

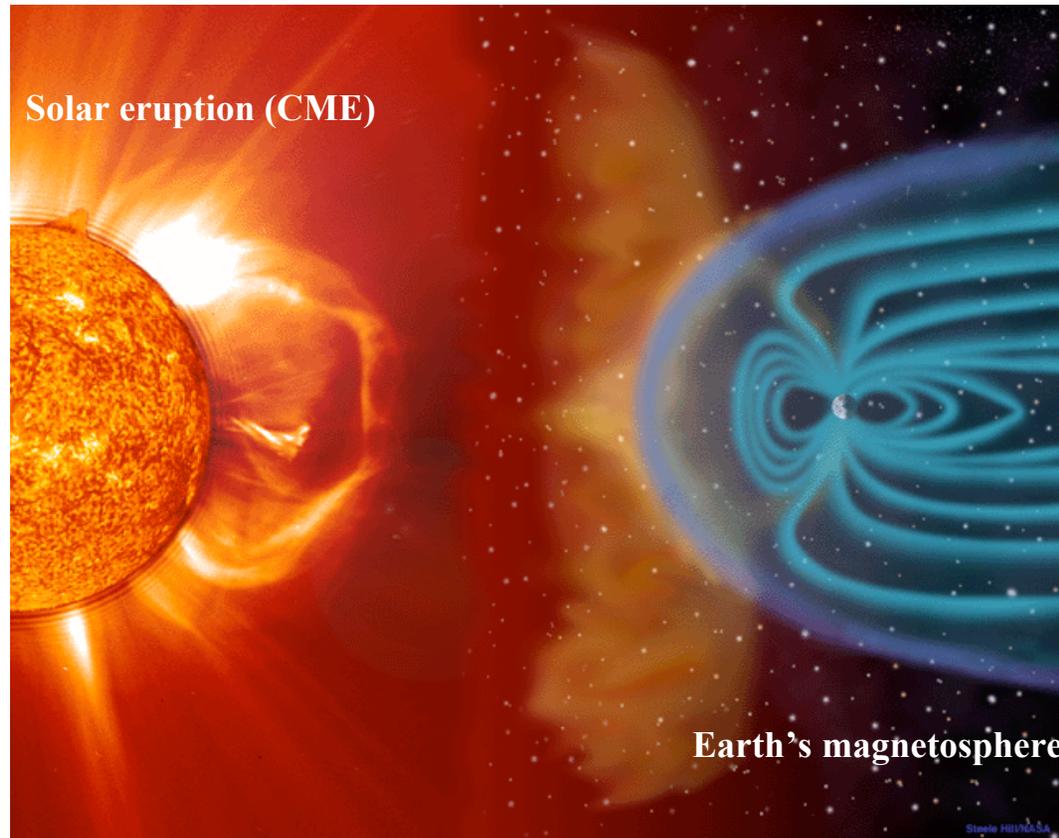
# Living in a Star

Sarah Gibson (NCAR/HAO)

Steele Hill/NAASA

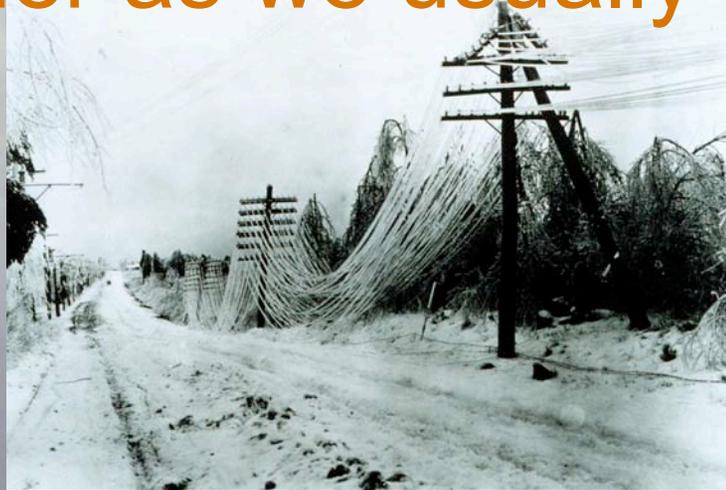


# 3D real-time astronomy



- We are observing a stellar system from within
- What we see may impact us in near-real time
- Unescapably three-dimensional
- Fundamentally magnetic

# Weather as we usually think of it



Power and telephone lines sagging after heavy ice storm

Historic NWS Collection

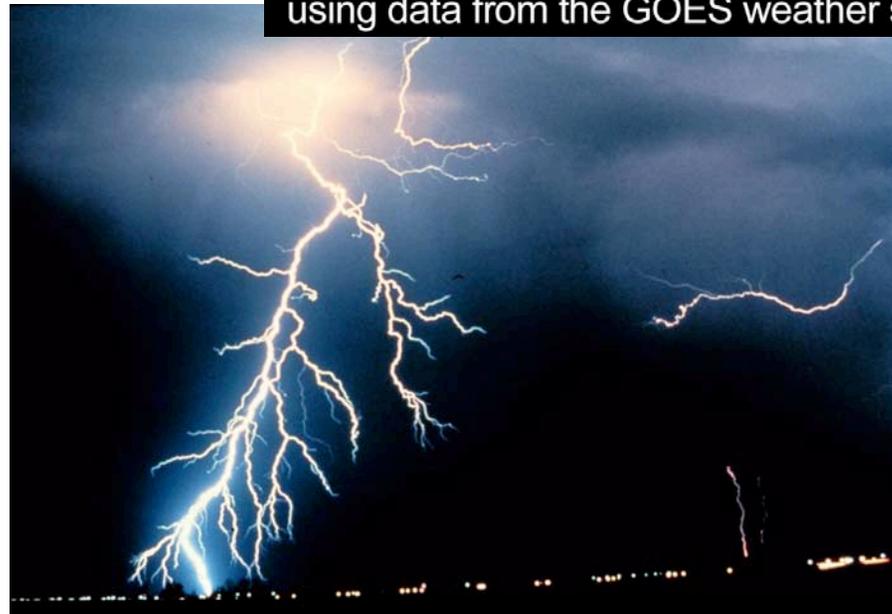


A computer-generated image of Hurricane Fran using data from the GOES weather satellites



Tornado in Union City, Oklahoma, May 1973

Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)



Multiple cloud-to-ground and cloud-to-cloud lightning strokes during a thunderstorm

Photographer: C. Clark Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)

# All weather originates at the Sun

## Solar Structure:

### Core

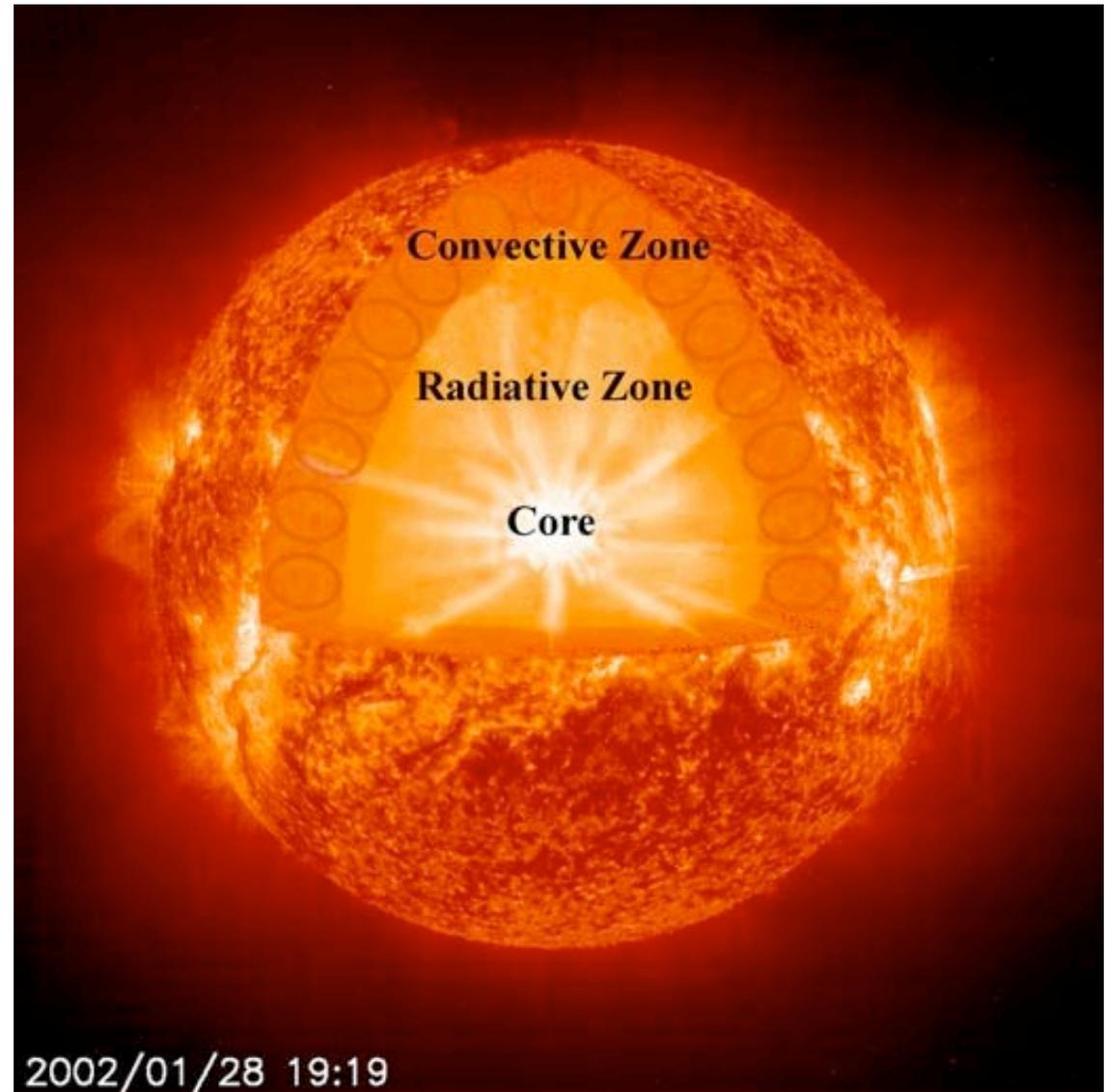
Where the energy is created. Nuclear reactions burn every second about 700 million tons of hydrogen into helium.

### Radiation Zone

Where energy is transported by radiation. Although the photons travel at the speed of light, they bounce so many times through the dense material that they use about a million years to escape the Sun.

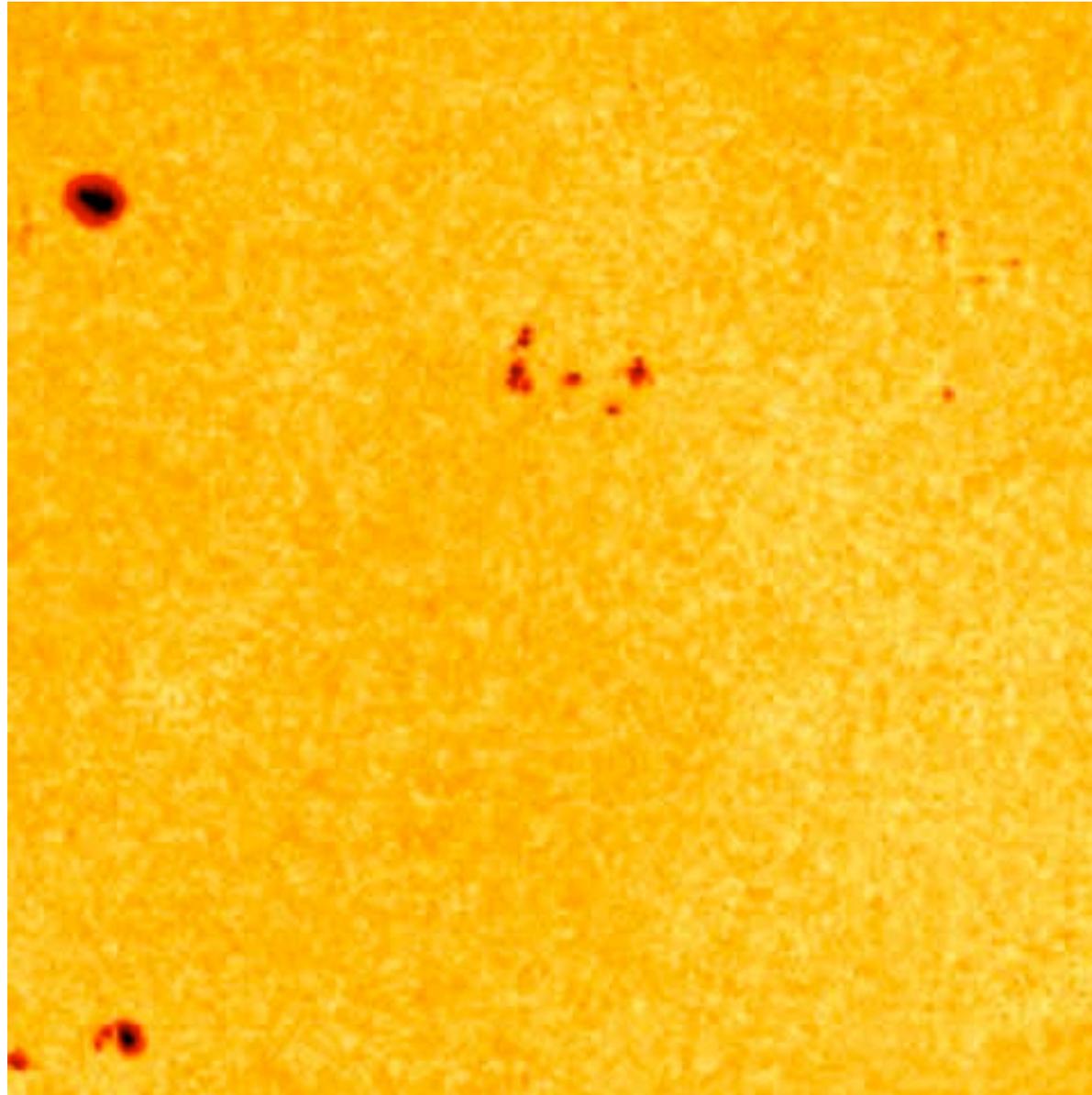
### Convection Zone

Energy transported by convection (just like boiling soup) where heat is transported to the photosphere.



Courtesy: SOHO (ESA/NASA)

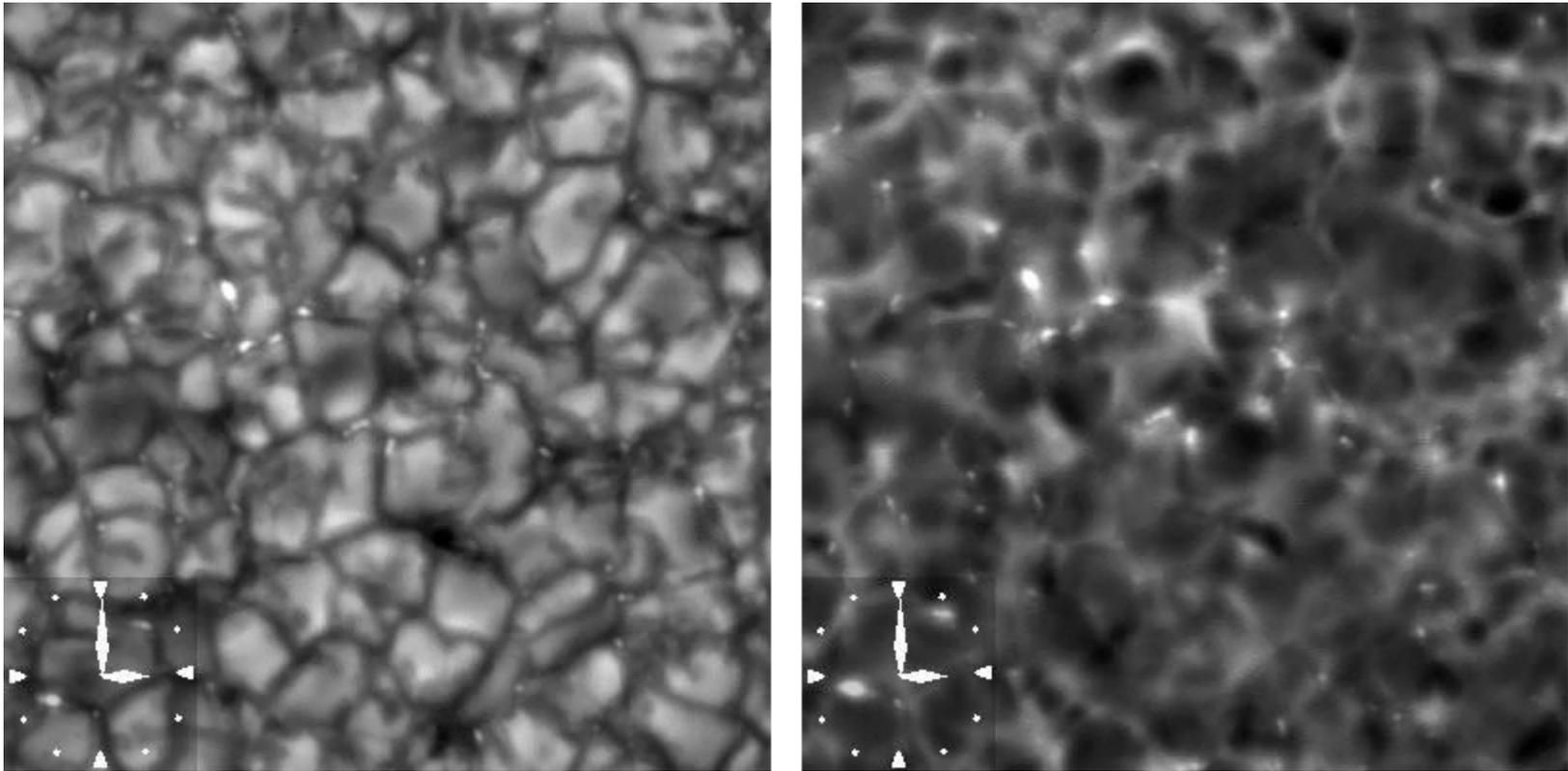
# The Sun at different temperatures/layers



Observations from SOHO satellite (ESA/NASA)

# Magnetic energy emerges through the solar surface (photosphere)...

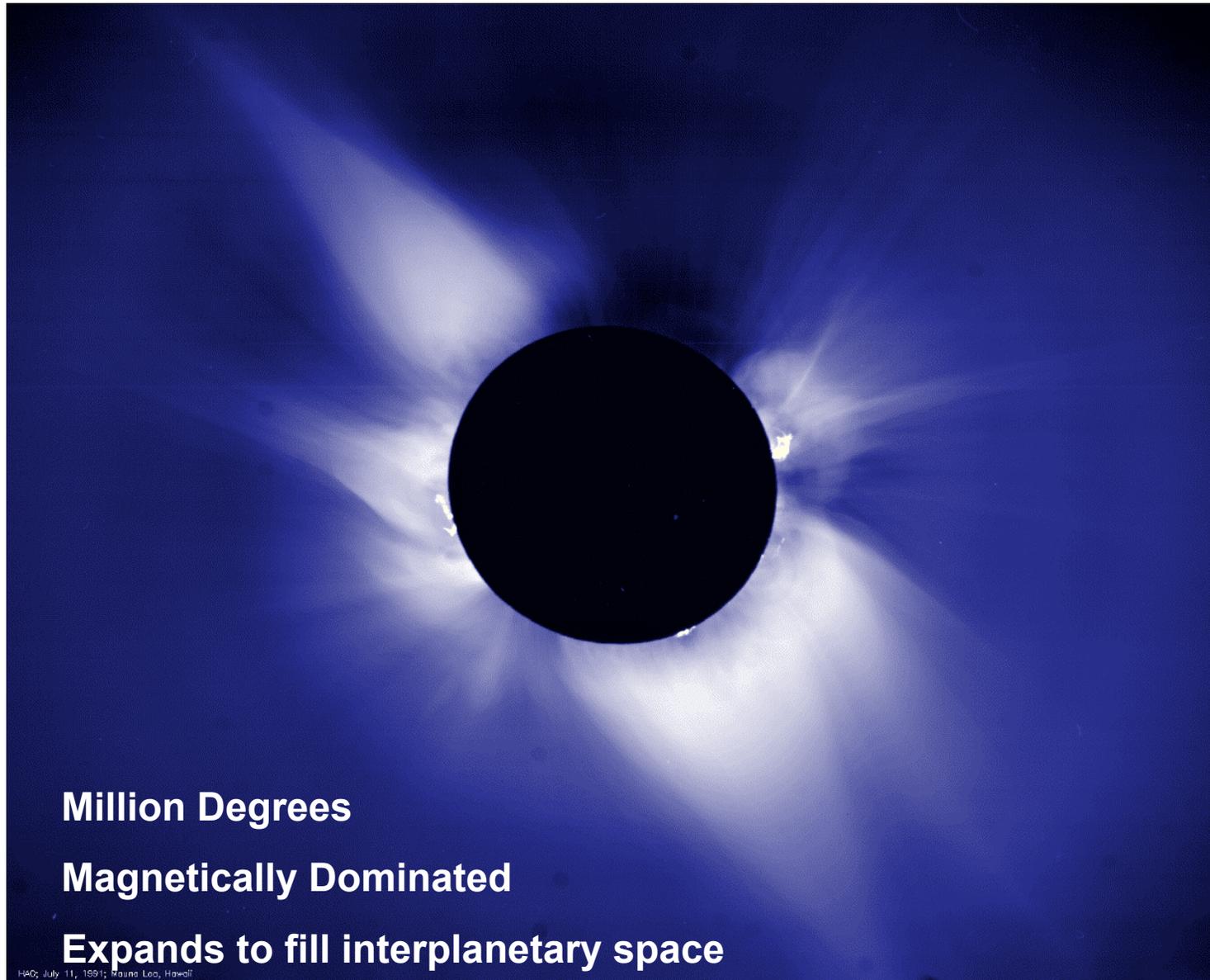
(boxes are about the size of a sunspot)



**Hinode SOT:** High resolution movies in G-band (430nm) and Ca II H (397nm) showing the motion of granules and small magnetic flux

(NASA/JAXA)

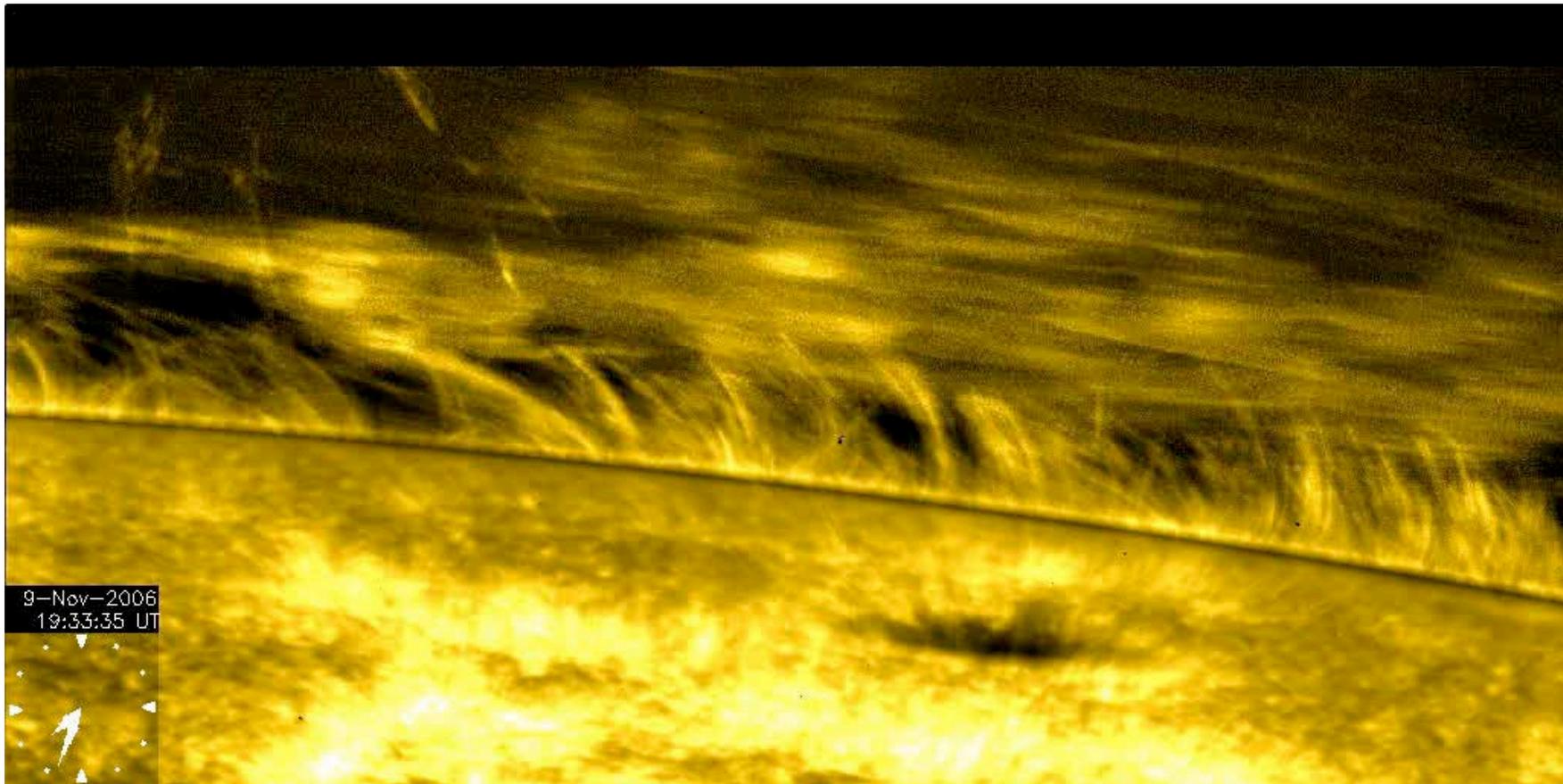
...but is trapped for a while in the **solar corona**



(NCAR/HAO)

# Coronal structures storing magnetic energy may survive for days, weeks....

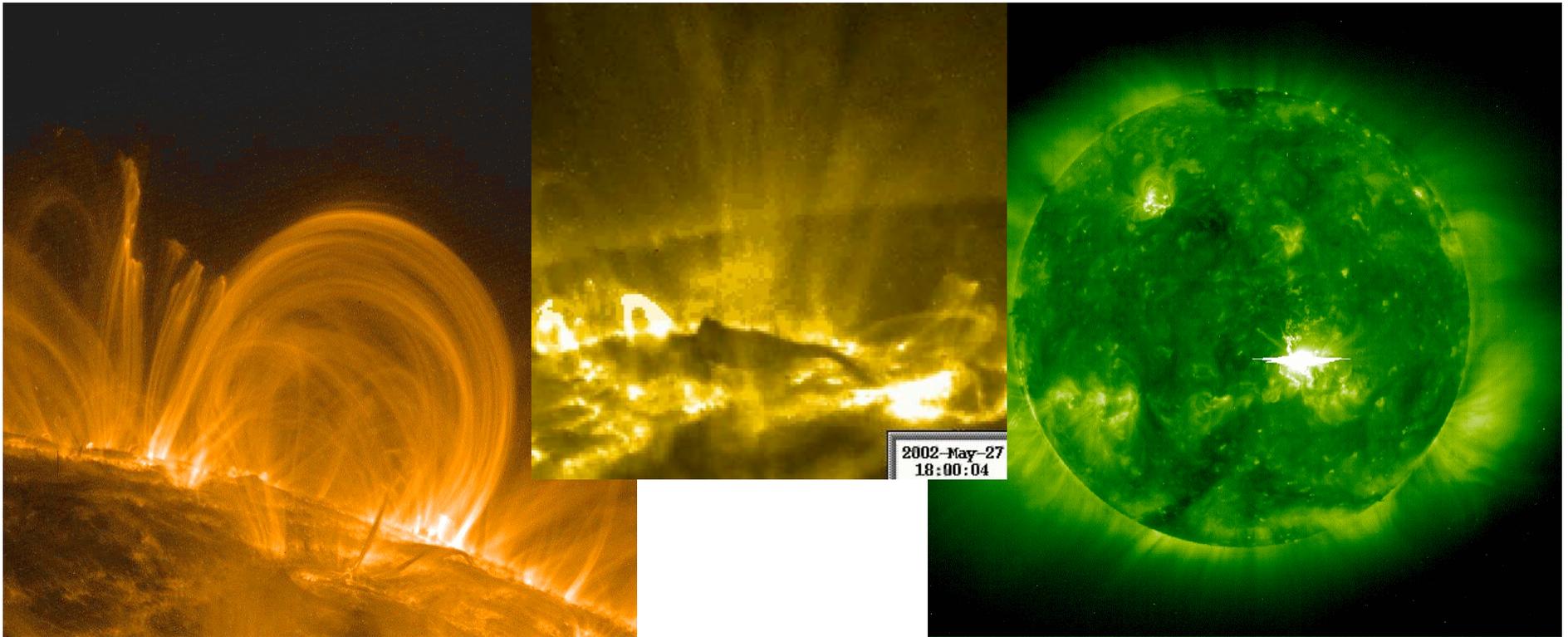
(Just about anything on the Sun is quite dynamic when you look closely enough. However, on large-scale, structures pretty much stay put...)



Hinode SOT (NASA/JAXA)

# Magnetic fields organize coronal structure and drive coronal dynamics

(...until they don't)



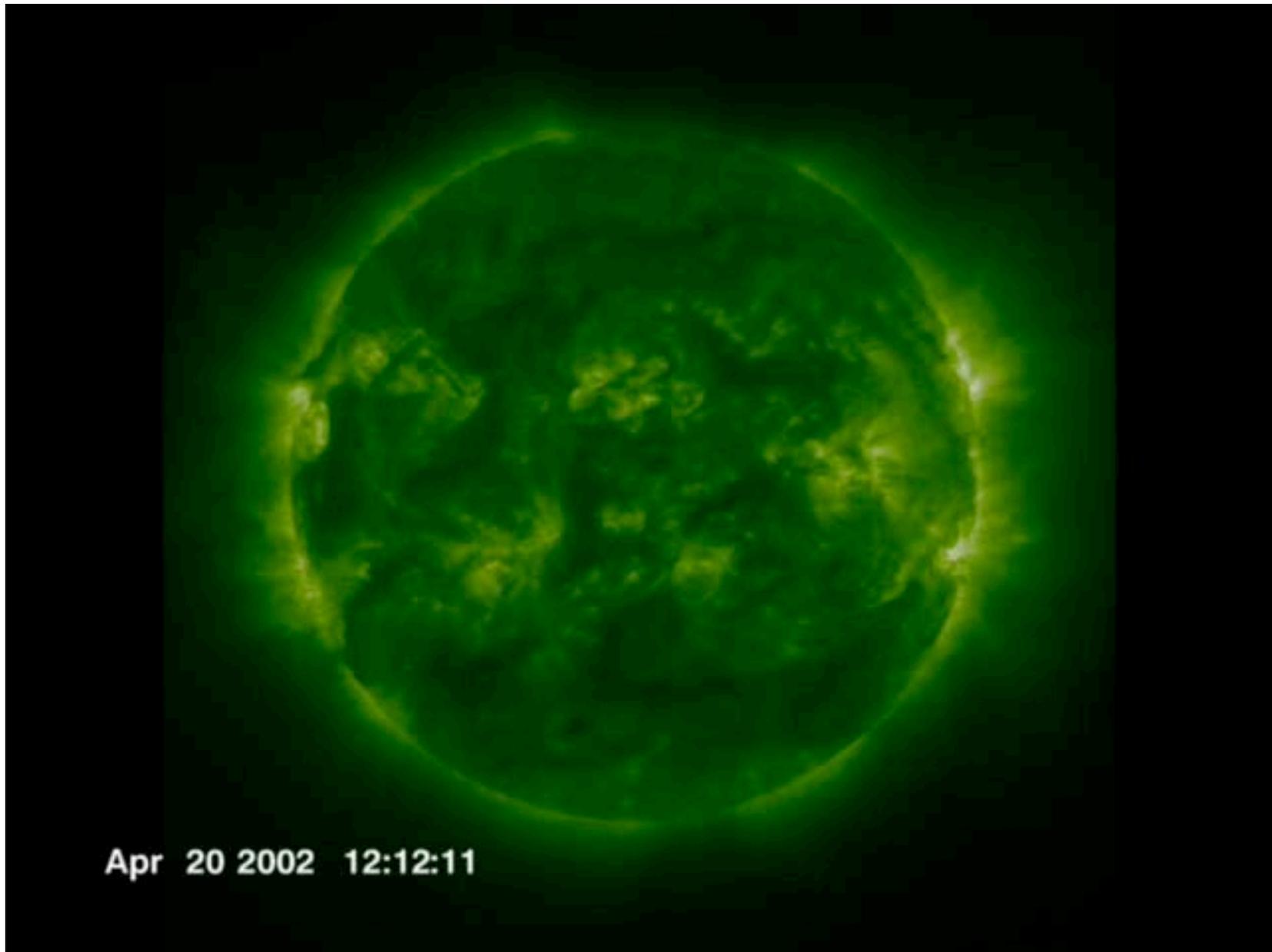
**TRACE 171 Angstroms**

**EIT 195 Angstroms May 2, 1998**

NASA/Stanford-Lockheed Institute for Space Research

(ESA/NASA)

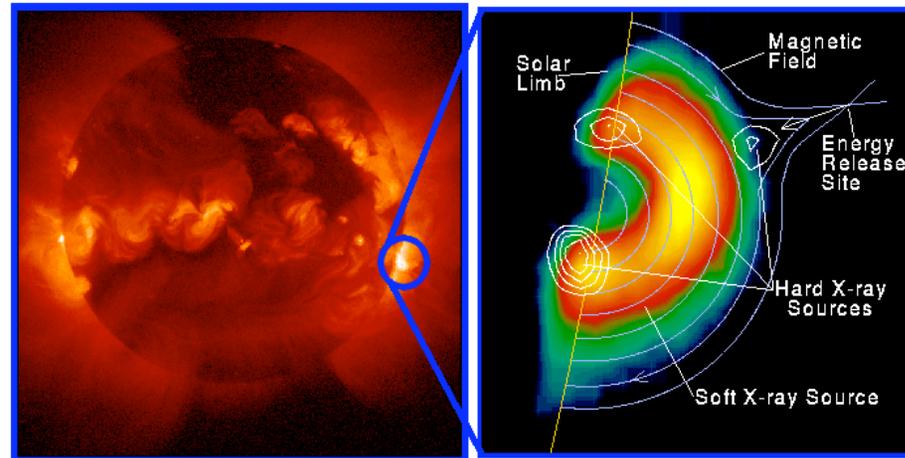
# Solar activity - Flares



Apr 20 2002 12:12:11

RHESSI (NASA) and SOHO-EIT (ESA/NASA)

# Space weather - Flares



Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

(JAXA/NASA)

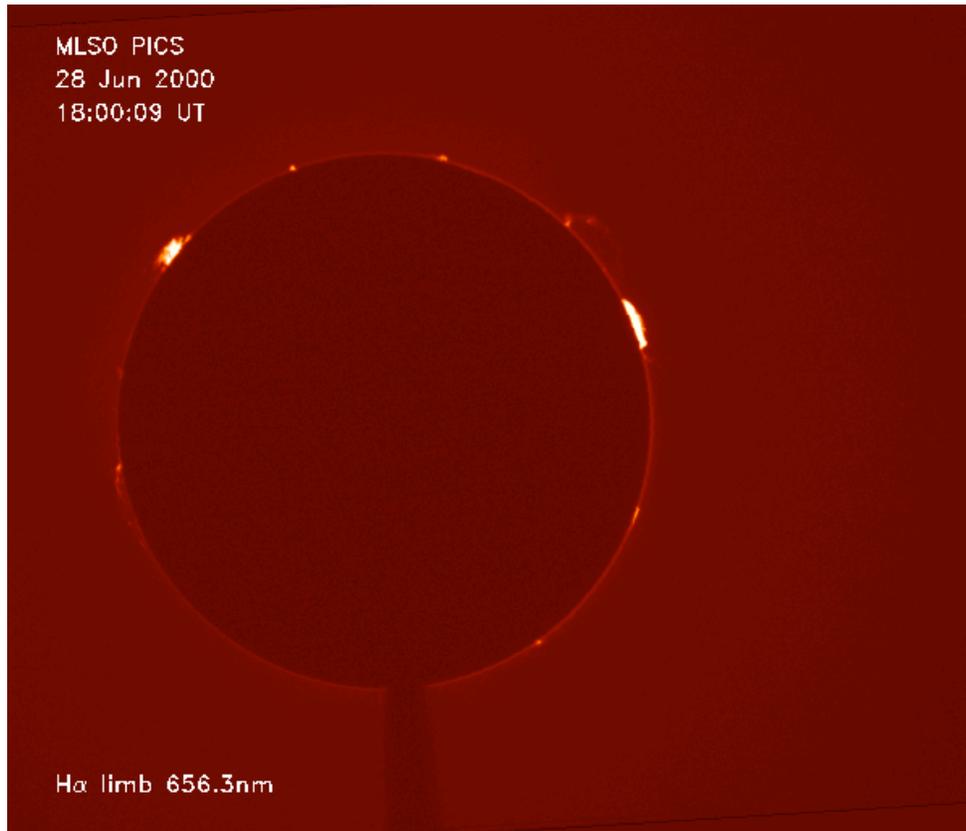
Flares represent transfer of magnetic energy to thermal/radiative energy.

Flares affect the ionosphere and radio communication at the Earth.

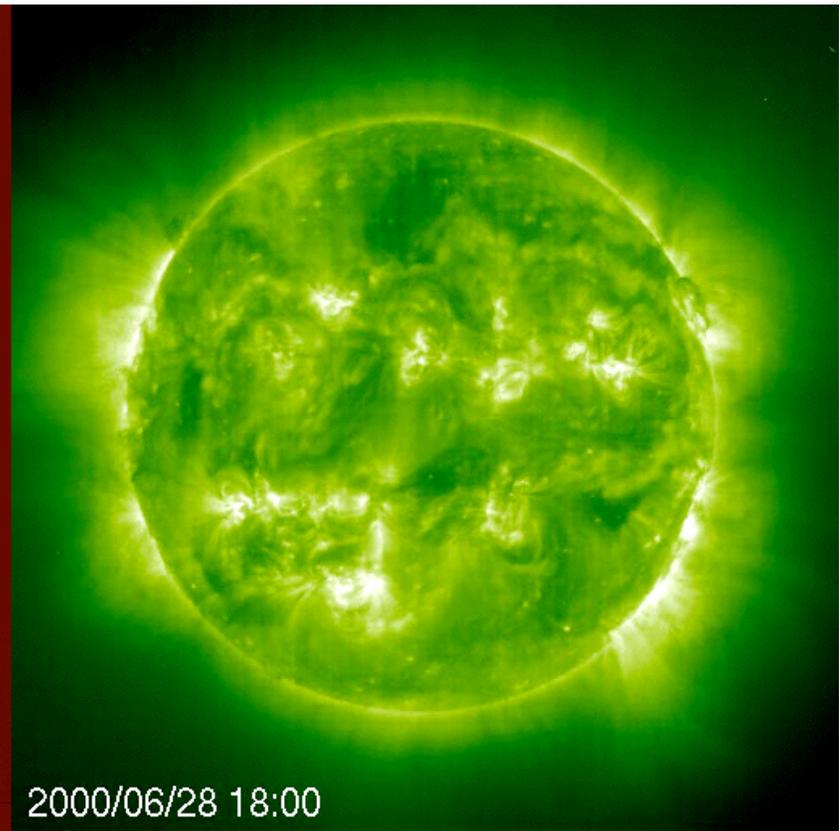
Flares also release energetic particles into space.

Flares are not the whole story, though!

# Solar activity - Coronal Mass Ejections



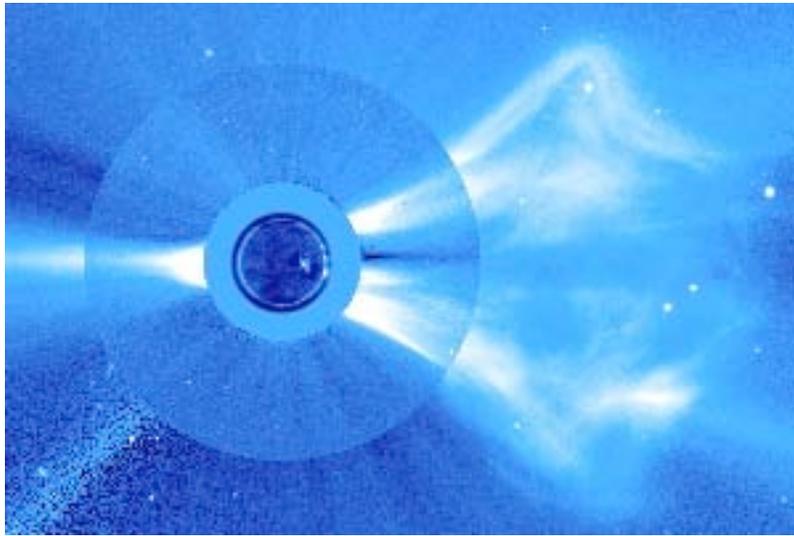
HAO-MLSO (NCAR)



SOHO-EIT (ESA/NASA)

Not just hot stuff involved in solar dynamics  
(Relatively) cool/dense “prominence” mass may erupt  
Coronal mass ejections: CMEs

# Space weather - CMEs



SOHO-LASCO (ESA/NASA)



CMEs represent transfer of magnetic energy into kinetic energy

The interaction of CME and Earth magnetic fields may drive geomagnetic storms

CMEs drive shock waves where energetic particles are accelerated

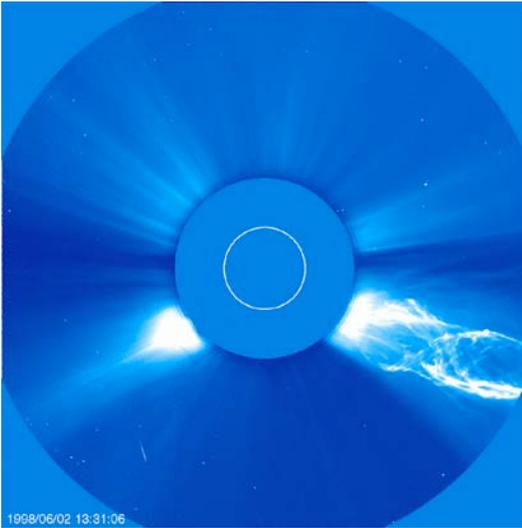
CMEs are often associated with flares -- double whammy!

# Magnetic fields are key!

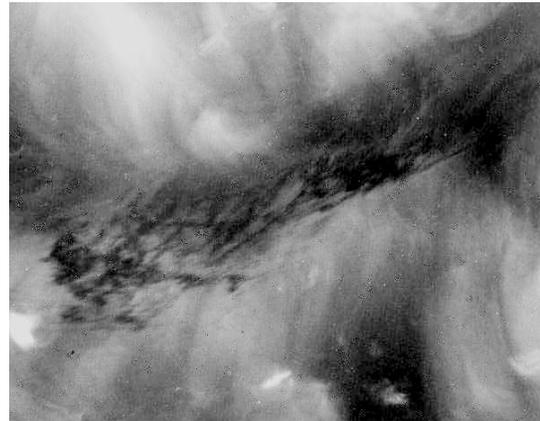


SOHO-MDI/TRACE NASA/Stanford-Lockheed Institute for Space Research

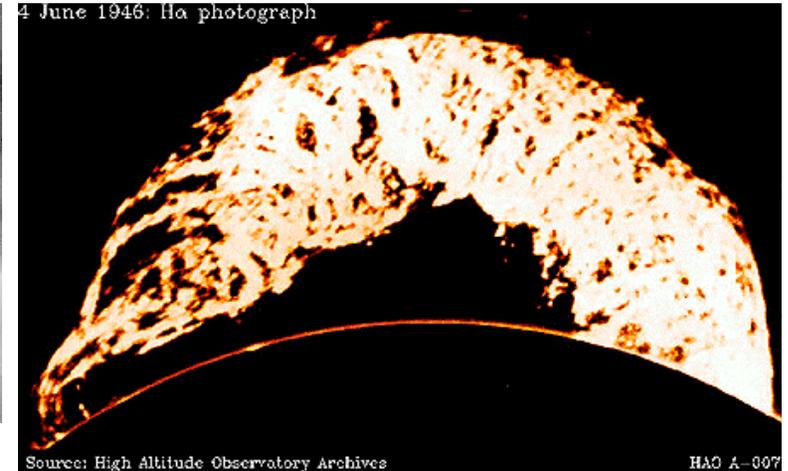
# Modeling storage and release of magnetic energy: 3D and twisted



SOHO-EIT (ESA/NASA)



TRACE (NASA/Stanford-  
Lockheed Institute for  
Space Research)



NCAR/HAO

A range of observations **suggest** twisted magnetic configurations for CMEs and their precursors

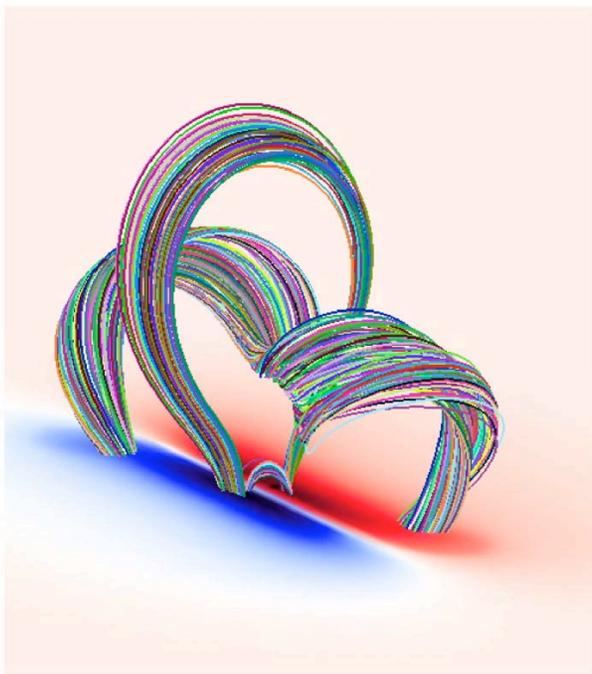
- plasma and field are “frozen together”
- plasma structures trace out field

# Modeling storage and release of magnetic energy: 3D and twisted

## What's a magnetic flux rope?

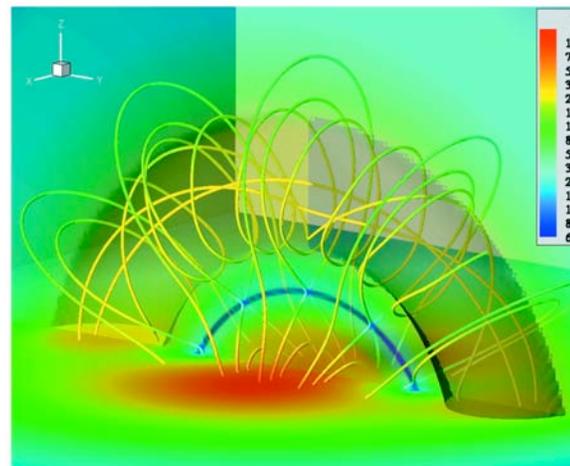
Suggested definition: A set of magnetic field lines winding about an axial field line

Loosely wound



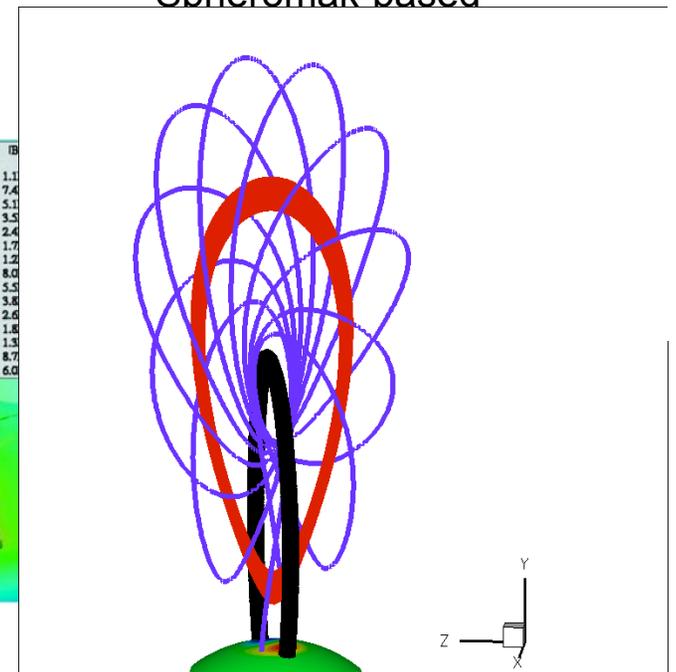
*Amari et al. (2003)*

Tightly wound



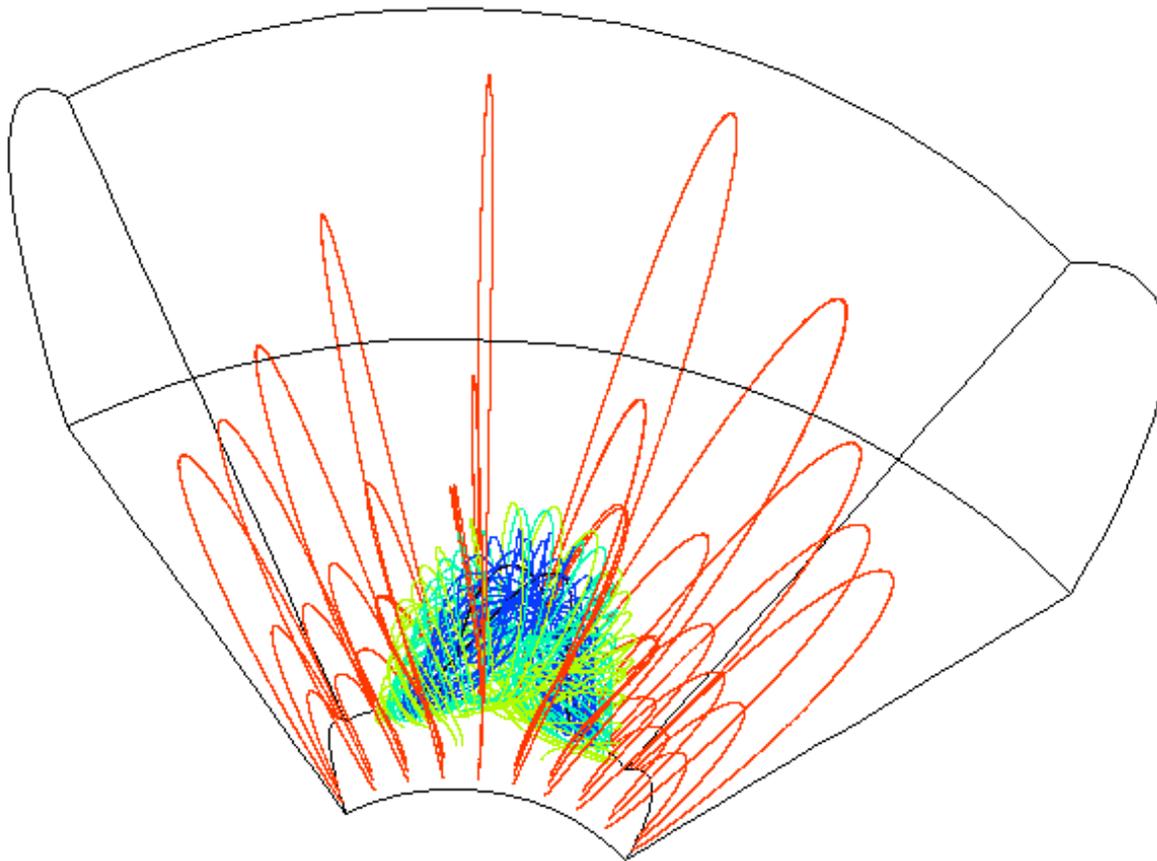
*Roussev (2003)  
(after Titov and Demoulin (1999))*

Spheromak-based



*After Gibson and Low (1998)*

# Modeling storage of magnetic energy

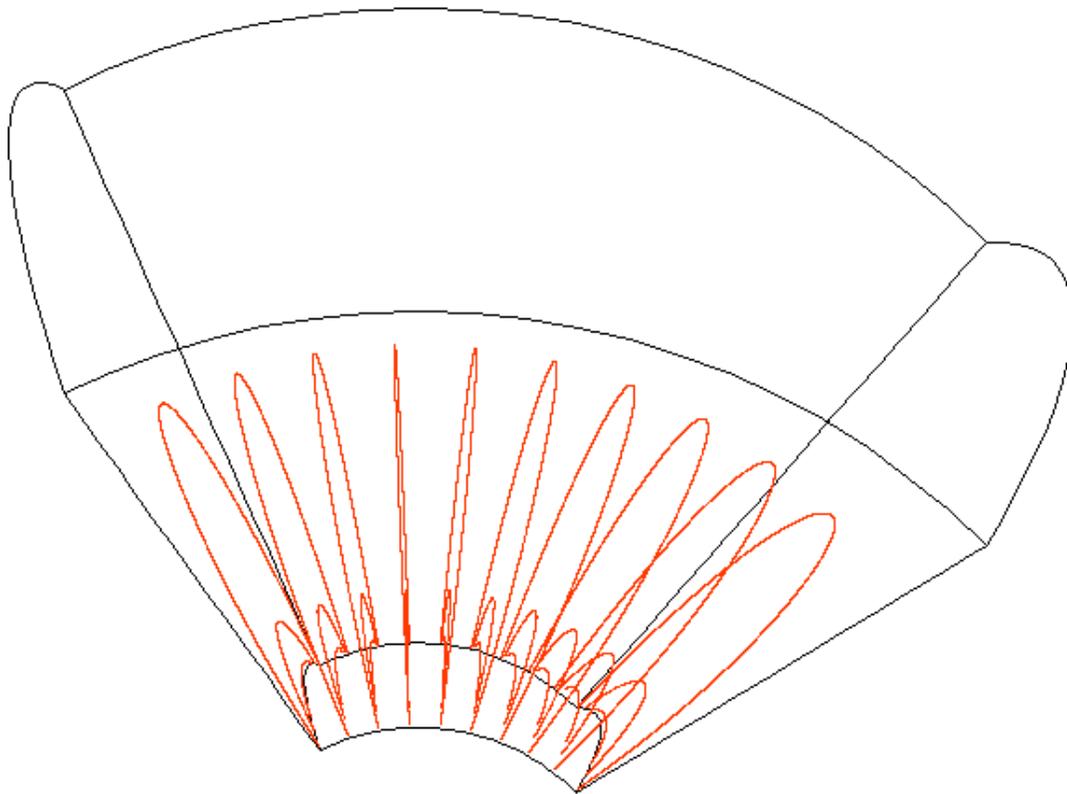


As magnetic field is constantly inputted from below the solar surface, a flux rope forms and exists quiescently

$$t = 138 (R_S/V_{A0})$$

*Fan and Gibson (2006)*

# Modeling **release** of magnetic energy



Eventually, too much twisted flux emerges, and the rope undergoes the “kink instability”, and ruptures the overlying field in a coronal mass ejection

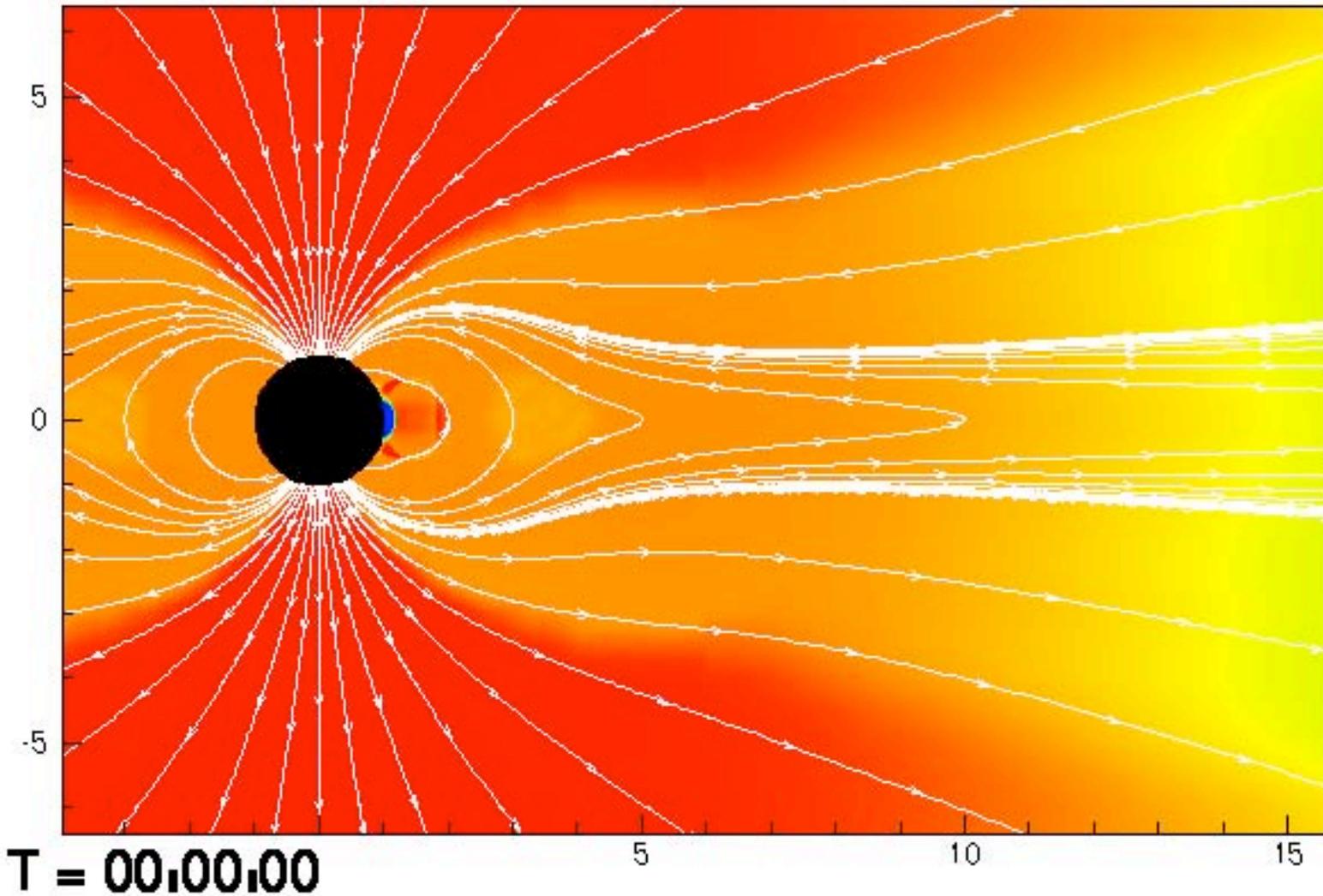
t=0.

*Fan (2005)*

# Modeling impact of CME at the Earth

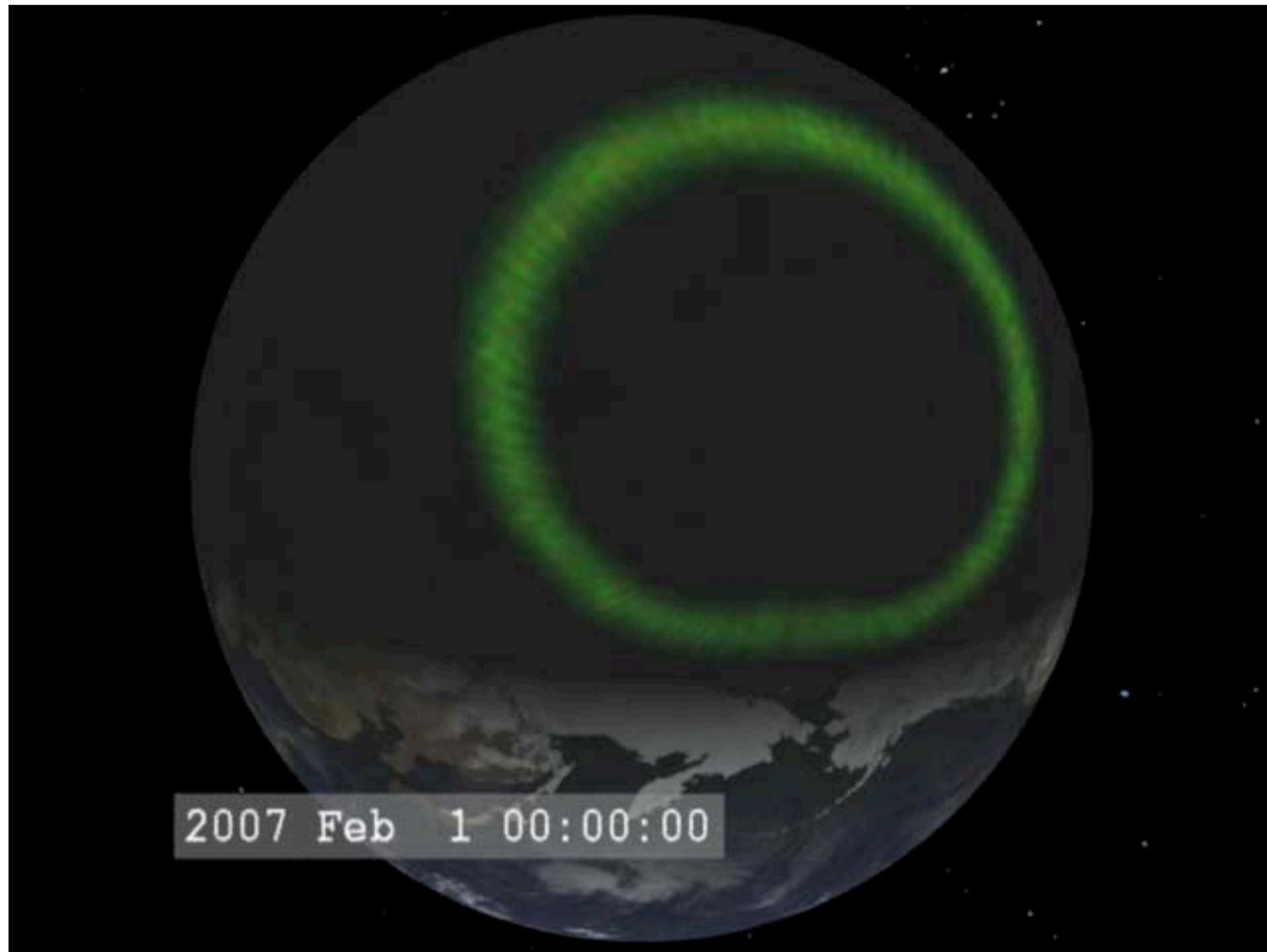


Center for Space Environment Modeling  
University of Michigan



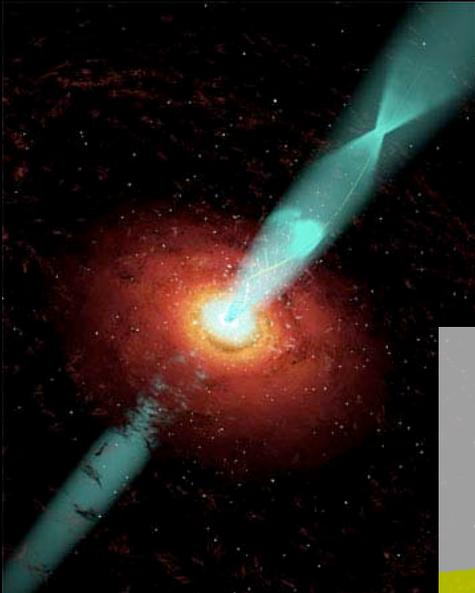
Center for Space Environment Modeling (University of Michigan)

# Modeling magnetospheric substorms at the Earth



Opening with a view of the aurora borealis, we zoom out to reveal the orbital configuration of the five THEMIS satellites and fade in a GGCM magnetosphere model. (NASA)

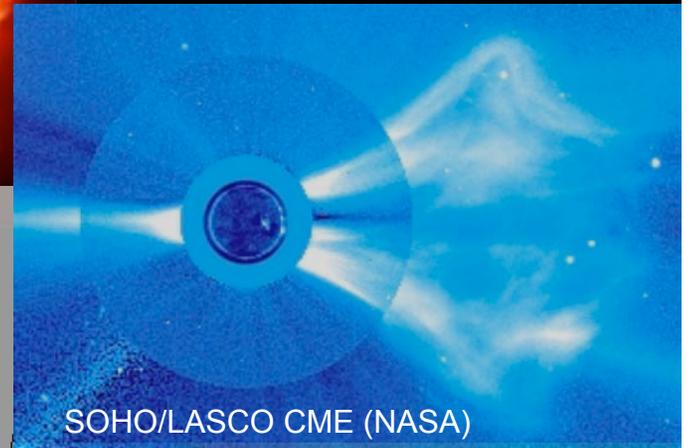
# Storage and release of magnetic energy is universal: laboratory and astrophysical plasmas



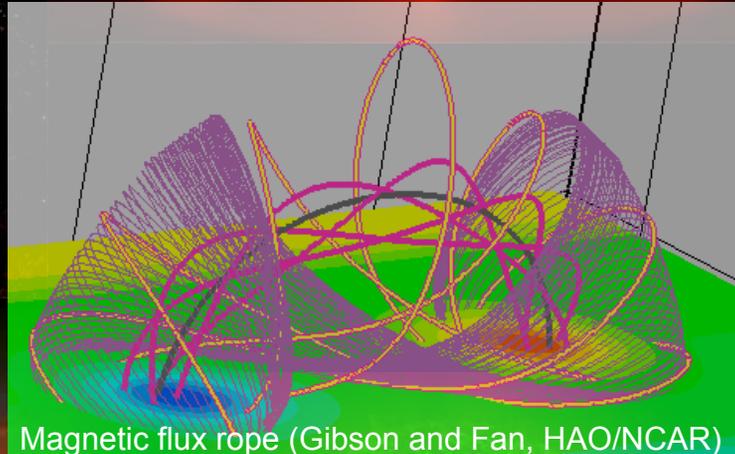
BL Lacertae (Steffen, UNAM)



Laboratory plasma (Bellan, CalTech)



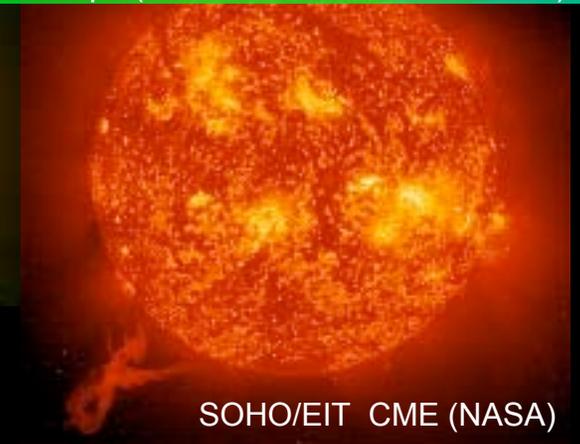
SOHO/LASCO CME (NASA)



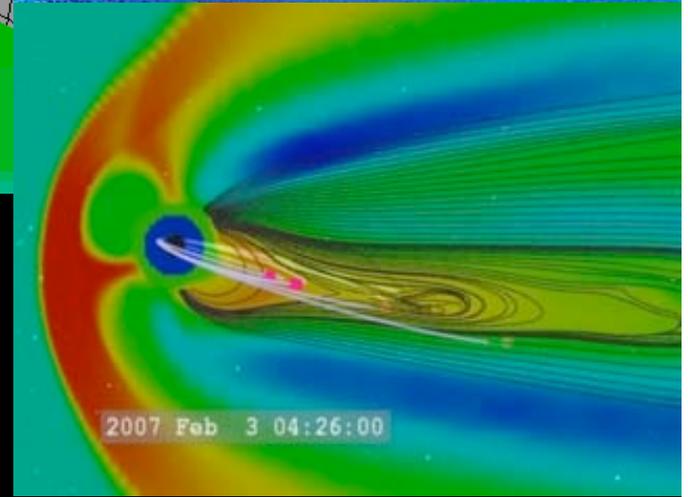
Magnetic flux rope (Gibson and Fan, HAO/NCAR)



EV Lacertae (Reed, NASA)

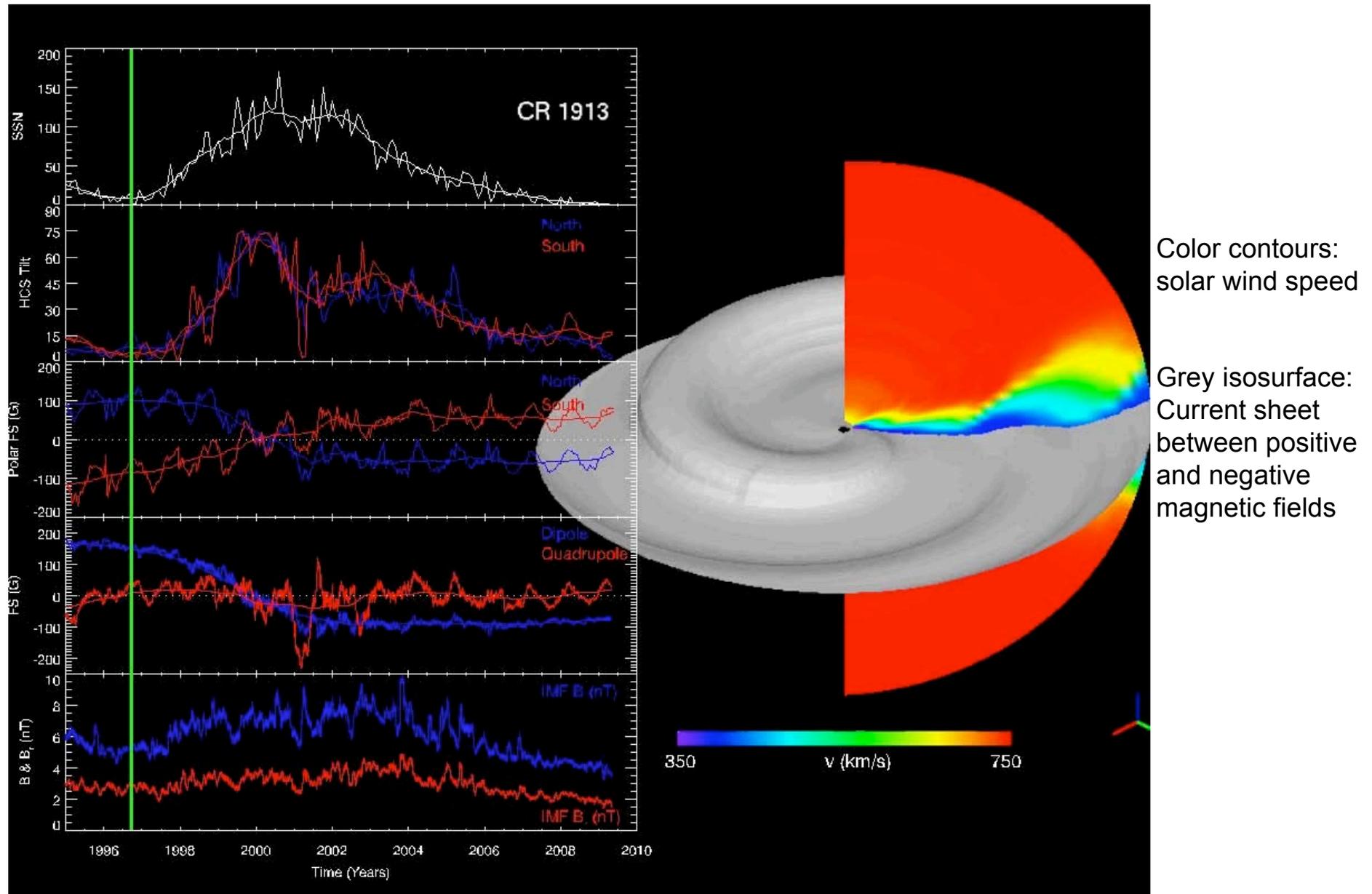


SOHO/EIT CME (NASA)



Magnetic substorm model (GGCM/NASA)

# The 3D magnetized solar wind fills the solar system



Solar wind model, Predictive Science Inc.

# Conclusions

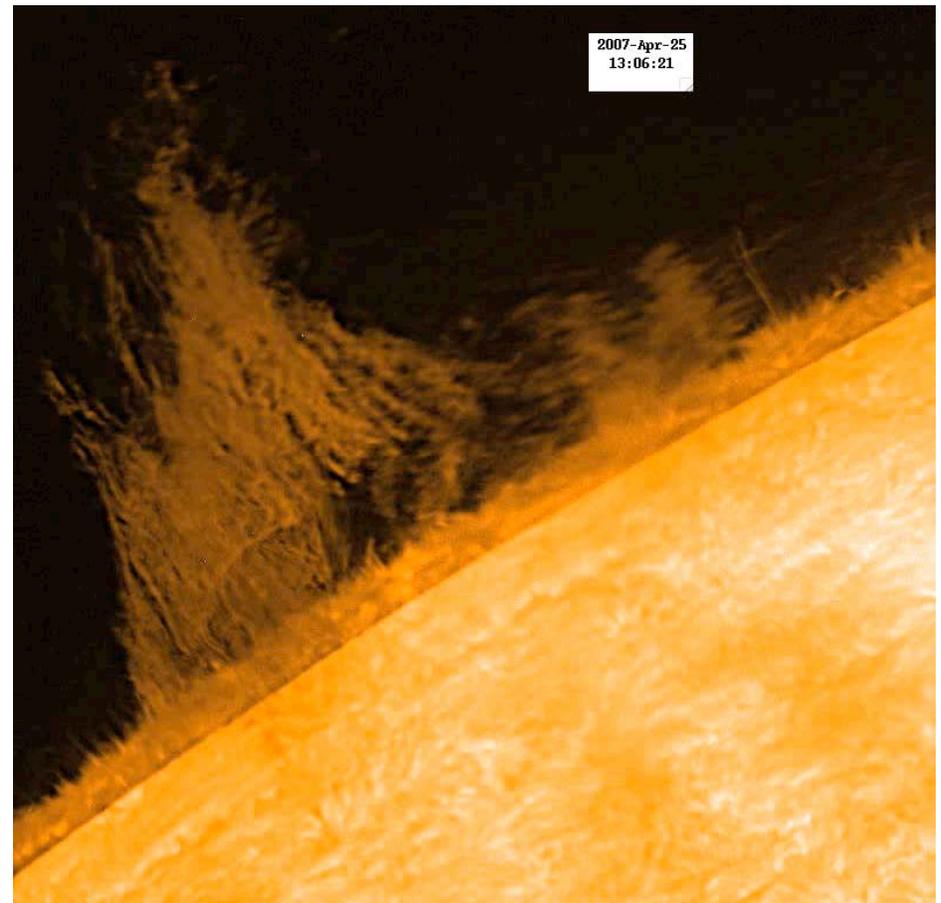
## We live in the outer atmosphere of a 3D, magnetic star

The sun uniquely affects us, but we have unique views (up-close and 3D) of it

Magnetic fields are the key to understanding, predicting, and mitigating space weather

*"If the sun didn't have a magnetic field, then it would be as boring a star as most astronomers think it is." (Leighton)*

*"Magnetic fields are to astrophysics what sex is to psychoanalysis" (van de Hulst)*



Hinode SOT (NASA/JAXA)