# Gamma-ray Astrophysics with VERITAS: Exploring the violent Universe

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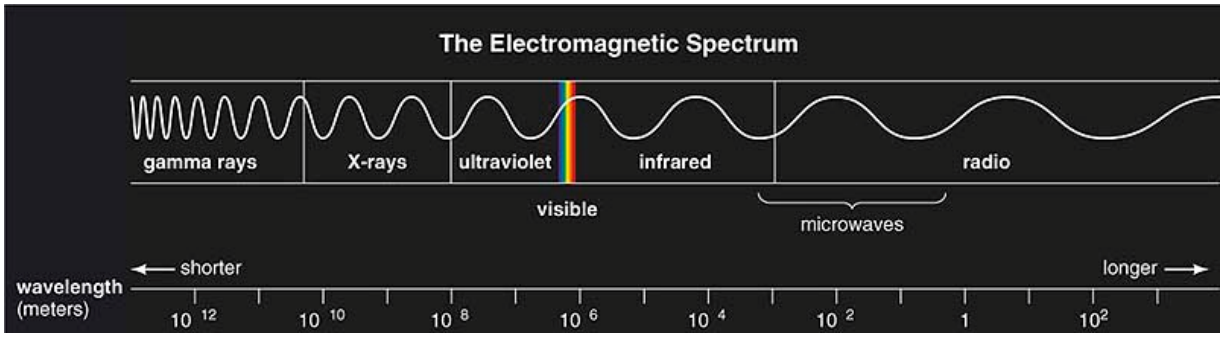
# How do we know about the Universe?

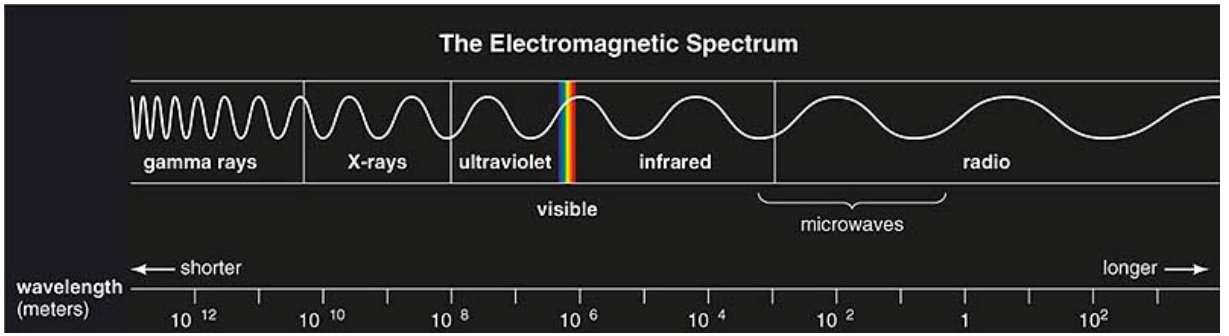
Historically, all observational information about the cosmos comes to us carried by electromagnetic radiation.

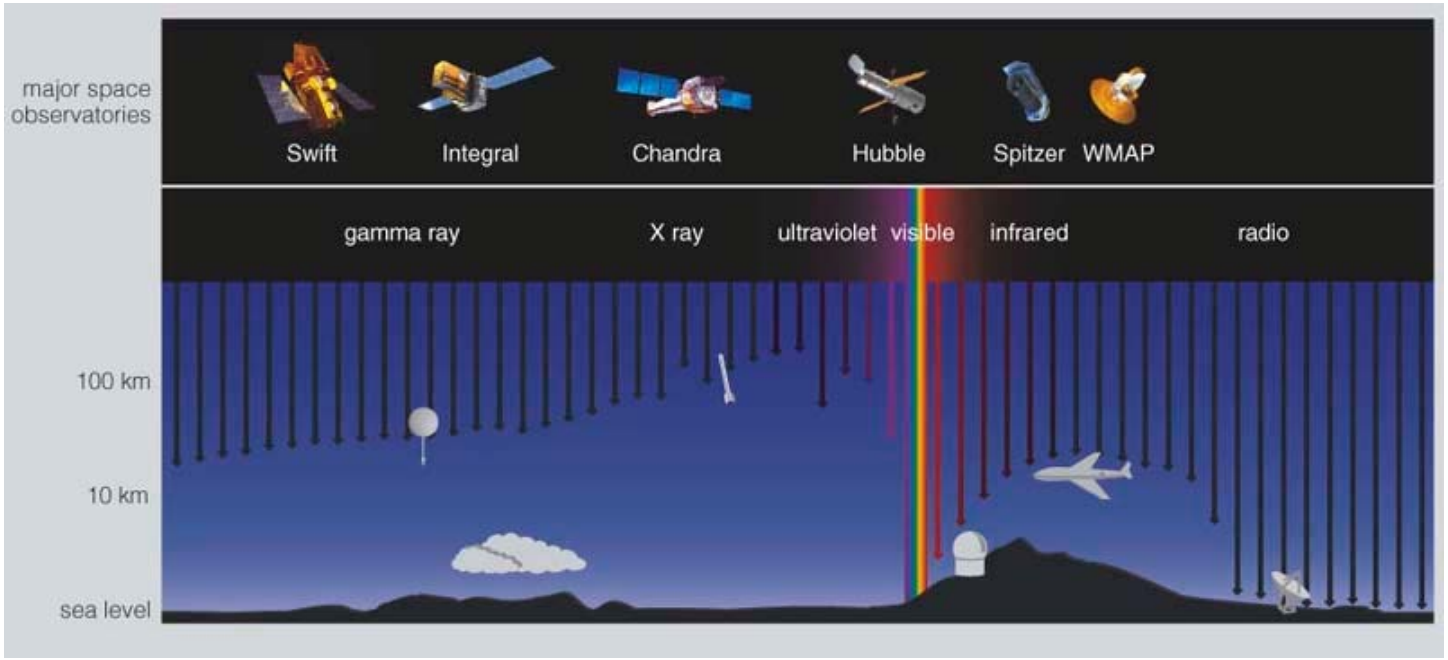
(More recently, we have begun to do particle astronomy with cosmic rays and neutrinos)

The EM spectrum is broad – from radio waves (very long wavelengths) to gamma-rays (very short wavelengths).

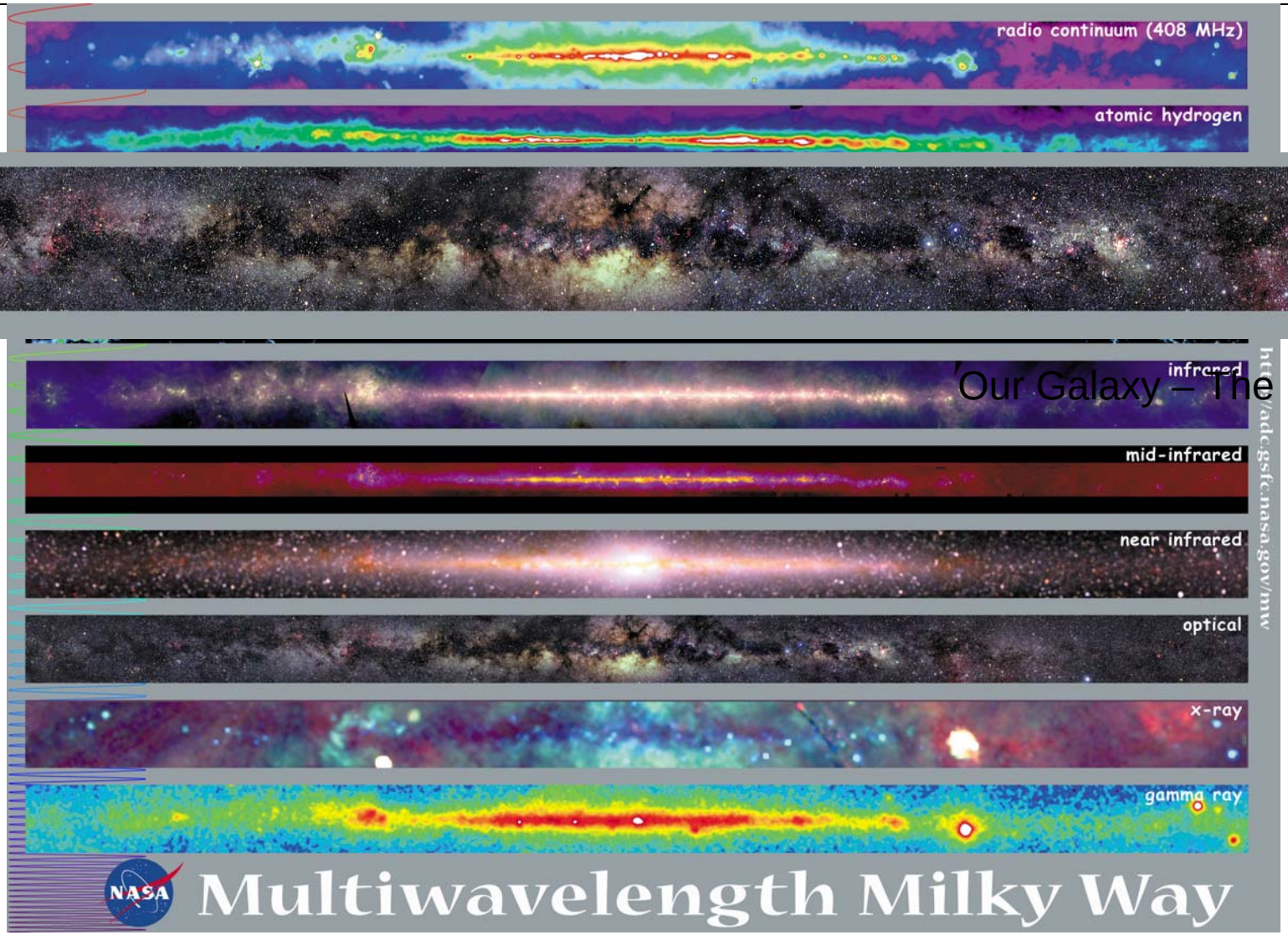


# The atmosphere doesn't make it easy…



# …but the Universe looks different at different wavelengths!




Our Galaxy – The Milky Way

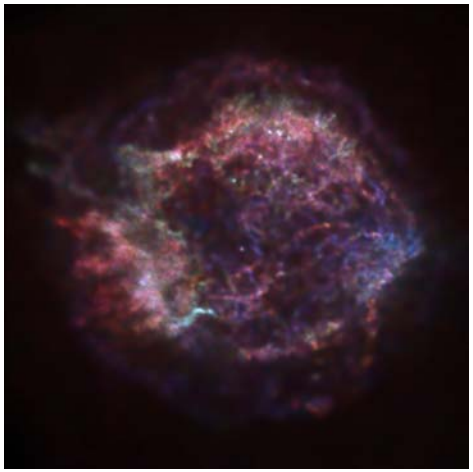
# Gamma-rays come from some of the most violent places in the Universe…

known

- Galactic stellar remnants
- Binary stars
- Active Galactic Nuclei

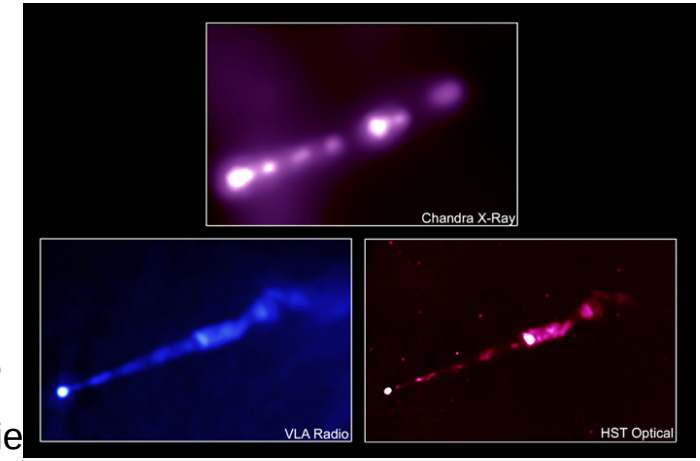
expected

- Gamma-Ray Bursts
- Dark matter annihilation



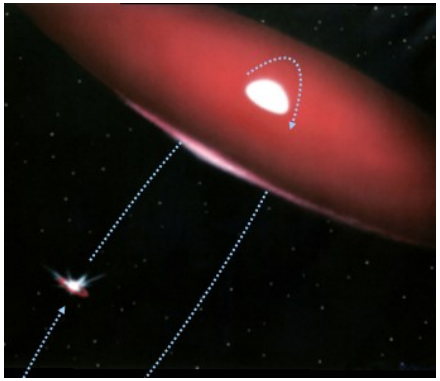
Cas A – XMM Newton

Crab: HST + Chandra




M87

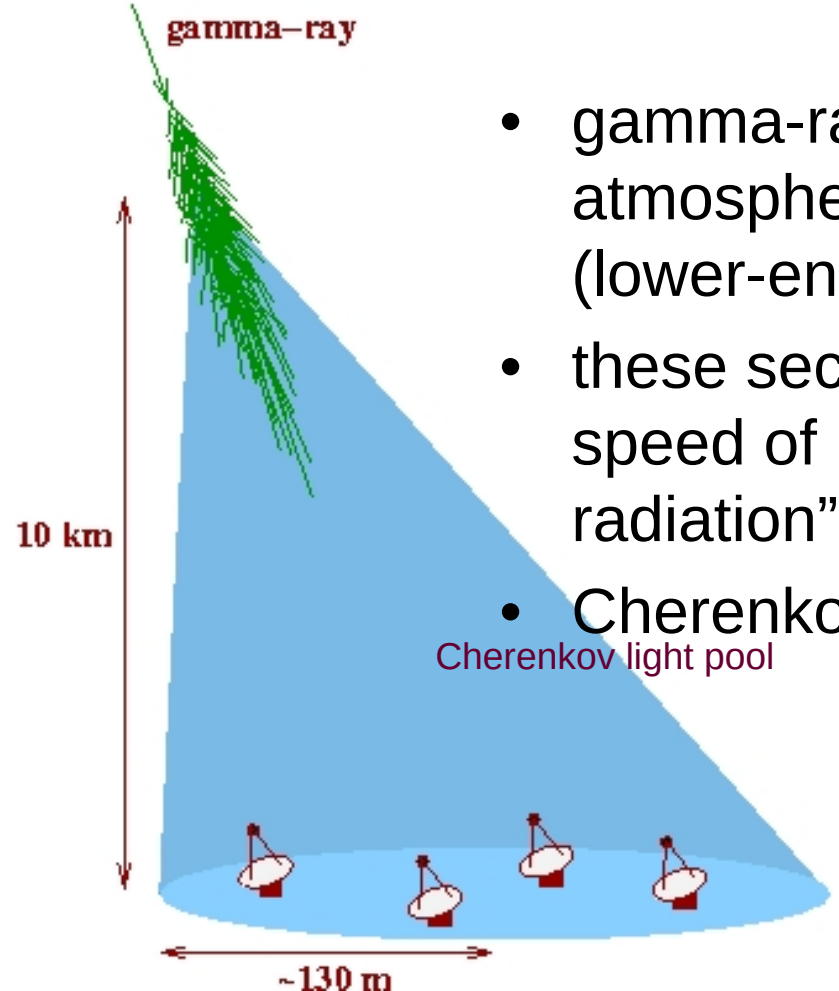
AGN



PSR B1259

# How do you detect gamma-rays from the ground?

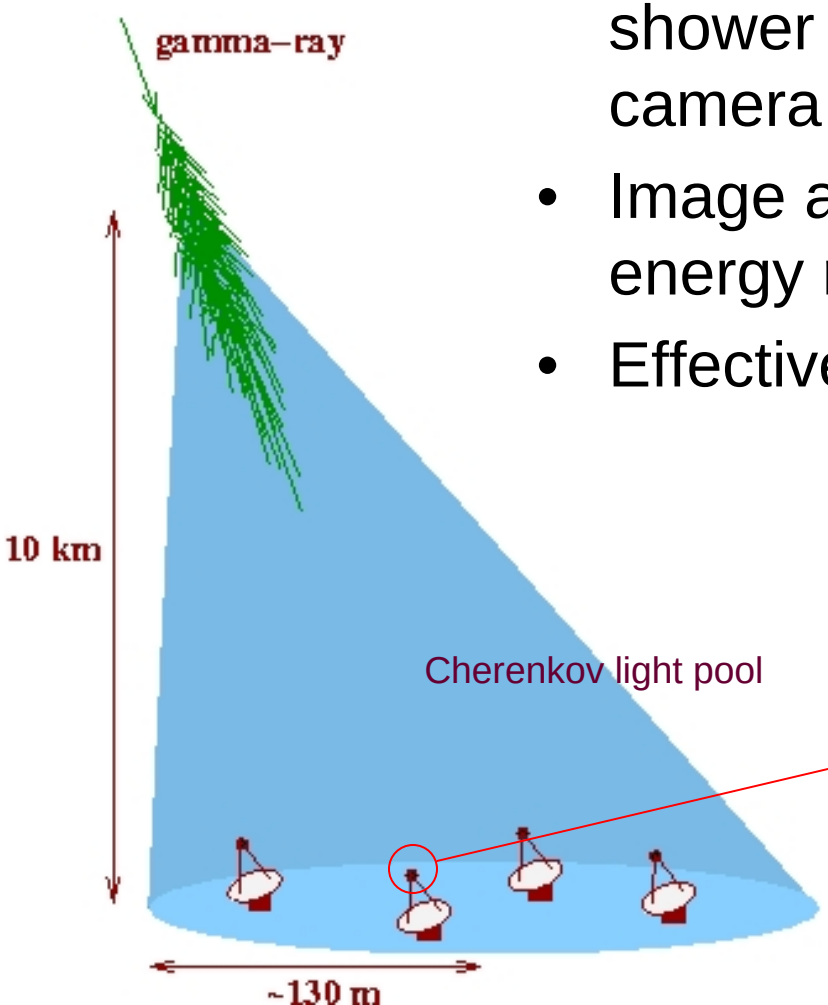
Use the atmosphere as part of your detector!




- gamma-ray interacting in the upper atmosphere creates a “shower” of secondary (lower-energy) particles
- these secondaries travel faster than the local speed of light and thus emit “Cherenkov radiation” (like a sonic boom in air)
- Cherenkov radiation penetrates to the ground

# How do you detect gamma-rays from the ground?

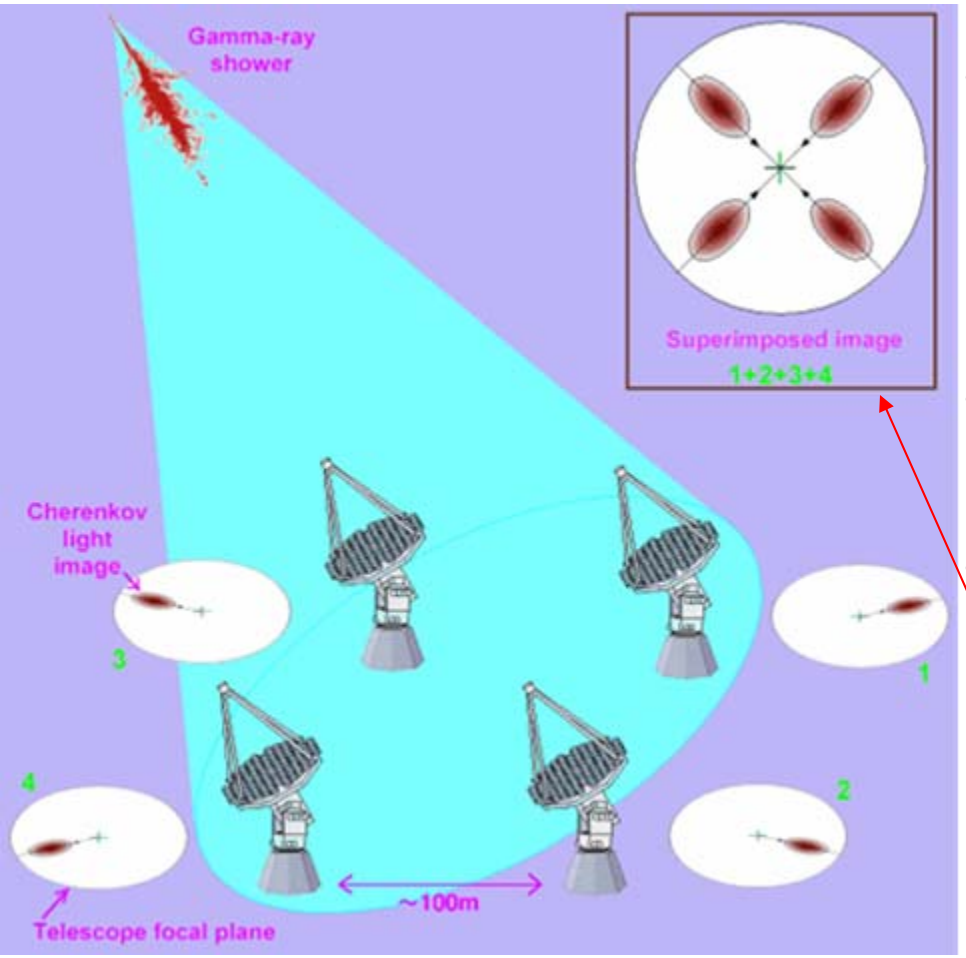
- VERITAS uses the *imaging technique:* shower is imaged in multi-phototube camera at focus of telescope
- Image analysis allows good angular and energy resolution
- Effective area ~ size of light pool ~ $10^4$ $m^2$




Cherenkov light pool

Multi-detector camera

# Ground-based observations - arrays




- Imaging *arrays* (multiple views of same shower) dramatically improve resolution & sensitivity
- Angular resolution << 1$^{o}$ possible
- Energy resolution ~15%

Multiple views allow reconstruction of gamma-ray origin

# VERITAS

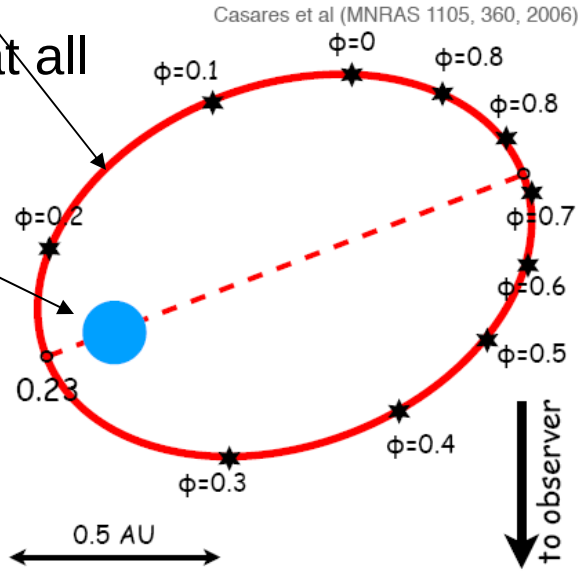
- An array of four 12-m imaging air Cherenkov telescopes
- Sited at Whipple Observatory basecamp near Tucson, Az
- International collaboration: Canadian, US, UK, Irish groups; ~ 80 collaborators at 20 institutions
- Science observations started in 2006

- 80 GeV to 50 TeV energy range
- Camera of each telescope composed of 499 PMTs

# VERITAS operational

# First Science Results – LSI +61 303

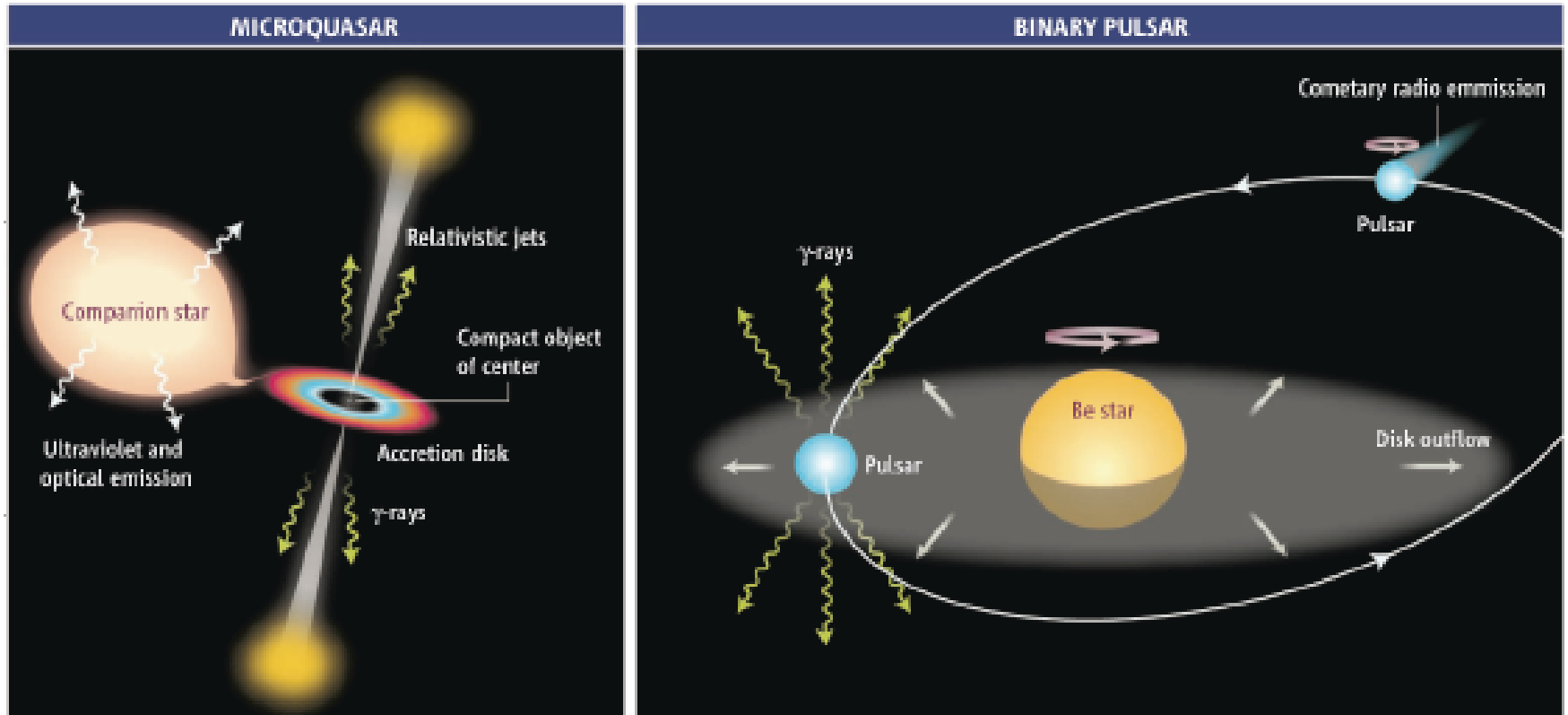
- LSI +61 303:
  - high-mass X-ray binary (period: 26.5 days)
  - massive Be star with compact companion (NS, BH) in tight orbit, and circumstellar disk
  - variable (phase-dependent) emission seen at all wavelengths




- Observations during 5 orbital cycles:
  - 2-telescope data: Sep – Dec ’06: 32 hours
  - 3-telescope data: Jan – Feb ’07: 12 hours

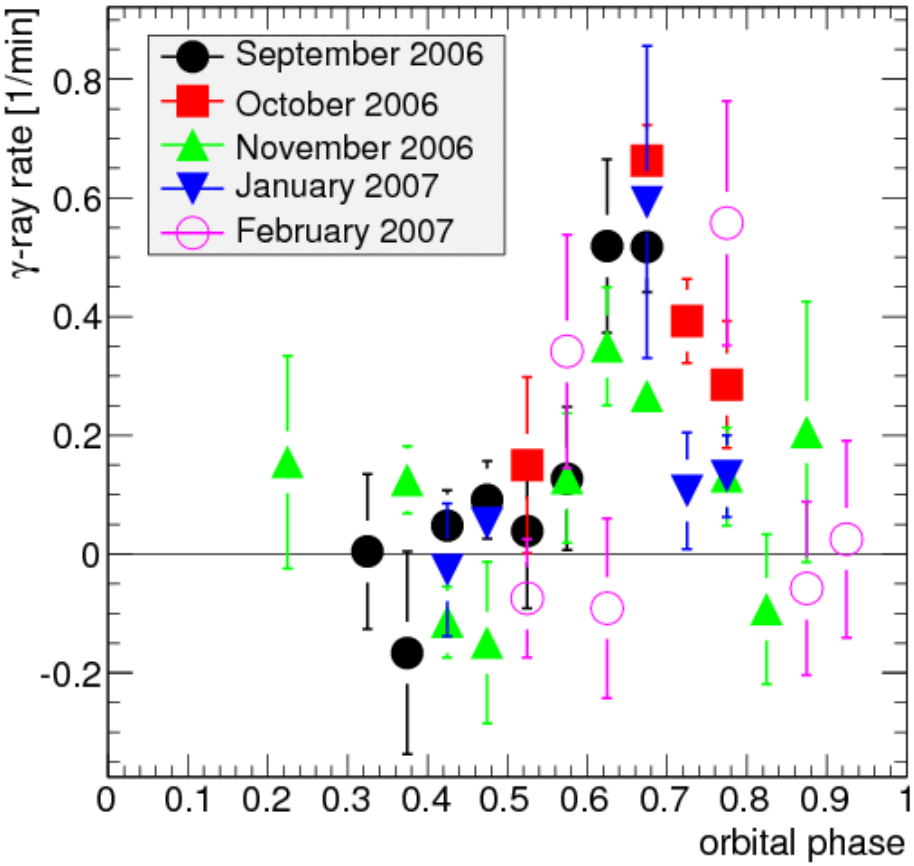
# First Science Results – LSI +61 303

- at least two models for VHE emission in system:
  - relativistic jet powered by accretion (“microquasar”)
  - acceleration in collision of relativistic pulsar wind with companion wind
  - in both models, VHE $\gamma$ emission believed to be inverse Compton



# First Science Results – LSI +61 303

- Detection:
  - VERITAS clearly observes variable emission; significance 8.8σ

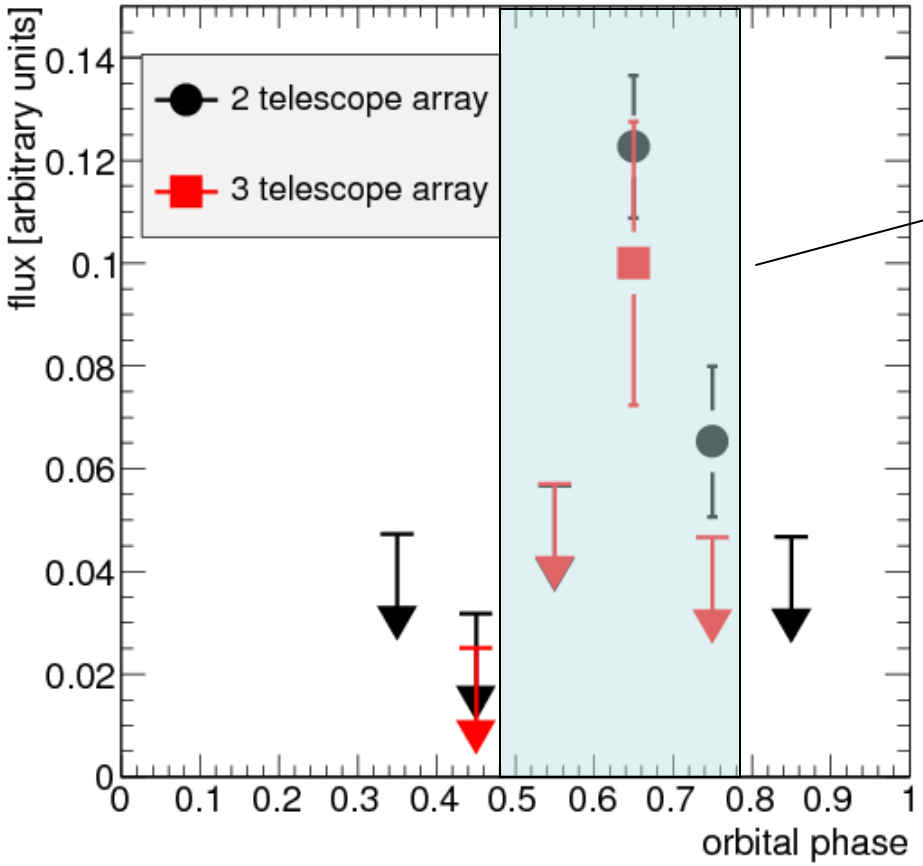



raw rates, binned *vs* binary phase

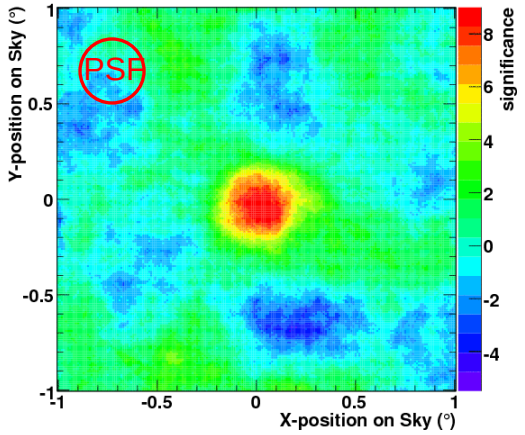
Because period is close to lunar period, no data in [0.95, 0.20]

# First Science Results – LSI +61 303

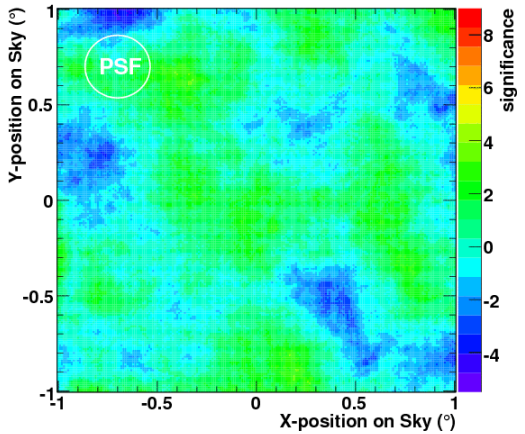
- emission observed near apastron (phase 0.73): flux > 0.10 Crab
- flux < 0.03 Crab outside in other observed phase bins
- 26.5 day period has 99.94% probability




0.5<ϕ<0.8
25 hours

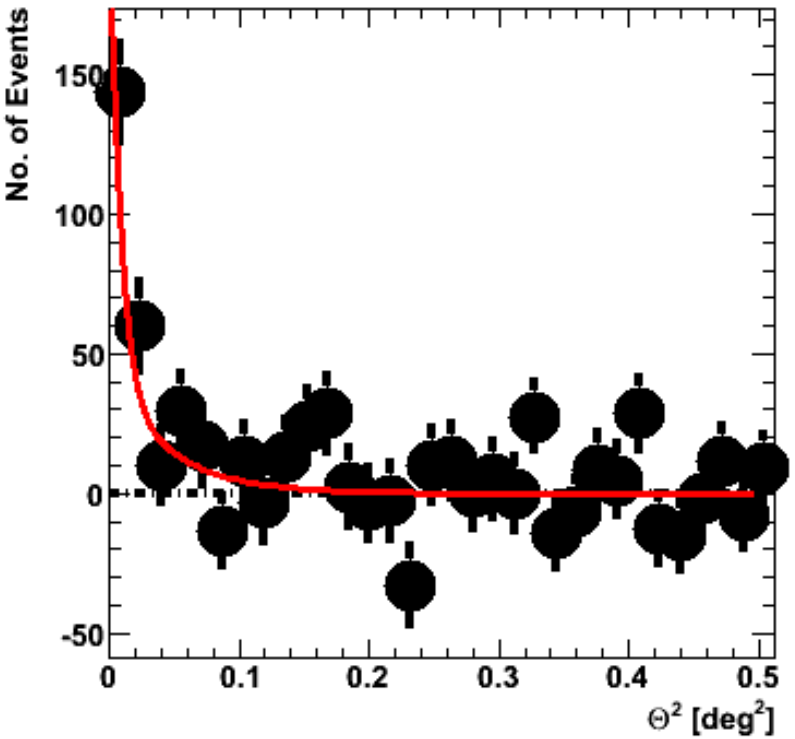


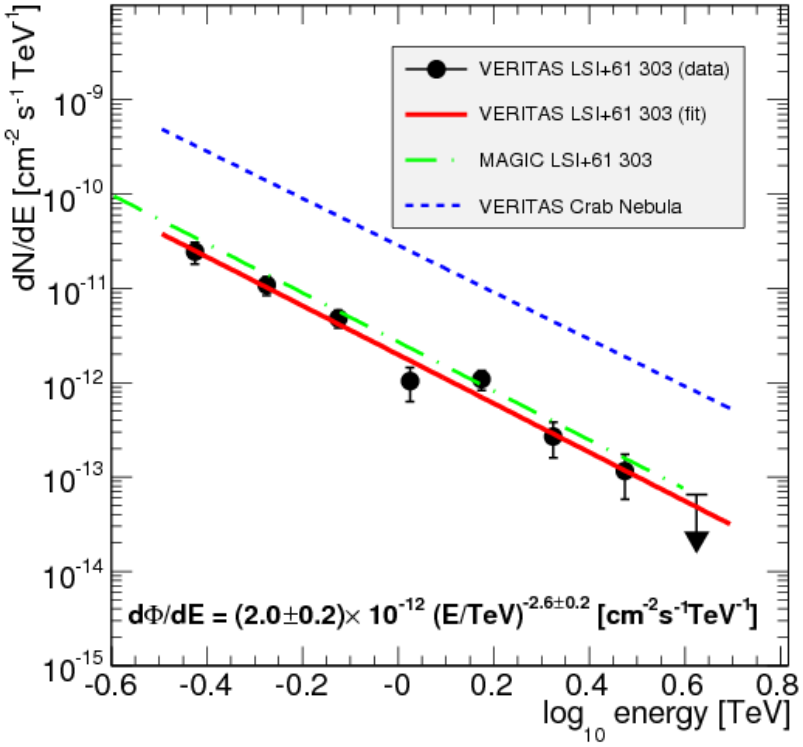

0.8<ϕ<0.5
19 hours



# First Science Results – LSI +61 303

- emission in high-flux bin consistent with point-source
- spectrum Crab-like (spectral index)



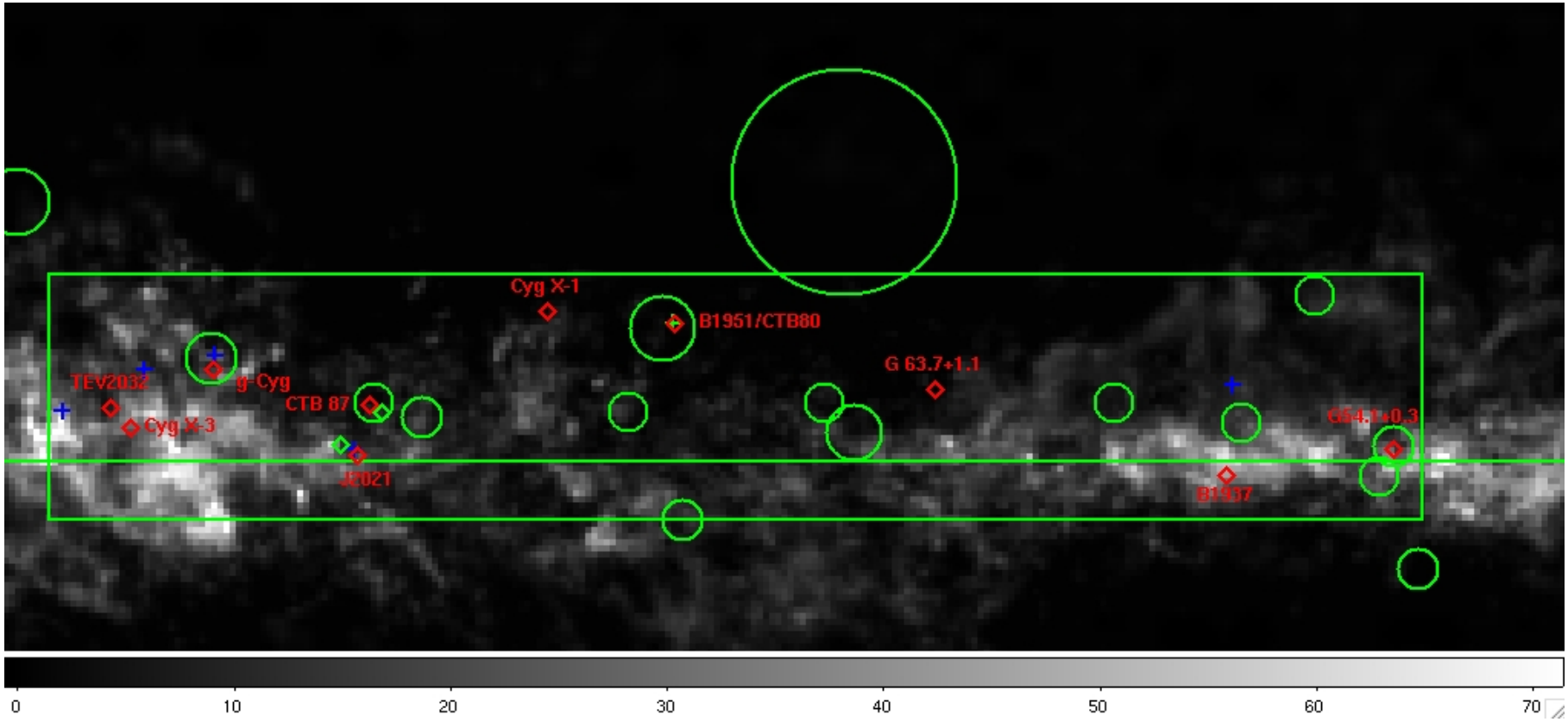



# VERITAS Observing Plan

- Typical year is 800-1000 hours of observing
- First two years: four Key Science Projects (50% of time)
  - Dark matter 60 hours/yr
  - AGN 110 “
  - SNR 100 “
  - Sky survey of Cygnus region 130 “
- Competitive observations (40% of time) decided by “TAC (time allocation committee)
- Discretionary time (10% of time)

# VERITAS Observing Plan

- Sky survey is over Cygnus region – containing many SNRs, PWNs, pulsars, EGRET sources
- Closer than Galactic centre



# Outlook

- Four-telescope VERITAS array is now in full operation
- Full science programme now underway with four Key Science Projects + competitive time
- Operation at FLWO basecamp until (at least) end of 2010
- Science results are emerging already…!