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

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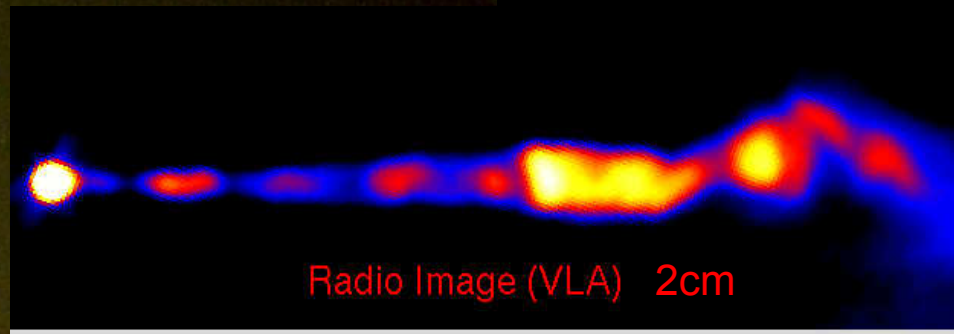
- M 87, Virgo A, B1228+126

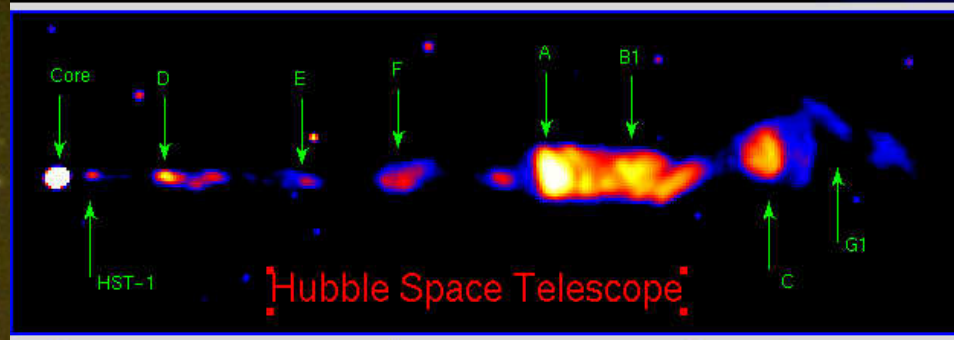
  V = 9.6

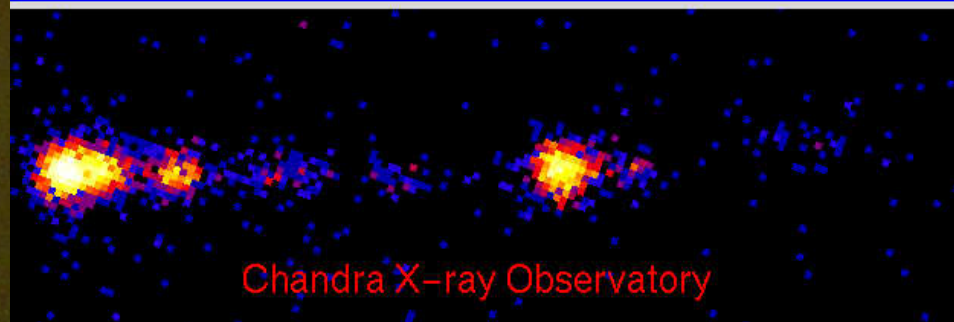
  z = 0.00436 (16 Mpc)
- Brightest galaxy in the Virgo Cluster
- Largest giant elliptical galaxy near the Earth
- M ~ $3x10^9$ solar masses within 3pc, indicating SMBH in the center
- Jet angle w.r.t. the line of sight: 30~40 degrees
- Superluminal motion (6" of the jet) observed by HST (1994-1998), v=4~6c (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.







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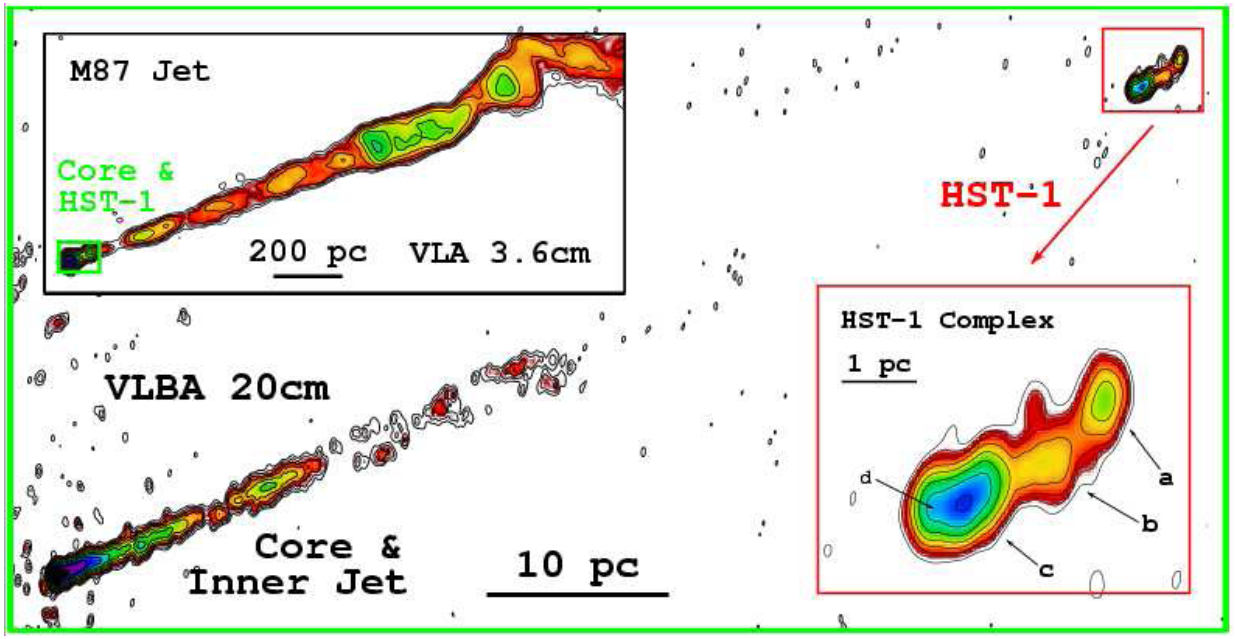
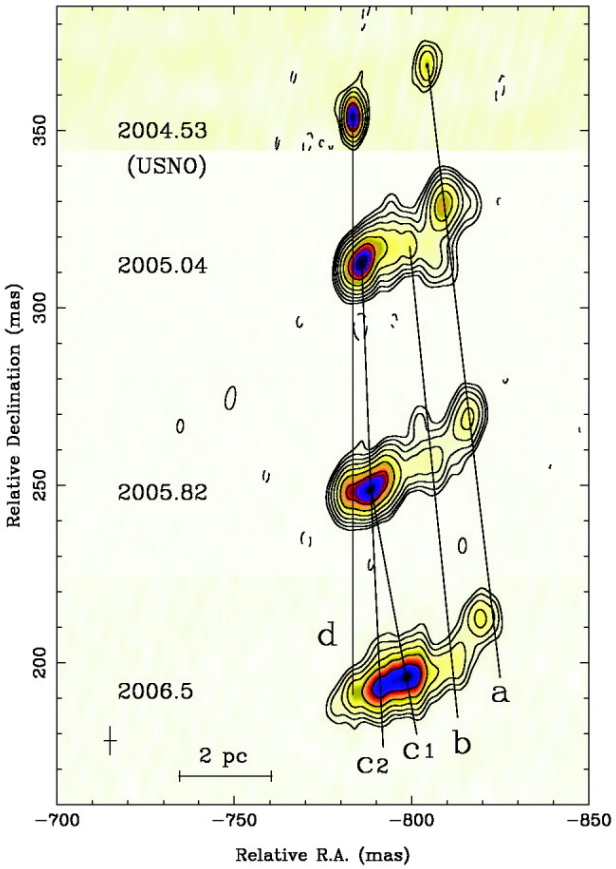
It has sub-structure...



Cheung et al. ApJ 663, 65, 2007



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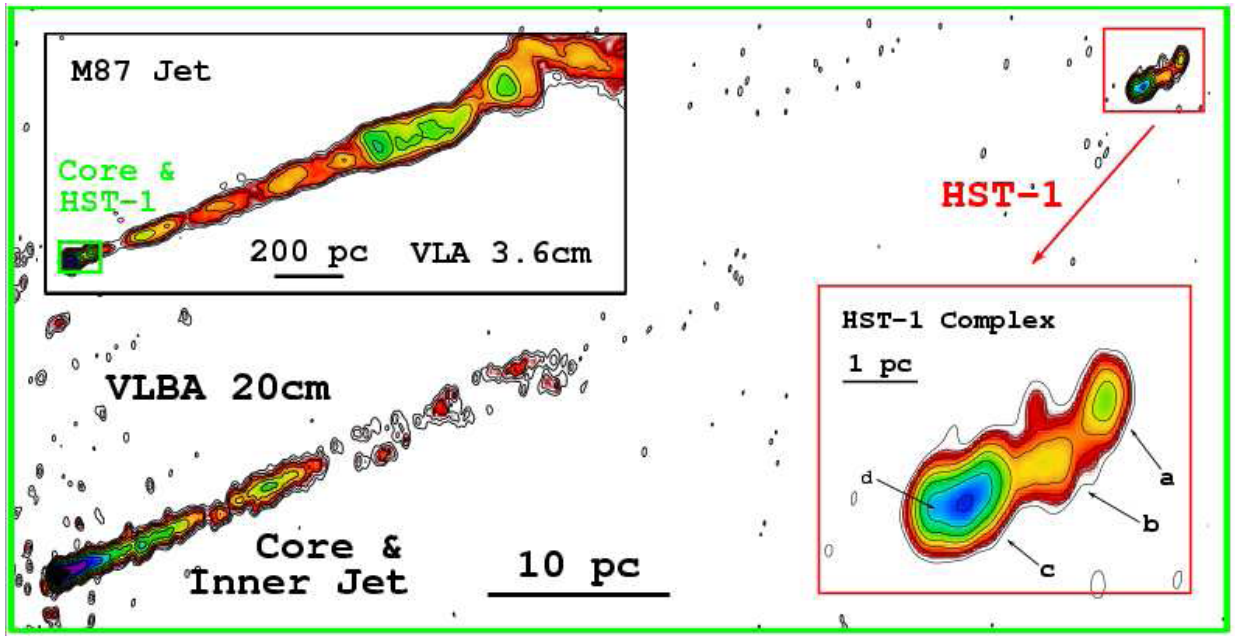
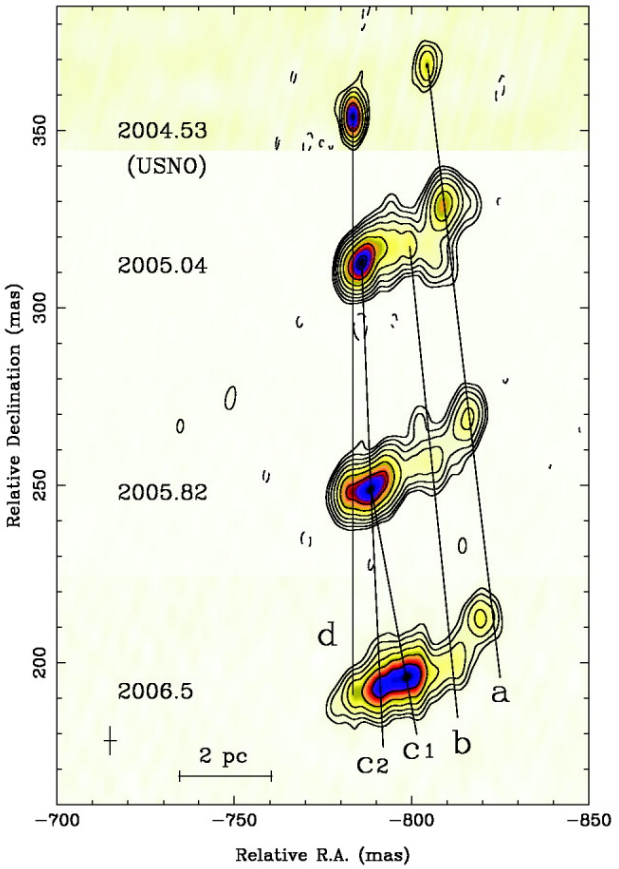
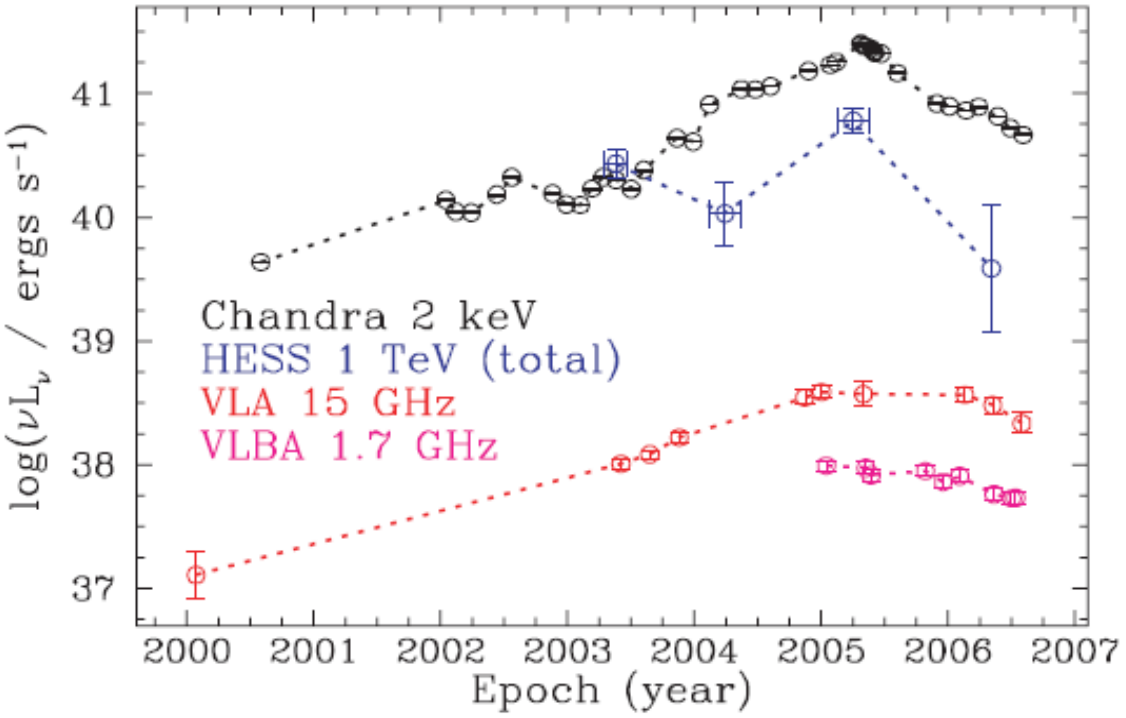


Cheung et al. ApJ 663, 65, 2007



Superluminal Motion up to 4c!

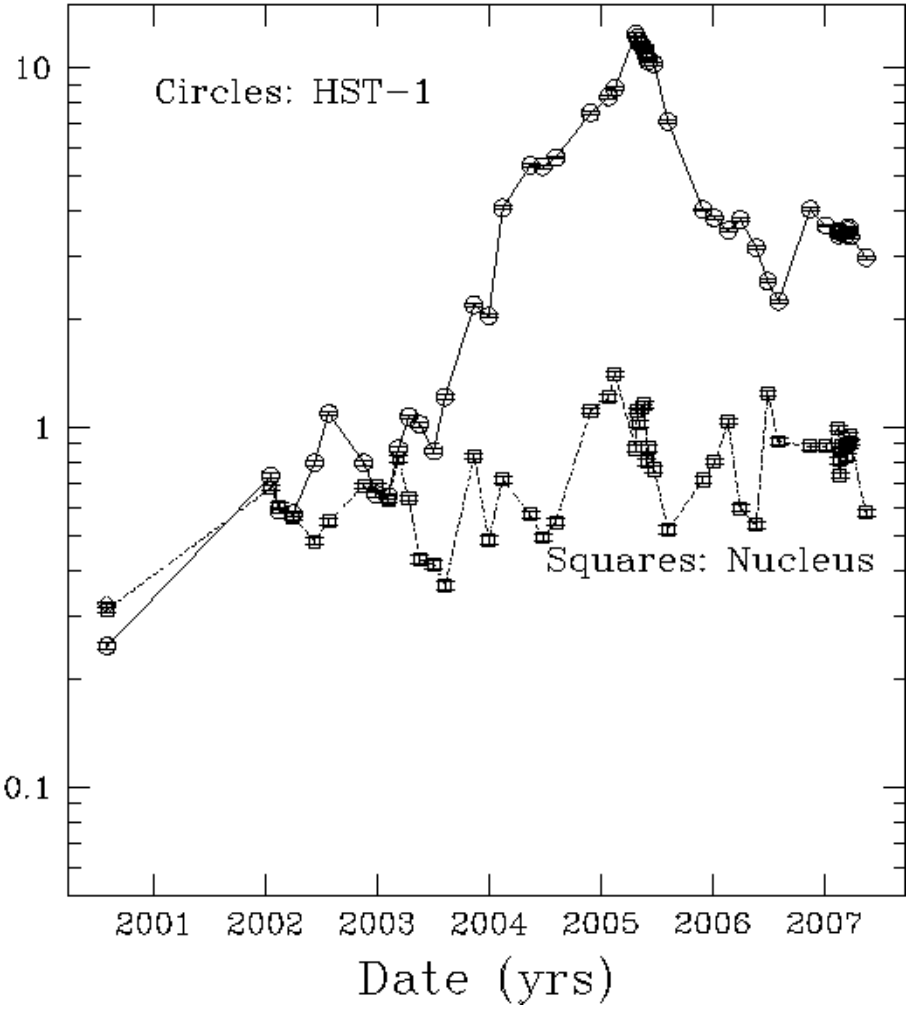
Radio & X-ray activities



Cheung et al. ApJ 663, 65, 2007

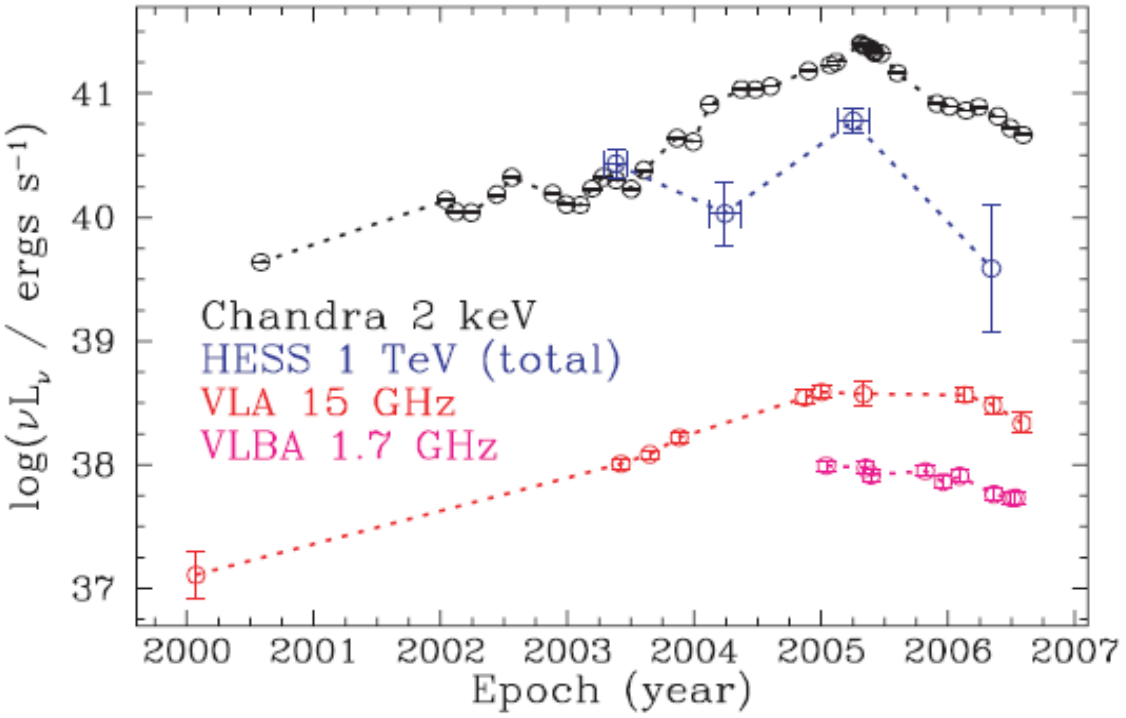
M87 Nucleus & HST−1

(Chandra data)



Harris et al., arXiv:0707.3124v1, 2007

Radio & X-ray activities



Cheung et al. ApJ 663, 65, 2007

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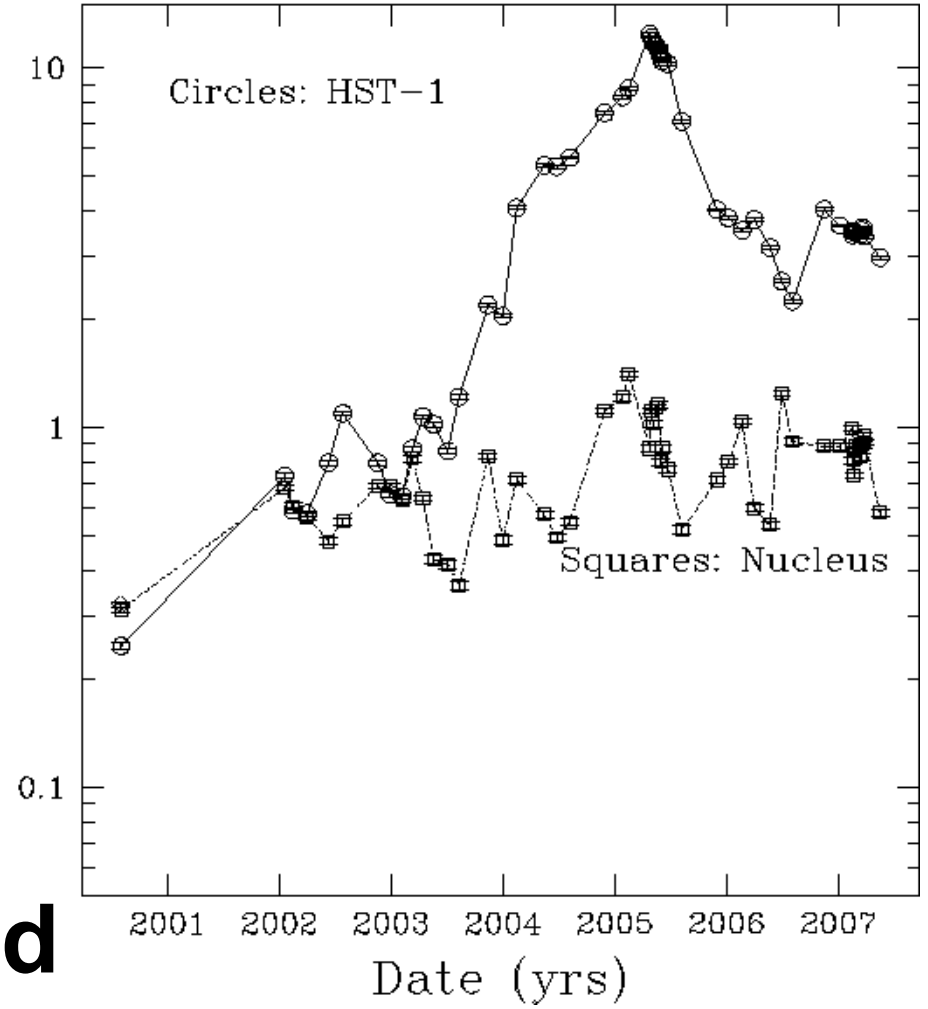


Harris et al., arXiv:0707.3124v1, 2007

TeV emission associated to HST-1??

Is HST-1 a blazar?

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

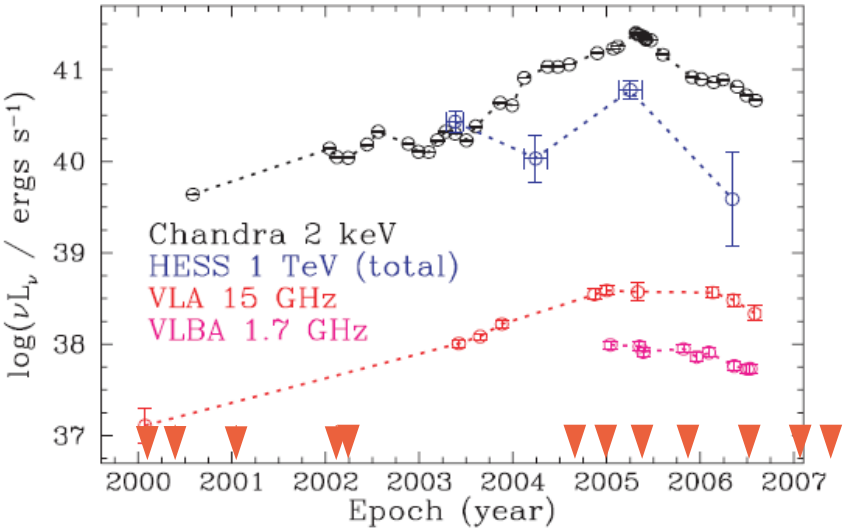
- The AGN standard model considers the blazar behavior to originate at the vicinity of SMBH. However, HST-1 is 100 pc away from the center.
- If HST-1 does have blazar nature, the AGN model is questioned!

15 GHz VLBI Monitoring

- 2cm Survey & MOJAVE data
- 13 epochs of M87 monitoring (2000 - 2008)

  - 11 survey epochs (8 min every hour for 8 hrs); 1 epoch only 20 min on-source

  - 1 full track on source (8 hr; P.I.: K. Kellerman)
- Beam size = 1.9 x 1.1 (mas), P.A. = 13˚
- Dynamic range: 1000 to 1



A special case

- HST-1 lies 800 x beam away from the core

  - Wide field imaging needed (averaging data produces time & bandwidth smearing)

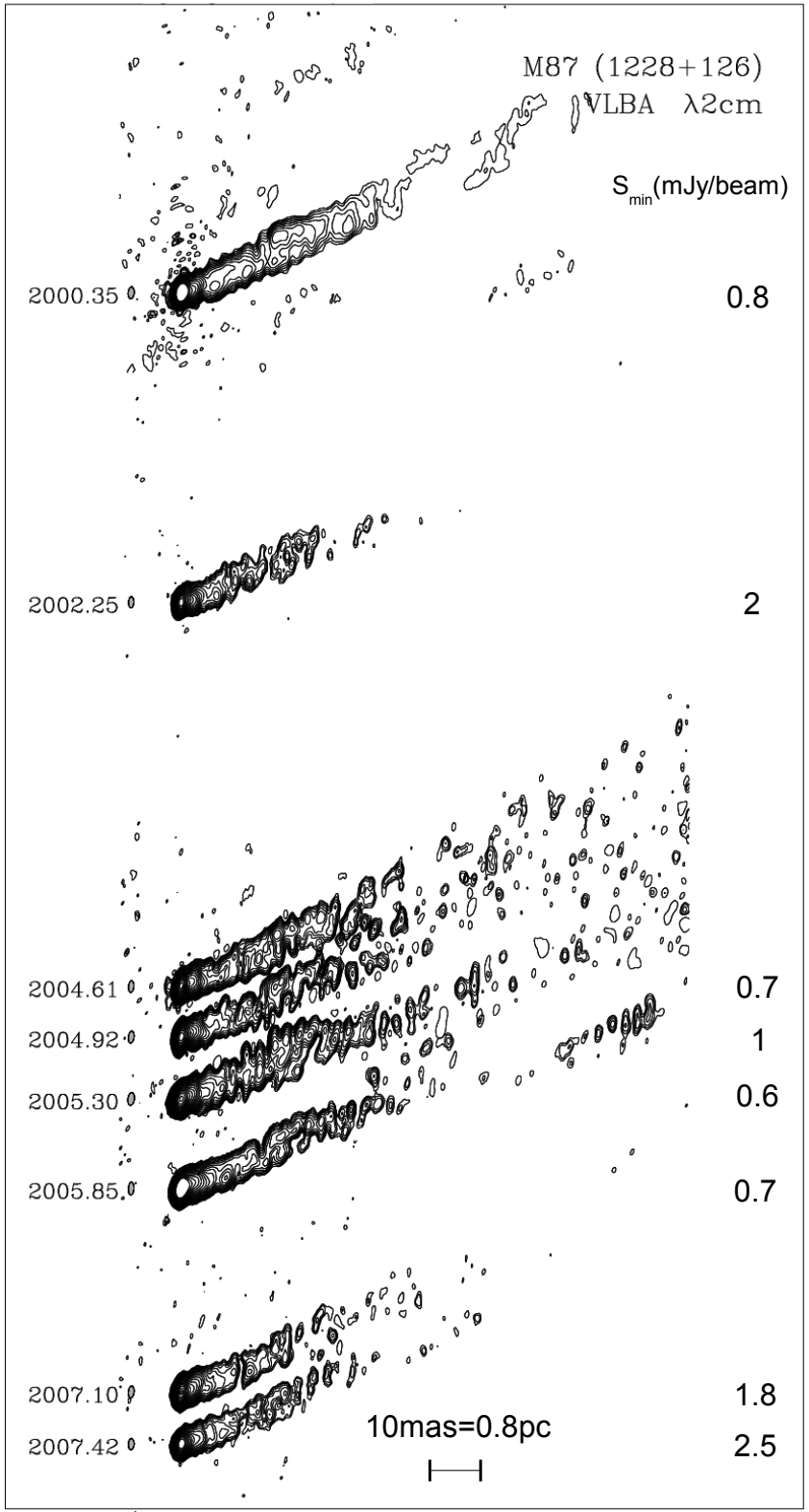
- Total flux: ~2.5 Jy, HST-1: mJy level

  - Imaging of the inner jet with extended structure

  - image reaches expected noise level

- Natural weighting & tapering (Gaussian 0.3 at 200 Mλ)

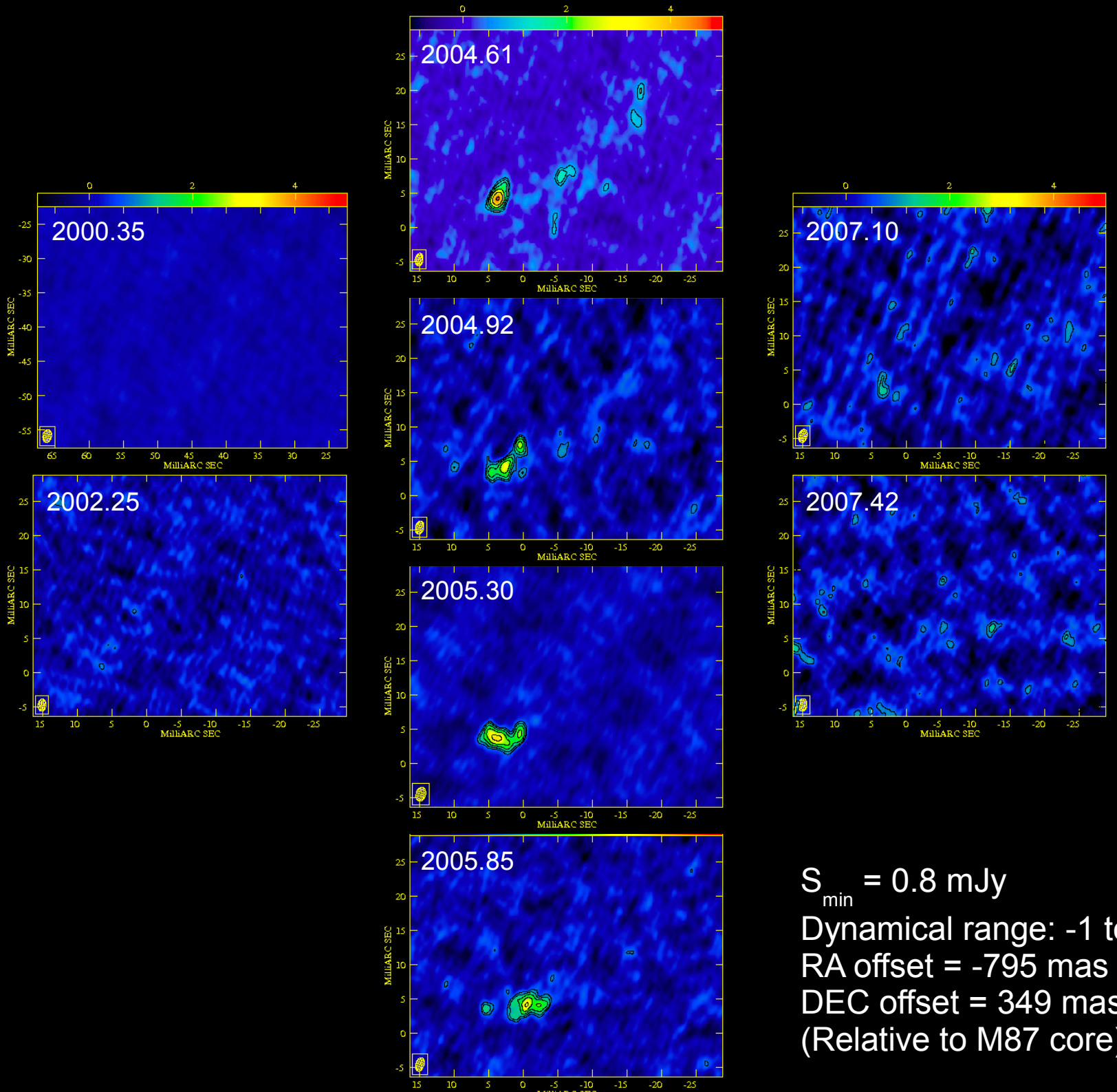
Imaging Results



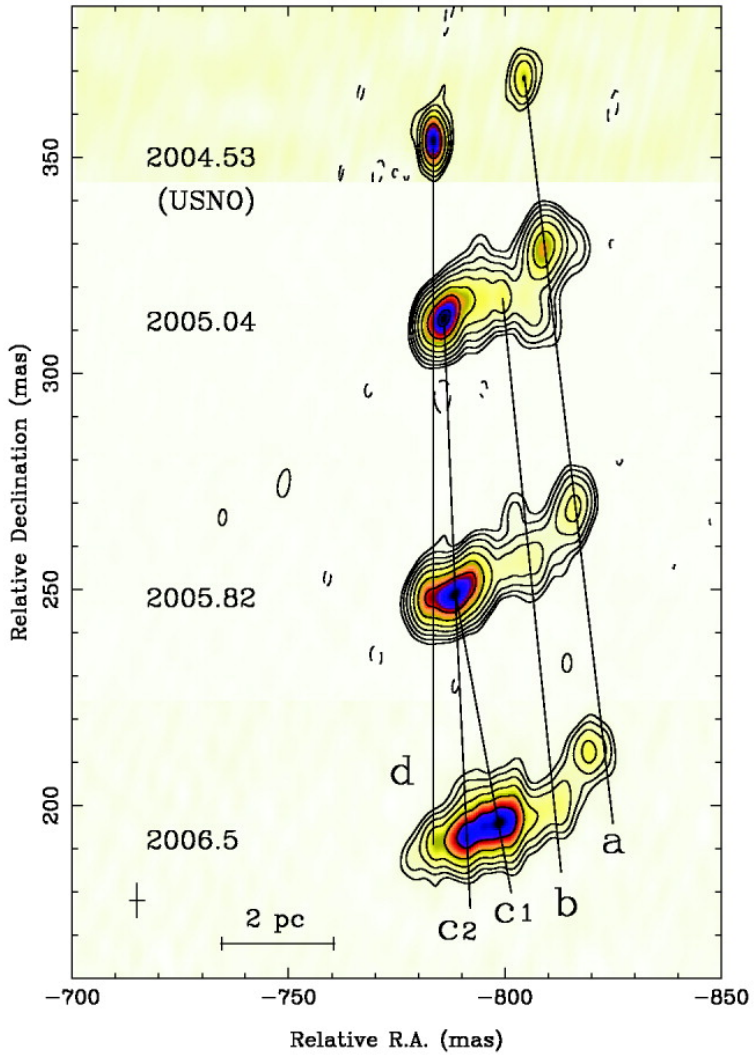
- 8 epochs analyzed: 2000 to 2007
- Inner jet imaging:

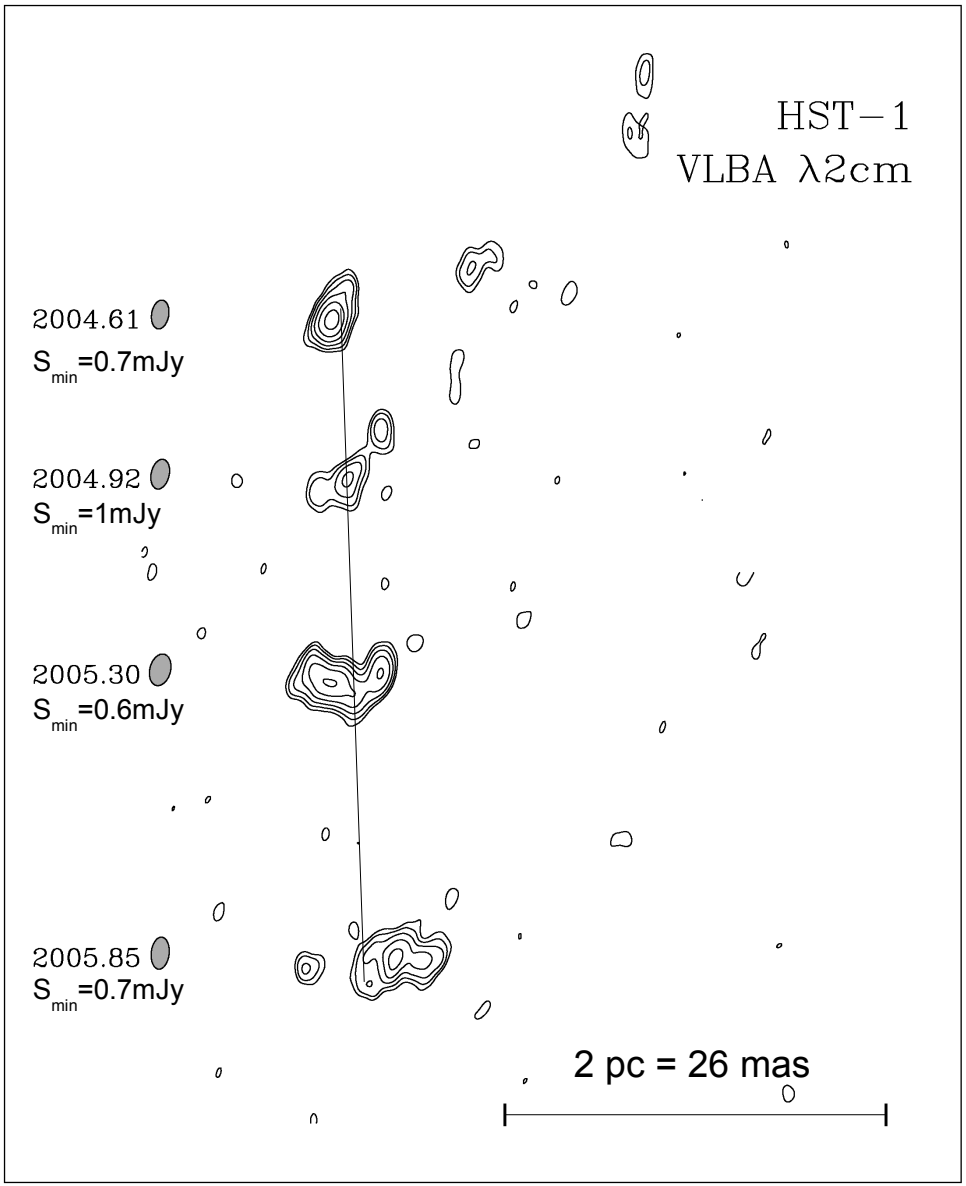
-16-sec averaged (200 mas smearing limit) data imaging in DIFMAP

- Model applied in AIPS CALIB to un-averaged data; IMAGR processing of inner jet and HST-1 region



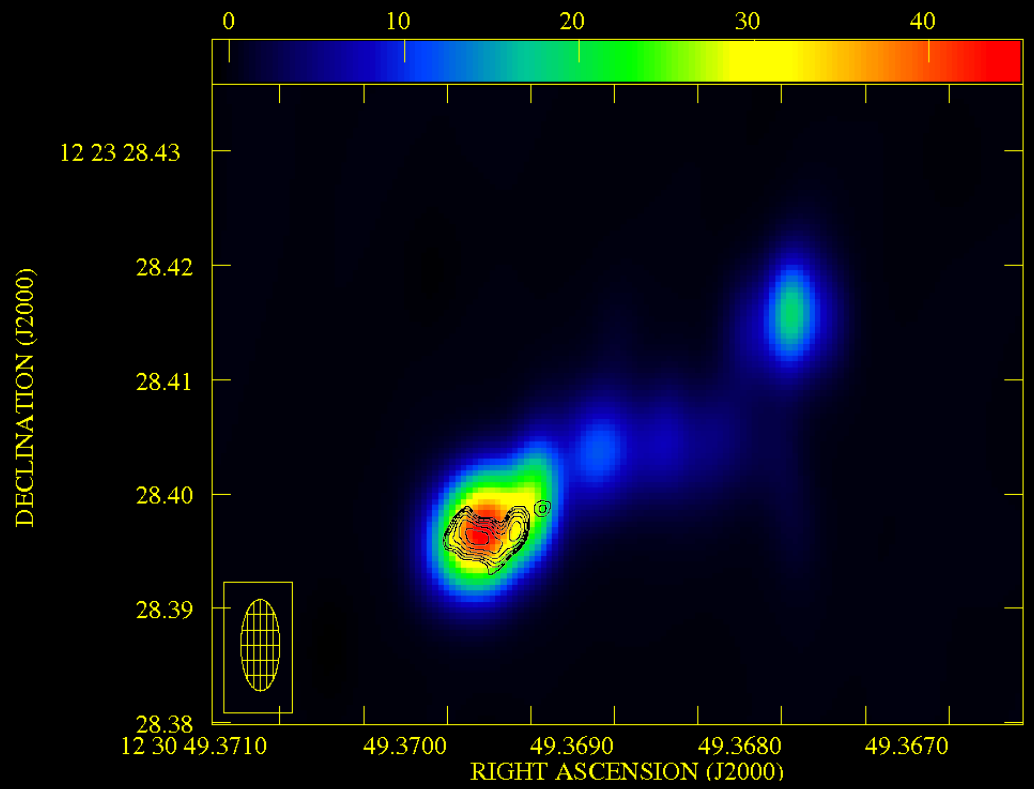
S_{min} = 0.8 mJy
Dynamical range: -1 to 5 mJy
RA offset = -795 mas
DEC offset = 349 mas
(Relative to M87 core)



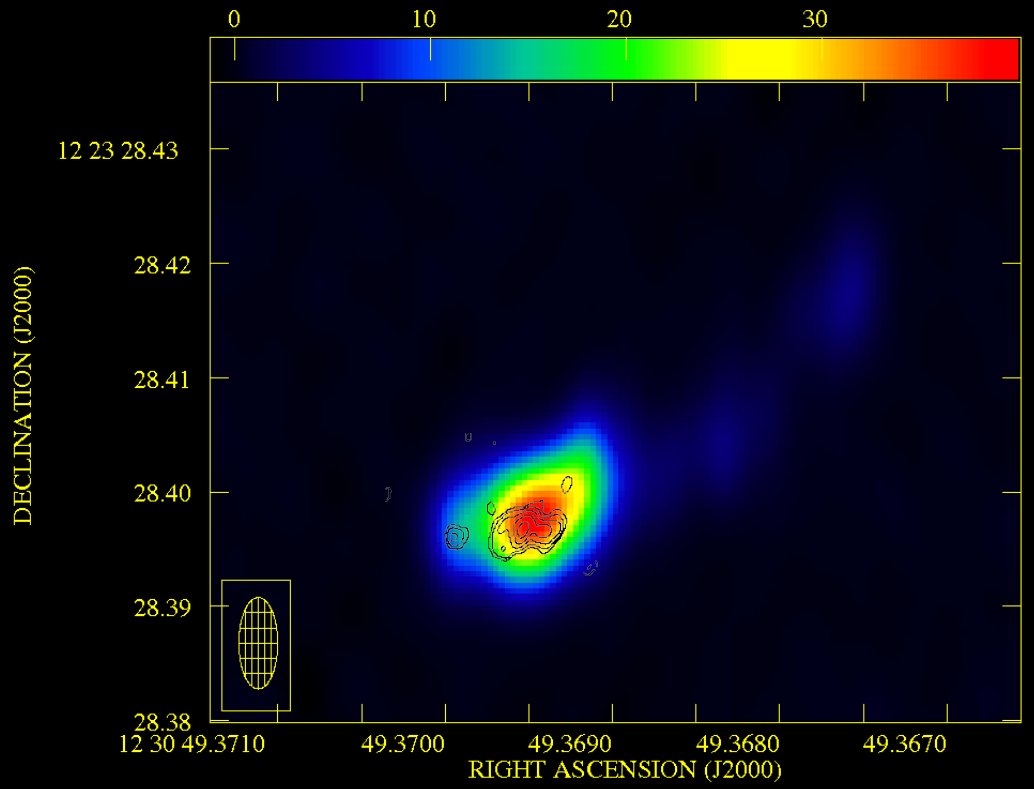


Beam: 8 x 3.4 mas; P.A. = 3˚

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

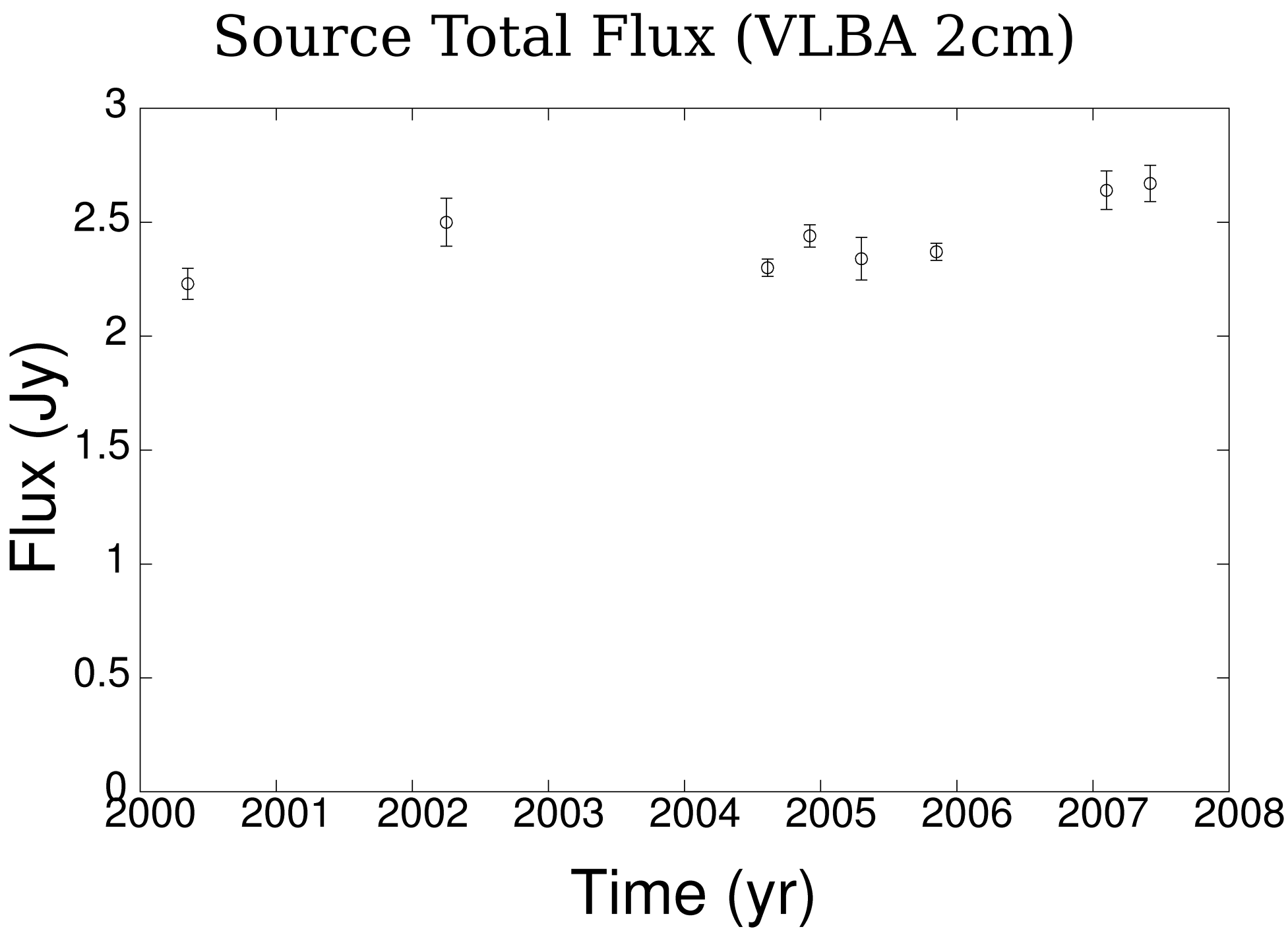


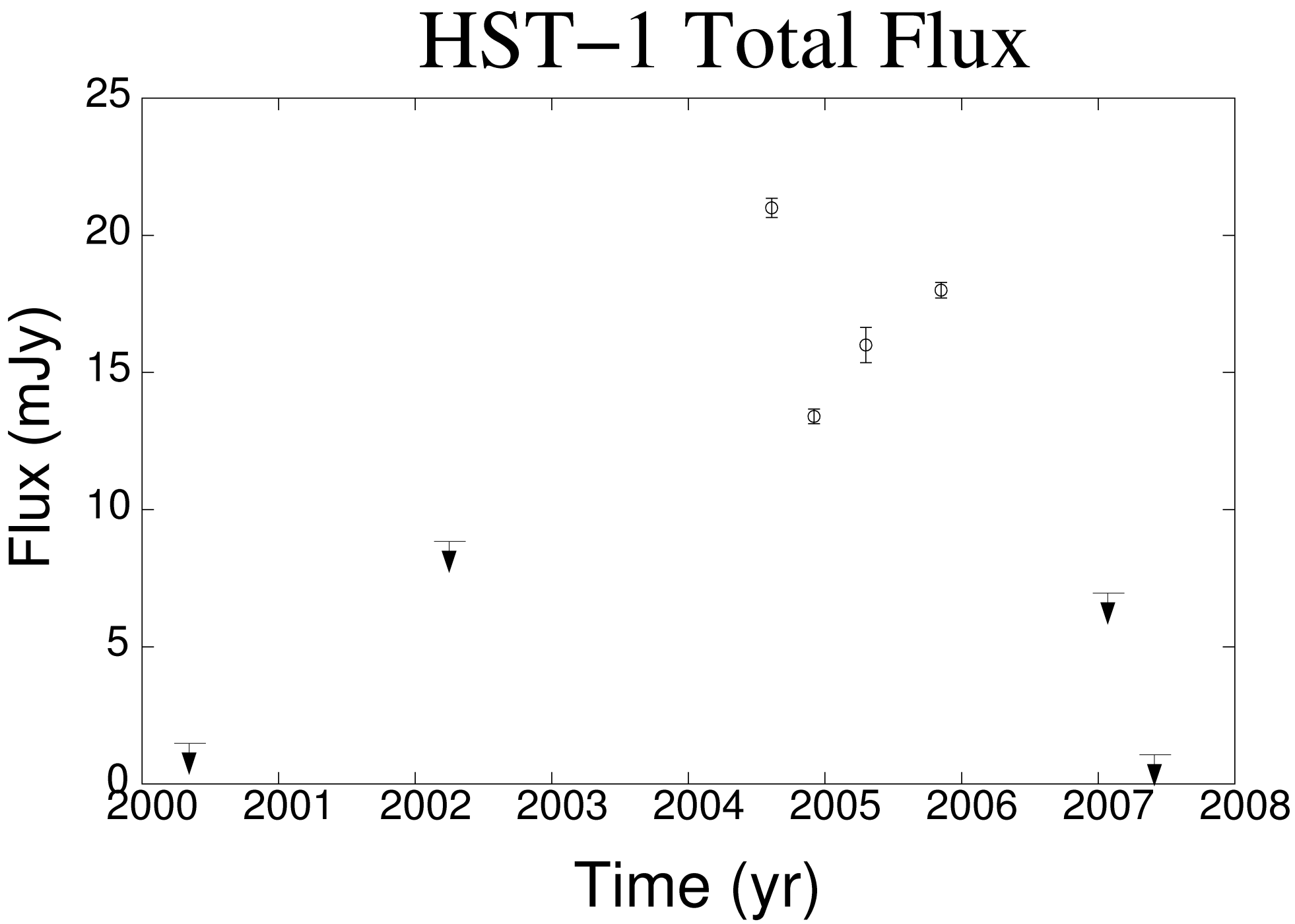
Contour: 2005.30 (VLBA 2cm)
Color scale: 2005.35 (VLBA 20cm)

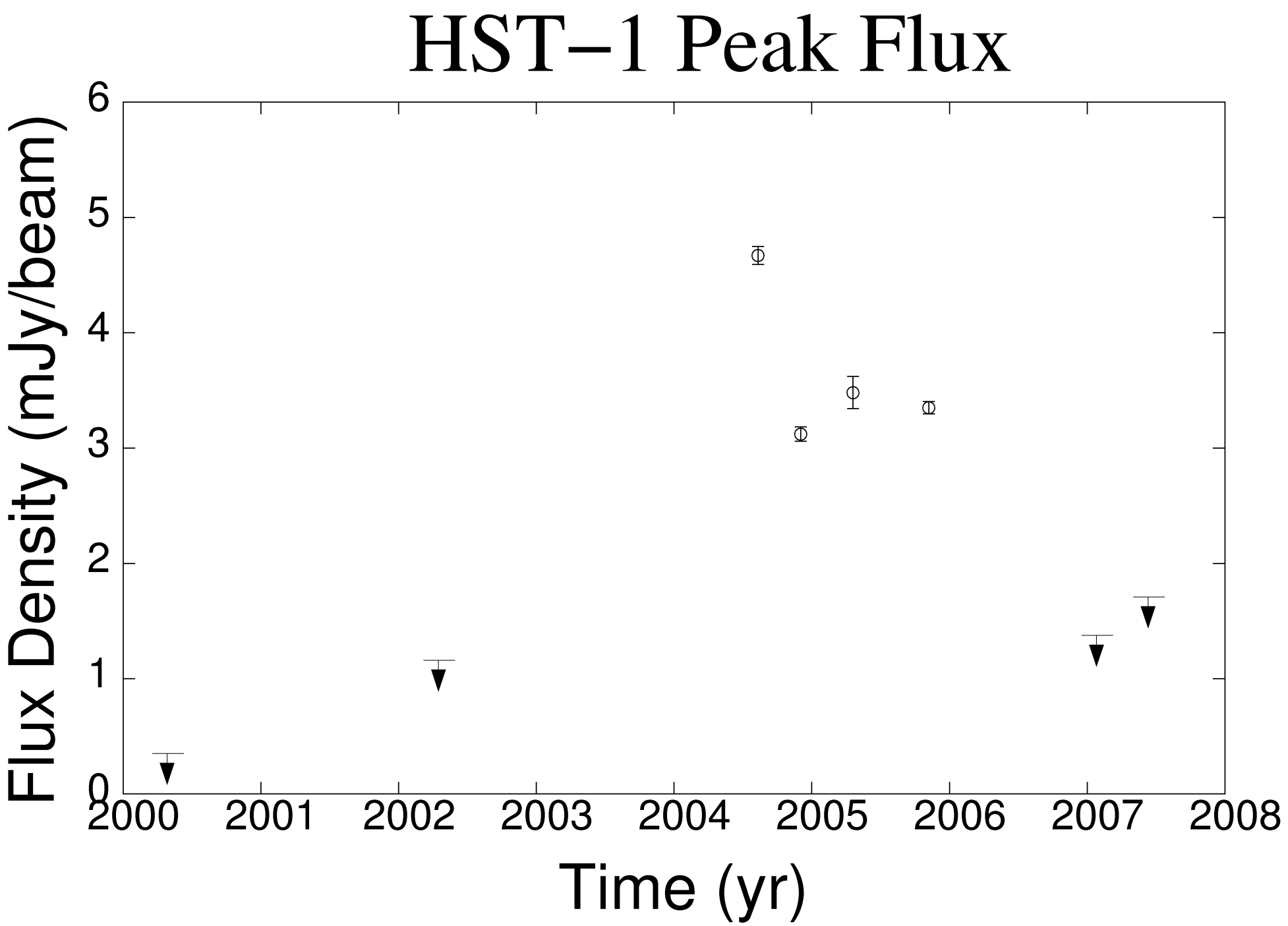


Contour: 2005.85 (VLBA 2cm)
Color scale: 2005.96 (VLBA 20cm)

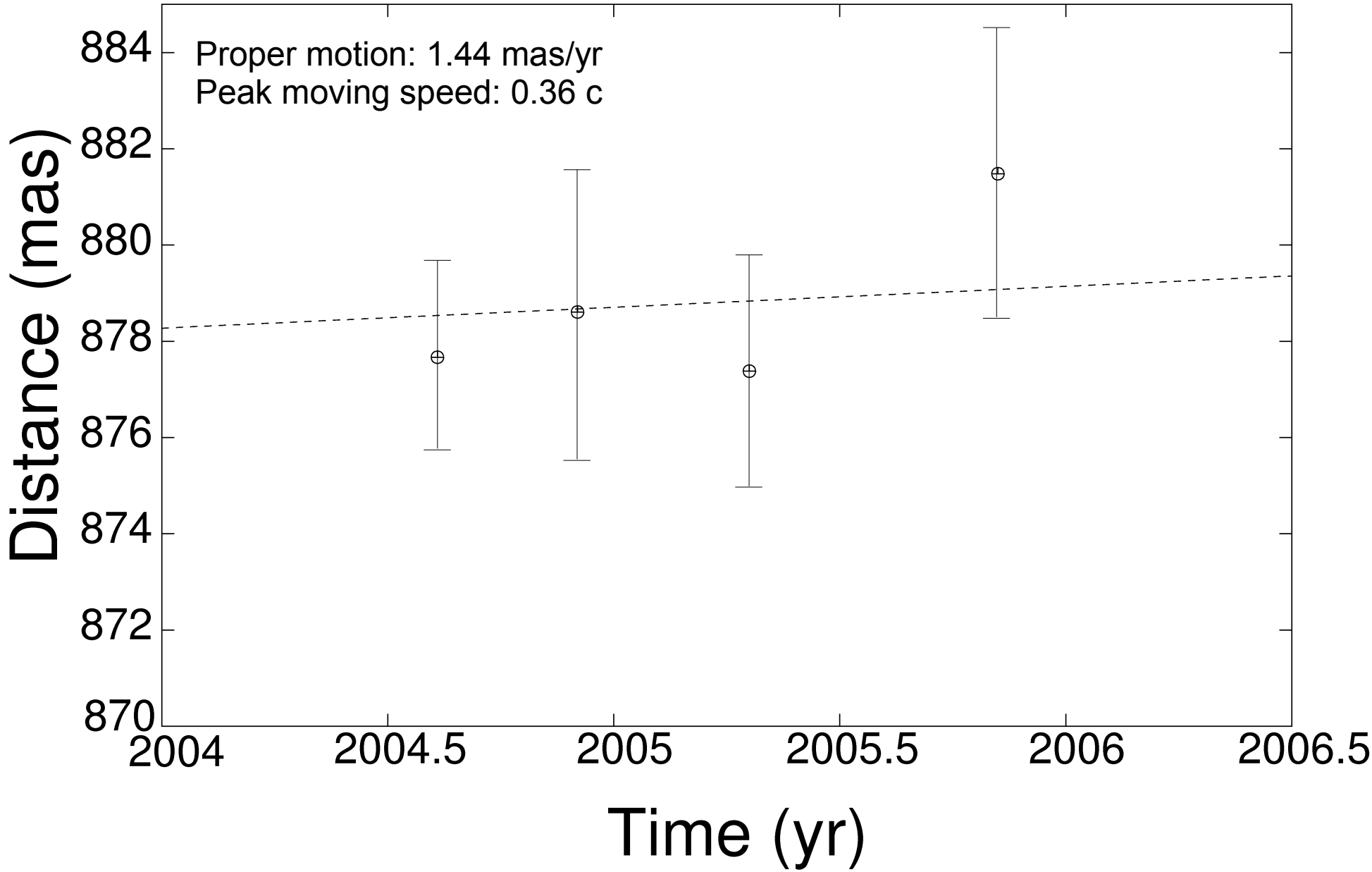
VLBA 20cm: Teddy Cheung (Private communication)


Source Total Flux (VLBA 2cm)
Flux (Jy)
Time (yr)
0
0.5
1
1.5
2
2.5
3
2000
2001
2002
2003
2004
2005
2006
2007
2008


HST−1 Total Flux
Flux (mJy)
Time (yr)
0
5
10
15
20
25
2000
2001
2002
2003
2004
2005
2006
2007
2008


HST−1 Peak Flux
Flux Density (mJy/beam)
Time (yr)
0
1
2
3
4
5
6
2000
2001
2002
2003
2004
2005
2006
2007
2008

HST−1 peak position w.r.t. the core



Results

- First detection of HST-1 with VLBI at 15 GHz during 2004 to 2006

  HST-1 peak flux: 3~5 mJy/beam

  HST-1 total flux density: 14~22 mJy
- Proper motion of brightest feature: 1.44 mas/year -> 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

Conclusions

- VLBI 15 GHz observations:

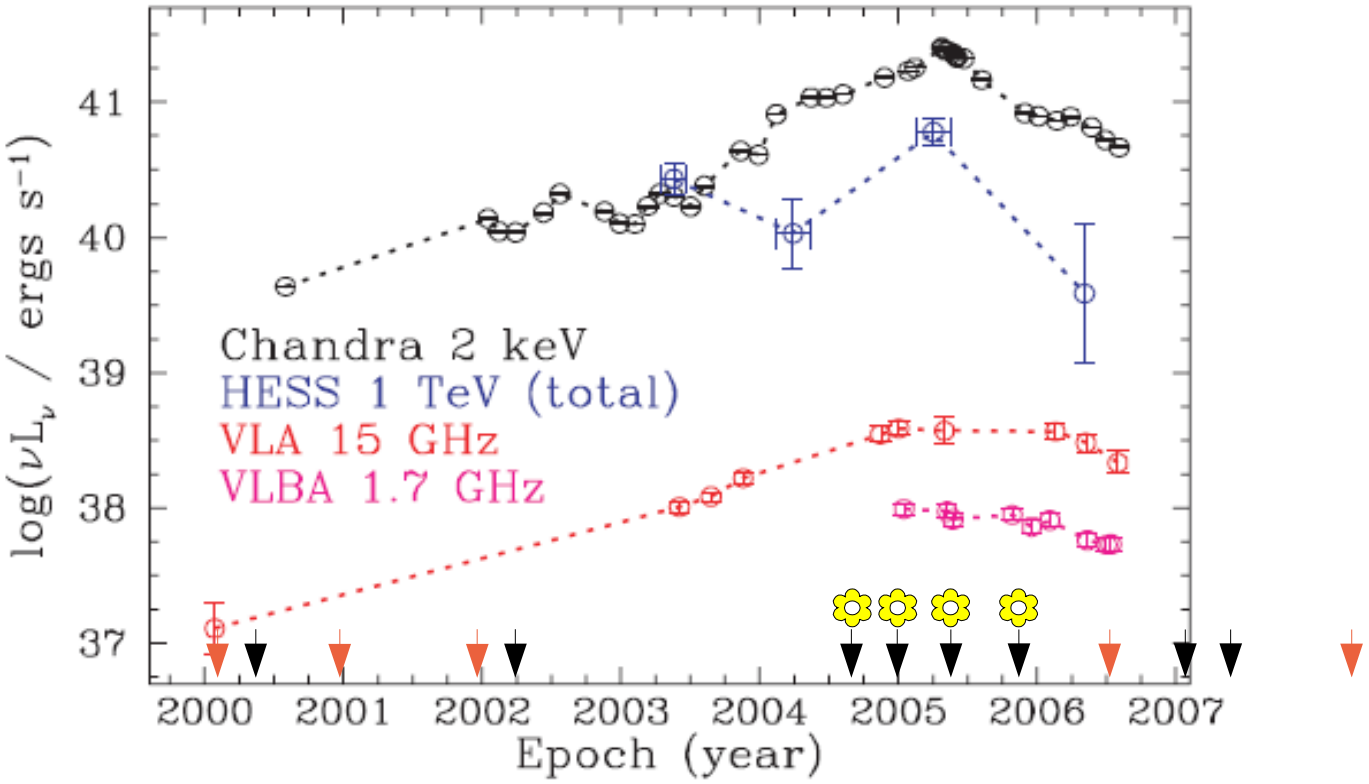
  - HST-1 is extended (low compactness)

  - no emerging, rapidly moving features during the flaring period in 2005

- Hypothesis of blazar nature is still open, but unlikely

Future Work

- Complete the analysis of the whole dataset
- Compare the results with longer band observations



Acknowledgements

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Thank you!