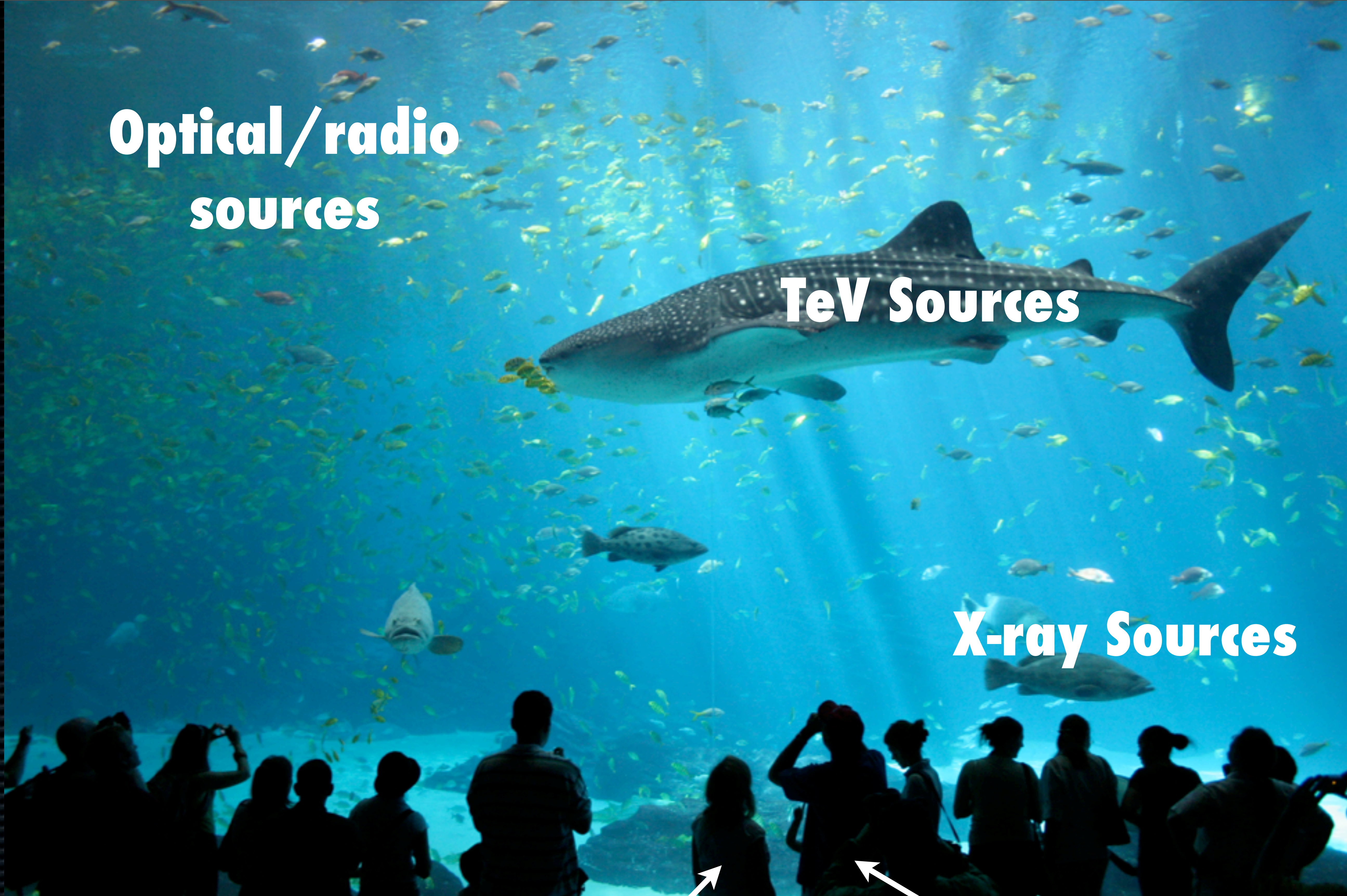
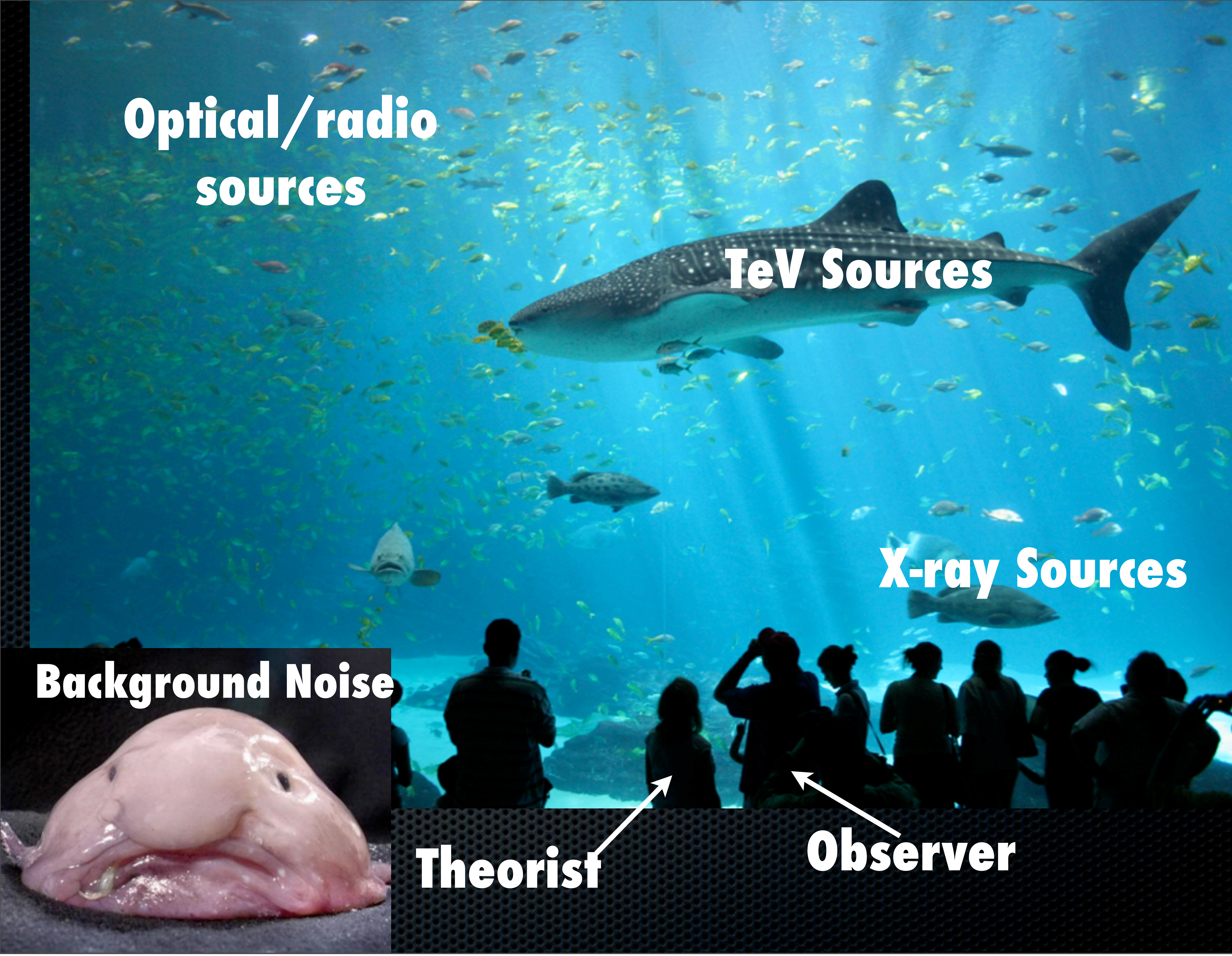
Highlights From The VERITAS TeV Gamma-ray Observatory

Andrew W. Smith
University of Utah

TeV Astronomy?


Optical/radio
sources
TeV Sources
X-ray Sources
Theorist
Observer


Optical/radio sources
TeV Sources
X-ray Sources
Background Noise
Theorist
Observer

What can you do with TeV astronomy?

Sources are rare! Interesting on their own, also yield key information about legacy problems in (astro)physics due to the phenomenal energy requirements for production:

-Cosmic Ray origins

-Particle Dark Matter

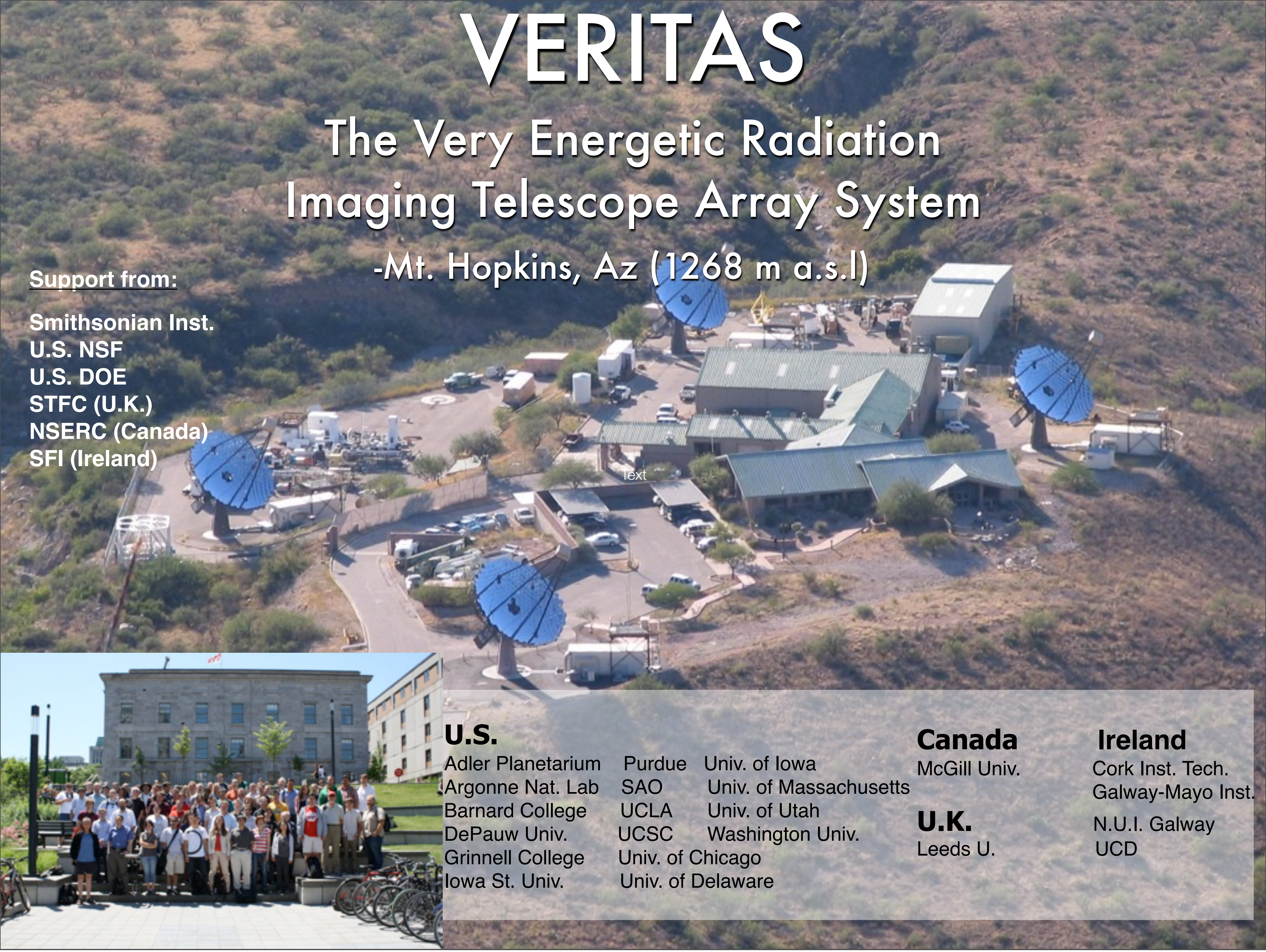
-Relativistic Acceleration Mechanisms (leptonic? hadronic?)

-Accretion (BH), shock physics

VERITAS

The Very Energetic Radiation Imaging Telescope Array System

-Mt. Hopkins, Az (1268 m a.s.l)



Support from:

Smithsonian Inst.
U.S. NSF
U.S. DOE
STFC (U.K.)
NSERC (Canada)
SFI (Ireland)

U.S.

Adler Planetarium
Argonne Nat. Lab
Barnard College
DePauw Univ.
Grinnell College
Iowa St. Univ.
Purdue
SAO
UCLA
UCSC
Univ. of Chicago
Univ. of Delaware
Univ. of Iowa
Univ. of Massachusetts
Univ. of Utah
Washington Univ.

Canada

McGill Univ.

U.K.

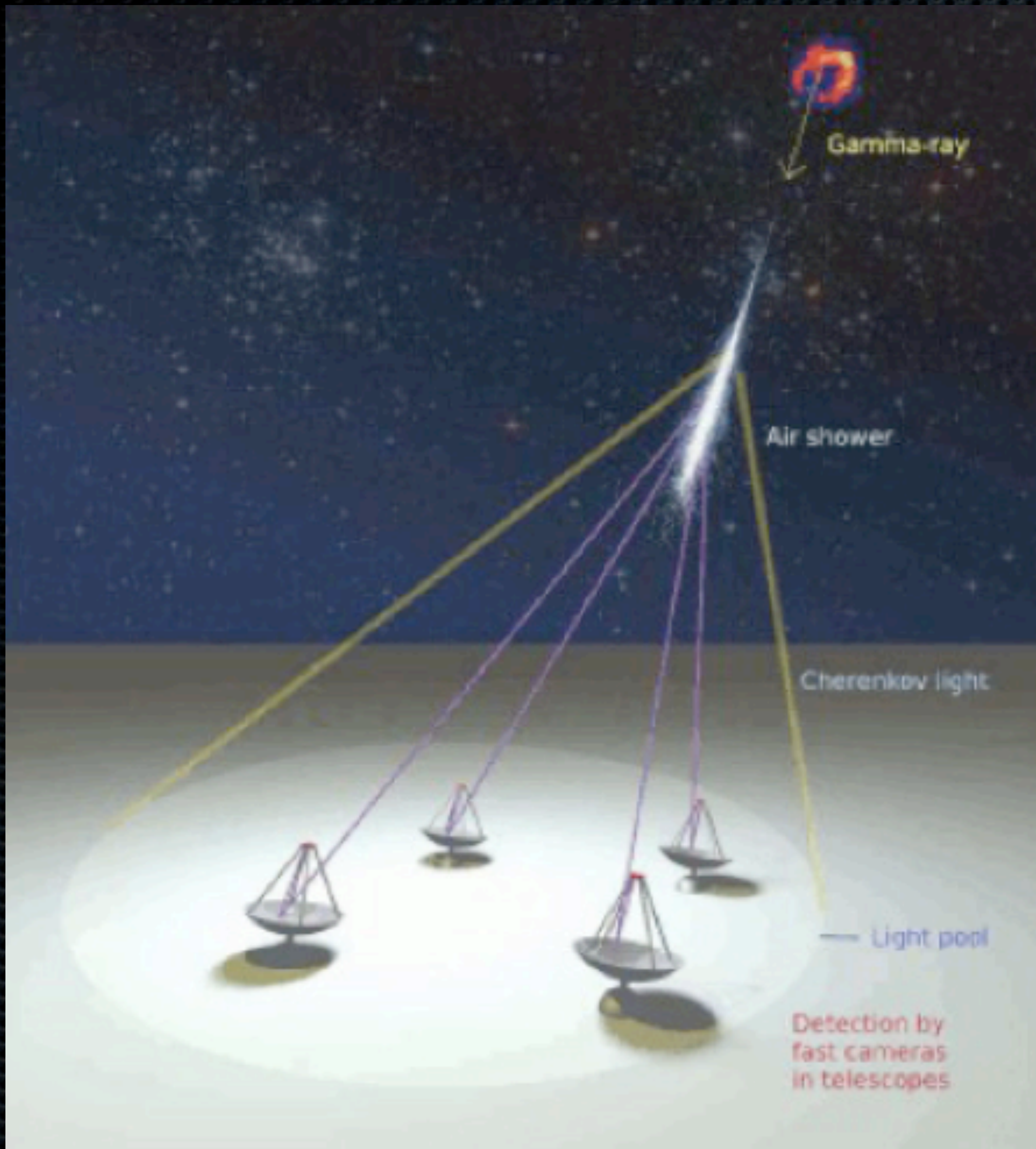
Leeds U.

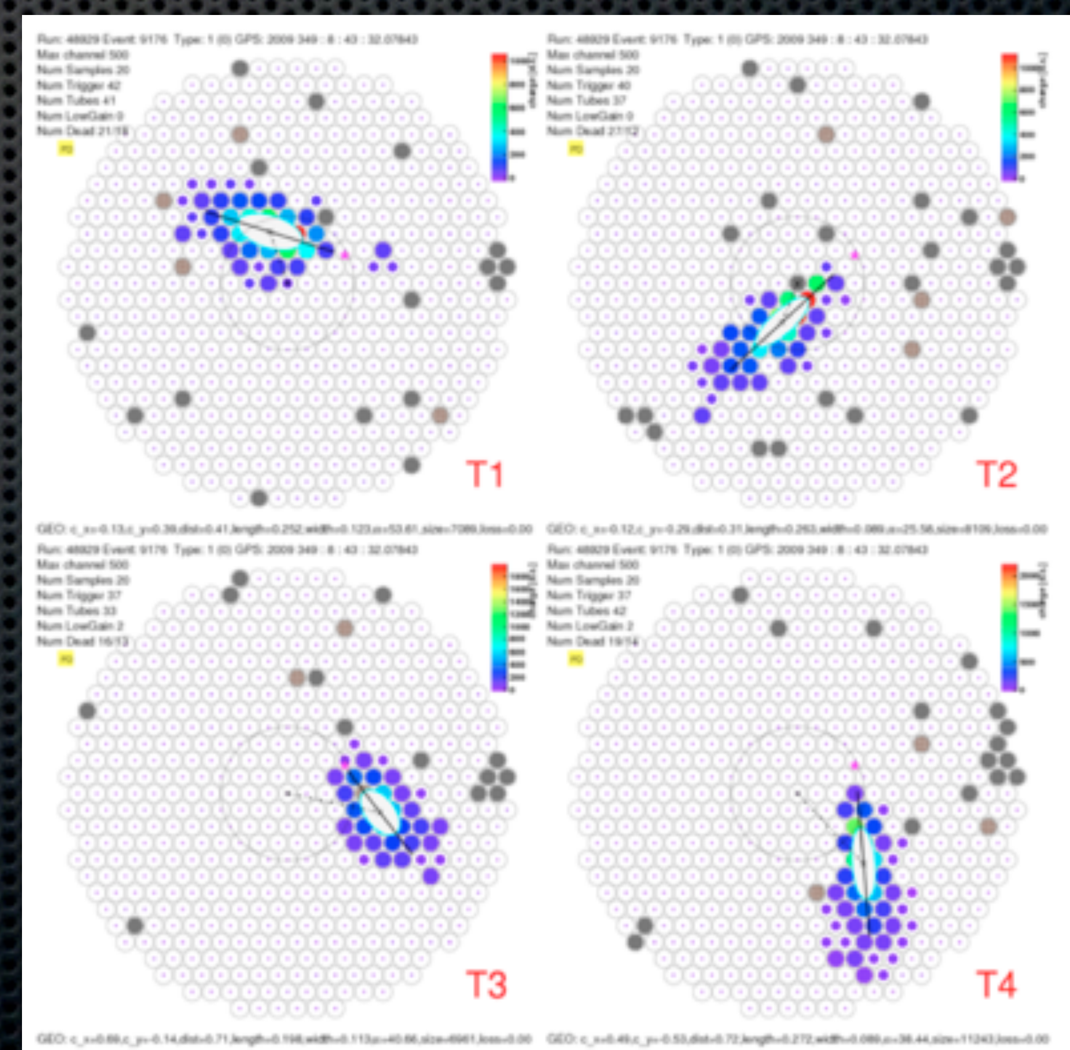
Ireland

Cork Inst. Tech.
Galway-Mayo Inst.
N.U.I. Galway
UCD

Imaging Atmospheric Cherenkov Technique:

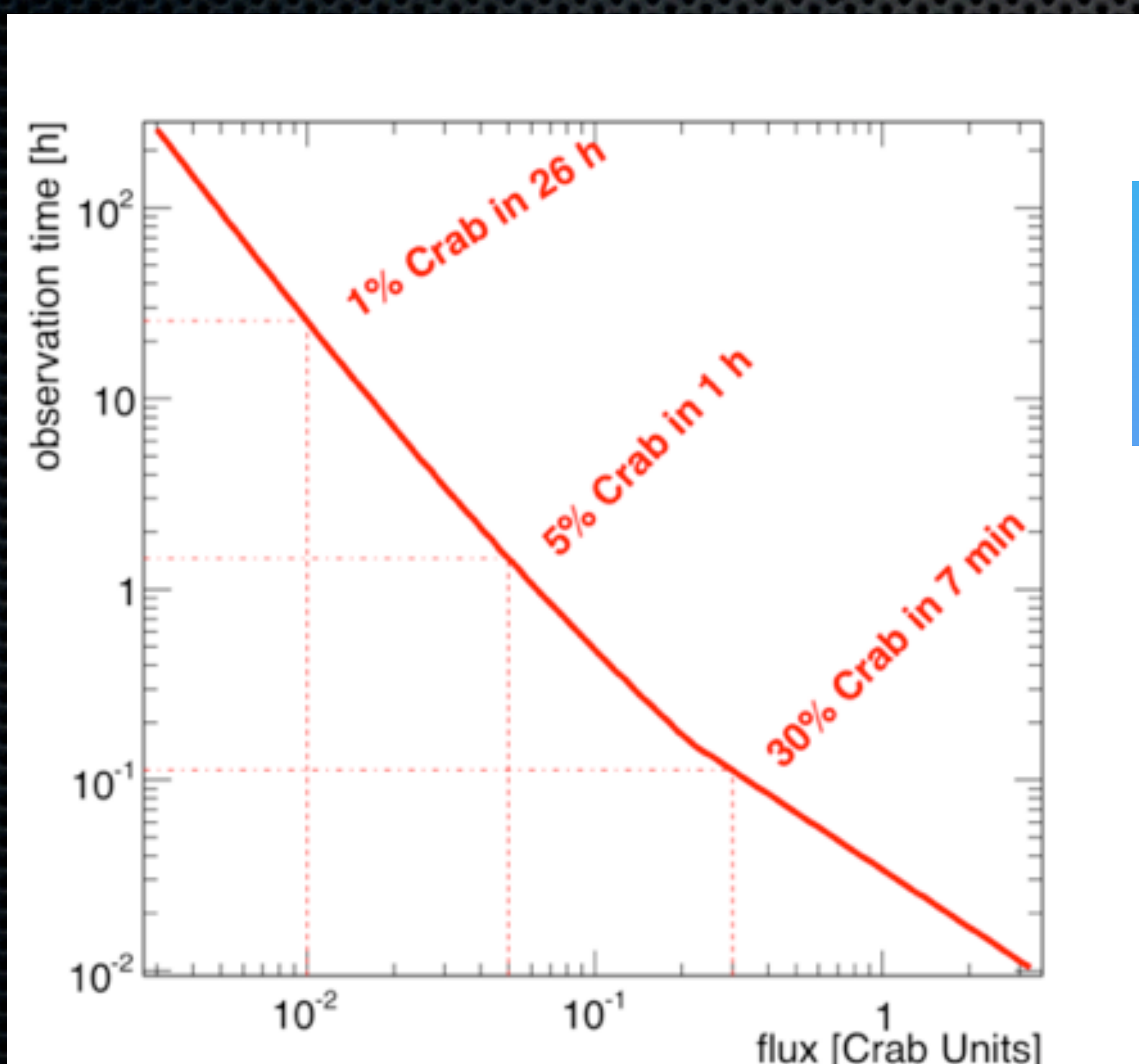
Primary gamma rays initiate EM showers w particle v>c: Cherenkov pulses

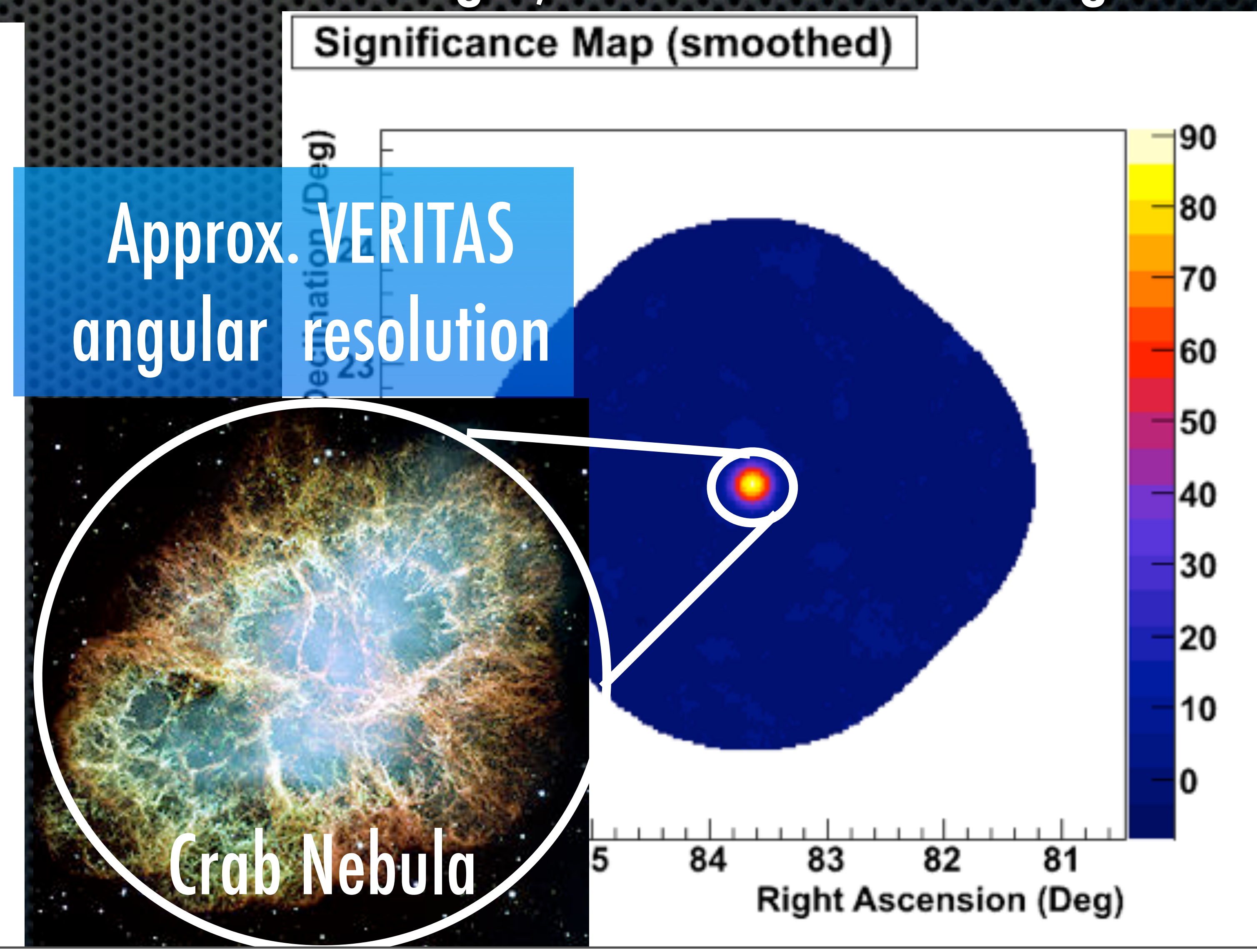




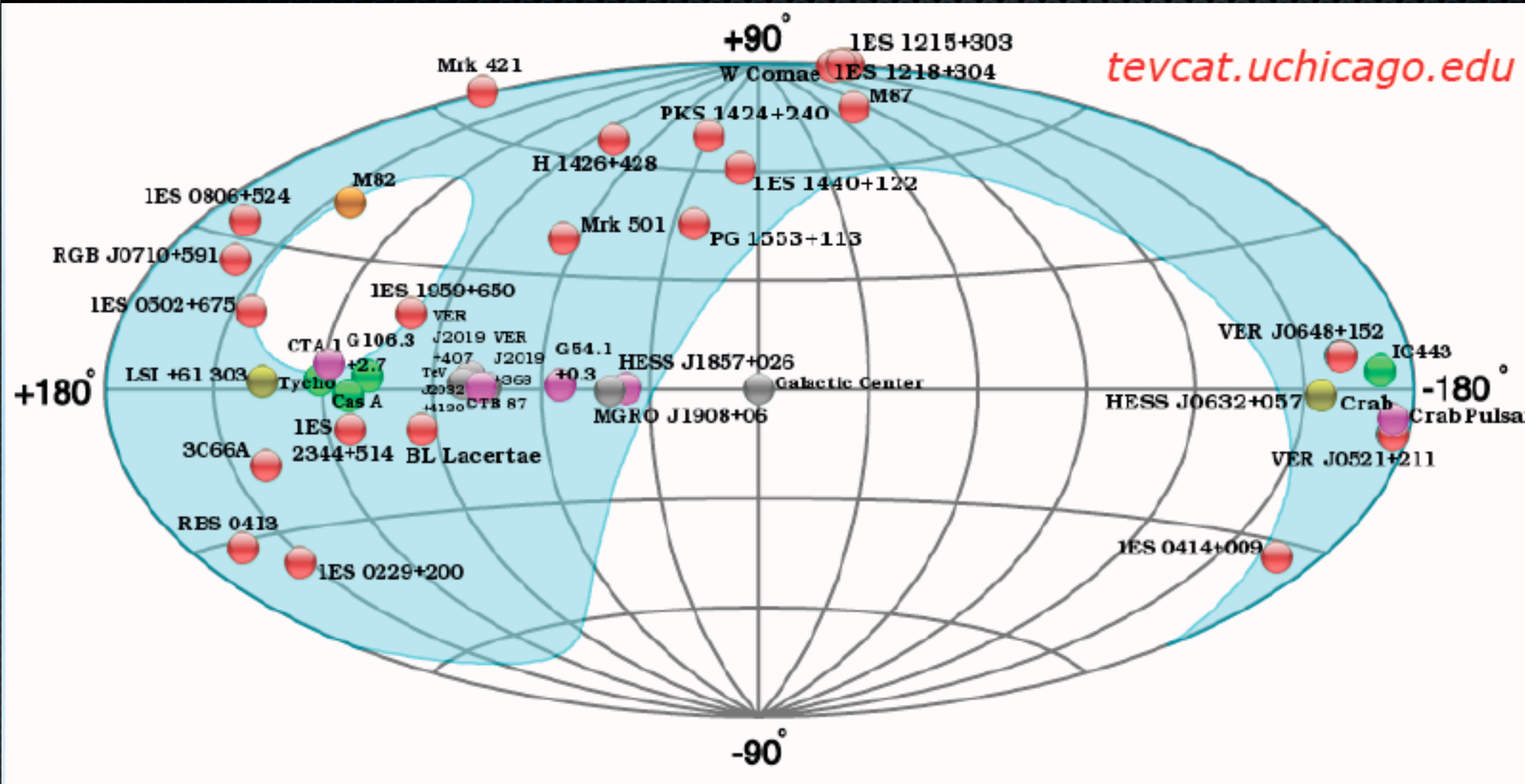
VERITAS

* energy range: 100 GeV to >30 TeV (spectral reconstruction starts at 150 GeV)
* energy resolution: 15% at 1 TeV
* angular resolution: <0.1 deg at 1 TeV, 0.14 deg at 200 GeV (68% values)
* source location accuracy: <50 arcseconds
* point source sensitivity: 1% Crab in <30h, 10% in <30 min
* observation time per year: 800 hours non-moonlight, ~400 hours moonlight



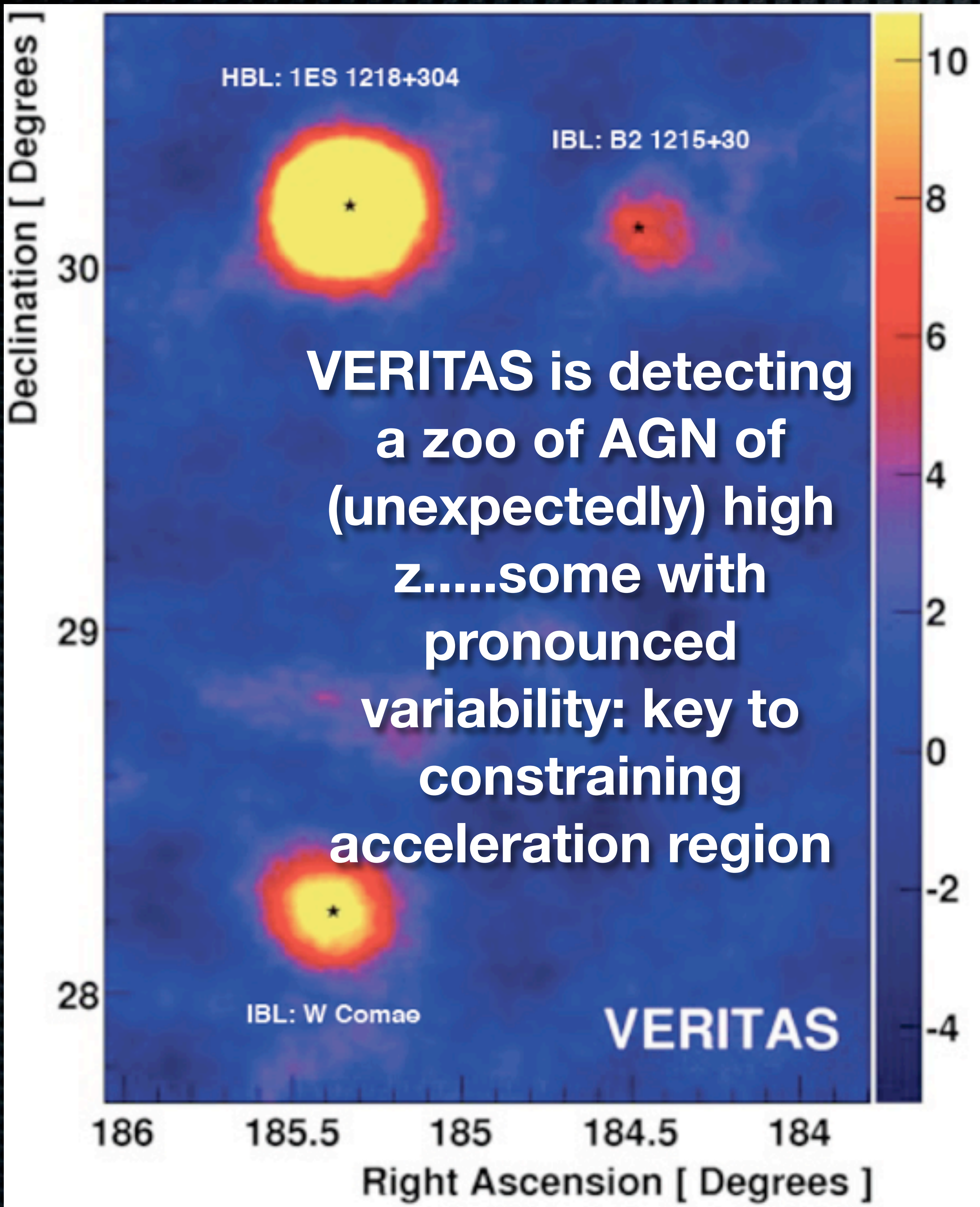


The VERITAS Catalog



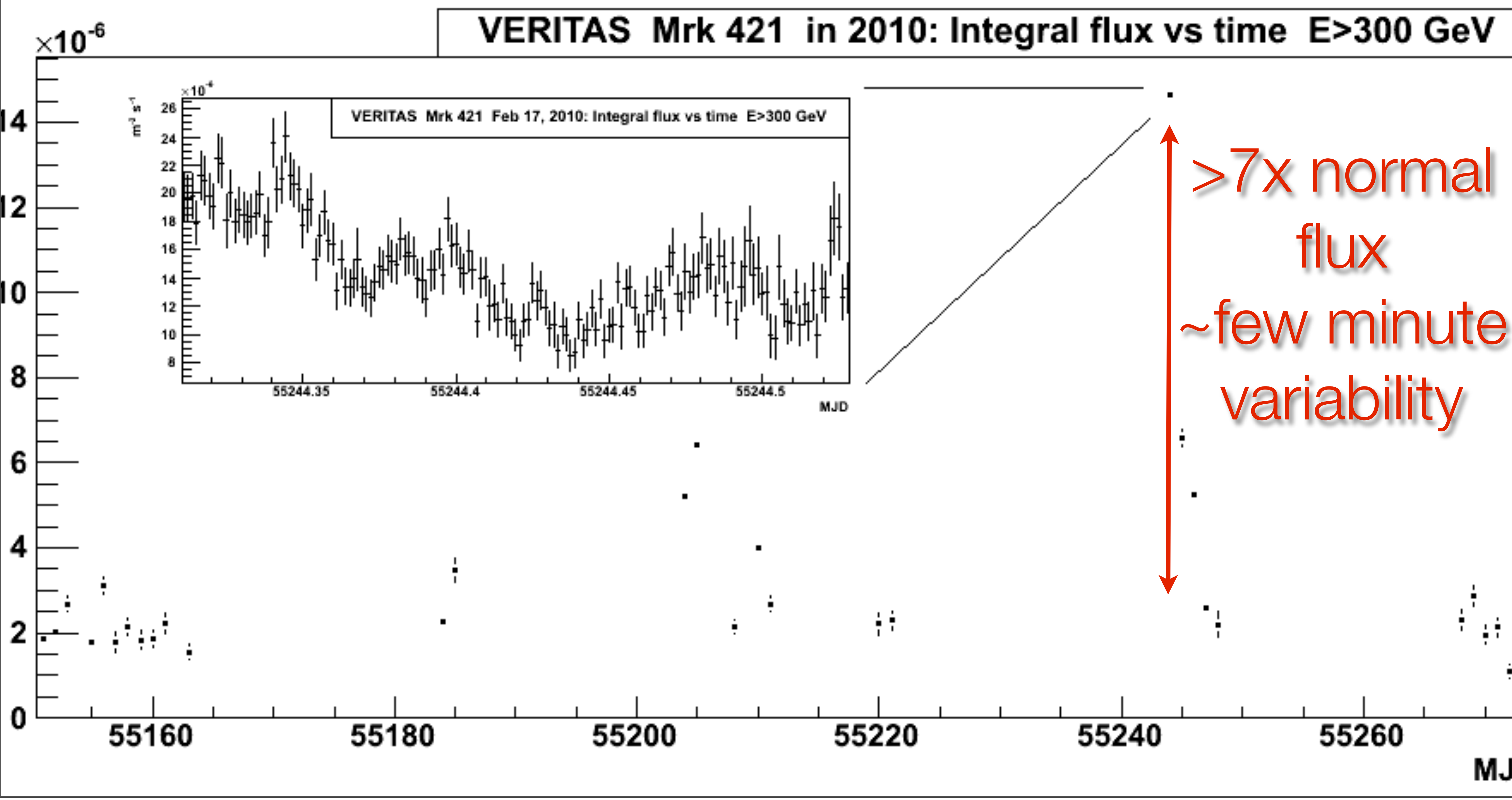
Wide range of cosmic sources detected: pulsar wind nebulae, supernova remnants, X-ray binaries, many AGN, 1 starburst galaxy, 1 pulsar...

Extragalactic Accelerators: Blazars:

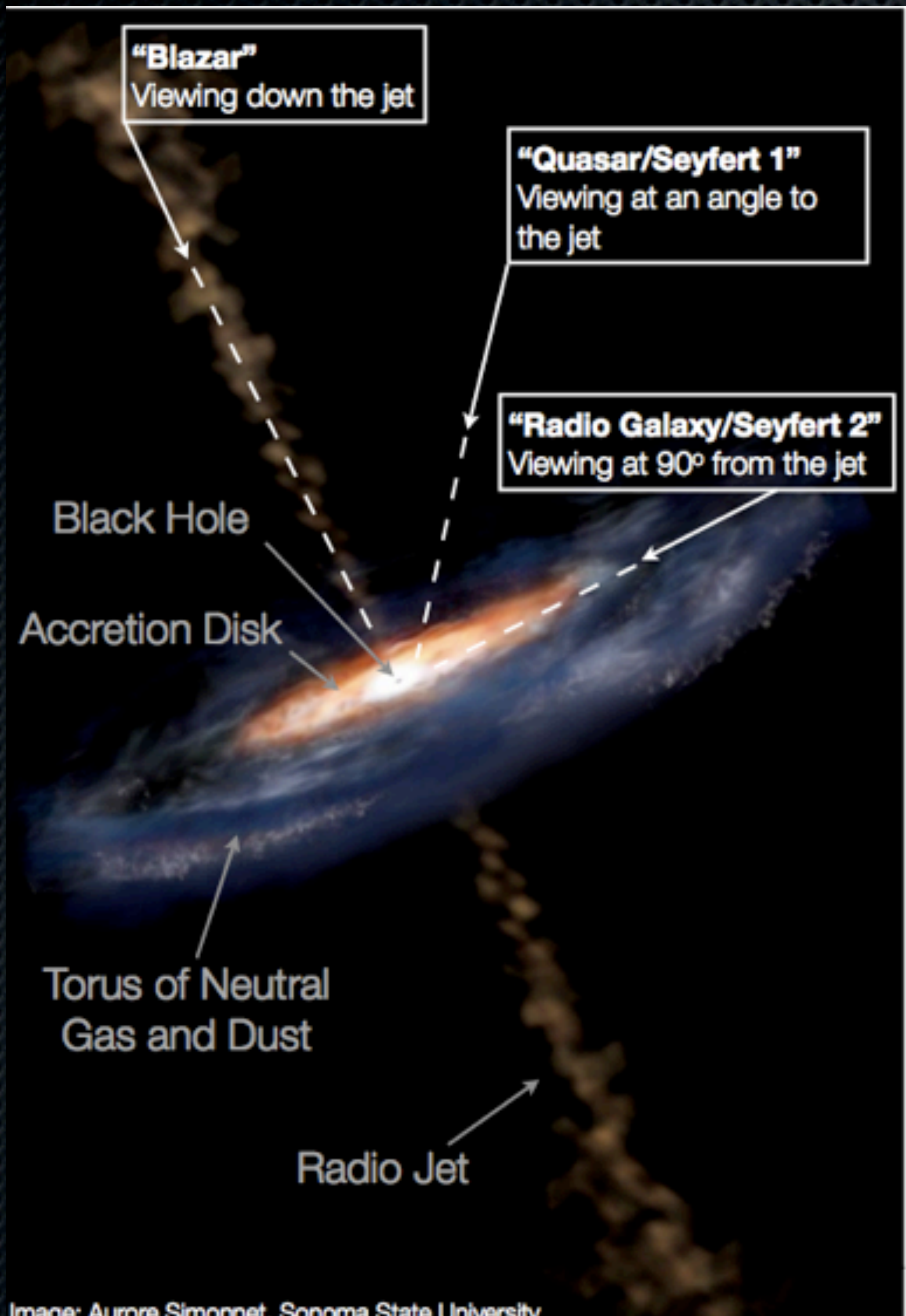


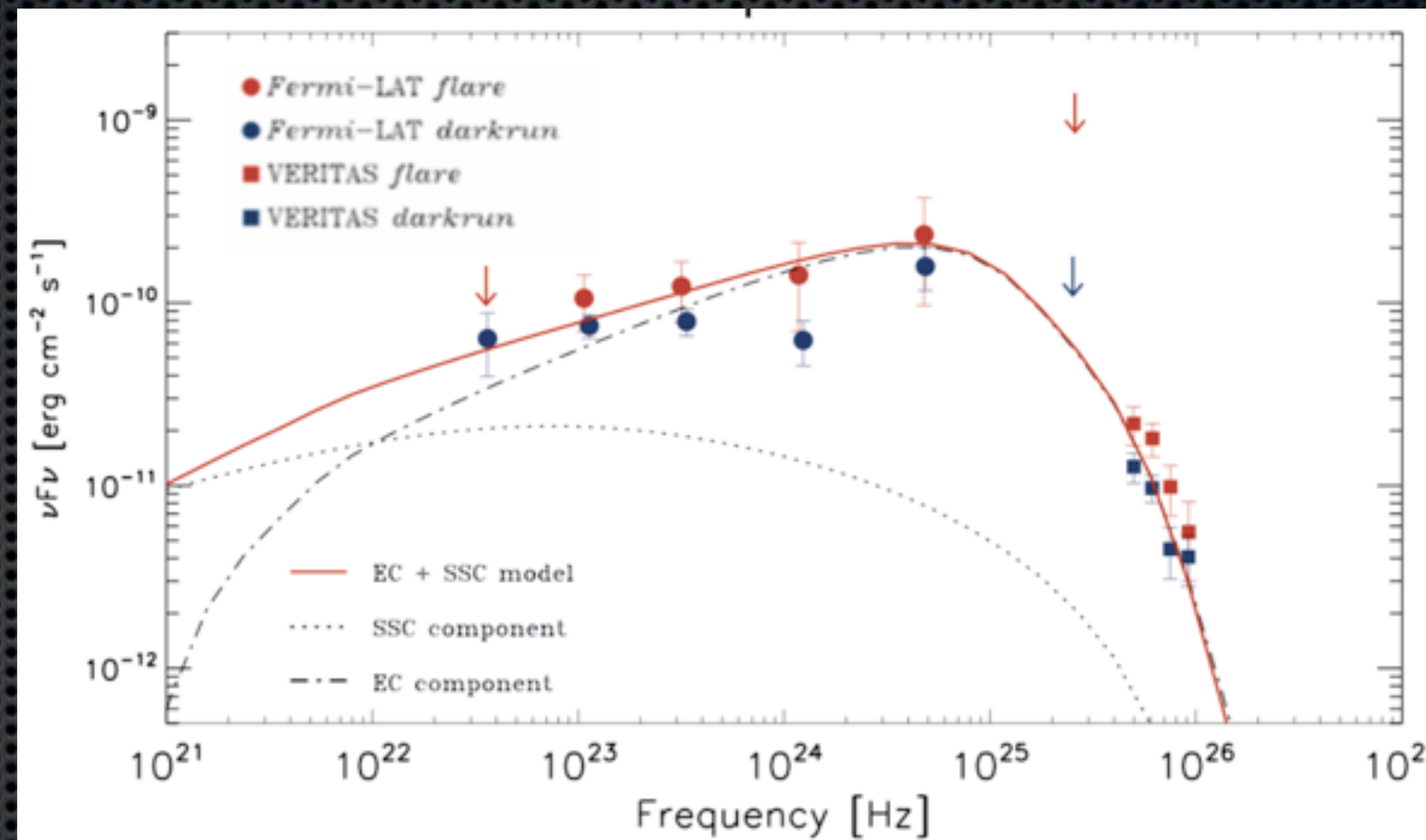
AGN	Type	z
M 87	FR I	0.004
Mkn 421	HBL	0.030
Mkn 501	HBL	0.034
1ES 2344+514	HBL	0.044
1ES 1959+650	HBL	0.047
BL Lac	LBL	0.069
W Comae	IBL	0.102
RGB J0710+591	HBL	0.125
H 1426+428	HBL	0.129
1ES 0229+200	HBL	0.139
1ES 0806+524	HBL	0.138
1ES 1440+122	IBL	0.163
RX J0648.7+1516	HBL	0.179
1ES 1218+304	HBL	0.182
RBS 0413	HBL	0.190
1ES 0414+009	HBL	0.287
PG 1553+113	HBL	$0.43 < z < 0.58$
1ES 0502+675	HBL	~~0.341~~ ?
3C 66A	IBL	~~0.444~~ ?
PKS 1424+240	IBL	?
VER J0521+211	HBL	?
B2 1215+30	IBL	~~0.13~~ ?

A Flaring Giant: Markarian 421



Extragalactic Accelerators: Blazars:

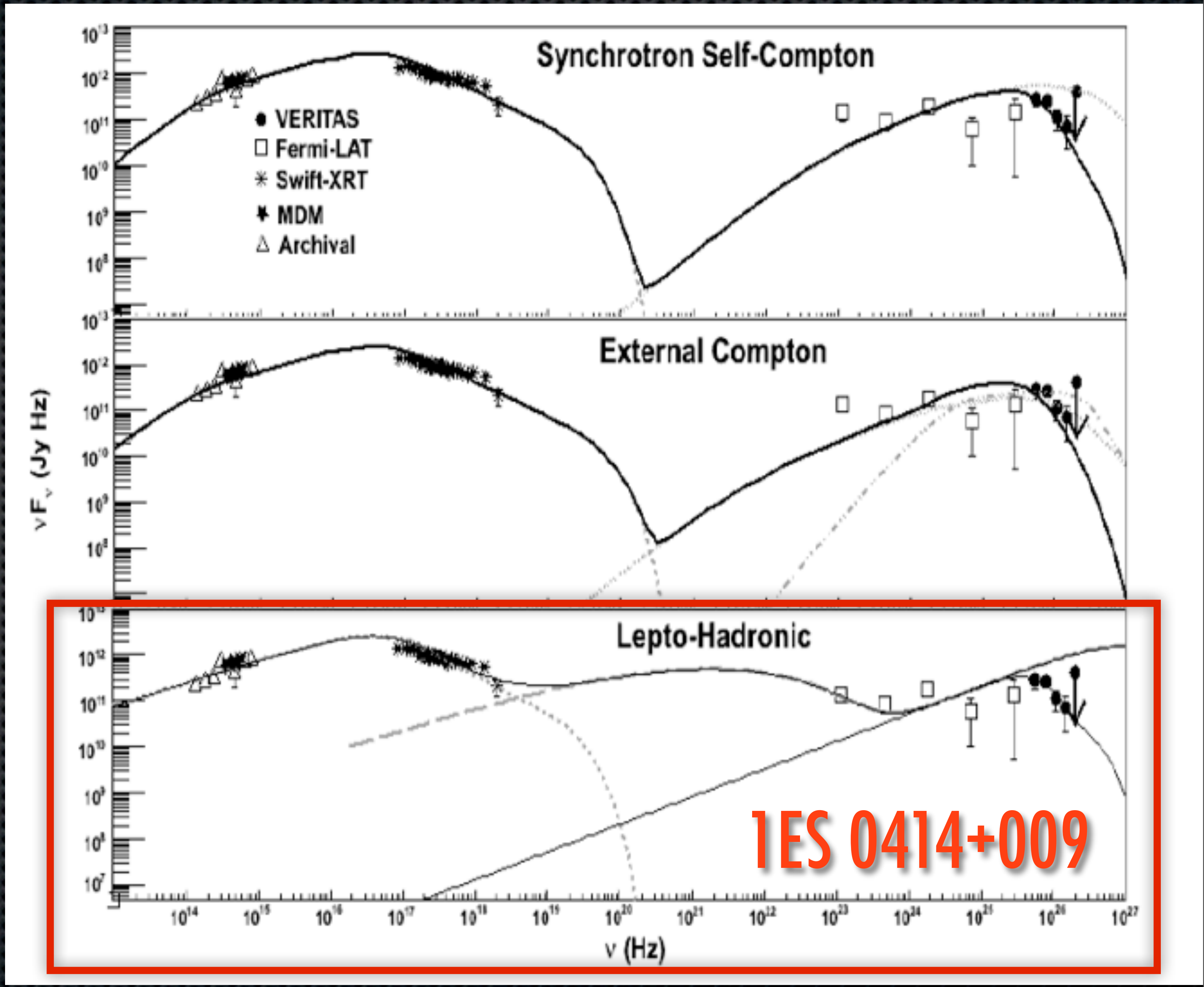




Traditionally, most blazar SED have been acceptably modeled by leptonic emission (EC/SSC)

Extragalactic Accelerators: Blazars:

Recently, however, modeling of newly VERITAS detected AGN could indicate some hadronic component may be required (i.e. synch. emission from rel. p^+, pion decay emission + low E synch. emission from e+/e- cascades) although modeling is far from conclusive...

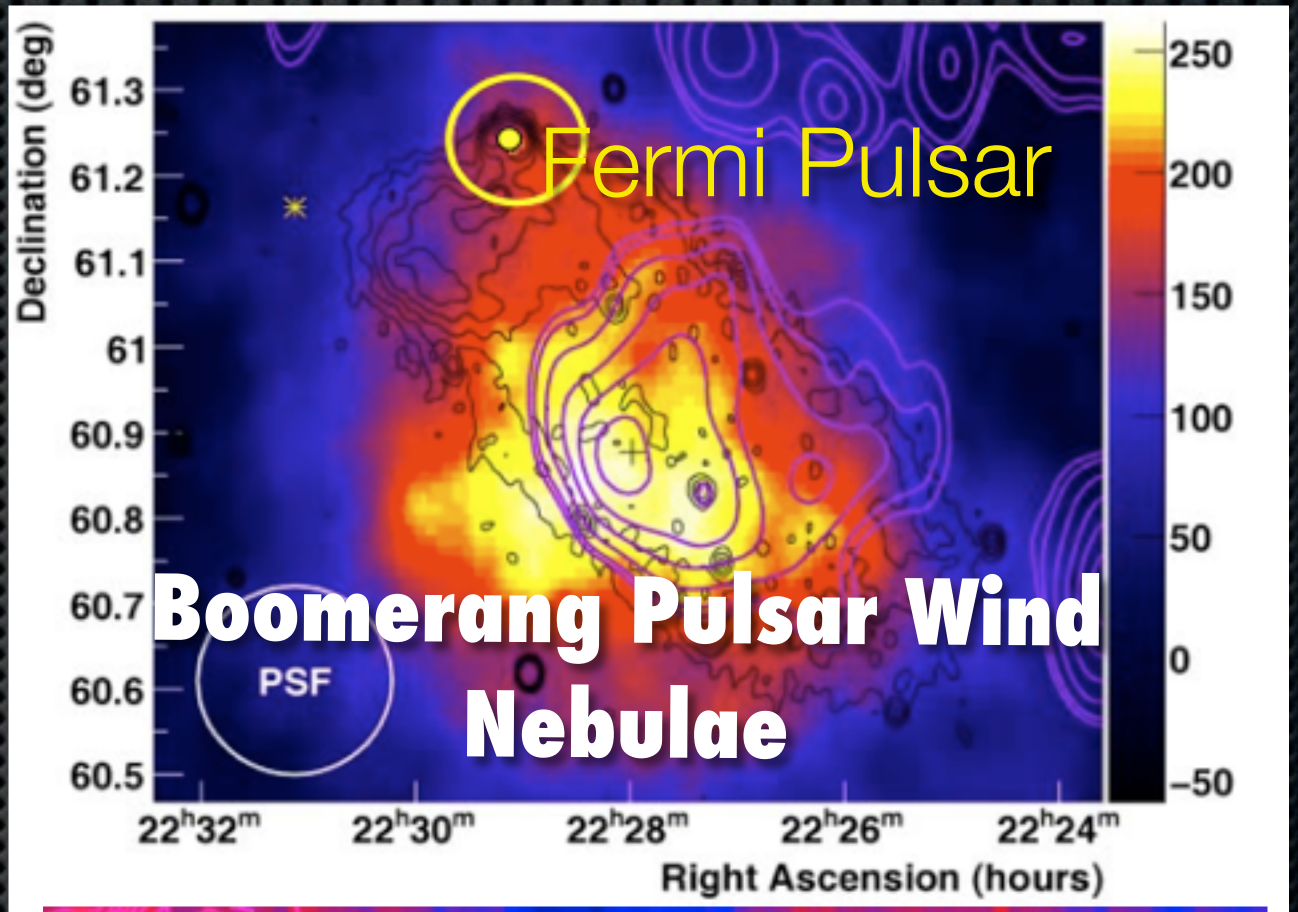


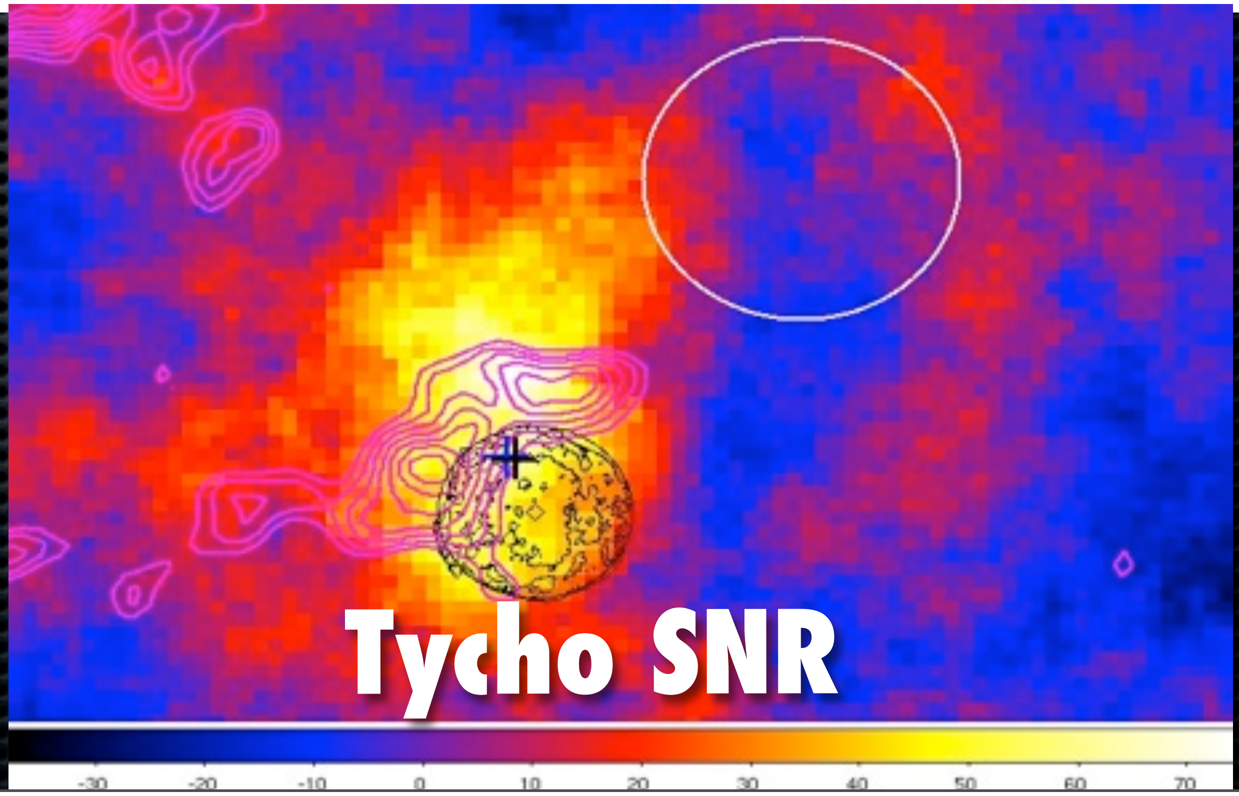
Galactic Accelerators:

Shock/MC Interactions

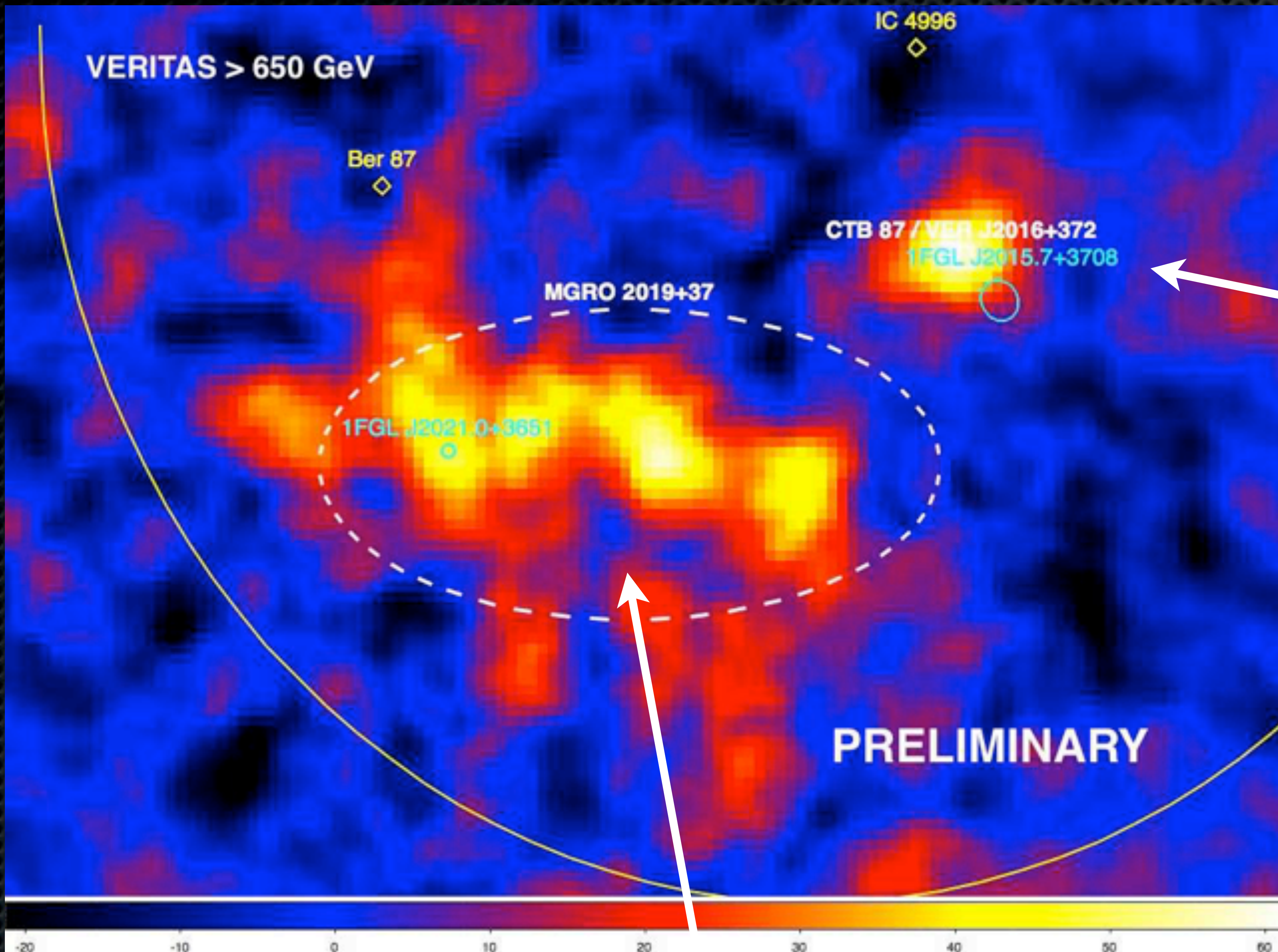
In general, VERITAS observations of objects such as PWNe and SNe show that the interaction between shocks and rich Molecular Cloud regions are excellent targets for TeV particle acceleration

Purple: CO emission
Colors: TeV Excess Maps





For ex: Cygnus OB1 Region



TeV emission associated with young PWN candidate CTB 87 (1% Crab flux in TeV)

PSR J2021, WR stars, young clusters....varying degrees of TeV emission- multiple sources?

VERITAS observations of Milagro hotspot reveal complicated network of TeV emission...rich environment for particle acceleration

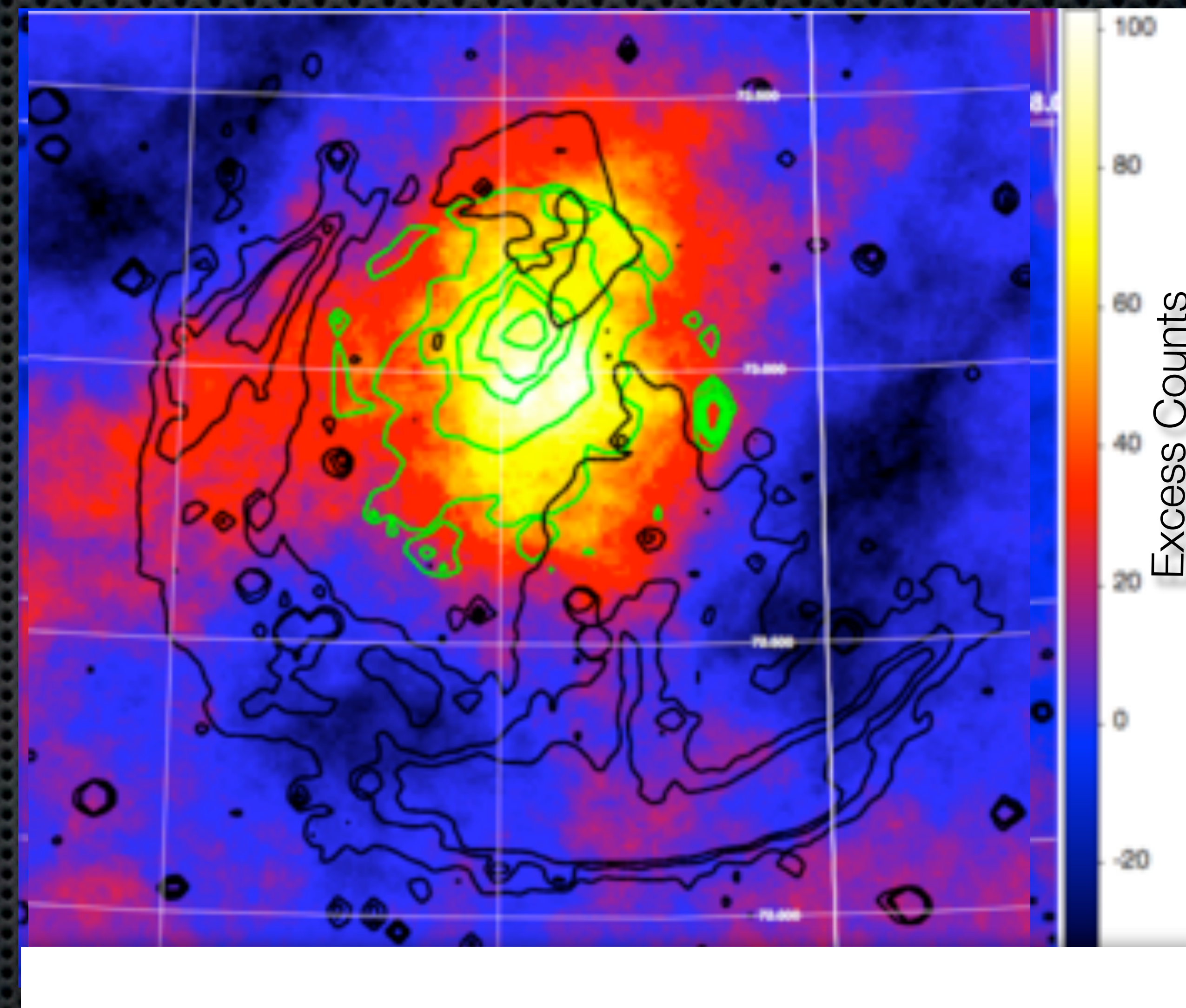
The Supernova Remnant CTA 1

VERITAS Observations:

27 hours in 2010-2011

6.3σ post trials detection

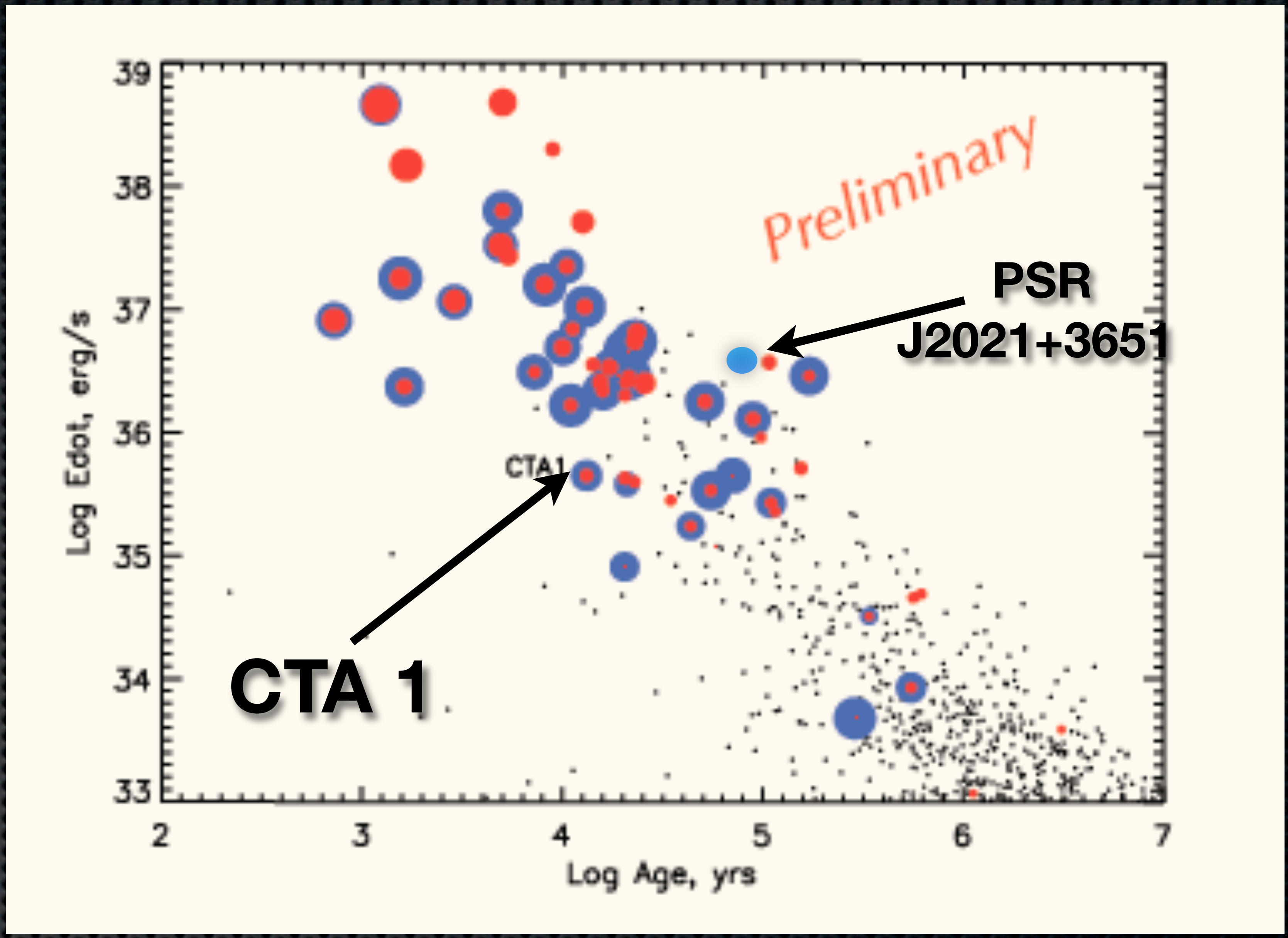
~4% of Crab Nebula Flux above 1 TeV



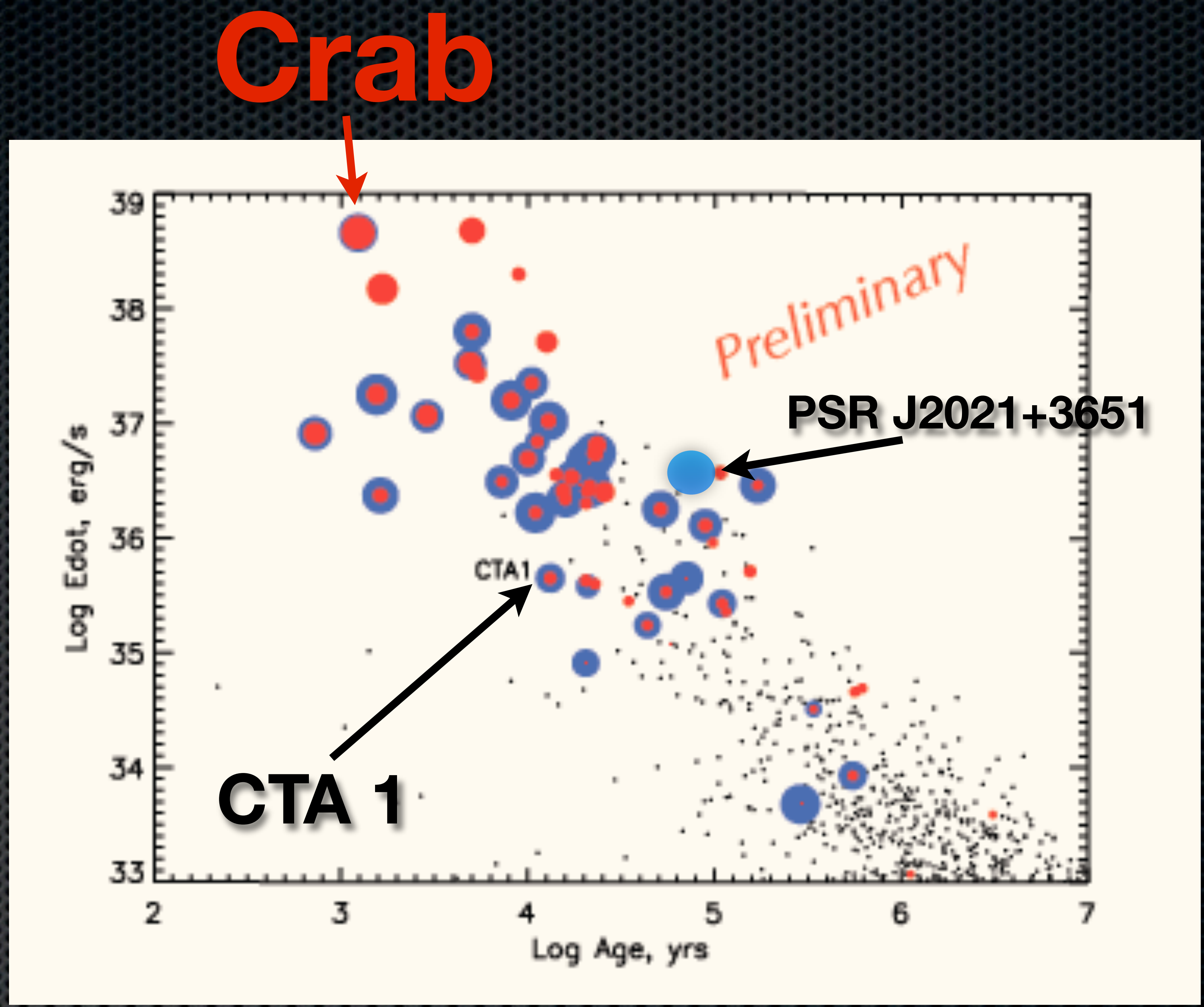
Emission lines up well with X-ray emission (green) and not radio emission (black). TeV emission most likely from young PWN.

Modified from Kargarltsev and Pavlov 2010

X-ray detected PWN (Red) and TeV (Blue), circle size represents luminosity.



Evidence seems to favor young, high Edot pulsars as being good targets for TeV PWN emission.

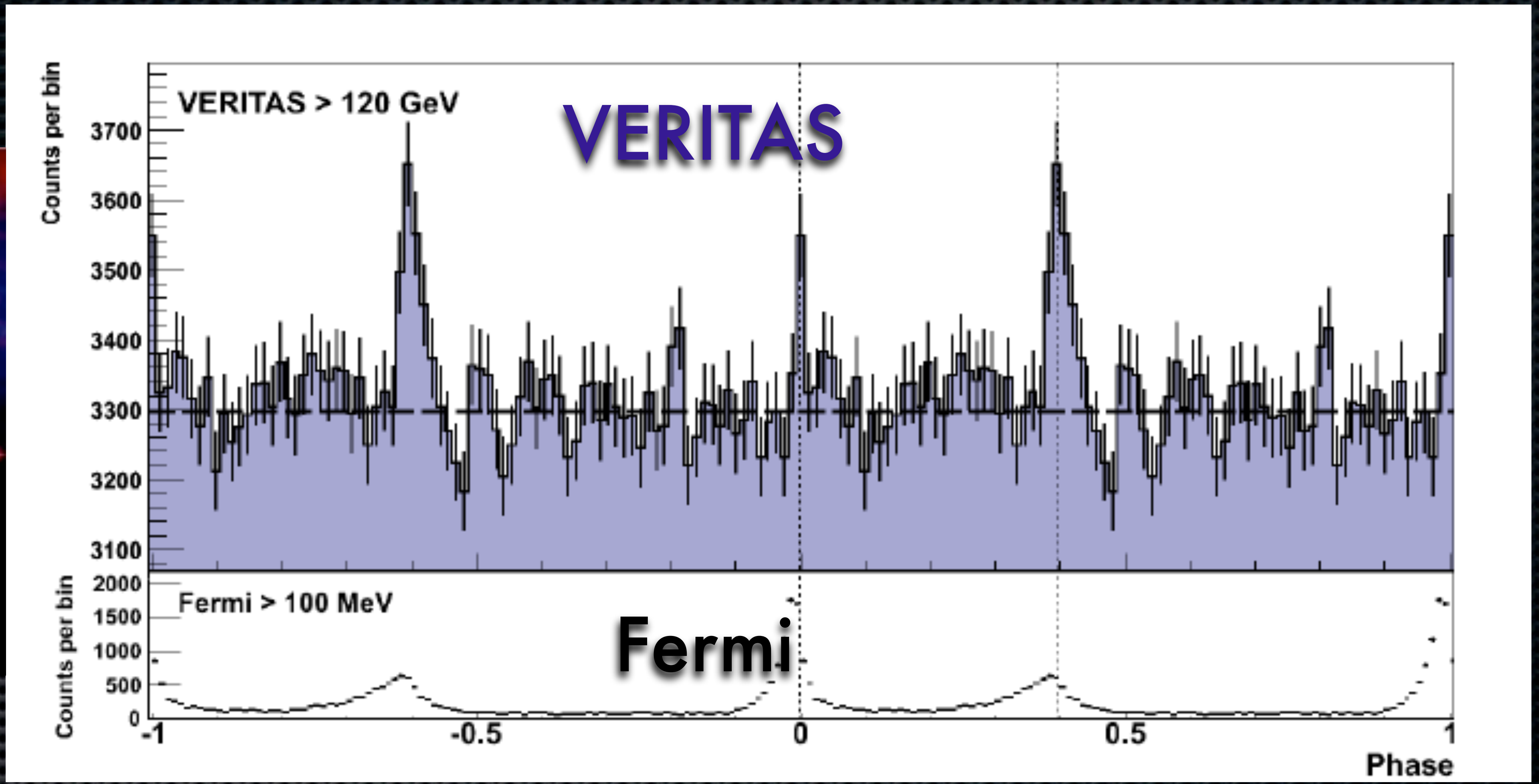


X-ray detected PWN (Red) and TeV (Blue), circle size represents luminosity.

Evidence seems to favor young, high Edot pulsars as being good targets for TeV PWN emission.

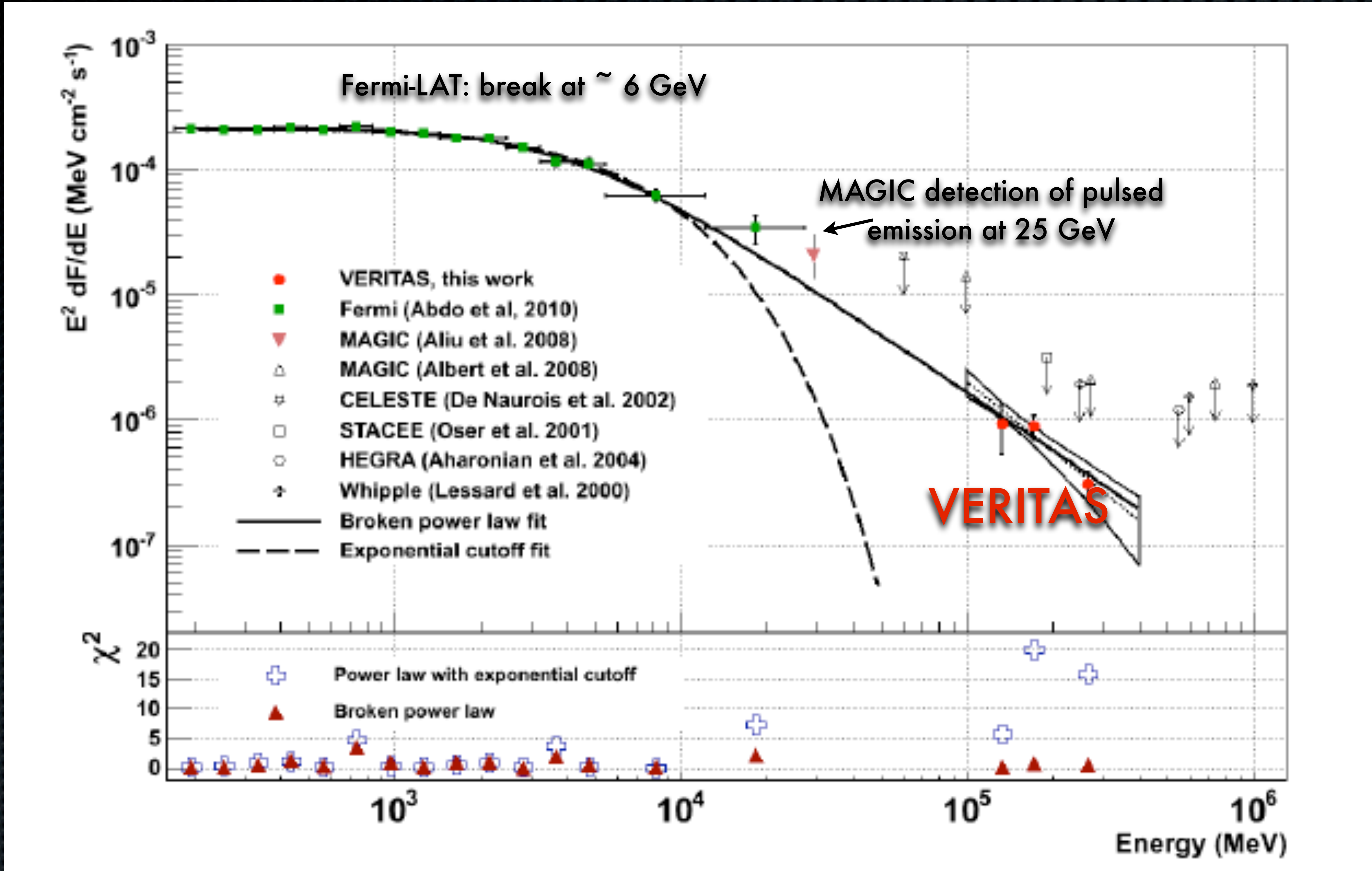
Pulsar Wind Nebulae: Crab Nebula

The First Pulsed VHE source above 100 GeV



VERITAS observations: 107 hours, 6σ detection of pulsed emission >100 GeV.

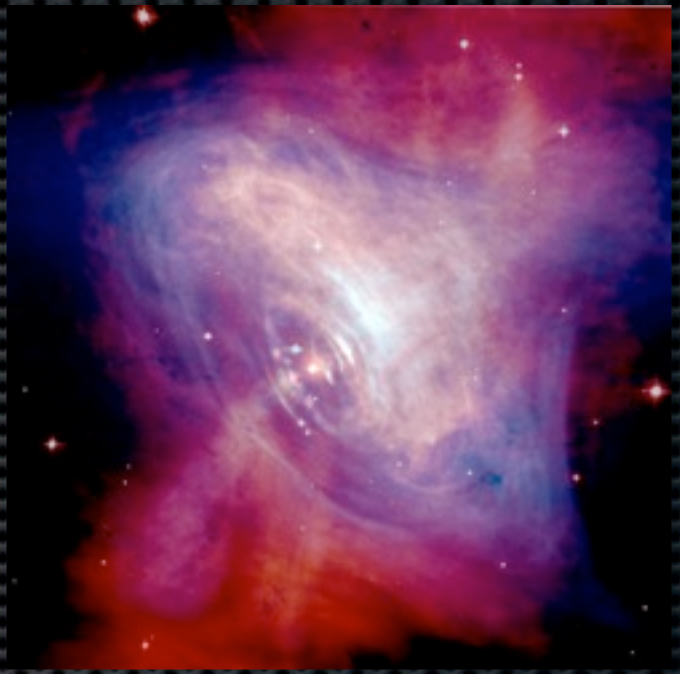
Narrower pulse profile than GeV



-VERITAS: Highest energy point: 280 GeV suggests large (> 10 stellar radii acceleration region)

-SED strongly disfavors curvature radiation (no spectral break)

Crab Nebula: A new variable galactic source?

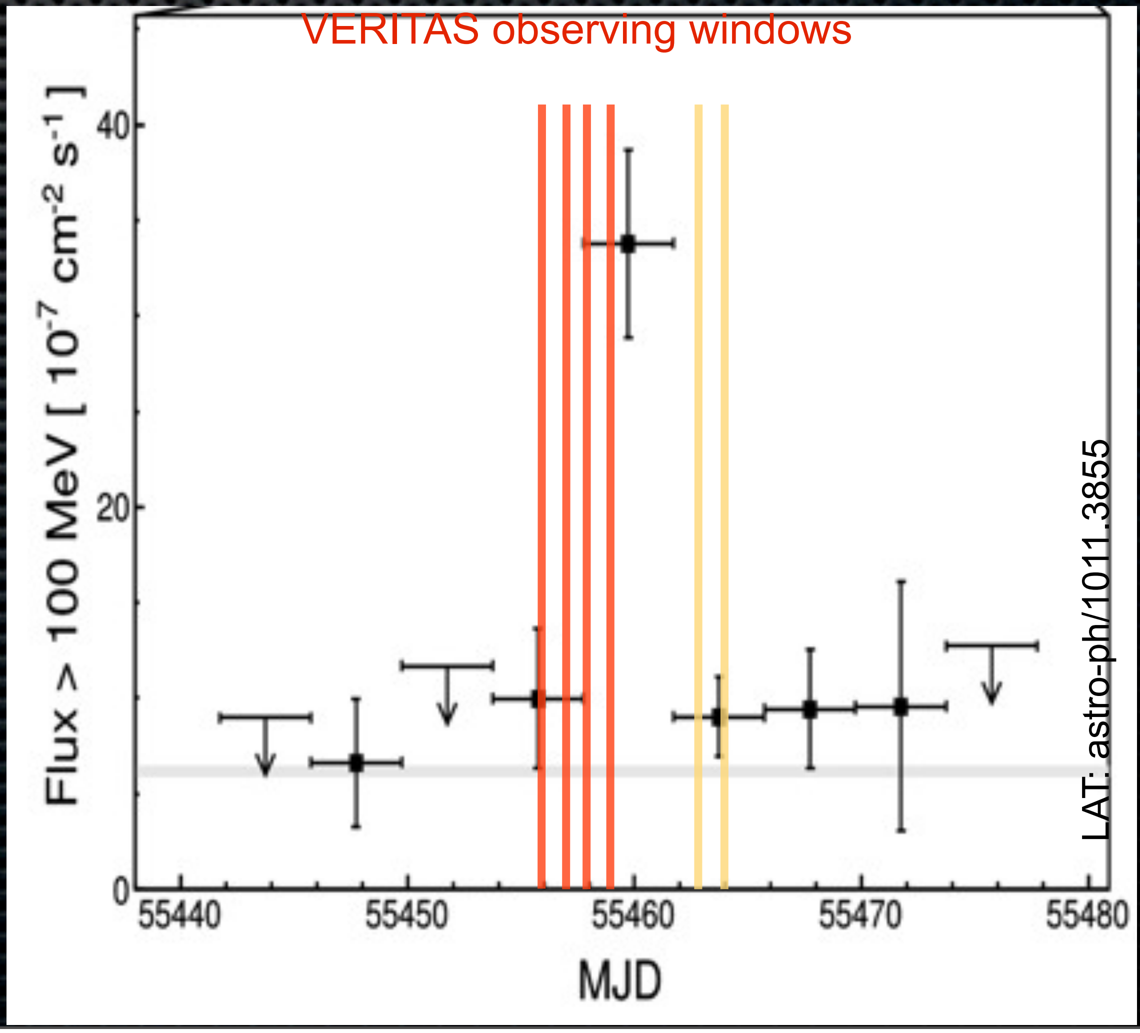


-Sep 2010, AGILE/Fermi report 2.2x/5.5x higher flux above 100 MeV

-ARGO-YBJ report 3-4x higher flux above 1 TeV (at 4σ significance)

-VERITAS observed during same windows and saw no evidence for enhanced flux above 0.2 or 1 TeV

-MAGIC collaboration confirms this non-detection



Crab Nebula: A new variable galactic source?

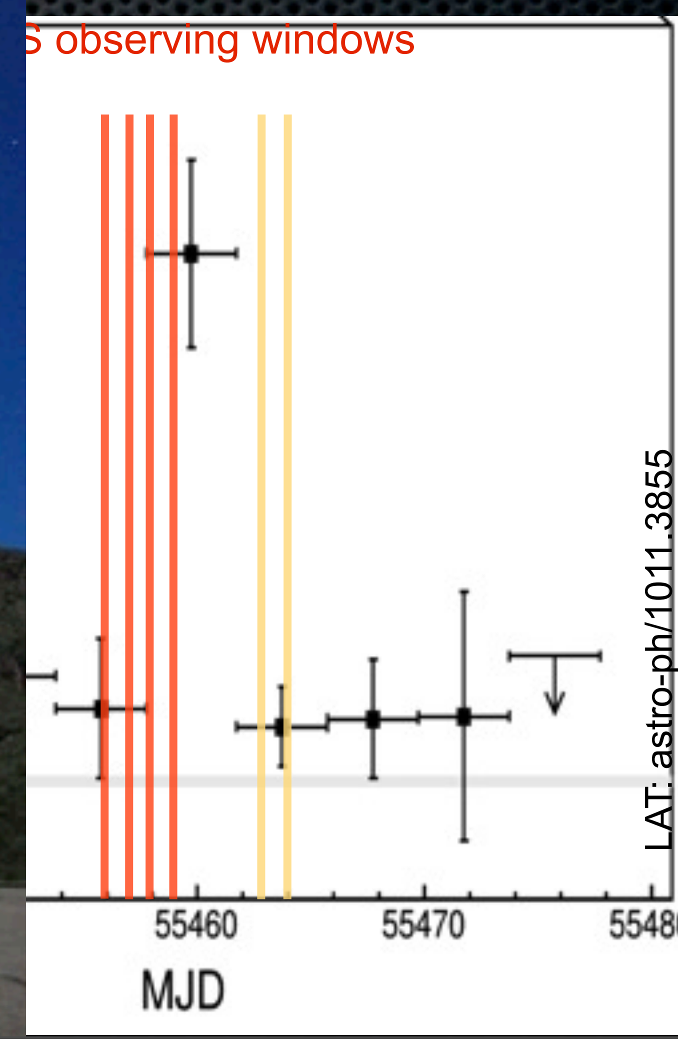
-Sep 2010, AGILE/Fermi
flux above 100 MeV

-ARGO-YBJ report 3-4x h
4σ significance)

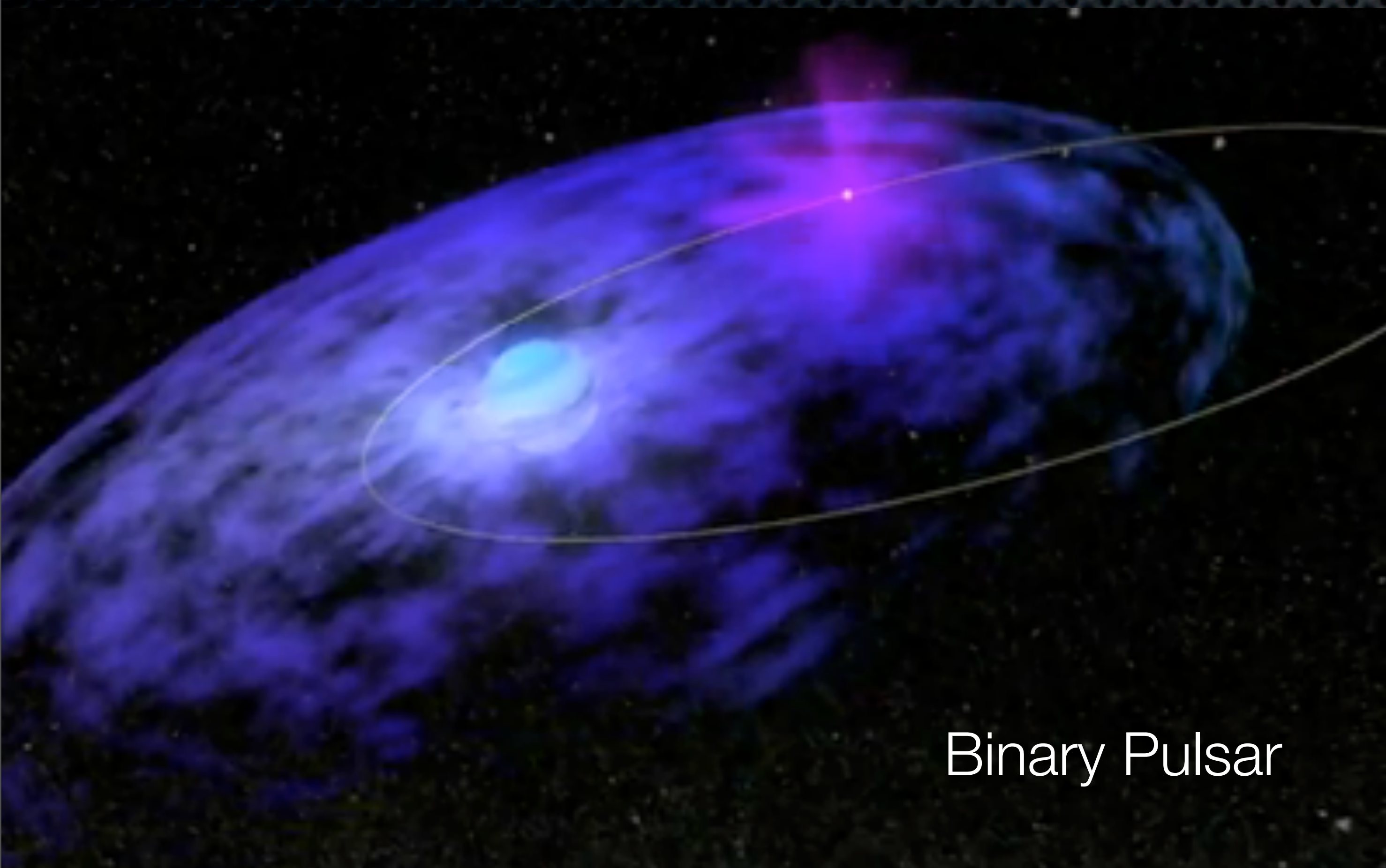
-VERITAS observed durin
windows and saw no evic
enhanced flux above 0.2

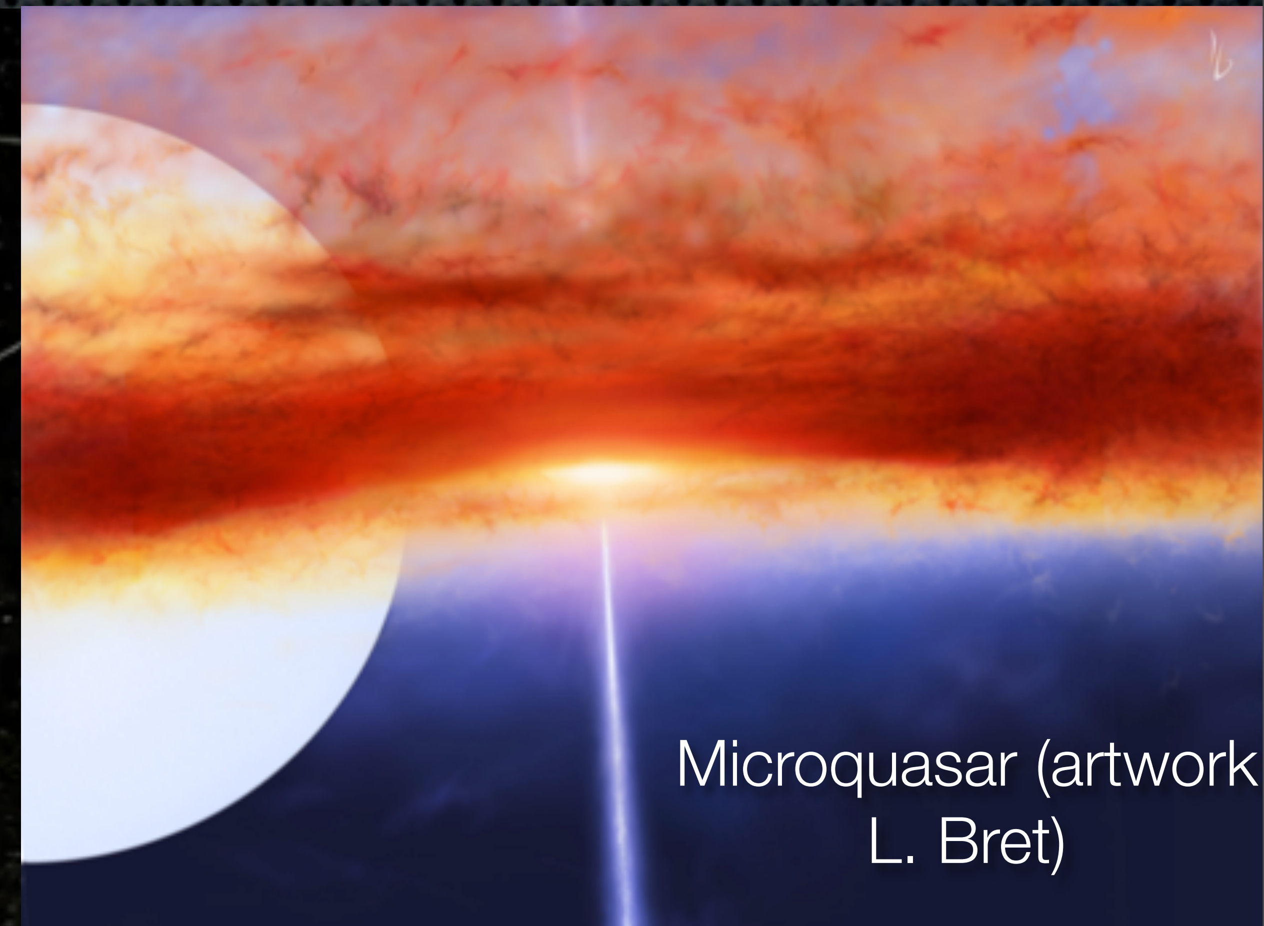
-MAGIC collaboration co
detection

(Photo by N.Otte)



TeV Binaries

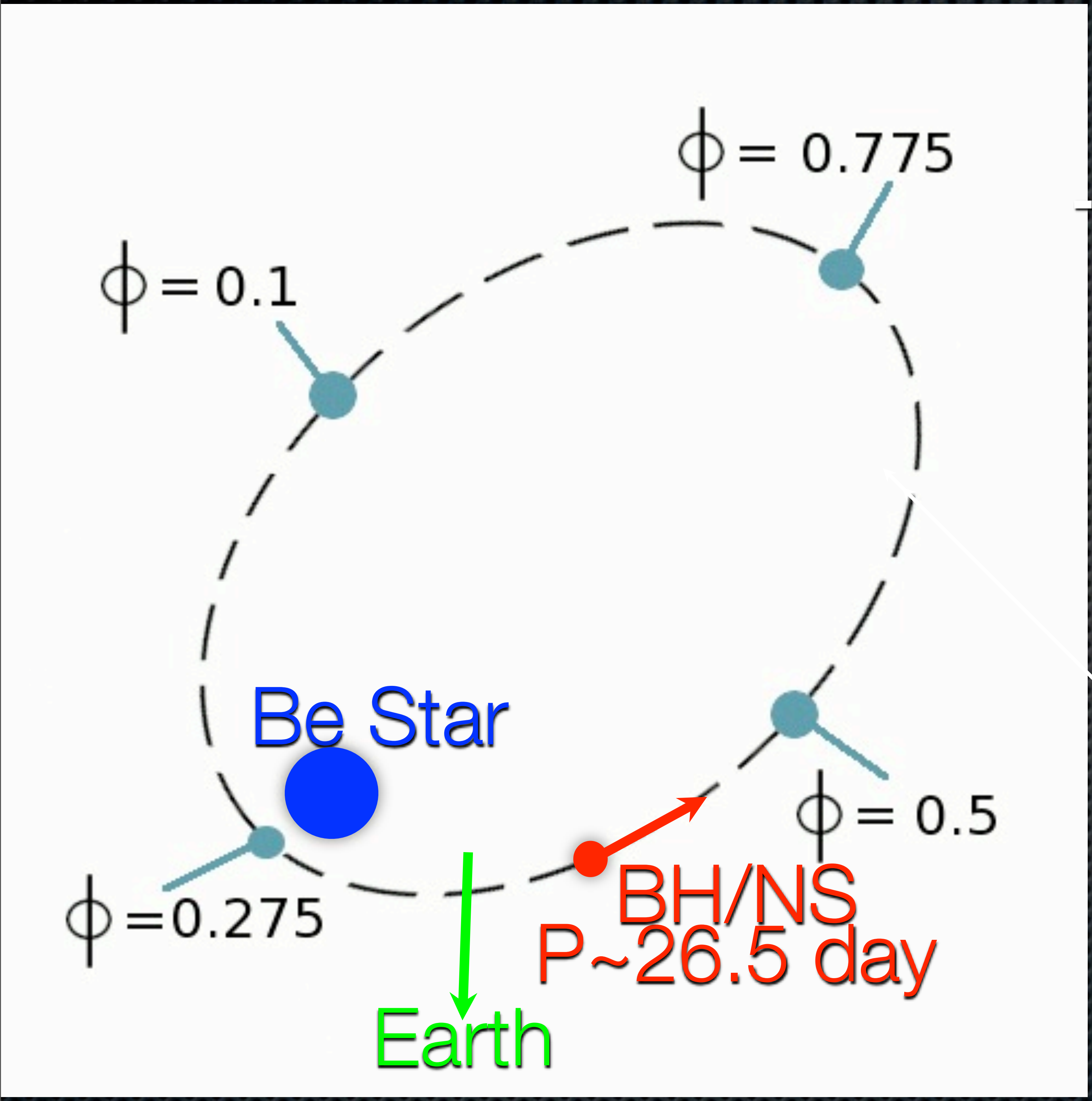




-Models divide between particle acceleration due to accretion powered (microquasar), and rotation powered (binary pulsar)

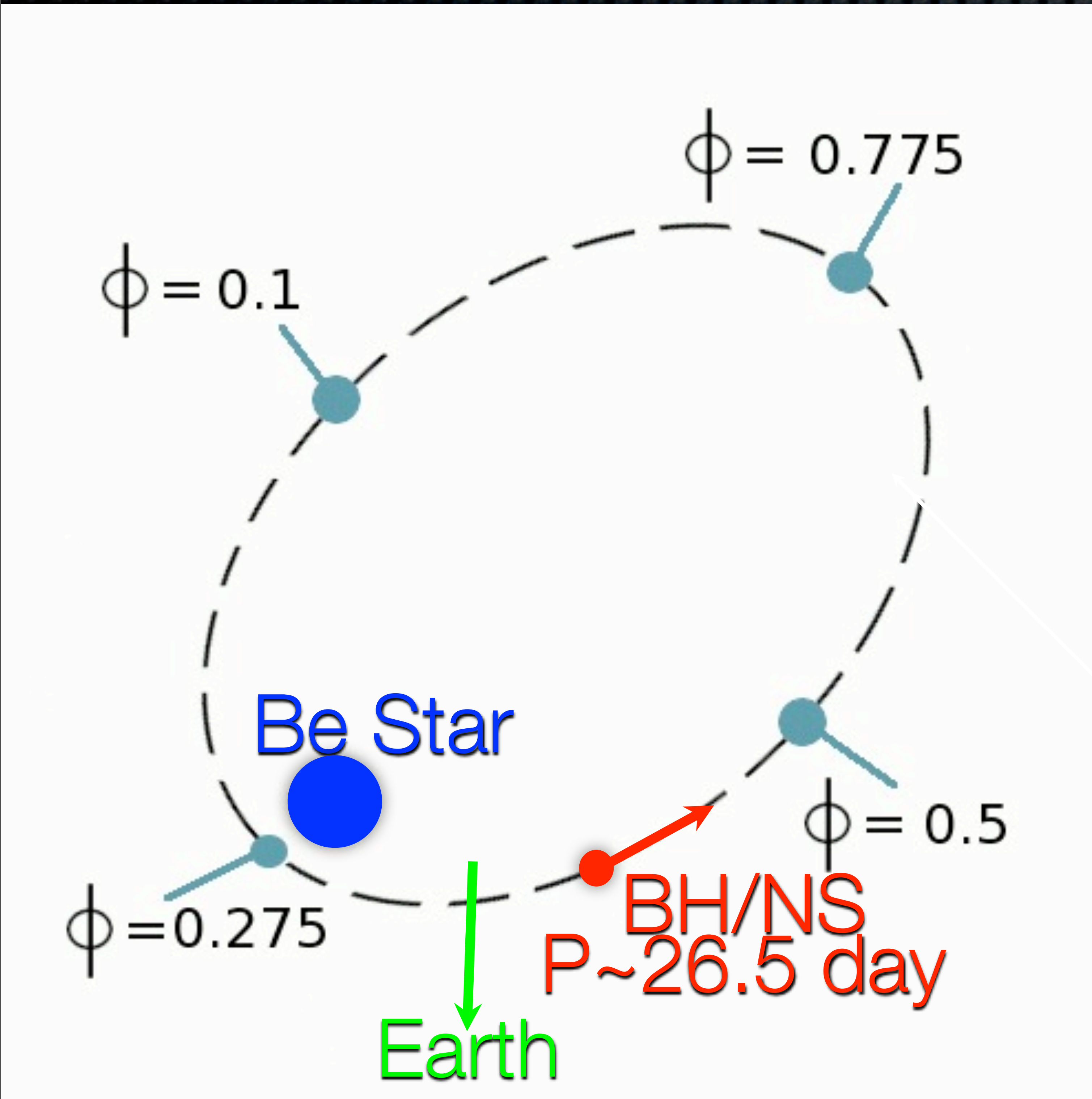
-4 Binaries seen by IACTs, only one with a definite nature (HESS PSR B1259 Binary Pulsar)

For Ex: LS I +61 303

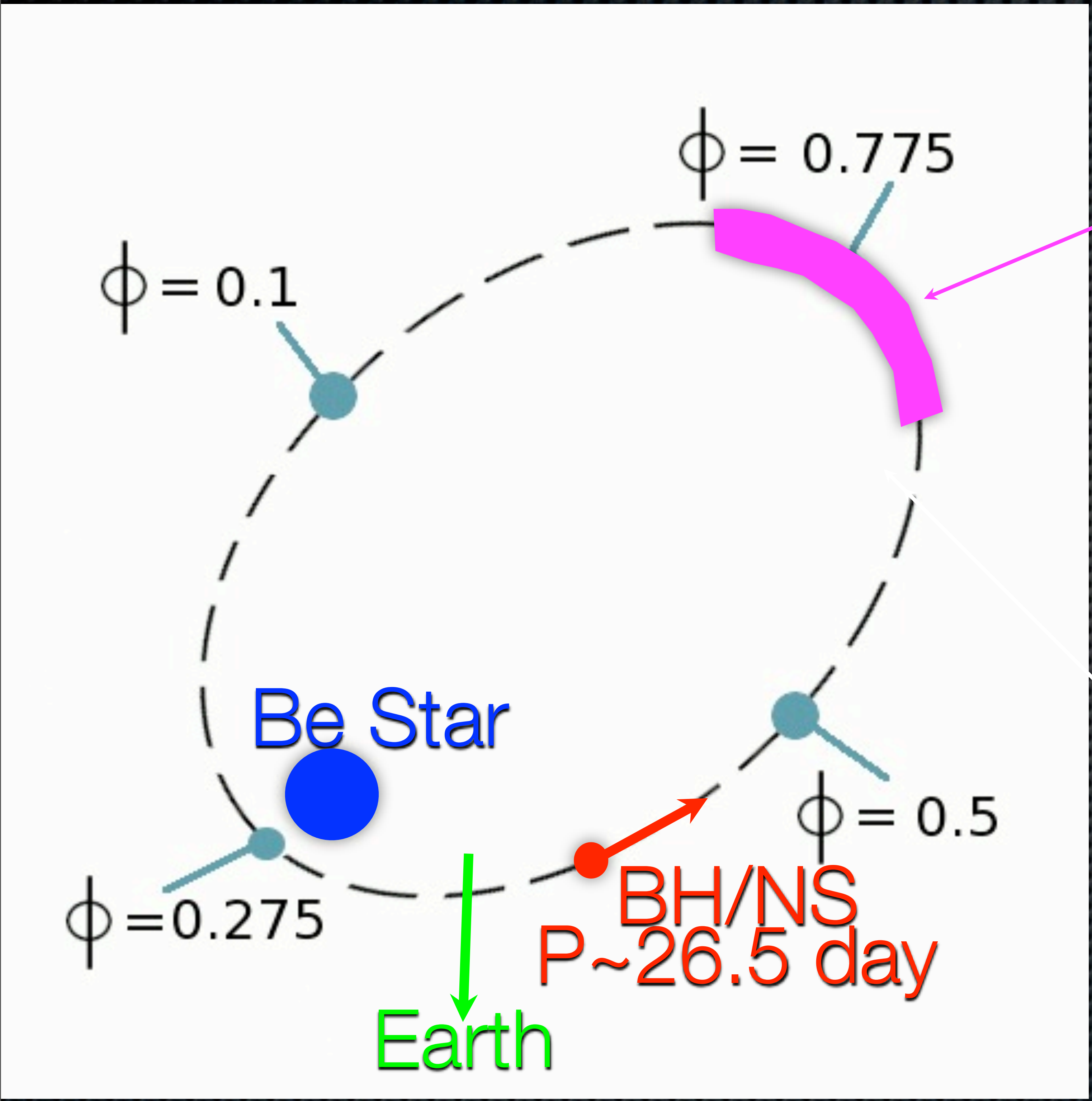


-High Mass X-ray Binary System
-2 kpc distance
-Pairing of Massive Be Star +Compact Object (unknown)
-26.5 day orbit

For Ex: LS I +61 303

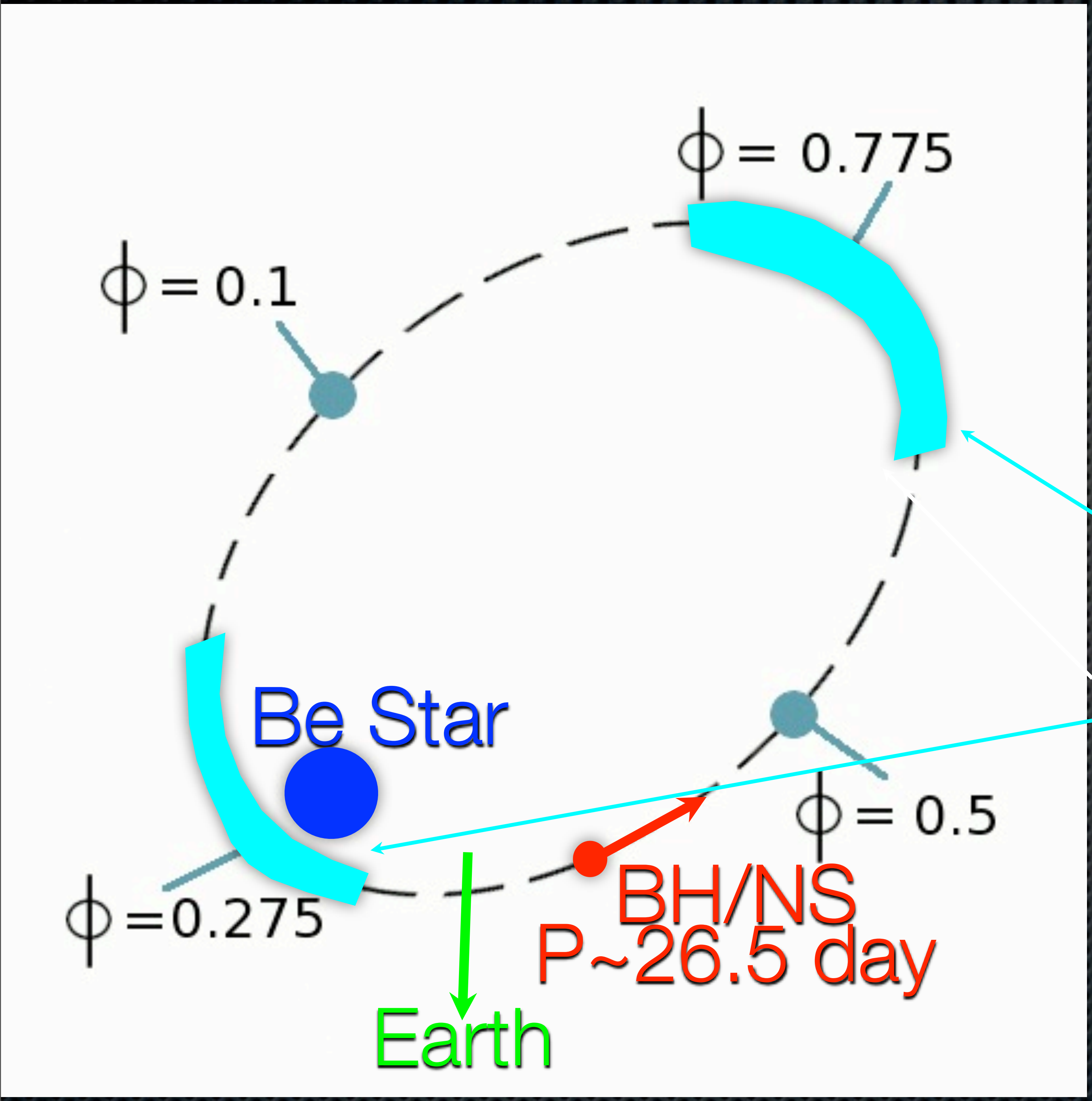


For Ex: LS I +61 303



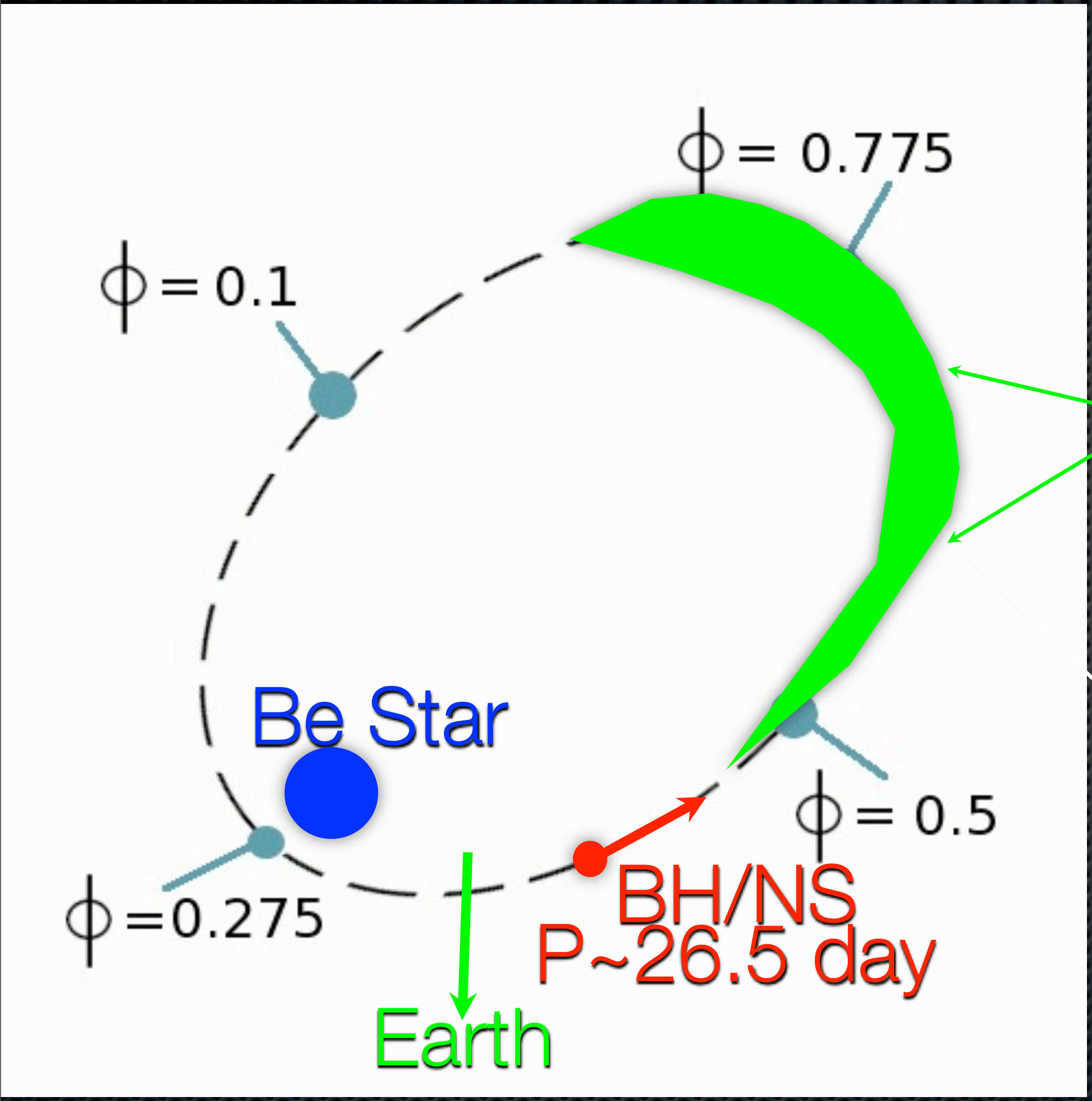
Radio Outbursts near apastron, ~4yr modulation (Gregory 2002)

For Ex: LS I +61 303

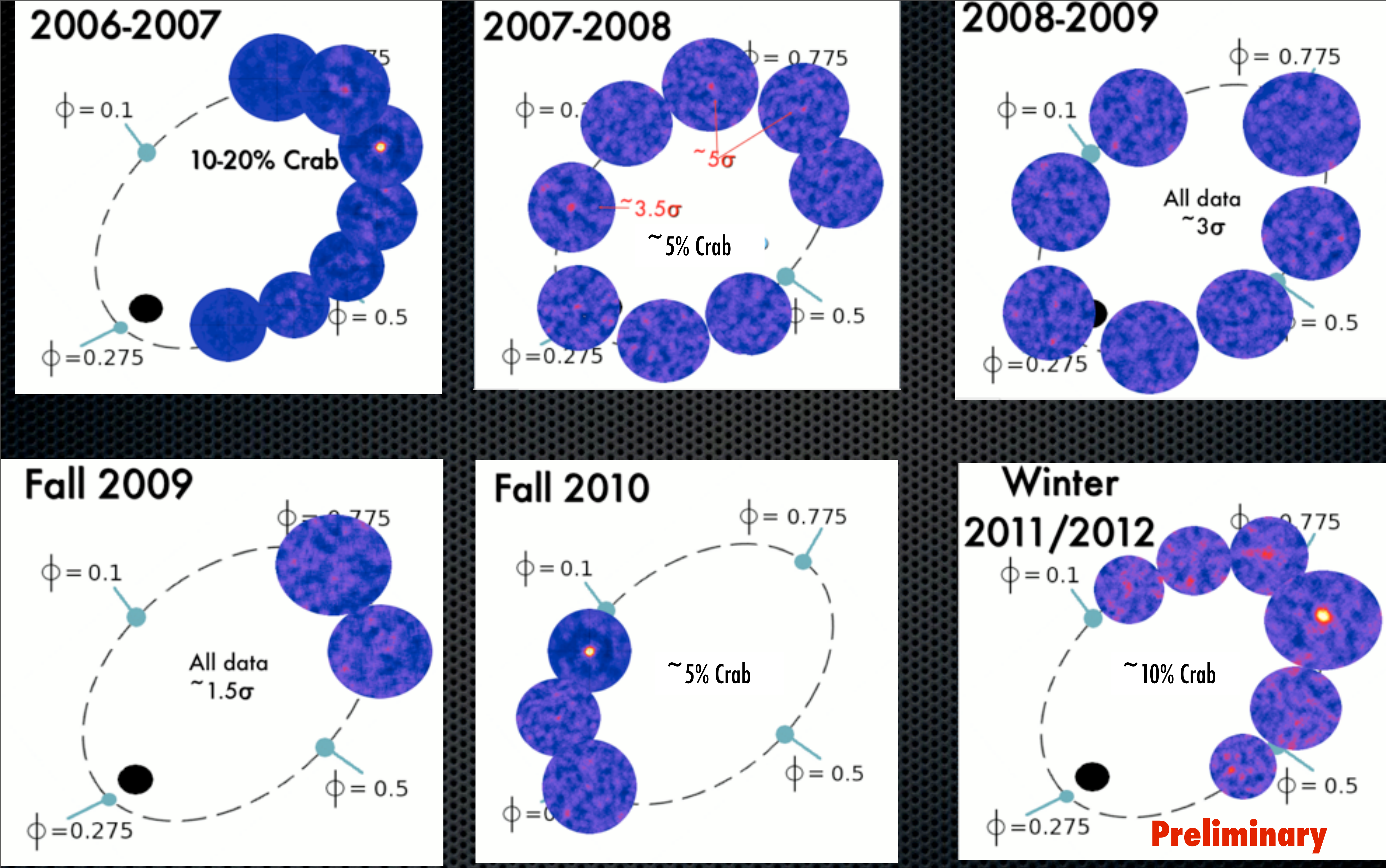


High X-ray activity throughout orbit (strongest at apastron, secondary near periastron)

For Ex: LS I +61 303

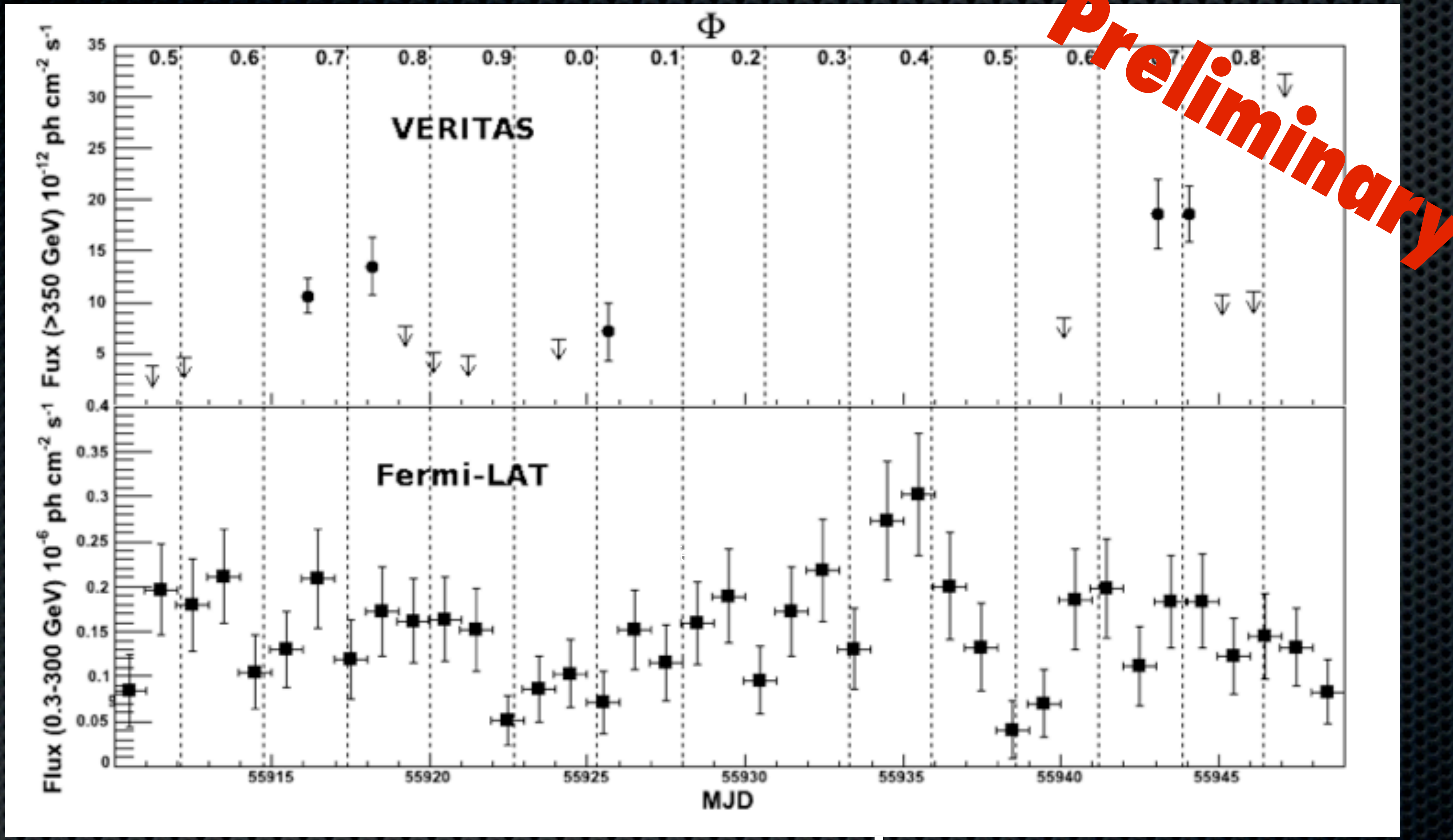


TeV Activity detected by MAGIC/VERITAS (typically, but not always) around apastron passage



While VERITAS cannot rule out the possibility that the normal emission was "missed" in intervening years, it appears LS I +61 303 may go through multi-year TeV modulation....perhaps related to changes in Be star disk??

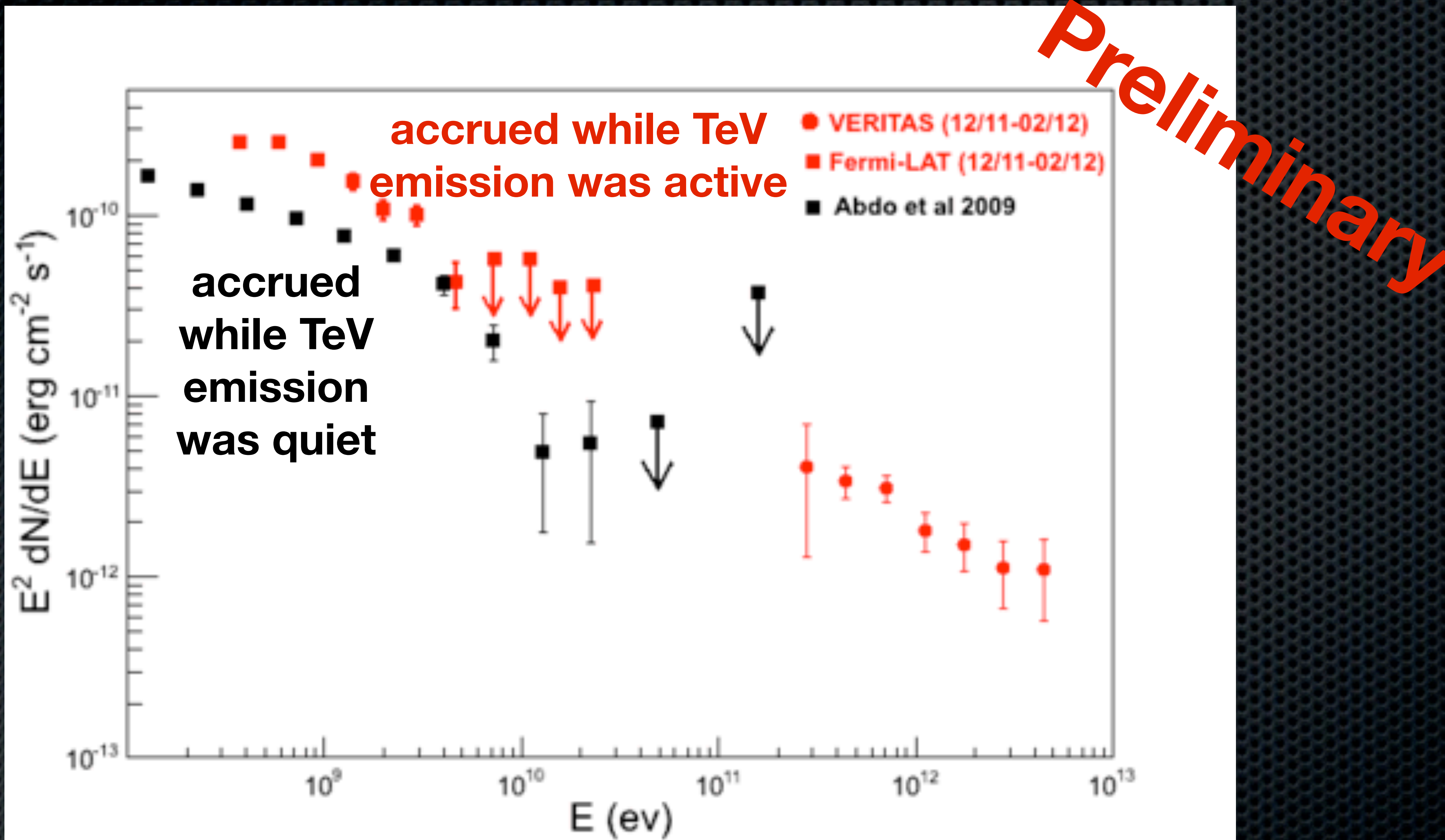
Winter 2011/2012



TeV detection at >10σ, evidence for nightly variability

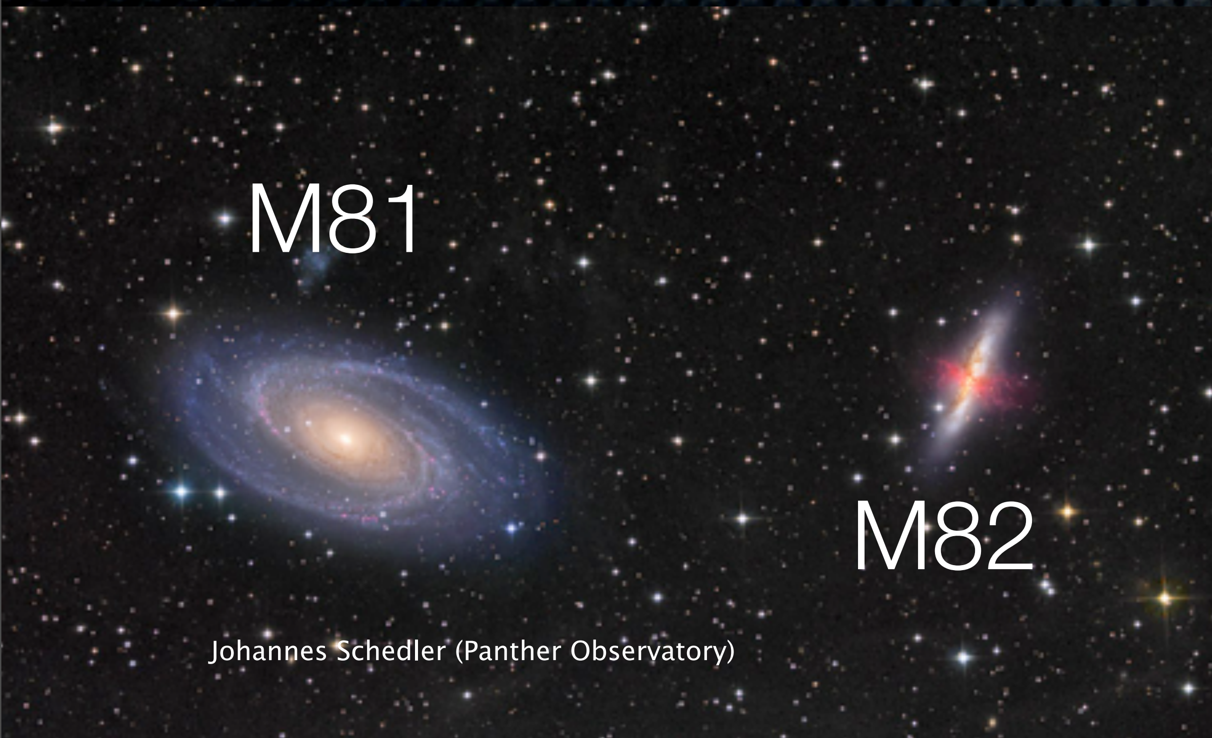
Overlapping monitoring with Fermi-LAT shows no indication of (anti) correlation.

Winter 2011/2012



Fermi-LAT shows emission "shoulder" coincident with VERITAS detection- system still shows cutoff at several GeV...connection between GeV and TeV could possibly be key to resolving debate between MQ and BP models.....possibly absorption plays a role also?

Starburst Galaxy M82



Johannes Schedler (Panther Observatory)


NASA, ESA, The Hubble Heritage Team, (STScI / AURA)

Prototypical Starburst Galaxy:

-Tidal disruption:500 lyr diameter starburst region

-High Star Formation -> High SNR Rate

-100x Milky Way CR density

-High Gas Density >150 cm^3

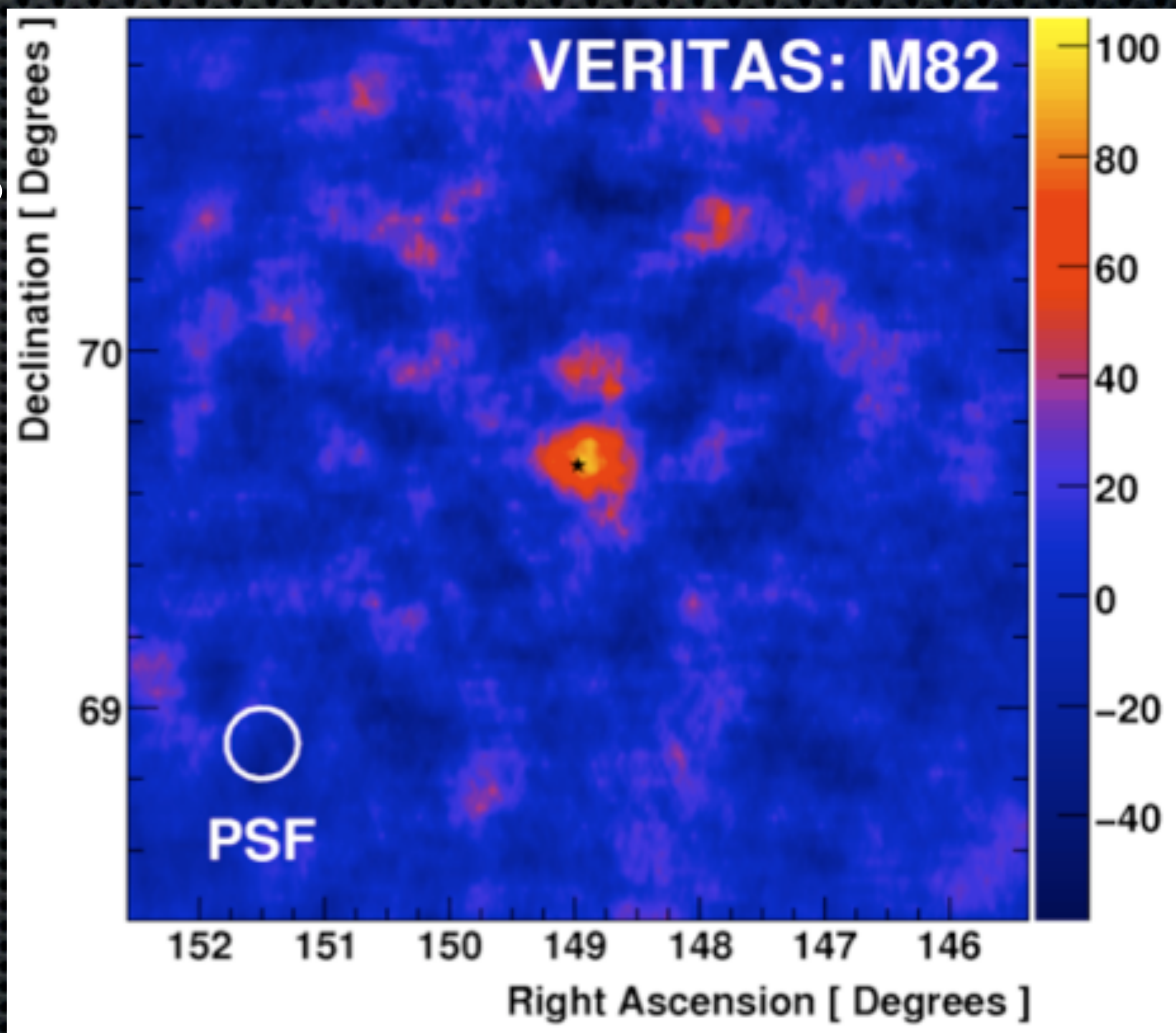
-No strong AGN or jet evidence

VERITAS Detection:

5σ in 137 hrs: Very weak source: 0.9% Crab >700 GeV

-Interpretation: TeV emission from CR interactions w gas

-Implies long standing CR physics prediction (CRs are created in SNRs, stellar winds)



Acciari et al, Nature, 462, 2009

Dark Matter Searches

-WIMPs in mass range of 50 GeV-10 TeV are well motivated DM candidates

Targets: Dsphs, Gal Center, Clusters, UIDs

-Self annihilation of neutralino in this mass range leads to GeV-TeV gamma-rays (spectral cutoff@WIMP mass or "line" signature)

No Detections (yet)- but can use null detection to set limits:

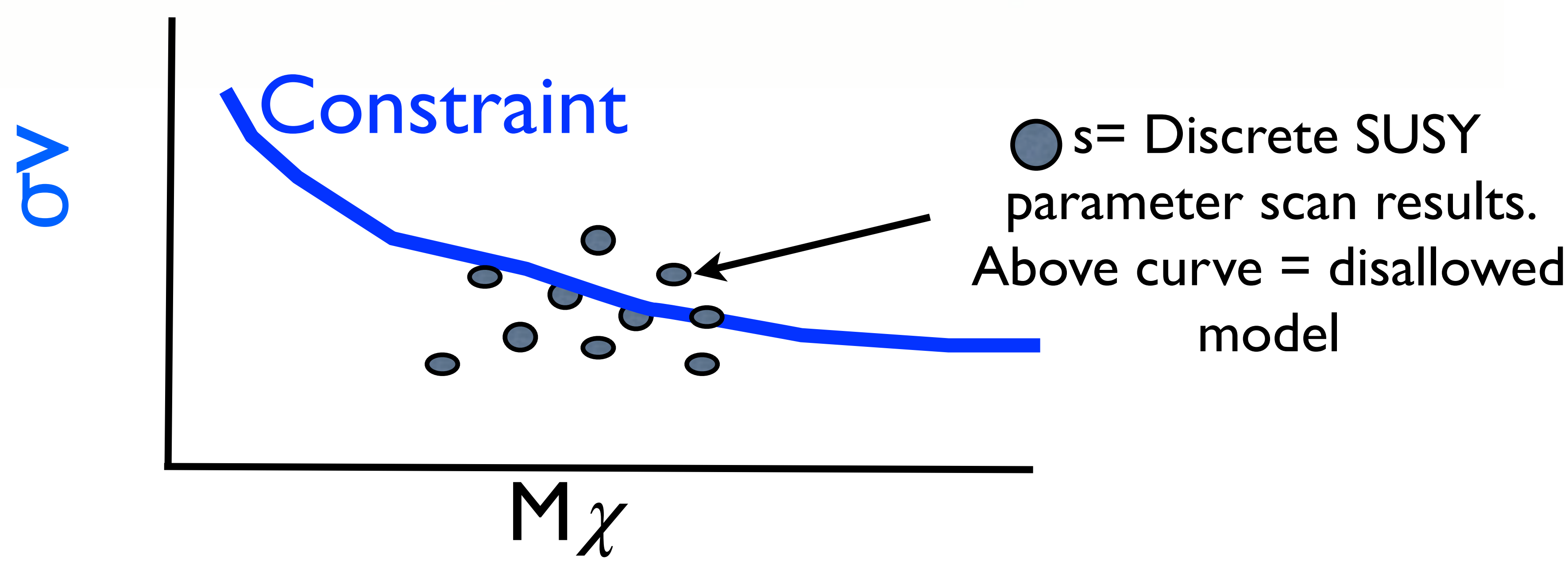
Assume all the γs you didnt see is this:

Constrain this

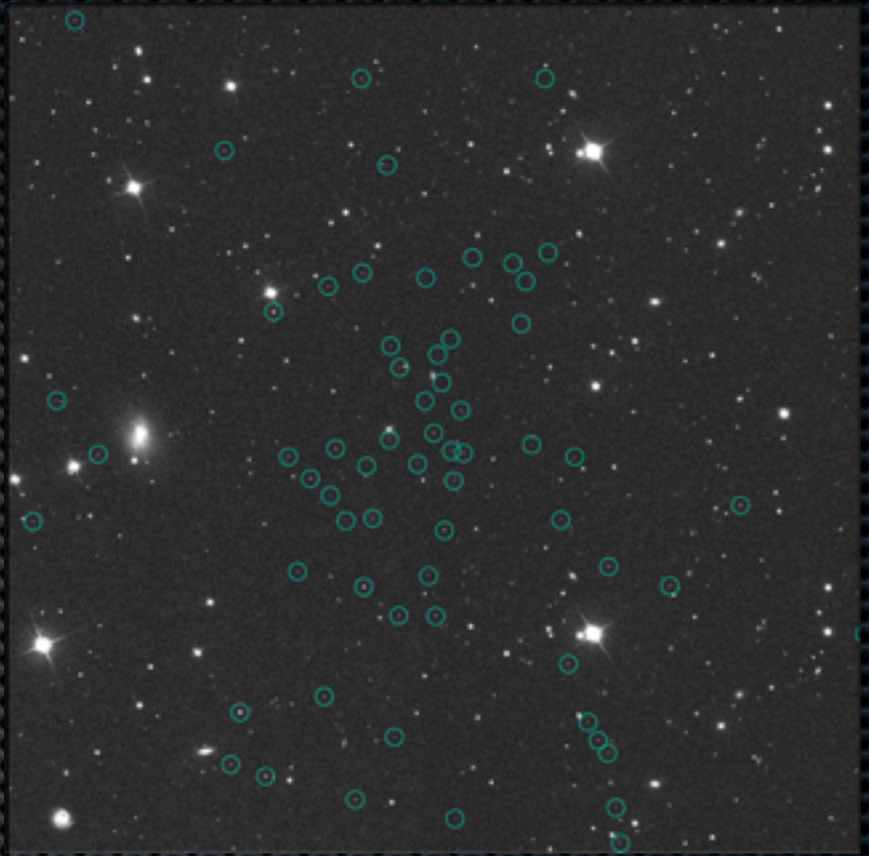
Choose some ppp model to tell you what you should have seen

Find an astronomer to model this for you

$$\frac{d\phi(E,\vec{\psi},\Delta\Omega)}{dE} = \left[\frac{\langle\sigma v\rangle}{8\pi m_{\chi}^{2}}\frac{dN(E,m_{\chi})}{dE}\right] J(\vec{\psi},\Delta\Omega)$$

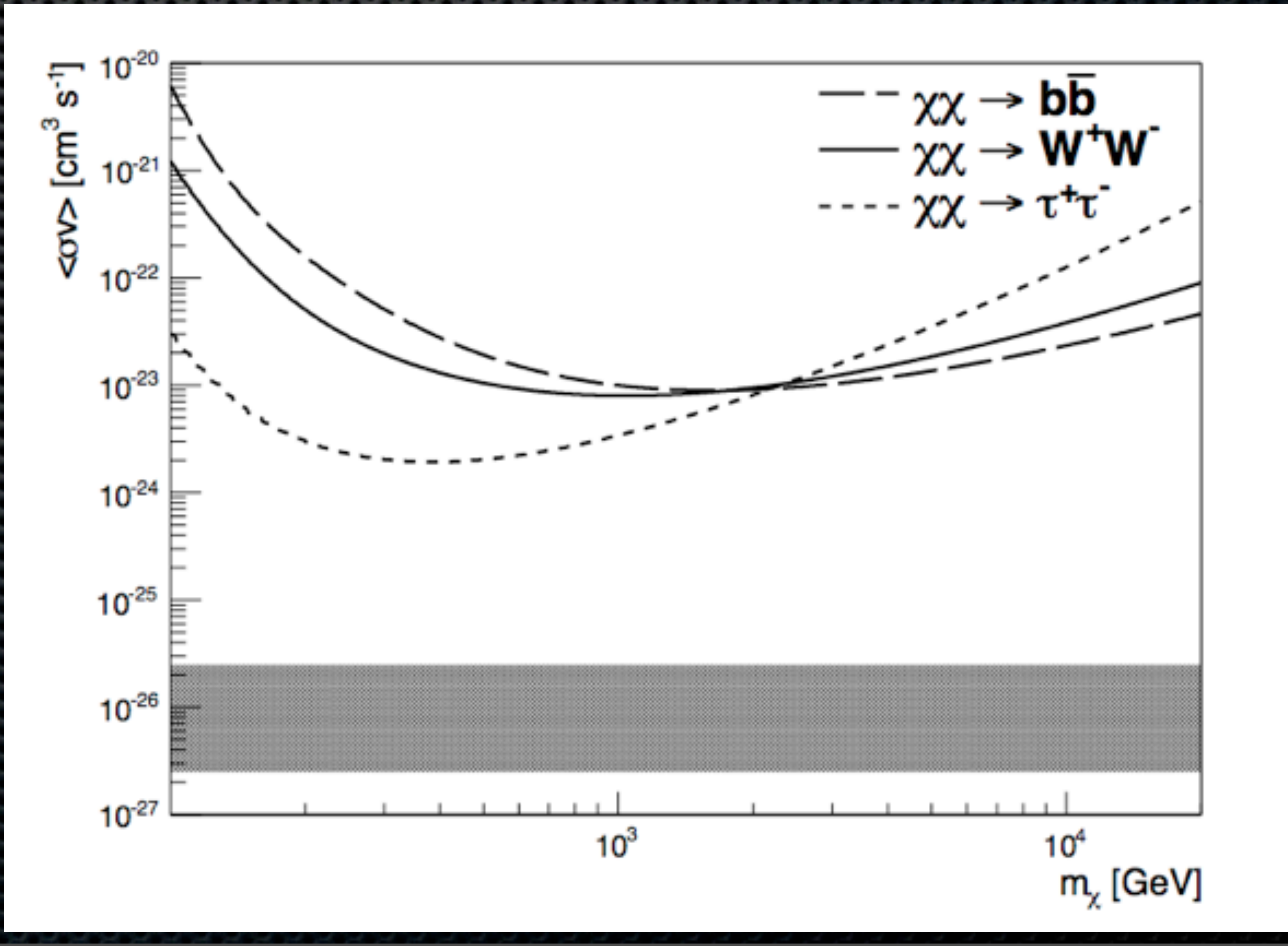


Segue 1 DSph

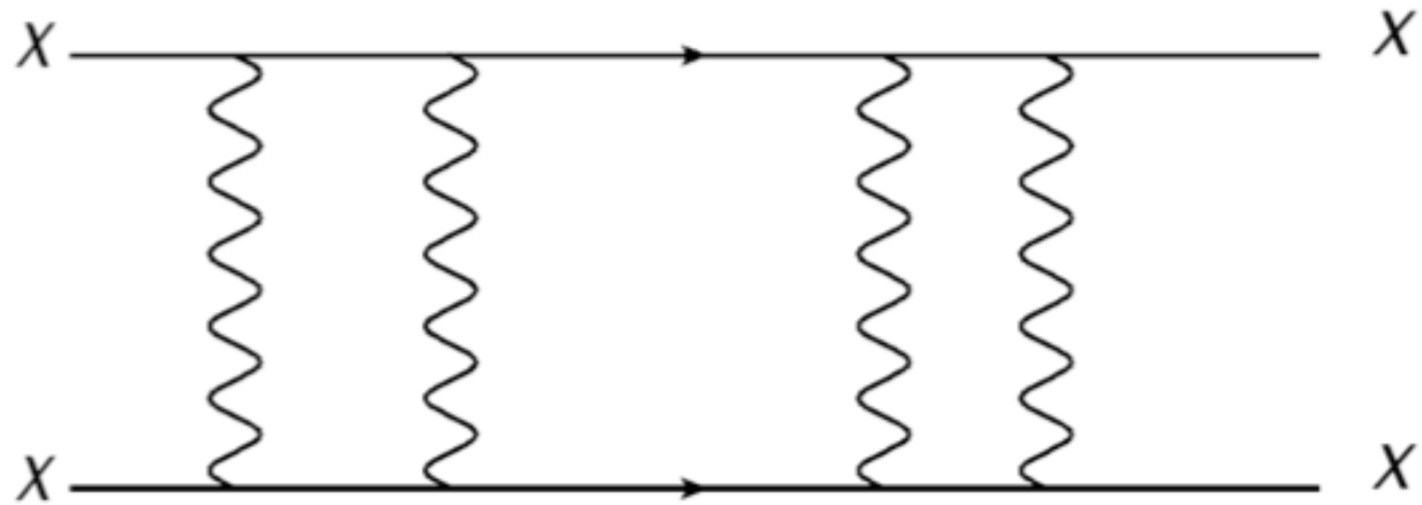


50 Hour VERITAS Observation

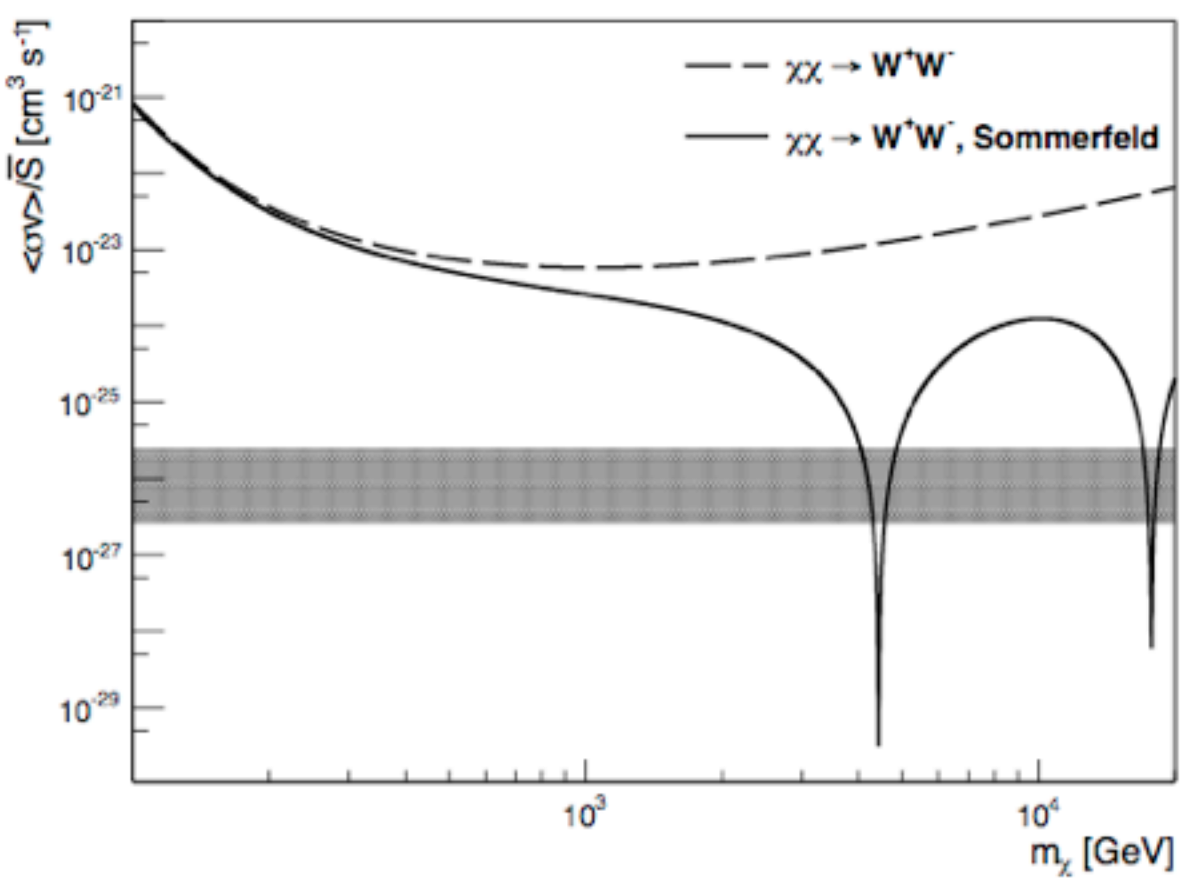
30 excess events (1.4σ)



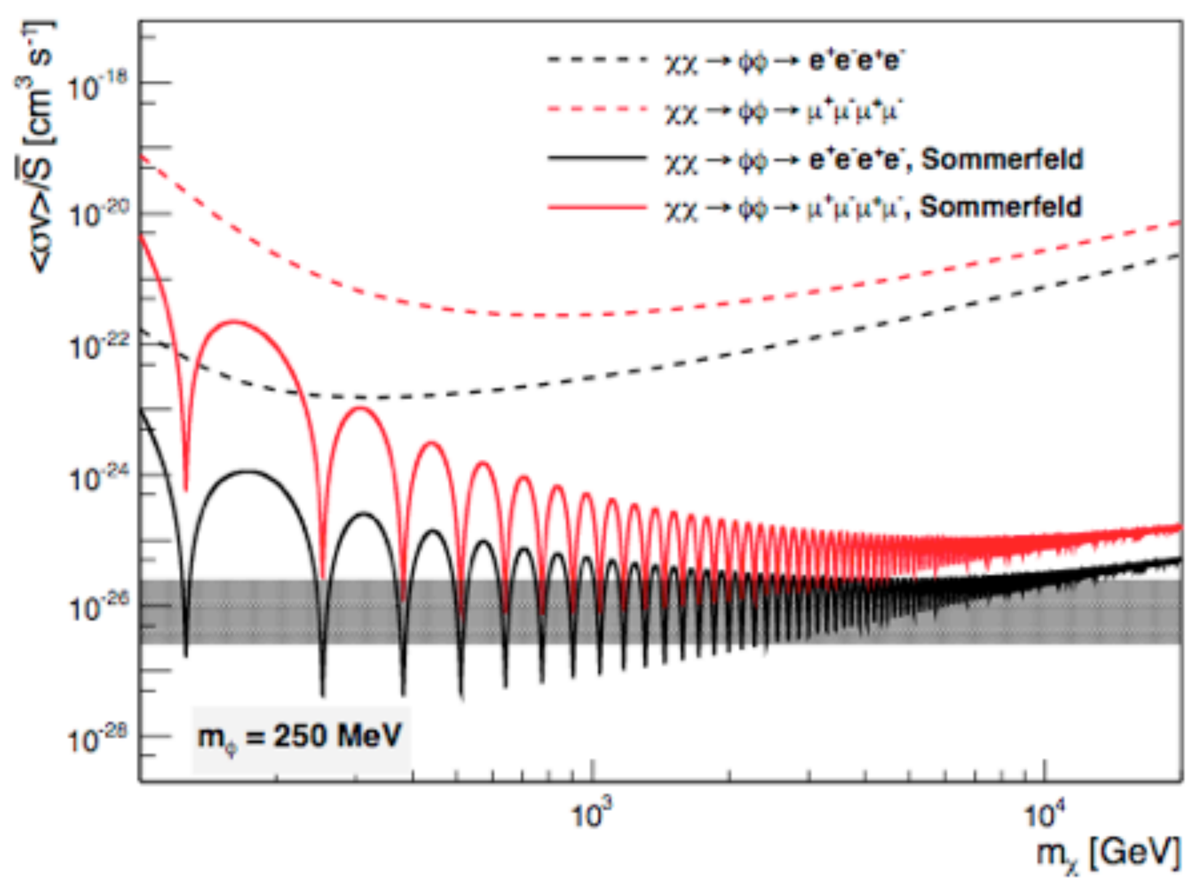
Constraints on low-velocity signal enhancement (Sommerfeld Boost)



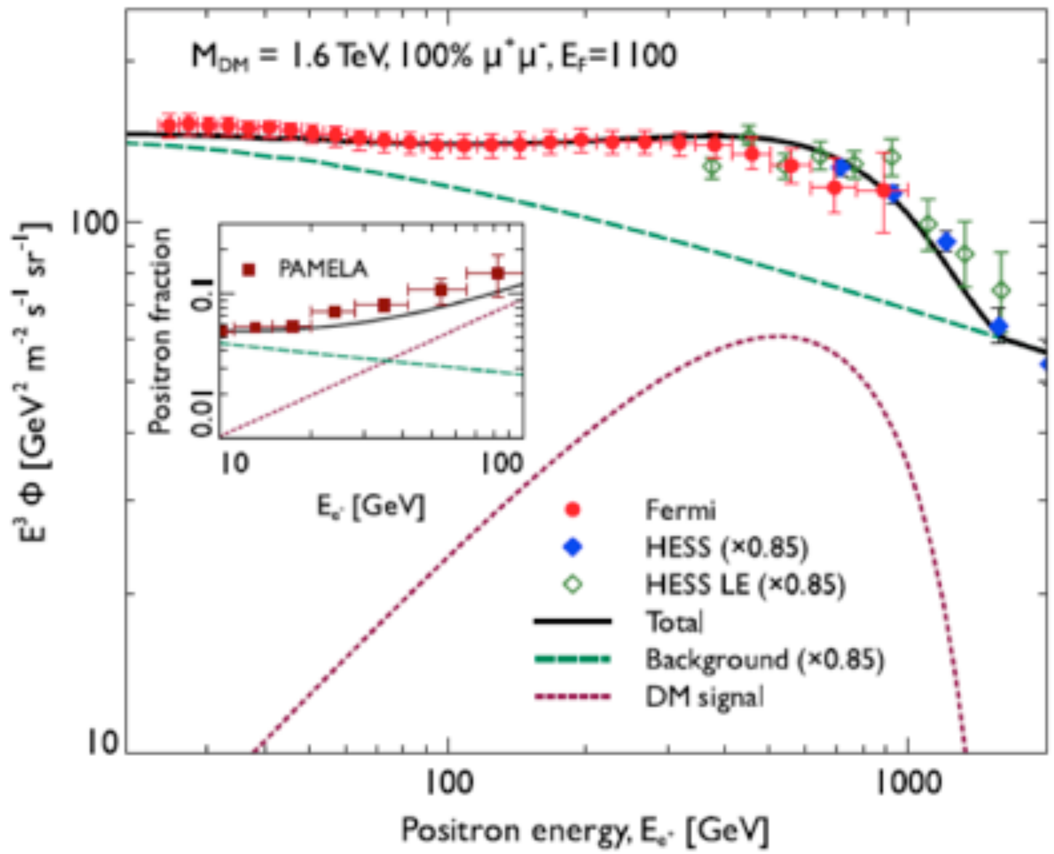
(Latanzi + Silk 2009) Model



Arkani-Hamed et al 2009 Model

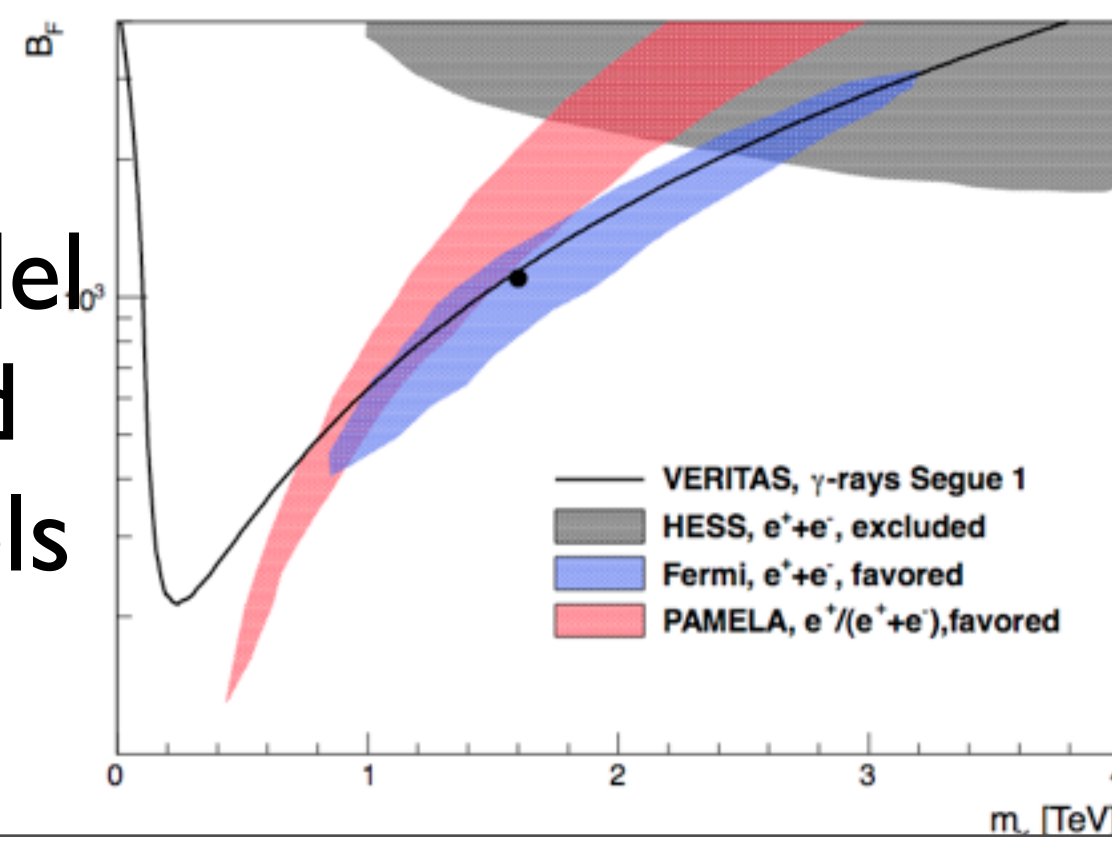


Constraints on DM explanation of Pamela excess



Bumps in Pamela/Fermi/HESS e+/e- data could be explained by leptophilic DM (annihilation exclusively into muons) (Bergstrom, Edsjo, Zaharijas, 2009)

Can use VERITAS muon model excl. curve to limit required "boost factor" in such models

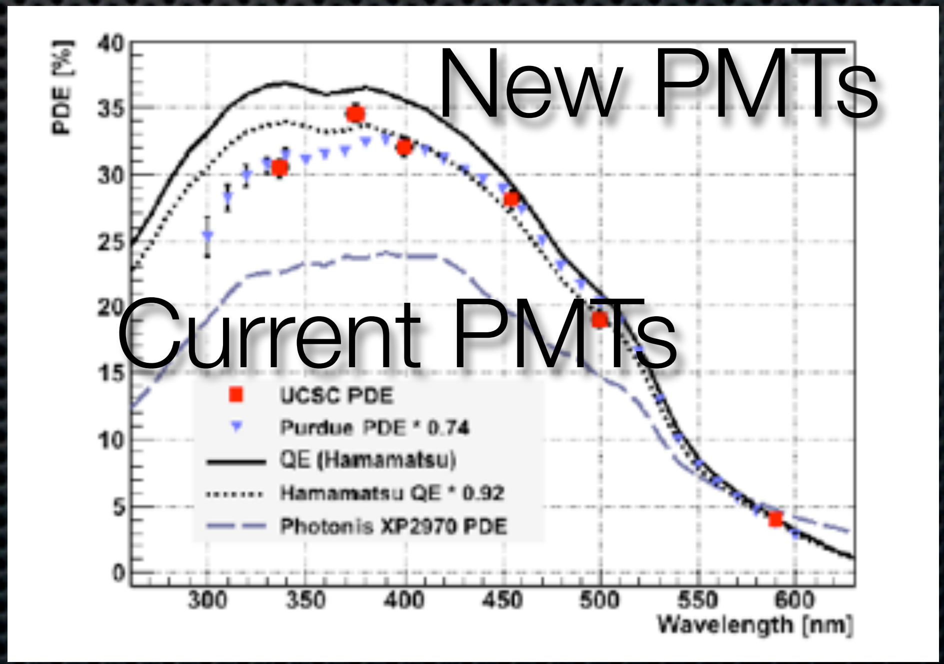


VERITAS Upgrade:

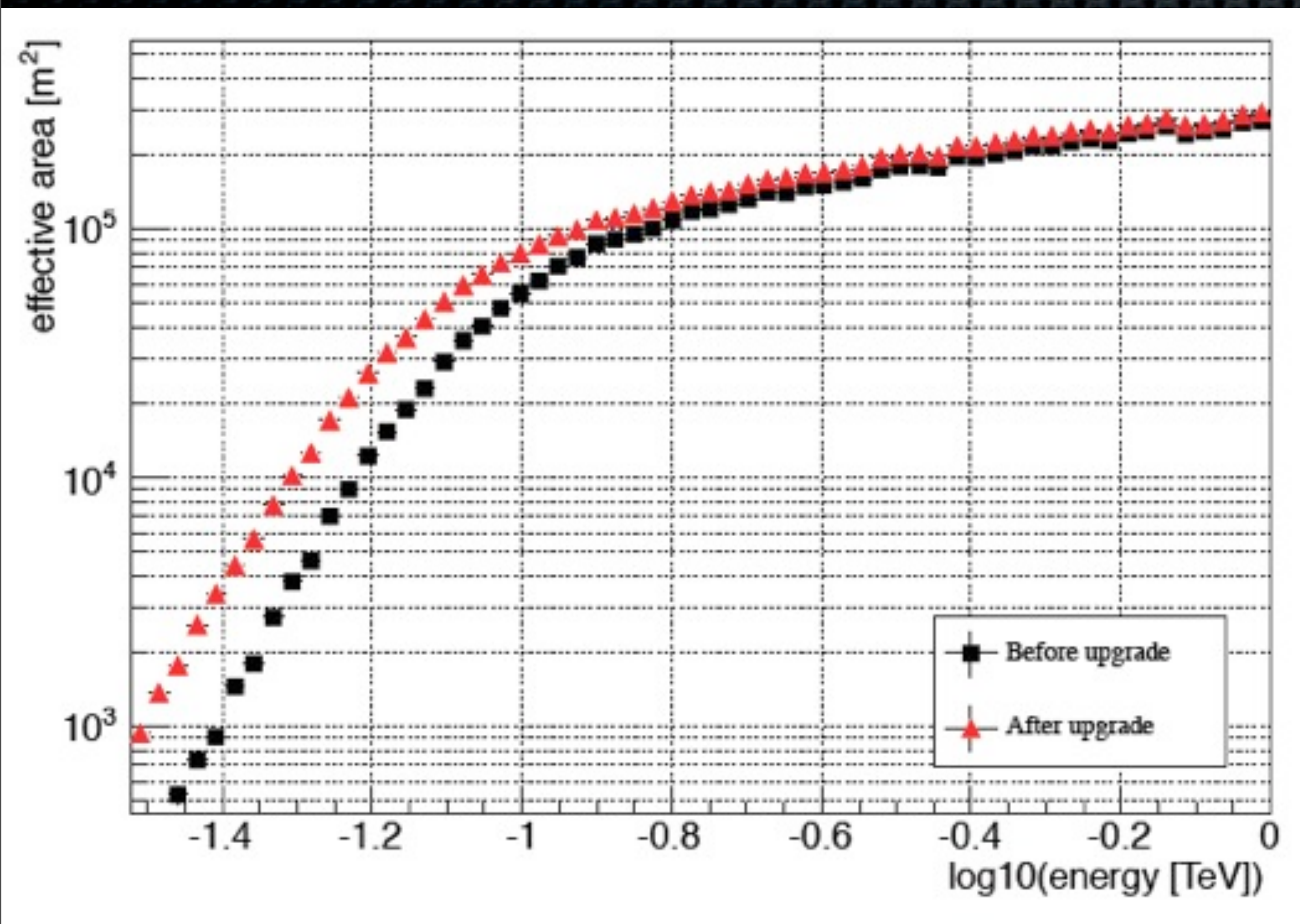
-Summer 2009: repositioned one Tel (T1) to give better array config. (increased sensitivity by 50%)

-New, faster array trigger (installed Fall 2011) gives better noise rejection, lower threshold

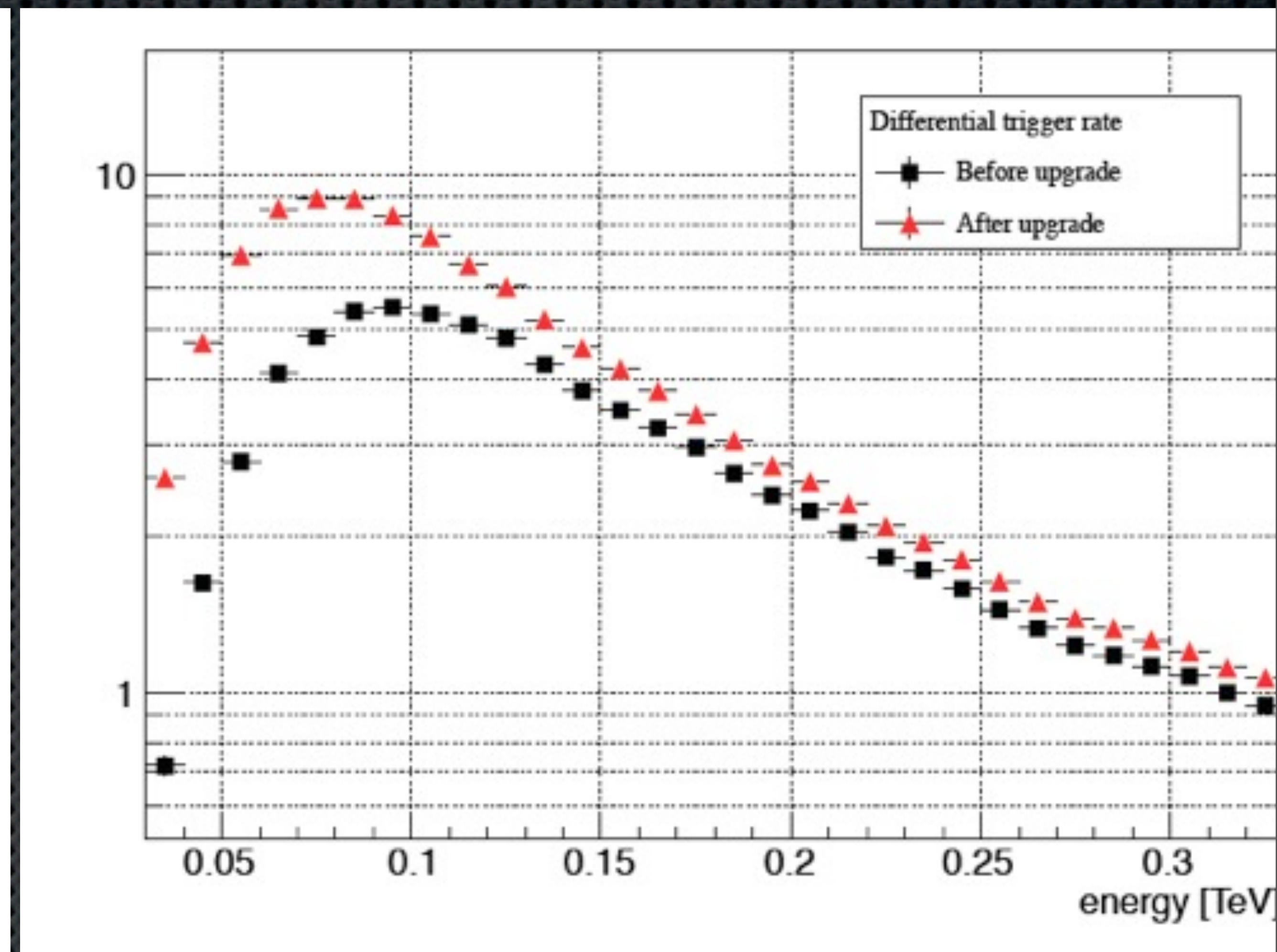
-Summer 2012: All 4 camera will be refurnished with high (~30-35%) Q.E. PMTs.



Expected Improvement

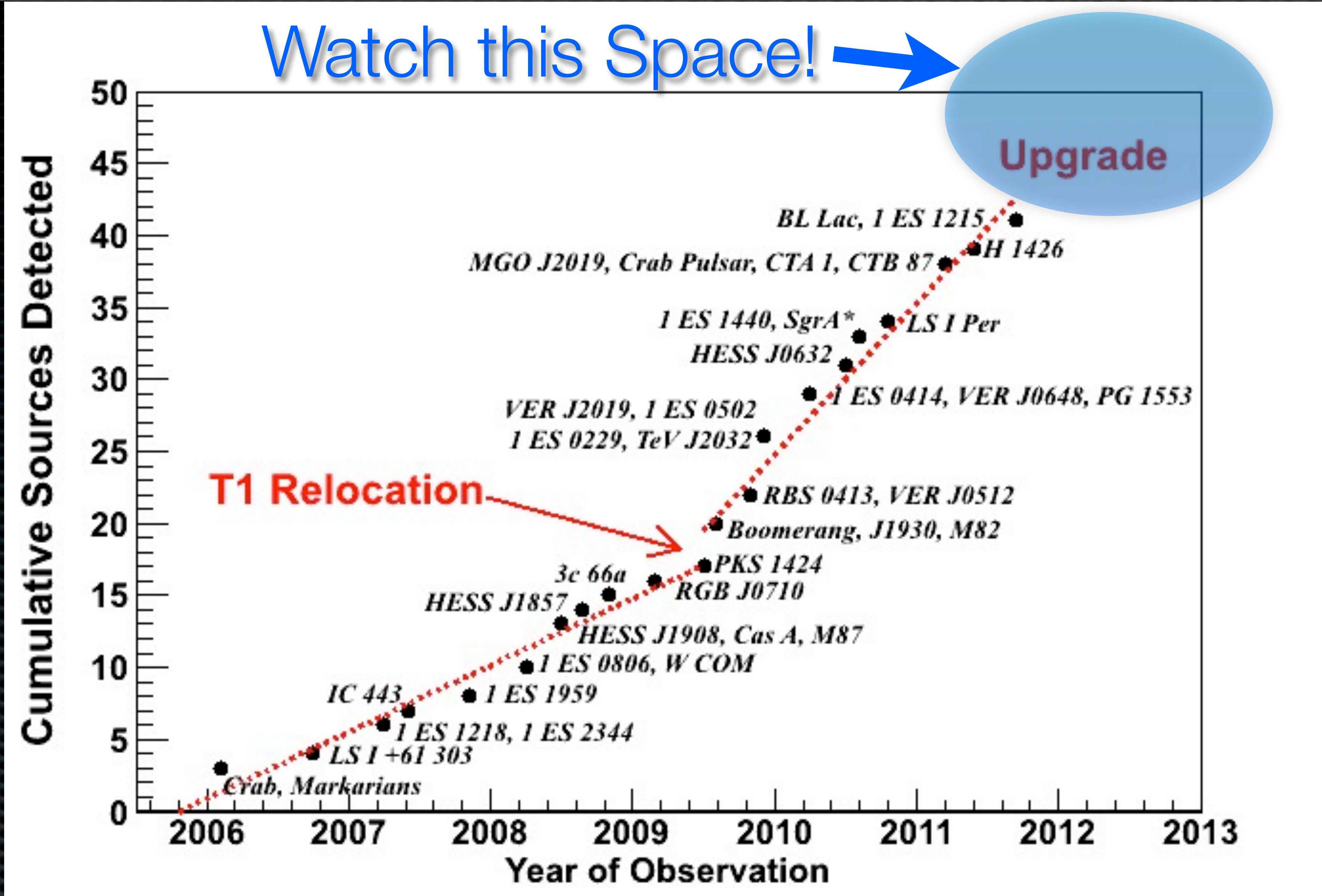


Effective Area vs Energy



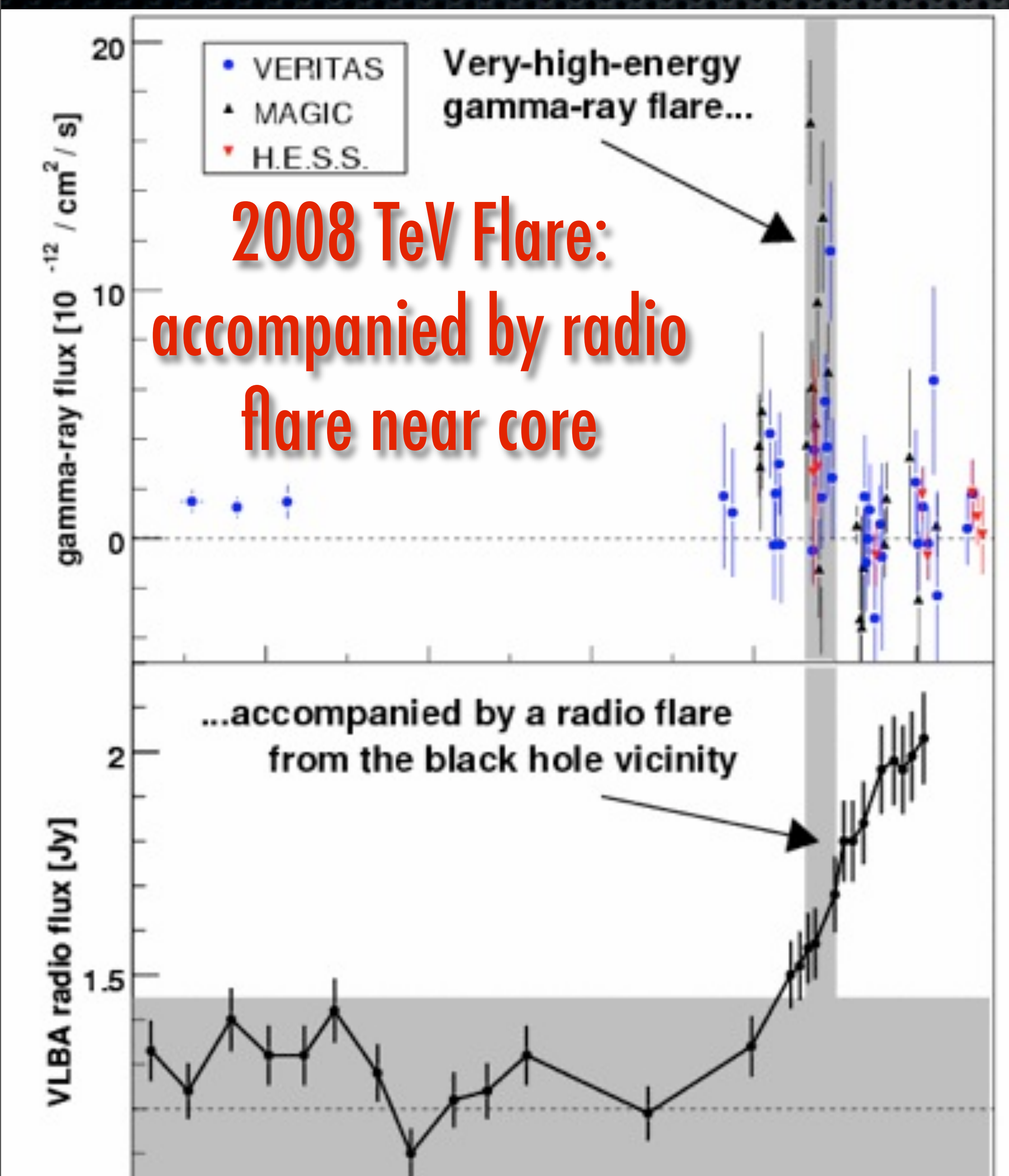
Trigger Rate vs Energy

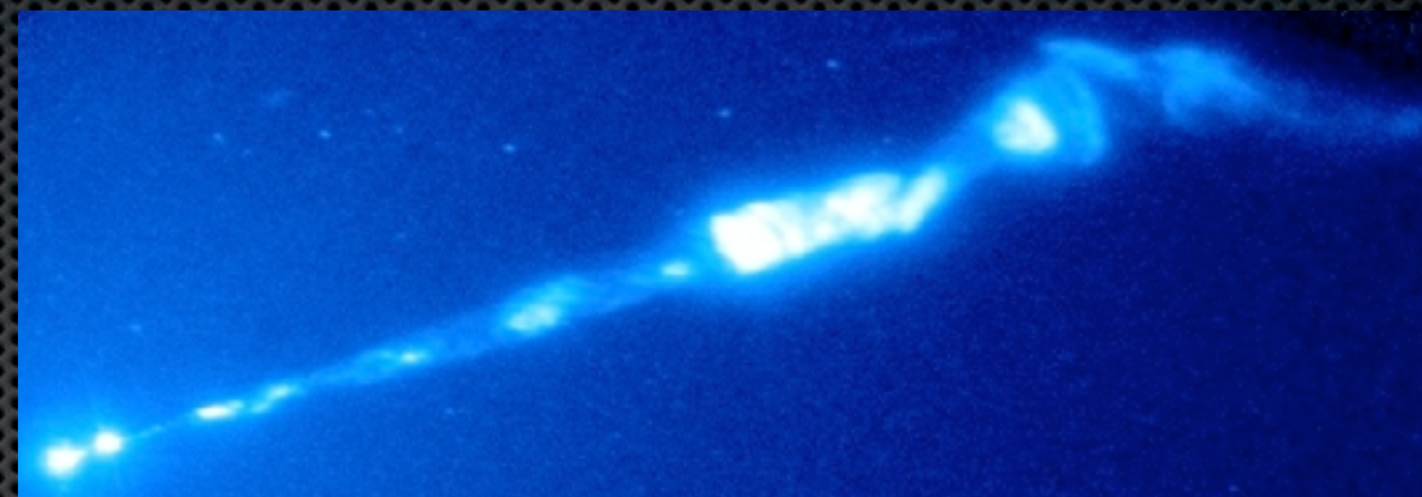
Upgraded array will raise sensitivity significantly around 100 GeV (expected trigger threshold of 75 GeV): Provide ideal overlap with Fermi, potentially unlock a range of new sources

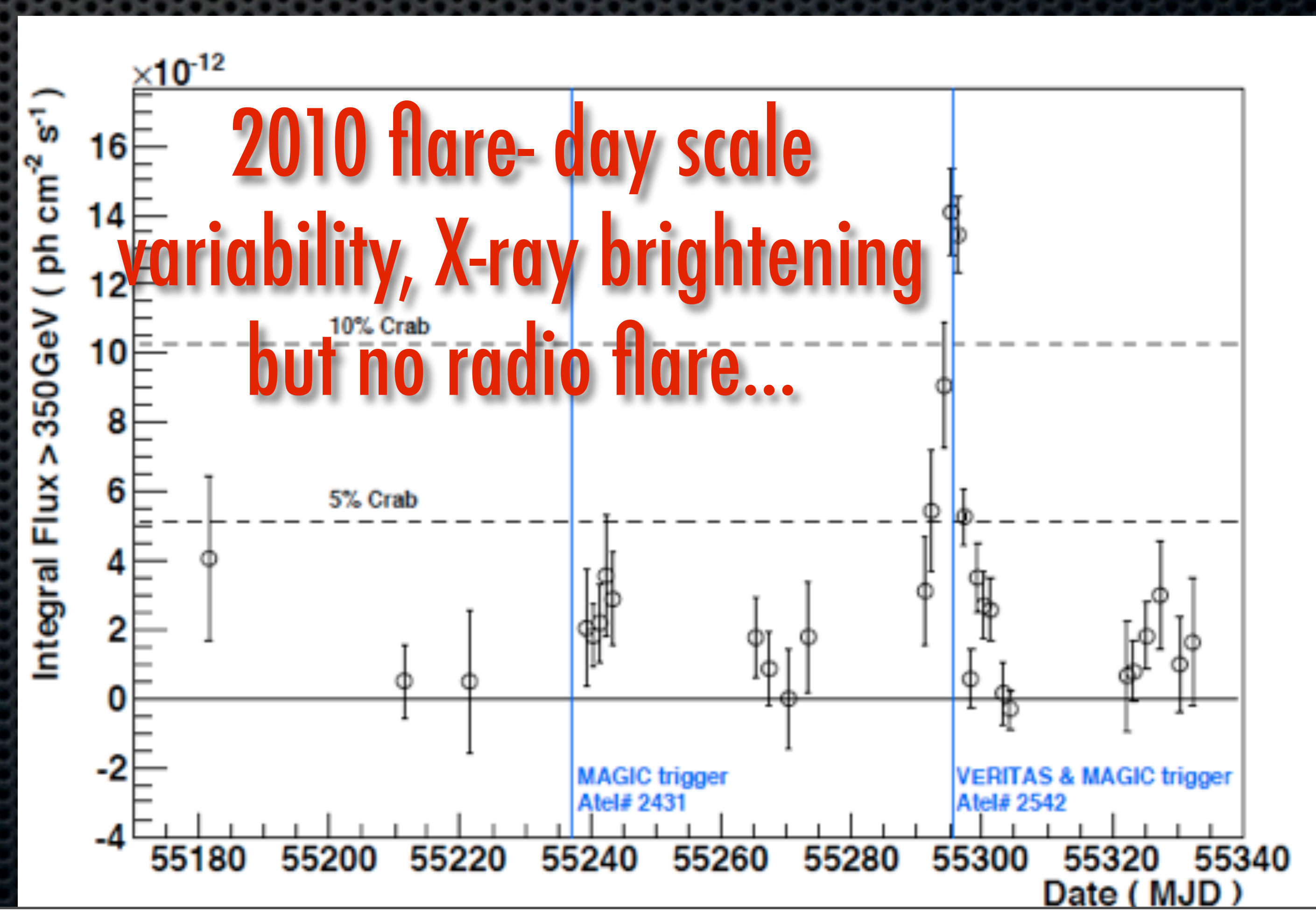


Summary: VERITAS is making key contributions to understanding of TeV emission from a wide variety of cosmic source classes as well as making unique and important measurements in particle astrophysics. Upgrade will only further enable great discoveries.....

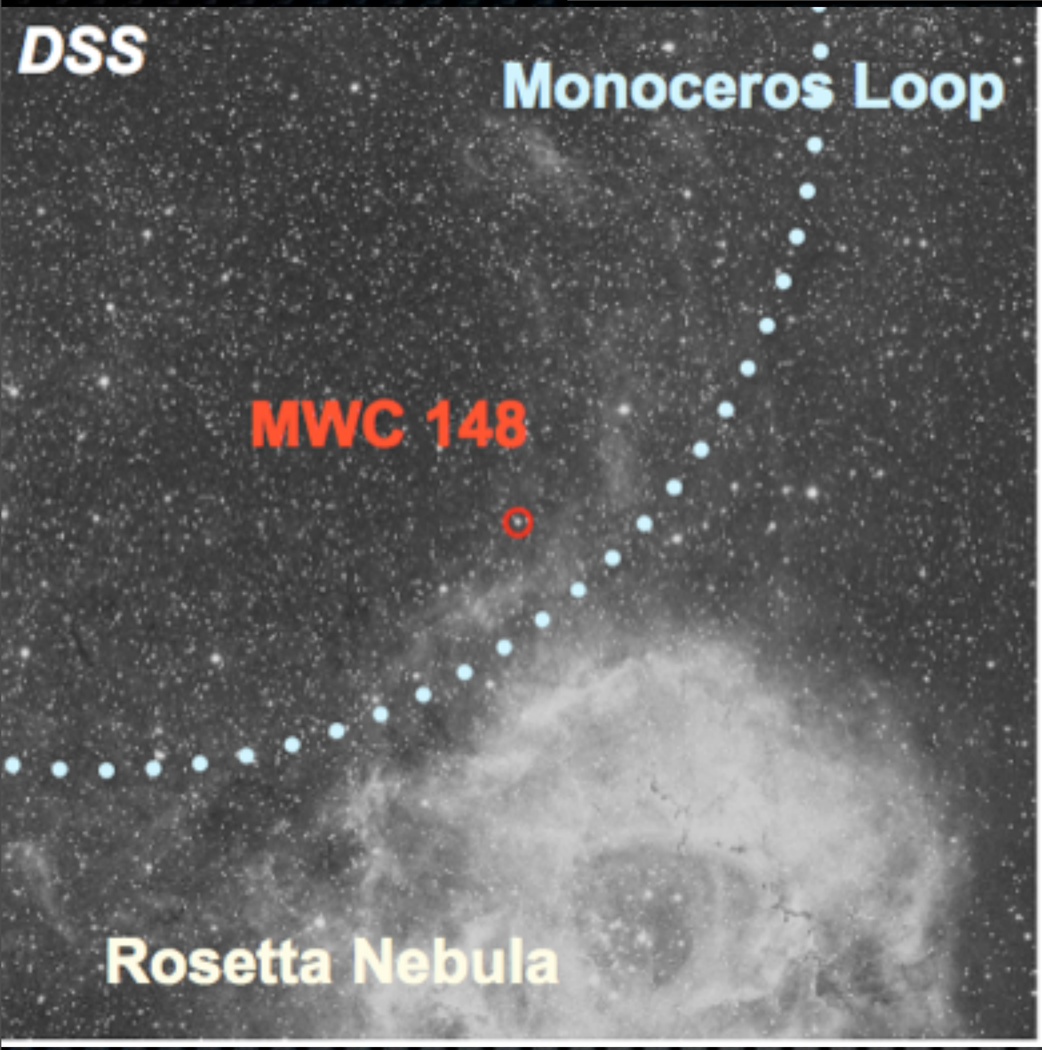
Other Extragalactic Highlights: M87 MW campaigns:





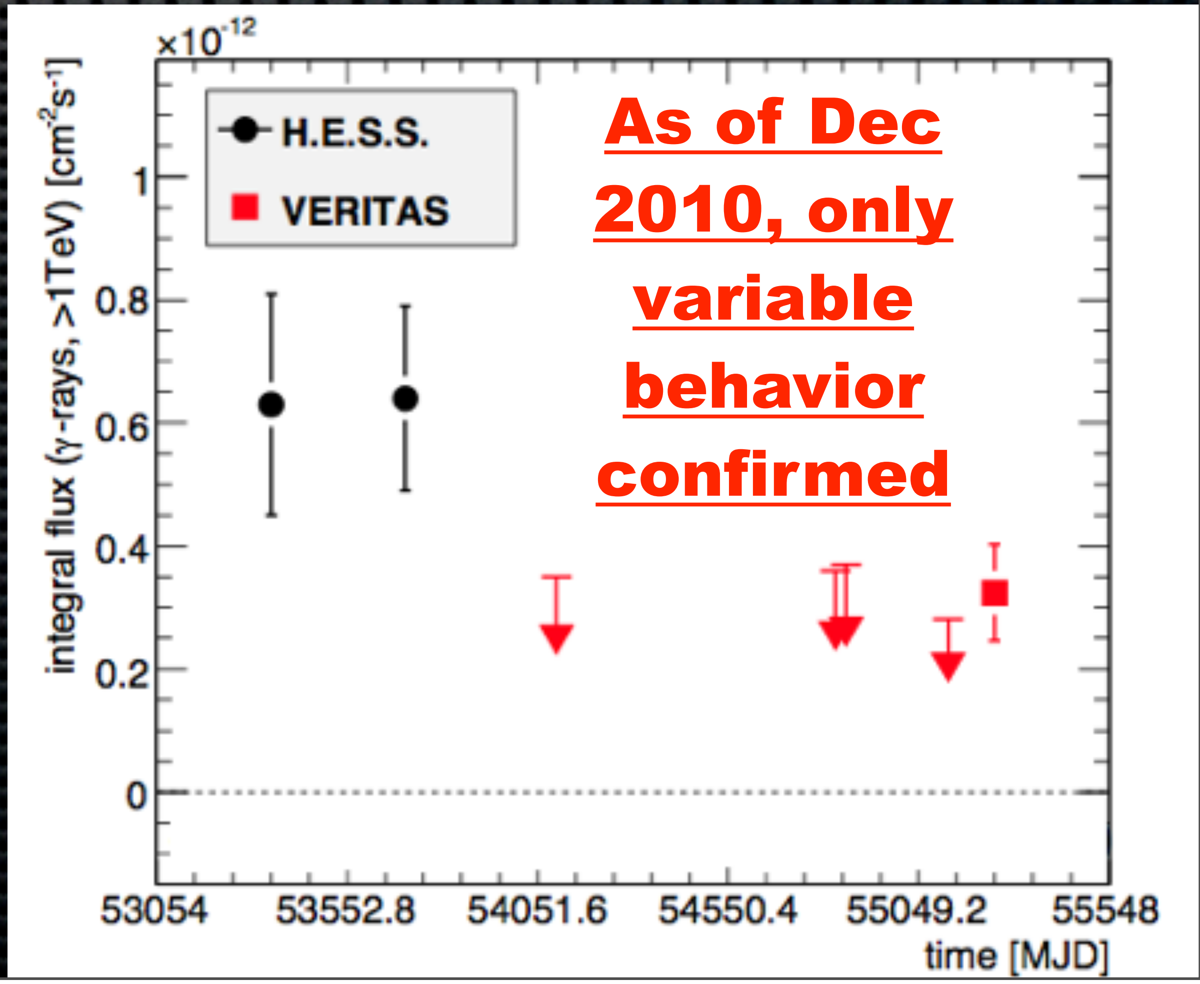


HESS J0632+057

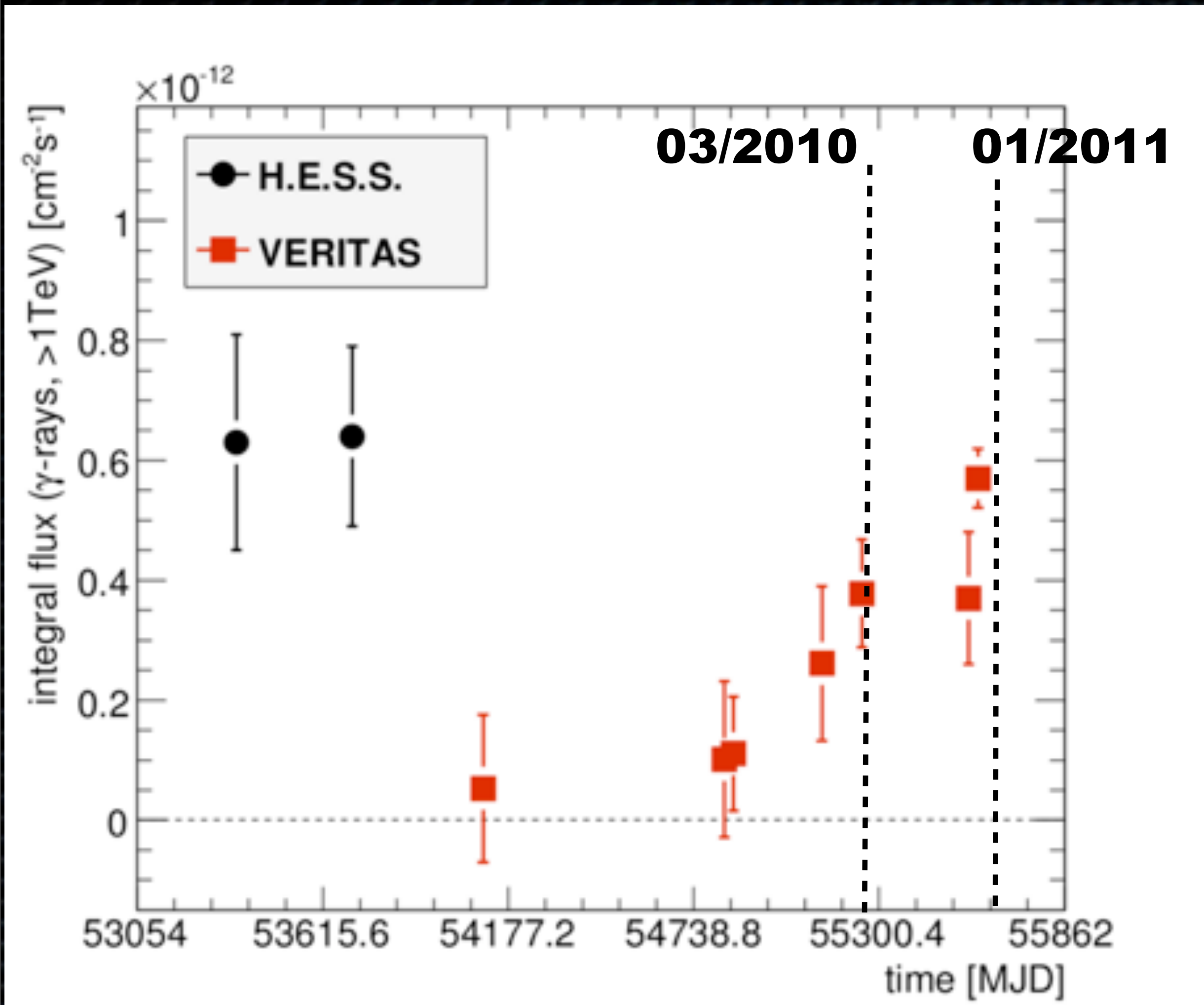


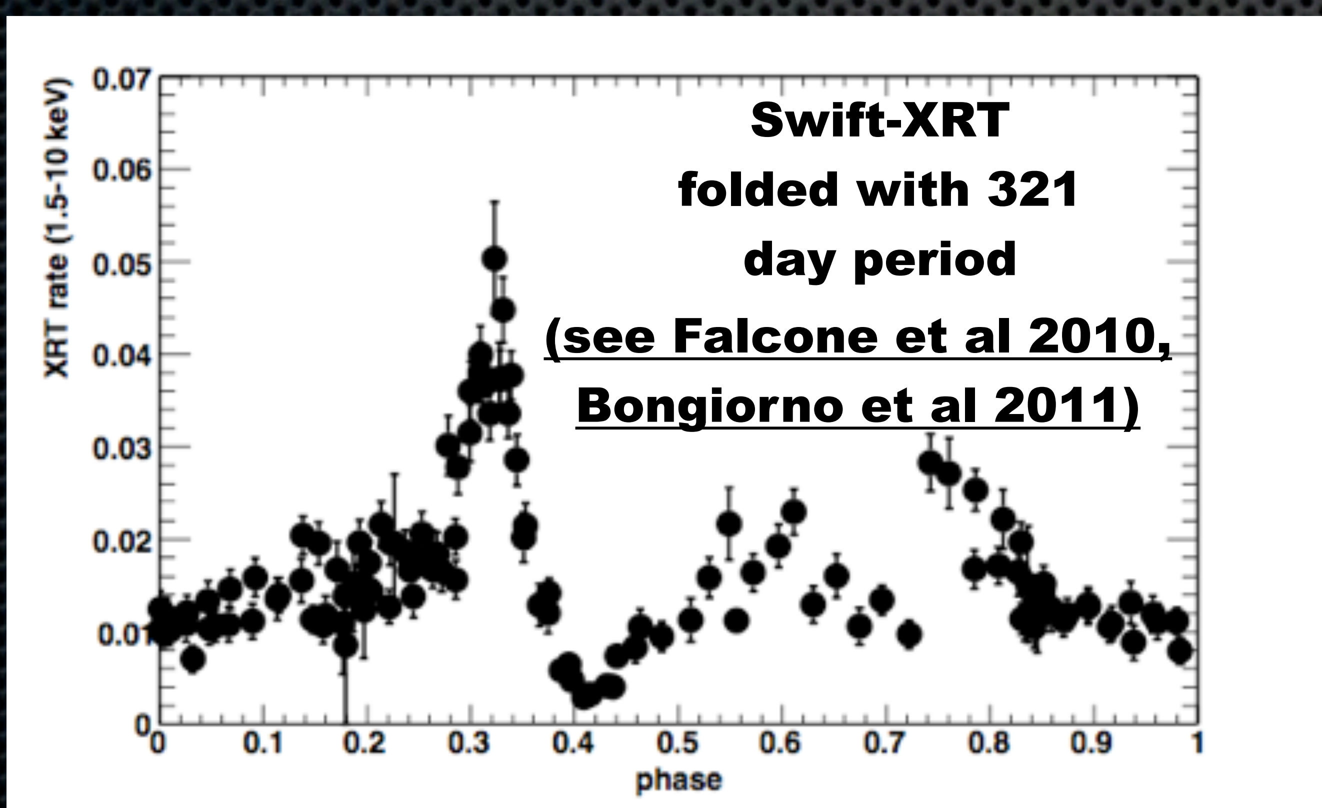
- -MWC 148, 16 $M_{\odot}$ B0pe Star, 1.5kpc
- -No binary companion observed
- -Original HESS TeV detection, VERITAS ULs and detection followed
- -No binary companion observed

Until 2011, source was only known to be variable in TeV with no obvious binary behavior. Swift/VERITAS partnership has been crucial in the identification as 4th TeV binary



HESS J0632+057

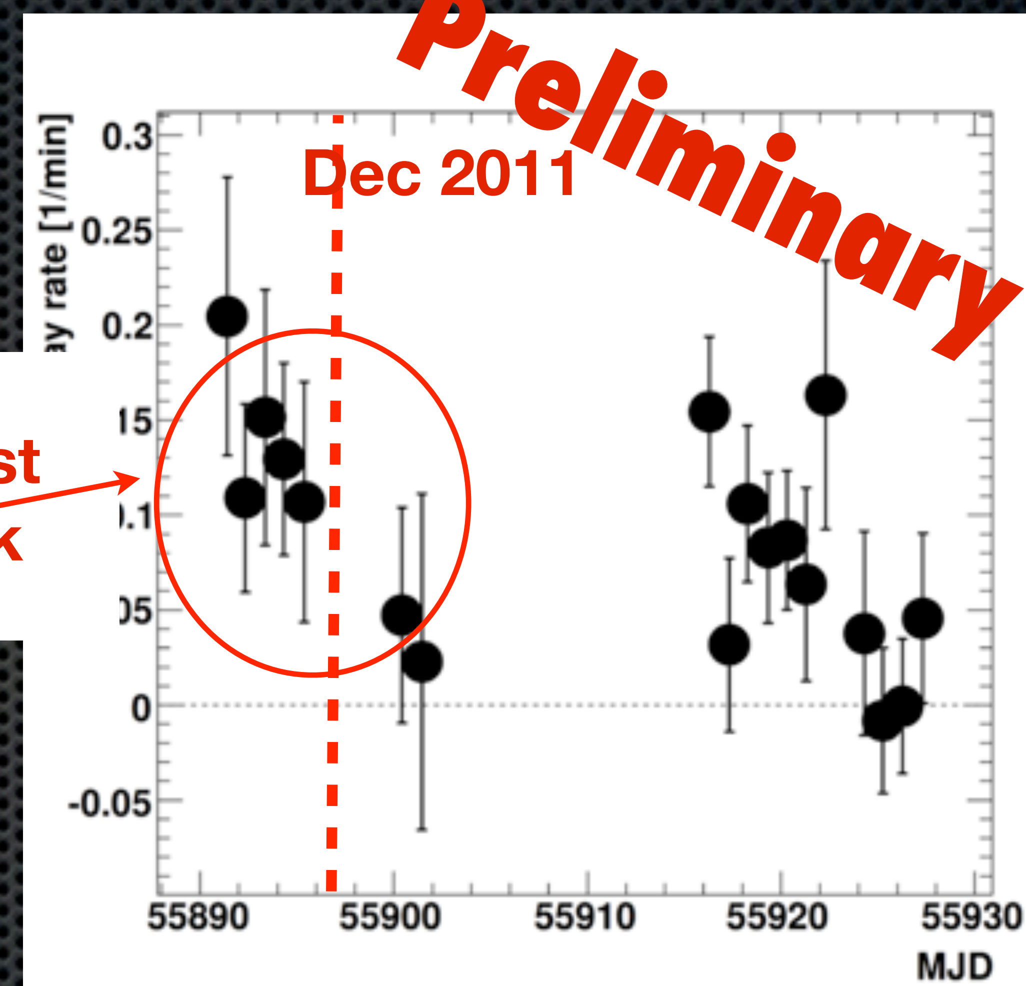


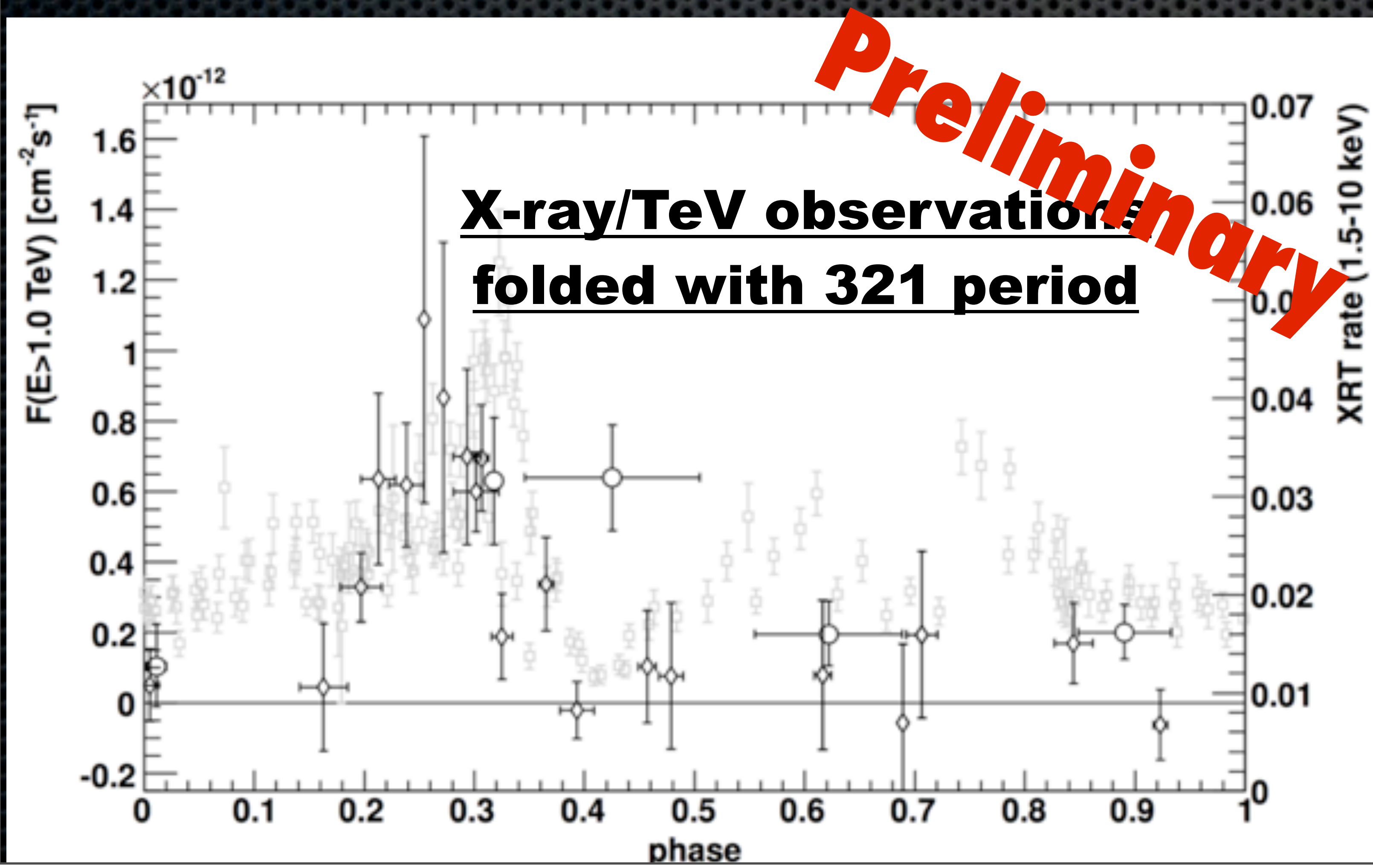


Previous TeV observations taken in conjunction indicated TeV should peak again in Winter 2011....

HESS J0632+057

Latest VERITAS Observations:
November 2011-January 2012

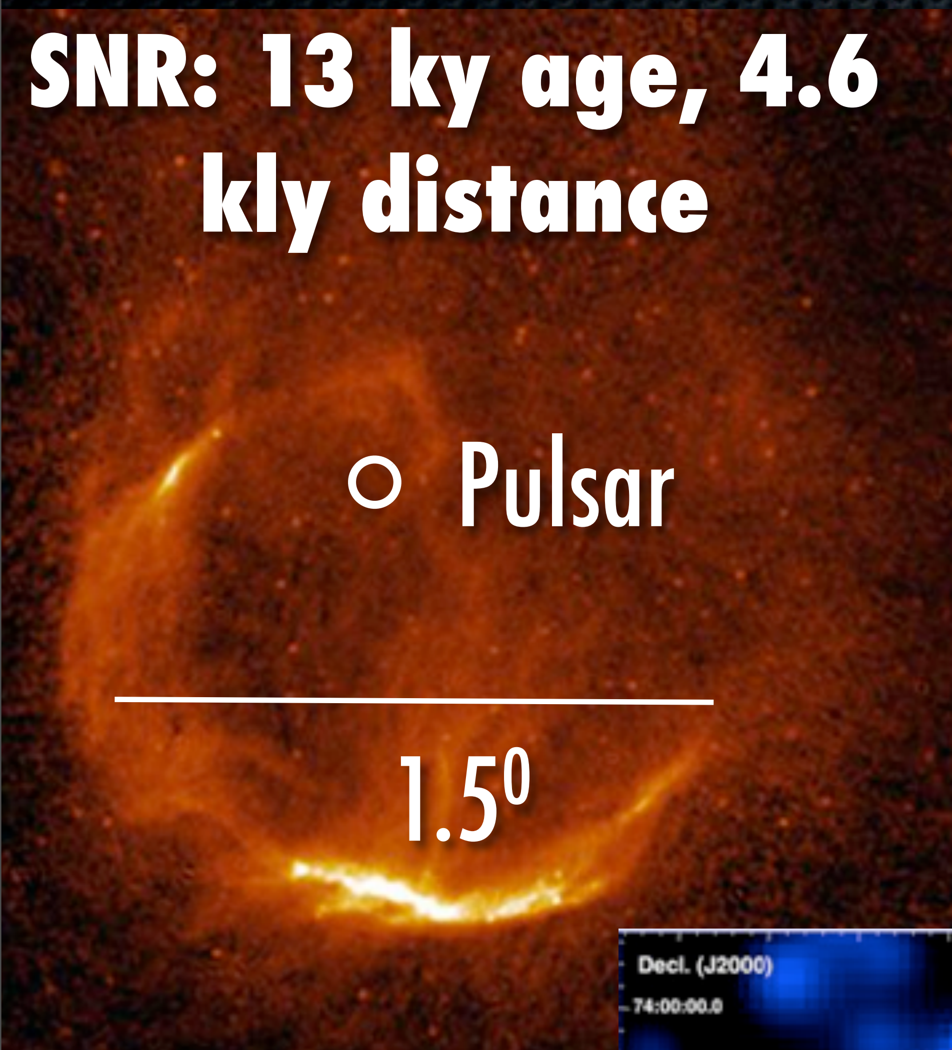




Source identified as a TeV Binary- possible X-ray/TeV lag?

Galactic Accelerators:

The Supernova Remnant CTA 1



Fermi Pulsar

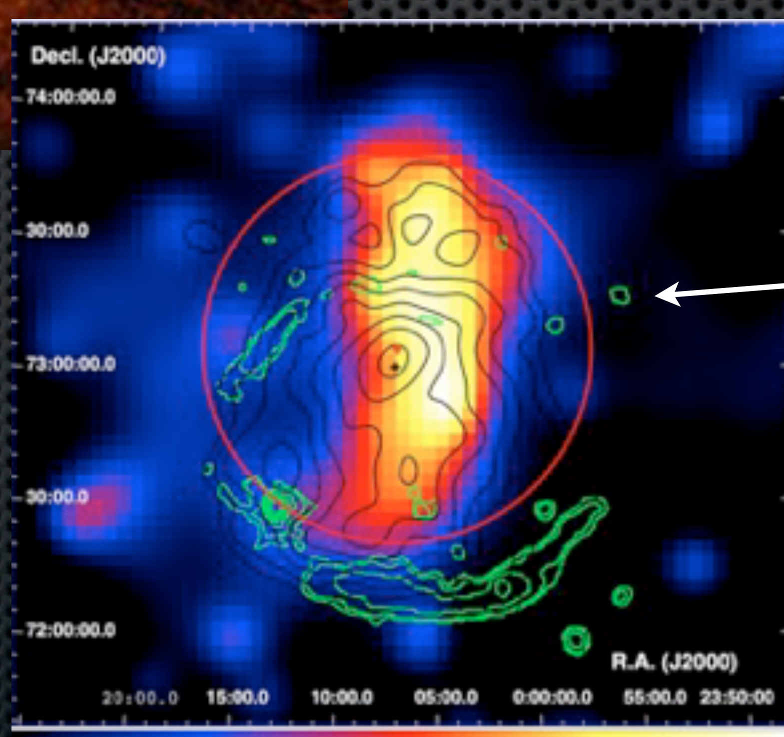
Discovered in blind search

(Abdo et al. 2008)

$\dot{E}$ = 4.5x10 35 erg s -1

P = 315 ms

char. age = 13.9 kyrs



Fermi-LAT off pulsed emission surrounds pulsar, not SNR shock

Original Array Reconfigured