Solar and stellar inverse Compton emission: a software package
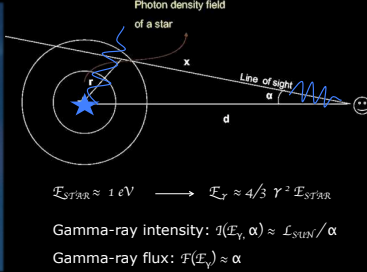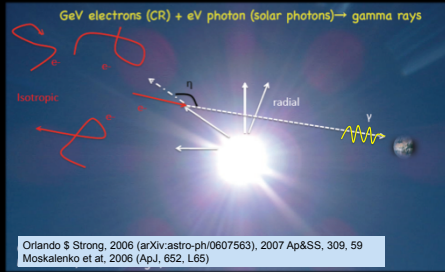
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Software to compute inverse-Compton scattering emission from the heliosphere and the photosphere of stars

ABSTRACT

We present our software to compute inverse-Compton scattering from the heliosphere, as well as the photospheres of stars. It includes a formulation of modulation in the heliosphere, but it can be used for any user-defined modulation model. It outputs profiles, spectra and differential flux to FITS files in a variety of forms for convenient use. The software is publicly available and it is under continuing development, taking into account updated observations in gamma rays and cosmic rays. It uses general-purpose inverse-Compton routines with other features like energy loss rates and emissivity for any user-defined target photon and lepton spectra.

FIRST PRESENTATION OF EXTENDED GAMMA-RAY INVERSE COMPTON EMISSION FROM STARS AND THE SUN (Orlando & Strong 2006)

GeV electrons (CR) + eV photon (solar photons)→ gamma rays

Photon density field of a star

Orlando $ Strong, 2006 (arXiv:astro-ph/0607563), 2007 Ap&SS, 309, 59
Moskalenko et at, 2006 (ApJ, 652, L65)

$$\mathcal{E}_{STAR} \approx 1\ eV \longrightarrow \mathcal{E}_\gamma \approx 4/3\ \gamma^2\ \mathcal{E}_{STAR}$$

Gamma-ray intensity: $\mathcal{I}(\mathcal{E}_\gamma, \alpha) \approx \mathcal{L}_{SUN}/\alpha$

Gamma-ray flux: $\mathcal{F}(\mathcal{E}_\gamma) \approx \alpha$
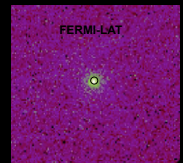
FIRST DETECTION OF THE SUN IN GAMMAS (Orlando & Strong, 2008)

Following the discovery of the quiet sun in EGRET data (left), now Fermi-LAT (right) is so sensitive that even the propagation of leptons in the inner heliosphere can be investigated by studying this emission
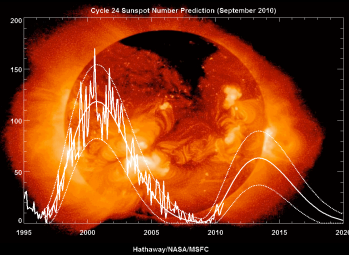
EGRET

FERMI-LAT
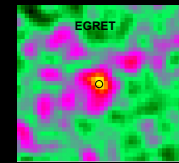
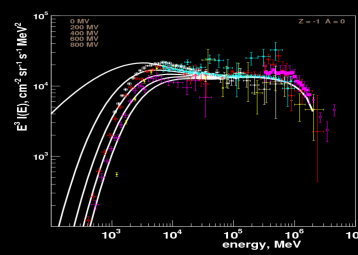Orlando & Strong, (2008)
A&A, 480, 847

Abdo et al. ApJ. (2011) 734, 116

SOLAR MODULATION OF THE ELECTRON SPECTRUM
It is unknown close to the Sun

Cycle 24 Sunspot Number Prediction (September 2010)

Hathaway/NASA/MSFC

Solar minimum -> max CR flux ->
max gamma-ray Inverse Compton

Solar maaximum -> min CR flux ->
min gamma-ray Inverse Compton

$$J_e(r, E) = J_e(\infty, E + \Phi[r]) \frac{(E^2 - m_e^2 c^4)}{(\{E + \Phi[r]\}^2 - m_e^2 c^4)}$$

spectrum at r=1AU as measured by Fermi

LIS
Local Interstellar Spectrum
=0 modulation

Modulation potential

THE SOFTWARE PACKAGE

C++ PROGRAM freely available at http://www.mpe.mpg.de/~aws/propagate.html

MODULAR: Klein-Nishina formulation, emissivity routines, Stellar Radiation field, electron and positron spectra separately, Solar Modulation, Independent classes.

Driver provided that can be adapted as required.

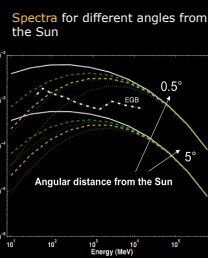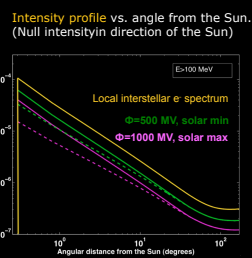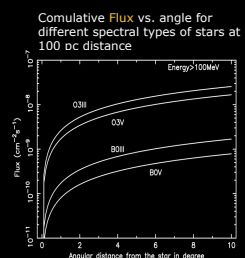New models of electrons, positrons and modulation can be easily added.

Fast – optimized emissivity computation for spectral integrations.
Parallel – OpenMP → high resolution computations in reasonable time

User-defined parameters for ranges, steps etc, very flexible

FITS output, in various forms (profiles, spectra and differential flux), energy integrations; also idl format.

The software is under continuing development, taking into account updated observations in gamma rays and cosmic rays

EXAMPLES OF PLOTTING OUTPUTS

Comulative Flux vs. angle for different spectral types of stars at 100 oc distance

Energy>100MeV

O3III
O3V
B0III
B0V

Angular distance from the star in degree

Intensity profile vs. angle from the Sun.
(Null intensityin direction of the Sun)

E>100 MeV

Local interstellar e⁻ spectrum
Φ=500 MV, solar min
Φ=1000 MV, solar max

Angular distance from the Sun (degrees)

Spectra for different angles from the Sun

Local interstellar e⁻ spectrum
EGB
0.5°
5°

Angular distance from the Sun

Energy (MeV)

SOLAR INVERSE COMPTON AS FOREGROUND EMISSION

Solar inverse Compton is also important as a background over the entire sky to be accounted for in studies of Galactic and extragalactic gamma-ray emission.

GLAT (deg)

60:00
0:00
-60:00

GLON (deg)
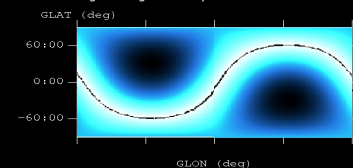
These models are used in the Fermi-LAT collaboration and will be officially available for the Science Tools analysis

eorlando@stanford.edu *and* **aws@mpe.mpg.de**