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ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

Implications of Space Weather for the Search of Life

Julian CHELA-FLORES
Staff Associate
The Abdus Salam International Centre for
Theoretical Physics (ICTP)
Trieste
ITALY

The Abdus Salam
International Centre for Theoretical Physics
Space weather at other planets

Smr 1749
COST Action 724

United Nations
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Origin, evolution and distribution of life in the Solar System: Constraints from space weather

Lecture 2: Implications of Space Weather for the Search of Life

Julian Chela-Flores

The Abdus Salam ICTP, Trieste, Italia and

Instituto de Estudios Avanzados IDEA, Caracas,

R.B. Venezuela

Plan of the lecture

- Space radiation sources in our own solar system.
- Space weather in the jovian system.
- A component of space weather from the Jovian system.
- Space weather in other planets of other solar systems.

Part 1

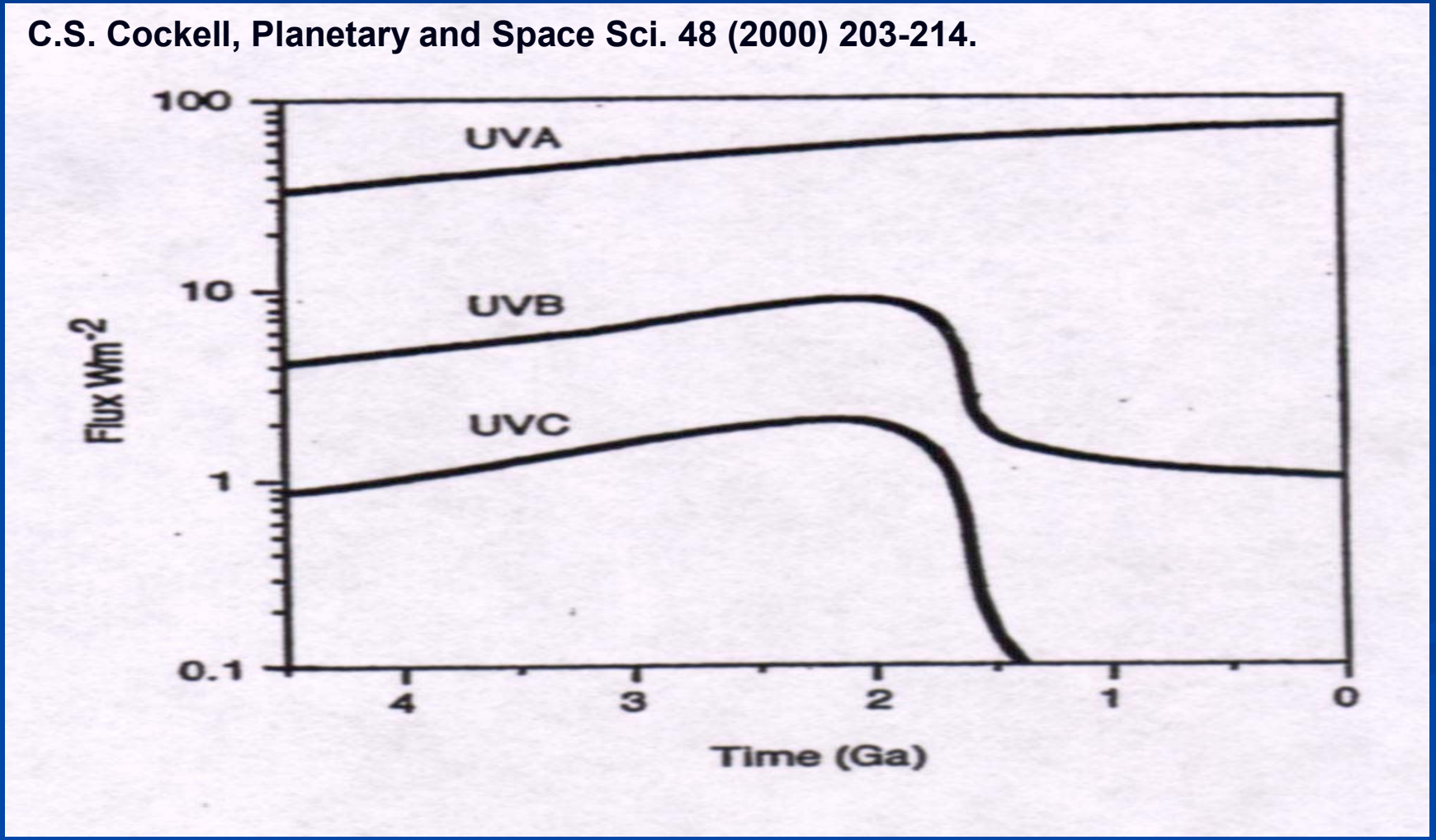
Space Radiation Sources in our own Solar System

Solar radiation in the Earth middle and lower atmosphere

Wavelength (nm)	*Abbreviation*	*Name and comments*	*Effects*	*Height range (km)*
Less than 280	UVC	arbitrary division in photobiology	cuts-off at 1.5 Gyr BP	20 - 40
280 - 320	UVB	arbitrary division in photobiology	dissociate O_3	20 - 40
320 - 400	UVA	arbitrary division in photobiology	induces a decrease in photosynthesis of cyanobacteria	reaches the Earth's surface

The Earth : History of Solar Radiation

C.S. Cockell, Planetary and Space Sci. 48 (2000) 203-214.

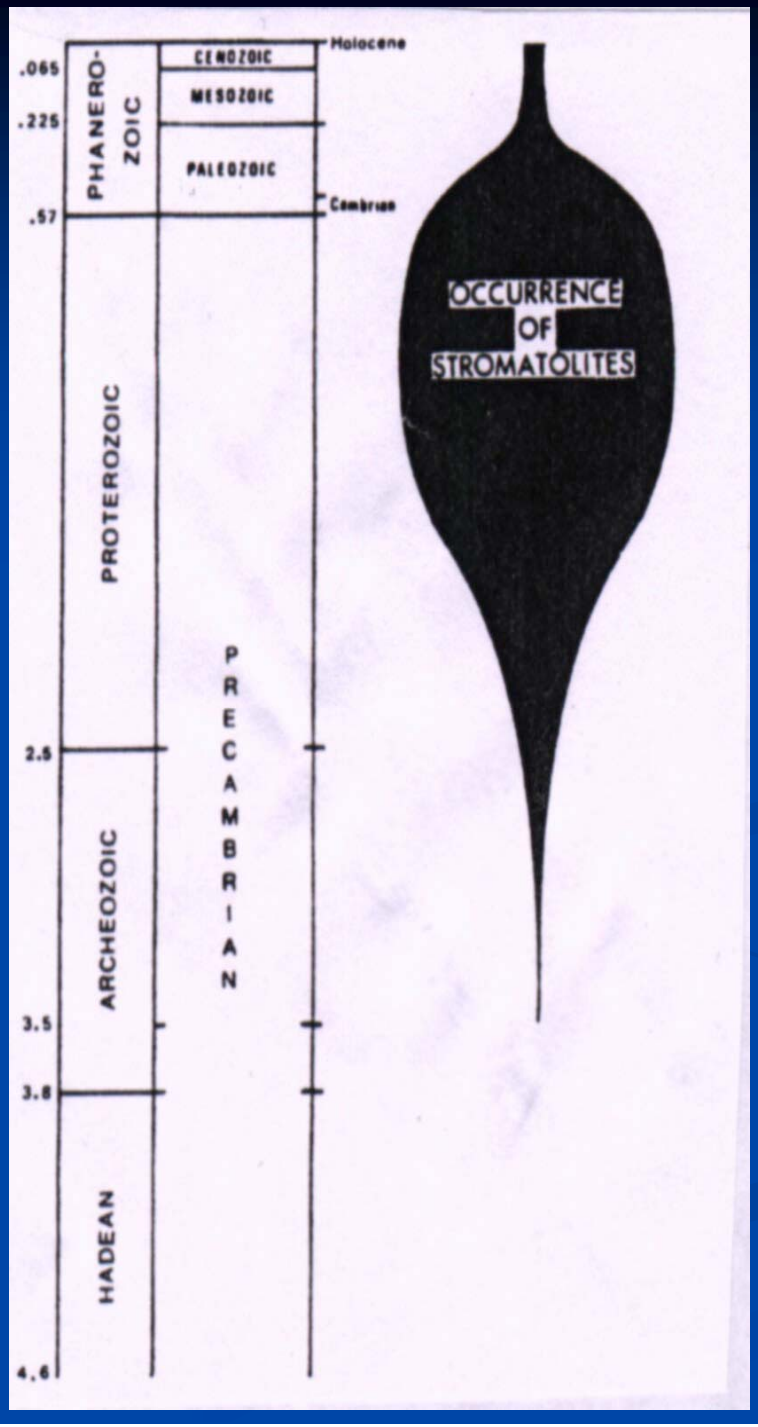


Present

2.5

3.5

4.6

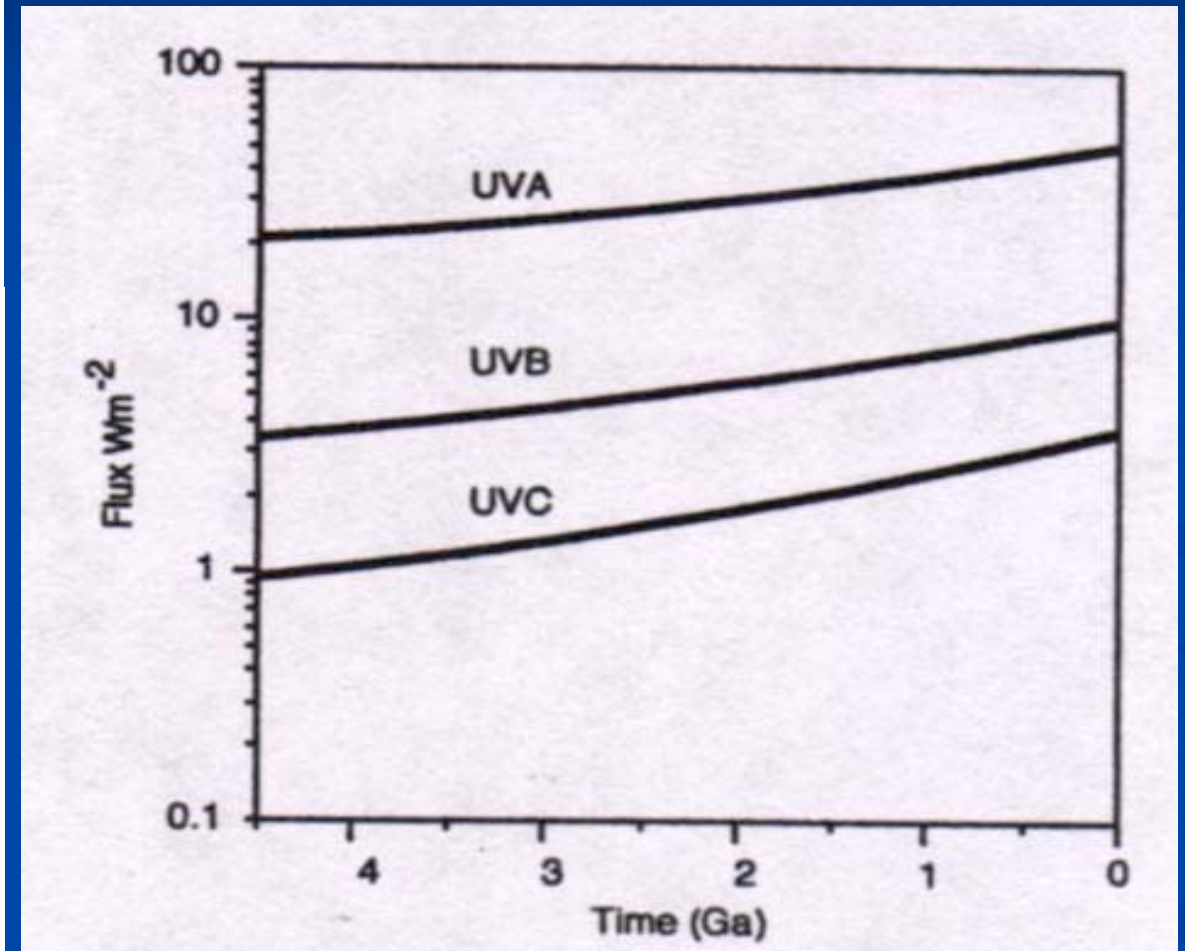


Abundance of stromatolites in the fossil record

(time scale in Gyrs)

Fossils of ancient life on Earth

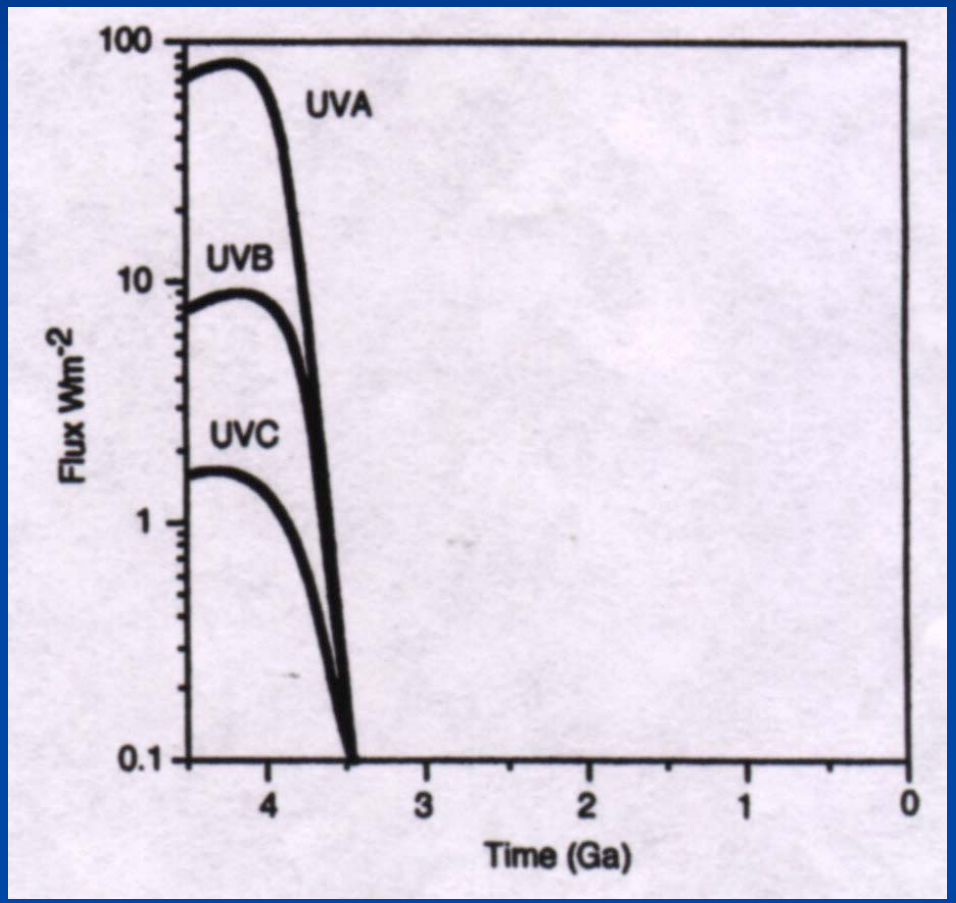
Mars: History of Solar Radiation

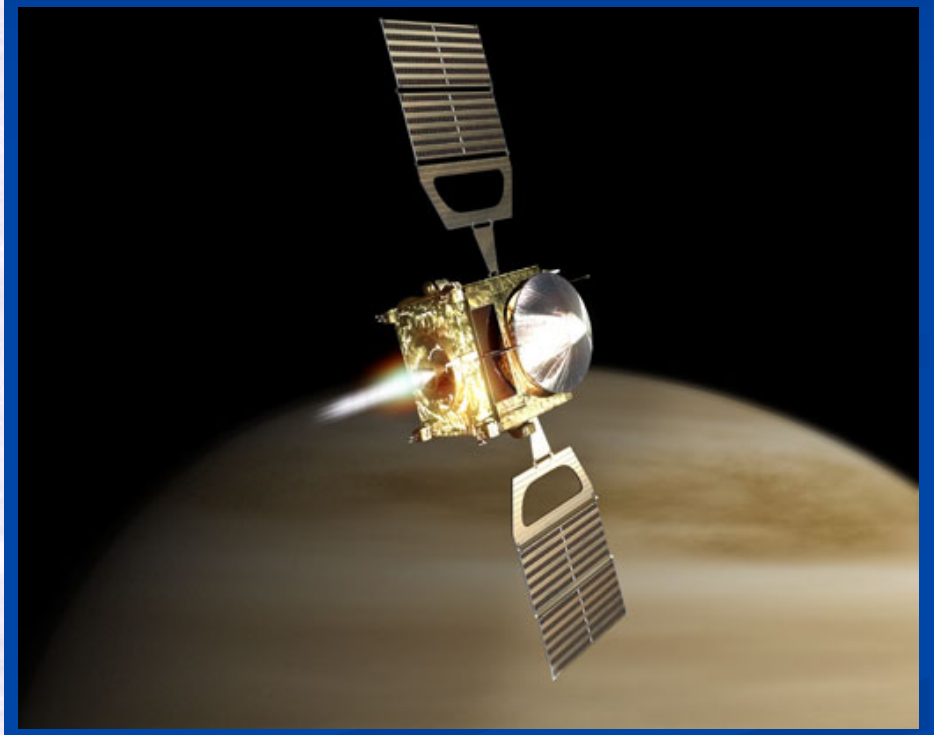


C.S. Cockell, Planetary and Space Sci. 48 (2000) 203-214.

Venus: History of Solar Radiation

C.S. Cockell, Planetary and Space Sci. 48 (2000) 203-214.

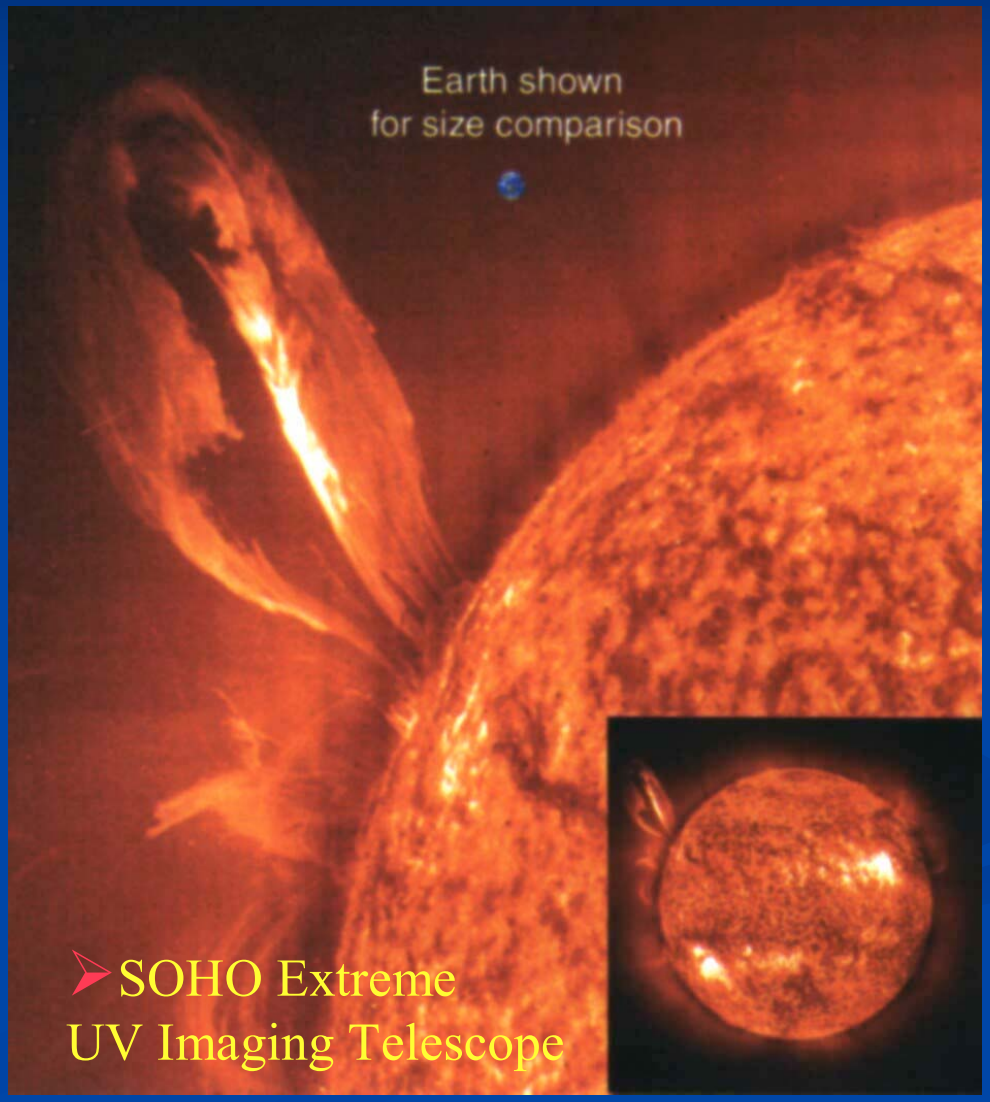




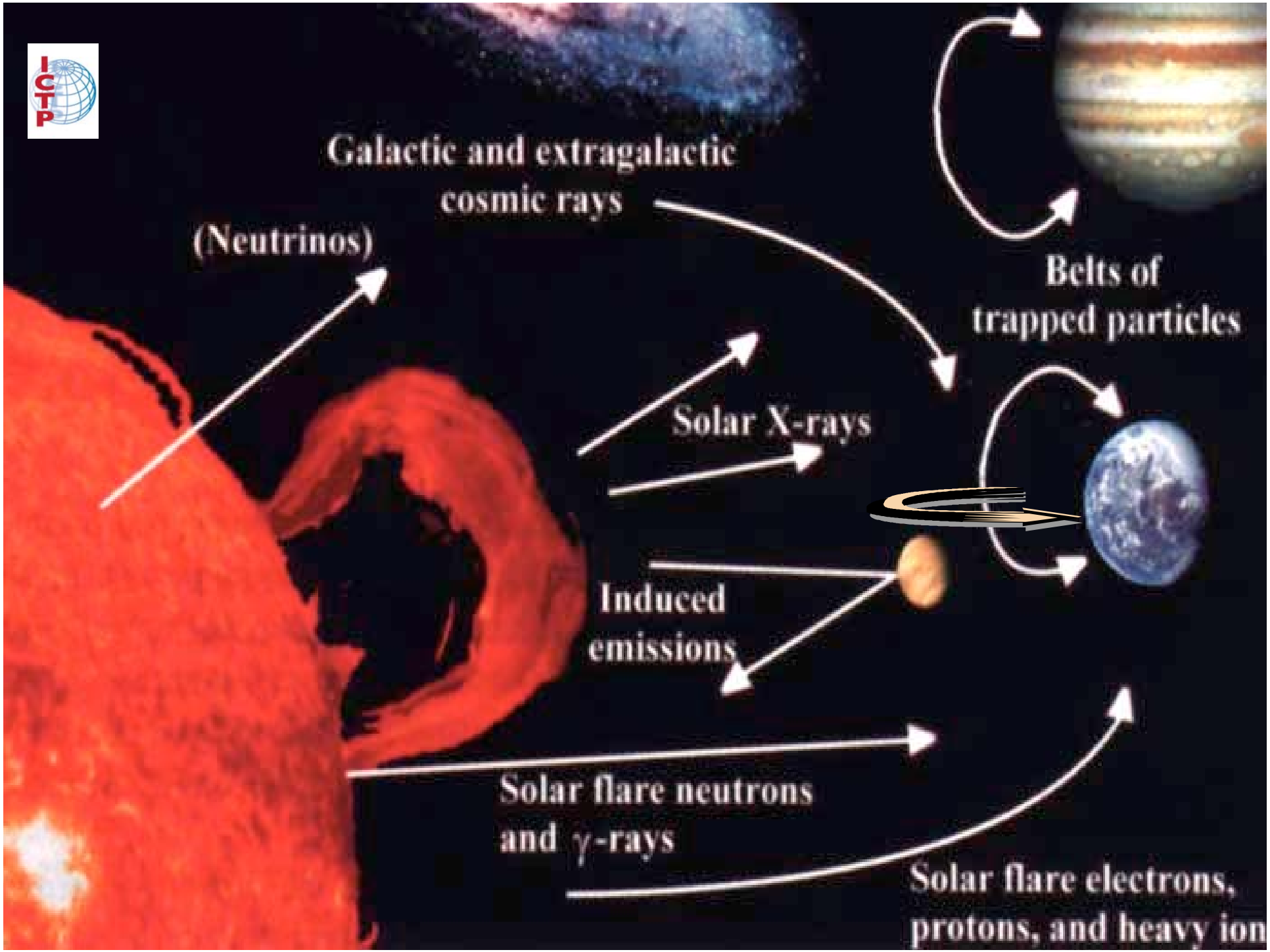
Space radiation sources:
Eruptive prominences

- The arch shown is associated with **coronal mass ejections** (CMEs) that are associated with magnetic field lines in coronal holes.

- Observed in the extreme UV light of a singly ionize atom of He (HE II) at 30.4 nm. This event took place on 24 July 1999.

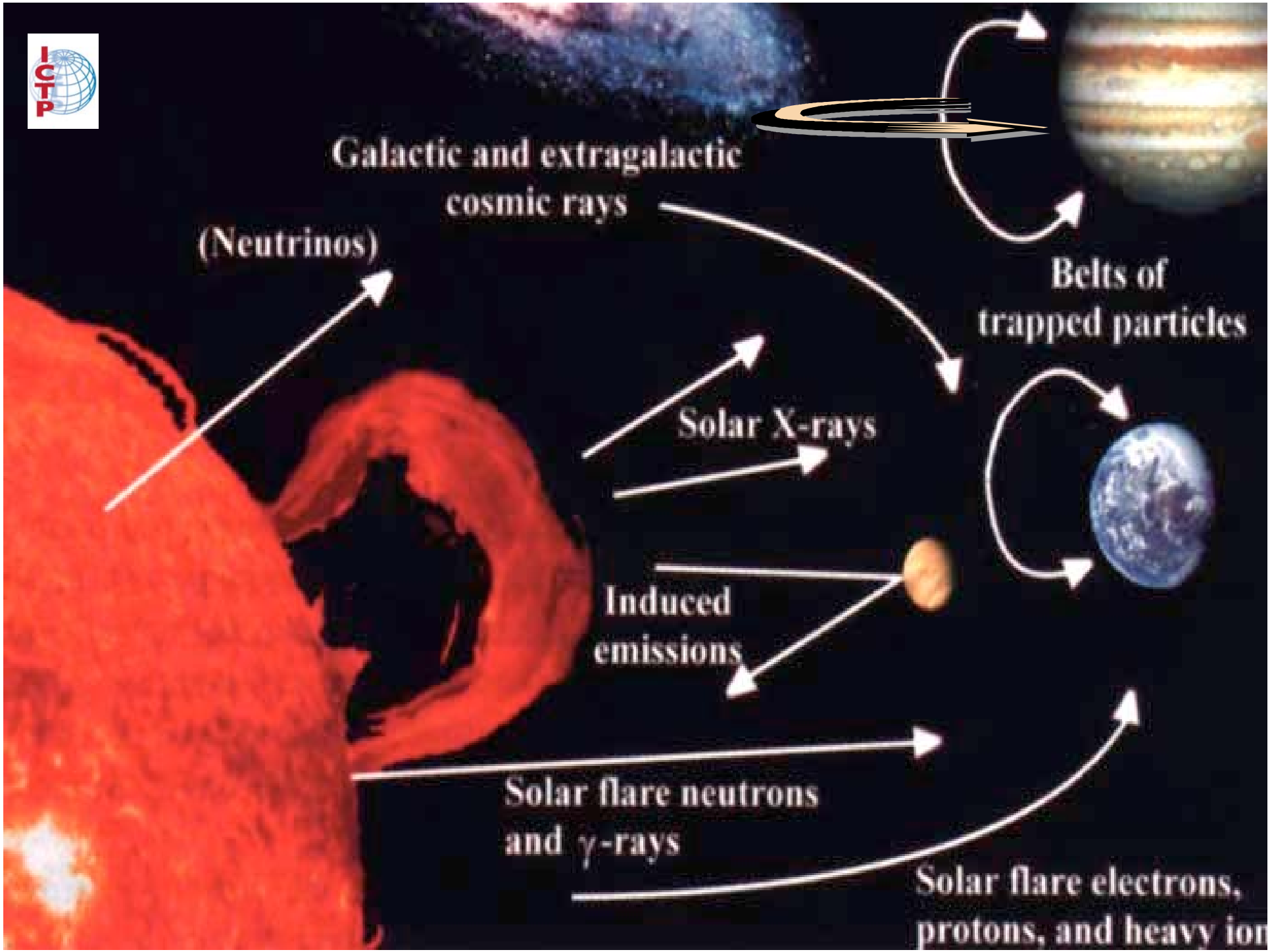


- SOHO Extreme UV Imaging Telescope


Galactic and extragalactic
cosmic rays
(Neutrinos)
Belts of
trapped particles
Solar X-rays
Induced
emissions
Solar flare neutrons
and γ-rays
Solar flare electrons,
protons, and heavy ion

The Genesis mission

- Launched in August of 2001 to capture samples from the Sun.
- The samples of **solar wind particles**, collected on ultra-pure wafers of gold, sapphire, silicon and diamond, were returned for analysis.


Galactic and extragalactic
cosmic rays
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Belts of
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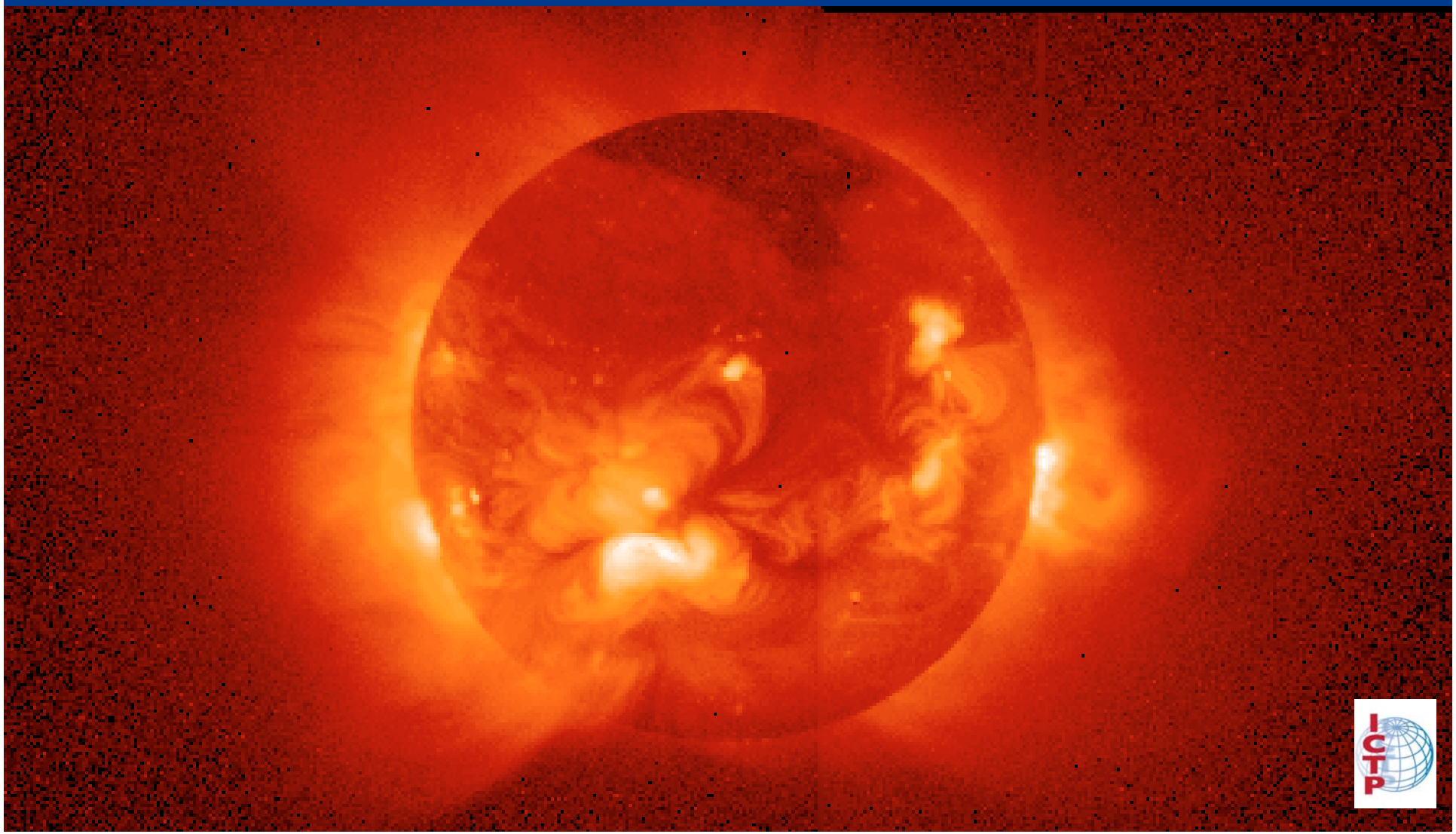
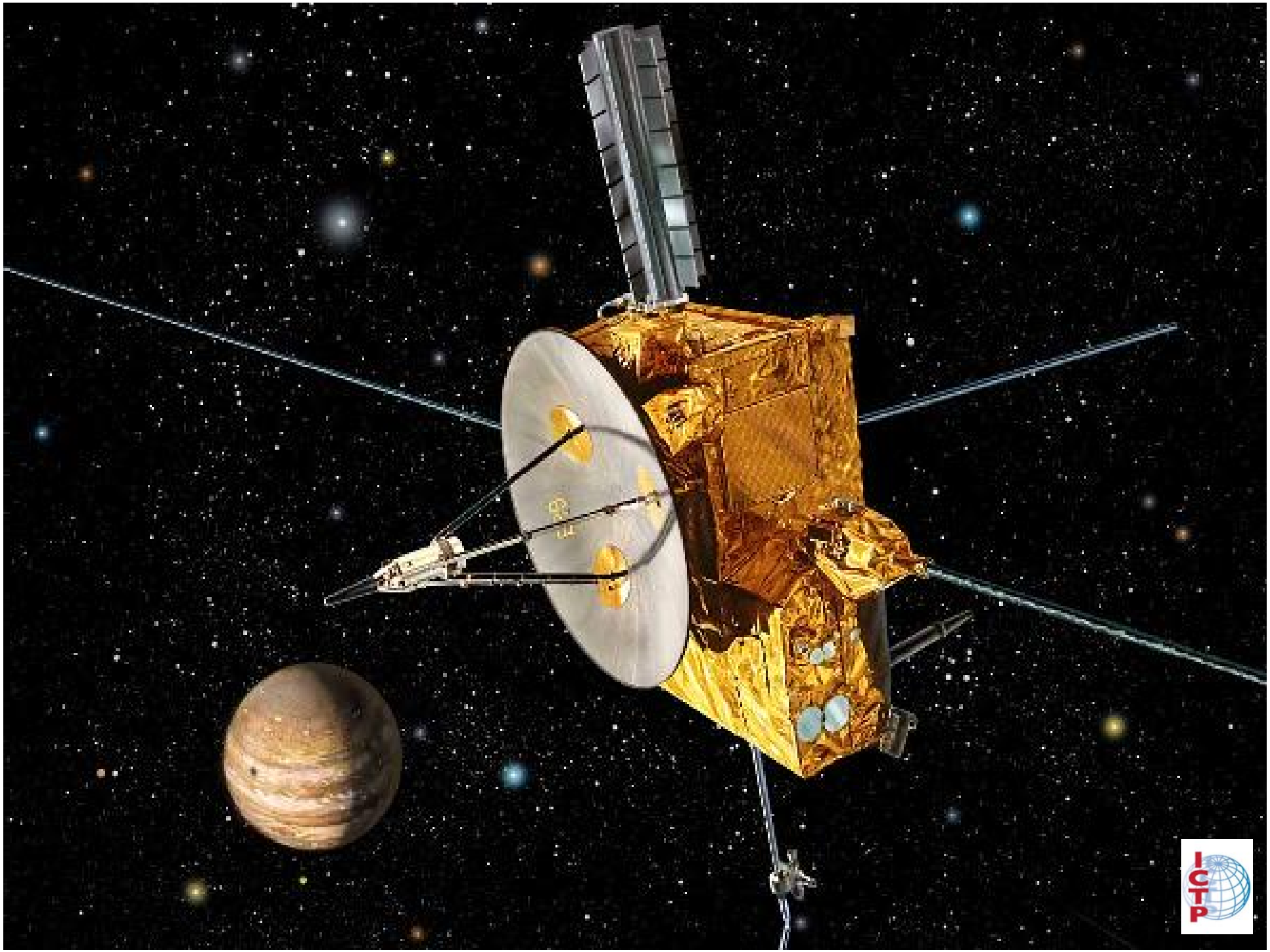
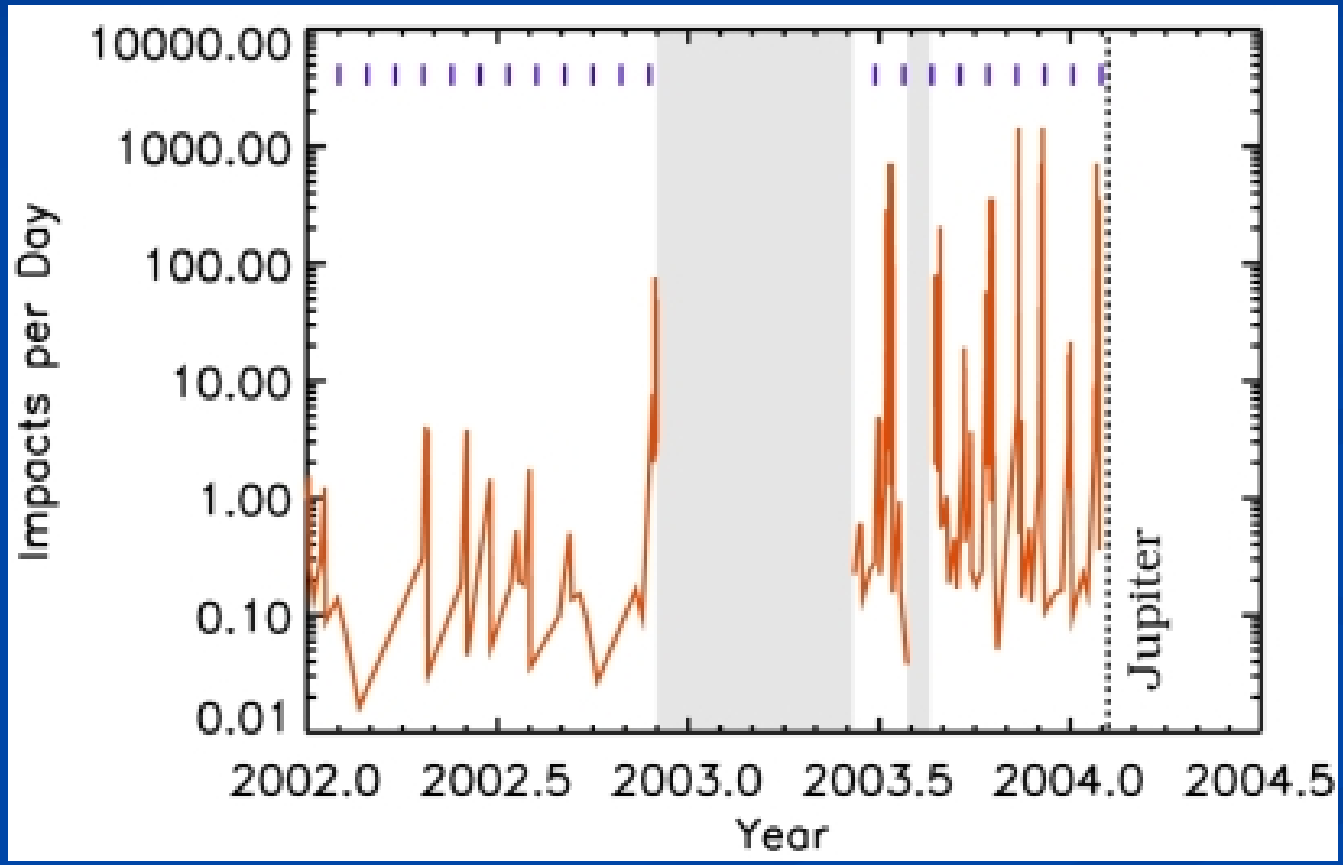
Solar X-rays
Induced
emissions
Solar flare neutrons
and γ-rays
Solar flare electrons,
protons, and heavy ion

A probe in a solar north-south polar orbit




ICTP

The Ulysses dust detector

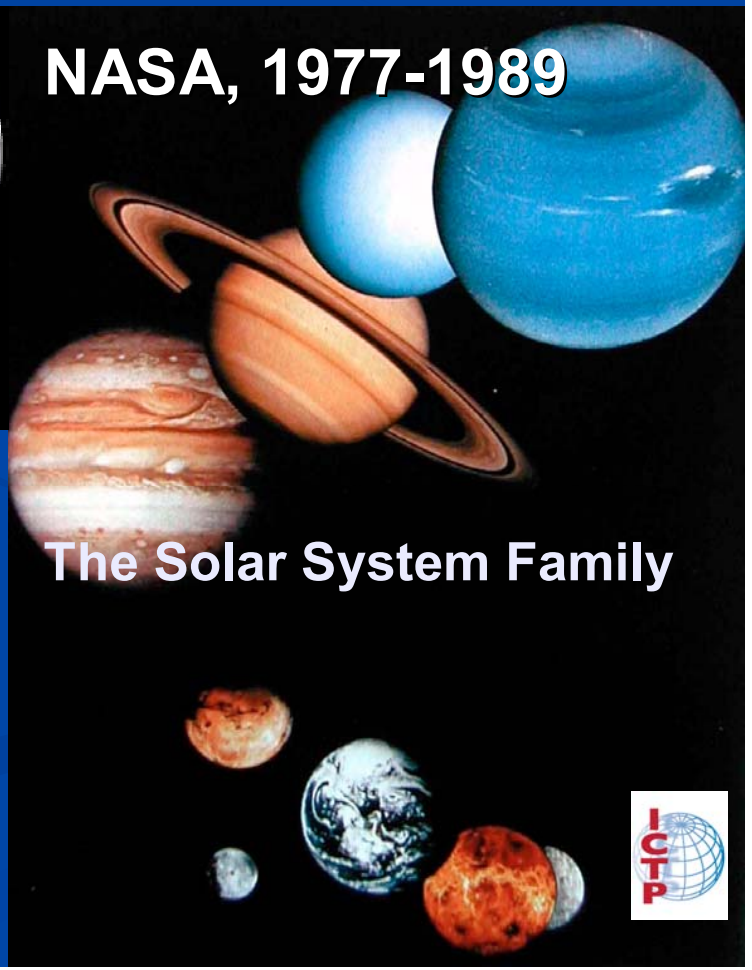


Part 2

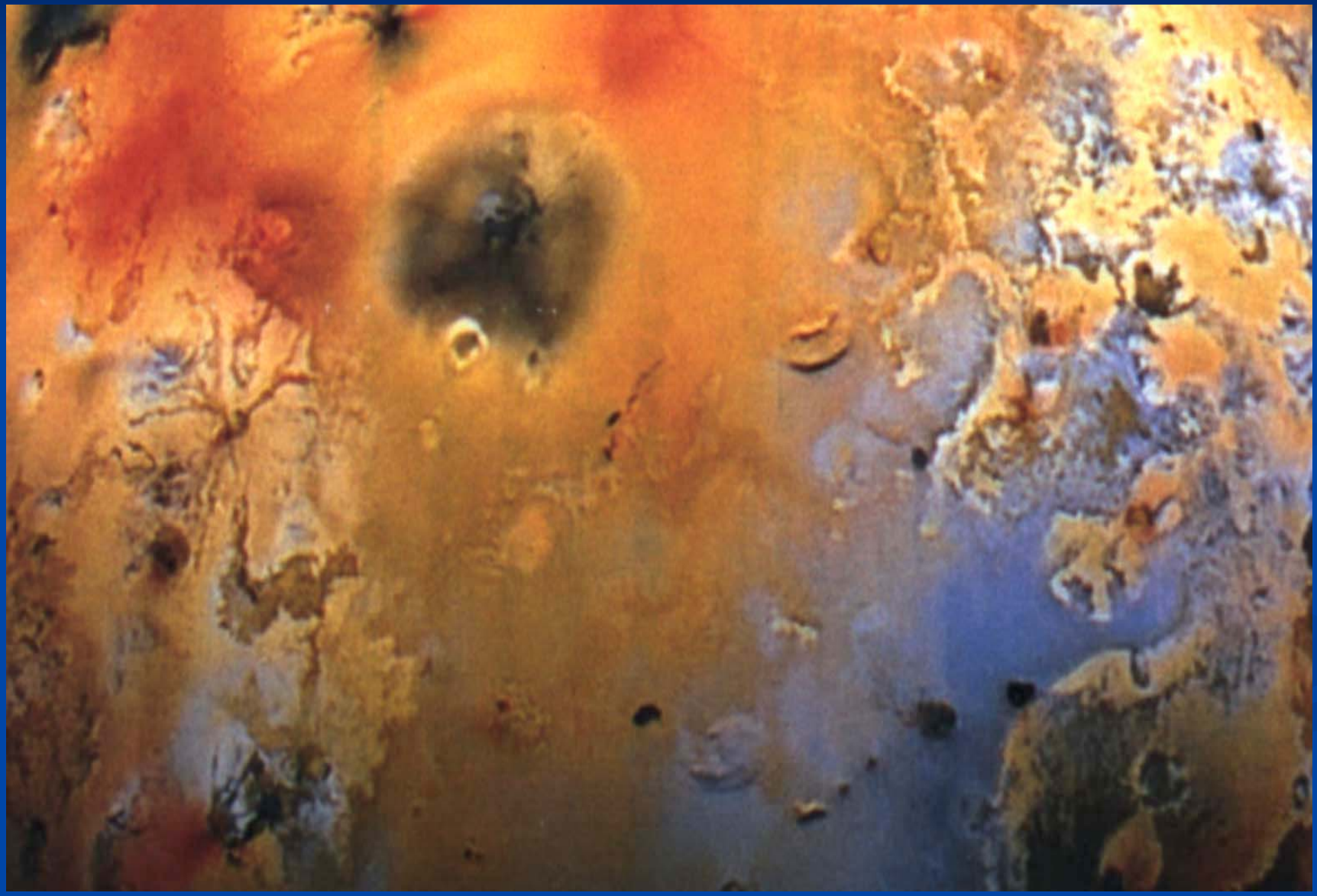
Space weather in the Jovian system

International Journal of Astrobiology (2006)

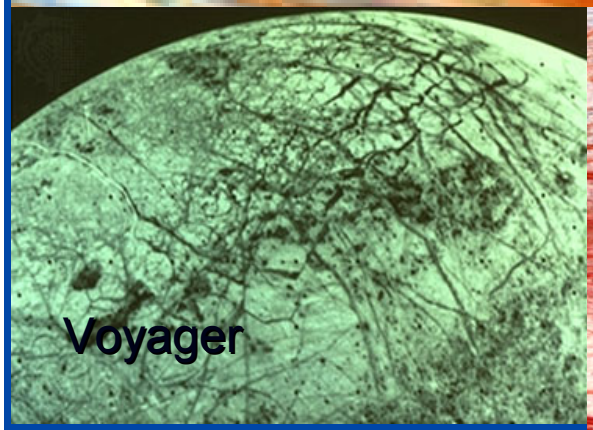
The images of Voyayers and Galileo

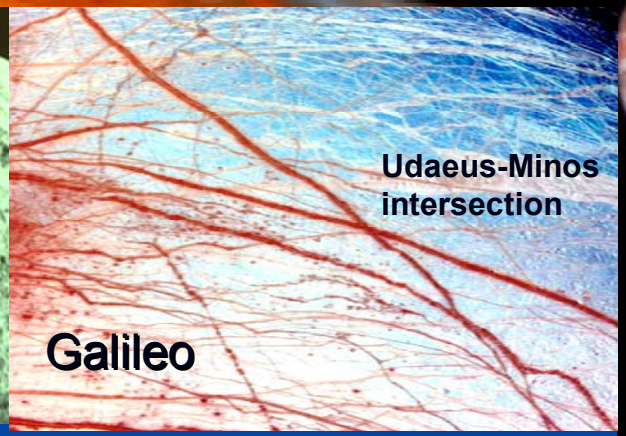


Io's volcanic surface
(Galileo)

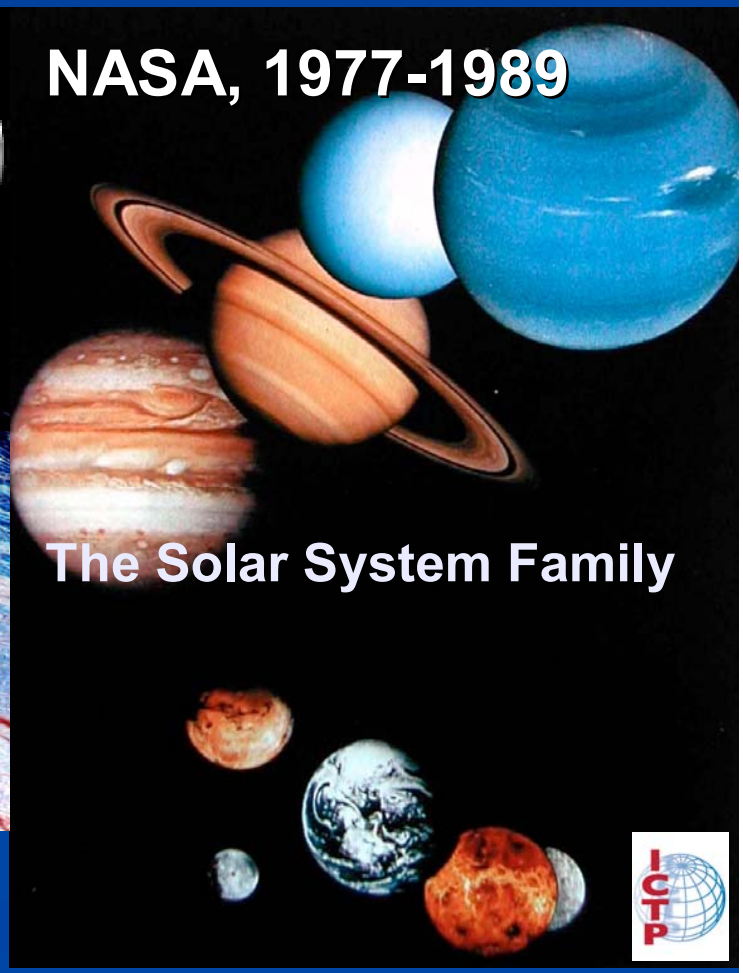


The images of Voyayers and Galileo

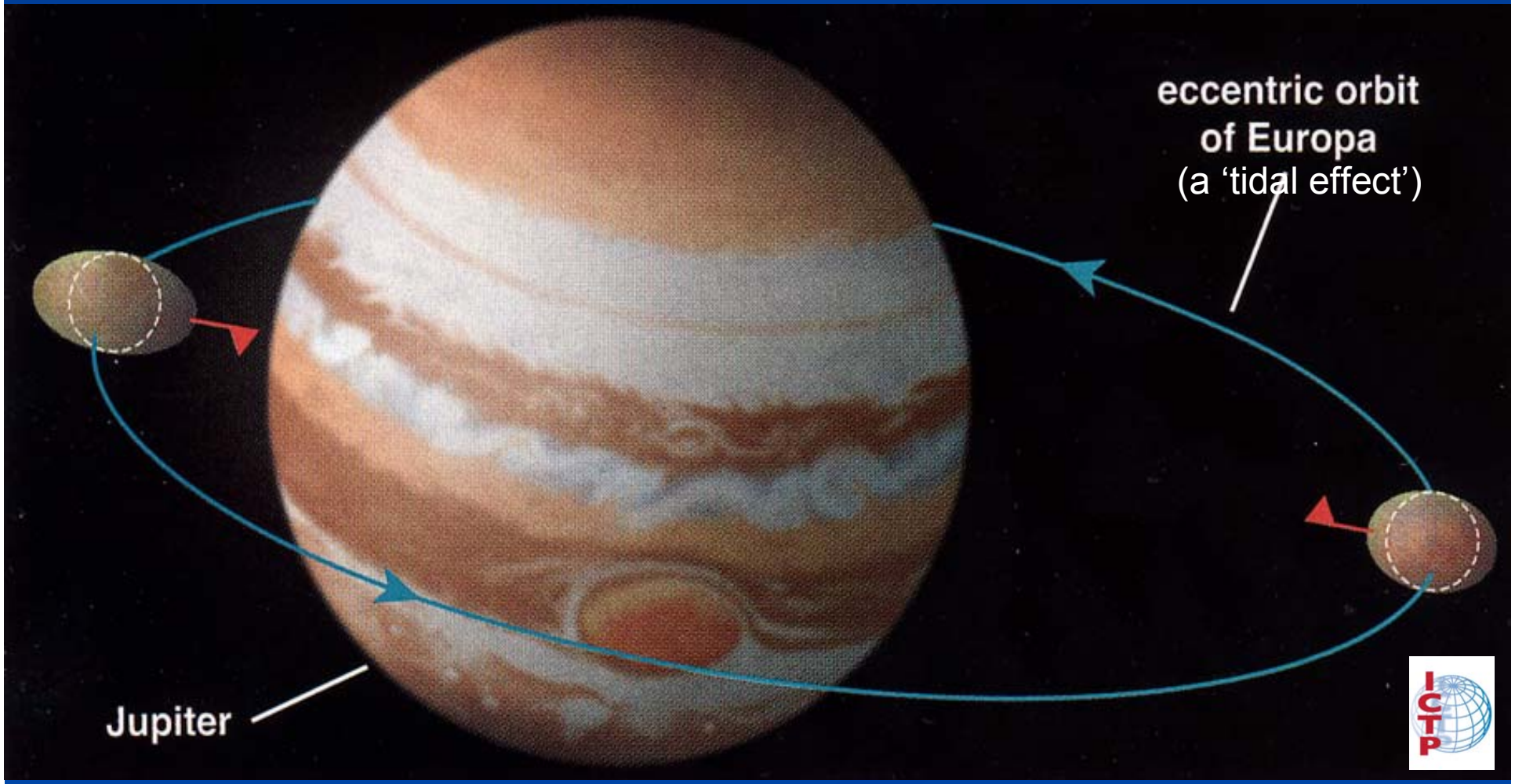


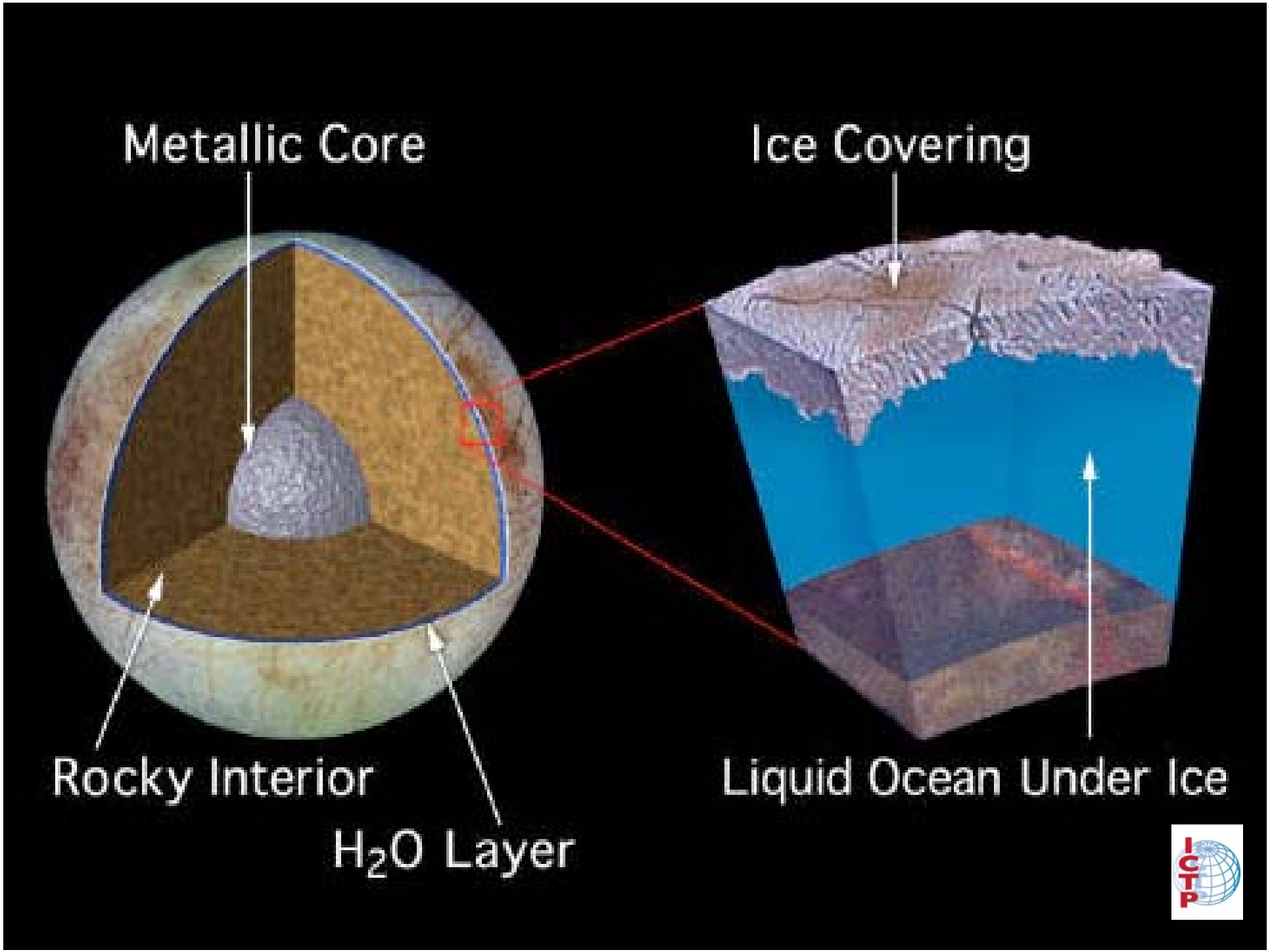


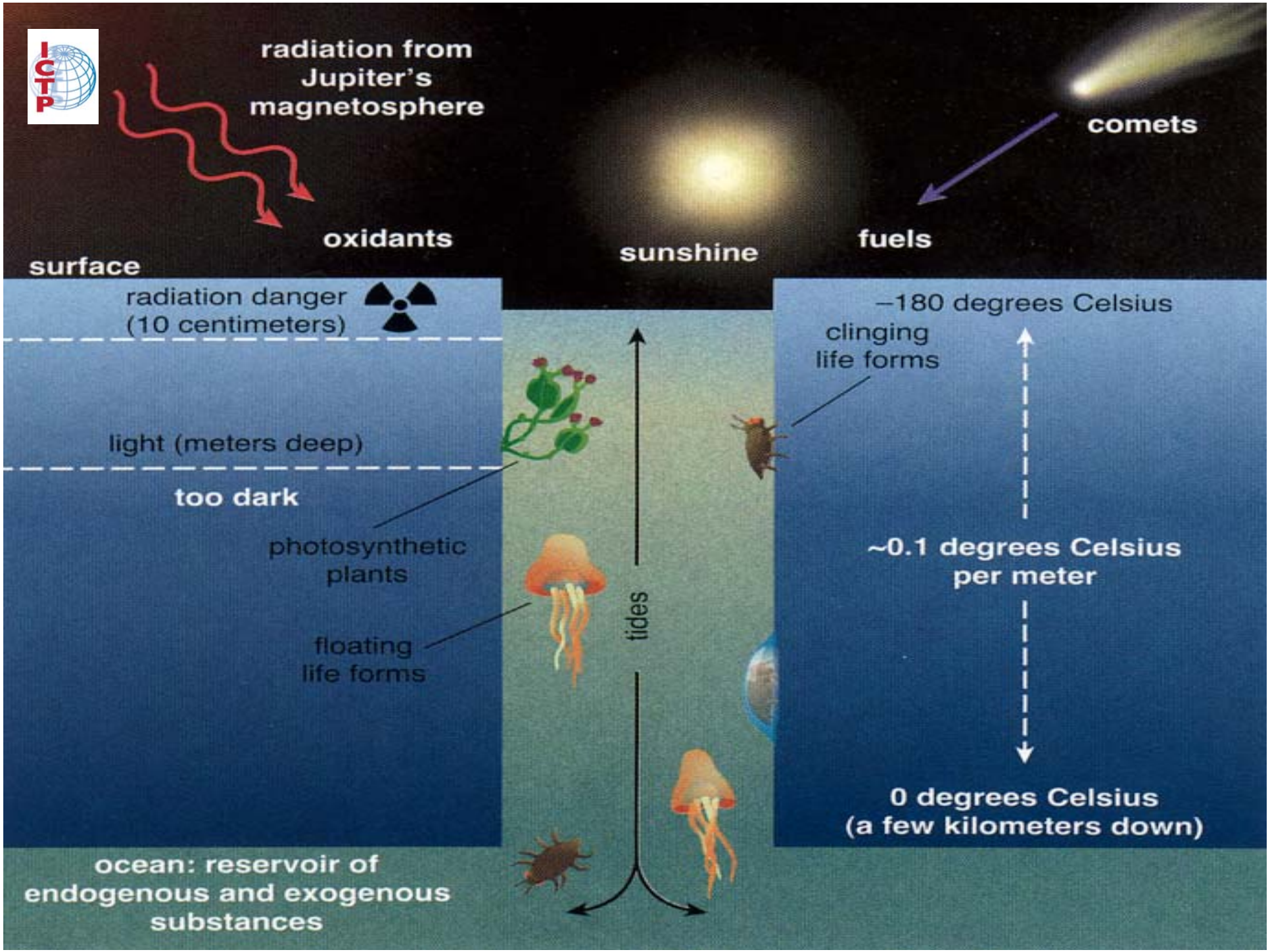
The icy surface of Europa



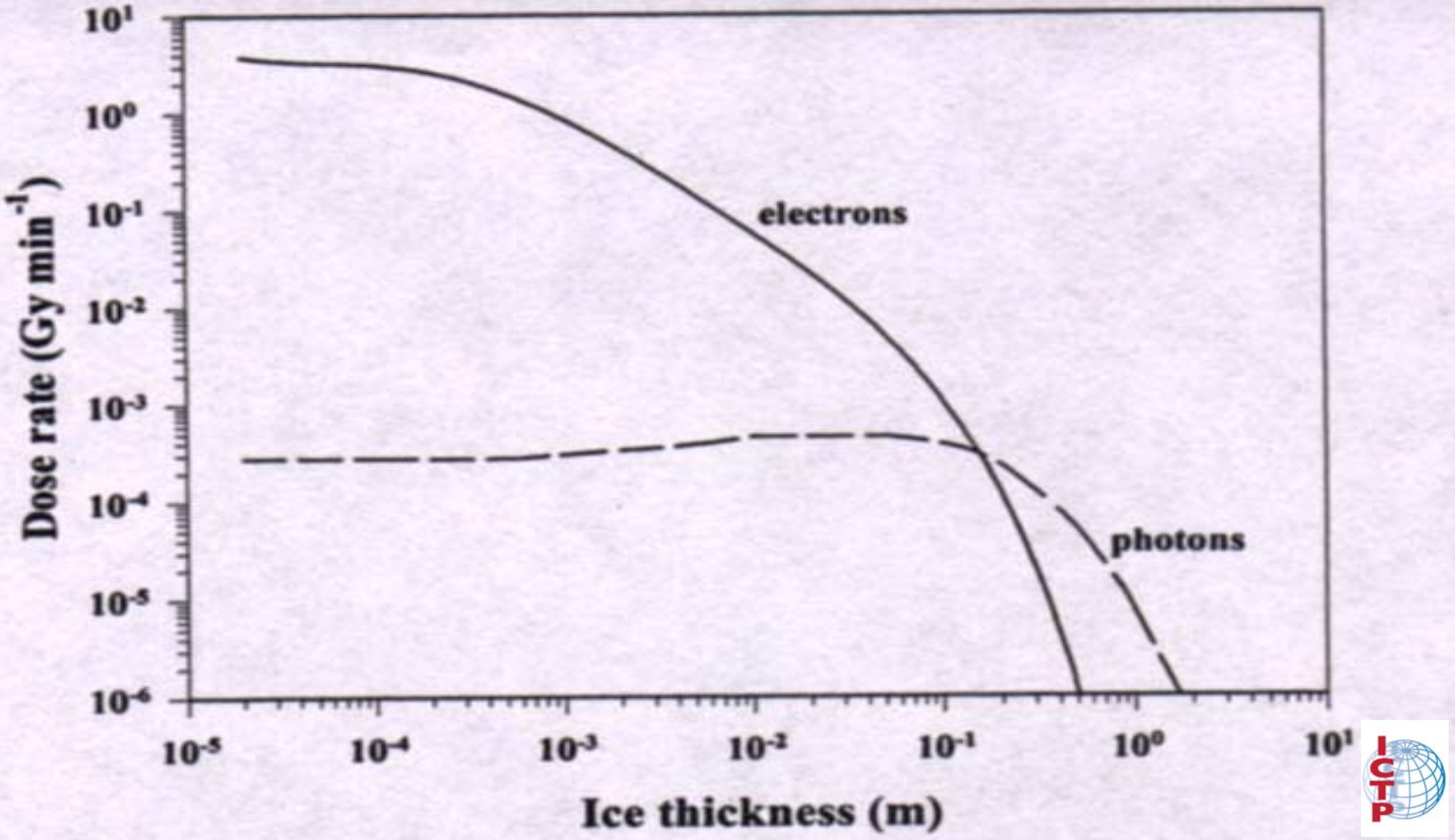
Internal heat may provide ecosystems driven by hydrothermal vents

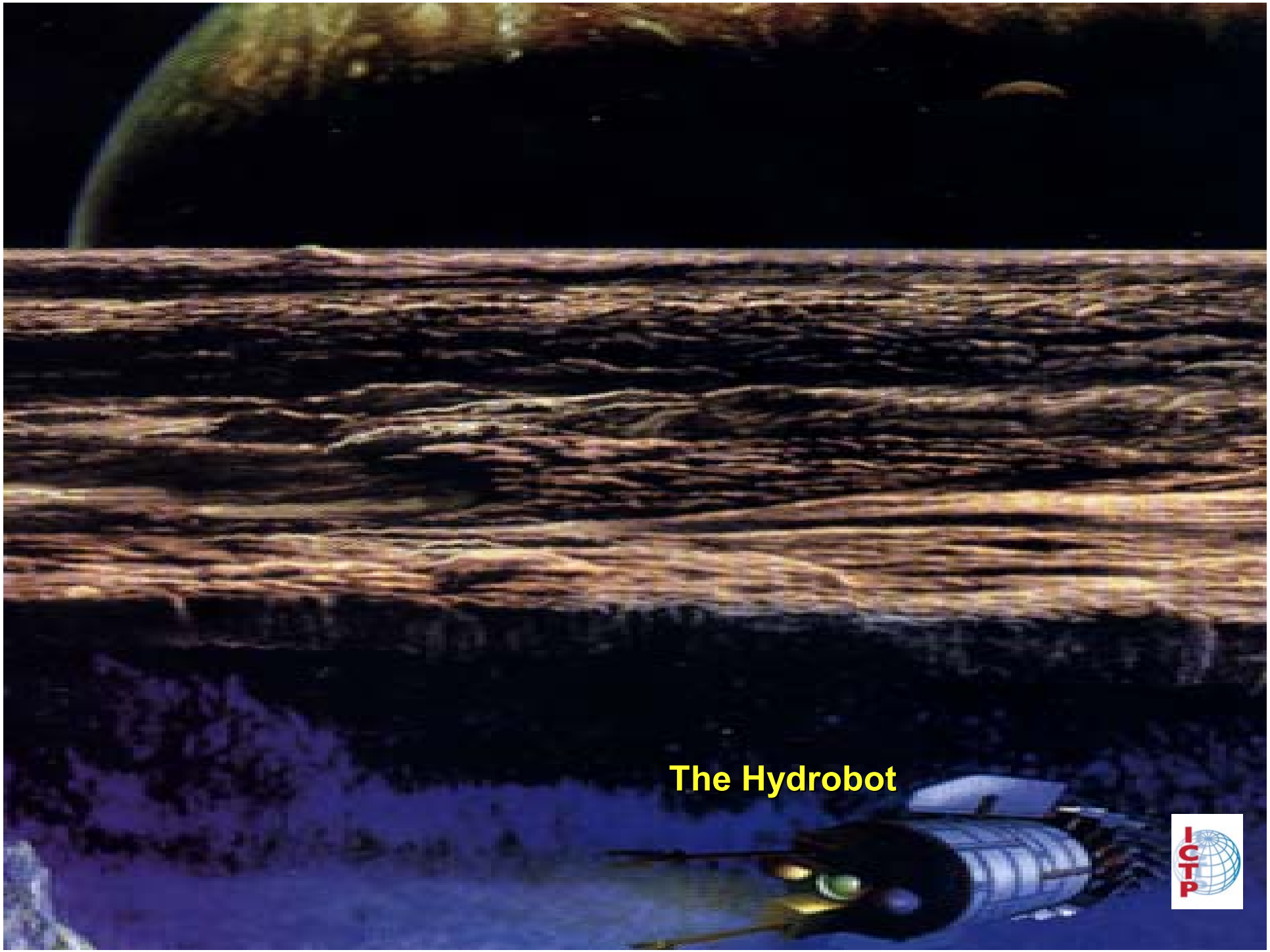


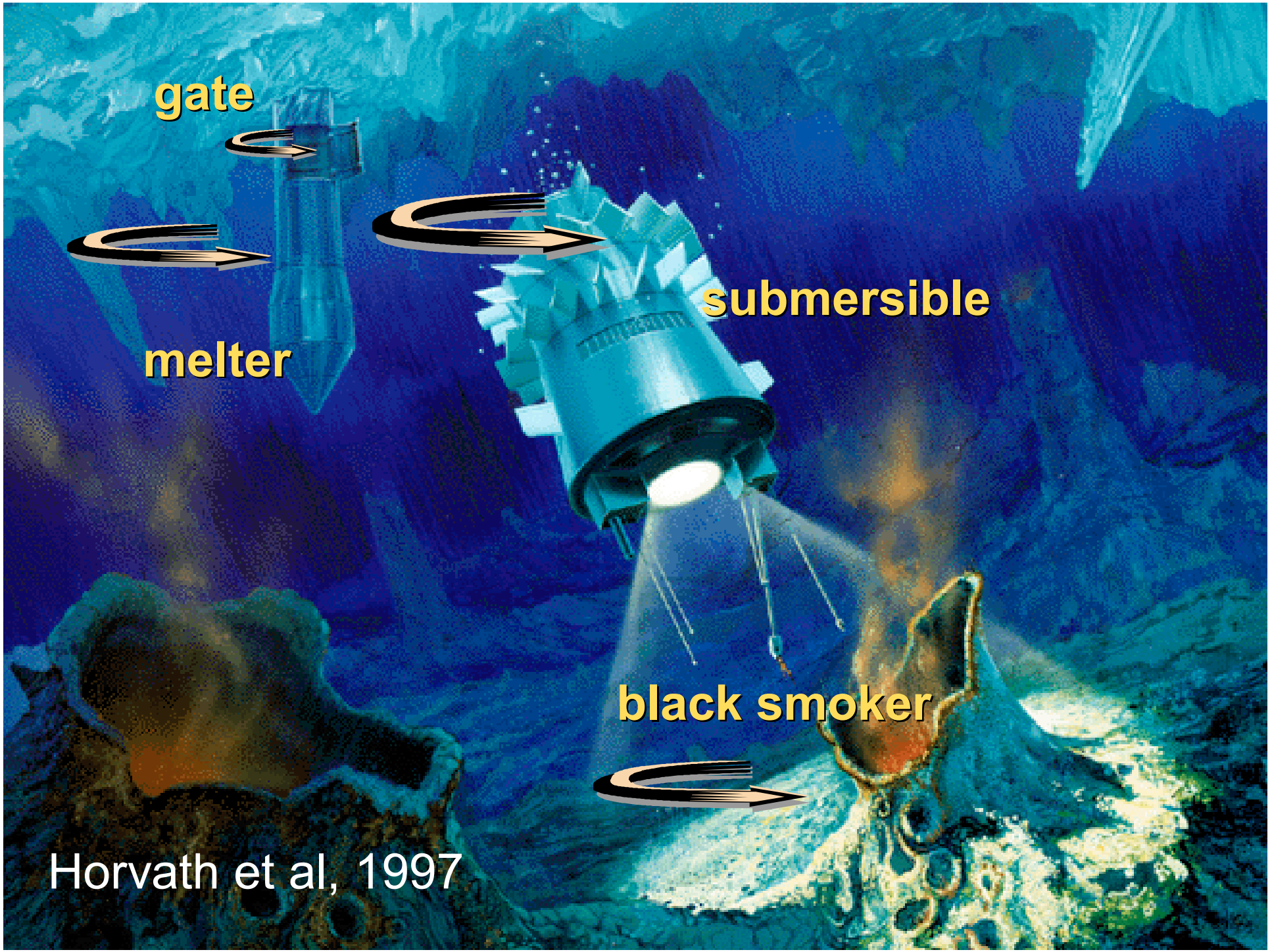

Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice


radiation from Jupiter's magnetosphere
comets
oxidants
sunshine
fuels
surface
radiation danger (10 centimeters)
–180 degrees Celsius
clinging life forms
light (meters deep)
too dark
photosynthetic plants
~0.1 degrees Celsius per meter
floating life forms
tides
0 degrees Celsius (a few kilometers down)
ocean: reservoir of endogenous and exogenous substances

Can life on Europa survive under ionizing radiation?

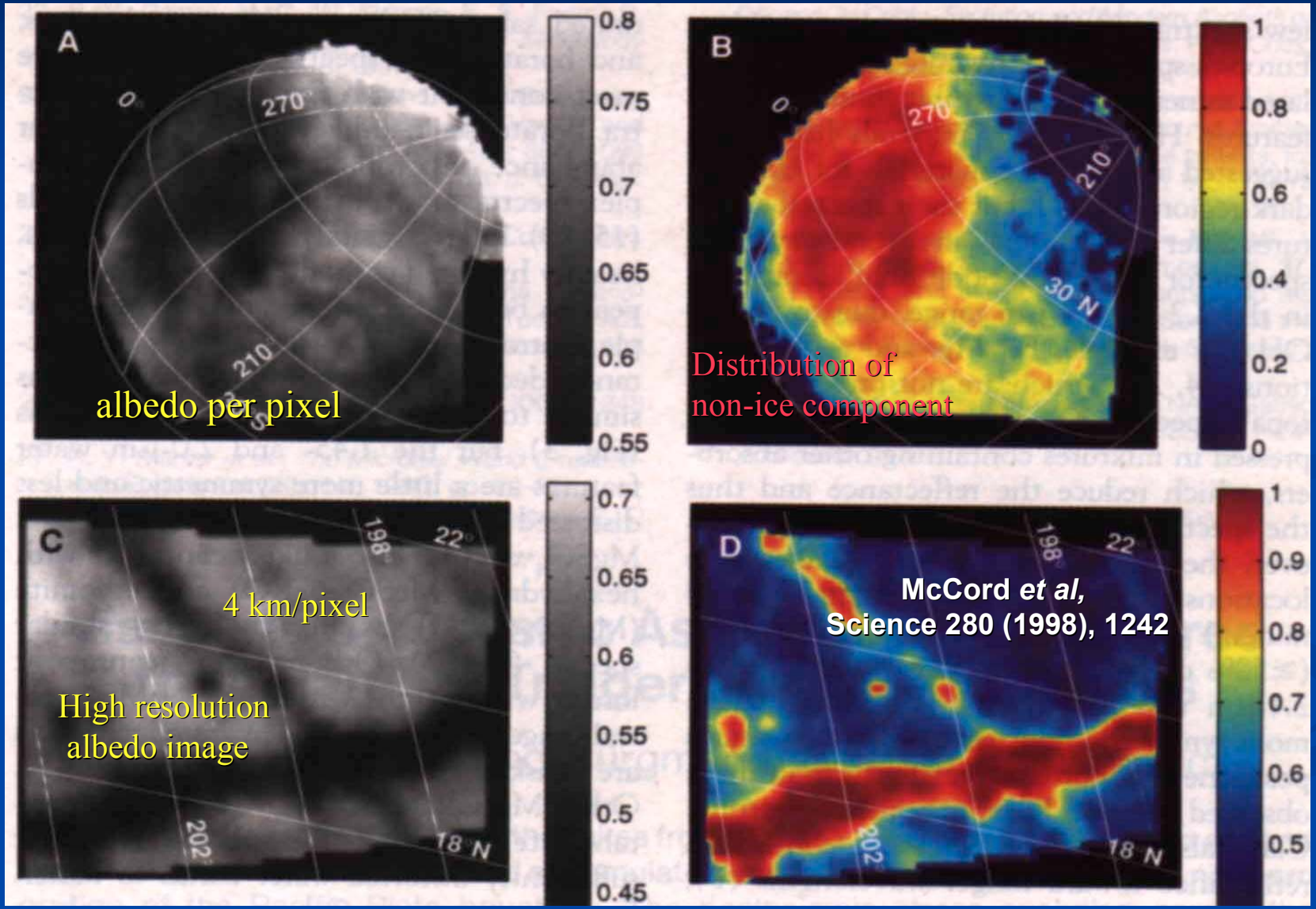



The Hydrobot

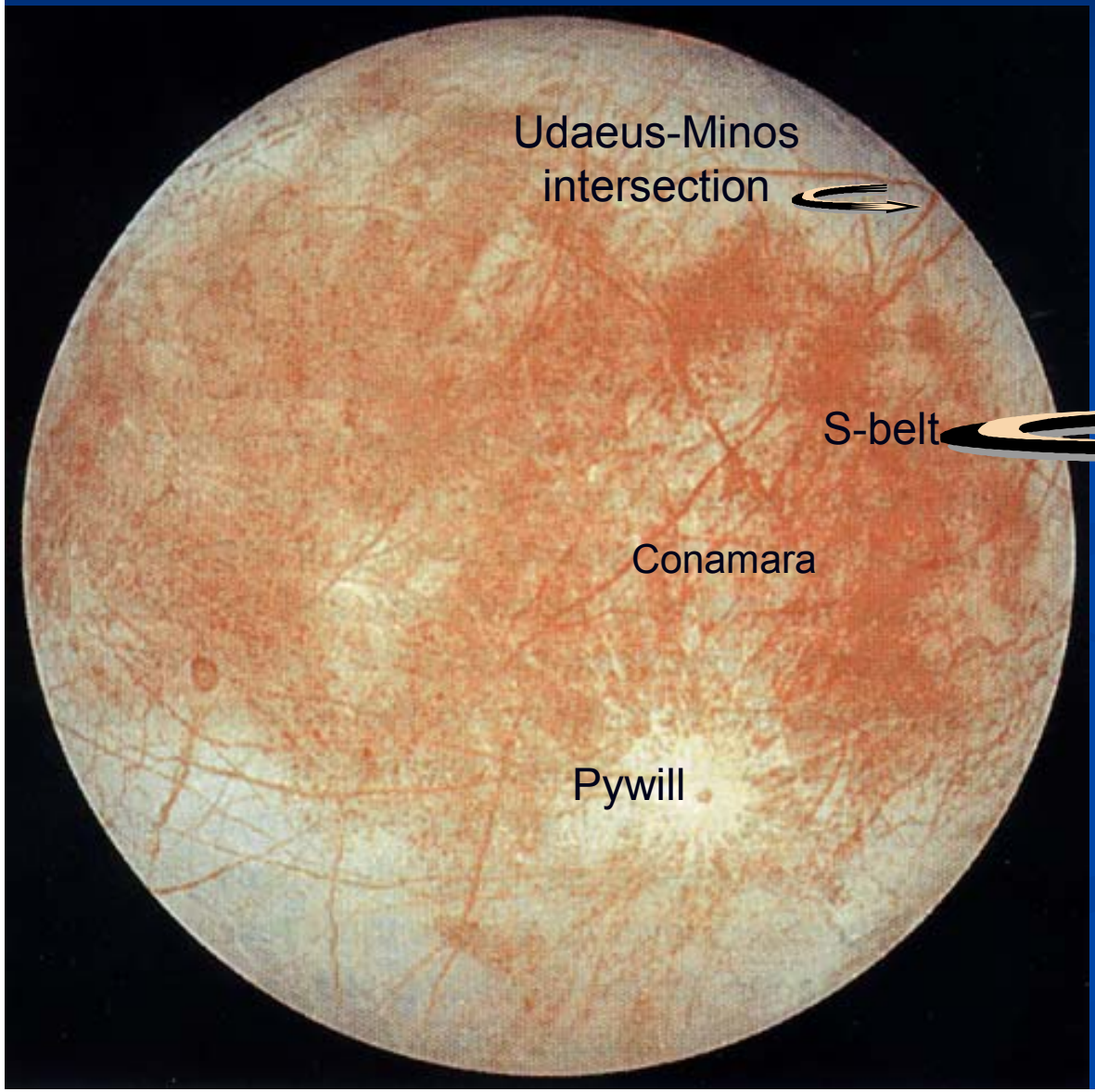

gate
submersible
melter
black smoker
Horvath et al, 1997

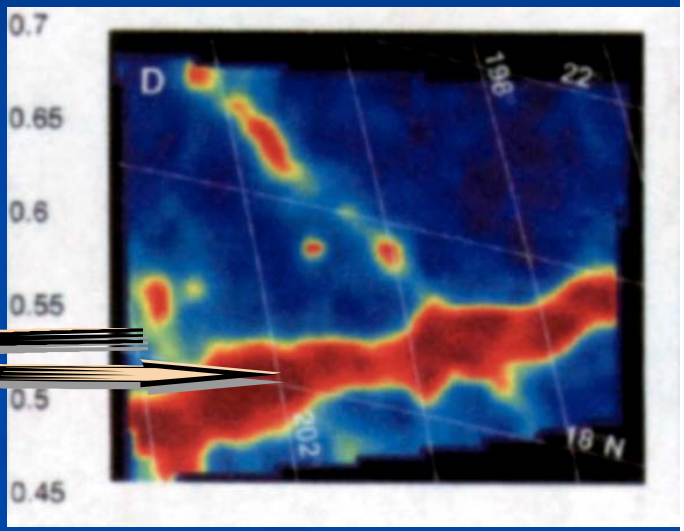
The Europa icy and 'patchy' surface

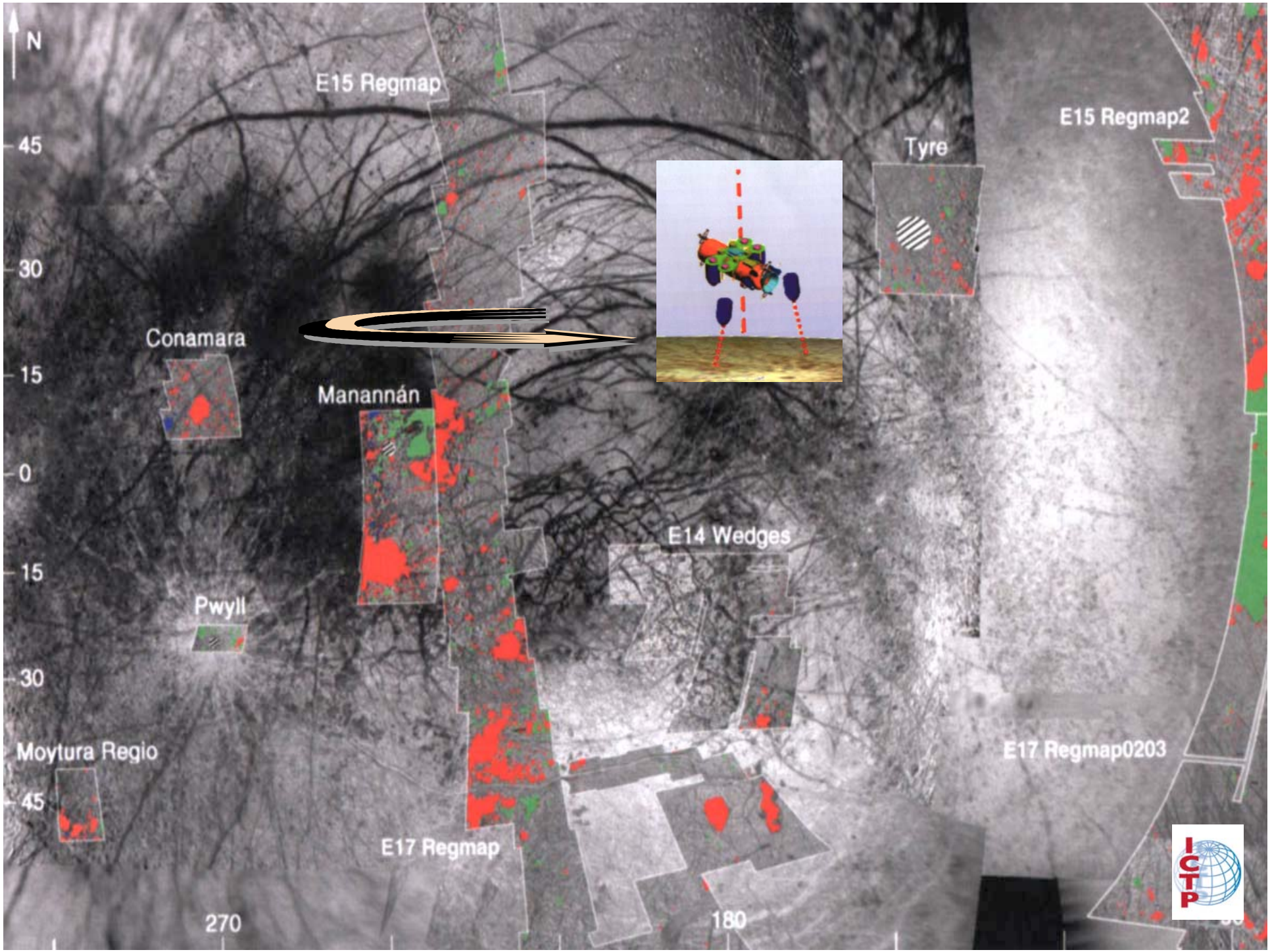
(Spectrometer data from near IR)



Where is the ‘S-belt’ region of highest concentration of non-ice elements?



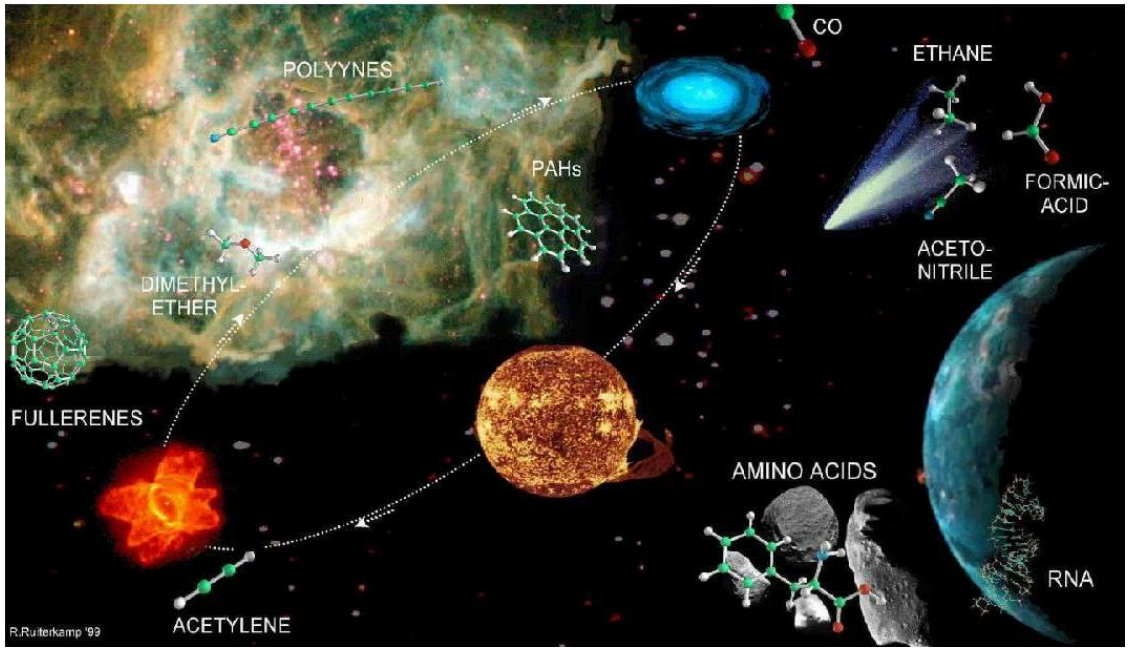



N
E15 Regmap
E15 Regmap2
Tyre
45
30
Conamara
15
Manannán
0
E14 Wedges
15
Pwyll
30
Moytura Regio
E17 Regmap0203
45
E17 Regmap
270
180

Interstellar molecules

(Pascale Ehrenfreund & Steven B. Charnley, 2000)

Number of Atoms										
2	3	4	5	6	7	8	9	10	11	12+
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N?	HC_9N	C_6H_6
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		$HC_{11}N$
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		PAHs
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			C_{60}^+?
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	[illegible]	CH_3OH	NH_2CH_3	$HOCH_2CHO$	C_8H			
CN	HCO	CH_2D^+?		CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN	CH_3								
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	H_2D^+									



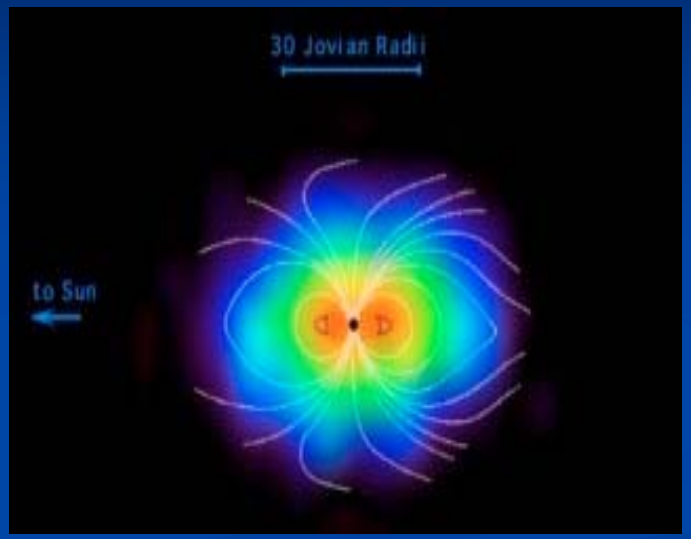
Non-water ice constituents staining the icy and patchy surface of Europa

New absorption features (μm)	3.50	3.88	4.05	4.25	4.57
Candidate elements	H_2O_2	C_2H_5SH mercaptan	SO_2	CO_2	$(CN)_2$ cyanogen

What are the conceivable sources of S-stains on the icy and patchy surface of Europa

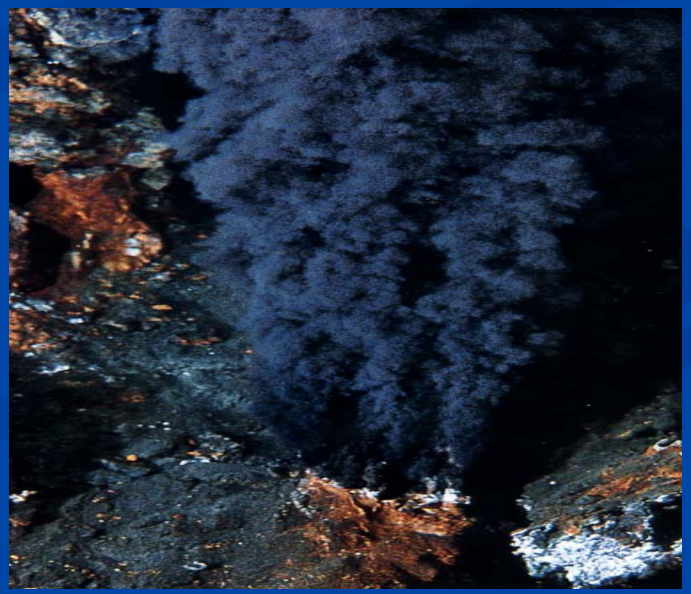
External:

Ions may be implanted from the Jovian plasma, or alternatively the source is



Internal:

Sulphur may be due to cryovolcanism, or we can ask:



Could the sulphur be biogenic?

The Europa Microprobe *in-situ* Explorer

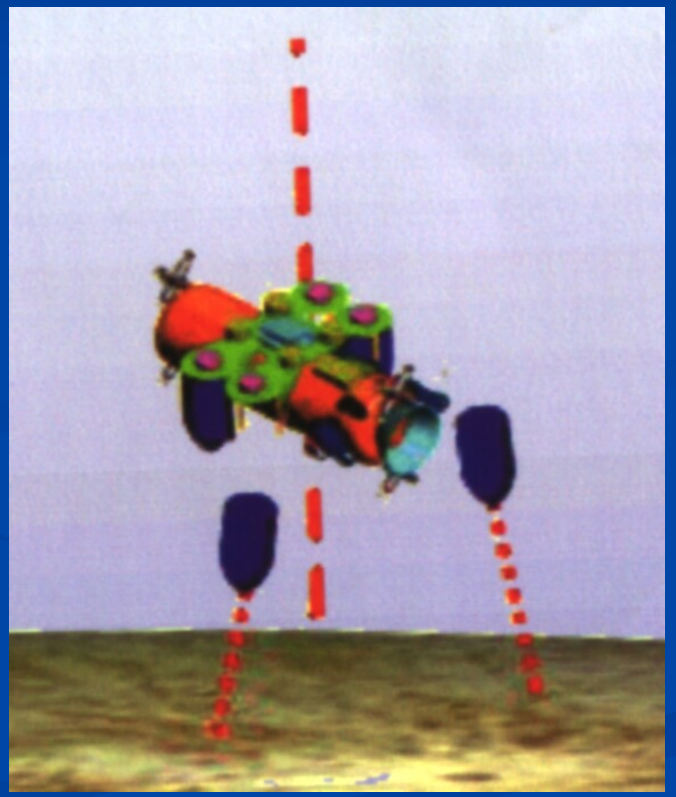
(The EMPIE study)

- One way to decide on the sulphur source is to land on the icy surface of Europa.
- The lander will have a set of 4 miniprobes (350 gm each).

Tirso Velasco and colleagues

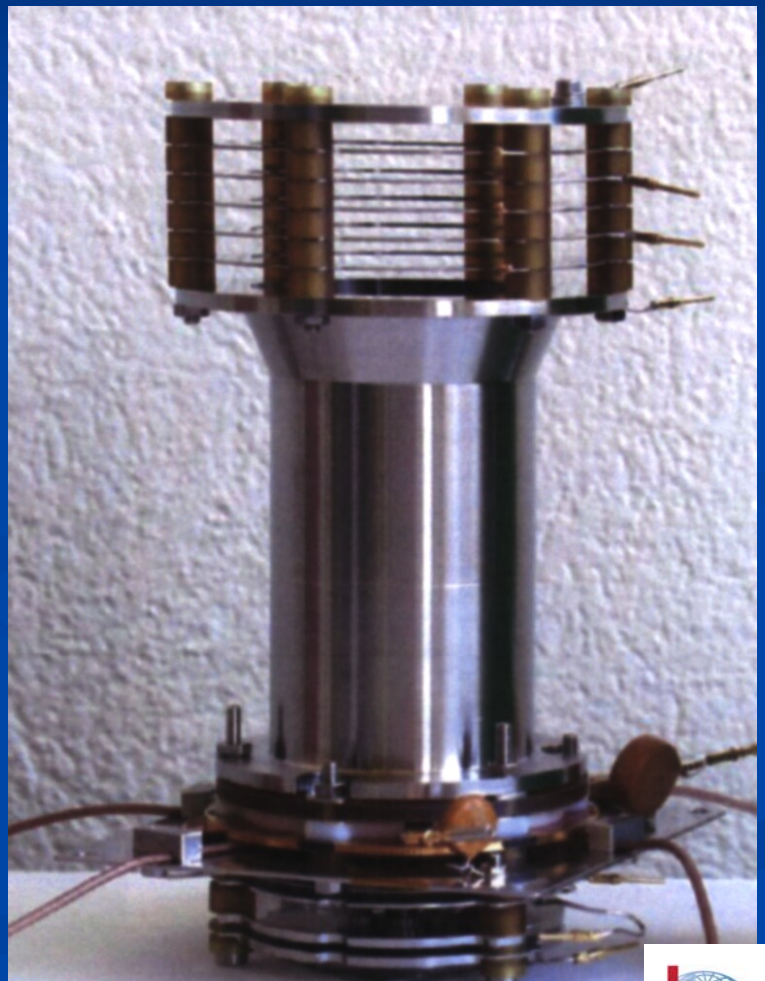
The proposed lander on the icy surface of Europa

- Expected penetration in ice is 72.5 cm.
- Mass constraint for the microprobes 1.7 kg.



Mass spectrometry

- MS is the right tool. The image shows a light one built for the Bepi-Colombo 2012 mission to Mercury, although the lander was later cancelled.
- When living organisms process sulfur they tend to fractionate isotopes differently from geological processes.



Lander instrument
(120 x 60 mm; 500 g)

Part 3

A component of space weather from the Jovian system

The delta^{34}S-parameter

$$\delta^{34}S = \left[\frac{(^{34}S/^{32}S)_{sa}}{(^{34}S/^{32}S)_{st}} - 1\right] \times 10^3 \text{ [‰, CDM]},$$

- Canyon Diablo Meteorite (CDM) is one of the most famous meteorites, a troilite (FeS), found in a crater, north of Phoenix, Arizona.

- CDM coincides with the average terrestrial ratio of the isotopes ^{32}S and ^{34}S.

Sulfate-reducing bacteria

- Unite H with S atoms from dissolved sulfate of seawater to form hydrogen sulfide:

$$4H_2 + H_2SO_4 \rightarrow H_2S + 4H_2O + 39 \text{ kilocalories}$$

- The H_2S then combines with Fe in sediments to form grains of pyrite.

Iron sulfide, FeS_2

Assimilatory sulfate reduction

- The biogenic uptake of S is by sulfate reduction of inorganic sulfate to sulfide.
- Sulfide eventually reacts with serine to yield the amino acid cysteine.
- Isotopic discrimination is minor.

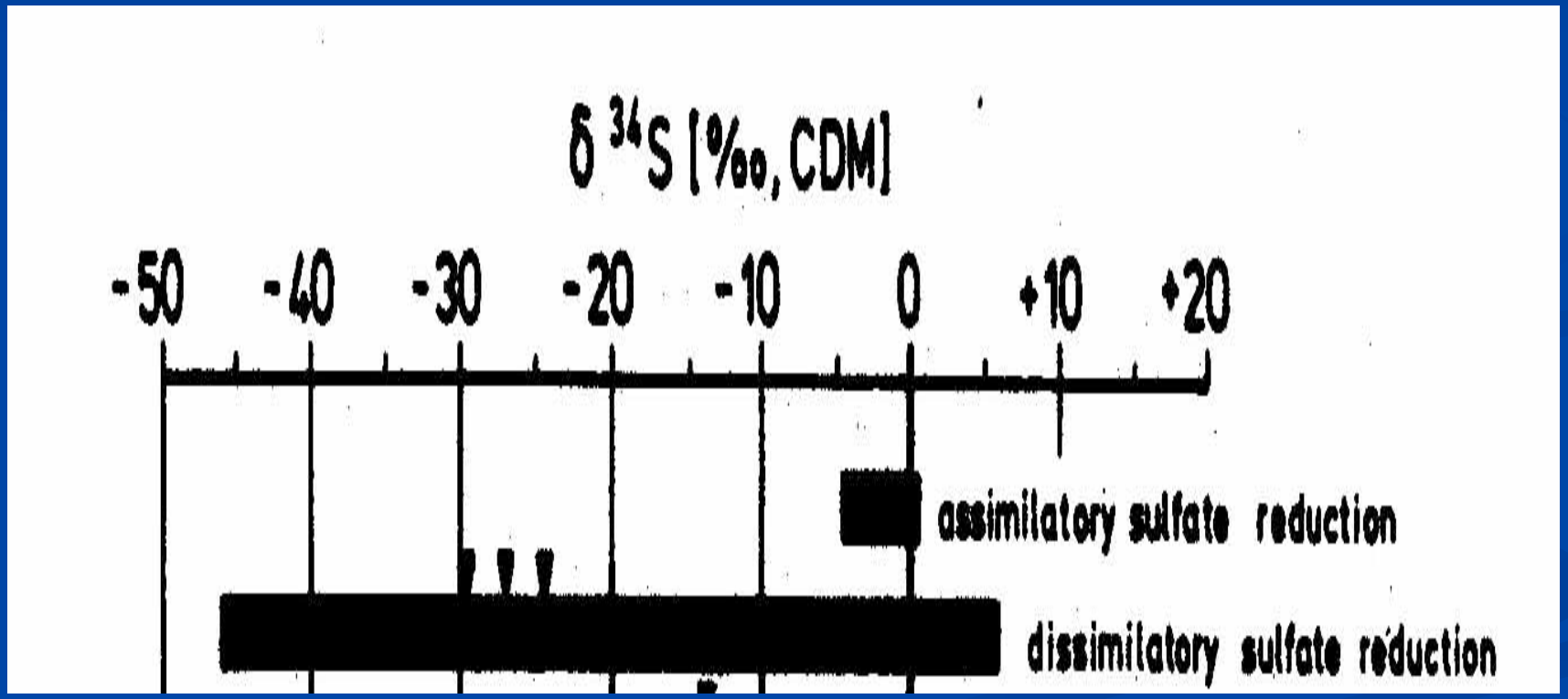
Dissimilatory sulfate reduction

Organic substrate

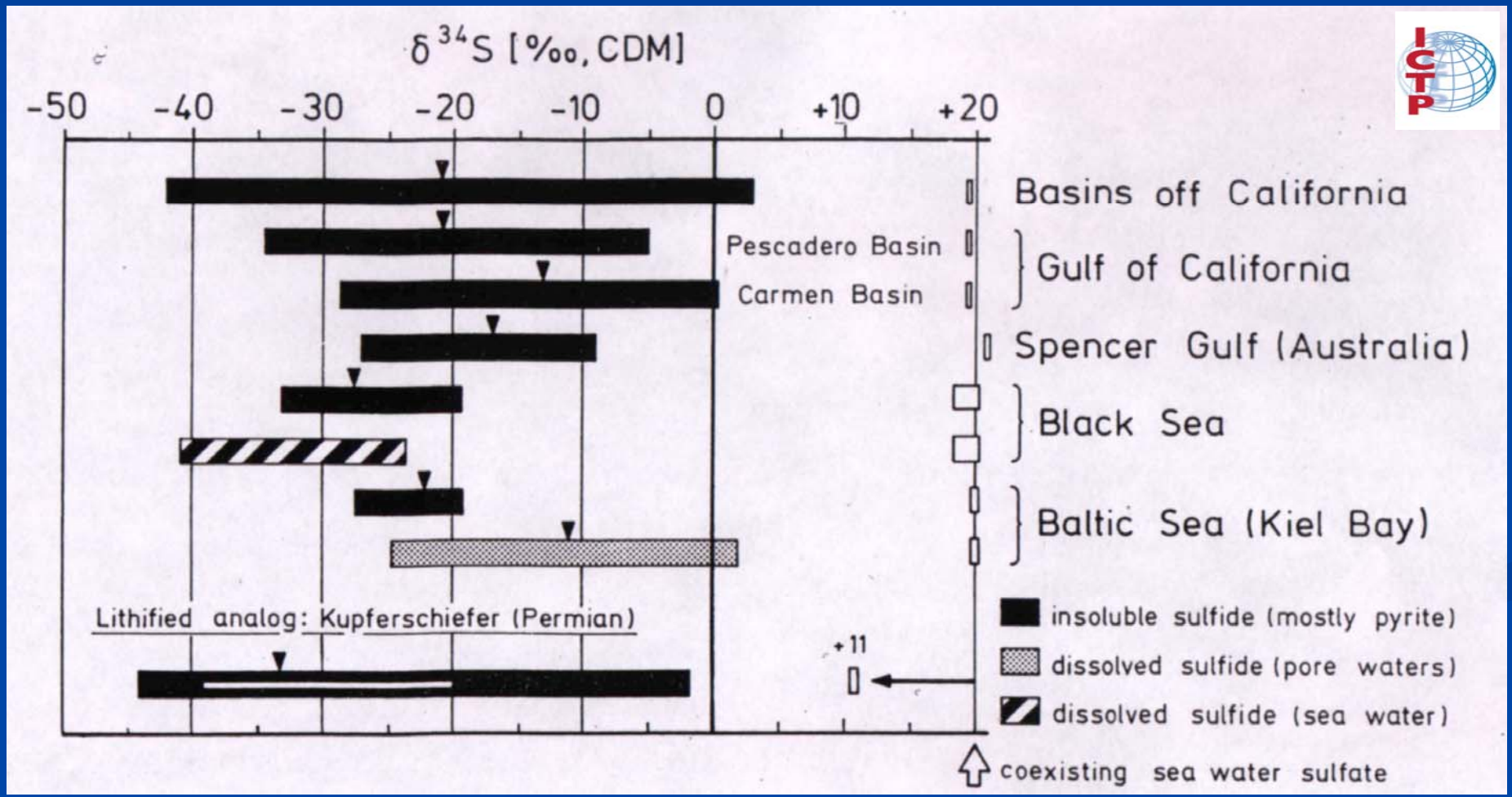
$$2\ \text{lactate} + SO_4^{2-} \longrightarrow 2\ \text{acetate} + 2\ H_2O + 2\ CO_2 + S^{2-}.$$

- A form of anaerobic respiration.
- Large scale reduction of biogenic sulfate to sufide.

Sulfur metabolism produces isotope fractionation

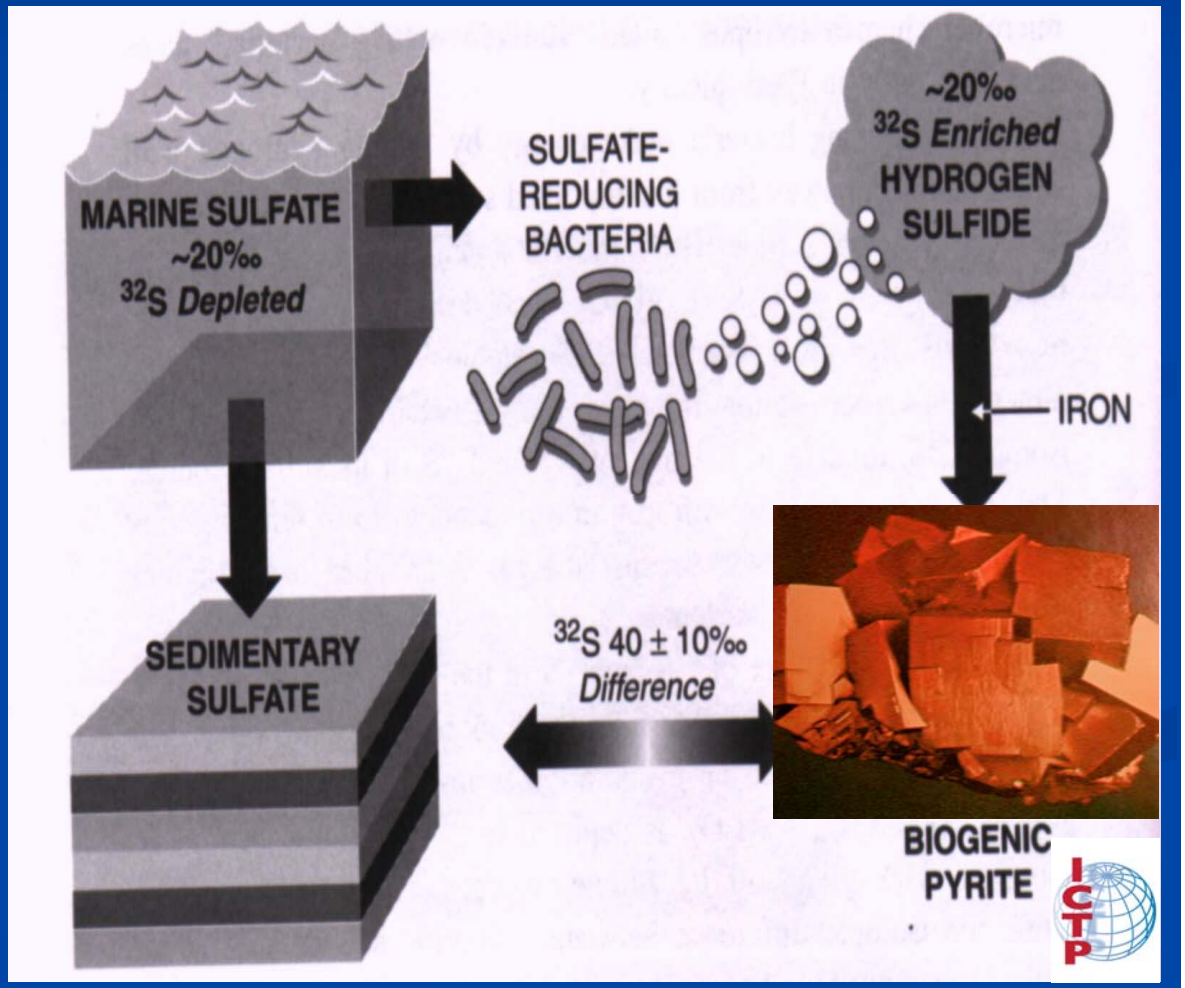


Bacterial sulfur isotope fractionation in marine environments



Partition of S isotopes between sedimentary sulfate and biogenic pyrite

- Dissolved sulfate on evaporation forms sulfate minerals depleted of ^{32}S by 20 per mil.
- The H_2S given off by the bacteria is enriched in ^{32}S by 20 per mil.



The Apollo missions

Apollo 1
January 27, 1967

Apollo 7
October 11, 1968

Apollo 8
December 21, 1968

Apollo 9
March 3, 1969
Gumdrop/Spider

Apollo 10
May 18, 1969
Charlie Brown/Snoopy

Apollo 11
July 16, 1969
Columbia/Eagle

Apollo 12
November 14, 1969
Yankee Clipper/Intrepid

Apollo 13
April 11, 1970
Odyssey/Aquarius

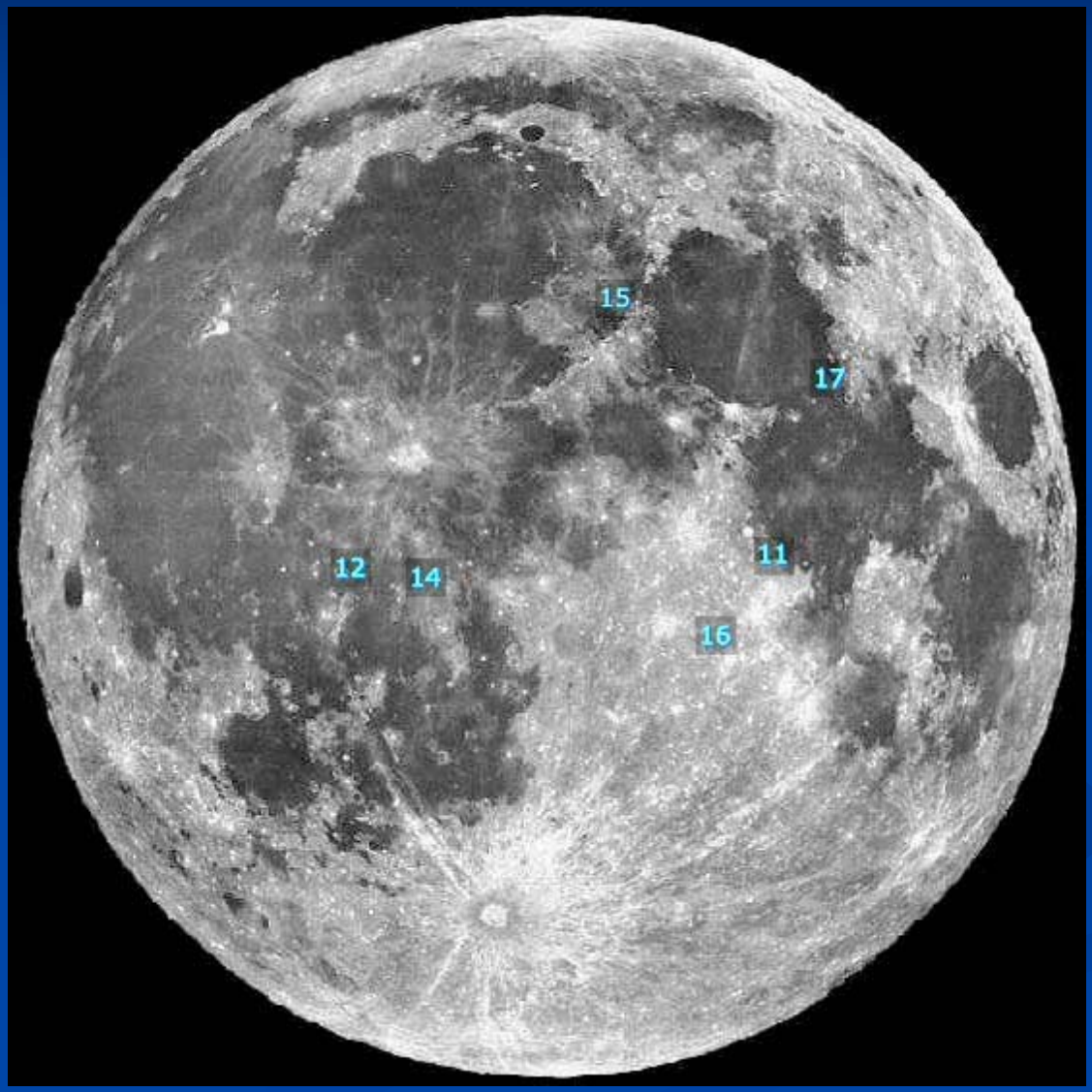
Apollo 14
January 31, 1971
Kitty Hawk/Antares

Apollo 15
July 26, 1971
Endeavour/Falcon

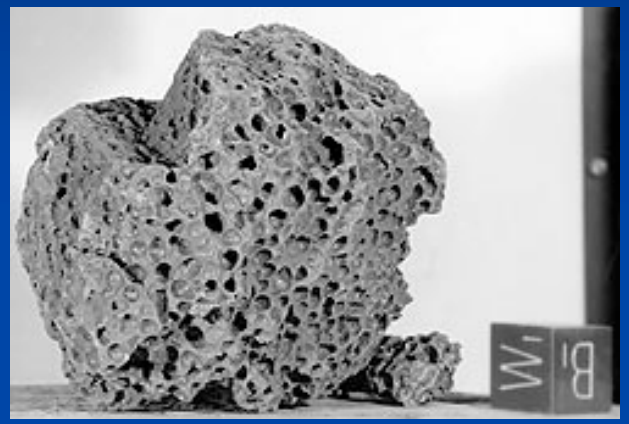
Apollo 16
April 16, 1972
Caspar/Orion

Apollo 17
December 7, 1972
America/Challenger

Landing sites of the Apollo missions

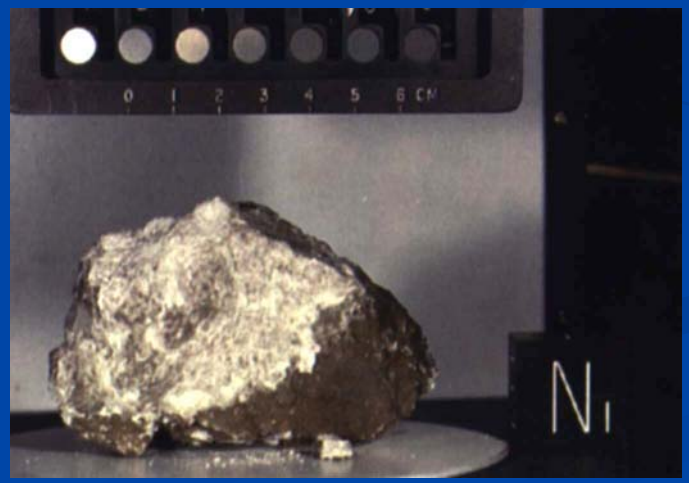


Lunar material from the Apollo missions



basalt

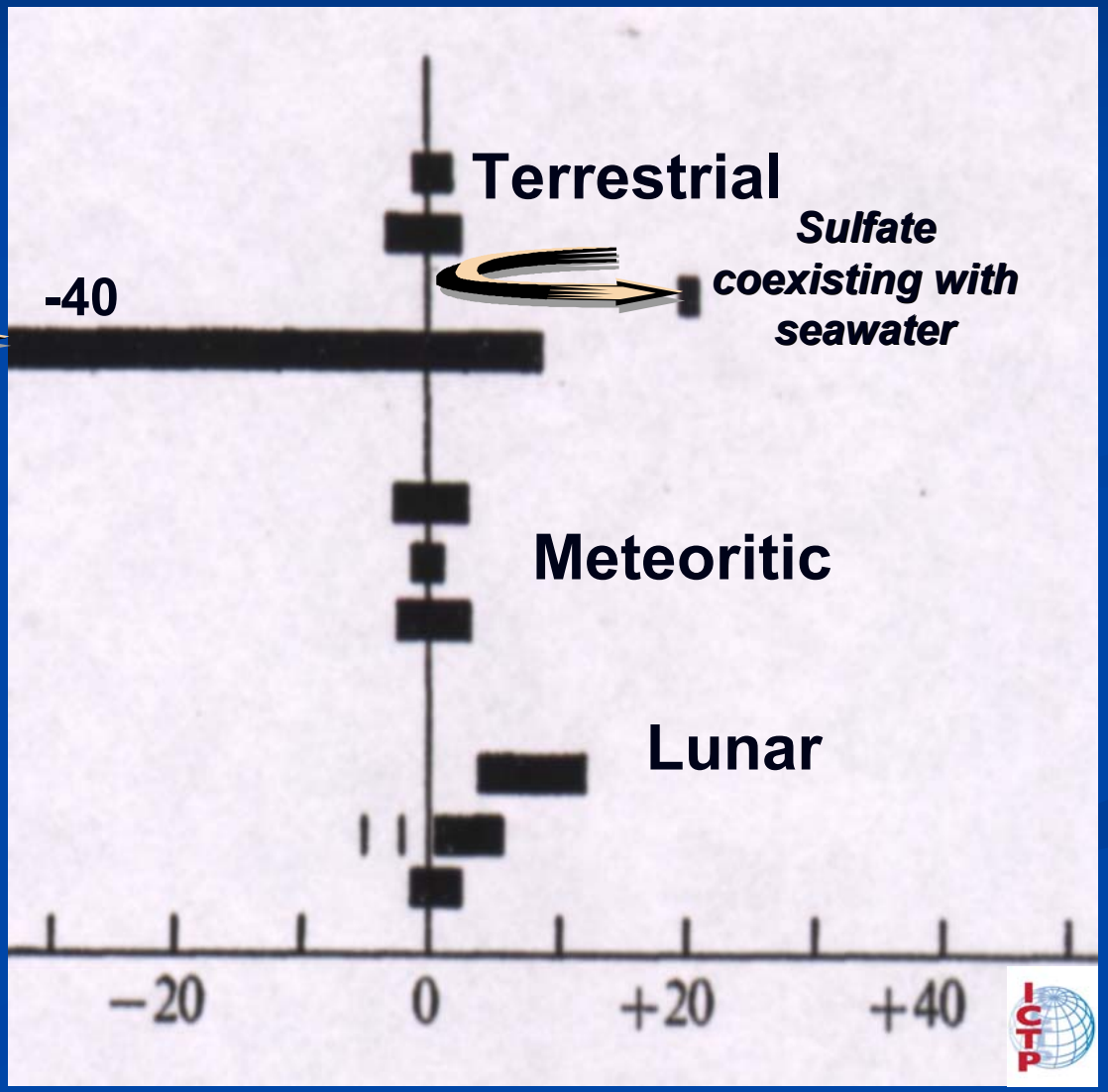
troctolite



arnothosite

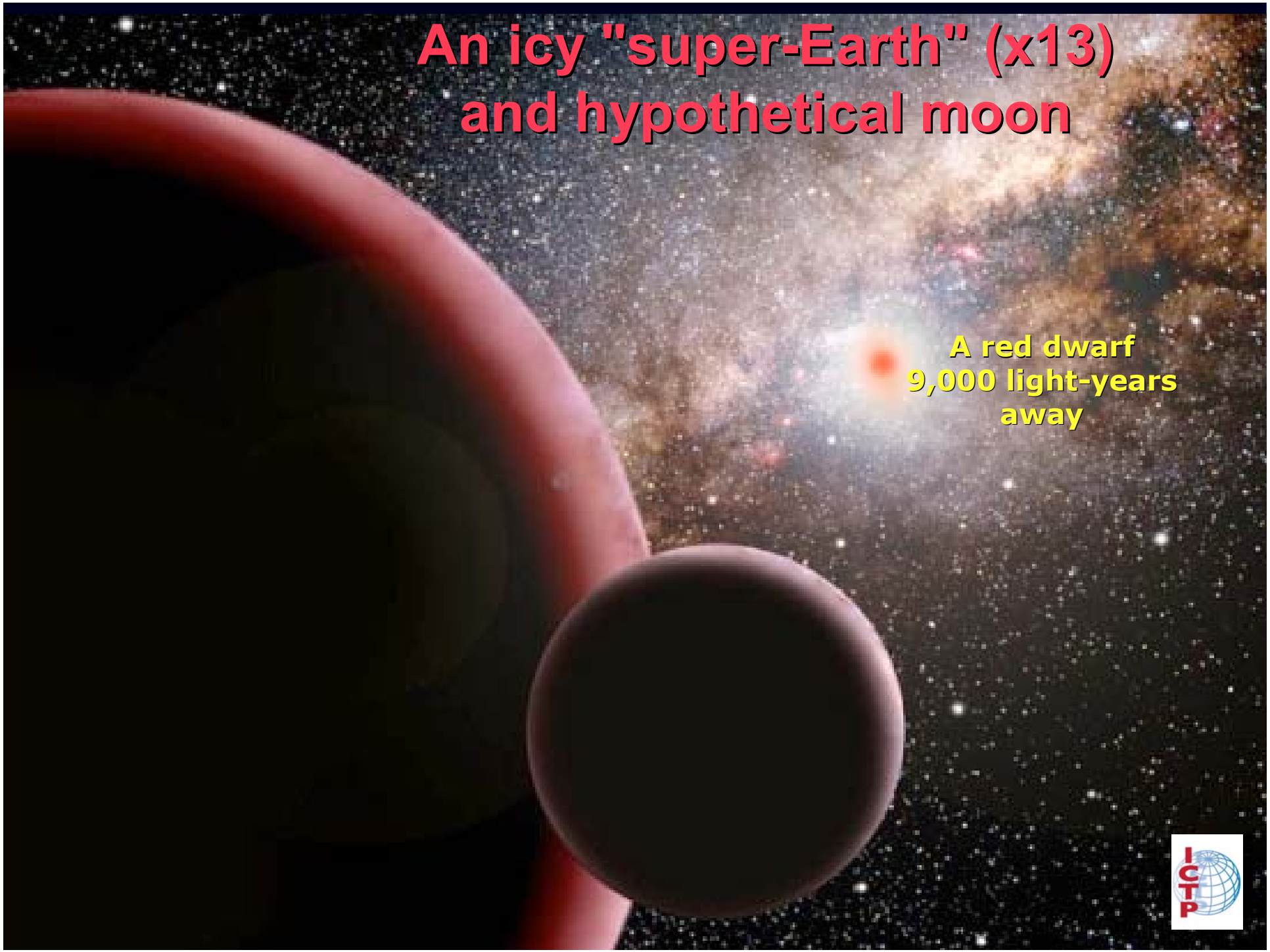
The delta^{34}S-parameter in terrestrial, meteoritic and lunar material

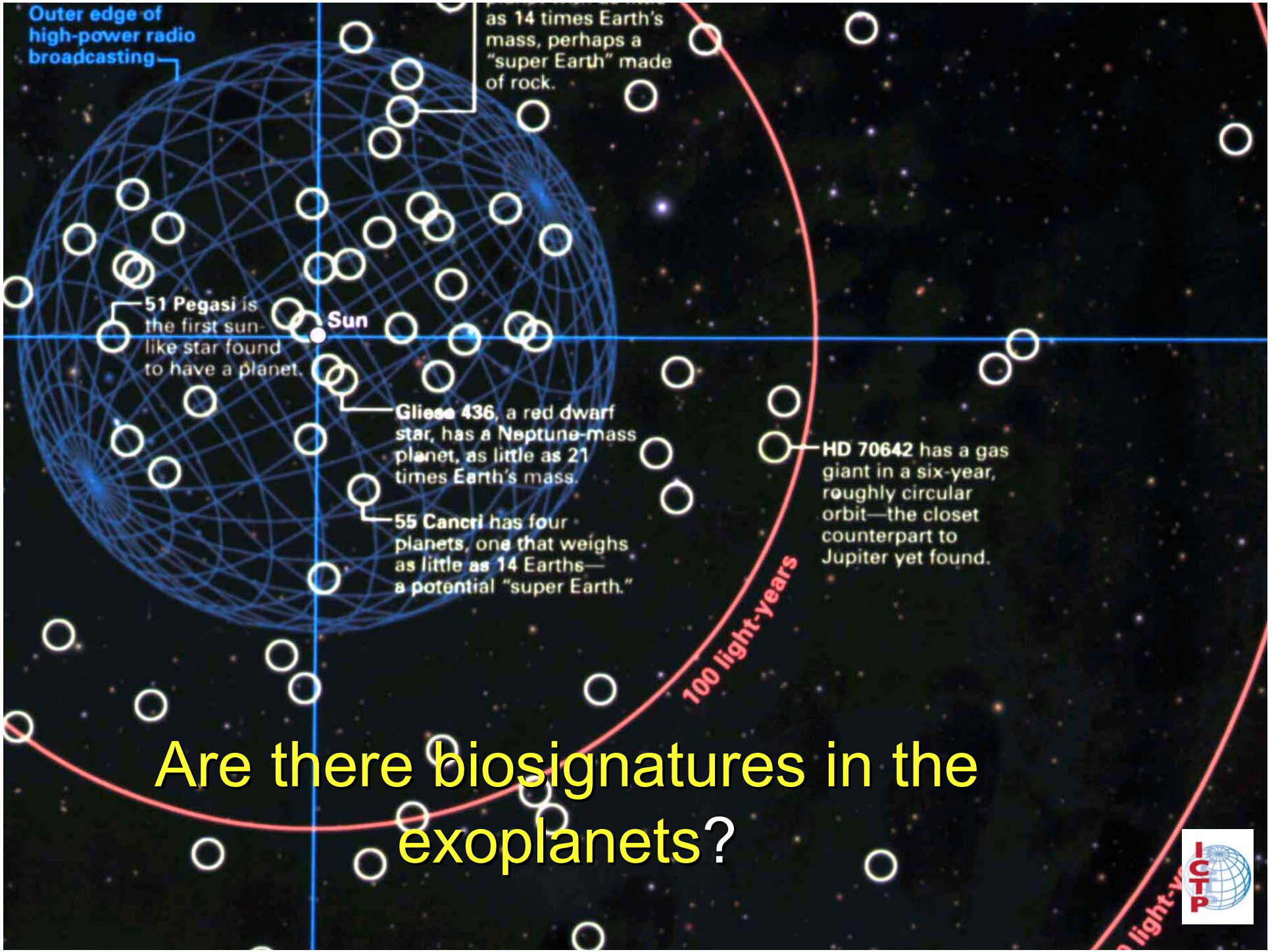
From measurements in basins off California: Insoluble sulfide, mostly pyrite



Part 4

Space weather in other planets of other solar systems


An icy "super-Earth" (x13)
and hypothetical moon
A red dwarf
9,000 light-years
away



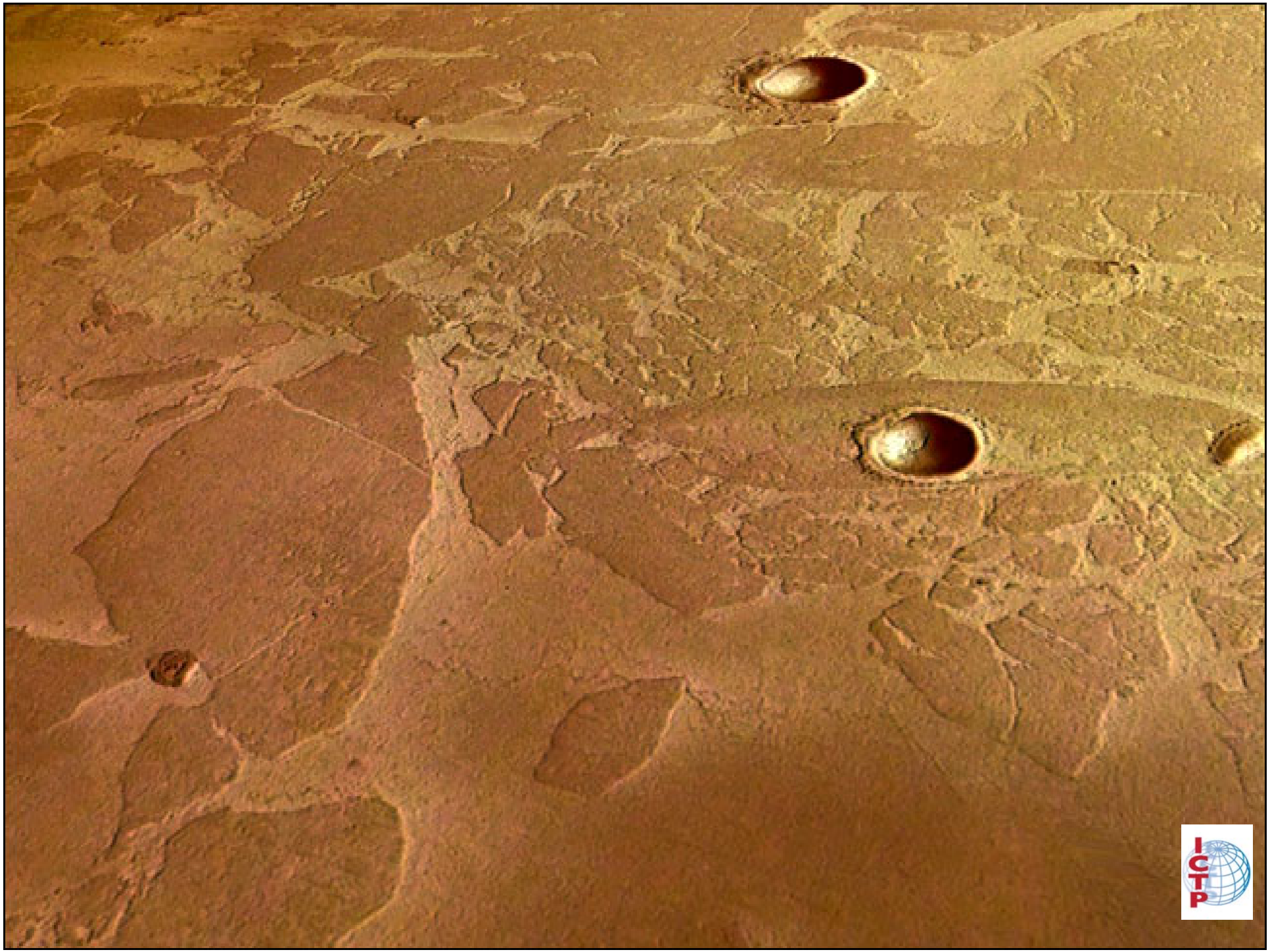
Are there biosignatures in the exoplanets?

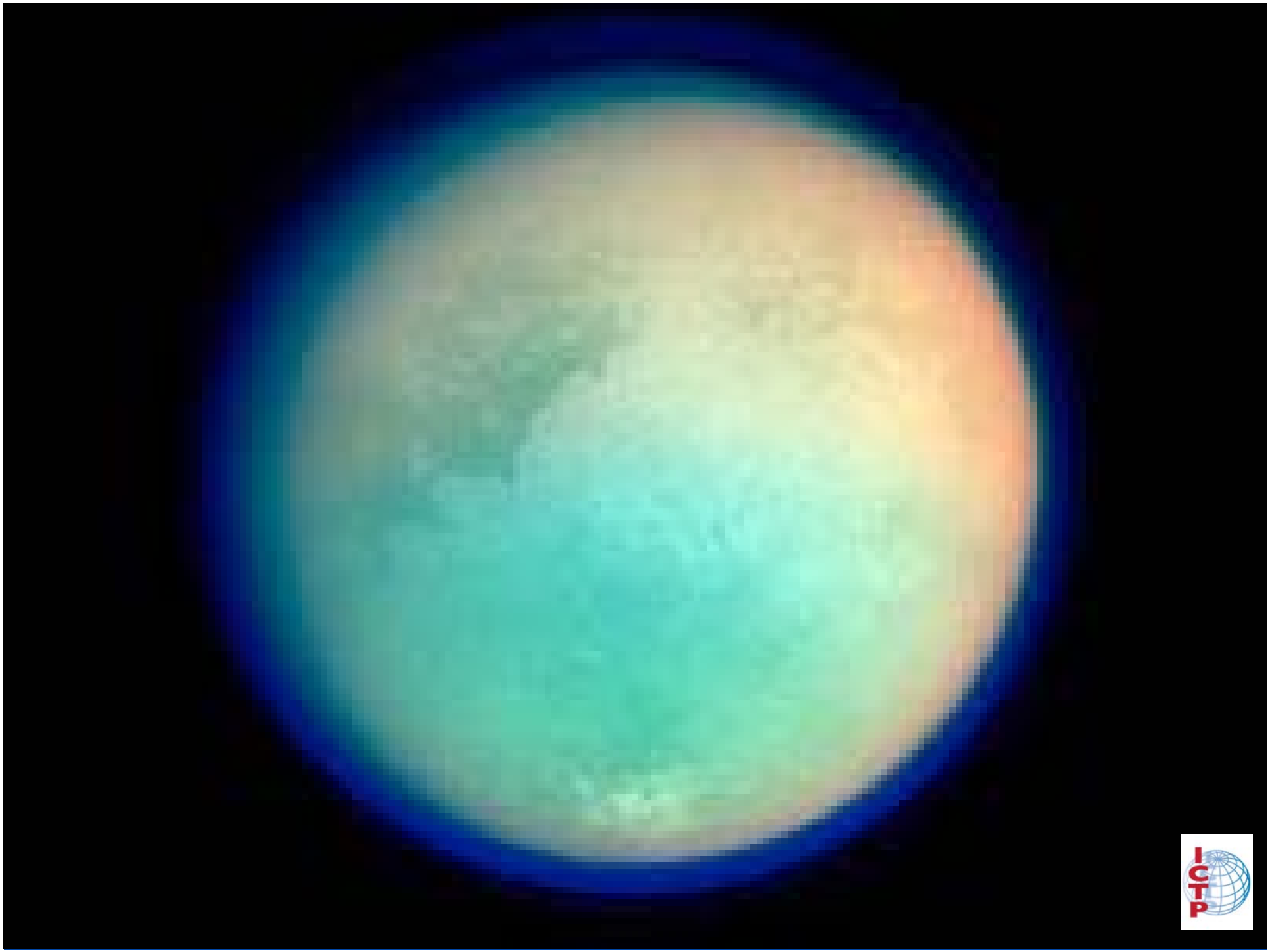
The search for Earth-like exoplanets

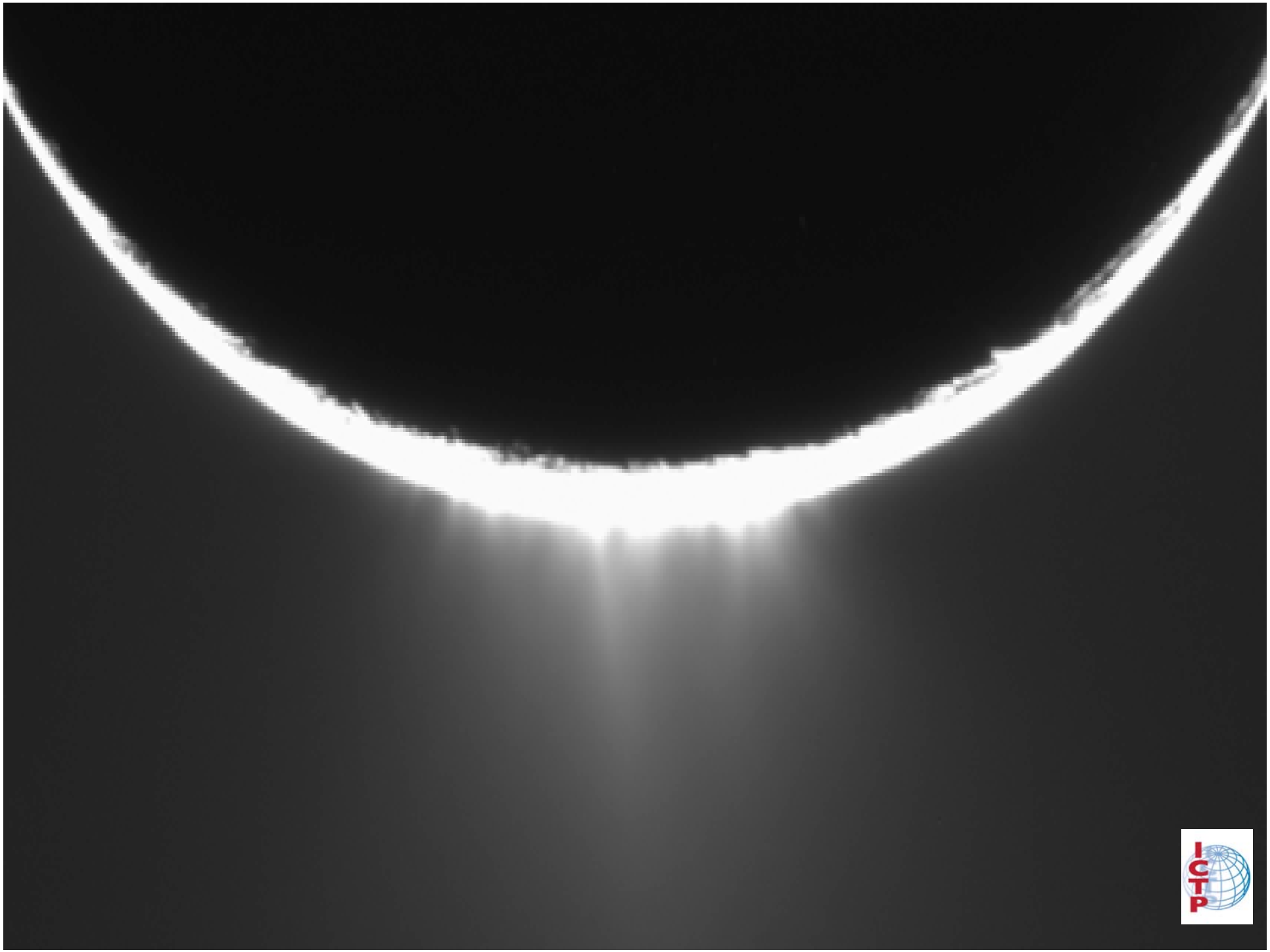
- The Terrestrial Planet Finder (TPF) will consist of space telescopes.
- Darwin will use three space telescopes (3 m in diameter) and a fourth spacecraft to serve as communications hub.
- TPF and Darwin will go beyond the three previous techniques for exoplanet hunting: wobbling stars, transits and microlensing (when a dark mass passes in front of a background star, the light from the star can be significantly magnified).

How, when and where did life start?

Give us in the short term an independent origin of life on Europa, Mars, Titan, or Enceladus and the doors to progress will open.







Discussion

- Brain evolution may offer hints of the probability that a human level of intelligence may arise in an independent evolutionary line provided the space weather conditions are favorable.

- The SETI project is an observational tool currently available to bioastronomers for searching for this aspect of evolution.

- The component of space weather generated by the Jovian magnetosphere is of interest for the understanding of potential biosignatures on Europa.

- The close integration of space weather research with astrobiology is at its preliminary stage.