SATELLITE THREAT DUE TO HIGH ALTITUDE NUCLEAR DETONATIONS

DENNIS PAPADOPOULOS
PHYSICS DEPARTMENT
UNIVERSITY OF MARYLAND

Acknowledge Input From

- **DTRA HAND/HALEOS STUDY**
- **TETHER PANEL HAARP STUDY**

OUTLINE

- **The Threat : Nuclear Detonations in Space**
  - **EMP Effects – Prompt (<1sec)**
    HEMP, MHD-EMP, SGEMP
  - **Relativistic Particle Injection into the Radiation Belts (Van Allen Belts) – Delayed Effects Months to Years**
- **Damage to Space Assets and Mitigation Options**

How Could It Happen?

- *Collateral damage from regional nuclear war or TMD/NMD intercept:*
  - ***Nuclear warning shot in a regional conflict;***
  - ***Effort to damage adversary forces/infrastructure with electromagnetic pulse;***
  - ***Detonation of salvage-fused warhead upon exoatmospheric intercept attempt.***

- *Deliberate effort to cause economic damage with lower likelihood of nuclear retaliation:*
  - ***By rogue state facing economic strangulation or imminent military defeat;***
  - ***Pose economic threat to the industrial world without causing human casualties or visible damage to economic infrastructure.***

From HALEOS Study

H and MHD EMP

Early (nanosecs) and late (secs)
GHz to Hz

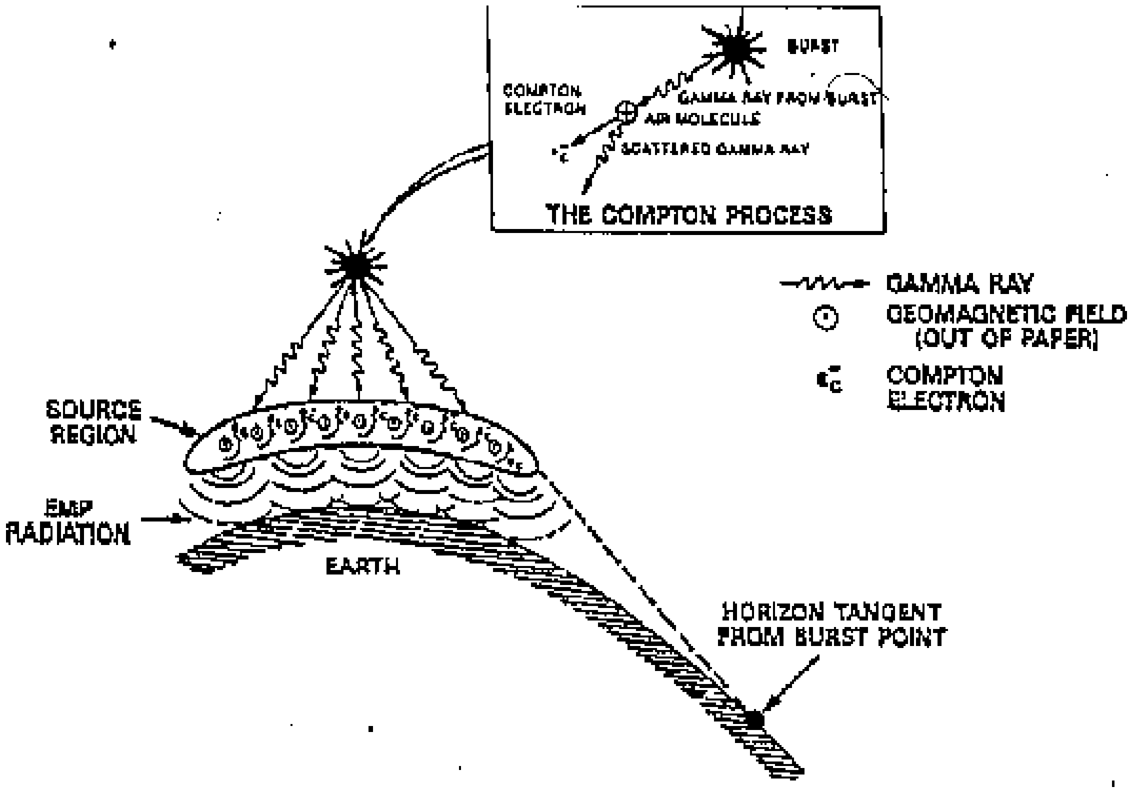


Figure 1. Mechanisms of High Altitude Emp (HEMP) Generation

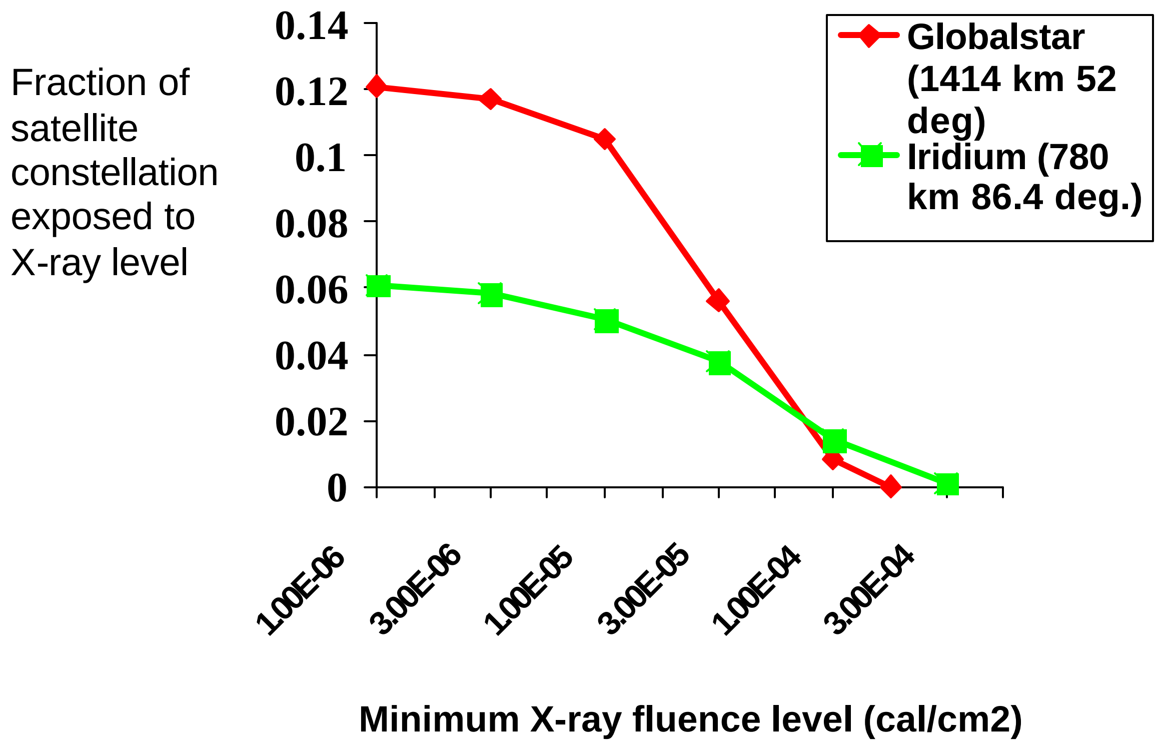
- **Line of Sight**
- **Not a Threat to space assets**
- **Major Threat to Ground Systems and ground infrastructure**

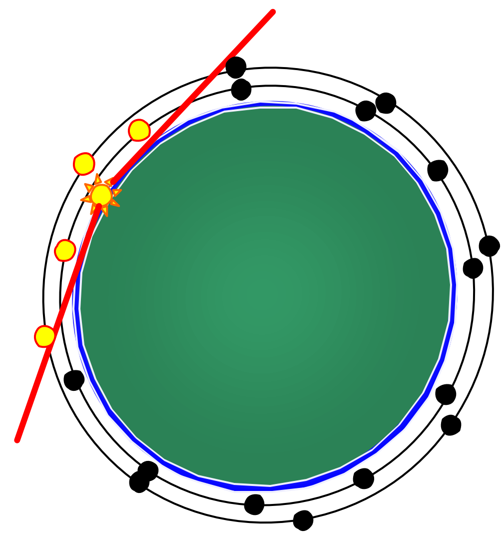
- **Mitigation Hardening except for MHD**

SYSTEM GENERATED EMP - SGEMP

•Prompt – line of sight – burst dependent

50 KT Burst over North Korea at 120 km altitude





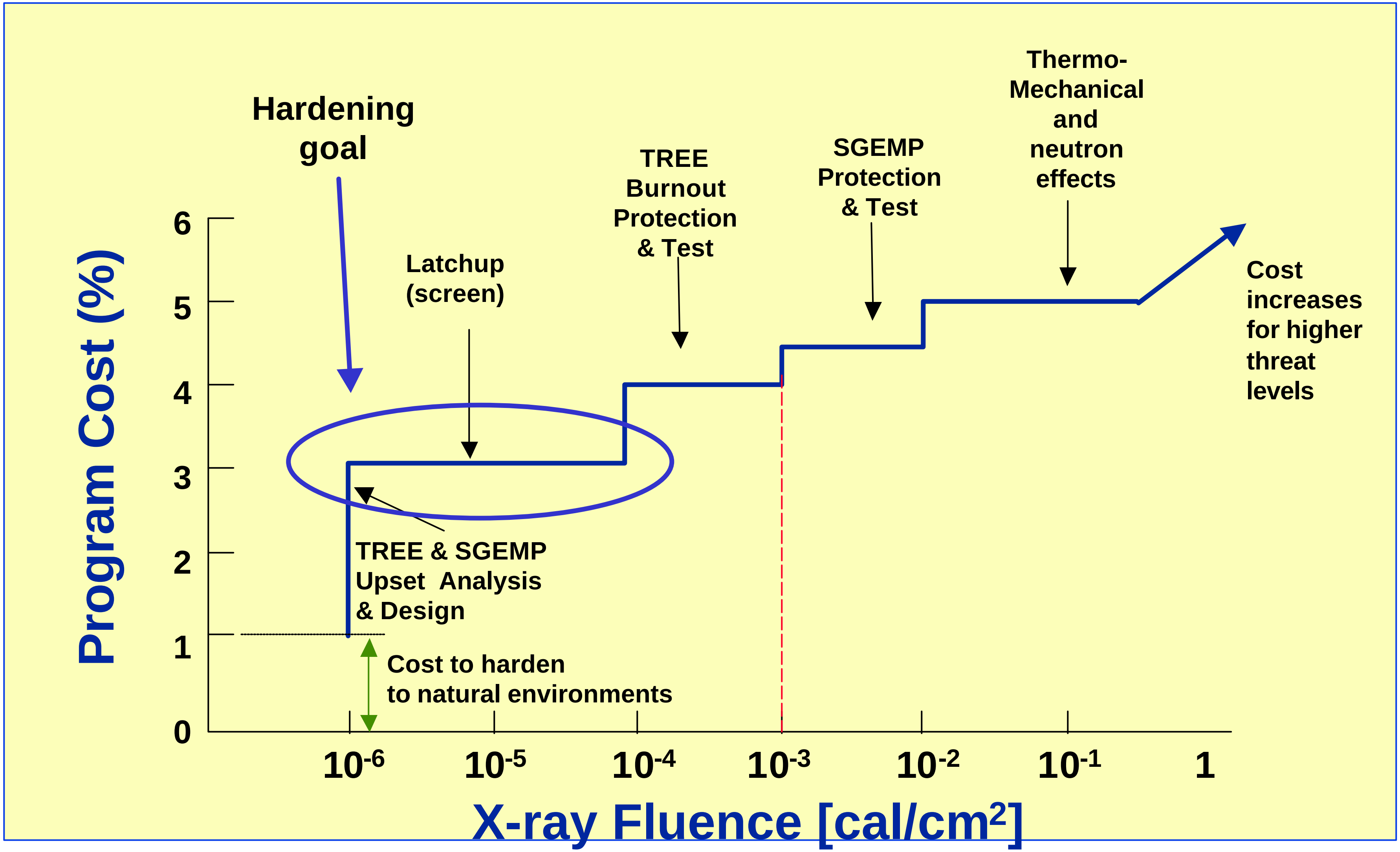
(Simplified, single-plane, polar orbit illustration.)

Upset >>>>>> Burnout

Prompt X-radiation impacts 5-10% of each LEO constellation.

From HALEOS Study

COST OF HARDENING AGAINST SGEMP



From HALEOS Study

RADIATION BELT PUMPING

- Effect of a single high altitude nuclear weapon detonation on LEO satellites
  - Nuclear burst “pumps” Earth’s Van Allen radiation belts with energetic electrons generated from beta decay of fission fragments
  - Satellites that fly through these enhanced belt regions will be rapidly degraded/destroyed due to a rapid accumulation of total ionizing dose on critical satellite electronic parts.

BASICS- THE EARTH's MAGNETIC FIELD

- Magnetic Configuration
- L - Shells
- Inner RB (1.5<L<2.2)
- Slot (2.2<L<3)
- Outer (L>3)
- Invariant Latitude

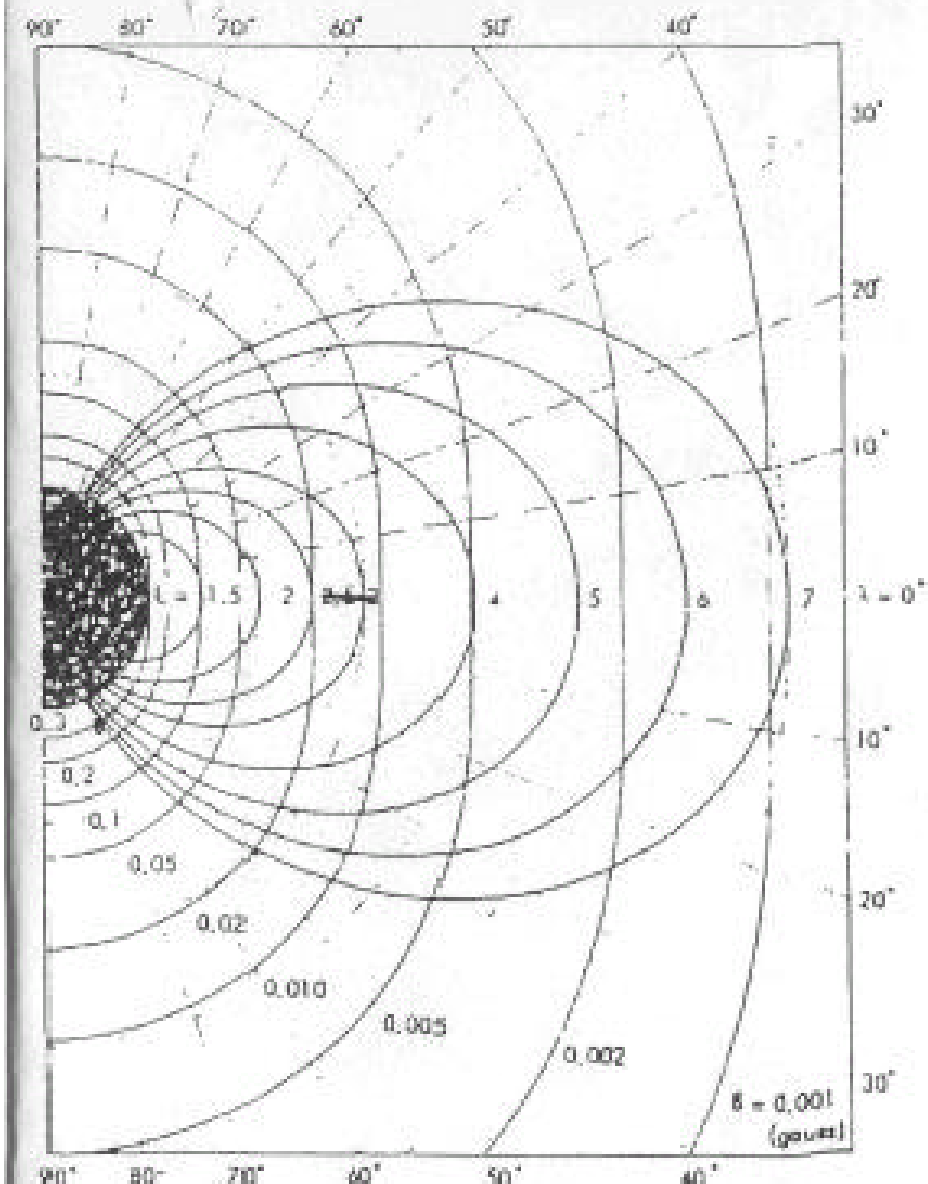
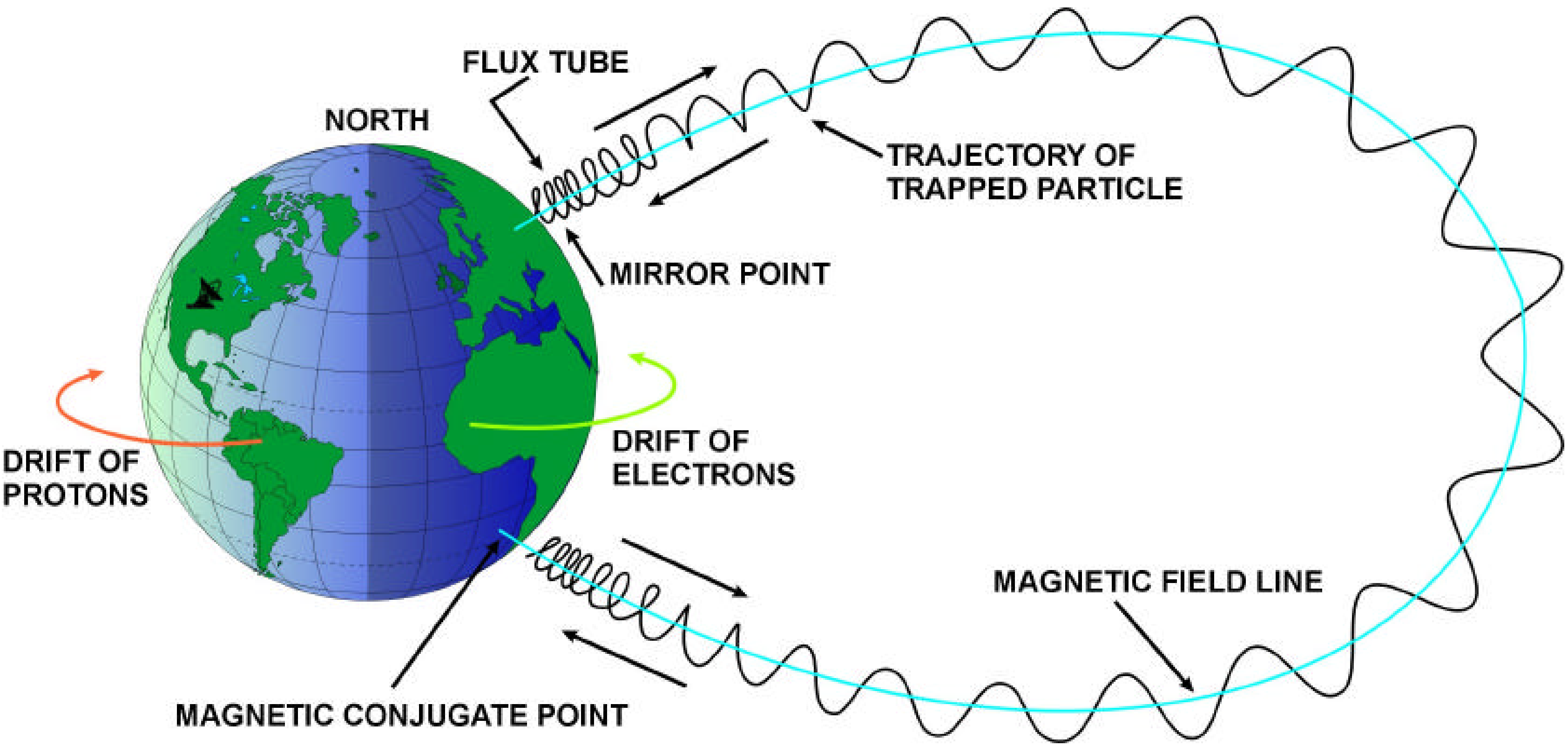


Figure 2-8. Constant-B surfaces in a dipole field.

TRAPPING AND MIRRORING OF ENERGETIC PARTICLES IN THE RADIATION BELTS



THE VAN ALLEN BELTS

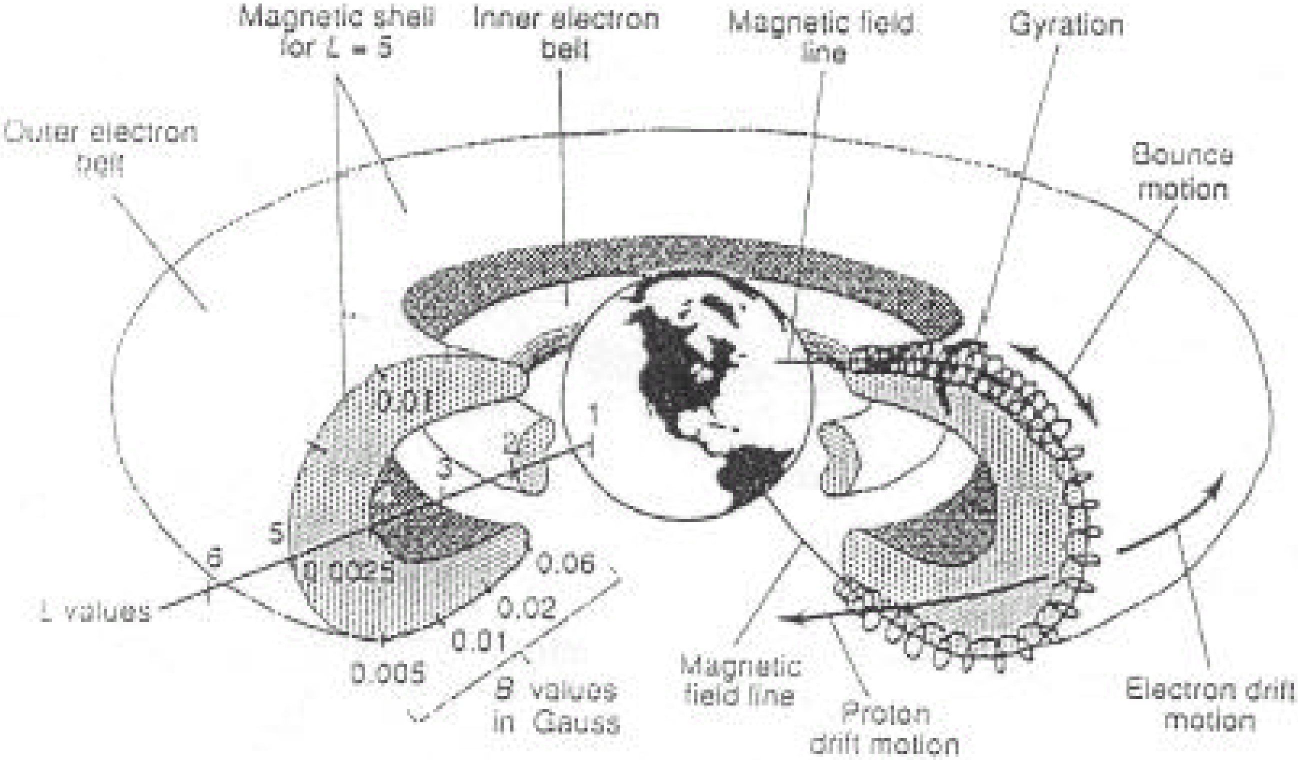


Figure 4. Sketch of a three-dimensional representation of the inner and outer radiation belts forming a ring current around Earth (after Mitchell, 1994).

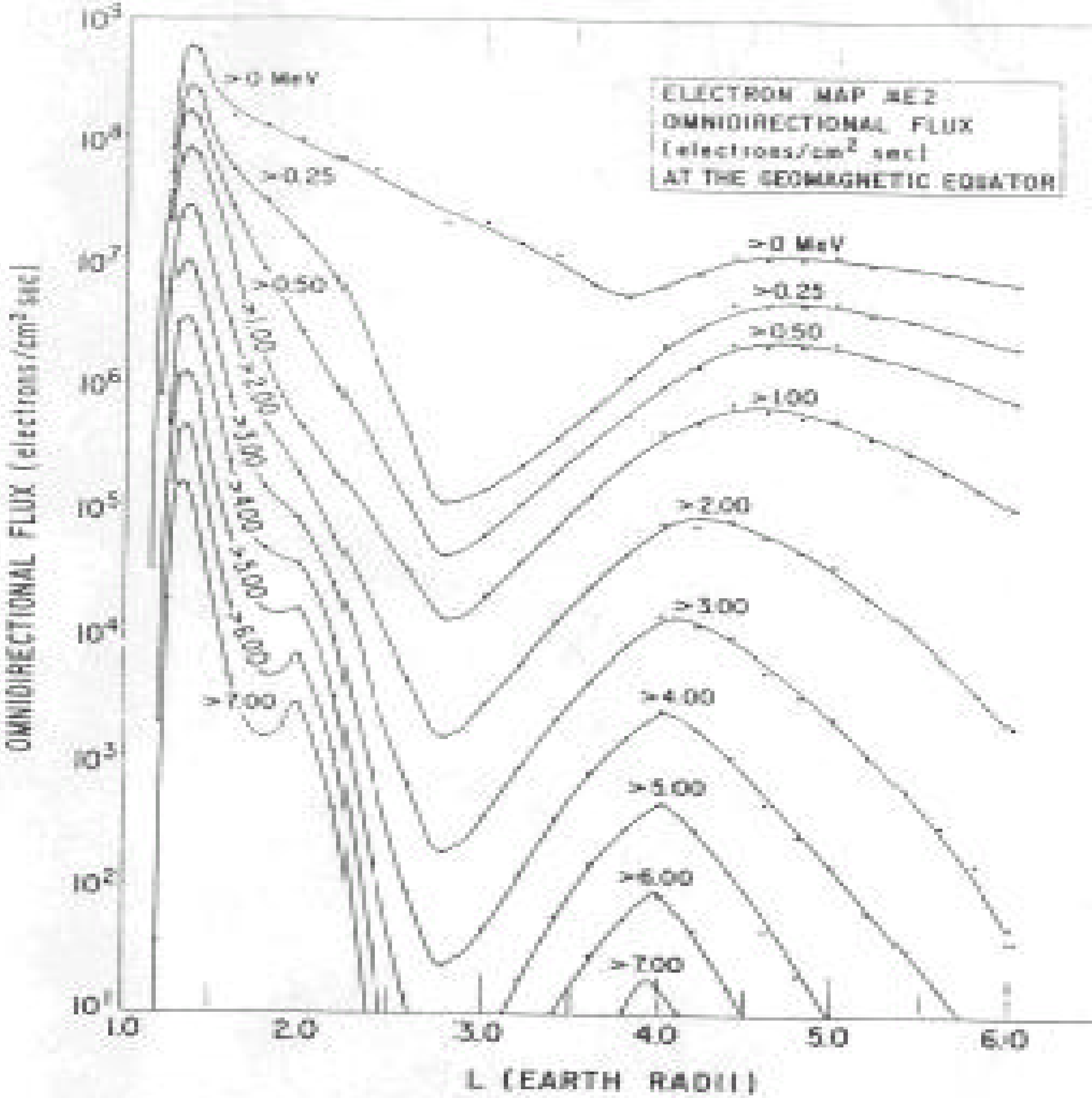
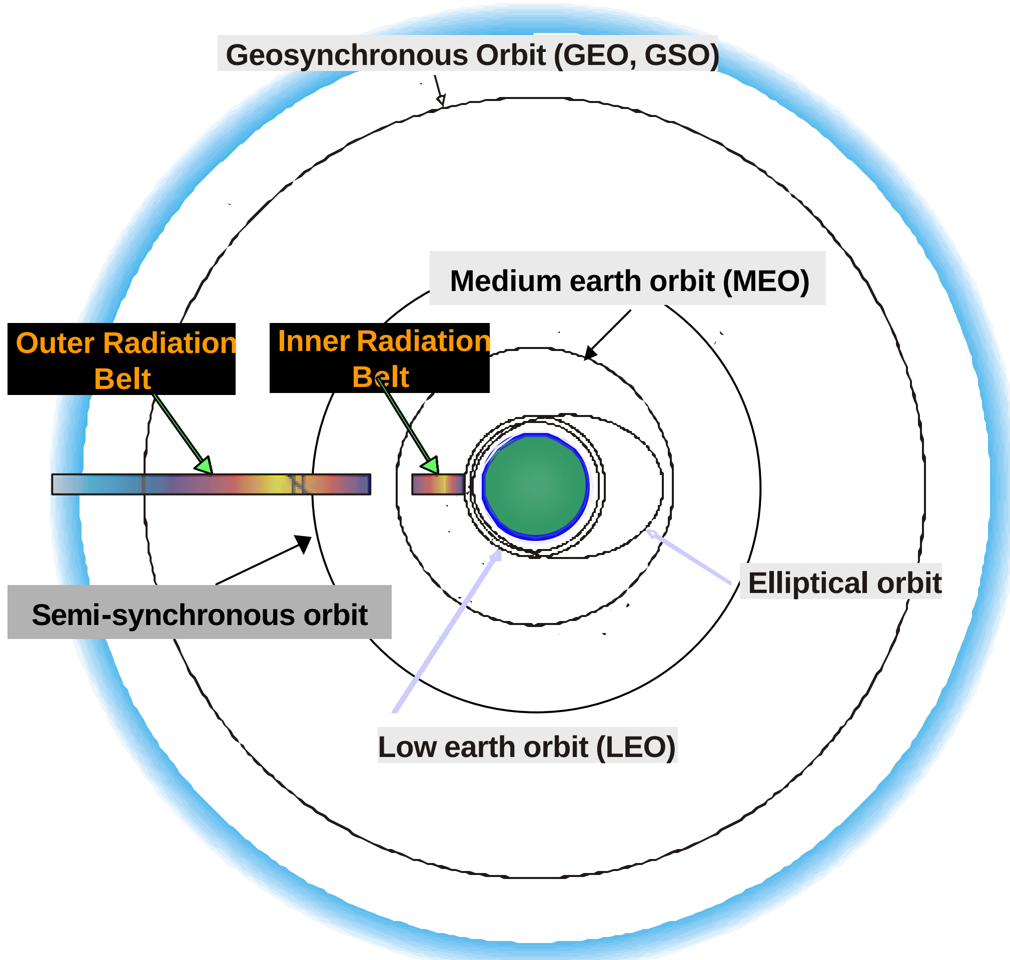


Figure 4-24. Equatorial, omnidirectional, electron flux profile.

SATELLITE MOTION THROUGH THE BELTS



Highly idealized depiction of natural radiation belts.
Inclination of each satellite orbit set to zero for display purposes.

THE ROLE OF MeV ELECTRONS

– MeV electrons cause internal charging of dielectric surfaces

-Cumulative radiation dose

-Loss of attitude control

•Degradation of performance

•Swelling of mirror surfaces

•Darkening of glassy surfaces

•Solar cell degradation

•Thermal control degradation

•Damage electronic components

•Limits lifetime

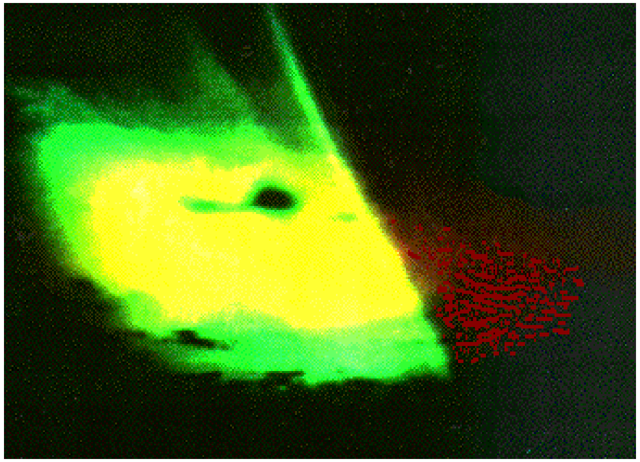
ESA Study 2001
Most of satellite designers identified internal charging caused by MeV electrons as their most important problem (Horne 2001)

- Internal charging and ESD is related to MeV electron flux (variations)
  - more than 20 spacecraft damaged [Wrenn and Smith, 1996]

- Several examples of spacecraft damaged during storms when flux was enhanced, e.g., Baker et al. [1998]
  - 1994: Intelsat K, Anik E1, & E2
  - 1997: Telstar 401
  - 1998: Galaxy IV

- US National Security Space Architect:
  - 13 satellites lost in 16 years that can be attributed clearly to natural enhancement (flux of 10^8 #/cm^2 sec) of MeV electrons

STARFISH
High Altitude Burst - 1962

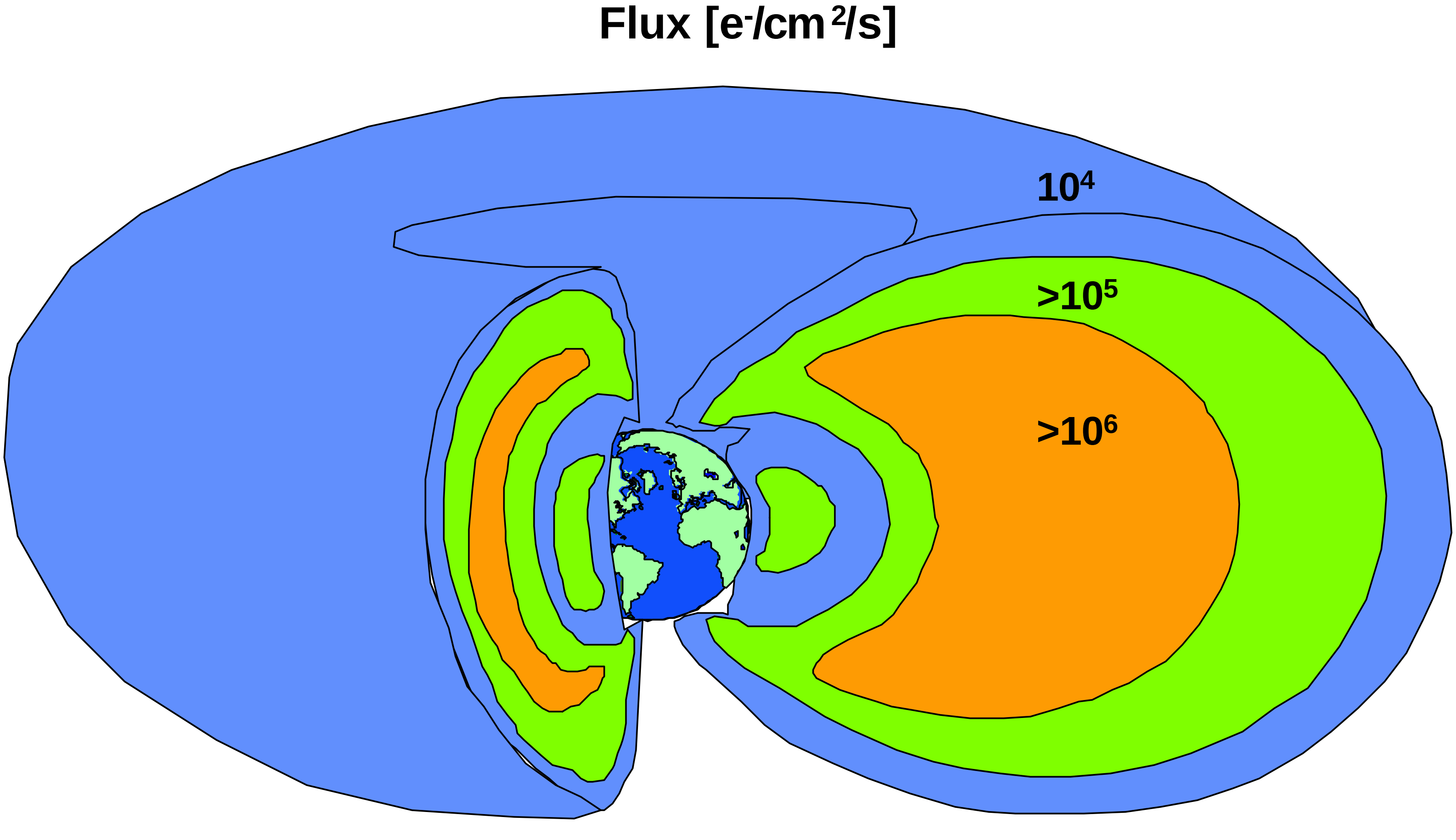


- Yield: 1.4 MT
- Altitude: 400 km above Johnson Island
- Produced a large number of beta electrons which became trapped in the Earth's magnetic field causing an intense, artificial radiation belt
- "Pumped Belts" lasted until the early 1970's

- **Seven satellites destroyed within seven months**
  - **Examples:**

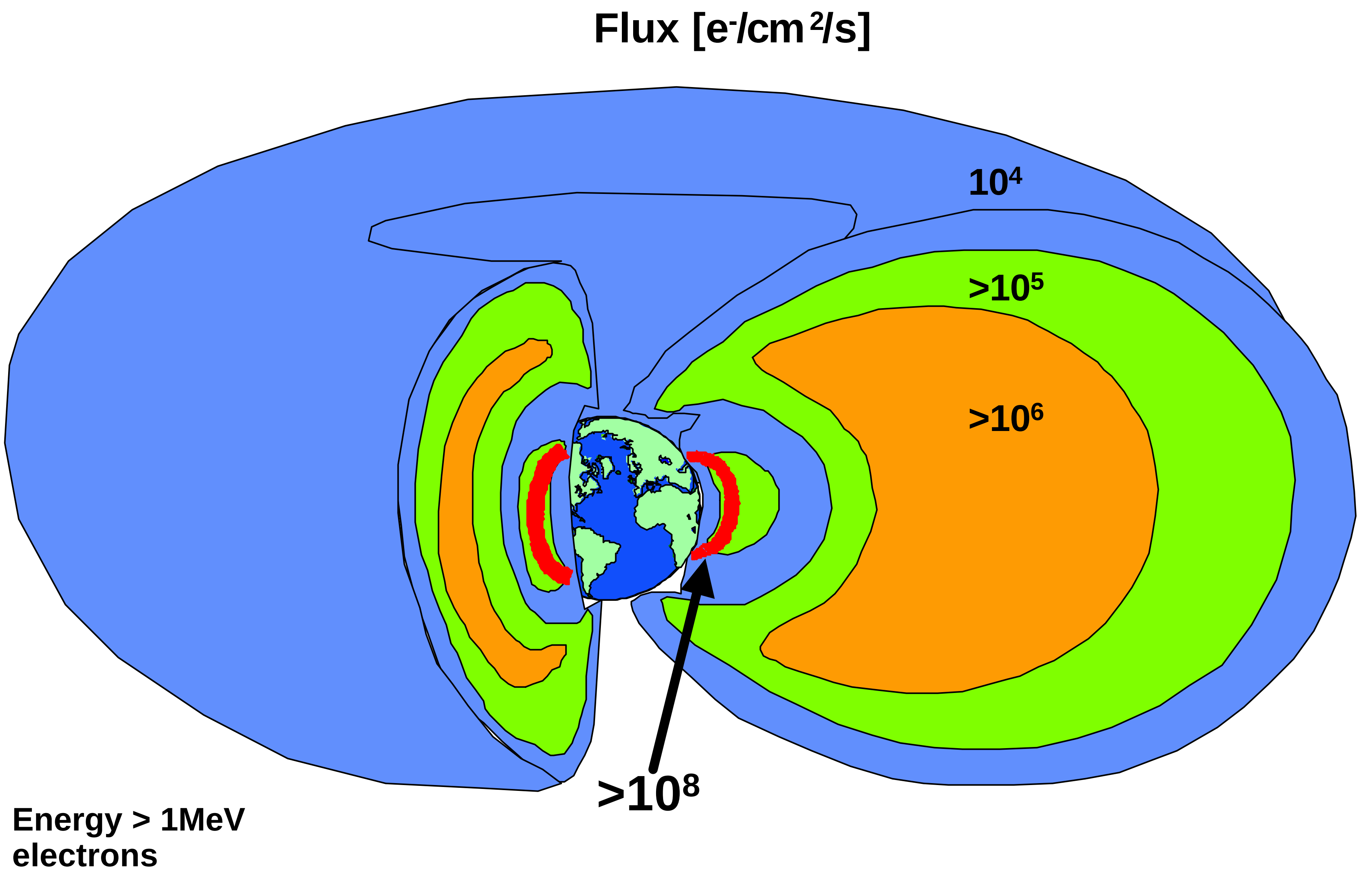
Satellite	Cause
Transit 4B	Solar Cell Degradation
Traac	Solar Cell Degradation
Ariel	Solar Cell Degradation
Telstar	Command Decoder Failure

Natural Electron Population

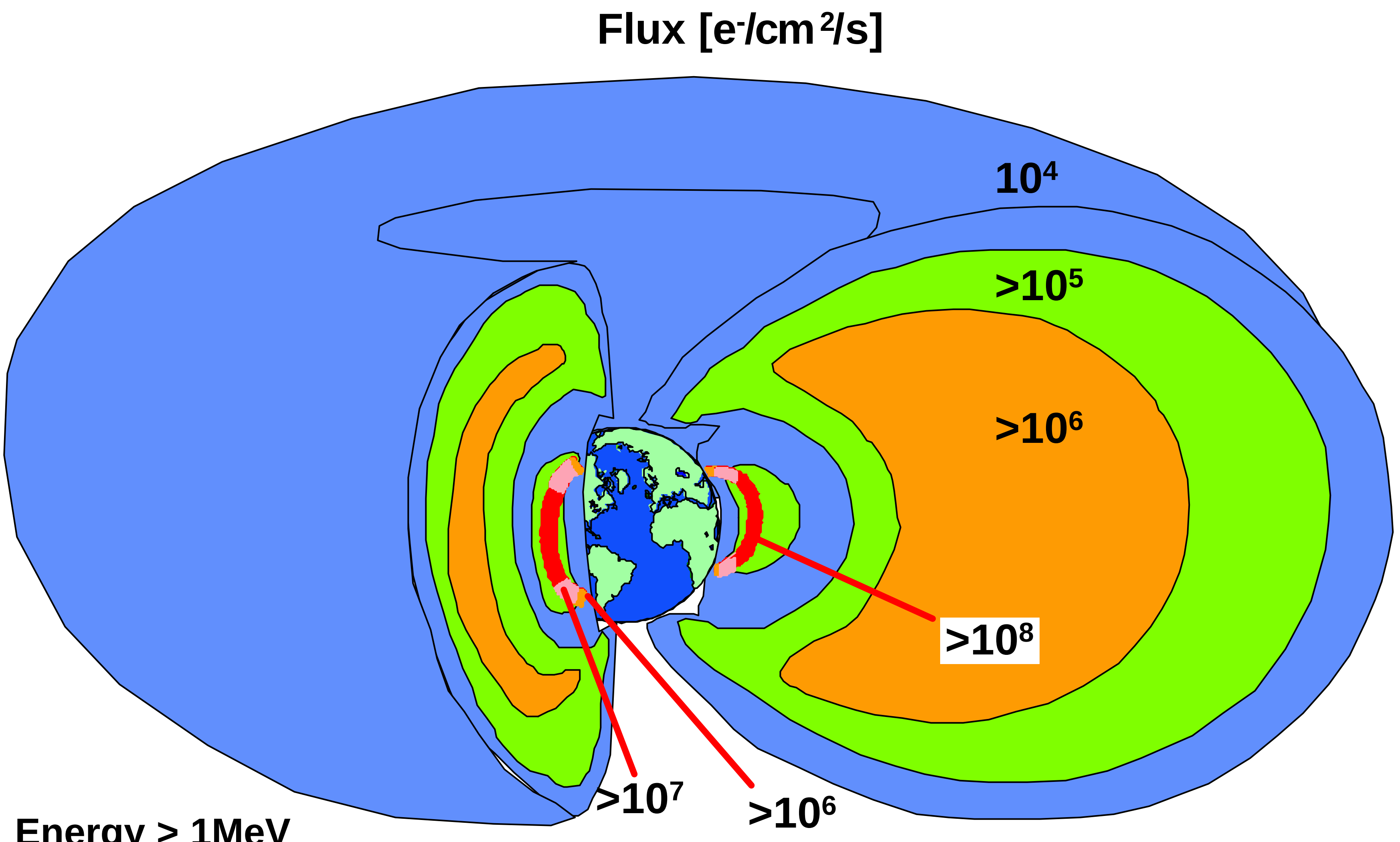


Energy > 1MeV
electrons

Natural and Enhanced Electron Population One Day After Burst Over Korea



Natural and Enhanced Electron Population Two Years After Burst Over Korea



Energy > 1MeV electrons

RUMSFELD II REPORT

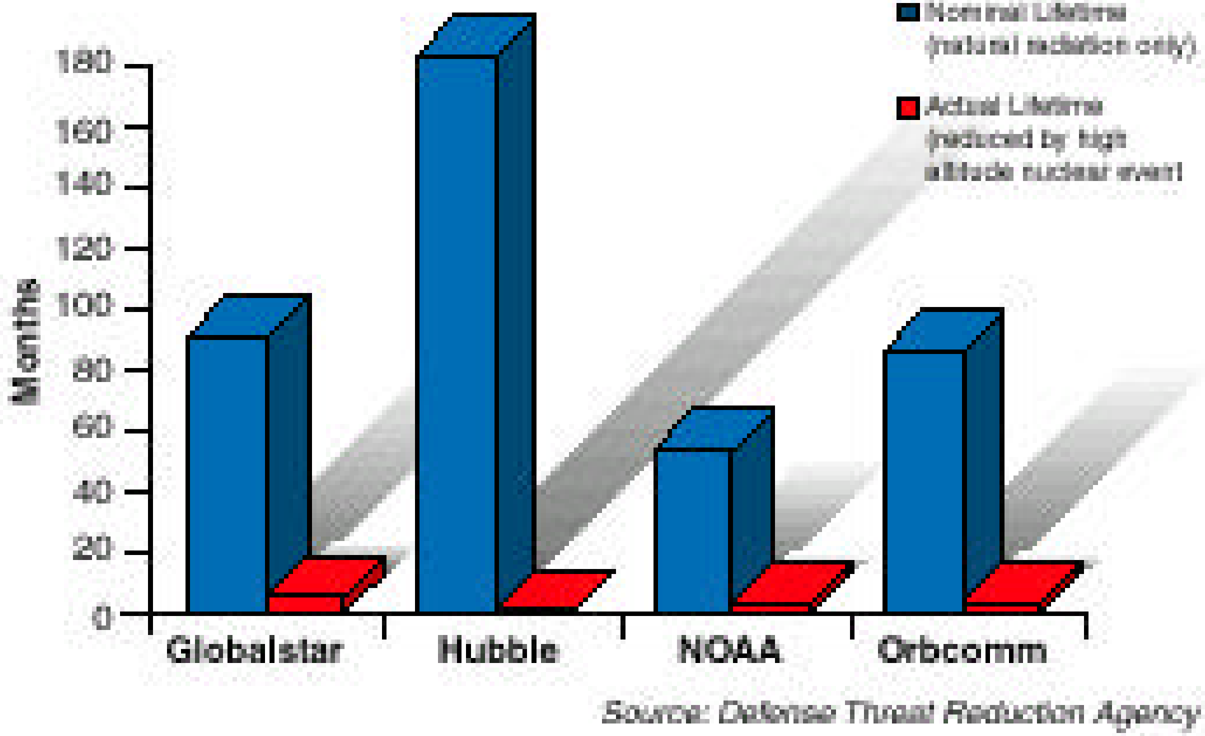


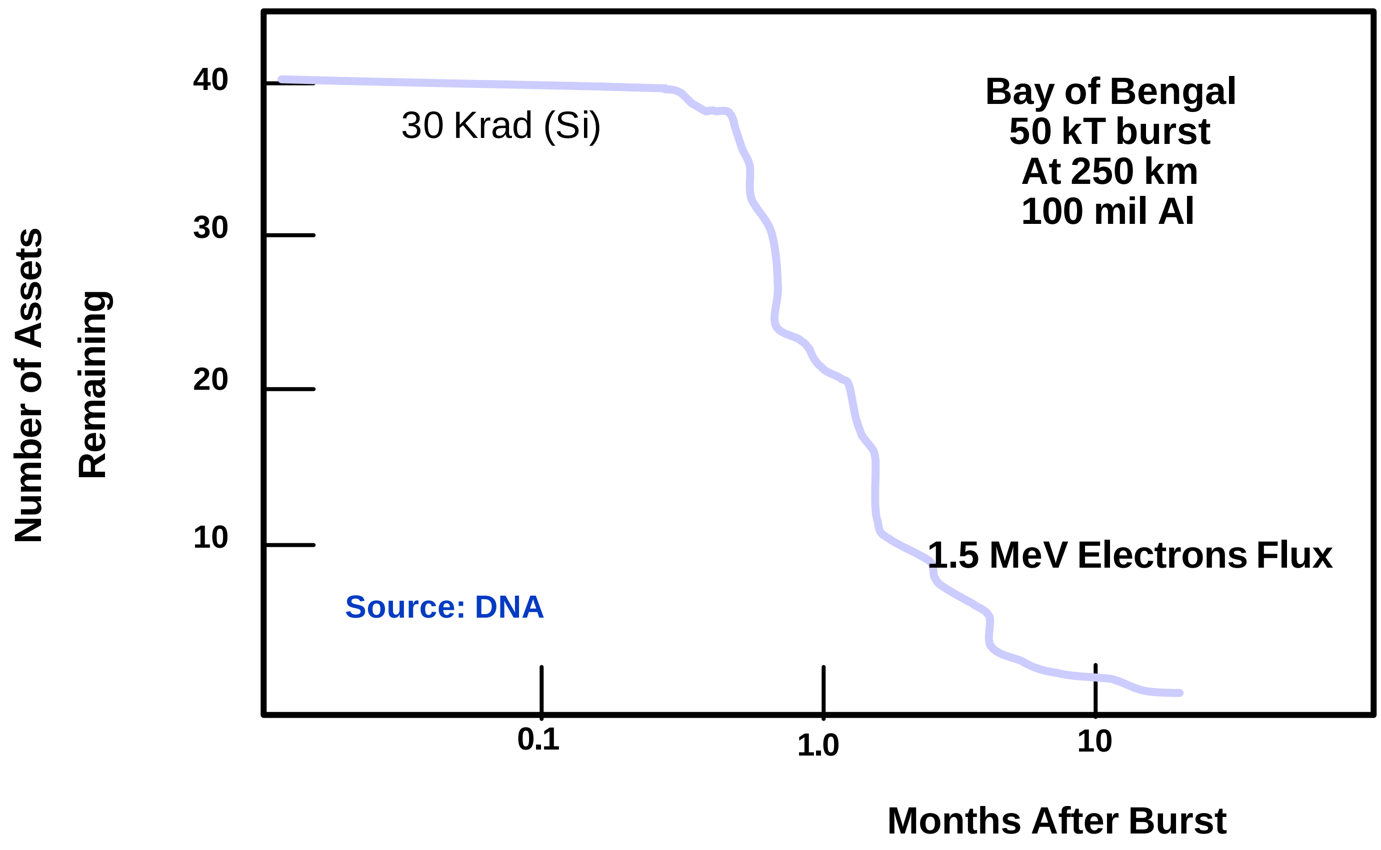
Figure 13: Impact of a nuclear detonation on the lifetime of satellities

SUMMARY

- LEO constellations present tempting targets to future nuclear-missile-armed rogues, lowering the nuclear threshold.
- LEO constellations may be destroyed as a by-product of nuclear detonations with other objectives (e.g., EMP generation, salvage-fusing at nmd intercept, nuclear interceptor).
- Loss of civilian and military communications, imaging, weather forecasting, scientific infrastructure in space
- Socio-economic and political damage due to dependence on LEO constellations

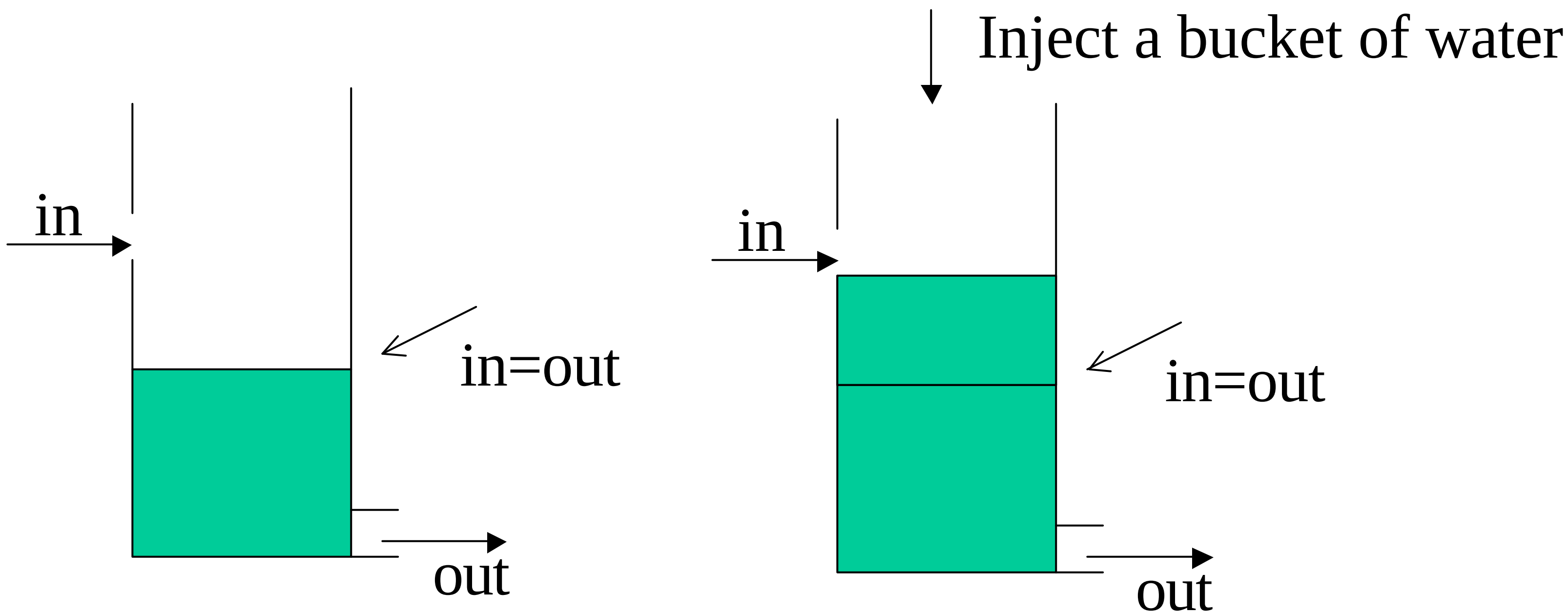
Is there mitigation besides hardening ?

LEO SATELLITE DEGRADATION



- **Possible mitigation if MeV electron lifetime is reduced to few days. TETHER PANEL RECOMMENDATION**

CONTROL OF ELECTRON LOSS RATE



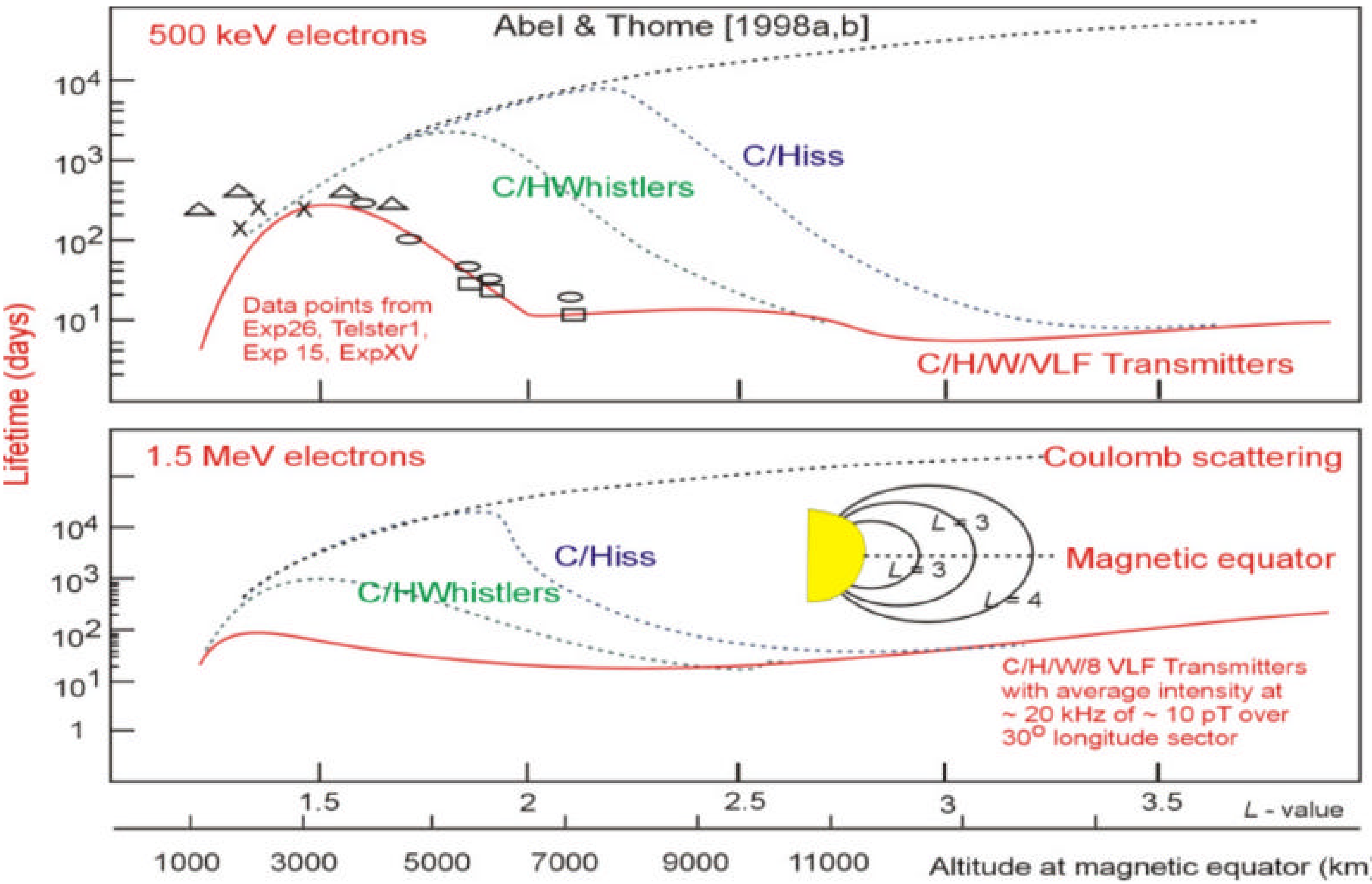
- **Time to return to the equilibrium level depends on outflow rate. The bigger the outflow hole the faster the system will get back to its natural equilibrium.**

- **What process controls the electron loss rate**

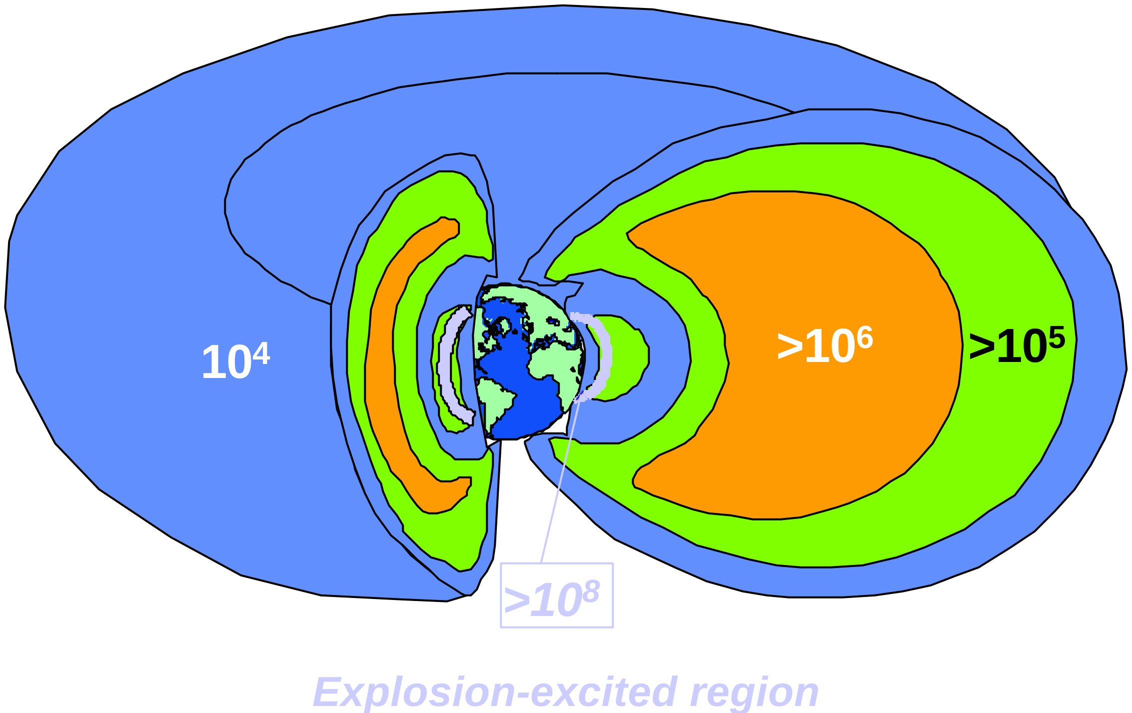
Interaction with VLF Waves Controls Loss Rate

- ELF/VLF waves resonantly interact with charged particles
- Interaction pushes the particle velocity vector toward the magnetic field line
  - long lifetime $\Leftrightarrow$ high reflection altitude $\Leftrightarrow$ low $v_{\parallel}$
- Particles become more likely to precipitate into the upper atmosphere
- Lifetime reduction is proportional to the ELF/VLF signal energy stored in the radiation belts

LIFETIME CONTROL BY VLF WAVES



Loss rate proportional to local energy density of VLF waves



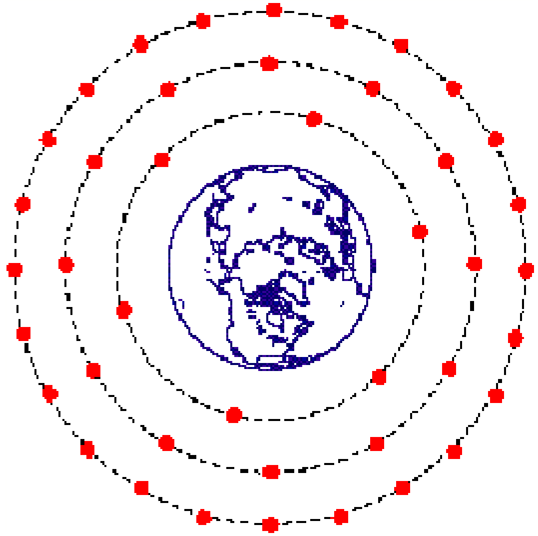
Is it feasible to pump up the VLF energy in the selected regions to the required level ?

• How many satellites are needed to reduce lifetime to ten days ?

• Too many (100s).

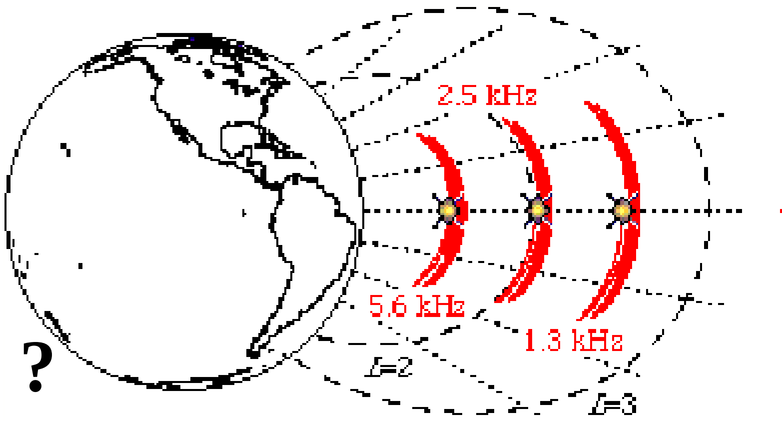
• Is there a way out ?

• Yes - Amplification



• The energy of the relativistic electrons can amplify the waves 10 dB amplification reduces the # of satts to tens while 20 dB to few.

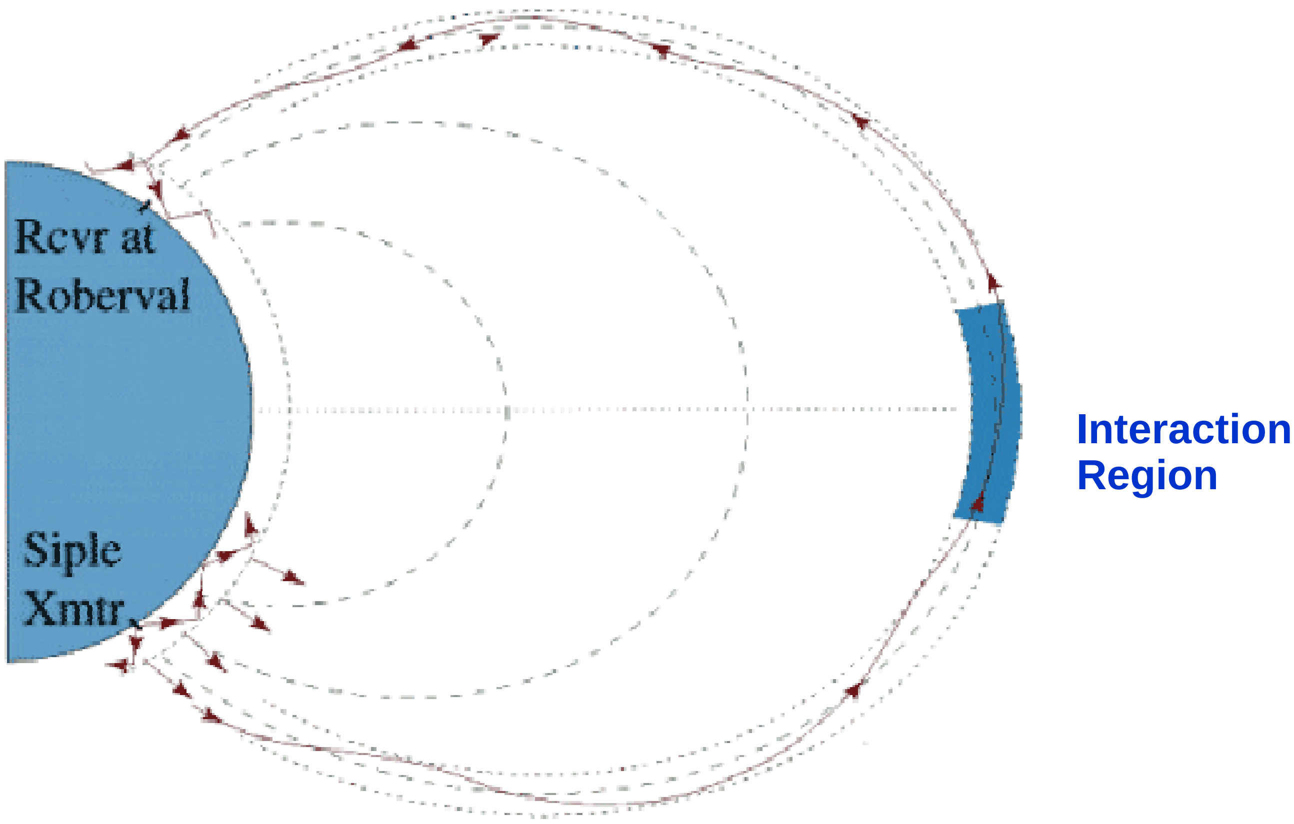
Is there evidence for amplification ?



VLF Wave-Injection Experiments

VLF Wave-injection from

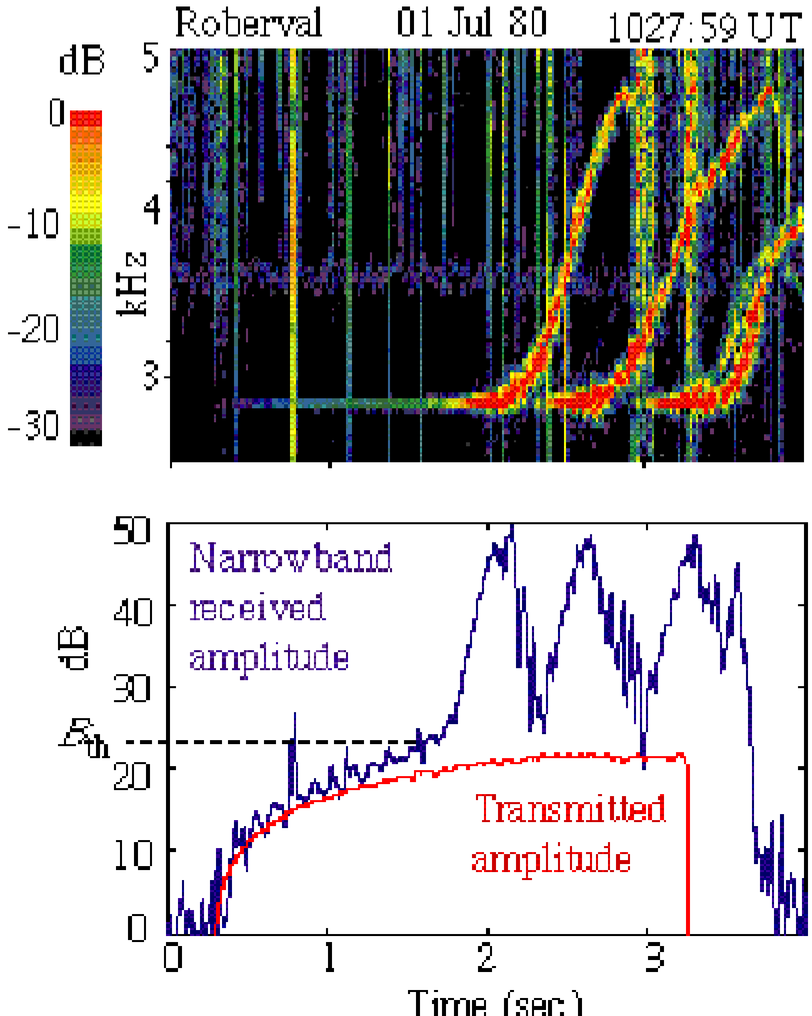
Siple Station, Antarctica



Siple Experiments
Natural Amplification of Injected Signal

- Injected Siple signals often amplified by 10 to 30 dB and new emissions triggered
  - For input $B_w > B_{th}$
    - B_{th} =0.1 to 0.5 pT

- Amplification is more likely to occur during times of enhanced fluxes of energetic radiation belt electrons



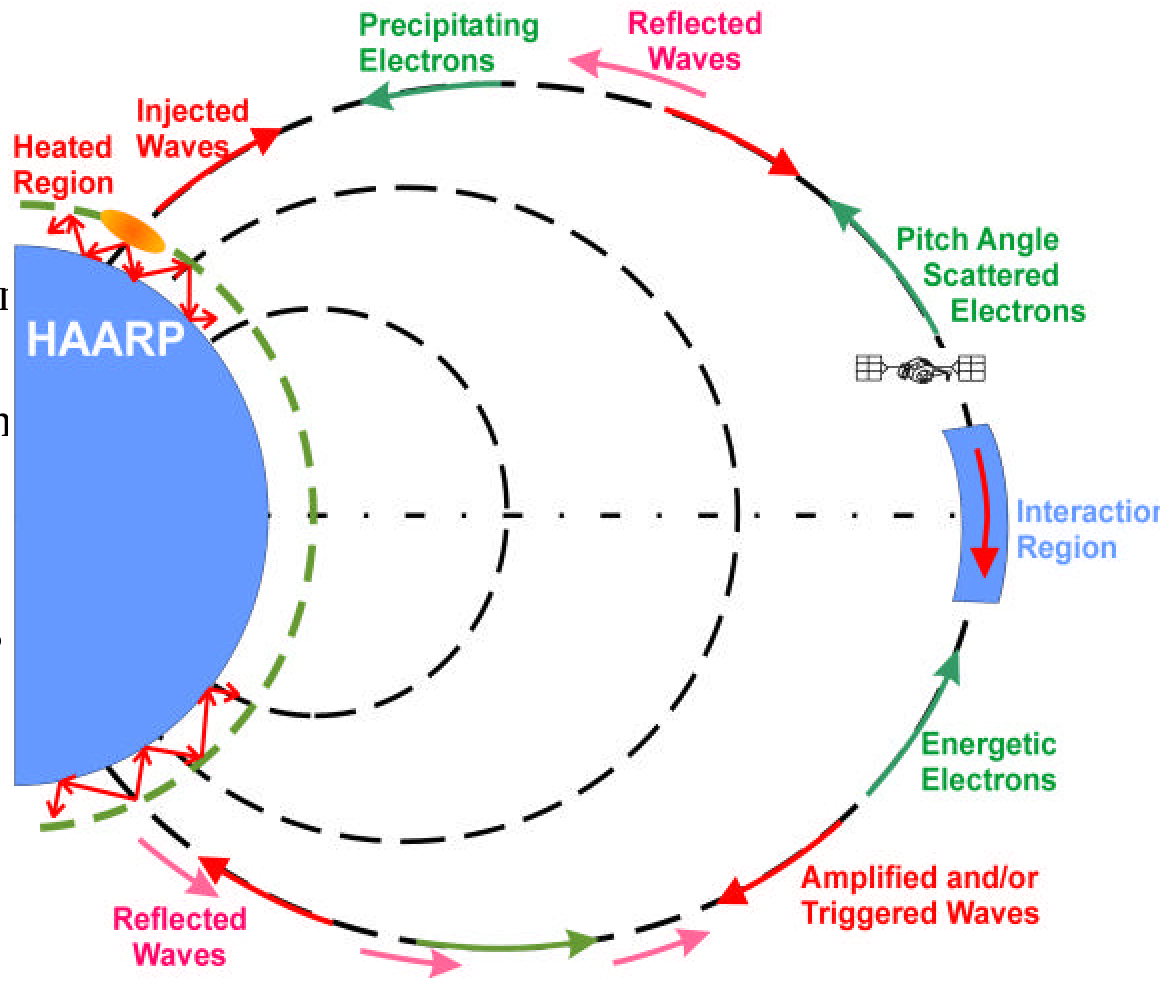
Understanding and Using Natural Amplification

- Using natural amplification can dramatically reduce the size and cost of a satellite protection system
- To use natural amplification reliably, experiments are needed which transmit and receive ELF/VLF over a wide range of frequencies
- Experiments could use satellite or ground-based transmitters, *but*: conventional transmitters (ground or satellite) can only cover a narrow frequency range

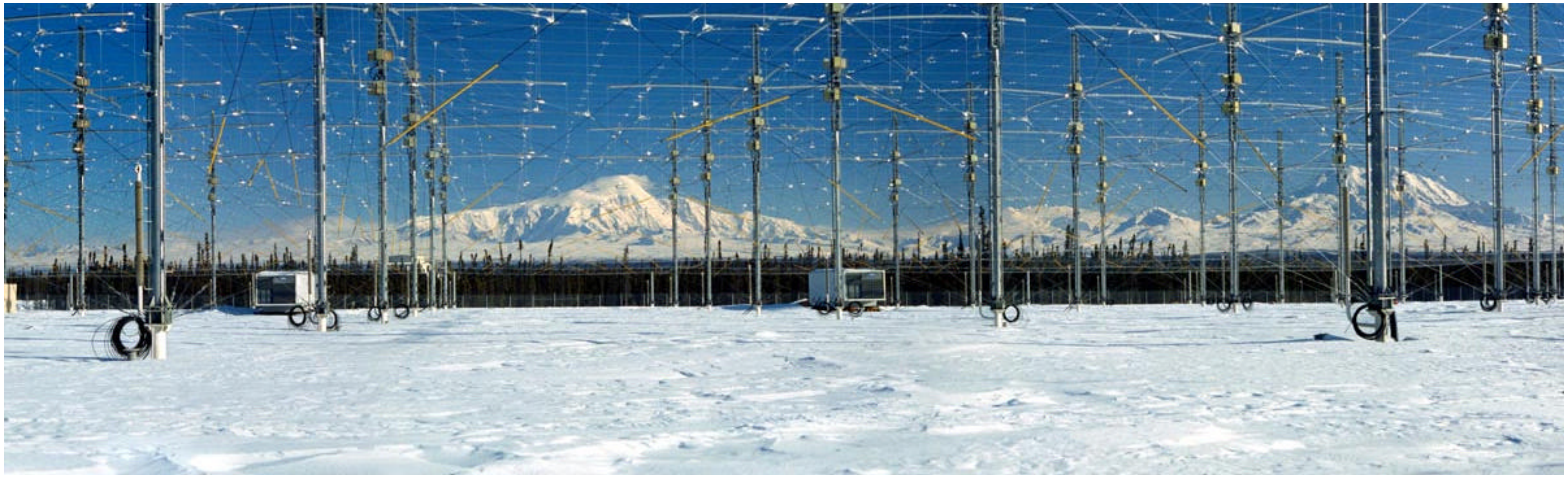
TETHER Panel Recommendation:
Use HAARP facility in Alaska as a "wind tunnel" to determine the feasibility and engineering specifications of a mitigation system.

- Observe amplified and triggered waves
  - At conjugate region (Southern Pacific)
  - Near HAARP upon reflection in the south

- Observe ionospheric effects of precipitated electrons with HAARP diagnostics

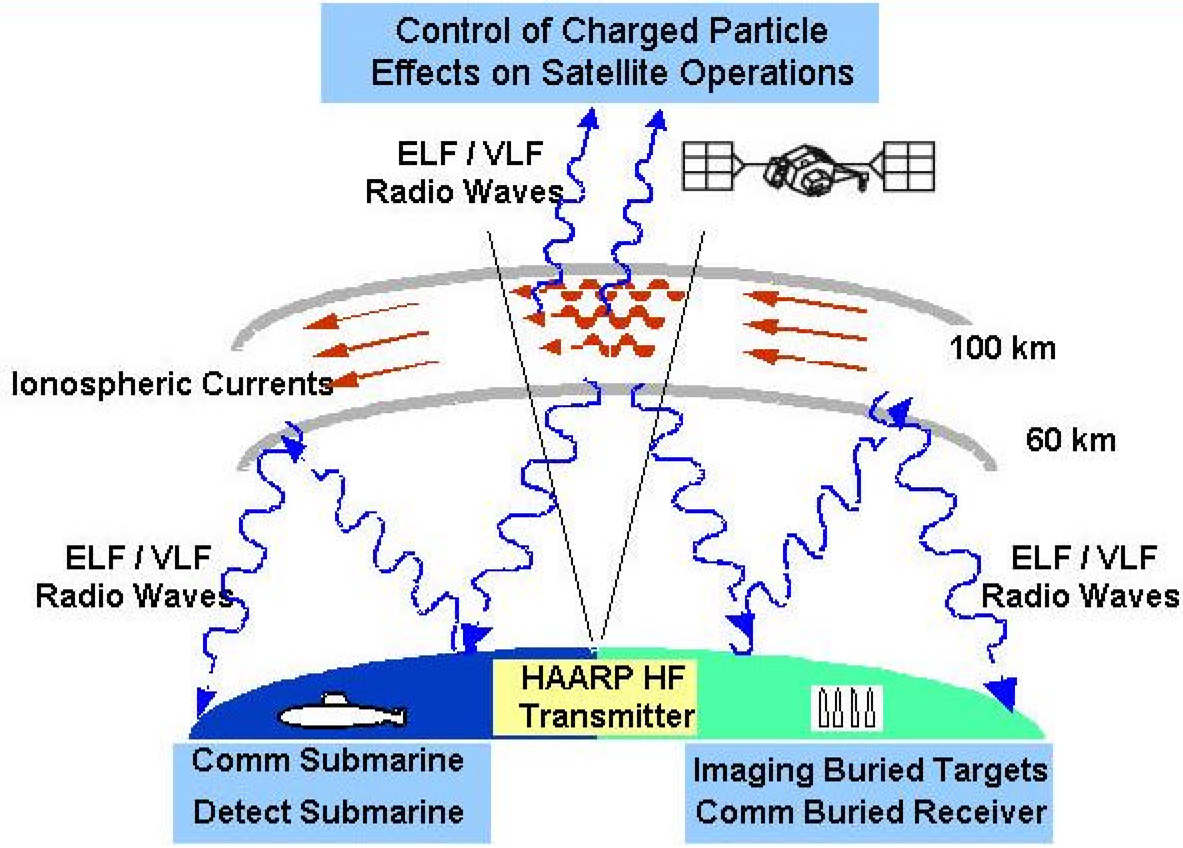


What is HAARP?



- Large ionospheric research facility in central Alaska
- Joint project of AFRL and ONR
- Powerful, flexible source of ELF/VLF signals over a very wide frequency range (0.1 Hz – 40 kHz)

HAARP Applications



CONCLUDING REMARKS

- **A HANE will have deleterious consequences to the LEO constellations**
  - **Prompt EMP effects will affect line of sight ground and space based systems**
    - **Affect < 10% of LEO constellations**
    - **Only mitigation is hardening**
    - **Replacement possible**
  - **Long term effects involve pumping of the radiation belts with MeV electrons due to beta decay**
    - **Affect the entire fleet of satellites at the injection L-shell**
    - **Replacement not possible for probably one year**
    - **Mitigation includes orbit changing and radiation belt "pump out"**