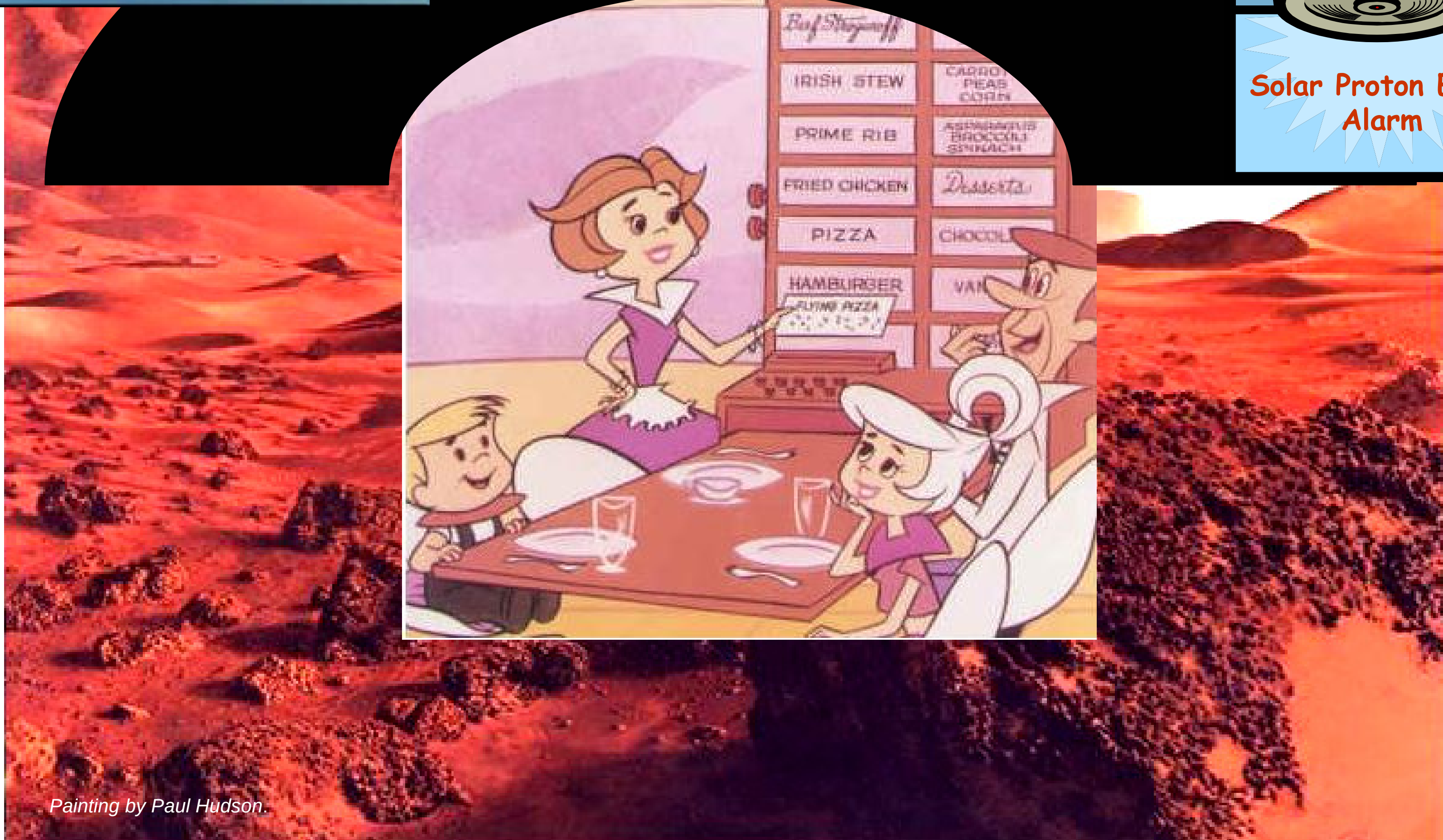
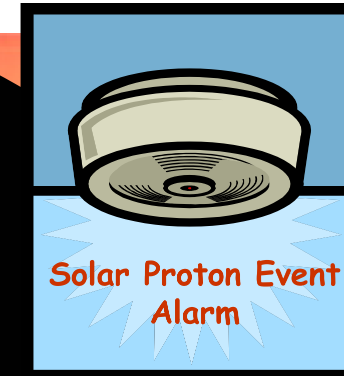
was originally supposed to take place
“one hundred years in the future” in the year 2062



Painting by Paul Hudson.



Solar Extreme Events 2005-2006:

Effects on Near-Earth Space Systems and Interplanetary Missions

Norma Bock CROSBY

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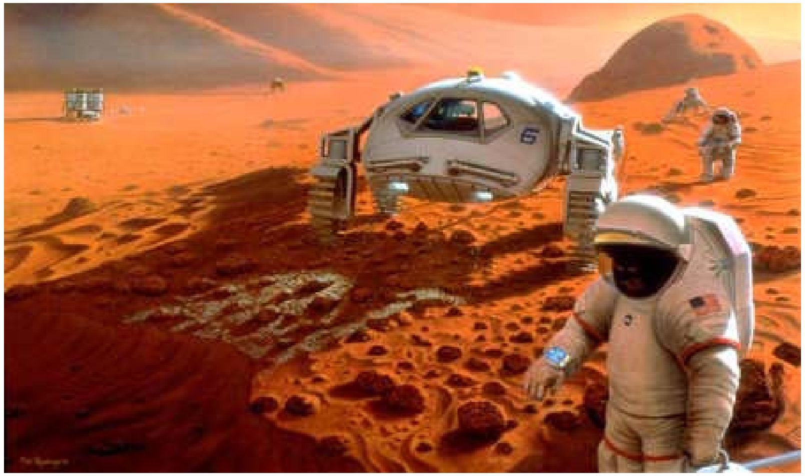


"Distant Shores."
NASA artwork by Pat Rawlings/SAIC

Solar Extreme Events 2007, Athens, Greece, 25 September 2007

aeronomie.be

OUTLINE

1. Introduction

2. Solar Extreme Event Examples [effects occurring and those that could have occurred in regard to interplanetary missions]

   - 15 DECEMBER 2006
   - 20 JANUARY 2005

3. How Good are we in avoiding Solar Extreme Events ?

4. Summary : Words for Thought

1. INTRODUCTION

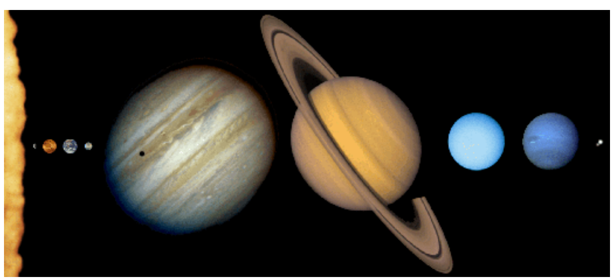
"Space Weather" as defined by the U.S. National Space Weather Program:

"Conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."

in more simple terms …

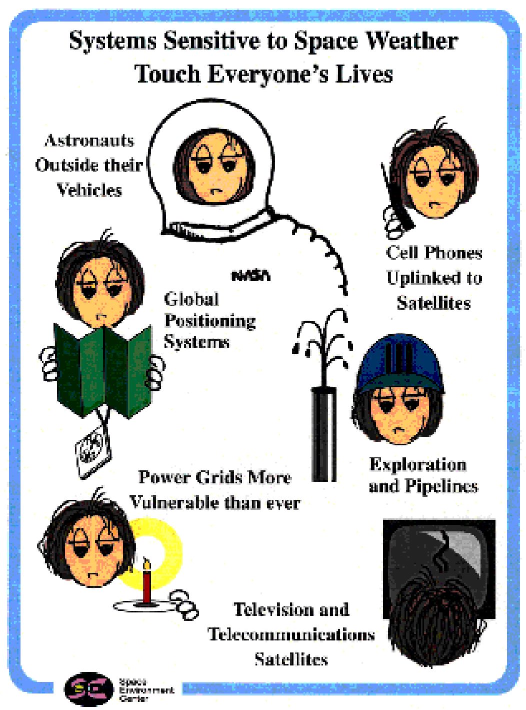
How solar activity may have unwanted effects on technological systems and human activity.

- Our location in the solar system,



http://www.nineplanets.org/

- Behavior of the Sun,
- Nature of Earth's magnetic field and atmosphere.



Earth's magnetic field shields us against high-energetic particles.

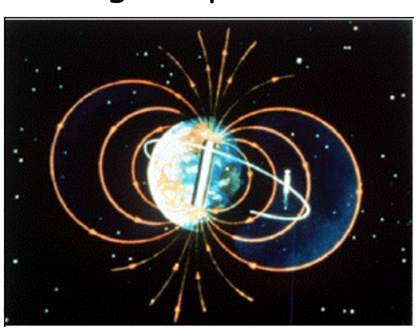


Image from NASA.

Major Radiation Environments in the Heliosphere.

Cosmic Rays
[super-thermal to more than 10^{21} eV]
Most cosmic rays are ionized atoms, ranging from protons, helium (α-particles), up to the iron nucleus and even beyond to heavier nuclei (e.g. uranium).

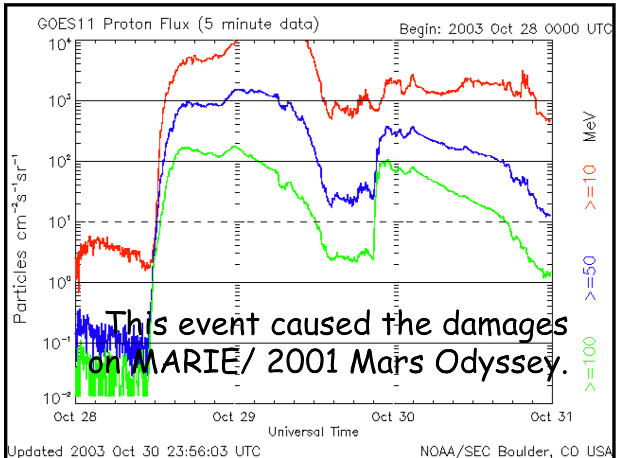
Cosmic rays also include high-energy electrons, positrons, and other subatomic particles.

Particle Populations	Energy Range	Temporal Range	Spatial Range (first order)
Galactic Cosmic Rays	0.1 – 1000 GeV (the 100 to 1000 MeV fluxes constitute the largest contribution)	Continuous (factor 10 variation with solar cycle)	Entire heliosphere
Anomalous Cosmic Rays	< 100 MeV	Continuous	Entire heliosphere
Solar Energetic Particles	keV – GeV	Sporadic (minutes to days)	Source region properties (flare/CME sites and evolution) and bound to CME driven shock
Energetic Storm Particles	keV - (>10 MeV)	Hours-Day	Bound to shock
Corotating Interaction Regions	keV – MeV	Few days (recurrent)	Bound to CIR shock and compression region
Particles accelerated at planetary bow shocks	keV – MeV	Continuous	Bound to bow shock
Trapped Particle Populations	Tens keV - couple of hundreds of MeV (for protons) Tens keV - several MeV (for electrons)	Variations "minutes-years"	Variations "height-width"

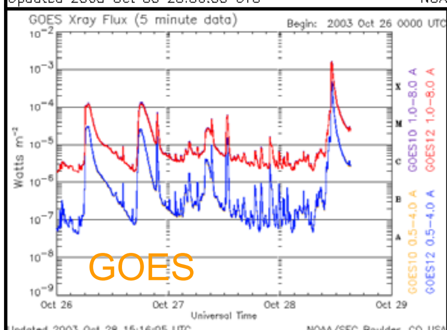
CME: coronal mass ejection CIR: corotating interaction region

Crosby N.B., V. Bothmer, R. Facius, J.-M. Griessmeier, X. Moussas, M. Panasyuk, N. Romanova, and P. Withers, "Interplanetary Space Weather and its Planetary Connection", meeting report, AGU Space Weather Journal, 2007, in press.

3. SOLAR PARTICLE EVENTS [sporadic]

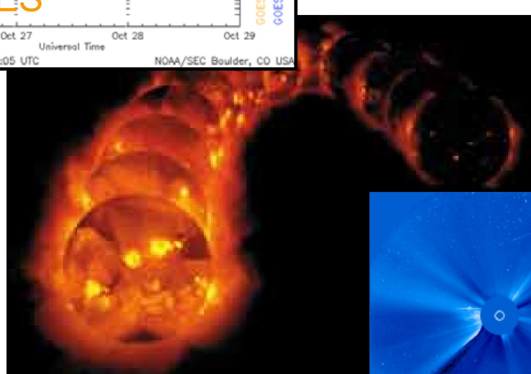


This event caused the damages on MARIE/ 2001 Mars Odyssey.

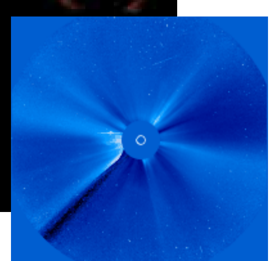


During SEPs the intensity of energetic particles in space can increase by a factor of 10^2 to 10^6 for hours to days.

Solar Flares



Twelve X-ray solar images (1991 – 1995) at 120-day intervals. Courtesy of Yohkoh.



SOHO / LASCO

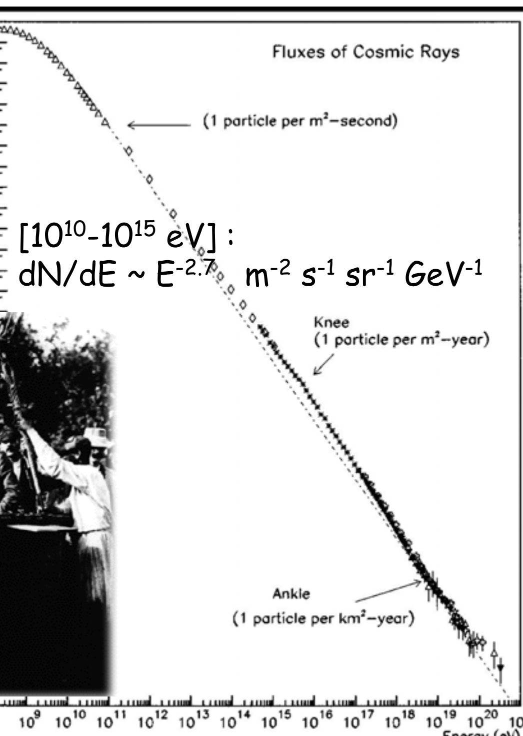
Coronal Mass Ejections

1. EARTH'S RADIATION BELTS

William Pickering, James Van Allen and Wernher von Braun (left to right) hoist a model of Explorer 1 after the launch, Jan. 31, 1958.

2. GALACTIC COSMIC RAYS

Hess's theory about "rays from space" did not receive general acceptance at the time he proposed it (Hess V.F., 1911, 1912).



$[10^{10}$-10^{15} eV] : $dN/dE \sim E^{-2.7}$ $m^{-2}\ s^{-1}\ sr^{-1}\ GeV^{-1}$

From Swordy (2001).

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.be

Space environment hazards - Microsoft Internet Explorer

Space Environment Hazards

Space hazard	Spacecraft charging		Single-event effects			Total radiation dose		Surface degradation		Plasma interference with communications	
Specific cause	Surface	Internal	Cosmic rays	Trapped radiation	Solar particle	Trapped radiation	Solar particle	Ion sputtering	O^+ erosion	Scintil-lation	Wave refraction
LEO <60°	Not applicable	Not applicable	Relevant	Important	Not applicable	Important	Relevant	Relevant	Important	Important	Important
LEO >60°	Relevant	Not applicable	Important	Important	Important	Important	Relevant	Relevant	Important	Important	Important
MEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GPS	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
GTO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GEO	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
HEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
Inter-planetary	Not applicable	Not applicable	Important	Not applicable	Important	Not applicable	Important	Relevant	Not applicable	Relevant	Relevant

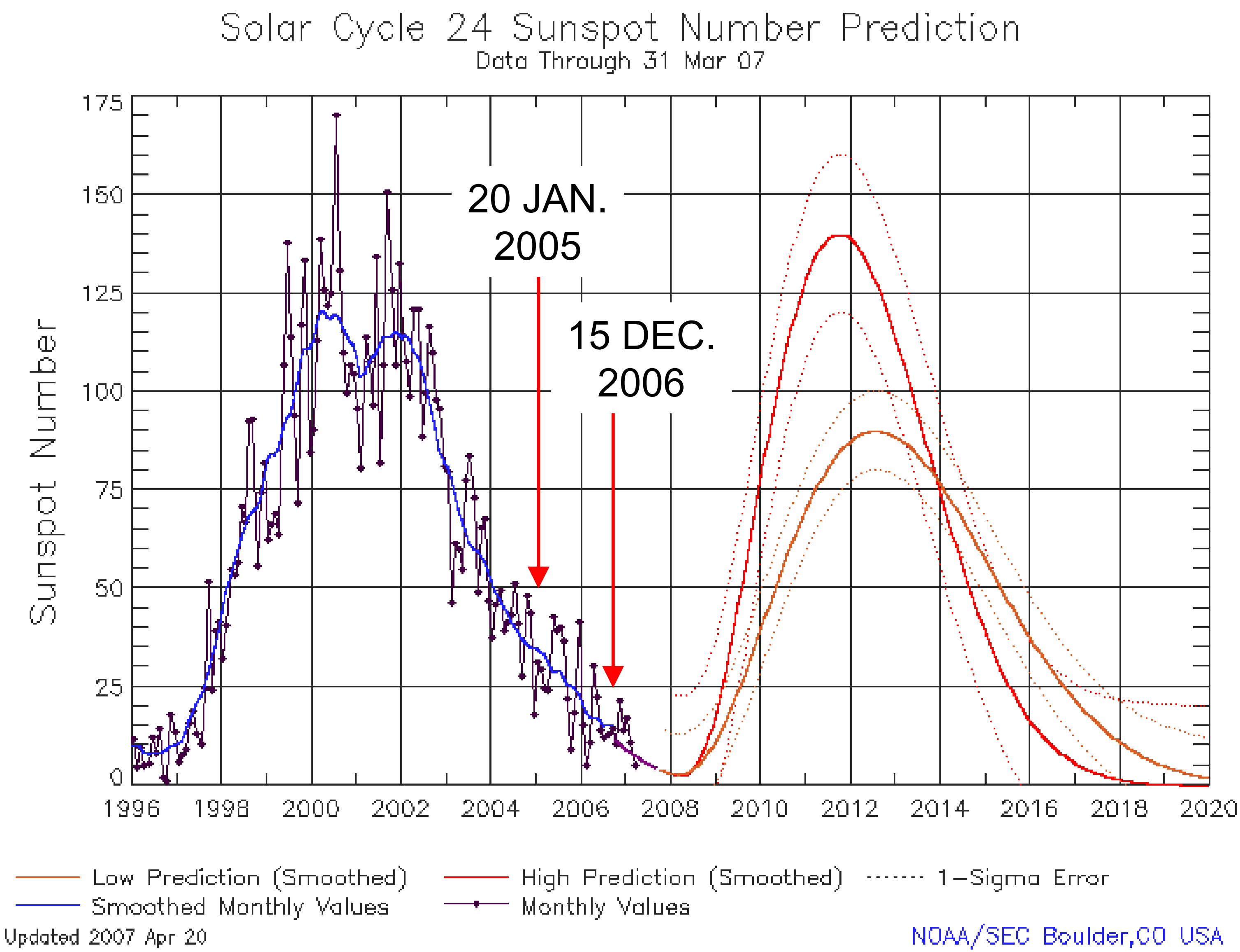
Important   Relevant   Not applicable

Space environment hazards for typical orbits. Key: LEO <60°—low Earth orbit, less than 60 degrees inclination; LEO >60°—low Earth orbit, more than 60 degrees inclination; MEO—medium Earth orbit; GPS—Global Positioning System satellite orbit; GTO—geosynchronous transfer orbit; GEO—geosynchronous orbit; HEO—highly elliptical orbit; O^+—atomic oxygen.

Courtesy of the Aerospace Corporation

Inter-planetary

2. SOLAR EXTREME EVENT EXAMPLES



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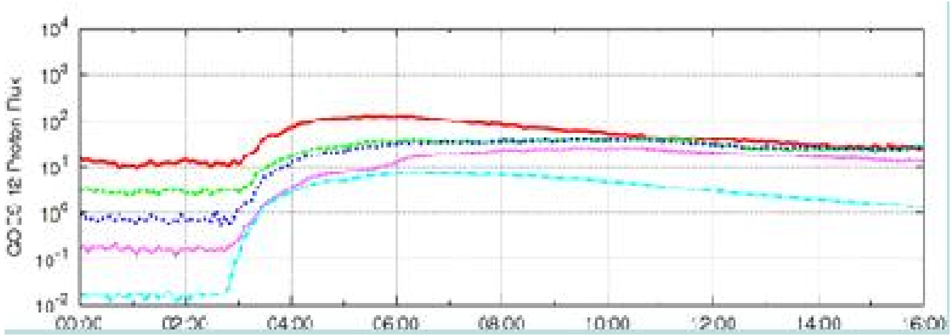
15 DECEMBER 2006 EVENT



National Weather Service
Space Environment Center

SPACE WEATHER ADVISORY BULLETIN #06- 5
2006 December 14 1704 UTC)

****** GEOMAGNETIC STORM IN PROGRESS ******

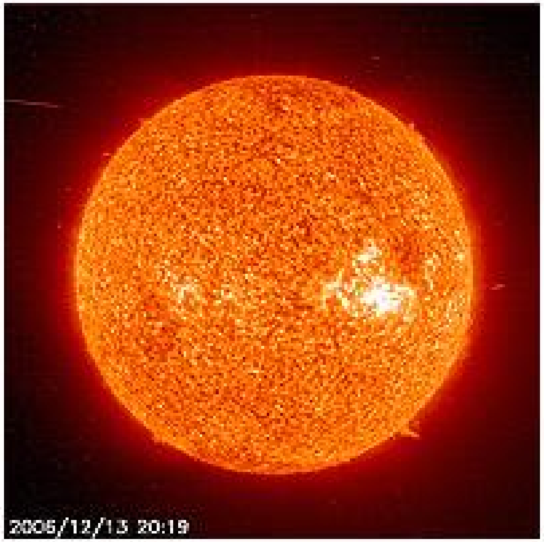
A geomagnetic storm began on December 14 at 1416 UTC (9:16 A.M. EST). A solar flare on 13 December at 0240 UTC (12 December, 9:40 P.M. EST) from NOAA Region 930 produced strong radio blackouts (R3) and an associated moderate (S2) solar radiation storm. A large Earth-directed coronal mass ejection was also observed with this event, producing today's geomagnetic storming. Strong to severe (G3 & G4) geomagnetic storming is expected to last through 15 December. Region 930 is a large sunspot group which is still rotating across the visible disk. Because of the current position of Region 930, additional activity has greater potential to quickly impact Earth.

Agencies impacted by space weather storms should continue to closely monitor space weather conditions during the next four days.

For current space weather conditions see: **Space Weather Now**, **Today's Space Weather** and **Space Weather Alerts**

European Space Agency

ESA mission controllers react to solar flare



SOHO image of storm on Sun, 13 December 2006

15 December 2006

An energetic storm on the Sun has forced ESA mission controllers to react to anomalies or take action to avoid damage to spacecraft. Several missions, including Integral, Cluster and Envisat, felt the storm's effects, highlighting the need for ESA's ongoing development of space weather forecasting tools.

The joint ESA/NASA spacecraft SOHO (Solar & Heliospheric Observatory) imaged a large solar flare on 13 December that led to an energetic solar radiation storm.

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Four-spacecraft Cluster II mission was one of the most affected

“We saw three anomalies on 13 December. Cluster 1 had a minor instrument anomaly, while Cluster 2 and 4 had on-board systems affected,” says Juergen Volpp, Spacecraft Operations Manager for Cluster at ESA’s Space Operations Centre (ESOC) in Germany. “The Attitude and Orbit Control unit on Cluster 2 lost power and autonomously switched over to its redundant unit, while the High-Power Amplifier on Cluster 4 switched itself off. This was a new occurrence which we hadn't seen before,” he said.

“When you have a burst, the flux of very fast charged particles increases dramatically. This can cause discharges in electronic components - the so-called ‘single-event upsets’ - on the spacecraft, as well as damage or loss of data in solid-state memories,” says Volpp.

Volpp says he can’t be certain that the increased energetic particle flux triggered the anomalies, but their occurrence is strongly correlated with the timing of the peak burst on 13 December. He expects the mission to be operating normally again in a few days.

Envisat & Integral affected

Envisat also experienced an unexpected anomaly correlated with the particle flux's arrival at Earth.

"Operation of the Envisat Payload Module Computer was autonomously suspended, causing all payload instruments to be switched off. It happened around 19:00 CET, just before the particle peak on the 13th," said Frank Diekmann, Spacecraft Operations Manager for Envisat. "We are still in a period of very high solar activity," he added.

Controllers working on Integral had perhaps the best sense of the recent solar activity - two of the mission's four instruments include the JEM-X and IBIS experiments, sensitive to X-rays and charged particles, respectively. However, they also had to take the most proactive action to avoid damage to the spacecraft's sensitive sensors.

"JEM-X automatically switched itself into safe mode twice, and we manually switched IRIS off to avoid over-exposure," says Michael Schmidt, Spacecraft Operations Manager for Integral.

Artist's view of Integral

ESA deep space missions avoid harm

The flurry of activity for controllers working on ESA missions orbiting in the region of the Earth was a direct result of Thursday's coronal mass ejection heading more or less directly towards our planet.

"The mass ejection headed from the Sun to Earth and our planetary missions, on the other hand, weren't affected," explains Paolo Ferri, Head of the Solar and Planetary Missions Division at ESOC.

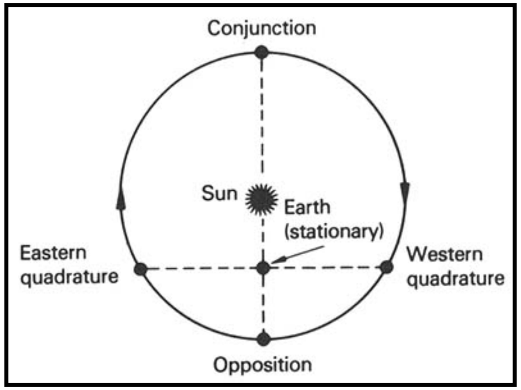
Ferri says that CME events are highly directional, and that by chance all three of ESA's deep space missions, Mars Express, Venus Express and Rosetta, happen to be oriented on the side of the Sun opposite to the Earth right now. "Our interplanetary spacecraft didn't see anything," he adds.

However, radio signals transmitted from the three deep space missions must pass by the Sun to reach Earth, and so flight control teams could in fact notice the increased solar activity as higher-than-normal interference in the signals received on the ground.

Interplanetary Space Weather Forecasting
« warning guidance »

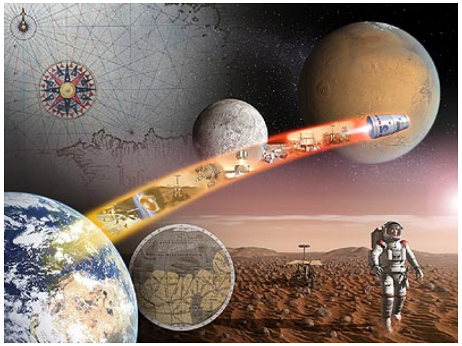
MARS SCENARIO

- telecommunications (signal travel time, 3.1 up to 22.2 min.)
- location of Earth and Mars in relation to forecasting
- radial extrapolations of SPEs (~ $r^{-3} \leq 1$ AU)
- Mars-Earth phasing (56 – 400 million km).



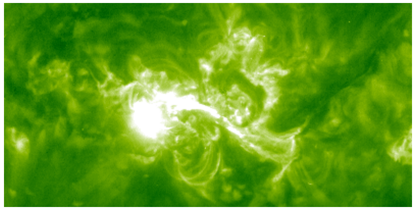
(Glasstone, 1968)

Mars Scenario
3 YEAR MISSION



AURORA Programme.
Courtesy of ESA.

Like on Earth, enhanced ionization due to solar radiation (UV and X-ray) in a target's atmosphere may cause communications problems.



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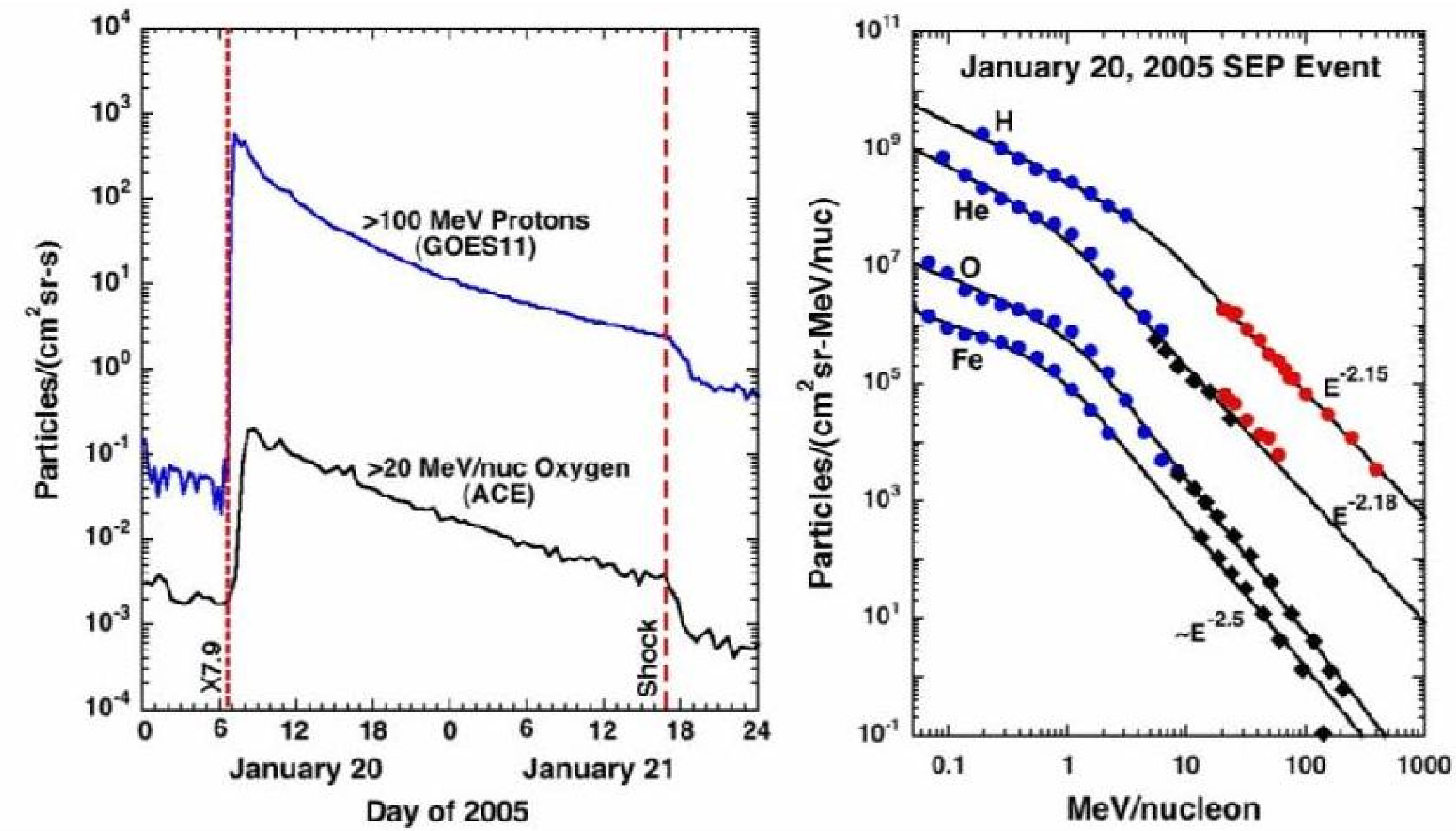
20 JANUARY 2005 EVENT

ACE News #87 - Feb 23, 2005

Space Weather Aspects of the January 20, 2005 Solar Energetic Particle Event



National Geophysical Data Center (NGDC)
NOAA Satellite and Information Service

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News of the Month Archive

2007 2006 **2005** 2004 2003

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

Recent Solar Activity Affects Satellites [*January 2005*]

NGDC's role as the archive of solar data for the NOAA Space Weather Program allows the data center to keeps close tabs on the sun as we move into a quieter period of solar activity. In an unusual event, an unassuming small sunspot group rotated onto the solar disk on 10 January 2005, and then suddenly started growing to a size wider than the planet Jupiter. Large solar flares and coronal mass ejections erupted from this amazing solar active region over the following week, culminating in an X7 level X-ray flare on 20 January, just before the region rotated off the West limb of the Sun.

Several satellite anomalies were reported, including "snow" on the coronal images of the SOHO satellite due to high energy solar protons hitting the lens.

The JCSAT-1B communications satellite experienced an anomaly on 17 January 2005 at 1226 UTC, leading to difficulties with services provided by the satellite.

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Recent Solar Activity Affects Satellites [*January 2005*] cont.

Another possible space weather effect was the loss of Intelsat's IS-804 which left 10 South Pacific nations without telephone contact with the outside world. Intelsat said it expects to record a non-cash impairment charge of approximately $73 million to write off the value of IS- 804. The satellite was not insured because Intelsat insures only those satellites with a net book value greater than $150 million.

Intelsat Reports Loss of IS-804 Satellite

PRESS RELEASE
Date Released: Monday, January 17, 2005
Source: Intelsat

Many customers already restored to normal operations

Pembroke, Bermuda, 16 January 2005

Intelsat, Ltd. announced today that its IS-804 satellite experienced a sudden and unexpected electrical power system anomaly on January 14, 2005, at approximately 5:32 p.m. EST that caused the total loss of the spacecraft. In accordance with existing satellite anomaly contingency plans, Intelsat is in the process of making alternative capacity available to its IS-804 customers. The satellite, launched in 1997, furnished telecommunications and media delivery services to customers in the South Pacific. Intelsat and Lockheed Martin Corporation, the manufacturer of the satellite, are working together to identify the cause of the problem. Intelsat currently believes that there is no connection between this event and the recent IA-7 satellite anomaly as the two satellites were manufactured by two different companies and their designs are different.

aeronomie.be

Space Weather Aspects of the January 20, 2005 Solar Energetic Particle Event

The very energetic particles in this event are difficult to shield against, and Frank Cucinotta of Johnson Space Flight Center estimates that an astronaut on the Moon, protected by only his spacesuit, would have received a radiation dose of ~300 rem, sufficient to cause radiation sickness.

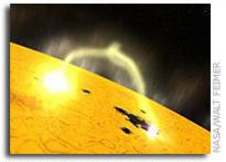
SpaceRef.com

Home | More News - Upcoming Events - Space Station - Get our Dai

Buy a - SpaceRef Mug - Arthur Clarke Mars Greenhouse

Solar Fireworks Signal New Space Weather Mystery

PRESS RELEASE
Date Released: Tuesday, May 24, 2005
Source: Goddard Space Flight Center



The most intense burst of solar radiation in five decades accompanied a large solar flare on January 20. It shook space weather theory and highlighted the need for new forecasting techniques, according to several presentations at the American Geophysical Union (AGU) meeting this week in New Orleans.

“This flare produced the largest solar radiation signal on the ground in nearly 50 years," said Dr. Richard Mewaldt of the California Institute of Technology, Pasadena, Calif. He is a co-investigator on NASA's Advanced Composition Explorer (ACE) spacecraft. "But we were really surprised when we saw how fast the particles reached their peak intensity and arrived at Earth.”

Normally it takes two or more hours for a dangerous proton shower to reach maximum intensity at Earth after a solar flare. The particles from the January 20 flare peaked about 15 minutes after the first sign.

“That's important because it’s too fast to respond with much warning to astronauts or spacecraft that might be outside Earth’s protective magnetosphere,” Mewaldt said. “In addition to monitoring the sun, we need to develop the ability to predict flares in advance if we are going to send humans to explore our solar system.”

Mission limits, valid for older crew (male above 35 and female above 45 year old), are based on a 3% stochastic increase of cancer risk (NCRP, 2000). The risk can be accepted for human deep space operations given the other mission risks. The one hour and one minute limits are intended as a tool for the early detection of SEPs (Wilson et al. 1997).

Table I. Proposed dose equivalent limits for a mission to Mars

	1 minute	1 hour	1 day	1 month	1 year	mission
Warning	$3\ \mu Sv$	$0.8\ mSv$	$10\ mSv$	$0.20\ Sv$	$0.40\ Sv$	$0.80\ Sv$
Alarm	$3\ warnings$	$1.0\ mSv$	$12\ mSv$	$0.25\ Sv$	$0.50\ Sv$	$1.00\ Sv$

1 Sv is the same as 100 rem.

While envisioned manned modules for future space missions to Mars are generally equipped with shielded astronaut shelters, adequate warning is necessary for these to be useful.

SPE → GO TO SHELTER

Energetic particles present a hazard to astronauts on space missions. During space missions, astronauts performing extra-vehicular activity (EVA) activities are relatively unprotected.

SPE → HELP !

Mission to Mars.
Courtesy of NASA.

Onboard Forecasting Capabilities are Essential for interplanetary Missions !

L1 forecasting is not enough

3. How good are we in avoiding Interplanetary Hazards?

What causes the limitations for mitigation techniques?

Health risks for long duration interplanetary explorative missions and those encountered so far in manned space flight differ significantly in two major features:

1.) "emergency returns" are ruled out

2.) the loss of geomagnetic shielding available in low Earth orbit with an associated non-negligible risk for acute early radiation diseases.

Routine human missions to the Moon will doubtlessly be the predecessor for any further human interplanetary mission. Only several days away the Moon offers new opportunities for studying the space environment outside the terrestrial magnetosphere, as well as being a host for a first solar system "space colony".

For missions that leave Earth orbit, like the Apollo missions to the Moon, the ability to rapidly traverse the radiation belts and to predict the occurrence of SEP events is essential.

Mitigation « shielding »

(EXCESSIVE MASS, SIZE and COST)

- ❑ Spacecraft "age" through continual bombardment by GCRs, Trapped Radiation and SPEs. Spacecraft components are manufactured to withstand high total doses of radiation.
- ❑The key to radiation protection is the understanding of the space environment and its interaction with shielding.
- ❑ An important issue concerning shielding is the problem of secondary radiation in materials.
- ❑ Testing facilities, etc.

The ultimate goal is to minimize radiation together with all other health effects and technical hazards by optimizing orbit parameters and shielding.

Of course, the faster the trip the better, i.e. development of innovative transportation technologies and new propulsion systems as well as orbit optimization, are highly important if not the most important challenges.

New forms of shielding materials are imagined and more impetus should be placed on polymer research in regard to the development of resistant light atomic weight shielding.

4. SUMMARY : WORDS FOR THOUGHT

1. WHAT ARE « SOLAR EXTREME EVENTS » ?

Are they or are they not « outliers » ?

Are the physical processes governing the extreme events the same as those governing the average events?

2. HOW TO STUDY « SOLAR EXTREME EVENTS » ?

"case by case" or "applying statistics"

Does one approach teach us more than the other or do the approaches complement each other ?

Have we yet observed the largest SPE ?

SPE data used in empirical models originate only from the satellite era.

McCracken et al., (2001a and 2001b) analyzed a total of 125 large fluence SPEs identified from the nitrate deposition in ice core from Greenland for the period 1561-1950. The largest SPE in the nitrate record (associated with the Carrington white light flare event in 1859) had a >30 MeV proton fluence that was a factor **4-8 times** greater than the value for the August 1972 event, which frequently is regarded as the "worst case" SPE.

More recently, McCracken (2007) has shown that the > 4 GeV fluence of large SEP events was a factor of 10 greater and the frequency of occurrence a factor of 4 greater prior to 1958 than during the space era.

- Studying radioactive isotopes and nitrates preserved in polar ice deposits make it possible to extend the cosmic-ray record back hundreds of years.

- The possibility of a relatively-rapid return to higher cosmic-ray intensities represents a risk that should be considered in planning manned exploration of the Moon and Mars.

Empirical Solar Proton Models

Essentially, 4 solar proton event models are available to spacecraft engineers for predicting long-term solar proton fluences.

- King model (King, 1974)
- JPL model (Feynman, 1993)
- Emission of Solar Protons (ESP) total fluence and worst case event models (Xapsos et al., 2000)
- MSU fluence and peak flux model (Nymmik, 2004).

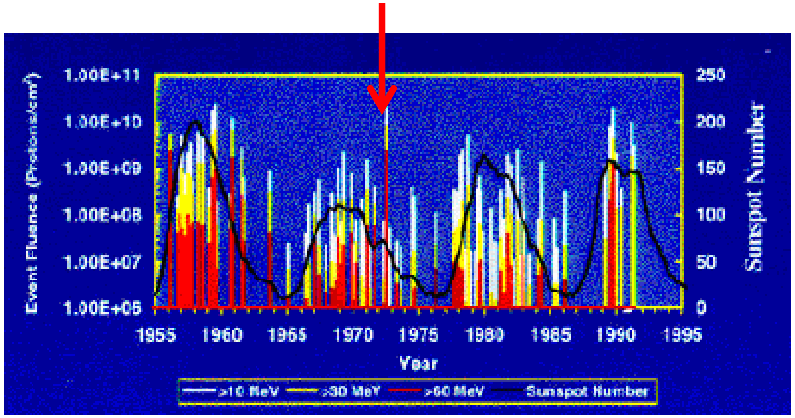
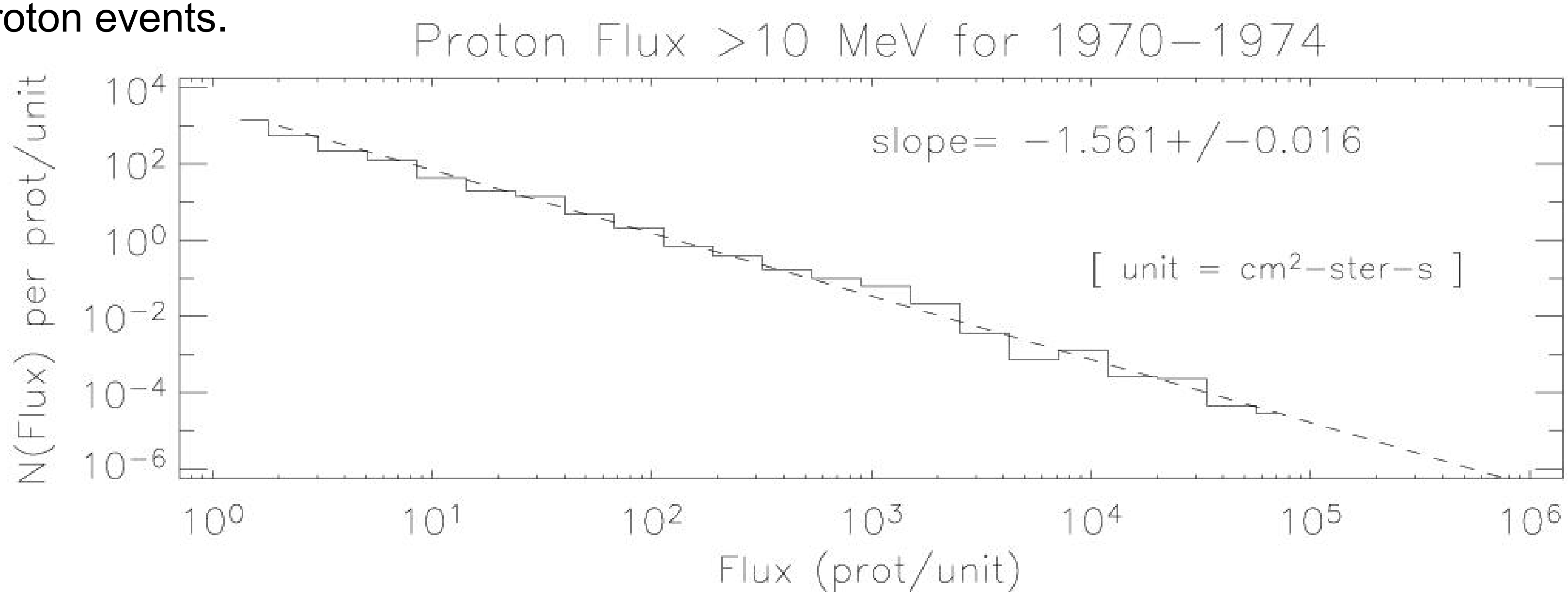


Image courtesy of Ron Turner of ANSER and Robert C. Reedy of Los Alamos National Lab.

Gabriel, S.B. and Feynman, J. (1995) Power-law distribution for solar energetic proton events.



WE NEED YOU !

Opportunities for tomorrow:

- ❑ Missions to other planets and moons
  [manned and robotic]
- ❑ Colonies on other planets (e.g. Mars)
- ❑ Mining on other planets, moons, asteroids
- ❑ Terra-forming
- ❑ Transportation technology
- ❑ Space tourism
- ❑ Space hotels.

= > Emergence of Space Entrepreneurs !

Space tourism 'a good thing'

POSTED: 1448 GMT (2248 HKT), April 6, 2007

American billionaire Charles Simonyi, left and cosmonauts Oleg Kotov, center and Fyodor Yurchikhin talk to reporters on Friday.

STORY HIGHLIGHTS

- American space tourist Charles Simonyi scheduled to fly into space Saturday
- Billionaire software designer paid $20 -$25 million for trip
- Longtime friend Martha Stewart came to Kazakhstan to see him off
- Stewart chose menu for crew's Cosmonaut Day meal

Adjust font size:

BAIKONUR, Kazakhstan (AP) -- Martha Stewart, the apostle of the cozy and the qu came Friday to the bleak space town of Baikonur to watch a billionaire friend blas for the international space station.

Stewart, who parlayed her vision of gracious living into a business empire, is a longtime friend of Charles Simonyi, a software engineer and developer of Micros

SPACE HOTEL 1
21-11-2136

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PARAMETER	DEFINITION
Dose Equivalent	The dose equivalent is the adsorbed dose multiplied by a biological effectiveness factor for the radiation to cause biological damage. Dose equivalents are typically expressed in rem (roentgen equivalent man). A dose of 100 rem to an adult normally produces some clinical signs of radiation sickness and requires hospitalisation. The international scientific community has adopted the use of a different term for rem called a Sievert (Sv). **One Sv is the same as 100 rem.**
Radiation Dose (or mrem)	The radiation dose is a generic term to describe the amount of radiation a person receives. Dose is measured in units of thousands of a roentgen equivalent man (rem) (called the millirem). The millirem is normally abbreviated as mrem. Dose is a general term used to assist in the management of individual exposure to radiation. The international scientific community has adopted the use of a different term for millirem called a milliSievert (mSv). **One mSv is the same as 100 mrem.**
Effective Dose Equivalent	The effective dose equivalent for the whole-body is the sum of dose-equivalents for various organs in the body weighted to account for different sensitivities of the organs to radiation. It includes the dose from radiation sources internal and/or external to the body. The effective dose equivalent is usually expressed in units of millirem (mrem).

http://eed.llnl.gov/mi/glossary.php

TECHNOLOGICAL EFFECTS

TABLE I

Various space weather phenomena occurring in the near-Earth space environment and the hazardous effects which they may have on different technical systems

Electromagnetic Radiation	← Energy increase				
Phenomena of Interest	Solar γ-rays Solar flare	Solar X-rays Solar flare	Solar UV Prominences	Solar Visible Solar flare	Solar Radio Solar flare
Consequences	SID	SID Heating, expansion of thermo-sphere, and satellite drag SWF	SID Heating of stratosphere and mesosphere		SWF

Energetic Charged Particles	← Energy increase		
Phenomena of Interest	Galactic Cosmic Rays (GeV)	Solar flare Proton events (MeV)	Trapped radiation (Van Allen belts) (10 MeV – 1 keV)
Consequences	SEE Contamination in data	SEE Contamination in data Radiation dose	SEE Radiation dose Increased charged particle fluxes Auroral oval expansion

Plasma	← Energy increase	
Phenomena of Interest	Energetic plasma (keV)	Low-energy plasma (eV)
Consequences	Internal (deep dielectric) charging	Surface charging

Neutrals	← Size increase		
Phenomena of Interest	Space debris and Meteoroids (Larger, > mm)	Space debris and Meteoroids (submm)	Dust (particulates)
Consequences	Pitting, cratering or puncturing of outer surfaces Damage to structure or equipment by penetration and spallation	Pitting, cratering of outer surfaces Degradation of optical, electrical, thermal, sealing or other properties	Lunar dust can contaminate surfaces Martian dust storms

SID: sudden ionospheric disturbance – large increase of ionization on the sunward facing side of the Earth.
SWF: short-wave fadeout.
SEE: single event effect – disturbance to electronic equipment onboard a spacecraft or aircraft.
Tracking: Objects larger then 10 cm in LEO and larger than about 1 m in GEO are regularly tracked by radar: Space debris is man-made and meteoroids are natural.

Crosby N., Rycroft M., and Tulunay Y., *Surveys in Geophysics*, Vol. 27, 3, 319-364, 2006.