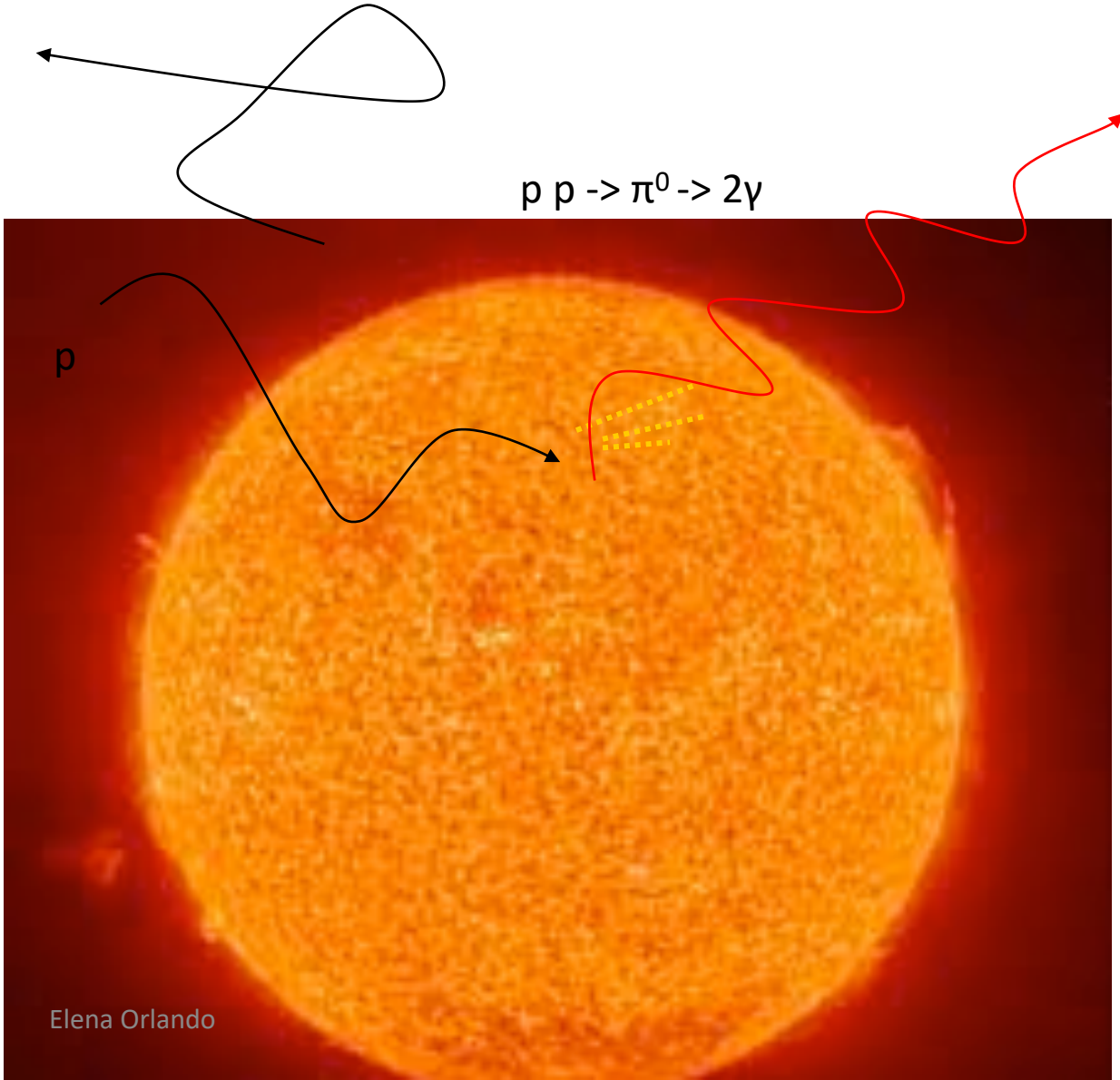
The Quiet Sun with Fermi LAT

Elena Orlando

RICAP 2024– Sep 2024

1) Hadronic Disk Component



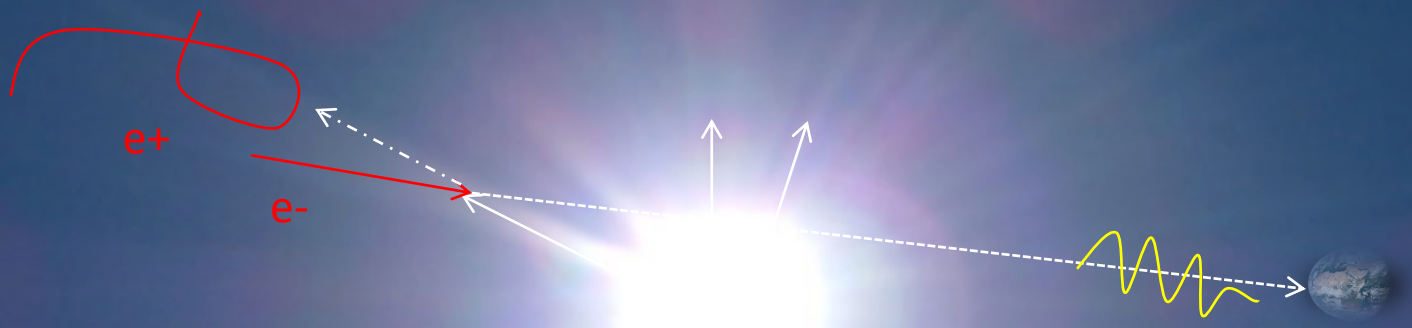
Seckel, Stanev and Gaisser (1991)

Recently:
Zhou et al. (2017)
Mazziotta et al. (2020);
Zhe (2020);
Li et al. (2020,2023);

2) Inverse Compton (IC) Spatially Extended Component

First theory:
Orlando & Strong (2006) arXiv:astro-ph/0607563; (2007) Ap&SS, 309, 59

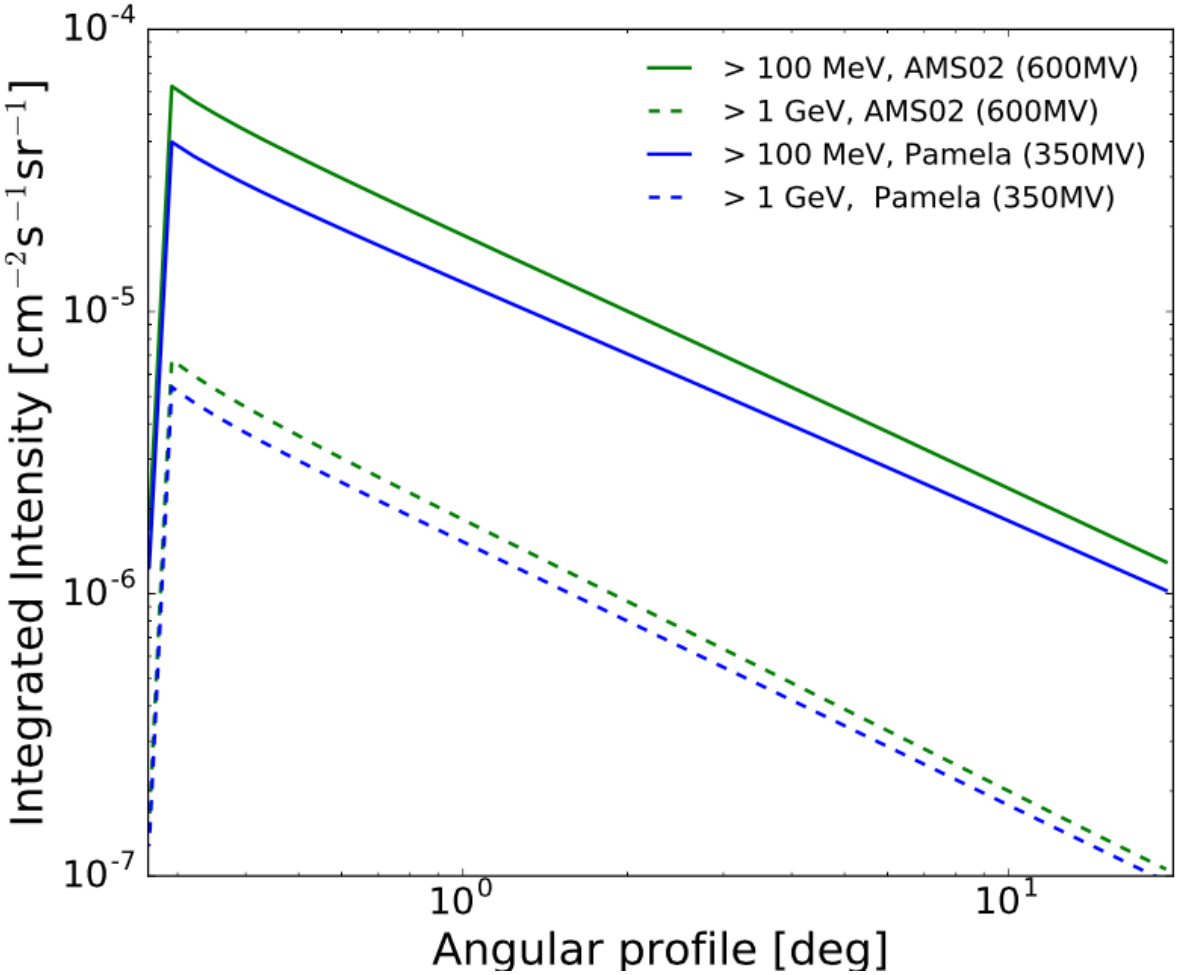
CR $e^{\pm}$ + eV photon → γ



Inverse Compton Modeling Updates

Orlando & Strong (2021) JCAP 04, 004

- StellarICs
- Extension at keV and TeV



IC from Luminous Stars & Associations

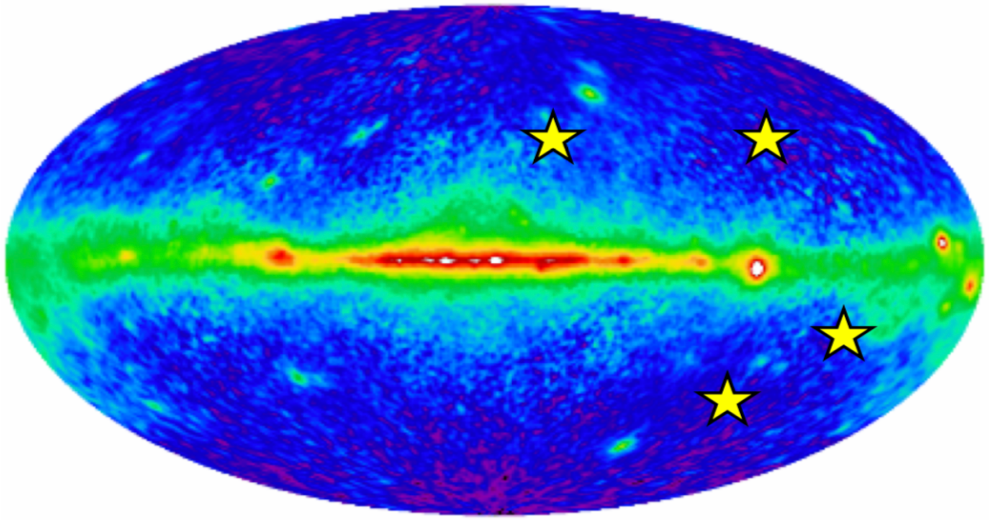
Original Article | Published: 20 April 2007

Gamma rays from halos around stars and the Sun

E. Orlando & A. W. Strong

Astrophysics and Space Science **309**, 359–363 (2007) | Cite this article

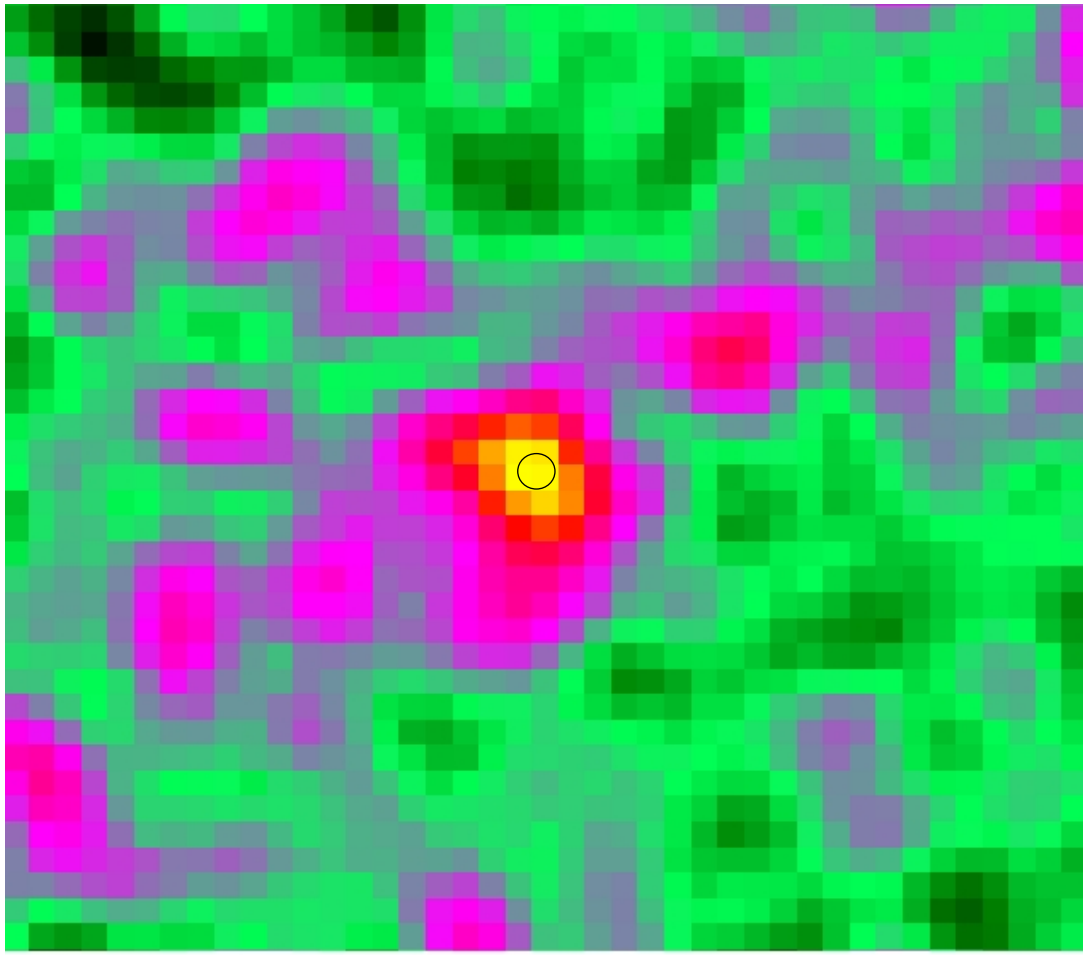
accounted in Cygnus OB2 Association: *Ackermann et al. (2011) Science 334, 1103*



Fermi upper limits: *De Menezes, Orlando et al. (2021) MNRAS 507, 680 – single stars*

First Detection of the Quiet Sun in Gamma Rays

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

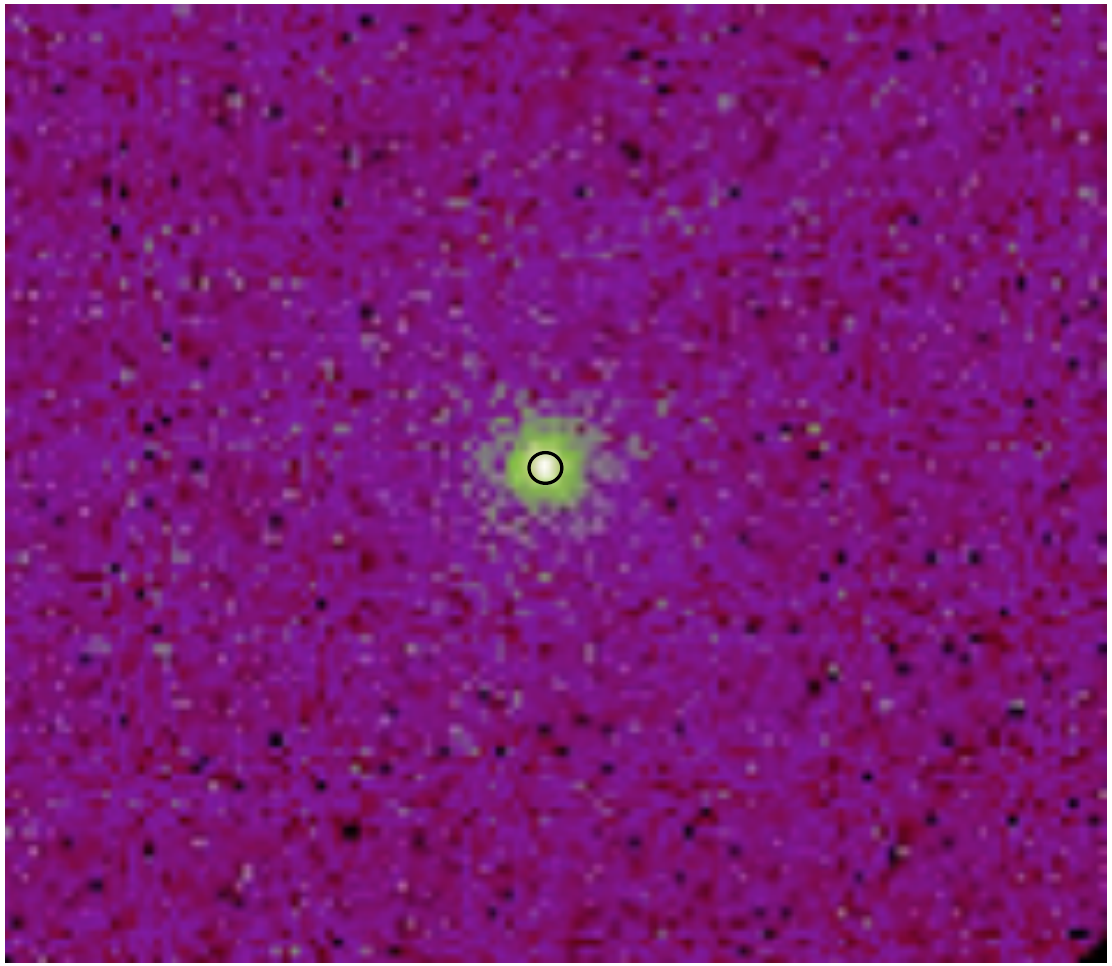


EGRET

The two components are detected and distinguished!

Fermi LAT – daily detections

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



FERMI

Higher significance than before

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]

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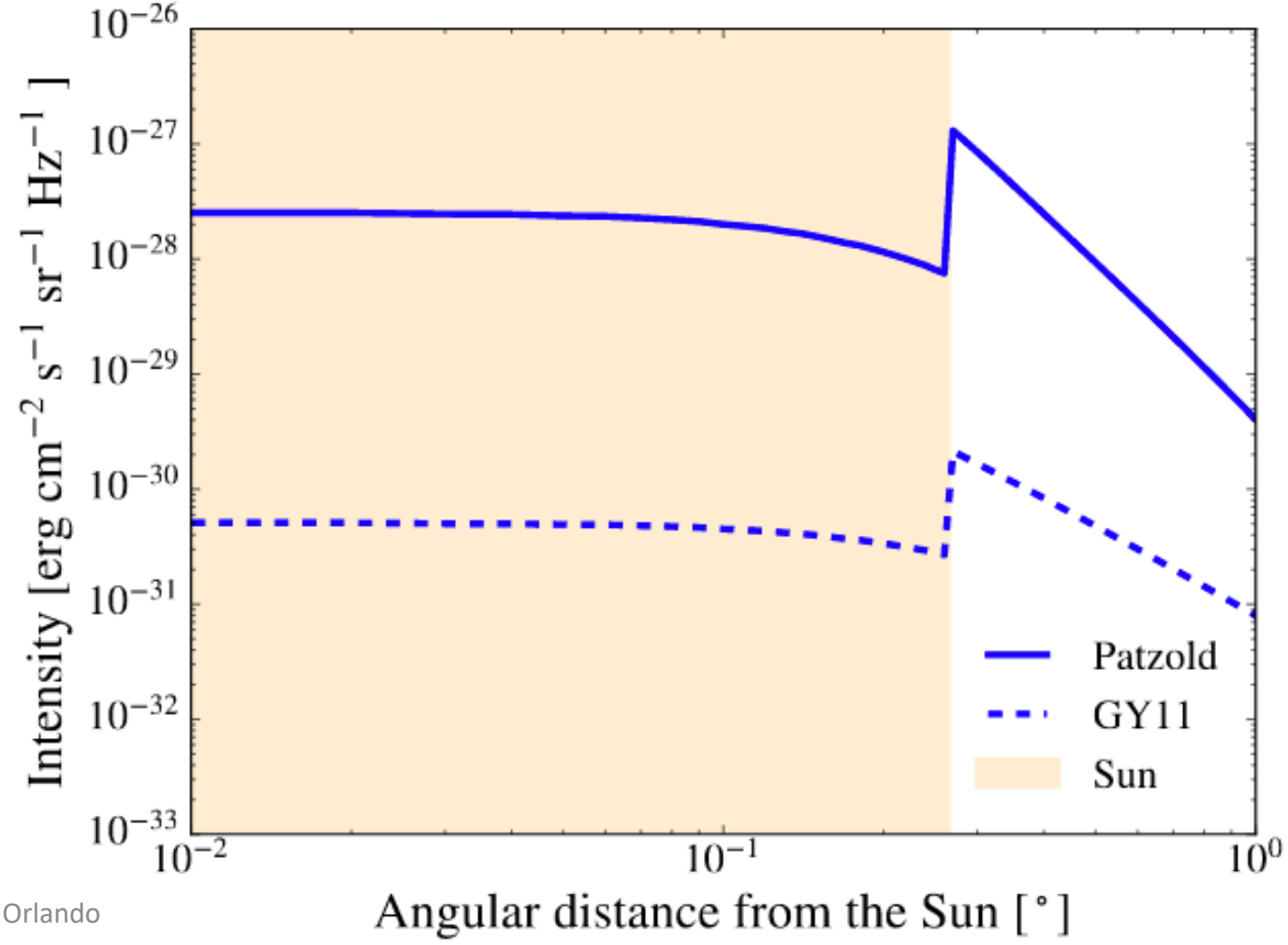

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from MHz to UV

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

The Astrophysical Journal, 943:173 (6pp), 2023 February 1 https://doi.org/10.3847/1538-4357/acad75

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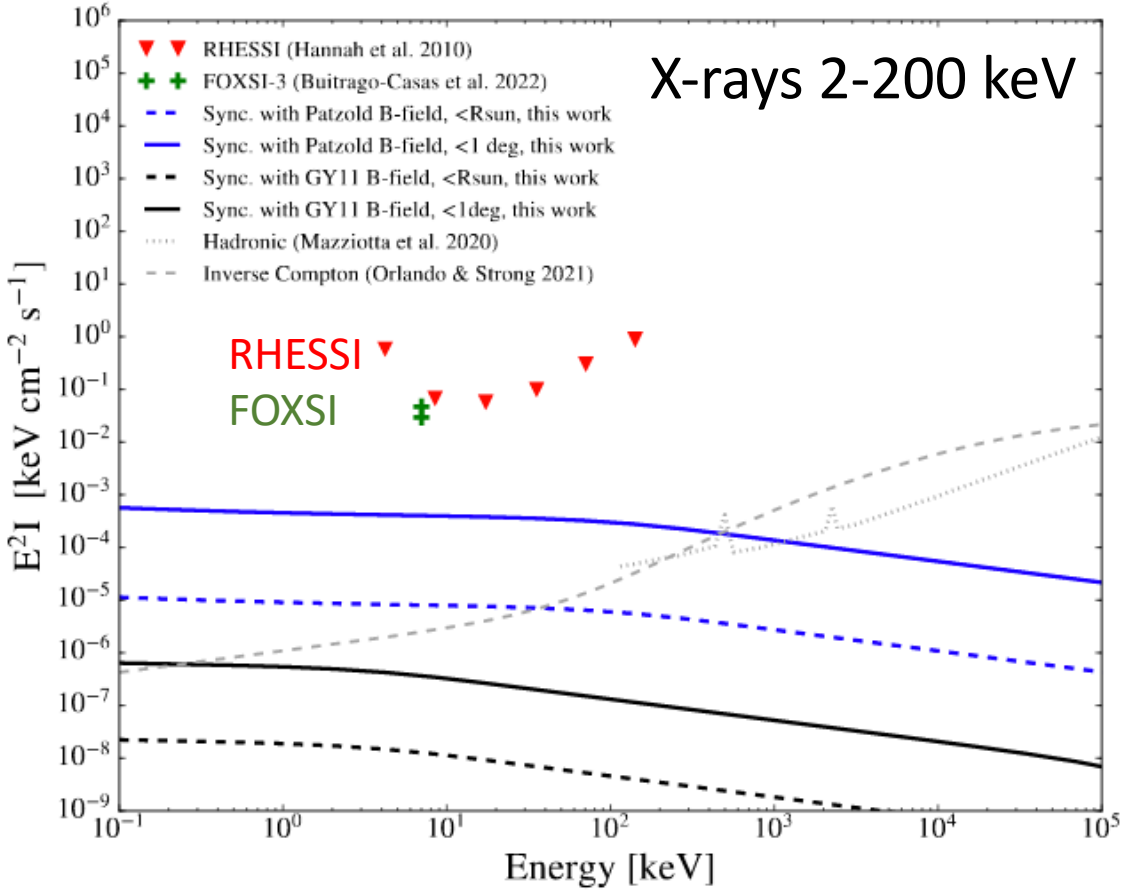
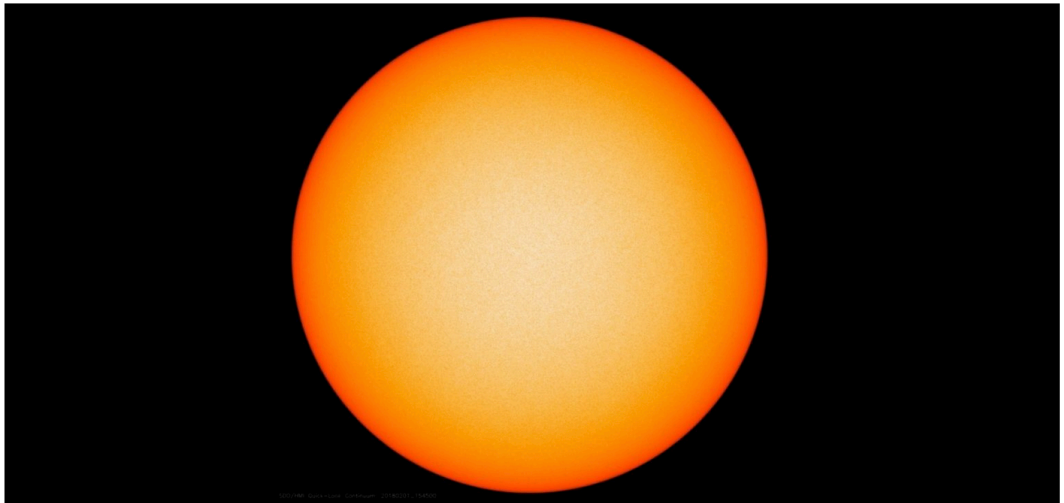


a few orders lower than upper limits -> promising in future!

New Phenomena on the Quiet Sun

By Kerry Hensley on 22 February 2023 FEATURES

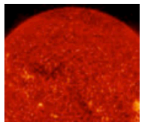


In early 2018, the Sun had almost no sunspots for two weeks. This image shows a spotless day. [**Solar Dynamics Observatory, NASA**]

RELATED HIGHLIGHTS

1 February 2023 FEATURES

Creating a Perfect Solar Storm

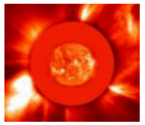


21 October 2022 FEATURES

First Light (and First Flight) for a New Solar Instrument

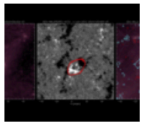
8 August 2022 IMAGES

Featured Image: A Twisted Magnetic Rope



3 August 2022 FEATURES

Caught in a Solar Storm on the Way to Mars



22 July 2022 FEATURES

Studying Solar BEARs in Their Natural Habitat

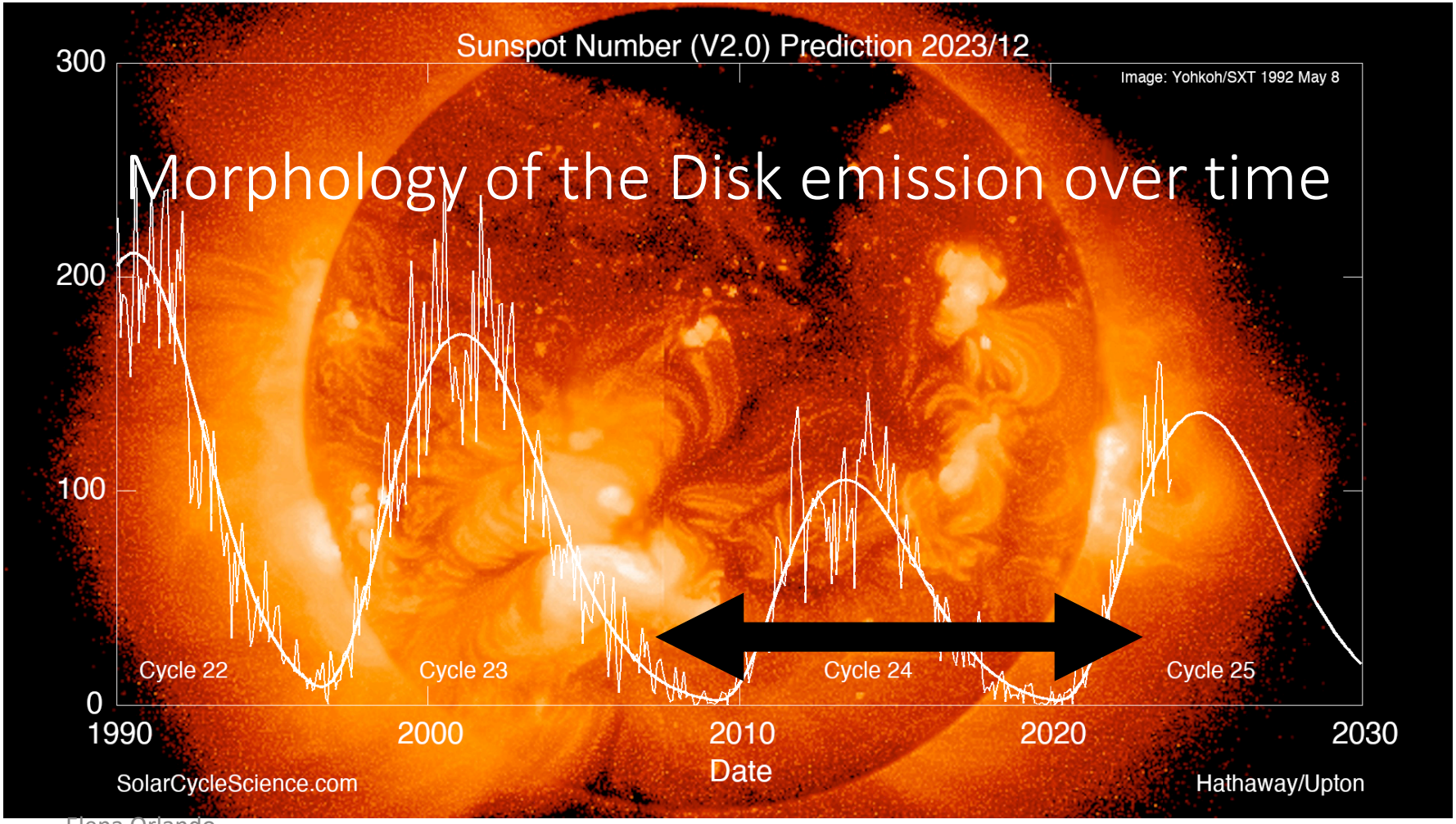
Elena Orlando

Emission from Spiraling Electrons

The Astrophysical Journal, 962:52 (16pp), 2024 February 10 https://doi.org/10.3847/1538-4357/ad1bd2

Yet Another Sunshine Mystery: Unexpected Asymmetry in GeV Emission from the Solar Disk

Bruno Arsioli[1,2,3,4] and Elena Orlando[3,4,5]



Elena Orlando

Analysis

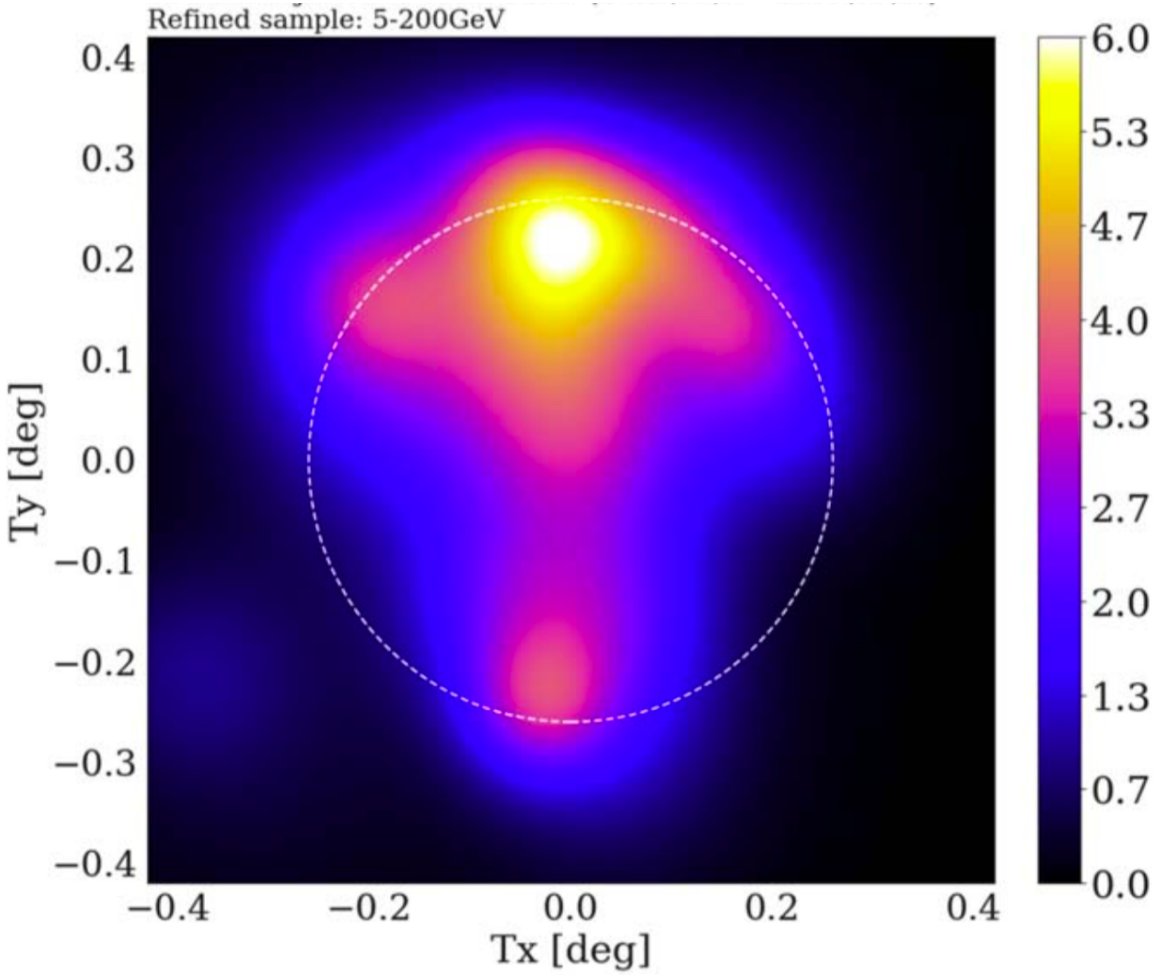
Morphology over time and deviations from isotropic emission as assumed by current models

- 14 years of data
- Solar Disk Photons > 5 GeV

  in Helioprojection system
- Careful data cleaning
- Optimization of

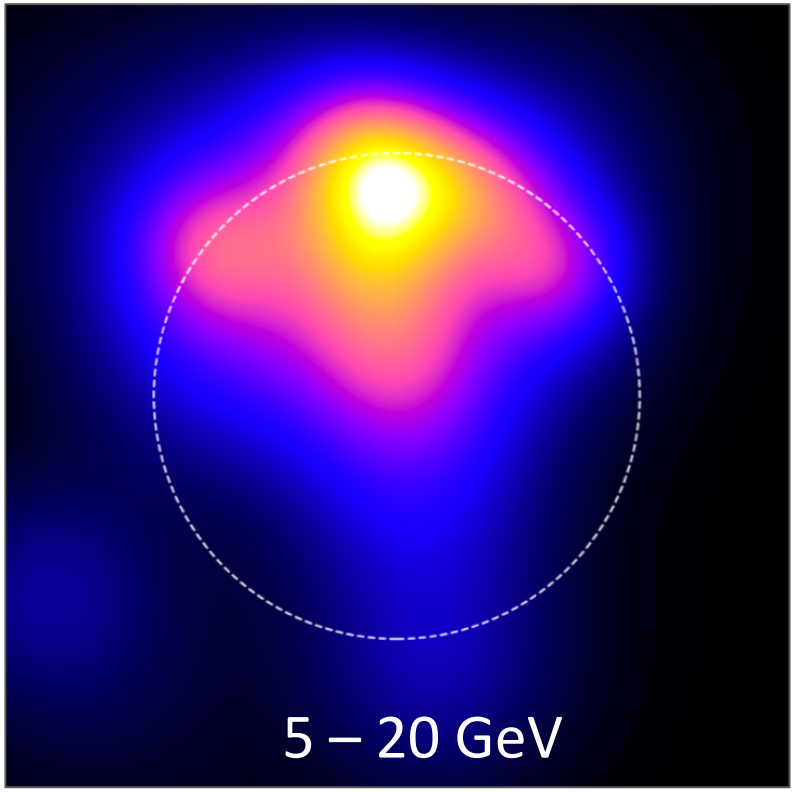
  spatial resolution and photon counts

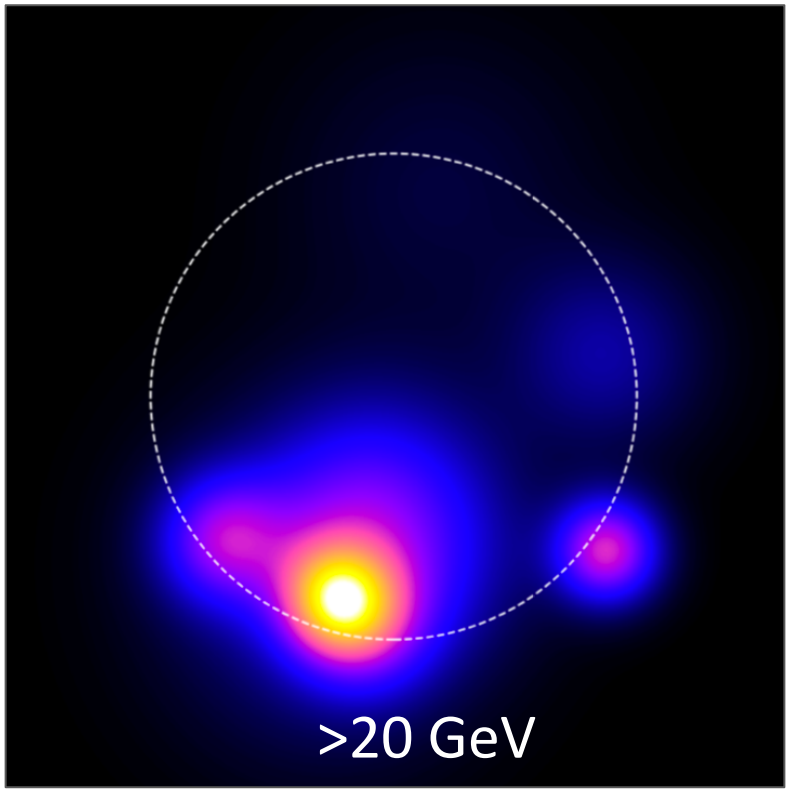
Non-uniformity of the Disk ~2014



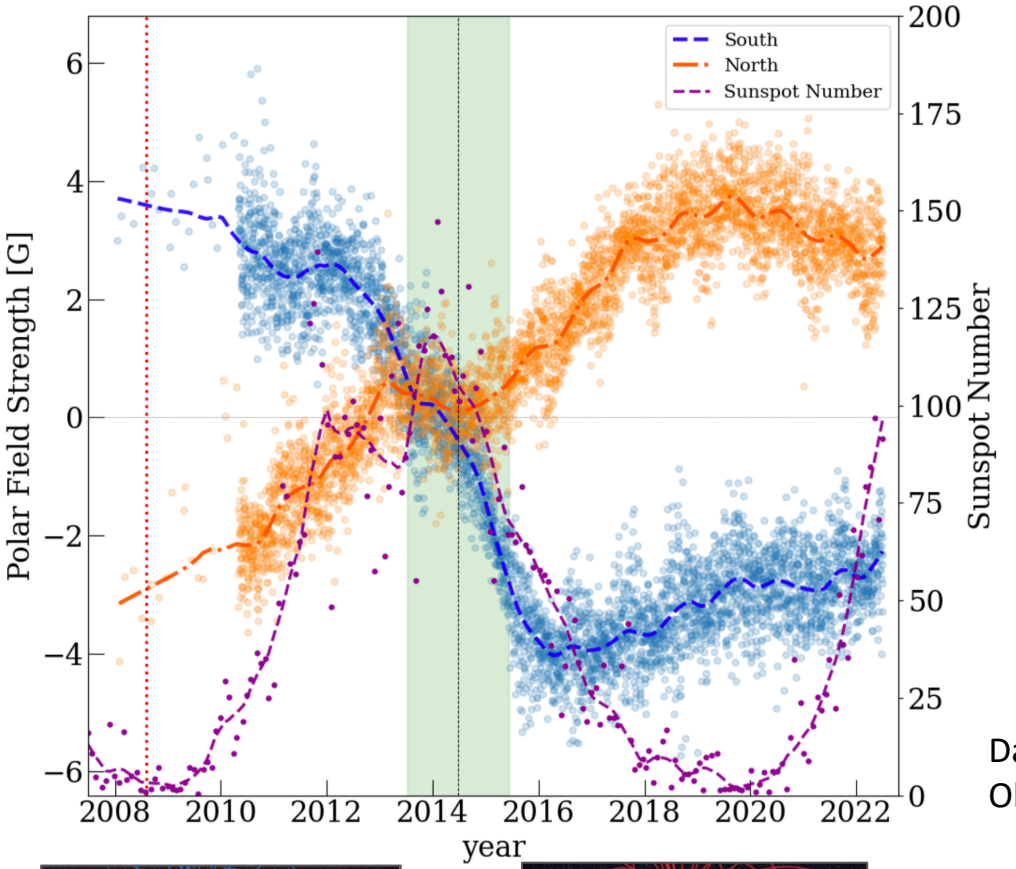
Significant deviations from isotropic emission for ~2014

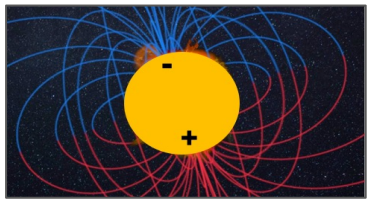
Asymmetry in Energy ~2014

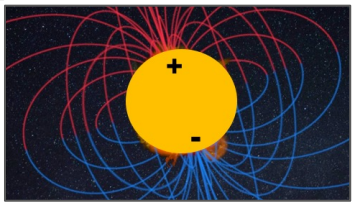




~2014:
Sun's Polar Magnetic Field Flip

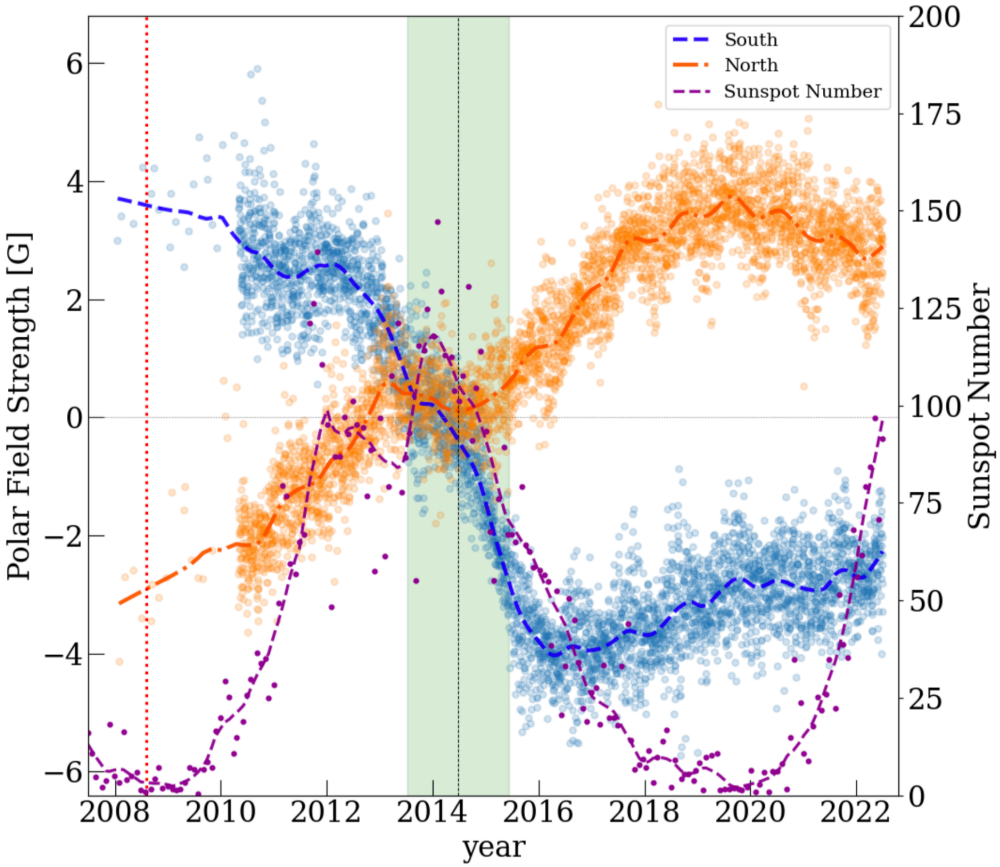






Data from the Wilcox Solar Observatory (WSO)

~2014:
Sun's Polar Magnetic Field Flip



Crucial Role of the Magnetic Field, but still unexplained, it opens up a link among plasma physics, astronomy, and particle physics

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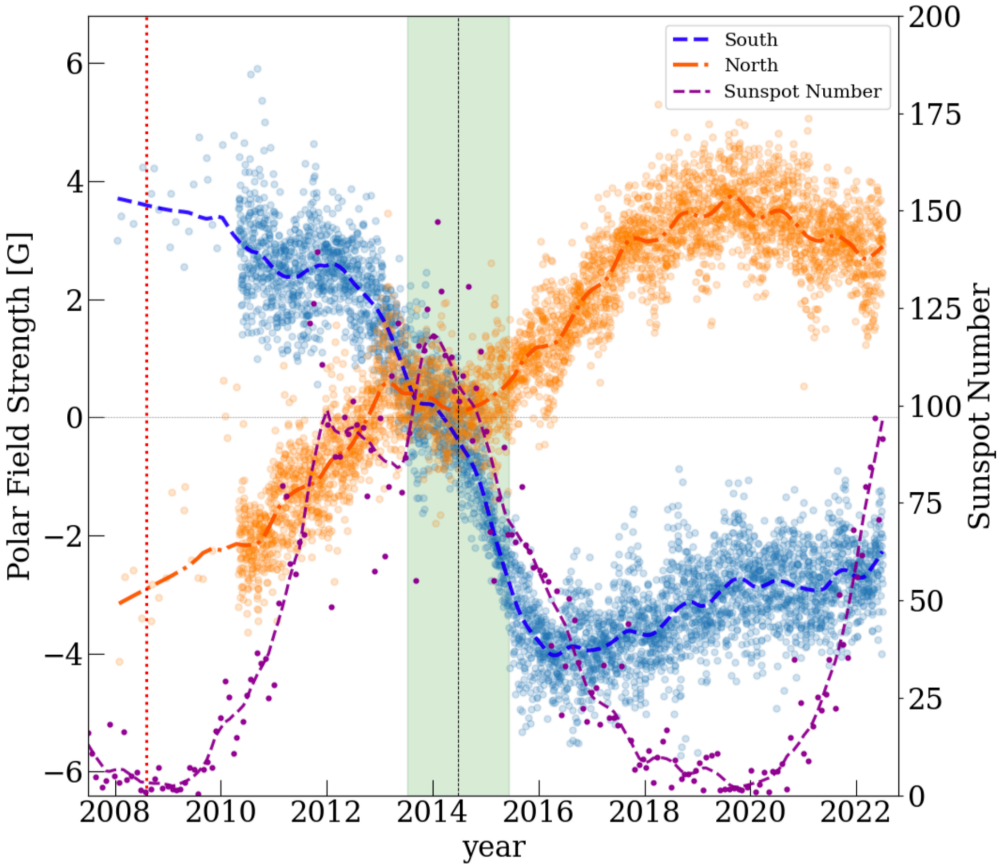
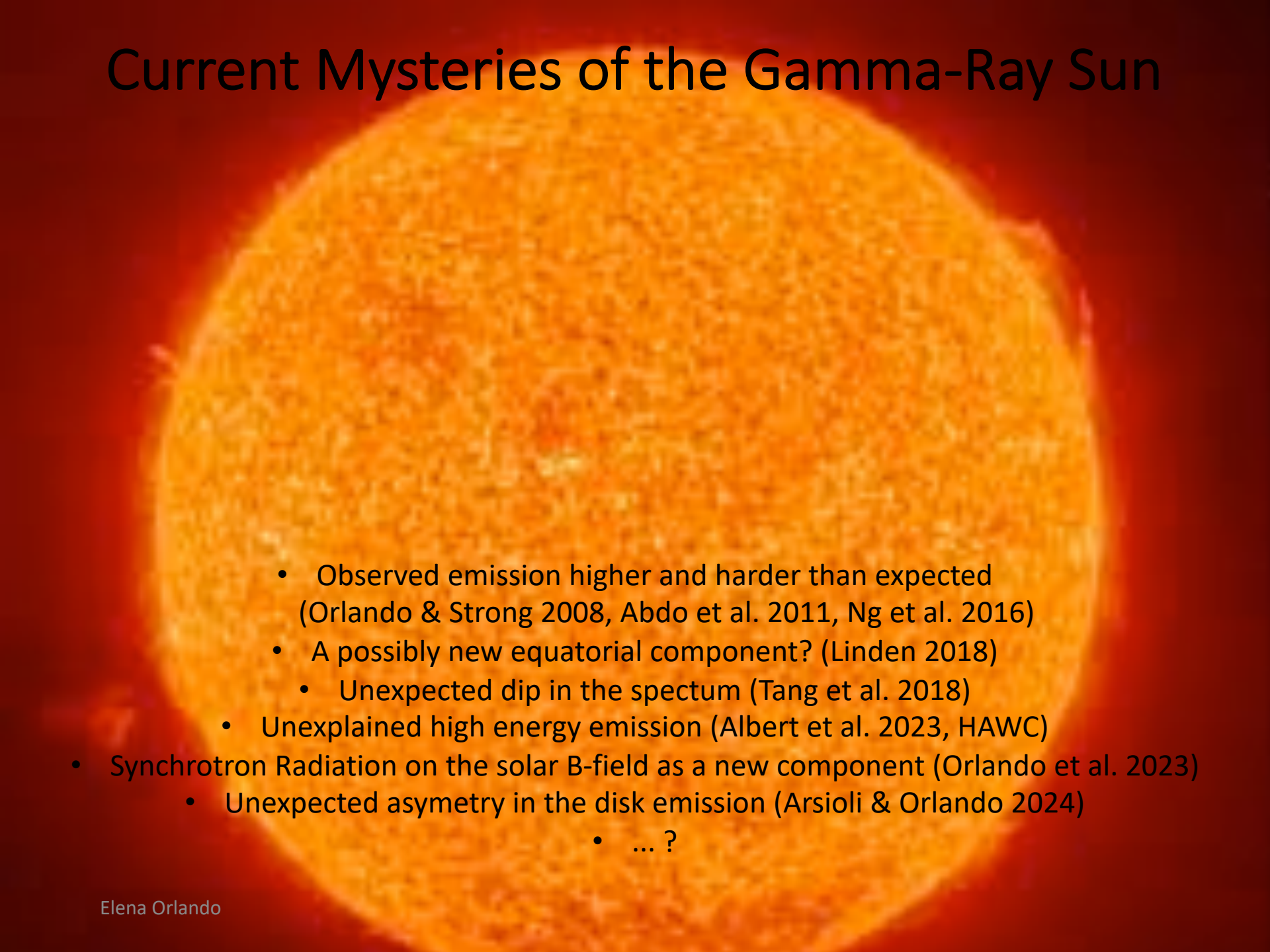


Crucial Role of the Magnetic Field, but still unexplained, it opens up a link among plasma physics, astronomy, and particle physics

AAS Press Conference

Current Mysteries of the Gamma-Ray Sun



- Observed emission higher and harder than expected (Orlando & Strong 2008, Abdo et al. 2011, Ng et al. 2016)
- A possibly new equatorial component? (Linden 2018)
- Unexpected dip in the spectum (Tang et al. 2018)
- Unexplained high energy emission (Albert et al. 2023, HAWC)
- Synchrotron Radiation on the solar B-field as a new component (Orlando et al. 2023)
- Unexpected asymetry in the disk emission (Arsioli & Orlando 2024)
- … ?

References to our works

Arsioli & Orlando (2024) ApJ 962, 52 - *Unexpected asymmetry of the solar emission during magnetic field reversal*

Orlando, Petrosian, Strong (2023) ApJ 943, 173 - *A New Component from the Quiet Sun from Radio to Gamma Rays: Synchrotron Radiation by Galactic Cosmic-Ray Electrons*

De Menezes, Orlando et al. (2021) MNRAS 507, 680 - *Gamma-rays from stars with Fermi LAT*

Orlando & Strong (2021) JCAP 04, 004 - *Refining model of the solar emission*

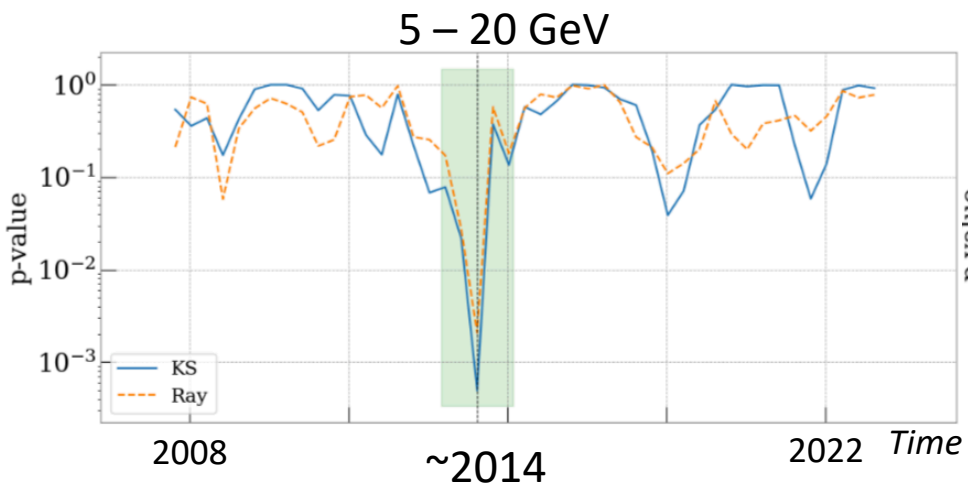
Abdo et al (2011) ApJ 734, 116 – *Observations of the Sun with Fermi LAT data*

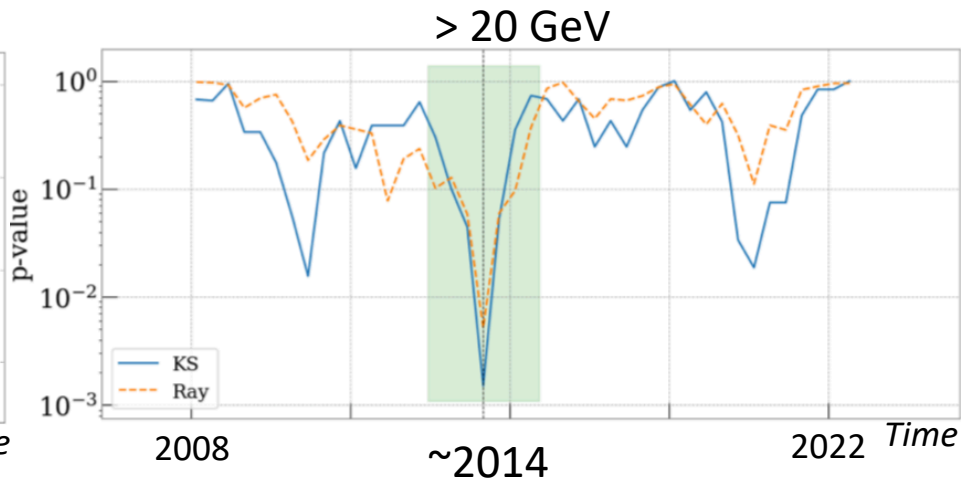
Orlando & Strong (2008) A&A 480, 847 - *First detection of the quiet Sun in gamma rays*

Orlando & Strong (2007) Ap&SS 309, 359 - *First theory of the extended inverse compton emission from the Sun and stars*

Thank you for your attention

Results: Asymmetry

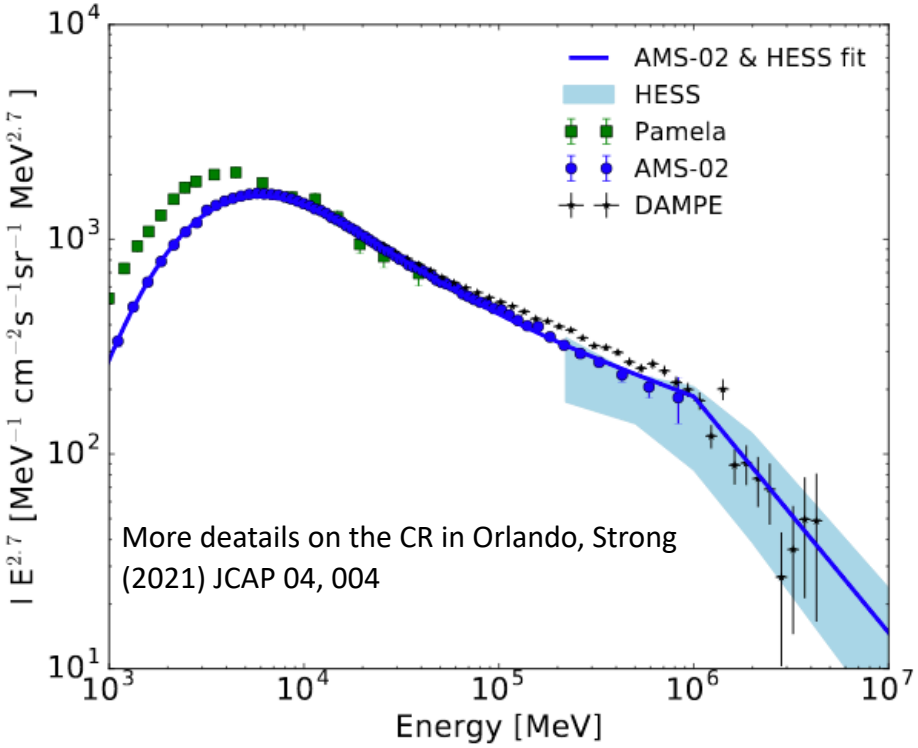




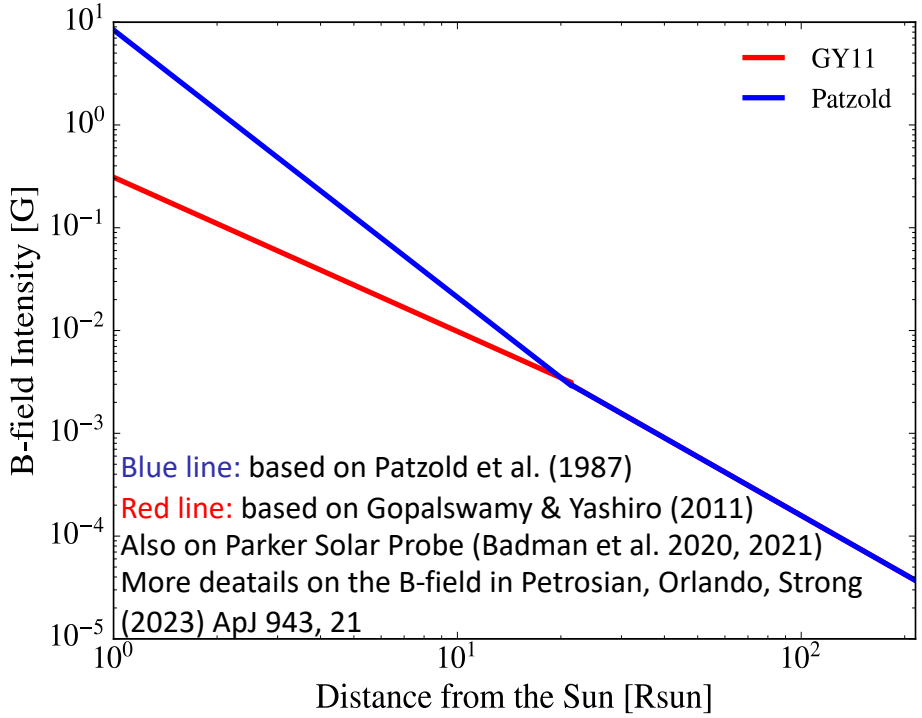
Kolmogorov Smirnov and Rayleigh statistical tests

Synchrotron Emission Modeling

CR e-

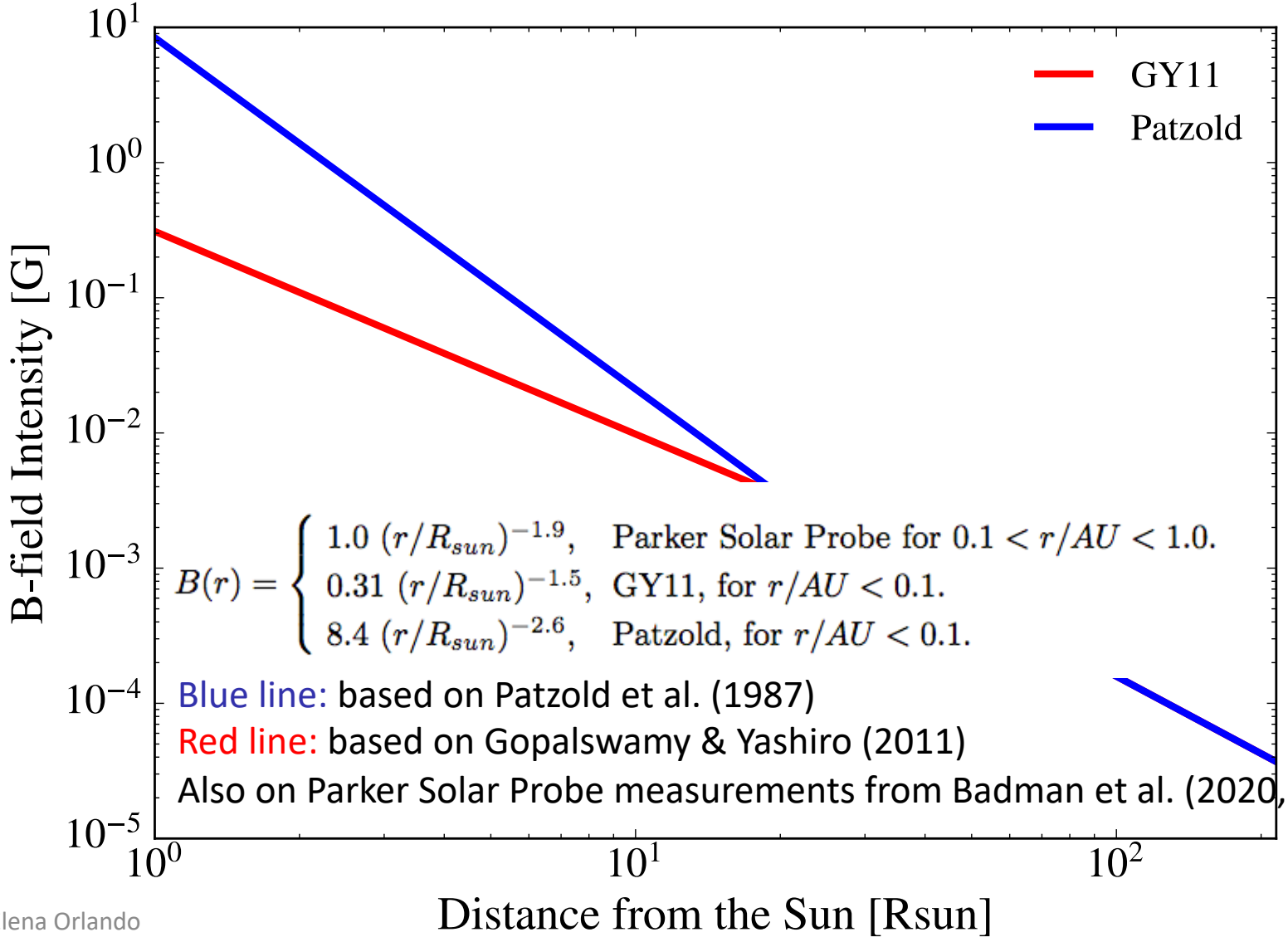


B-field



Orlando, Petrosian, Strong 2023

Solar B-field



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).