# RadioAstron correlation and activities at MPIfR


**Gabriele Bruni**
Max Planck Institute for Radioastronomy

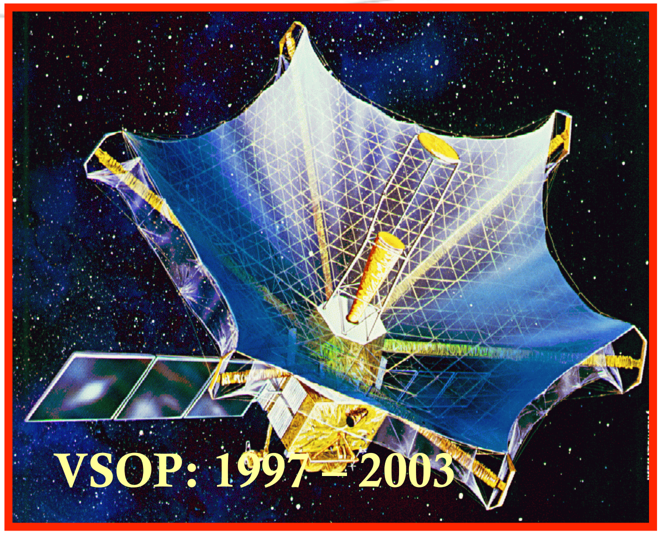

*Third international VLBI technology workshop*
*Groningen, 10-13/11/2014*

ASTRO SPACE CENTER

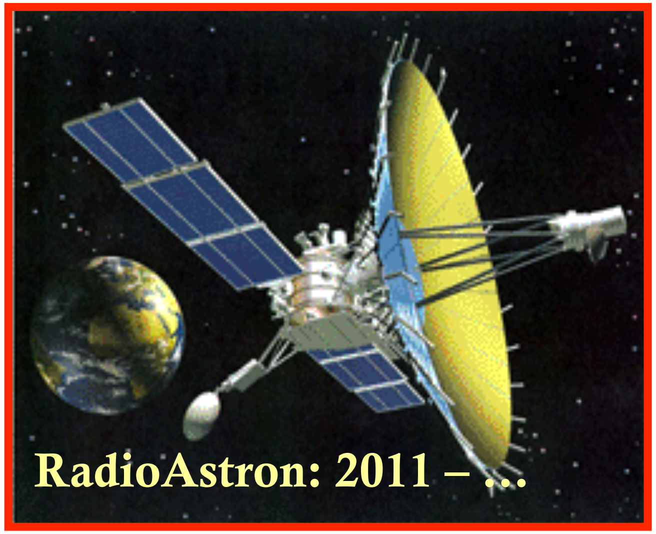
Max-Planck-Institut für Radioastronomie

# Space VLBI during the decades


1986-88

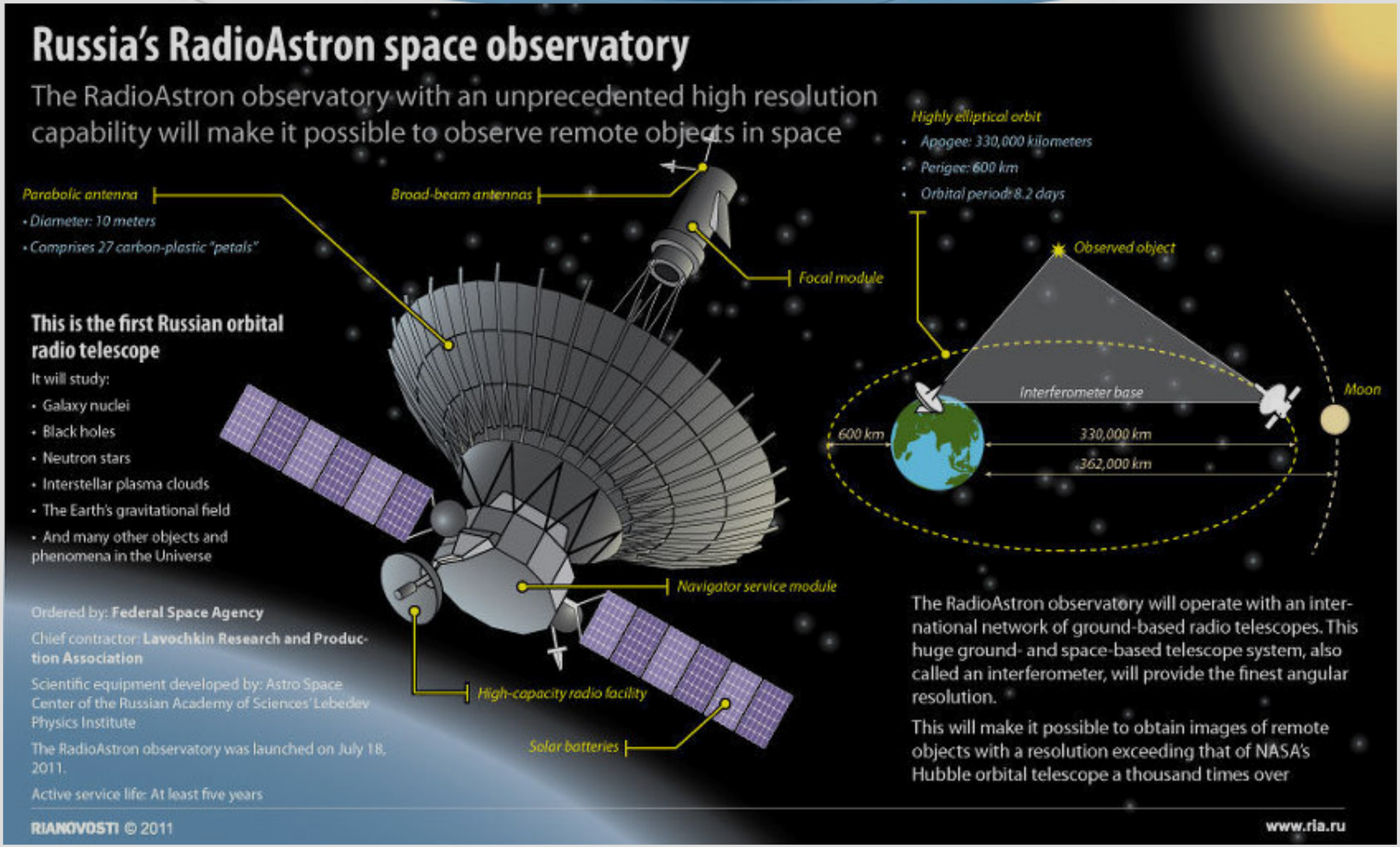



1990s

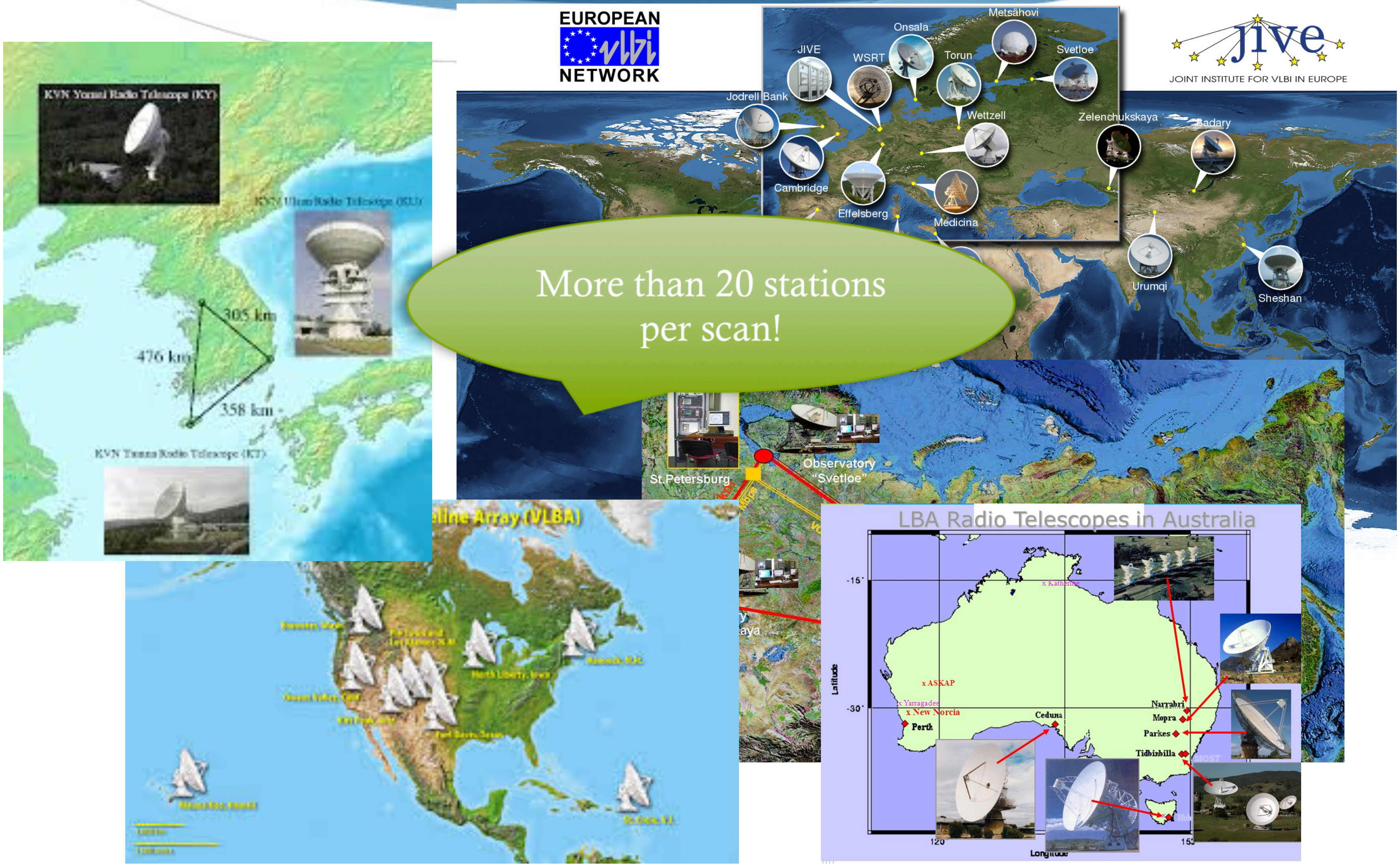



2010s

# The RadioAstron telescope



# The ground segment



# The correlation

Four correlators are processing RadioAstron data:

- ASC software FX-correlator: AGN survey, Russian PIs projects
- Dra-DiFX software correlator: upgraded version of the DiFX to correlate space-based antennas. AGN imaging projects
- JIVE SFXC software correlator: mainly pulsar projects
- CURTIN University correlator (Dra-DiFX): Cen A imaging project (Australia)

# The HPC cluster

13 RAIDs, 650 Tb

60 Tb reserved for RadioAstron

60 nodes,
8 cores each
(480 cores)

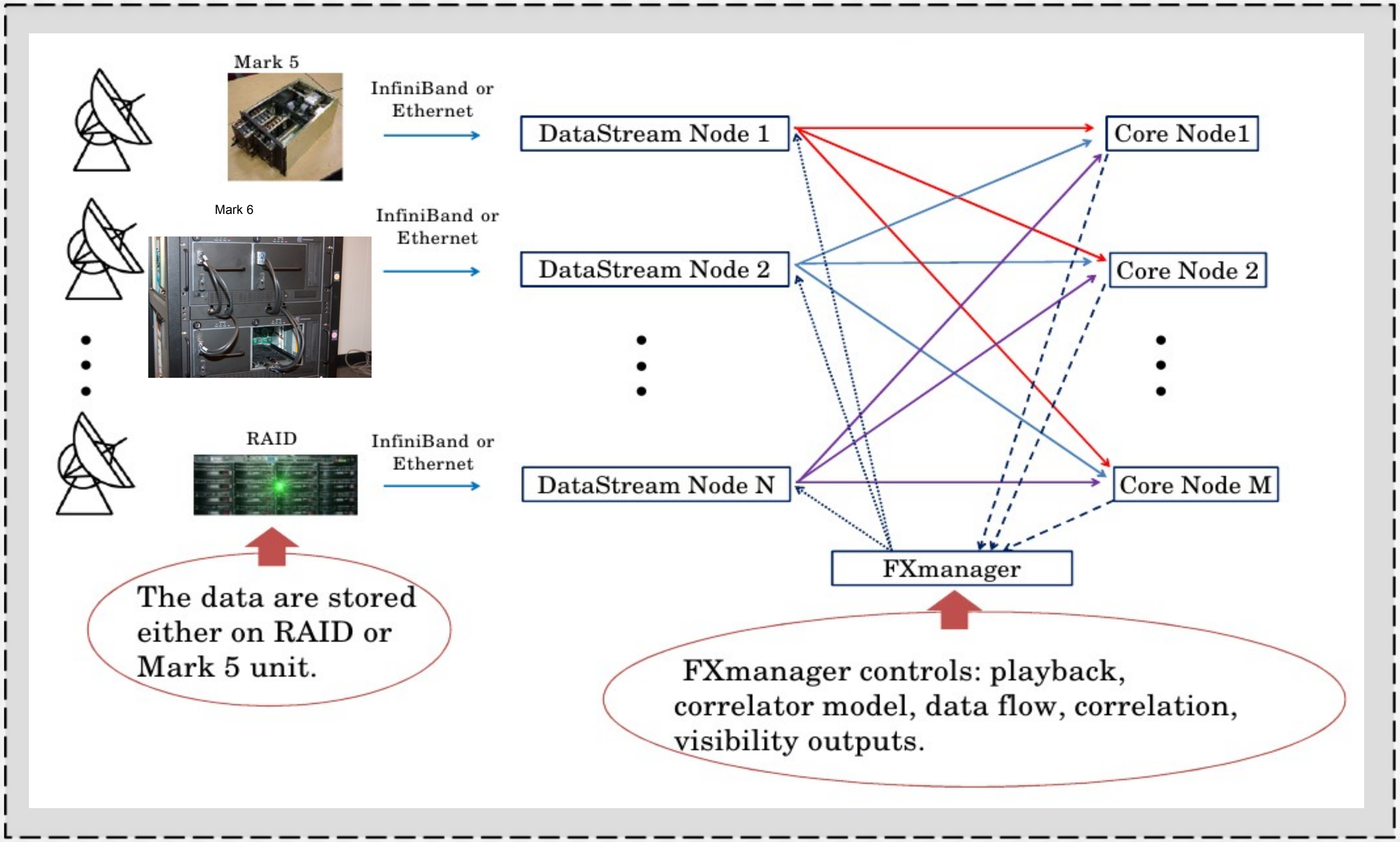
fxmanager

appliance

Interconnected via 20 Gbps infiniband to RAIDs and 15 Mark5 units

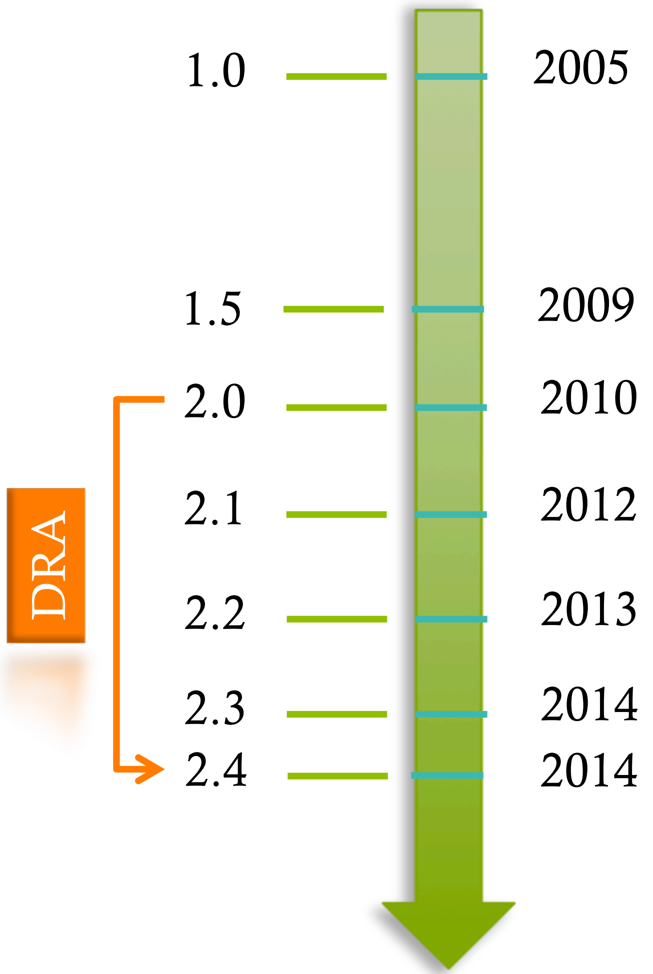
# The HPC cluster

Individual ground stations data are sent to Bonn, on diskpacks or by e-transfer (when e-VLBI link is available). Correlation both from diskpacks and RAIDs



# dra-DiFX

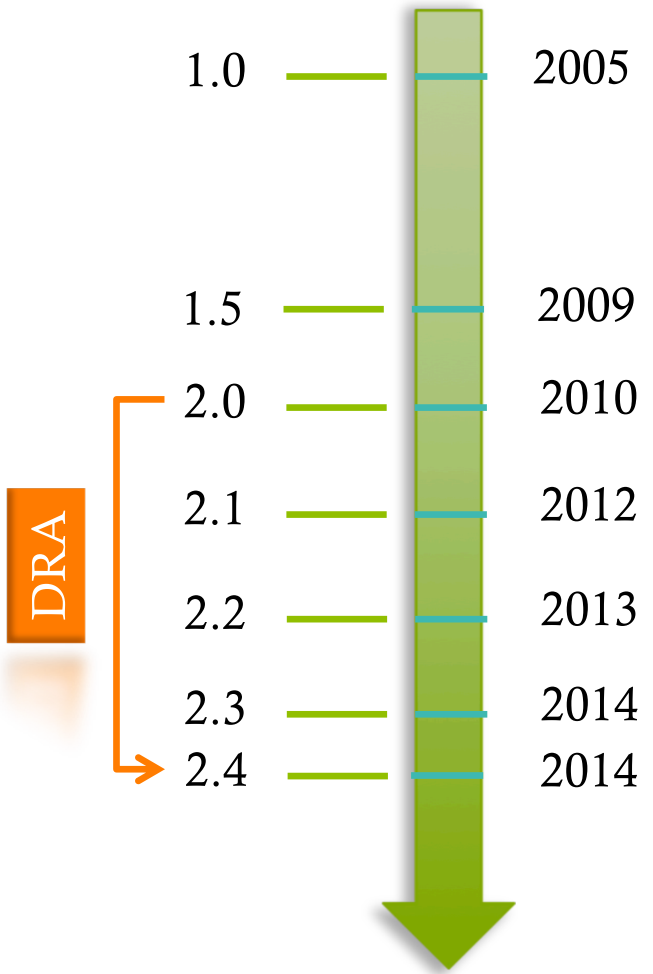
- DRA branched from version 2.0 by J. Anderson, on-going merging with 2.4
- RDF-Mark5B conversion routine, to read in data from RadioAstron
- Enabling delay model server Calc (Calc/Solve Package) to calculate delay information
- Introducing general relativistic corrections in the delay model
- Changing DiFX metadata system to deal with variable position/velocity of the spaceborne antenna



# dra-DiFX

- Calculating the delay for the transmission of the signal from the spacecraft to the tracking station

- Calculating the equivalent of parallactic angle correction for the spaceborne antenna from the antenna orientation obtained from the telemetry information.

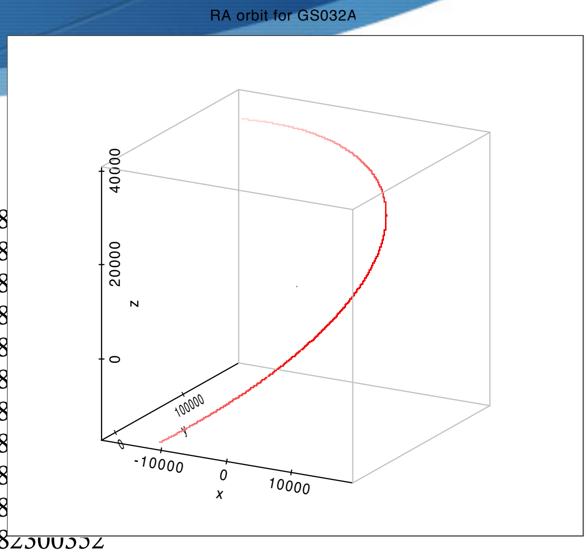


# dra-DiFX

## Orbit file:

…

| | | | | | | |
|---|---|---|---|---|---|---|
| 2013-03-10T09:00:00.000 | -40177.873238 | 179880.300449 | 112805.540864 | -.533000678 | 1.045017344 | -.28 |
| 2013-03-10T09:00:01.000 | -40178.406237 | 179881.345463 | 112805.258606 | -.532999118 | 1.045010237 | -.28 |
| 2013-03-10T09:00:02.000 | -40178.939236 | 179882.390470 | 112804.976343 | -.532997557 | 1.045003131 | -.28 |
| 2013-03-10T09:00:03.000 | -40179.472233 | 179883.435469 | 112804.694077 | -.532995996 | 1.044996025 | -.28 |
| 2013-03-10T09:00:04.000 | -40180.005228 | 179884.480462 | 112804.411805 | -.532994435 | 1.044988919 | -.28 |
| 2013-03-10T09:00:05.000 | -40180.538221 | 179885.525447 | 112804.129529 | -.532992874 | 1.044981813 | -.28 |
| 2013-03-10T09:00:06.000 | -40181.071214 | 179886.570426 | 112803.847249 | -.532991314 | 1.044974707 | -.28 |
| 2013-03-10T09:00:07.000 | -40181.604204 | 179887.615397 | 112803.564964 | -.532989753 | 1.044967601 | -.28 |
| 2013-03-10T09:00:08.000 | -40182.137193 | 179888.660361 | 112803.282675 | -.532988192 | 1.044960495 | -.28 |
| 2013-03-10T09:00:09.000 | -40182.670180 | 179889.705318 | 112803.000381 | -.532986631 | 1.044953389 | -.28 |
| 2013-03-10T09:00:10.000 | -40183.203166 | 179890.750268 | 112802.718083 | -.532985070 | 1.044946283 | -.282300352 |
| 2013-03-10T09:00:11.000 | -40183.736151 | 179891.795210 | 112802.435781 | -.532983510 | 1.044939177 | -.282304812 |
| 2013-03-10T09:00:12.000 | -40184.269133 | 179892.840146 | 112802.153474 | -.532981949 | 1.044932071 | -.282309273 |




## Orientation file:

\# RadioAstron position information for experiment raks03a
\# Coordinates are equatorial J2000 measured in degrees
\# Time is UTC

| #obscode | time | X R.A. | X DEC | Y R.A. | Y DEC | Z R.A. | Z DEC |
|---|---|---|---|---|---|---|---|
| raks03a | 2013-09-21 15:10:35 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:06 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:08 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:12 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:22 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:26 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |
| raks03a | 2013-09-21 15:11:31 | 49.9768825932 | 41.4751393042 | 89.22400818 | -41.2214168807 | 159.691649 | 20.8881066585 |

…

# dra-DiFX

```
NUM_IF is 2
NUM_TIME is 5690
NUM_CHAN is 512
NUM_STOKES is 4
INT_TIME is 1.000000E-01
CHAN_BW is 3.125000E+04
r00
FFT along the channel direction for many timeslots
FFT along the time direction for many channels, for 1 stagger groups
Stagger   0 Mean   1.9159460E+02 StdDev   1.0017288E+02
Stagger   0 Peak  0 Delay_Pos    46   1.438E-06 [s] Rate_Pos   4985   4.380E+00 [Hz] Value   7.1873825E+00
Stagger   0 Peak  1 Delay_Pos   484   1.513E-05 [s] Rate_Pos   3152   2.770E+00 [Hz] Value   7.1171250E+00
Stagger   0 Peak  2 Delay_Pos  -112  -3.500E-06 [s] Rate_Pos  -3646  -3.204E+00 [Hz] Value   6.5512319E+00
Stagger   0 Peak  4 Delay_Pos   267   8.344E-06 [s] Rate_Pos  -5182  -4.554E+00 [Hz] Value   6.4332413E+00
Stagger   0 Peak  8 Delay_Pos    15   4.687E-07 [s] Rate_Pos   3424   3.009E+00 [Hz] Value   6.3186945E+00
Stagger   0 Peak  9 Delay_Pos   309   9.656E-06 [s] Rate_Pos   -956  -8.401E-01 [Hz] Value   6.2007380E+00
Stagger   0 Peak 10 Delay_Pos   393   1.228E-05 [s] Rate_Pos  -4665  -4.099E+00 [Hz] Value   6.1537276E+00
Stagger   0 Peak 11 Delay_Pos   183   5.719E-06 [s] Rate_Pos   1061   9.323E-01 [Hz] Value   6.1517279E+00
Stagger   0 Peak 14 Delay_Pos   380   1.187E-05 [s] Rate_Pos  -1049  -9.218E-01 [Hz] Value   6.0672048E+00
Peak closest to 0,0
Stagger   0 Peak  9 Delay_Pos   309   9.656E-06 [s] Rate_Pos   -956  -8.401E-01 [Hz] Value   6.2007380E+00
Fringe-fitting has  1024 frequency channels (center at    512)
Fringe-fitting has  11380 time slots (center at   5690)
r01
FFT along the channel direction for many timeslots
FFT along the time direction for many channels, for 1 stagger groups
Stagger   0 Mean   1.9093617E+02 StdDev   9.9786536E+01
Stagger   0 Peak  0 Delay_Pos    27   8.437E-07 [s] Rate_Pos   -174  -1.529E-01 [Hz] Value   1.1176270E+01
Stagger   0 Peak  8 Delay_Pos   457   1.428E-05 [s] Rate_Pos  -3596  -3.160E+00 [Hz] Value   6.7450432E+00
Stagger   0 Peak  9 Delay_Pos  -437  -1.366E-05 [s] Rate_Pos  -2309  -2.029E+00 [Hz] Value   6.6589090E+00
Stagger   0 Peak 11 Delay_Pos    -2  -6.250E-08 [s] Rate_Pos   3751   3.296E+00 [Hz] Value   6.3564898E+00
Stagger   0 Peak 13 Delay_Pos  -123  -3.844E-06 [s] Rate_Pos   4276   3.757E+00 [Hz] Value   6.2546752E+00
Stagger   0 Peak 14 Delay_Pos  -108  -3.375E-06 [s] Rate_Pos   3098   2.722E+00 [Hz] Value   6.2131167E+00
Stagger   0 Peak 15 Delay_Pos  -428  -1.337E-05 [s] Rate_Pos   3721   3.270E+00 [Hz] Value   6.1976198E+00
Stagger   0 Peak 17 Delay_Pos  -180  -5.625E-06 [s] Rate_Pos    545   4.789E-01 [Hz] Value   6.1765788E+00
Stagger   0 Peak 21 Delay_Pos   270   8.438E-06 [s] Rate_Pos  -2191  -1.925E+00 [Hz] Value   6.0806752E+00
Peak closest to 0,0
Stagger   0 Peak  0 Delay_Pos    27   8.437E-07 [s] Rate_Pos   -174  -1.529E-01 [Hz] Value   1.1176270E+01
Fringe-fitting has  1024 frequency channels (center at    512)
Fringe-fitting has  11380 time slots (center at   5690)
…
```

- After correlation fringe-fitting with dedicated software by J. Anderson. Larger fringe-search window needed, (HOPS limit is 1024 channels)
- No limits to delay & rate window, only CPU time.
- Output is first 10 peaks for every IF (BBC channel) and polarisation (RR, LL, RL, LR) in the fringe-search window
- RadioAstron fringes are usually found in a 1024 chan x 0.1 sec search window

# dra-DiFX

Open issues & future developments:

- Spacecraft acceleration terms correction: a posteriori inclusion possible with PIMA
- Inclusion of the on-board maser information from telemetry data: no clock-reference for RA is present at the moment. Delay & rates added for every scan in the VEX (rate) and V2D (delay) file as clockfudge
- Automatic conversion of the native RDF data format to Mark5B: now performed through python script before correlation
- VDIF full compatibility: at the moment correlation possible only after multi-thread to single-thread conversion with *vmux*

# KSPs at MPIfR

- Structure of compact jets in strong AGN (*AGN-S*)

M. Perucho, A.P. Lobanov, T. Savolainen, T.B. Muxlow, I. Agudo, J.M. Anderson, U. Bach, R. Beswick, R. Davis, P. Edwards, J.A. Eilek, C.M. Fromm, S.T. Garrington, J.L. Gómez, P.E. Hardee, Y.Y. Kovalev, T.P. Krichbaum, S.-S. Lee, J.M.Martí, D.L.Meier, P. Mimica, E. Ros, F. Schinzel, K. Sokolovsky, P. Wilkinson, J.A. Zensus

- Nearby AGN at scales of 5—500 gravitational radii (*AGN-N*)

T. Savolainen, G. Giovannini, K. Hada, S. Tingay, T.P. Krichbaum, A. Lobanov, M. Orienti, J.M. Anderson, U. Bach, B. Boccardi, C. Casadio P. Edwards, J. Eilek, C.M. Fromm, M. Giroletti, P. Hardee, Y. Hagiwara, M. Honma, M. Kino, Y.Y. Kovalev, S.-S. Lee, D.L. Meier, H. Nagai, S.P. O'Sullivan, C. Reynolds, F. Schinzel, B.W. Sohn, K.V. Sokolovsky, J.A. Zensus

- Polarization and magnetic fields in compact jets (*AGN-P*)

J. L. Gómez, A. P. Lobanov, I. Agudo, A. Alberdi, J. M. Anderson, U. Bach, M. Bell, S. Bernhart, C. Casadio, T. V. Cawthorne, E. Clausen-Brown, J. Eilek, C. Fromm, D. Homan, S. G. Jorstad, M. Keck, Y. Y. Kovalev, T. P. Krichbaum, S. S. Lee, A. P. Marscher, J. M. Mart, S. Molina, K.-I. Nishikawa, M. A. Perez Torres, M. Perucho, E. Ros, T. Savolainen, B. W. Sohn, K. V. Sokolovsky, G. B. Taylor, J. A. Zensus

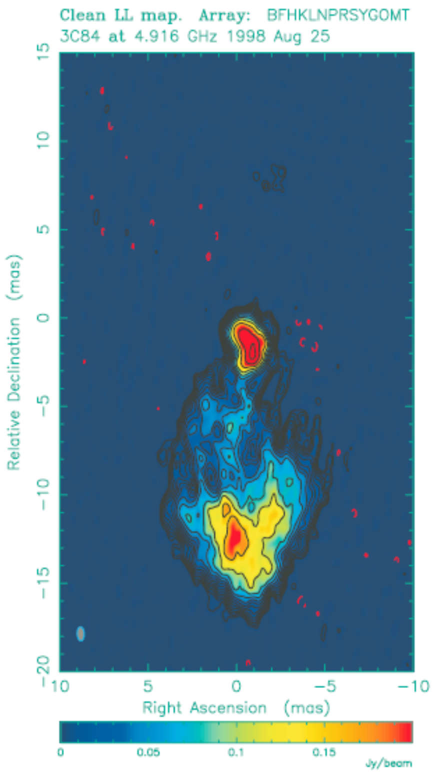
# Nearby AGNs

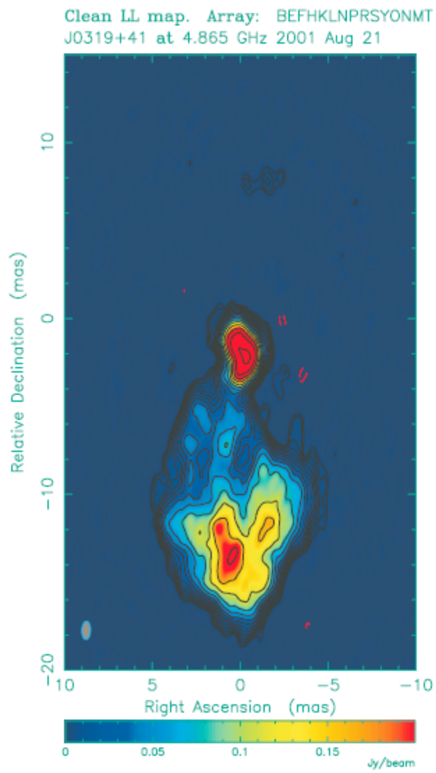
RadioAstron by Savolainen et al. (2013)

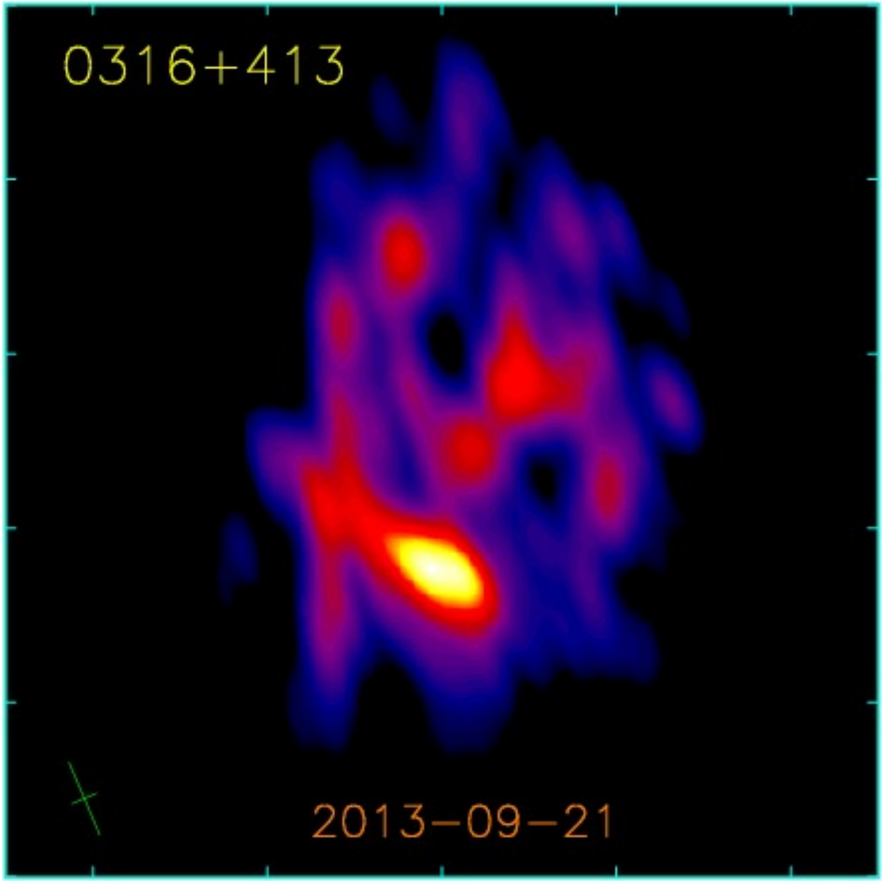
resolution of 0.45x0.15 mas at 5GHz

VSOP observations by Asada et al. (2006)

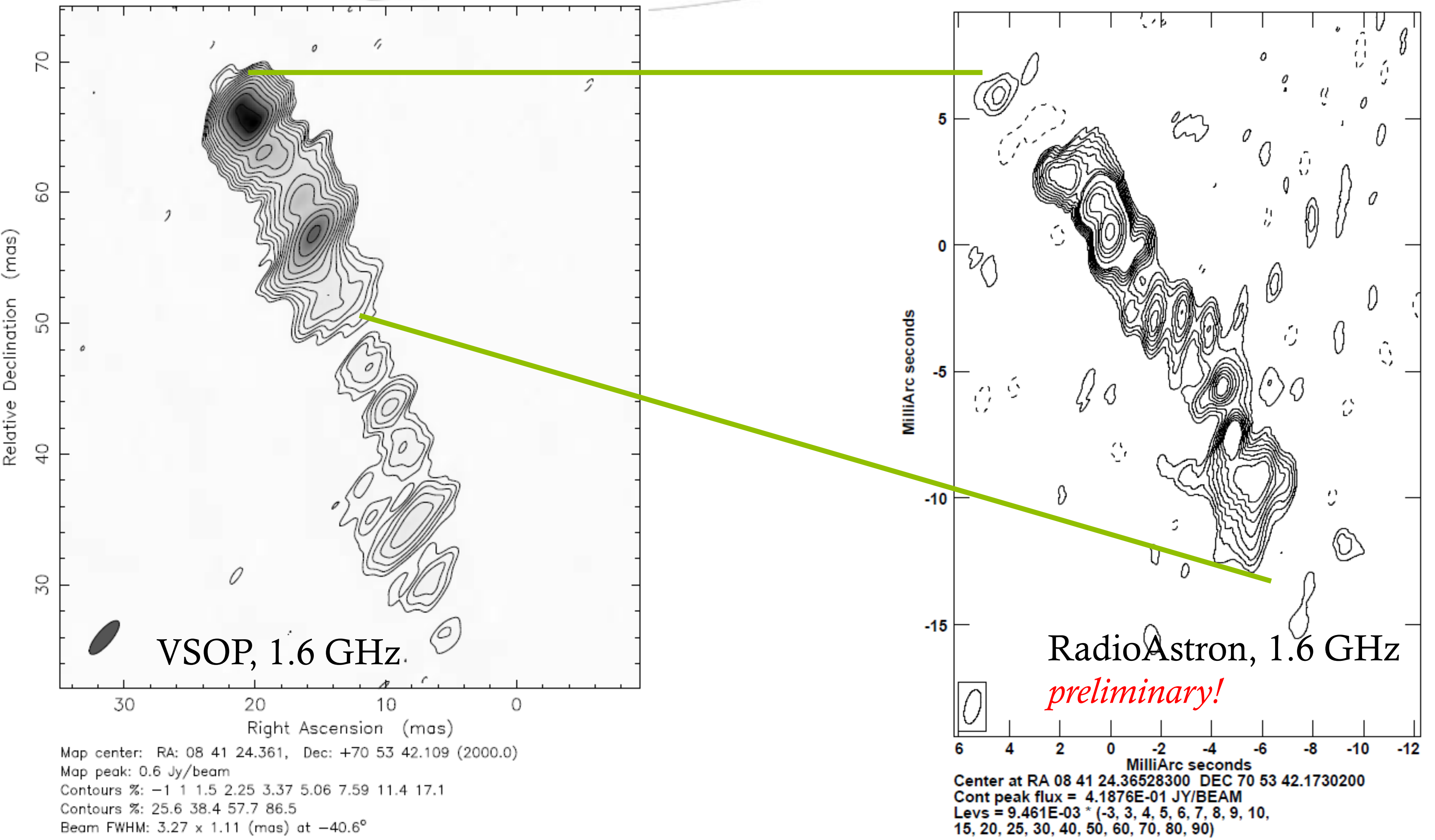
Resolution of 0.78x0.39 mas at 5GHz



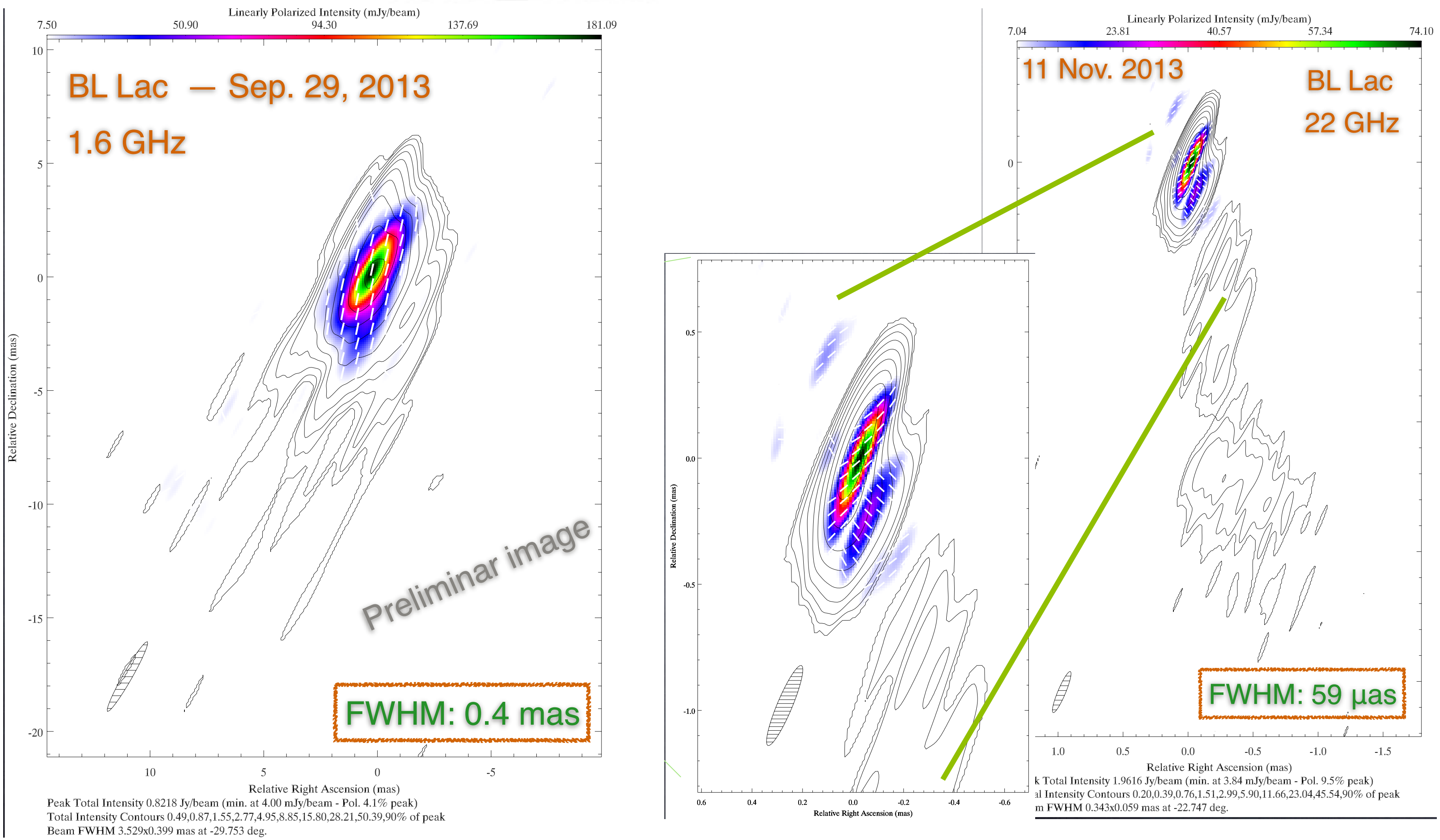



# Strong AGNs



Relative Declination (mas)
70
60
50
40
30
30
20
10
0
Right Ascension (mas)
VSOP, 1.6 GHz
Map center: RA: 08 41 24.361, Dec: +70 53 42.109 (2000.0)
Map peak: 0.6 Jy/beam
Contours %: −1 1 1.5 2.25 3.37 5.06 7.59 11.4 17.1
Contours %: 25.6 38.4 57.7 86.5
Beam FWHM: 3.27 x 1.11 (mas) at −40.6°
MilliArc seconds
5
0
-5
-10
-15
6
4
2
0
-2
-4
-6
-8
-10
-12
MilliArc seconds
RadioAstron, 1.6 GHz
preliminary!
Center at RA 08 41 24.36528300 DEC 70 53 42.1730200
Cont peak flux = 4.1876E-01 JY/BEAM
Levs = 9.461E-03 * (-3, 3, 4, 5, 6, 7, 8, 9, 10,
15, 20, 25, 30, 40, 50, 60, 70, 80, 90)

# Polarisation in AGNs



…Thanks for your attention!