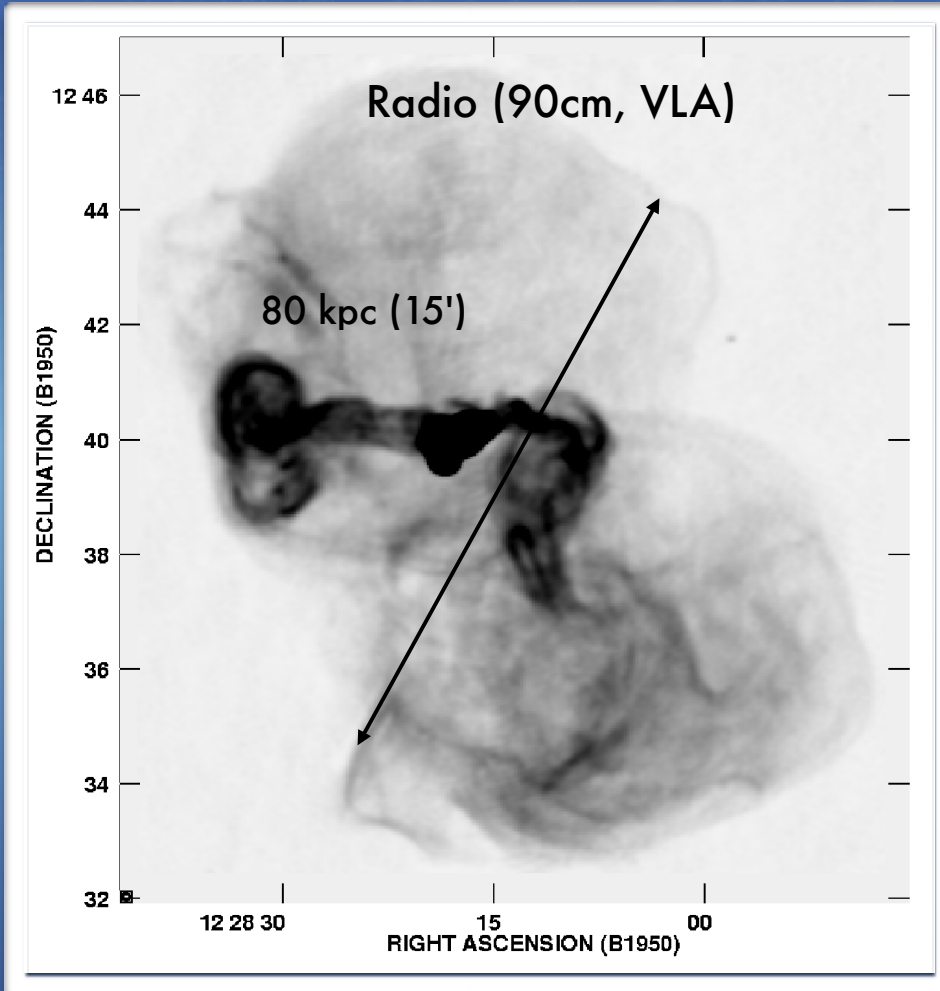


Pinpointing the Gamma-Ray Emission Region in M87 using TeV and 43-GHz Radio Monitoring

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on behalf of the VERITAS, MAGIC, and H.E.S.S. Collaborations
and the M87 43-GHz Monitoring Team

The Giant Elliptical Radio Galaxy M87



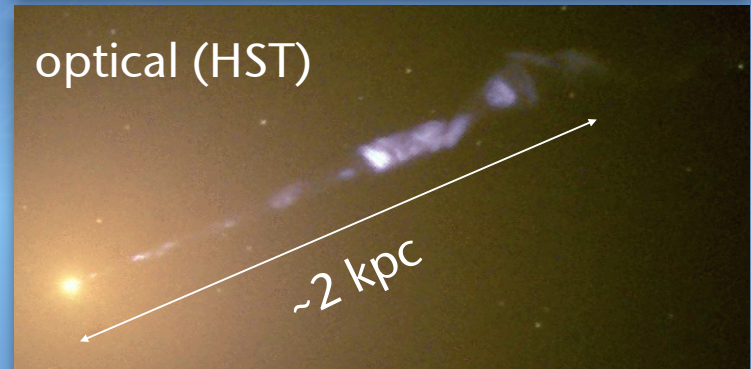
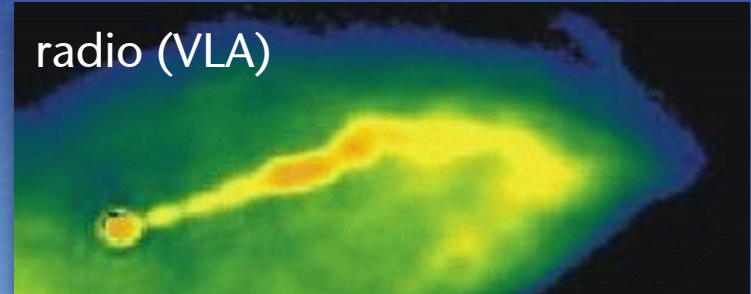
- Close-by radio galaxy:
~16.7 Mpc ($z=0.00436$)
- Radio structure:
outflows and halo
- Jet angle: $\sim 30^\circ$ \rightarrow not a blazar!
But inner region $< 19^\circ$
- Central black hole:
 $M_{\text{BH}} \sim 6 \cdot 10^9 M_\odot$ Gebhardt+Thomas09
- Highly structured jet,
knots resolved in radio, optical
and X-rays
- Jet is variable: flares in radio,
optical and X-rays
- Unique laboratory to study blazar
and jet physics

Owen+00

The Relativistic Plasma Jet of M87

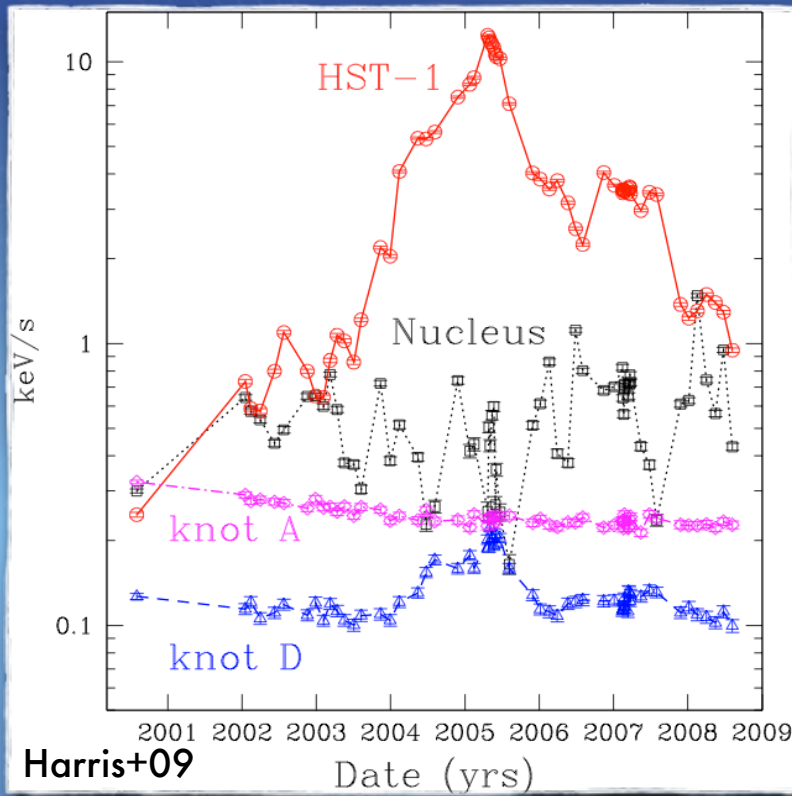
- 👁️ **X-ray/optical/radio knots:** concentrated structures... shocks?
- 👁️ **Radio/optical:** similar polarization synchrotron emission
- 👁️ **X-ray:** spectrum with $\alpha=2.0-2.9$ synchrotron emission?
- 👁️ **Inner jet:** superluminal motion ($\sim 2c$)
=> relativistic particle population
- 👁️ **Variability time-scales:** weeks to months to years

Predictions of VHE γ -ray
and UHECR particle emission



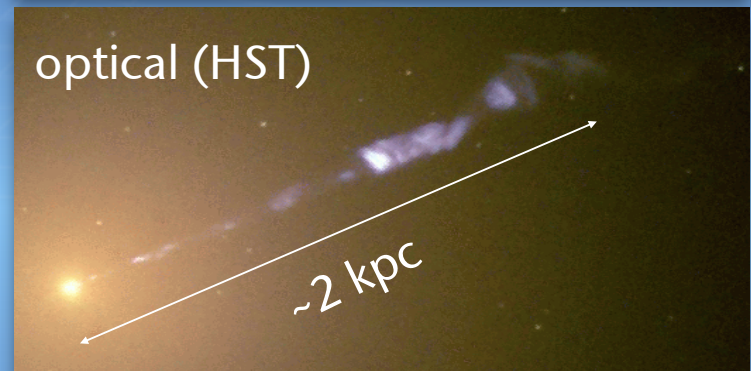
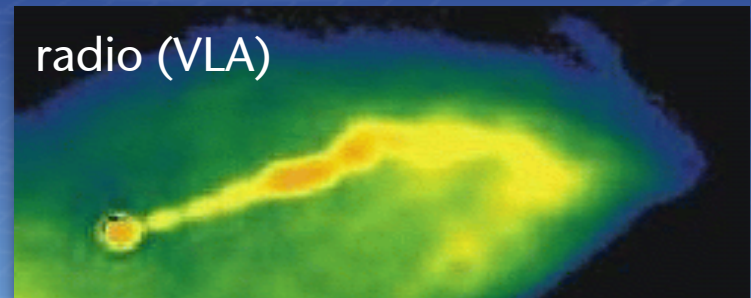
Wilson&Young02

The Relativistic Plasma Jet of M87



Variability time-scales:
weeks to months to years

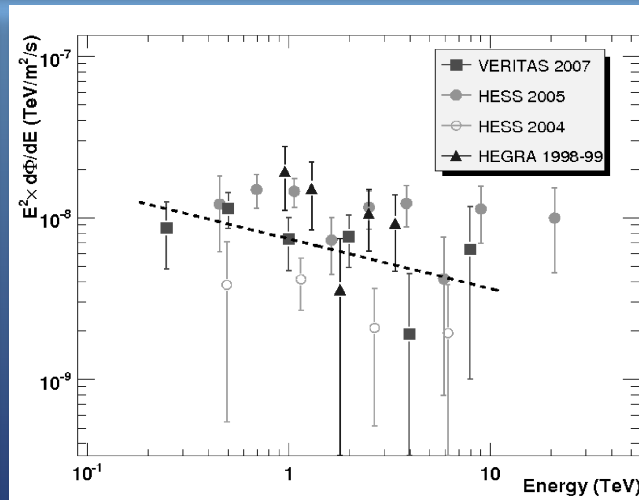
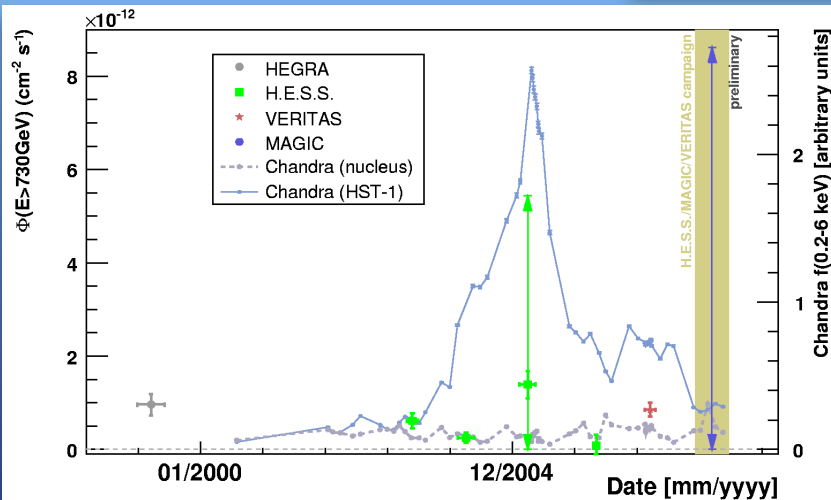
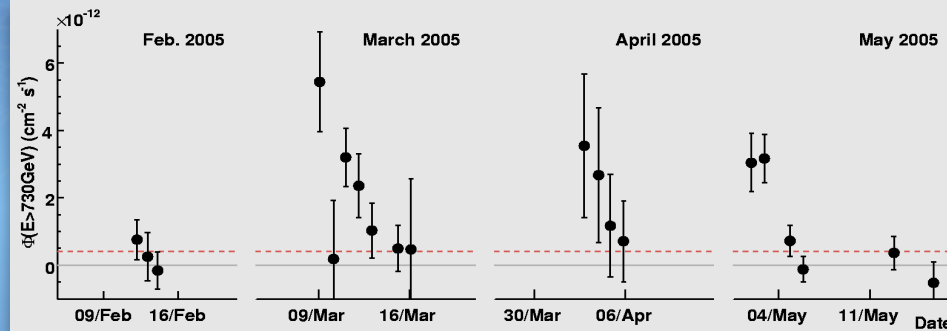
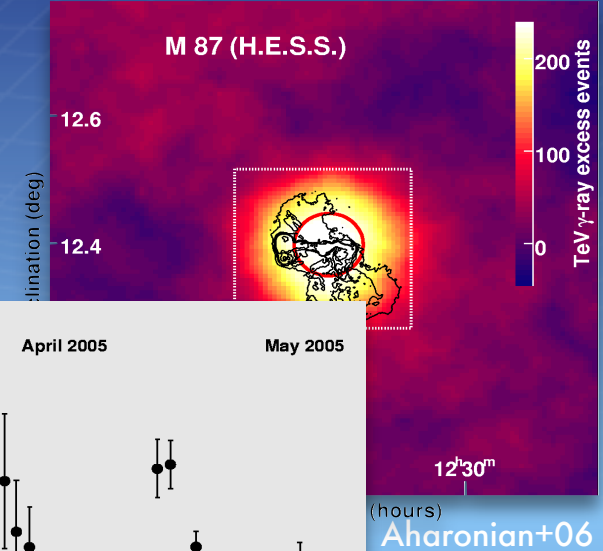
Predictions of VHE γ -ray
and UHECR particle emission



Wilson&Young02

M87: 10 Years of VHE Observations

- >4 σ excess seen by HEGRA in 1999
- 11 σ detection by H.E.S.S. 2003/4,
- Signal confirmed by MAGIC and VERITAS 2005-8
- Day-scale flares 2005 H.E.S.S., 2008 MAGIC
- Variations on timescales of years
- Energy spectrum stable
 - hard: $\alpha=-2.3$
 - 100 GeV to 20 TeV

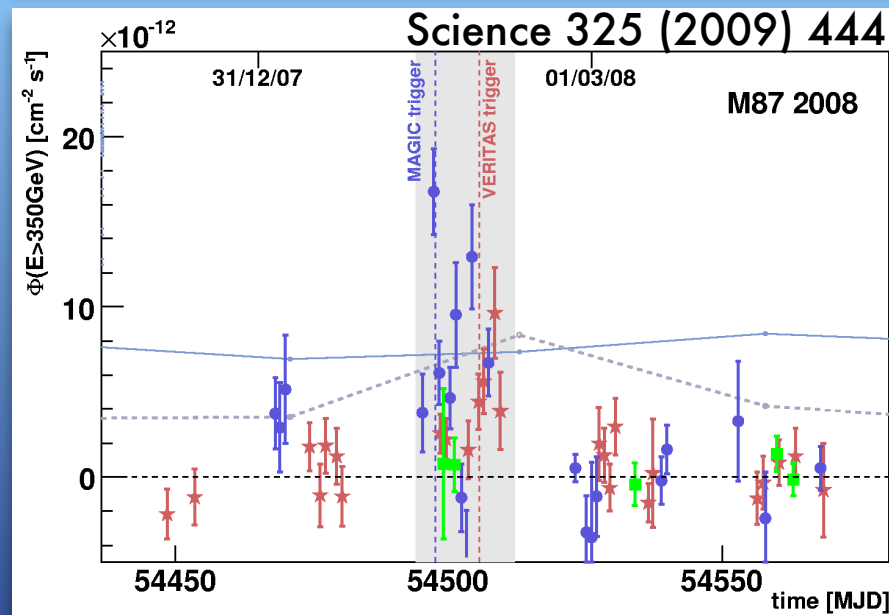
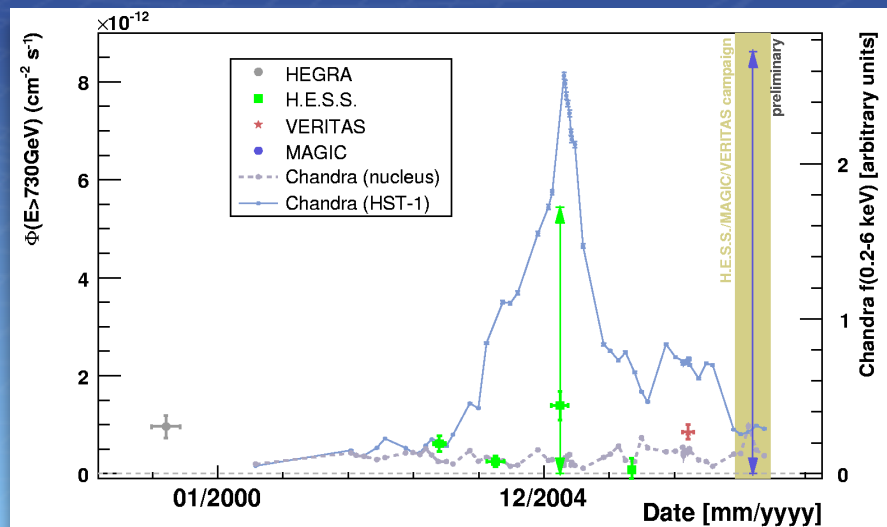


The 2008 Joint VHE Campaign

- Coordinated observations: VERITAS/MAGIC/H.E.S.S.
- plus 5 Chandra pointings in 2008
- Coverage: 120h, 50 nights
- Outburst** in February 2008 (2 weeks after a MAGIC trigger, X-ray low-state of HST-1)
- Confirmed short-term variability



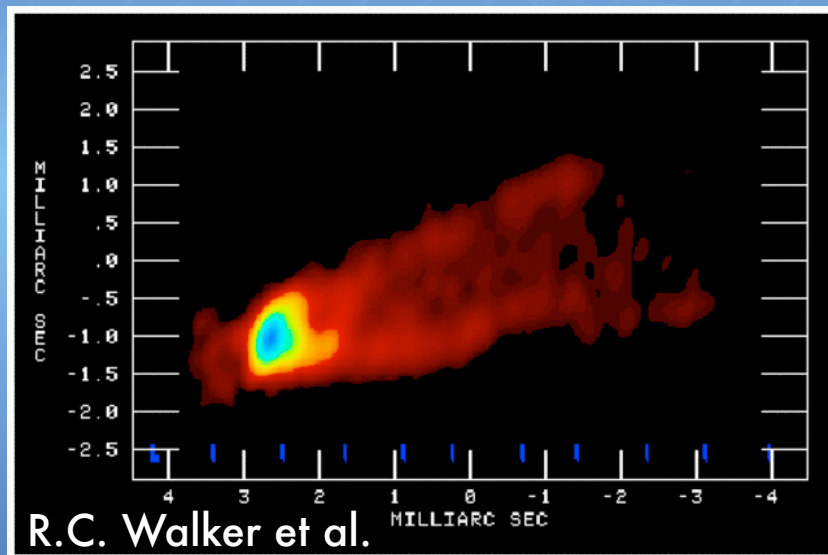
HST-1:
unlikely source of VHE emission



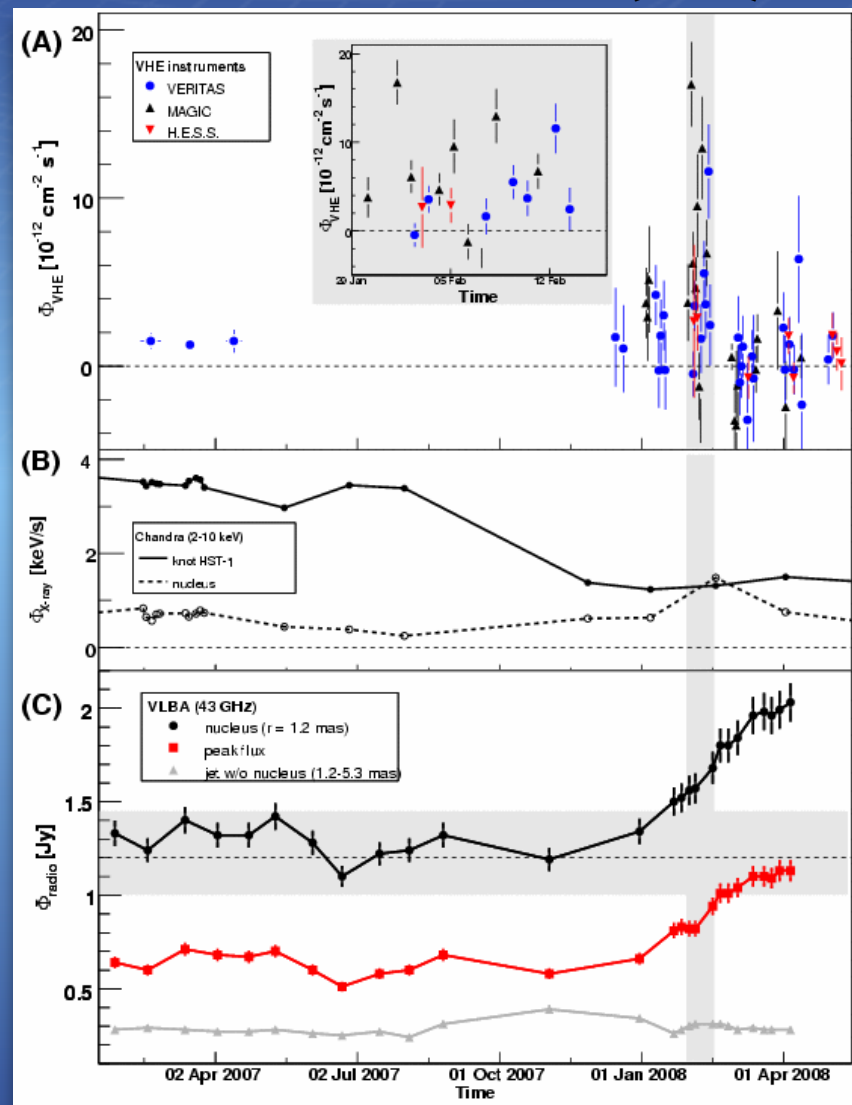
VHE/Radio Collaboration Reveals...

Science 325 (2009) 444

- VLBA Monitoring of the M87 jet at 43 GHz (2007/8), Walker et al.
- Resolution: 0.43×0.21 mas
100 Schwarzschild radii
= 0.37 mas (1 mas = 0.078 pc)

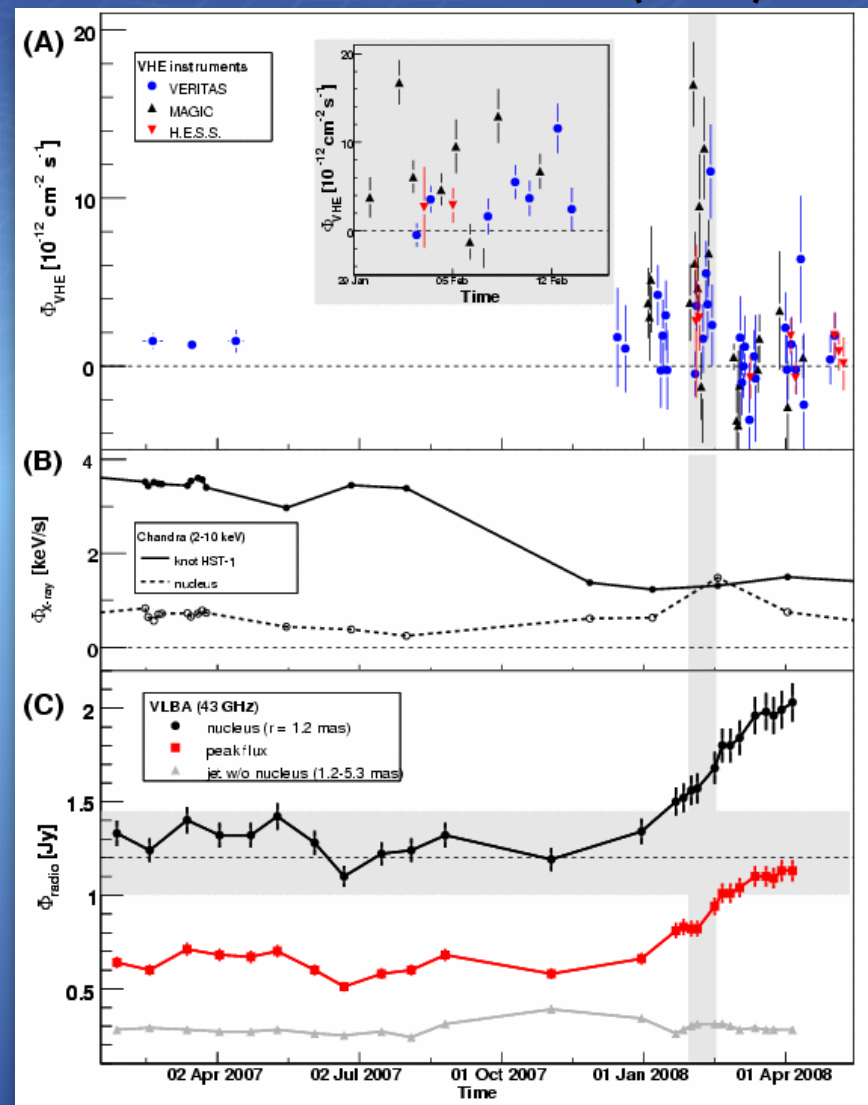
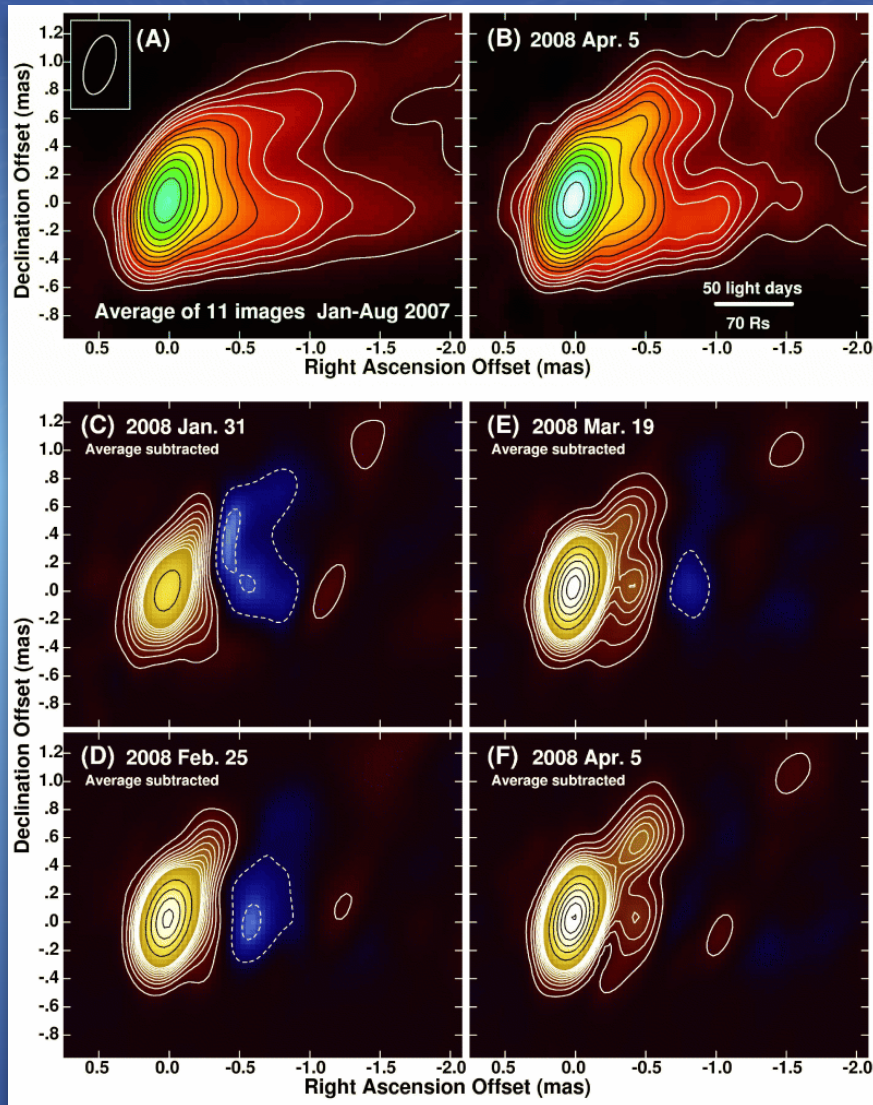


- Jet formation @ $30 \times 60 R_s$
- VHE flare accompanied by radio flare from BH vicinity



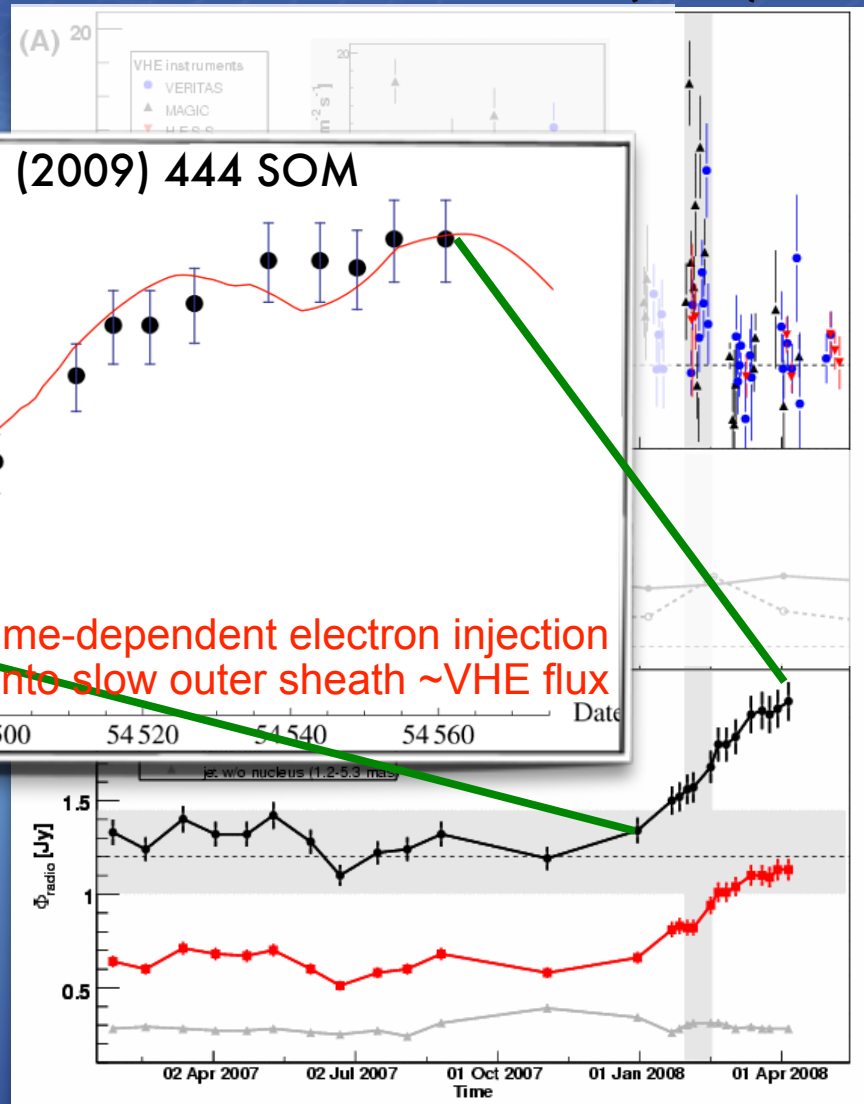
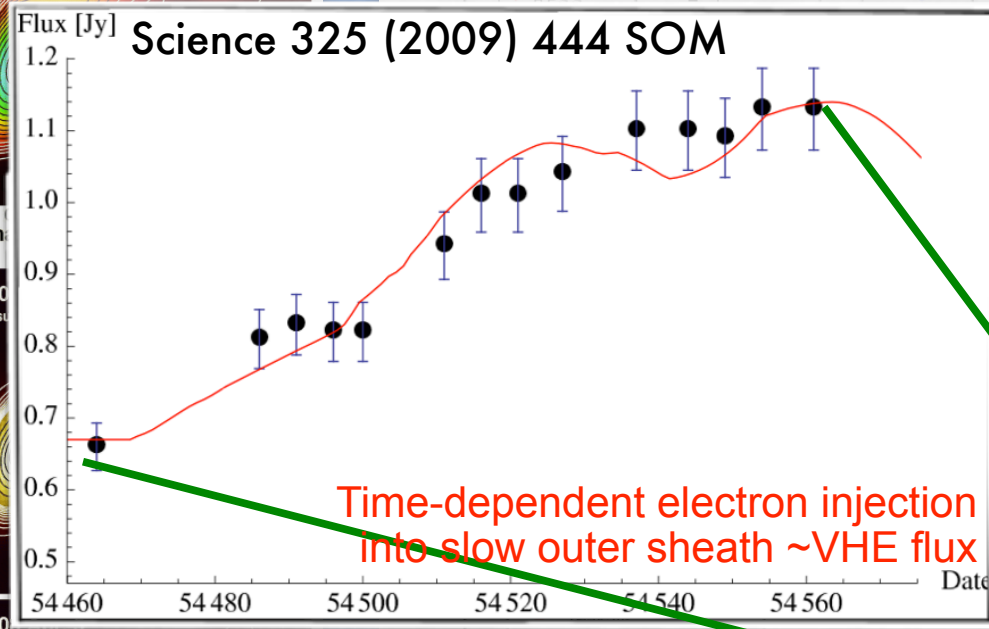
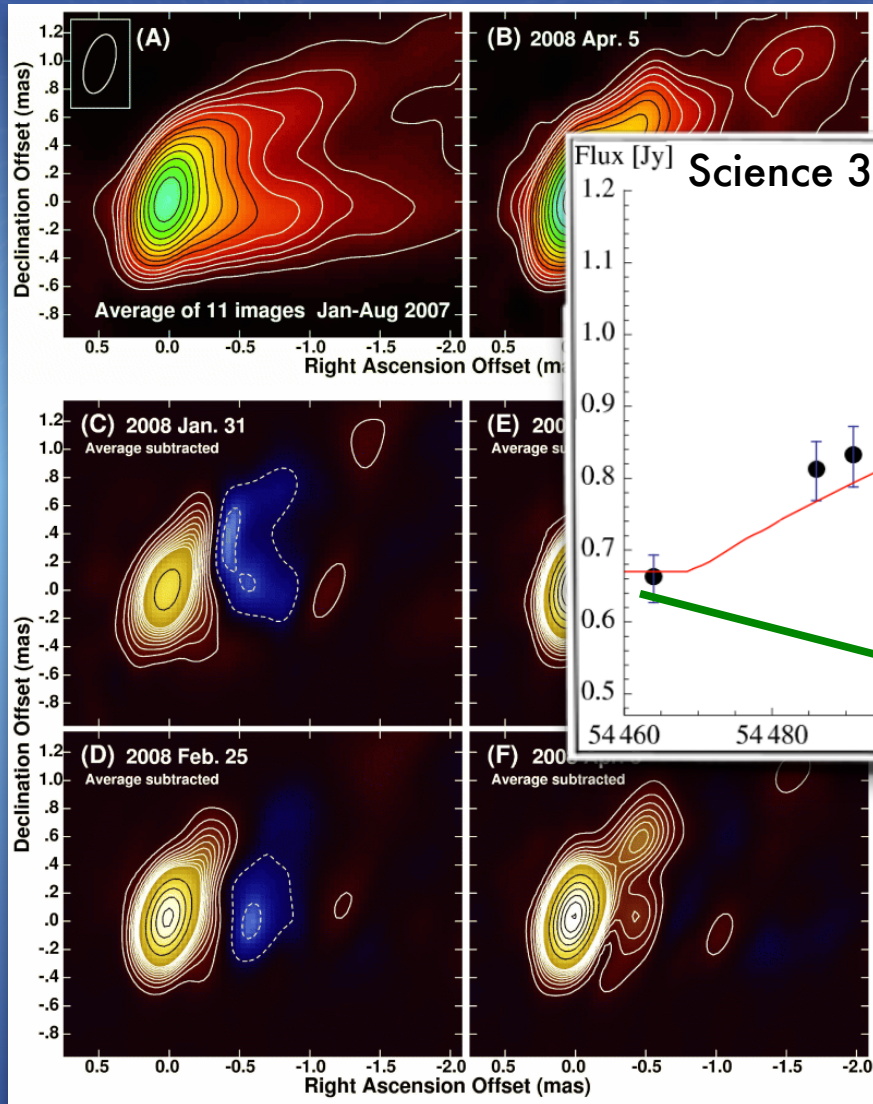
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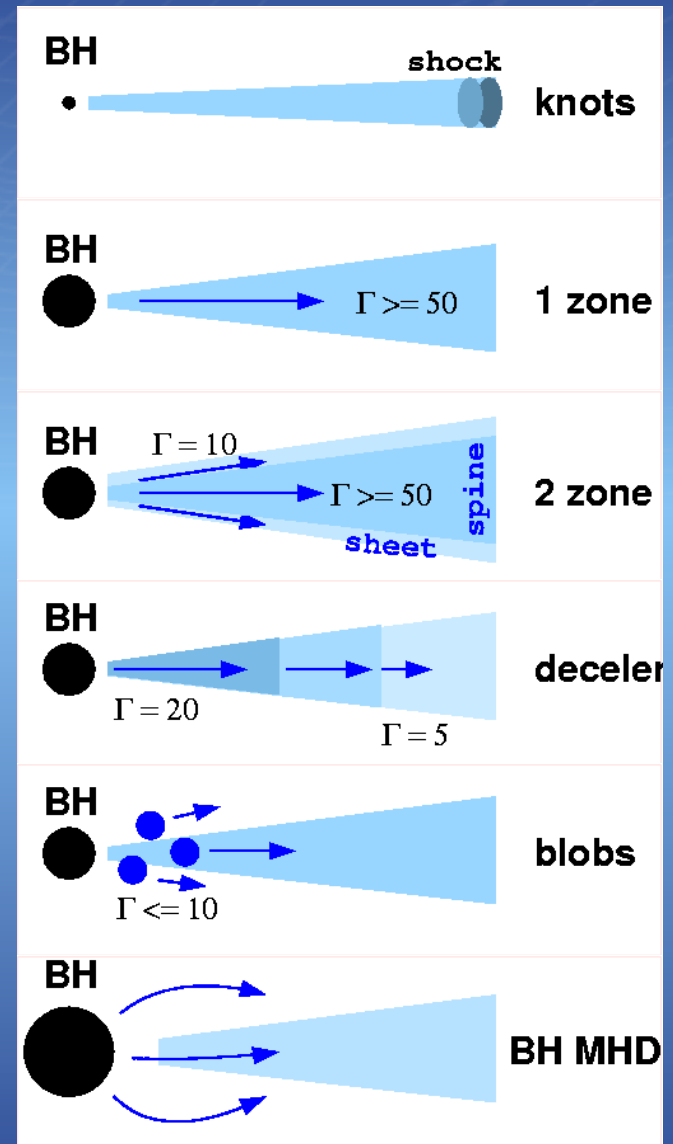


M87 in VHE γ -rays: What did we learn?

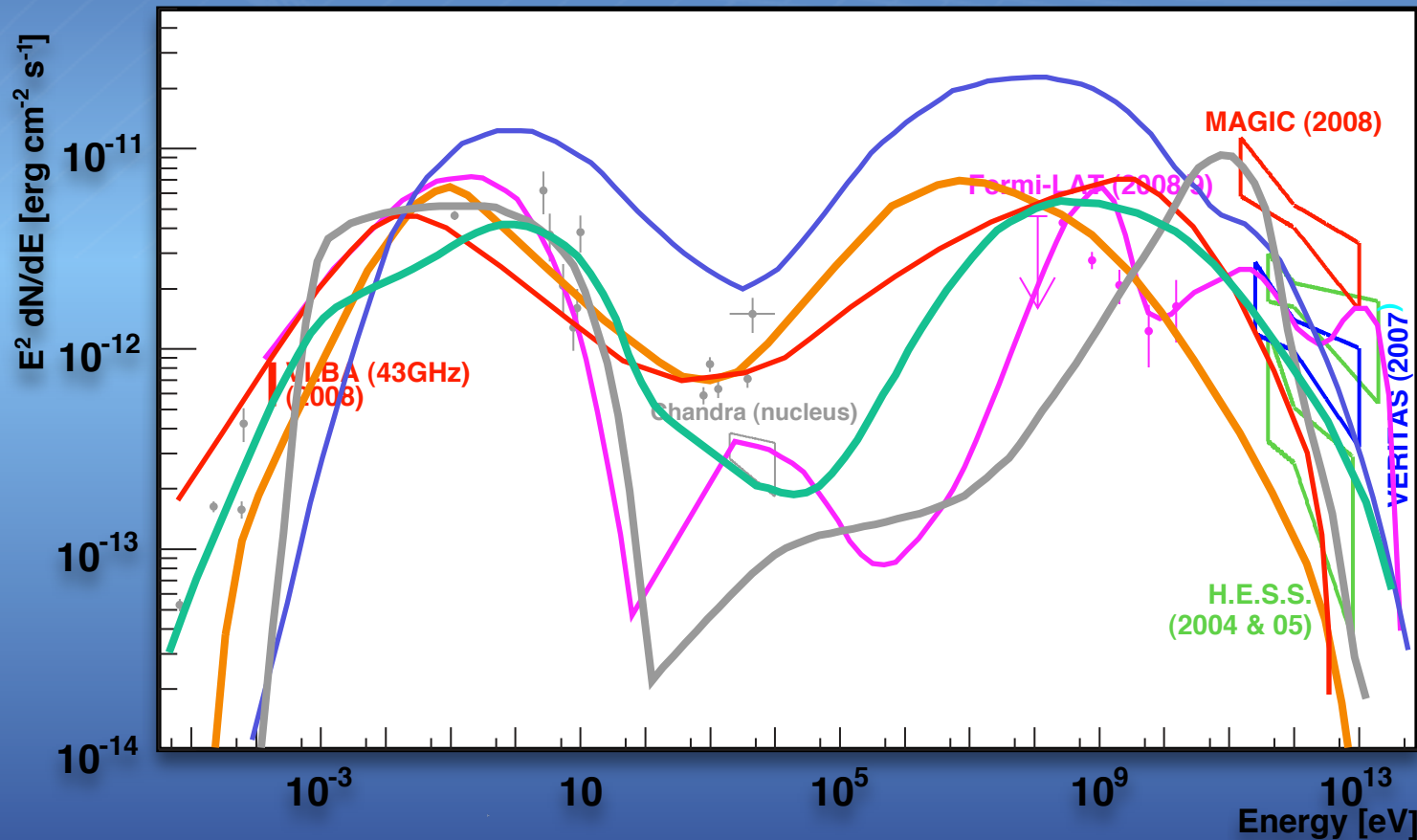
- ▶ First non-blazar emitting VHE γ -rays:
Misaligned blazar, AGN unification?
- ▶ Short-term variability:
 - * Excludes models
 - * Constrains size of emitting region
($R < 5 \times 10^{15} \delta$ cm, $\sim 100 R_{\text{schw}}$)
- ▶ Hard energy spectra:
modeling, emission mechanism
- ▶ Upper limit on VHE extension:
14 kpc \rightarrow location unknown
- ▶ Radio/TeV connection:
First experimental evidence: charged
particles accelerated in BH vicinity



**Key question:
origin/(location)
of the TeV emission**



M87 (non-simultaneous) SED



Data non-simultaneous

Partly published before TeV flaring was known in M87

M87: Importance of Results & Future

TeV/radio connection:

- TeV emission from BH vicinity
- Important input for TeV modeling
- Accretion & jet formation physics

Future questions:

- Can pattern be observed repeatedly?
- TeV emission & radio core: How close to BH?
- More detailed sampling of light curves
- Other TeV sources: Similar pattern?

Future dense campaigns including radio and γ -rays: promising approach!

