Total Flux and Polarimetric Blazar Behavior at Millimeter Wavelengths

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für
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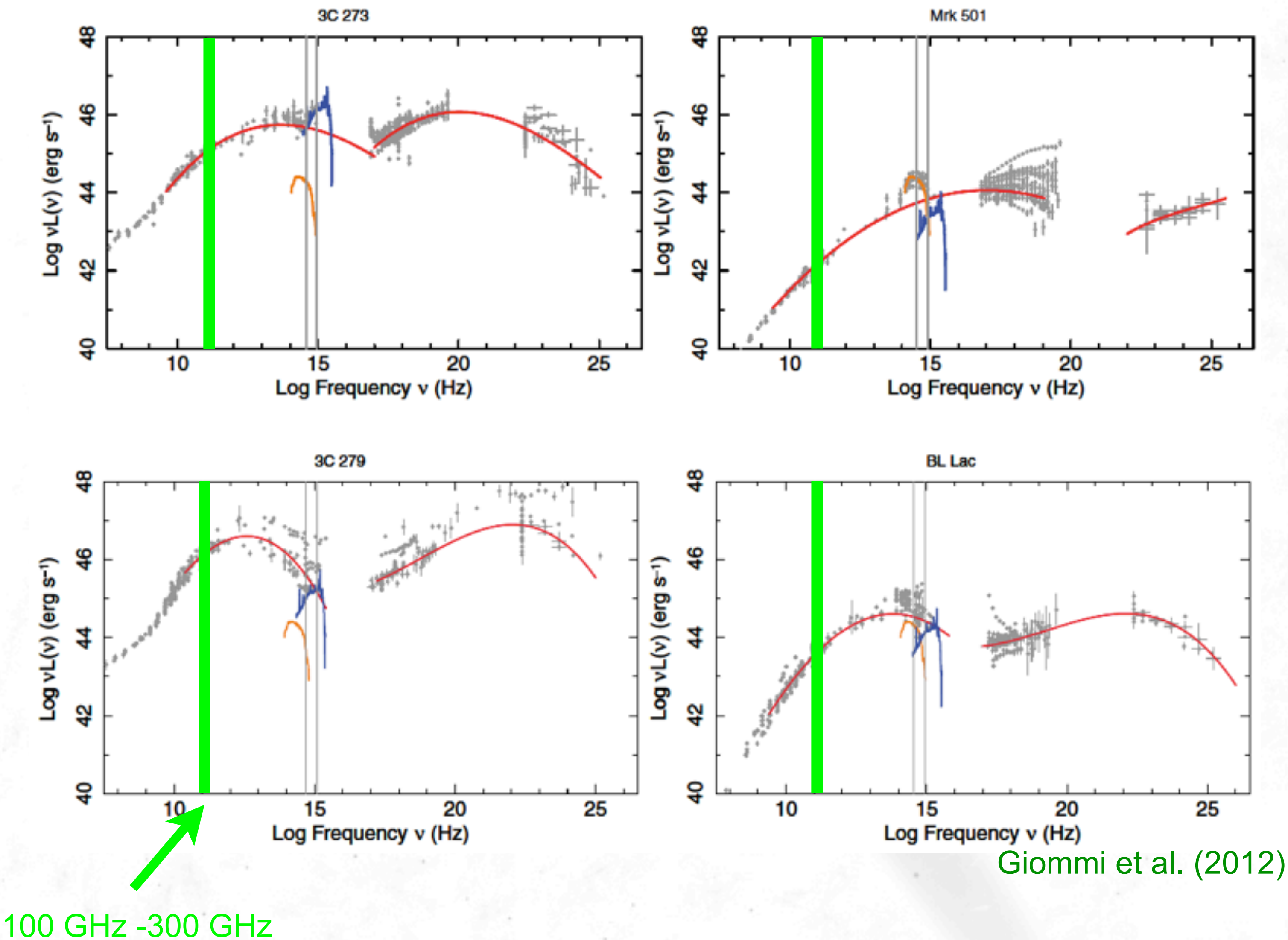
BOSTON UNIVERSITY

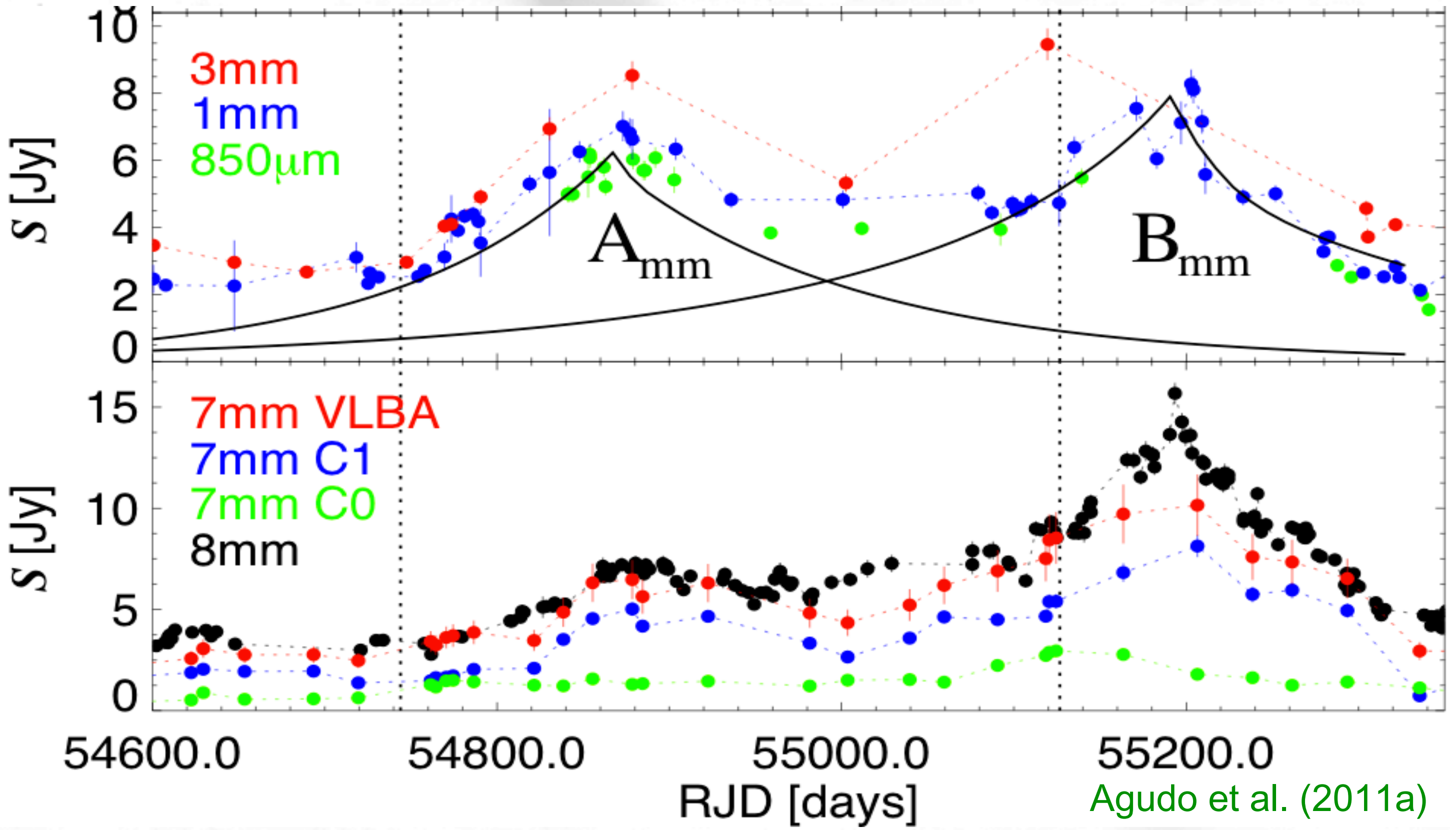
Millimeter emission mechanism



Total flux variability and its origin

- Blazars show extreme total flux variability at millimeter λλ
- Up to one order of magnitude
- On time scales from months to days.

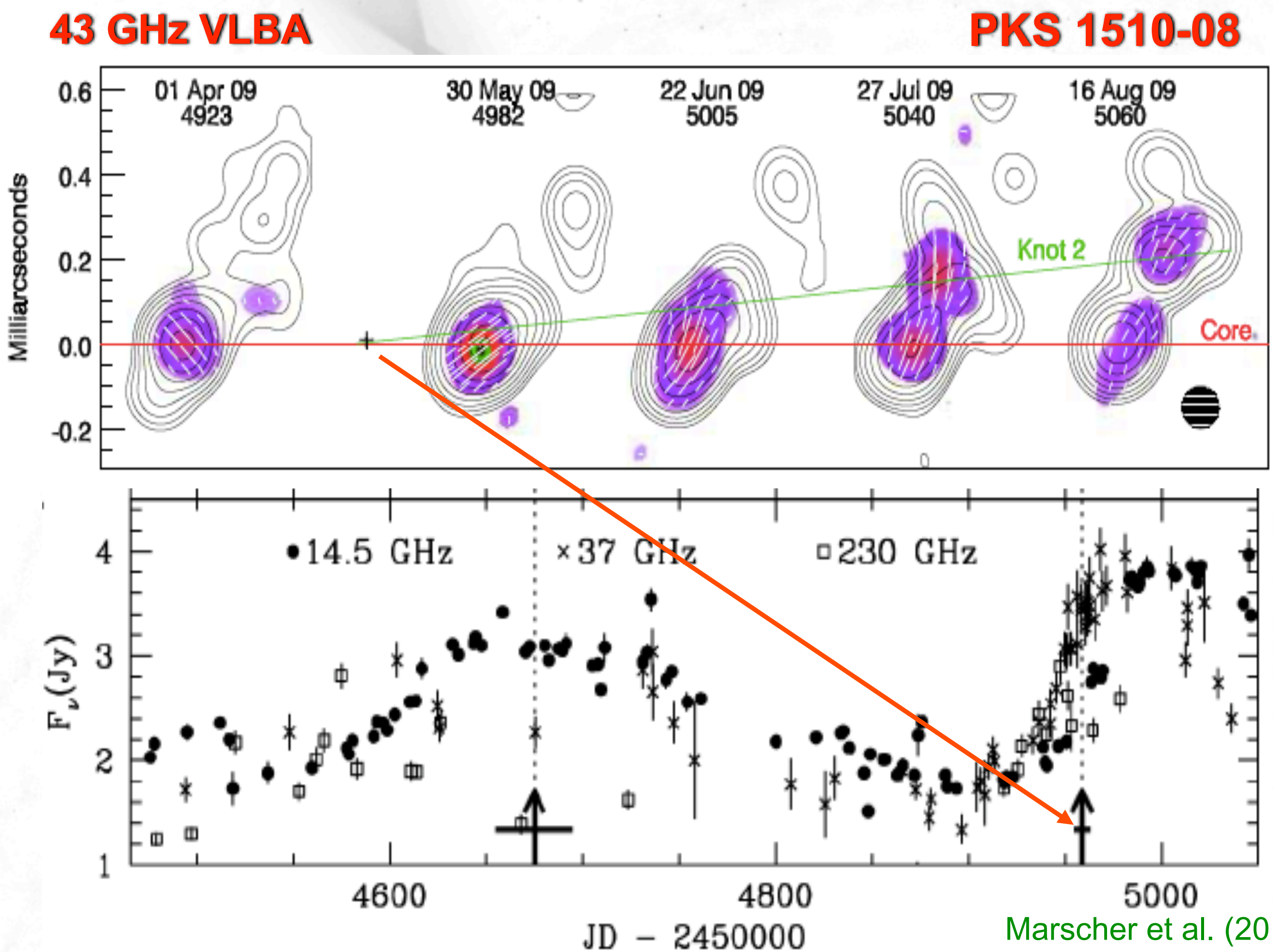
OJ287



Agudo et al. (2011a)

Total flux variability and its origin

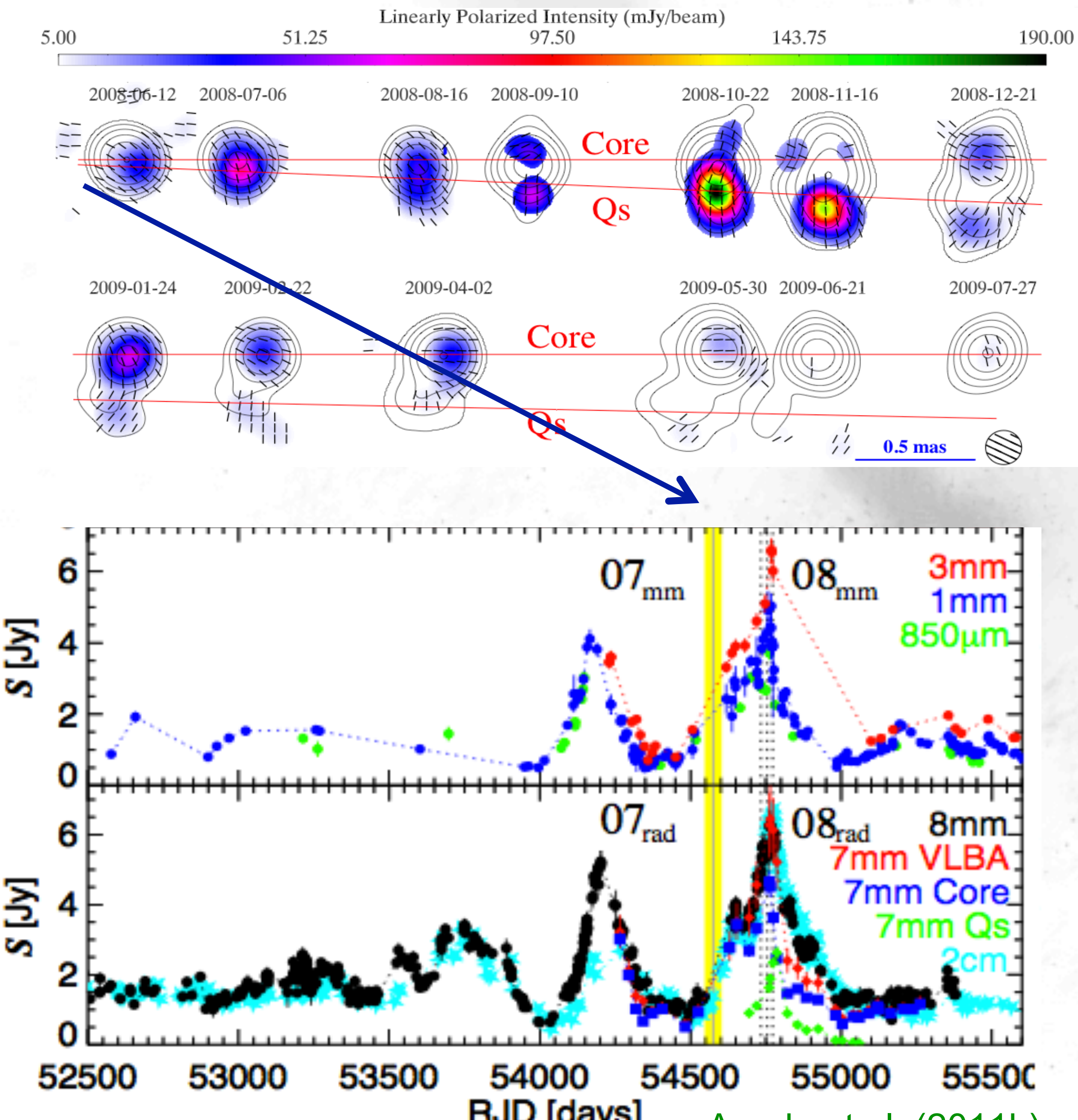
- Often connected to ejection of strong jet features (blobs, knots, shocks...) from the innermost regions of the source



Marscher et al. (2010)

Location of short millimeter emission region

43 GHz VLBA **AO 0235+164**



Agudo et al. (2011b)

Location of short millimeter emission region

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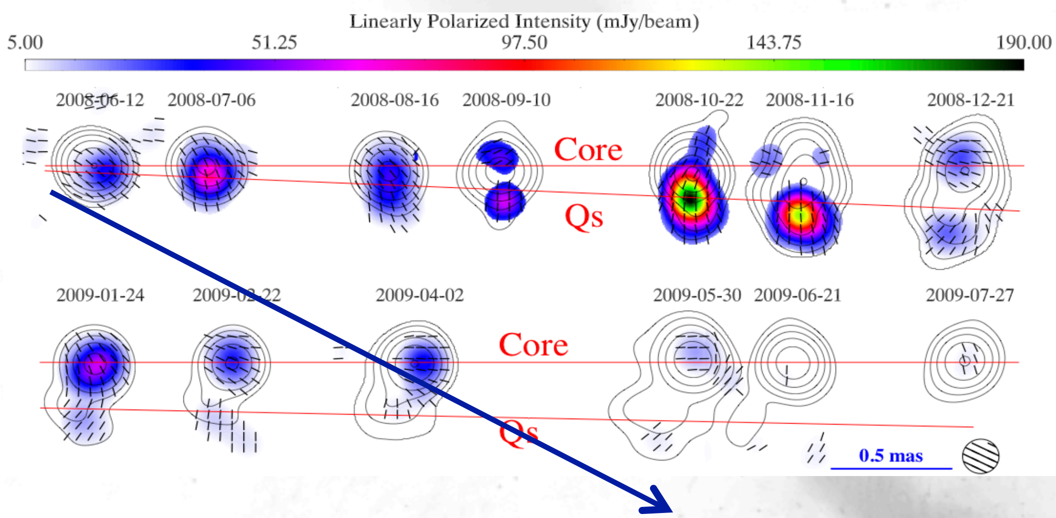
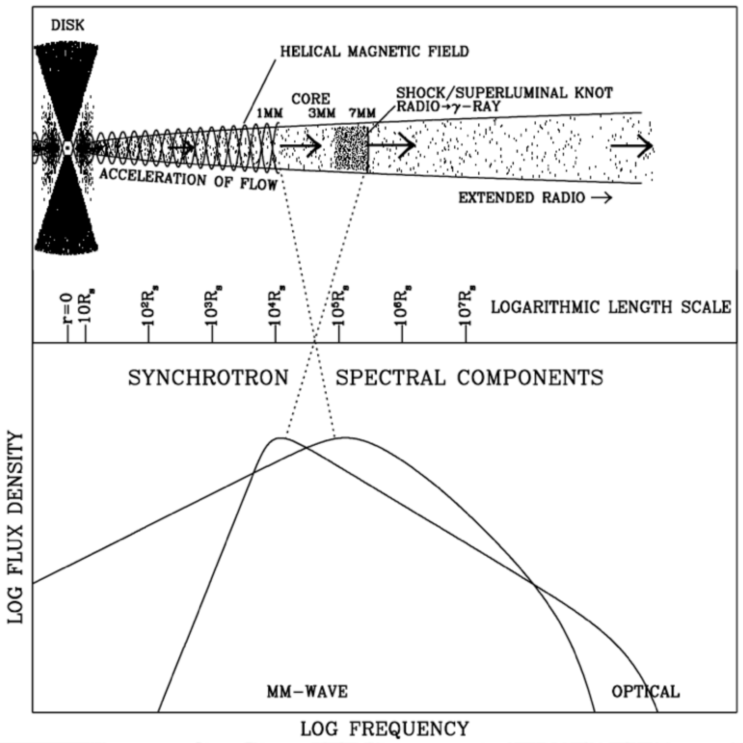
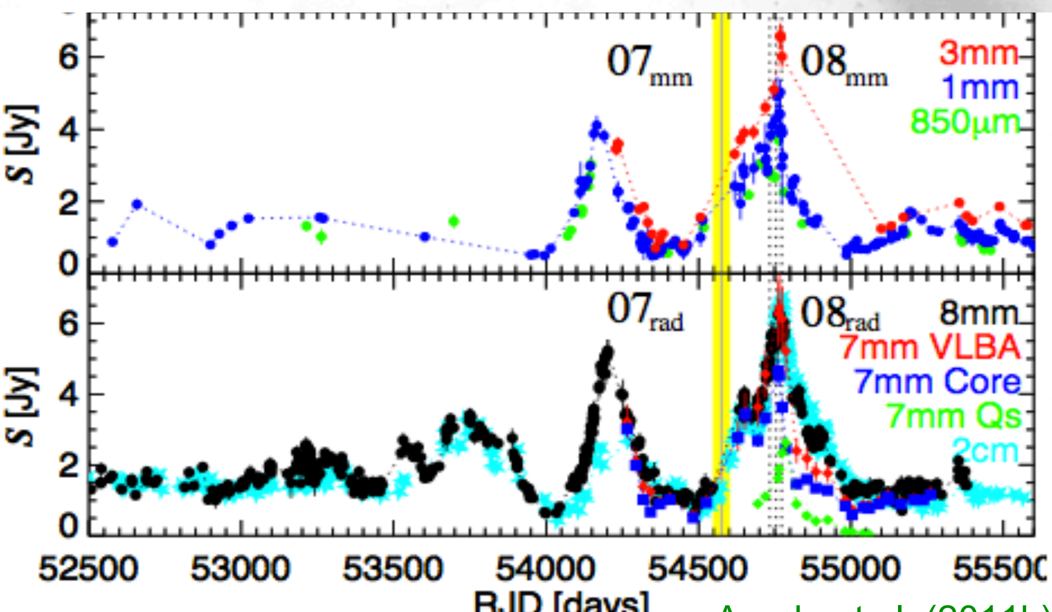


Jorstad et al. (2007)





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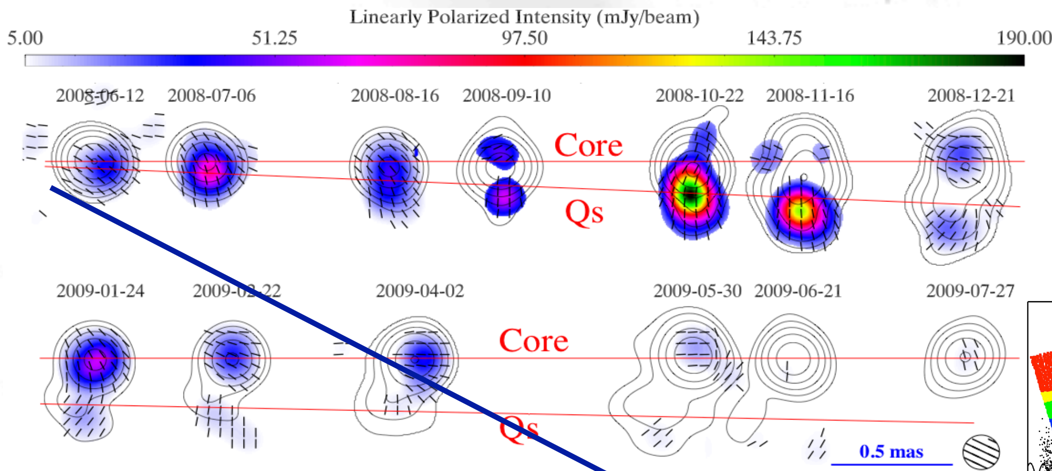
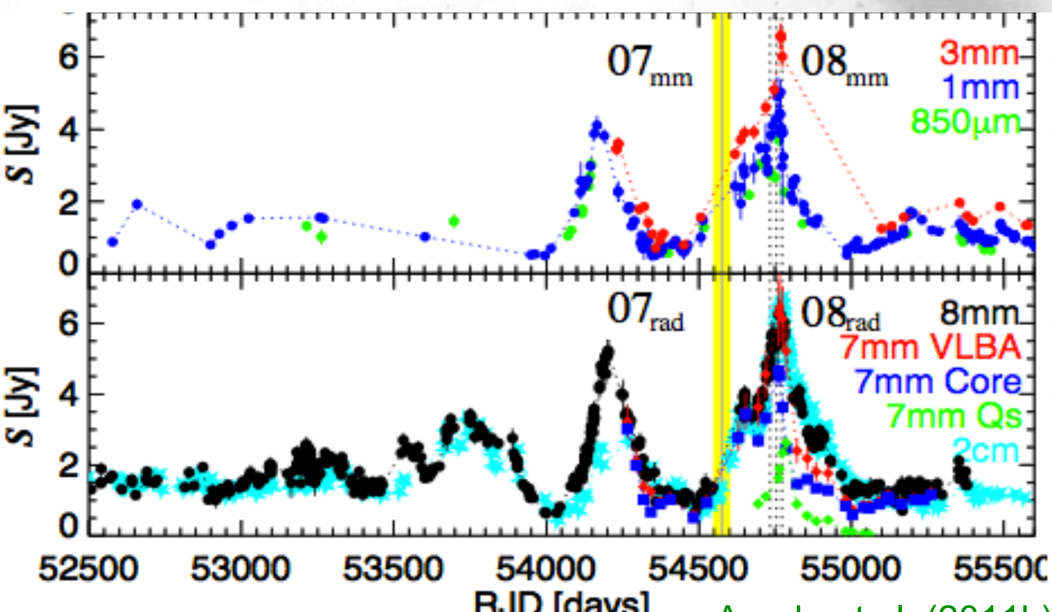
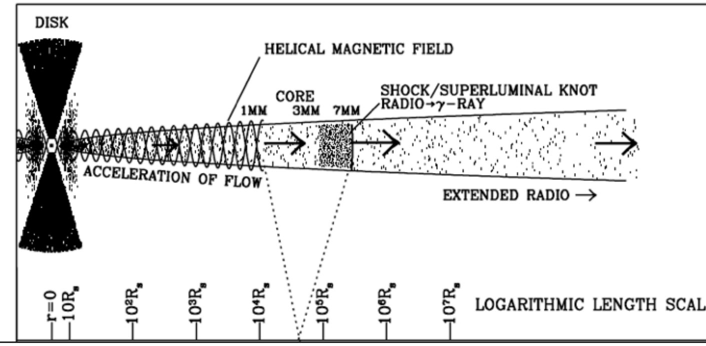
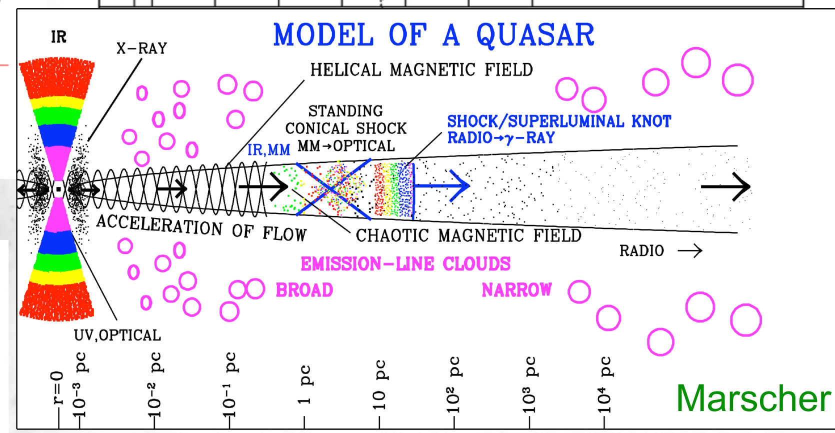




Agudo et al. (2011b)

Jorstad et al. (2007)





Marscher

Location of short millimeter emission region

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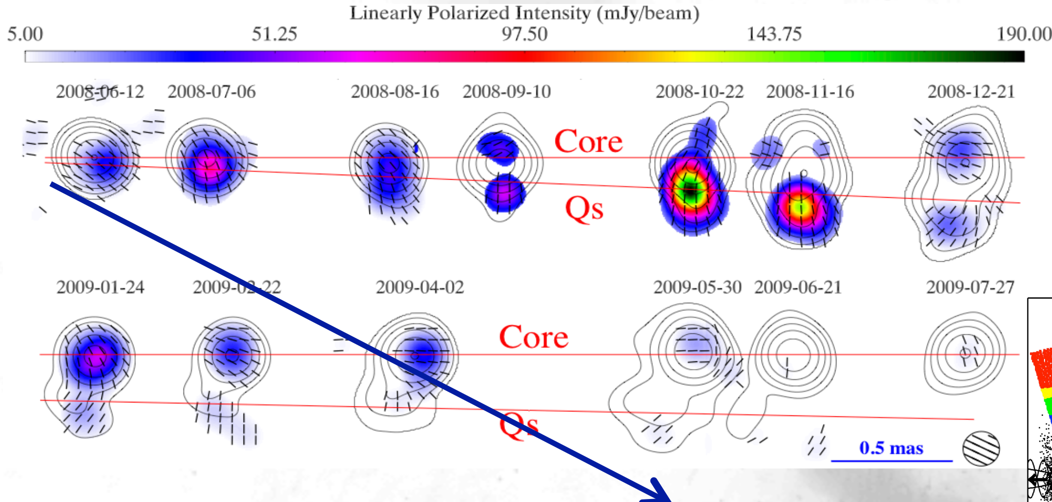

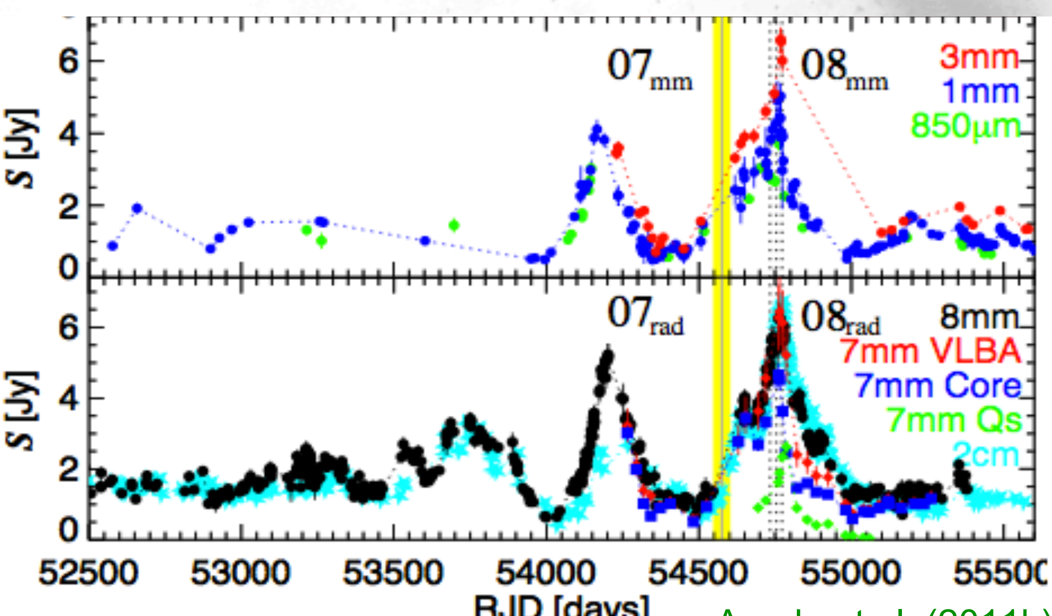

Agudo et al. (2011b)

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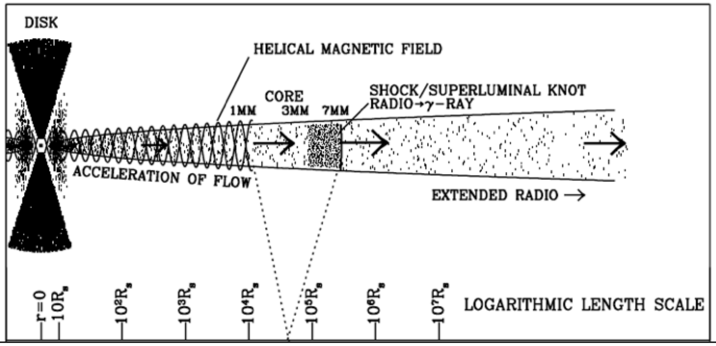

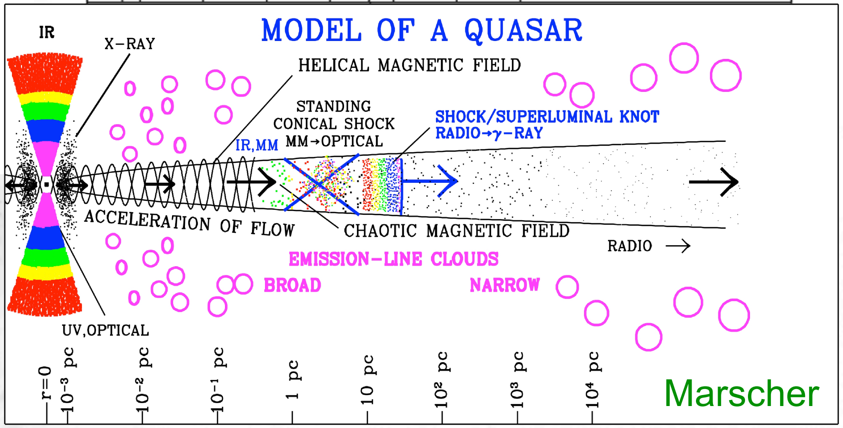

Marscher

Millimeter emission region located at progressively upstream jet regions as mm-λλ decreases

Location of short millimeter emission region

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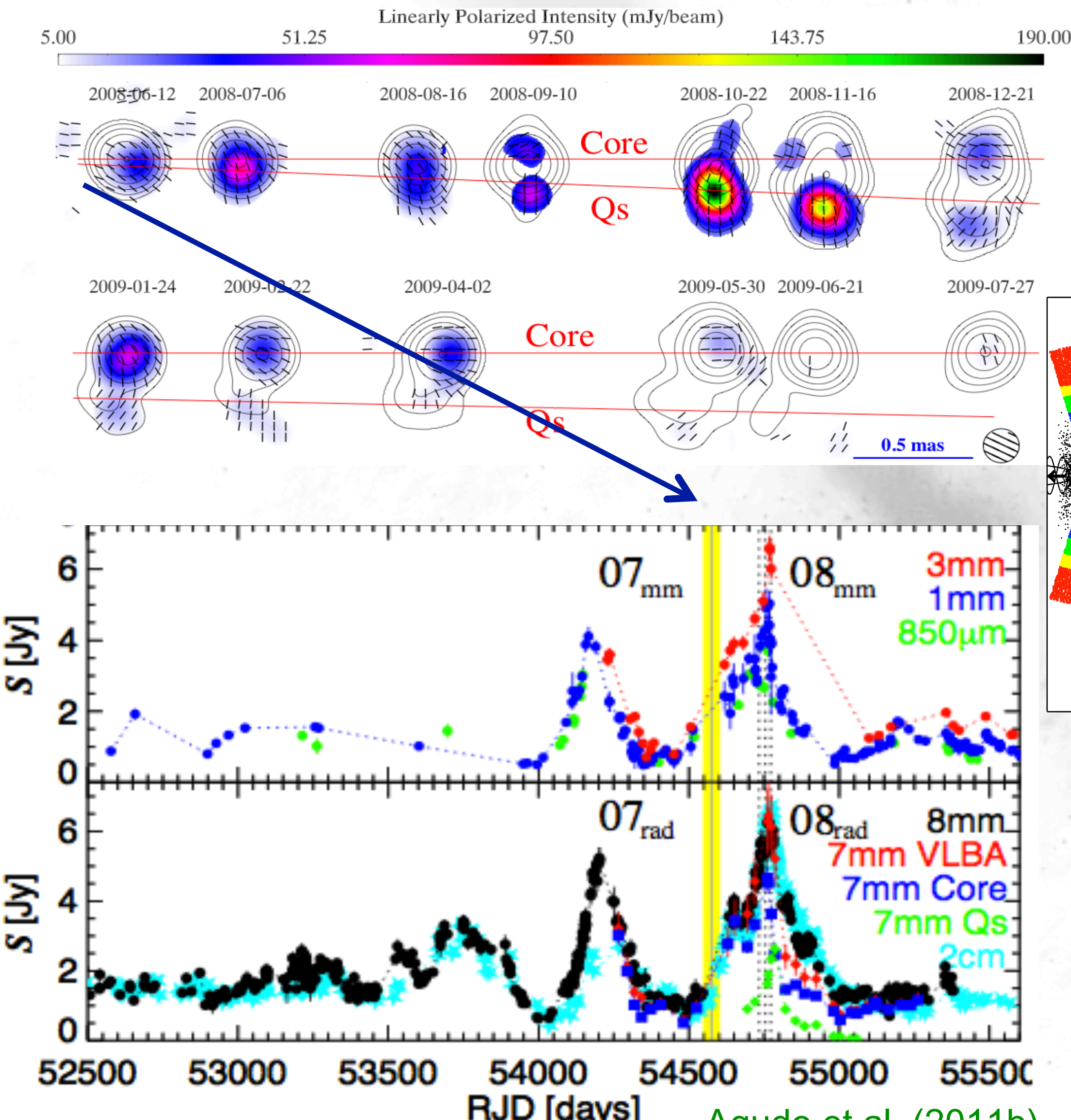

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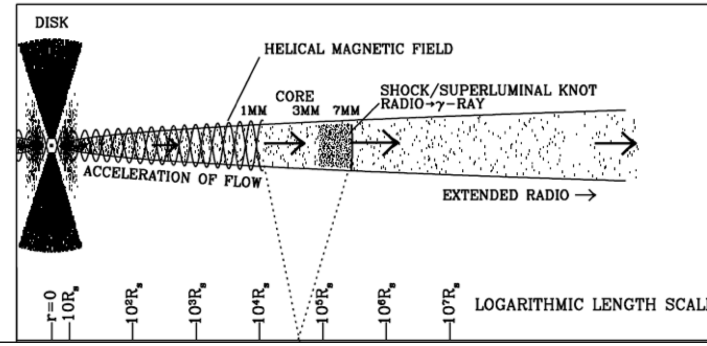
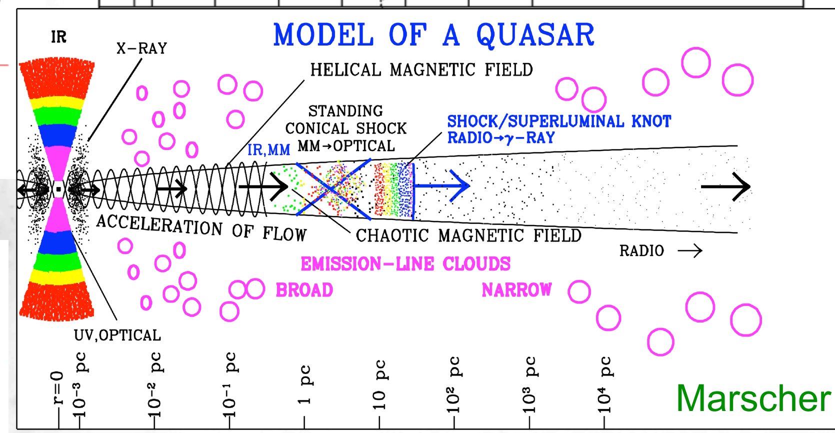


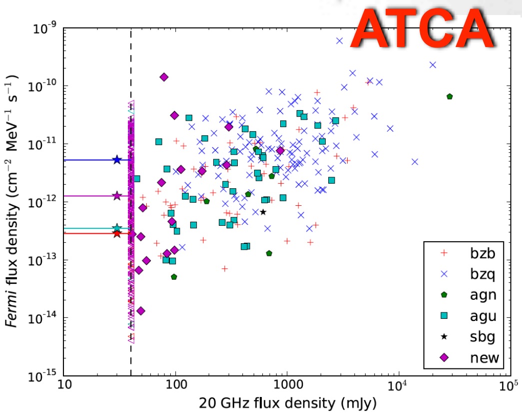


Marscher

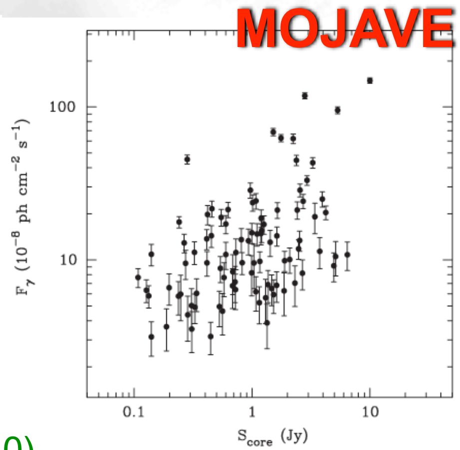
Millimeter emission region located at progressively upstream jet regions as mm-λλ decreases

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

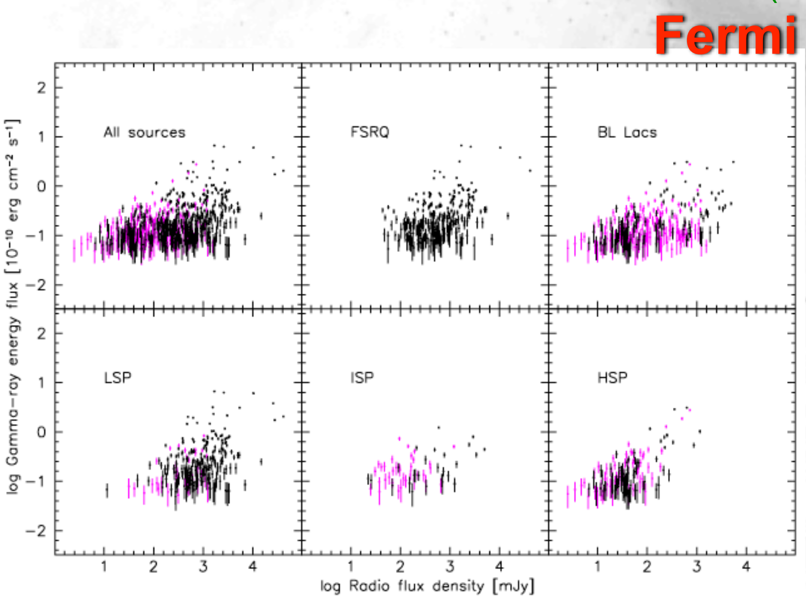
Relation to gamma-ray emission



Mahony et al. (2010)



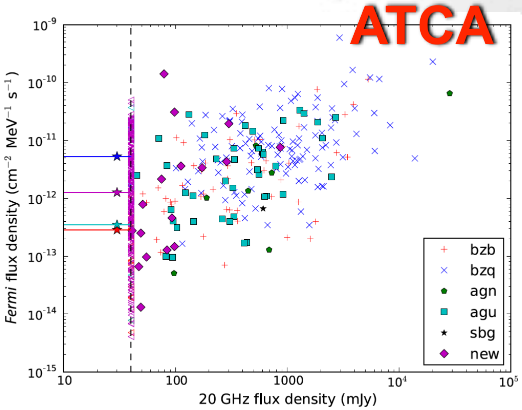
Pushkarev et al. (2010)



Ackermann et al. (2011)

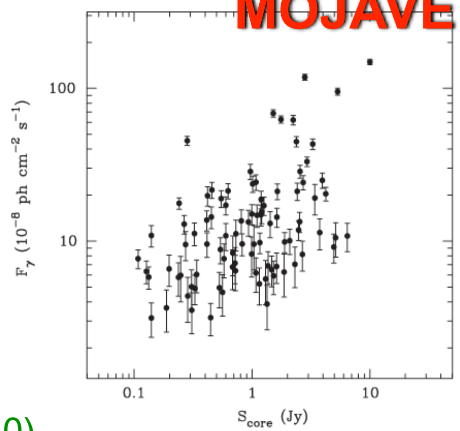
Relation to gamma-ray emission

ATCA



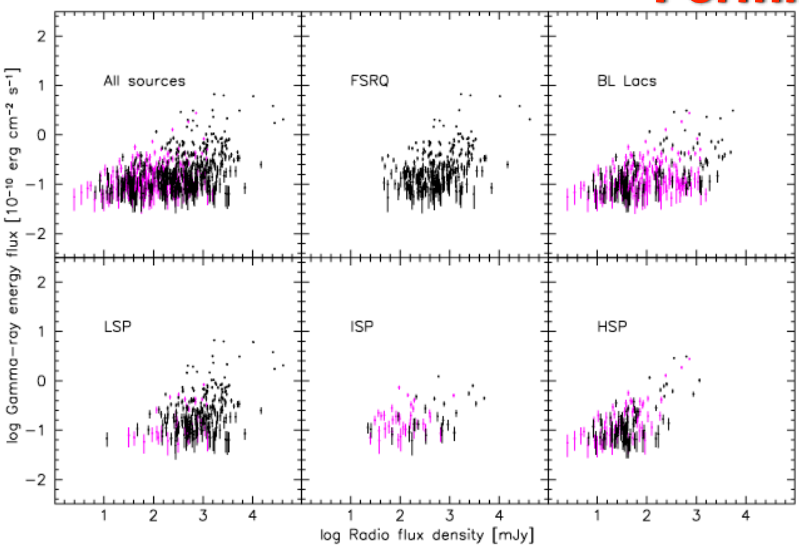
Mahony et al. (2010)

MOJAVE



Pushkarev et al. (2010)

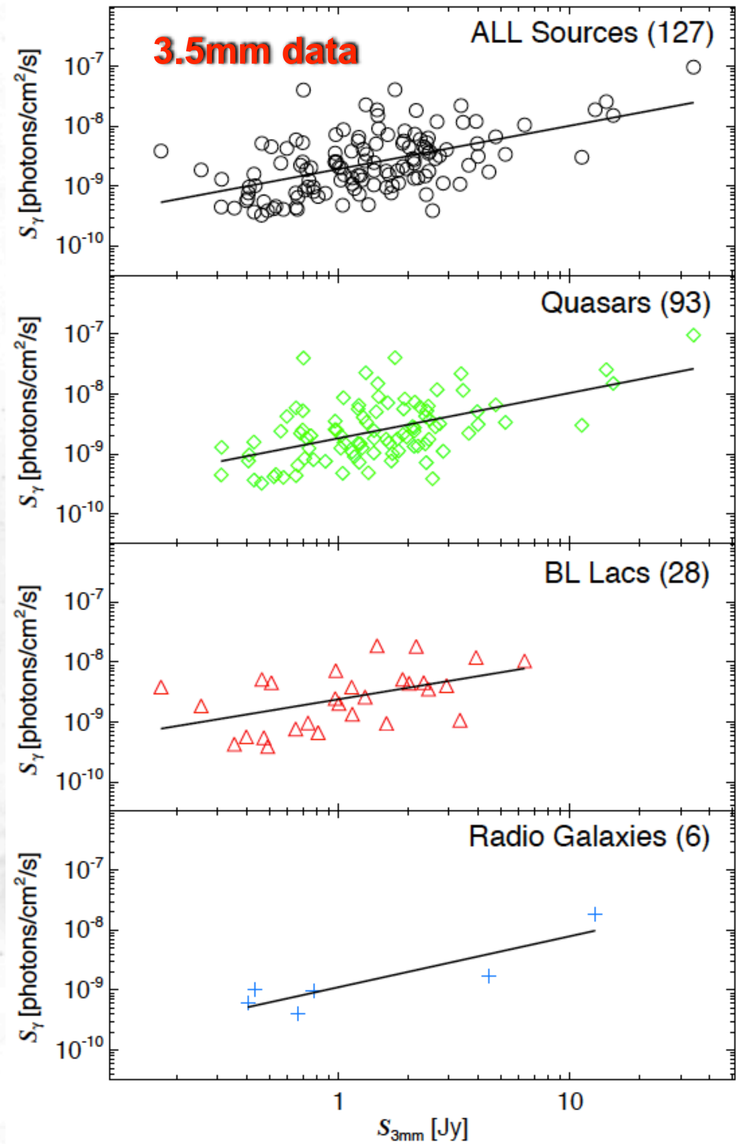
Fermi



Ackermann et al. (2011)

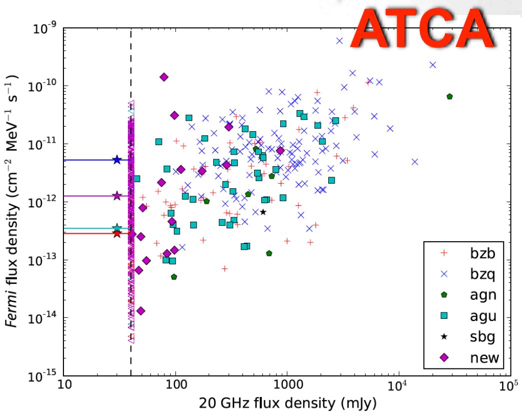
IRAM 30m

3.5mm data



Agudo et al. (in prep.)

Relation to gamma-ray emission



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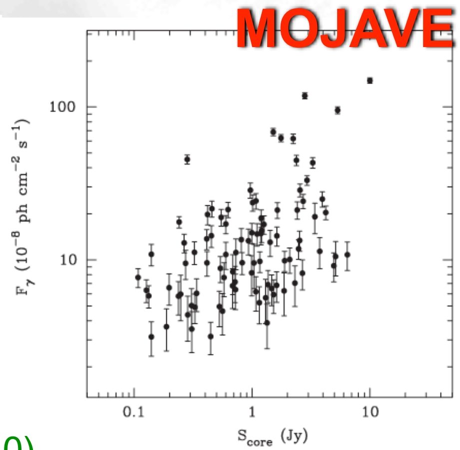

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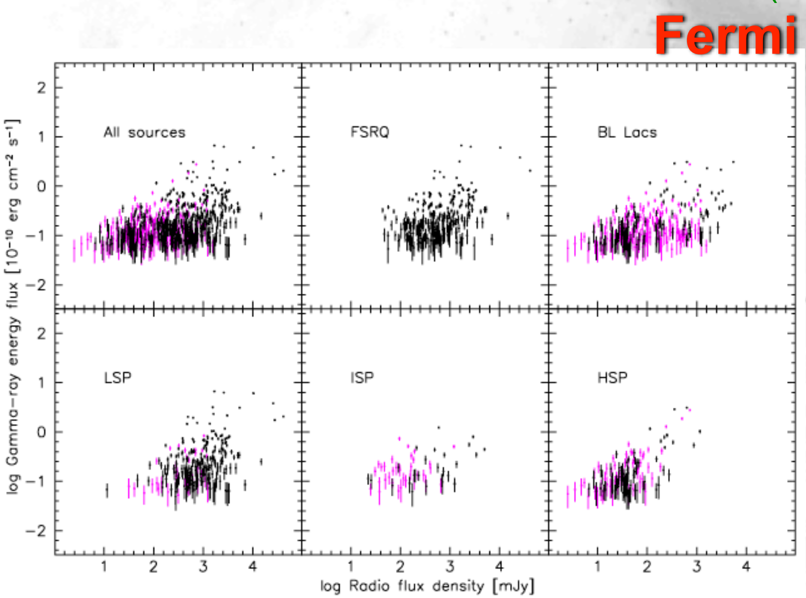

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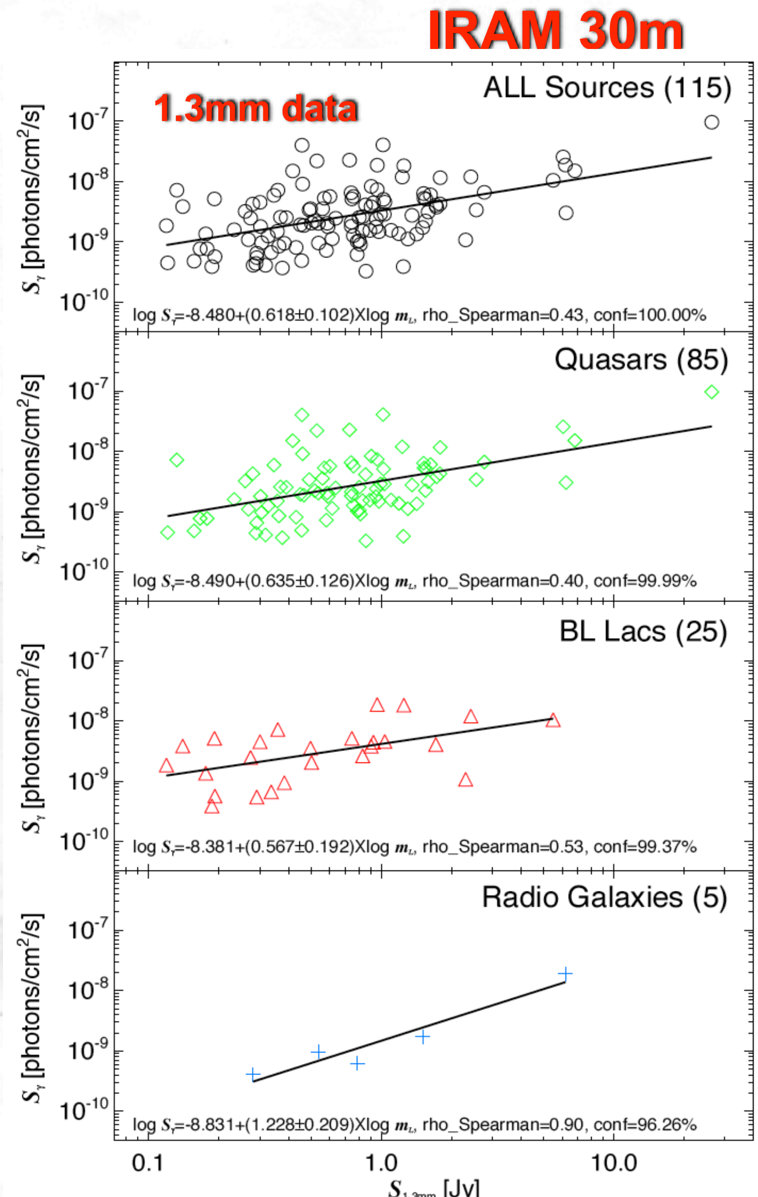

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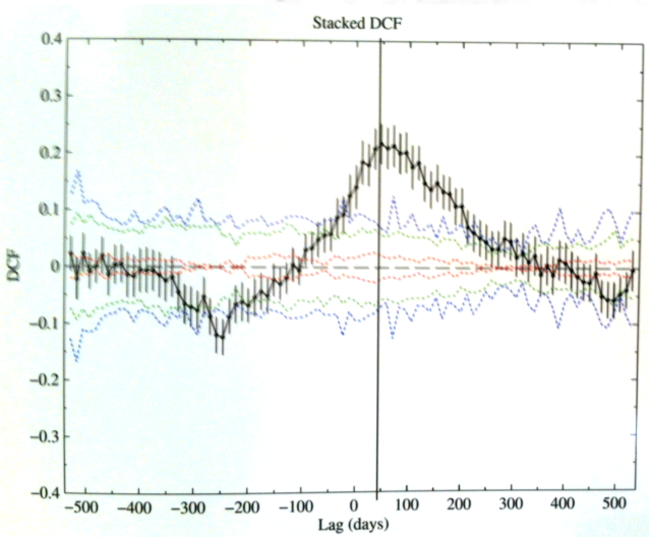
Relation to gamma-ray emission

8mm-γ Metsähovi



From poster by V. Ramakrishnan

Relation to gamma-ray emission

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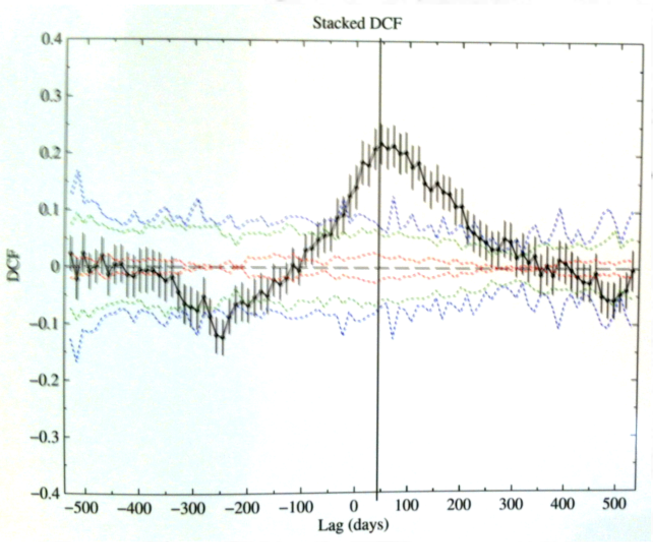

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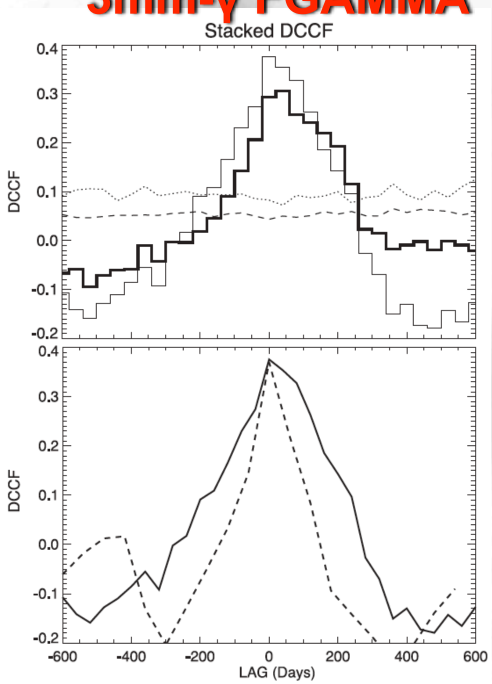
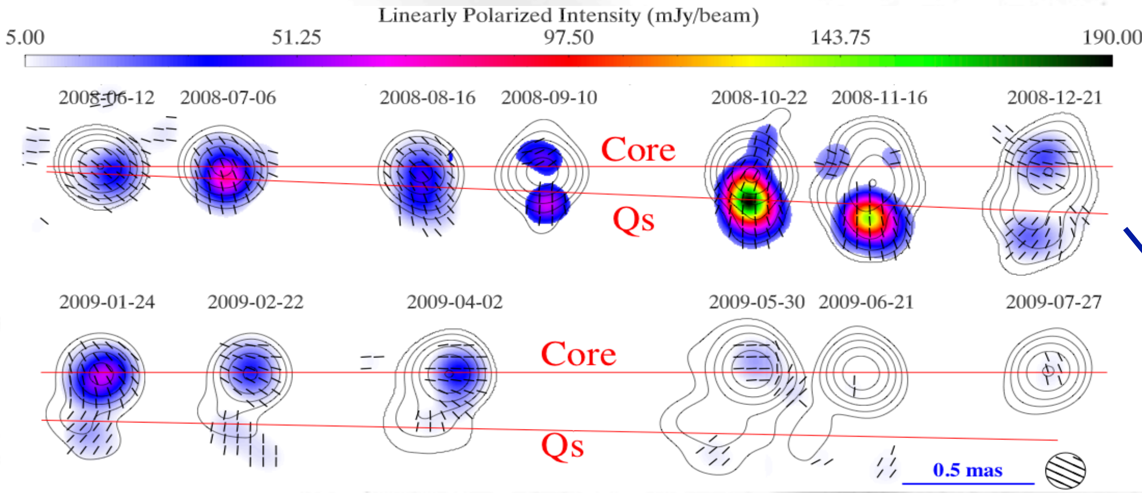
3mm-γ FGAMMA



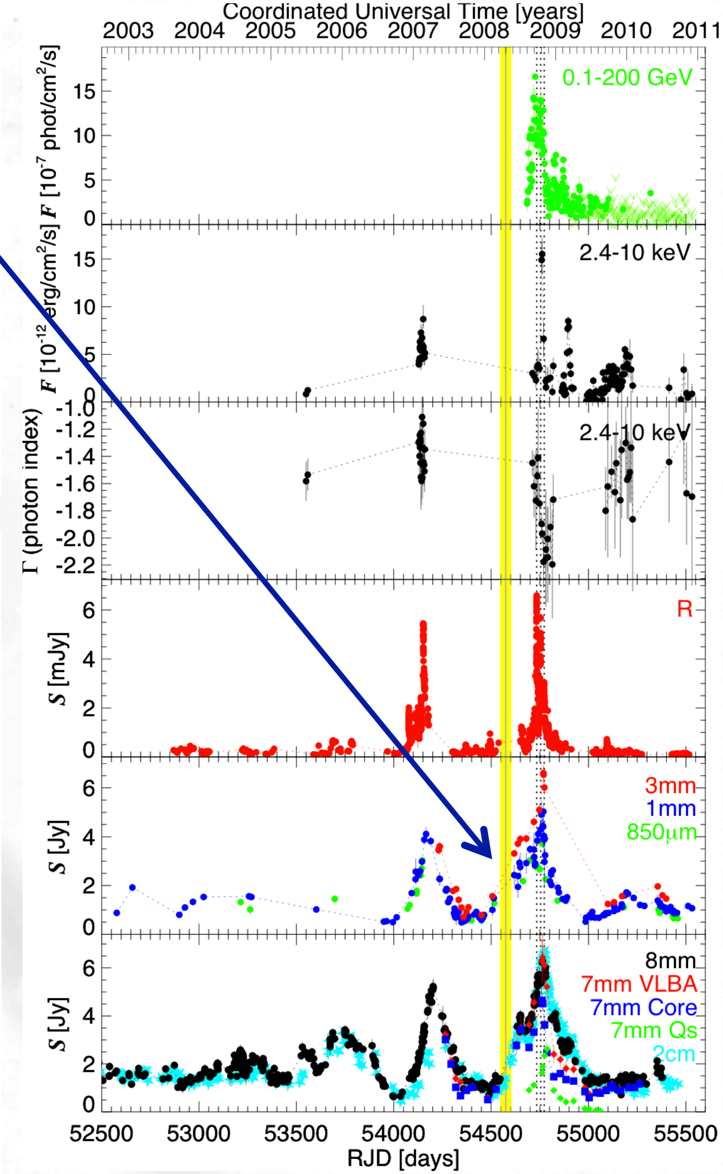
Fuhrmann et al. (2014)

Relation to gamma-ray emission

43 GHz VLBA



AO 0235+164



Agudo et al. (2011b)

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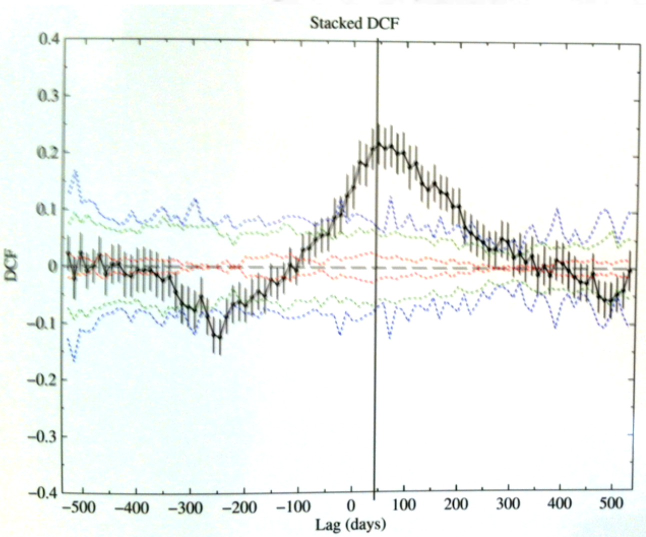

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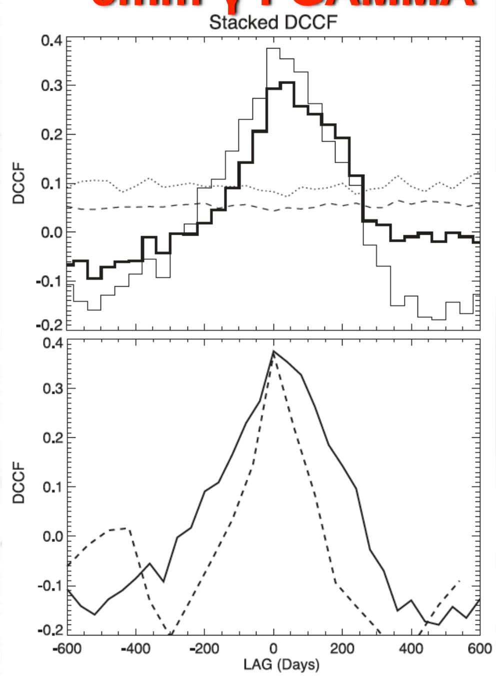

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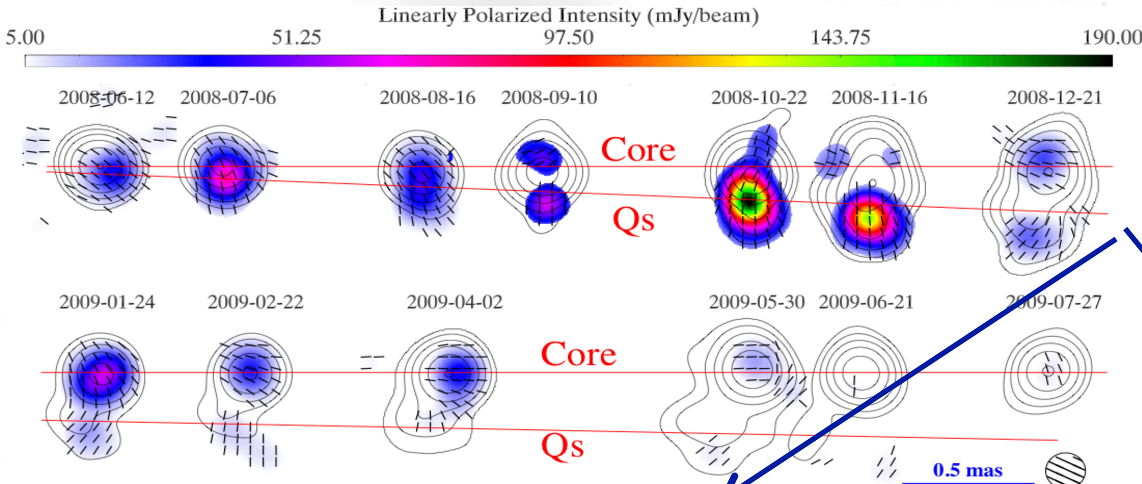
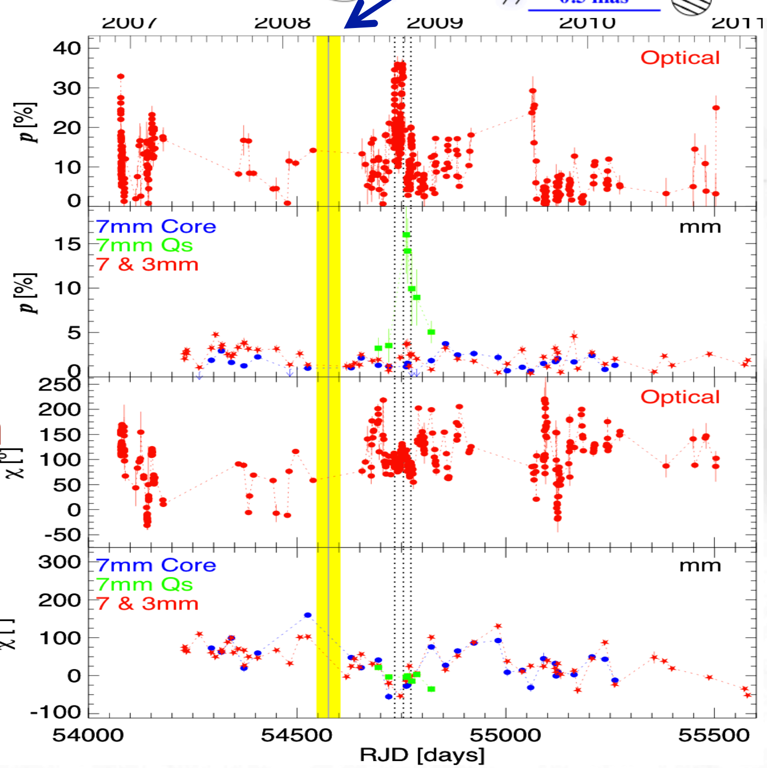
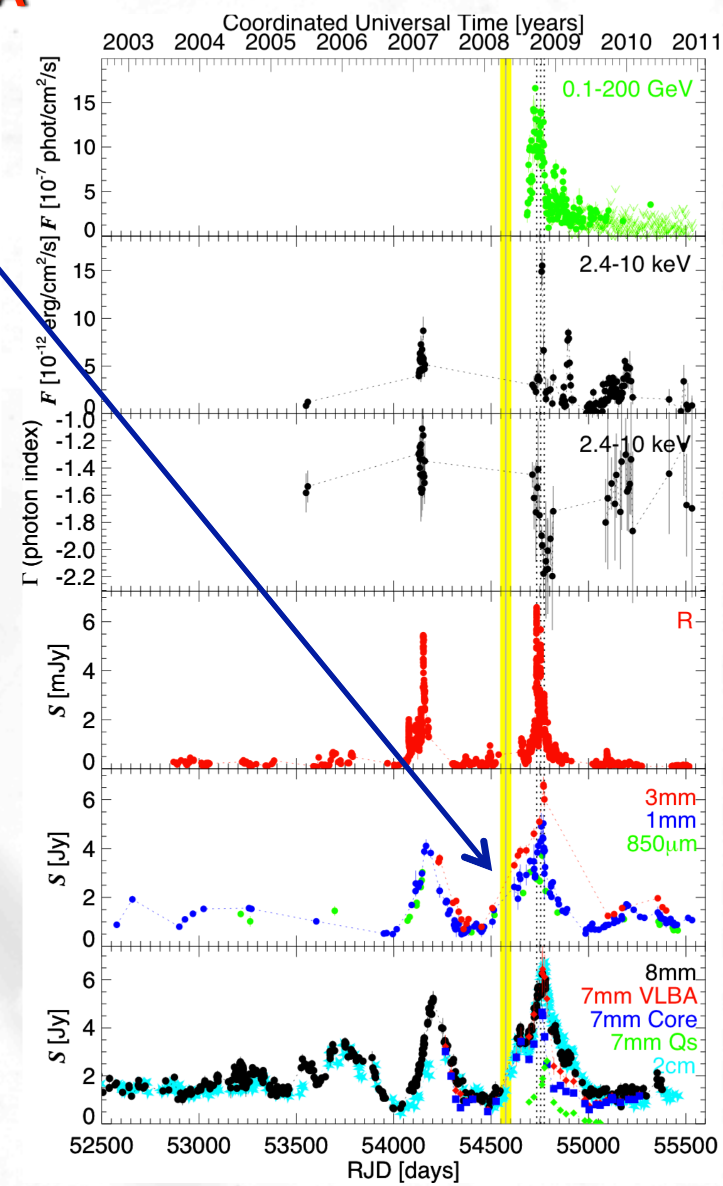






- For particular cases, robust evidence that he γ-ray emission is co-spatial with the mm emission

Agudo et al. (2011b)

A polarimetric survey at 3.5 & 1.3mm?

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

- Essentially no Faraday rotation of linear polarization emission from the jet at mm wavelengths

- Essentially no Faraday depolarization

- mm emission well represents the innermost (less known) regions of jets

- 4 Stokes polarimeter @ IRAM 30m Telescope (XPOL, Thum et al. 2008)

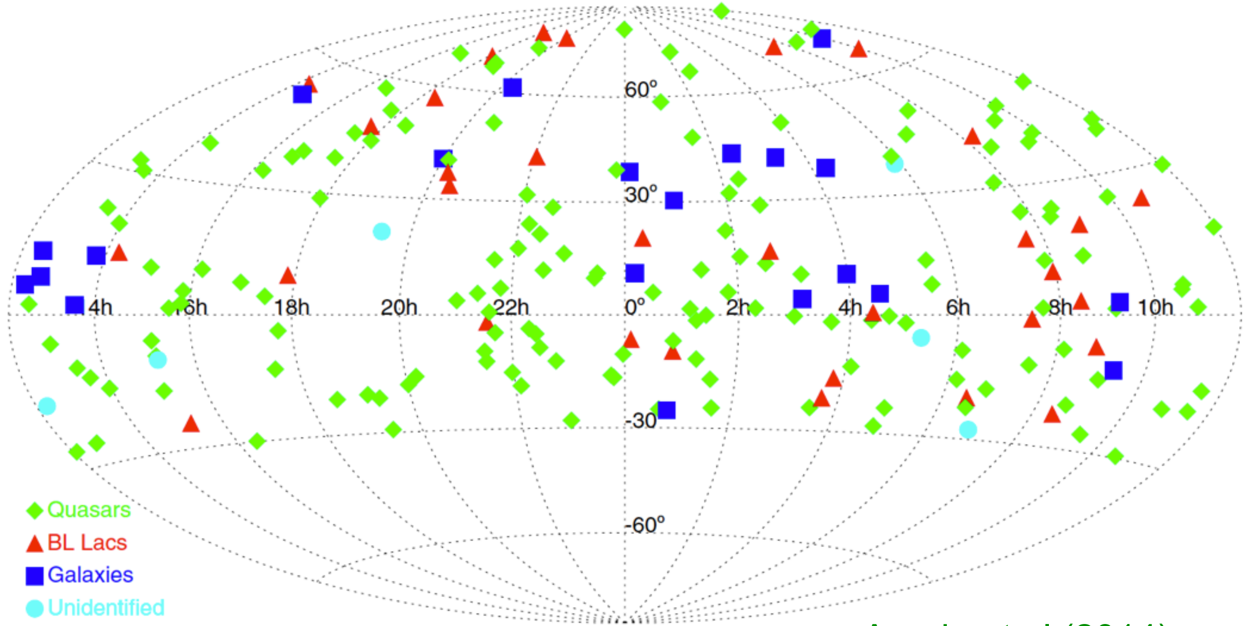
Latest generation Rx (up to 16 GHz simultaneous BW)
~70% the collecting area of Pateau de Bure (cannot still do polarimetry)
A factor ~4 larger collecting area than SMA

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

Almost complete source list can be checked at: http://www.iaa.es/~iagudo/_iagudo/MAPCAT.html

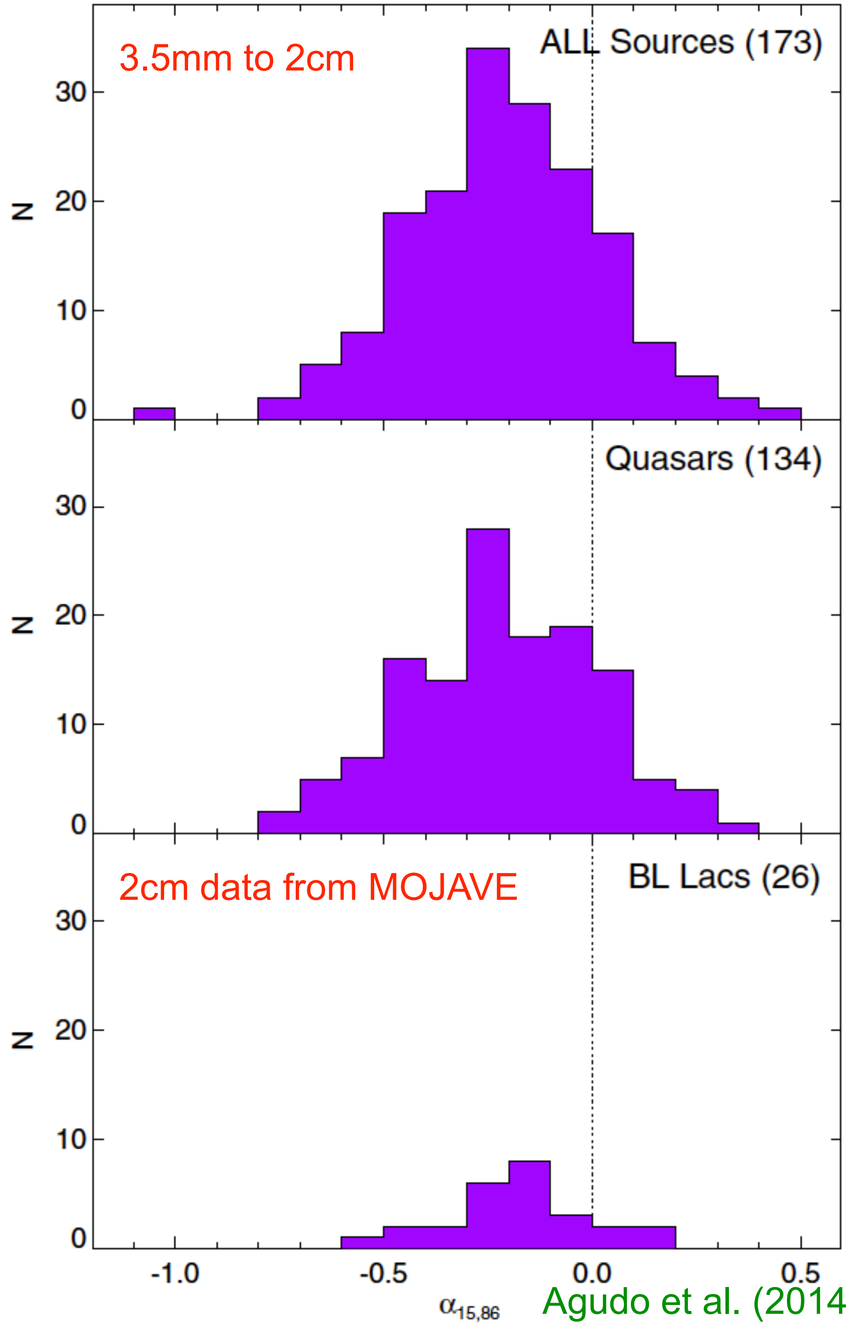
3C 66A
AO 0235+16
3C 84
CTA 26
3C 111
PKS 0420−01
3C120
PKS 0528+134
S5 0716+71
PKS 0735+17
OJ 248
OJ 49
4C 71.07
OJ 287
S4 0954+65
PKS 1055+01
MRK 421
PKS B1127-145
4C 29.45
ON 231
PG 1222+216
3C 273
3C 279
B2 1308+30
PKS 1416−076
PKS 1510−08
DA 406
PKS 1622-29
4C 38.41
3C 345
NRAO 530
OT +081
BL Lacertae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

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 $\alpha_{15,86} > 0$



Agudo et al. (2014)

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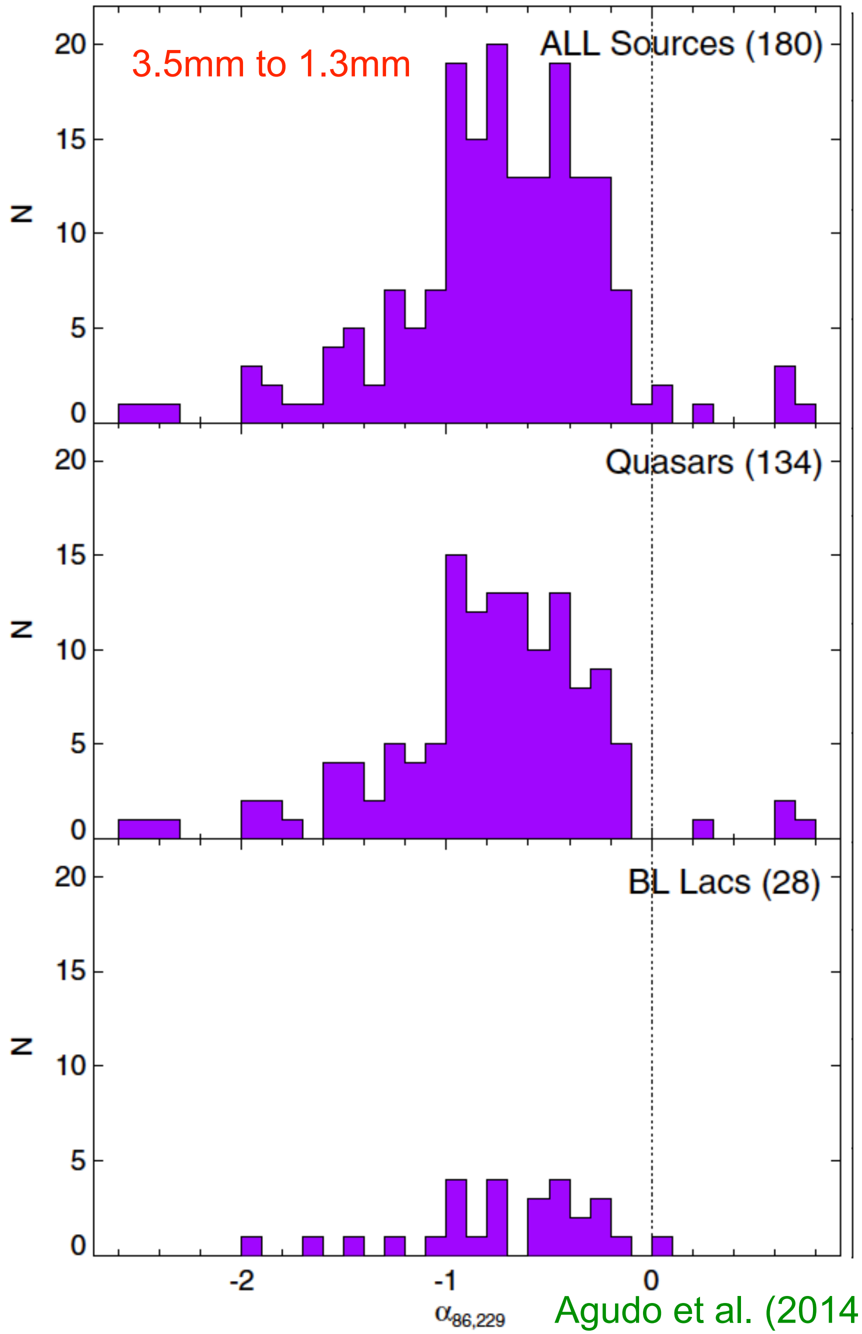
- More optically thin from 3.5 and 1.3mm ($\tilde{\alpha}^{Q}_{86,229}$=−0.75 for quasars and $\tilde{\alpha}^{B}_{86,229}$= −0.56 for BL Lacs)

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



Agudo et al. (2014)

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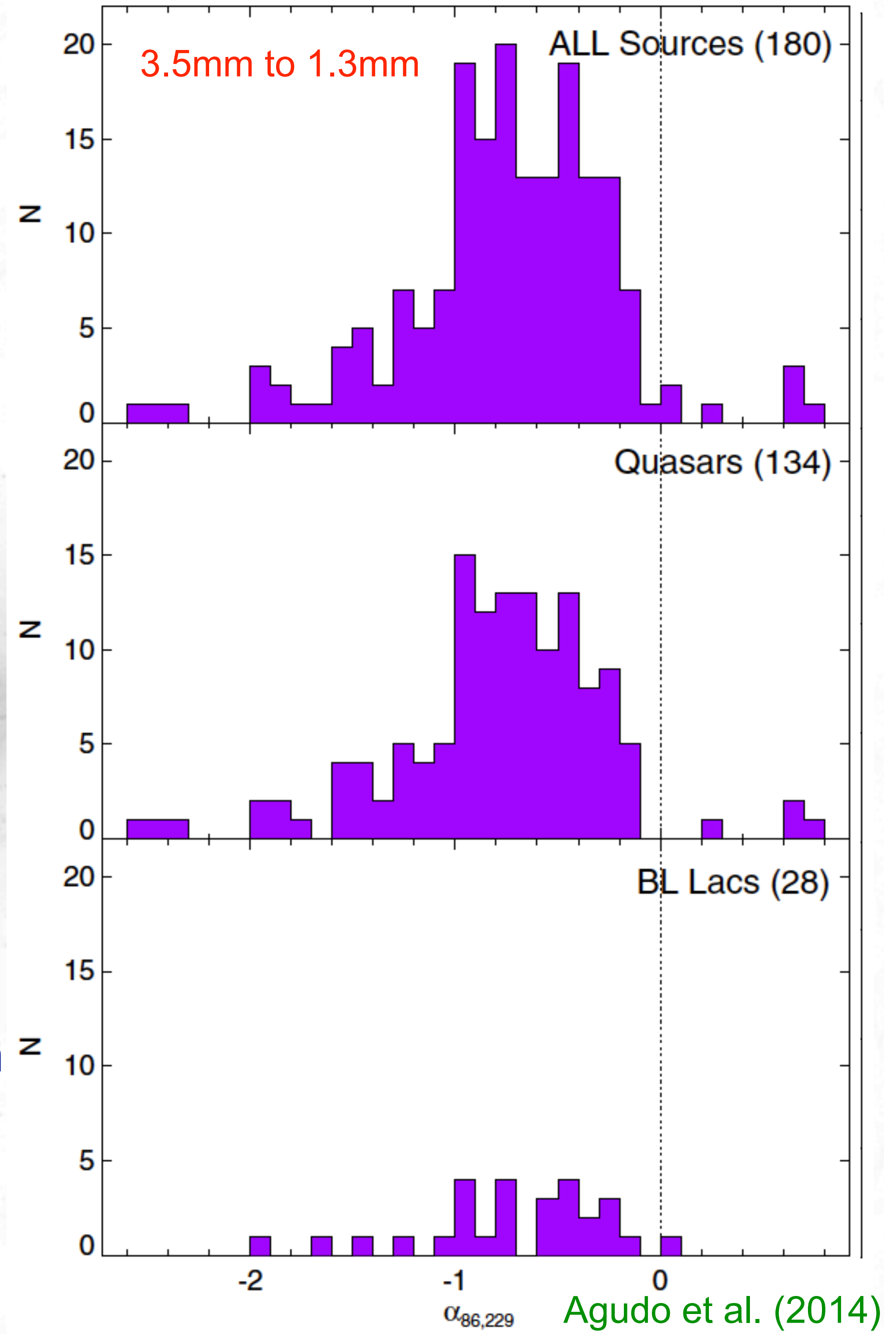
Blazars display optically thin radiation between 86 and 229 GHz in general

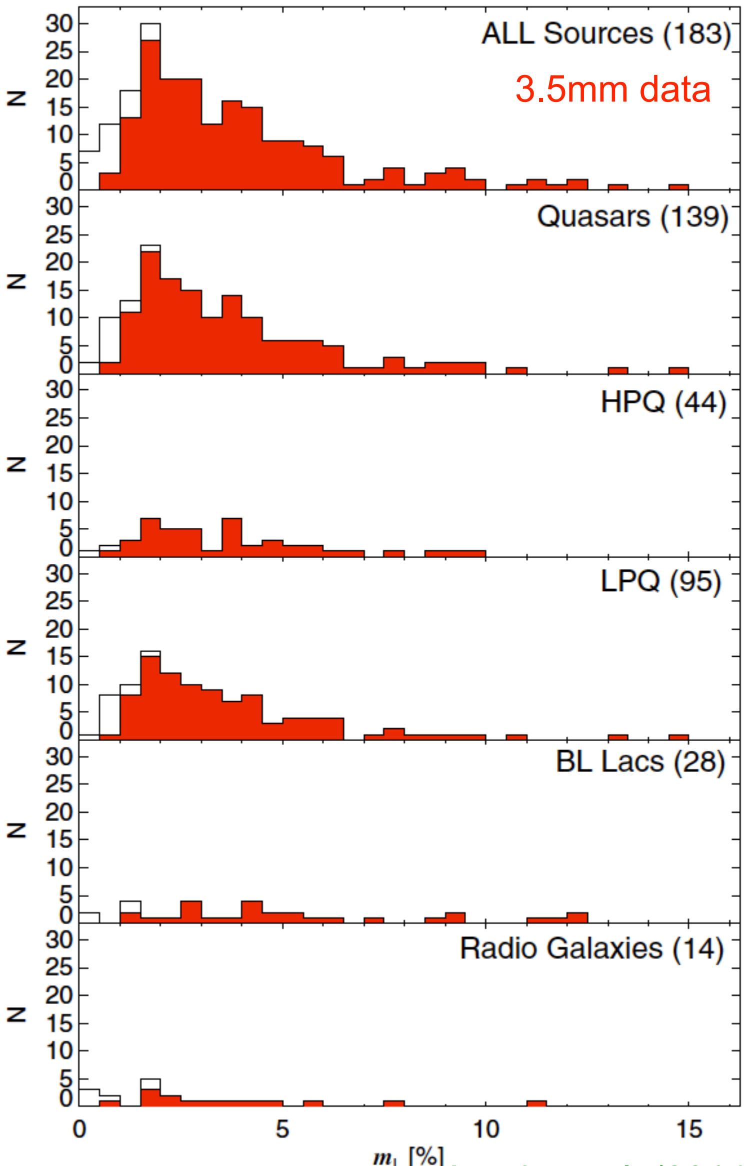
- Not affected by opacity effects angle rotation & depolarization ⟹ intrinsic polarization properties of sources

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



Agudo et al. (2014)

Linear polarization degree

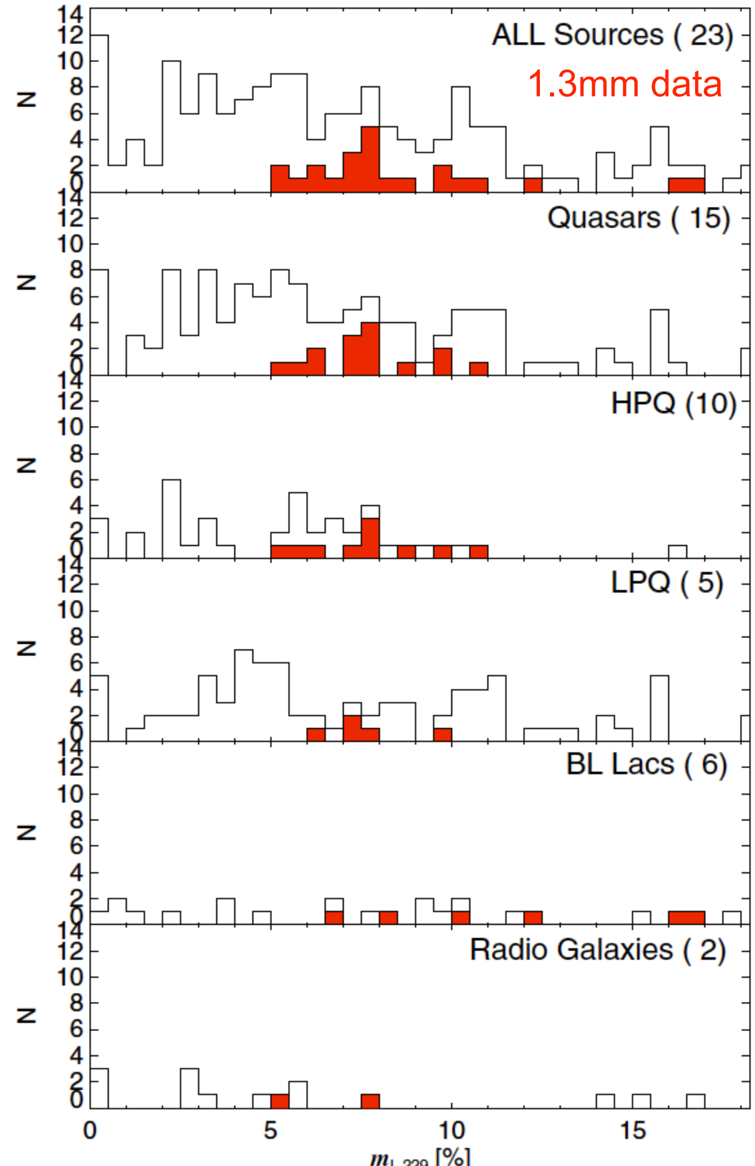


Agudo et al. (2014)

At 3.5mm:

- We detected linear polarization above 3σ levels of m_L~0.96% for 88% of the sample
- BL Lacs, with median(m_L)= 4.6%, are more strongly polarized than quasars, with median(m_L)= 3.2%

Linear polarization degree



Agudo et al. (2014)

At 3.5mm:

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- BL Lacs, with median(m_L)= 4.6%, are more strongly polarized than quasars, with median(m_L)= 3.2%

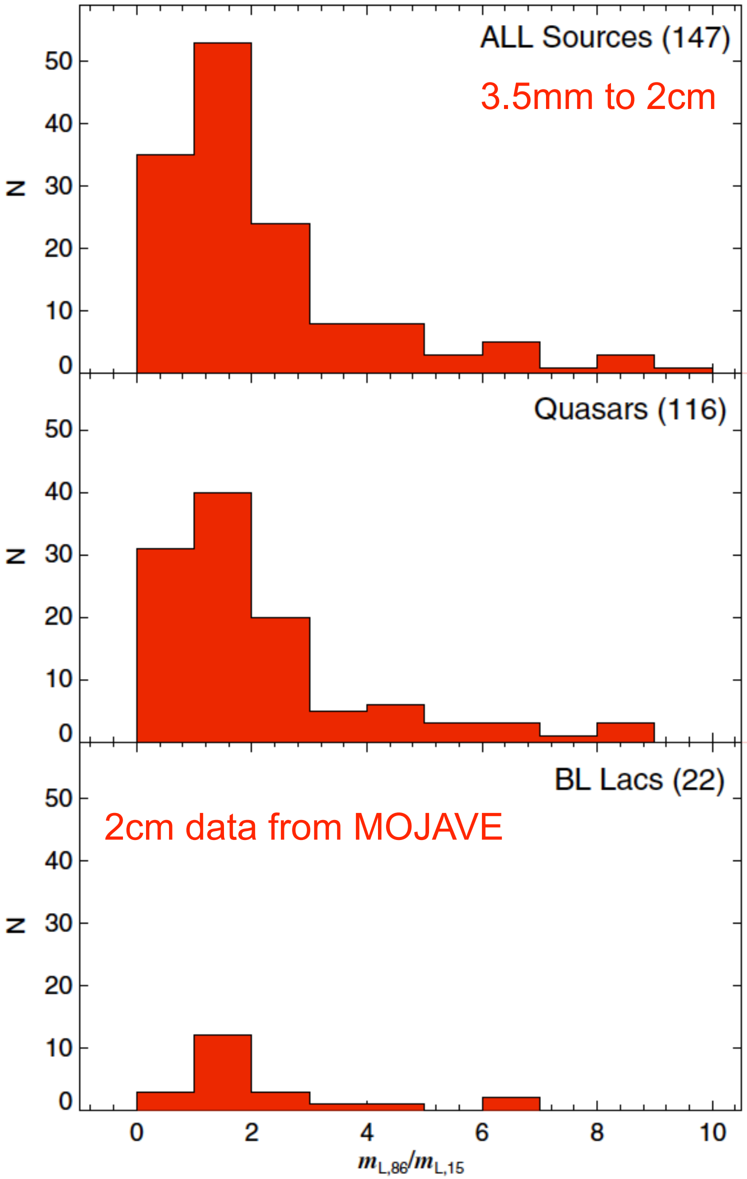
At 1.3mm:

- We detected linear polarization above 3σ levels of m_L~6.0% for 13% of the sample (23 sources)
- BL Lacs, with median(m_L)= 12.0%, are more strongly polarized than quasars, with median(m_L)= 7.7%

Increase of linear polarization degree with ν_{obs}

- Significantly larger fractional linear polarization at 3mm than at 2cm by median factors ~1.6

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



Agudo et al. (2014)

Increase of linear polarization degree with ν_{obs}

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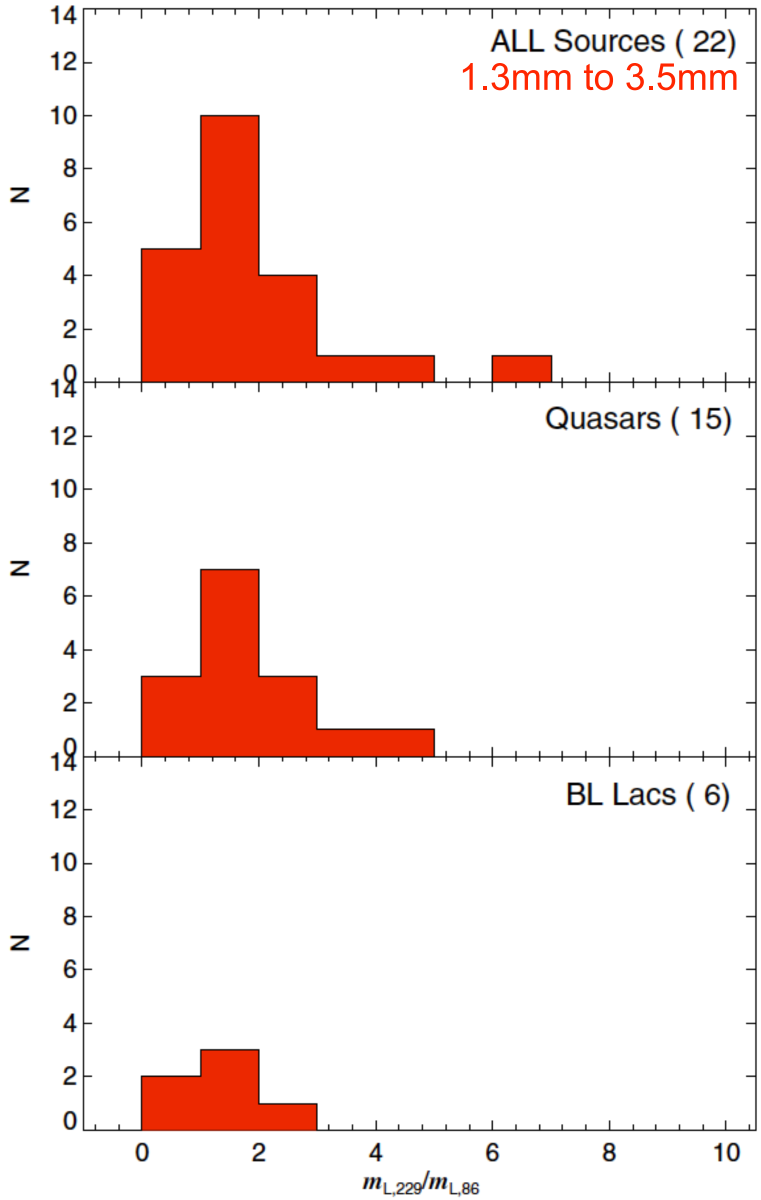
- 18% of sources with $m_{L,86}/m_{L,15} > 4$

- Same for comparison of 3.5mm and 1.3mm with 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}

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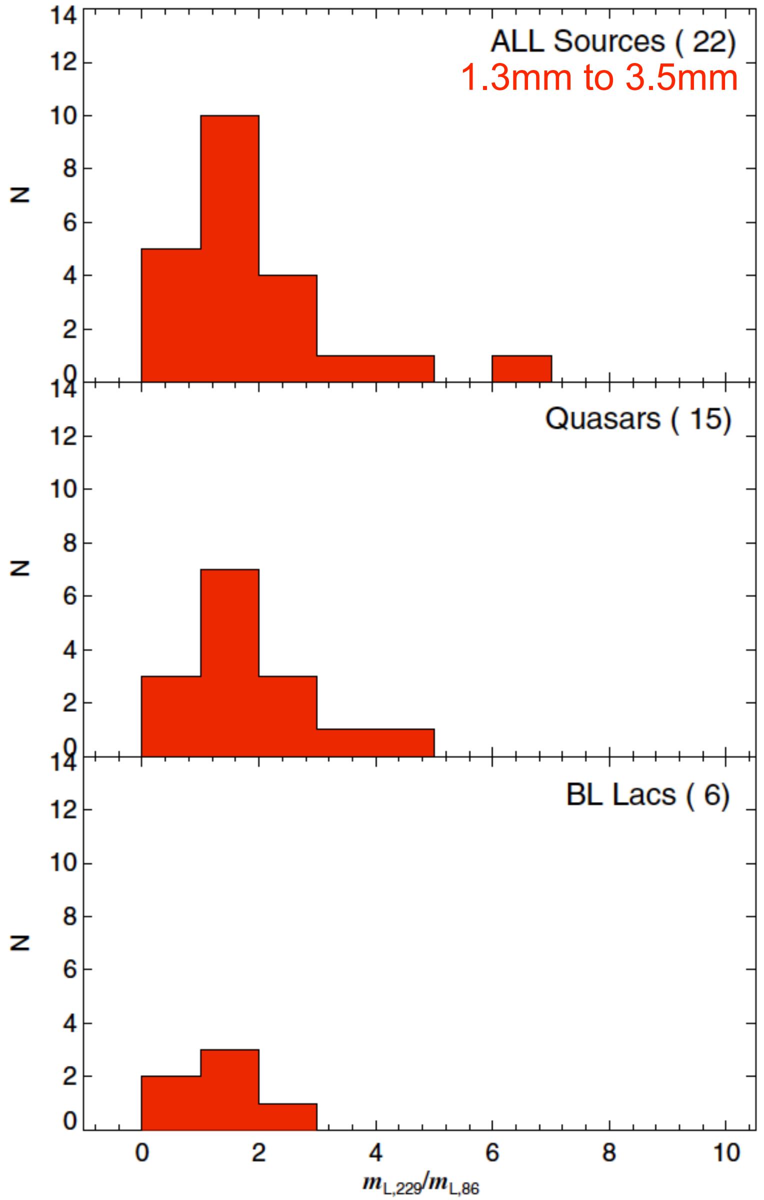
- 18% of sources with $m_{L,86}/m_{L,15} > 4$

- Same for comparison of 3.5mm and 1.3mm with median factors ~1.7

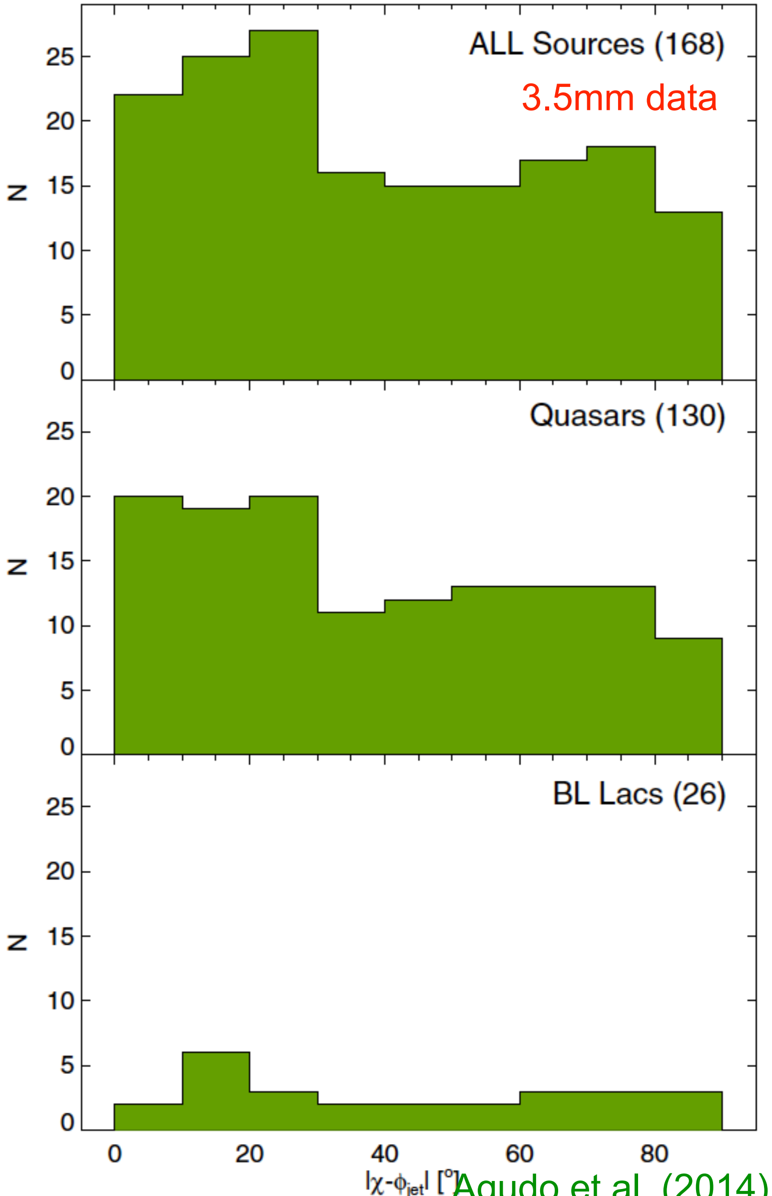
- 9% of sources with $m_{L,229}/m_{L,86} > 4$

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



Agudo et al. (2014)

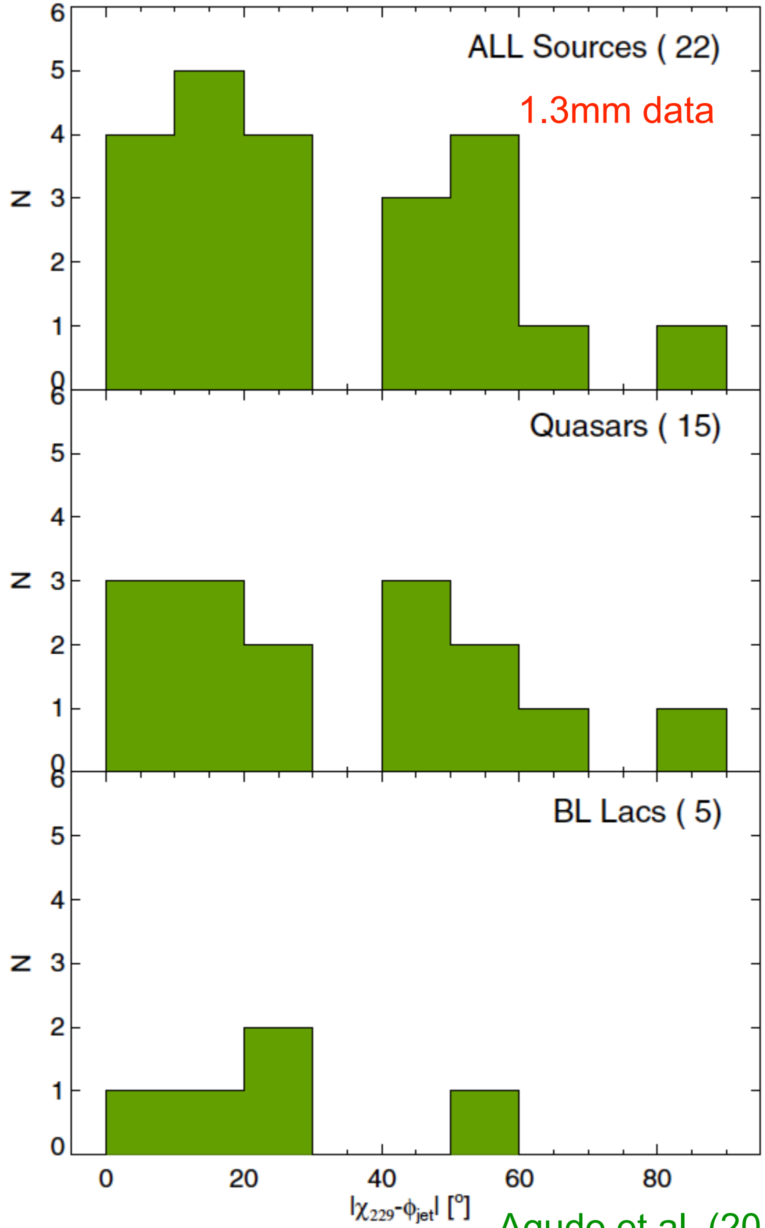
Linear polarization angle behavior



Agudo et al. (2014)

- At 3.5mm, 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)

Linear polarization angle behavior



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- At 3.5mm, weak trend to align χ almost parallel to the jet axis (for ~17% of sources)
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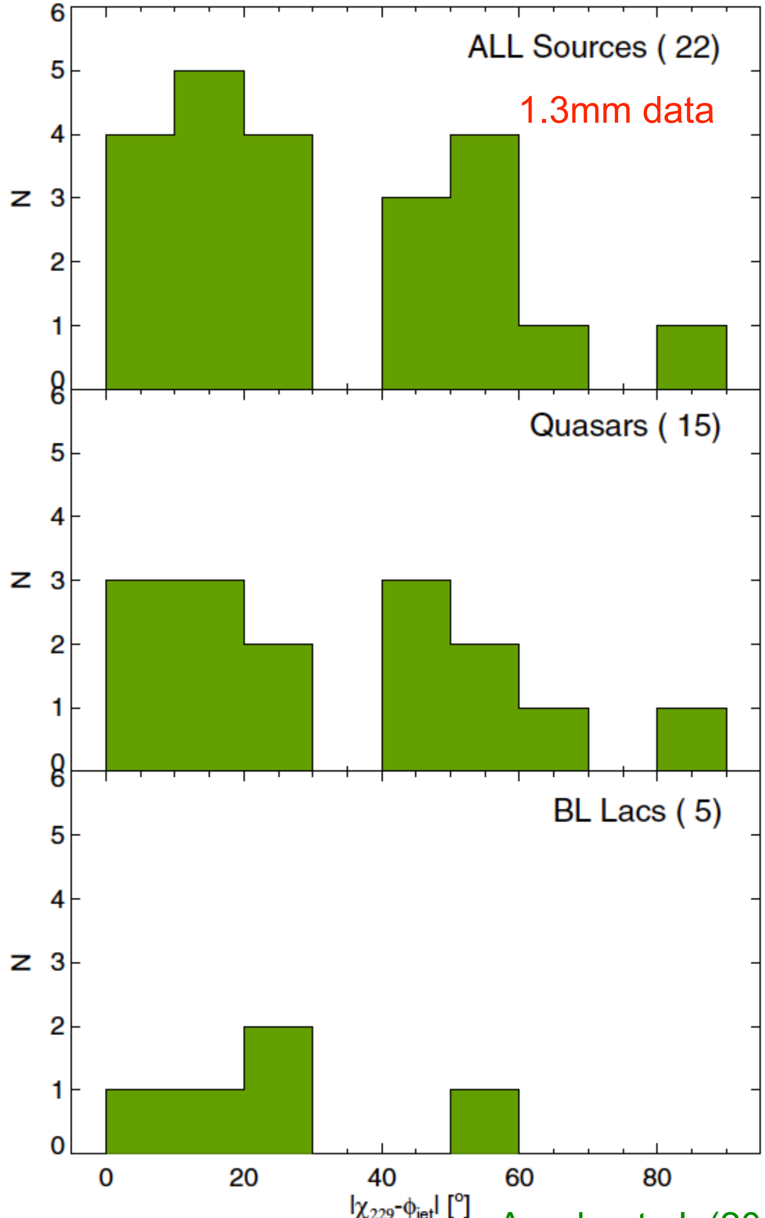
- Similar results for 1.3mm data

Linear polarization angle behavior



Agudo et al. (2014)

- At 3.5mm, 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)
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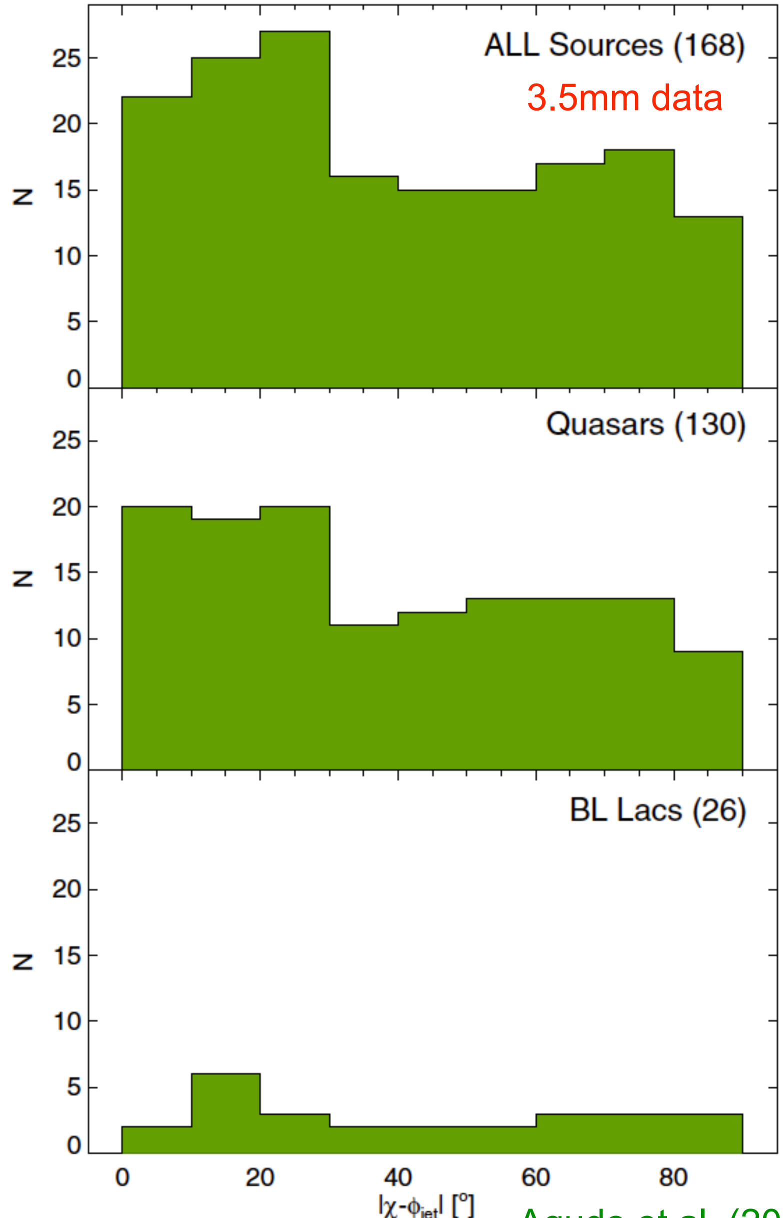

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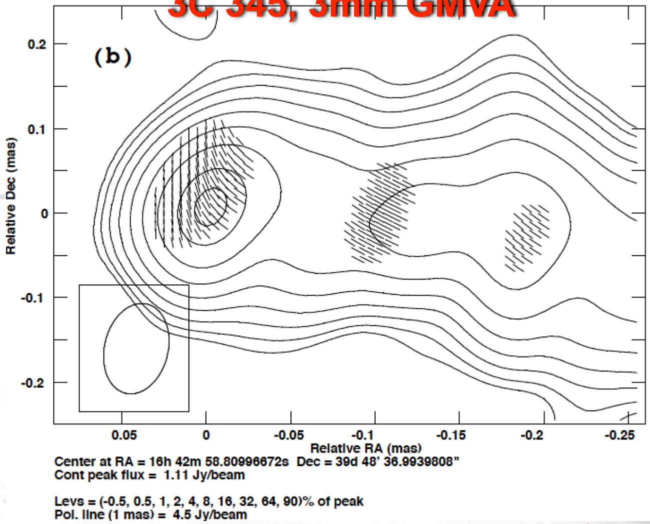
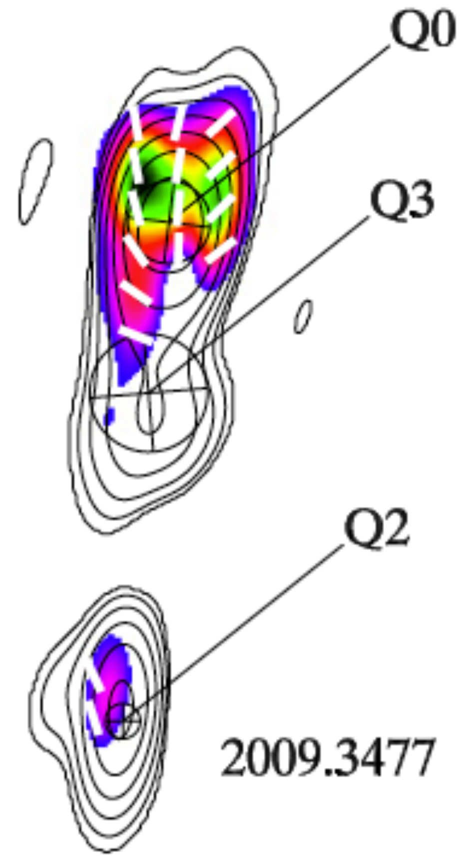
Linear polarization angle to jet position angle misalignment

3C 345, 3mm GMVA

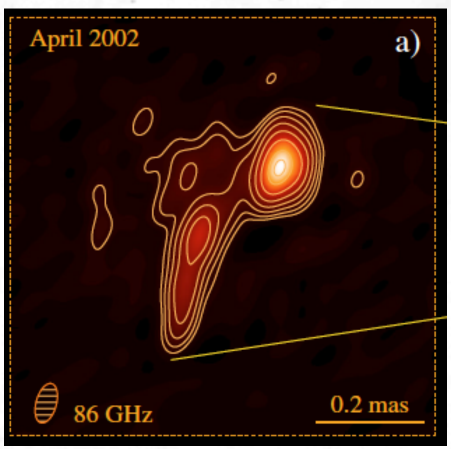


Martí-Vidal et al. (2012)



Molina et al. (2014)

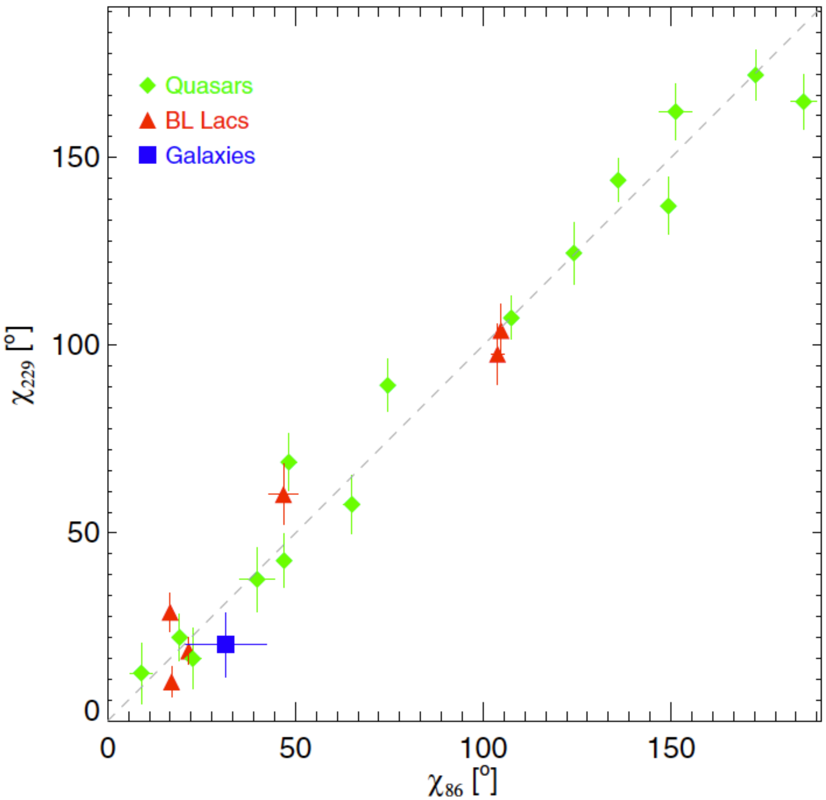
NRAO 150, 3mm GMVA



Agudo et al. (2007)

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

Faraday rotation



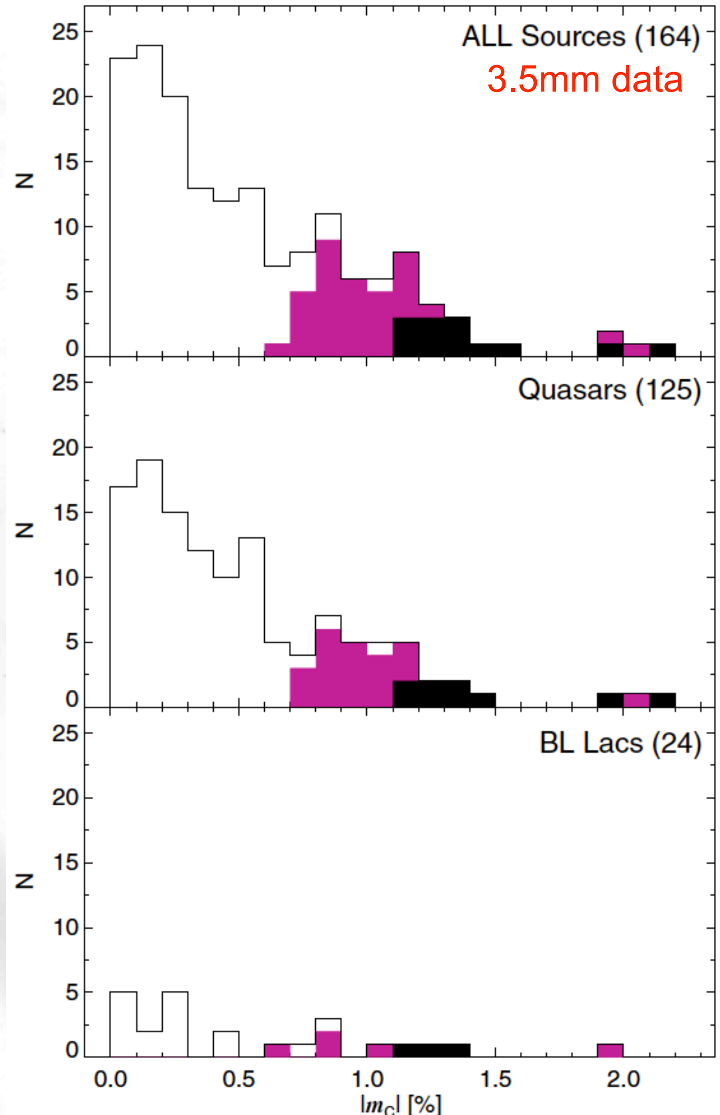
Agudo et al. (2014)

- 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).
- The record has just been established last week on PKS 1830−211 through ALMA measuremetns at 3.5, 1.3 & 0.8 mm, time variable RM=(2.53±0.08)x10^7 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 maxima of up to ~2%!

- No m_C detected at 1.3mm (1σ errors ≈ 0.6%)



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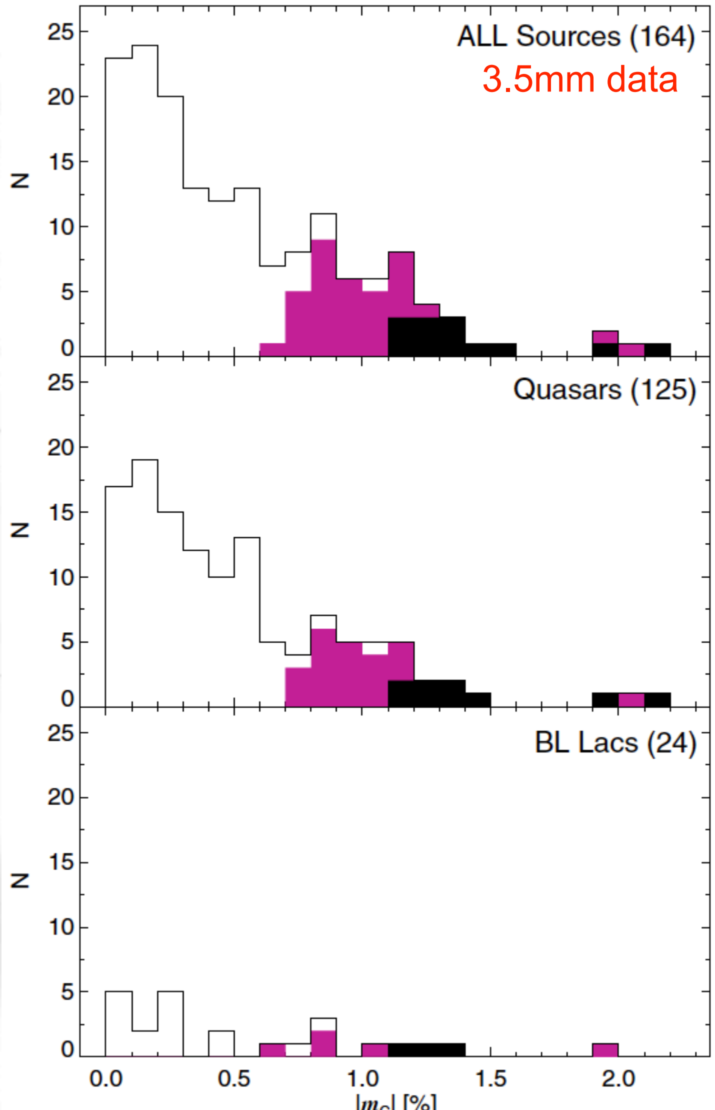

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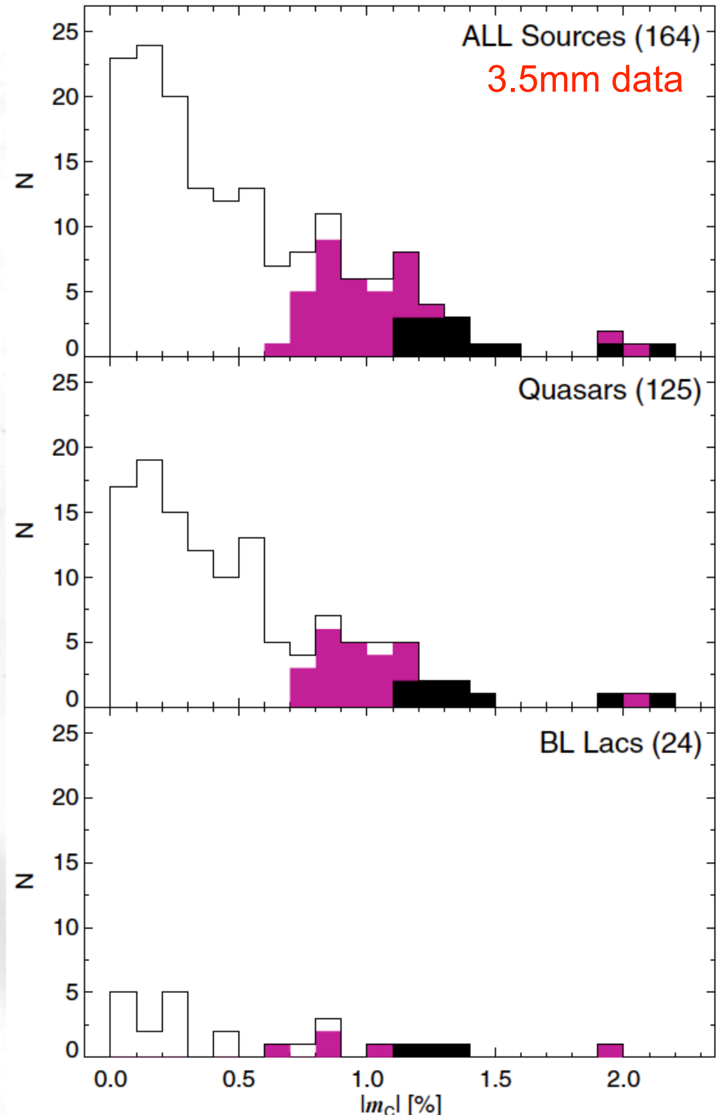
- Only one source (1124−186, $m_{C,86}$=−1.98±0.35%) was also detected in 2005 ($m_{C,86}$=0.58±0.19%).

- We invoke m_C variability to explain strong change, sign reversal, and non detection of more sources on both 2005 and 2010 surveys, (consistent with Aller et al. 2003).



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Circular polarization

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

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

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

Circular polarization variability

Time evolution curves show hints of:

- Time scales of months
- Perhaps also much shorter time scale (~weeks)
- Frequent sign changes

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- 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

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