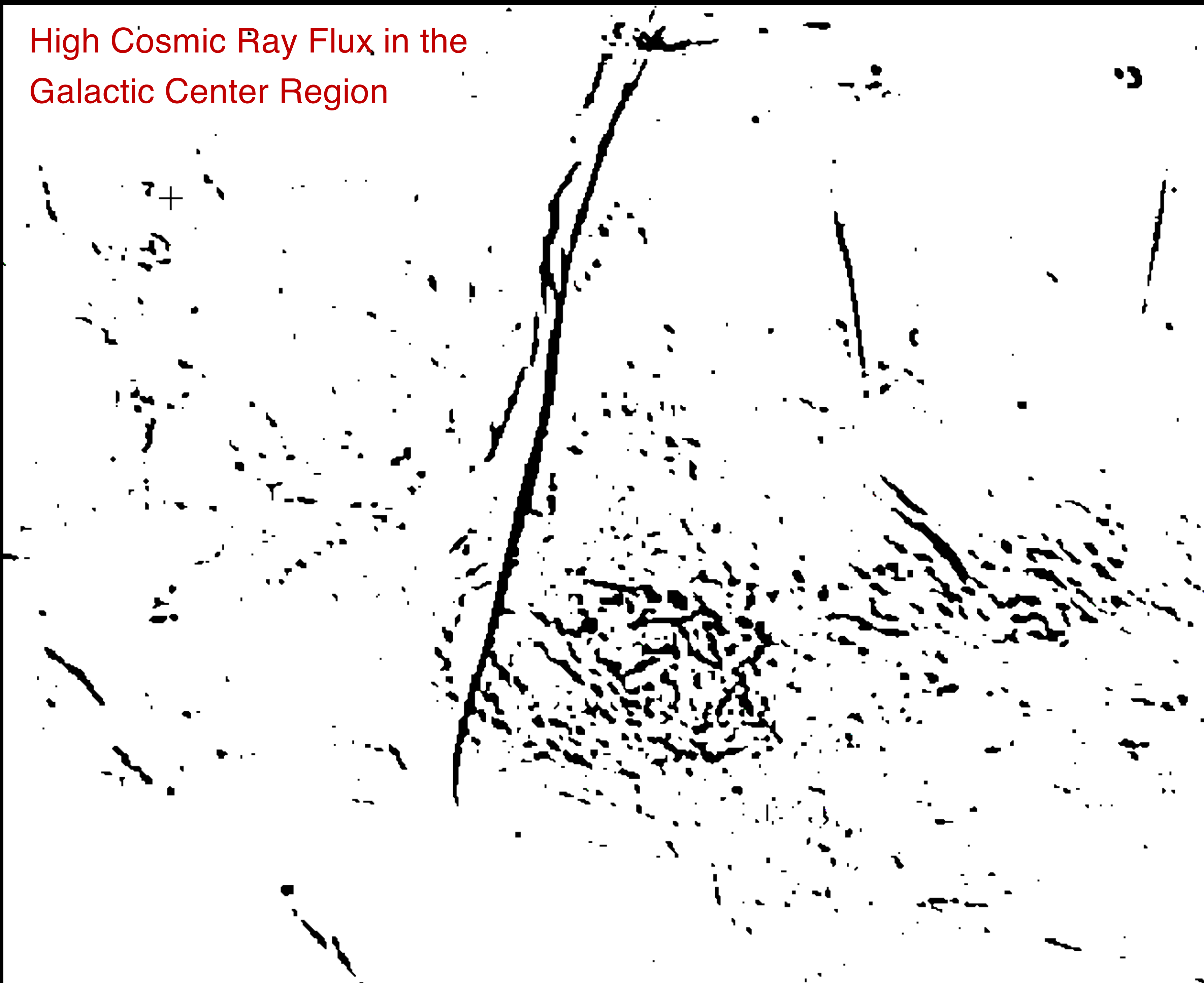
High Cosmic Ray Flux in the Galactic Center Region



High Cosmic Ray Flux in the Galactic Center Region (the ICM)

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Northwestern University

Outline

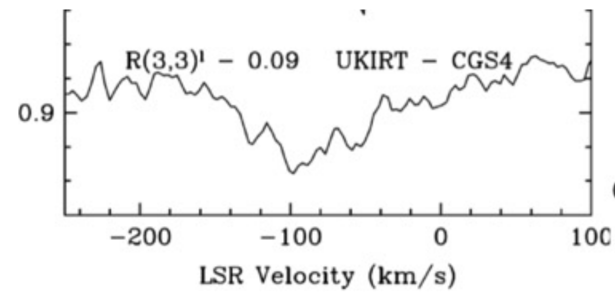
- **Galactic Center ISM**
  - high cosmic ray flux
  - 100's of needle-like filaments
  - morphology
- **Intracluster Medium**
  - morphology
  - 10-20 filaments
- **Origin of GC and ICM Filaments**
  - cometary
  - turbulent

High CR Flux

Four pieces of evidence for high cosmic ray Ionization rate $\zeta \sim 10^{-15}$-10^{-14} s^{-1}

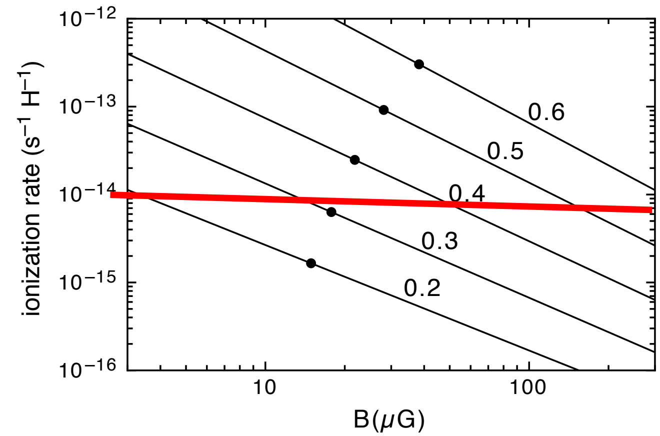
1. High ζ from H_3^+

- Simple chemistry and straightforward analysis



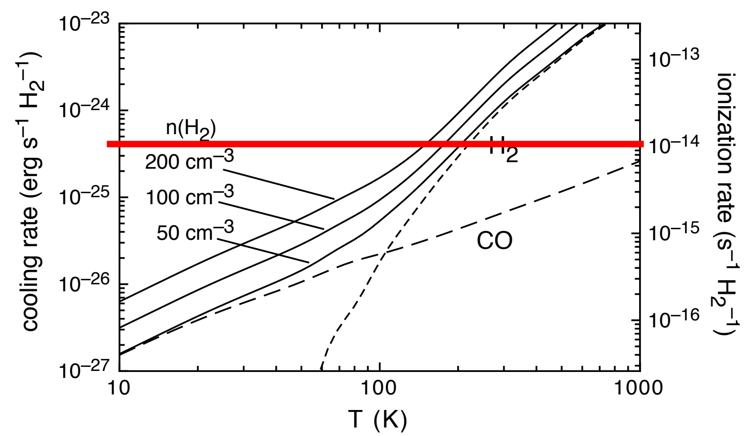
2. High ζ from NT radio flux

- 280x70x280 pc
- B_{eq}=10-20μG (uncertainty e/p ratio)



3. High ζ from warm gas (T)

- Warm temp to cooling rate to heating rate (ζ_H)
- Total heating rate ~ 1-2x10^{39} erg/s

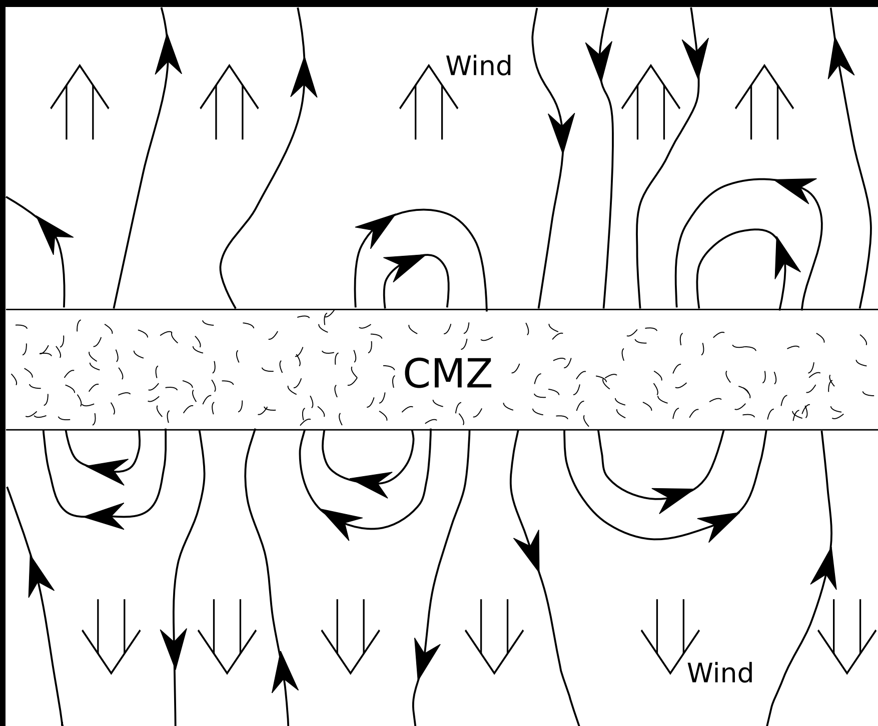


4. High ζ: 6.4 keV line from molecular clouds

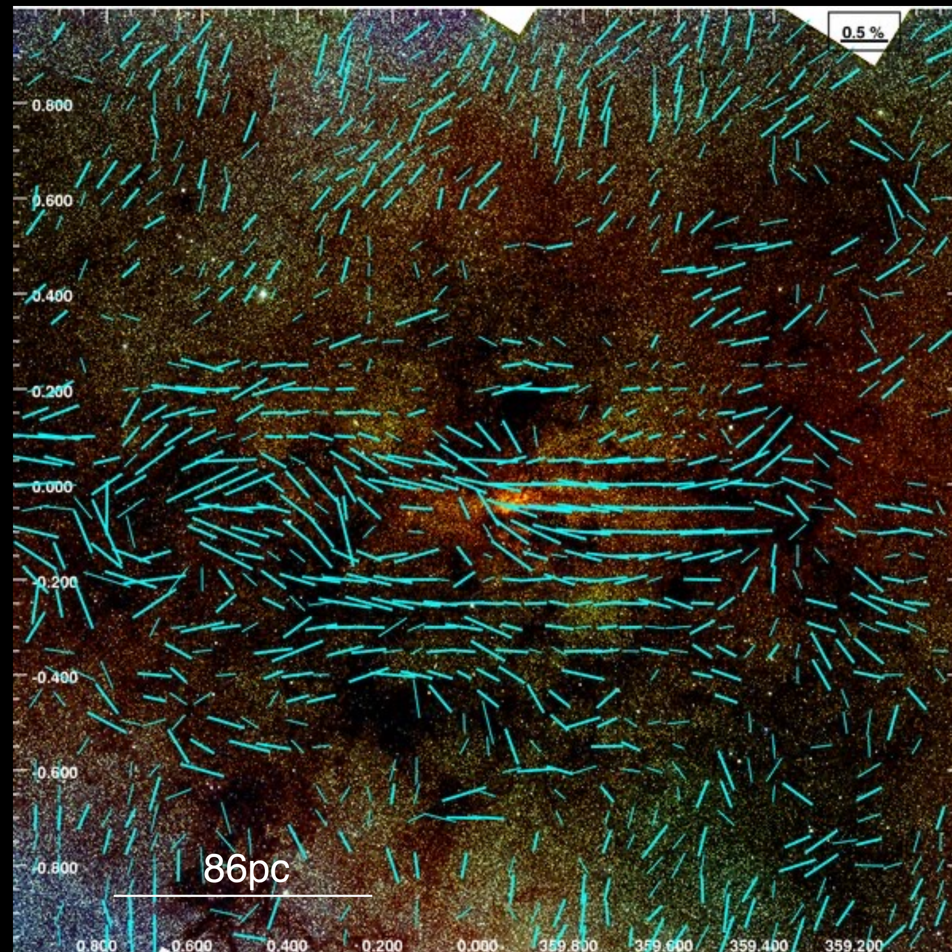
FYZ et al. 2013

High CR Flux

Azimuthal to vertical magnetic field



FYZ+Wardle 2019



The inner ~2 degrees in Galactic Center

- CR-driven wind
  - Lift the material
  - Heat the gas to high latitudes
  - Magnetic field geometry

- Linear polarization of infrared starlight indicates direction of magnetic field projected on the sky....
  – aspherical dust particles are aligned with short axis parallel to magnetic field
  – more strongly absorb linear polarization parallel to long axis – remainder is polarized perpendicular to magnetic field
  - Blue line segments show inferred field direction
  – horizontal within the galactic plane but transitions to vertical above and below

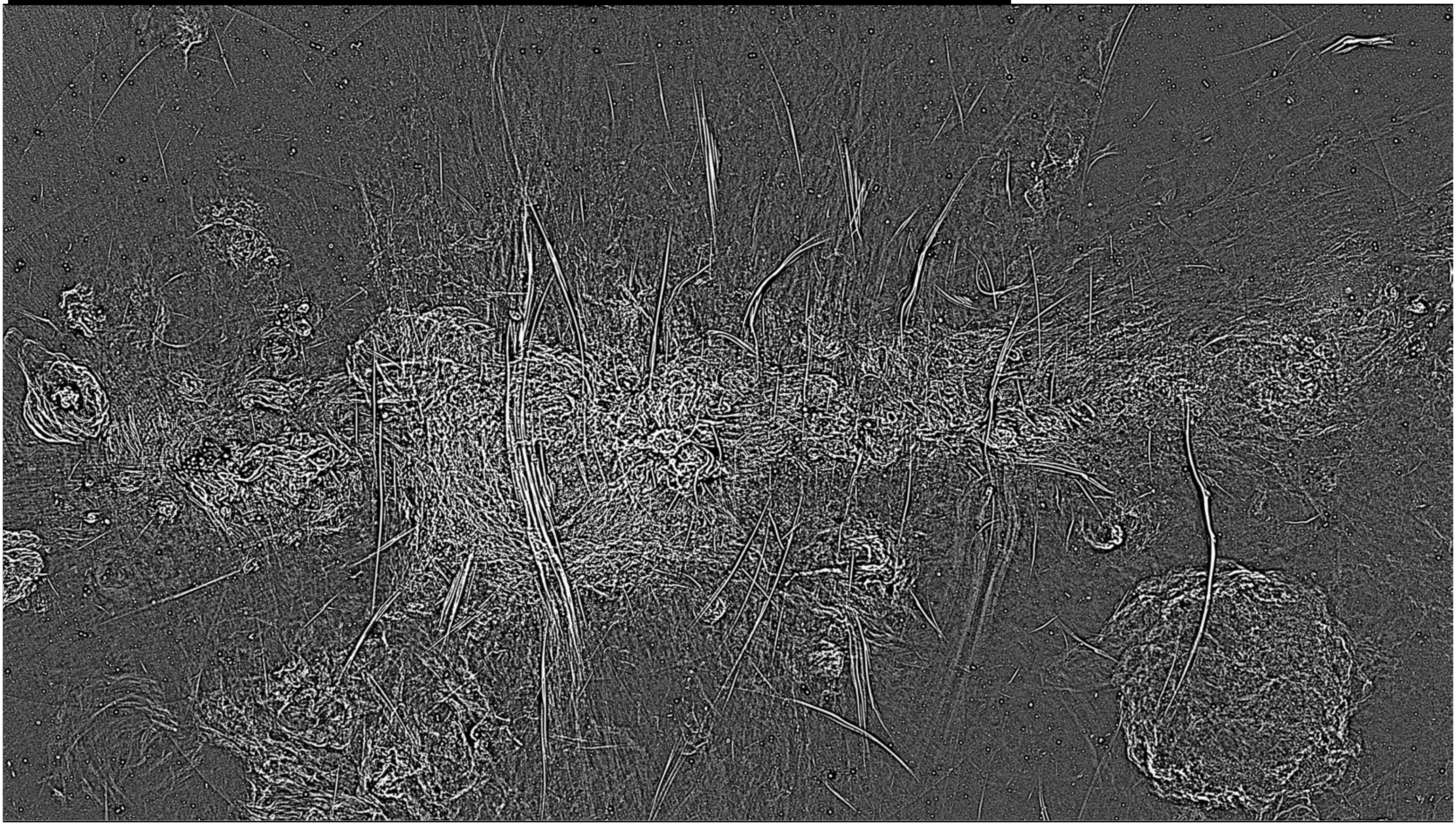
High CR Flux

Numerous magnetized filaments

- MeerKAT data
- ~1000 identified filaments
- The emission tracks CR electrons
- High concentration of CR sources
- GeV cosmic ray electrons
- $P_{cr} \sim 10^3$ eV cm^{-3}

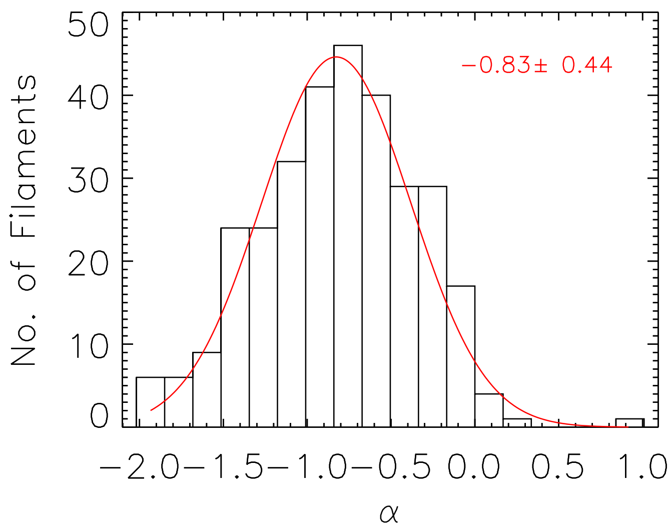
FYZ, Arendt, Wardle, Heywood, Cotton and Camilo (2022)

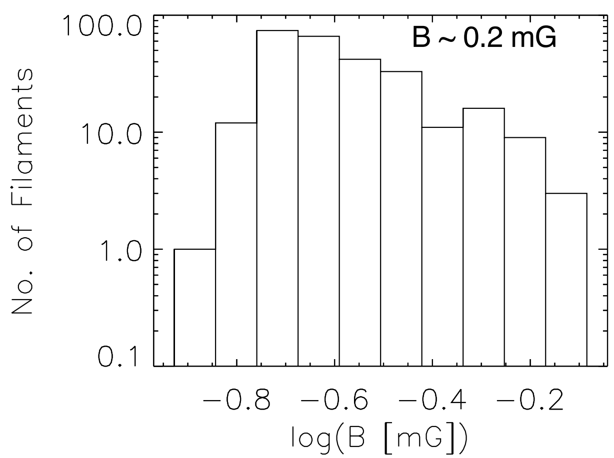
Filtered Image 20 cm (MeerKAT)



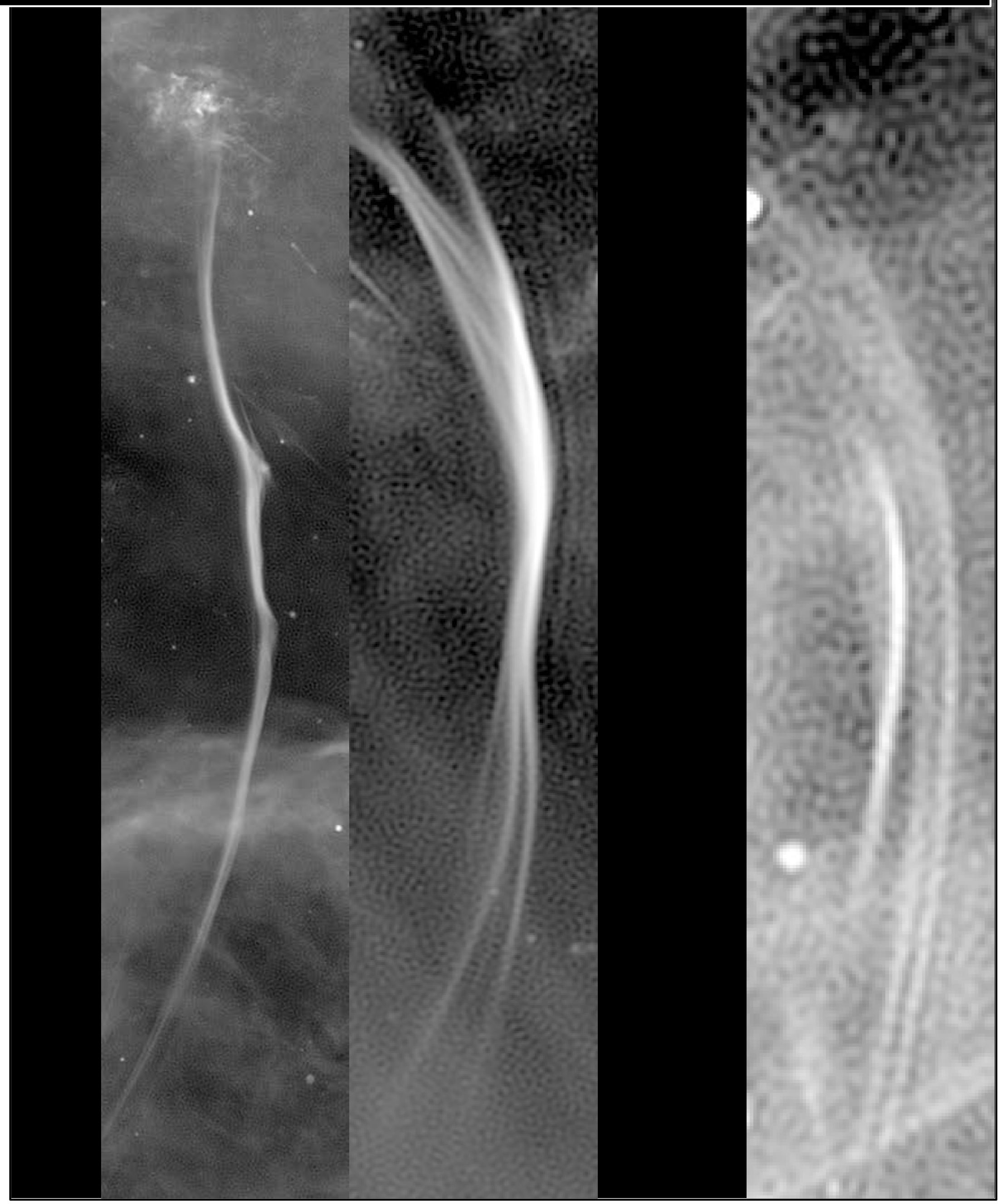
High CR Flux

Numerous magnetized filaments



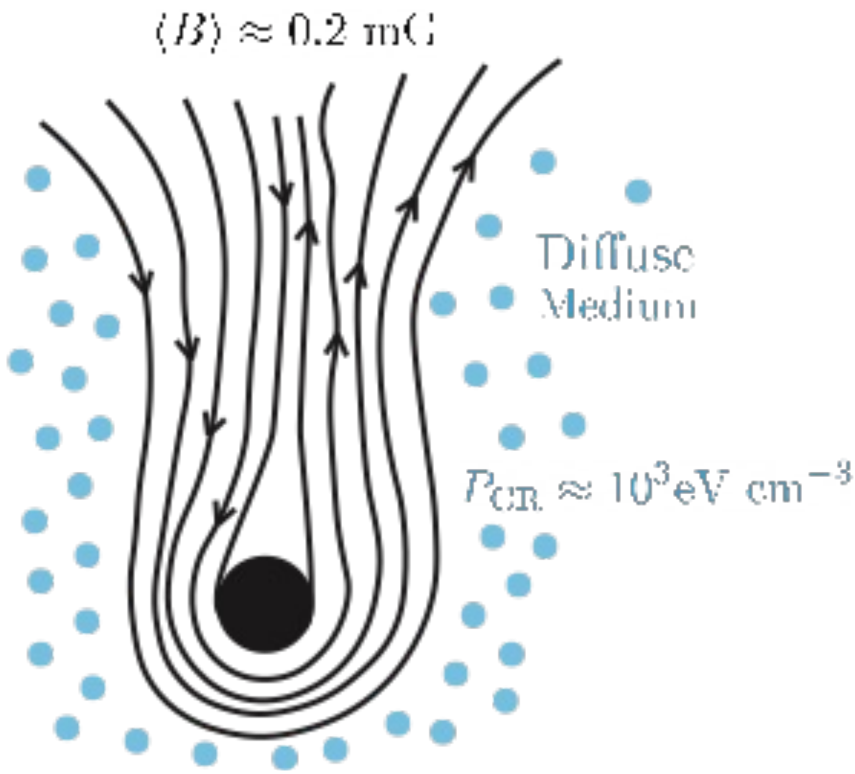


Length > 132 asec



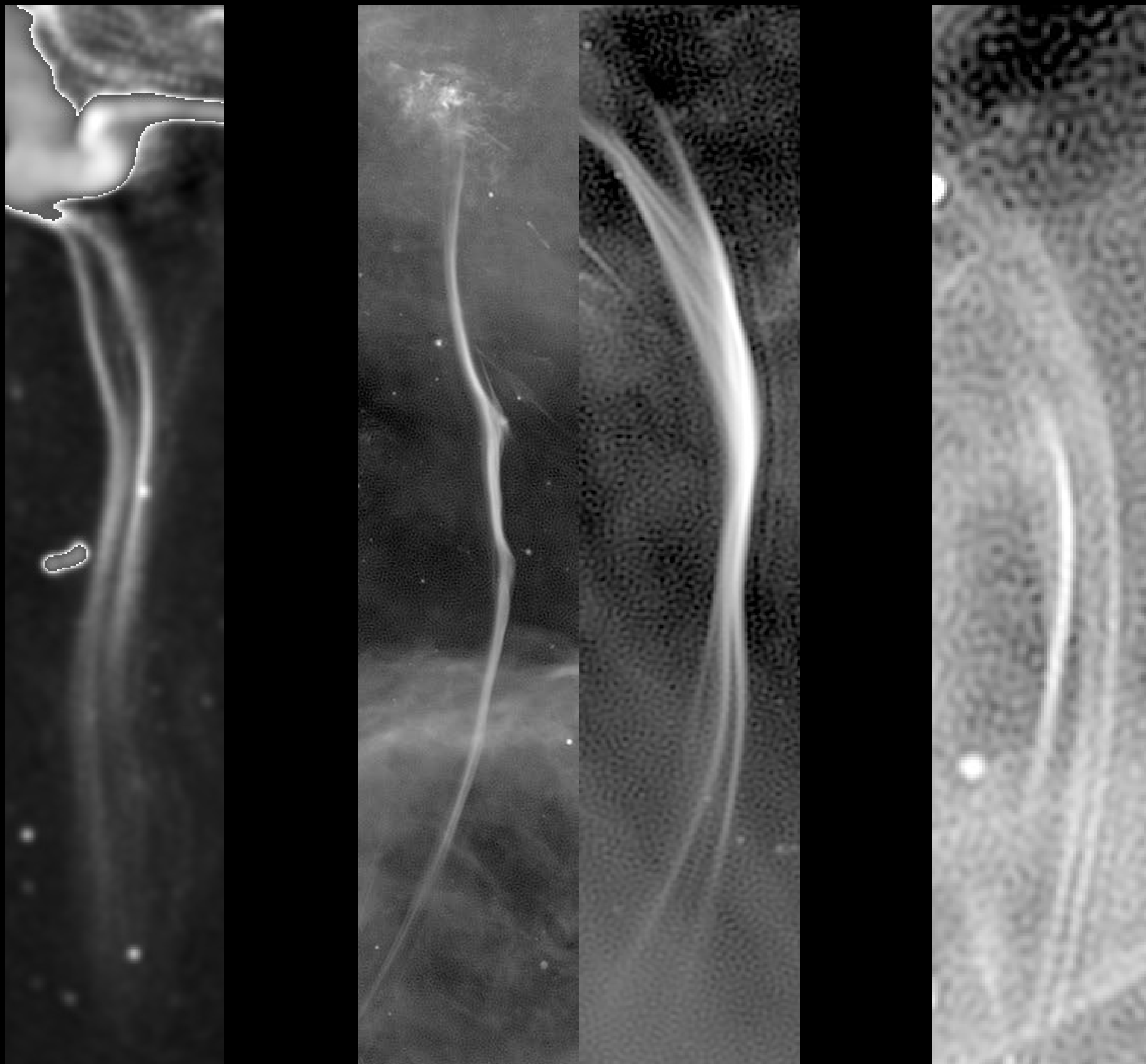
Filaments as cometary tails

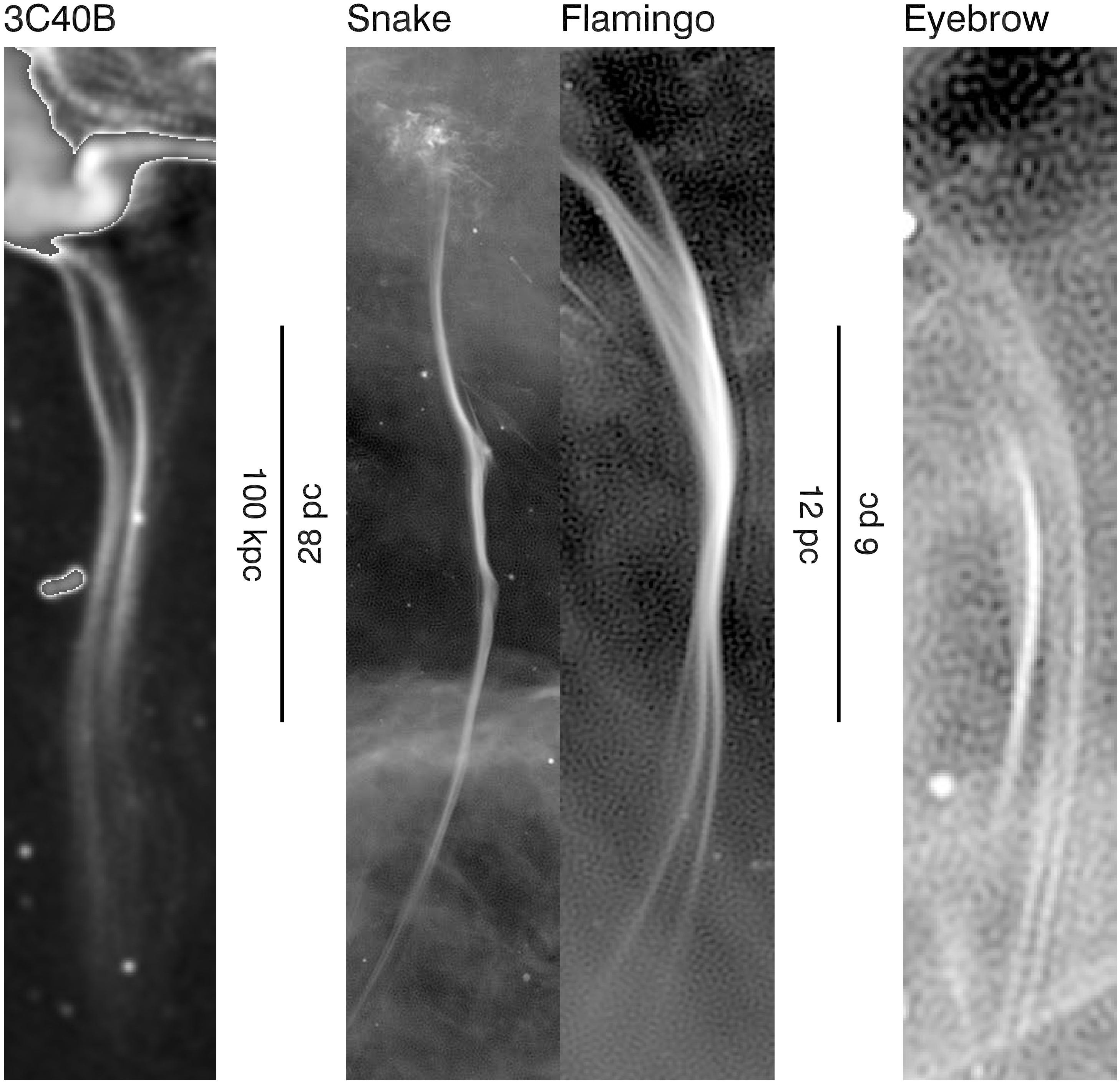
Pressure equilibrium with diffuse low-energy CRs

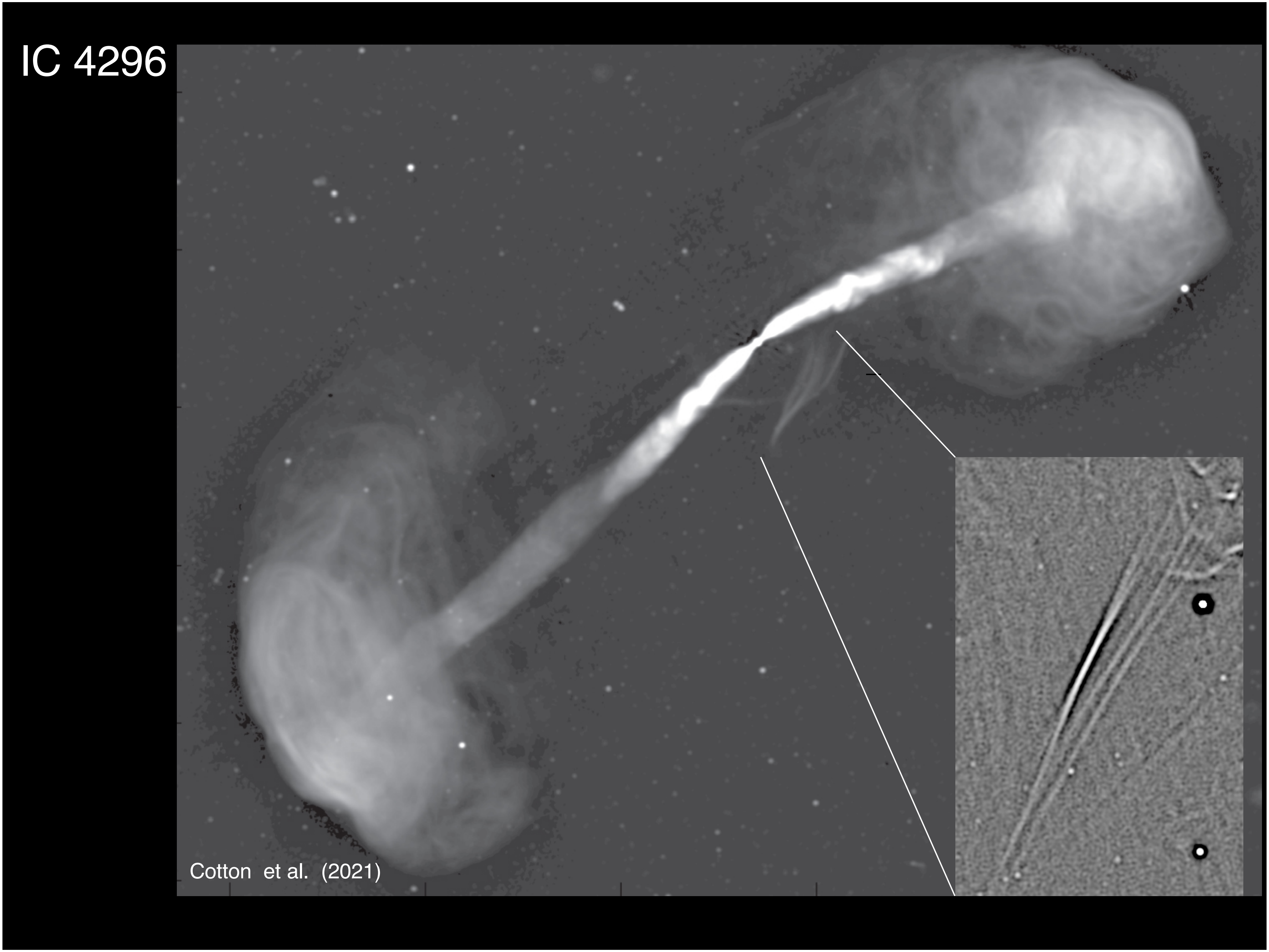


- The wind wraps magnetic field around a moving obstacle
- Magnetic field and CR electron density pressure

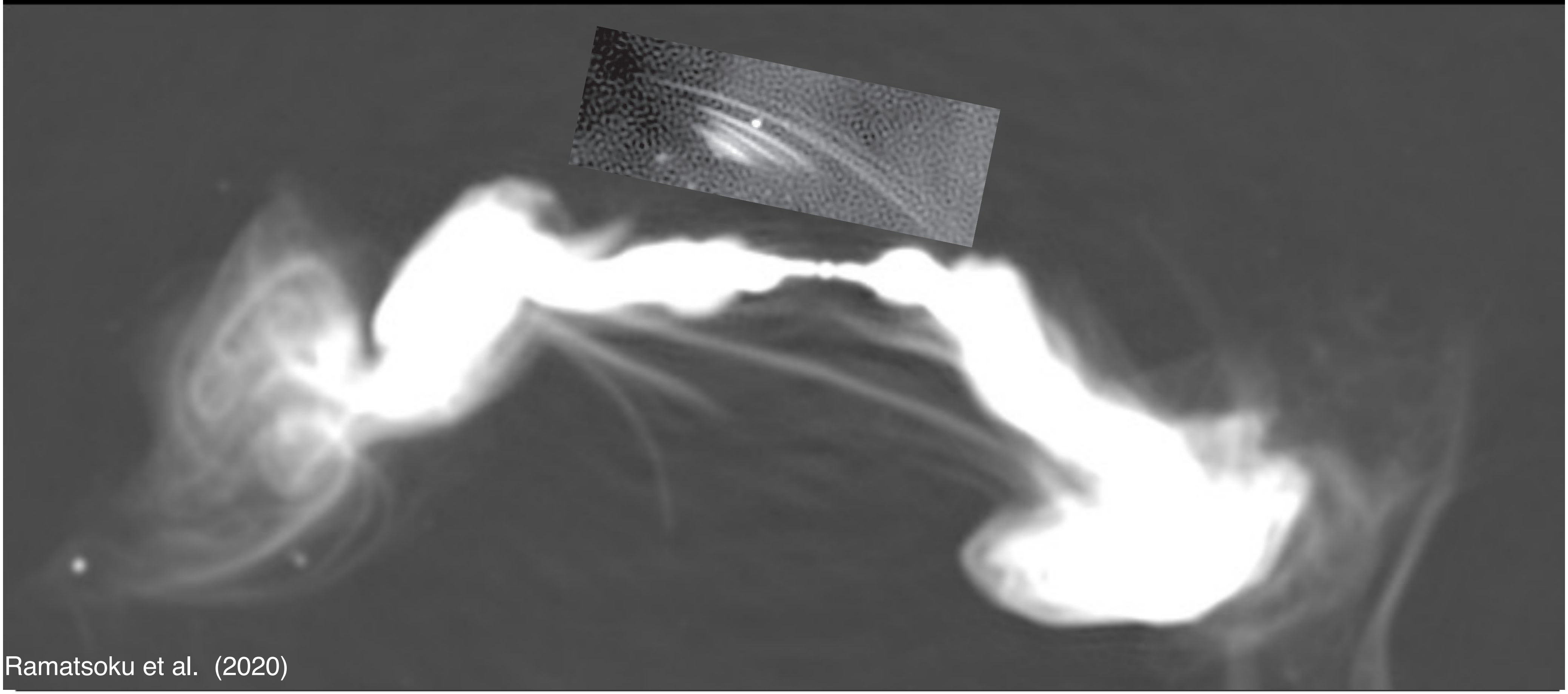
3C40B filaments




3C40B
Snake
Flamingo
Eyebrow
100 kpc
28 pc
12 pc
6 pc

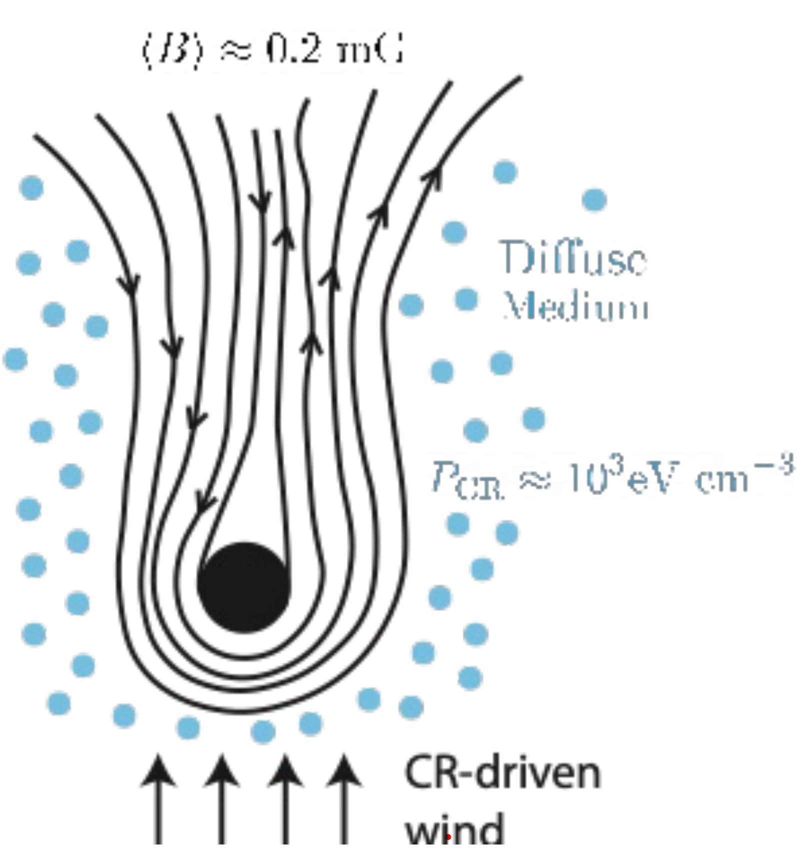

IC 4296
Cotton et al. (2021)

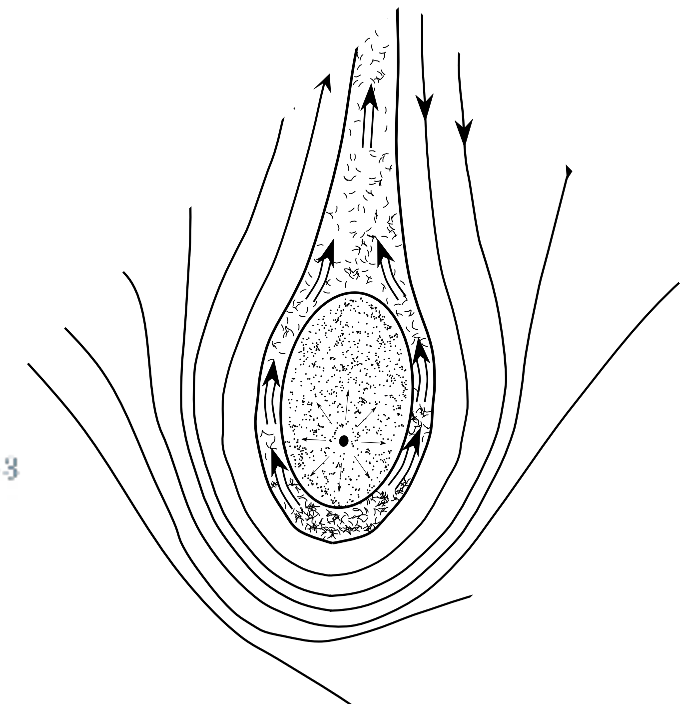
ESO0137

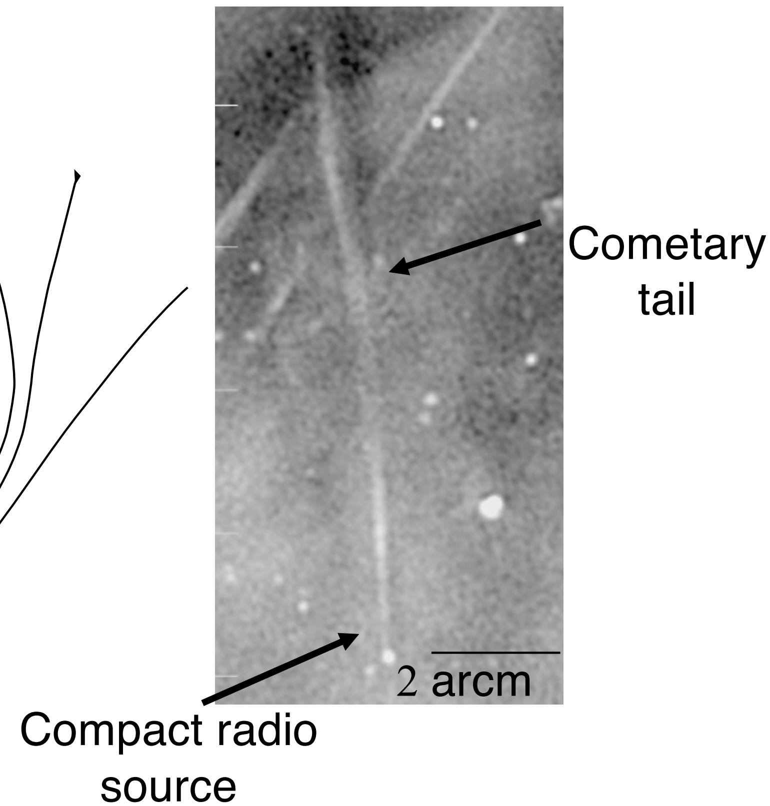


Physical Parameters	Galactic Center Filaments	Radio Galaxy Filaments
length (pc)	[4, 60]	10^{3-5}
typical width (pc)	0.5	few$\times 10^3$
typical aspect ratio	[10, 100]	[10, 70]
magnetic field strength (mG)	[0.1, 0.6]	few$\times 10^{-3}$
spectral index (α)	~ -0.8 (mean) [−2, 0]	[−2, −1]
surface brightness (mJy beam^{-1})	[0.01–10]	[0.01, 10]
spacing between filaments (pc)	$\sim$0.7 mean [0.4, 1.2]	[10–20]$\times 10^3$

Filaments as cometary tails
Cometary tail behind obstacles

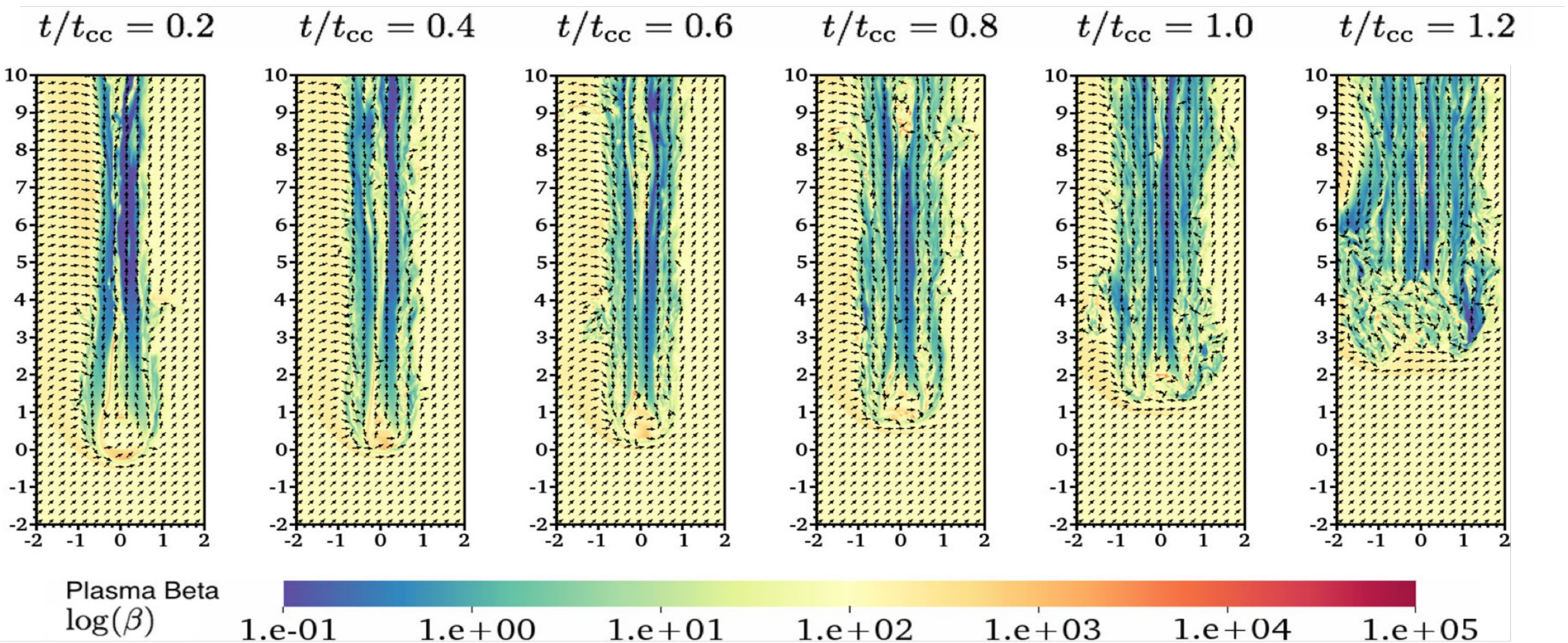






- The wind wraps magnetic field around a moving obstacle
- Magnetic field and CR electron density amplified by compression

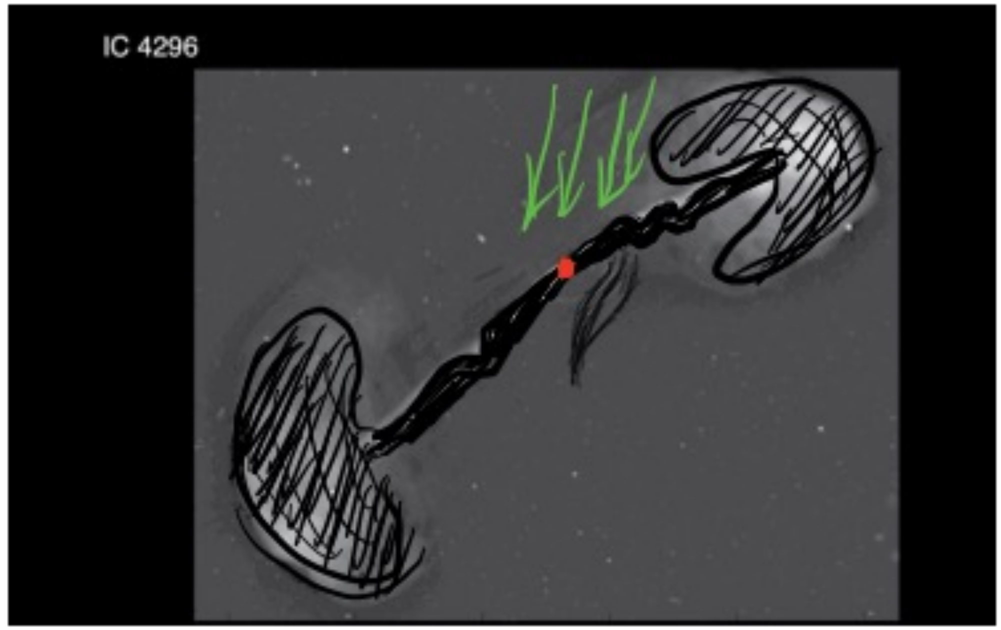
Cometary tail behind a cloud

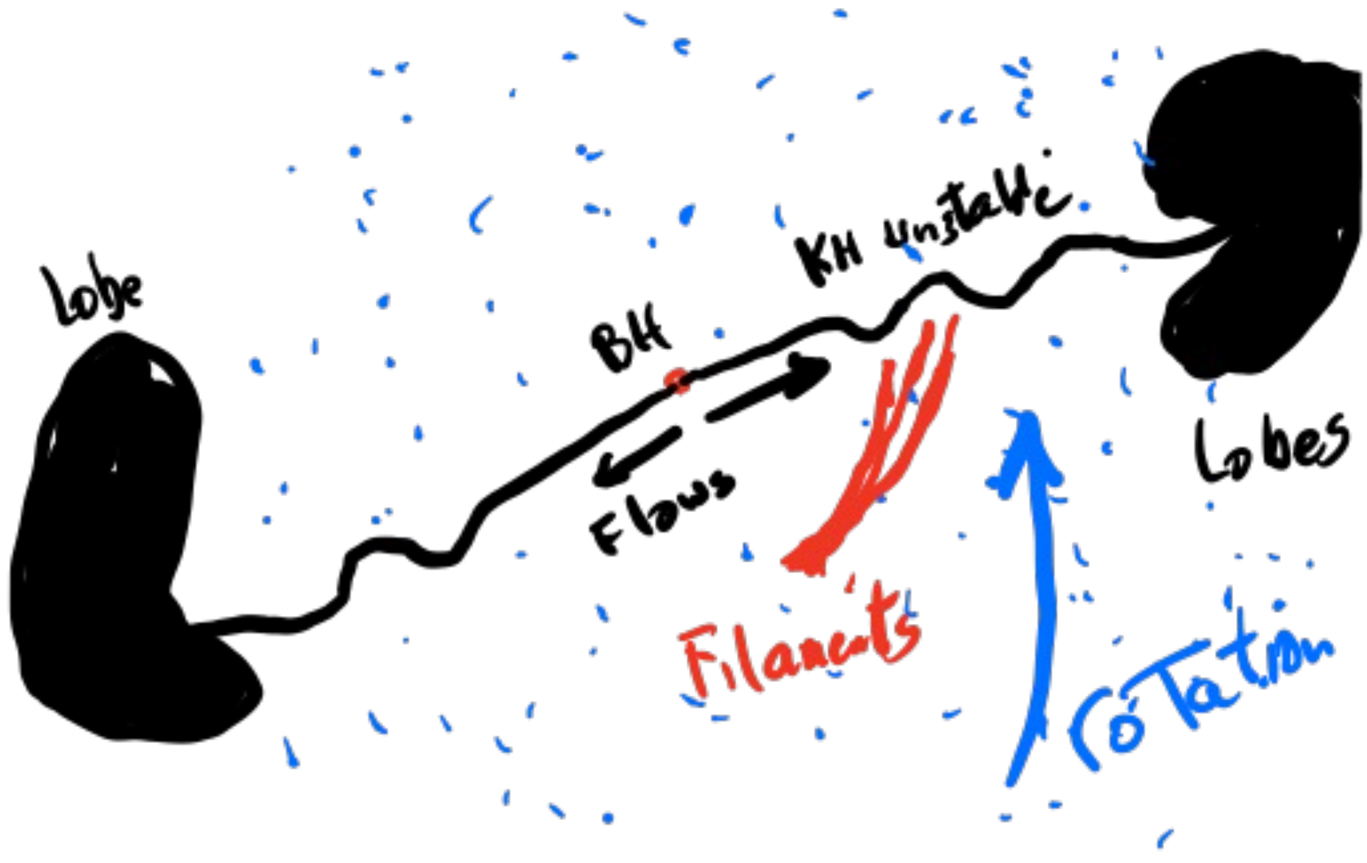


Banda-Barragán et al 2016

- The wind wraps magnetic field around a moving obstacle
- Magnetic field and cr electron density amplified by compression

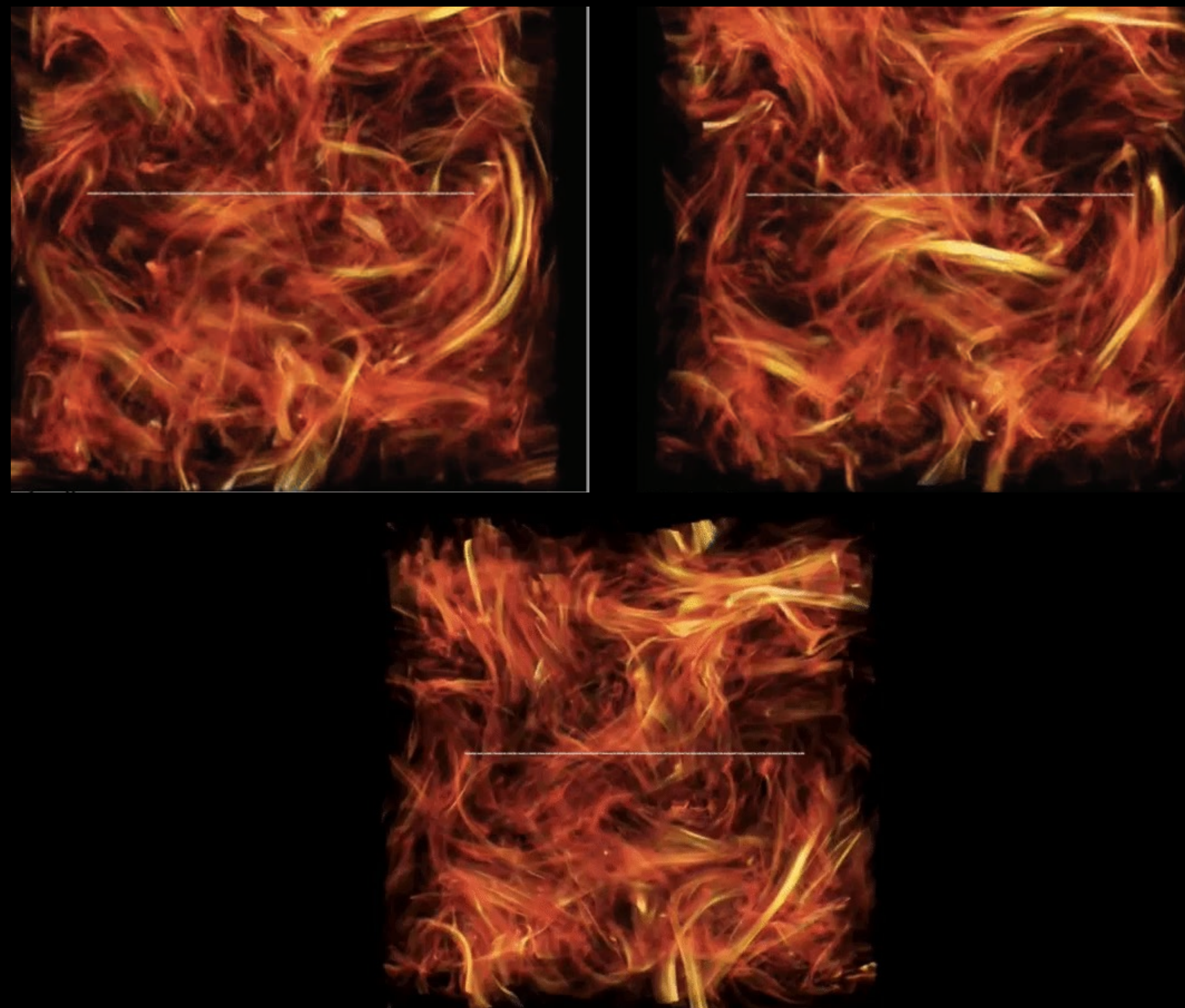
Extragalactic Filaments





Turbulent Simulations

- Field made by turbulence
- Field is wrapped around turbulent eddies
- Amplified by shear
- Field aligns along sheared layer of an outflow



Porter et al. (2015)

- Summary

- Multiple lines of evidence for high cosmic ray pressure

- High cosmic-ray pressure drives a wind

- Magnetized filaments

  Created by winds interacting with an obstacle ?

  Turbulence amplification of the magnetic field?

- Future
  - High resolution to test the interaction picture