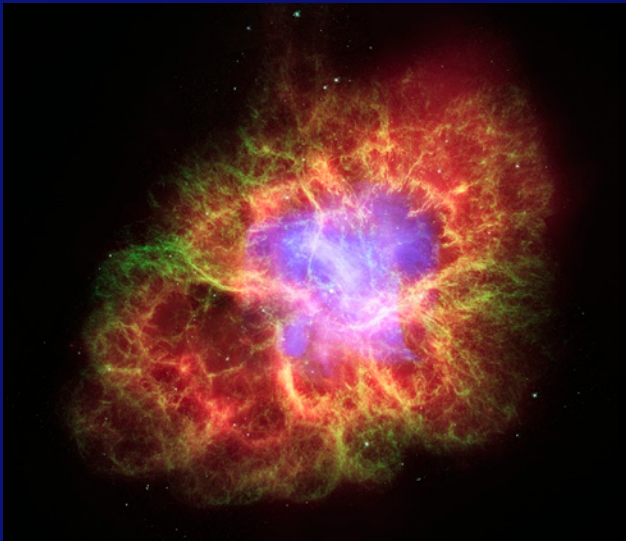


# Observations of the Crab Nebula



Elizabeth Hays

# What is the Crab?

- ✦ 1st analysis of every VHE grad student

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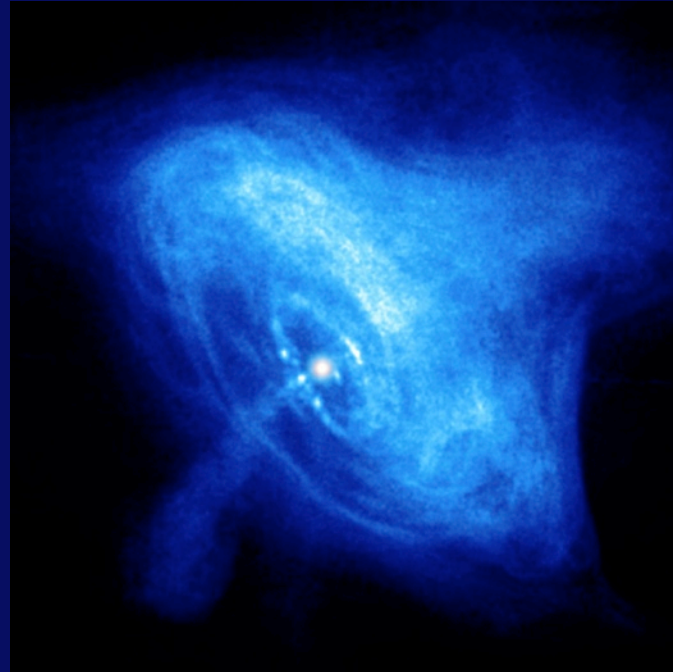
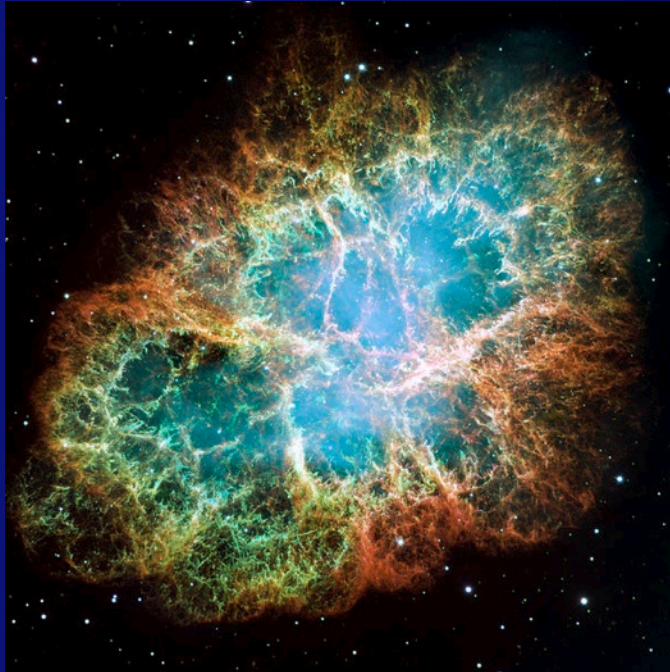
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- ✦ Beacon?
- ✦ Calibrator and Unit
- ✦ A friggin' pain in the rear
- ✦ An accessible, enigmatic, and continuously surprising source of radiation

# What is the Crab?

- ✦ The most observed object in the sky  
5000+ references (close to 200 this year so far)



“ There are two kinds of astronomy – the astronomy of the Crab Nebula and the astronomy of everything else ”

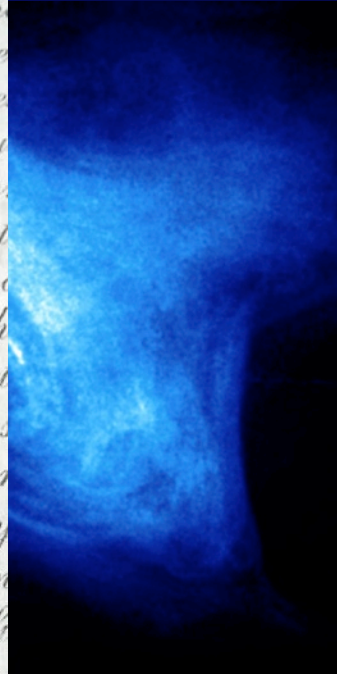
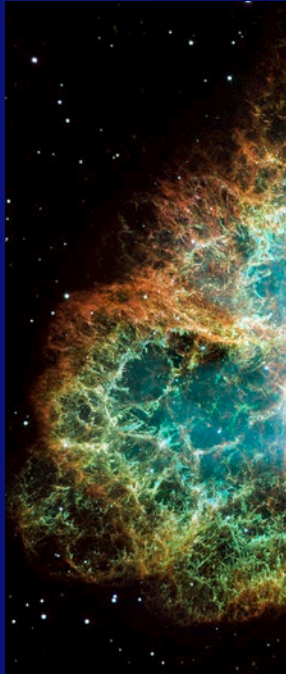
~~ G. Burbidge



# What is the Crab?

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“ There are two  
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astronomy of the Crab  
”

# The Crab Nebula

A Cosmic  
Trickster?

# The Crab Nebula

## A Cosmic Trickster?



# The Crab Nebula



A Cosmic  
Trickster?





# The Crab Nebula



## A Cosmic Trickster?



**OR THE ULTIMATE ASTROPHYSICS LIFE COACH?**

# SN 1054



Chaco Canyon, New Mexico

Observed  
in Asia and  
the Middle  
East. Also  
perhaps in  
the North  
American  
Southwest

# SN 1054



Chaco Canyon, New Mexico

Observed





# SN 1054



Observed



Lesson 1: Sometimes the important thing is to go outside and look up.



# M1

“This nebula had such a resemblance to a comet in its form and brightness that I endeavored to find others, so that astronomers would not confuse these same nebulae with comets just beginning to shine.” –Charles Messier



Image credit: Chris Brankin's Deepsky (Messier) Objects, from <http://www.stargazing.net>

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Image credit: Chris Brankin's Deepsky (Messier) Objects, from <http://www.stargazing.net>

Lesson 2: Be open minded. What you find might be more interesting than what you were looking for.

# A Nebula (is a fuzzy thing)

- ✦ Association of the Crab Nebula with SN 1054 in 1939 and evidence that the supernova was Type I, launched a search for the central star powering the nebula
- ✦ Discovery of the Crab pulsar period (33 ms) in radio in 1968 (IAU Circ. No. 2113, 1968) supported the existence of neutron stars
- ✦ Optical pulsations first found at Kitt Peak (Cocke, Disney, and Taylor, 1969, Nature)

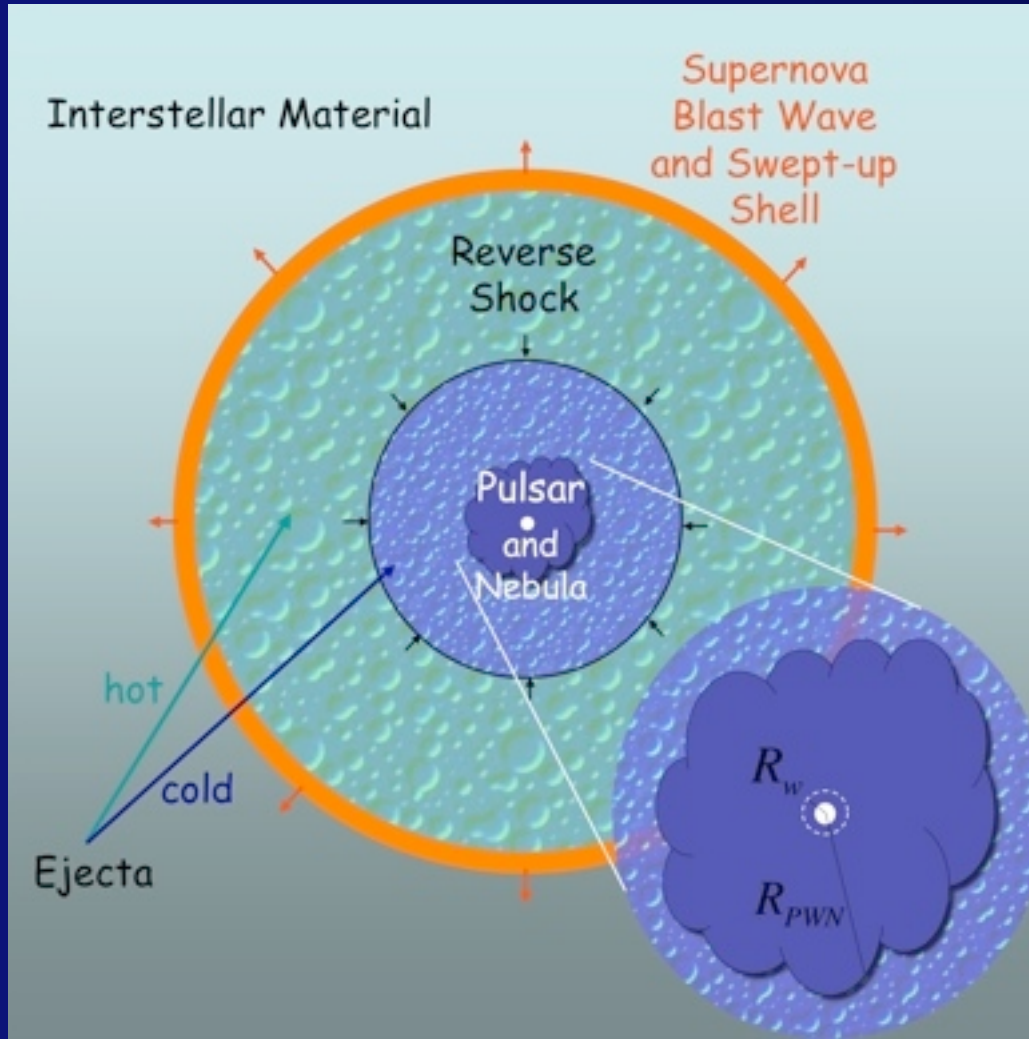
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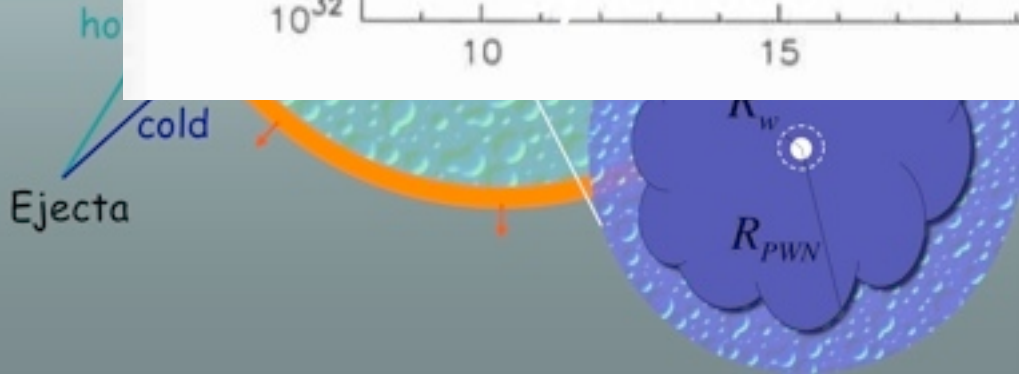
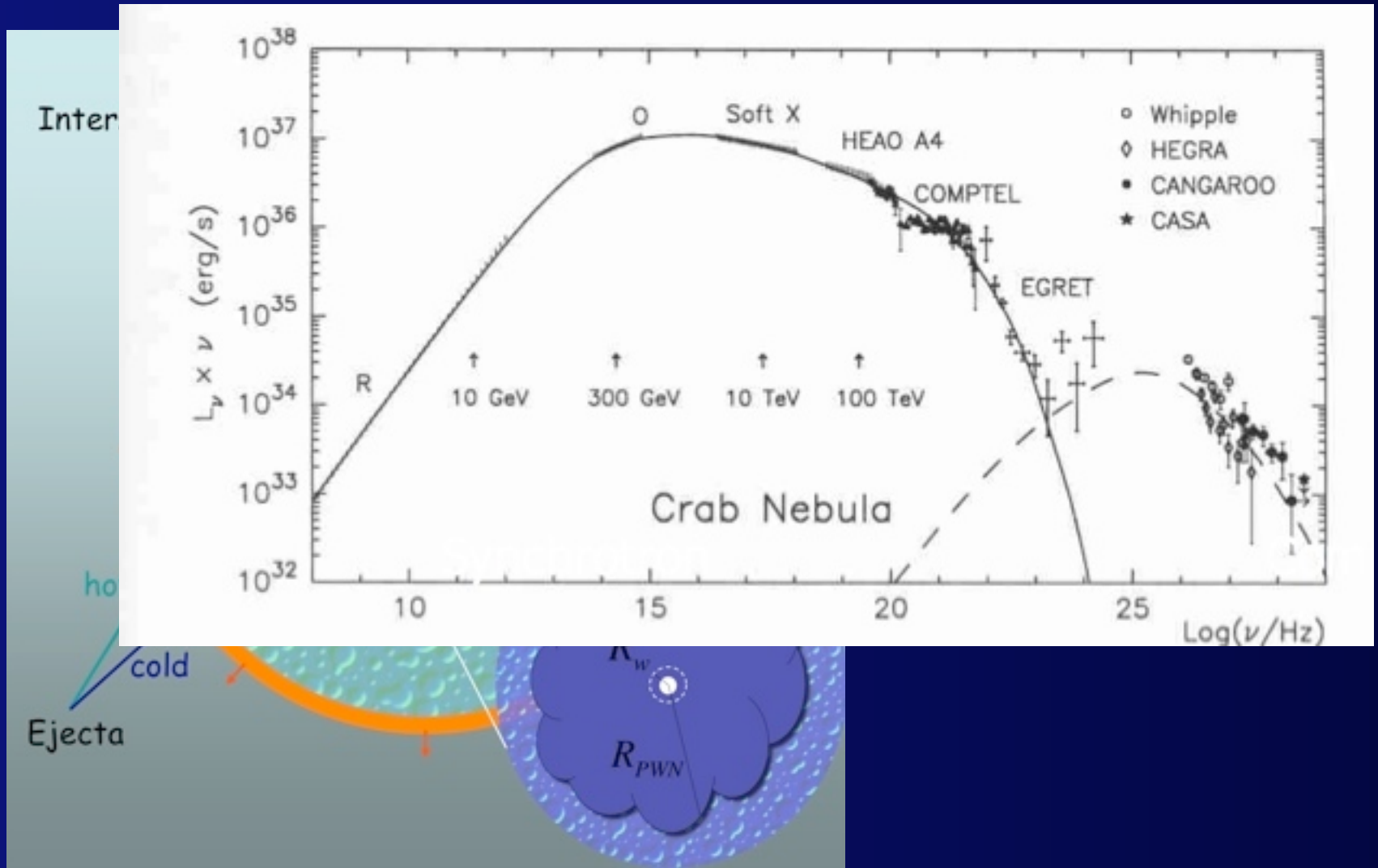
Lesson 3: Where's there's smoke...



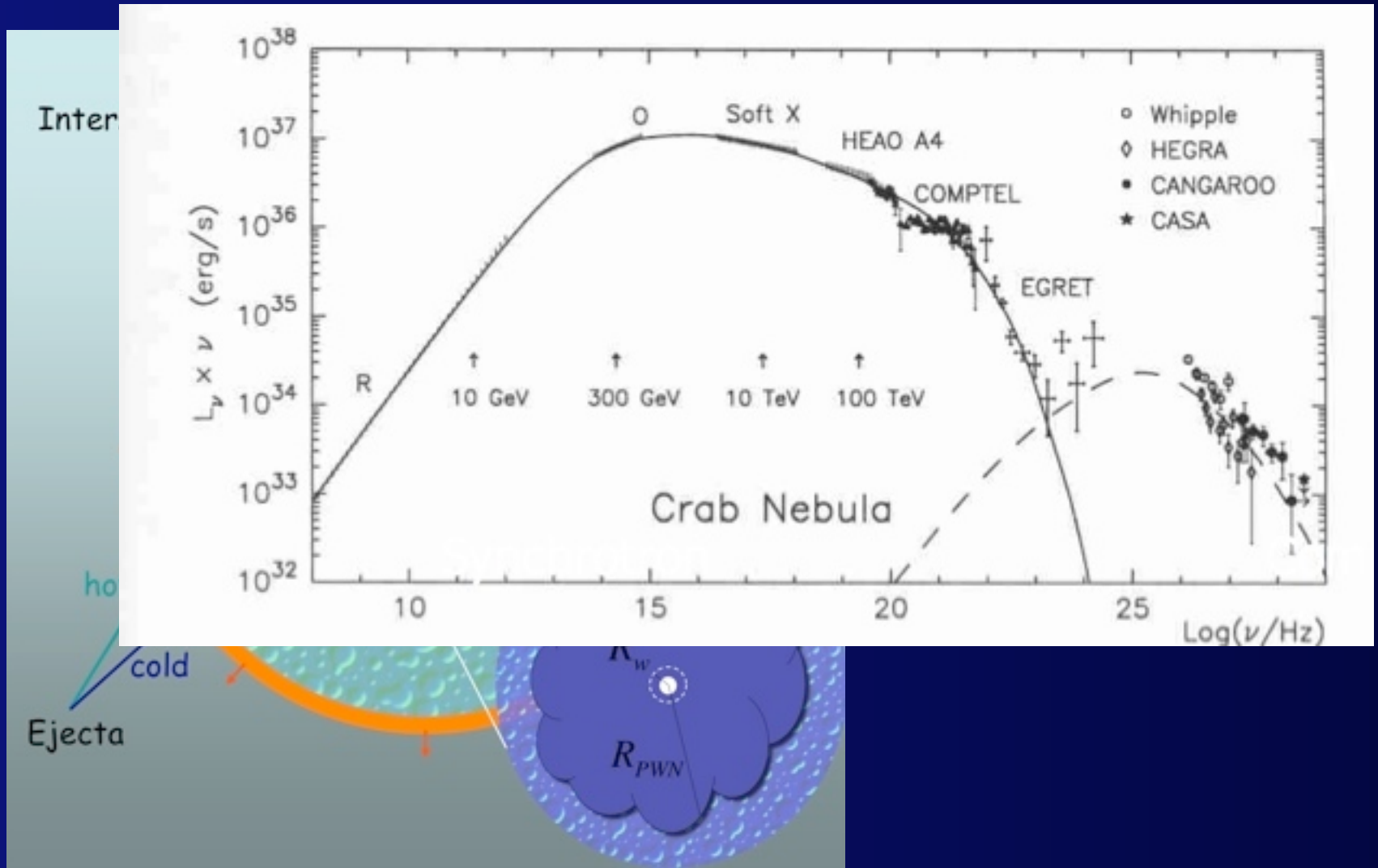
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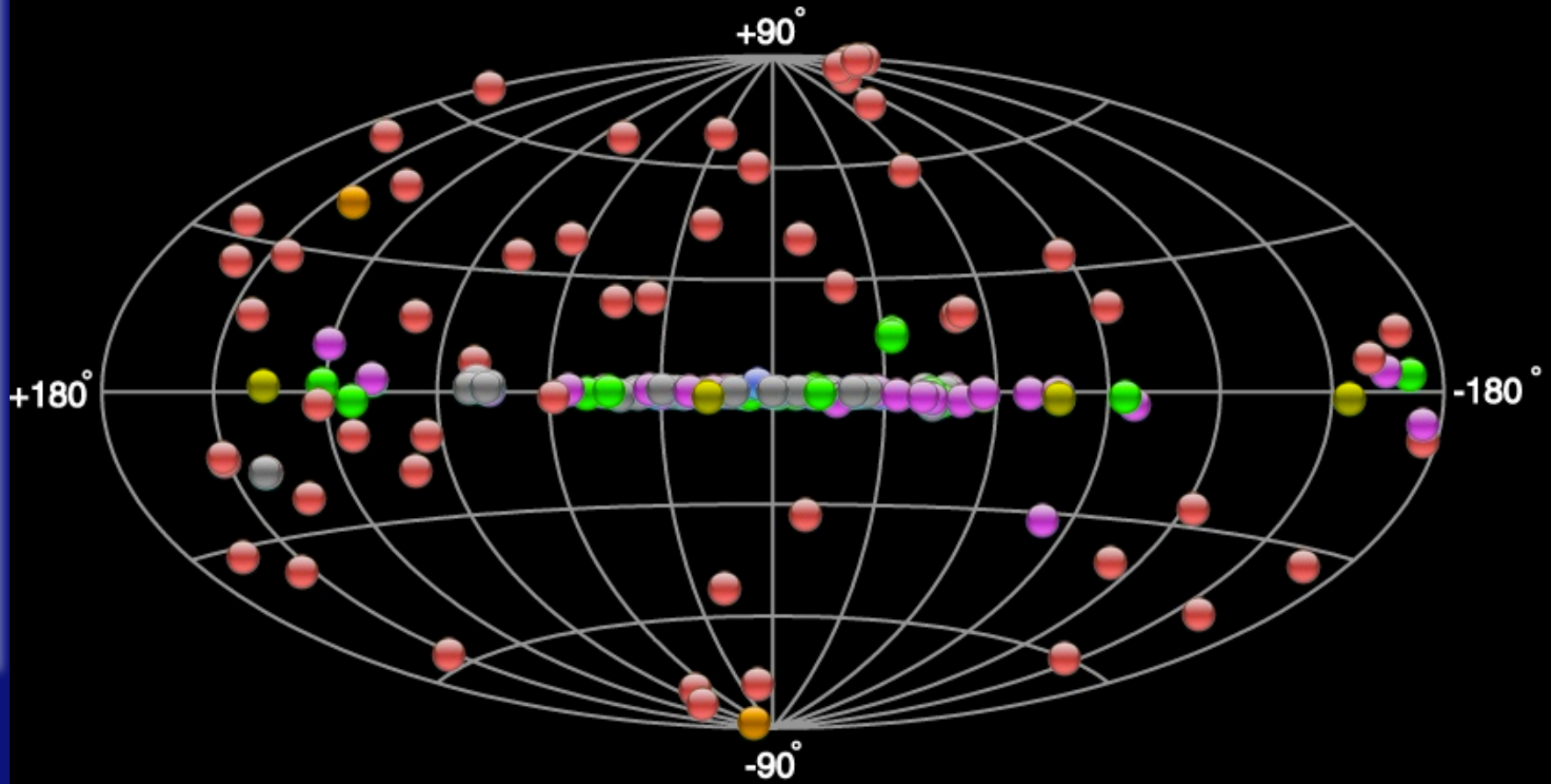
# A Pulsar Wind Nebula



Lesson 4: Watch out for the archetypes.

# Opening a new astronomy

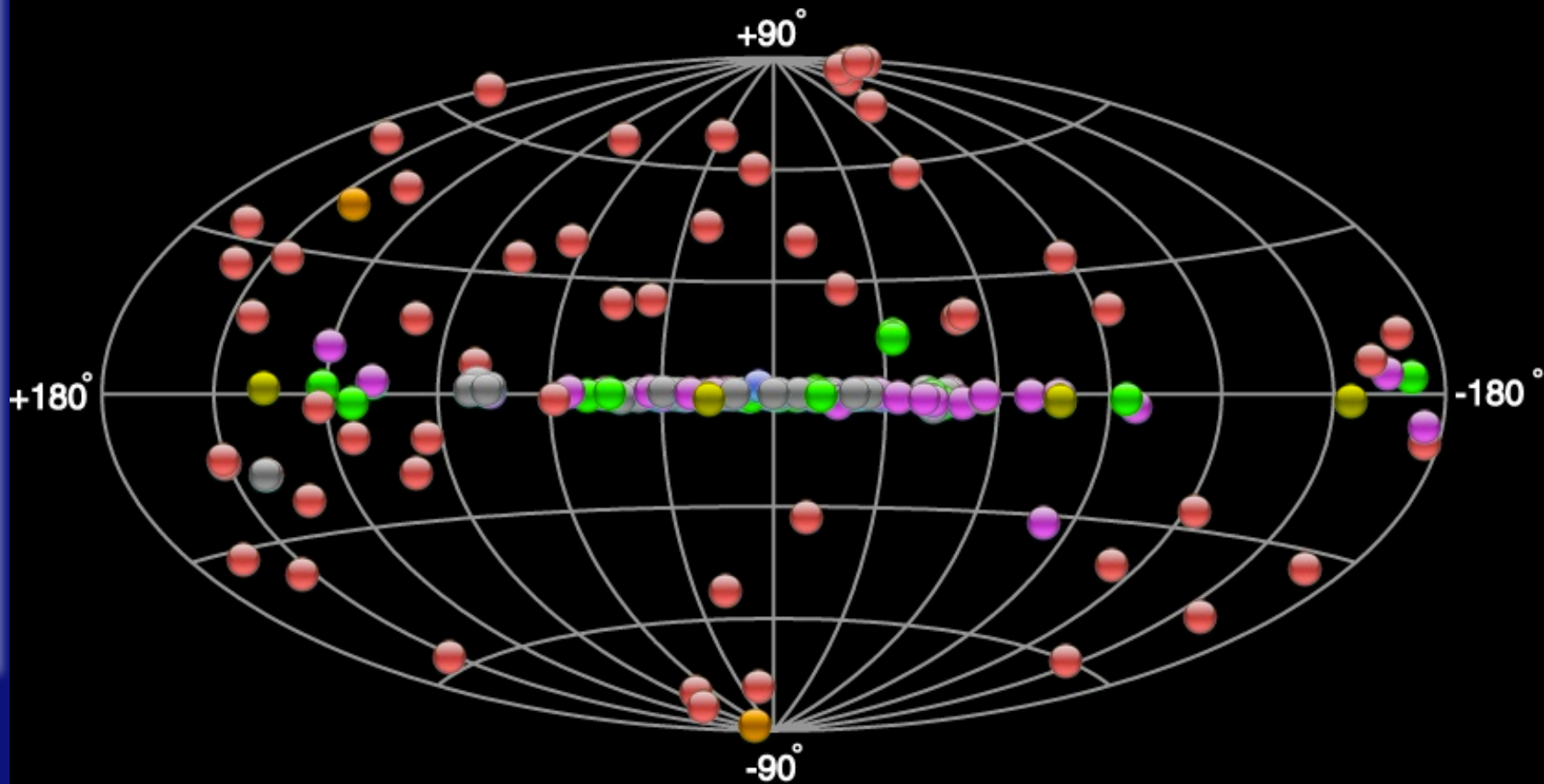
*Welcome to TeVCat!*





# Opening a new astronomy

*Welcome to TeVCat!*



Lesson 5: Don't stop believin'

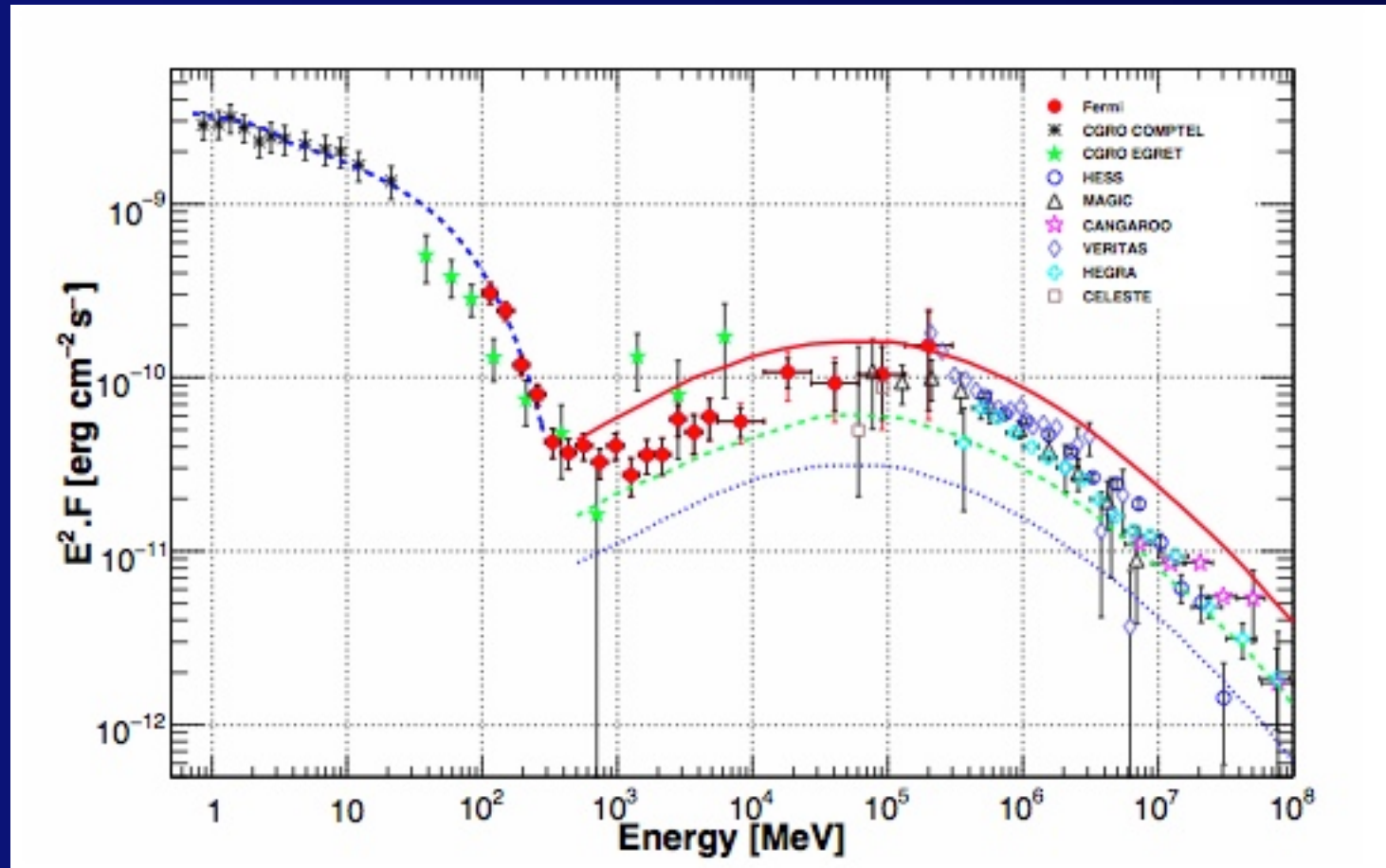
# A brief aside on irony



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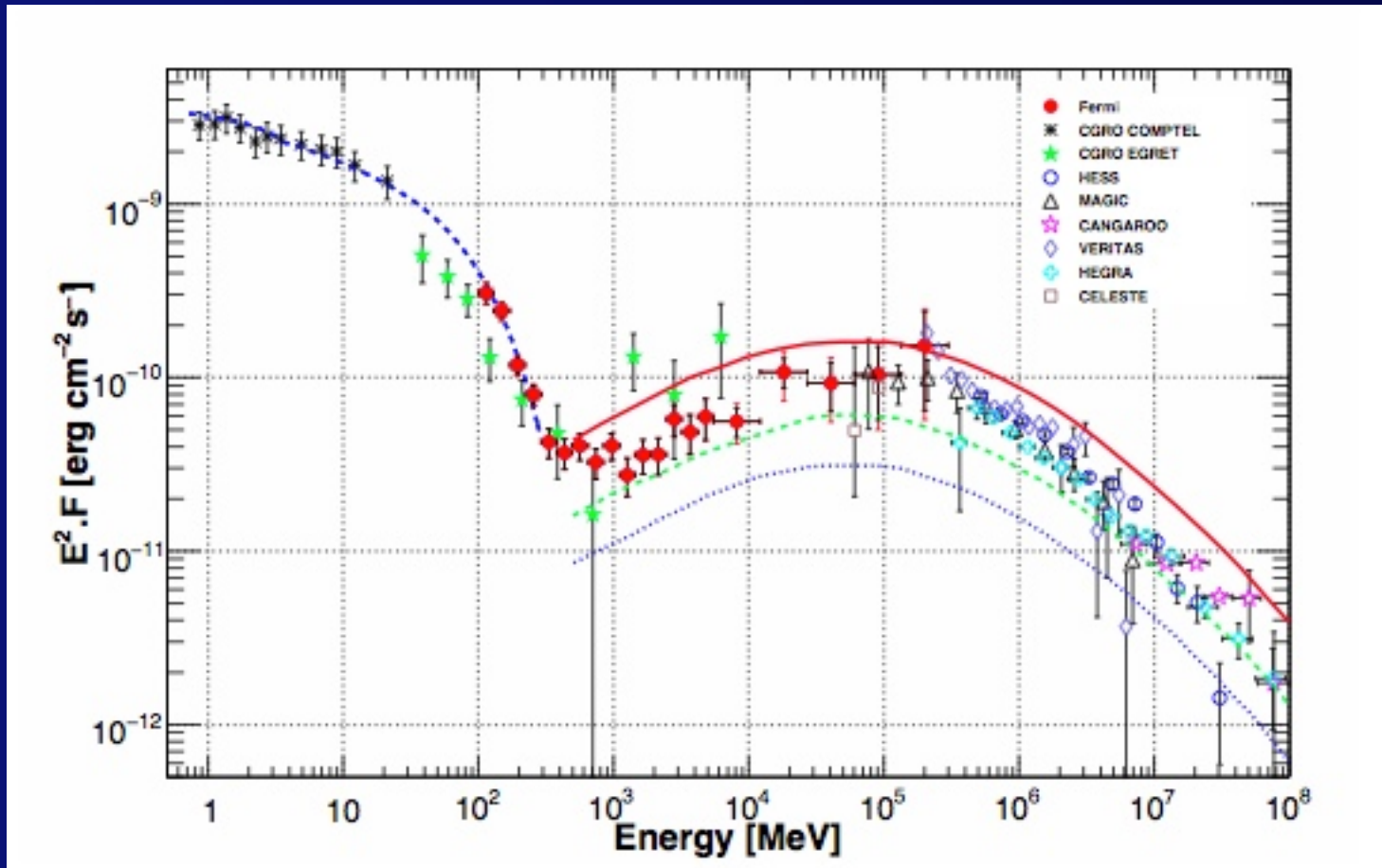
Or how I met Trevor

# A standard candle for high energy astronomy!



Abdo et al. 2010, ApJ, 708, 1254

# A standard candle for high energy astronomy!

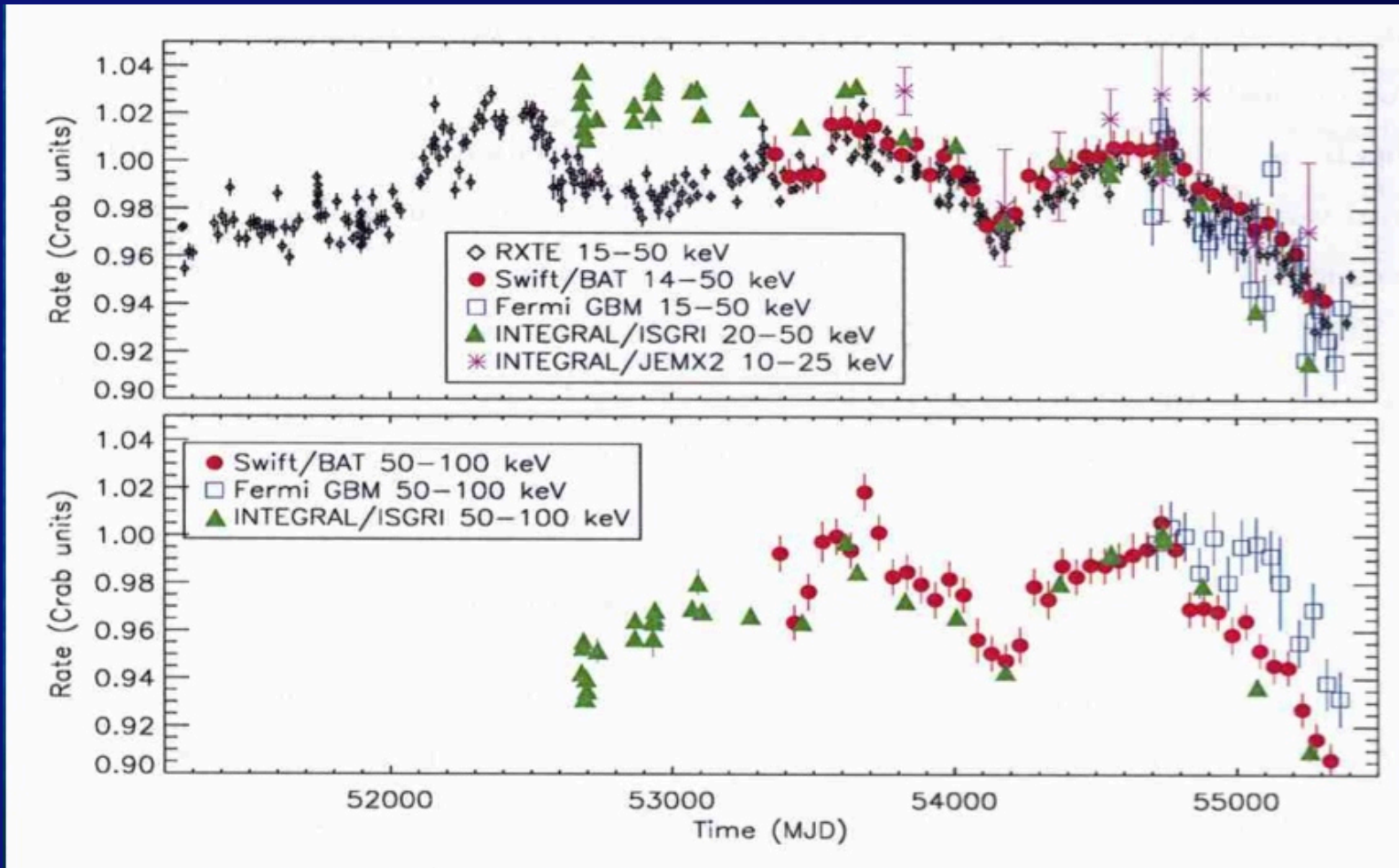


Abdo et al. 2010, ApJ, 708, 1254

Lesson 6: If it seems too good to be true...

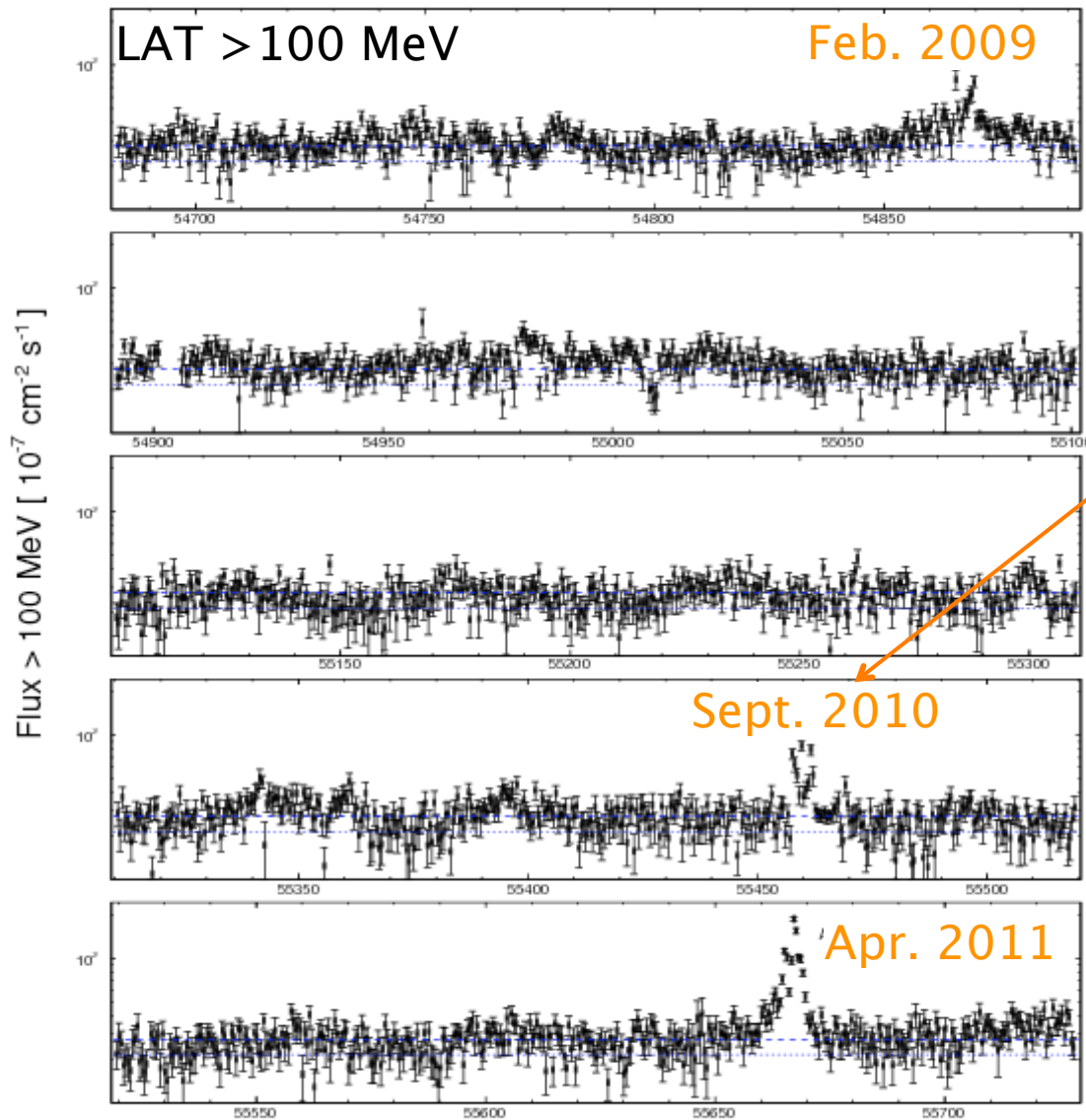
# Or not!

Long-term hard X-ray lightcurve ( $\sim 10\text{--}50$  keV)



Wilson-Hodge et al. 2011, ApJL

# An intense gamma-ray flare machine



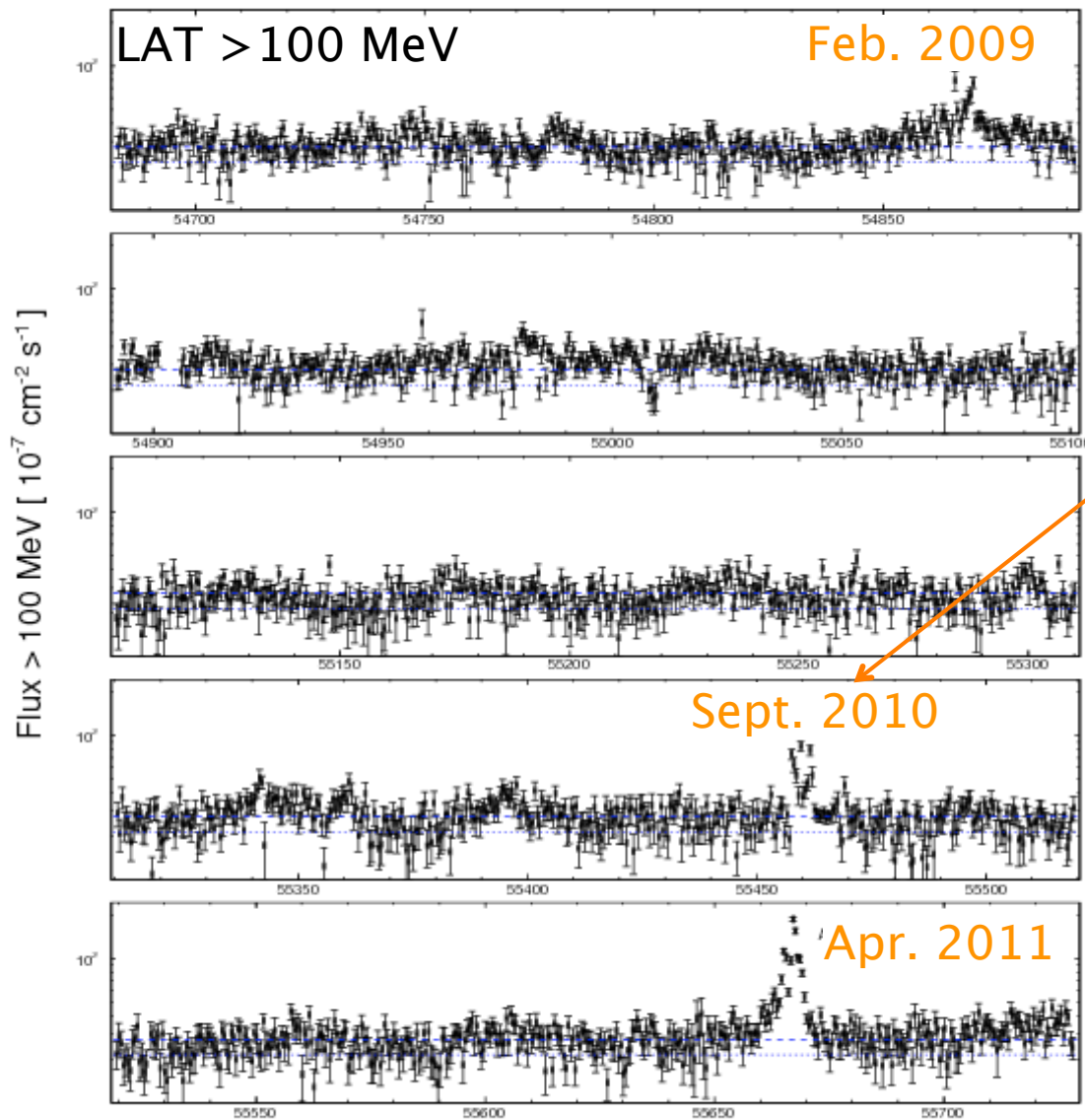
Initial Report from AGILE and first Fermi TOO on Crab

3 additional flares to date (and TOOs)

Buehler, R. et al. 2011, ApJ



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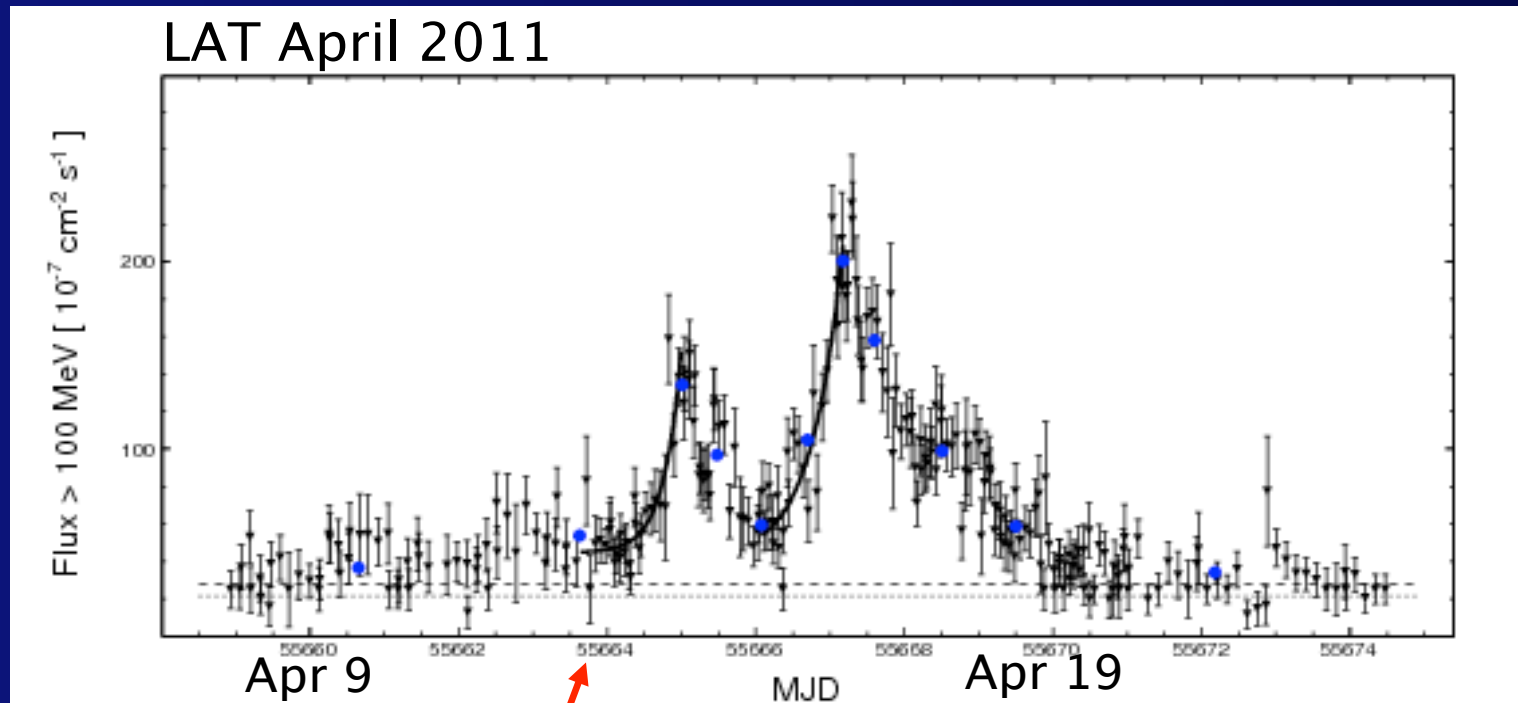
Lesson 7: If you only look for what you've been told to expect, that's all you'll find.

Buehler, R. et al. 2011, ApJ



# Closer look at the GeV flare structure

LAT Lightcurve in bins of equal exposure (mean 9 minutes!)

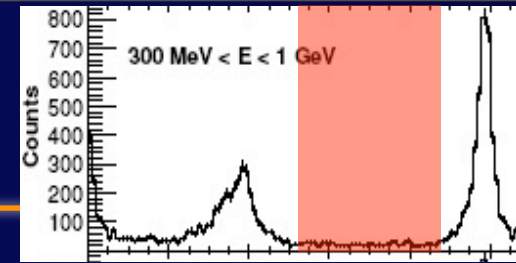


Beginning of LAT TOO

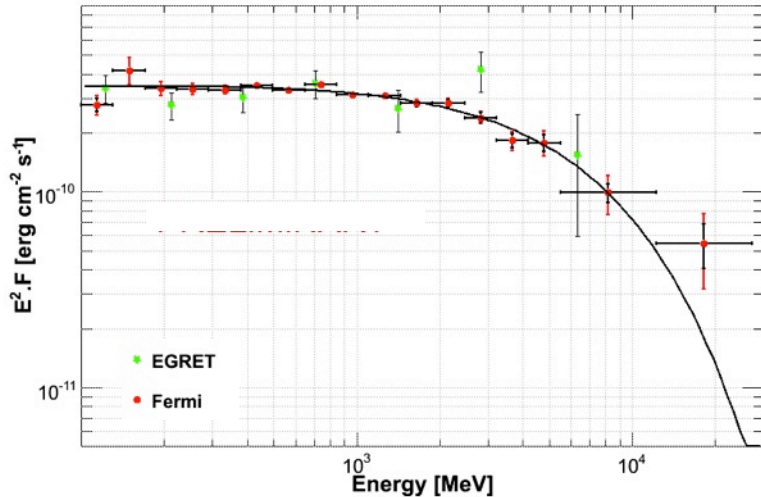
Flux doubling in 8 hours constrains emission region size  $< 0.0003$  pc

Buehler, R. et al. 2011, ApJ

# The Crab above 100 MeV



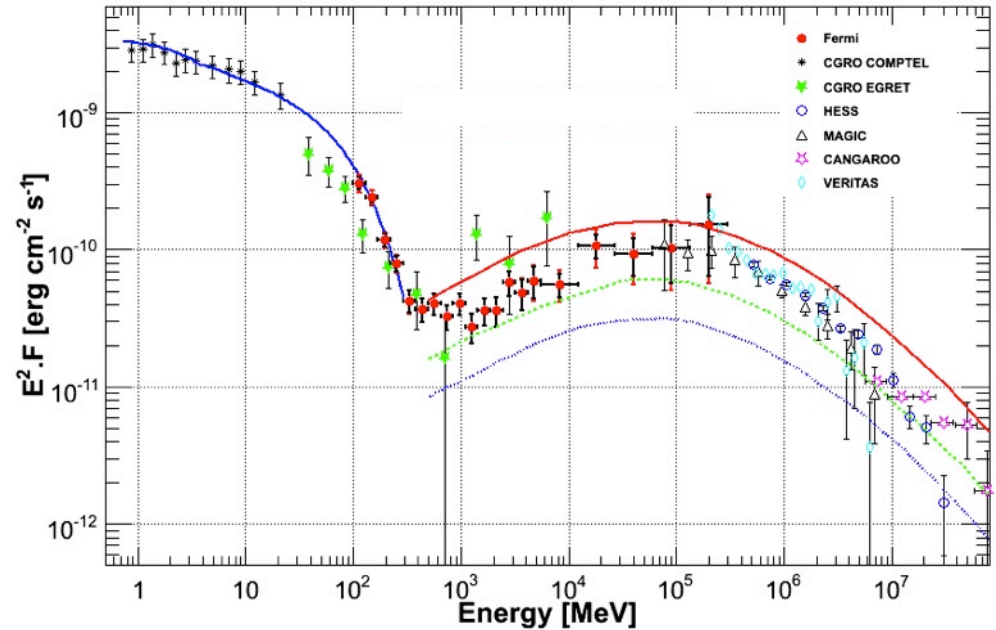
## Pulsar 100 MeV to 20 GeV



Hyper-exponential cutoff excluded in phase-averaged spectrum.

WARNING: Phase matters!

## Nebula from MeV to TeV

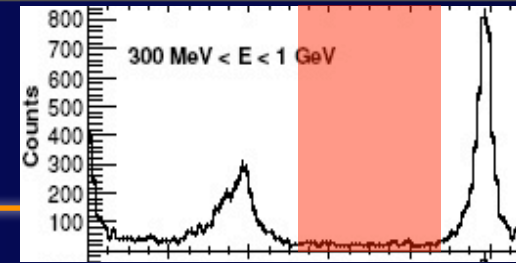


2 components: Synchrotron + Inverse Compton extending to TeV.

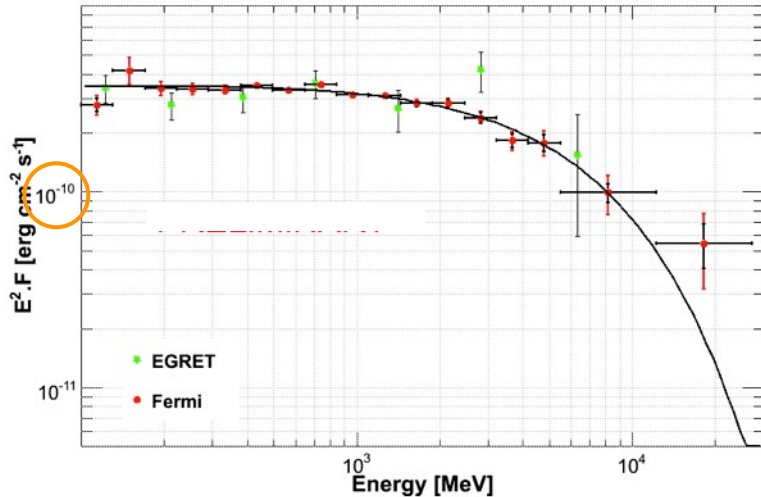
Mean B field in nebula 100 to 200  $\mu$ G.

Abdo et al. 2010, ApJ, 708, 1254

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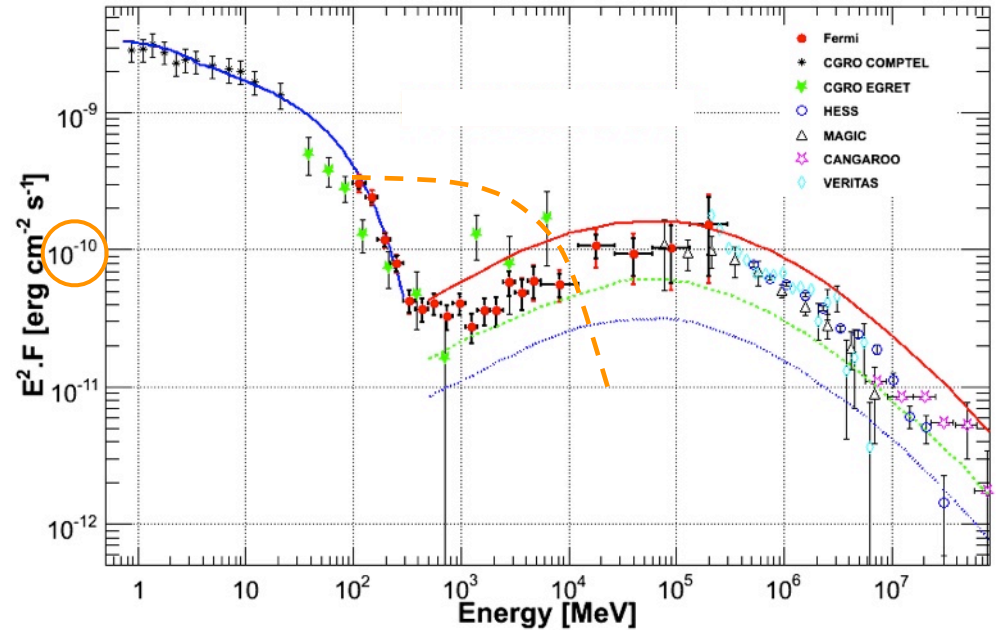
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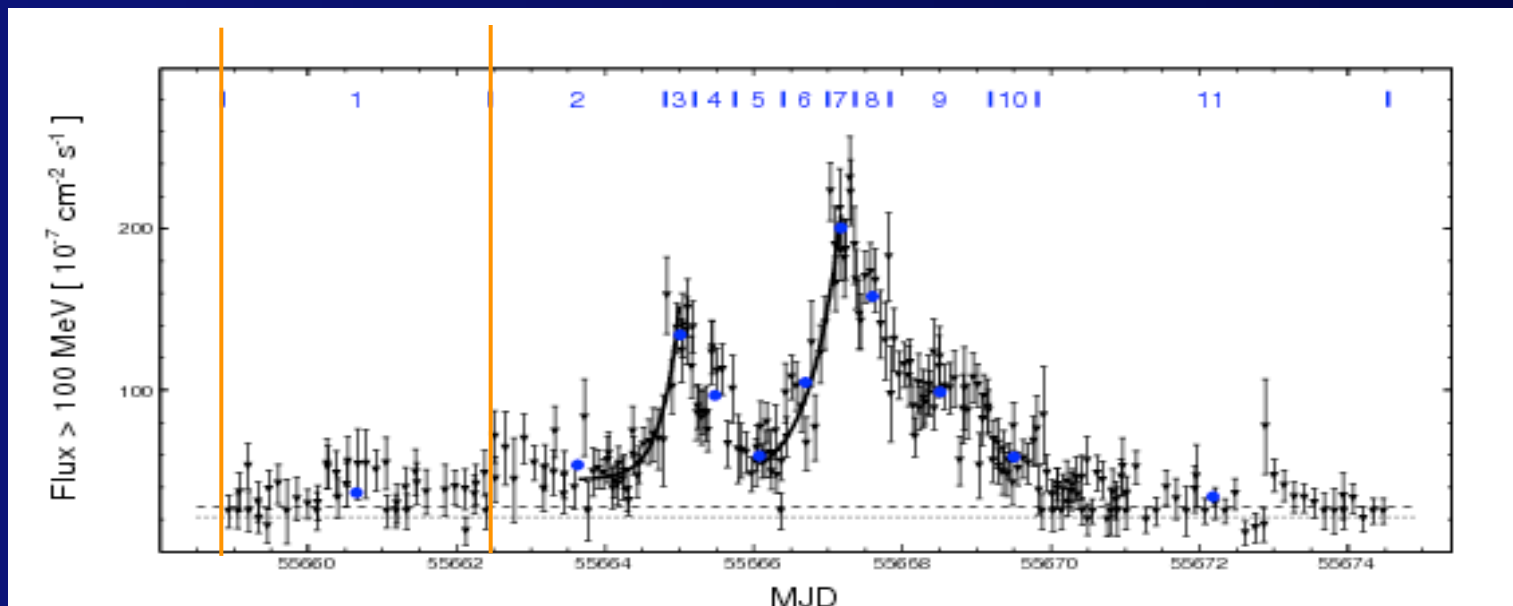
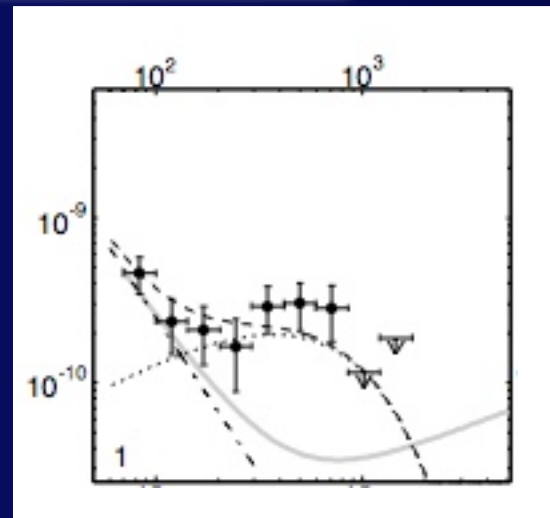
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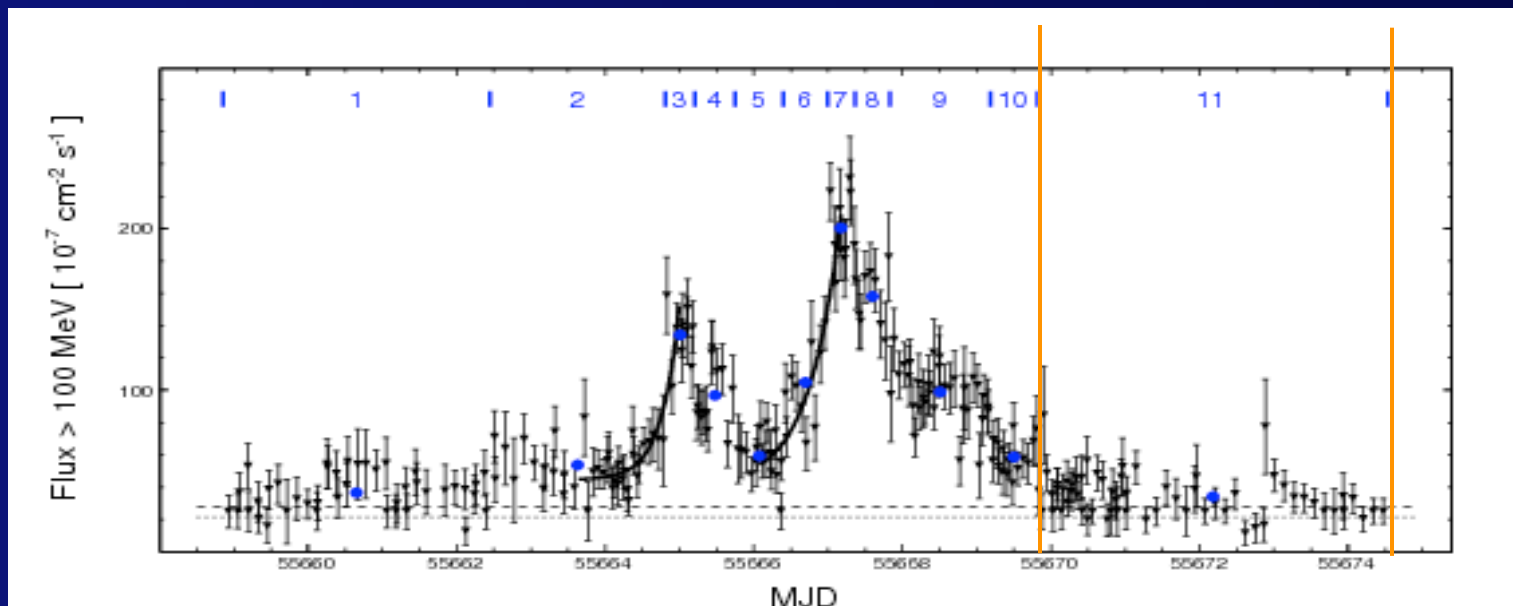
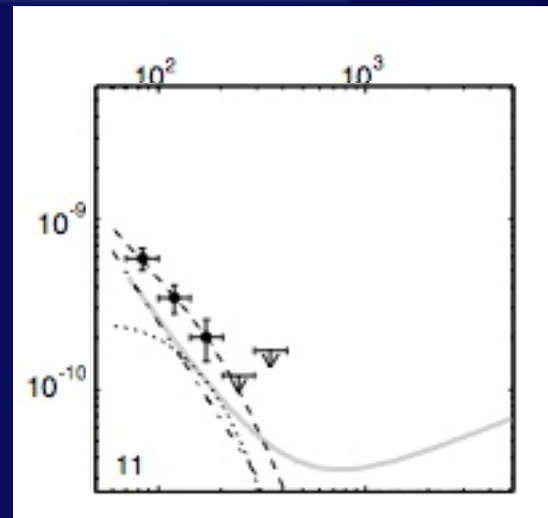
# Spectral Evolution of April Flare

Sufficient statistics to partition the spectral fit into 11 bins of constant flux (as defined by Bayesian Blocks analysis).

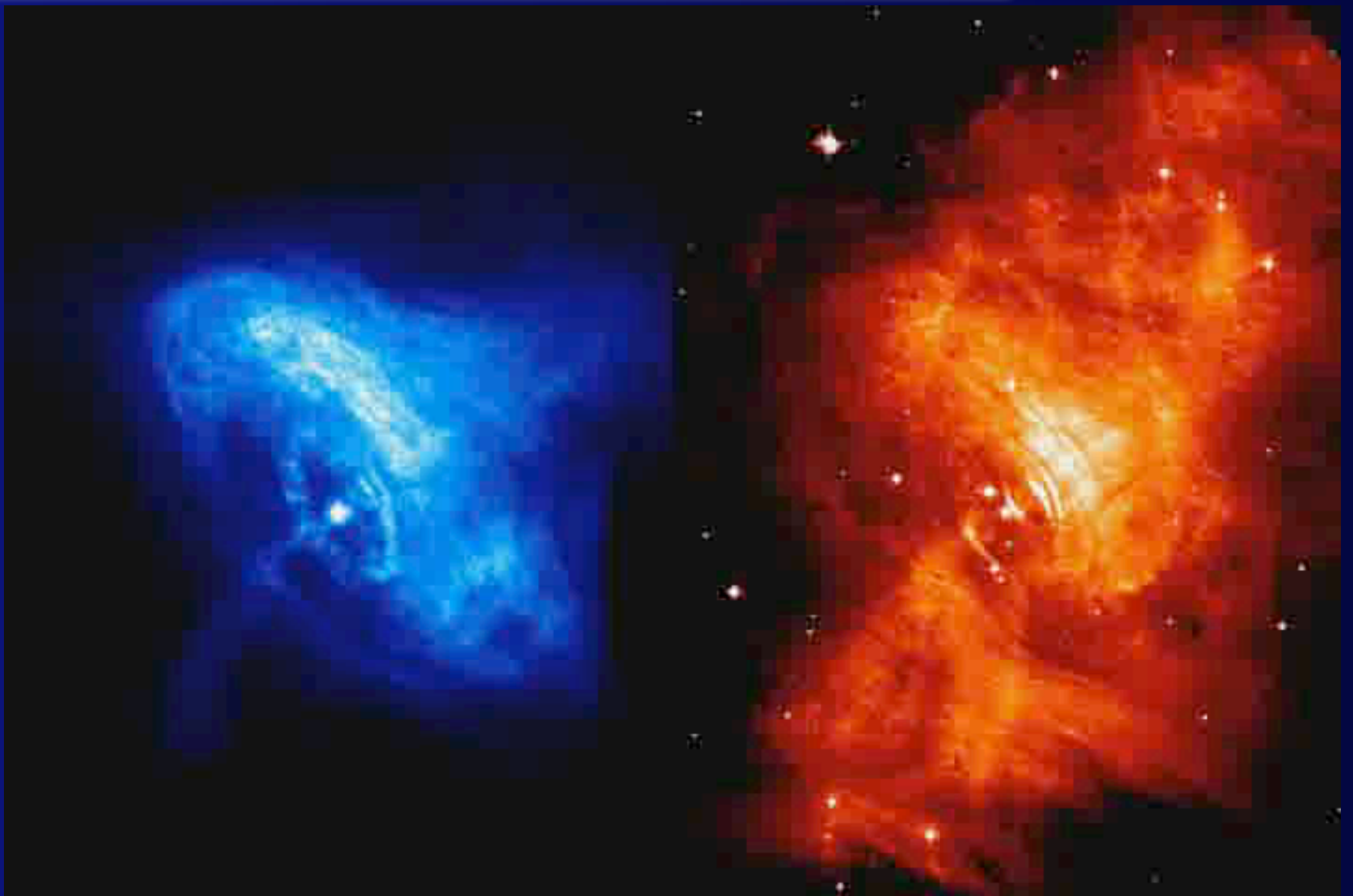


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# Inner Nebula is highly dynamic



Credits: X-ray: NASA/CXC/ASU/J.Hester et al.; Optical: NASA/HST/ASU/J.Hester et al.

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# Open Questions

- ✦ Electron/positron synchrotron emission is most reasonable but energies suggest beaming
- ✦ How is the acceleration accomplished?
  - ✦ Particle spectrum is hard (index  $\sim 1.6$ )
  - ✦ Region is small (0.0003 pc)
  - ✦ Electrons reach very high energy in a very short time (<8 hour flux doubling time)
- ✦ Where do the gamma rays originate in the nebula?
  - ✦ No pulsations  $\rightarrow$  outside the pulsar light cylinder
  - ✦ 0.0003 pc constraint is smaller than the termination shock region
  - ✦ Despite good coverage, no correlated variations or changes in features found at other wavelengths yet



# More surprises ahead?

- ✦ What is the nature of the gamma-ray flares?
- ✦ Is the Crab fading away? 7% drop in 1<sup>st</sup> 2 years of Fermi GBM operations.
- ✦ Pulsed emission extends to VHE! (lovely paper from VERITAS)
- ✦ Still in pursuit of hard X-ray and HE polarization measurements
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Lesson 8: Keep pushing the limits

# Thanks, Trevor!



Final Lesson: Don't anthropomorphize your work!

# Spectral Fits April 2011

