TeV γ -ray observations with VERITAS and the prospects of the TeV/radio connection

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NEW SCIENCE ENABLED by MICROARCSECOND ASTROMETRY
21-23 July 2009, Socorro, New Mexico, USA

- TeV γ -ray astrophysics with VERITAS
- Galactic TeV γ -ray sources
- Extragalactic TeV γ -ray sources (AGN)
  - ➔ The special case of M87

VERITAS

McDONNELL CENTER FOR THE SPACE SCIENCES

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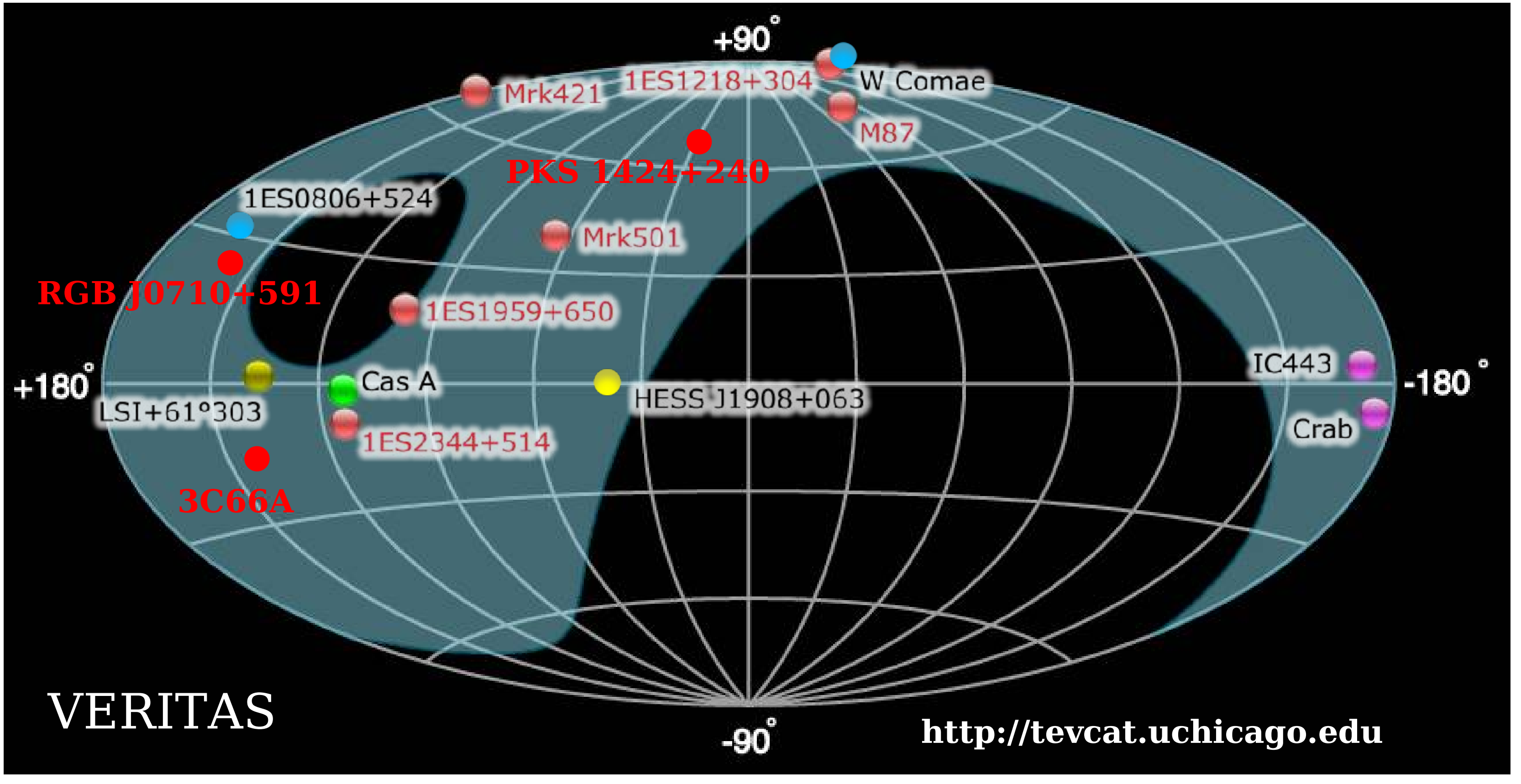
ARTS & SCIENCES

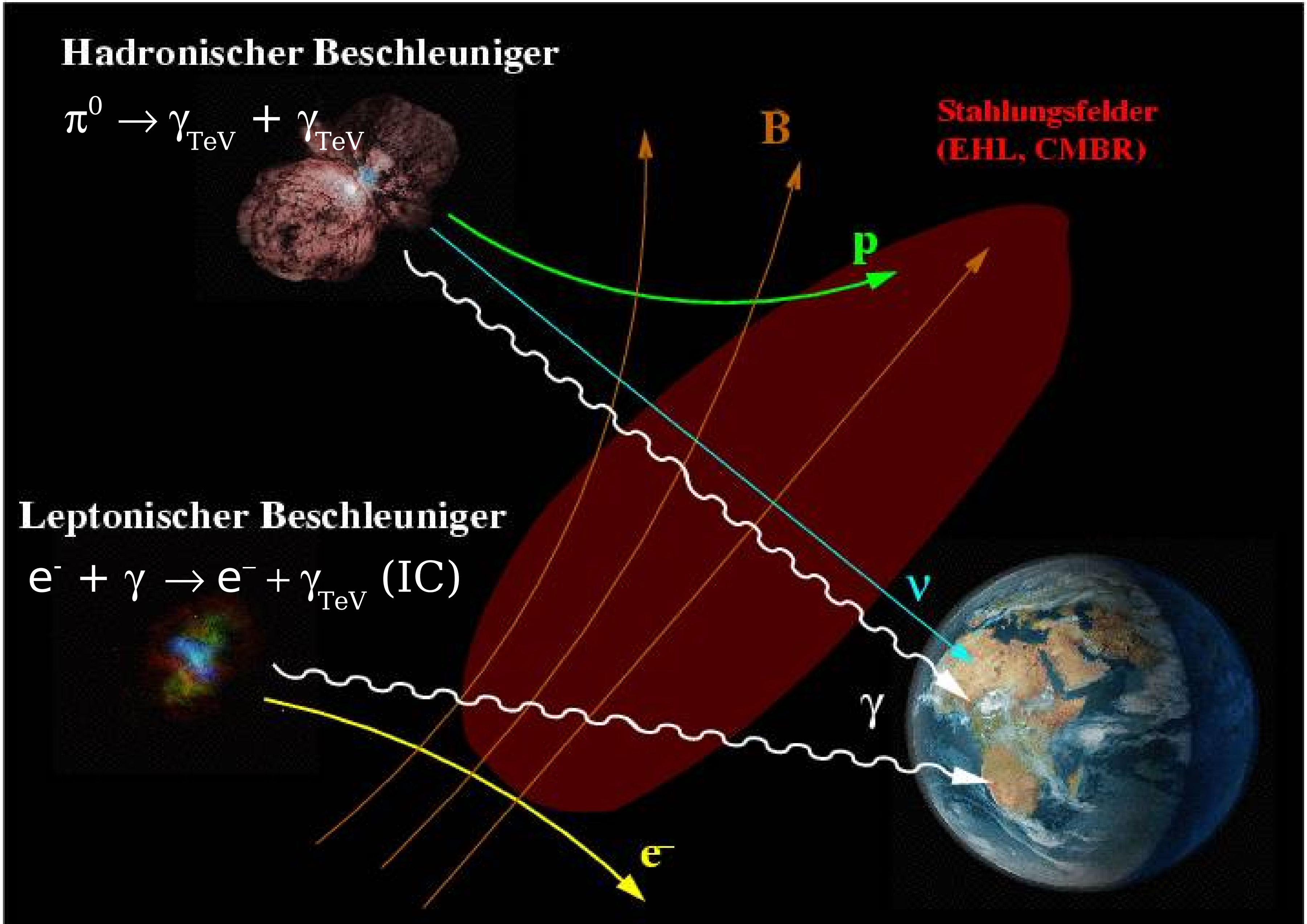
TeV γ -ray astrophysics with VERITAS

Introduction: TeV γ -ray astrophysics

- **1 TeV = 240,000,000,000,000,000 GHz**
- **Angular resolution: ~360,000 mas**
- **Observations per year:** 700-800h (+200h moon data)
- **Dynamical field:** 2000: handful of sources, 2009: **>60 sources**
- **Almost all TeV sources are radio sources**

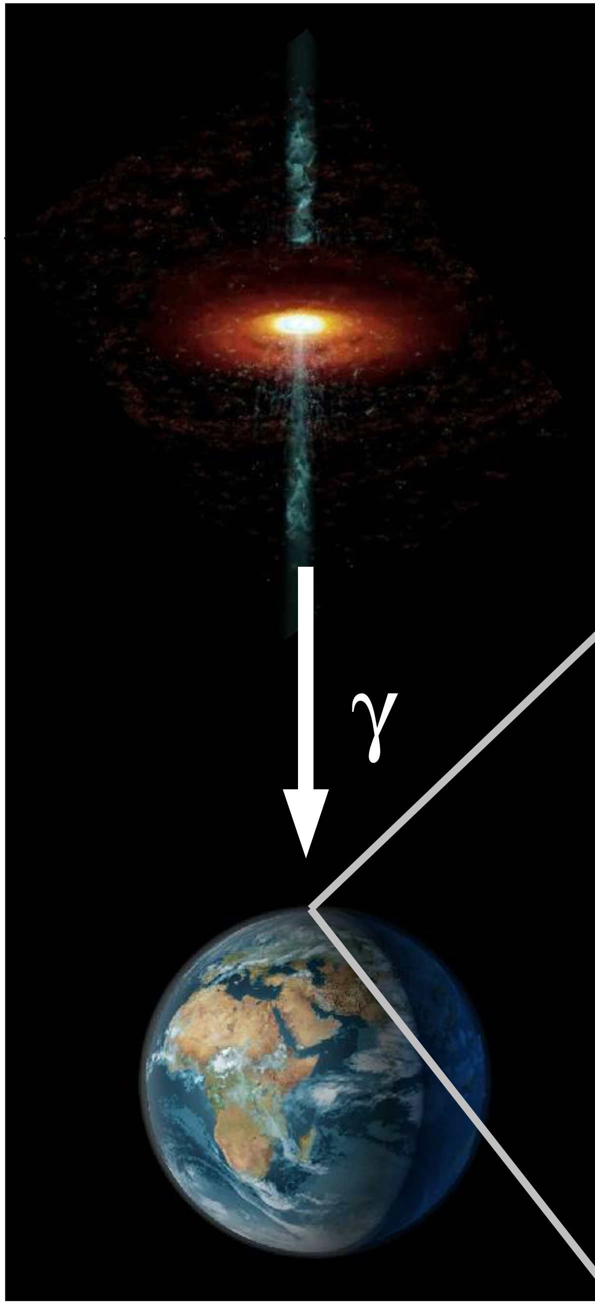


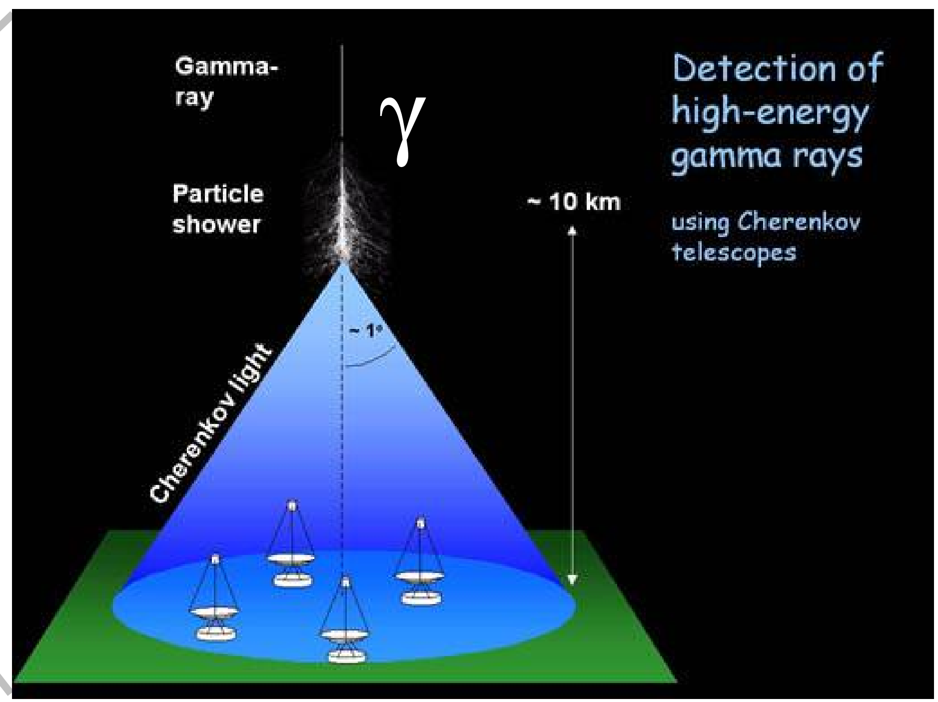
TeV γ -ray astrophysics:
Study hadronic/leptonic particle accelerators



TeV γ -ray astrophysics with Cherenkov telescopes

- **Gammas enter earth's atmosphere** and produce air showers & Cherenkov light
- **Imaging** of Cherenkov light with telescopes: reconstruct direction & energy
- **Reject CR background:** image properties

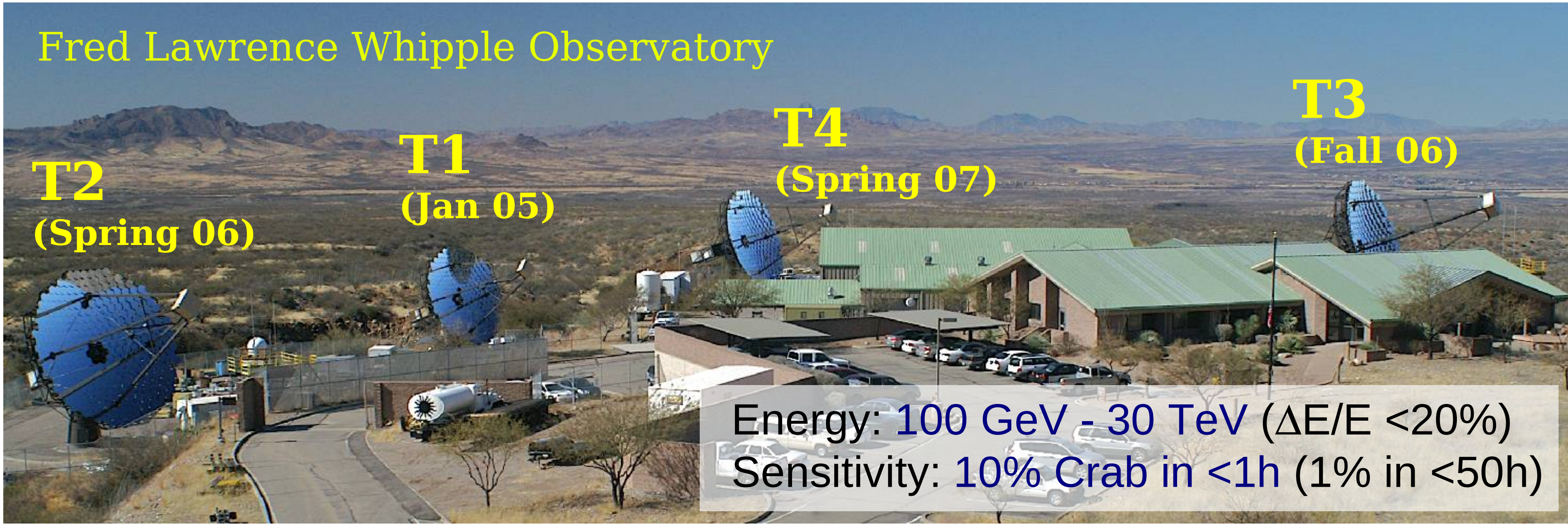


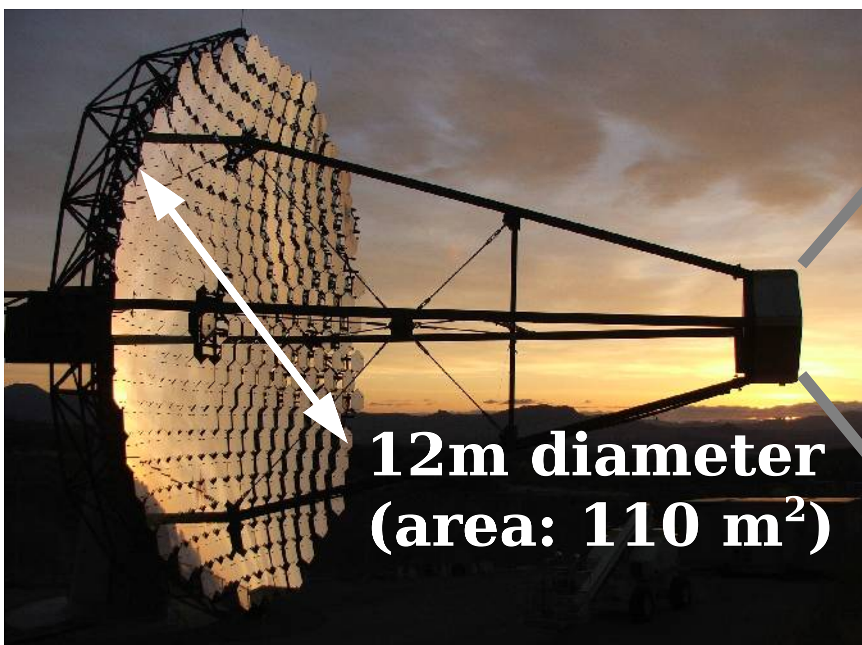


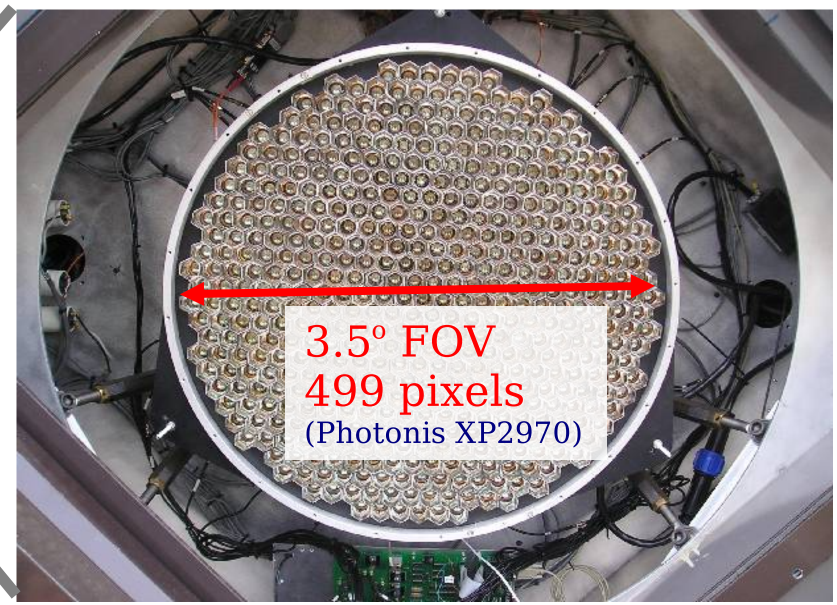
W.Hofmann

The VERITAS Cherenkov Telescope Array

(Very Energetic Radiation Imaging Telescope Array System)







PMT camera

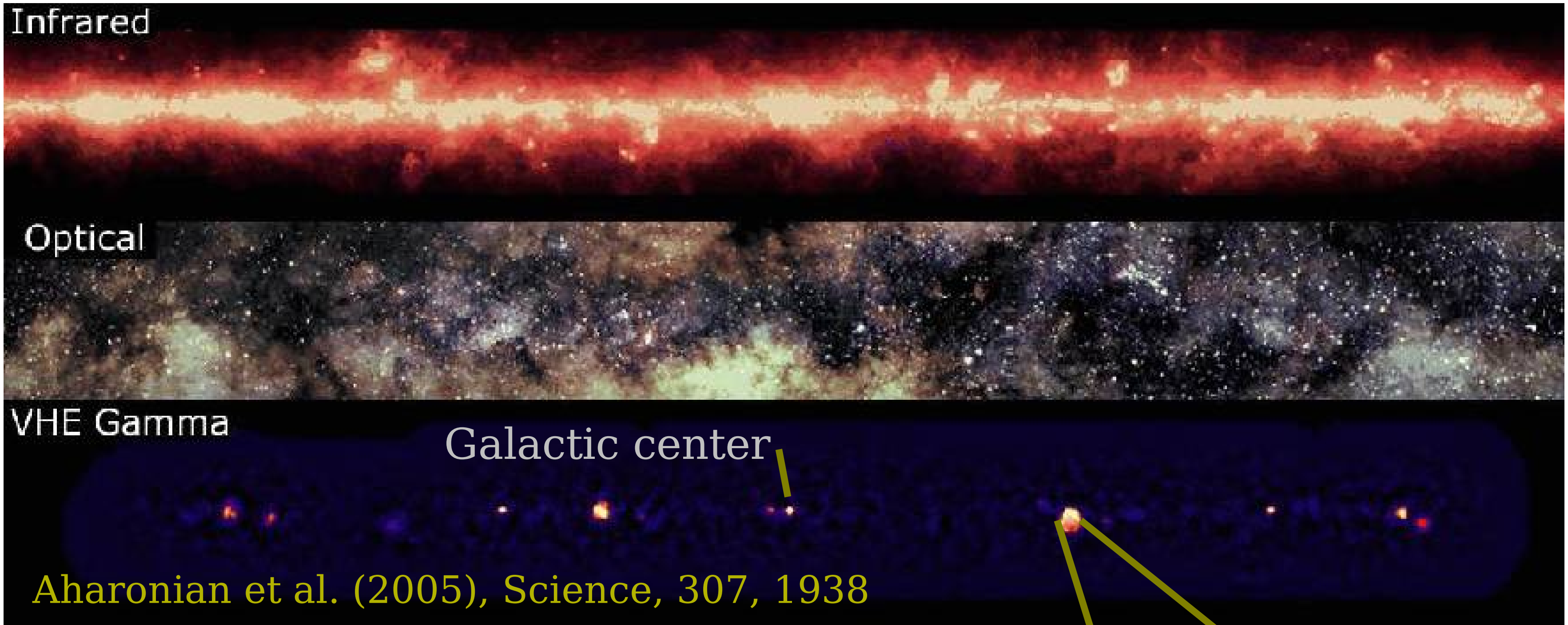
Galactic TeV sources

The galactic plane at TeV energies

IR

Opt

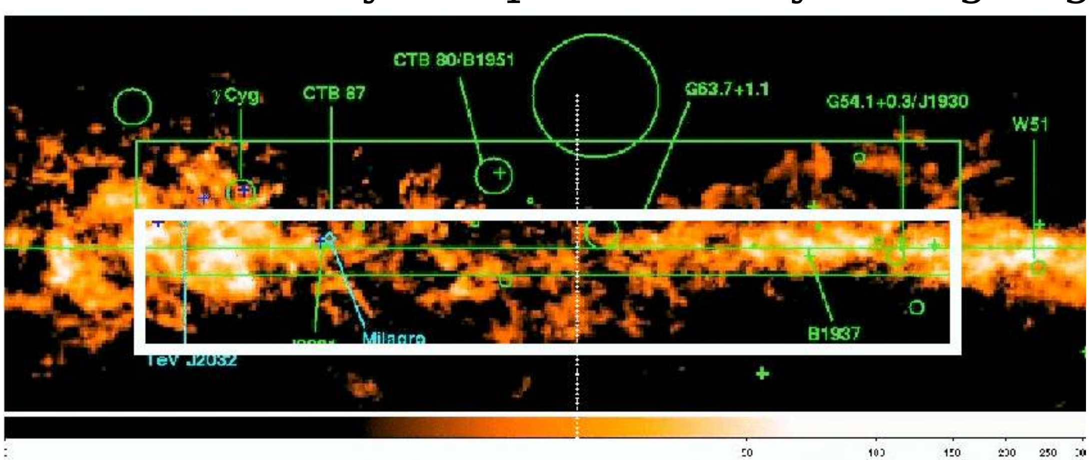
TeV

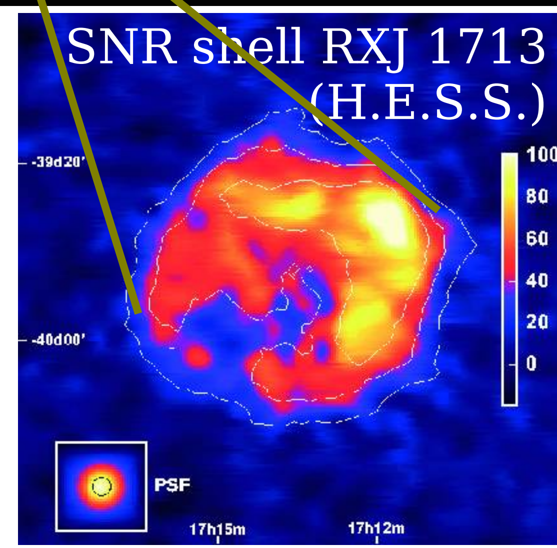


NASA

H.E.S.S.

VERITAS survey completed, analysis ongoing

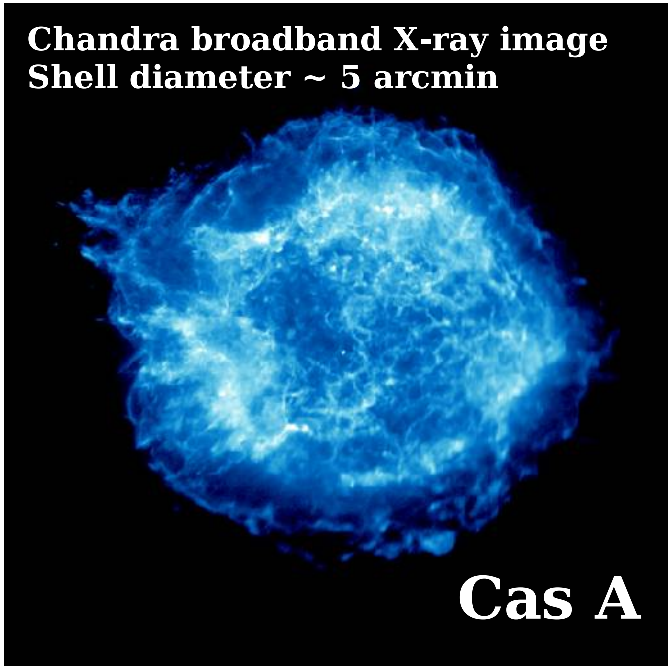




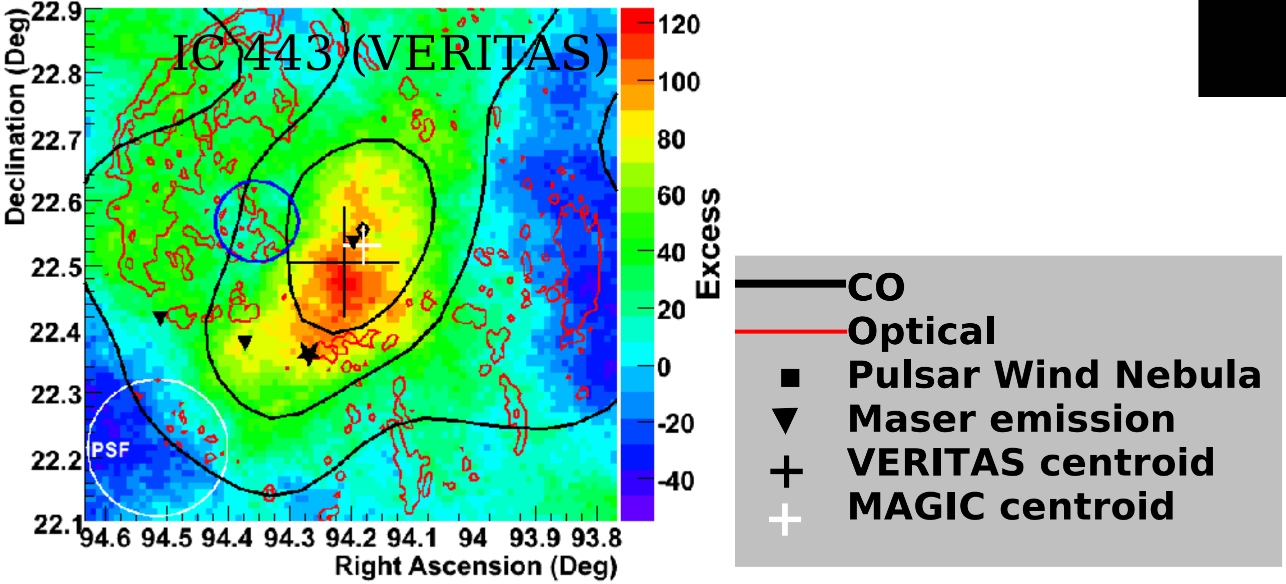
Aharonian et al.(2004),Nature,432,75

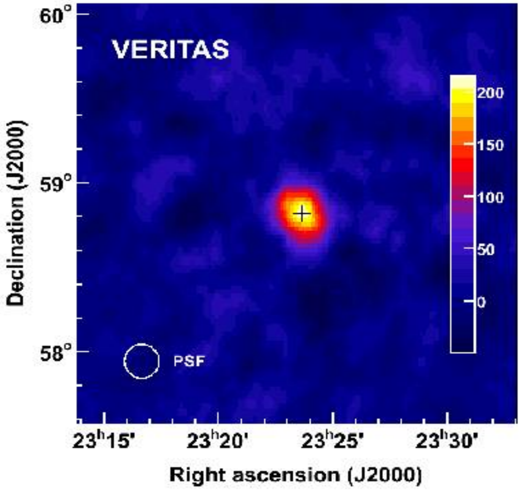
Supernova Remnants (SNRs)

- **TeV emission from SNR:**
  - SN ejecta expand into ISM or molecular cloud
  - shock acceleration of charged particles
  - these emit TeV γ -rays (secondary reactions)
- **Open question:** hadronic or leptonic?
- **MWL picture (morphology and SED):**
  particle population & emission mechanisms



Acciari et al. (2009), ApJ, 698, L133

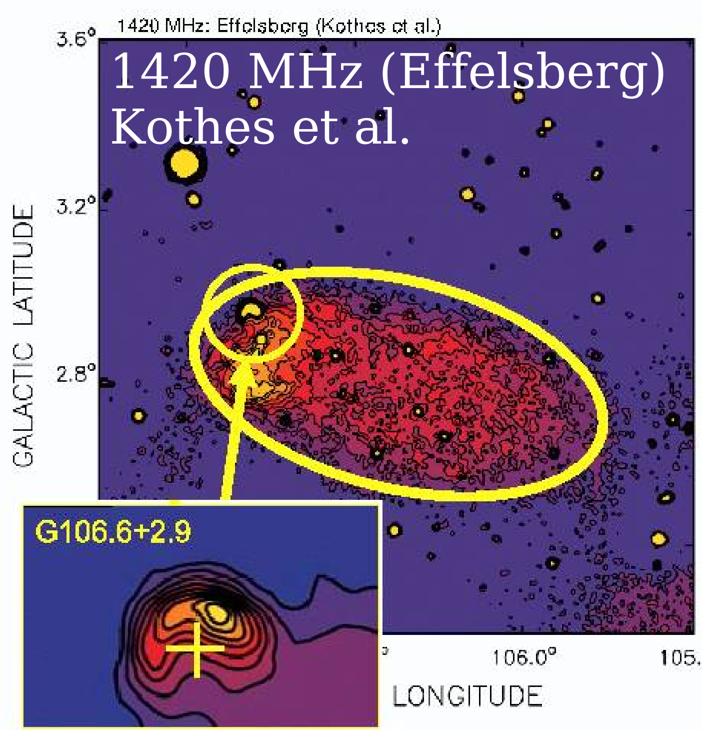


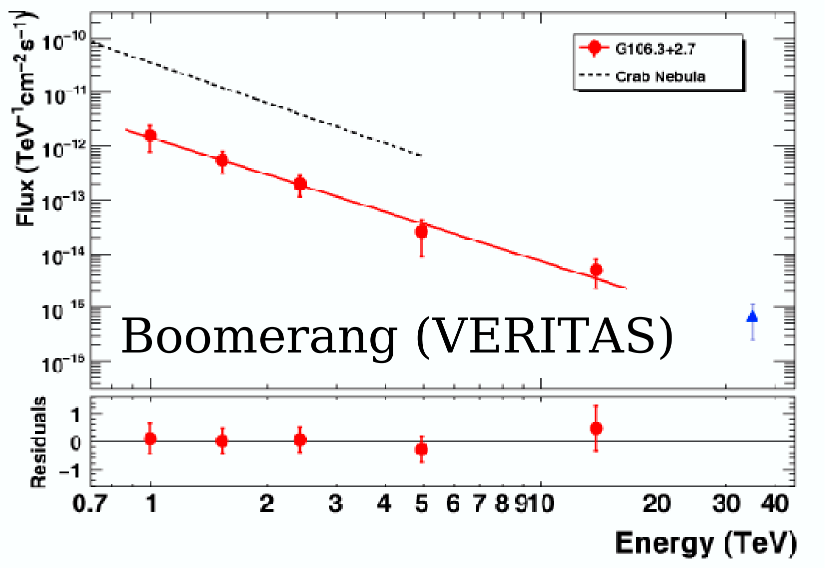


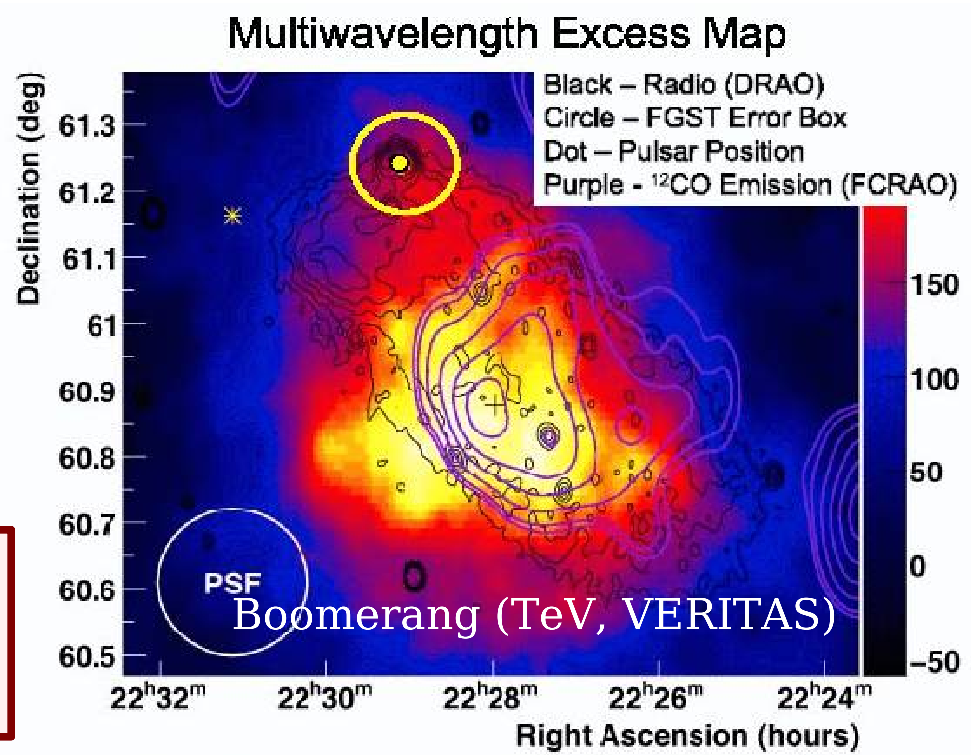
Radio: Trace relativistic particles and molecular clouds

Class2: Pulsar wind nebulae (PWN)

- **TeV emission from PWN:**
  - pulsar driven bubble of relativistic particles
  - shock acceleration (SNR or ISM interaction)
  - TeV γ -rays emission (secondary reactions)
- **Example 'Boomerang':**
  age: 10,000 years, dE/dt = 2.2 x 10^{37} erg/s



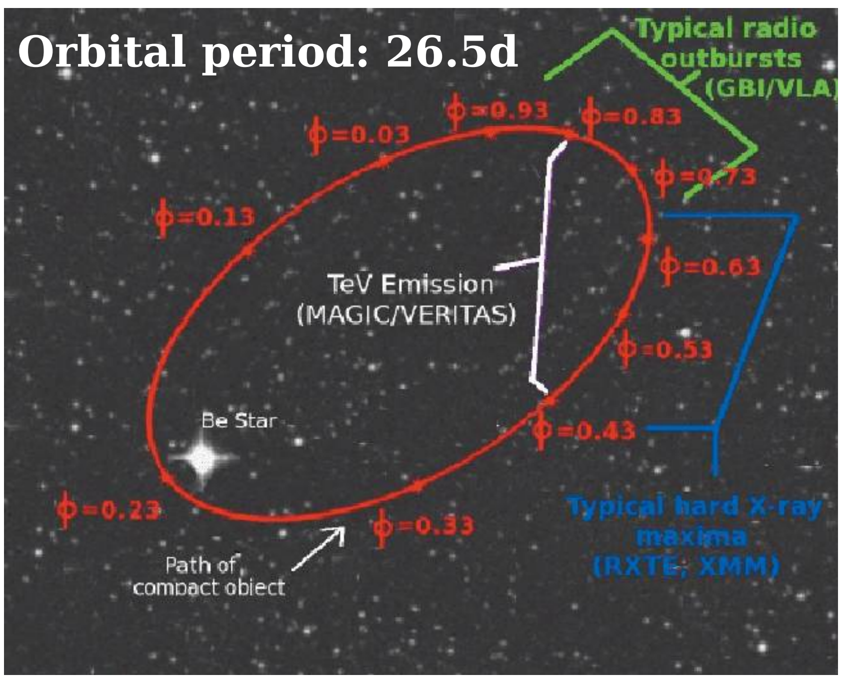


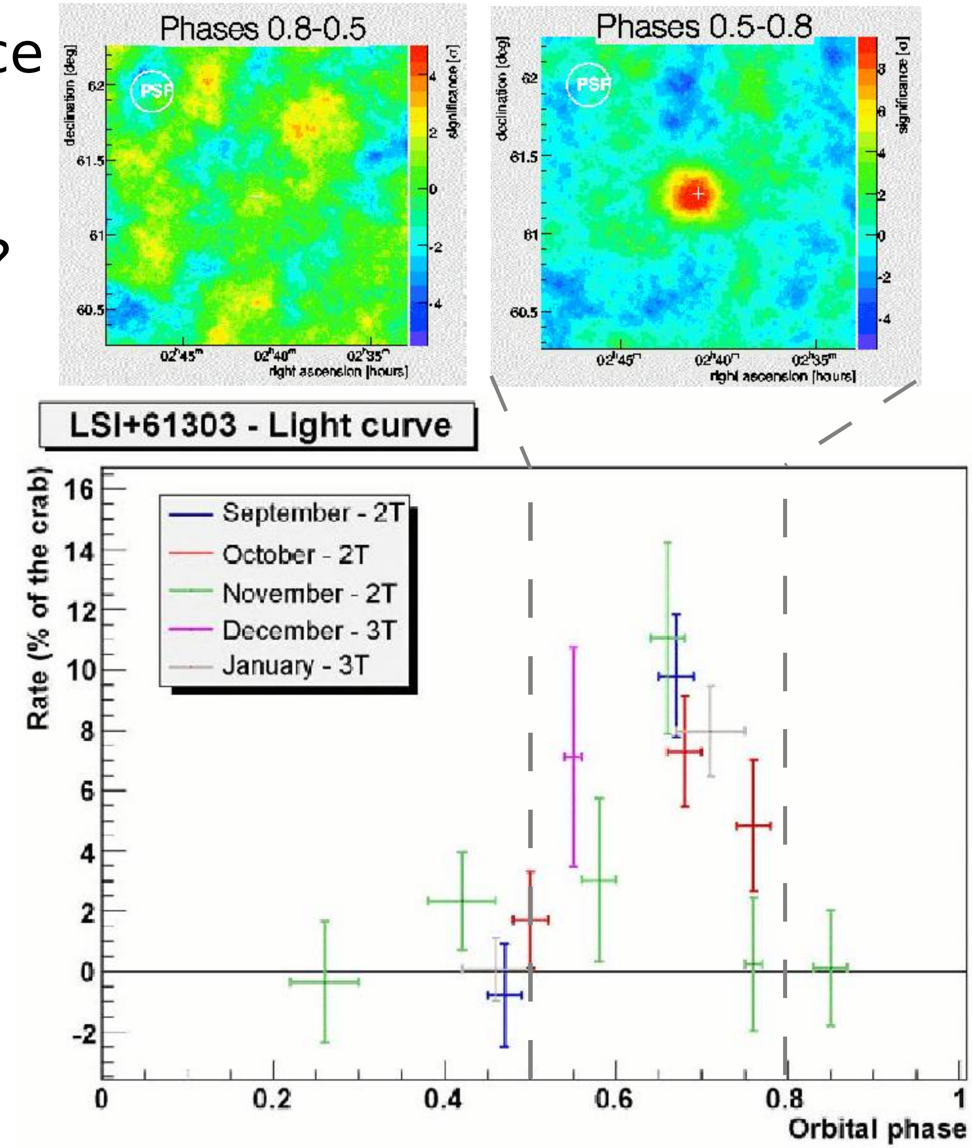


Radio (non-thermal):
Trace relativistic particles

Class3: High mass X-ray binaries (LSI +61 303)

- LSI+61: Variable TeV γ-ray source (seen by MAGIC/VERITAS)
- Emission mechanism unknown: Microquasar or interacting PWN? (+strong propagation/absorption effects)
- Radio flares (GBI/VLA)





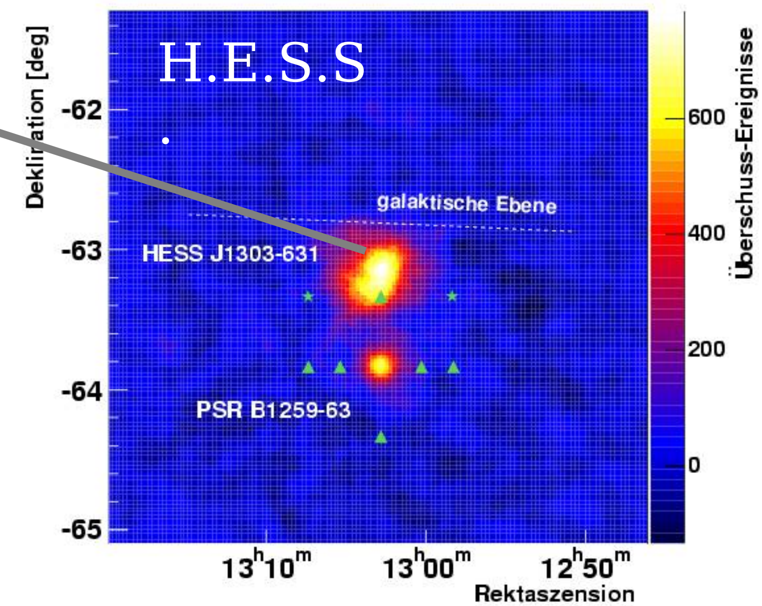
Acciari et al., ApJ, 679, 1427 (2008)

Phase-dependent **radio**-VHE emission: Input for modeling

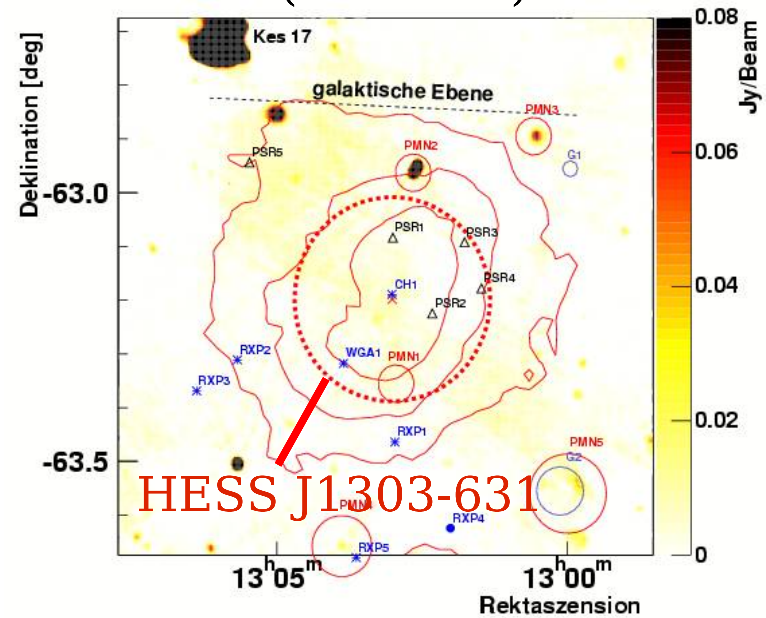
Class4: Unidentified TeV γ -ray sources

- **Unidentified TeV γ -ray sources:**
  - no counterpart at other wavelengths
  - mostly extended, emission mech. unknown
- **Variable emission:** unidentified TeV γ -ray point source -> binary candidate?

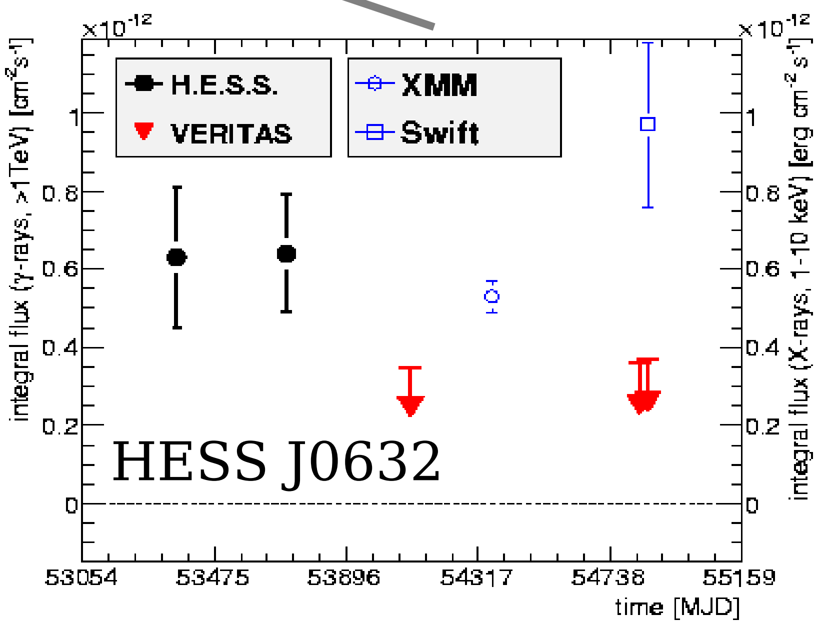
Aharonian et al.(2005),A&A,439,1013



SUMSS (843 Mhz) Radio



Acciari et al. (2009), ApJ, 698, L94

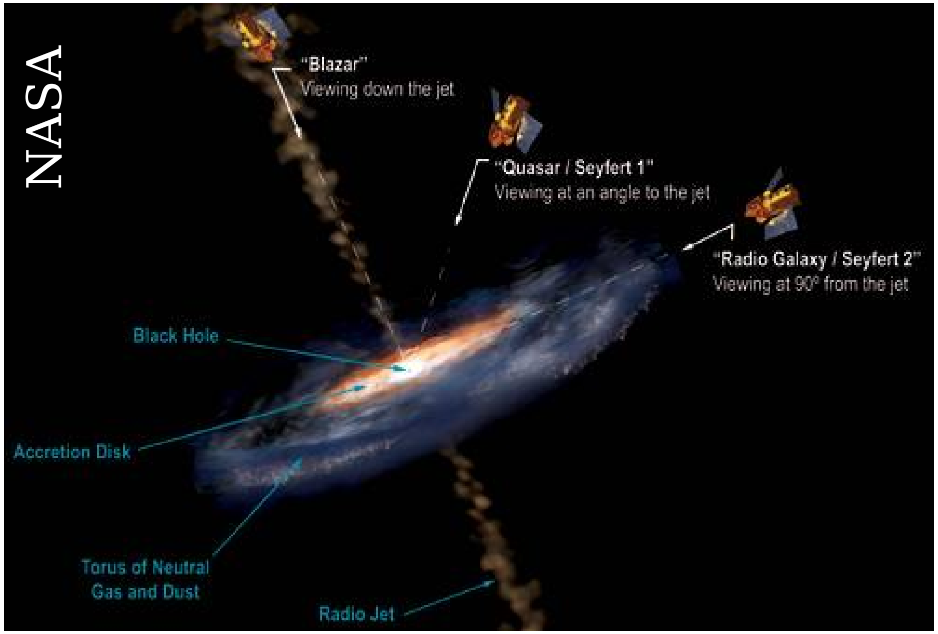


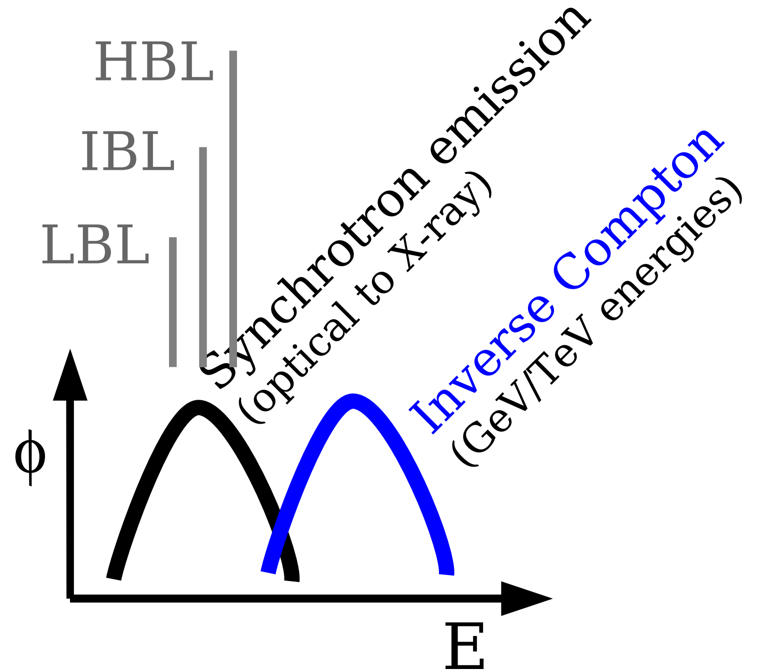
Radio: Identify TeV γ -ray sources: counterparts, molecular clouds, etc.

Extragalactic TeV sources

The VERITAS Blazar Program: Science Motivation

- **AGN:** Black hole / accretion disk power relativistic plasma jets
- **VERITAS key science project:**
  (1) Discovery program:
  new blazar types, expand VHE catalog
  (2) Multi-wavelength observations:
  time variability, energy spectral, etc.
  (3) ToO: X-ray, optical, Fermi, ...
- **Science Driver1:** Mechanisms of ultra-relativistic jet production:
  - Particle accel. & emission mechanisms
  - Jet structure & jet formation
  - TeV origin: leptonic or hadronic?
  - Black hole / jet connection
- **Science Driver2:** Blazars as probes of the extragalactic background light (EBL) through pair absorption



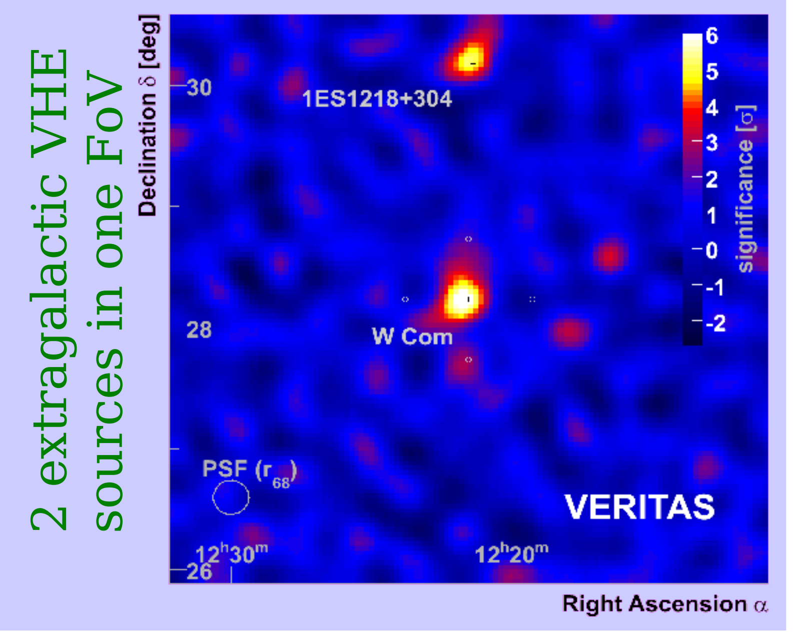


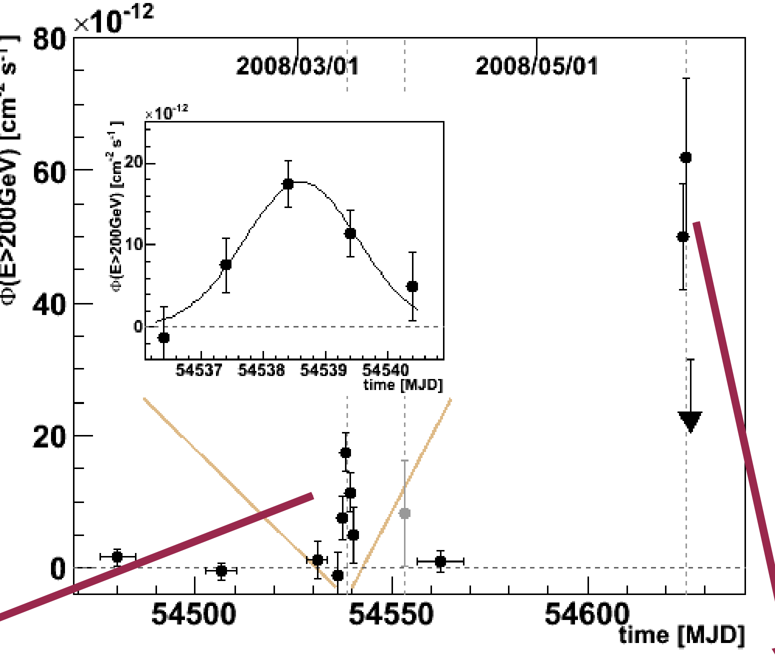
Example 1:
The intermediate-peaked BL Lac W Com

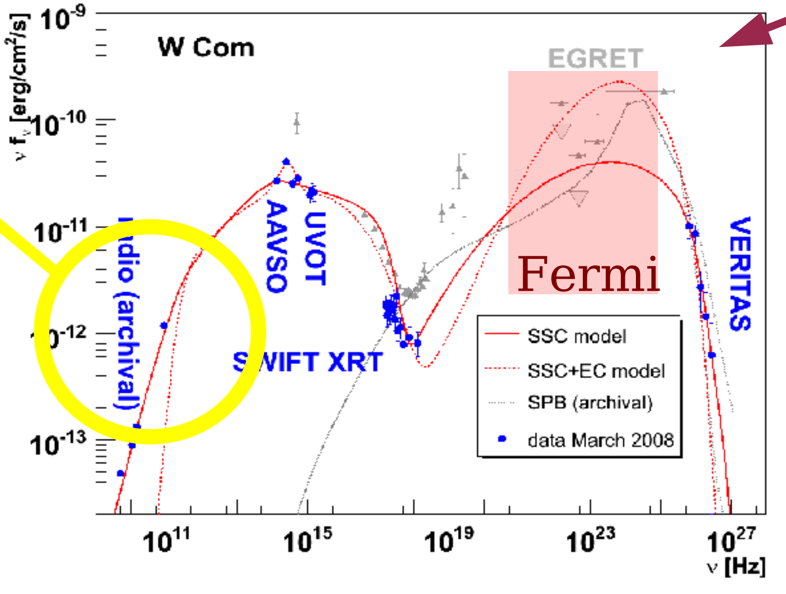
W Com, IBL (z=0.102) [Acciari et al., ApJ, 684, L73 (2008) & Atel #1582]

Often non-simultaneous (yet)

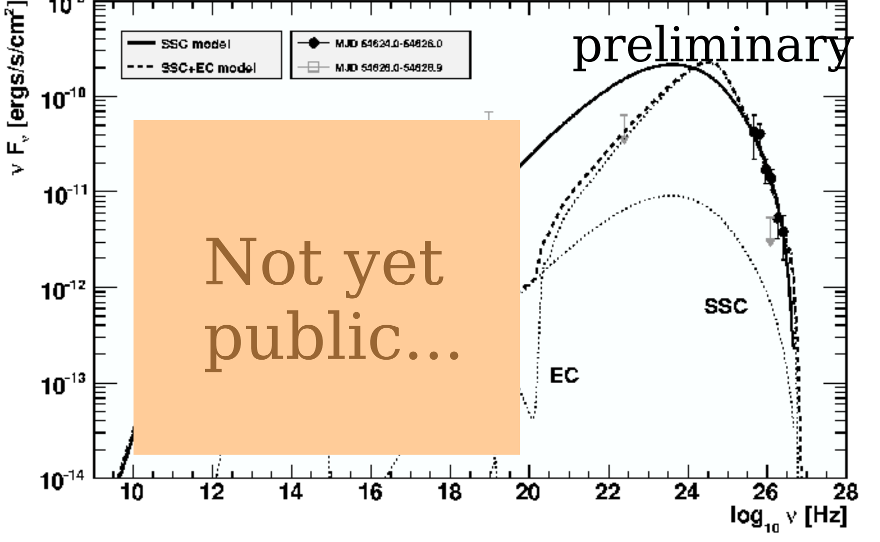
2 extragalactic VHE sources in one FoV







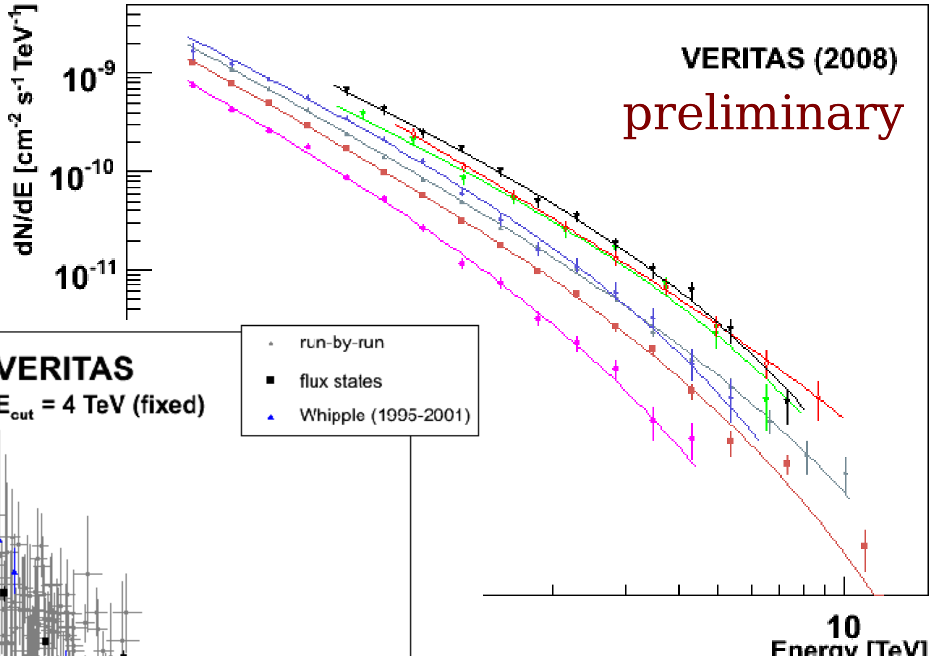
SSC (B=7mG) & SSC+EC

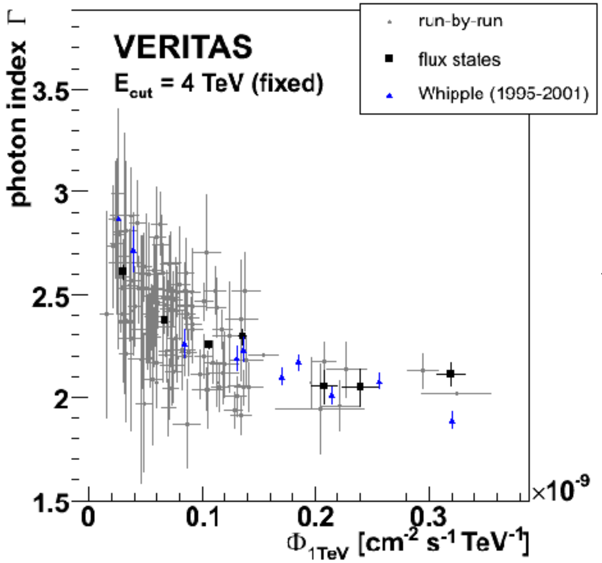


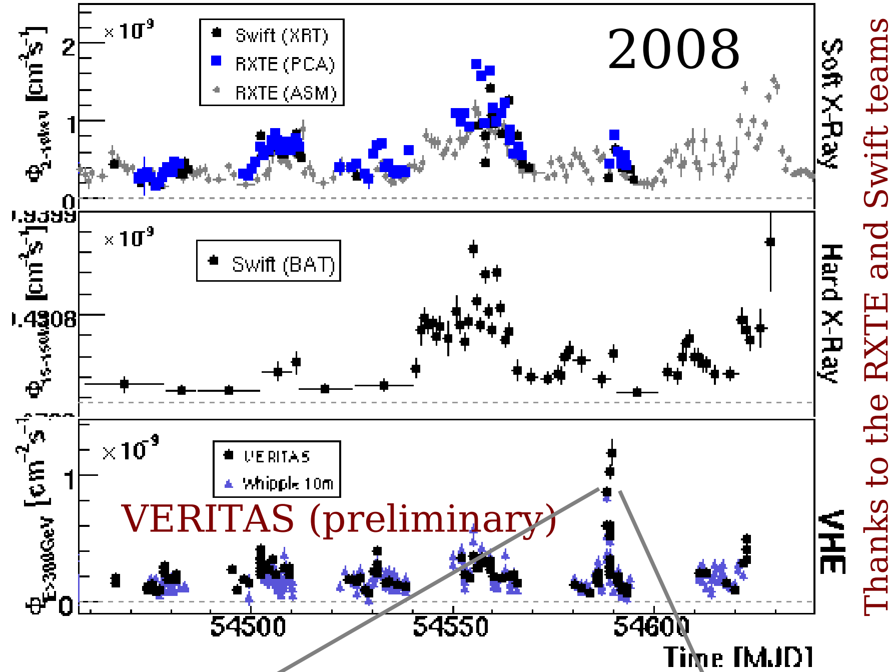
Example 2:
The Mrk421 2007/2008 MWL Campaign

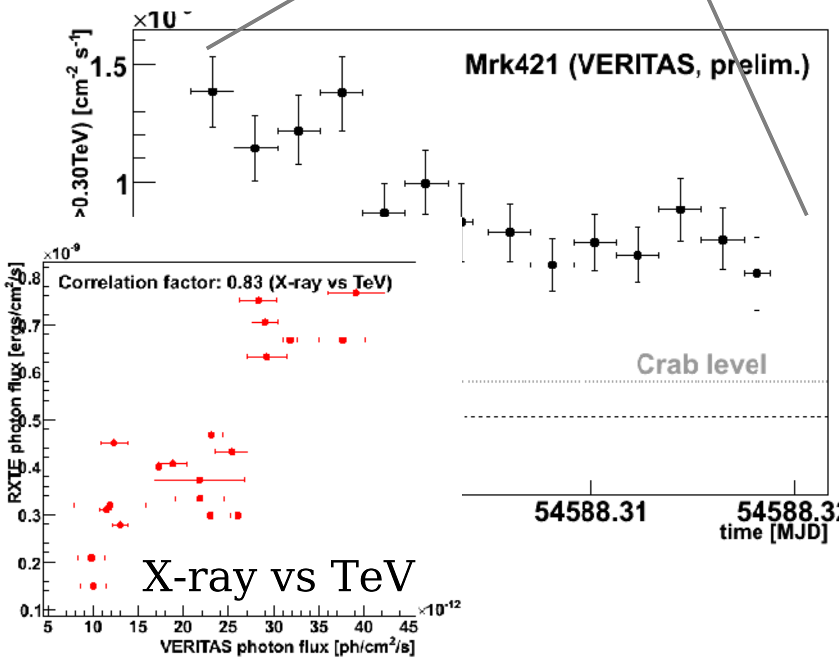
MWL data:

- **Radio**: Metsahovi, UMRAO
- **Optical:** BRT/NMS, UVOT, RCT, WIYN, Turola
- **X-ray:** RXTE, Swift, Suzaku (tbd)
- VHE: 42 h VERITAS + Whipple monitoring

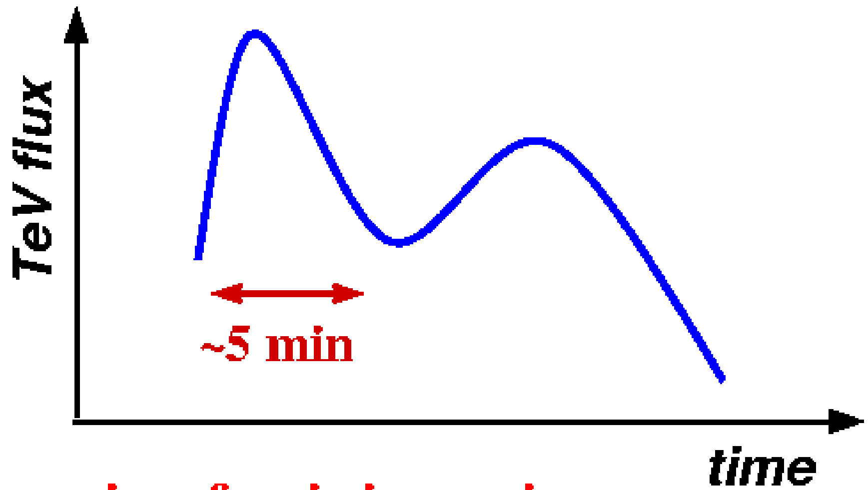




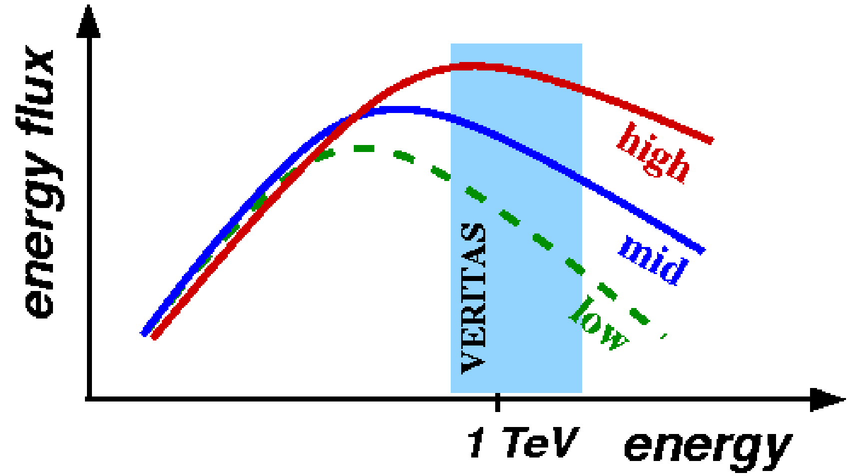




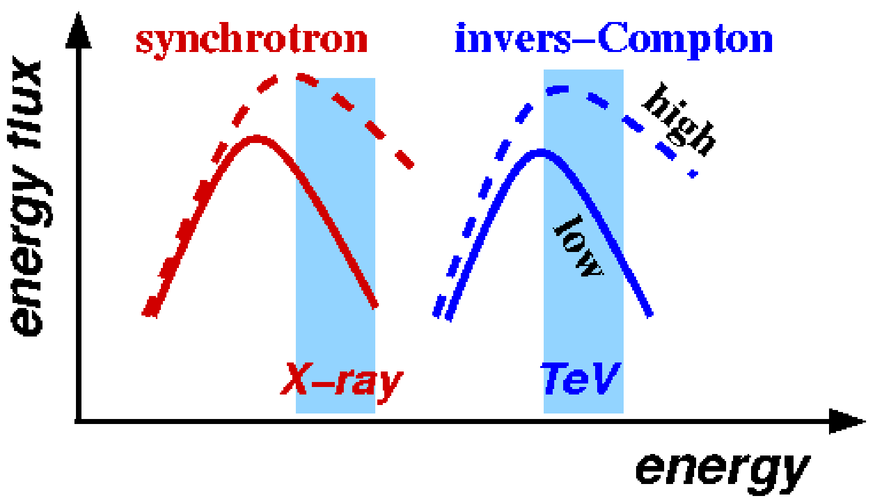
What did we learn from TeV blazars?



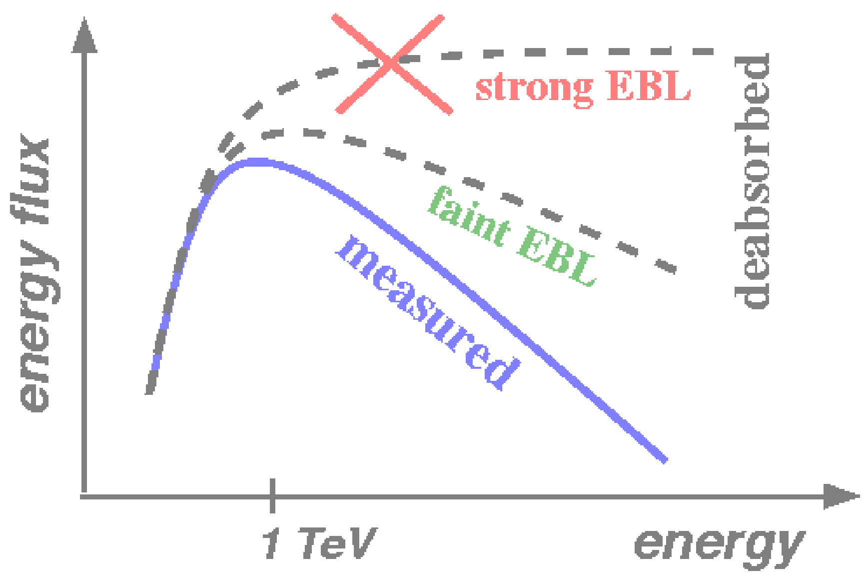
=> size of emission region



=> Γ/flux correlation (mechanism?)



=> same particle population

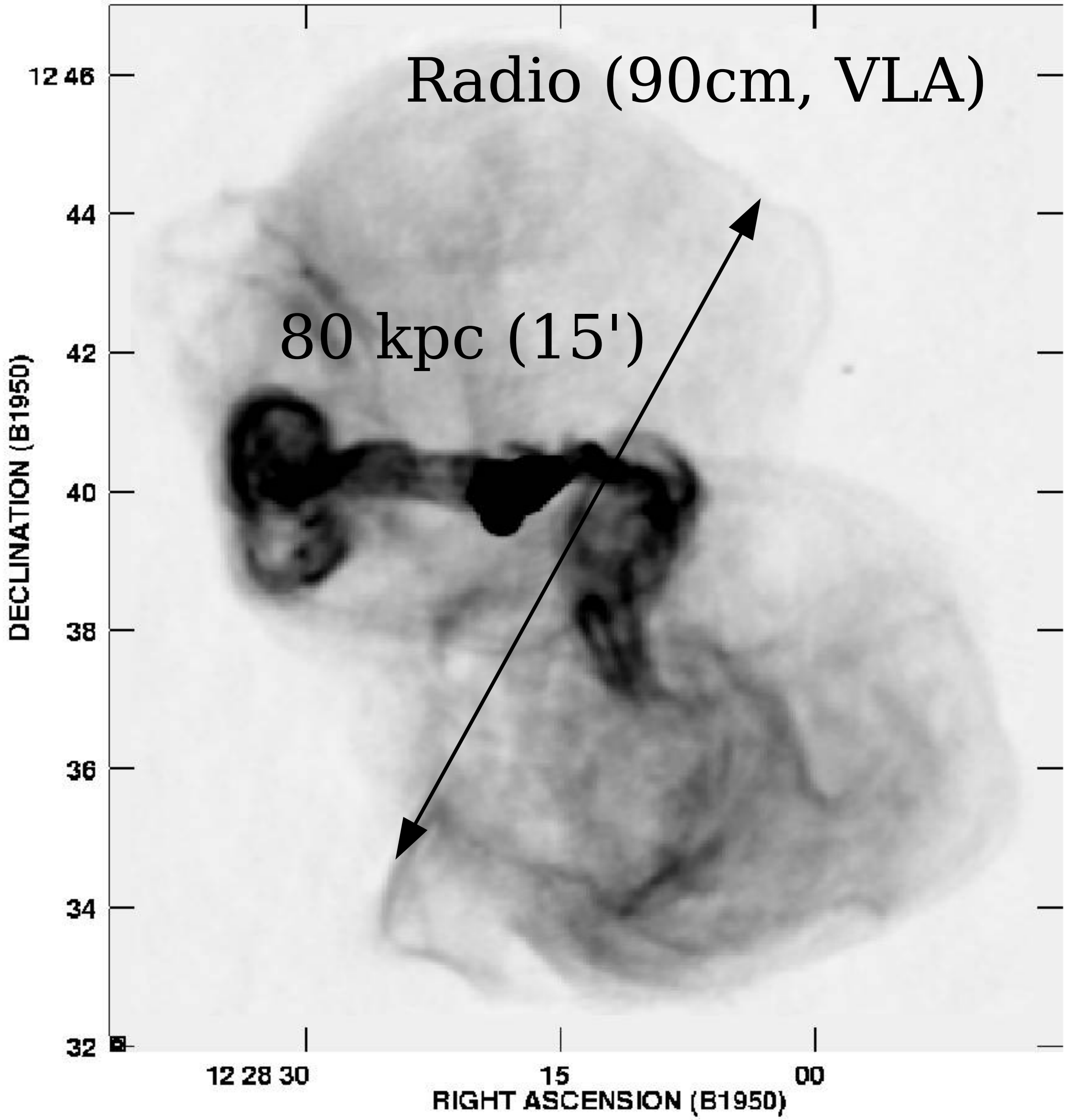


=> strong EBL excluded

Open questions: exact location => M87?

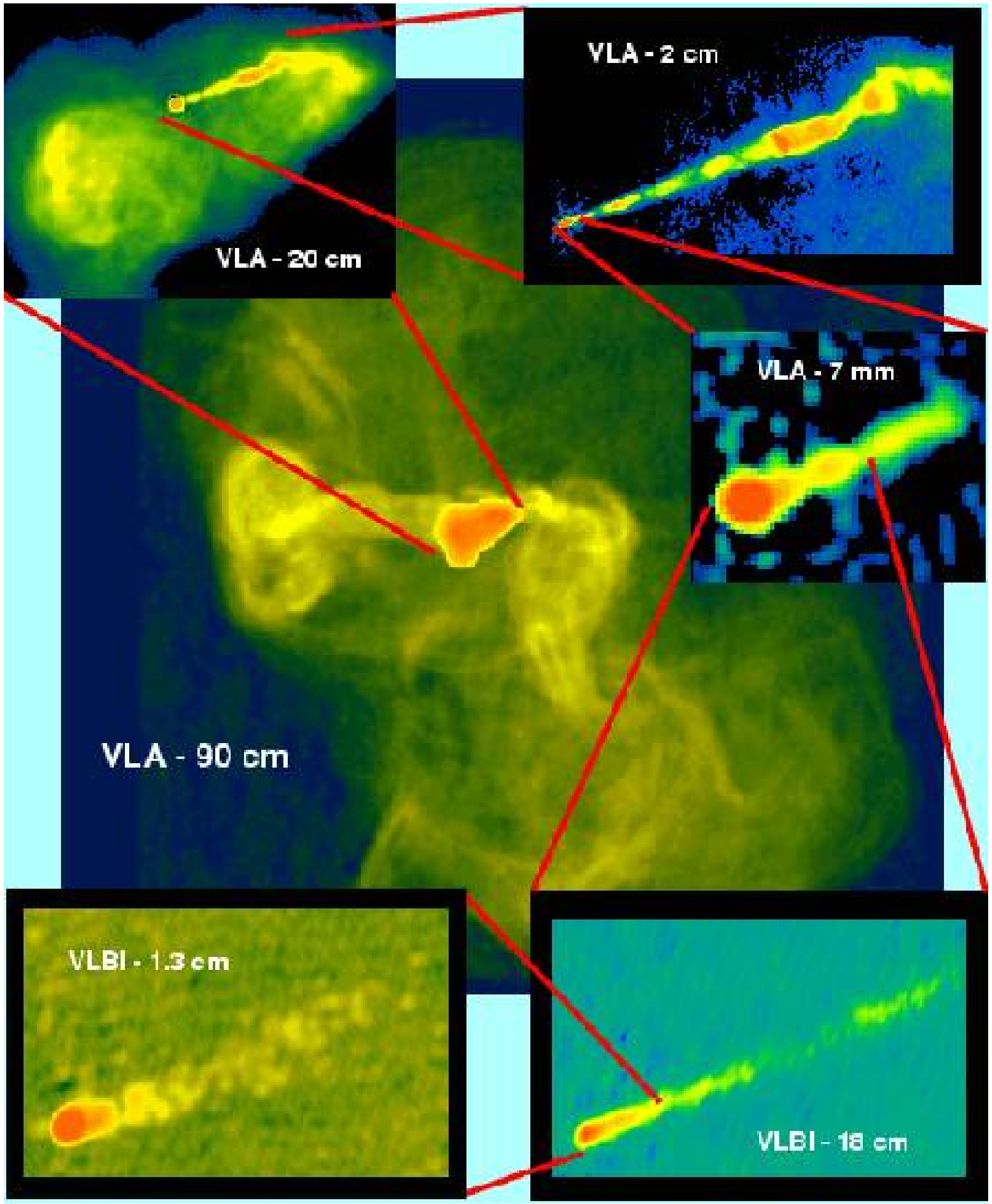
The giant elliptical radiogalaxy M87

Owen et al. (2000), ApJ, 543, 611



- **Close-by radio galaxy:**
  ~16 Mpc (z=0.00436)
- **Radio structure:**
  outflows and halo
  $Age_{halo} << Age_{M87}$
  => Variable jet activity
- **Jet angle:**
  ~30° ⇒ not a blazar!
- **Central black hole:**
  $M_{BH} = (6.4 \pm 0.5)\ 10^9\ M_{sun}$
  [Gebhardt&Thomas, arXiv0906.1492]
  Bondi accretion: 0.1 M_{sun}/yr
  luminosity 10^4 times lower
  => radiatively inefficient or lower (B < 10 G)

The relativistic plasma jet of M87



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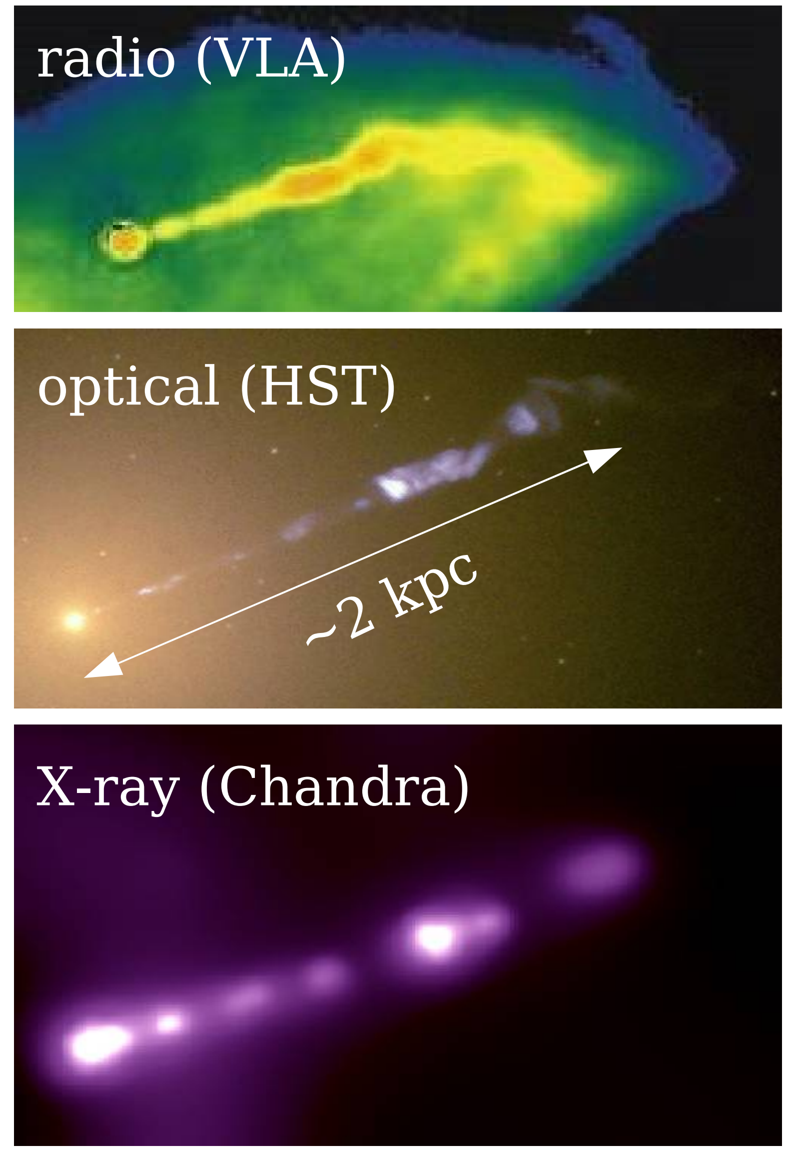
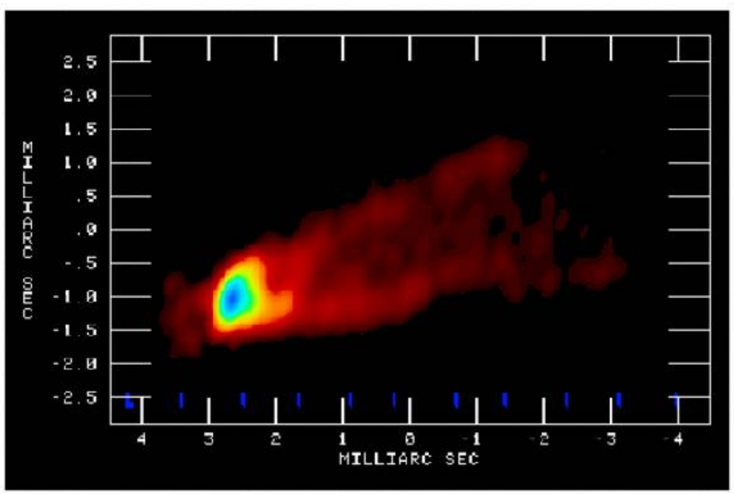


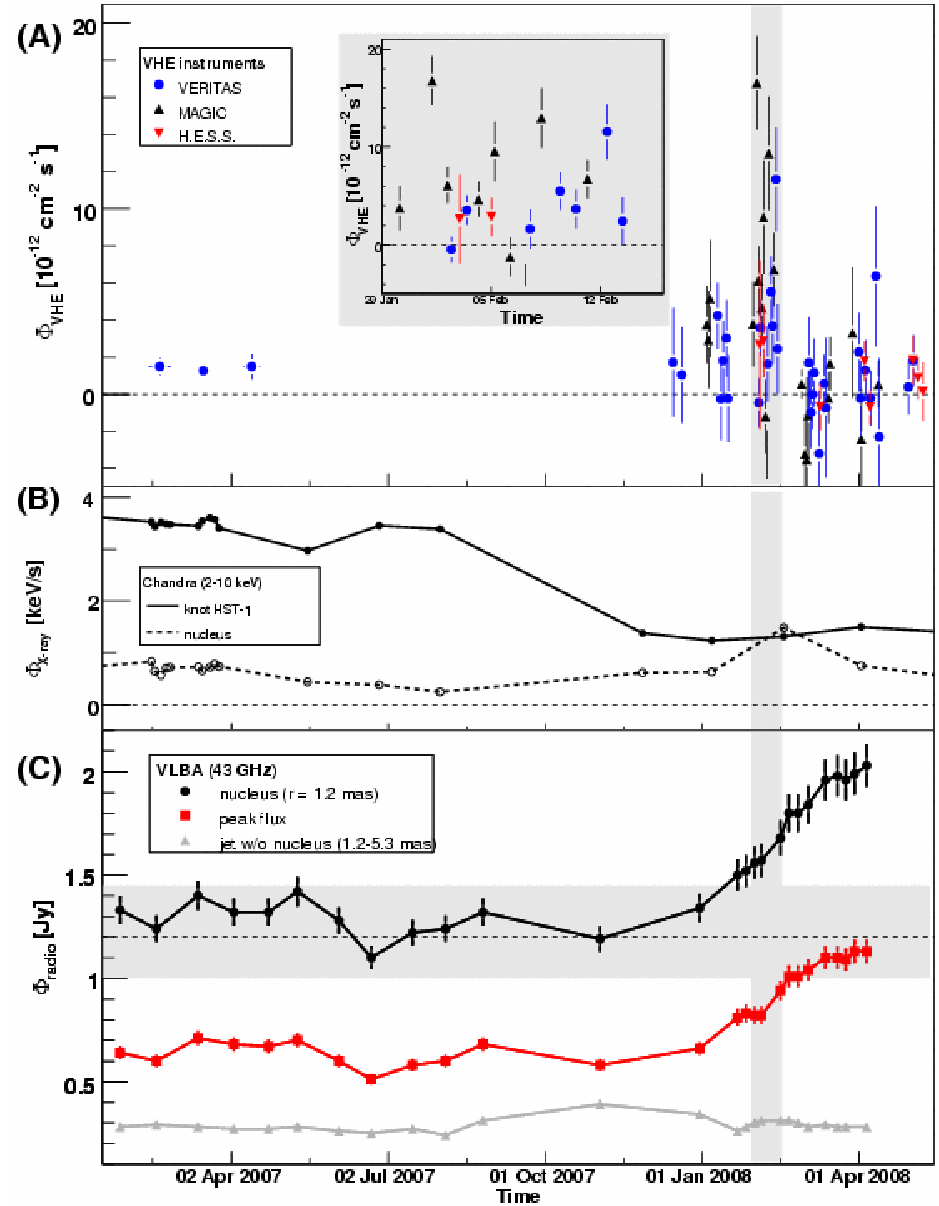
Wilson & Yang (2002), ApJ, 568, 133

Close cooperation between VLBA, H.E.S.S., MAGIC and VERITAS reveals...

- **VLBA (43GHz, C.Walker et al.):**
  Jet formation @ 30 x 60 R_s
- **VHE: Coordinated campaign:**
  - H.E.S.S./MAGIC/VERITAS
  - More than 120h (>50 nights)
- **VHE flare accompanied by radio flare from BH vicinity**
- **Published in Science:**
  Acciari et al., Science, 325, 444 (2009)



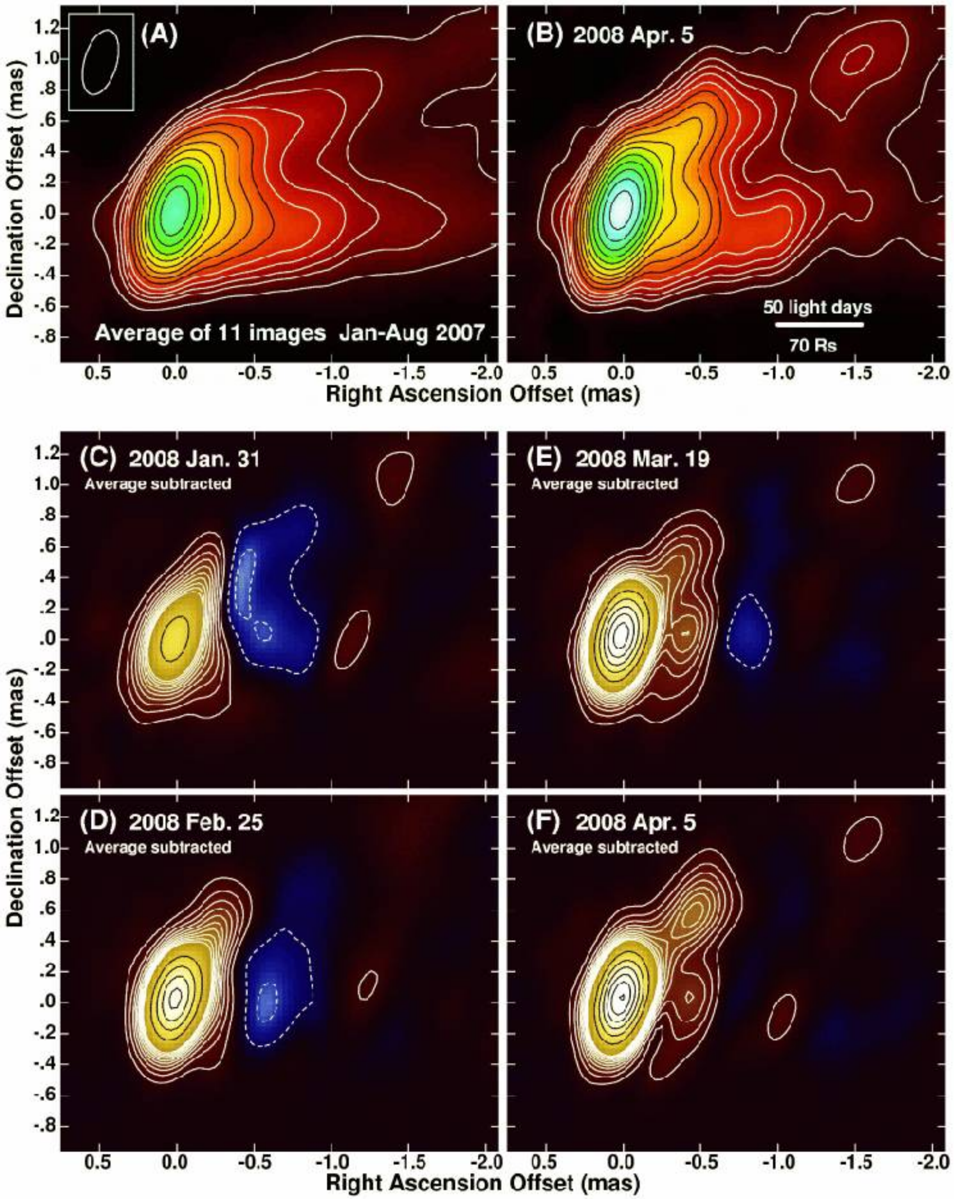
C.Walker et al.



Acciari et al., Science, 325, 444 (2009)

Contact: VLBA: C.Walker, F.Davies, P.E.Hardee, B.Junor, C.Ly, H.E.S.S., MAGIC and VERITAS

Close cooperation between VLBA, H.E.S.S., MAGIC and VERITAS reveals...



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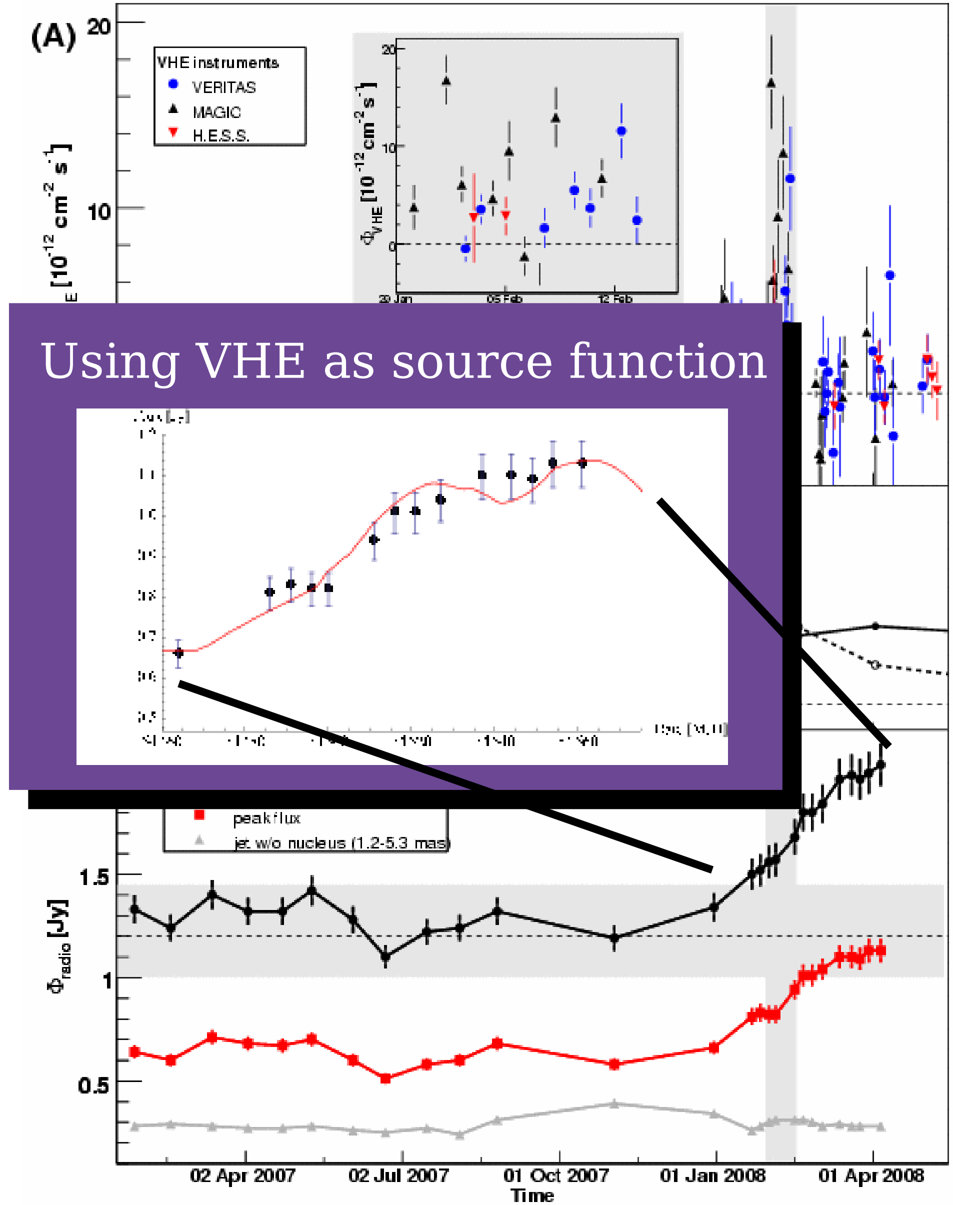

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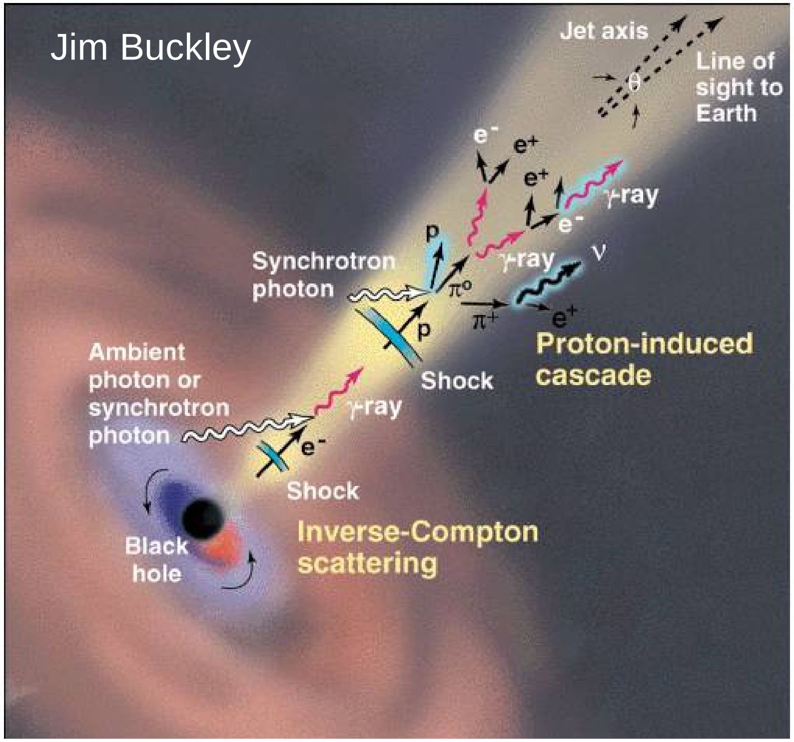
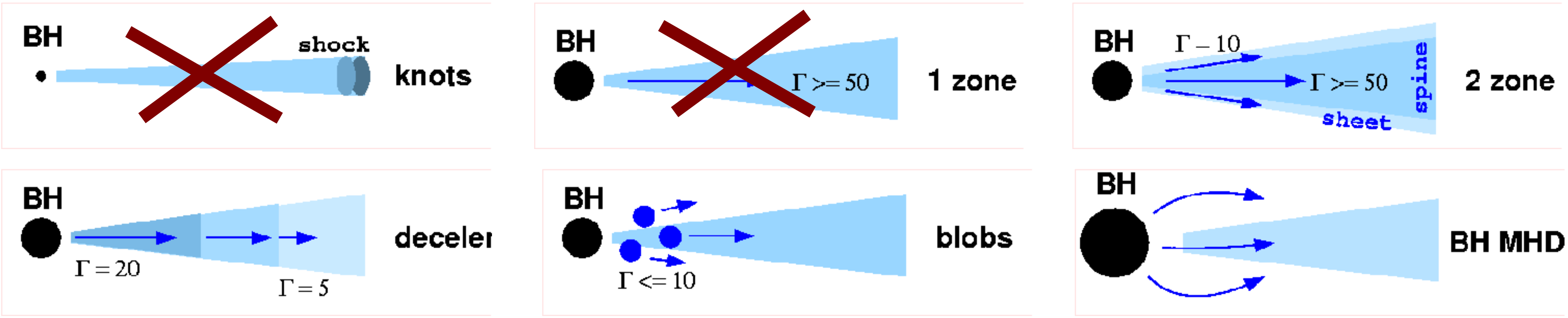
M87: Importance of results & future

- **TeV/radio connection:**
  - TeV emission from BH vicinity
  - Important input for TeV modeling
  - Accretion & jet formation physics
- **Future questions/goals:**
  - Can pattern be observed repeatedly?
  - TeV emission: How close to BH?
  - More detailed sampling of light curves
  - Polarization in radio?
  - Other TeV sources: Similar pattern?





Future TeV/radio cooperation: promising approach!