



Trento Institute for
Fundamental Physics
and Applications



Ioni pesanti: dalla terapia del cancro al viaggio su Marte

Marco Durante, TIFPA

www.tifpa.infn.it





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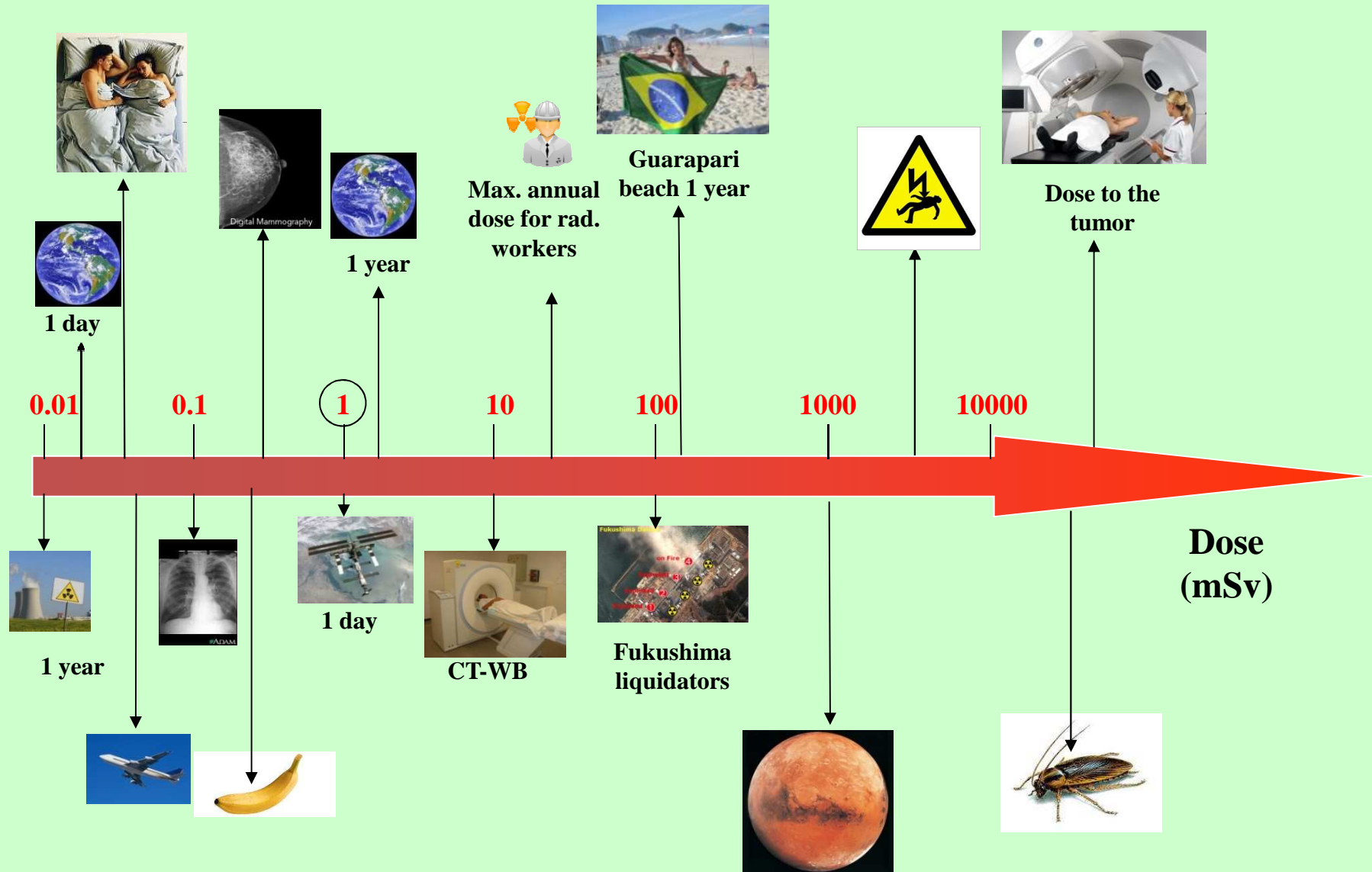


Therapeutic
benefit (cancer
therapy,
noncancer
targets...)

Health risk
(cancer, CVD,
CNS...)

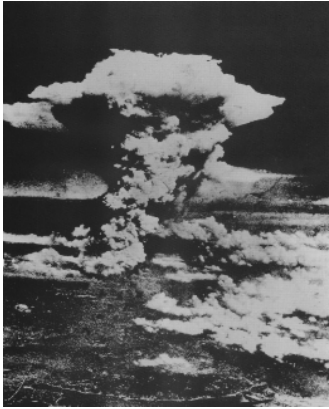
Radiation effects depends on the DOSE

Dose is an energy per unit mass and is measured in Sievert = Joule/kg



A-bomb : blast wave, thermal radiation nuclear radiatio



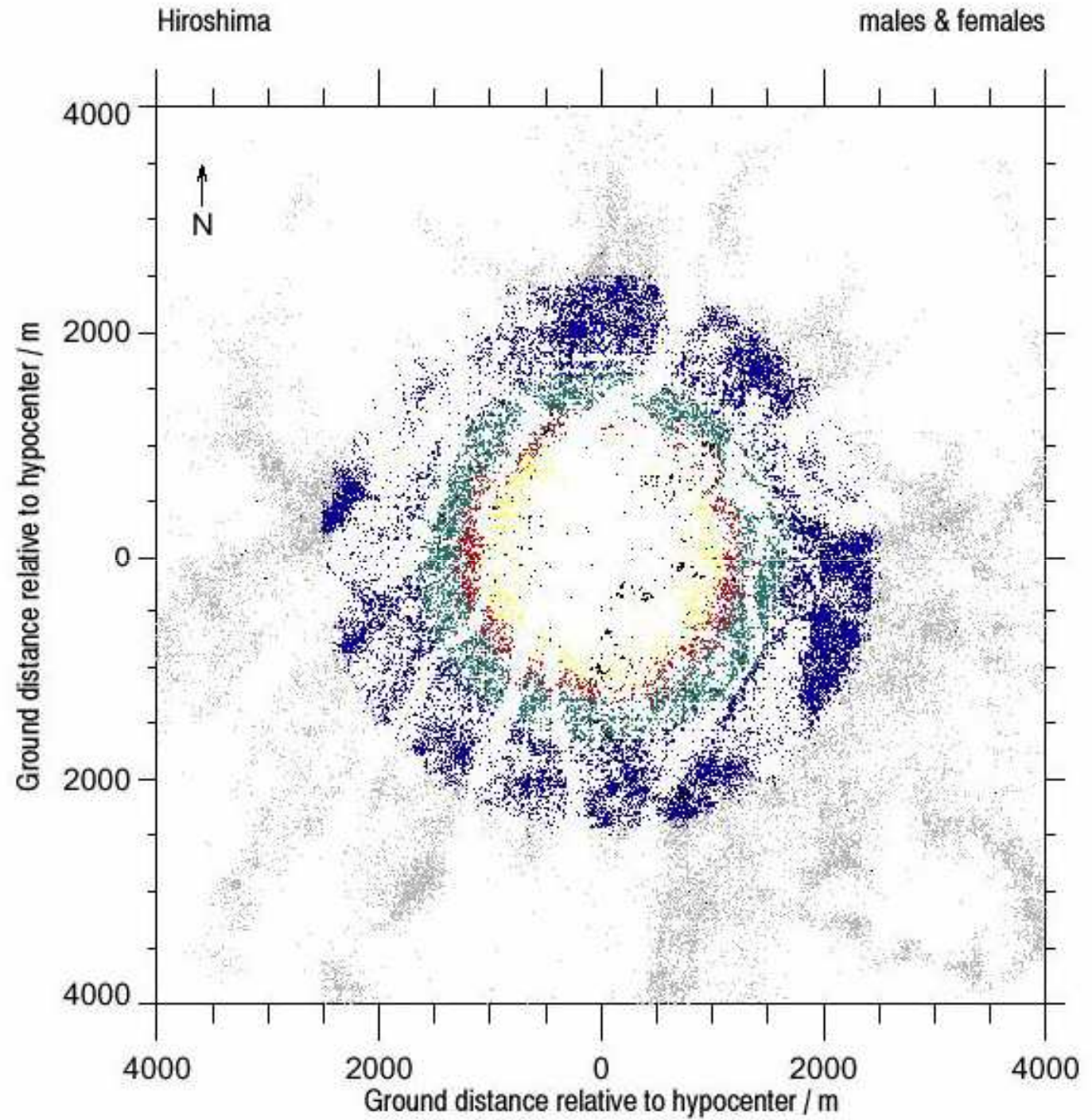


Stochastic effects: A-bomb survivors

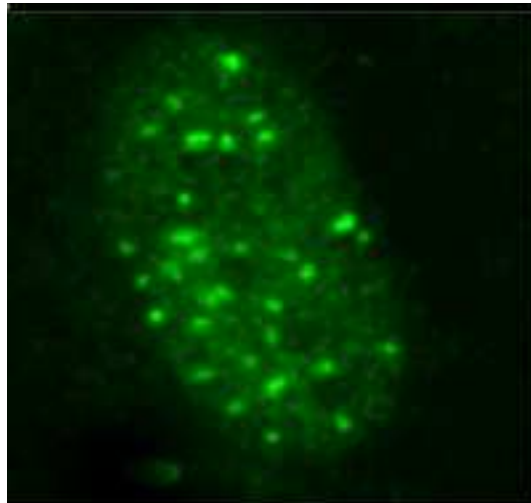
- 86,661 survivors followed (Life Span Study)
- 58% of this population died between 1950 (RERF foundation) and 2003 (last analysis in report 14, published in March 2012)
- 10,929 solid cancer deaths observed
- Approximately 644 (6%) attributed to radiation
- Approximately 1% of noncancer deaths are radiation-induced

Radiation doses in Hiroshima survivors

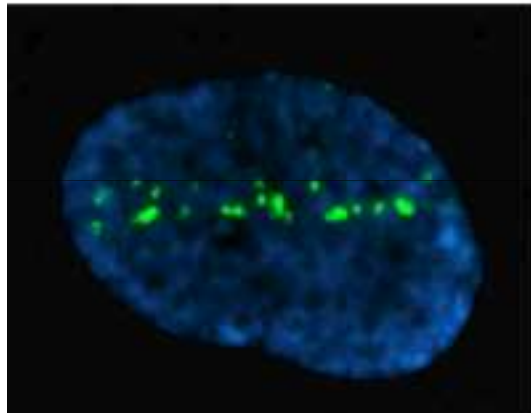
- $D < 5 \text{ mSv}$
- $5 \text{ mSv} < D < 0.1 \text{ Sv}$
- $0.1 \text{ Sv} < D < 0.5 \text{ Sv}$
- $0.5 \text{ Sv} < D < 1.0 \text{ Sv}$
- $D > 1 \text{ Sv}$
- unknown dose



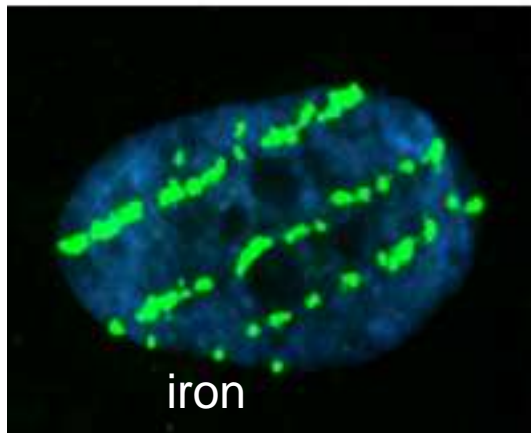
Charged particles



γ-rays

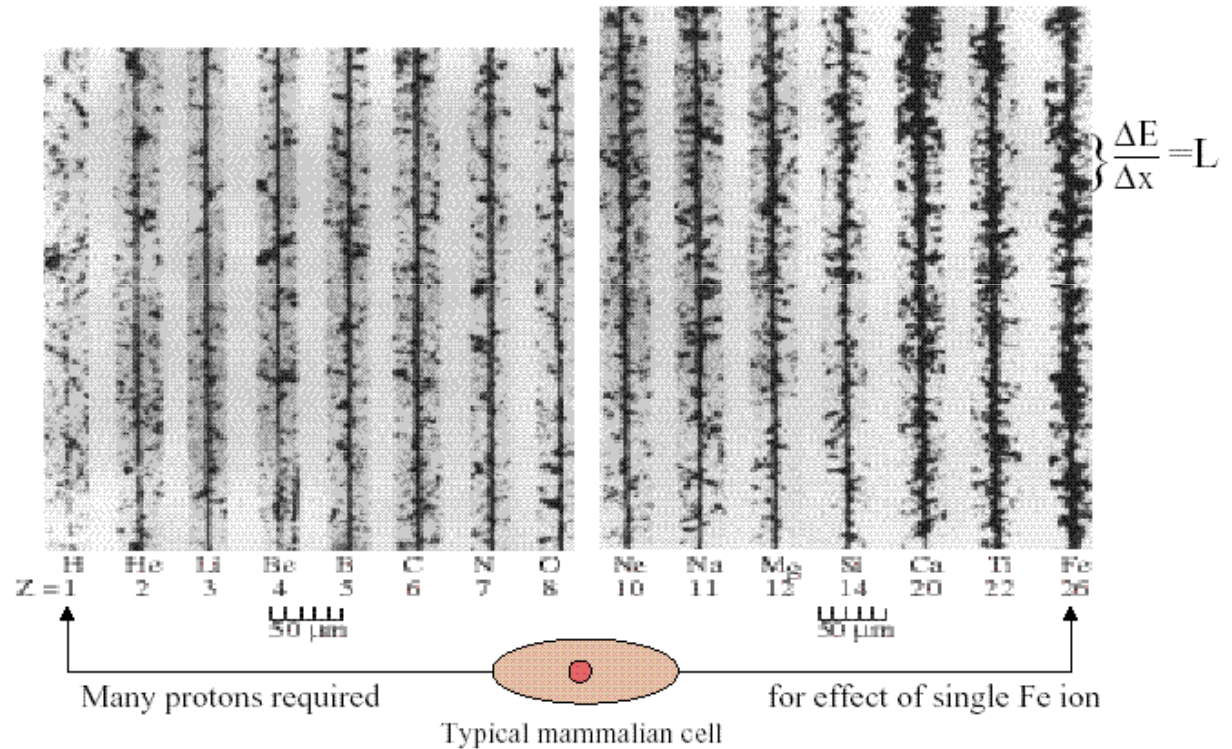


silicon



iron

GCR Ion Tracks Are Dangerous
 ← Better Biological knowledge → Poor



Cucinotta and Durante, *Lancet Oncol.* 2006

An Analogy for Structured Energy Deposition and its Consequences



Low LET radiation produces isotropic damage to organized targets.



High LET radiation produces correlated damage to organized targets.

LET: Linear Energy Transfer

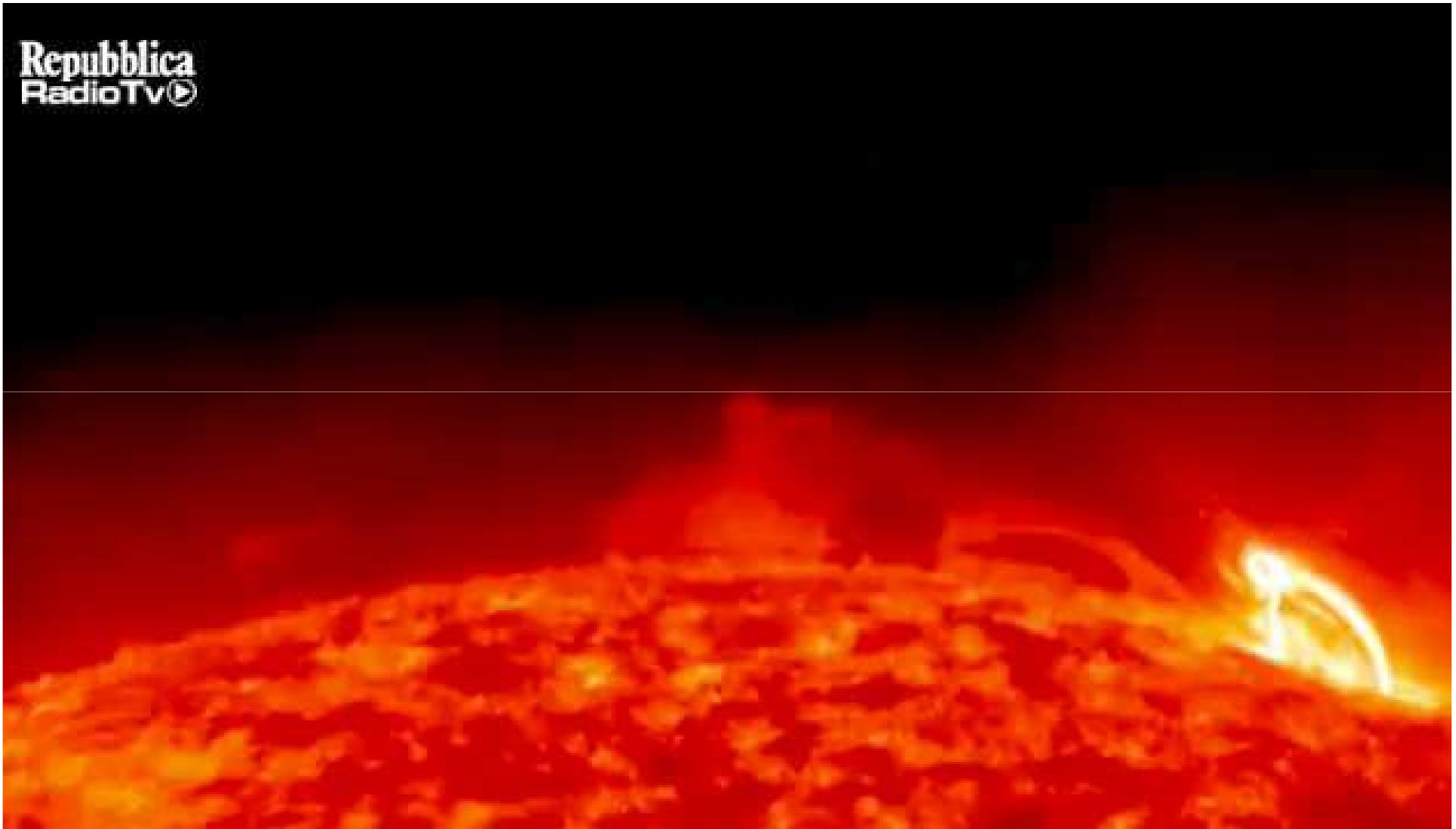


Why are we interested in energetic heavy ions?



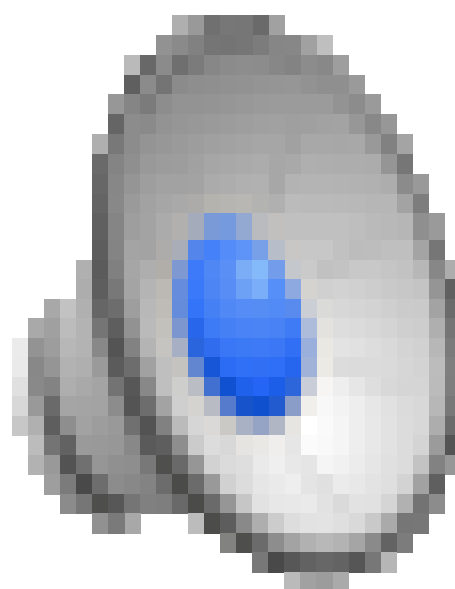
Heavy ion radiation is not present naturally on Earth

Valentine's Solar flare 14.2.2011





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The New York Times

Space & Cosmos

WORLD U.S. N.Y. / REGION BUSINESS TECHNOLOGY SCIENCE HEALTH SPORTS OPINION
ENVIRONMENT SPACE & COSMOS

Data Point to Radiation Risk for Travelers to Mars



Dose rate=1.8 mSv/day
Total dose=1.8x501 \approx 1 Sv



Health in Deep Space

1. Protection from space radiation (particularly very high energy heavy ions)
2. Psychosocial and behavioural problems
3. Physiological changes caused by microgravity

Modified by Mike Lockwood

Disclaimer

Preview File Edit View Go Tools Window Help

Secure <https://www.youtube.com/watch?v=sriaiuWjUHE> Mon 13:37

YouTube Search Sign In

NASA, GSI & CERN Explain Why We Cannot Go To The Moon Today

Joe Maddox [Subscribe](#) 196 **12,920 views**

Published on Sep 1, 2016
NASA shows on their heliophysics .gov site that there is nothing filtering or slowing the particles from the sun. There are things accelerating them and condensing them like our accelerators do.

COMMENTS - 40

Up next

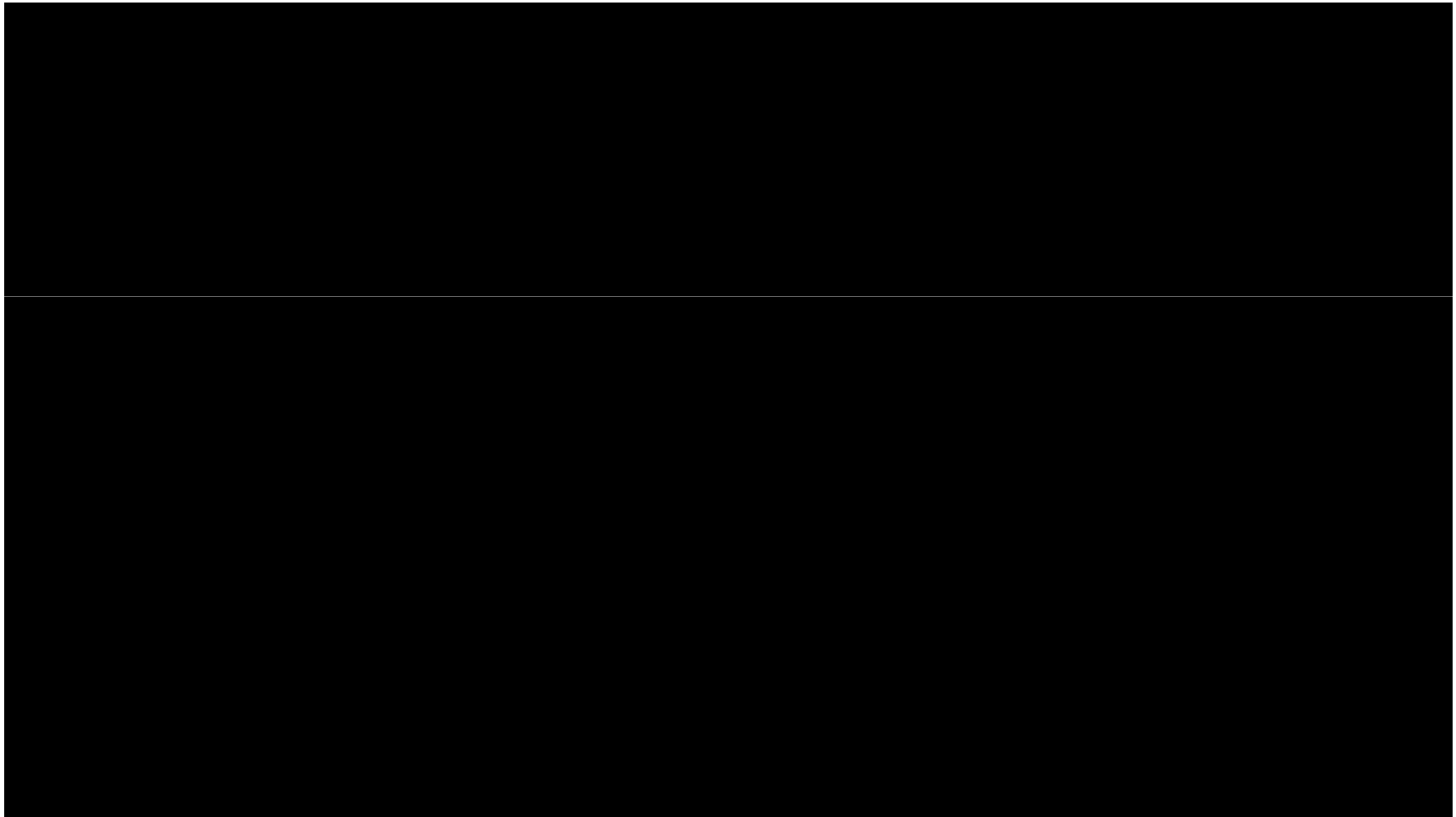
- WAKE UP WE NEVER WENT TO THE MOON AND WE NEVER WILL** 42:56
jeranism 158,375 views
- Why No Pictures Of The Moon Landing?** 11:16
Joe Maddox 116 views NEW
- Curious Droid: Did Apollo Go Through The Van Allen Belts?** 17:16
Joe Maddox 42 views NEW
- How Particle Physics Killed The Moon Landing...** 36:30
Joe Maddox 33,803 views
- EUF: In Lies we trust, Earth appears not to be as told.** 1:57:36
Erik Verbeek 71,305 views
- EUF: Hall of Mirrors Moon Landing and Mars Hoax Proven** 1:57:14
Erik Verbeek 39,337 views
- Richplanet - New evidence on Stanley Kubrick faking the Apollo Moon landing (full version)** 48:06
Robert Ritter 182,681 views
- National Geographic The Truth Behind The Moon Landings - BBC**

ASI
CNAO
concorsi
congressi
CSNS
CSN
Dallas
didattica
ESA

I do believe that humans landed on the Moon!

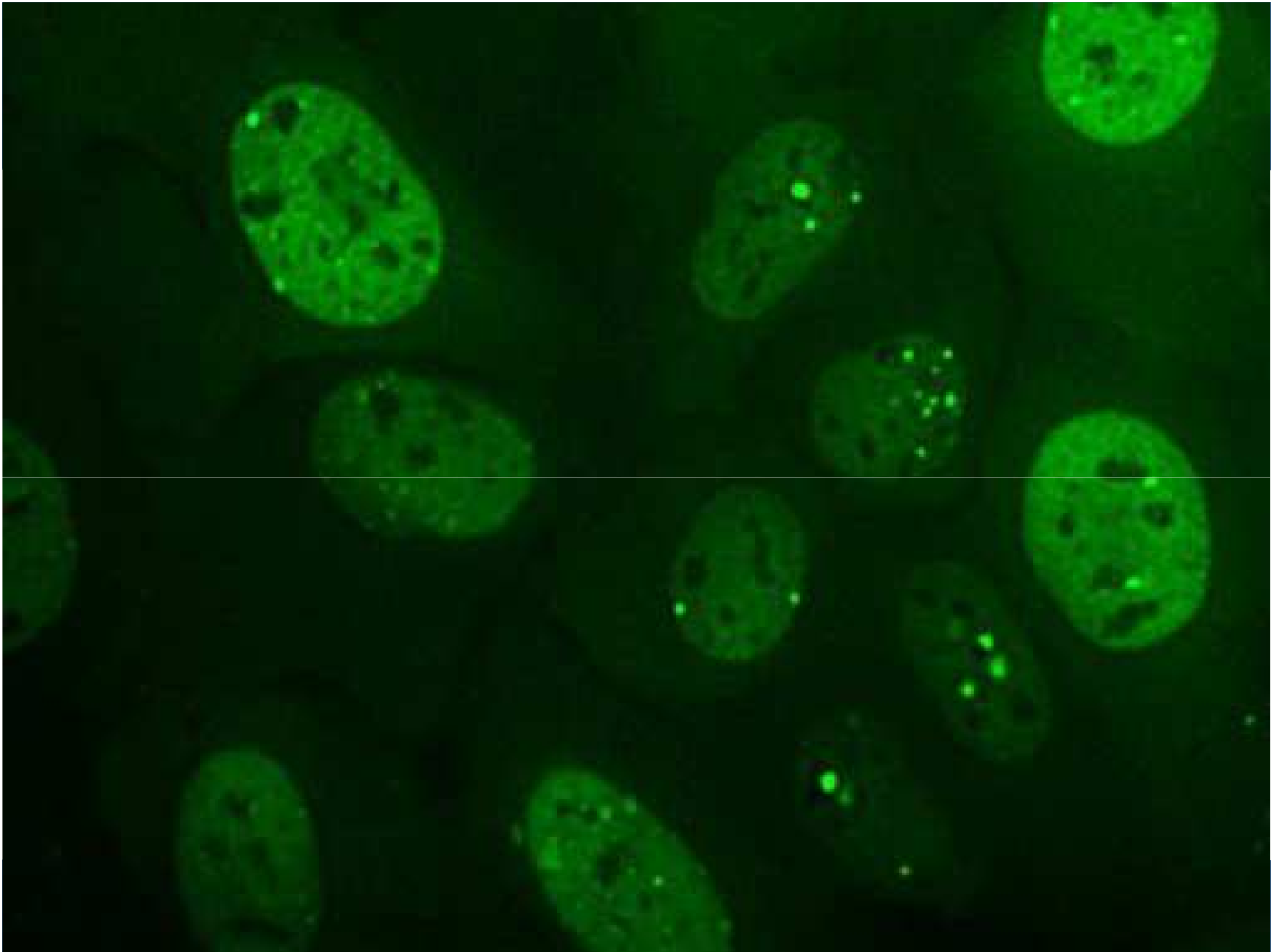
Biological effects of heavy ions

No human epidemiological data



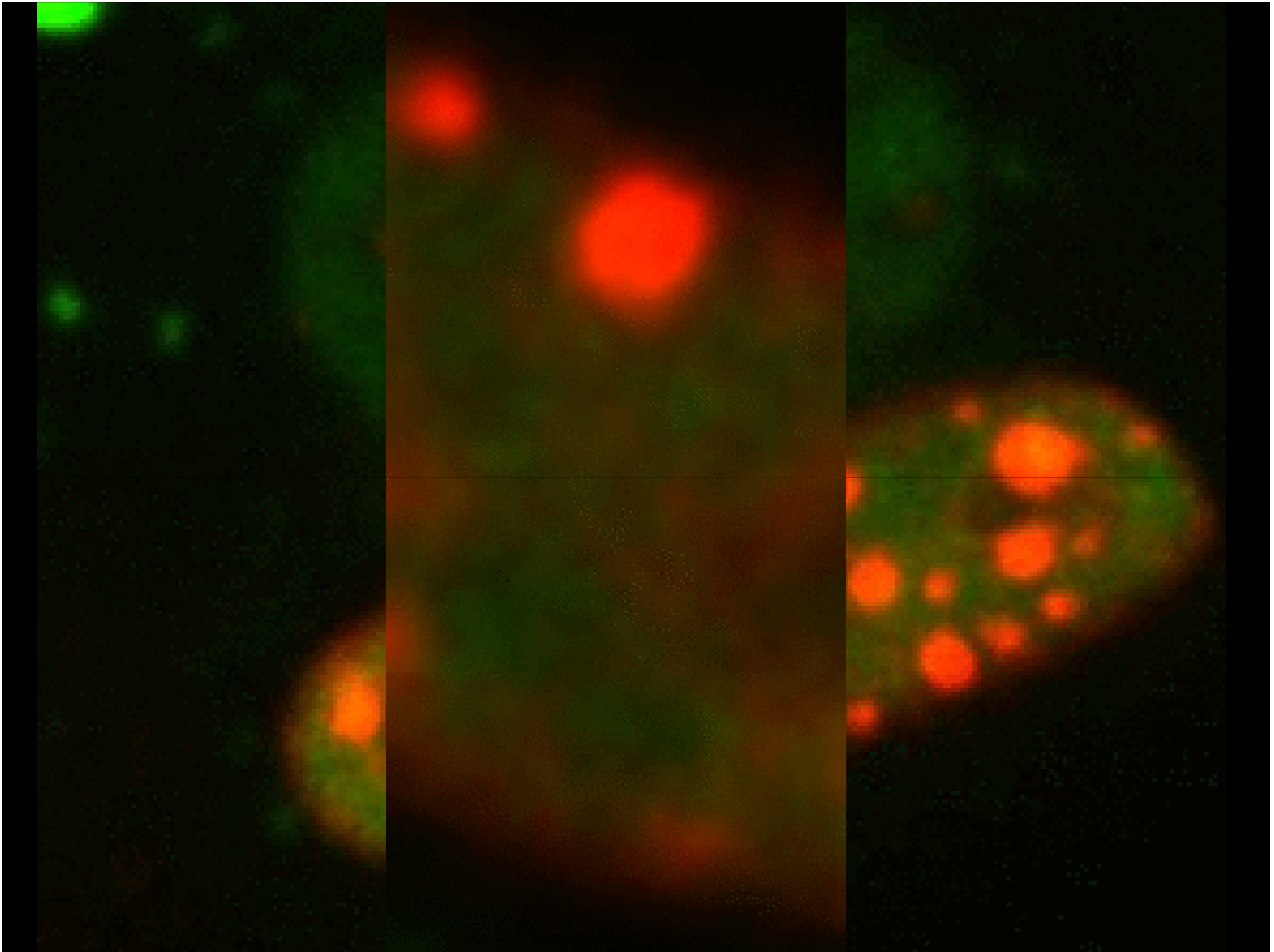
A wide-angle photograph of a large industrial facility, likely a particle accelerator. The room is filled with complex machinery, including large yellow and red components. Several people are visible, working or observing the equipment. The ceiling is high and features a complex network of metal beams and cables. The lighting is bright, illuminating the scene. In the foreground, there are yellow cylindrical components on a surface. In the background, a long red structure extends into the distance. A blue cart with red and white containers is visible in the lower right corner.

An accelerator can simulate
cosmic rays on Earth



-10.0 sec

Cosmic rays in a human cells

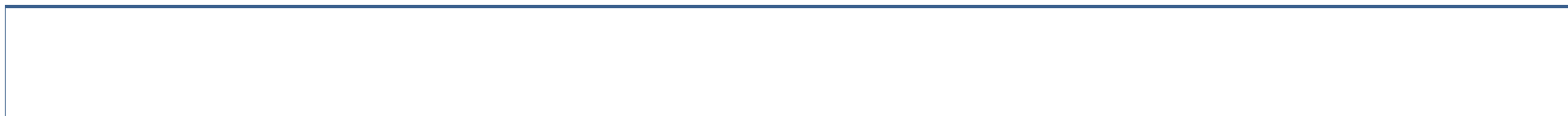
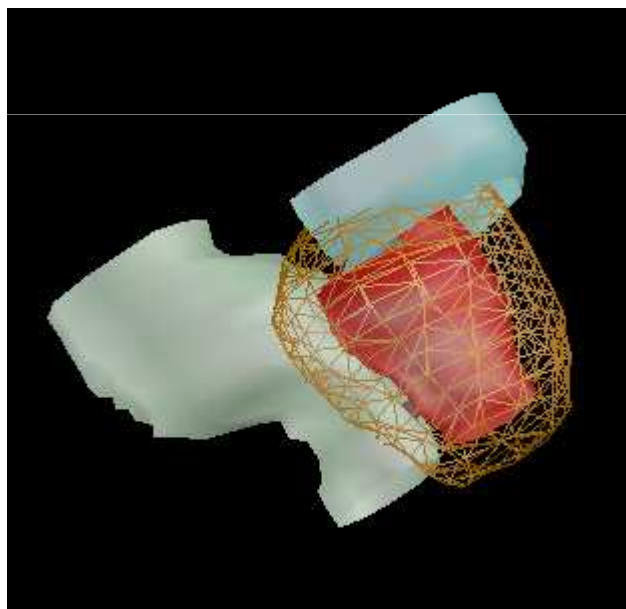




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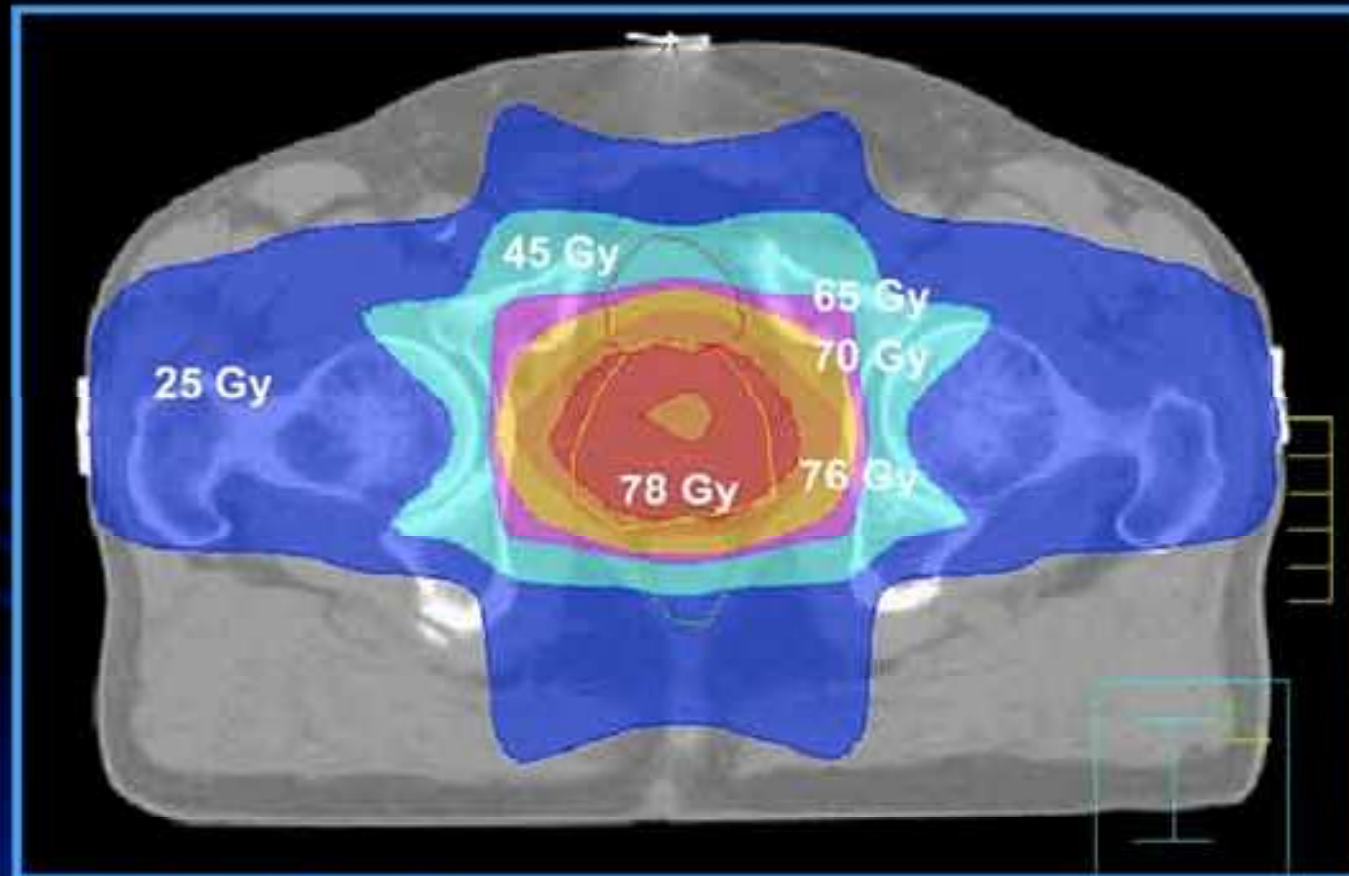


The good side of radiation: radiotherapy



External Beam Radiation Therapy

Treatment
planning

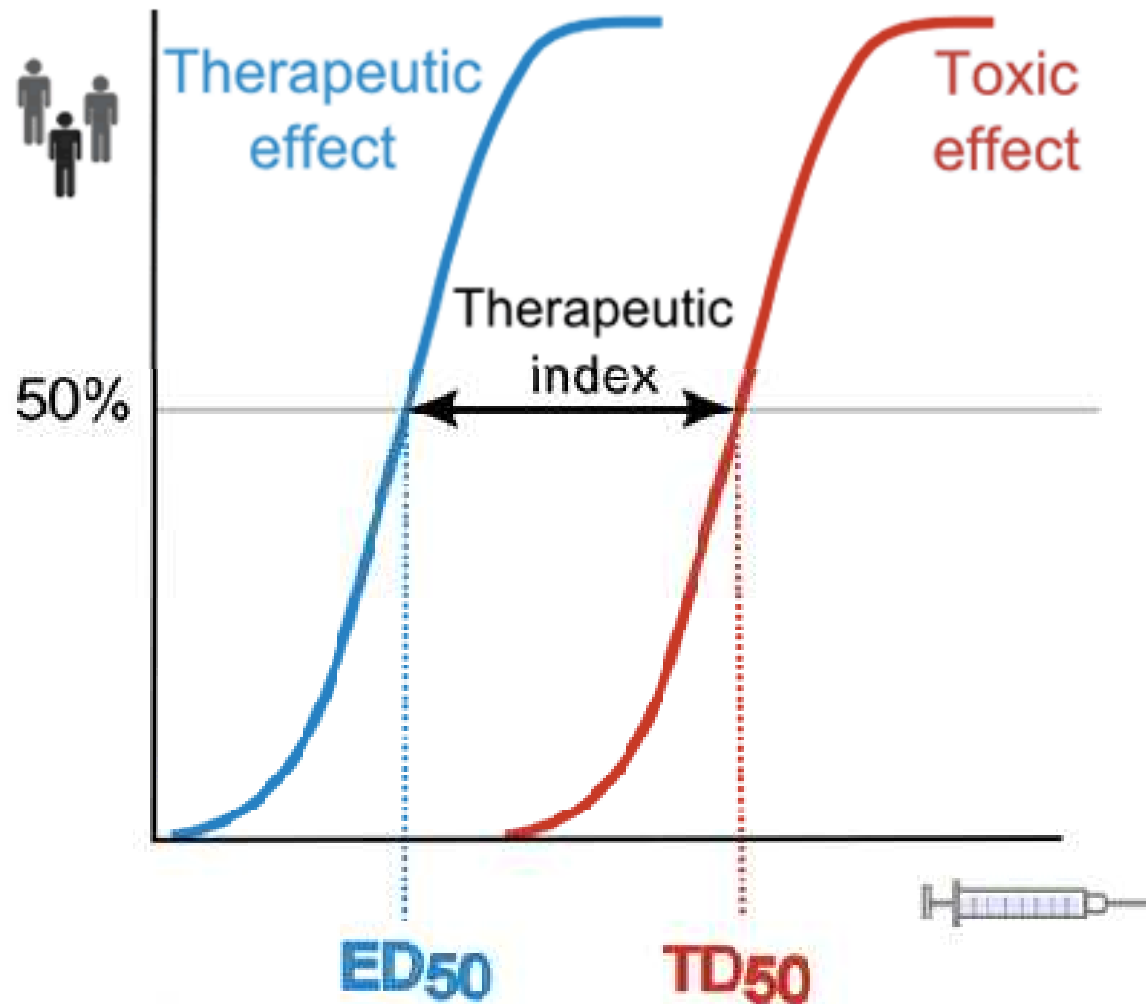


Generally, the total dose to the tumor is about 60 Gy, given in daily fractions of 2 Gy to spare the normal tissue

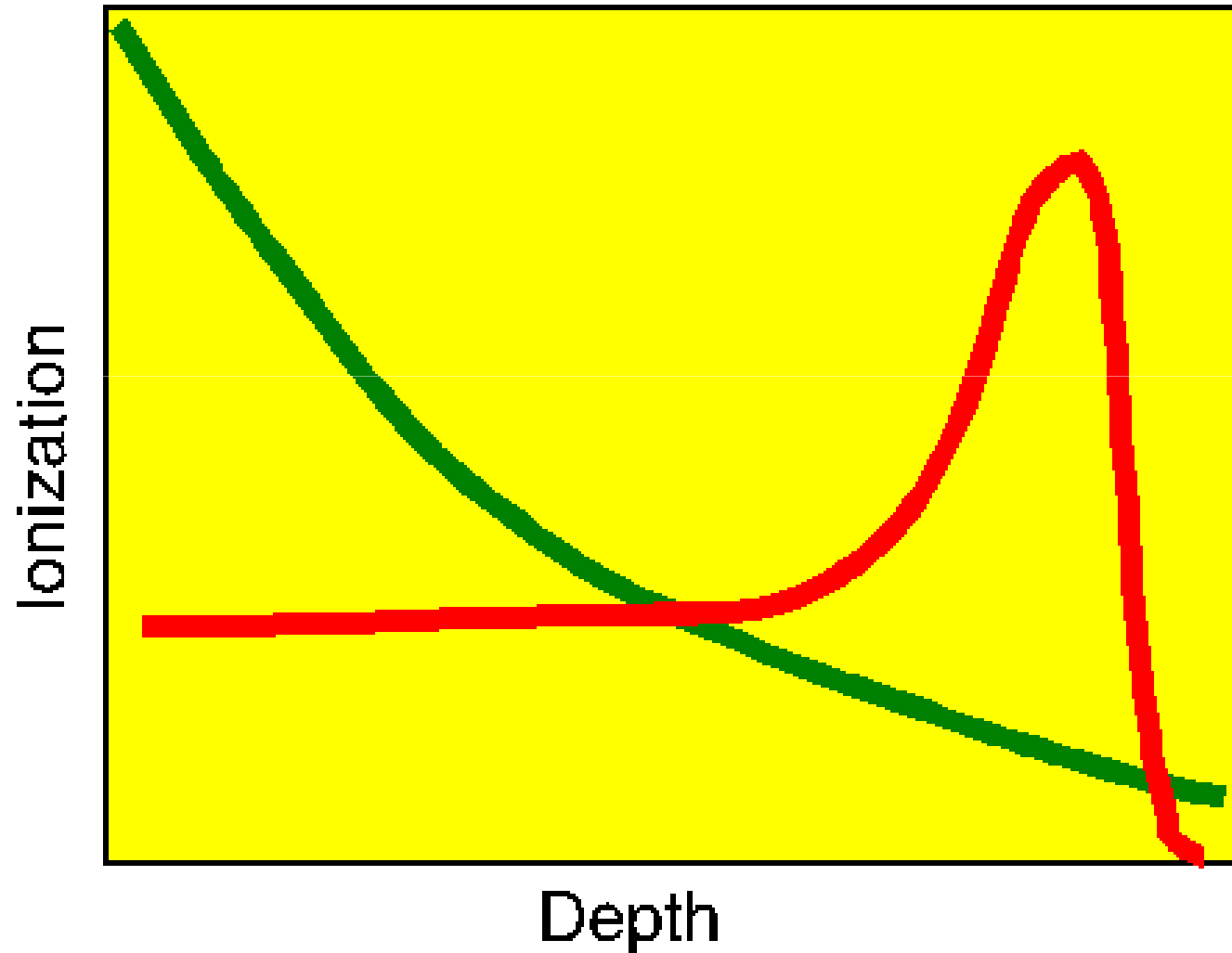
X-rays produced by LINACS (6-15 MV) are normally used

3D Conformal Technique for Treating Prostate Cancer

Therapeutic window

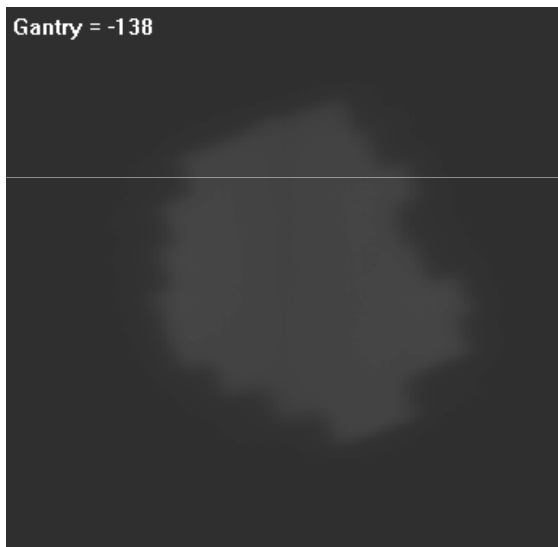


Charged particles for therapy

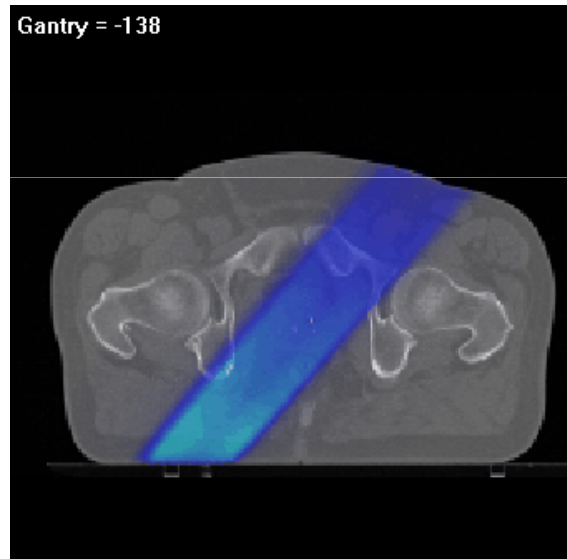


X-ray dose decrease with depth
We have to cross-fire on the tumor from many angles

Single field



Dose per field

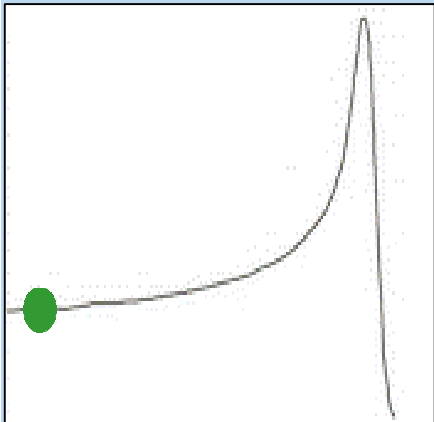
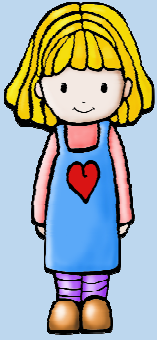


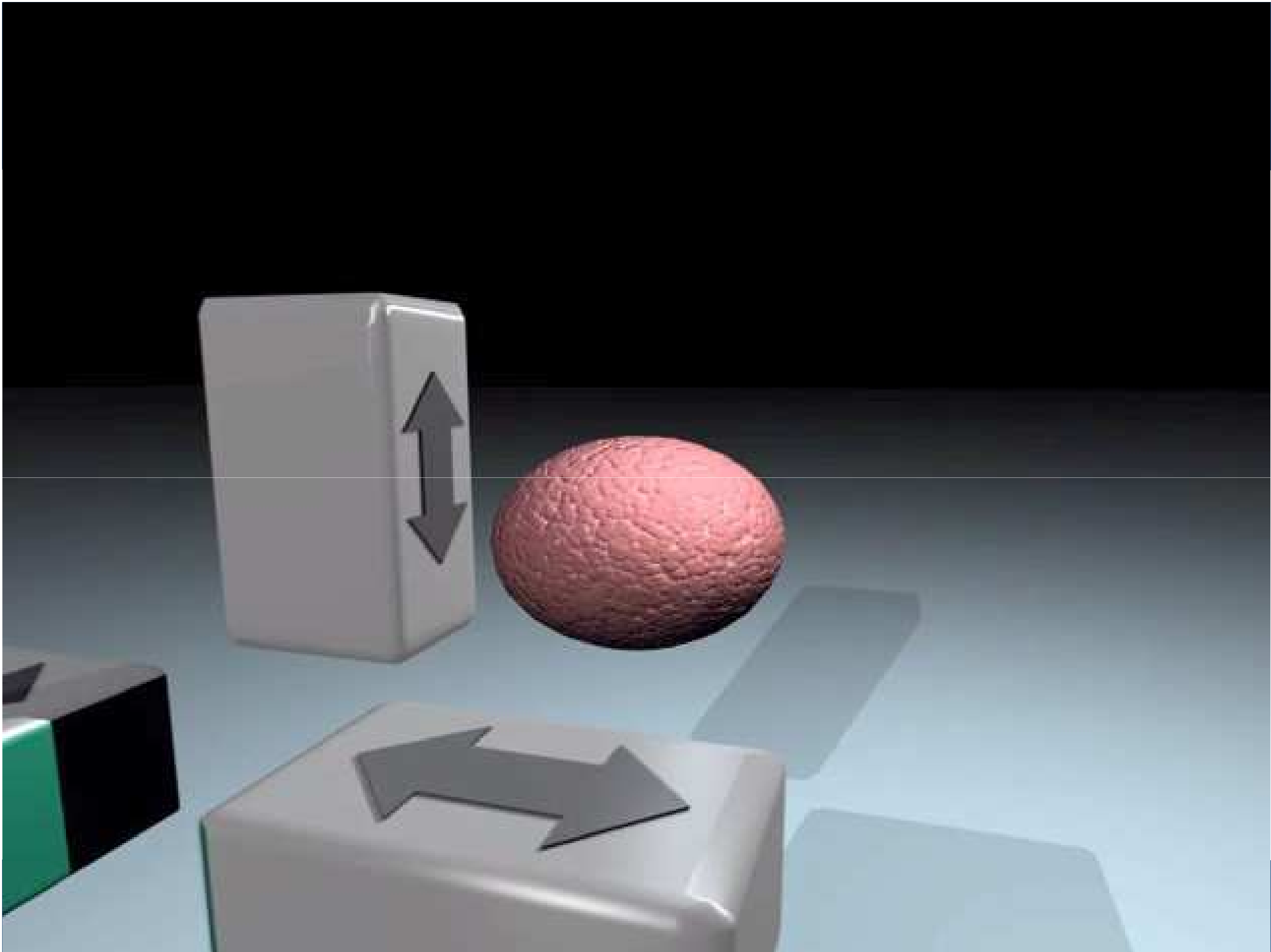
Total dose



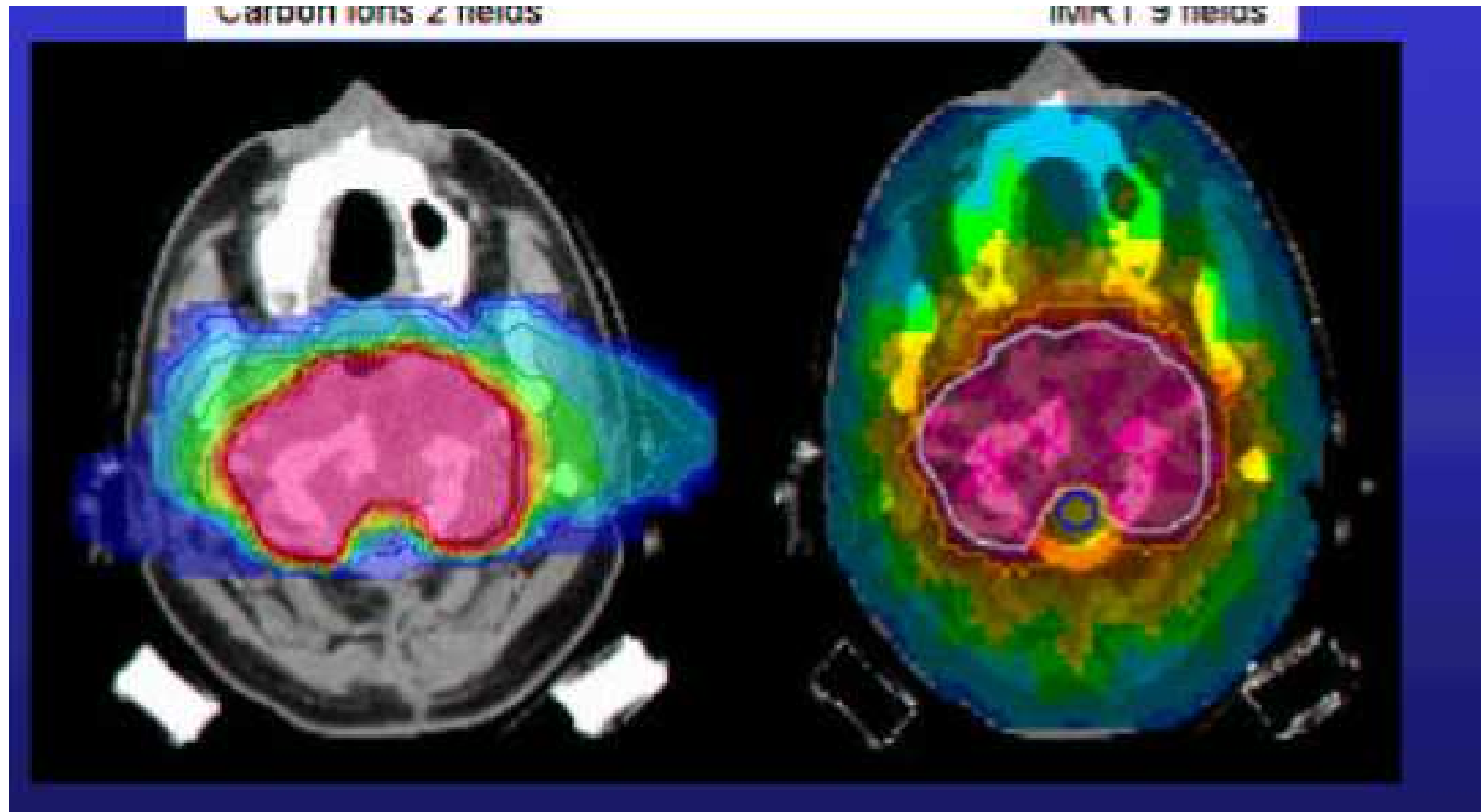
Excellent target conformity
Large normal tissue volume irradiated

Courtesy B. Mijnheer





C-ions vs. X-ray therapy





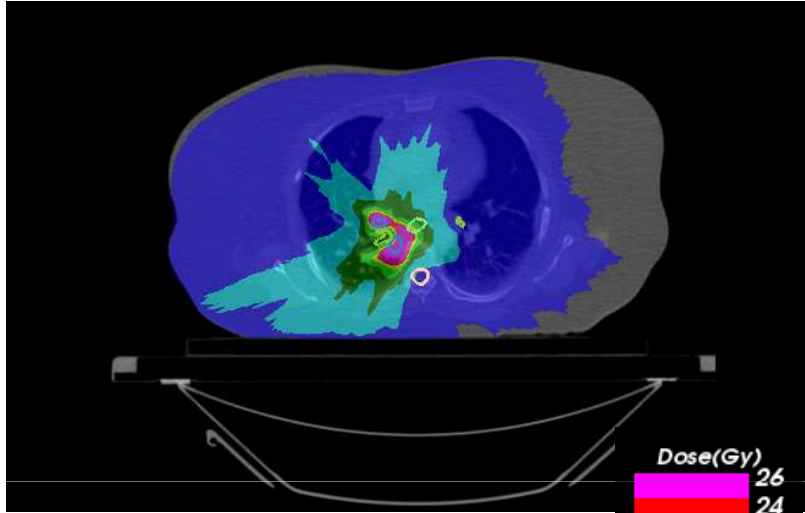
Champalimaud
Foundation



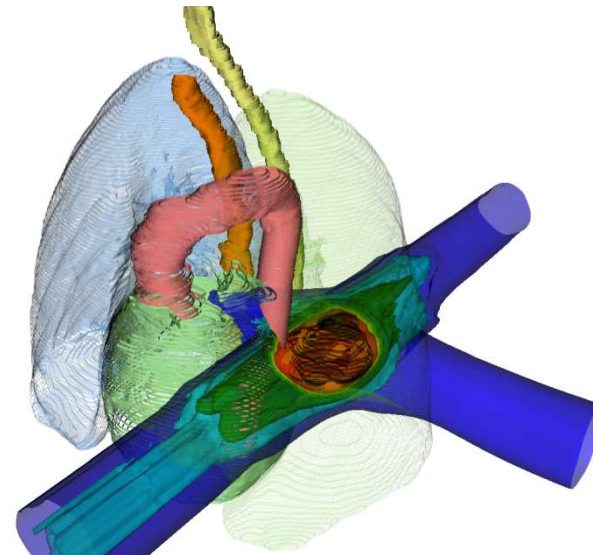
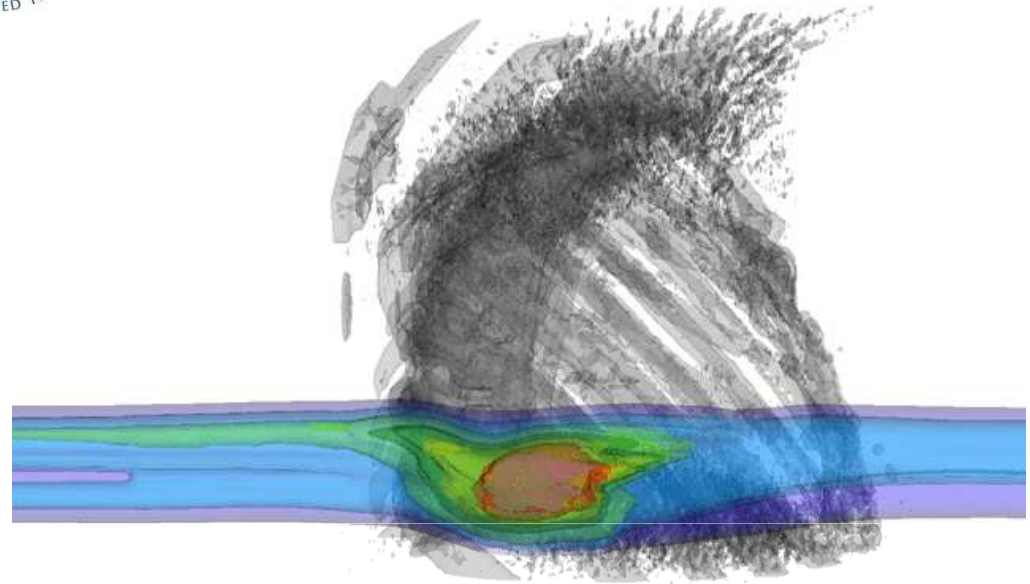
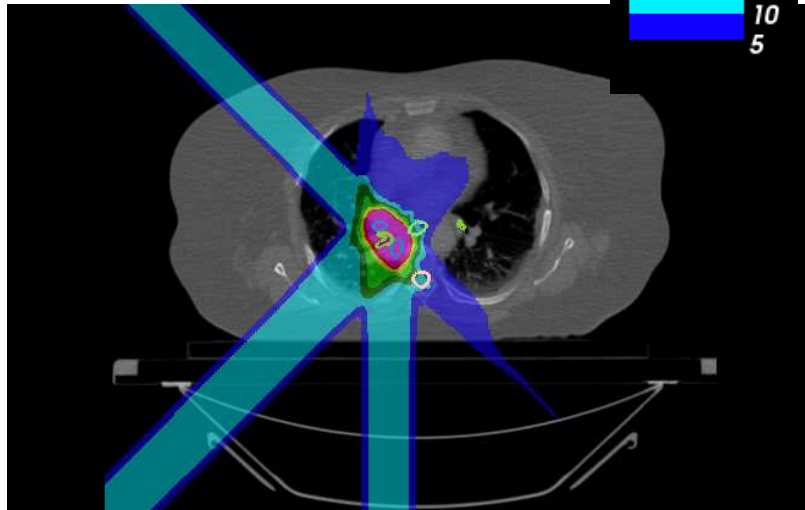
Lung tumors: SBRT vs. C-ions

Single fraction, 25 Gy

X-rays



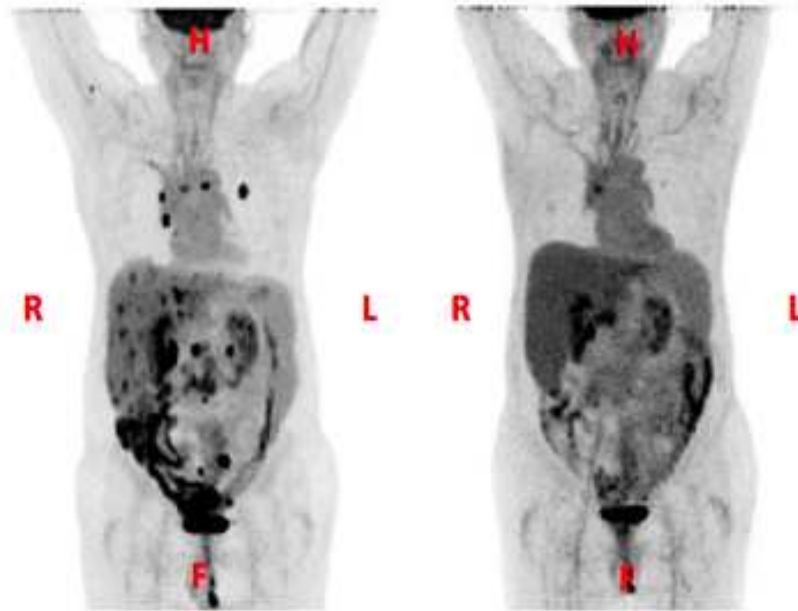
C-ions



Kristjan Anderle, Ph.D. thesis, TU Darmstadt, 2014

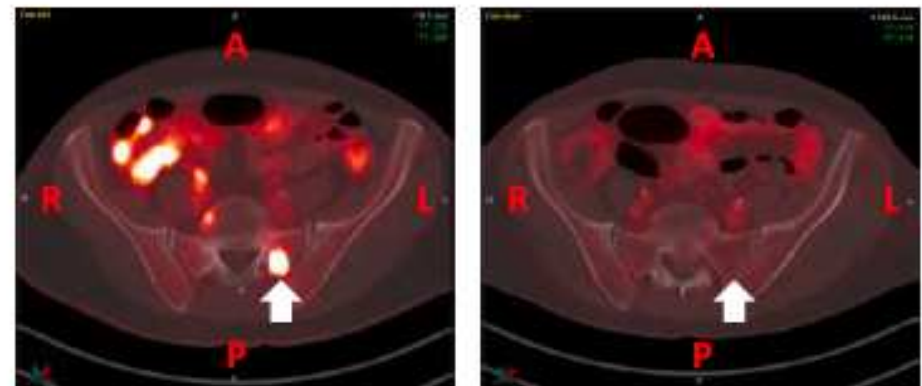
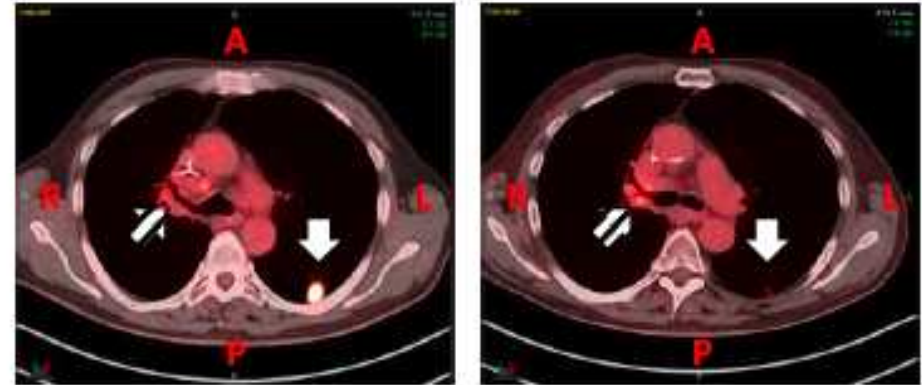
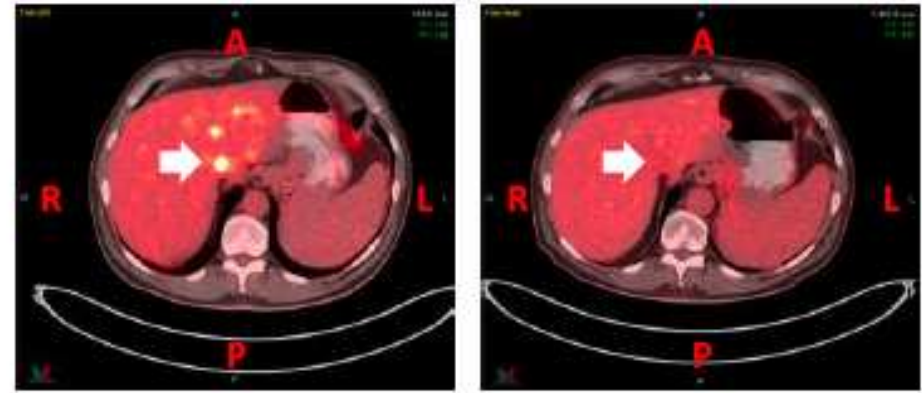
Combined radiotherapy and immunotherapy in the clinics: lung cancer trial

NSCLC progressing after 3 lines of
and chest RT. Multiple lung bone

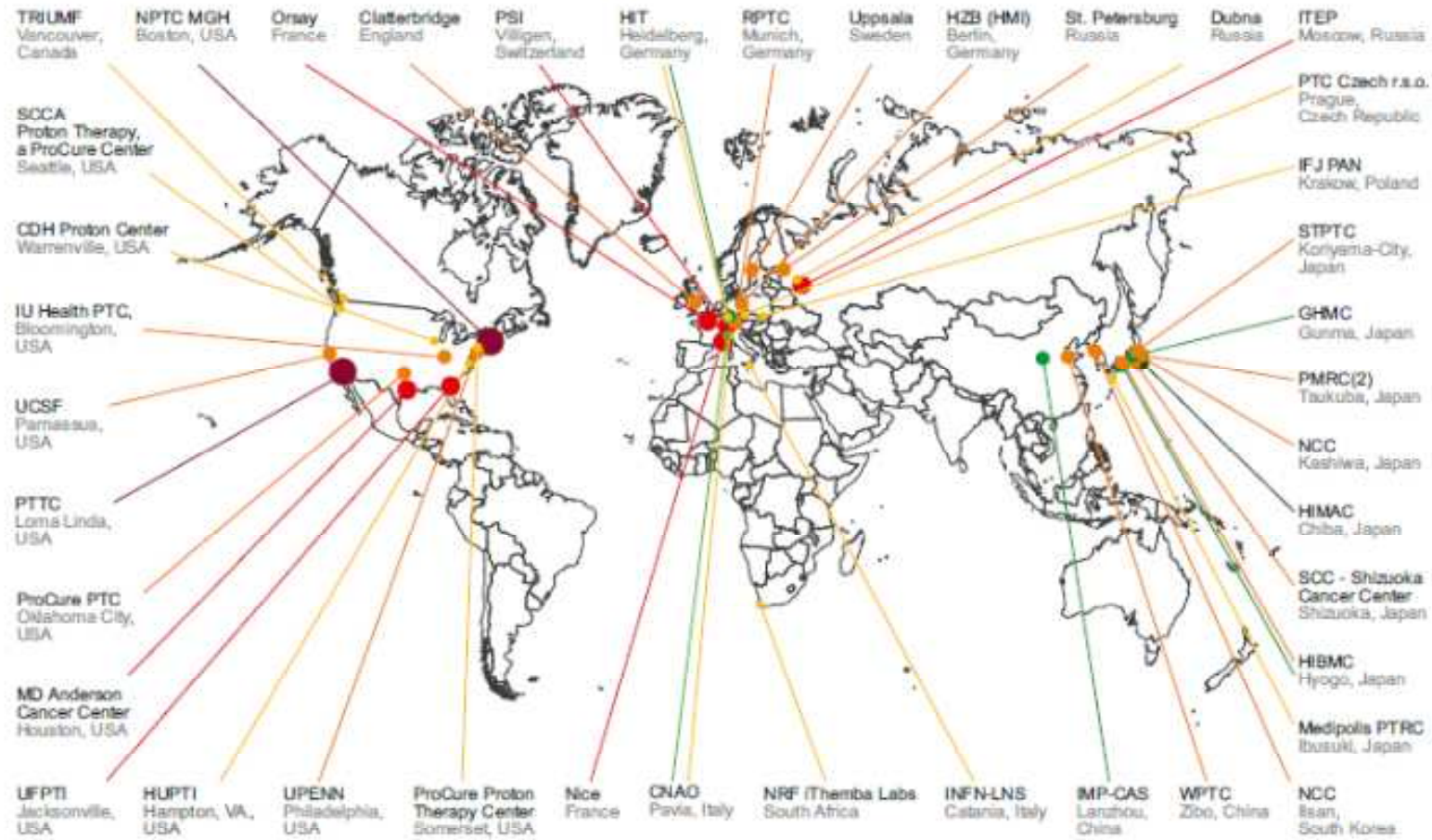


August 2012 PET/CT January 2013 PET/CT

RT to one liver met 6 Gy X 5 (TD 30 GY)
Ipilimumab, 3 mg/Kg, after first RT q3 weeks, X 4 c



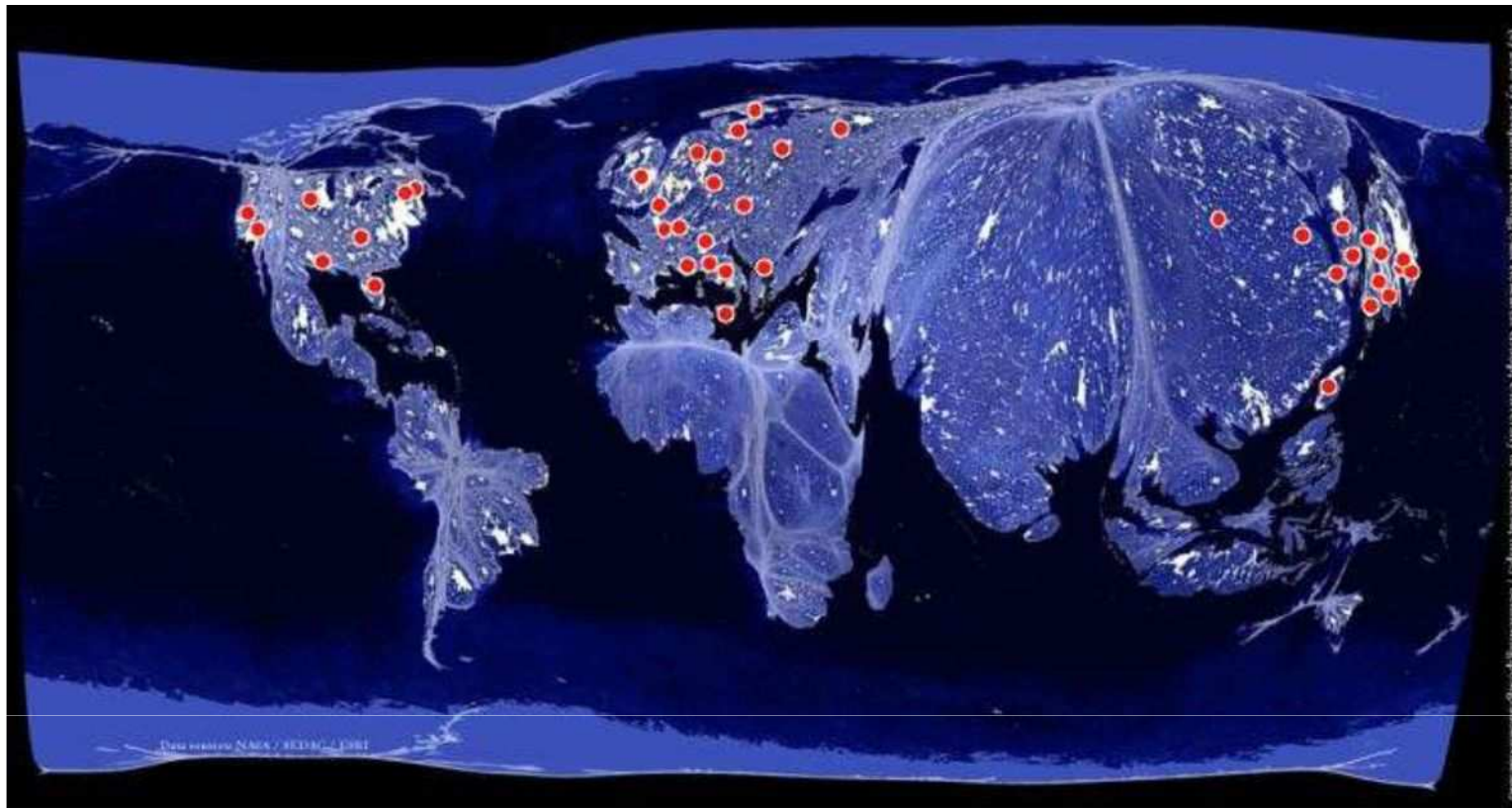
August 2012 PET/CT January 2013 PET/CT



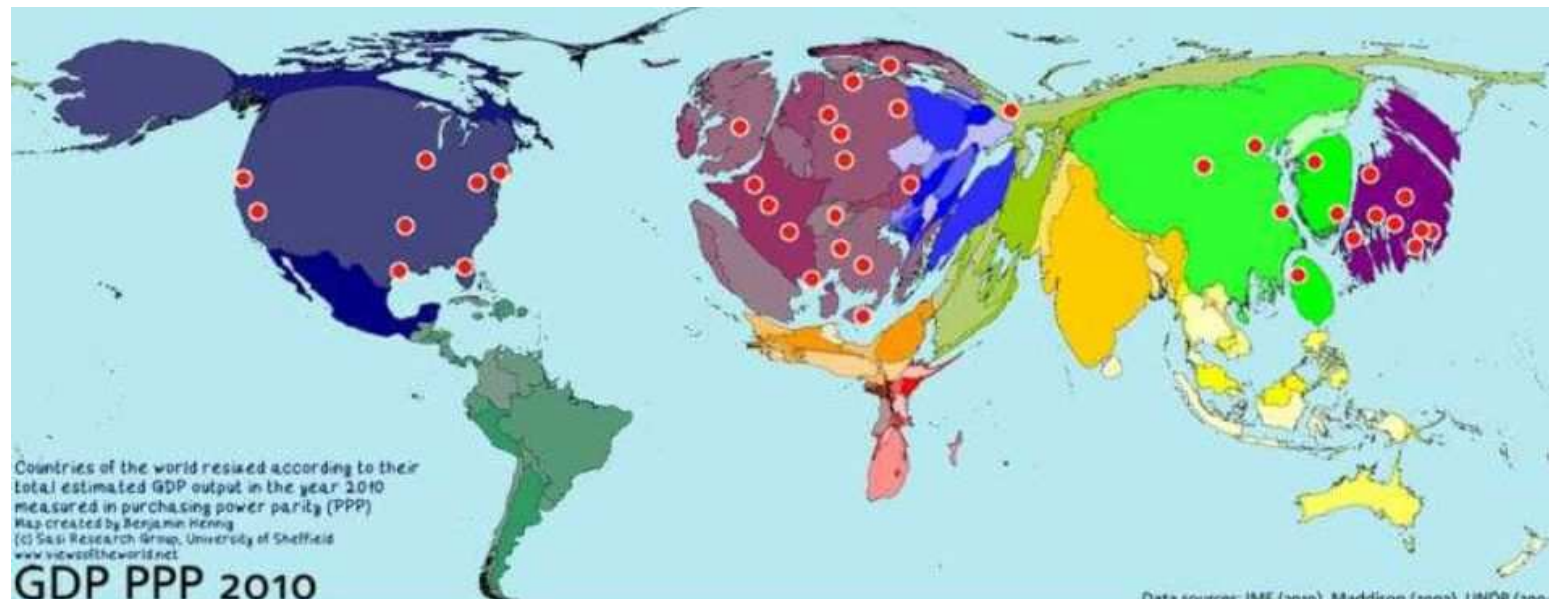
March 2014: 44 proton/7 heavy ion centers
Under construction: 25 proton/ 4 heavy ion centers
Only in USA, 27 new centers expected by 2017



NuPECC report „Nuclear Physics in Medicine“, 2014
 Available online www.nupecc.org

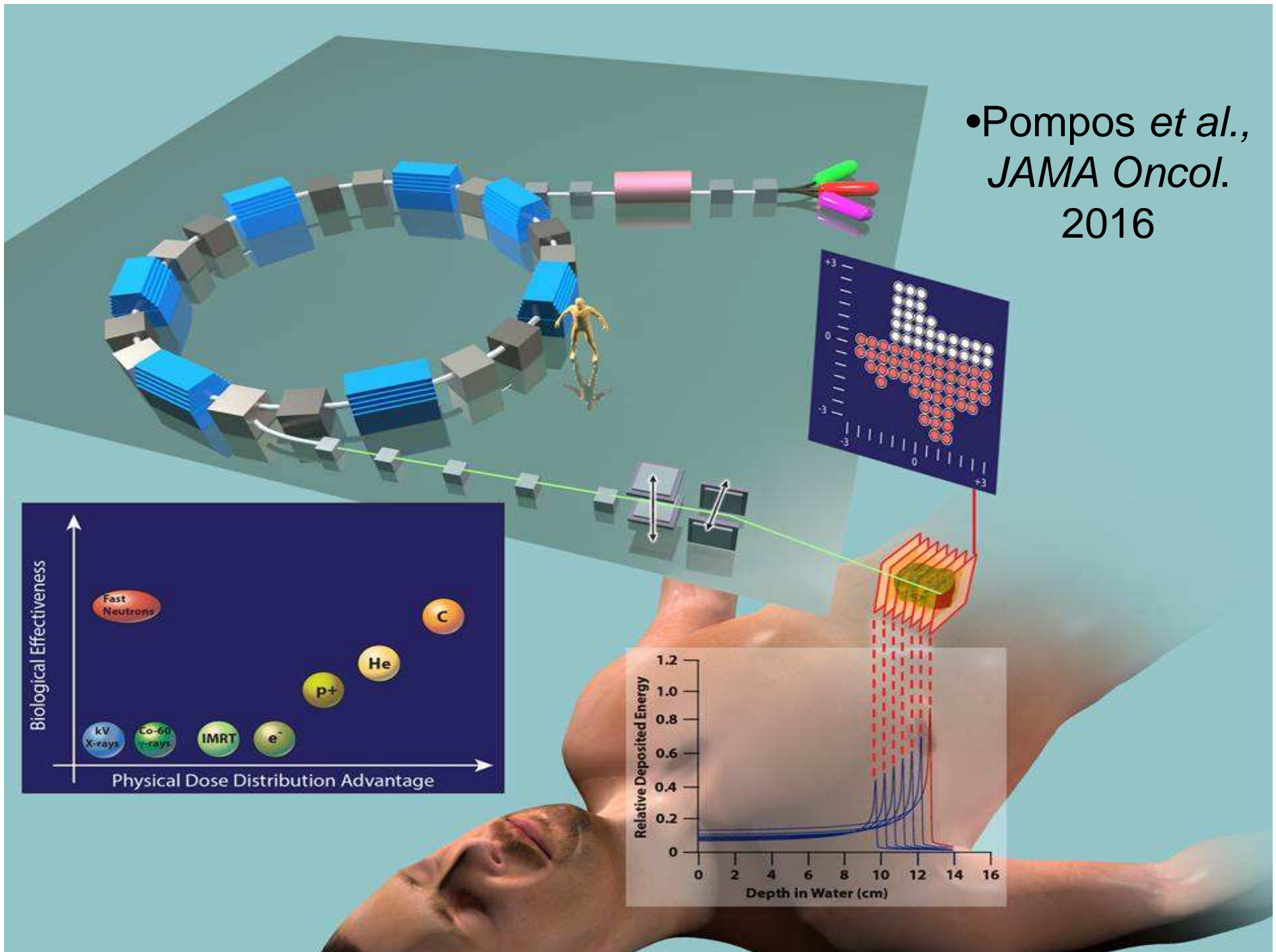


Population
– scaled



GDP-
scaled

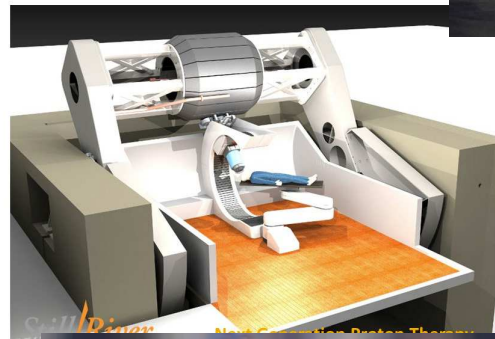
• Pompos *et al.*,
JAMA Oncol.
2016



200



Heavy ions (protons + carbon ions)



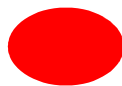
proton single-room

2

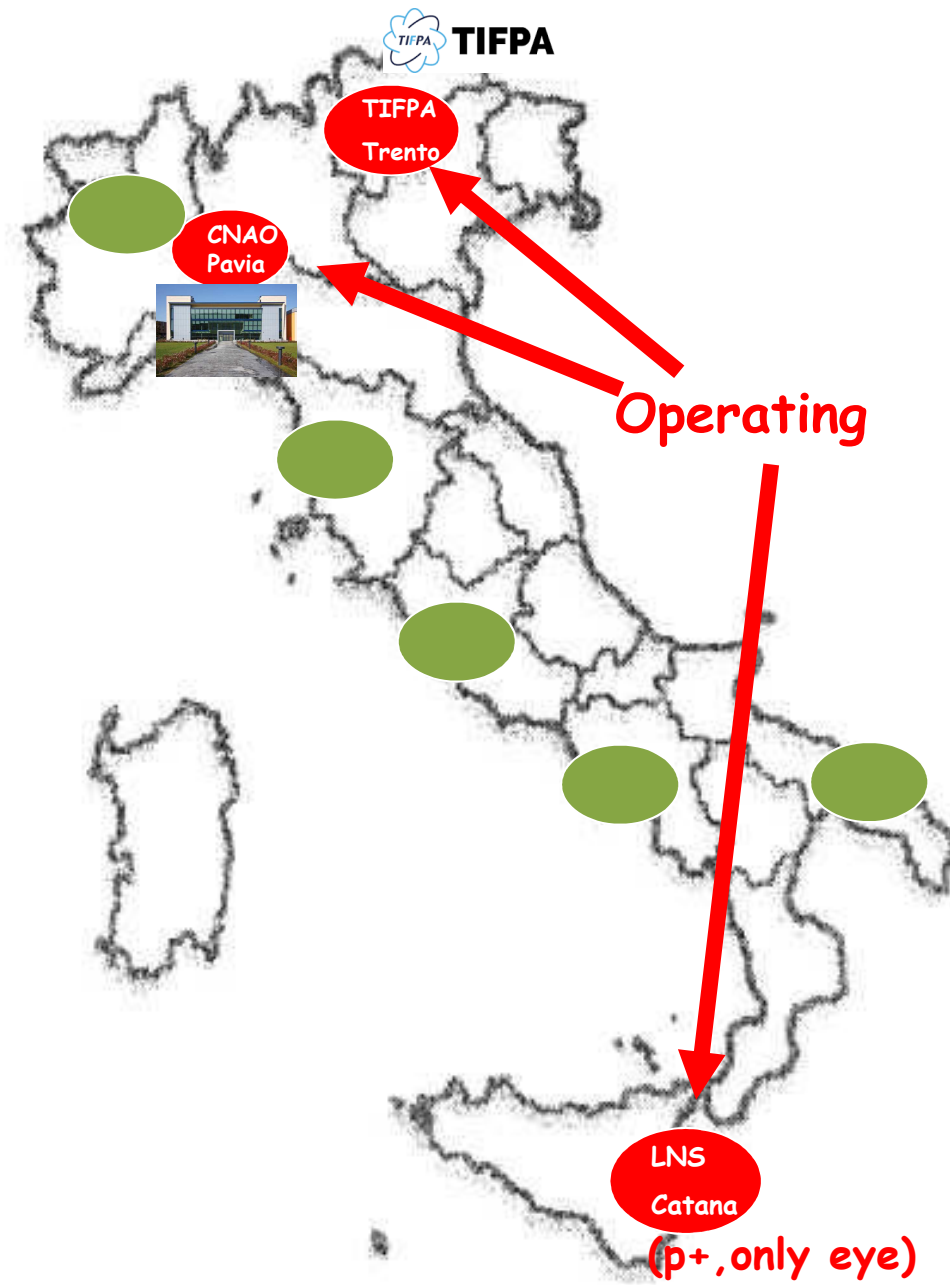


ITALIAN NETWORK FOR HADRONTHERAPY

EXISTING CENTRES



INTEREST FOR PROTONS



LEA adroterapia – Settembre 2016



- Cordomi e condrosarcomi della base del cranio e del rachide;
- Tumori del tronco encefalico (esclusi i tumori intrinseci diffusi del ponte) e del midollo spinale;
- Sarcomi del distretto cervico--cefalico, paraspinali, retroperitoneali e pelvici;
- Sarcomi delle estremità ad istologia radioresistente (osteosarcoma, condrosarcoma);
- Meningiomi intracranici in sedi critiche (stretta adiacenza alle vie ottiche e al tronco encefalico);
- Tumori orbitari e periorbitari (es. seni paranasali) incluso il Melanoma oculare;
- Carcinoma adenoideo---cistico delle ghiandole salivari;
- Tumori solidi pediatrici;
- Tumori in pazienti affetti da sindromi genetiche e malattie del collagene associate ad un'aumentata radiosensibilità;
- Recidive che richiedono il ritrattamento in un'area già precedentemente sottoposta a radioterapia;



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Tumori pediatrici



Pianificazione



In trattamento

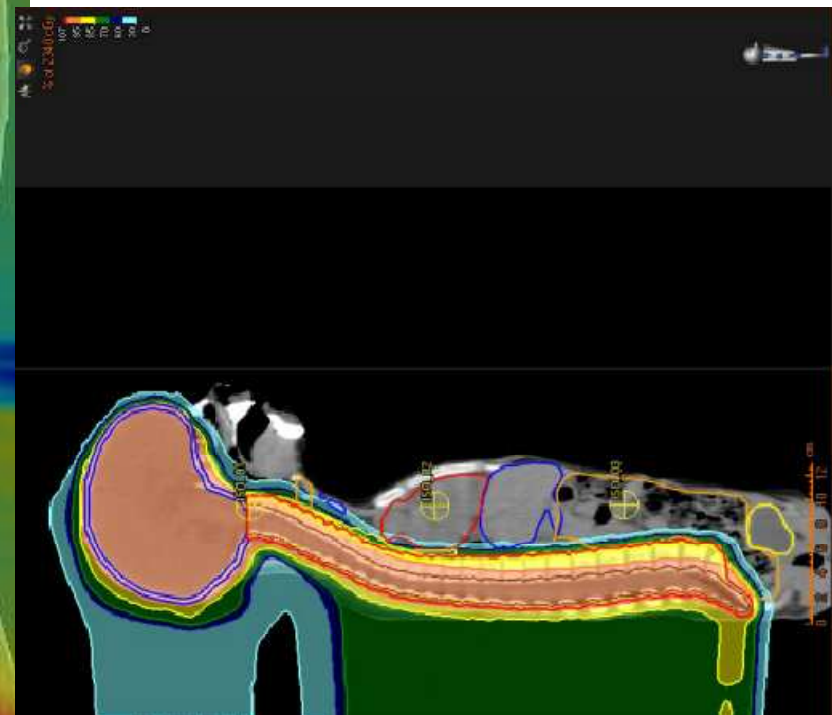
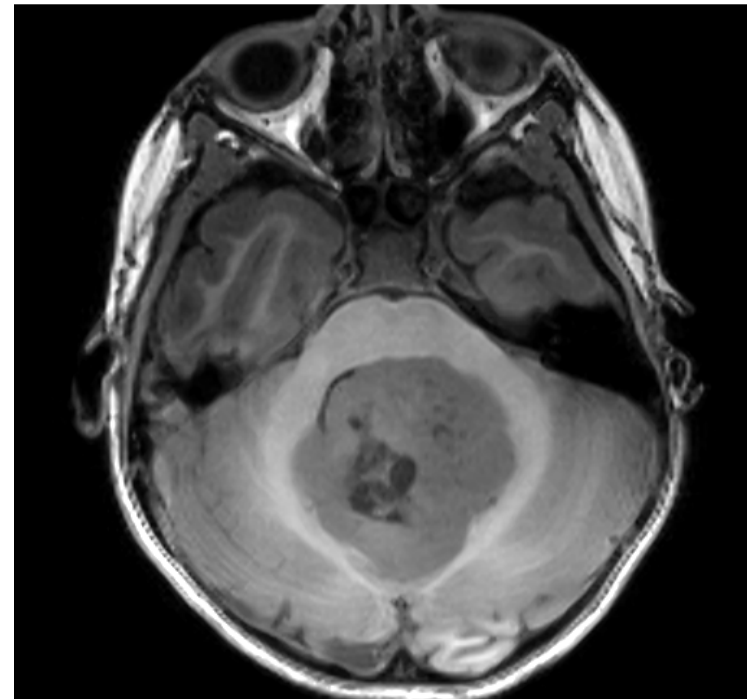
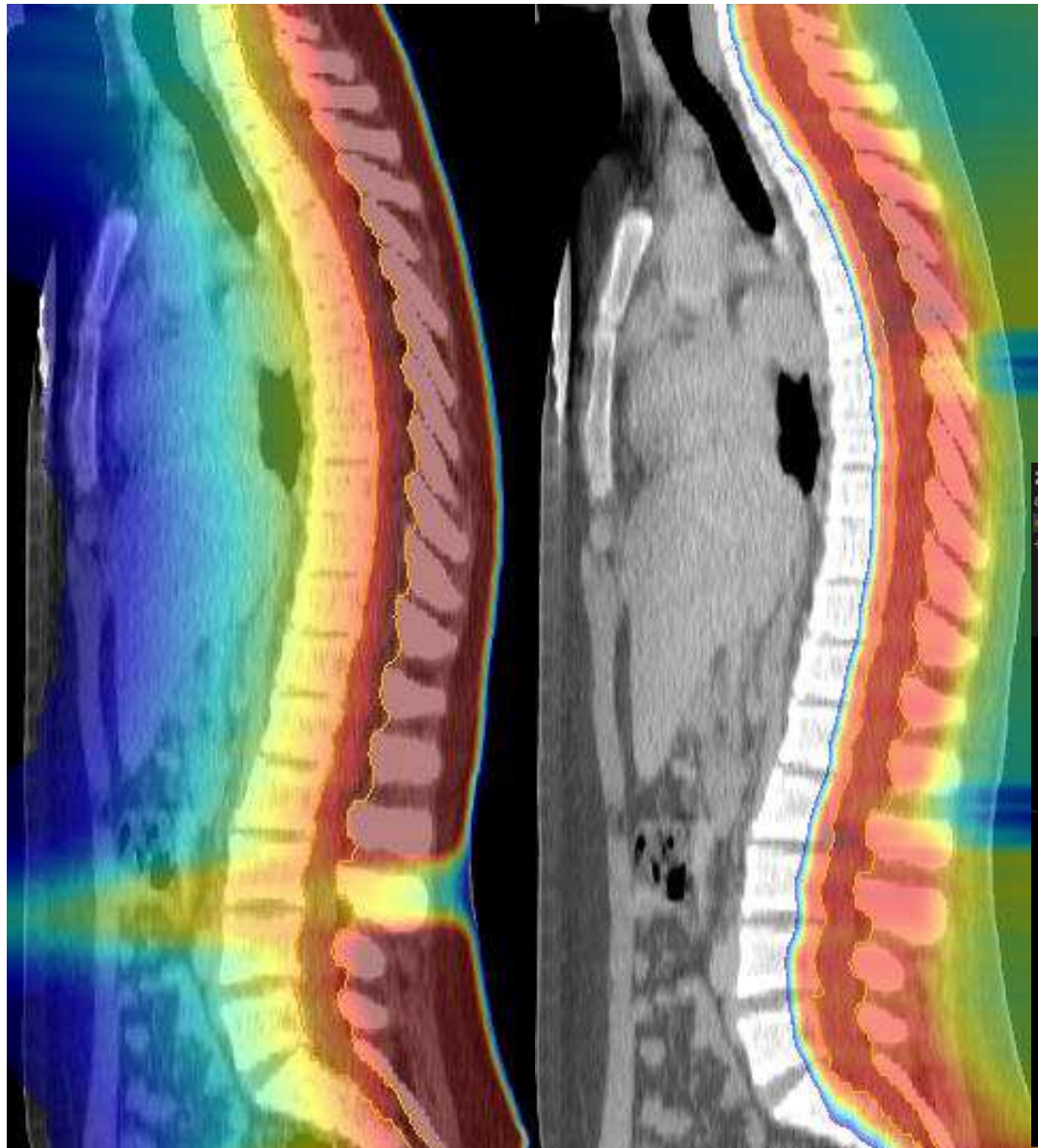


Ultimo giorno



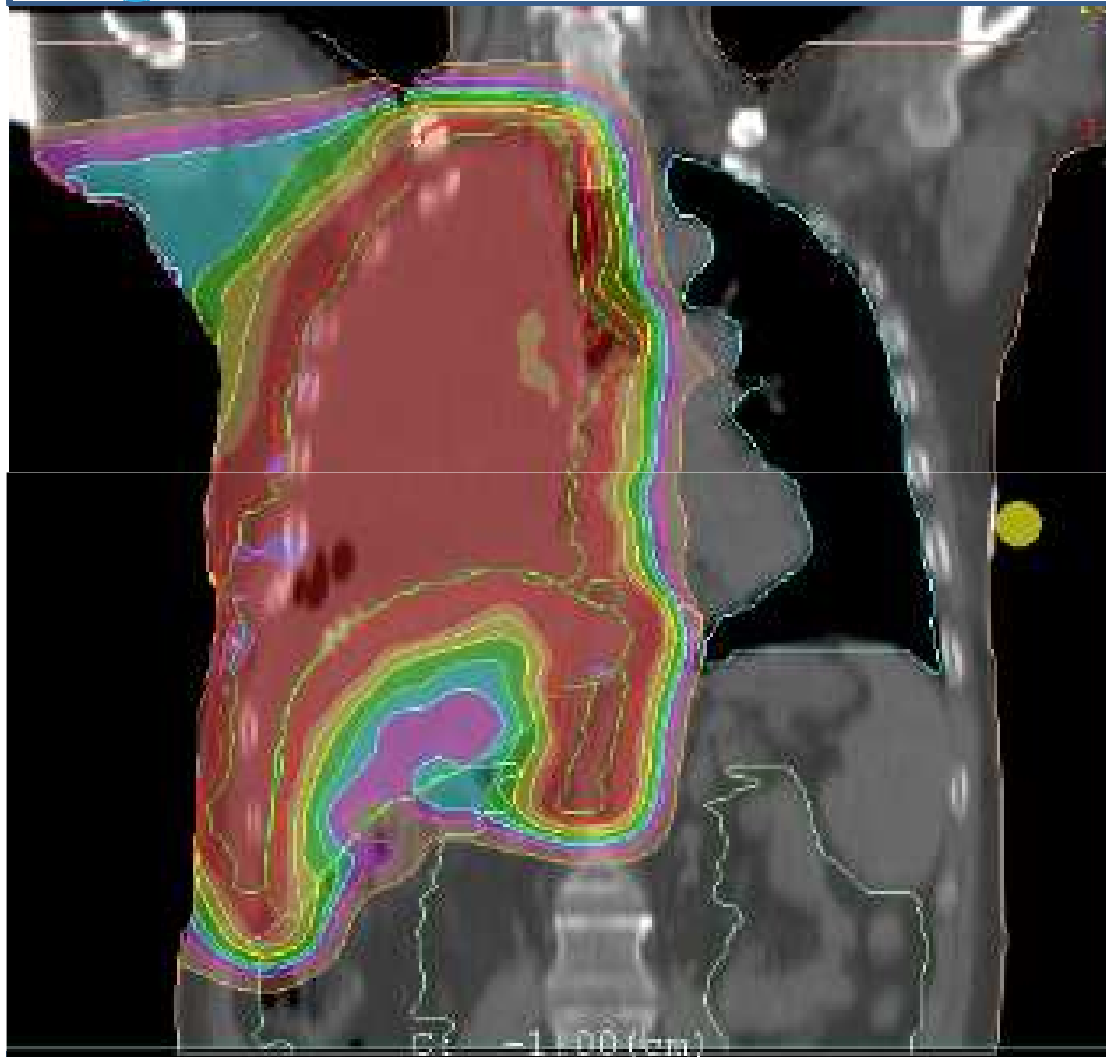
6 m post- P

MEDULLOBLASTOMA PEDIATRICO





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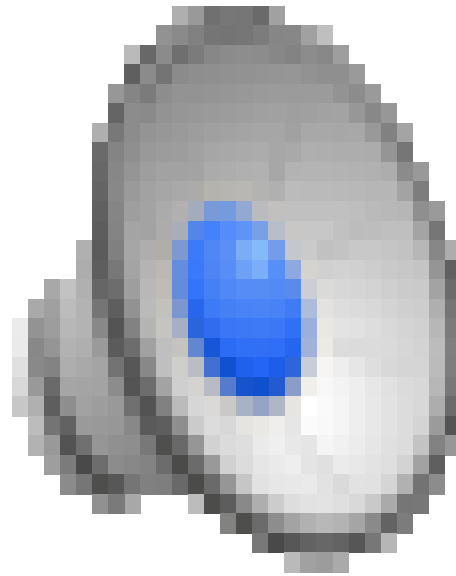


Treatment plan
with protons:
pleural
mesothelioma

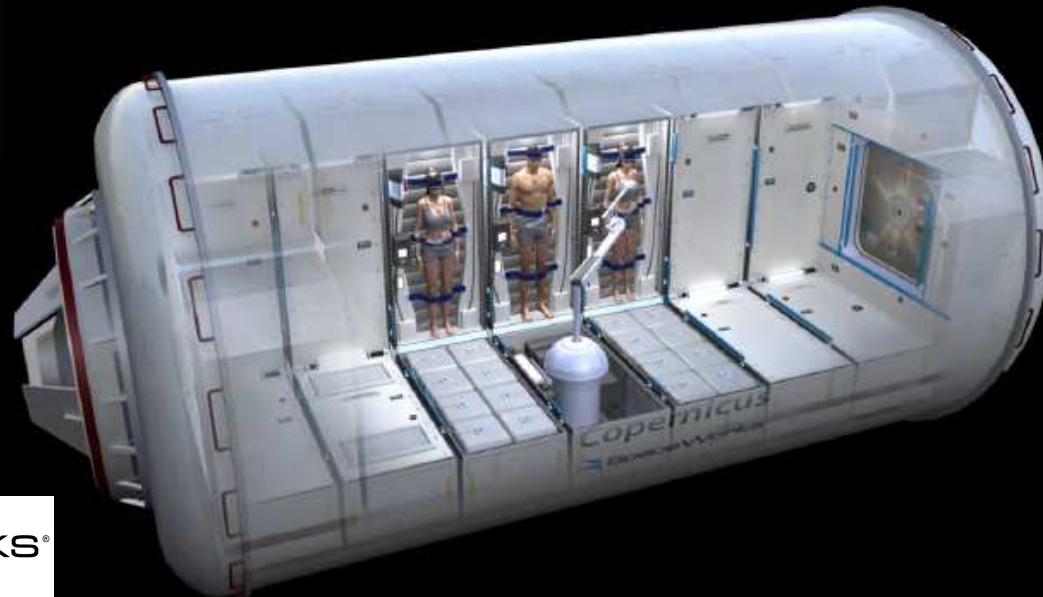
Courtesy of Marco Schwarz, TIFPA, Trento, Italy

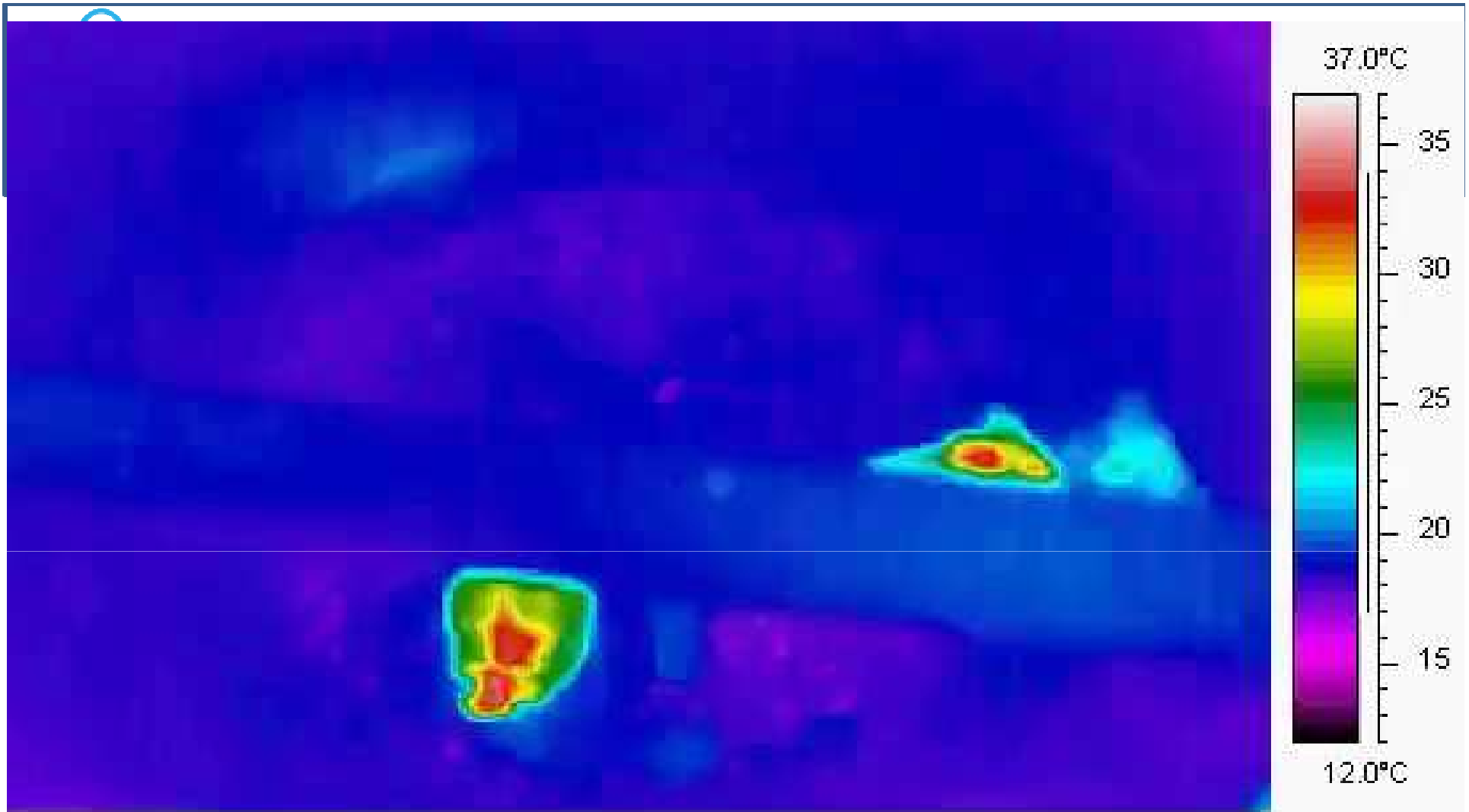
Range uncertainty: protons stop, but where?





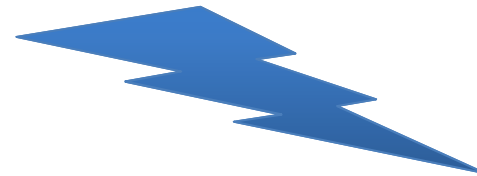
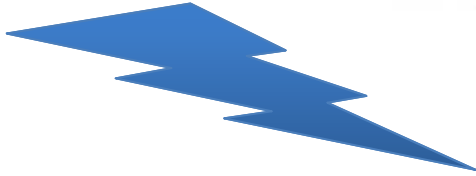
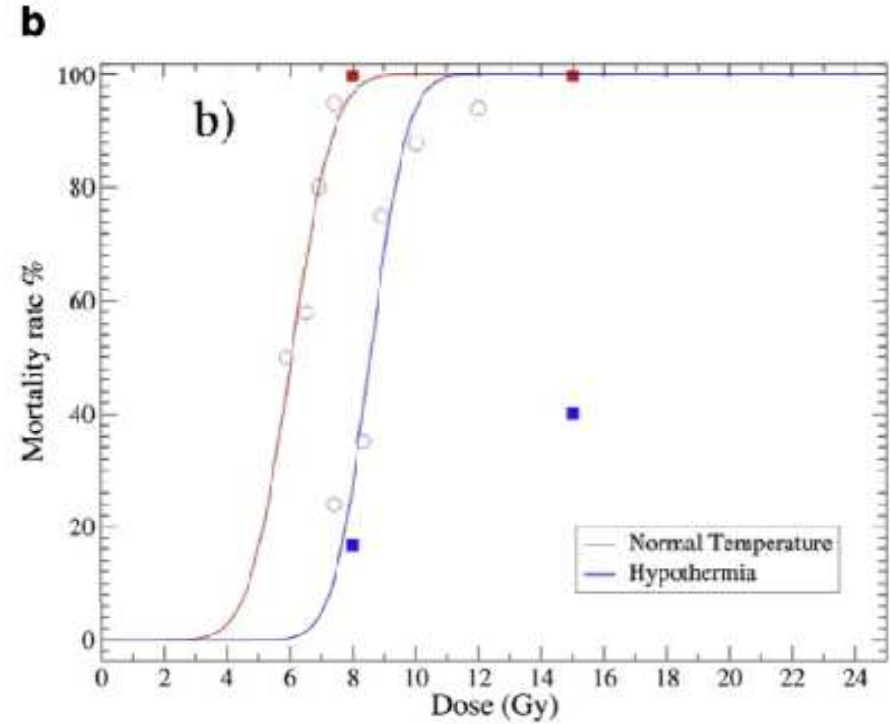
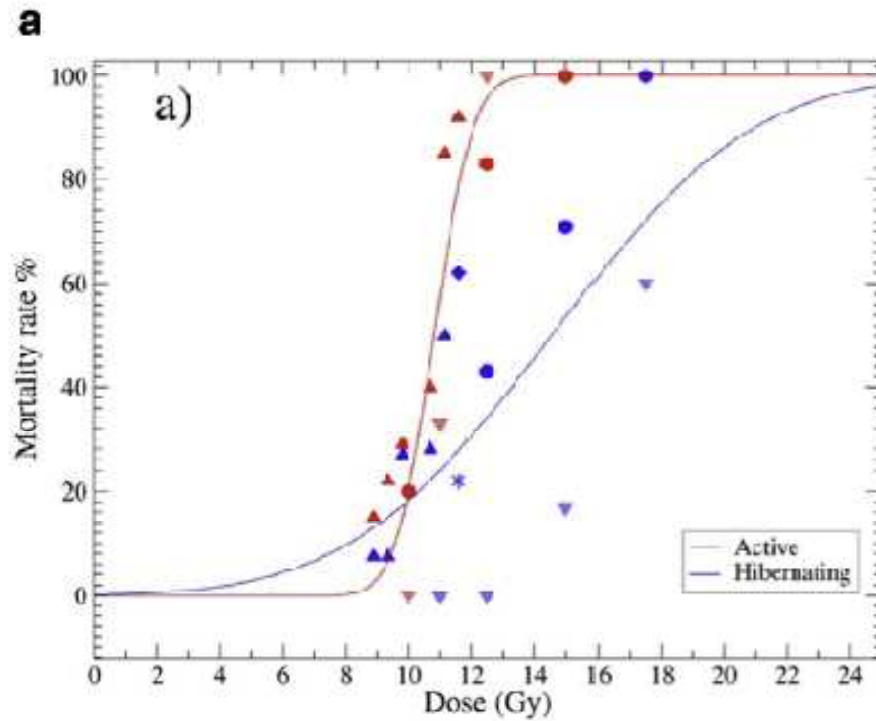
Hibernation: space and therapy





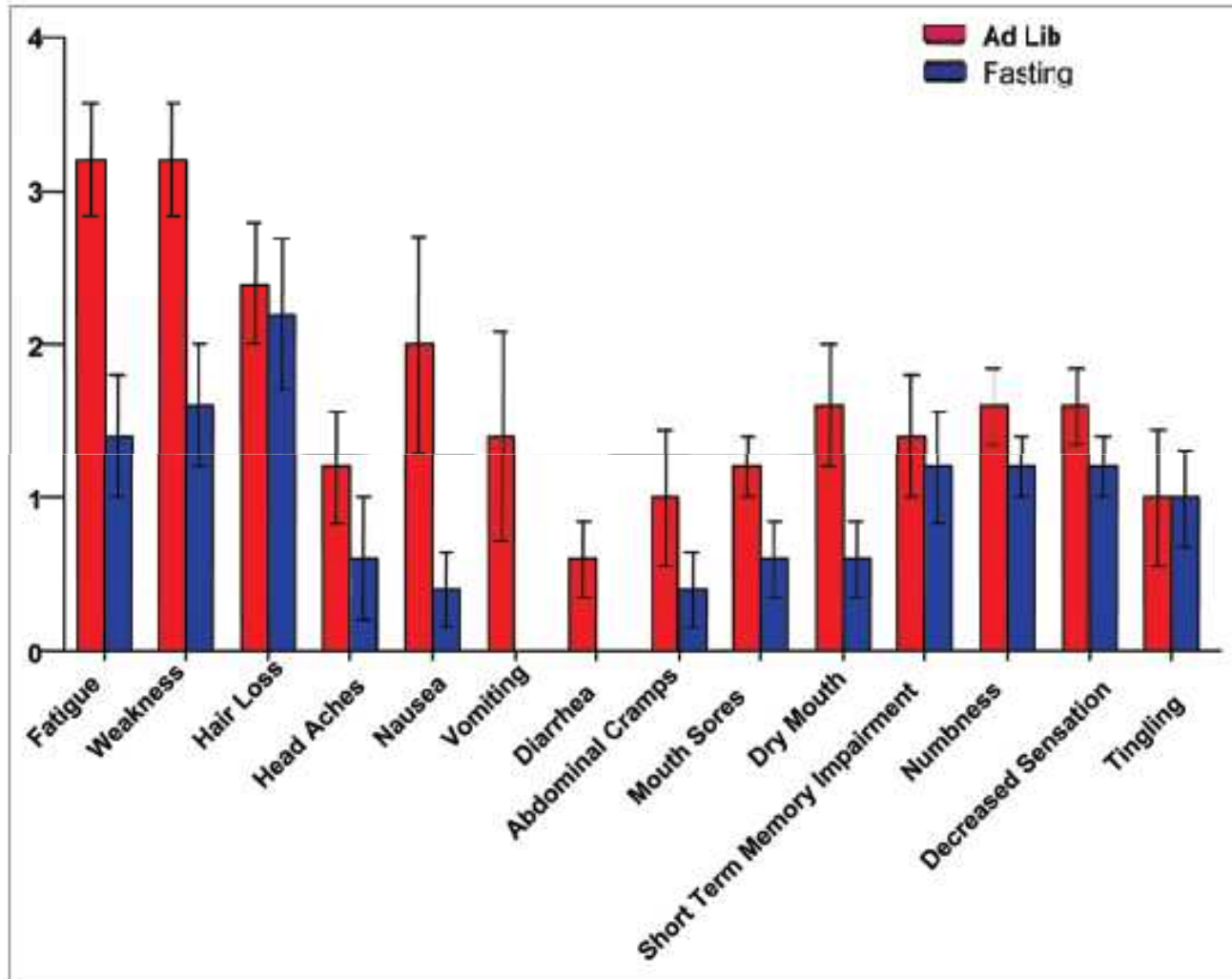
Courtesy of Prof. Matteo Cerri, University of Bologna

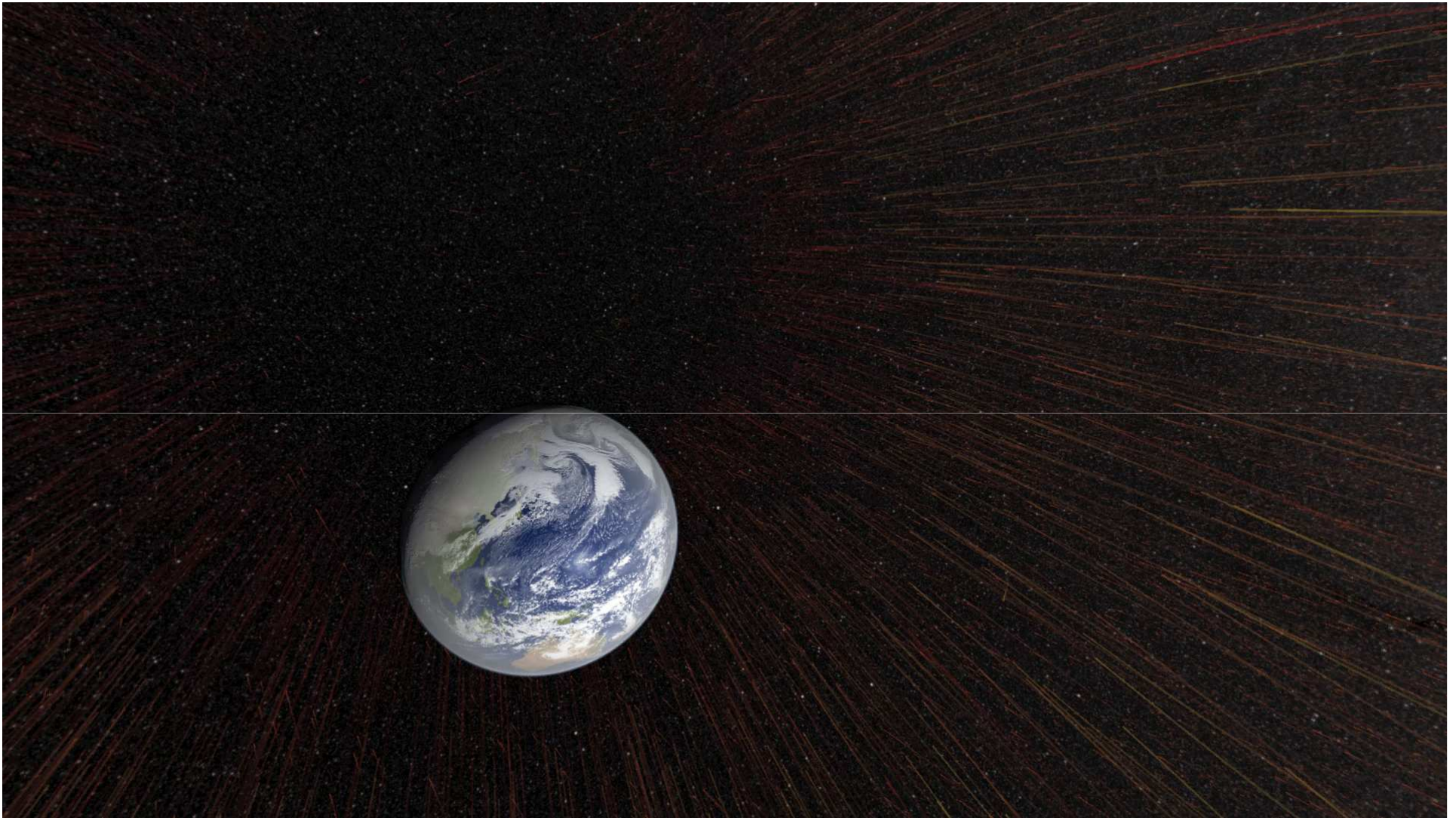




Animal	Normal conditions		Hibernation/hypothermia		Protective factor
	γ	LD50 (Gy)	γ	LD50 (Gy)	
Squirrels	4.4 ± 1.2	10.82 ± 0.17	1.1 ± 0.4	14.6 ± 1.1	1.35 ± 0.07
Rats	2.3 ± 0.5	6.03 ± 0.13	3.6 ± 2.7	8.6 ± 0.4	1.42 ± 0.10

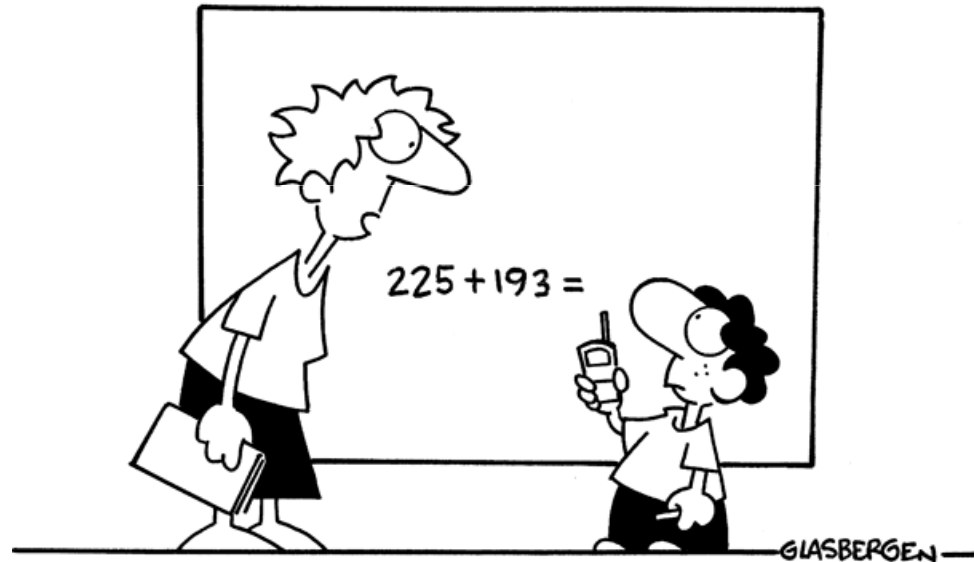
Hibernation in therapy?





Thank you for attention!

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"You have to solve this problem by yourself. You can't call tech support."