Blazars at short millimeter wavelenghts: Total flux and polarimetry

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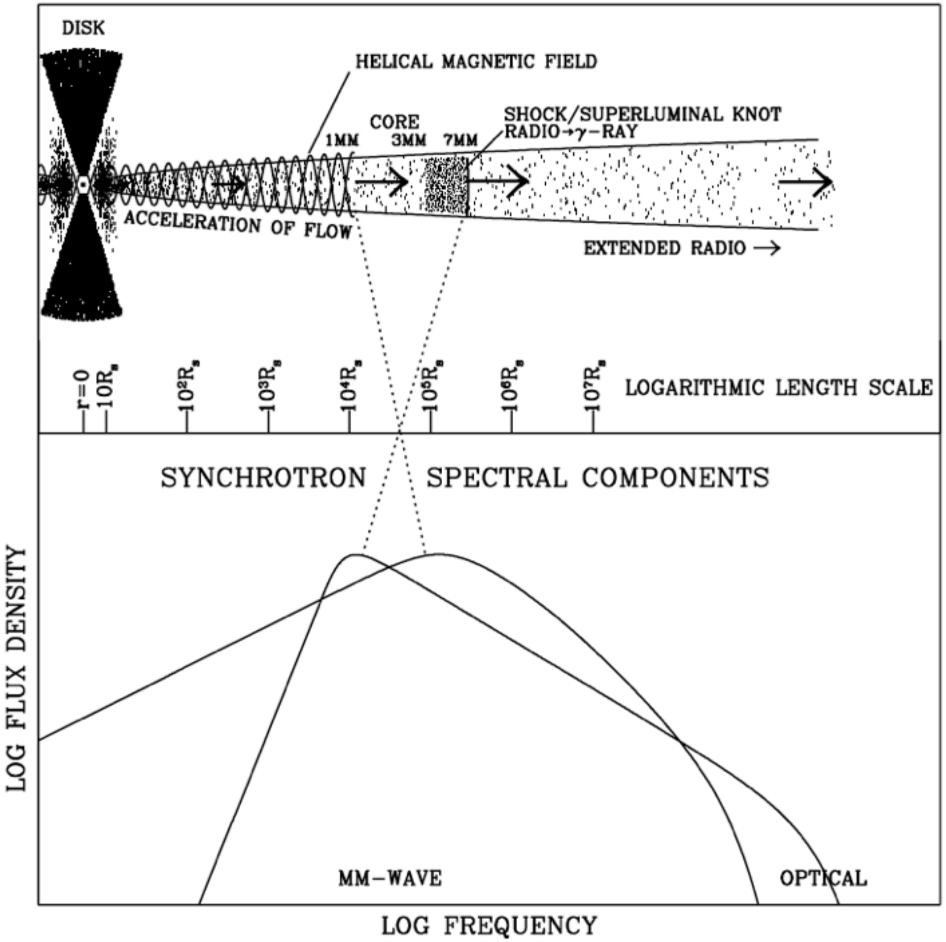
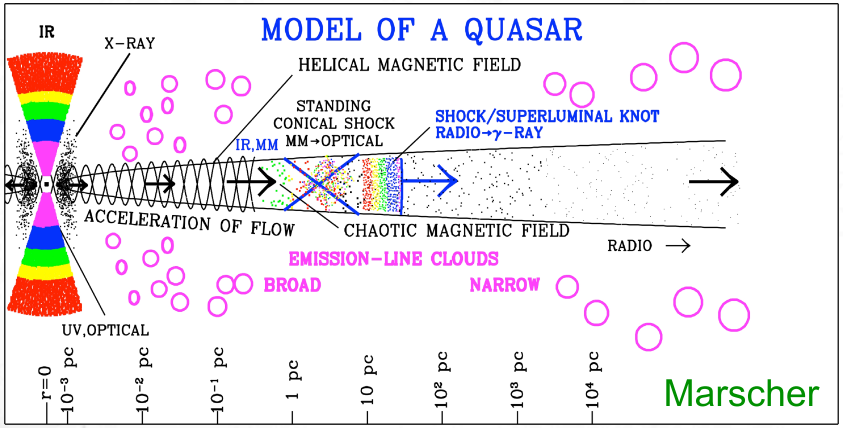
Location of short millimeter emission region

Jorstad et al. (2007)



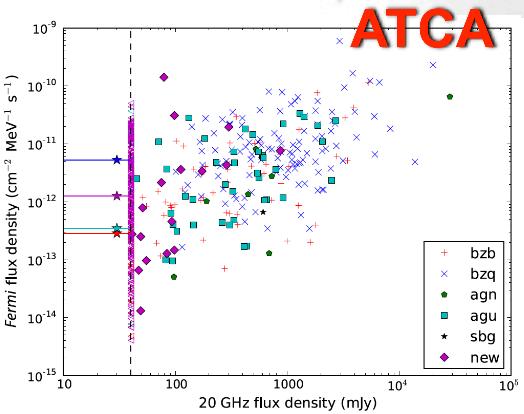


Marscher

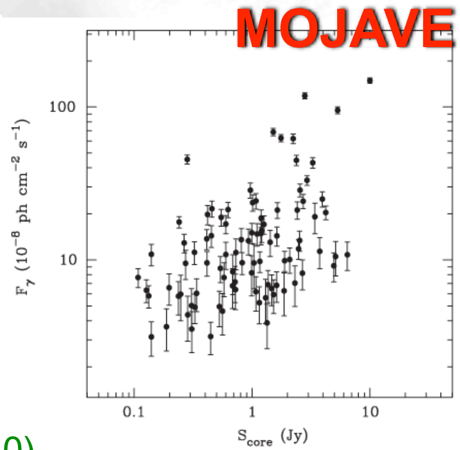
1. Millimeter emission region located at progressively upstream jet regions as mm-λλ decreases, untill reaching the recollimation shock

[~1,~10] pc from central engine (Marscher et al. 2008, 2010; Agudo et al. 2011a,b; Fuhrmann et al. 2014; Fromm et al. 2015)

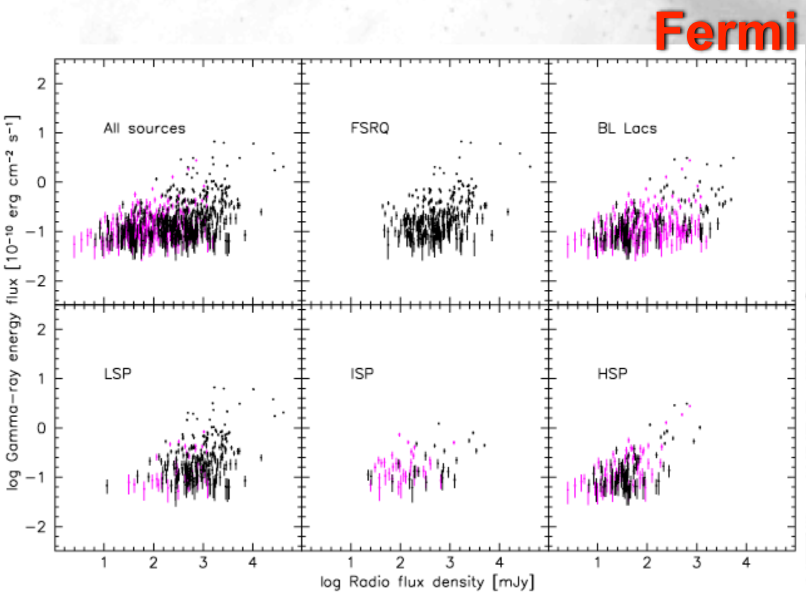
Relation to gamma-ray emission



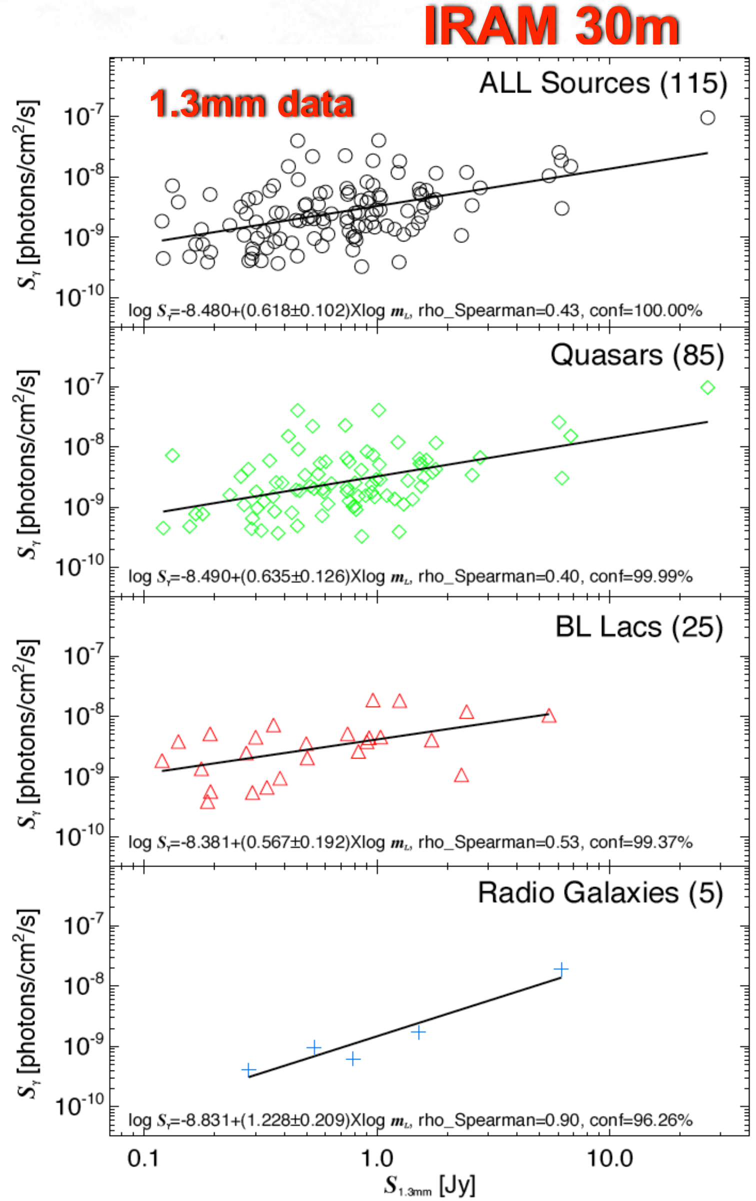
Mahony et al. (2010)



Pushkarev et al. (2010)



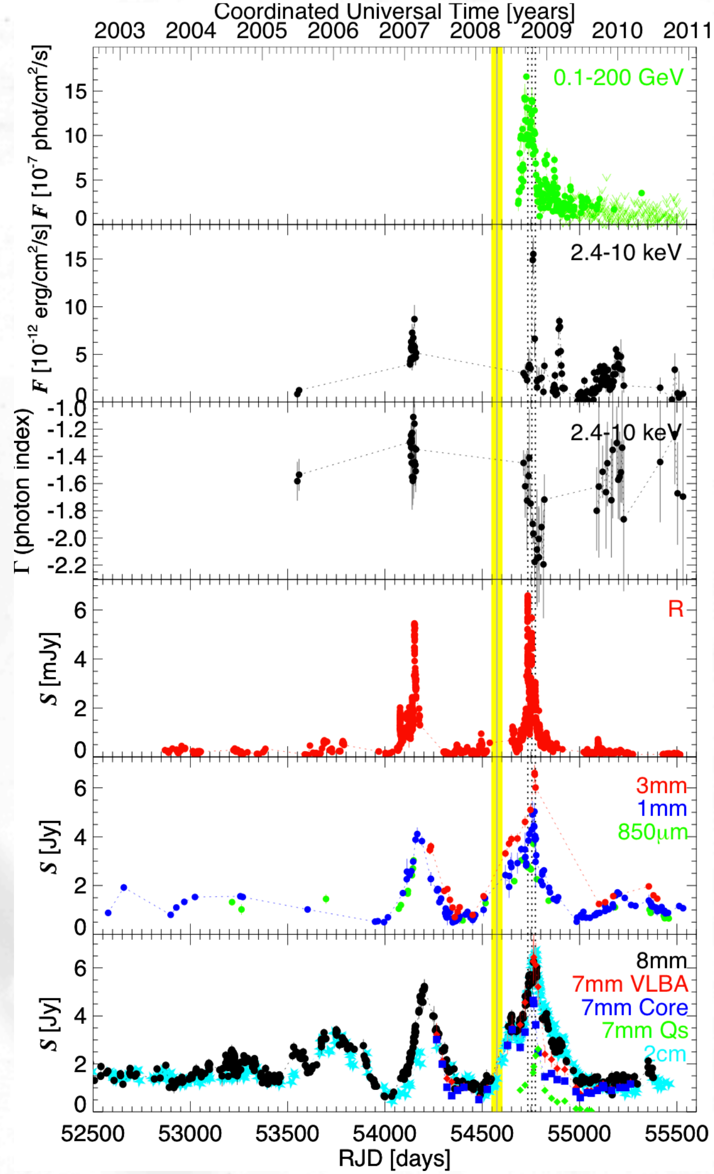
Ackermann et al. (2011)



Agudo et al. (in prep.)

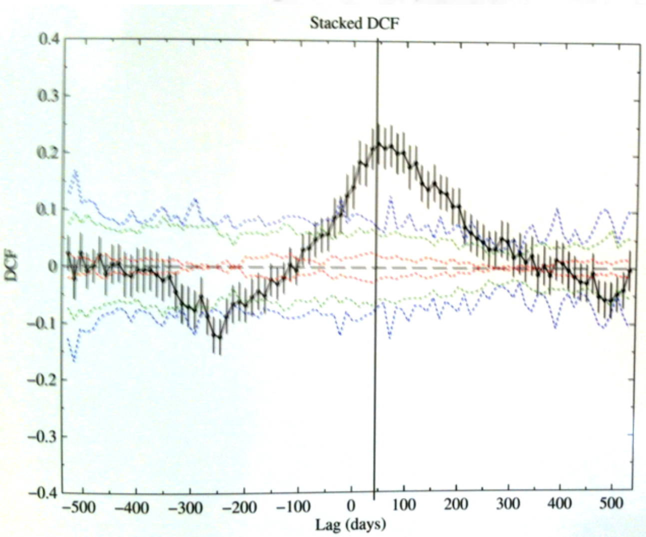
Relation to gamma-ray emission

AO 0235+164



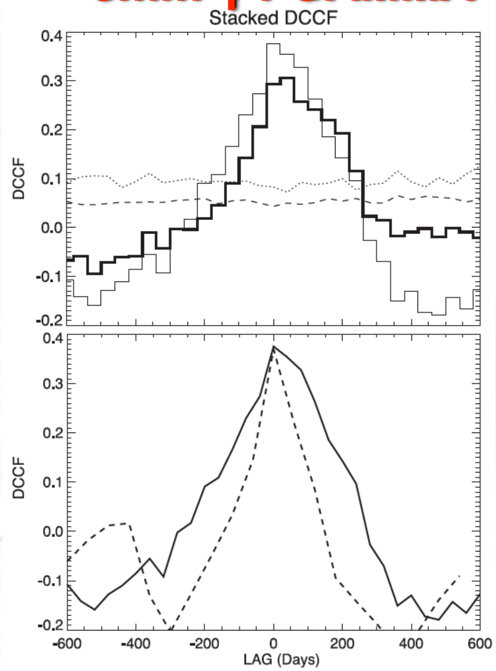
Agudo et al. (2011b)

8mm-γ Metsähovi



Ramakrishnan et al. (2015)

3mm-γ FGAMMA

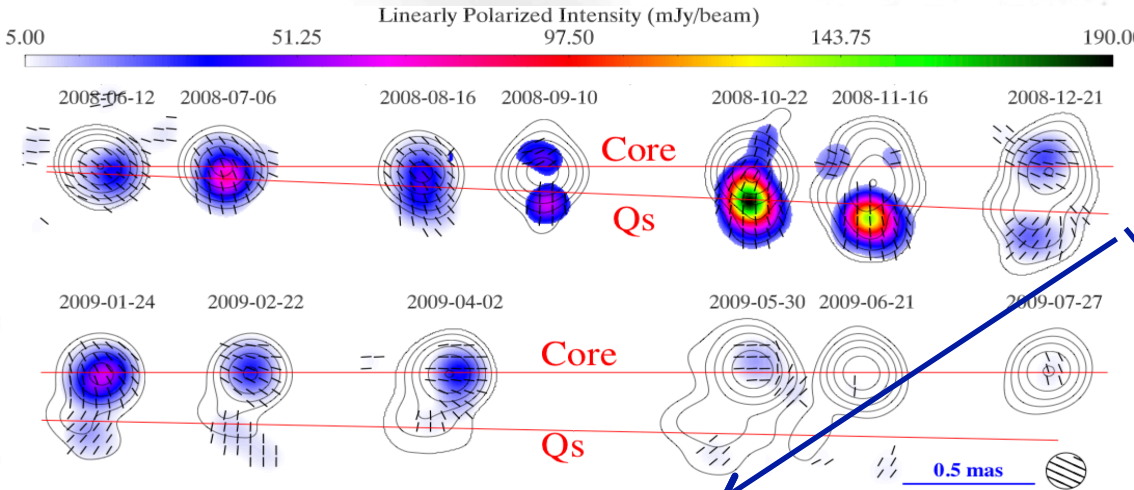


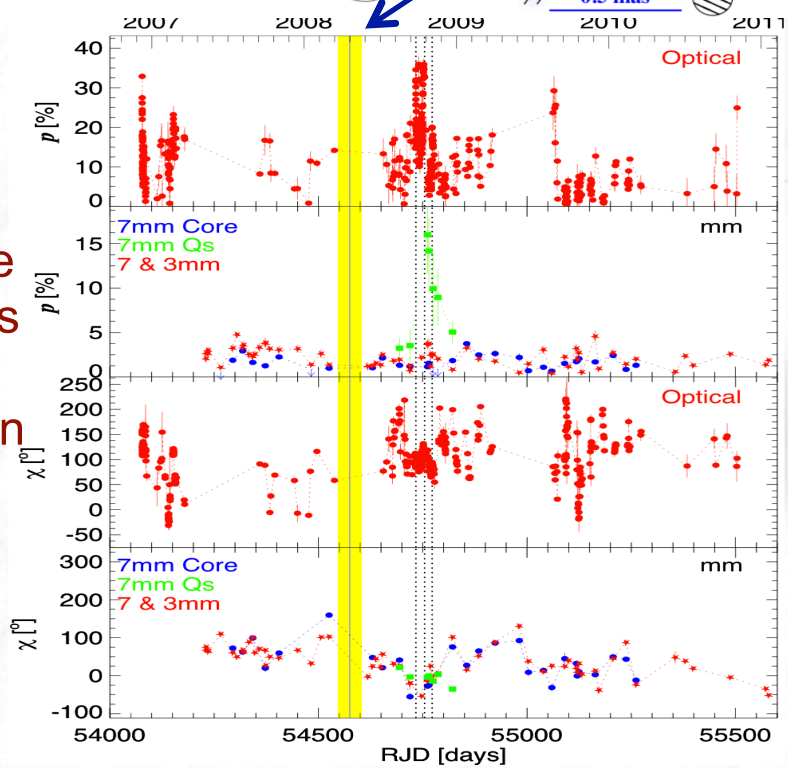
Fuhrmann et al. (2014)

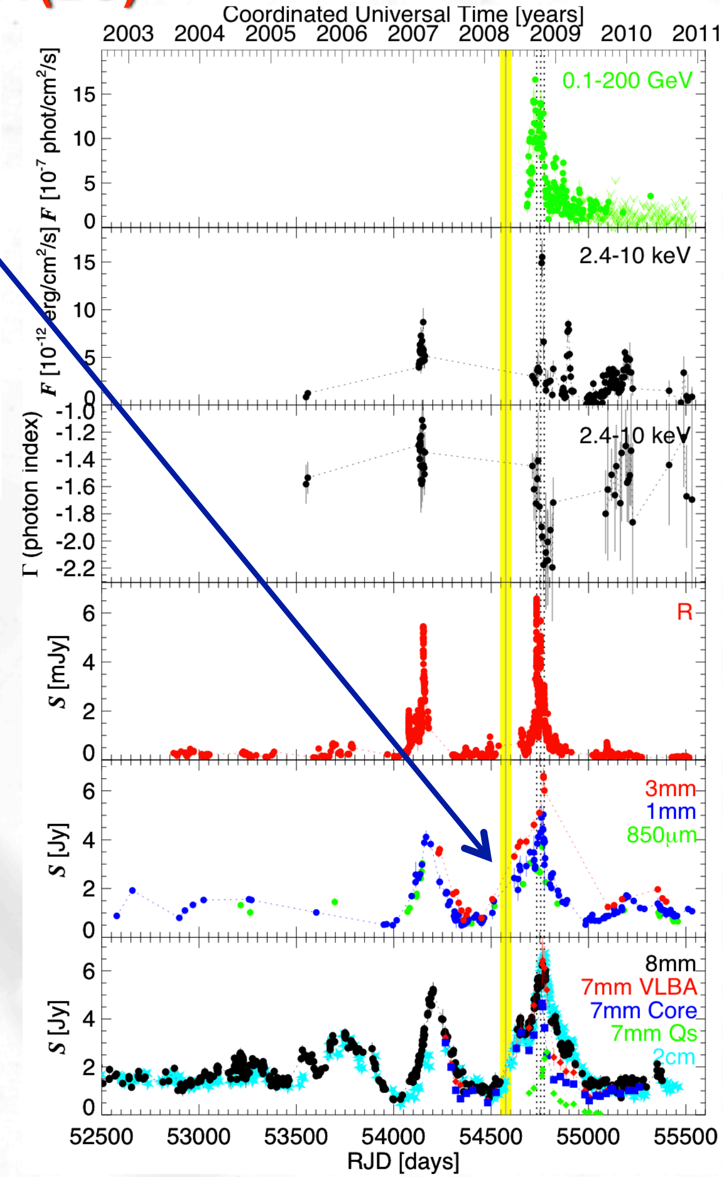
Relation to gamma-ray emission

43 GHz VLBA (BU)

AO 0235+164







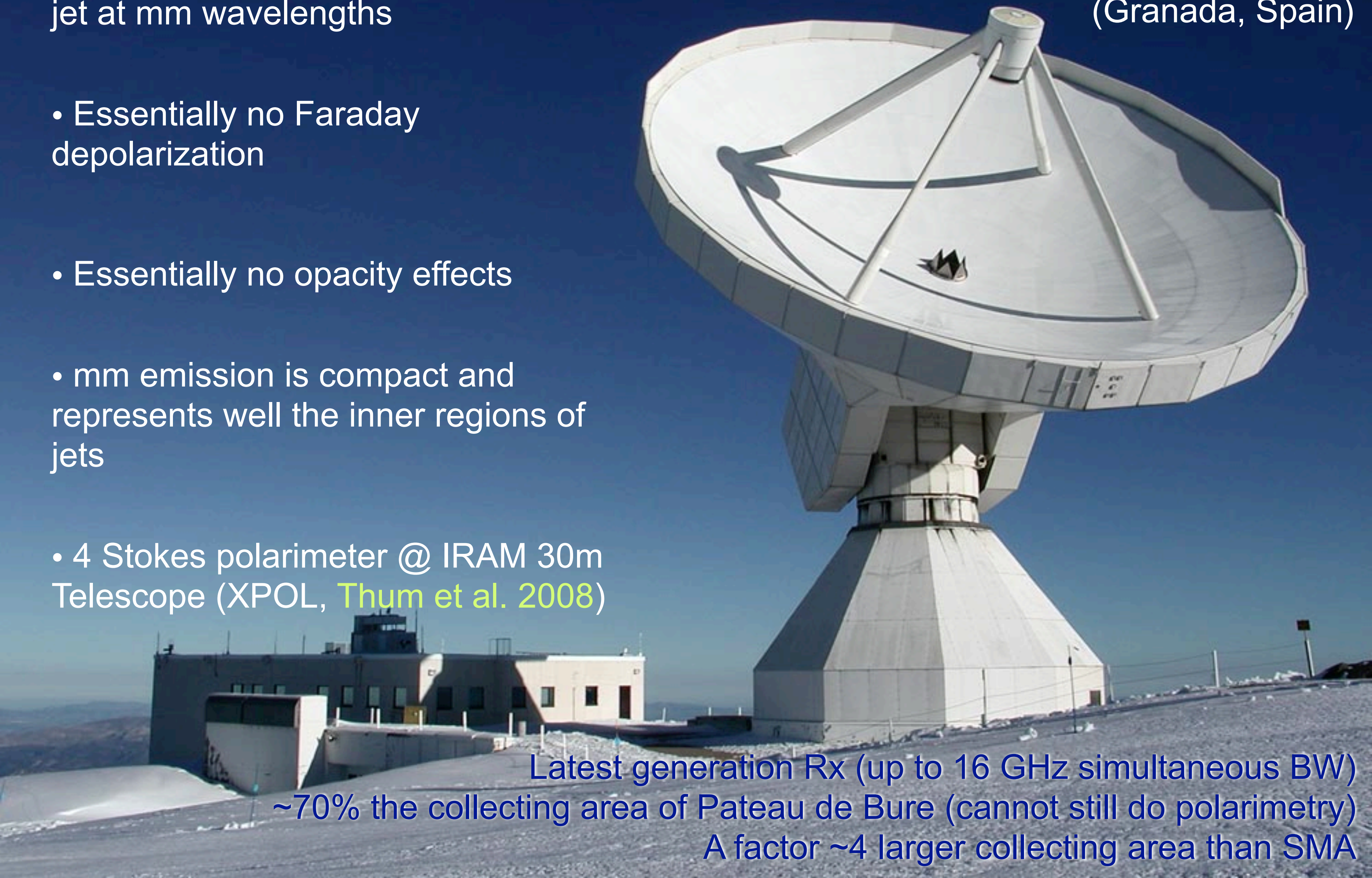
- For particular cases, robust evidence that he γ-ray emission is co-spatial with the mm emission

Agudo et al. (2011b)

A polarimetric survey at 3.5 & 1.3mm?

- Essentially no Faraday rotation of linear polarization emission from the jet at mm wavelengths
- Essentially no Faraday depolarization
- Essentially no opacity effects
- mm emission is compact and represents well the inner regions of jets
- 4 Stokes polarimeter @ IRAM 30m Telescope (XPOL, Thum et al. 2008)

IRAM 30m Millimeter Telescope
Sierra Nevada, 2850m
(Granada, Spain)



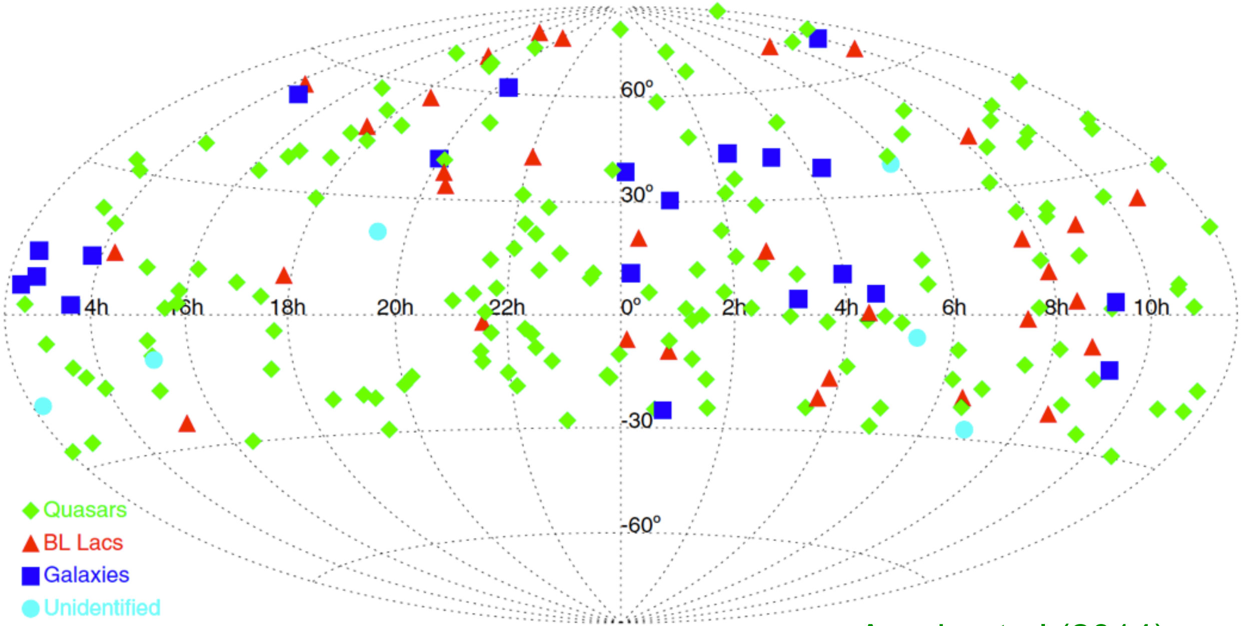
Latest generation Rx (up to 16 GHz simultaneous BW)
~70% the collecting area of Pateau de Bure (cannot still do polarimetry)
A factor ~4 larger collecting area than SMA

Observations

- Mid 2010 (also mid 2005)
- I, Q, U, V @ 3.5 & 1.3mm simultaneous observations

The sample

- 211 radio loud AGN (z≤3.4)
- S_{90GHz}>0.9Jy
- J2000.0 Dec. >-30º



Agudo et al (2014)
(see also Agudo et al. 2010)

Completeness

- Selected as complete (flux density limited) with S_{90GHz}≳1 Jy.
- BUT, ~50% of sources <1Jy, most likely because of source variability

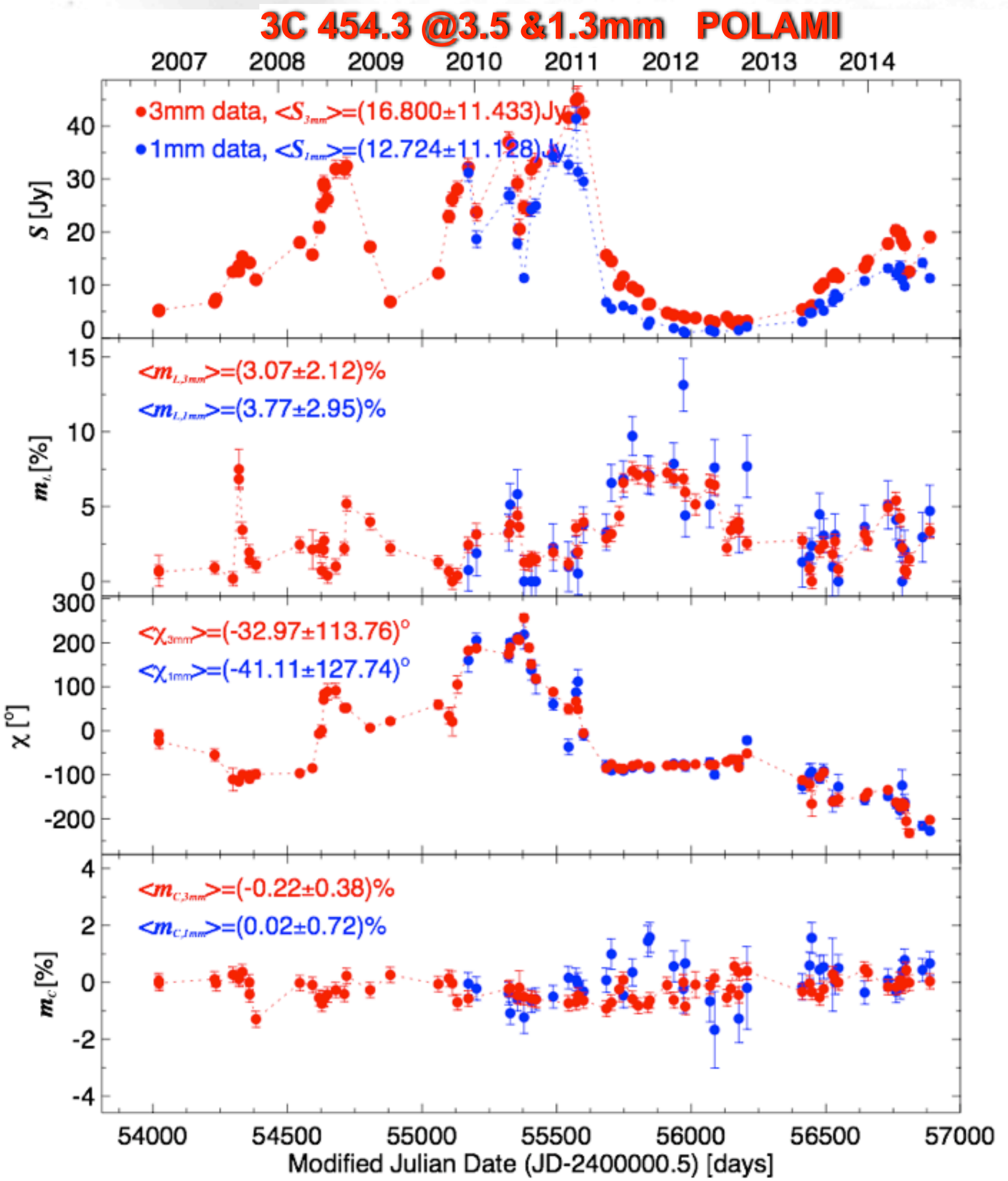
Simple sample properties

- Dominated by radio flat-spectrum compact AGN, i.e., by blazars.
- 152 quasars, 32 BL Lacs, 21 radio galaxies, and 6 unclassified sources.
- 110 of our sources are contained in the MOJAVE sample

POLAMI: Polarimetric AGN Monitoring at the IRAM-30m-Telescope

Check POLAMI web page at: http://www.iaa.es/~iagudo/_iagudo/POLAMI.html

3C 66A
AO 0235+16
3C 84
CTA 26
3C 111
PKS 0420−01
3C120
PKS 0528+134
S5 0716+71
PKS 0735+17
OJ 248
OJ 49
4C 71.07
OJ 287
S4 0954+65
PKS 1055+01
MRK 421
PKS B1127-145
4C 29.45
ON 231
PG 1222+216
3C 273
M 87
3C 279
B2 1308+30
PKS 1416−076
PKS 1510−08
DA 406
PKS 1622-29
4C 38.41
3C 345
NRAO 530
OT +081
BL Lacertae
3C 446
CTA 102
3C 454.3



- ~40 γ-ray bright sources, most of them on list of Boston University VLBA monitoring program.
- Time sampling ~2 weeks since ~mid 2007
- Identical setup as for the survey, i.e. I, Q, U, V @ 3.5 & 1.3mm simultaneous

Agudo et al. (in prep.)

Millimeter spectral index

- Flat to optically thin between 3.5mm and 2cm ($\tilde{\alpha}^{Q}_{15,86}=-0.22$ for quasars and $\tilde{\alpha}^{B}_{15,86}=-0.12$ for BL Lacs)

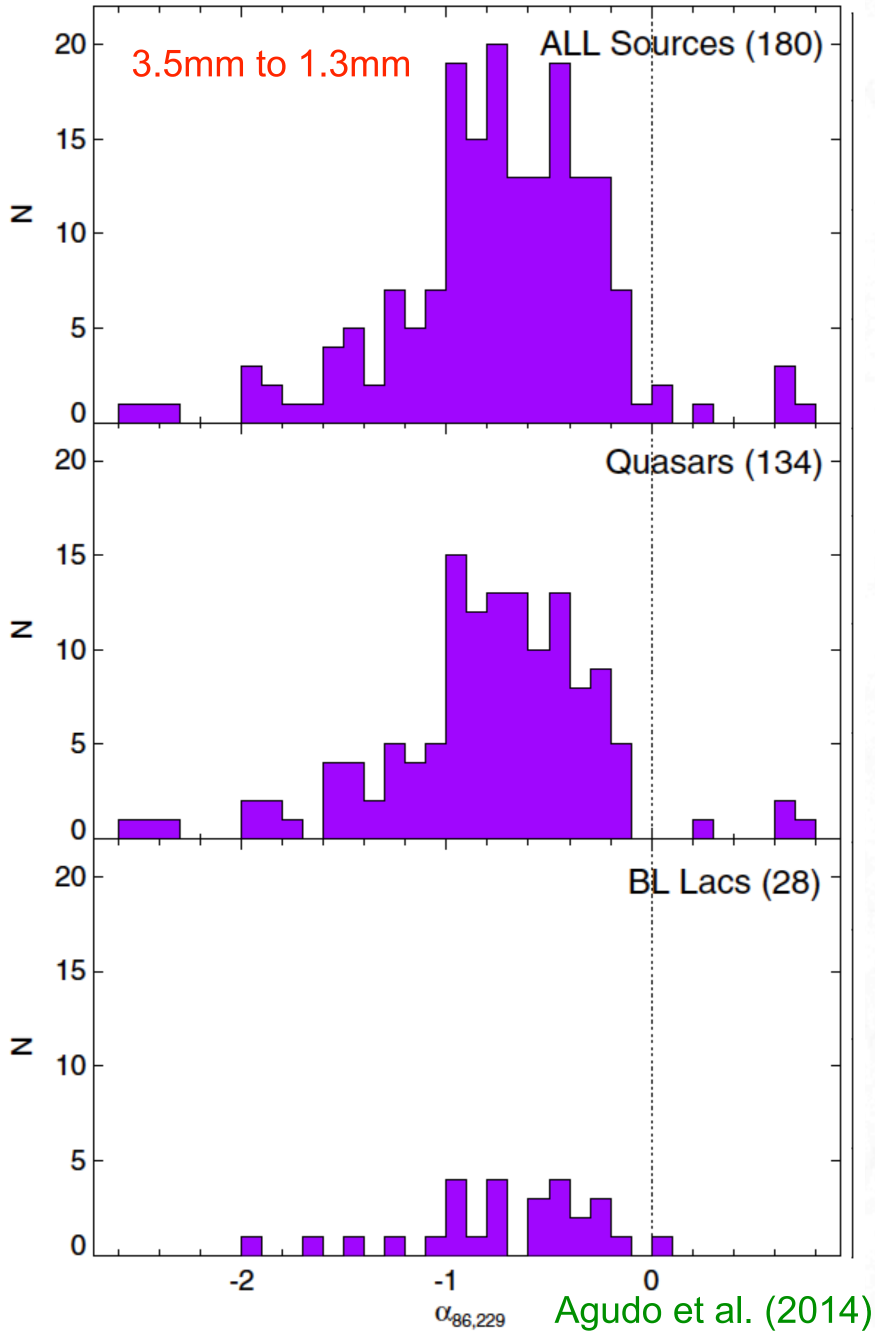
- Only a small fraction (19% of quasars and 15% of BL Lacs) show $\alpha_{15,86} > 0$

- More optically thin from 3.5 and 1.3mm ($\tilde{\alpha}^{Q}_{86,229}=-0.75$ for quasars and $\tilde{\alpha}^{B}_{86,229}=-0.56$ for BL Lacs)

2. Blazars display optically thin radiation between 86 and 229 GHz in general

- Not affected by opacity effects angle rotation & depolarization ⟹ intrinsic polarization properties of sources

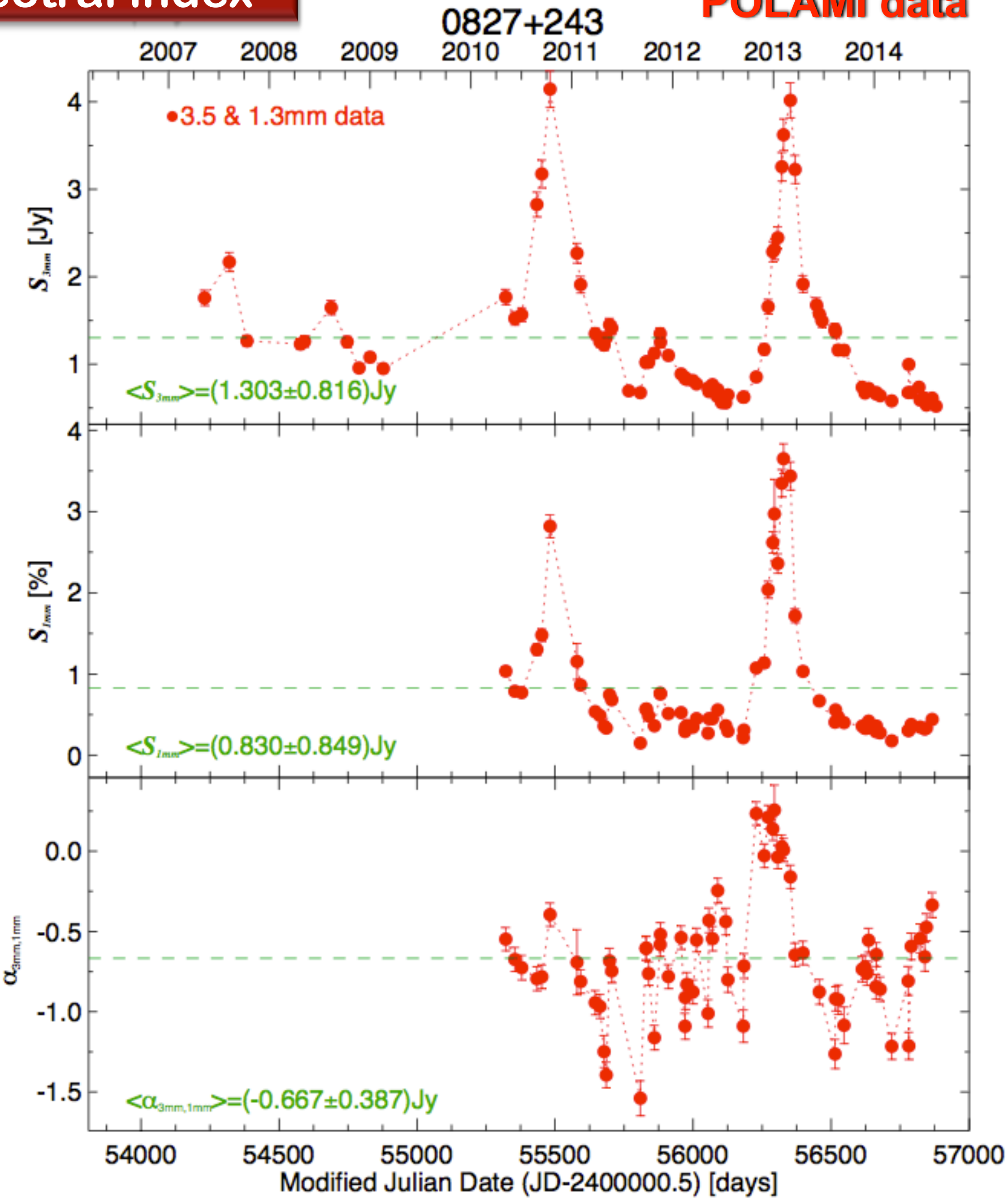
- Few exceptions happen for flaring sources with opticaly thick spectral indexes



Agudo et al. (2014)

Millimeter spectral index

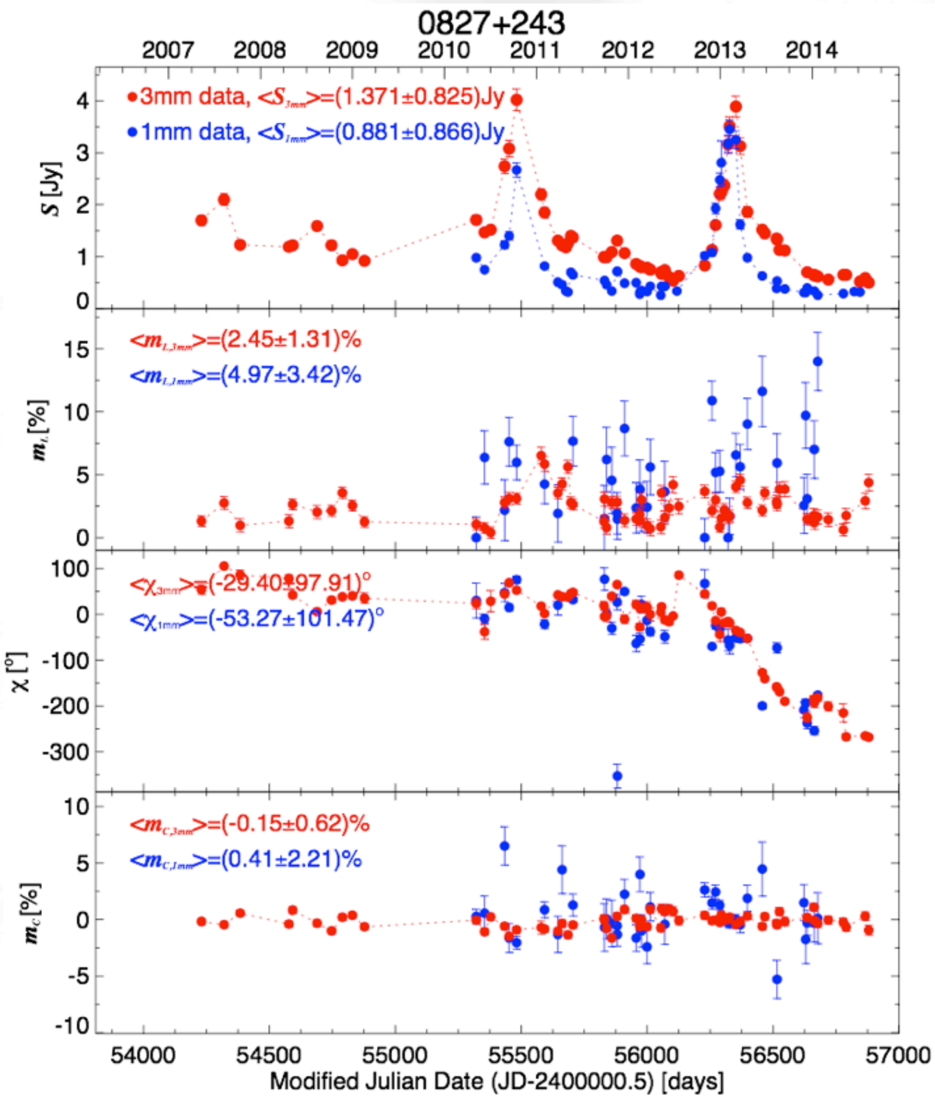
POLAMI data

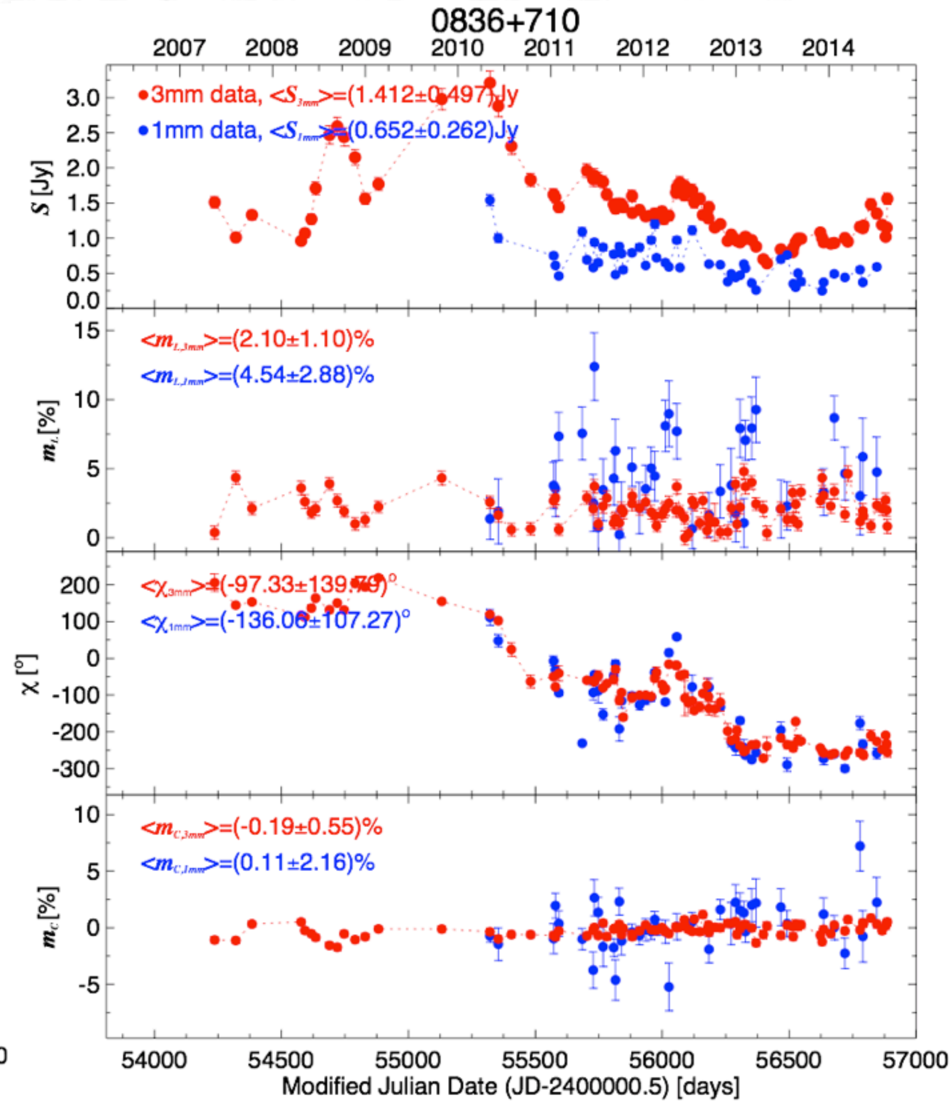


Agudo et al. (in prep.)

Linear polarization degree

POLAMI data



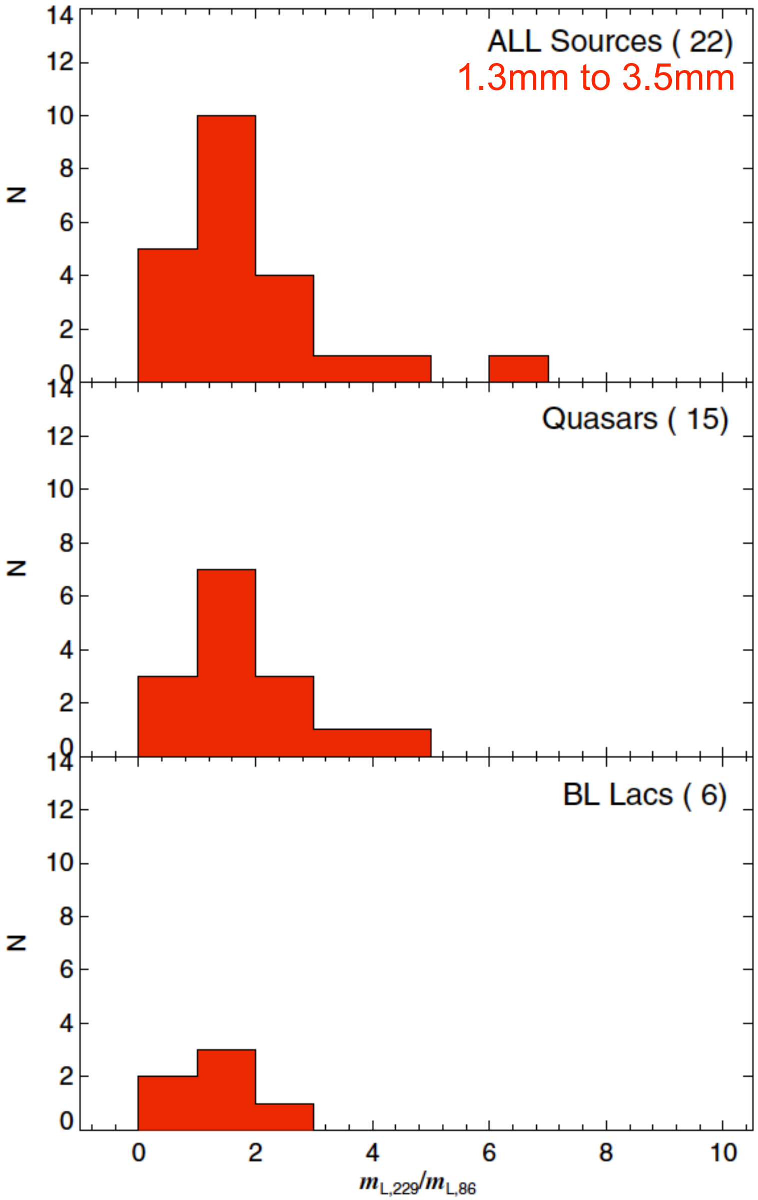


Agudo et al. (in prep.)

Increase of linear polarization degree with ν_{obs}

- Significantly larger fractional linear polarization at 1mm than at 3mm by median factors ~1.7

- 9% of sources with $m_{L,229}/m_{L,86} > 4$



Agudo et al. (2014)

Increase of linear polarization degree with ν_{obs}

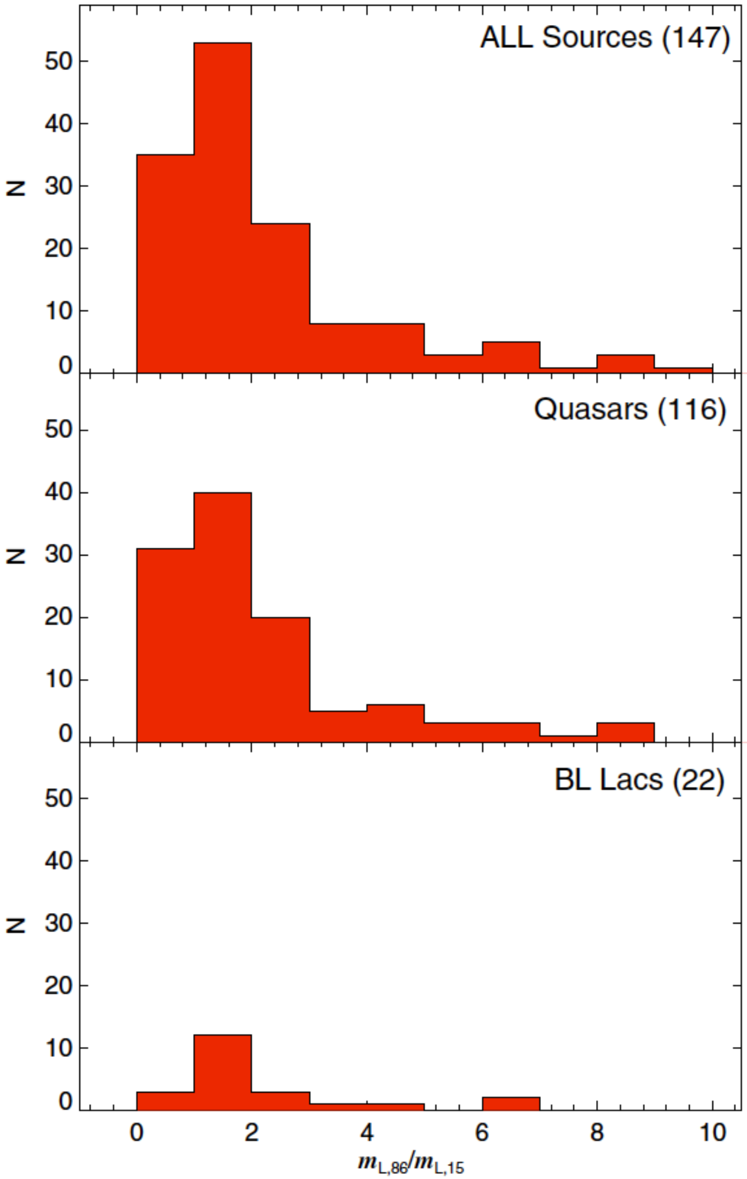
- Significantly larger fractional linear polarization at 1mm than at 3mm by median factors ~1.7

- 9% of sources with $m_{L,229}/m_{L,86} > 4$

- Same for comparison of 3mm and 2cm with median factors ~1.6

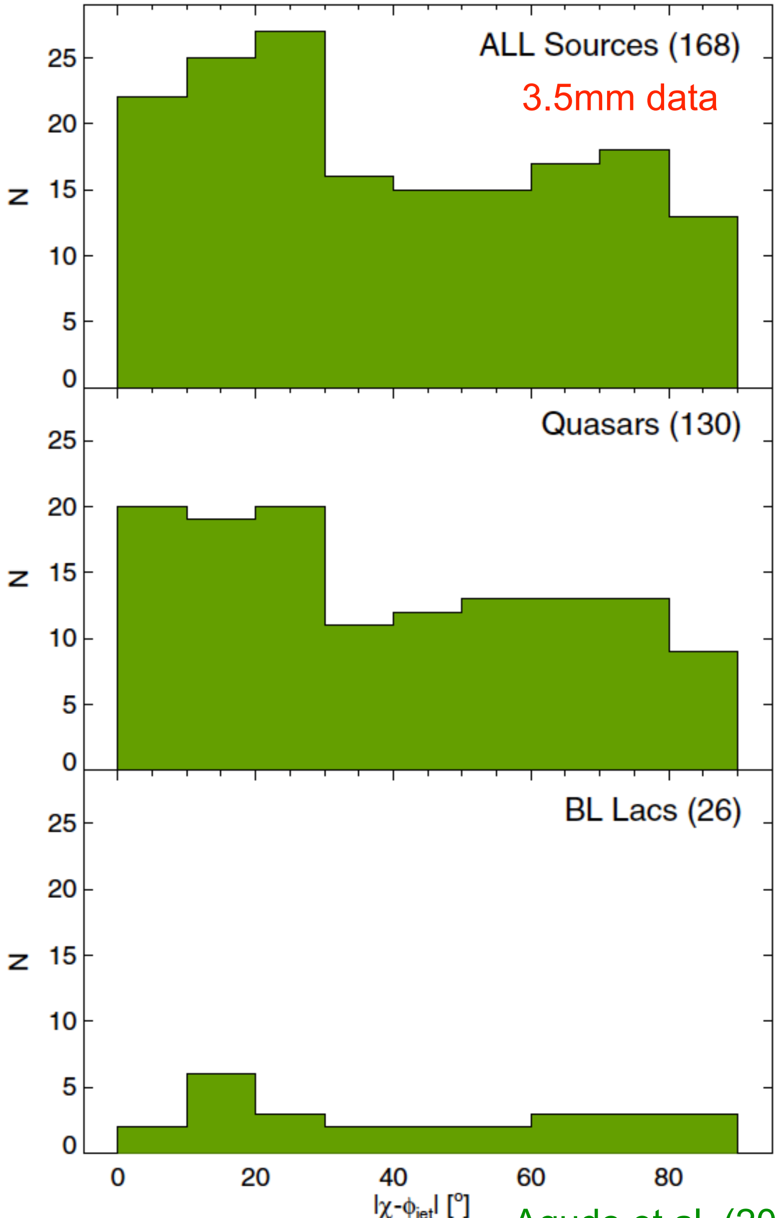
- 18% of sources with $m_{L,86}/m_{L,15} > 4$

3. The higher frequency emission in blazars comes from regions with progressively better B order



Agudo et al. (2014)

Linear polarization angle vs. jet position angle



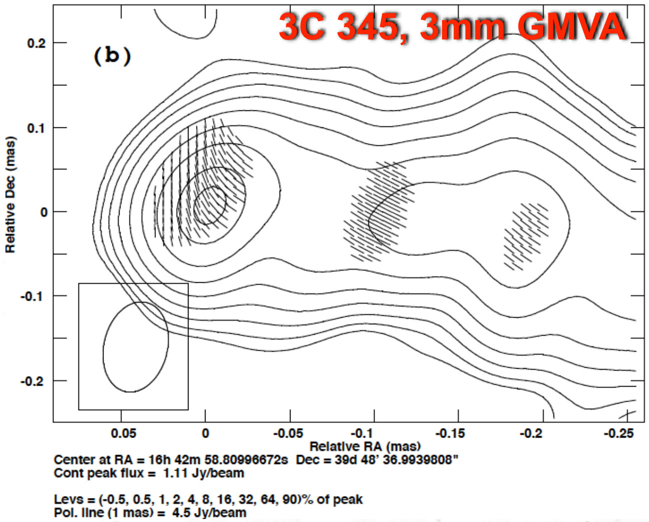
Agudo et al. (2014)

- At 3.5mm, very weak trend to align χ almost parallel to the jet axis (for ~17% of sources)
- Similar results found in Agudo et al. (2010) for survey in 2005, and Lister & Homan (2005)
- Similar results for 1.3mm data
- For purely axisymmetric jets, χ has to be observed either parallel or perpendicular to the jet axis owing to cancellation of orthogonal polarization components (e.g, Lyutikov et al. 2005; Cawthorne 2006)
- **What we get for most of the sources is the other way round!**

4. Blazar jets are not axisimmetric, at least regarding their polarization emission

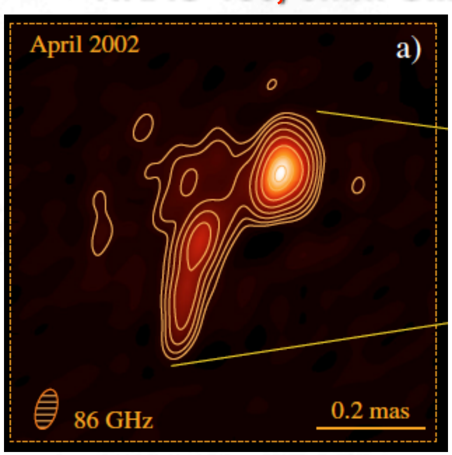
Linear polarization angle to jet position angle misalignment

POLAMI data

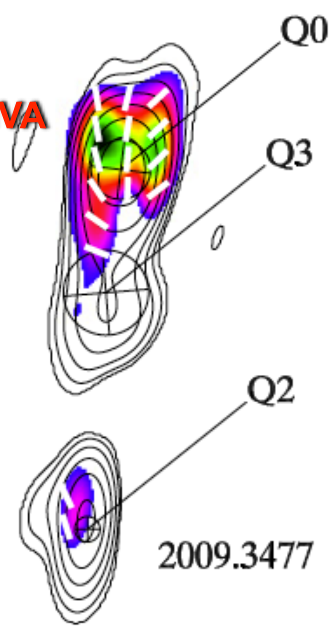


Martí-Vidal et al. (2012)

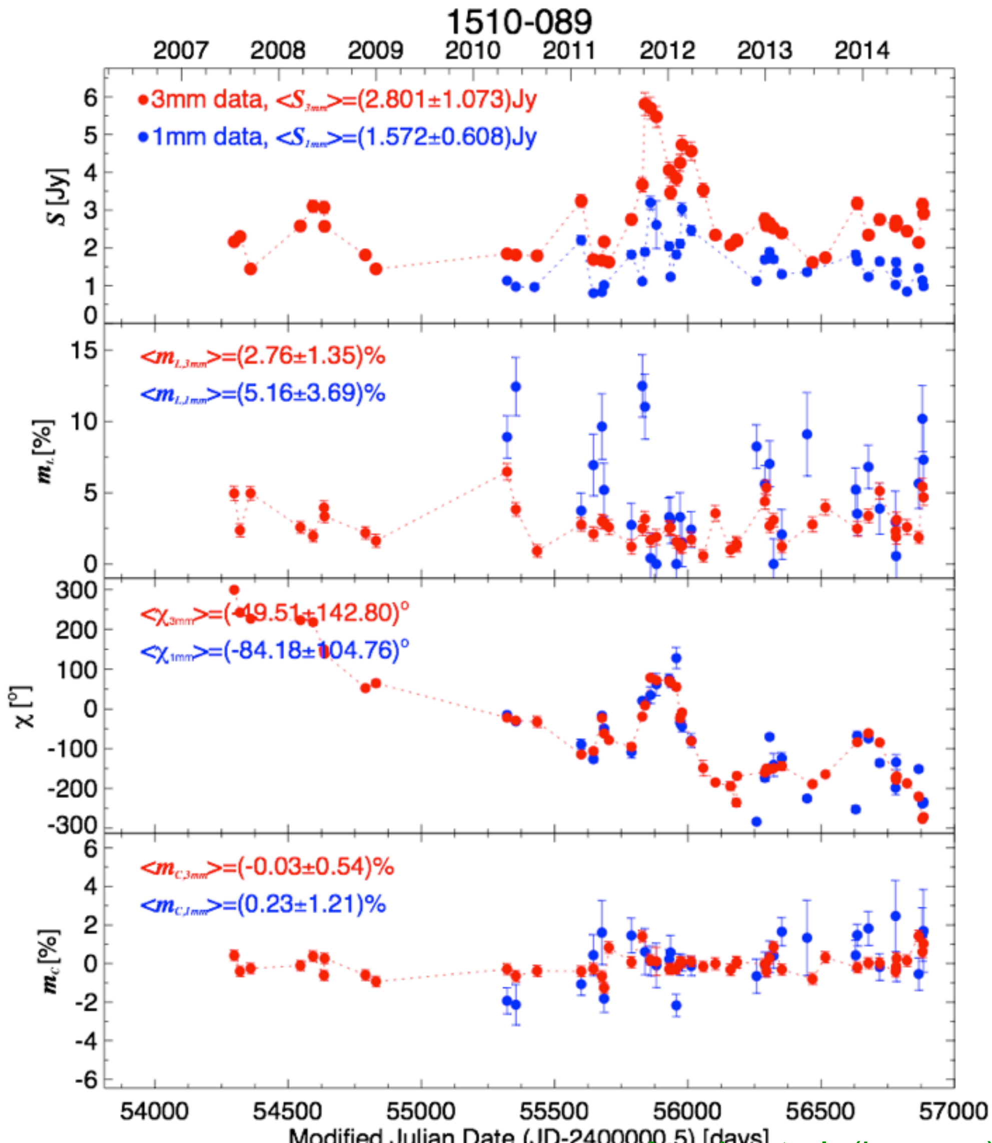
NRAO 150, 3mm GMVA



Agudo et al. (2007)



Molina et al. (2014)



Agudo et al. (in prep.)

5. It is diffcult to find a long period of time when the polarization angle is stable

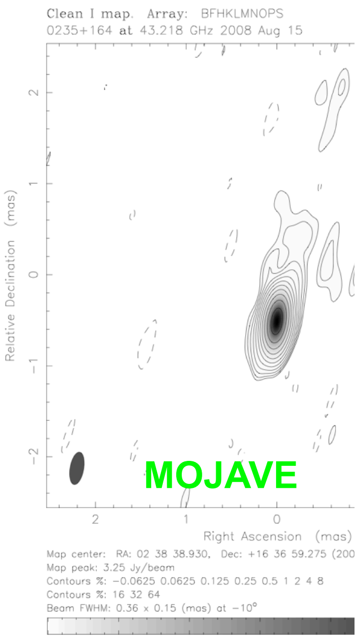
Linear polarization angle to jet position angle misalignment

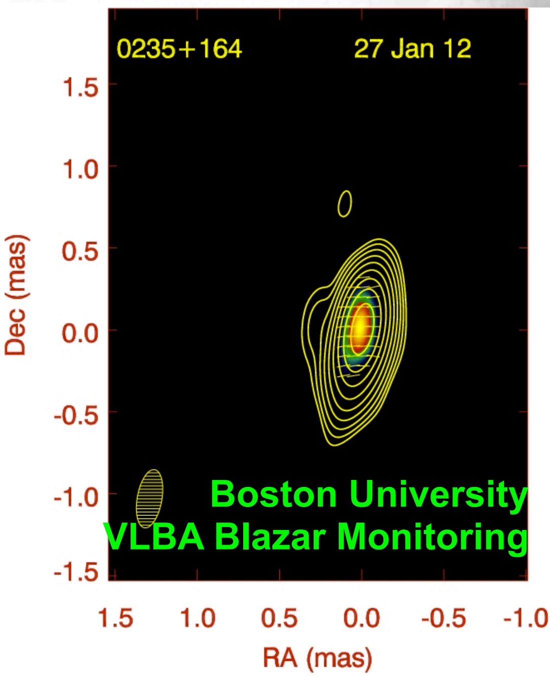
POLAMI data

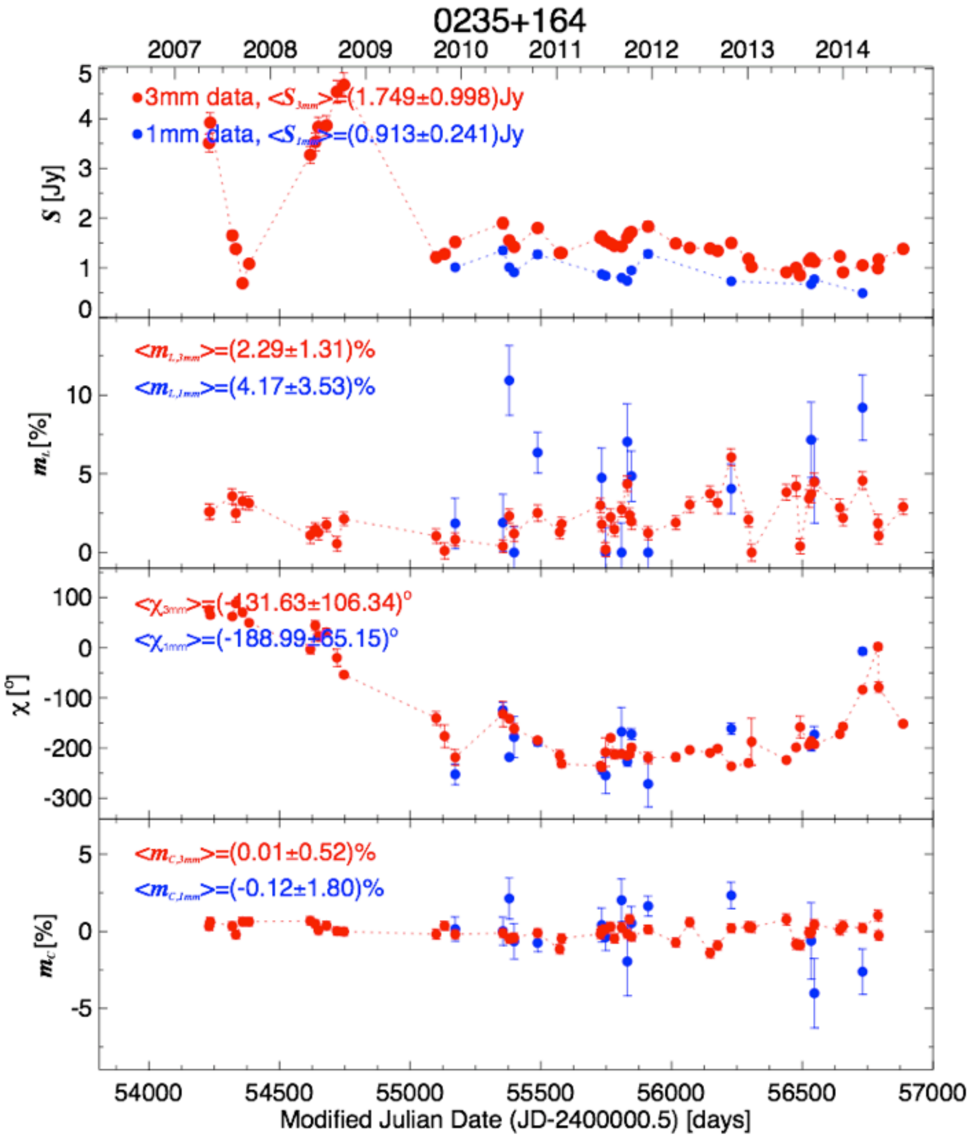
In some cases (~17-20%?):

If quiescent states reflect underlying B field of the jet, such magnetic field is perpendicular to jet axis ⟹ shock (transverse or conical) or toroidal field

On non-quiescence departure from axisimmetry ⟹ inhomogeneous jet



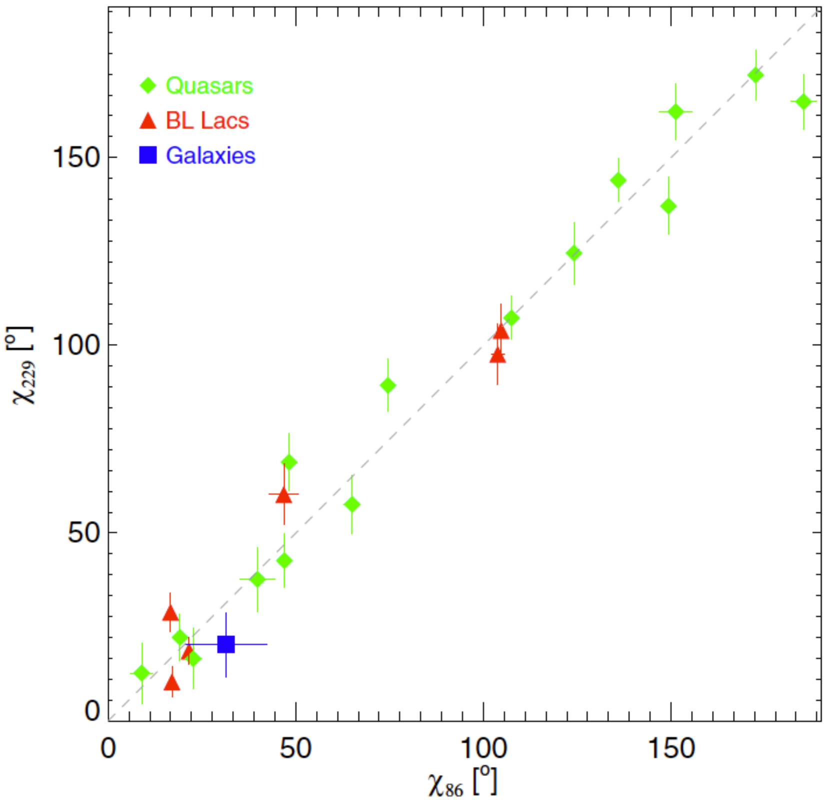




Agudo et al. (in prep.)

5. It is diffcult to find a long period of time when the polarization angle is stable

Faraday rotation



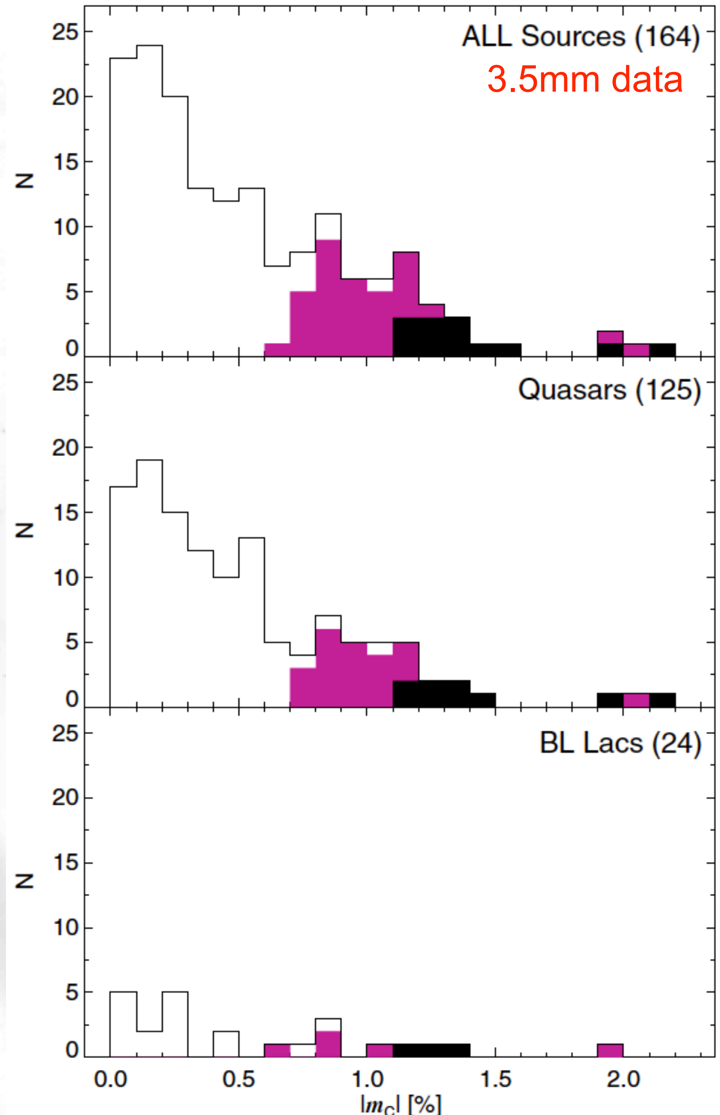
Agudo et al. (2014)

- General good match between χ_{86} and χ_{229} within the errors.
- Large χ_{229} uncertainties, do not allow > 3σ measurements of Faraday rotation
- RM upper limit ≈ 10^5 rad/m^2 for our 22 sources
- Consistent with previous claims of large RM (≈ 10^4-10^5 rad/m^2) detected in some sources through ultra-high-resolution and high-precision polarimetric-VLBI observations (e.g., Attridge et al. 2005 ; Gómez et al. 2008 , 2011; Hovatta et al. 2012; Plambeck et al. 2014).
- Record established on PKS 1830−211 through ALMA measuremetns at 3.5, 1.3 & 0.8 mm, time variable RM=$(2.53\pm0.08)\times10^7$ rad/cm^2 (Marti-Vidal et al. 2015, Science)

Circular polarization

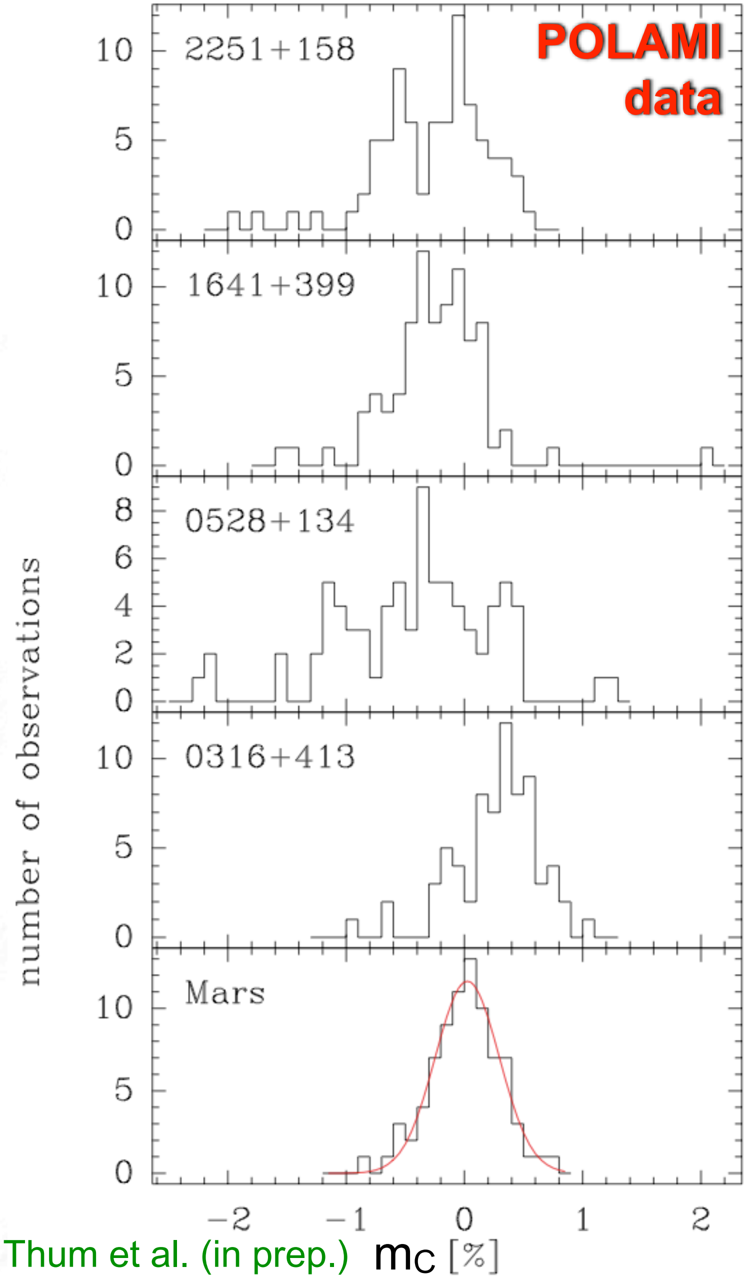
- m_C@3.5mm >3σ (~0.9%) detected for 6% of the sample (13 sources) with values between ~0.6% and ~2%

- At cm λλ, typically m_C< 0.5% (with maxima in the range 0.7-3%, (Aller et al. 2003; Homan & Wardle 2004, Homan & Lister 2006)



Agudo et al. (2014)

Circular polarization



Thum et al. (in prep.)

- Mars (unpolarized), shows Gaussian profile with σ~0.3% (all time dependent measurements together) and $<m_C>=0.0\%$

- Blazars show:
  - Broader m_C distributions, even double-peaked
  - Sometimes significantly shifted from 0.0%
  - Frequent detections >3σ up to ~1% (even 2-3%)

- Measurements made with single-dish telescope ⟹ perhaps affected by beam depolarization

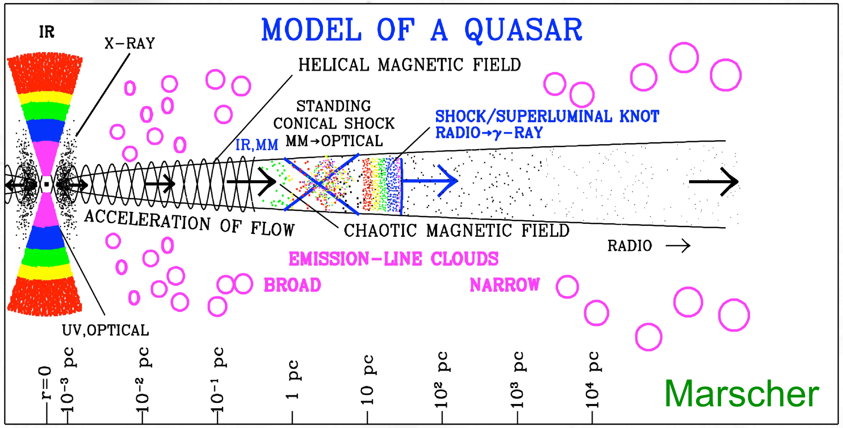
6. Circular polarization at mm-λλ are as large as those reported at cm-λλ!

- Opens posibilities for extremelly high m_C>>1% measurements with millimeter interferometers

Summary

- Shorter millimeter emission region located at progressively inner jet regions
- Blazars display optically thin radiation at short mm-λλ
- Shorter mm emission in blazars comes from regions with progressively better B order
- **Blazar jets not axisimmetric, regards to their polarization emission**
- If quiescent states reflect underlying B field of the jet, such field is perpendicular to jet axis ⟹ shock (transverse or conical) or toroidal/helical field
- **Hints of fast CP variability and frequent sign changes**
- **Conversion of LP into CP from stochastic/turbulent processes** seems feasible

Detailed modeling of full polarization spectra may reveal key jet parameters (e.g. e^+ content, γ^{min}, γ^{max}, actual B configuration and intensity), which can hopefuly be estimated from the help of (sub-)mm spectra



Unpublished result

"Relativity will twist your brain until it hurts"

(Marscher 2005; private communication)