Coronal radiation belts

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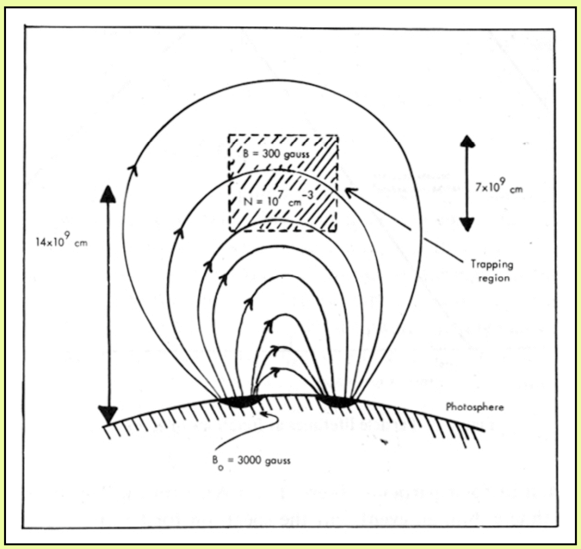
Abstract: We re-examine the idea of long-term particle storage in the solar corona in the context of modern PFSS (potential-field source surface) magnetic models. As pointed out by H. Elliot in 1964 and others since then, such particles can be energetically important, at the level of some large fraction of the magnetic energy density $B^2/8\pi$.
We estimate the distribution and time scales of particle trapping by using representative PFSS coronal models from the Schrijver-DeRosa SolarSoft code. As the coronal field simplifies during solar minimum, it approaches axisymmetry and thus contains volumes inaccessible to charged particles under the guiding-center approximation.
We conclude that time scales can be sufficiently long, so long in fact that the azimuthal drift time scale (third adiabatic invariant of guiding-center motion), for the large-scale dipolar configuration characteristic of solar minimum, can exceed one solar cycle.
We discuss the possible sources of trapped particles, starting with the basic CRAND (cosmic-ray albedo neutron decay) mechanism, and relate their X-ray and γ-ray signatures to future observational capabilities including the **Sentinels** spacecraft.

Thesis

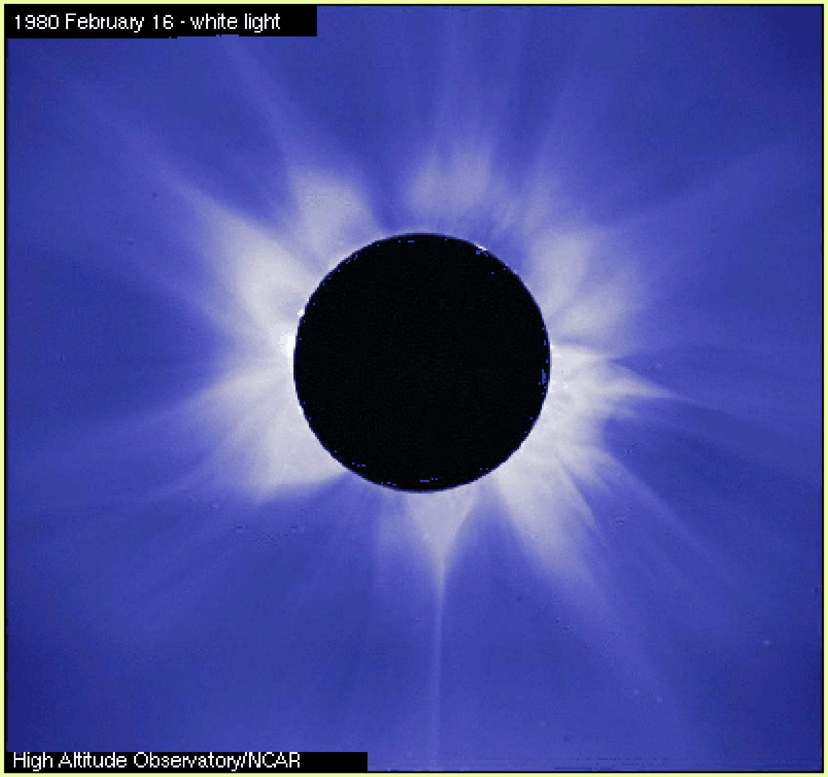
- Elliot (1964) suggested the possibility of particle accumulation in mirror geometries in the solar corona
- Large amounts of energy can probably be stored in the corona without substantial effects on the field and without externally driven current systems
- There's a nice practical framework in which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

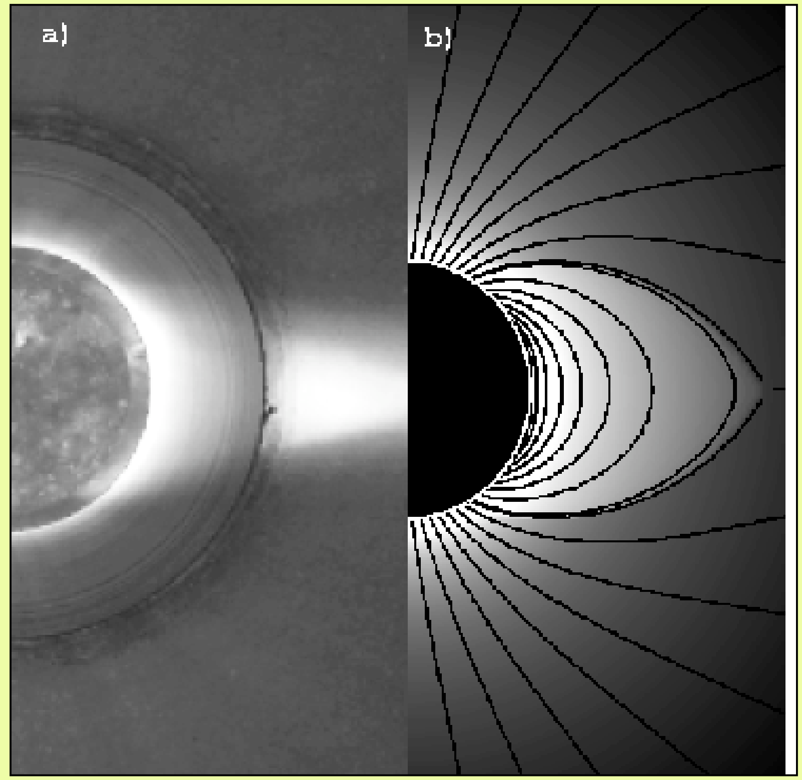


Elliot (1973) cartoon, from
http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/

Topics

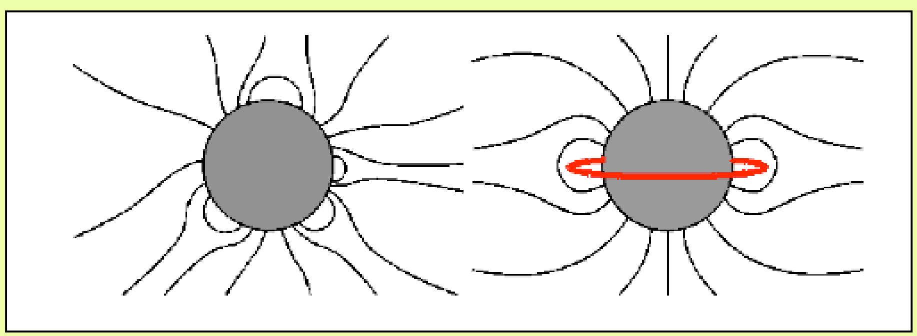
- Coronal magnetic field: morphology, PFSS modeling, comparison with geomagnetic field
- Particle trapping: lifetimes, stability, signatures, effects
- Sources of particles: CRAND, low-level activity, convection
- Applications: energy storage (Elliot), CH boundaries, SEPs
- Detectability





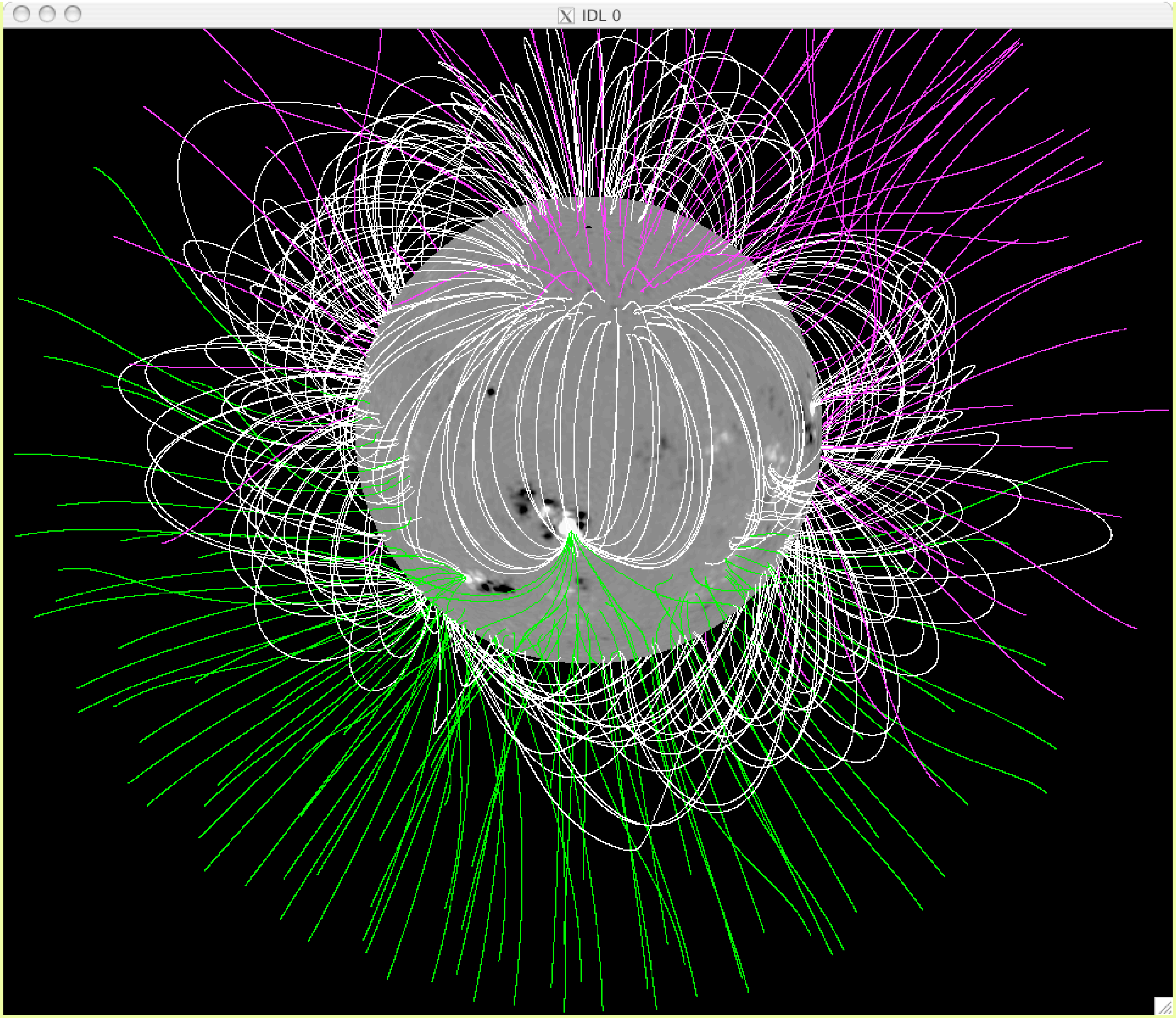
Sunspot cycle maximum

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

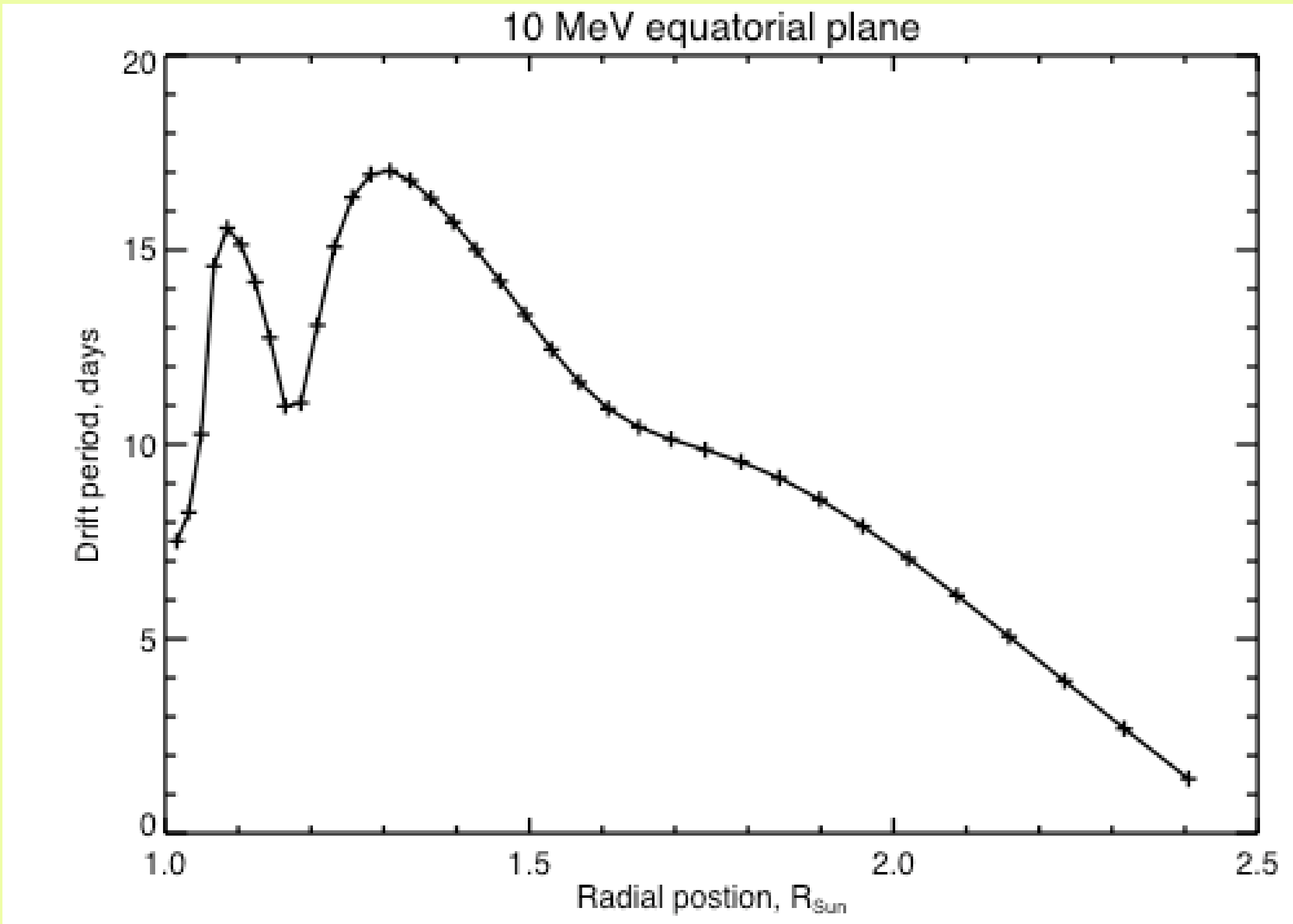


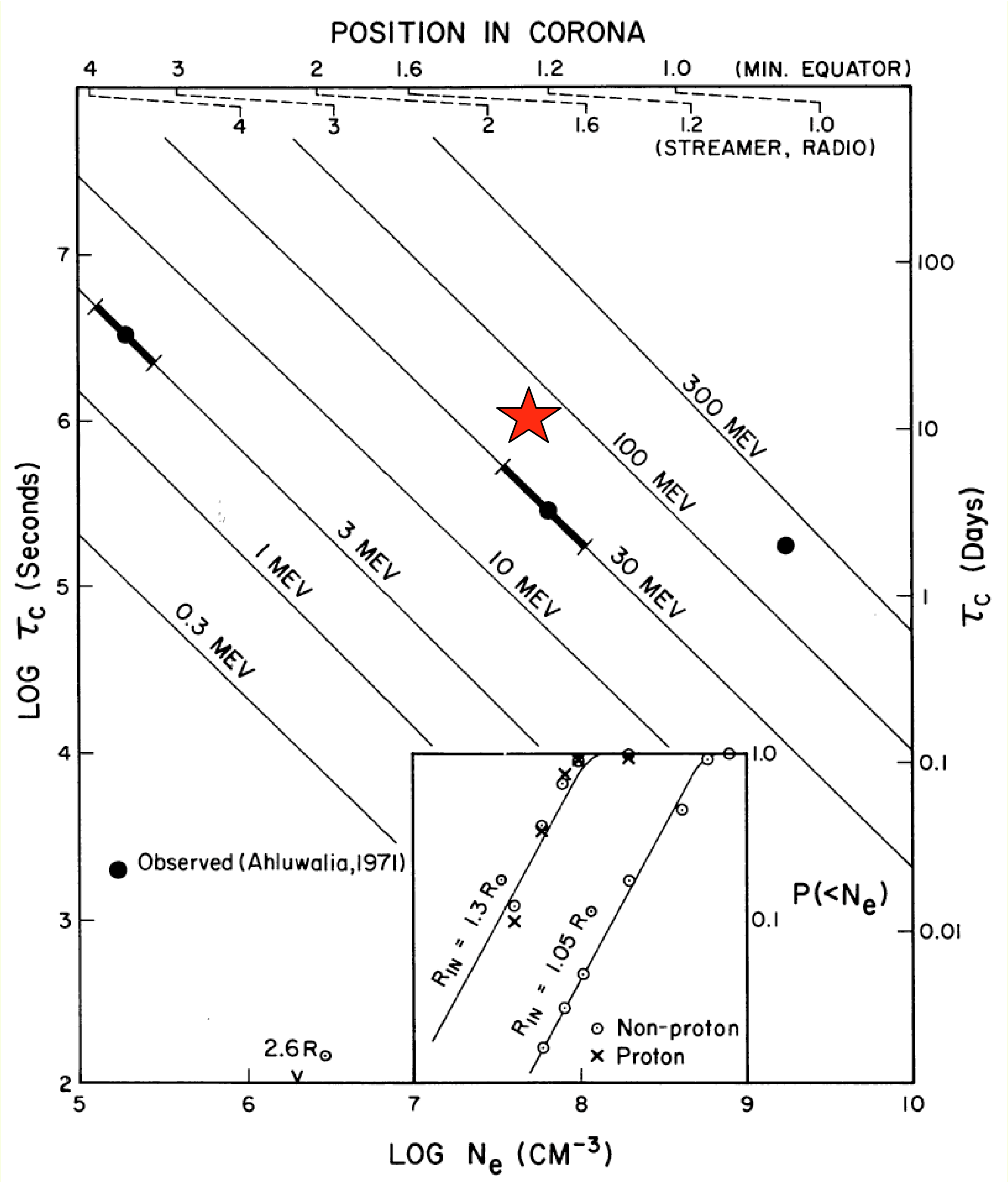
Schrijver-DeRosa PFSS example

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

Mean drift times





Newkirk, 1974 (Surfers Paradise proceedings)

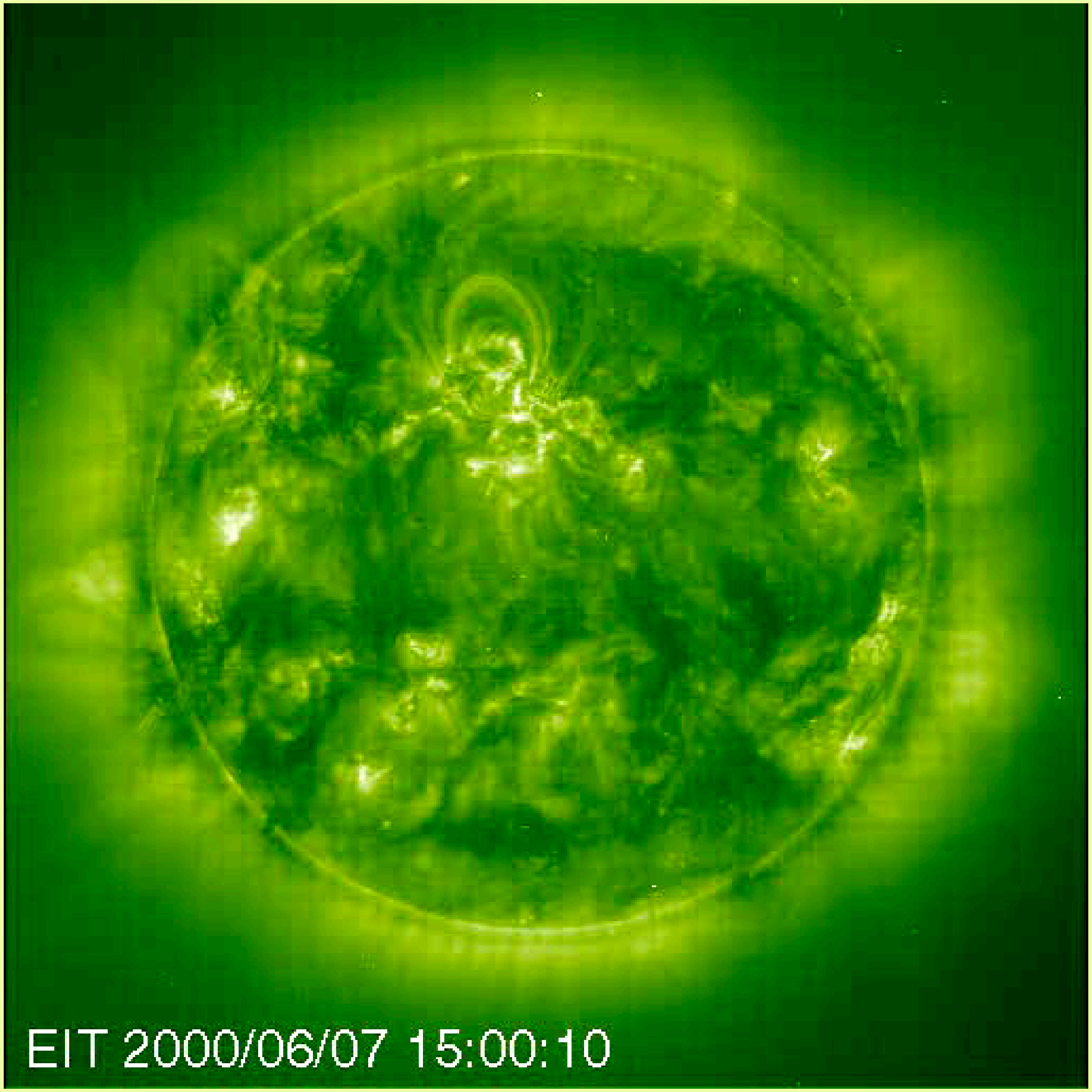
Physics of Elliot model

- 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

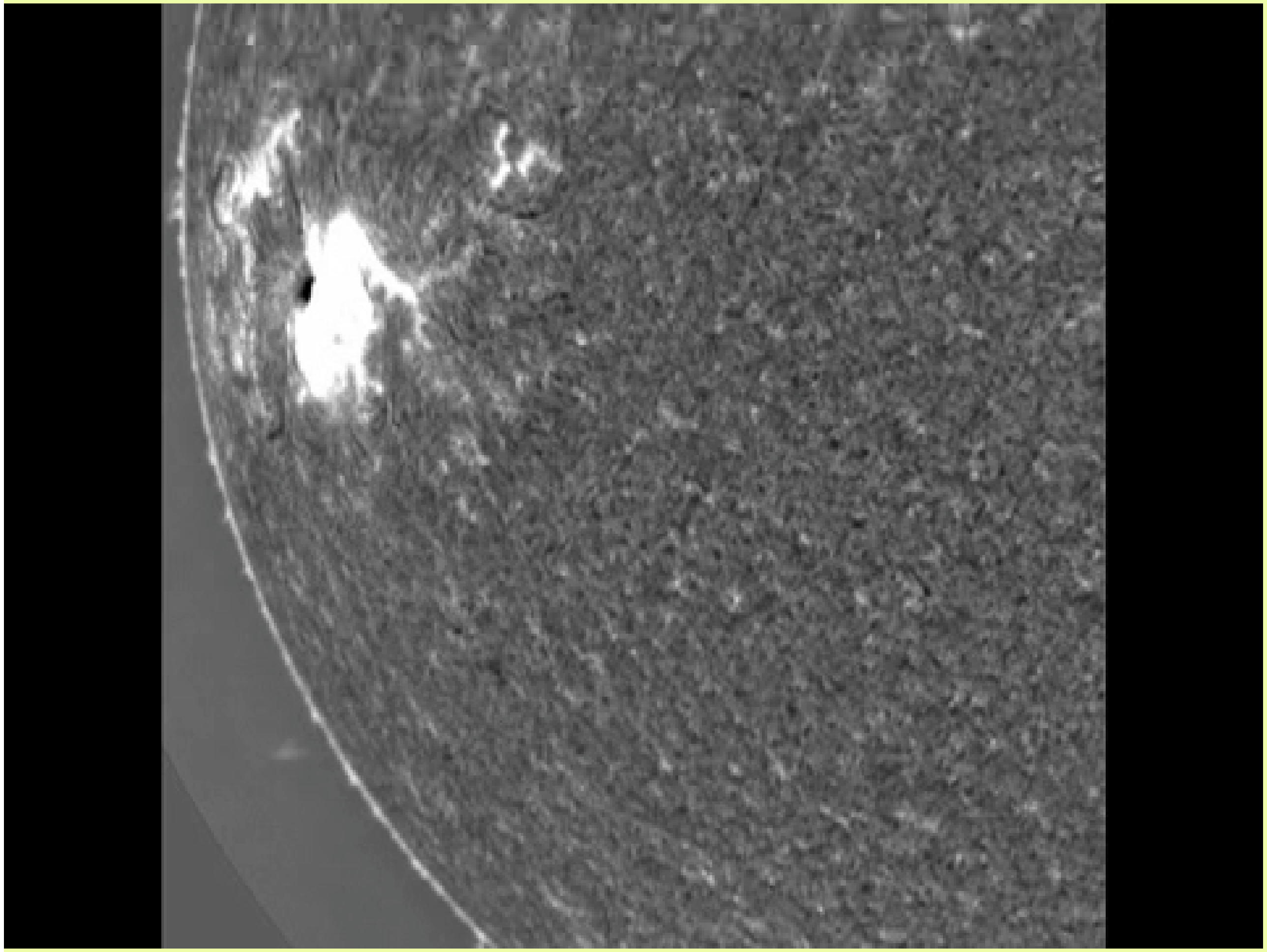
- CRAND: Cosmic Ray Albedo Neutron Decay
- CR interactions mainly (p, p), unlike Earth's atmosphere
- Most CRAND neutrons escape from the corona before decaying
- Diffusive acceleration should follow, as in the case of the Earth's radiation belts
- Flares, CMEs, and "leaves in the wind"
- Helmet streamer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

Large-scale imperturbability



Coronal structure is essentially stable on large scales. A flare or CME has only a transient influence outside its sector.

Moreton wave



The Moreton wave is one example of a shock structure in the closed corona that could be a source of energetic particles

Balasubramanian, OSPAN

Conclusions

- Particles can be trapped in belts analogous to the Earth's
- The CRAND mechanism can provide a seed population
- Coronal trapped particles have several interesting applications

“To do” list

- Banana orbits and 2.2 MeV late γ-ray emission; coronal γ-rays
- Complete guiding-center calculations & diffusion
- Particle drift energization
- “Convective” effects due to solar wind stress (**E**x**B**)
- PFSS mirror ratios and stability considerations
- Flare/CME shock-accelerated particles
- Patterns of untrapping - what do CMEs do?
- SEP injection
- Coronal-hole signatures?
- Wang density model
- Electron detectability via synchrotron emission
- Ion detectability via γ-ray imaging?