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Light Flashes in space: does low LET radiation have effects on brain functions?

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Content

- ALTEA program

    - results from ALTEA CNSM

- a model for Light Flash

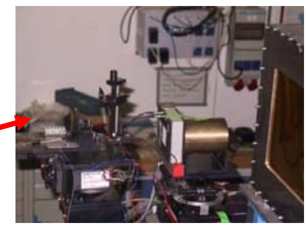
- the low LET possibility: from CNSM ..

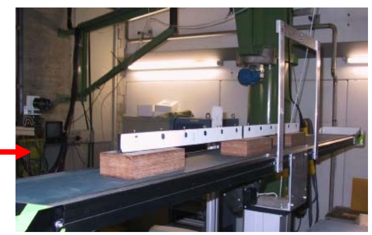
    to MICE

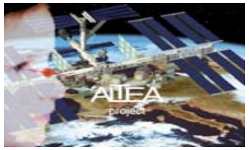
    to in vitro studies

    also a re-thinking of old results

- conclusions







ALTEA program: a multiple approach *(Financed by ASI and INFN)*

SilEye
MIR

ASI
SRAG-NASA
agreement




Experiment in Space on ISS

Alteino/ALTCRISS

On board ISS
since April 2002

ALTEA-space

ISS - July 4th 2006

ALTEA-shield

2010- 2012

ALTEA
shield

ground
exps.

ALTEA
L.F. questionnaire

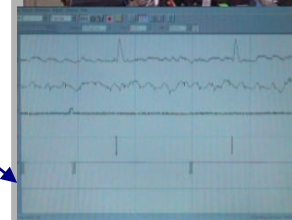
Published 2006

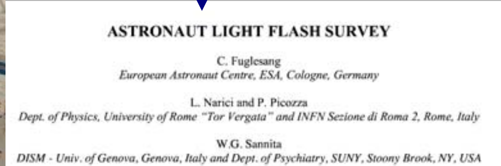
Controlled, laboratory based experiments

ALTEA-MICE
GSI-BNL
Started 2001

ALTEA-HIT
GSI
Started 2004

ALTEA-biophys
GSI-BNL
Started 2003



ASTRONAUT LIGHT FLASH SURVEY

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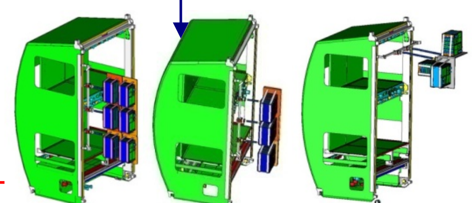

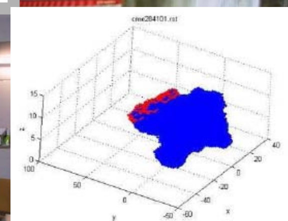

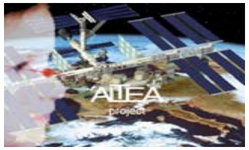

ALTEA: the international team

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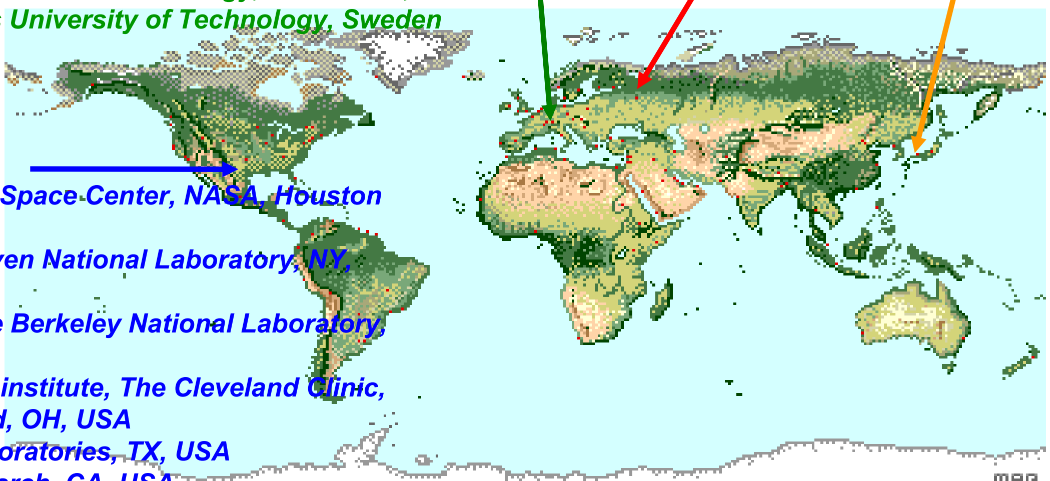
Dept. of Sc. and Chemical Tec., Univ. of Rome "Tor Vergata"
Dept. of STB - Univ. of L'Aquila, L'Aquila
GSI - Biophysik, Darmstadt, Germany
Royal Institute of Technology, Stockholm, Sweden
Chalmers University of Technology, Sweden

Institute for BioMedical Problems, Moscow, Russia.
Russian Space Corporation "Energia" by name Korolev, Korolev, Moscow region, Russia
Moscow State Engineering Physics Institute, Moscow, Russia

JAERI, Japan



Johnson Space Center, NASA, Houston TX, USA
Brookhaven National Laboratory, NY, USA
Lawrence Berkeley National Laboratory, CA, USA
Cole Eye institute, The Cleveland Clinic, Cleveland, OH, USA
Wyle Laboratories, TX, USA
Eril Research, CA, USA

+ others joining in

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Bencardino R.
Bengin V.
Benton E.
Bidoli V.
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Zaconte V.
Zampa N.
Zapp N.

ALTEA data acquisition - status and perspectives

≈ 1 year of DOSI data + ***7 CNSM***

Early 2009: DOSI ops up again

≈ 2010: Shield survey
shield
CNSM

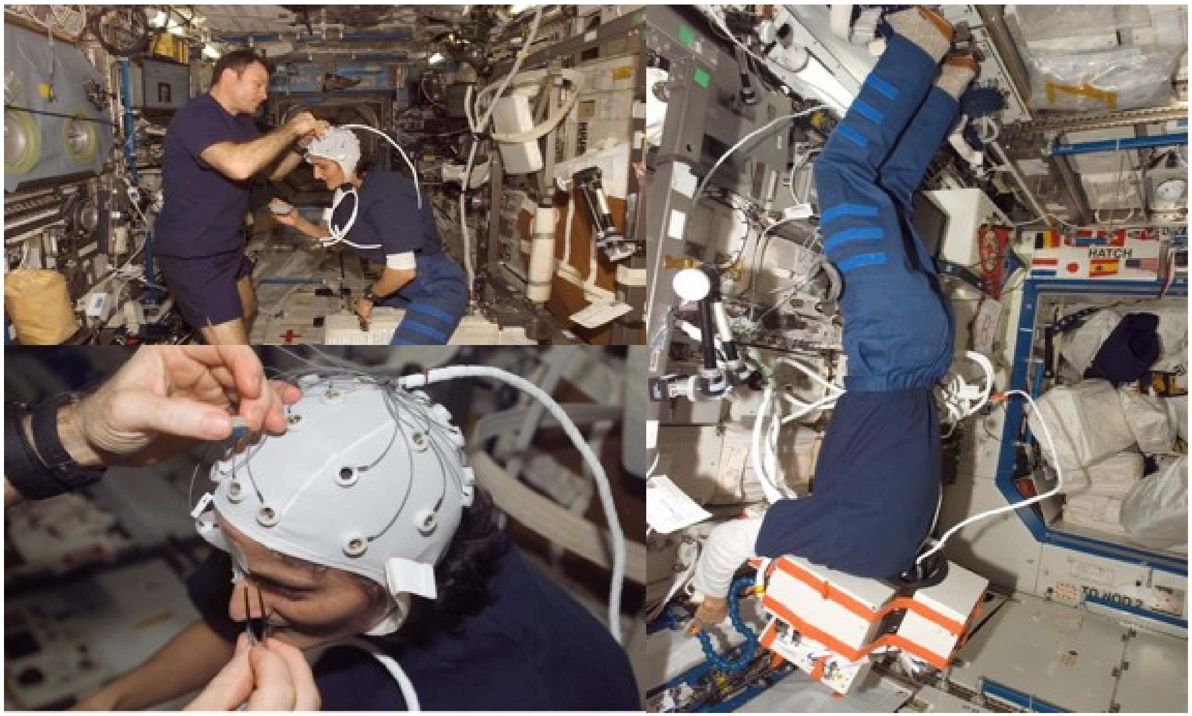
ALTEA reflight

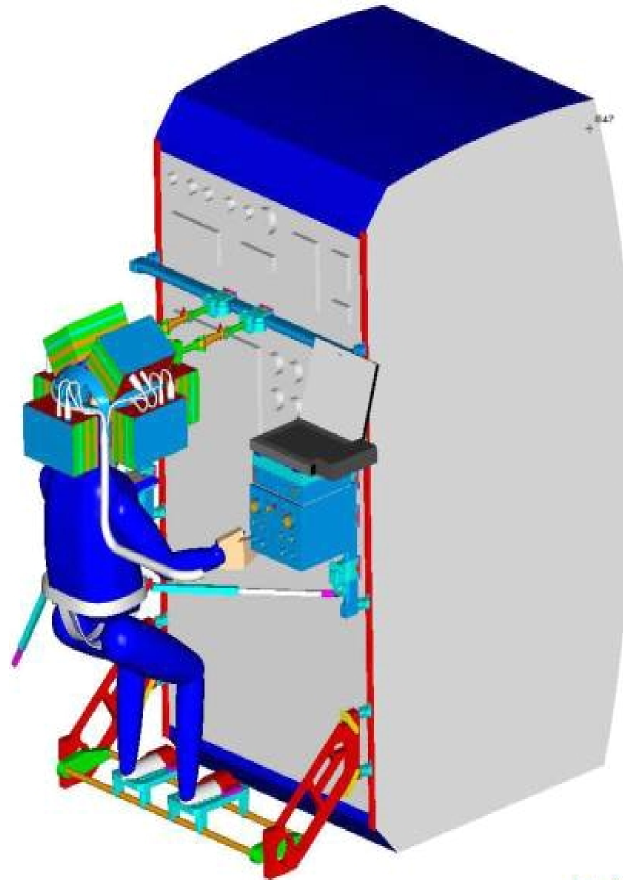
ALTEA2

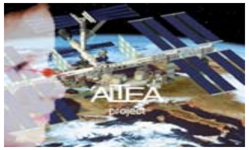
ALTEA Central Nervous System Monitoring

CNSM protocol:

- the astronaut wears the EEG cap
- slides into the detector
- relaxes during the stimulation
- signals the LF with the PB







ALTEA Central Nervous System Monitoring

- The LF rate - 1

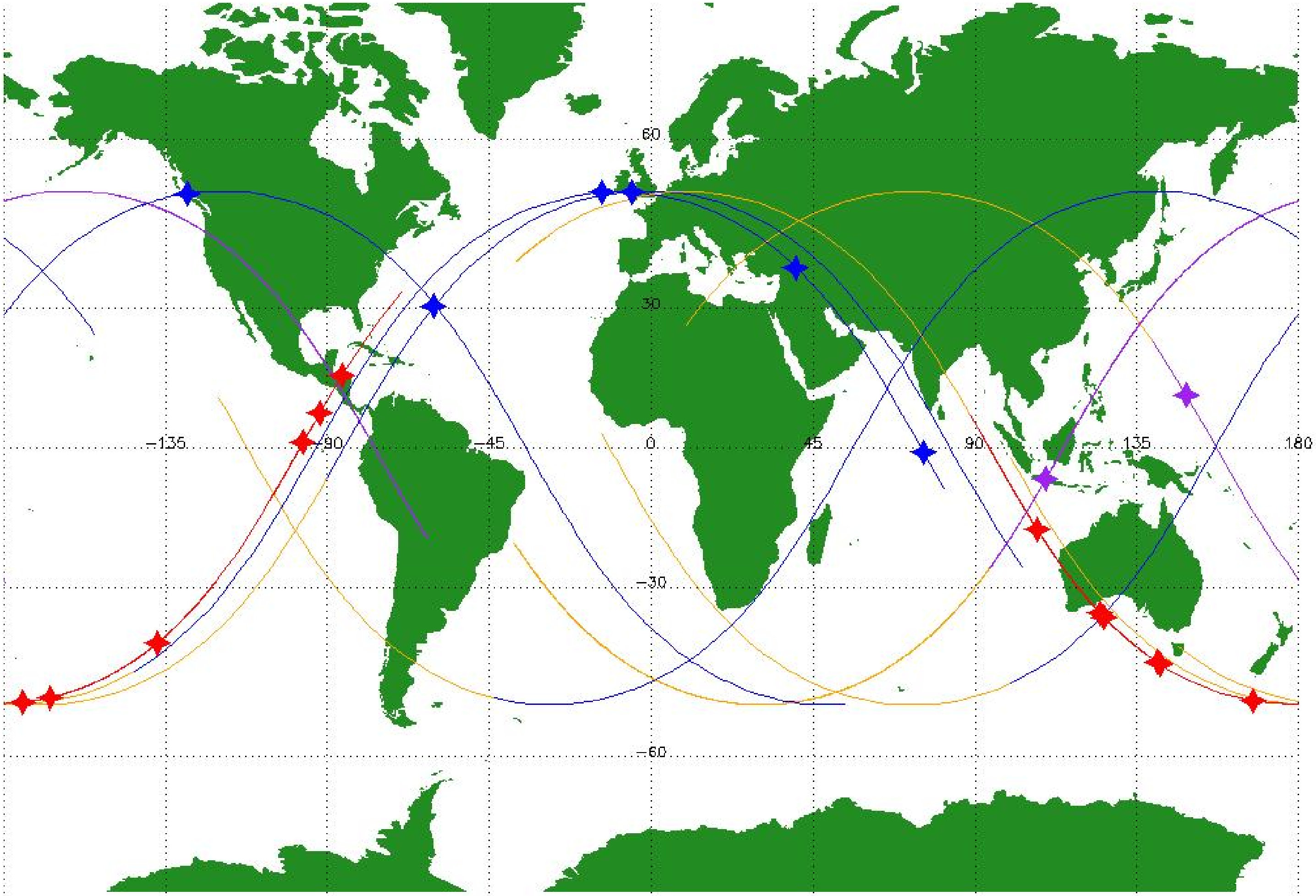
Astronaut	LF	Duration (min)	Mean interval between LF(min)
CF	**12**	58	5
MLA	**4**	65	16
SW	**1**	18	--
MLA	**0**	63	--
SW	**1**	61	--
MLA	**1**	62	--
MLA	**1**	87*	--
TOTAL	*20*	*414*	*21*

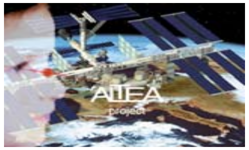
* *passage in the SAA*

ALTEA Central Nervous System Monitoring

- The LF rate - 2: the geographical distribution

CF
MLA
SW





ALTEA Central Nervous System Monitoring

• The LF rate - 3 - *Comparison with previous results*

Mission	Mean Time between LF (min)	Approx Min – Max Time between LF (min)
Apollo	4.3	1.3 – 8.6
Skylab	0.6	1.1 – 4.4 {***3.8 s in SAA***}
ASTP	2.2	0.8 – 6.0
MIR (SilEye)	6.8	3 - 13
ISS Pirs (Alteino)	10.5	6.4 – 22
ISS USLab (ALTEA)	20.7	5 – > 60

Rate lower than expected

- dark adaptation?
- shielding?
- comfort?

ALTEA Central Nervous System Monitoring

• ion counting in the eyes

Average ion rate per minute passing through both eyes of an astronaut
(with an estimation of Z and energy):

• *averaged over all 7 sessions*

	all	E<=100MeV	E>100MeV
all	22	4	18
z<6	21	4	17
z>=6	1	0,08	1

≈ 4 - 500 ions/min
in the brain

≈ 20 LF/7 h → ≈ 5 x 10^{-2} LF/min
with ≈ 2 x 10^{1} ions/min

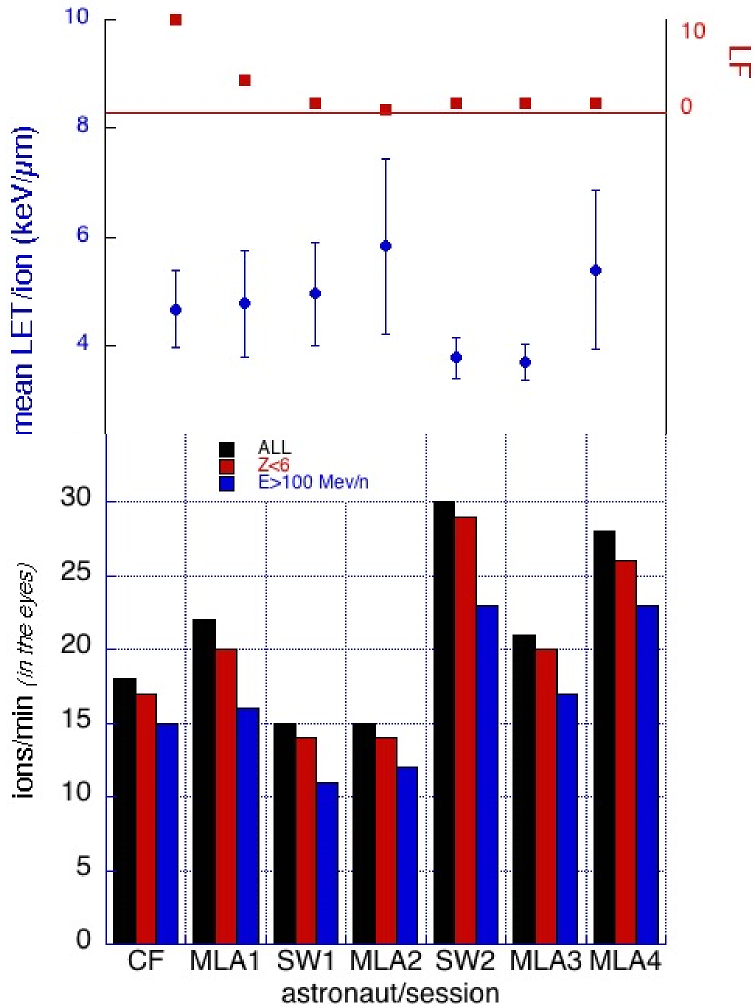
→ **≈ 2 x 10^{-3} efficiency**
higher limit
when considering other targets

• *first measurement of the charged radiation in the eyes in space*

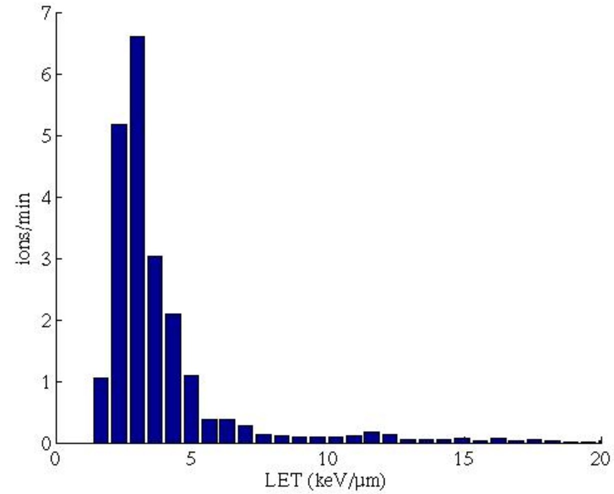
Searching for the ions generating LF - 5

- measuring the radiation in the eyes

- no relation between LET and LF



- ions/min values show variability across sessions

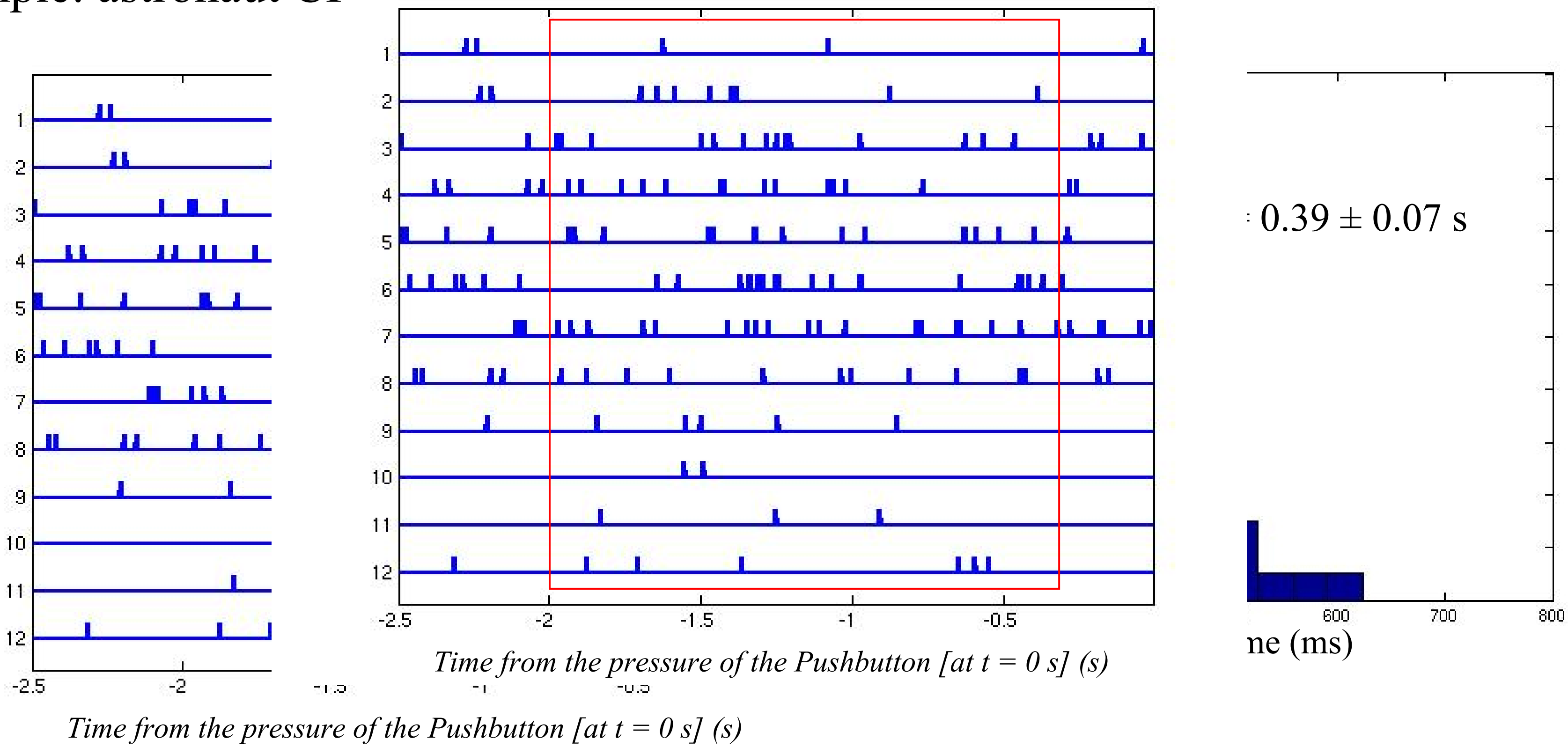


- Radiation in the eyes is mostly low LET

Searching for the ions generating LF - 1

- discriminating the radiation in the right eye, just before PB - 1

Example: astronaut CF

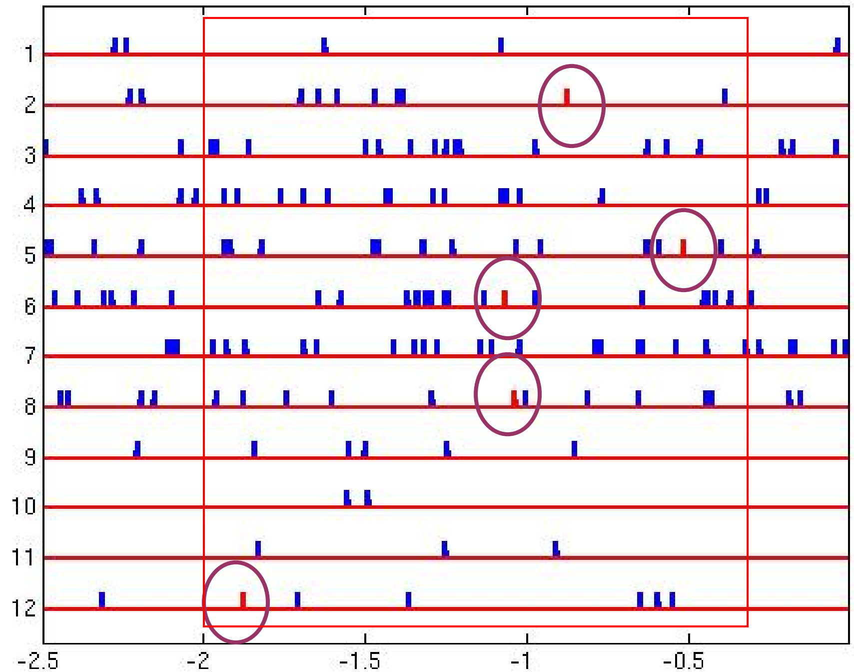


Ions detected by the ALTEA detector in the 2.5 s prior the pressure of the pushbutton

Searching for the ions generating LF - 2

- discriminating the radiation in the right eye, just before PB - 2

In red the ions traveling through the right eye

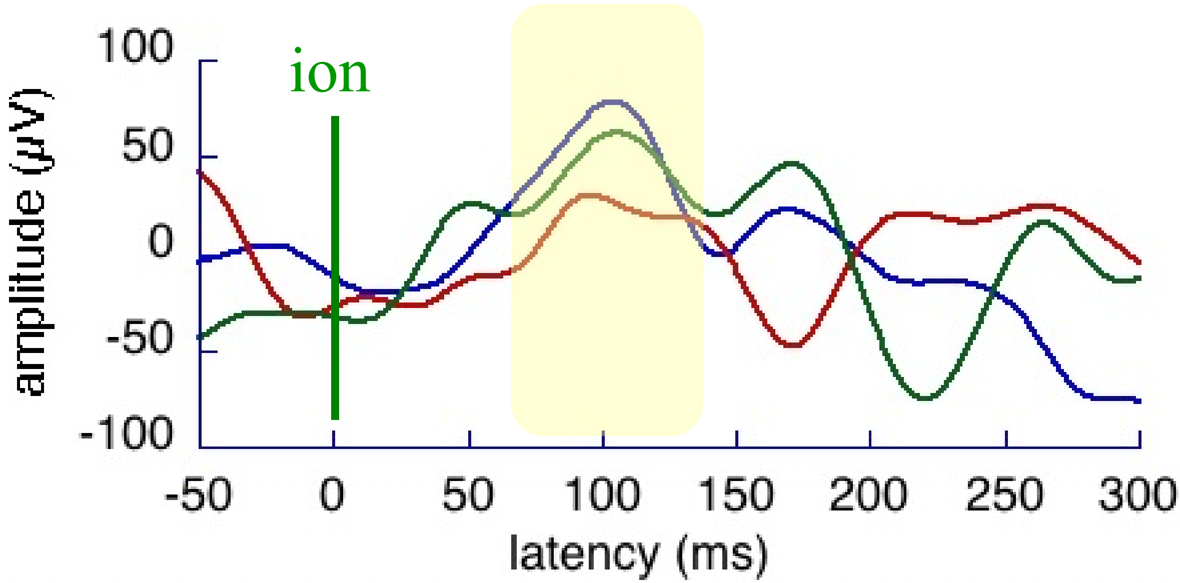


Time from the pressure of the Pushbutton [at t = 0 s] (s)

Searching for the ions generating LF - 4

• the electrophysiological candidates

We found three candidates from the retinal responses

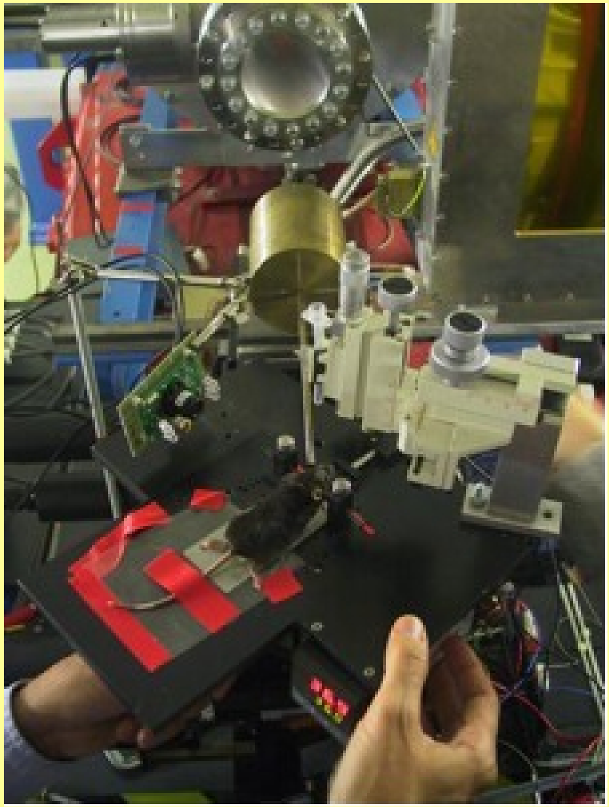


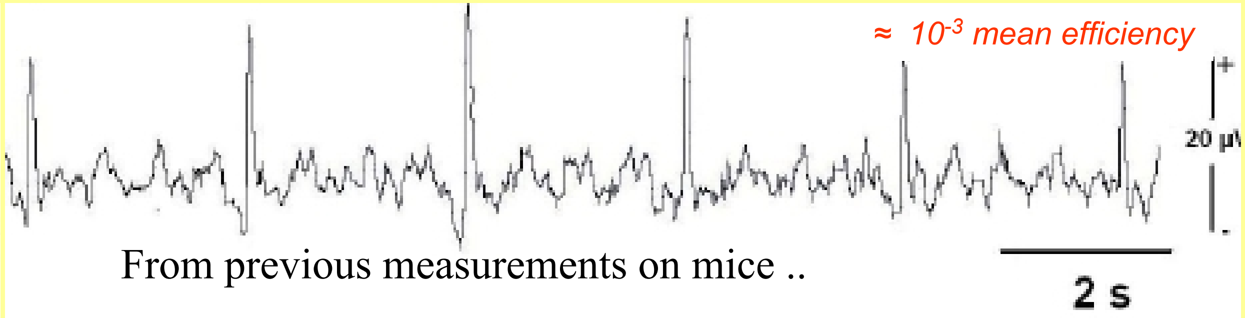
ratio of eye acceptance to SDS acceptance is ≈ 6.3

→ **we expect about 3-4 candidates**

Searching for the ions generating LF - 5

- comparison with MICE results

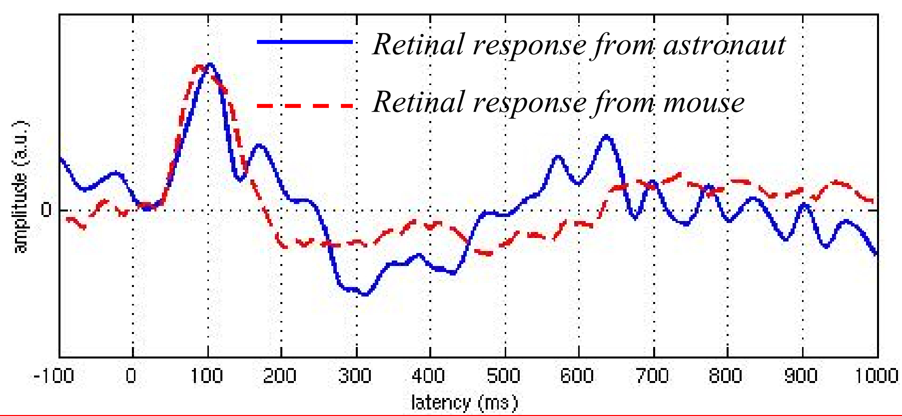




From previous measurements on mice ..

(*Sannita et al., Neurosci. Lett. 2007*)

..we may attempt a morphology comparison:



Searching for the ions generating LF - 6

- measuring the radiation in the right eye, before PB

- All ions in the 2 s before the PB, for all sessions

- These are the ions with the shown possible electrophysiological counterparts

All ions are low LET

<LET> in SDU *keV/μm*	estim versus	estim LET in eye *keV/μm*
4,3	**in**	**≈6**
2,9	**-**	**2,9**
2,9	**-**	**2,9**

- in all cases $1 \leq Z \leq 3$

Low LET & low Z?

• our measurements show that low LET and low Z can induce LF

Is this an indication that LET and Z do not play a major role?

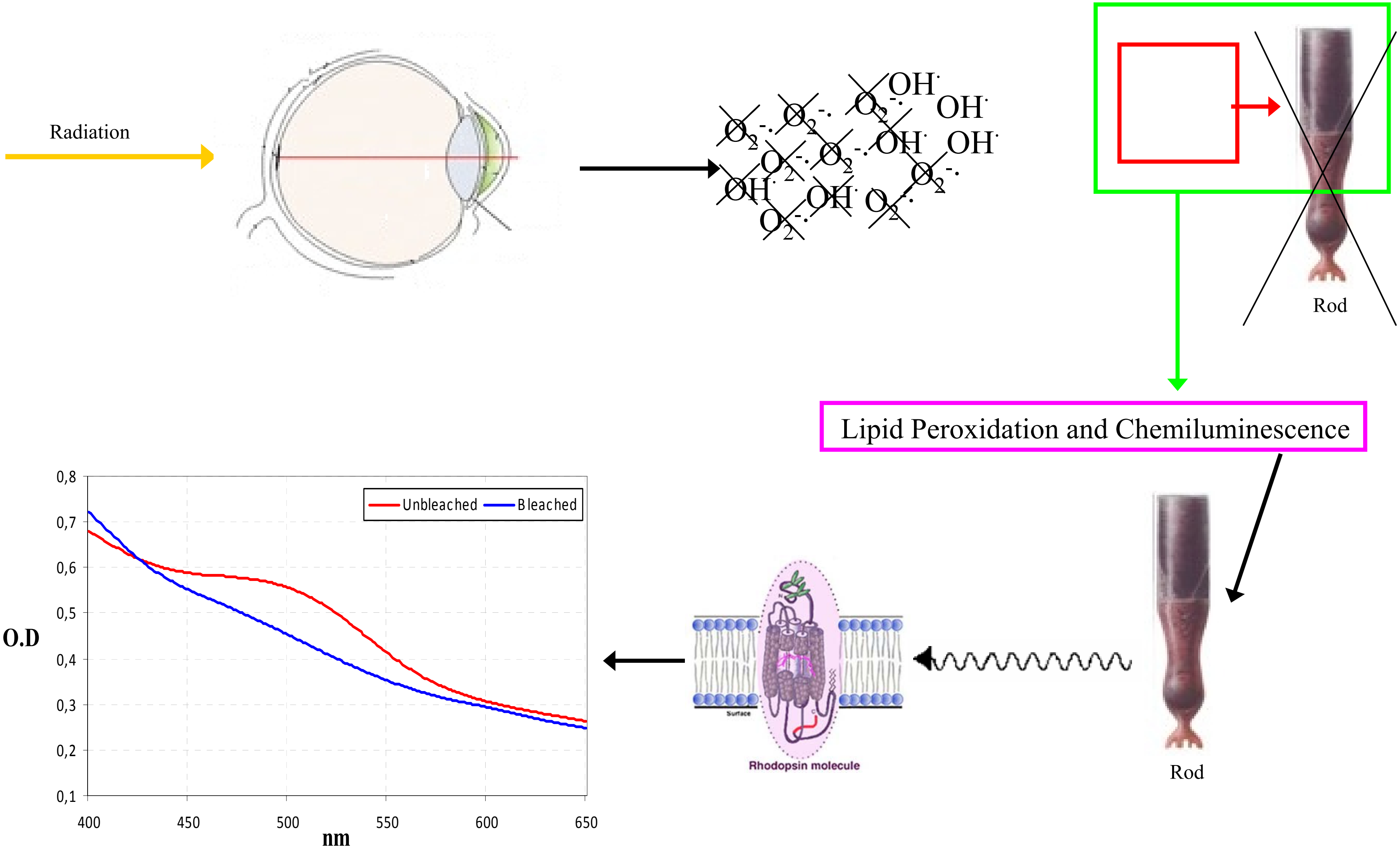
we see low LET and low Z just as due to the abundances of these ions..?

Or can be also suggested that LET and Z may play a role ..?

low LET and Z may be more favorable for generating LF?

We recently proposed a model which could help in providing suggestions ..

Experimental model for retinal interaction



Experimental model for retinal interaction

The model

• is in agreement with in vitro tests

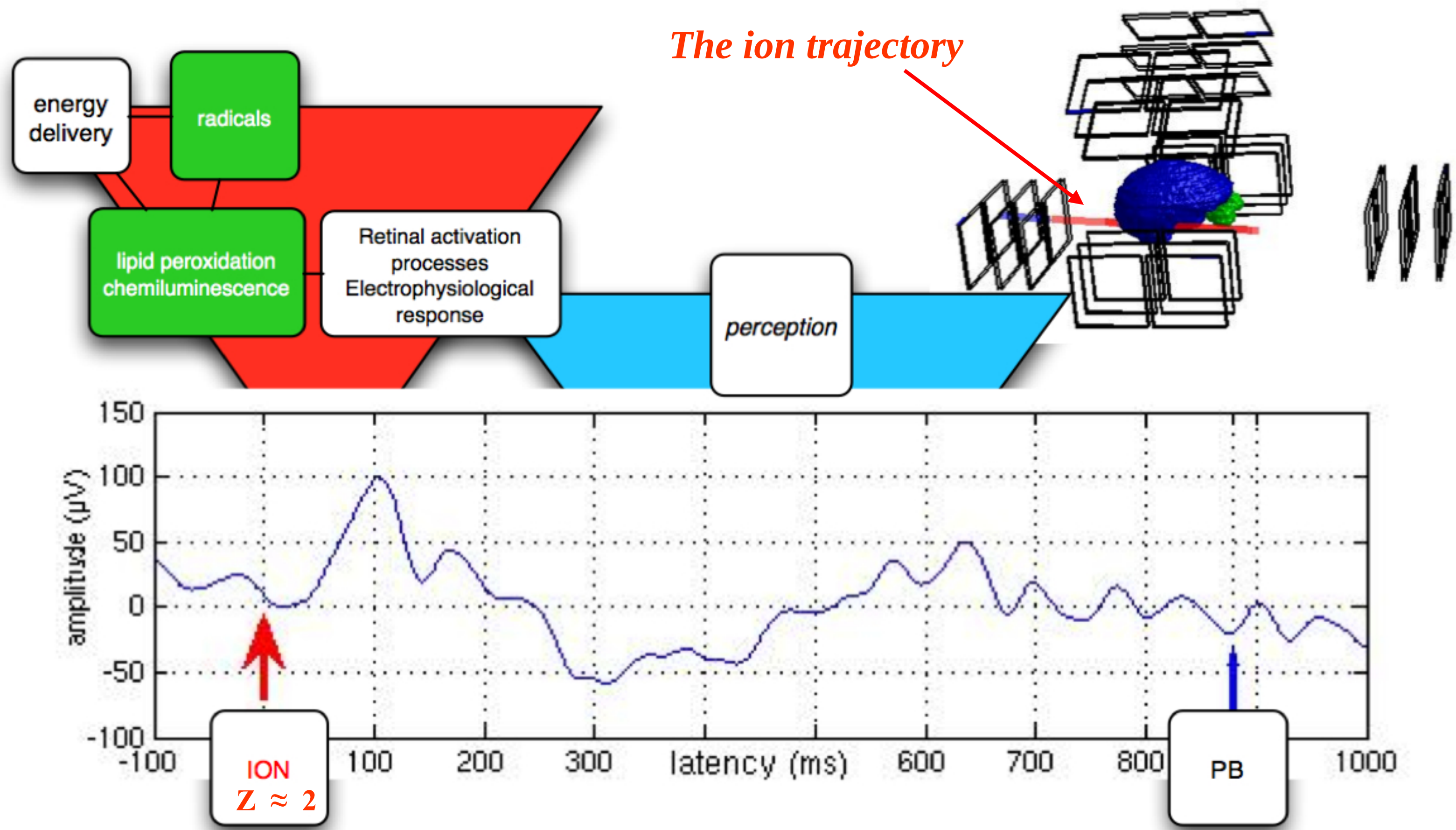
• is supported by the order o magnitude of the LF efficiency as measured in space and on ground (≈ geometrical cross section of portion of the retina)

• may help explaining the interindividual variability (concentration of antioxidant in the eyes, depending on stress, diet, etc)

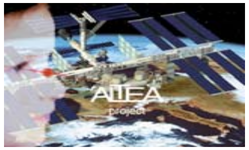
• describes a “signal” for a radical excess in the retina

Activity *flow* after the ion hit

- one of the electrophysiological candidates

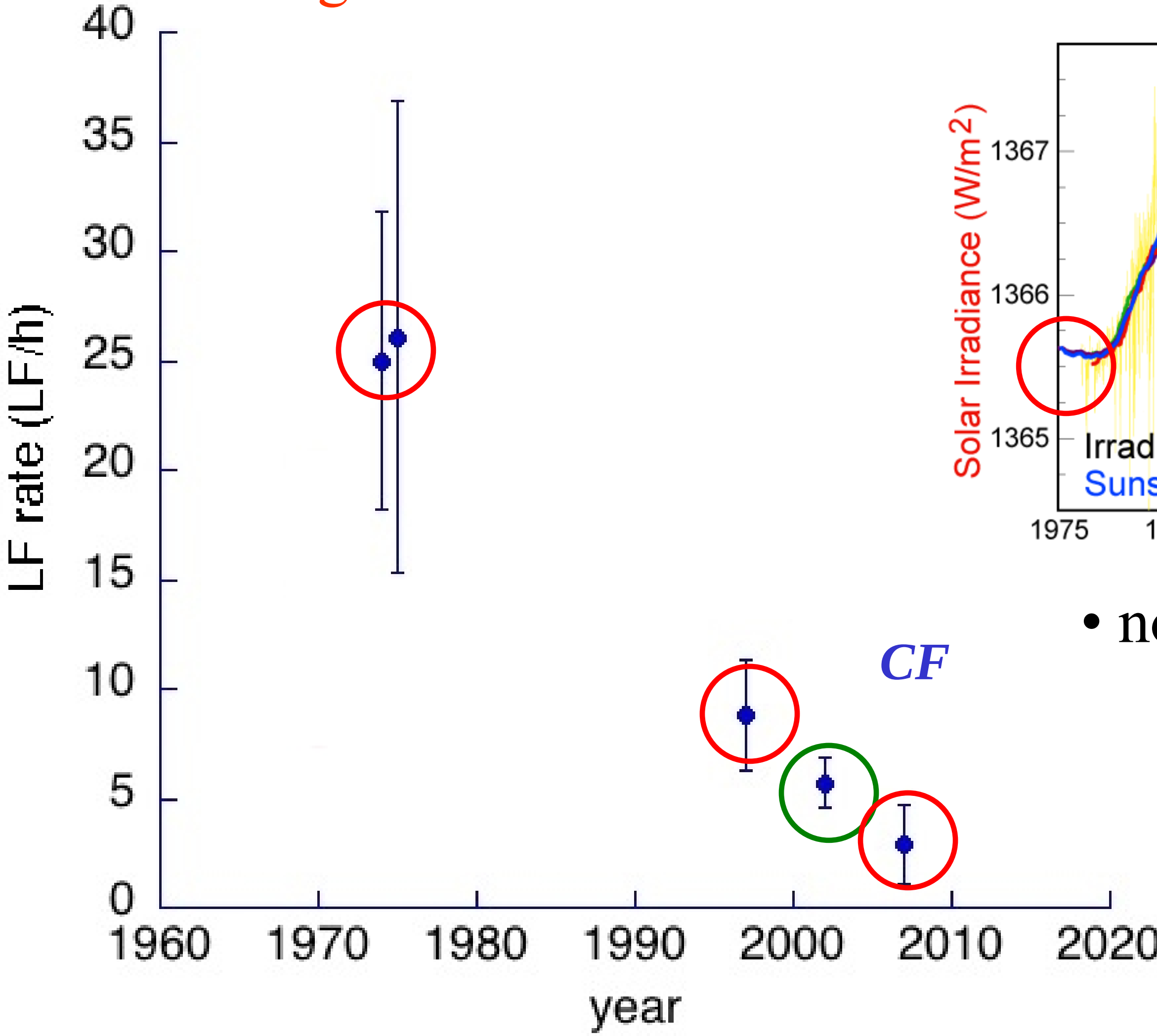


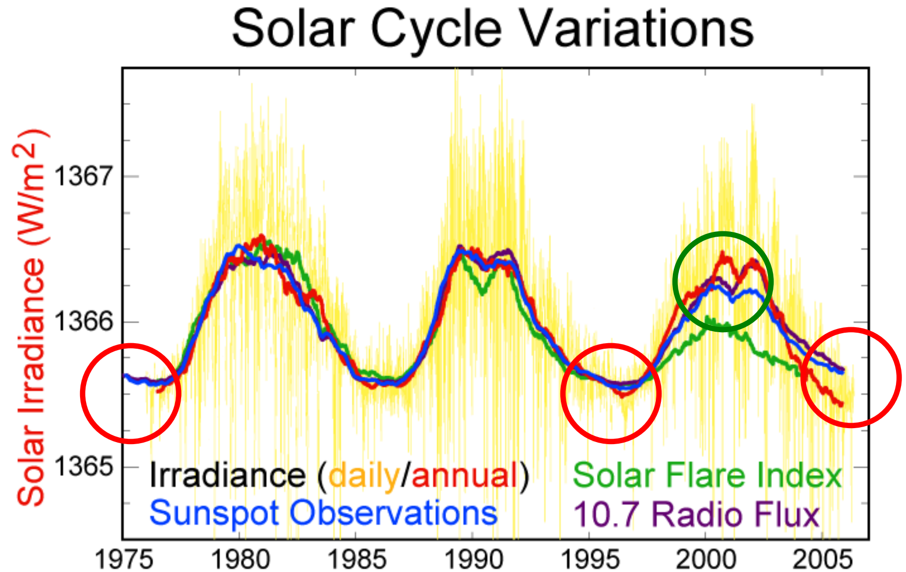
The retinal response candidate for the 2nd LF perceived by CF



Measured Light Flashes rates in space during 40 yrs

- decreasing rate??





- no evident reason for the decreasing rate

…. diet??

Low LET & low Z - 2

- a possible model

  - High LET and high Z produce a higher concentration of radicals

however

- Radicals can recombine before they diffuse

so

- Effects may have an inverse LET relation

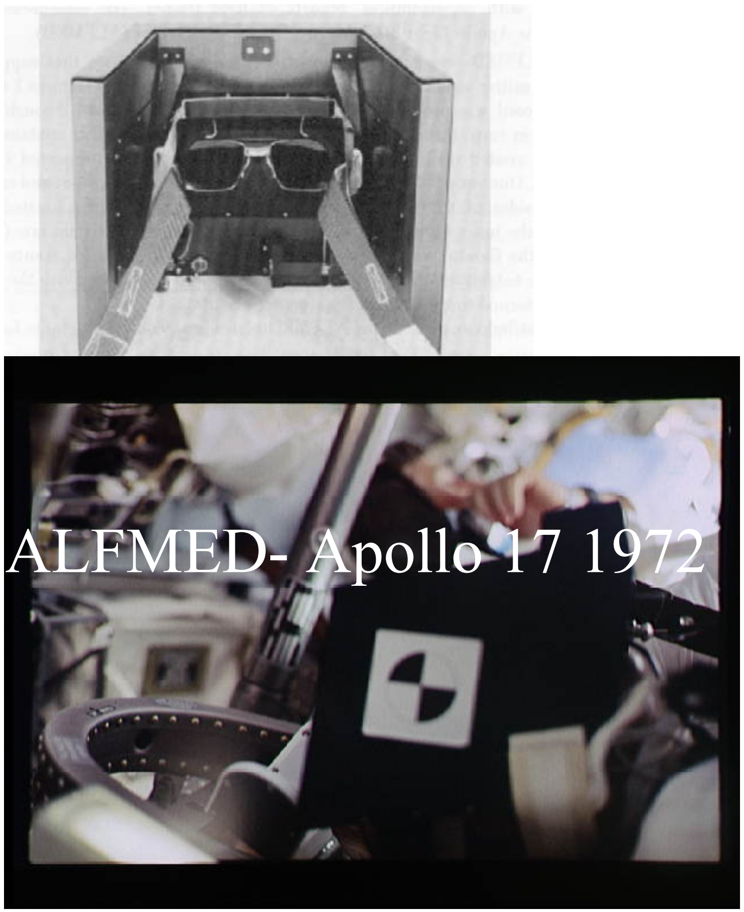
In our case there may be two competing requests:

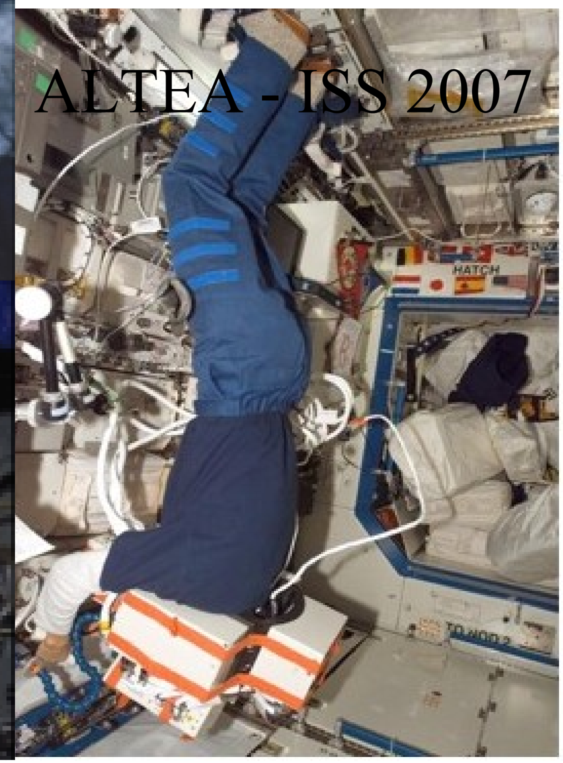
i) enough radicals to “reach” the Rods before being quenched
ii) .. not that many to avoid recombination before they diffuse

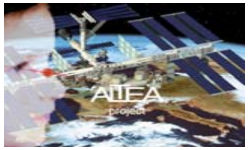
… how does this inverse LET/Z hint agree with previous space and ground findings?

Low LET & low Z - 3

- only three experiments in space able to suggest candidates







Low LET & low Z - 4

- how does ALTEA compare with previous measurements?

All the ions "candidates"as Light Flashes generators ever measured in space

mission	number		Z
Apollo (ALFMED)	2		> 8
MIR (SilEye2)	8:		
		3	2
		2	2-3
		2	8
		1	≈ 24
ISS (ALTEA)	*3*		*1-3*

More than 60% of all candidates have Z≤ 3!

Low LET & low Z - 5

- what about ground experiments - 1?

Very extensive measurements in the 70's.
They **leave open** suggestions for .. any LET or Z, for example:

He 240 MeV	40% 10/pulse	Budinger et al 1972
N 531 MeV/n	10% 1/pulse	McNulty et al 1972
C 595 MeV/n	10 - 66% 1 (or +)/pulse	McNulty et al 1978

Also quite recently:

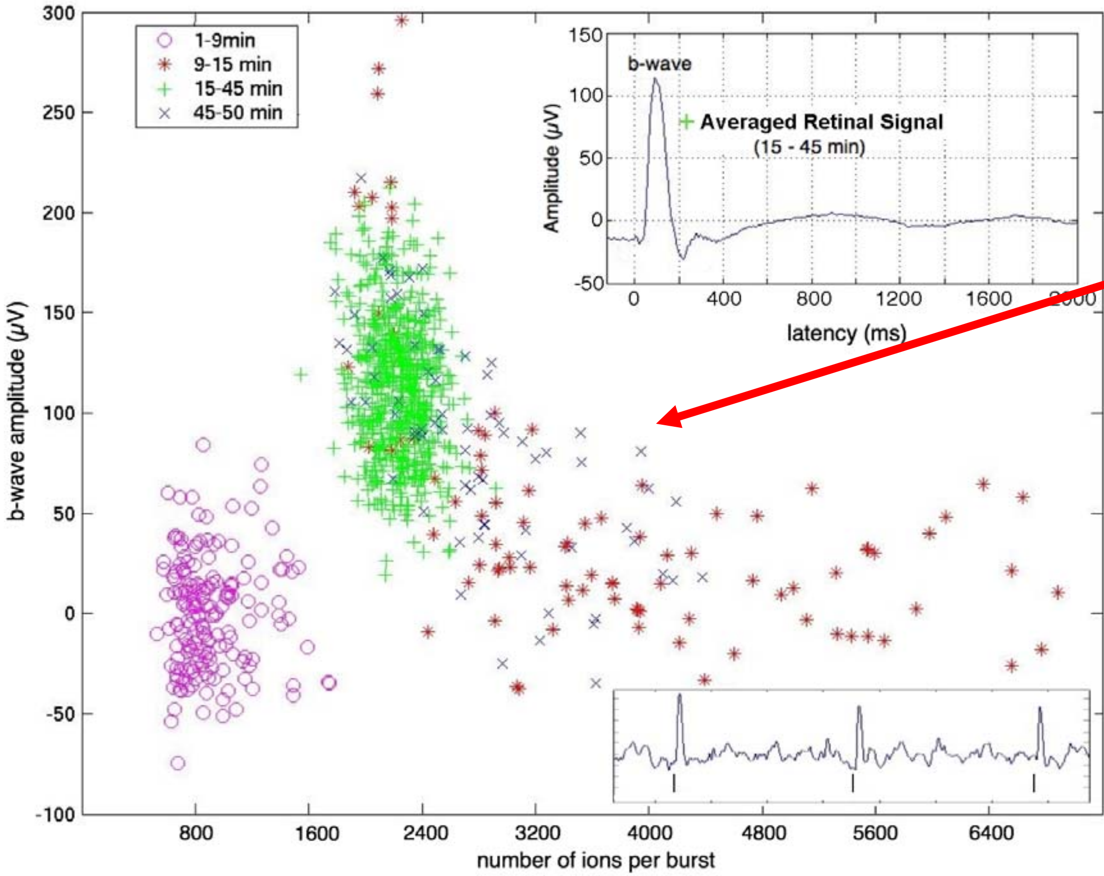
H 73 Mev	Orsay - patients report LF

Using the same rationale … 1

- what about ground experiments-2?

The Low LET rationale may explain the results in our MICE experiment

Sannita et al 2007

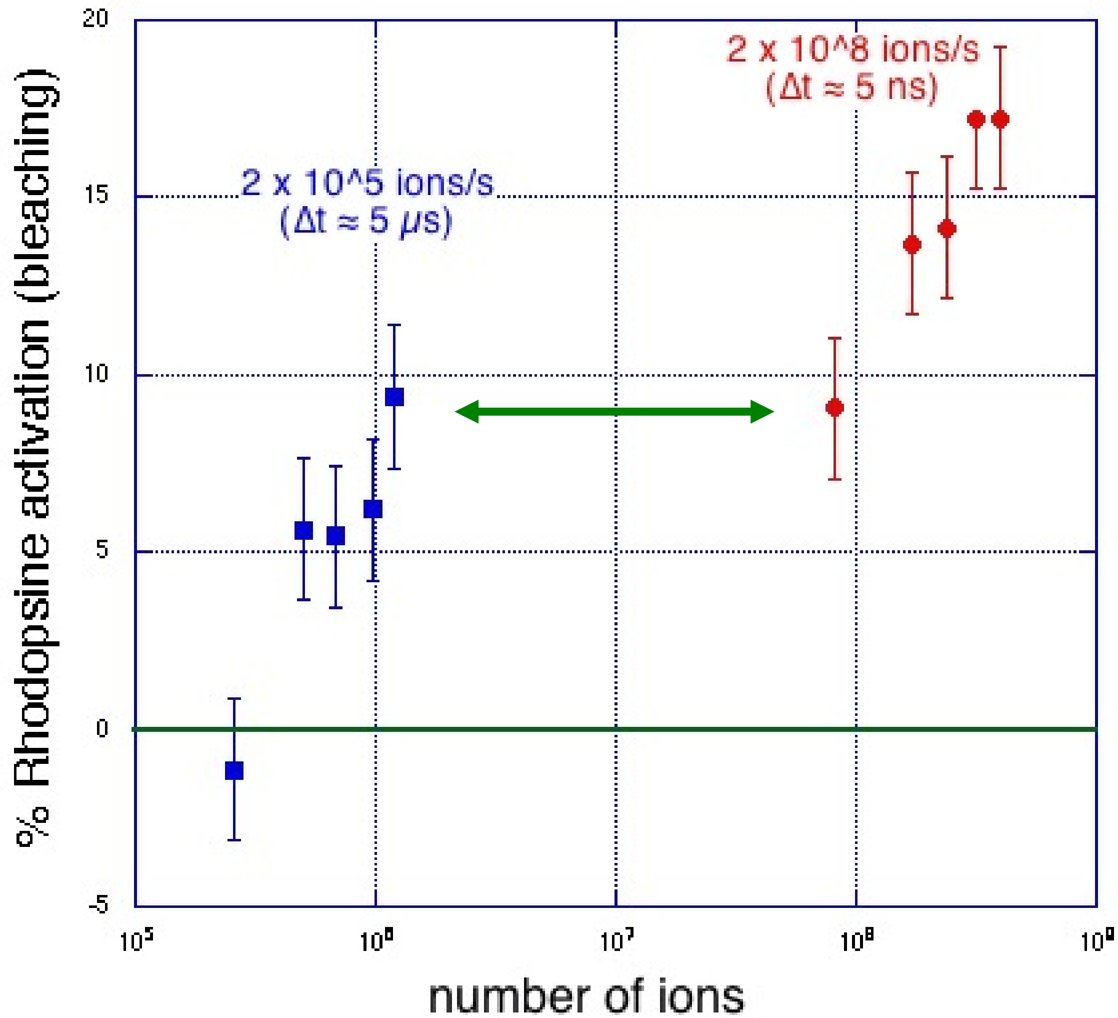


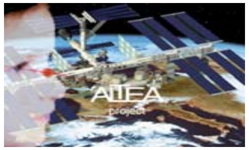
decrease of retinal response with increase of number of ions in the burst

Using the same rationale … 2

• what about ground experiments - 3?

• results of in vitro experiments using 12C to activate rhodopsine may be explained by the same rationale





Conclusion

• We provide the first measurement of the radiation impinging in the eye (and brain) of the astronauts

• We report retinal responses from radiation, in coincidence with LF

• LF appear generated by low LET and Z radiation

• There are several reasons to suggest that low LET and Z radiation may be at least equally able to generate LF than high LET and Z

• … and this may have influence in the countermeasures design

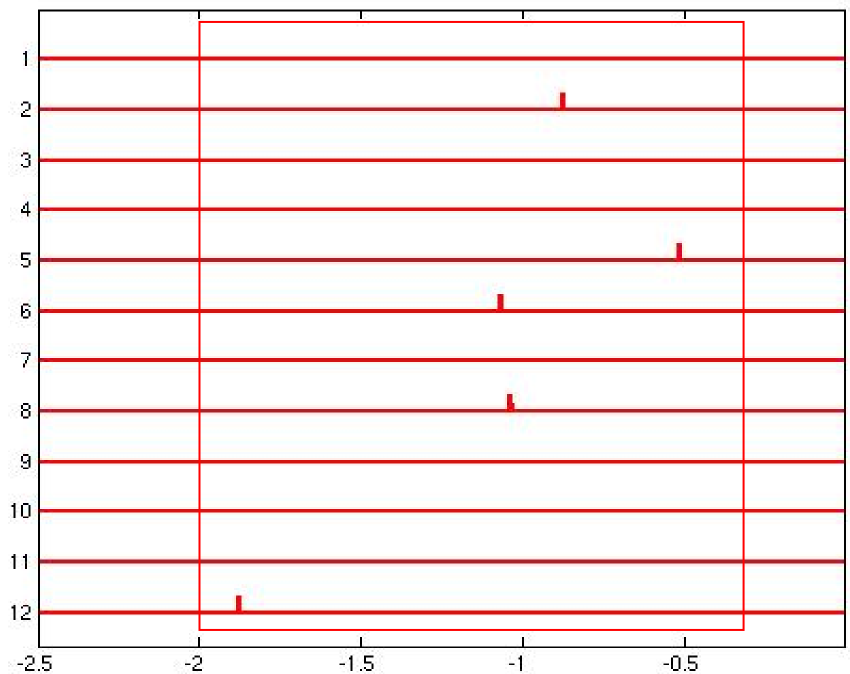
FUTURE (for the existing set of data):
• improve analysis to more detailed nuclear discrimination
• study cortical responses
• improve the model(s) and provide risk assessment

Thank you for your attention

Searching for the ions generating LF - 3

- discriminating the radiation in the right eye, just before PB - 3

In red the ions traveling through the right eye



Time from the pressure of the Pushbutton [at t = 0 s] (s)

SilEye: an experiment on MIR - 6

- results: light flashes

Table 4. Events in LF time windows and tracks through an eye (all data)

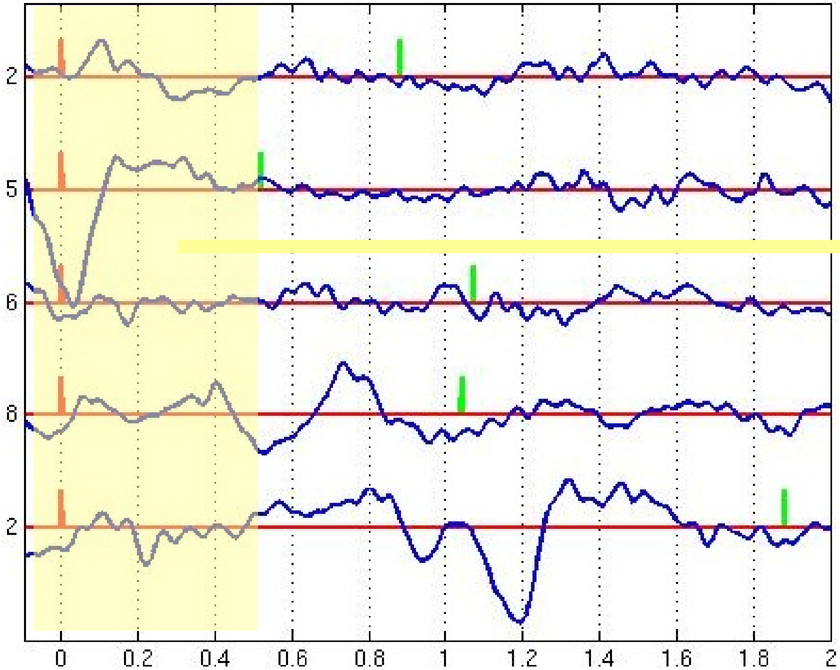
Time-cut	All time (48 850 s)				In LF time window (total: 116 s)			
Eye-cut	All data		Track through eye		All data		Track through eye	
Event	Number	Rate (Hz)	Number	Rate (Hz)	Number	Rate (Hz)	Number	Rate (Hz)
Protons (p)	115 508	2.50 ± 0.01	59 414	1.29 ± 0.005	557	5.1 ± 0.2	[illegible]	2.8 ± 0.2
Nuclei (N)	858	0.0186 ± 0.0006	479	0.0104 ± 0.0005	11	0.10 ± 0.03	8	0.074 ± 0.026
Showers	4434	0.0960 ± 0.014	—	—	10	0.091 ± 0.029	—	—
LF	116	0.0024 ± 0.0002	—	—	116	1	—	—
N/p	0.0074 ± 0.0002		0.0081 ± 0.0004		0.020 ± 0.006		0.026 ± 0.009	
Showers/p	0.0384 ± 0.0006		—		0.018 ± 0.006		—	

3 ions Z = 2 (He)
2 ions Z ≈ 2-3 (He or Li)
2 ions Z ≈ 8 (O)
1 ion Z ≈ 24 (Cr)

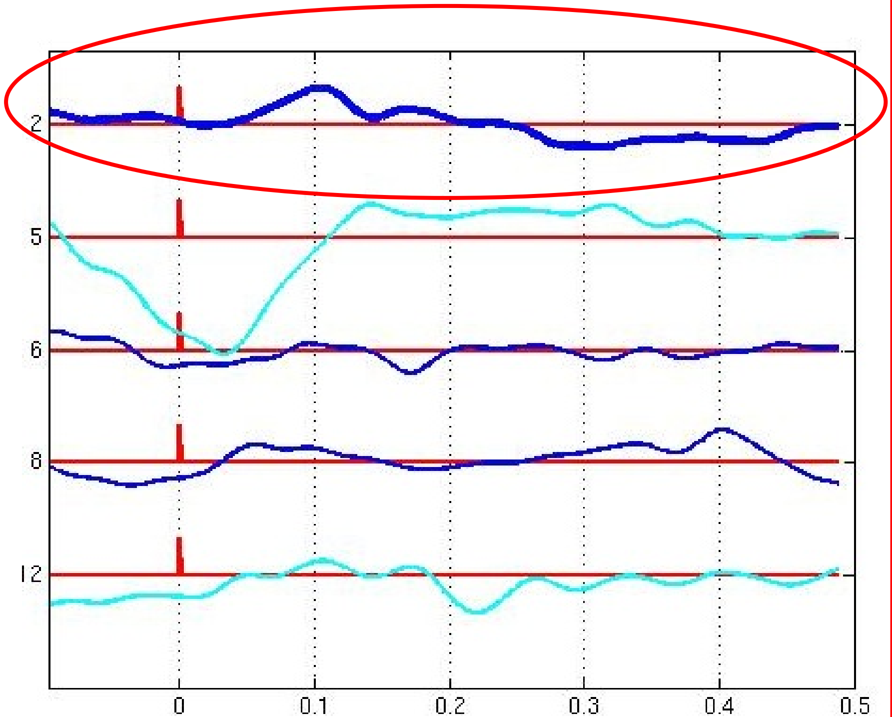
Note: very small solid angle: geometrical factor = 100 cm²/sr

Linking ions and electrophysiology 4

The red eye retinal signal following the identified ions (in red). Pushbutton pressures in green.

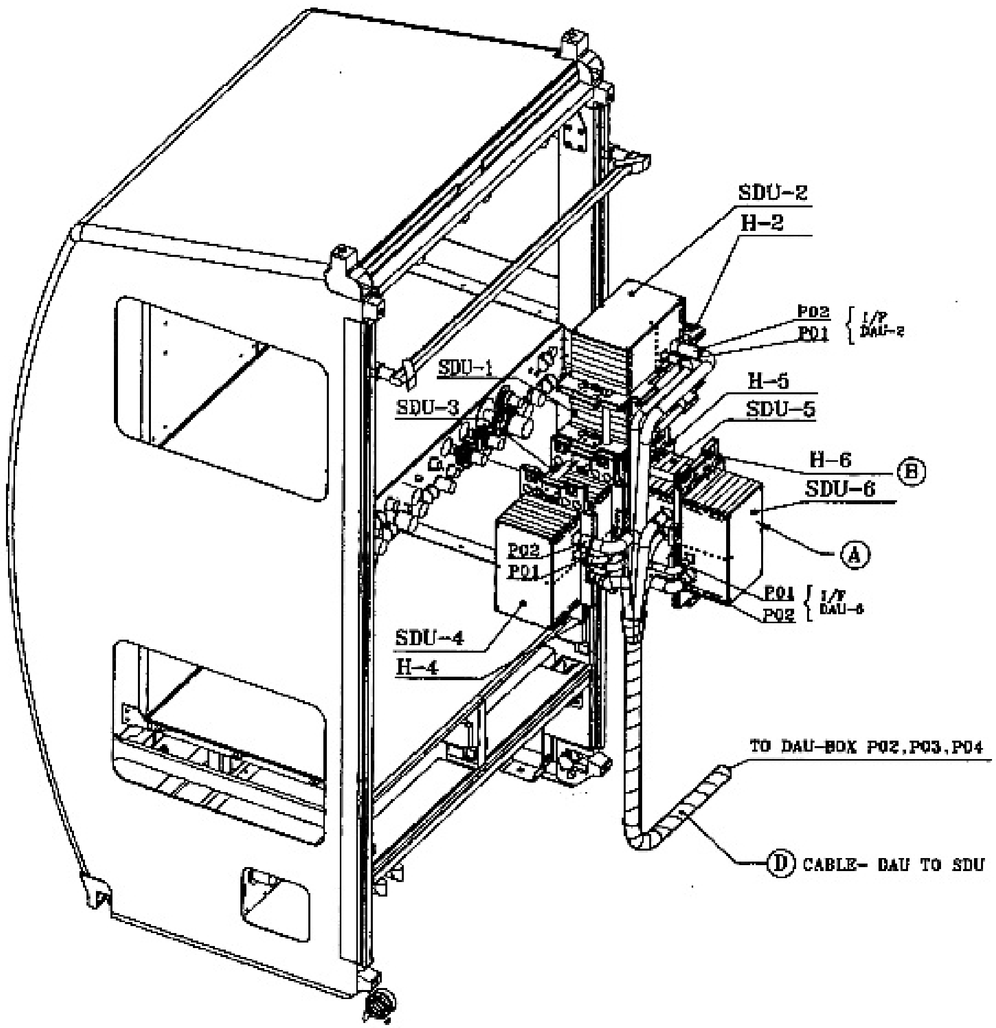


Time from the detection of the ion [at t = 0 s] (s)

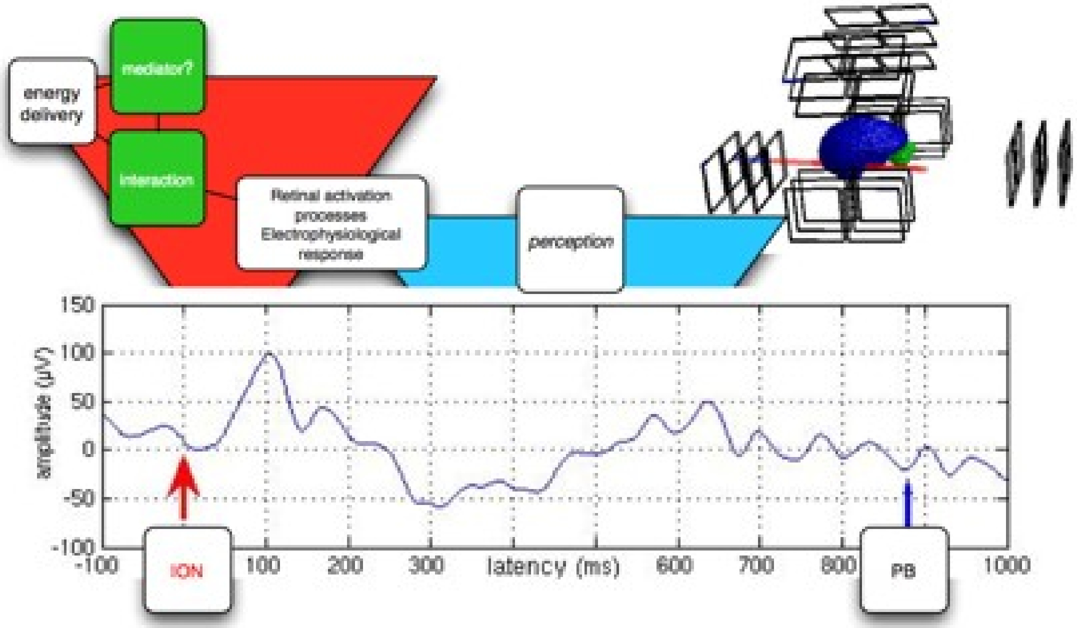


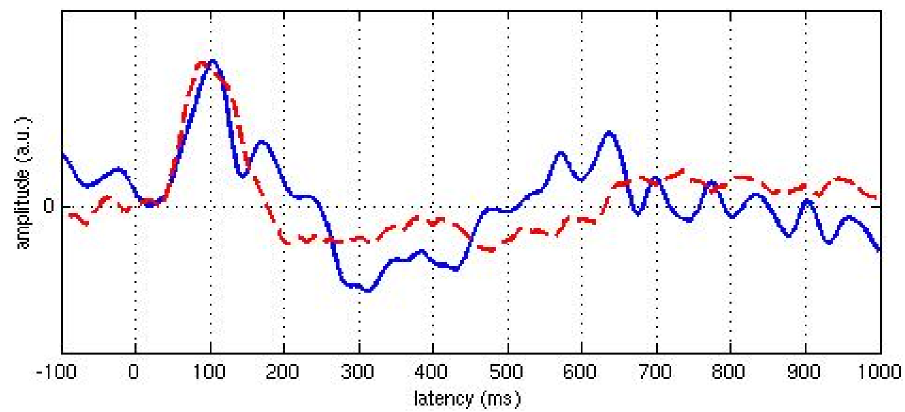
Time from the detection of the ion [at t = 0 s] (s)

Content

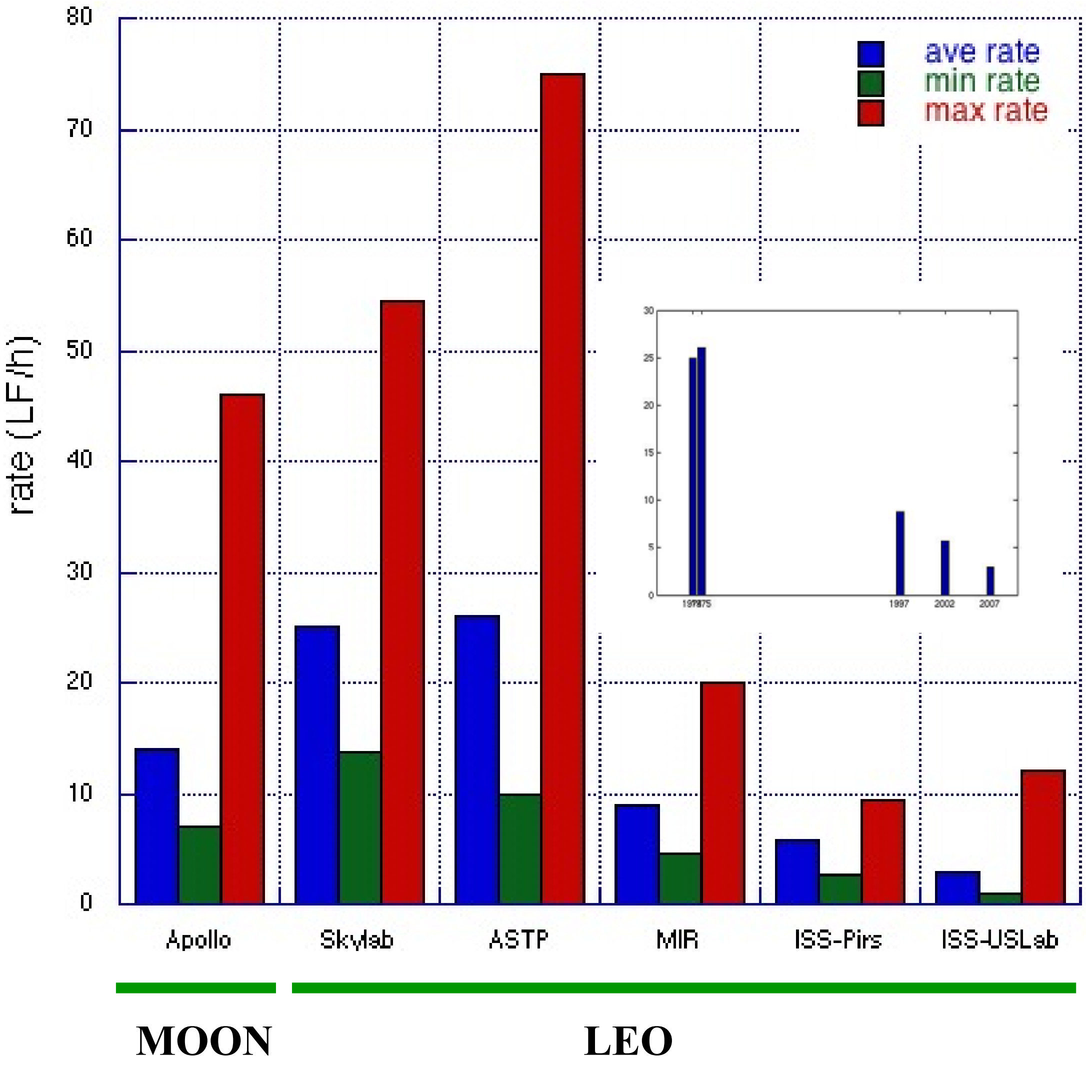


SDU-2
H-2
P02
P01
I/F
DAU-2
SDU-1
SDU-3
H-5
SDU-5
H-6
B
SDU-6
A
P02
P01
P01
P02
I/F
DAU-6
SDU-4
H-4
TO DAU-BOX P02,P03,P04
D CABLE- DAU TO SDU


energy delivery
mediator?
interaction
Retinal activation processes Electrophysiological response
perception
amplitude (μV)
150
100
50
0
-50
-100
-100
ION
100
200
300
latency (ms)
600
700
800
PB
1000


amplitude (a.u.)
0
-100
0
100
200
300
400
500
600
700
800
900
1000
latency (ms)

Measured Light Flashes rates in space

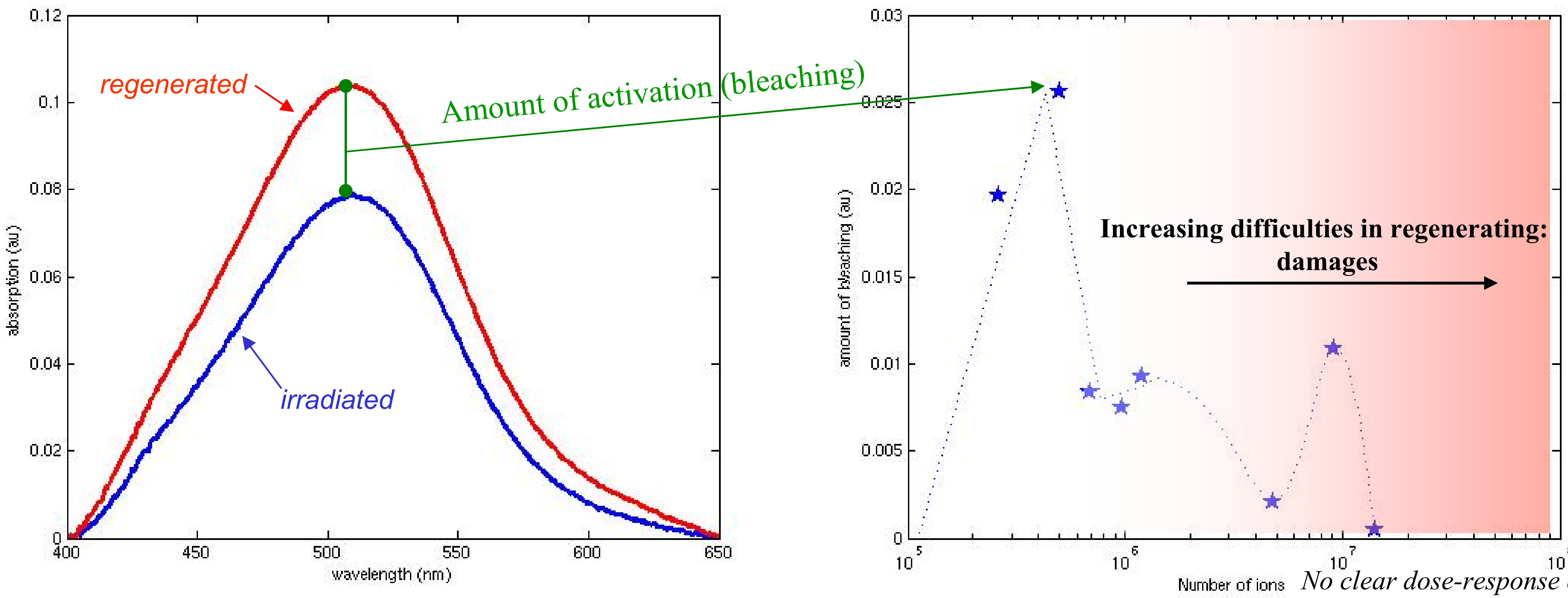


ALTEA - biophys (ground)

• Experiments aimed at studying the interaction mechanism(s) between radiation and CNS

• First experiment aimed at rhodopsin (at the start of the photo-electronic cascade in the visual pathway): activation (bleaching) of rhodopsin with different doses

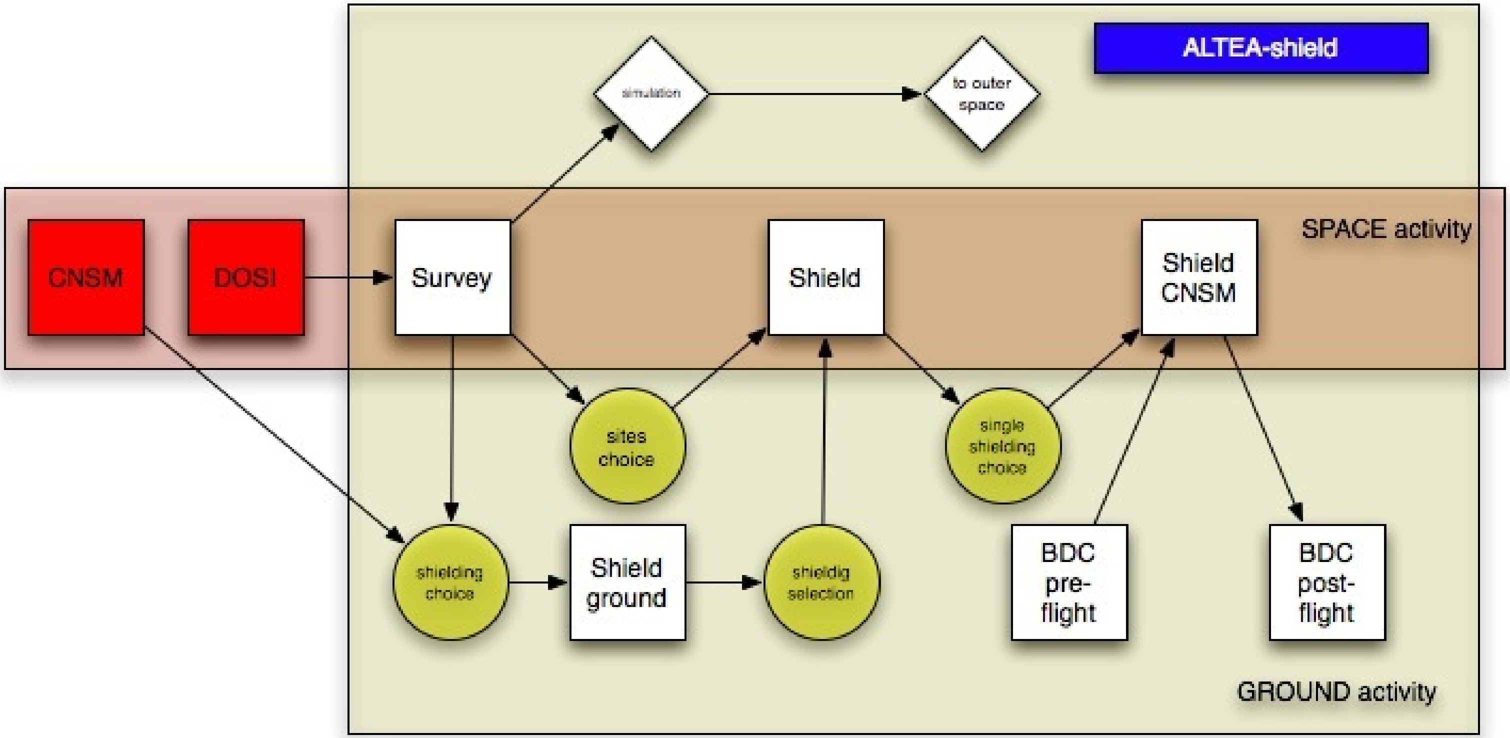
Radiation activates rhodopsin

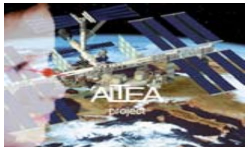


No clear dose-response curve

ALTEA - shield

ACTIVITIES flux diagram (no time scaled)

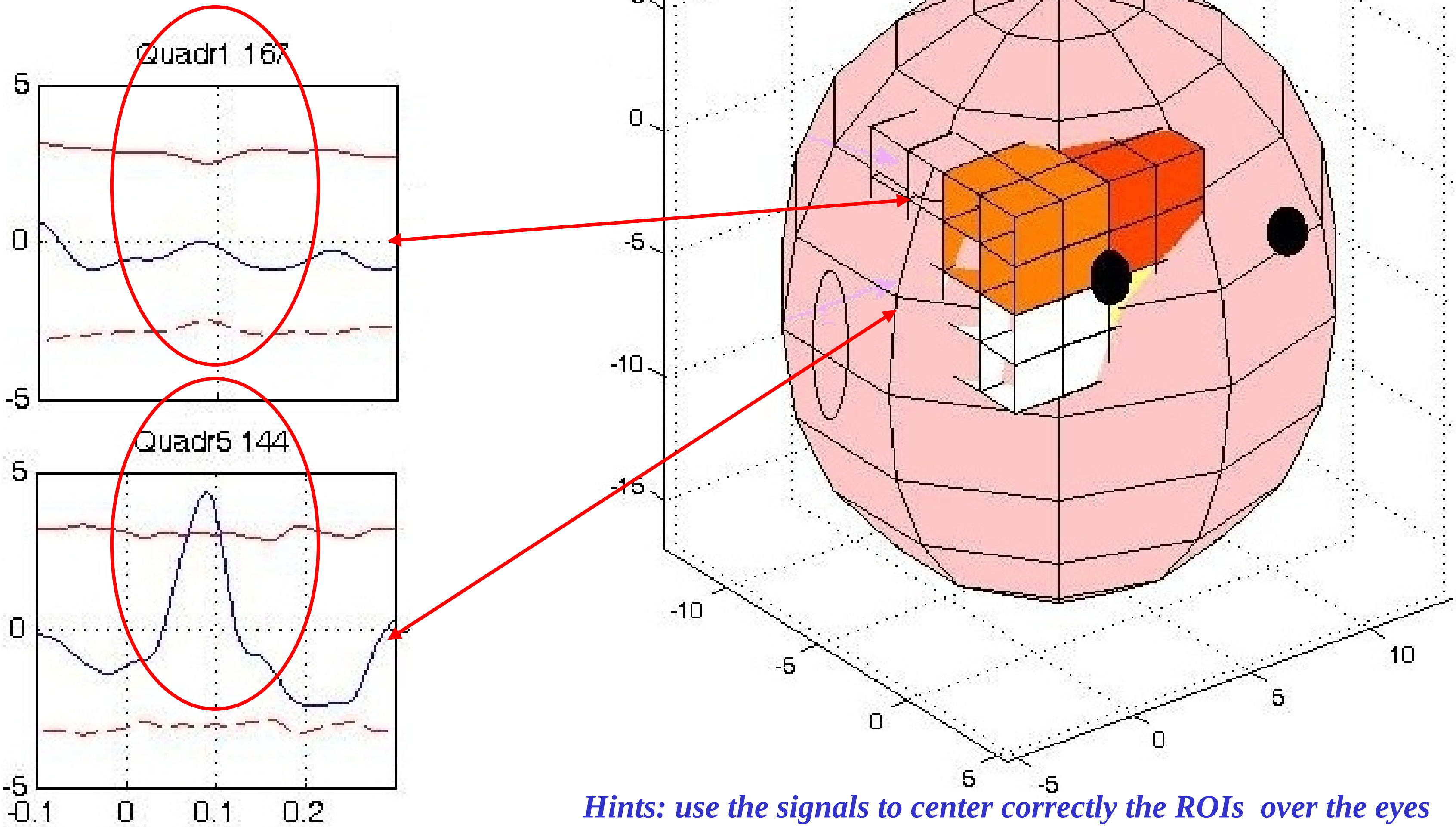




Linking ions and electrophysiology 8

Astronaut 2

Average of retinal signals following all detected particles passing in the indicated Region of Interest (ROI)

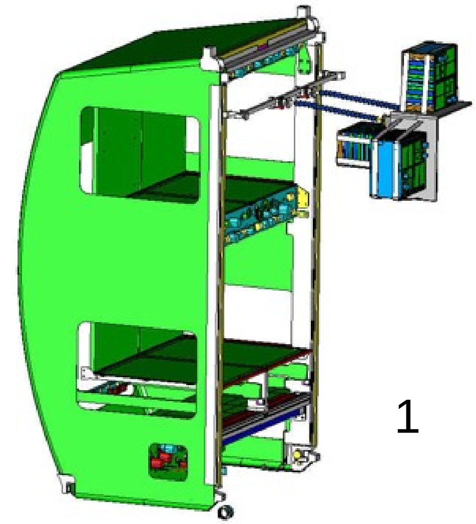


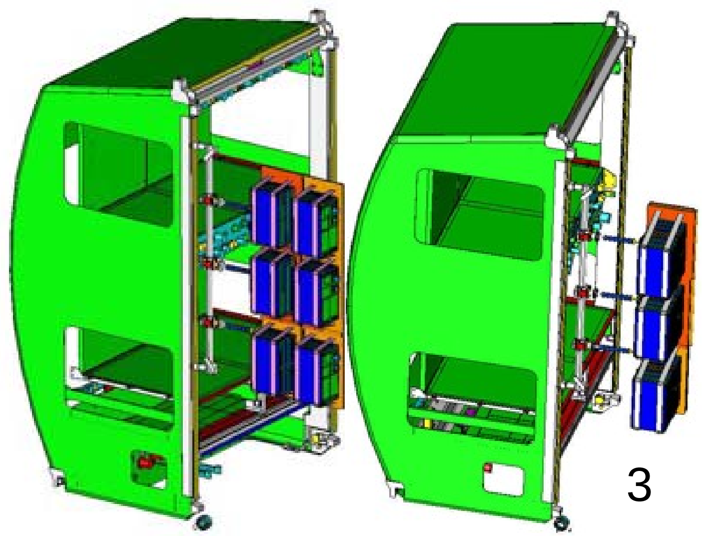
Hints: use the signals to center correctly the ROIs over the eyes

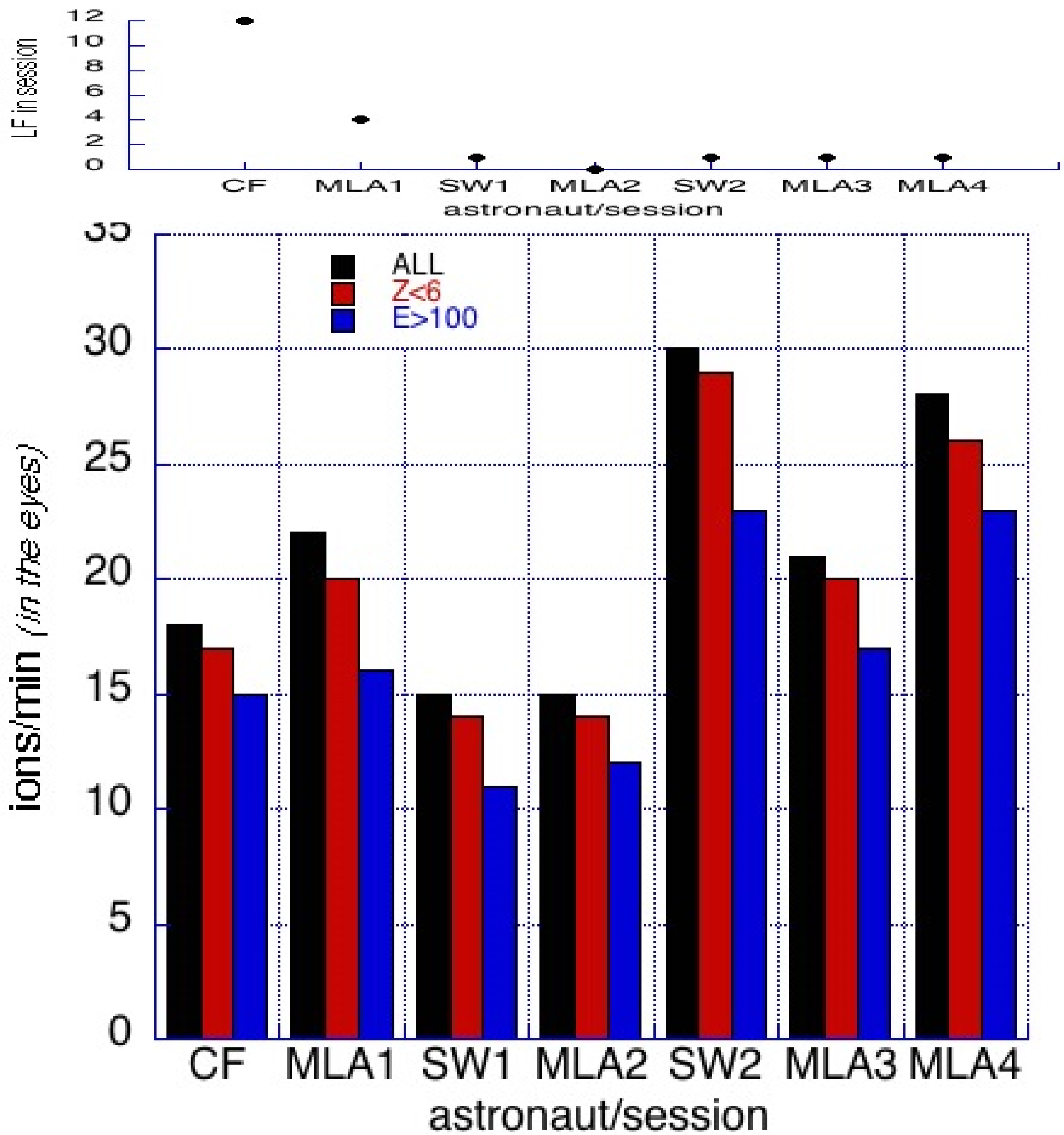
ALTEA - shield

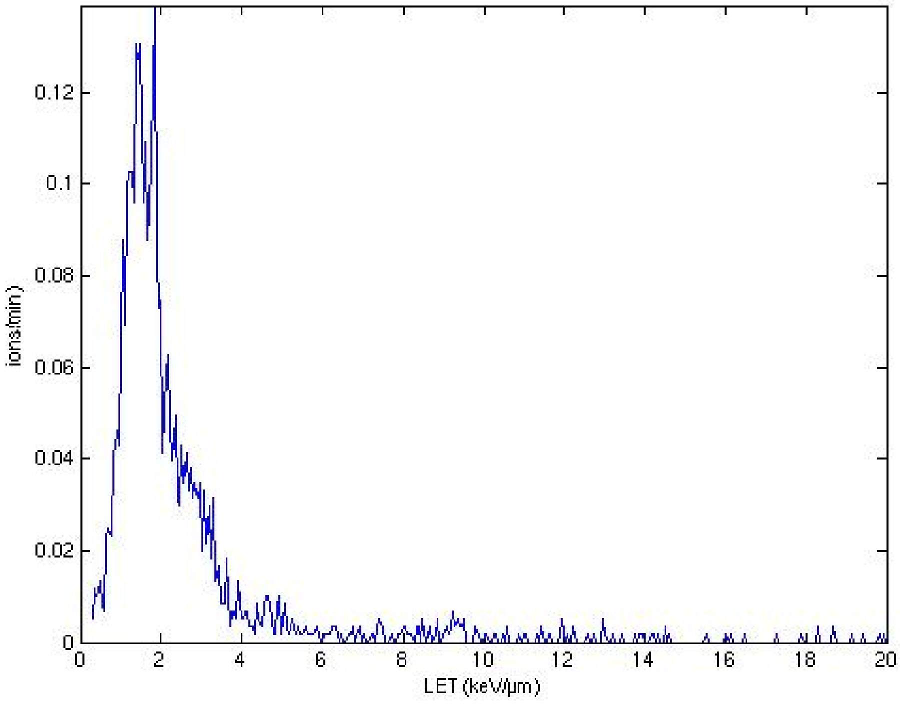
ALTEA - shield uses the ALTEA hardware with different holders and harness, it may be divided in 4 steps

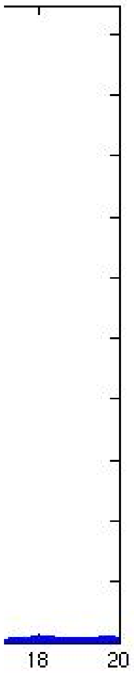
1. Survey: survey the radiation environment within the habitable volume of the ISS
   - identification of hot and cold spots for CNS functional risks
   - validation of computer models that will provide description of the radiation flux, transport through the spacecrafts materials, shielding efficiency, interactions and dose deposited in the human brain.
2. Ground base tests of shielding materials (irradiation measurements & mice EEG measurements)
3. Shield: ISS-based tests of above shielding
4. CNSM with shielding






LF in session
12
10
8
6
4
2
0
CF
MLA1
SW1
MLA2
SW2
MLA3
MLA4
astronaut/session
ions/min (in the eyes)
35
30
25
20
15
10
5
0
ALL
Z<6
E>100
CF
MLA1
SW1
MLA2
SW2
MLA3
MLA4
astronaut/session


ions/min)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
20
LET (keV/μm)


18
20