

15 GHz VLBI detection of the HST-1 feature in the M87 jet

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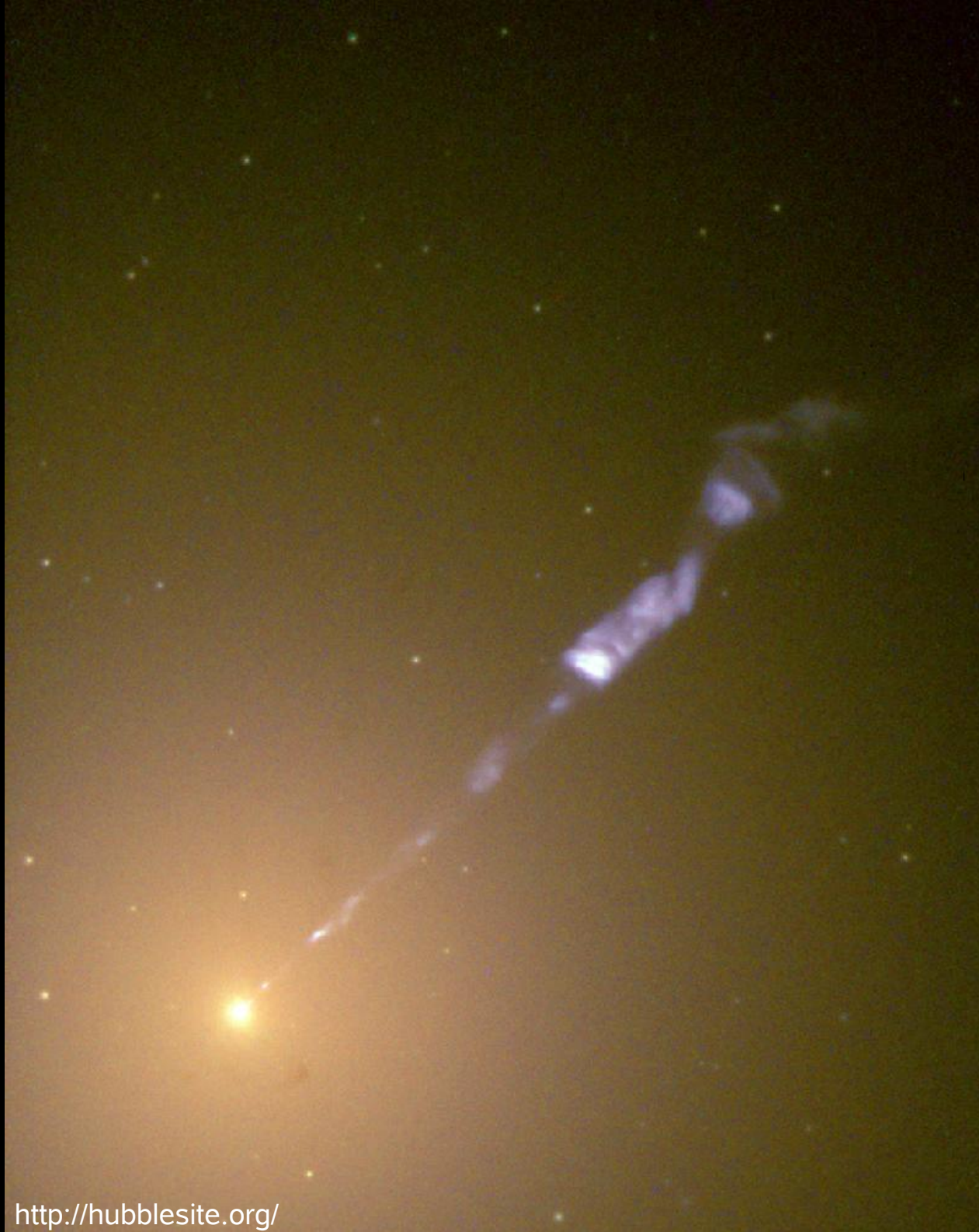
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⁵Purdue University

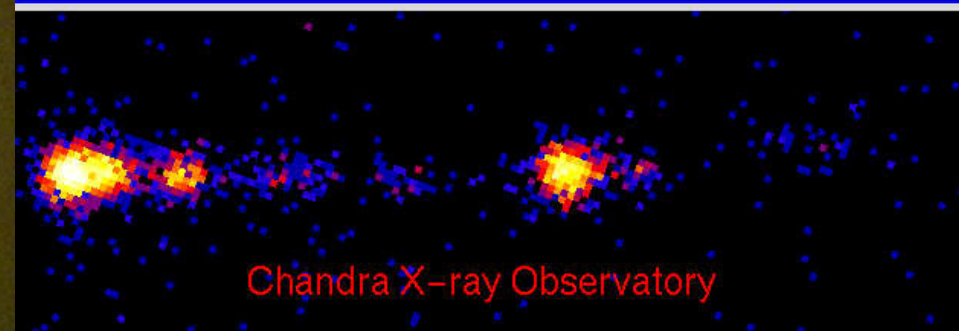
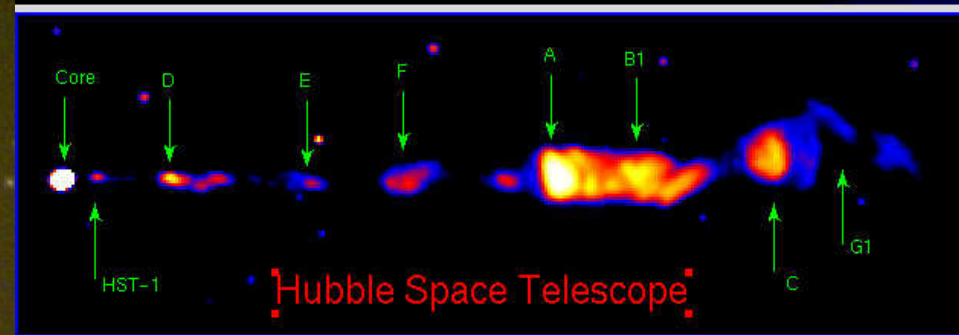
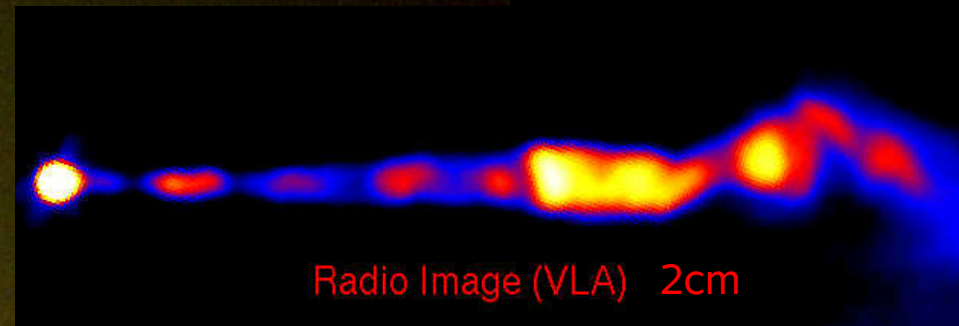




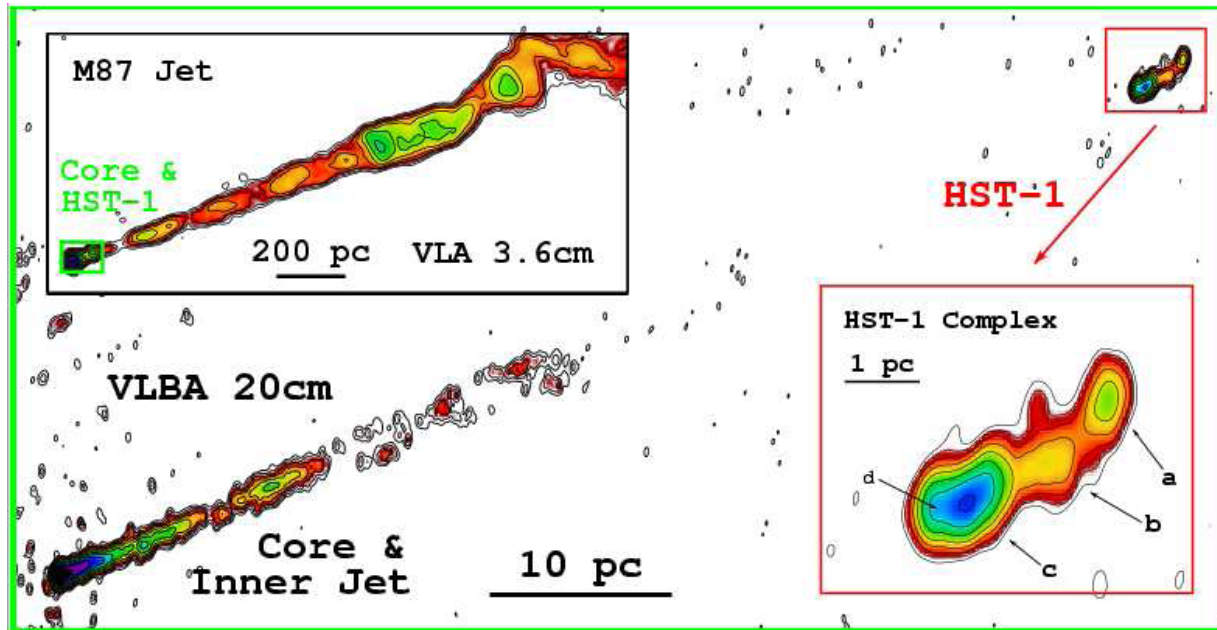
- M 87, Virgo A, B1228+126
 $V = 9.6$
 $z = 0.00436$ (16 Mpc)
- Brightest galaxy in the Virgo Cluster
- Largest giant elliptical galaxy near the Earth
- $M \sim 3 \times 10^9$ solar masses within 3pc, indicating SMBH in the center
- Jet angle w.r.t. the line of sight: 30~40 degrees
- Superluminal motion (6" of the jet) observed by HST (1994-1998), $v=4\sim6c$ (Biretta et al. ApJ, 520, 621, 1999)
- Jet speed 0.25-0.4c observed with VLBA at 43 GHz (Ly et al. ApJ, 660, 200, 2007)

- HST-1: discovered in 1999 (0.8 arcsec from the core)
- Active in the radio, optical, and X-ray regimes

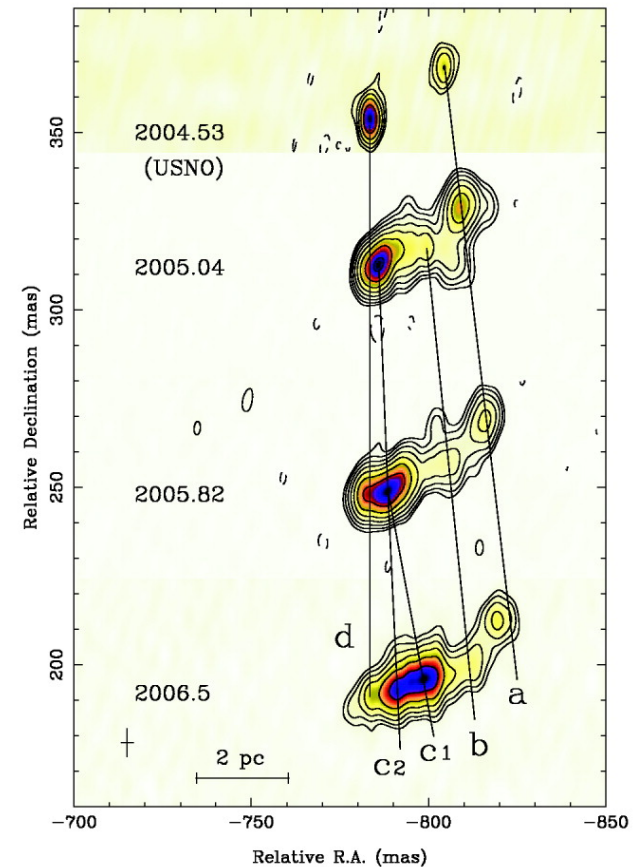
X-ray: NASA/CXC/MIT/H.Marshall et al.
 Radio: F.Zhou, F.Owen (NRAO), J.Biretta (STScI)
 Optical: NASA/STScI/UMBC/E.Perlman et al.



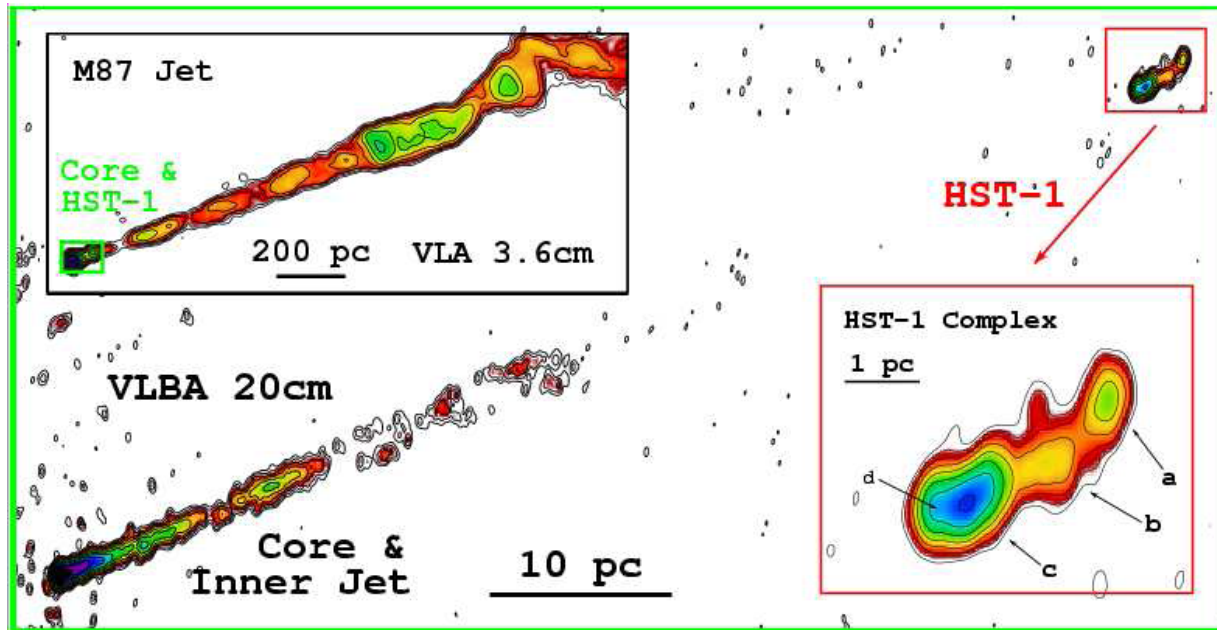
It has sub-structure...



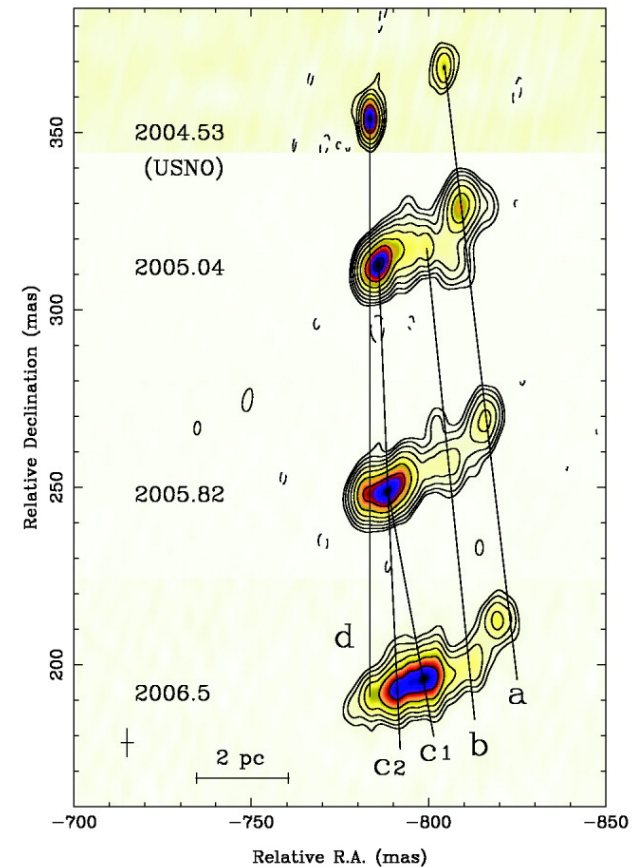
Cheung et al. ApJ 663, 65, 2007



It has sub-structure...



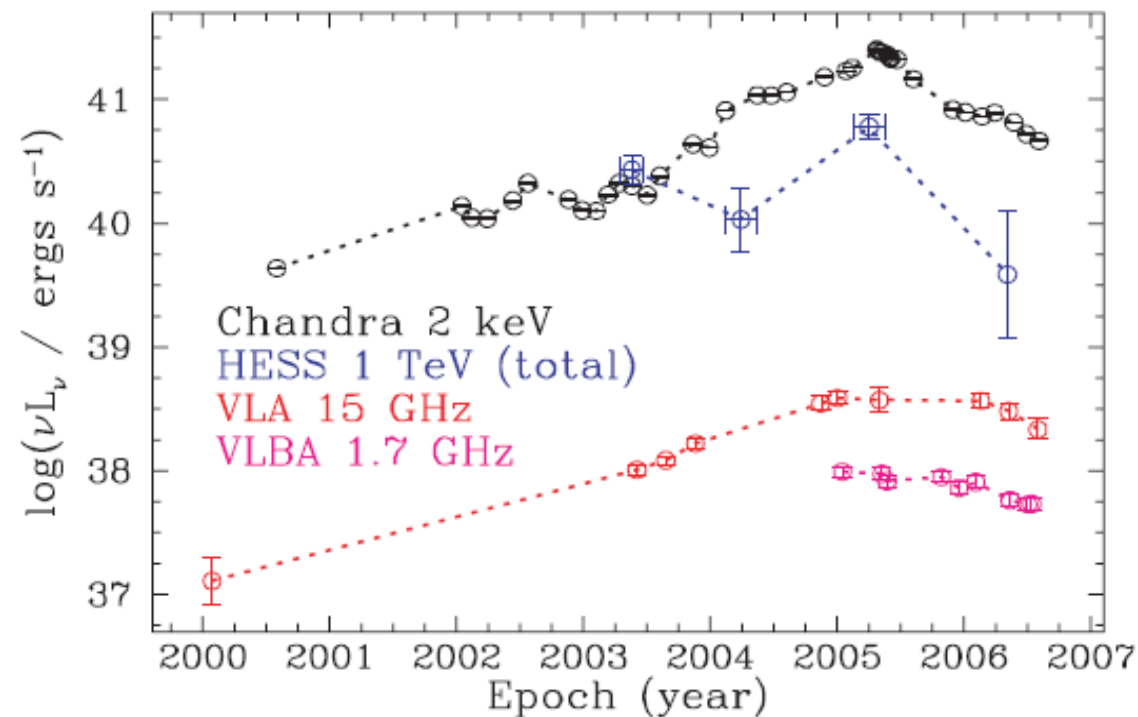
Cheung et al. ApJ 663, 65, 2007



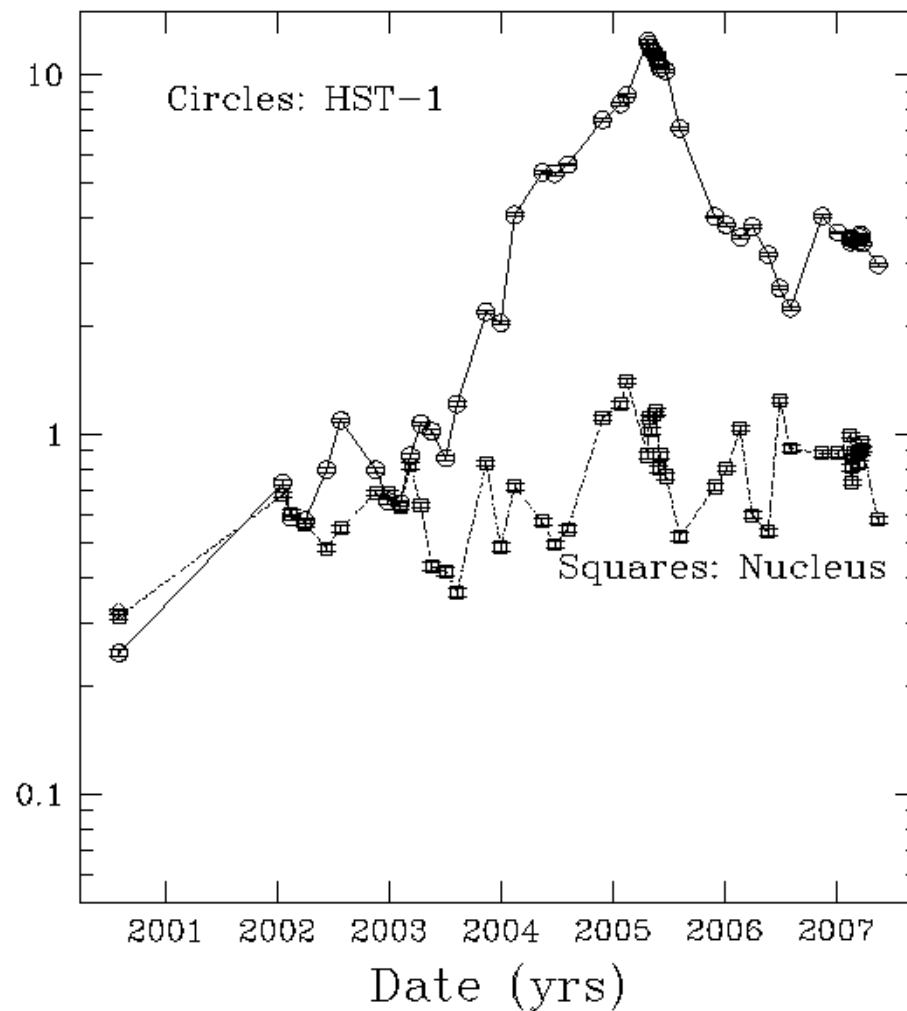
Superluminal Motion up to $4c$!

Radio & X-ray activities

M87 Nucleus & HST-1
(Chandra data)



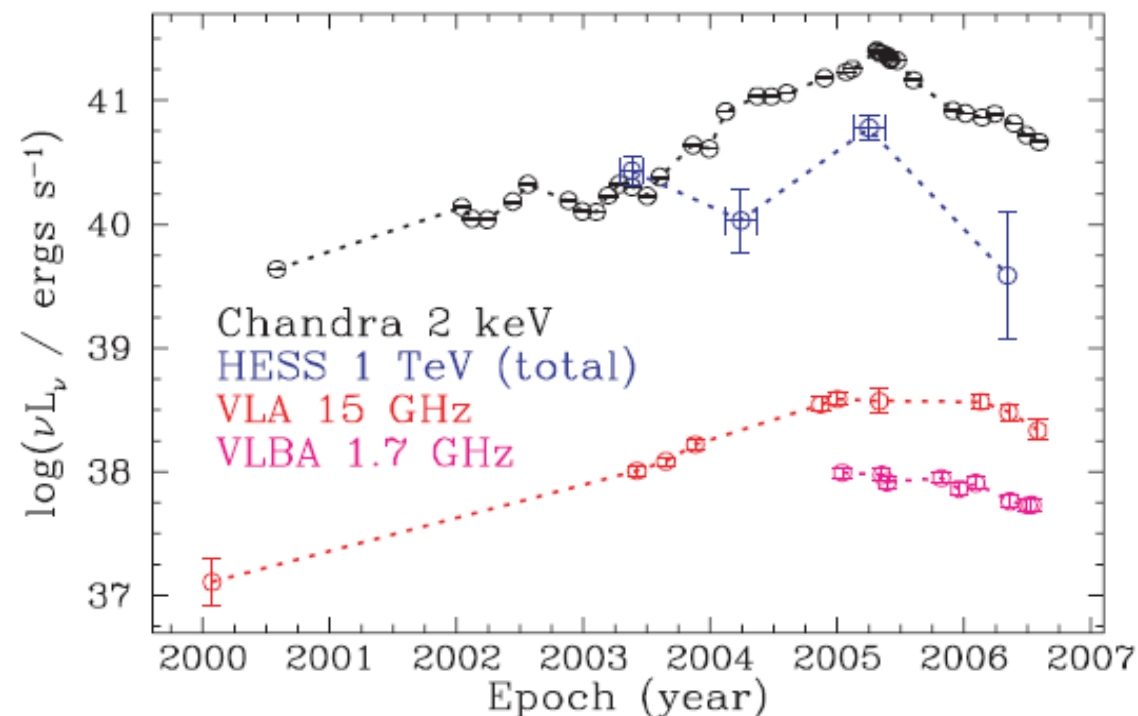
Cheung et al. ApJ 663, 65, 2007



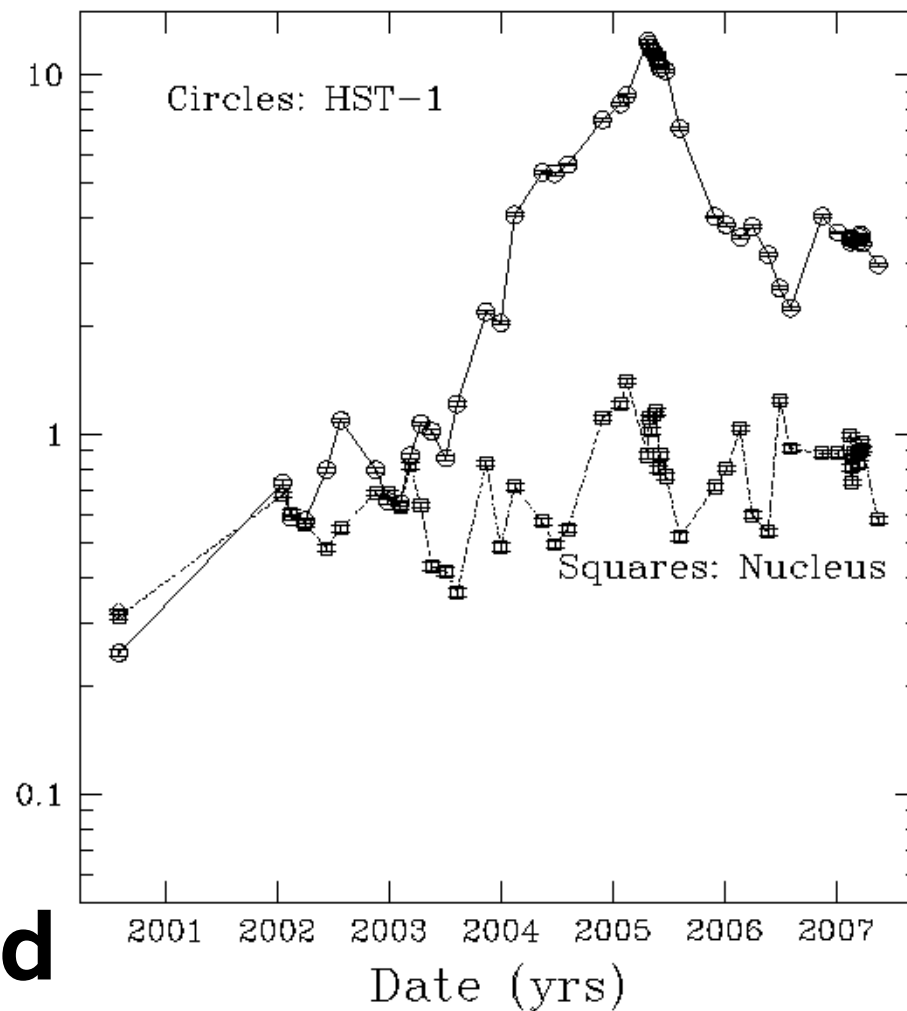
Harris et al., arXiv:0707.3124v1, 2007

Radio & X-ray activities

M87 Nucleus & HST-1
(Chandra data)



Cheung et al. ApJ 663, 65, 2007



Harris et al., arXiv:0707.3124v1, 2007

**TeV emission associated
to HST-1??**

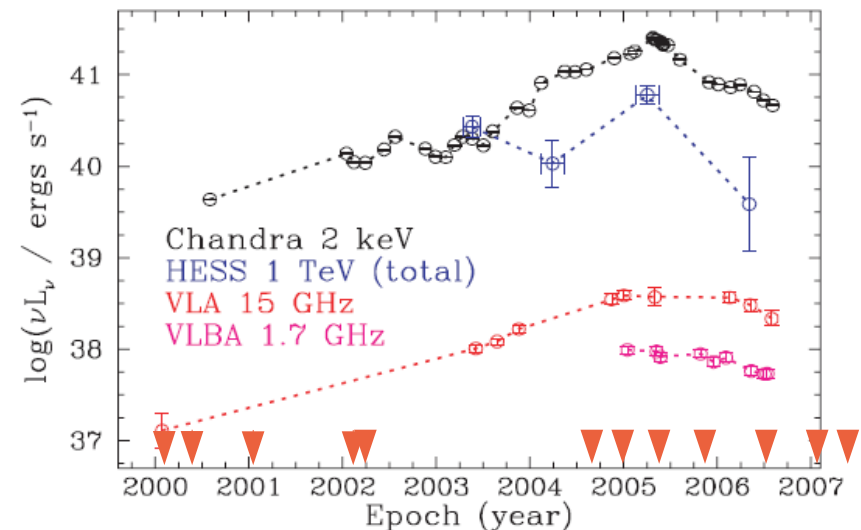
Is HST-1 a blazar?

Or say, a blazar-like feature located 100 pc away from the core?

- The AGN standard model considers the blazar behavior to originate at the vicinity of SMBH. However, HST-1 is 100 pc away from the center.
- If HST-1 does have blazar nature, the AGN model is questioned!

15 GHz VLBI Monitoring

- 2cm Survey & MOJAVE data
- 14 epochs of M87 monitoring (2000 - 2008)
 - 10 survey epochs (8 min every hour for 8 hrs); 1 epoch only 20 min on-source
 - 3 full track on source (8 hr; P.I.: K. Kellerman)
- Beam size = 1.9×1.1 (mas), P.A. = 13°



A special case

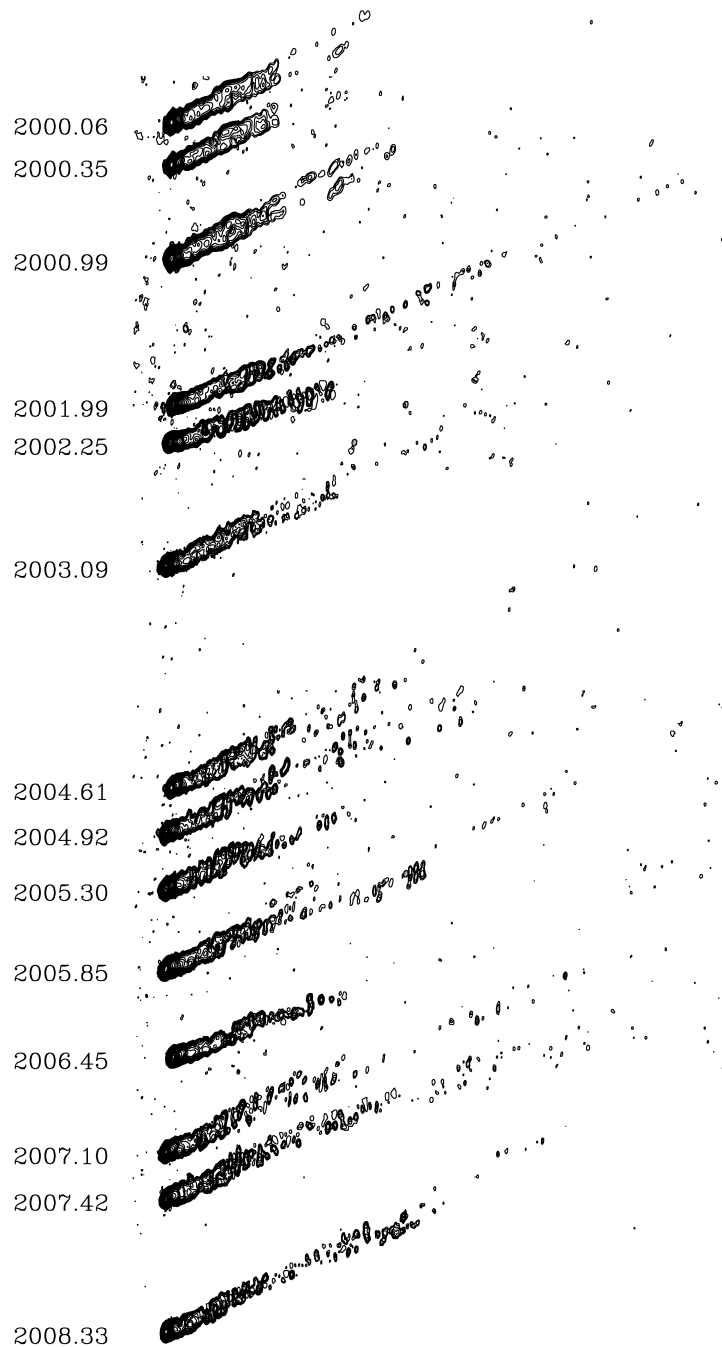
- HST-1 lies 800 x beam away from the core
 - Wide field imaging needed (averaging data produces time & bandwidth smearing)
- Total flux: ~ 2.5 Jy, HST-1: mJy level
 - Imaging of the inner jet with extended structure
 - image reaches expected noise level
- Natural weighting & tapering (Gaussian 0.3 at $200\text{ M}\lambda$)

Imaging Results

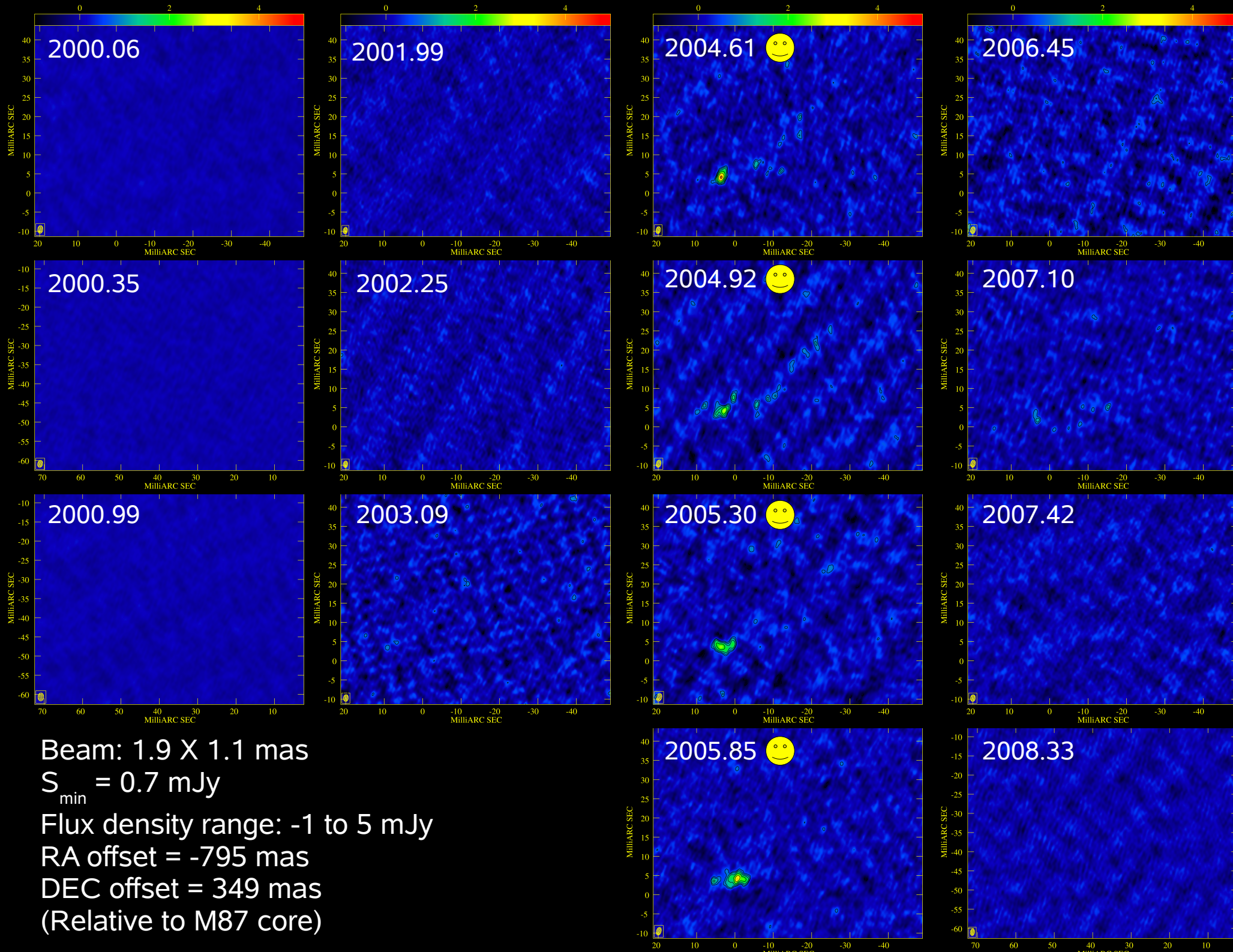
M87 (1228+126)

VLBA $\lambda 2\text{cm}$

• beam



- 14 epochs analyzed: 2000 to 2008
- Inner jet imaging:
 - 16-sec averaged (200 mas smearing limit) data imaging in DIFMAP
 - Model applied in AIPS CALIB to un-averaged data; IMAGR processing of inner jet and HST-1 region



M87 (1228+126)

VLBA $\lambda 2\text{cm}$

beam

2000.06

2000.35

2000.99

2001.99

2002.25

2003.09

2004.61

2004.92

2005.30

2005.85

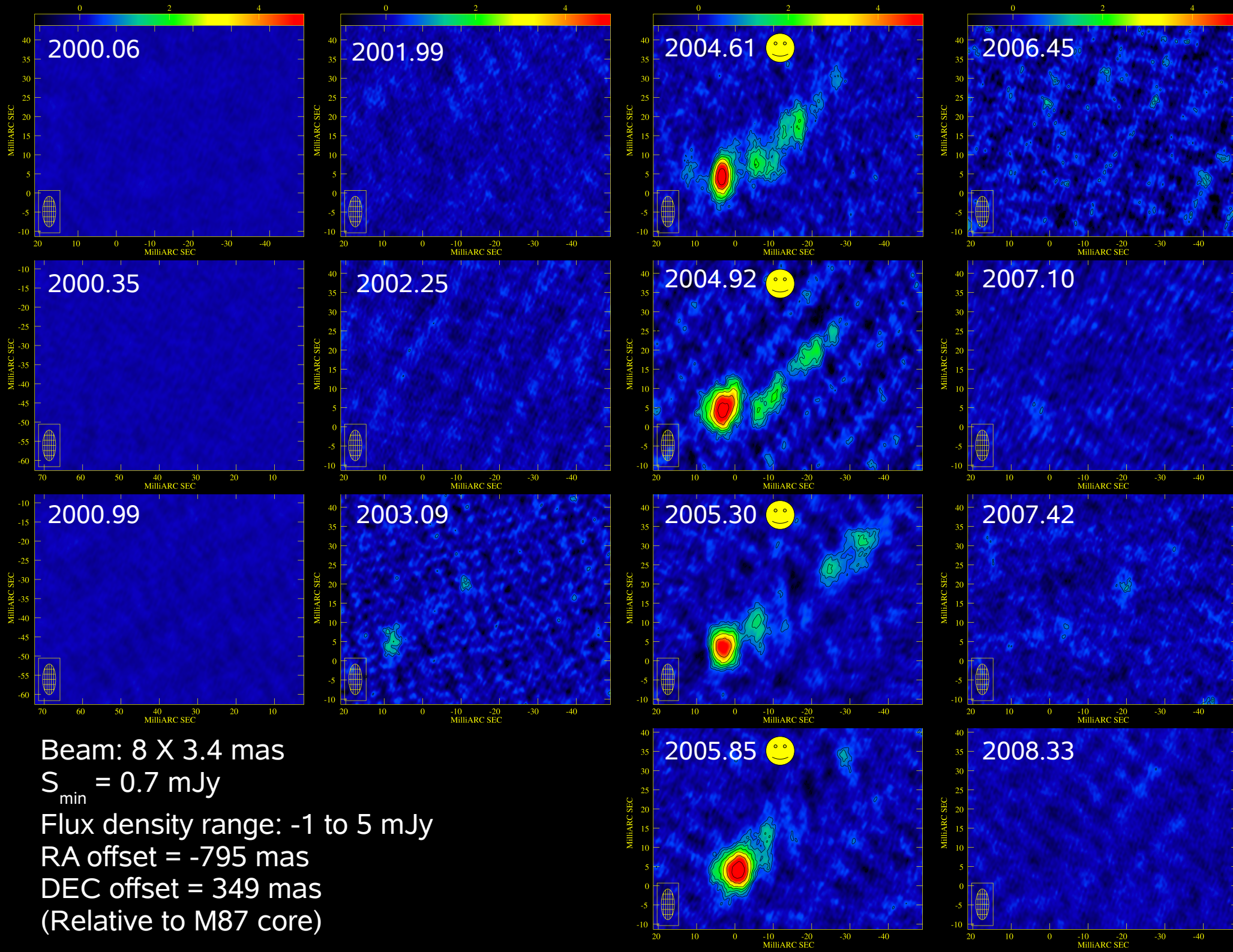
2006.45

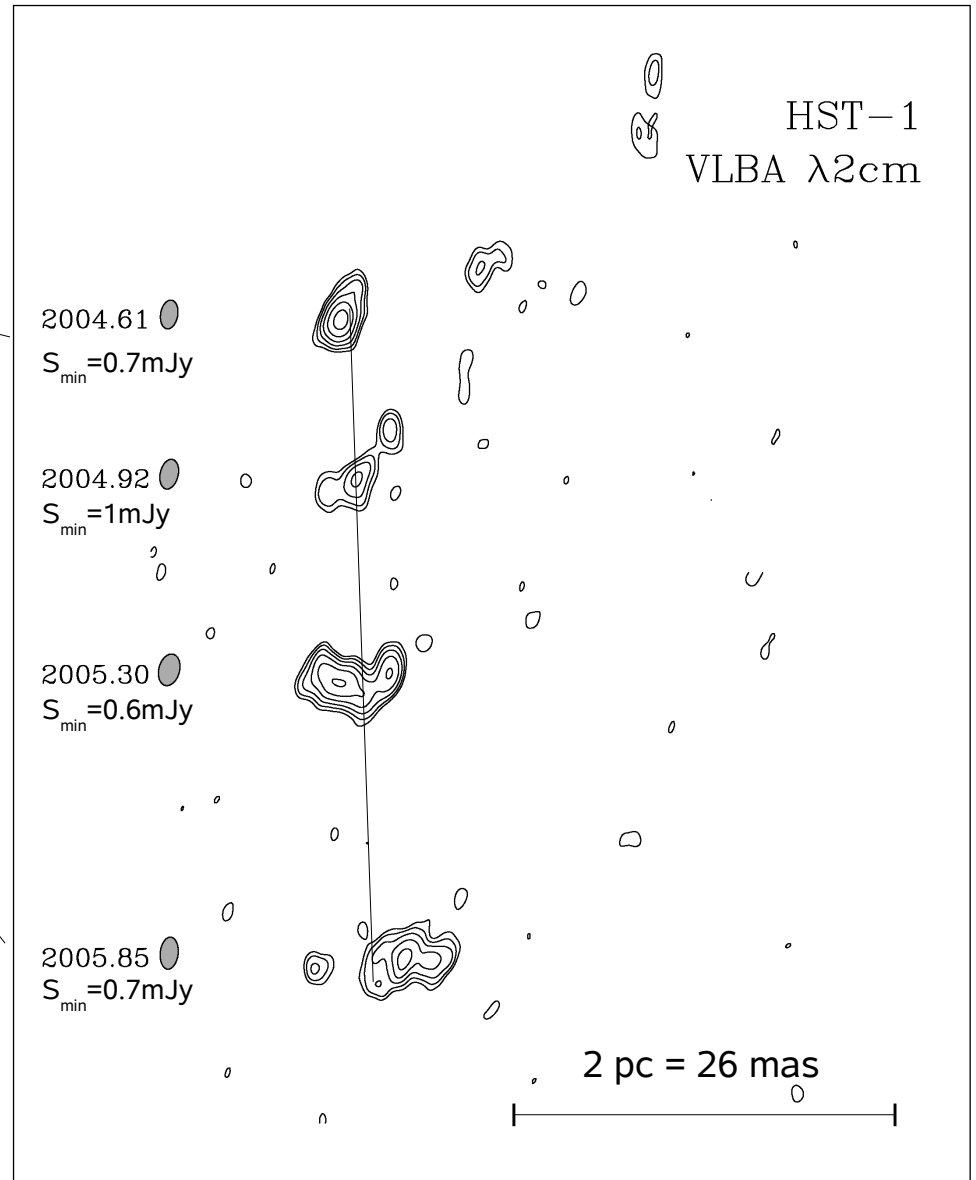
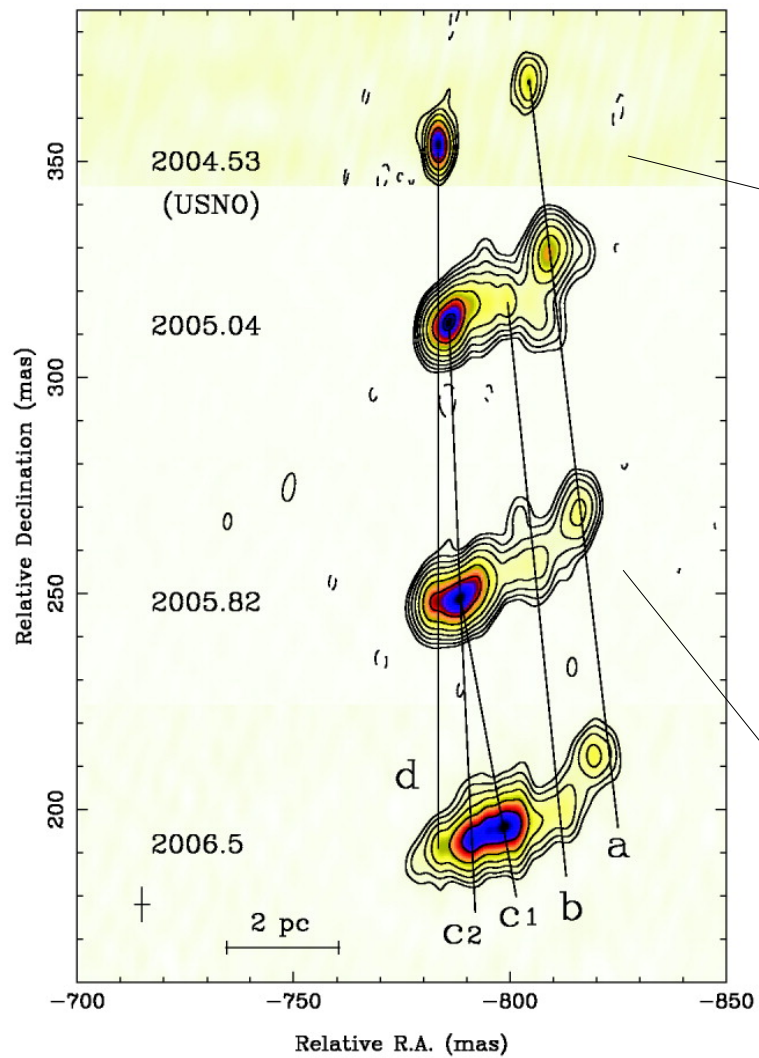
2007.10

2007.42

2008.33

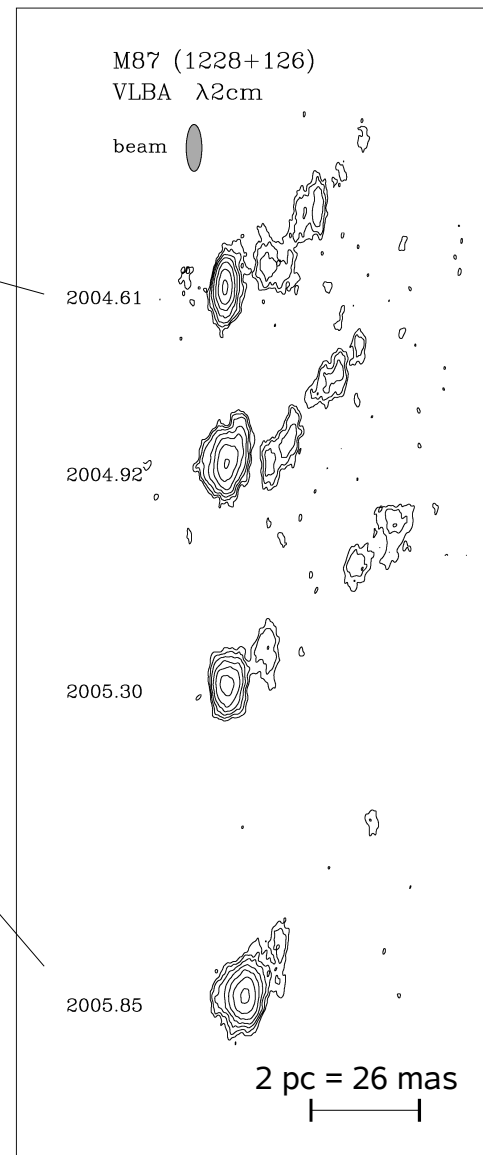
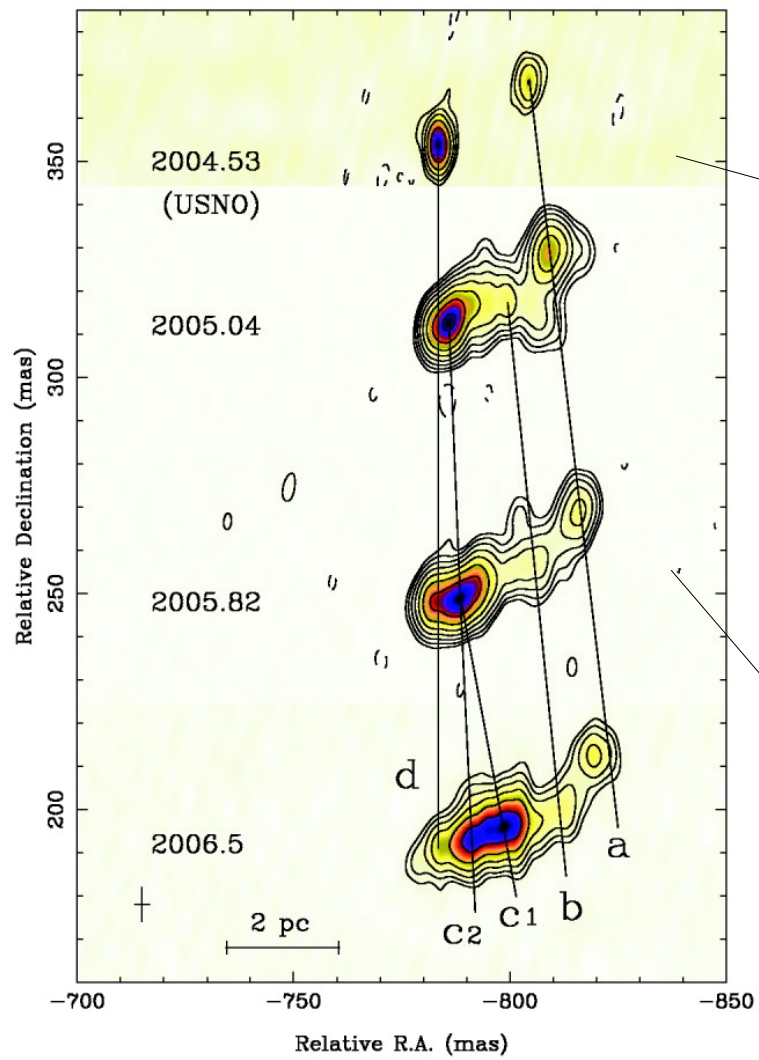
- Image with a bigger beam: 8X3.4 mas, P.A.= 0
- Beam size defined in IMAGR





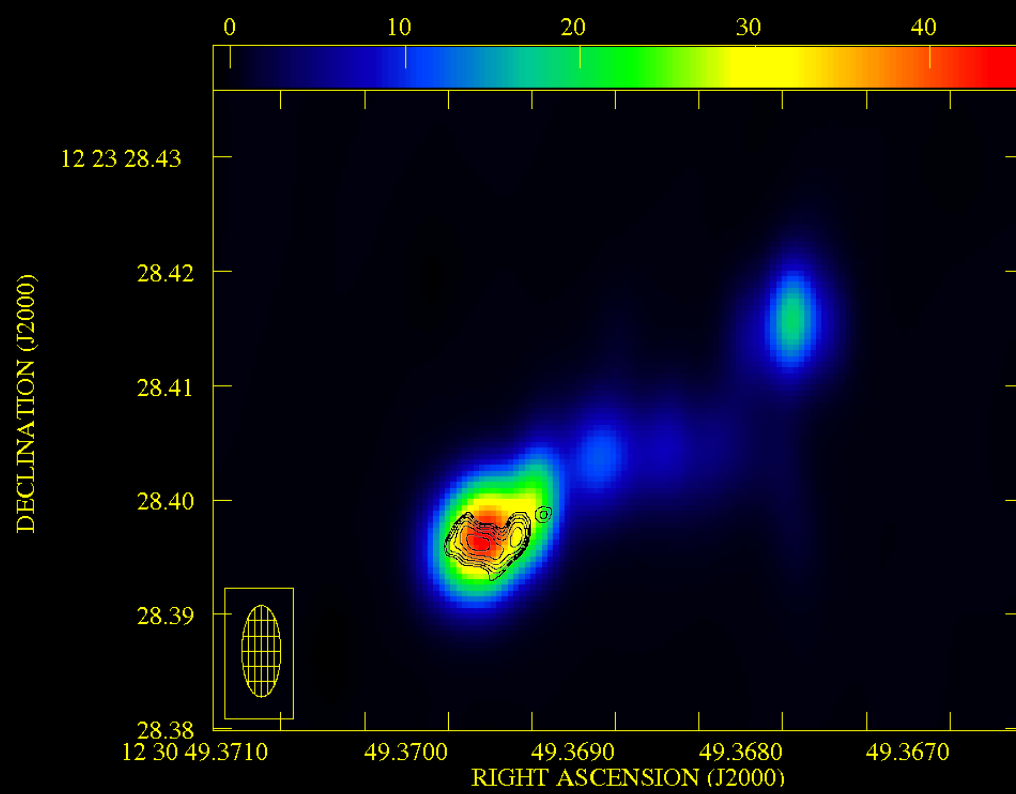
Beam: 8×3.4 mas; P.A. = 3°

Cheung et al. (2007) ApJ 663, L65-L68

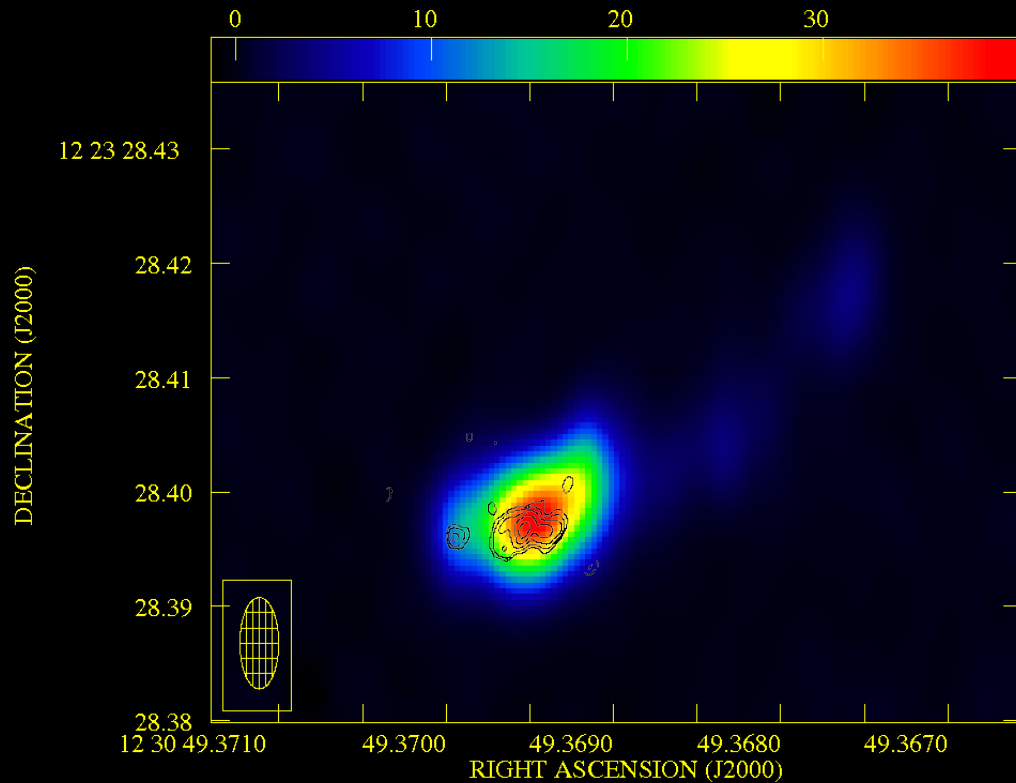


Beam: 8×3.4 mas; P.A. = 3°

Cheung et al. (2007) ApJ 663, L65-L68



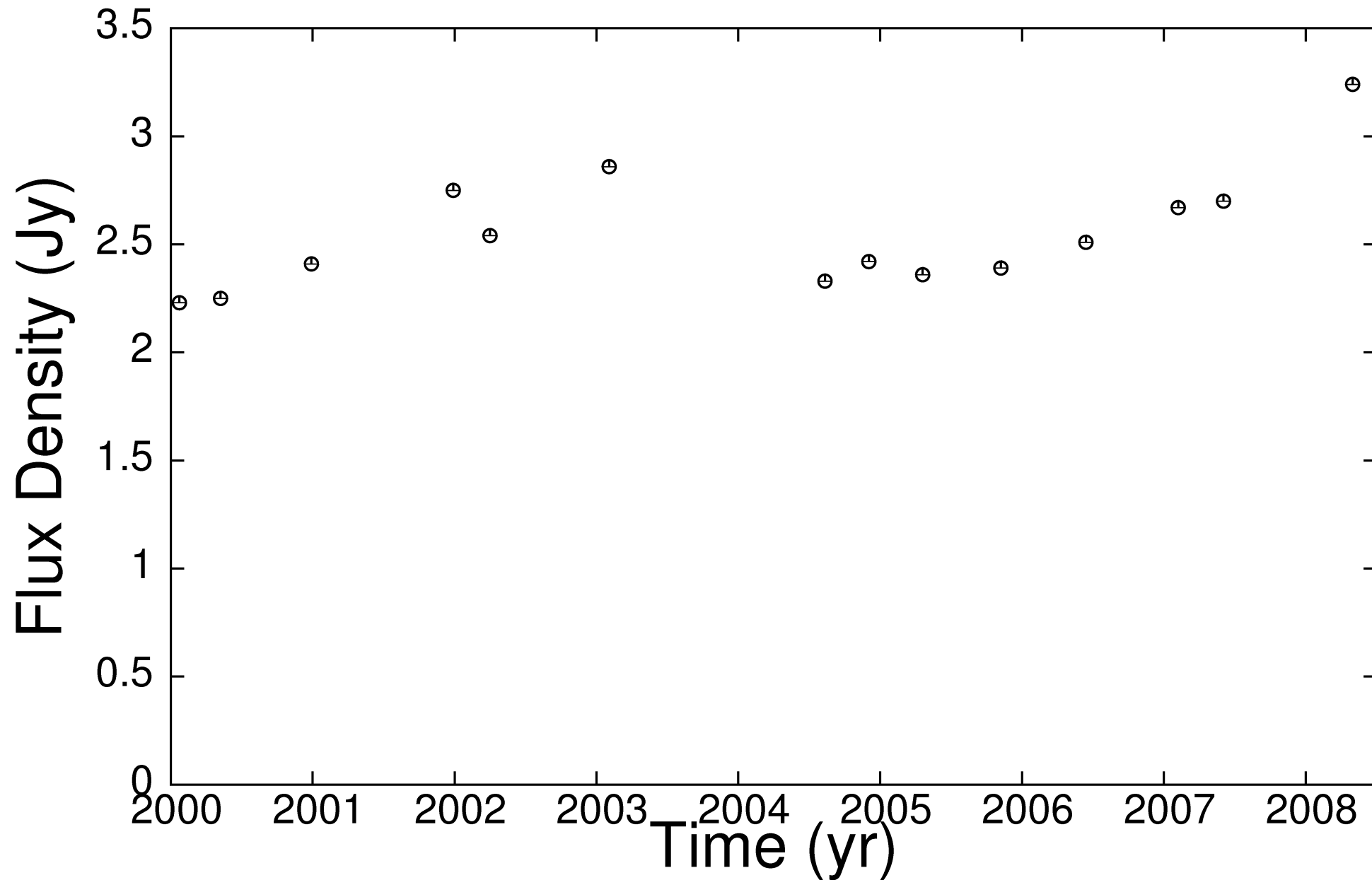
Contour: 2005.30 (VLBA 2cm)
Color scale: 2005.35 (VLBA 20cm)



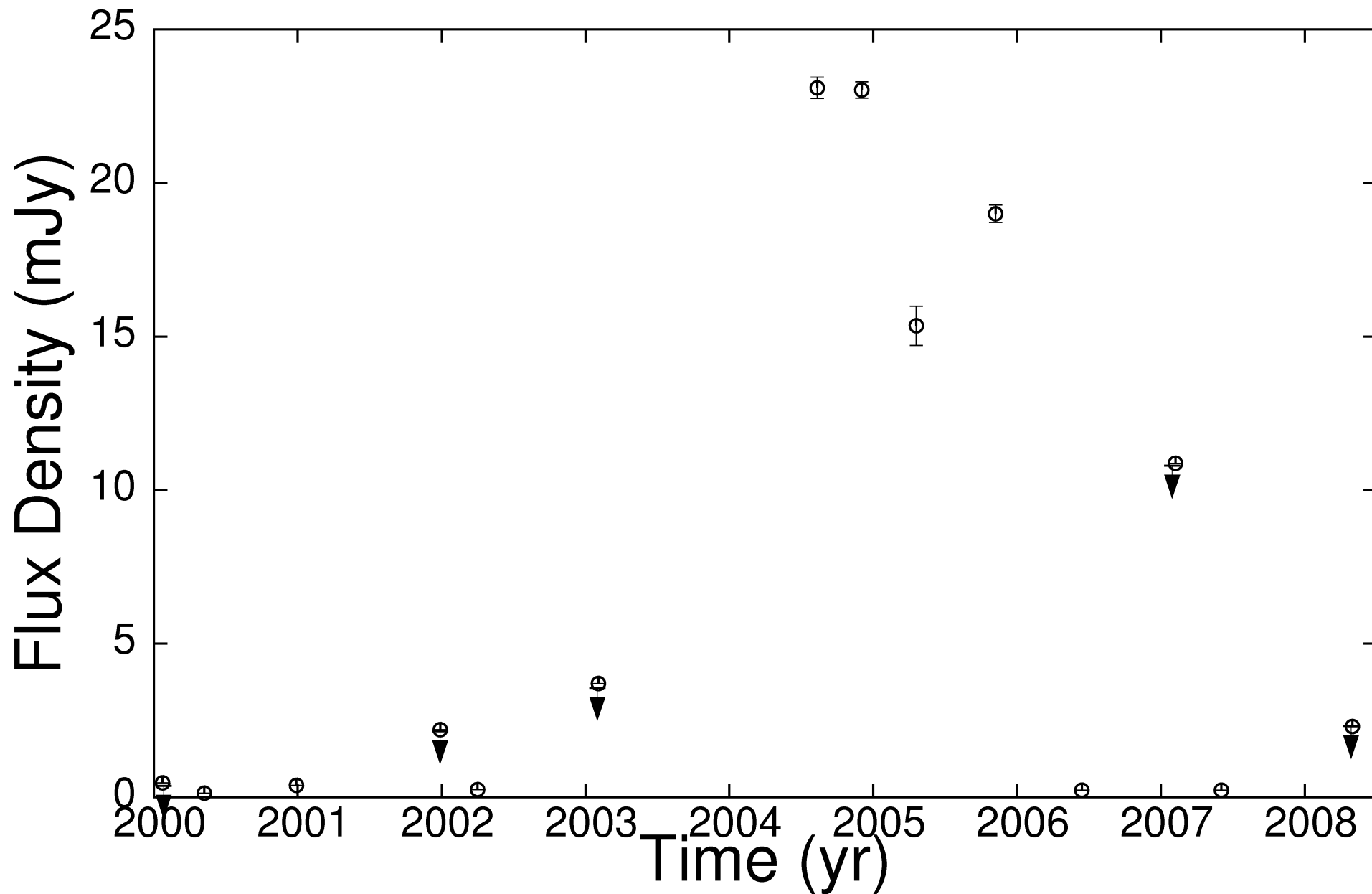
Contour: 2005.85 (VLBA 2cm)
Color scale: 2005.96 (VLBA 20cm)

VLBA 20cm: Teddy Cheung (Private communication)

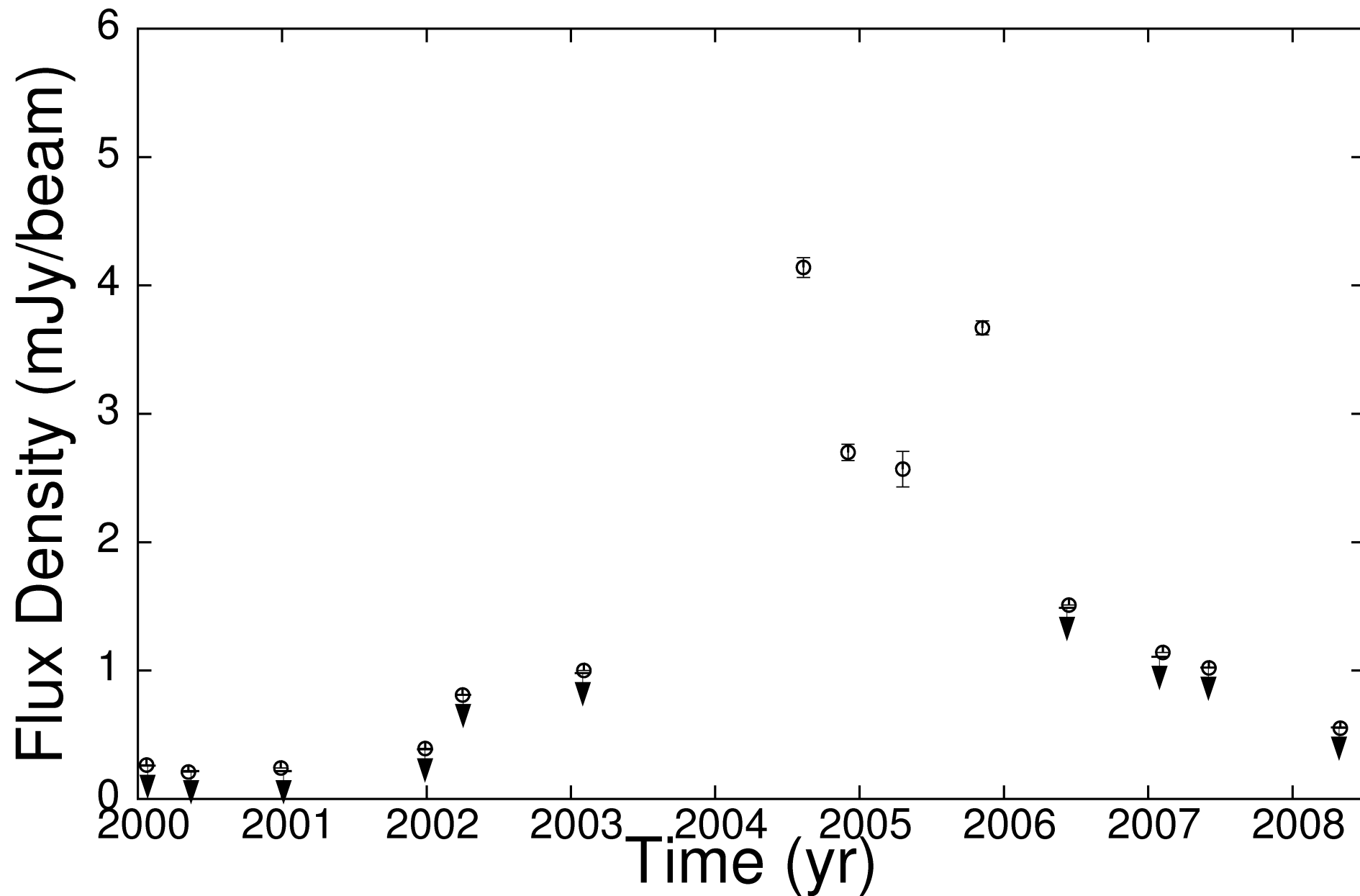
Source Total Flux



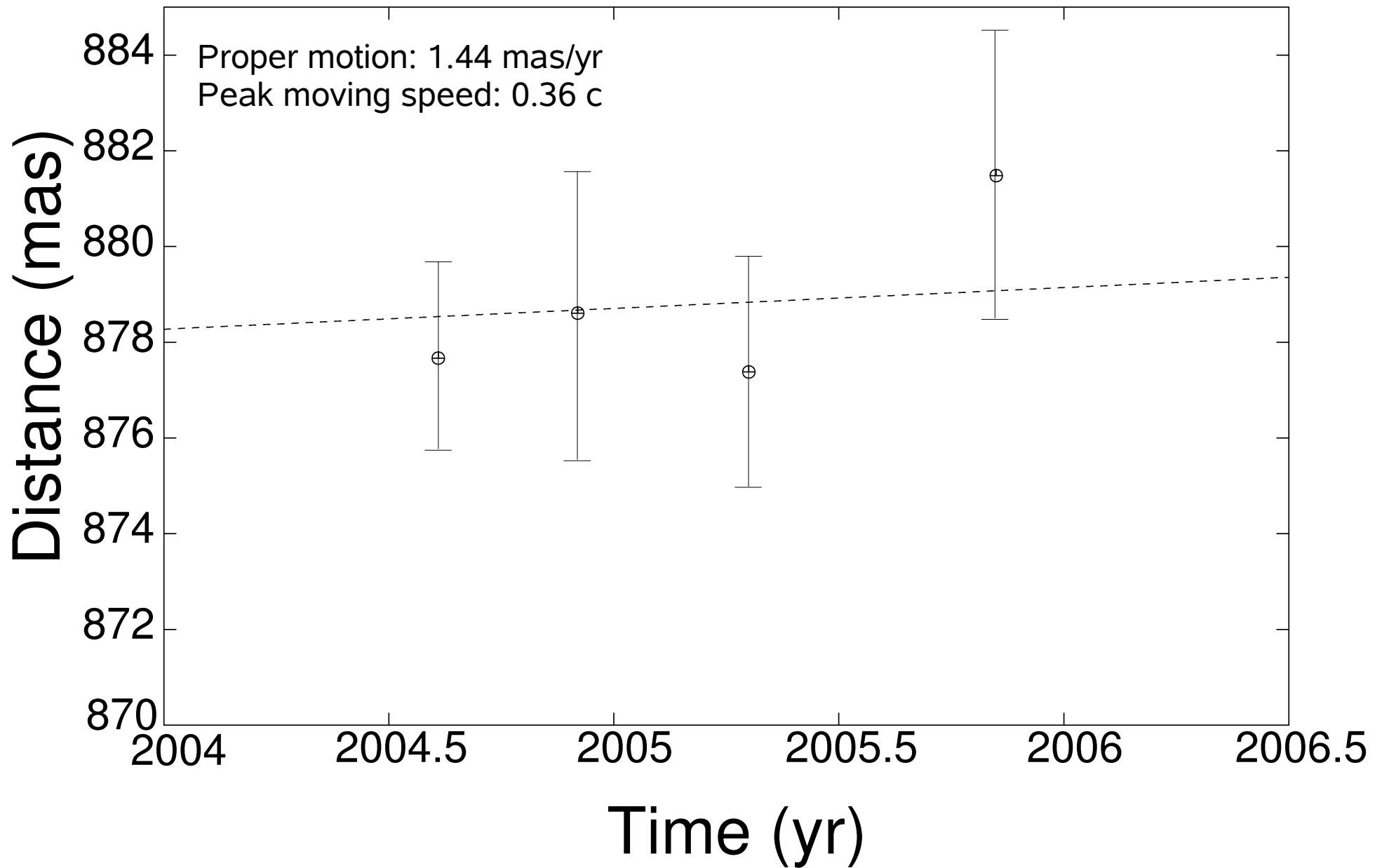
HST-1 Total Flux



HST-1 Peak Flux



HST-1 peak position w.r.t. the core



Results

- First detection of HST-1 with VLBI at 15 GHz during 2004 to 2005
HST-1 peak flux: 3-5 mJy/beam
HST-1 total flux density: 19-23 mJy
- Proper motion of brightest feature:
1.44 mas/year $\rightarrow$ 0.36 c
- HST-1 VLBI radio light curve at λ 2cm is similar to VLA & X-ray light curves
- Flux density variations of the inner jet show no correlation with HST-1 behavior

Discussion

- VLBI 15 GHz observations:
 - HST-1 is extended (low compactness)
 - no obviously emerging, rapidly moving features during the flaring period in 2005
 - HST-1 shows more structural changes in the images with bigger beam
- Hypothesis of blazar nature is still open, although unlikely

Future plans

- For M87
 - VLA archival data
 - Wrap up the results & publish a paper
- For my PhD
 - *Fermi* gamma-ray telescope & MOJAVE
 - SED study on AGNs

Radio (VLBI), X-ray (*Swift*), Gamma-ray (*Fermi*)

Acknowledgements

- Thanks to the 2cm Survey/MOJAVE team
- Special thanks to Mike Garrett, Craig Walker, Giuseppe Cimò, Anupreeta Moré, Stephanie Mühle, Teddy Cheung and Christian Fromm for valuable discussions

Thank you!