# High Energy Astrophysics

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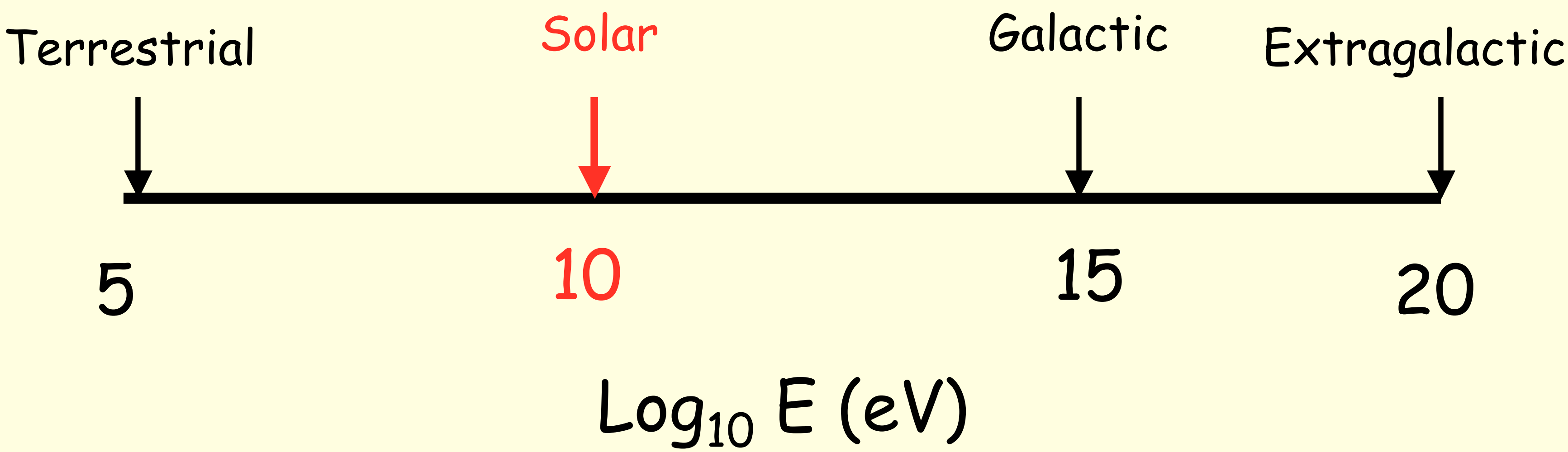
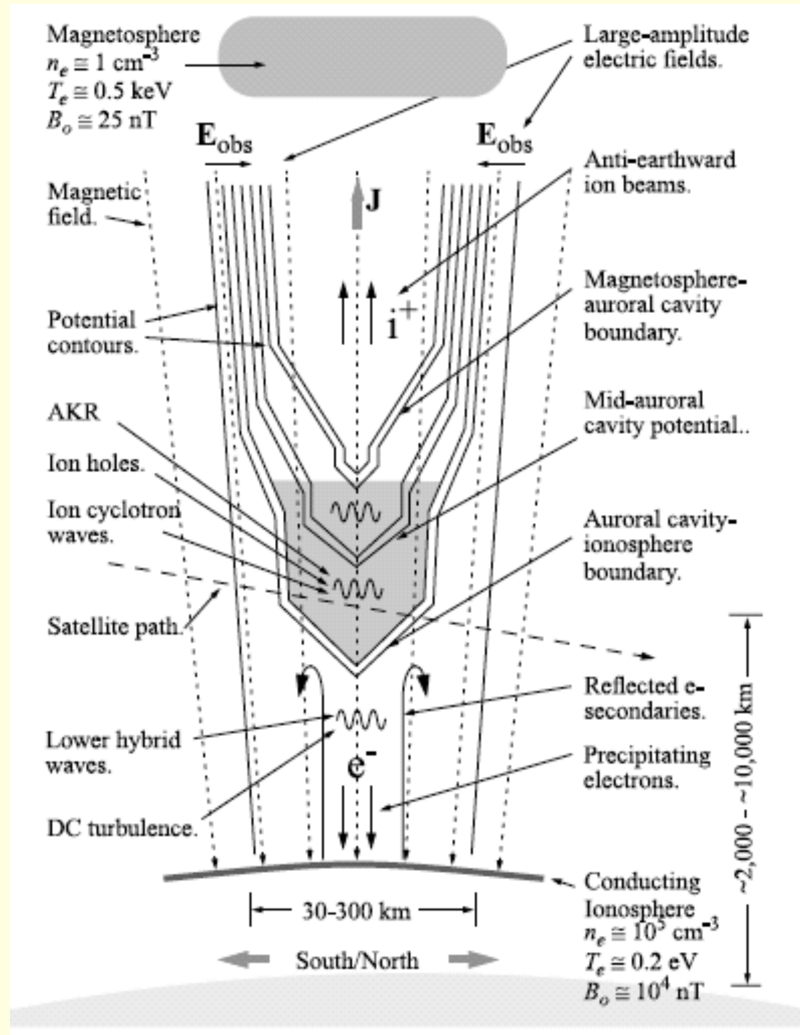
# High Energy Solar Physics

We can use the Sun as a case study of cosmic rays and particle acceleration.

After all it is a star.



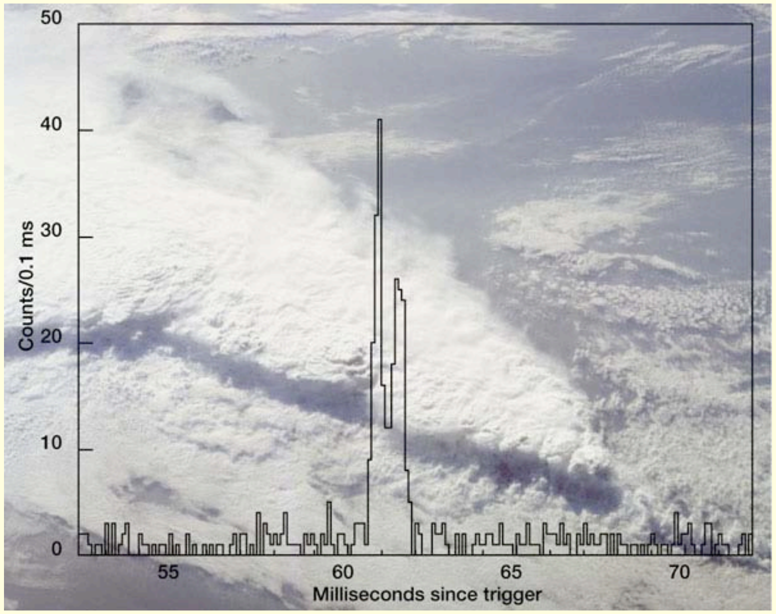
# The Earth System




~10 keV, upward **E**

**Seen in x rays disrupted upward currents induce resistance (IR drop)**

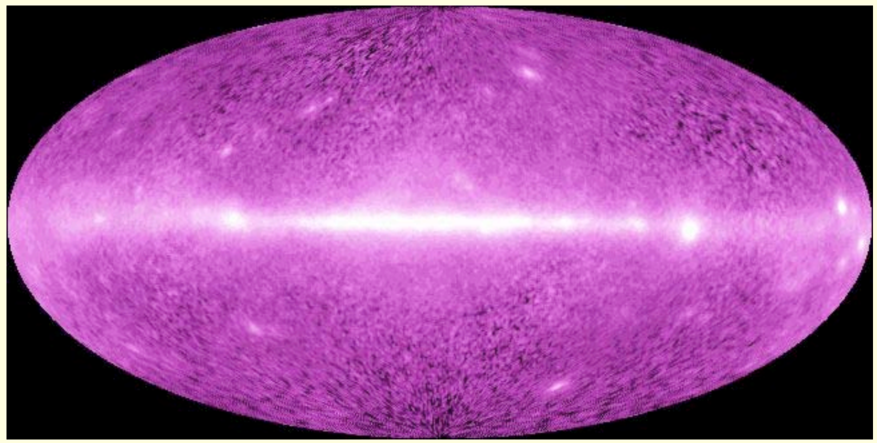
Terrestrial Gamma Flashes




~ ms duration, few hundred keV

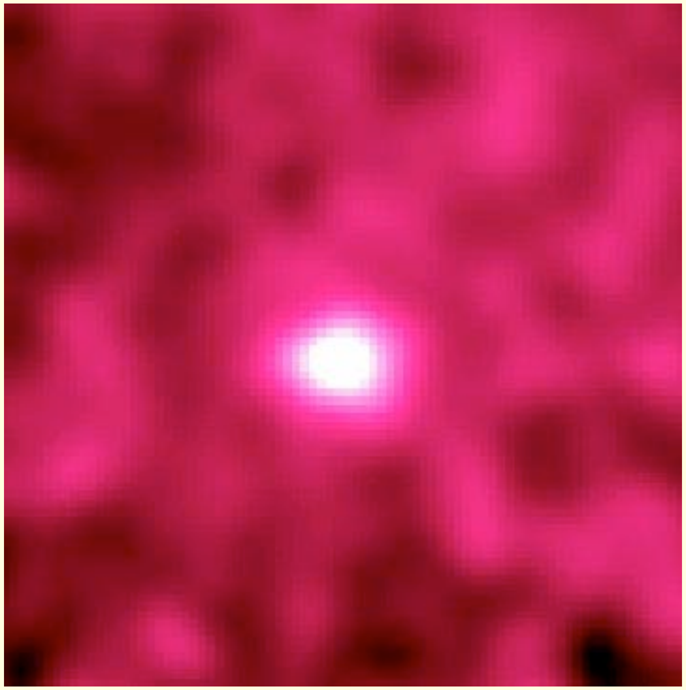
Associated with sprites

# We see the electromagnetic signature of CR

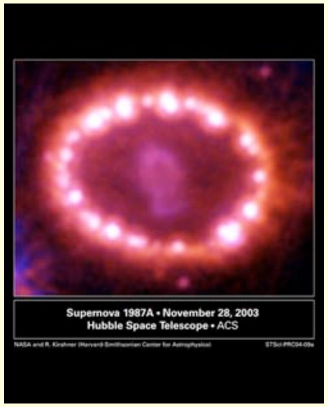


The 100 MeV full sky picture

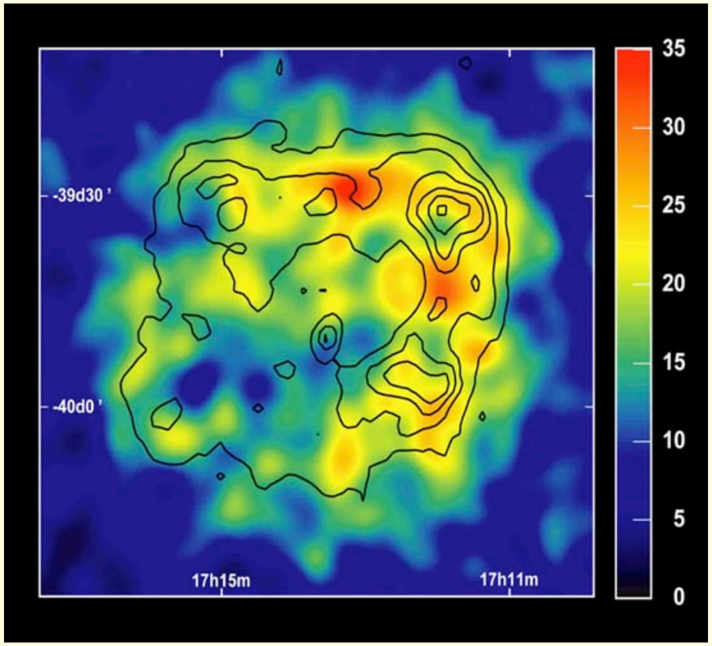
# Gamma-ray moon



# Galactic CR

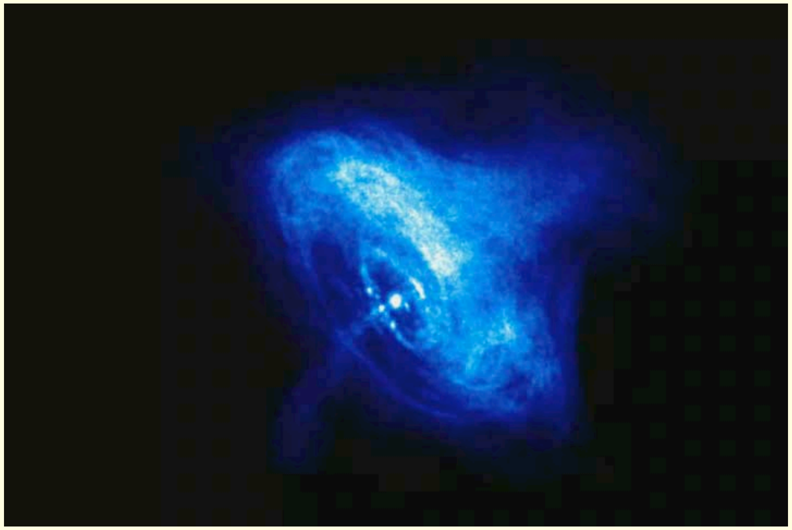


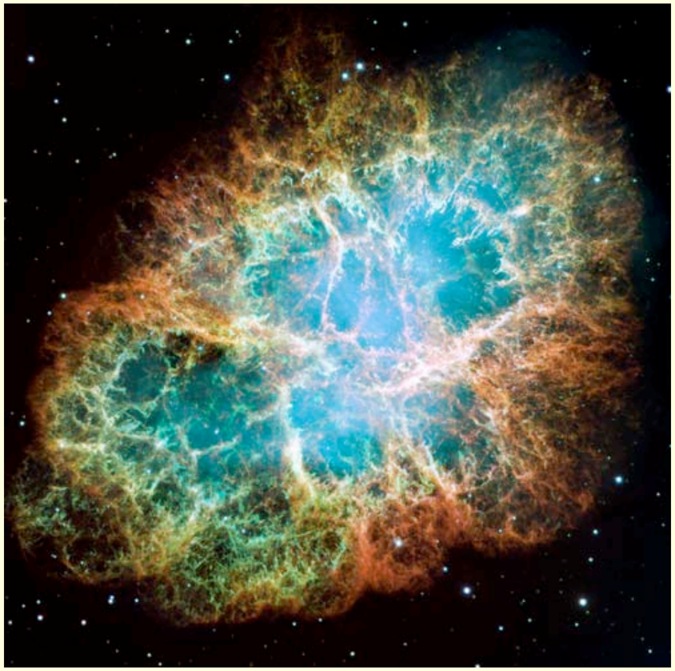

TeV $\gamma$ ray image of SNR
Particles being accelerated at interstellar shock
Can achieve ~$10^{15}$ eV




RXJ1713-3946
H.E.S.S

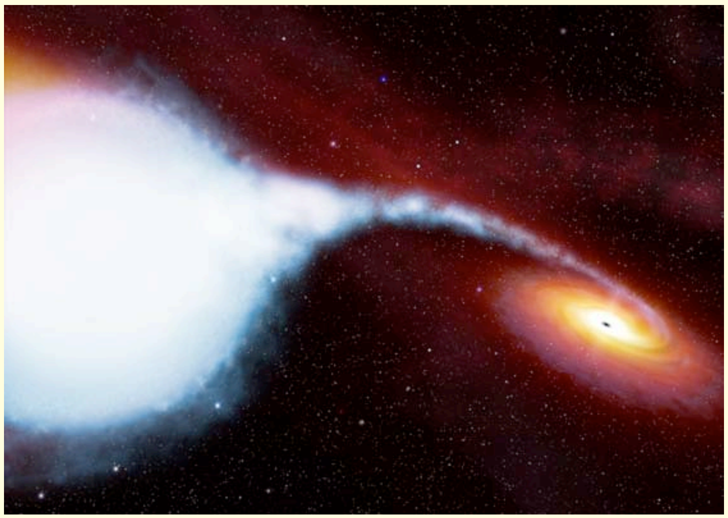
# Pulsars



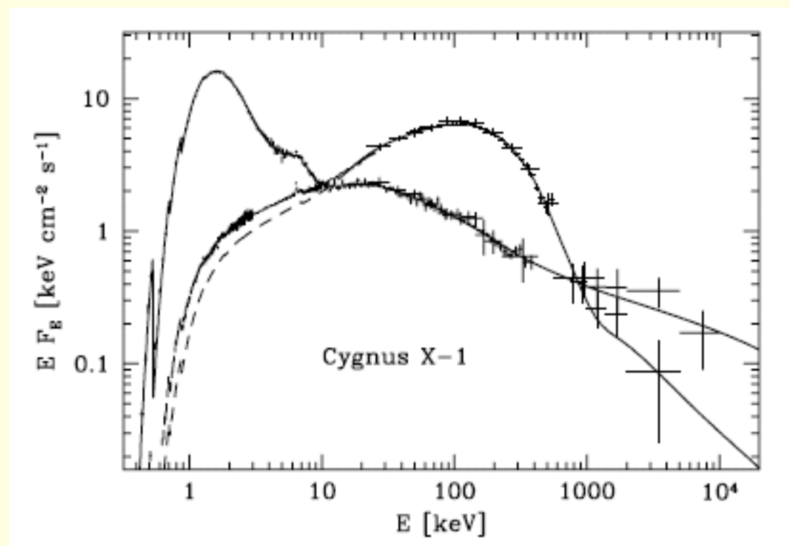


Acceleration to $\sim 10^{13}$ eV via inductive **E** field, maybe higher with shocks.

# Maybe Blackholes



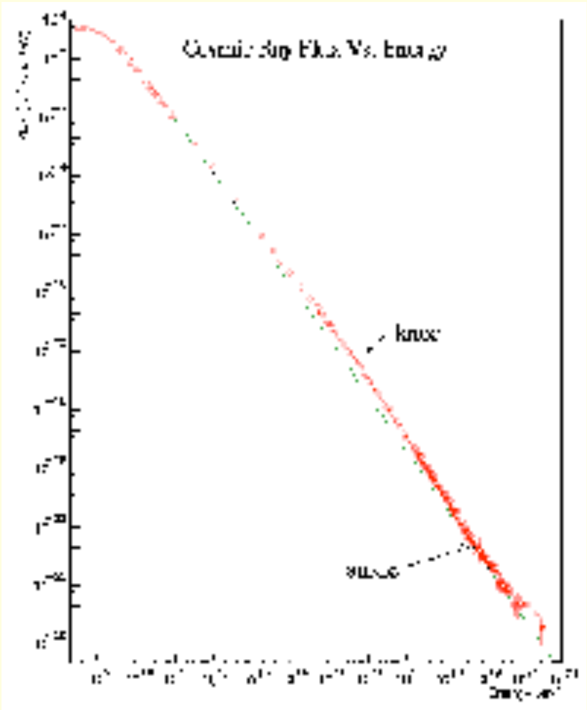
Your basic galactic BH

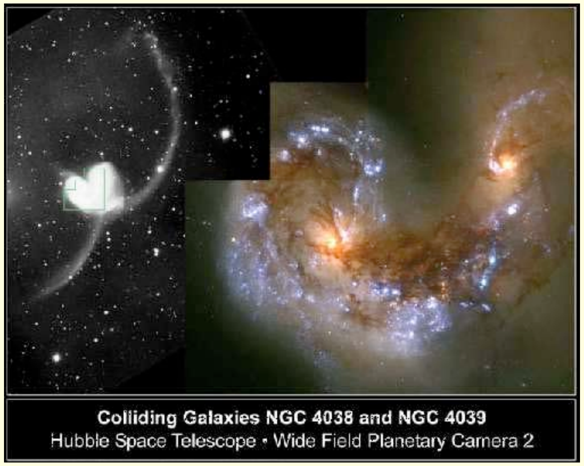


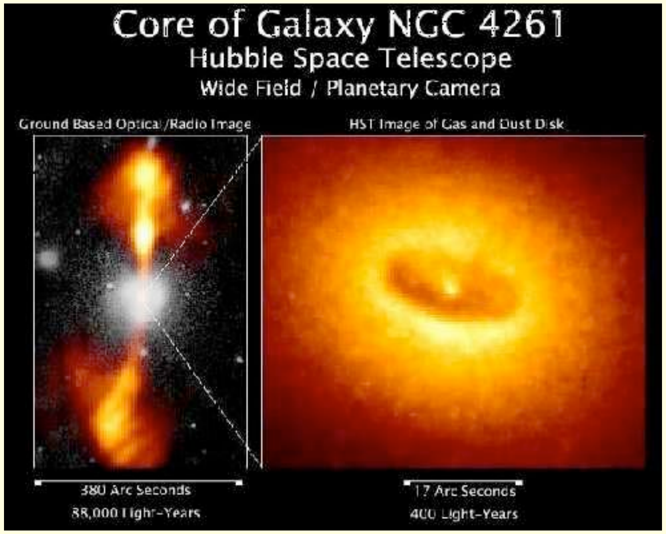

Variable high-energy spectrum
Reconnection in accretion disk?

McConnell et al. 02

# Extragalactic CR



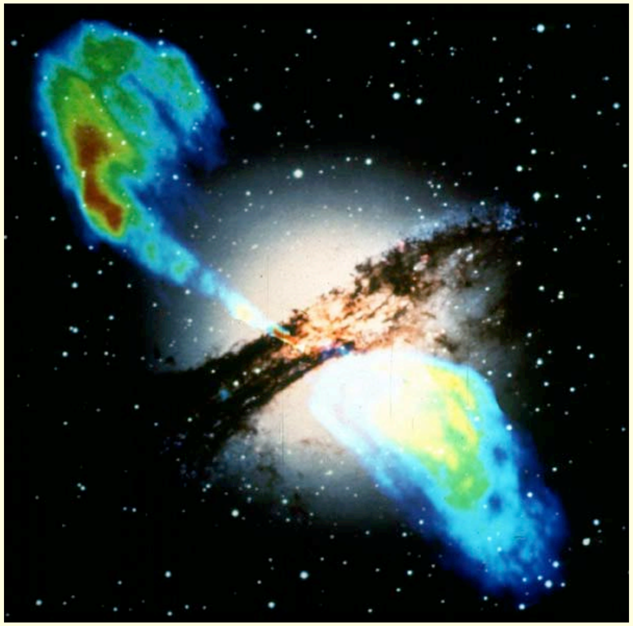



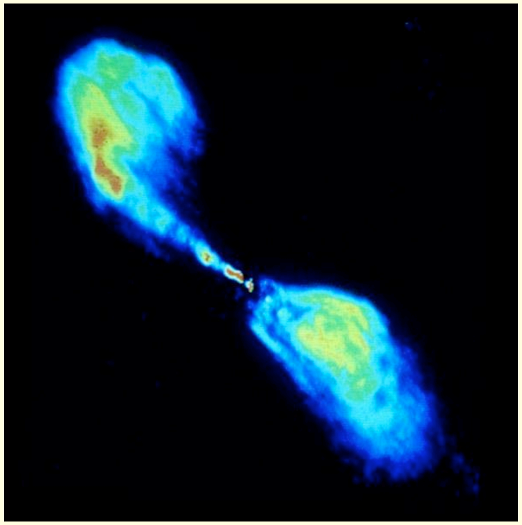

As high as $10^{20}$ eV

$r_g$ > Milky Way

# Cen-A
# Nearest AGN

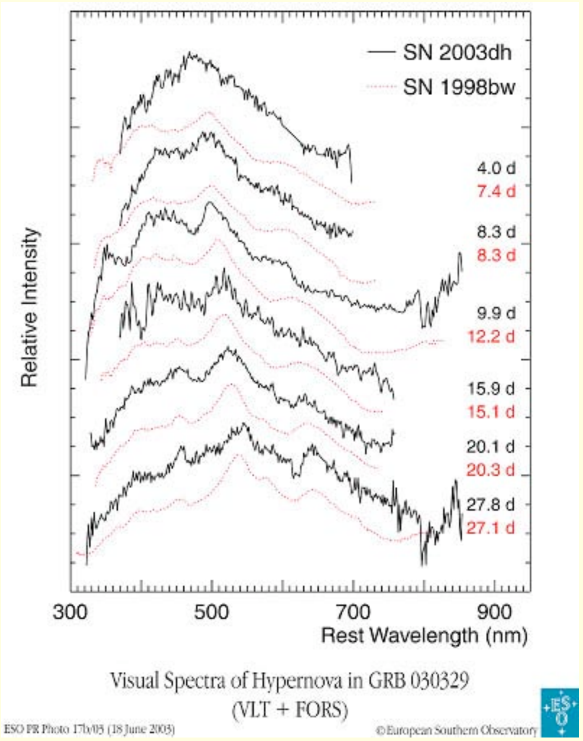
Chandra



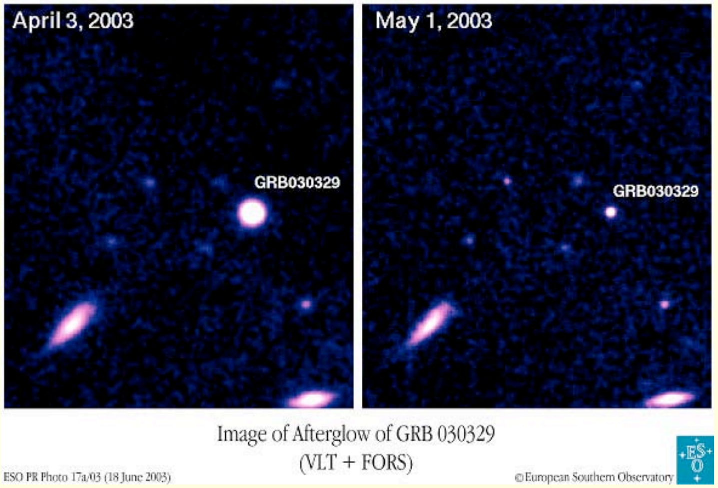
VLA

Large structures and strong high speed shocks

# Gamma Ray Bursts




Lightcurve of SN

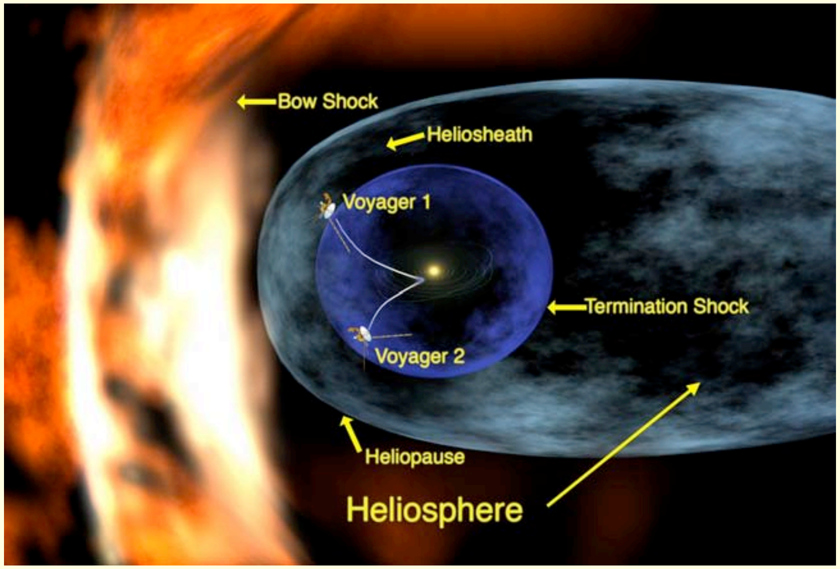



Cosmological Distances
With high Lorentz ($\gamma$)
factor jets

# Heliospheric Acceleration

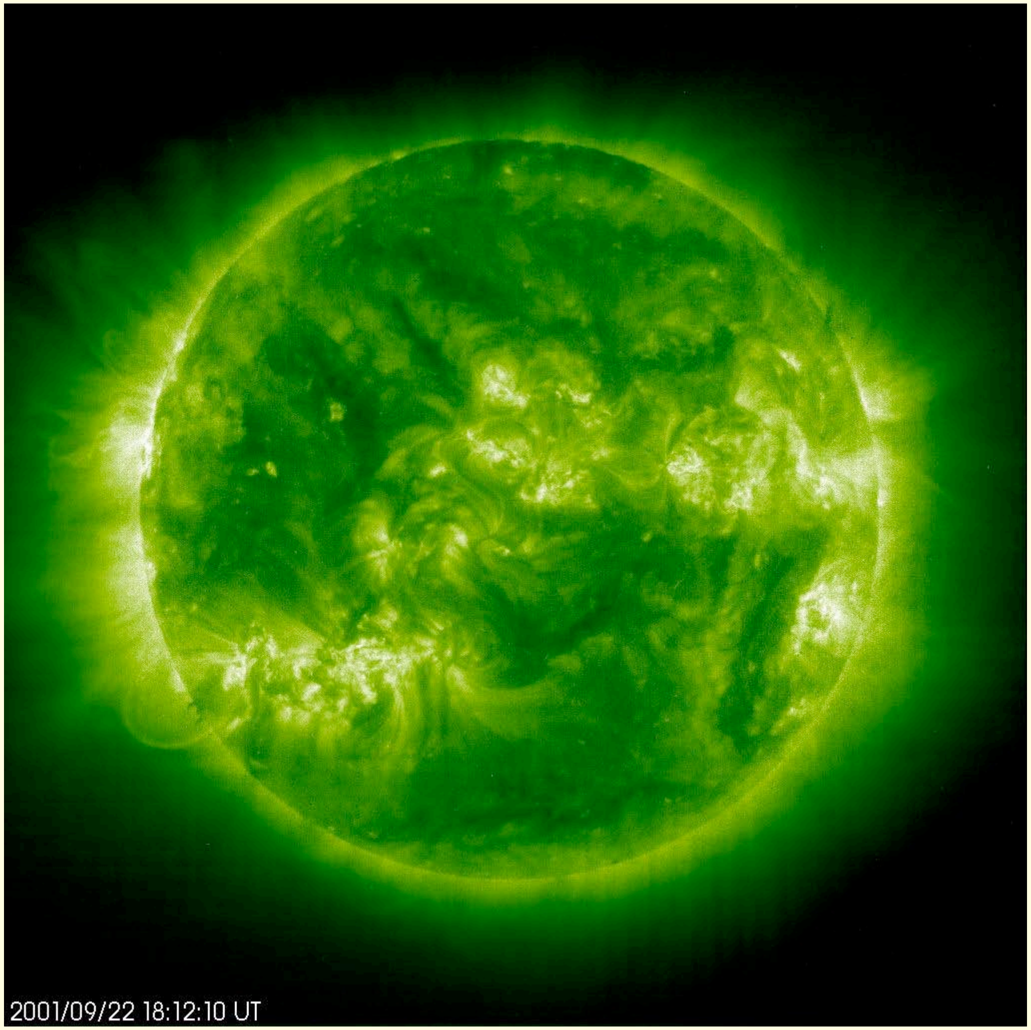
Termination shock crossed by Voyager, but no increase in CRs!

There are things we do not understand.



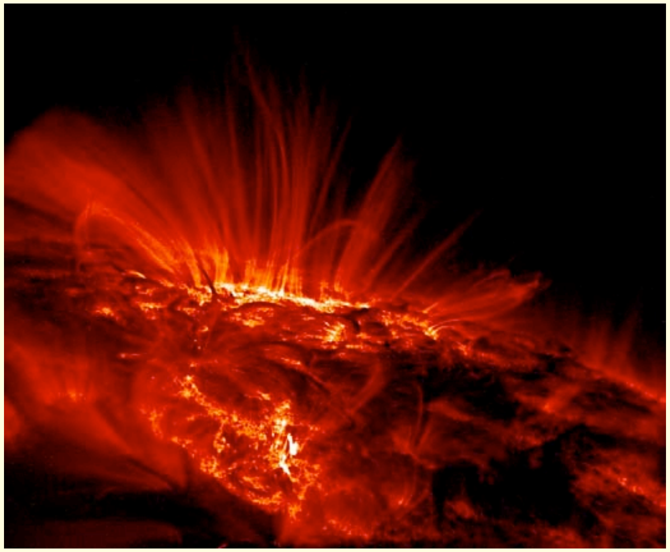
# Now for the Sun

1) Close to home
2) Produces bona fide CRs
3) Can see their effect on the Sun
4) Can detect them directly on Earth
5) Just can't go there, although we can see what is happening.



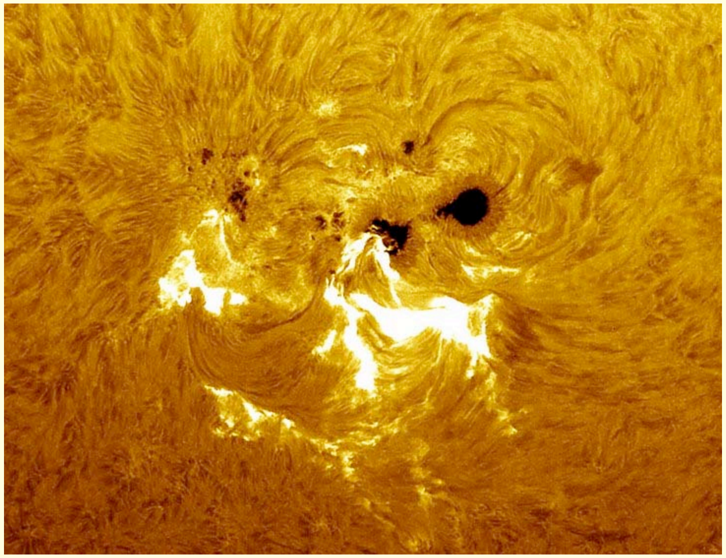

It is difficult to hide the activity

# We can see what is going on. You can't do this with AGNs.

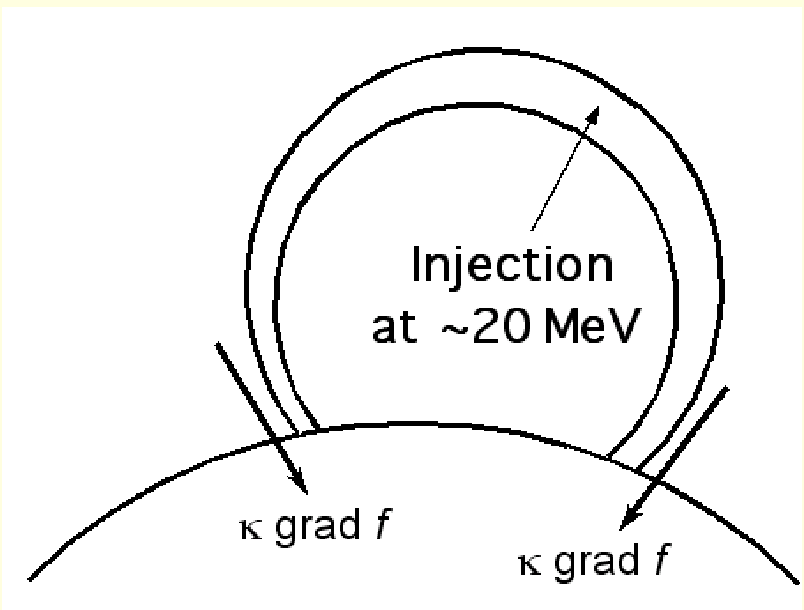


Ultraviolet structure (TRACE)

Optical



# Model for trapping and acceleration




- Impulsively inject a monoenergetic particle distribution.
- Follow coupled space-momentum (acceleration) diffusion.
- Compute $\kappa\nabla f$ at both ends.

- Protons:
  - We have plenty of information, perhaps too much.

Narrow nuclear lines

Broad nuclear lines

Neutrons at 1 AU

Pions

Positron emitters

Bremsstrahlung from the decay of charged pions

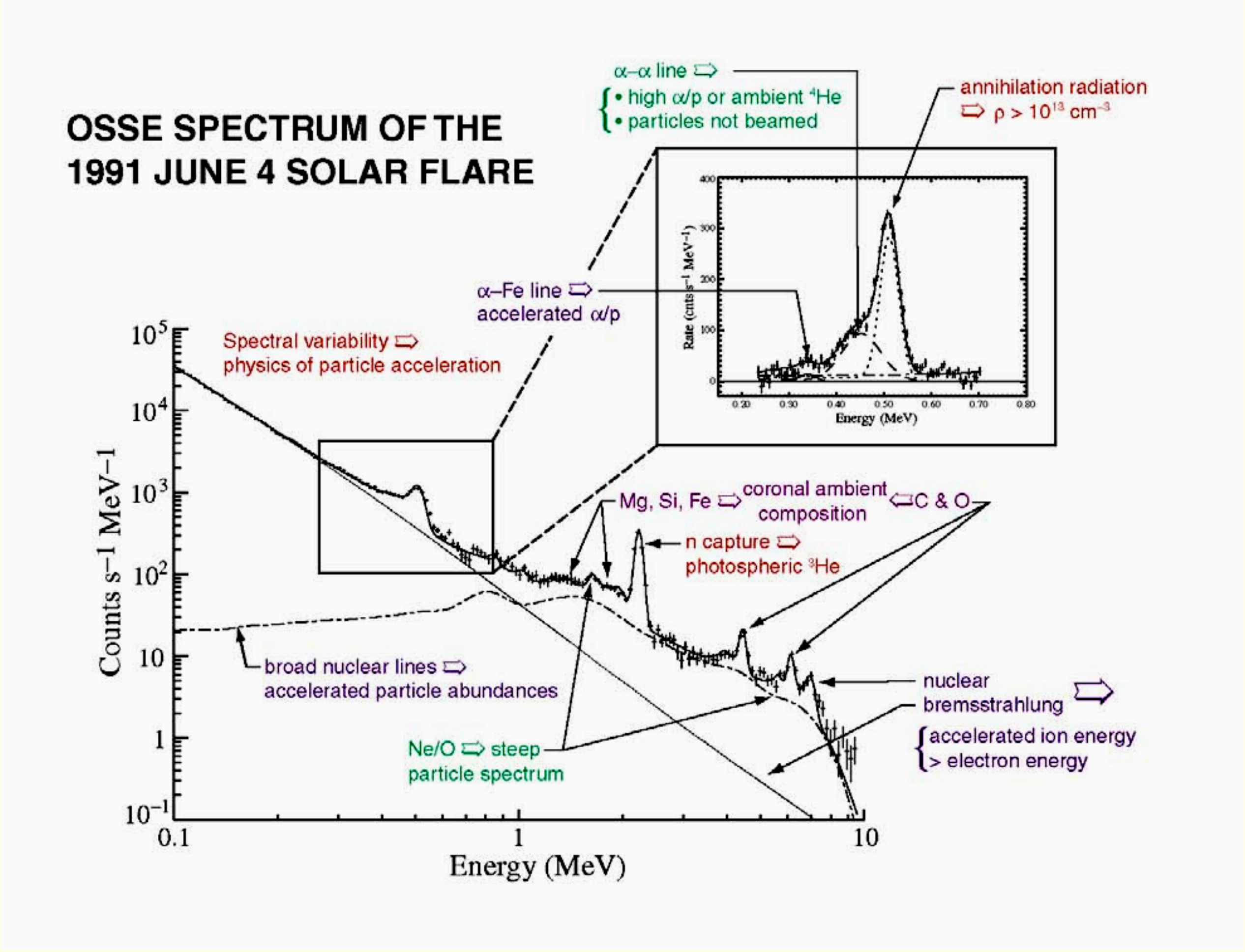
Deuterium formation line

Proton capture lines

Broadened $\alpha$-$\alpha$ line

High FIP lines and Low FIP lines

# If we measure the $\gamma$ rays produced what do we end up with?

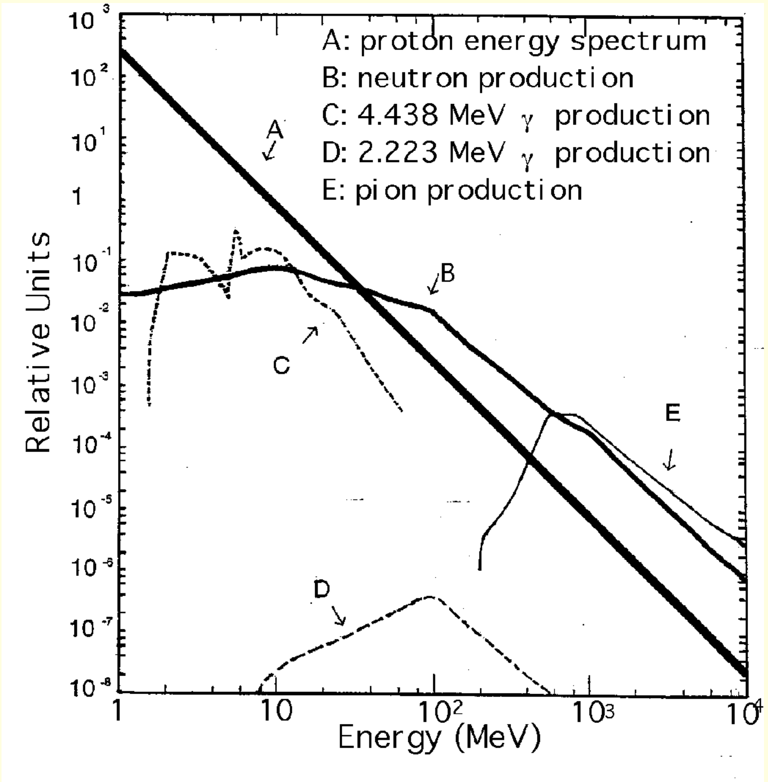


# High-E Reaction Channels

However, $\gamma$ rays do not give the full picture.

✔They collapse the projectile identity and energy into a single monochromatic emission.

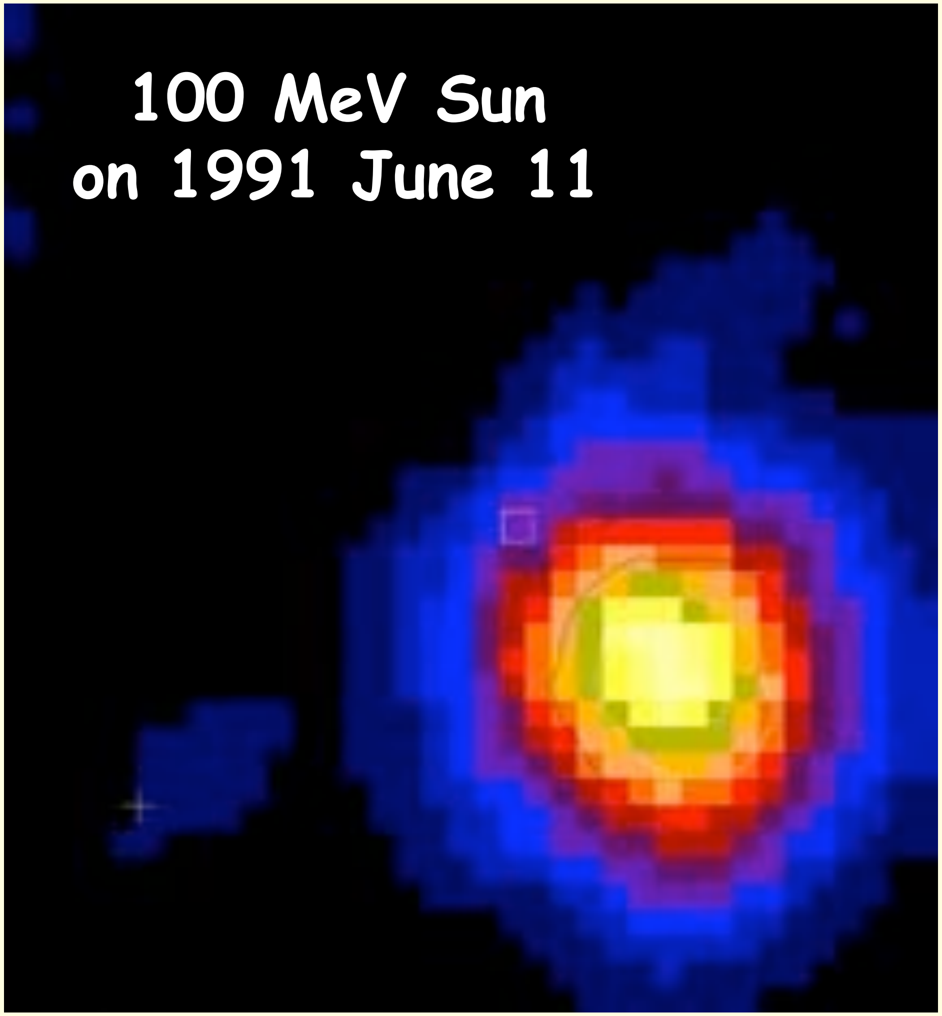
✔They also provide only a limited coverage of the ion spectrum.




$^{12}C(p,p')^{12}C^*$

$^{16}O(p;p',\alpha)^{12}C^*$

→ 4.443 MeV $\gamma$



(Kanbach, priv. comm.)

# Prolonged $\gamma$-ray Emission

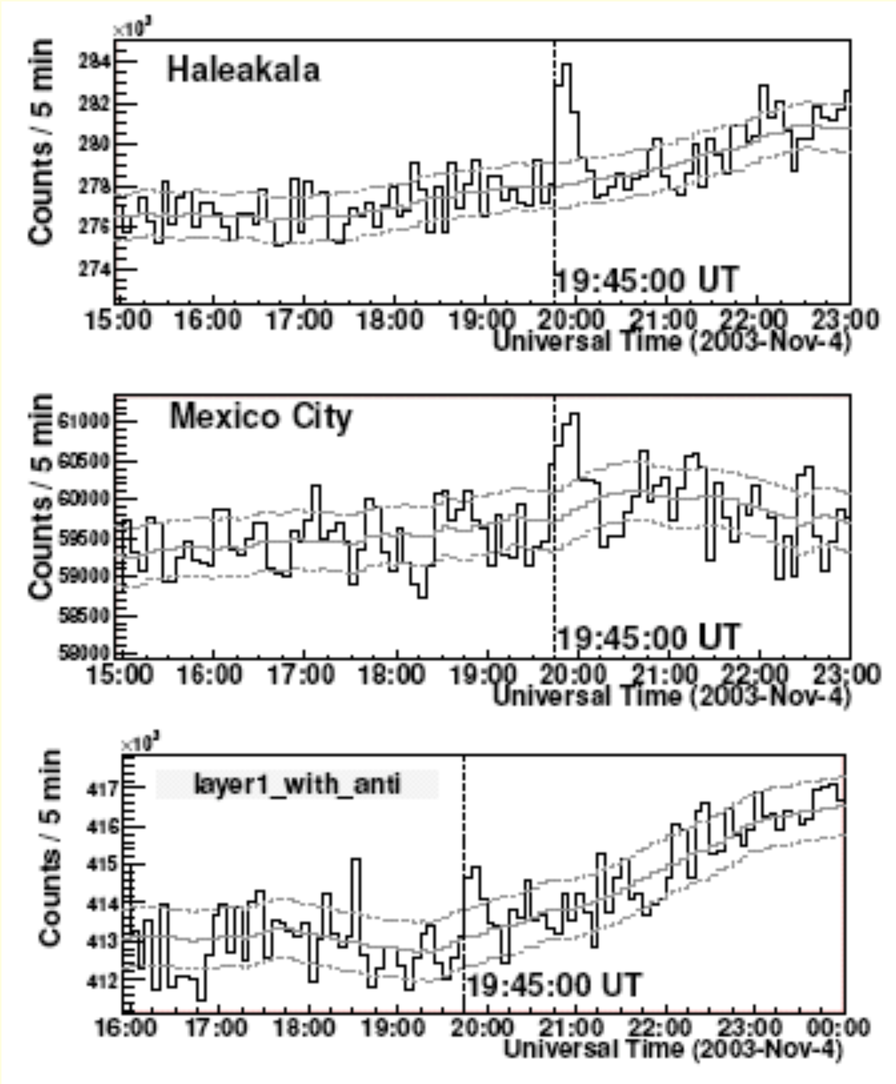
- Steady >100 MeV (pion decay) emission, **hours** after impulsive phase
- Other examples:
  - June 1, 4, 6, 9, 15

(all from same region)

# 4 November 2003

An even harder spectrum of $E^{-4}$ measured later with $10^{27}$ **ergs** in neutrons (>30 MeV),implying $10^{30}$ **ergs in protons** with $E^{-5}$ spectrum.

**These energies approach the total energy for many smaller flares.**

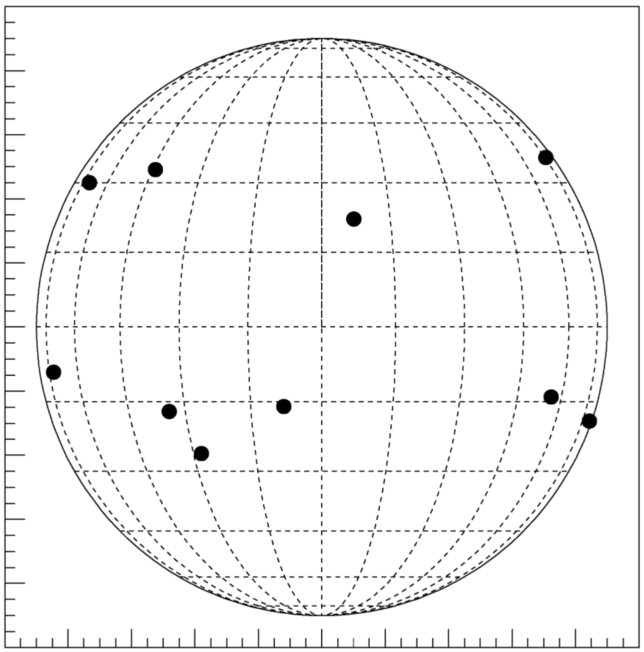



Watanabe et al. SH1.1

# Are these truly neutrons or protons?

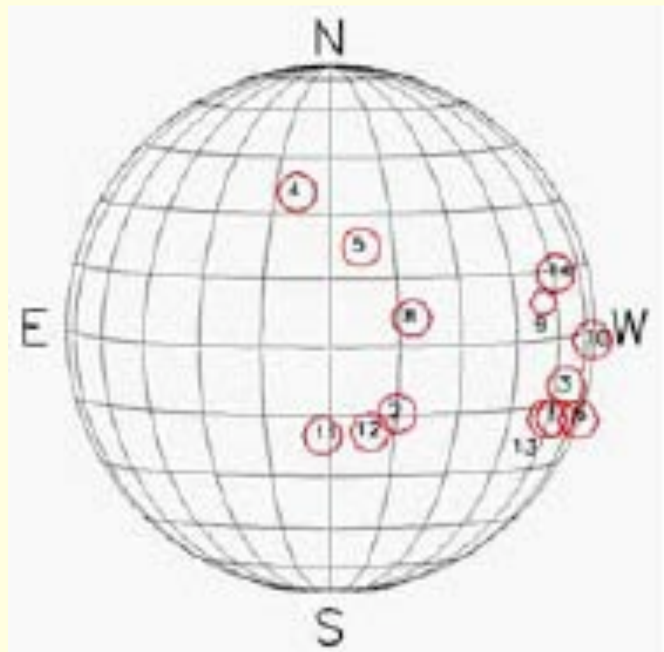
## Both produce neutrons at ground level

Detectable 'neutron' flares



Watanabe et al. SH1.1

Flares with *bona fide* ground level proton signal.



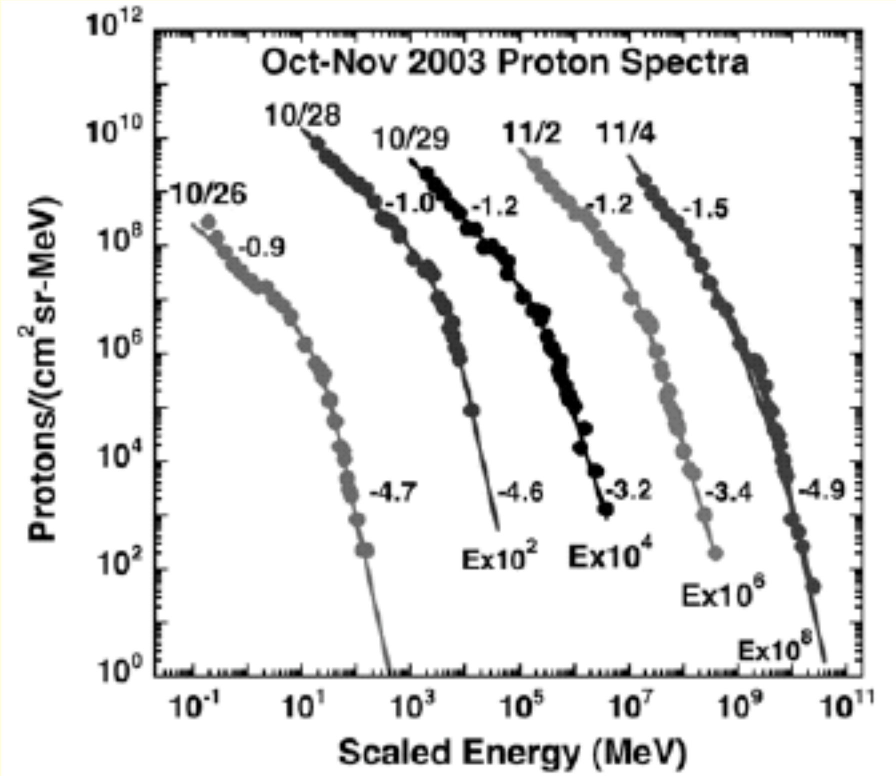

Gopalswamy et al. SH1.4

# Proton Spectra

Typical Broken power law

'Saturation' spectrum at low energy

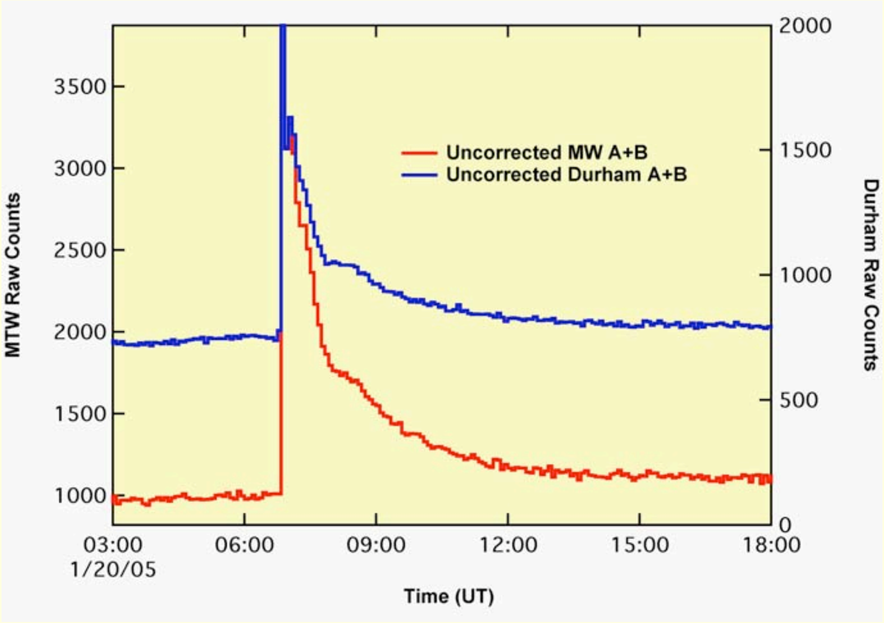
Ions possess **1-15%** of the CME and its shock that produced the event, with **~70%** of energy in protons. (Mewaldt et al. SH1.3)



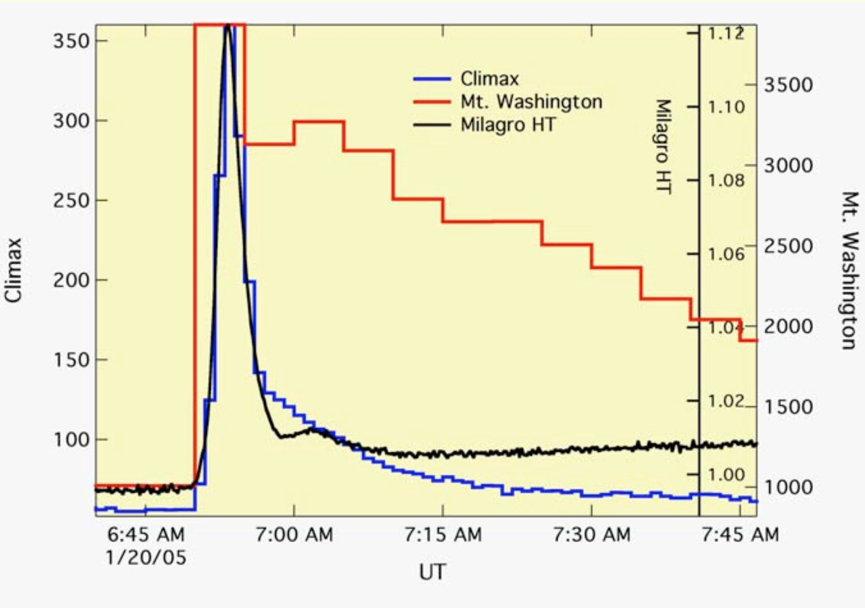

Mewaldt et al. SH1.2

# 2005 January 20

Ratio between MW and Durham indicates *p*$^{-6.5}$ spectrum.

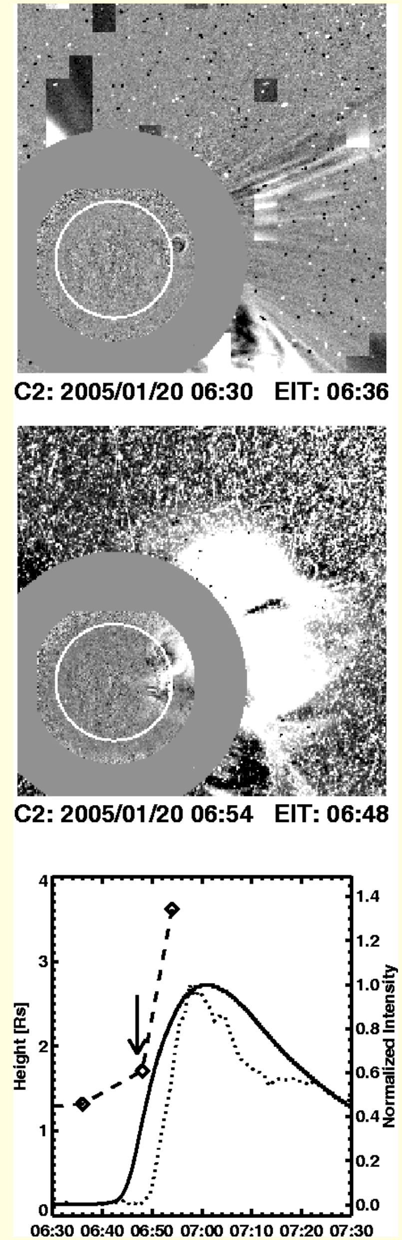



Rise time and initial decay in both Climax and *Milagro* are identical.



Very rapid CME. Speed estimate of 3500 km-$s^{-1}$.

Necessary to produce accelerating shock close to Sun.




Gopalswamy et al. 2005

# Where was the 5 GV proton acceleration and release?

| | |
|---|---|
| CME (SXI loops) liftoff time | 0633 UT |
| CME speed (Gopalswamy et al. 05) | 3500 km-s$^{-1}$ |
| Solar Wind Speed (Farrugia, priv. comm.) | ~560 km-s$^{-1}$ |
| Pitch angle cone half angle | $\leq 20°$ |
| *Milagro* GLE onset | 0651.2 UT |

⇨ ~2.3-2.7 $R_s$

# So, what do we learn?

- We can study processes that produce serious cosmic rays.
- We are close enough to constrain and model these processes based on what we see.  (Solar theory is not for wimps.)
- We always see new things that stimulate new thinking—that's why we do this.

# So, what do we need in future?

γ ray measurements:

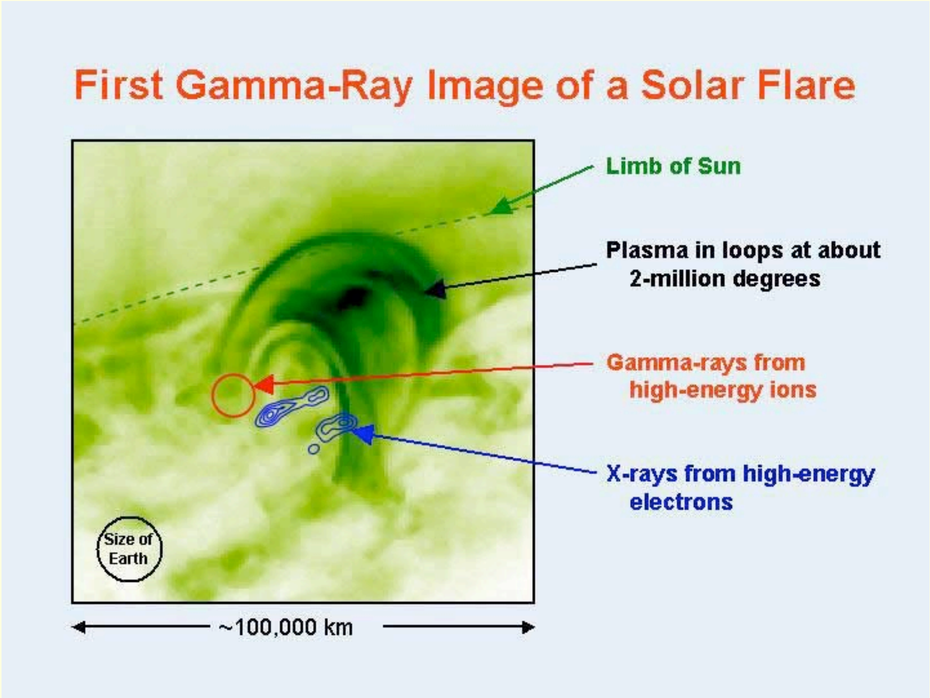
✓good E resolution from 0.2 to 100 MeV and a diagonal response,

✓Imaging like RHESSI

Neutrons:

✓At 1 AU 15 to 200 MeV spectroscopy

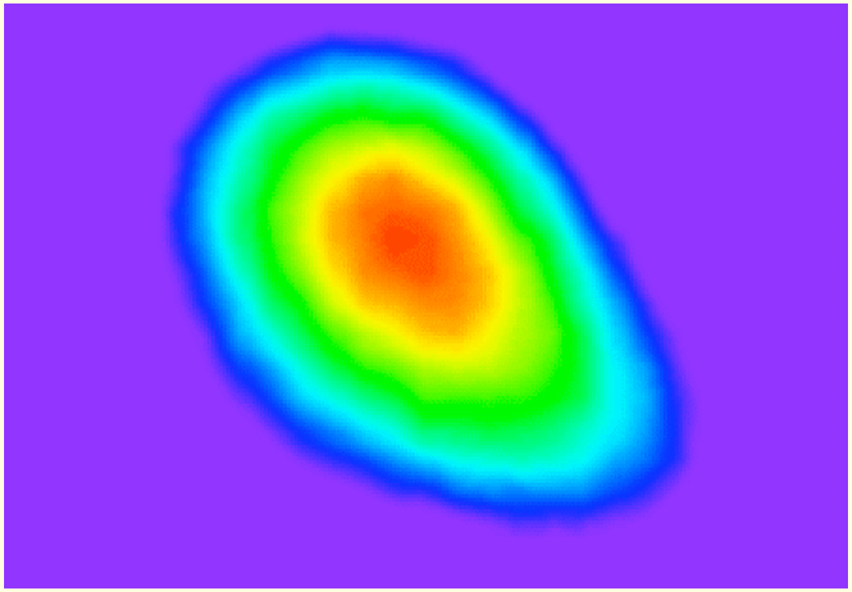
✓At <0.5 AU 1 to 15 MeV spectroscopy



# New Windows

The neutron Sun

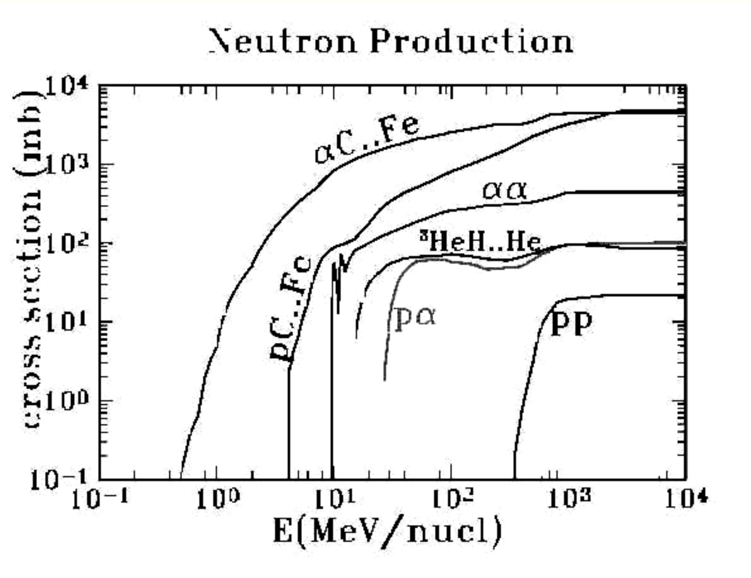
"Thou comst in such a questionable shape."
(Hamlet)



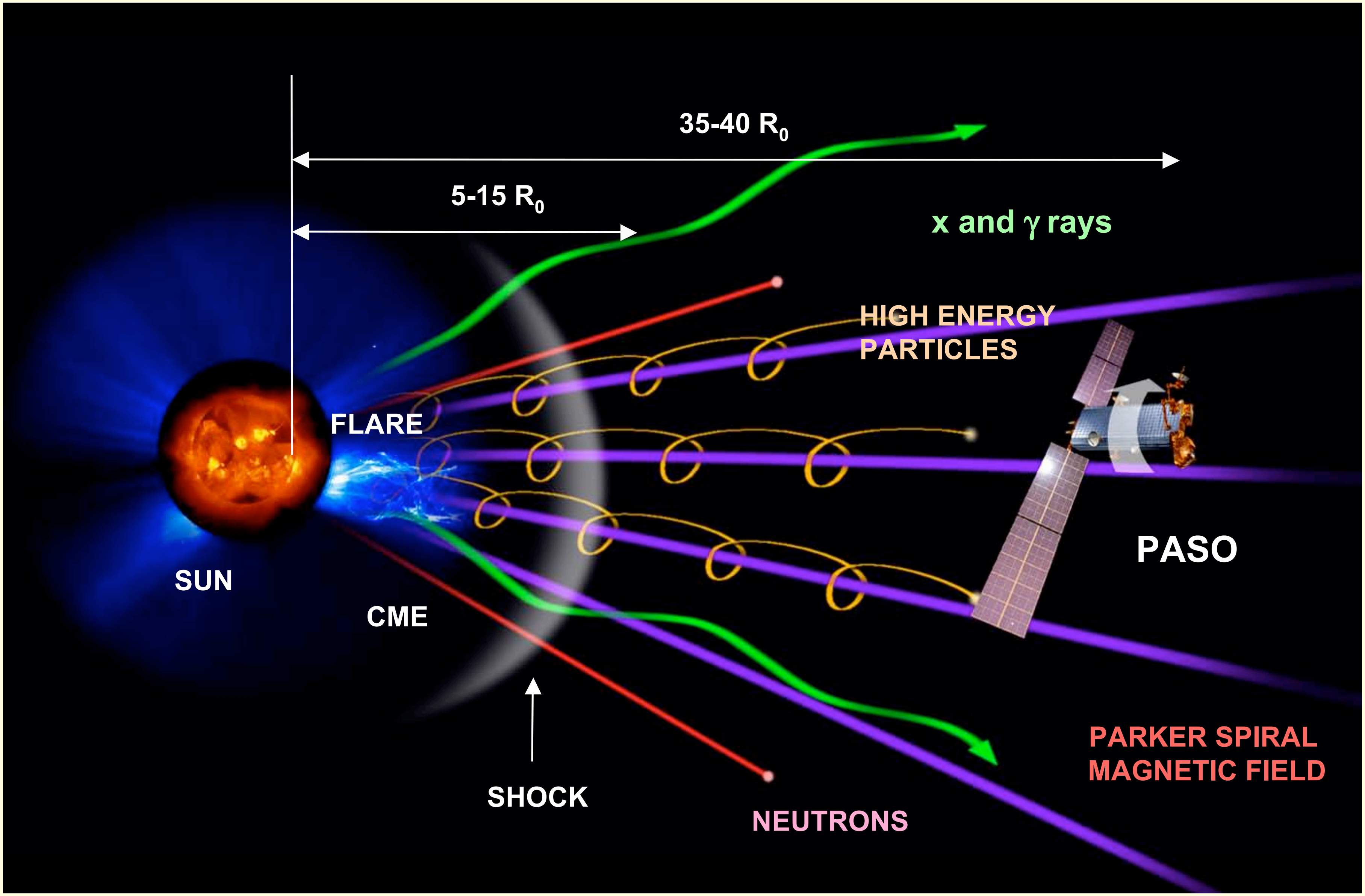
# Resolving the spectrum/composition problem with neutrons

Need additional diagnostics and measures to constrain the combinations of spectrum and composition.

The answer may be in measuring gammas and neutrons – neutrons at all energies.




Would provide new sensitivity above 50 MeV and independent measure of 'heavy' constituent.



35-40 $R_0$
5-15 $R_0$
x and γ rays
HIGH ENERGY
PARTICLES
FLARE
PASO
SUN
CME
SHOCK
NEUTRONS
PARKER SPIRAL
MAGNETIC FIELD