Solar flares and coronal mass ejections

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List of HESPE papers with Graz contribution:

- Pre-flare activity and magnetic reconnection during an eruptive flare
- Two-stage eruption, secondary heating
- Relation between CME dynamics and non-thermal flare characteristics
- Solar “tornadoes” and filament formation
- Multiple flare activity and filament eruption related with HXRs
- Imaging of magnetic reconnection
- Energy partitioning
- Motions in CME-Flare Current Sheet
1) Solar “magnetic tornadoes”
   - Ongoing work

2) Magnetic reconnection and energy release in flares

3) Relation between CME dynamics and flare characteristics
1) Solar „magnetic tornadoes“
Hypotheses:
- Rotating vertical magnetic structures
- Related to the formation of filaments
- Rotation enforces magnetic twist, which eventually may lead to eruption
Solar “magnetic tornadoes”

Relation to filament barbs and filament formation.
Idea of vortex-driven filament formation and eruption.

Solar “magnetic tornadoes”

Vortex at supergranular junctions
Attie et al. (2009)
Wedemeyer-Böhm et al. (2012):
Magnetic tornadoes are related to vortex motions in lower layers („chromospheric swirls“)
Transport energy to corona (heating)
http://www.solartornado.info/

SST / CRISP observations
Related papers & controversial discussion:

- **Solar “Tornadoes”**

- Latest support for rotating barbs:

- Objections:
  - Panasenco et al. 2013, *Solar Phys.* (plasma motion, oscillation or projection; not rotation)
Solar “magnetic tornadoes”
Su et al., ongoing study

- Evidence of rotational motion in tornado-like barbs via EIS/Hinode spectroscopy
  - Systematic red/blue shift pattern
Solar “magnetic tornadoes”
Su et al., ongoing study

- Evidence of rotational motion in tornado-like barbs via EIS/Hinode spectroscopy
  - Systematic red/blue shift pattern
  - Signs do not change for at least 3 hours → **not oscillation but rotation**
2) Magnetic reconnection and energy release
Imaging observations of magnetic reconnection

- GOES C2.3 flare on 17-Aug-2011; confined event (no CME detected)
- Comprehensive imaging of reconnection by SDO/AIA EUV and RHESSI X-rays
Cool loops merge and disappear.

Imaging observations of magnetic reconnection
AIA 131 Å images show plasma at ~10 MK in newly formed loops (re-connected).

Imaging observations of magnetic reconnection
Imaging observations of magnetic reconnection
Magnetic reconfiguration: A-B and C-D → A-C (shrinking) and B-D (expanding)

Inflow loops, outflow loops, flare ribbons and X-ray sources: comprehensive picture of reconnection & energy release from AIA and RHESSI

17-Aug-2011 04:10 UT
04:15 UT
04:19 UT
04:20 UT

4–10 keV
10–20 keV

Imaging observations of magnetic reconnection
Double coronal X-ray sources: first seen in RHESSI data alone
(Sui & Holman 2003, Veronig et al. 2006)

Imaging observations of magnetic reconnection

RHESSI images: MEM NJIT
Imaging observations of magnetic reconnection

AIA 131 + RHESSI

SDO/AIA 131 Å
17-Aug-2011 04:00:09.620 UT

RHESSI 4-10 keV
RHESSI 10-20 keV
RHESSI X-ray spectra:

- Fitting model: two isothermal component
- May indicate a small contribution of heating from non-thermal electrons.

Imaging observations of magnetic reconnection
Inflow profiles (along C1)

Outflow profiles (along C2)

Imaging observations of magnetic reconnection
Imaging observations of magnetic reconnection

Inflow:
- accelerating
- non-uniform
- non-steady
- asymmetric

GOES flux started decreasing after last inflows were seen → Energy input stopped

Estimated reconnection rate changes with time: ~0.05-0.5

\[ M_A = \frac{V_{in}}{V_A} \approx \frac{V_{in}}{V_{out}} \]
3) Relation between CMEs and flares
CME dynamics and nonthermal flare characteristics

CME kinematics from combined STEREO EUVI, COR1, COR2 observations.
CME dynamics and nonthermal flare characteristics

STEREO EUVI & COR1 & COR2:
- overlapping FOV
- high cadence
CME dynamics and nonthermal flare characteristics

10-Feb-2010 CME & flare

CME height vs time

CME velocity vs time

CME acceleration vs time

RHESSI flare X-rays

6-12 keV
12 - 15 keV
25 - 50 keV

Start Time (08-Feb-10 02:30:00)
CME dynamics and nonthermal flare characteristics


3-Jun-2007

- CME height vs time
- CME velocity
- CME acceleration

10-Feb-2010

- Flare GOES SXR & derivative
- Flare RHESSI HXR flux
CME dynamics and nonthermal flare characteristics

1) CME kinematics: h(t), v(t), a(t); v(h), a(h).

2) Derived and fitted RHESSI spectra during peak of the associated flare.

3) Statistical relation between CME and flare properties.
CME dynamics and nonthermal flare characteristics

- CMEs with larger peak acceleration are associated with flares with harder electron spectra and larger electron fluxes.

- CMEs erupting from low in the corona (stronger fields) are associated with flares with harder electron spectra and larger electron fluxes.
- CME acceleration starts before fast particle acceleration in associated flare (~85%).
- Peak of CME acceleration and flare energy release occur closely synchronized in impulsive CMEs, in 75% \( |\Delta t| < 5 \text{ min} \)
CME dynamics and nonthermal flare characteristics

- Estimate of the current sheet length at the onset of impulsive magnetic reconnection and particle acceleration.

$H \sim 21 \pm 7 \text{ Mm}$
Two-stage eruption, secondary heating
Su, Dennis, Holman et al. 2012b, ApJL

Case study: Secondary heating phase in flare is related to delayed CME eruption.
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