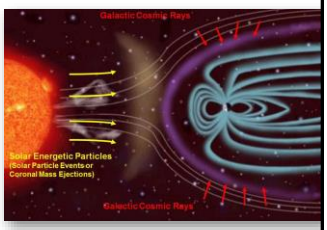
Today's Class: Space Radiation

Exam 2 on Friday

- All the reading since Sep. 23th through Oct. 21st.
- All homework assignments.
- Space in the News articles/discussions.
- All material discussed in class including in-class group exercises.
- You may bring one page (front + back) of notes.
- Bring a calculator not on your phone.
- Study with another member in the class, if possible.



1

Space in the News

Russia Planning to go Reusable by 2026 with new Amur Rocket

Presented by: Andrew Czekay

- Roscosmos is planning to develop a two stage rocket called the Amur
- First stage will return to Earth and land vertically, similar to SpaceX's Falcon 9 rocket
- Much smaller, only capable of injecting 11.6 tons of payload to LEO (vs Falcon's 25.1 tons)
- Pre-launch cost of $22 million compared to Falcon's $50-60 million
- Total Program cost planned to be under $1 billion

Question: Do you think Russia's move to develop a reusable launch vehicle program so similar to SpaceX will spark a second Space Race, where this time commercial companies are involved too, or is SpaceX's already so far ahead to consider the Amur competition?

2

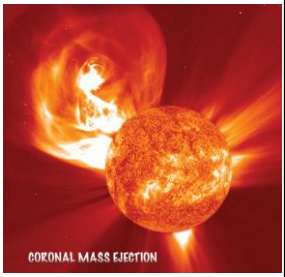
Last Class

- The Sun-Earth Connection.
- The solar wind & Coronal Mass Ejections.
- Space Radiation Effects:
  - Damage to electronics on spacecraft.
  - GPS satellites
  - Airlines flying over the poles
  - Electrical power grid

3

Class Exercise

The Carrington Event of 1859 was the most powerful Coronal Mass Ejection that struck the Earth in the past 200 years. What would the consequences be today for a similar solar storm reaching the Earth?



4

Today's Class

- Introduction to Radiation
- Sources of Space Radiation
  - Solar wind (Van Allen Belt)
  - Galactic Cosmic Rays
- Damage to DNA
- Space Radiation Exposure
- Possible protection from space radiation

Today's class notes adapted from presentation by H. Wu, NASA Johnson Space Center

5

Discovery of X-rays
Wilhelm Roentgen (1845-1923)

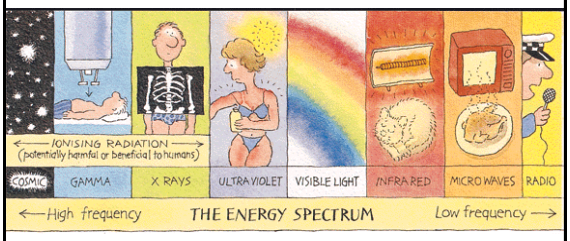
6

Introduction to Radiation

- Non-ionizing radiation – Microwaves, UV, laser and etc.
- Ionizing radiation – X-rays, alpha, beta and gamma radiation
- Energetic particles – Charged particles and neutrons

7

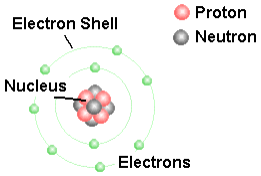
Introduction to Radiation



8

Introduction to Radiation

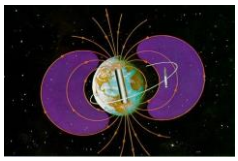
- Space radiation is composed of energetic charged particles (atoms with all of the electrons stripped).
- Astronauts are exposed to secondary neutrons as well.

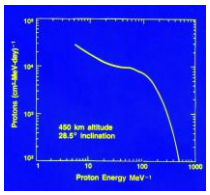


9

Van Allen Belts (Trapped radiation)

James Van Allen (1914 – 2006)

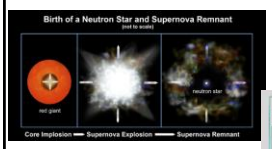


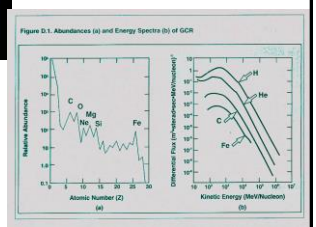


Energy spectrum of trapped protons.
eV = electron-volt.
1 MeV = 2 x rest energy of electron.

10

Galactic Cosmic Radiation (GCR)





11

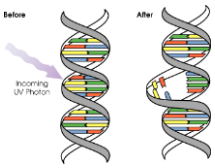
Summary of space radiation environment

- Major sources: GCR, solar particle events
- Radiation type: Protons and heavy ions
- Energy of interest: 100 MeV/proton to ~10,000 MeV/proton
- Secondary neutrons generated by primaries striking spacecraft walls/shielding.
- Small amount of other types of radiation
- Ultraviolet radiation

12

Ultraviolet radiation

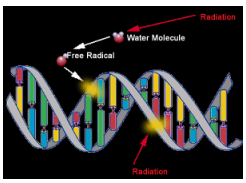
- Skin cancer and damages to the eye
- Most of the spacecraft windows are coated with UV blockers
- EVA visors are coated with UV blockers
- EVA suit has a layer of material to block UV

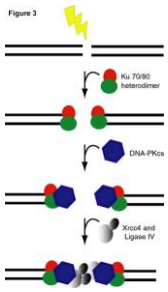


Ultraviolet (UV) photons harm the DNA molecules of living organisms in different ways. In one common damage event, adjacent bases bond with each other, instead of across the "ladder." This makes a bulge, and the distorted DNA molecule does not function properly.

13

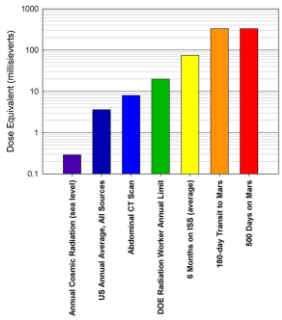
DNA damage from ionizing radiation: DNA strand breaks





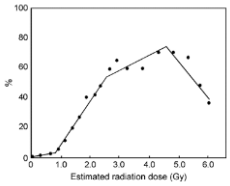
14

Space Radiation Exposure



15

Acute radiation syndrome



video

16

Identified Space Radiation Risks

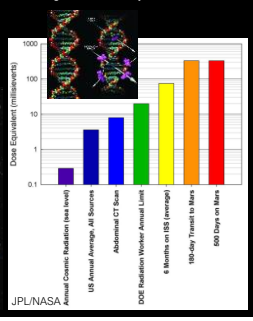
- **Carcinogenesis --** Increased cancer morbidity or mortality risk in astronauts may be caused by occupational radiation exposure
- **Acute and late CNS risks --** Acute and late radiation damage to the central nervous system (CNS) may lead to changes in motor function and behavior, or neurological disorders.
- **Chronic and degenerative tissue risks --** Radiation exposure may result in degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory, or digestive diseases, as well as cataracts.
- **Acute radiation risks --** Acute radiation syndromes may occur due to occupational radiation exposure.

17

Ionizing Radiation Effects on Technology and Humans

- Energetic charged particles leave ionized track with penumbra of energetic electrons at hundreds of micron distance
- Single Event Effects can change state of devices, alter memory
- Drives need for redundancy

- Direct damage to DNA,
- Indirect effects due to generation of reactive oxygen species,
- Changes biochemistry of cells and tissues



18

Possible Protection from Space Radiation

- Spacecraft can be constructed out of hydrogen-rich plastics, rather than aluminum.
- Other material shielding that has been considered:
  - Liquid hydrogen, which would be brought along as fuel in any case, tends to give relatively good shielding, while producing relatively low levels of secondary radiation. But, it is consumed during flight.
  - Water could also contribute to shielding. But it too is consumed during the journey unless waste products are utilized.
  - Magnetic deflection of charged radiation particles and/or electrostatic repulsion is a hypothetical alternative to pure mass shielding. In theory, power requirements for the case of a 5 meter torus drop from an excessive 10 GW for a simple pure electrostatic shield (too discharged by space electrons) to a moderate 10 kilowatts (kW) by using a hybrid design. However, such complex active shielding is untried, with workability and practicalities more uncertain than material shielding.
- None of the above are effective for Galactic Cosmic Rays.

20

Conclusions

- Astronauts receive the highest occupational radiation exposure
- Effective protections are needed to ensure the safety of astronauts on long duration space missions
- No completely effective solution currently exists for radiation problem. Major problem for long duration interplanetary space flights!

21