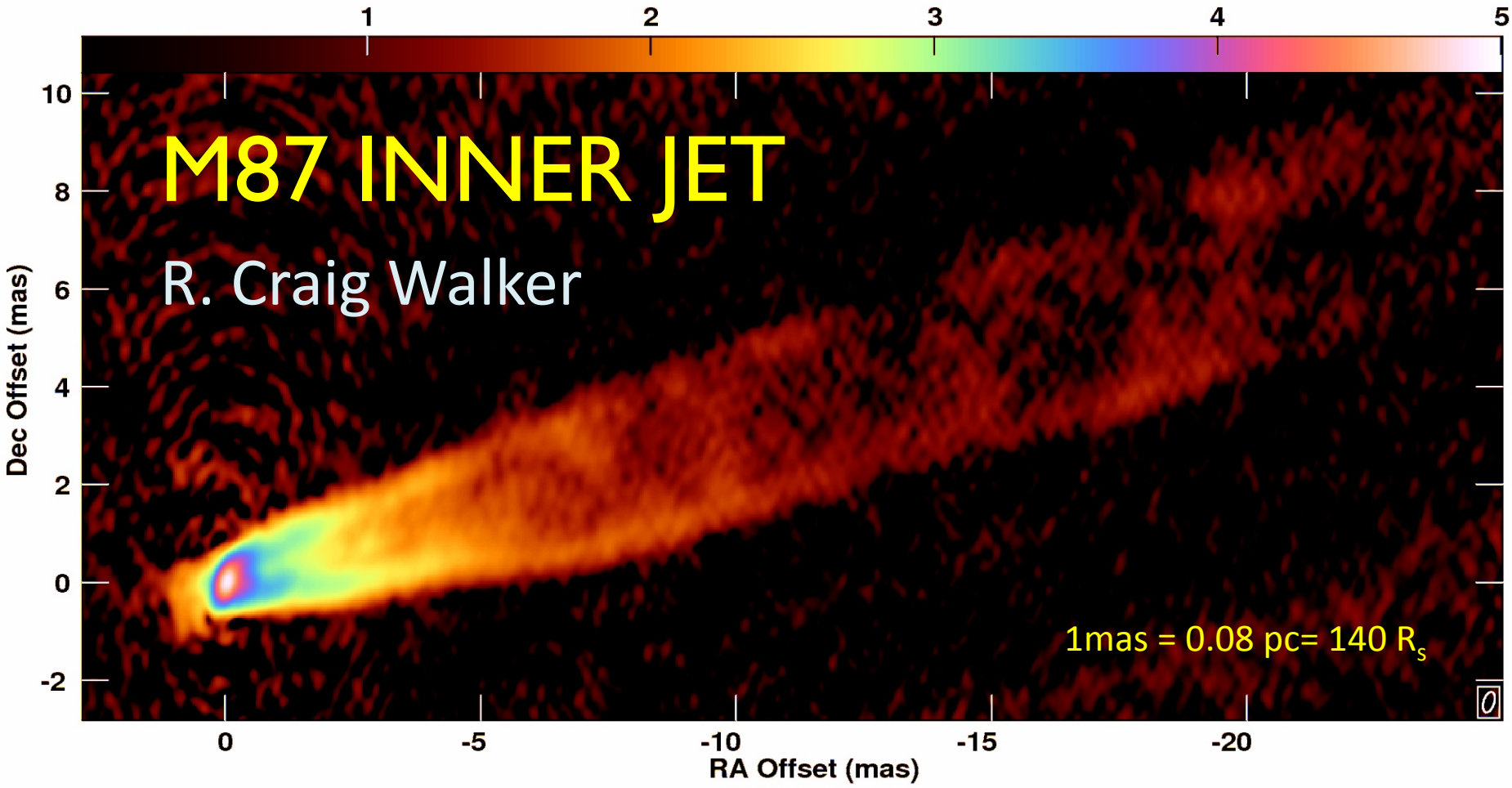


Collaborators:

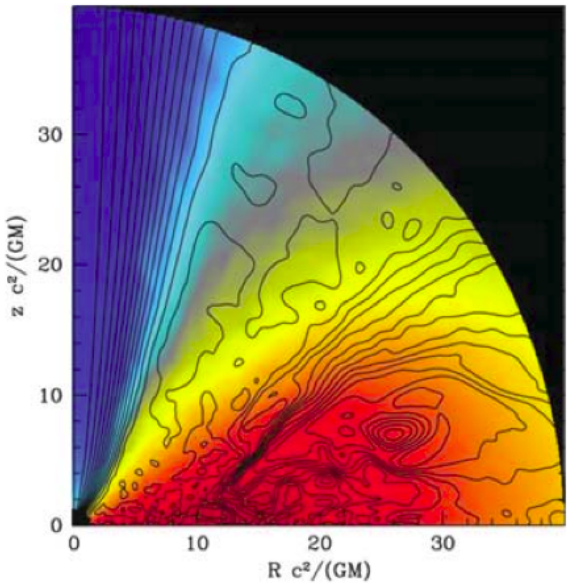
Radio: P. E. Hardee (U. Alabama), W. Junor (UC/LANL), F. Davies (UCLA), C. Ly (STSci)
High Frequencies: M. Beilicke (WUSTL), C. C. Cheung (NRC/NRL), D. E. Harris (DfA), H. Krawczynski (WUSTL), D. Mazin (IFAE), W. McConville (U. Maryland), M. Raue (U. Hamburg), and R. M. Wagner (MPI für Physik), The VERITAS, H.E.S.S., and MAGIC collaborations.

M87 - THE BEST SOURCE FOR IMAGING A JET BASE

- Large angular size black hole
  - 6.1 X 10^9 $M_\odot$ at 16.7 Mpc.
  - R_s = 7.2 μas = 120 au (2GM/c^2)
  - 1 c = 3.8 mas/yr
  - Variations slow enough for Earth rotation synthesis
- Bright jet with complex observable structure
  - 43 GHz Peak ~0.7 Jy – can self-calibrate VLBI data
  - Resolved transversely very near core
  - Easy to observe with northern hemisphere instruments
- VLBA 43 GHz resolution; 210 X 430 μas (~30 X 60 R_s)
- Well studied at all wavelengths from radio to TeV
- Other candidates have no jet (SgrA*) or smaller black hole (CenA)

OBSERVATIONAL CONSTRAINTS FOR JET LAUNCH THEORY

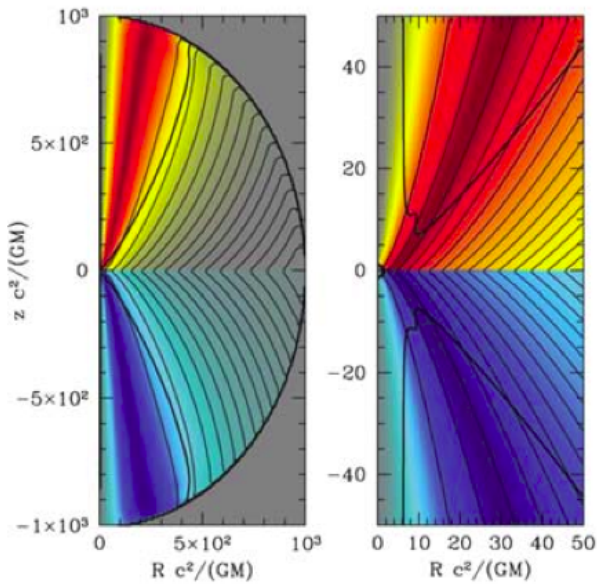
- There is overlap between regions imaged and regions simulated
- Potentially can compare:
  - Shape – Wide opening angle base, width vs distance
  - Transverse structure – Edge brightening
  - Polarization structure – Implications for magnetic field
  - Dynamics including apparent velocity field and acceleration
  - Counterjet – including velocity information from beaming



A random example of jet launch numerical modeling McKinney & Narayan 2007

Max scale

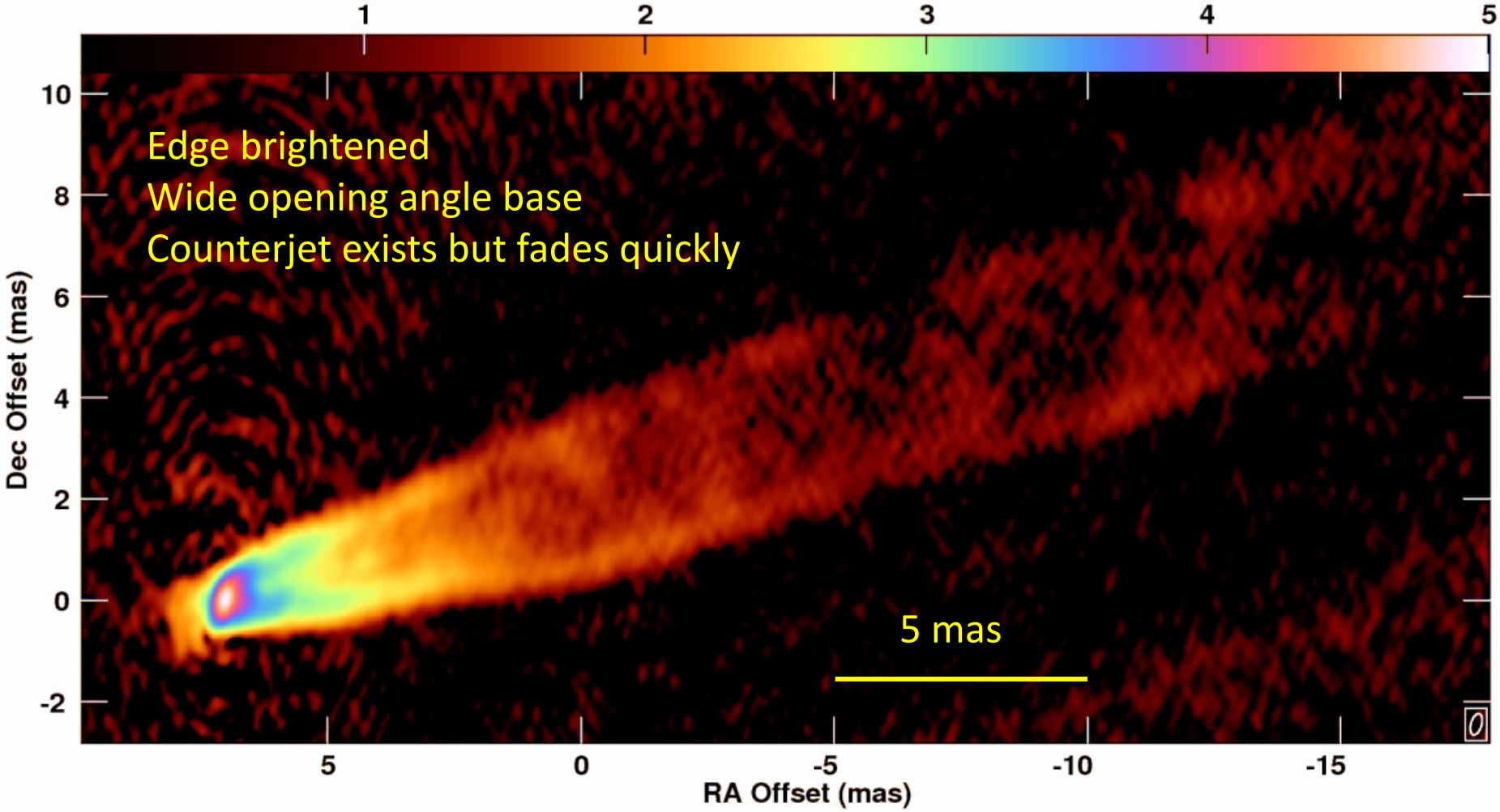
40 $c^2/(GM)$ 1000



THE VLBA 43 GHz M87 MOVIE PROJECT

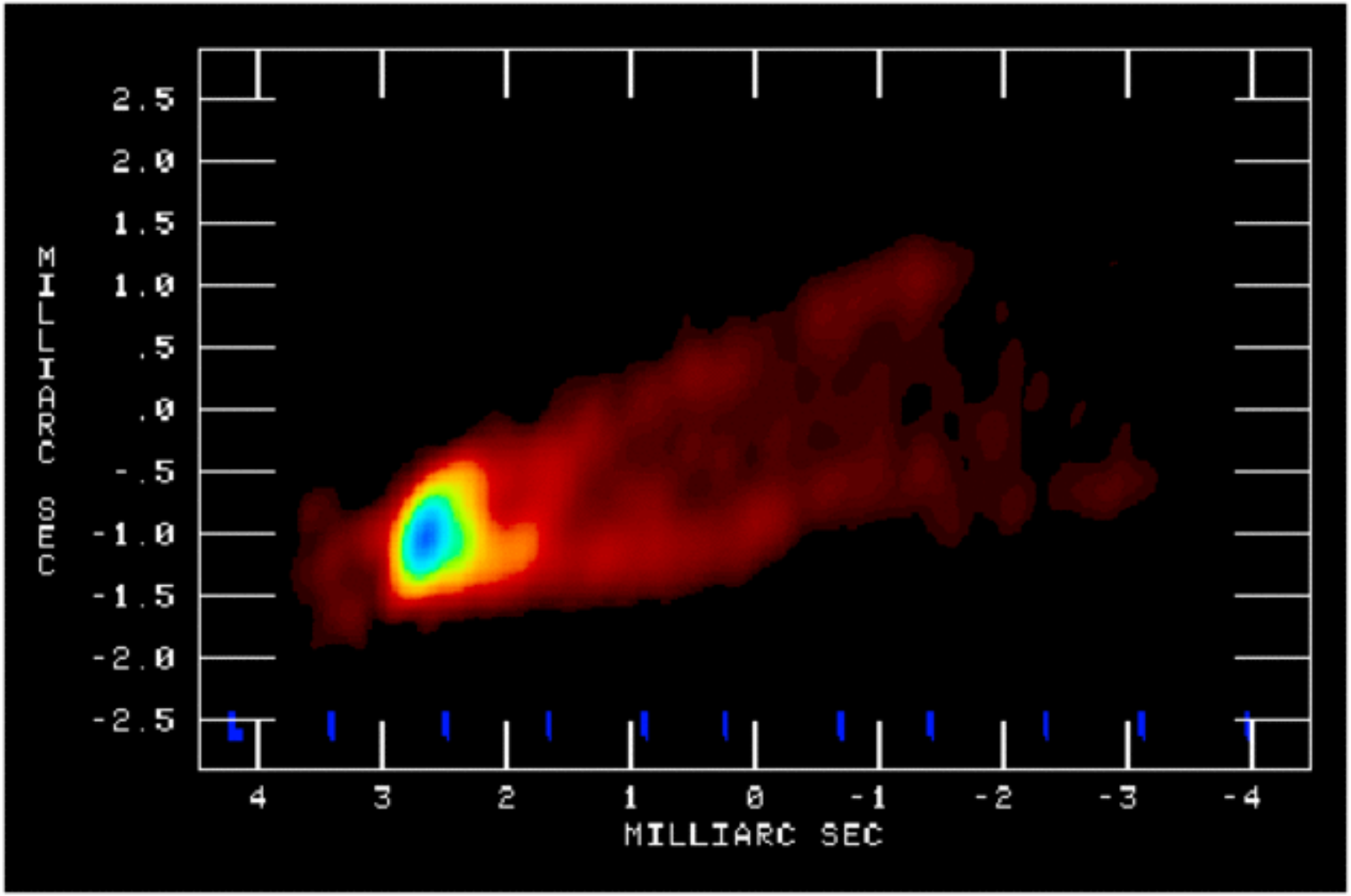
- Pilot observations to determine sampling interval
- 18 Observations at 3 week intervals through 2007
  - Current best movie from first 11 observations
  - Undersampled despite pilot
- 14 Observations at 5 day intervals in early 2008
  - Hampered by less effective dynamic scheduling
  - Major flare seen coinciding with a TeV flare
- Prepared to respond to TeV trigger 2009 – 2011
  - Triggered in 2010
- Reduction and analysis continuing

THE VLBA 43 GHz M87 MOVIE PROJECT
AVERAGE OF 23 OBSERVATIONS



Beam: 0.43x0.21 mas 0.2mas = 0.016pc = $28R_s$ 1mas/yr = 0.25c

The VLBA 43 GHz M87 Movie - First 11 Observations

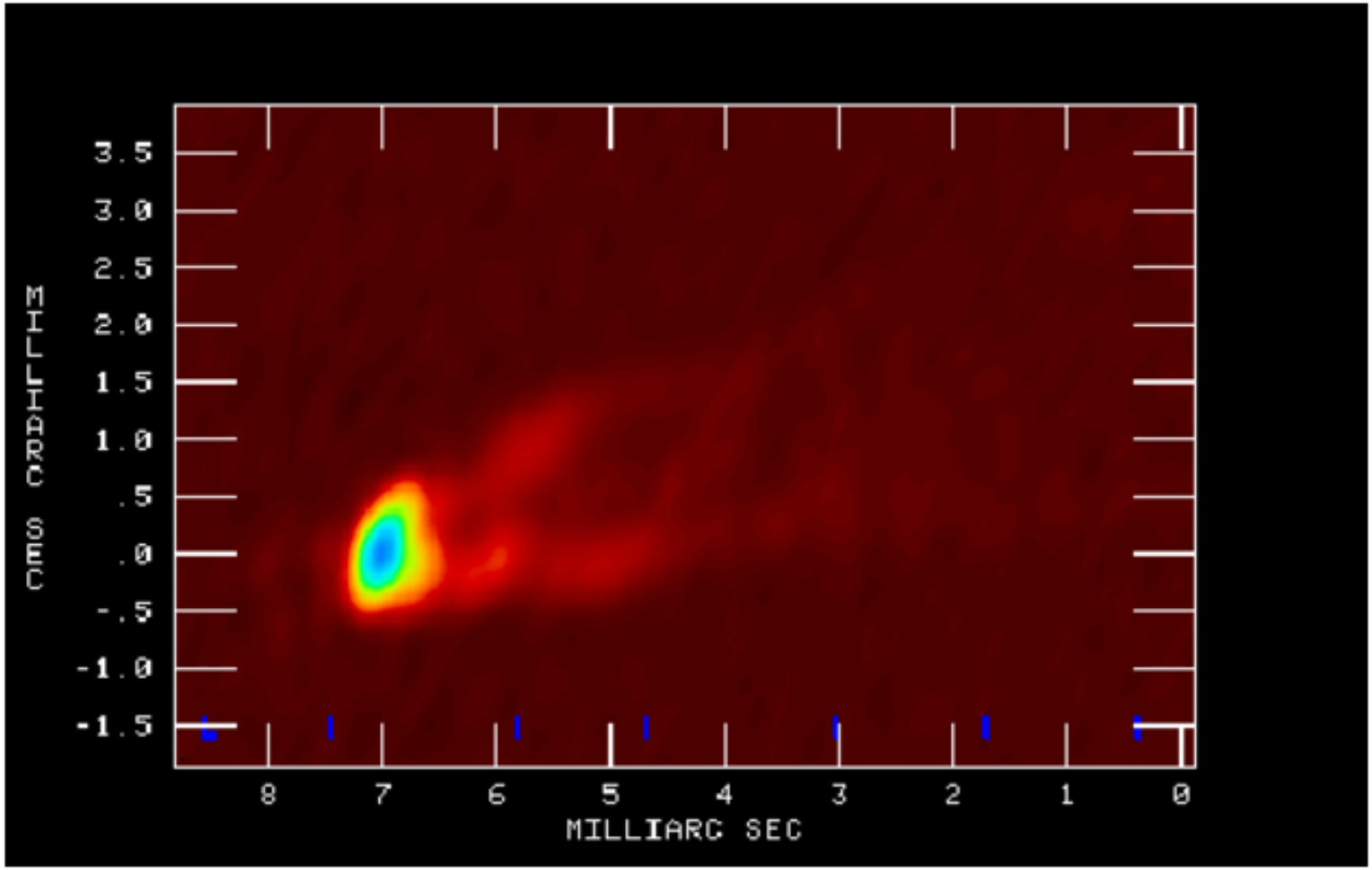


Beam: 0.43x0.21 mas 0.2mas = 0.016pc = $28R_s$ 1mas/yr = 0.25c

Motions ~0.5 mas/frame (3 weeks) which is about 2c

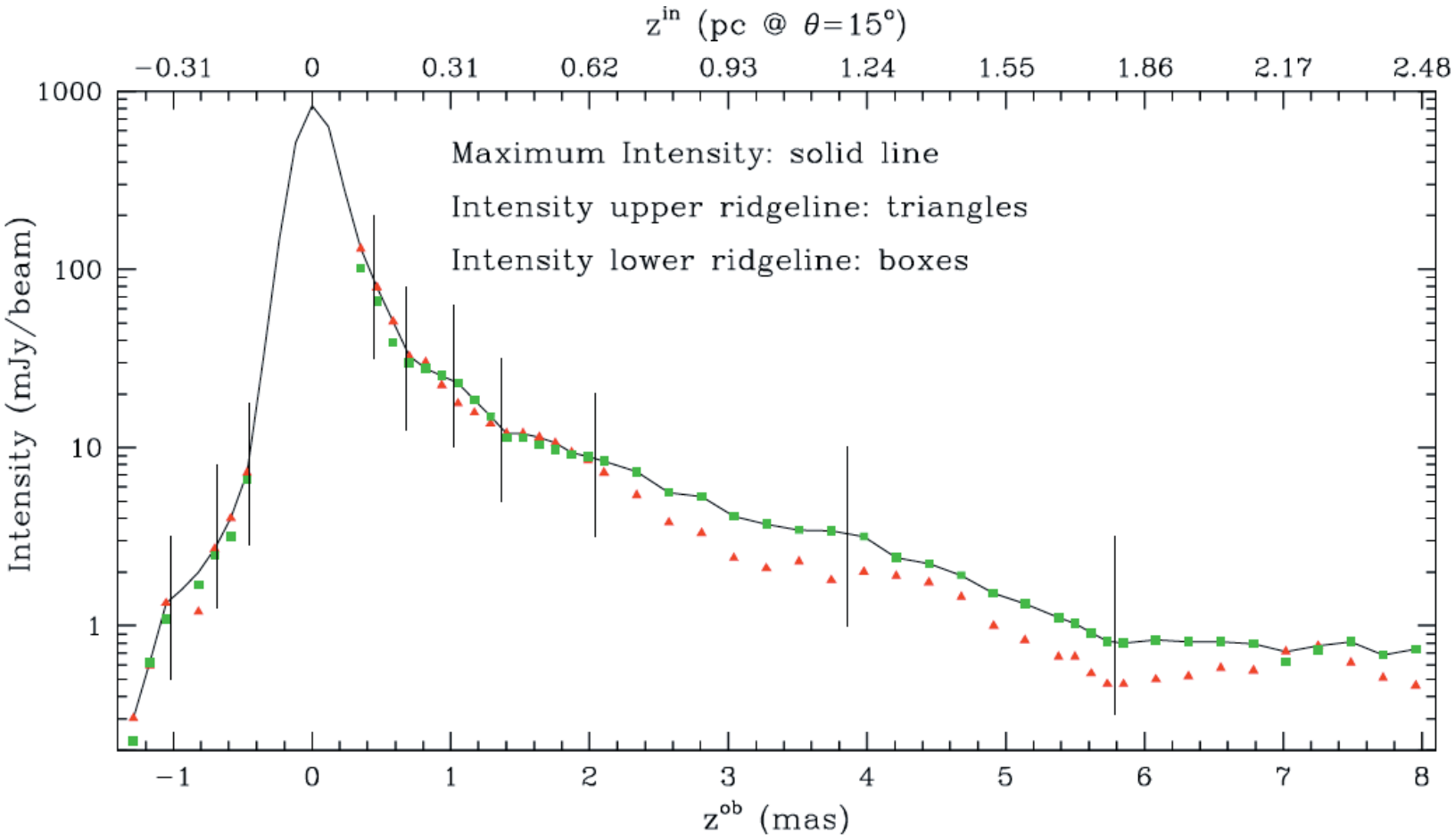
Much faster than 15 GHz results from MOJAVE

The VLBA 43 GHz M87 Fast Sample Movie



- Image every 5 days
- Flare on core. New features
  - Flare coincides with TeV flare

M87 Brightness Profile Along Jet

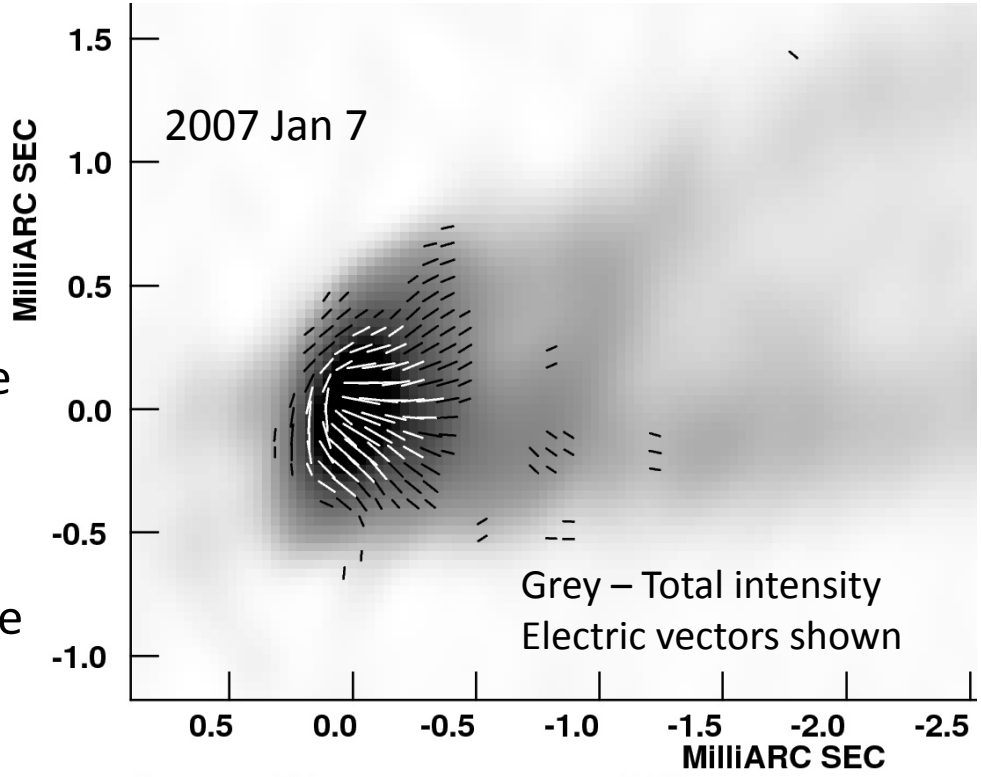


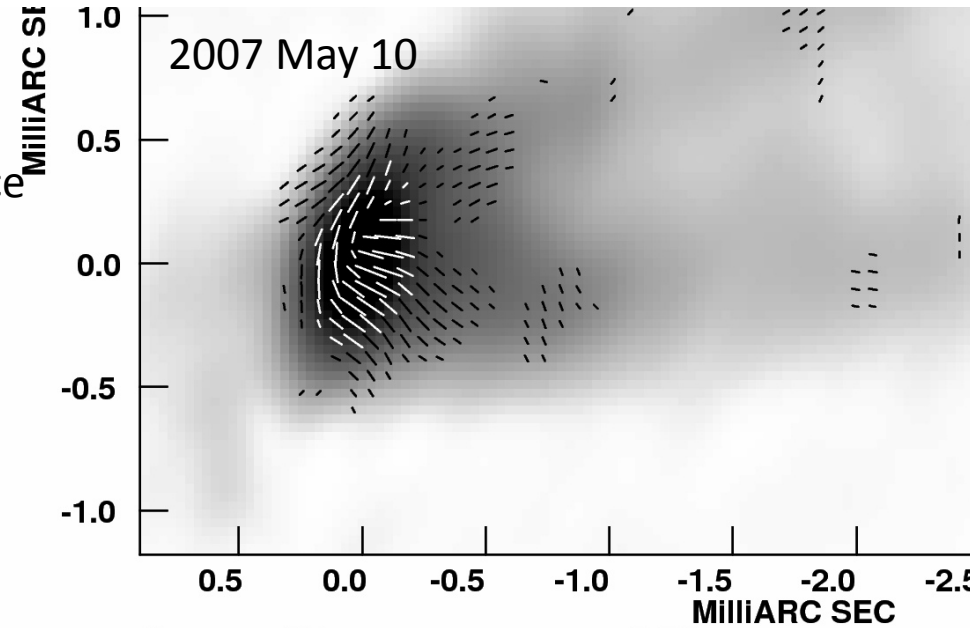
Analysis of this and other structure data in progress

Rapidly increasing jet/counterjet sidedness radio suggests acceleration

Teaser: New Polarization Results

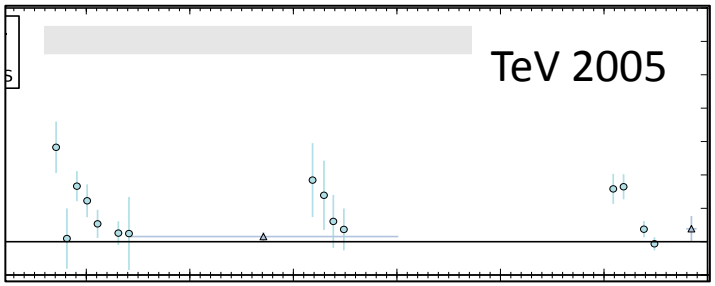
- Jet side of core: E vectors are along the jet direction
  - Vectors show the wide opening angle base
- Counterjet side: E vectors are across the jet, or wrapped around core
- Probable azimuthal field geometry, but modeling needed
  - Close angle to line of sight
  - Wide opening angle base
  - Rapid brightness decrease with distance
  - Counterjet
  - Possible acceleration, beaming, optical depth and faraday rotation effects
- Will stack images when have more to see the fields farther down jet

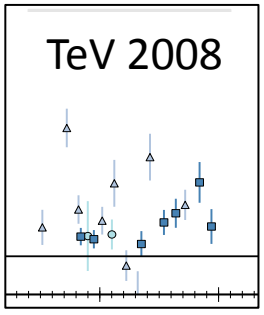


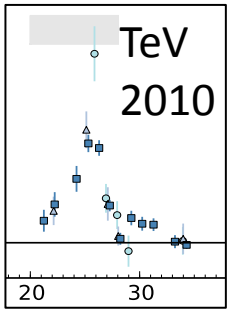


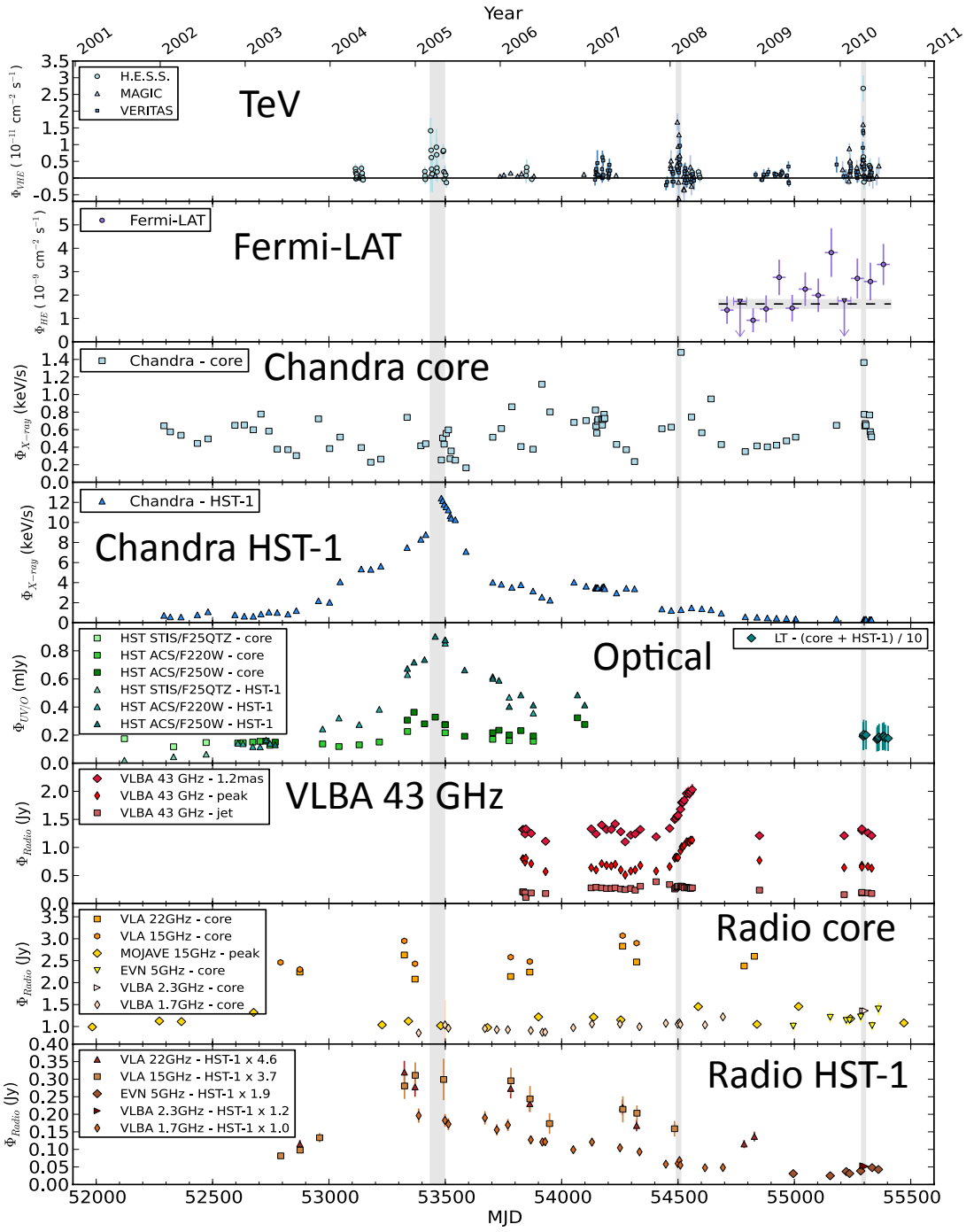
TeV/VLBI Connection

- Location of TeV emission not known
- TeV and 43 GHz VLBI flares at same time in 2008 - suggests TeV in core
  - Acciari et al. 2009, *Science*, 325, 444.
- But no 43 GHz with 2010 TeV flare
  - Abramowski et al, 2012, Ap. J. 746, 151.
  - Possible activity at HST1
  - Giroletti et al 2012 A&A



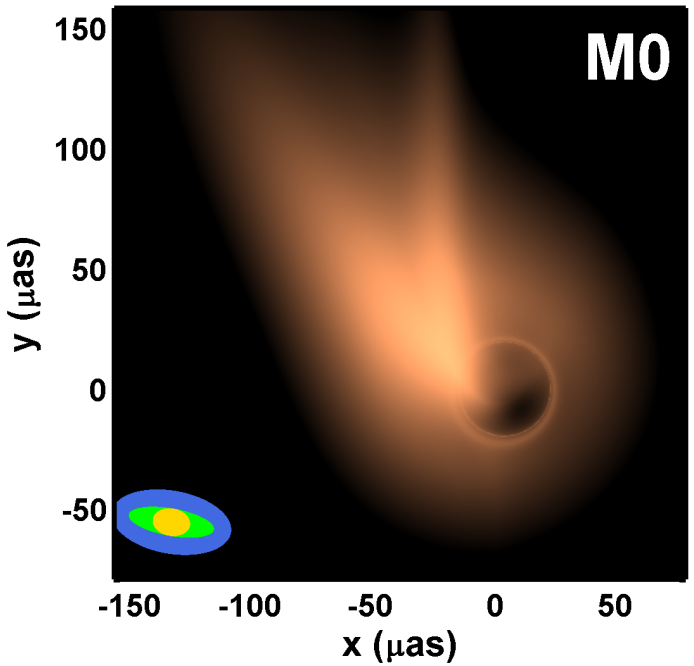






Event Horizon Telescope

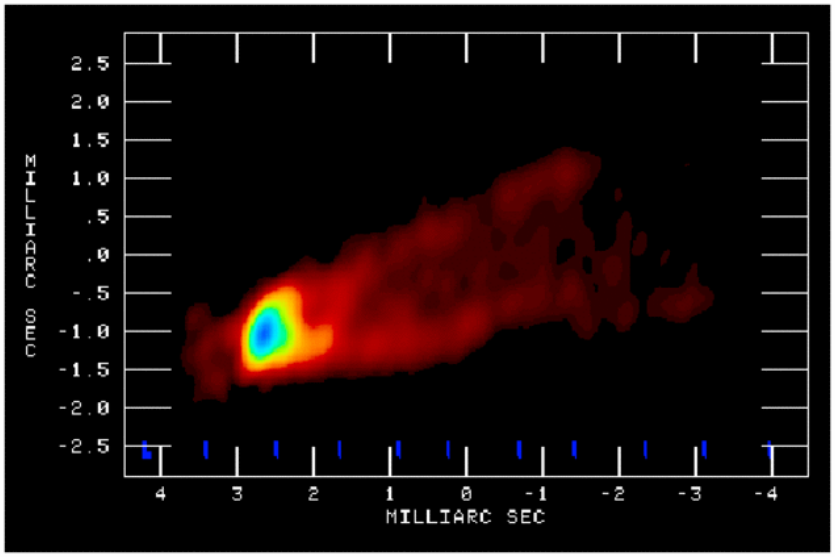
- mm VLBI resolution similar to event horizon in M87 and SgrA* (~10μas)
- Current observations with JCMT, CARMA, SMTO
  - Determined SgrA* size near 4 R_s
- Add several more telescopes
- Anchored by phased ALMA
- Main goal to study relativistic effects near the black hole
- Also study the jet base



Black hole and jet, 345 GHz
Broderick and Loeb 2007

End

SUMMARY



- M87 is the best source for imaging a jet launch region
- Multi-epoch VLBA observations of M87
  - 30 × 60 R_s resolution at 43 GHz
  - Edge brightened structure
  - Rapidly changing “smoke plume”
  - Apparent 2c motions. Maybe acceleration in inner 1mas.
  - Counterjet seen – decays faster than main jet
  - Interesting polarization structure. Not yet modeled
  - Radio flare seen at time of 2008 TeV flare
    - Suggests TeV from very close to the black hole.
    - Issue confused by lack of radio flare with 2010 TeV flare