# Coronal radiation belts?


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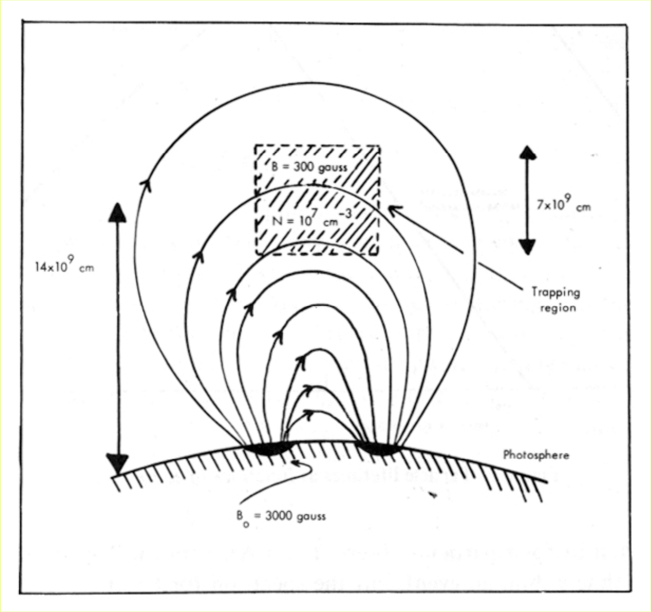



Elliot (1973) cartoon, from
http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/

# Thesis

- Elliot (1964) suggested the possibility of particle accumulation in mirror geometries in the solar corona
- Large amounts of energy can probably be stored in the corona without substantial effects on the field and without externally driven current systems
- There's a nice practical framework in which to assess various aspects of this - PFSS as made available by Schrijver and DeRosa

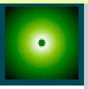
# Topics

- Coronal magnetic field: morphology, PFSS modeling, comparison with geomagnetic field
- Particle trapping: lifetimes, stability, signatures, effects
- Sources of particles: CRAND, low-level activity, convection
- Applications: energy storage (Elliot), CH boundaries, SEPs
- Detectability

# Two RHESSI science nuggets

http://sprg.ssl.berkeley.edu/~tohban/nuggets/

**A Solar Hard X-Ray Halo: Exploring the Quiet Sun II**
***2006-02-27 • by Alec MacKinnon and Hugh Hudson***

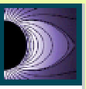


### Introduction

This nugget is a continuation in our quiet Sun series (see our previous quiet Sun nugget). During solar minimum, RHESSI has a wonderful opportunity to search for X-rays not related to solar flares. This nugget describes a new component of the hard X-ray emission from the quiet Sun.

The usual process through which X-rays are produced on the Sun is bremsstrahlung. In the context of the Sun, this term usually refers to radiation produced by free energetic electrons deflected by other charged particles. Another variety of this bremsstrahlung process exists, "inner" bremsstrahlung. When a neutron beta-decays, which it does with a half-life of about ten minutes, the beta particle (another name for an electron) - can emit an X-ray as it "exits" the decaying neutron. Such neutrons can be produced on the Sun through galactic cosmic rays interacting with the solar material. These interactions produce secondary neutrons which can then scatter back out of the Sun into the corona and beta-decay.

**Solar radiation belts?**
***2006-10-10 • by Hugh Hudson and Alec MacKinnon***



### History

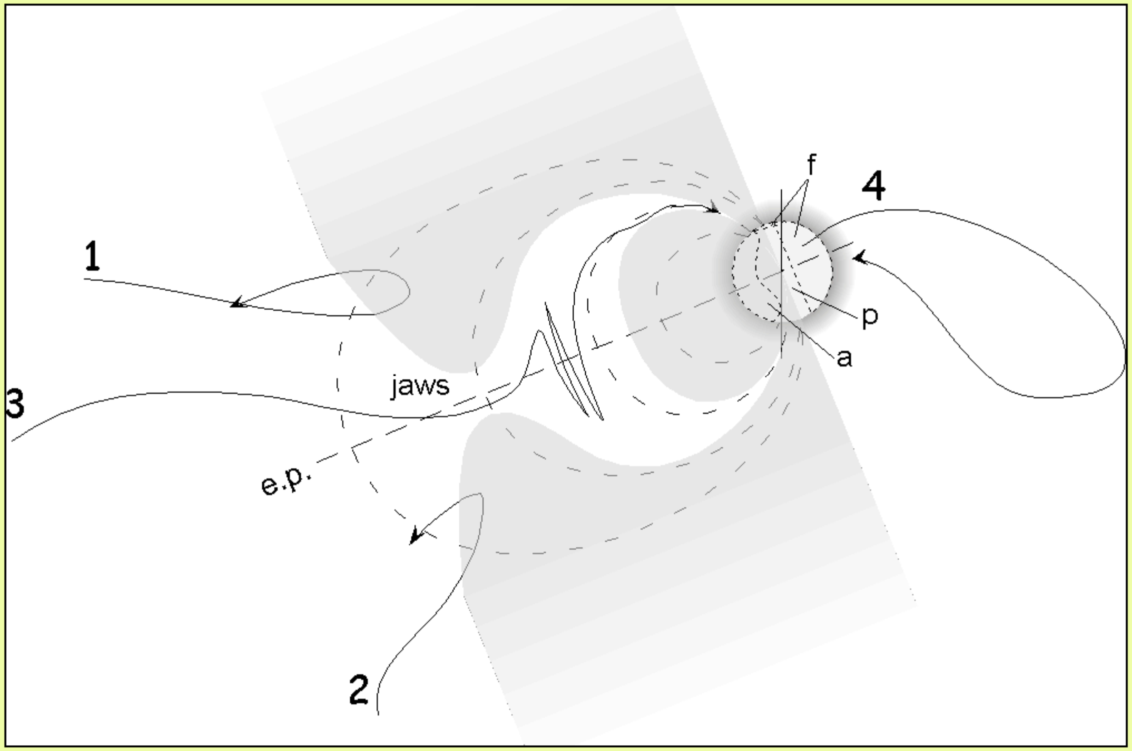
The Van Allen Belts were discovered in 1958 with data from Explorer 1, a forbear of RHESSI which is also an Explorer class satellite. The existence of this intense radiation was a surprise; people knew that there were "forbidden zones" into which galactic cosmic rays could not penetrate, and yet parts of these zones were loaded with similar particles. This discovery launched the field of *space plasma physics* and many subsequent satellites. The original mathematics explaining this phenemonon are quite complicated and were originally worked out by Karl Størmer.

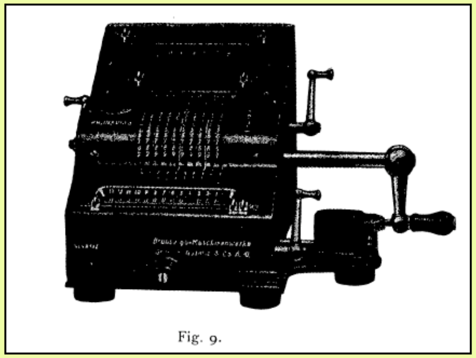
The key theoretical problem is that the magnetic force on a charged particle is proportional to **v** x **B** and is perpendicular to both the particle's velocity **v** and to the local magnetic field **B**. Thus to a first approximation no cross-field motion is possible - the particle just gyrates around field lines in a uniform field. A uniform field is probably impossible to achieve, however, and if the gyration orbit of the particle becomes comparable to the scale length of the non-uniformity, then the particle trajectory can include *non-adiabatic* (read unexpected) motions across the field. This is the very complicated mathematical problem that Størmer tackled.

# Inspiration

- RHESSI quiet-Sun search
- MacKinnon remembers "inner bremsstrahlung"
- PFSS convenience

# Carl Stoermer



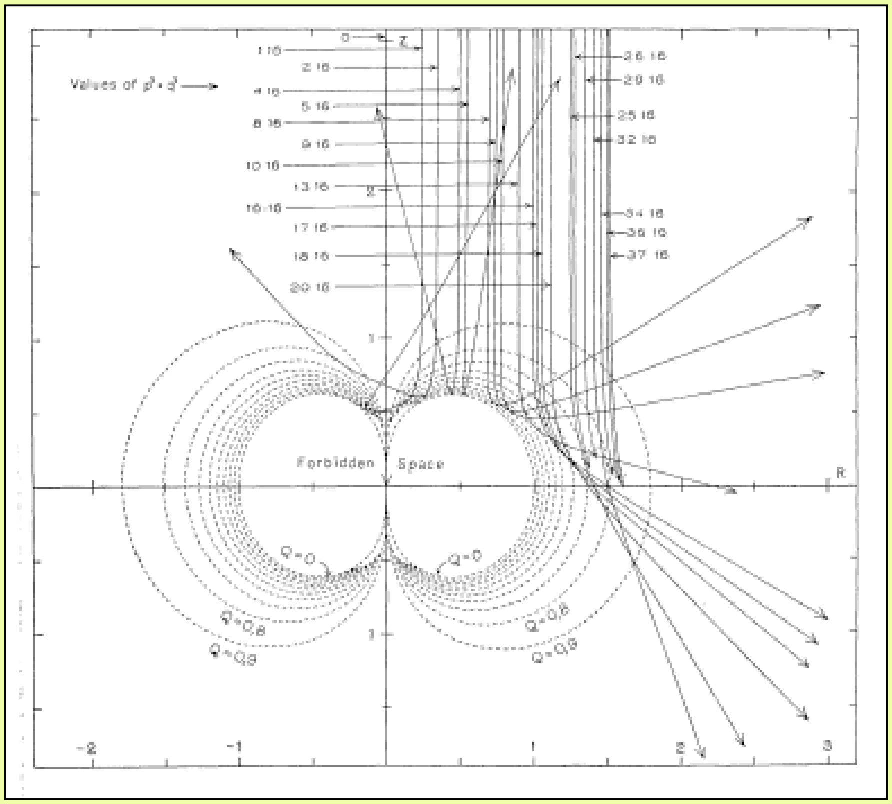

ASTROPHYSICA NORVEGICA

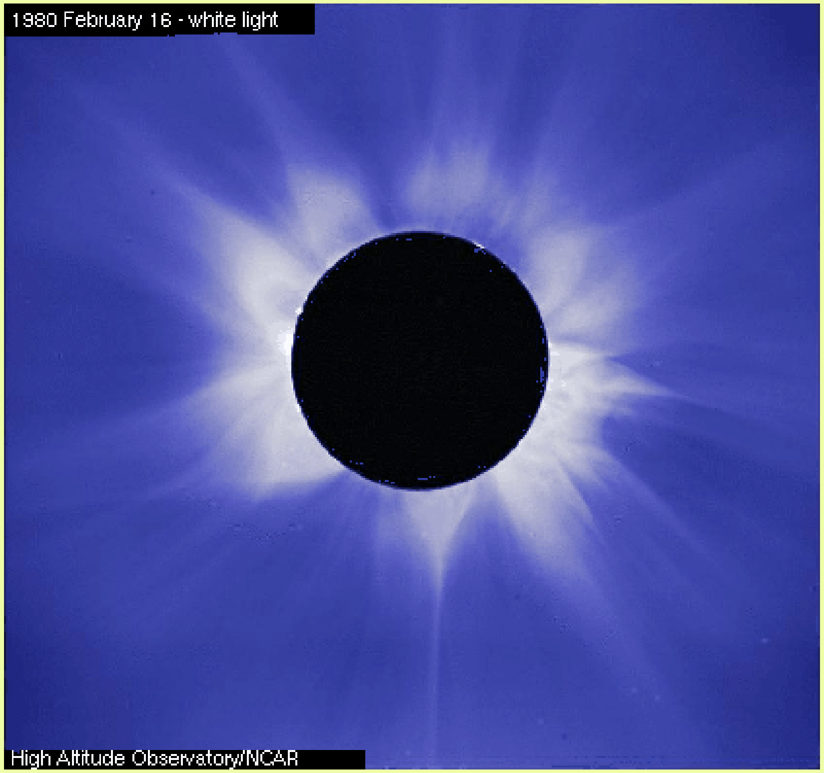
VOL. II NO. 1

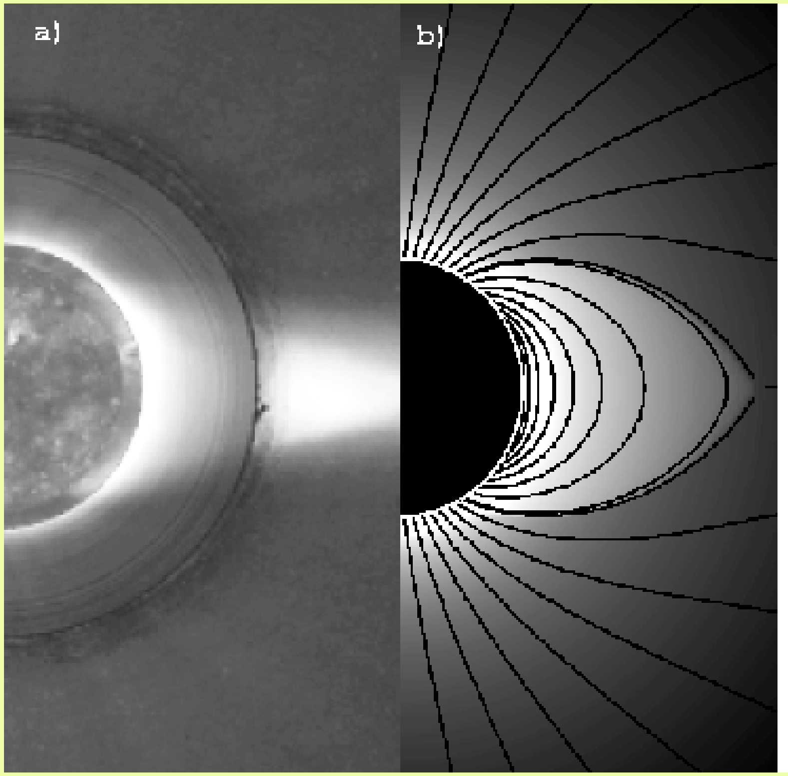
# ON THE TRAJECTORIES OF ELECTRIC PARTICLES IN THE FIELD OF A MAGNETIC DIPOLE WITH APPLICATIONS TO THE THEORY OF COSMIC RADIATION

FIFTH COMMUNICATION

BY CARL STØRMER

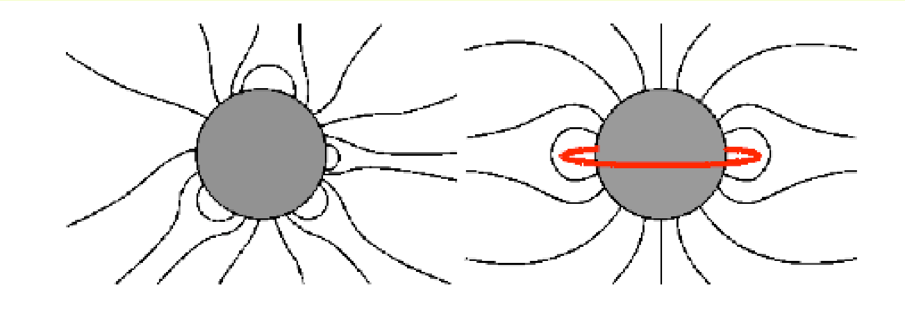




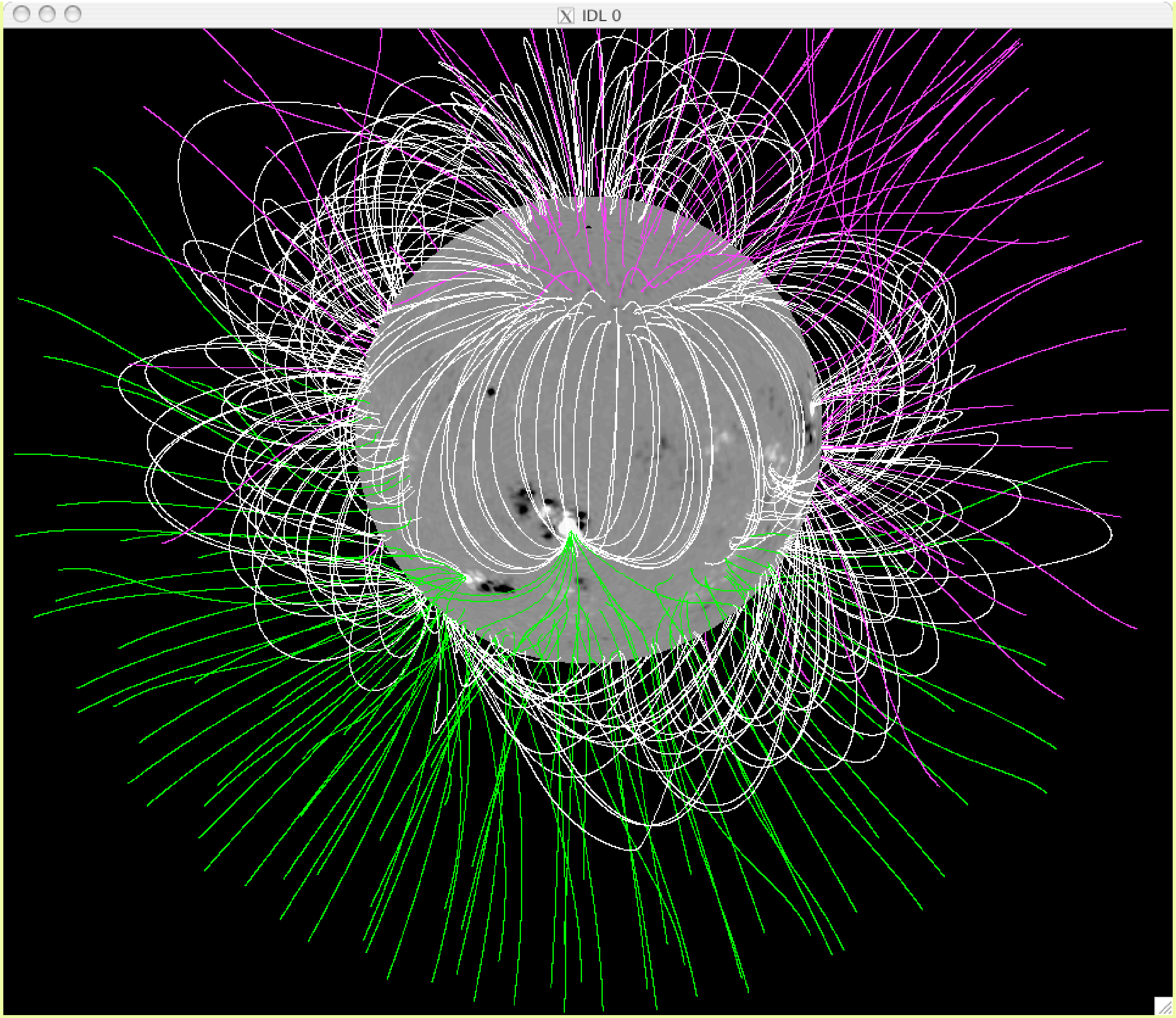

Sunspot cycle maximum

Sunspot cycle minimum

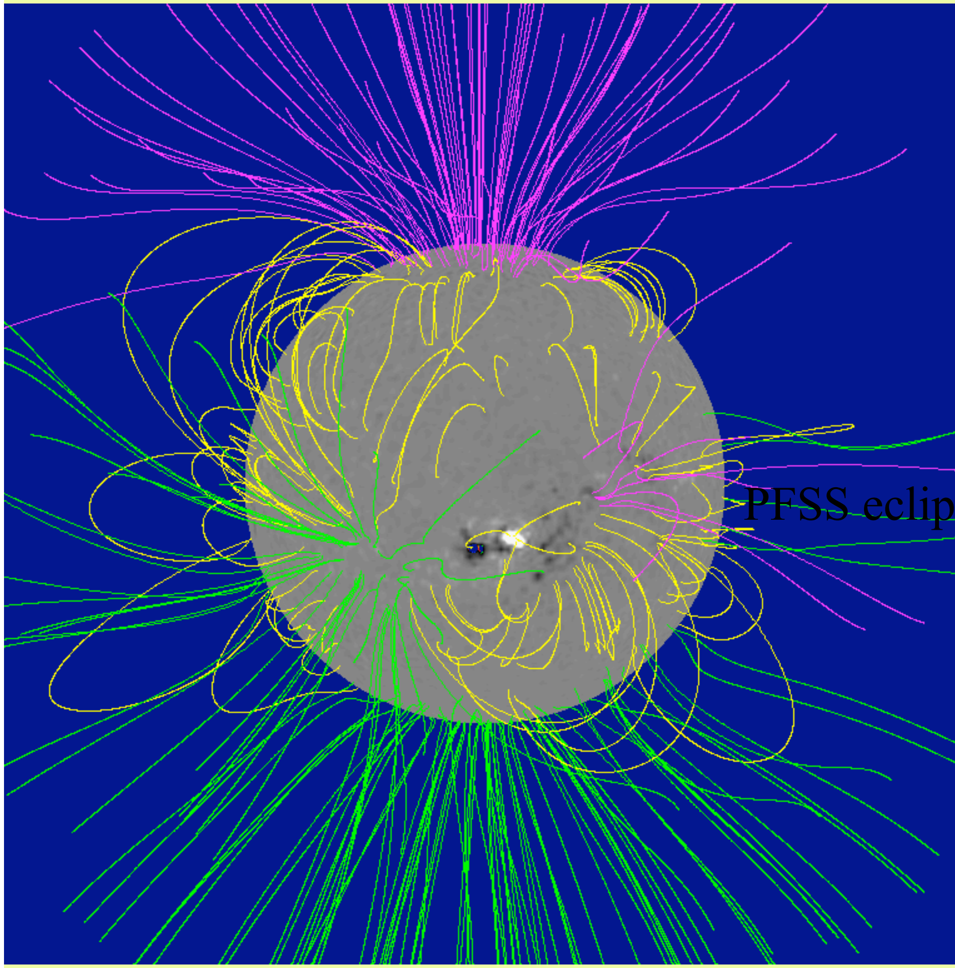


# “Potential field source-surface model” (PFSS)

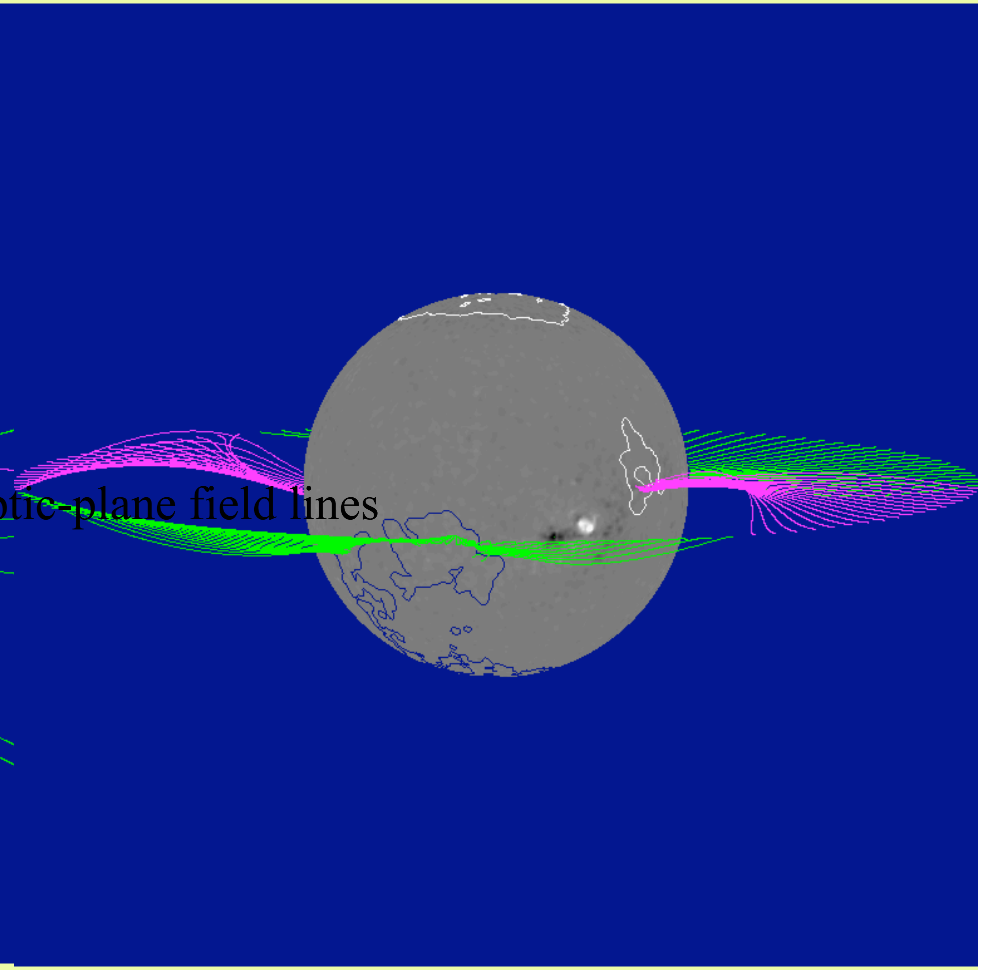
- Altschuler-Newkirk (1969), Schatten et al. (1969)
- Ingeniously simple theory of coronal structure
- Fictitious currents above “source surface” represent the solar wind
- T. Hoeksema PhD thesis (1984). $R_{ss}$ = 2.5 exactly and forever
- Model meets great success in the morphology of the solar wind and elsewhere




Schrijver-DeRosa PFSS example




PFSS “hairy ball” example

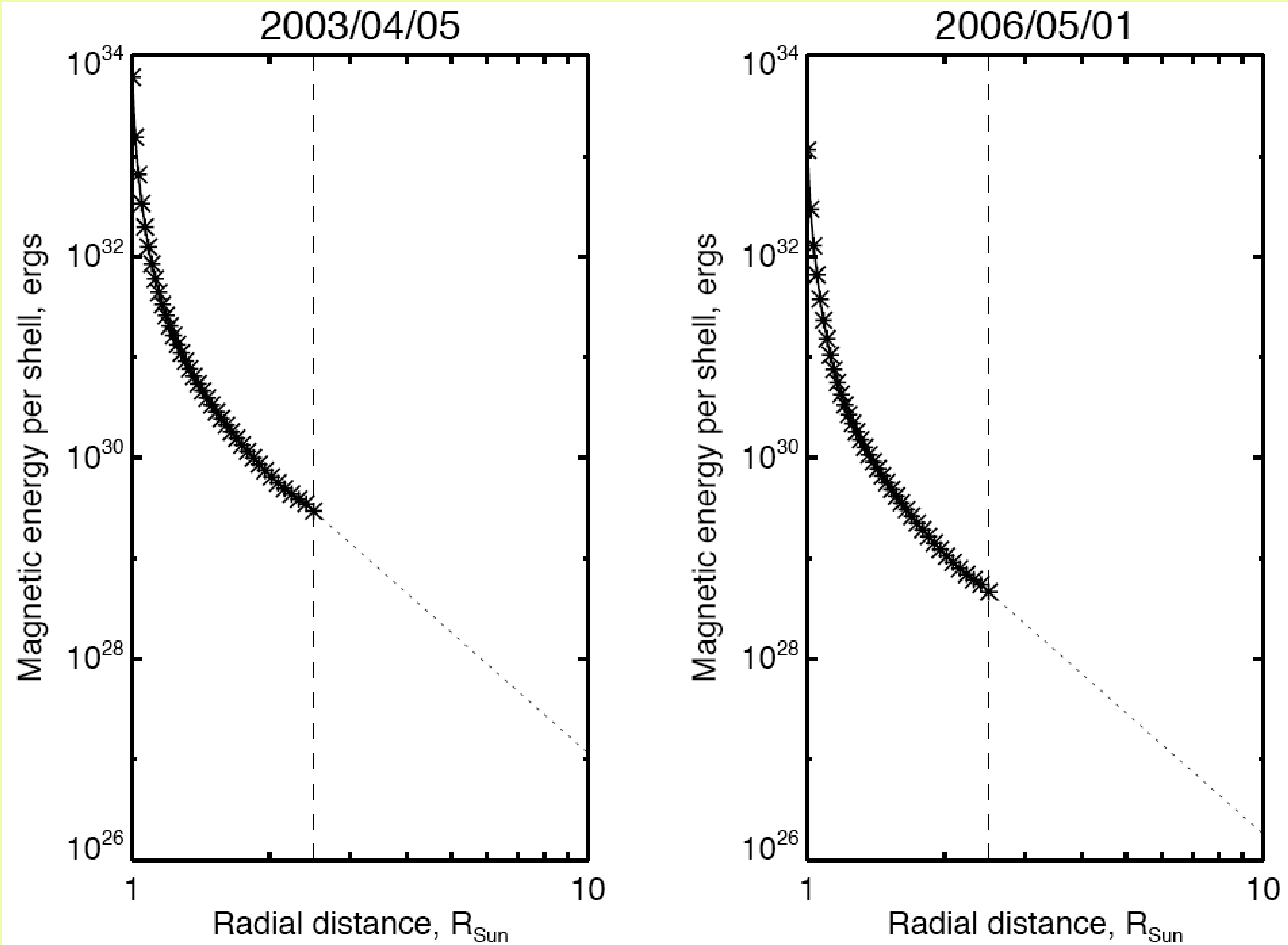


PFSS ecliptic-plane field lines

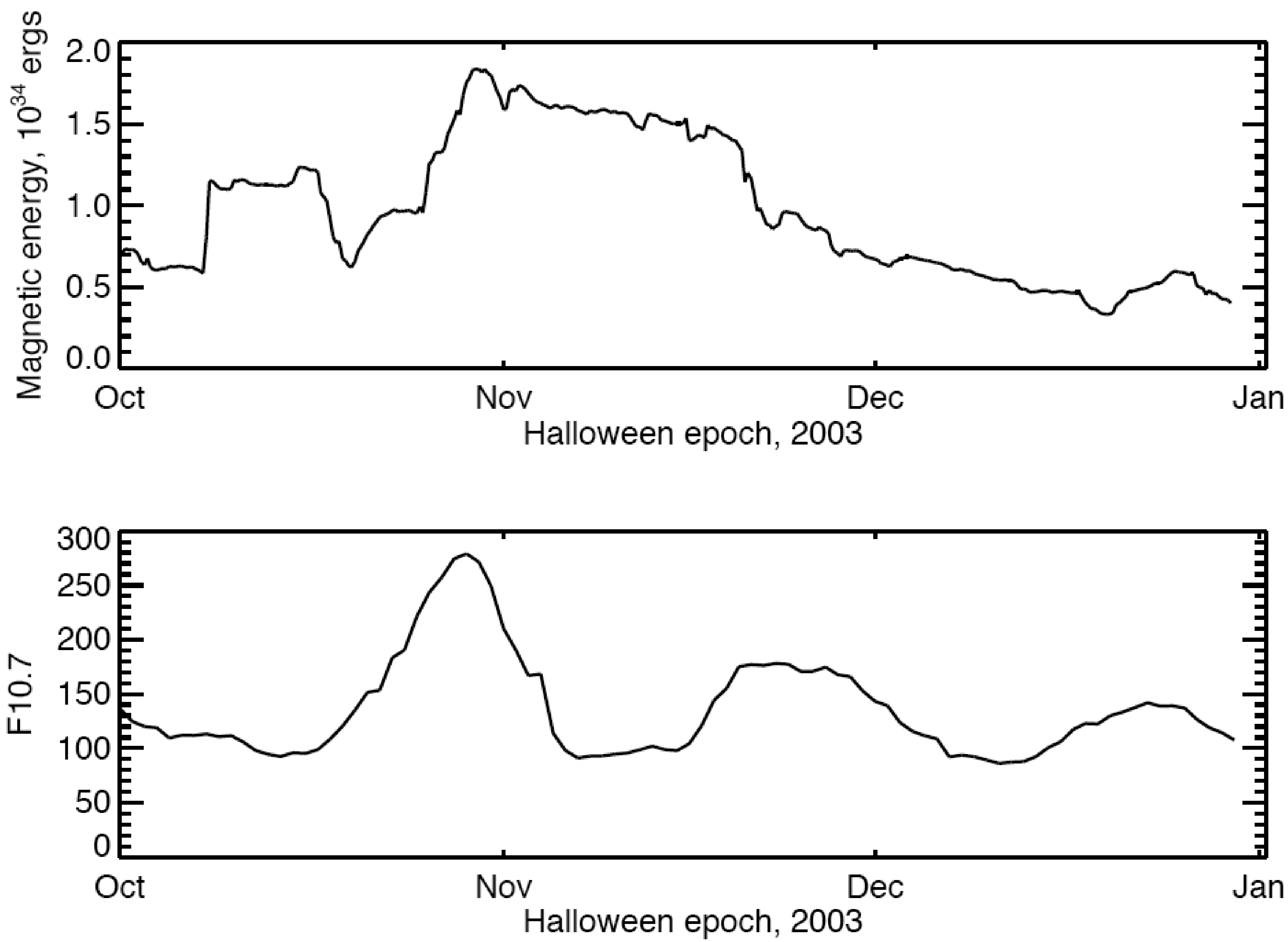
# Schrijver-DeRosa PFSS

- Package of routines to generate complete 3D models of the coronal field in the PFSS approximation
- Update every 6 hours
- Automatic database access via SolarSoft
- GUI or command line
- Code for particle propagation easily added

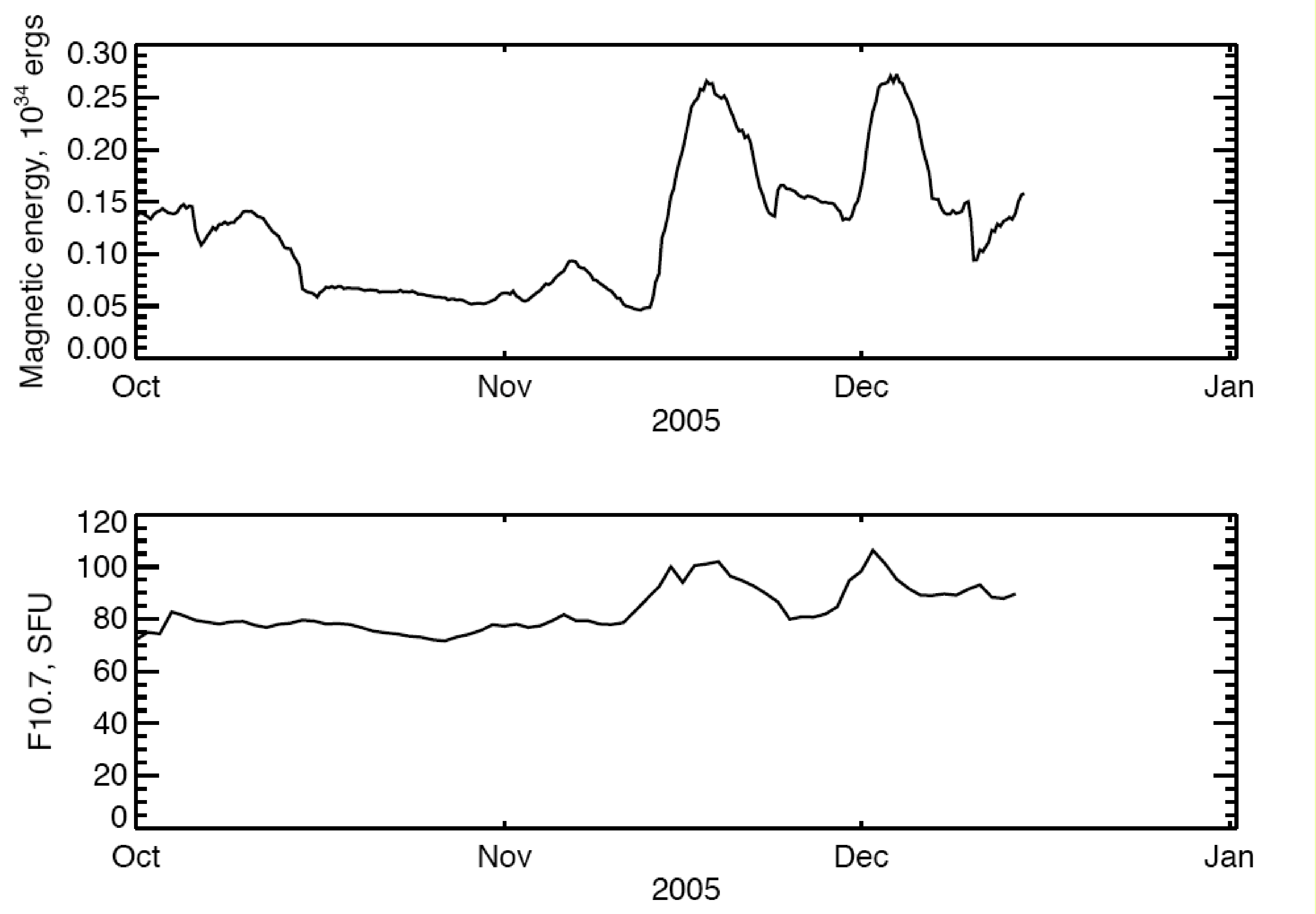
# Energy content of PFSS models



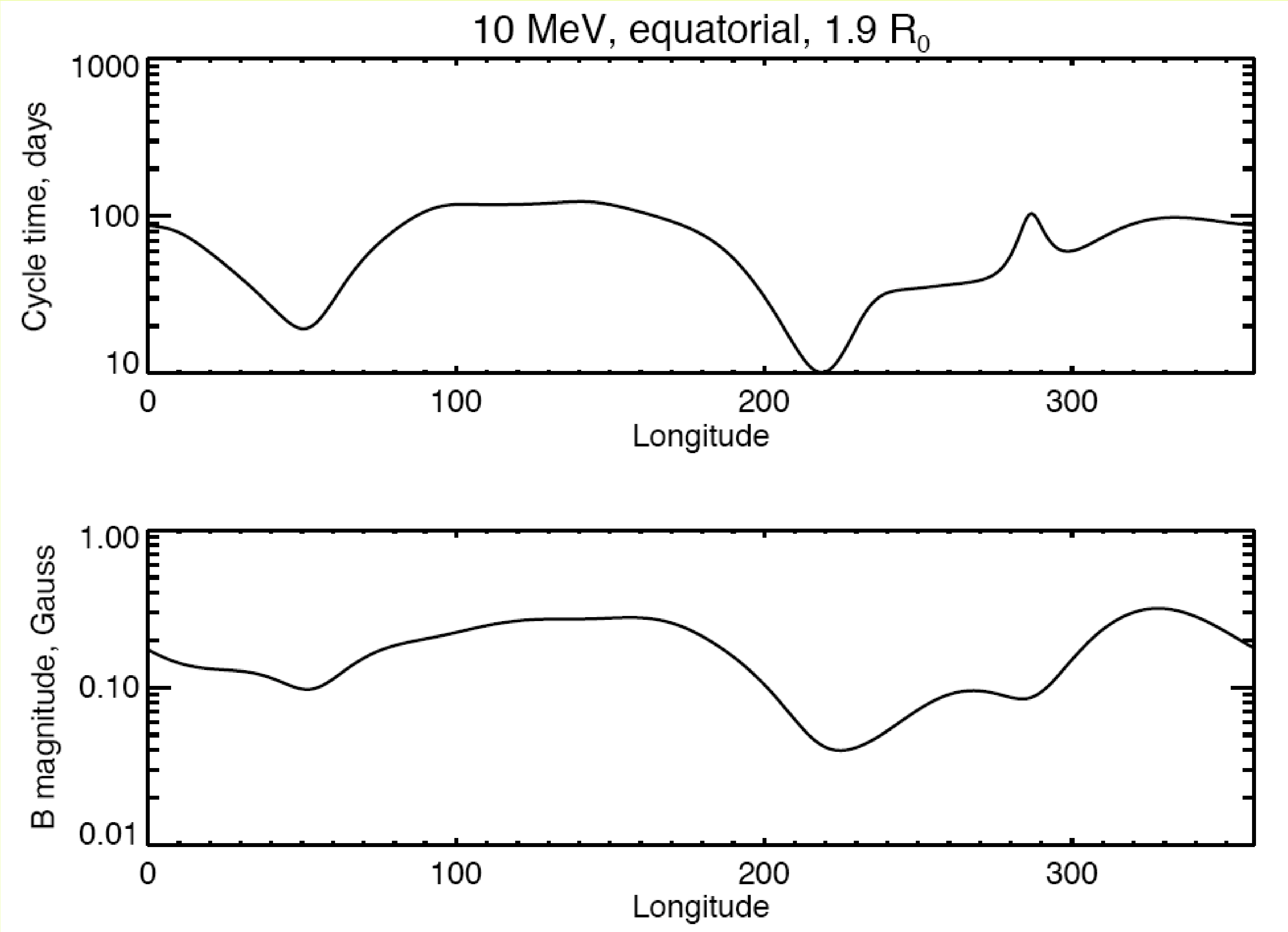
# Total magnetic energy vs time



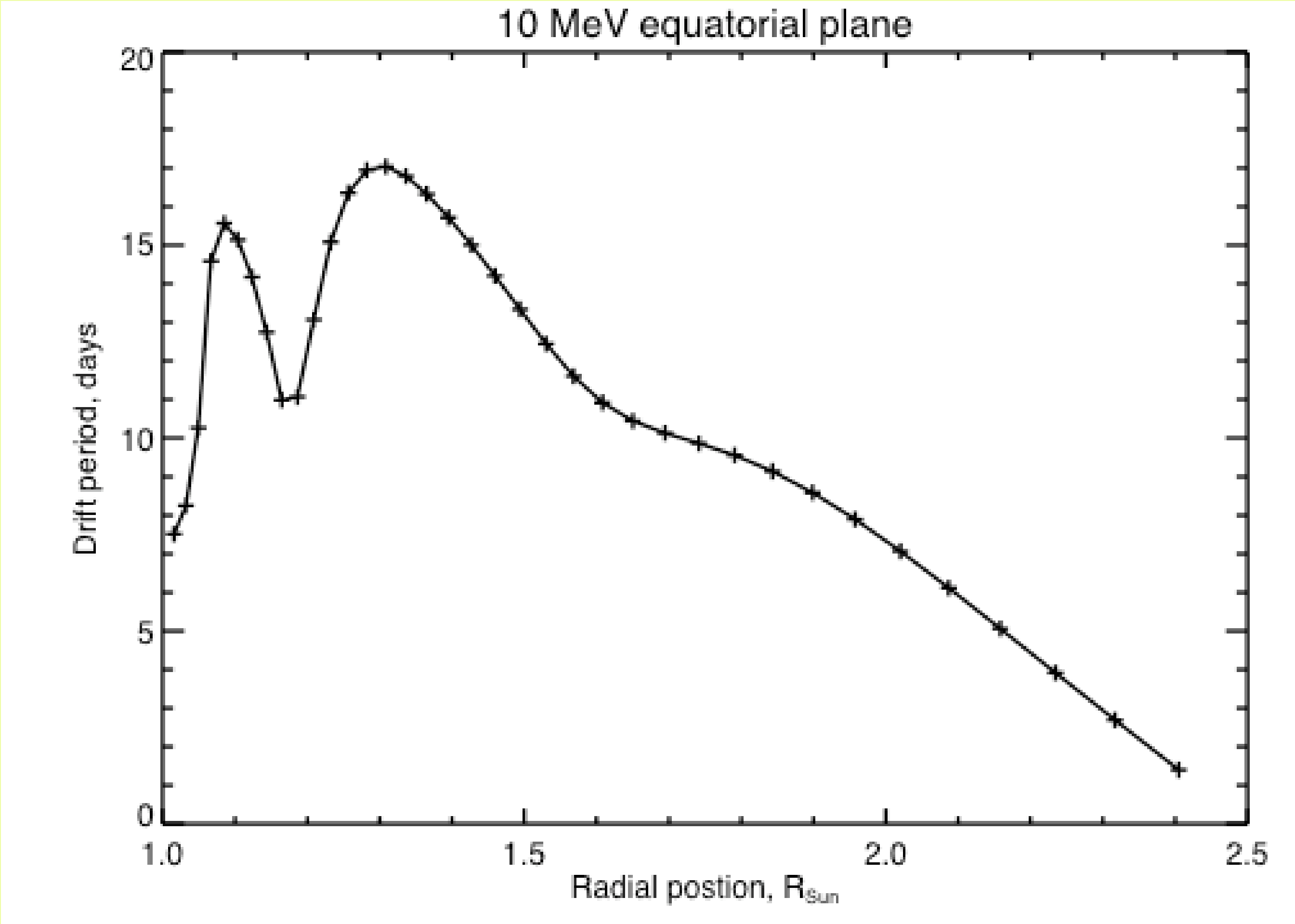
# Energy vs time at solar minimum



# Drift time scale



# Mean drift times



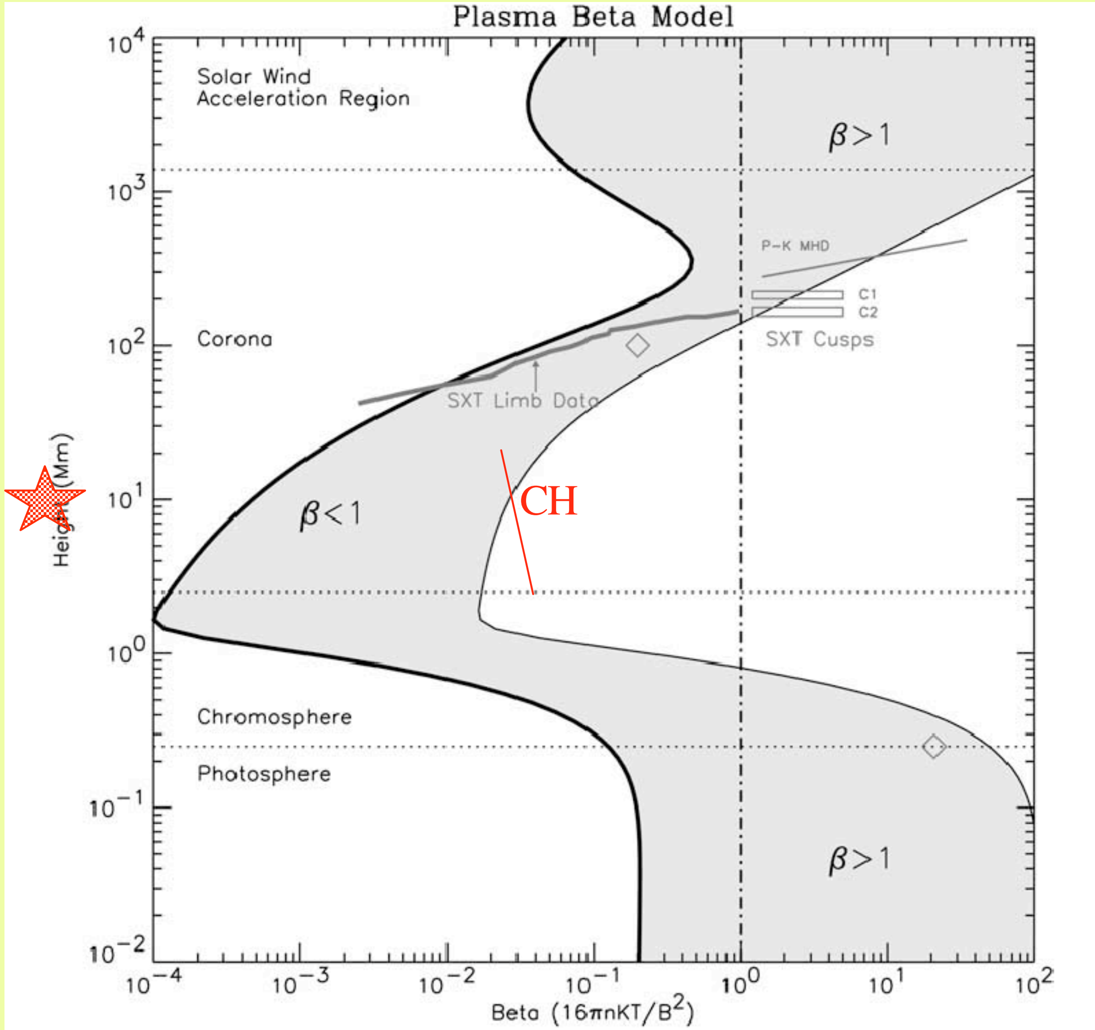
# Physics of Elliot model

- Energy storage by trapped particles corresponds to a stress in the magnetic field
- This stress involves current systems closed in the corona itself and not injected through its boundary
- The particle stress is equivalent to an additional anisotropic pressure ("non-thermal pressure") term, not normally considered in describing global equilibria?
- Large energy densities may lead to ballooning instabilities?
- No reconnection, no helicity!

# Populating the trapping zones

- CRAND: Cosmic Ray Albedo Neutron Decay
- CR interactions mainly (p, p), unlike Earth's atmosphere
- Most CRAND neutrons escape from the corona before decaying
- Diffusive acceleration should follow, as in the case of the Earth's radiation belts
- Flares, CMEs, and "leaves in the wind"
- Helmet streamer geometry does not lead to convective electric field?

# Distribution of coronal plasma $\beta$



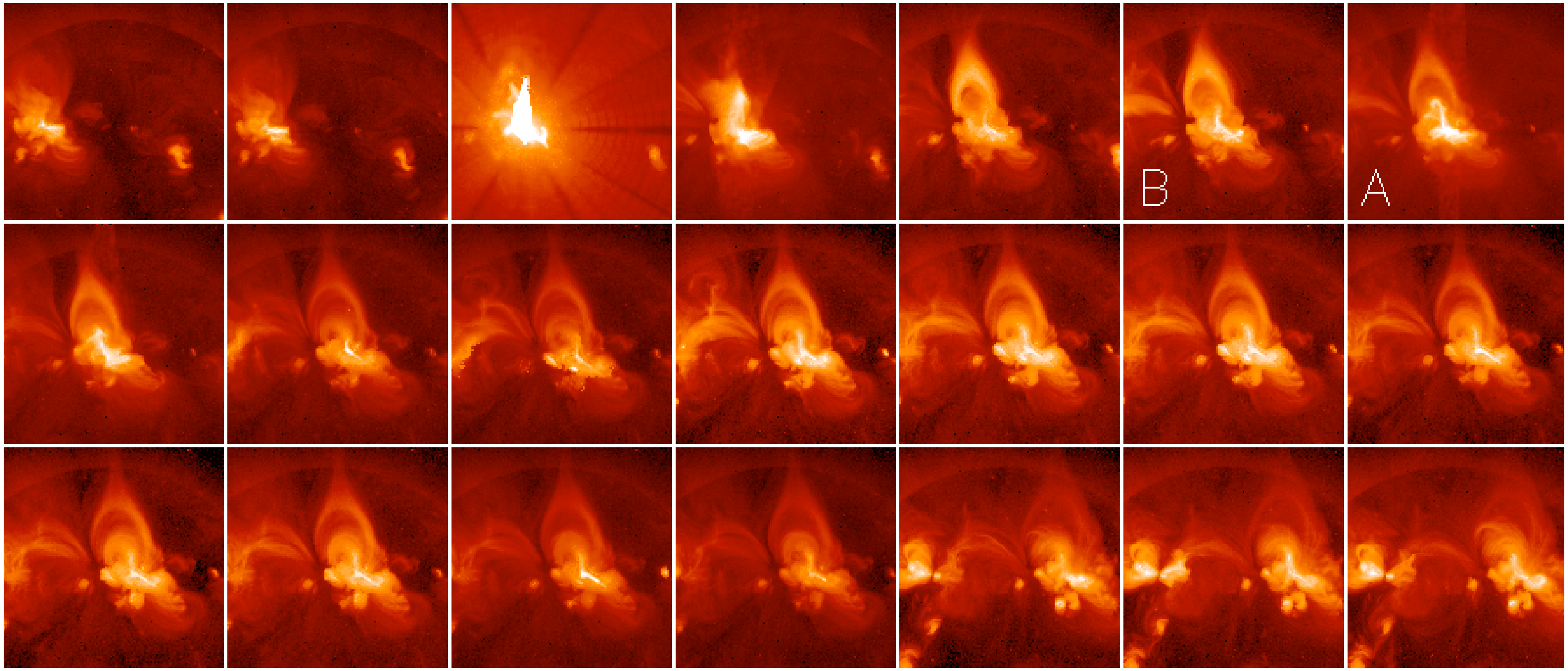

G. A. Gary, Solar Phys. 203, 71 (2001)

($v_A \sim 200\ \beta^{-1/2}$ km/s)

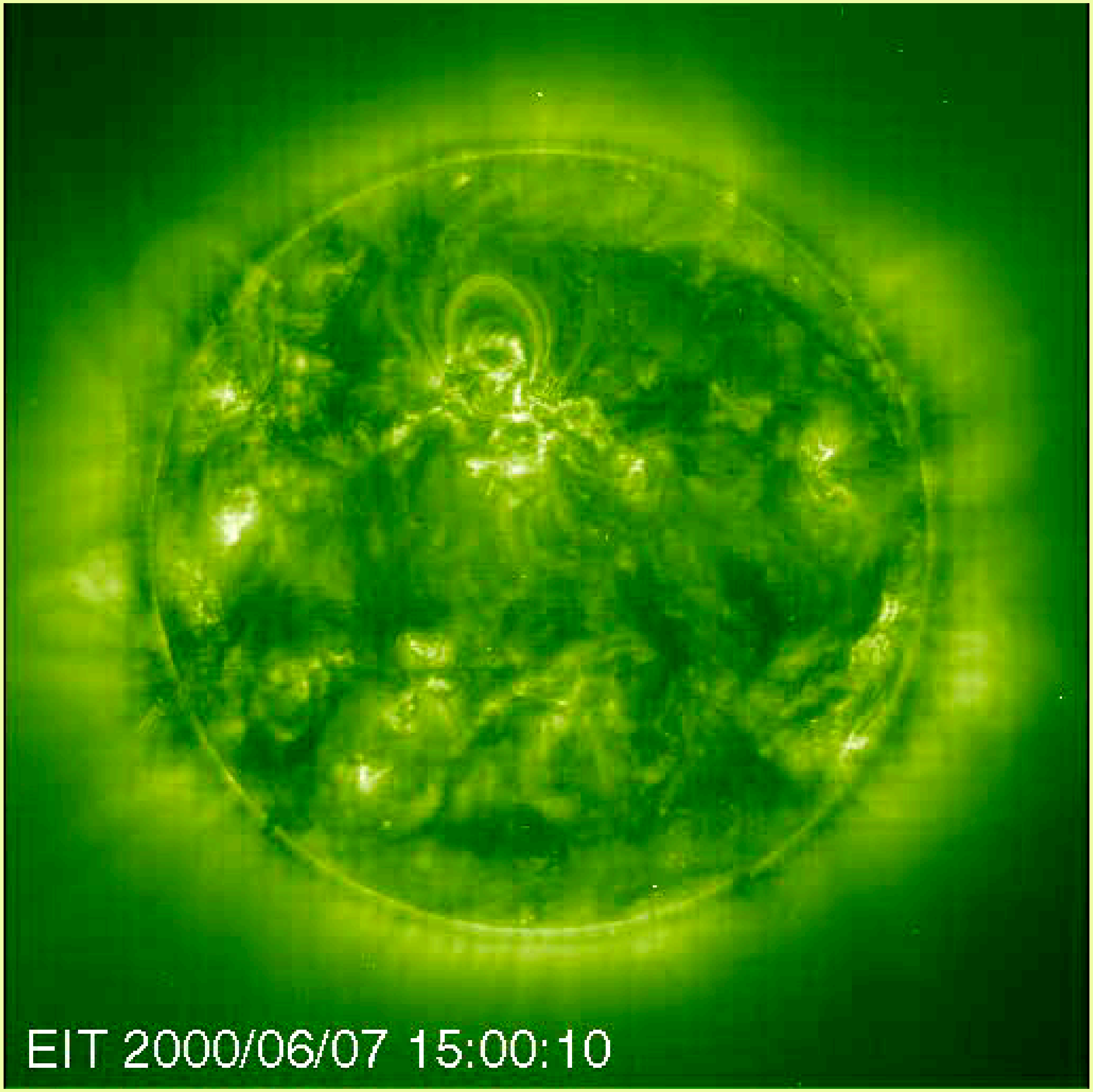
# Stability worry

- Non-thermal particle pressures would have to amount to 10% or so to be very interesting
- Is this a potential source of instability?
- How does the Earth's magnetosphere handle this issue?

# Imperturbability



# Imperturbability II



# Conclusions

- Yes, the solar magnetic field can store particles for long times, but they may not form “belts”
- Yes, there are mechanisms to provide particles
- No, we have no idea if interesting numbers of particles are there
- There are some theoretical applications these particles could be applied to

# “To do” list

- Banana orbits and 2.2 MeV late γ-ray emission
- Particle energization mechanisms
- “Convective” effects in the corona (**E**x**B**)
- Complete guiding-center calculations & diffusion
- PFSS mirror ratios and stability considerations
- Patterns of untrapping - what do CMEs do?
- SEP injection
- Coronal-hole signatures?
- Electron detectability via synchrotron emission
- Ion detectability via γ-ray imaging?