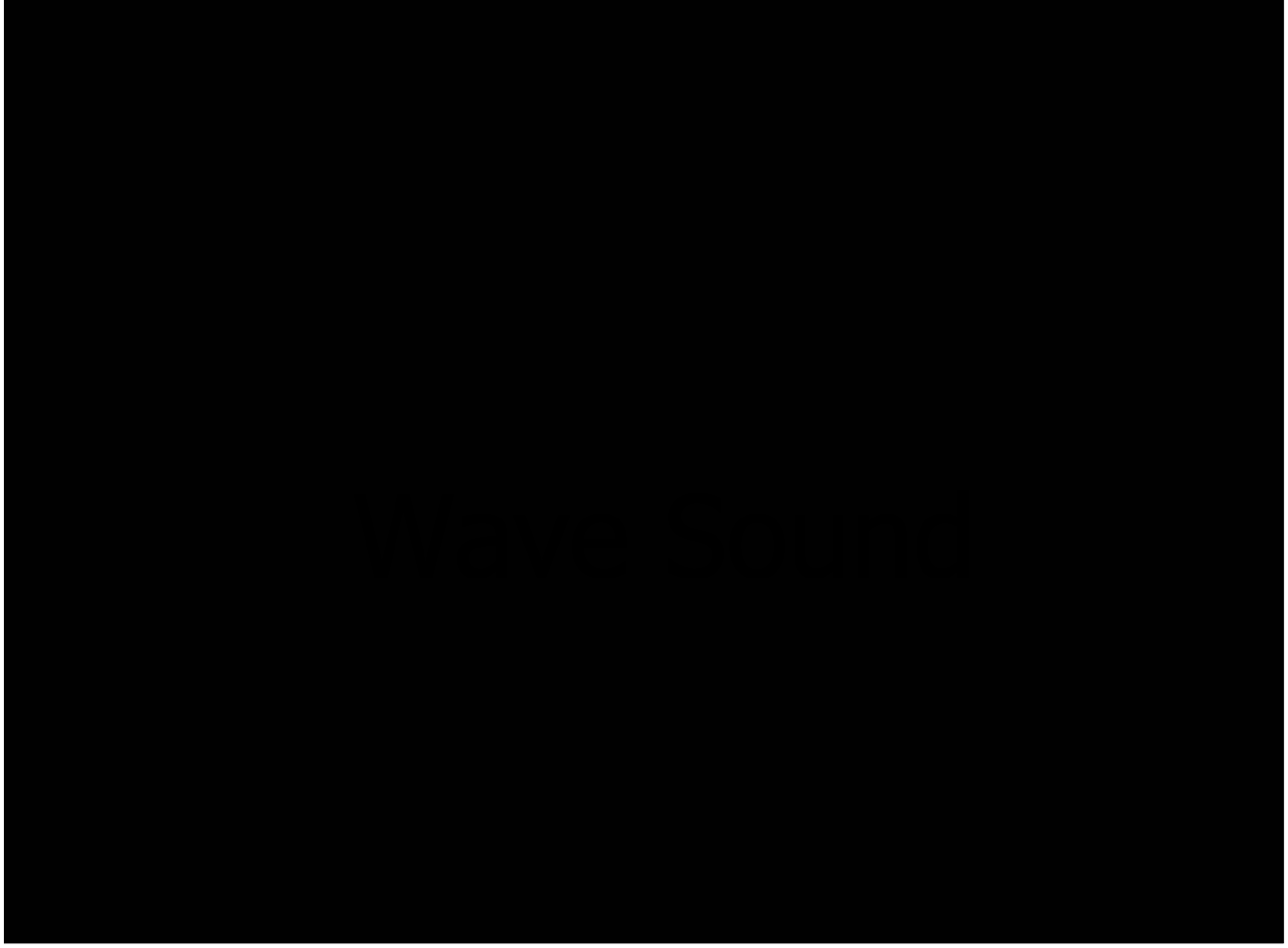



Space
Tourist
On-board
Protection

Space Tourist On-board Protection

Summer School on Space Weather: Physics, Impacts and Predictions,
Alpbach/Austria, 1st August 2002, Team 2

Summer school Alpbach 1st August 2002 - Space Weather : Physics, Impacts and Predictions
Team 2 Workshop

Outline

- Motivation
- STOP Prediction Centre
- STOP Space Segment
- STOP Data Centre
- Cost Analyses
- Conclusions

Why Space Tourism?

- The first step toward mankind habitats out in space
- A new driver for future resource investment in space science
- Inspiring and educating students
- Popularising space science

Why Space Weather Service For Space Tourism?

- Providing tailor-made service for a new sector of clients
- Lack of awareness of the Space Weather hazard
- Insuring the long term safety for Space Tourists guarantees the longitivity of the business
- Drawing the public attention to the hazard of SW
- A new fund source for Space Weather Missions

People Interests

- 34% of 1500 families said that they are ready to take a Space Vacation and pay in average **$ 10,800** for it
- Already 200 person paid $ 100,000 each to go into sub-orbital flights

Market Forecasting

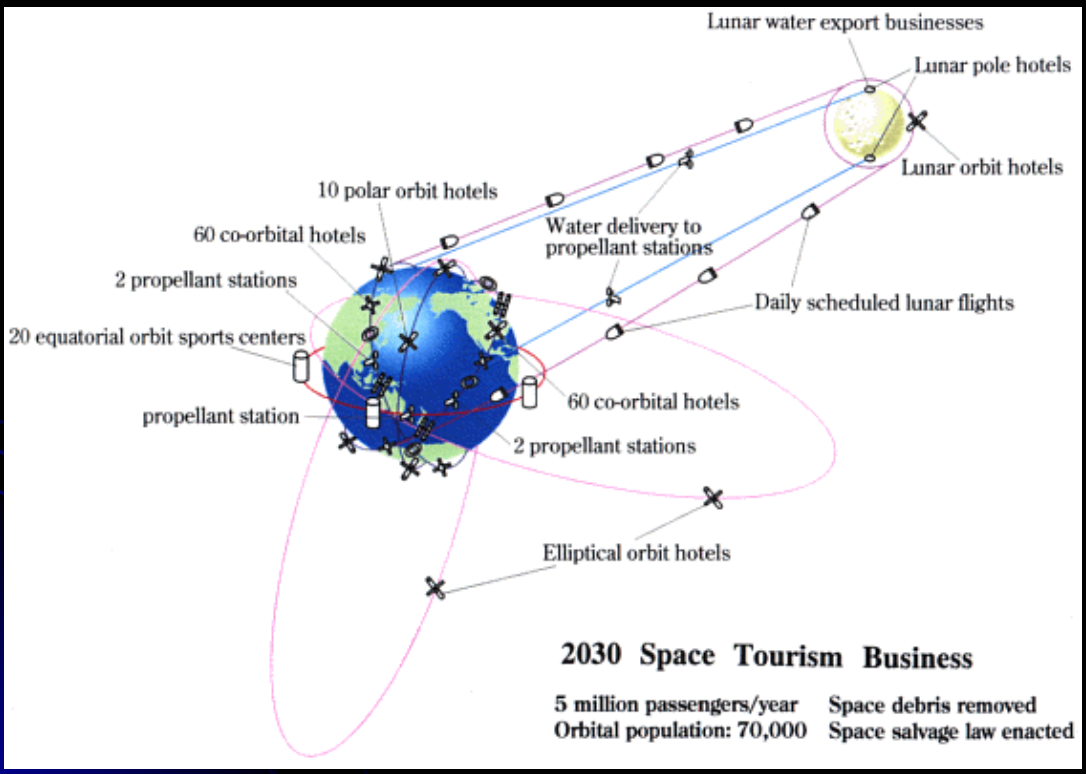
- JSR study (1993)
  - [illegible]ar in Japan
  - [illegible] of **$ 14 billion** for ticket under $ 14,000
- DASA study
  - **450,000** [illegible]rope
  - Annual turnover [illegible]n for ticket under $ 50,000
- NASA study (1997)
  - $ 10-20 billion per year
- TU Berlin study (97/98/2002)
  - **100,000 ST/year** globally
  - Annual turnover of **$ 9 billion** for ticket [illegible]er $ 100,000

No study counted for the hazard of Space Weather and its costs

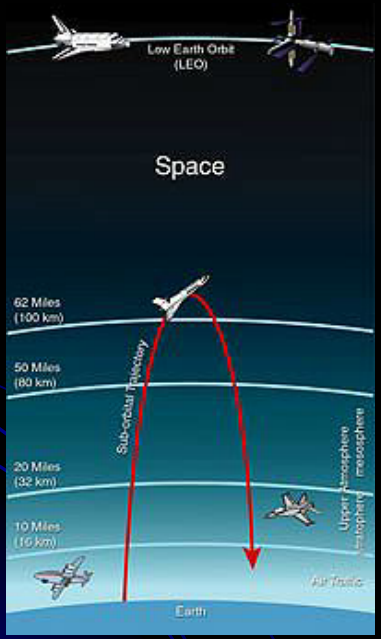
Reactions From The Market

- „We know little or nothing about the subject of „Space Weather", but it is encouraging to know that there are people who have a vision for the future."
- „...Predictions ~ 24 hours into the future would be especially helpful..."
- „We may have an interest, please send us more information."

Space Tourism 2030



Motivation



- Space Hotels
- Orbital Flight
- Suborbital Flight

Motivation

- Starting business
- People interest
  - 800 people in 28 countries
  - Over 20 people have put in reservation
- Not only tourism → physics behind
- Creation of new generation of heroes
- Inspiring and educating students
- Focusing public attention and investment capital on this new business frontier

Motivation

Ranking List for people to fly into space

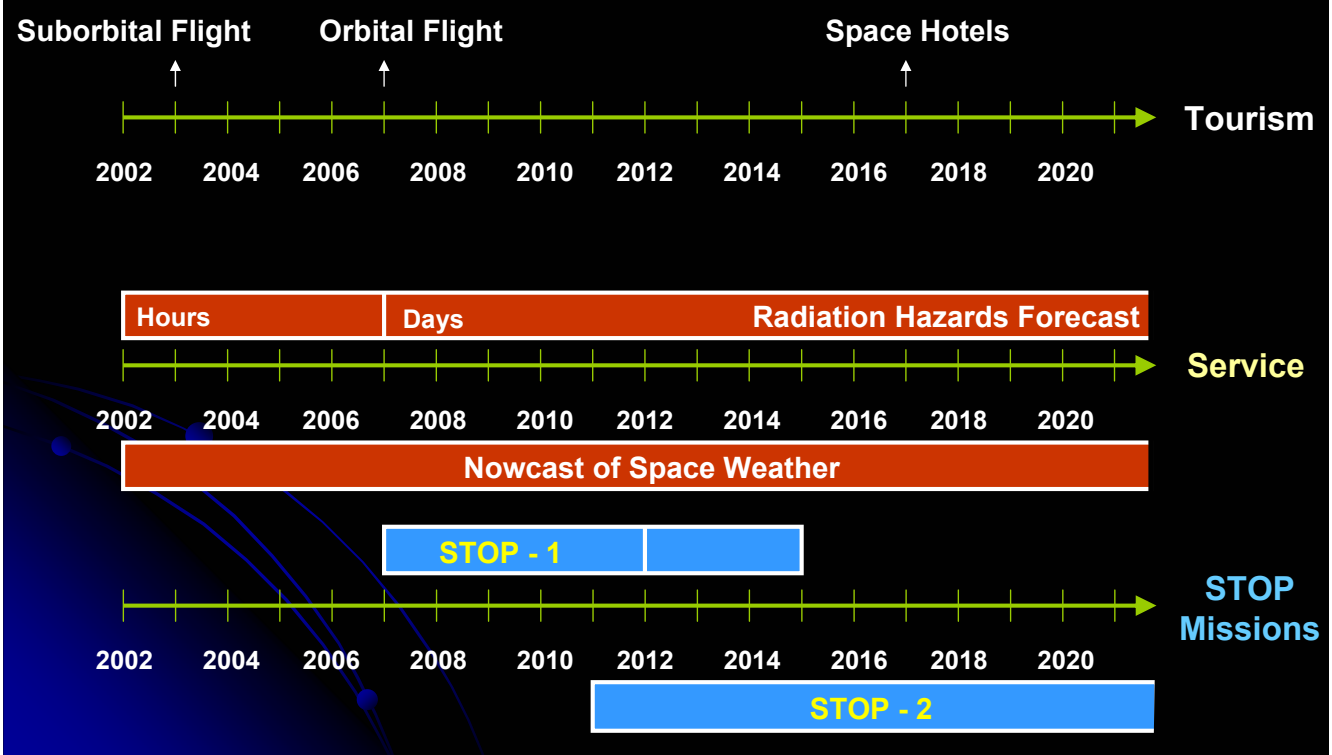
1. The desire to look at Earth from space
2. The desire to look at space from space
3. Actually being in space
4. Staying aboard a space station
5. Experiencing weightlessness

Motivation

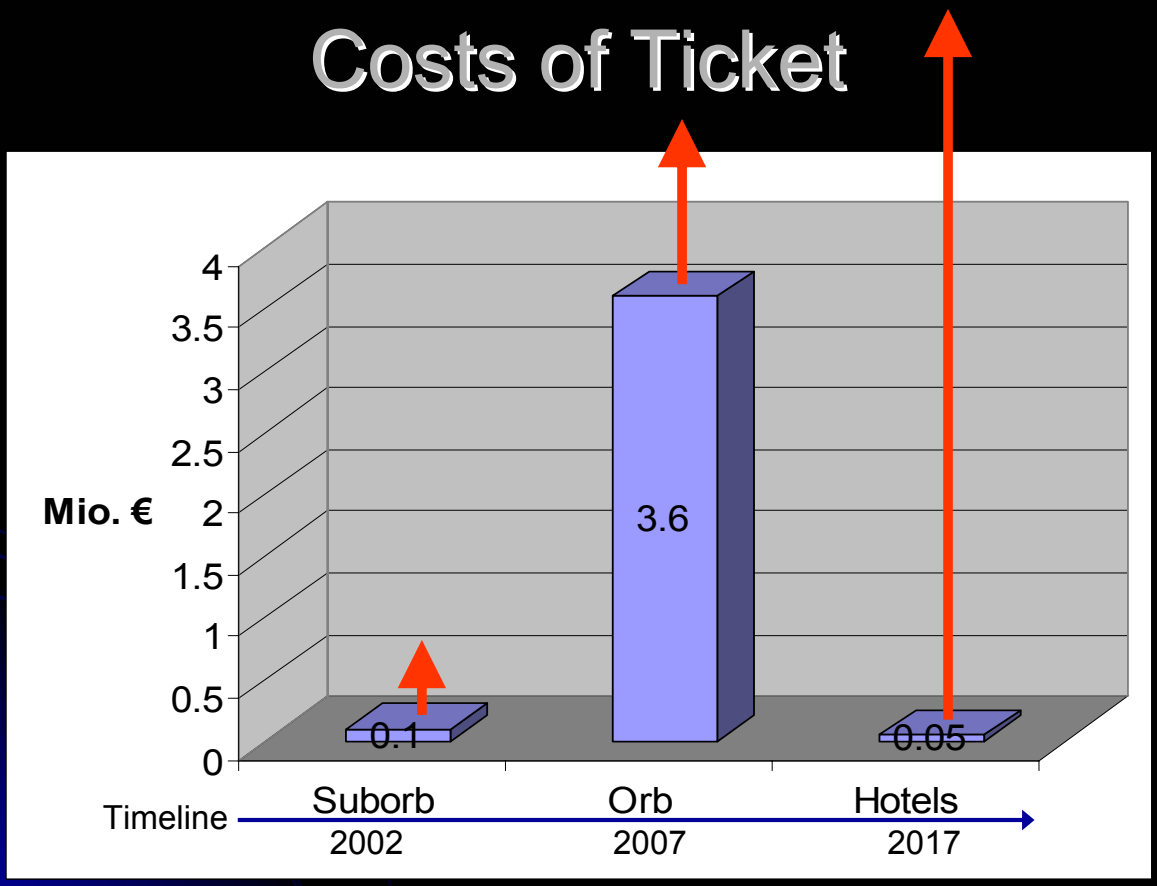
„The strong consenus view of the Workshop was that is a very real potential for a large profitable commercially-driven general public space travel and tourism business to begin to develop beginning a very few years from now."

NASA Workshop March 1998

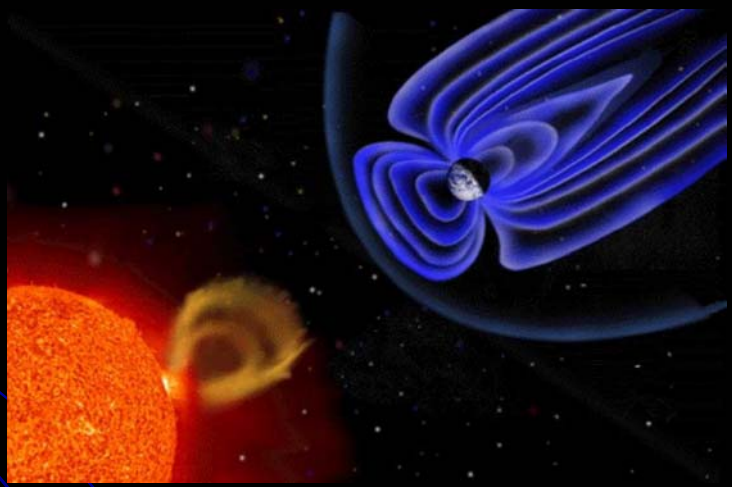
Timeline



Costs of Ticket



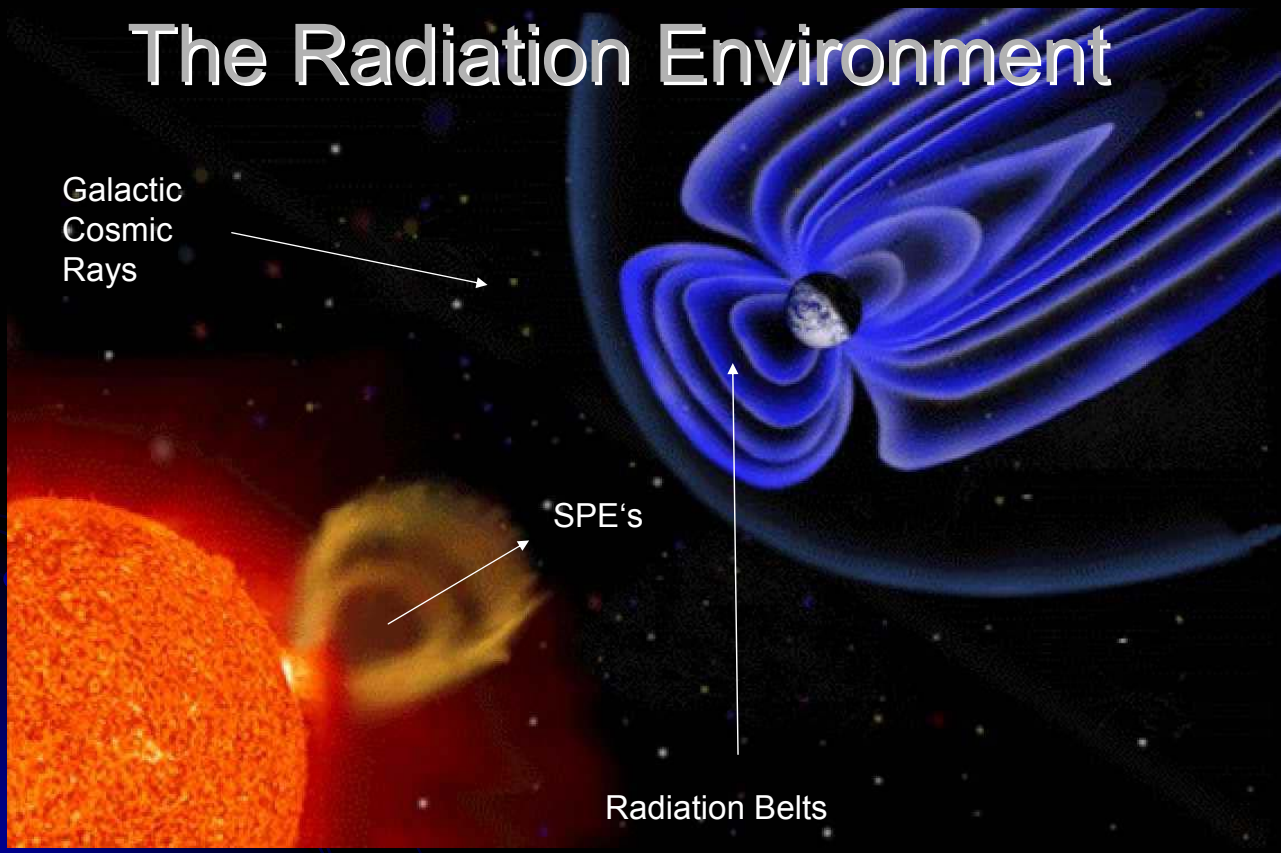
STOP Prediction Centre



Focus of STOP Services

- Radiation hazards
- Tissue damages

The Radiation Environment



The Radiation Environment

Three sources of radiation:

- Galactic Cosmic Rays
  - Has predictable 11-year cycle associated with solar activity
  - Effect greatest at Solar minimum
- Earth Radiation Belts
  - Also relativily predictable at low orbits
  - South Atlantic Anomaly (SAA) gives largest effect
- Solar Particle Events (SPE)
  - Rare and difficult to predict
  - Highly energetic particles from solar flares & CME´s

Radiation Hazards

	Galactic Cosmic Rays	Radiation Belt	SPE
Sub-orbital ~100km			
Orbital ~400km			
Lunar missions			

Risk Assessment

Flight Inclination		Dose at 2mm Al (REM) *e.g Space suit*	Dose at 10mm Al (REM) *e.g Space shuttle*
53 °	SPE	20	3.3
	No SPE	4.2	0.03

Compare:

- Public Radiation limit
  < 1 REM/year
- NASA Crew 30 day limit for blood forming organs
  = 25 REM

Solar Particle Events During Apollo Program

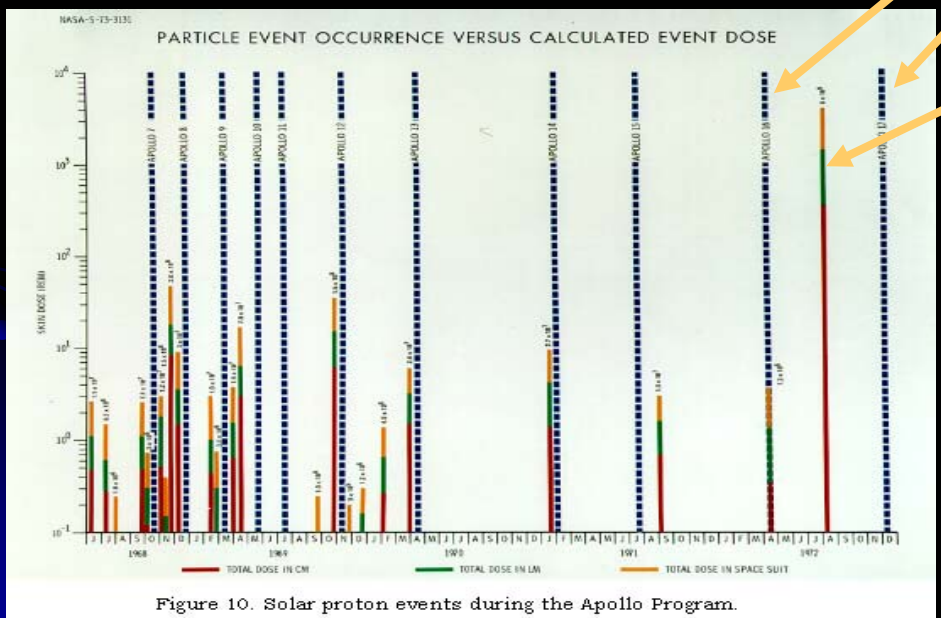


Figure 10. Solar proton events during the Apollo Program.

Apollo 16

Apollo 17

SPE of 7000 REM

User Requirements

- **Forecast**
- **Nowcast**
- **Post-event analysis**
- **Consultancy**

User Requirements

- **Forecast**
  - Fluences of protons and electrons at the spacecraft orbit that can penetrate the shielding
  - Warning about the possibly erupting regions at the surface of the Sun
  - Estimation for the reliability of forecasts

User Requirements

- **Nowcast**
  - Onset of magnetic storm or L1 event (e.g. prolonged southward IMF)
  - Alert of SEP event when observed
  - Fluences of SEP events at interplanetary medium (e.g. L1)
  - Fluences of protons and electrons at the spacecraft orbit
  - Fluences of Galactic Cosmic Rays at ground-based neutron monitor locations

User Requirements

- **Post-event analysis**
  - We provide the high energy particle (protons, electrons, neutrons) measurement devices, installed inside S/C and dosimeters worn by the crew

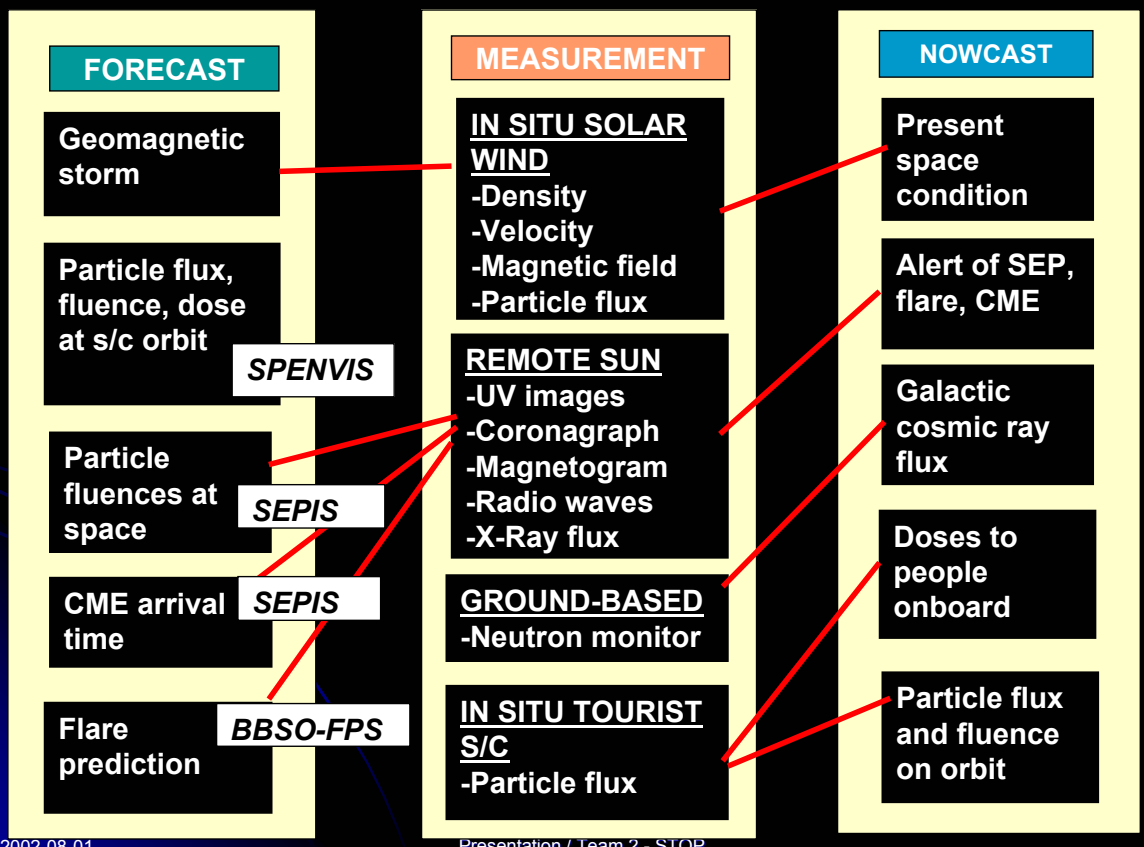
    Radiation history of flights (total fluence of each flight)

    Personal fluence history / log of each crew member
  - Continuous checking and improvement of prediction models and information provided to the client

User Requirements

- **Consultancy**
  - Information about prediction models used for forecasting
  - Information on health issues (e.g. the effect of certain amount of total equivalent doses)
  - Information about shielding needed for given radiation environment
  - General information about space weather

Prediction Centre Flowchart



Physical Parameters to be Measured (1)

MEASUREMENT	PURPOSE	LOCA-TION	TIME RESOLUTION
SW - IMF	Nowcast; Prediction Geomagnetic Storm	L1	≤ 15 min
SW - density and bulk velocity	Nowcast; Prediction Geomagnetic Storm	L1	≤ 1 hr
UV images	Localizing flares; Corona hole tracking	——	≤ 20 min
Coronograph	CME detection and propagation	——	≤ 20 min
Proton flux (50 keV – 200 MeV)	Nowcasting; Forecast evaluation	L1	~ minutes

Physical Parameters to be Measured (2)

MEASUREMENT	PURPOSE	LOCA-TION	TIME RESOLUTION
X-ray flux	Flare magnitude; SPE prediction	L1/GEO	1 min
Neutron monitor	Galactic cosmic ray flux	Ground	~ hrs
Magnetogram Sun surface	Flare prediction; Sunspot number	——	~ hrs
Radio flux	Estimating CME arrival time	L1	~ hrs
High energetic particles flux	Evaluate model performance; Nowcasting passengers radiation environment	At the tourists s/c	as good as possible
Dst, Kp indices	Nowcasting geomagnetic storms	Ground	10 min

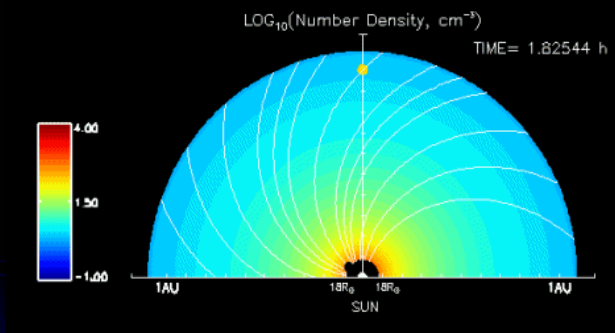
Prediction of Solar Flares

Method used: Big Bear Solar Observatory Flare Prediction System (BBSO-FPS)

- A statistical model which gives an estimate of a flaring probability for the following 24-hours
- Data needed: magnetograms
- Final products: the active regions on the Sun together with each regions probability for producing C-, M-, or X-class events

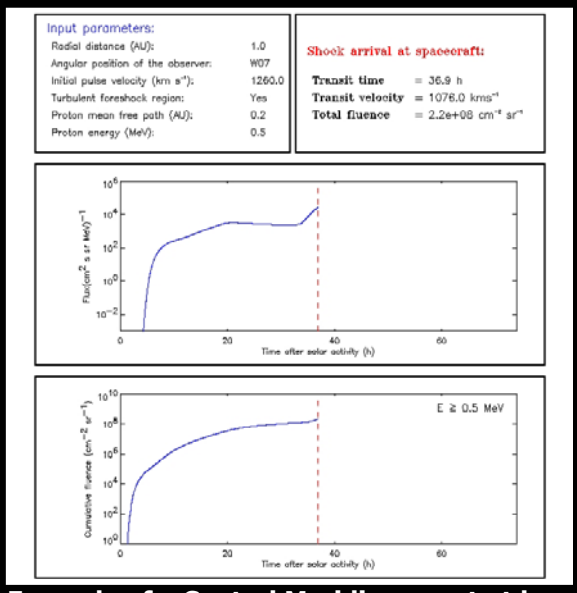
Forecast of Solar Energetic Particle (SEP) Events in the Interplanetary Space – SEPIS Model

SEPIS – Engineering Model for Solar Energetic Particles in Interplanetary Space [1]



MHD shock propagation simulation for a Central Meridian event

[1] A. Aran, B.Sanahuja, D. Lario, V. Domingo, proc. Space Weather Workshop: Looking towards an European Space Weather Programme, 16-19 Dec, 2001



Example of a Central Meridian event at low energy for a spacecraft located at 1 AU.

SPENVIS

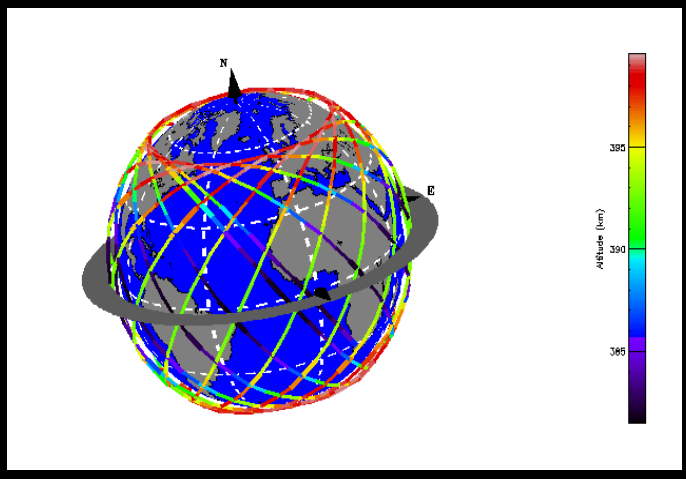
Tool kit for modeling radiation environment

- Calculates particle flux, fluence and dose at given s/c orbit
- Radiation belt electrons and protons: AE8 & AP8
- Solar particle events: statistical model (JPL)
- Galactic cosmic rays: sine wave approximation

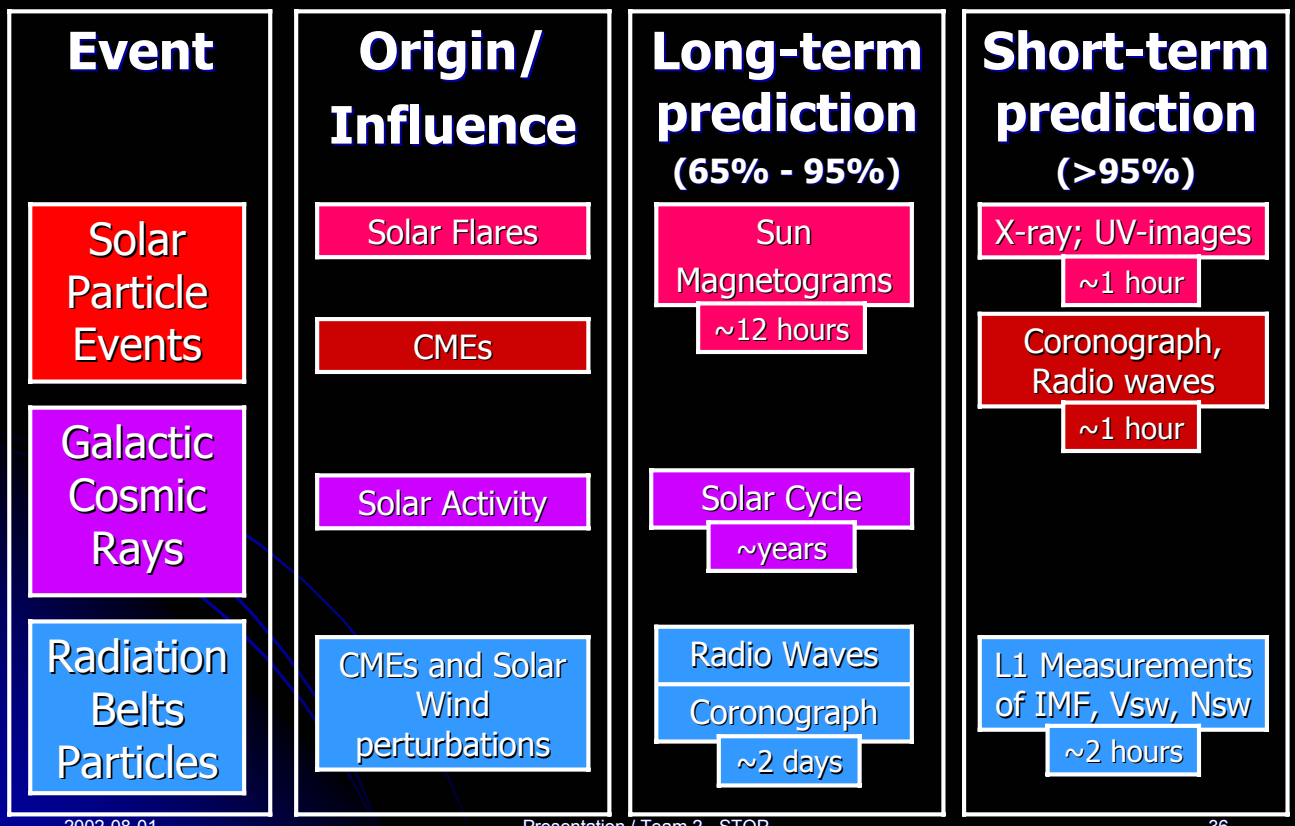
SPENVIS

Tool kit for modeling radiation environment

- Doses: Monte Carlo method
- Static model - no geomagnetic activity
- 95% reliable worst case scenario prediction



Forecast



Future Models

- Dynamical Radiation Belt models
- Improved CME propagation models (Density, Velocity, Magnetic Field?)
- Scientists needed to monitor, evaluate and implement new models

0101001011101 0100101
100101 10101010 1101 0
101 S 0100 10101101 01
01 0101001011 00001 0111
0101 0101 T 1001 010010
1010 01 010 1010 101010
01 0101010 11110 1010 1
010010 10 1001 O 101 01
1010 1001 01010 1010100
1010101 010001 01010 P
010 101 010101 010 10100
1000 0101 100101101 100
10010 010101 0101001111
01010101 1010100 110010
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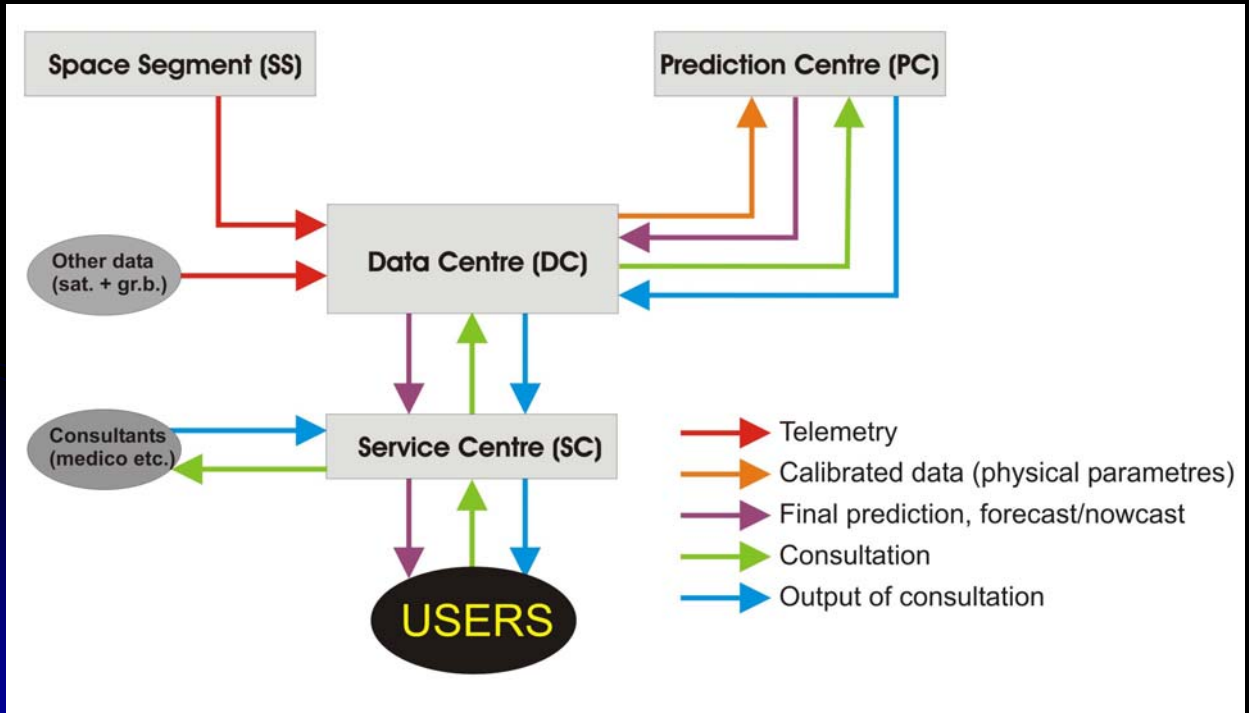
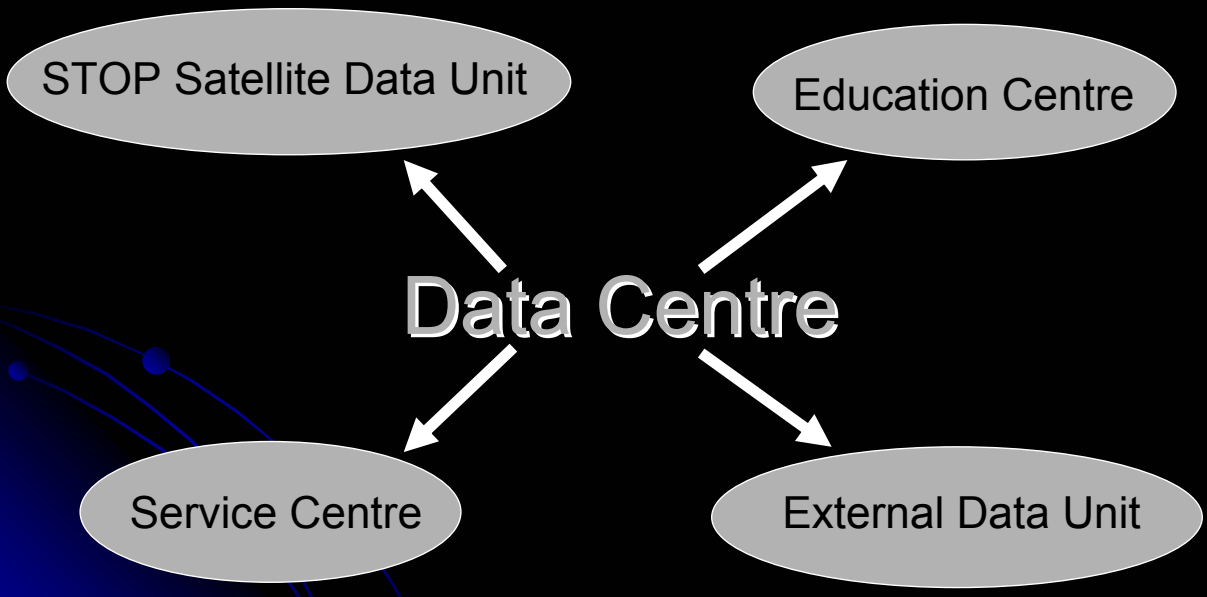
....

STOP Data Centre

General STOP Infrastructure



Units of STOP Data Centre



STOP External Data Unit

Data sources

- In the beginning:
  - Usage of allready existing data via scientific networks
  - Target: cooperation with institutions providing data
- In the future:
  - Continue cooperations with instiutions
  - Establish new cooperations i.e. with the LWS-project
  - Receive data from our own satellite

STOP External Data Unit

External data sources for the near future

Space crafts	Instruments	Parameter		Update time
ACE	MAG	Solar wind (L1)	B-field	1 min.
	SWEPAM		velocity	1 min.
			density	1 min.
	EPAM & SIS	Proton flux	65keV–100 MeV	5 min.
	EPAM	Electron flux	38–316 keV	5 min.
GOES	GOES 8 & GOES 10	X-ray flux	0,5 - 4,0 Å 1,0 – 8,0 Å	1 min.
SOHO	LASCO	Sun	Corona-graph	4 h
	EIT		UV-images	4 h
	MDI		Magneto-gram	4 h

STOP External Data Unit

External data sources for the near future

Ground based Instruments	Instruments	Parameter		Update time
WDC, Kyoto	----------	Geomag. storms	Dst, Kp index	1 h
BBSO	----------	Sun	Hα images	daily
CSO	Spectrograph	Shock wave	Radio flux	1 min.
Global Neutron Monitors	----------	Galactic cosmic ray flux	Neutron	1 h

High energetic particles flux at the tourist spacecraft for nowcasting will be measured with a instrument on the spacecraft.

Dynamic Data Access Strategy

- Monitor the External Data Sources (EDS)
  - Up-coming space programmes
- Continuous evaluation of EDS products
  - Reliability
  - The integration of EDS data to our internal data flow
  - Direct server-to-server distribution between co-operating organizations and STOP
  - Ranking of the EDS's data ⟶ back-up plans
- Case-by-case contracts with the co-operating organisations

Case-by-case contracts with the co-operating organisations

What can STOP offer ?

- Scientific data of STOP-1 (STOP-2, etc.)
- Hardware for the data distribution
- Funding for the maintenance done in/by the co-operating organisations

STOP will focus on the Space Weather services – fundamental research is NOT our main concern!

STOP Satellite Data Unit

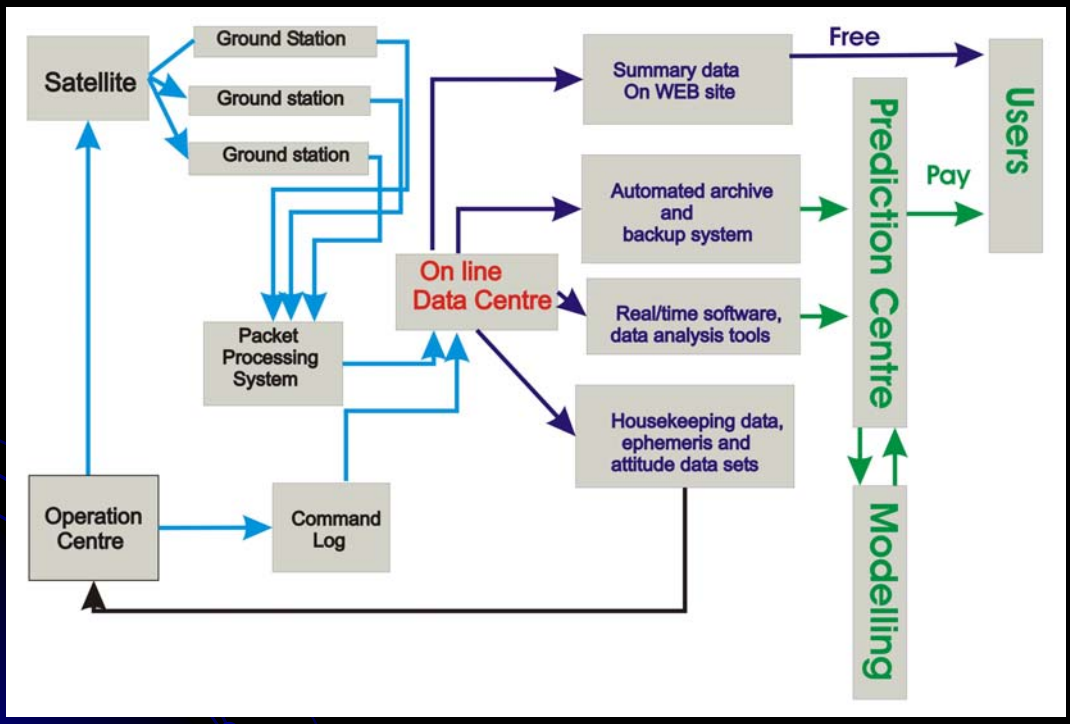


Diagram of the data flow

STOP Satellite Data Unit

- Ground Stations
- Packet Processing System (PPS)
- Operation Centre
- Online Data Centre

STOP Satellite Data Unit

- Ground Stations
  - 3 stations around the world, preferably near already existing station
  - Each station receive binary data from S/C 8 h per day (10 kbps)
  - Send data, rate buffered in real-time, over dedicated lines to the PPS
- Packet Processing System (PPS)
  - A semi-automated system
  - The PPS repacks and stores telemetry as it is received
  - Sorts and file data by type, time, instrument and housekeeping
  - Eliminates duplications and remove untrustworthy packets
  - Send scientific row data to the Online Data Centre

STOP Satellite Data Unit

- Operation Centre
  - Provides daily commands for S/C and instruments
- Online Data Centre
  - Data calibration and converting to physical values
  - Providing summary data for STOP web site
  - Automated archivation of data and system backup
  - Real-time software and data analysis tools
  - Storing housekeeping data
  - Production of ephemeris and attitude data sets
  - Storing command log

STOP Satellite Data Unit

Instrument	Measurements	Time resolution	Physical value
1.FGM (Magneto-meter)	Interplanetary magnetic field	1/16 seconds	Magnetic field vector: Bx, By, Bz
2. SWD (Solar Wind Detector)	Ions, with energy 5eV/Q – 32 keV/Q	12 seconds	3D Ions distribution: Velocity vector, Heat flux vector, Density, Pressure tensor
3. PT (Proton Telescope)	High energy protons, E=20-300 MeV/Q	12 seconds	Energy flux as a function of energy

Available data from STOP satellite

Service Centre

The Service Centre is the link between the STOP company and the users

Users:

- Paying (e.g. Space Tourist Companies)
- Non-paying (e.g. Public Users, Scientist)

Service Centre

- **Commercial Services**
  - Alerts
  - Warnings
  - Flight specific forecast for Space Tourist Companies
  - Nowcast
  - Hardware and post-event analysis
  - Consultancy

- **Procedure of Commercial Services**

  Client (flight specific information) →
  Service Centre → Prediction Centre (forecast) →
  Service Centre → Client

Service Centre

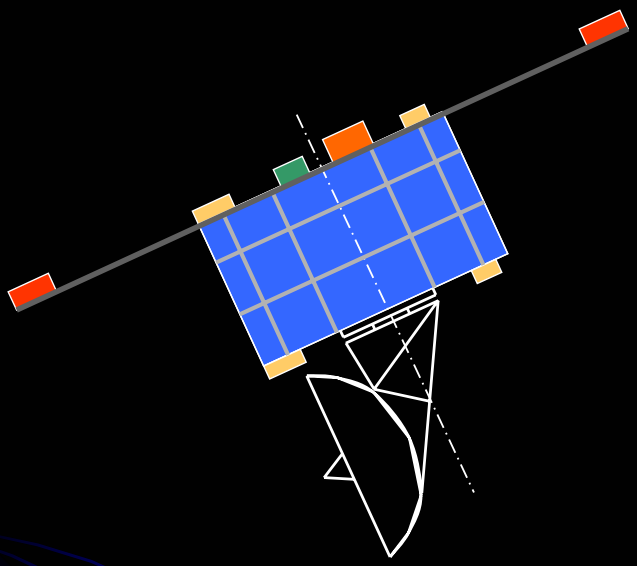
- **Free Services** (via web site)

  - **Public Users**:

    Selected data (non-real time)
    General information about Space Weather + links

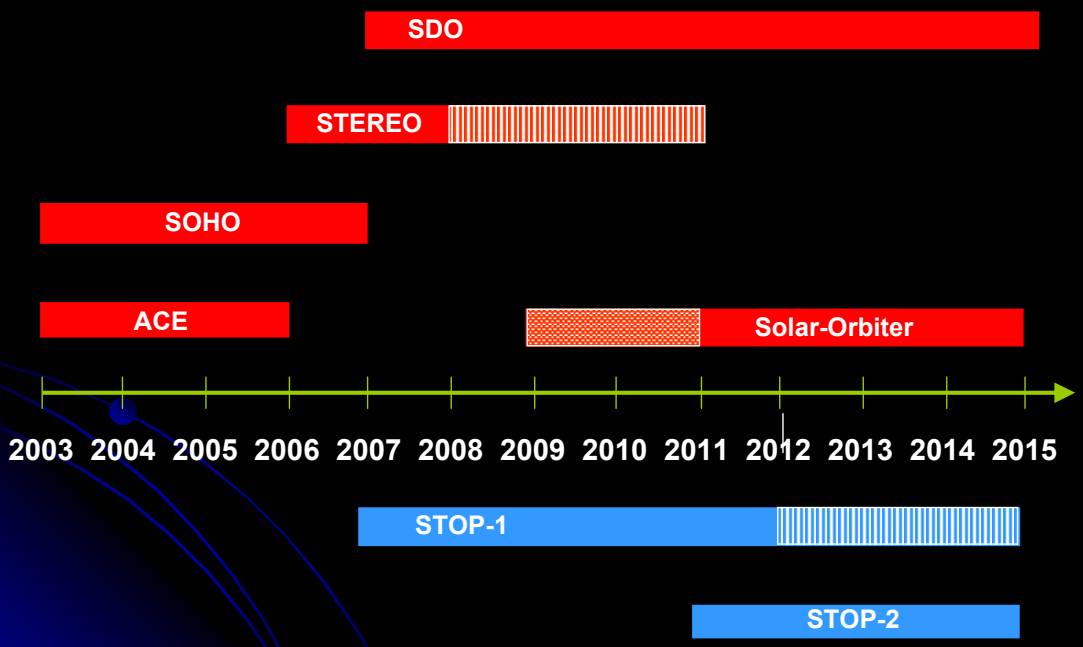
  - **Scientific Research (registration):**

    All data are free (non-real time)



STOP
Space Segment

Status



Measurements needed for Prediction

- Interplanetary magnetic field (IMF)
- Solar wind velocity and density
- High energy proton flux
- Coronagraph
- UV images

STOP-1 Mission

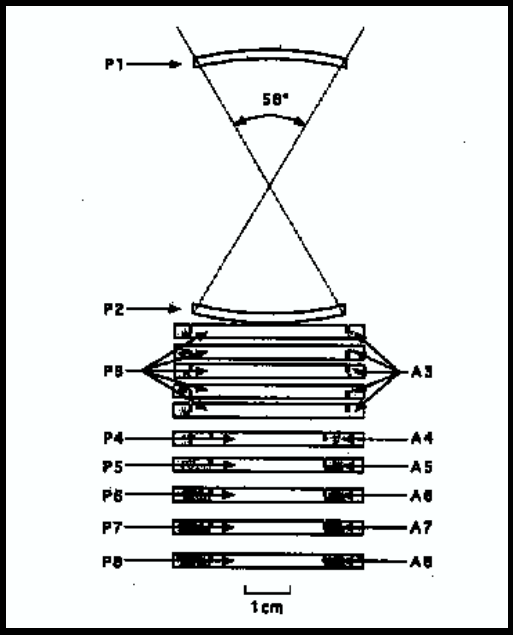
- Spinning spacecraft
- Reuse of existing instruments and subsystems
- STOP-1
  - Total mass: 350 kg (payload: 13,5 kg)
  - Size: cylinder of 0.8 m width x 1.3 m height
  - Orbit: around L1
  - Launcher: Soyouz

Flux-Gate-Magnetometer

- Design used from Cluster Mission
- Two Sensors mounted on booms
- Highly redundant Data Processing Unit

Proton-Telescope

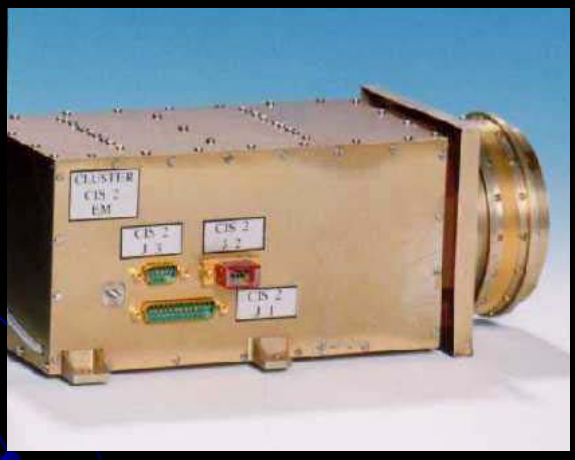
- Basic design from SAMPEX PET
- Simplified Solid State Detector (SSD) Array
- Energy range 20 Mev – 300 MeV



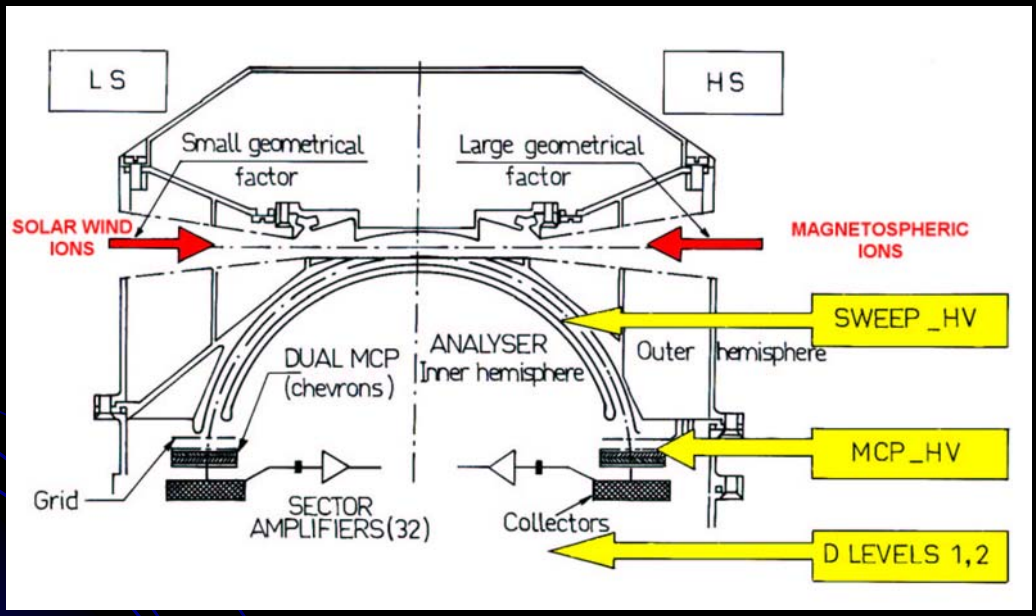
SAMPEX PET SSD ARRAY

Solar Wind Proton Detector (1)

- Design used from Cluster Ion Spectrometre Hot Ion Analyzer (HIA)
- Energy range ~ 5 eV – 32 keV

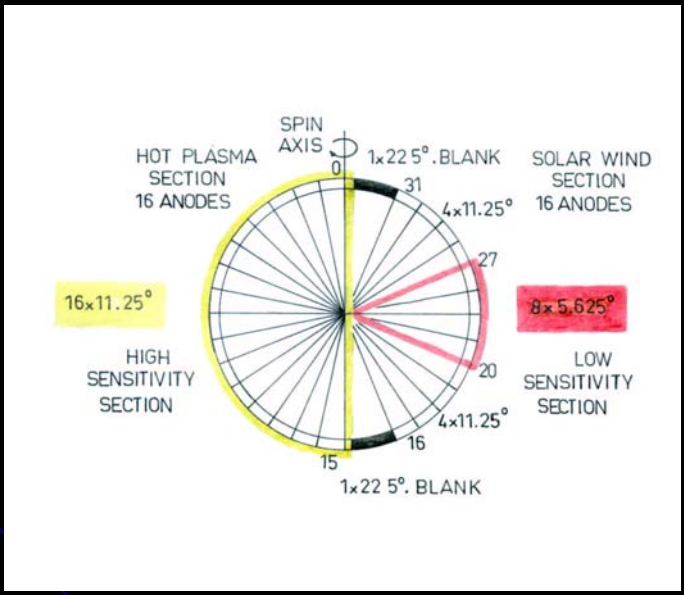


Solar Wind Proton Detector (2)



Cross-sectional view of the Cluster Hot Ion Analyzer

Solar Wind Proton Detector (3)



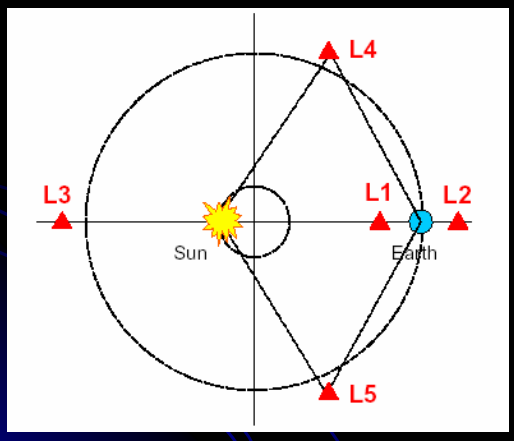
High and Low Sensitivity Anode Sections of the Hot Ion Analyzer

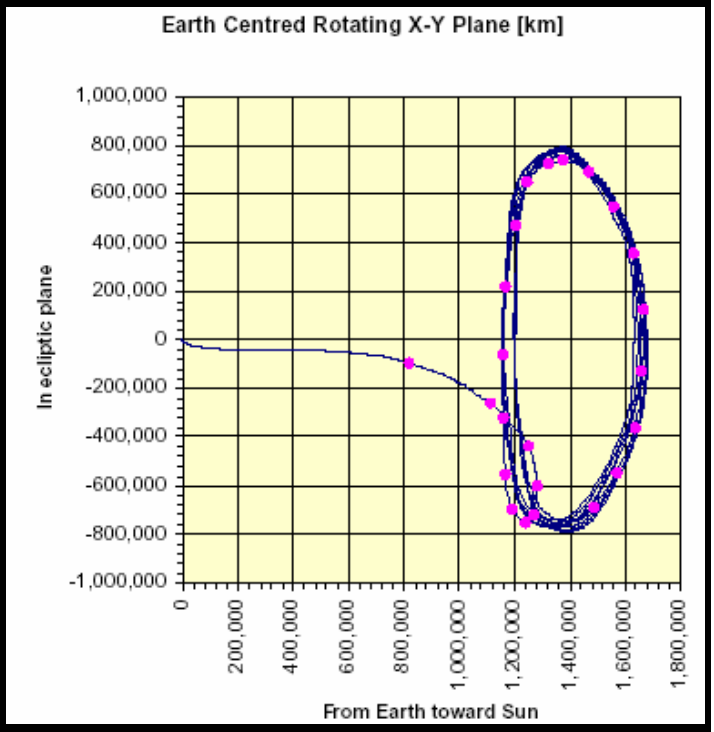
STOP-1 Mass Estimation

Element	Without margin [kg]	Margin [%]	Total [kg]	% of total
Structure	70	10	77	22,0
Thermal control	10	10	11	3,1
Mechanisms	15	10	16	4,7
Communications	20	5	21	6,0
AOCS	10	10	11	3,1
Propulsion	40	5	42	12,0
Propellant	100	0	100	28,6
Power	40	10	44	12,6
Harness	10	20	12	3,4
Payload alloc	13,5	10	15	4,3
Total			**350**	

STOP-1 Orbit

- Tranfser orbit to L1
- Final orbit in L1 halo

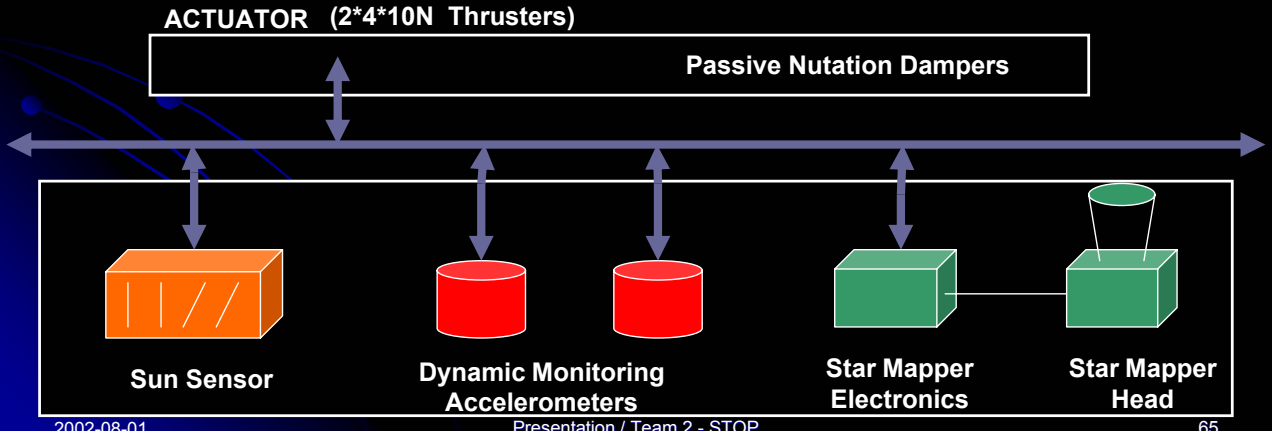




Attitude and Orbit Control (AOCS)

AOCS provides STOP-1 spacecraft with:

- the spacecraft attitude
- the spin rate
- performing orbit manoeuvres
- pointing and manoeuvring of spin axis
- controlling the spin rate
- dumping nutation motions

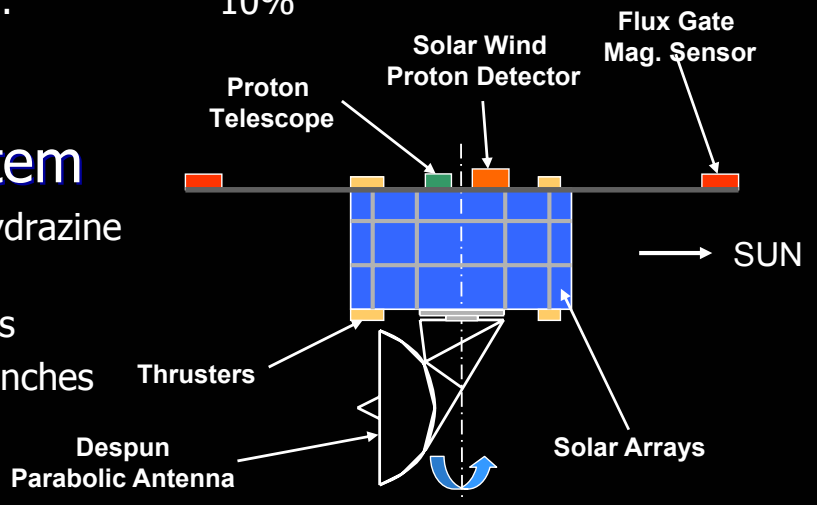


AOCS

- Pointing Requirements

Pointing Accuracy (APE):	0.5 deg.
Pointing Stability (RPE):	0.2 deg.
Pointing Knowledge (AMA):	0.25 deg.
Spin Rate Accuracy:	10%

- Propulsion System
  - Mono-propellant hydrazine system
  - Eight 10 N thrusters
  - Two redundant branches



Radiation Environment

- Cumulative solar proton dose defines the shielding
  - 4 mm aluminium equivalent for electronics
  - Expected dose in silicon components will be 5 kRads
- Impulsive events might penetrate the shielding
  - Radiation hardened components desired in critical systems
- Based on Feynman´s model (JPL-91)

Telecommunication

- 3 ground stations
  - for 24 h connection (crucial for real-time prediction)
- X-band (e.g. Transponder from STORMS)
  - 4 low gain antennas with spherical coverage
  - Additional high gain antenna
    (despun, pointing to earth, 35 dBi gain)
  - middle sized ground stations
    e.g. 15 m Kourou ground station
- Telecommunciation system fully redundant
- Data rates: uplink: 2 kbps, downlink: 10 kpbs

Further Subsystems

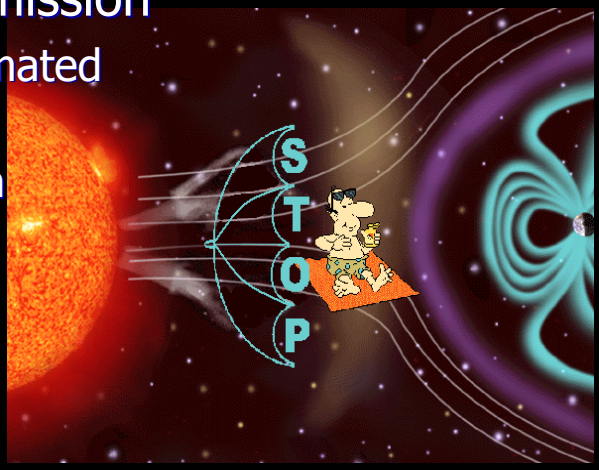
- Power budget

Instrument	Power [W]
Flux Gate Magnetometer	3,5
Solar Wind Proton Detector	5,3
Proton-Telescope	5,0
Total +10% margin	15

- Passive thermal control technique
- Data handling system (tbd)

STOP-1 Summary

- Required and independent data for our company
- Need of 3 ground stations
- Low cost, easy and fast mission
  - Cost 65M€ (including estimated launch cost of 15M€)
  - Reliable and simple design
  - Launch 2007



STOP-2 Mission

- 3-axis stabilized
- Additional imaging sensors
  - Plasma instruments
  - UV and EUV imagers
- Phase-A will start in 2004
- Launch approx. 2011

STOP
Cost Analysis

Cost Analyses

- Two phases:
  - Phase I, (2002-2007) working under an existing SW service, covering sub-orbital flights
  - Phase II, (2007-2015) independant space mission, staff and ground station

Phase I

Costs of:	**Consumption of Fixed Assets**	**Renting of Ground Station**	**Operating Staff**	**Overhead costs + Main-tenance**
Data Centre	250 M €	2000 M €	300 M €	100 M €
Prediction Centre	150 M €		400 M €	100 M €
Sum	400 M €		700 M €	200 M €
Total Sum: 3,300 M €				

Phase II

Space Mission	50
Launching	15
Ground Station	10
Sum	**75**

Costs of:	**Consumption of Fixed Assets** Including equipments and housing	**Renting of Ground Station**	**Maintenance**	**Salaries of operating staff**	**Overhead costs**	**Health consulting**
Data center	8.5	0.6	0.2	0.6	1.2	
Prediction center				0.9	1.8	
Sum				1.5	3	
Total Sum 13.9						

All numbers in M€

Income of STOP

Forecasting	14
Consultancy for companies	3
Consultancy for individuals	0.5
Total sum	17.5

- Annual turnover of the business in Japan, Europe and the USA will be **$ 43 Billion**
- If at least 0.5 of this goes to the costs of Space Weather Prediction Service that will leave **$ 215 M** for this new sector

Income of STOP

- Annual turnover of the business in Japan, Europe and the United States will be **$ 43 Billion**
- If we estimate that at least 0.5 of this goes to the costs of Space weather prediction service that will leave **$ 215 M** for this new sector

Conclusion

- Space Weather forecasting for space tourism is a required service to be provided to the emerging market to insure safety of tourists and longevity of the business
- Building an independant Space Weather service for space tourism is a feasible project
- Now is the right time to start ...

  STOP – Space Tourist On-board Protection

For Further Information...

www.STOP.org

Acknowledgement

Many thanks to everyone, who has been supporting us during these two weeks, especially: Hannu Koskinen and all the other Tutors, Organisation Committee and Martin for technical assistance

We are grateful to the space tourism companies for helping us to define the users´ needs.

Team 2