A WEAK FERMI GAMMA-RAY EVENT ASSOCIATED WITH A HALO CME AND A TYPE II RADIO BURST

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MOTIVATION

• The Sustained Gamma-ray Emission (SGRE) from the Sun is closely associated type II radio bursts in the decameter-hectometric (DH) wavelengths (Share et al. 2018; Gopalswamy et al. 2018; 2019; 2020)

• There exists a quantitative relation between the SGRE and type II durations indicating that the shock responsible for type II burst can also accelerate >300 MeV protons that produce SGRE via neutral pion production (Gopalswamy et al. 2018)

• The number of type II bursts after the launch of Fermi/LAT is an order of magnitude larger than the number of SGRE events

• The question is: why don’t all DH type II bursts are associated with SGRE?

• While searching for potential SGRE signatures associated with DH type II bursts from Wind/WAVES, we came across an event on 2015 June 25. We show that this event is consistent with the SGRE – type II relationship
THE SGRE EVENT

- Type II burst in Wind/WAVES dynamic spectrum with superposed SGRE flux (>100 MeV) from Maximum Likelihood Method.
- GOES X-ray M7.9 flare (start: 08:02 UT, peak: 08:16 UT, end: 09:05 UT) from N09W42
- >100 MeV proton intensity along with the >100 MeV gamma-ray flux
- SGRE peak flux is only $2.21 \times 10^{-5}$ cm$^{-2}$ s$^{-1}$ (Background flux $\sim 1.66 \times 10^{-5}$ cm$^{-2}$ s$^{-1}$)
- SGRE duration: $3.1 \pm 0.79$ hr.
- Type II duration: $6.13 \pm 1.38$ hr; ending frequency: $250 \pm 100$ kHz
DURATION COMPARISON

- (a) Scatter plot between SGRE duration and type II ending frequency for 19 events with duration >3 h.
- (b) Scatter plot between SGRE duration and type II duration for 19 SGRE events
- The red data points: the 2015 June 25 SGRE event; agrees with the relationships
- The shaded areas correspond to 95% and 99% confidence intervals.

The longer the SGRE duration, the lower is the ending frequency.

The longer the type II duration, the longer is the SGRE duration.
THE SOLAR ENERGETIC PARTICLE EVENT

- >300 MeV protons needed for SGRE events
- The SEP event is weak: barely exceeds 10 pfu (>10 MeV protons)
- Barely discernible at >50 MeV
- Similar to the strong 2011 March 7 SGRE
- How is this possible?
CORONAL MASS EJECTION

SGRE Ends when the CME is \(~30\) Rs from the Sun

- SOHO/LASCO/C2 CME heading along position angle (PA) \(327^\circ\) from N09W42
- Halo CME
- Fast (sky-plane: \(1627\) km/s; deprojected: \(1805\) km/s)
- Fast enough to accelerate particles to \(>300\) MeV
- Eruption longitude well-connected to Earth
- The discordance between source latitude and CME direction (about \(60^\circ\) from the ecliptic)
- The shock nose, where higher-energy particles are energized, is not connected to Earth observer
- Thus the soft spectrum (see Gopalswamy et al. 2018 for a similar event on 2011 March 7)

The speed is similar to the typical CME speed \(\sim2000\) km/s in SGRE events with duration \(>3\) h
WHY THE CME NON-RADIAL MOTION?

- The magnetic environment of the eruption region is highly inhomogeneous
- The CME moves away from the large closed field region and the open field (coronal hole) region
- Such deflections are well known caused by pressure gradients surrounding the eruption region

Eruption from AR 12371

SDO/AIA Image at 171 A + PFSS field lines
The SGRE fluence is correlated with CME speed (Gopalswamy et al. 2019)

The 2015 June 25 SGRE event (red data point) agrees with the CME speed – SGRE fluence relationship

\[ Y = 6X - 2 \]

(Y is the SGRE fluence in cm\(^{-2}\) and \(X\) is log of speed in 1000 km/s)
### OTHER CMEs FROM AR 12371

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<th>Date</th>
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- SGRE events from the two highest-speed halos from AR 12371
- The fluence of the June 21 event was the highest among Fermi/LAT
- Why is this so?
COMPARING TYPE II BURSTS

Stronger Type II results in stronger, longer SGRE
SUMMARY

• The 2015 June 25 SGRE event had all the typical signatures of an SGRE event: a fast halo CME, a metric to kilometric type II radio burst, and a large SEP event.

• The SGRE event was identified based on the existence of type II burst, further strengthening the shock connection.

• The SGRE event is a strong evidence for the presence of >300 MeV protons in the event.

• The SEP event observed at Earth was of soft spectrum with not many high-energy particles observed because of the non-radial propagation of the associated CME.

• The previous SGRE event from the same active region occurred on June 21. This was much stronger event and had a more intense and broadband type II burst, consistent with the shock acceleration of >300 MeV particles.
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