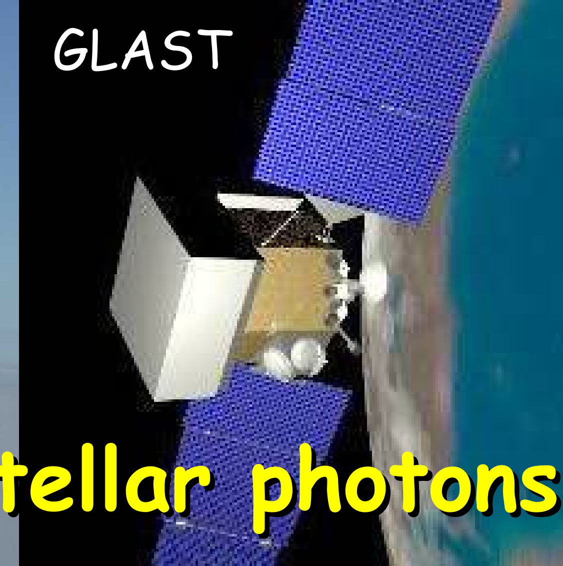
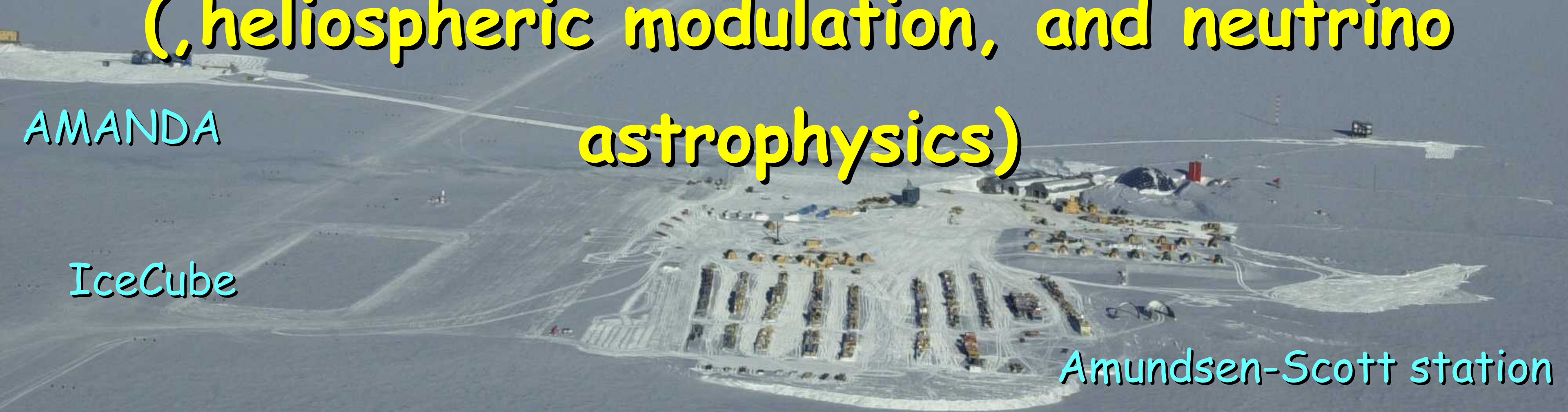


Inverse Compton scattering on stellar photons (,heliospheric modulation, and neutrino astrophysics)



Troy A. Porter

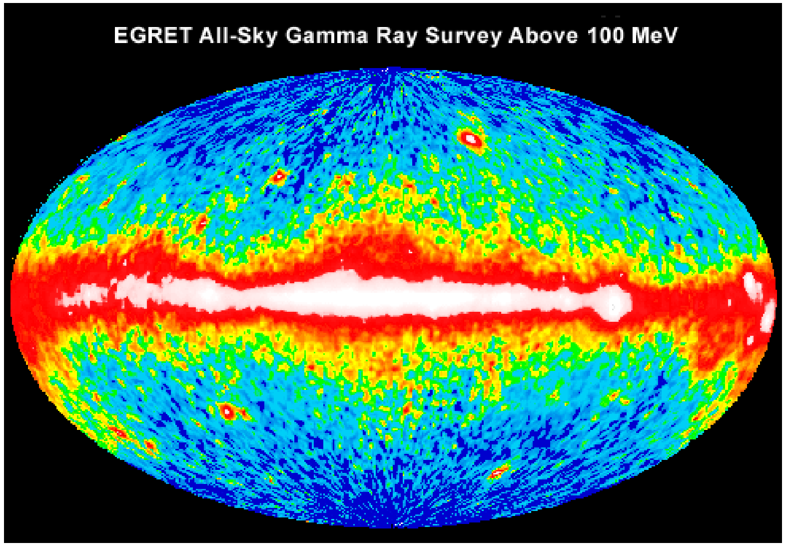
with

Igor V. Moskalenko and Seth W. Digel

Diffuse γ-ray Emission

Galactic: CR interactions in ISM (π^0, brem) and with ISRF (IC) - interesting

Extragalactic (EGRB): unresolved sources, true diffuse emission (DM?) - very interesting



After extracting foregrounds can get at 'background'

Galactic: GalProp + other approaches

What about other 'celestial' sources ?

Today's talk

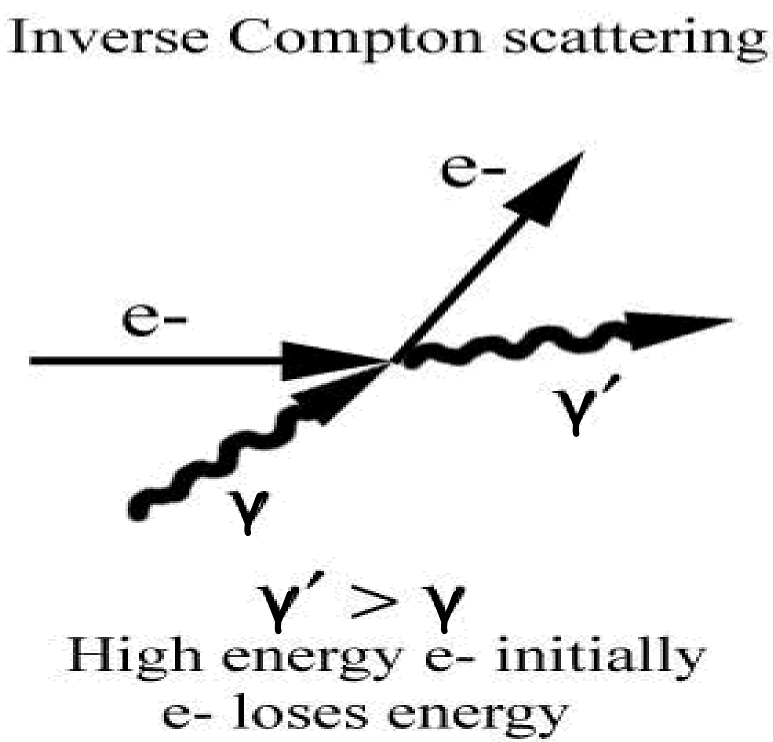
Outline

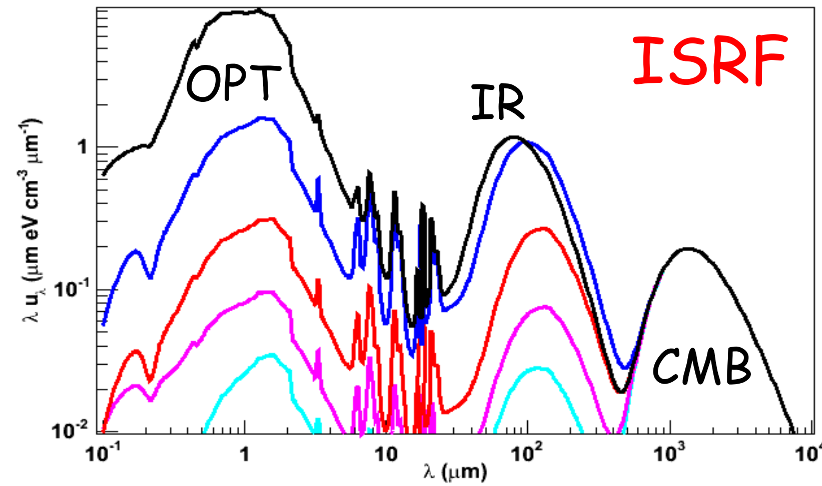
- Inverse Compton scattering in Galaxy
- Study of 'local' heliosphere
  - Foreground for EGRB
  - Using GLAST as a solar modulation probe
  - Implications for other studies (gammas and neutrinos from Sun, etc.)
- Other stars
  - Electron spectrum in ISM?

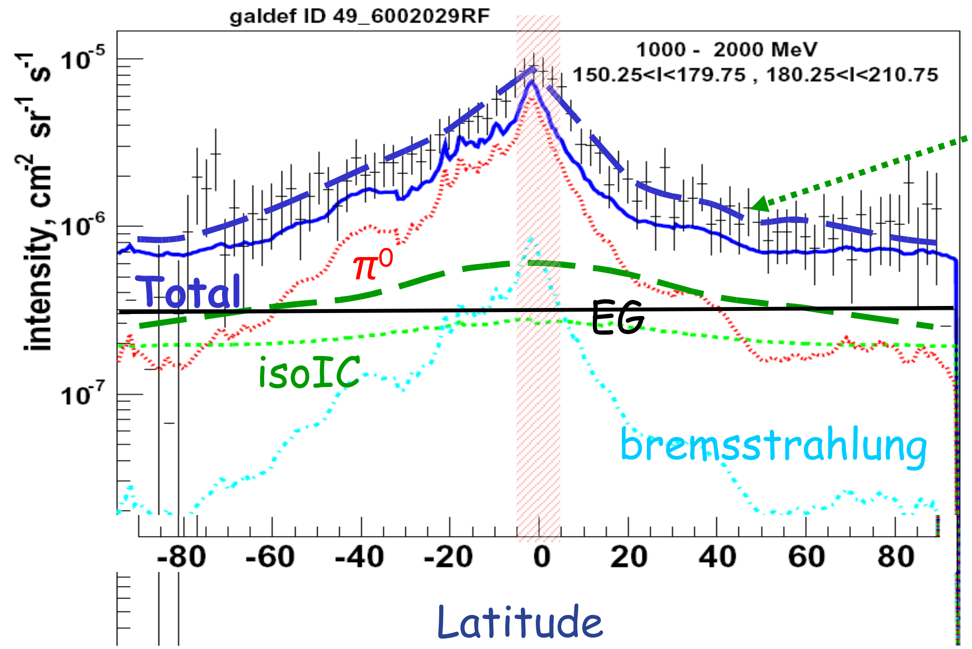
Inverse Compton Scattering

Most familiar: diffuse Galactic emission

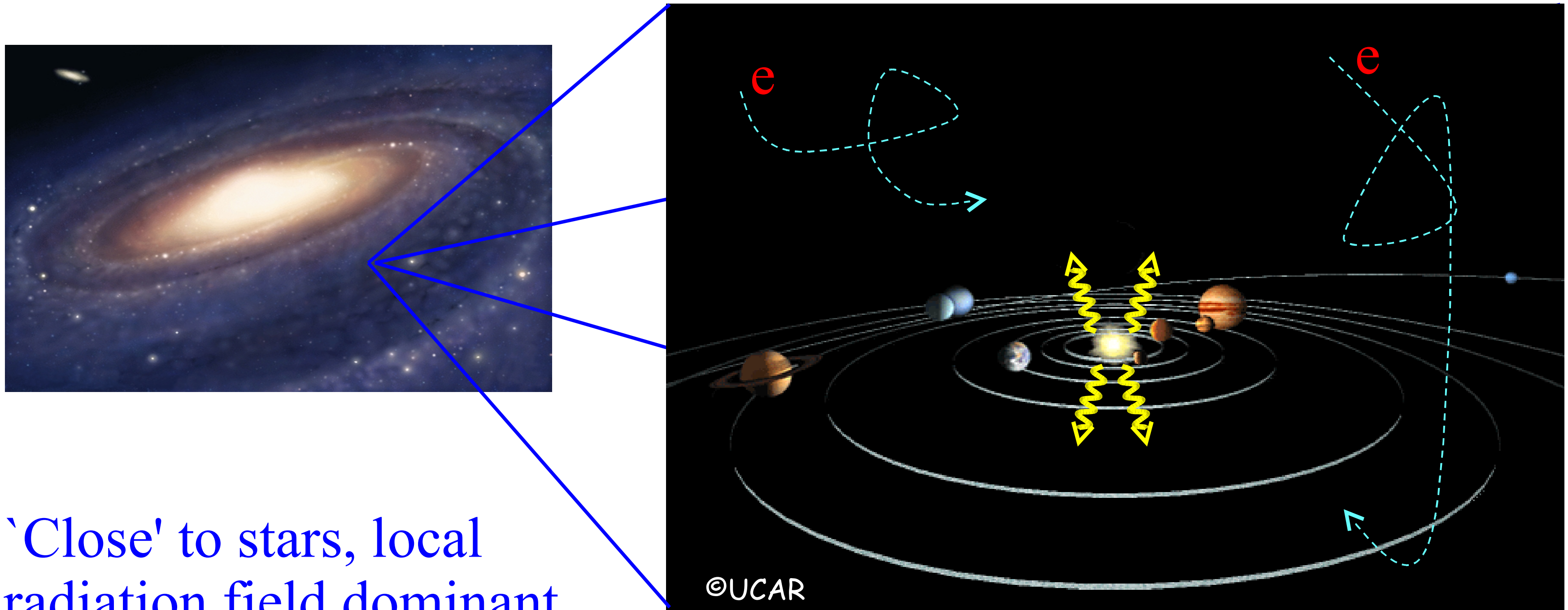
Large scale Galactic ISRF + CR electron distribution







Inverse Compton Scattering Continued



`Close' to stars, local radiation field dominant

Star nearby called the 'Sun'

- Solar photons stream outward from Sun - anisotropic
- CR electrons distributed throughout heliosphere - isotropic

Anisotropic ICS

Intensity:

$$\frac{dF_\gamma}{d\epsilon_2} = \frac{1}{4}\int_L dx\, \frac{R_\odot^2}{r^2} \int d\gamma_e \frac{dJ_e(r,\gamma_e)}{d\gamma_e} \times \int d\epsilon_1 \frac{dn_{bb}(\epsilon_1, T_\odot)}{d\epsilon_1} \frac{dR(\gamma_e,\epsilon_1)}{d\epsilon_2}$$

$E_\gamma/m_e c^2 = \varepsilon_2$, $\varepsilon_\nu/m_e c^2 = \varepsilon_1$

Head-on collision:

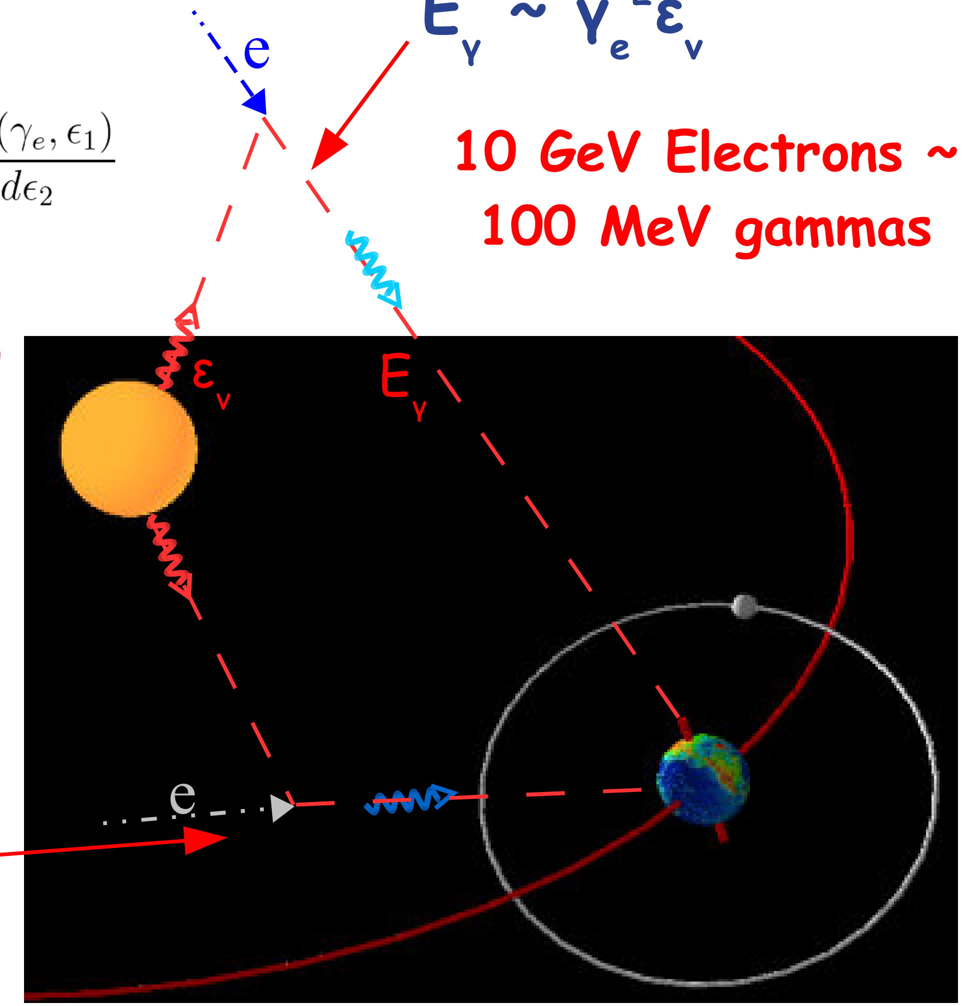
$E_\gamma \sim \gamma_e^2 \varepsilon_\nu$

10 GeV Electrons ~ 100 MeV gammas

Target photons distributed radially outward from Sun:

$\rho \sim n_{bb}(R_{Sun}/r)^2$

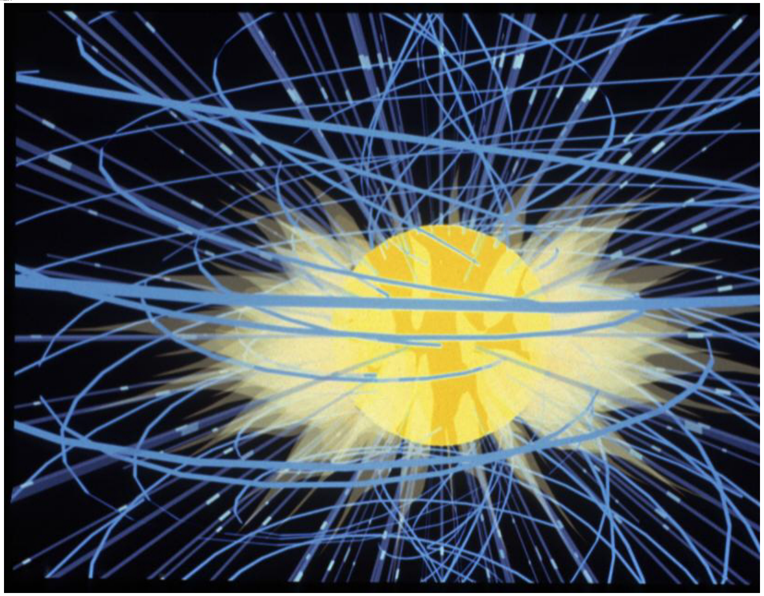
$T_{Sun} \sim 6000$ K BB

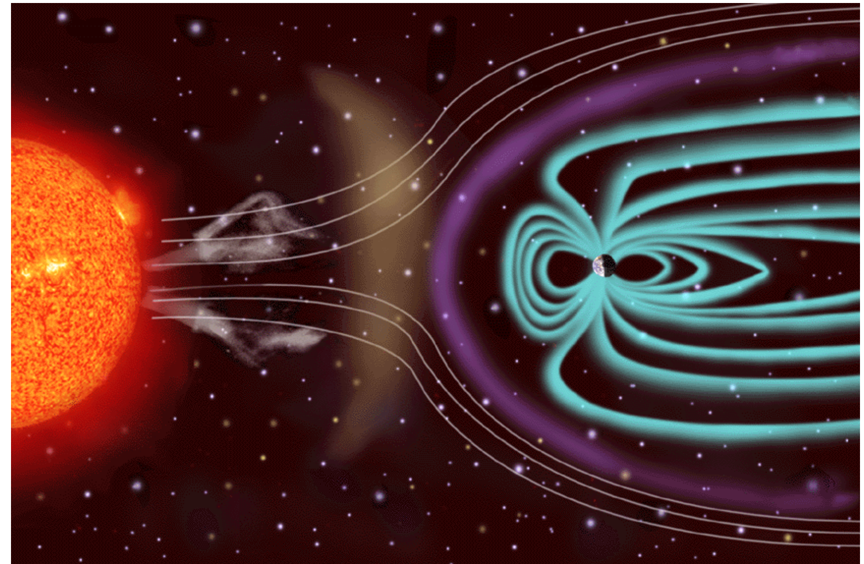


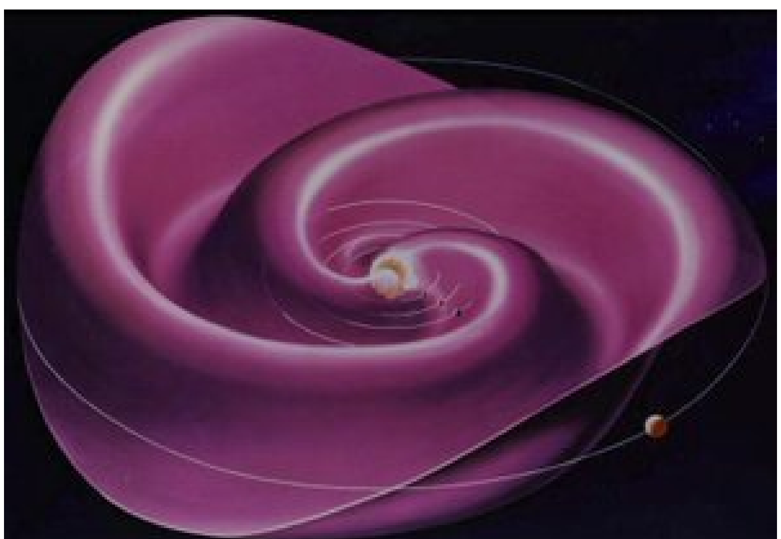
Following collision:

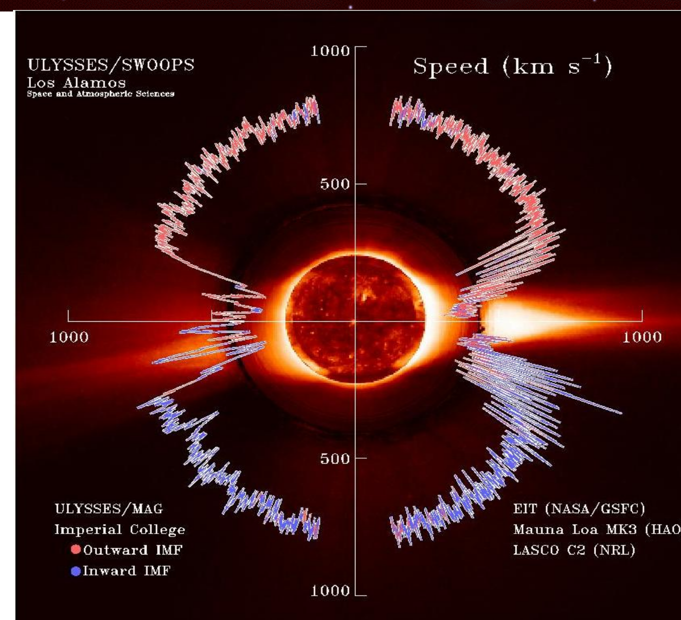
$E_\gamma \sim (1/\gamma_e)\gamma_e \varepsilon_\nu \sim \varepsilon_\nu$

Interplanetary B-field and Solar Wind

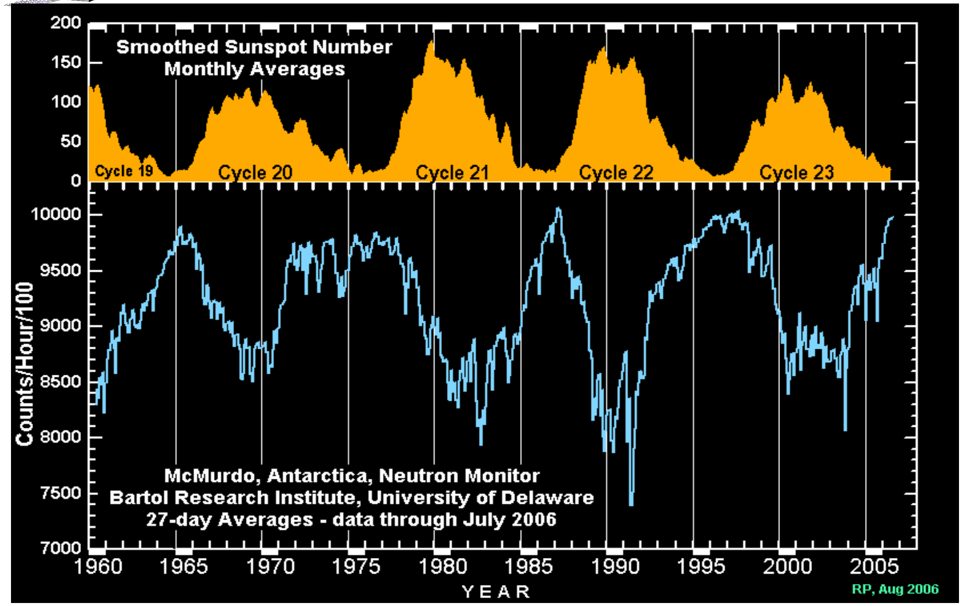




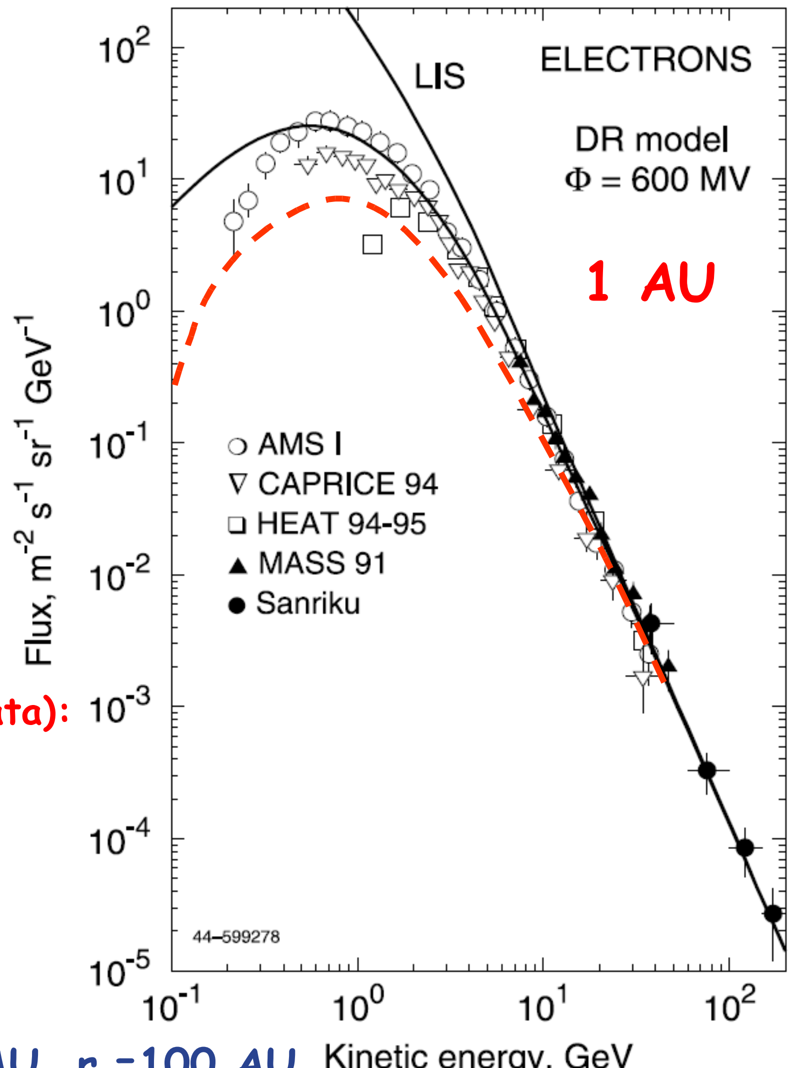




Local Electron Spectrum and Heliospheric Modulation



Solar modulation refers to the influence the Sun exerts upon the intensity of galactic cosmic rays. As solar activity rises (top panel), the count rate recorded by a neutron monitor in McMurdo Antarctica decreases (bottom panel).



Force-field approximation (+Voyager & Pioneer data):

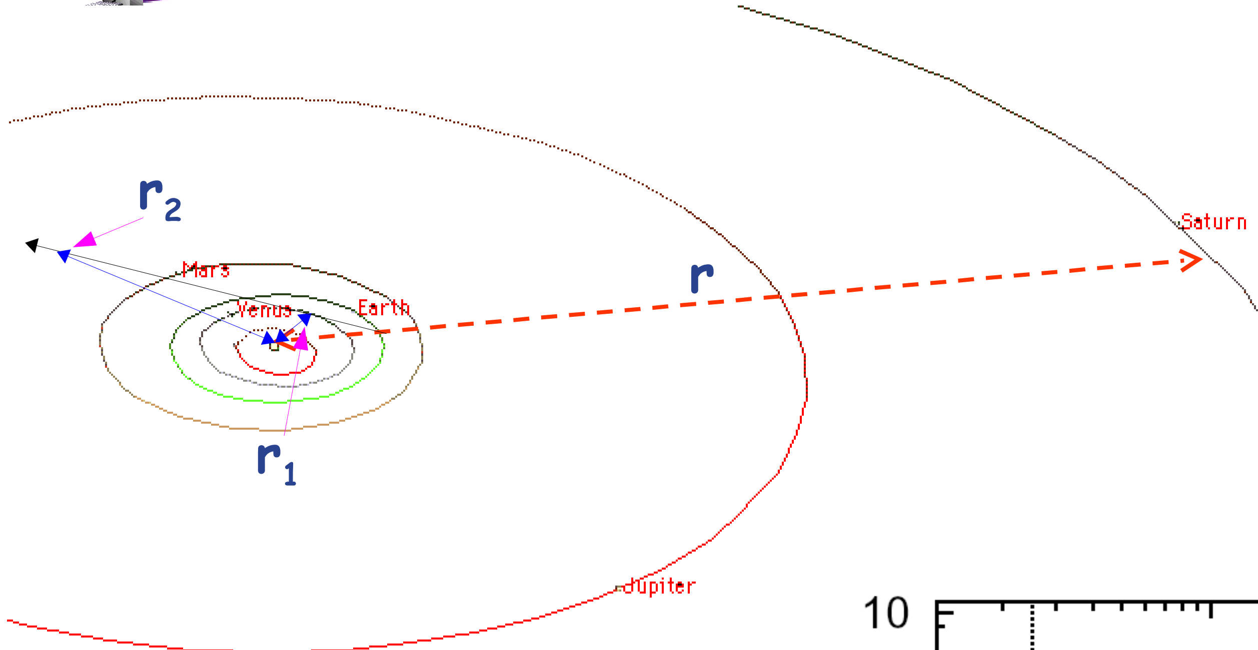
$$\Phi(r,t) = \int_r^{r_b(t)} dx \, \frac{V(x,t)}{3\kappa_1(x,t)} \begin{cases} \kappa_1 \propto r^{\delta}, \text{ and } V = const, \\ \Phi(r,t) \propto r^{-\delta+1} - r_b^{-\delta+1}. \end{cases}$$

$$\Phi_1(r) = \frac{\Phi_0}{1.88} \begin{cases} r^{-0.4} - r_b^{-0.4}, & r > r_0, \\ 0.24 + 8(r^{-0.1} - r_0^{-0.1}), & r < r_0, \end{cases}$$

$$\Phi_2(r) = \Phi_0(r^{-0.1} - r_b^{-0.1})/(1 - r_b^{-0.1})$$

r_0=10 AU, r_b=100 AU

Probing the Electron Spectrum in the Heliosphere

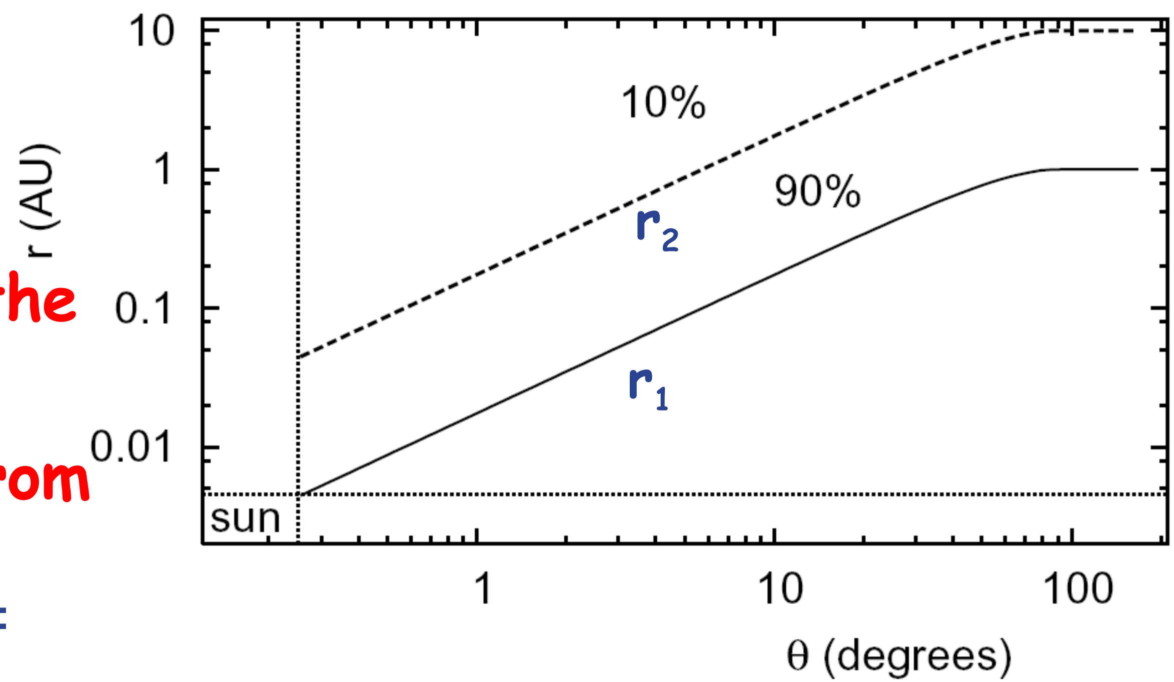


$Flux_{IC} \sim 1/r$

r_1 (AU) = sinθ, θ<90°

r_1 (AU) = 1, θ>90°

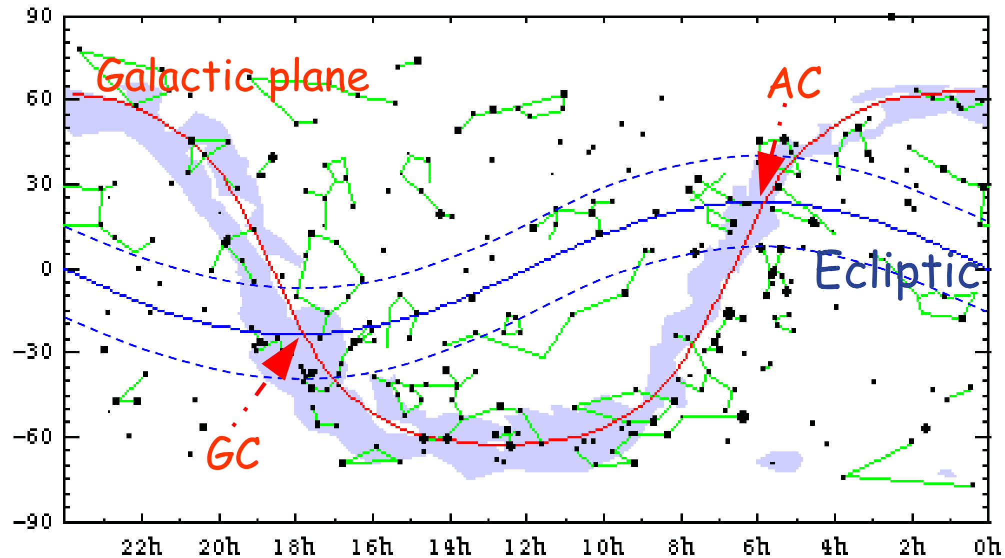
$r_2 = 10 r_1$

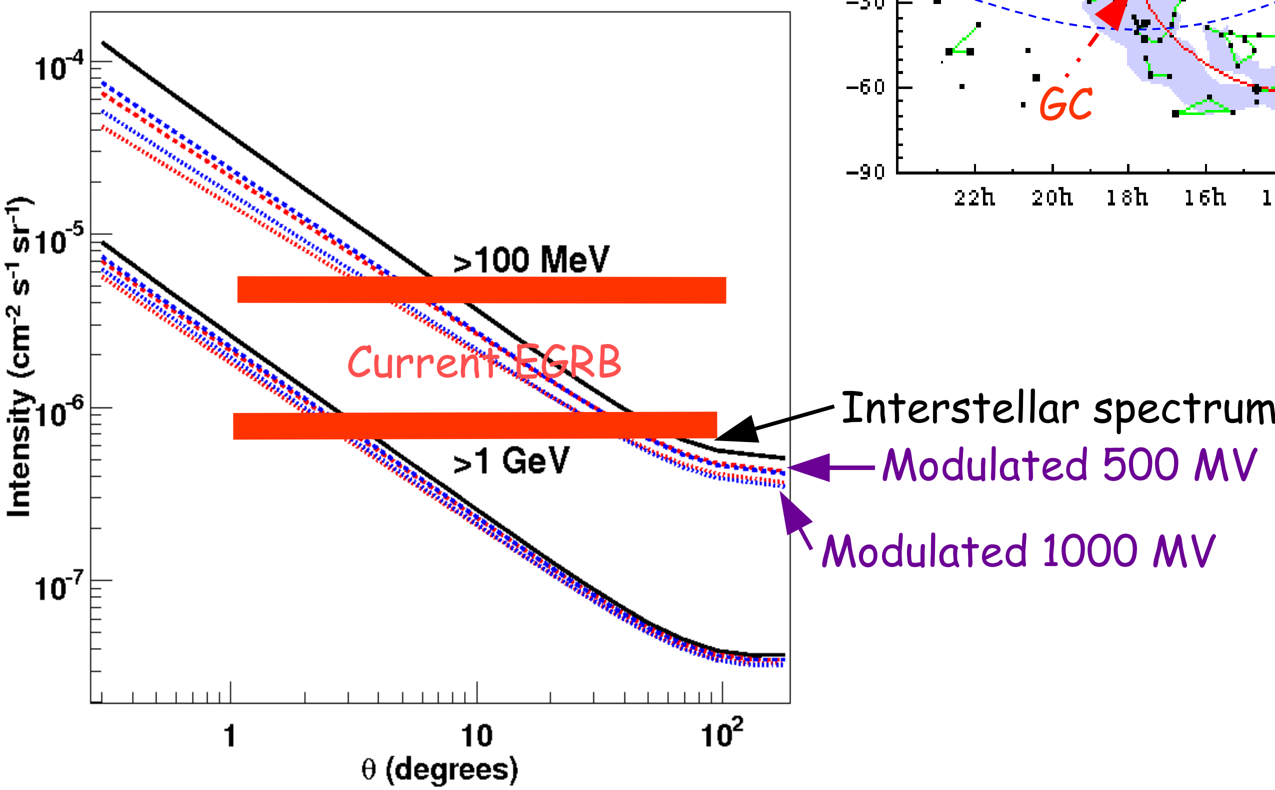


Looking in different directions can probe the electron spectrum at different distances from the Sun

The Ecliptic

Averaged over one year, the ecliptic will be seen as a bright stripe on the sky, but the emission comes from all directions

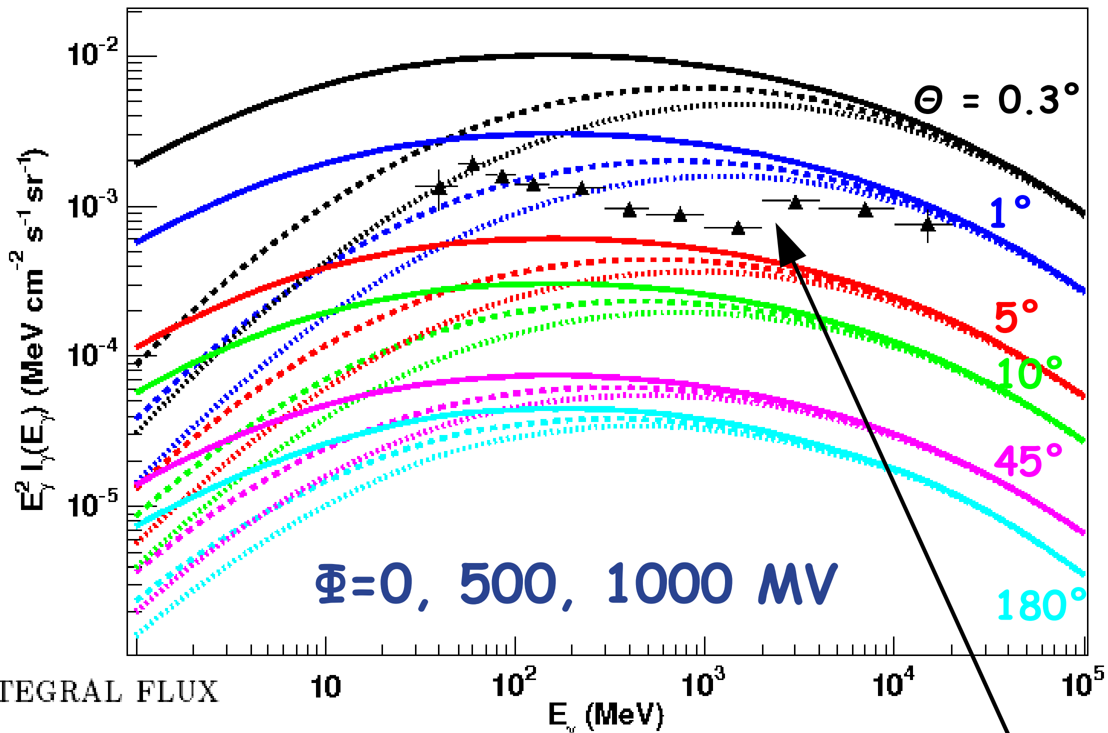




Differential Spectrum

Spectrum < 1 GeV shows variation dependent on modulation level

⇒Variations of γ-ray flux over solar cycle



EGRB from SMR2004

TABLE 1. ALL-SKY AVERAGE INTEGRAL FLUX

E	$\Phi_0 = 0$	500 MV	1000 MV
>10 MeV	5.6	3.4	2.4
>100 MeV	0.69	0.56	0.47
>1 GeV	0.05	0.04	0.04

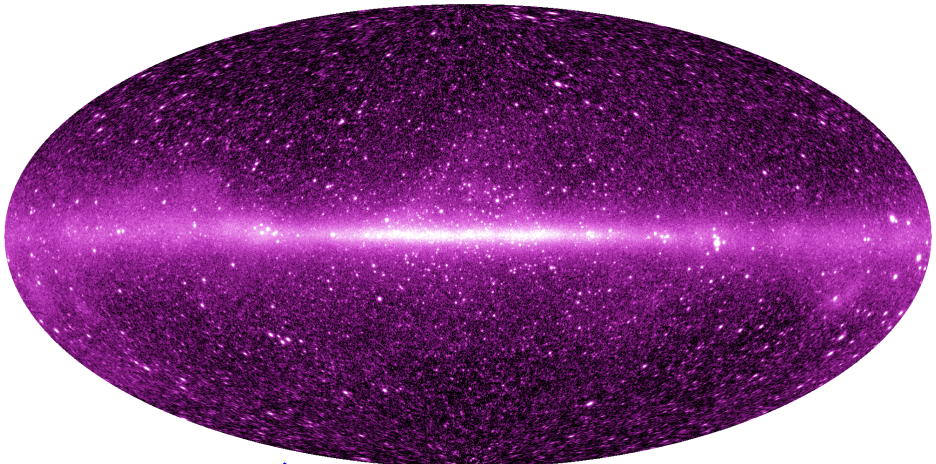
NOTE. — Flux units 10^{-6} cm^{-2} s^{-1} sr^{-1}.

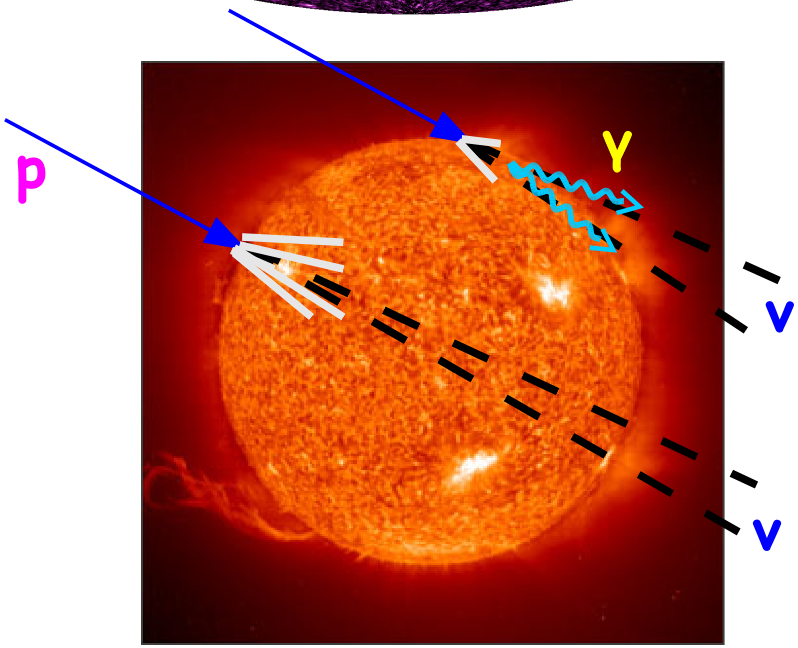
F_{IC}(>100MeV) < 6°~ 2 x 10^{-7} cm^{-2} s^{-1}

EGRET: F(>100MeV) UL = 2 x 10^{-7} cm^{-2} s^{-1}

Why it is interesting

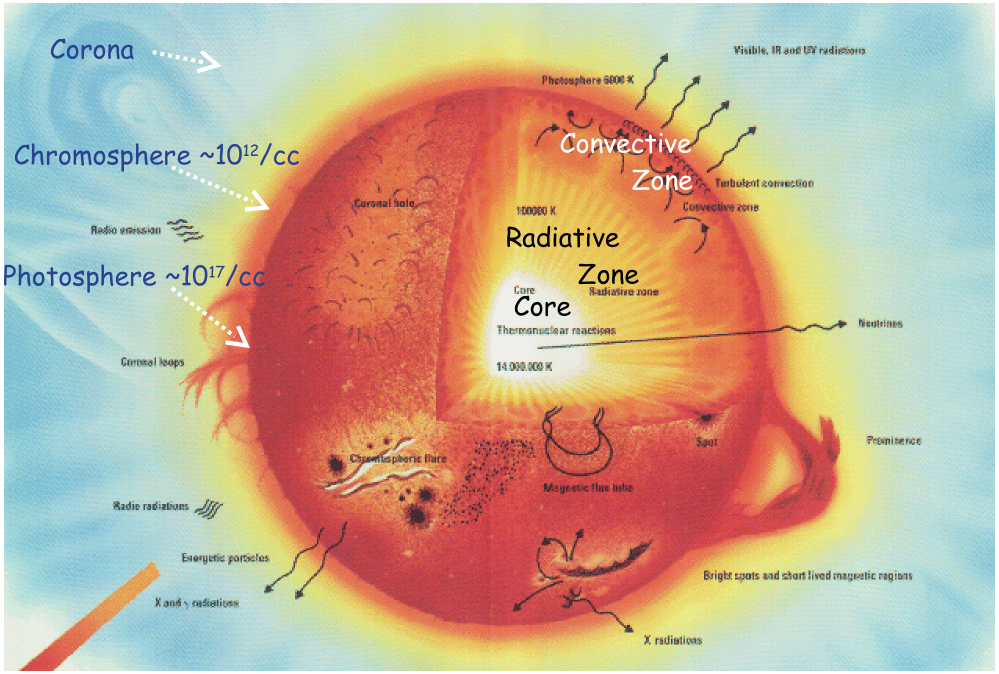
Simulated GLAST skymap >1 GeV





- GLAST will resolve 1000s of blazars, main contributors to the EGRB; thus solar IC becomes more important
- Studies of heliospheric modulation and monitoring of the heliosphere 0-10 AU
- Determination of the CR proton flux near the solar surface:
  - albedo gammas $pp \rightarrow \pi^{\circ} \rightarrow 2\gamma$ $F(>100\ \mathrm{MeV}) \sim 0.5\times10^{-7}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
  - CR cascade development

Solar Atmosphere and Interior

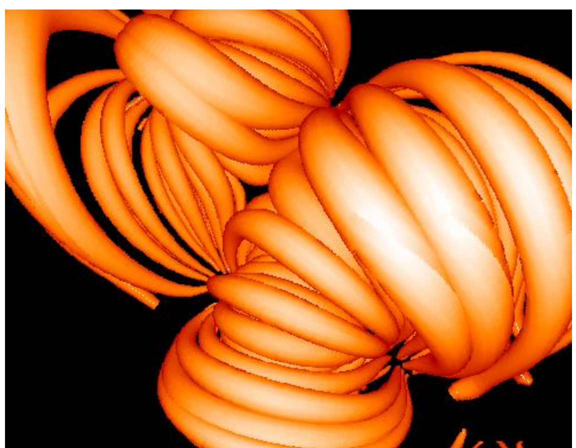


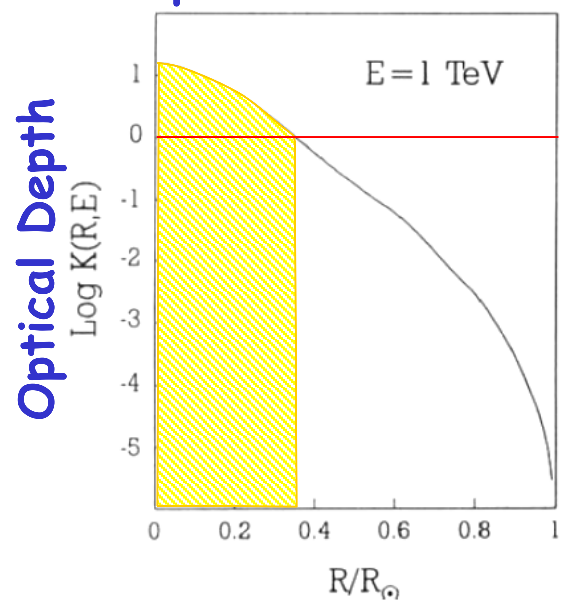
CR cascade development in the solar atmosphere depends on:

- the gas density profile
- underlying B-field structure

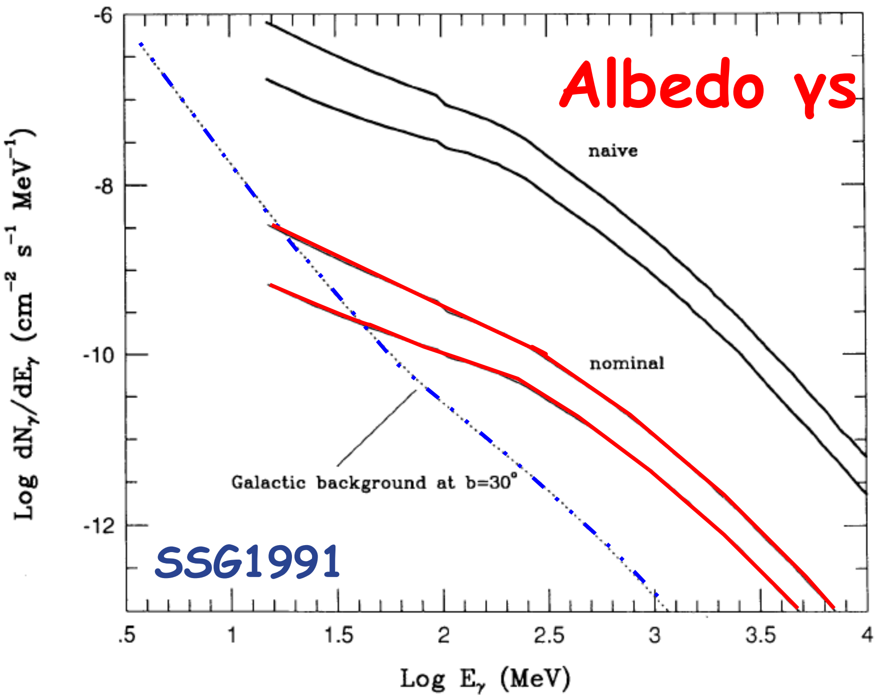
Neutrino flux is affected by absorption in the solar core

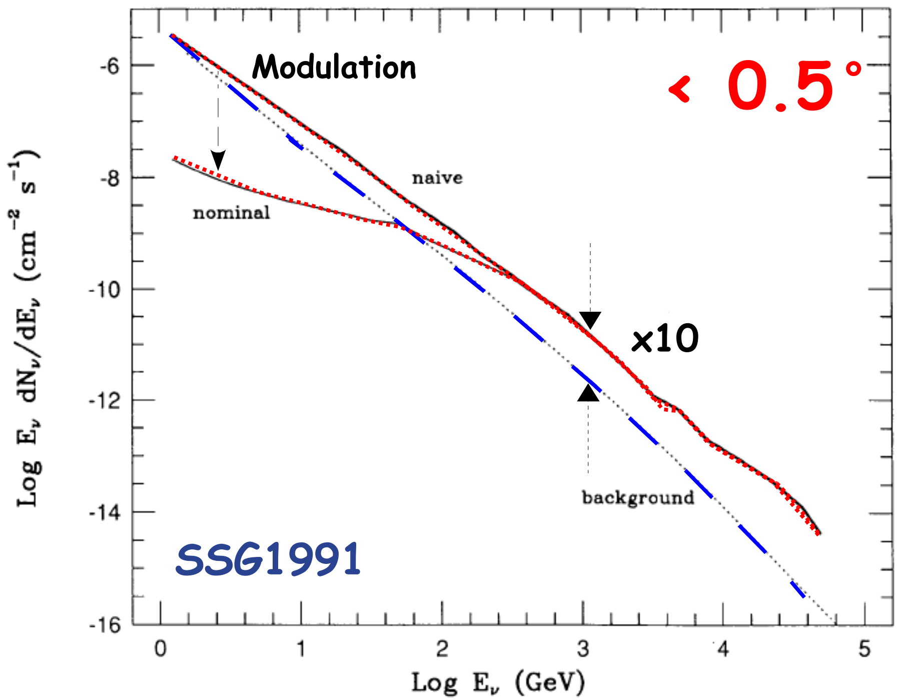
Magnetic flux tubes





Gamma rays and neutrinos from the Sun





$F_\gamma(>100\ \mathrm{MeV}) \sim (0.2\text{-}0.7)\times10^{-7}\ \mathrm{cm^{-2}\ s^{-1}}$

~20 ν/yr (>100 GeV) in a km³ detector

- *Seckel, Stanev, Gaisser 1991, ApJ 382, 652 (γ,ν)*
- *IM, Karakula, Tkatzyk 1991, A&A 248, L5 (ν)*
- *IM, Karakula 1993, J.Phys.G 19, 1399 (ν)*
- *Ingelman, Thunman 1996, PRD 54, 4385 (ν)*

GLAST Perspective

Based on the expected sensitivity of the LAT:

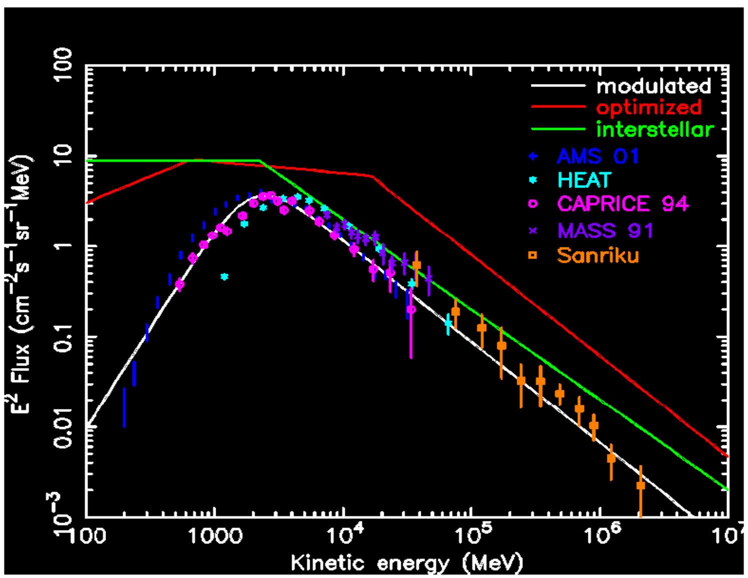
- A source with flux 10^{-7} cm^{-2} s^{-1} and the hardness of the solar IC emission will be detectable on a daily basis when the Sun is not close to the Galactic plane, where the diffuse emission is brightest
  - Sensitive variability studies of the bright core of the IC emission surrounding the Sun should be possible on weekly time scales
- With exposure accumulated over several months, the Sun should be resolved as an extended source and potentially its IC and pion decay components separated spatially

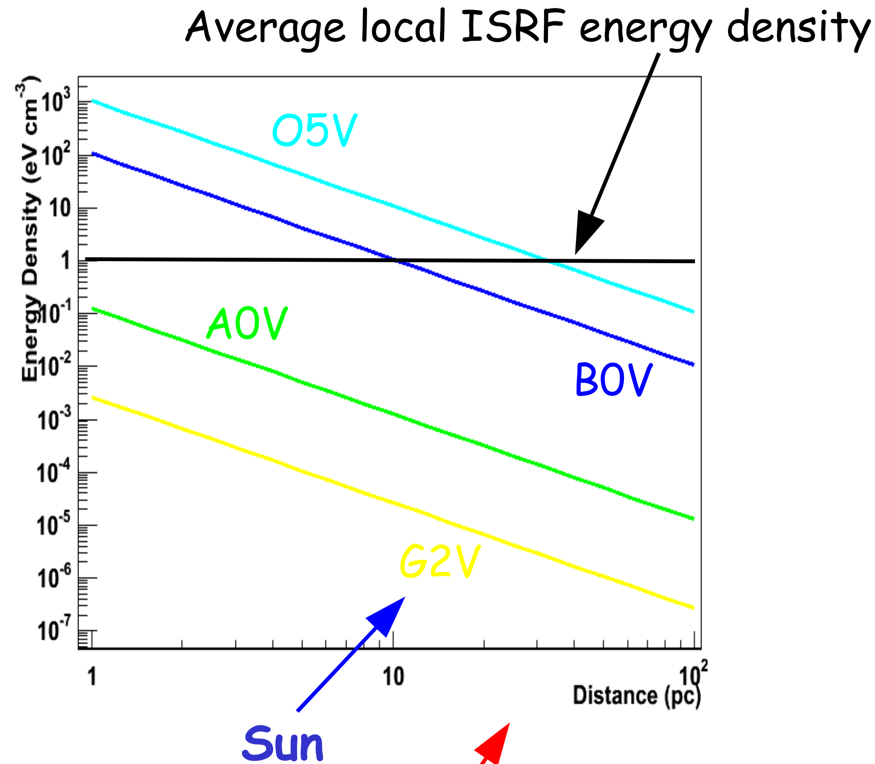
Shameless advertising: astro-ph/0607521

Other Stars

What about other stars?

Look at luminous stars since their radiation field is more extensive



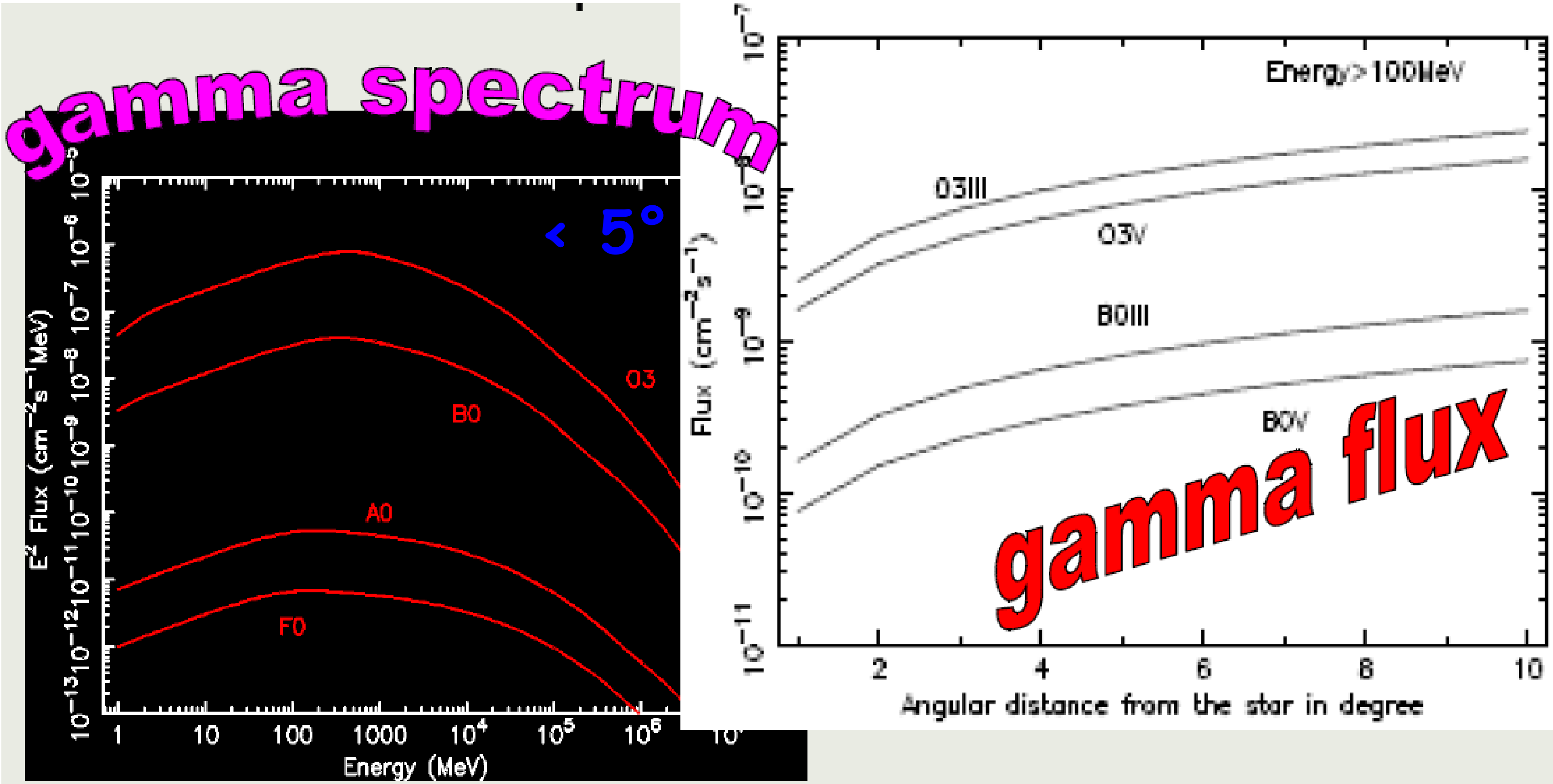


Probe electron spectrum at locations other than 'local'

$L_{IC} \sim rL_{Star}$, $F_{IC} \sim L_{IC}/d^2$, $\theta \sim r/d \Rightarrow F_{IC} \sim L_{Star}\theta/d$

Spectrum and Flux

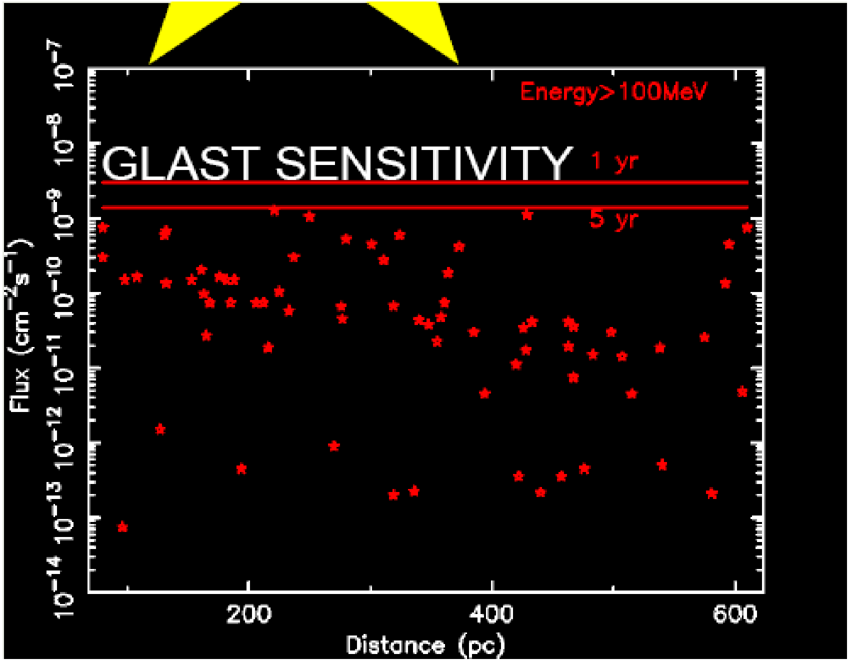
Source @ 100 pc:



Orlando & Strong astro-ph/0607563

Candidates for Detection

Single Stars: 70 most luminous from Hipparcos



x0.5

OB associations:

e.g., Cygnus OB2

1700 pc

~100 O stars

~2500 B stars

$F_{>100MeV}$ within 1° ~ 4×10^{-9} cm^{-2} s^{-1}

Conservative, could be higher if CR spectrum different

Bottom Line ....

- On-going work
  - Trying methods on EGRET data but difficult ...
  - Good exercise for when GLAST is 'flying'
- Practical
  - Solar modulation
    - Using GLAST as a solar modulation probe is exciting
    - Multi-wavelength with other instruments
  - IC halos
- Theoretical
  - CR interactions in the Sun
    - Reduce uncertainty in flux at solar surface, feed in to CR cascade calculations
    - π^0 gammas + neutrinos
    - Neutrino detectors
- The future is (γ-ray) bright for GLAST