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Studies of Galactic VHE γ-ray Origin with VERITAS

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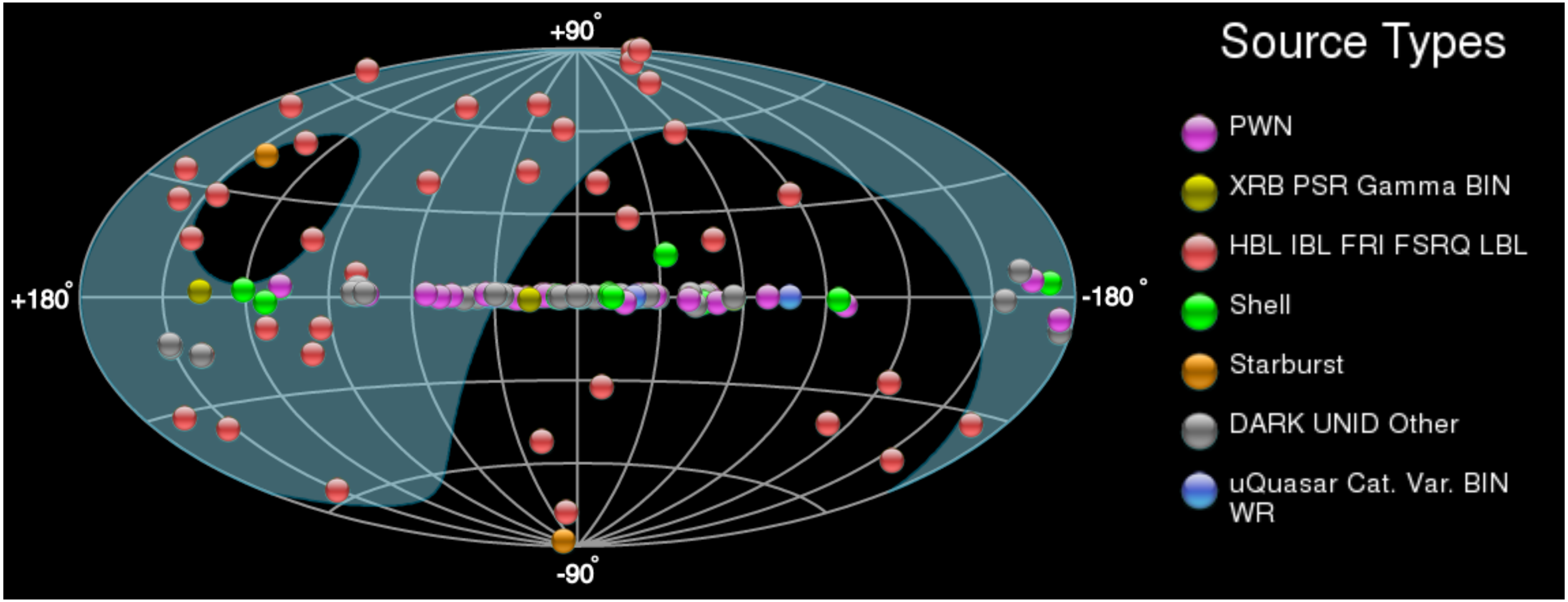
Andy Smith
University of Utah
Department of Physics and Astronomy

Ground-based VHE Instruments

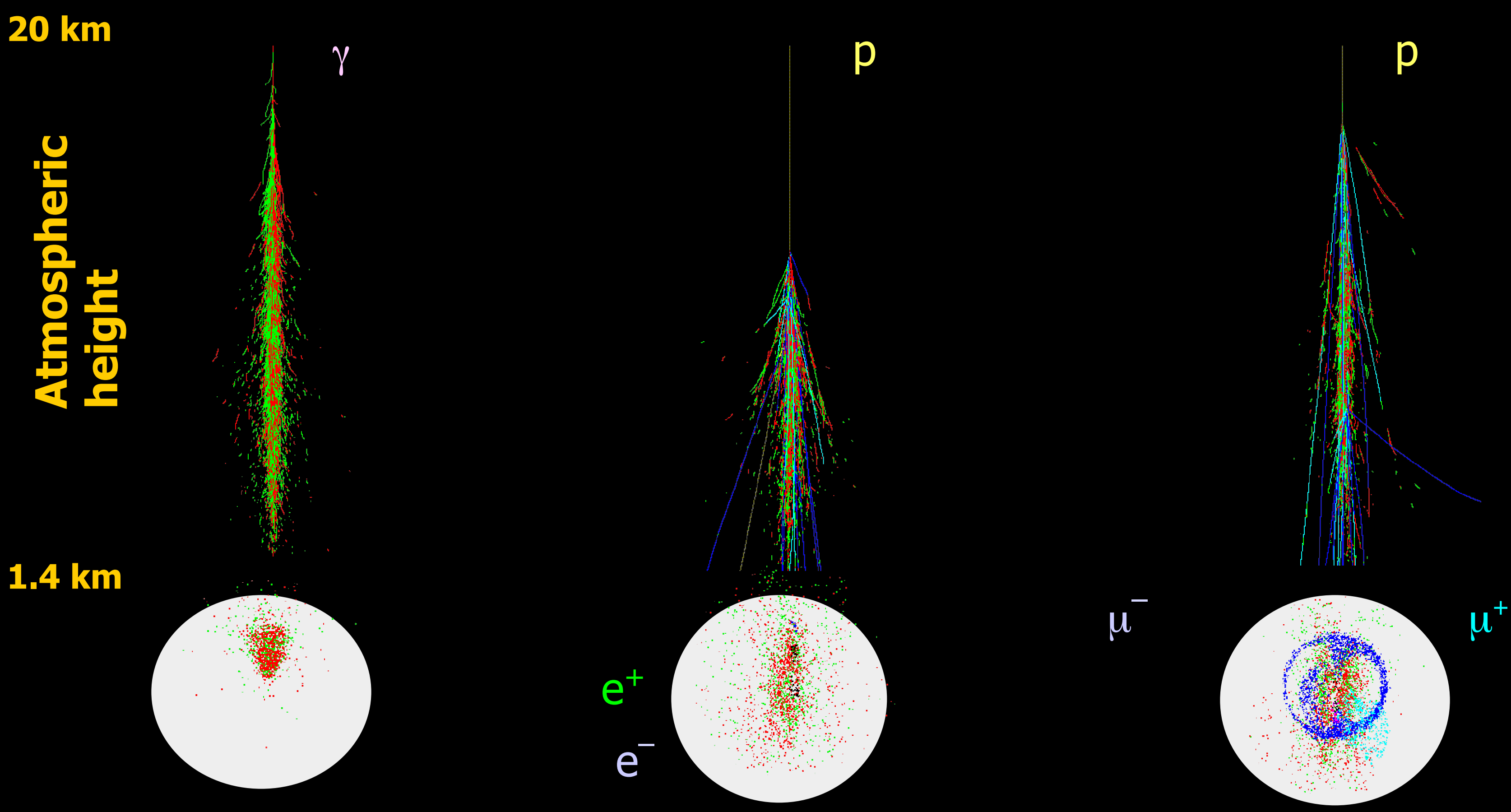
VHE sky c. 2011

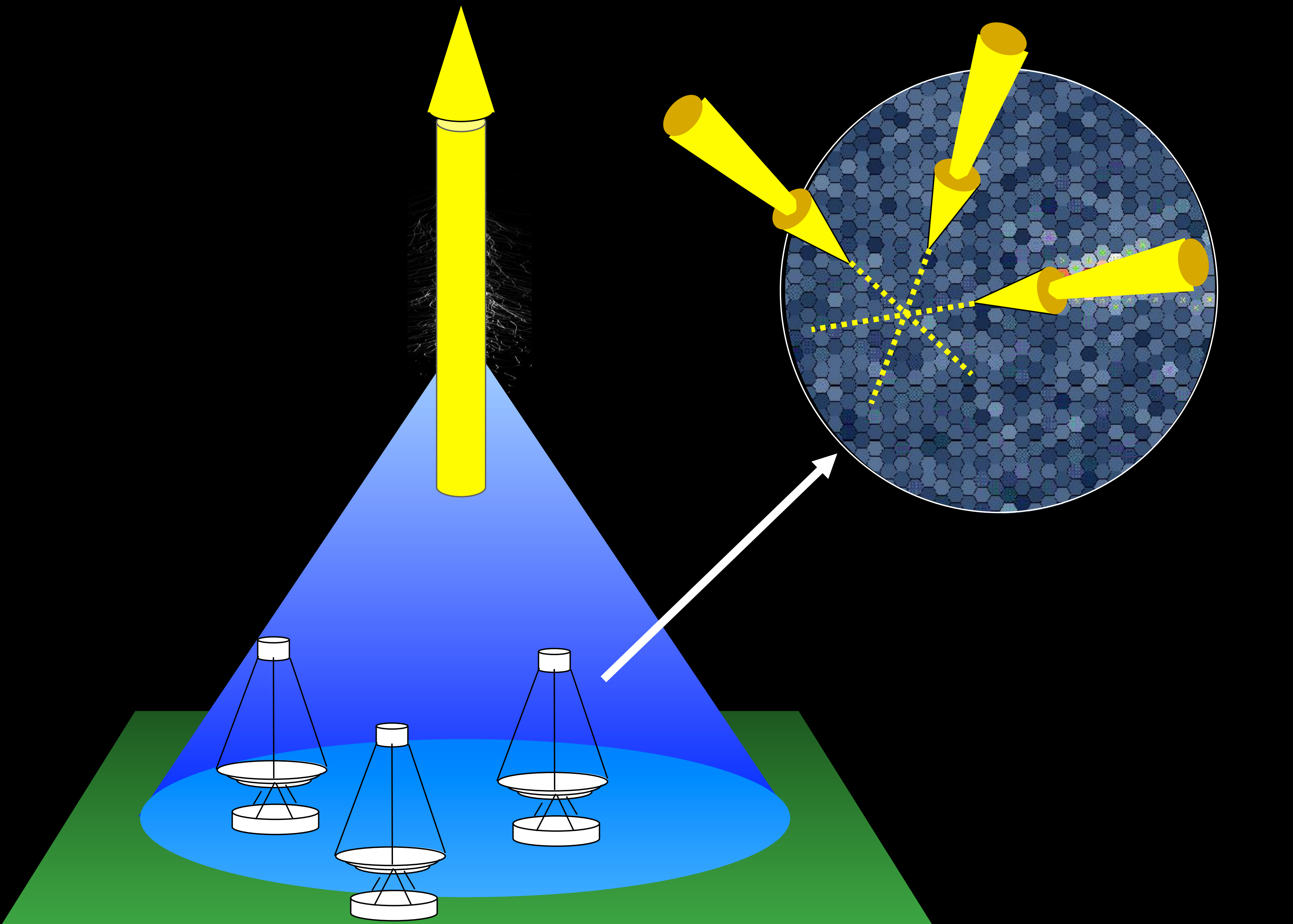


132 known Sources (doubled since 2007)
VERITAS has discovered a large fraction of the new VHE sources

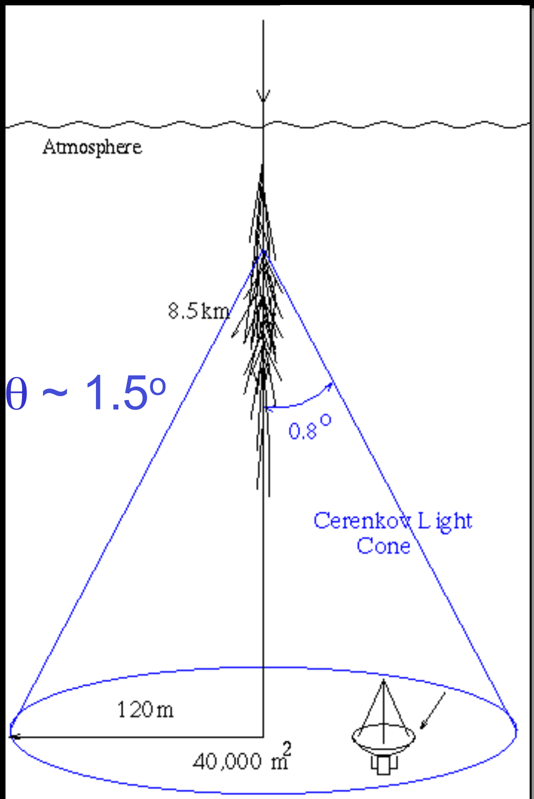
New Source discovery requires continually increasing VERITAS sensitivity
=> Reduction in threshold energy can allow access to new science

Cherenkov radiation images from atmospheric cascades



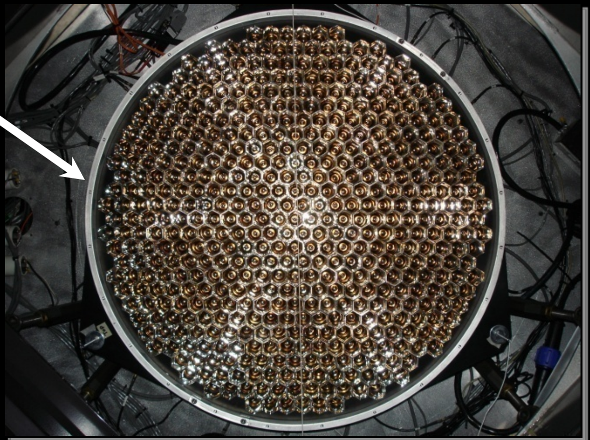


Ground Based Gamma-Ray Astronomy

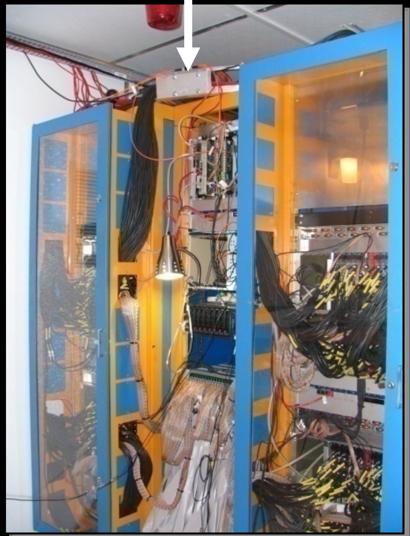


Gamma-Ray detection

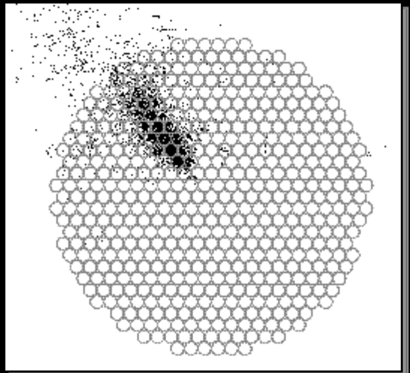
12 m dia. Mirror



499 pixel camera



500 Mhz FADC electronics

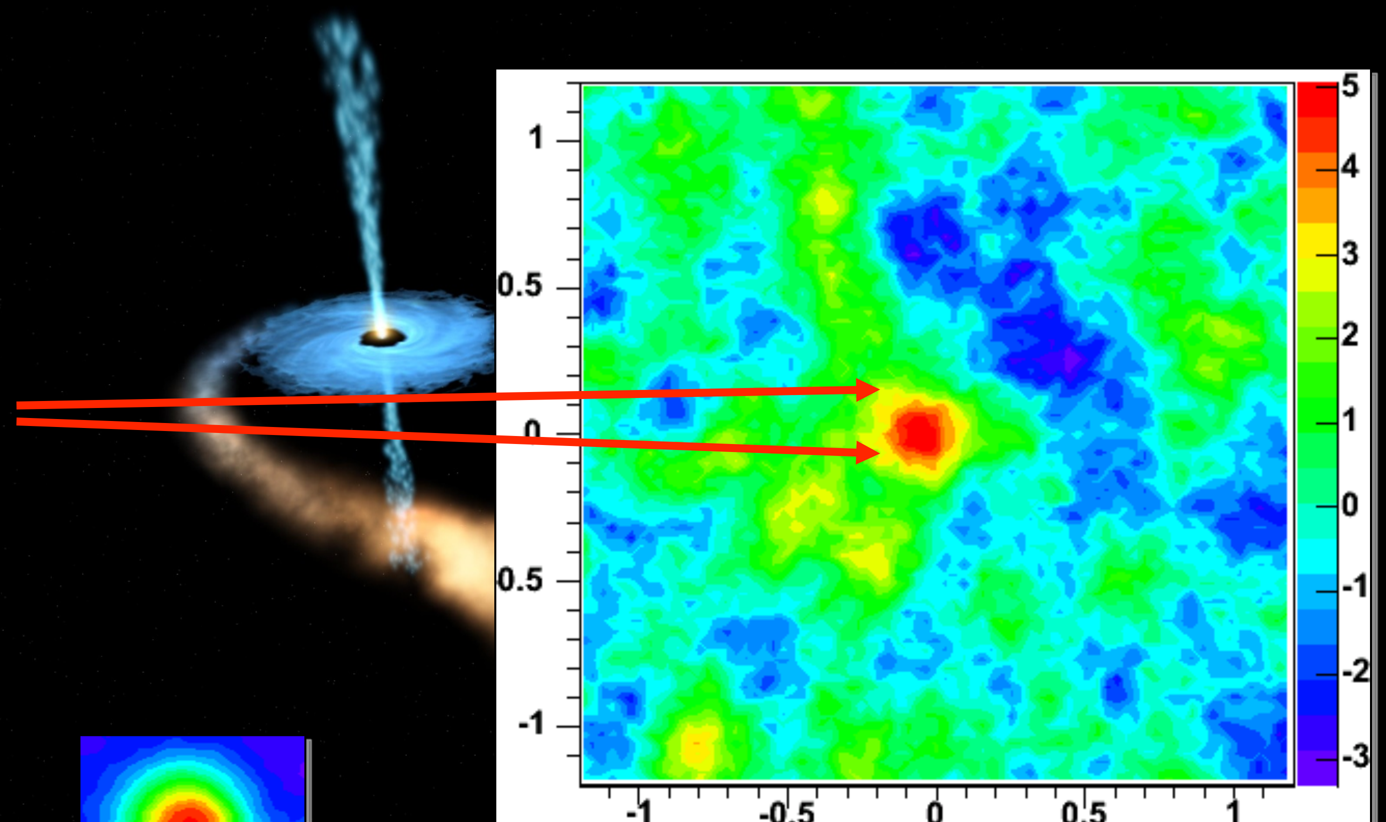


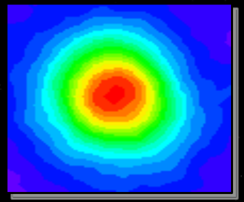
Gamma-Ray image

VERITAS Observatory

- ☞ Square Array of Four 12m Ø optical reflectors (Amado, AZ): D-C, 350 segments
- ☞ Detects Very High Energy (VHE) gamma-rays (10^{11}-10^{14} eV)
- ☞ World's most sensitive VHE gamma-ray observatory (1% std Crab, 5σ : 28 hrs)
- ☞ Fully operational since May 2007

Galactic Binary Systems

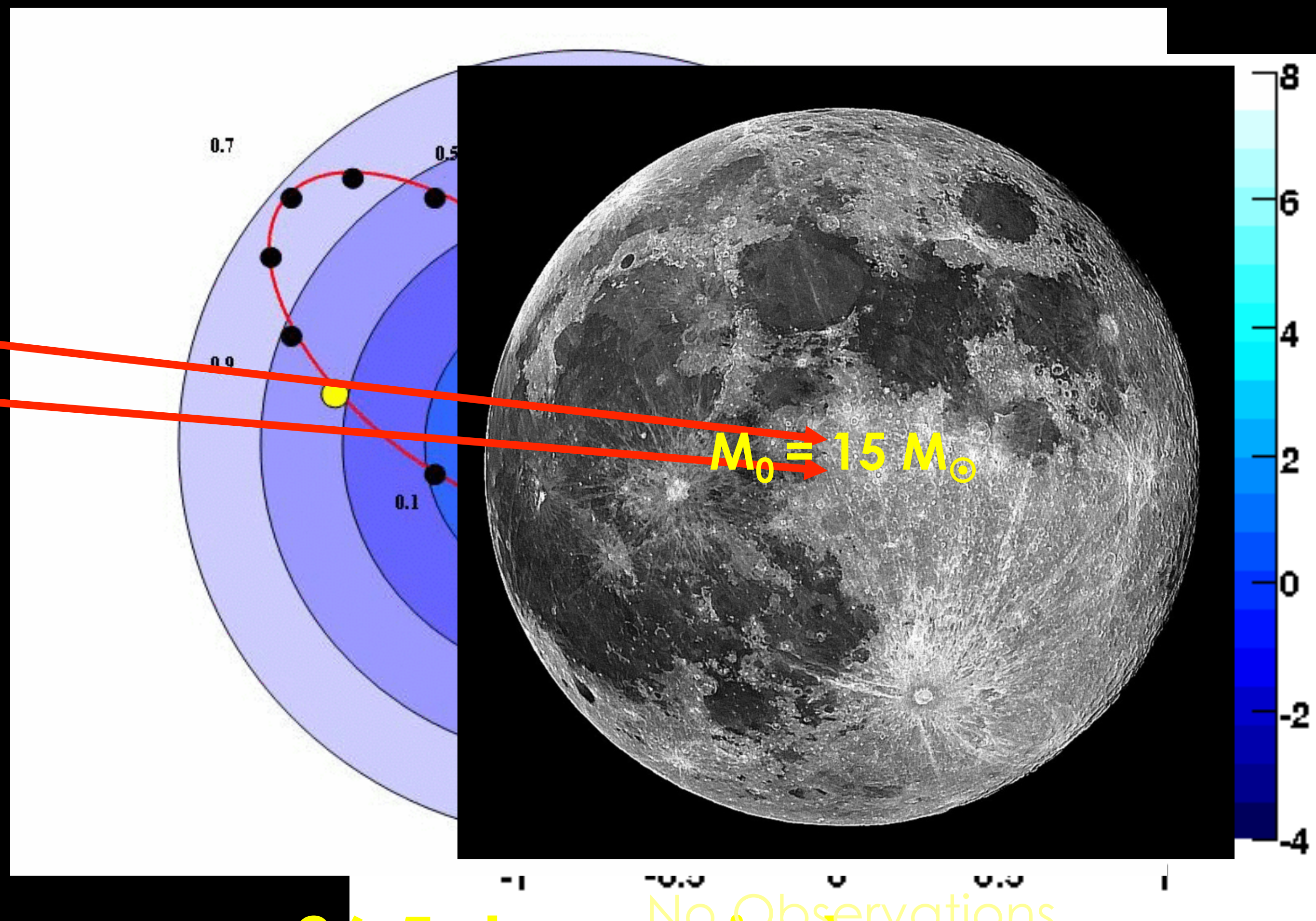




Crab Point source size

LSI 61+303
VERITAS:1 gamma-ray every 8 minutes

Compact Object /Massive Binary Companion



No Observations

26.5 day period

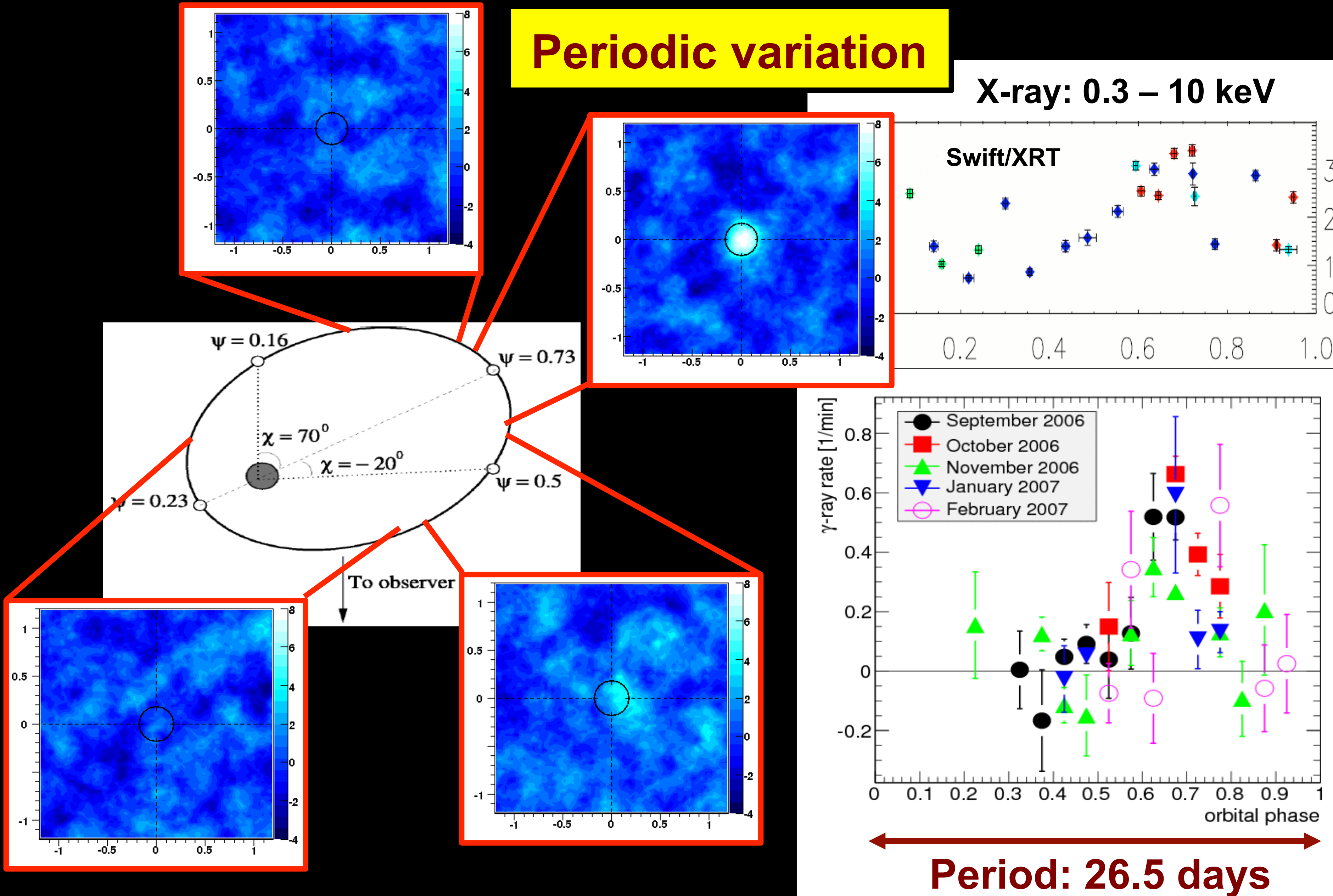
1< gamma-ray every 15 minutes

1 gamma-ray per **3** hours

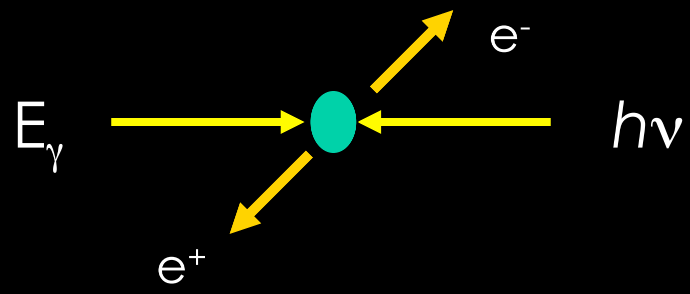
->Unambiguous Identification of Source

Variability of LSI 61+303

Periodic variation



γ-Photon Attenuation



Minimum (Threshold) Energy:

$h\nu$ =10^{15} Hz (optical): **$E_\gamma >$ 0.1 TeV**

$h\nu$ = 10^{14} Hz (IR) : **$E_\gamma >$ 1 TeV**

$$E\gamma \geq \frac{\left(2m_e c^2\right)^2}{h\nu}$$

Optical Depth: $$\tau_{\gamma\gamma} = \frac{1}{3}\sigma_T r n_0 \approx 200\left(L_0/10^{40}\,\mathrm{erg\,sec^{-1}}\right)\left(\nu/10^{13}\,\mathrm{Hz}\right)\left(r/R_g\right)^{-1}$$

Companion Star γ-ray Attenuation

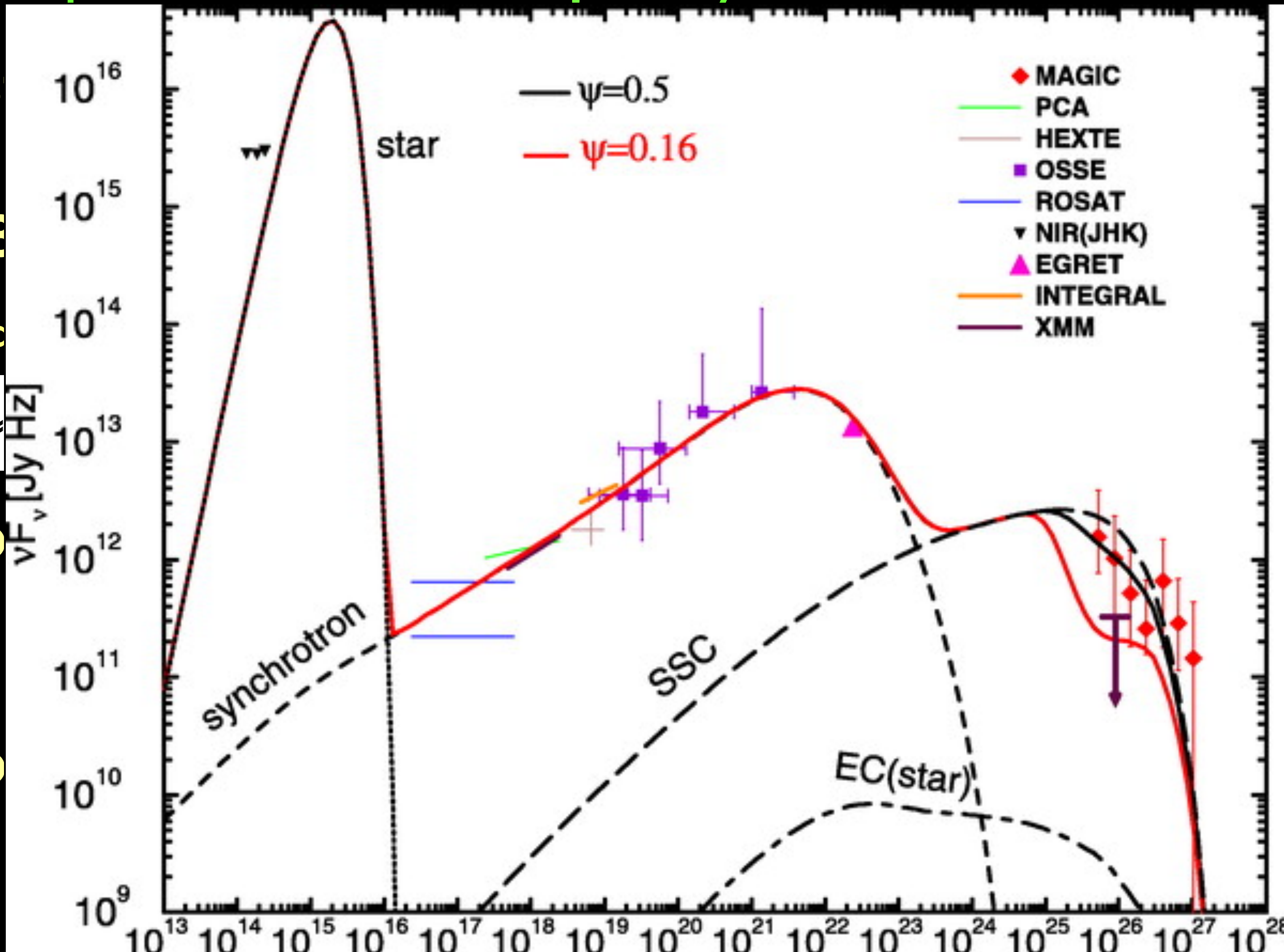
BE S

T=28
λ_{mc}

$\tau_{\gamma\gamma} \approx$

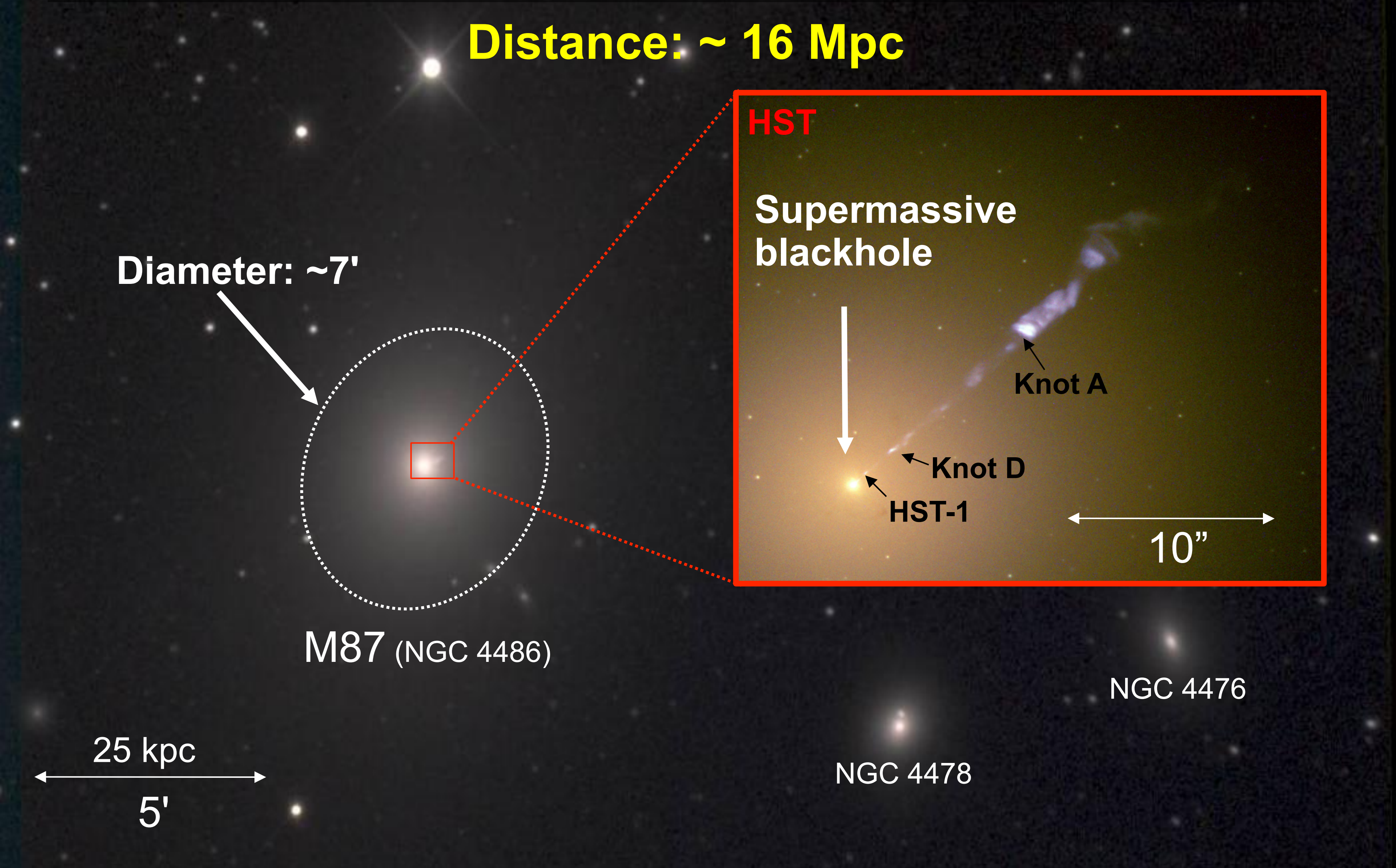
At p

At p

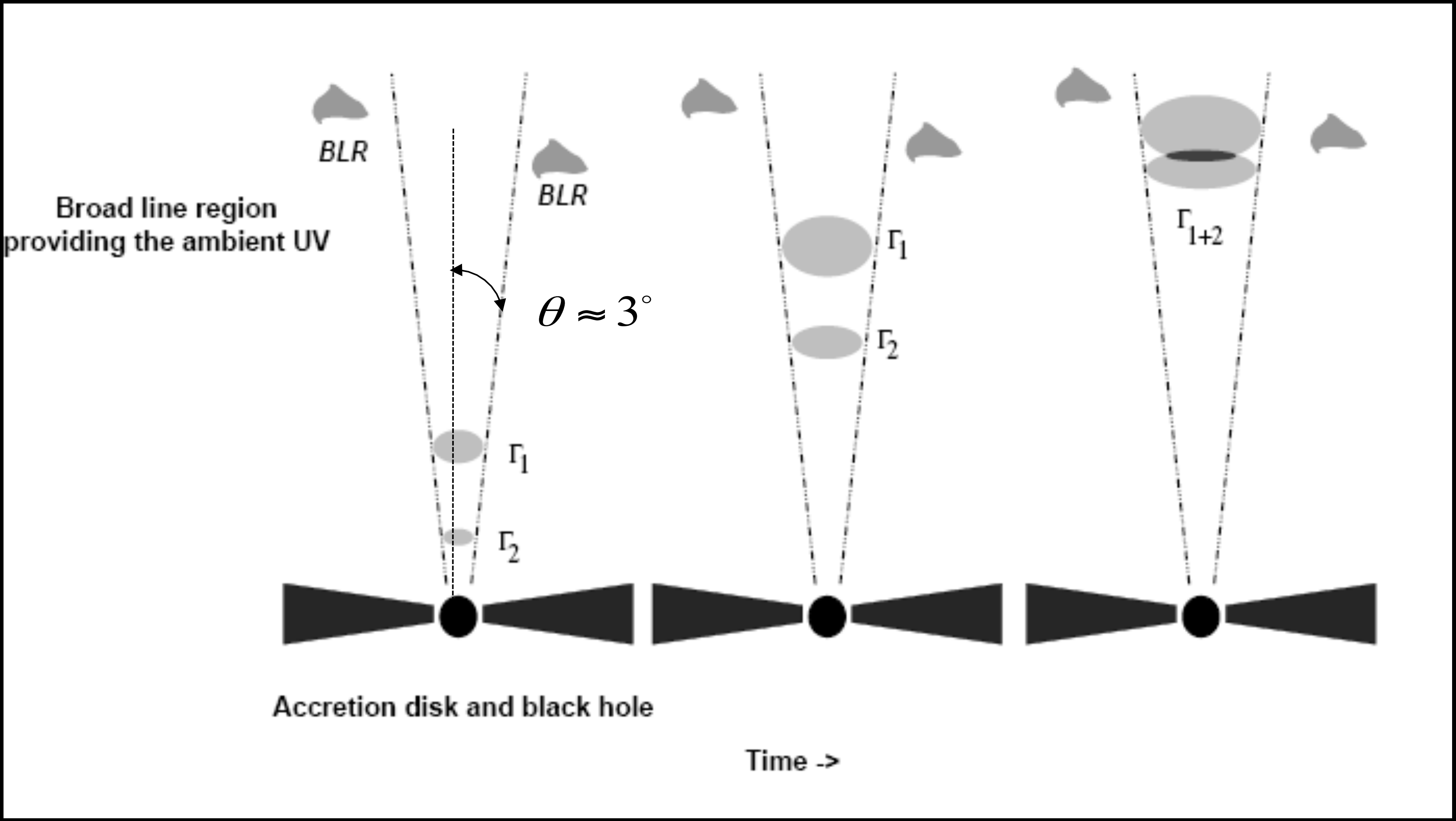


Gupta and Bottecher 2006

M87: Giant elliptical galaxy in the center of the VIRGO cluster



VHE Emission Mechanism



Typical : γ_{el}~10^3-10^6 ,B=1 G, Γ = 1/ θ =0.05

γ-IR Attenuation

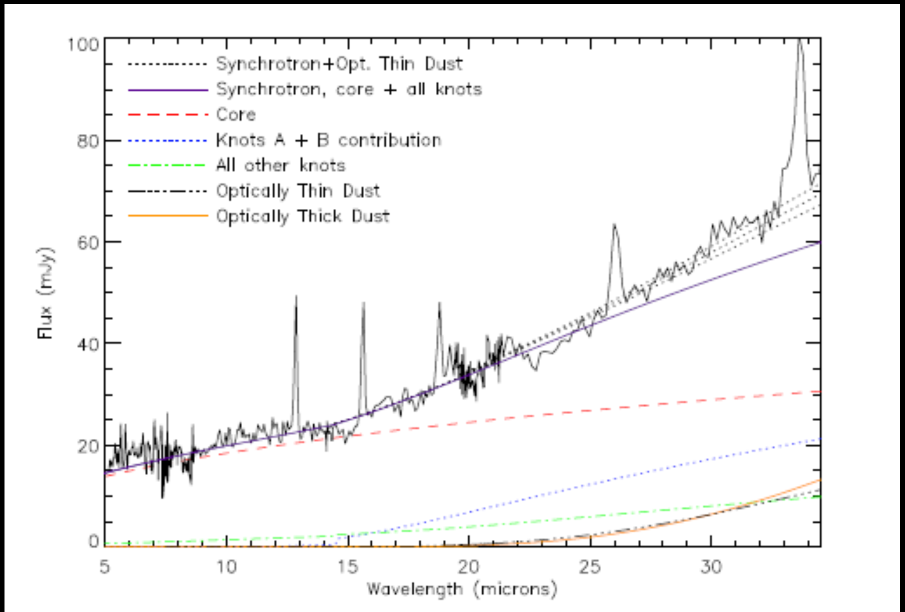
Optical Depth: $$\tau_{\gamma\gamma} \approx 200\left(L_0/10^{40}\,\mathrm{erg\,sec^{-1}}\right)\left(\nu/10^{13}\,\mathrm{Hz}\right)\left(r/R_g\right)^{-1}$$

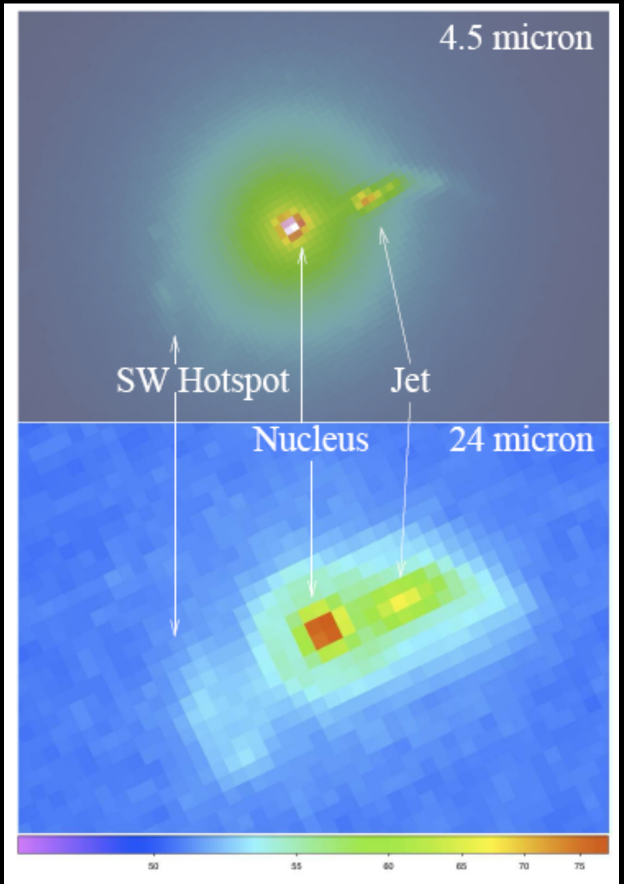
Cheung et al (2007): $L_0=3\text{x}10^{40}$ erg sec^{-1}

at $r=3\text{-}10R_g$ $\tau_{\gamma\gamma} >> 1$

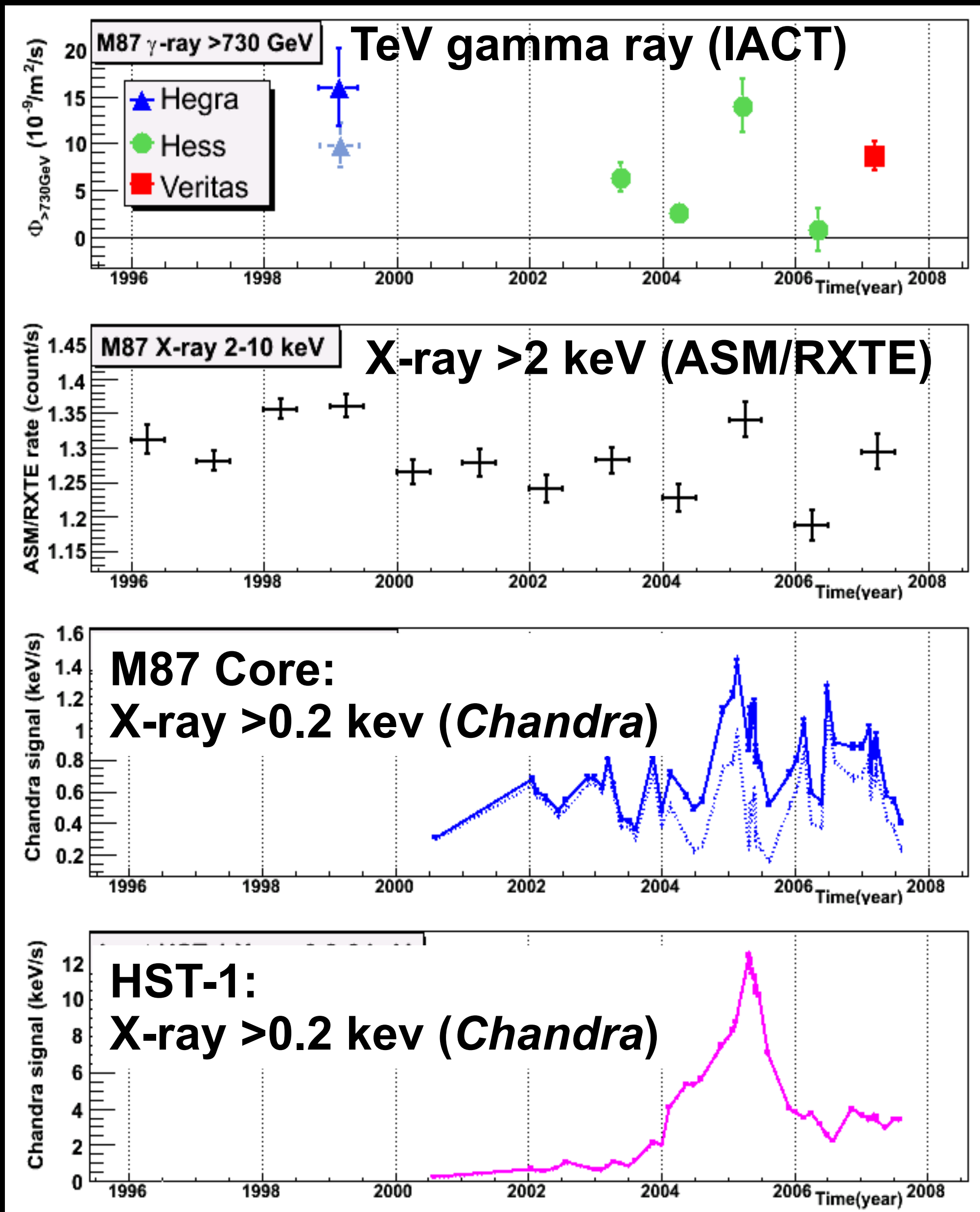
Spitzer IR (2008): $L_0= 1\text{x}10^{39}$ erg sec^{-1}

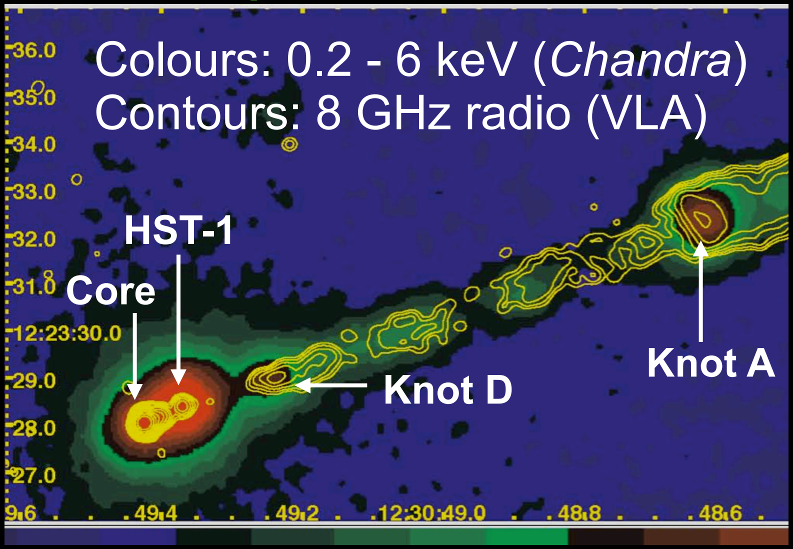
at $r=3\text{-}10R_g$ $\tau_{\gamma\gamma} << 1$





Correlation study with X-ray emission



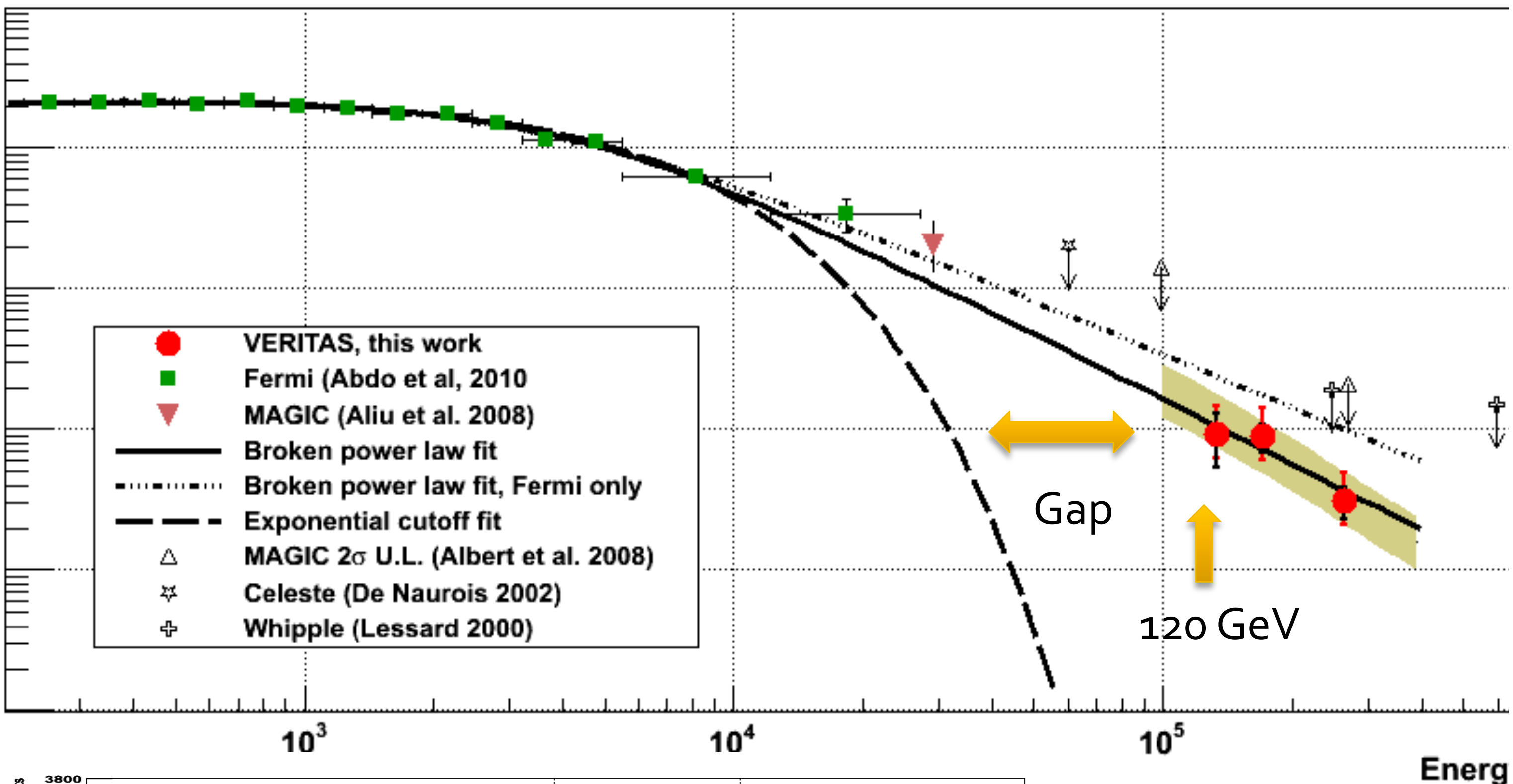


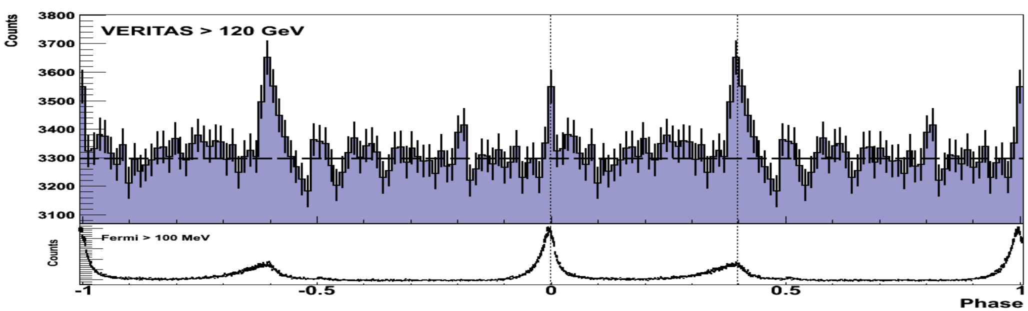
→ **Correlates well with ASM**

→ ***M87 Core: Perhaps?***

→ ***HST-1: Perhaps not…..***

Crab Pulsar 2011



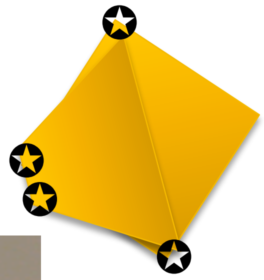


A. McCann, 2012 ICRC

Sensitivity < 100 GeV

can help connection to FERMI pulsars…

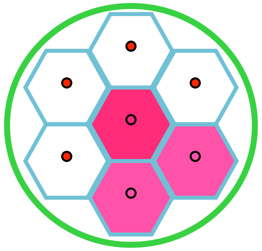
2009-2012 VERITAS Upgrade

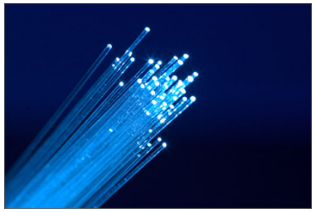


☆ Rearrange Telescopes to Better Geometry
(SAO, U. Utah + collaboration)

☆ Higher sensitivity Photomultiplier Tubes
(Purdue, U Delaware, U. Utah, Wash U, UCSC)

☆ Faster Pattern (Level 2) Trigger
(Iowa State U, Argonne NL)

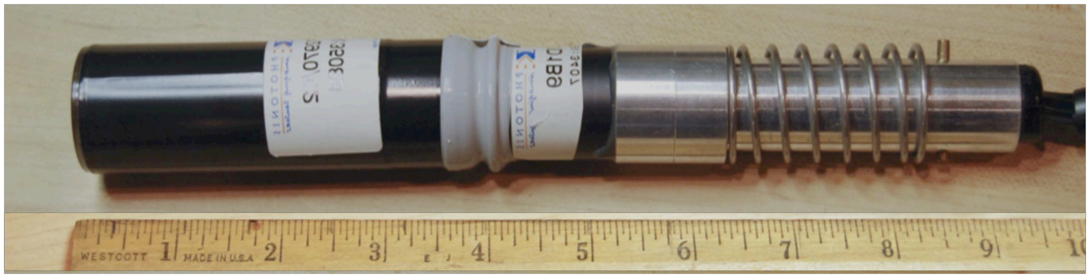




☆ Communication (Fiber Optic) Network Upgrade
(SAO, U. Utah)

2.1 M$ MRI-R2 funded project (National Science Foundation, University of Utah)
Main cost is the new photomultiplier tubes (1.2 M$)

Higher QE PMTs



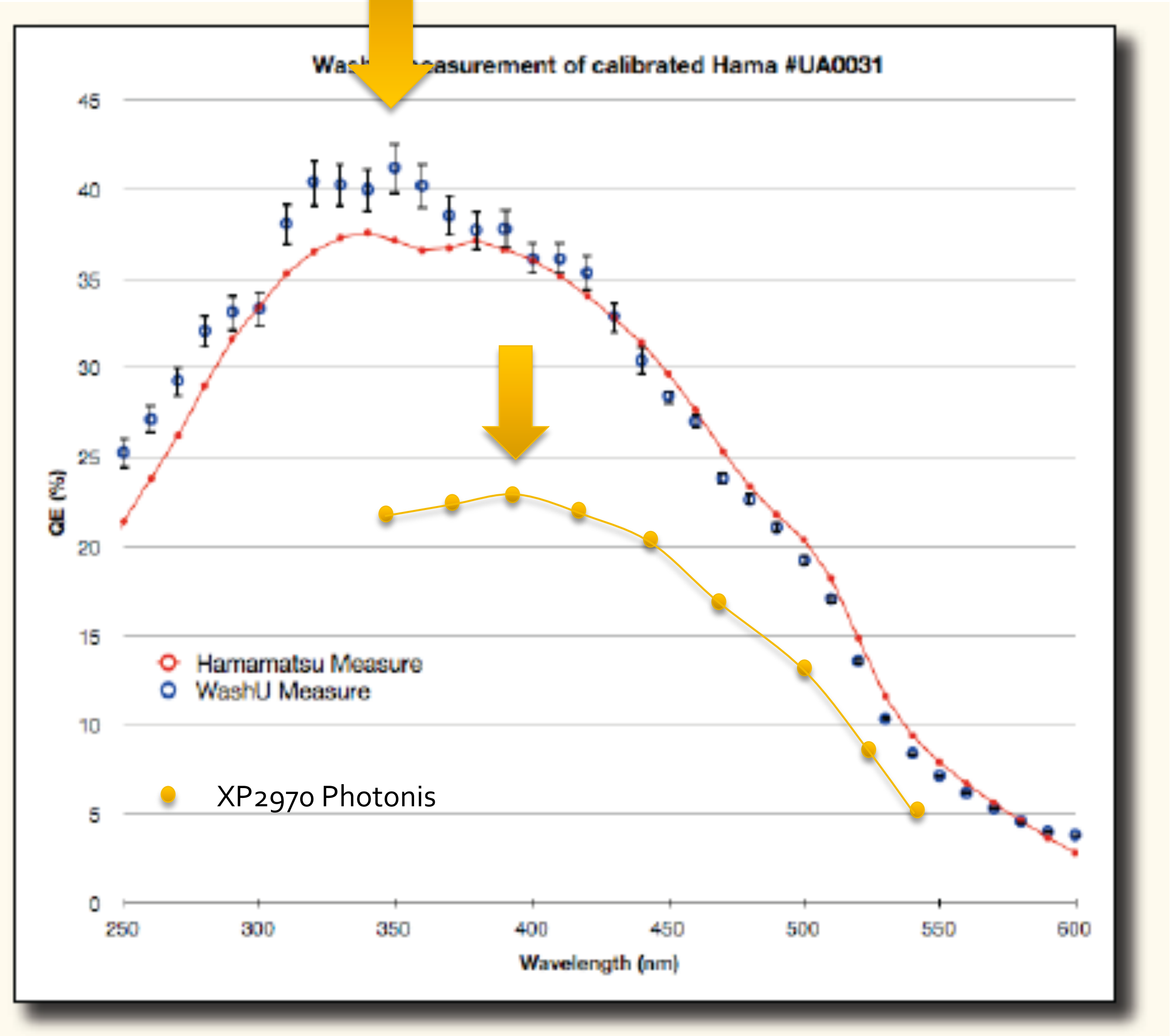
Current:
Photonis PMT
XP2970
~18-22% peak QE

New:
Hamamatsu PMT
R10560
~34-40% peak QE

$495 each (x 2200) = $1M

PMT Quantum Efficiency

Nepomuk Otte
2012 ICRC Talk

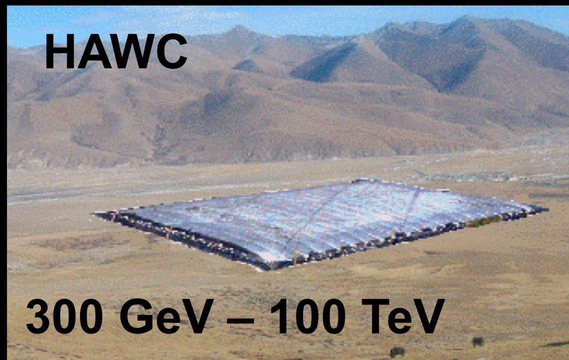


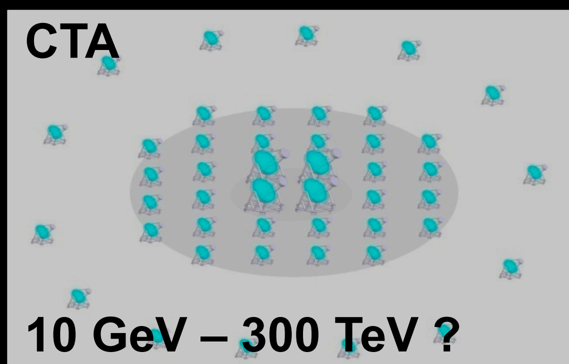
Long-term VHE Future

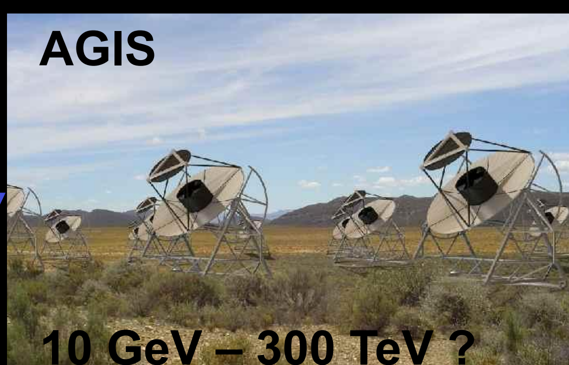
Should study 100s of sources !

2012

2015







> Need 2 kinds of instrument:

- Large FOV (sky monitoring)
- High resolution/γ statistics (deep study)

> Energy range extension

- At low energy (large mirrors)
- At high energy (sq km area)

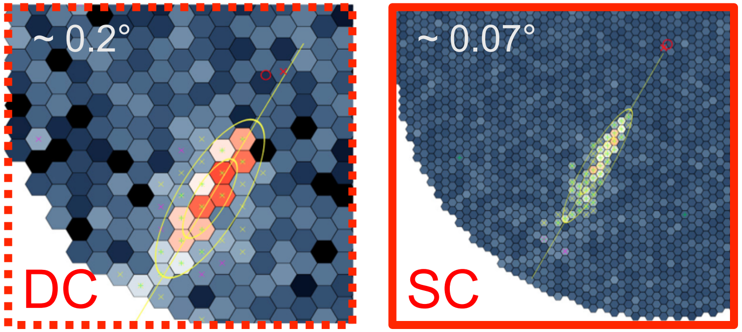
> Improved angular resolution

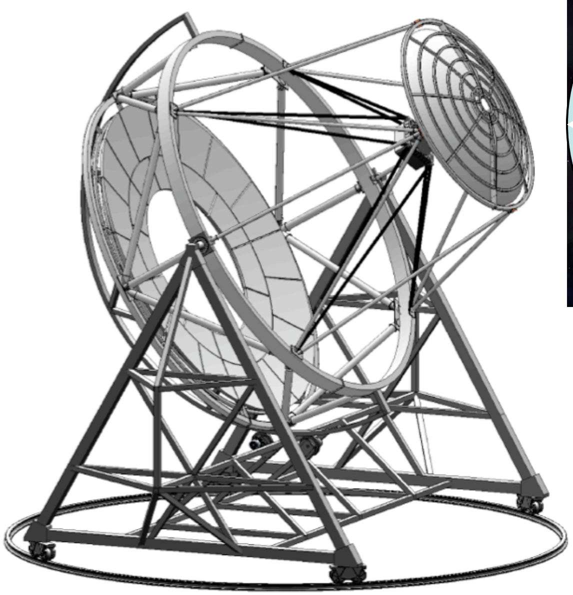
- Large telescope array
- Improved sensitivity

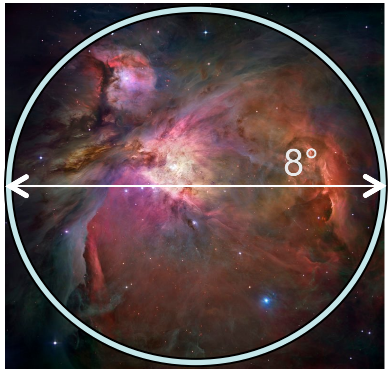
> Design Challenges

- Decreased Cost
- Increased reliability

High resolution SC-telescope

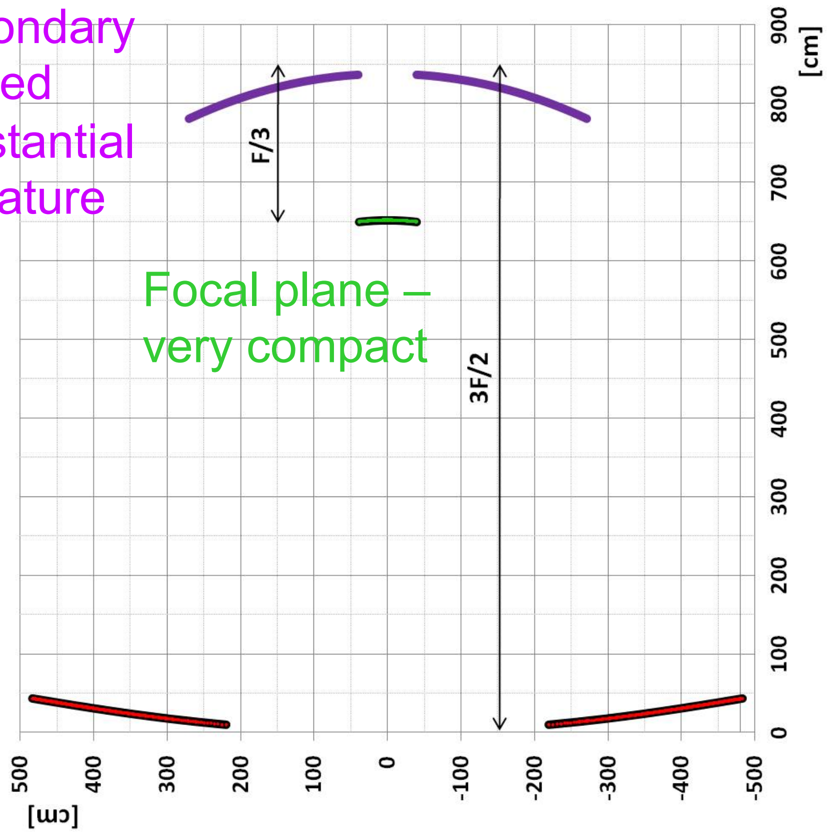






Secondary – need substantial curvature

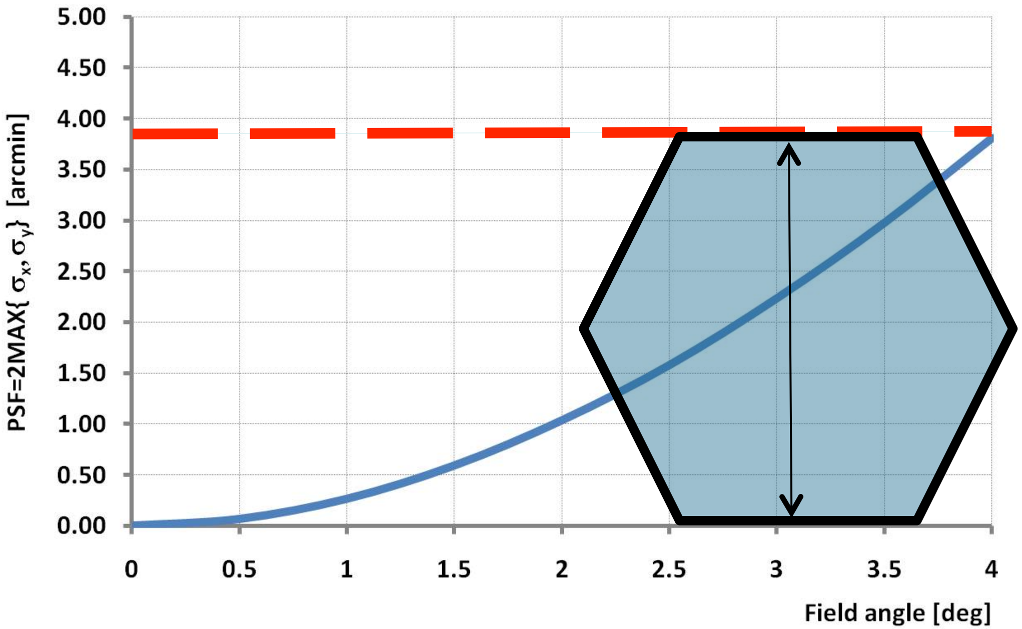
Focal plane – very compact



Primary – need low surface roughness

PSF Across Field of View

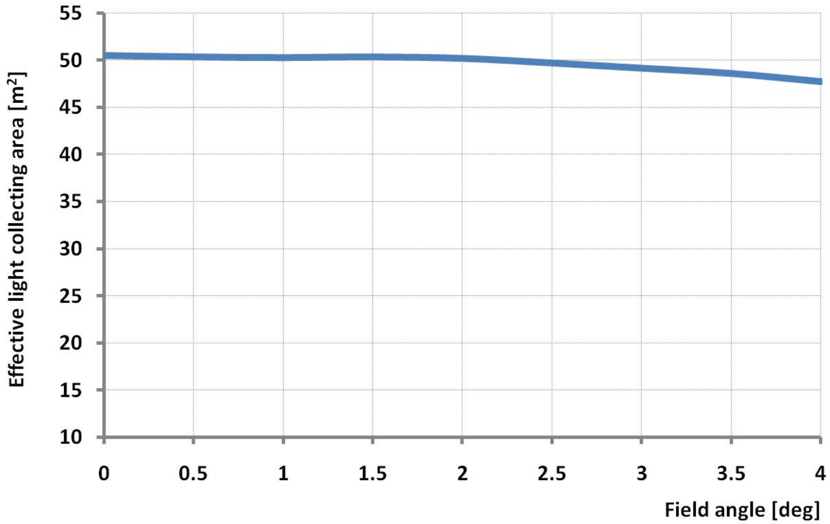
Parameter \ OS Name	OS8
Focal Length [m]	5.5863
Aperture [m]	9.66
f/# [1]	$f/0.5781$
Primary Radius max [m]	4.8319
Primary Radius min [m]	2.1933
Secondary Radius max [m]	2.7083
Secondary Radius min [m]	0.3945
Effective light collecting area /unvignetted [m^2]	50.33
Unvignetted Size [deg]	3.50
Effective light collecting area at FoV edge [m^2]	47.73
Vignetting at the FoV edge [%]	−5.17
Primary projected area [m^2]	58.23
Secondary projected area [m^2]	22.55
Design FoV [deg]	8.00
Design FoV solid angle [deg^2]	50.35
PSF at the FoV edge (2MAX{RMS}) [arcmin]	3.81



< 0.06° optical PSF across FoV

Light Collecting Area

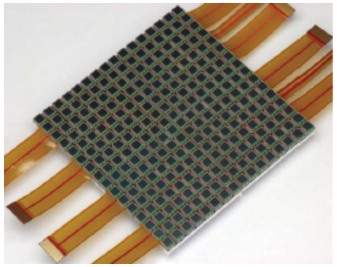
Effective Collection Area
vs Field Angle



Major goal of R&D program is to evaluate performance of this telescope w.r.t. 12 m DC (110 m^2)

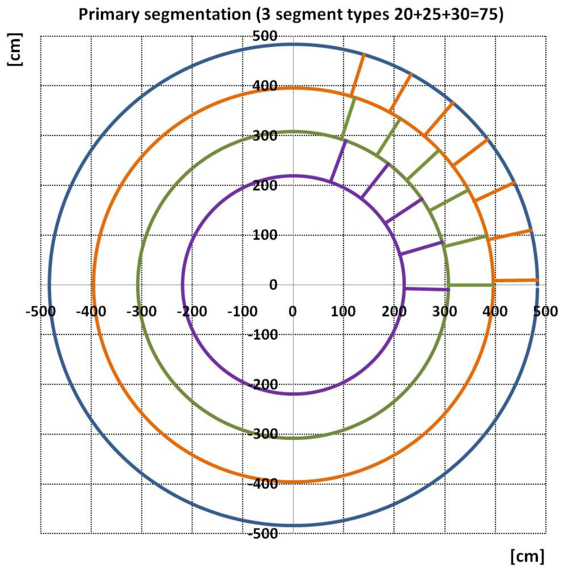
Other factors that affect the effective light collecting area:

MAPMTs



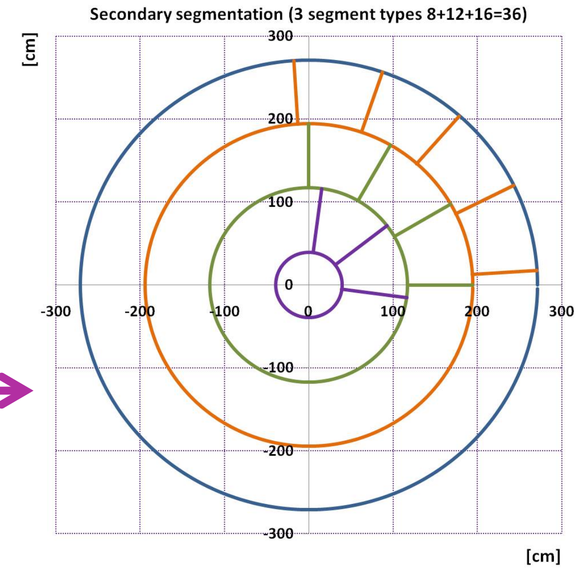
SiPMs

Ongoing R&D: Mirrors



Primary
Need excellent optical surface

Secondary
Need large curvature

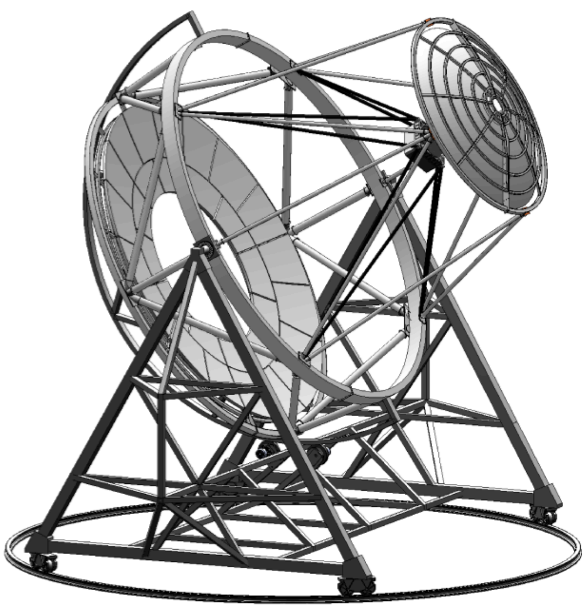


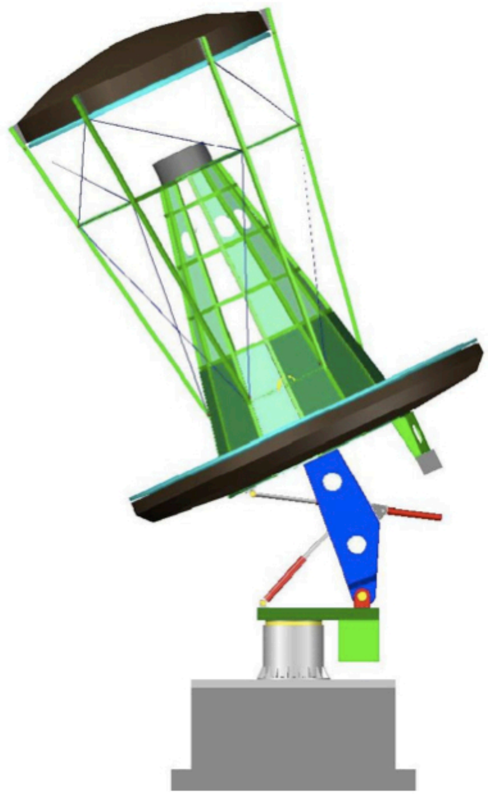
Several fabrication methods being explored:

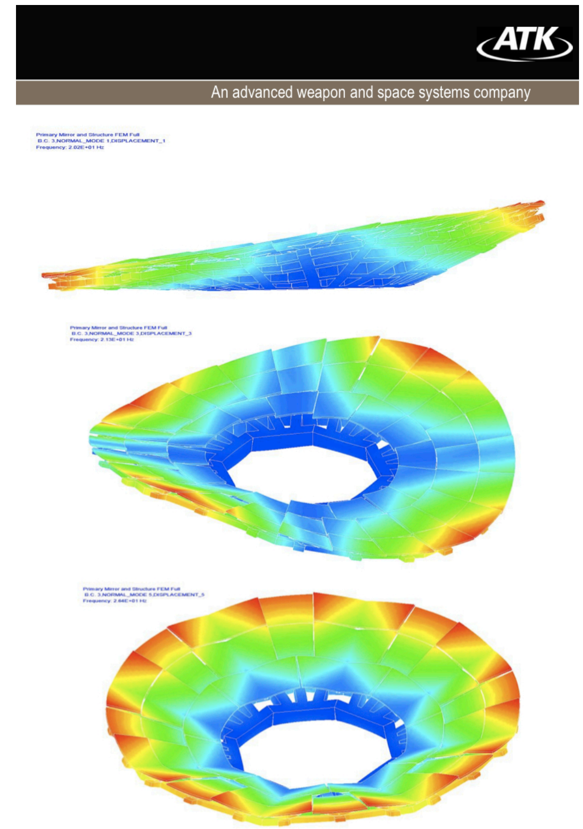
- Electroforming; Media Lario Technologies; UA Huntsville
- Composite laminates; ATK Space Systems
- Cold glass slumping (primary); similar to MAGIC-II
- Hot glass slumping (secondary); FLABEG GmbH

Ongoing R&D: Telescope

Argonne group will continue to lead and coordinate







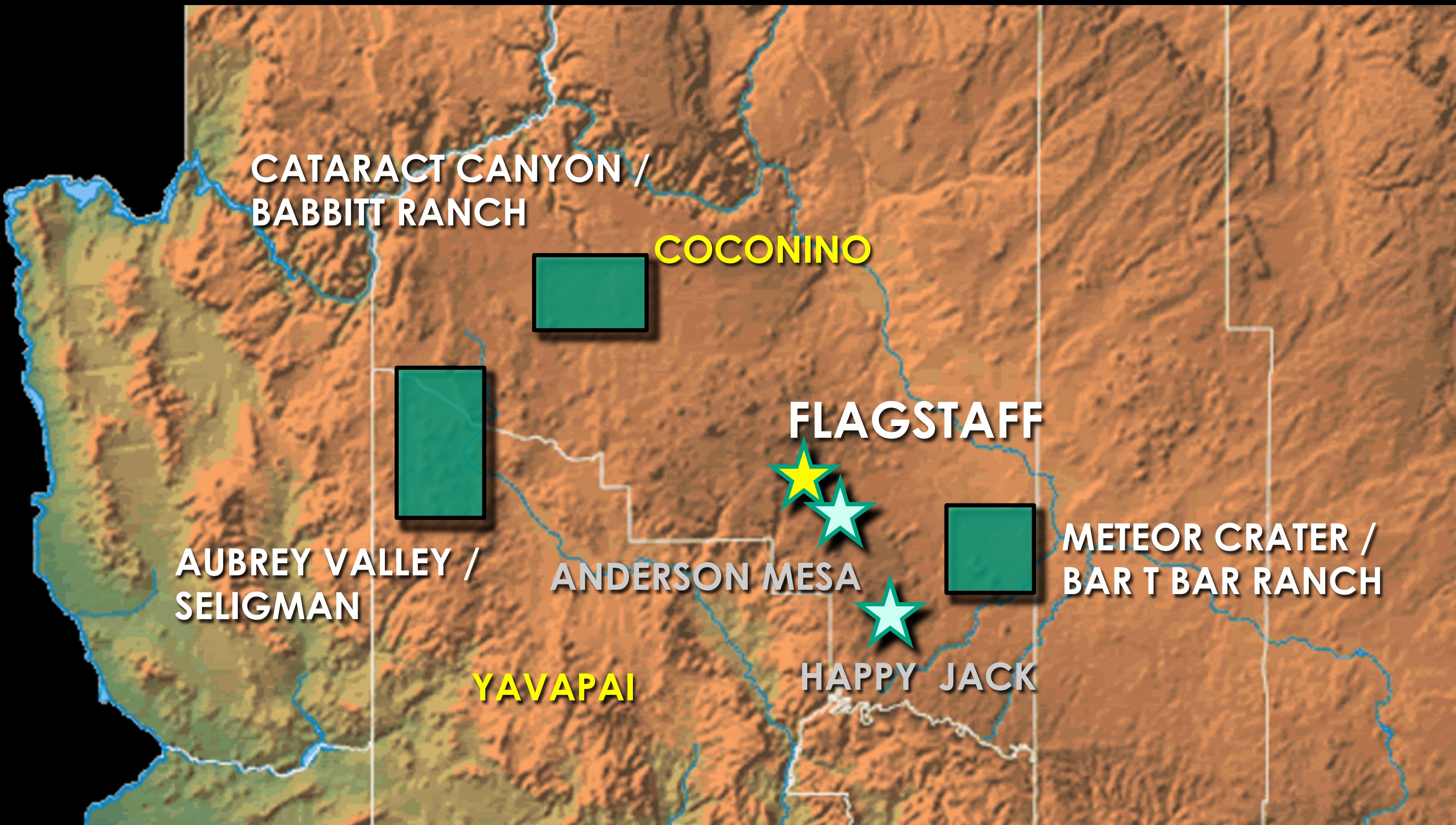
ATK PROPRIETARY – DO NOT DISCLOSE

Argonne

Krakow

ATK Space Systems

CTA Sites in Northern Arizona



Photos and Next Steps

Flat, dry, good roads, power, throughout

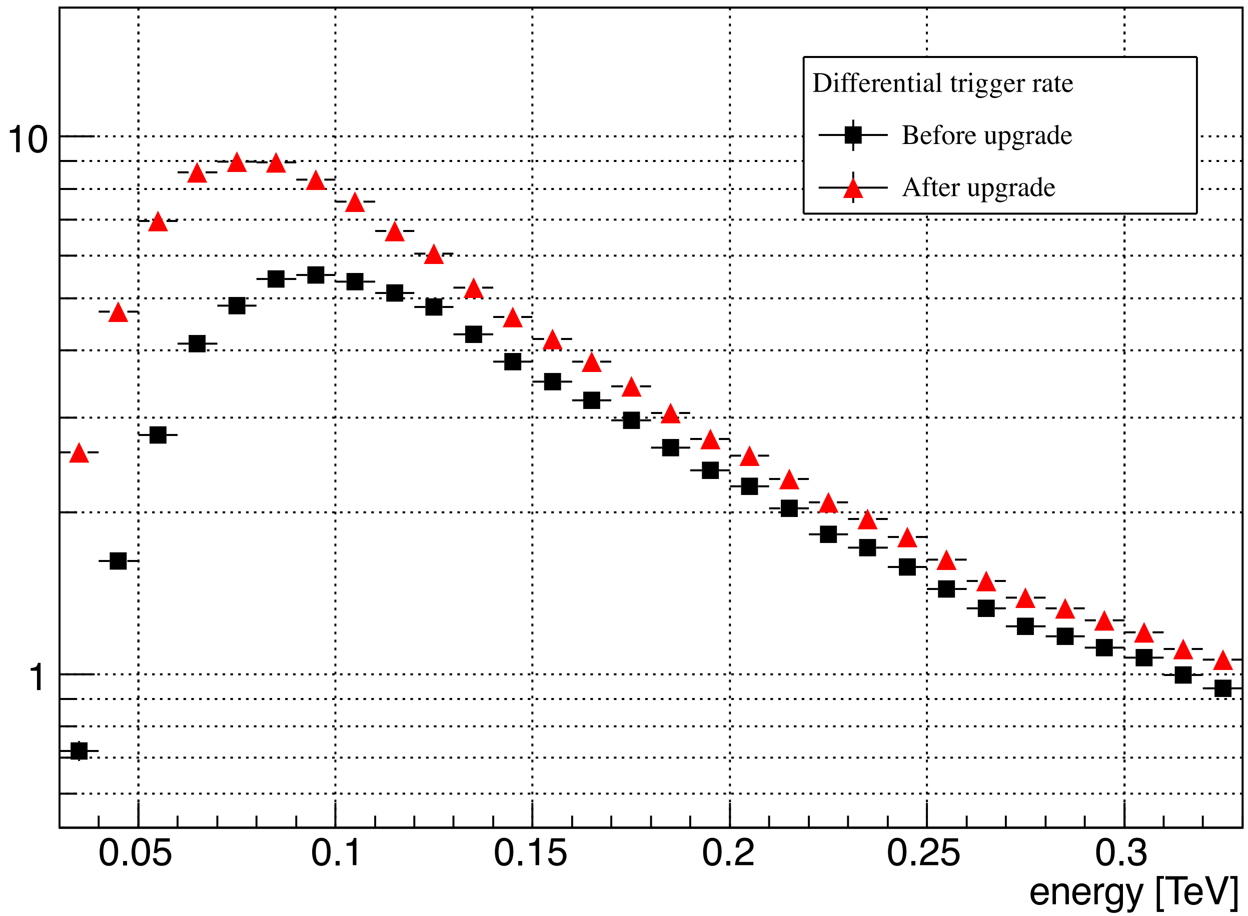
<u>Next steps:</u>

- *Work out relevant details with local land-owners for letters of intent on two locations.*
- *Finalize survey to complete matrix.*
- *Proposal for CTA N. site to be submitted by CTA-US & Lowell Obs.*
- *Visit to U.S. funding agencies to discuss site proposal (Jan 2012).*
- *Install ATMOSCOPE(s) as soon as possible.*
- *Visit to candidate sites by CTA management (Spring 2012?).*

Summary

- TeV Arrays: O(5) now; O(100) in 5 years
- Telescope Quality: imaging required
- Common OSS/positioner framework: desireable
- Reduce cost, increase reliability: Mass Production..
- Mirror technologies/production: Synergies?
- Northern AZ site: Synergies?
- SII is better match to imaging quality..Science is lower priority (currently)

Simulated Energy Spectrum



- Use $E^{-2.5}$ source spectrum
- Peak energy:
  95 GeV before upgrade
  70 GeV after upgrade
- Conservative estimate

RXTE Super-orbital modulation

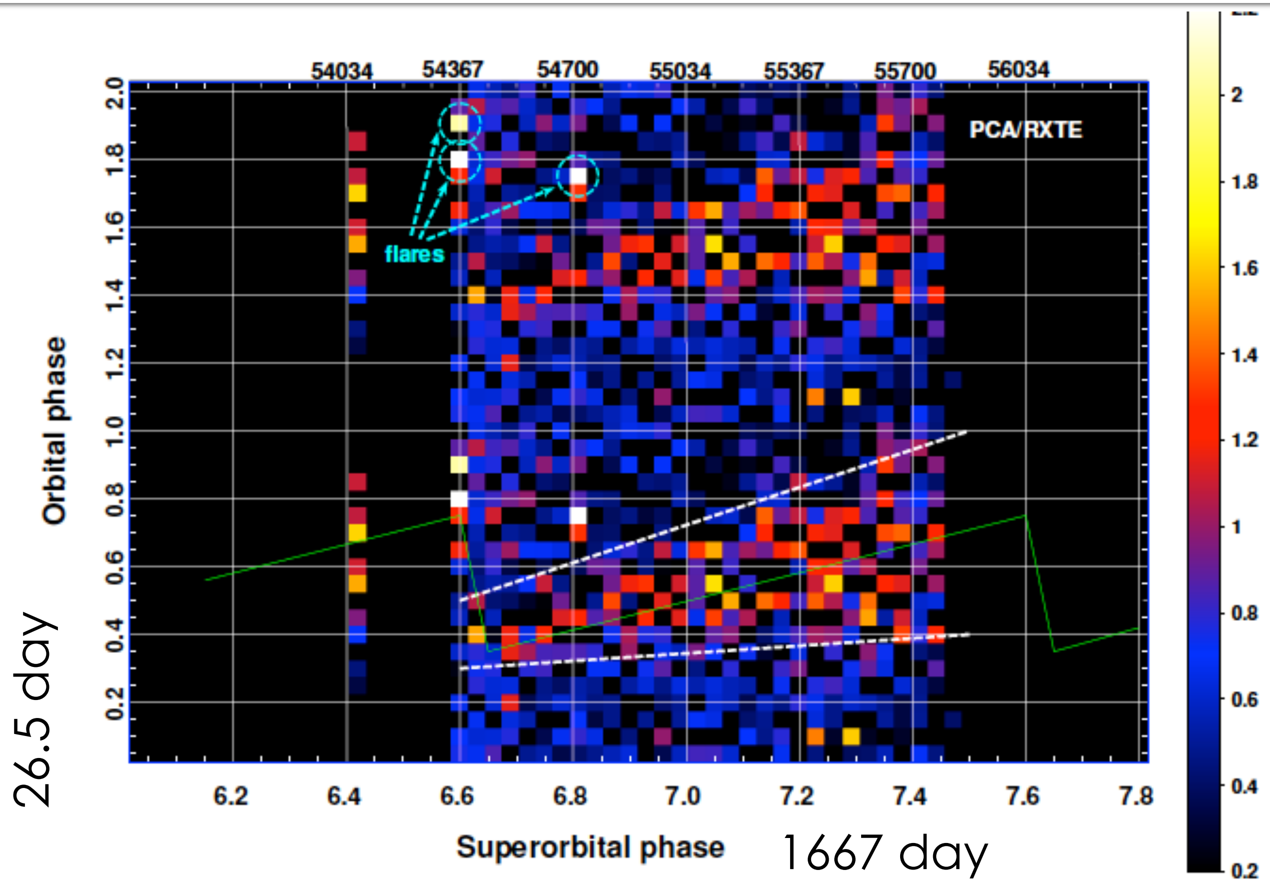


FIG. 1.— 3 – 20 keV flux from LSI +61 303 as a function of the orbital vs. superobital phase. The color scale is expressed in mCrab units.

X-ray emission
Advances
& broadens

Be disk effect?

Chernyakova et al 2012

Radio Super-orbital modulation

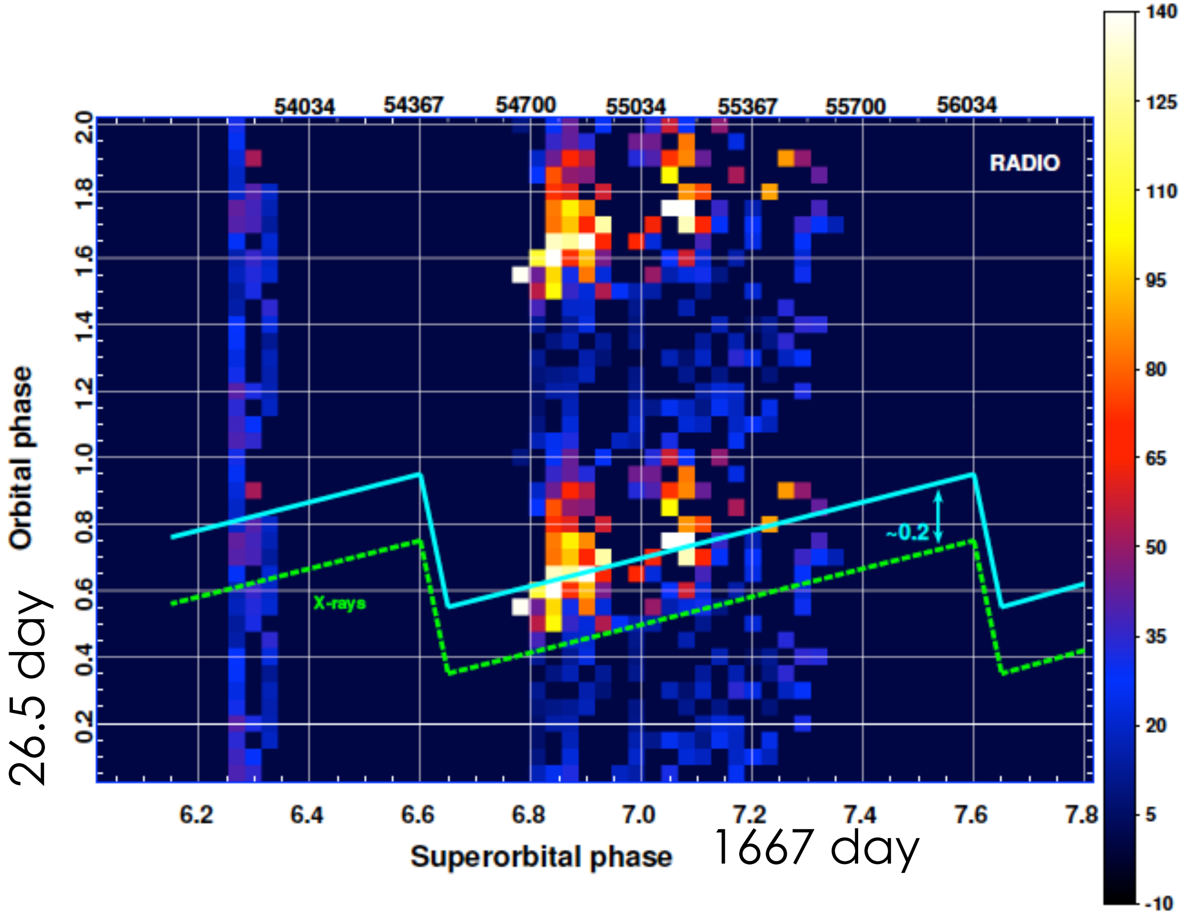


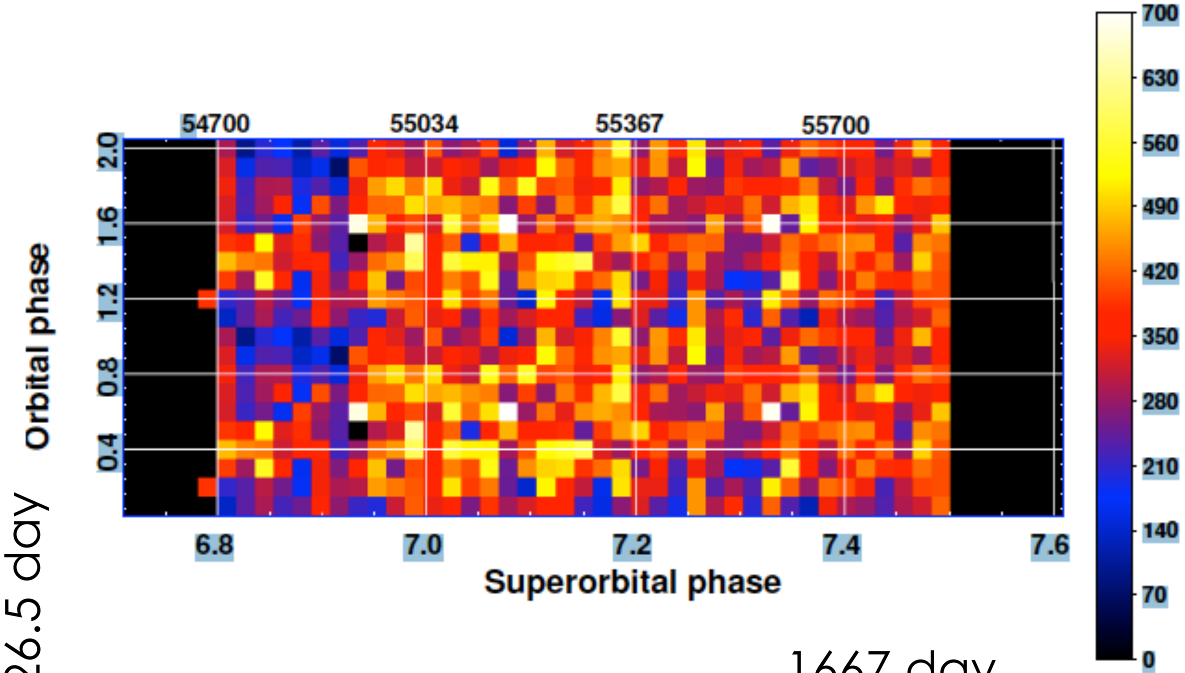
FIG. 3.— Radio flux from LSI +61 303 as a function of the orbital and superorbital phases. The color scale is expressed in mJy units.

0.2 orbital phase
Delay between
X-Ray to radio

- radio at larger emission radius
~ 10 x binary separation

Chernyakova et al 2012

FERMI Super-orbital modulation



26.5 day

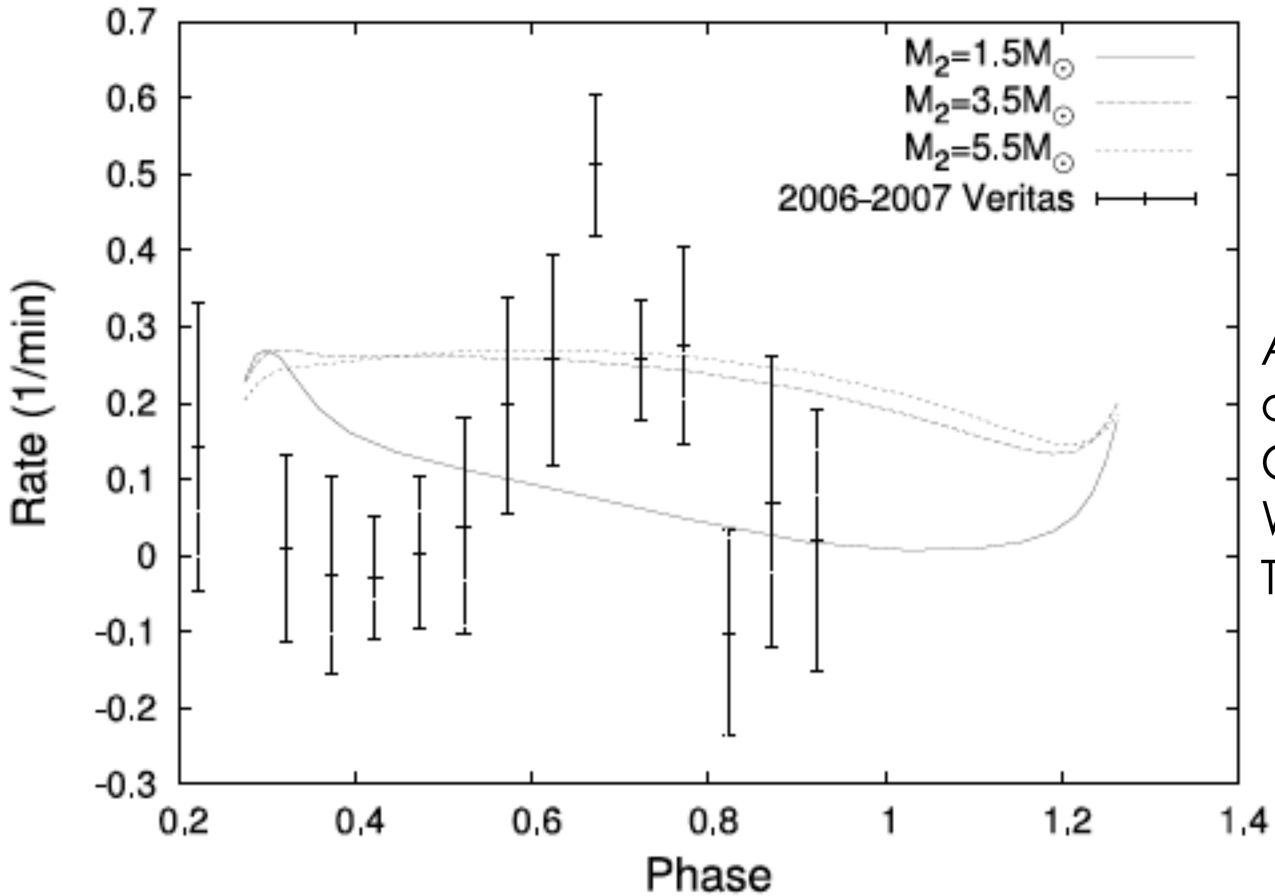
1667 day

- Advances with superorbital phase
- Disappaear after superorbital ~6.9
- Consistent with VERITAS observations

FIG. 4.— Very high energy (E>100 MeV) flux from LSI +61 303 as a function of the orbital and superorbital phases. The color scale is expressed in mCrab units.

Chernyakova et al 2012

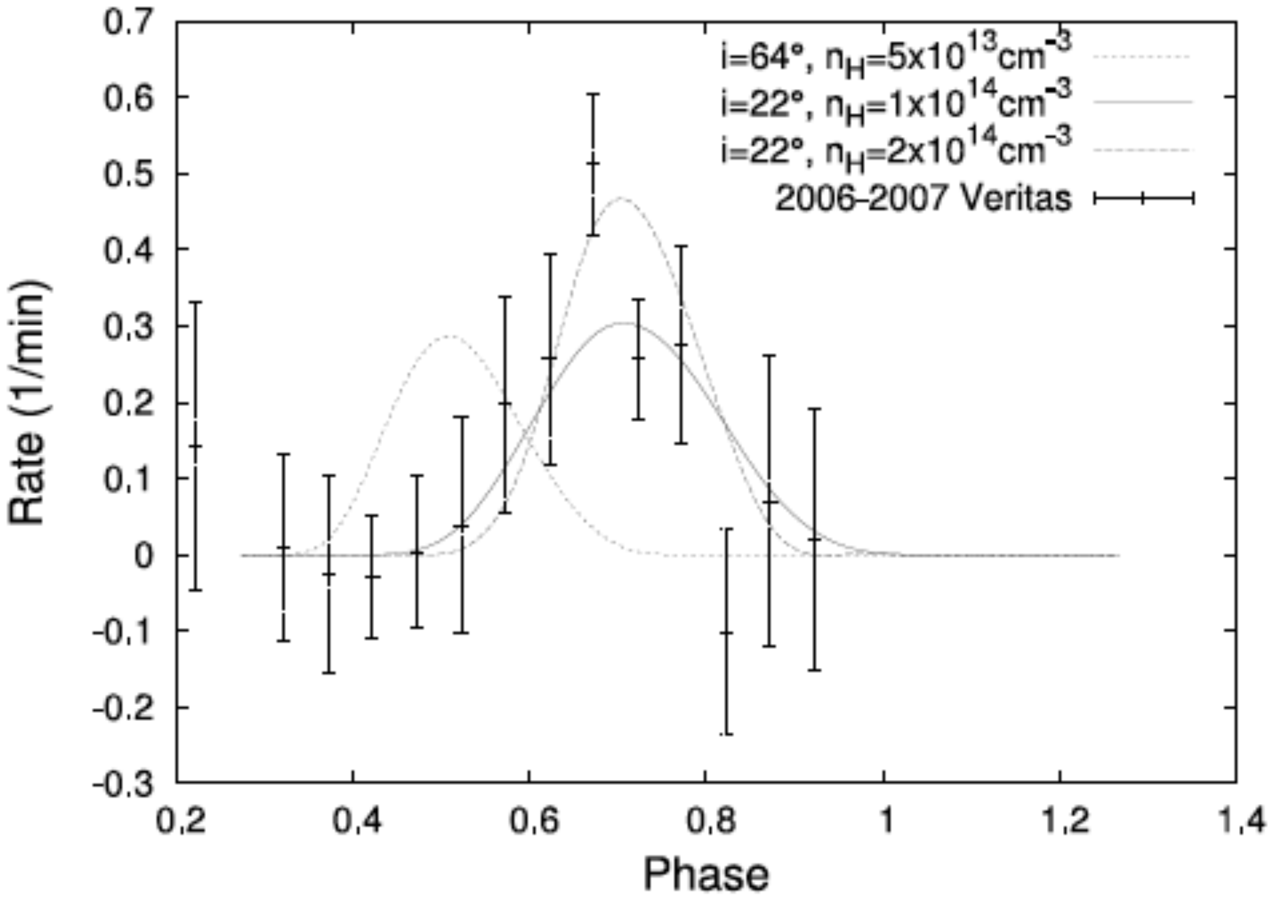
γ-γ Attenuation only



Angular dependence
of pair production
Cross section
Works against
This idea…

Nunez et al 2011

γ-γ Attenuation & n_h density



$\rho \sim 1/r^q$

q=2.3-3.

But N_h is

$\gg N_H$ from X-ray

(Time variable?)

Nunez et al 2011