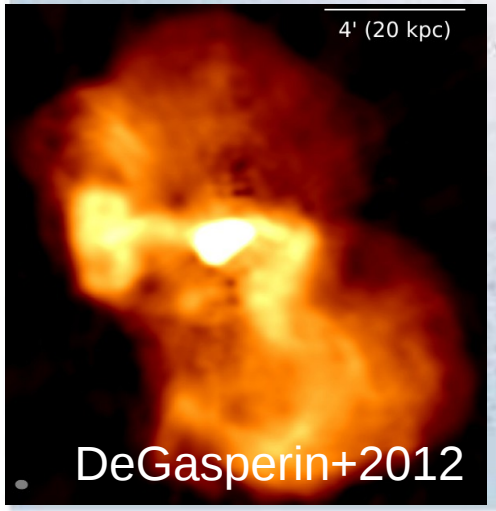
Ho 2008

Blandford-Znajek jet

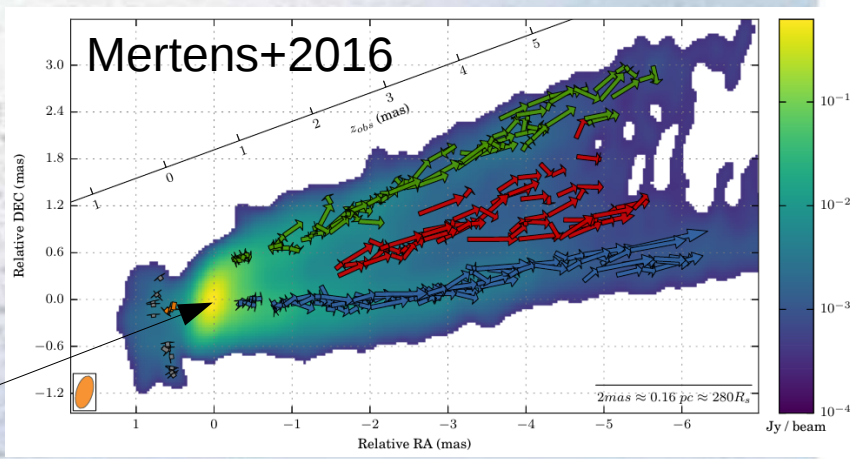
Thin disk

$R_{tr} \approx 100 - 1000\ R_S$

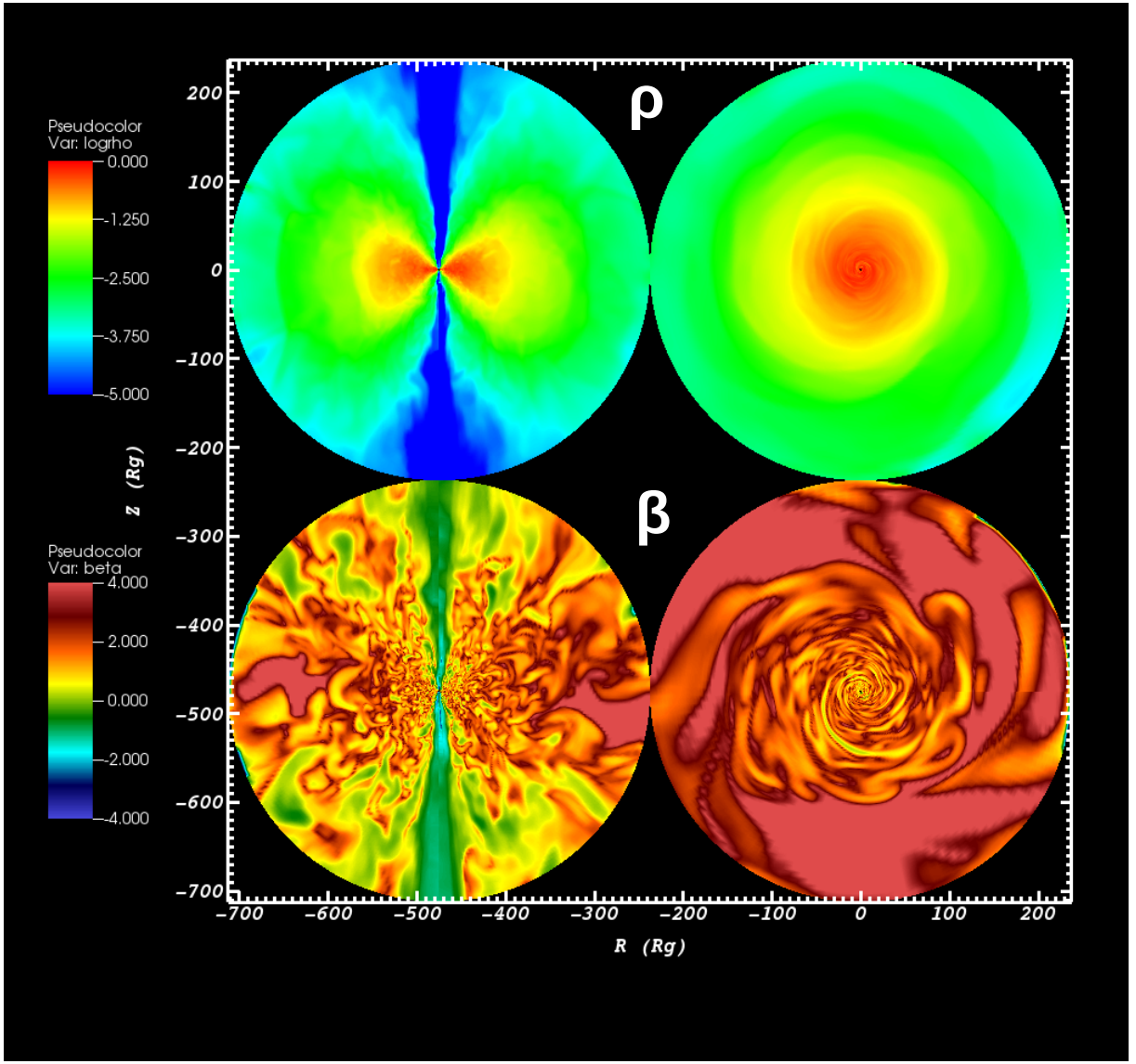
Jet/outflow



EHT will resolve inner 100 μas



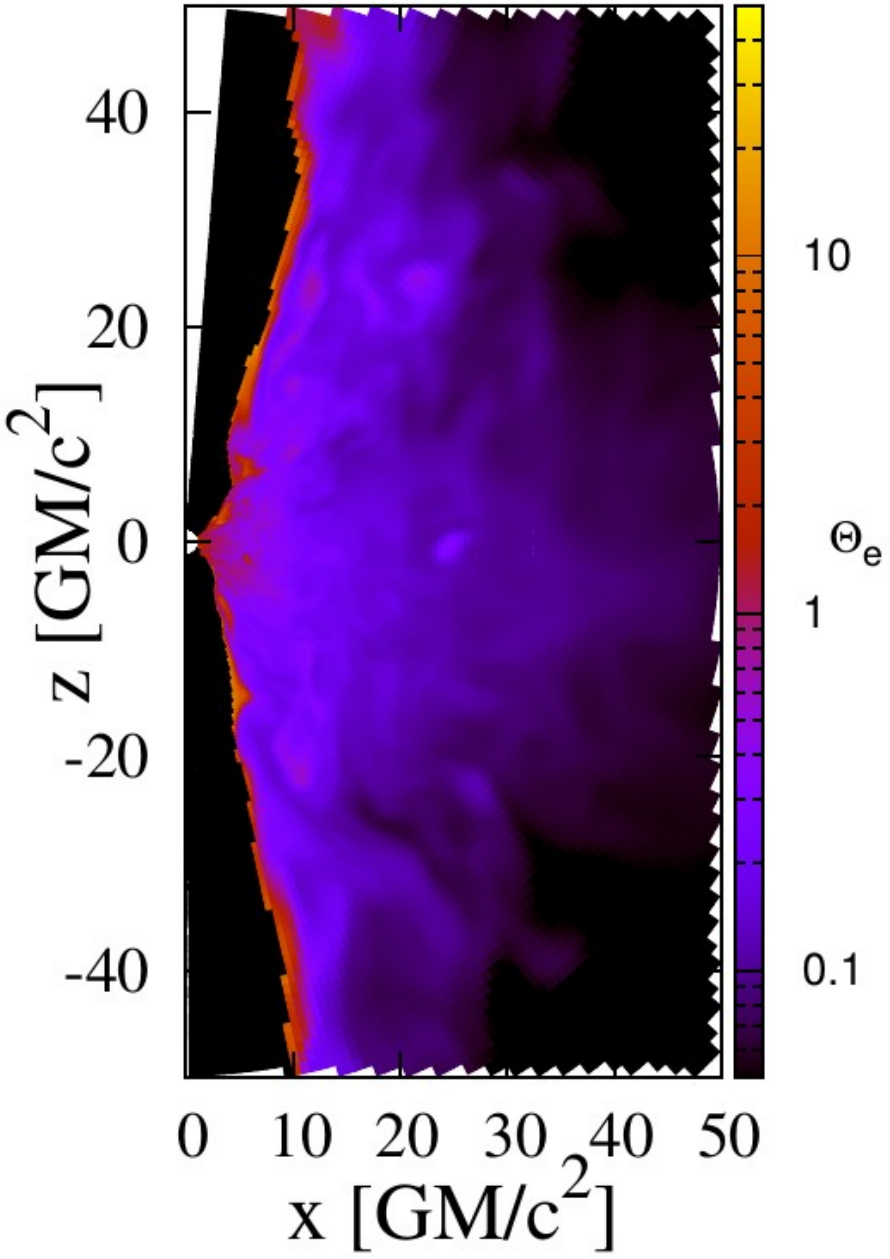
General relativistic MHD simulations of RIAF



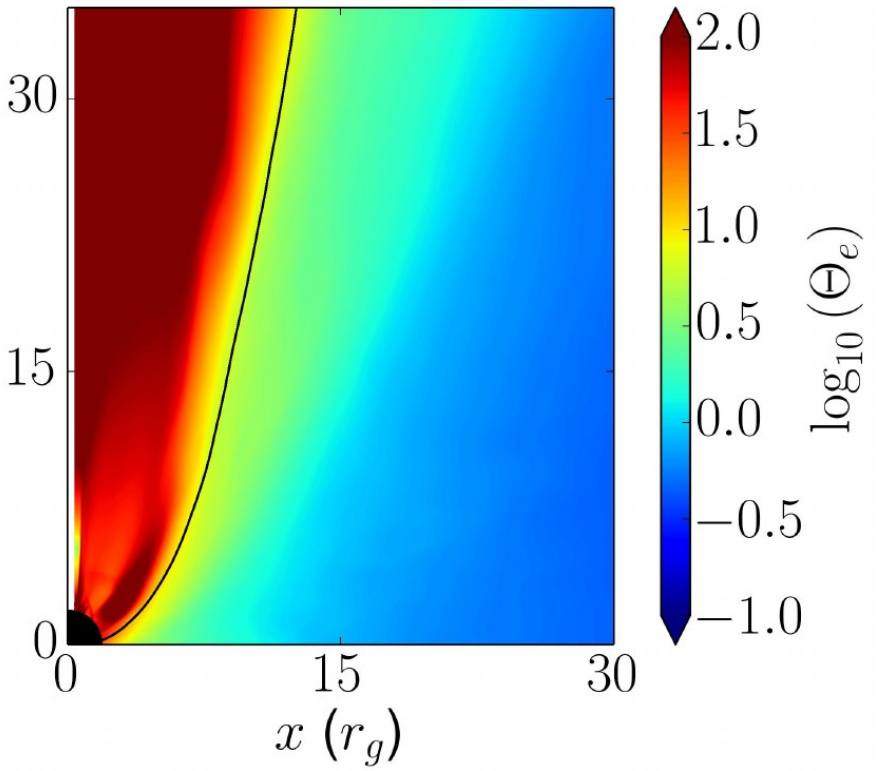
- Ideal-MHD in 3D
- No cooling
- Disk: MRI turbulence
- Magnetized outflows, jets
- Other models
- Collisionless, two-temperature plasma, model for electron distribution function assumed

Disk jets (jet sheath)

Moscibrodzka et al. 2013, 2014, 2016, 2017



Ressler, Tchekhovkoy et al. 2017:
Extended GRMHD Sgr A* model

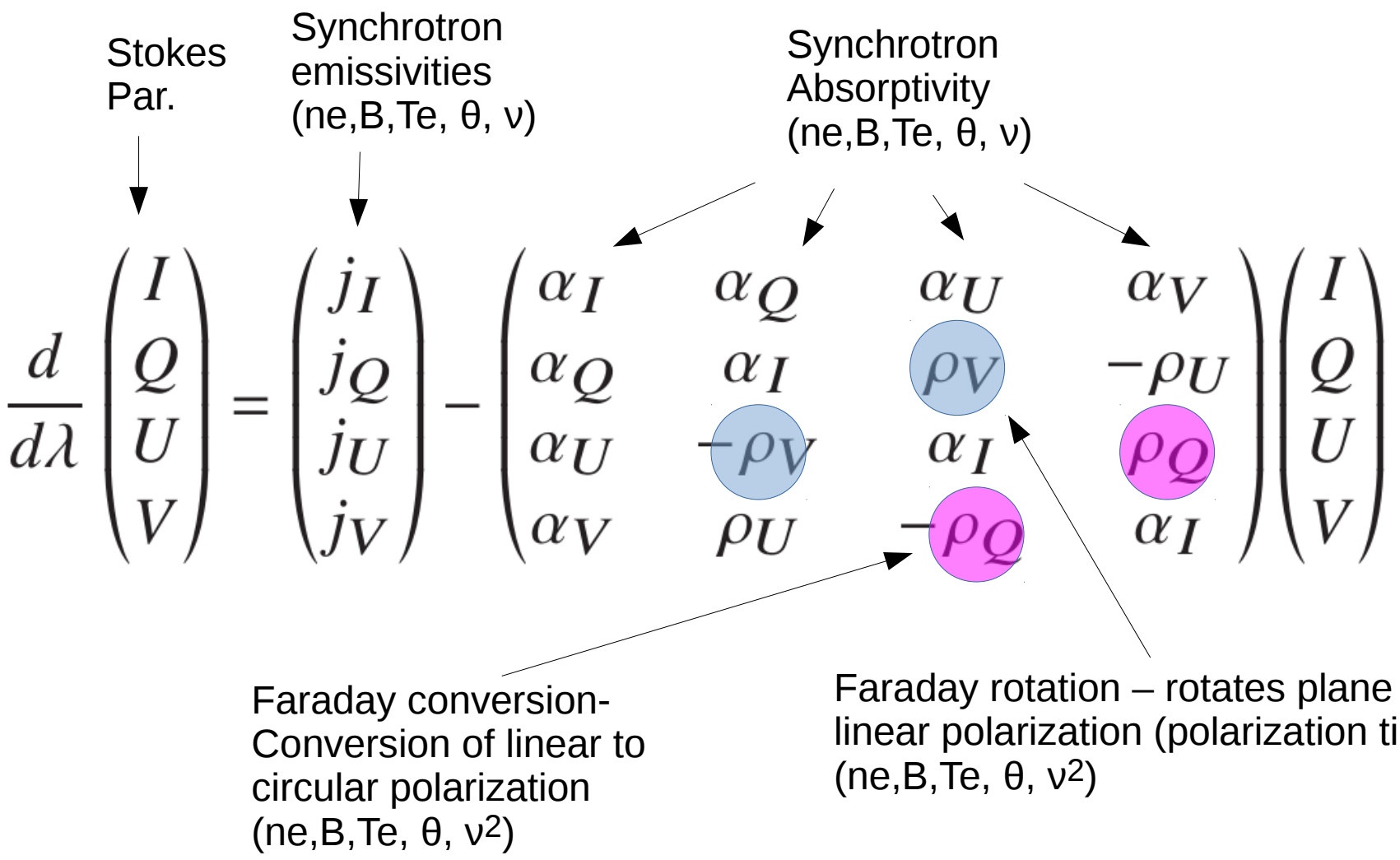


Modeling emission from GRMHD models of RIAF

- We model millimeter emission
  - 43,86,230GHz-limited by the model size (larger scale jets see e.g., C. Fromm talk)
  - synchrotron emission
  - near horizon emission – Doppler boosts, gravitational lensing

- The goal is to constrain the model free parameters:
  - accretion rate , i
  - spin
  - Geometry of near horizon B fields

Relativistic Polarized Radiative Transport by ray-tracing



Optical thickness – frequency dependent $\tau \sim> 1$

Faraday optical thickness $\tau_F >> 1 \sim 10^6$ (equations can be stiff)

Relativistic Polarized Radiative Transport by ray-tracing ipole

Other GR polarized codes:

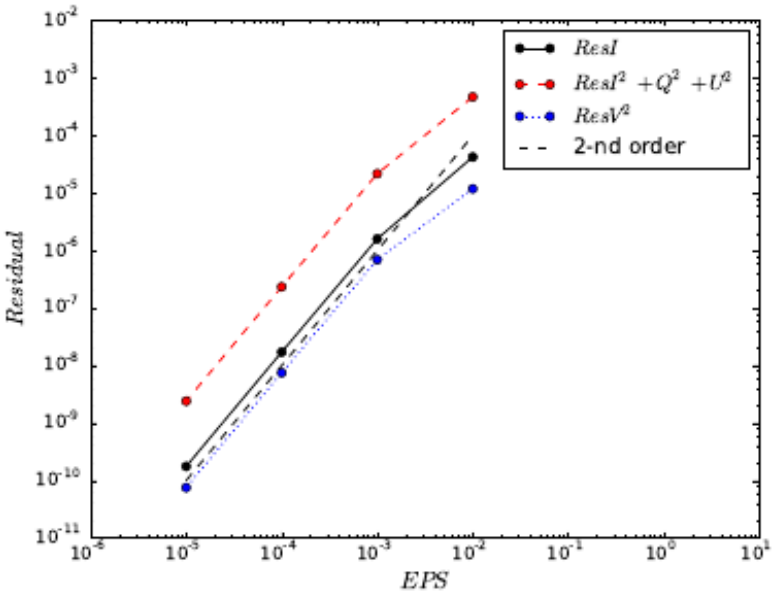
Vray (Broderick 2006)
Astroray (Scherbakov Huang 2011-2012)
Grtrans (Dexter 2016)
RAPTOR (Bronzwaer et al. 2017)

Fully covariant equations for polarized radiative transport

$$\frac{dN^{\alpha\beta}}{d\lambda} = -\Gamma^{\alpha}_{\mu\nu} k^{\mu} N^{\nu\beta} - \Gamma^{\beta}_{\mu\nu} k^{\mu} N^{\alpha\nu} + J^{\alpha\beta} + H^{\alpha\beta\gamma\delta} N_{\gamma\delta}$$

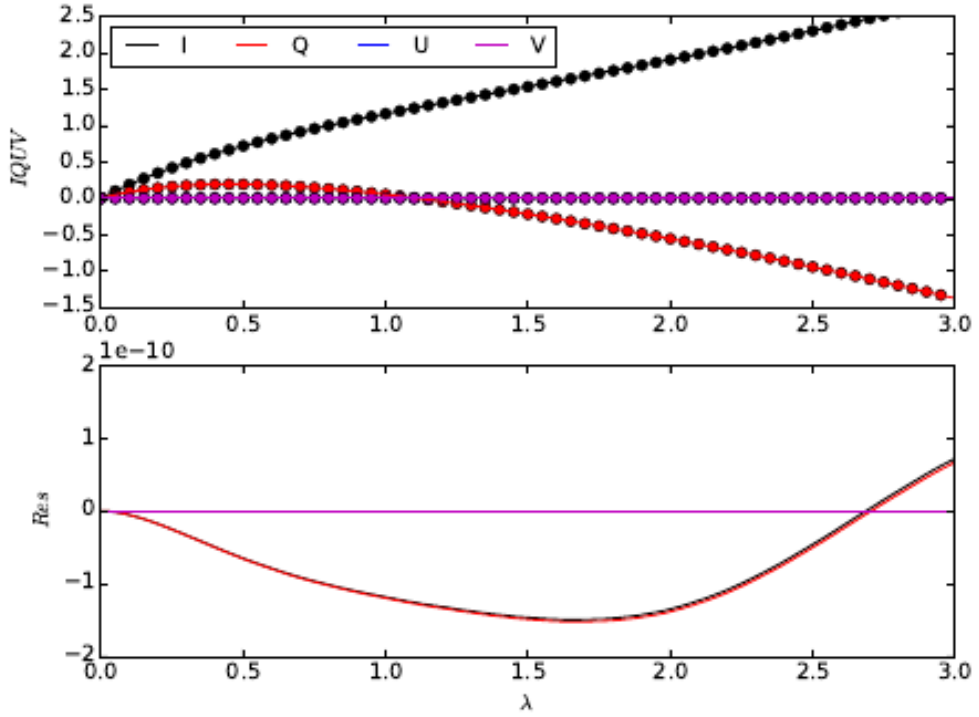
Gammie & Leung 2012
Weinberg “Cosmology”

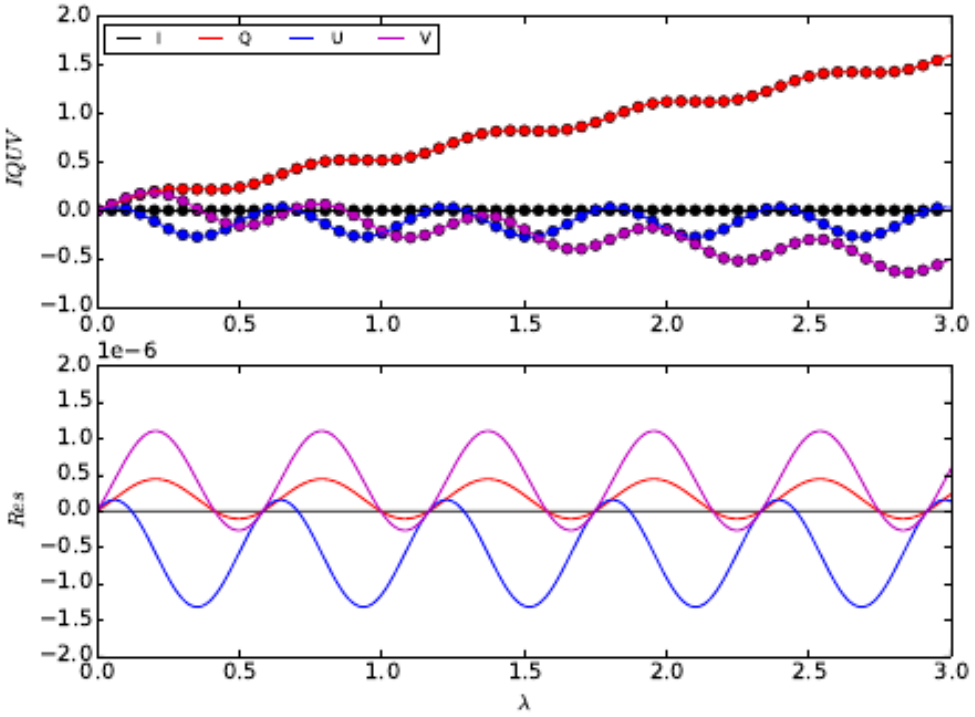
Relativistic Polarized Radiative Transport by ray-tracing ipole



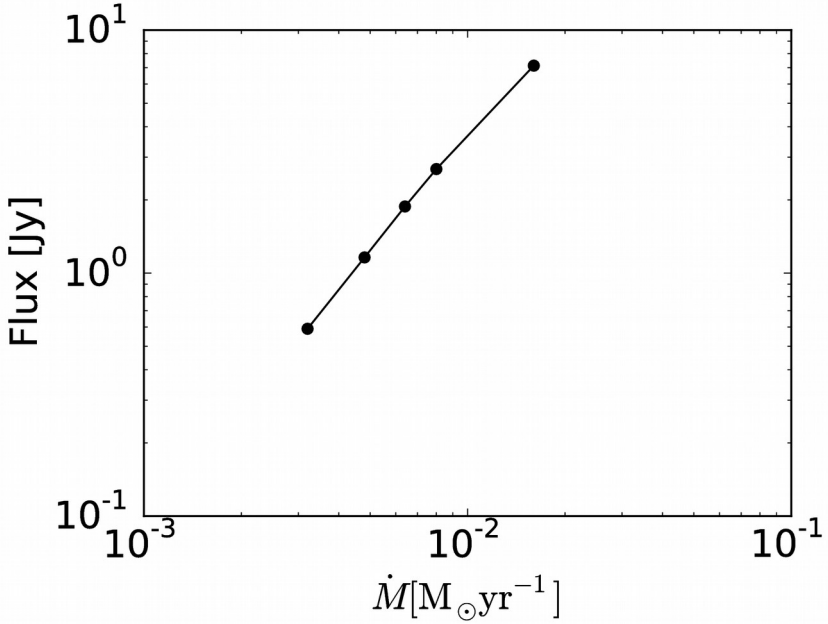
Carefully tested in curvilinear coordinates

Moscibrodzka & Gammie



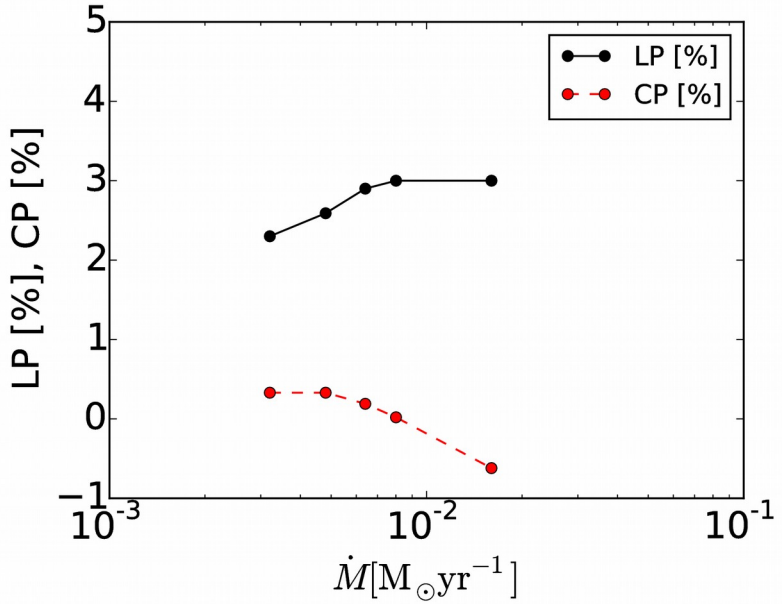


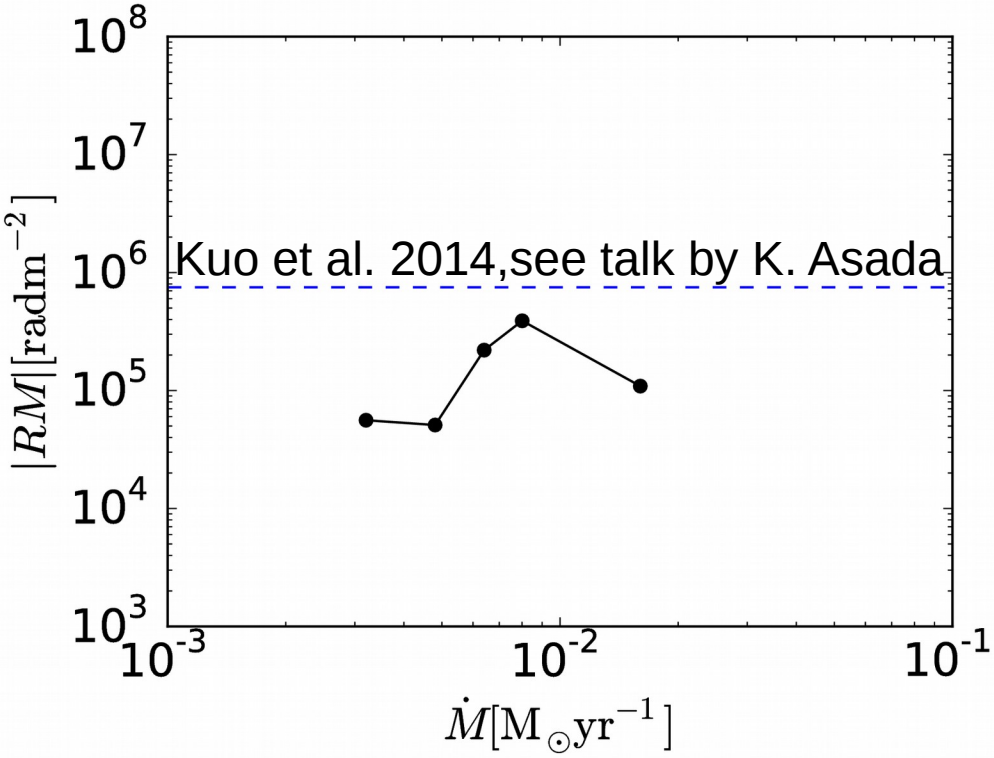
LP, CP, RM (Macc) at 230 GHz [M=6x10^9 M$_{SUN}$,i=10°,a=0.94,Te]

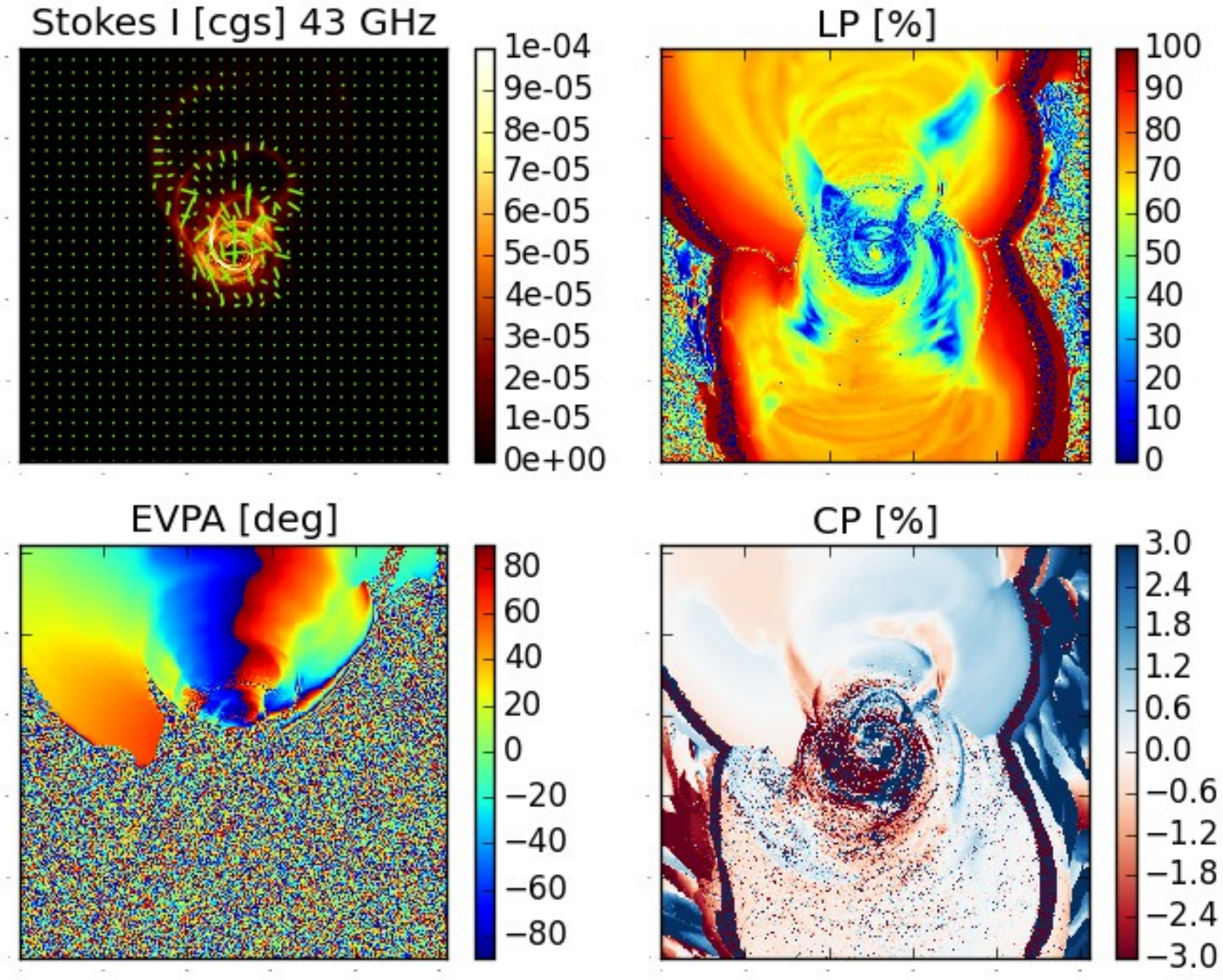


$$\chi_{\mathrm{tot}} \equiv arg(Q_{\mathrm{tot}} + iU_{\mathrm{tot}})/2$$

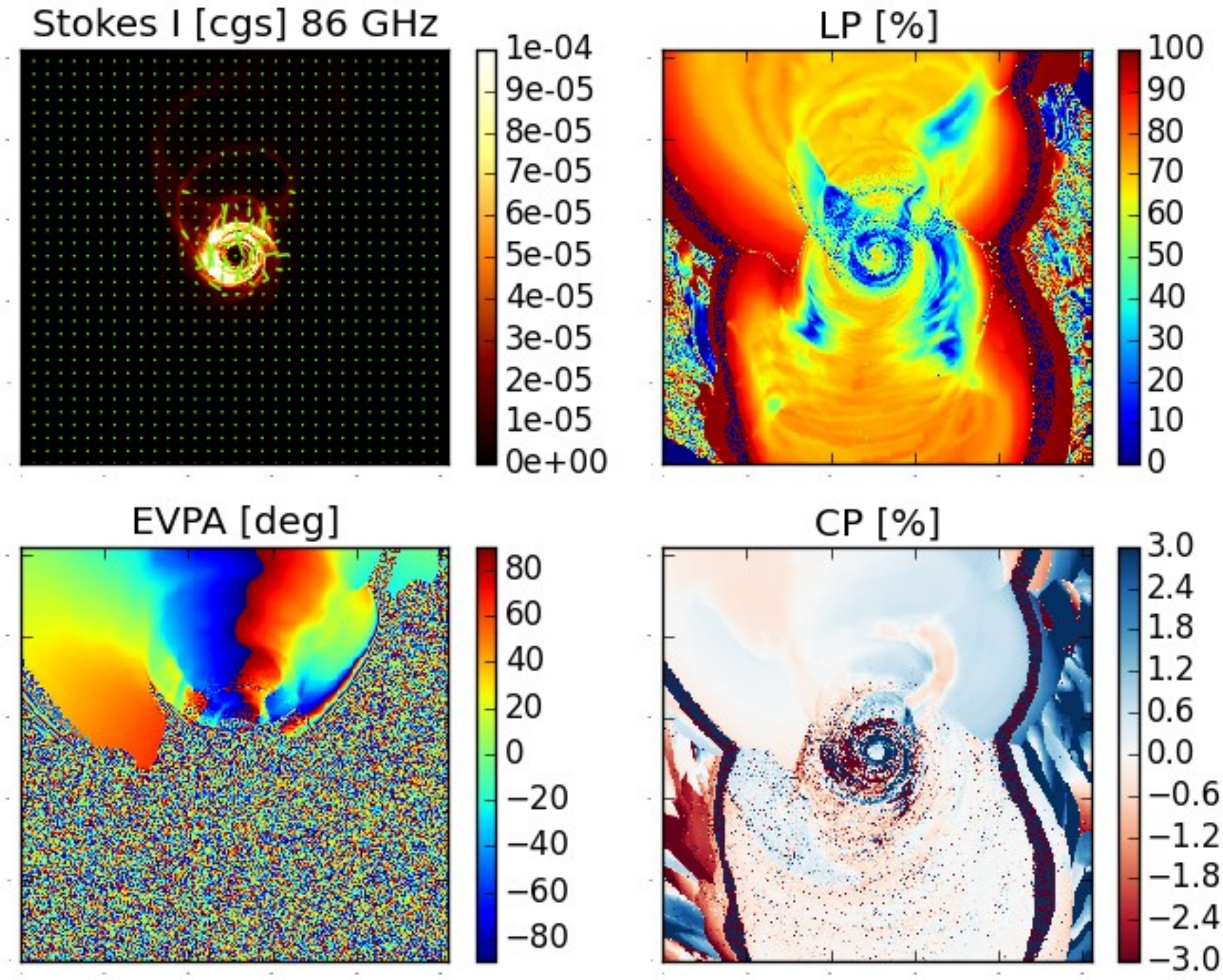
$$RM_{observed} = \frac{\chi_{tot}(\lambda_1) - \chi_{tot}(\lambda_2)}{\lambda_1^2 - \lambda_2^2}$$



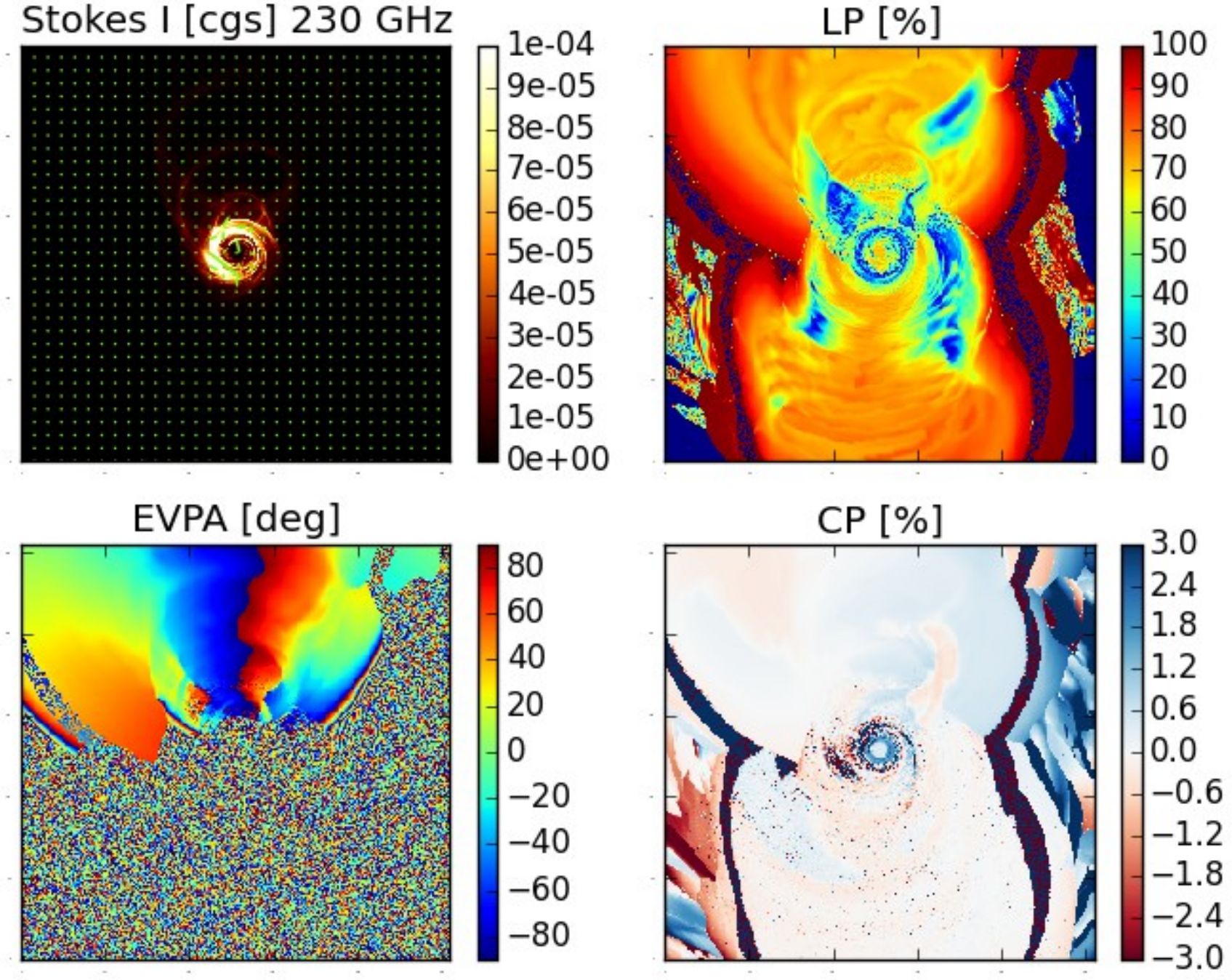




Moscibrodzka et al. 2016 100 GM/c2 = 0.36 mas

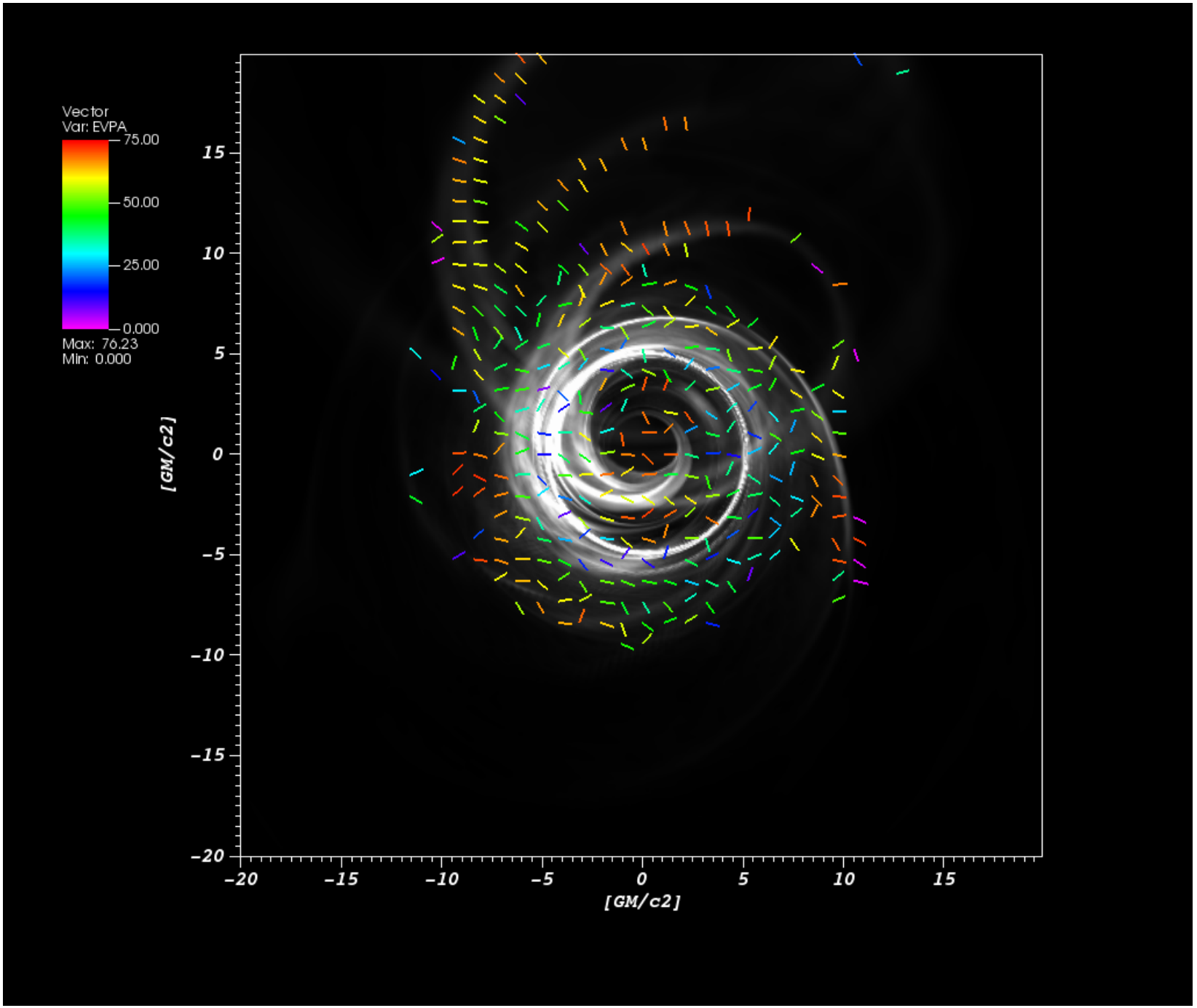


Moscibrodzka et al. 2016

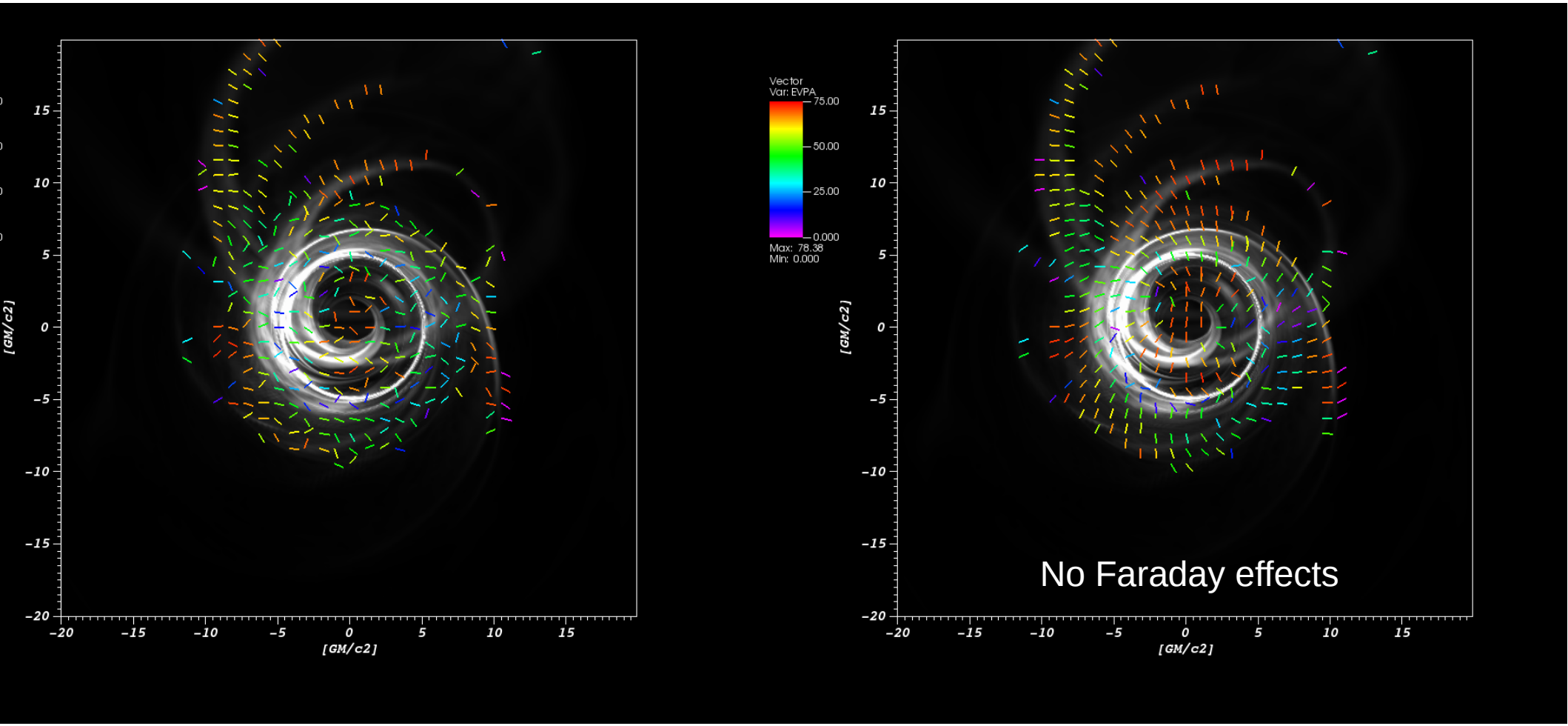


Moscibrodzka et al. 2016, Moscibrodzka, Dexter et al. 2017, and Dexter 2012

Jet launching point

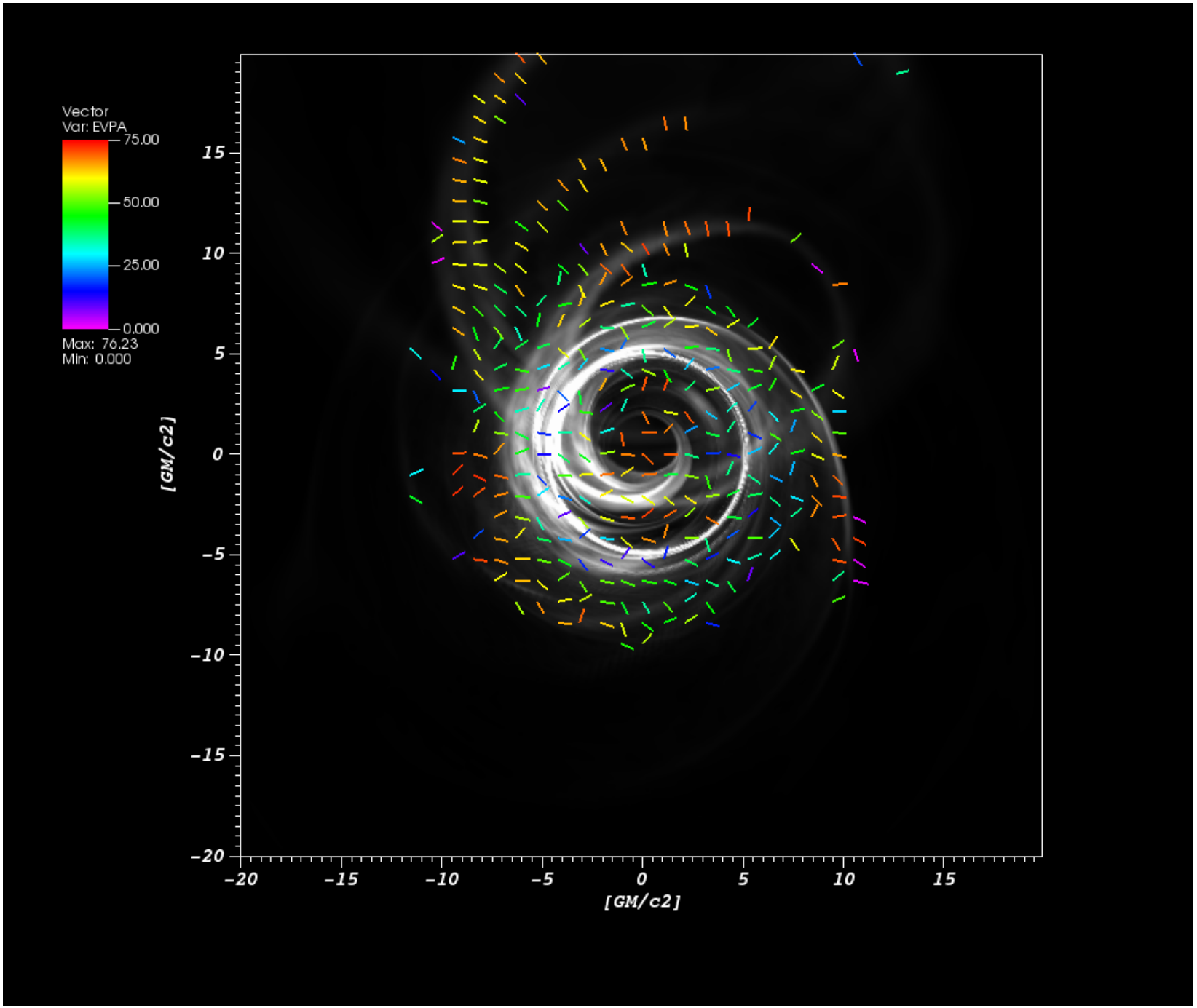


Strong Faraday rotation/conversion



Similar effect in Sgr A* - see talk by Jimenez-Rosales

Variability at jet launching point



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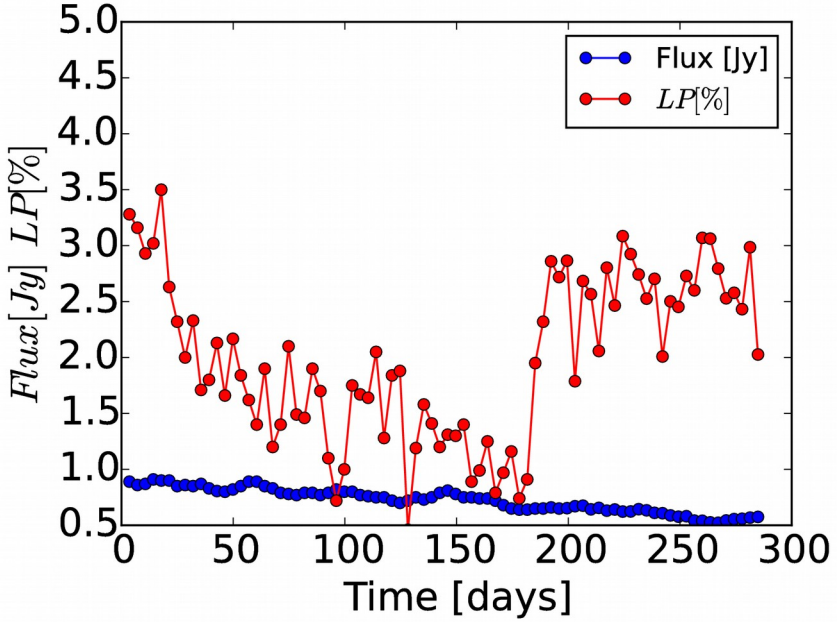
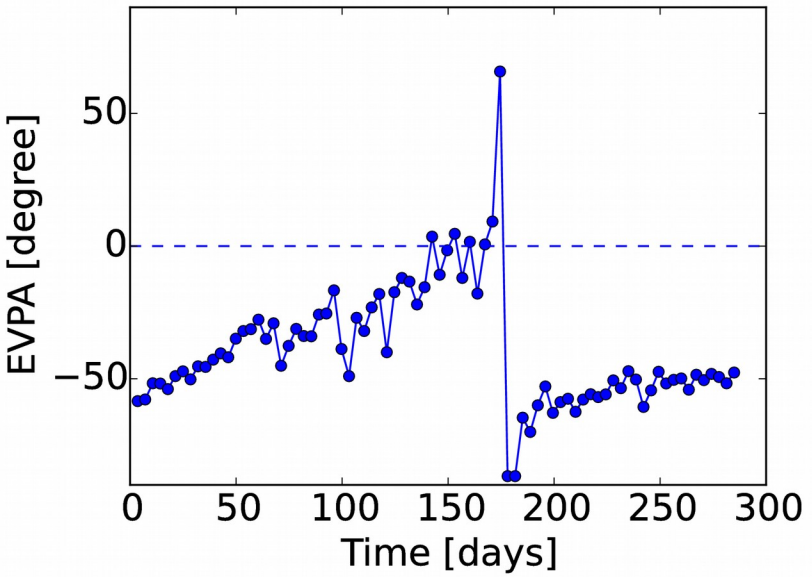
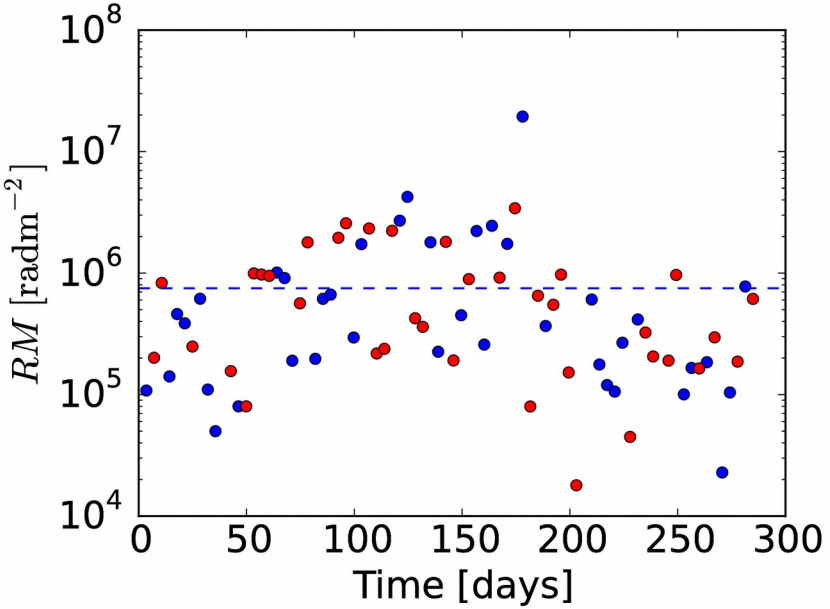
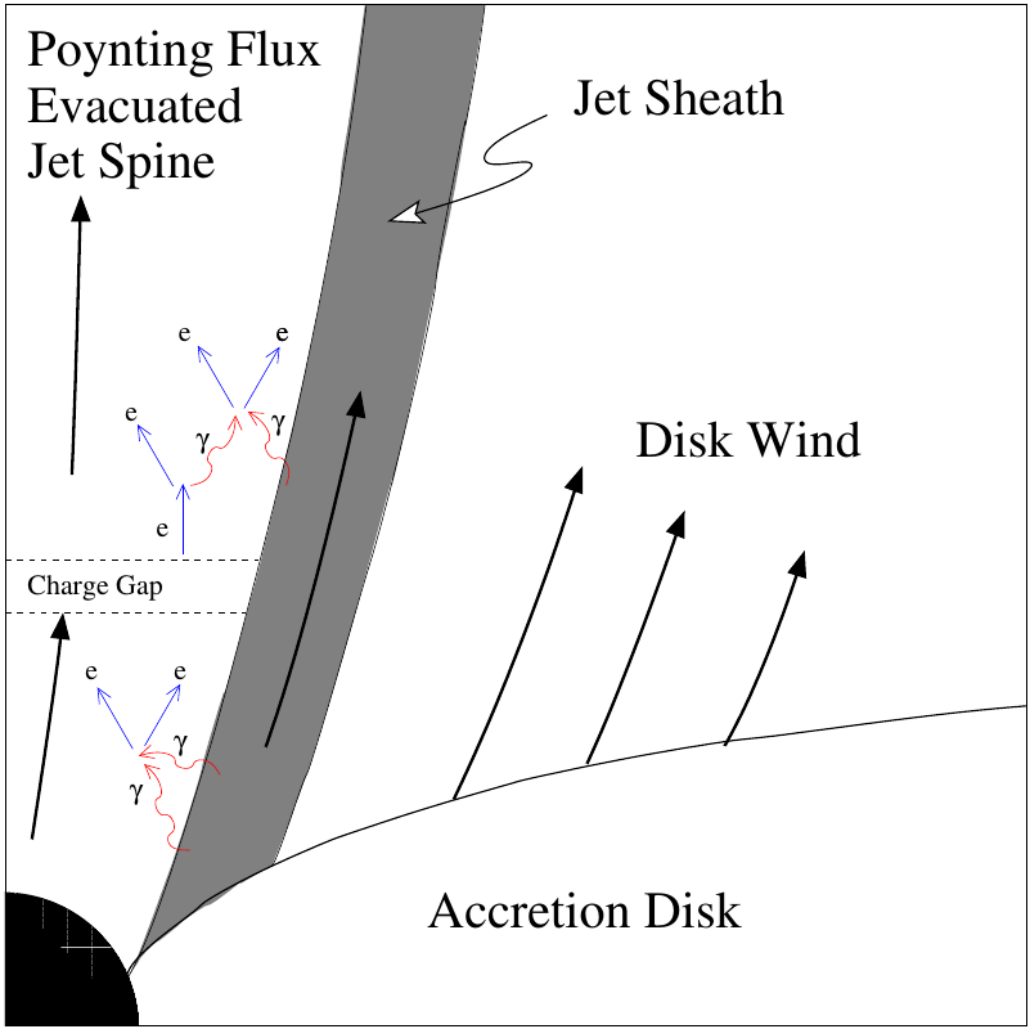




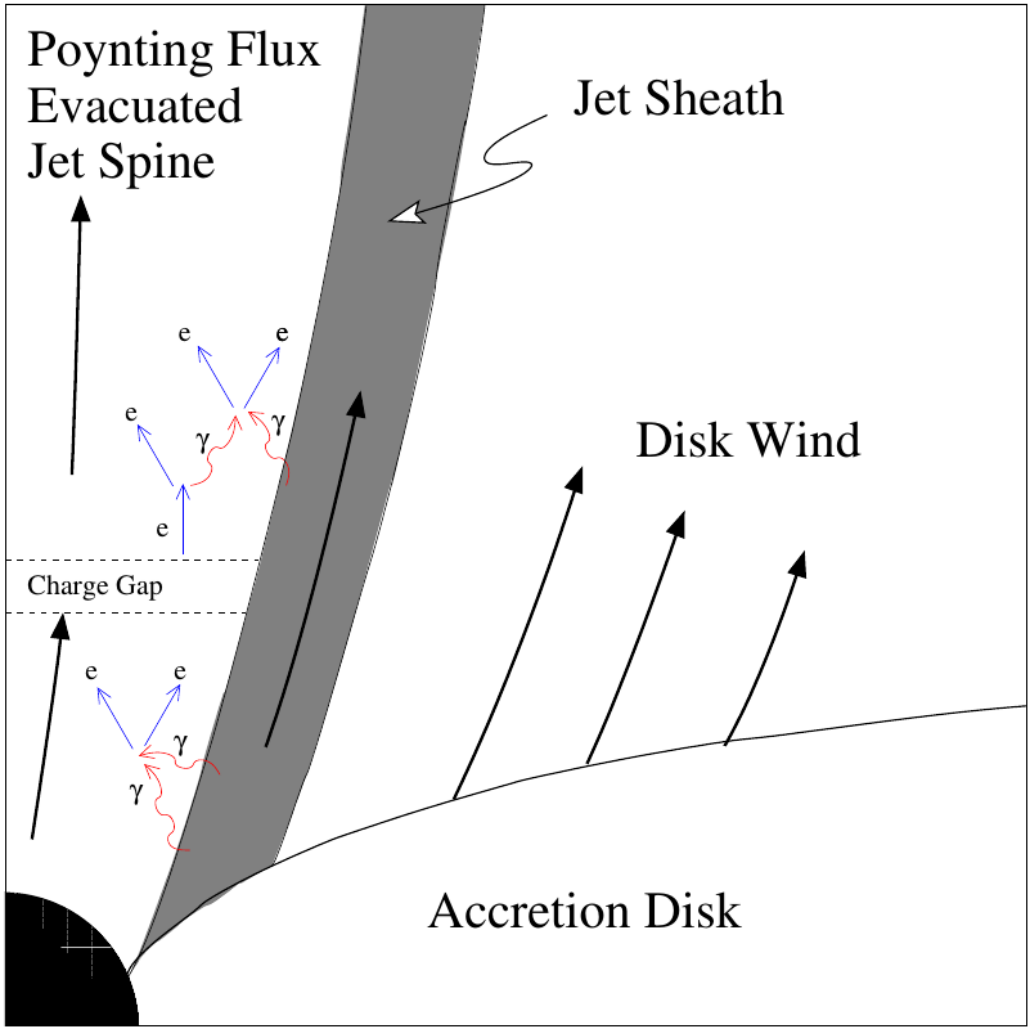


Jet spine



Goldreich Julian 1969
Blandford Znajek 1977
Beskin 1992
Hirotani Okamoto 1998
Levinson et al. 2011
Broderick, Tchekhovkoy 2016 and others

Jet spine



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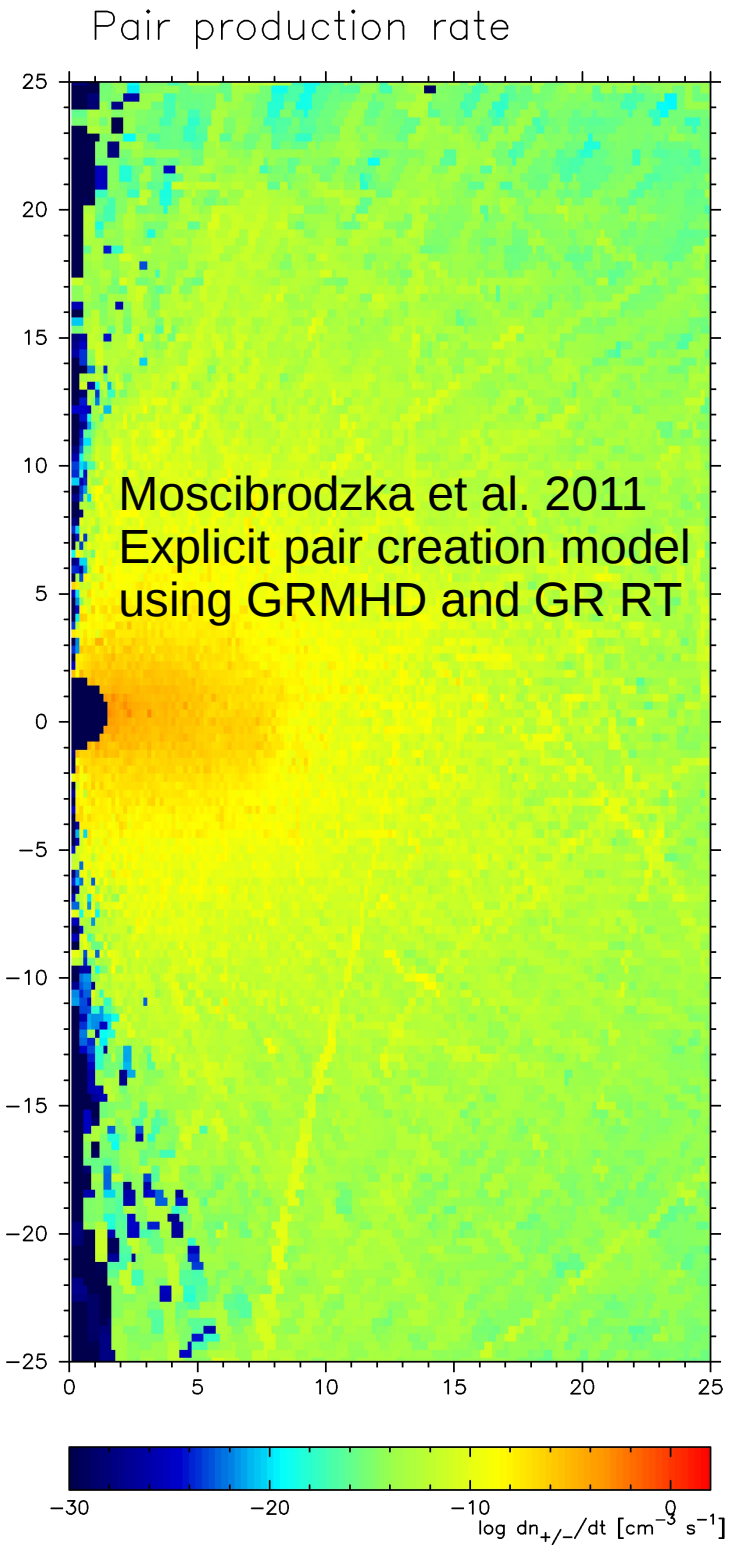

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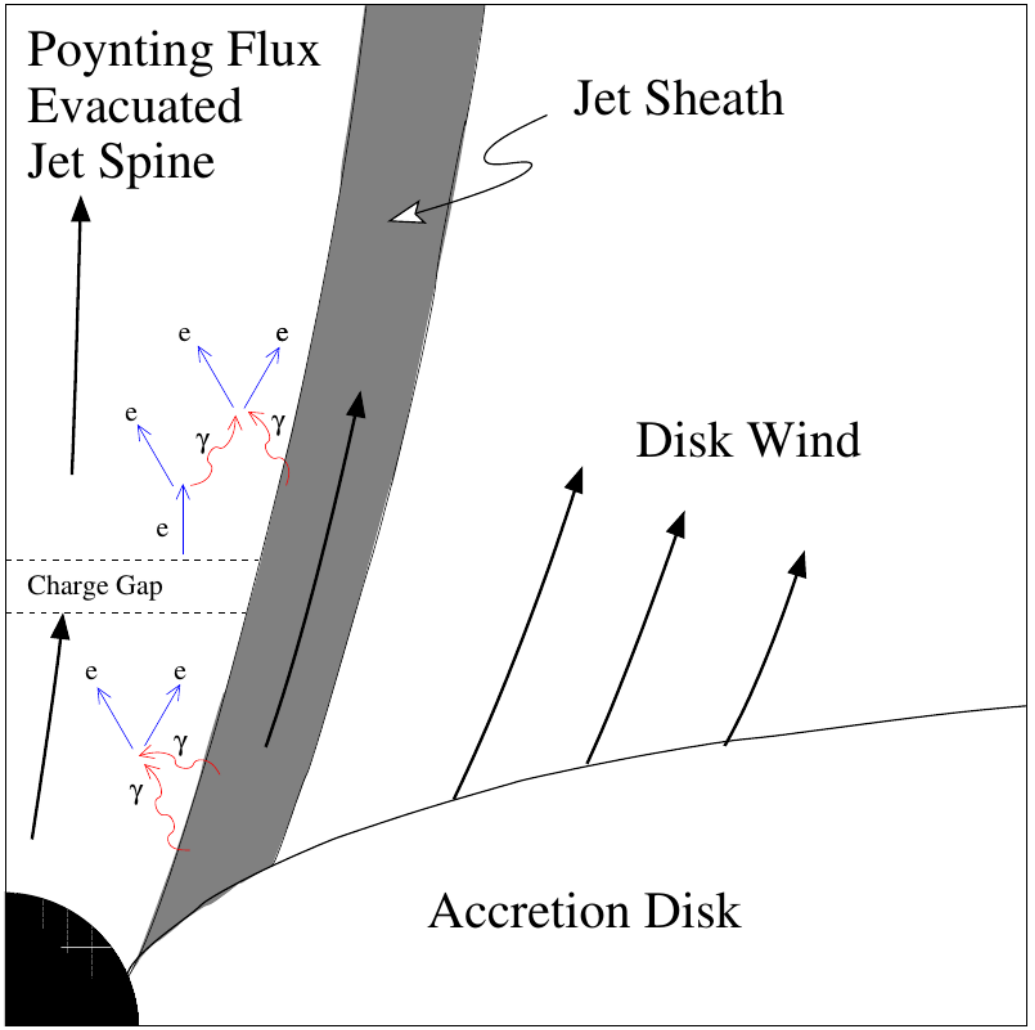

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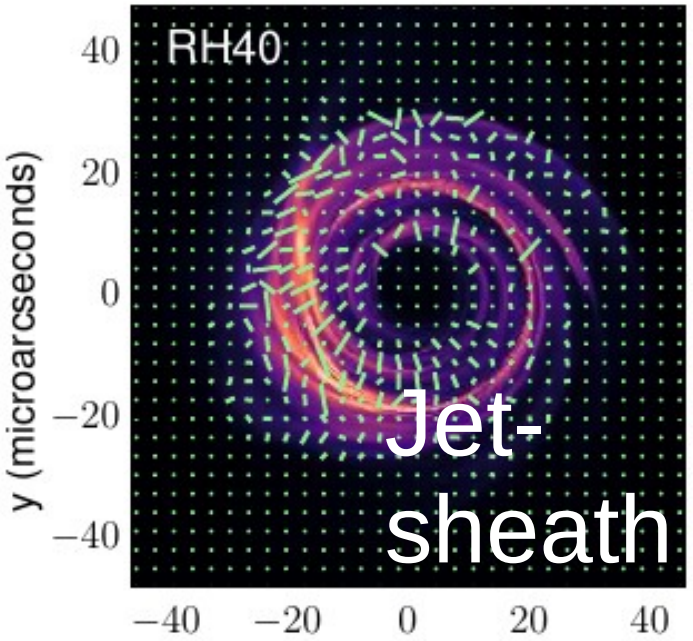
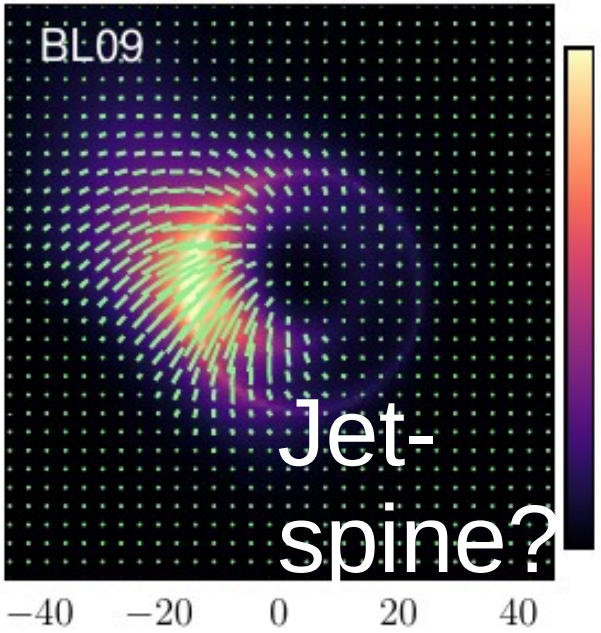


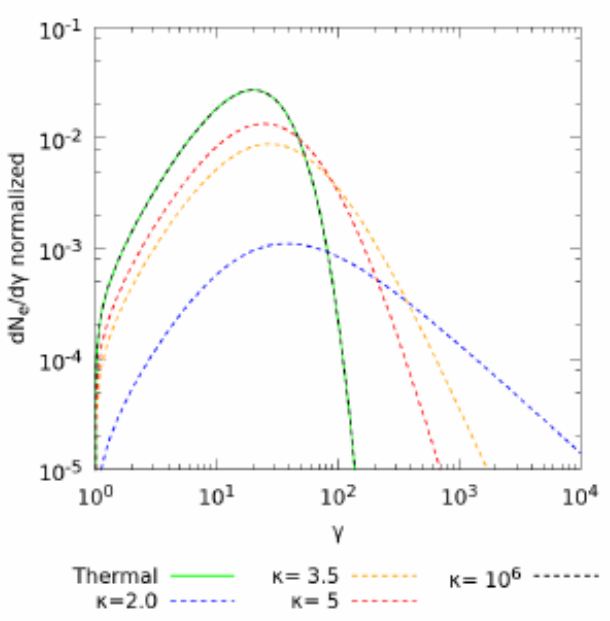
MM et al. 2017



Broderick Loeb 2009

Summary

- I showed first synthetic polarized simulations of M87 jet near BH
- The largest uncertainty in models: particle content and particle acceleration (impact on image morphology and SED)
- Structure of B fields and surrounding (RM)
- Detailed comparison of all models to the EHT data (M87, Sgr A*) in preparation by EHT collaboration



Davelaar, MM 2017