Hurrikans im Sonnenwind: neueste Erkenntnisse

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just came back from...

UC Berkeley, CA, USA

Graz in Space 2012

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http://www.uni-graz.at/~moestlc/


Mars
Touching
mars
Sampling
mars
s Science Laboratory Rover
Full-Scale Model
Launch
Fall, 2011
Landing
Summer, 2012
Several Years

In the news

- Sonnensturm = „koronaler Masseauswurf“
- “coronal mass ejection“ CME

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8 March 2012 Last updated at 12:55 ET

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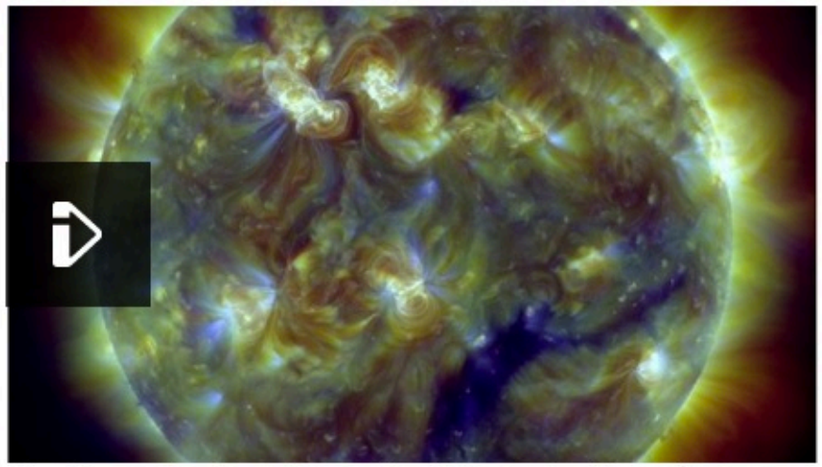
Solar storm passes without incident



Nasa image showing extreme ultraviolet wavelengths on Sun's surface

A solar storm in the Earth's magnetic field has passed by the Earth with minimal effects, experts say.

"The freight train has gone by, and is still going by, and now we're just watching for how this is all going to shake out," said Joseph Kunches, a scientist with US weather agency Noaa.

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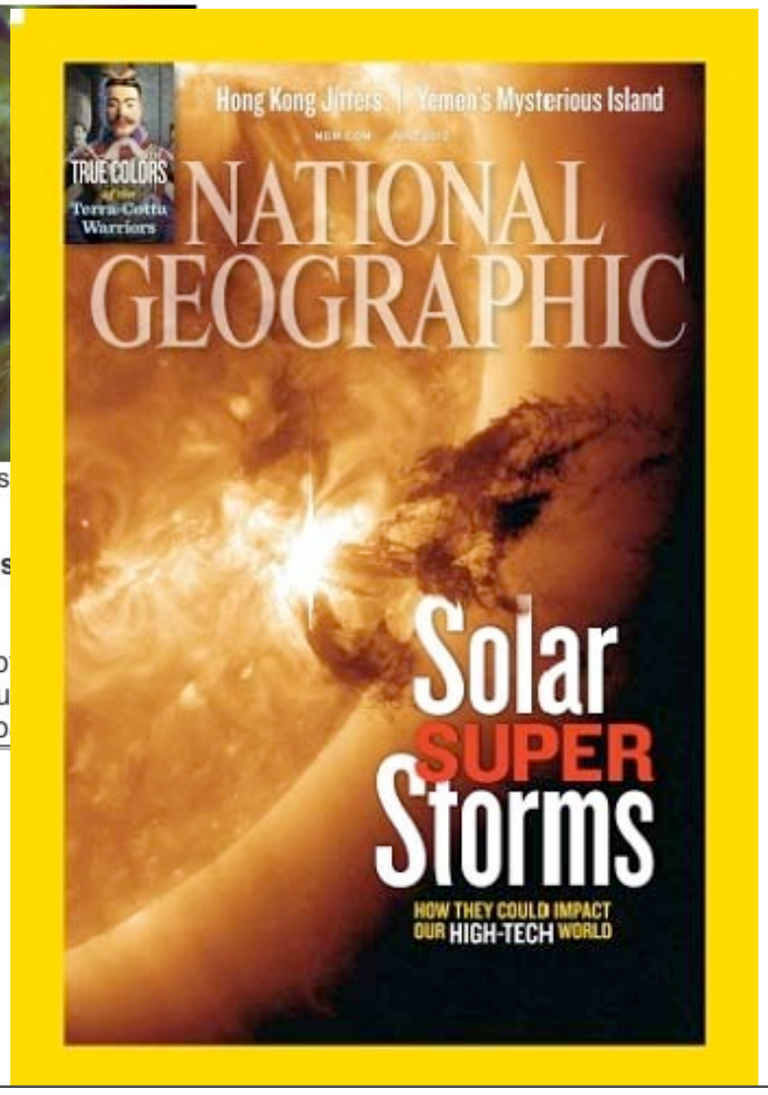

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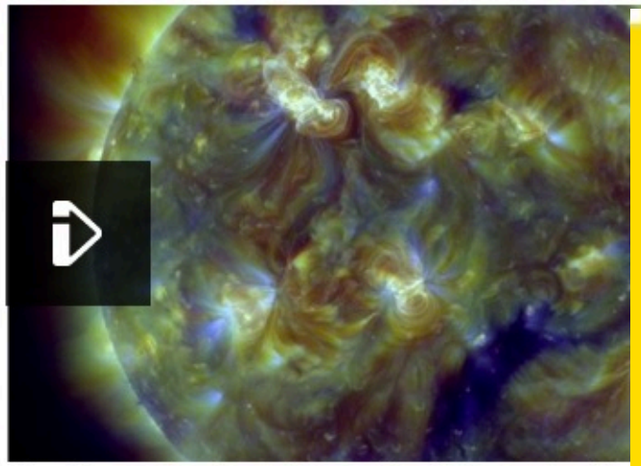

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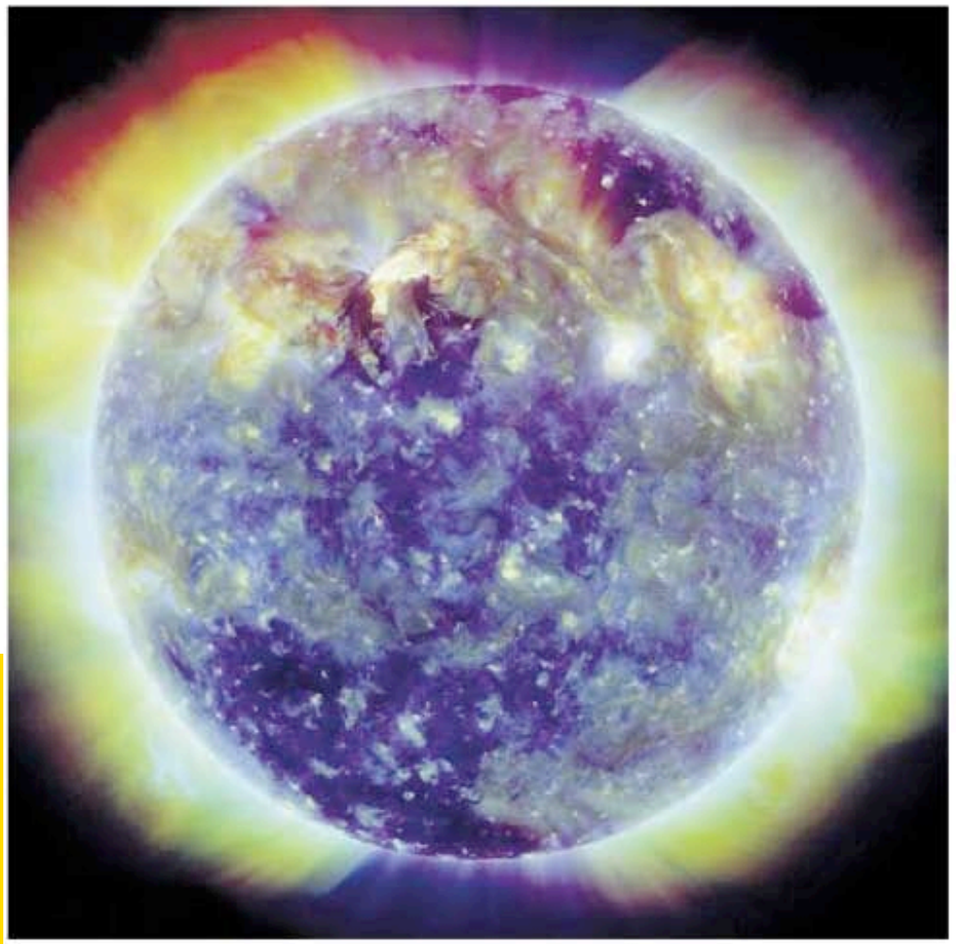
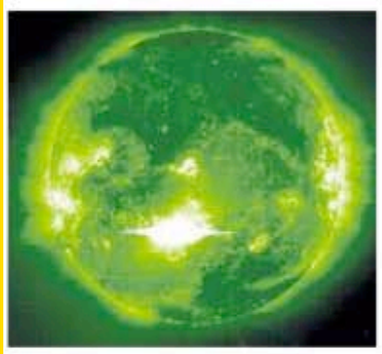
10 | INTERNATIONAL

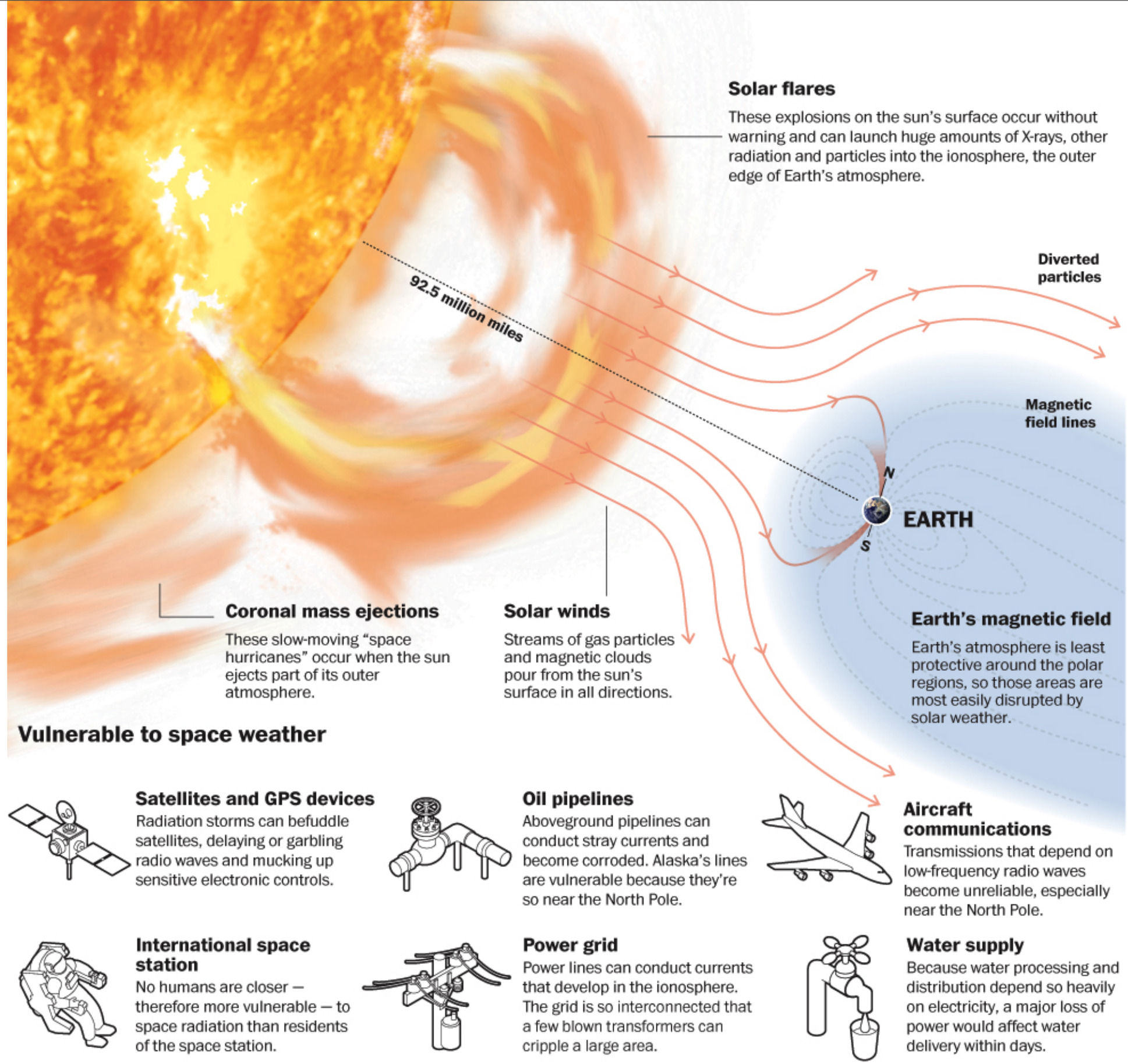
WENN DIE SONNE STÜRMT



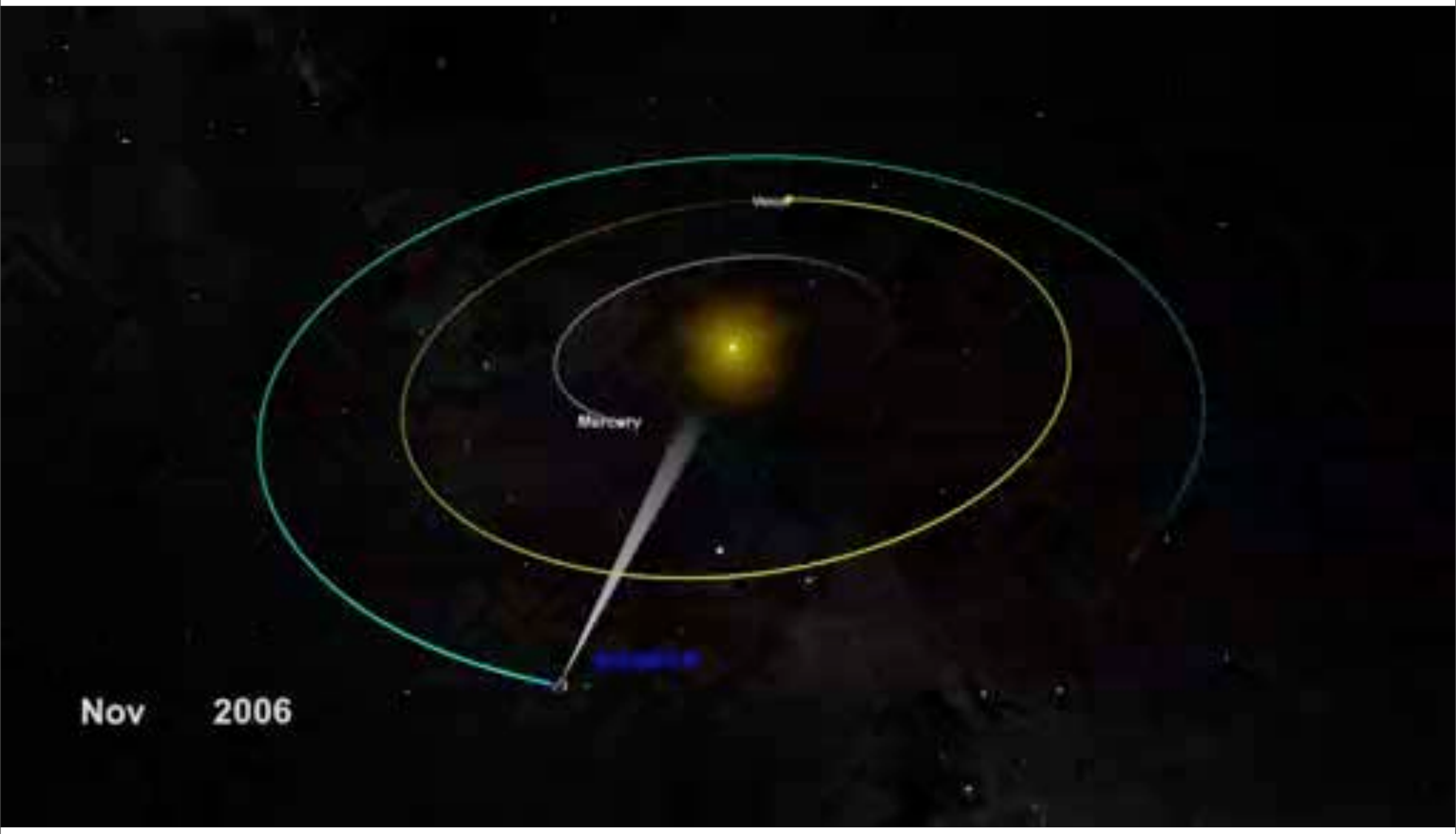


Lichtshow. Die Erde ist von einem der stärksten Sonnenstürme der vergangenen Jahre getroffen worden. Das Gebiet auf der Sonne, in dem die aktuelle Eruption erfolgte, ist aber weiter aktiv. Am Wochenende ist die Wahrscheinlichkeit für gewaltige Sonnenstürme, die die Erde direkt treffen, am höchsten. Solche Eruptionen können zum Ausfall von Flügen und Stromnetzen führen und Satelliten beeinträchtigen.

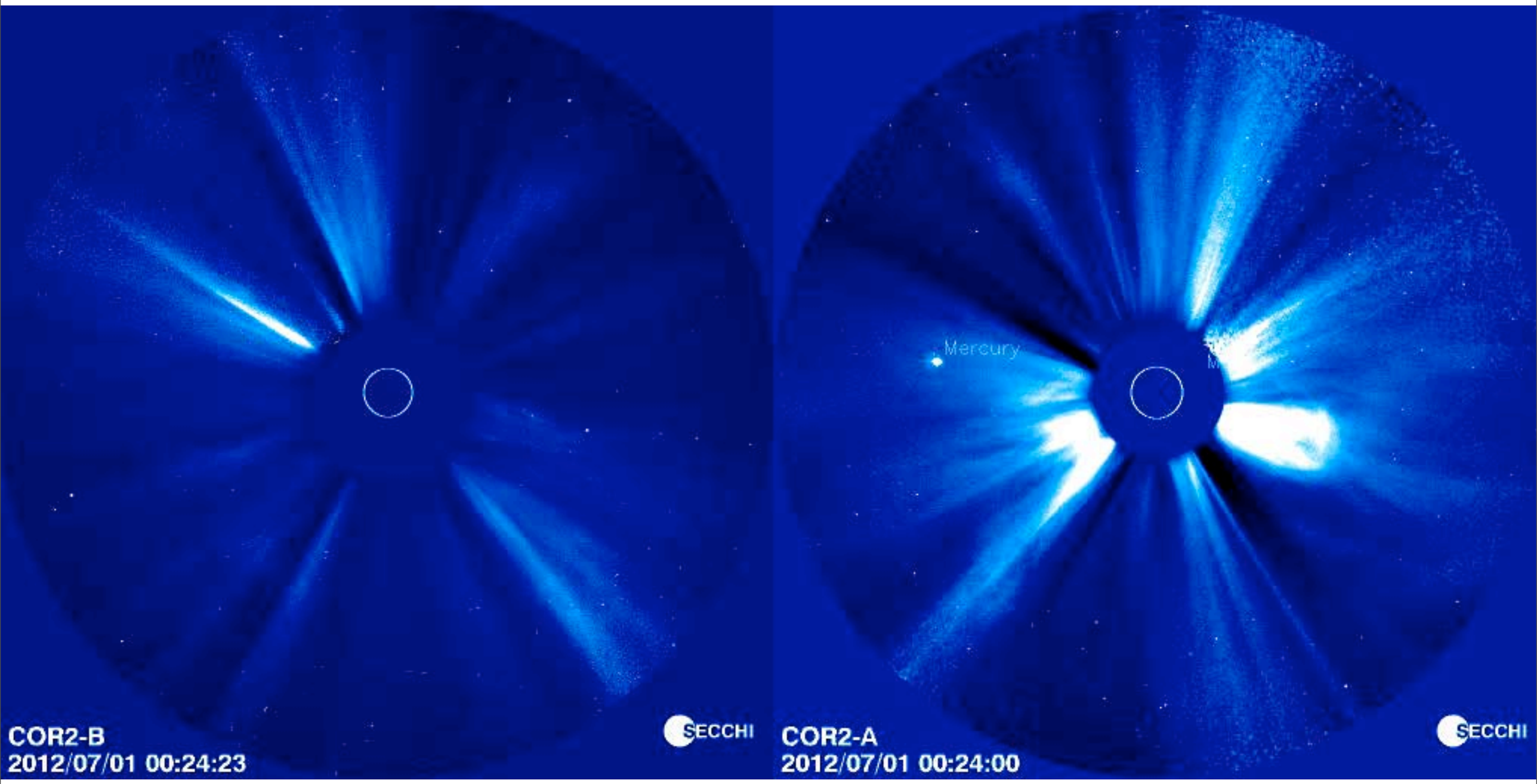
NASA


Solar flares
These explosions on the sun's surface occur without warning and can launch huge amounts of X-rays, other radiation and particles into the ionosphere, the outer edge of Earth's atmosphere.
92.5 million miles
Diverted particles
Magnetic field lines
N
EARTH
S
Earth's magnetic field
Earth's atmosphere is least protective around the polar regions, so those areas are most easily disrupted by solar weather.
Coronal mass ejections
These slow-moving "space hurricanes" occur when the sun ejects part of its outer atmosphere.
Solar winds
Streams of gas particles and magnetic clouds pour from the sun's surface in all directions.
Vulnerable to space weather
Satellites and GPS devices
Radiation storms can befuddle satellites, delaying or garbling radio waves and mucking up sensitive electronic controls.
Oil pipelines
Aboveground pipelines can conduct stray currents and become corroded. Alaska's lines are vulnerable because they're so near the North Pole.
Aircraft communications
Transmissions that depend on low-frequency radio waves become unreliable, especially near the North Pole.
International space station
No humans are closer — therefore more vulnerable — to space radiation than residents of the space station.
Power grid
Power lines can conduct currents that develop in the ionosphere. The grid is so interconnected that a few blown transformers can cripple a large area.
Water supply
Because water processing and distribution depend so heavily on electricity, a major loss of power would affect water delivery within days.
Sun and Earth are shown to approximate scale, but distance is not to scale.

NASA STEREO



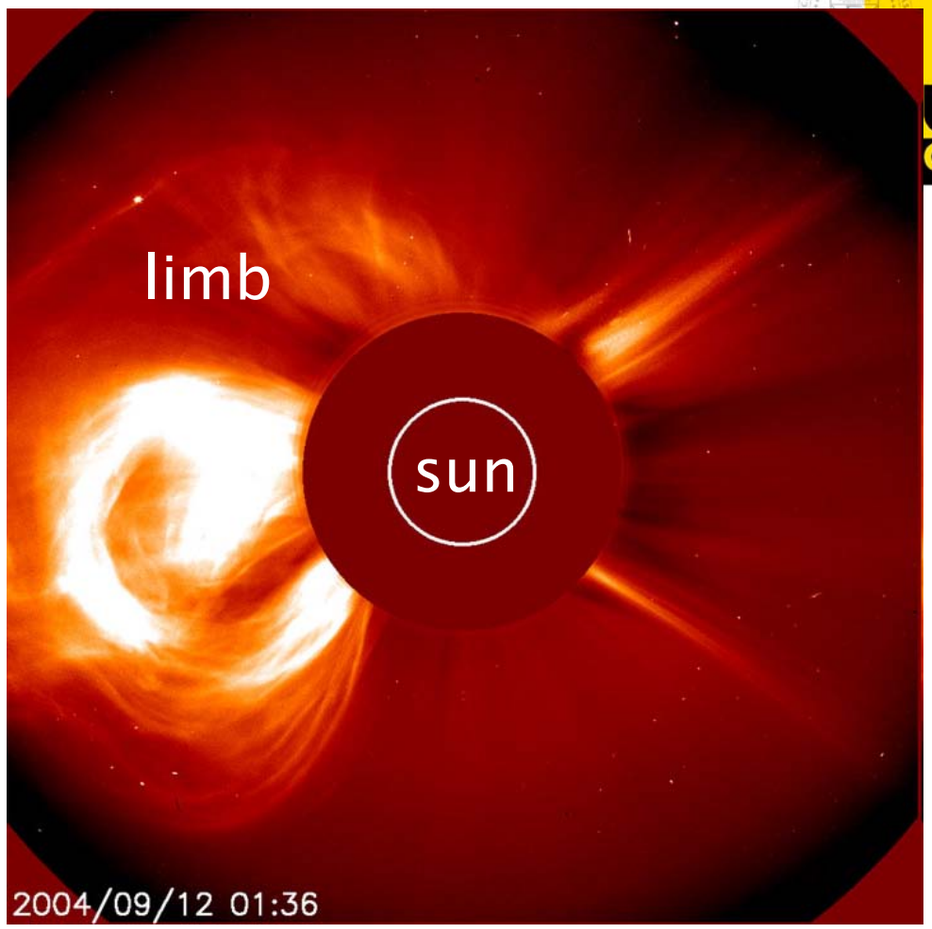
NASA STEREO COR2 Juli 2012

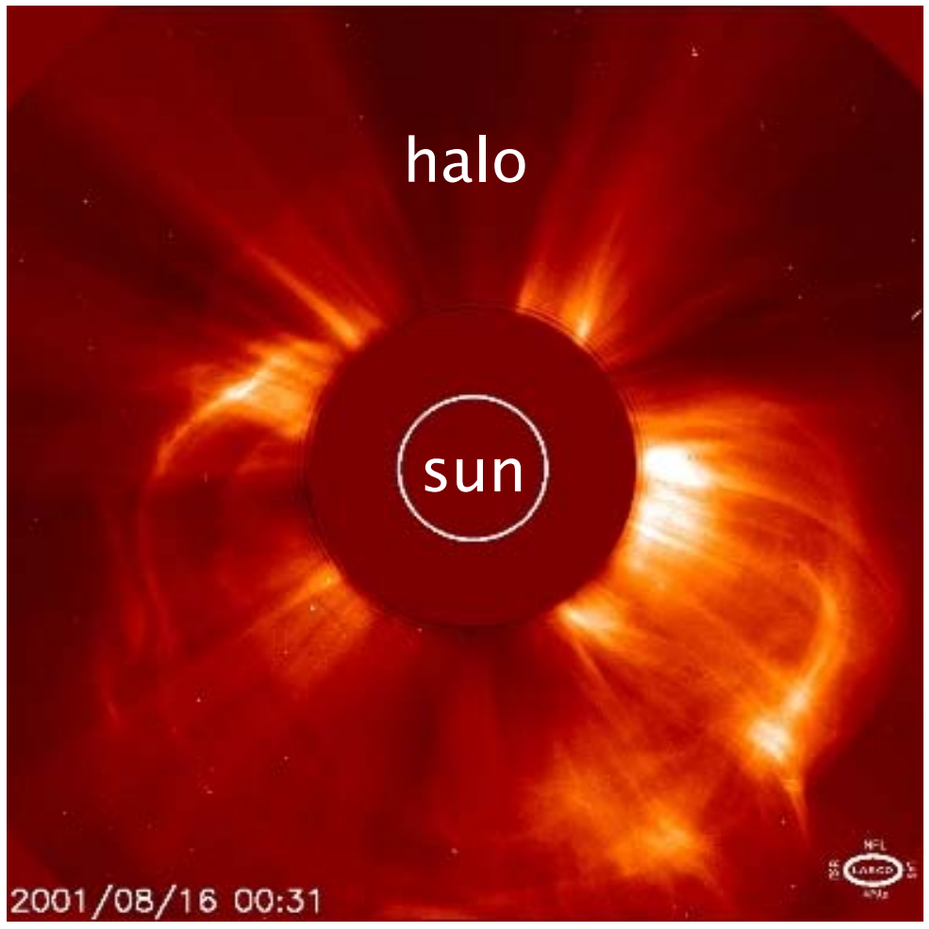


Was man über CMEs weiß...

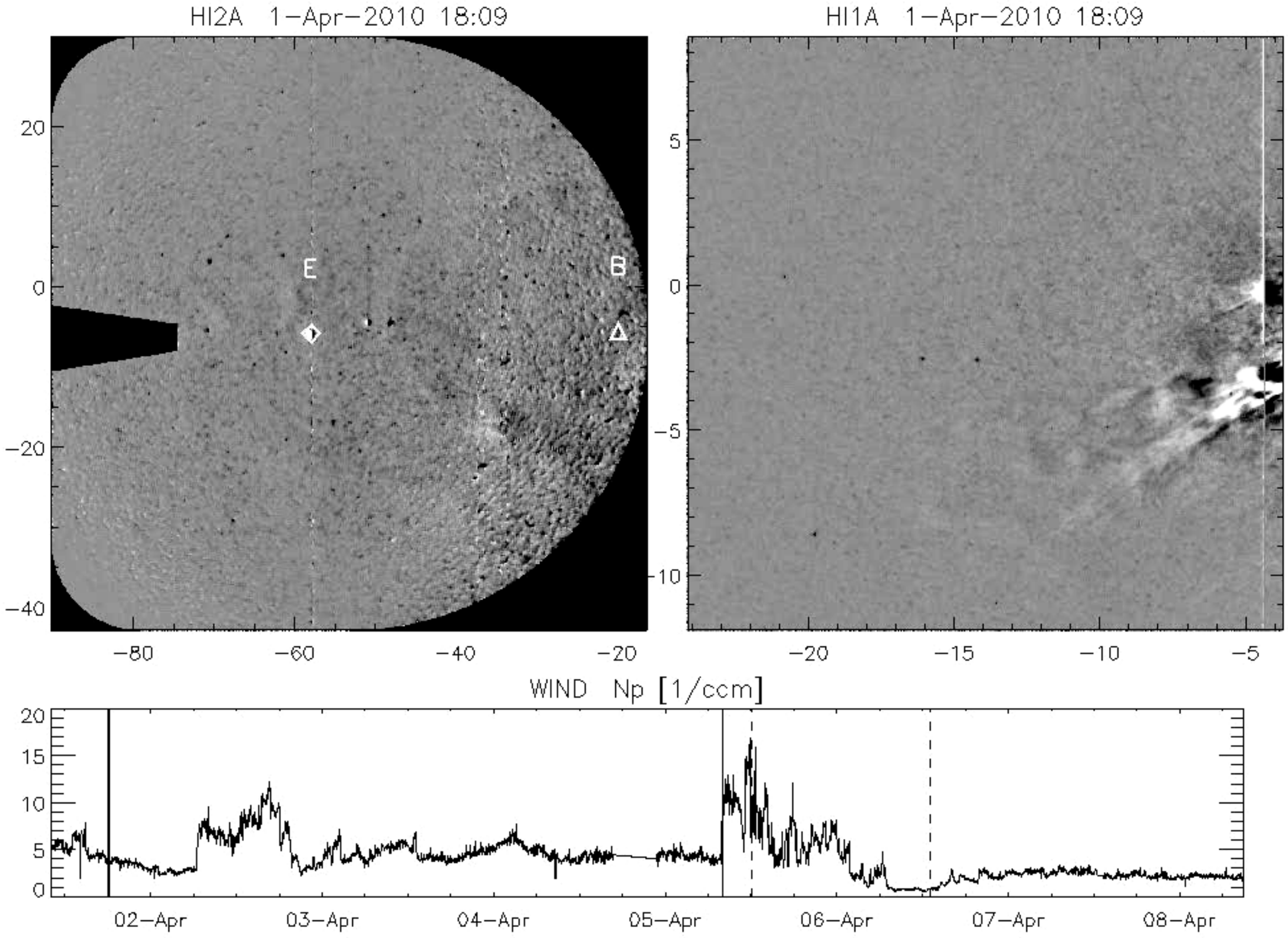
Facts

- 1971 entdeckt (OSO-7)
- Größe: Sonne: ~ Sonnenradius (110 Erdradien)
  1 AU: bis 0.5 AU (oder ~11 000 Erdradien)
- Masse ~10^{12} kg =
  Weltjahresproduktion von Rohöl, ein Teelöffel eines Neutronensterns, 1/1000 Mount Everest
- Energie: bis 10^{25} J =1/10 der Gesamtabstrahlung der Sonne pro Sekunde, Erd-Hurricanes 10^{19} J pro Tag
- Magnetfeld: bei 1 AU: < 60 nT. Erdmagnetfeld am Boden: 10^{5} nT Spielzeugmagnet: 10^{7} nT
- V: 200 – 3500 km/s (Millionen km/h)
  Sonne-Erde: 14 h – 5 Tage
- CMEs sind Teilchenbeschleuniger!
  energiereiche Teilchen haben 10% der CME Energie





schnelle CMEs treiben Stosswellen



Möstl et al. 2010 GRL

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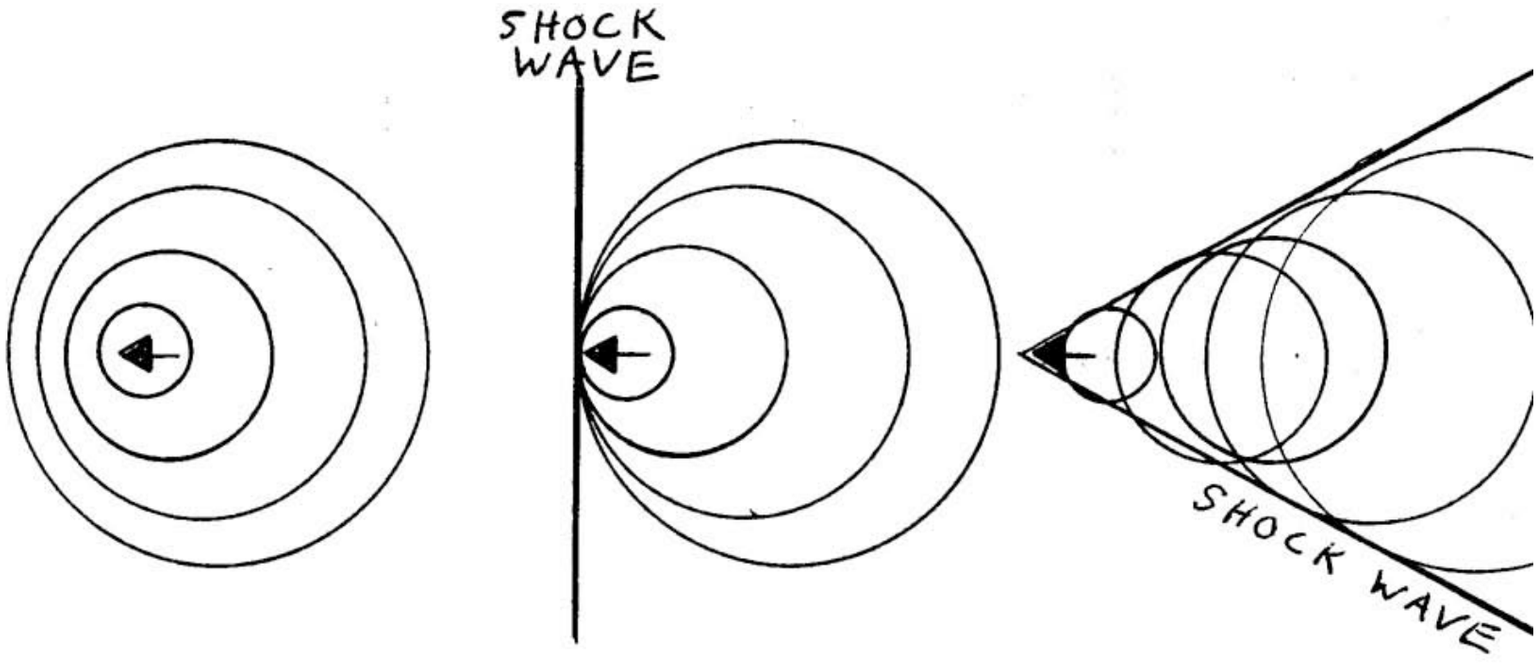
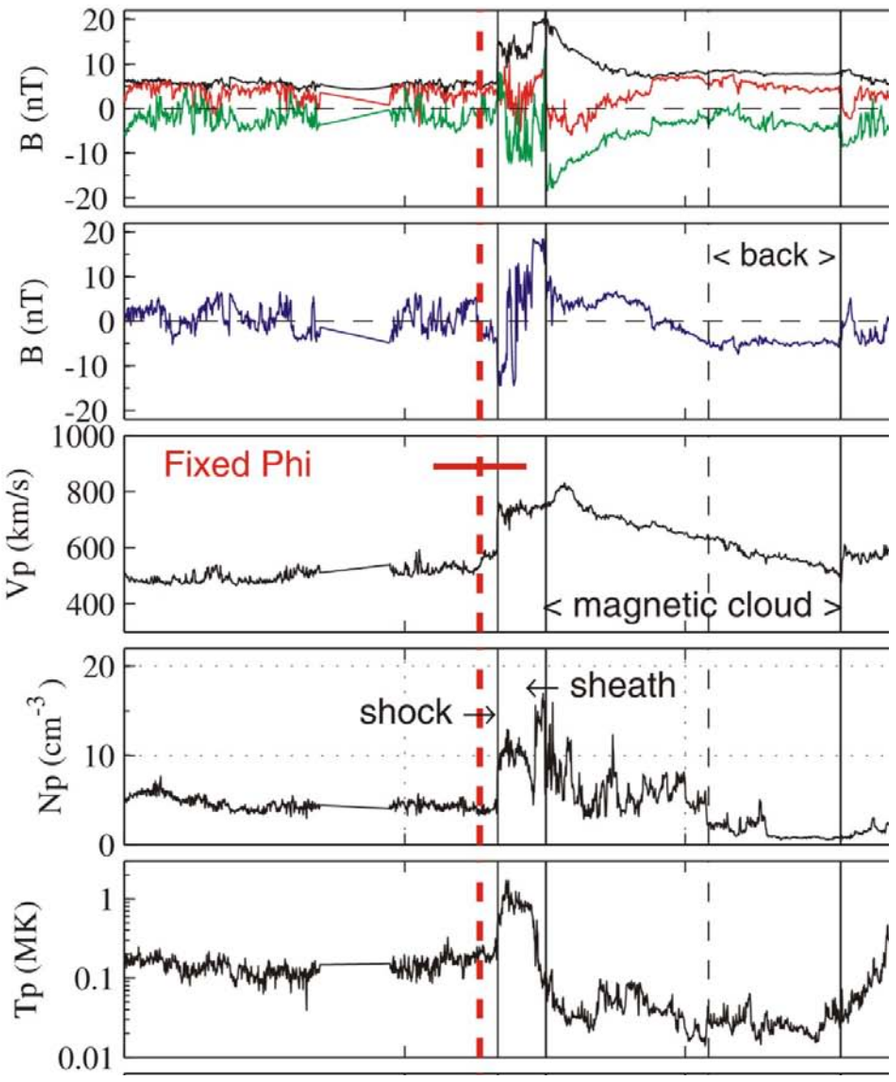
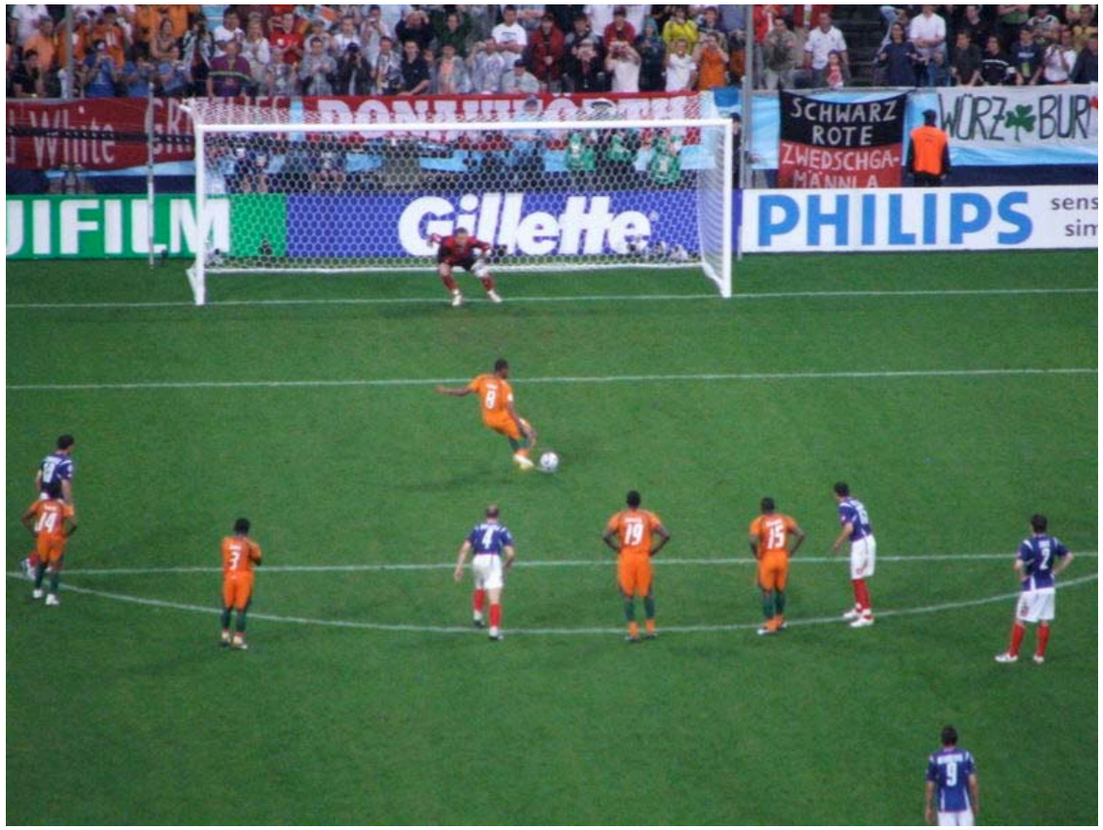
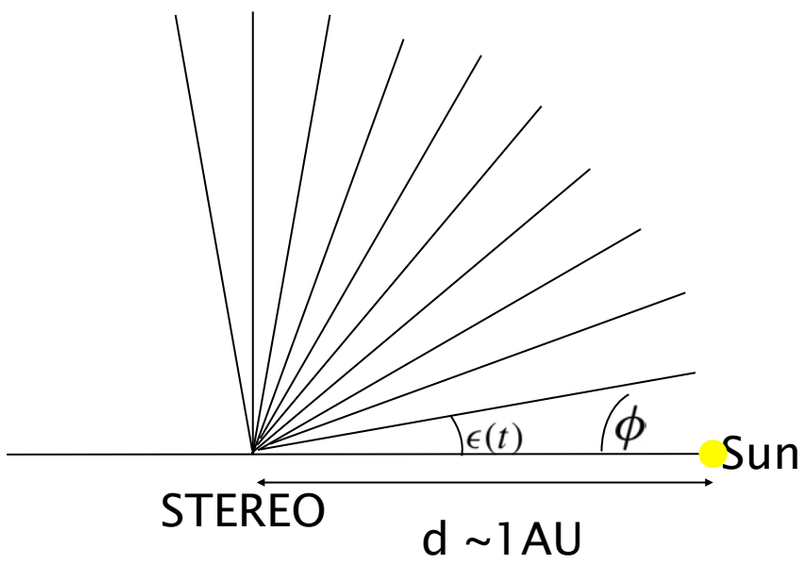




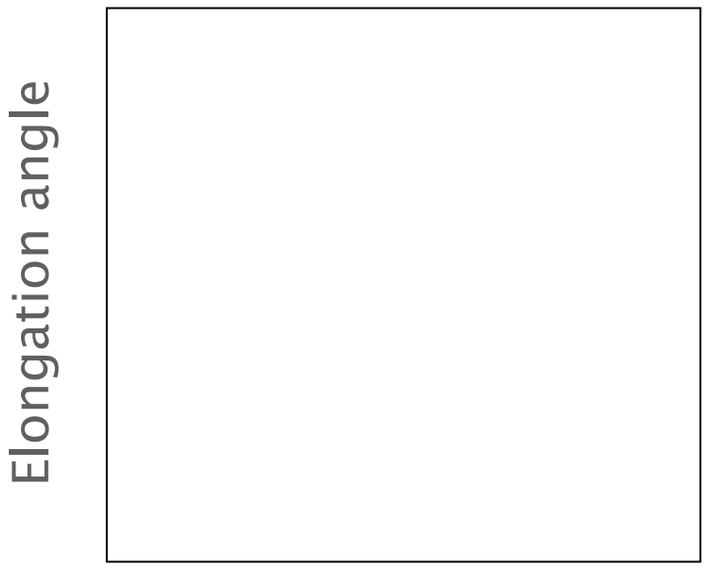
Möstl et al. 2010 GRL

Geschwindigkeit und Richtung vorhersagen





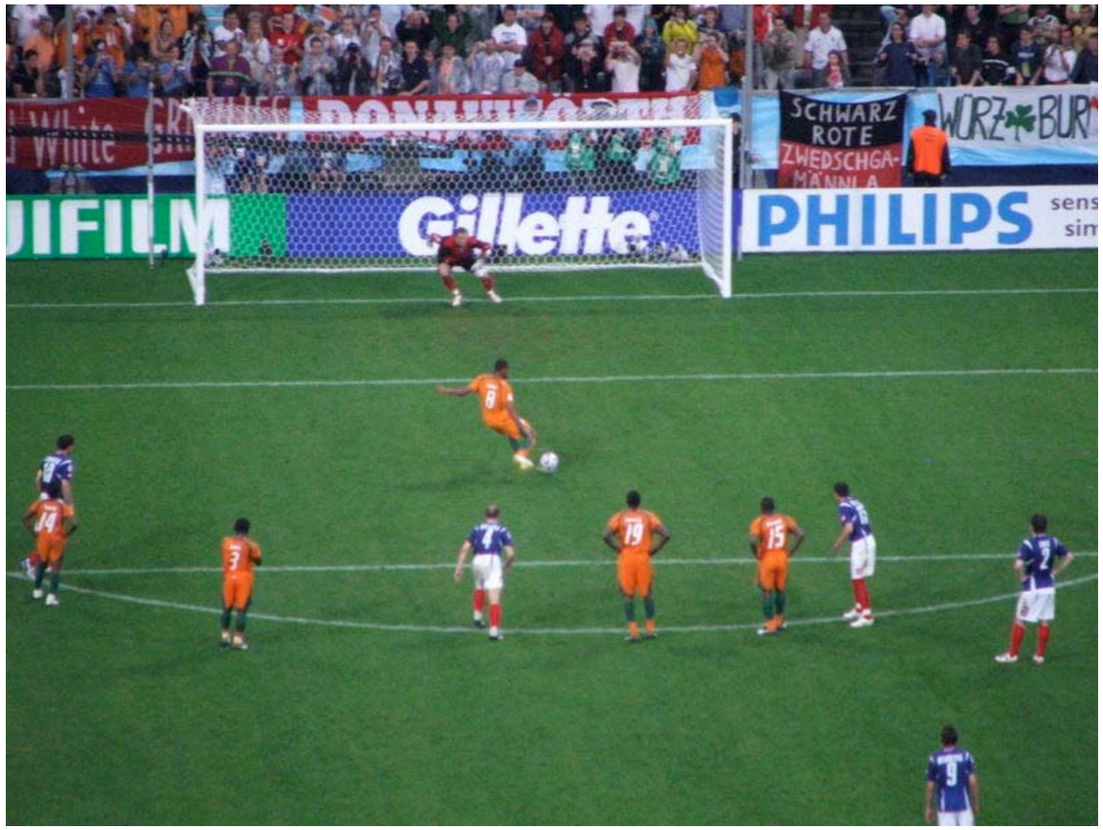
Rouillard et al., 2008, GRL

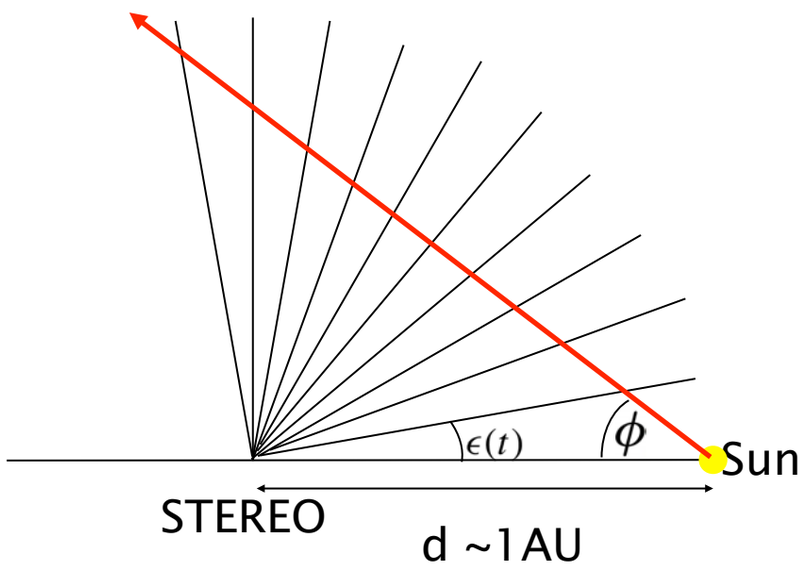


assumptions:
constant speed
and direction

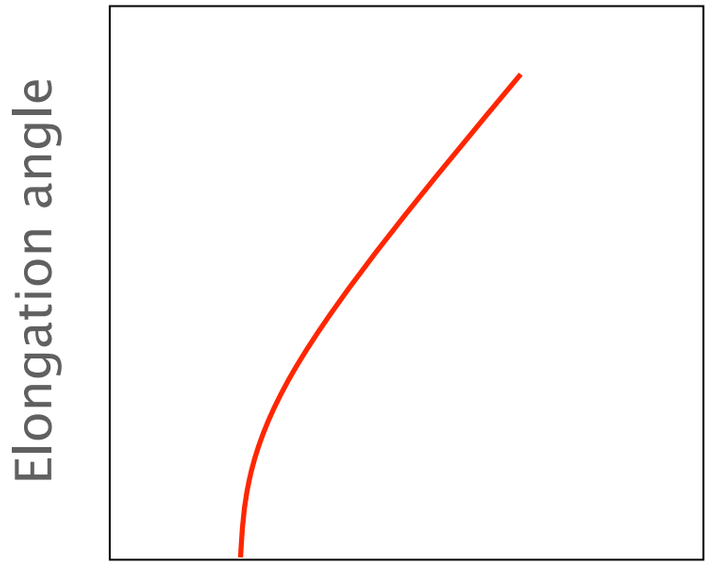
$$\epsilon(t) = \arctan\left(\frac{V_{FP} t \sin(\phi_{FP})}{d - V_{FP} t \cos(\phi_{FP})}\right),$$

Geschwindigkeit und Richtung vorhersagen





Rouillard et al., 2008, GRL



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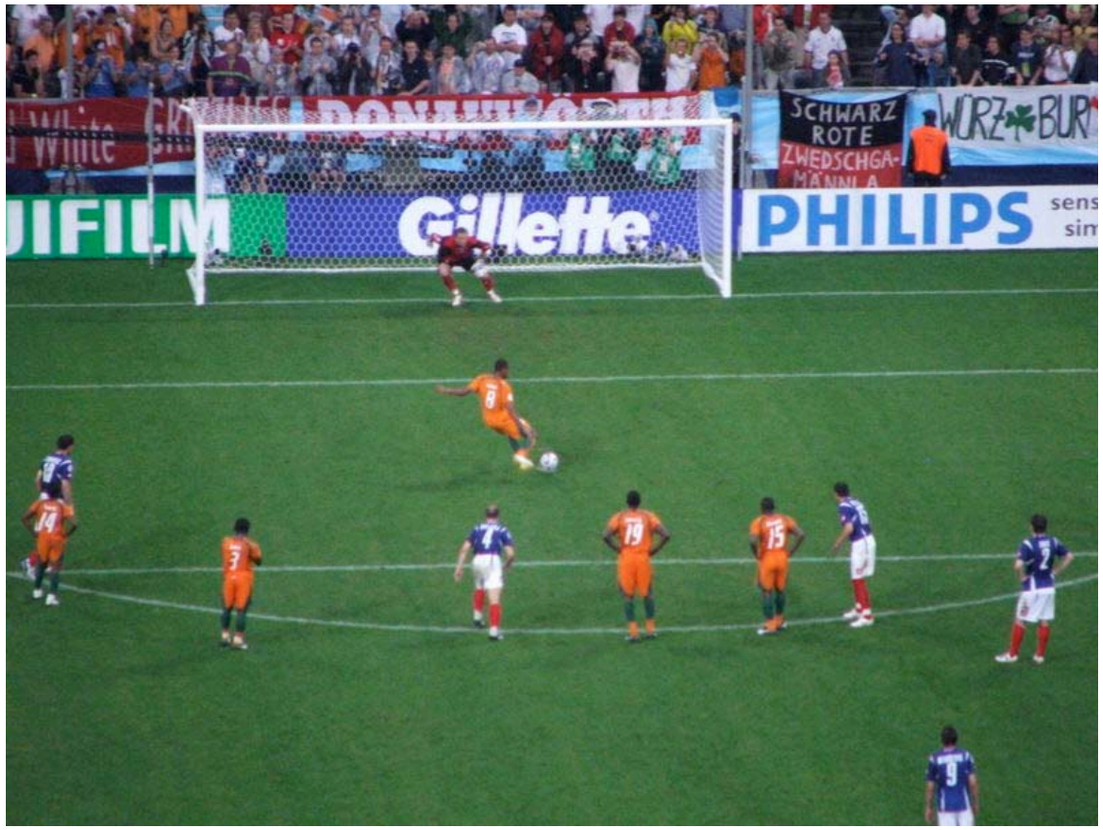
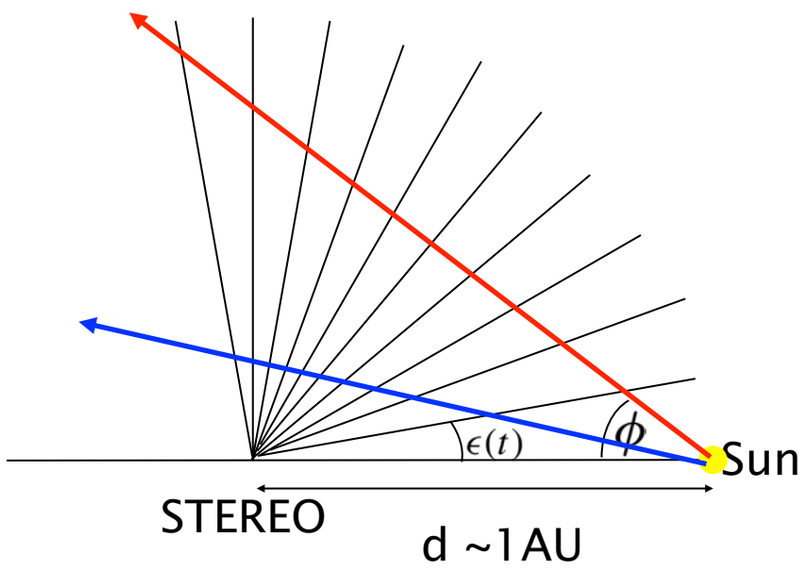
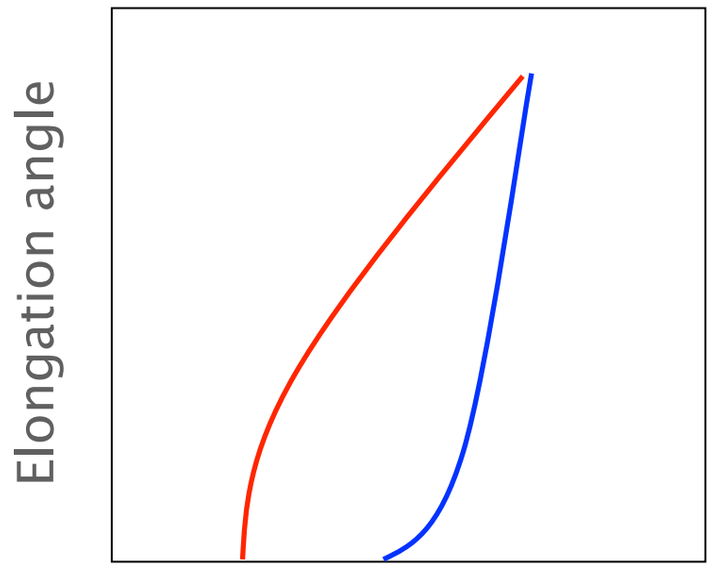




Rouillard et al., 2008, GRL



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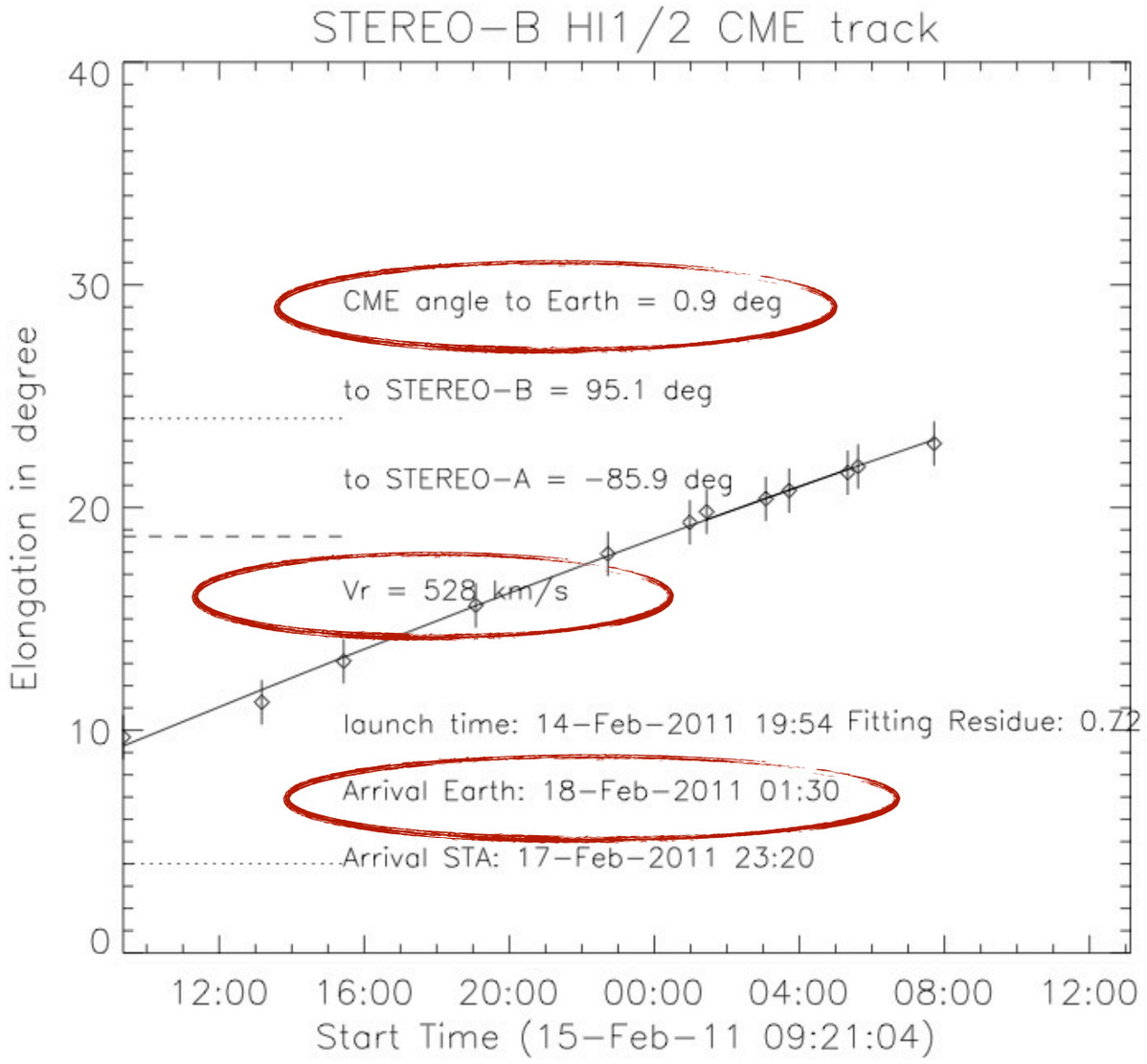
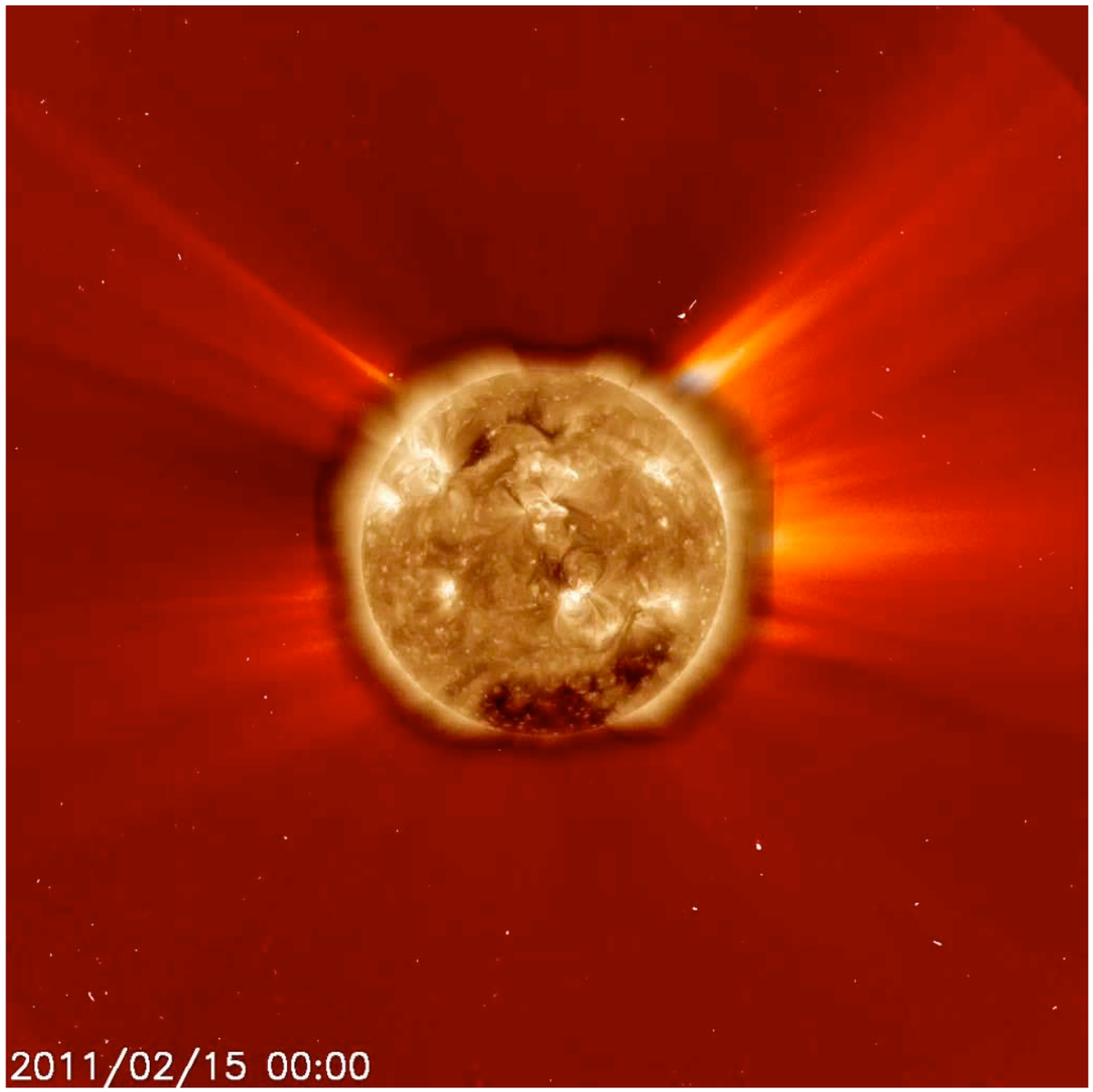
Echtzeit Vorhersage

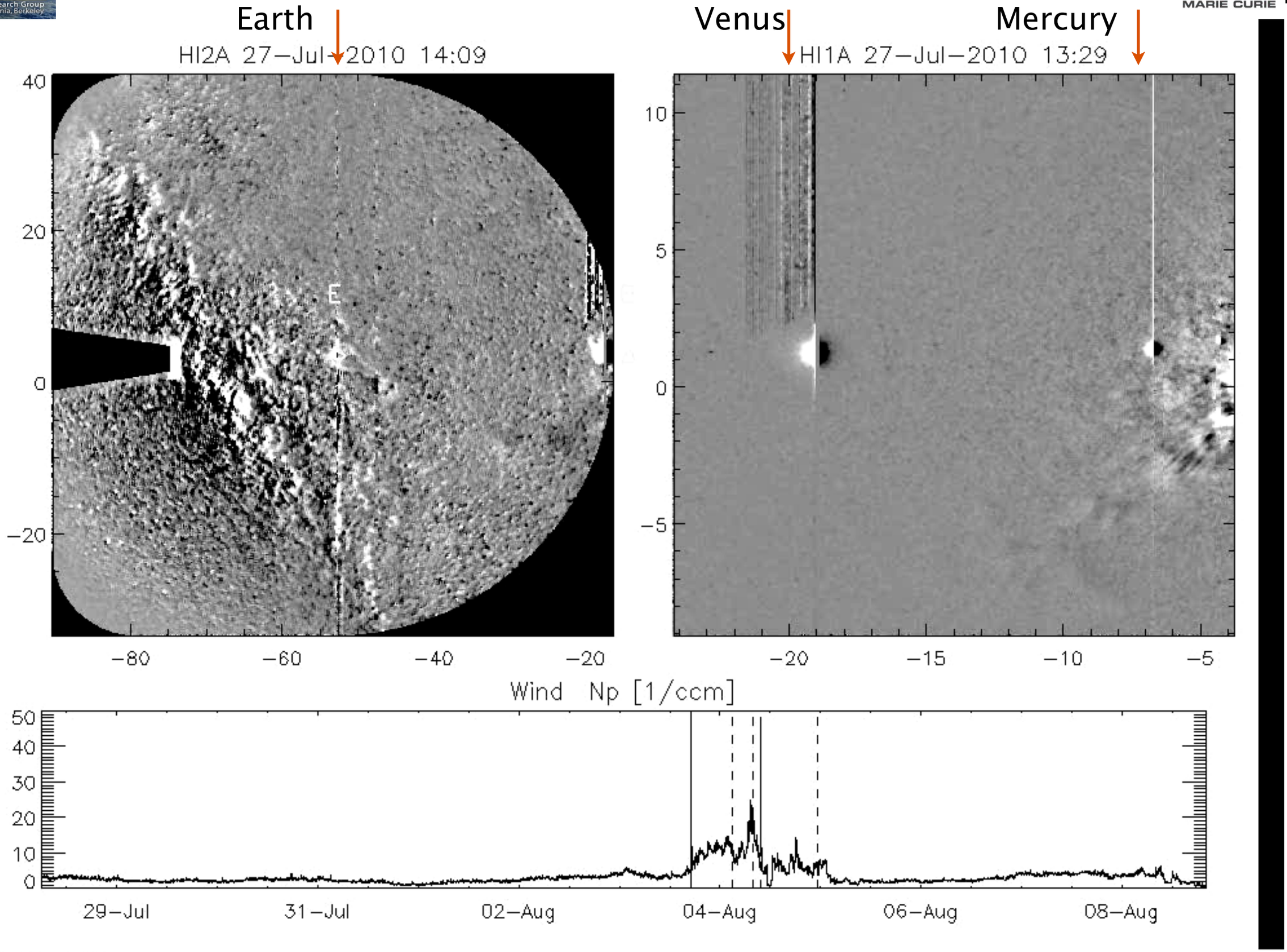
- CME am 15 Feb 2011 – erstes X-flare des neuen Sonnenzyklus
- Vorhersage: Ankunft 18 Feb 2011 01:30 (30h vor Ankunft weggeschickt)
- tatsächliche Ankunft 18 Feb 2011 00:48 – nur 42 min daneben!





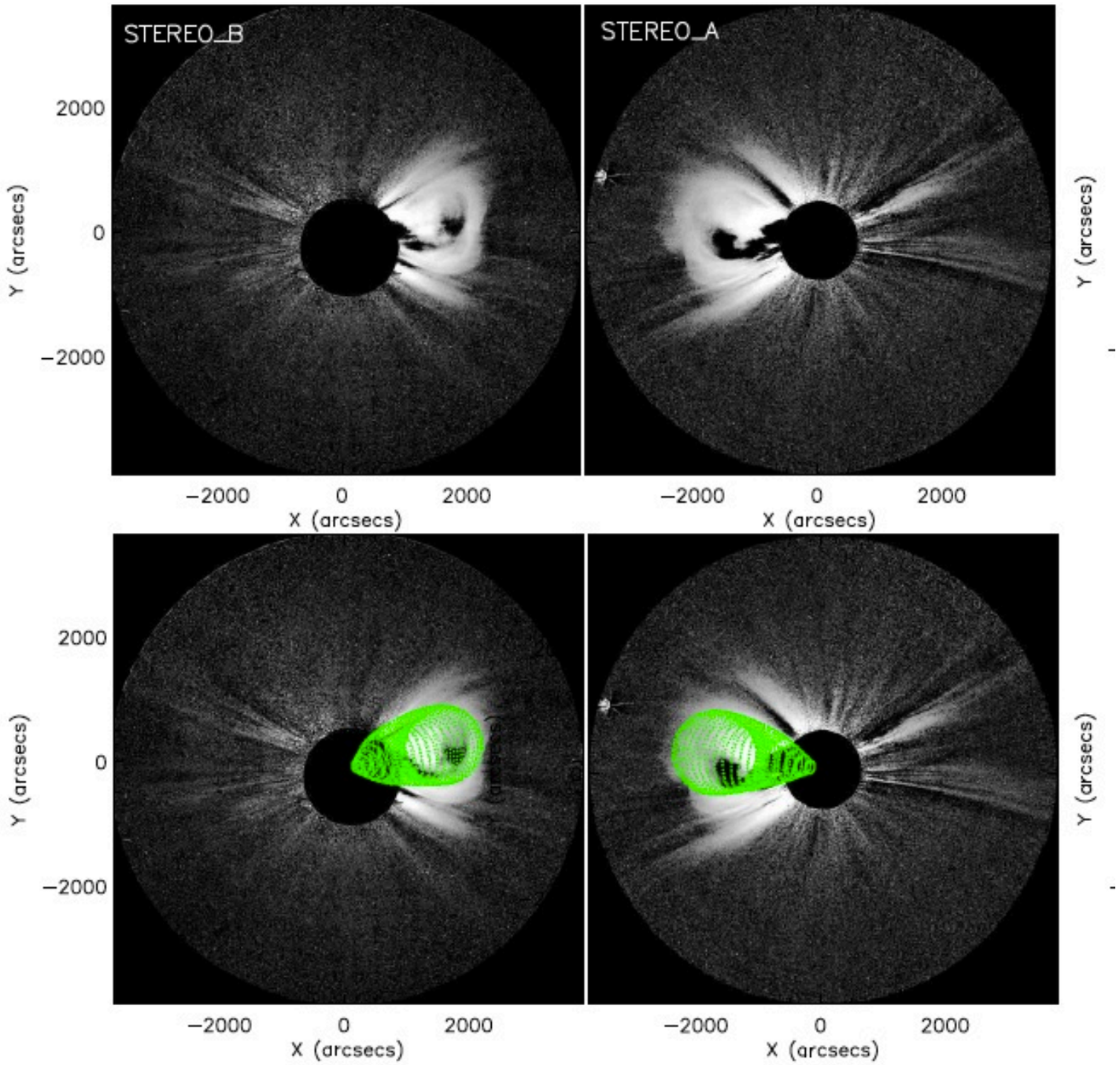
C. Möstl March 2012

CMEs treten gern gemeinsam auf

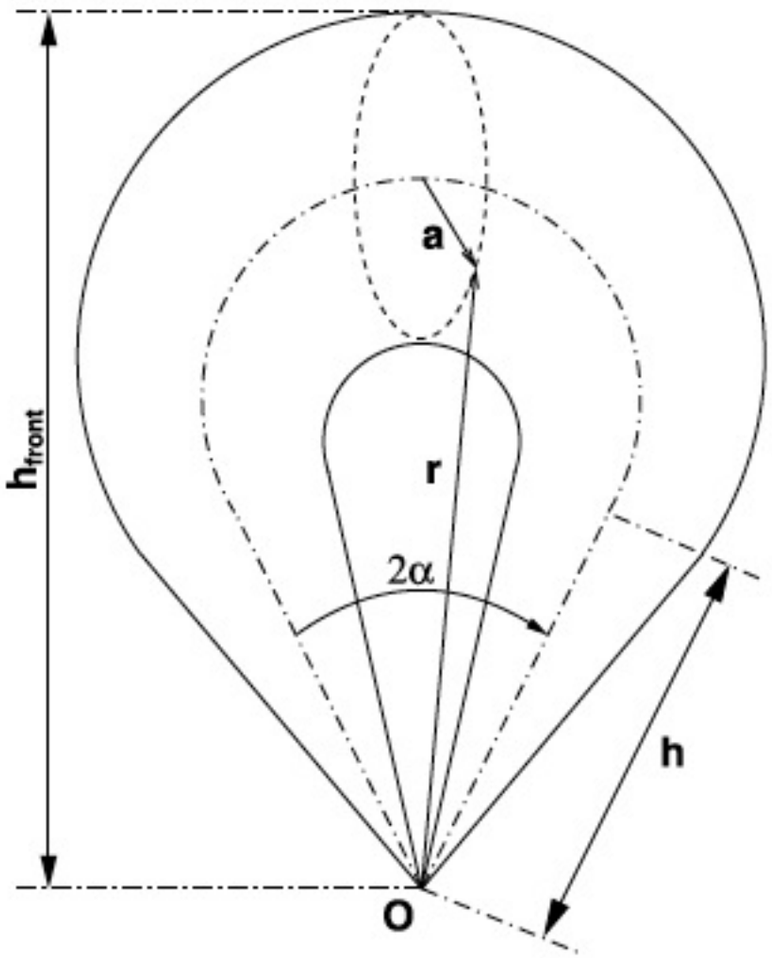


C. Möstl March 2012

CMEs sind „Croissants“

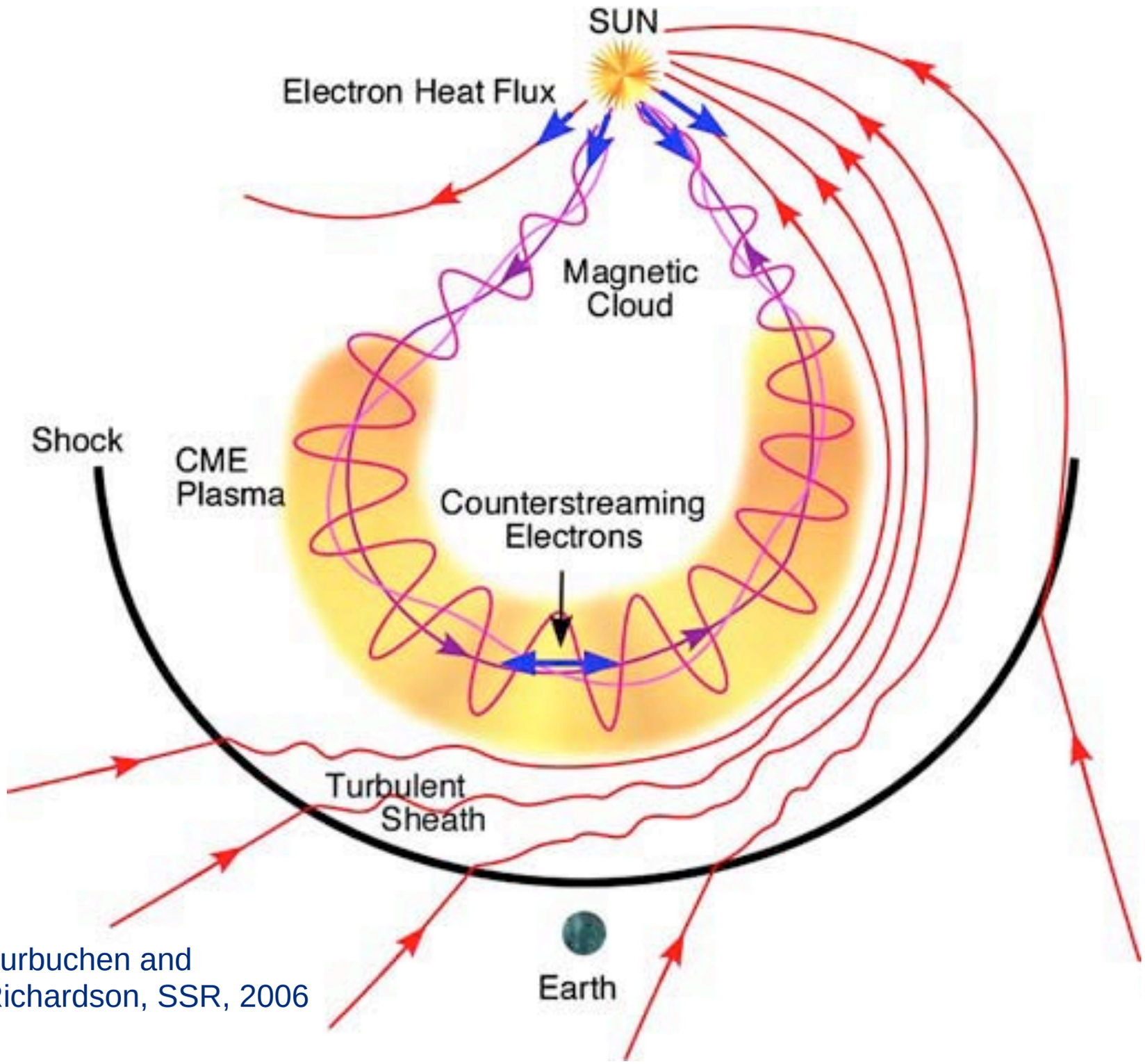


Lugaz et al. 2012, ApJ in press



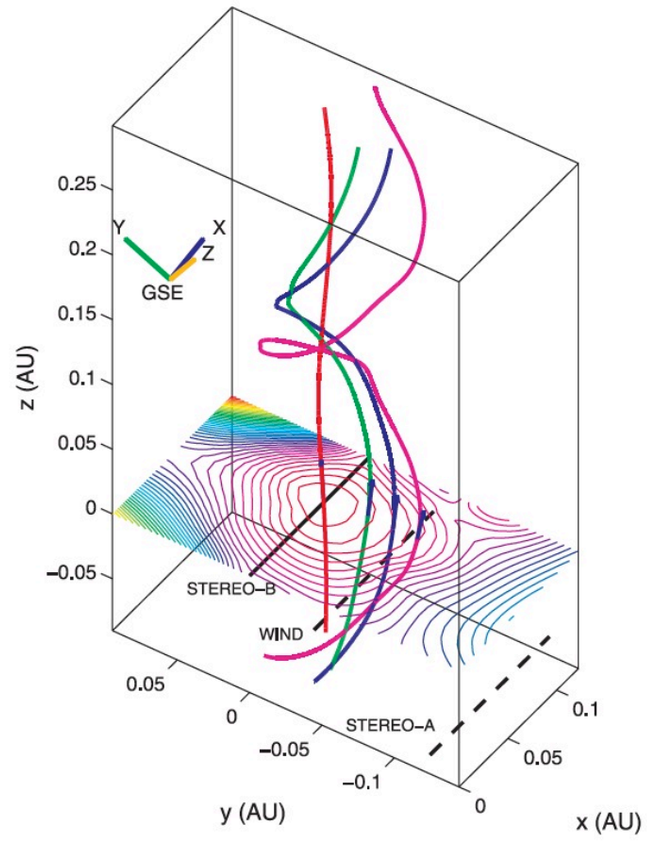
Thernisien et al. 2009, Sol. Phys.

CMEs im Sonnenwind sind magnetische Flußröhren



Zurbuchen and Richardson, SSR, 2006

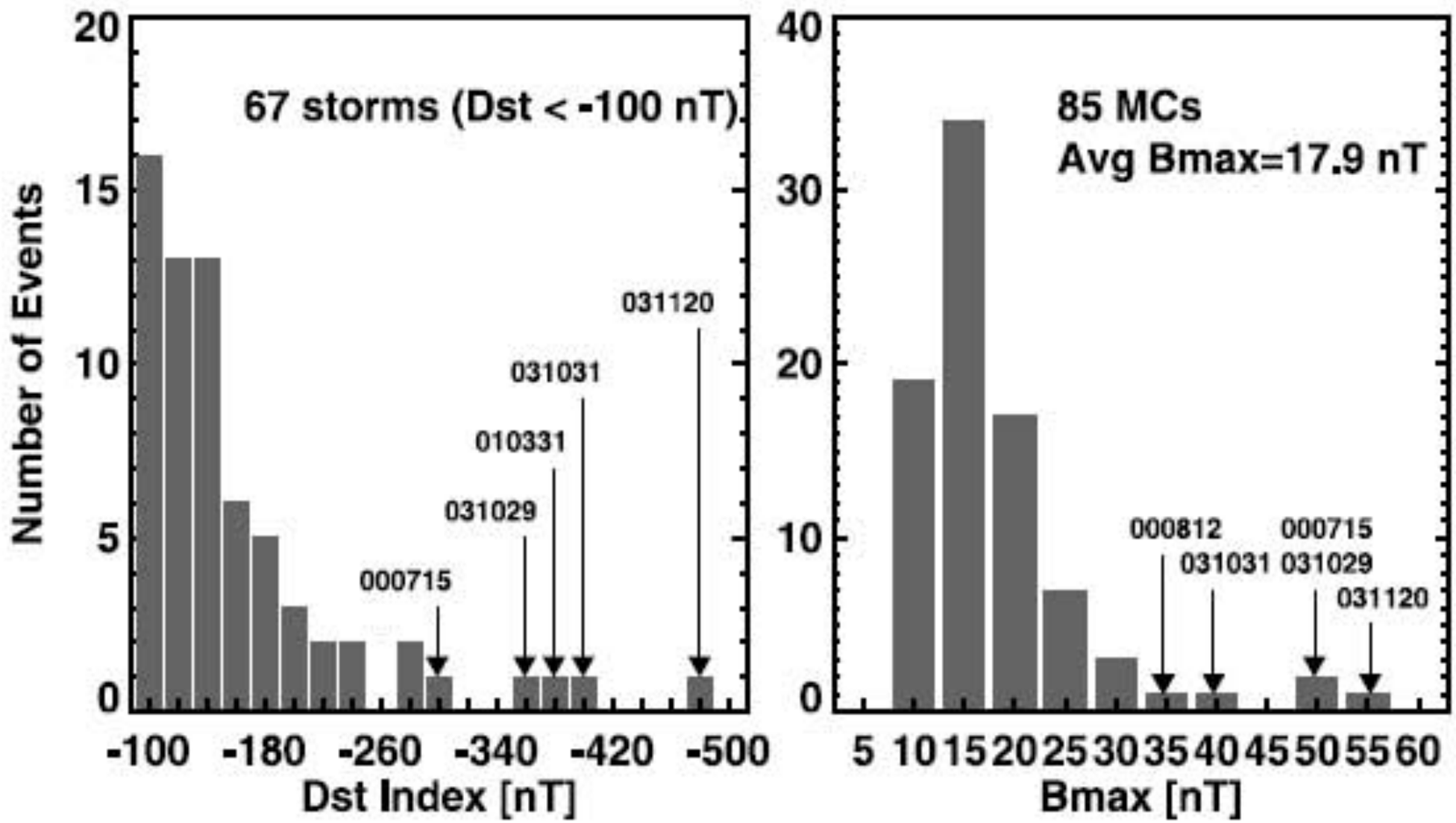
Möstl et al. (2009) JGR



vgl DNA:

zumindest glaubt man dass es meistens so ist....

CMEs sind Auslöser der stärksten geomagnetischen Stürme



Gopalswamy et al. 2005, GRL

Was man über CMEs nicht weiß...

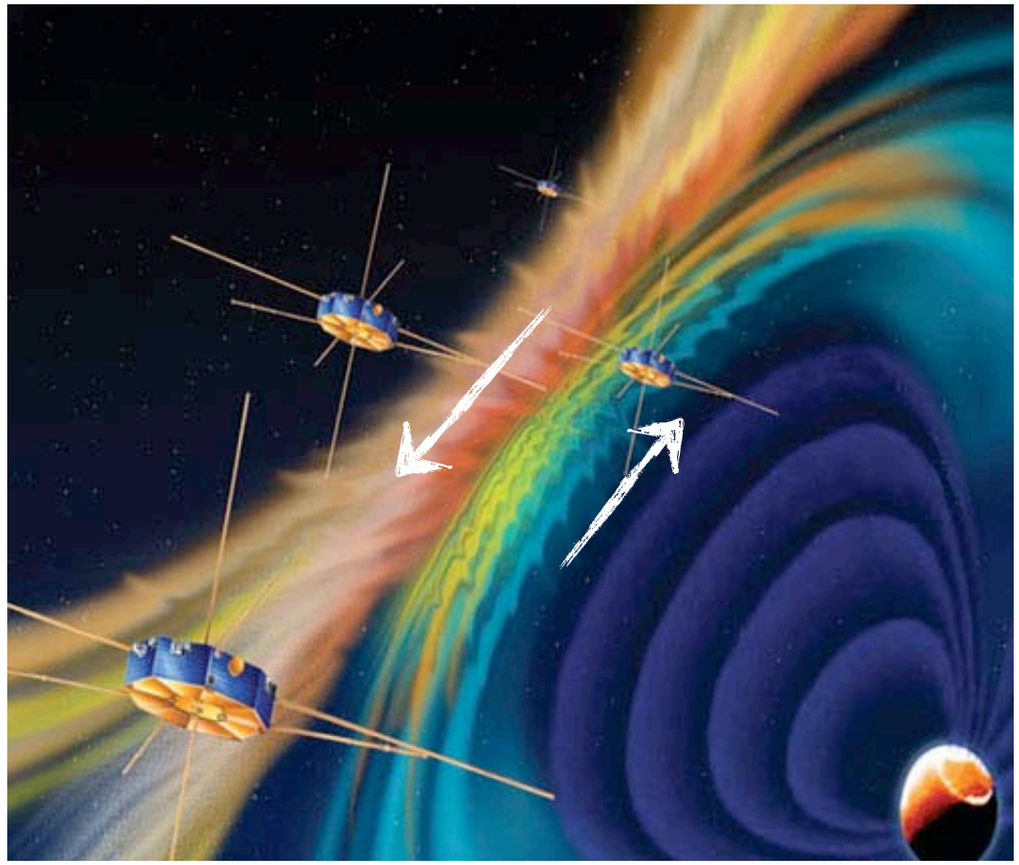
Fragen über Fragen...

- **Wie entstehen sie überhaupt?**
  -> Wie sieht das Magnetfeld in der Quellregion aus?
  -> (Wieso ist die Korona überhaupt so heiß?)

- **Vorhersage der Eigenschaften aus Bildern** (koronagraph, HI <> in situ)
  -> Sind alle CMEs wirklich gleich aufgebaut?
  -> Wie sehen sie in Erdnähe aus? Deformiert?

- **Ausbreitung im Sonnenwind – V(t)**
  -> Wieso ist die Berechnung
  der Ankunftszeit so ungenau?

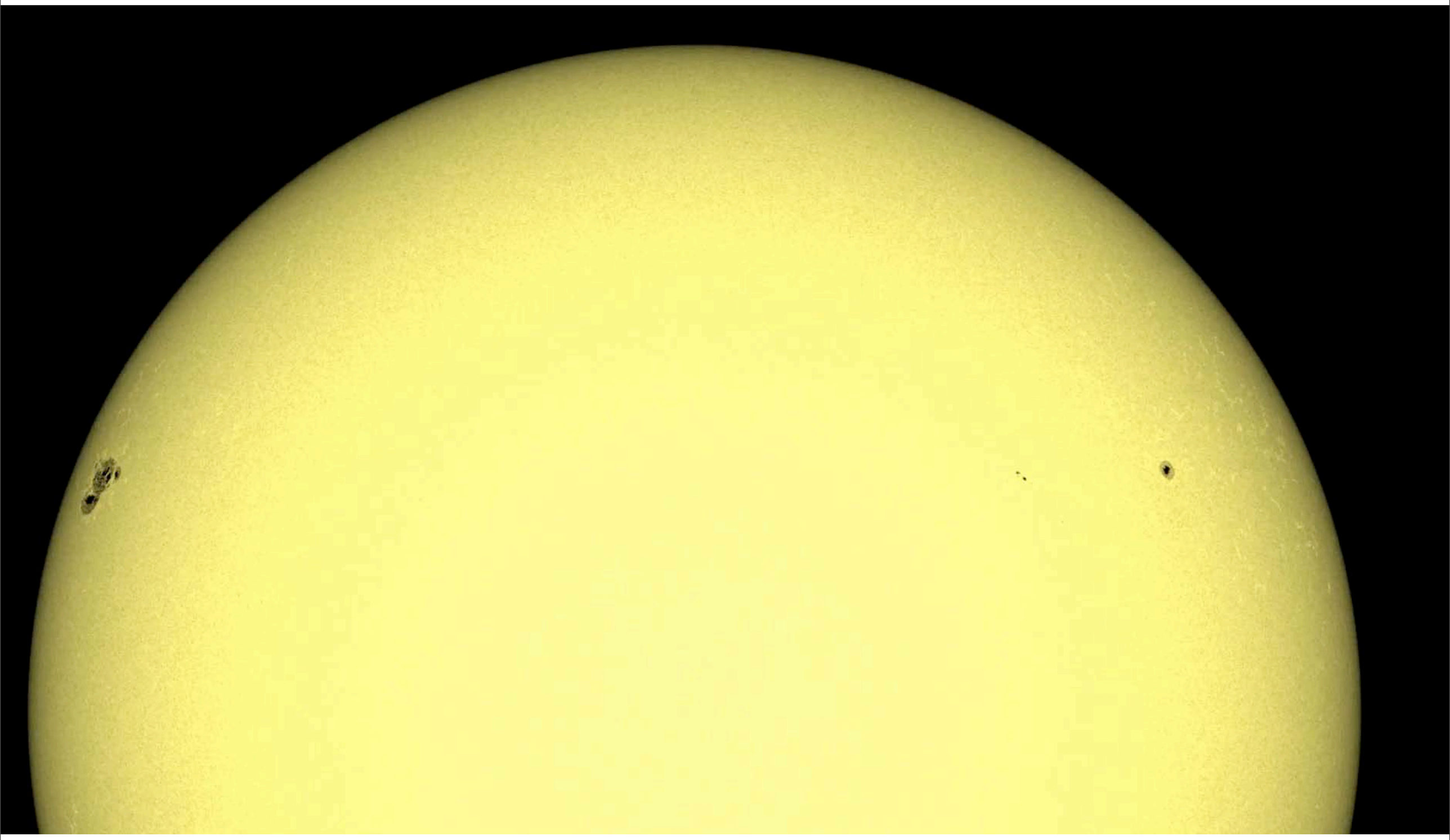
  mit richtiger Anfangsgeschwindigkeit
  ist der Fehler +/- 7h
  (Vgl. vor STEREO +/- 1 Tag)

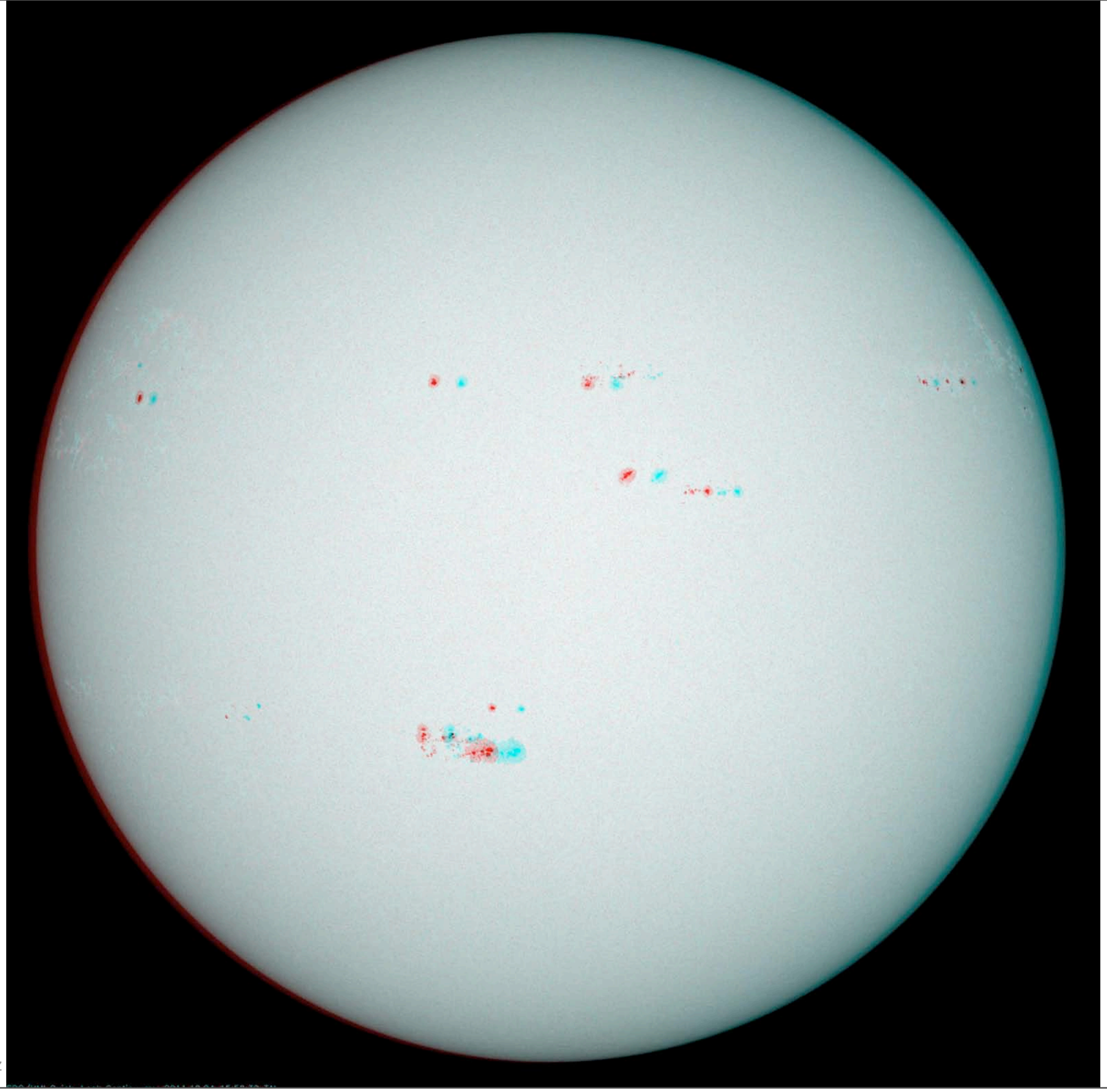


- **Wird Erde getroffen oder nicht?**
  -> genaue Richtungsberechnung

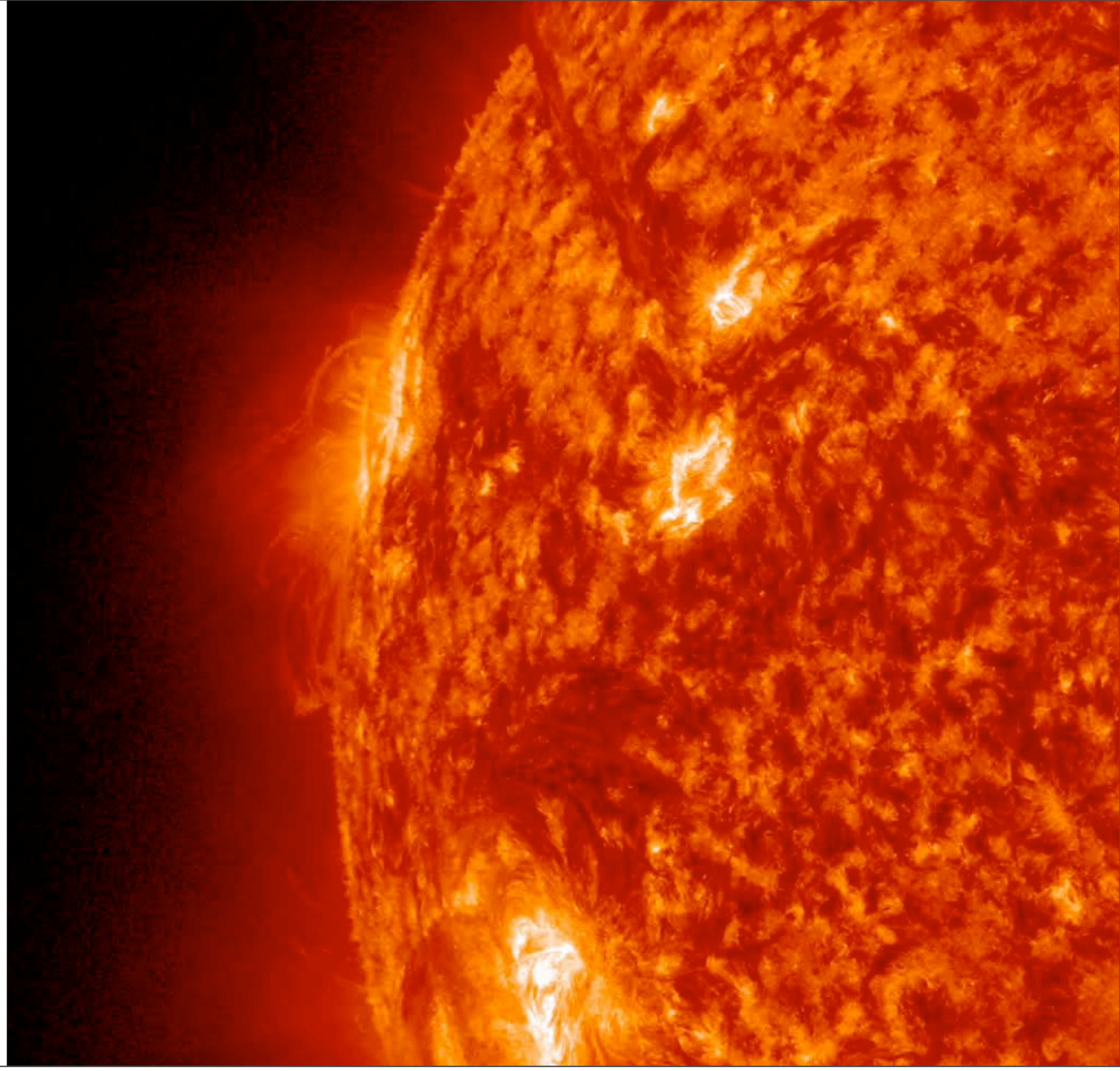
- **Findet überhaupt ein geomagnetischer Sturm statt?**
  -> dazu muss man die negative Bz Komponente (antiparallel zur Erde) vorhersagen
  -> also muss man Magnetfeld im inneren der magn. Wolke aus Beobachtungen herauslesen/simulieren – **das funktioniert aber noch nicht....**

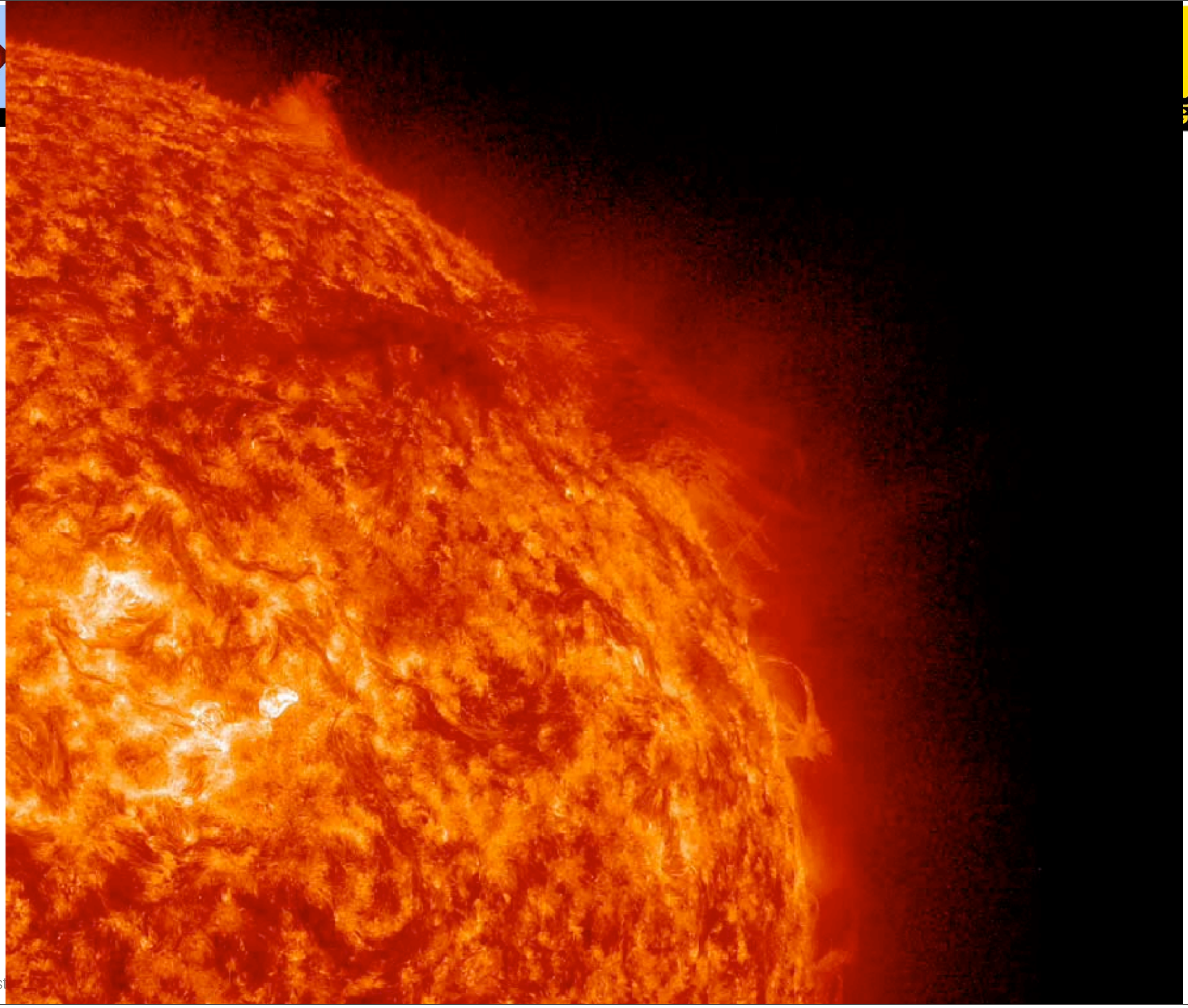
NASA SDO – Sonnenflecken



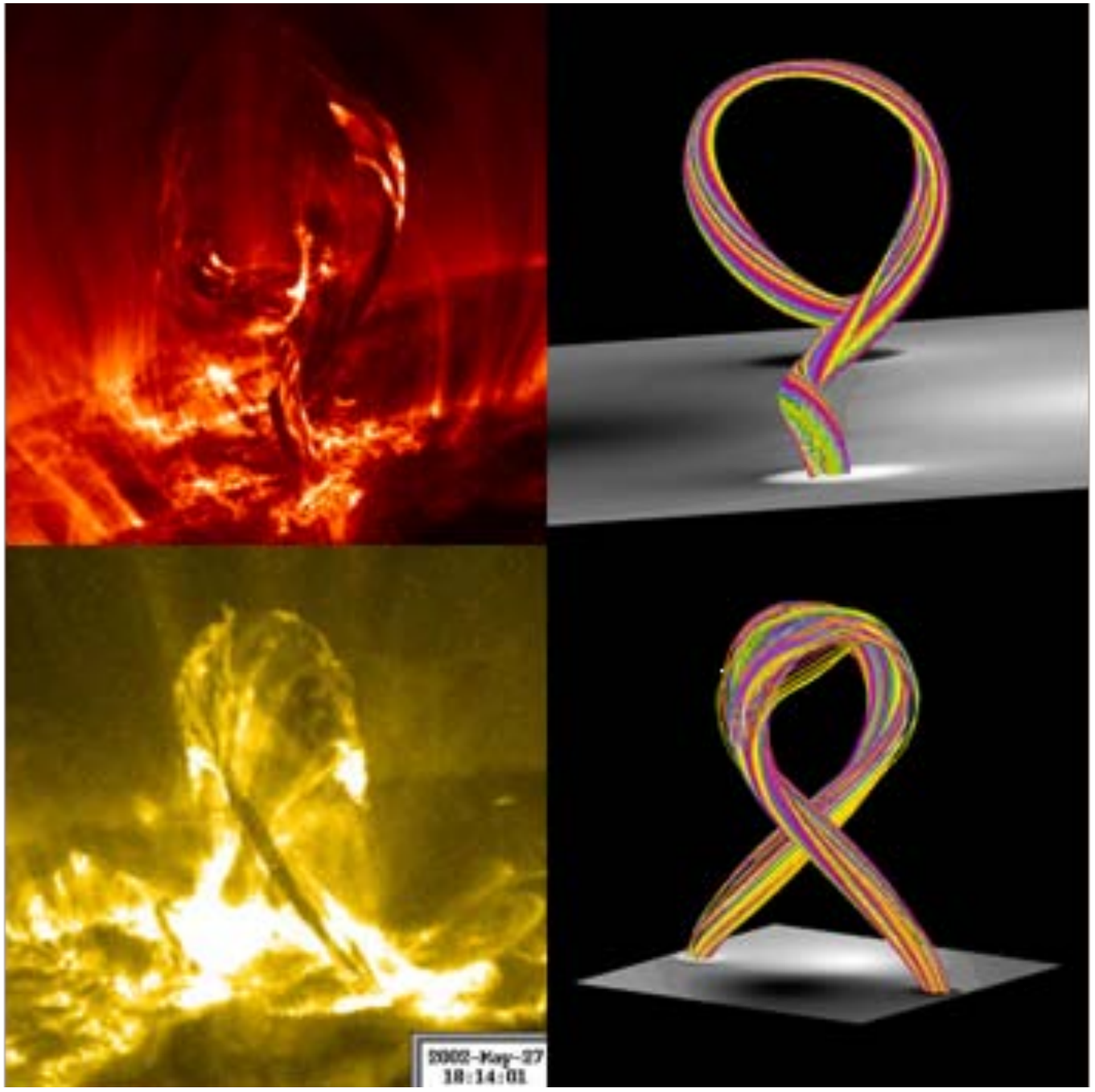


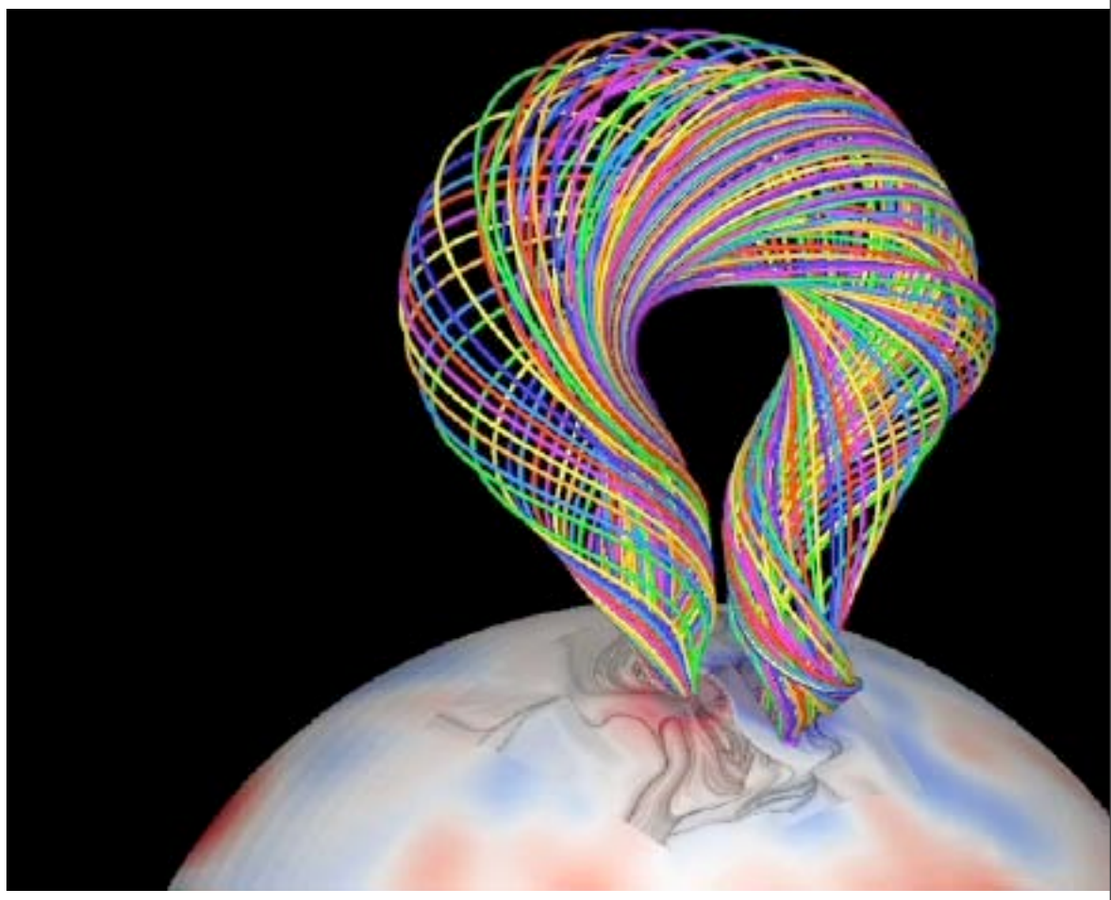
Filamente





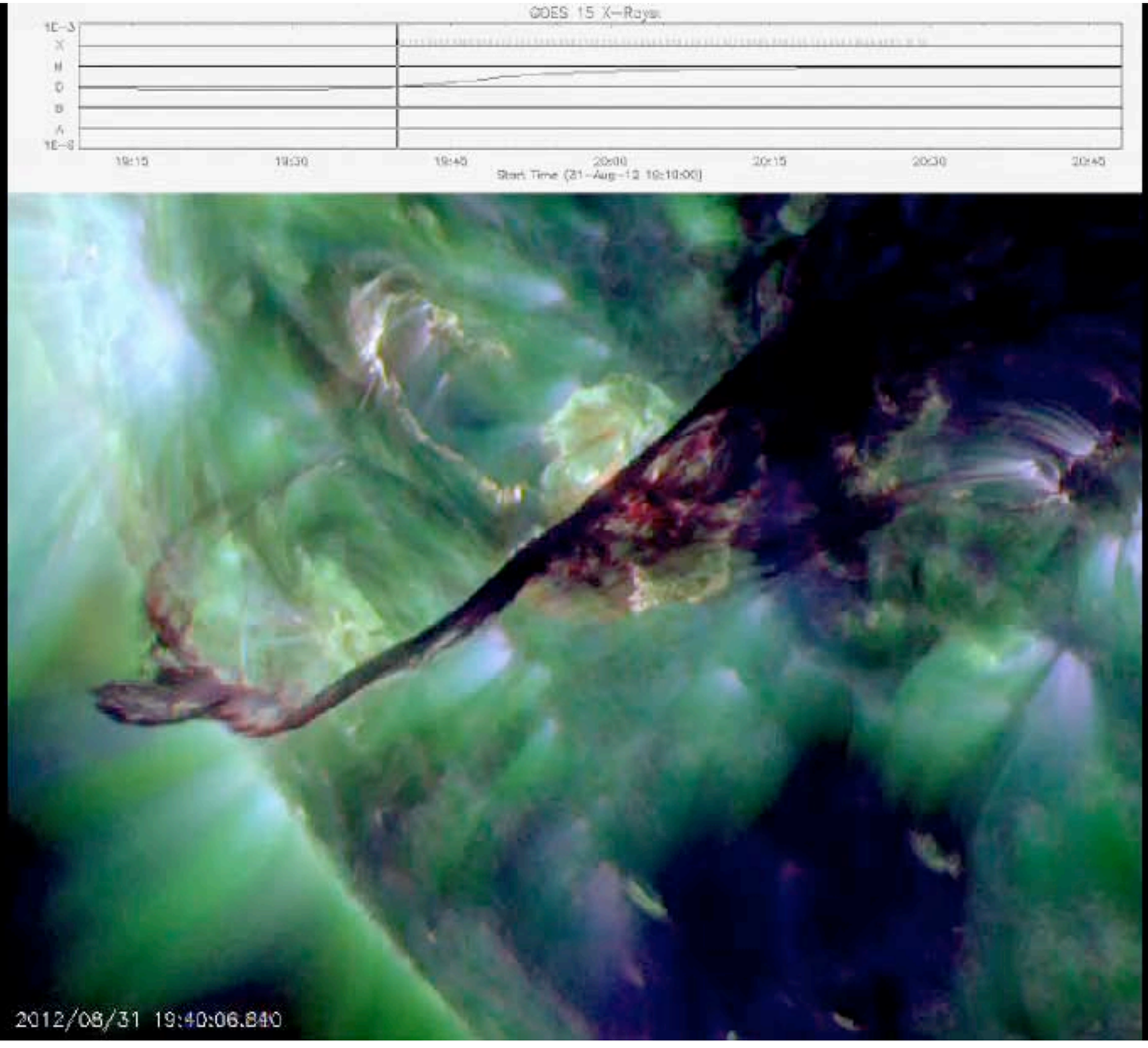
Filamente



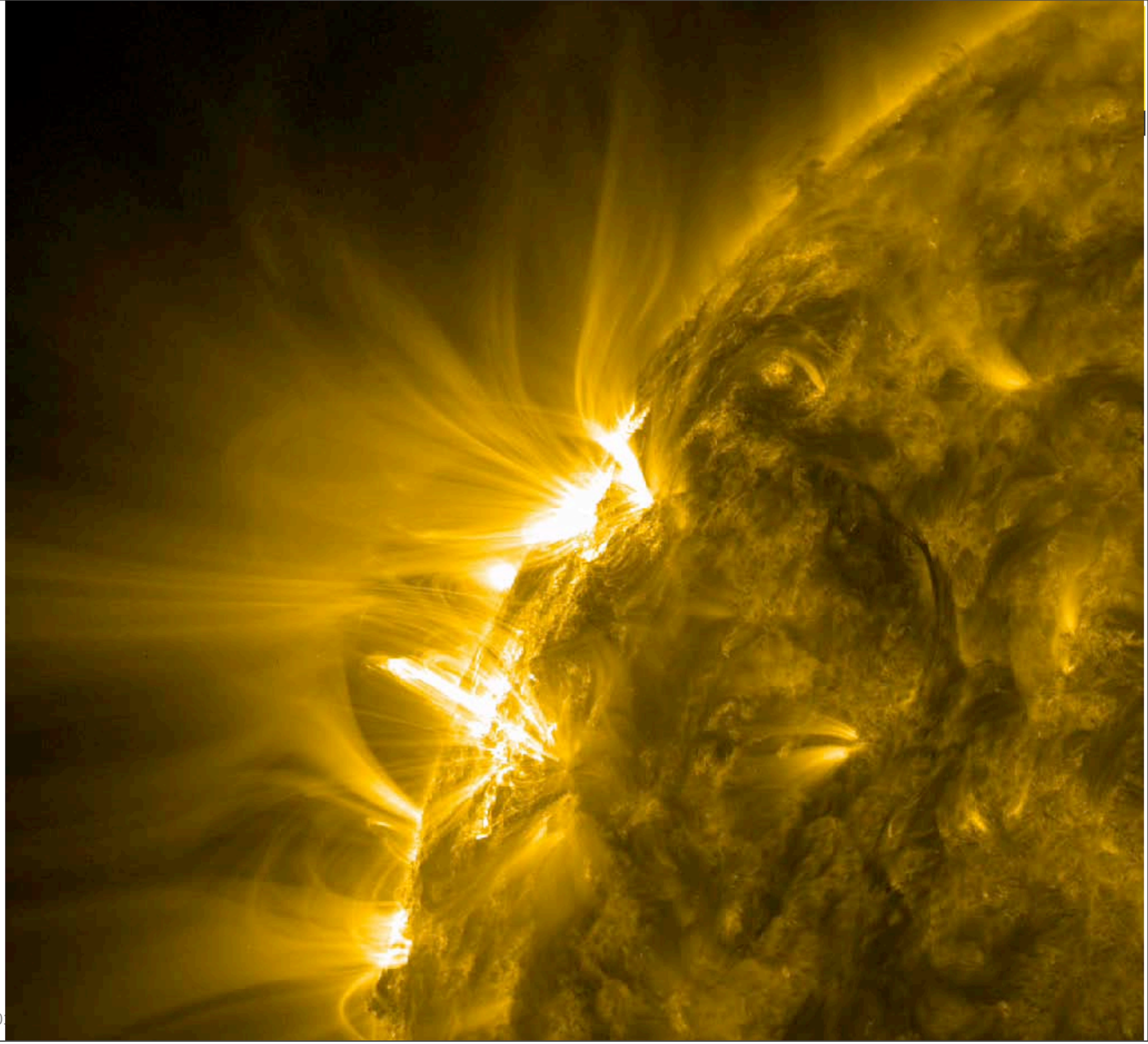


Török et al., Predictive Science Inc., San Diego

filament, flare ribbons

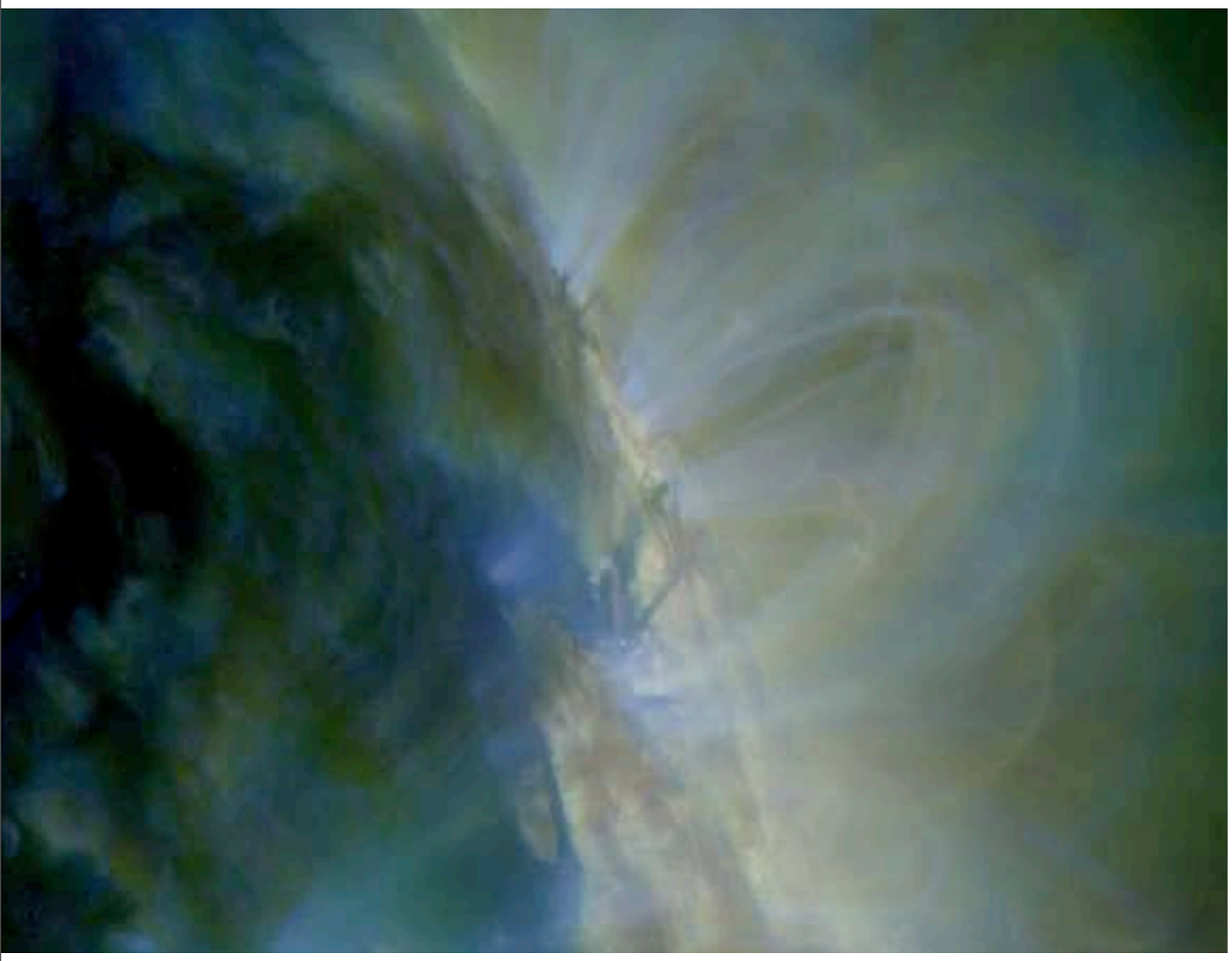


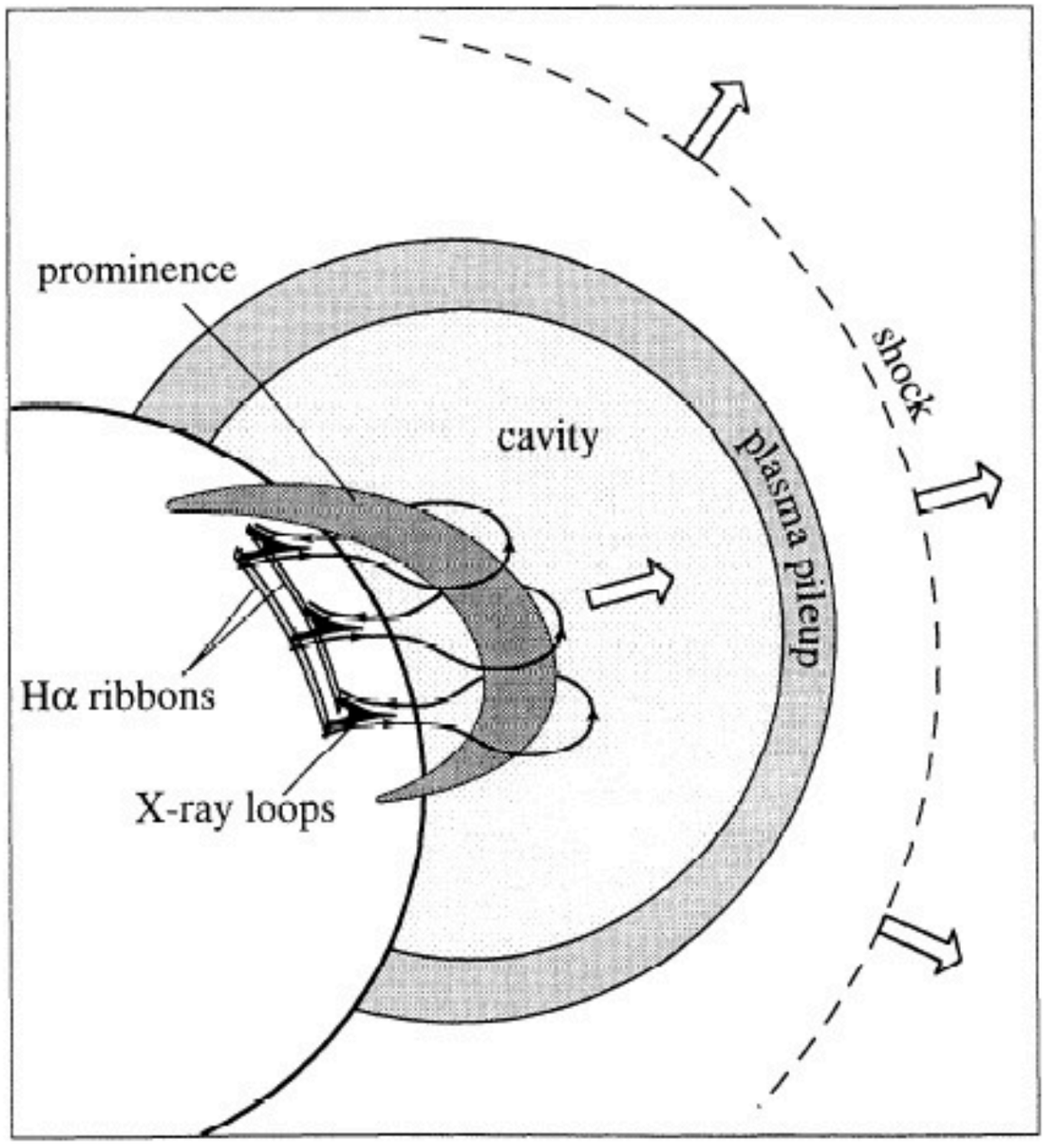
Post Eruption Arcades



Standardmodell

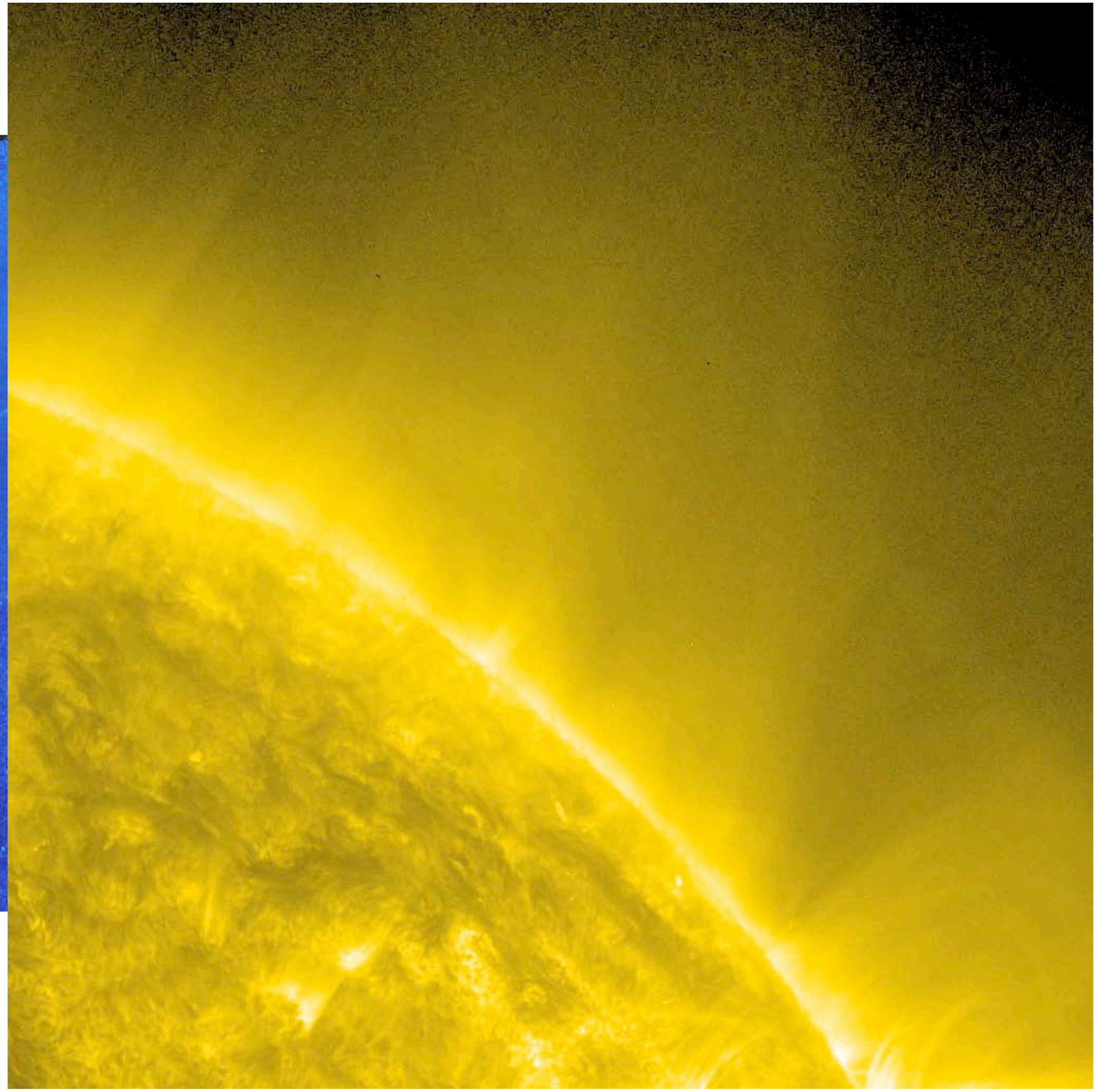
filament-> instabil-> feedback-> beschleunigung





Forbes, 2000, JGR

Komet Lovejoy im Dezember 2011

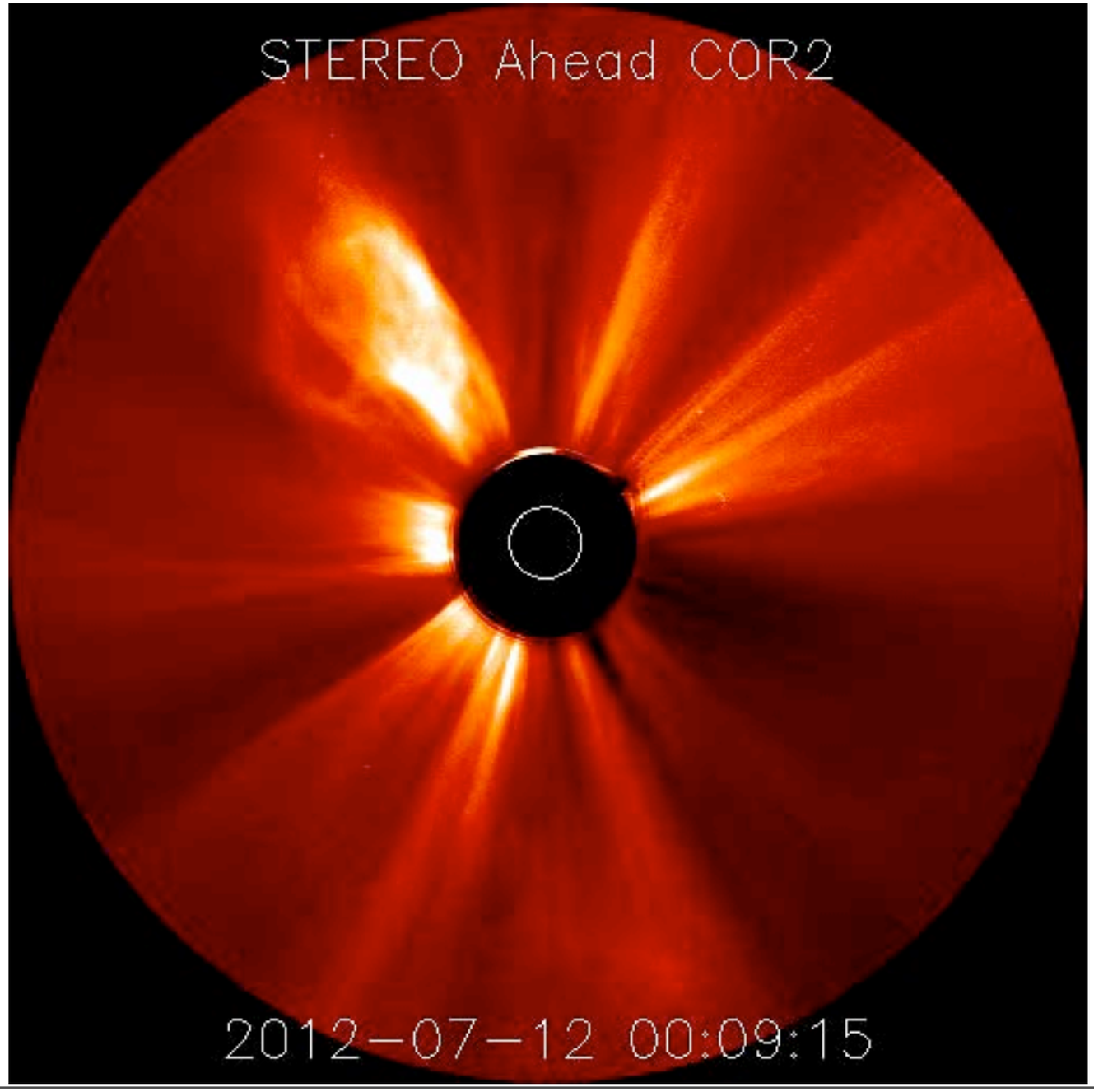


Echtzeit-Vorhersage

- Juli 12-14 2012 Vorhersage mit **drag model** (Vrsnak et al. 2012, Solar Physics)

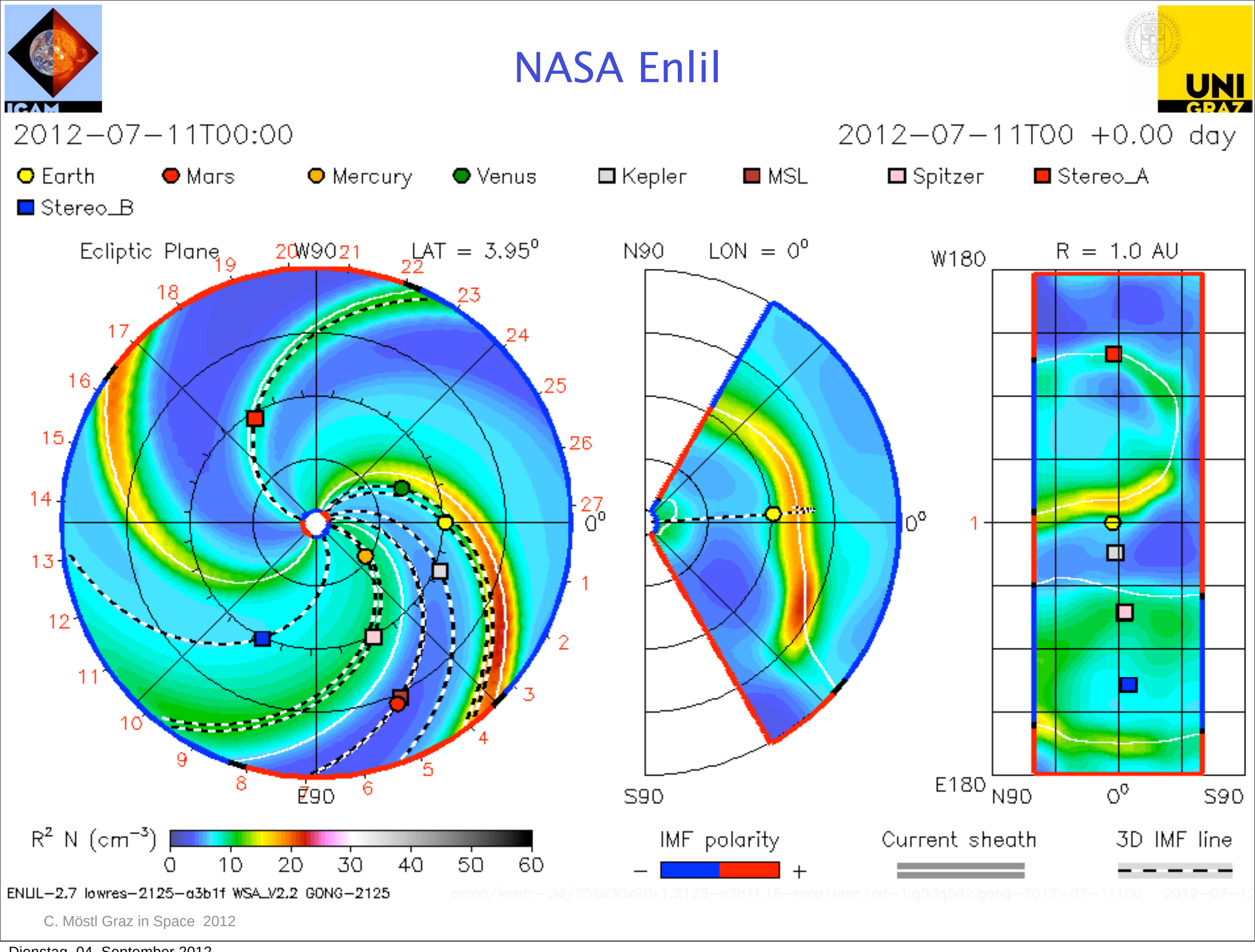
$$\frac{\mathrm{d}^2 r}{\mathrm{d}t^2} = -\gamma(r)\left(\frac{\mathrm{d}r}{\mathrm{d}t} - w(r)\right)\left|\frac{\mathrm{d}r}{\mathrm{d}t} - w(r)\right|, \qquad \gamma = \frac{c_\mathrm{d} A \rho_\mathrm{w}}{V(\rho + \frac{\rho_\mathrm{w}}{2})} = \frac{c_\mathrm{d}}{L(\frac{\rho}{\rho_\mathrm{w}} + \frac{1}{2})},$$

- beste Vorhersage inkl. NOAA und NASA / 40h vor Eintreffen auf 5h genau



NASA Enlil

NASA Enlil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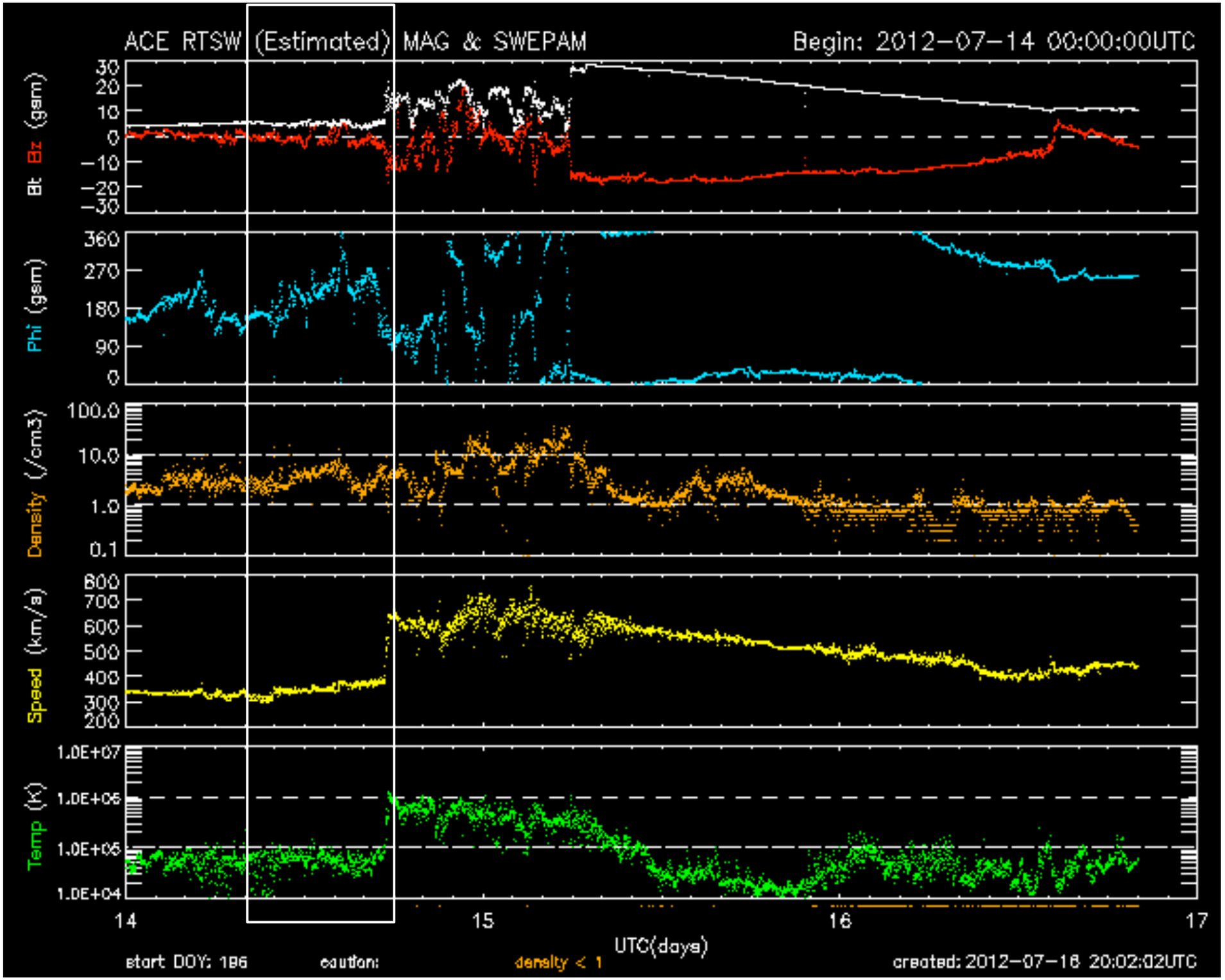
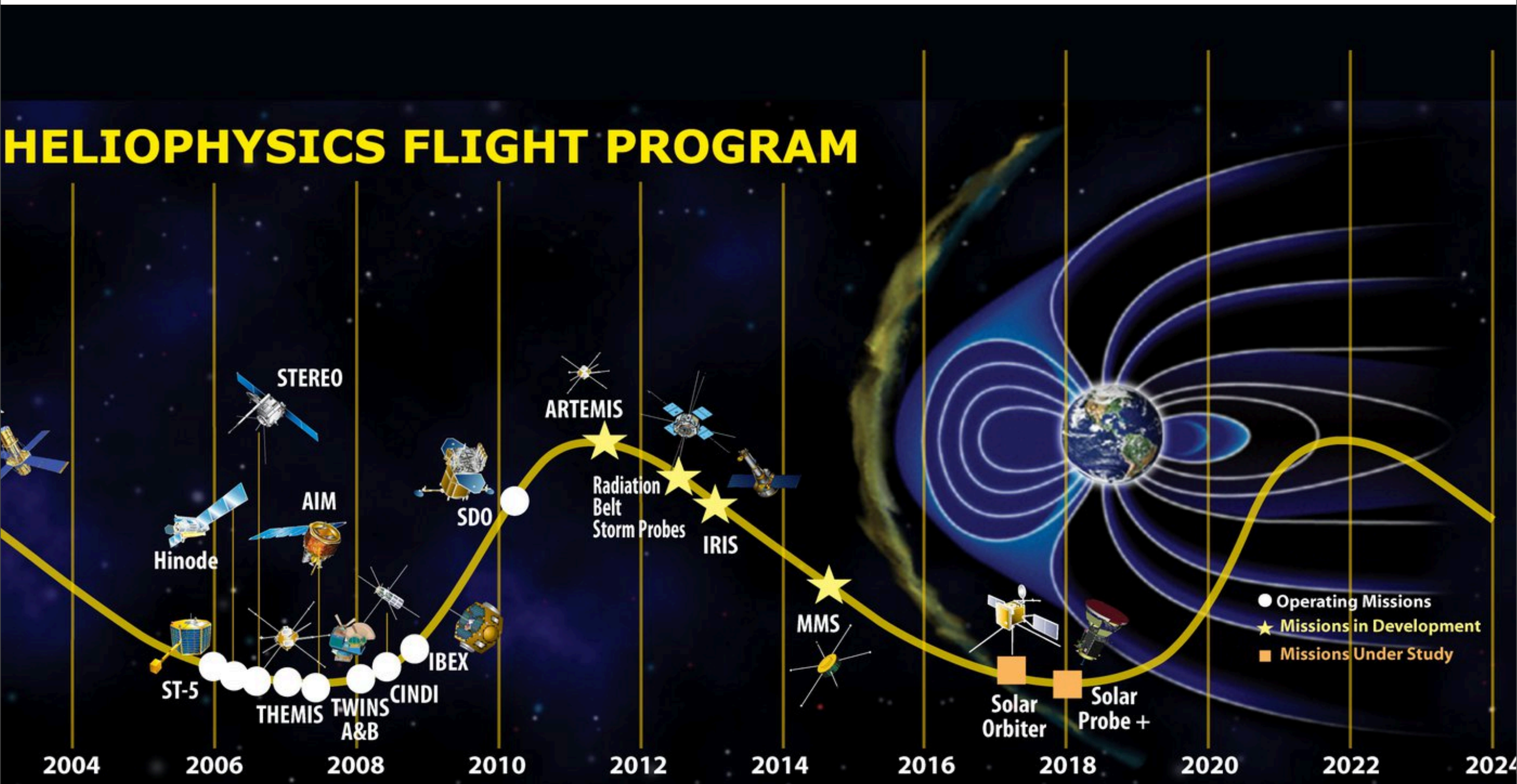
Earth
Mars
Mercury
Venus
Kepler
MSL
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
W90
LAT = 3.95°
N90
LON = 0°
W180
R = 1.0 AU
E90
S90
E180
N90
0°
S90
R² N (cm⁻³)
0
10
20
30
40
50
60
IMF polarity
–
+
Current sheath
3D IMF line
ENLIL-2.7 lowres-2125-a3b1f WSA_V2.2 GONG-2125

in situ Daten am L1 Punkt



Missionen


HELIOPHYSICS FLIGHT PROGRAM
STEREO
ARTEMIS
SDO
AIM
Hinode
Radiation
Belt
Storm Probes
IRIS
MMS
IBEX
ST-5
CINDI
THEMIS
TWINS
A&B
Solar
Orbiter
Solar
Probe +
Operating Missions
Missions in Development
Missions Under Study
2004
2006
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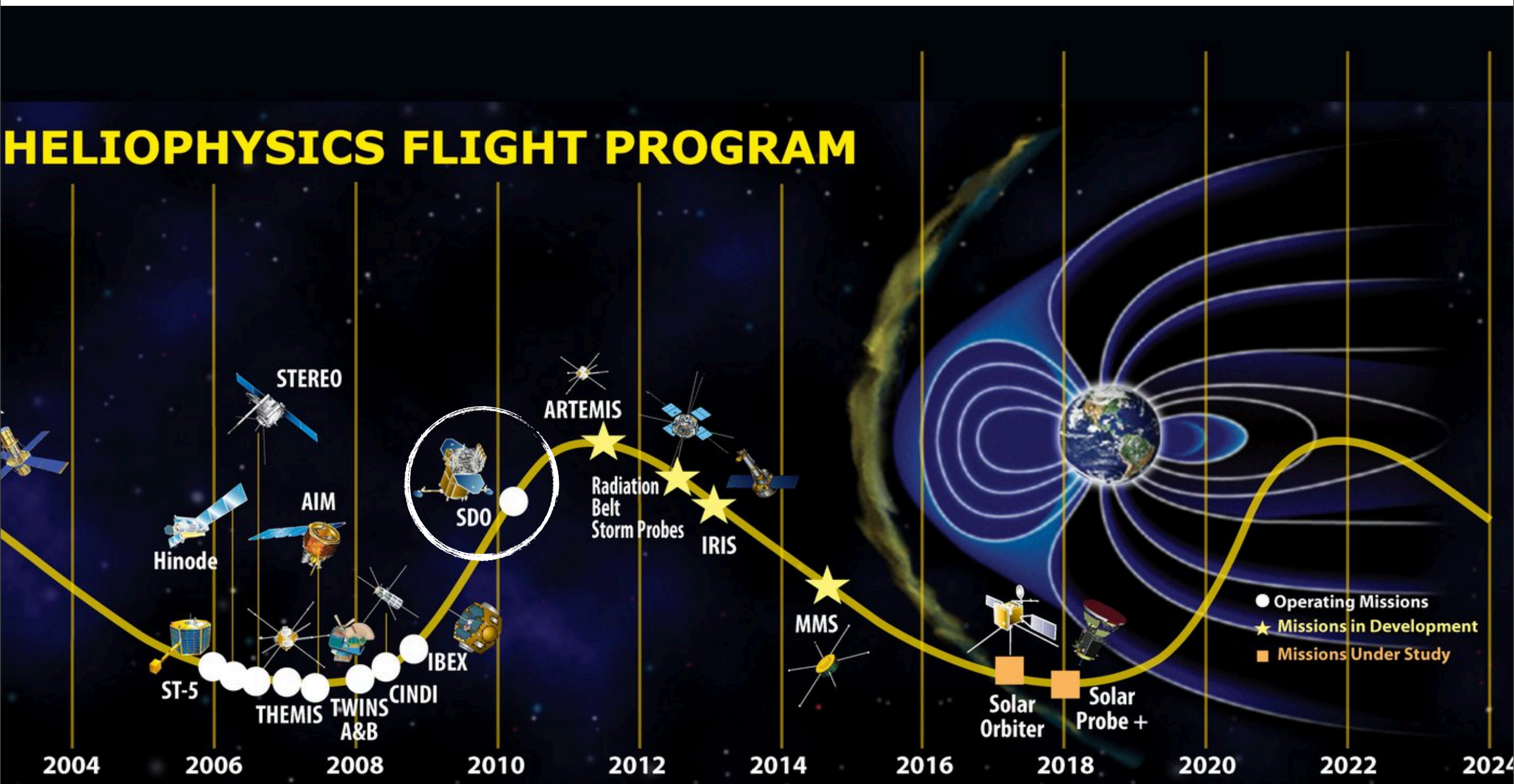
2024

Missionen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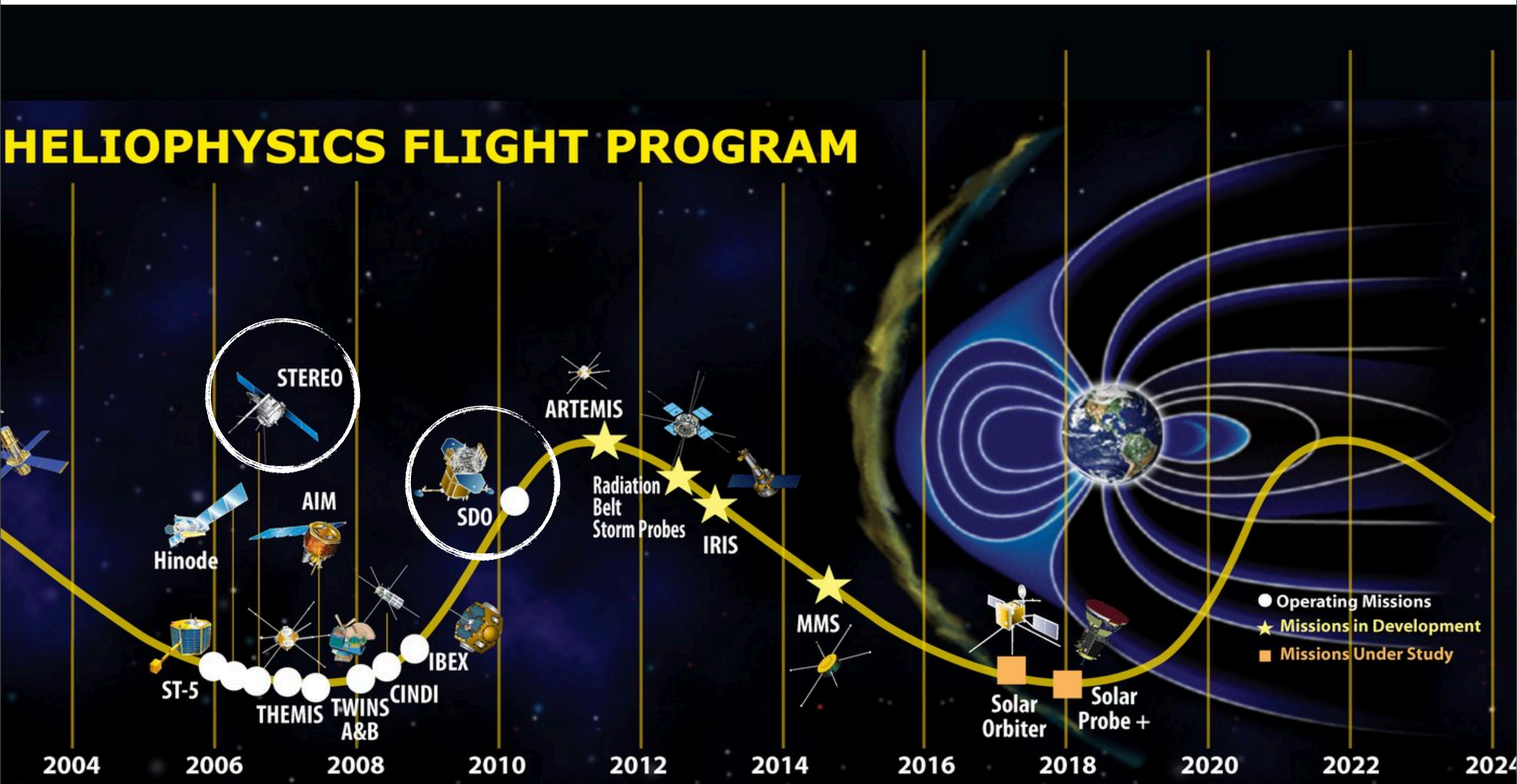
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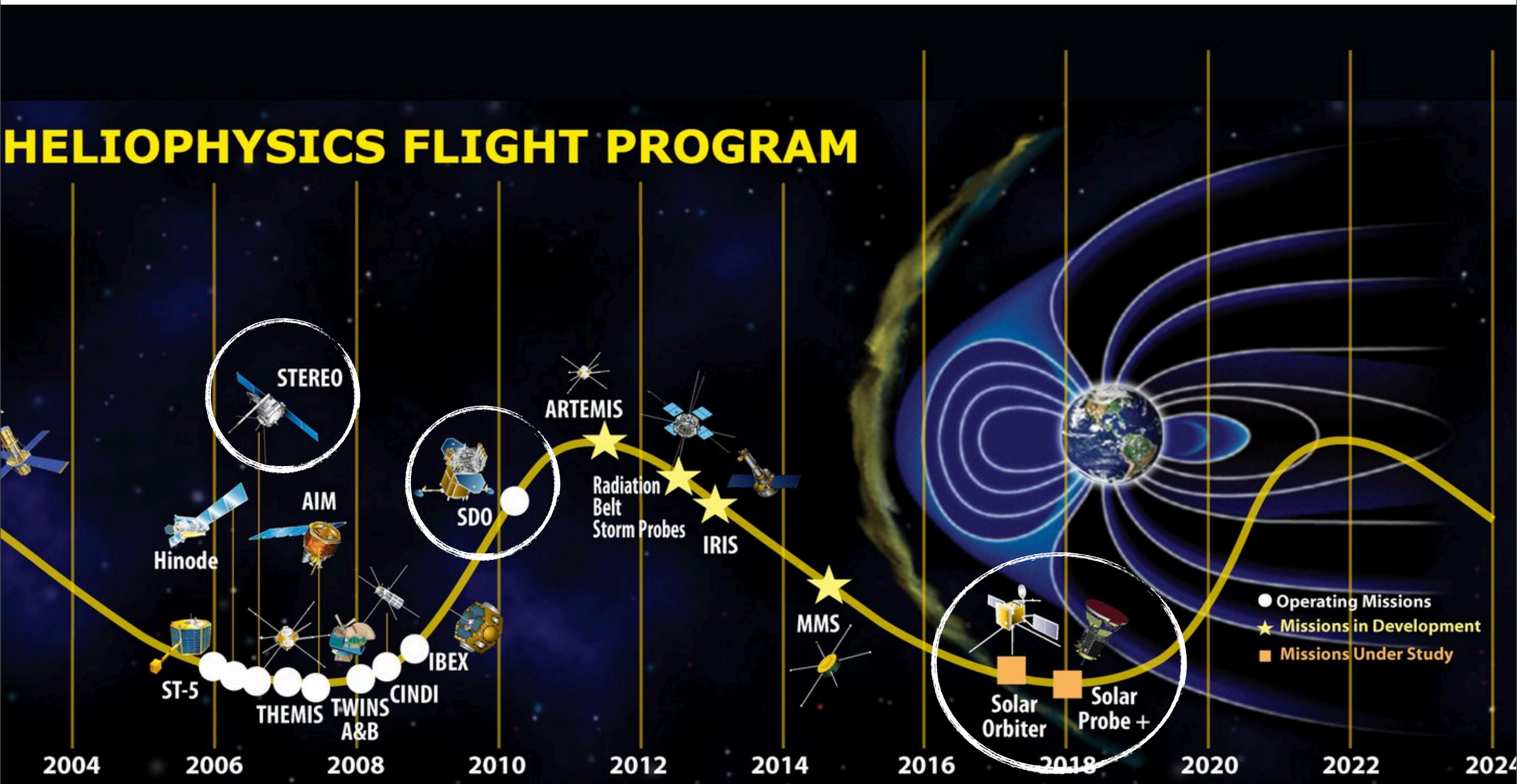
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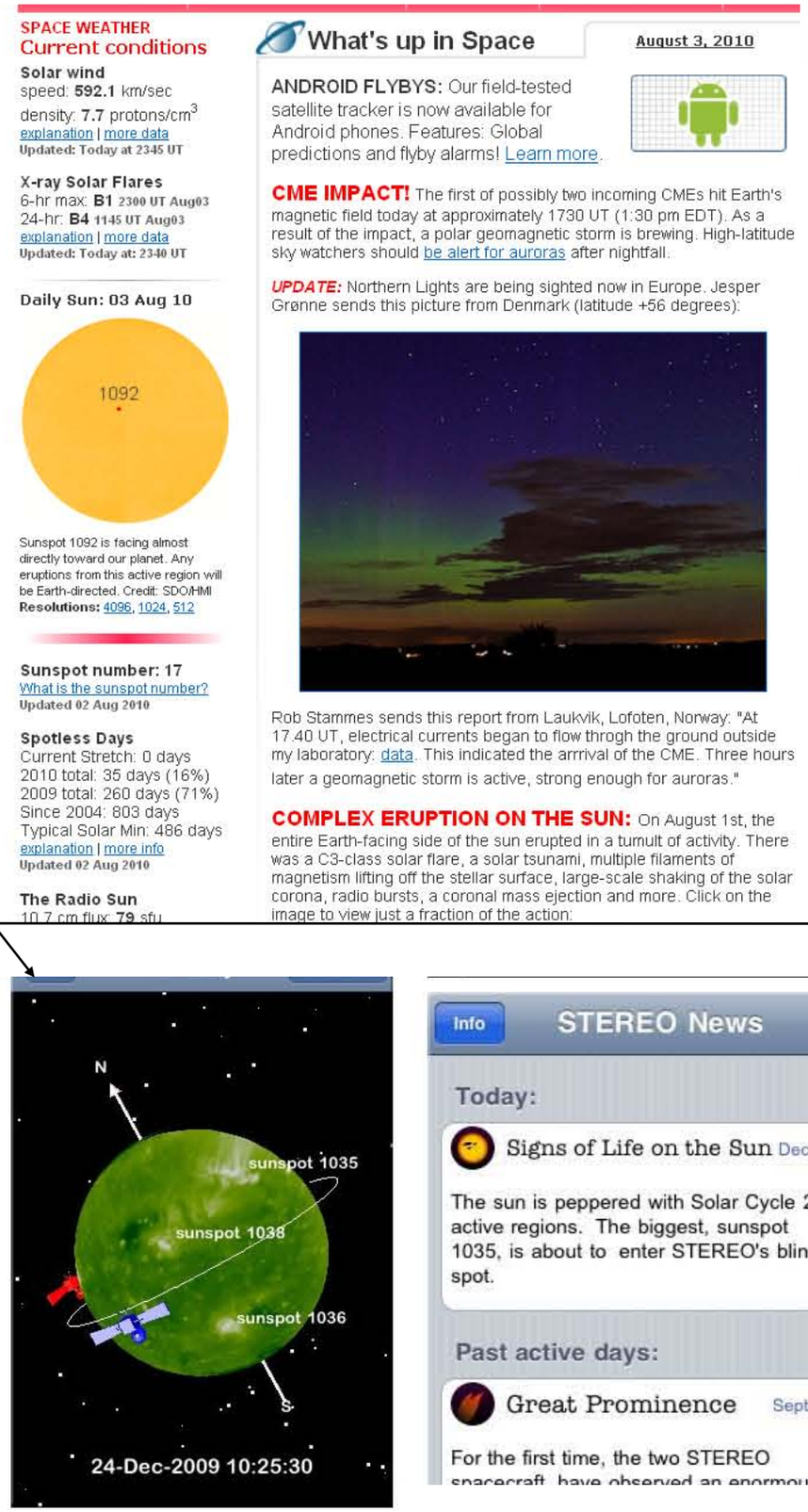
2024

Weitere Infos

Spaceweather.com

App: 3Dsun.org

The Sun Today



SDO: Year 2

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.... and it would have been entirely impossible without the dedicated people working on all those instruments! Thanks!