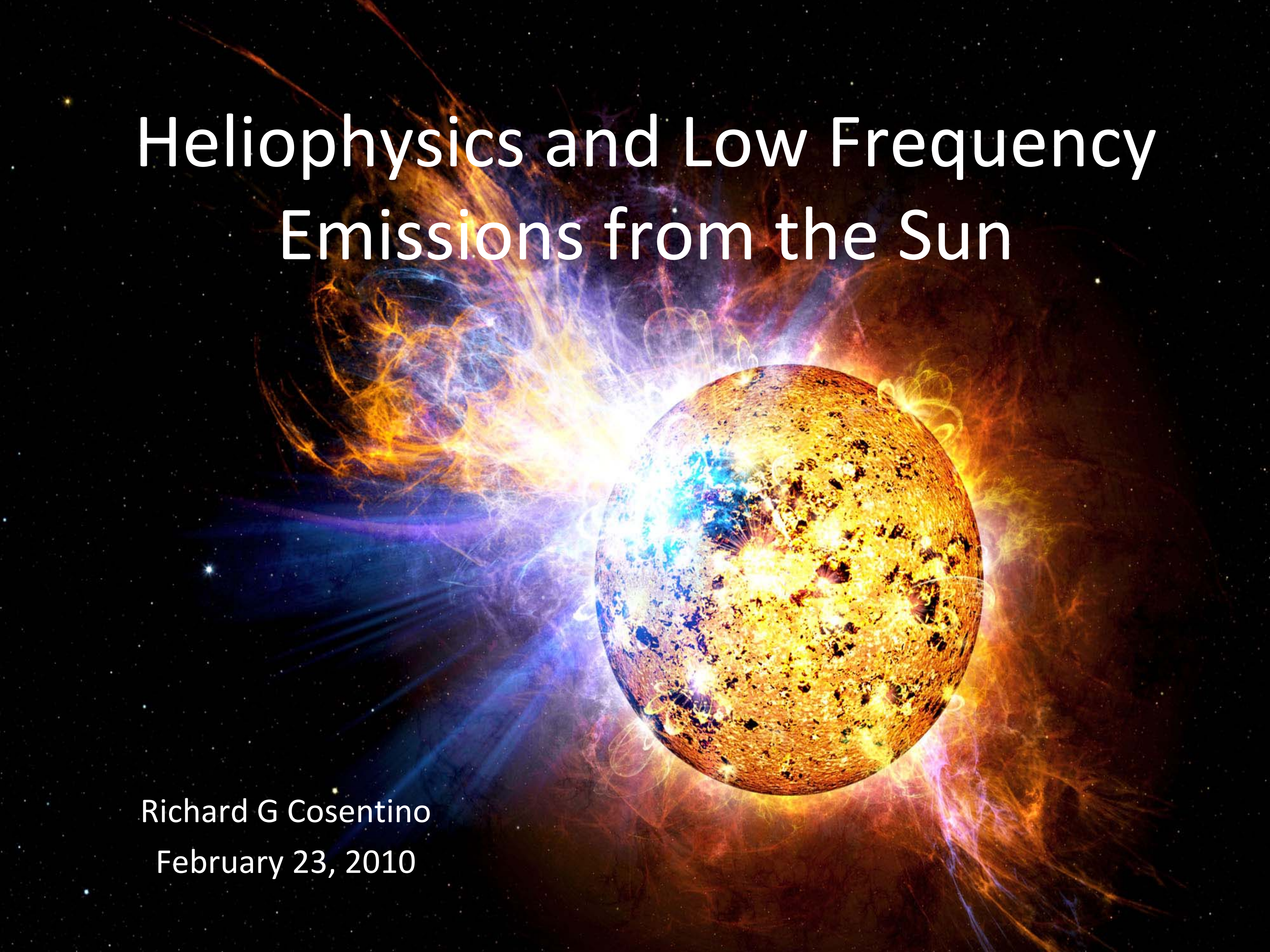
Heliophysics and Low Frequency Emissions from the Sun

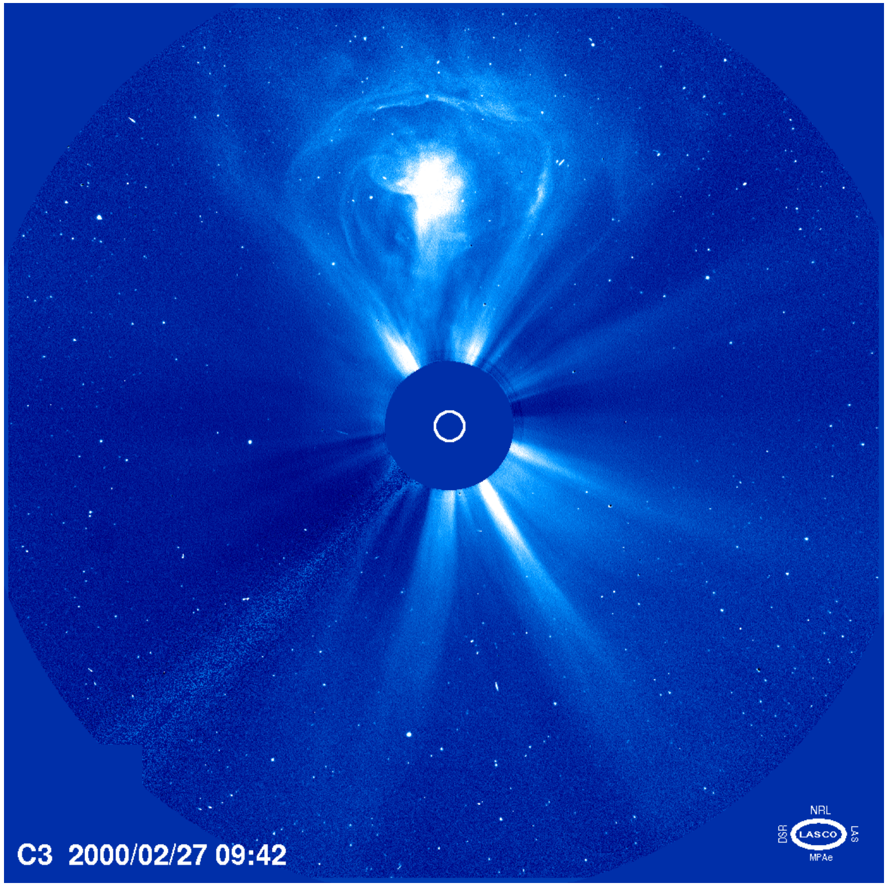


Richard G Cosentino

February 23, 2010

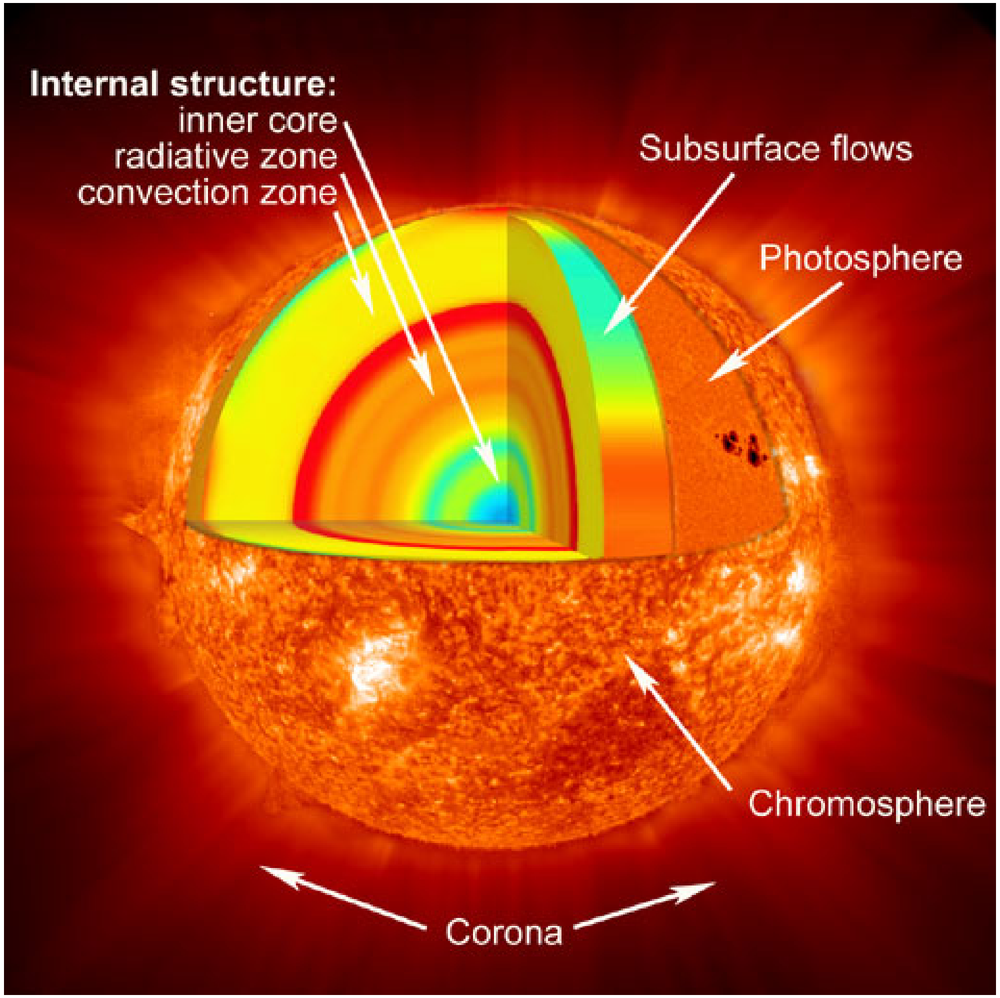
Outline

- Review Solar Physics
- Coronal Mass Ejections & other Solar Phenomenon
- Gopalswamy Paper
- Lunar Radio Interferometer



Our Star - The Sun

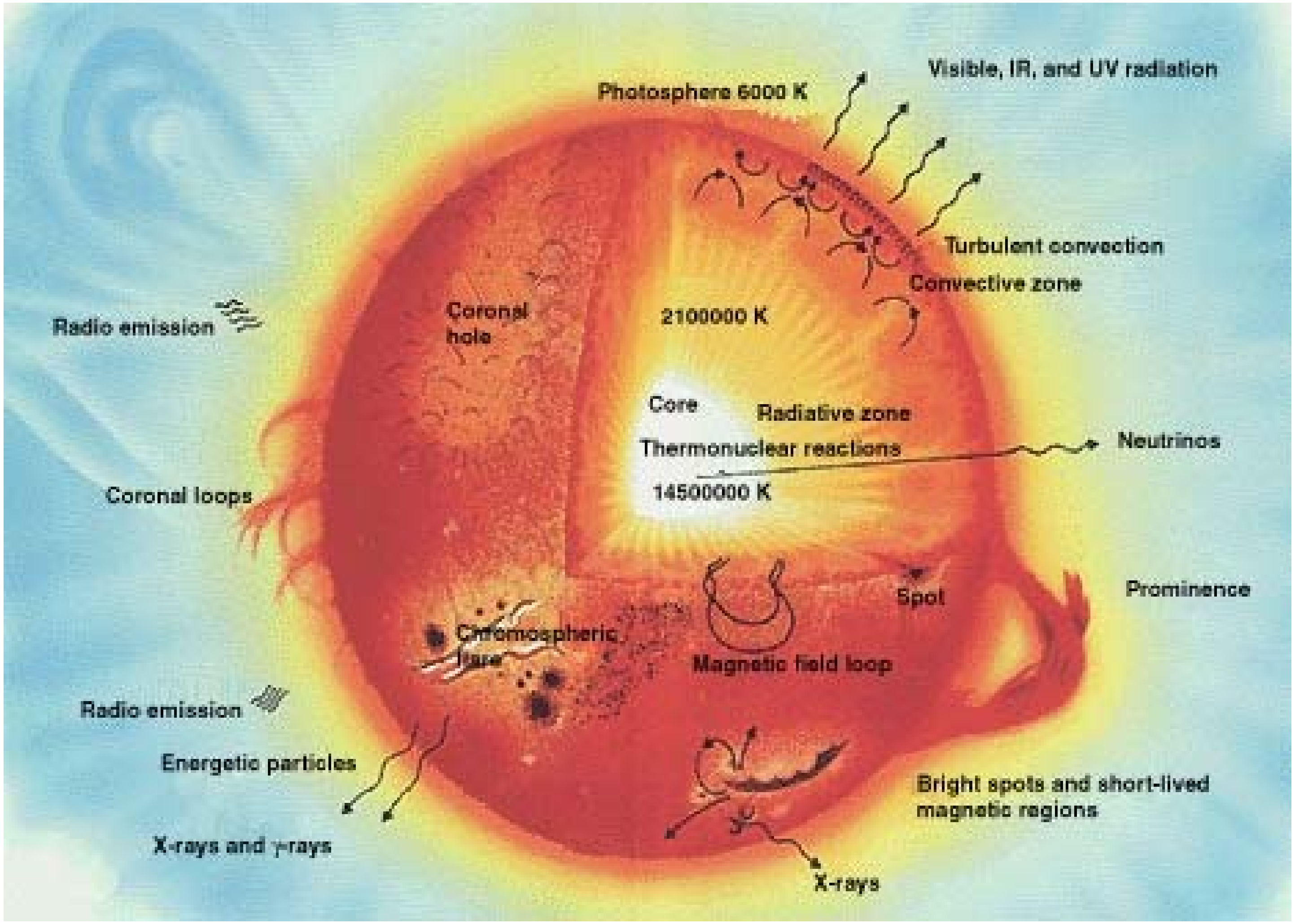
- Not just a ball of hot gas
- Large sphere of plasma
- Differential Rotation
- Complex Layering



Anatomy of the Sun

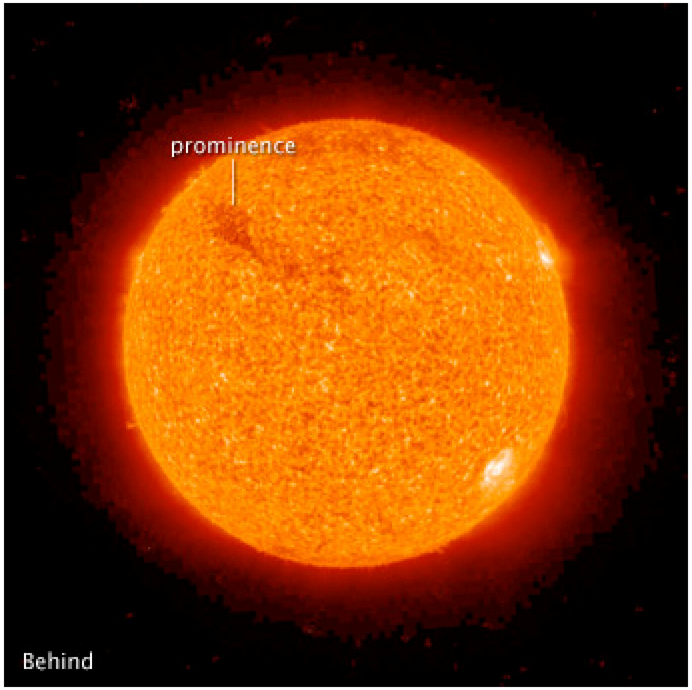
Region	Solar Radii	Temp (Kelvins)
Core	.25	14 million
Radiative Zone	.25 to .7	7 to 2 million
Convective Zone	.7 to 1	5700K
Photosphere	Visible Surface	6000K
Atmosphere		
• Chromosphere	• 1 to 1.005	• 4100 to 20,000
• Corona	• ~ 20 (.1AU)	• 1 to 20 million
• Heliosphere	• 50AU - Heliopause	

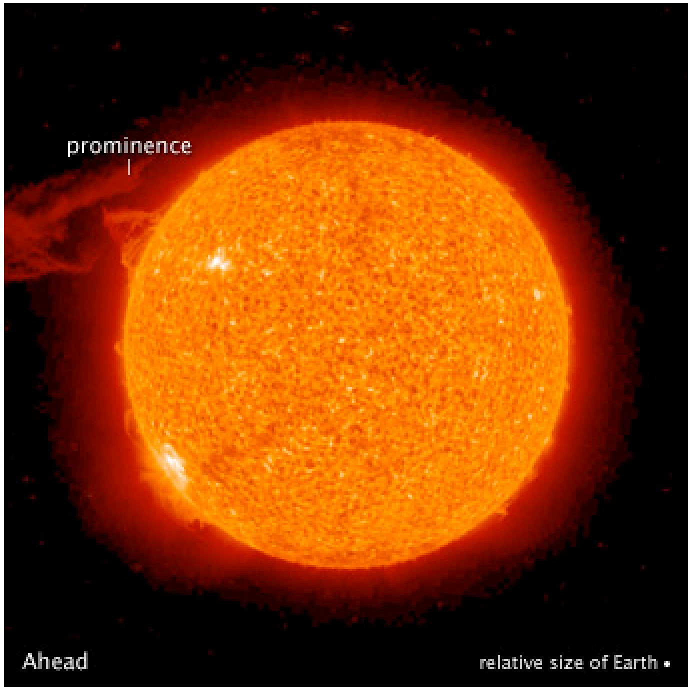
Solar Dissection



Solar Prominence

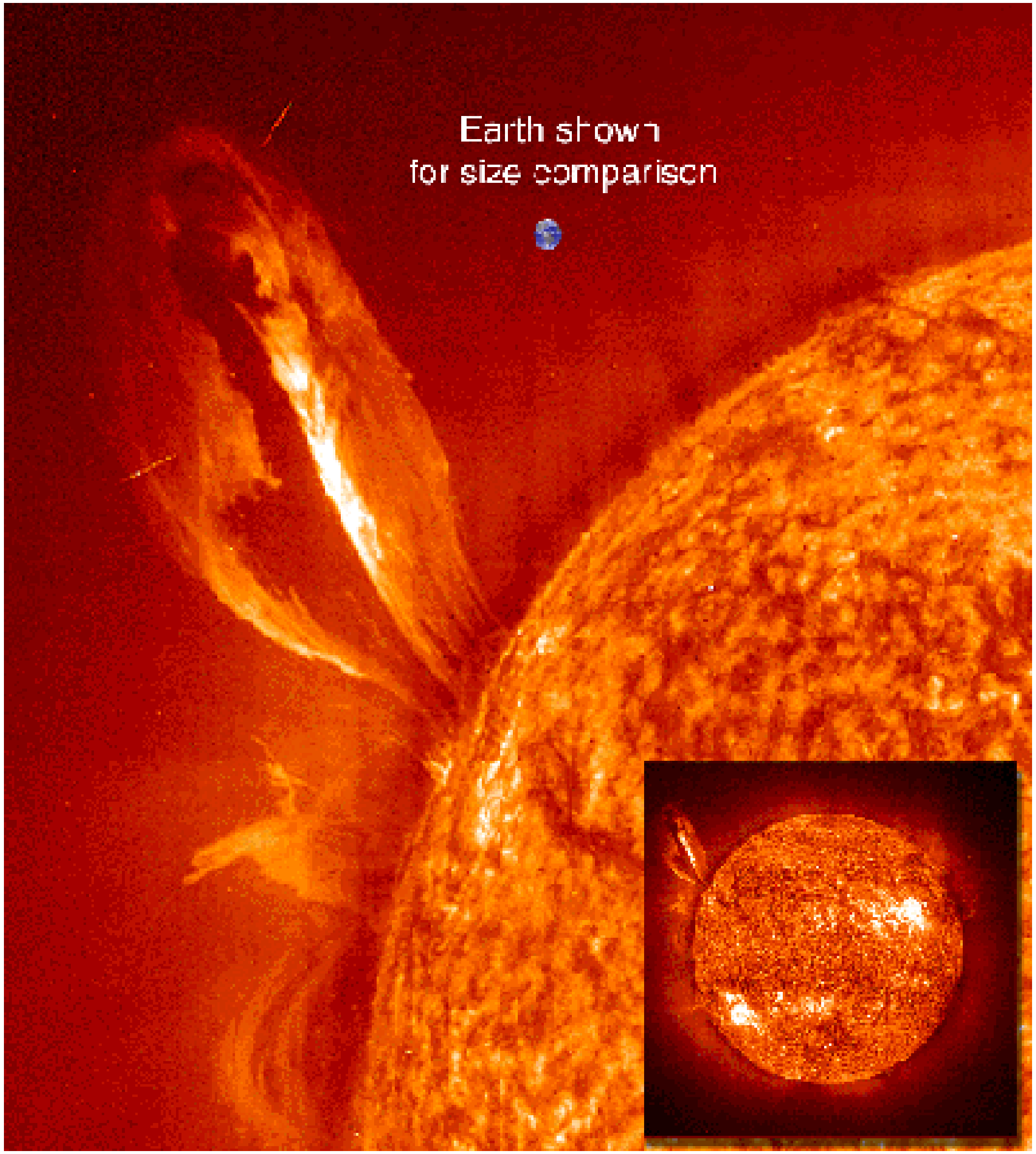
- Cooler temperature plasma
- Material held in loops by magnetic fields
- Solar Filaments are same as Prominence (viewing angle)





Solar Flares

- Properties
  - Ionized gas large explosions (10^32 ergs)
  - Release of magnetic energy
  - Accelerate ions & electrons
  - Emissions across entire spectrum
  - Potential trigger of CME's
  - Vary with solar cycle

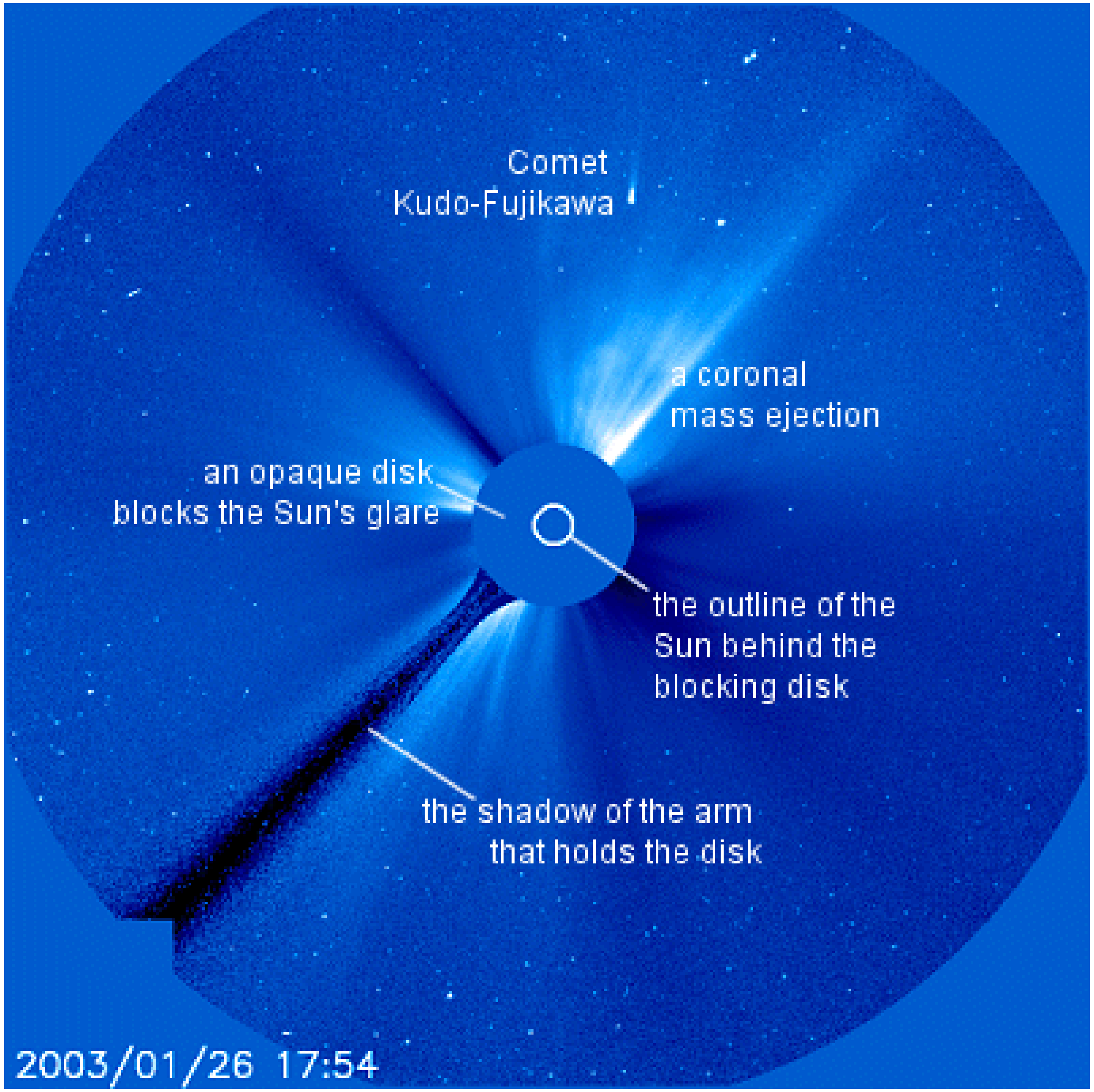


The Corona

- Invention of Coronagraph
- Why is it so hot?
  - Possible wave heating
    - Dissipating MHD, gravity & sound waves
  - Possible magnetic heating
    - Magnetic reconnection
    - Magnetic Energy

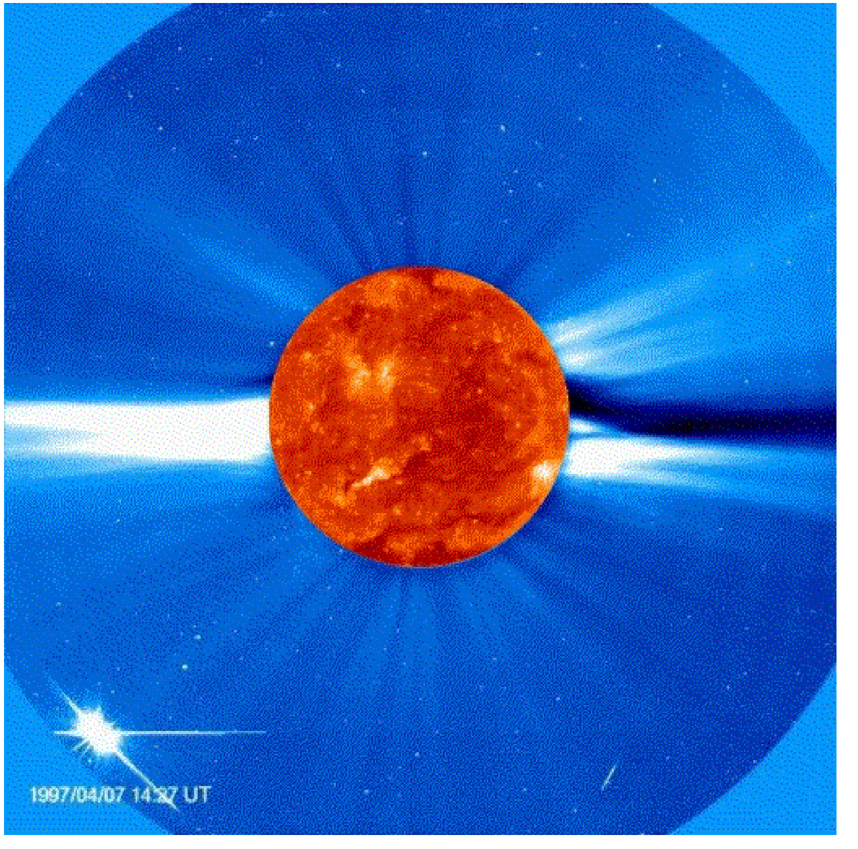
$$\varepsilon = \frac{B^2}{8\pi}$$

$$10^{34}\, ergs$$

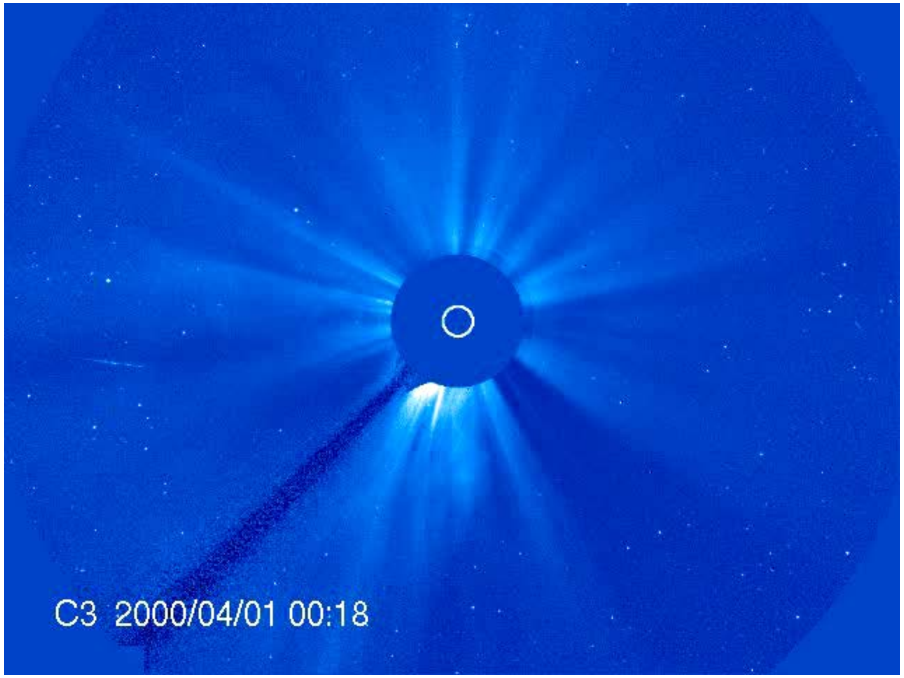


Coronal Mass Ejections

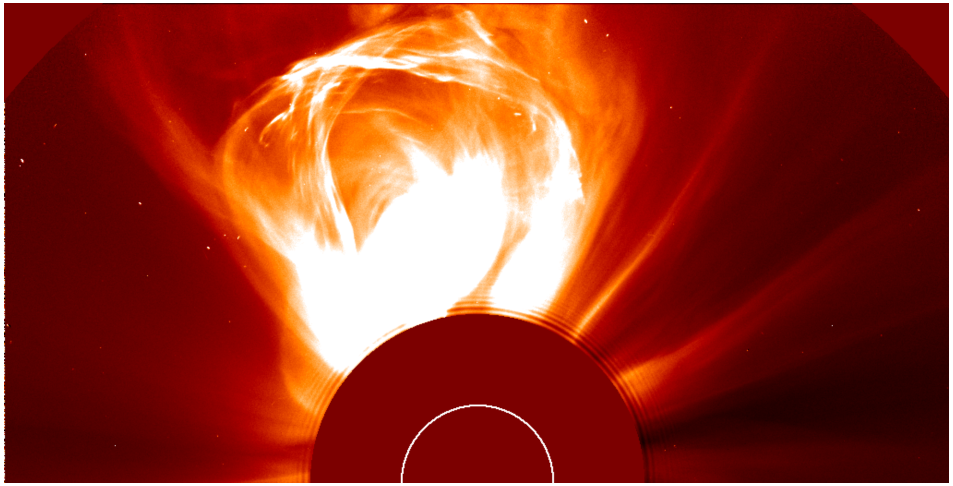
- Gas blown from Corona
  - 10^15 grams of gas (lower limit average)
- Velocity range
  - 20km/s to 3000km/s
- Frequency Occurrence
  - 1/week @ Solar min
  - 2-3/day @ Solar max
- Location
  - Focused on equator during solar min
  - Varying latitudes during solar max
- Origin
  - Correlation to solar flares, prominences & sunspot regions
  - Also occur in absence of the above



Anatomy of Coronal Mass Ejections



- Explosion from Corona
- Shape of a Croissant
  - Outer Leading Edge
  - Cavity
  - Core

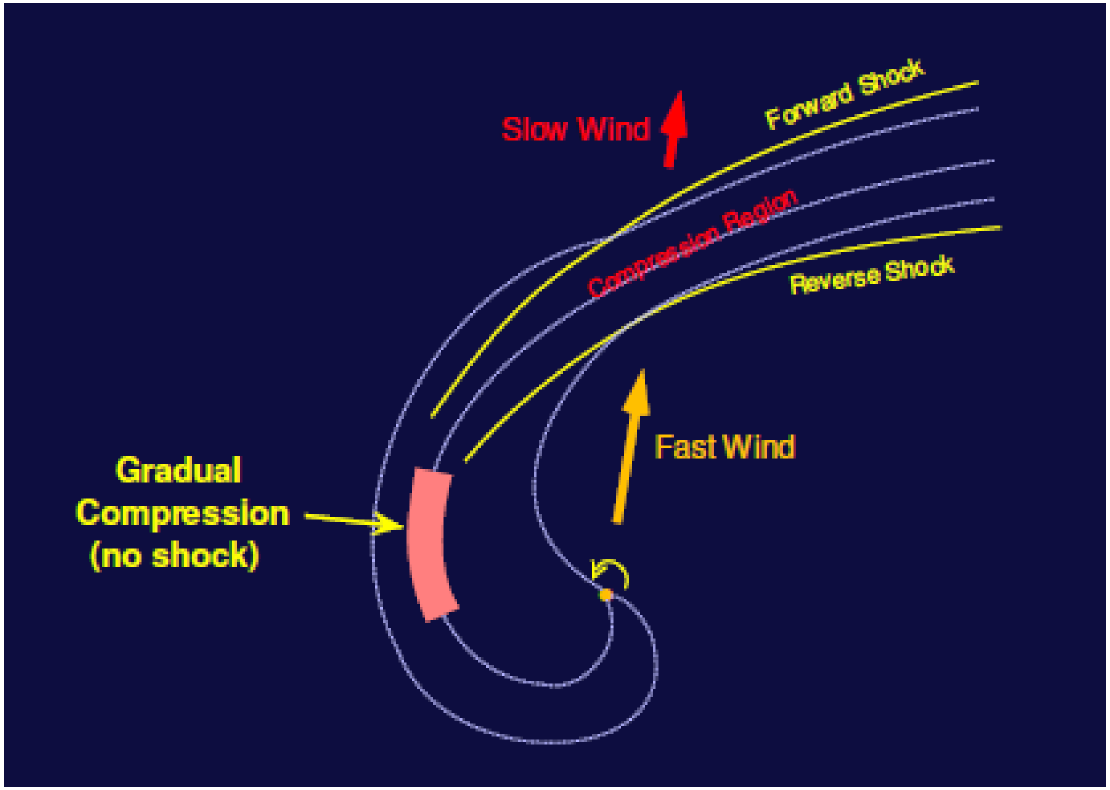


CME Propagation

- Ejected material reaches millions of Kelvins
- Slow to fast acceleration, then constant velocity
- Velocity can be greater than sound speed of solar wind
  - Solar wind velocity (avg) – 145km/s
- As these velocities increase the mach number of the CME increases
- CME’s produce shock fronts

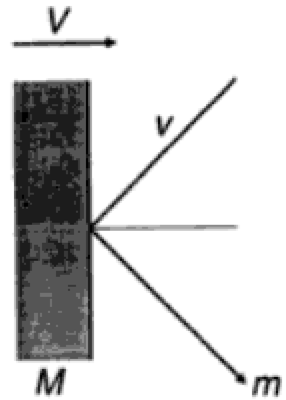
Fermi Acceleration

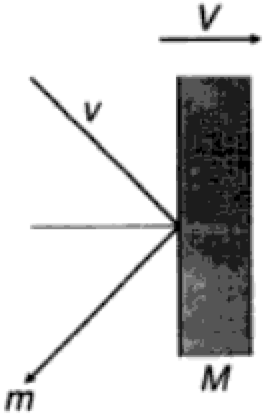
- a.k.a. *Diffusive Shock Acceleration*
- Charged particles (ie: electrons) get accelerated by shock front moving through plasma
- Cyclotron or synchrotron radiation occurs



Fermi Acceleration Mechanism

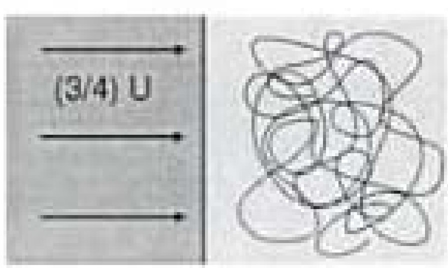
- Changing reference frames for relativistic particles
- Change of energy increases each occurrence
- Symmetry of head on or following collisions across shock front
- Each boundary crossing increases energy

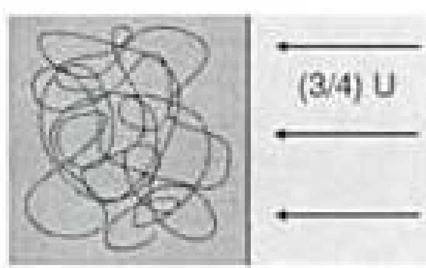




$$E' = \gamma * (E + Vp\cos\theta)$$

$$E'' - E = \Delta E = \frac{2Vv\cos\theta}{c^2} + 2 * \frac{V^2}{c^2}$$



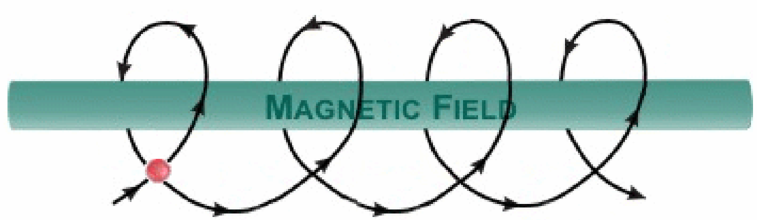


$$\frac{\partial N(\varepsilon)}{d(\varepsilon)} \propto \varepsilon^{-\eta}$$

Cyclotron & Synchrotron Radiation

- Photons created from charged particles being deflected by magnetic fields
- Lorentz Force acts on velocity perpendicular to magnetic field and causes emission of radiation and spiraling of particle
- Origin of radio emissions in astrophysics

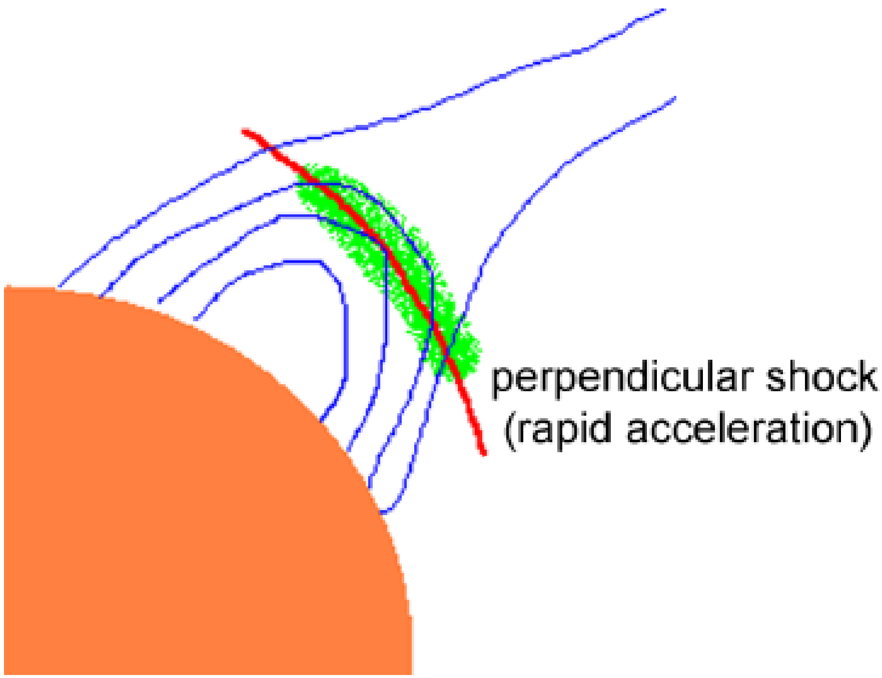
$$\frac{-dE}{dt} = \frac{\sigma_t B^2 V^2}{c\mu_o}$$

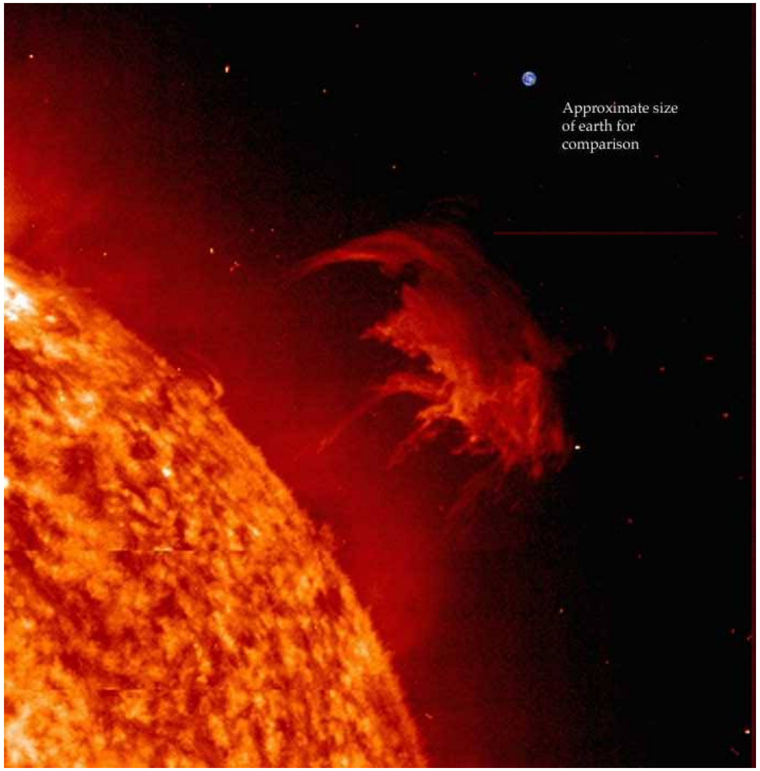


$$\frac{\partial N(\varepsilon)}{d(\varepsilon)} \propto \varepsilon^{-\eta} \quad \Rightarrow \quad \frac{\partial P(\upsilon)}{d(\upsilon)} \propto \upsilon^{-\alpha}$$

Shock Acceleration Energies

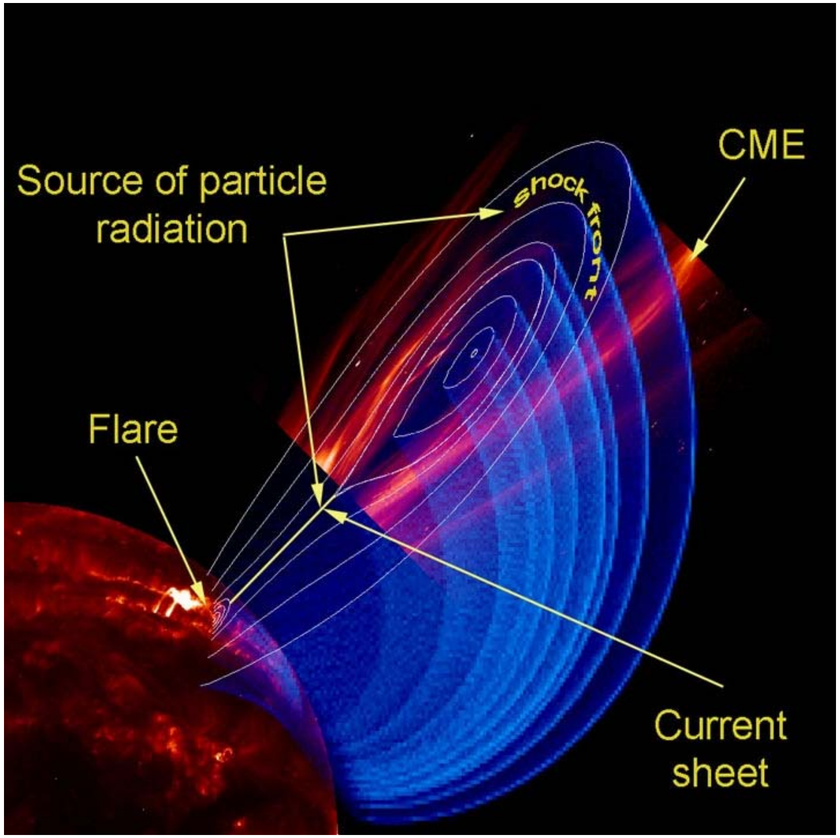
- Field Orientation
- High energy class
  - MeV to GeV
- Highest Energies
  - 80% speed of light
- SEP event origins?





Solar Energetic Particles

- Solar Energetic Particles (SEP's)
  - Protons, electrons and ions
  - Can reach 80% speed of light
  - Energy Range keV to GeV
- Origins
  - Solar Flares
  - Shock Fronts in CME's
- Harmful to us and technology above 40MeV
- Need to predict and forecast

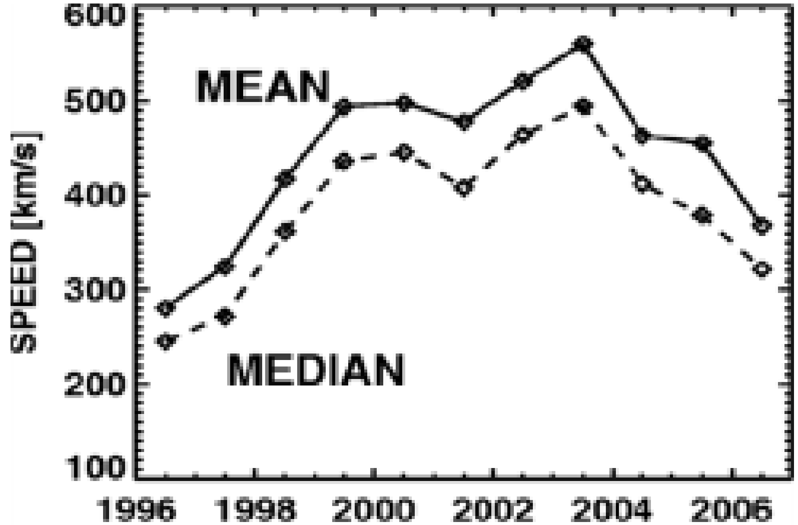


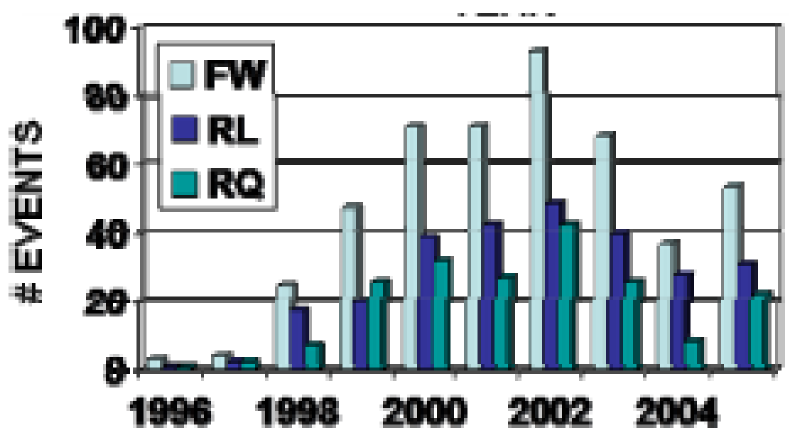
Paper Intro

- Categorize CME’s by velocity and Radio volume (quiet RQ or loud RL)
- Type II Bursts by wavelength
- CME’s with Type II bursts are more energetic
- Type II Bursts at longer wavelengths are good indicators of SEP events
- Correlation between CME’s and SEP events remains unclear

Solar Cycle & CME's

- Solar cycle maximum was 2001-2002
- Velocity and frequency match solar cycle output
- 1999 RQ>RL

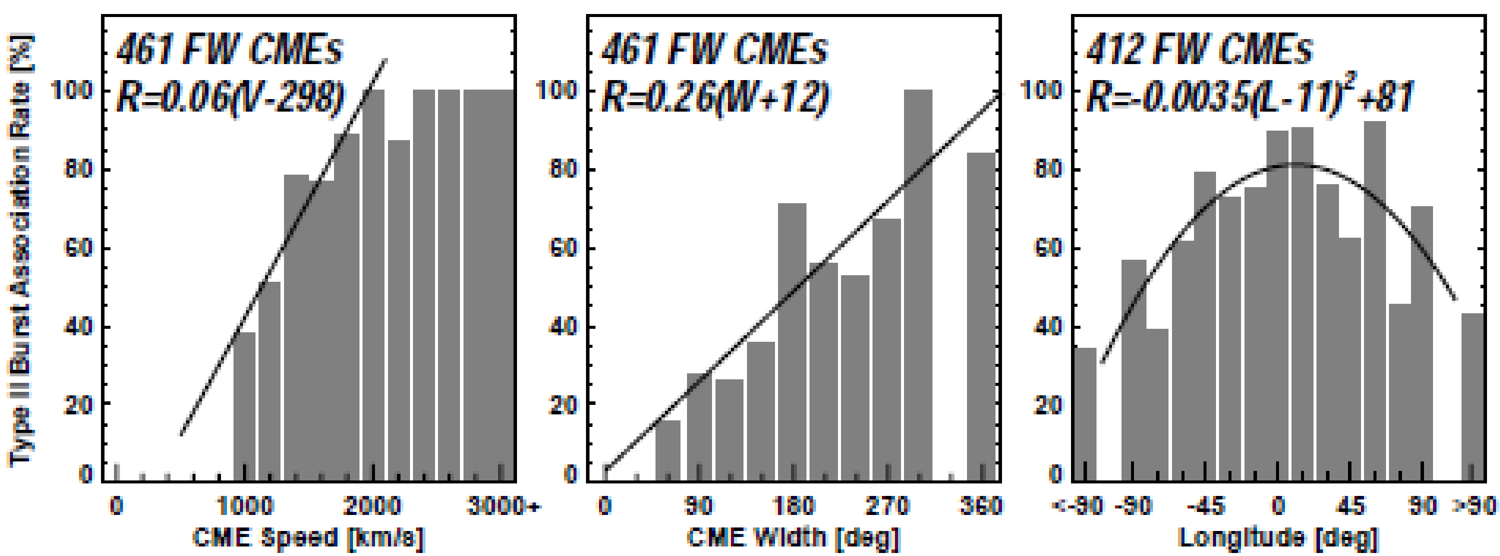




CME's & Type II Bursts

Property	Radio-quiet	Radio-loud
Number of FW CMEs	193 (42%)	268 (58%)
Average speed	1117 km/s	1438 km/s
Average width	86°	89°
Fraction of halos	16%	60%
Median flare size	C6.9	M3.9
Fraction of backside CMEs	55%	25%
East-west asymmetry	−0.02	0.2
Center-to-limb variation	increase	decrease
SEP association[b]	none	55%

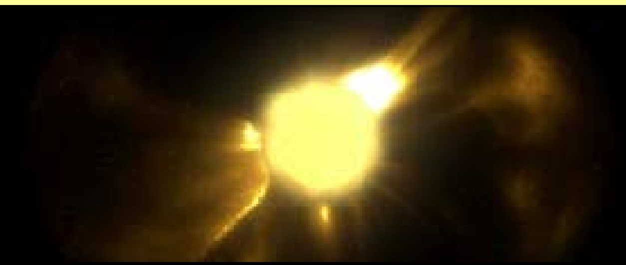
- Good correlation seems to exist
- Statistically this relationship is proven
- However not all Type II Bursts are SEP event



Paper Findings

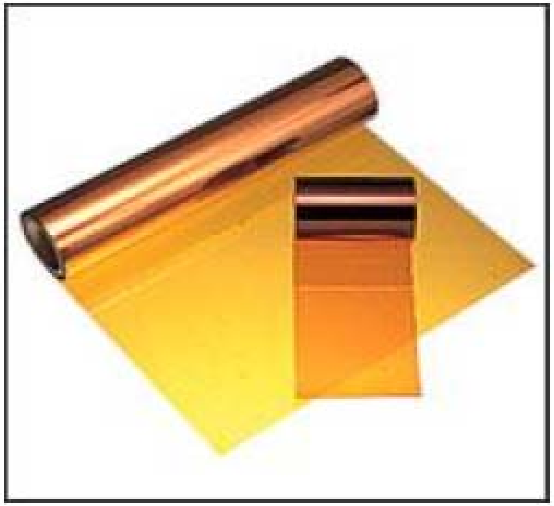
- CME's and Radio Emissions are linked
- Why are some CME's radio quiet?
- Why don't all CME's produce SEP events?
  - 1.) They don't produce shocks
  - 2.) They do produce shocks but are 'too' radio quiet to detect
- Statistical analysis of event correlation only produced similar results to Sheeley (1984)

ROLSS: Radio Observatory for Lunar Sortie Science



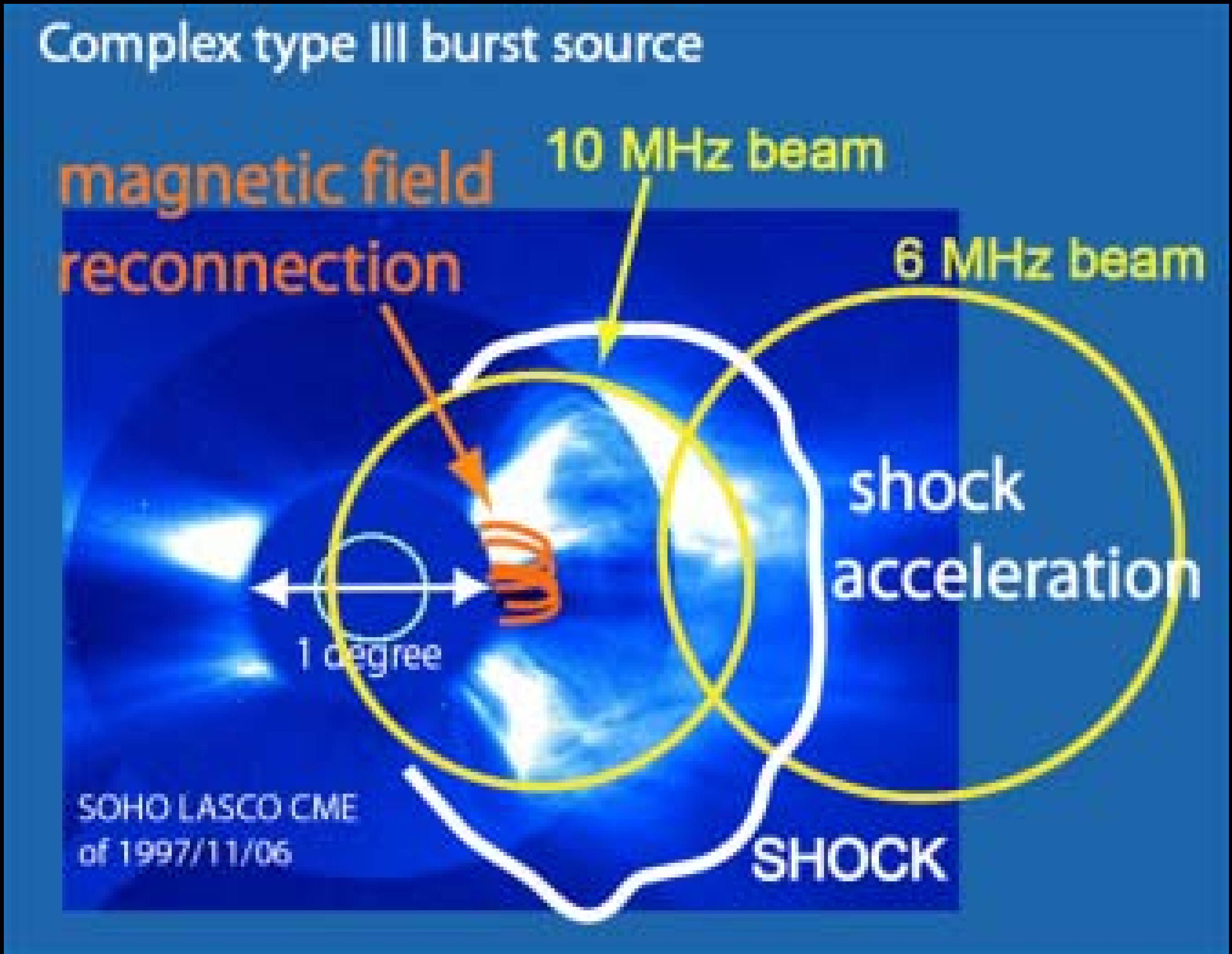
A Pathfinder for a future long-wavelength farside lunar array (10-100 sq. km). Operating at 1-10 MHz (30-300 m). Array consists of three 500-m long arms forming a Y; each arm has 16 antennas.

- Arms are thin polyimide film on which antennas & transmission lines are deposited.
- Arms are stored as 25-cm diameter x 1-m wide rolls (0.025 mm thickness).



Key Project: Radio Heliophysics from the Moon

Lead Scientists: J. Kasper (CfA) and R. MacDowall (GSFC)



Lunar Interferometer & the Sun

- Allow first low frequency imaging of sun
- Locate origin of radio emissions with resolution
- Large collecting area can yield sensitivity to detect weaker radio emissions
- Test current models of CME’s and Type II Bursts
- Allow the prediction of Solar Energetic Particle events (SEP’s)

References

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- SOHO NASA movie site http://sohowww.nascom.nasa.gov/bestofsoho/Movies/movies2.html
- NRAO website
- Solar Science NASA website

Discussion