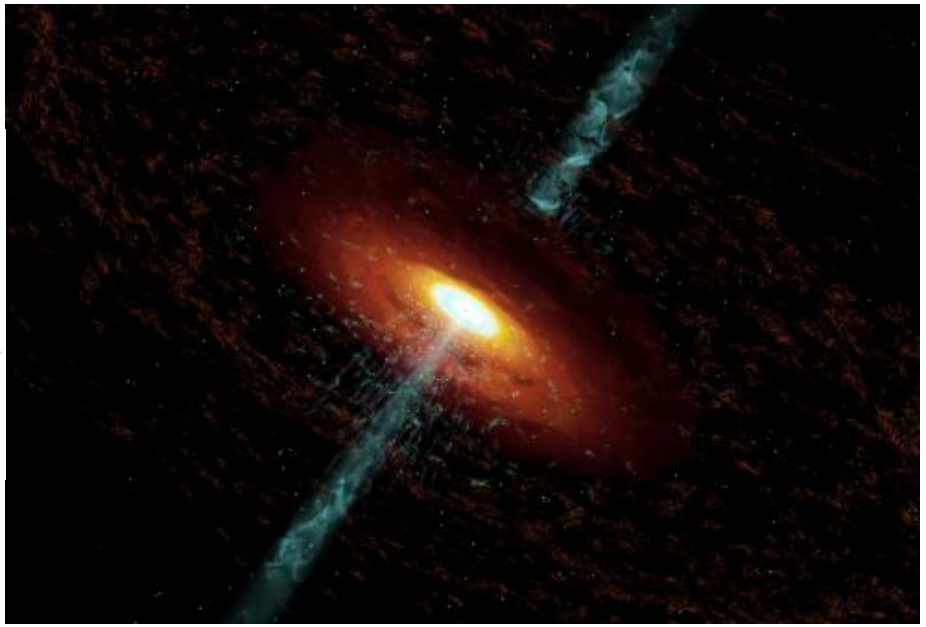


Outstanding Problems in Blazar Astrophysics

Alan Marscher

Institute for Astrophysical Research, Boston University

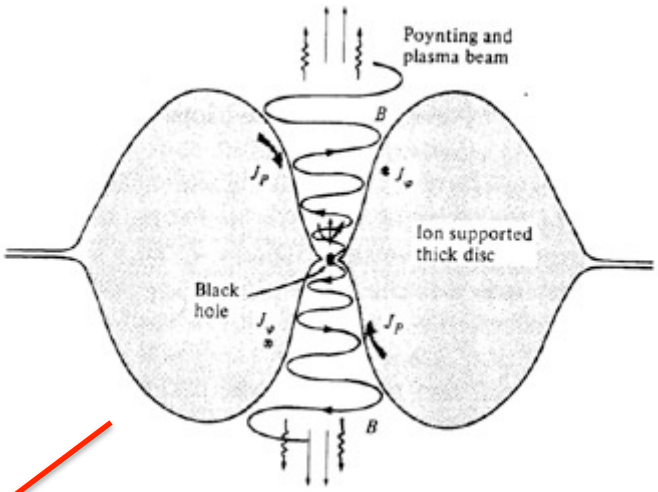
Research Web Page: www.bu.edu/blazars

Recordings of original songs: www.soundclick.com/cosmosii

A Very Brief History of Blazars

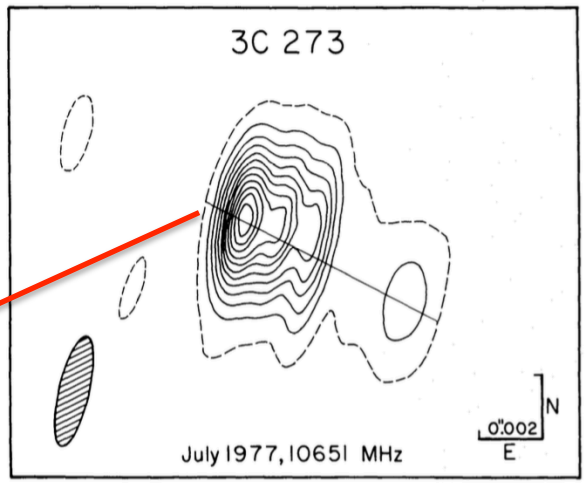
1968: MacLeod & Andrew (ApJL, 1, 243): BL Lac noted as inverted-spectrum radio source with optical ID

1978 Pittsburgh conference on BL Lac Objects:
Term "blazars" coined by Ed Siegel
- Blandford & Rees: blazars are compact relativistic jets



<u>Jet Models</u>
Blandford & Znajek 1977: BH spin → jet
Blandford & Payne 1982: disk-launched jets

1979: Readhead, Cohen, et al.:
"Hybrid" VLBI images → they <u>are</u> jets!



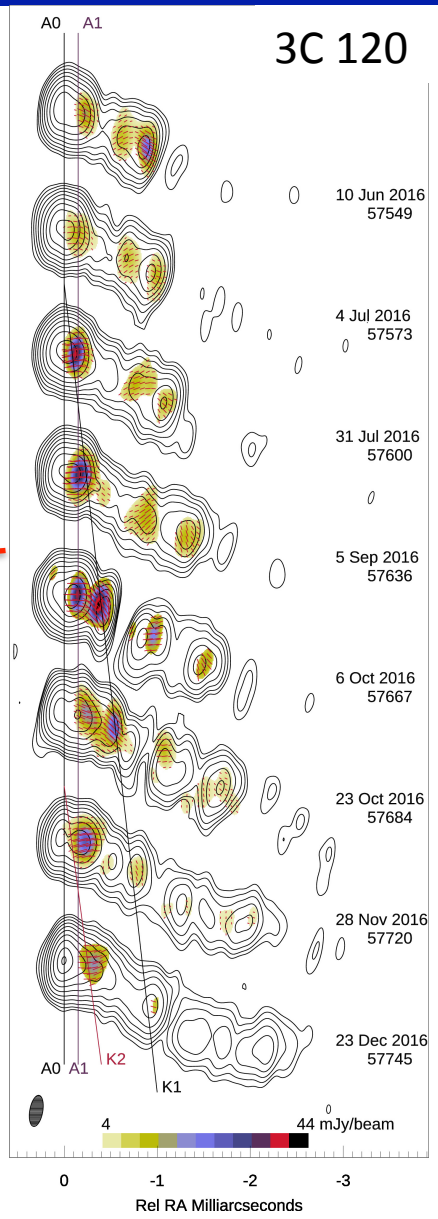
A Very Brief History of Blazars (part 2)

1966: Relativistic motion to explain radio variability (Rees, Nature, 211, 468)

- **Predicted superluminal motion**

→ Observed with VLBI in 1971 by Whitney et al. (Science, 173, 225) in 3C 279

- **Now observed routinely**

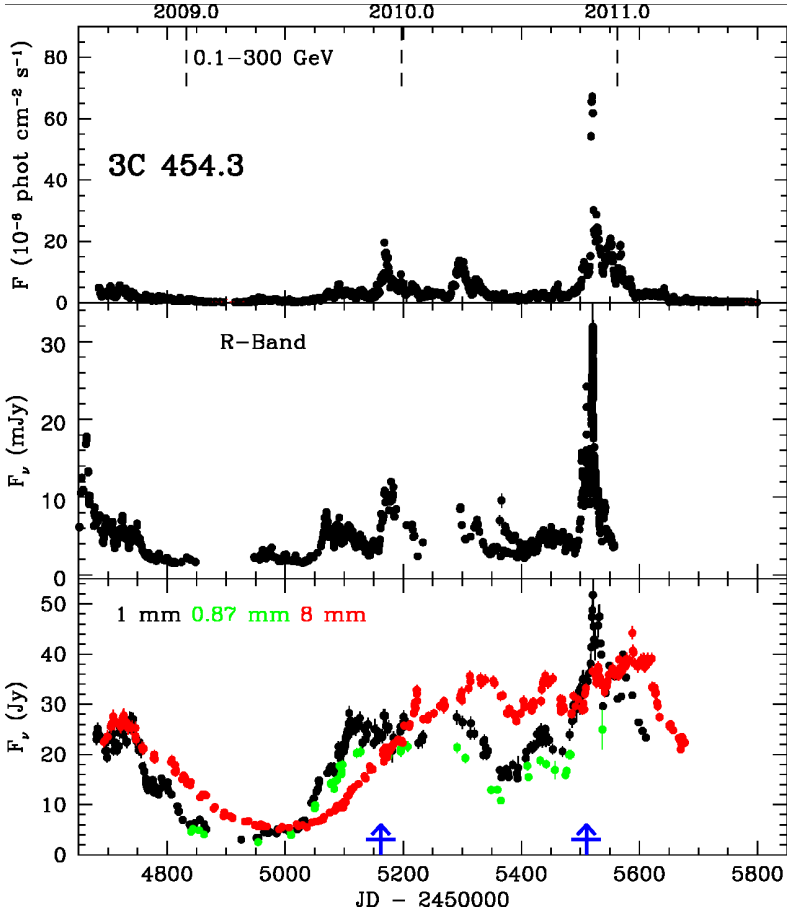


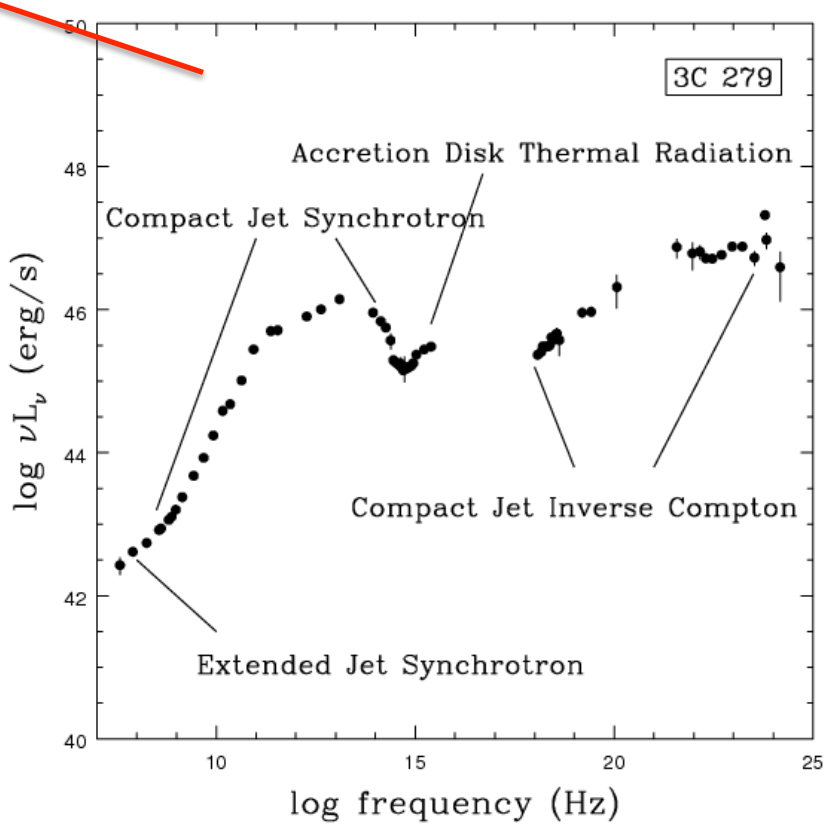
A Very Brief History of Blazars (part 3)

Multi-wavelength Connections: expected, since nonthermal radiation is broad-band and involves synchrotron + inverse Compton scattering

→ Double-humped SED

→ Correlated variability:

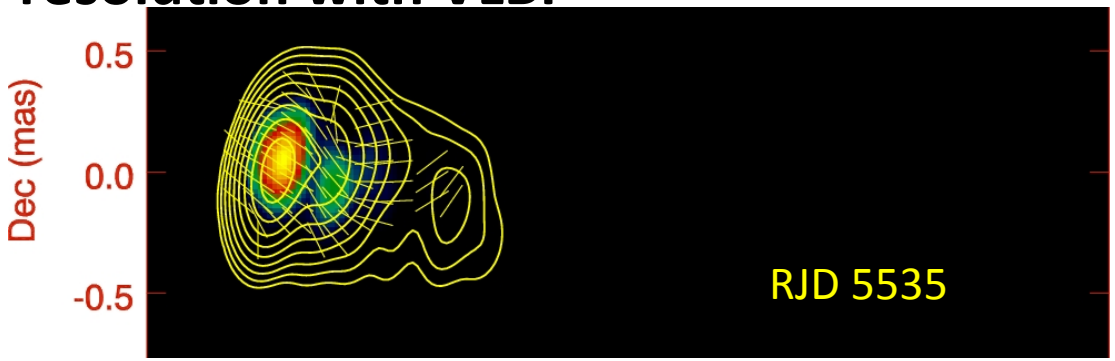


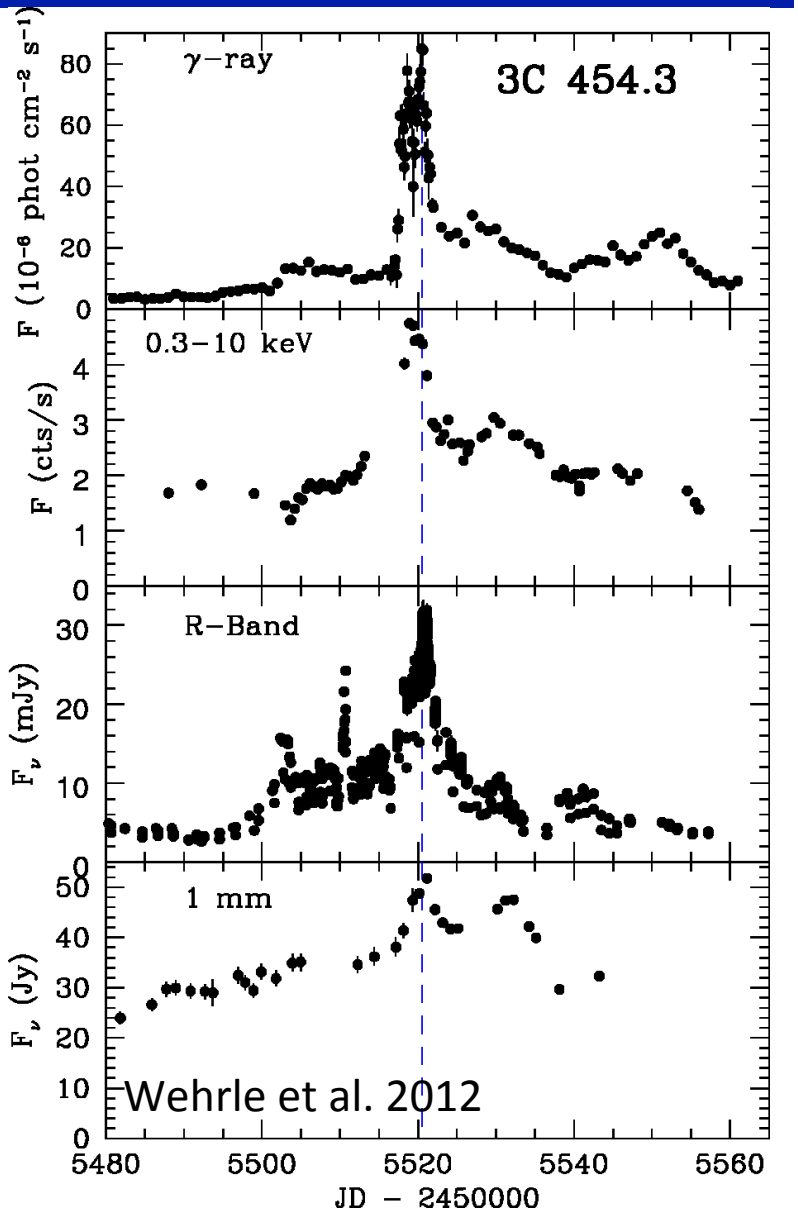


Current Status

Our data sets are becoming extremely rich, with multi-wavelength monitoring at high sampling rates of many blazars

- **Fermi LAT: continuous, highly sampled**
- **Swift: X-ray, UV, optical**
- **WEBT + "freelance" telescopes: optical**
- **Metsähovi, SMA, Effelsberg, OVRO: mm/cm**
- **Radio & optical + some IR polarization**
- **Multi-epoch images at sub-milliarcsec resolution with VLBI**





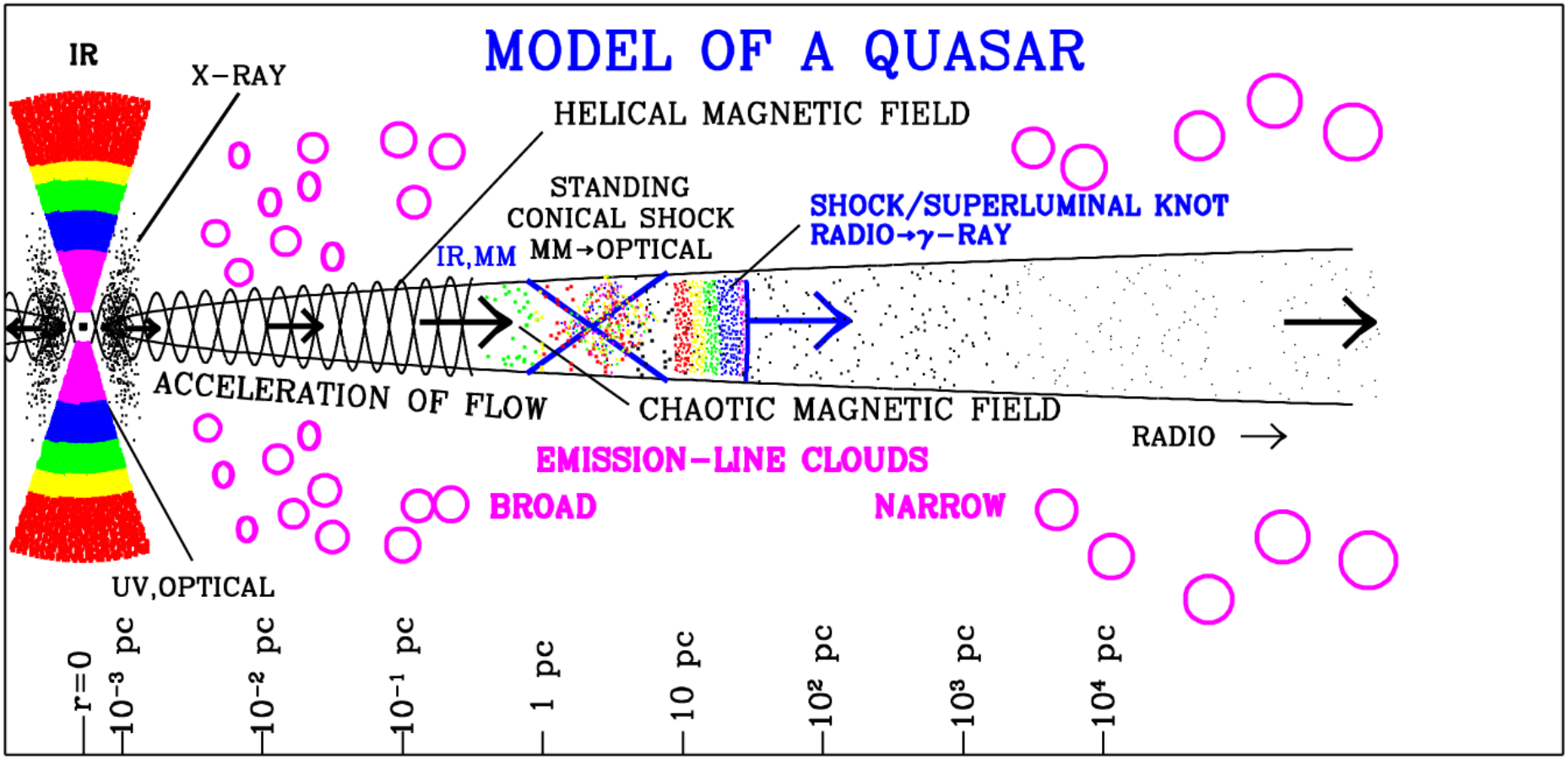
What We Know

So, we know that the blazar phenomenon involves relativistic jets formed by some accreting black holes at the centers of massive galaxies

The rest of this talk is about what we don't know, or what we are not yet certain about

- The reason why this conference is more than just a 50-year celebration

Sketch of a Quasar-Blazar: Uncertainties



Is AD thin or fat? Is the corona an AD atmosphere or base of jet? How wide is BLR? What is disk-jet connection? What causes strong vs. weak jets? Where is B helical, turbulent, poloidal, transverse? What are blobs? What is the "core"? What accelerates particles? Where does jet flow accelerate & decelerate? What is the jet's transverse structure? Where & how are γ-rays & X-rays emitted? What is the e^+/p^+ ratio in the jet? What is role of HD/MHD/EM processes?

Blazar Demographics

Lorentz factor probability distribution: not all jets have same Γ

Is there a blazar sequence or a continuum of physical properties + selection effects?

How do NLS1s fit into the unified scheme?

How do blazars relate to X-ray binaries & GRBs?

Blazars as cosmological probes

When did the first blazars appear?

Bad Behavior of Blazars

Variability time-scales are often ridiculously short

Variations well/partially/not correlated across wavebands

Most variations seem random
Some seem periodic … for a while (e.g., PG1553+113)

Doppler factor "crisis" in some HBLs: VLBI motions too slow

Brightness temperatures can exceed 10^{12} K limit

Polarization rotations, changes in % that relate/do not relate to flux variations

Mis-aligned radio galaxies can emit high flux of γ rays (NGC1275)

Why We Study Blazars (Justification for Proposals)

Blazars are the most luminous objects in the universe on time scales longer than a few minutes

Observations of blazars probe:

– The formation, acceleration, & propagation of relativistic plasma jets
– Acceleration of charged particles to ultra-relativistic energies
– The physics of relativistic plasmas
– Phenomena associated with accreting black holes
– The extragalactic background light
– Energy deposited into the host galaxy (feedback)

Blazars are the most exciting cosmic phenomenon that can be observed on time scales convenient to humans

New Ways of Studying Blazars

Event Horizon Telescope: Global VLBI at 1 mm

Multi-messenger astrophysics: neutrinos & ultra-high-energy γ rays & cosmic rays
→ But who is sending the message?

X-ray polarization: IXPE, launch scheduled in 2021

Cherenkov Telescope Array: γ rays at 20 GeV – 300 TeV

LSST: Big data monitoring studies of a vast number of blazars

We need a sensitive X-ray all-sky monitor!

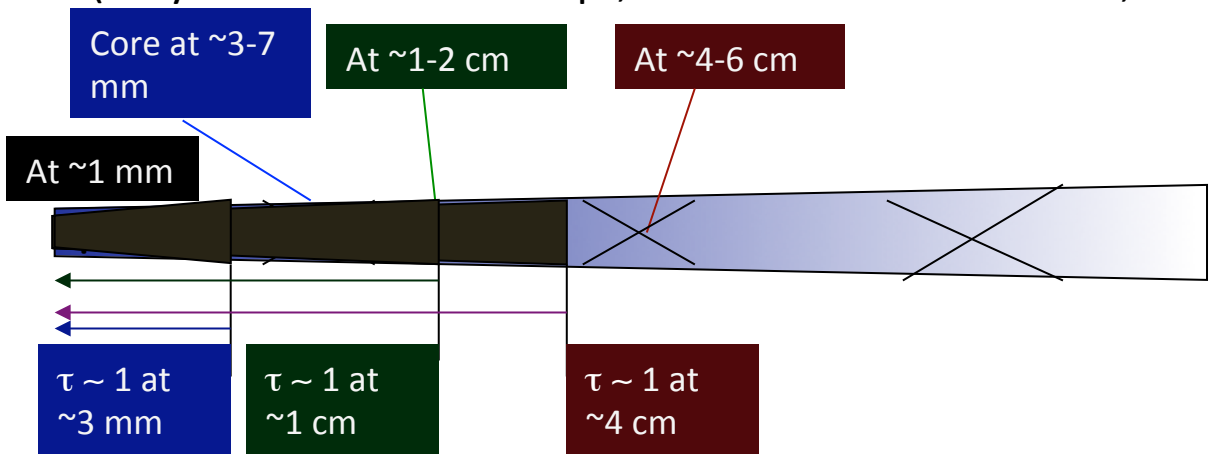
Extra Slides Follow

What Is the "Core" of Blazar Jets?

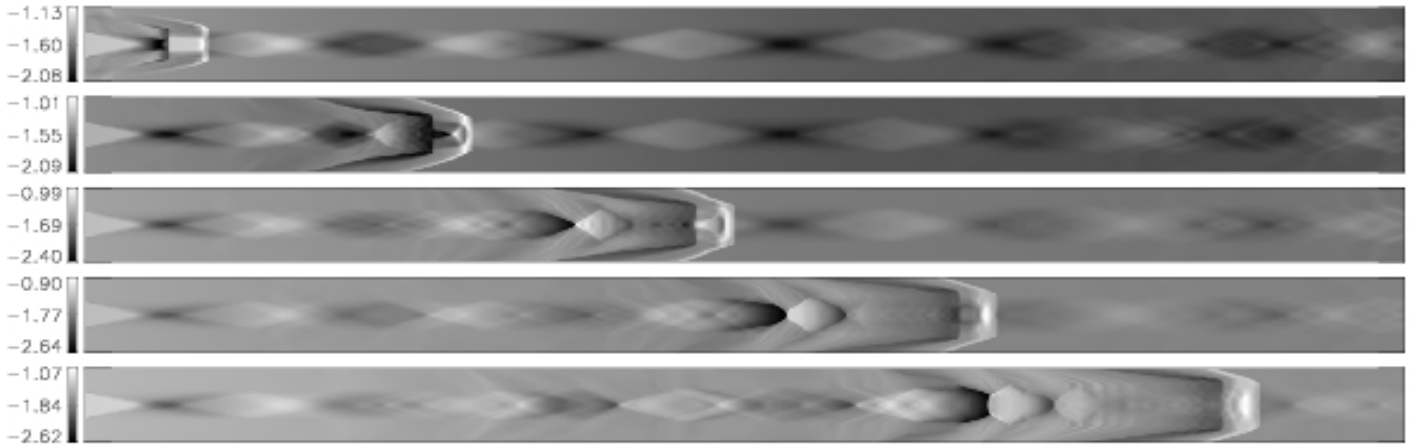
Observations suggest that core on VLBI images is <u>either</u>:

1. $\tau \sim 1$ surface (τ = optical depth to synchrotron absorption)
2. First standing (oblique or conical) shock outside $\tau \sim 1$ surface

(Daly & Marscher 1988 ApJ; Cawthorne & Cobb 1990; Cawthorne 2006; Cawthorne + 2013)



Lobanov (1998): Can determine B from core shift)



HD simulation (Gómez et al. 1997)

The “Core” of Blazar Jets (continued)

3. If accelerating relativistic jet is viewed within ~ 10° of axis, core can be location where Doppler factor approaches its ultimate value

4. If viewed from a wider angle, base of jet can be seen as the core if a sufficient number of relativistic electrons are present there

   - Appears to be the case in M87, Cyg A, NGC1052, 3C 84