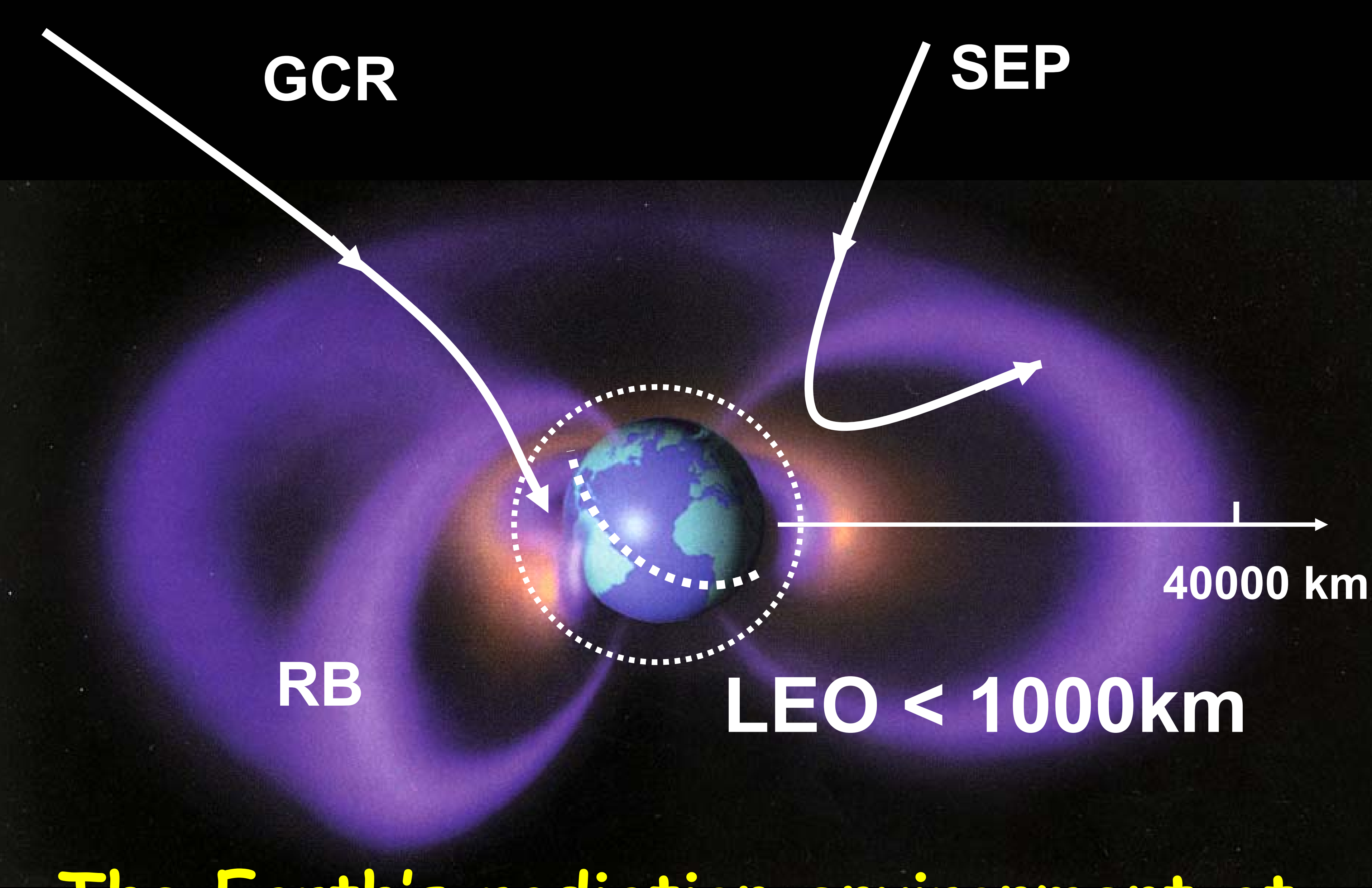
Radiation Environment of the Inner Magnetosphere: Ouiet and Storm Periods

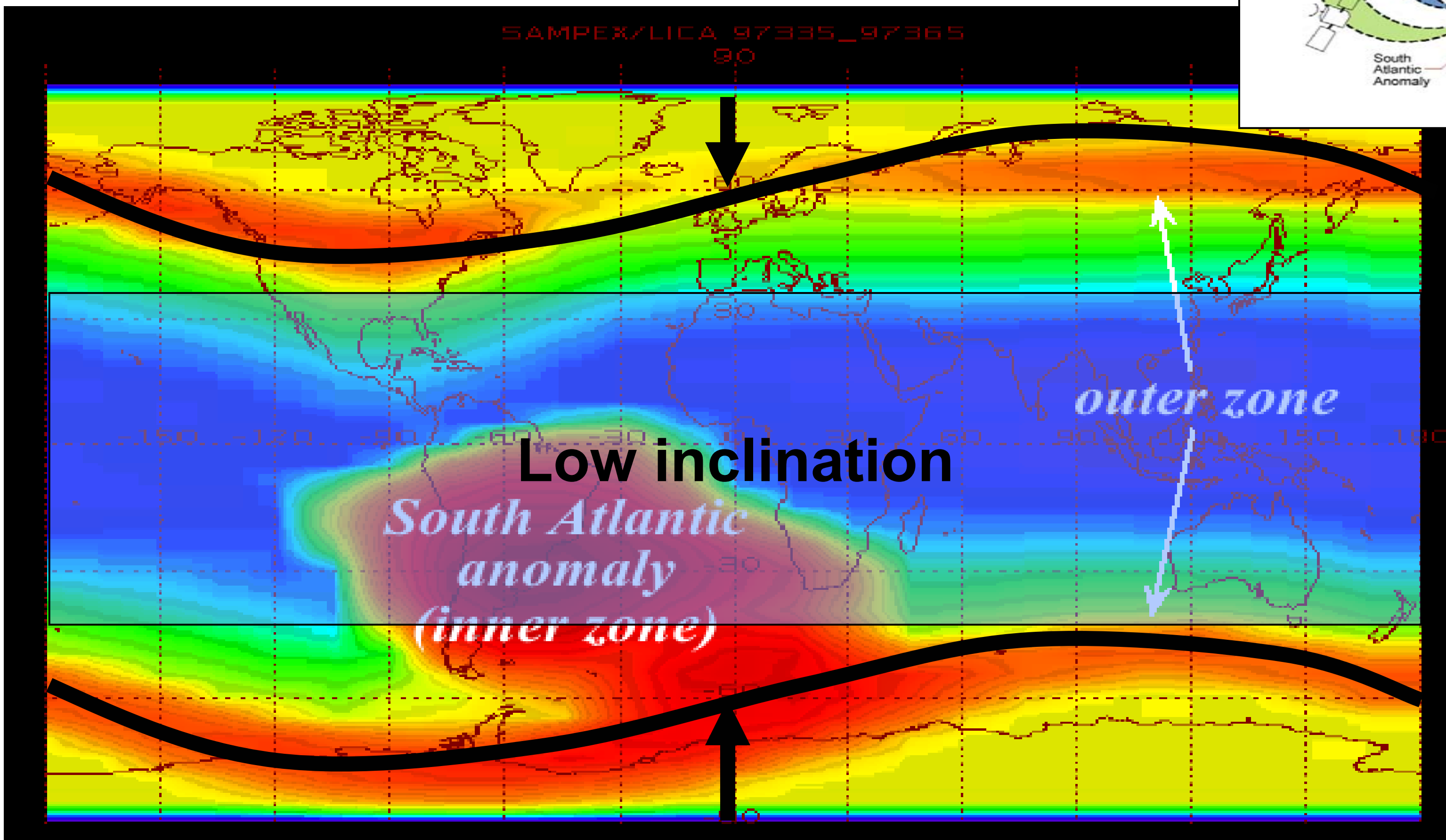
Mikhail Panasyuk

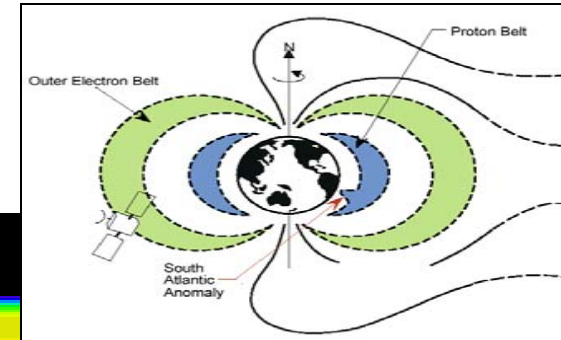
Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University



The Earth's radiation environment at LEO

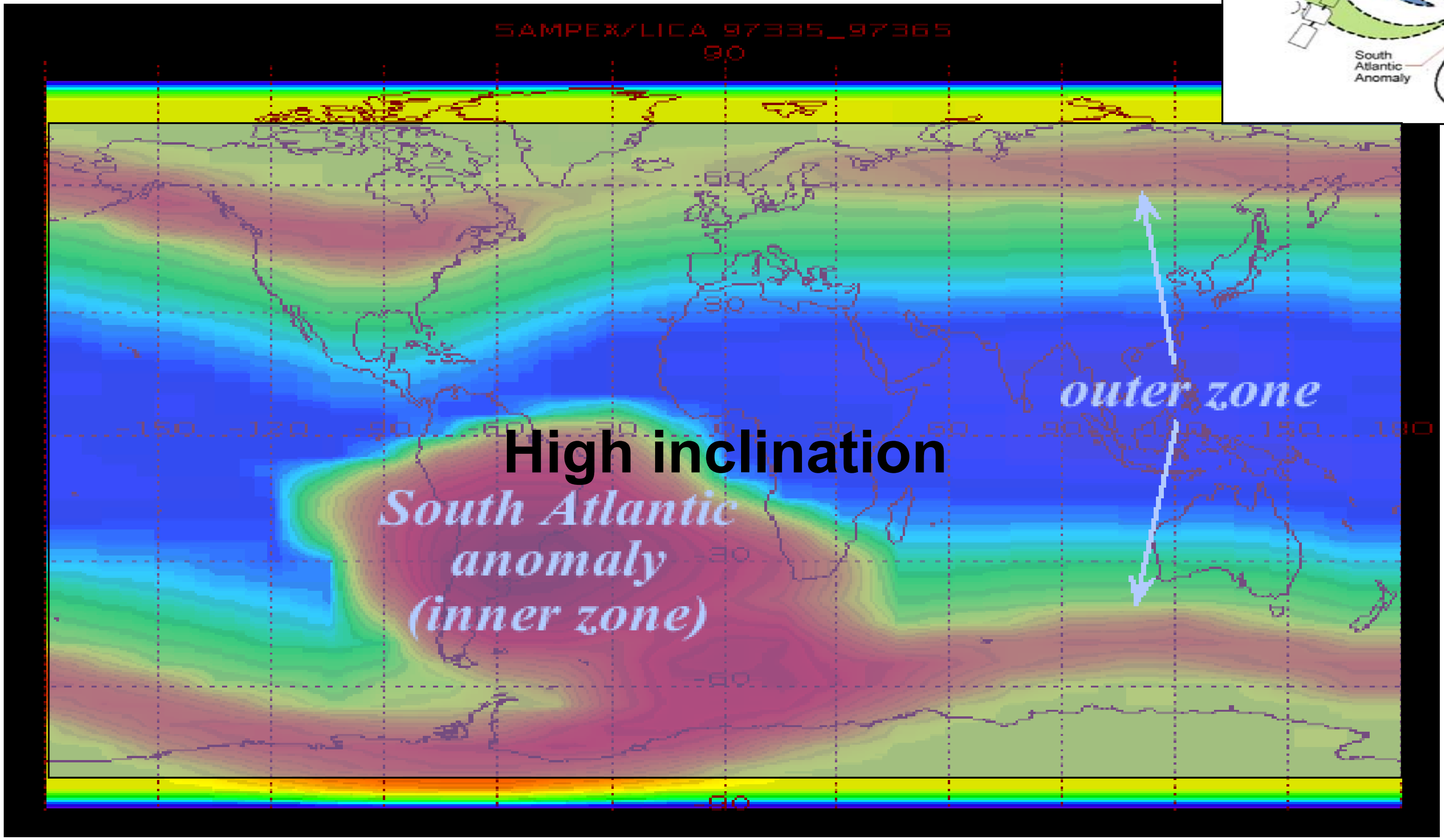
Near- Earth space radiation environment:

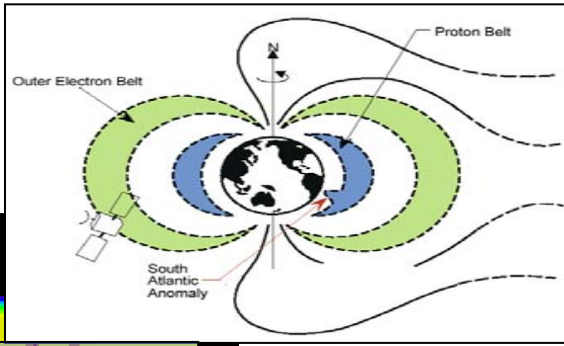




Count rates (arbitrary units) of protons with energy higher of 0.7 MeV and electrons with energy higher than 0.5 MeV for the NASA SAMPEX Satellite in the low earth orbit (LEO) at ~ 600 km altitude.

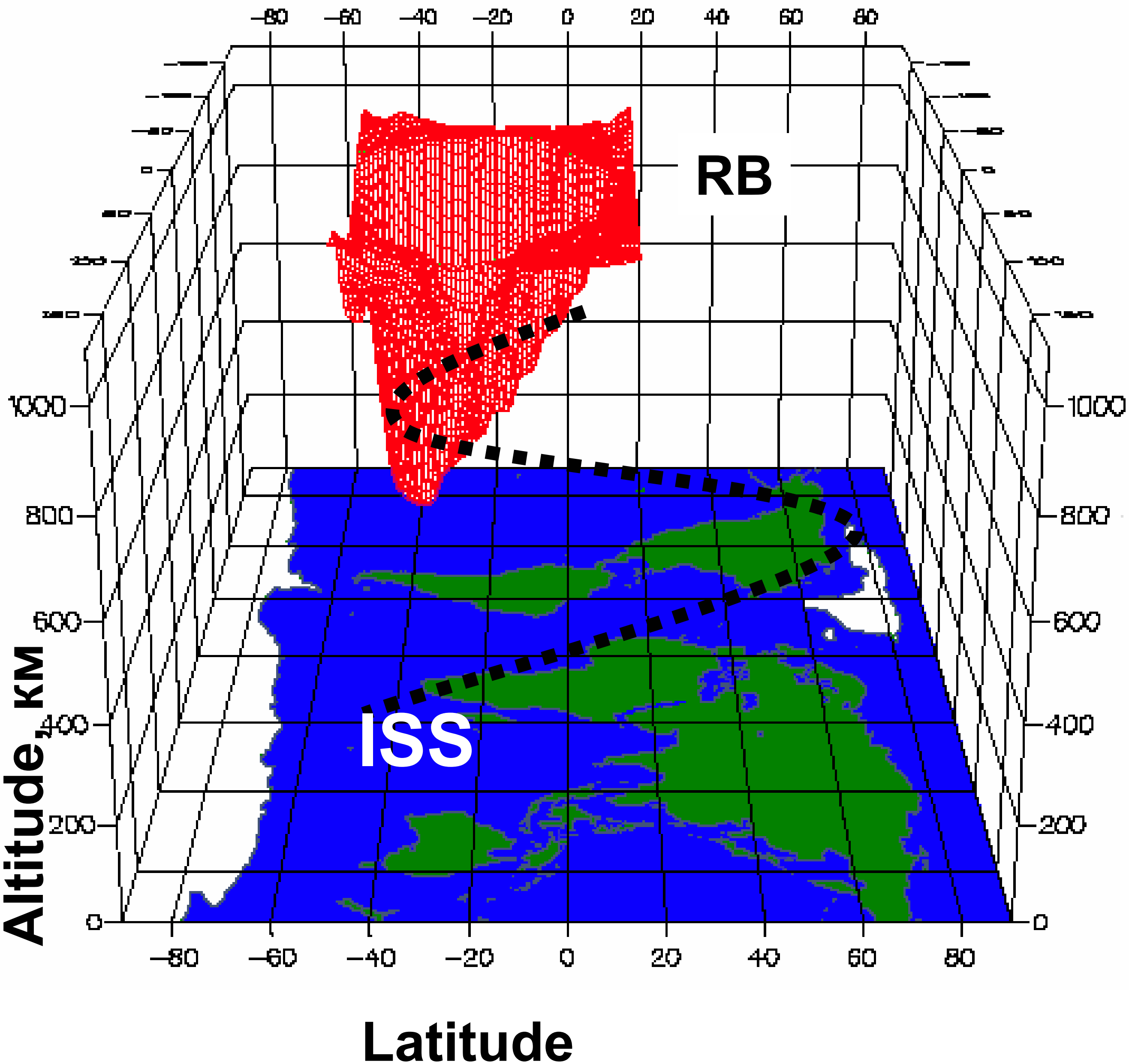
Near- Earth space radiation environment:

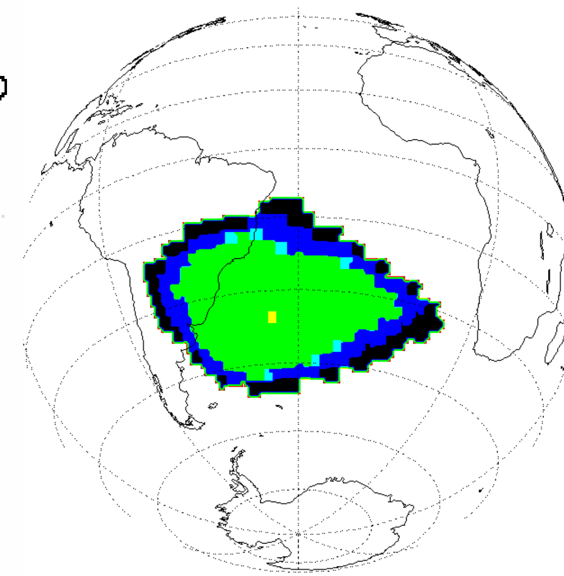




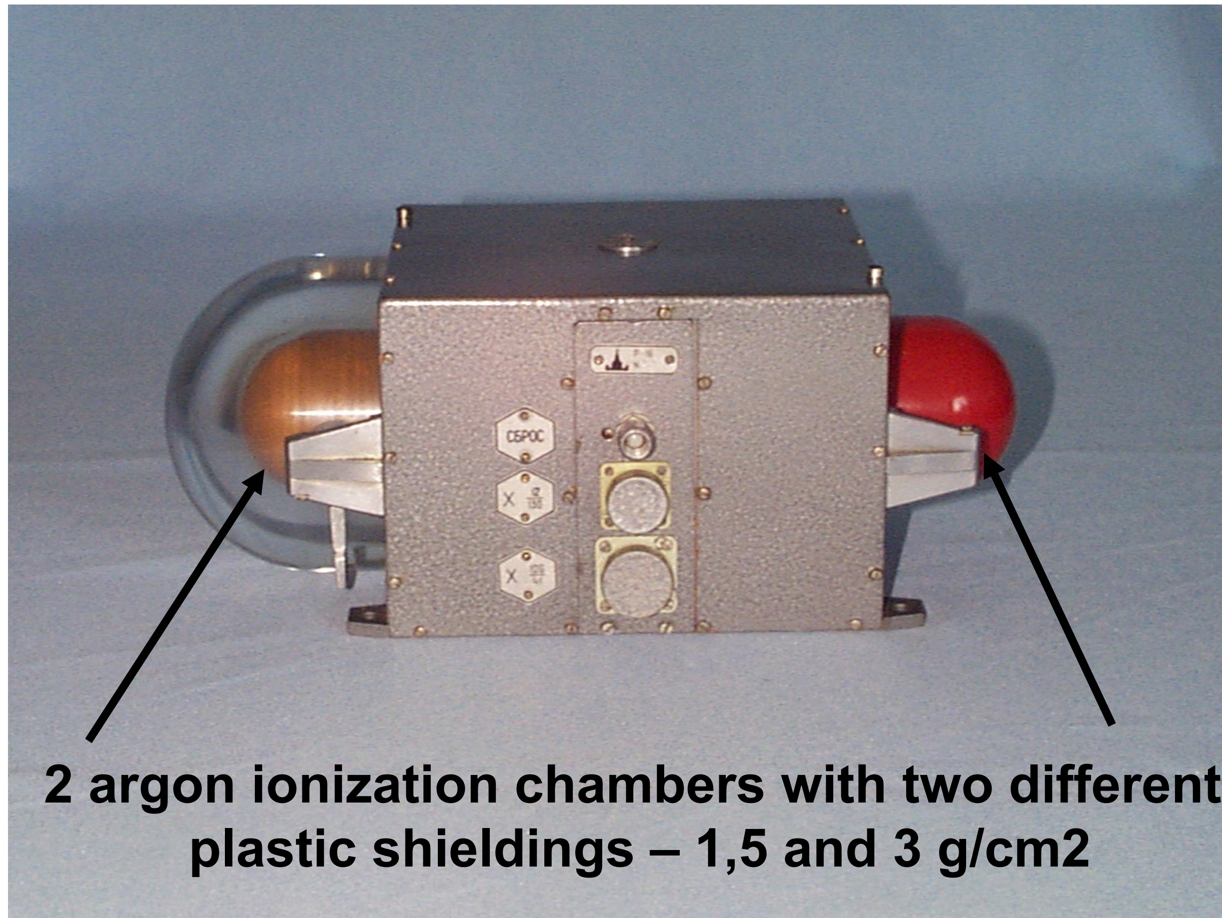
Count rates (arbitrary units) of protons with energy higher of 0.7 MeV and electrons with energy higher than 0.5 MeV for the NASA SAMPEX Satellite in the low earth orbit (LEO) at ~ 600 km altitude.

SAA


RB
ISS
Altitude, км
Latitude
1000
800
600
400
200
0
−80 −60 −40 −20 0 20 40 60 80



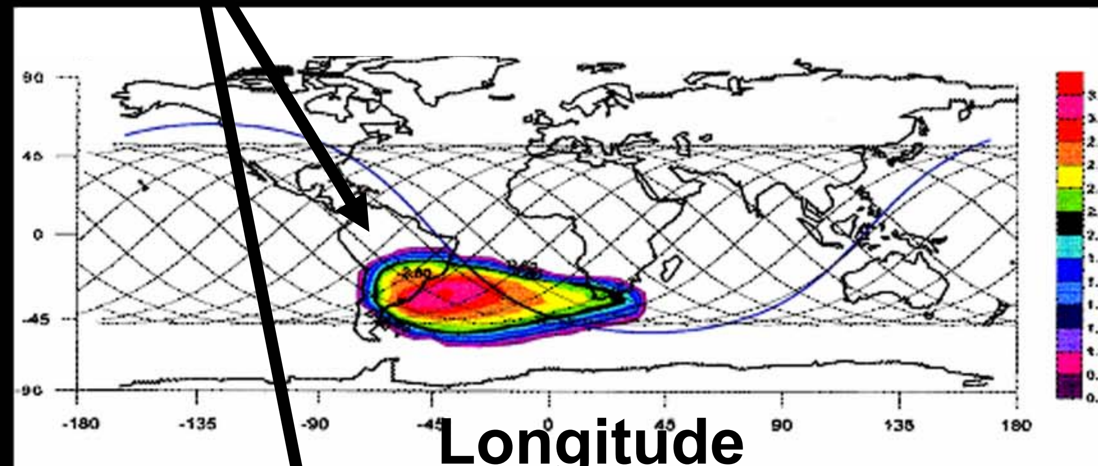
R- 16 dosemeter



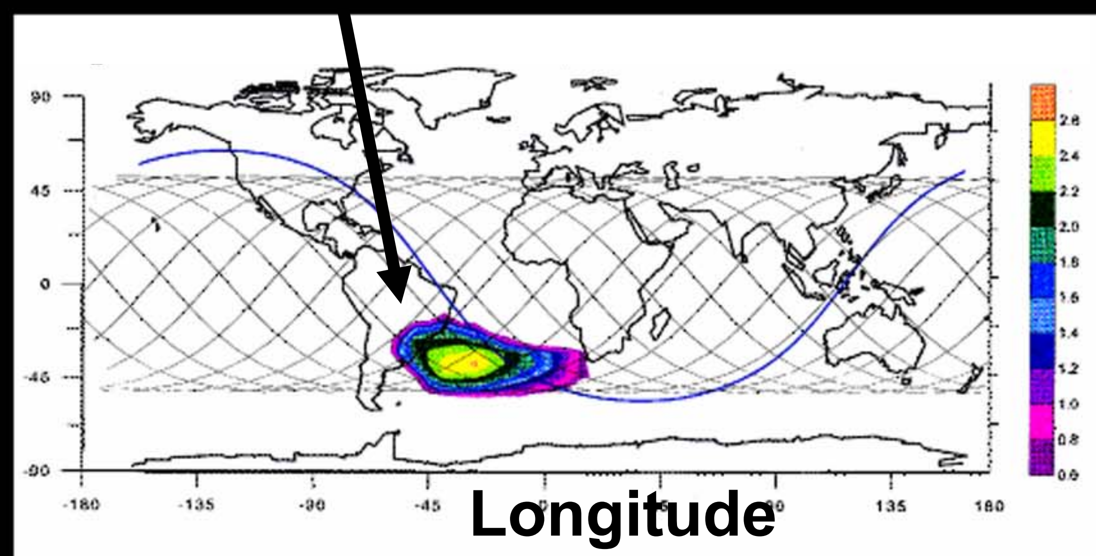
Onboard MIR station since 1987 till 2000!

South Atlantic Anomaly

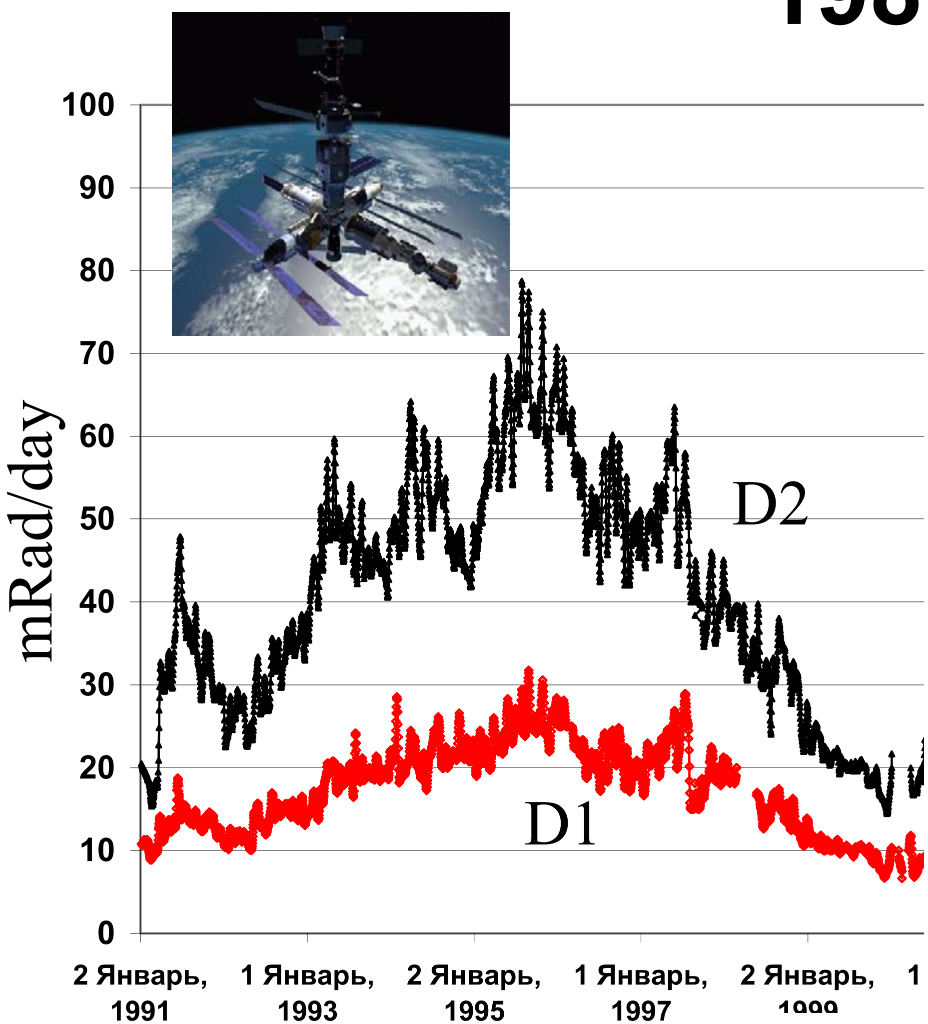
Solar minimum -
the middle of 90's



Solar maximum –
the beginning of 90's



Daily averaged doses rates since 1987

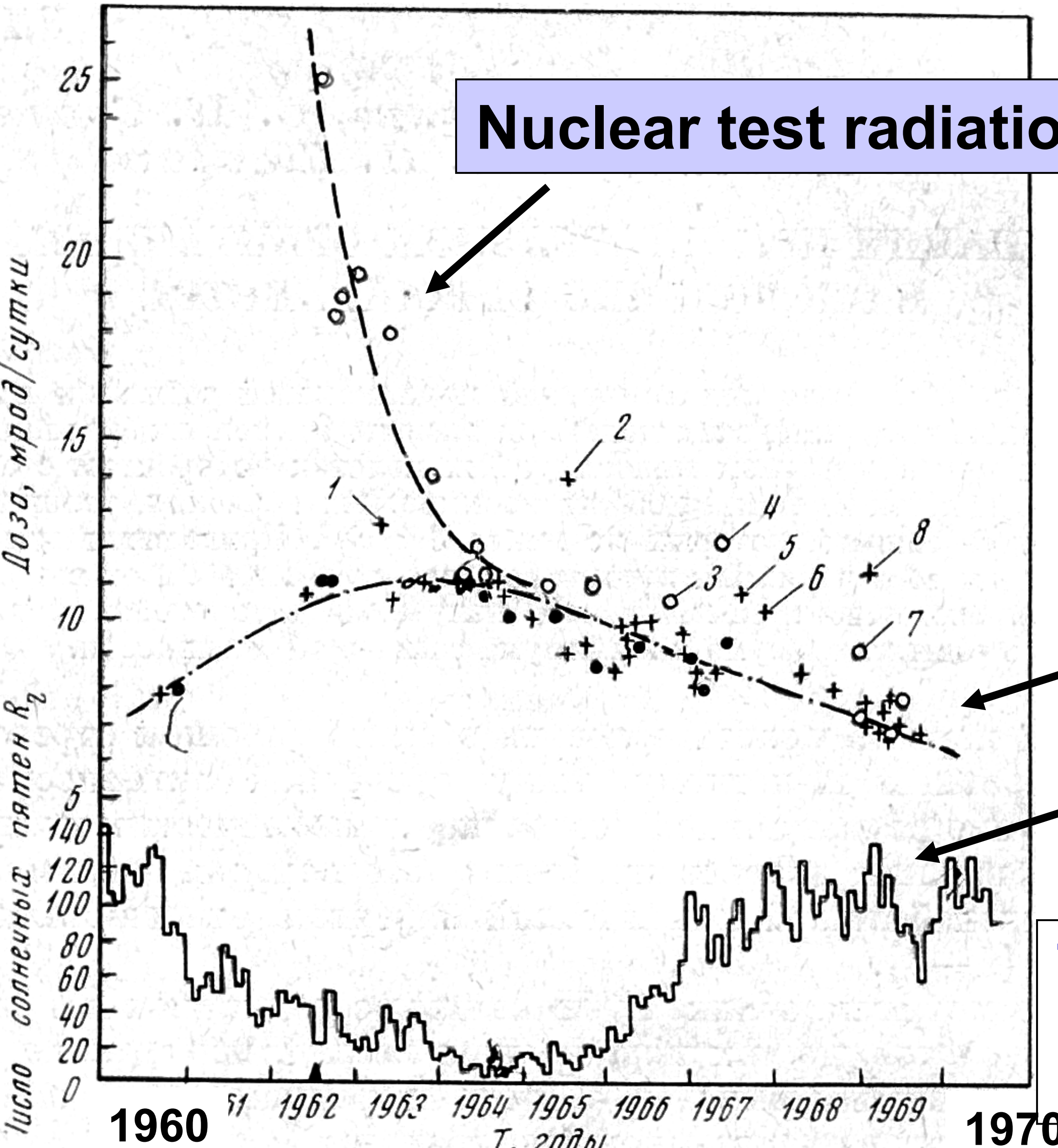


1991 2000 Year

MIR data since 1991 till 2000

The strong solar-cycle variation

Daily averaged doses rates since 1960 till 1969



Nuclear test radiation

Different spacecrafts h ~ 350 – 400 km, i~ 65°

Solar cycle variation

W

The first observational result of solar sycle variations at LEO (Vernov, et al, 1972)

The main mechanizm of radiation belt formation

Balance between

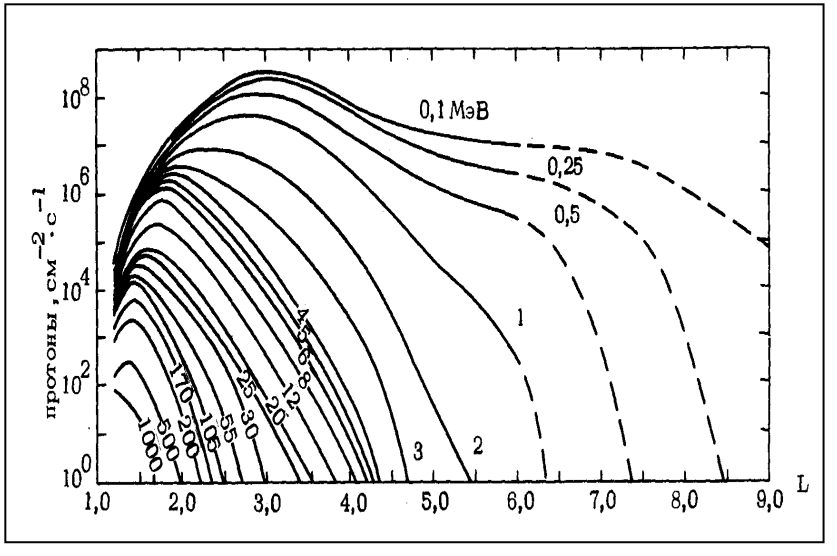
transport time (radial diffusion from outer RB edge) - τ_t

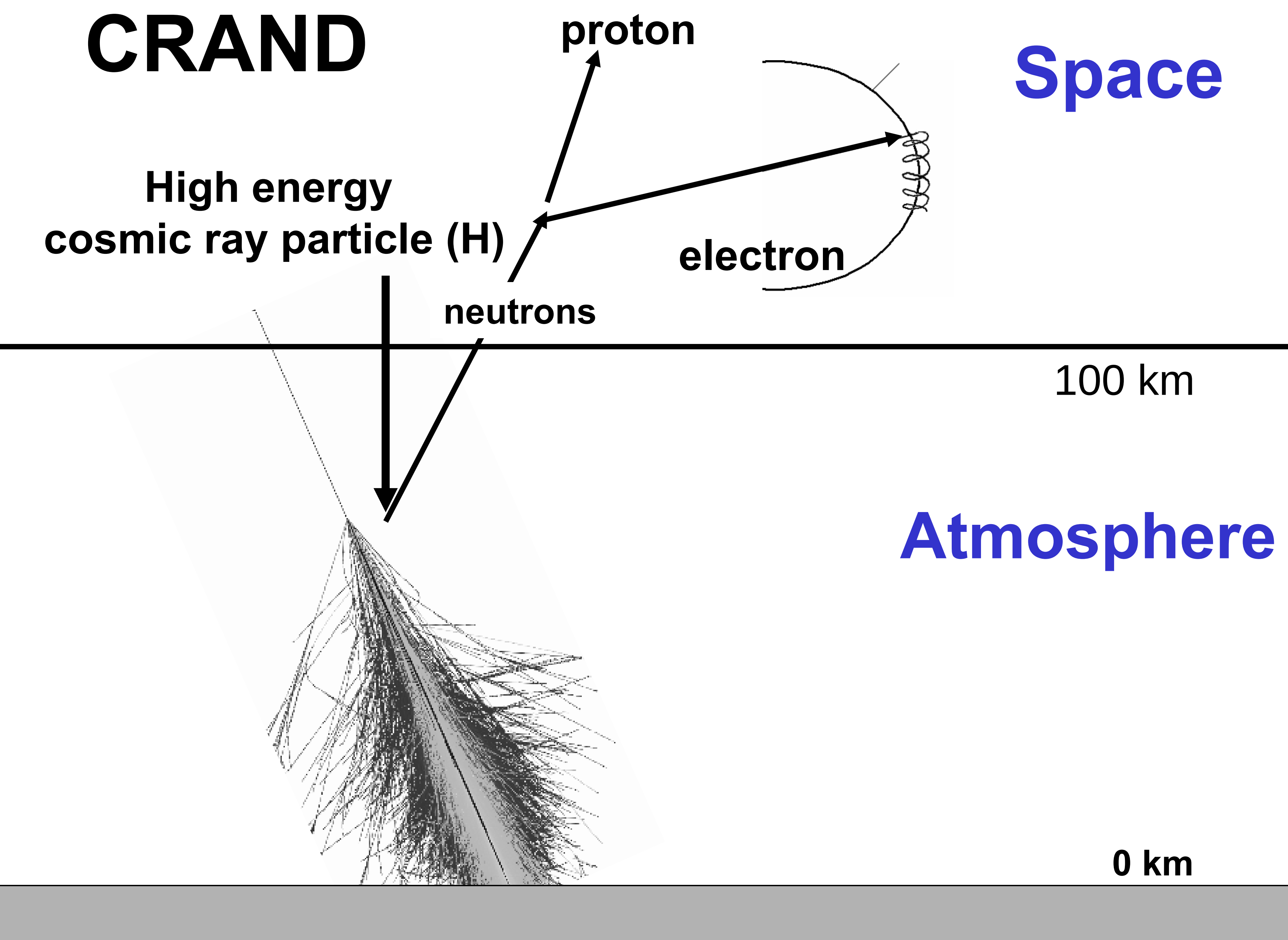
and loss time - τ_l

For inner belt, say at L< 2

$$\tau_t >> \tau_l$$

But there is a local source for inner RB protons – CRAND



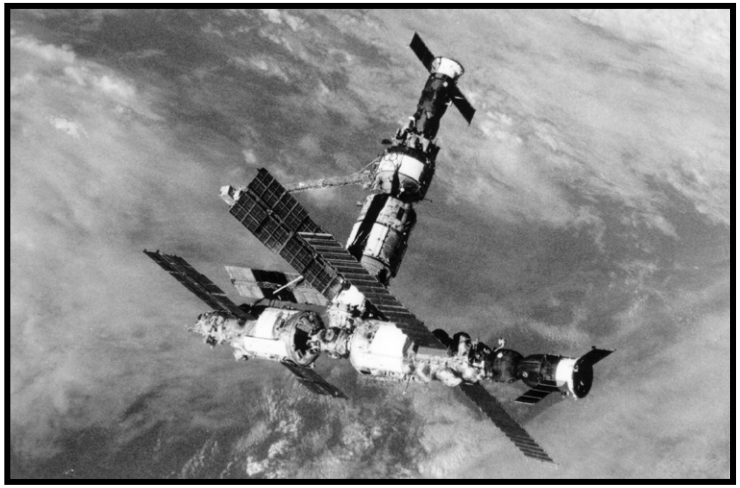

CRAND
proton
Space
High energy
cosmic ray particle (H)
electron
neutrons
100 km
Atmosphere
0 km

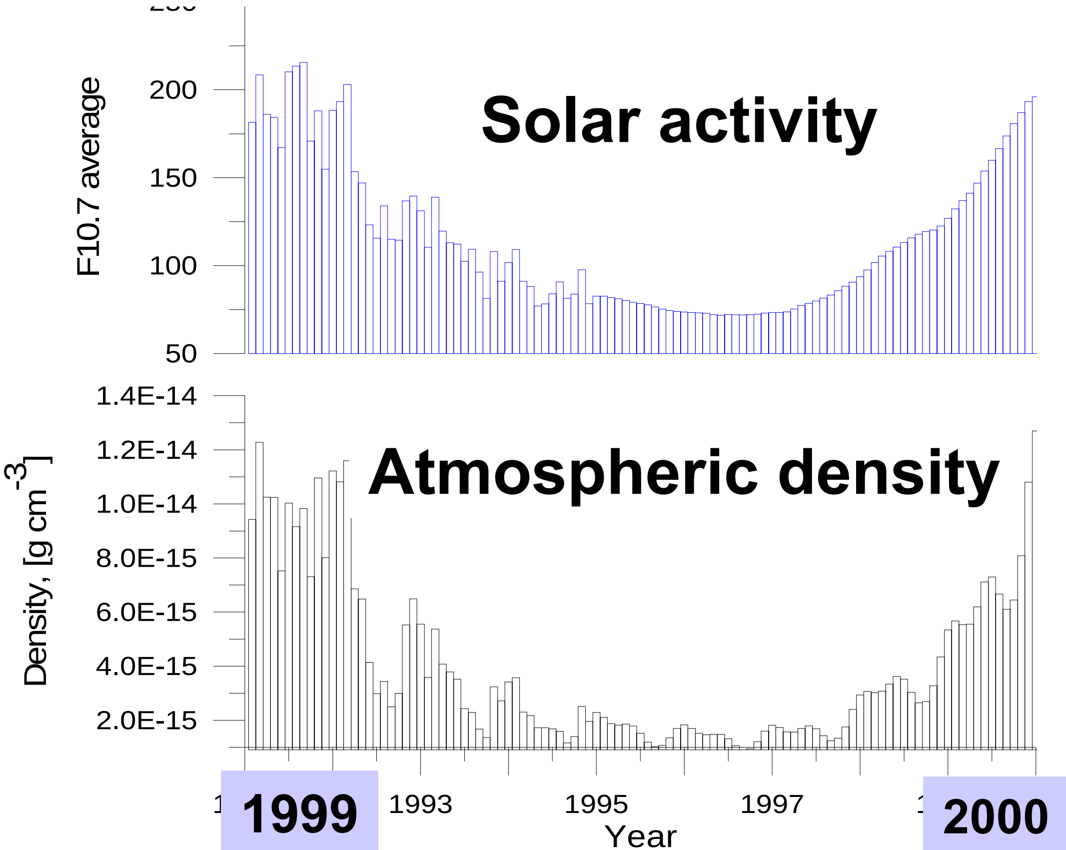
The space-temporal structure of the inner radiation belt will be determined mainly by losses only (for steady-state source)

→ ***For high energy protons***

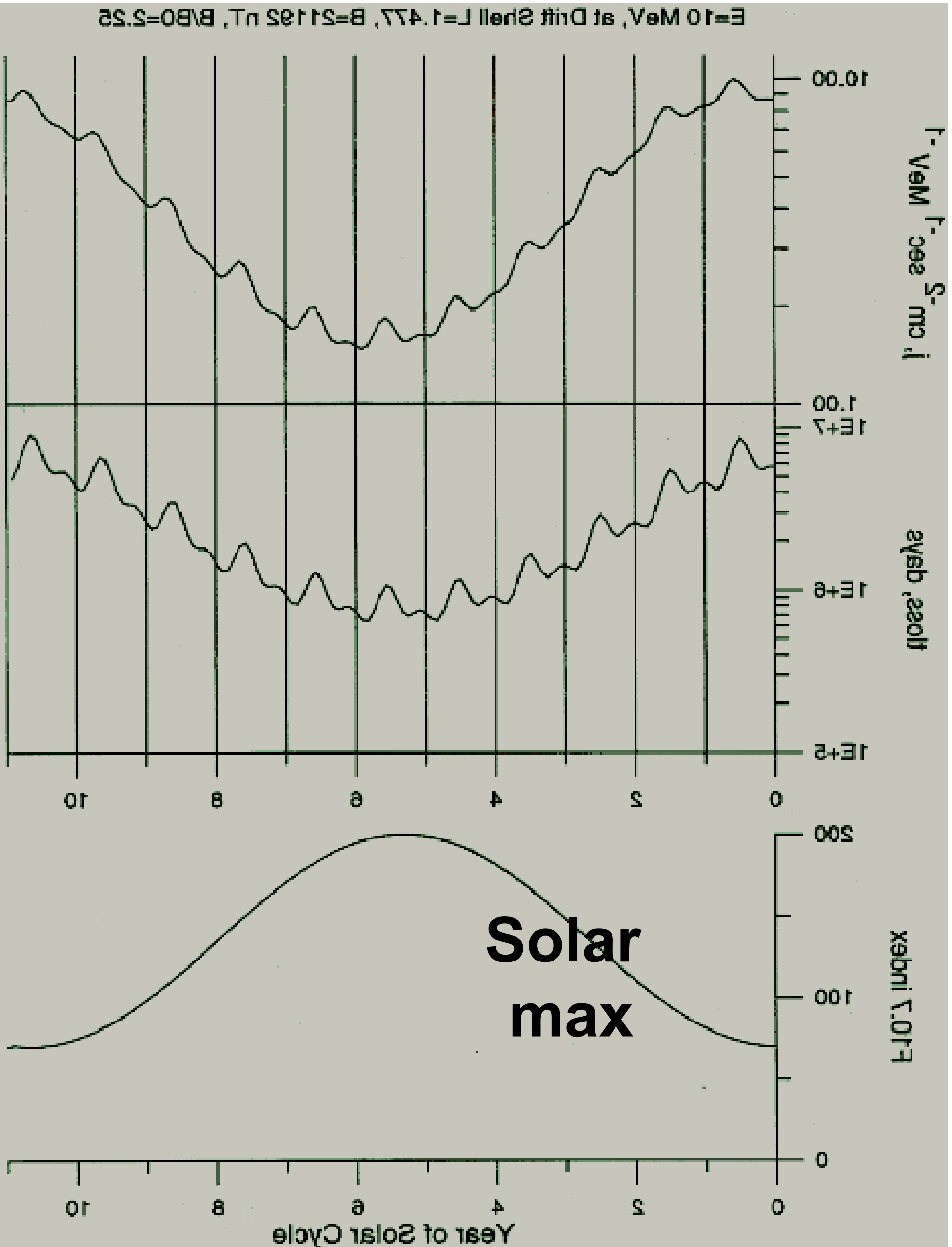
it is ionization losses with residual atmosphere

MIR station radiation doses in the 22nd solar cycle





Solar cycle flux/atmospheric density variations



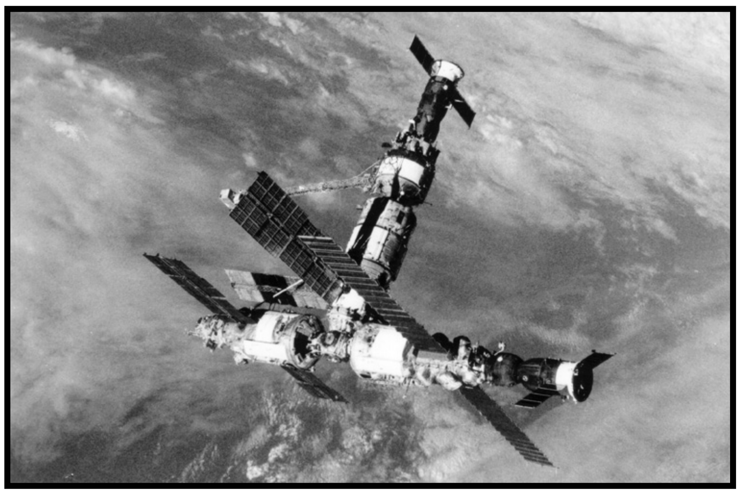
RB proton (>10 MeV) flux

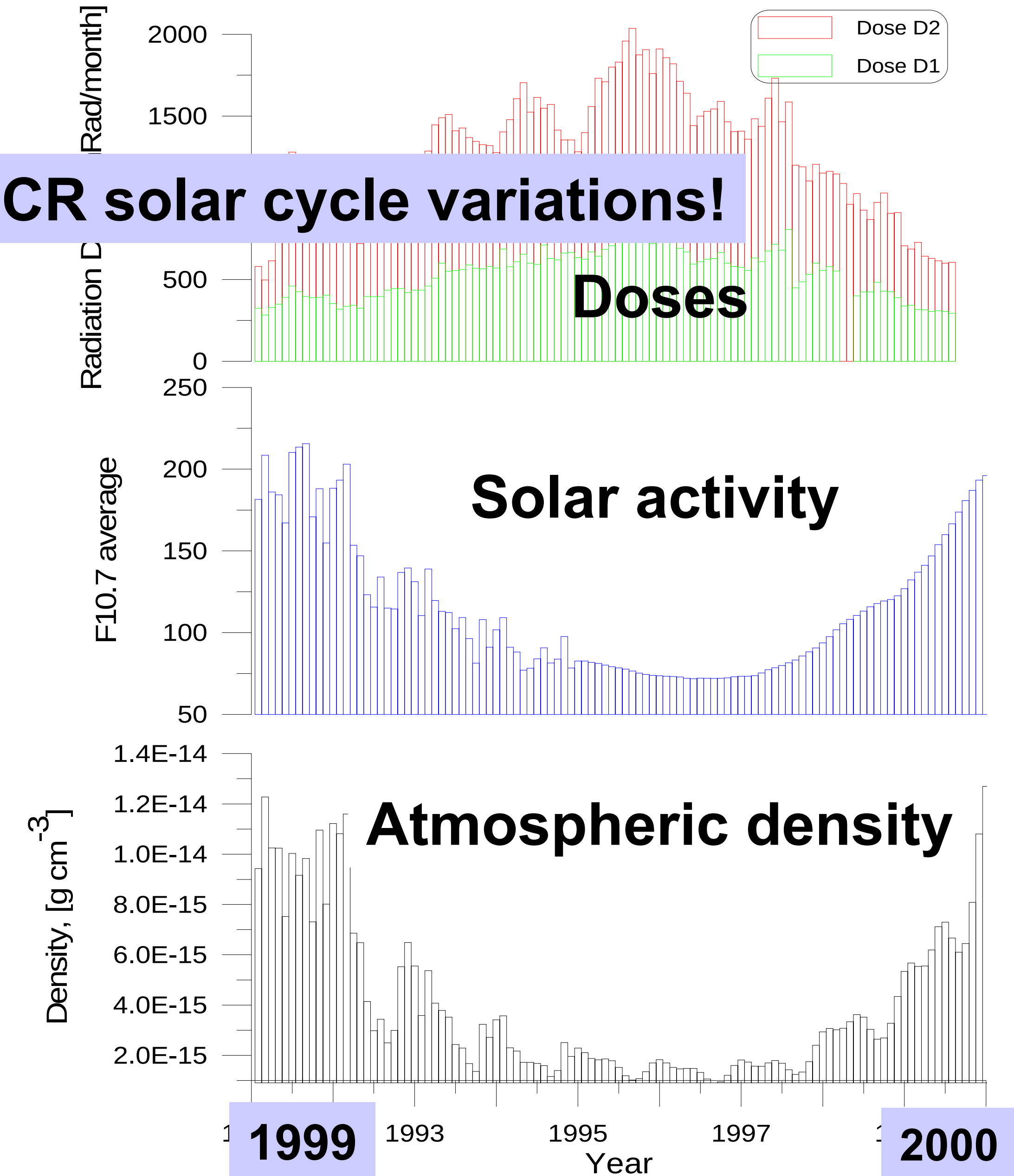
Loss time as a function of atmospheric density variations

Solar activity variations

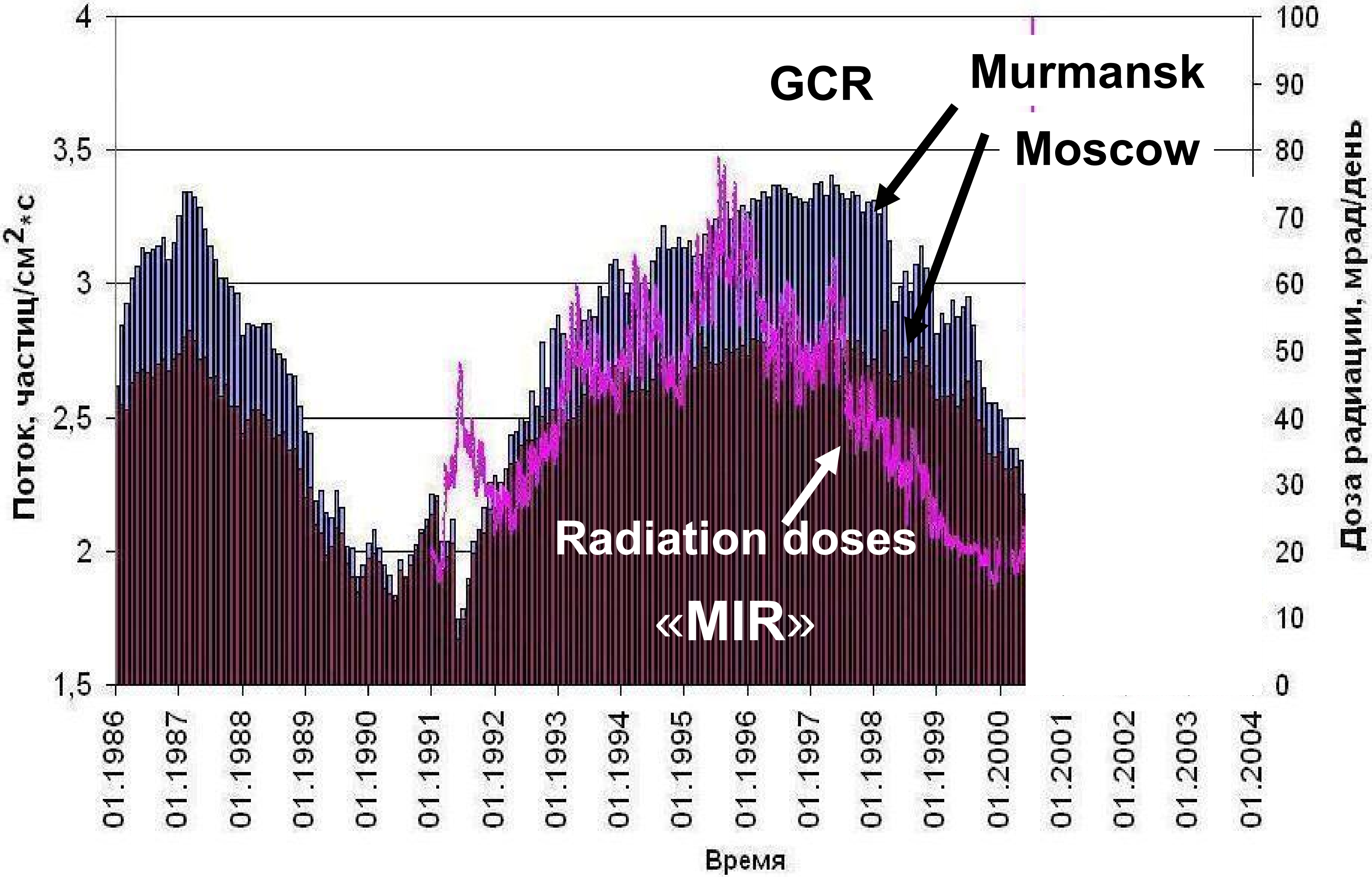
MIR station radiation doses in the 22nd solar cycle

The same sign for GCR solar cycle variations!

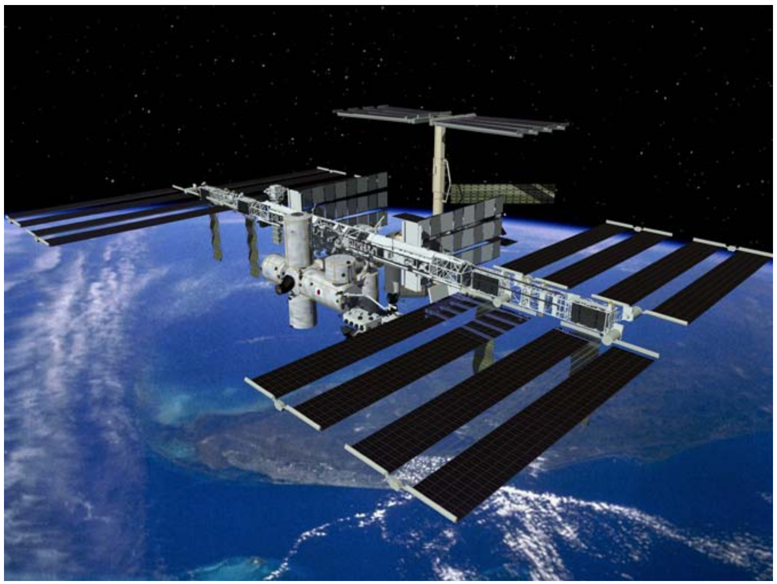


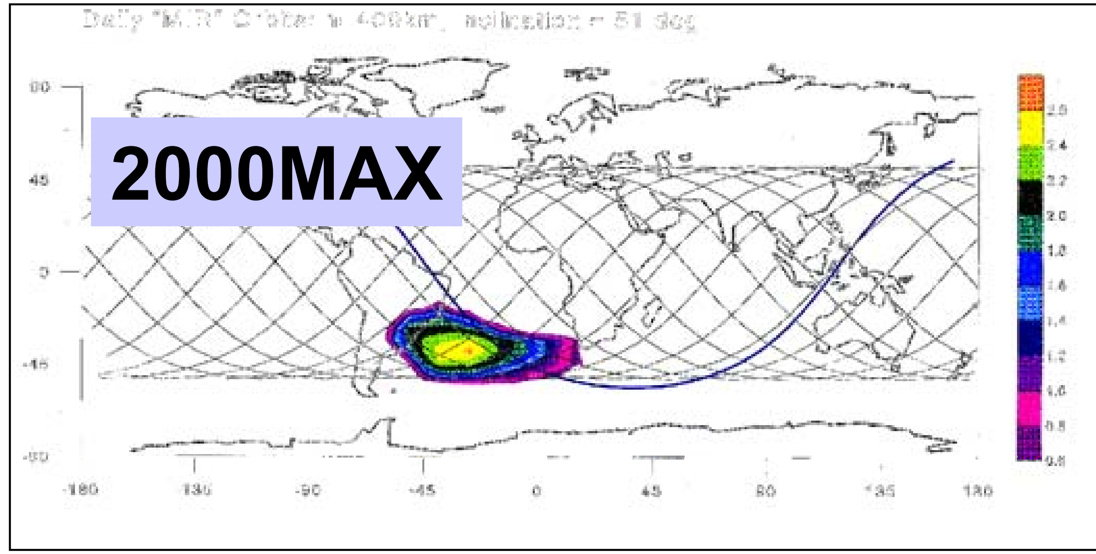


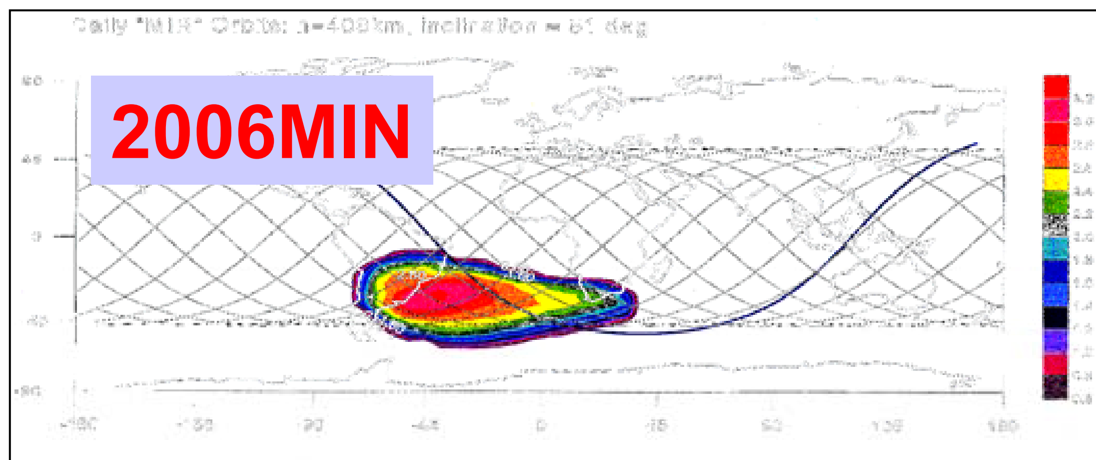
Radiation doses vs GCR variations



ISS expected results



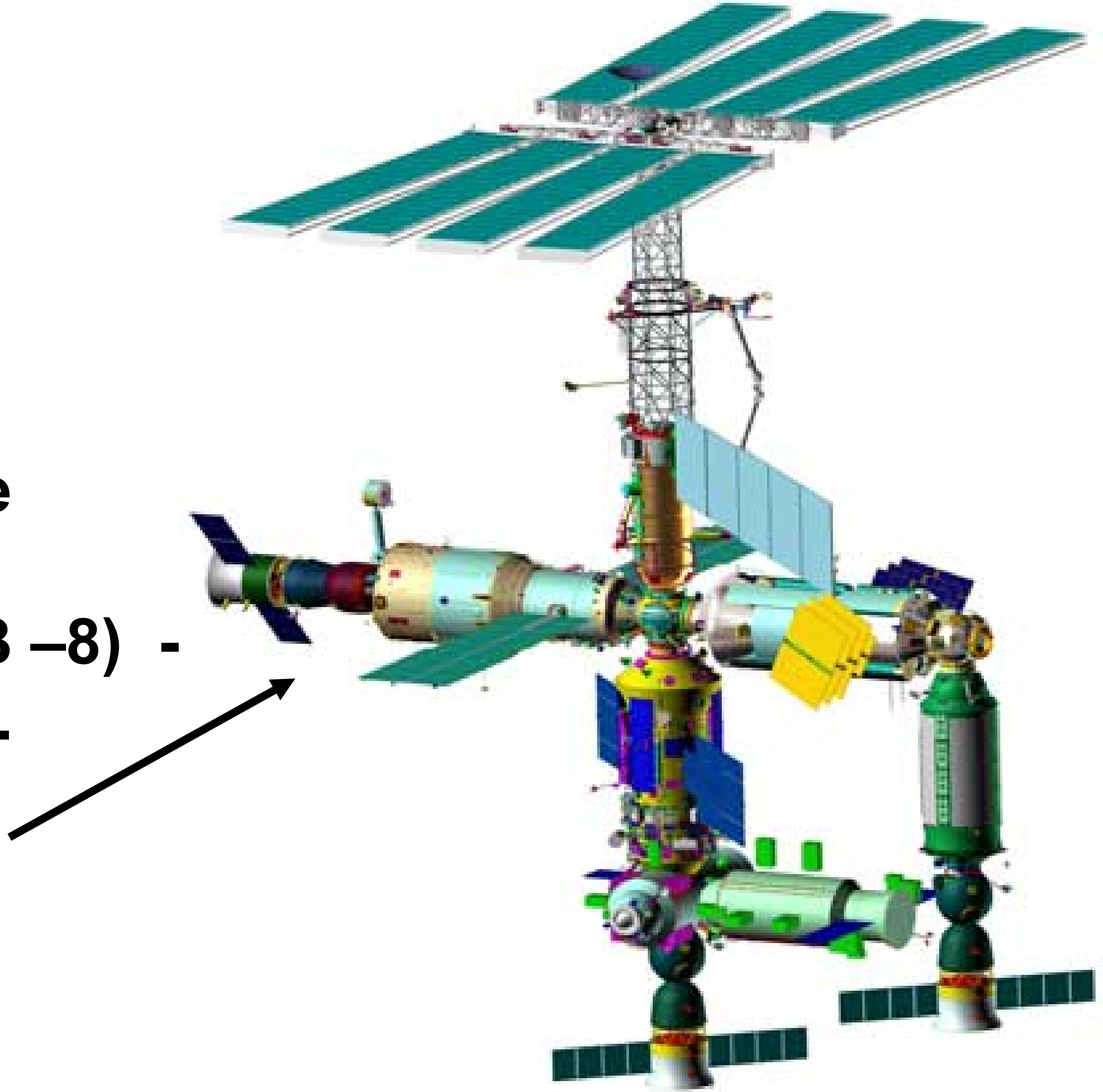




ISS radiation puzzle

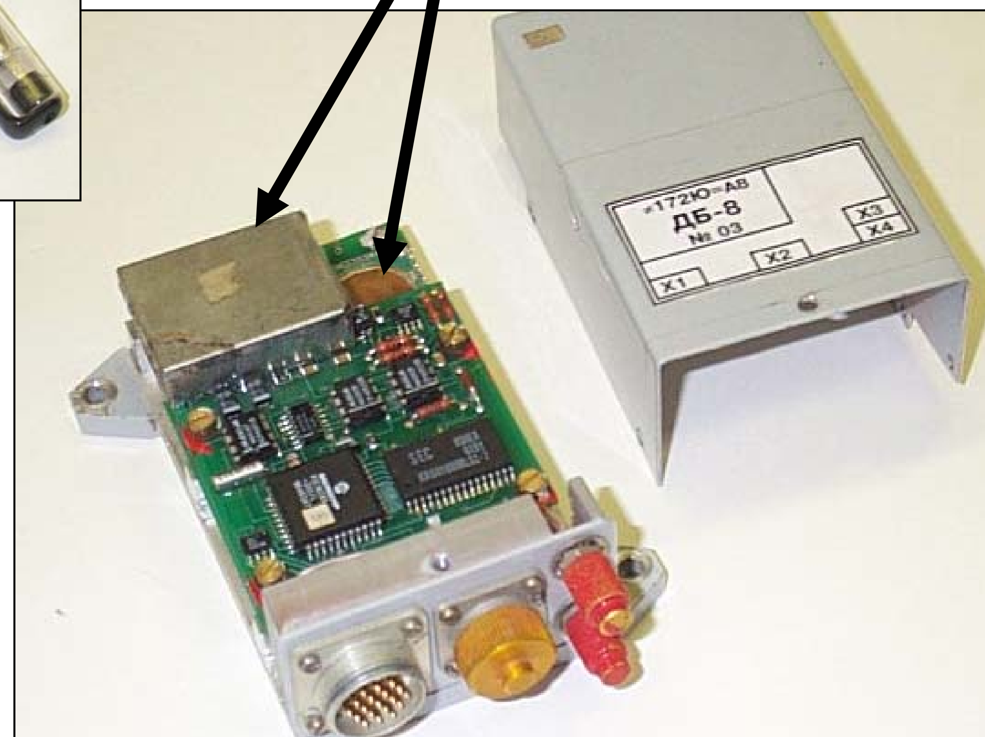
ISS/Russian module

R-16 in operation since summer of 2000.
SRC (4 instruments DB –8) - since summer of 2001.

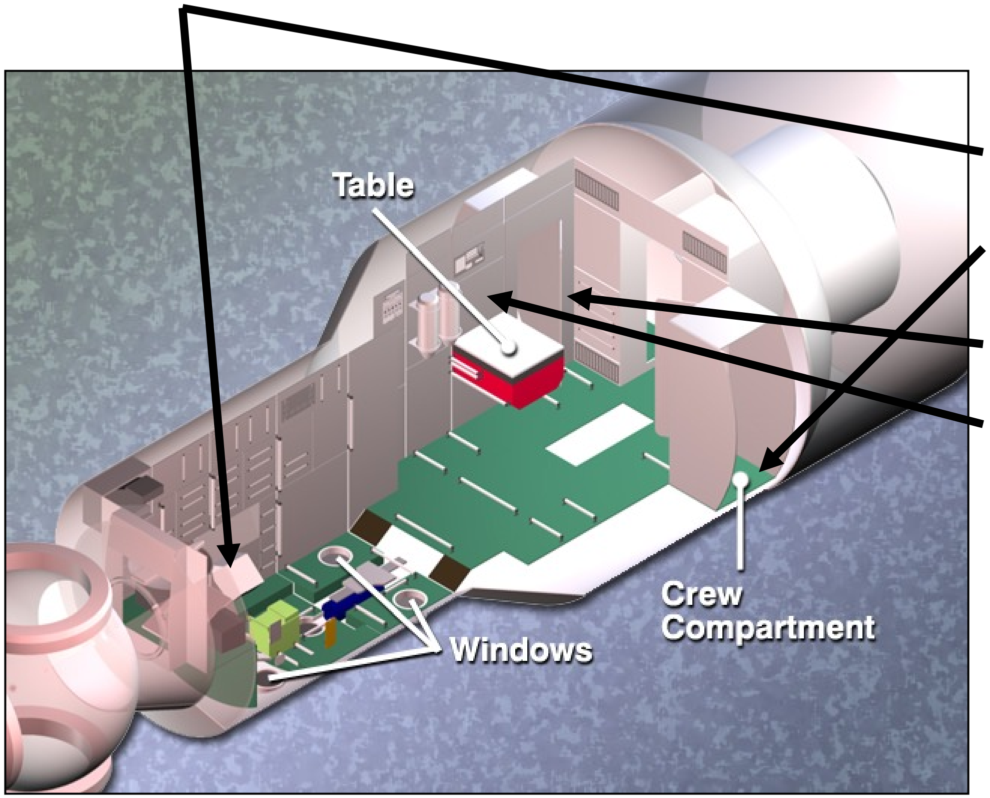


DB-8 instruments

2 (shielded and unshielded) semiconductor detectors

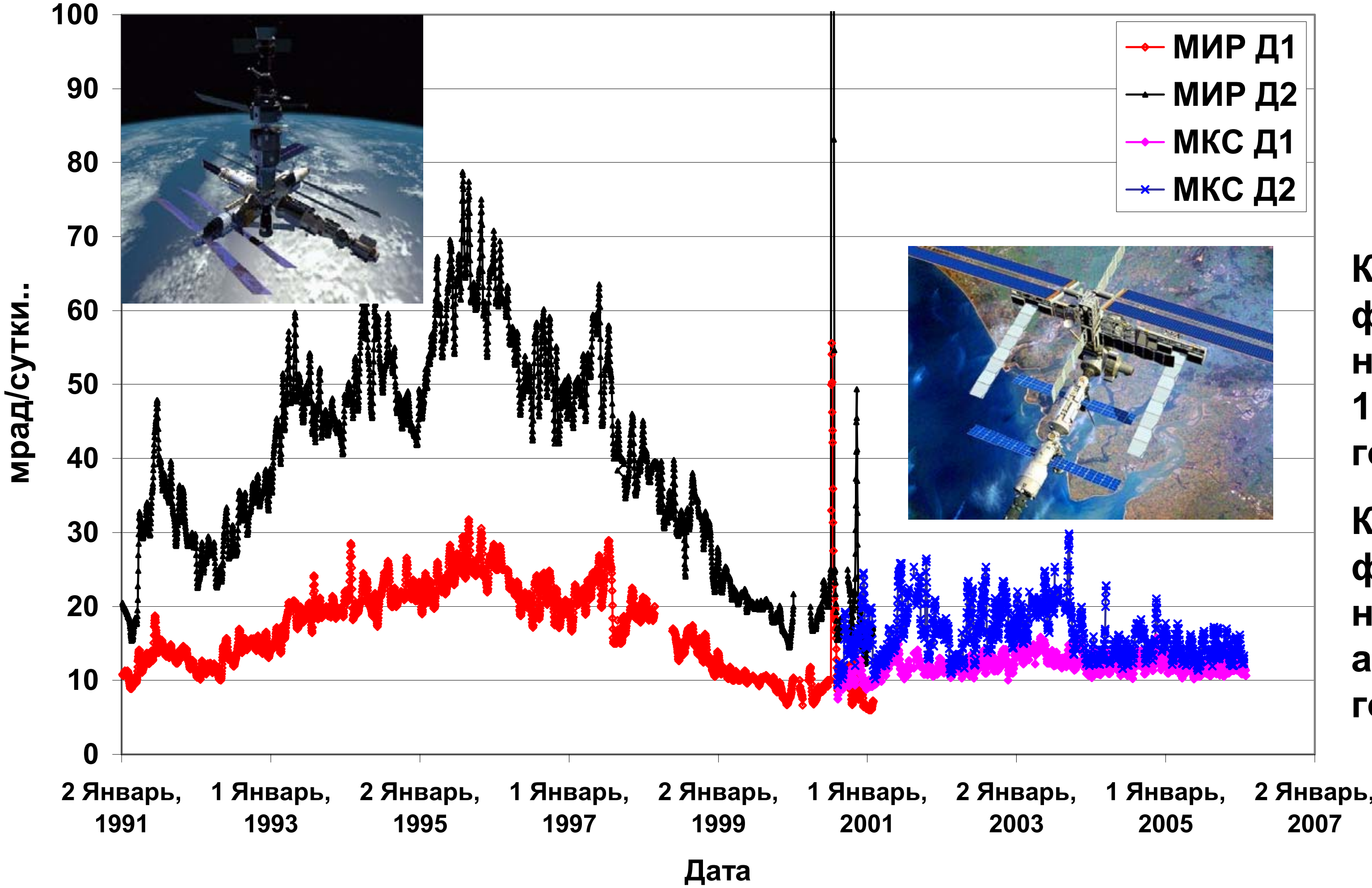


SRC placements on board ISS



Блок	Расположение
ДБ-8 №1	Правый борт, за панелью № 410
ДБ -8 №2	Левый борт, за панелью № 244
ДБ -8 №3	Правый борт, за панелью № 447
ДБ -8 №4	Правый борт, за панелью № 435
Р-16	На потолке салона большого диаметра, за панелью № 327
АИ	Правый борт, за панелью № 447
БКР	Правый борт, за панелью № 447

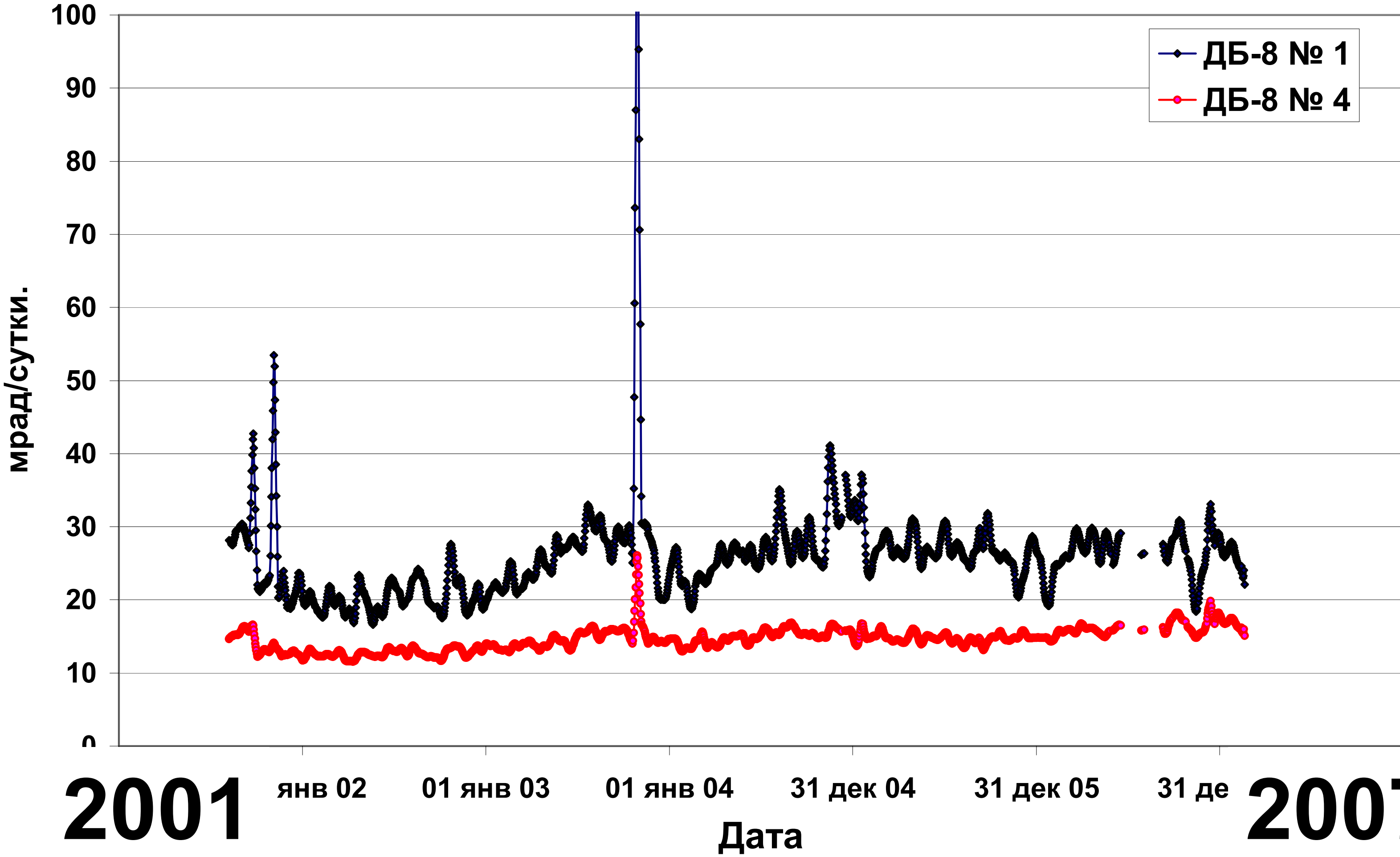
R-16 daily averaged doses rates



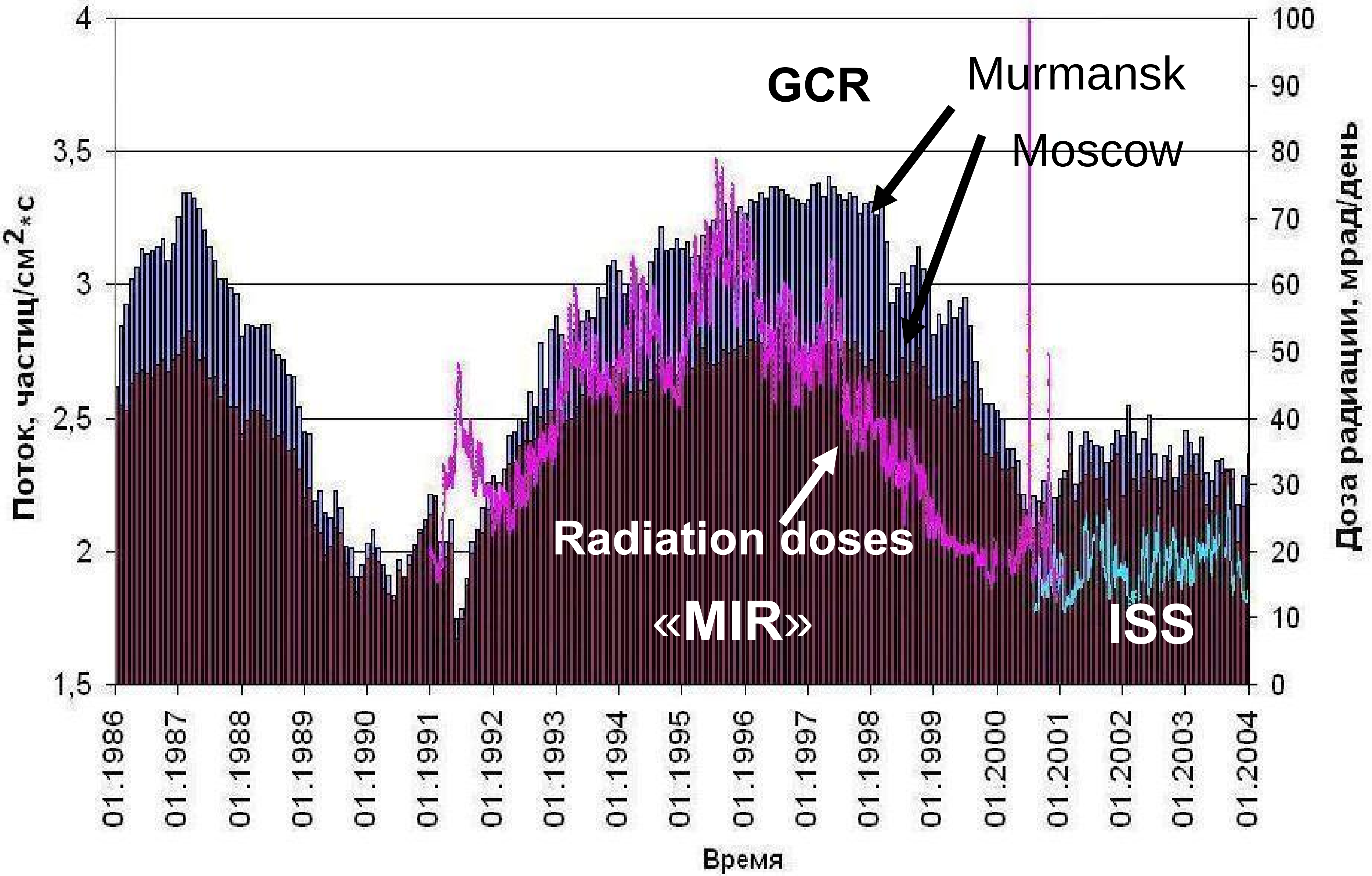
Канал Д1 функцио-нировал до 12 мая 2006 года

Канал Д2 функцио-нировал до 9 апреля 2006 года

DB-8 daily averaged doses rates since 2001



2001 2007



GCR
Murmansk
Moscow
Radiation doses
«MIR»
ISS
Поток, частиц/см2*с
Доза радиации, мрад/день
Время
4
3,5
3
2,5
2
1,5
100
90
80
70
60
50
40
30
20
10
0
01.1986
01.1987
01.1988
01.1989
01.1990
01.1991
01.1992
01.1993
01.1994
01.1995
01.1996
01.1997
01.1998
01.1999
01.2000
01.2001
01.2002
01.2003
01.2004

Dynamics of the inner proton radiation zone

Losses:

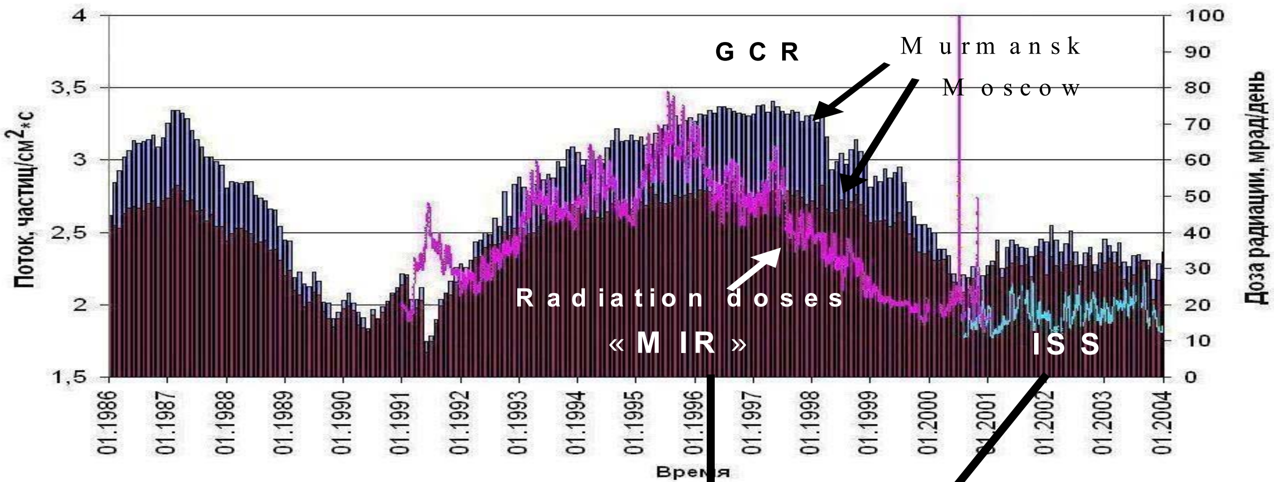
particle interactions with residual atmosphere

Source:

For ~100 MeV protons - CRAND

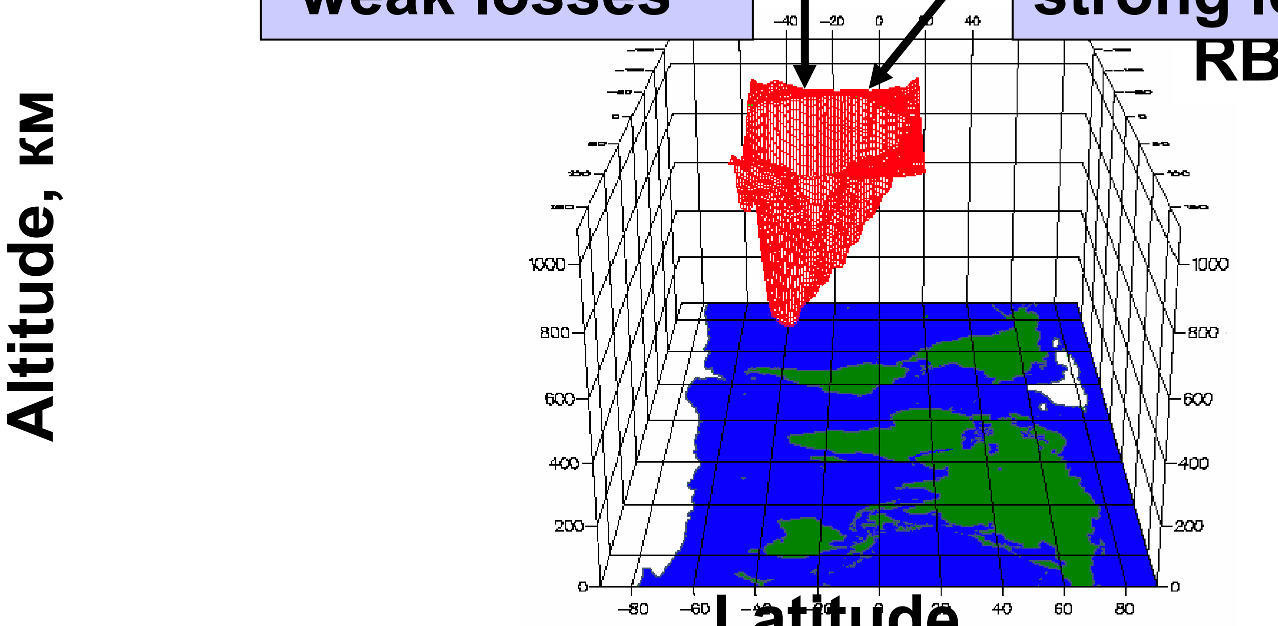
Balance between losses and "local" source strength

GCR as a source of SAA protons (CRAND)

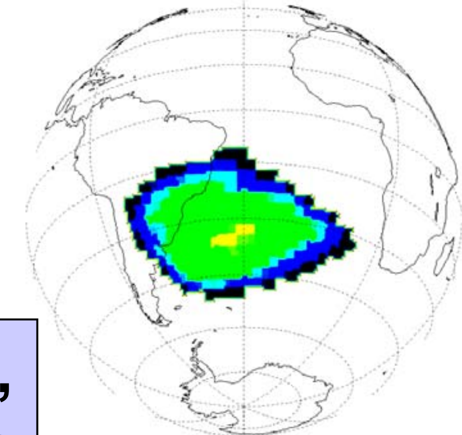


Strong source, weak losses

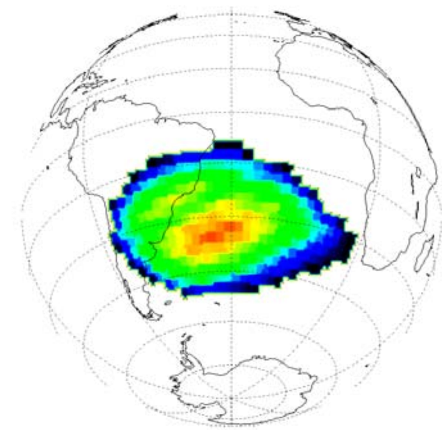
Weak source, strong losses



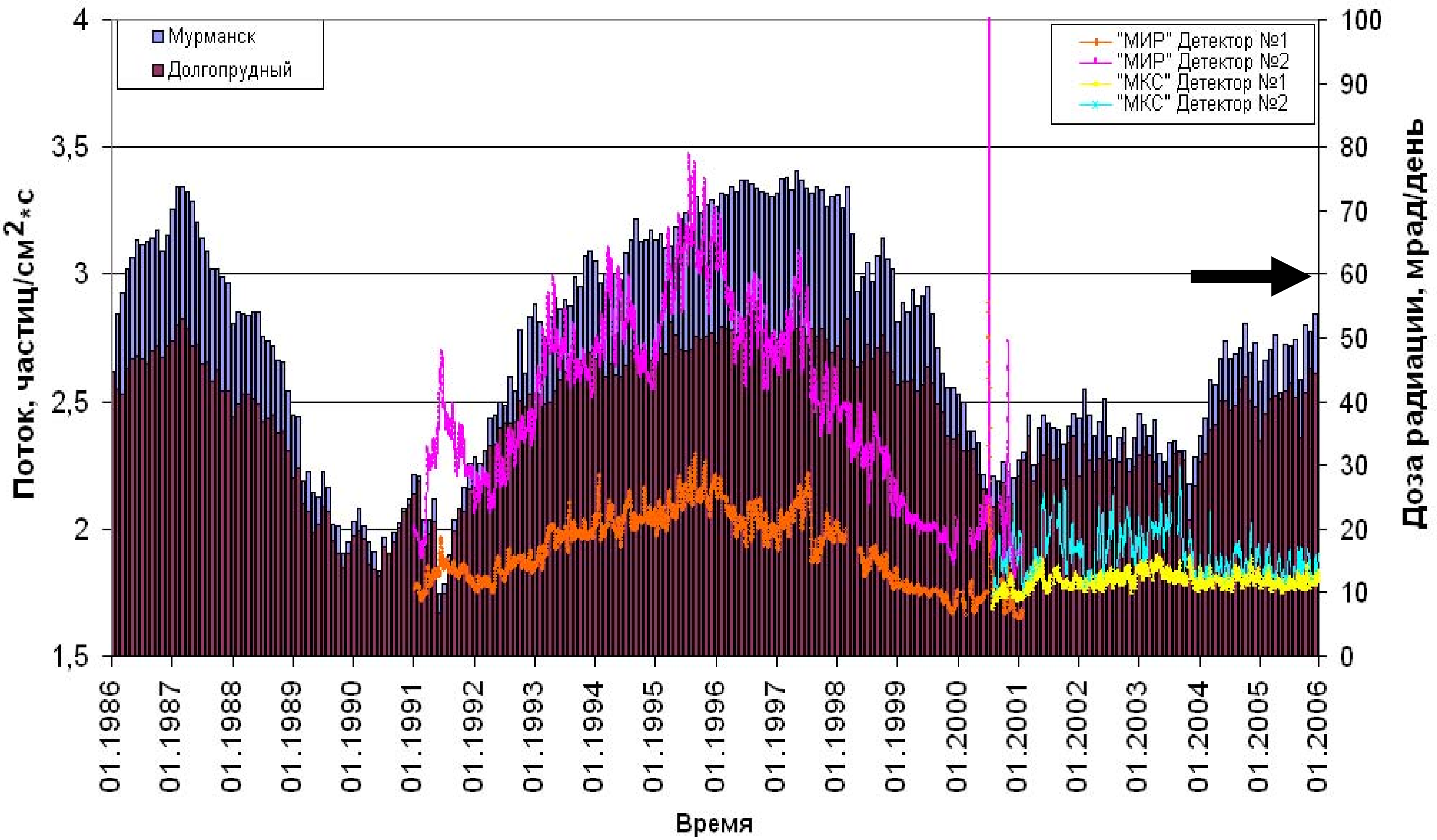
Weak source



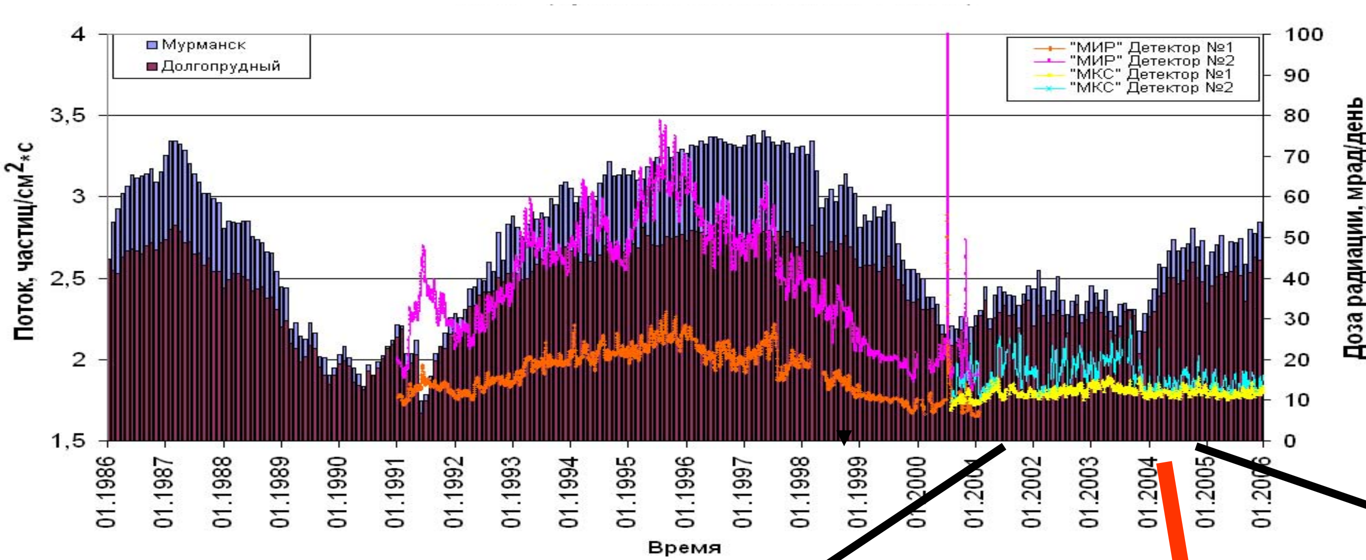
Strong source



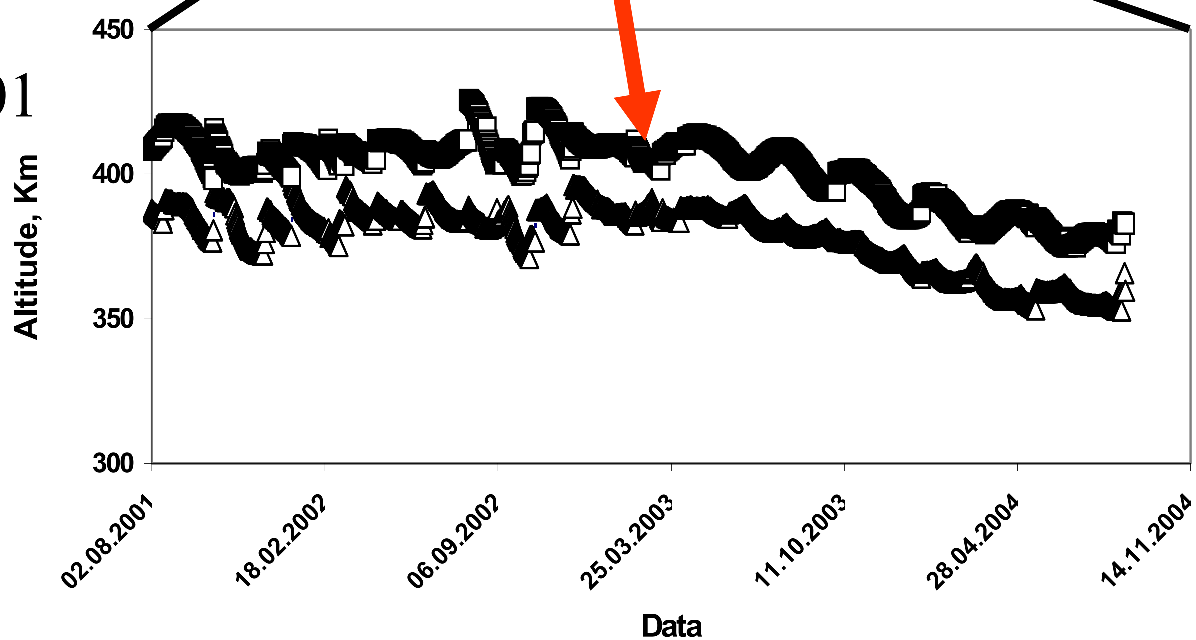
Daily averaged doses rates



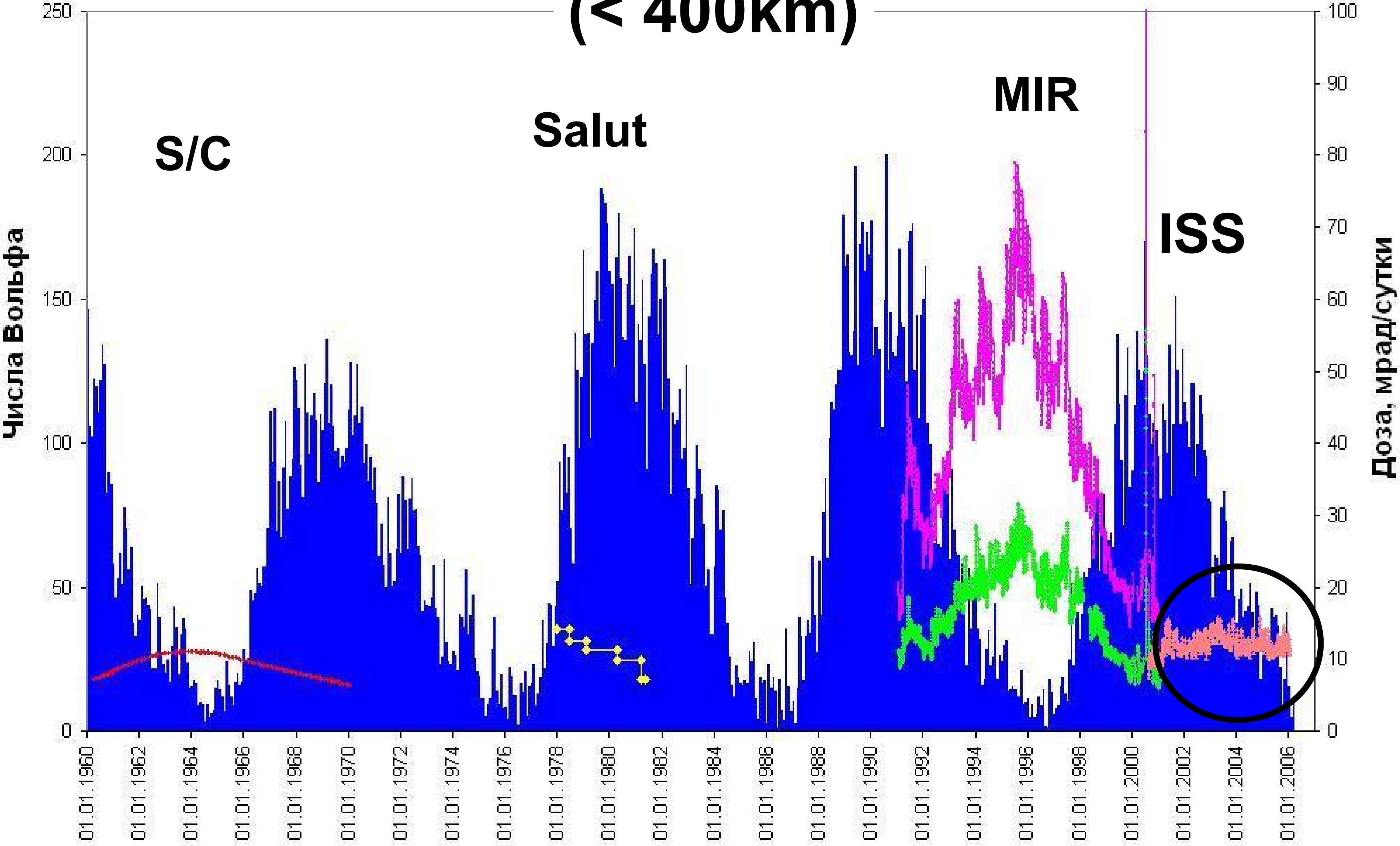
Daily averaged doses rates



ISS altitude since 2001



Solar cycle variations at LEO since 1960 (< 400km)



1960 2006

Conclusions

1.SAA anomaly radiation is the principal source of radiation hazard at altitude >350 km

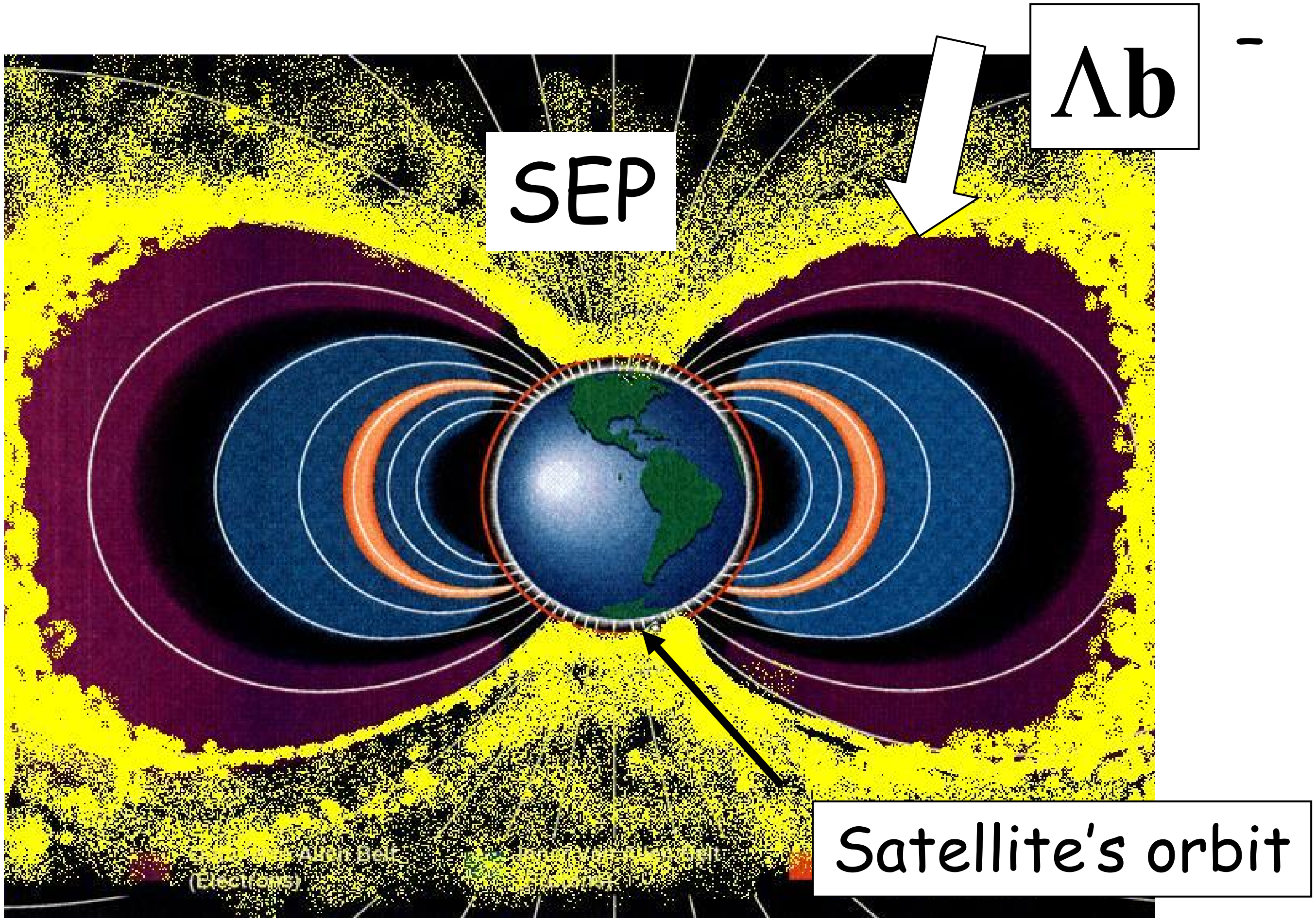
2. Long–term variations of radiation doses are dependent both losses and strengh of source(CRAND) of particles during solar cycle

3. During very strong SEE epoch from 2001 till 2004 there was a very quite radiation condition onboard ISS (and at LEO)

Storm periods:

SEP penetration at low altitudes

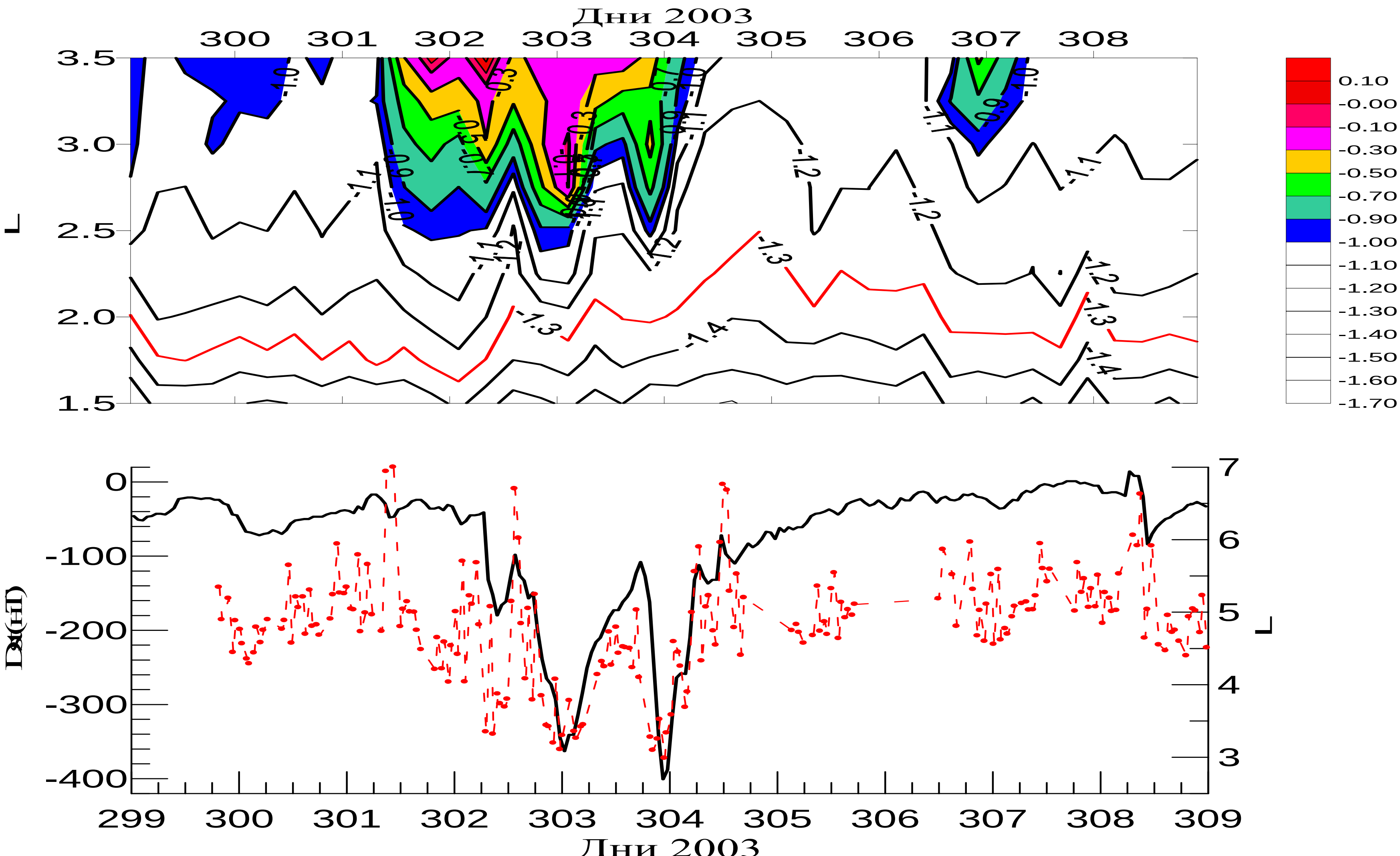
SEP penetration at low altitudes



– low-latitude boundary of SEP penetration

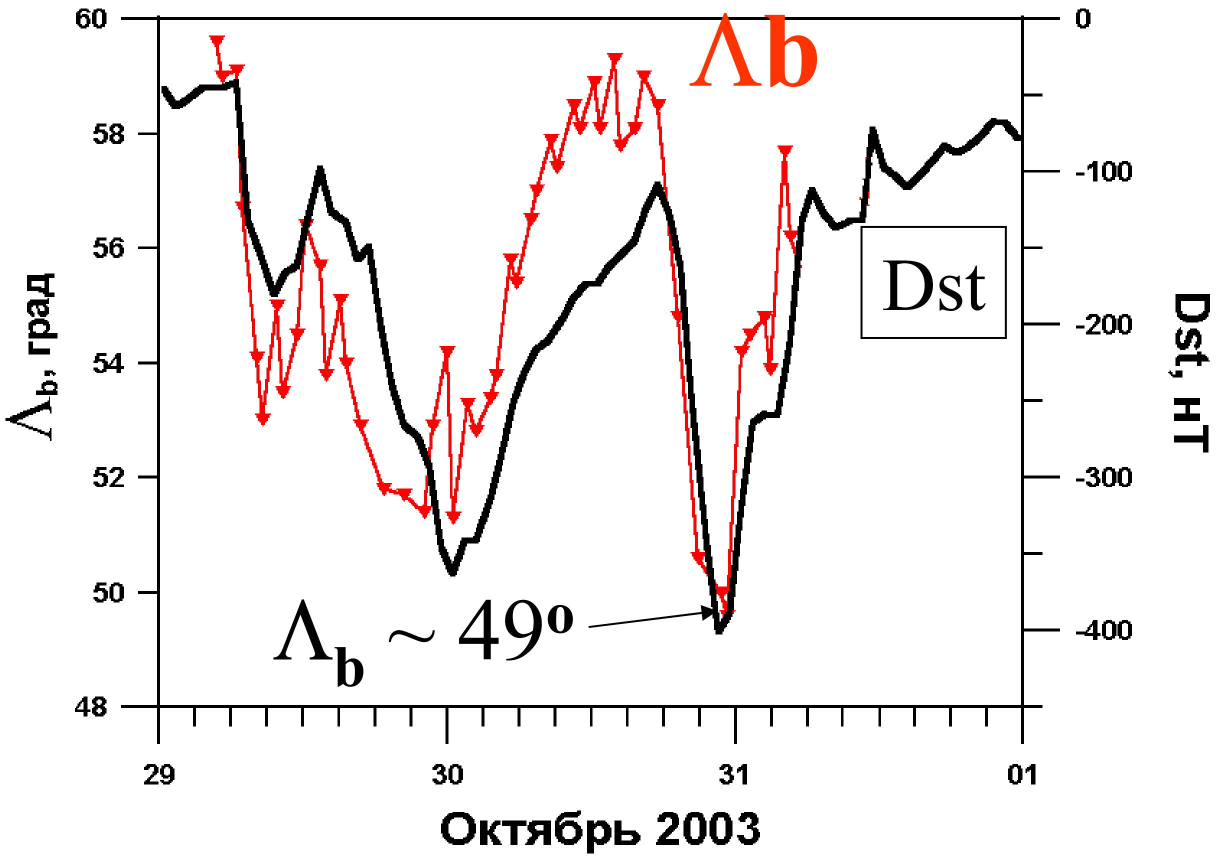
October- November'03 Radiation Storm

SEP penetration at low altitudes



October- November Radiation Storm

SEP penetration at low altitudes



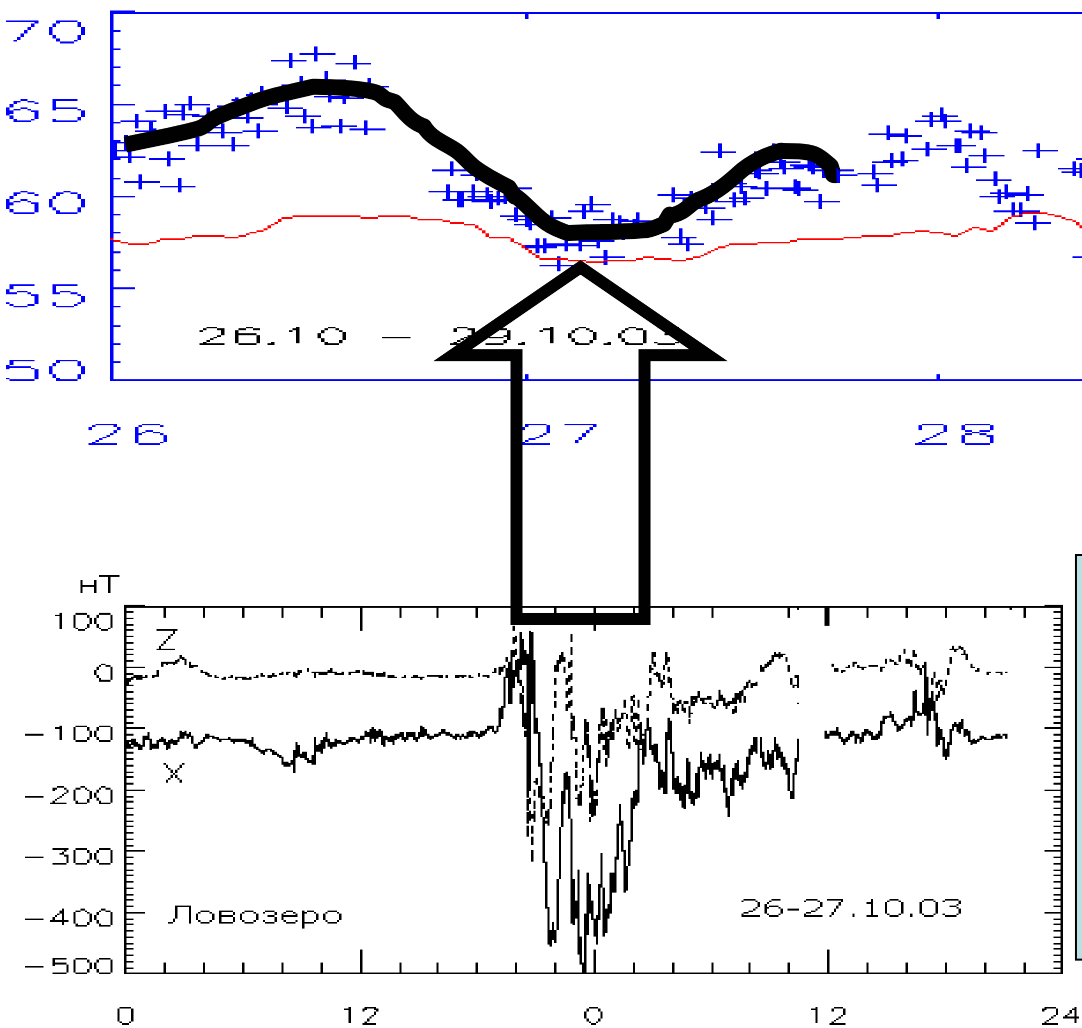
90 MeV proton's penetration boundary moves toward the equator accordingly with Dst

***Meteor-3 data**, Skobeltsyn Institute of Nuclear Physics,Applied Geophysical Institute*

October- November'03 Radiation Storm

SEP penetration at low altitudes

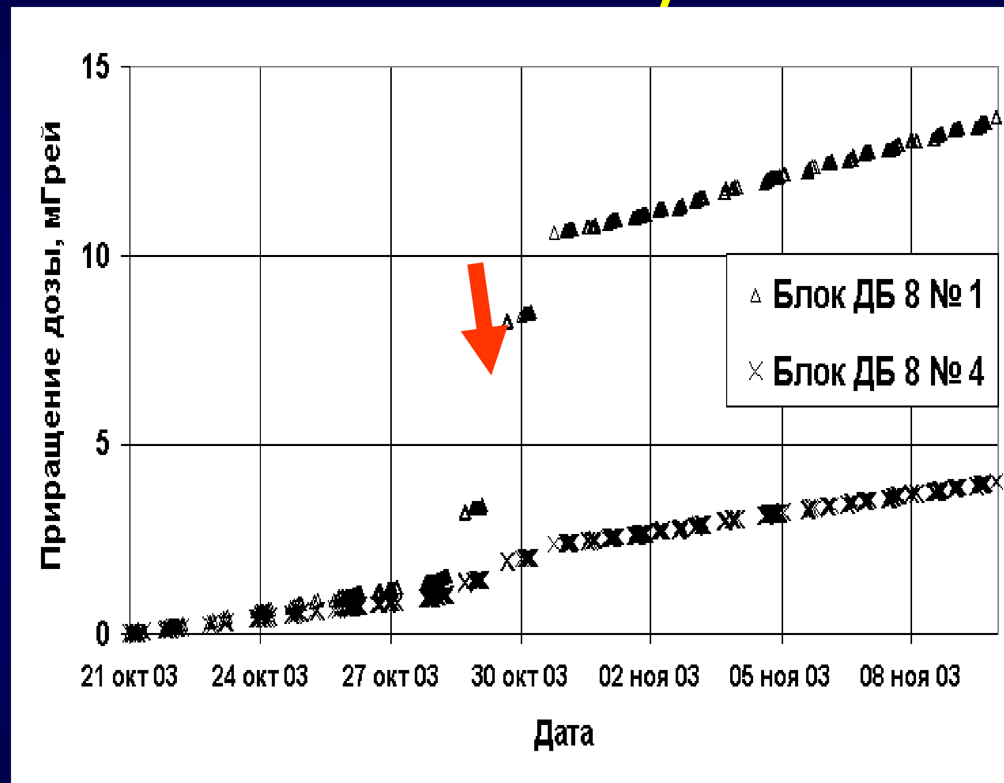
Variation of proton penetration boundary during isolated substorm



Substorm activity as a regulator of SEP's penetration

Radiation Storm of October- November,2003

ISS dosimetry



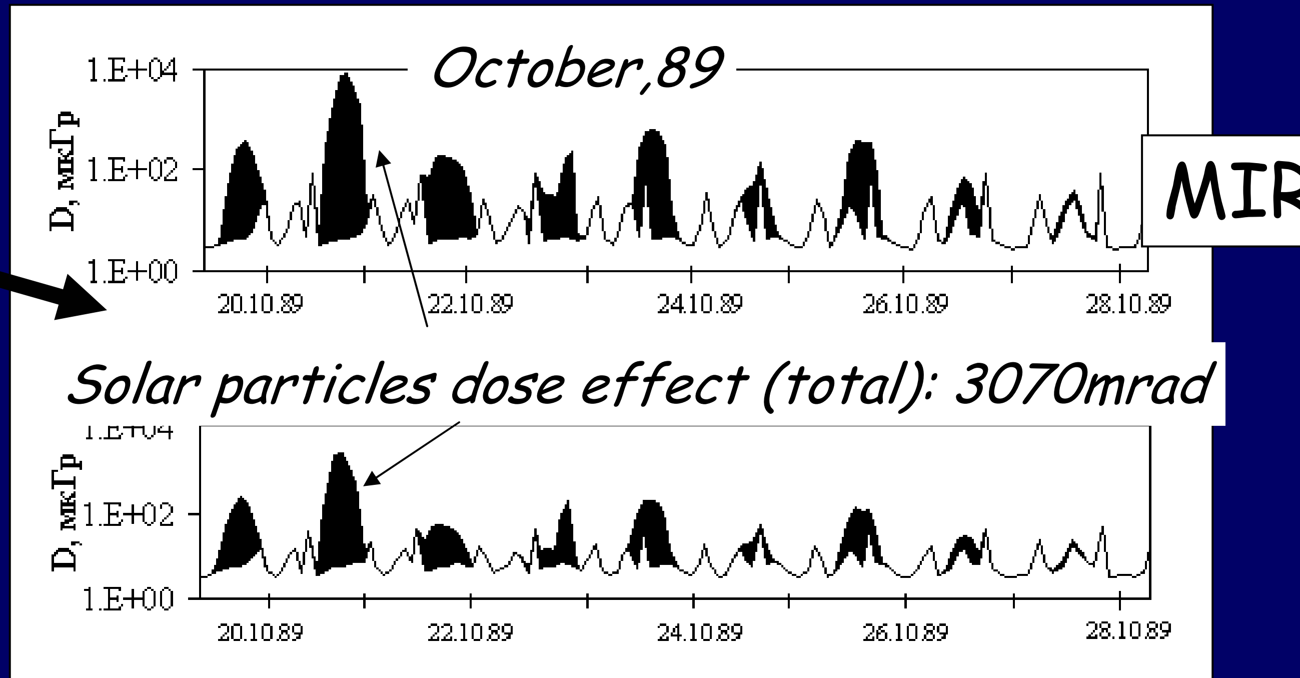
DB-8

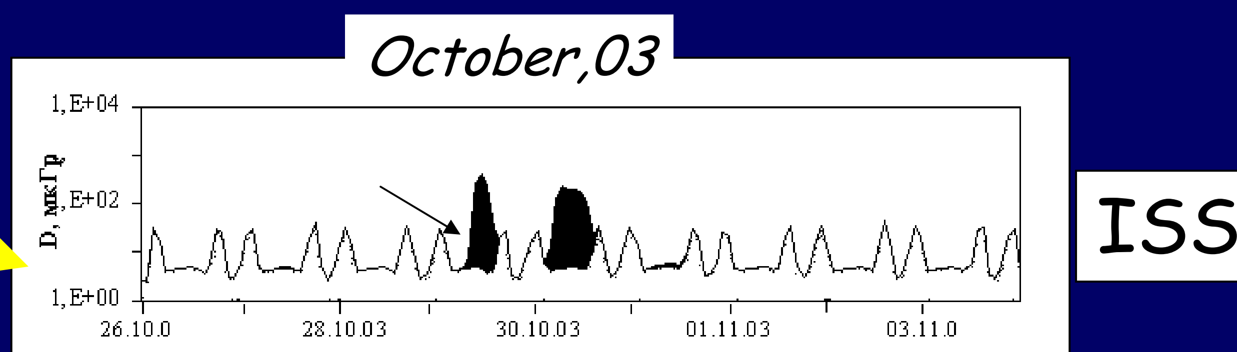
ISS/SRC,R16

data,

SINP, IMBP

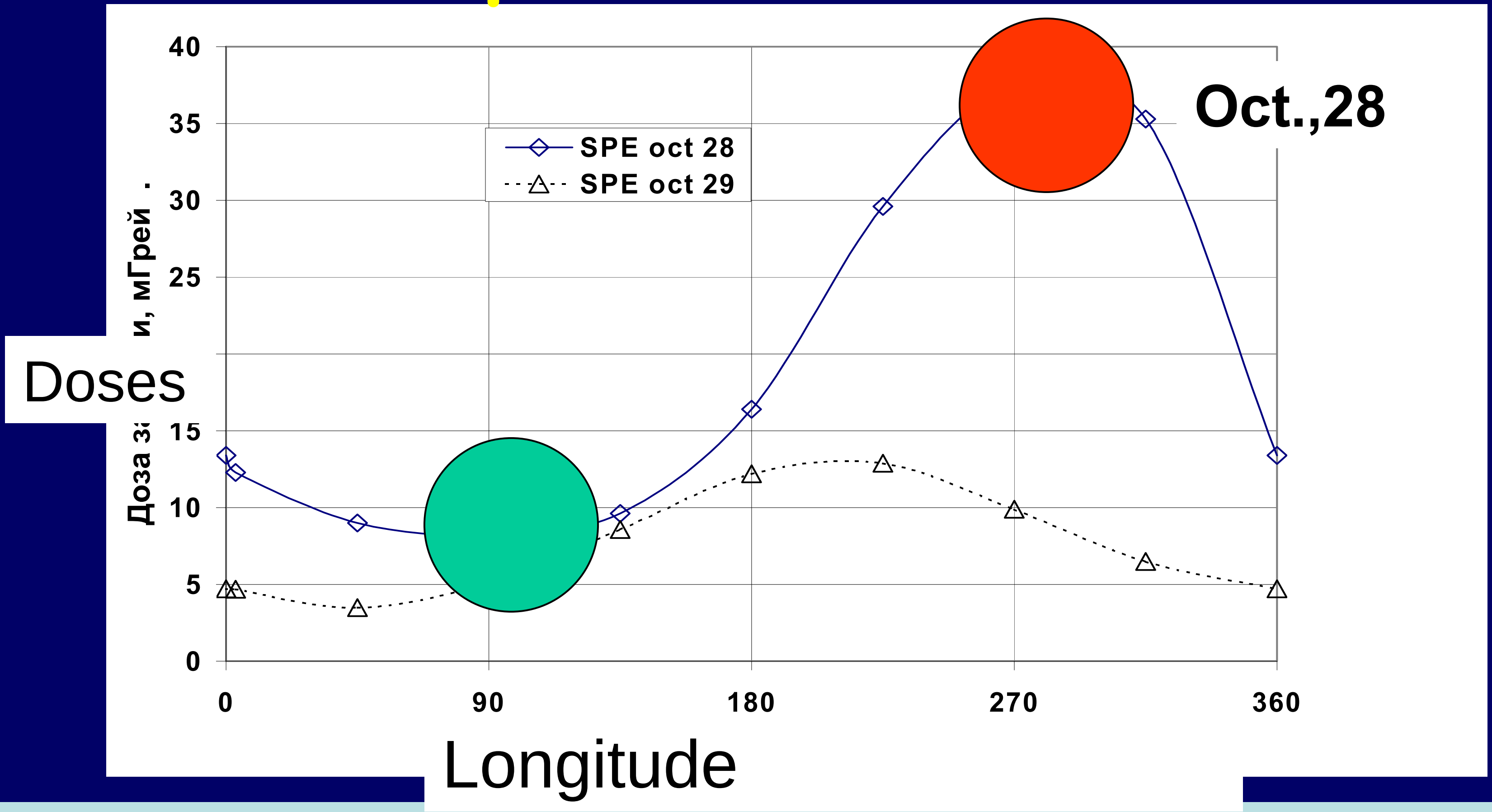
October- November' 03 vs October' 89 Radiation Storms: ISS/R16 data





Solar particles dose effect : 140mrad

Calculated ISS doses vs initial orbital parameters



Calculated doses fo DB8 in dependence of initial longitude of ISS for October, 28,29 event

Storm periods:

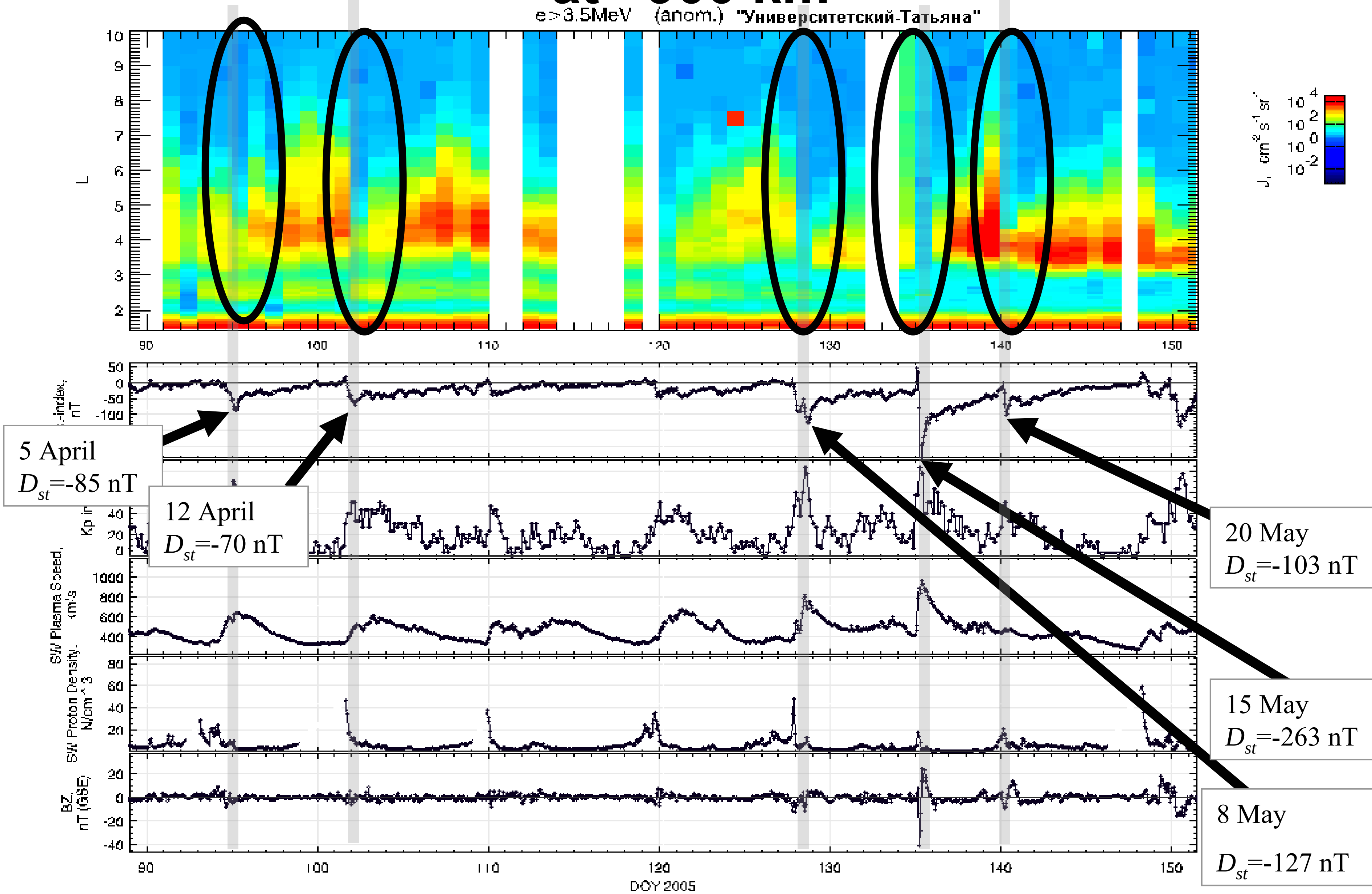
2. Relativistic electron precipitations from radiation belts

What's new in this field?

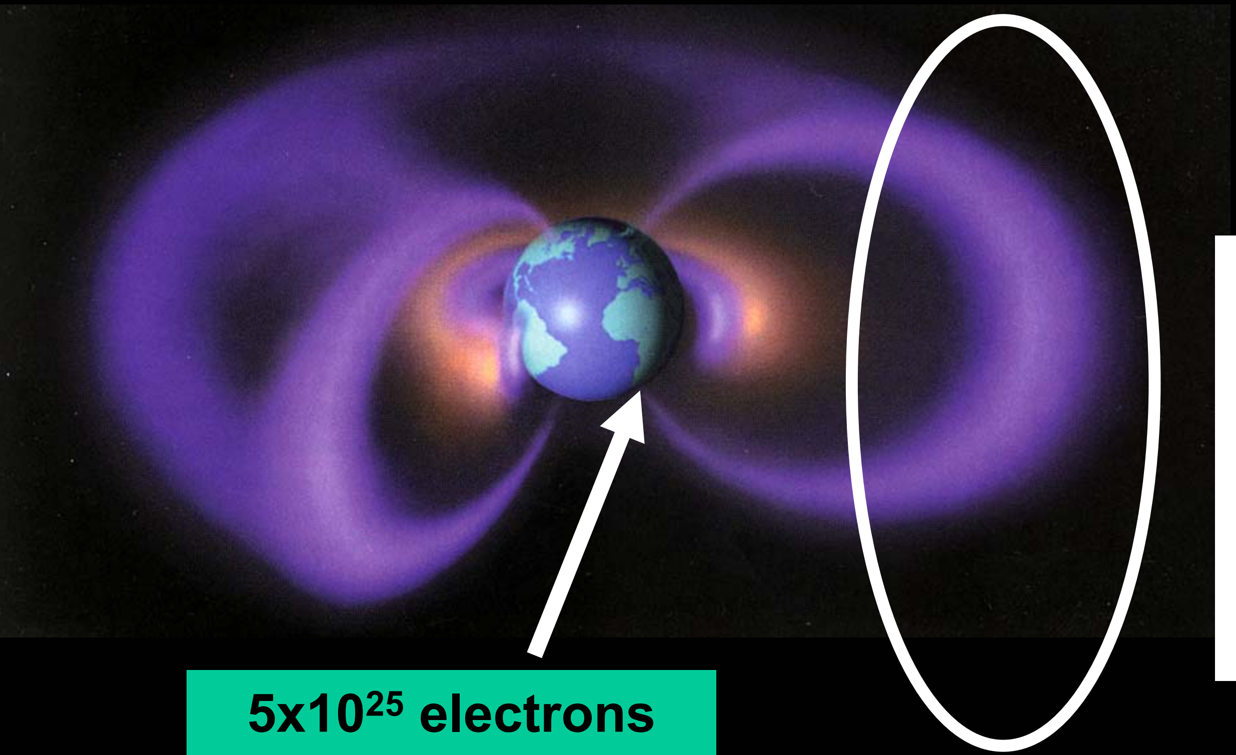
2. Relativistic electron precipitations from radiation belts

What's new in this field?

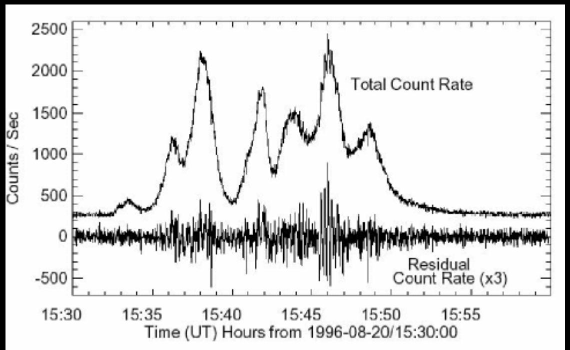
"Tatiana" satellite data E_e>3.5 МэВ) at ~900 km



“Catastrophic” precipitations of relativistic electrons



$5x10^{25}$ electrons during ~8 days



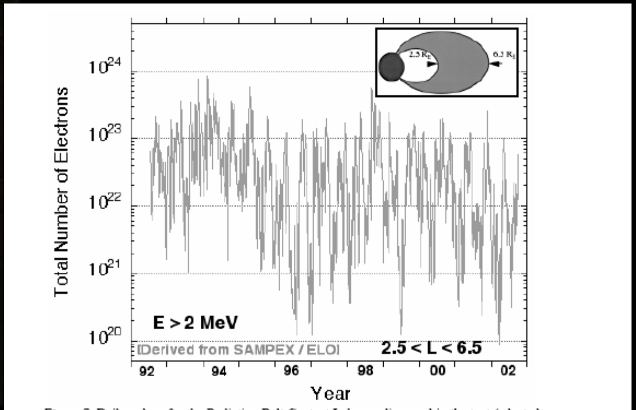
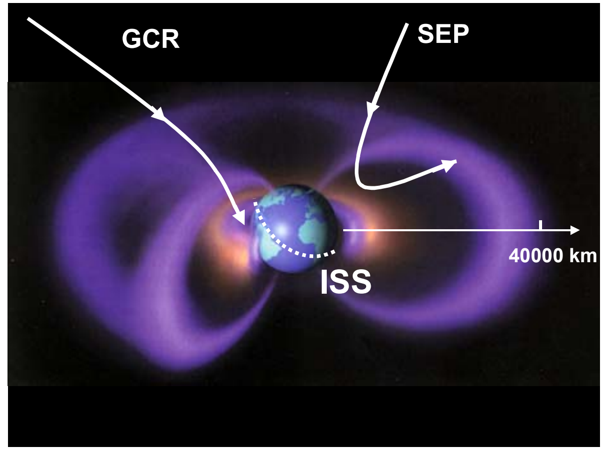


Figure 7. Daily values for the Radiation Belt Content Index as discussed in the text (adapted from Baker et al., 2003).

Outer belt:
$2x10^{25}$ electrons !

Balloon experiments at high latitudes
R. Myllan, et al

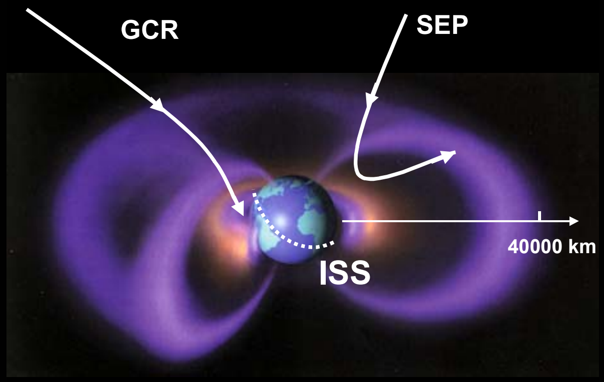


Conclusions

1. Radiation “quite-time” level at LEO is mainly defined by the balance between the strength of CRAND and losses at SAA;

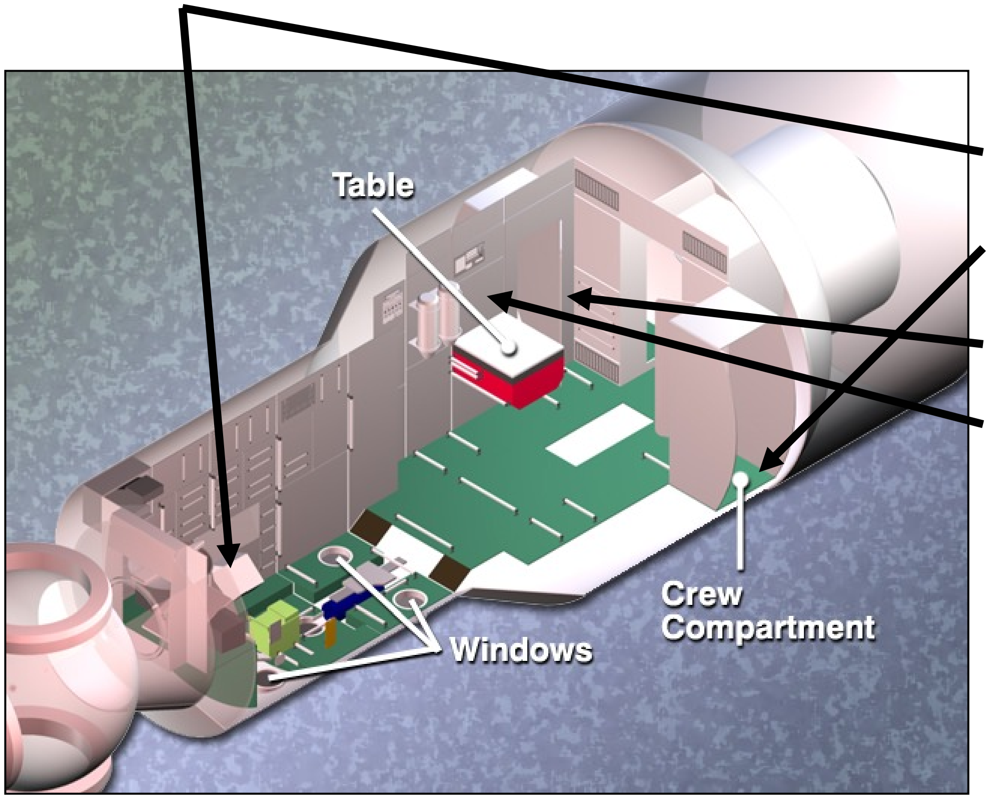
2. Radiation “ storm-time” level at LEO is mainly defined by SEP’s (>1 MeV) penetration pattern at low latitudes, which is ruled by substorm and storm activity;

3. More complex picture one should expect for electron component which is needed for further study



Thank you

SRC placements on board ISS



Блок	Расположение
ДБ-8 №1	Правый борт, за панелью № 410
ДБ -8 №2	Левый борт, за панелью № 244
ДБ -8 №3	Правый борт, за панелью № 447
ДБ -8 №4	Правый борт, за панелью № 435
Р-16	На потолке салона большого диаметра, за панелью № 327
АИ	Правый борт, за панелью № 447
БКР	Правый борт, за панелью № 447

SEP's doses rates from 2001 till 2003

Dosemeters		24.09.2001, mGrey(mRad)	04.11.2001, mGrey(mRad)	28.10.2003, mGrey(mRad)	29.10.2003, mGrey(mRad)
DB-8 № 1	nonshielded	1,65 (165)	2,60 (260)	6,63 (663)	2,02 (202)
	shielded	0,75 (75)	1,10 (110)	3,19 (319)	1,20 (120)
DB-8 № 2	nonshielded	1,26 (126)	1,14 (114)	2,88 (288)	0,906 (91)
	shielded	0,80 (80)	0,40 (40)	1,16 (116)	0,49 (49)
DB-8 № 3	nonshielded	0,59 (59)	0,75 (75)	2,20 (220)	0,86 (86)
	shielded	0,41 (41)	0,39 (39)	1,45 (145)	0,64 (64)
DB-8 № 4	nonshielded	0,19 (19)	0,09 (9)	0,73 (73)	0,28 (28)
	shielded	0,14 (14)	< 0,04 (<4)	0,60 (60)	0,246 (25)
R-16	nonshielded	1,25 (125)	0,60 (60)	> 0,60 (>60)	0,40 (40)
	shiekded	0,20 (20)	0,10 -0,15 (10)	0,25 -0,30 (25)	0,05 – 0,10 (5)

1. The value of doses highly dependent on particular place inside ISS
2. The value of doses - highly dependent on particular longitude of ISS during onset of SEP event