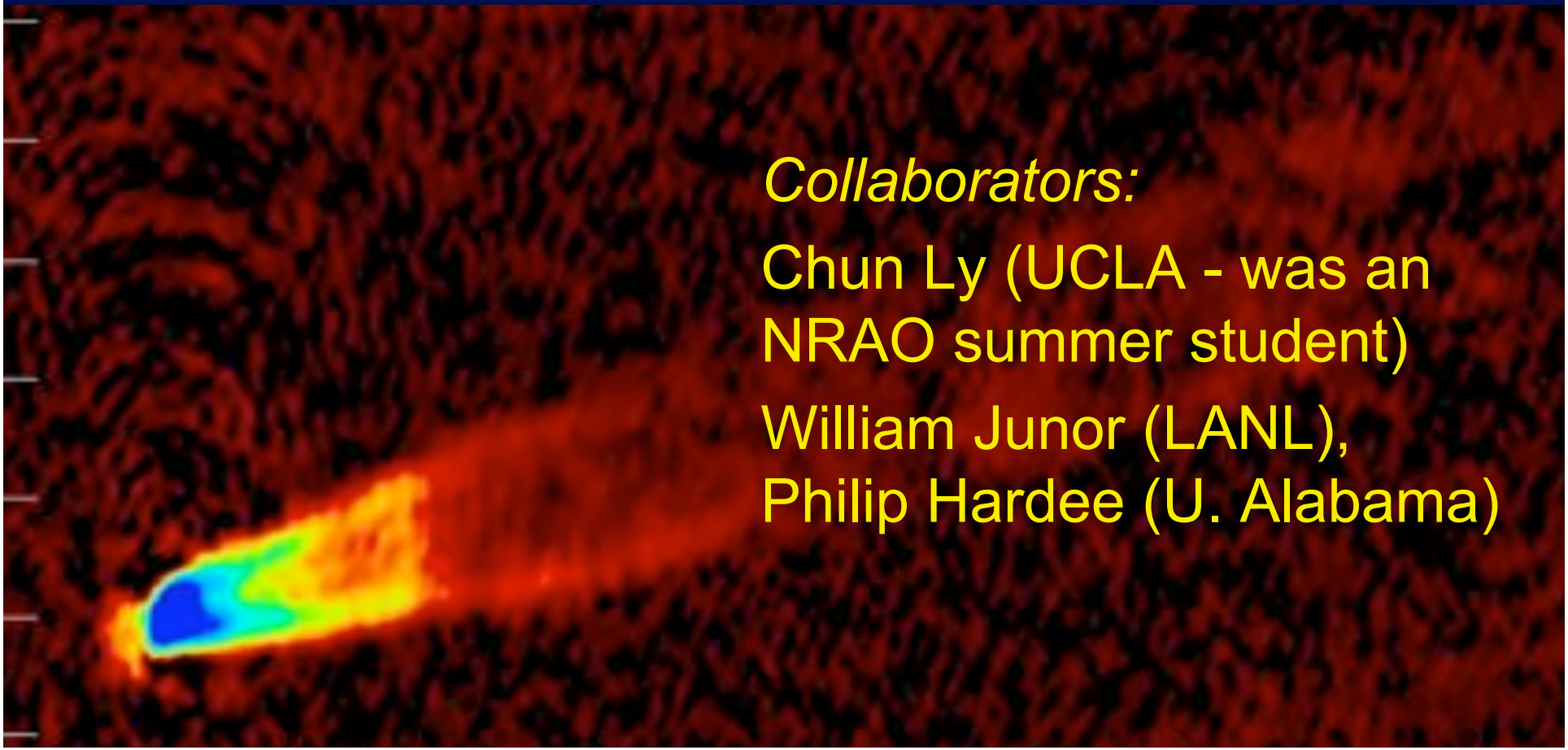
IMAGING A JET BASE - PROSPECTS WITH M87

R. Craig Walker NRAO



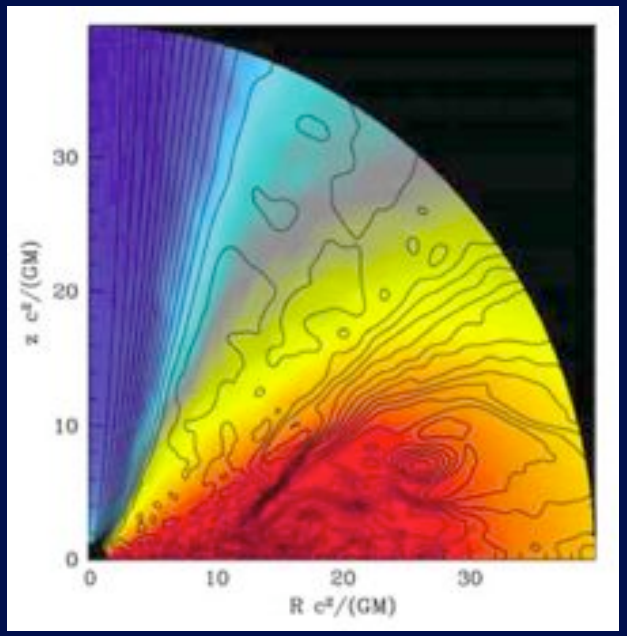
Collaborators:

Chun Ly (UCLA - was an NRAO summer student)

William Junor (LANL),
Philip Hardee (U. Alabama)

MOTIVATION - JET LAUNCH REGION

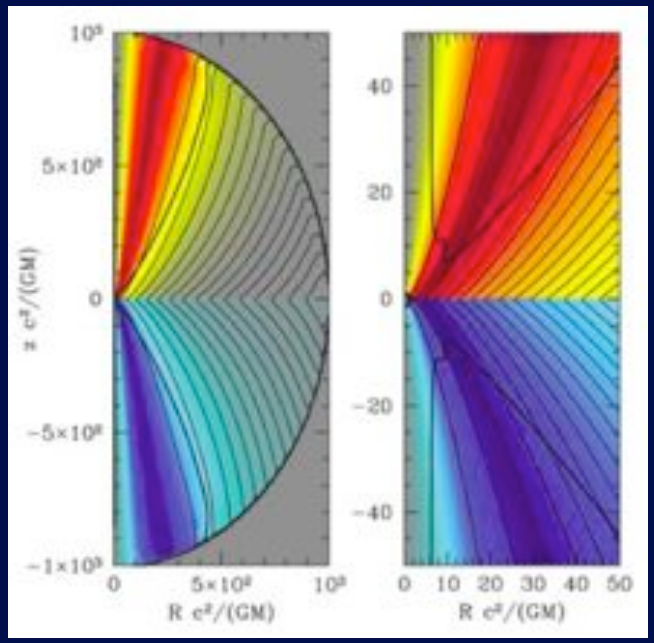
- Jet launch and collimation theory is progressing rapidly
  - Jets are a natural consequence of accretion
  - Magnetic fields play a critical role
  - Black hole spin is important
  - Typical structure includes a central Poynting jet and outer disk wind jet
  - The Poynting jet transitions to a kinetic dominated jet downstream
- Simulations reaching observable scales



Max scale

40 $c^2/(GM)$ 10^3

McKinney & Narayan 2007

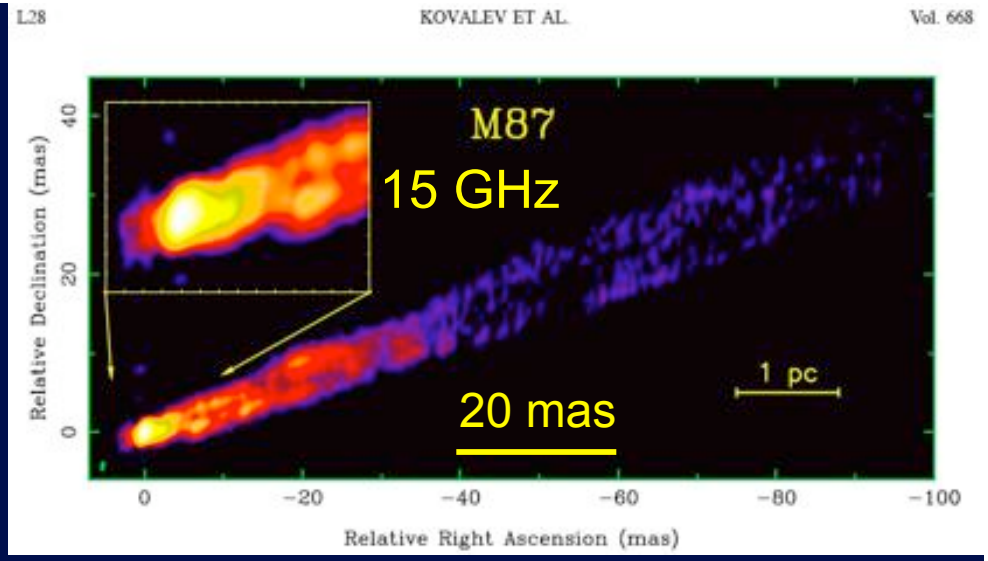


M87 - THE BEST SOURCE FOR IMAGING A JET BASE

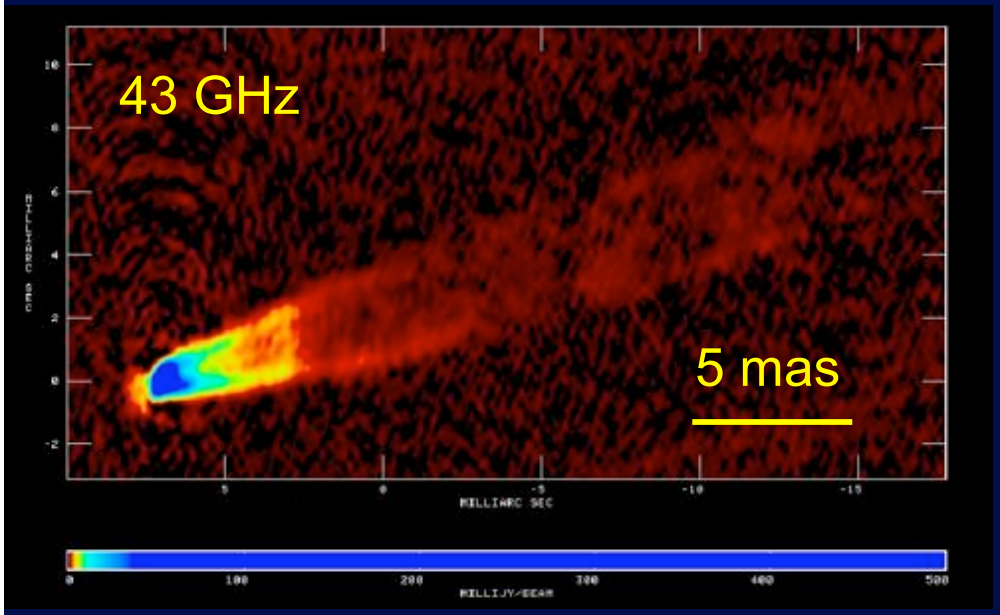
- Good resolution in gravitational units
  - Nearby: 16 Mpc
  - Large black hole mass: ~3X10^9 M_{sun}
  - VLBA resolution is about 60 Schwarzschild radii at 43 GHz
  - Scale 1 mas = 0.078pc = 270 Rs. 1 c = 4 mas/yr
- Jet bright enough to see significant structure
  - Core has about 0.7 Jy at 43 GHz - can self-calibrate
  - Jet well resolved transversely very near core
- Wide range of speeds seen in the jet
  - Includes 6c superluminal speeds which suggest a relativistic jet orientated near the line-of-sight
  - Many VLBI measured speeds subluminal
- Well studied at all wavelengths from radio to TEV

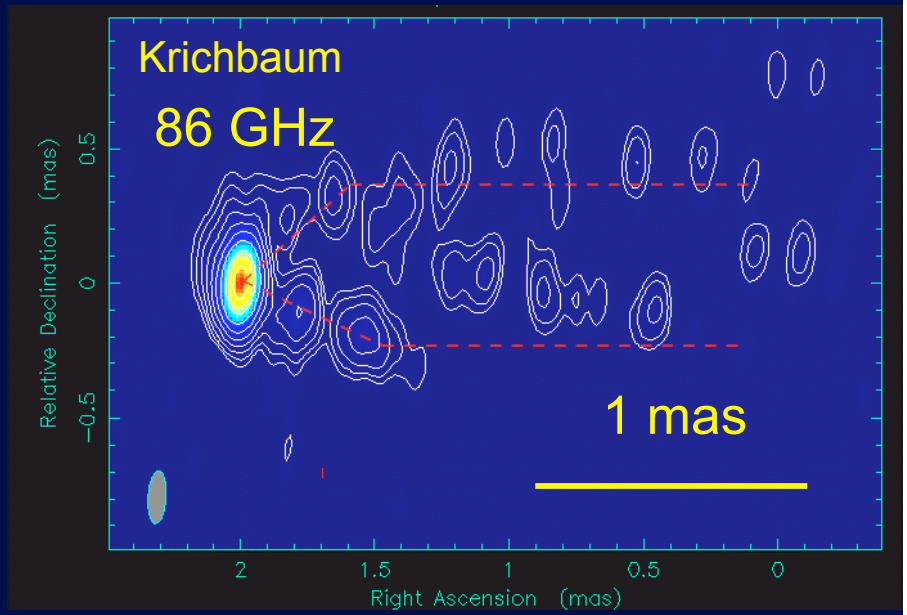
HIGH RESOLUTION STRUCTURE

- 15, 43, and 86 GHz images
- Wide opening angle base
- Edge brightened
- Counter feature



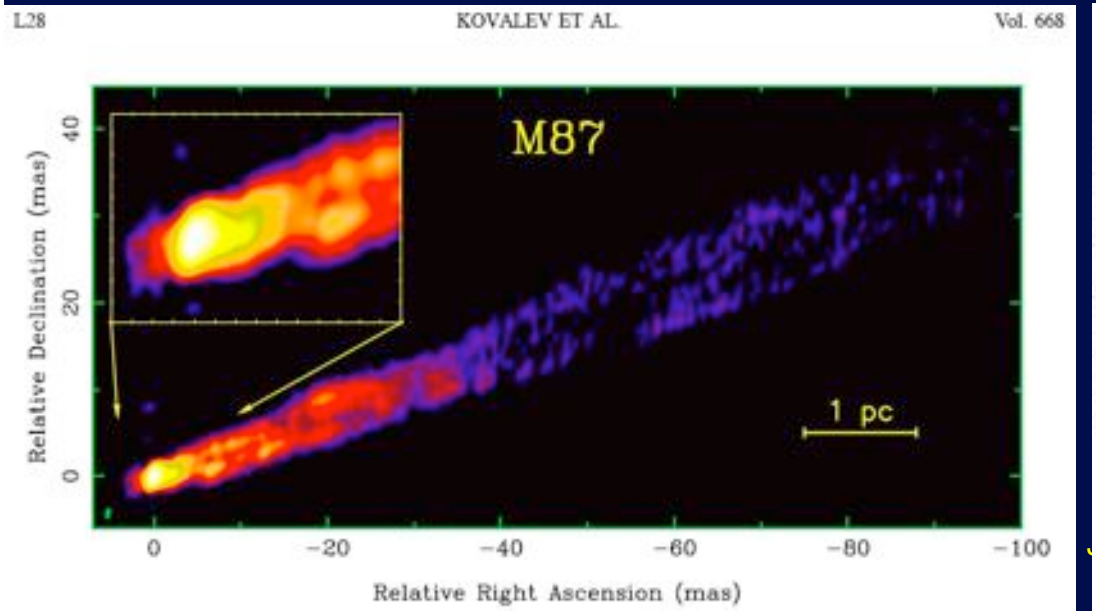
1 mas = 0.08 pc = 300 Rs

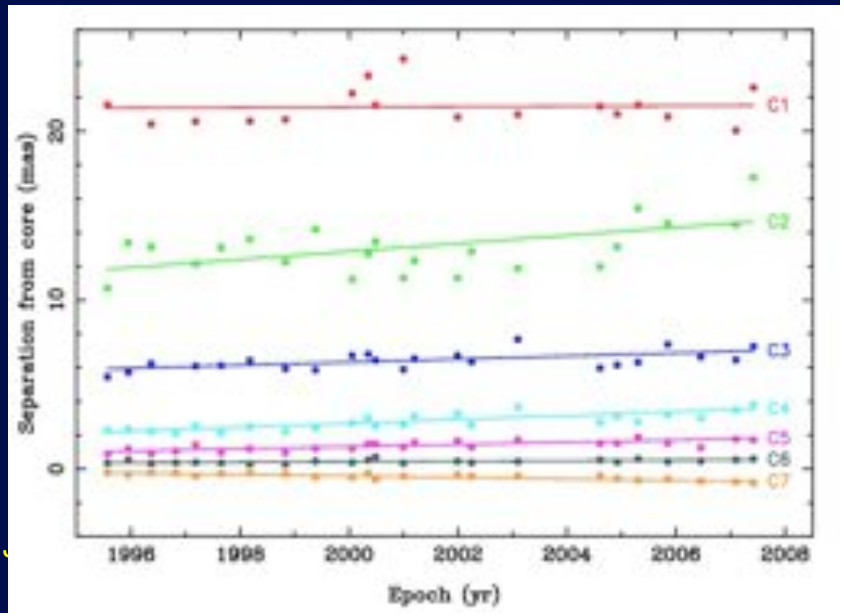




VLBI SUBLUMINAL MOTION MEASUREMENTS

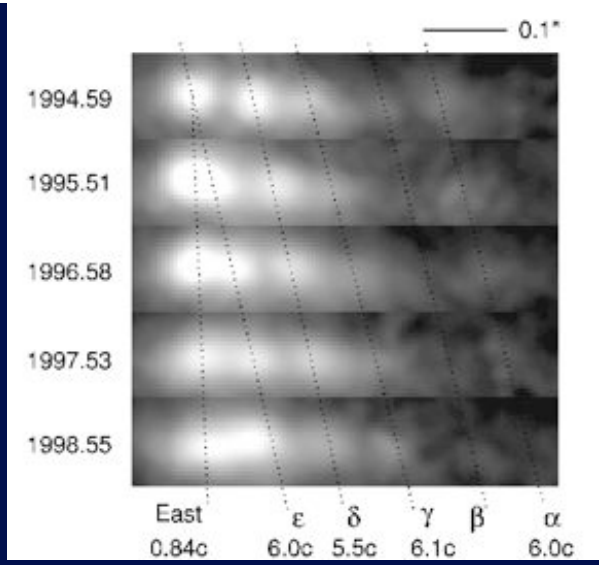
- Many VLBI observations show slow motions
  - VLBA < 0.1c (Biretta & Junor 1995; Junor & Biretta 1995)
  - VSOP No motions (Dodson et al 2006)
  - VLBI 1.6 GHz 0.28c (Reid et al 1989)
  - VLBA 43 GHz 0.25-0.40c (Ly et al 2007)
- Perhaps best case is 15 GHz monitoring (Kovalev et al. 2007)
  - A few percent of the speed of light
  - Sampling interval 5±3 months
- Slow material or patterns, perhaps from instabilities?

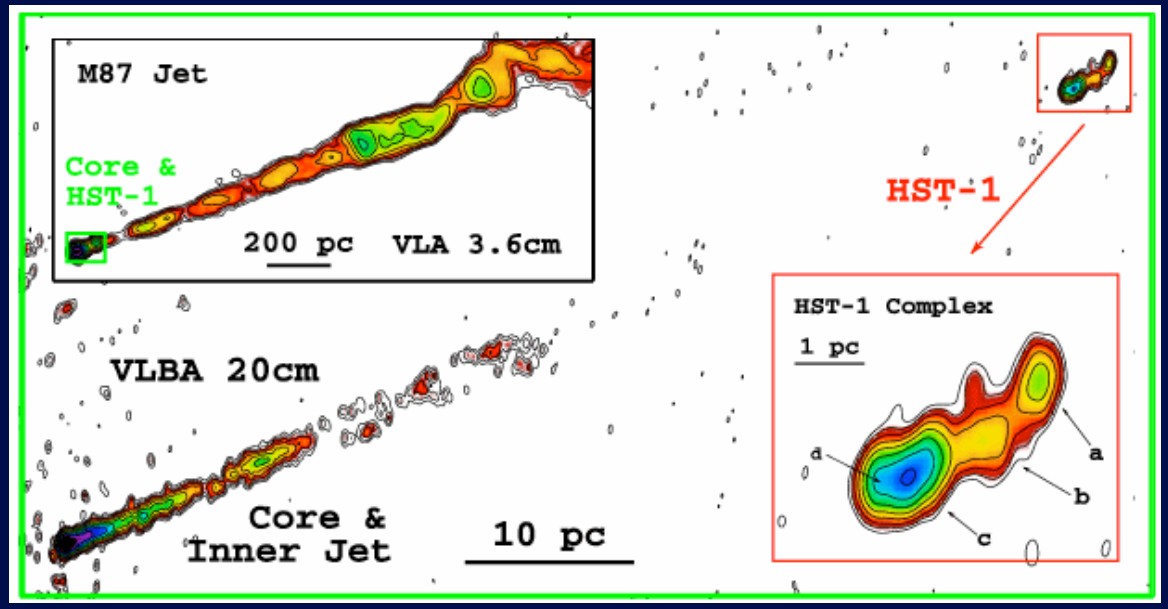


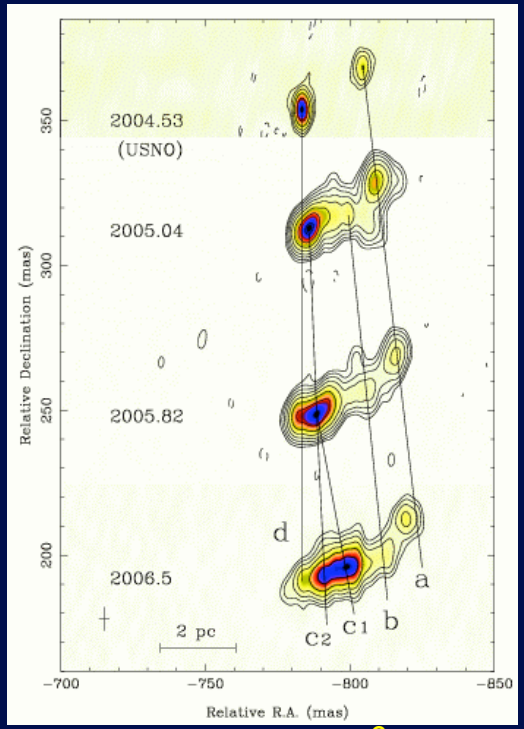


SUPERLUMINAL MOTIONS

- VLA Typical 0.5 c, but up to 2.5c (Biretta et al 1995)
- HST-1 Optical with HST (Biretta et al 1999)
  - Knot at 0.9" (70pc projected) Speeds ~5-6 c
- HST-1 VLBA 20cm (Cheung et al 2007)
  - Speeds 2.5 - 4.5 c.
  - Feature near core slow
  - HST-1 Plausible site for TEV emission

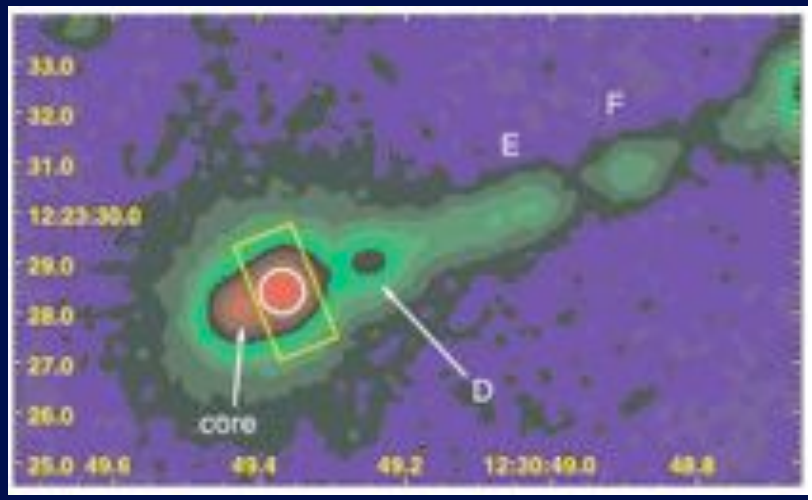


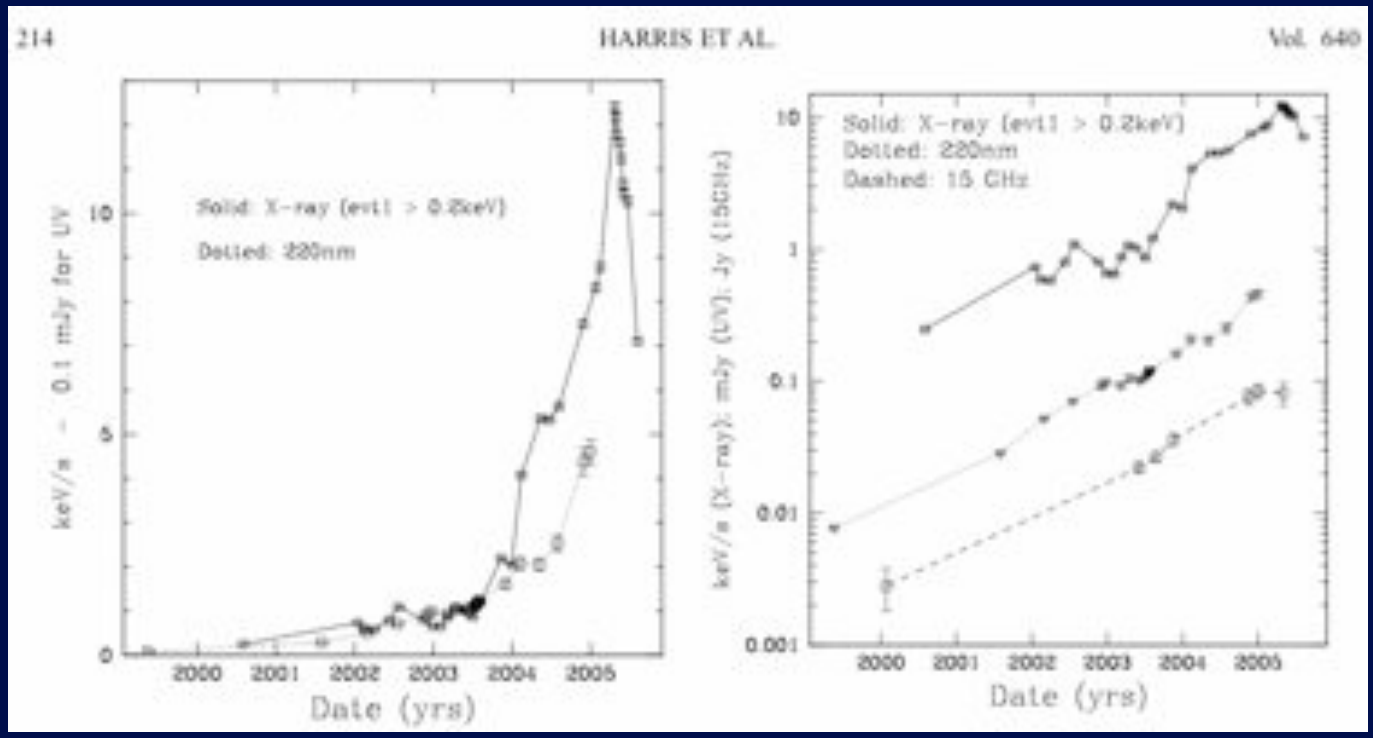




HST-1 FLARE

- Factor of 50 increase radio to X-ray flux (Harris et al 2006)
- Possible site of TEV emission (Cheung et al 2007)
- Clue to content of the jet

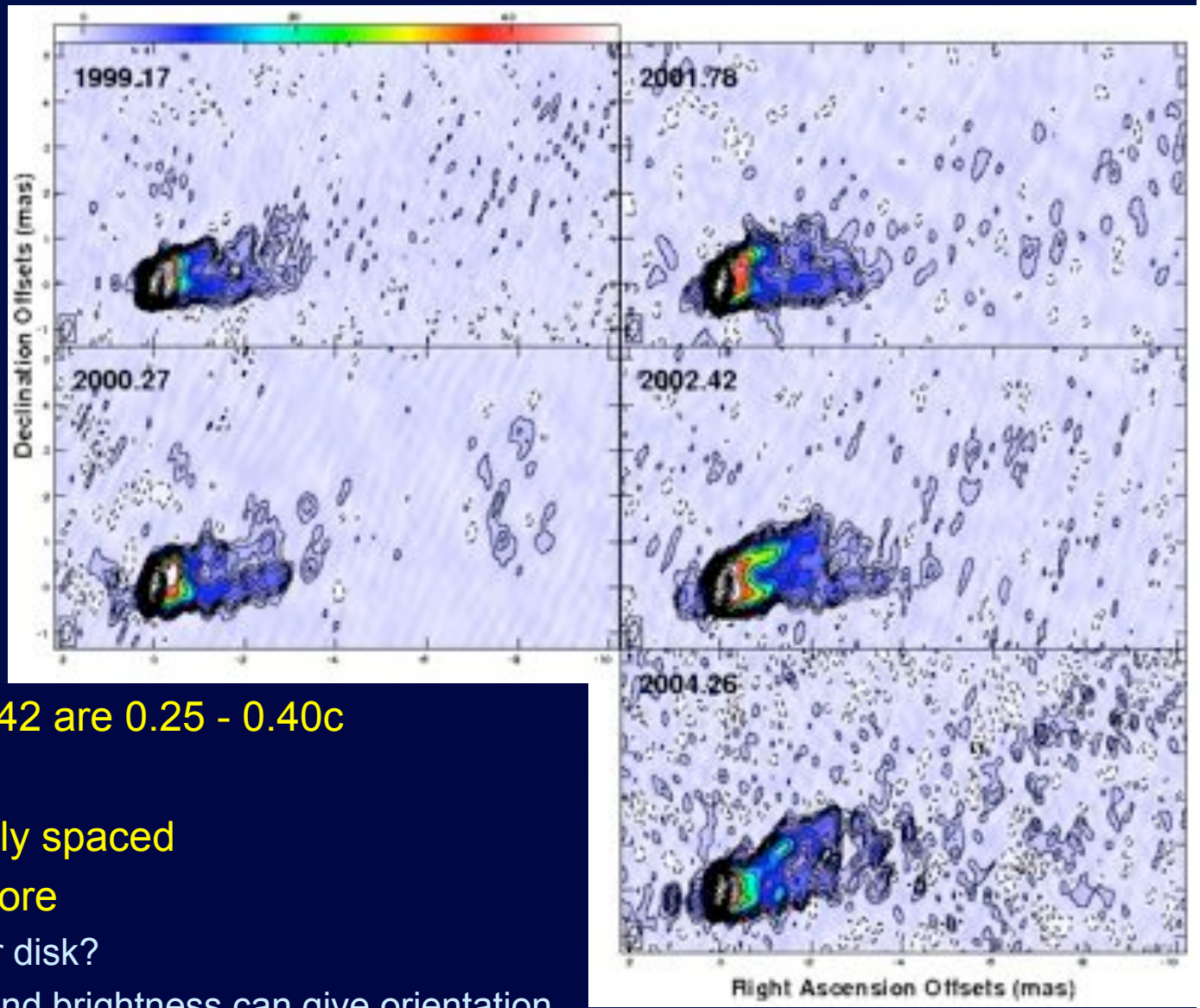




M87 43 GHz Images at ~1 yr Intervals

Our old observations and archive data. Mostly from use of M87 as phase reference source.
(Ly, Walker, & Junor, 2007, Ap. J. 660, 200.)

- Basic edge brightened structure maintained
- Dominant edge shifts from south to north



- Rates 2001.78 - 2002.42 are 0.25 - 0.40c
  - 1.0 to 1.7 mas/yr
- Other epochs too widely spaced
- Feature seen east of core
  - Counterjet, inner jet or disk?
  - If counterjet, speeds and brightness can give orientation

ARE THE VLBI OBSERVATIONS UNDERSAMPLED?

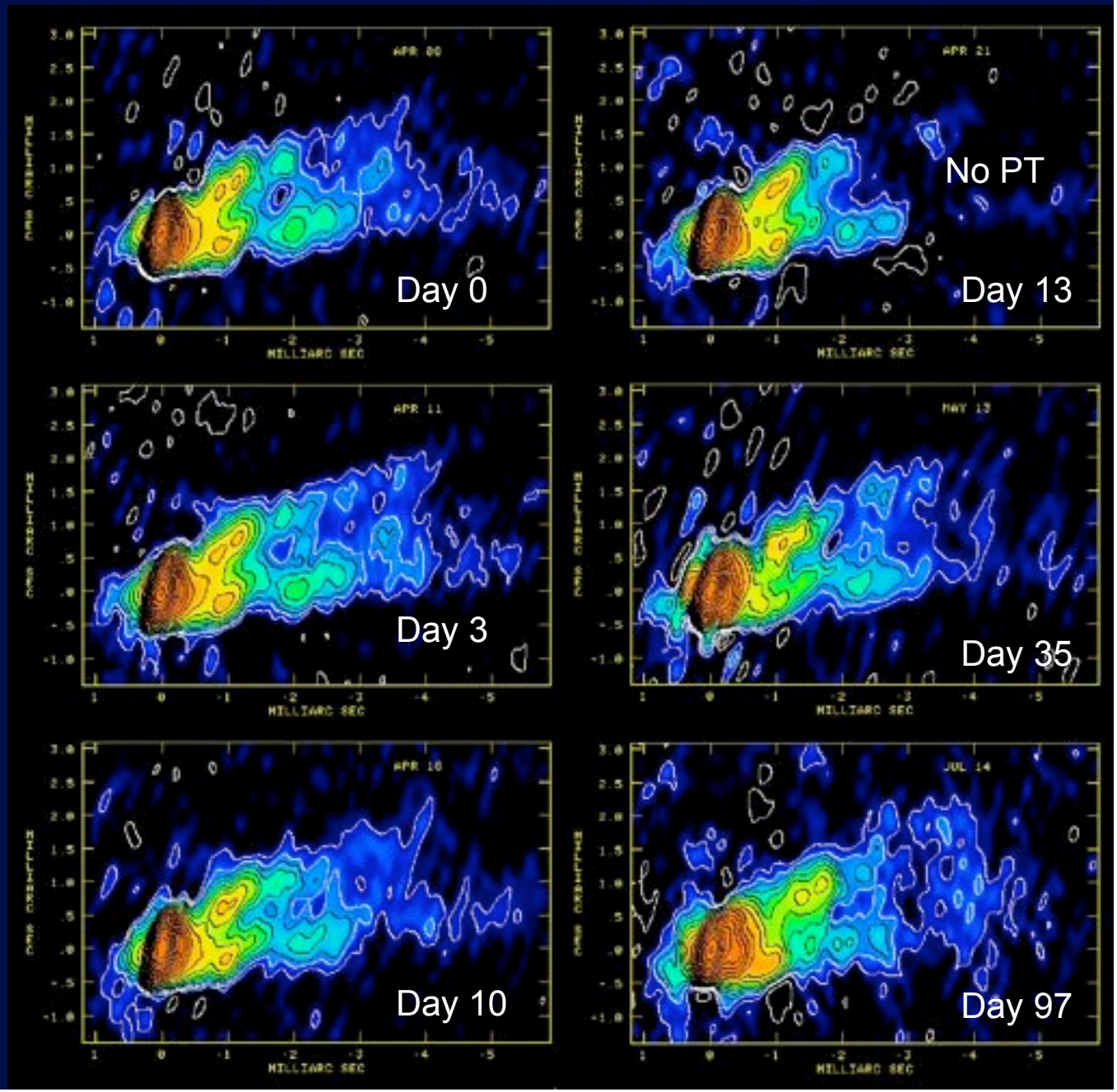
- Previous VLBI observations had sampling intervals of months to years
- Is this too slow?
  - 43 GHz beam is 0.2 mas
  - 1 c is 4 mas/yr or 1 beamwidth in 18 days
  - 6 c is 24 mas/yr or 1 beamwidth in 3 days
  - Observations every few months too slow
  - But clearly some features are slow - patterns?
- VLBA 43 GHz movie project - fast sampling at high resolution

PILOT PROJECT

- To determine movie frame rate:
  - –VLBA 43 GHz 2006
  - –10hr observations, 128 Mbps, full polarization
- Good consistency between close epochs
- Motions near 2.2 mas/yr (0.6c) at 1.5 mas from core
- About 1.5 mas/yr near core
- Superluminal motions not seen
- Feature east of core still seen

Beam: 0.42x0.18 mas
0.2mas = 0.016pc = 60R_s
1mas/yr = 0.25c

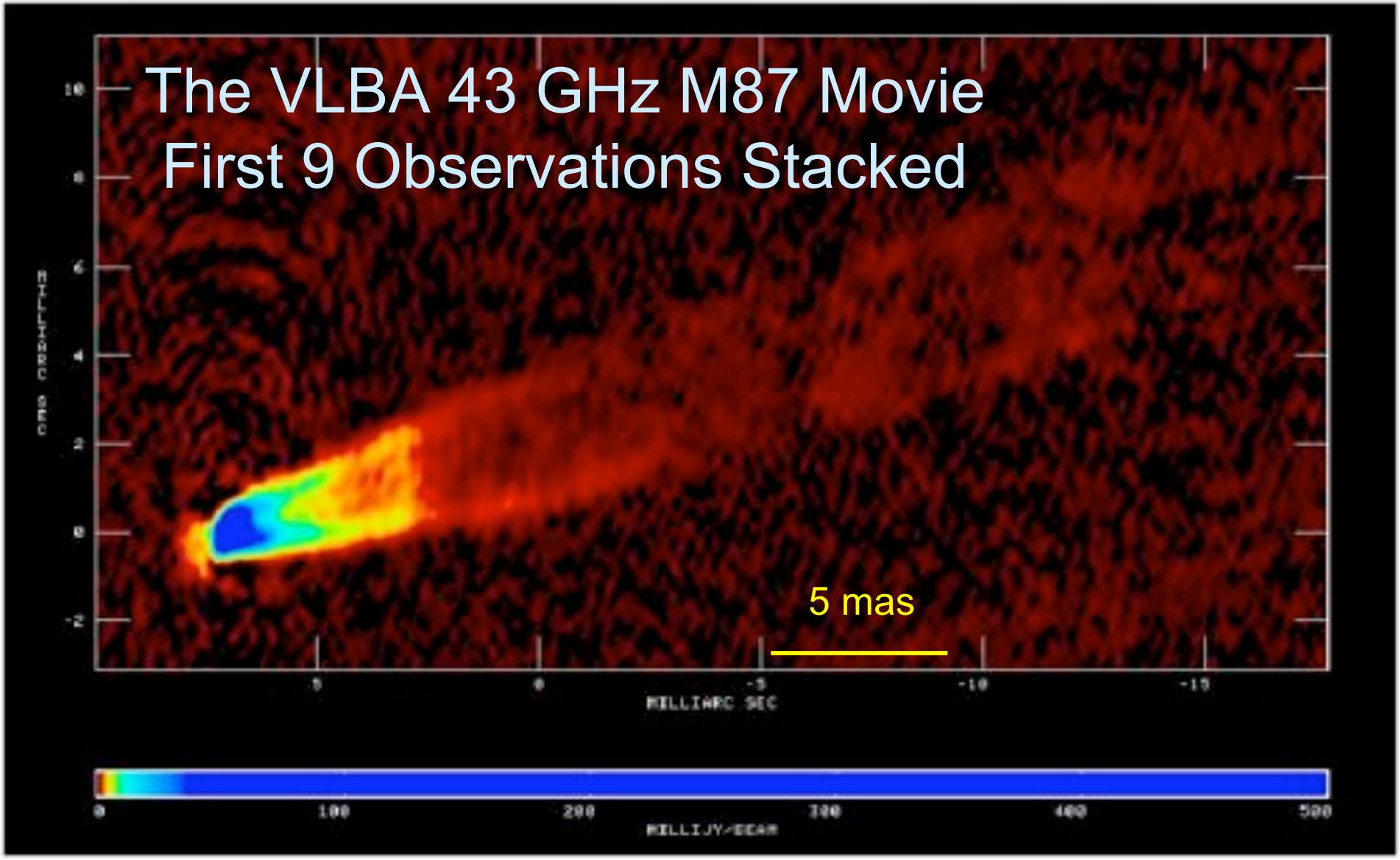
M87 - Walker



THE VLBA 43 GHz M87 MOVIE

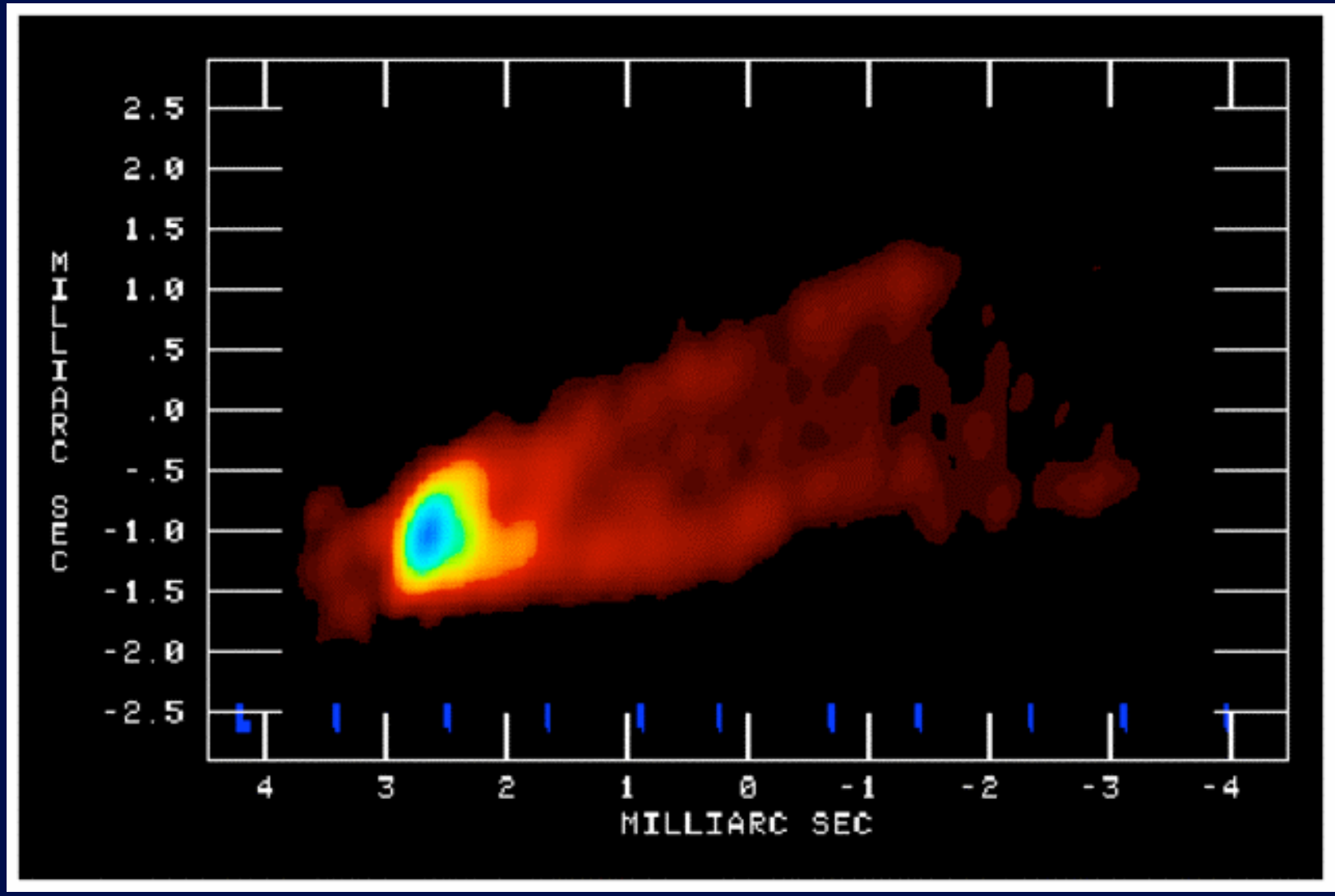
- Scheduled for 18 frames at 3 week intervals
  - Interval based on Pilot Project results
  - Dynamic scheduling within windows of ±5 days
  - Observations began Jan. 27, 2007
    - 13 frames observed and correlated so far. 11 imaged
- Observational parameters
  - 10 hr/frame
  - 256 Mbps (Twice the bandwidth of pilot)
  - Full stokes
  - Primary calibrators 3C279 and OJ287

The VLBA 43 GHz M87 Movie
First 9 Observations Stacked



Beam: 0.56x0.41 mas 0.2mas = 0.016pc = 60R_s 1mas/yr = 0.25c

The VLBA 43 GHz M87 Movie First 11 Observations

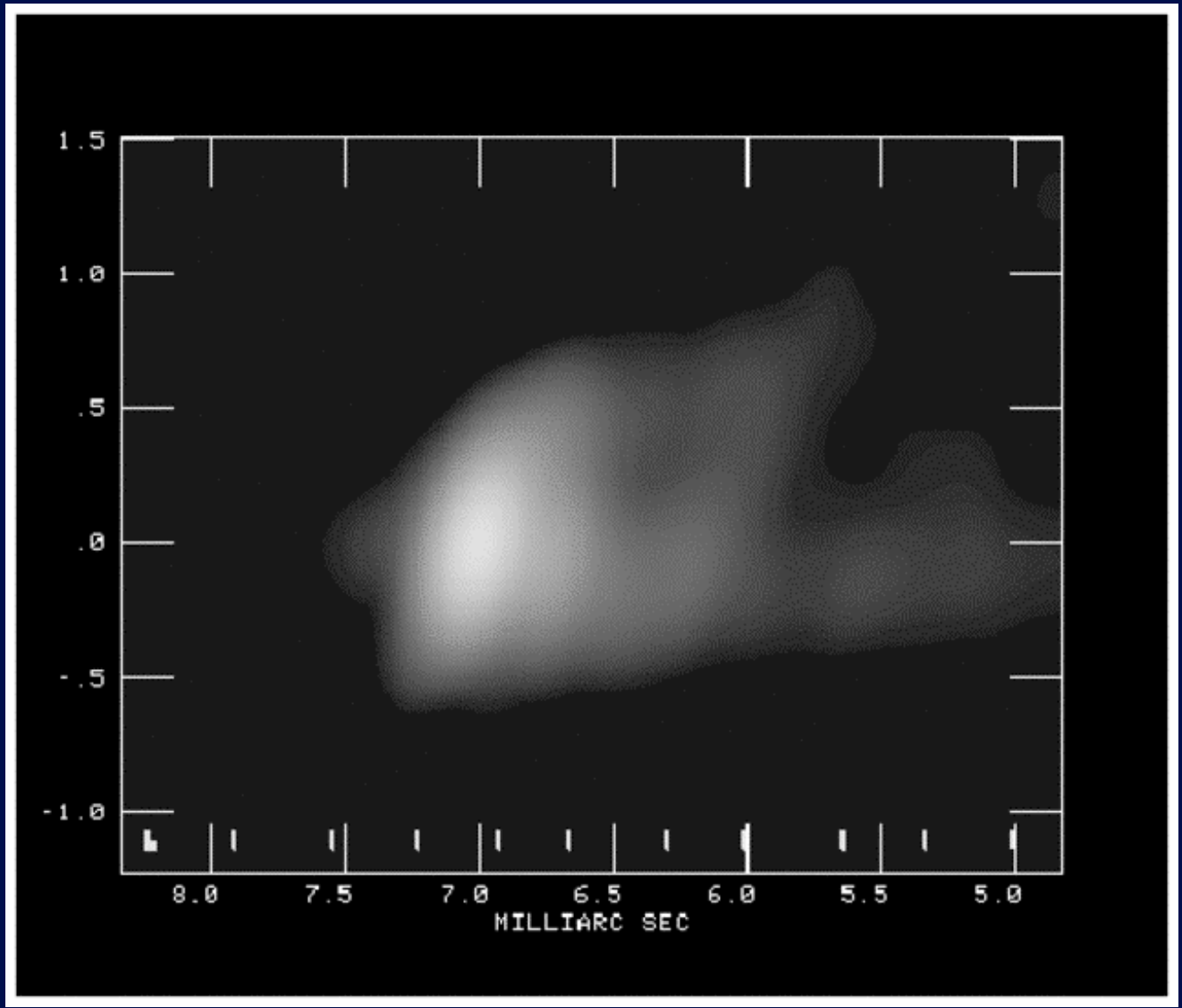


Beam: 0.43x0.21 mas 0.2mas = 0.016pc = 60R_s 1mas/yr = 0.25c

THE CENTRAL REGION

Alternate display of bright region

300 R_s

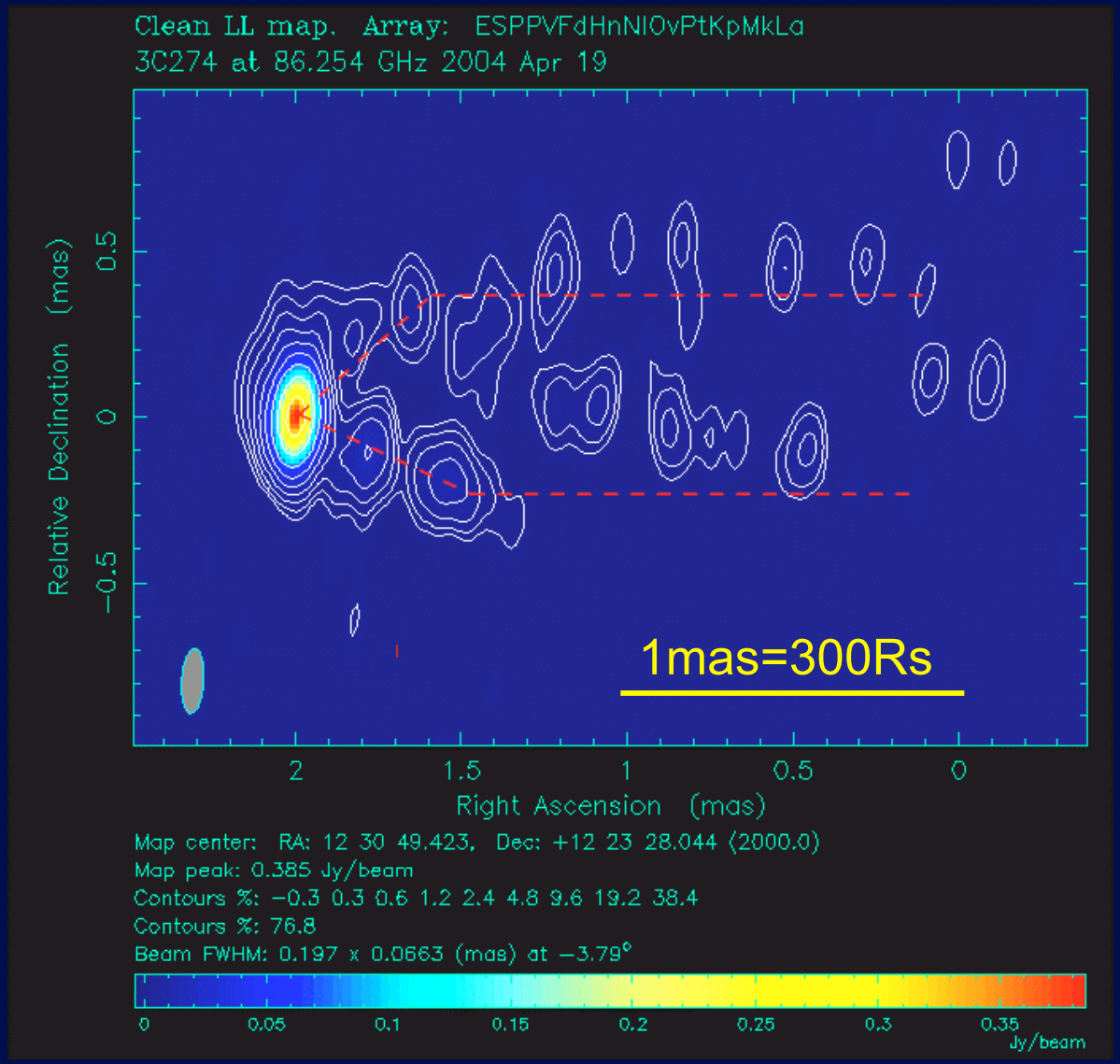


43 GHz MOVIE PROJECT - MORE TO COME

- Remaining analysis
  - 7 more observations for the movie
    - Ends in January 2008
  - Polarization, at least near core
  - Proper motion test
    - Observations include some phase reference scans to M84
- Faster sampling project
  - Have proposed 10 observations at 5 day intervals
  - Hope to add to end of current movie

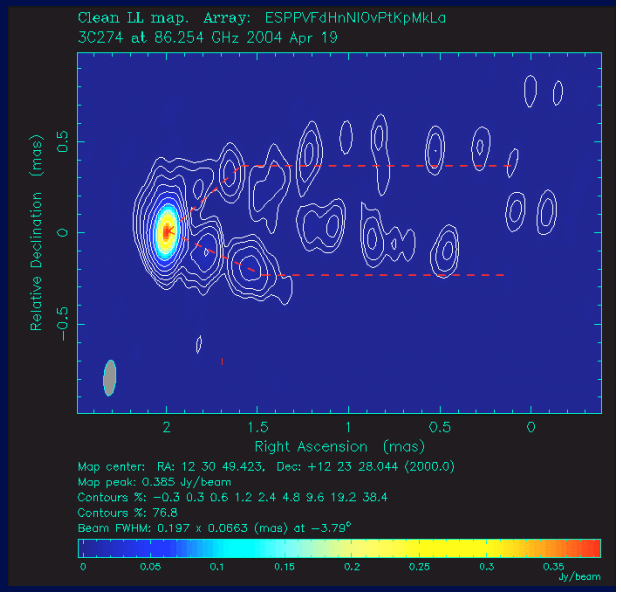
Higher Resolution: M87 at 86 GHz

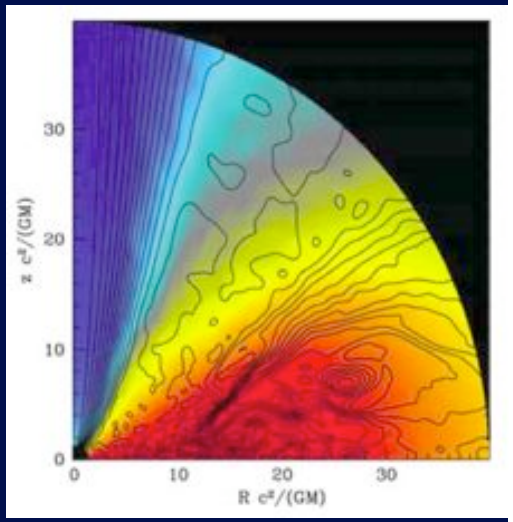
- Global VLBI
  - Starting to resolve high opening angle region
  - Krichbaum et al 2007
  - Data from Apr 2004
- Beam 0.20 x 0.066 mas
- Peak 0.38 Jy
  - Lowest contour 1.1 mJy



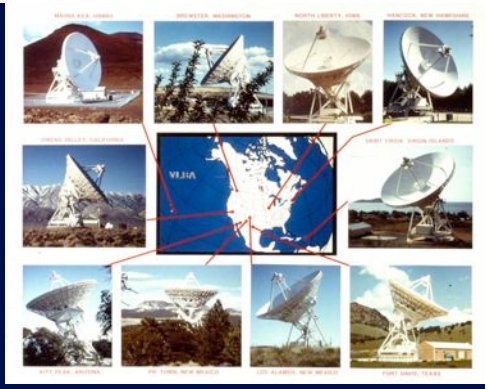
M87: PROSPECTS FOR VSOP-2

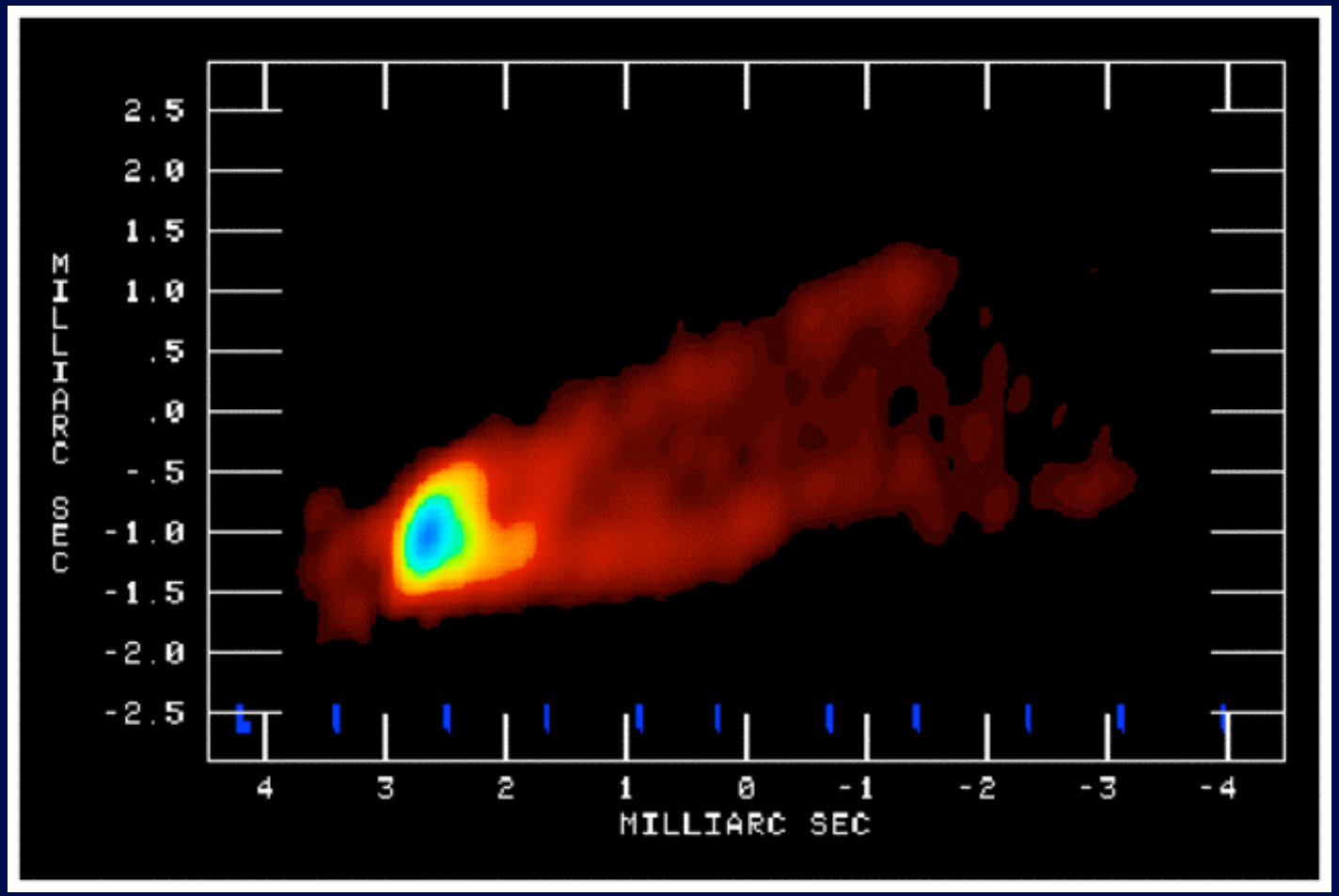
- VSOP-2 capability for M87
  - Will have more resolution and will see at least as much detail as the 86 GHz results
    - 40 vs 66 μarcsec (11 vs 18 Rs)
    - Jet stronger at 43 GHz
- Circumstances contrive that the extra VSOP-2 resolution will be very useful to clarify the structure in the wide opening angle region
- A VSOP-2 Movie
  - At 2c, the motion is 8 mas/yr or 0.02 mas/day
  - About half of the VSOP beam per day!
  - A VSOP-2 movie should use daily observations





THE END

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