Constraints on Blazar Jet Conditions During Gamma-Ray Flaring from Radiative Transfer Modeling

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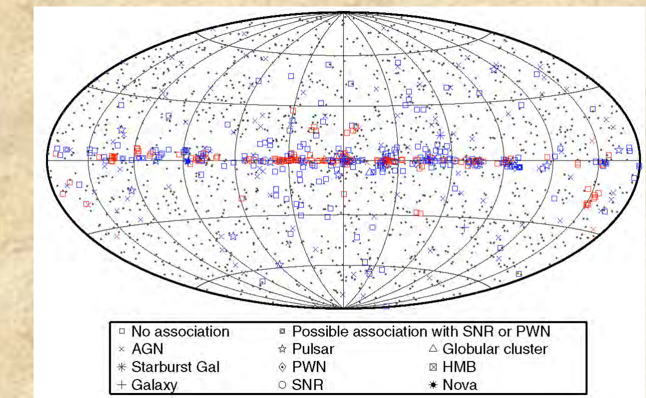
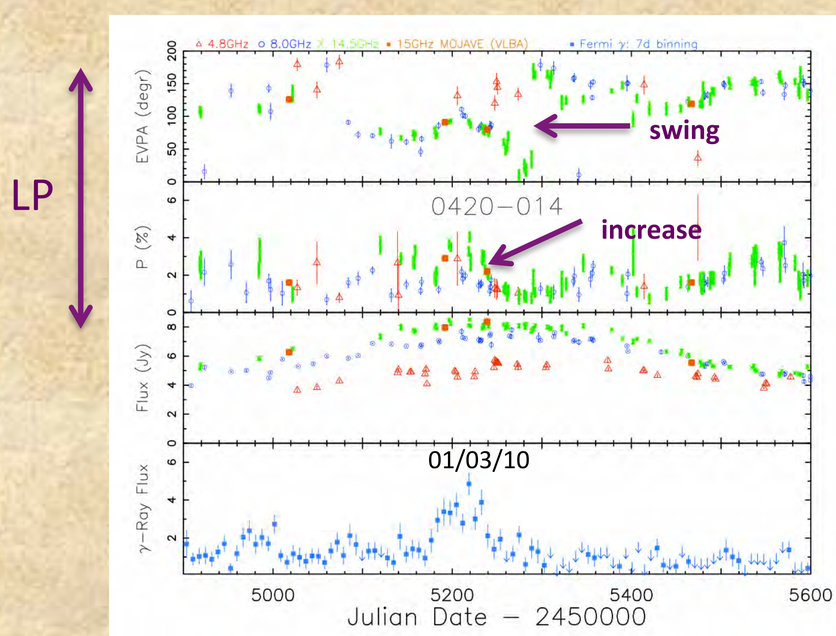
Motivation: 1) prevalence of γ-ray blazars;
2) increasing evidence that γ-ray emission arises in the parsec-scale jet

The γ-ray sky seen by FERMI

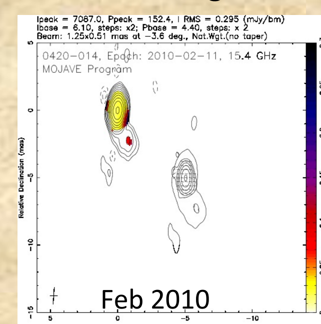


Nolan et al. 2012



Correlated flaring

MOJAVE image



Core-dominated source

UMRAO Light Curves As Model Constraints

Questions:

1. Is there evidence in the UMRAO data for the presence of shocks during (at least some) γ-ray flares?

2. Can we use the data in combination with shock models to constrain jet conditions during these γ-ray flares?

THE DATA

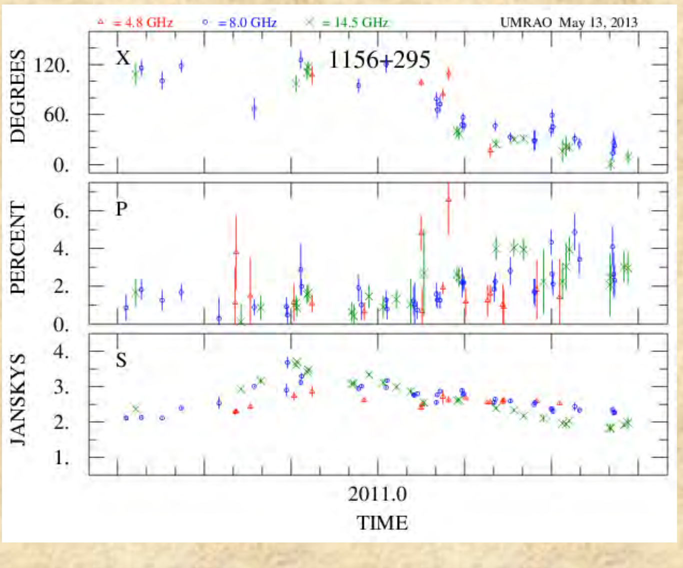
UMRAO: multi-frequency LP & S (primary model constraints)

Time window: 2009.5 - 2012.5

The Sample: initially ≈ 30 sources (reduced to increase the cadence)

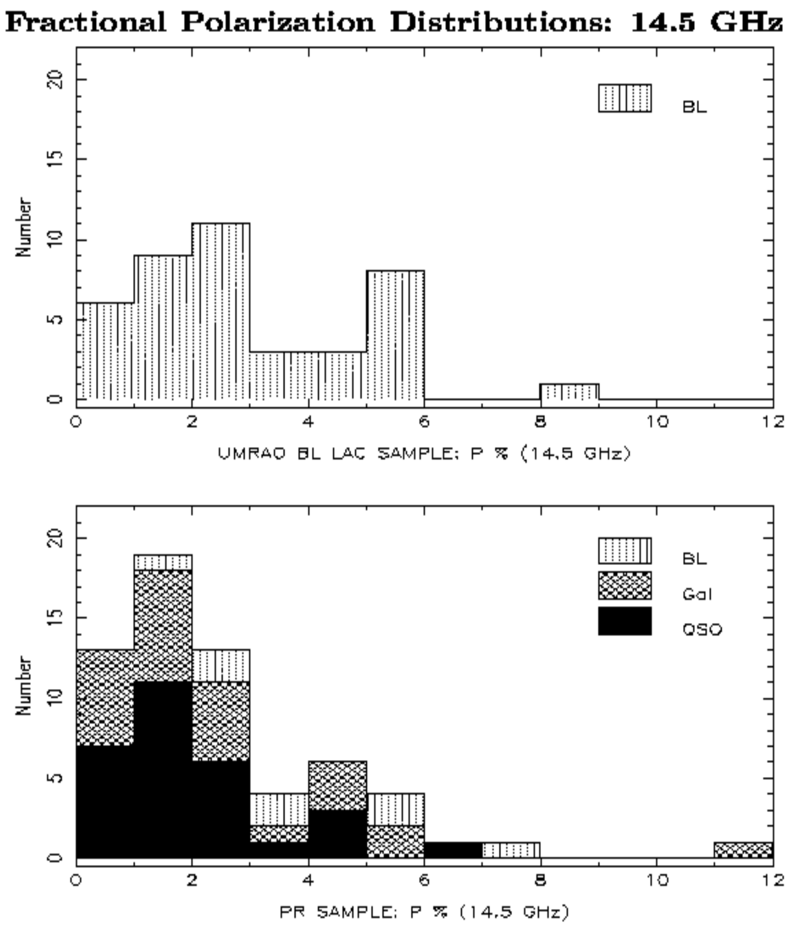
VLBA data: all sources in MOJAVE; several in BU program

Example of UMRAO data



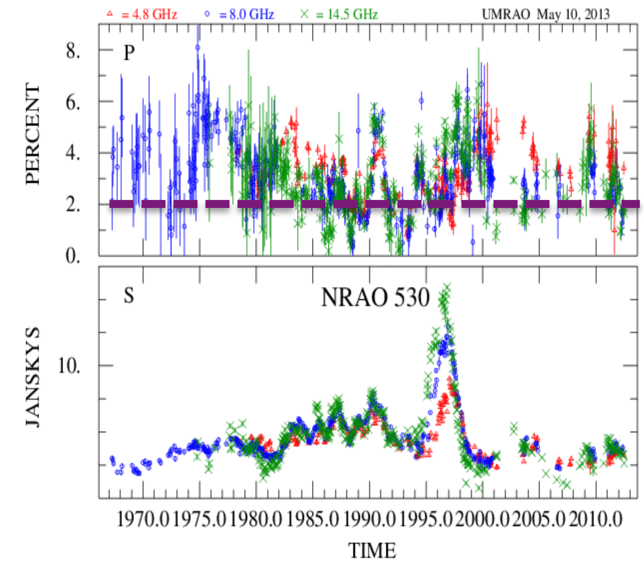
The Model (Framework): The B Field is Initially Turbulent

Histograms of time-averaged LP



Aller, Aller & Hughes 2003

Fractional LP: values are only a few %

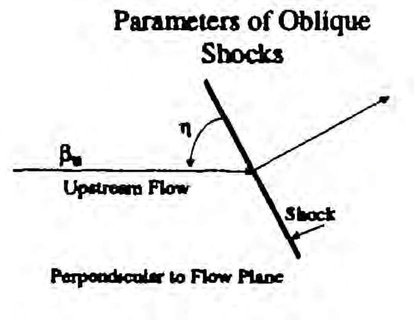


Individual sources: baseline level during `quiescent' phase: <2%

Statistical: time-averaged Q & U in flux-limited samples

The Oblique Shock-in-Jet Model framework and assumptions

- Magnetic Field Structure: random before shock compression (but a fraction of the magnetic energy is in an ordered component to give a well-defined EVPA in the quiescent state)
- Shock Orientation: at arbitrary angle to the flow direction & spans the cross section of the flow. The orientation is specified by the obliquity (η) and the azimuthal direction of the shock normal (ψ).
- Shock Propagation: the shock propagates at a constant speed (no acceleration or deceleration).
- Shocked Flow: specified by a length, width, and compression factor



Definition of η

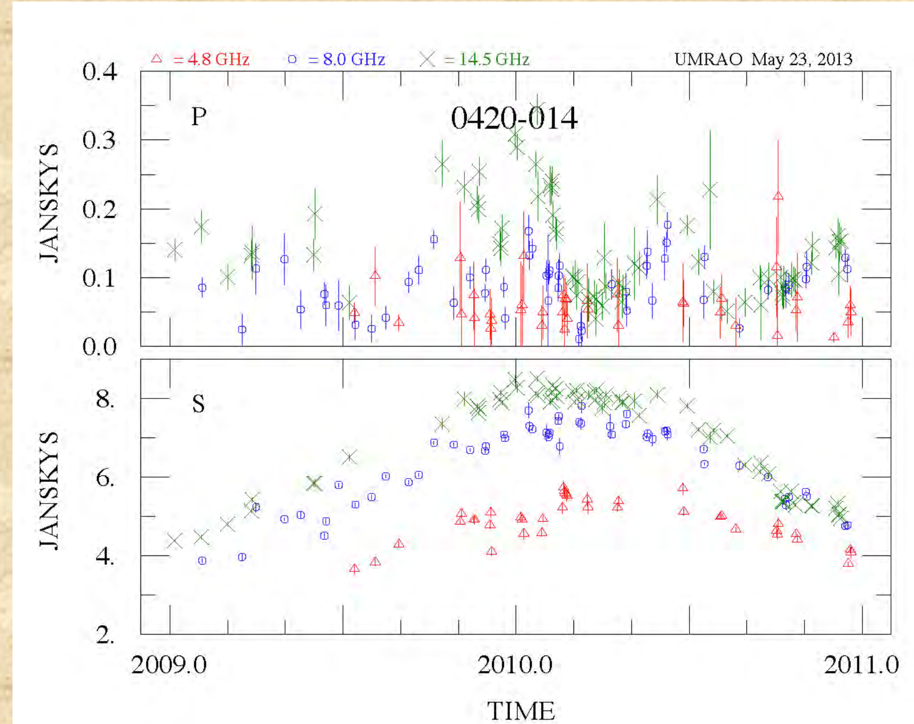
THE MODEL: values for `free' parameters Flow + shock

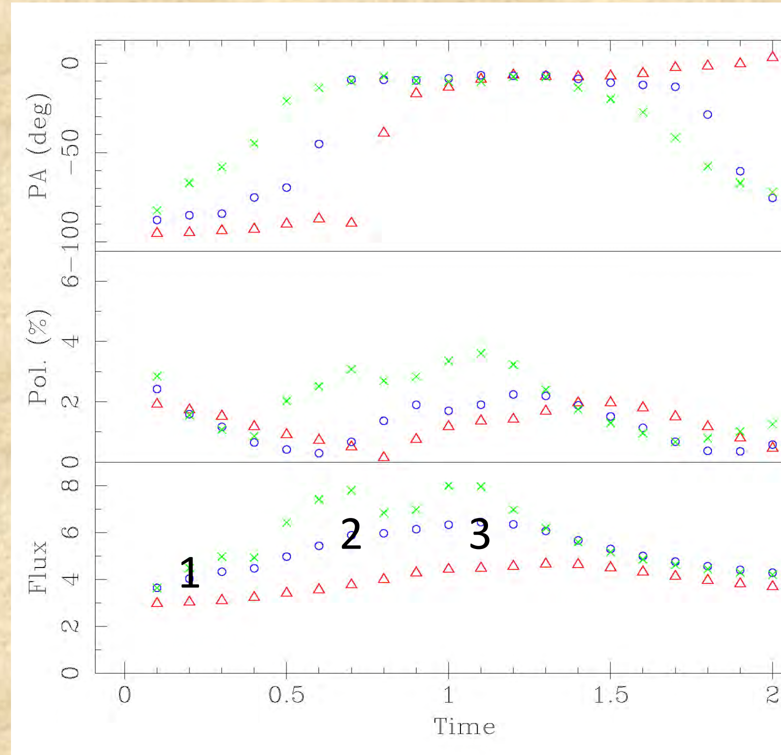
Parameter	UMRAO Constraint
Cutoff Lorentz Factor (energy spectrum)	UMRAO spectral behavior
Bulk Lorentz factor (flow)	UMRAO P%
Shock Sense (F or R)	UMRAO light curves
Shock Length (l)	UMRAO flare shape
Observer's Azimuthal Angle (ψ)	Primarily from UMRAO P%
Shock Compression (κ)	ΔS and P% from UMRAO data
Shock Obliquity (η)	ΔEVPA

Additional parameter

Observer's Orientation (θ):
VLBI gives consistency check

Separation of Blended Events

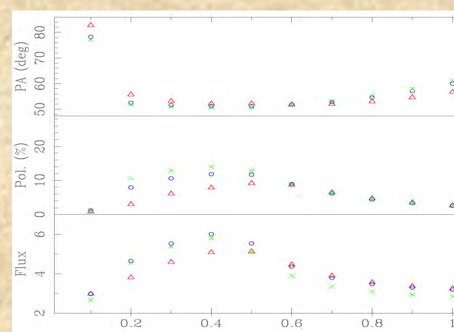




Structure in the S and P profiles

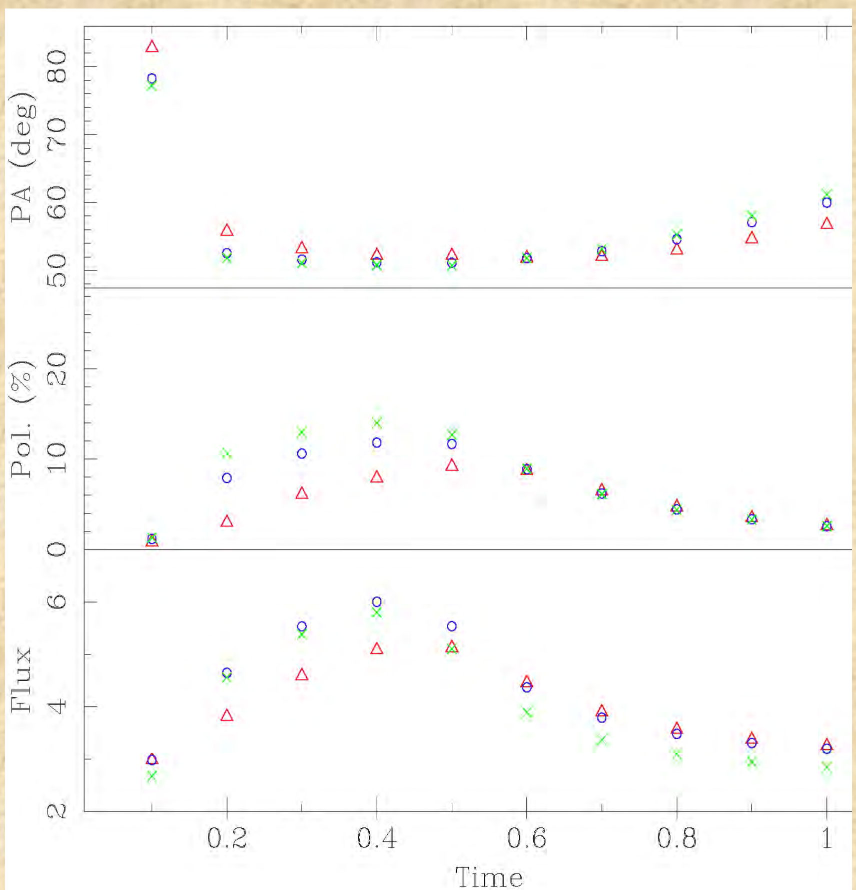
3 shocks required for the best `fit’

+

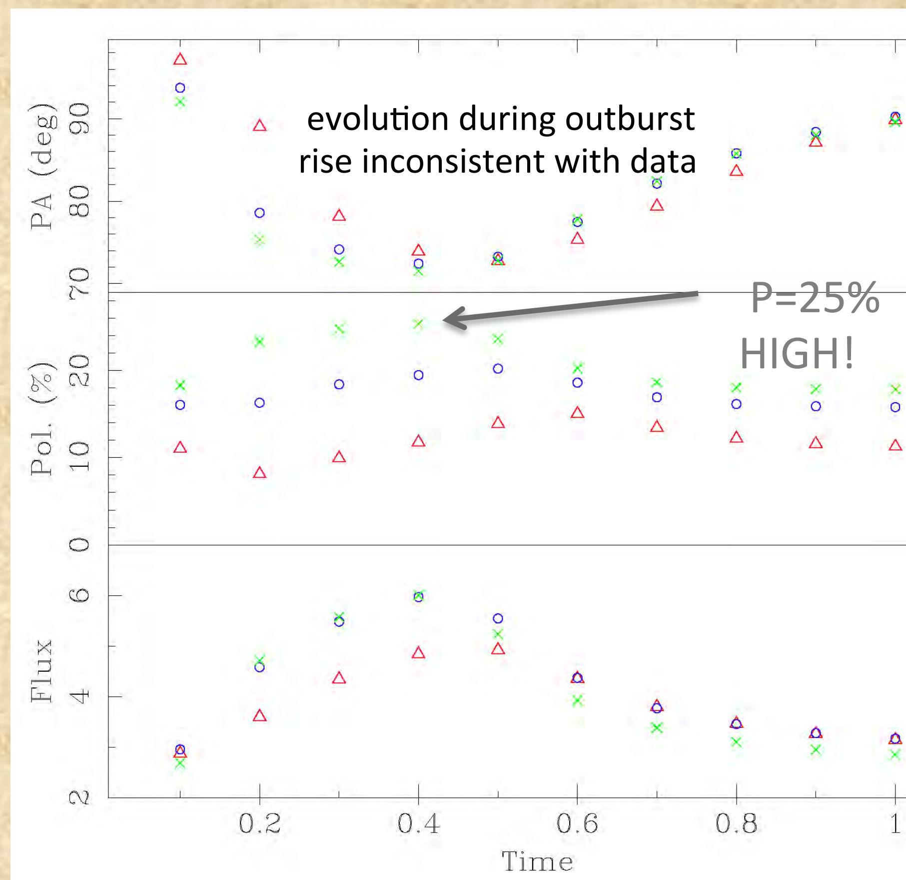


Simulated burst profile shape: single shock

Random or a Helical B field? simulation for a single shock



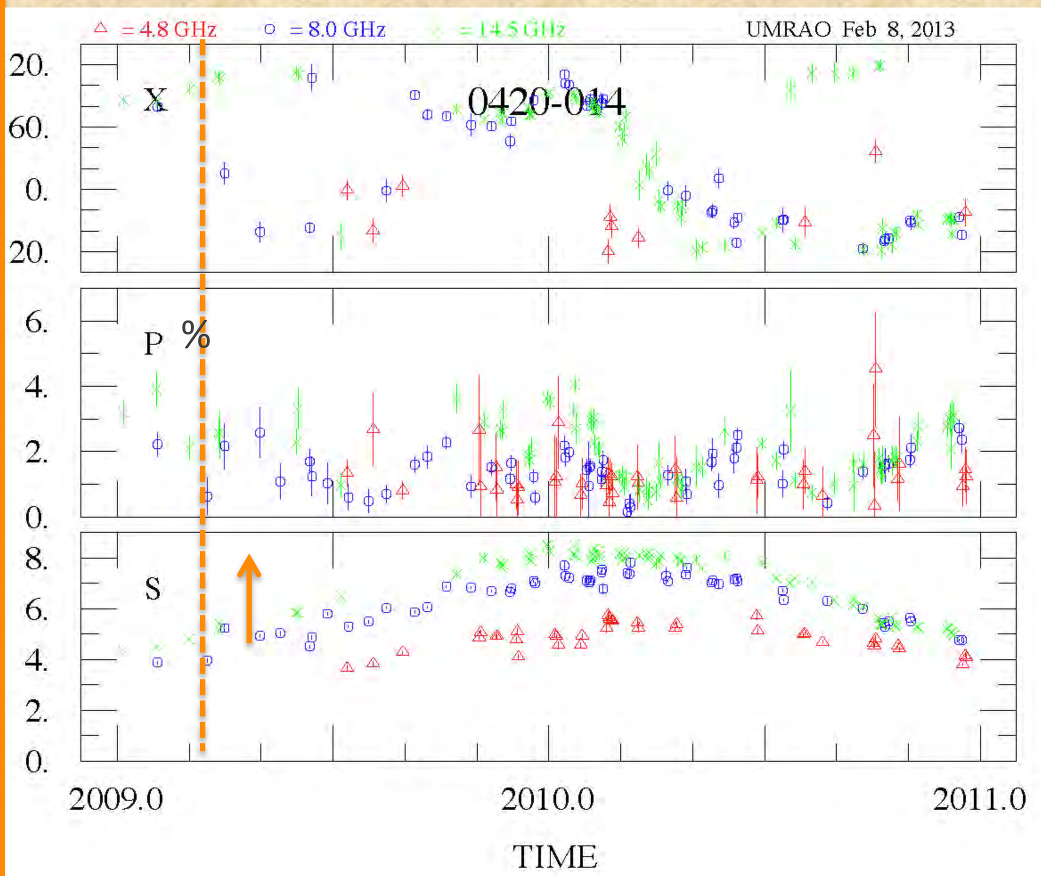
Random B field dominates

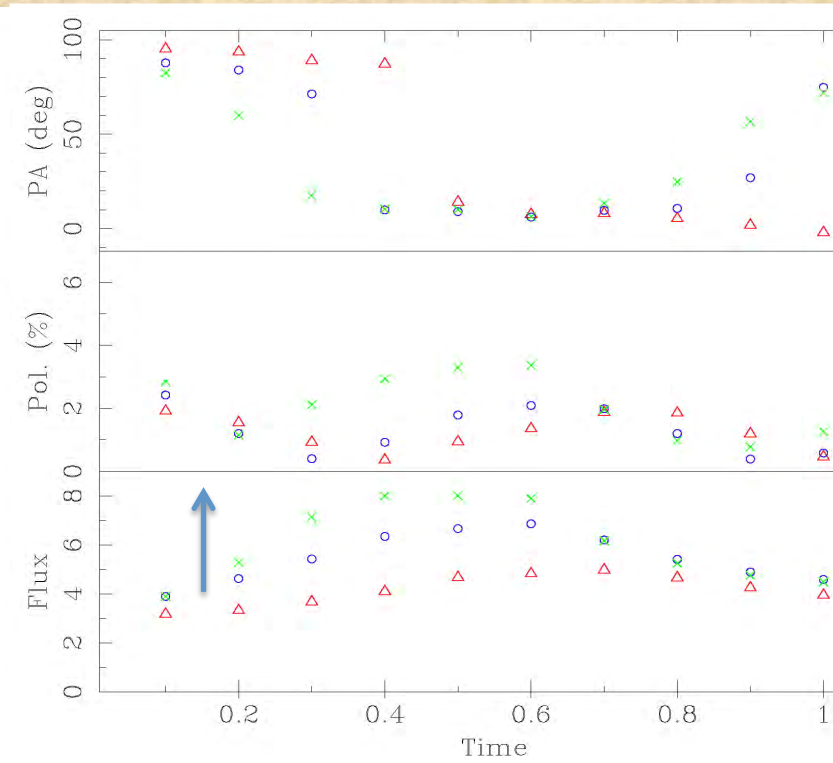


Hughes, Aller & Aller 2011)

Helical B field dominates

Patterns in 0420-014: data & simulation



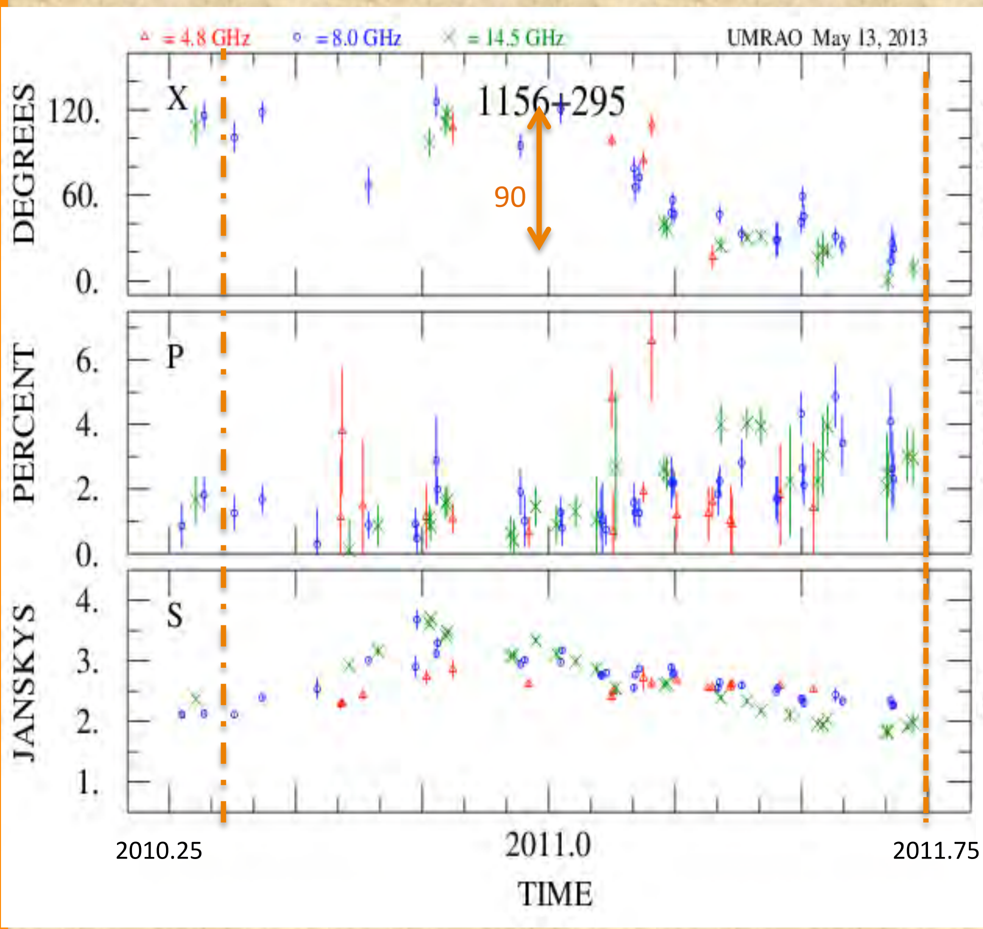


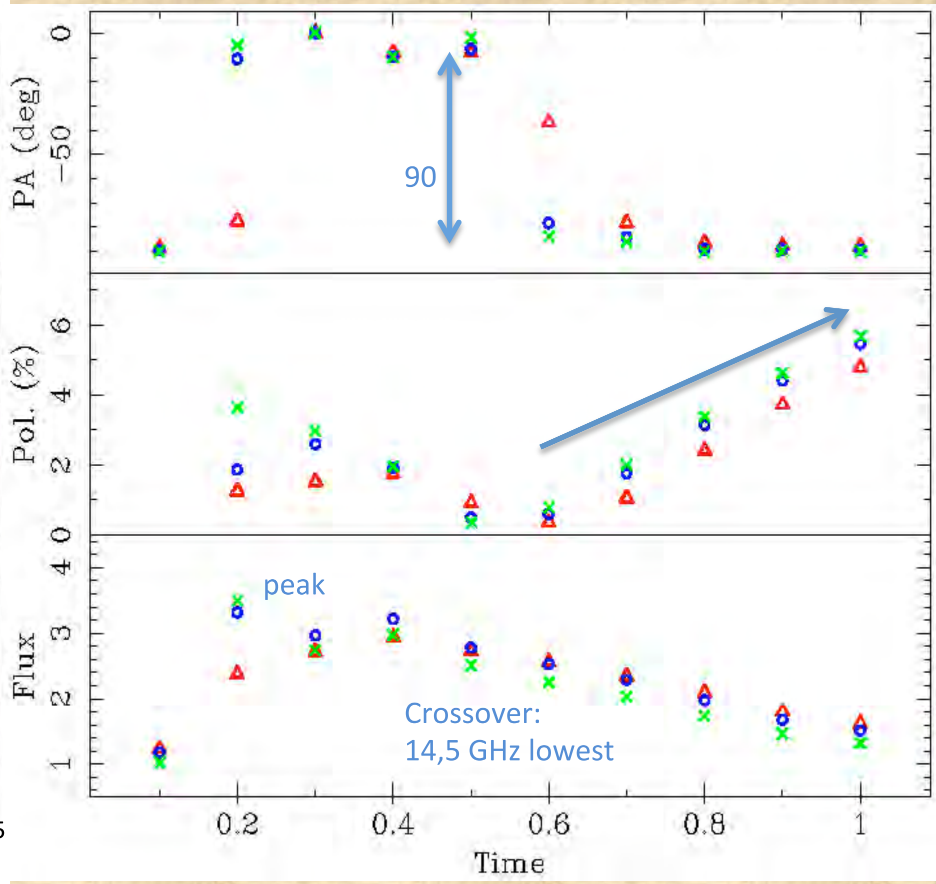
03/09

02/11

property	observed	simulatd
ΔS(14.5)	4-8	4-8
α(S) ev	Flat,inv.,flat	Flat,inv.,flat
ΔP%	1-3	1-3
EVPA	complex	complex

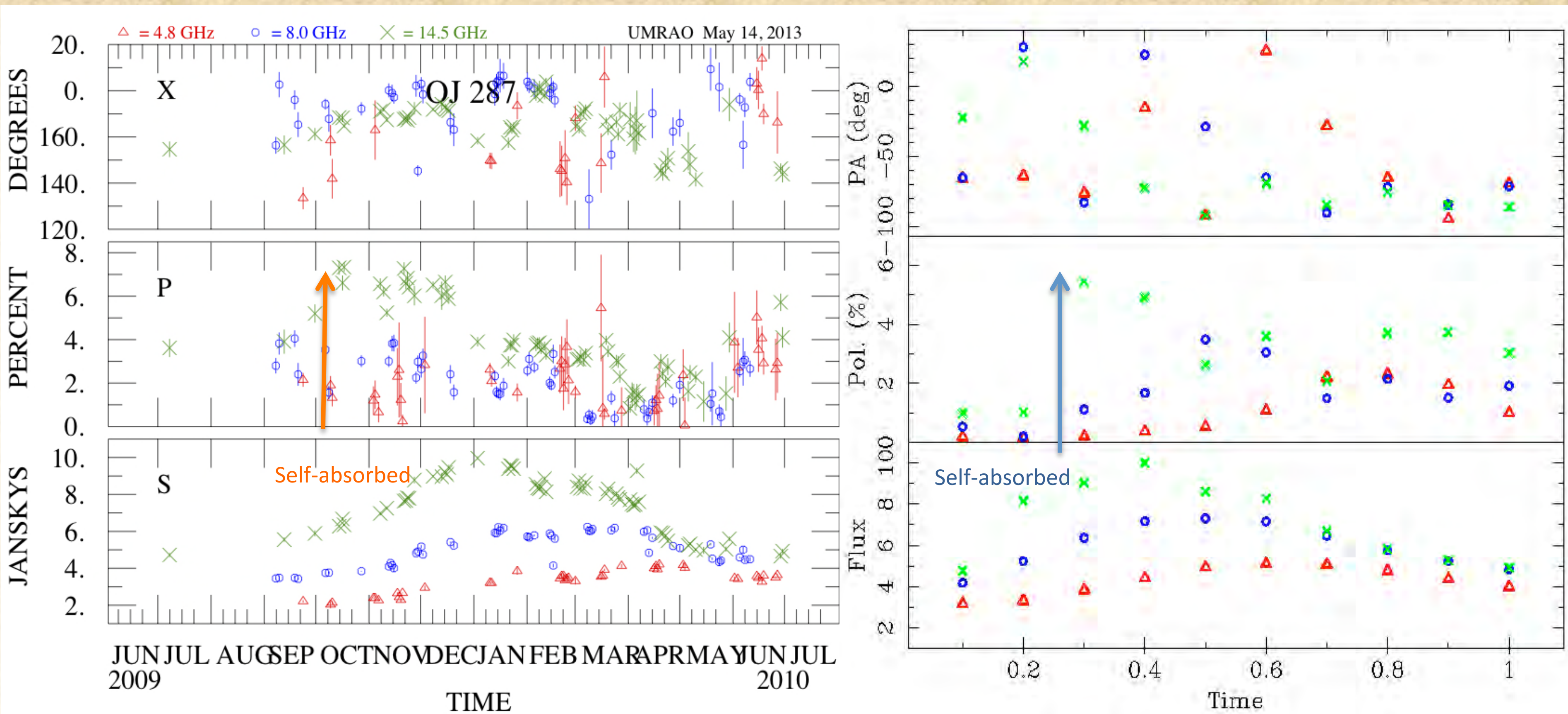
Patterns in 1156+295 event: data & simulation





EVPA: simulation reproduces `swing' thru 90° & spectral behavior
P% : simulation reproduces amplitude (6%), bump near peak S, & monotonic rise
S: simulation reproduces peak value, spectral rise, and duration of fall

Patterns in OJ 287: data & simulation



EVPA: ΔEVPA reproduced but detailed spectral behavior complex

P%: range of variation and peak value reproduced by model

S: self-absorbed spectrum during rise with approximate time delay of peak reproduced; change in spectral behavior during the burst decline is reproduced.

Summary of source properties from modeling UMRAO data:

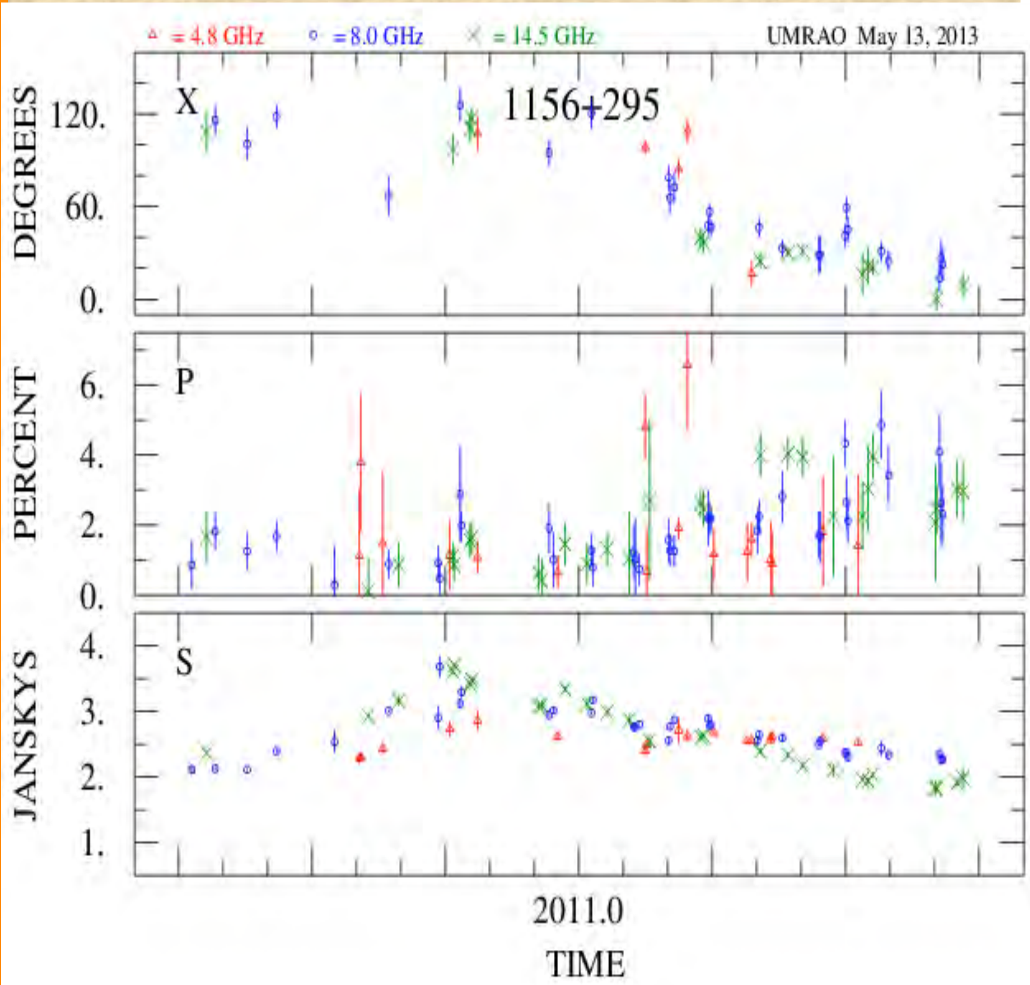
Parameter	0420-014	OJ 287**	1156+295
Cutoff LF (energy)	50	10	50
Bulk Lorentz factor	5.0	5.0	10
Shock Sense	F	F	F
Number of shocks	3	3	4
Shock Obliquity	90° (transverse)	30° (oblique)	90° (transverse)
Viewing angle	4°	2.5°	2.0°
Axial magnetic field*	16%	50%	50%

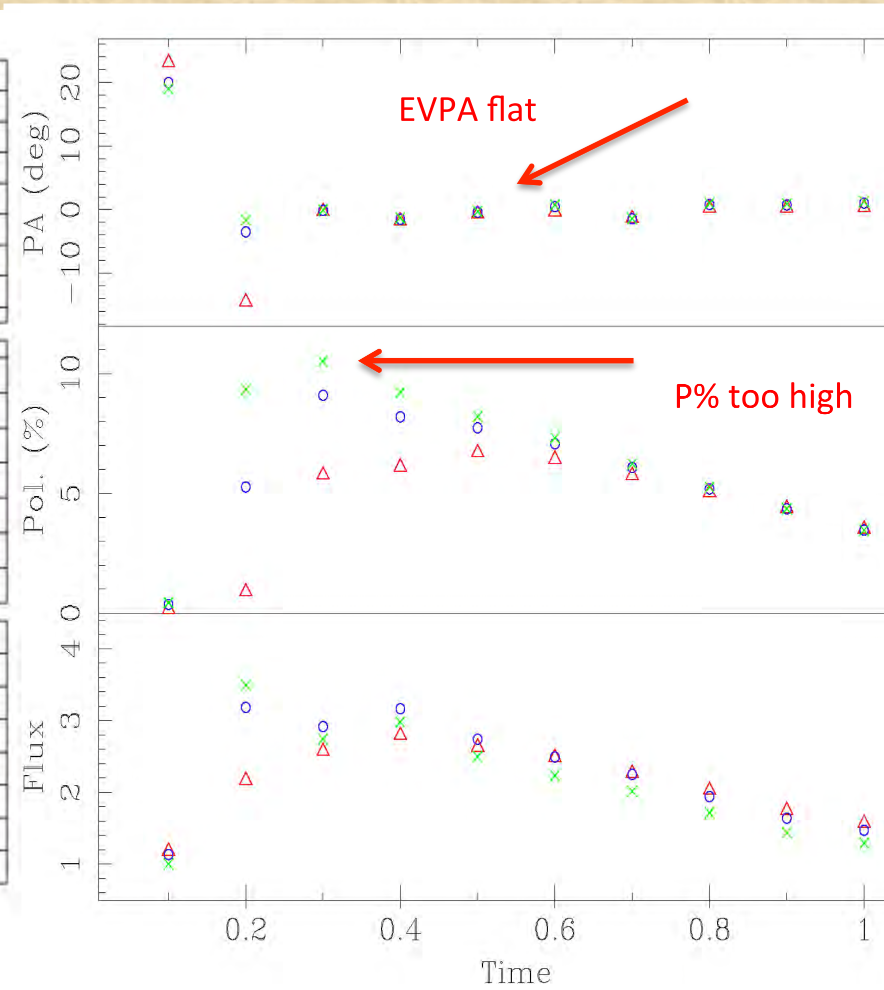
Consistency checks based on VLBI data:

1. viewing angle agrees with the value from VLBI analysis
2. the deduced apparent motion given the viewing angle and the derived shock speed agrees with the speed from VLBI-scale component motions

Table notes: * axial B field is in terms of energy density which is a small quantity
** the first shock in OJ 287 is strong but narrow

Evidence for an Axial Magnetic Field
simulation for 1156+295 assuming no axial B field





Fermi Gamma-ray Space Telescope

Conclusions

- Several centimeter-band events associated with GEV γ-ray flaring show changes in LP and in S expected from a propagating shock scenario.
- Comparison of models with UMRAO monitoring data can be used to derive jet flow conditions during these flares, and to constrain the particle energy distribution responsible for the radio-band synchrotron emission.
- The simulated P% is very sensitive to viewing angle; derived values are nearly line of sight and in agreement with independently-determined values from VLBI studies.
- The magnetic field is predominantly turbulent in the quiescent jet, but a substantial ordered axial component is required to fit the LP data (50% of the the energy density in magnetic energy). Models dominated by a helical field are not required.