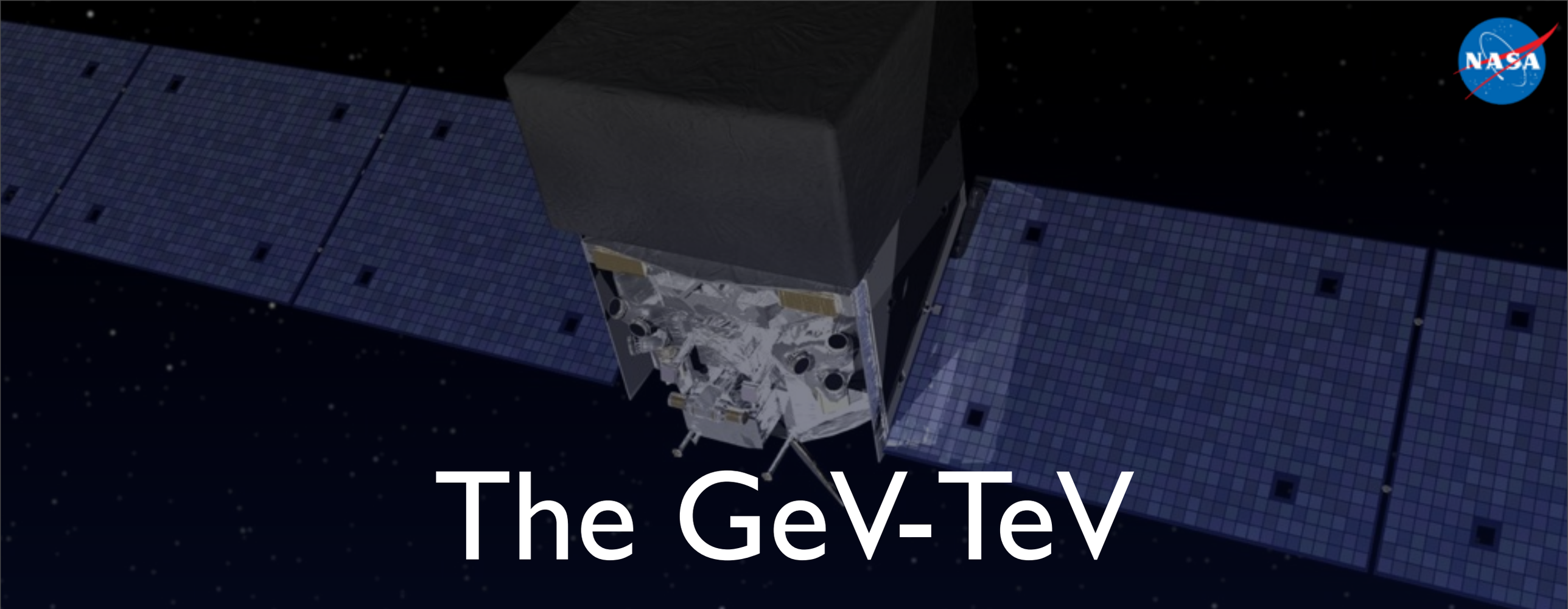

The GeV-TeV Connection

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This is the detector description.

(see every talk before this one)

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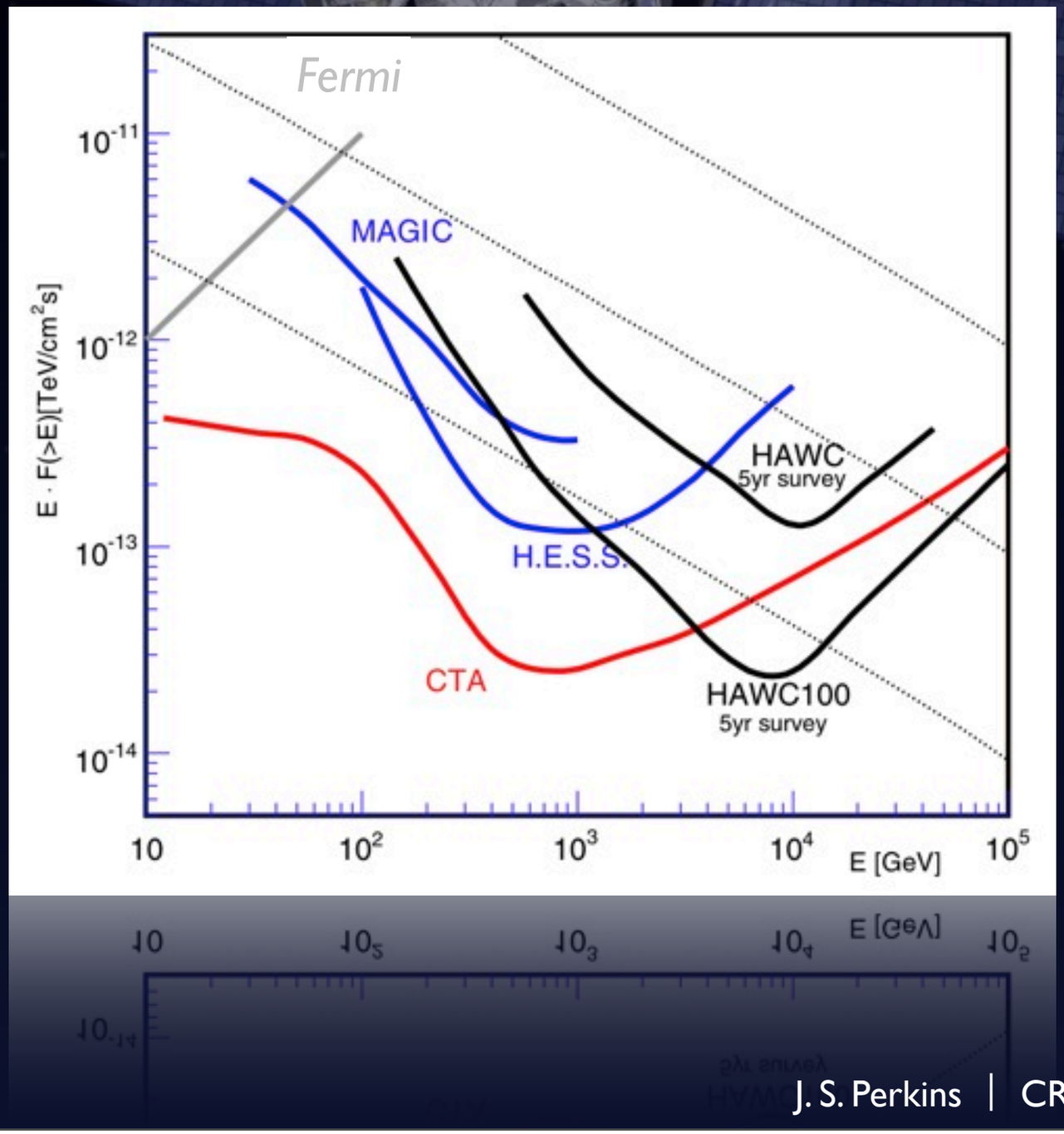
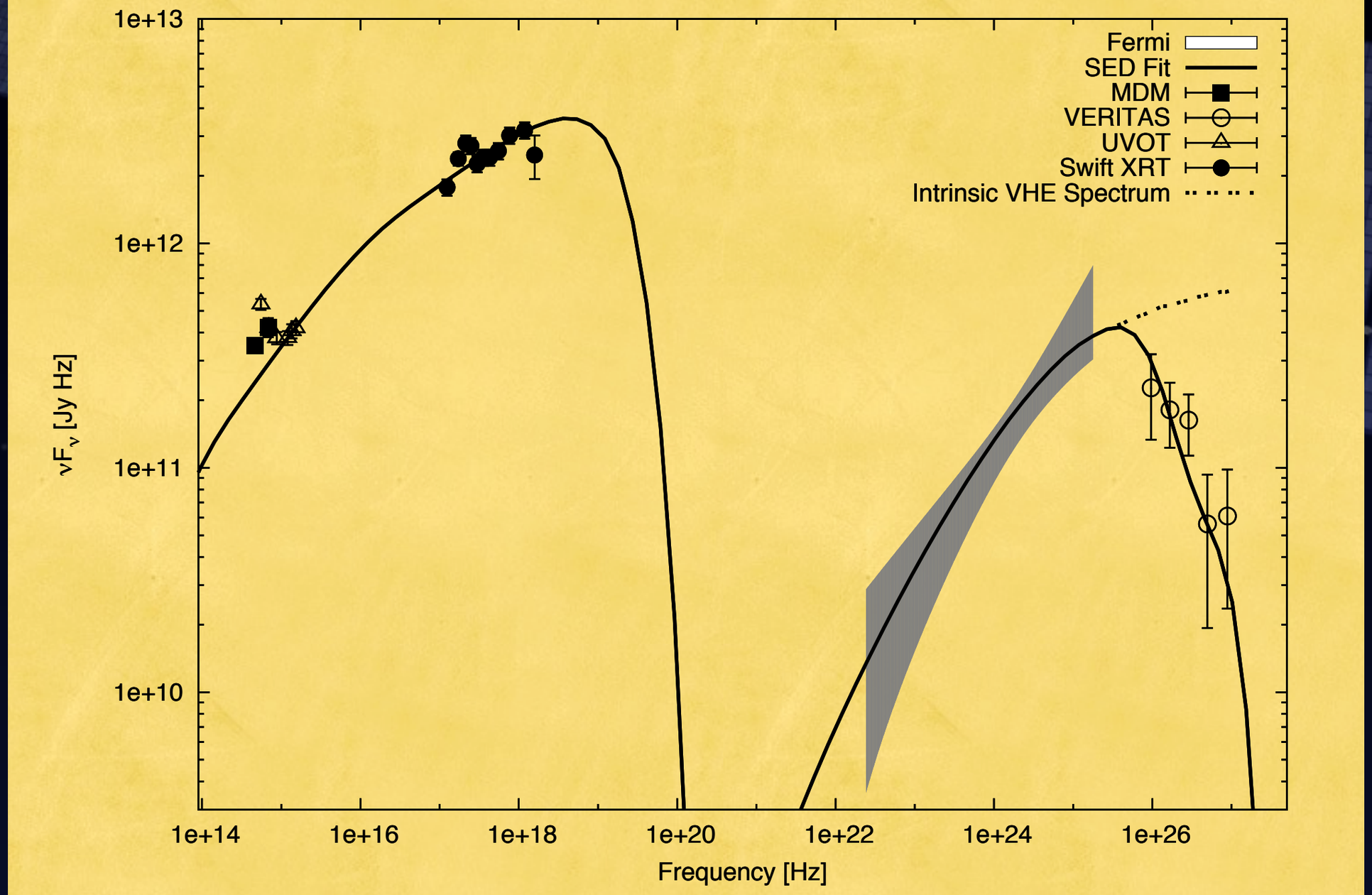
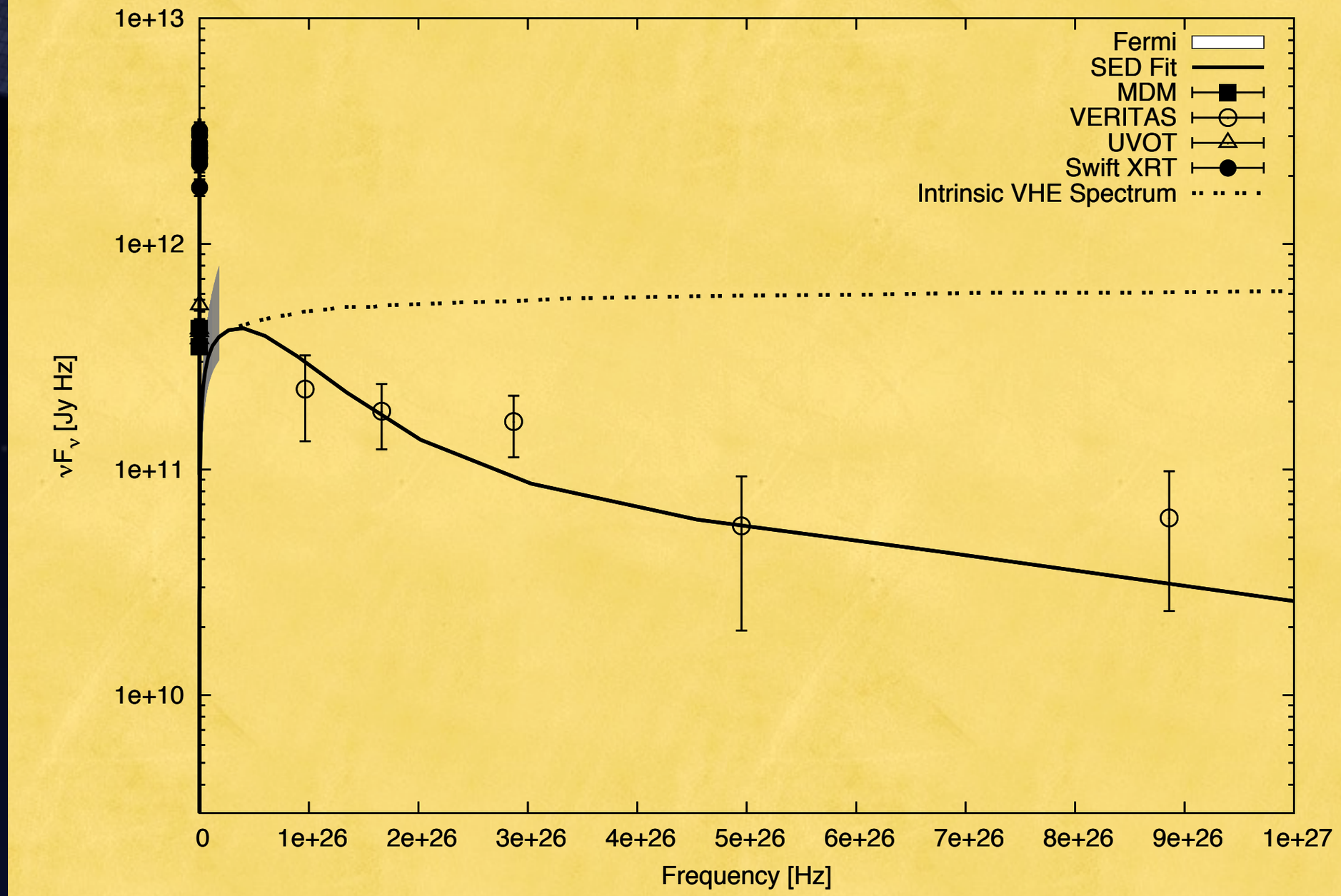
Sensitivity Overlap



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



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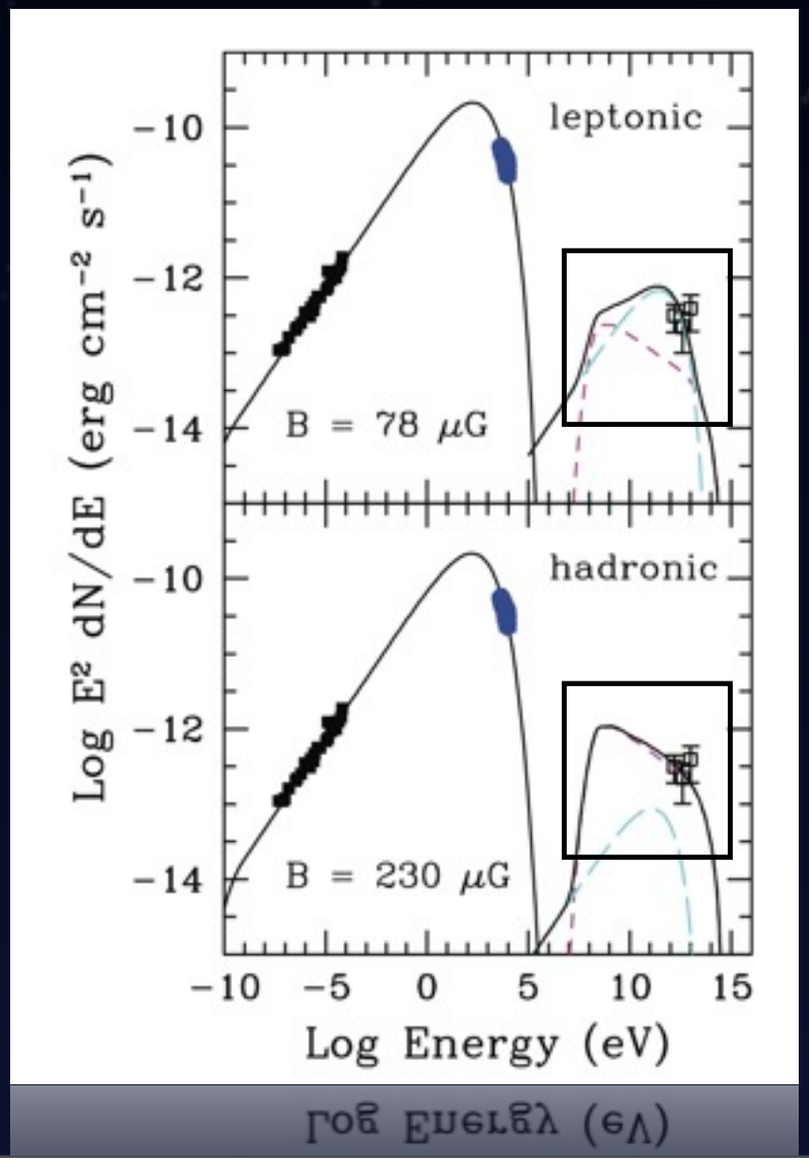
Why is the GeV-TeV Connection Important

Constrain Emission Mechanisms



Sample the same component

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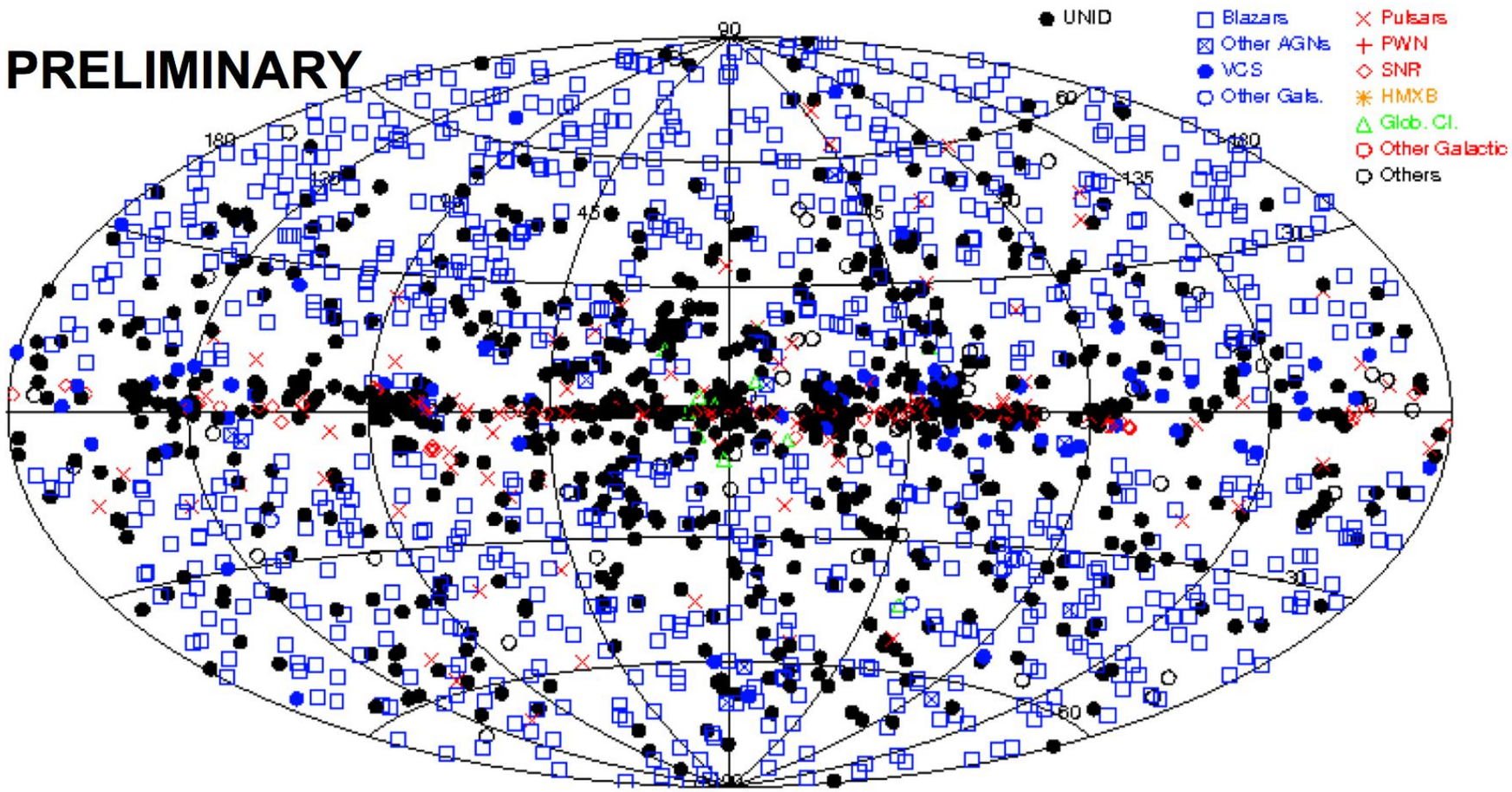
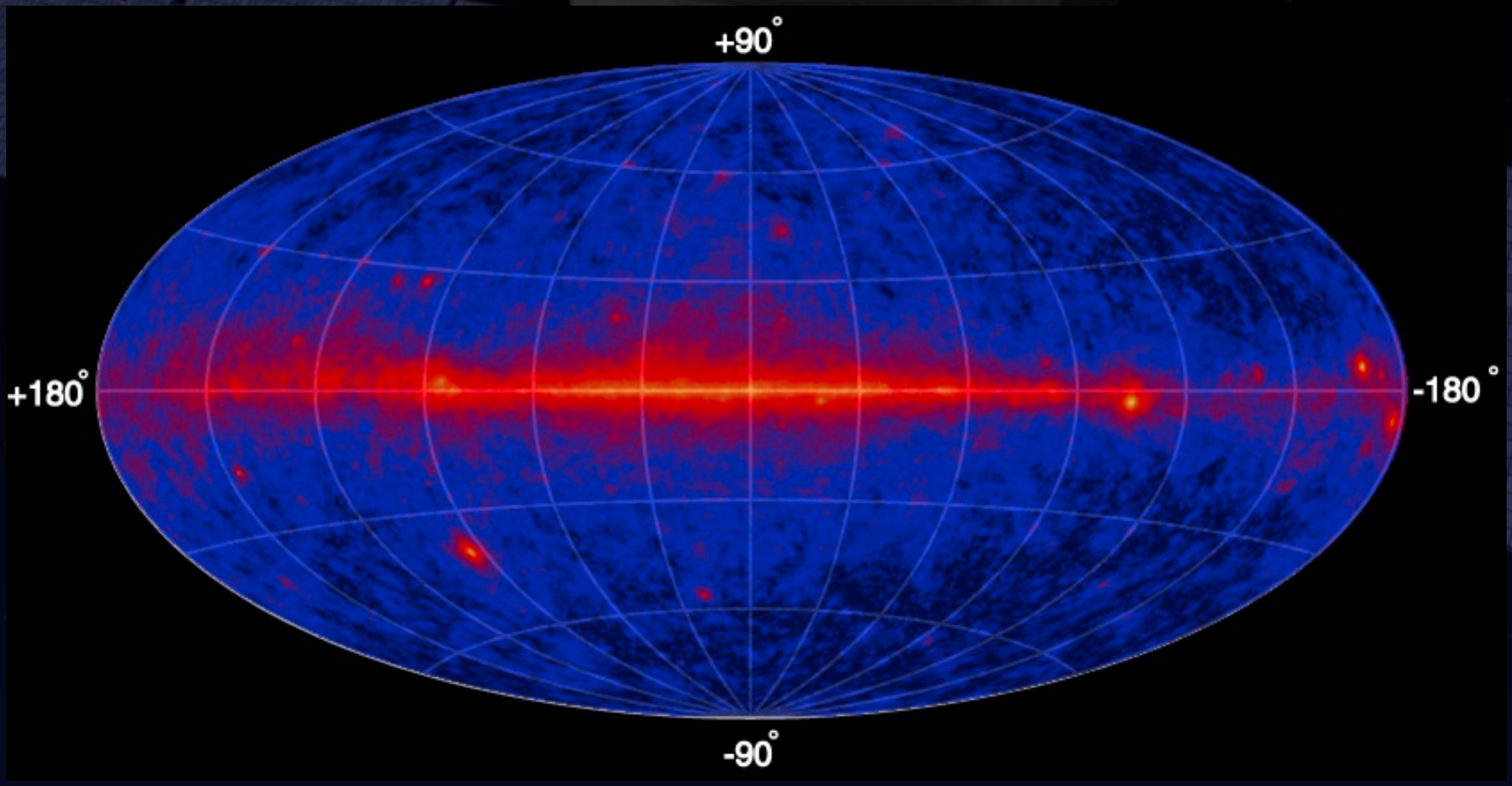
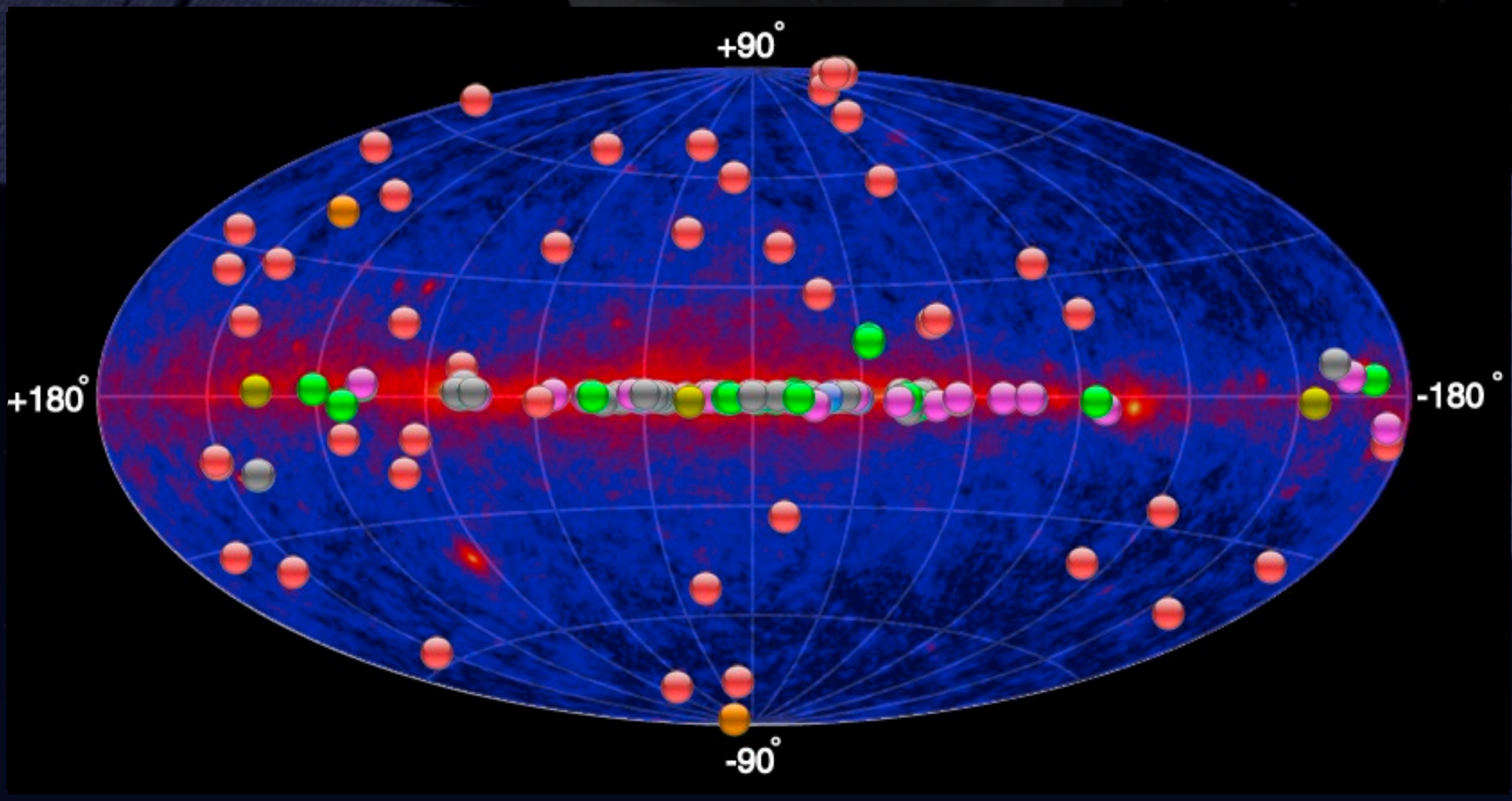
All SKy View

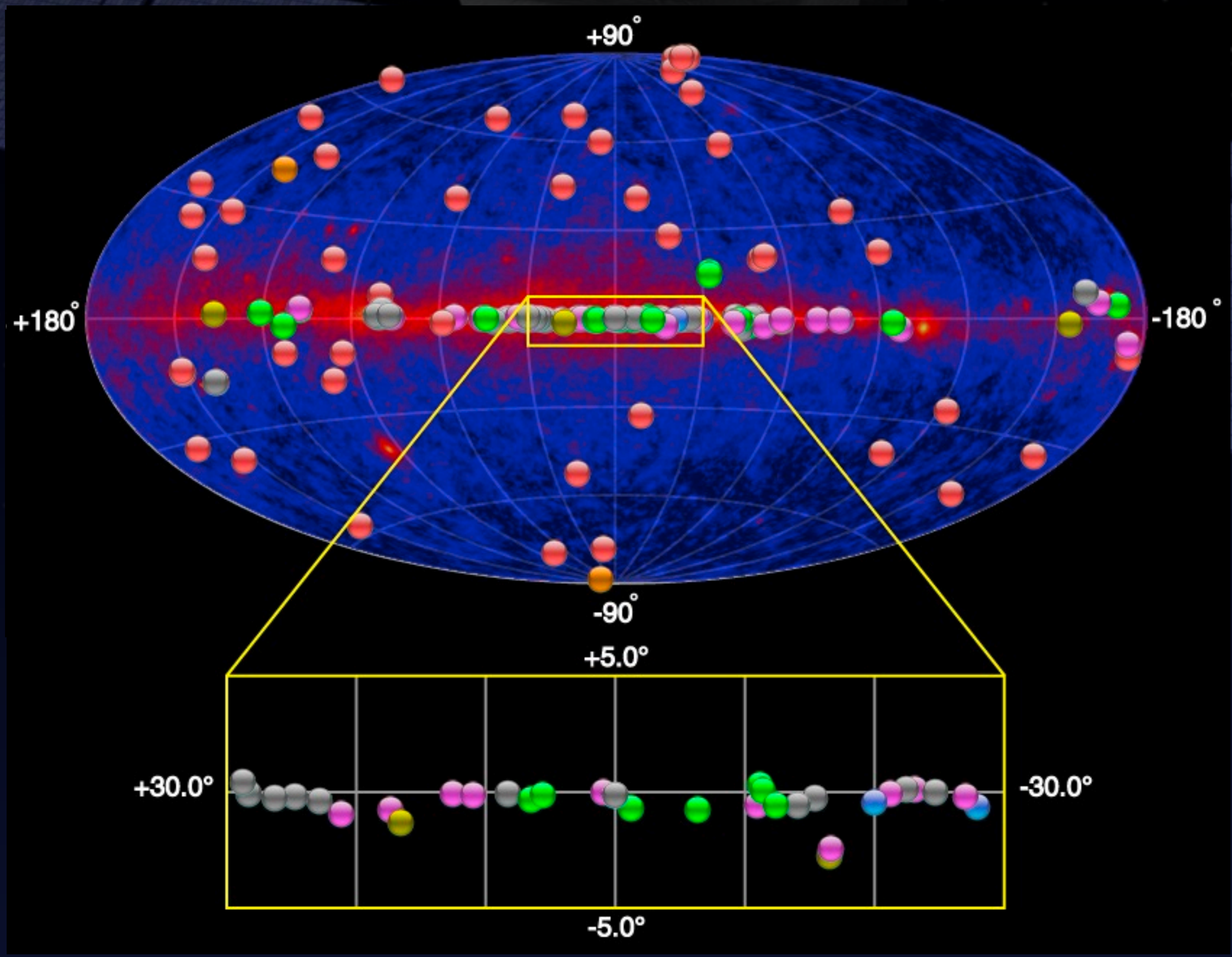

PRELIMINARY
UNID
Blazars
Other AGNs
VCS
Other Gals.
Pulsars
PWN
SNR
HMXB
Glob. Cl.
Other Galactic
Others
90
60
30
0
45
135
180
225
315



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC

+90°

+180°

-180°

-90°

+5.0°

+30.0°

-30.0°

-5.0°

Source Types

- PWN
- XRB PSR Gamma BIN
- HBL IBL FRI FSRQ LBL AGN (unknown type)
- Shell SNR/Molec. Cloud
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Cat. Var. Massive Star Cluster BIN WR

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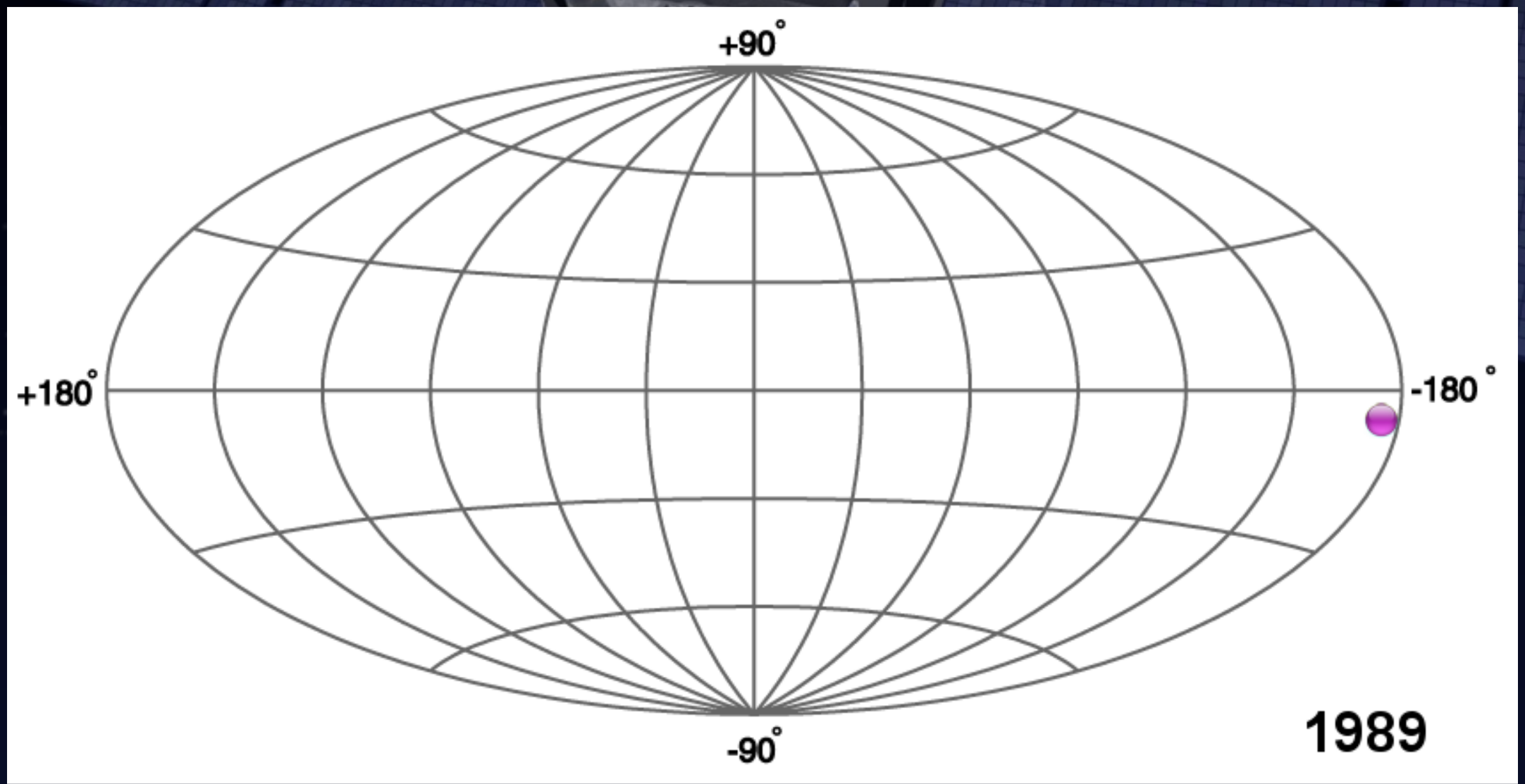
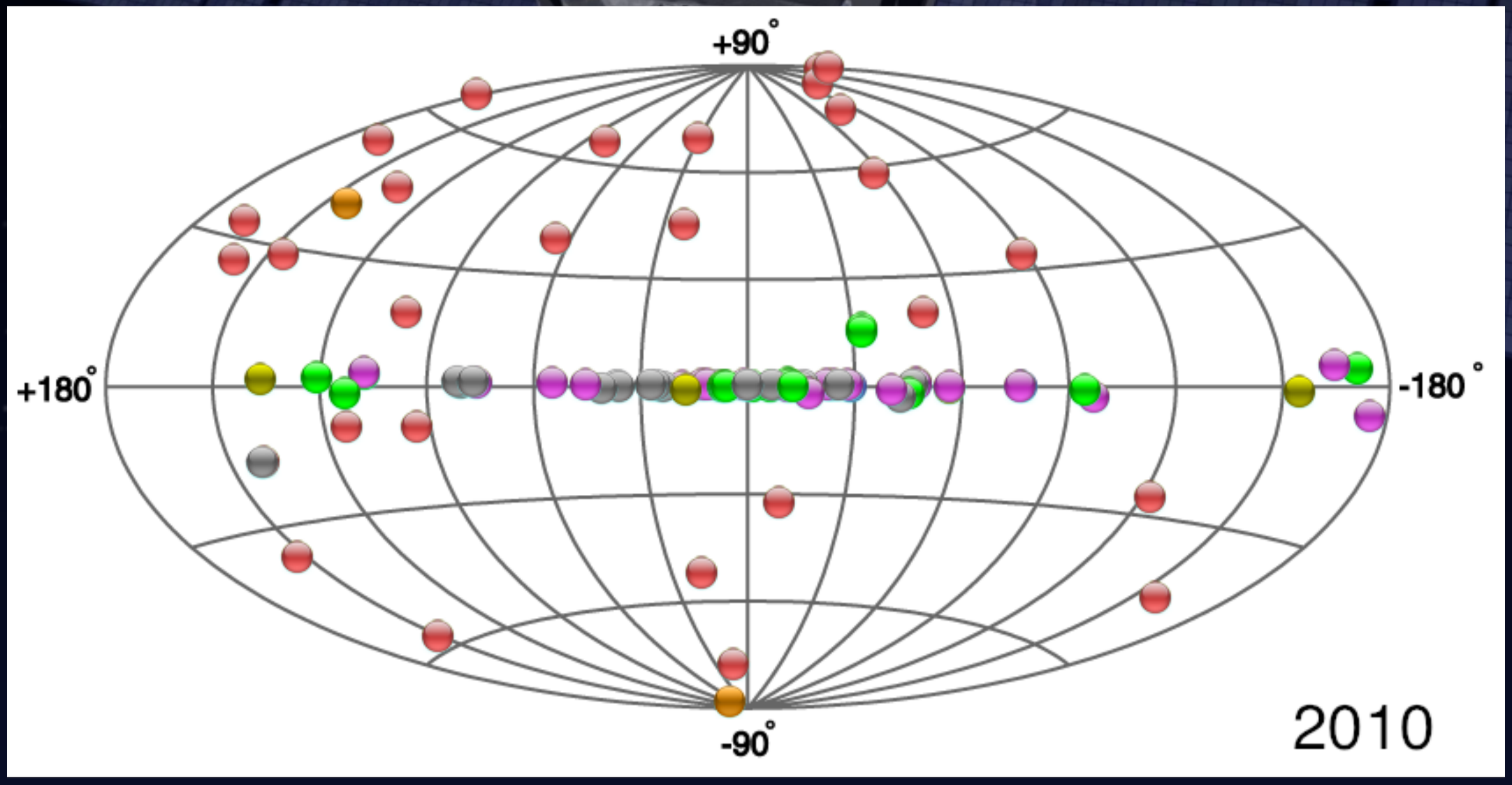
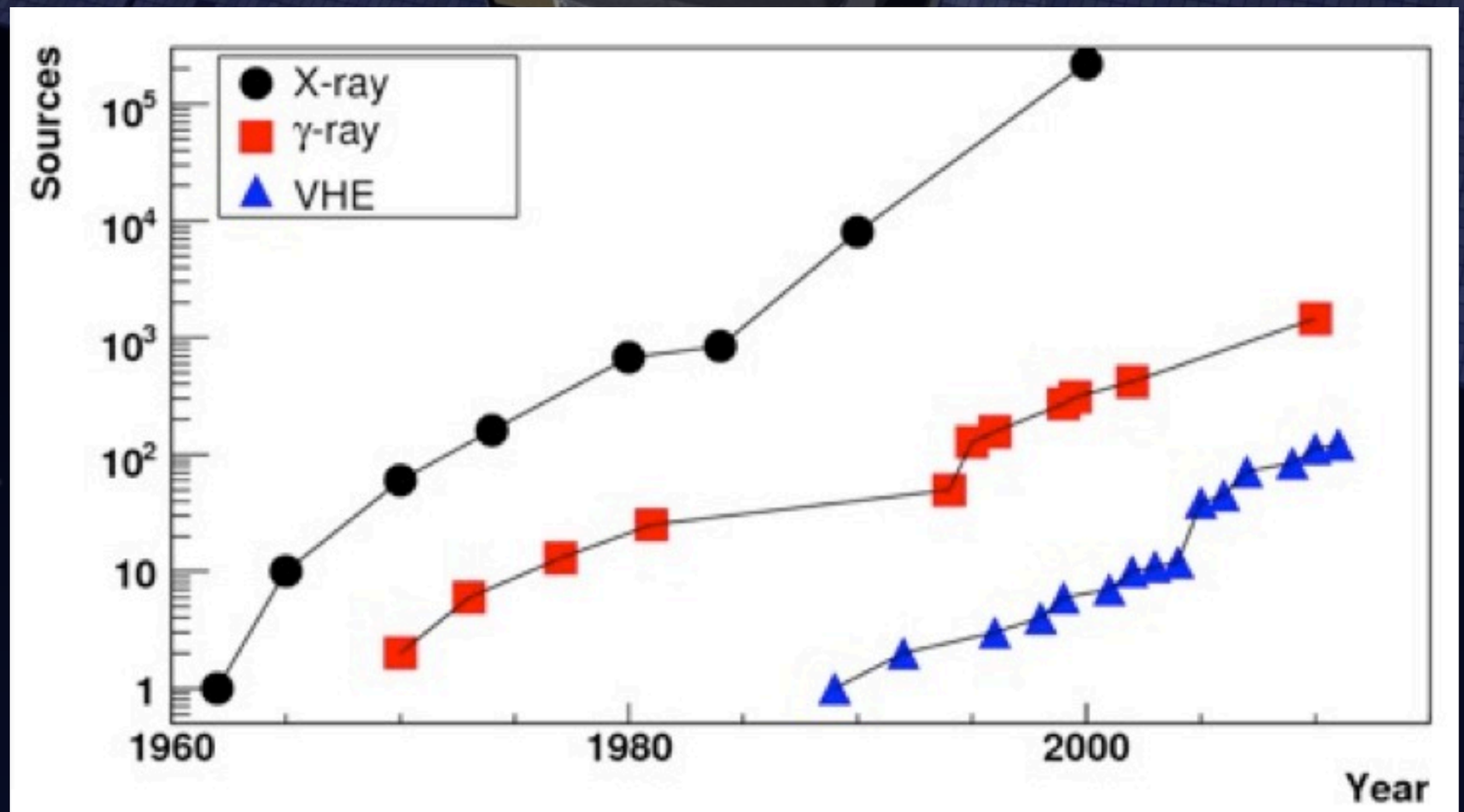


J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



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Starburst Galaxies

- High star formation rate (10-100x MW) leads to high SN rate (0.1 to 1 / year)
- High Cosmic ray density (100x MW)
- High Gas Density (150 particles/cm^3)
- The Origin of Cosmic-rays?
  - Maybe SN and massive stellar winds?
- M82/NGC 253: Lots of SNe, stars and gas
  - CR hadrons + gas ⇒ pions ⇒ Υ-rays
  - CR electrons + photons ⇒ Υ-rays

M82 / NGC 253

Galaxy	d (Mpc)	R_{SN} (yr^{-1})	M_{Gas} ($10^9\ M_\odot$)	F_γ [a] (10^{-8} ph cm^{-2} s^{-1})	$4\pi d^2 F_\gamma$ [a] (10^{42} ph s^{-1})	L_γ [a] (10^{39} erg s^{-1})
LMC[b]	0.049 ± 0.001	0.005 ± 0.002	0.67 ± 0.08	26.3 ± 4.7	0.074 ± 0.013	0.041 ± 0.007
Milky Way[c]	1	0.02 ± 0.01	6.5 ± 2.0	4.6 ± 2.3	5.5 ± 2.8	3.2 ± 1.6
M82	3.6 ± 0.3	0.2 ± 0.1	2.5 ± 0.7	1.6 ± 0.5	25 ± 9	13 ± 5.0
NGC 253	3.9 ± 0.4	0.2 ± 0.1	2.5 ± 0.6	0.6 ± 0.4	11 ± 7	7.2 ± 4.7

- M82: Galactic Interactions over 100s millions of yrs (~1 with M81)
  - Tidal forces created an active starburst region (1000 light yrs. in dia., 200+ star clusters).
- NGC 253: Central region contains high densities (60% of MW gas)
  - Both have very active star forming regions
  - Best candidates in N/S

GeV/TeV Detections

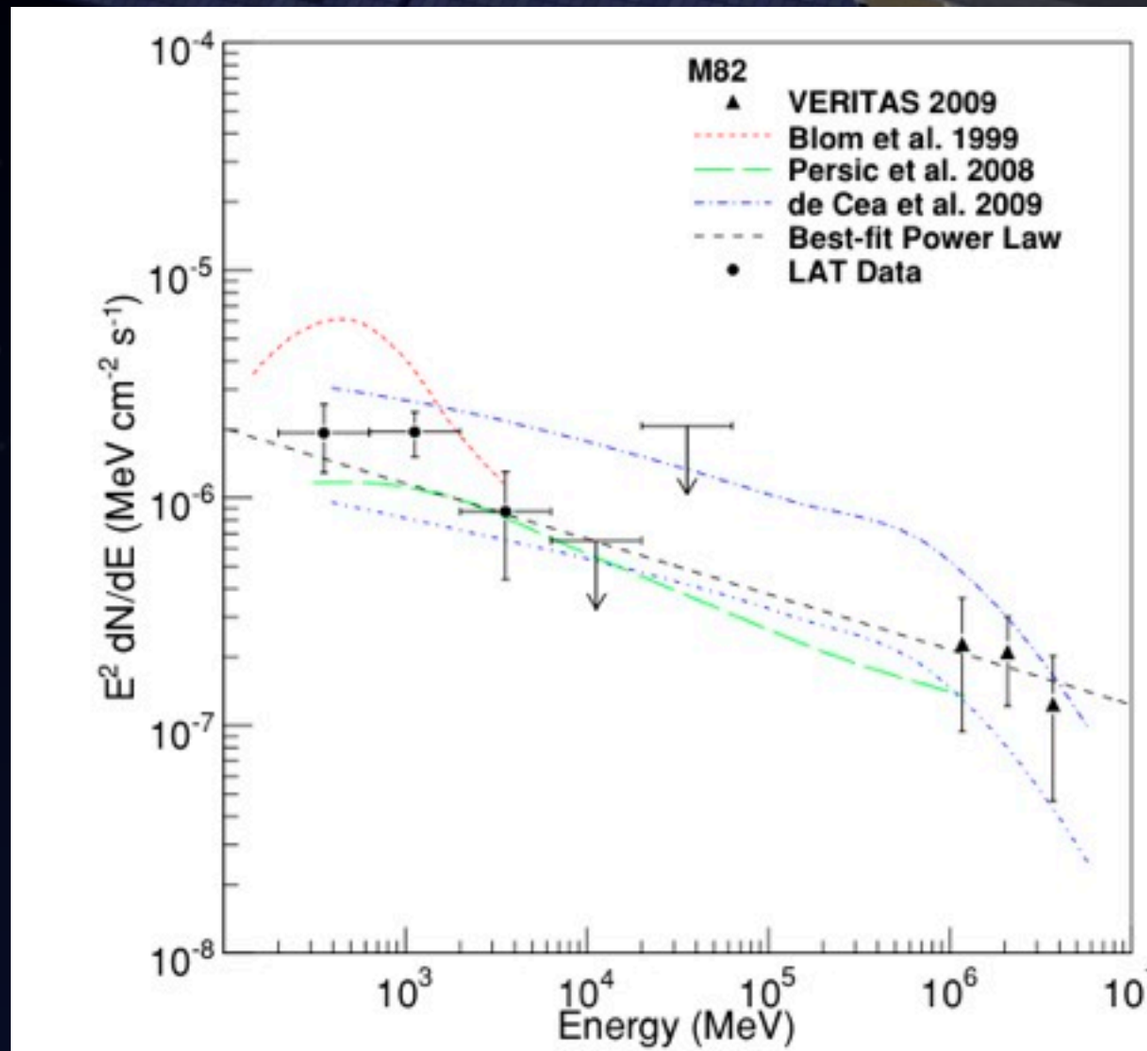
GeV

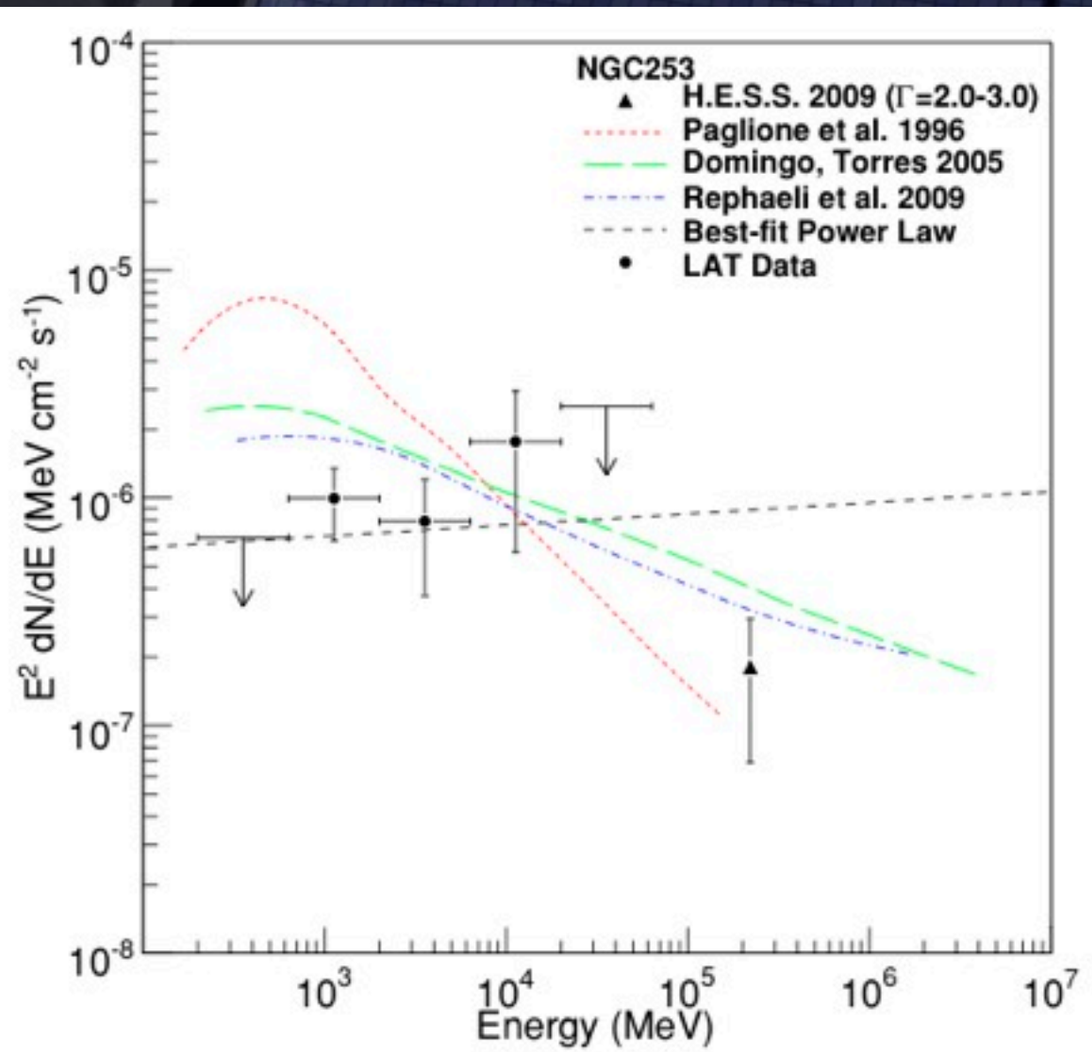
Galaxy	R.A.[a] (deg)	Decl.[a] (deg)	r_{95}[a] (deg)	$F(>100\ \mathrm{MeV})$[b] (10^{-8} ph cm^{-2} s^{-1})	Photon Index[b]	Significance[c]
M82	149.06	69.64	0.11	$1.6 \pm 0.5_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}$	$2.2 \pm 0.2_{\mathrm{stat}} \pm 0.05_{\mathrm{sys}}$	6.8
NGC 253	11.79	−25.21	0.14	$0.6 \pm 0.4_{\mathrm{stat}} \pm 0.4_{\mathrm{sys}}$	$1.95 \pm 0.4_{\mathrm{stat}} \pm 0.05_{\mathrm{sys}}$	4.8

TeV

Galaxy	Flux (10^-13 ph cm-2 s-1)	Photon Index	Significance	Excess	Time (hours)
M82 (VTS)	3.7 + 0.8 + 0.7 (>700 GeV)	2.5 + 0.6	5.0 (4.8)	91	137
NGC 253 (HESS)	5.5 + 1.0 (>220 GeV)	N/A	5.2	247	119

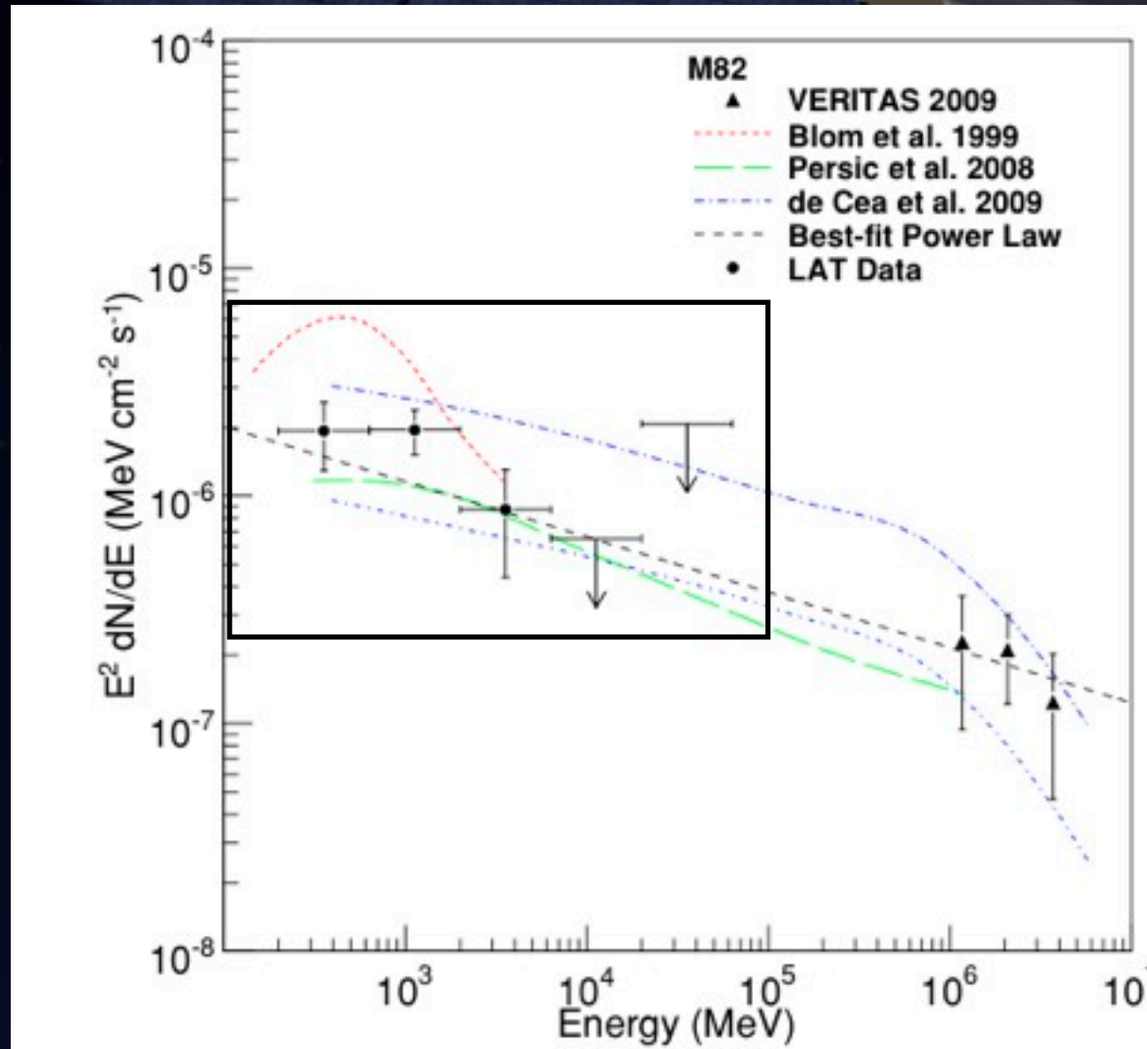
Starburst Galaxies

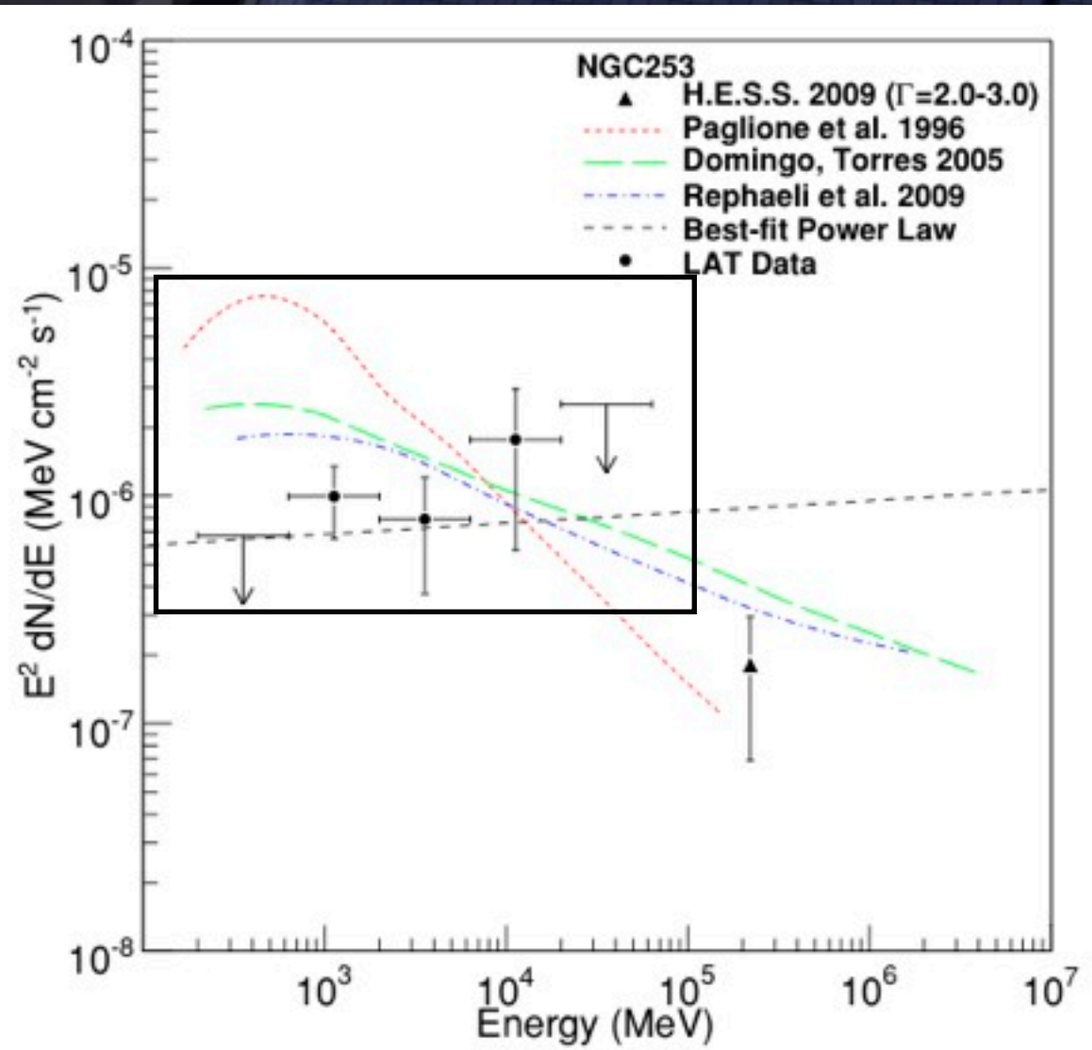




Abdo et. al. ApJL 709, 2010

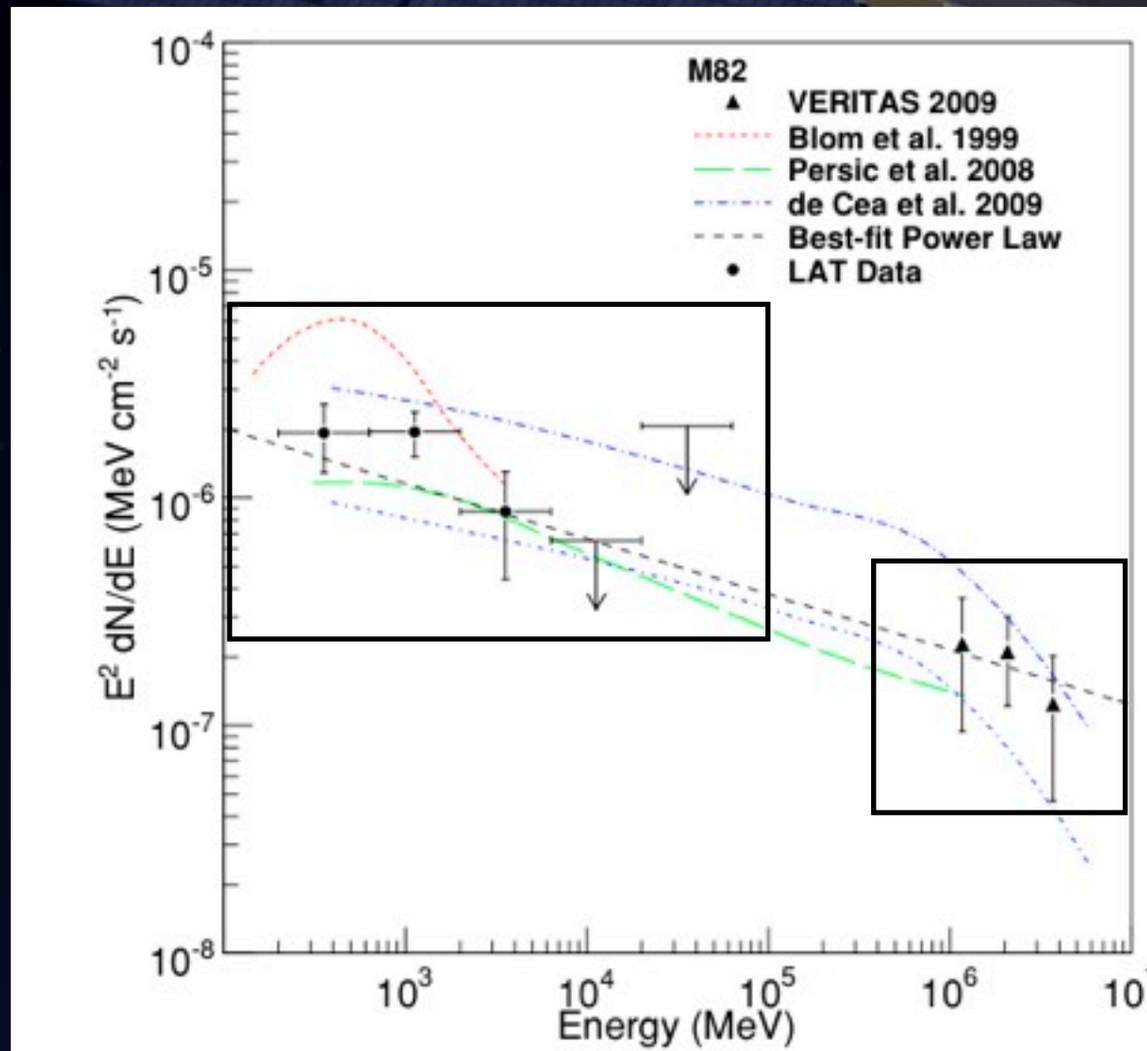
Starburst Galaxies

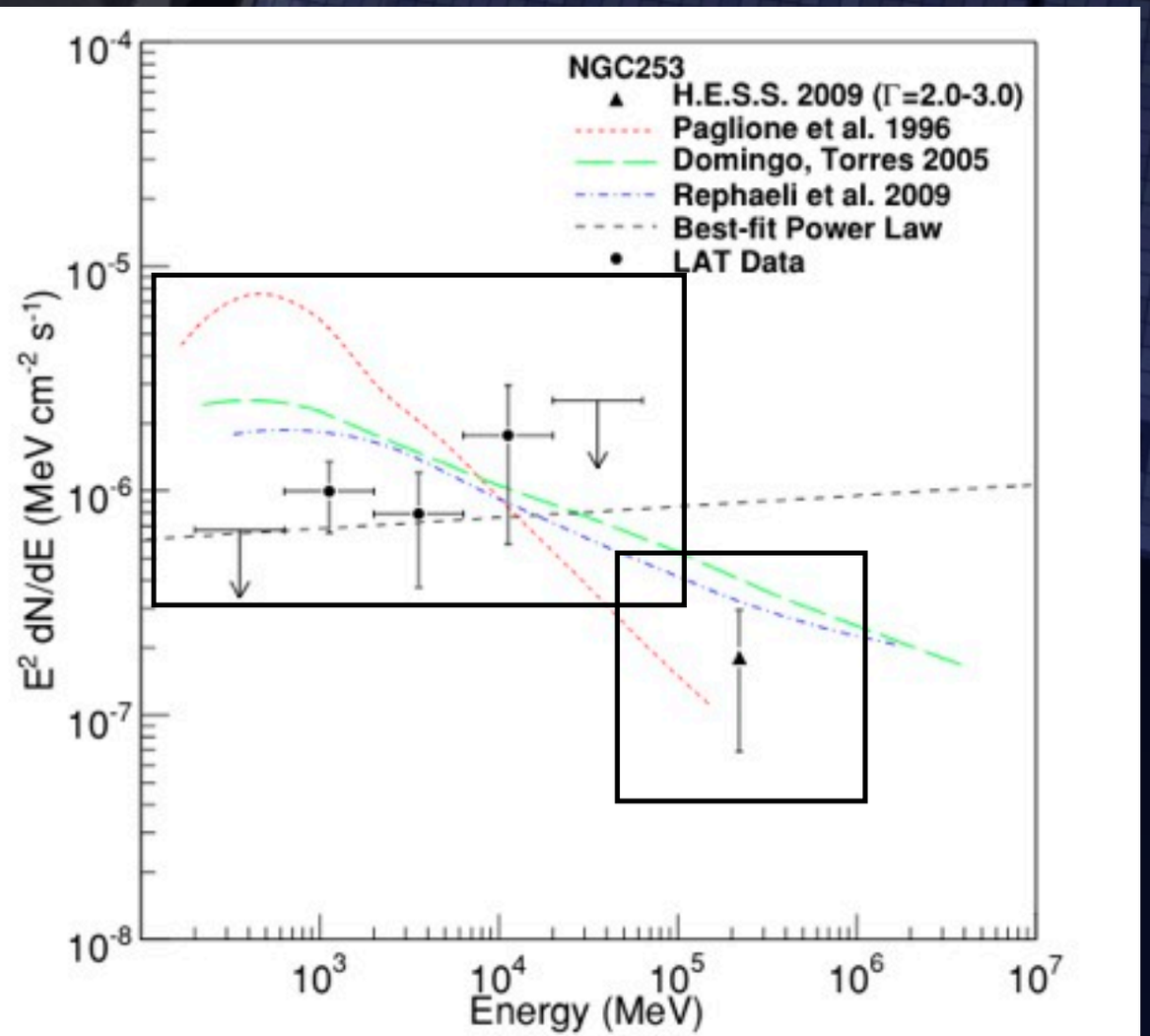




Abdo et. al. ApJL 709, 2010

Starburst Galaxies





Abdo et. al. ApJL 709, 2010

What Does it Mean?

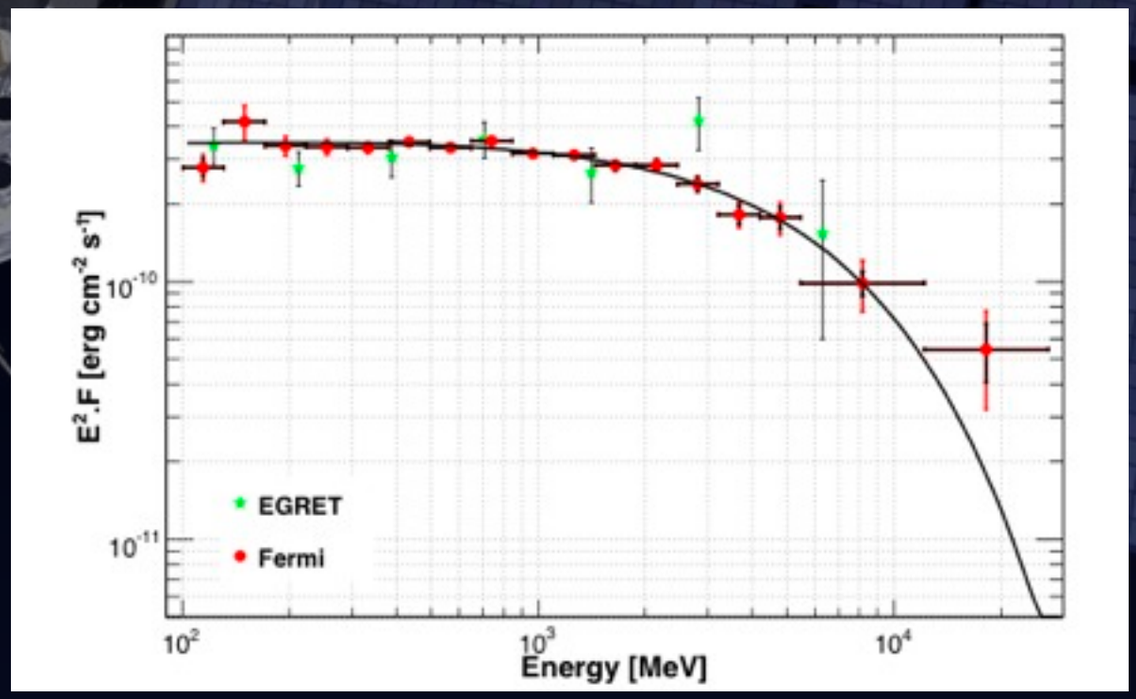
- Strongly Suggests Star-formation/Gamma-ray connection (which implies Cosmic-ray connection)
- No variability as would be expected from CR acceleration (any variability would rule out CR interpretation)
- (all of these conclusions limited by low statistics)

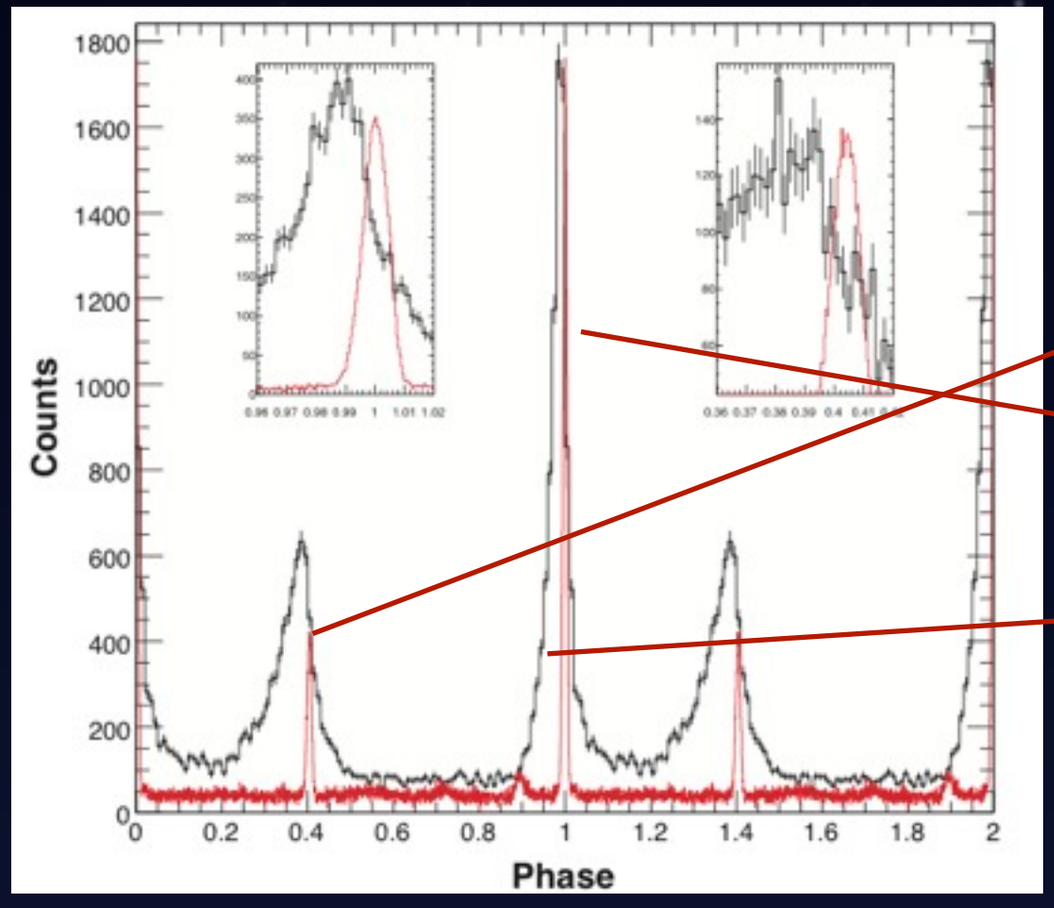
Pulsars: The Crab

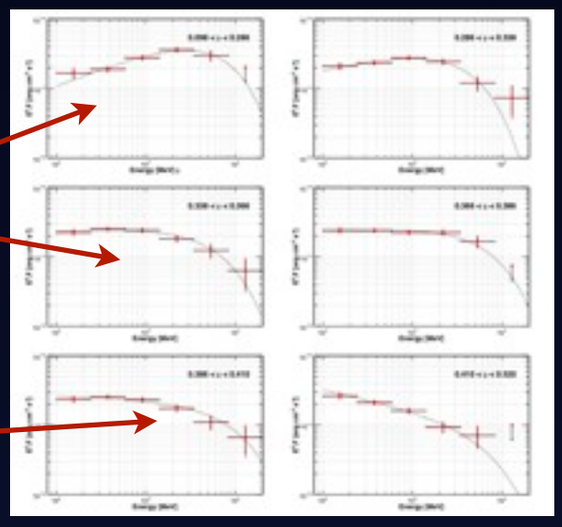
- Remnant of historic SN (1054 A.D.)
- Distance of 2 kpc
- Most energetic pulsar (4.6 x 10^38 erg/s)
- Powers the brightest (~steadiest) VHE gamma-ray source, the Crab Nebula

Pulsars: The Crab

- LAT: beautiful measurements of the pulsar and spectral break





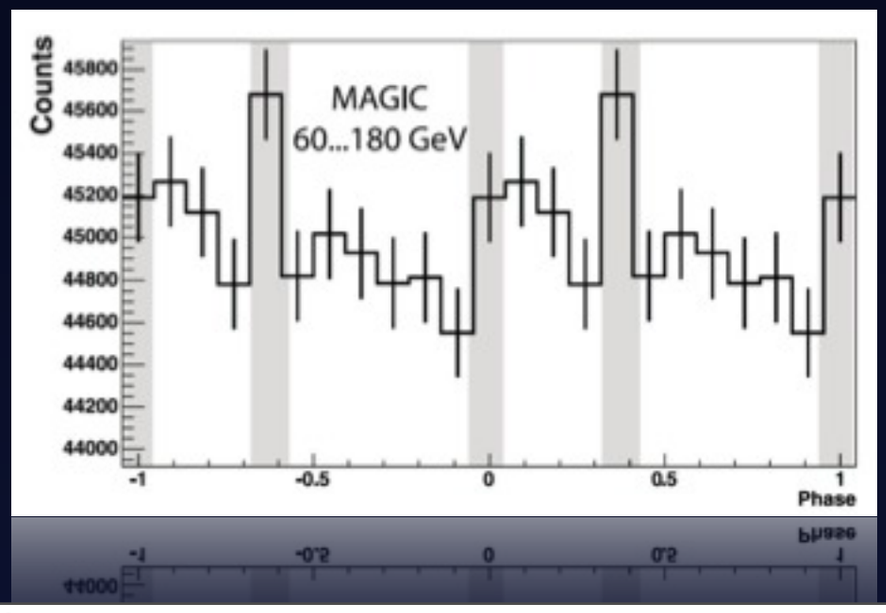


Phase Resolved Spectra

Abdo et. al. ApJ 708, 2010

The Crab

- Spectral break is described by an exponential cutoff
- Curvature radiation most favored gamma ray production mechanism
- Emission comes from region >6 stellar radii -> out gap scenarios favored



MAGIC: Detection at 25 GeV and hints at 60 GeV.

Albert et al., 2008

The Crab: VTS Detection

See Upcoming Publication for Details.

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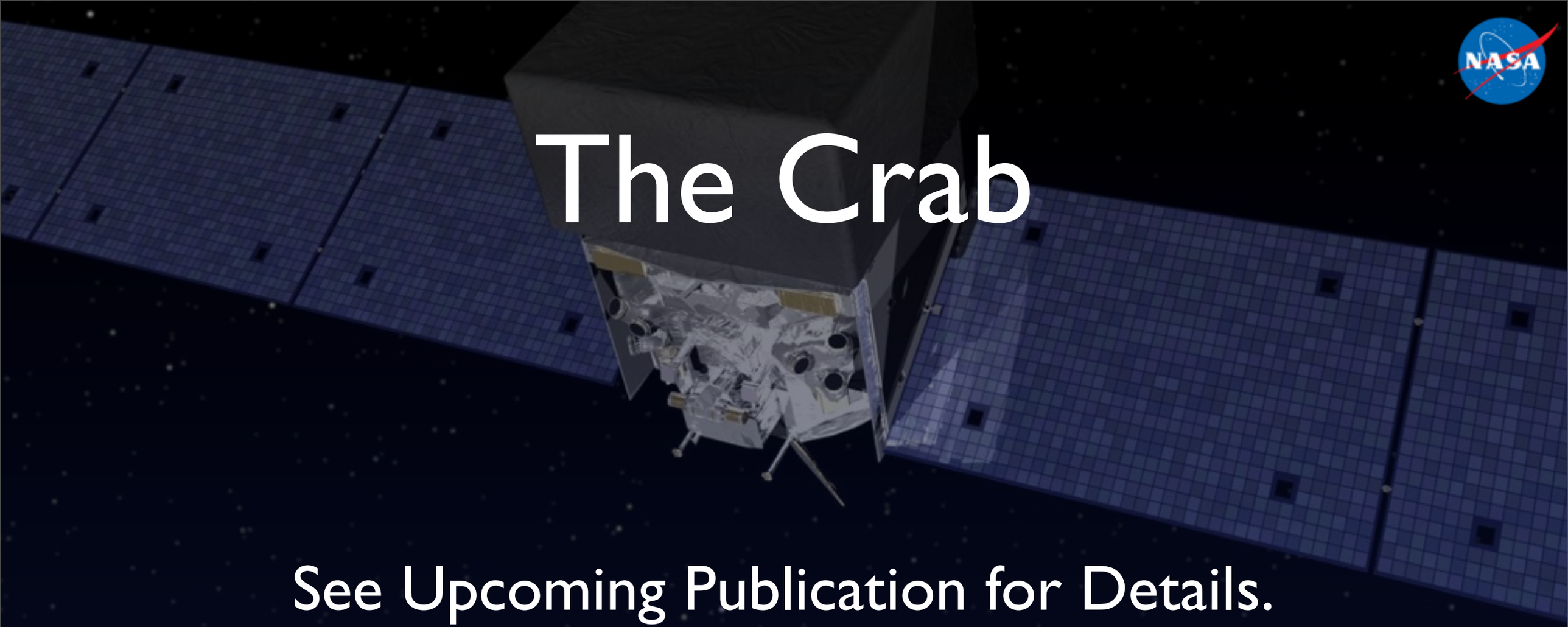
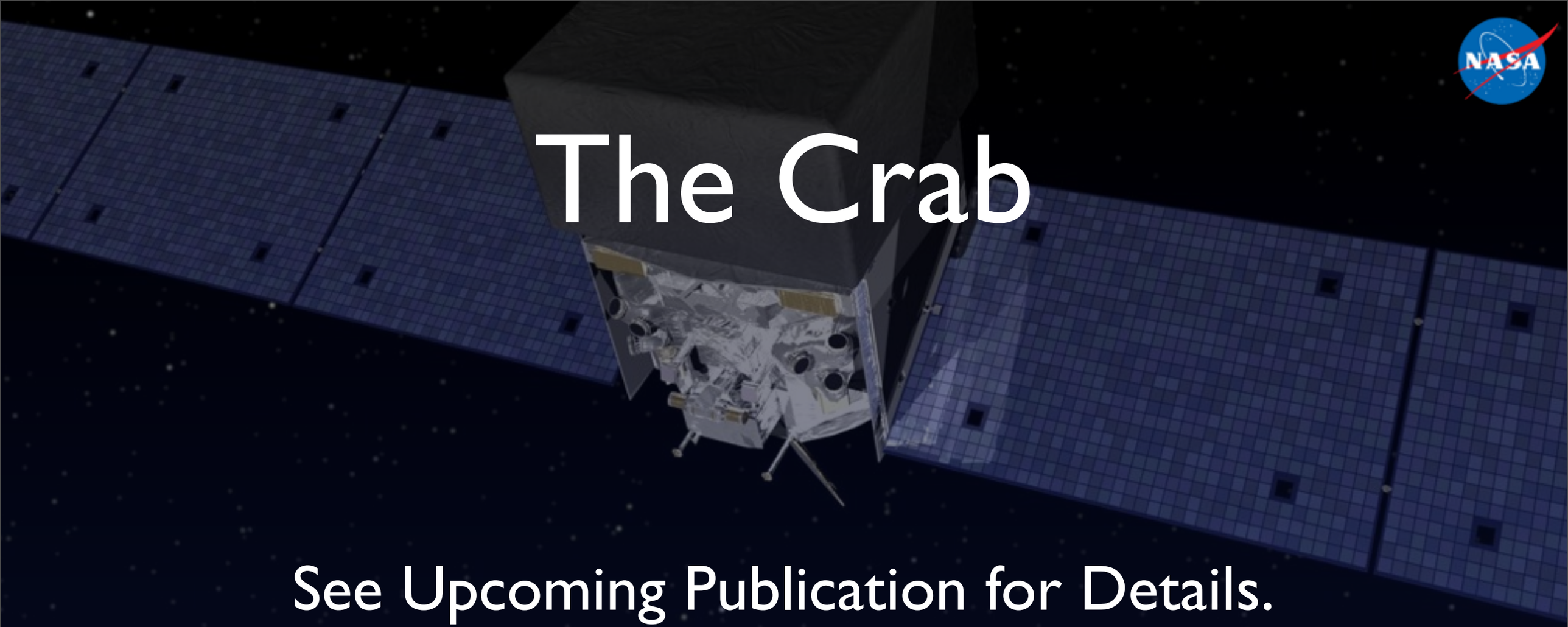


The Crab

See Upcoming Publication for Details.

J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC



The Crab

See Upcoming Publication for Details.

J. S. Perkins | CRESST/UMBC/GSFC | *Fermi* FSSC

Active Galactic Nuclei

- AGN "Standard Model": Black Hole and Accretion Disk Power Relativisitc Jet
- Viewing Angle Determines Source Type
- Open Questions
  - Emission Mechanisms?
  - Jet Structure?
  - Black Hole Accretion?
  - Leptonic or Hadronic?
  - Emission Region?
  - EBL and IGMF?
  - Quantum Gravity?

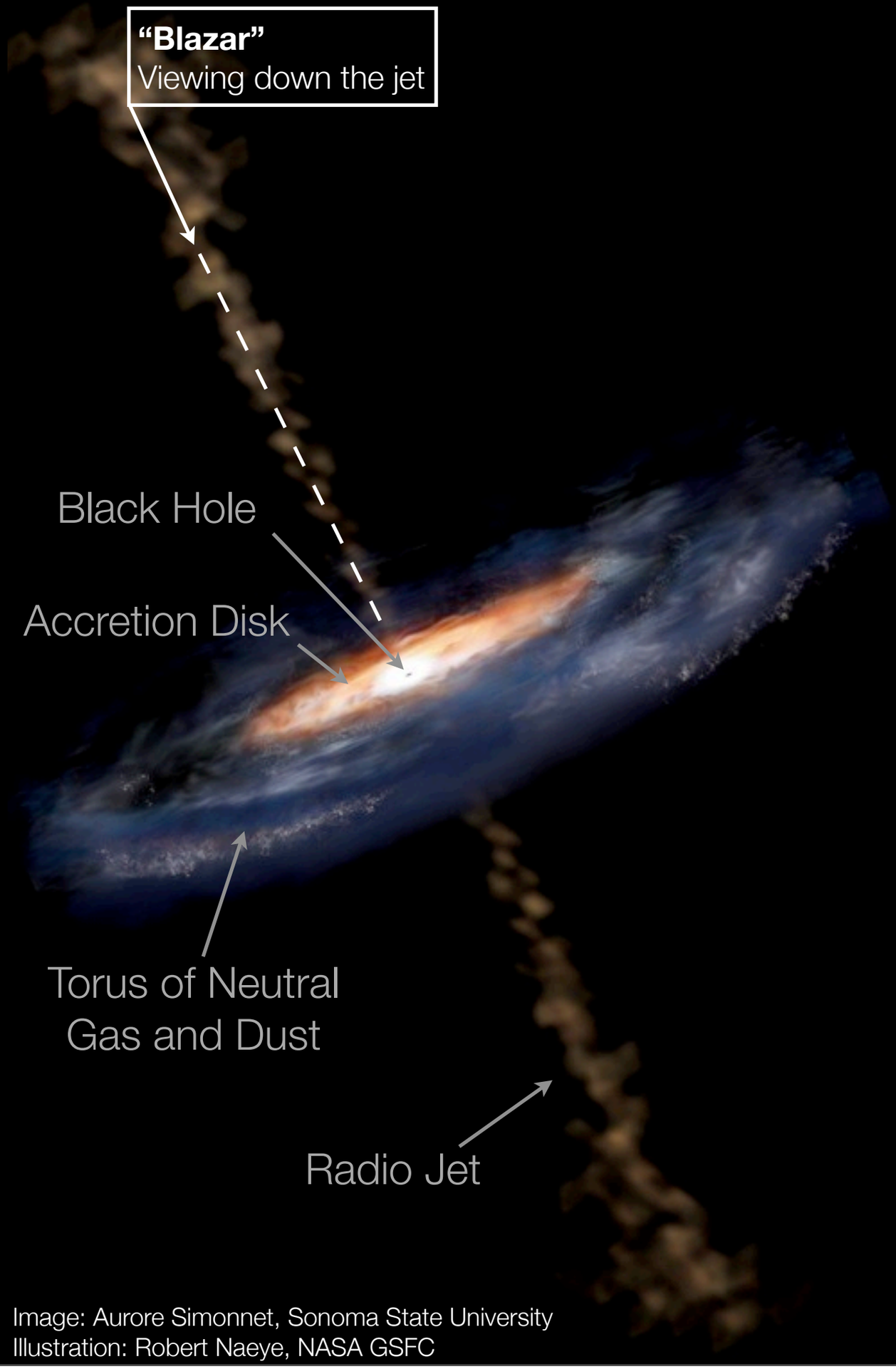


Image: Aurore Simonnet, Sonoma State University
Illustration: Robert Naeye, NASA GSFC

State of Affairs

Slide concept from M. Beilicke

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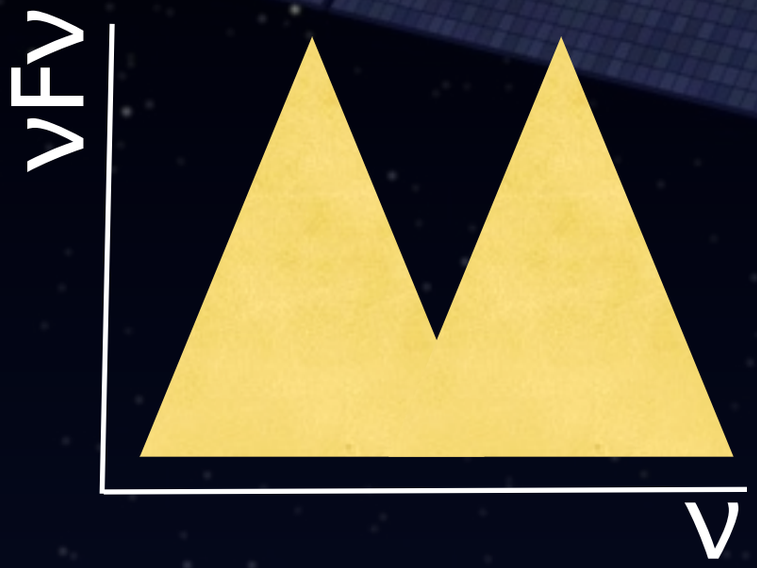
State of Affairs



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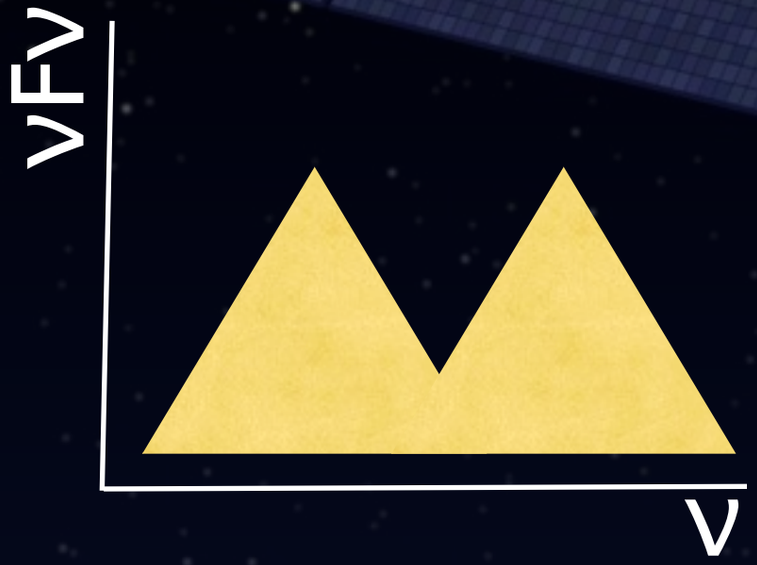

Slide concept from M. Beilicke

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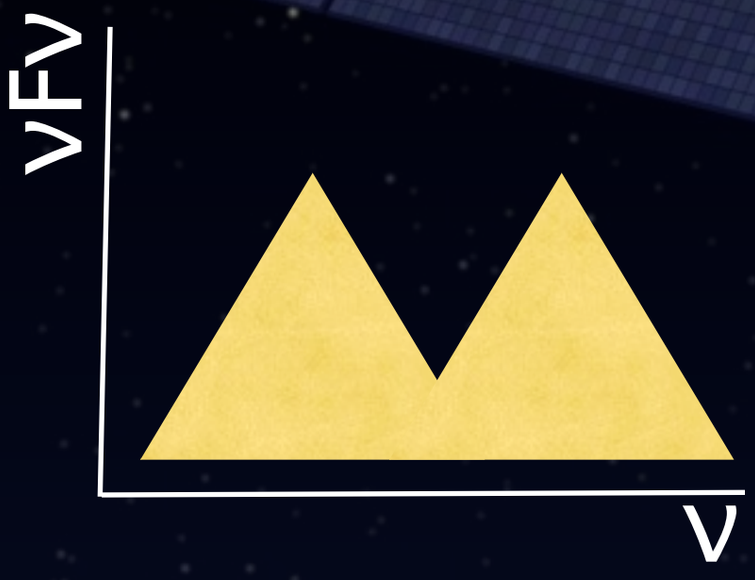

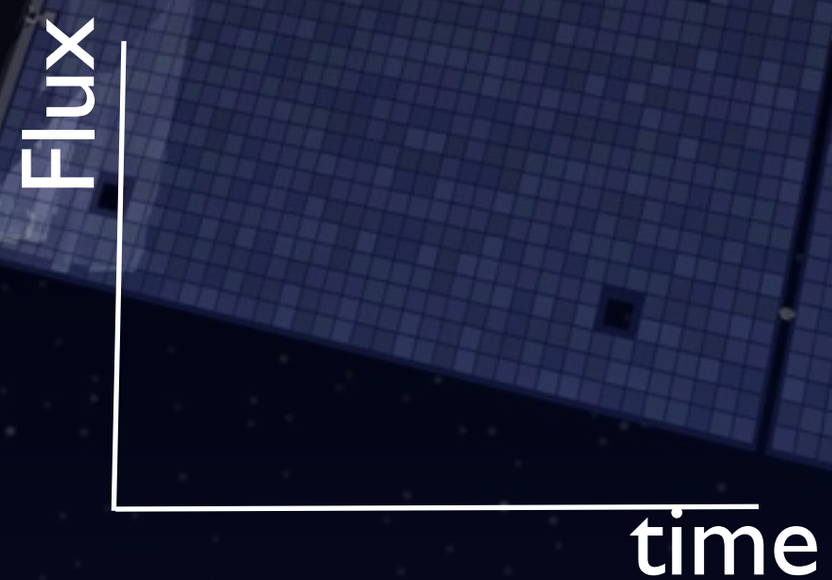

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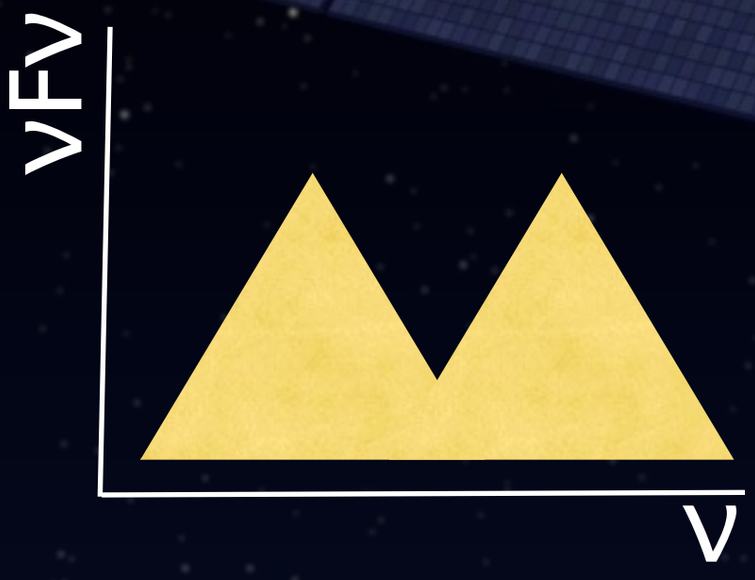

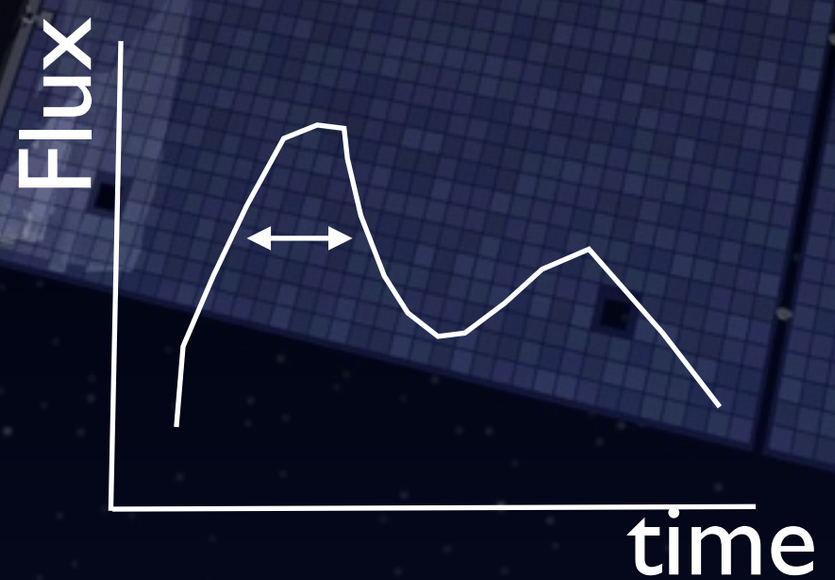

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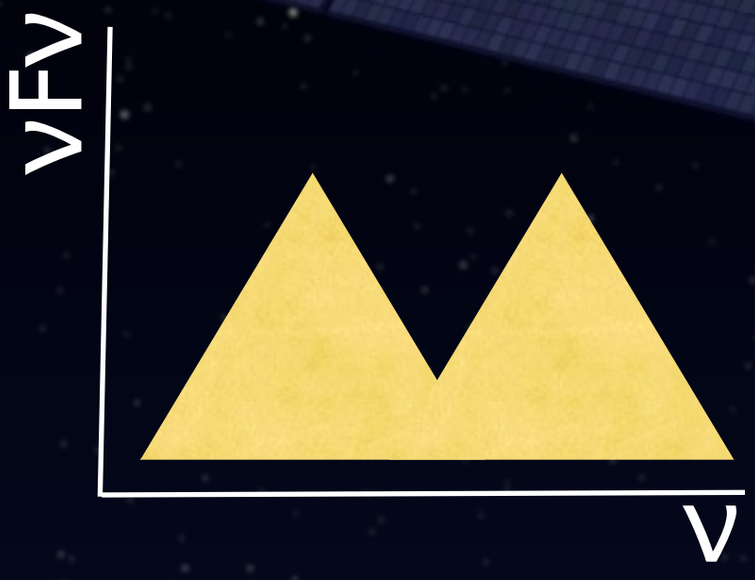

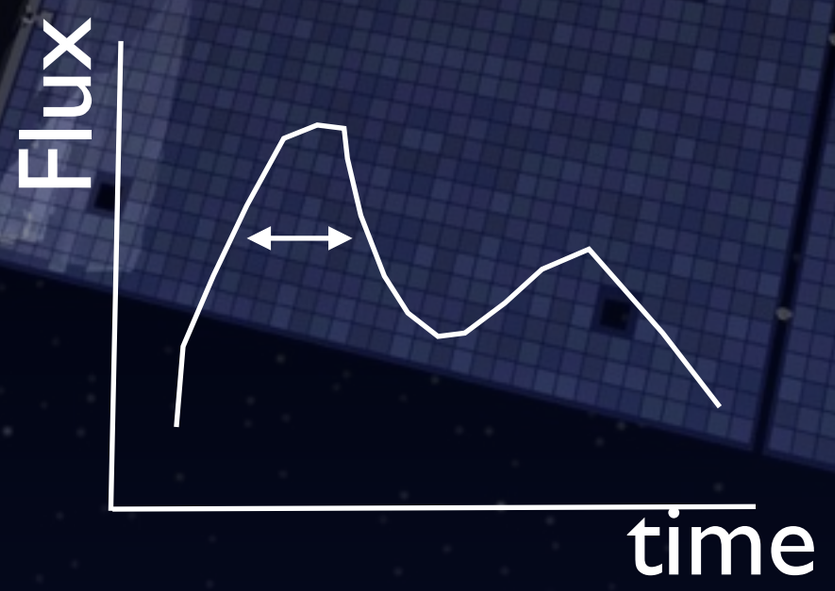

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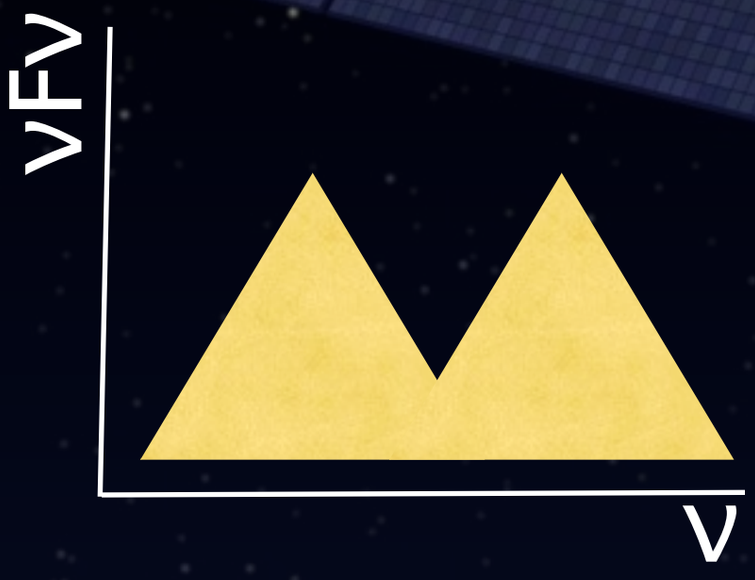

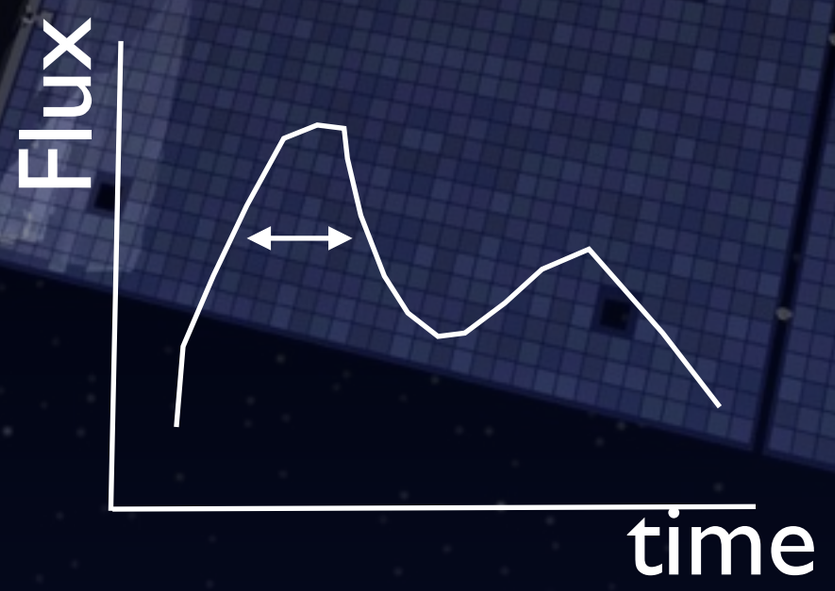

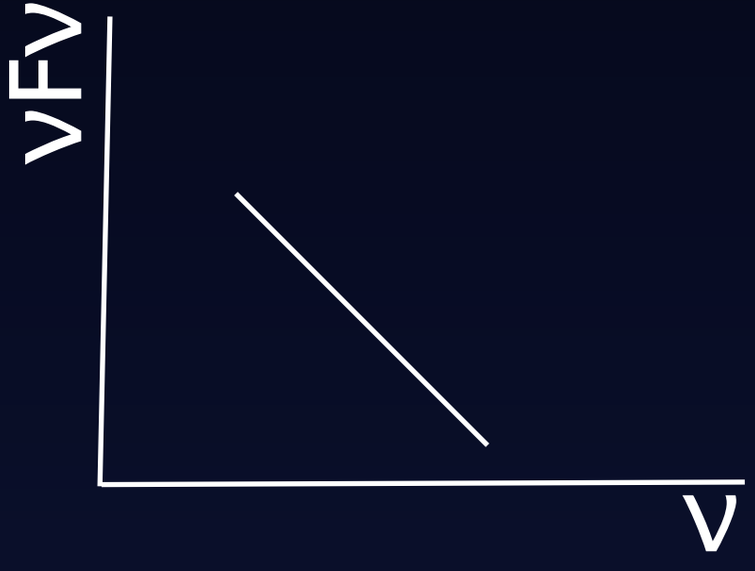

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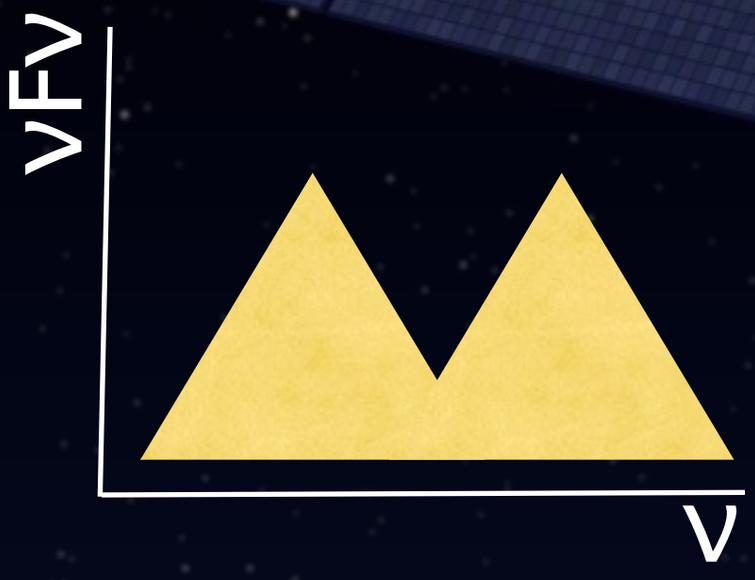

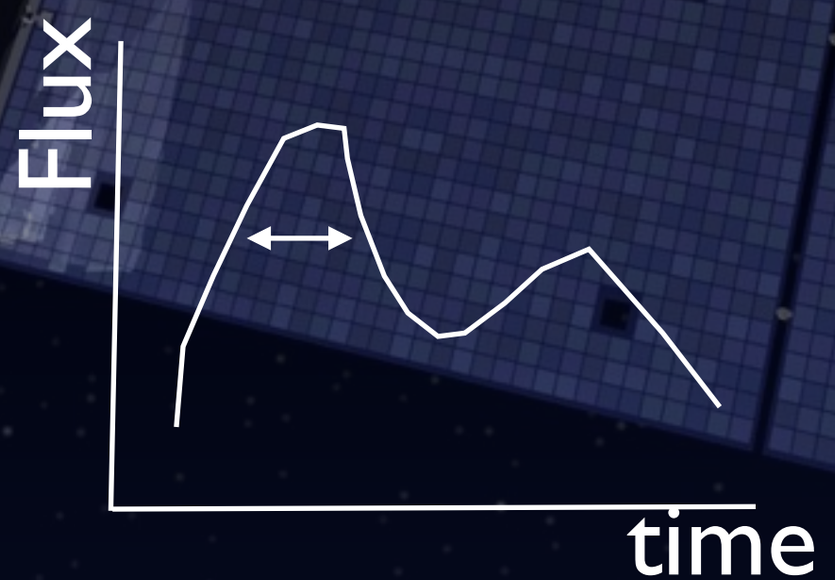

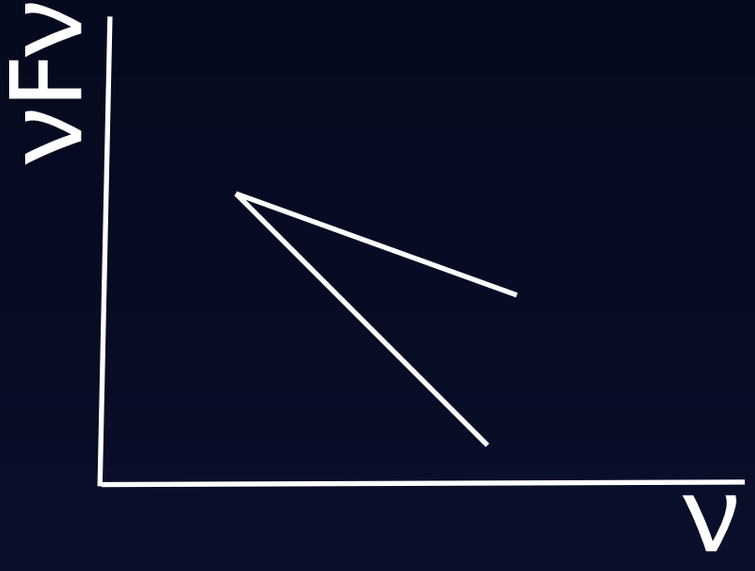

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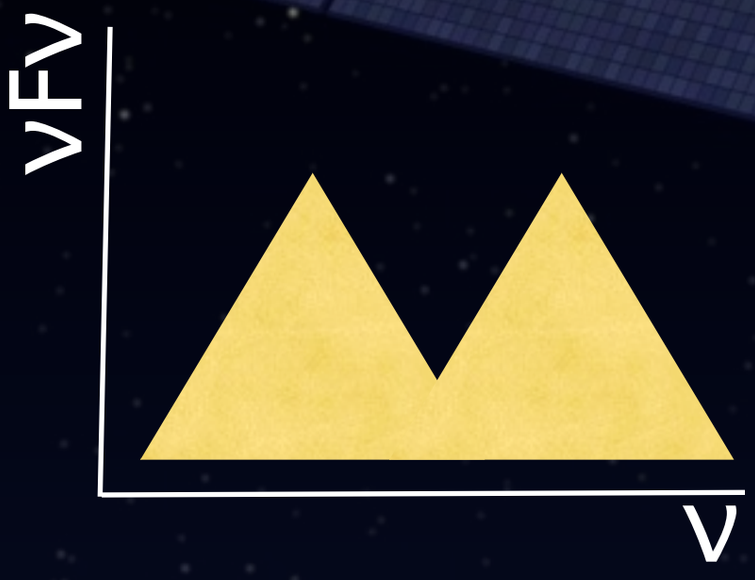

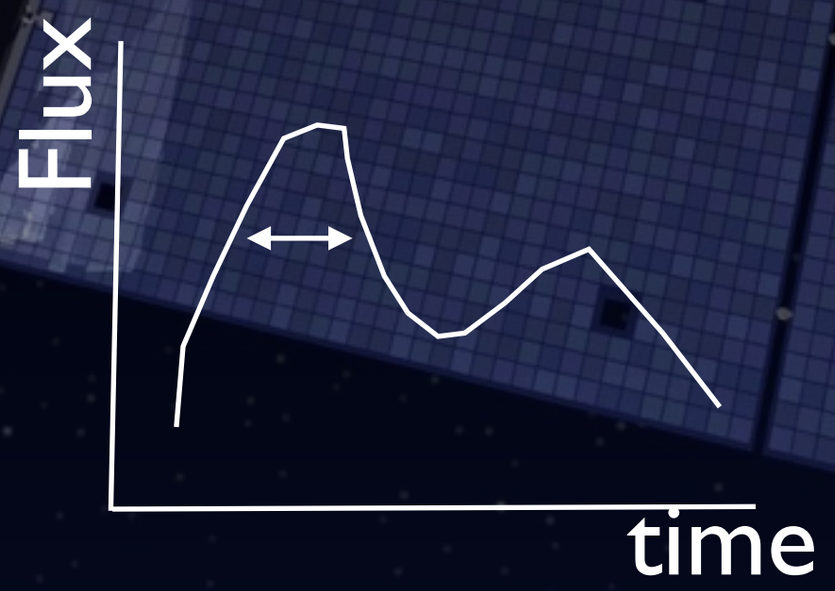

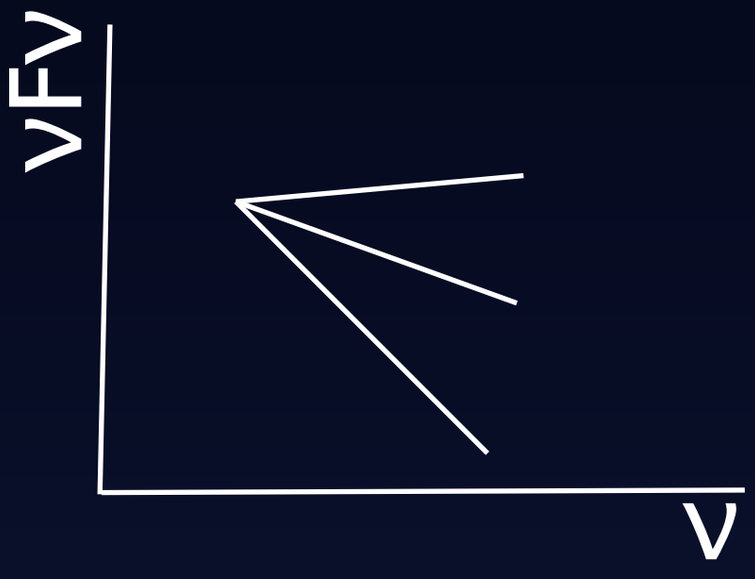

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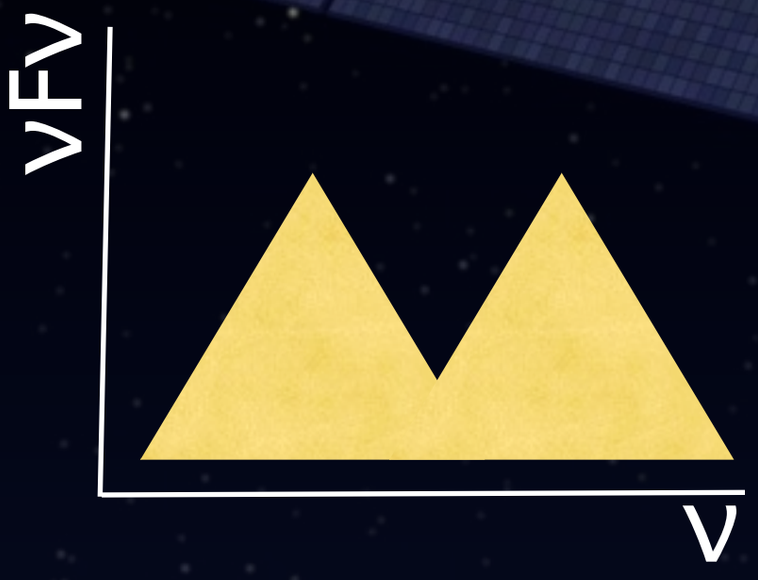
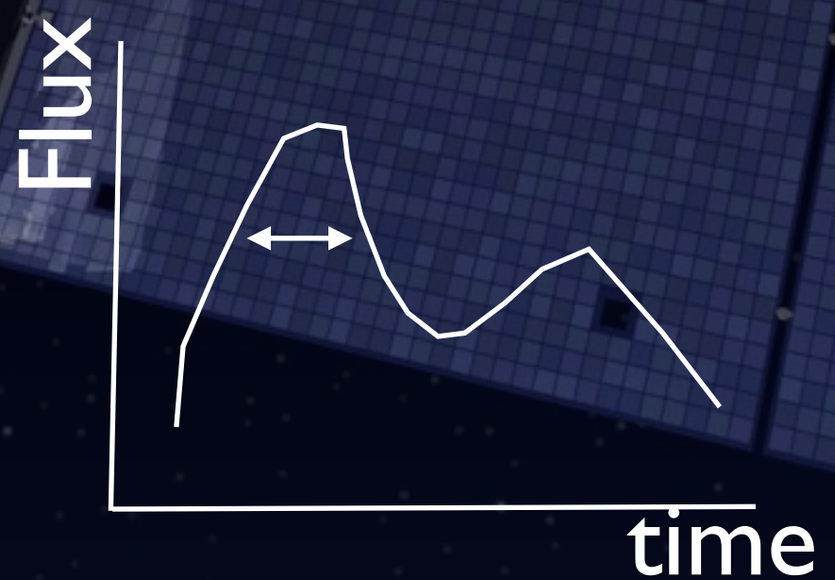
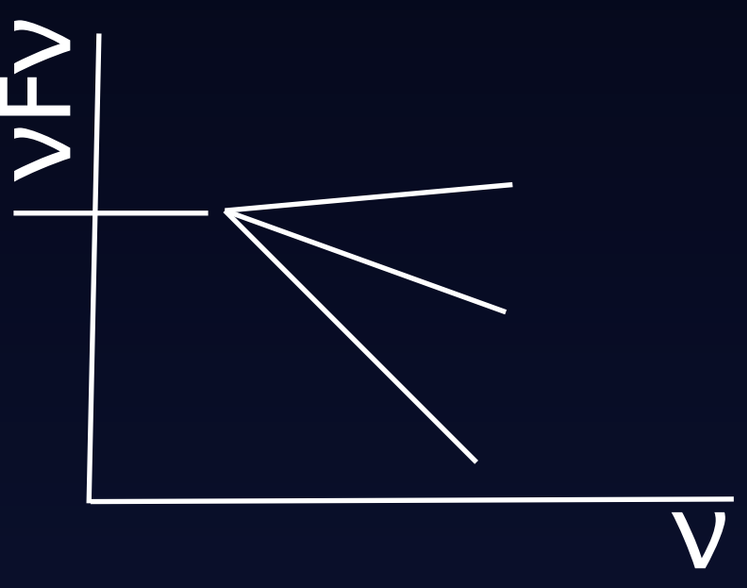
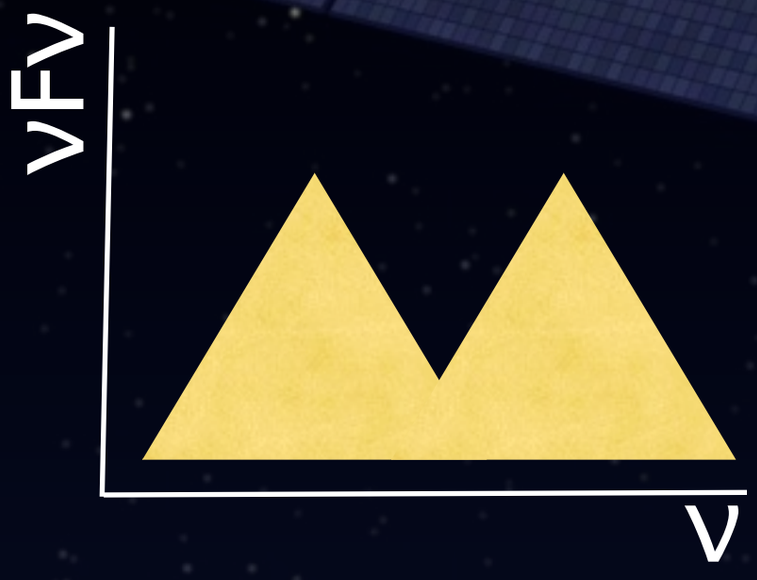


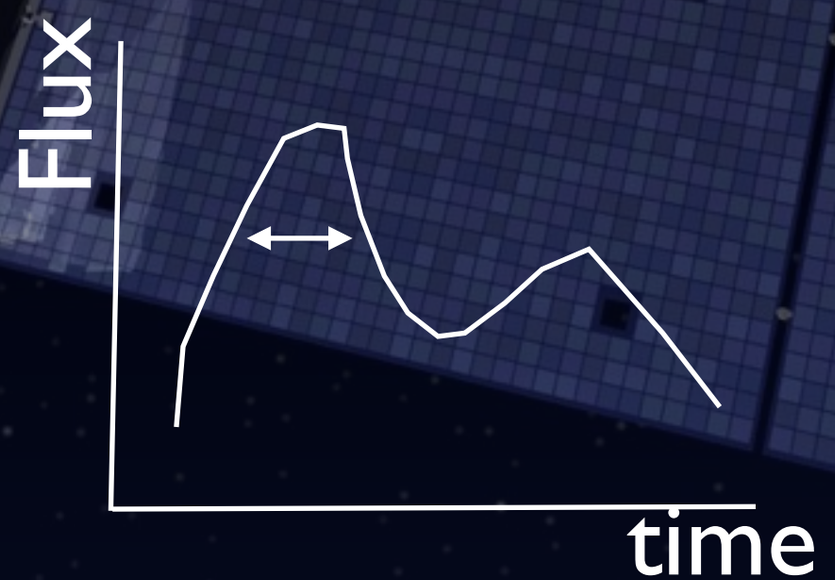


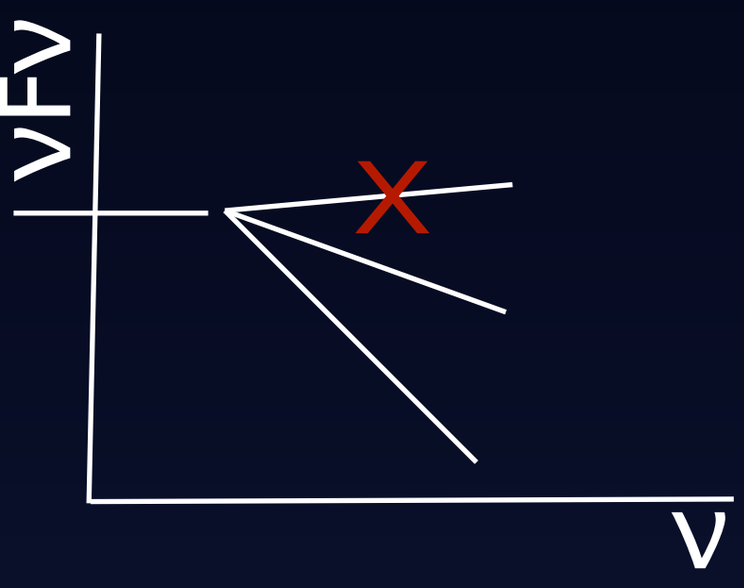


Slide concept from M. Beilicke

State of Affairs







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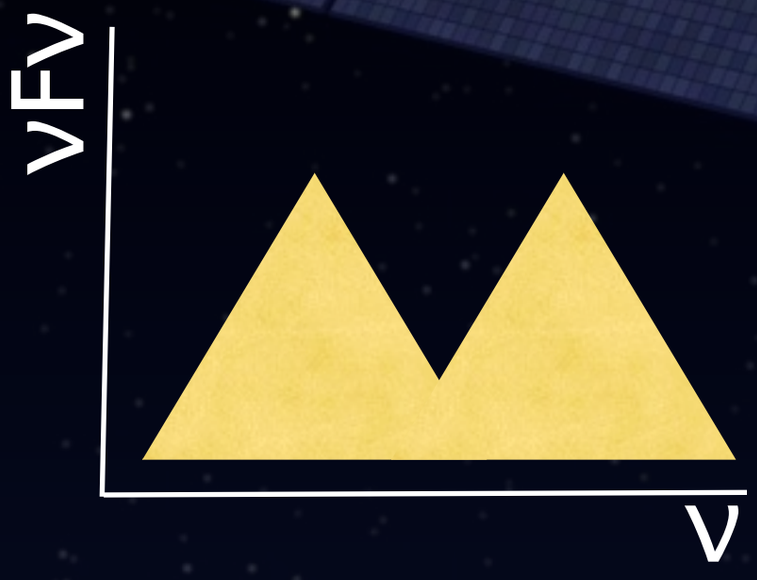

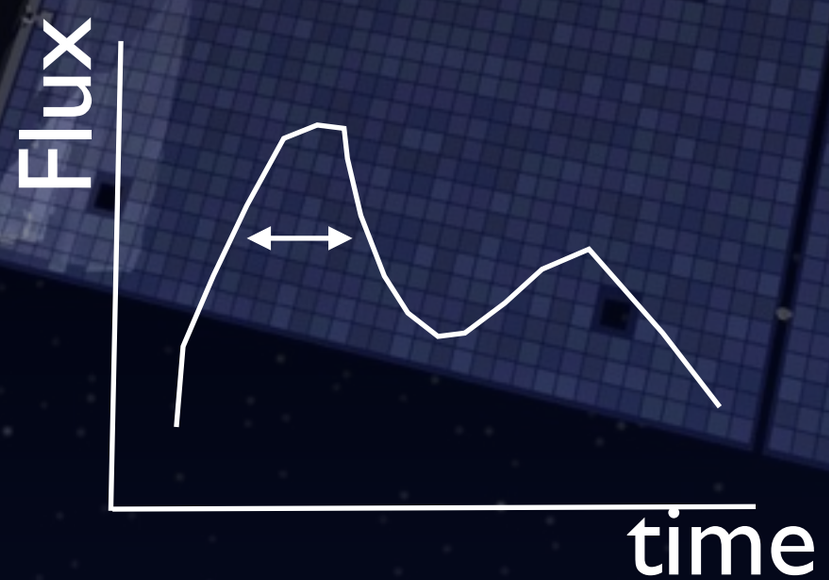

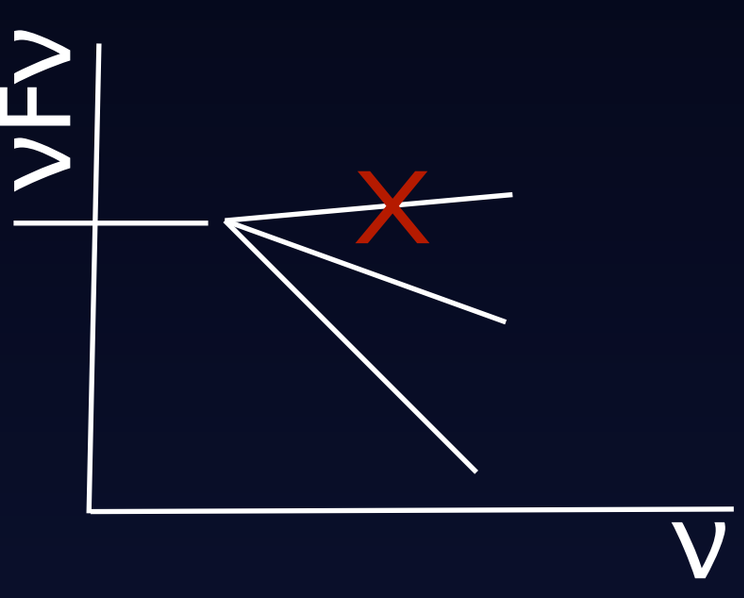

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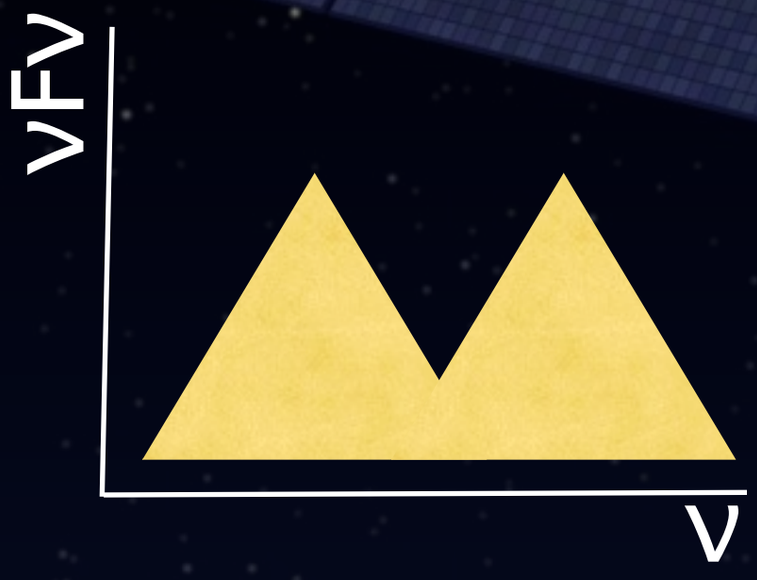

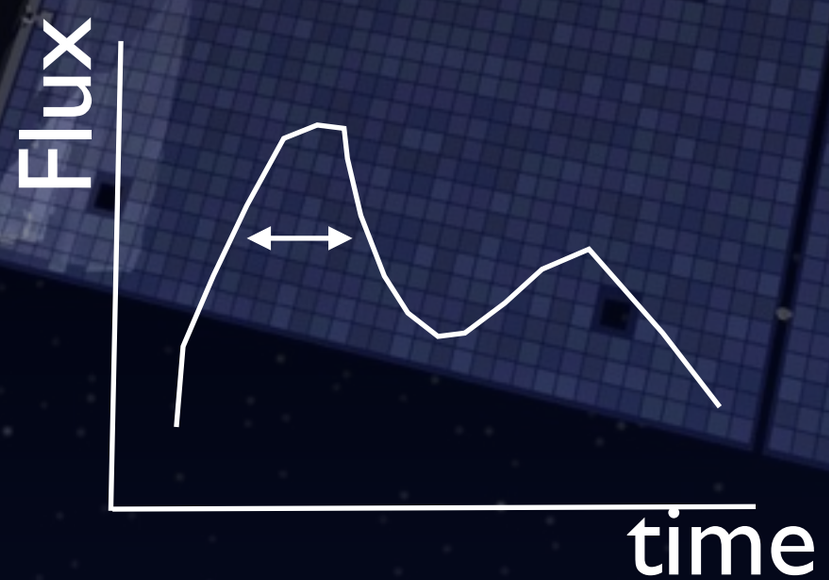

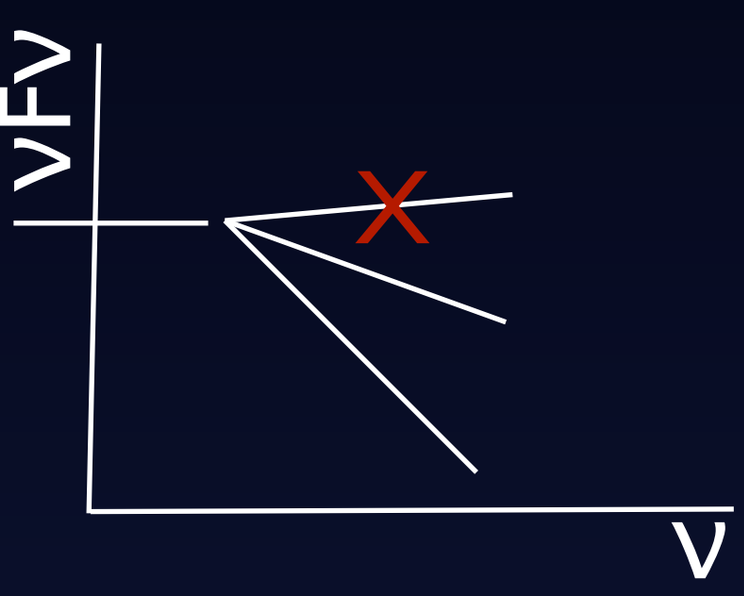

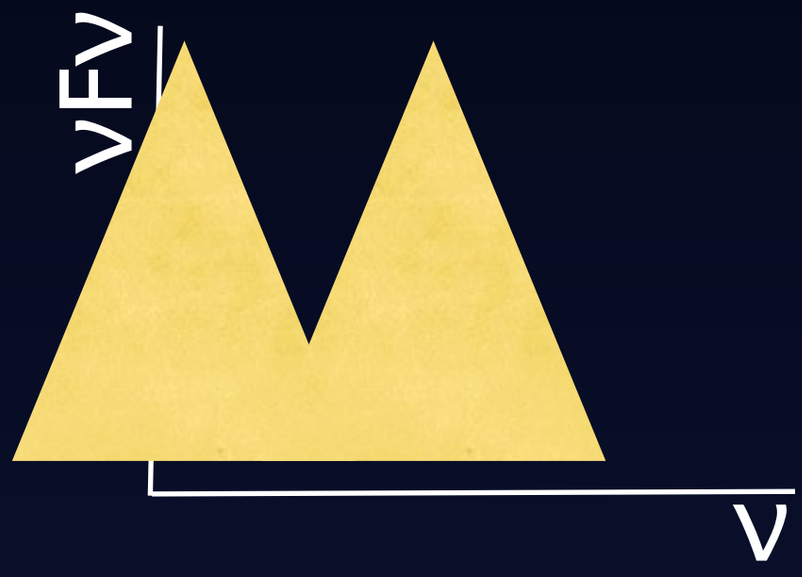

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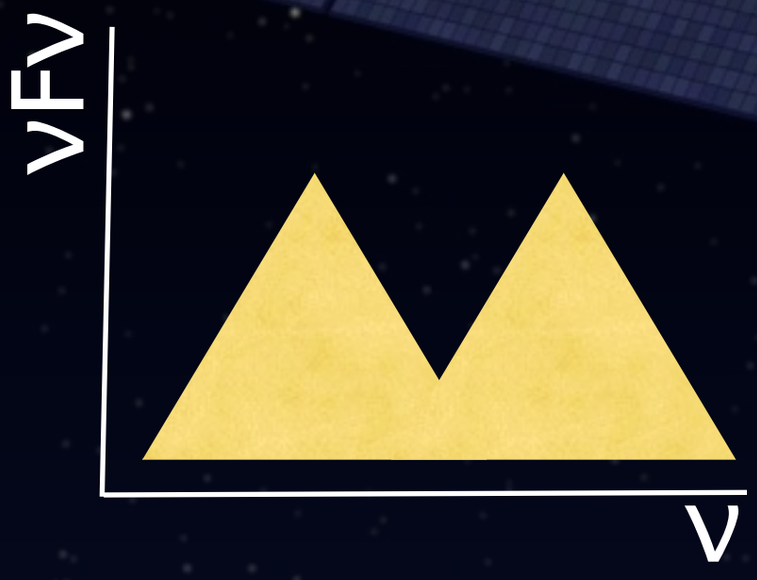

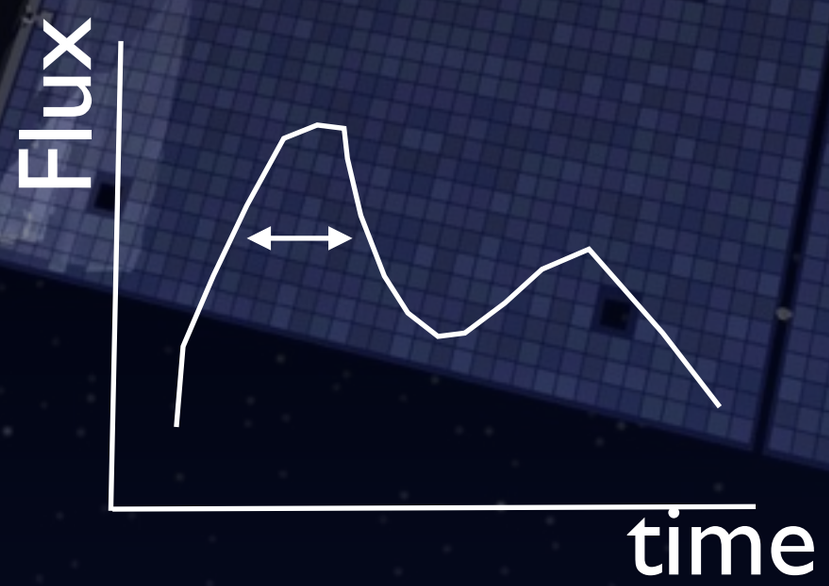

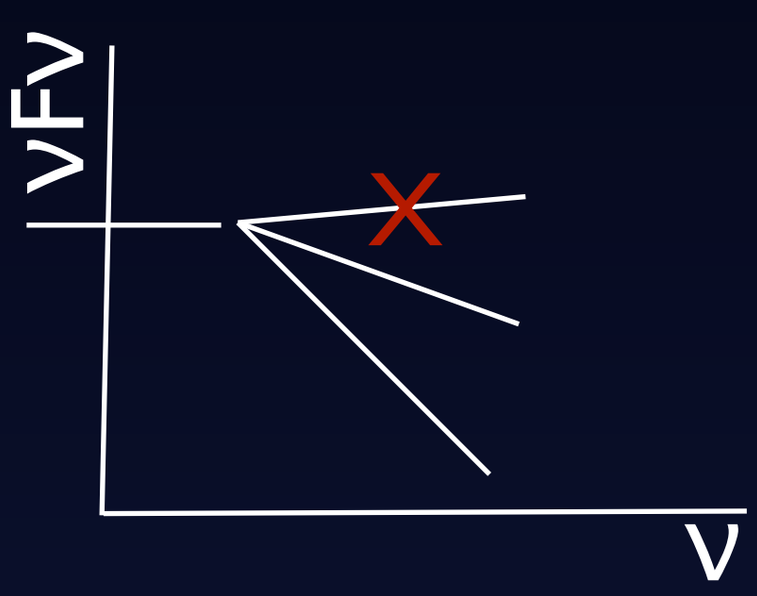

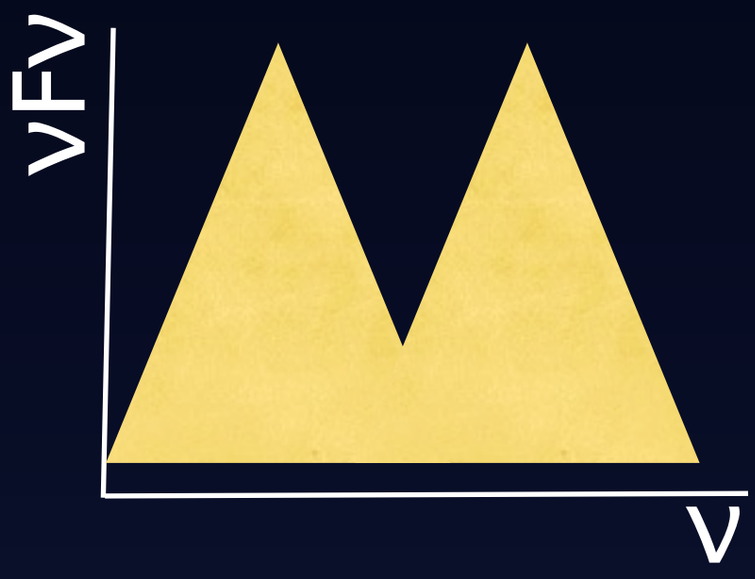

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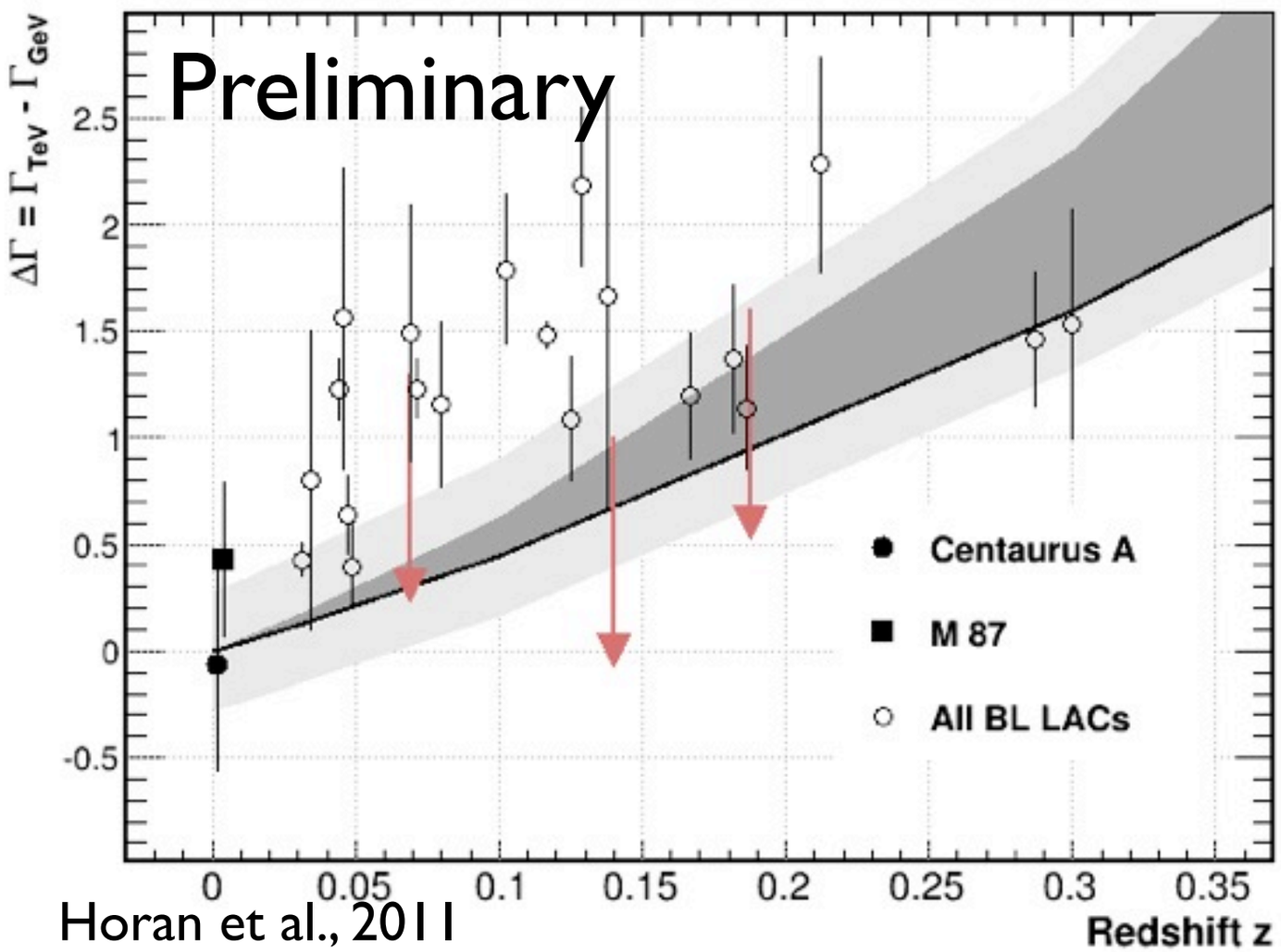
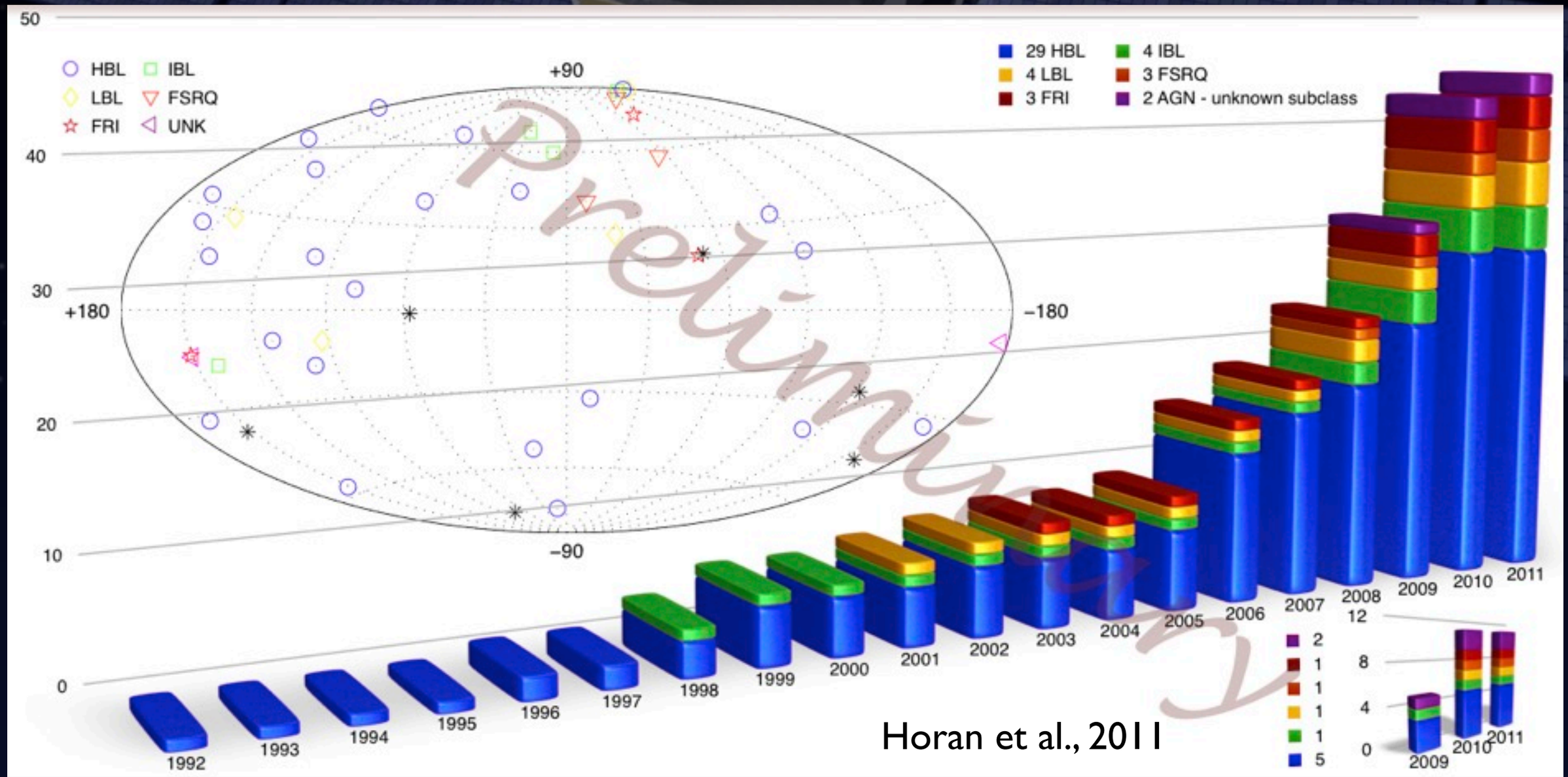
Overall Picture



Horan et al., 2011

- Difference between VHE and HE indicies increases with distance.
- Interpretation: EBL softens the VHE spectra.

Overall Picture 2



Horan et al., 2011

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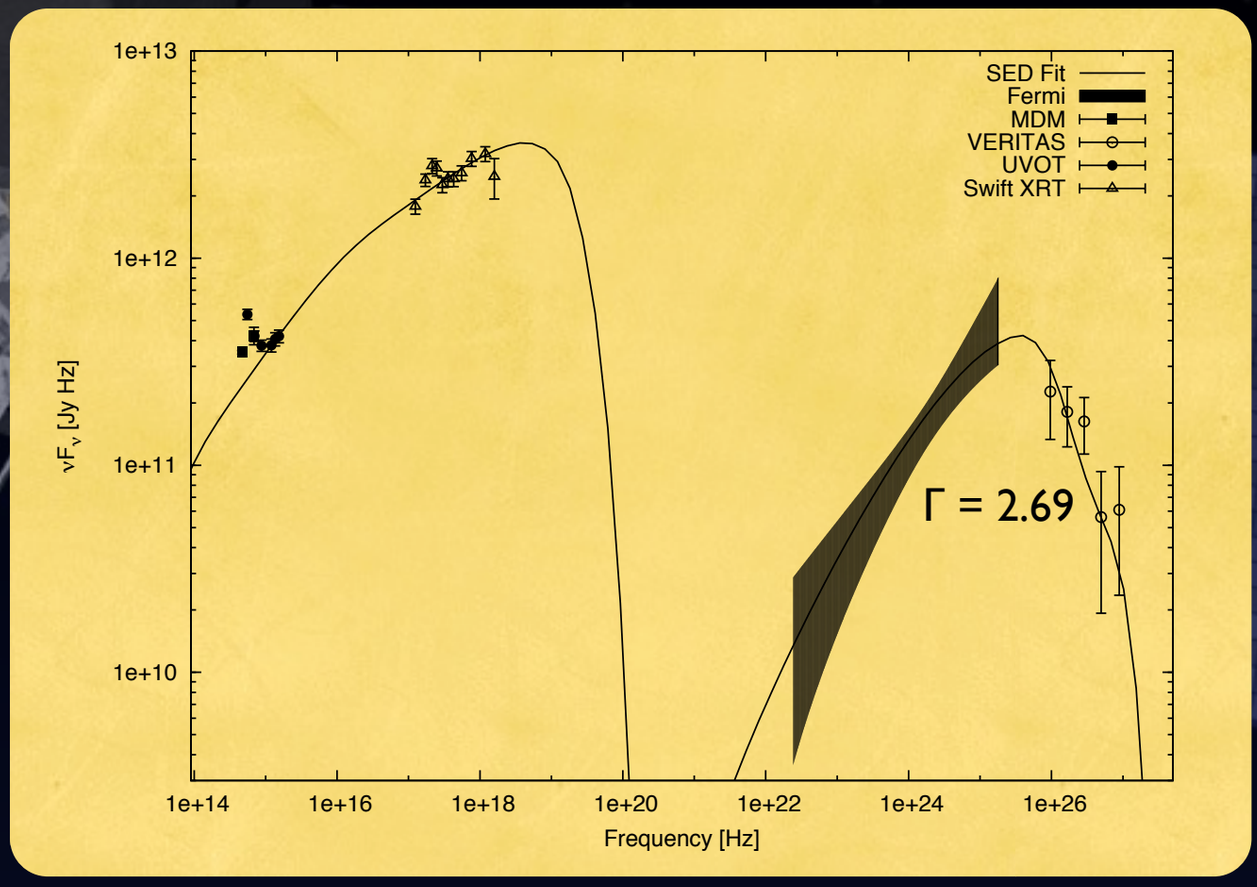
HBL: RGB J0710+591 (z = 0.125)

- Discovered in gamma-rays by VERITAS (2.8% Crab)
- Can be fit by a simple SSC model
  - Sync. peak below X-ray
  - Needs hard injection index (2nd order Acc?)
  - Needs low B-field
- Fit with EC does not solve these issues



Many Parameters Unconstrained

Parameter	Value
γ_{min}	6×10^4
γ_{max}	2×10^6
e^- Injection spectral index	1.5
Escape time parameter	$\eta_{esc} = 100^a$
Magnetic field at z_0	0.036 G
Bulk Lorentz factor	$\Gamma_{bulk} = 30$
Blob radius	2×10^{16} cm
θ_{obs}	1.91^b degrees
Redshift	z = 0.125
L_e (jet)	4.49×10^{43} erg/s
L_B (jet)	1.75×10^{42} erg/s
L_B/L_e	3.90×10^{-2}

ApJL 715: L49 (2010)

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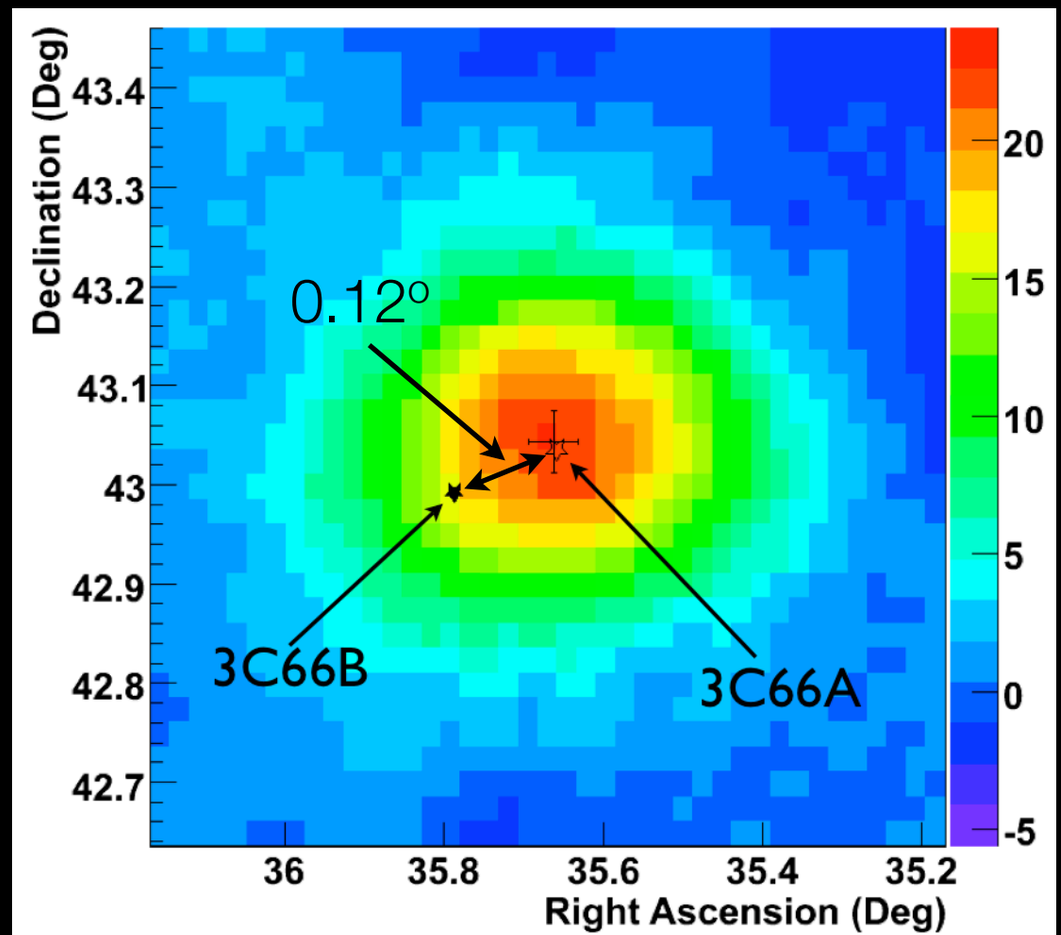
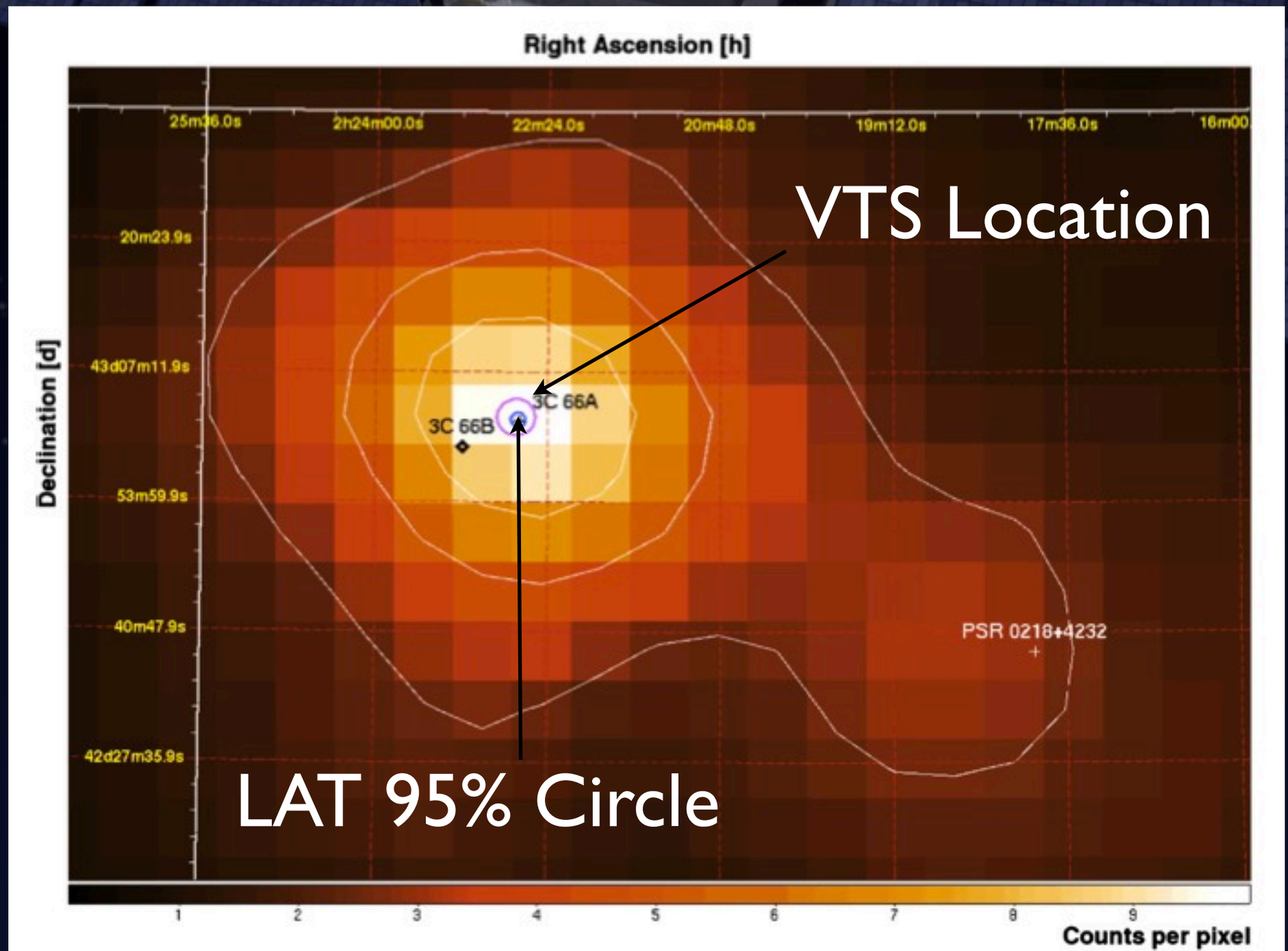
3C 66A

- First evidence of detection (5.1σ) at TeV by Crimean Astrophysical Observatory
- MAGIC detected emission from 3C 66A/B at 5.4 σ
  - Excludes ‘A’ at the 85% level
- VERITAS: 20σ detection
  - **Exclude 3C 66B at 4 σ level**



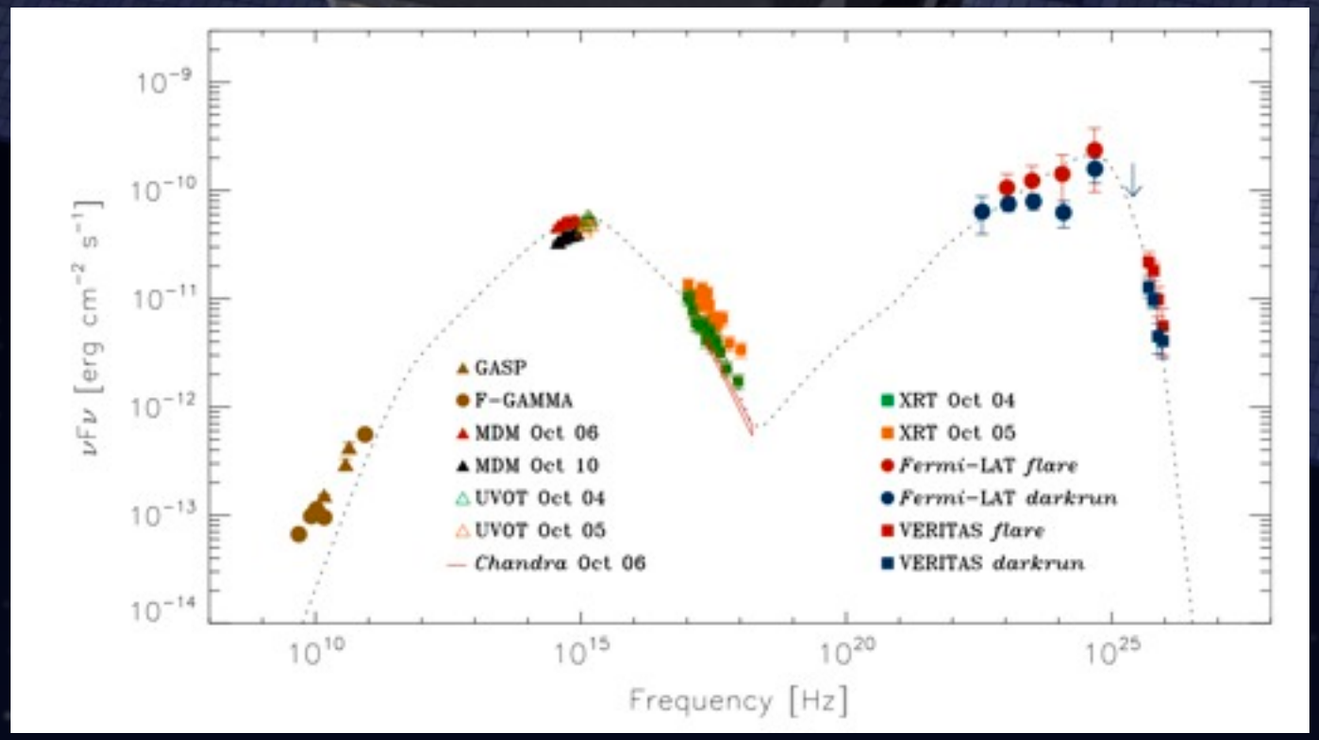
ApJ 693, L104 (2008)

LAT Position



Abdo et al., ApJ 726, 2010

IBL: 3C 66A



- IBL at an uncertain redshift detected in a flaring state
- SSC model requires extremely high Doppler factors and very low magnetic fields.
- Adding an ad-hoc radiation field (SSC+EC) gets closer to equipartition

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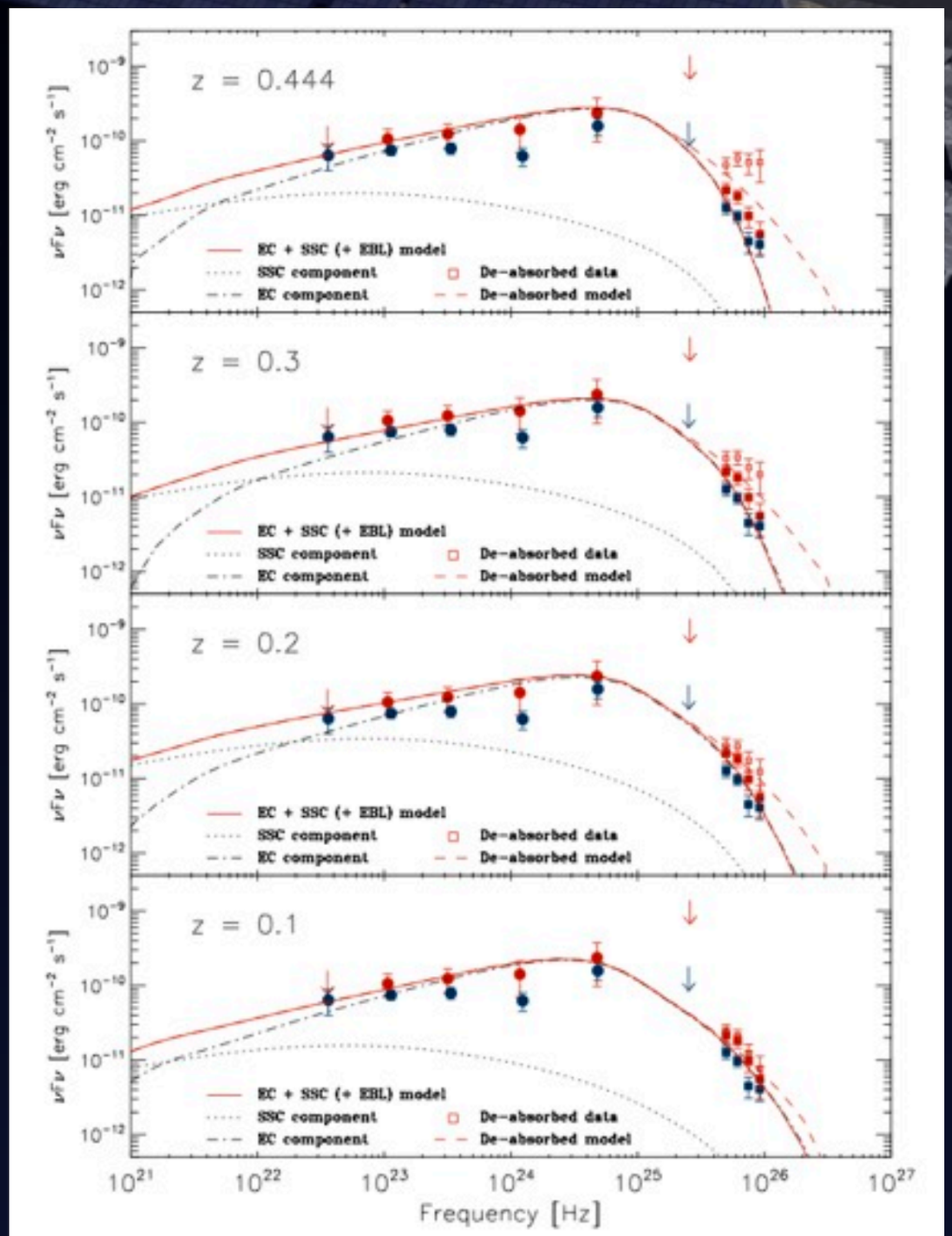
Redshift Limit



- Uncertain Redshift can be constrained by the GeV-TeV observations.
- Best fit is for z ~ 0.2 - 0.3
- Agrees with other estimates

IBL vs. HBL

- 5 VHE IBL
  - 3C 66A and W Com detected in flares: Need SSC + EC component
  - PKS 1424+240, 1ES1440+122 steady: SSC works without EC component
- 30+ VHE HBL: 1-zone SSC works well (c.f. RGB J0710, Mrk 421 etc.)
- Extra Component during IBL flaring Maybe a trend?
- Need VHE+HE to do accurate modelling

Radio Galaxies: Cen A

- Nearest (3.7 Mpc) radio galaxy (FR1)
- Giant Radio Lobes!
  - Can separate the Core and Lobe emission using the LAT
- VHE/HE spectra are barely consistent (must shift one in flux)

Credit: Ilana Feain, Tim Cornwell & Ron Ekers (CSIRO/ATNF); ATCA northern middle lobe pointing courtesy R. Morganti (ASTRON); Parkes data courtesy N. Junkes (MPIfR); ATCA & Moon photo: Shaun Amy, CSIRO

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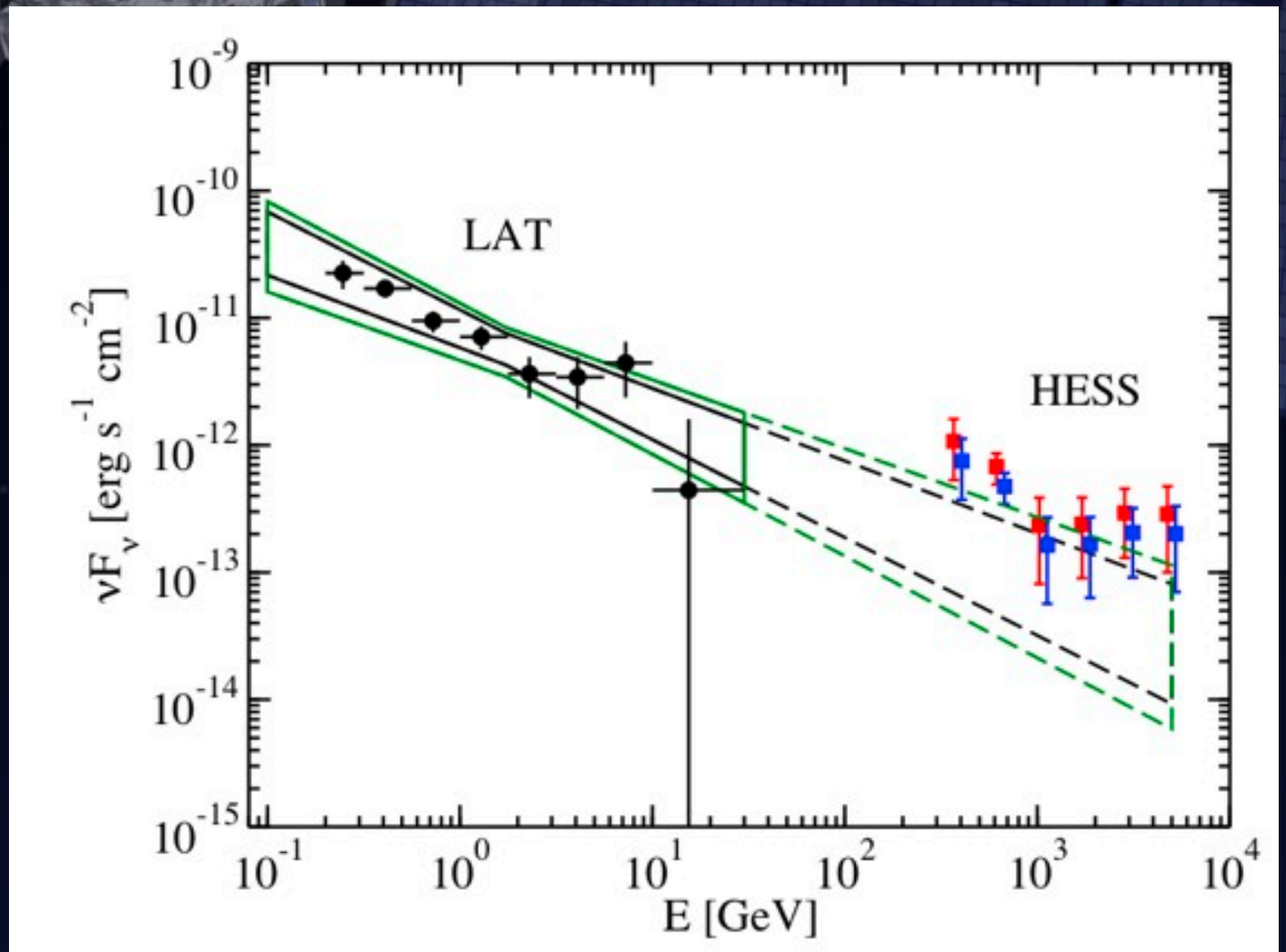
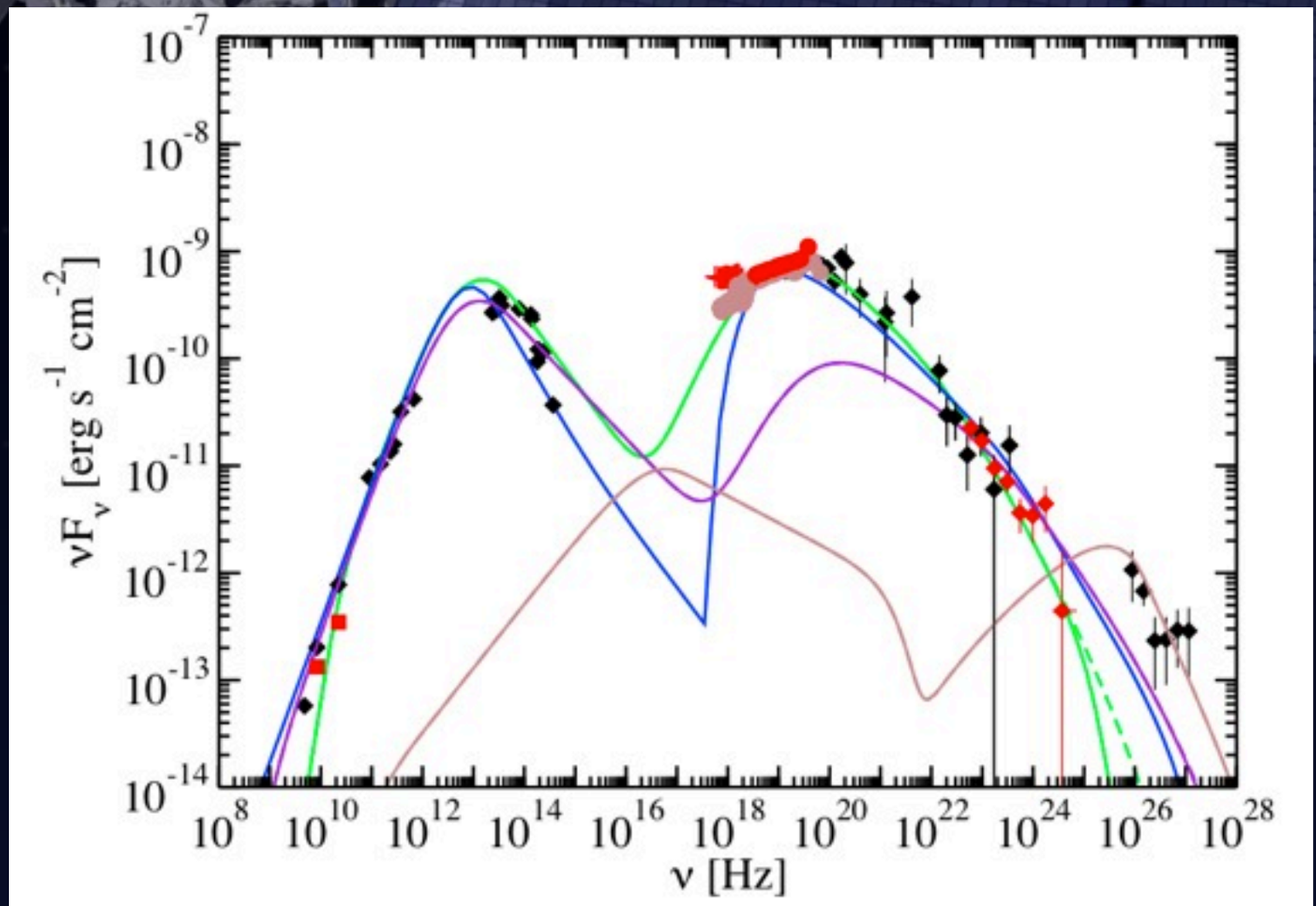


Abdo et al., ApJ, 2010

SSC Modelling

- If FR1's are the parent population of blazars than SSC models should work
- However, an SSC can't explain the VHE emission.
- Different origin for the HE/VHE?



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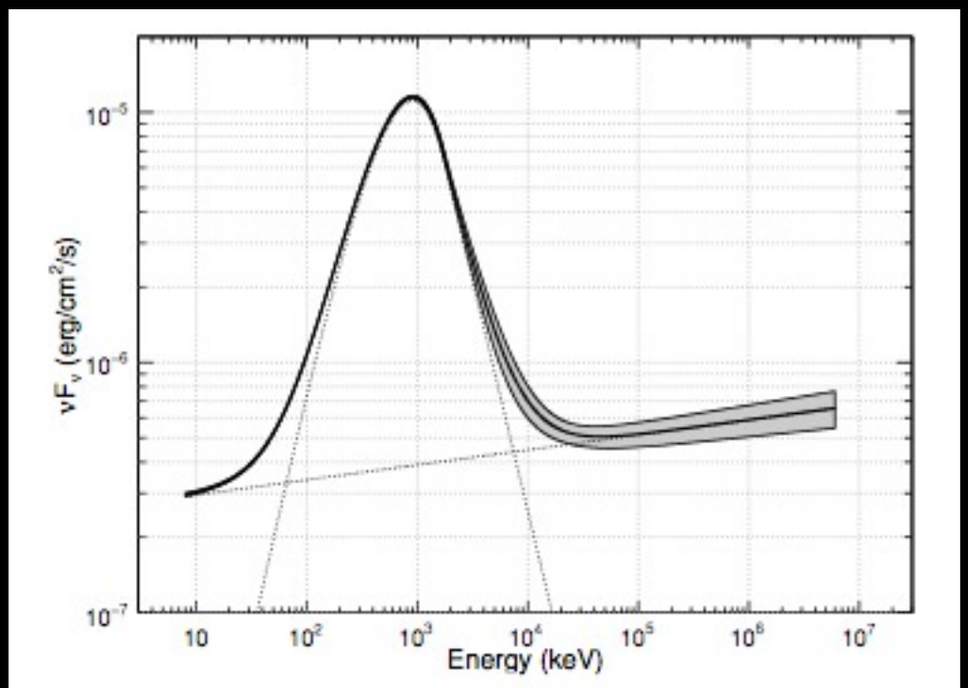
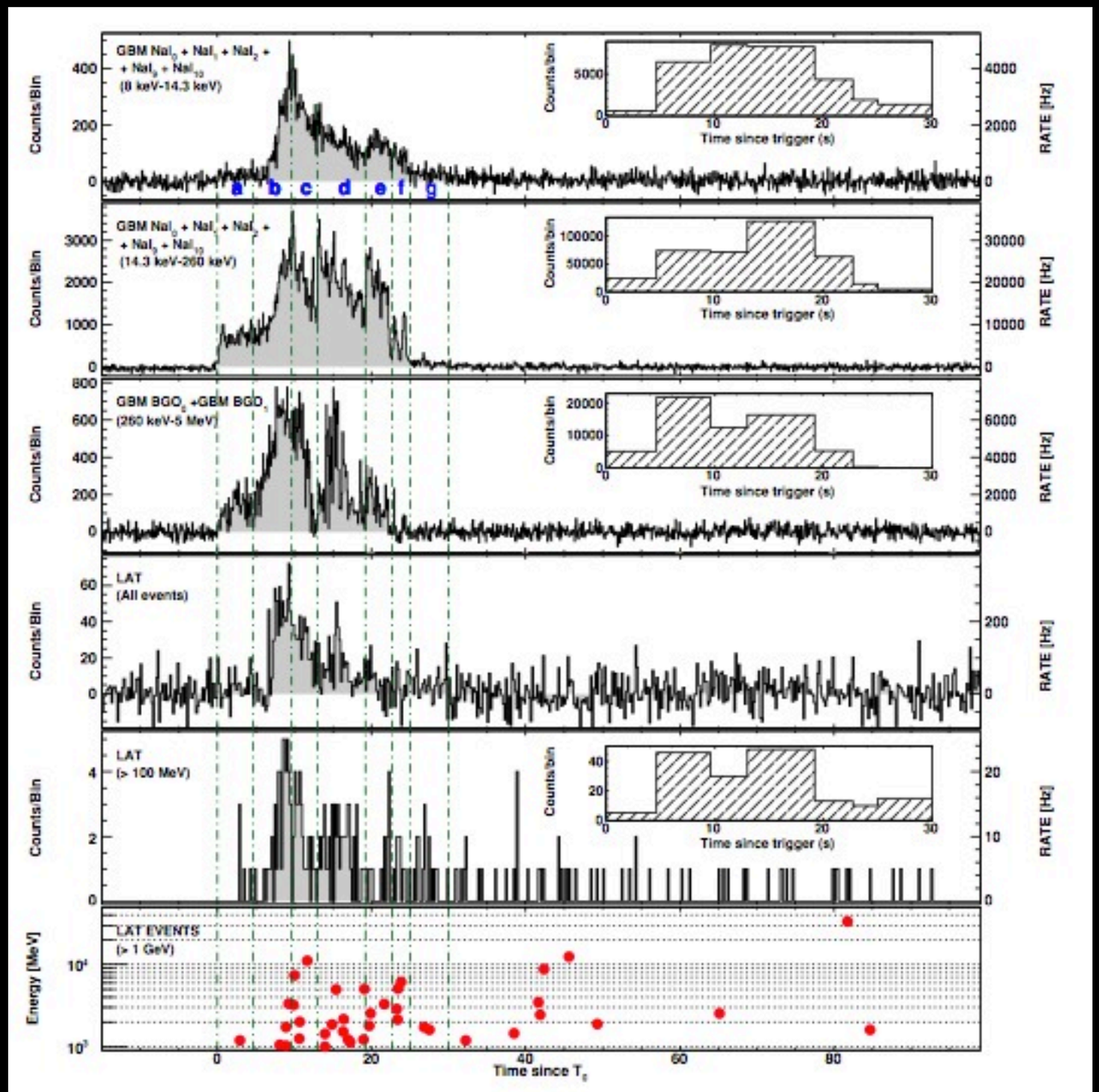
GRBs: Why

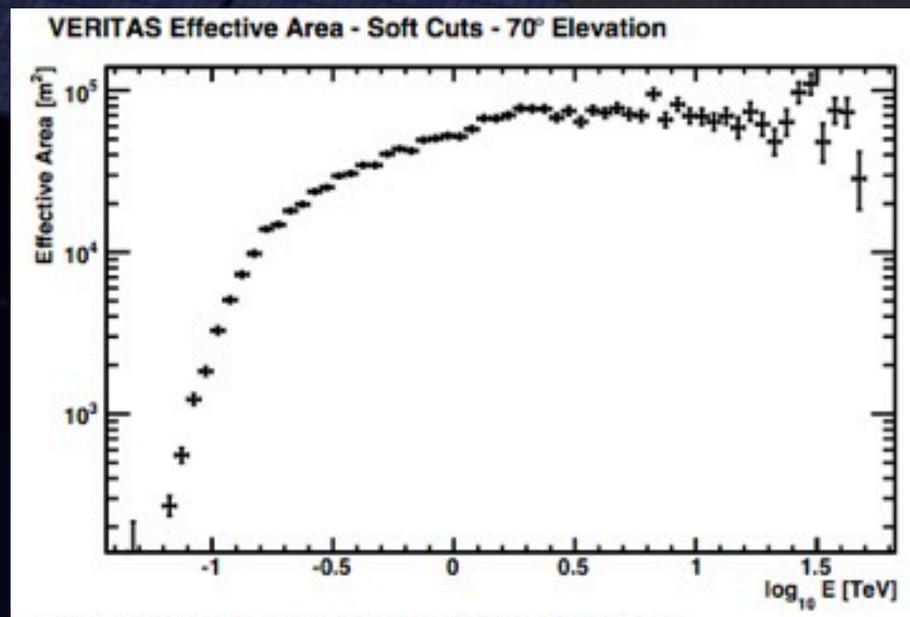
- Gamma-Ray-Bursts are some of the most energetic phenomenon in the Universe
- Many models predict a double-humped SED
- One VHE detection would be ground breaking
- However...
  - Bursts are transient
  - Bursts are distant

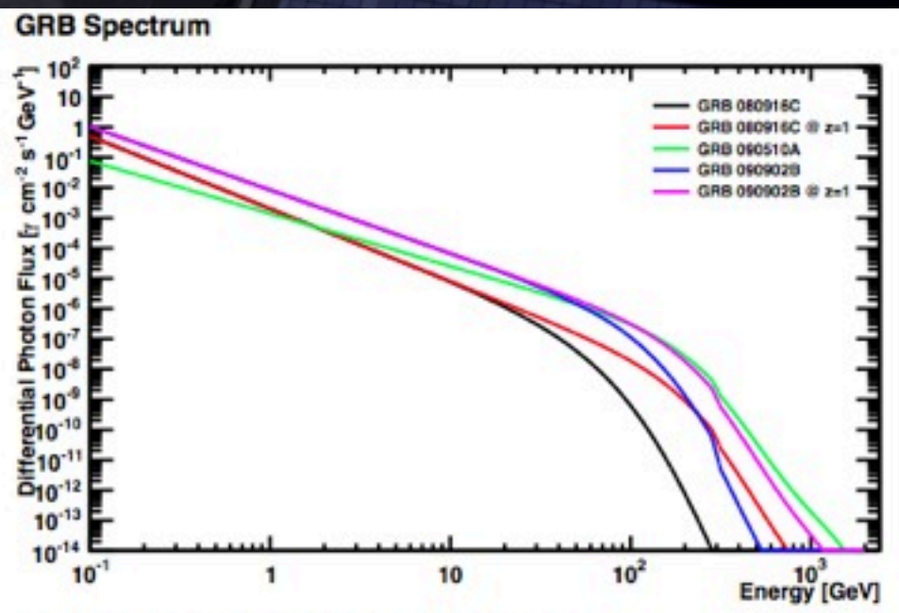
Hope for VHE Emission

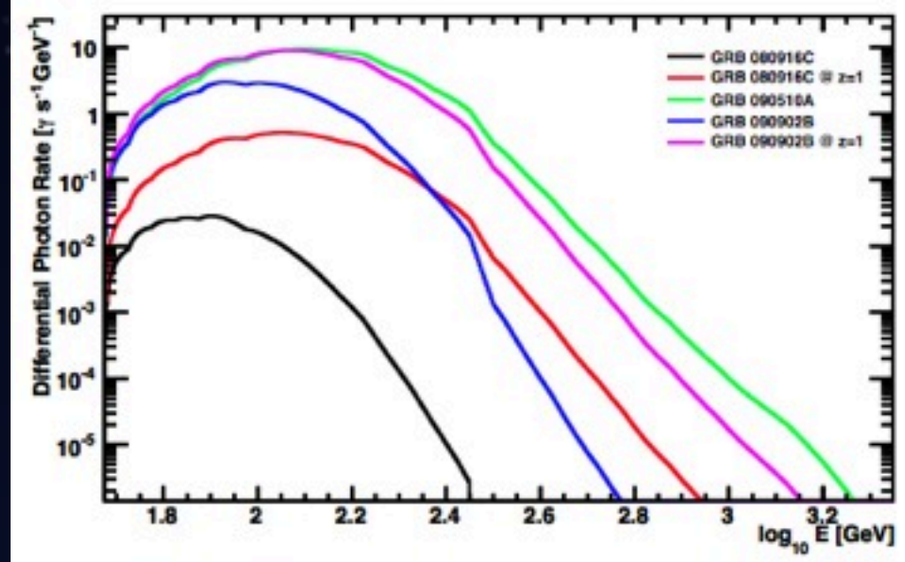
- LAT Bursts:
  - Band fxn + Power Law
  - HE Photons Come Late

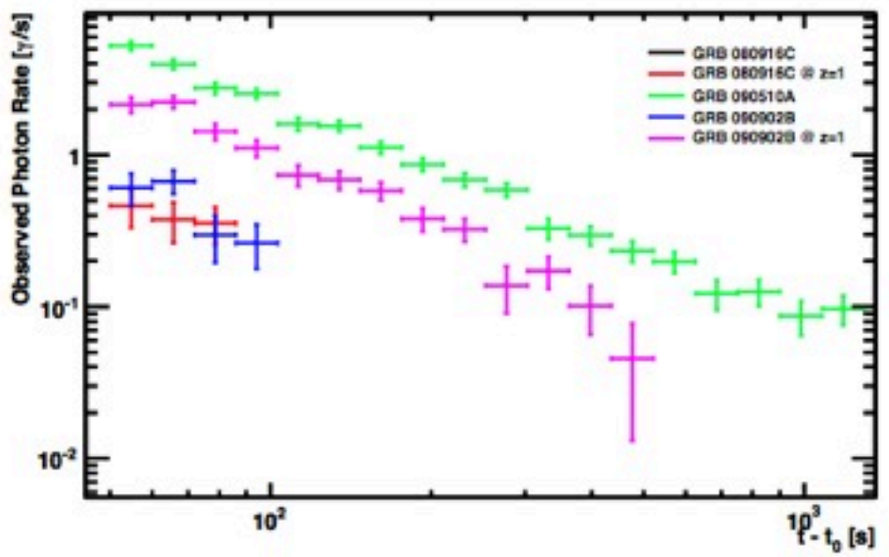












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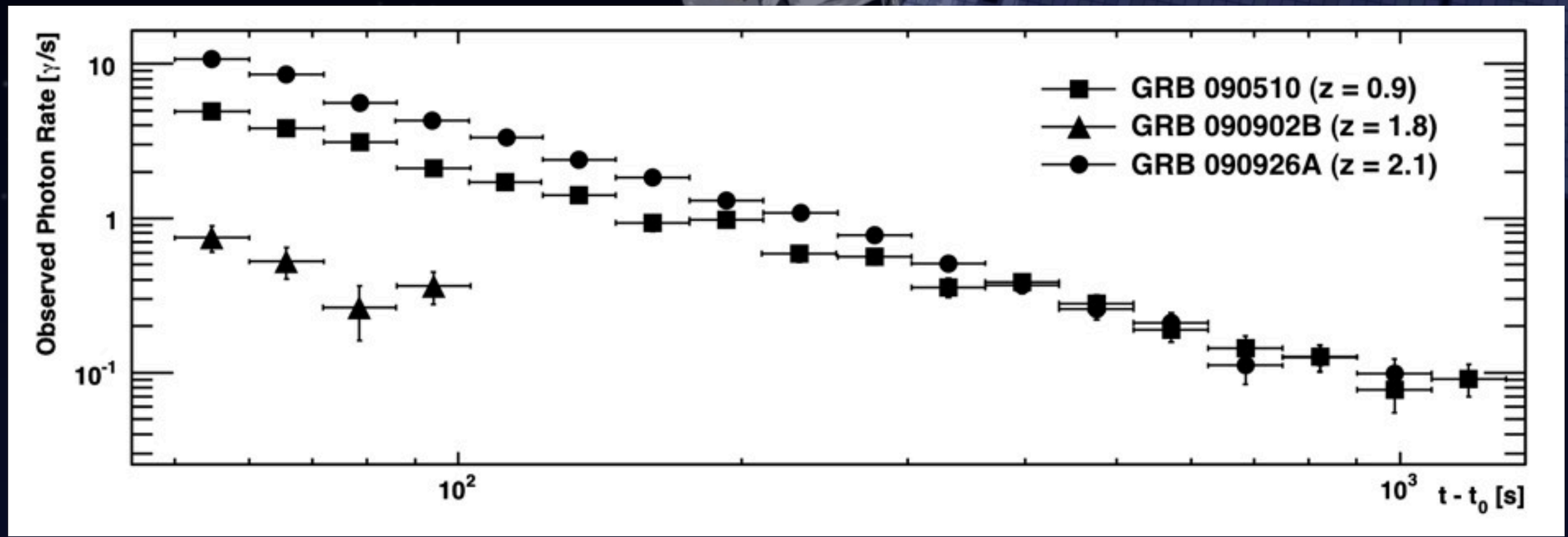
GRBs: Hope



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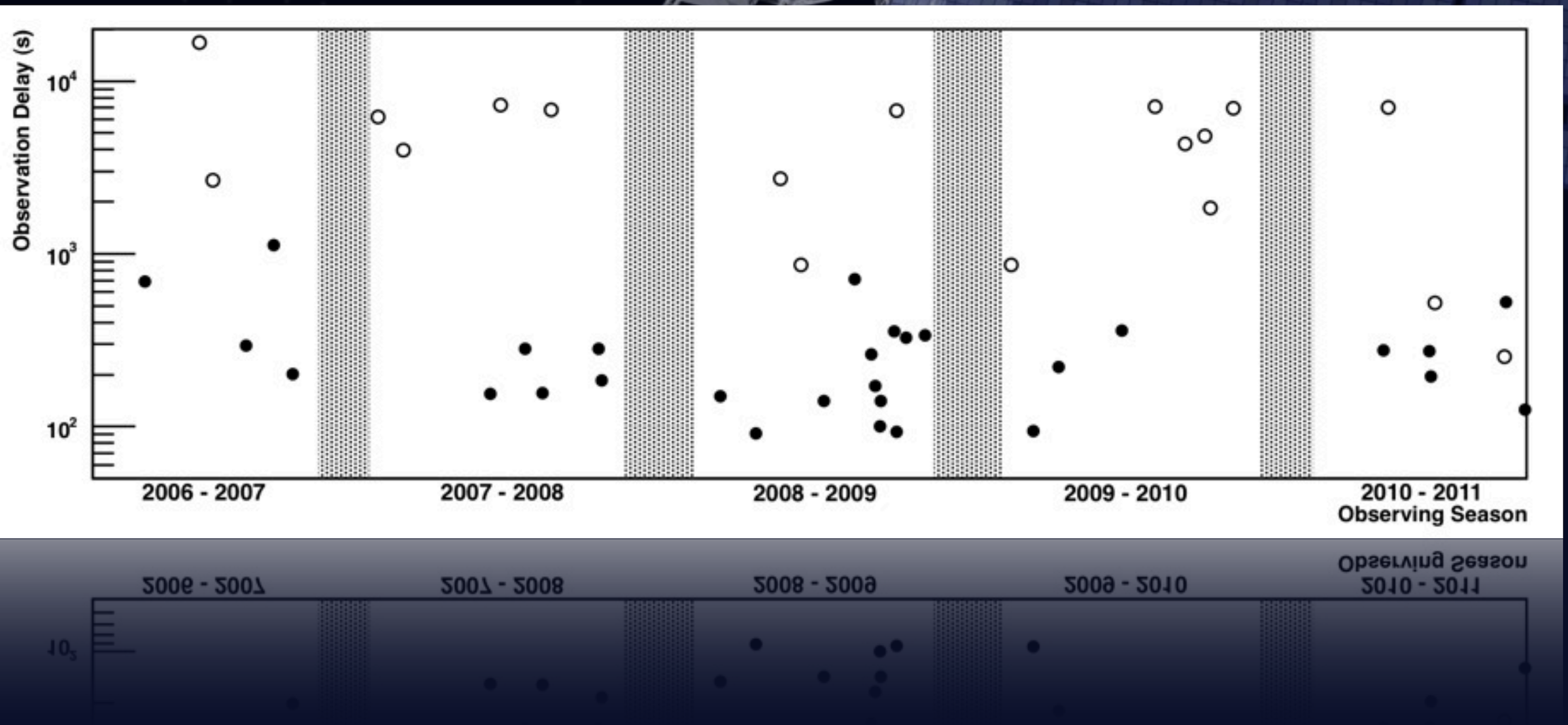
GRBs: Observations



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What isn't seen...

- Most Pulsars (cutoffs)
- Globular Clusters (see above)
- Radio Lobes like Cen A (diffuse)
- Galaxy clusters (none in *Fermi* either)
- Galactic/Isotropic Diffuse (really hard)

What I didn't talk about

- SNR: see Pat's talk or W49A/B for an example
- PWN: see the Crab Nebula or numerous other examples
- X-ray Binaries: see Jamie's talk or check out LSI+61 303 (this is an example of seeing more means knowing less)

Future Prospects

- The GeV/TeV connection is critical in the modeling of many sources.
- The VHE future looks bright (CTA) - order of magnitude improvement in sensitivity
  - Explosion of sources in all classes
- Overlap of HE/VHE not so bright - justification to continue Fermi observations is high