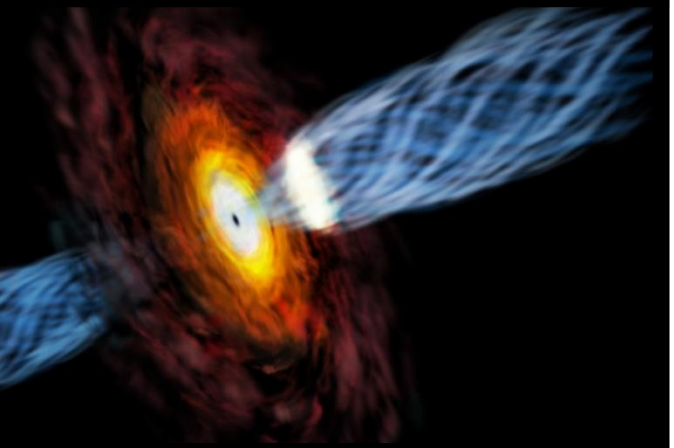
High frequency VLBI imaging of OVV 1633+382

Hyunwook Ro (KASI / Yonsei Univ.)

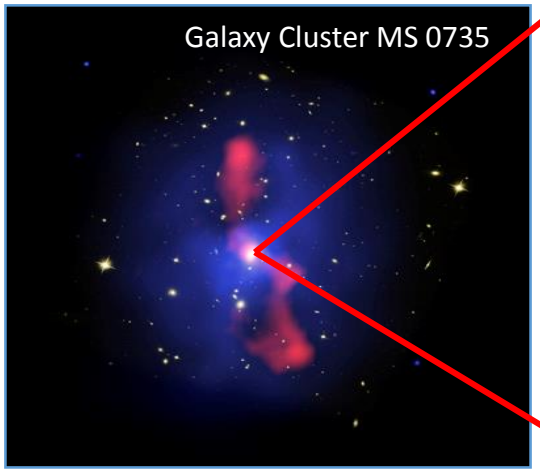
Bong Won Sohn (KASI), Aeree Chung(Yonsei Univ.)



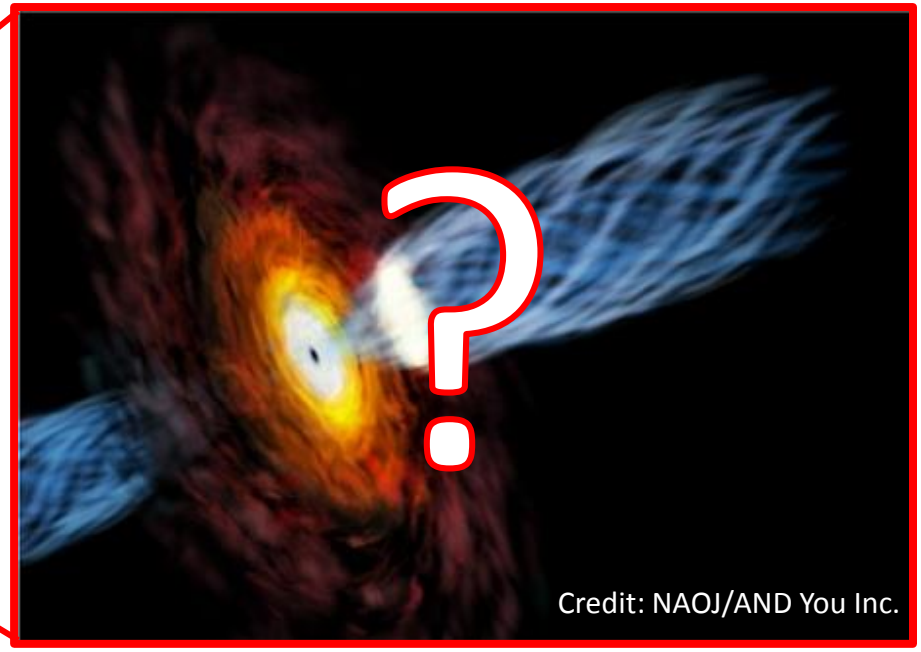
Credit: NAOJ/AND You Inc.

Introduction : pc-scale AGN jet

- pc-scale jet physics : missing link between AGN jet and feedback
  - "We suggest that radio, maintenance-mode feedback is responsible for keeping hot gas hot in individual giant ellipticals and in clusters of galaxies. The microphysics of this process is not well understood. Can radio jet energy be confined within individual galaxies and can it be thermalized?" (Kormendy & Ho 2013 Review)

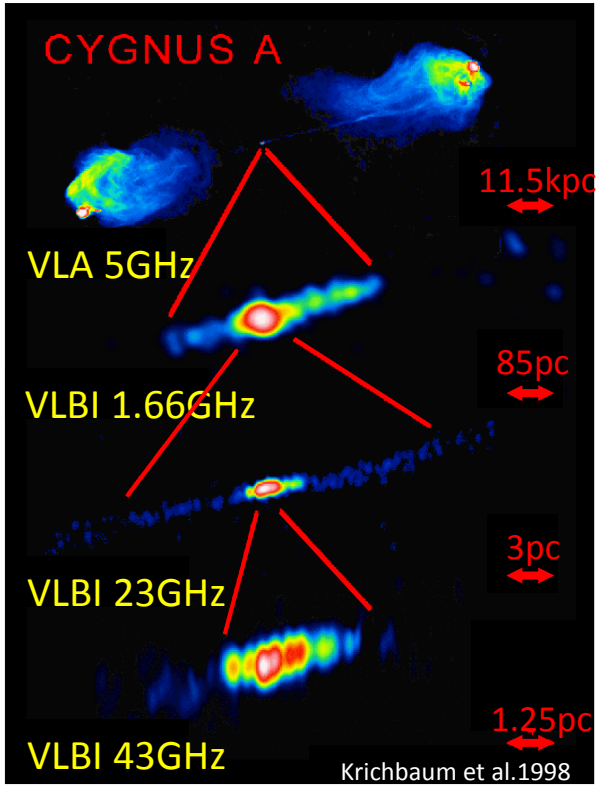


Credit: NASA, ESA, CXC, STScI, NRAO, B. McNamara and L. Birzan



Introduction : pc-scale AGN jet

- Needs for VLBI (Very Long Baseline interferometry) observation
  - Very high anglular resolutions can be synthesized (e.g. @43GHz, ~ 0.17mas has using the largest VLBI on the Earth)
  - High radio frequencies allow us to probe detailed structures of the inner region of the AGN jet

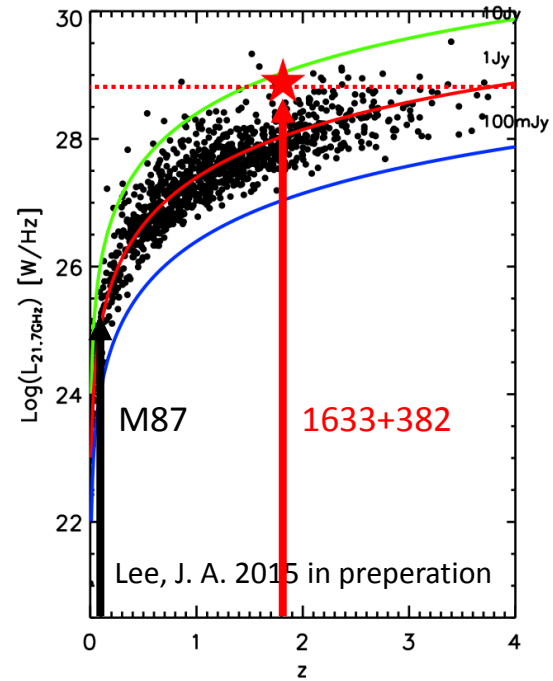


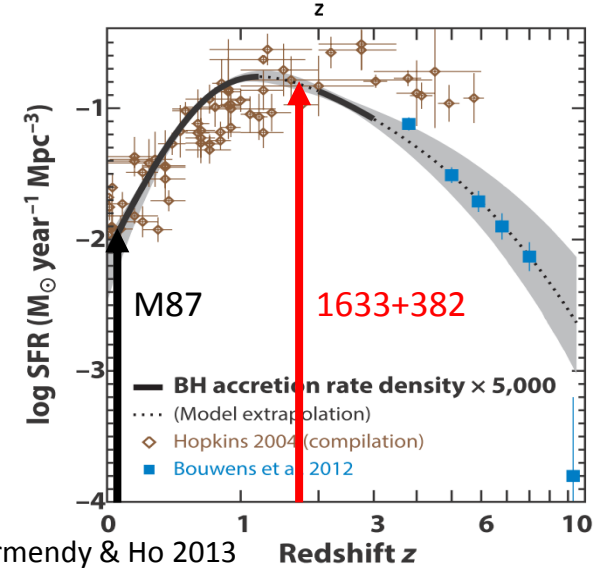
Krichbaum et al.1998

Target of this study : OVV 1633+382

- **OVV 1633+382**
  - FR II with small line-of-sight angle : blazar
  - Very powerful radio luminosity
  - High z : 1.813
  - High accretion rate
  - Feedback is active ('quasar' mode)?

c.f. M87
  - FR I
  - Low z : 0.004238 (17Mpc)
  - Relatively low accretion rate
  - Modest feedback ('maintanence' mode)?

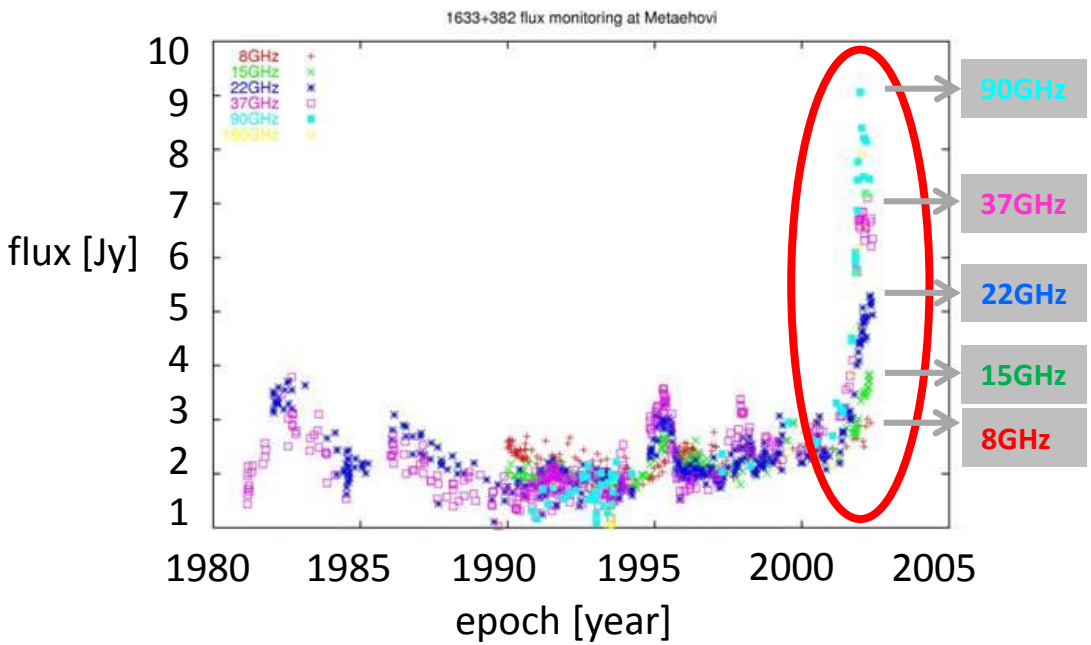




Kormendy & Ho 2013

Target of this study : OVV 1633+382

- Near 2002, a major flare occurred in mm wavelength
  - A dense and bright outflow is expected after the flare
- Larger flux at higher frequency
  - Flare occurred inner part of the jet



Terasranta, H. in private communication

Observation

- Very Large Baseline Array (VLBA) + Effelsberg 100m radio telescope

- 12 epochs between 2002 – 2005
  - VLBA + EB for 9 epochs

→ Investigate the evolution of the jet properties

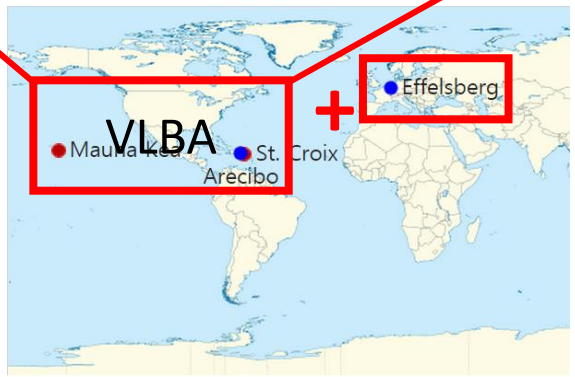
- 3 frequencies : 22, 43, 86 GHz

→ Probe jet structure in different scales and probe spectral index

- Full polarization observations

→ Probe magnetic field properties

https://www.nasa.gov/sites/default/files/images/615020main_VLBA_labels.jpg



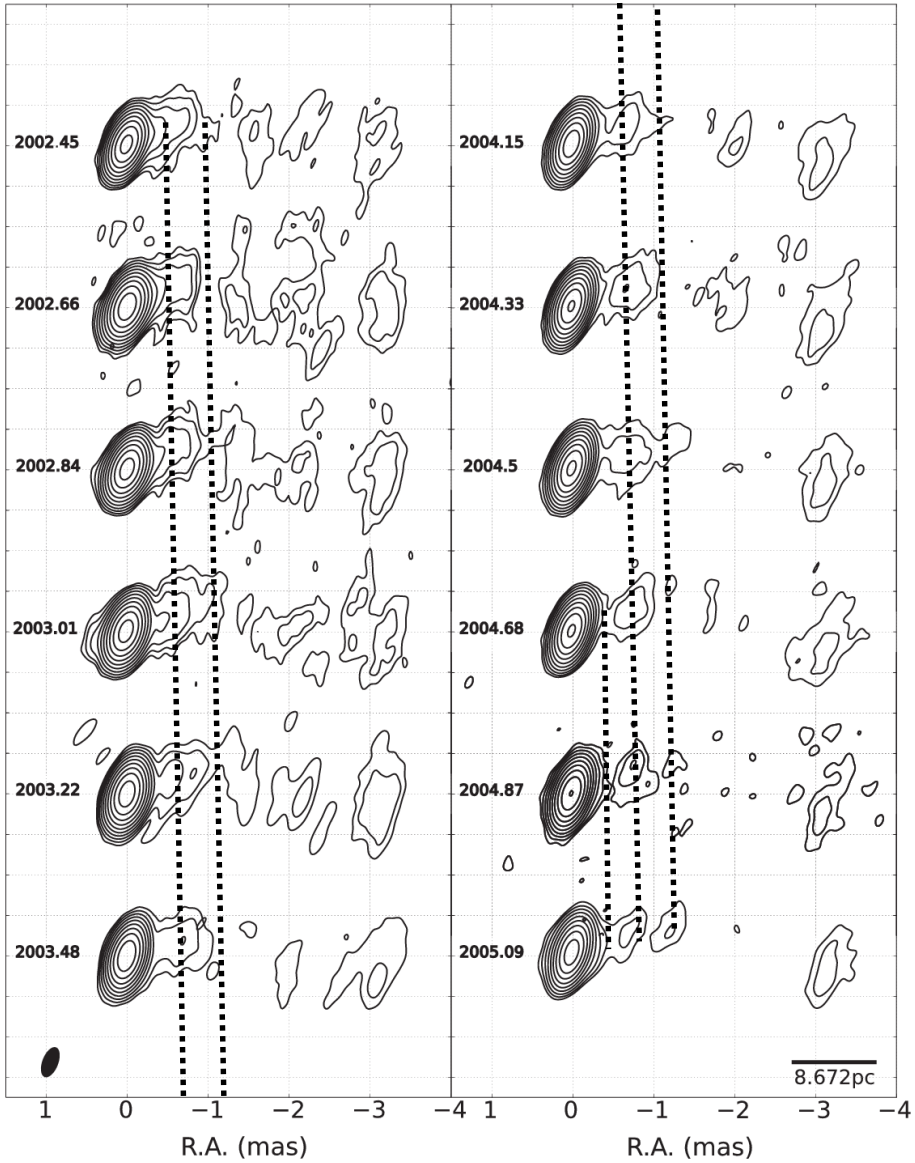
https://en.wikipedia.org/wiki/Very_Long_Baseline_Array

Data reduction and imaging

- Data reduction and imaging tools
  : AIPS(Astronomical Image Processing System), difmap
- Current progress of data reduction : all 43 GHz data and 5 epochs of 22GHz data have been processed (polarization not calibrated yet)

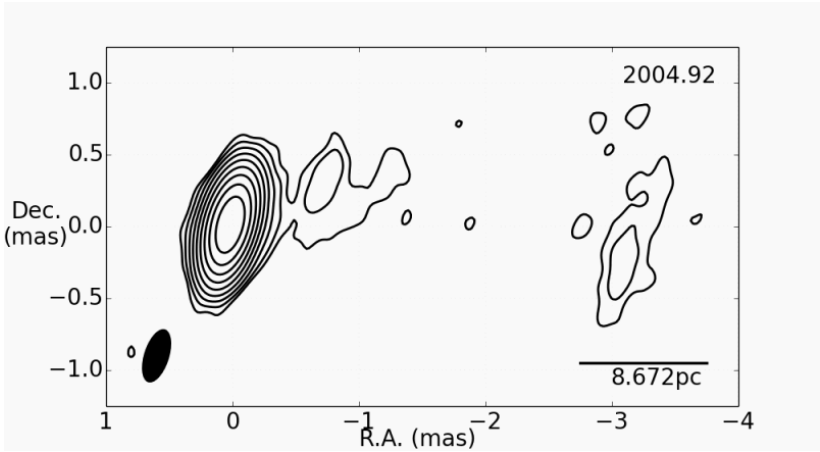
obs. epoch	2002.45	2002.66	2002.84	2003.01	2003.22	2003.48
22GHz	…	…	o	o	…	…
43GHz	o	o	o	o	o	o
86GHz	…	…	…	…	…	…
obs. epoch	**2004.15**	**2004.33**	**2004.50**	**2004.68**	**2004.87**	**2005.09**
22GHz	…	o	…	o	…	o
43GHz	o	o	o	o	o	o
86GHz	…	…	…	…	…	…

<Time sequence of 43GHz images>

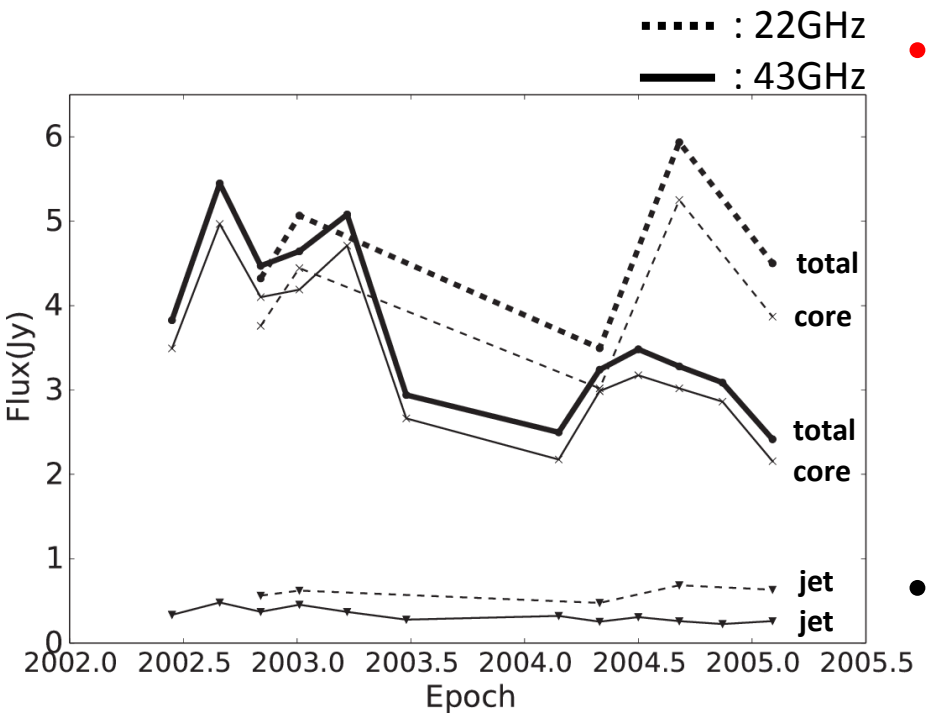


Result 1 : Total intensity maps

- One-sided jet, overall extends ~30pc
- The component located ~ 3mas from the core is stationary
- Inner jet (< 1.5mas) : grows with time, consists of 2-3 components



Result 2 : Flux variation



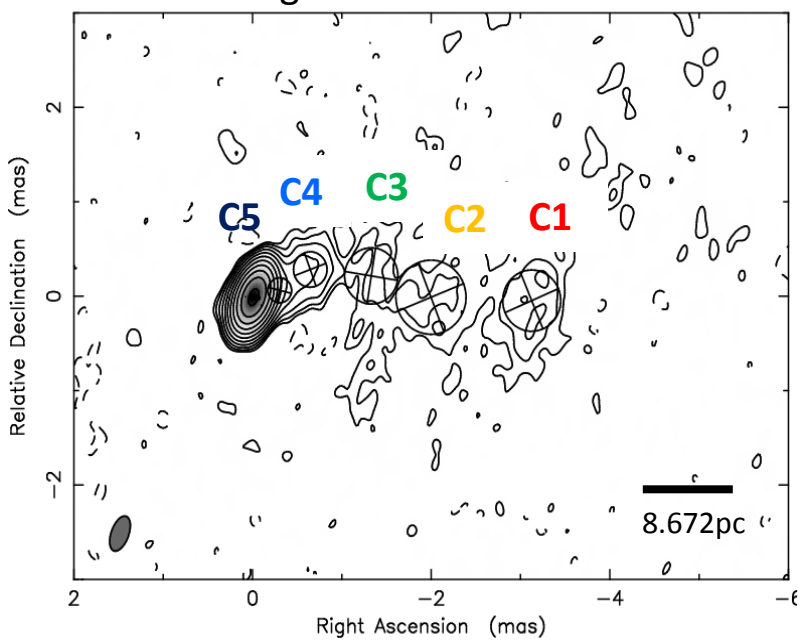
- Significant flux variation
  : characteristic of blazar

	average [Jy]	stdev. [Jy]	**stdev. / average [%]**
43GHz	3.70	0.96	**25.8**
22GHz	4.66	0.81	**17.4**

- The total flux variation strongly correlates with the core flux variation

Result 3 : Model-fitting

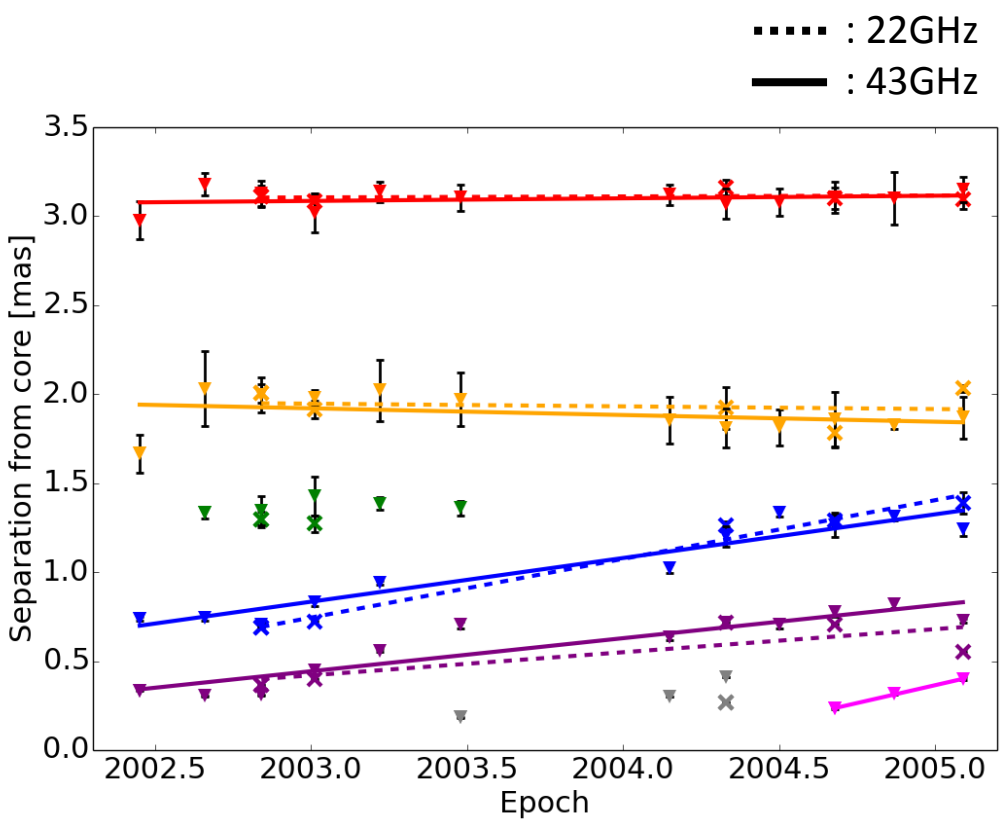
model-fitting result



- ‘modelfit’ task inside the difmap package
- Independent components that are found by 2D Gaussian fitting
- Distance from the core, position angle, size, and the flux can be measured from each Gaussian component

component	C5	C4	C3	C2	C1
distance [mas]	0.31±0.0	0.71±0.01	1.35±0.08	2.0±0.1	3.13±0.07
position angle [˚]	-78.36±0.46	-66.36±0.97	80.82±3.47	-90.31±2.81	-90.86±1.29
width [mas]	0.27±0.01	0.38±0.02	0.6±0.16	0.79±0.2	0.65±0.14
flux [mJy]	75.6±69.2	82.5±21.0	27.9±9.2	63.6±16.8	77.1±17.8

Discussion 1 : Superluminal motion and jet orientation



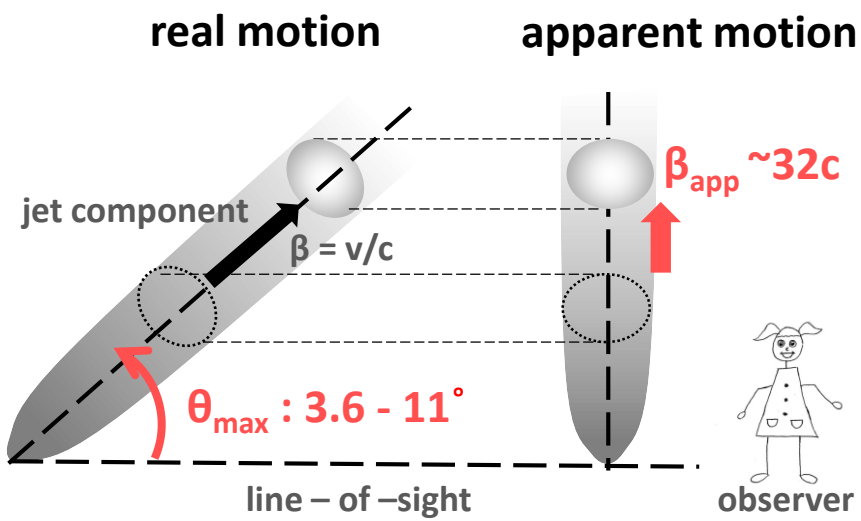
	proper motion μ [mas/yr]		apparent velocity β_{app} (= v/c)	
	22GHz	43GHz	22GHz	43GHz
C1	0.01 (0.0)	0.01 (0.03)	0.43 (0.28)	1.16 (2.6)
C2	-0.02 (0.04)	-0.04 (0.12)	-1.2 (2.96)	-2.99 (9.42)
C4	0.33 (0.01)	0.25 (0.05)	26.25 (0.75)	19.54 (4.27)
C5	0.13 (0.04)	0.19 (0.07)	10.33 (3.3)	14.77 (5.25)
C7	-	0.4 (0.0)	-	31.9 (0.0)

- Outer components (C1, C2) : almost stationary during the epochs
- Inner components (C4, C5, C7) : superluminal motion (up to ~ 32c)

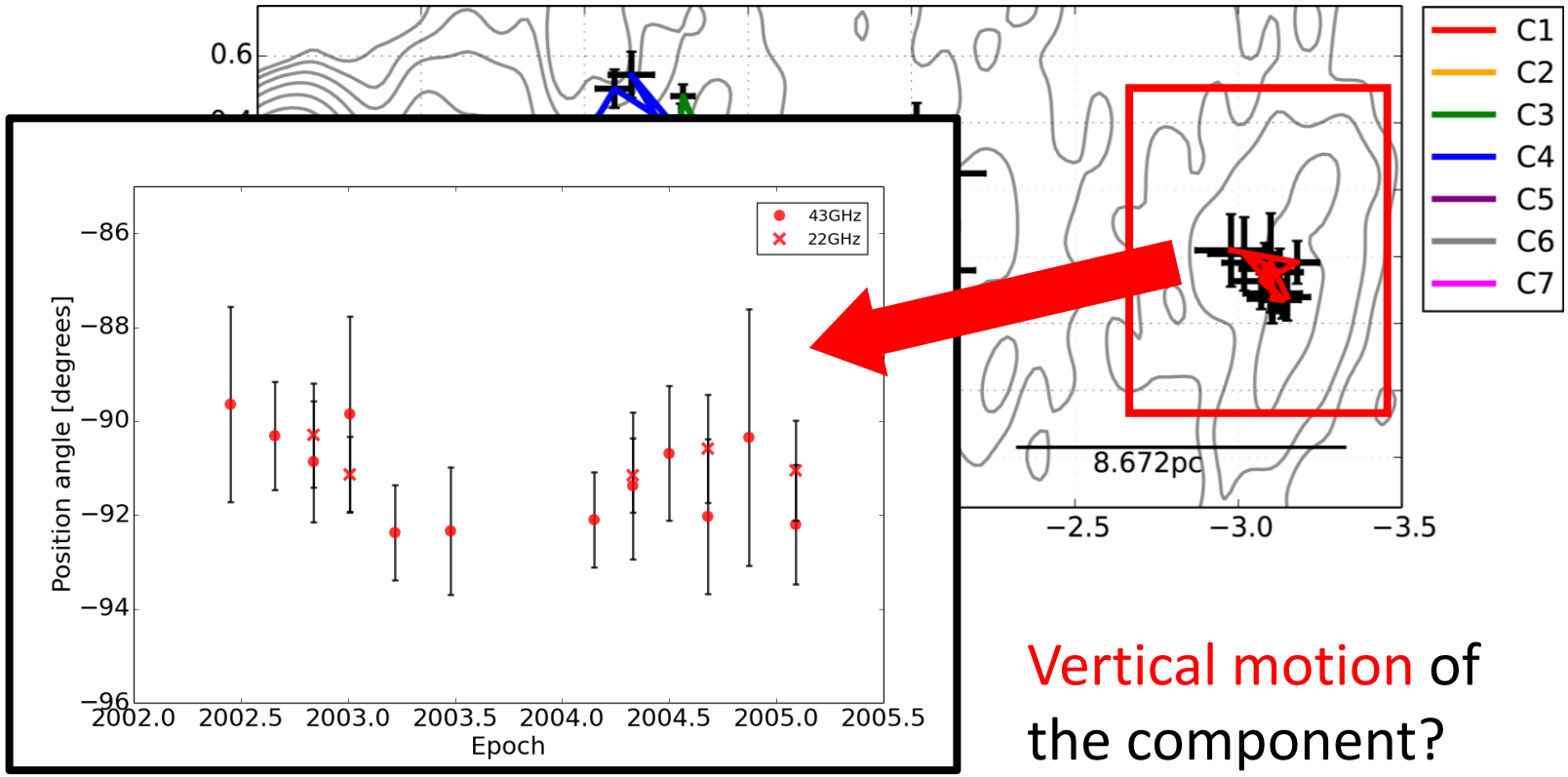
Discussion 1 : Superluminal motion and jet orientation

	apparent velocity β_{app} (= v/c)		maximum viewing angle θ_{max} [˚]	
	22GHz	43GHz	22GHz	43GHz
C1	0.43 (0.28)	1.16 (2.6)	133.29 (27.07)	81.38 (126.52)
C2	-1.2 (2.96)	-2.99 (9.42)	79.49 (138.66)	36.94 (108.38)
C4	26.25 (0.75)	19.54 (4.27)	4.36 (0.1)	5.86 (1.28)
C5	10.33 (3.3)	14.77 (5.25)	11.06 (3.51)	7.75 (2.74)
C7	-	31.9 (0.0)	-	3.59 (0.0)

- Maximum viewing angle : 3.6 ~ 11˚
- The jet is slightly offset from the observer's line-of-sight



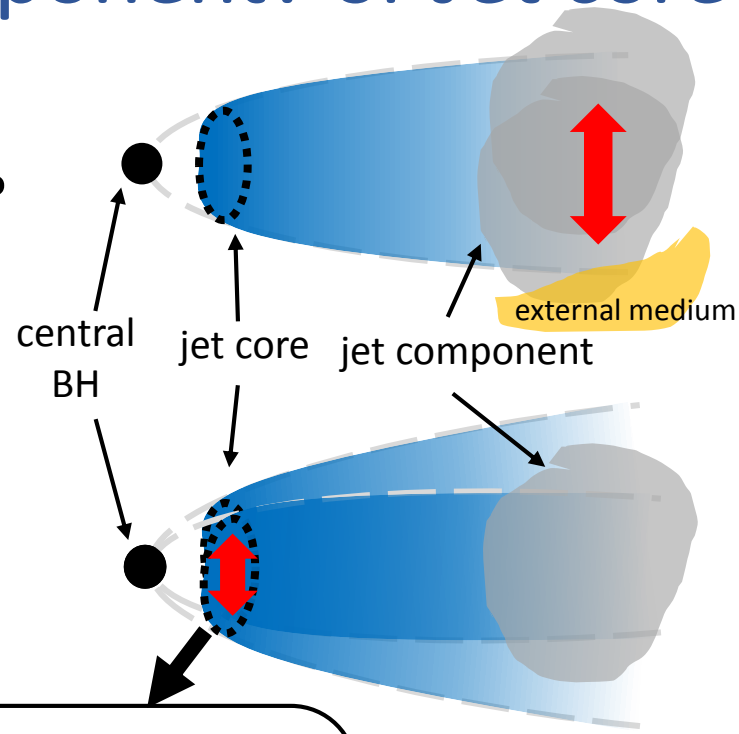
Discussion 2 : Which one is moving. Component? or Jet core?

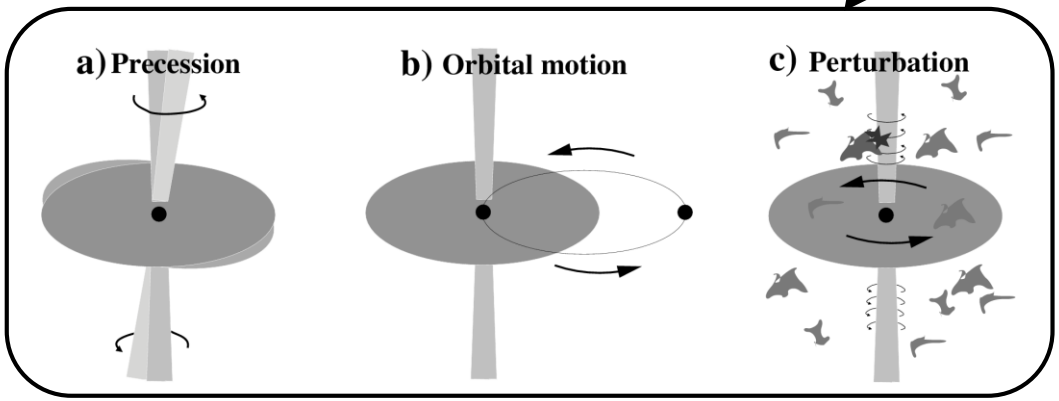


Vertical motion of the component?

Discussion 2 : Which one is moving. Component? or Jet core?

- Possible scenarios
  1. Motion of the component
     - Interaction with external medium?
  2. Motion of the jet core (reference position)
     - Accretion disk precession?
     - Binary blackhole?
     - Perturbation by something else (e.g. Kelvin Helmholtz instability)?





Agudo 2009

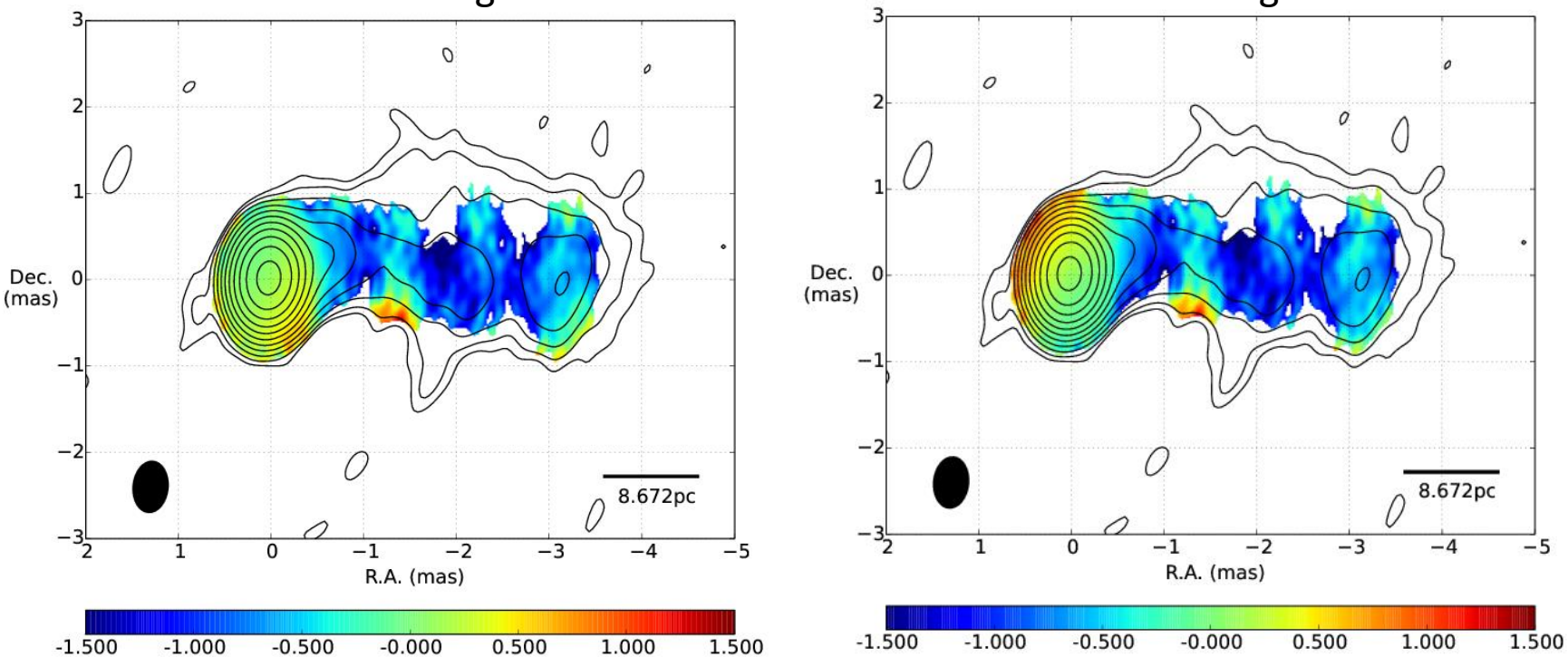
Future works

- Further test the robustness of the results from the model-fit and compare the results of different frequencies and epochs
  - Study detailed motion of outer(~3mas) and inner(<1.5mas) components
- 22 - 43GHz Spectral index properties
  - Amout of synchrotron self-absorption (electron density)
  - Compare synchrotron ages along the jet
- Polarization properties : magnetic field structure
  - Rotation measure → magnetic field strength along line of sight
  - Degree of polarization → amount of depolarization
  - Polarization angle → magnetic field direction

Spectral index maps : Preliminary result

ΔR.A = 0.02mas, ΔDec. = -0.035mas

before align → after align

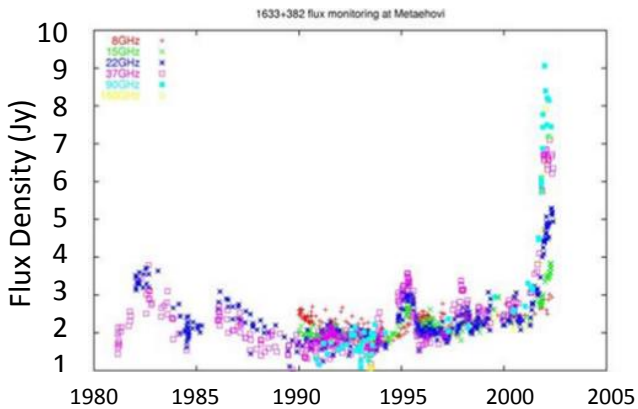


- Model fitting result is not unique.

→ Combine additional way of image alignment (2D correlation method)

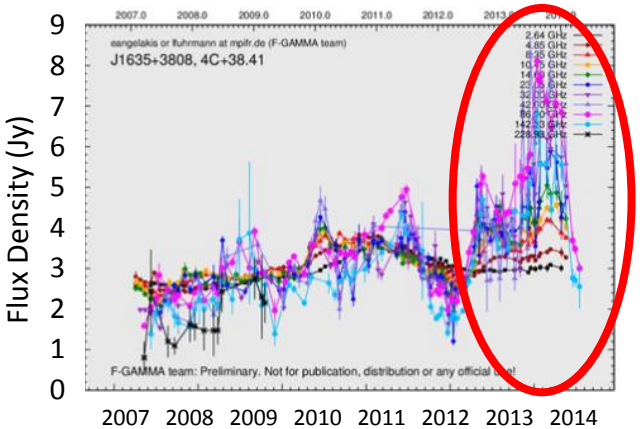
New major flare – KaVA proposal

flare @ mm wavelength ~2002

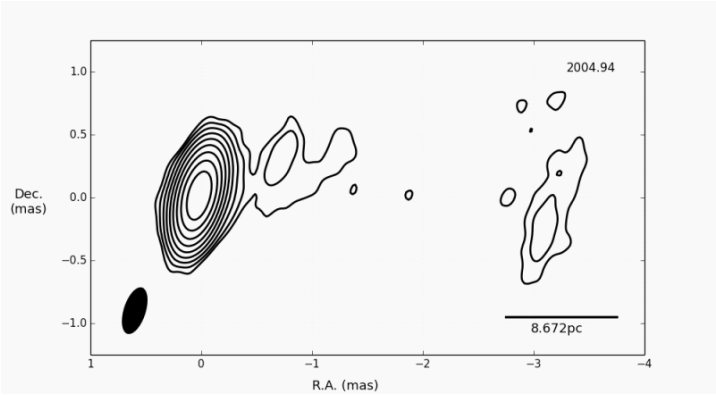


Credit : Terasranta, H.

flare @ mm wavelength ~2013



http://www3.mpifr-bonn.mpg.de/div/vlbi/fgamma/results.html



?

KaVA proposal :
22GHz and 43GHz
2 epochs