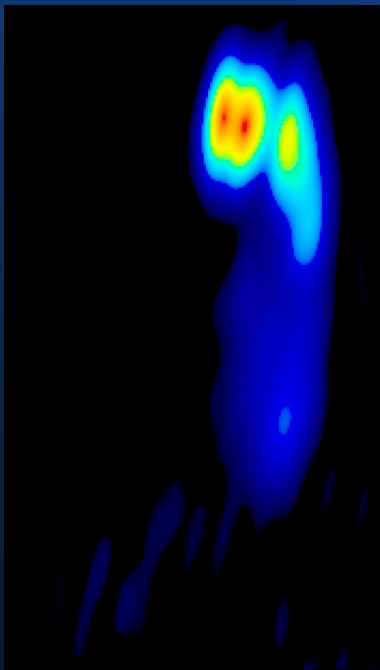


# The Parsec-Scale RM Distribution of Quasars at $z > 3$

Shane O'Sullivan, CSIRO Astronomy and Space Science (CASS)



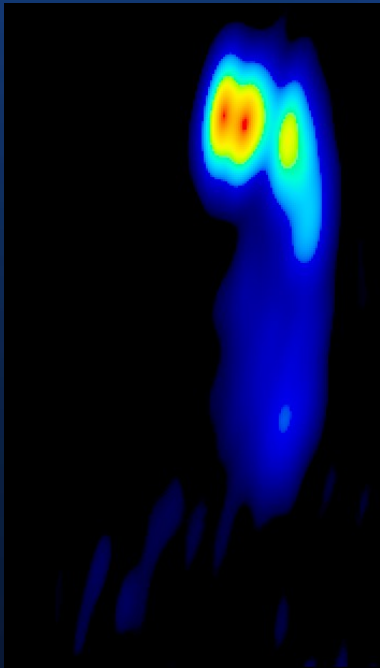
- » Global VLBI Polarization Observations
- » 11 quasars at 5 and 8.4 GHz
- » Benefits of polarization imaging
- » Removal of foreground RM
- » Do quasars or their environment change with cosmic time?
- » Brightness temperature distribution

Collaborators: Denise Gabuzda (UCC), Leonid Gurvits (JIVE), Andrea Reichstein (UCC)

# The Parsec-Scale ~~RM~~ Distribution of Quasars at ~~z~~

something

Shane O'Sullivan, CSIRO Astronomy and Space Science (CASS)



- » Global VLBI Polarization Observations
- » 11 quasars at 5 and 8.4 GHz
- » Benefits of polarization imaging
- » Removal of foreground RM
- » Do quasars or their environment change with cosmic time?
- » Brightness temperature distribution

Collaborators: Denise Gabuzda (UCC), Leonid Gurvits (JIVE), Andrea Reichstein (UCC)

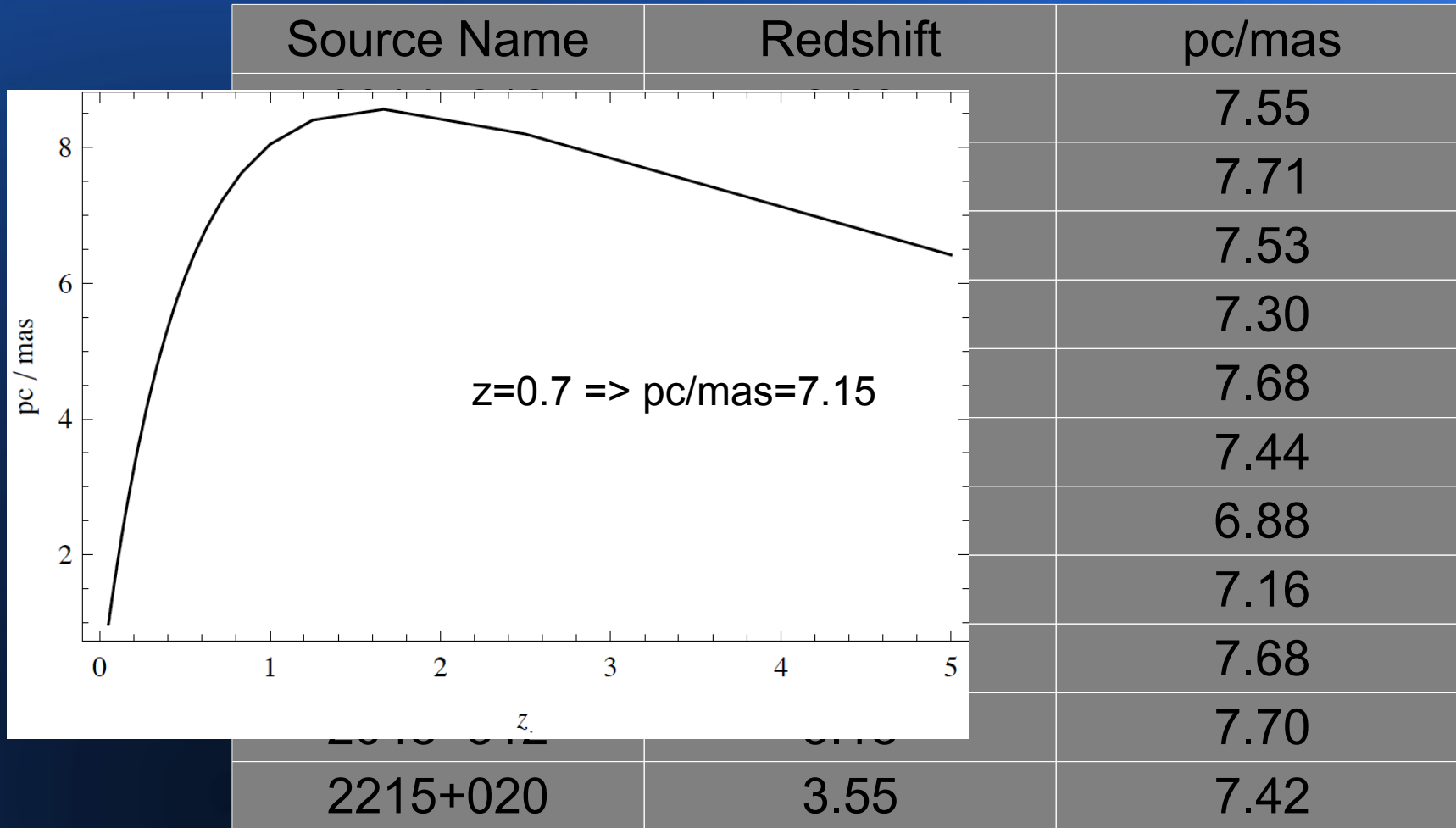
# Global VLBI Observations

- 11 quasars with  $z > 3$  at 5 & 8.4 GHz
- Previously imaged in Stokes I only with VLBI
- All VLBA antennas plus 5 EVN (EB, WB, JB, NT, MC)
- AIPS, Difmap, Visfit (Bezrukovs & Gabuzda)
- Simultaneous VLA obs for 2 hrs during expt

# VLBP Source List

Source Name	Redshift	pc/mas
0014+813	3.38	7.55
0636+680	3.17	7.71
0642+449	3.41	7.53
1351-018	3.71	7.30
1402+044	3.21	7.68
1442+101	3.53	7.44
1508+572	4.30	6.88
1557+032	3.90	7.16
1614+051	3.21	7.68
2048+312	3.18	7.70
2215+020	3.55	7.42

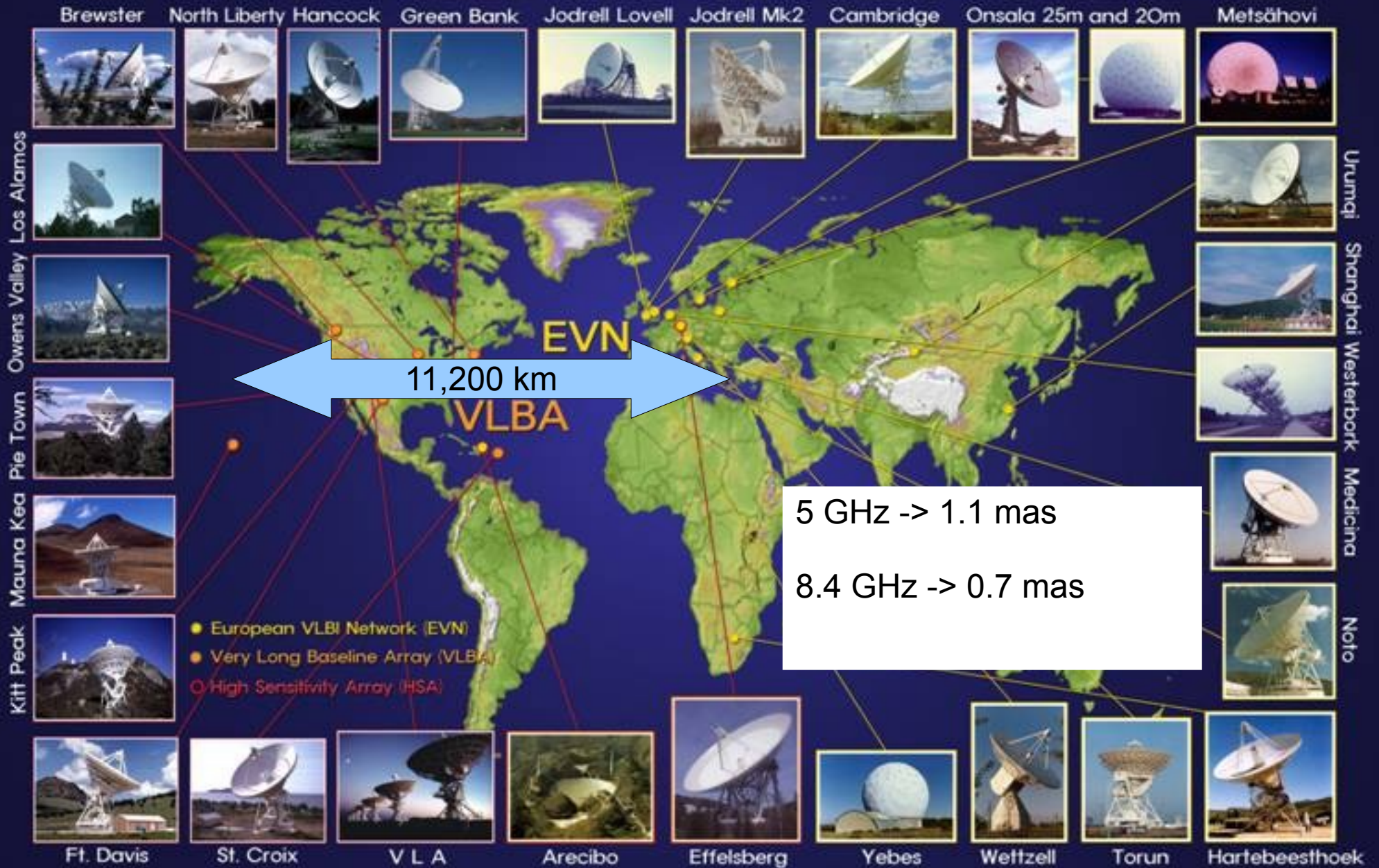
# VLBP Source List



# Global VLBI Observations

- 11 quasars with  $z > 3$  at 5 & 8.4 GHz
- Previously imaged in Stokes I only with VLBI
- All VLBA antennas plus 5 EVN (EB, WB, JB, NT, MC)
- AIPS, Difmap, Visfit (Bezrukovs & Gabuzda)
- Simultaneous VLA obs for 2 hrs during expt

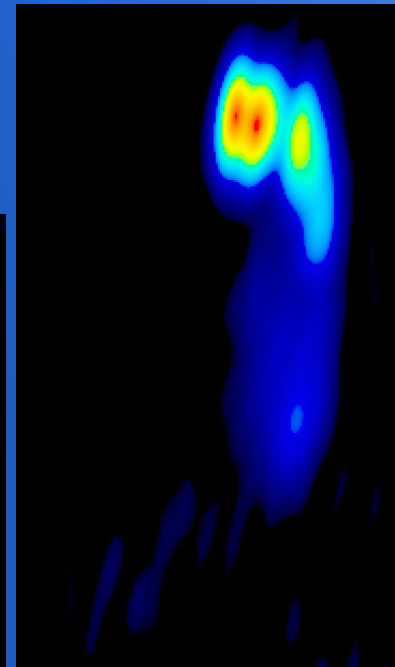
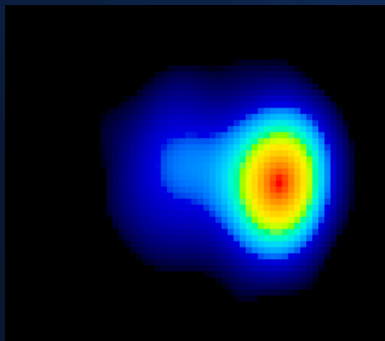
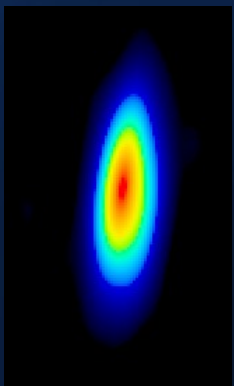
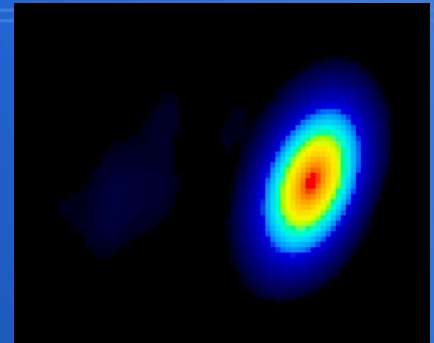
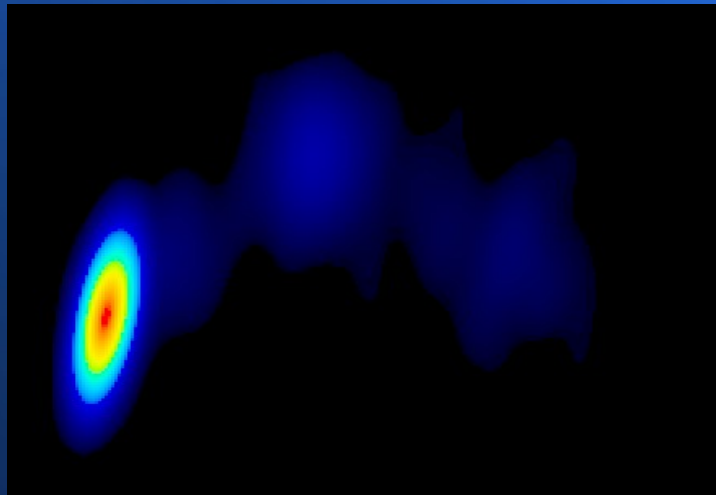
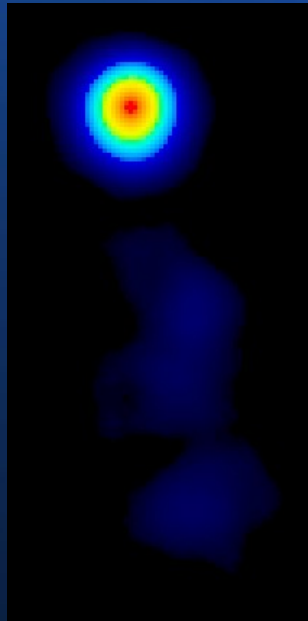
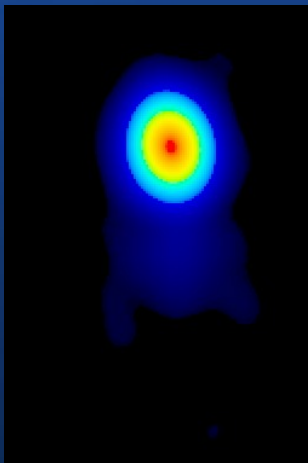
# The Global VLBI – Array



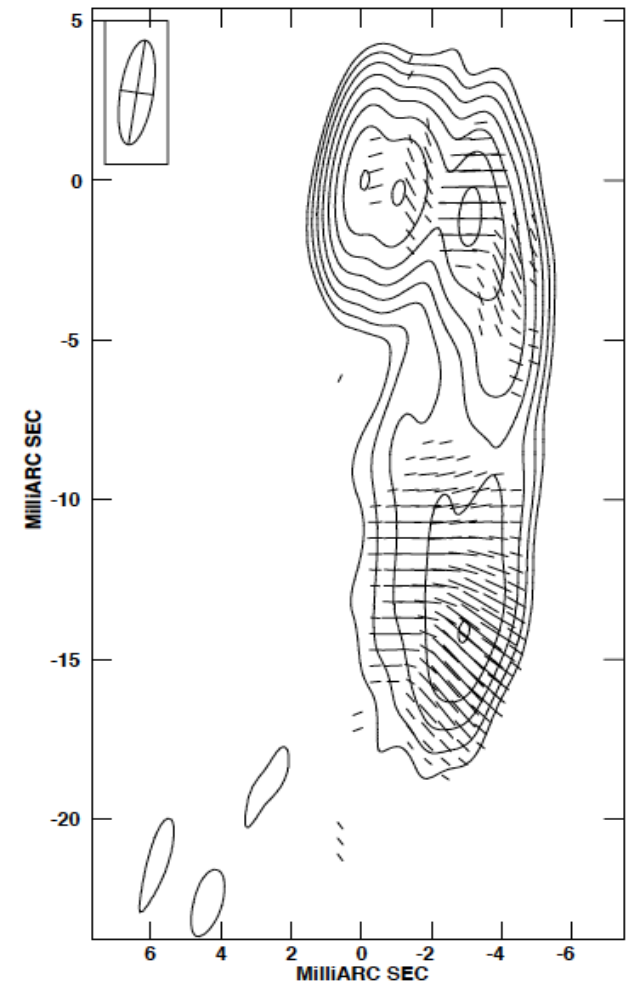
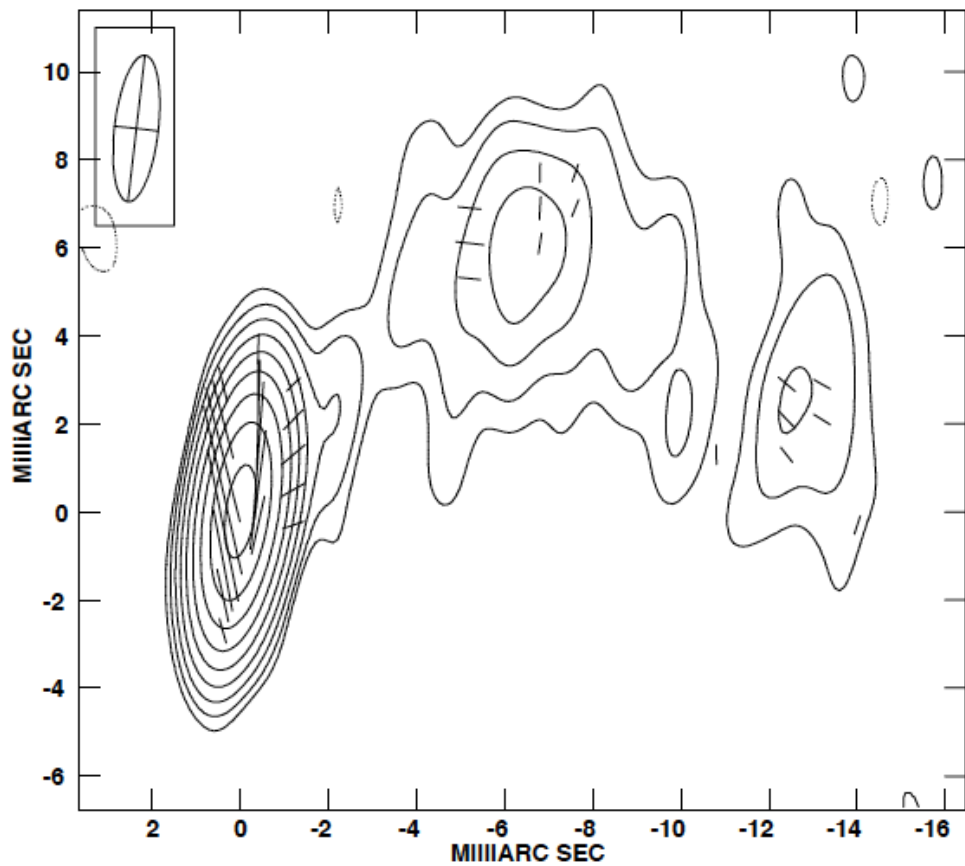
# Global VLBI Observations

- 11 quasars with  $z > 3$  at 5 & 8.4 GHz
- Previously imaged in Stokes I only with VLBI
- All VLBA antennas plus 5 EVN (EB, WB, JB, NT, MC)
- AIPS, Difmap, Visfit (Bezrukovs & Gabuzda)
- Simultaneous VLA obs for 2 hrs during expt

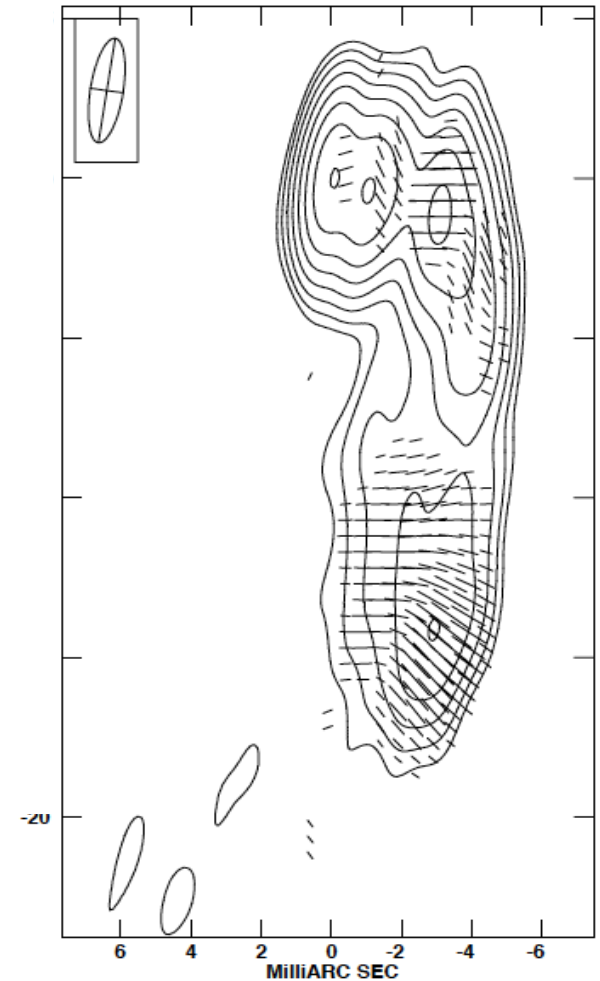
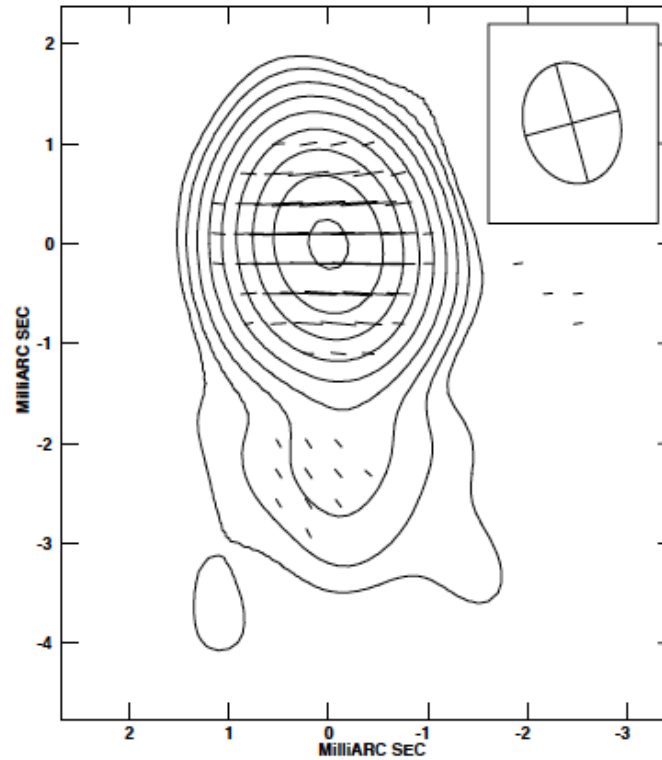
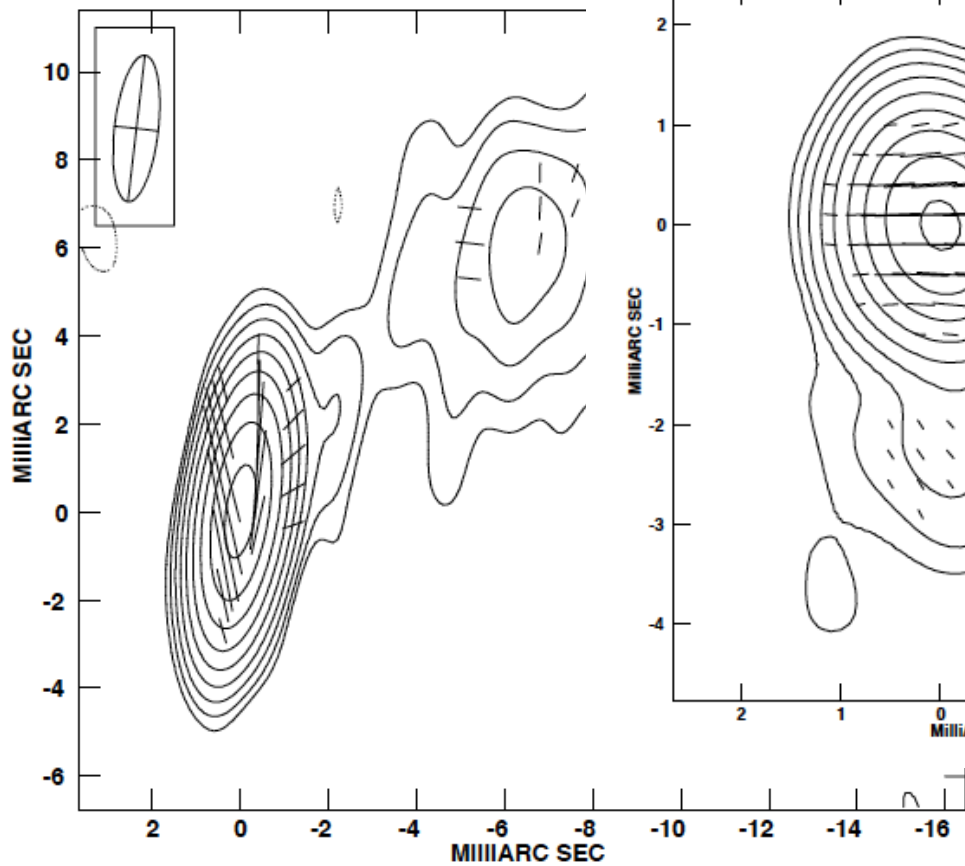
# Total Intensity Images



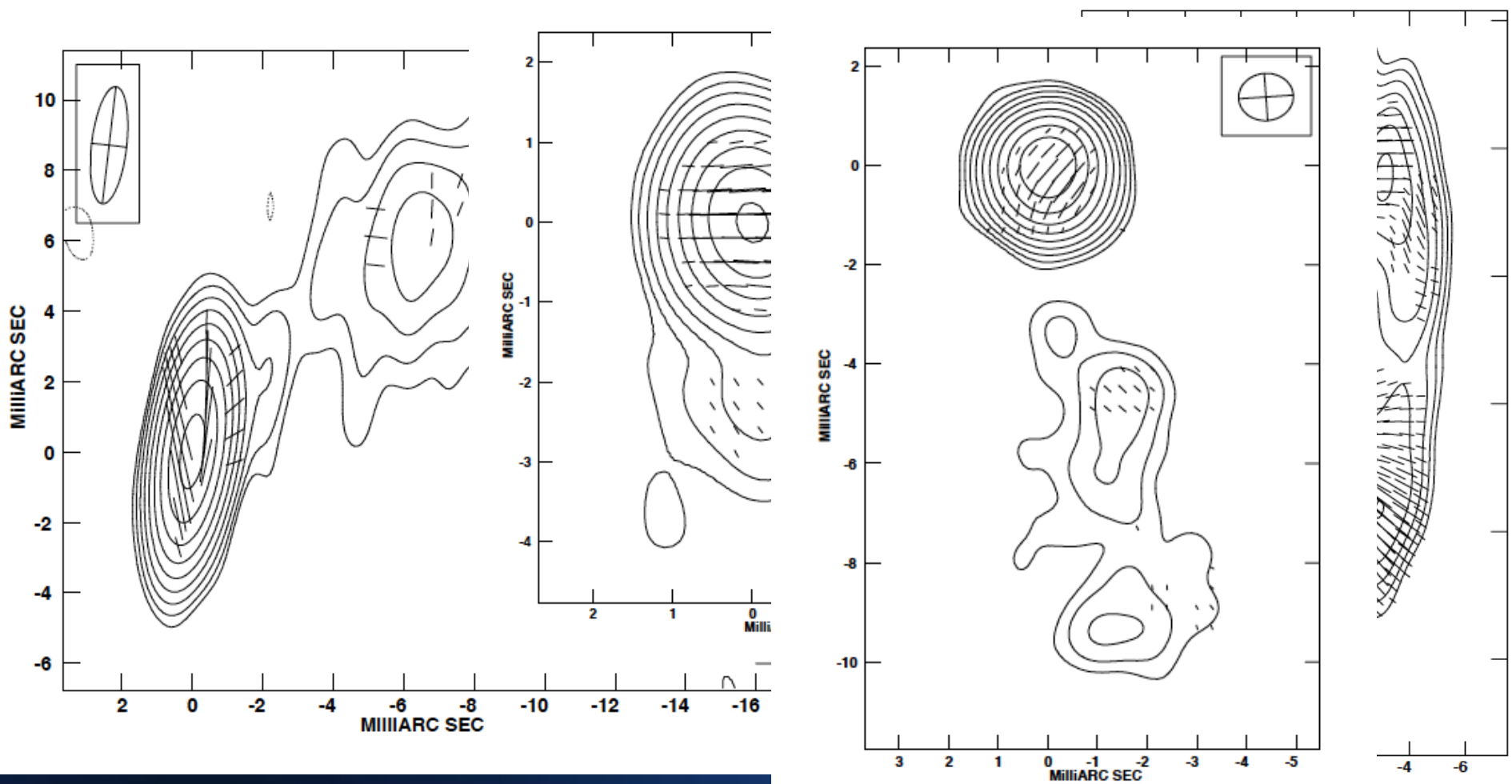
# Rich Polarization Structure



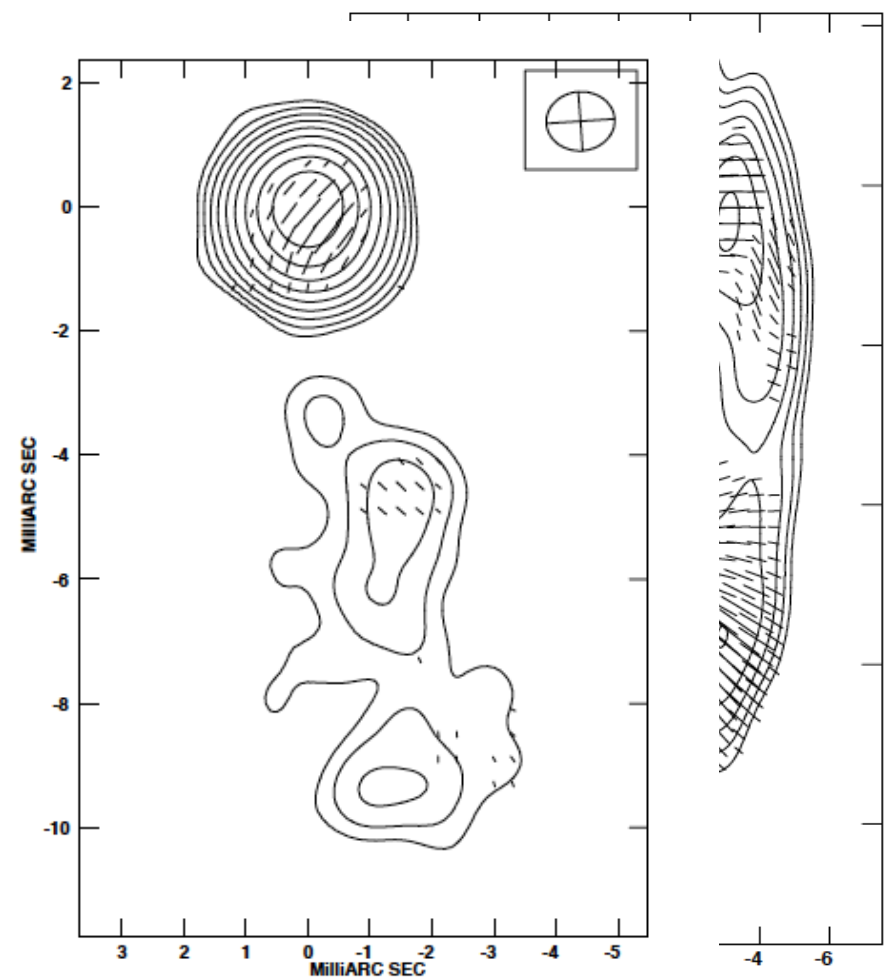
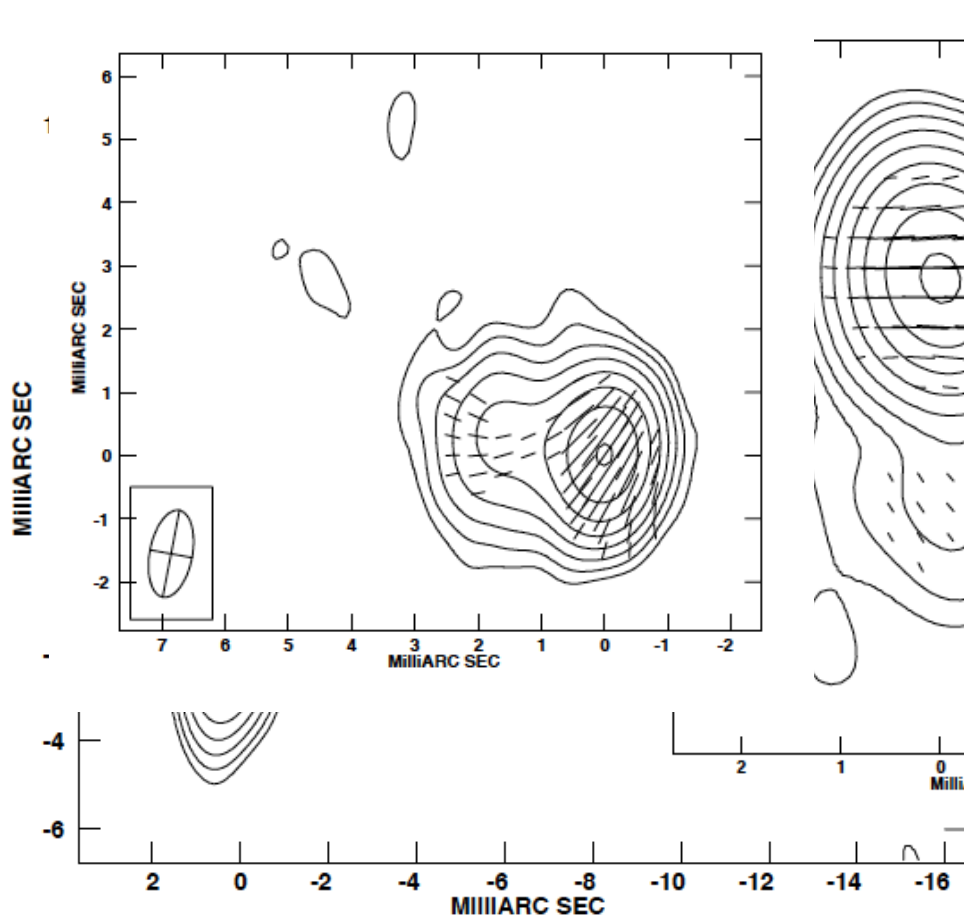
# Rich Polarization Structure



# Rich Polarization Structure



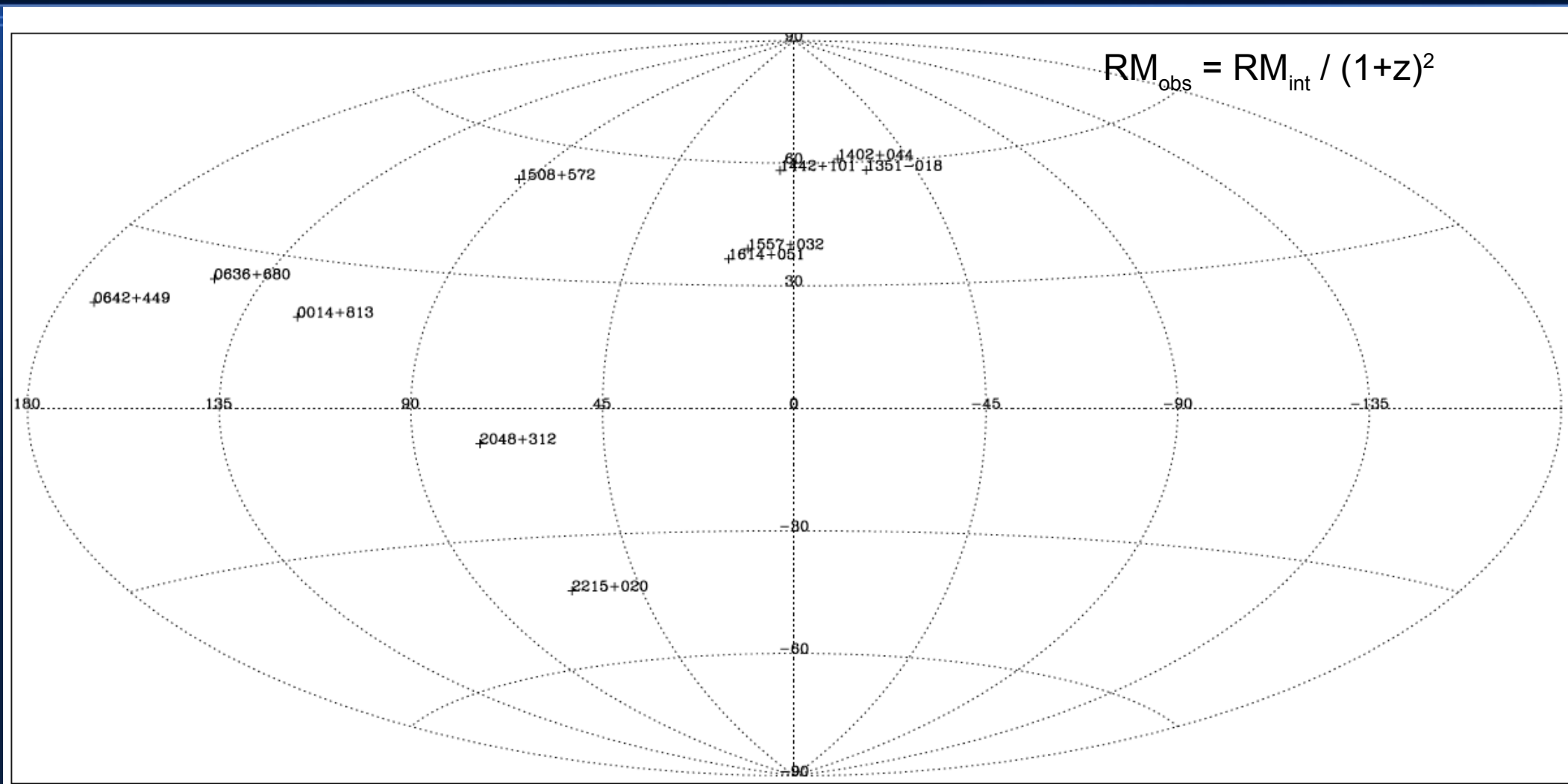
# Rich Polarization Structure



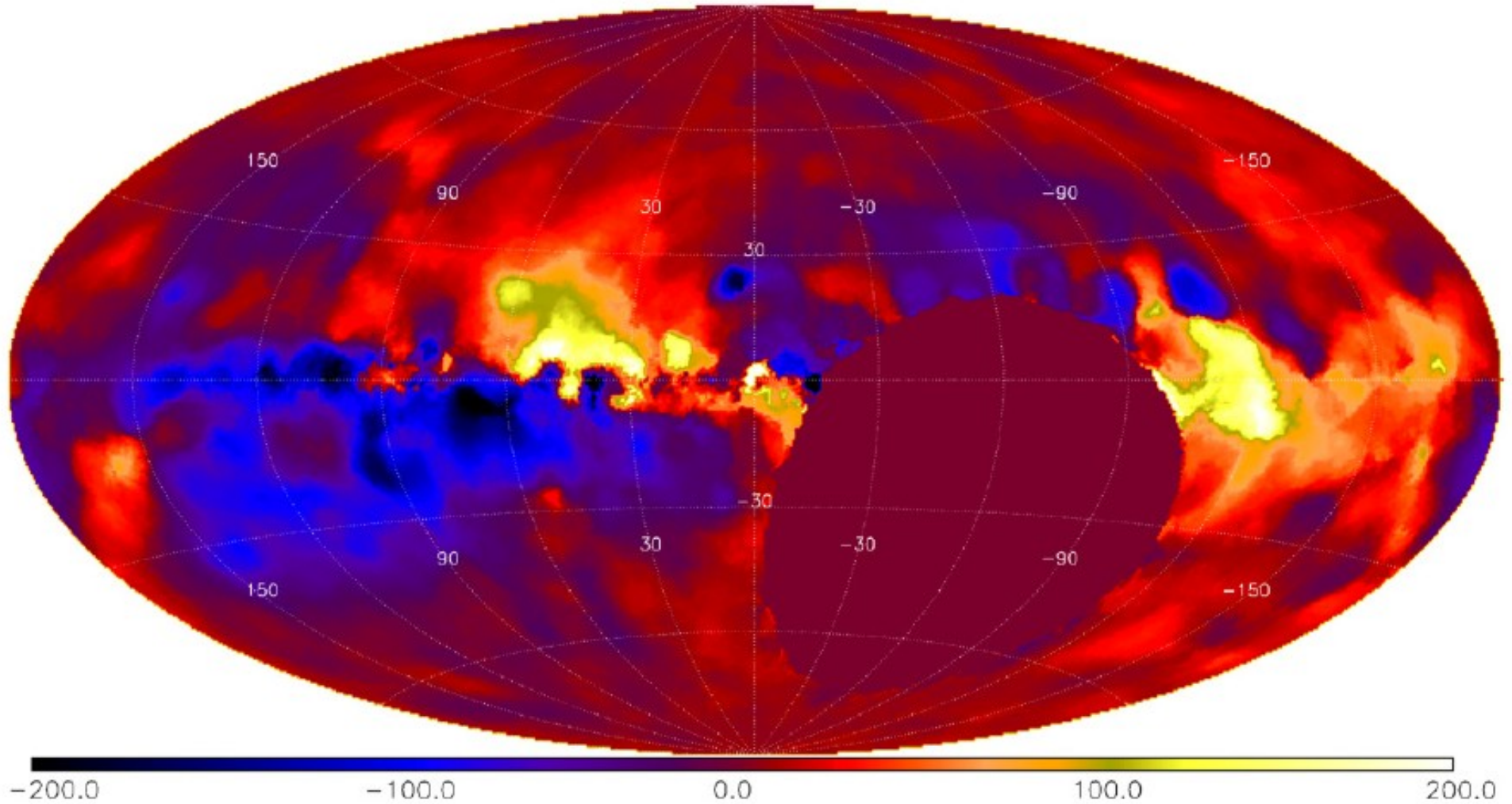
# Core Rotation Measure

- Minimum RM estimated from minimum separation between 5 and 8.4 GHz EVPAs
- Removal of foreground (mainly Galactic) RM using VLA obs of individual sources
- $RM_{int} = RM_{obs} * (1+z)^2$
- Minimum intrinsic core RMs ranging from 500 to 10,000 rad/m<sup>2</sup>

# Source Distribution in Galactic coordinates

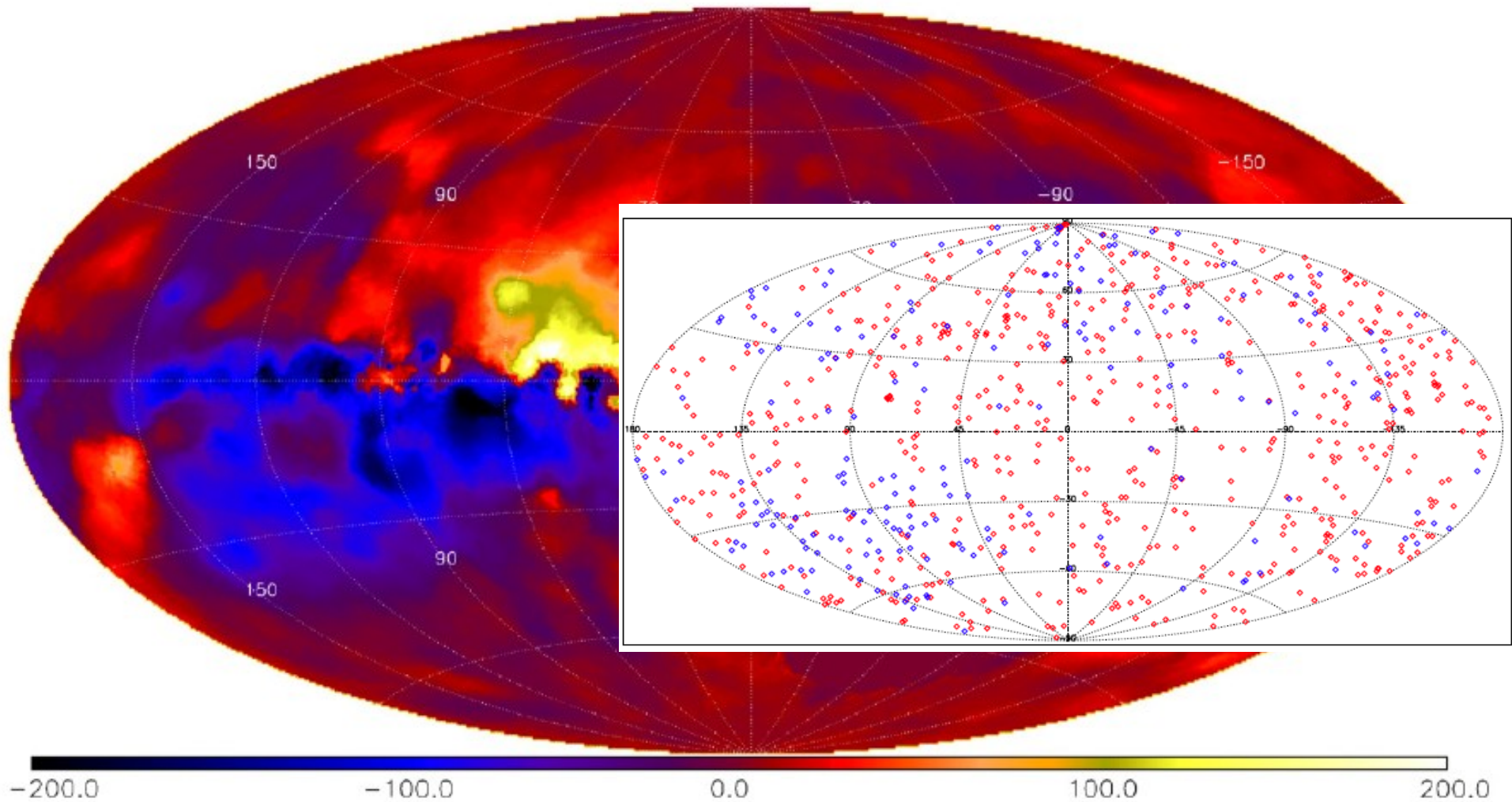


# Rotation Measure Image of the Sky (Taylor et al. 2009)



# Foreground RM values from

Taylor et al. (2009), Oren & Wolfe (1995), Frick et al. (2001),  
Simard-Normandin et al. (1981), Rusk (1988), Rudnick et al. (1983), etc.



# Foreground RM values from

Taylor et al. (2009), Oren & Wolfe (1995), Frick et al. (2001),  
Simard-Normandin et al. (1981), Rusk (1988)

Source Name	Redshift	Foreground RM
0014+813	3.38	9
0636+680	3.17	...
0642+449	3.41	30
1351-018	3.71	-8
1402+044	3.21	...
1442+101	3.53	34
1508+572	4.30	-11
1557+032	3.90	3
1614+051	3.21	8
2048+312	3.18	323
2215+020	3.55	57

# Core Rotation Measure

- Minimum RM estimated from minimum separation between 5 and 8.4 GHz EVPAs
- Removal of foreground (mainly Galactic) RM using VLA obs of individual sources
- $RM_{int} = RM_{obs} * (1+z)^2$
- Minimum intrinsic core RMs ranging from 500 to 10,000 rad/m<sup>2</sup>

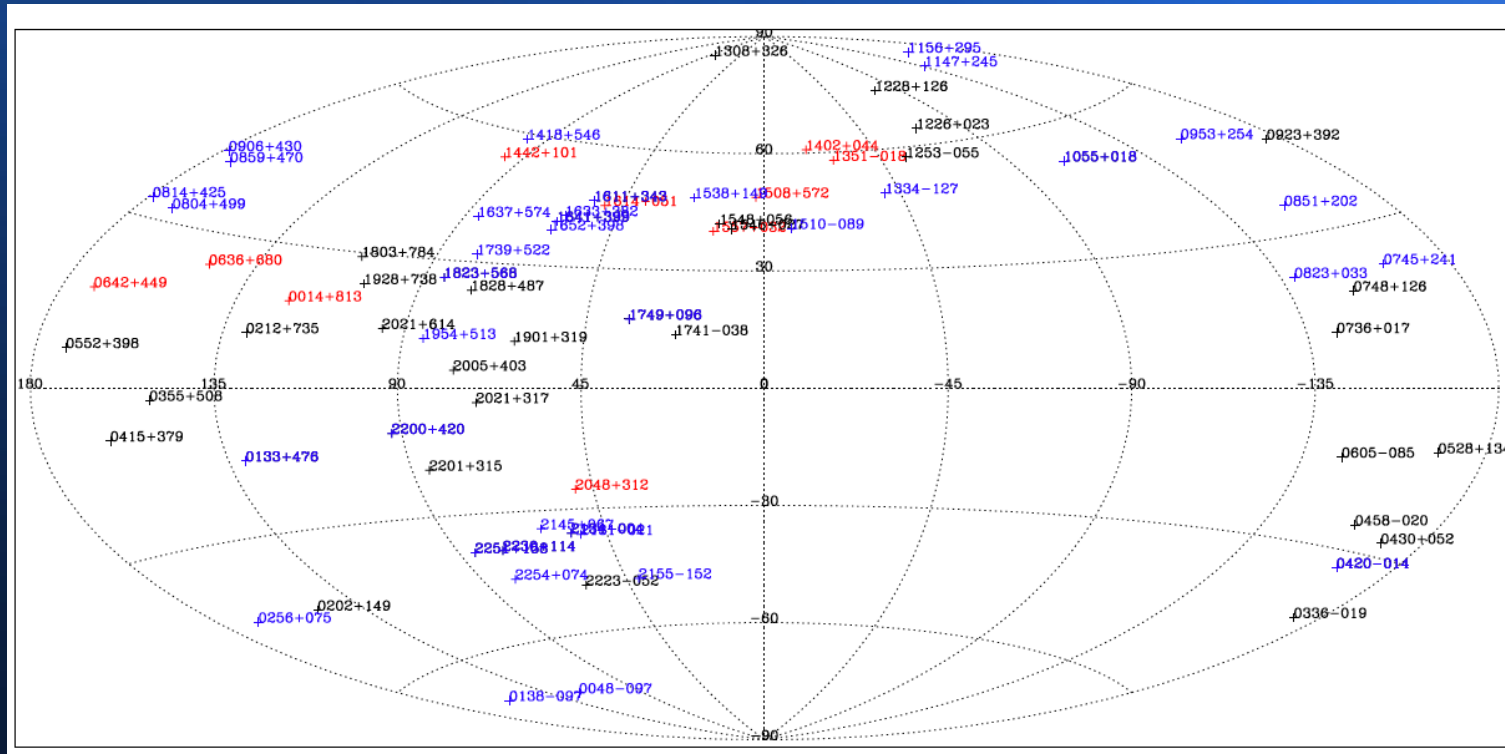
# Intrinsic Core RMs

Source Name	Redshift	Foreground RM	Intrinsic RM
0014+813	3.38	9	7194
0636+680	3.17	...	...
0642+449	3.41	30	- 545
1351-018	3.71	-8	4592
1402+044	3.21	...	-3527
1442+101	3.53	34	-12067
1508+572	4.30	-11	- 2247
1557+032	3.90	3	1561
1614+051	3.21	8	9110
2048+312	3.18	323	- 6238
2215+020	3.55	57	- 683

# Comparison of RM v redshift

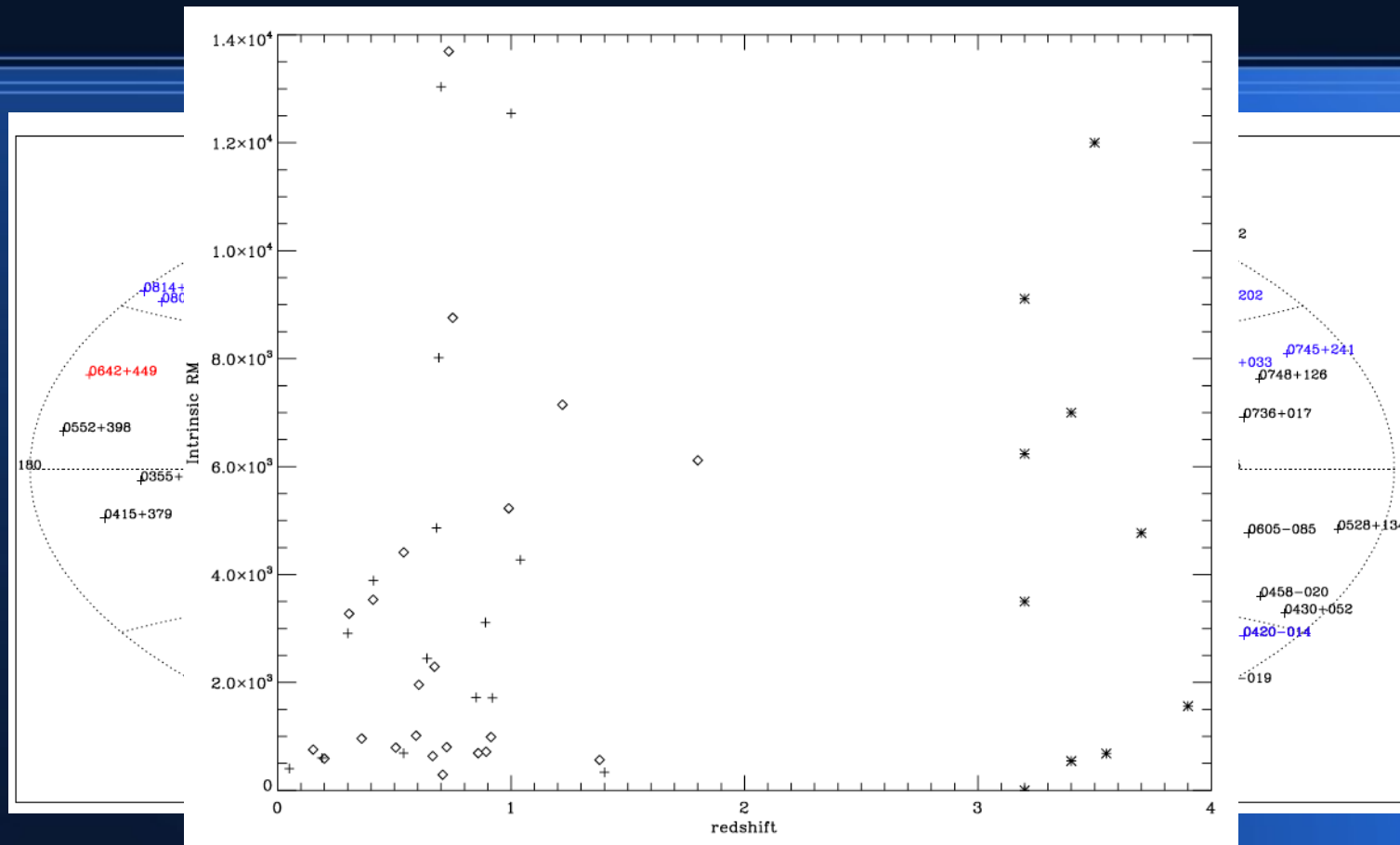
- Dealing with emitted frequencies ranging from 20 – 45 GHz at 5 – 8.4 GHz VLBI resolution
- Comparison with low  $z$  sources
  - $z=0.7$  with VLBA at 15 GHz
  - emitted freq = 25 GHz, resolution  $\sim 0.5$  mas
- Not many 15 – 43 GHz RMs for EGS

# Comparison of RM v redshift



- Gabuzda et al. (2006), Algaba et al. (in prep), Zavala & Taylor (2004) => 75 AGN

# Comparison of RM v redshift



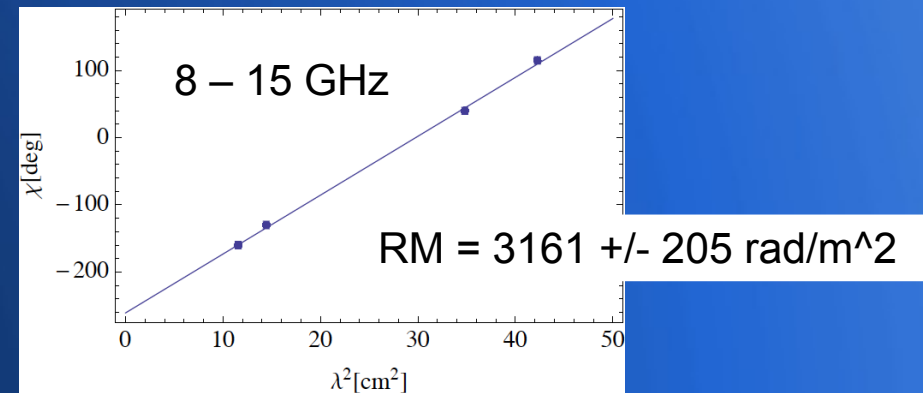
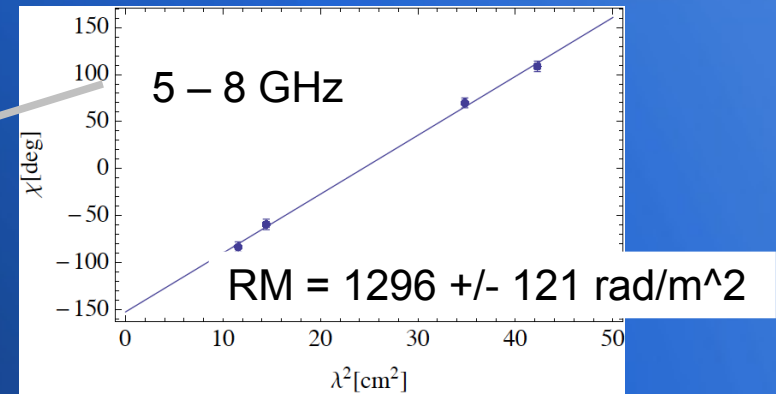
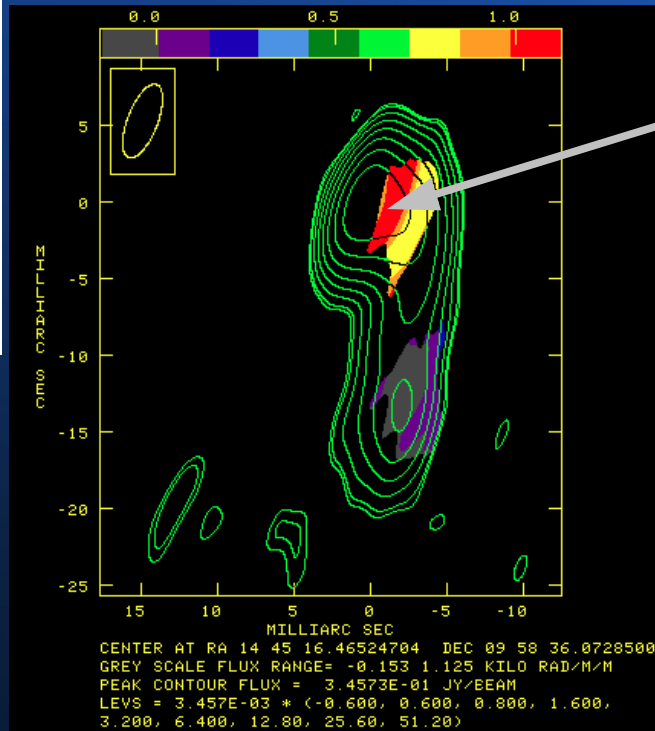
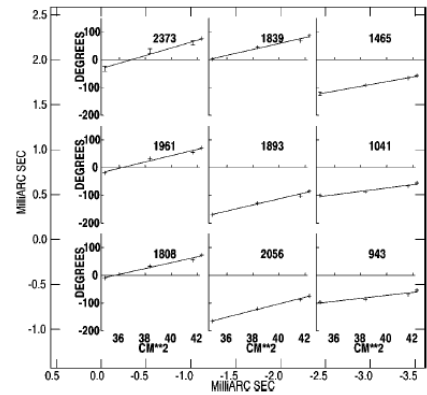
- Gabuzda et al. (2006), Algaba et al. (in prep), Zavala & Taylor (2004) => 75 AGN

# 1442+101 RM

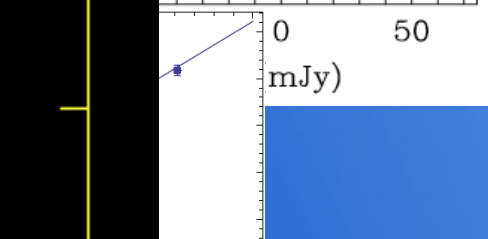
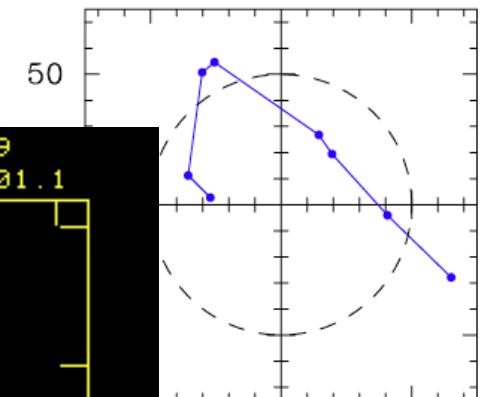
- Focus on source with highest intrinsic RM
- Udomprasert et al. (1997): VLBA observations at 4 frequencies around 5 GHz  
RM<sub>int</sub> ~ 40,000 rad/m<sup>2</sup>
- 4 times RM<sub>min</sub> from Global VLBI obs
- Follow up VLBA 5 – 15 GHz observations
- RM<sub>int</sub> ~ 60,000 rad/m<sup>2</sup> from 8 – 15 GHz

# 1442+101 RM

Udomprasert, Taylor et al. 1997



- Follow up obs required for other sources to see if true  $RM \gg RM_{min}$



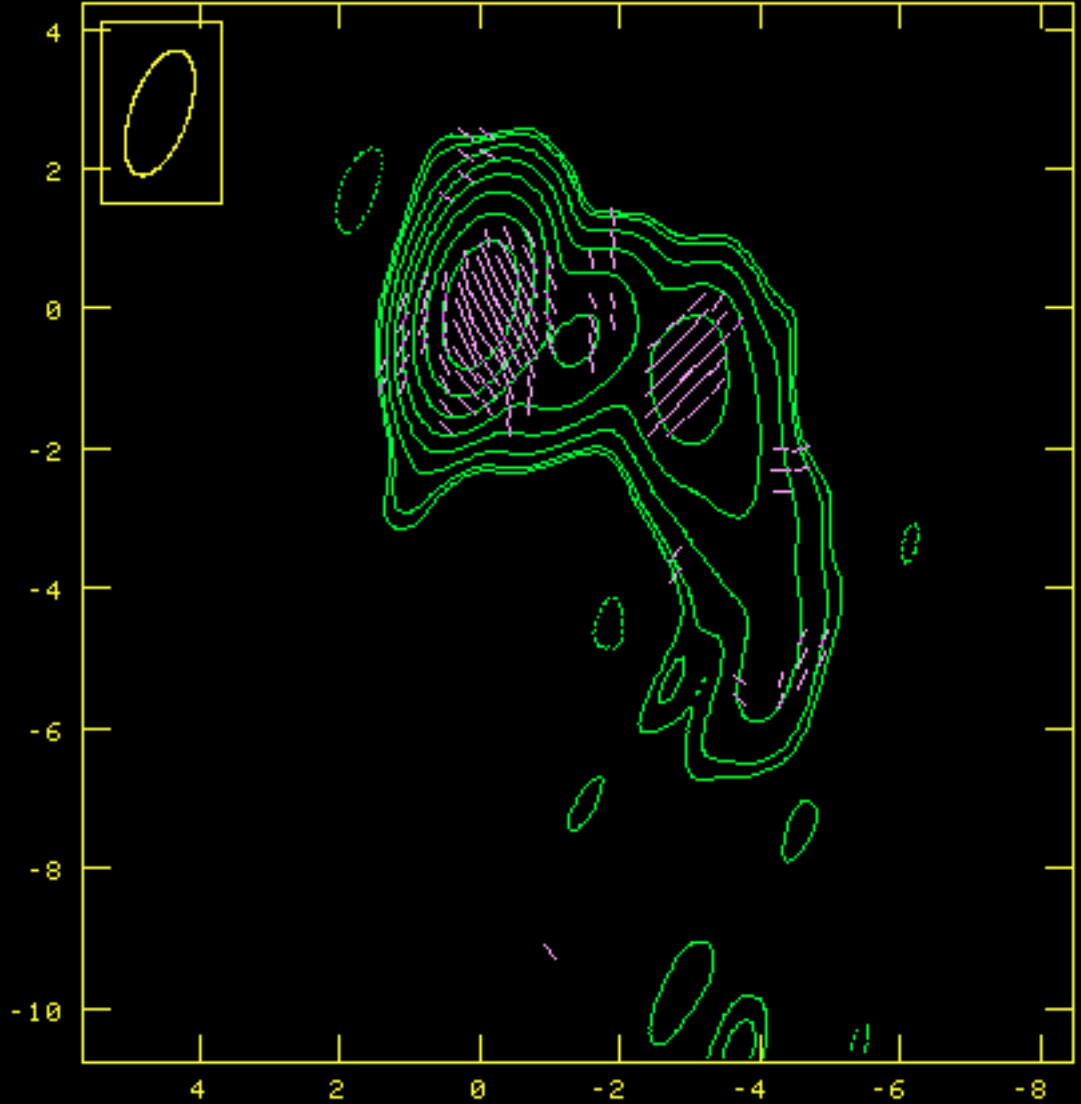
121 rad/m<sup>2</sup>



+/- 205 rad/m<sup>2</sup>

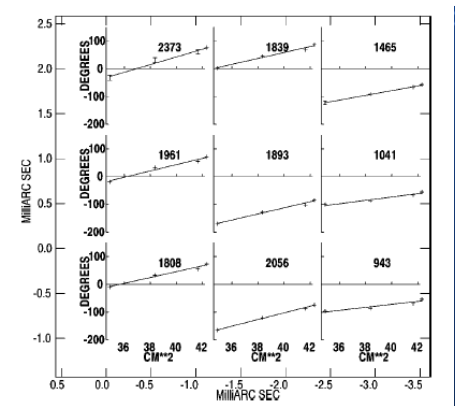
s to

PLOT FILE VERSION 0 CREATED 13-MAY-2010 13:38:09  
 1442+101 IPOL 12938.959 MHZ 1442+101 F4E.ICL001.1



CENTER AT RA 14 45 16.46524704 DEC 09 58 36.0728500  
 PEAK CONTOUR FLUX = 2.0644E-01 JY/BEAM  
 LEVS = 2.064E-03 \* (-0.600, 0.600, 0.800, 1.600,  
 3.200, 6.400, 12.80, 25.60, 51.20)

Udomprasert, Taylor et al

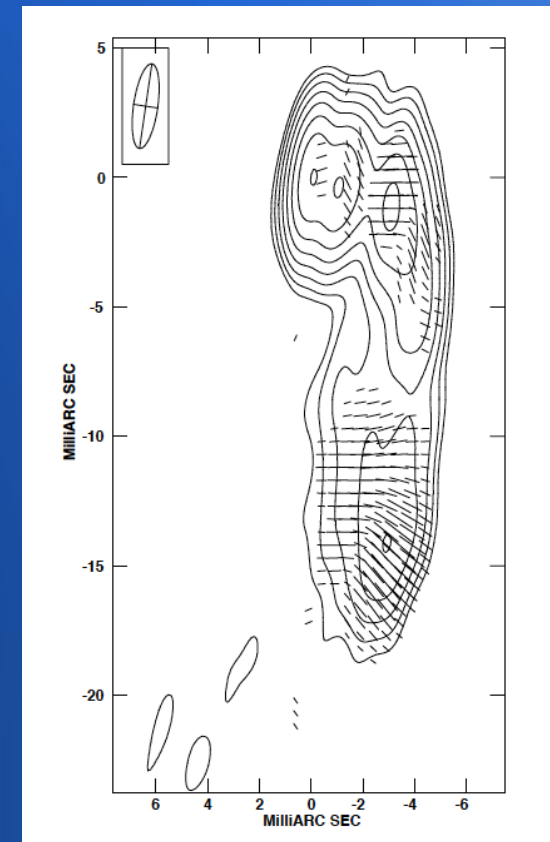
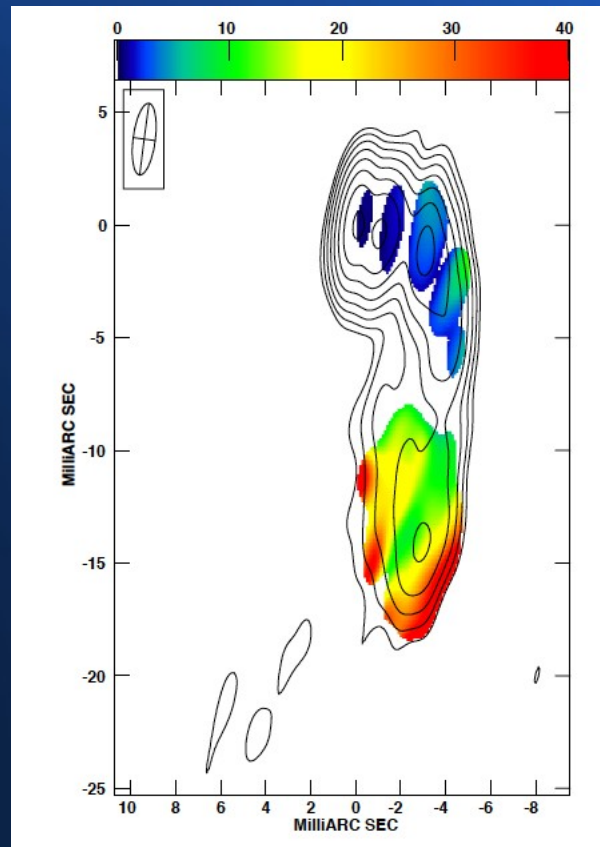
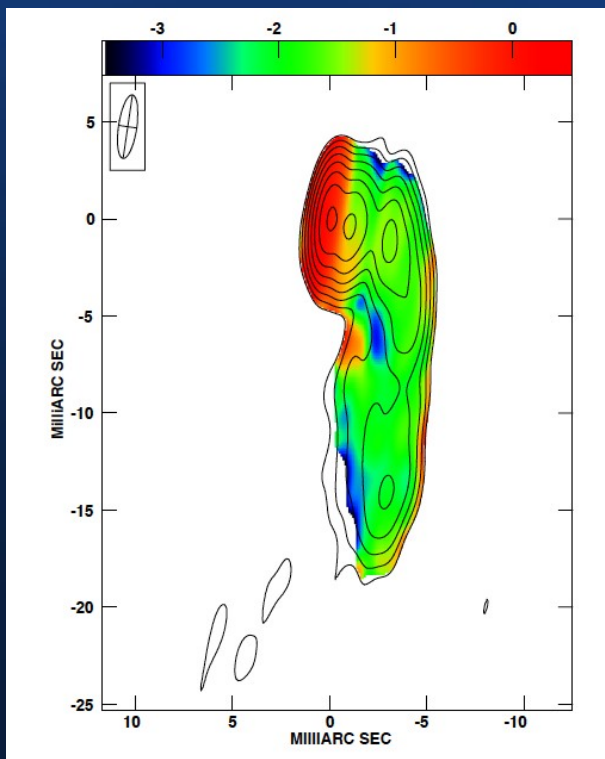


MILLIARC SEC

Follow  
 see if tr

# 1442+101 Environment

- Other indicators of a dense environment?

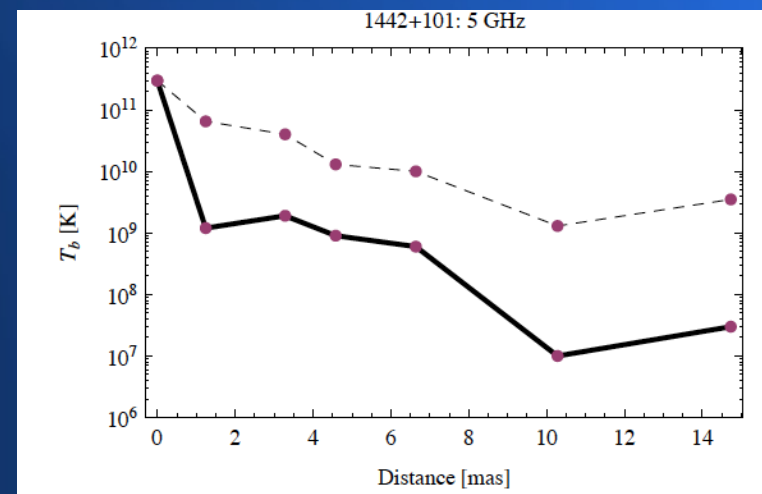


# 1442+101 Environment

- Energy losses not consistent with purely adiabatic expansion
- This may lend support to the idea of a dense medium confining the jet of 1442

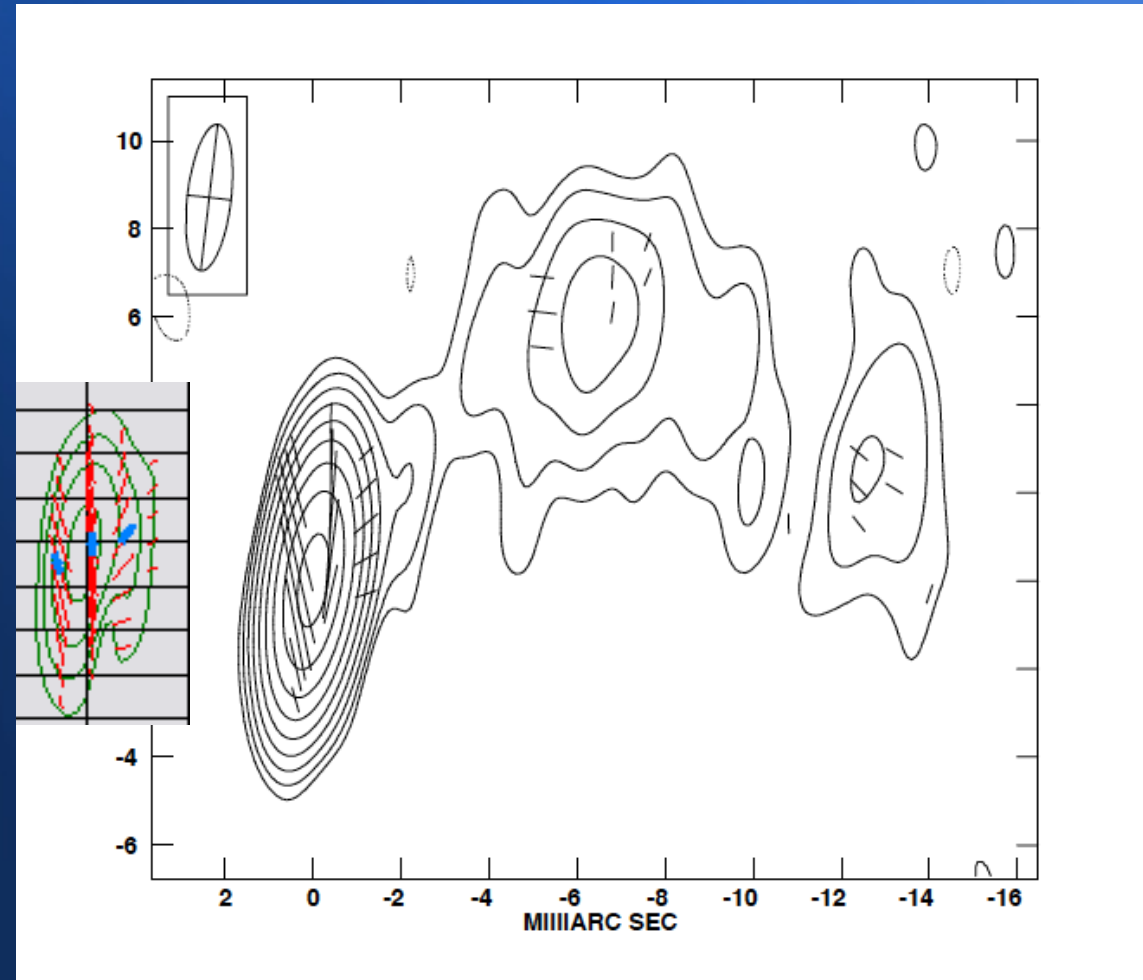
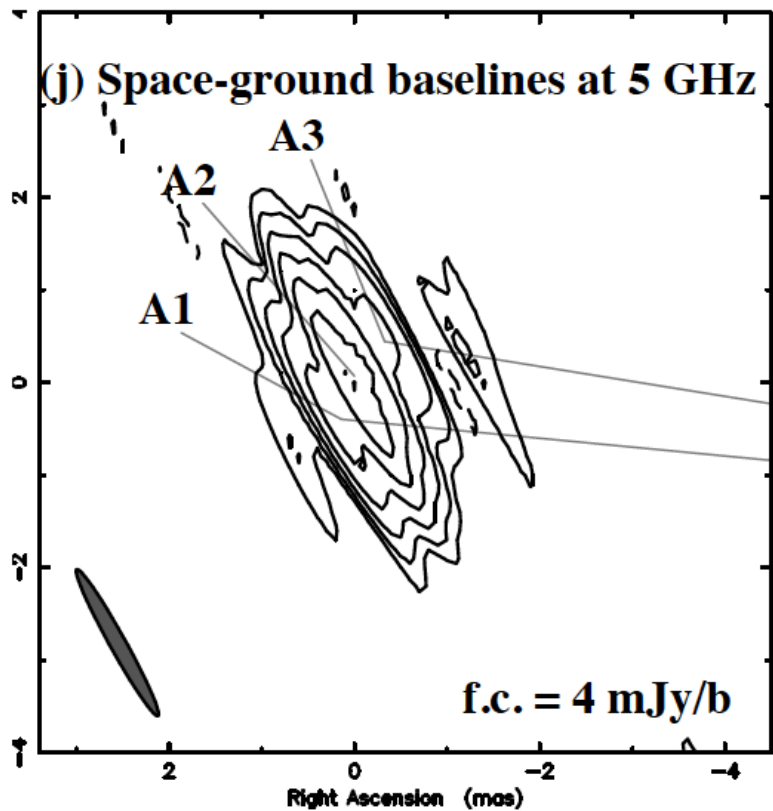
From the observed brightness temperatures of the individual jets components, we can investigate the assumption of adiabatic expansion following Lobanov et al. (2001) and Marscher (1990), who model the individual jet components as independent relativistic shocks with adiabatic energy losses dominating the radio emission. Note that this description of the outer jet differs from the  $N \propto r^{-2}$ ,  $B \propto r^{-1}$  case describing the compact inner jet region, which is not adiabatic. With a power-law energy distribution of  $N(E) \propto E^{2\alpha-1}$  and a magnetic field varying as  $B \propto r^{-1}$ , we obtain

$$T_{b,\text{jet}} = T_{b,\text{core}} \left( \frac{d_{\text{core}}}{d_{\text{jet}}} \right)^{(6-7\alpha)/3} \quad (5.3)$$



# Some other interesting features of VLBI polarization (1402+044)

Yang et al. (2008)

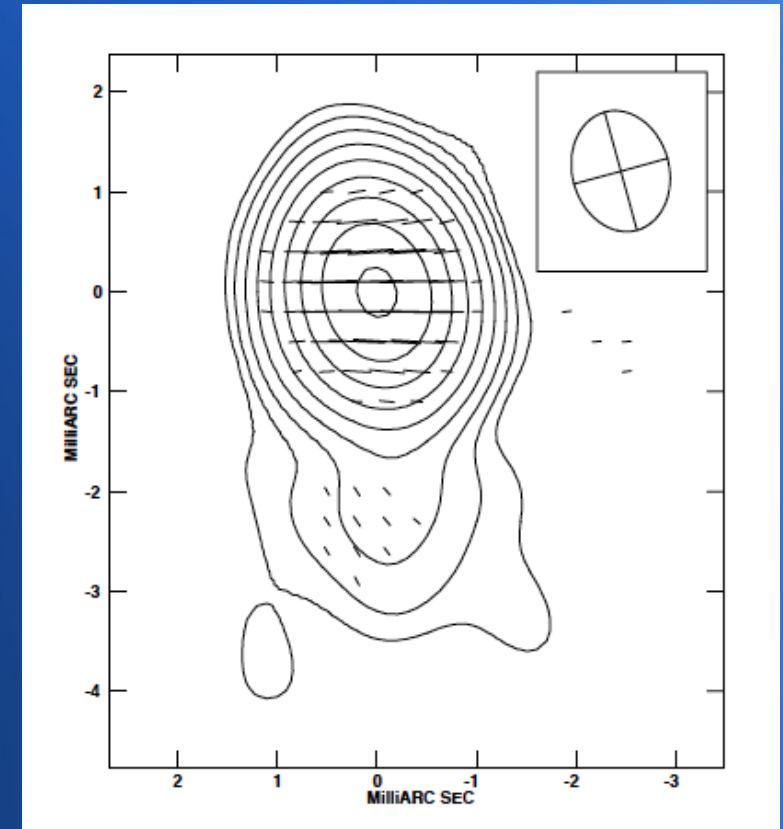
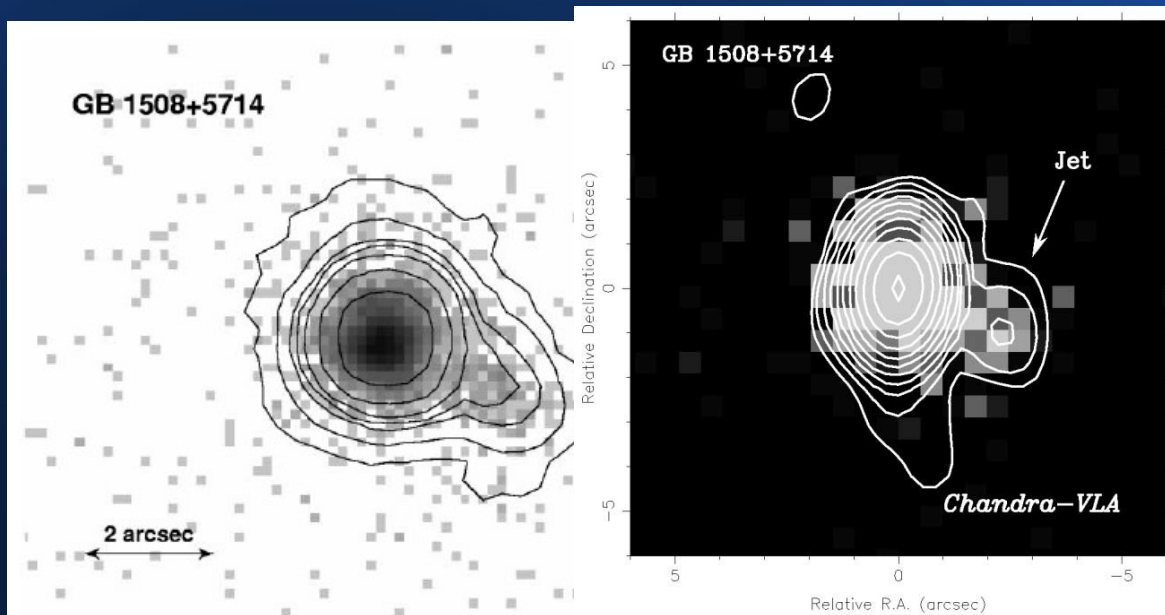


# Some other interesting features of VLBI polarization (1508+572)

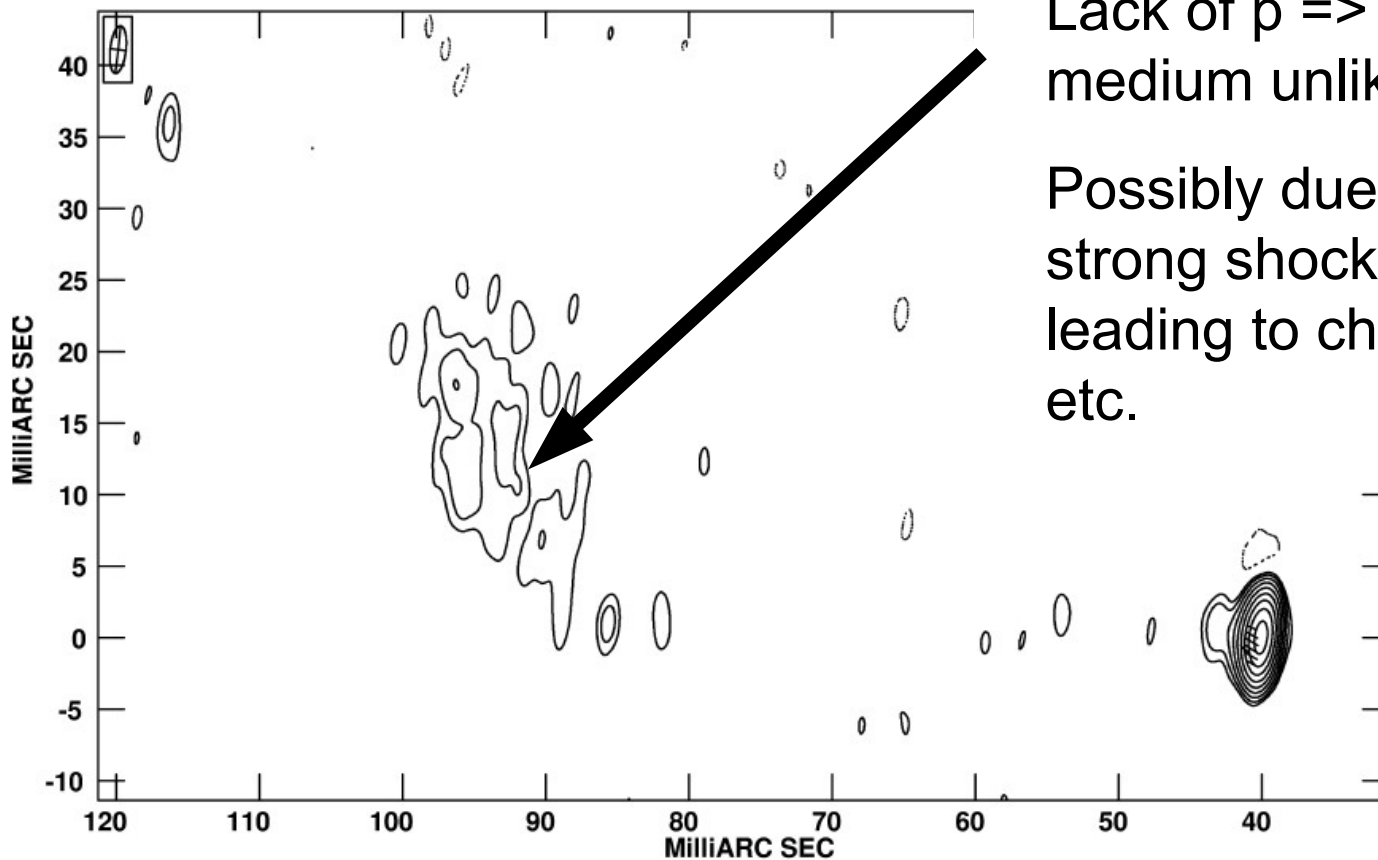
Cheung (2004)

Siemiginowska et al. (2003),

Yuan et al. (2003)



# Some other interesting features of VLBI polarization (2215+020)

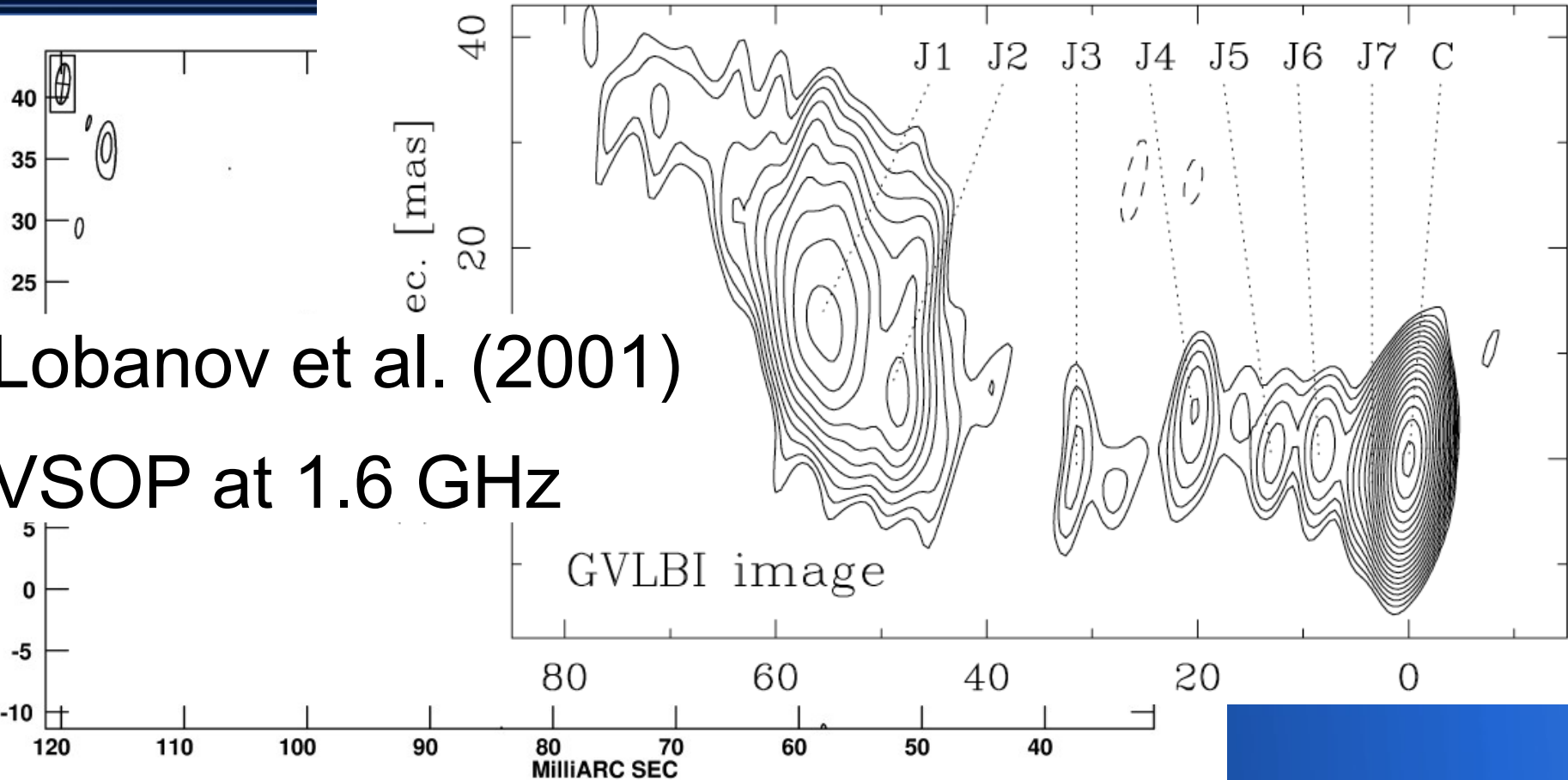


Lack of  $p$  => interaction with ambient medium unlikely cause of brightening

Possibly due internal jet dynamics: strong shock, change in jet dirn leading to change in Doppler factor, etc.

80 mas -> 600 pc

# Some other interesting features of VLBI polarization (2215+020)



Lobanov et al. (2001)

VSOP at 1.6 GHz

80 mas  $\rightarrow$  600 pc

# Summary

- Estimate of min RM for 11 high  $z$  quasars
- Diverse jet structures and pol properties
- No clear evidence from these results for significantly different quasar environment at high  $z$ , however follow up obs needed
- Dearth of VLBI jet RMs at  $z > 1.5$
- Importance of polarization for investigation of innermost regions of VLBI jets

