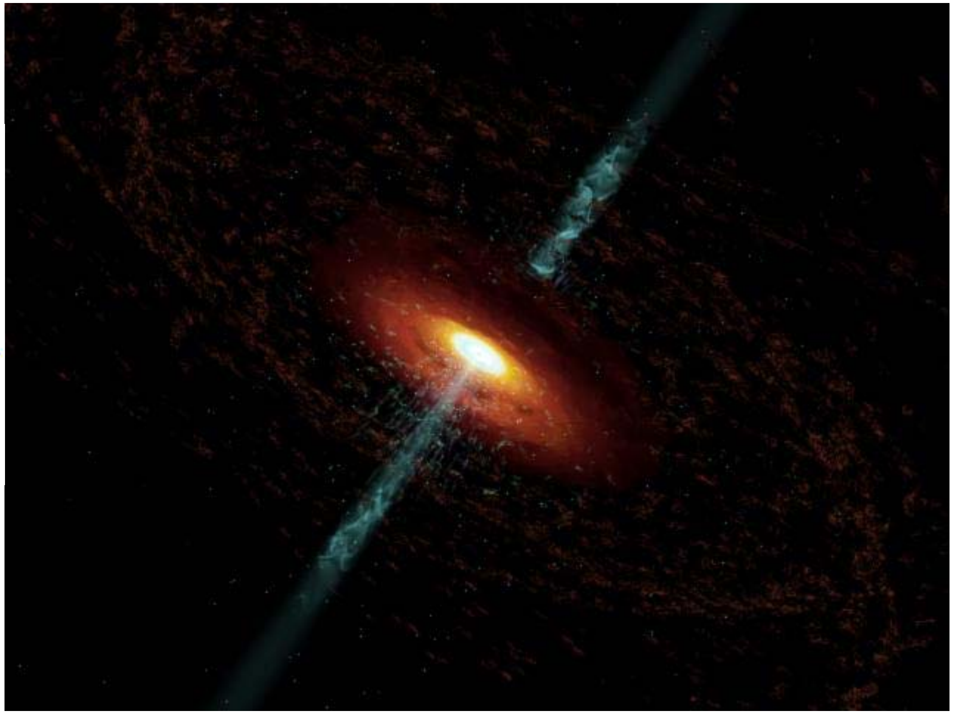

Observations and Modeling of Multi-waveband Variations of Blazars during γ-ray Outbursts

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Research Web Page: www.bu.edu/blazars

Posters N1, N3, N41, N42, N49 by our group & collaborators

Main Collaborators in the Study

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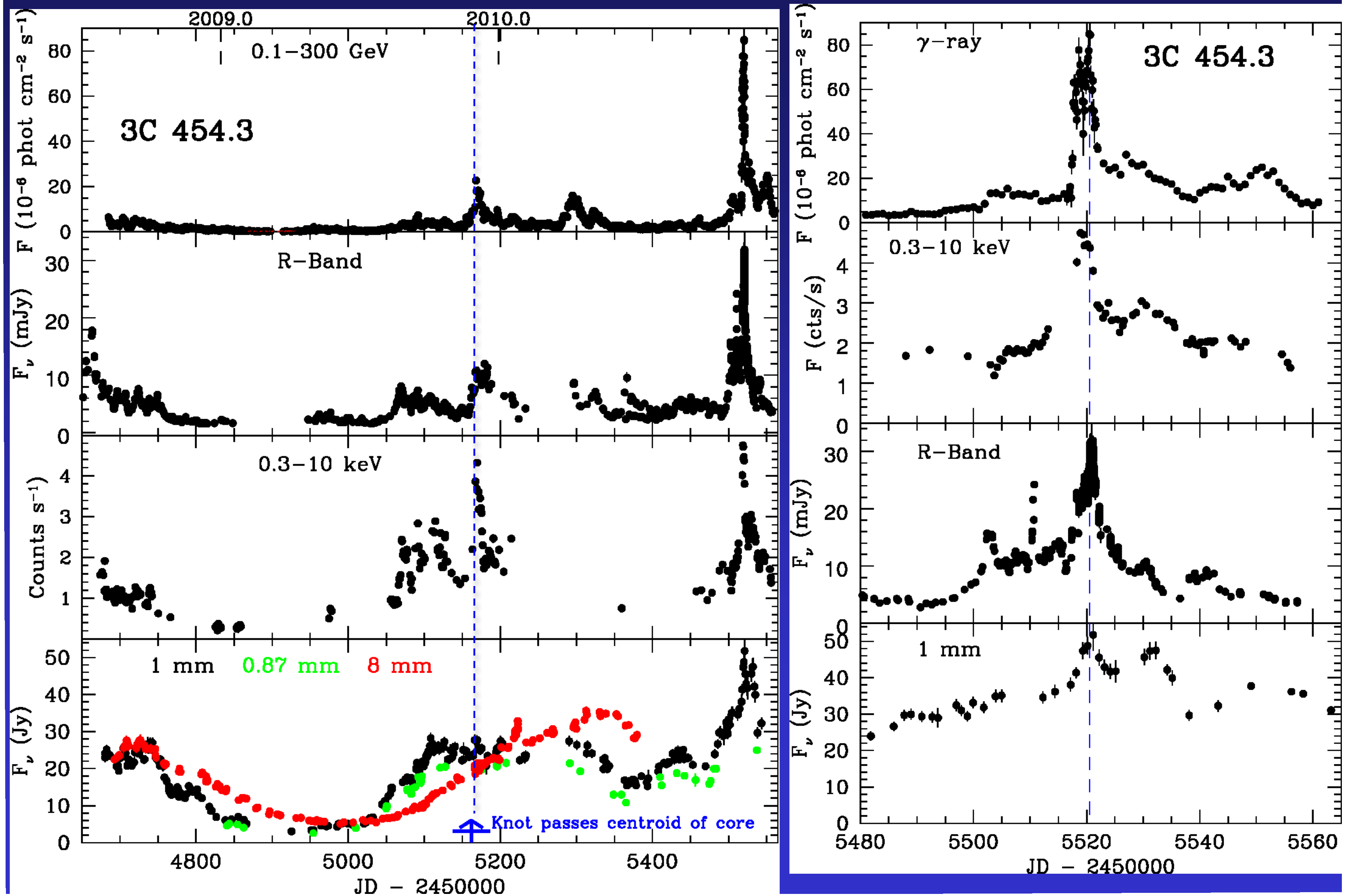
Vladimir Strelnitski & Gary Walker (Maria Mitchell) + many others

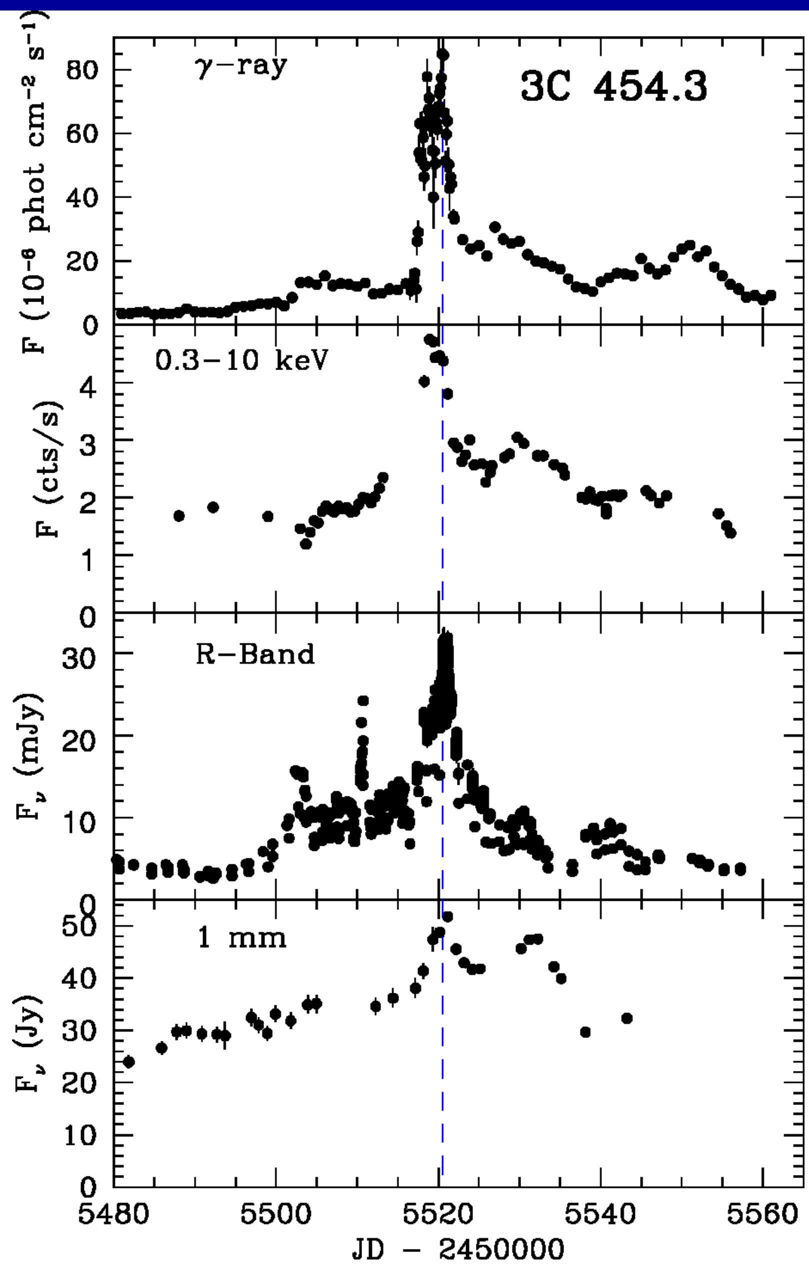
Telescopes: VLBA, GMVA, EVLA, Fermi, RXTE, Swift, Herschel,
IRAM, UMRAO, Lowell Obs., Crimea, St. Petersburg U.,
Pulkovo, Abastumani, Calar Alto, Steward, + many others

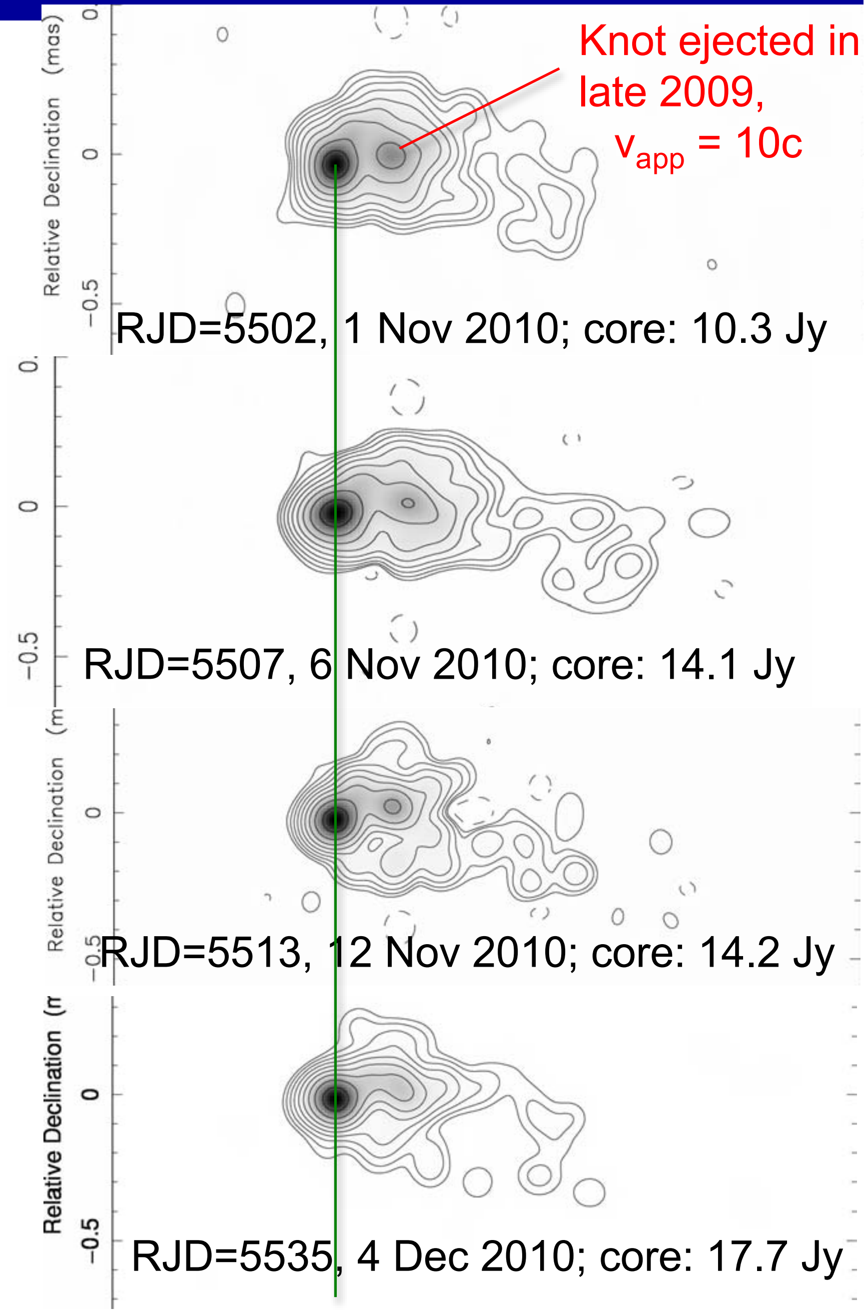
Funded by NASA & NSF

3C 454.3: Outbursts seen first at mm wavelengths, optical & gamma-ray closely related but do not vary exactly together on short time-scales

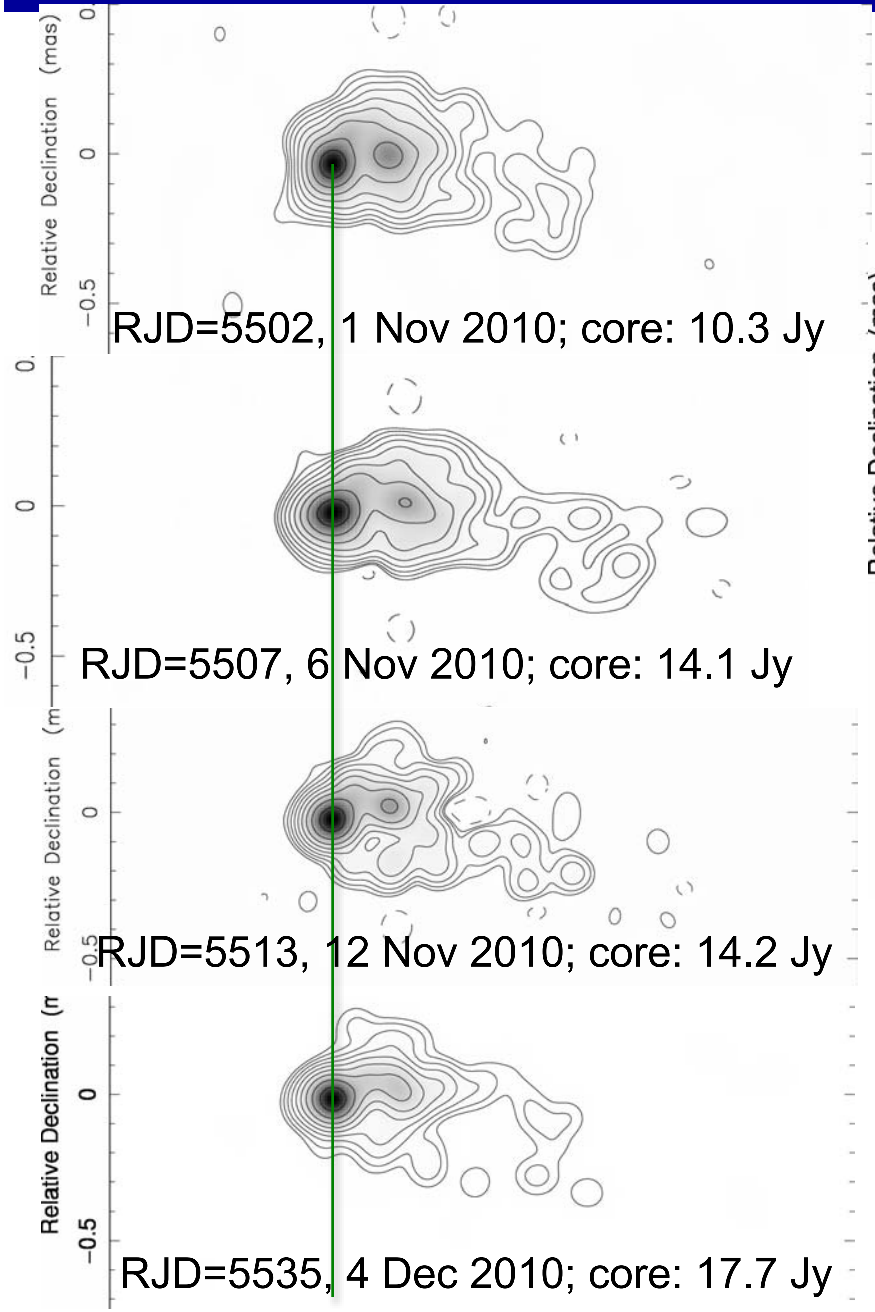


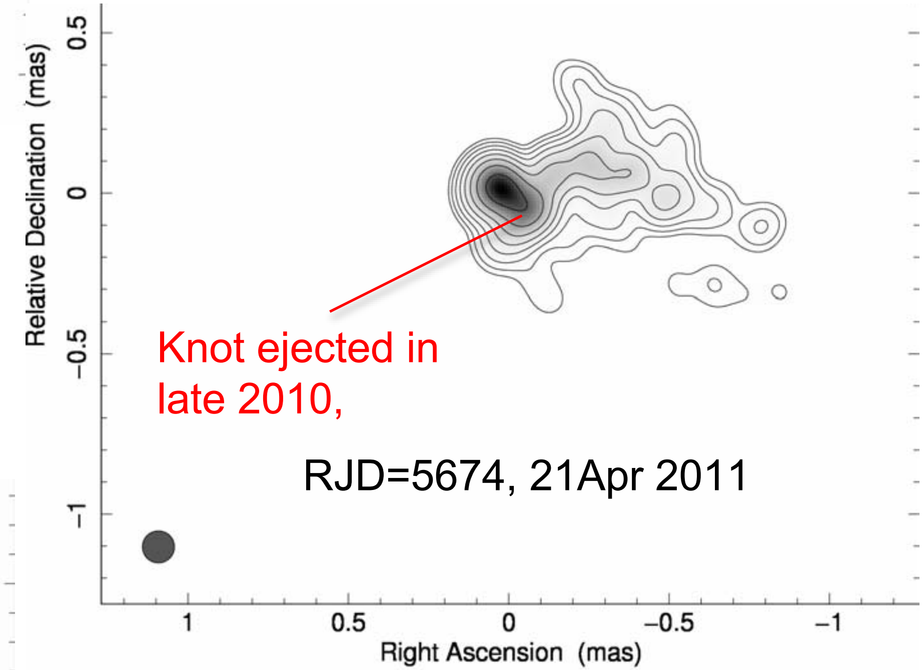
3C 454.3: 2010 super-outburst from gamma-ray to mm-wave





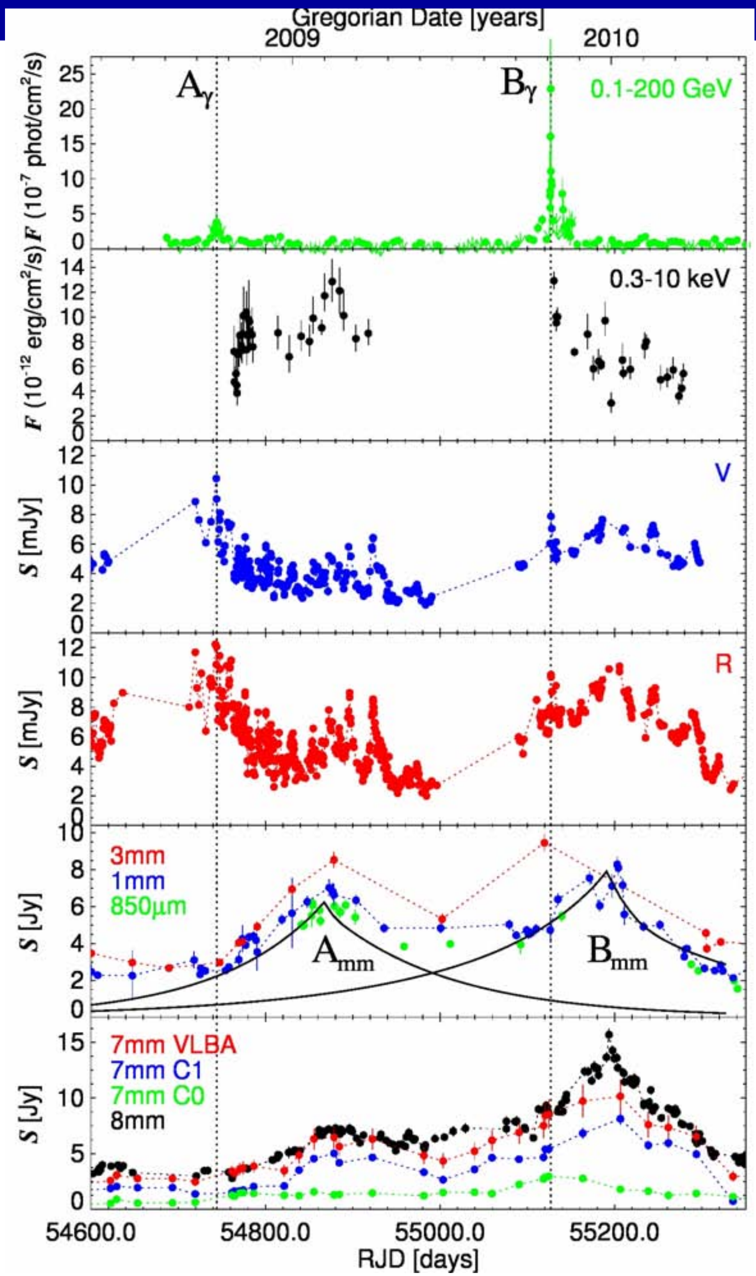
3C 454.3: Knot from mega-outburst moving in new direction

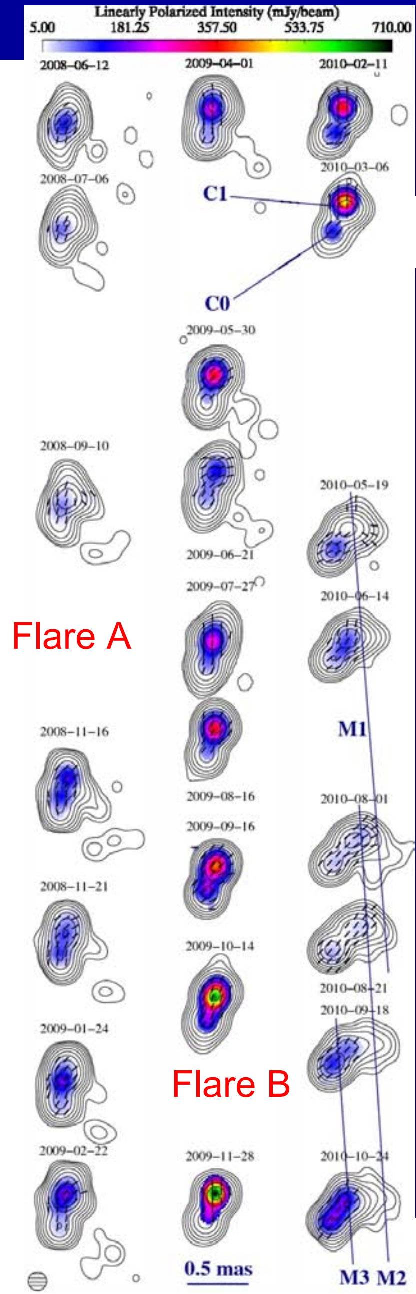




Jorstad et al. (2010 ApJ): core has triple structure, with a flare occurring as a knot passes each feature

OJ287 (Agudo et al. 2011, ApJL, 726, L13)



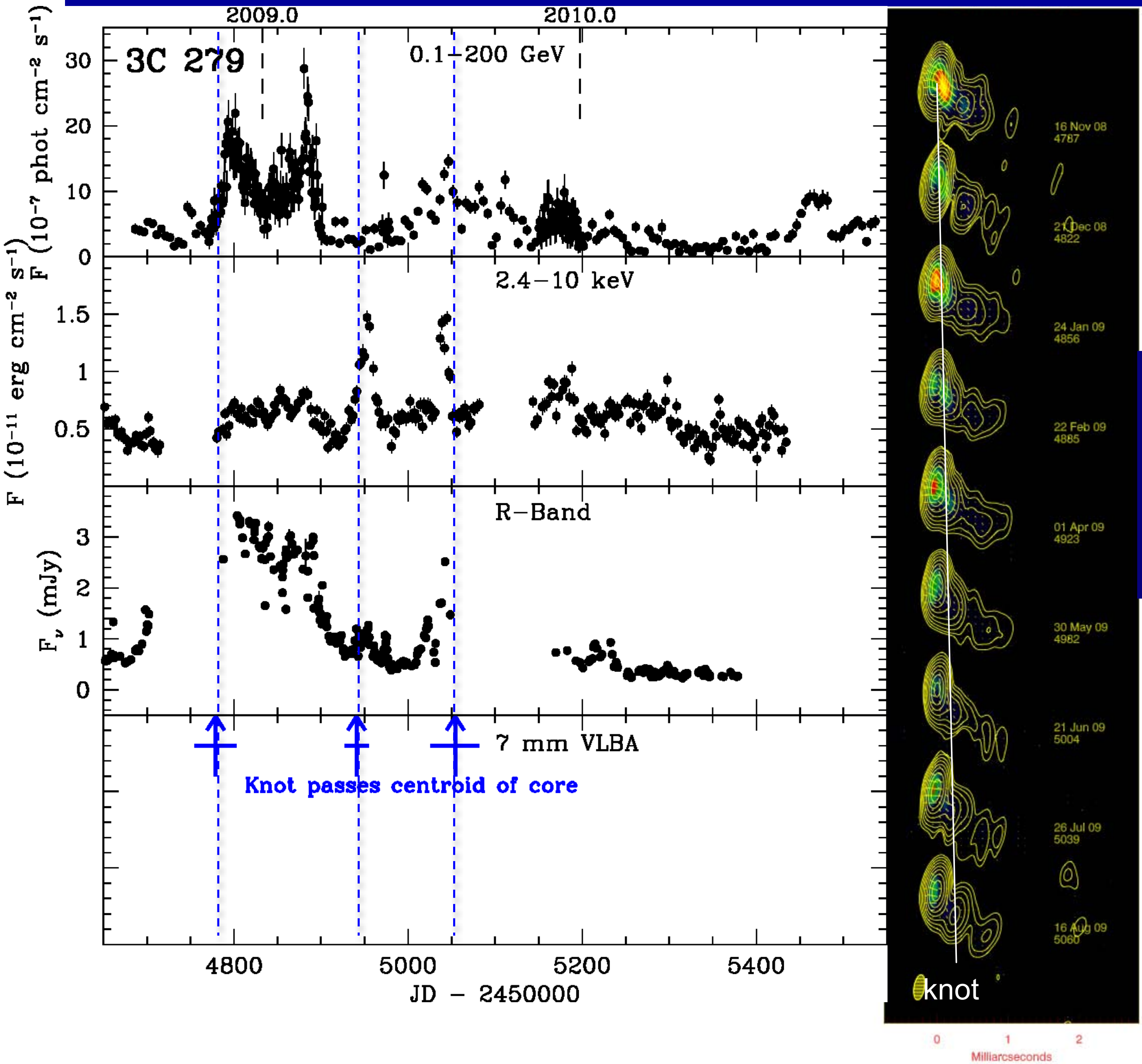


Change in jet direction starting ~ 2005

Core is the more southern compact feature, C0

Flare B appears to occur as superluminal knot passes through C1, which is probably a quasi-stationary shock. The same may be true for Flare A based on the increase in polarization of C1

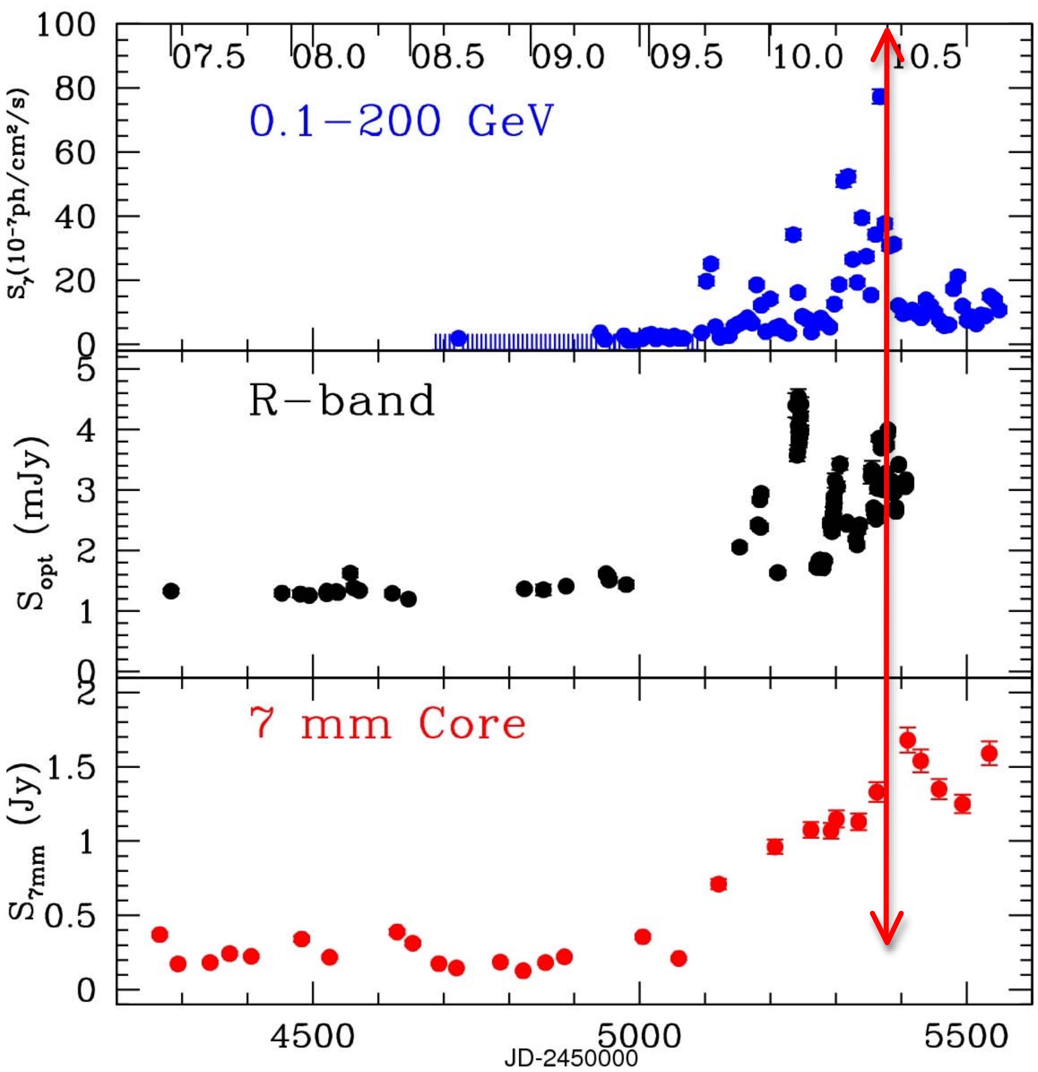
3C 279 in 2008-09



1. High-energy utbursts occur after new superluminal knot appears

2. Note optical/γ-ray general correlation but poor detailed correspondence on short time-scales.

Strong Outburst in 4C21.35 (1222+216) in 2010

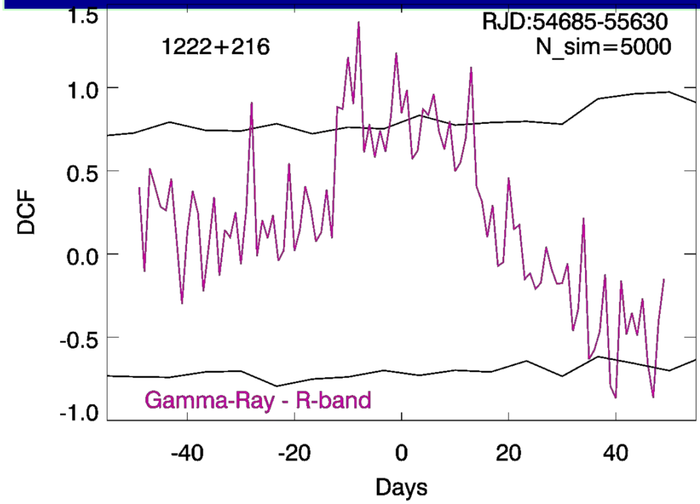


See Jorstad et al. poster N41 for VLBI images

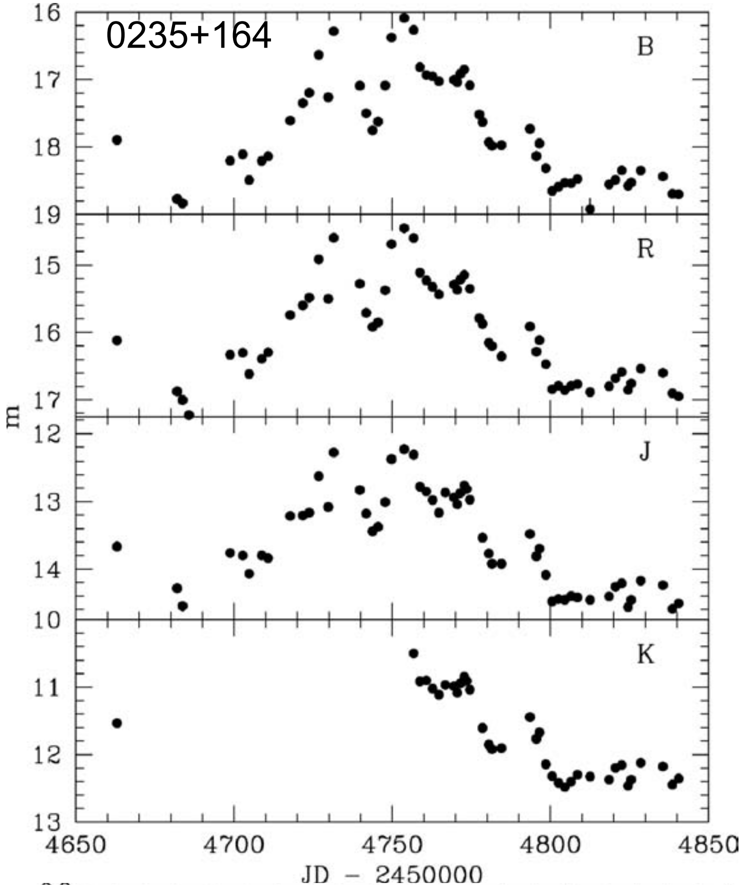
Good optical-gamma correlation but not detailed agreement

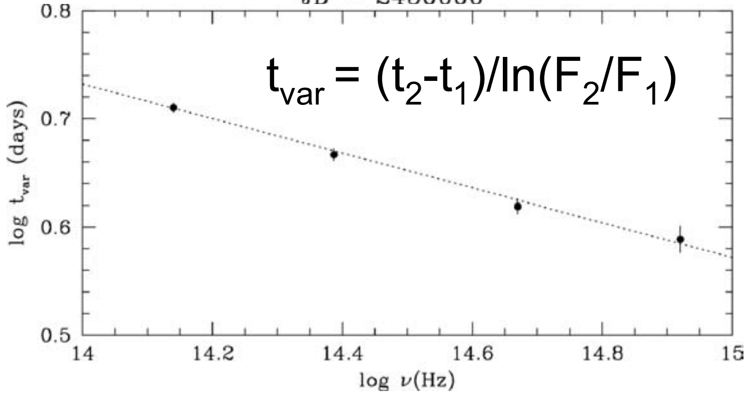
Outburst started at mm wavelengths

Detection at 0.4 TeV (Aleksic et al. 2011) ➔ flare must occur on pc scales to avoid high pair-production opacity



Variations in Flux vs. Frequency





Gamma-ray + optical variations usually faster than X-ray, IR, & mm-wave variations

Shorter variations → smaller volume and/or more severe energy losses of radiating electrons

Smaller = closer to black hole?

Problems:

- Observed coincidence of γ-ray flares with events in radio jet

- high-E gamma-rays cannot escape before producing e^+-e^- pairs

Puzzle: How can high fraction of flux vary on intra-day scales parsecs from the black hole?

→ High-Γ jets are very narrow (< 1º), Γ~50 seen

→ Proposal: Particle acceleration efficiency in jet is highly variable with position & time

- Related to direction of magnetic field?

Working toward a Modified Model

Imagine that many "blobs" are just random fluctuations in turbulent jet flow (others might be strong moving shocks)

- Agrees with power-law power spectrum of fluctuations in flux

Electrons in blob are accelerated when blob passes through standing shock in core (or elsewhere)

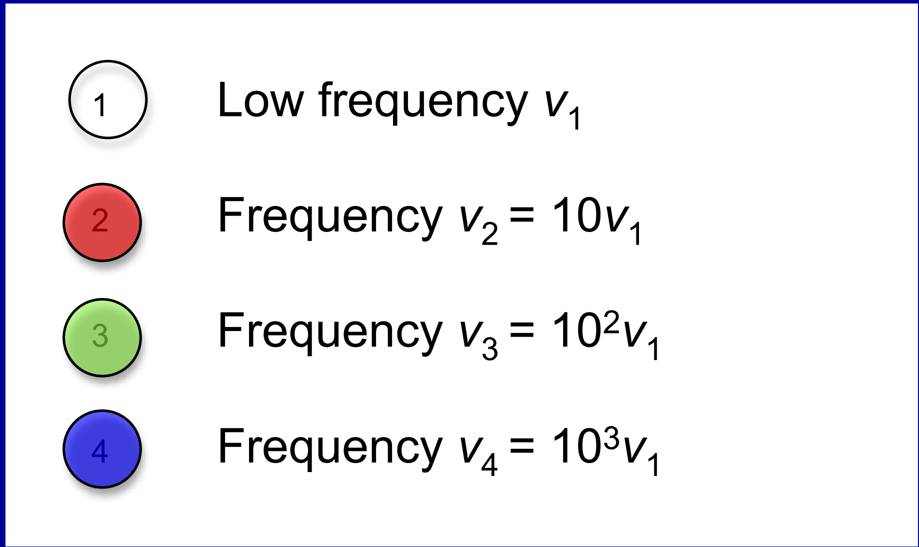
- Maximum electron energy achieved varies from one turbulent cell to another → number of cells with energies as high as E depends on E

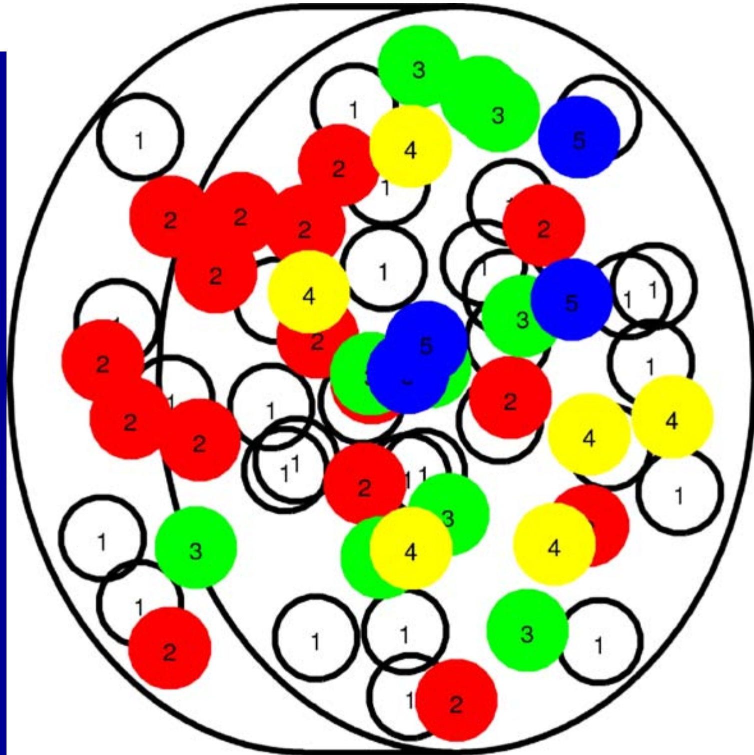
→ Frequency-dependent volume of emission $V(\nu) \propto \nu^{-p}$

Flux density $F_\nu \propto \nu^{-(s-1)/2}\, V(\nu) \propto \nu^{-[p+(s-1)/2]}$ [where $N(E)=kE^{-s}$]

Radiative energy losses can steepen this further

Advantages of Model





Smaller number of turbulent cells are involved in emission at higher frequencies

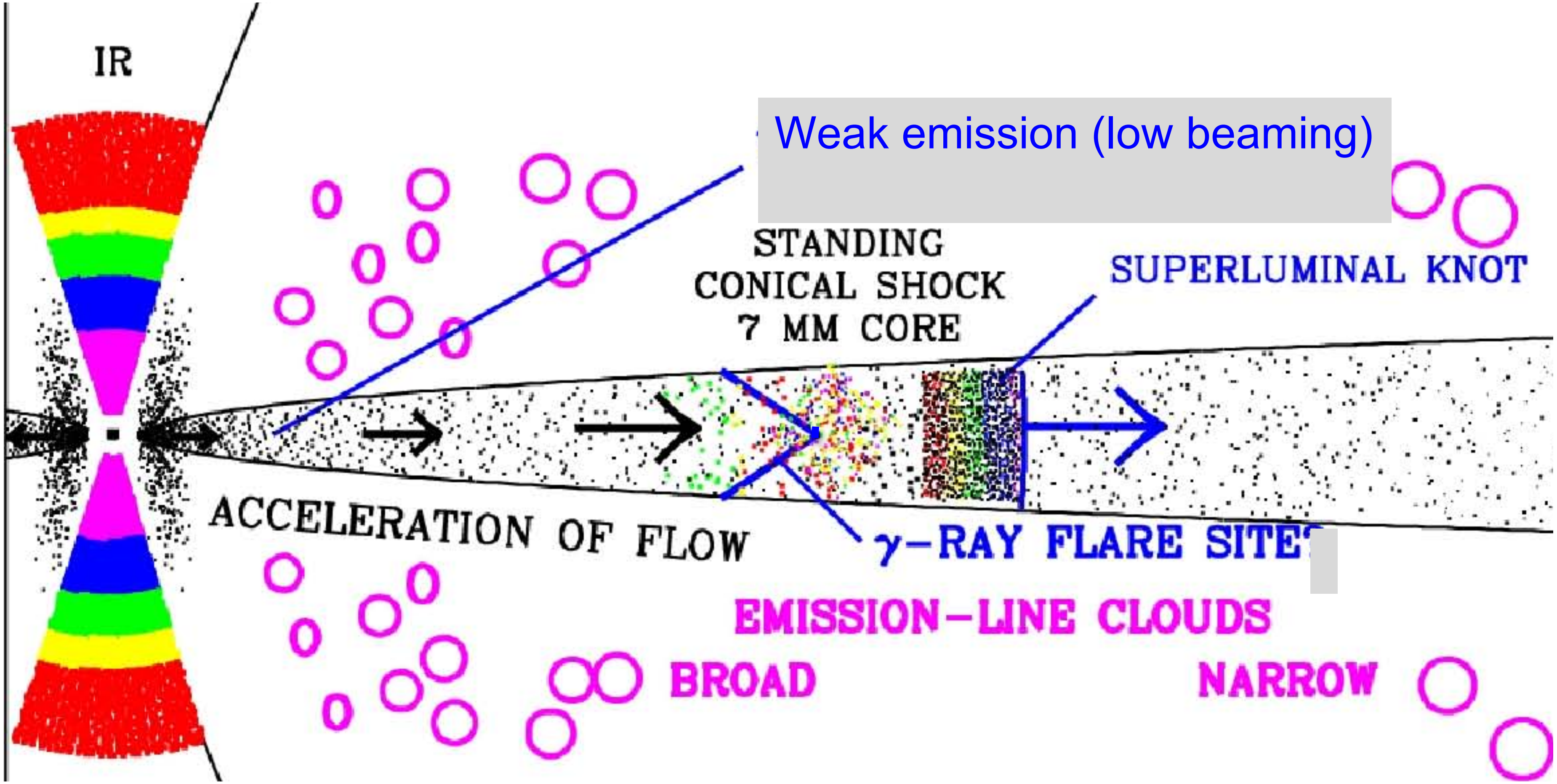
→ Variability time scale shorter (approx. $\propto \nu^{-p/2}$)

→ Linear polarization higher & more highly variable in degree & position angle at higher ν (as observed)

Works well for blazar AO 0235+164, $V(\nu) \propto \nu^{-0.32}$

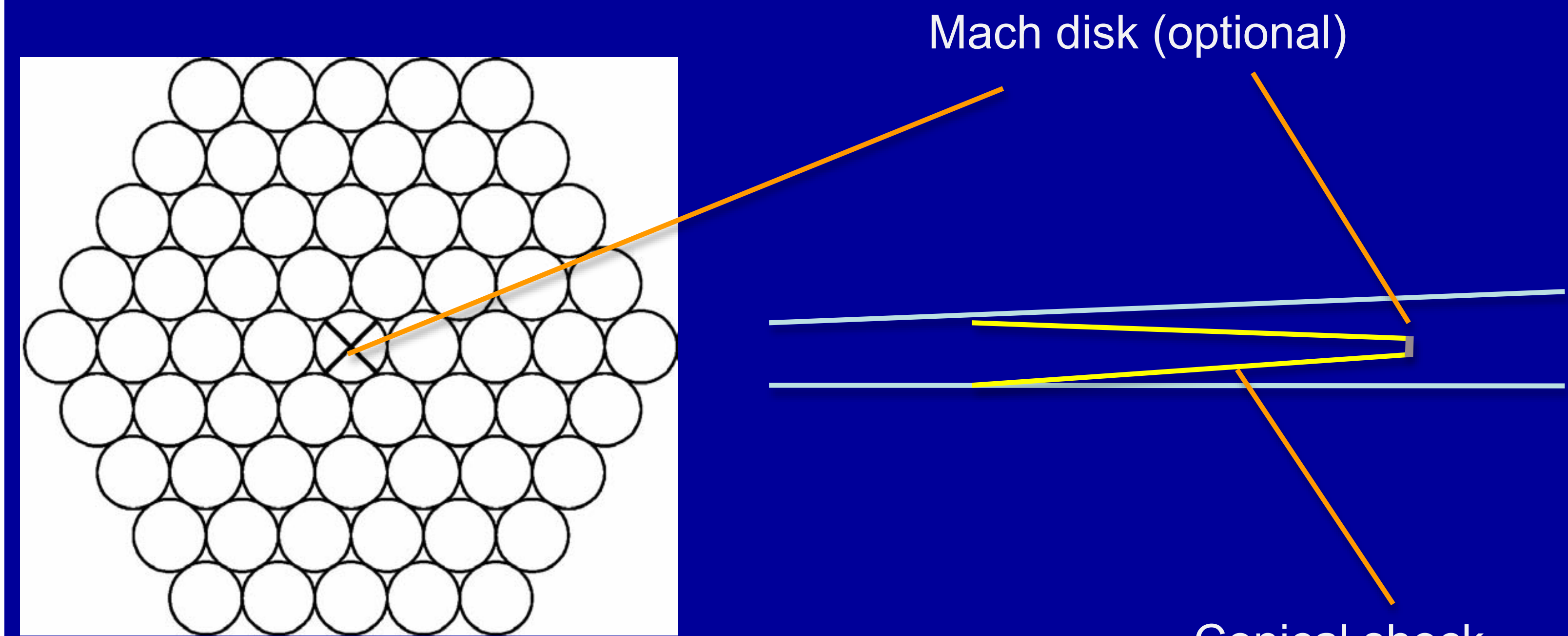
Sketch of Jet with Conical Shock + Mach Disk

Outburst of this type occurs when turbulent “blob” crosses standing oblique shock, perhaps with a Mach disk near the axis



Turbulent Extreme Multi-zone (TEMZ) Model

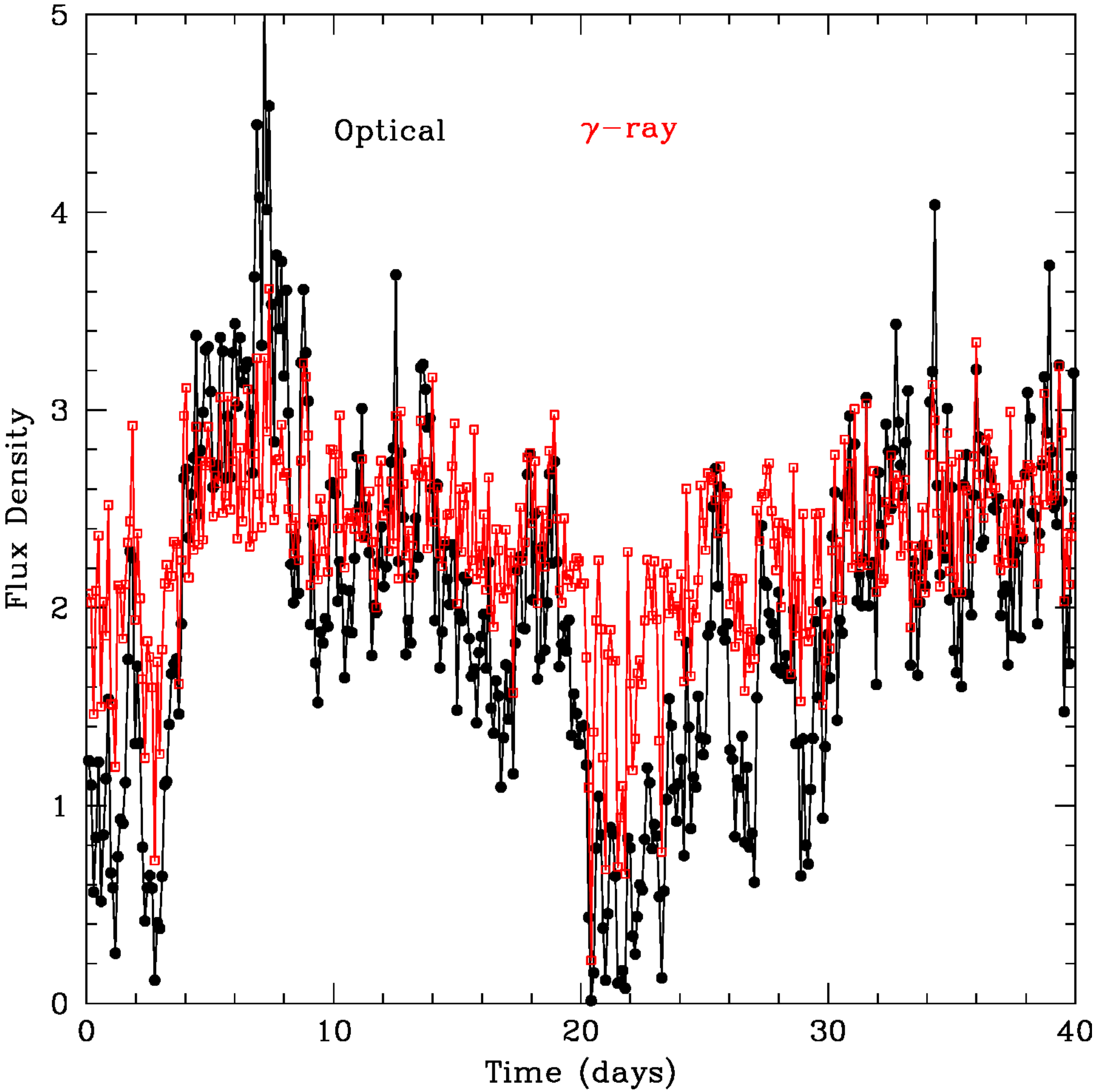
60 turbulent cells across jet cross-section, each followed for 100 cell lengths after crossing shock ➔ 6000 emission zones



60 cells in each of 100 nested cones beyond shock

Each cell has random B direction, B & N_0 vary according to PSD

Sample Simulated Light Curves (seed photons from dust as in 4C21.35; Malmrose et al. 2011 ApJ,732, 116)



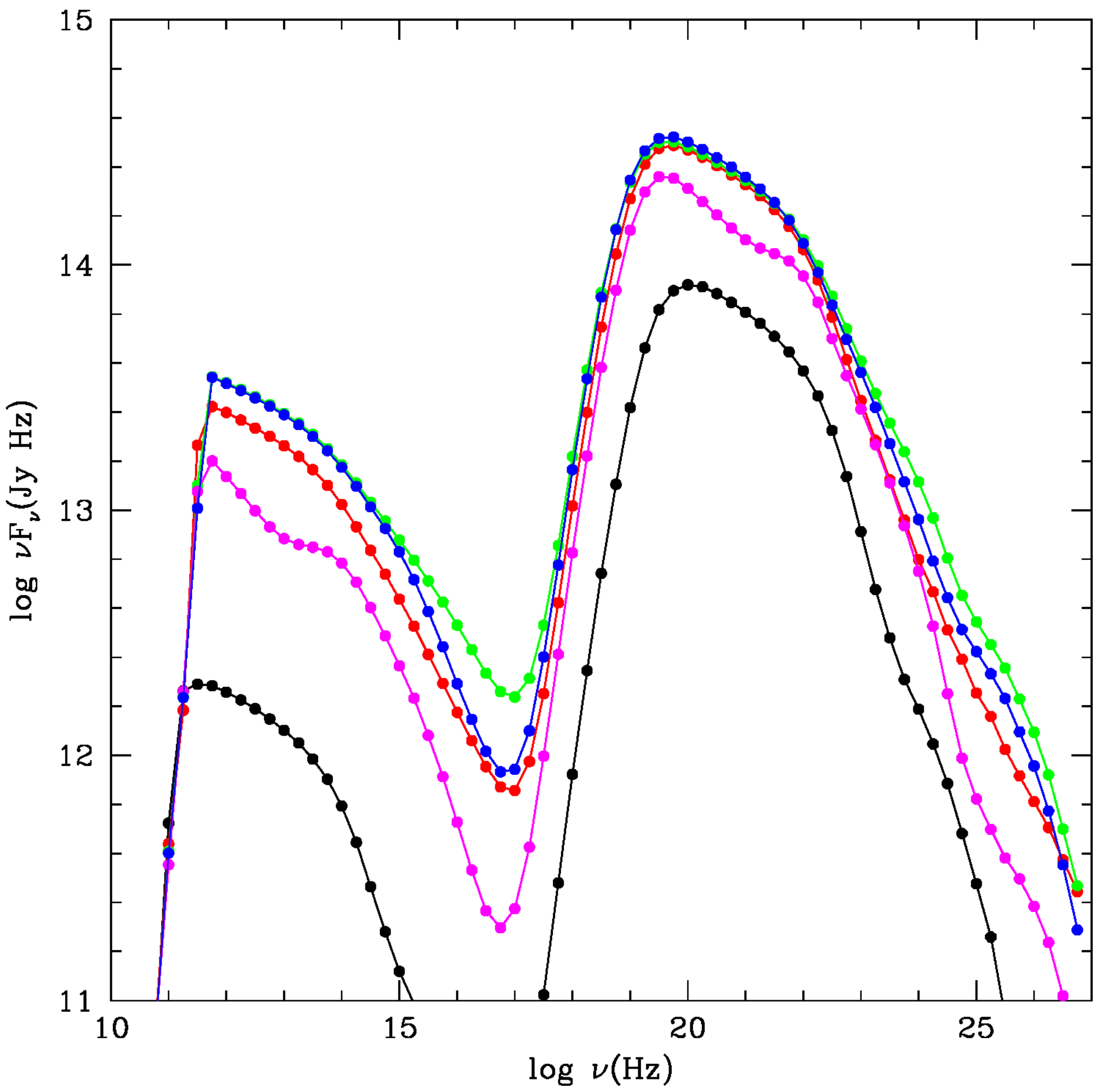
Note excellent general correlation but frequent deviation from one-to-one correspondence

Also, optical fluctuations have higher amplitude (characteristic of external Compton scattering of a steady source of seed photons)

-Both characteristics caused by dependence of synchrotron flux on magnetic field amplitude & direction as well as number/energy distribution of electrons

- Can create time delays if Mach disk is present since it provides time-variable synchrotron seed photons blueshifted in plasma frame

Sample SED (seed photons from dust)



Breaks by more than 0.5 occur, but do not yet reproduce gamma-ray break by 1.3 seen in 3C 454.3

Lots more work to be done to add features to code

[e.g., polarization calculation & pair production opacity are not yet included, synchrotron self-absorption is calculated only crudely at this point, cell-to-cell SSC will require moving to a supercomputer]

and to explore different parameter regimes

So, no conclusions yet but the model looks promising