A New Component from the Quiet Sun from Radio to Gamma Rays: Synchrotron Radiation by Galactic Cosmic Ray Electrons

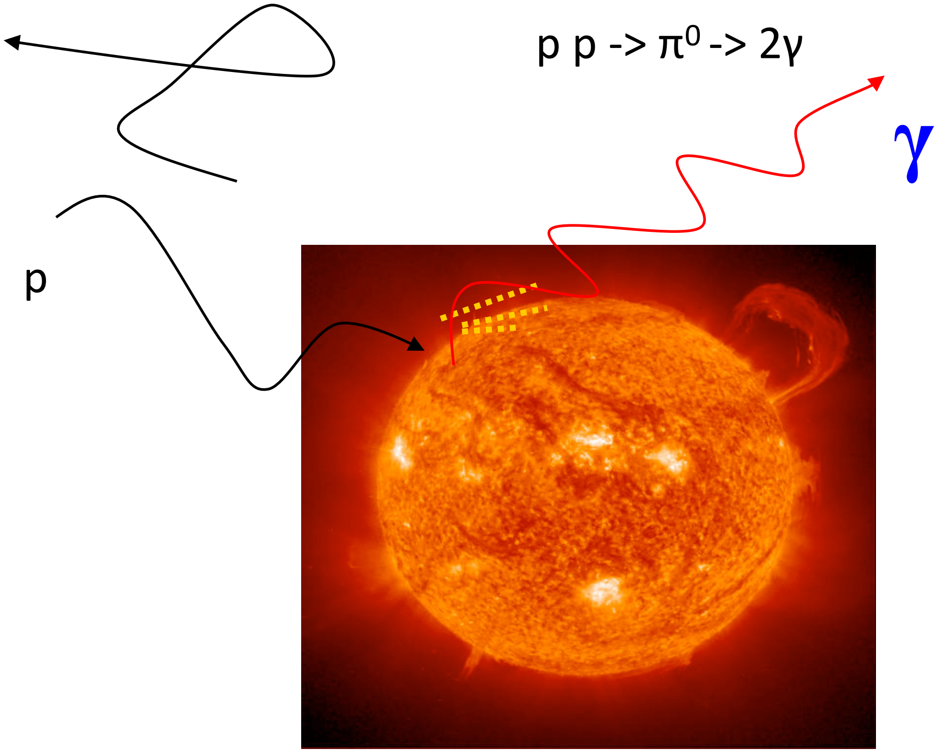
Elena Orlando

Orlando, Petrosian, Strong 2023 ApJ 943, 173

TeVPa 2023

1) Disc Component

Hadronic interactions of Galactic CRs with solar atmosphere

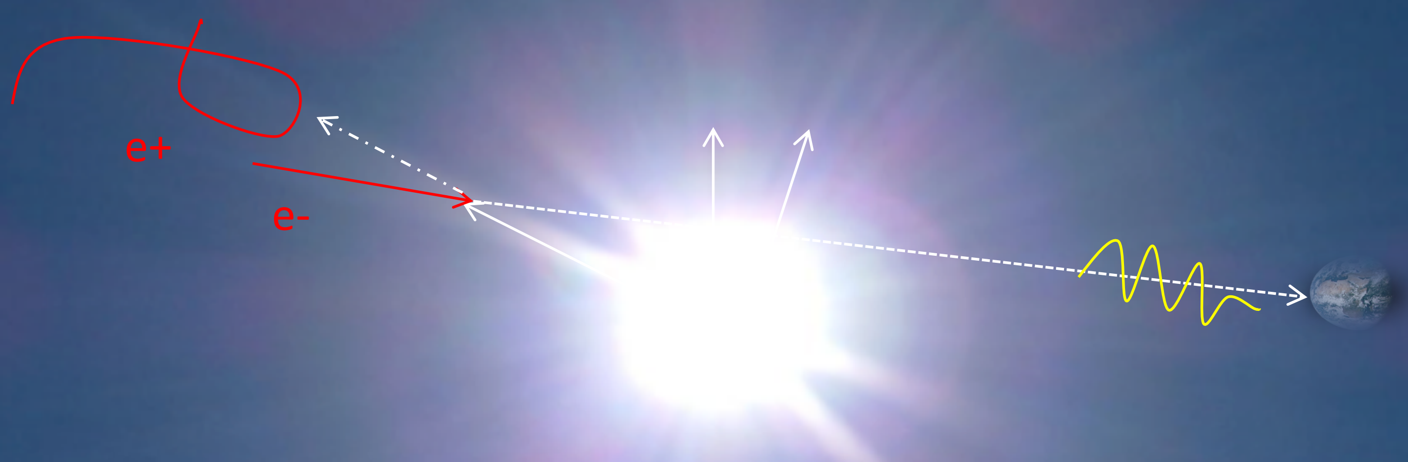


Seckel, Stanev and Gaisser (1991) ApJ 382, 652

2) Spatially Extended Component

First theory:
Orlando & Strong (2006) arXiv:astro-ph/0607563; (2007) Ap&SS, 309, 59
and Moskalenko et al (2007) ApJ 652, 65 independently

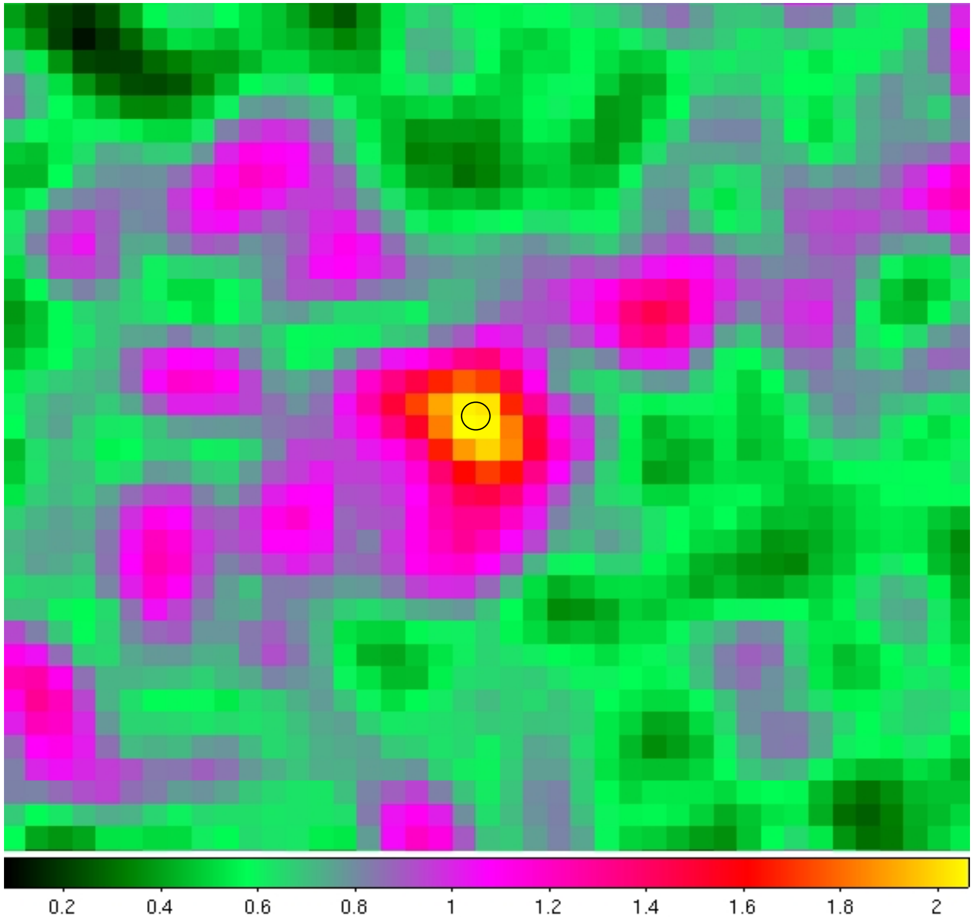
CR $e^{\pm}$ + eV photon → γ



(See also talk by De Menezes on Luminous Stars, GA Session)

First Detection of the Quiet Sun in Gamma Rays

Orlando & Strong (2008) A&A, 480, 847

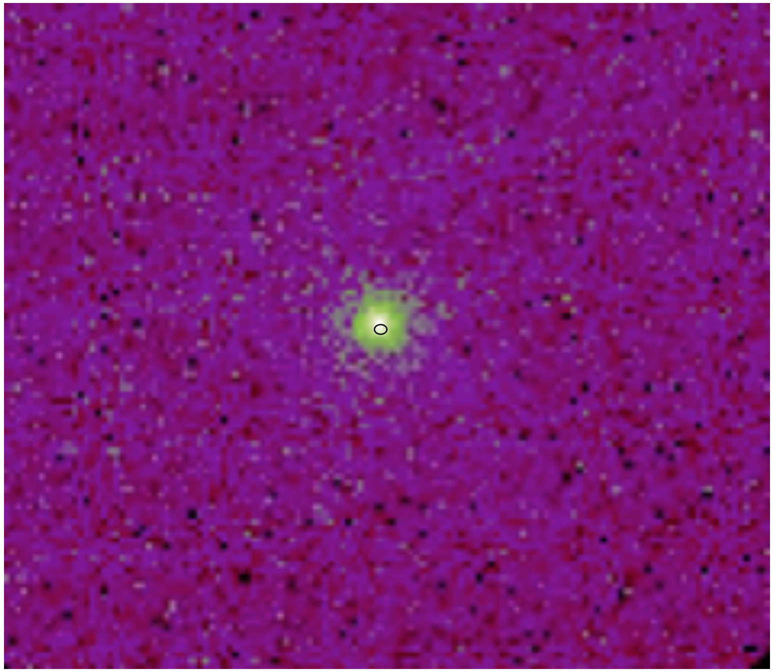


EGRET

The two components are detected and distinguished!

Following studies with Fermi data

Fermi LAT Coll. ApJ. (2011) 734, 116



See also: *Linden, T., Zhou, B., Beacom, J. F., et al. 2018, PRL, 121, 131103*
Ng, K. C. Y., Beacom, J. F., Peter, A. H. G., et al. 2016, PhRvD, 94, 023004

(*See also related talks by Zhe Li, Puzzoni, and Jung-Tsung Li this conference*)

Journal of Cosmology and Astroparticle Physics

PAPER

StellarICS: inverse Compton emission from the quiet Sun and stars from keV to TeV

Elena Orlando[1,2] and Andrew Strong[3]

Published 1 April 2021 •

Journal of Cosmology and Astroparticle Physics, Volume 2021, April 2021

Citation Elena Orlando and Andrew Strong JCAP04(2021)004

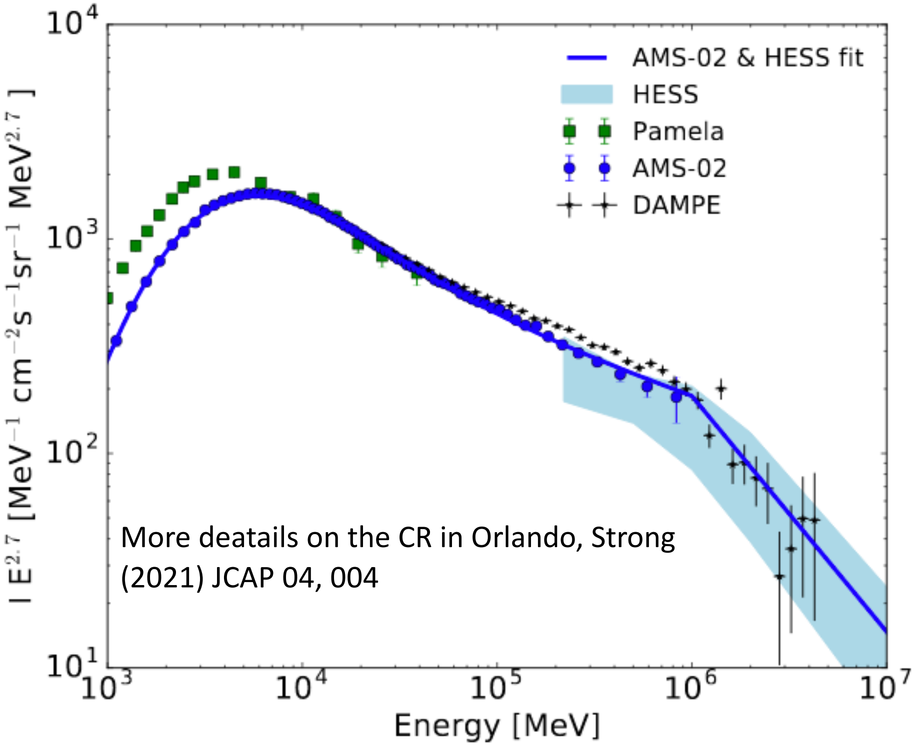
THE ASTROPHYSICAL JOURNAL, 943:173 (6pp), 2023 February 1 https://doi.org/10.3847/1538-4357/acad75

A New Component from the Quiet Sun from Radio to Gamma Rays: Synchrotron Radiation by Galactic Cosmic-Ray Electrons

Elena Orlando[1,2], Vahe' Petrosian[2], and Andrew Strong[3]

Synchrotron Emission Modeling

CR



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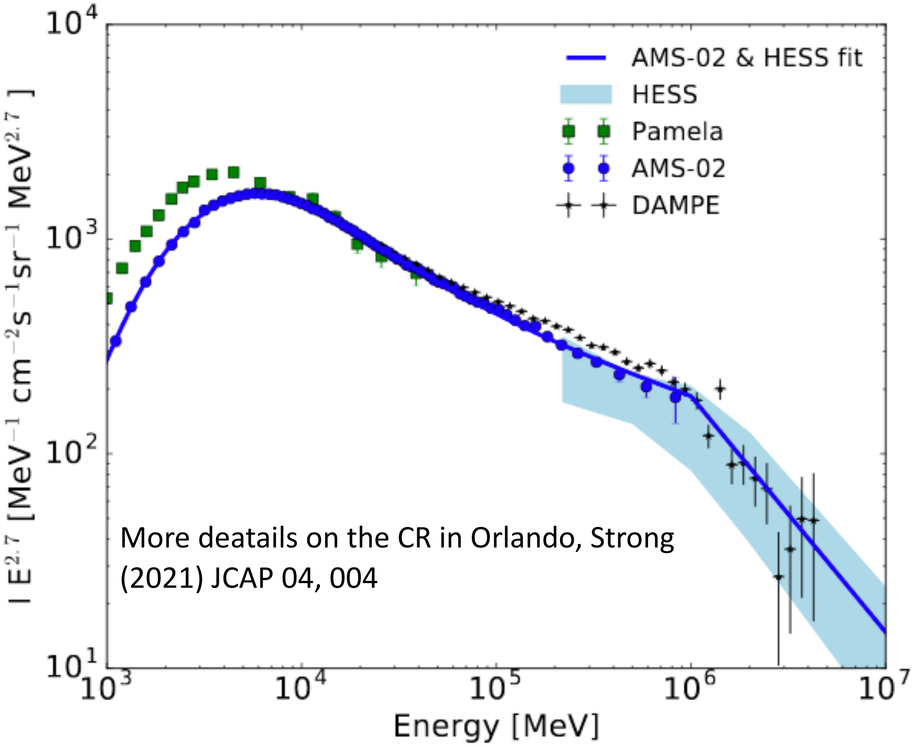
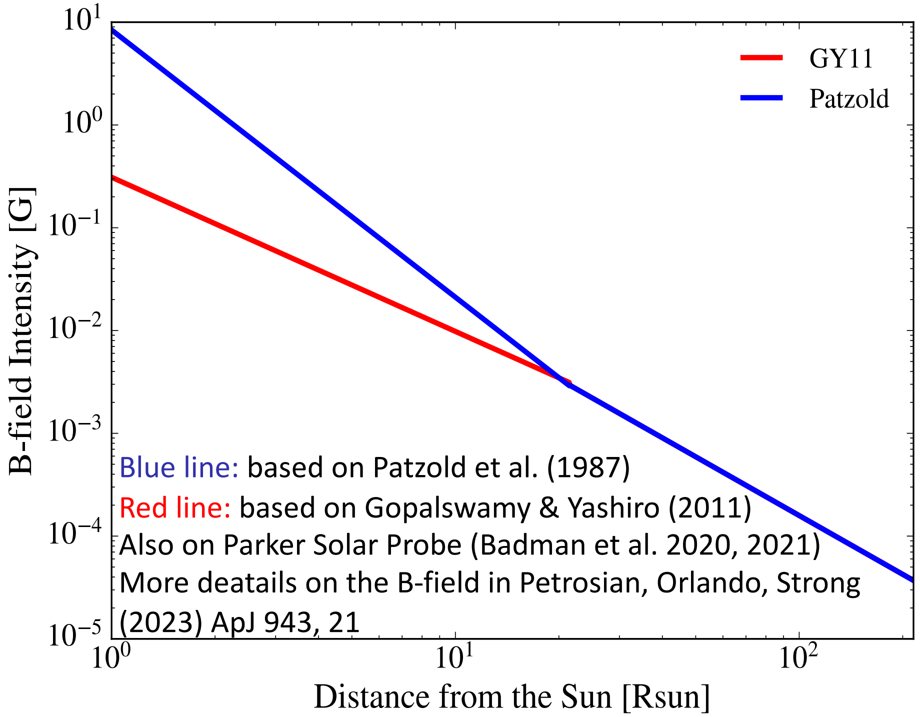
Synchrotron Emission Modeling

CR e-



B-field



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Synchrotron Intensity from MHz to UV

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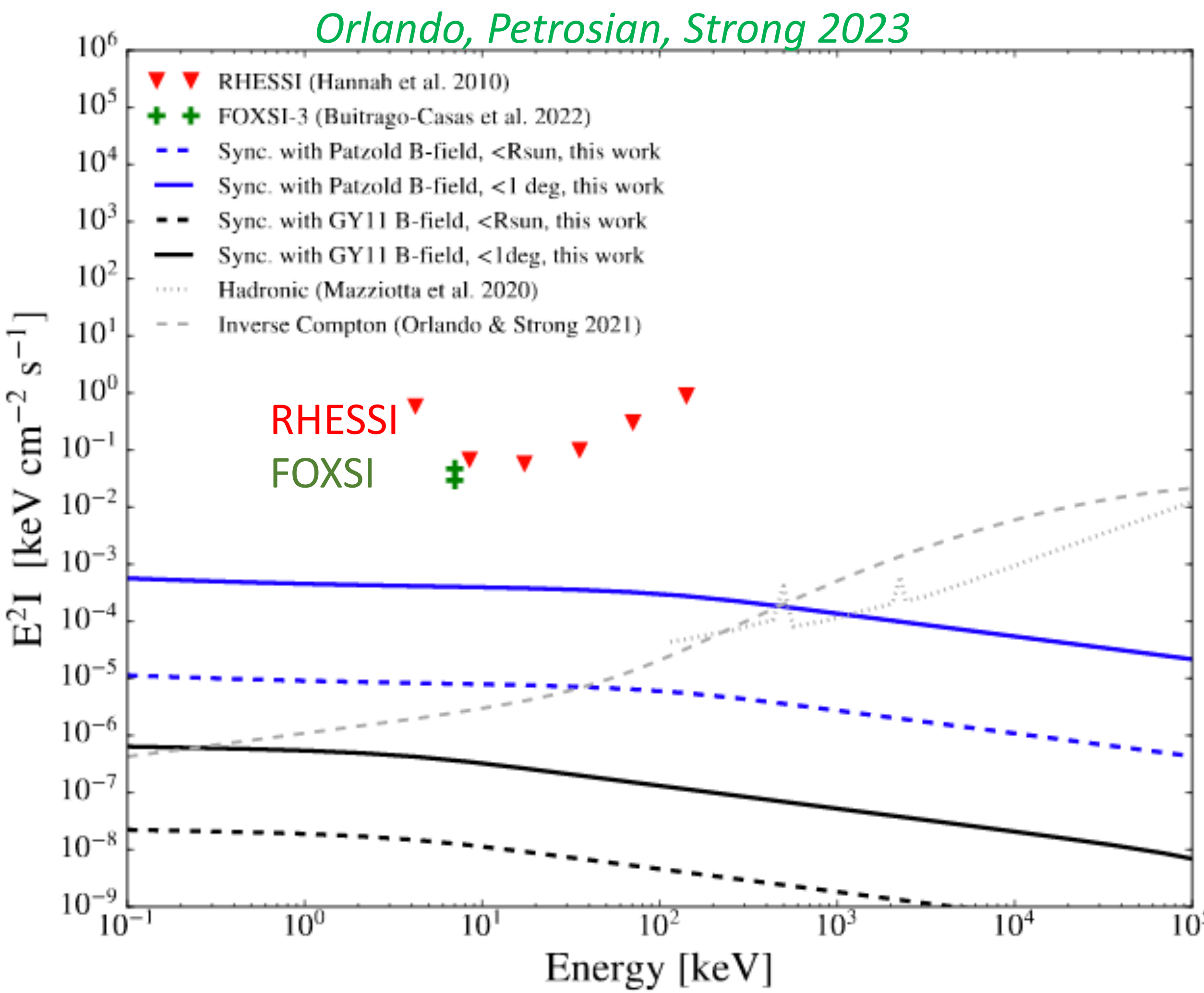
Many orders lower than present data (e.g. LOFAR and ALMA)
and of the solar thermal emission

Synchrotron Intensity in X-rays



In X-rays: a few orders lower than upper limits -> promising in future!

Synchrotron Profile in X-rays

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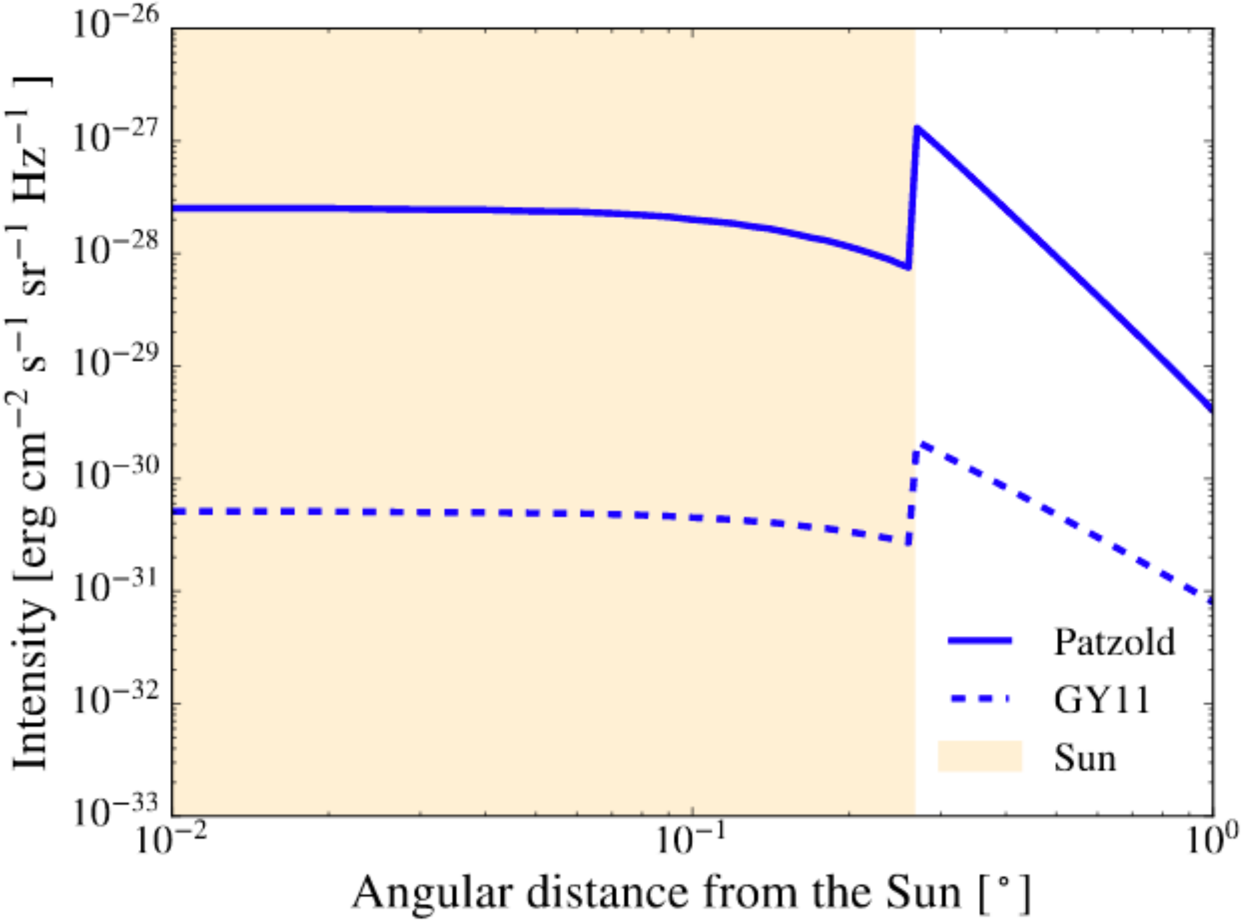
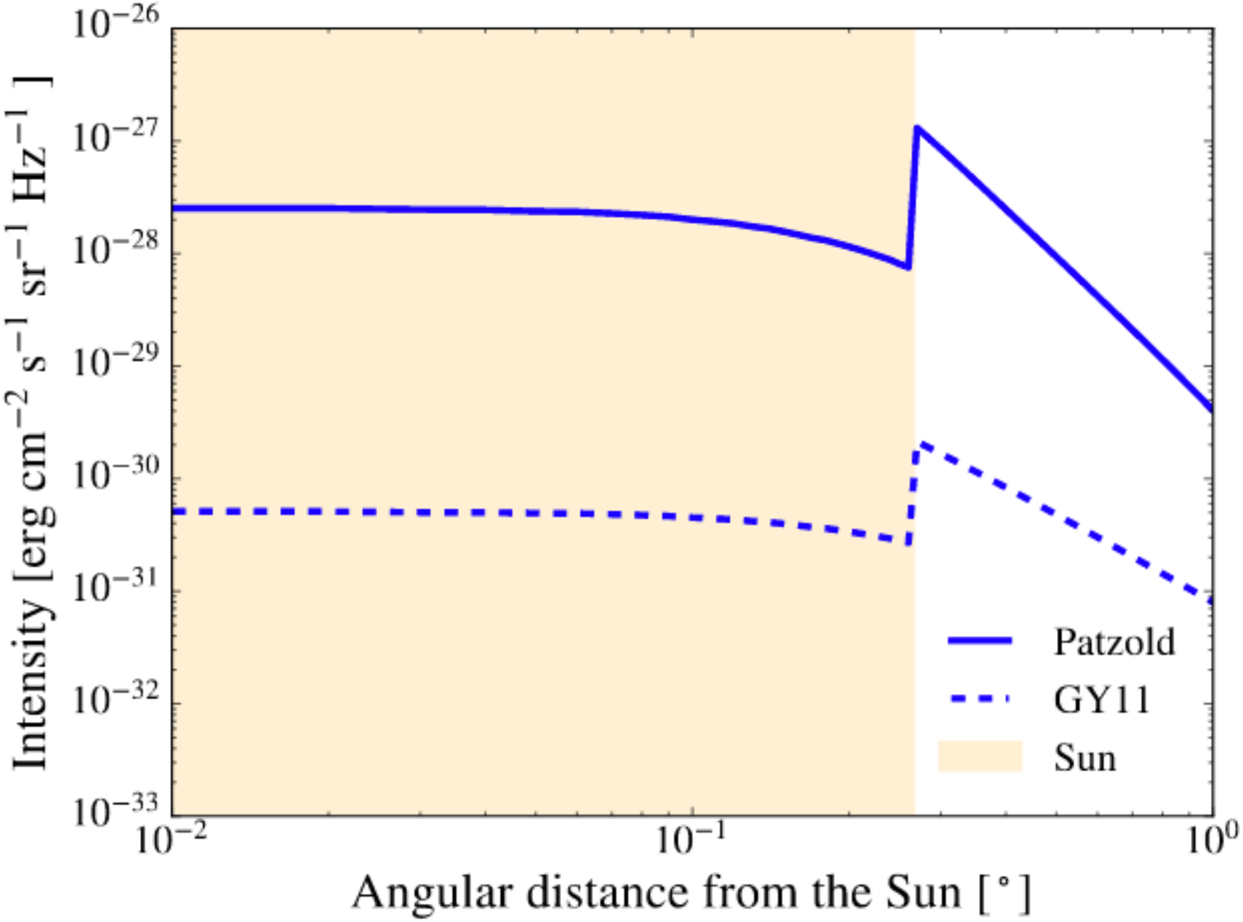


Synchrotron Profile in X-rays

Orlando, Petrosian, Strong 2023



Future observations in X-rays could potentially allow for constraining CR densities and B-field intensities at the Sun.

AAS Press Release + UNIV TS

New Phenomena on the Quiet Sun

By Kerry Hensley on 22 February 2023 FEATURES

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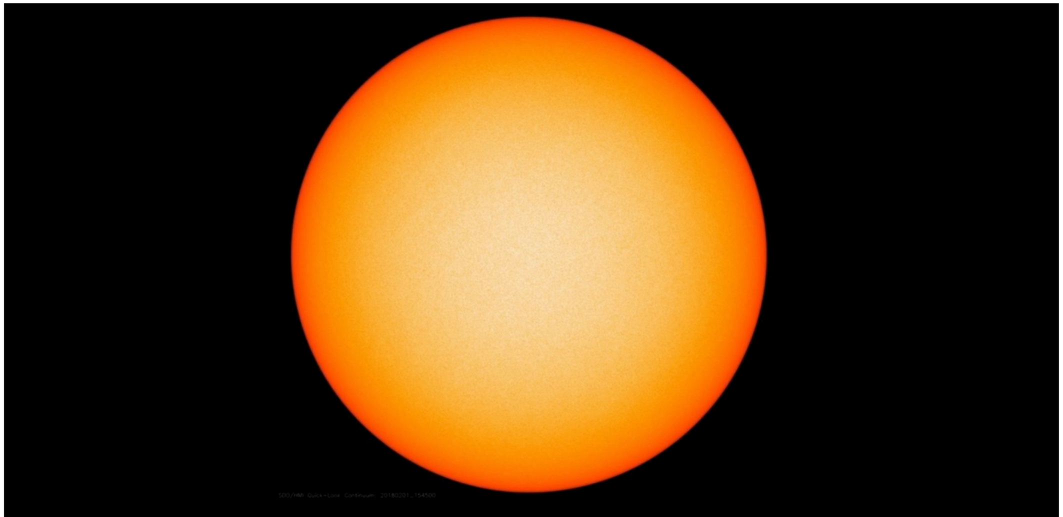

In early 2018, the Sun had almost no sunspots for two weeks. This image shows a spotless day. [**Solar Dynamics Observatory, NASA**]

Emission from Spiraling Electrons

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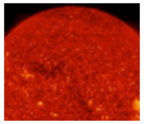

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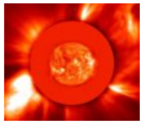

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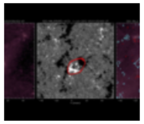

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Summary of Results & Conclusions

- First time this component has been claimed and modeled
- It spans from radio to high energies
- It is negligible from radio to UV compared to the solar thermal radiation
- CR electrons with energies from tens of GeV to a few TeV produce X-rays, which is a few orders of magnitude lower than current upper limits by RHESSI and FOXSI
- It can potentially be observed at high energies with more promising future FOXSI observations
- For a radially decreasing solar magnetic field we find the expected synchrotron intensity to be almost constant in the solar disk, to peak in the close proximity of the Sun, and to quickly drop away from the Sun.
- Observations could potentially allow for constraining GCR densities and magnetic-field intensities at the Sun.

Thank you

- back up

Synchrotron Modeling

For a magnetic field with intensity B and for an electron with Lorentz factor γ, the emissivity is isotropic and obtained with the formulation given by Ghisellini et al. (1988):

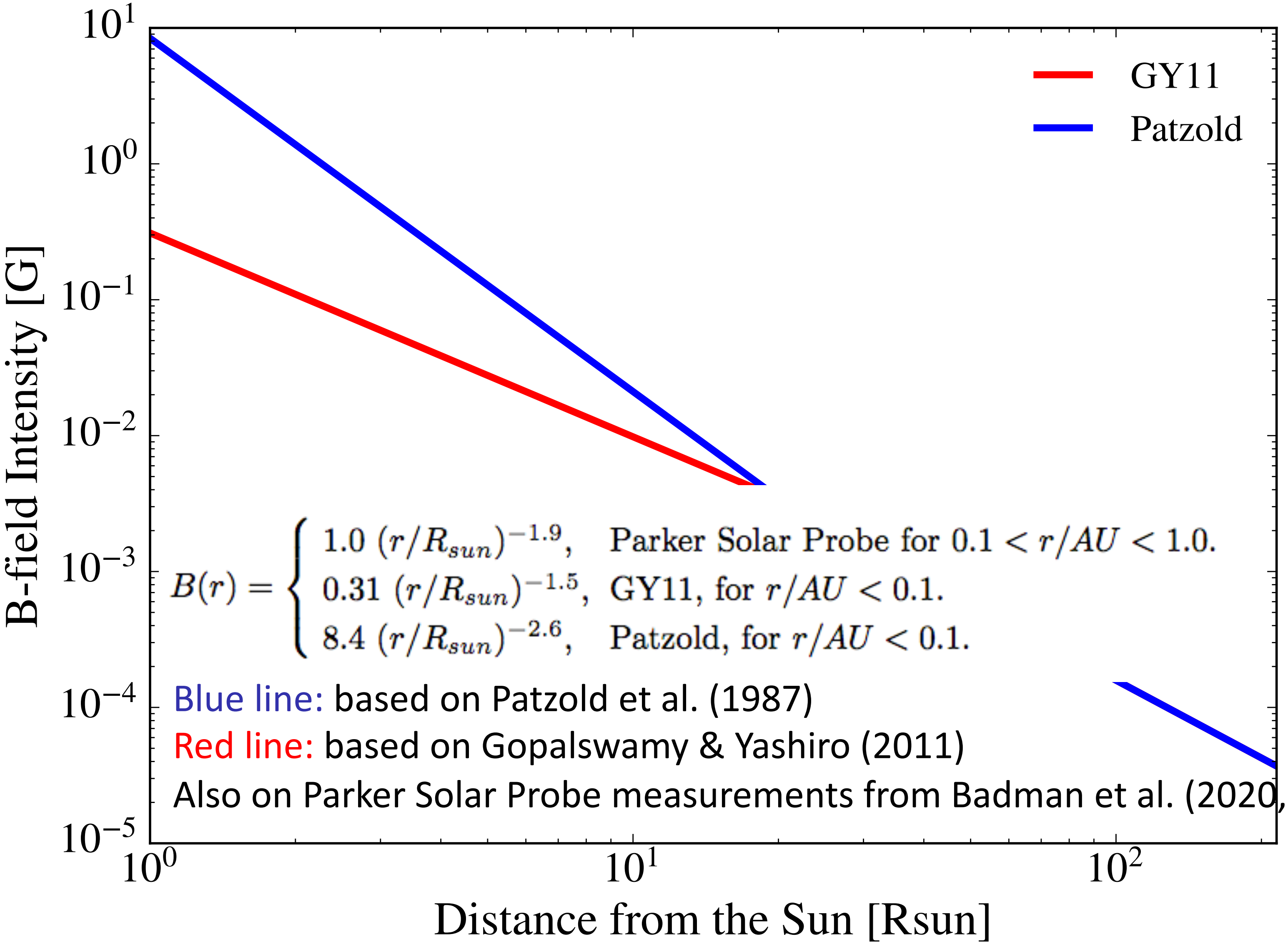
$$\epsilon(\nu,\gamma) = C\ x^2[K_{4/3}K_{1/3} - \frac{3}{5}x(K_{4/3}K_{4/3} - K_{1/3}K_{1/3})]$$

$x = \nu/\nu_c$, $\nu_c = \frac{3}{2\pi}\frac{e}{mc}B\gamma^2$, $C = 2\sqrt{3}\frac{e^3}{mc^2}B$ erg s^{-1} Hz^{-1}, and $K_{4/3}$, $K_{1/3}$ Bessel functions

The synchrotron intensity along a line-of sight s, at frequency v, for a given isotropic distribution and spectrum of CR electrons, nγ, is given by

$$I(\nu) = \int\int \epsilon(\nu,\gamma)\ n_\gamma\ d\gamma\ ds$$

Solar B-field



$$B(r) = \begin{cases} 1.0\ (r/R_{sun})^{-1.9}, & \text{Parker Solar Probe for } 0.1 < r/AU < 1.0. \\ 0.31\ (r/R_{sun})^{-1.5}, & \text{GY11, for } r/AU < 0.1. \\ 8.4\ (r/R_{sun})^{-2.6}, & \text{Patzold, for } r/AU < 0.1. \end{cases}$$

Blue line: based on Patzold et al. (1987)

Red line: based on Gopalswamy & Yashiro (2011)

Also on Parker Solar Probe measurements from Badman et al. (2020, 2021).