VERITAS Observations of Microquasar/Candidates

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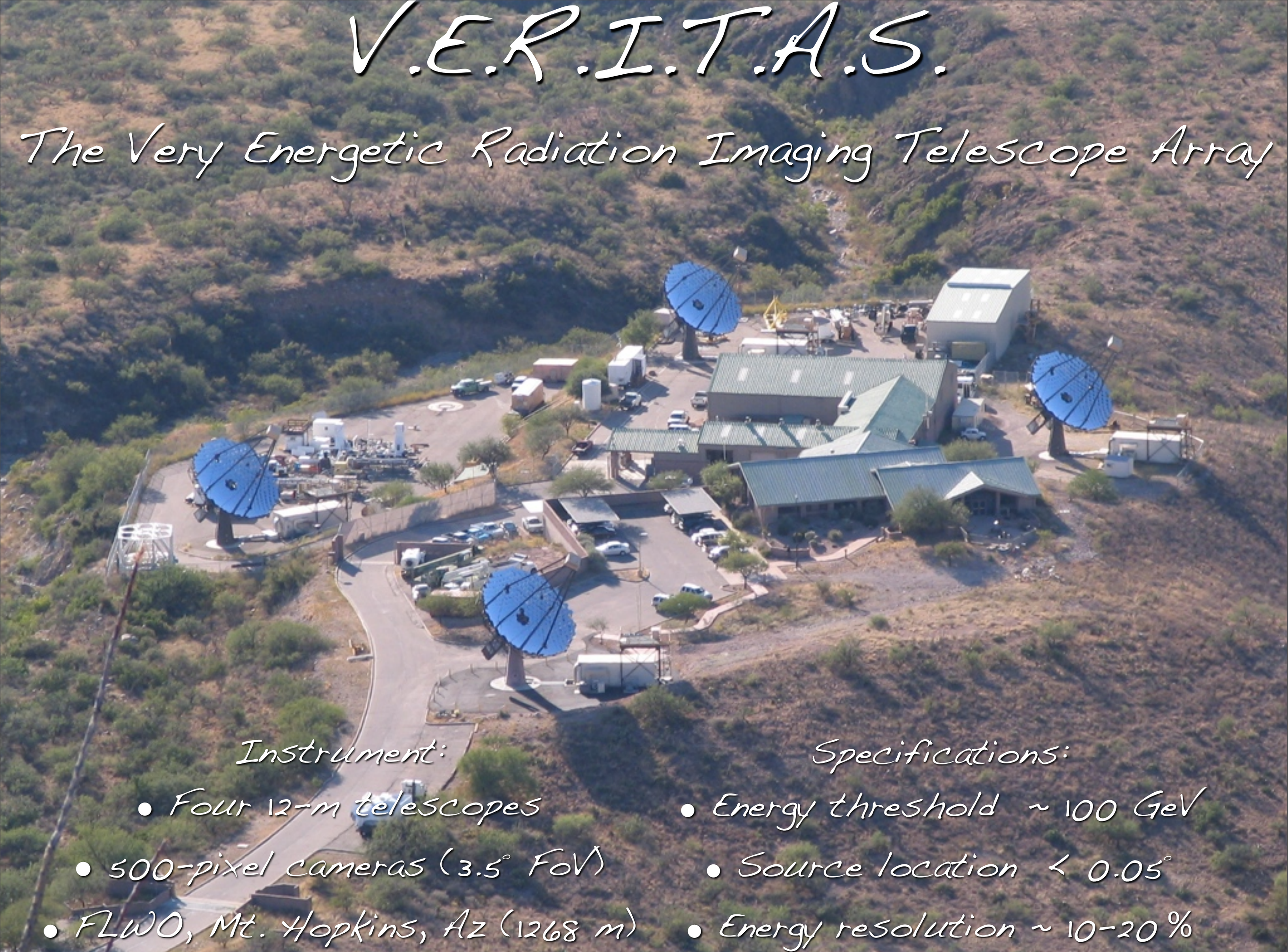
V.E.R.I.T.A.S.

The Very Energetic Radiation Imaging Telescope Array



Instrument:

- Four 12-m telescopes
- 500-pixel cameras (3.5° FoV)
- FLWO, Mt. Hopkins, Az (1268 m)

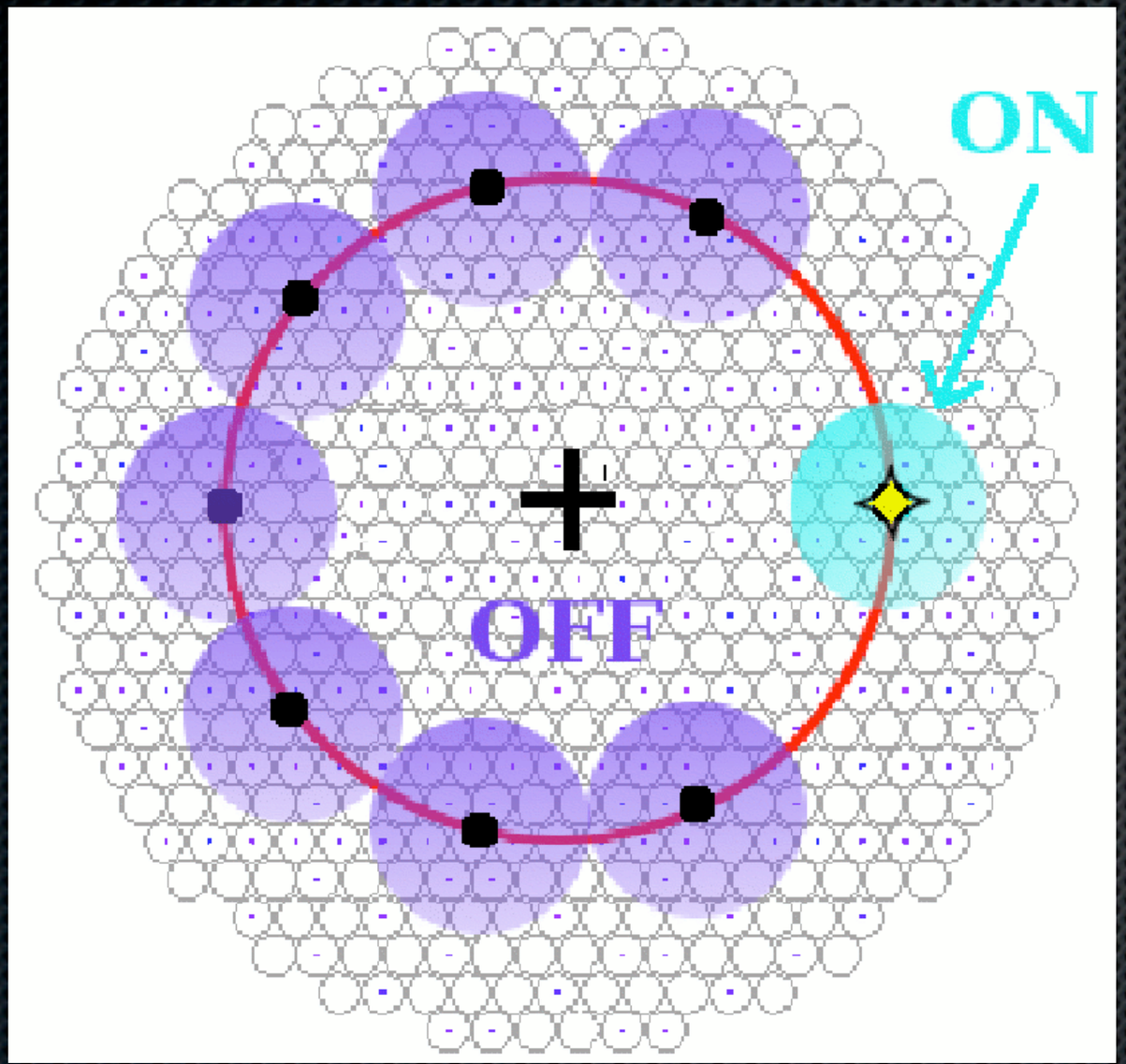
Specifications:

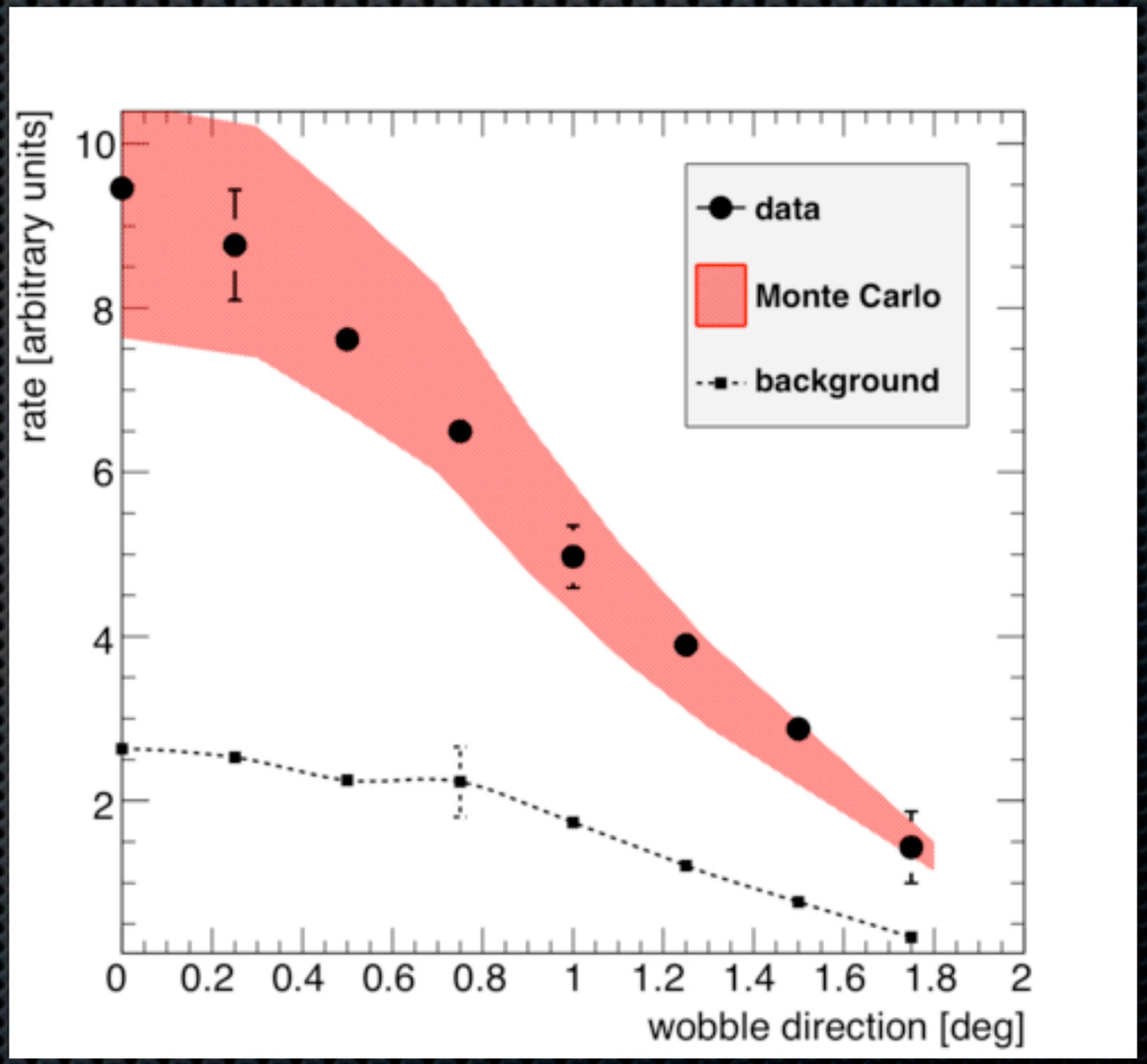
- Energy threshold ~ 100 GeV
- Source location < 0.05°
- Energy resolution ~ 10-20 %

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: 90 arcseconds
* point source sensitivity: 1% Crab in < ~~50h~~ 30h, 10% in ~~5~~ 30min
* observation time per year: 750 hours non-moonlight, 100 hours moonlight

Observations: "Wobble Mode"





Source offset (typically 0.5 deg) in FOV, allows for simultaneous source+BG measurement

VERITAS Galactic Observations

- Over 200 hours accrued on LMXBs, HMXBs, UIDs.....
- VHE observations probe local accretion/ejection phenomena, pulsar wind shocks, additional poorly understood phenomena

1A 0620-00

- Low Mass Black Hole XRB
  - P~7.75 hours, D~1 kpc
  - Powerful X-ray Bursts

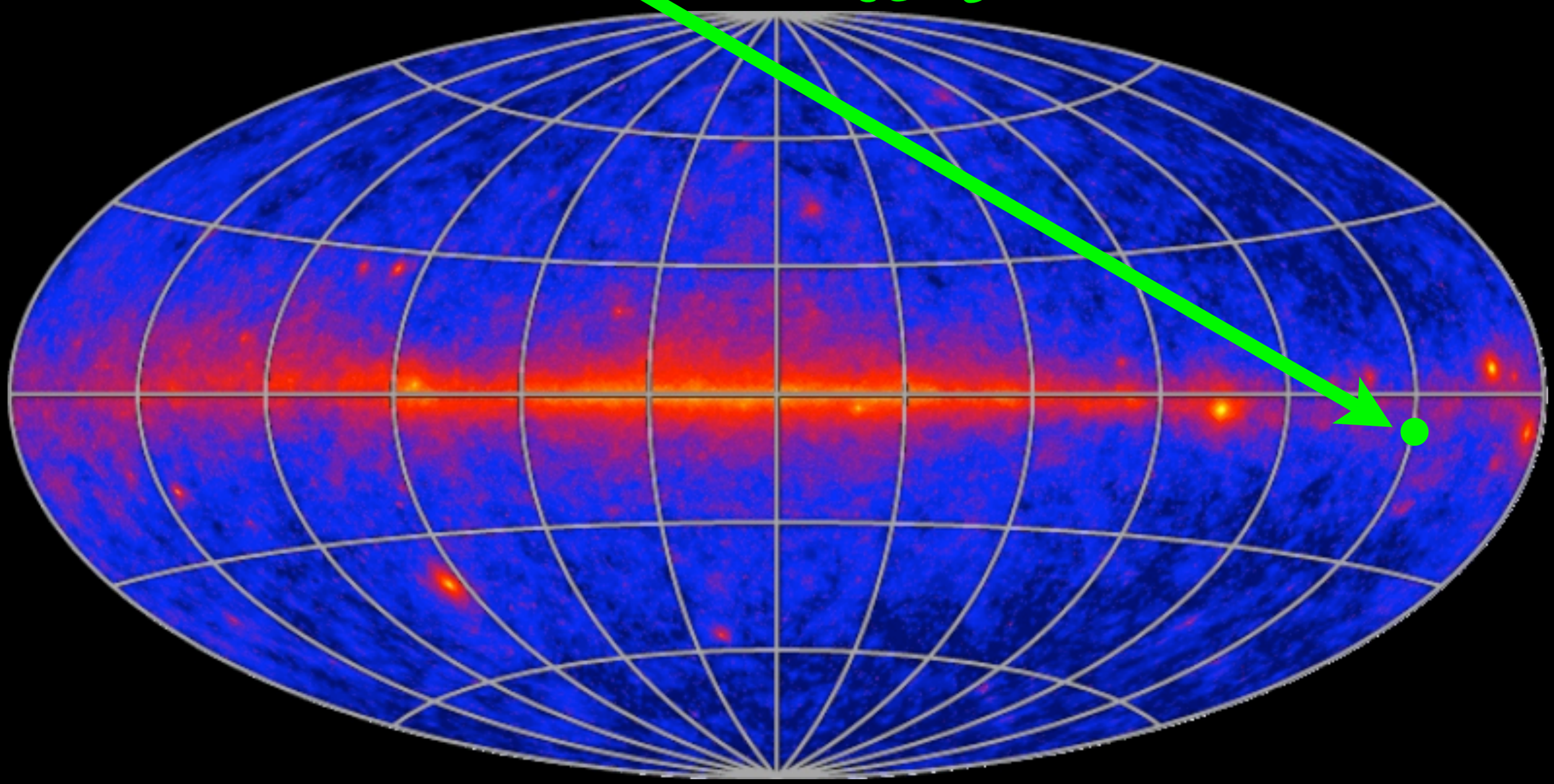
VERITAS Observations:

4.15 Hours Livetime

No Signal Detected

99% Flux Upper Limit >0.4 TeV

1.86×10^{-12} cm^{-2} s^{-1} ~3% Crab



XTE J2012+381

- Cygnus Region 3-6 kpc
- Probable BH + Red MS Star
- X-ray Bursts

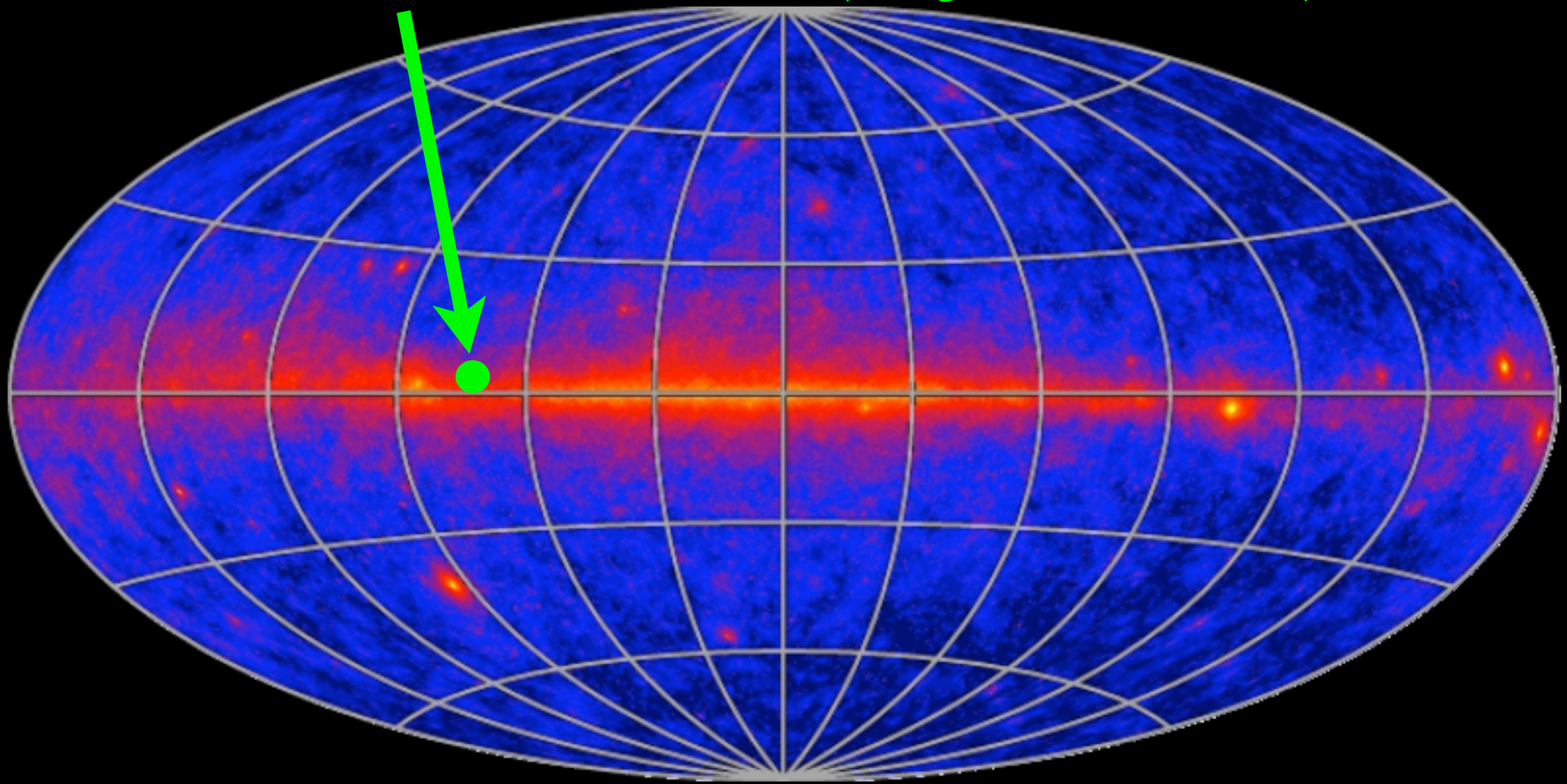
VERITAS Observations:

13 Hours Livetime

No Signal Detected

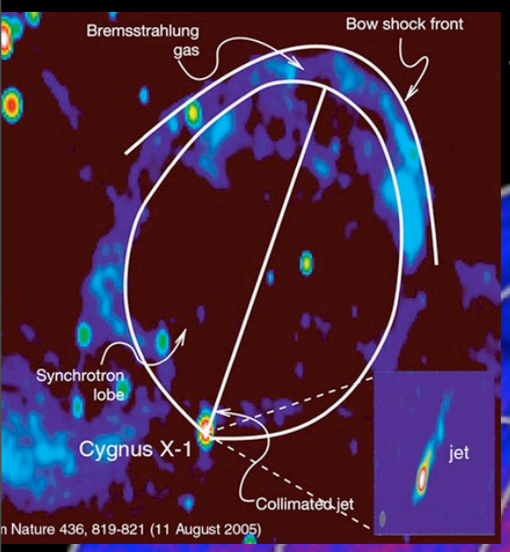
99% Flux Upper Limit >0.4 TeV

2.45×10^{-12} cm^{-2} s^{-1} ~4% Crab



Cygnus X-1

- BH + O Supergiant
- P~5.6 days, d~2.5kpc
- Accretion powered jets
- MAGIC transient coincident w/ X-ray flare



VERITAS Observations:

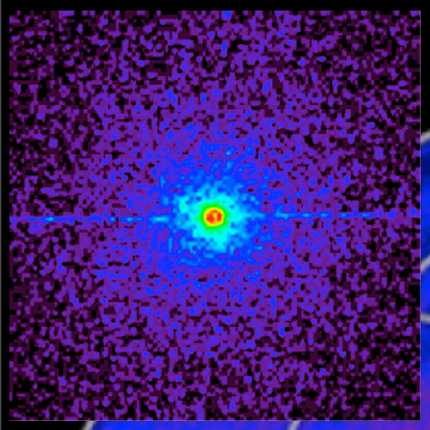
10 Hours Livetime

99% Flux Upper Limit >0.4 TeV

1.05×10^{-12} cm^{-2} s^{-1} ~2% Crab

Cygnus X-3

- Compact Object + WR star
- Strong X-ray source, radio jets
- Transient, unconfirmed TeV detections



VERITAS Observations:

10 Hours Livetime

No Signal Detected

99% Flux Upper Limit >0.4 TeV

1.42×10^{-12} cm^{-2} s^{-1} ~2% Crab

SS 433

-Compact Object + A-star

-P~13 days, d~3 kpc

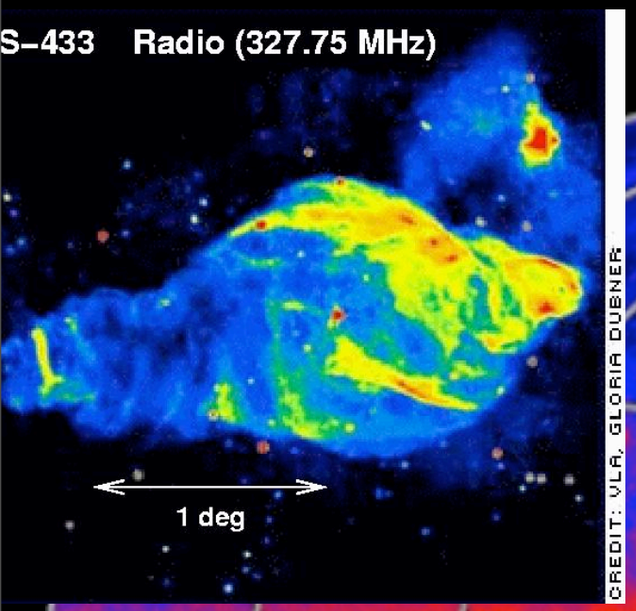
-Well Studied Relativistic Jets

VERITAS Observations:

10 Hours Livetime

99% Flux Upper Limit >0.4 TeV

1.5×10^{-12} cm^{-2} s^{-1} ~2% Crab



HESS J0632+057

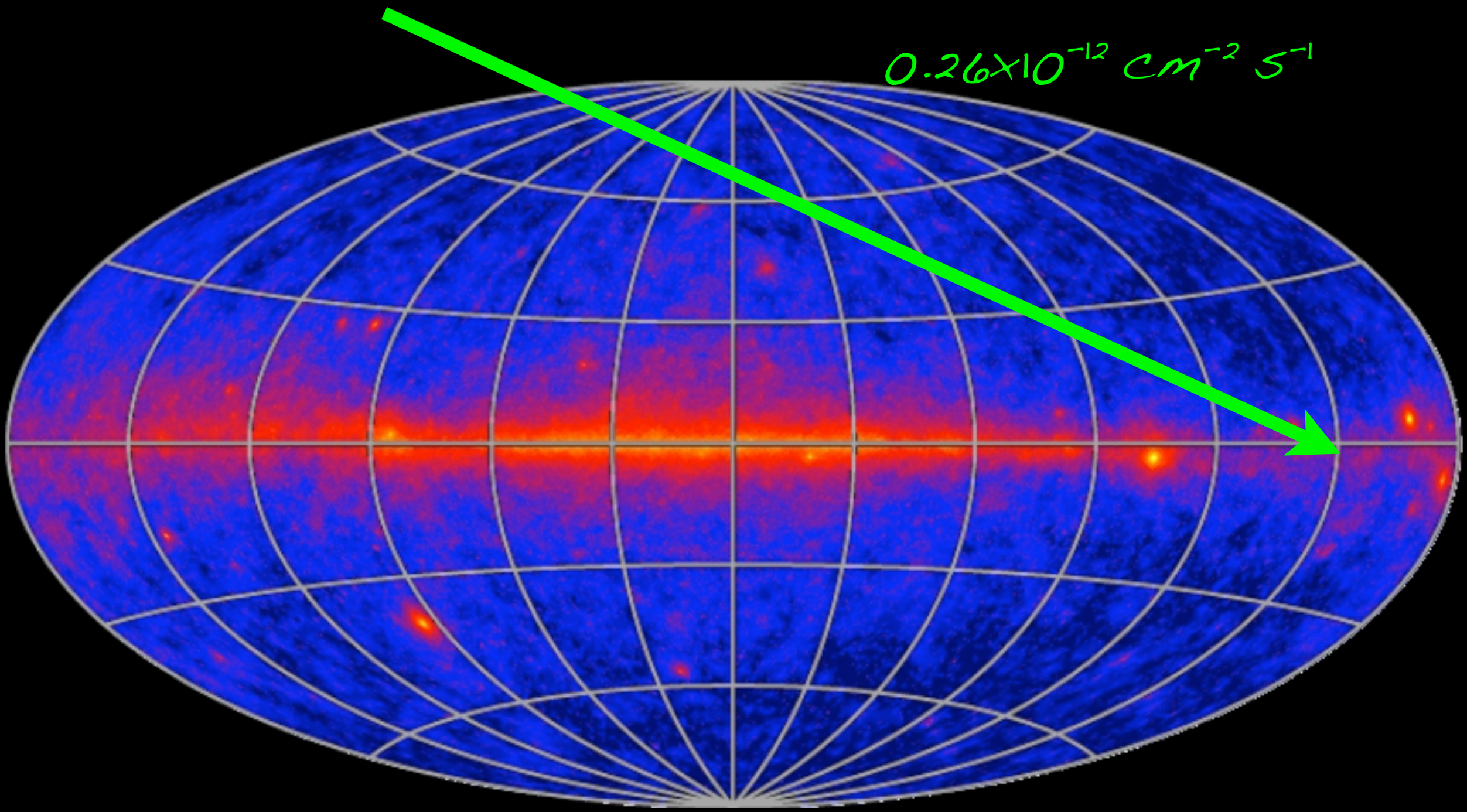
- HESS "dark" TeV source
- No known counterpart

VERITAS Observations:

~30 Hours Livetime

99% Flux Upper Limit >0.72 TeV

$0.26 \times 10^{-12}\ cm^{-2}\ s^{-1}$



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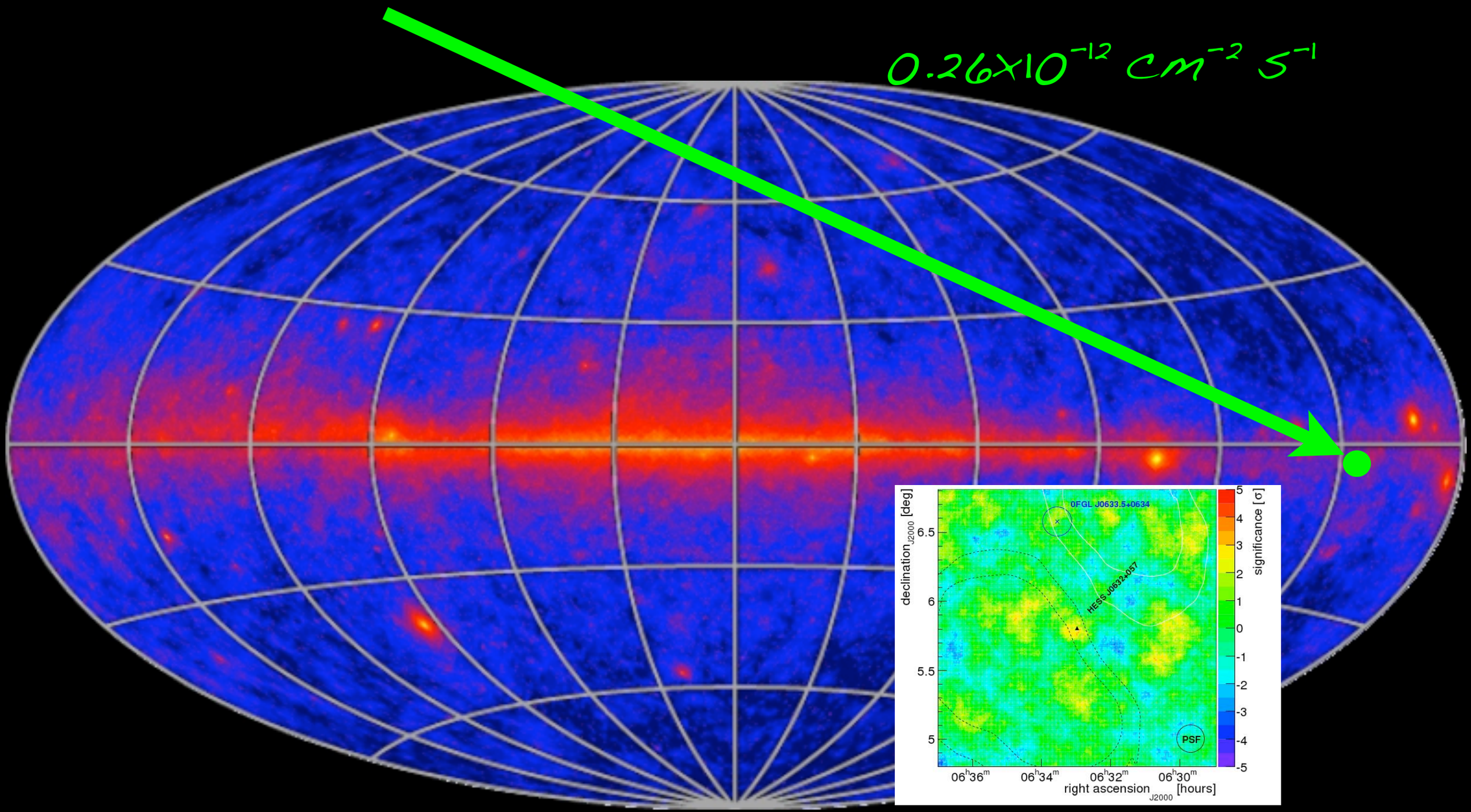

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VERITAS Observations:

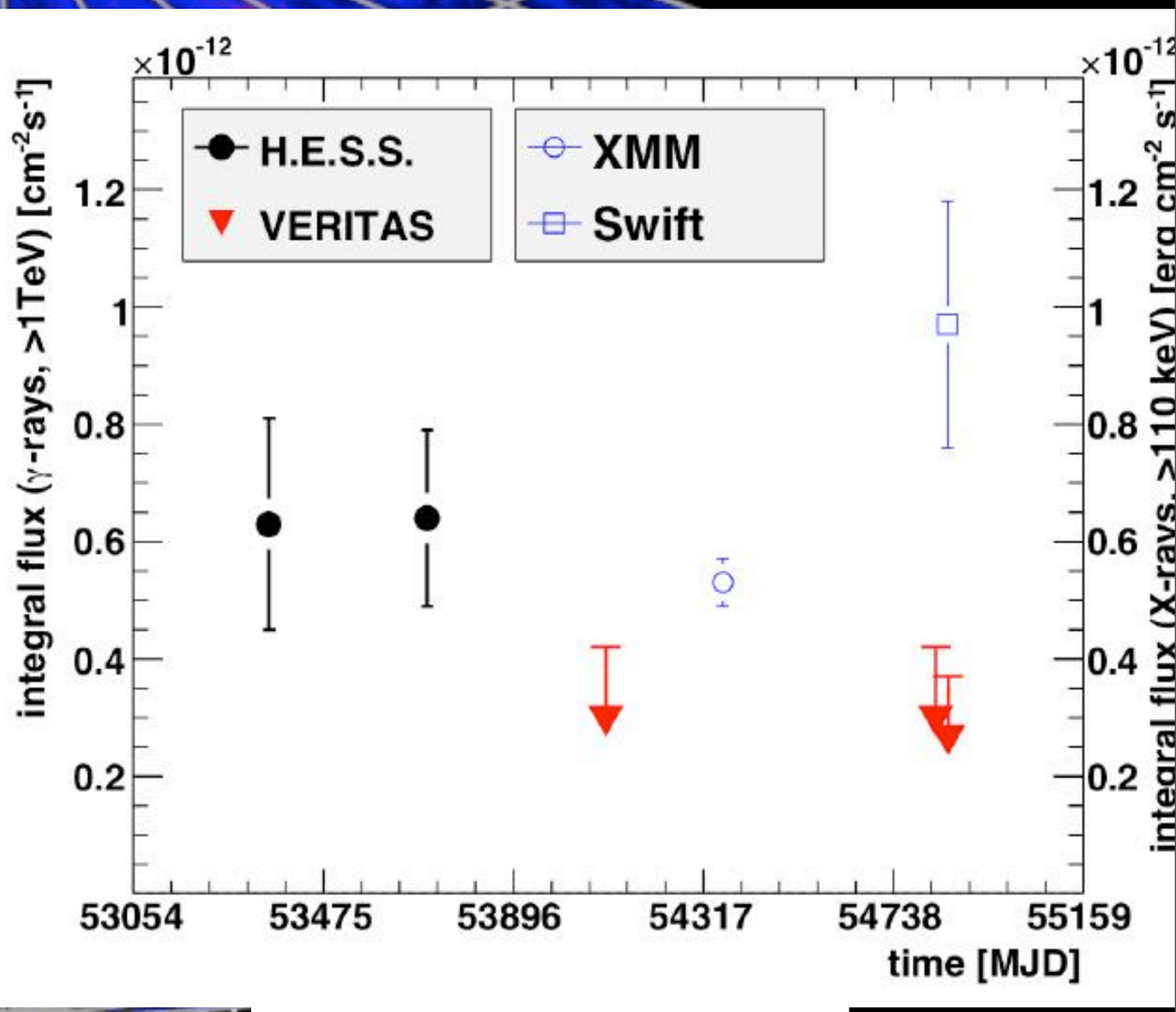
~30 Hours Livetime

99% Flux Upper Limit >0.72 TeV

0.26×10^{-12} cm^{-2} s^{-1}

Result:

- Flux upper limit ~2.4x lower than HESS flux
- Variable Source at 4σ
- Plausible explanation: XRB



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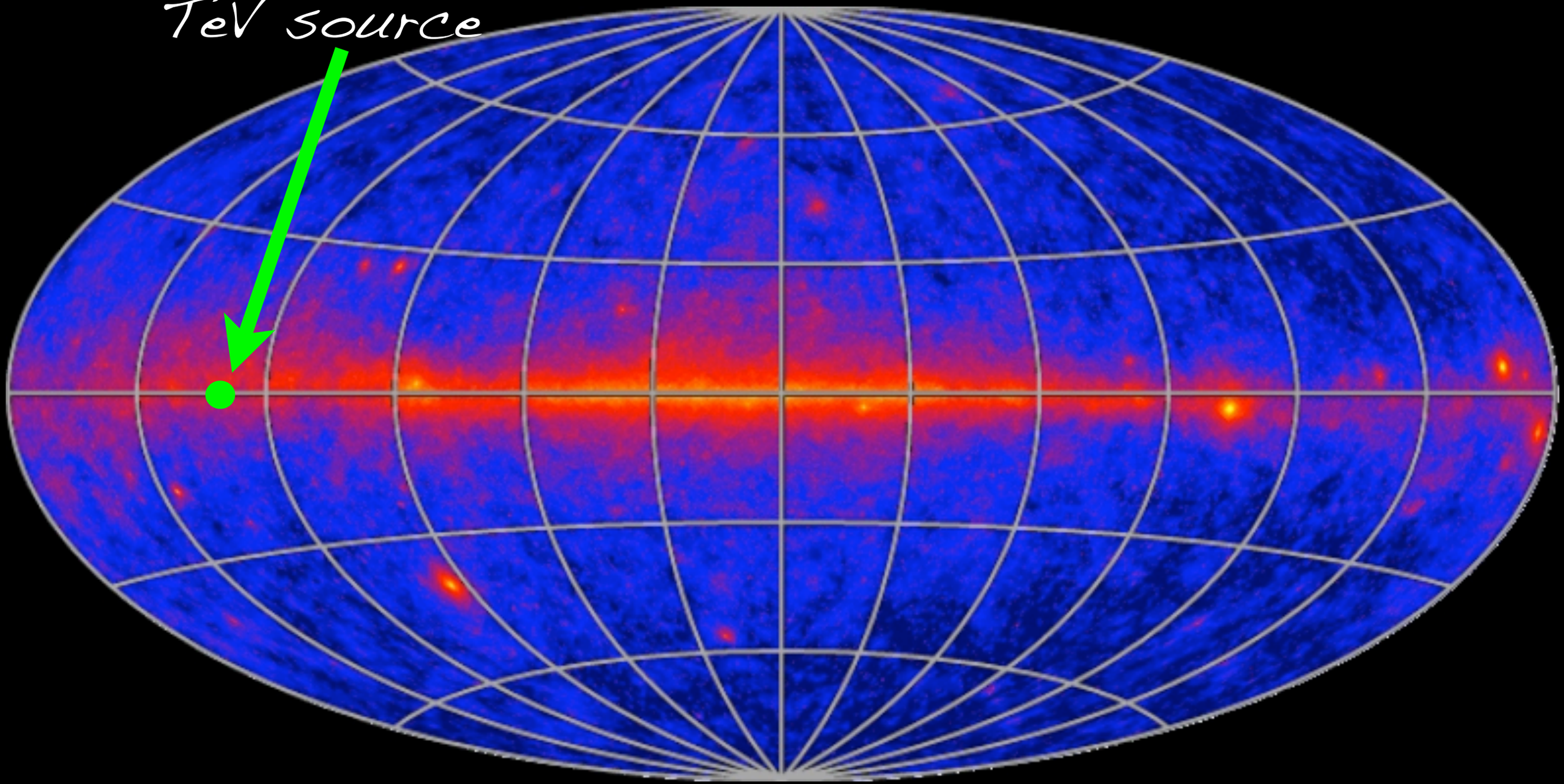
-BH/NS + Be Star

-MAGIC + VERITAS variable TeV source

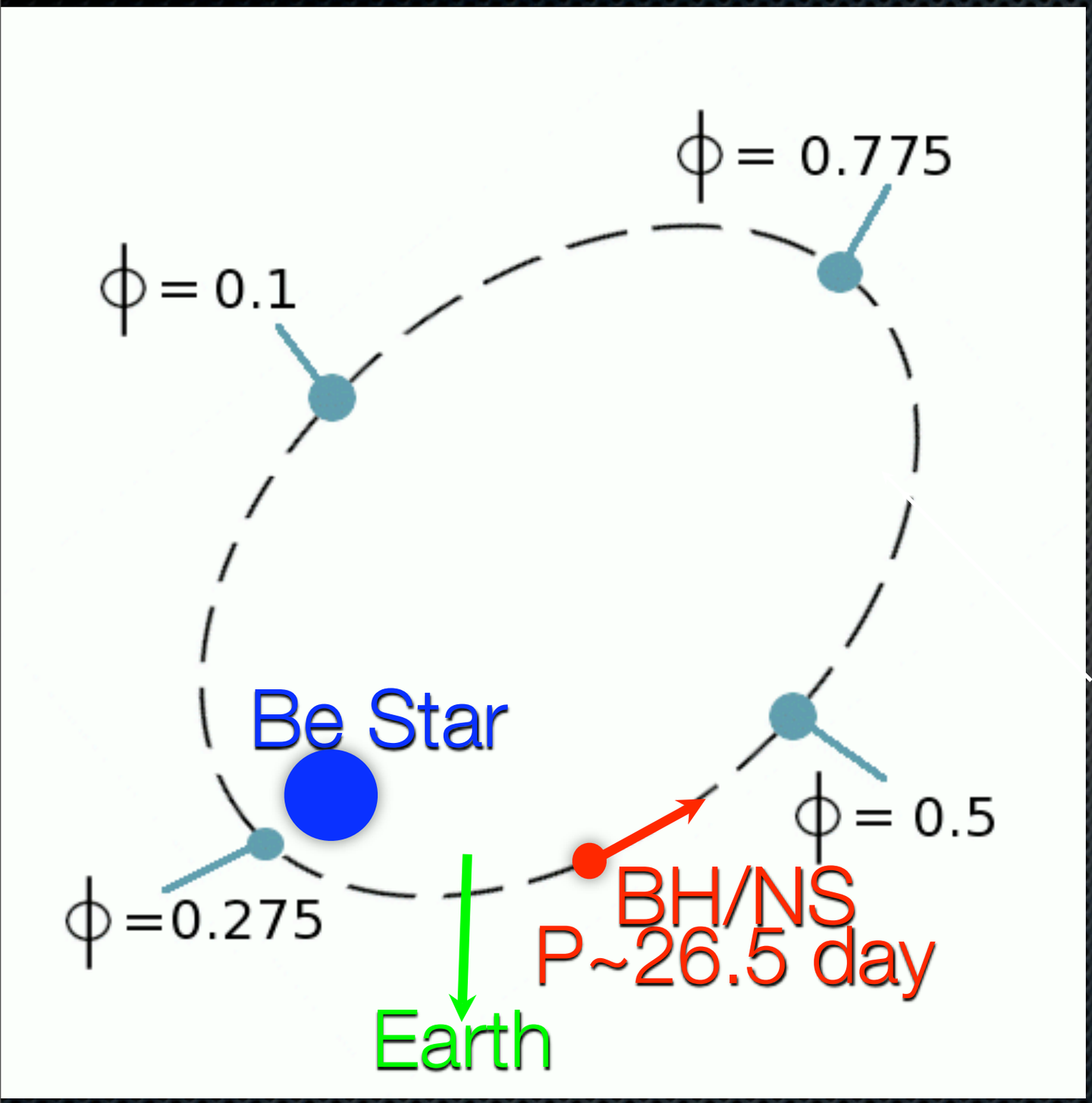
VERITAS Observations:

-3 years of observations

-MW coverage w Fermi, Swift, RXTE.....



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

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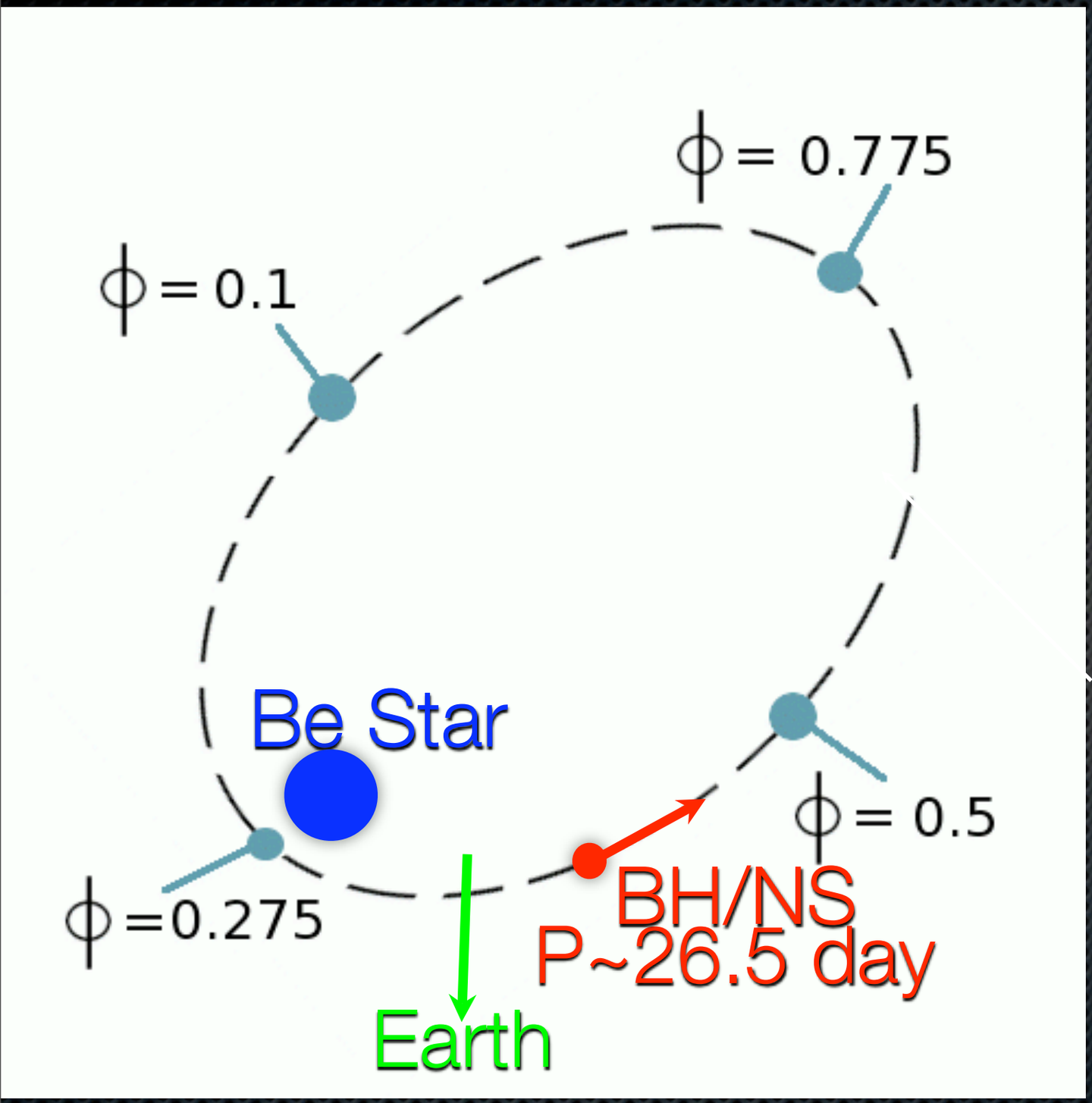

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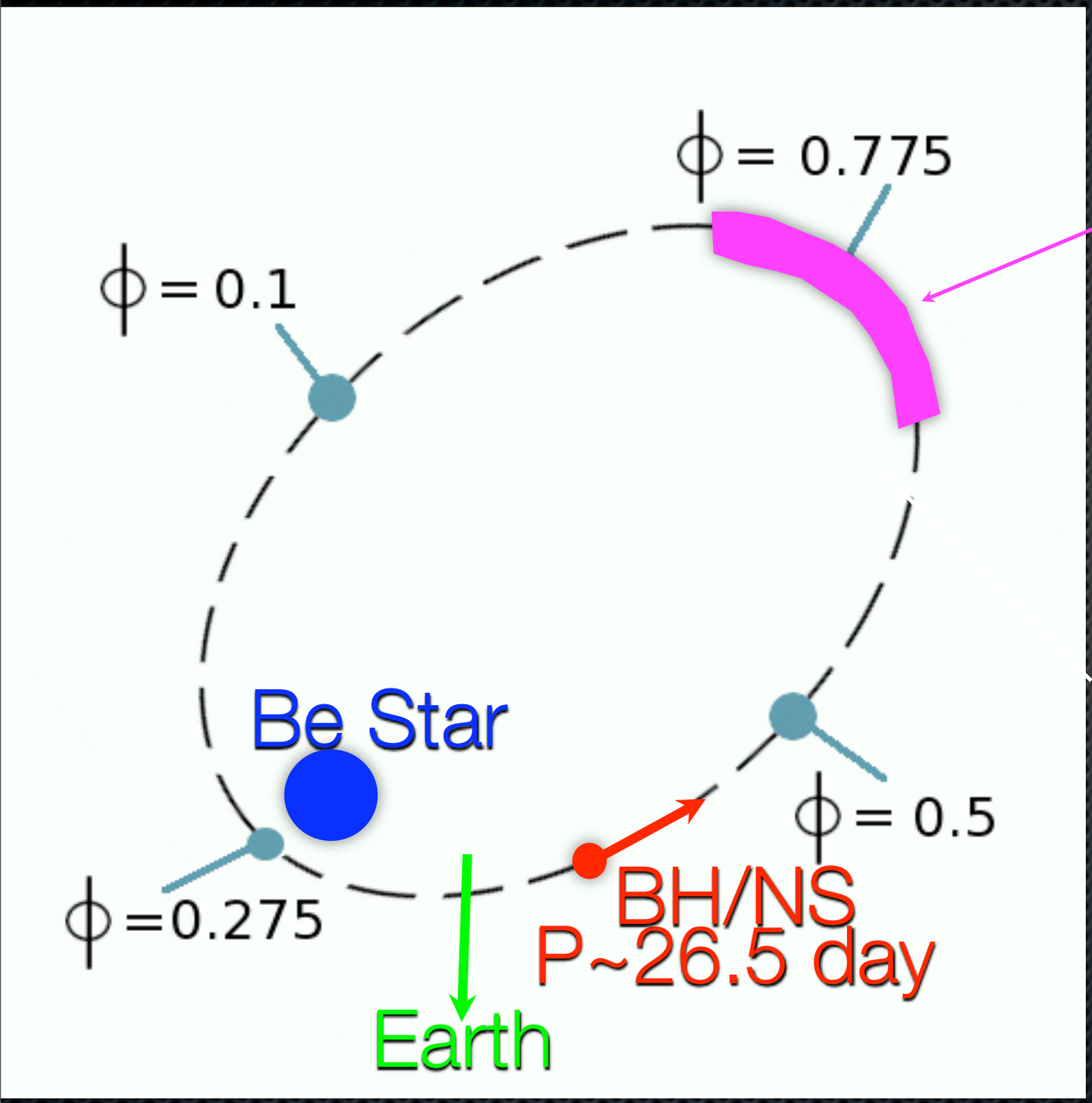

Radio Outbursts near apastron, ~4yr modulation (Gregory 2002)

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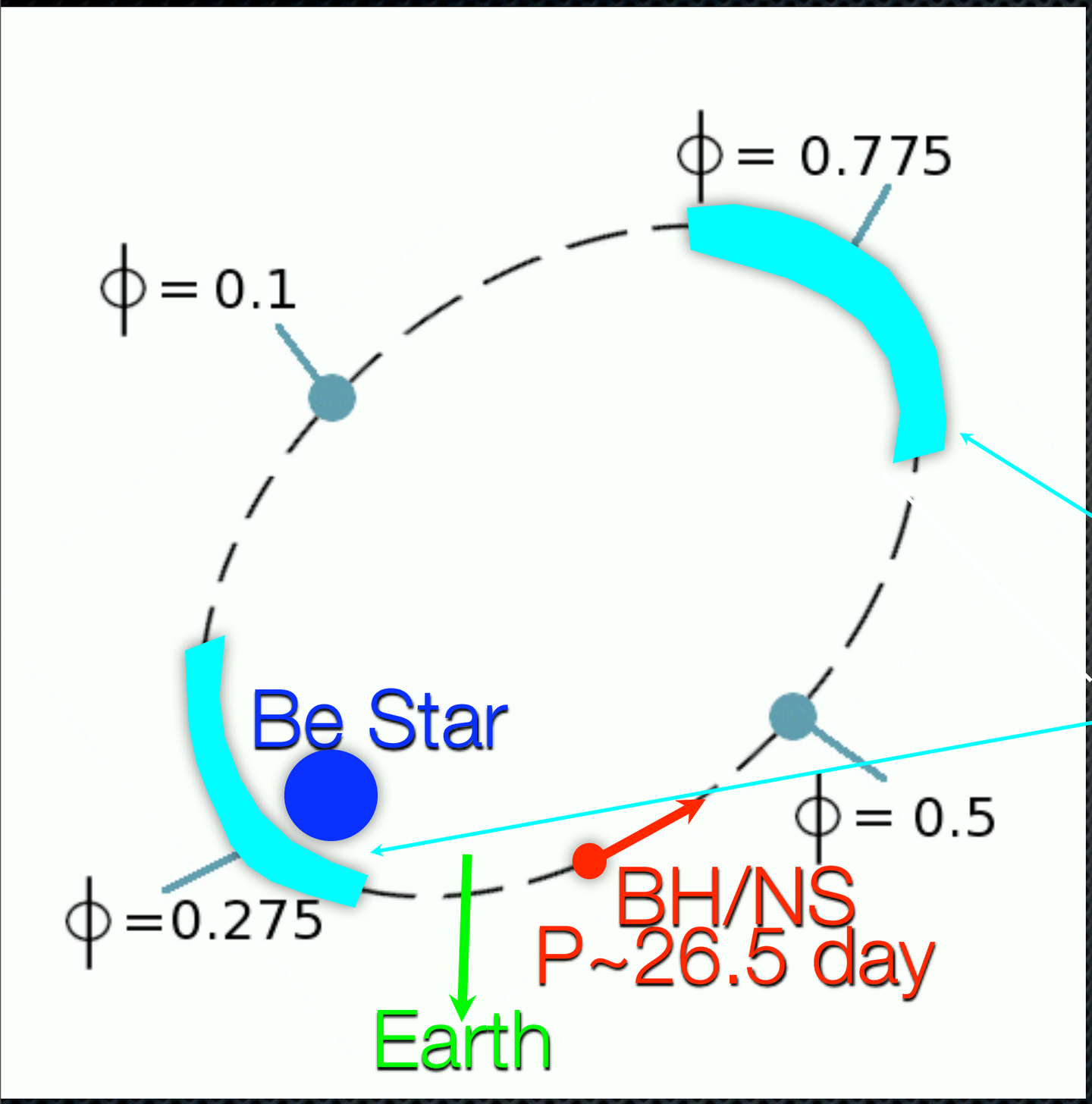

High X-ray activity throughout orbit (strongest at apastron, secondary near periastron)

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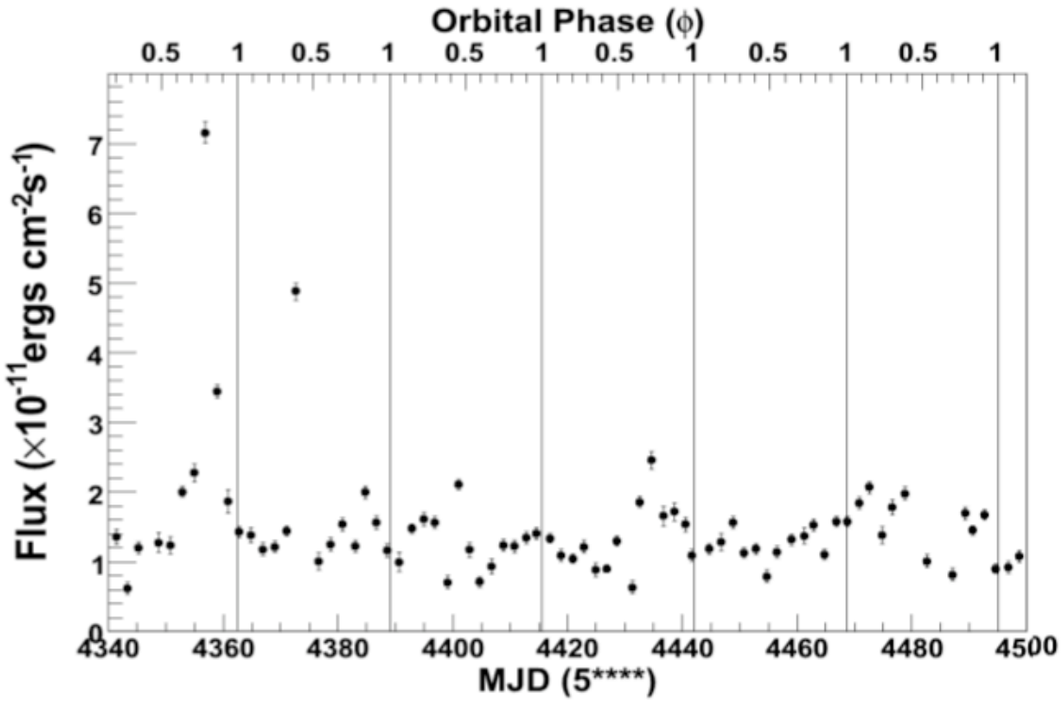
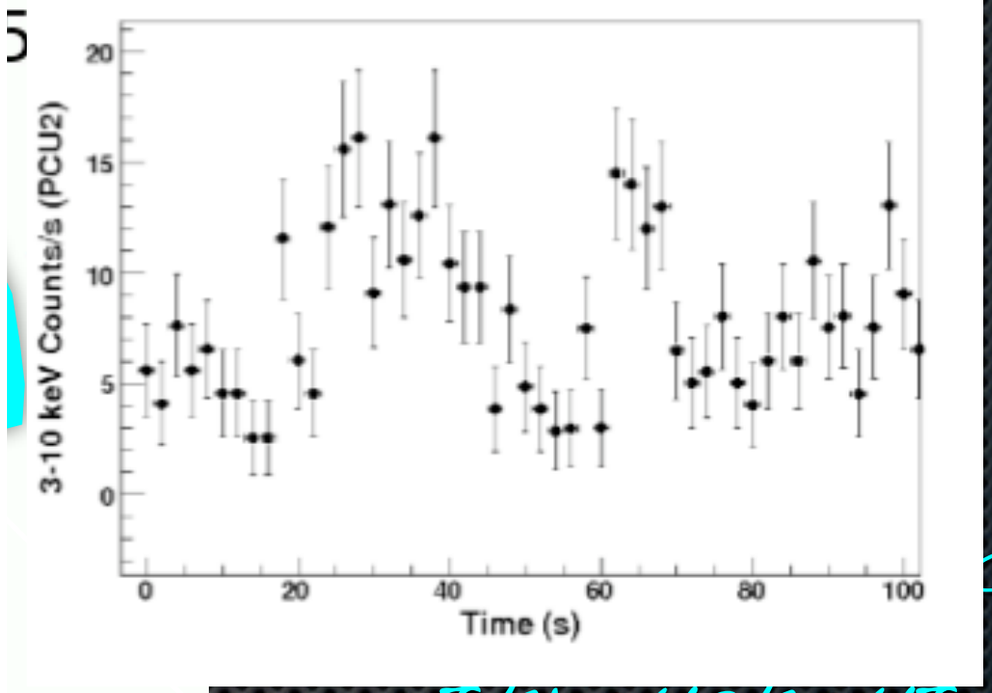
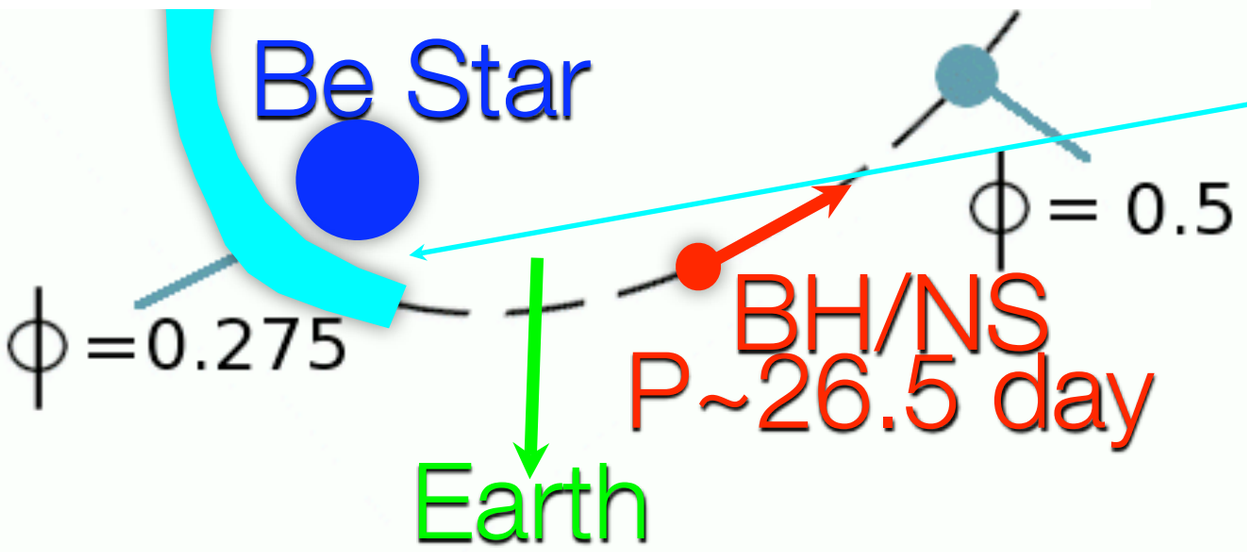
(Smith et al 2008)







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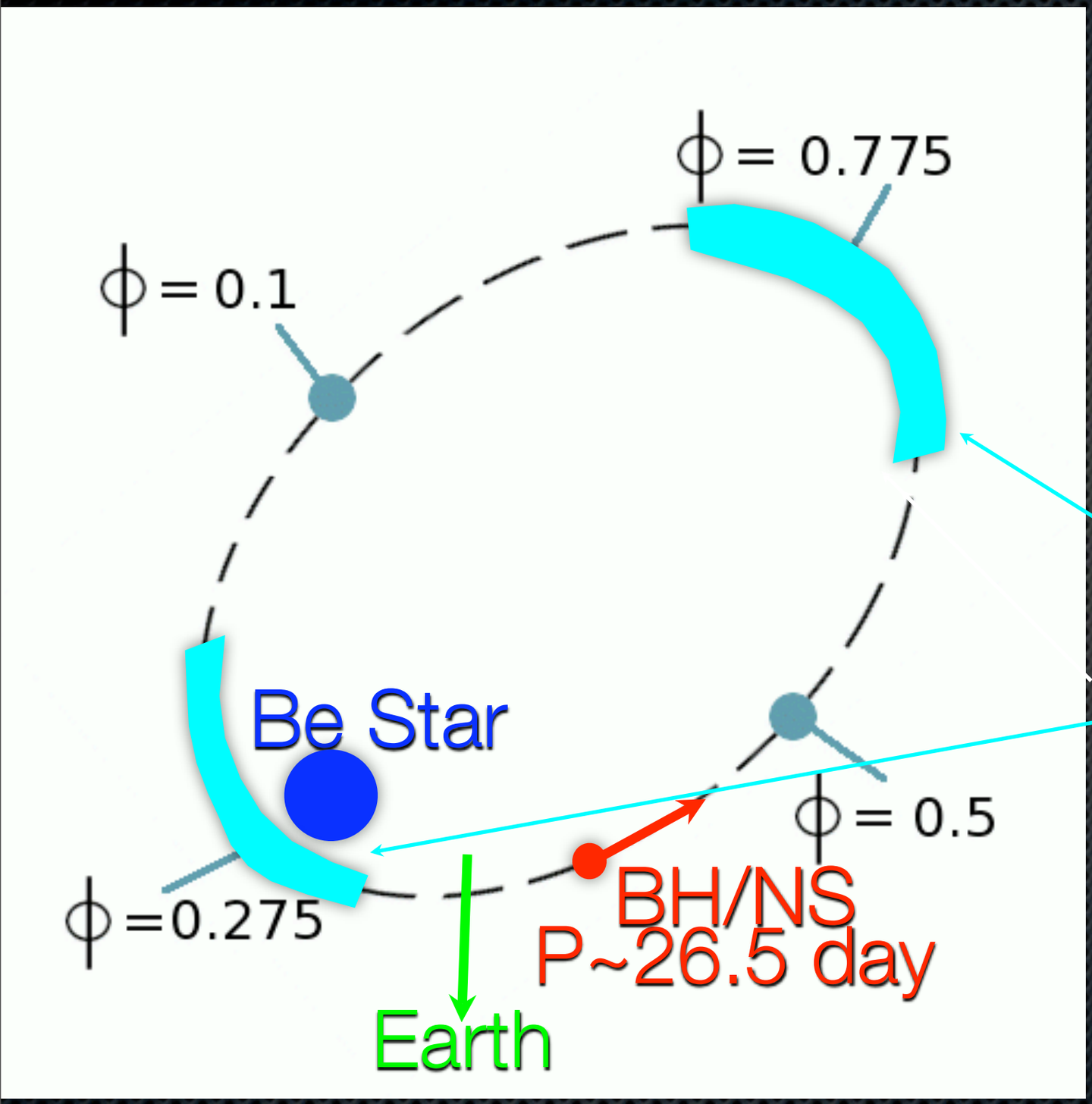

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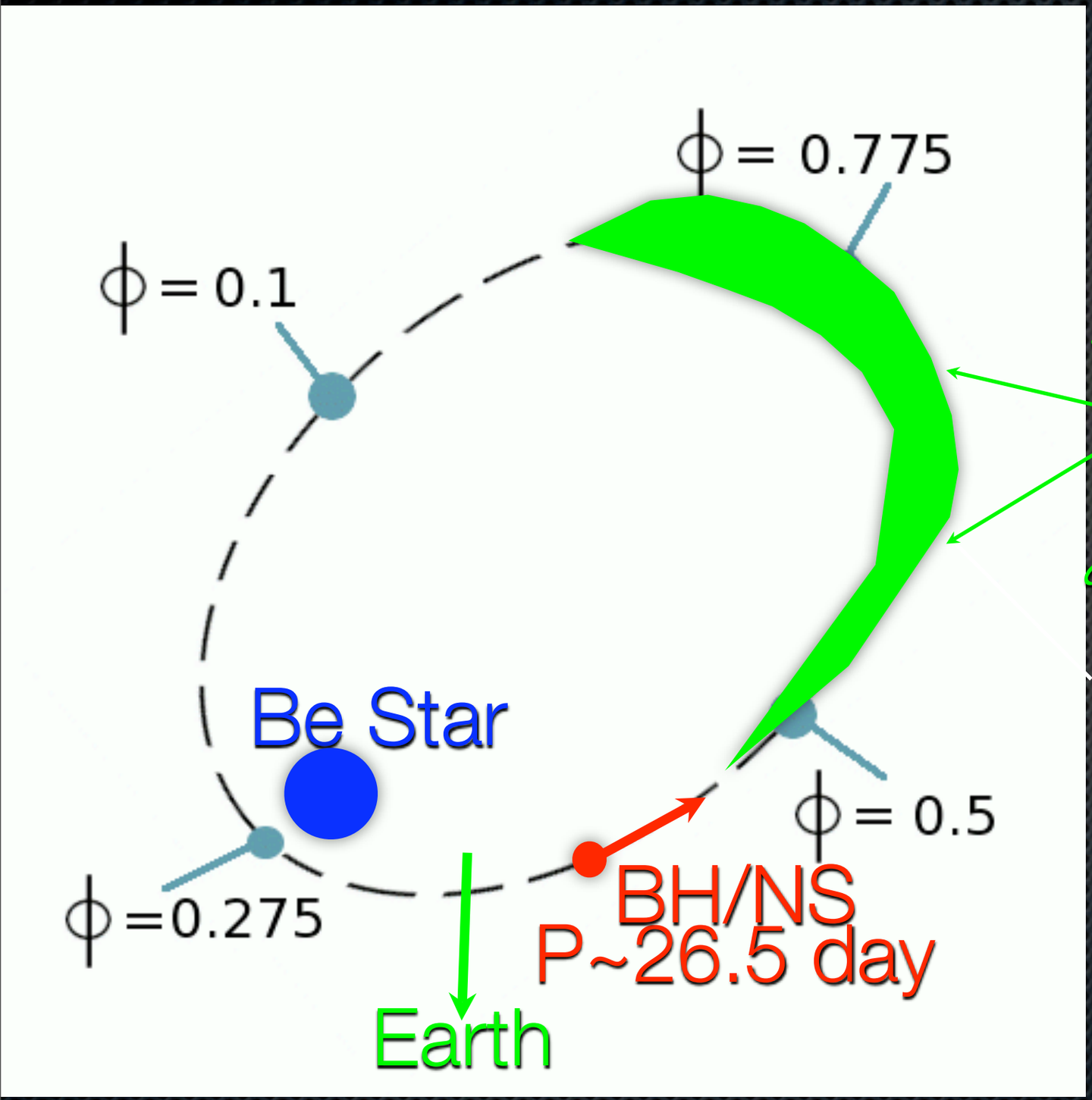
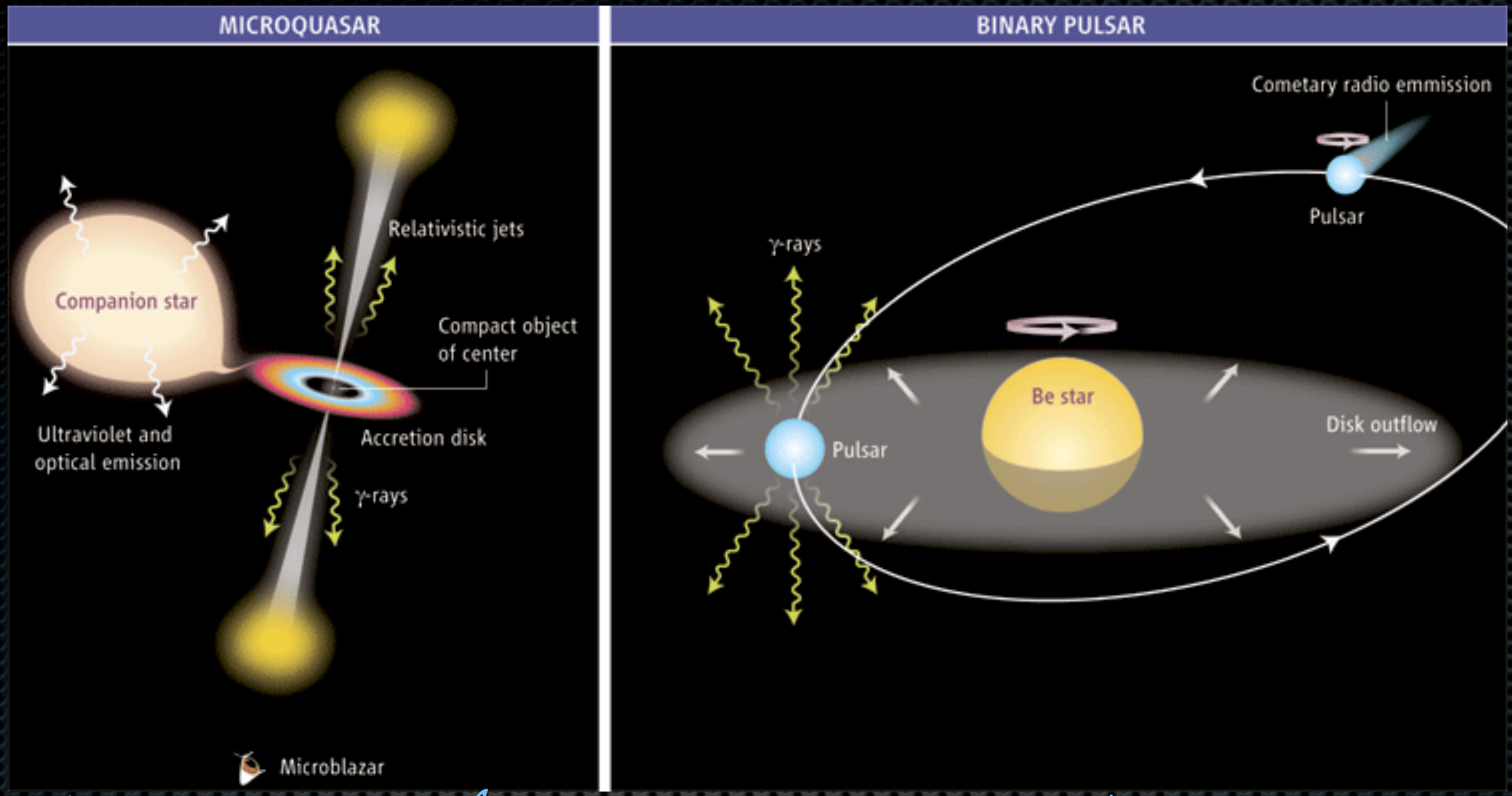


TeV Activity detected by MAGIC/VERITAS around apastron passage (Albert et al 2006, Acciari et al 2008)

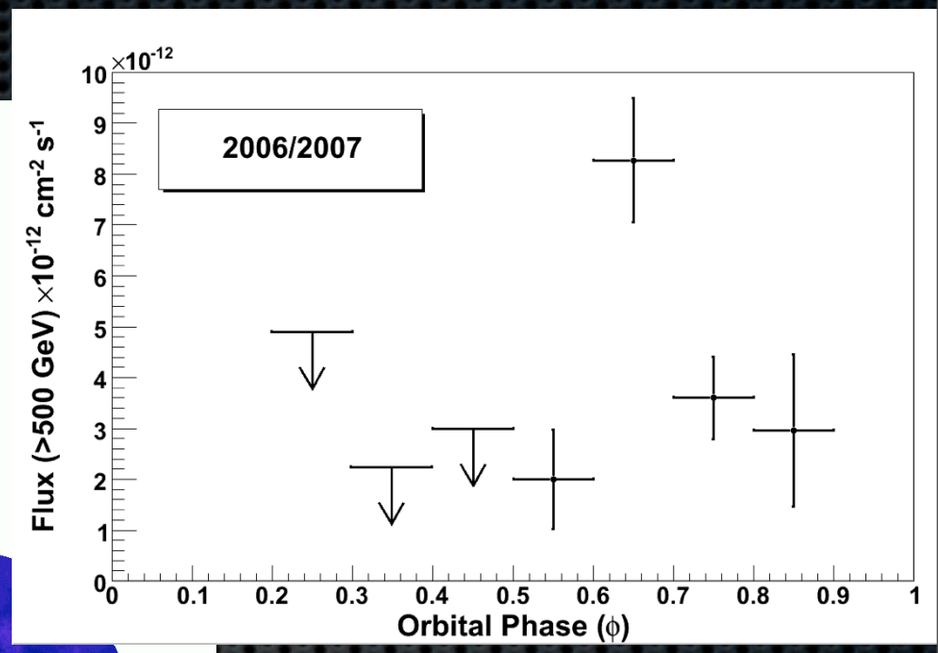


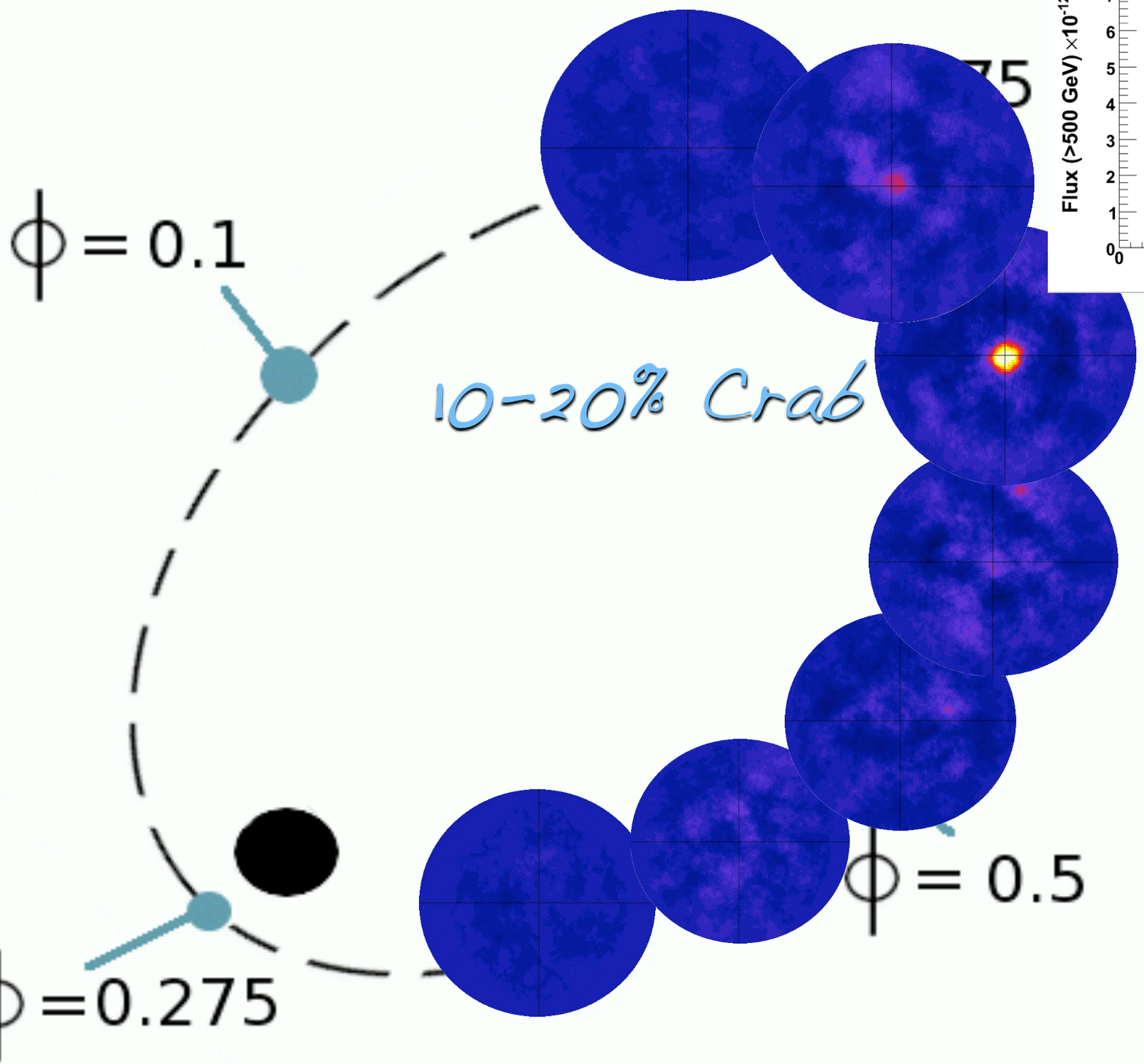
-Microquasar: Accretion driven jet electrons upscatter photons

-Binary Pulsar: Shock driven electrons upscatter photons

-Many variations in both models: clumpy winds, absorption.....need MW observations to detail emission evolution

2006-2007

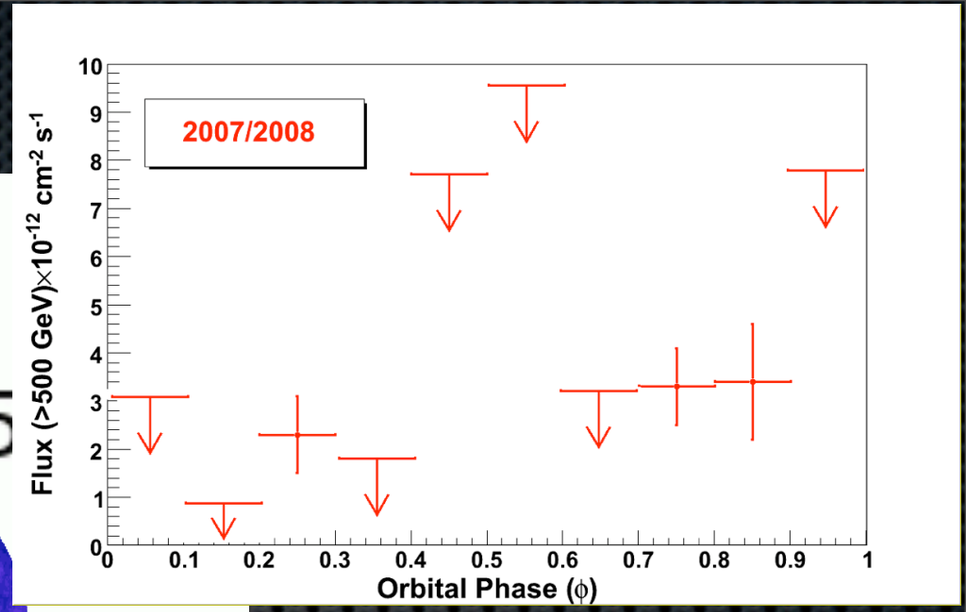


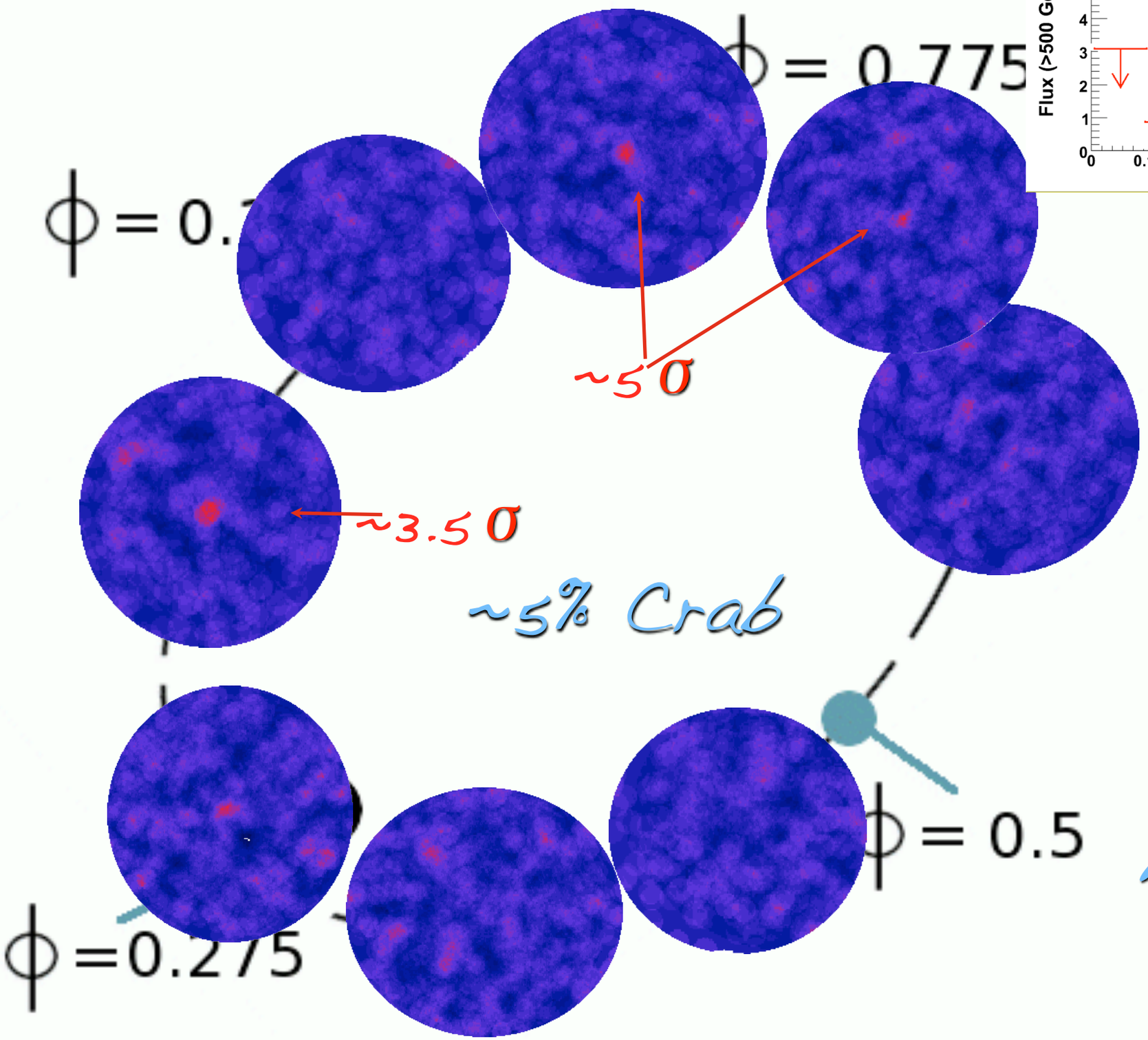


10-20% Crab

Strong Detection around apastron

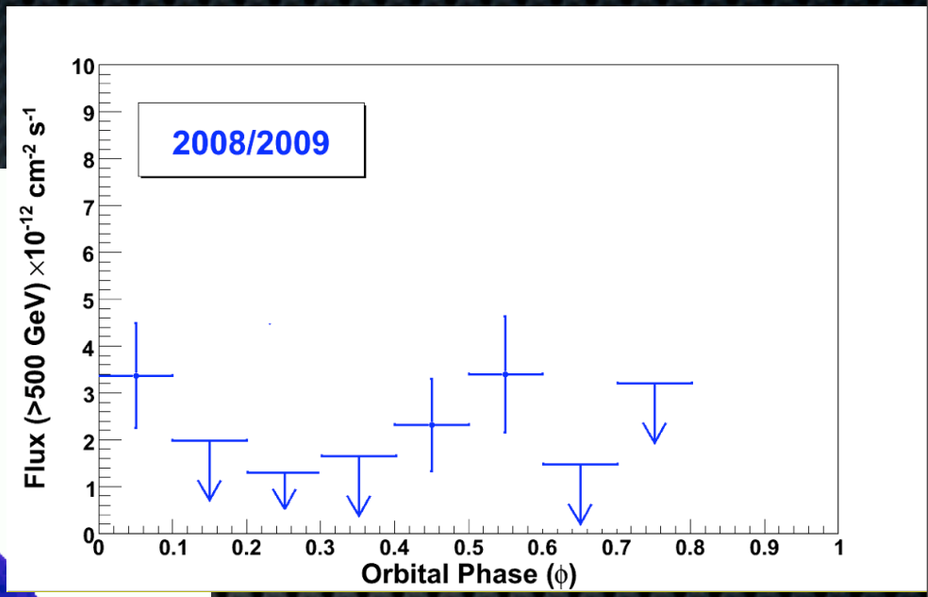
2007-2008

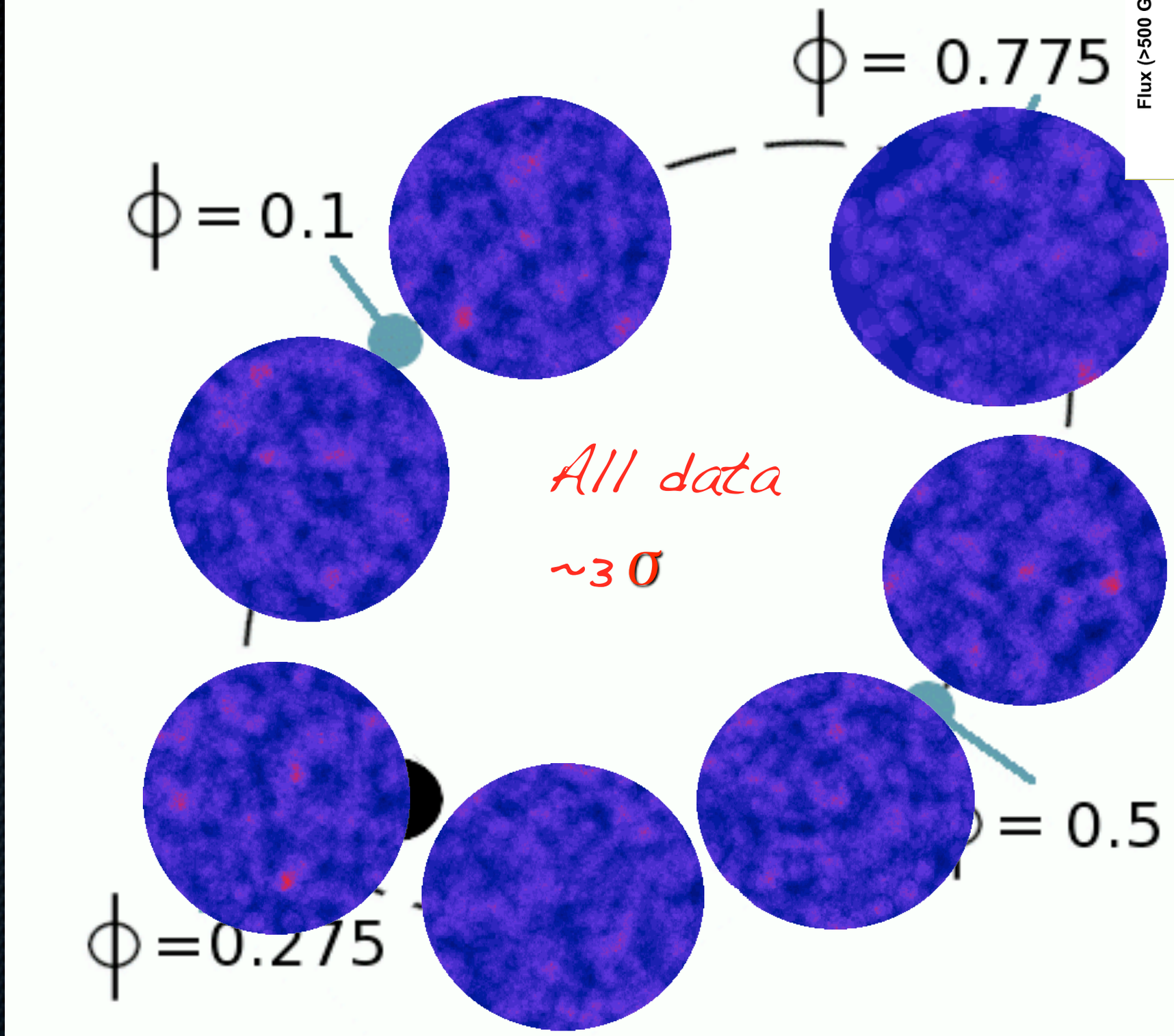




Borderline detection around apastron, hint of signal near periastron

2008-2009



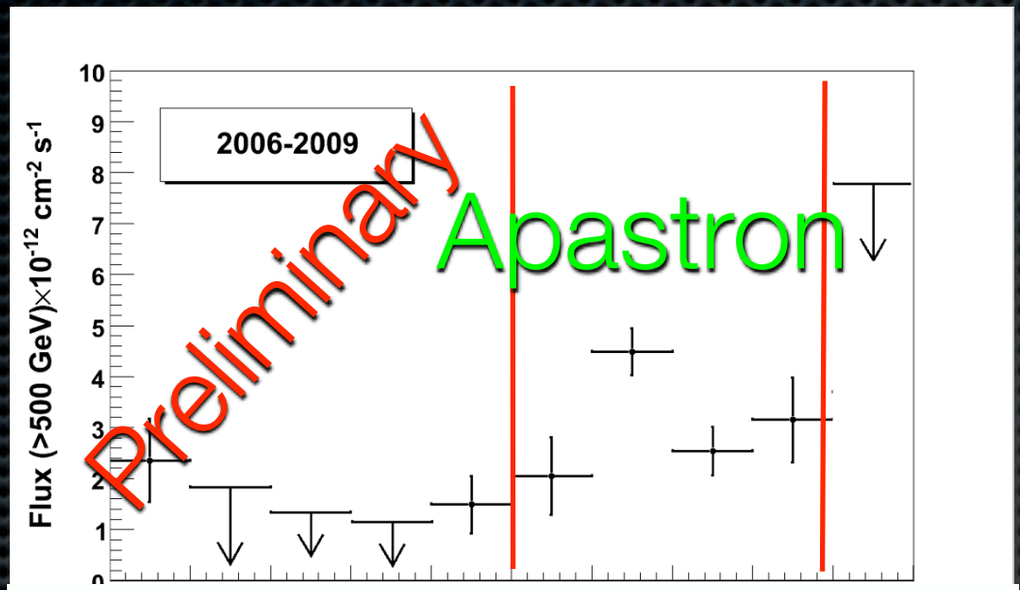


All data

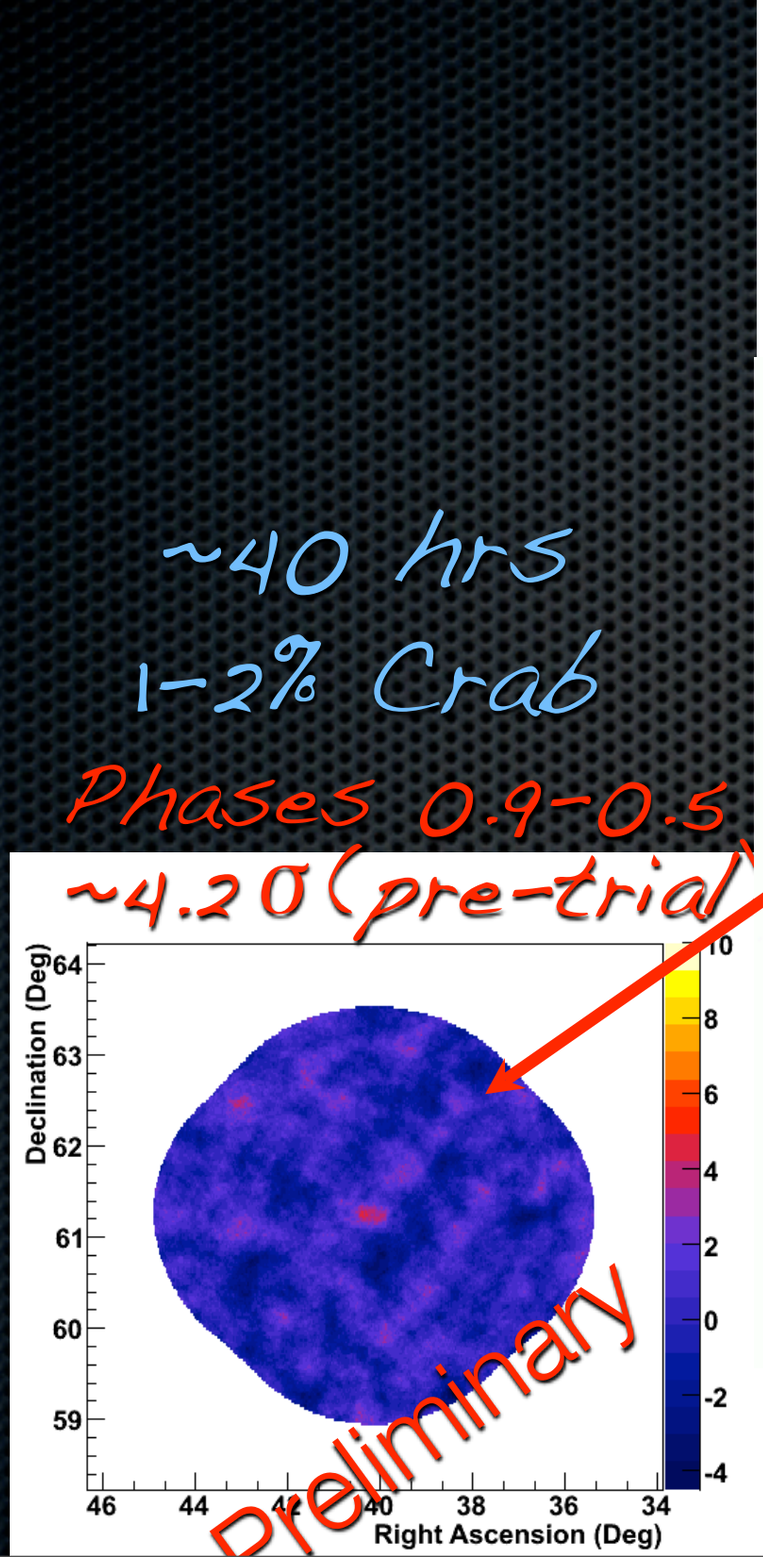
~3σ

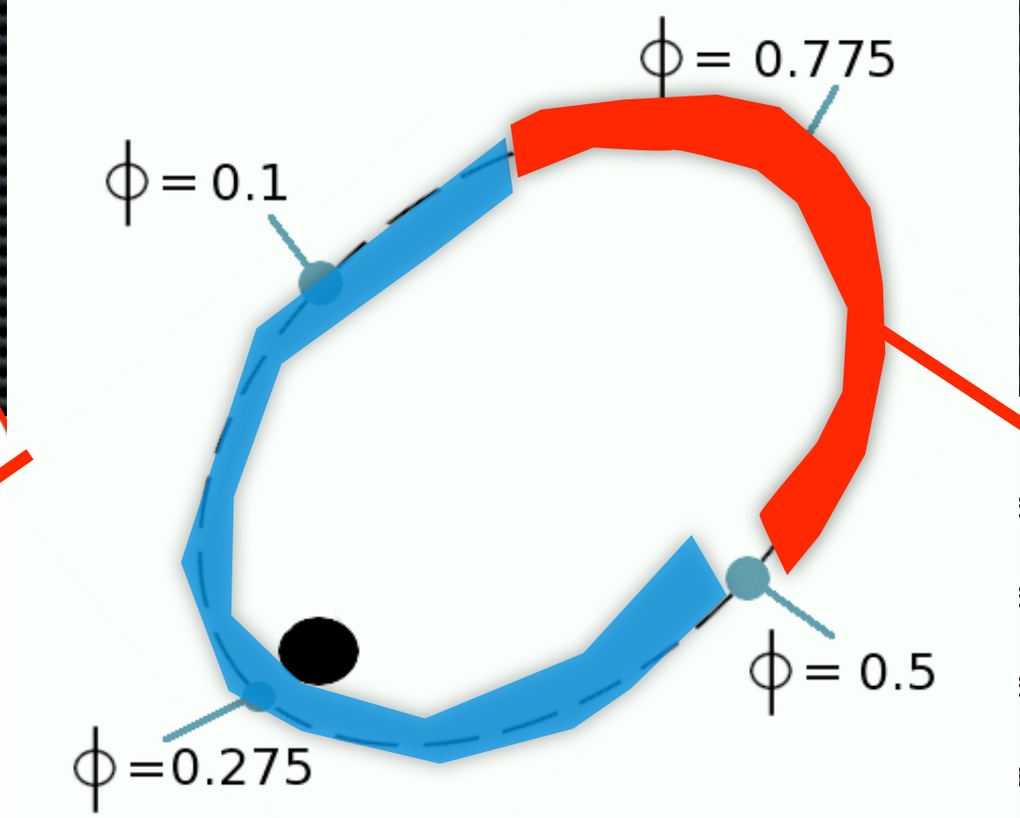
No Significant Signal detected!

All Data 2006-2009

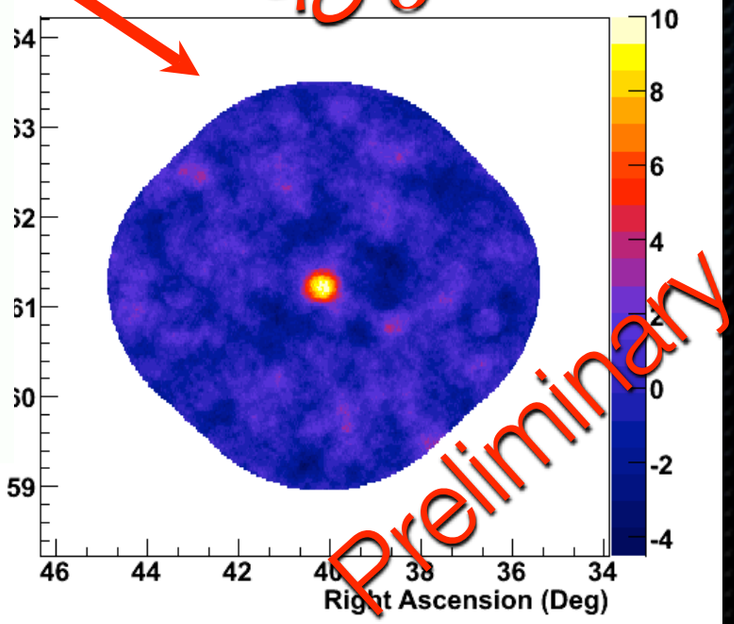


~40 hrs
1-2% Crab
Phases 0.9-0.5
~4.2σ (pre-trial)

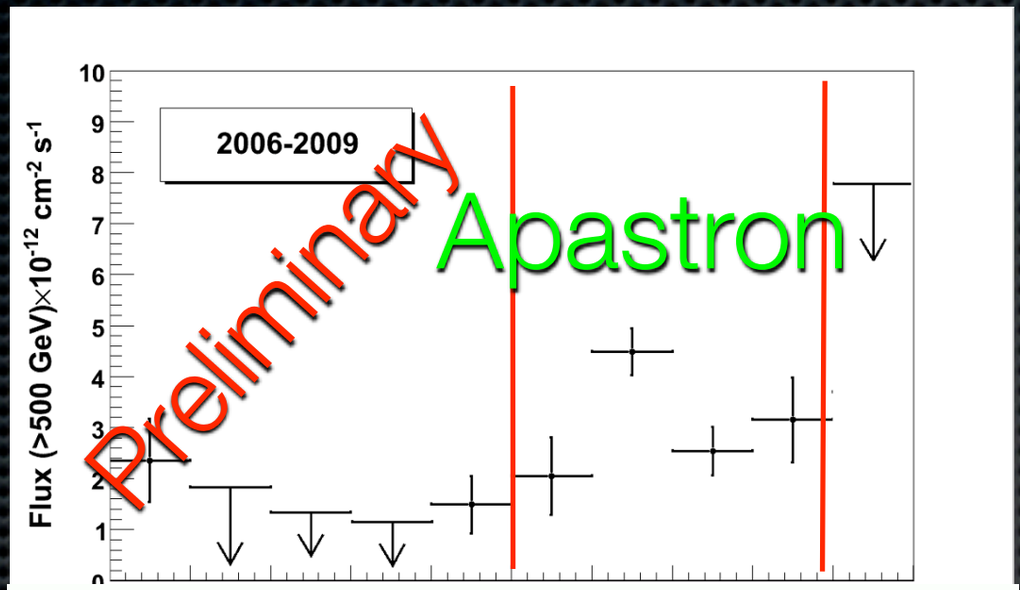




~40 hrs
Avg 3-4% Crab
Phases 0.5-0.9
~10σ



All Data 2006-2009



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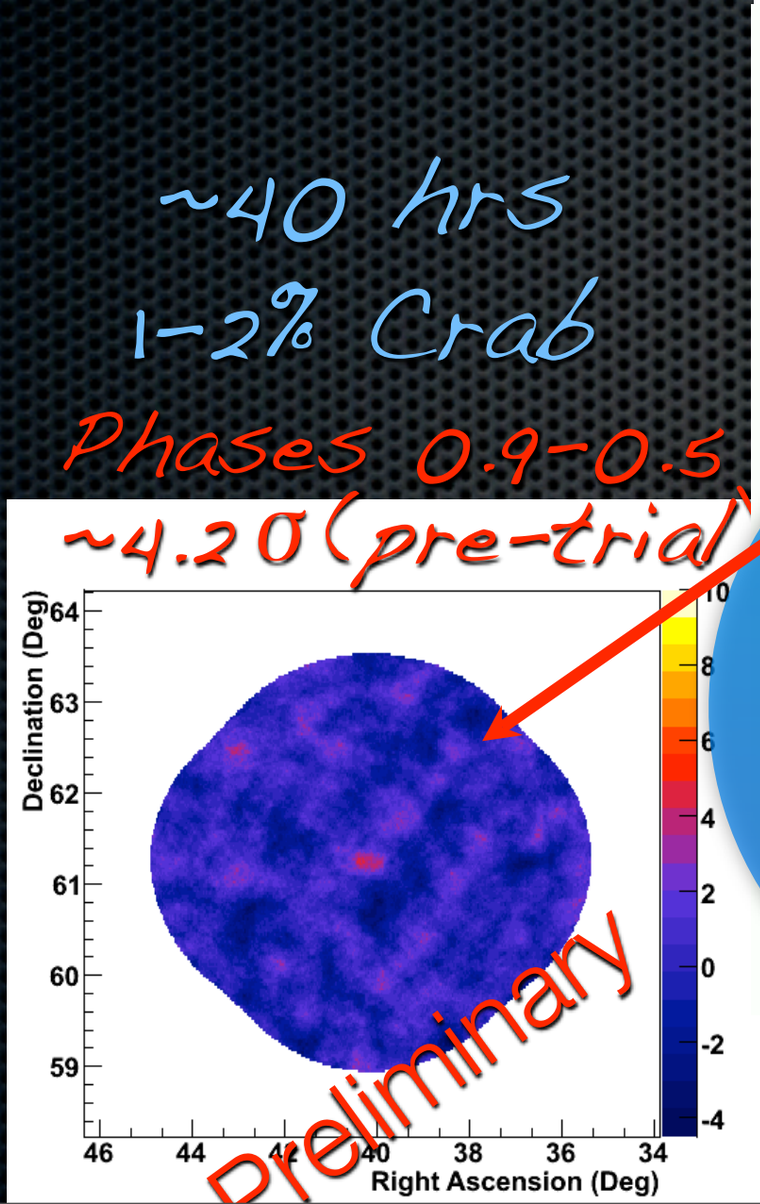

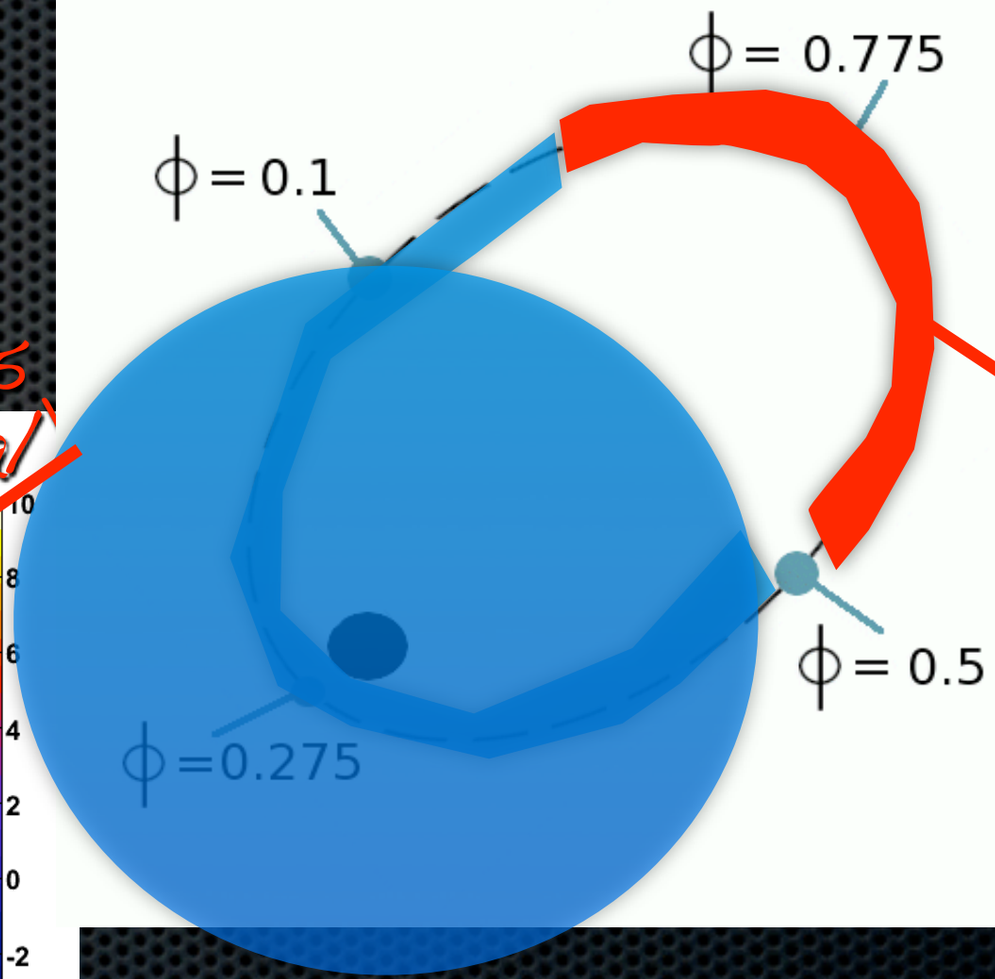

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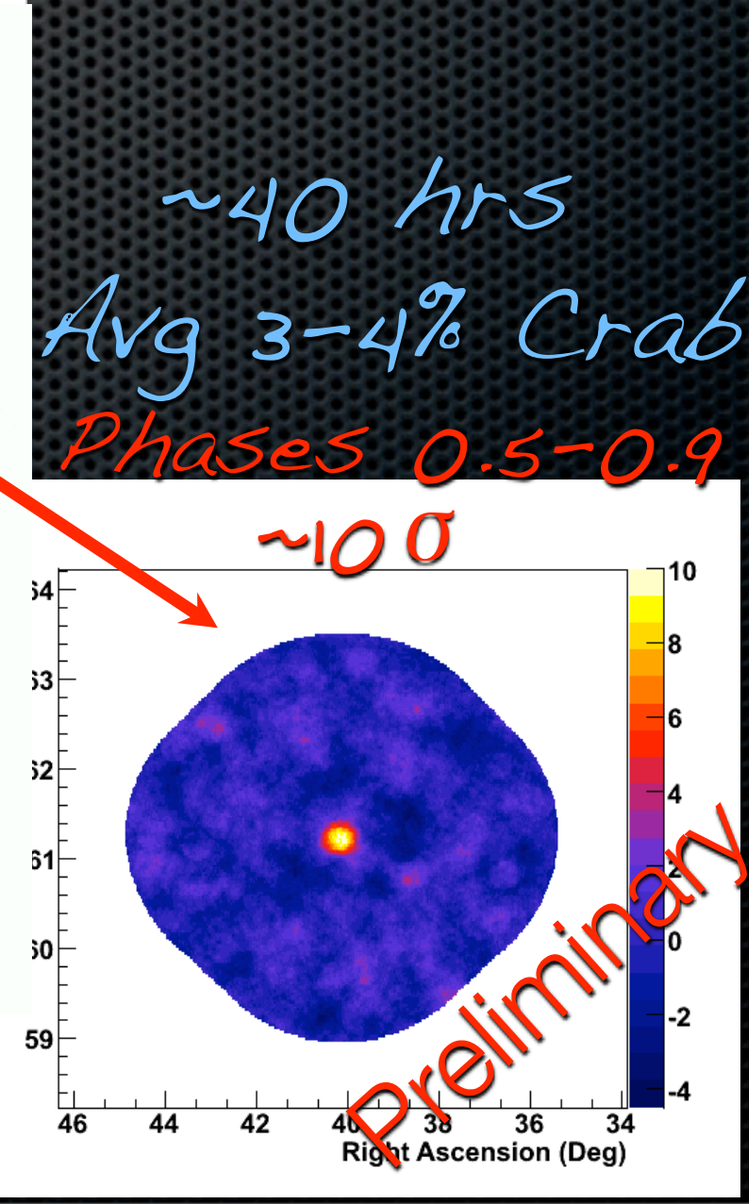
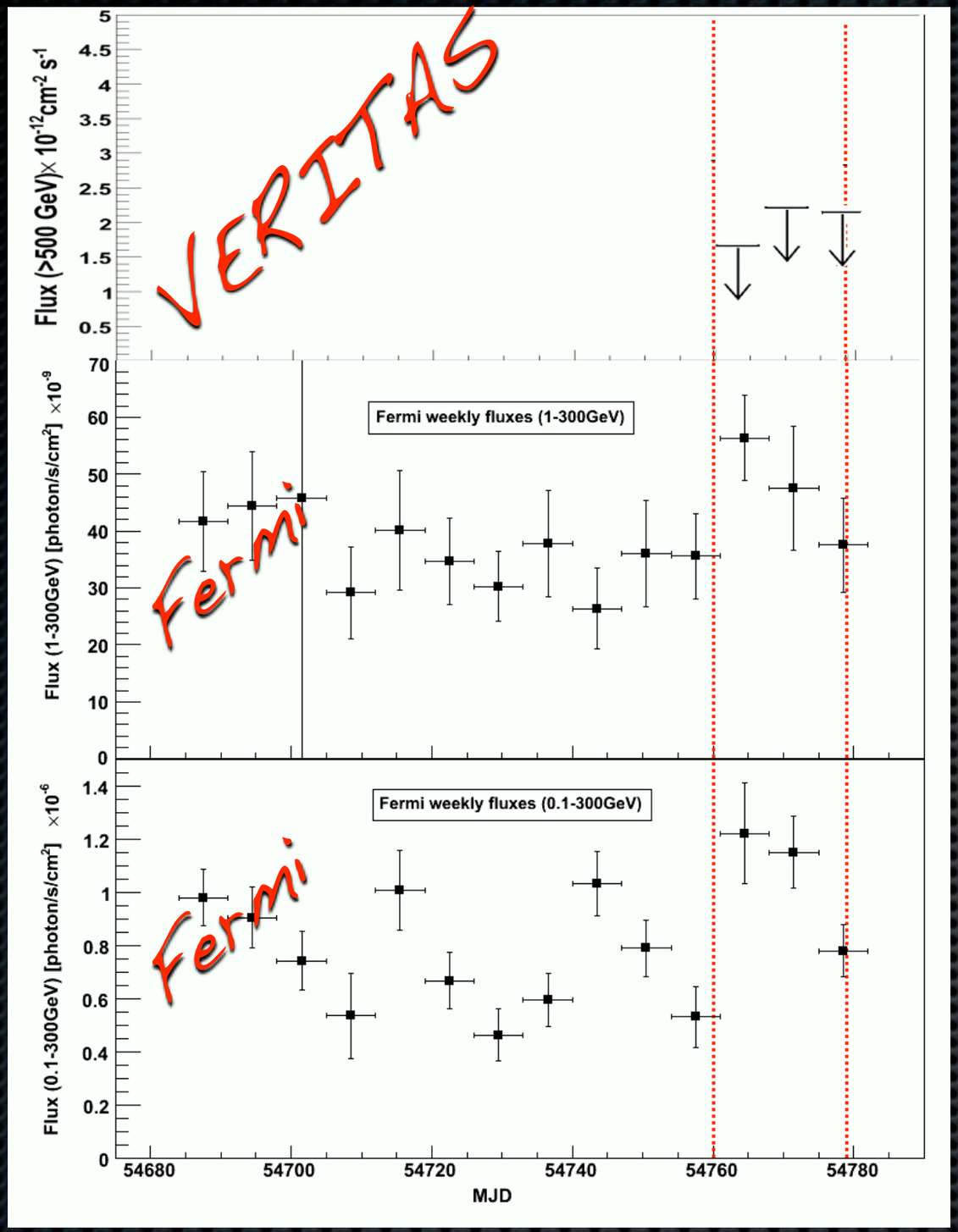
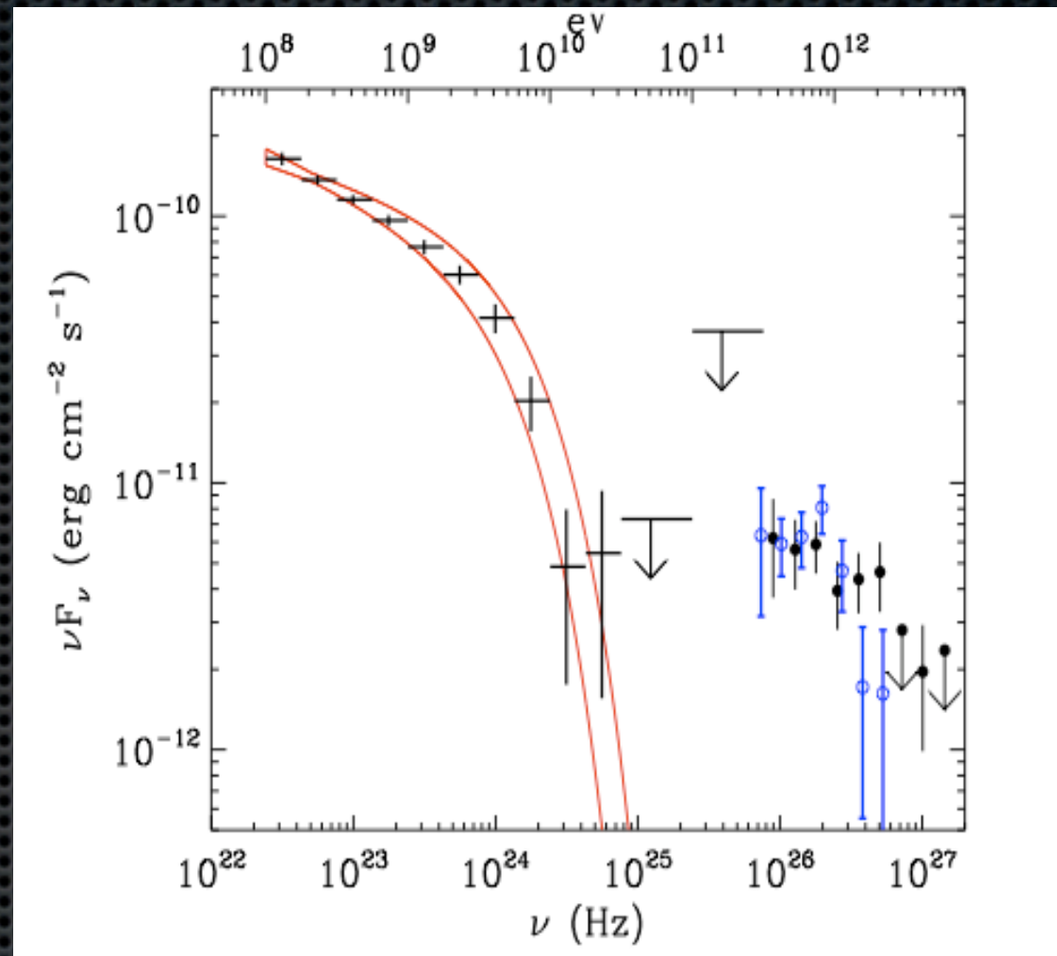


Fermi+VERITAS





No sign of spectral variability, Strong cutoff ~several GeV

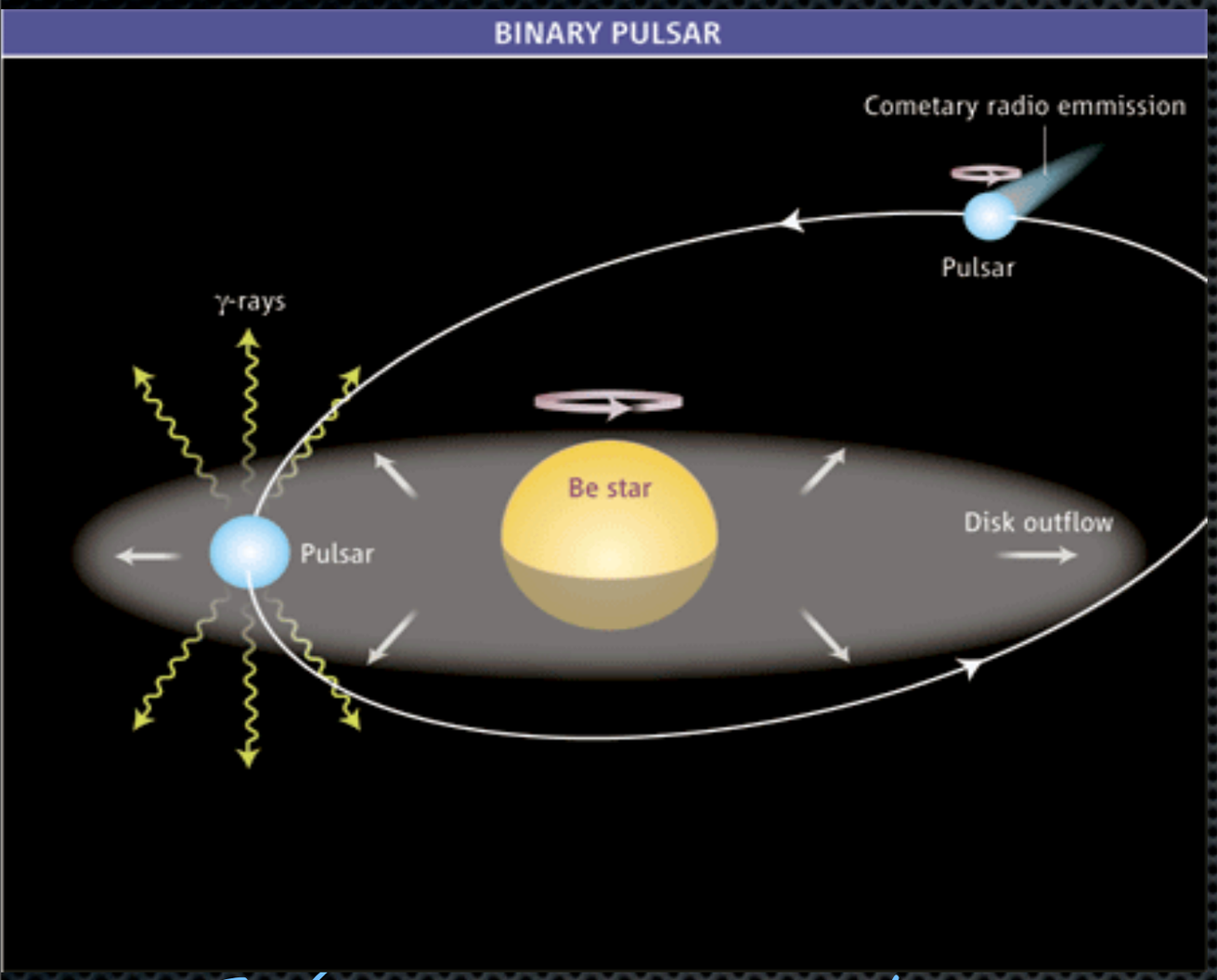
Life just got more complicated....

Summary of Observations:

-TeV emission: variable, peaks at apastron, some evidence for weak signal near periastron.

-GeV/TeV campaigns- Fermi + possibility of periastron emission may point to strong role of absorption, different GeV/TeV spectral components?

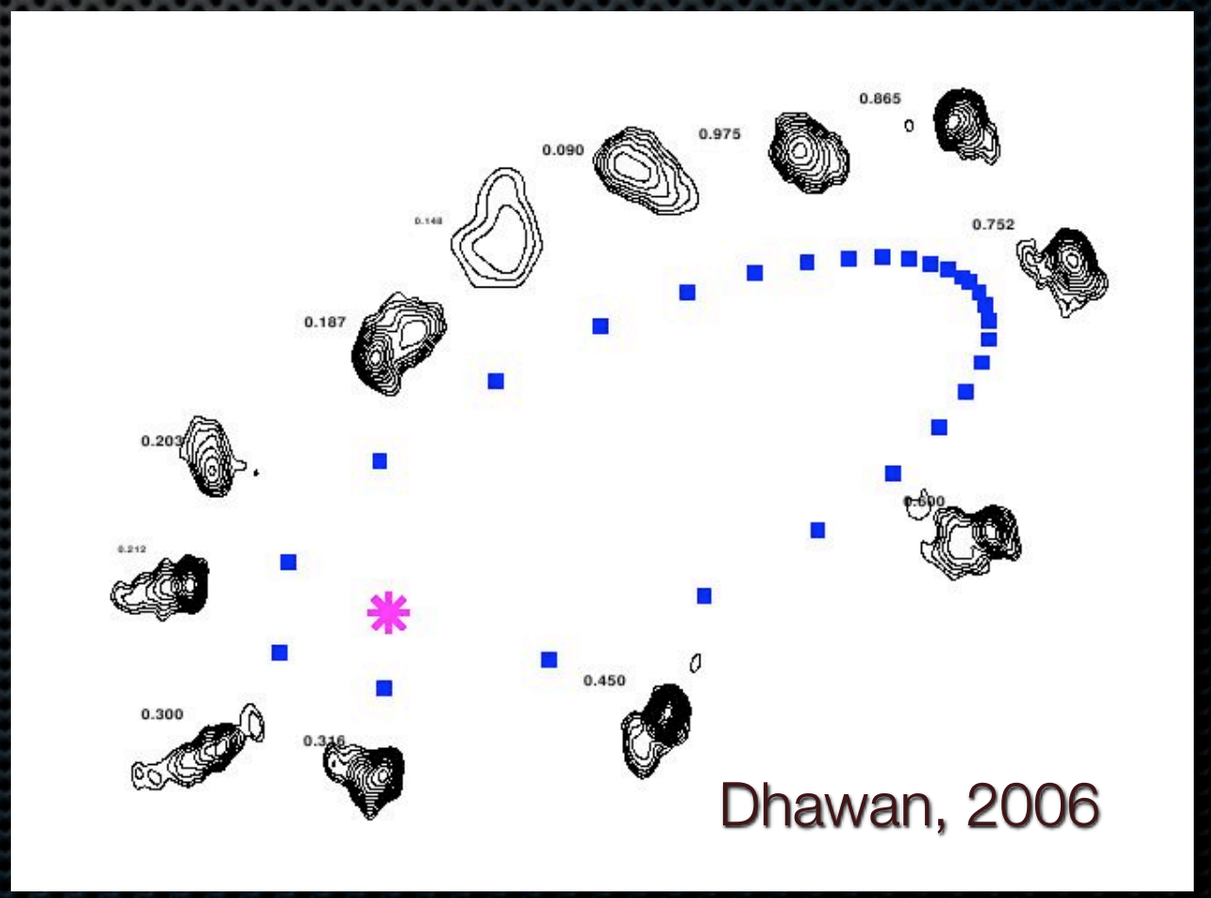
Possible Explanations for TeV:



-Binary Pulsar model:

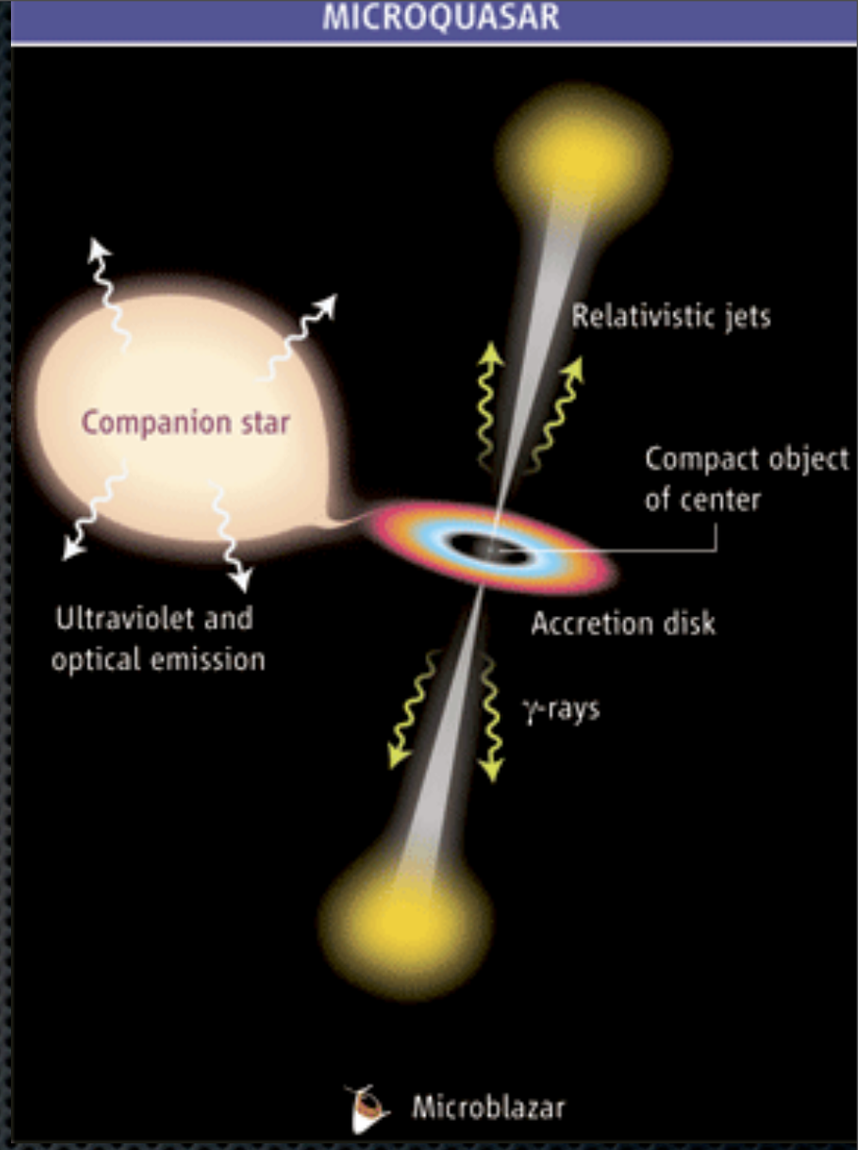
Crushed B-field at periastron-less TeV emission due to synchrotron losses

-TeV emission peaks near apastron, cometary radio emission (seen in VLBA)



Possible Explanations for TeV:

-Microquasar model: Accretion, jet power peaks at periastron, but TeV strongly absorbed- need to simultaneously measure spectra..... TeV



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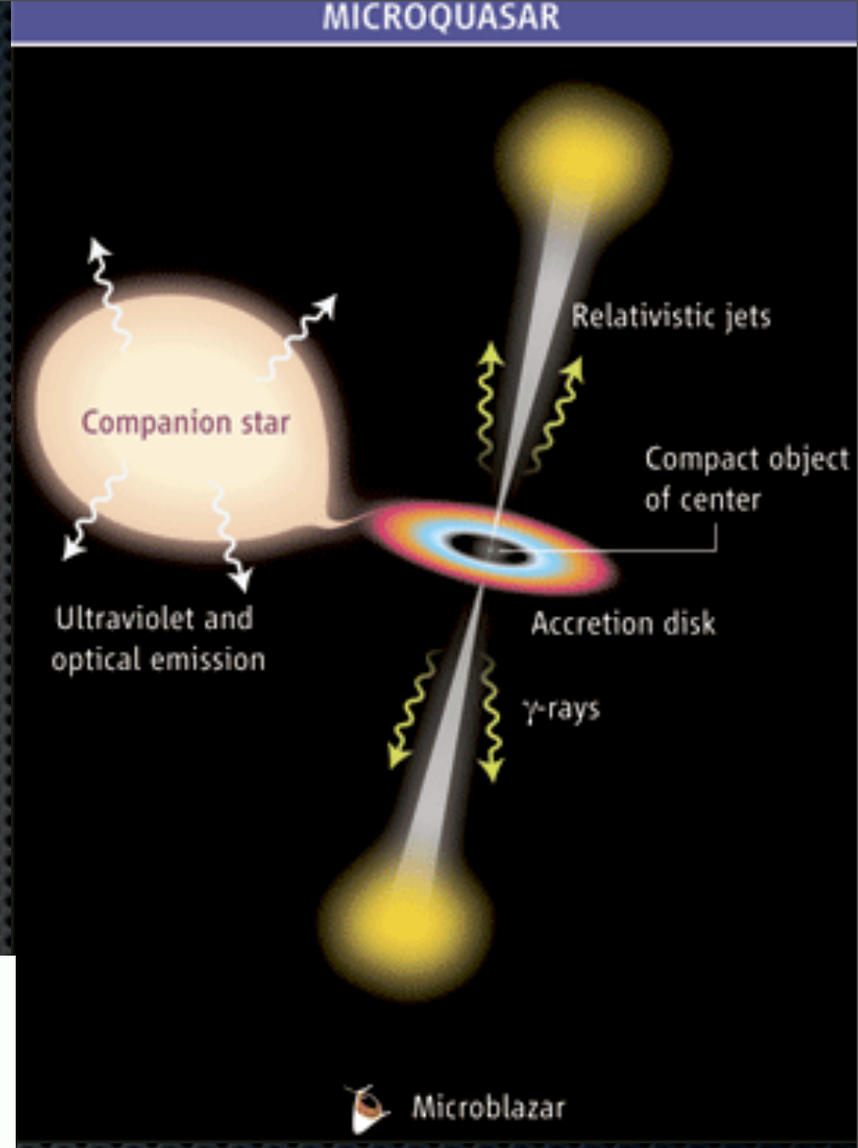

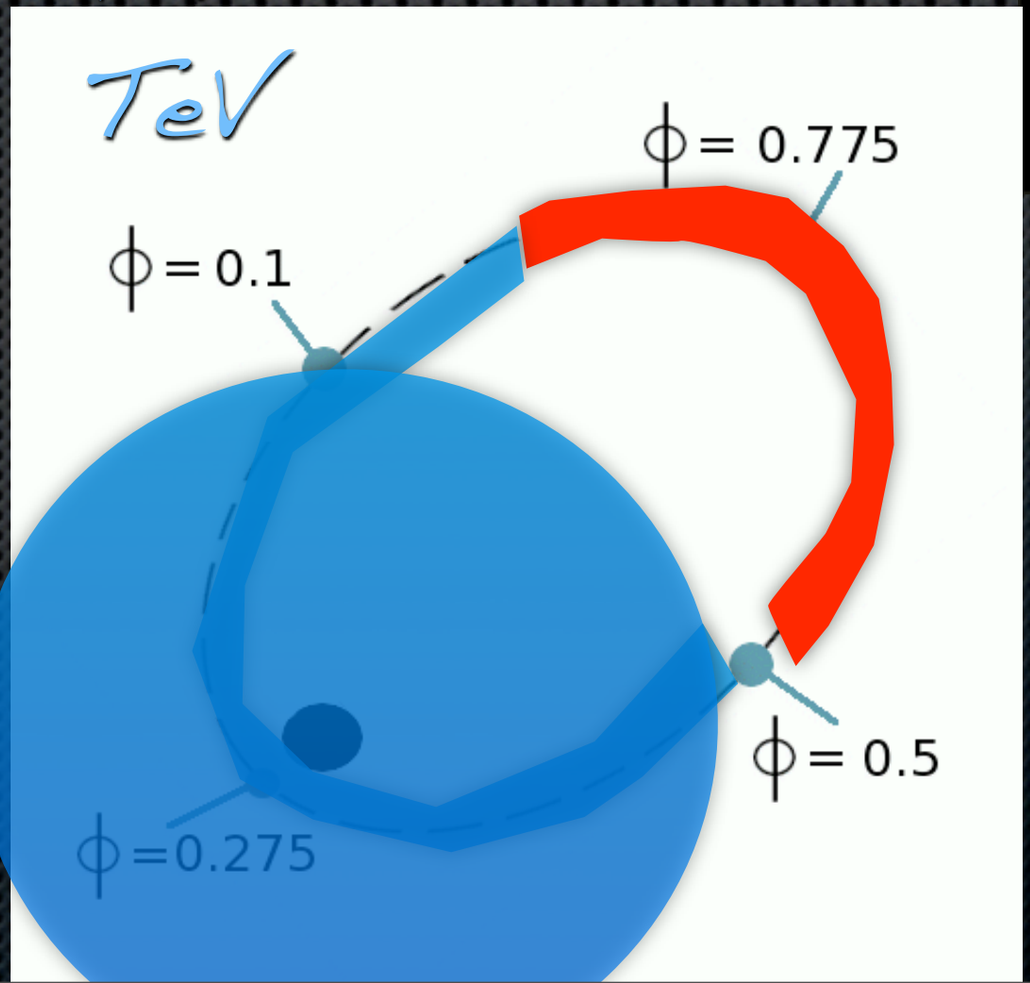

Open Issues:

-The more we learn, less we know- how does GeV connection fit into models?

-LS I +61 303 is a very complex (and local) laboratory for the study of astrophysical processes (accretion, ejection, shock physics, absorption?

-If absorption is key player, possible to indirectly study stellar environments of massive stars....

-Intense MW campaign underway currently: VERITAS, Fermi, Swift, KPNO, Liverpool

Open Issues:

Known Binary TeV Sources:

LS 5039

LS I +61 303

PSR B1259+63

(Cygnus X-1)

(HESS J0632+057)

Binaries with no TeV signal detected:

GRS 1915+105

Cygnus X-3

1A 0620-00

XTE J2012+381

What is fundamentally different about sources on left (and middle)?