

# VLBI Location of the Sites of High-Energy Emission Production in AGN

Nicholas MacDonald  
(on behalf of Anton Zensus)

Max Planck Institute for Radio Astronomy

CTA Science Symposium  
Exploring the High-Energy Universe with CTA



MAX-PLANCK-GESELLSCHAFT



Max-Planck-Institut  
für Radioastronomie

Bologna, Italy  
May 8th 2019

# Talk Outline

VLBI Locations of the Sites of High-Energy Emission Production in AGN

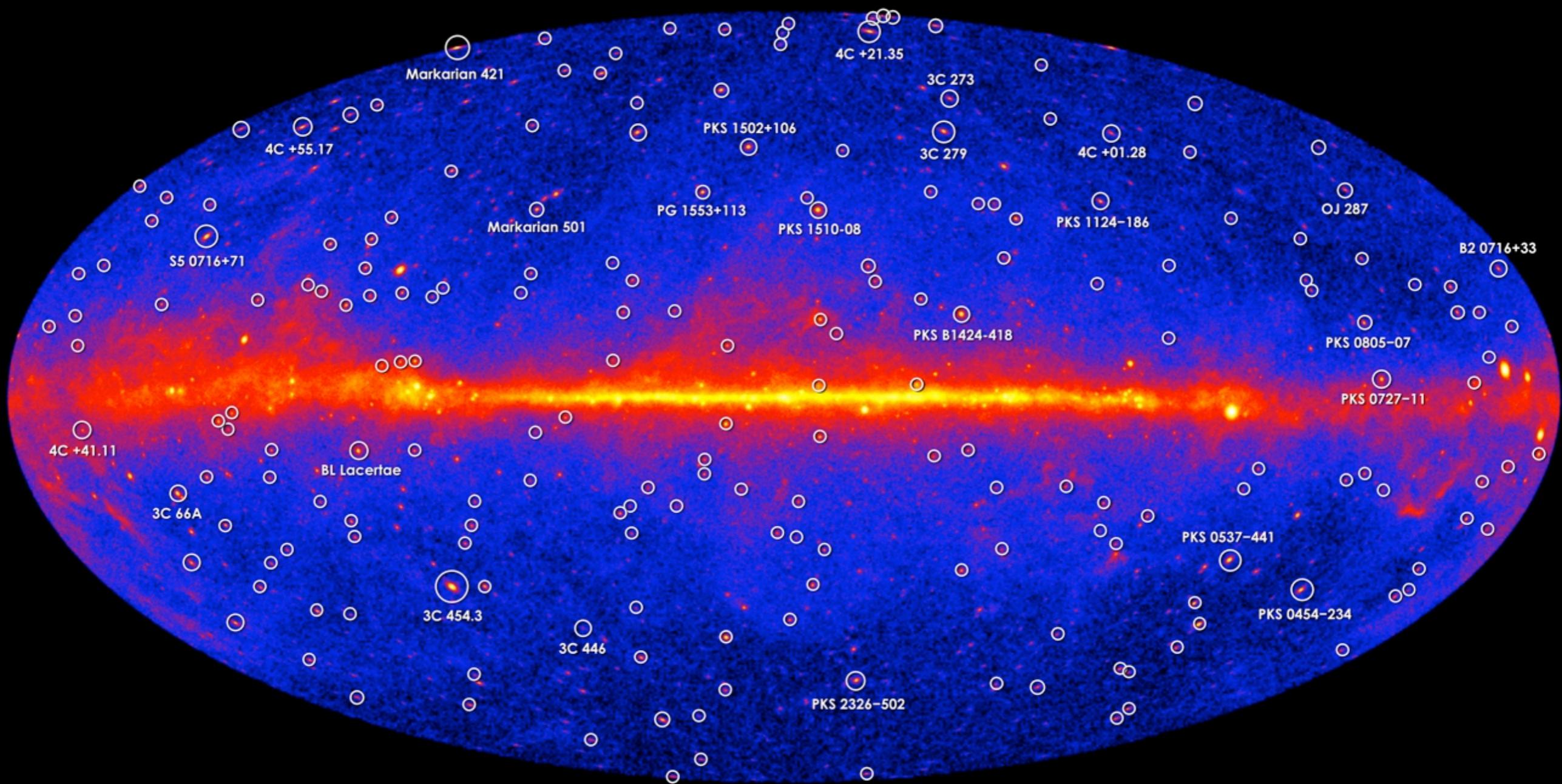
Relativistic Magnetohydrodynamic (RMHD) Jet Modeling

Relativistic Particle-in-Cell (PIC) Jet Modeling

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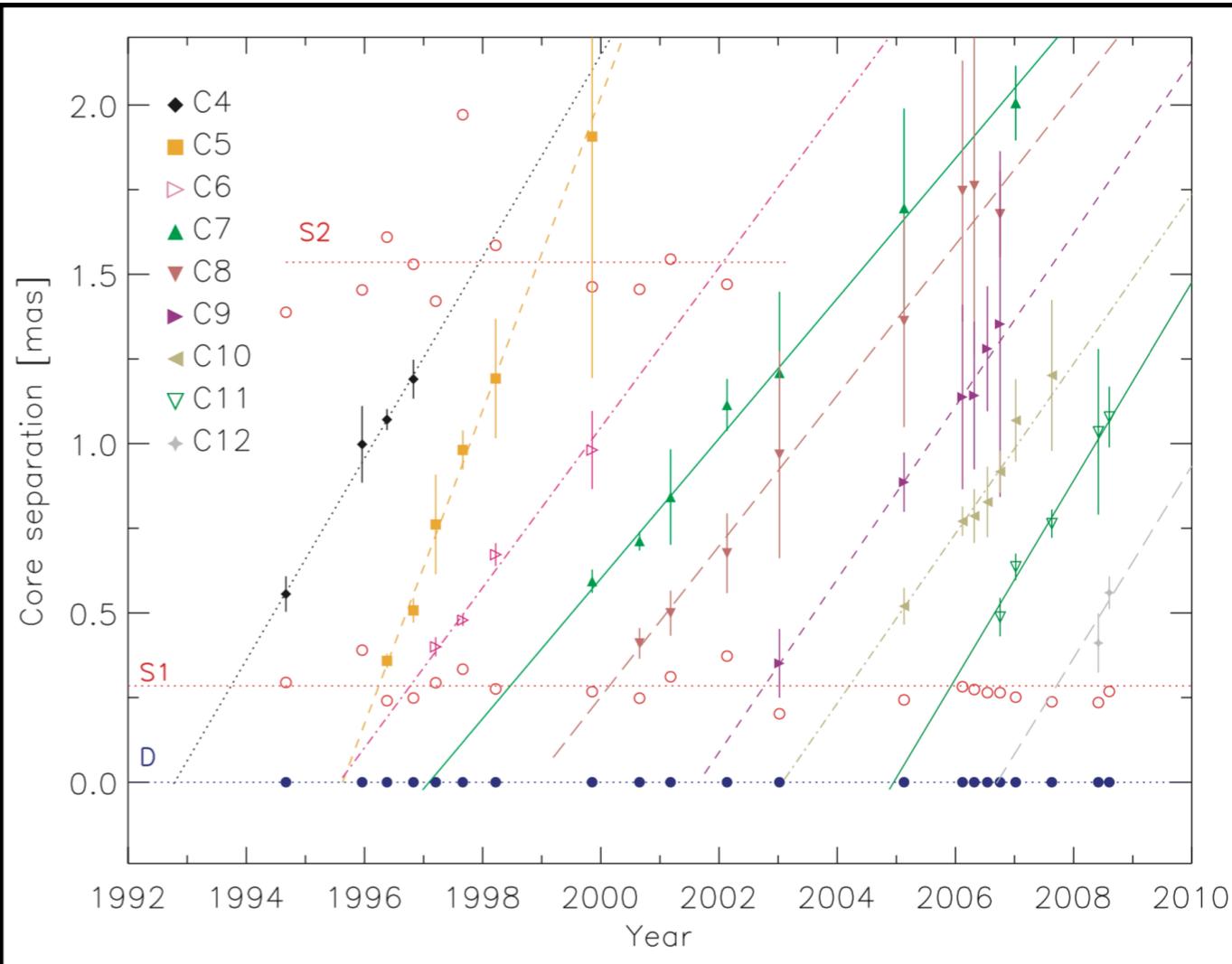
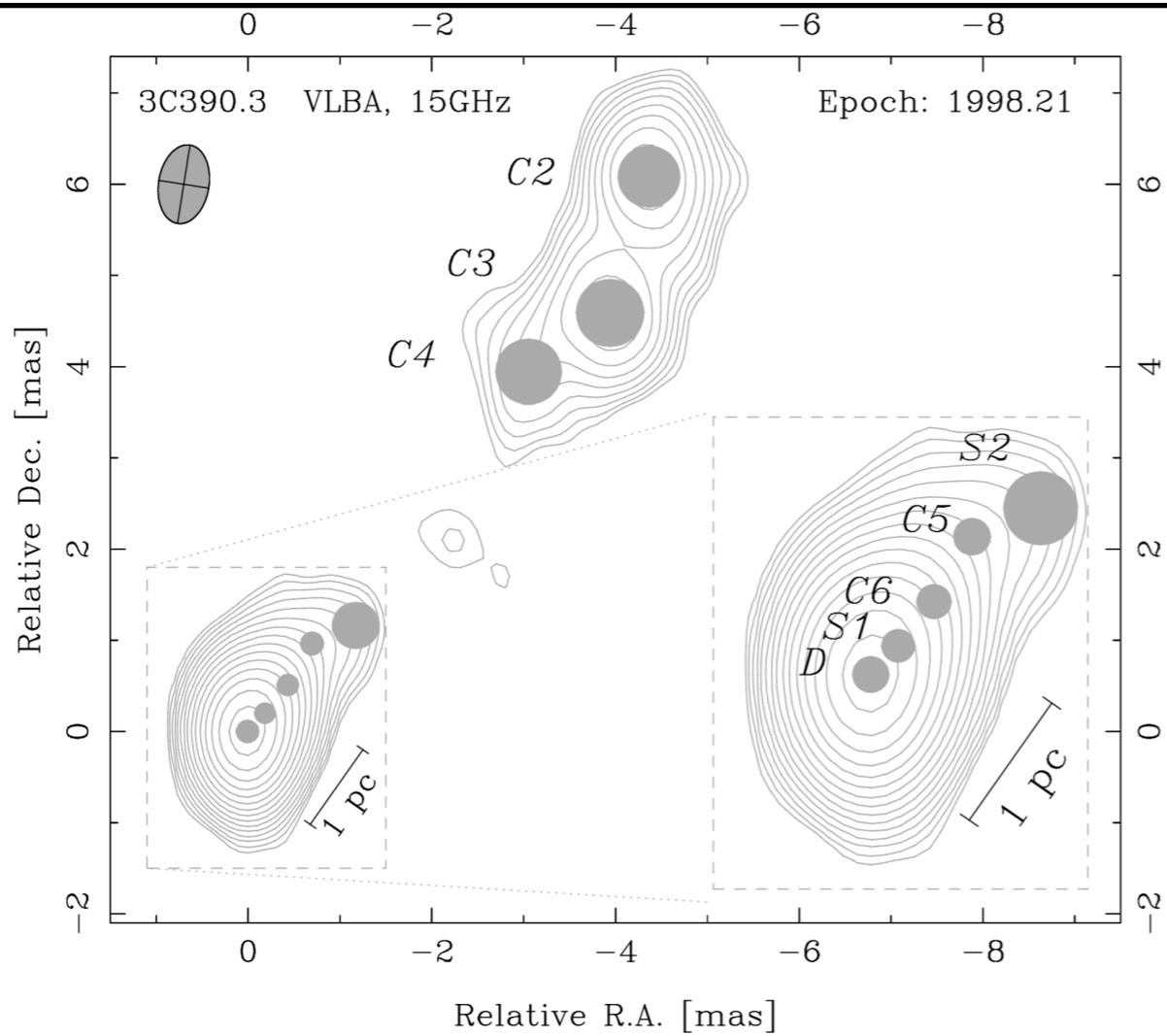
# Very Long Baseline Interferometry (VLBI)





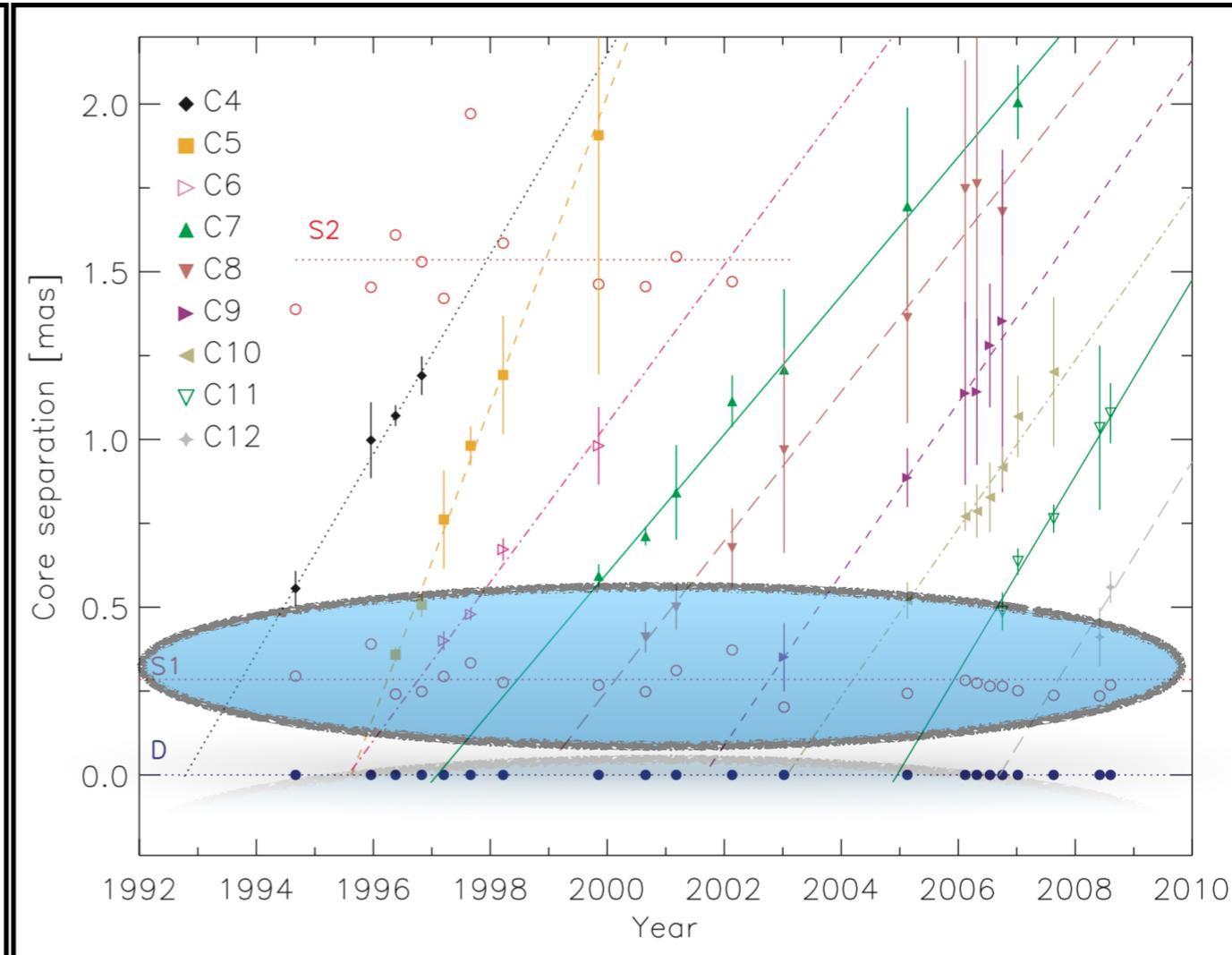
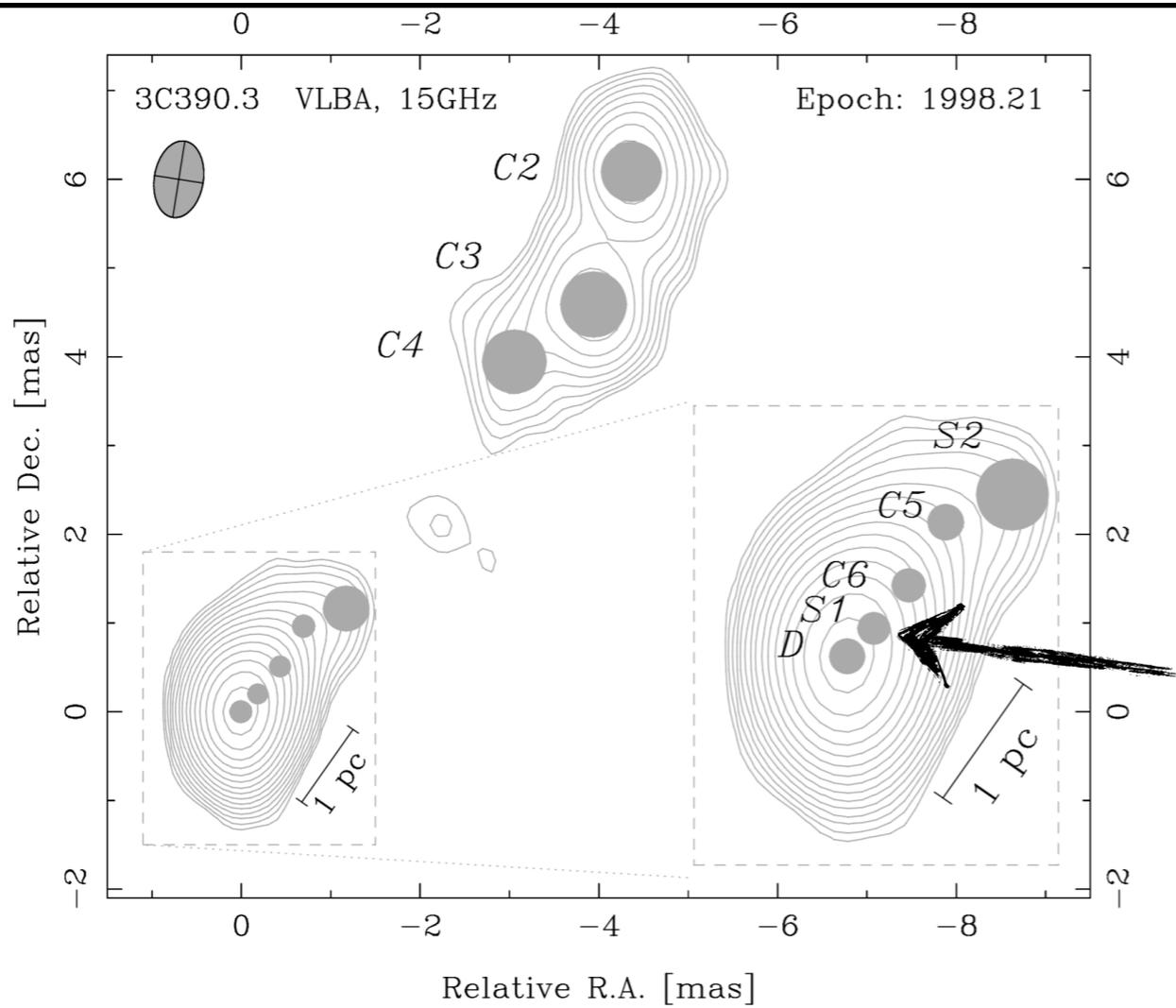
Image Credit: nrao.edu

# 3C 390.3



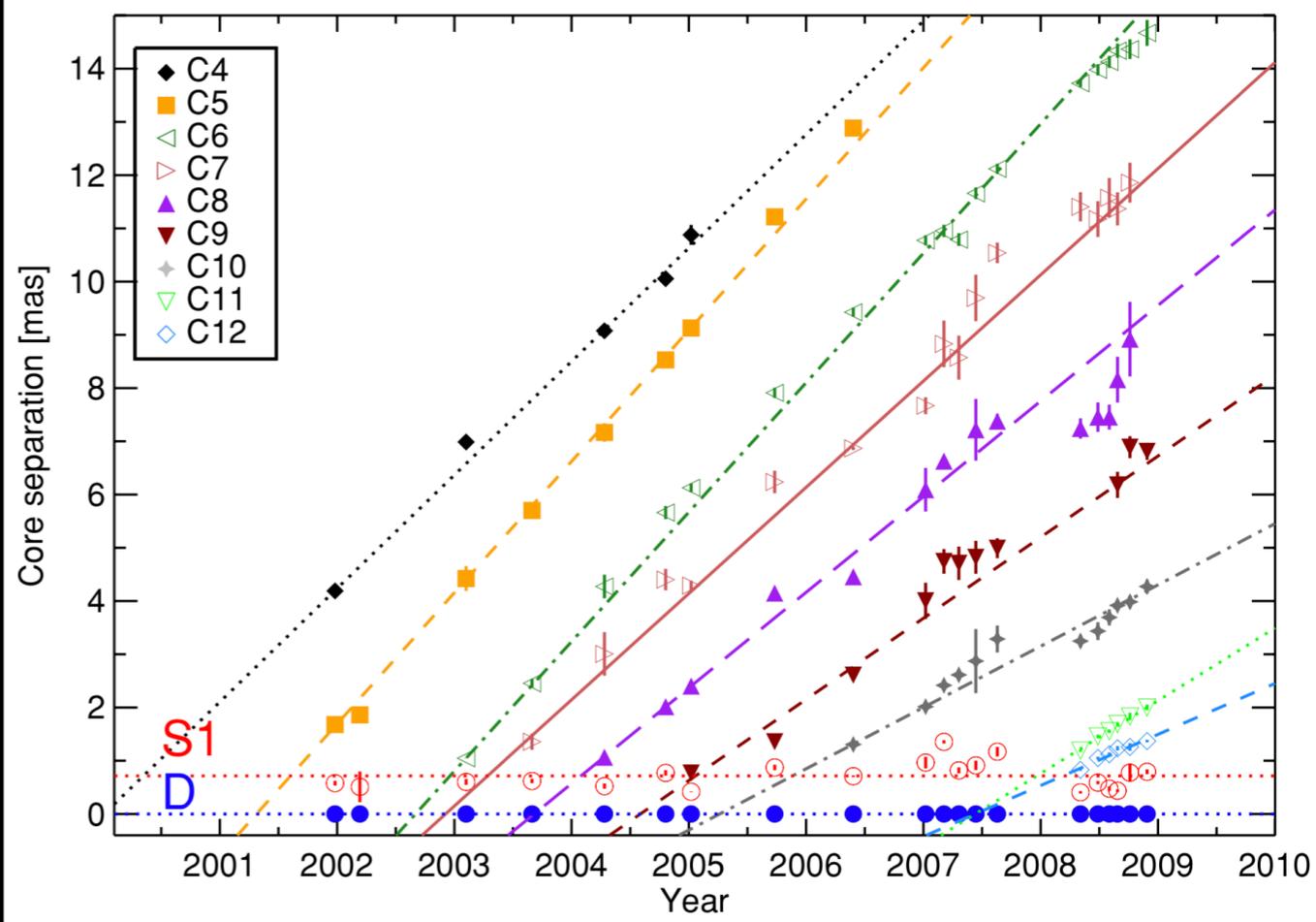
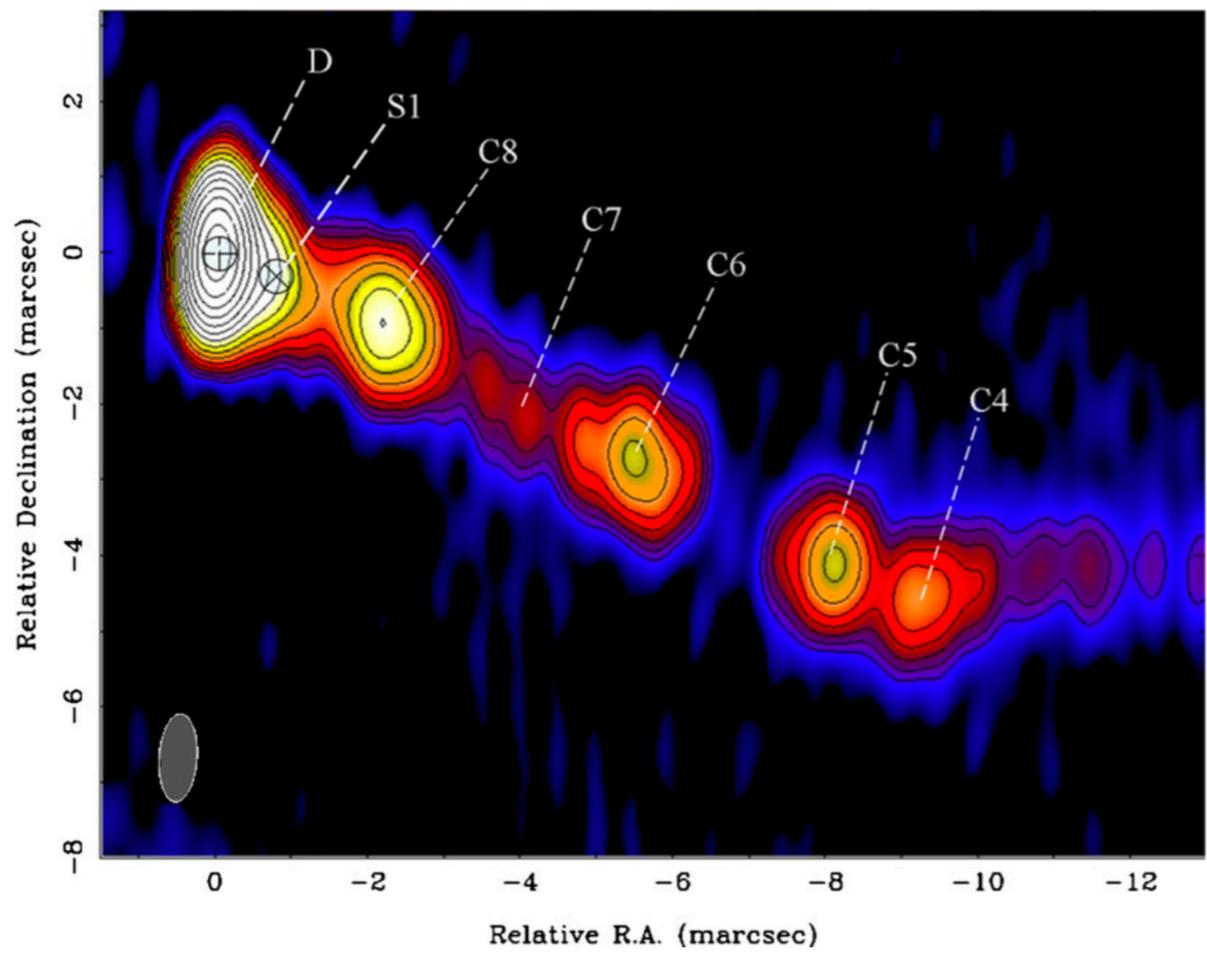
Arshakian et al. (2010)

# 3C 390.3



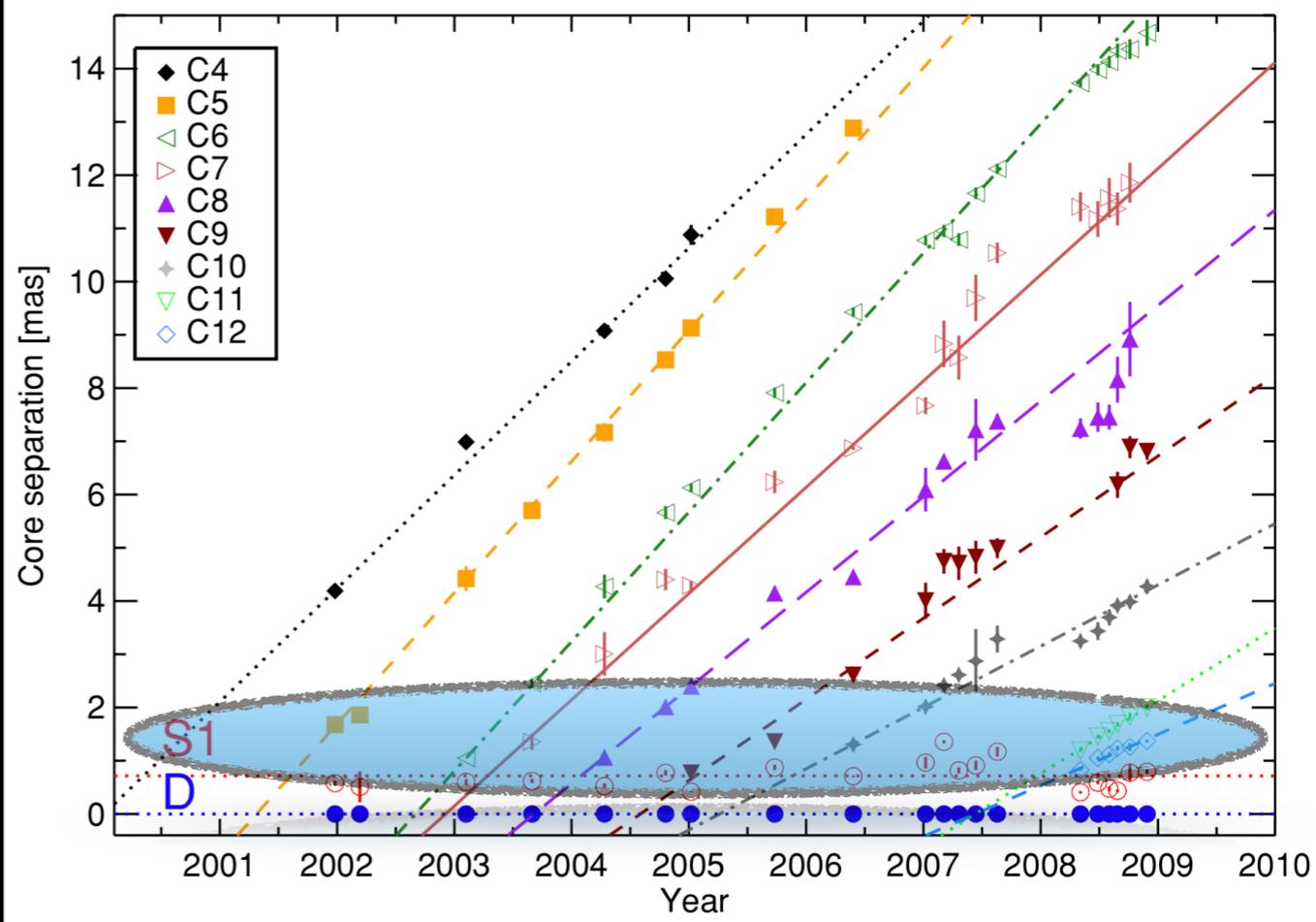
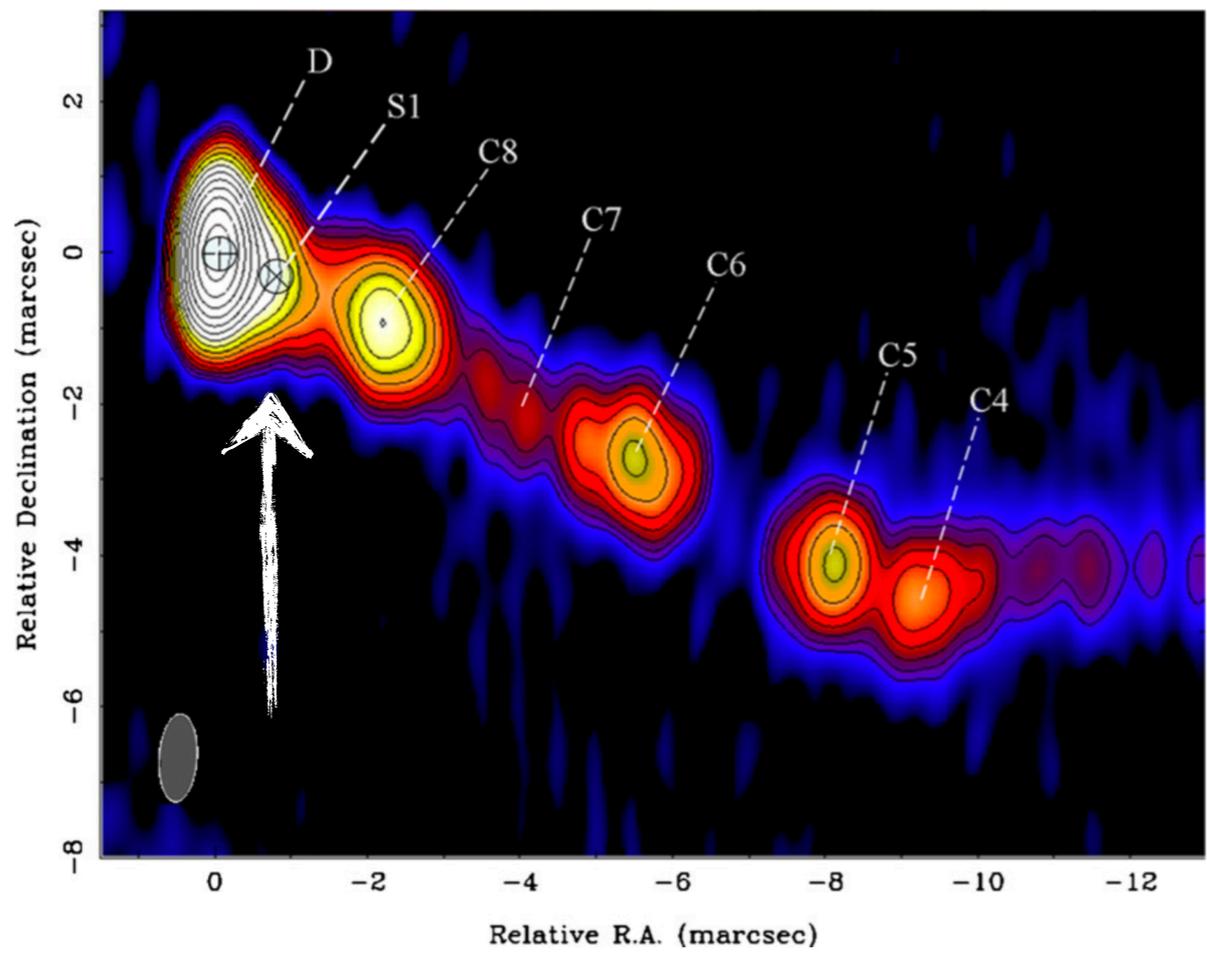
Arshakian et al. (2010)

# 3C 120



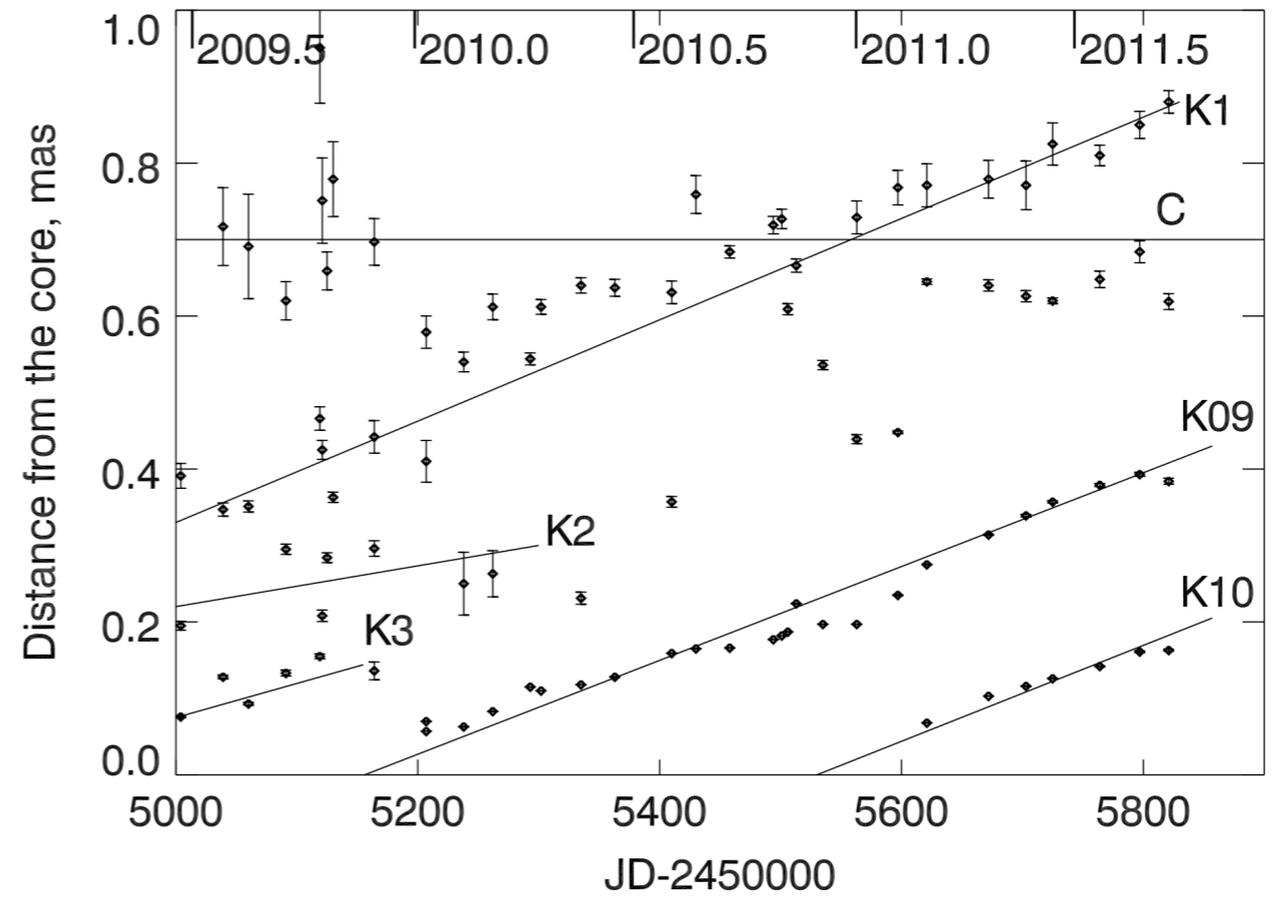
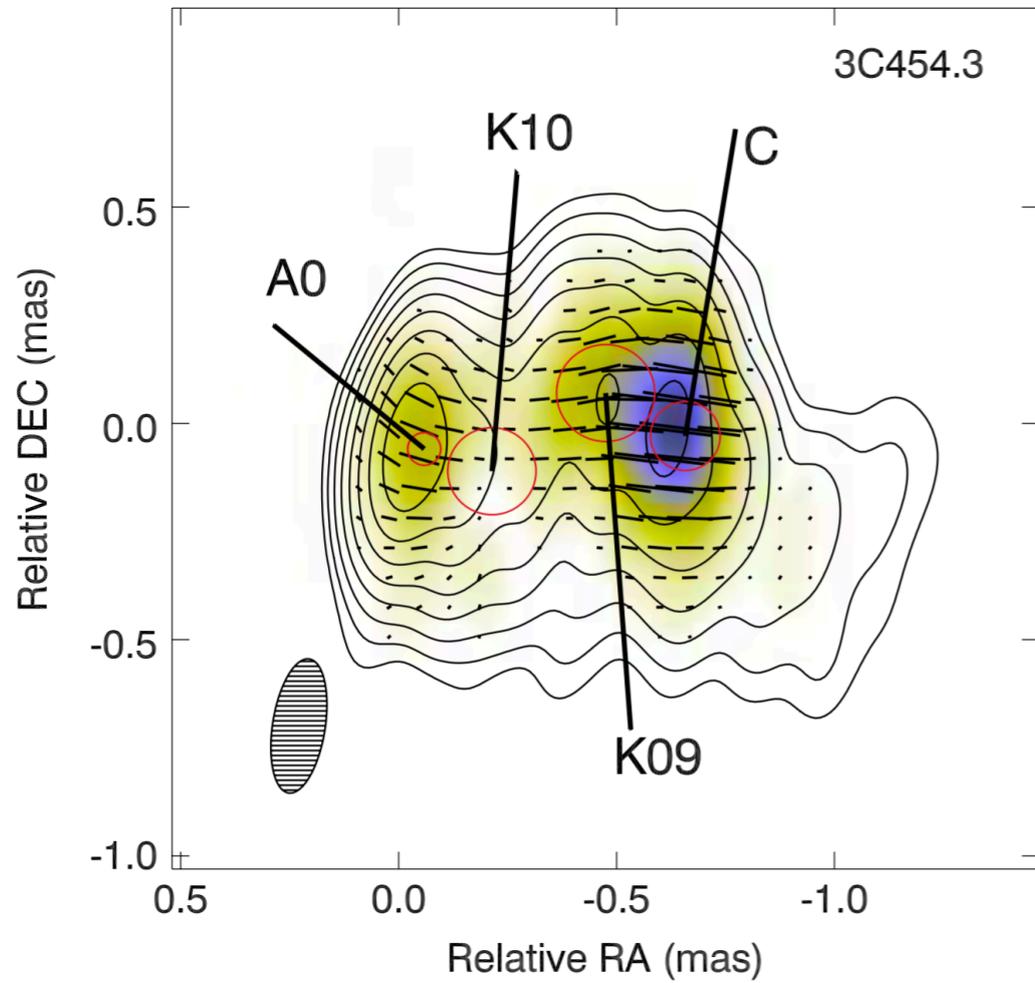
Leon-Tavares et al. (2010)

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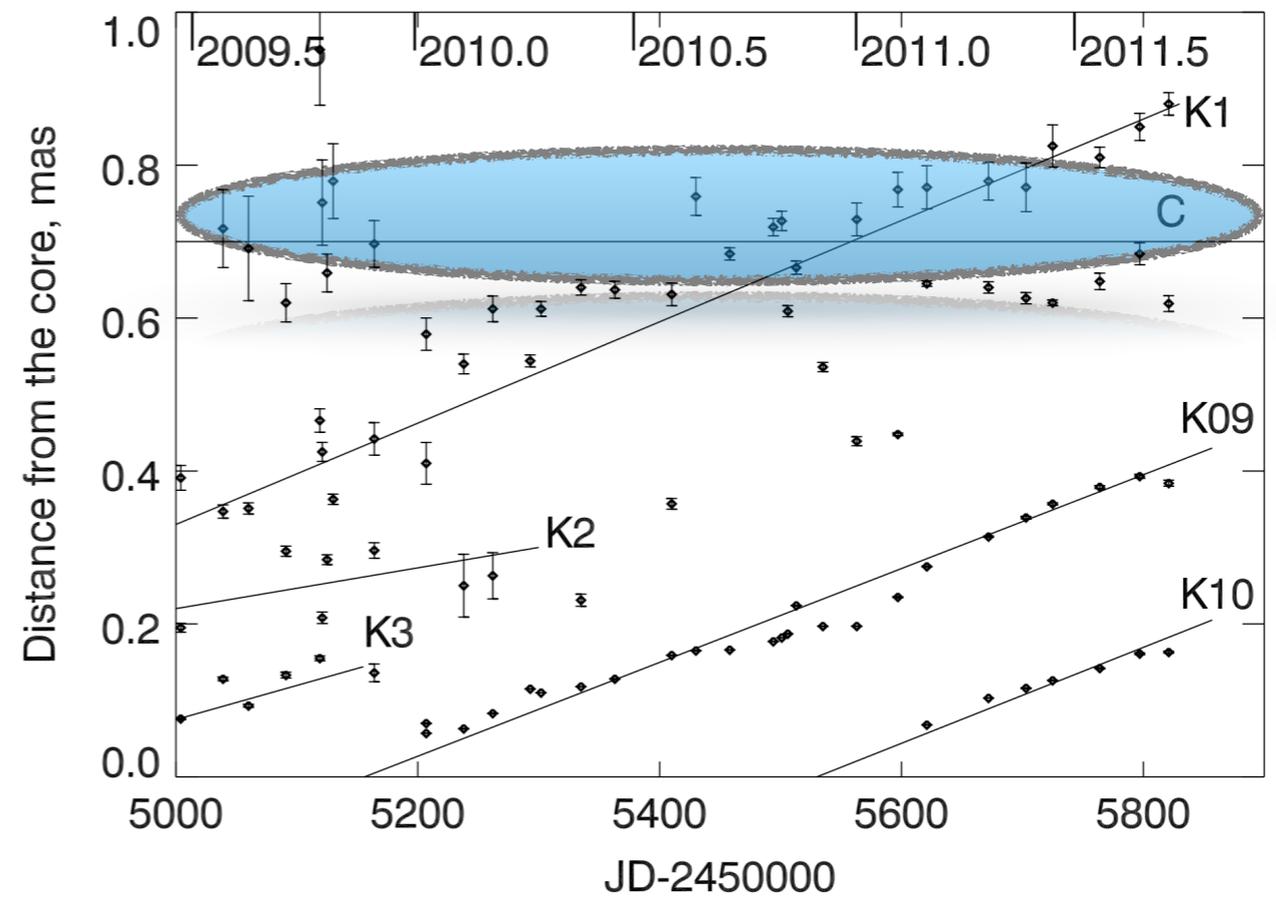
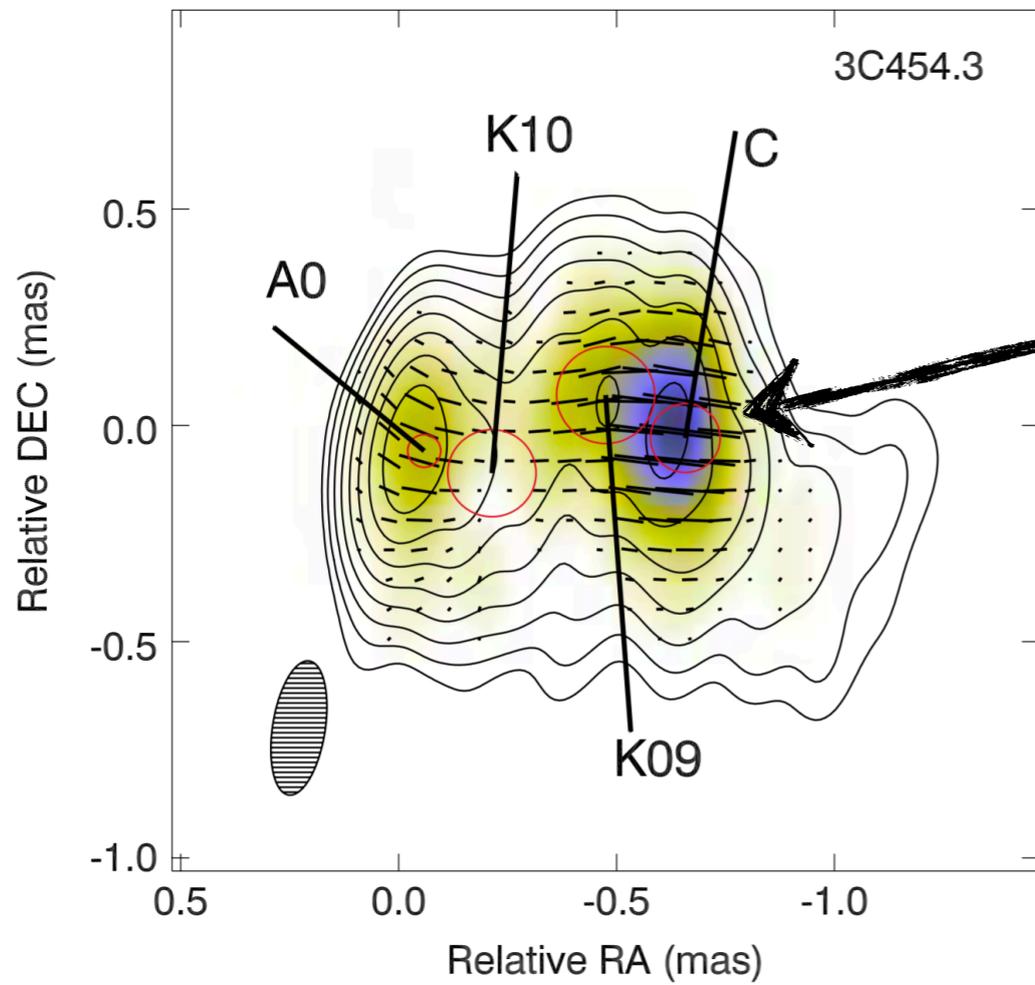
Leon-Tavares et al. (2010)

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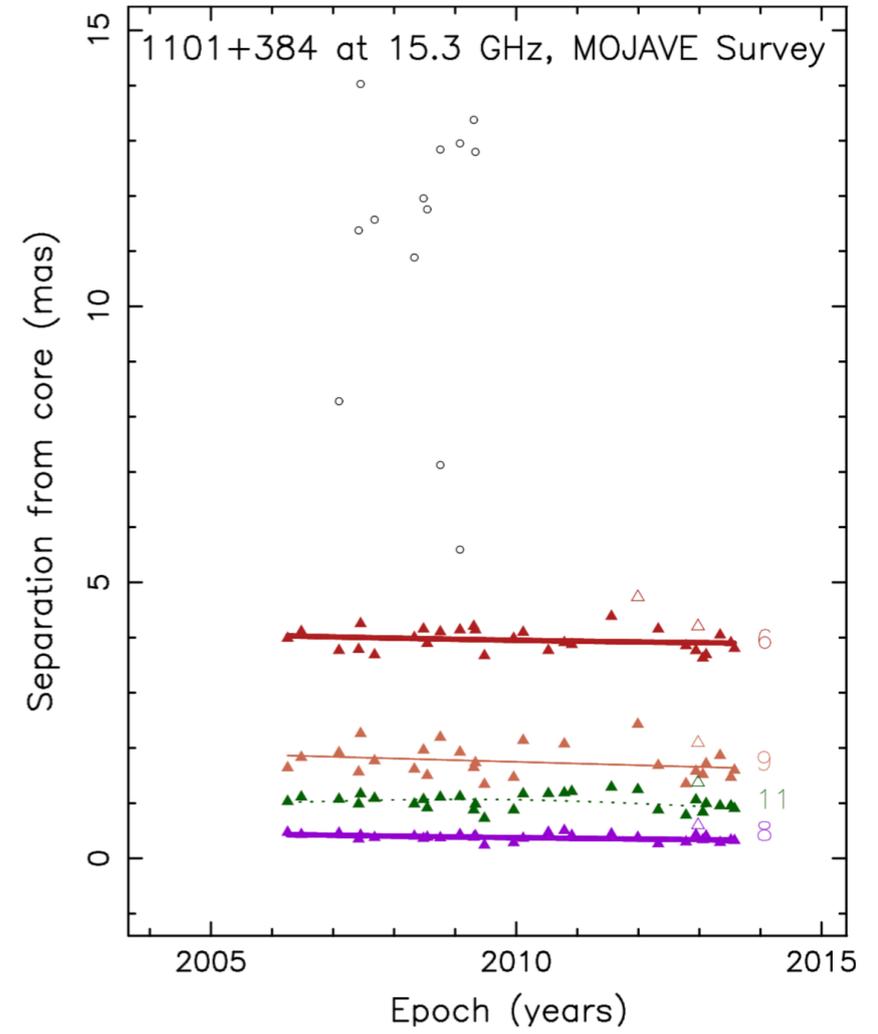
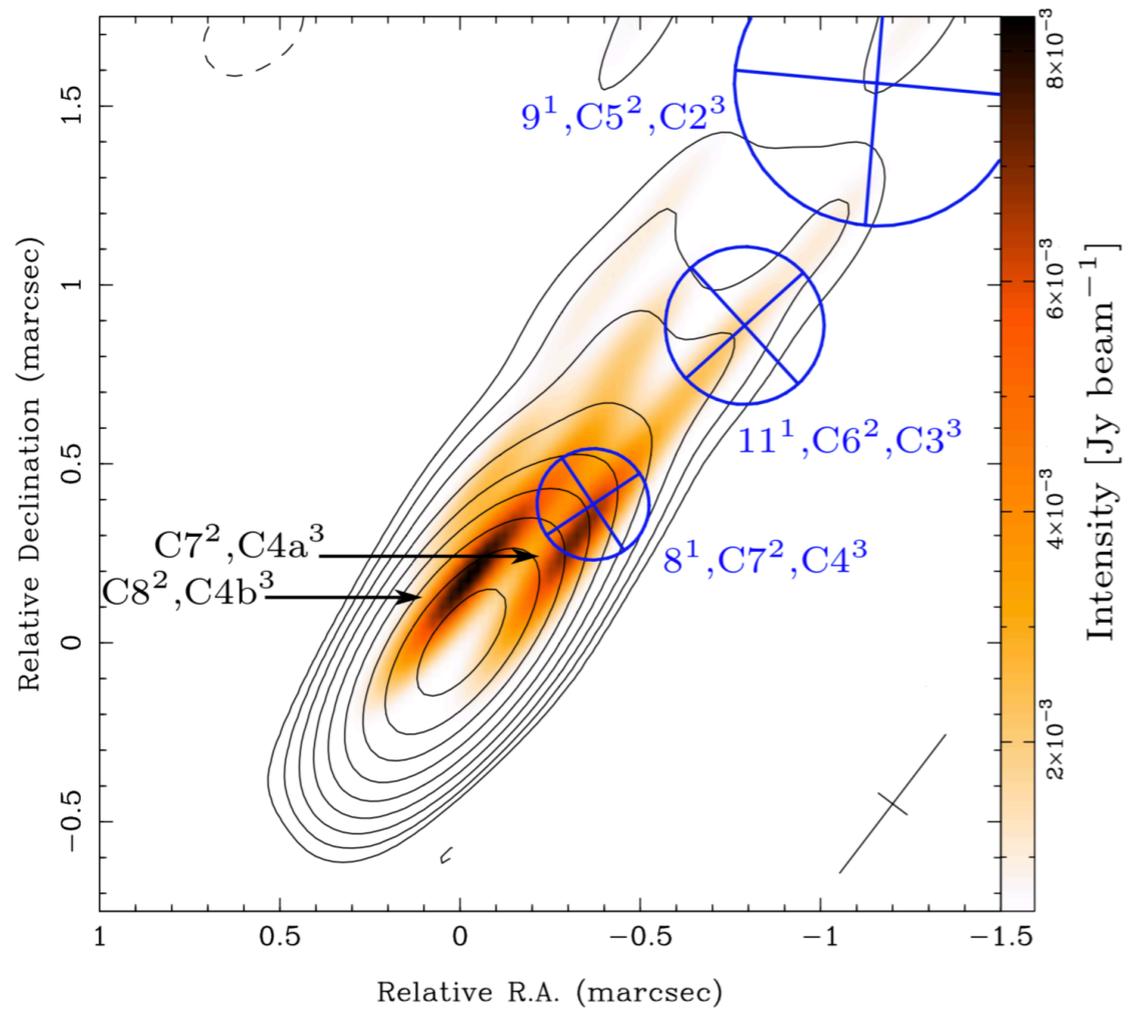
Jorstad et al. (2013)

# 3C 454.3



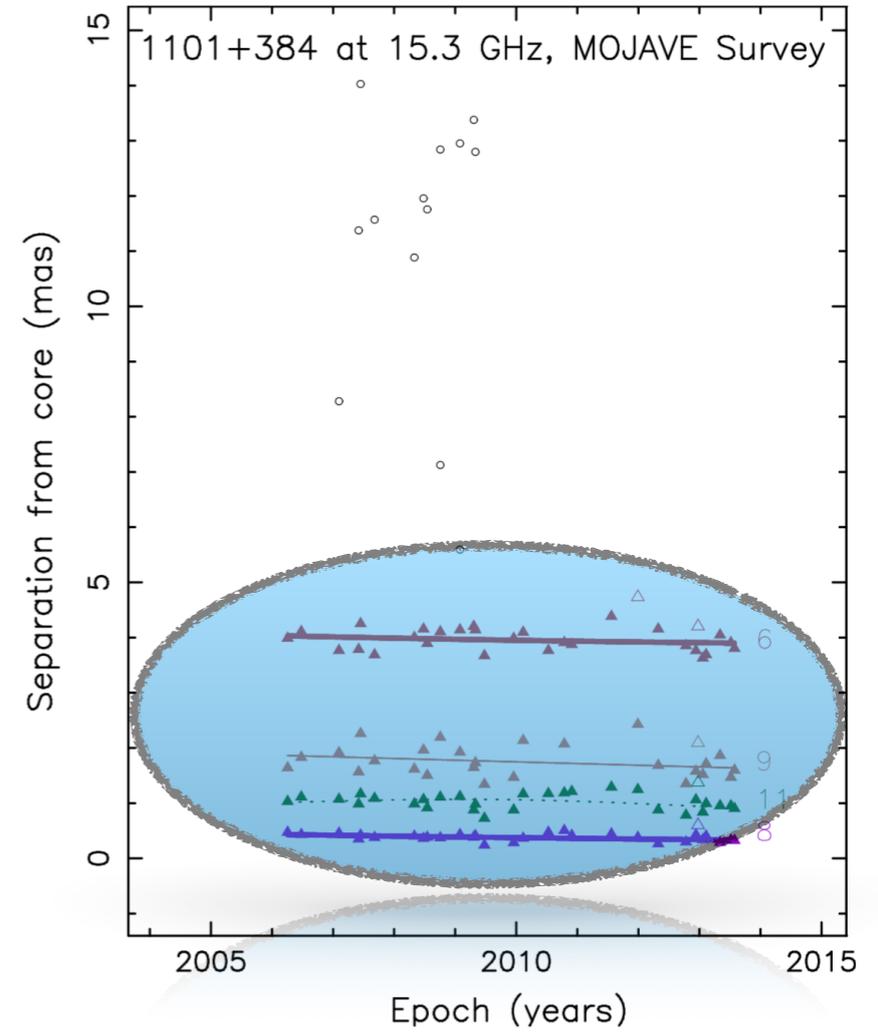
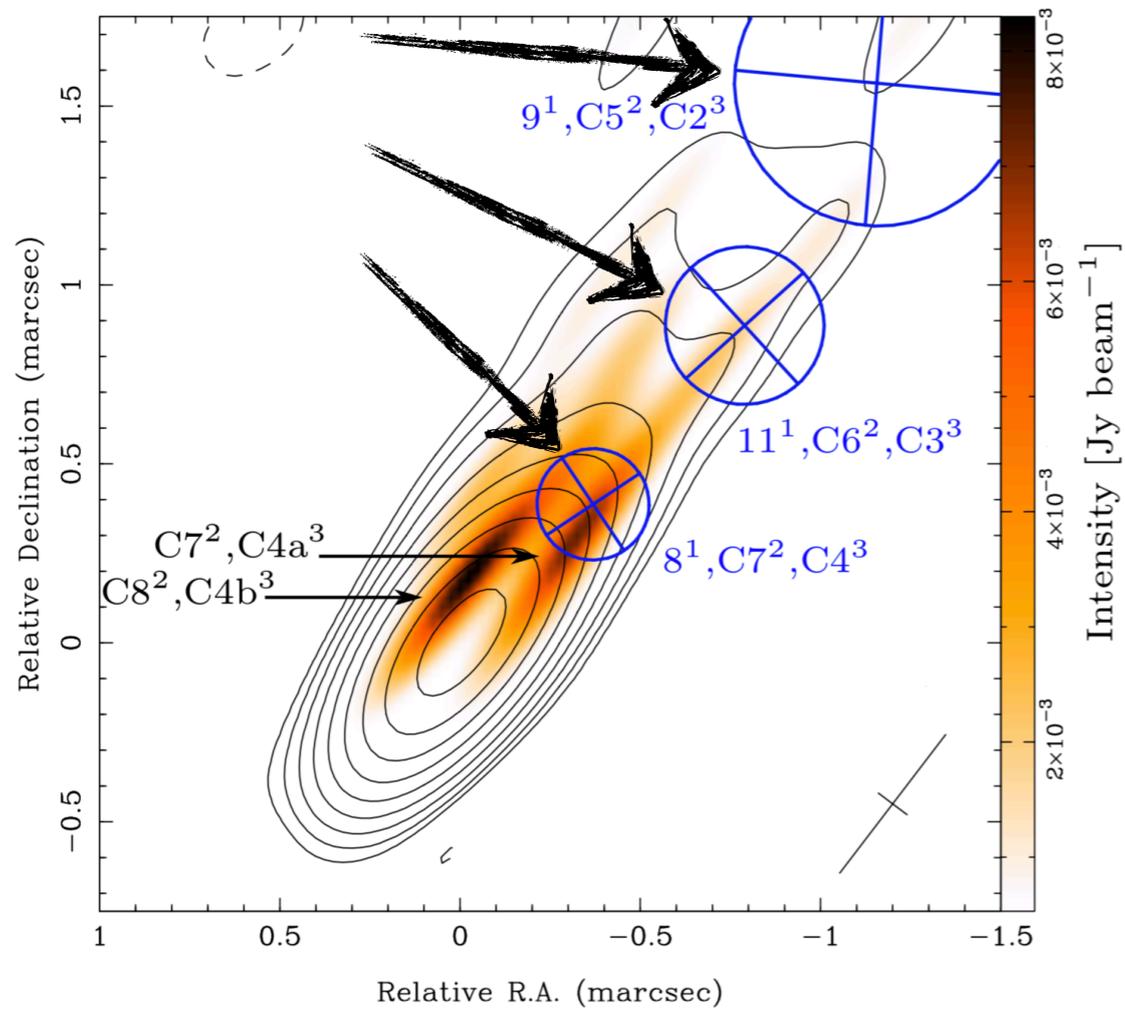
Jorstad et al. (2013)

# Mrk 421



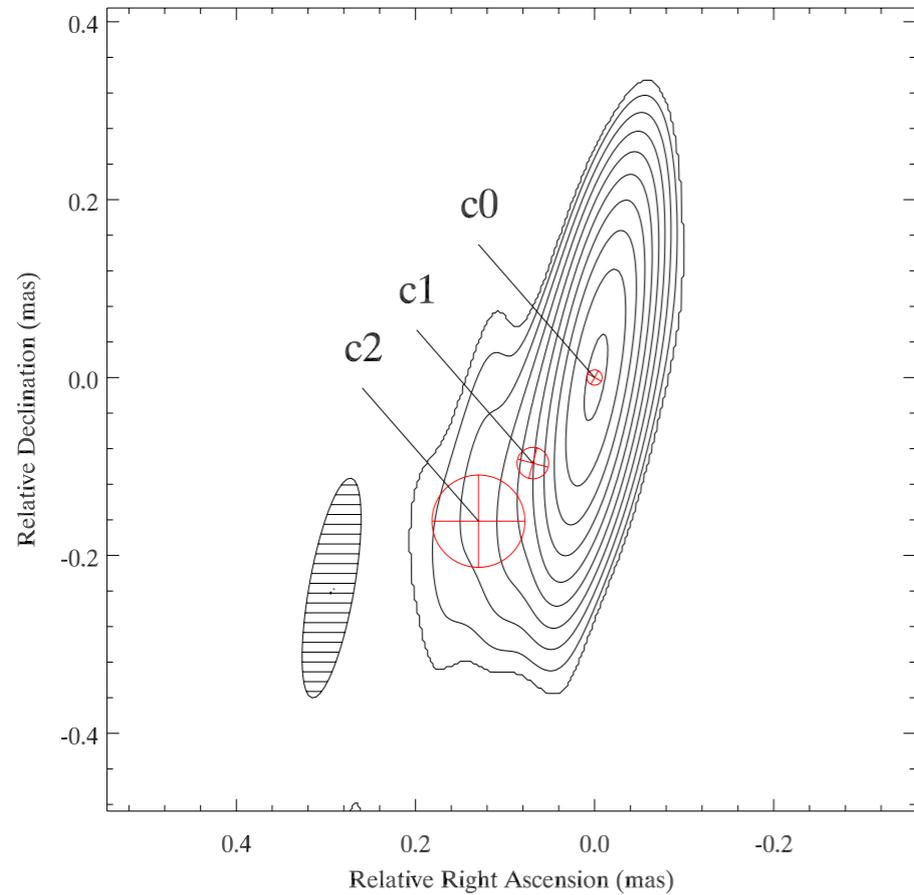
Hervet et al. (2019)

# Mrk 421

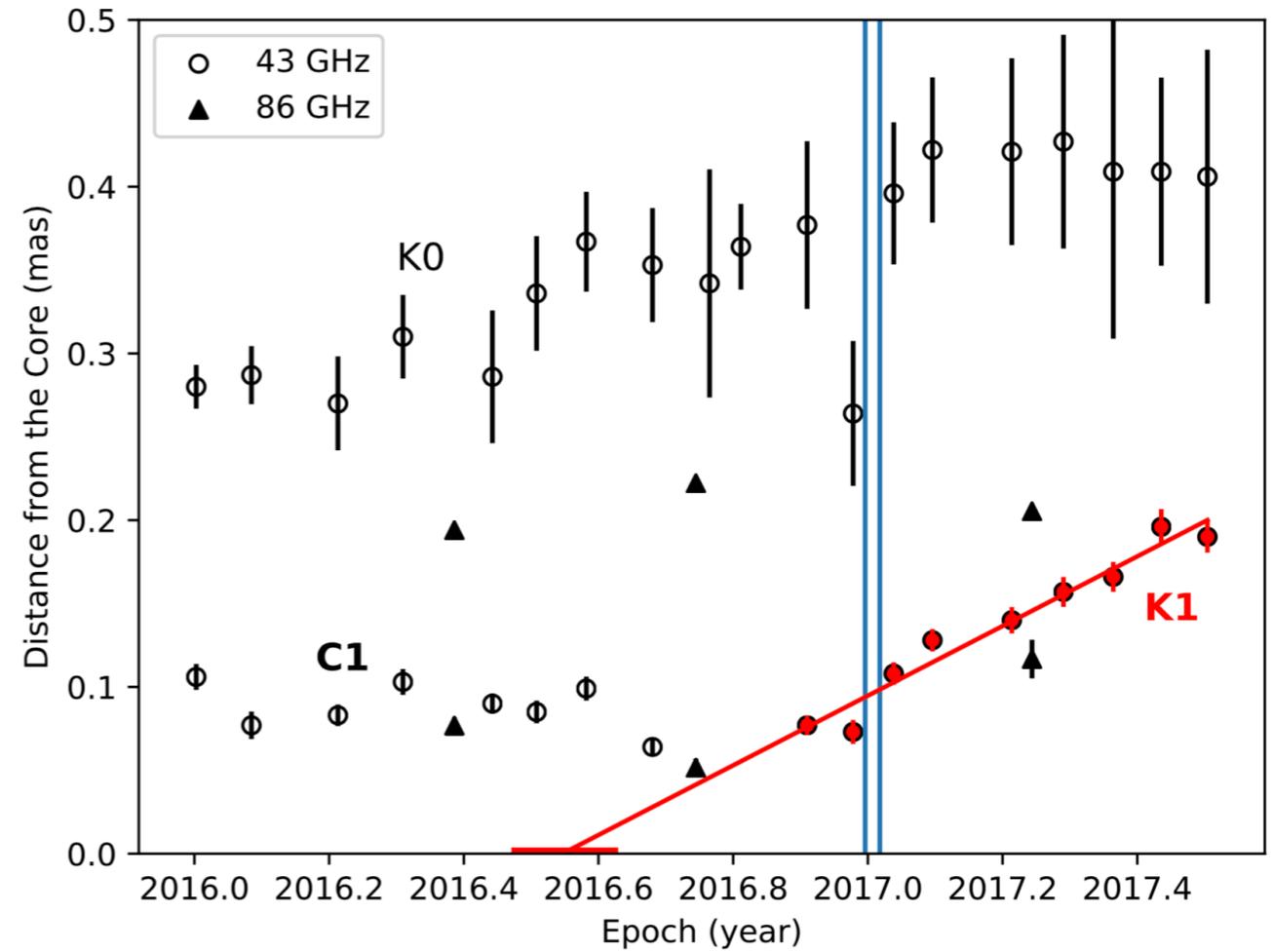


Hervet et al. (2019)

# CTA 102

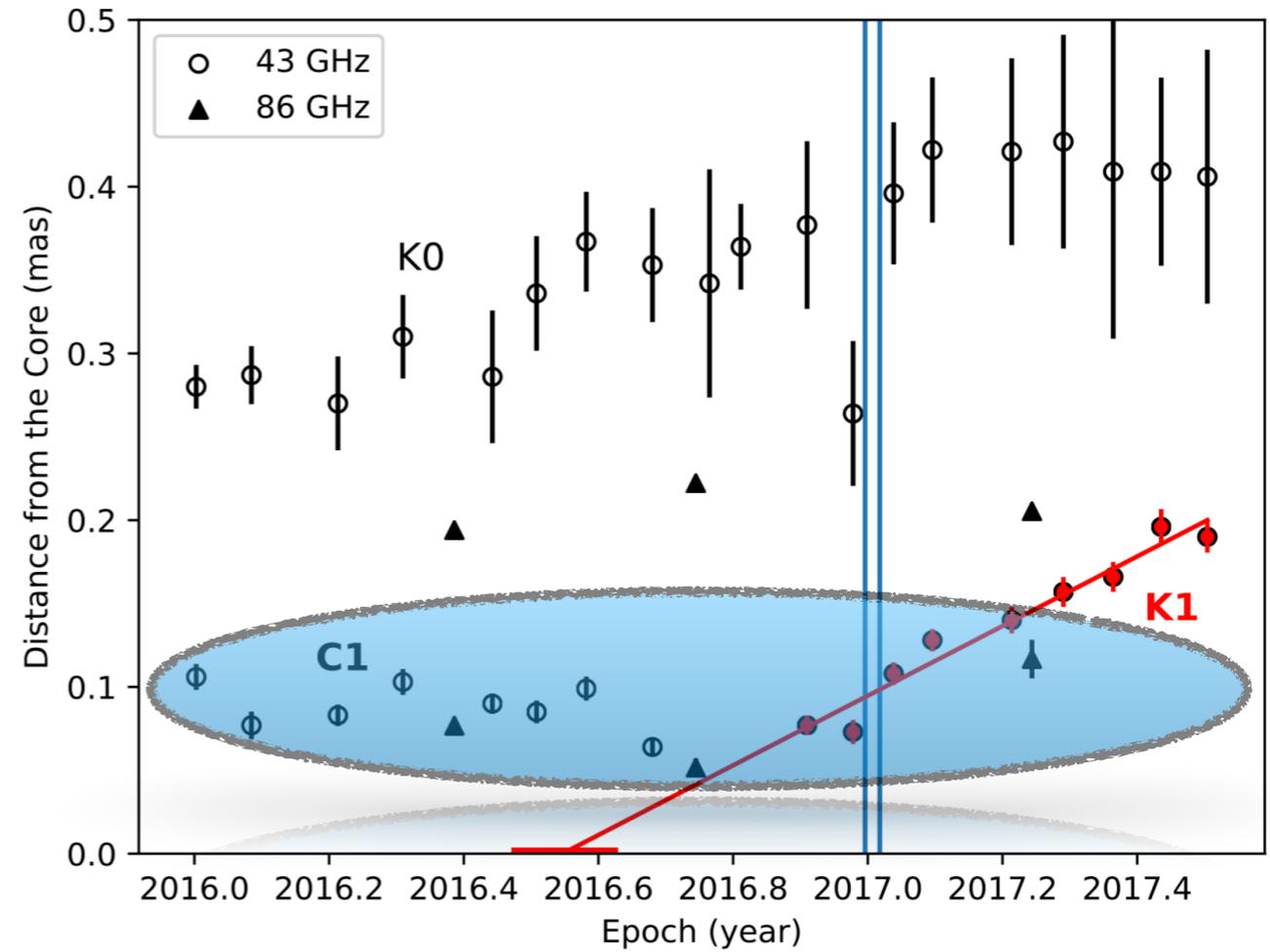
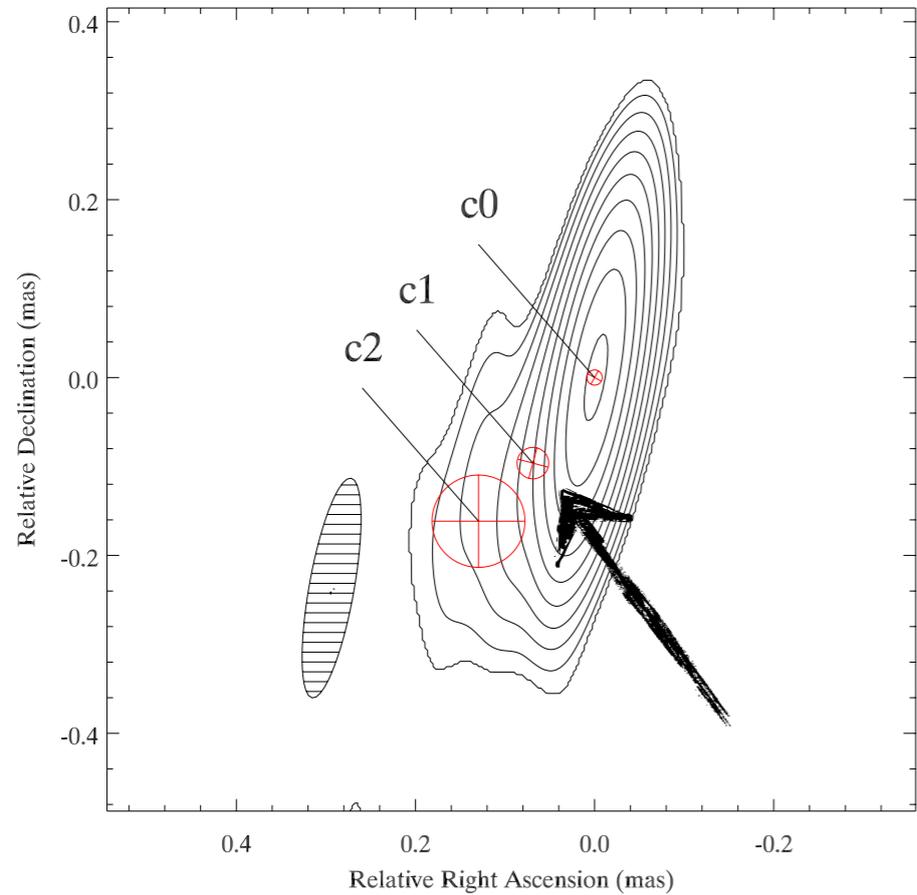


Peak Total Intensity 0.8609 Jy/beam (first cont. at 4.74 mJy/beam)  
 Total Intensity Contours 0.55,0.97,1.71,3.01,5.30,9.34,16.45,28.99,51.08,90% of peak  
 Beam FWHM 0.25x0.05 mas at -10.00 deg.



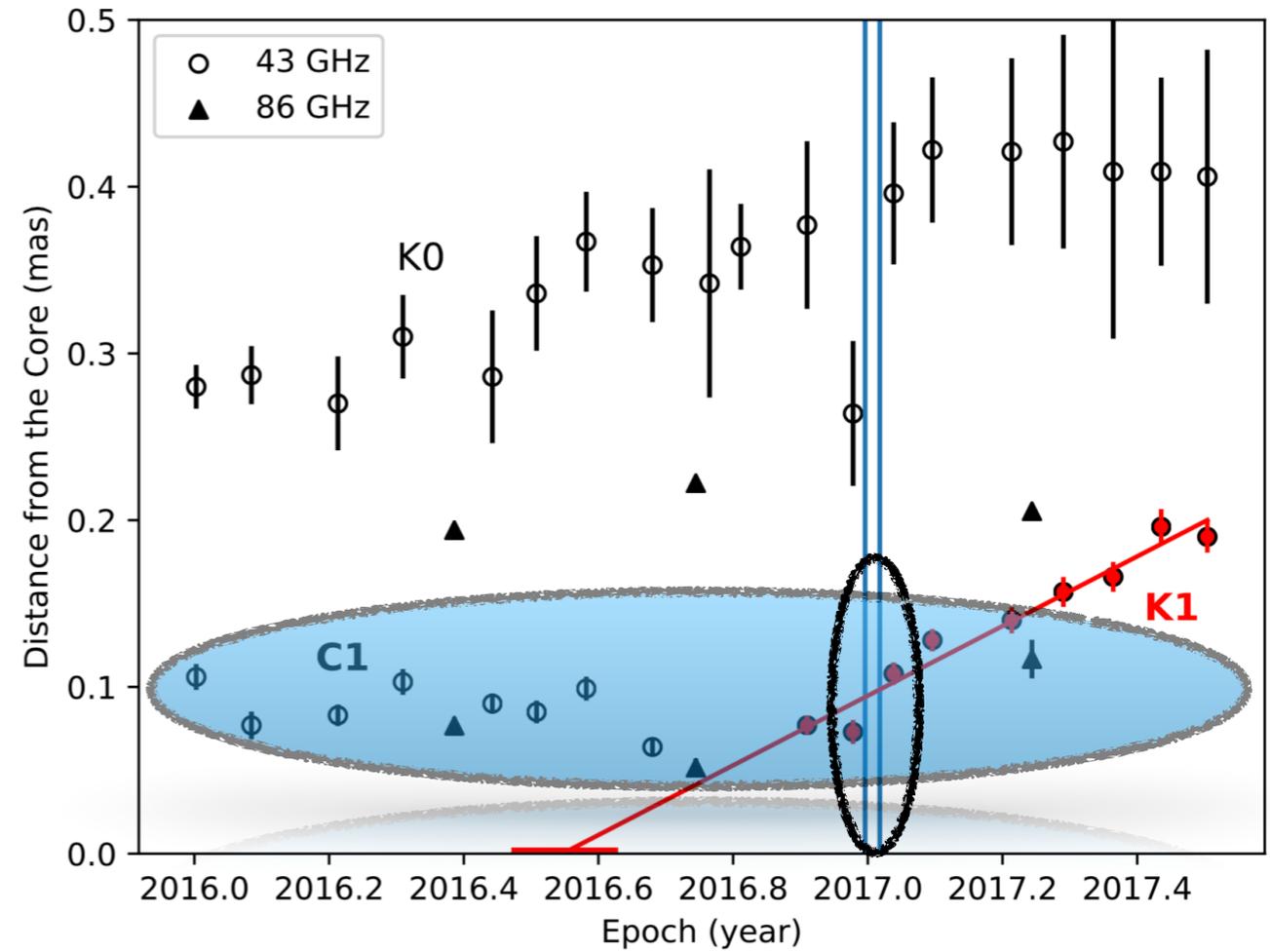
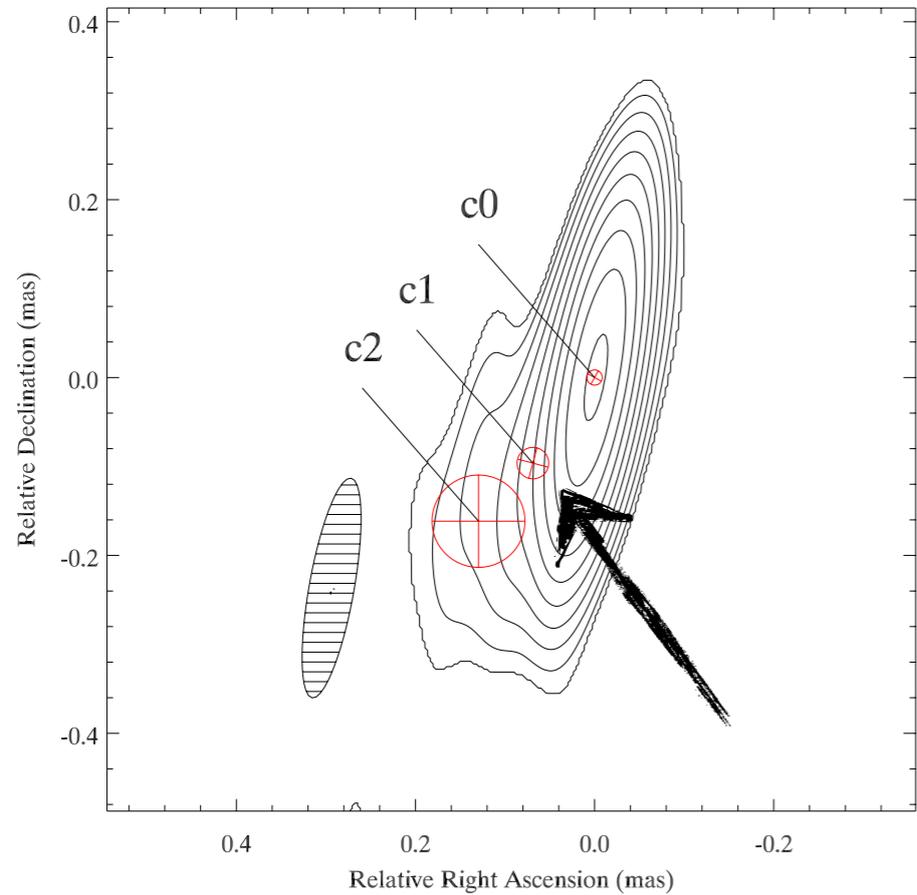
Casadio et al. (2019)

# CTA 102



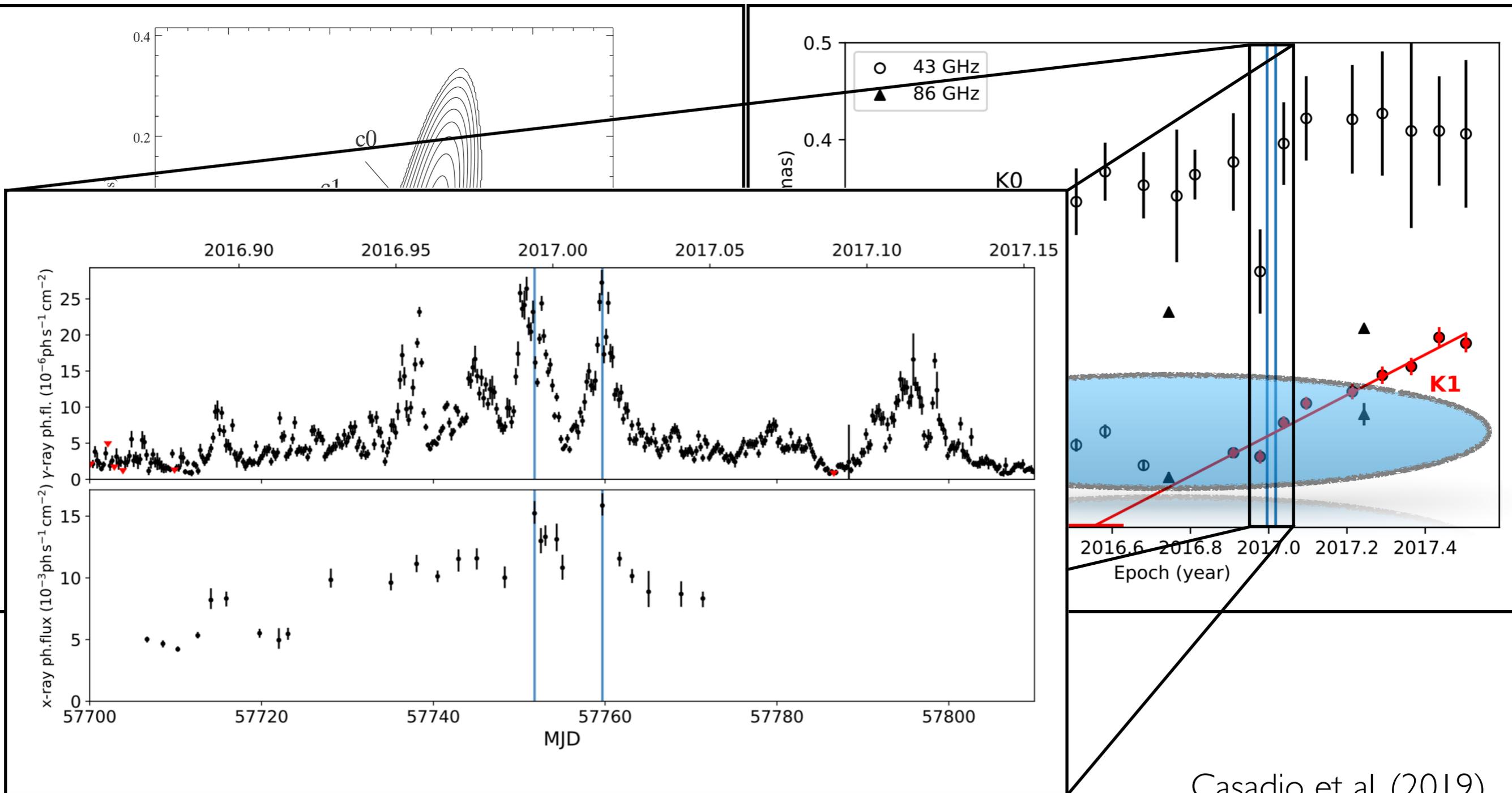
Casadio et al. (2019)

# CTA 102



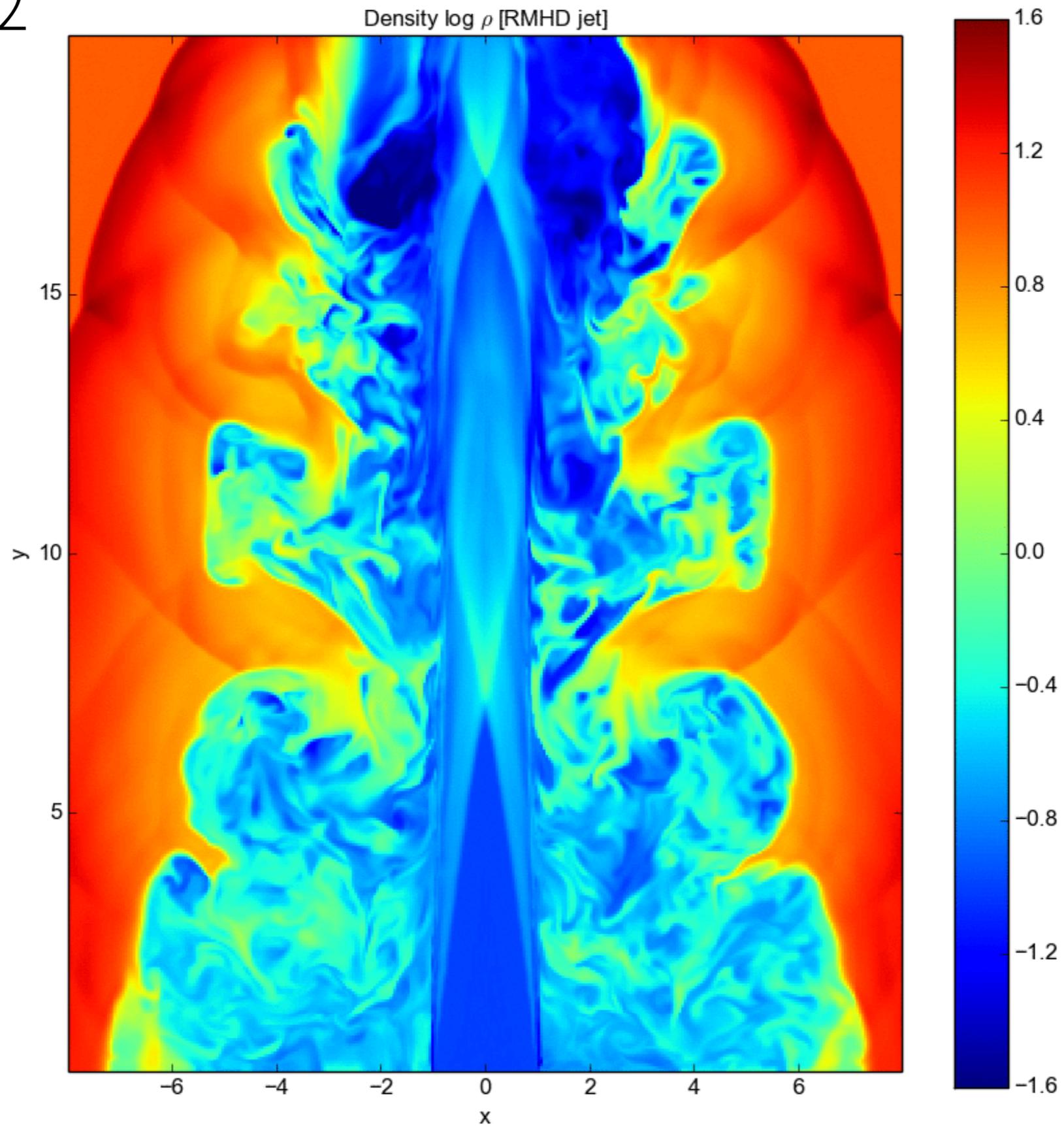
Casadio et al. (2019)

# CTA 102



Casadio et al. (2019)

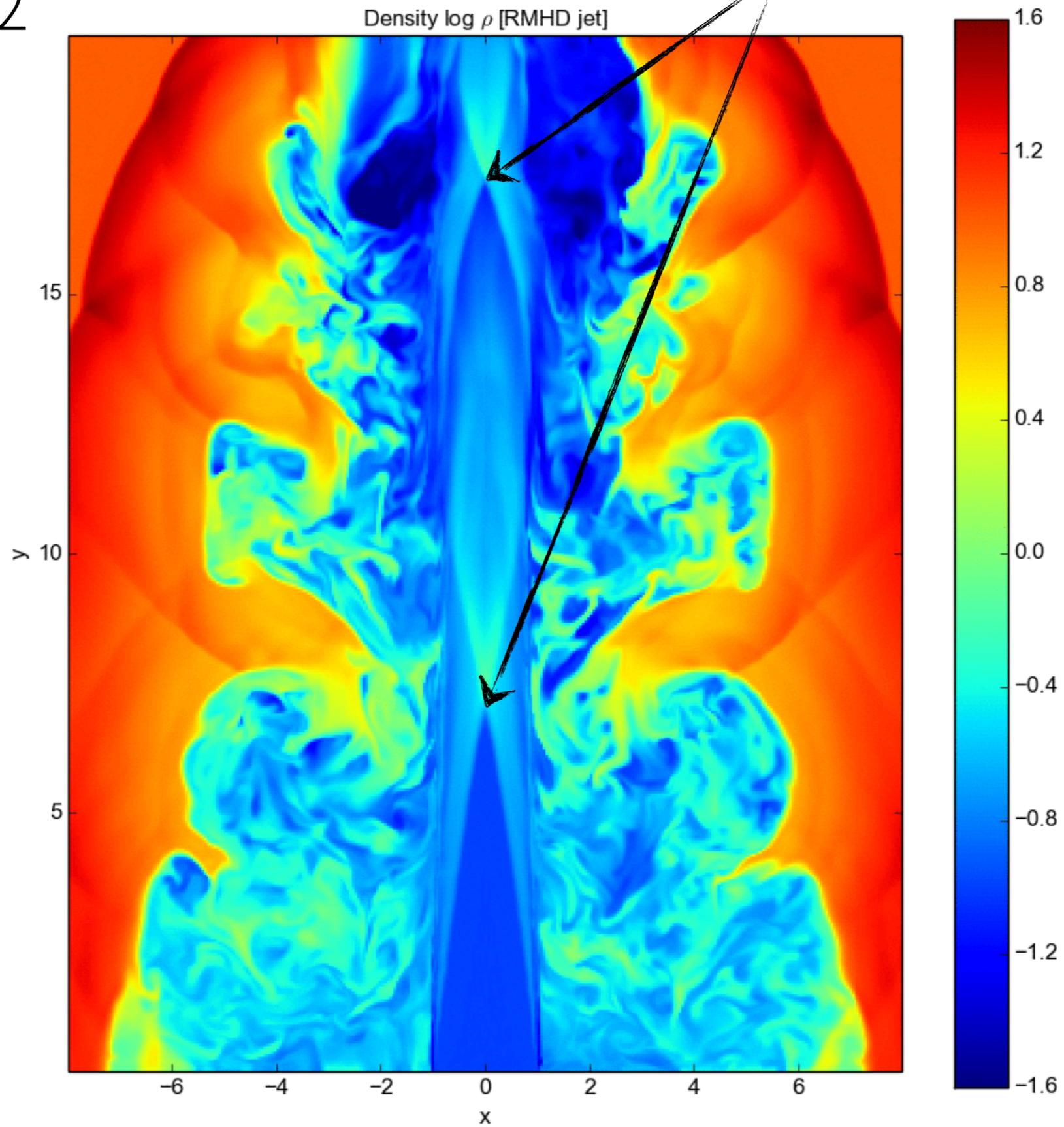
# CTA 102



MacDonald & Casadio (in prep)

CTA 102

Recollimation Shocks

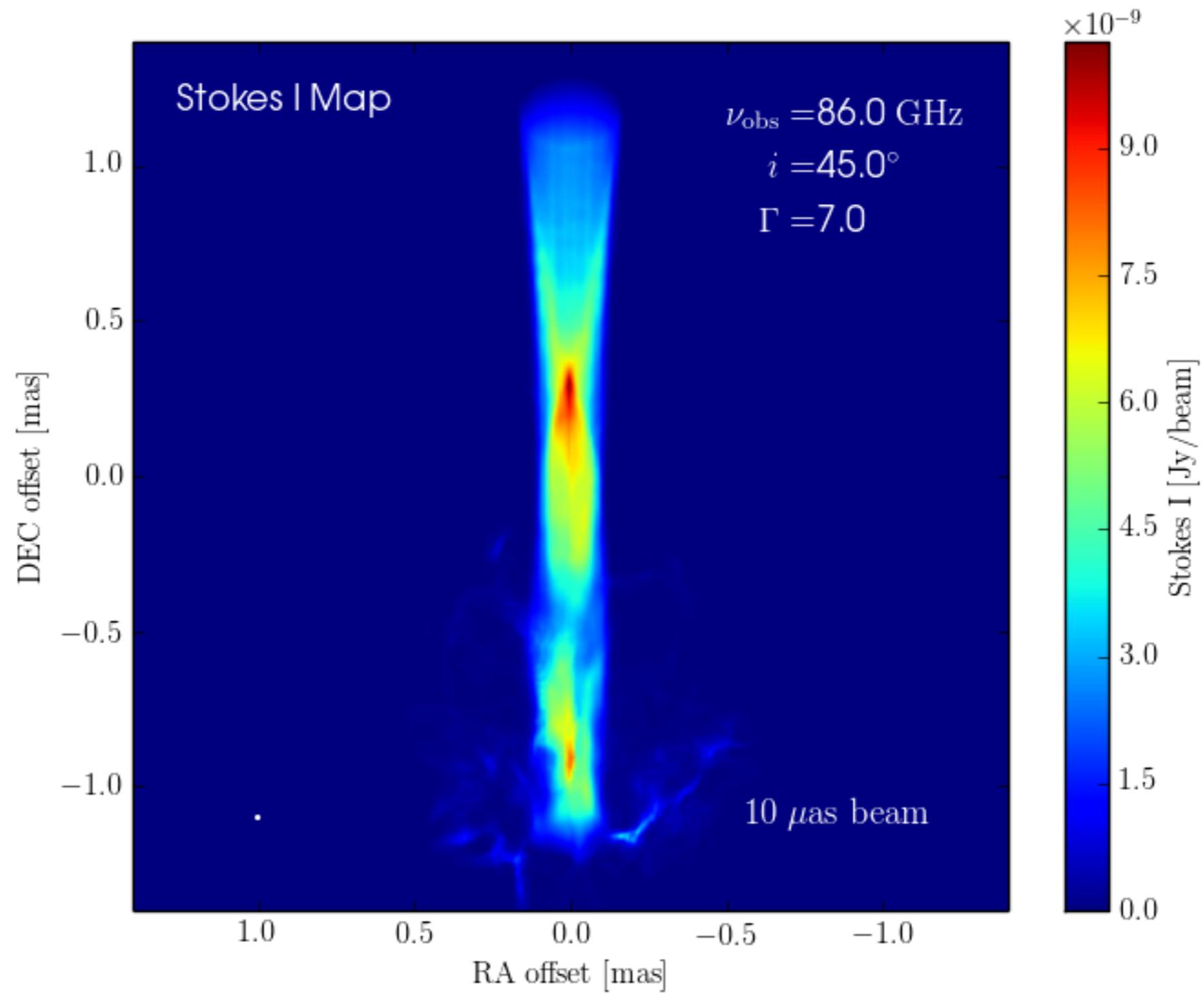


MacDonald & Casadio (in prep)

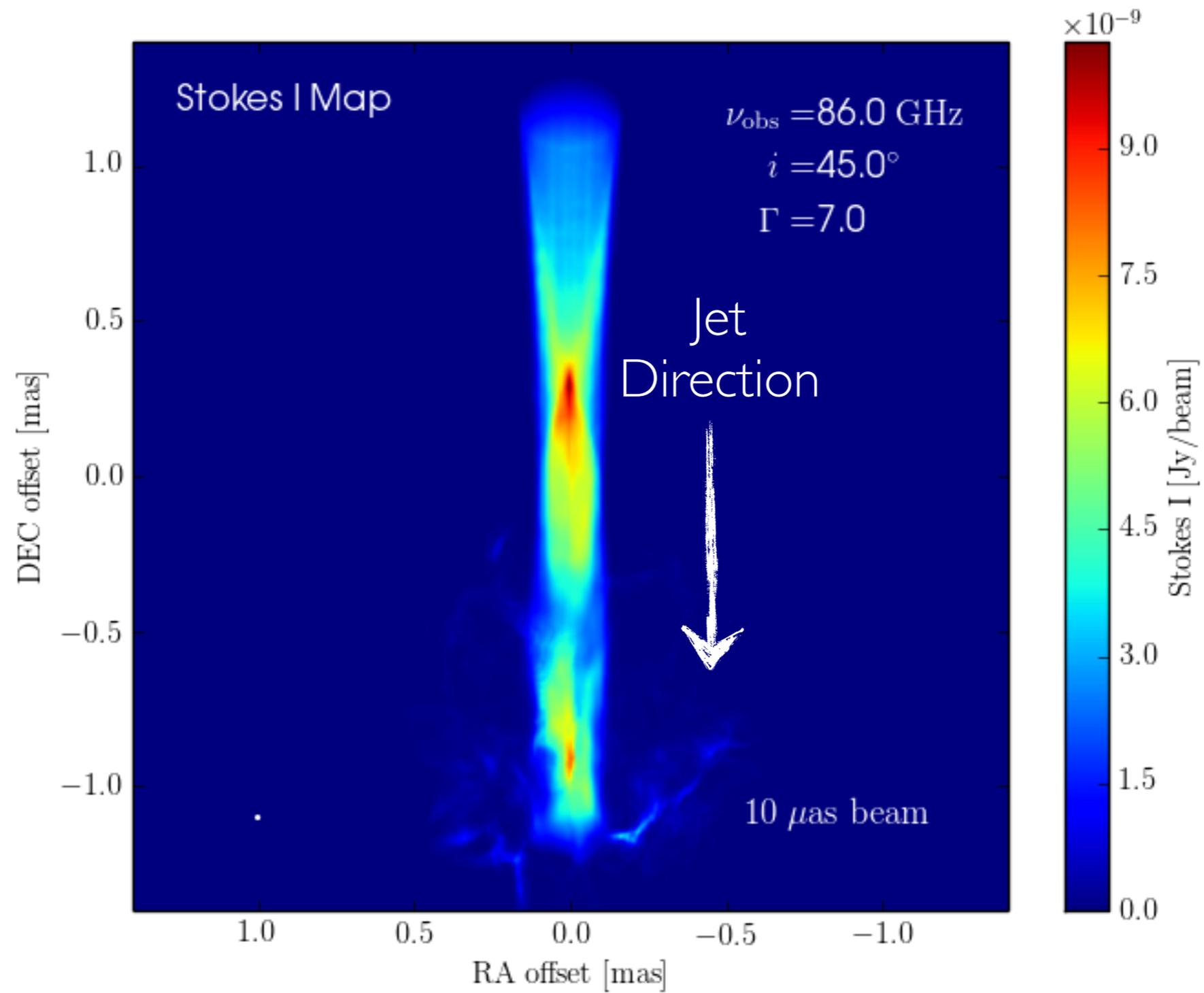


Recollimation Shock

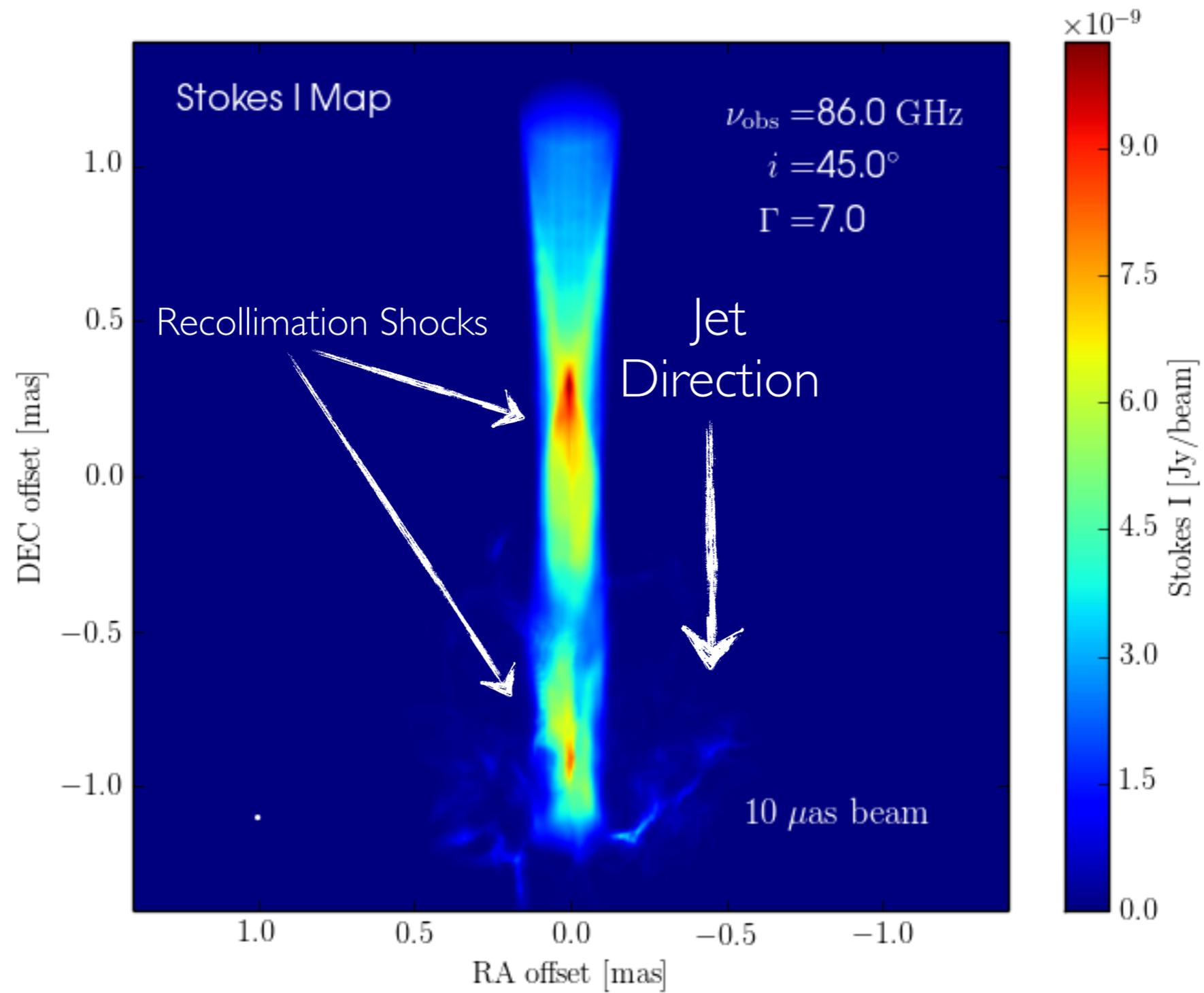
# CTA 102



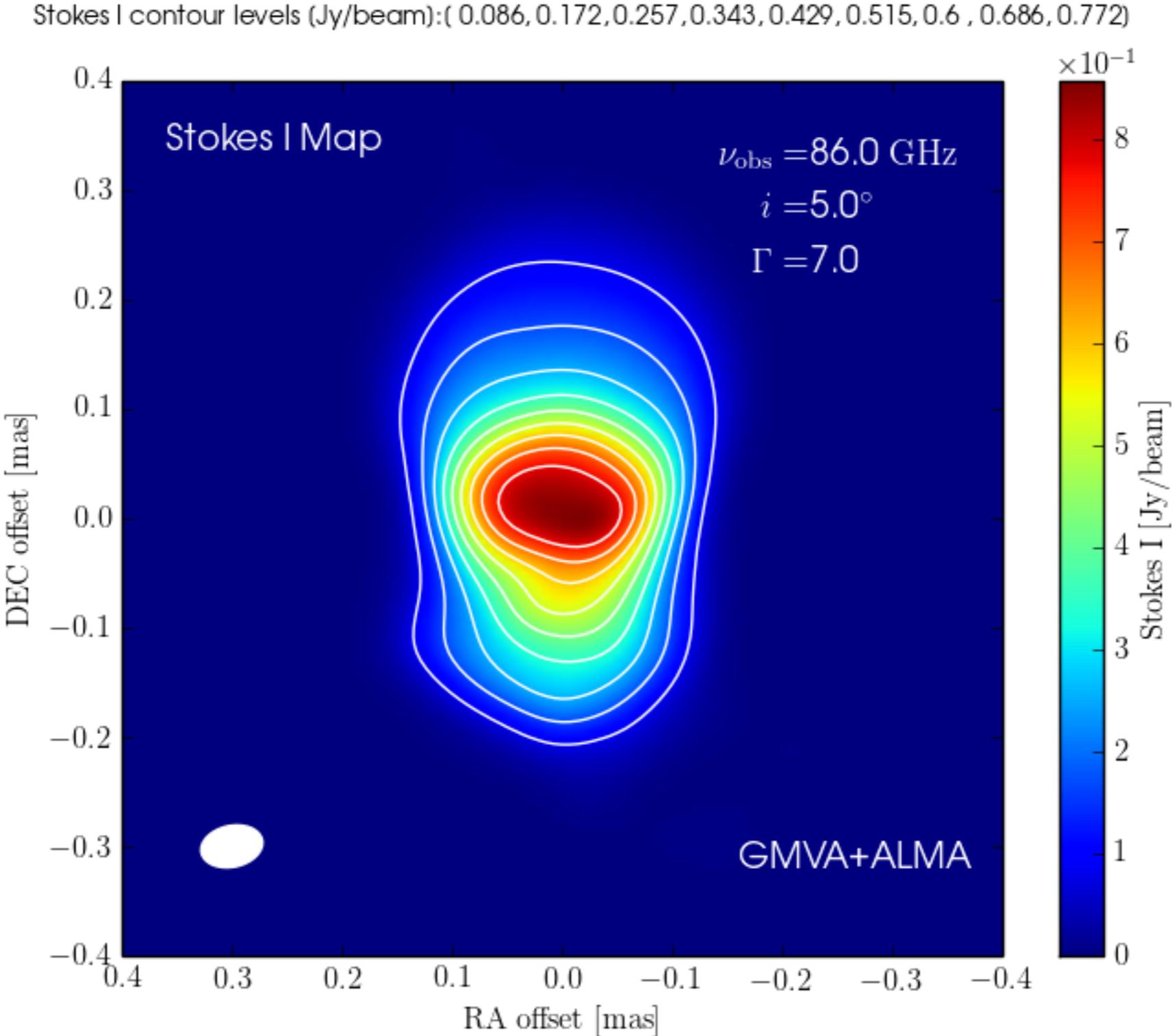
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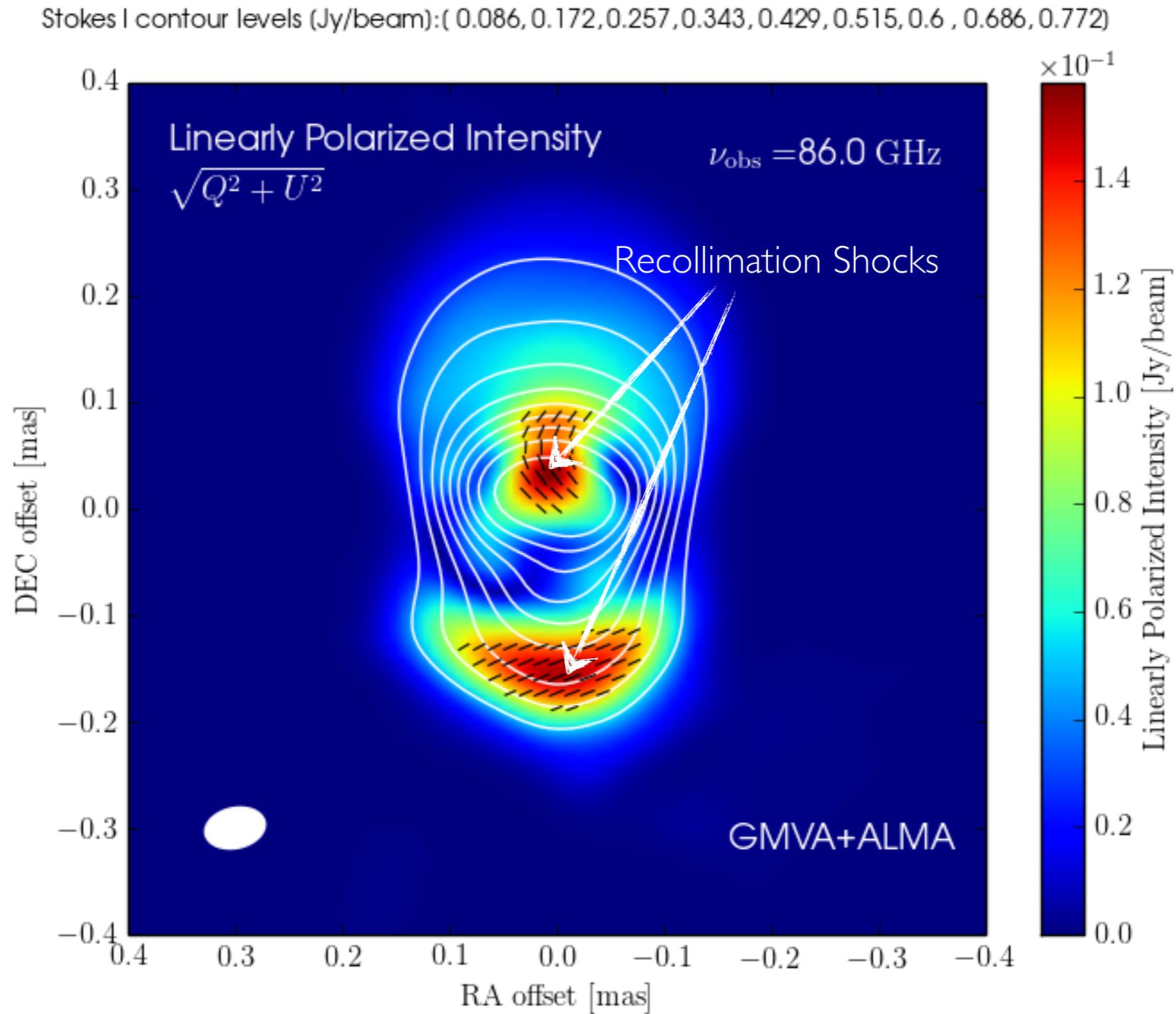
# CTA 102



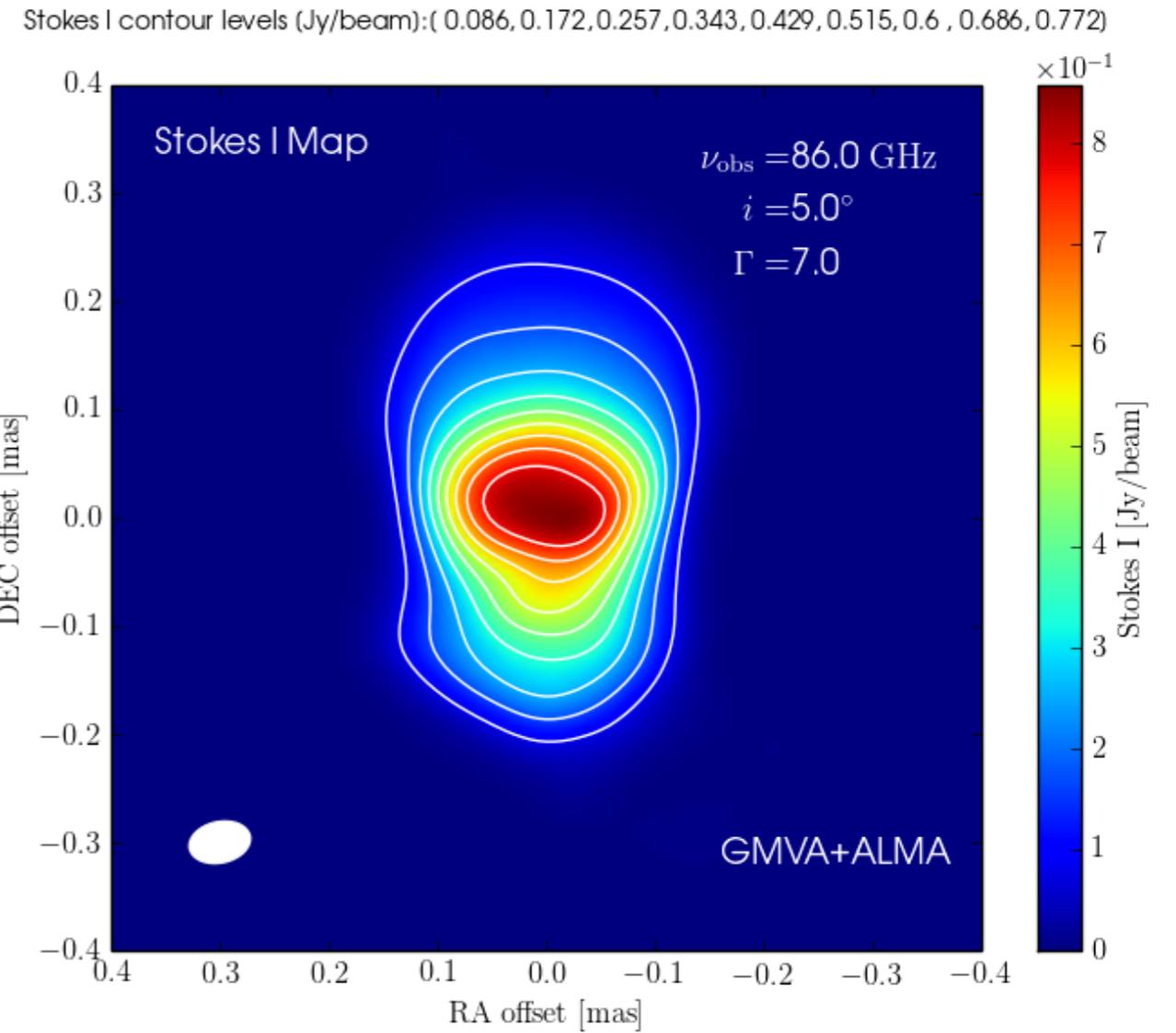
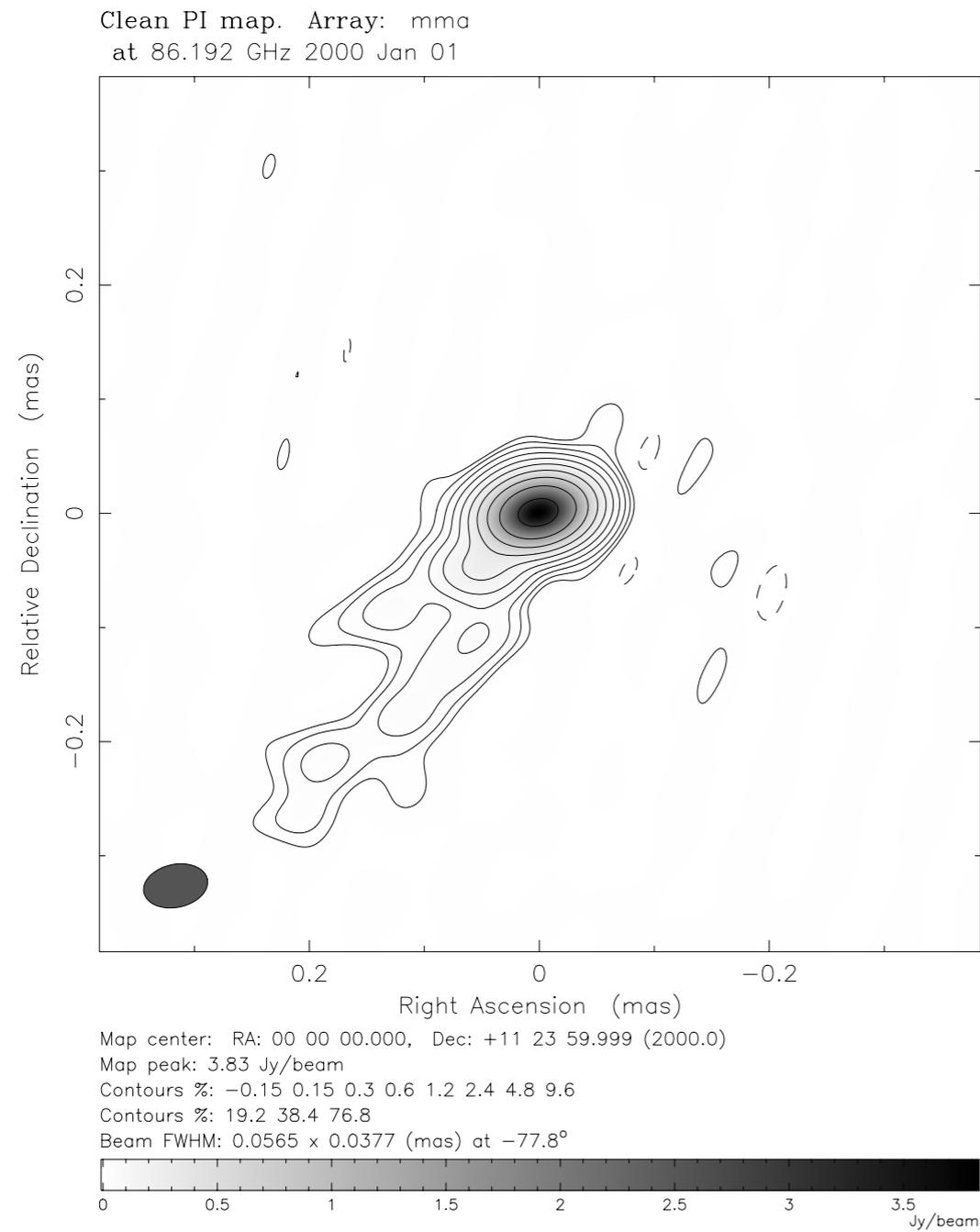
# CTA 102



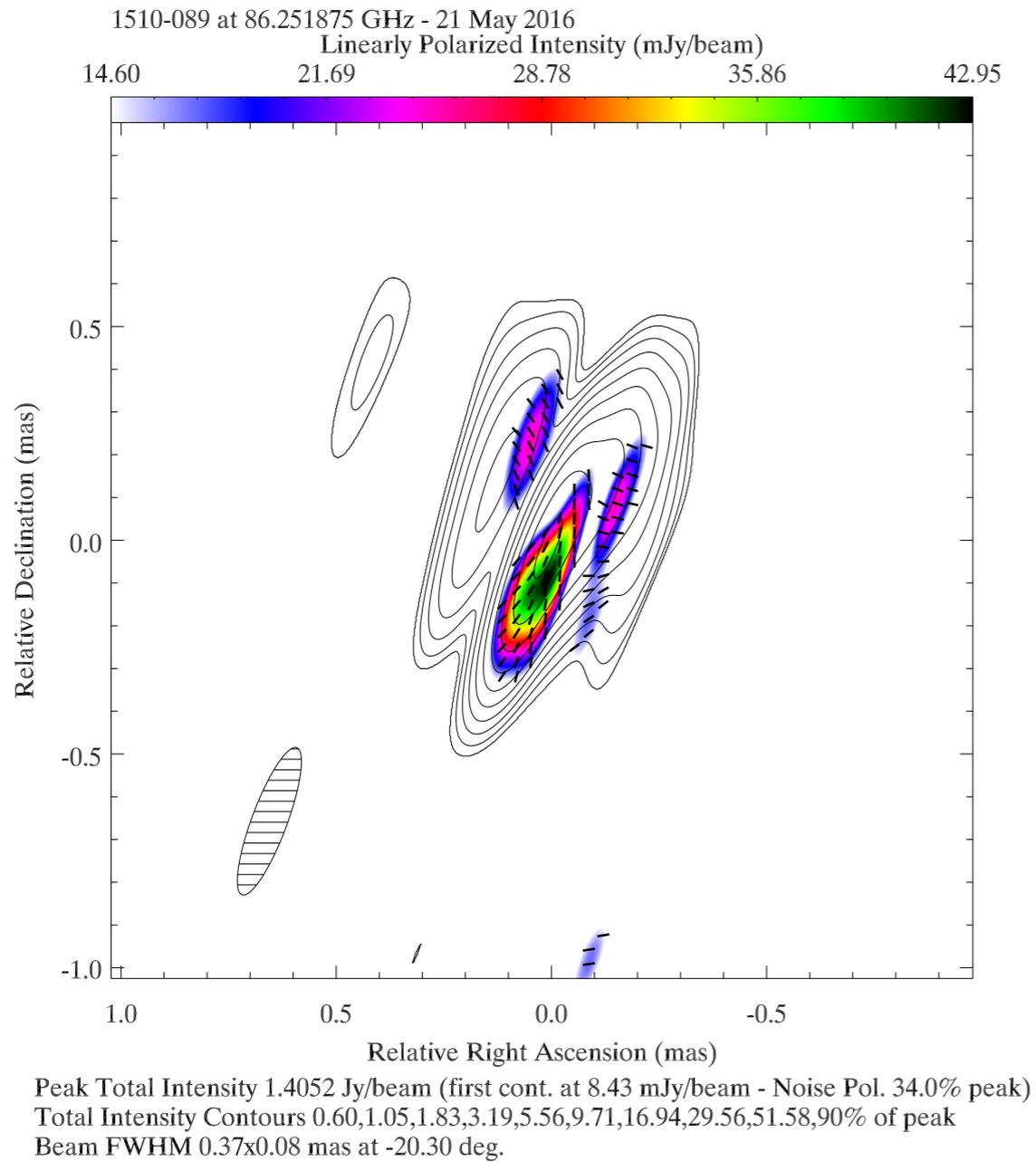
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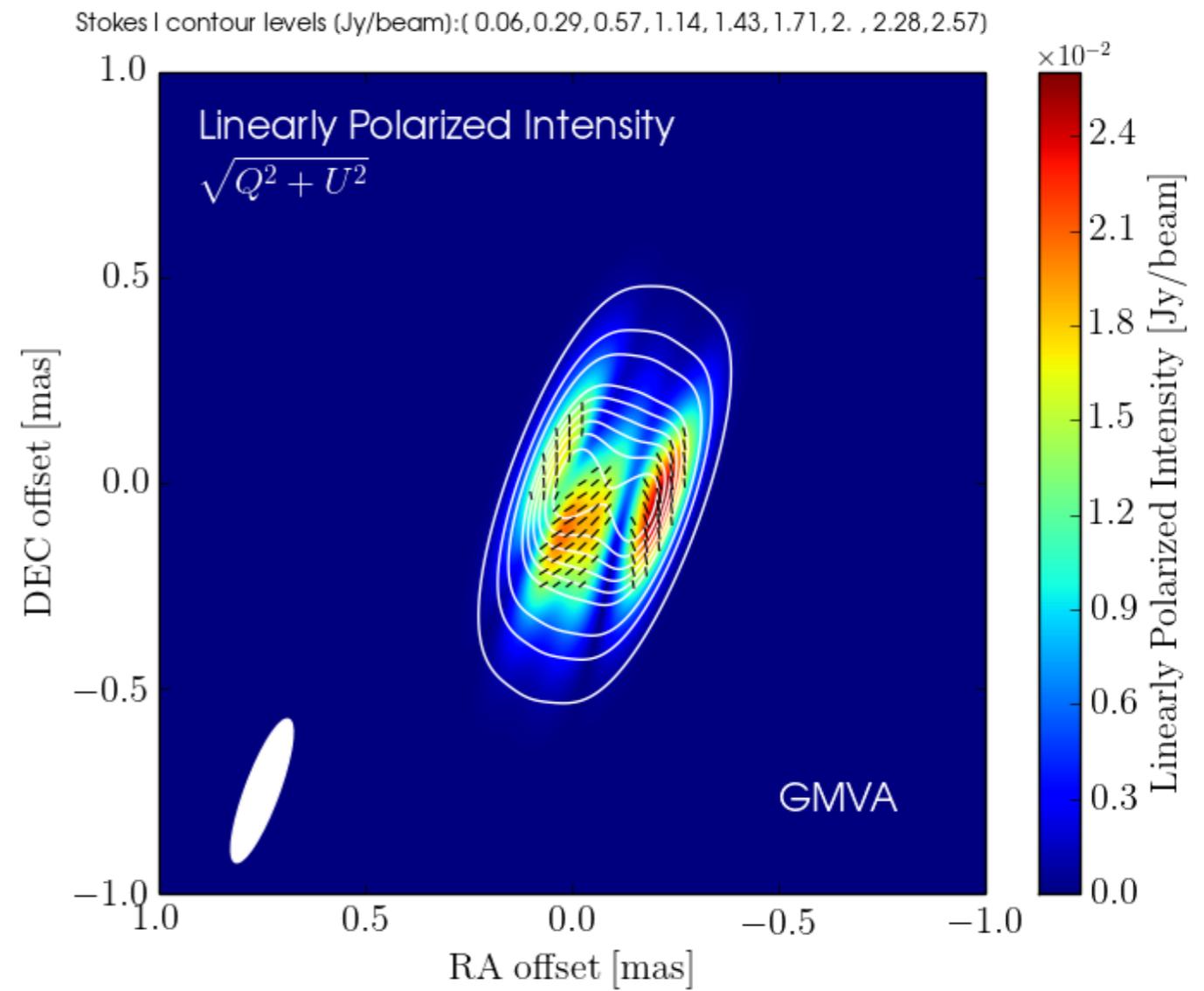
# CTA 102



# PKS 1510-089



Casadio et al. (2017)



MacDonald & Casadio (in prep)

# Phased ALMA



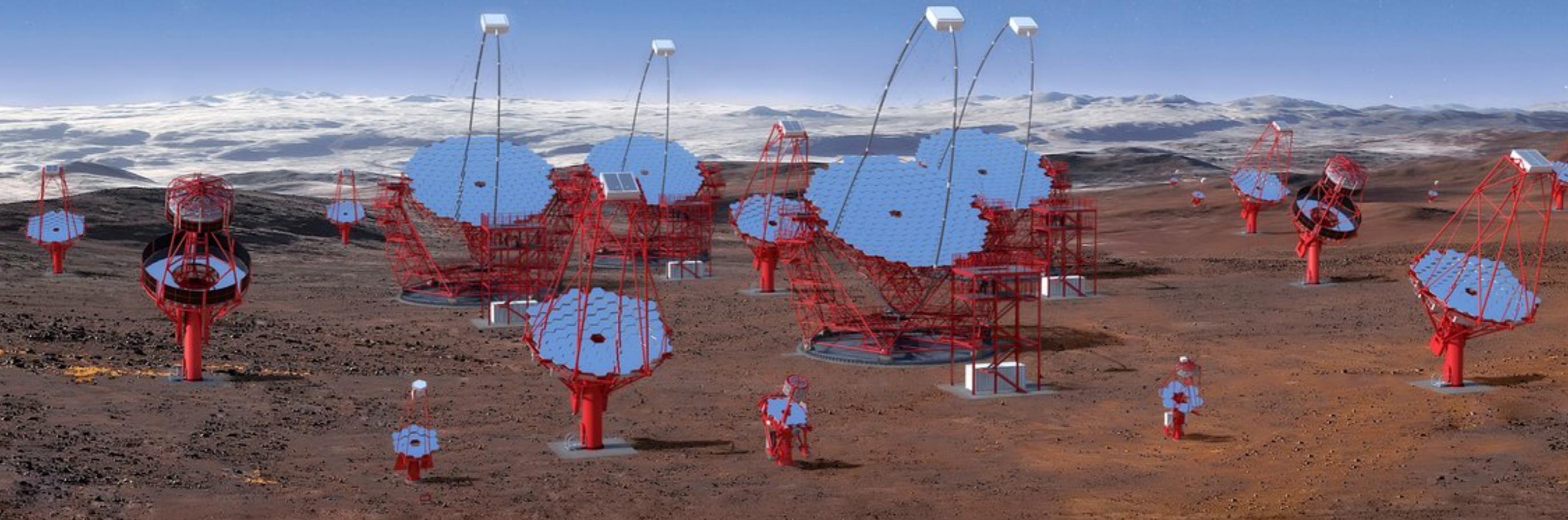
Image Credit: [almaobservatory.org](http://almaobservatory.org)

# Global VLBI



Image Credit: ESO/ L. Calçada

# Cherenkov Telescope Array



# RMHD Jet Modeling

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

$$\rho_e = \frac{m_e c^2}{\epsilon_e} \int_{\gamma_{\min}}^{\gamma_{\max}} n(\gamma) \gamma d\gamma$$

# RMHD Jet Modeling

From the Macro...

$$\begin{array}{l} \rho \\ \rho_e \end{array} = \begin{array}{l} \frac{m_p}{\zeta_e} \int_{\gamma_{\min}}^{\gamma_{\max}} n(\gamma) d\gamma \\ \frac{m_e c^2}{\epsilon_e} \int_{\gamma_{\min}}^{\gamma_{\max}} n(\gamma) \gamma d\gamma \end{array}$$

# RMHD Jet Modeling

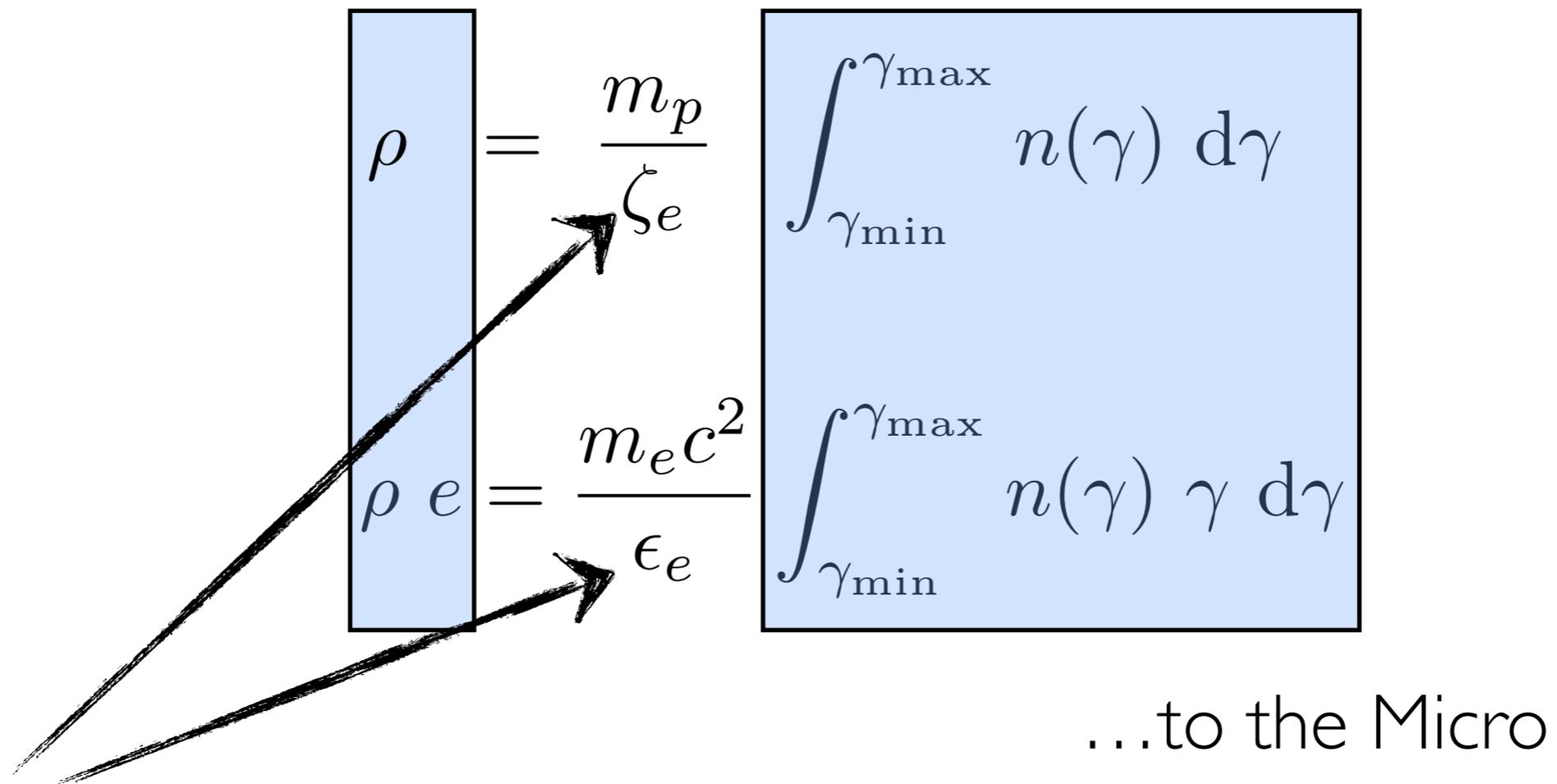
From the Macro...

$$\begin{array}{l} \rho \\ \rho_e \end{array} = \begin{array}{l} \frac{m_p}{\zeta_e} \\ \frac{m_e c^2}{\epsilon_e} \end{array} \int_{\gamma_{\min}}^{\gamma_{\max}} \begin{array}{l} n(\gamma) d\gamma \\ n(\gamma) \gamma d\gamma \end{array}$$

...to the Micro

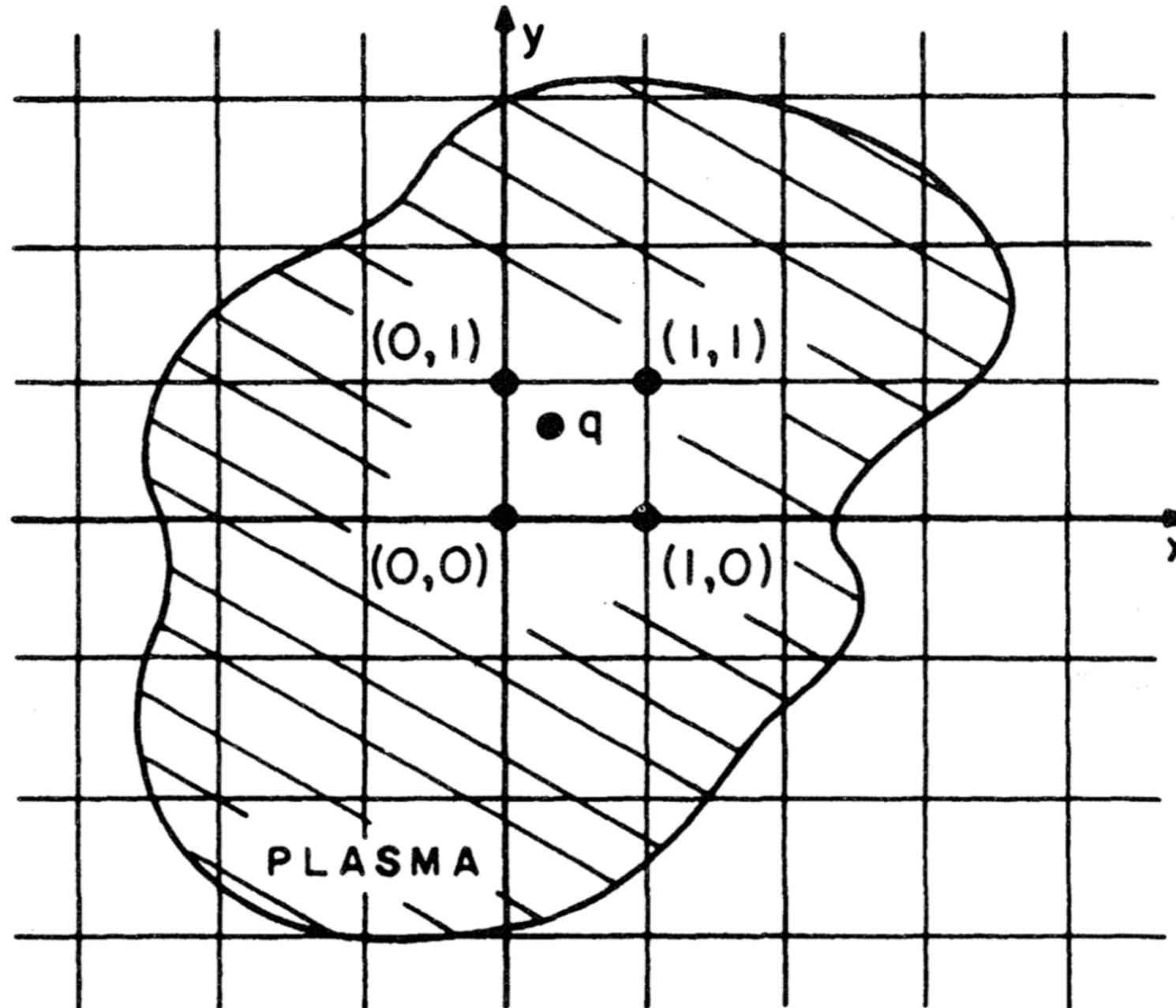
# RMHD Jet Modeling

From the Macro...

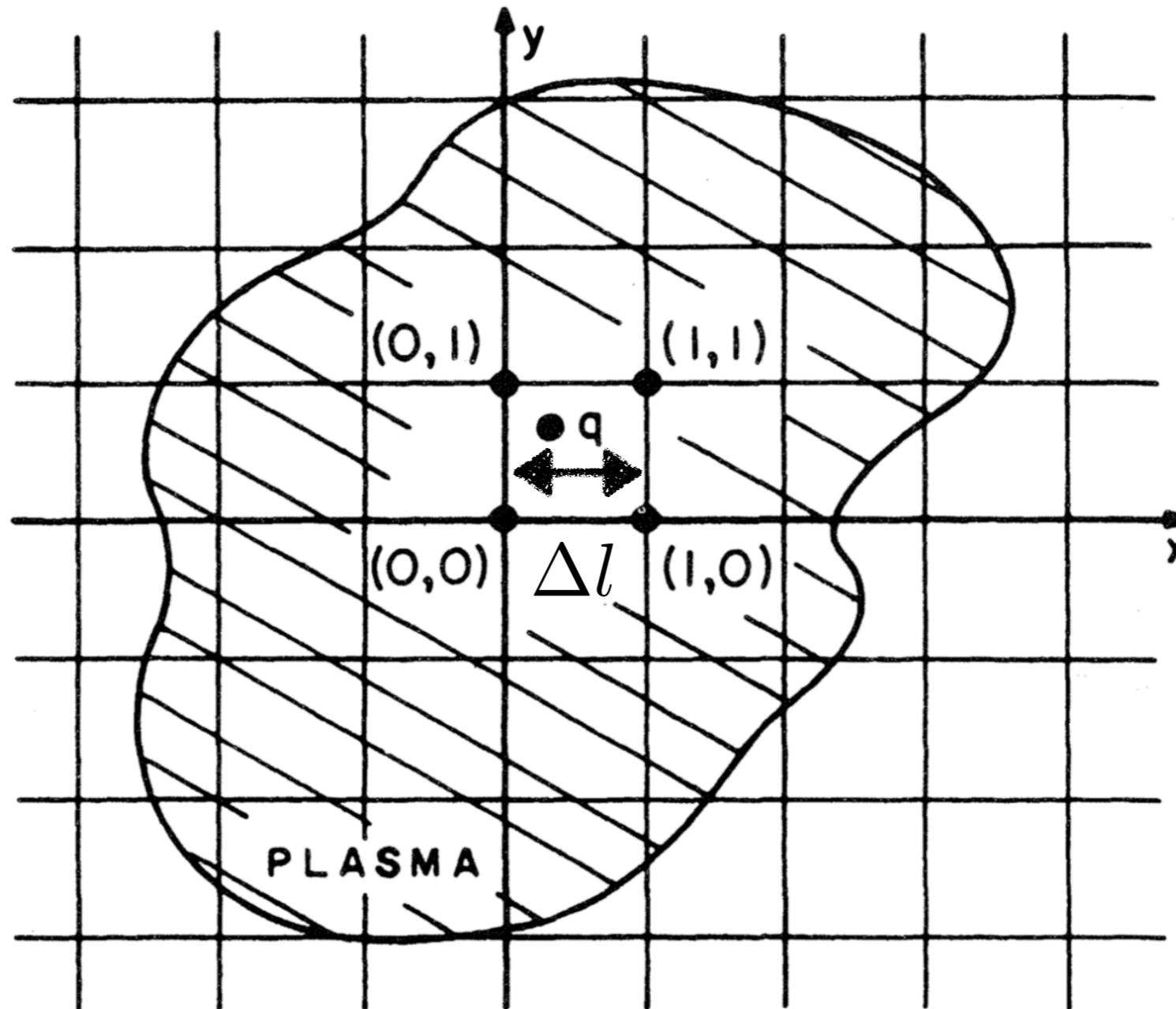


Fromm et al. (2016)

# Relativistic Particle-in-Cell (PIC) Jet Modeling



# Relativistic Particle-in-Cell (PIC) Jet Modeling



# PIC Jet Modeling

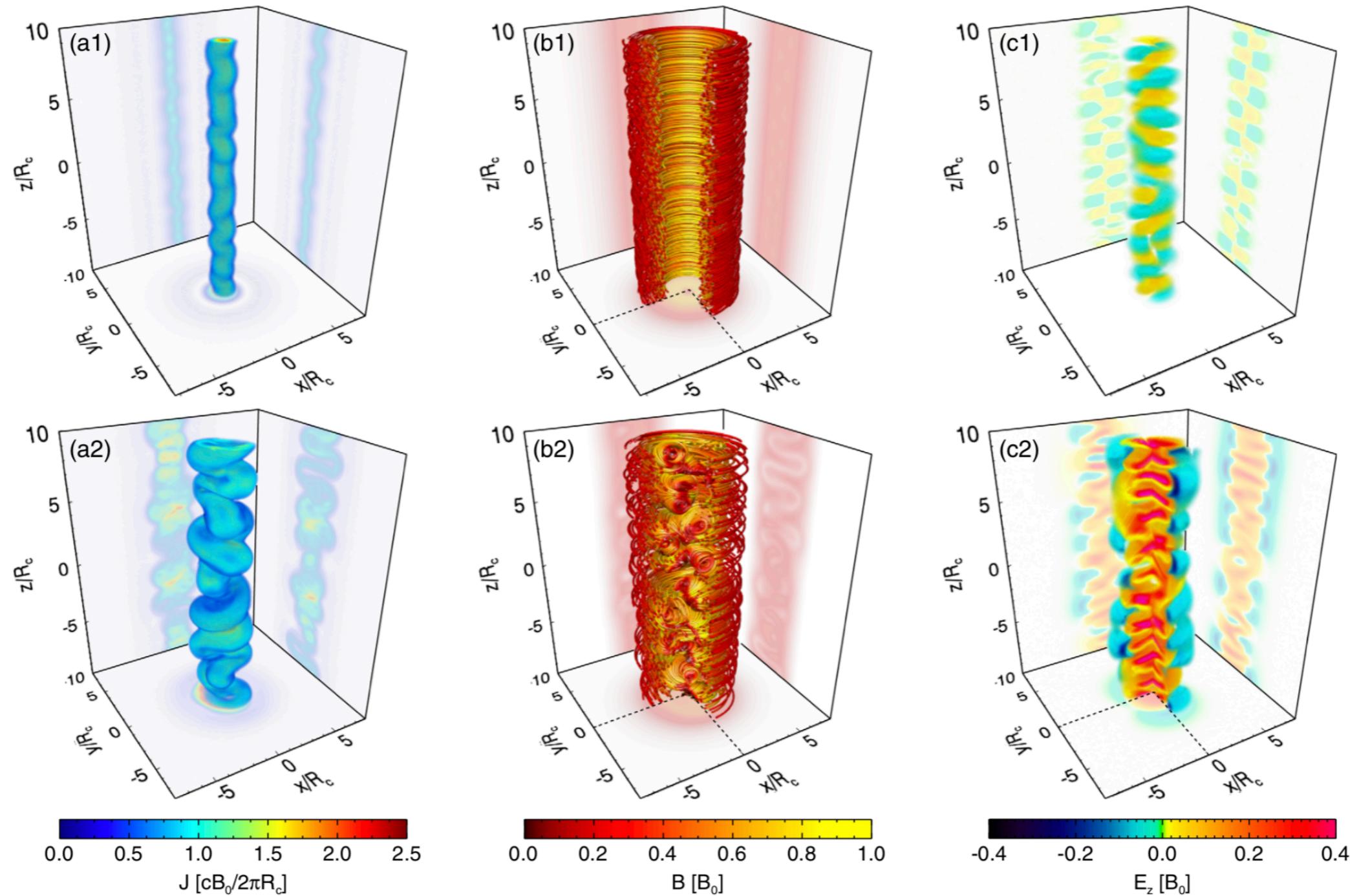
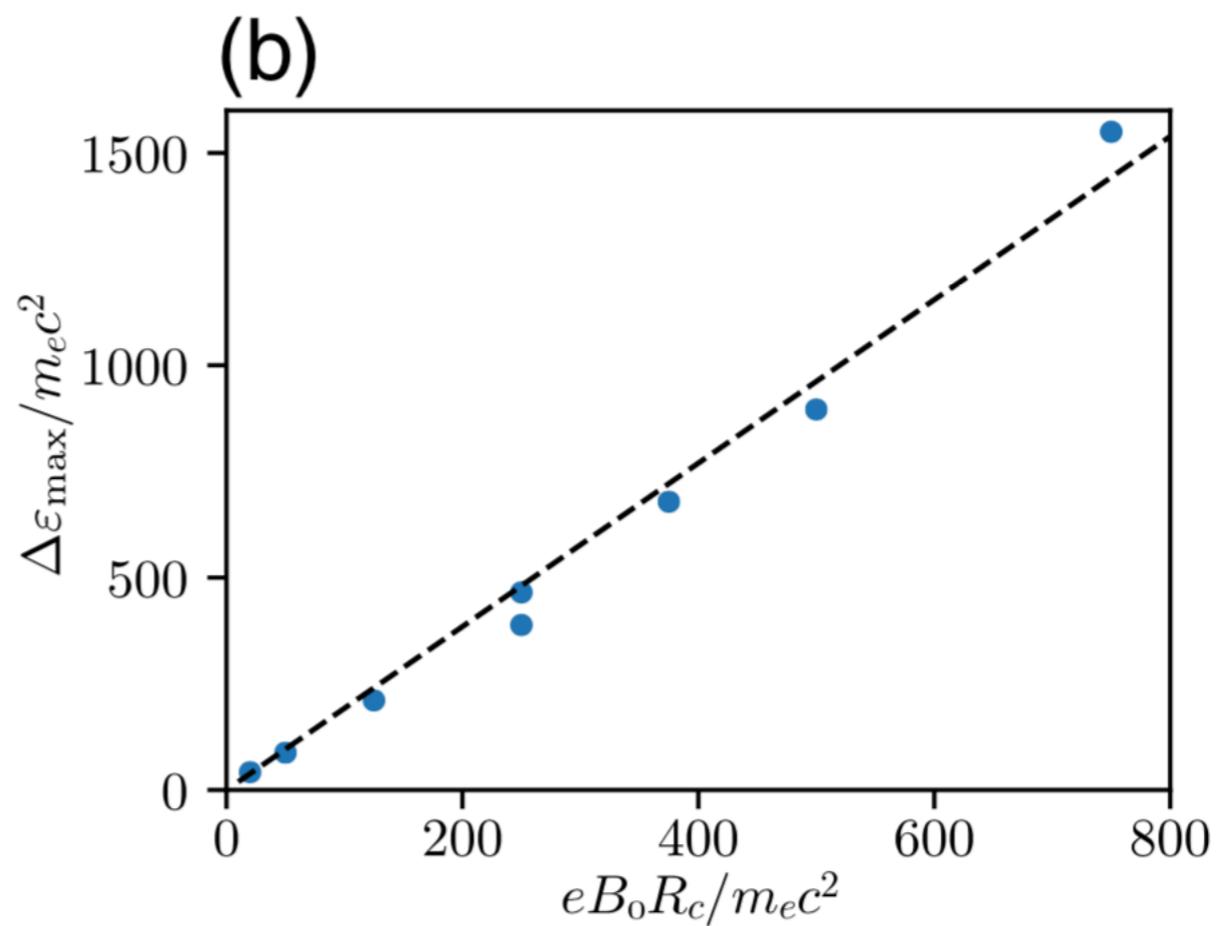
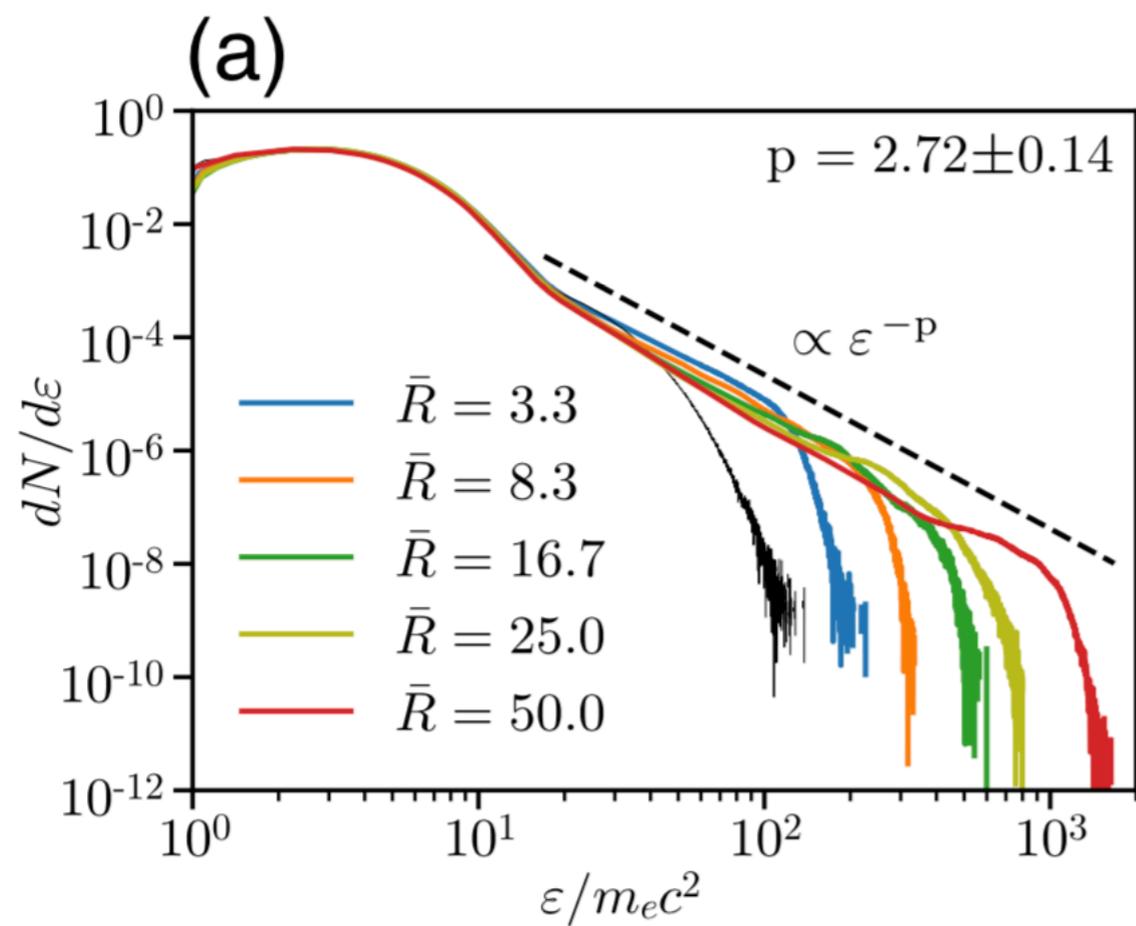
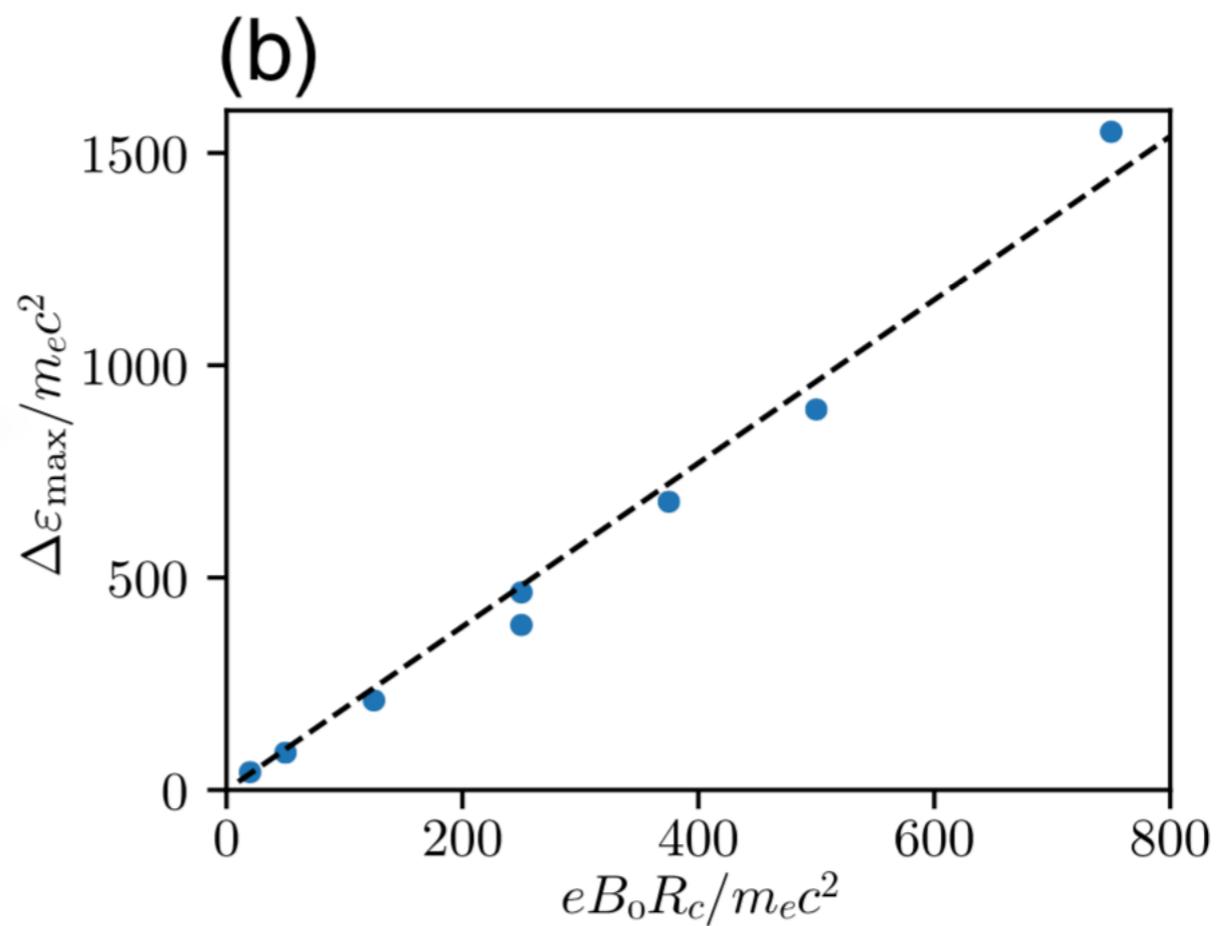
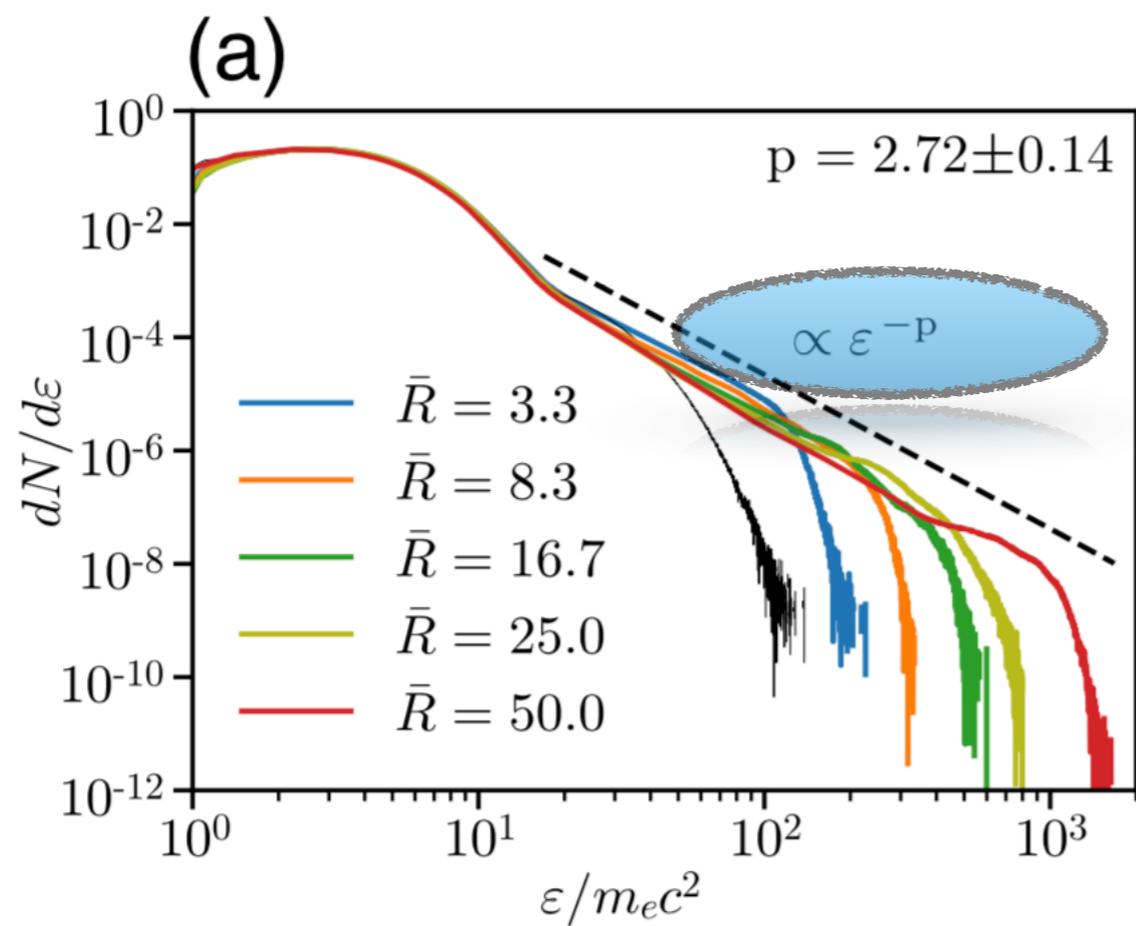


FIG. 1. Evolution of the jet structure subject to the kink instability. (a) Current density, (b) magnetic field lines, and (c) axial electric field, taken at times (1)  $ct/R_c = 16$  and (2)  $ct/R_c = 24$ . These times correspond to the linear and nonlinear stages of the kink instability. Note that a quarter of the simulation box has been removed in (b1), (b2), and (c2) to reveal the inner field structure of the jet.

# PIC Jet Modeling



# PIC Jet Modeling





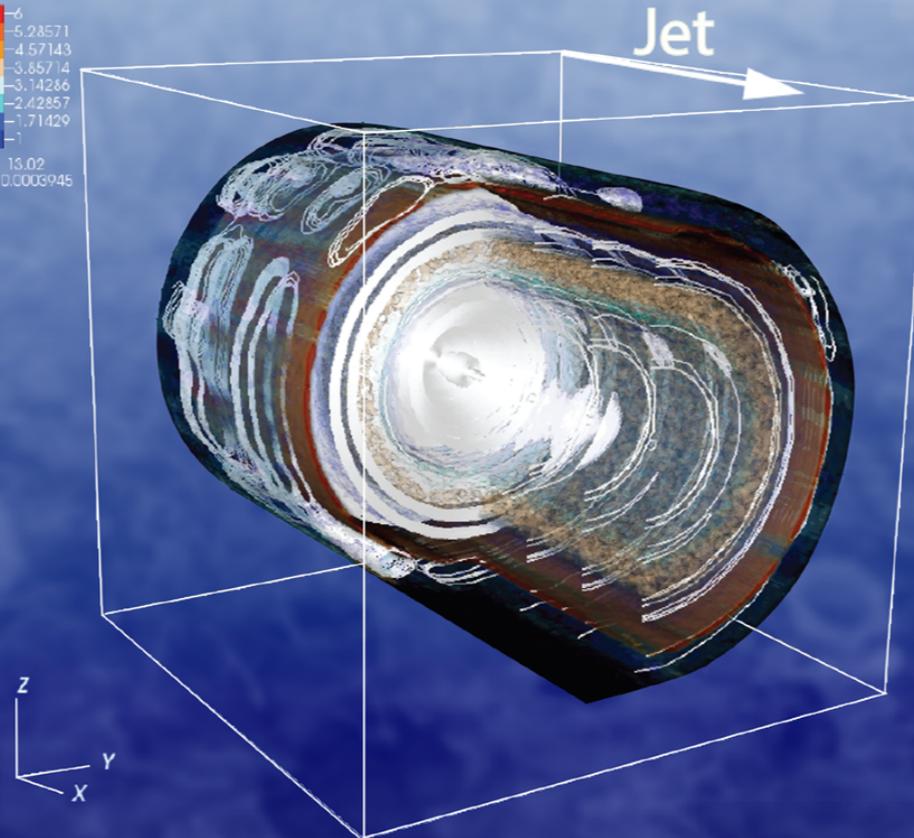
galaxies



Contour  
Var: xcurrent\_magnitude



Max: 13.02  
Min: 0.000945



# Relativistic Jet Simulations of the Weibel Instability in the Slab Model to Cylindrical Jets with Helical Magnetic Fields

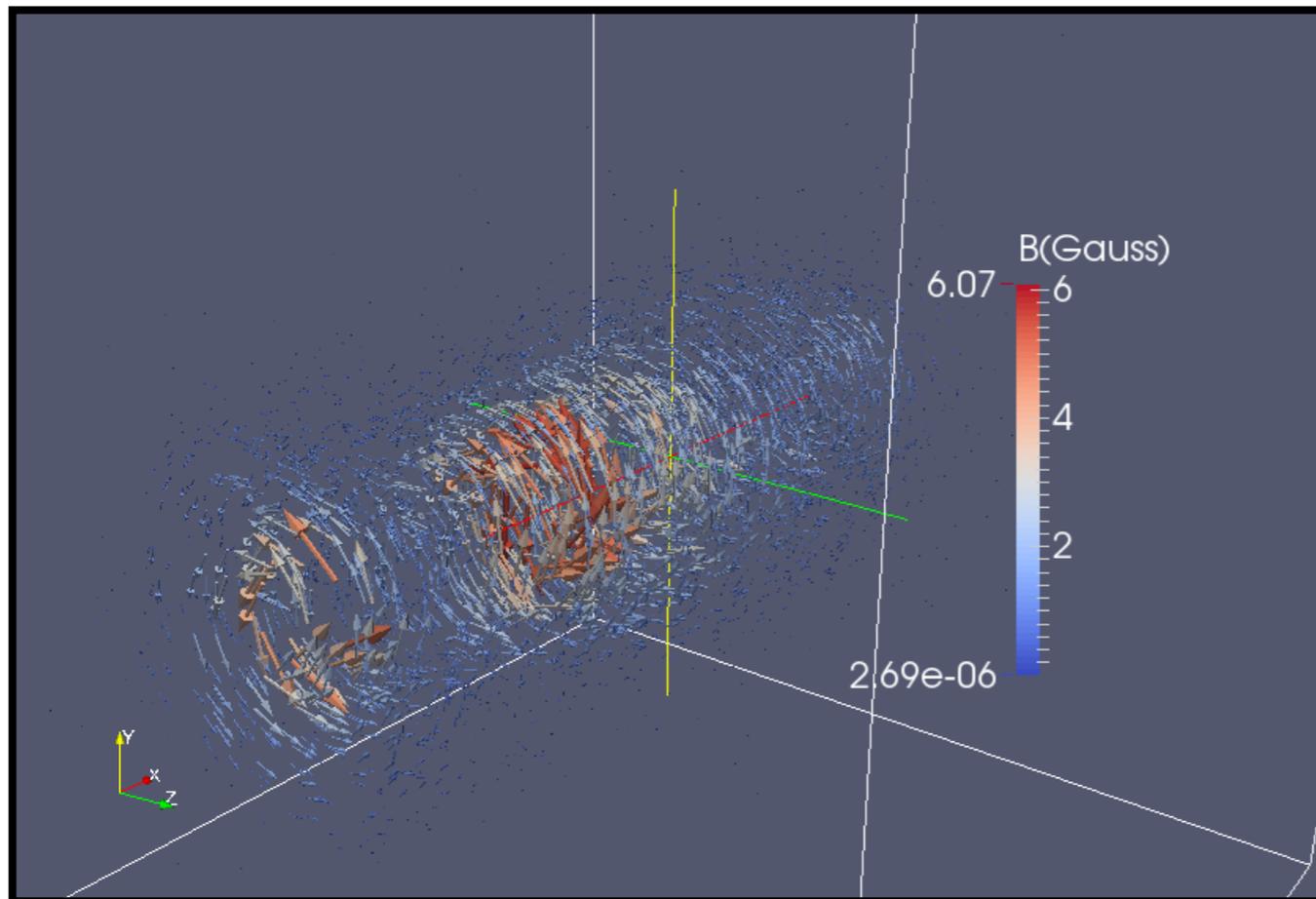
Volume 7 · Issue 1 | March 2019



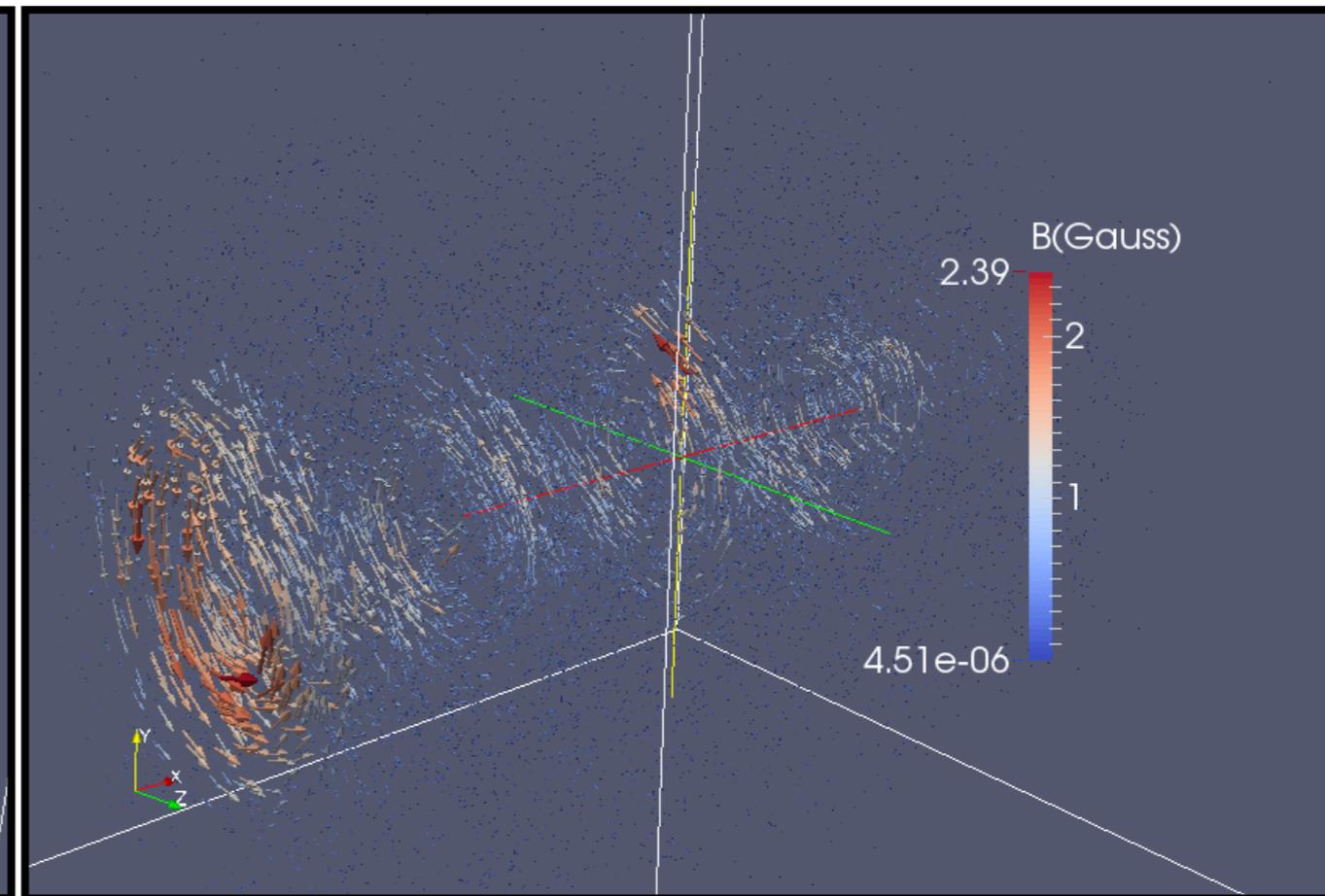
mdpi.com/journal/galaxies  
ISSN 2075-4434

Nishikawa et al. (2019)

# PIC Jet Modeling



Normal Plasma Jet



Pair Plasma Jet

# Down the Rabbit Hole: Scaling PIC Simulations



Image Credit: pinterest.com

# The Plasma Skin Depth ( $\equiv c/\omega_p$ )

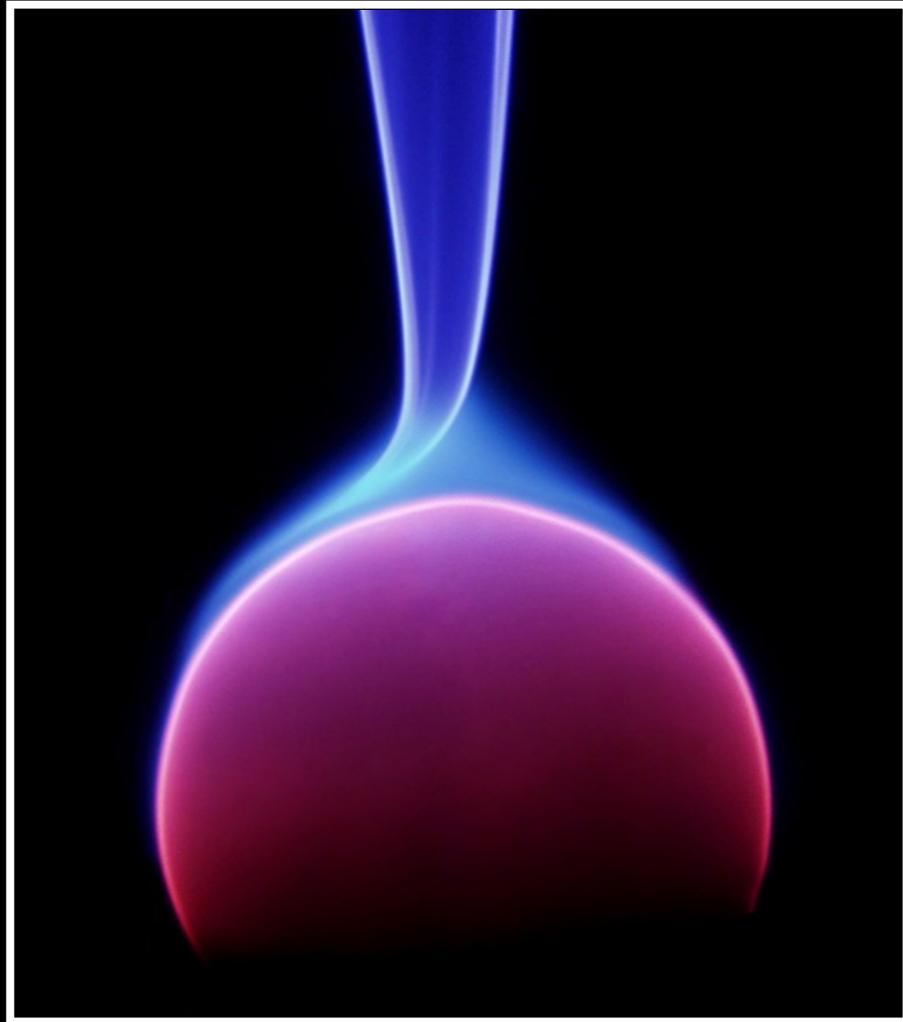


Image Credit: <https://www.mcgill.ca/chemeng/research/plasma>

$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m_e}}$$

# The Plasma Skin Depth ( $\equiv c/\omega_p$ )

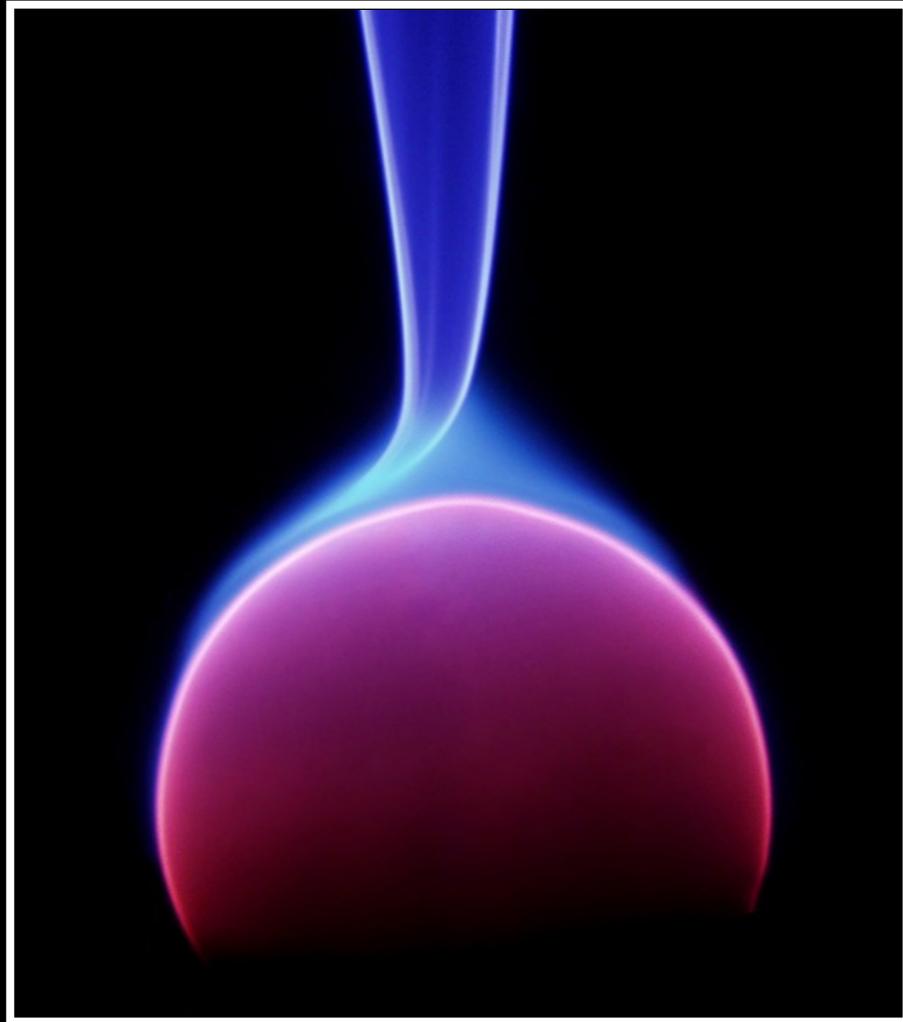


Image Credit: <https://www.mcgill.ca/chemeng/research/plasma>

$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m_e}}$$

$$n_e \simeq 10^{21} \text{ cm}^{-3}$$

Fiducial Jet Electron Number  
Density

# The Plasma Skin Depth ( $\equiv c/\omega_p$ )

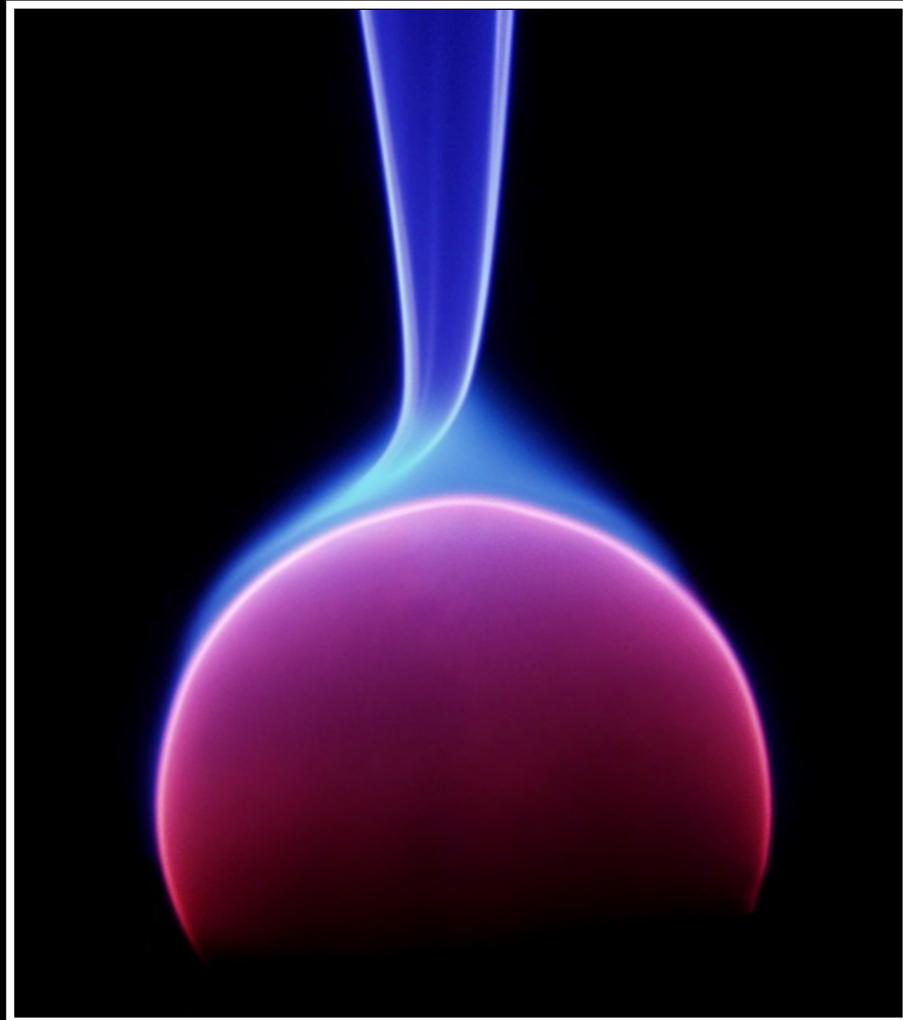


Image Credit: <https://www.mcgill.ca/chemeng/research/plasma>

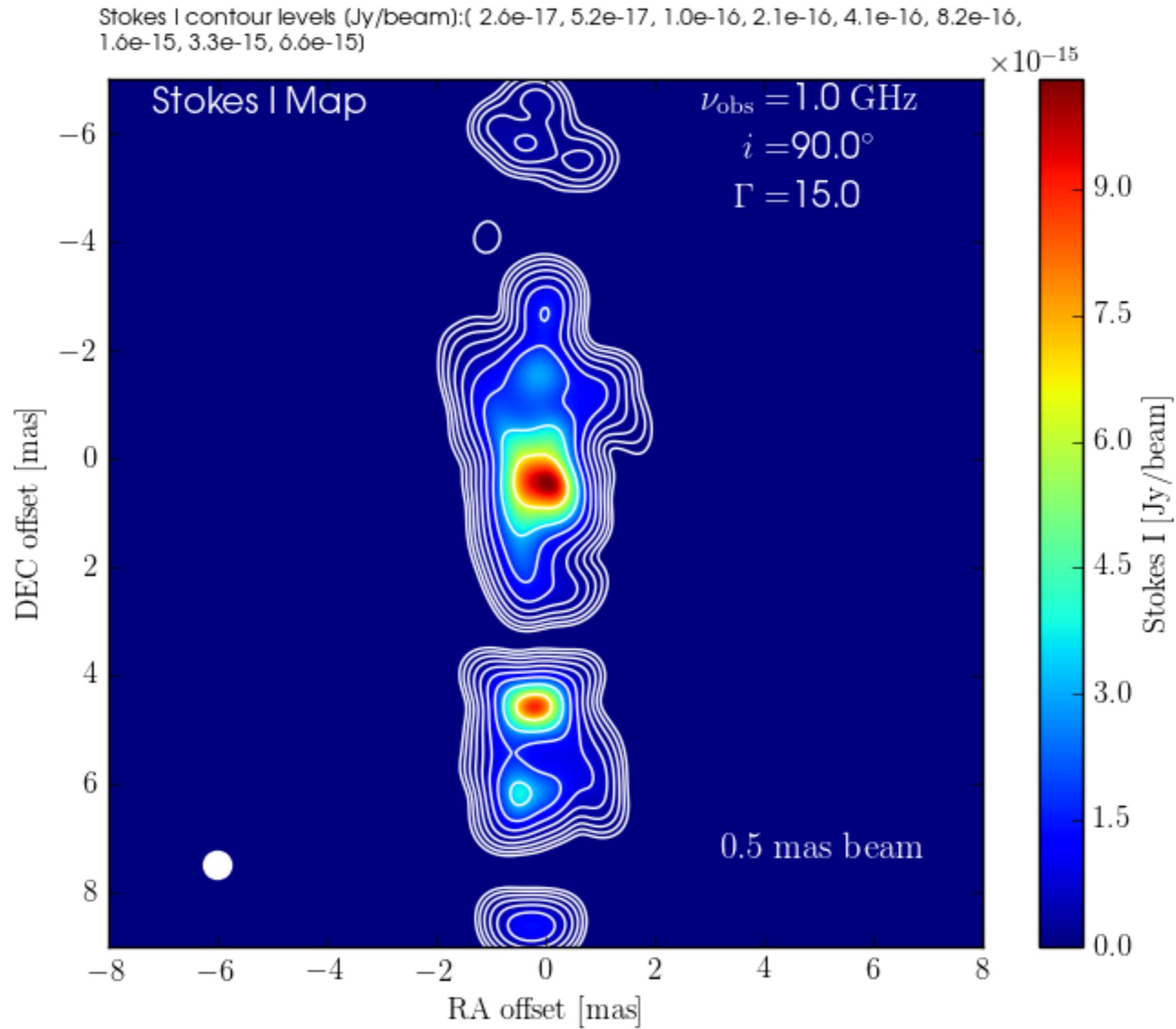
$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m_e}}$$

$$n_e \simeq 10^{22} \text{ cm}^{-3}$$

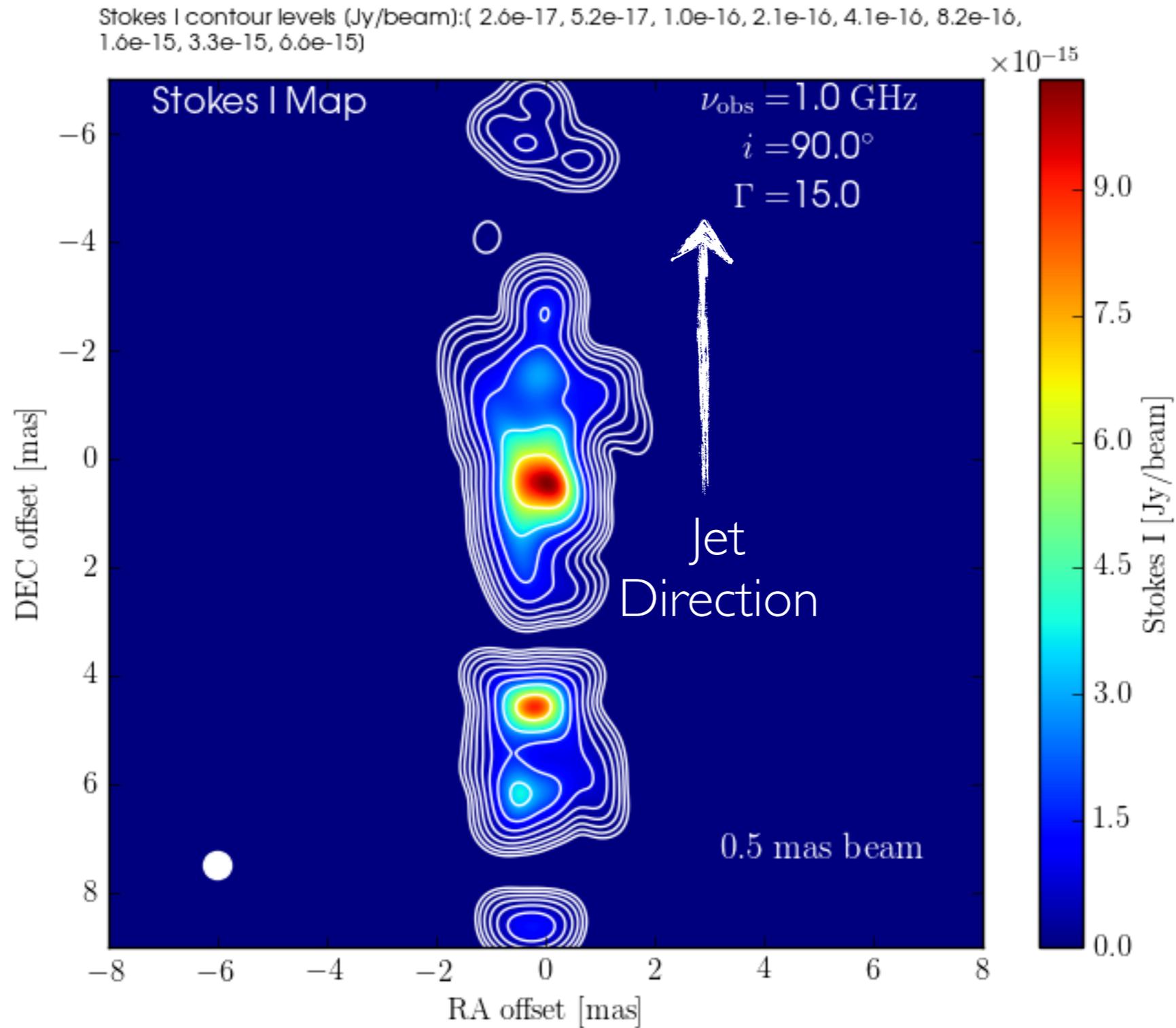
Fiducial Jet Electron Number  
Density

$$\Delta l \simeq 5.3 \times 10^3 \text{ cm}$$

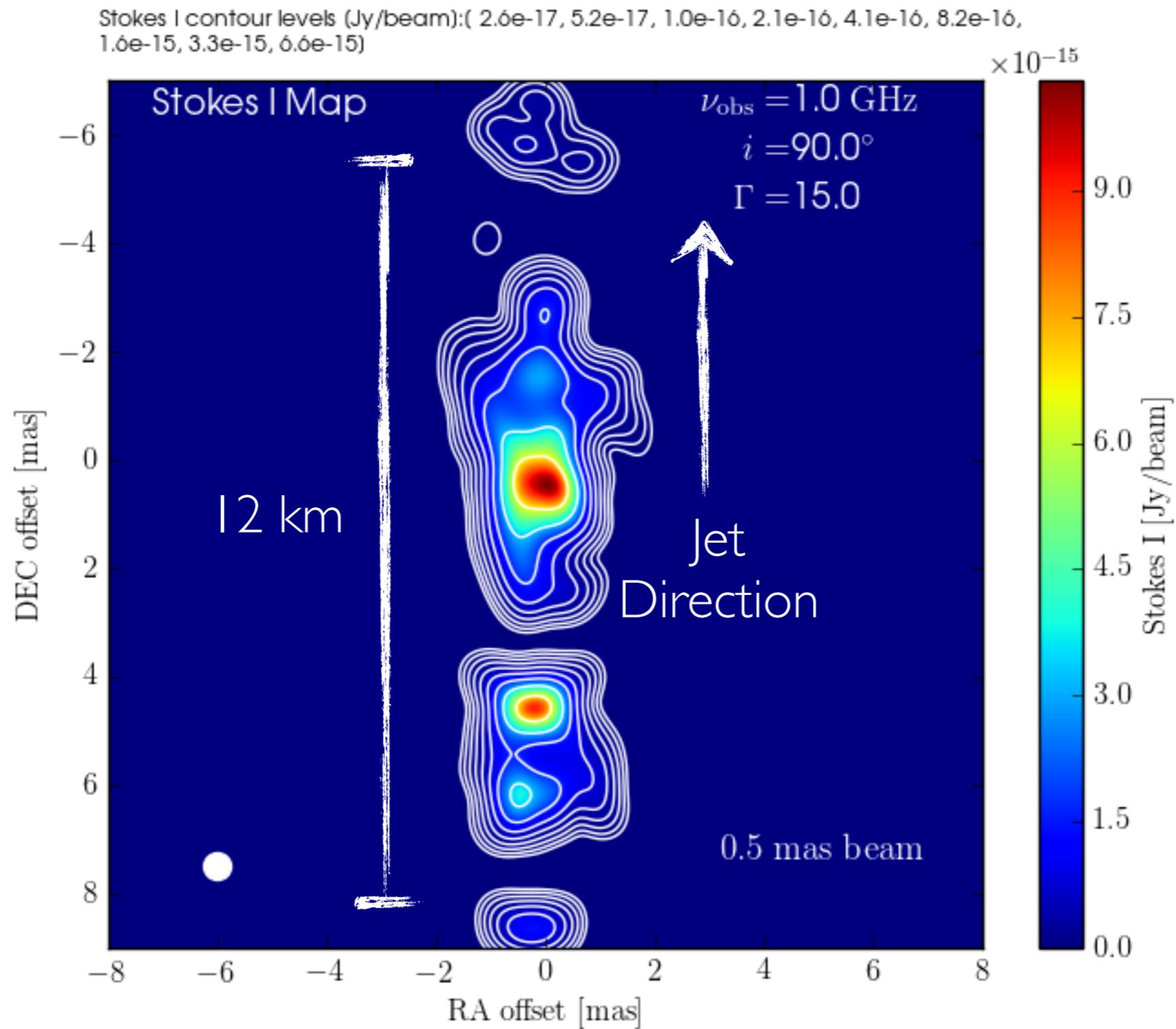
# Normal Plasma Jet



# Normal Plasma Jet



# Normal Plasma Jet



A blue-toned image of a galaxy, possibly a spiral galaxy, with a bright central core. The text "Questions?" is overlaid in the center of the galaxy. A thin white line points from the text down towards the bottom right corner of the image.

Questions?