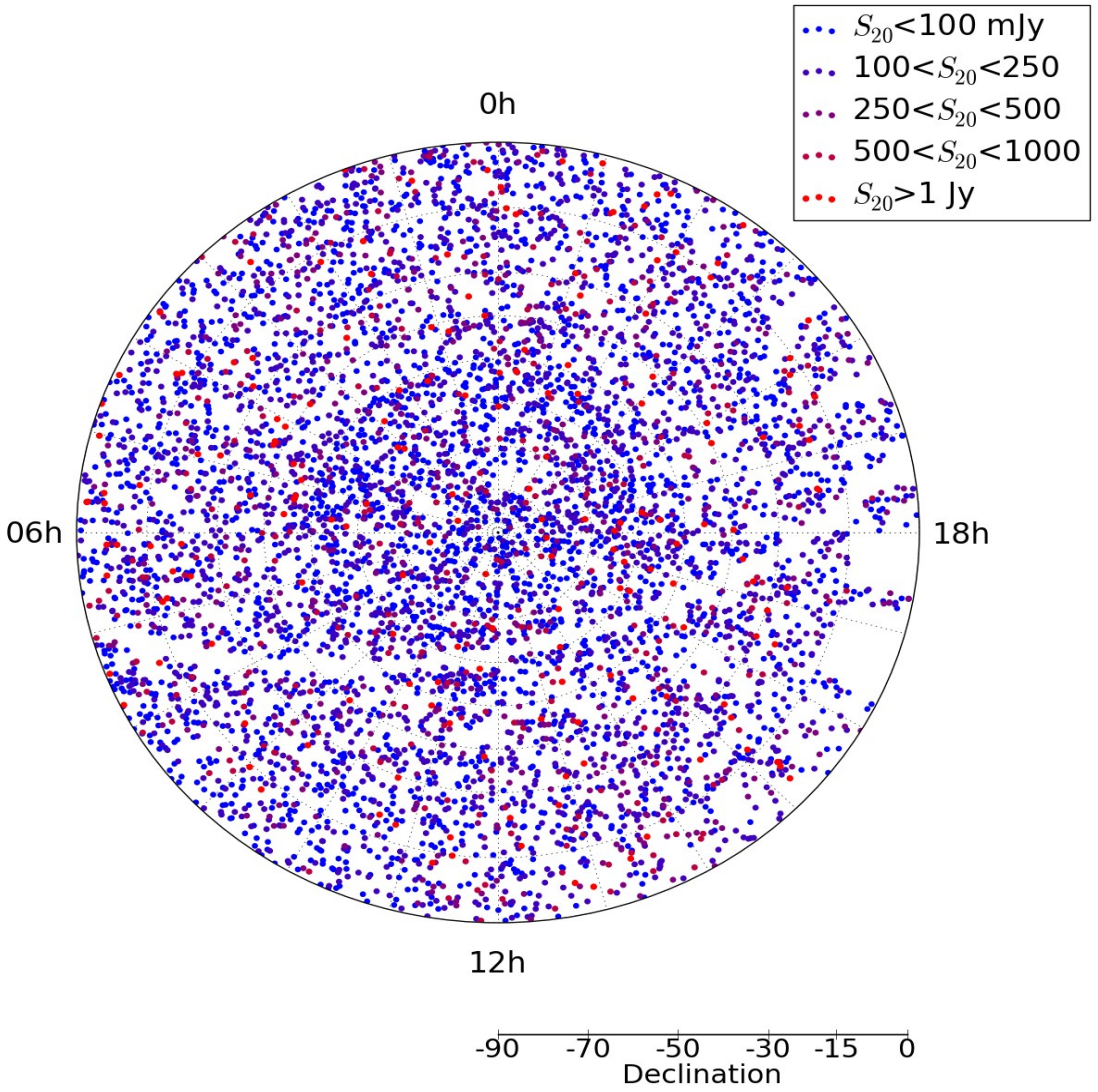
Extended extragalactic source polarization with ATCA and perspectives for ALMA

M. Massardi & the Italian ARC node

The Australia Telescope 20GHz survey

The AT20G Survey is a blind 20 GHz survey of the entire southern sky with |b|>1.5deg. Observations were carried out using the Australia Telescope Compact Array (ATCA) from 2004-2008. The final AT20G catalogue consists of 5890 sources above a 20 GHz flux density limit of 40 mJy and includes near-simultaneous observations at 4.8 and 8.6 GHz for most sources south of -15deg.



ATCA: 6x22m antennas Hybrid configs
31m-4.5km spacings
linear feeds
[At that epoch] 2x128 MHz bands

NOTE: polarization available for all the antennas at all the freqs except CA06 @3mm

Extended sources in the AT20G survey

AT20G data reduction is based on triple product analysis in the vis plane.
Triple product is well suited for compact objects in the phase center.
Extended sources (within the beam) are underestimated and for this reason flux densities are estimated from images.

It needed a dedicated observing run for
"very extended"= not resolved in the 60m H168 ATCA config
(larger than the 2.4 arcmin)
& with multiple components detected as separate sources
(& dec<-30deg & extragalactic not in MC & $S_{20GHz\ TOT}$>500mJy)

Results in Burke-Spolaor et al. (2009)

Searched in PMN @ 4.85GHz and SUMSS @843MHz
(where sources appear as more extended),
selecting multiple components @ 20 GHz
or sources extended in PMN (i.e. larger than 4.2 arcmin
Missing about 10 objects in the range 2.4-4.2 arcmin)

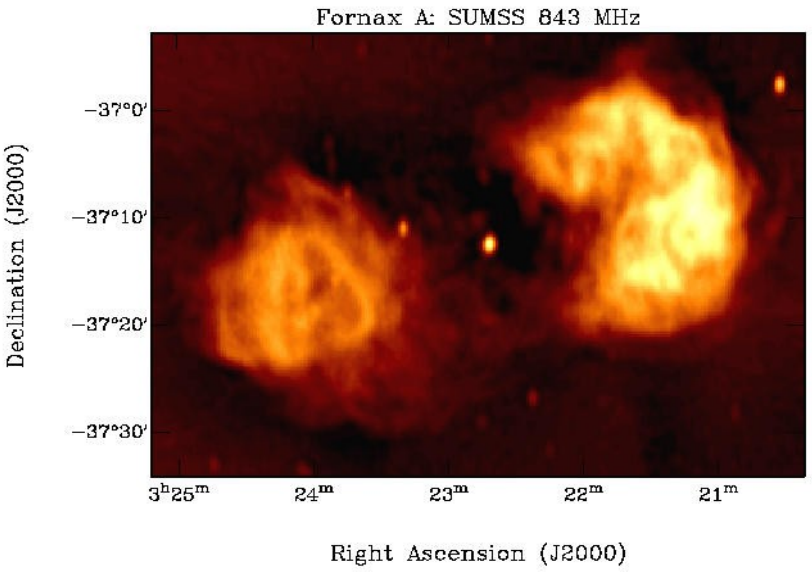
The bright and extended sources in the Southern Hemisphere

Source name	*WMAP* ID	RA (J2000)	Dec. (J2000)	Redshift	Size (major axis) arcsec	Size (major axis) kpc	Observed regions (# mosaic subfields)
PKS 0131−36	–	01:33:33.2	−36:29:11.0	0.0298	365	206	Observed brighter western lobe and core region (7 pointings)
Fornax A	*WMAP* 138	03:22:41.7	−37:12:30	0.0059	2840	335	Did not observe (see Section 2)
Pictor A	*WMAP* 150	05:19:26.0	−45:45:54	0.0342	442	293	13 pointings
Centaurus A	–	13:25:27.0	−43:01:00	0.0018	5°	648	Observed only ∼12 arcmin inner double (14 pointings)
PKS 1333−33	*WMAP* 185	13:36:39.0	−33:57:56	0.0125	1863	463	Observed inner double (5 arcmin inner jet region) (7 pointings)
Centaurus B	–	13:46:49.4	−60:24:29	0.0129	960	239	24 pointings
PKS 1610−60	–	16:15:15.8	−60:39:14.0	0.0184	755	274	16 pointings
PKS 2153−69	*WMAP* 190	21:57:05.9	−69:41:23.7	0.0283	110	61	2 pointings
PKS 2356−61	*WMAP* 187	23:58:49.0	−60:53:07	0.0963	381	661	7 pointings

For A: not in AT20G because too extended with too steep core

Includes FRII (PKS0131-36, PKS2356-61),
head-tail (PKS1610-60),
triples (PKS1333-33)
with jet and node structures

In some cases there are evidences of
merging events,
interactions with the environment
(for cluster galaxies), dust features.



Observing extended objects in polarization

ATCA: 6 antennas H75 configs
31m-75m spacings
2x128 MHz bands
16.7-19.4 GHz

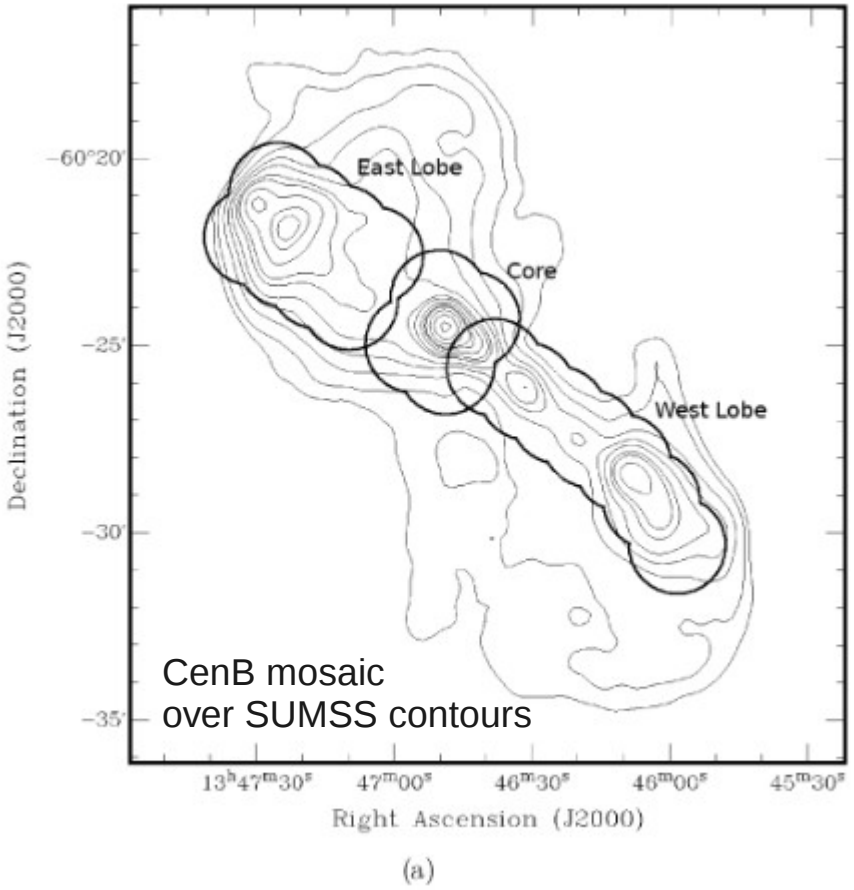
Mosaic mode with Nyquist sampling spacing
40s on each mosaic subfield

Repeated at 4 different hour angles

1921-293 and 1934-638 once

A secondary calibrator before and after each source

Secondary used to solve for gains, residual xy-phase difference (xy-phase difference @ ATCA is solved via injection techniques) and leakages



Miriad data reduction vs CASA data reduction

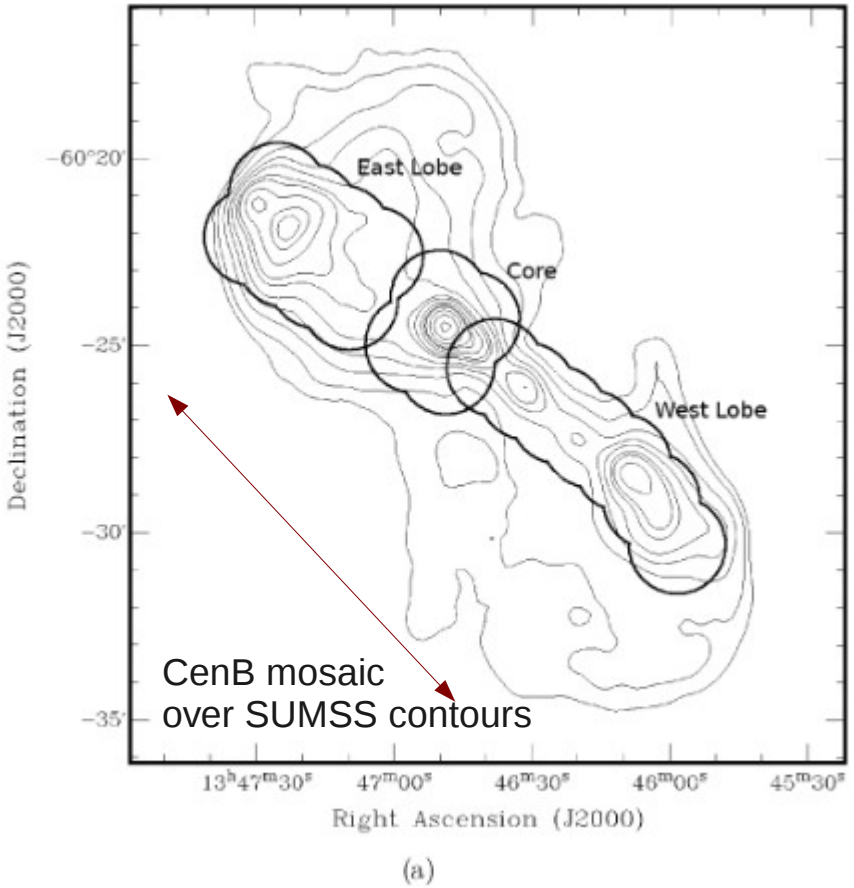
Images generated with MIRIAD'S joint deconvolution polarization maximum entropy method algorithm (PMOSMEM). All subfields are inverted as one image. The algorithm performs a MEM deconvolution simul-taneously for all polarizations, using morphological information from bright emission in the total intensity image to solve for the Q and U polarized Stokes images.

Total intensity measurements extracted from the multiscale clean deconvolution algorithm implemented in CASA, joining mosaic subfields.

P images were created by combining aligned Q and U images pixel-by-pixel: $\mathbf{P^2=Q^2+U^2-\sigma_P^2}$

Position angle (PA) maps are also calculated on a per pixel basis, $\mathbf{\psi=(1/2)\ arctan\ (U/Q)}$

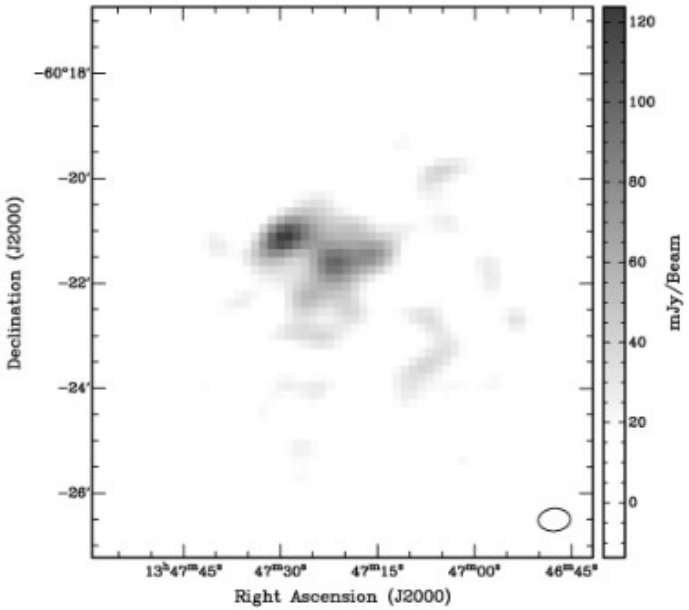
Vector maps of fractional polarized intensity were formed by dividing the masked total polarization maps by the total intensity maps; in this way, the maps will only show fractional polarization above the detection threshold. Polarization vectors were then calculated using lengths determined by fractional polarization levels, and PAs from PA maps. Note that the orientation of a polarization 'vector' is ambiguous by 180◦, and does not provide a preferred electric or magnetic field direction along the printed rods.

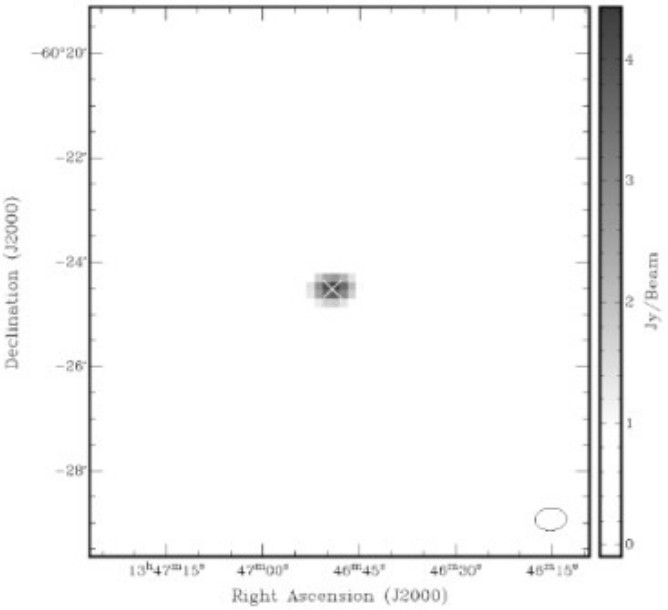


(a)

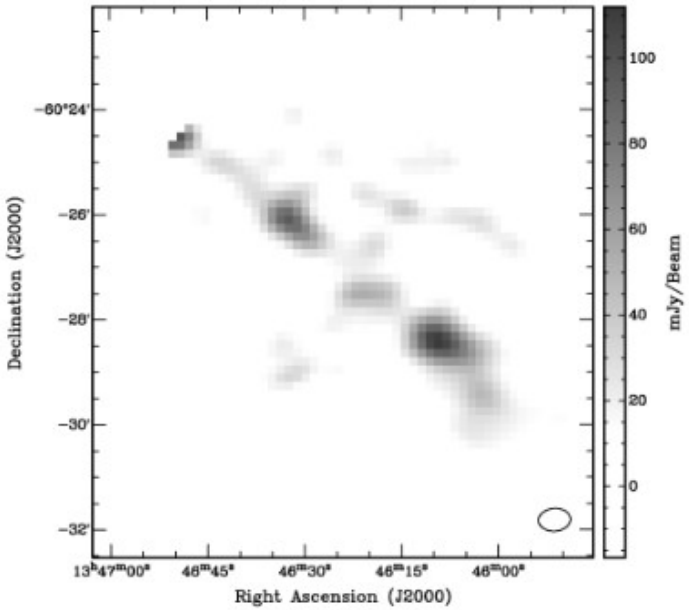
Some maps

Contours 1,2,4,8,16...x sigma



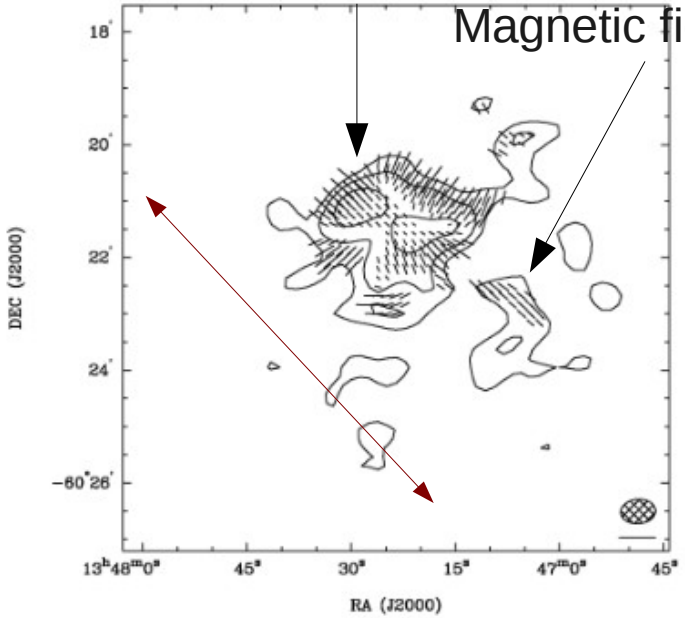


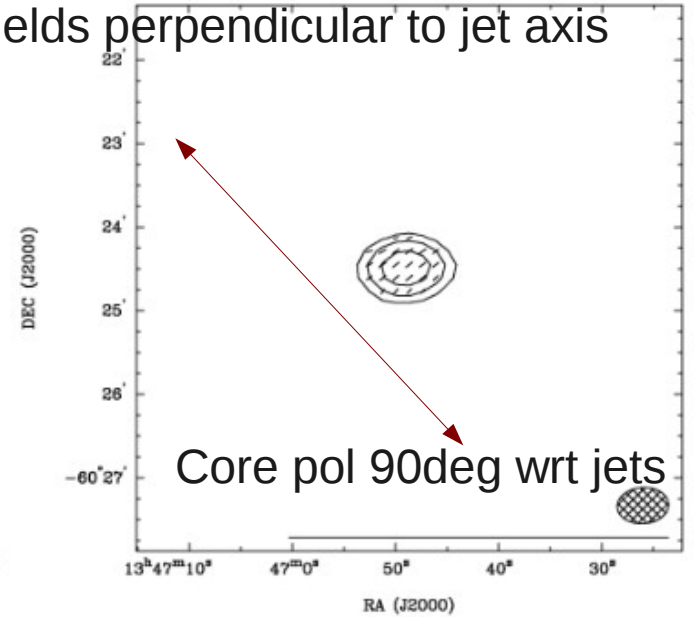
(b)

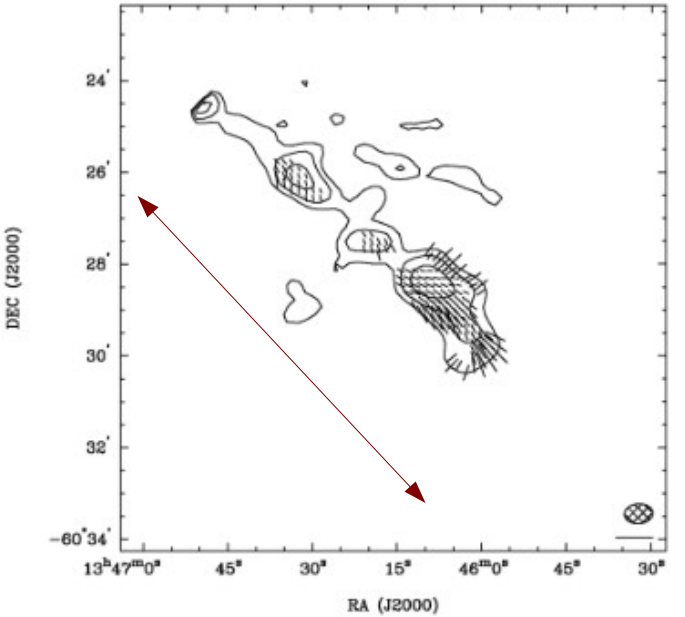


Edge brightening

Magnetic fields perpendicular to jet axis





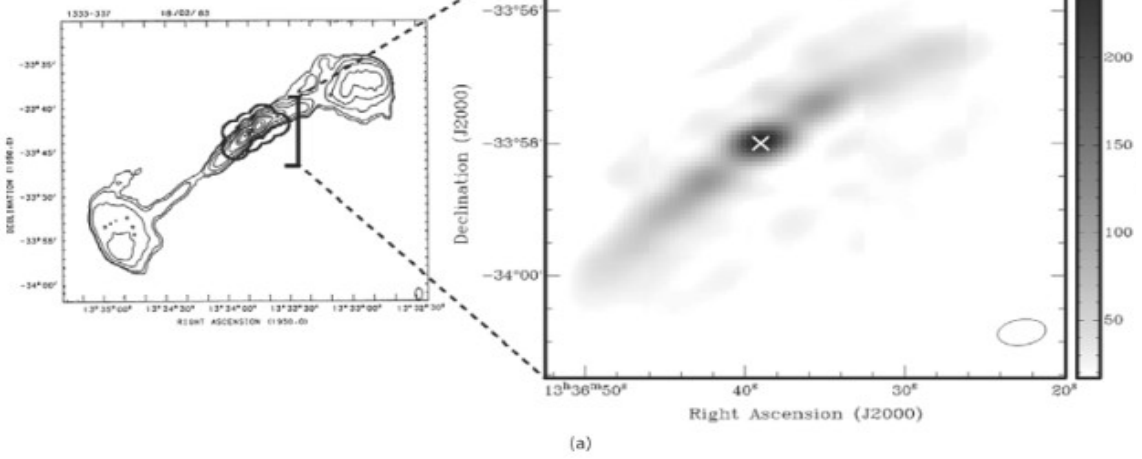


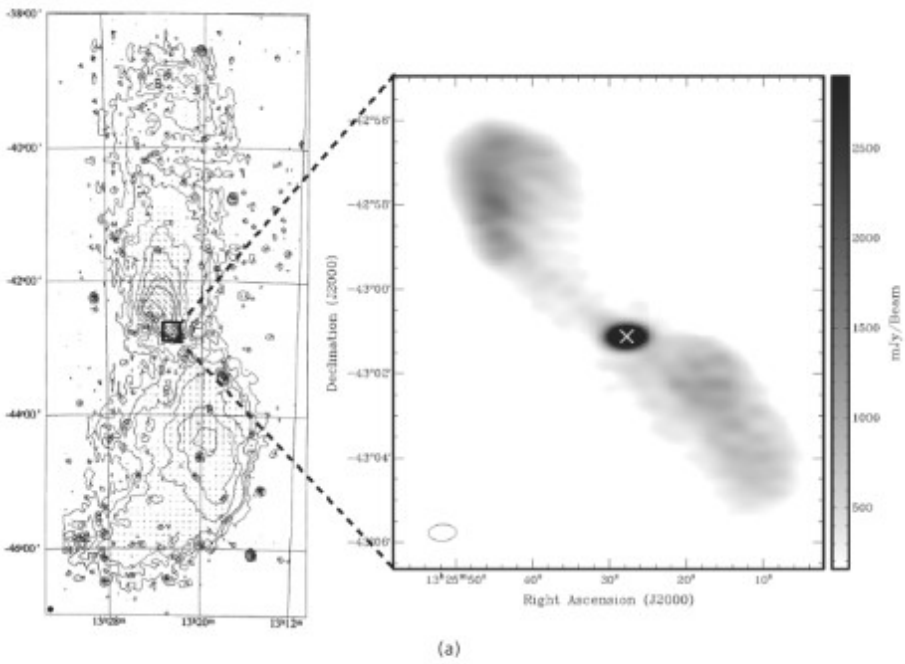
Cen B E-lobe

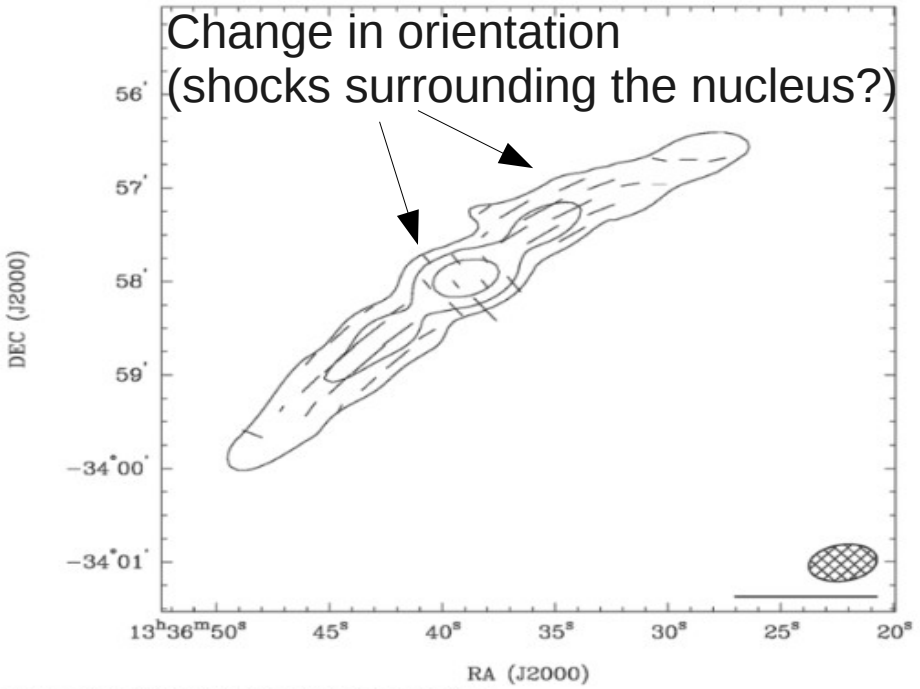
Cen B core

Cen B W-lobe

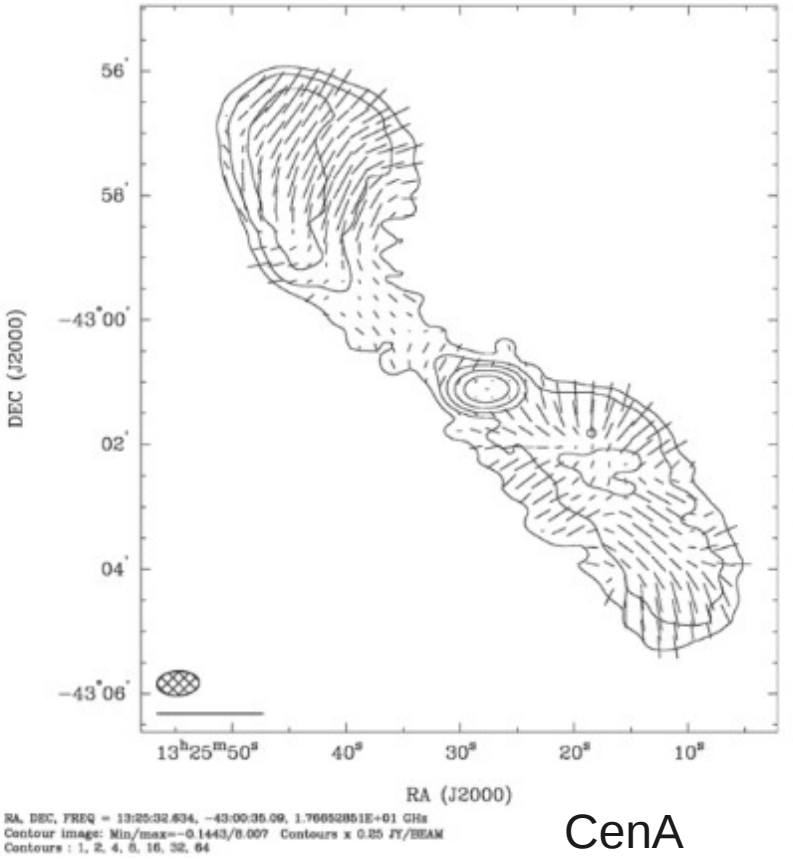
Some maps





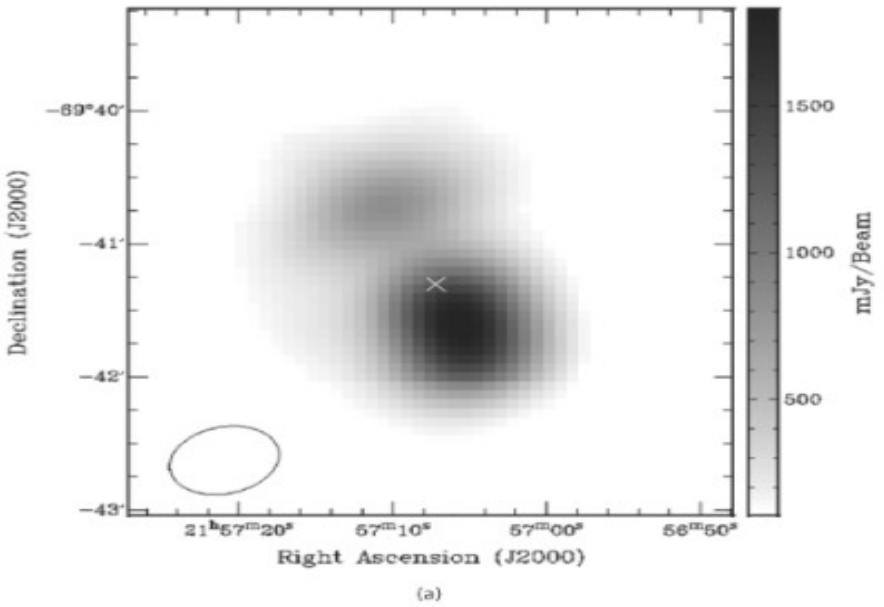


PKS 1333-33

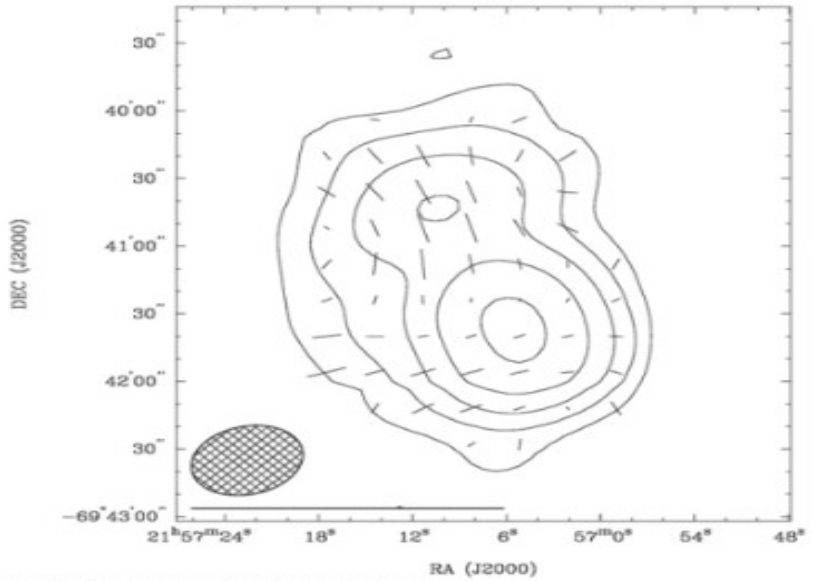


CenA

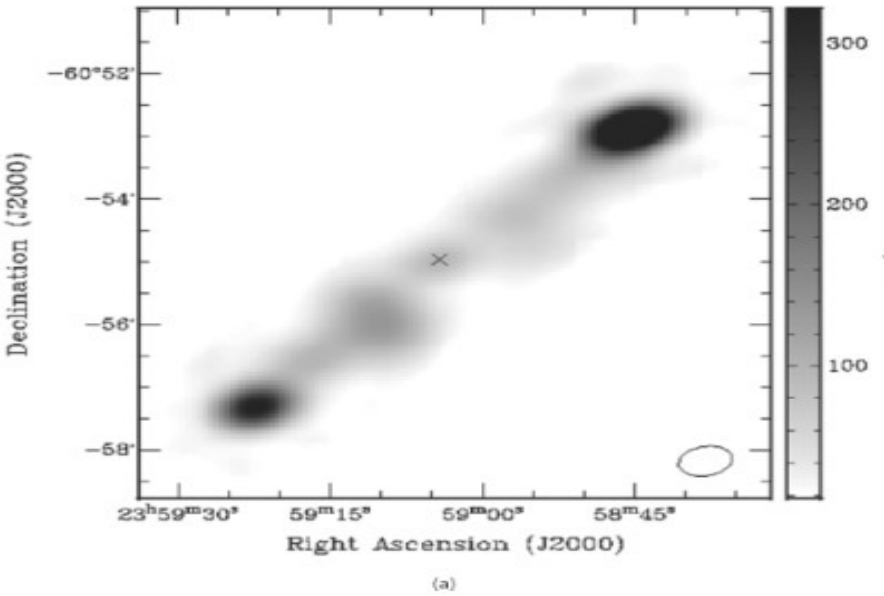
Some maps



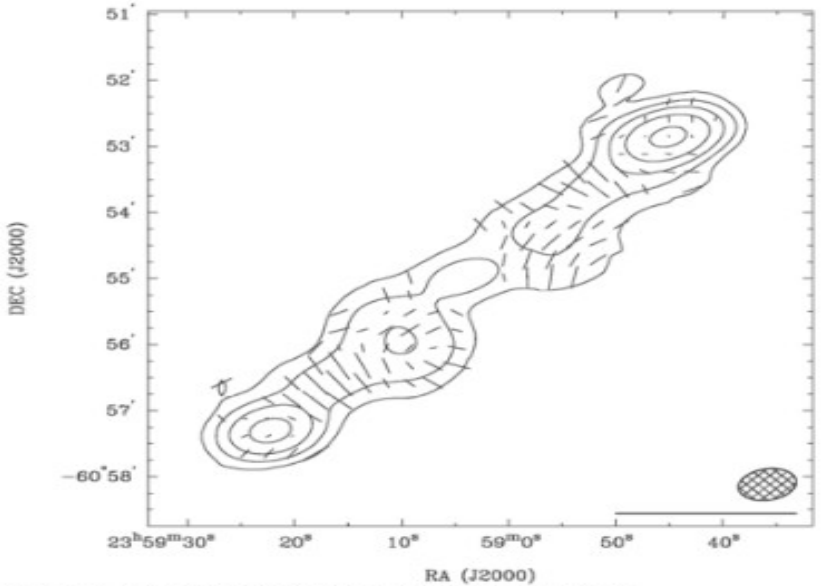
(a)



PKS 2153-69

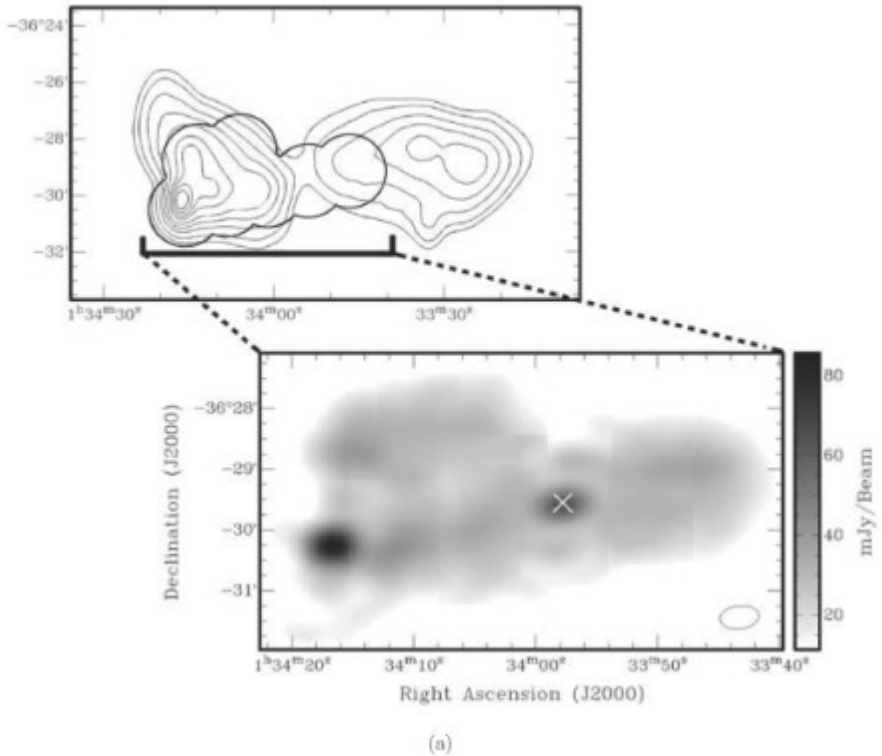


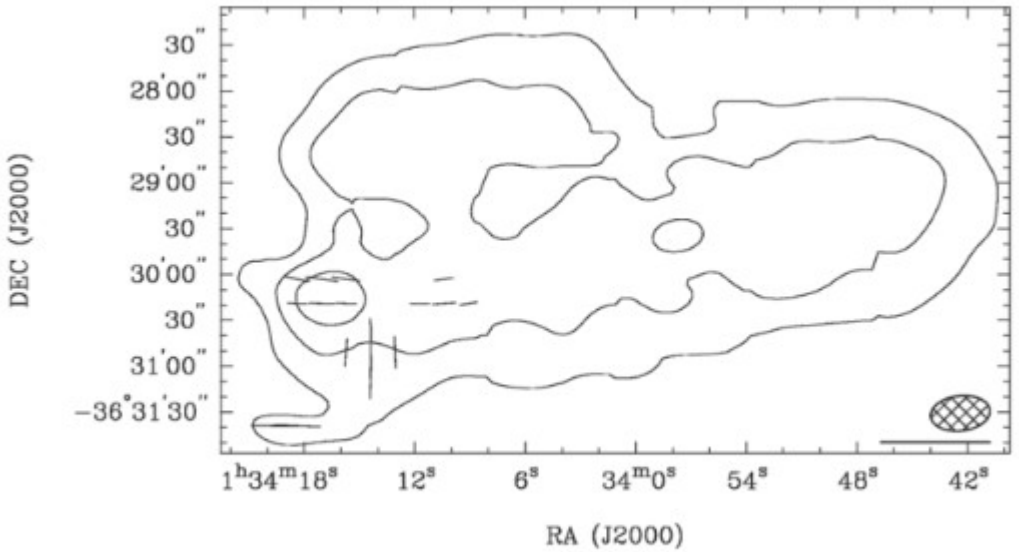
(a)



PKS 2356-61

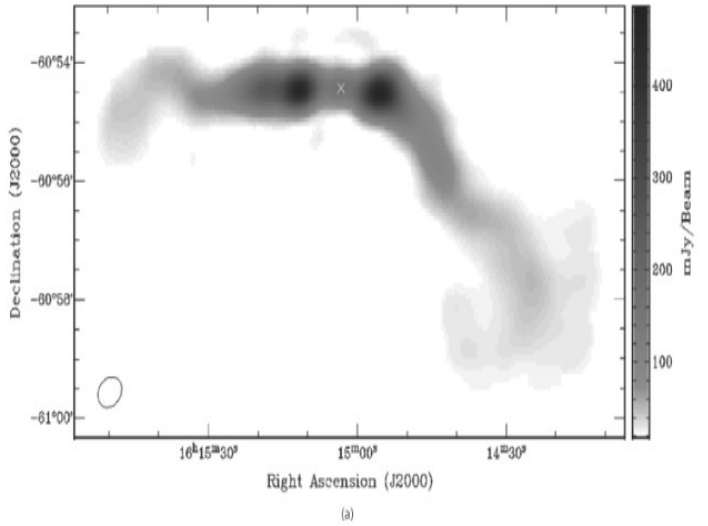
Some maps

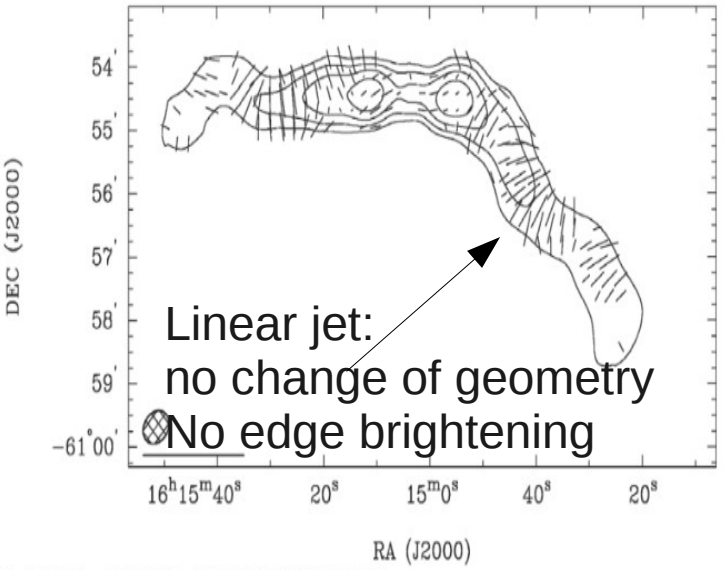




RA, DEC, FREQ = 1:34:01.115, −36:29:51.16, 1.76652851E+01 GHz
Contour image: Min/max=−1.843×10^{-3}/0.08541 Contours x 0.013 JY/BEAM
Contours : 1, 2, 4, 8, 16, 32, 64

PKS 0131-36





RA, DEC, FREQ = 16:14:50.981, −60:54:45.76, 1.76652851E+01 GHz
Contour image: Min/max=−0.01118/0.485 Contours x 0.035 JY/BEAM
Contours : 1, 2, 4, 8, 16, 32, 64

PKS 1610-60

Summary of findings

Source name	RA (core)	Dec. (core)	$S_{\rm core}$	S_{18}	P_{18}	Π_{18}	α_5^{18}	S_{23}
PKS 0131−36	01:33:57.9 ± 3.0	−36:29:35.3 ± 1.9	0.03 ± 0.01	>0.44	0.02*	4.6	–	–
Pictor A	05:19:49.7 ± 0.8	−45:46:43.7 ± 0.5	1.32 ± 0.04	6.32 ± 0.11	0.50 ± 0.06	7.9	−0.70	6.80
Centaurus A	13:25:27.6 ± 0.7	−43:01:04.9 ± 0.4	5.98 ± 0.17	>28.35	3.81*	13.4	–	46.2†
PKS 1333−33	13:36:39.0 ± 4.1	−33:57:57.7 ± 2.6	0.30 ± 0.05	>0.74	0.07*	9.8	–	1.70
Centaurus B	13:46:49.1 ± 0.3	−60:24:30.0 ± 0.2	5.02 ± 0.06	8.89 ± 0.43	0.08 ± 0.01	0.9	−0.87	–
PKS 1610−60	16:15:05.6 ± 8.8	−60:54:27.1 ± 8.9	0.14 ± 0.05	2.11 ± 0.04	0.128 ± 0.008	6.0	−0.93	1.7†
PKS 2153−69	–	–	–	3.40 ± 0.21	0.05 ± 0.03	1.5	−0.96	3.60
PKS 2356−61	23:59:04.9 ± 7.8	−60:55:03.4 ± 6.1	0.09 ± 0.03	1.64 ± 0.05	0.032 ± 0.004	1.9	−0.94	1.80

All cores have undetected or low polarization

(because of scattering medium surrounding the region of inner jet formation, or dense plasma, or beam depolarization of unresolved components ...)

Magnetic fields aligned with jet axis if geometry doesn't change along the jet

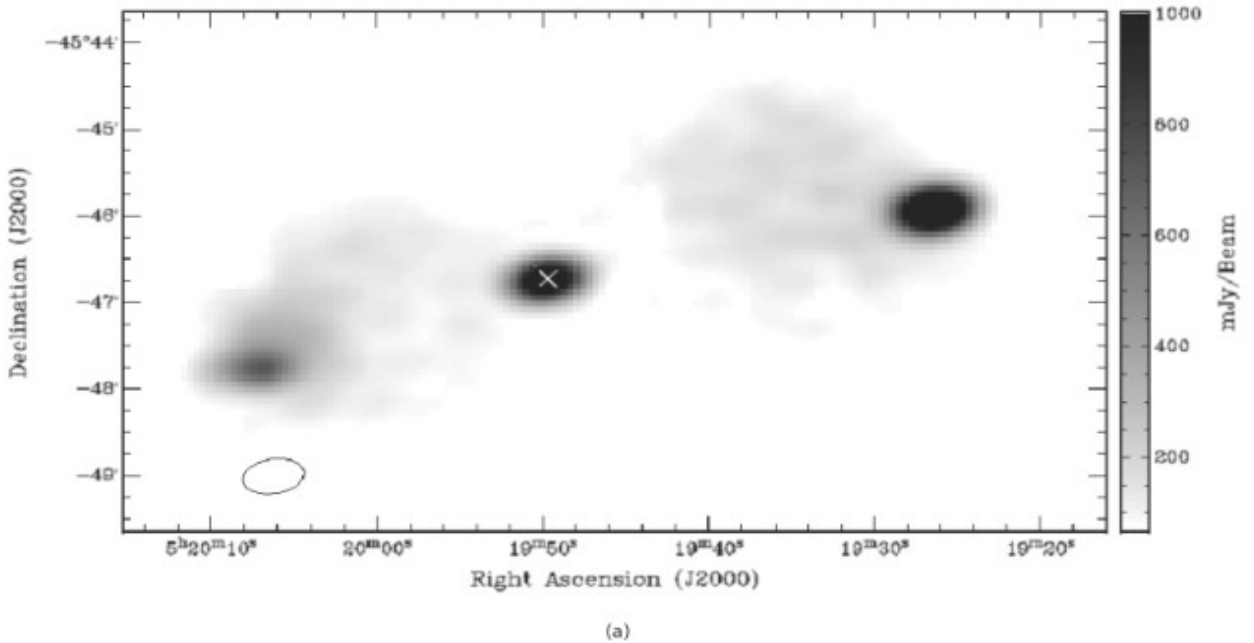
(in such cases there is no edge brightening)

Edge brightening and polarization aligned to isocontours of total intensity in case of complex geometries.

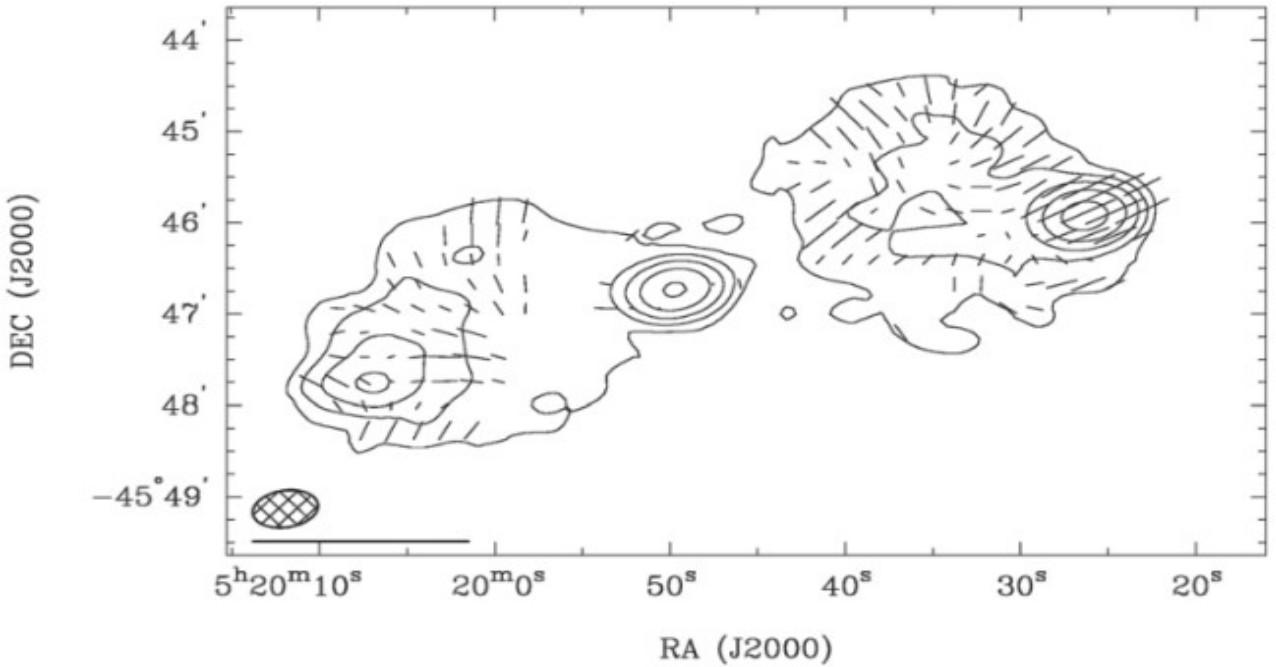
Name	$P_{23\rm GHz}$	$P_{33\rm GHz}$	$P_{41\rm GHz}$	$P_{64\rm GHz}$	$S_{23\rm GHz}$	$S_{33\rm GHz}$	$S_{41\rm GHz}$	$S_{64\rm GHz}$
Fornax A	1074 31	867 44	589 64	<354	9321 134	5350 184	3275 173	905 255
PicA - AT20GJ051949-454643	457 35	372 50	280 82	< 484	6464 207	5661 235	4656 210	3139 270
CenA - AT20GJ132527-430104	3322 70	2699 81	2323 120	2075 173	51006 260	41909 248	35731 245	26767 335

WMAP 9-yr coadded maps detections

The case for PictorA



Pic A is a classical double. The roundness of the lobes indicates that the source is quietly expanding in a uniform medium, in which the source is confined. However, the strength of the hotspots suggests that it was recently re-activated.



Change of geometry & Edge brightening

Wlobe highly polarized with arcsec scale structures
Elobe highly depolarized
The Elobe requires a higher resolution to identify structure on the kpc scale (corresponding to 1.45 arcsec at the source redshift).

The case for PictorA: high frequency with ATCA

Because of its angular size (10arcmin) and position in sky
was a good extragalactic polarization calibrator for Planck satellite.
Only caveat is the steep spectrum

ATCA: 6 antennas H75 configs
31m-80m spacings
2x2048 MHz bands (2009 new CABB!!!!)
18-24 and 33-39 GHz

Mosaic mode with Nyquist sampling spacing
30s on each mosaic subfield

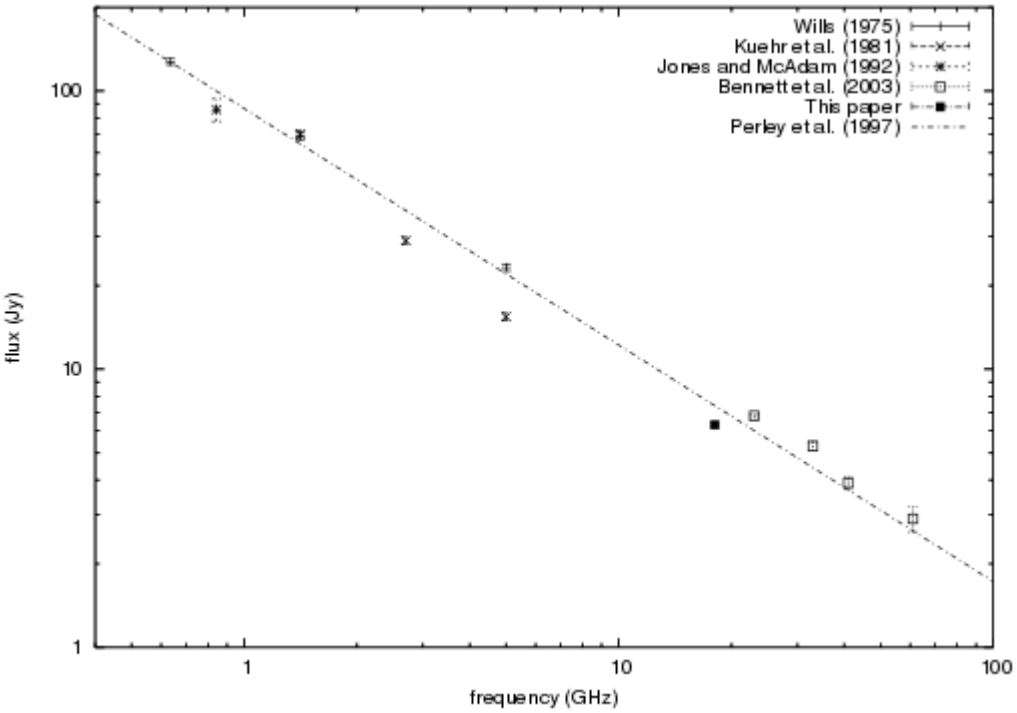
Repeated at 8 different hour angles

1921-293 and 1934-638 once

0537-441 as secondary interleaved

Secondary used to solve for gains, residual xy-phase difference and leakages

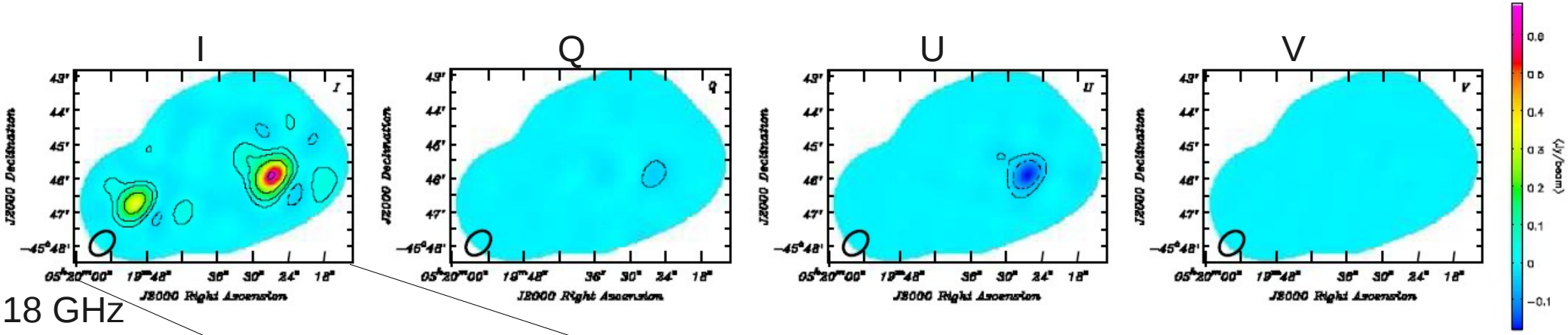
Data reduction in Miriad+CASA



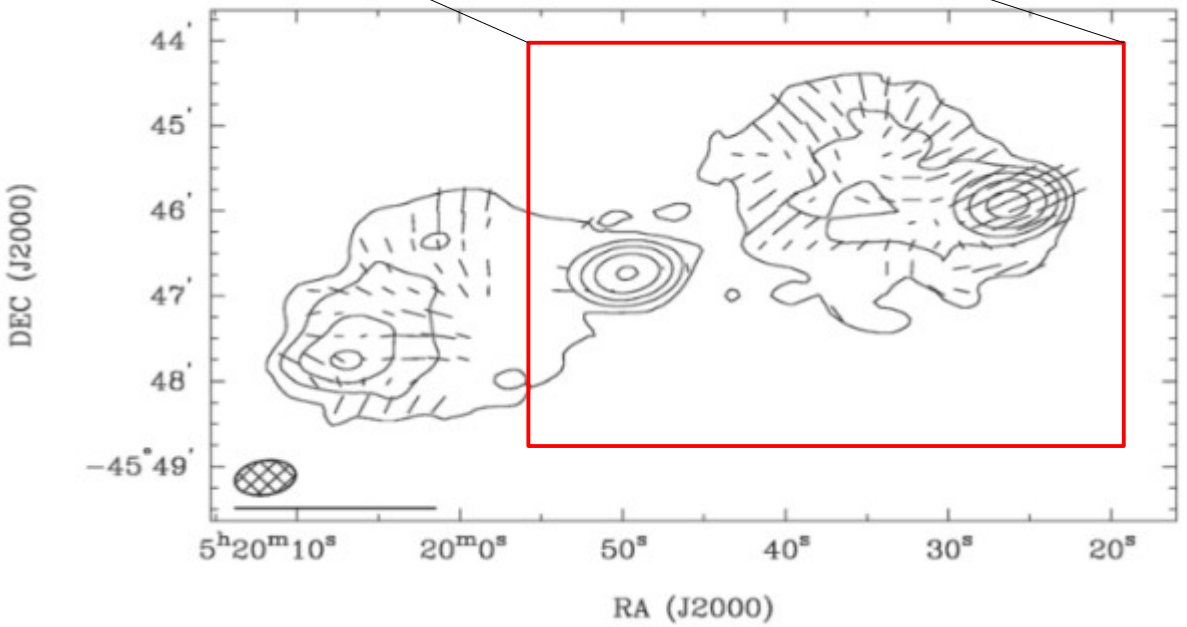
20 GHz Polarized intensity 0.50±0.06 Jy

20 GHz Total intensity 6.32±0.11 Jy

The case for PictorA: high frequency with ATCA



18 GHz

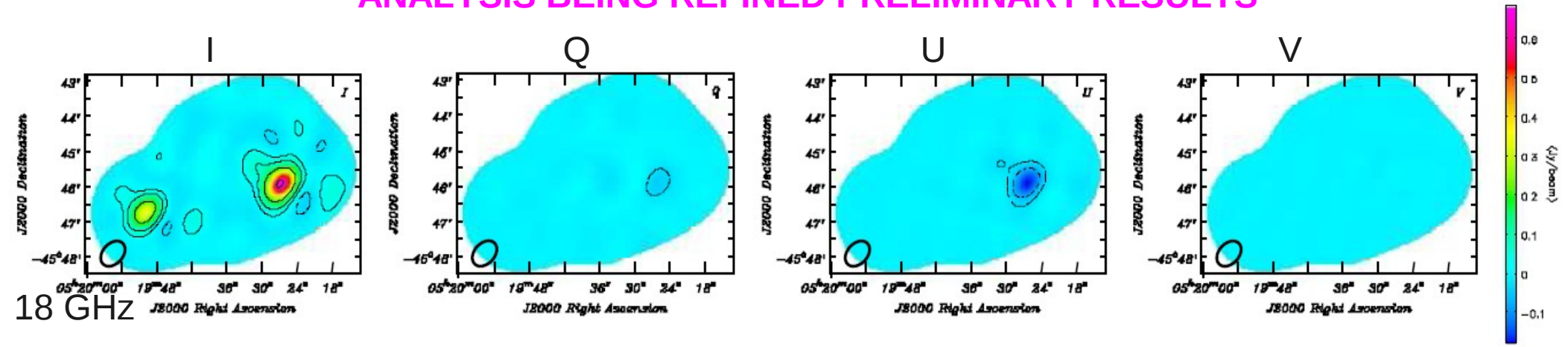


We focused on the wlobe and the core

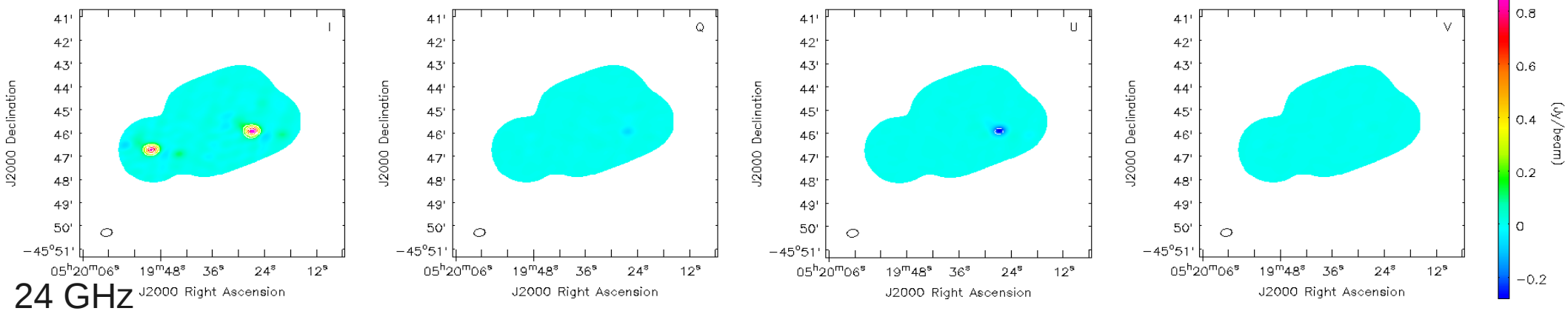
The case for PictorA: high frequency with ATCA

ANALYSIS BEING REFINED PRELIMINARY RESULTS

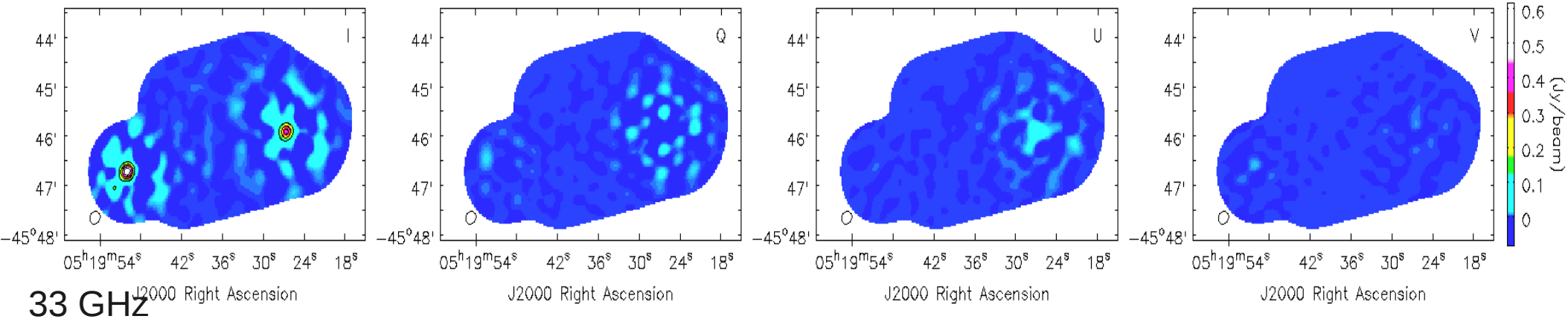
I Q U V



18 GHz



24 GHz



33 GHz

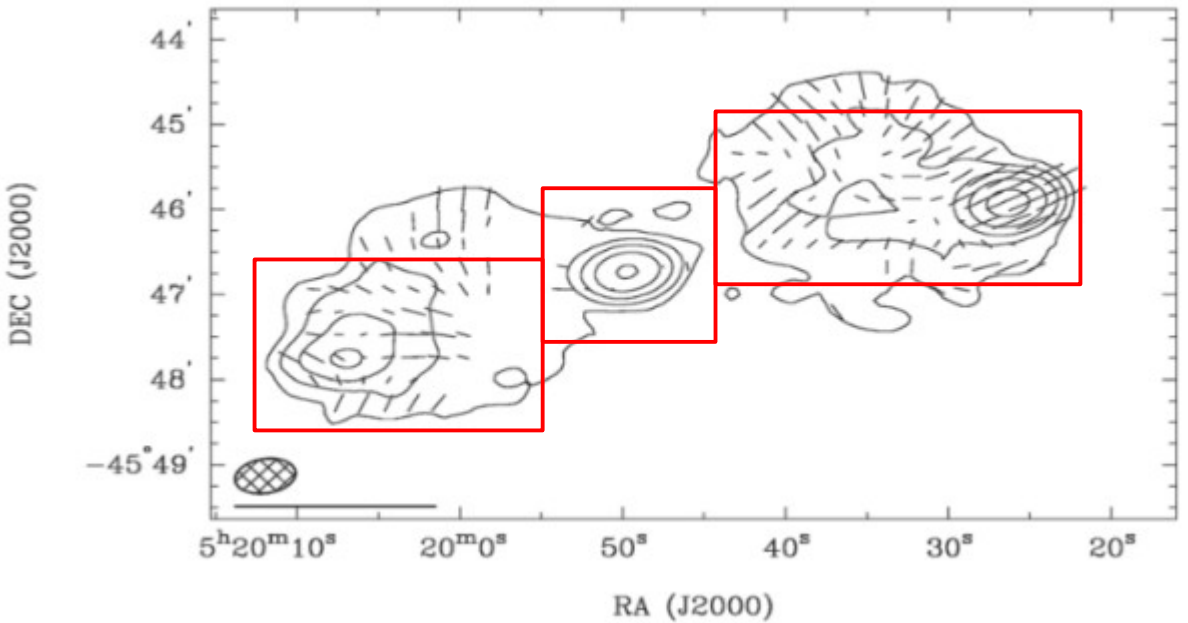
A science case for ALMA?

Science case:
- high frequency polarization properties
- filamentary structures in the W lobe/core region
- depolarization for the E lobe (?)
- high resolution field geometry

Technical justification:
- B3 (mosaic+steep spectrum), 90GHz
- expected integral P about 76mJy (10% polarized)

- reached 1mJy in P in 2.6 min with ACA (1s in MA)
- 25 ACA pointings (72 MA) to cover the areas (12.5x2 arcmin) => 1hr on source

- 0537-441 closeby pointsource calibrator (0.71% polarized at 18 GHz)



Summary

AT20G observations @ 20 GHz pointed out interesting features for a sample of extended objects in polarization

High sensitivity and resolution are required to dig into the mechanism at the basis of geometry changes (or not) across the jet/lobes regions, edge brightening and/or interaction with the environment. -> ALMA!!!

PictorA stands as a well known very bright double lobes galaxy within dense environment over about 12.5x2 arcmin region
-> could be an interesting guinea pig observable in ALMA in about 1hr on source

Caveat in data reduction:
- Imaging deconvolution for wide band corr difficult to handle in Miriad
  CASA is better
- Leakage across the band has to be dealt by band splitting but not modified for all the Miriad tasks
- At time of calculation, there were problems with ATCA data interface in CASA and polarization information was corrupted