First generation CR experiments on The first generation Moon based condominium

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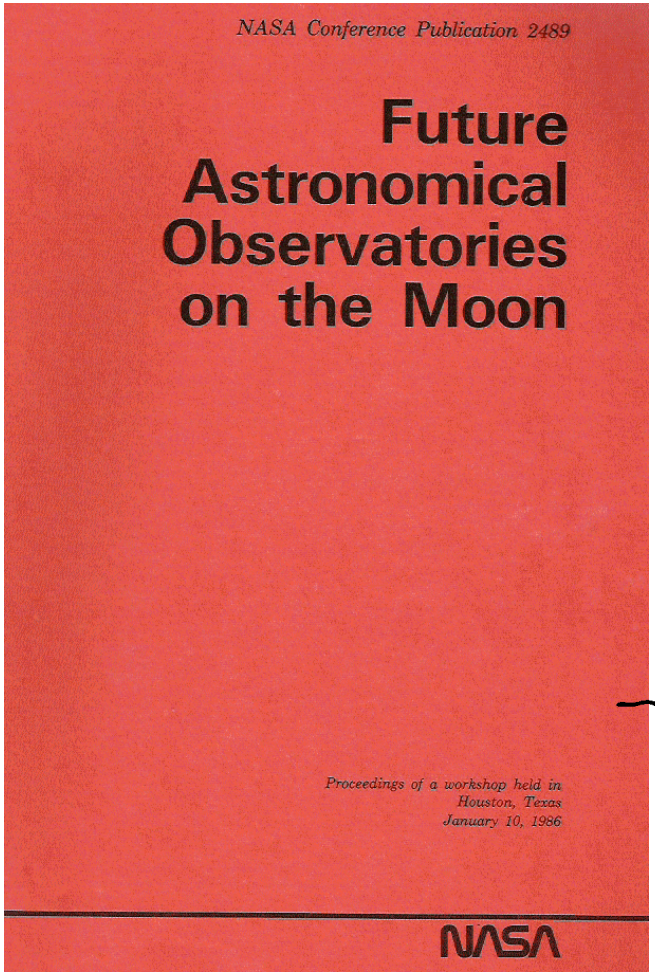
Univ. and INFN, Firenze, Italy

[Continuation of the Washington 2005 and Vulcano 2006 talks
"Moon Base: Scientific Opportunities for Astroparticle Physics"]



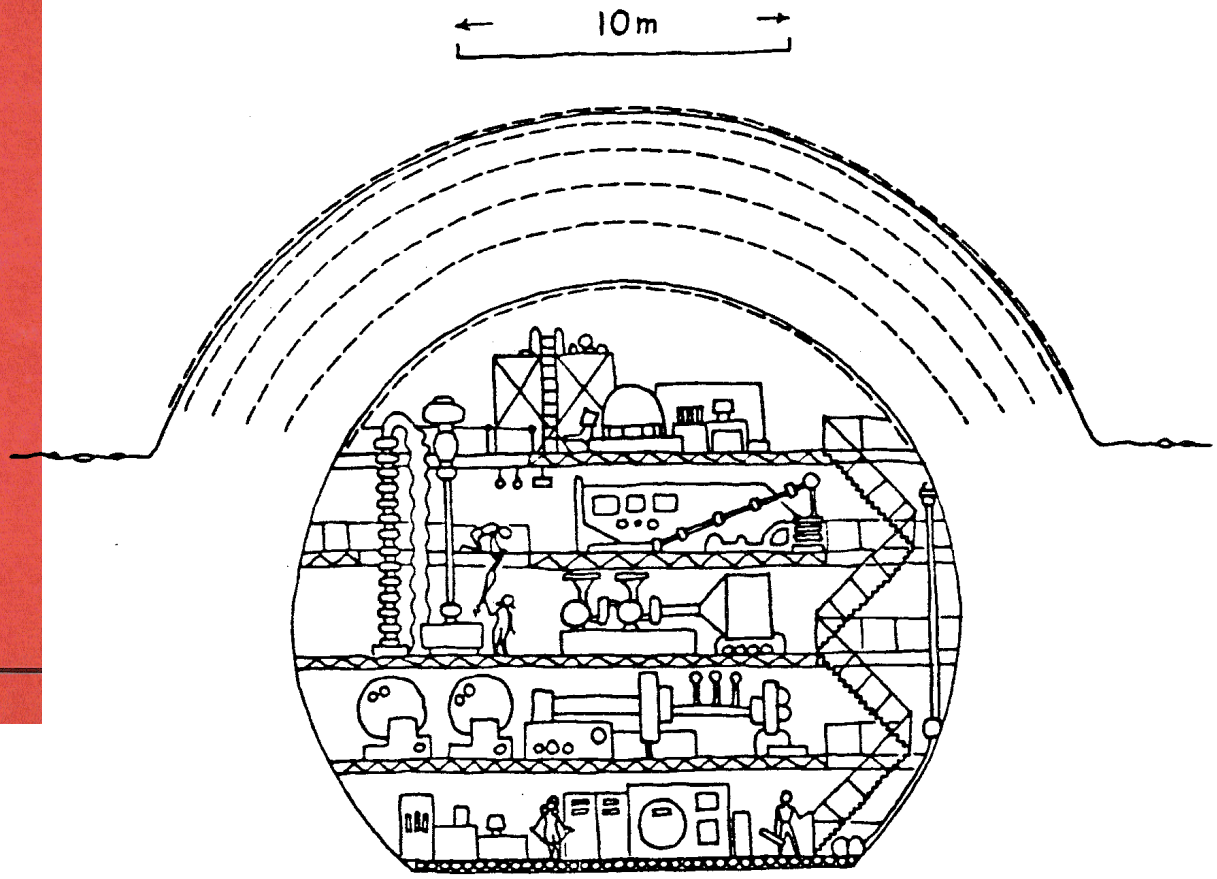


Figure 1.- A large ionization calorimeter built into the shielding of a manufacturing facility or a laboratory on the Moon. The dashed lines represent layers of gas-filled ionization counters.

Response to the *Cosmic Vision 2015-2025* ESA call

LUNAR OBSERVATORY FOR COSMIC RAY PHYSICS

We propose the ambitious idea of observing **Primary Cosmic Rays (PCR) and High Energy Gamma Ray (HEGR) from the Moon**, discussing its major scientific and technological advantages as well as the exceptional opportunity for an incomparable breakthrough in this frontier science.
There are some important measurements that can be conducted on the Moon surface:

……

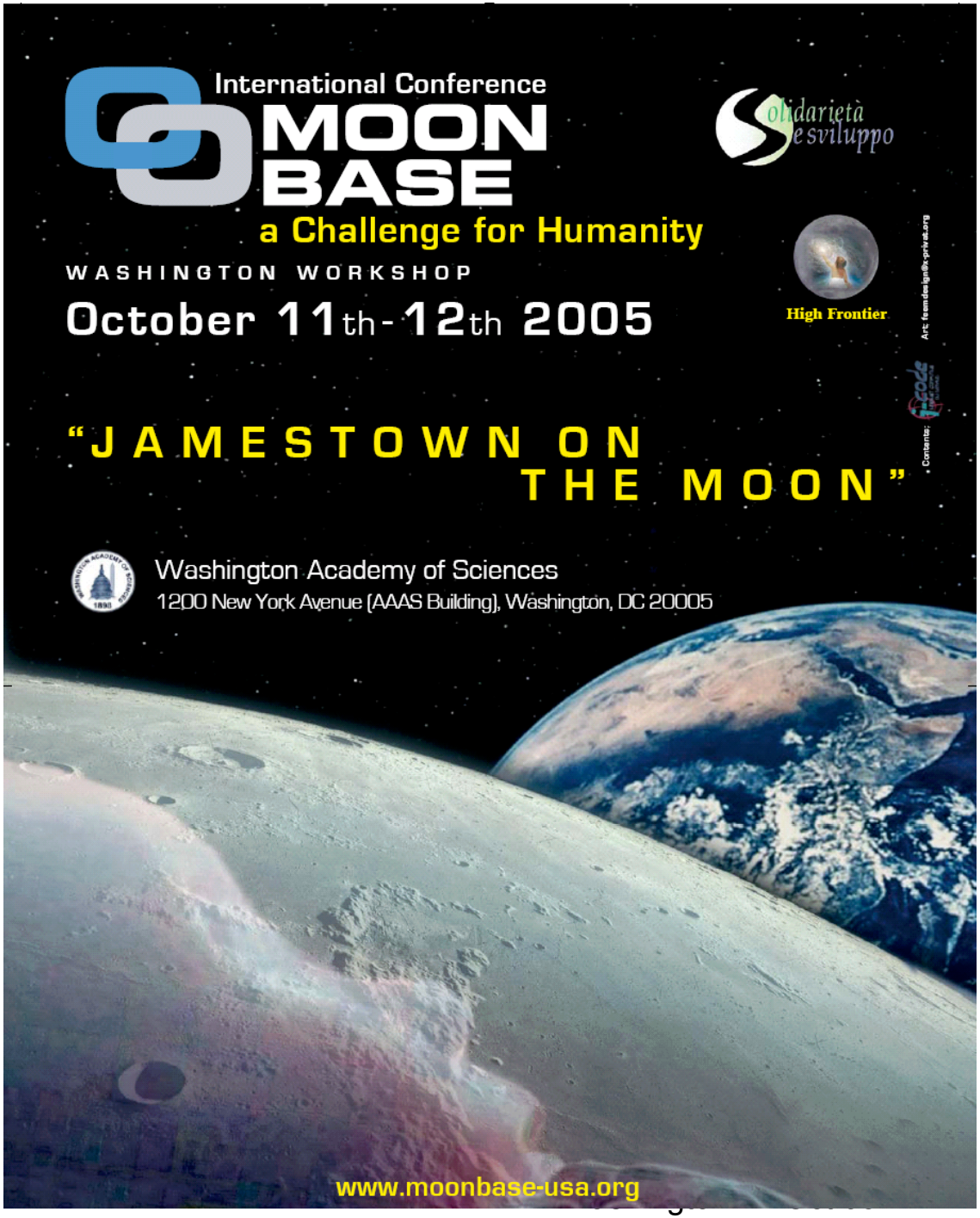
Each of these measurements could take advantage from, and be the target of, a specific project for a dedicated Moon-based experimental facility. However, the **combination of all of them in a single base** represents the very challenging and really advanced program, because of the synergy of different detection systems and measurements.

……

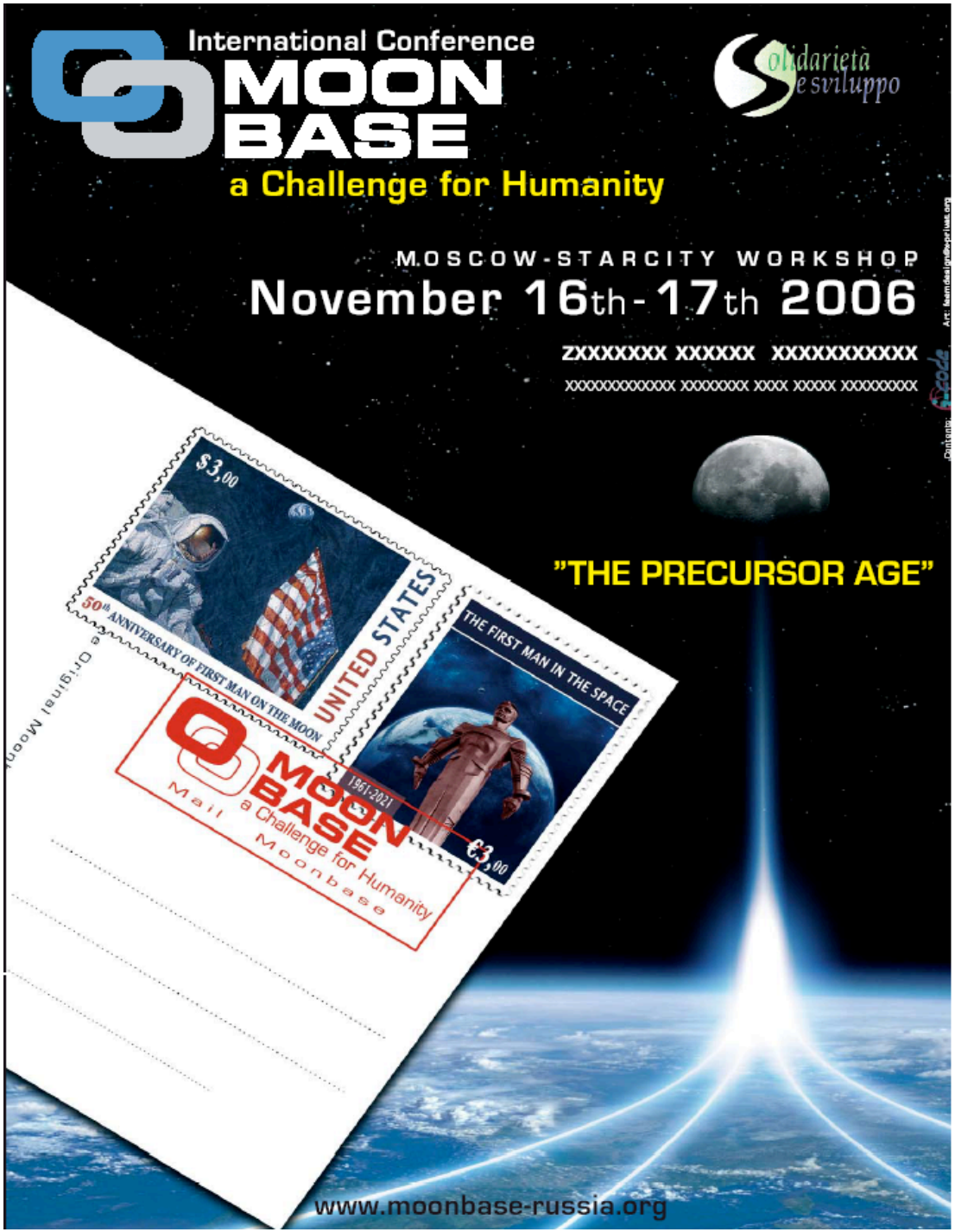
Pace Emanuele, University and INFN, Florence, Italy
Spillantini Piero, University and INFN, Florence, Italy

Florence, 30 May 2004

Gilmozzi R.,
"Moon Base: Scientific Opportunities (in Astronomy)", International Workshop Moon Base, Venezia, May 27, 2005



Spillantini P.,
"Moon Base: Scientific Opportunities for Astroparticle Physics",
International Workshop Moon Base, Washington, October 12, 2005.


International Conference
MOON BASE
a Challenge for Humanity
Solidarietà e sviluppo
MOSCOW-STARCITY WORKSHOP
November 16th-17th 2006
"THE PRECURSOR AGE"
$3,00
50th ANNIVERSARY OF FIRST MAN ON THE MOON
UNITED STATES
THE FIRST MAN IN THE SPACE
1961-2021
MOON BASE
a Challenge for Humanity
Mail
Moonbase
www.moonbase-russia.org

Preamble

In most of the satellite borne CR experiments, as in general in all satellite borne experiments, the mass and cost of the spacecraft and of its services (altitude and attitude control, power generation and distribution, telemetry, etc.) largely exceed the mass and cost of the experimental device. This fact, as well the increasing concurrence by other field of the science and applications, greatly reduced in last two decades the number of flown satellite borne cosmic ray experiments.

As matter of fact the possibility of installing CR experiments on an already organized and serviced lunar habitat can significantly reduce the required investment, as already proven for the many experiments performed on board of the MIR Space Station and of the ISS. This compensates for the cost of the Earth-Moon transportation, that in addition it is anticipated to decrease by a sensible factor in the next decade.----------

As it was the case in the seventies for the Great Observatories (Hubble telescope, CGRO, AXAF, SIRF) in view of the shuttle operations, a complete program at the forefront of space science and technology should include a set of Moon based Observatories to explore any aspect of the Universe.----------
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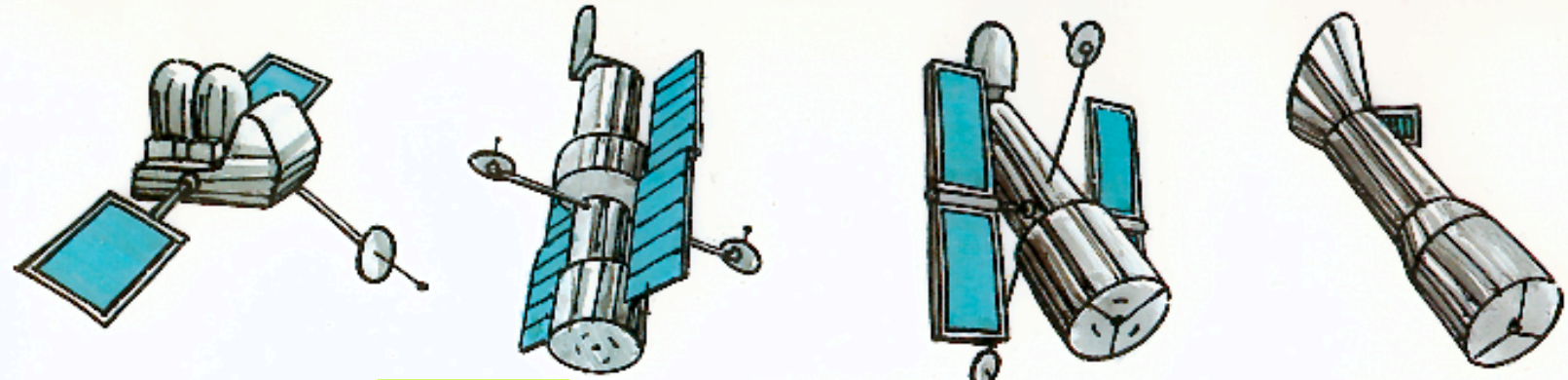
For expanding our knowledge to the extreme Universe at higher energies the Moon based CR observation must be part of this program. --



CGRO

AXAF (CXO)

THE GREAT OBSERVATORIES

FOR SPACE ASTROPHYSICS

HST

SIRTF

\+

Advanced Composition Explorer (ACE)

\+

Particle-Antiparticle Superconducting Magnet Facility (ASTROMAG)

on board of the Freedom SS

\+

Very Long Base Interferometer (VLBI)

What could be obtained installing on the future Moon Base the experiments selected in the last two decades but never flown for several reason, among them the high cost of the spacecraft?

They could be considered the basic instruments, whose evolution will constitute the ‘first generation Moon based CR experiments’.

They were discussed in Vulcano-06 for the five typical ‘categories’ already used in the Washington workshop:

(1) high Z,
(2) rare isotopes,
(3) antiparticles and antinuclei,
(4) composition at the knee,
(5) UHECR.

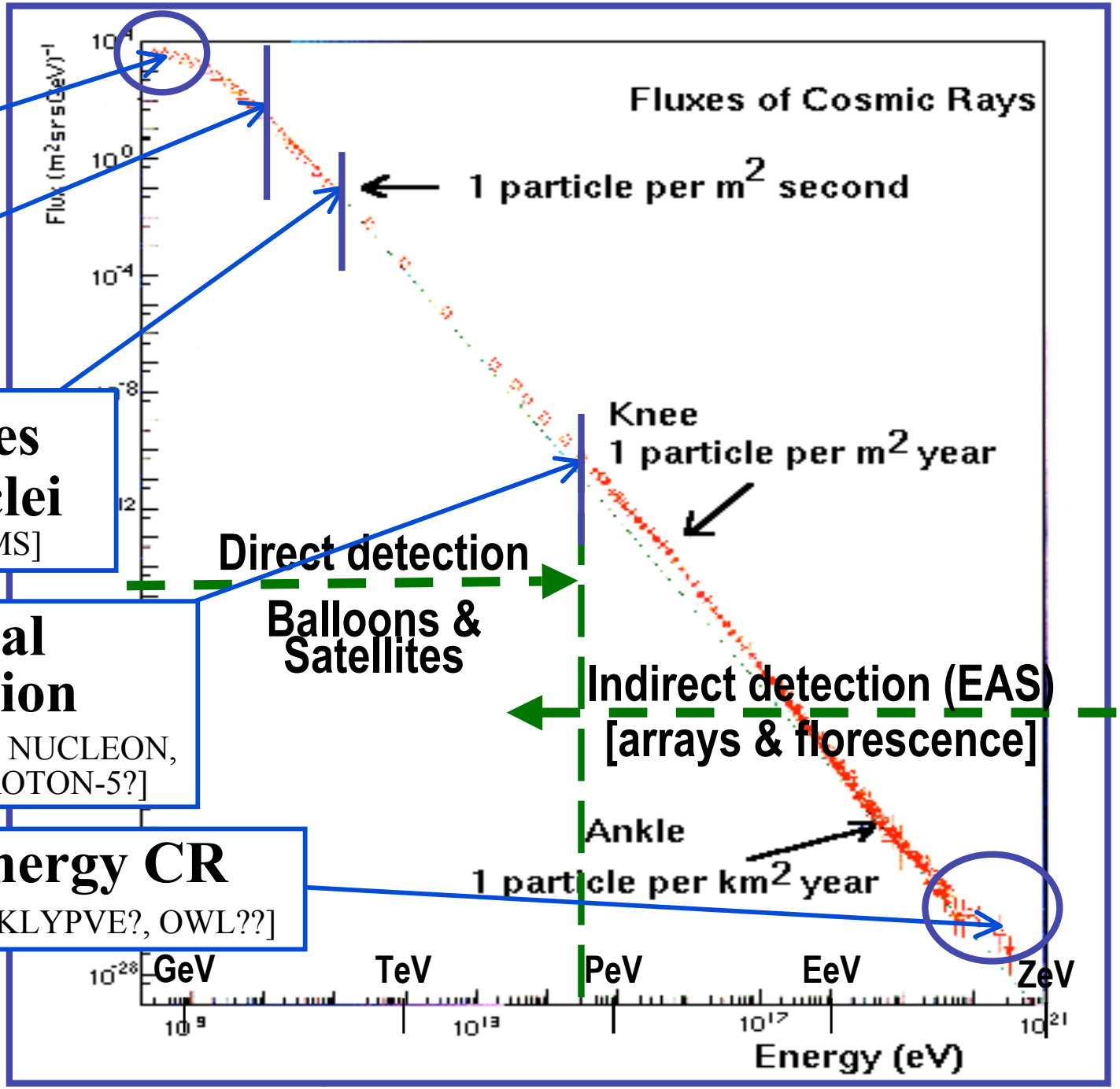
High Z
[ENTICE, ECCO]

Light elements and Isotopes
[ACE]

Antiparticles and Antinuclei
[BESS,PAMELA,AMS]

Elemental Composition
[CREAM, ATIC, BEAR, NUCLEON, ACCESS?, INCA?, PROTON-5?]

Extreme Energy CR
[AUGER, EUSO, TUS, KLYPVE?, OWL??]



High Z: HNeXplorer (HNX) [exp. ENTICE + ECCO] in 'stand by'
possible only on the Moon surface

Isotopes (E>GeV/n): on Earth orbit ≈80 are accessible but no plans exist
light isotopes from BESS, PAMELA, AMS in next years
high rate assured on the Moon up to very high E

Rare components: antiN/N up to $<10^{-9}$ (AMS)
antip, e+ up to a >200 GeV (PAMELA ed AMS)
electrons up to >3 TeV (PAMELA, AMS, CALET)
1-10 TeV region on reach on the Moon surface

Elemental composition: up to 100 TeV by ballooning (going on)
up to 1 PeV in orbit (several projects and concepts)
up to 100 PeV (well behind the knee) on the Moon

Ultra High Energies: up to few * 100 EeV on Earth surface (going on)
up to 1000 EeV from orbit (but EUSO in 'stand by')
up to a few 10 ZeV from the Moon surface,
a UHE Neutrino Observatory ($E_{\nu}>10^{19}$) is feasible

***Zero generation experiments*:**

Install on the Moon the experiments planned for satellites or ISS, and that are long time in stand by because too massive and difficult to be operated In LEO:

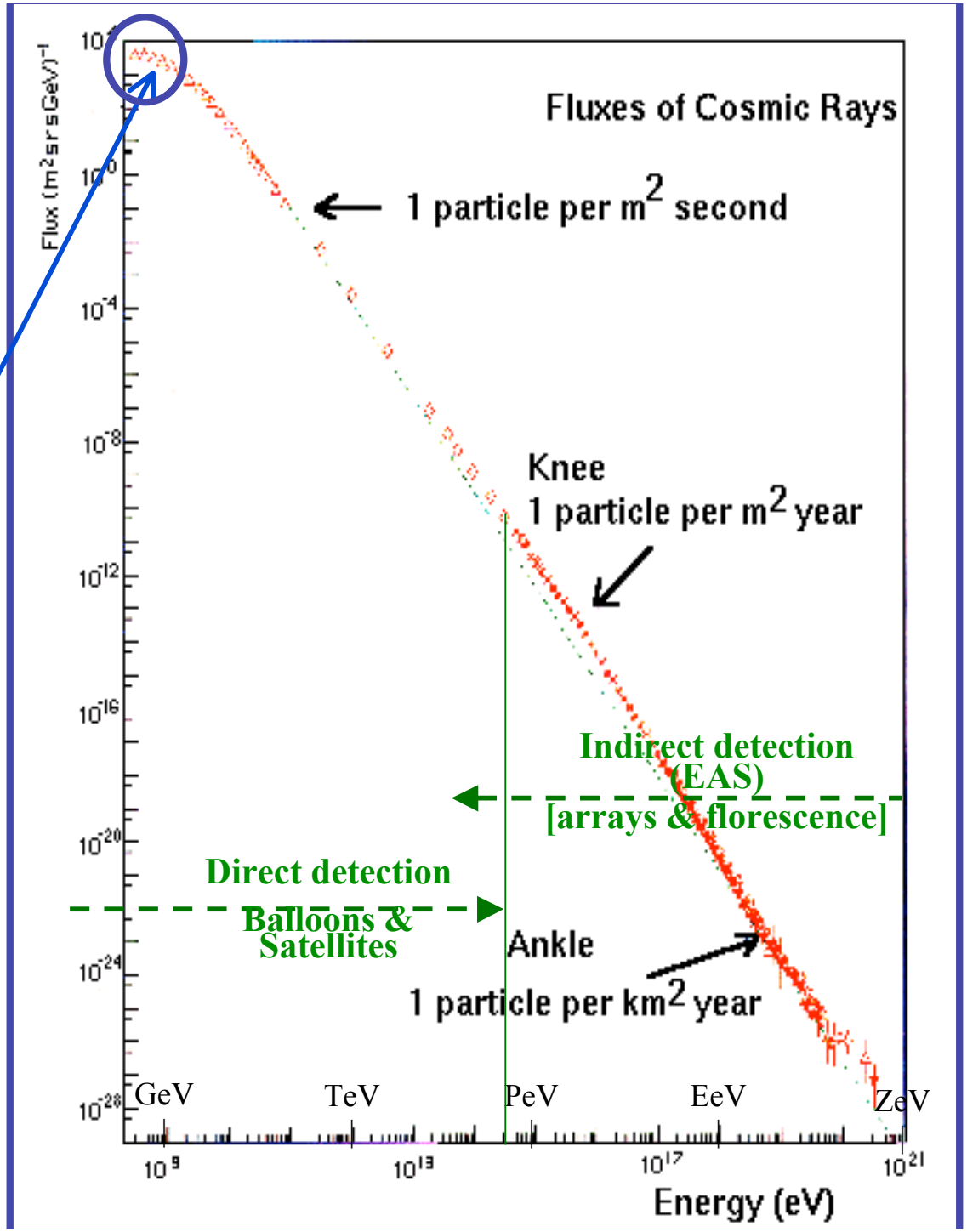
Examples:

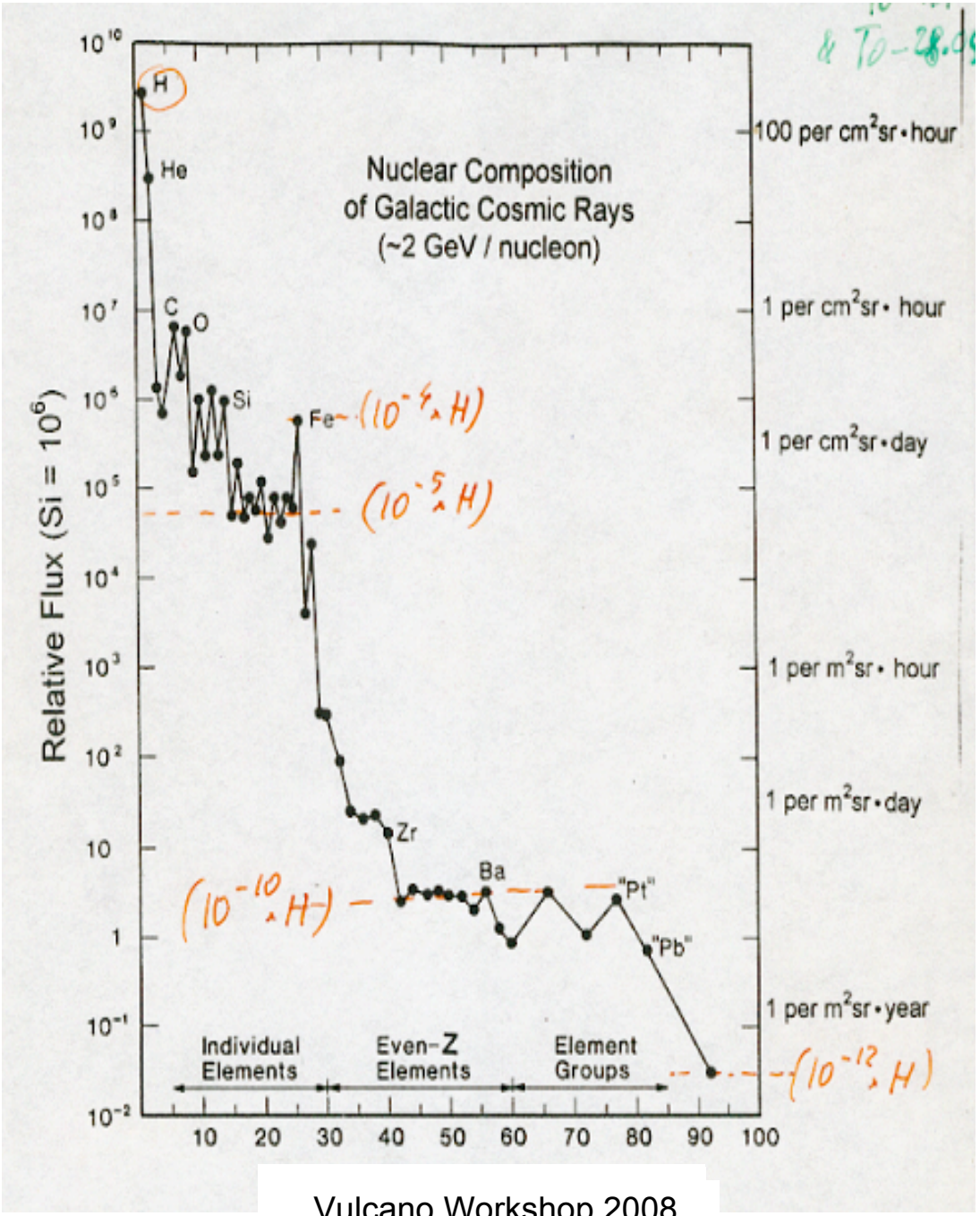
1 - ECCO for very high Z (supernovae rate counting) [small changes]

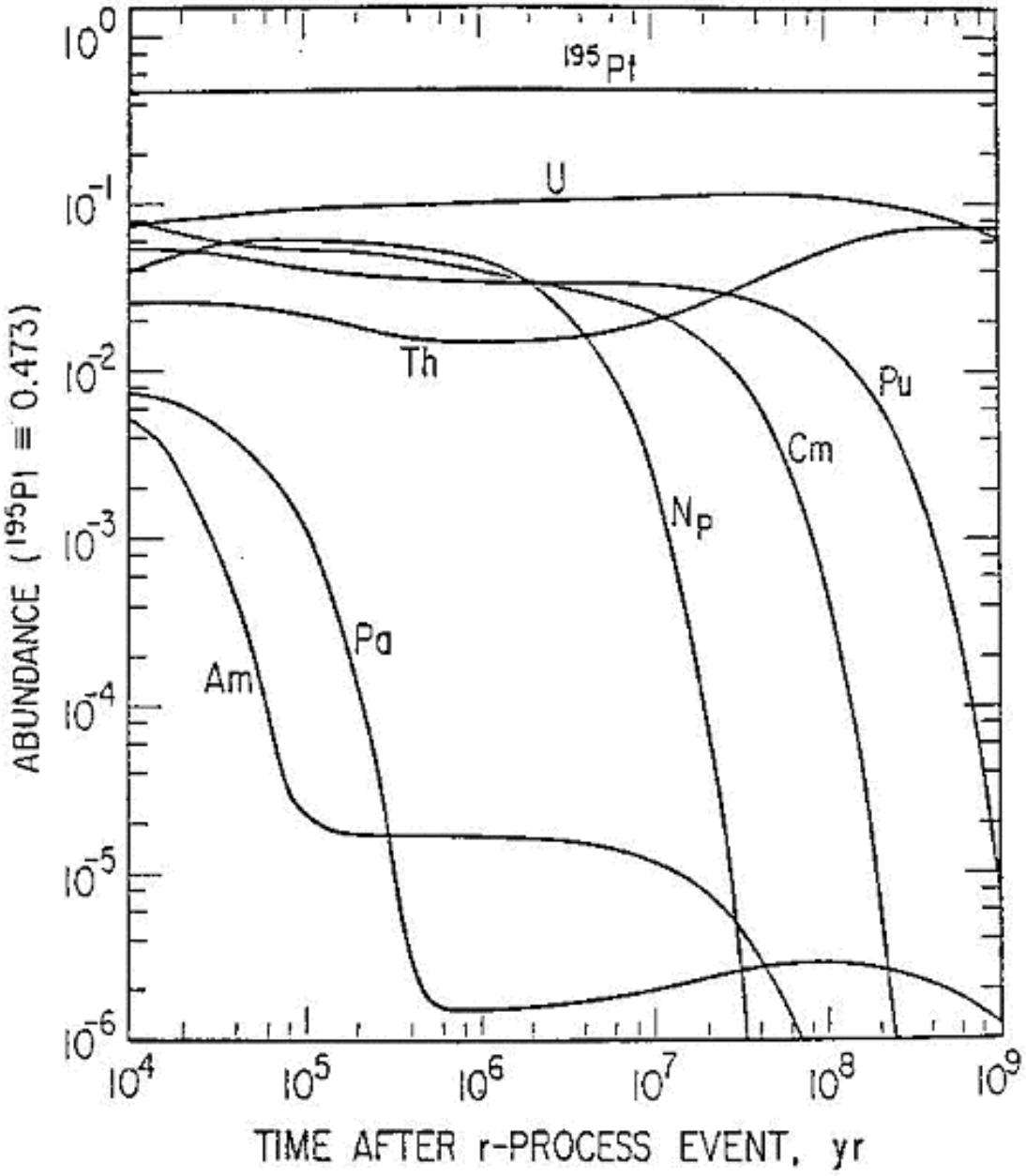
2 - Rare elements, radioattive isotopes [new, ISOMAX-like magnetic spectr.]
small changes + supply of services (electric power, data elaboration and transmission)

4 - Elemental composition at knee
- [ACCESS class, possibly larger acceptance]
- [CHICAGO EGG spectrometer, but longer exposition]

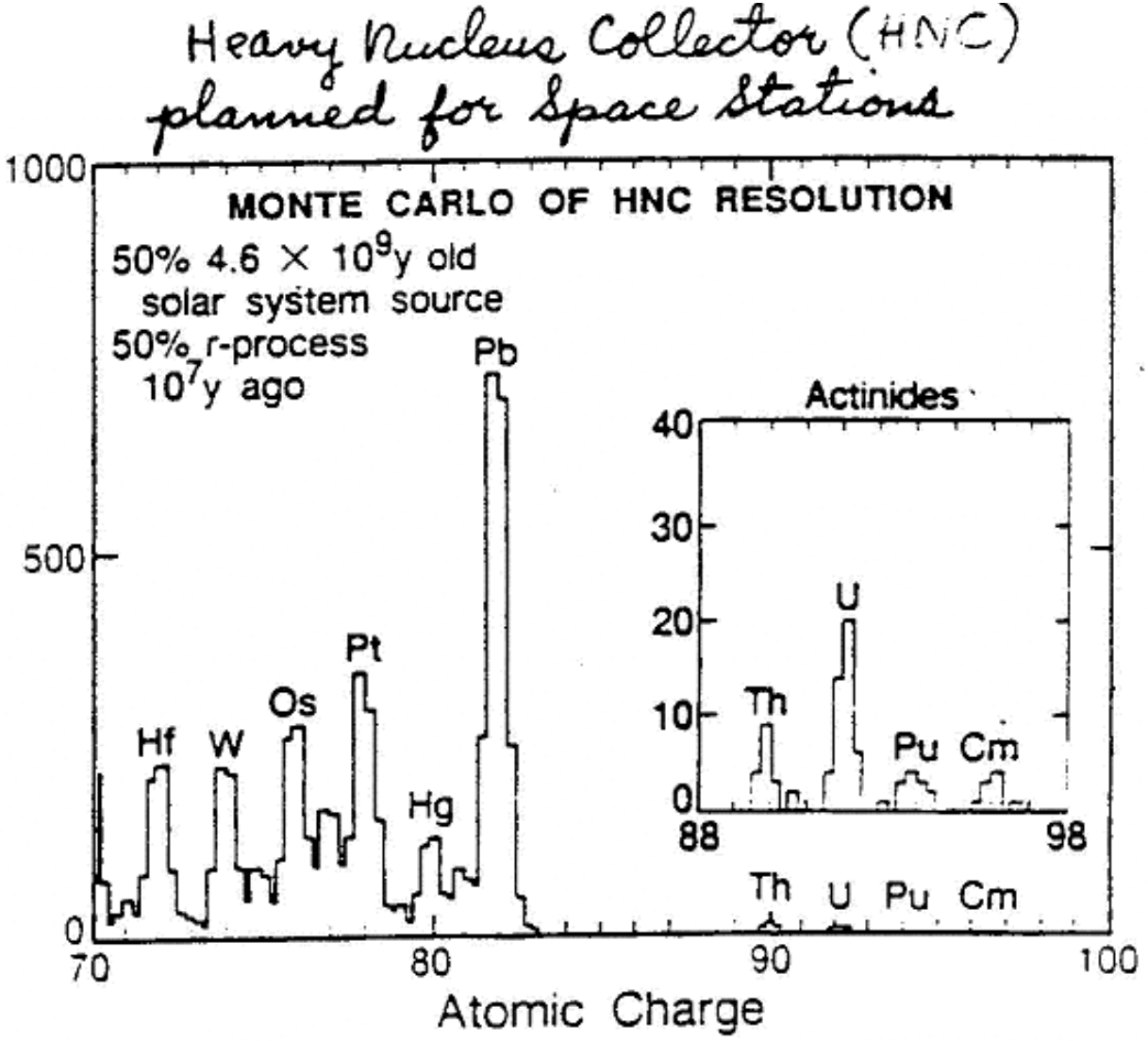
High Z
[ENTICE, ECCO]

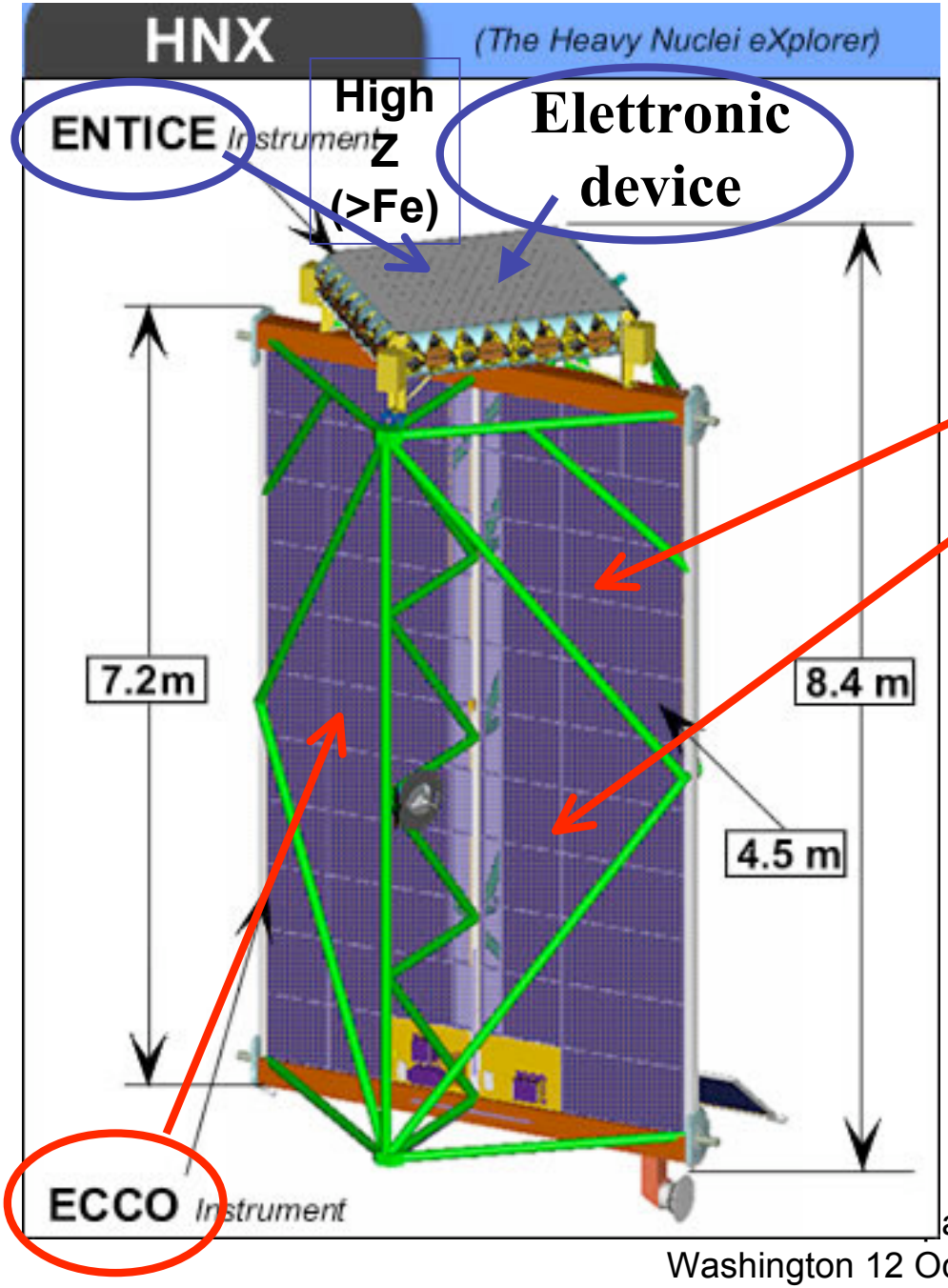



Nuclear Composition
of Galactic Cosmic Rays
(~2 GeV / nucleon)
Relative Flux (Si = 10^6)
H
He
C
O
Si
Fe
Zr
Ba
"Pt"
"Pb"
Individual Elements
Even-Z Elements
Element Groups
100 per cm²sr•hour
1 per cm²sr• hour
1 per cm²sr•day
1 per m²sr• hour
1 per m²sr•day
1 per m²sr•year
10 20 30 40 50 60 70 80 90 100


10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
^{195}Pt
U
Th
Pu
Cm
Np
Pa
Am
ABUNDANCE (^{195}Pt ≡ 0.473)
10^4
10^5
10^6
10^7
10^8
10^9
TIME AFTER r-PROCESS EVENT, yr

Heavy Nuclei Collector (HNC) [30m^2] planned for 'Freedom' Space Station



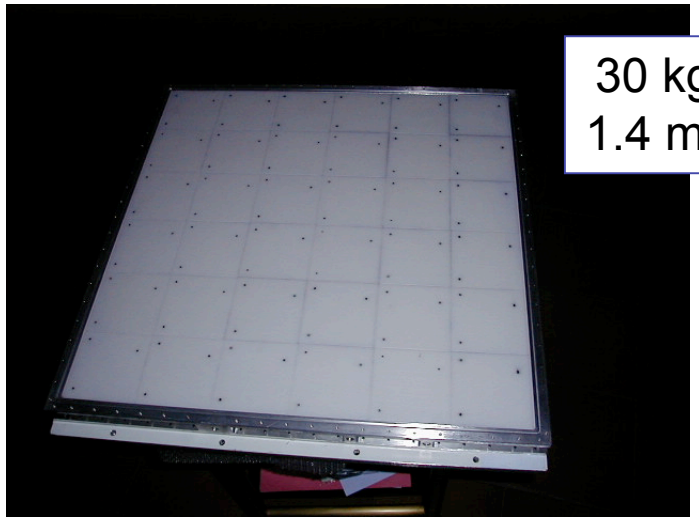


Etching of "charged" glasses

On the Moon:
- no magnetic field
- easily deploied
- easily recovered

Very High Z (actinides)

Mass << 100 kg/m2



30 kg
1.4 m^2

article,
Washington 12 Oct 05

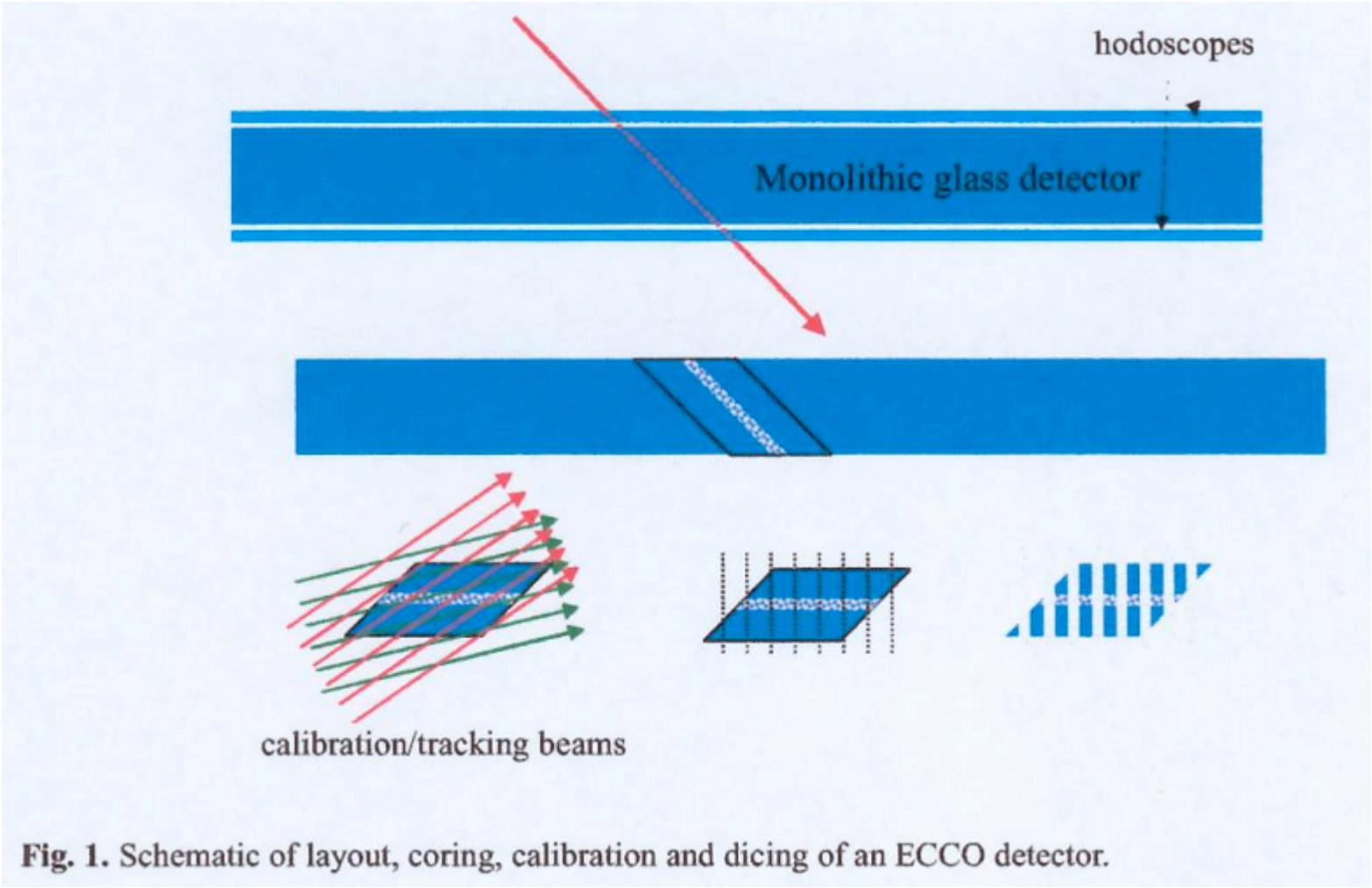
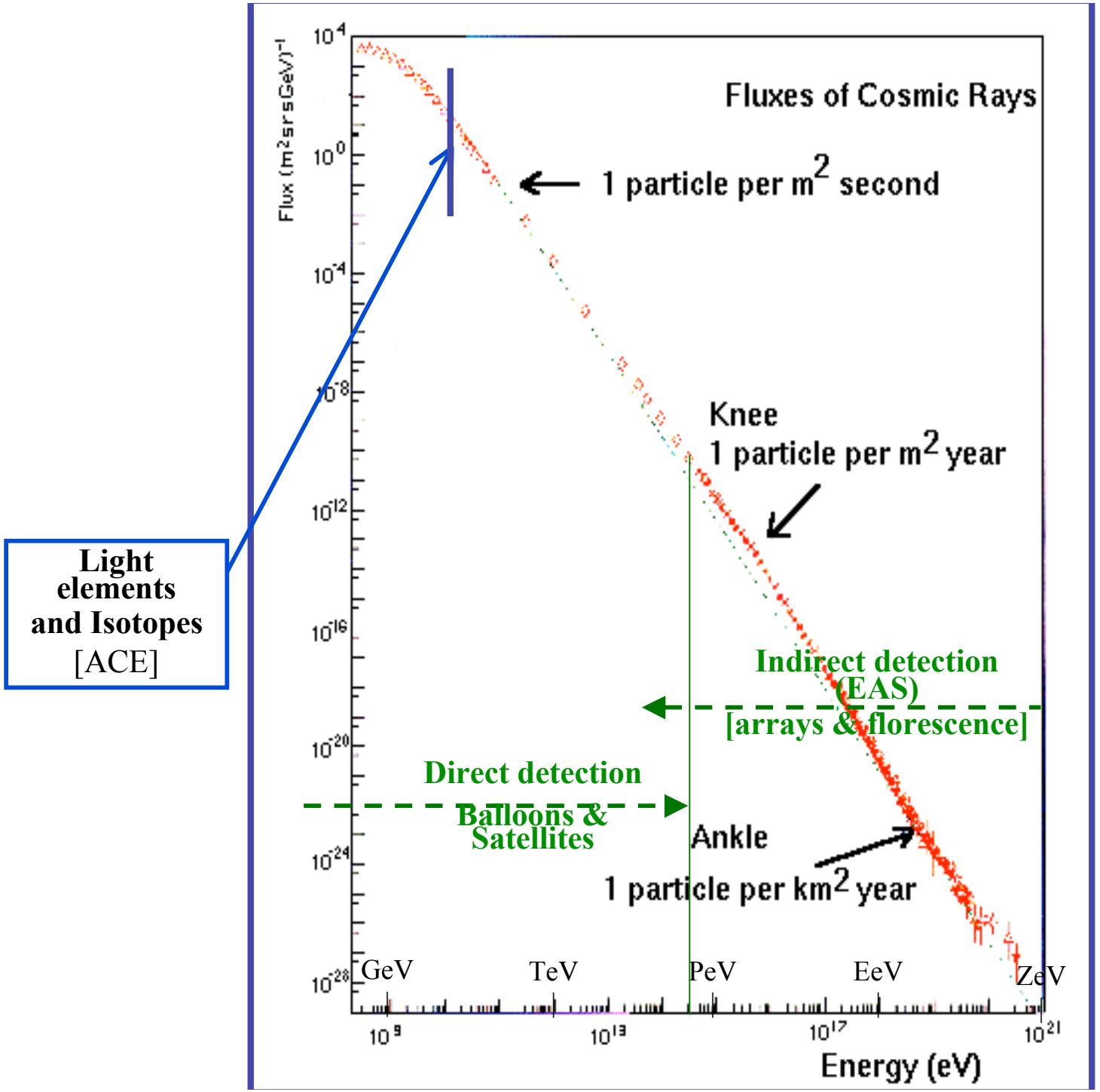
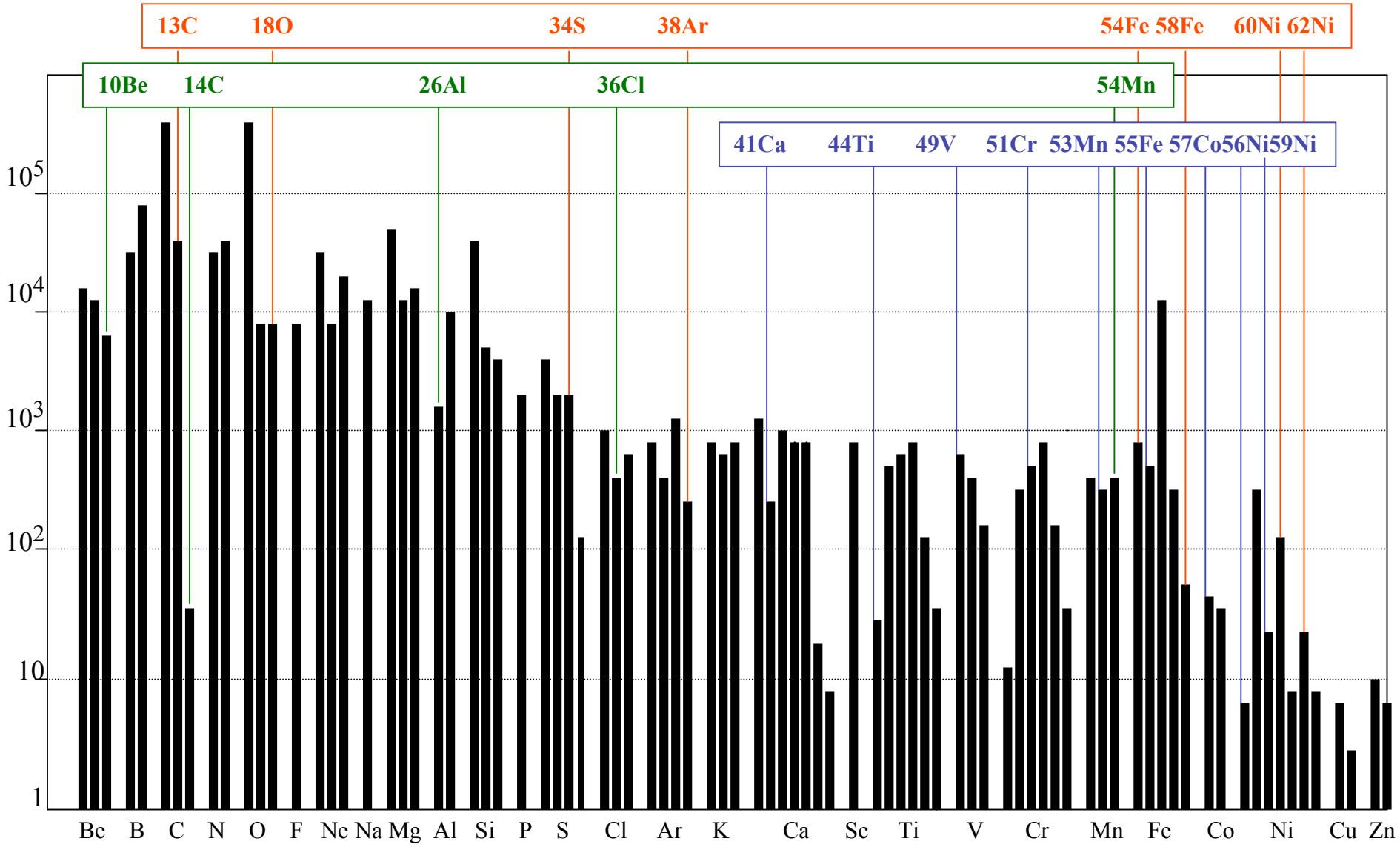


Fig. 1. Schematic of layout, coring, calibration and dicing of an ECCO detector.


Light elements and Isotopes [ACE]
Fluxes of Cosmic Rays
Flux (m²sr s GeV)⁻¹
1 particle per m² second
Knee
1 particle per m² year
Indirect detection (EAS) [arrays & florescence]
Direct detection Balloons & Satellites
Ankle
1 particle per km² year
GeV
TeV
PeV
EeV
ZeV
Energy (eV)

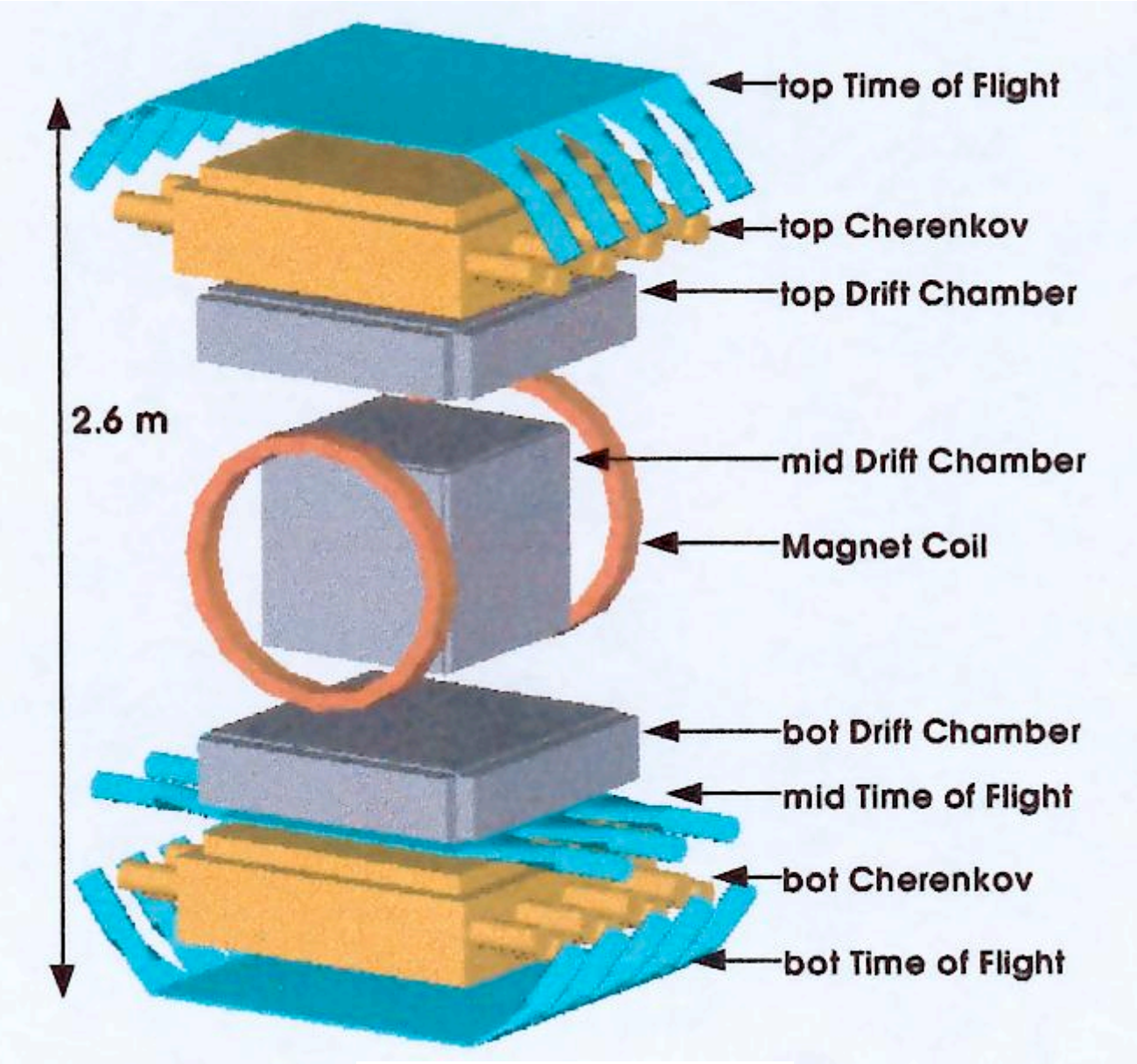


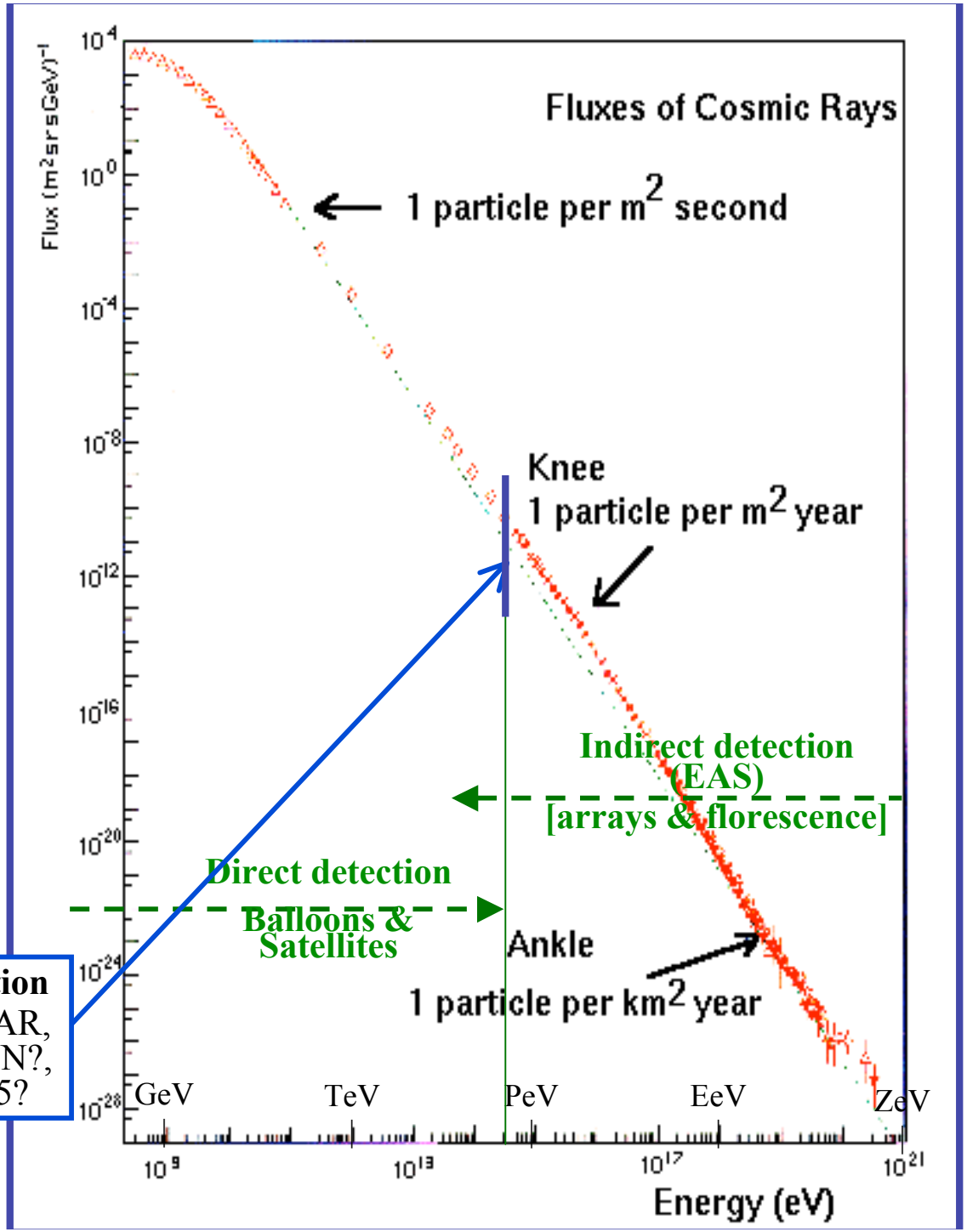
LISA project for ASTROMAG: Events/3years (80% duty cycl., losses 50%)

"rare" isotopes:
nucleosintetic origin of CR

Beta decay:
Residence time in the Galaxy

electronic capture:
time between nucleos. and accel.


top Time of Flight
top Cherenkov
top Drift Chamber
2.6 m
mid Drift Chamber
Magnet Coil
bot Drift Chamber
mid Time of Flight
bot Cherenkov
bot Time of Flight



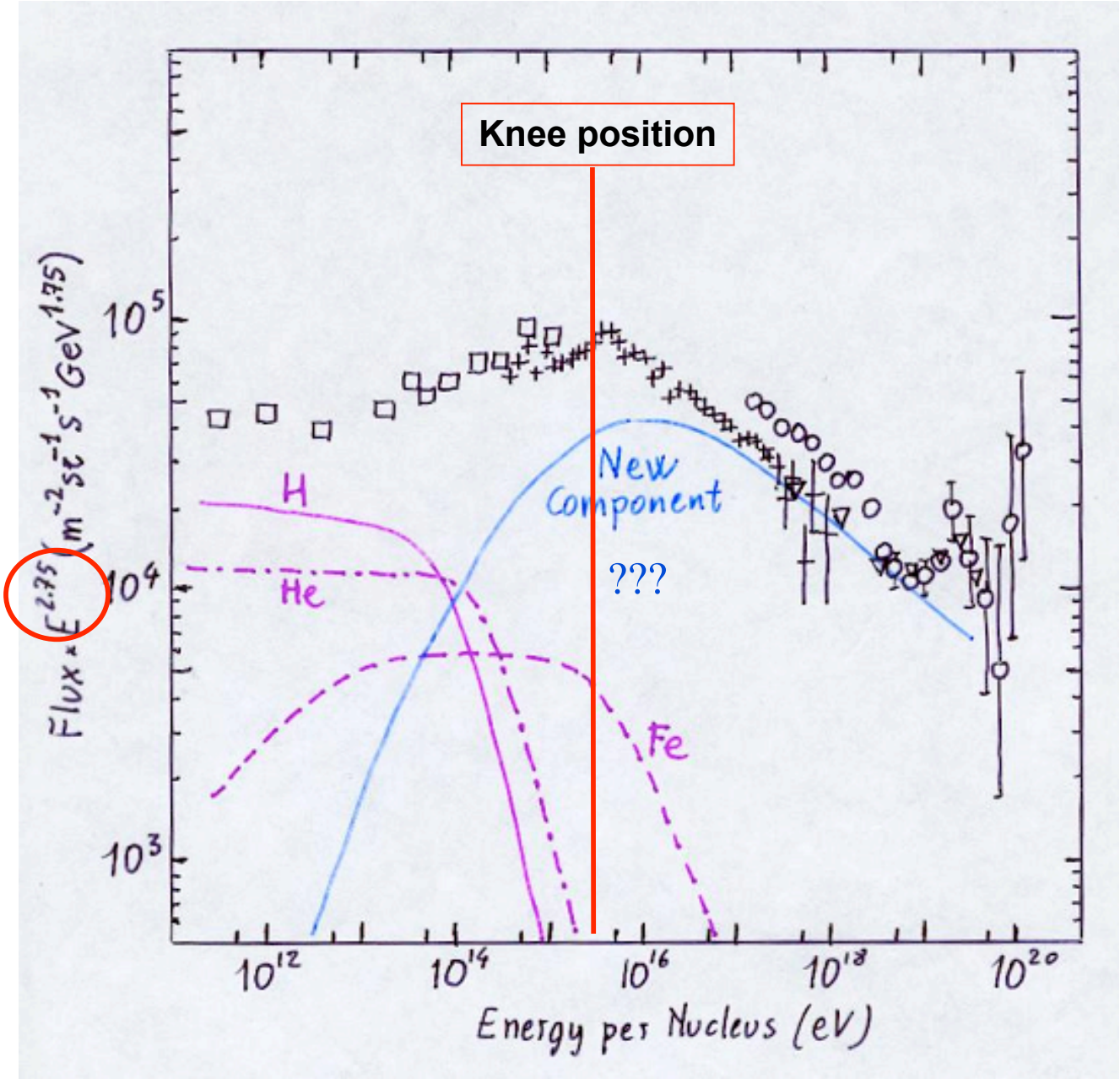
Elemental Composition
[CREAM, ATIC, BEAR, ACCESS?, NUCLEON?, INCA?, PROTON-5?

The KNEE region
(3 x 10^{15} eV)

Border energy between space (balloon and satellite borne) and ground based experiments.

but also

Border energy between different acceleration processes of cosmic rays in the Universe.


Knee position
H
He
Fe
New
Component
???
Flux × E^2.75 (m^-2 sr^-1 s^-1 GeV^1.75)
10^5
10^4
10^3
10^12
10^14
10^16
10^18
10^20
Energy per Nucleus (eV)

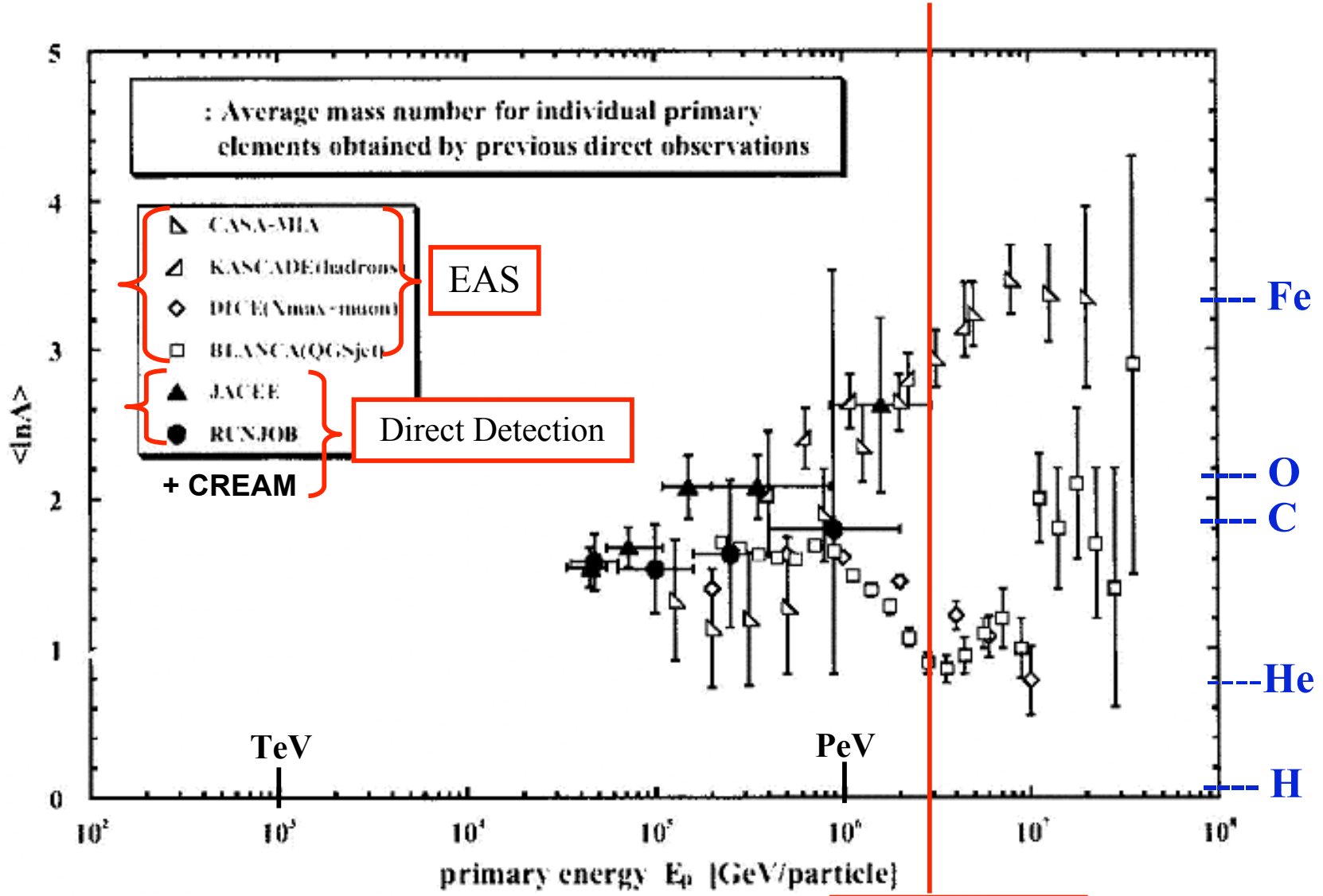
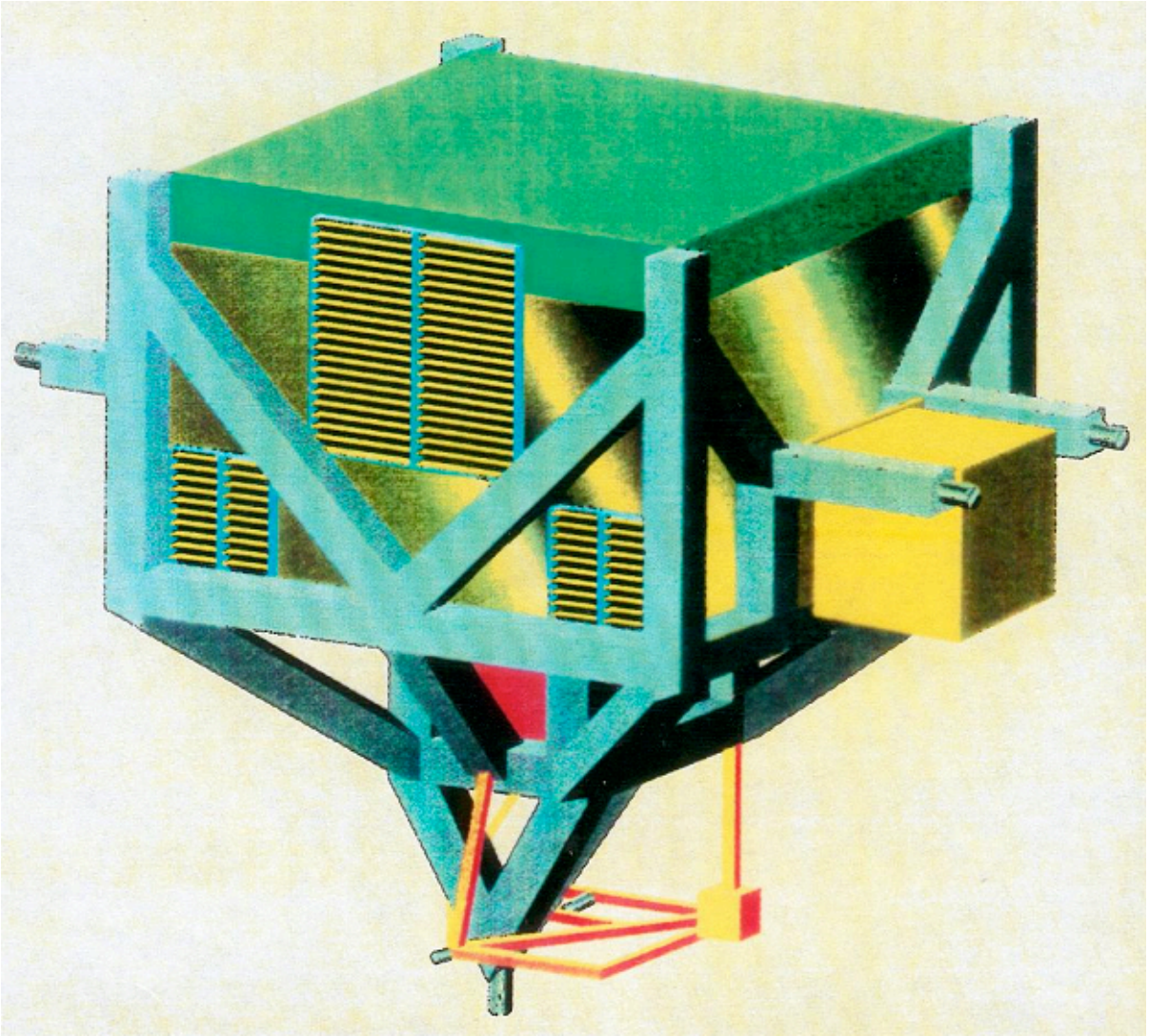
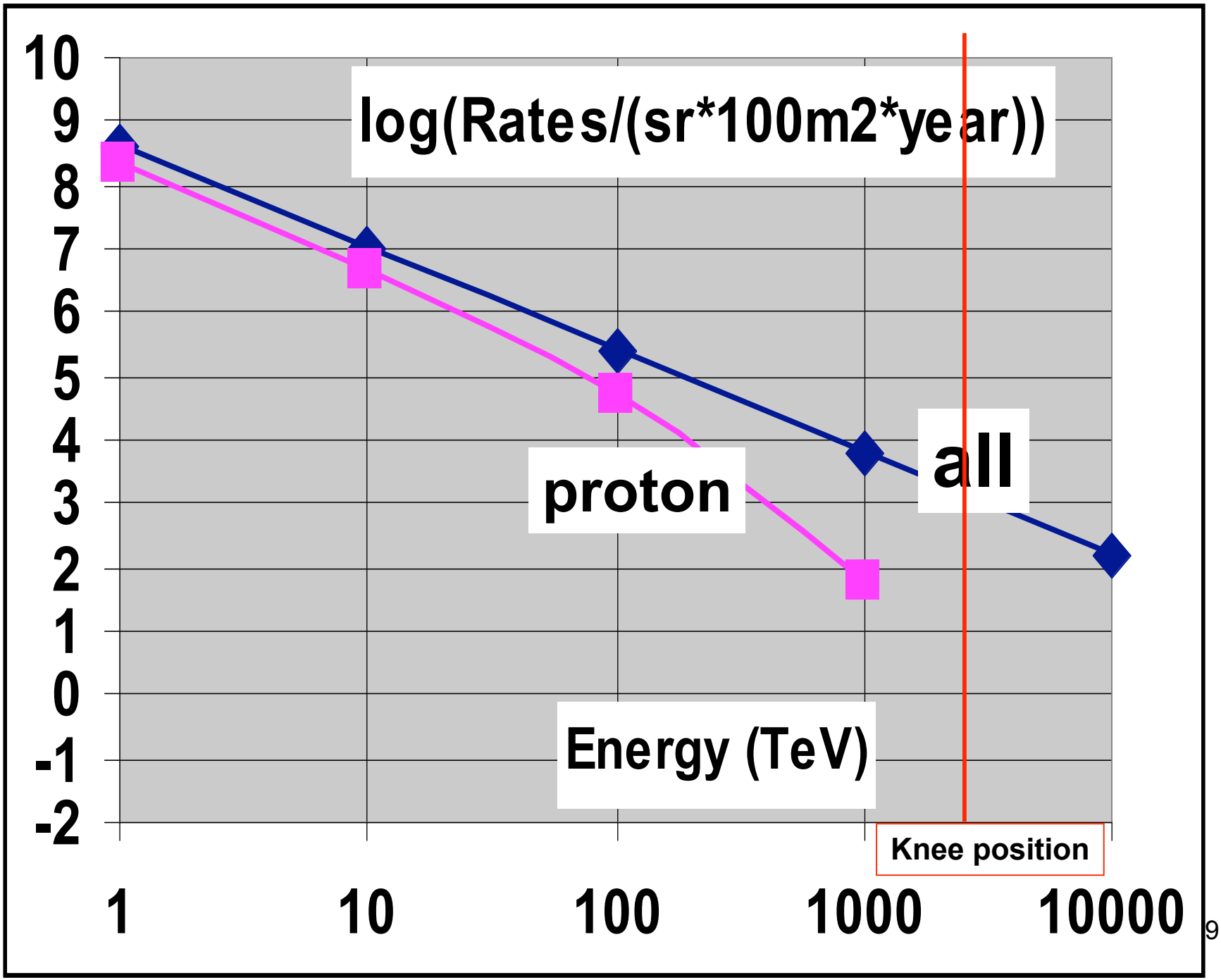


Fig. 3. Energy dependence of average mass number of primary cosmic-ray particles.

ACCESS

GF ≈ 2x2m^{2}x1sr
Mass ≈ 5t




log(Rates/(sr*100m2*year))
proton
all
Energy (TeV)
Knee position
10
9
8
7
6
5
4
3
2
1
0
-1
-2
1
10
100
1000
10000

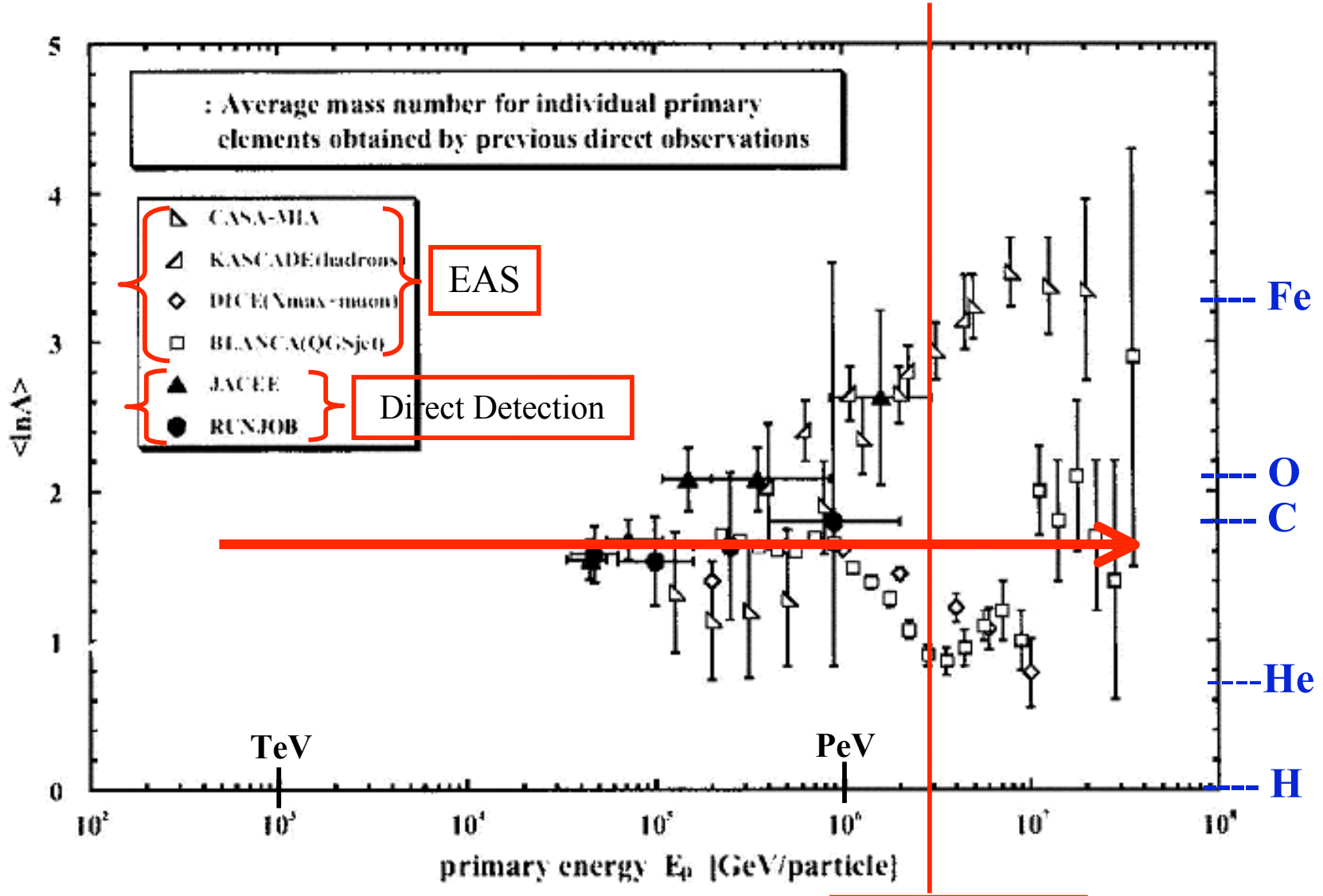
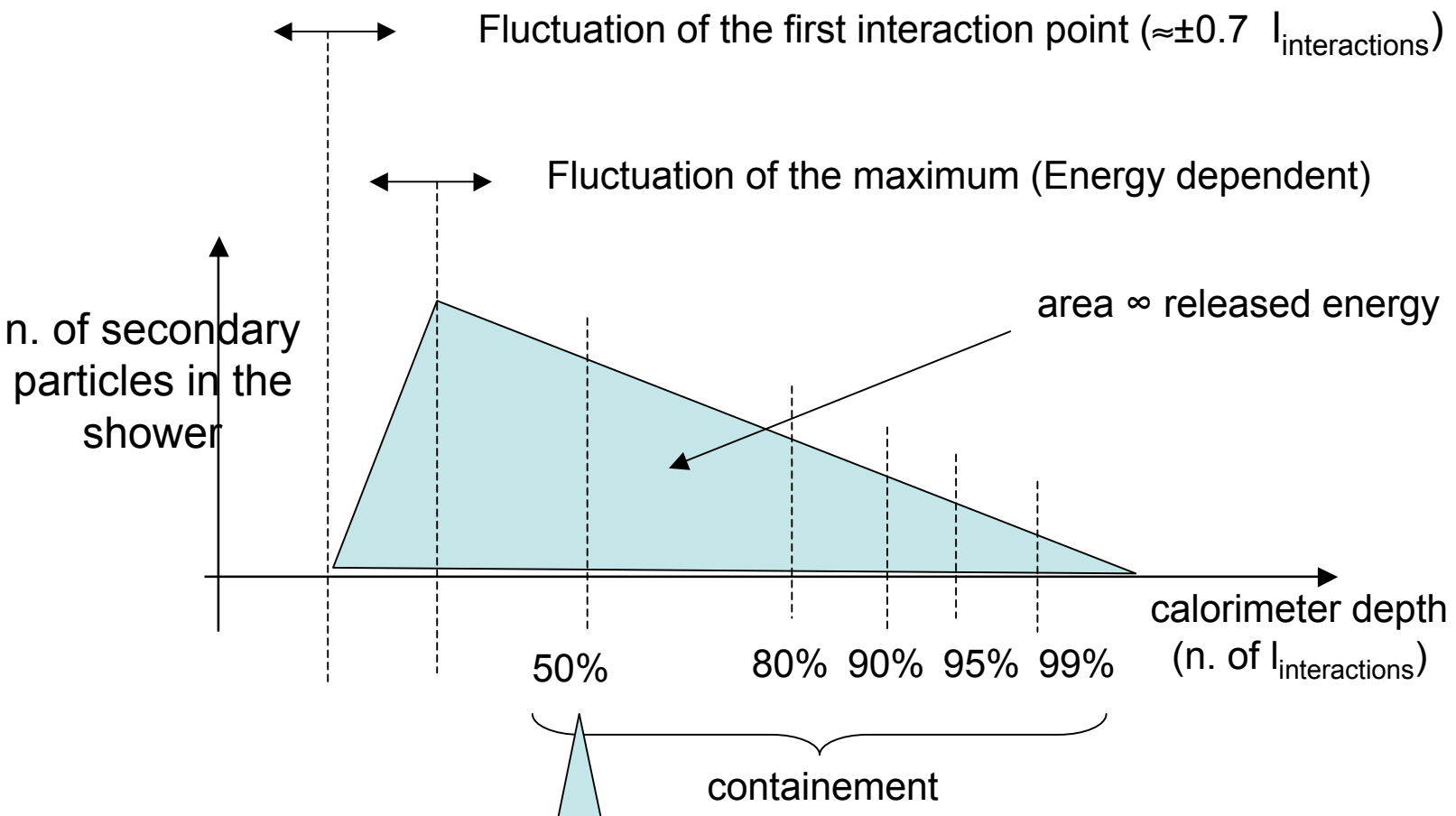
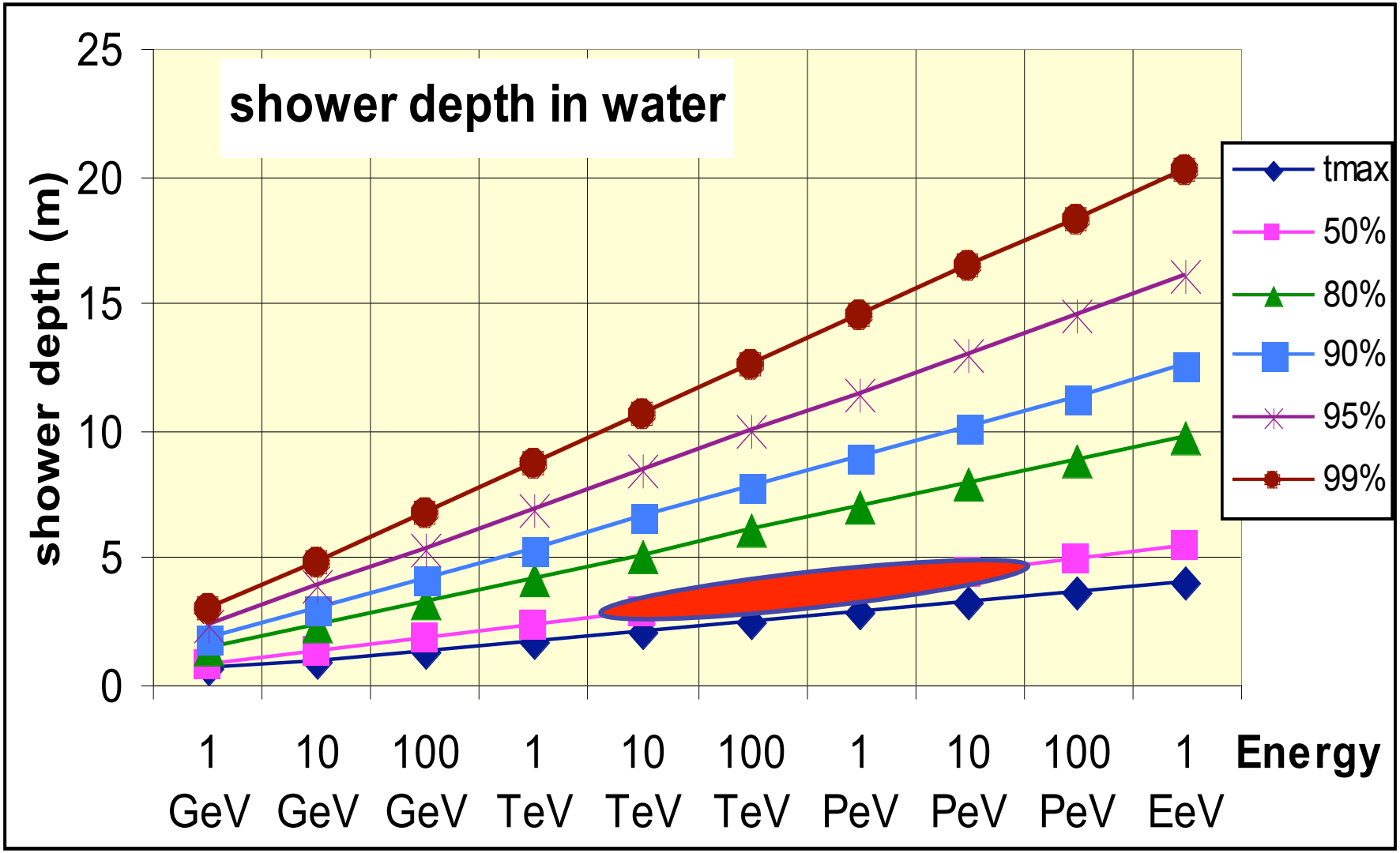


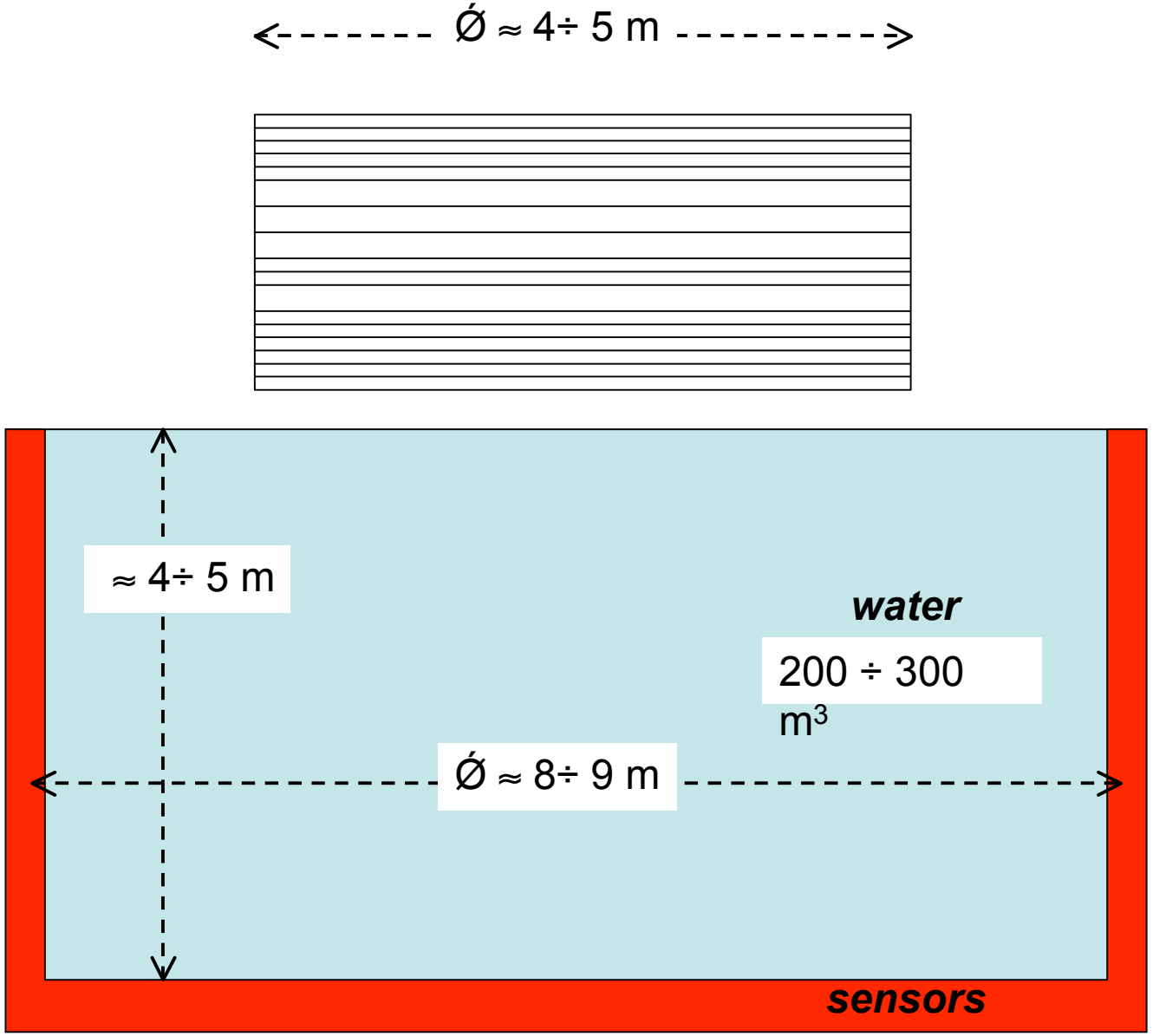
Fig. 3. Energy dependence of average mass number of primary cosmic-ray particles.



Poor containement
Poor Sampling
No compensating
CALORIMETER
<150%/sqrt(E(GeV)) + (few)%

100 GeV	(15+few)%
1 TeV	(5+few)%
10 TeV	(few)%
100 TeV	(few)%
1 PeV	(few)%
10 PeV	(few)%


shower depth in water
shower depth (m)
25
20
15
10
5
0
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
1 PeV
10 PeV
100 PeV
1 EeV
Energy
tmax
50%
80%
90%
95%
99%



TRD's + Calorimeter Spectrometer

Water on the Moon???

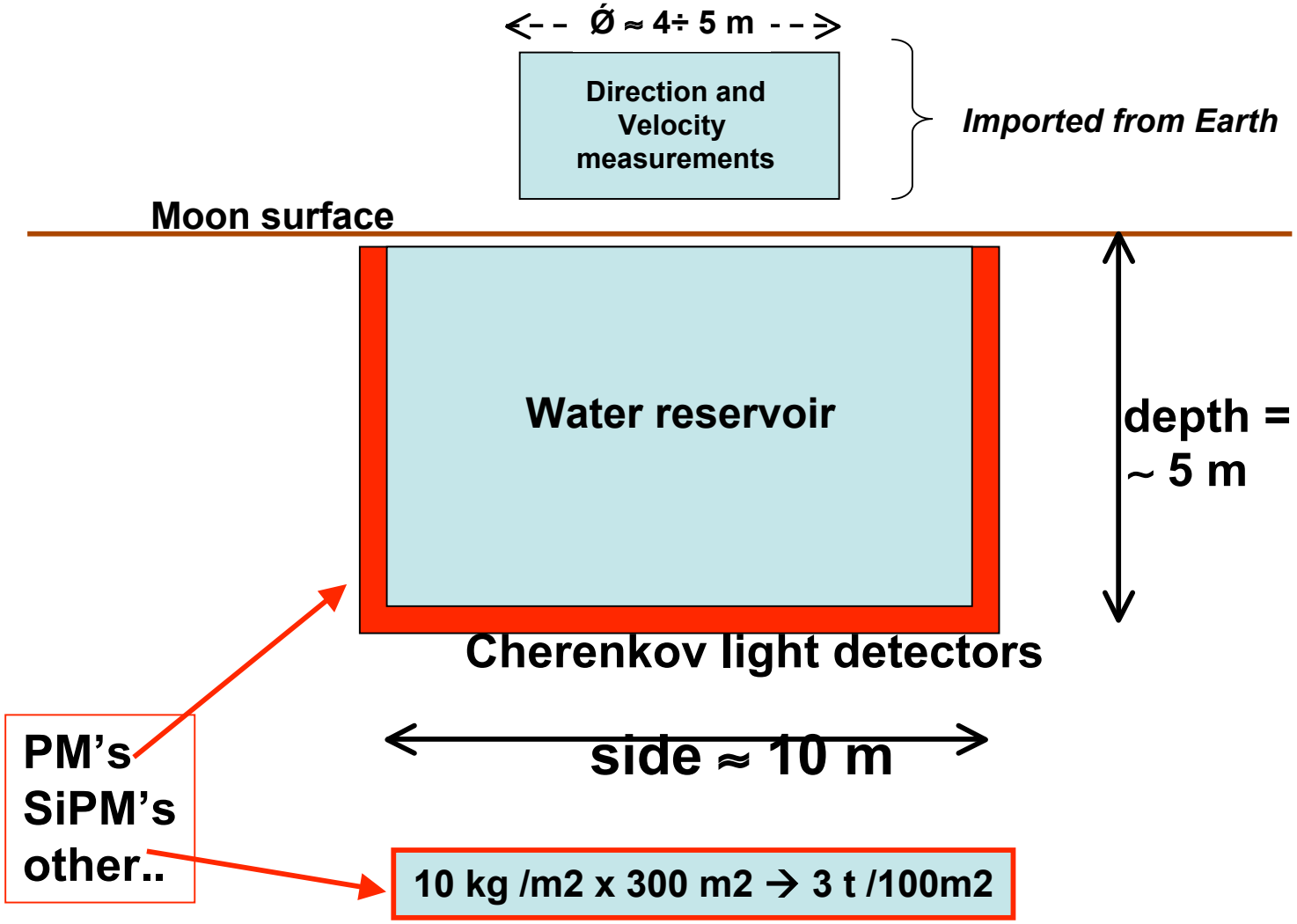
- Perequisite for the establishement of a permanently inhabited Moon base

- We now believe that water is present:
  1%÷10% concentration in the regolith in polar craters
  (H signature of the Clementine mission)

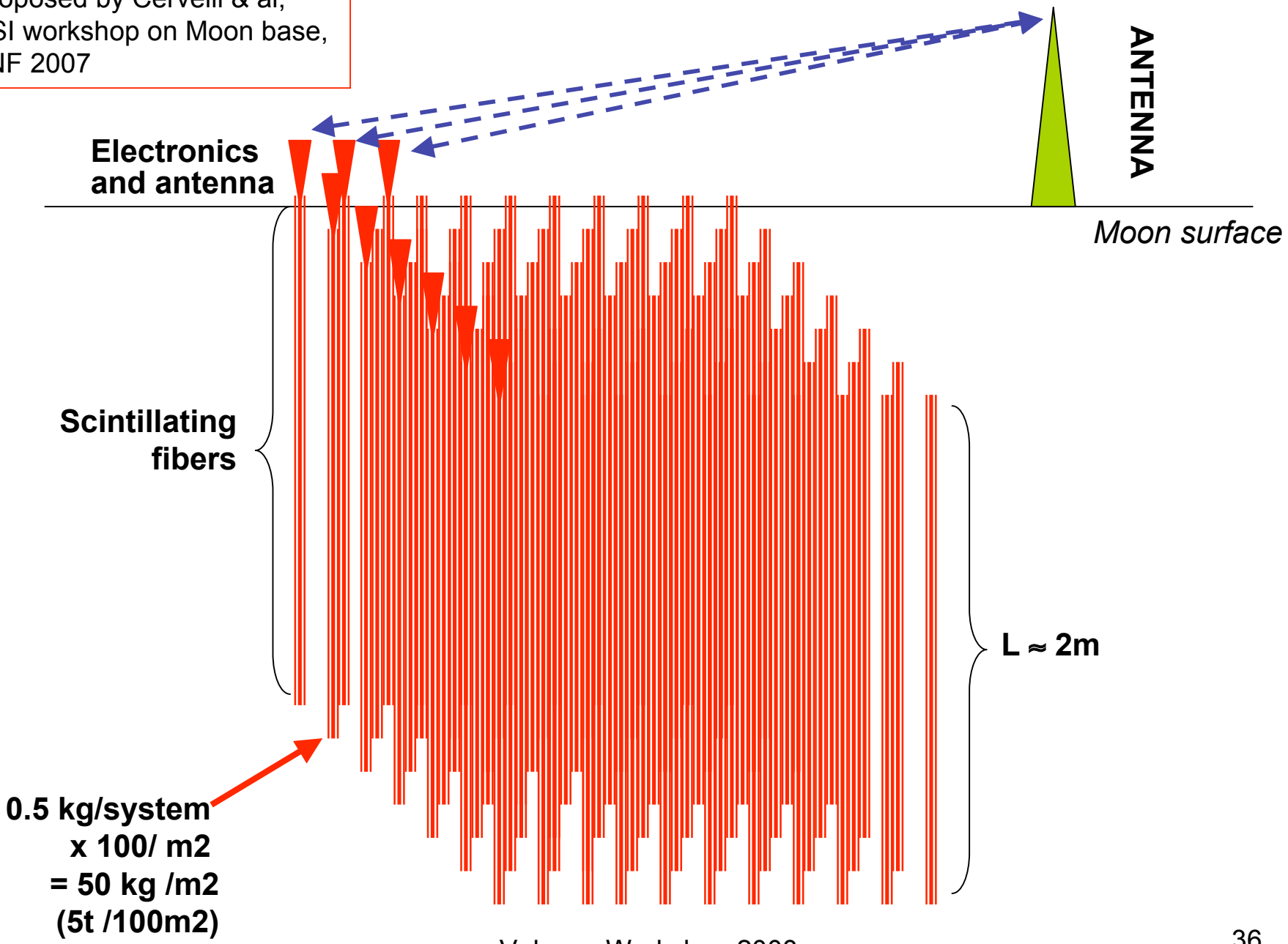
-extraction:
  - mechanically
  - thermodinamically

>200 t/year employing 120 kw
(Jamestwon Group LCC study, Feb. 2006, Heiss et al., June 2006)

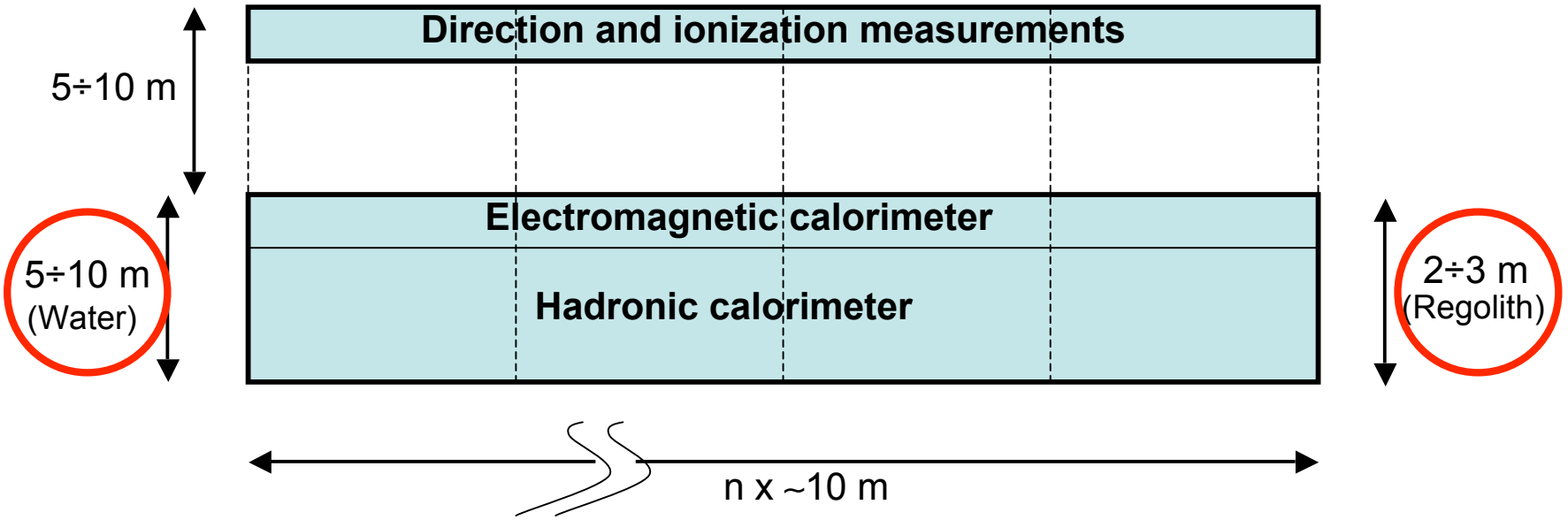
Lunar facility for HE gamma rays and HE Cosmic Rays (surface ~ 100m^2 /module)

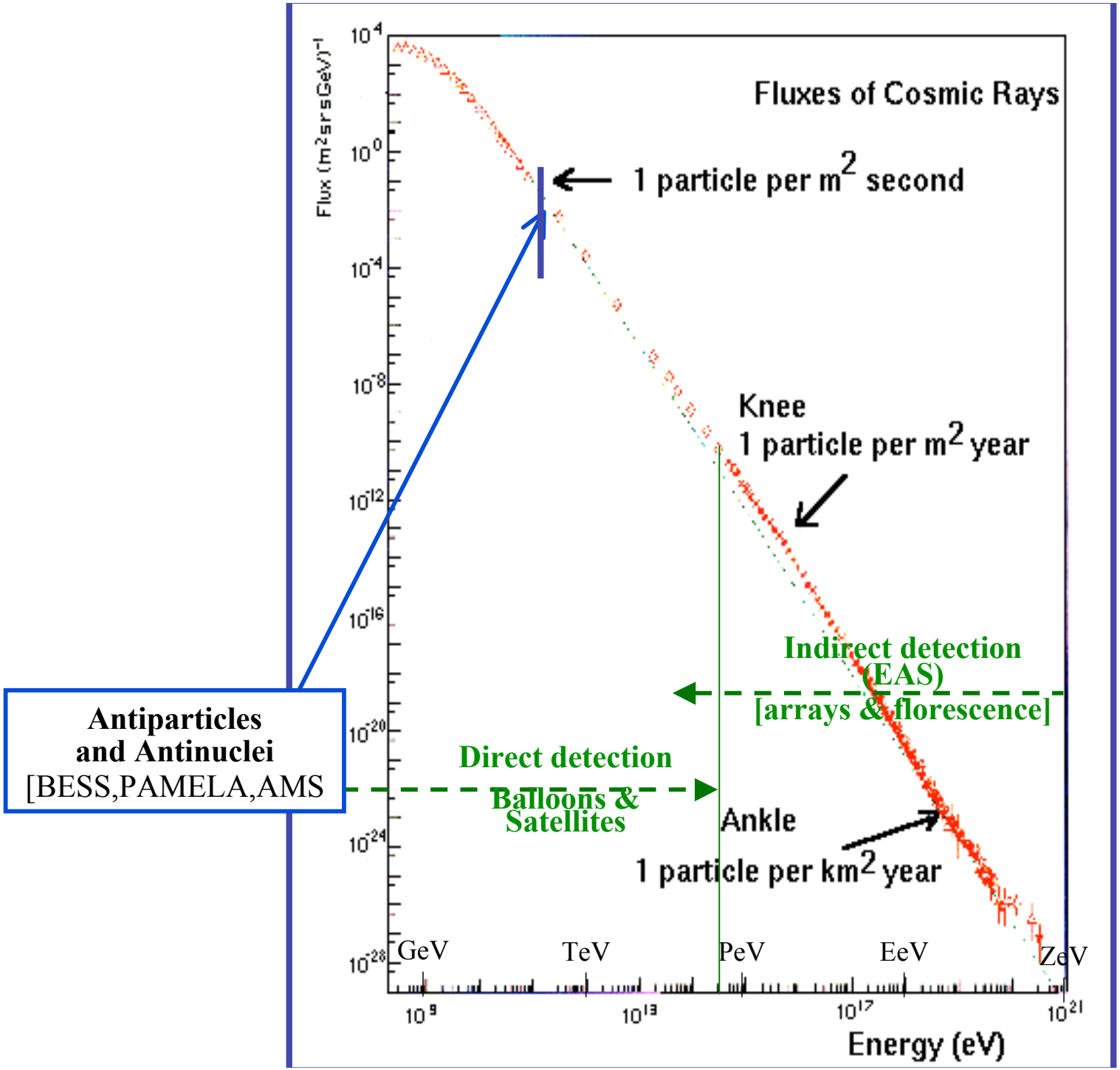


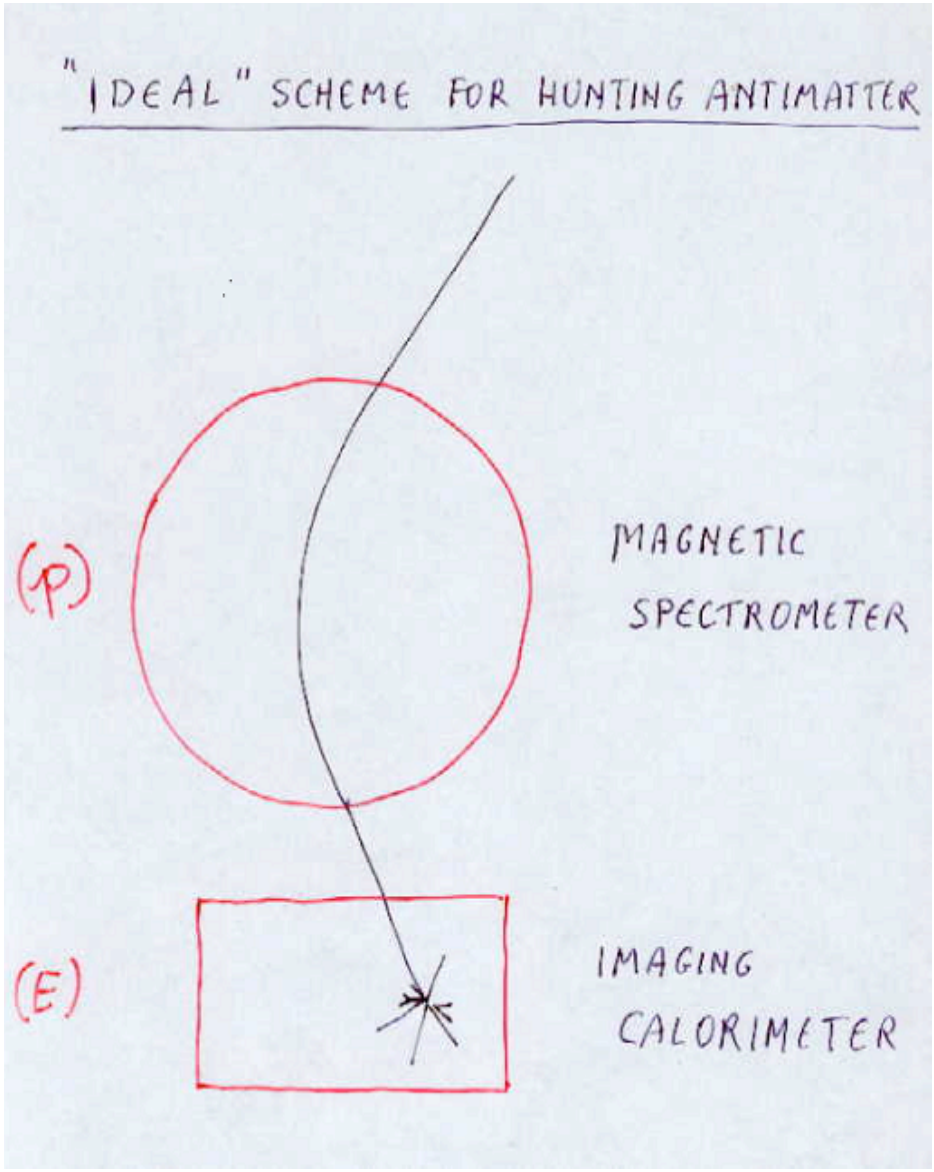
Proposed by Cervelli & al, ASI workshop on Moon base, LNF 2007

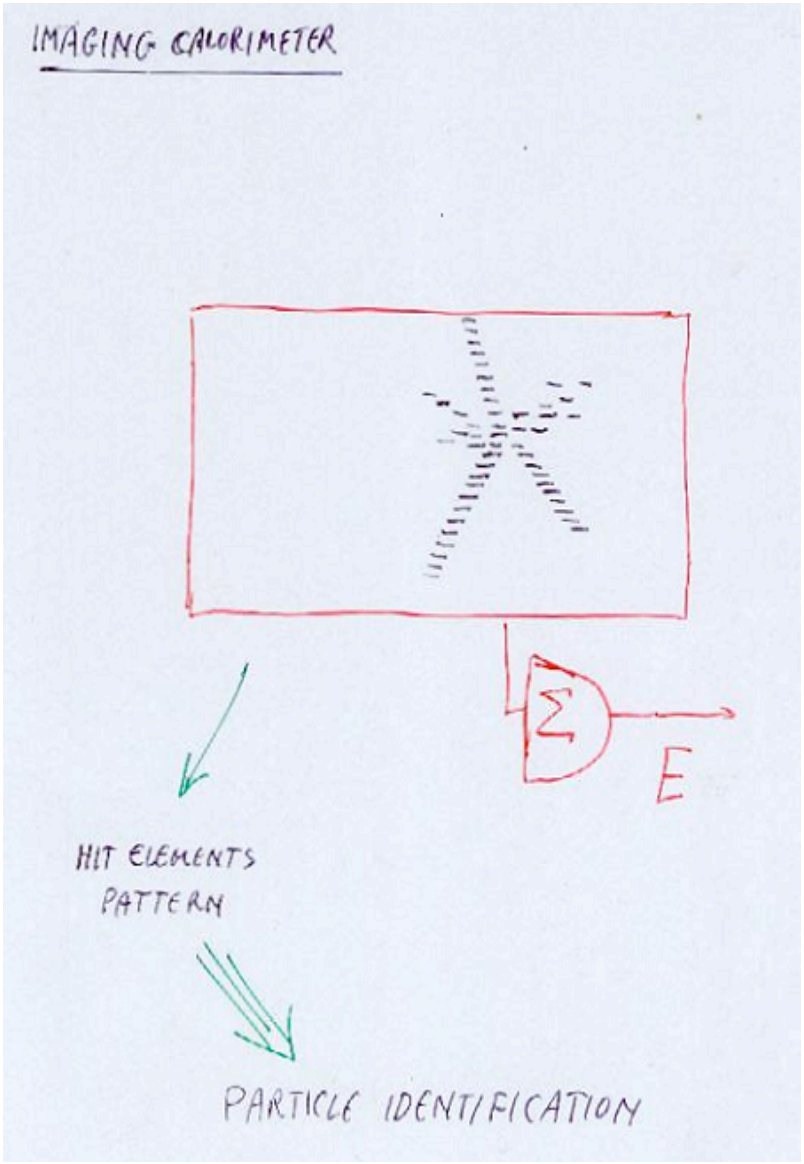


Lunar facility for HE gamma rays and HE Cosmic Rays (several ~100m^2 modules)



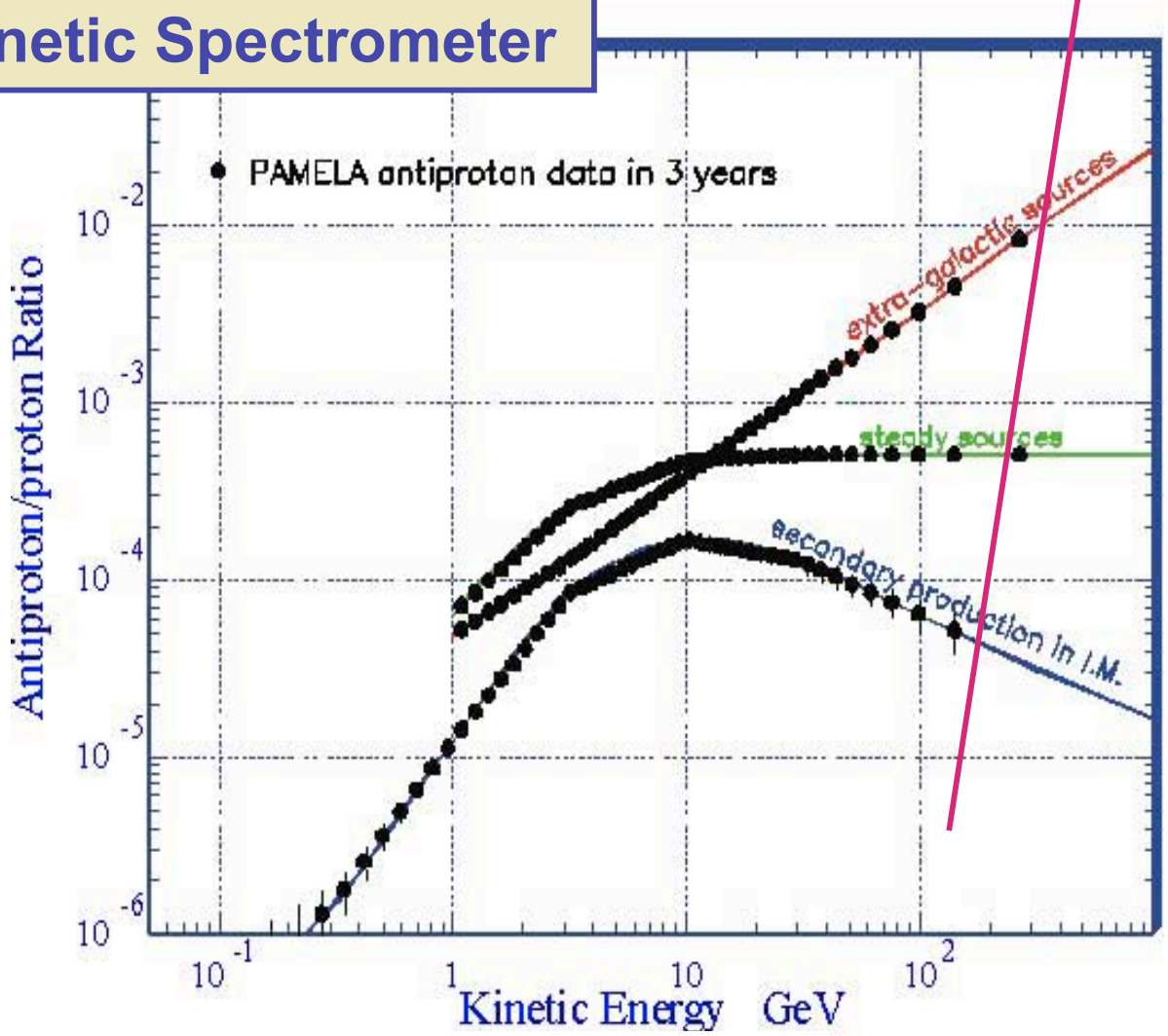

Fluxes of Cosmic Rays
Flux (m²sr s GeV)⁻¹
1 particle per m² second
Knee
1 particle per m² year
Ankle
1 particle per km² year
Indirect detection
(EAS)
[arrays & florescence]
Direct detection
Balloons &
Satellites
Antiparticles
and Antinuclei
[BESS,PAMELA,AMS
GeV
TeV
PeV
EeV
ZeV
Energy (eV)

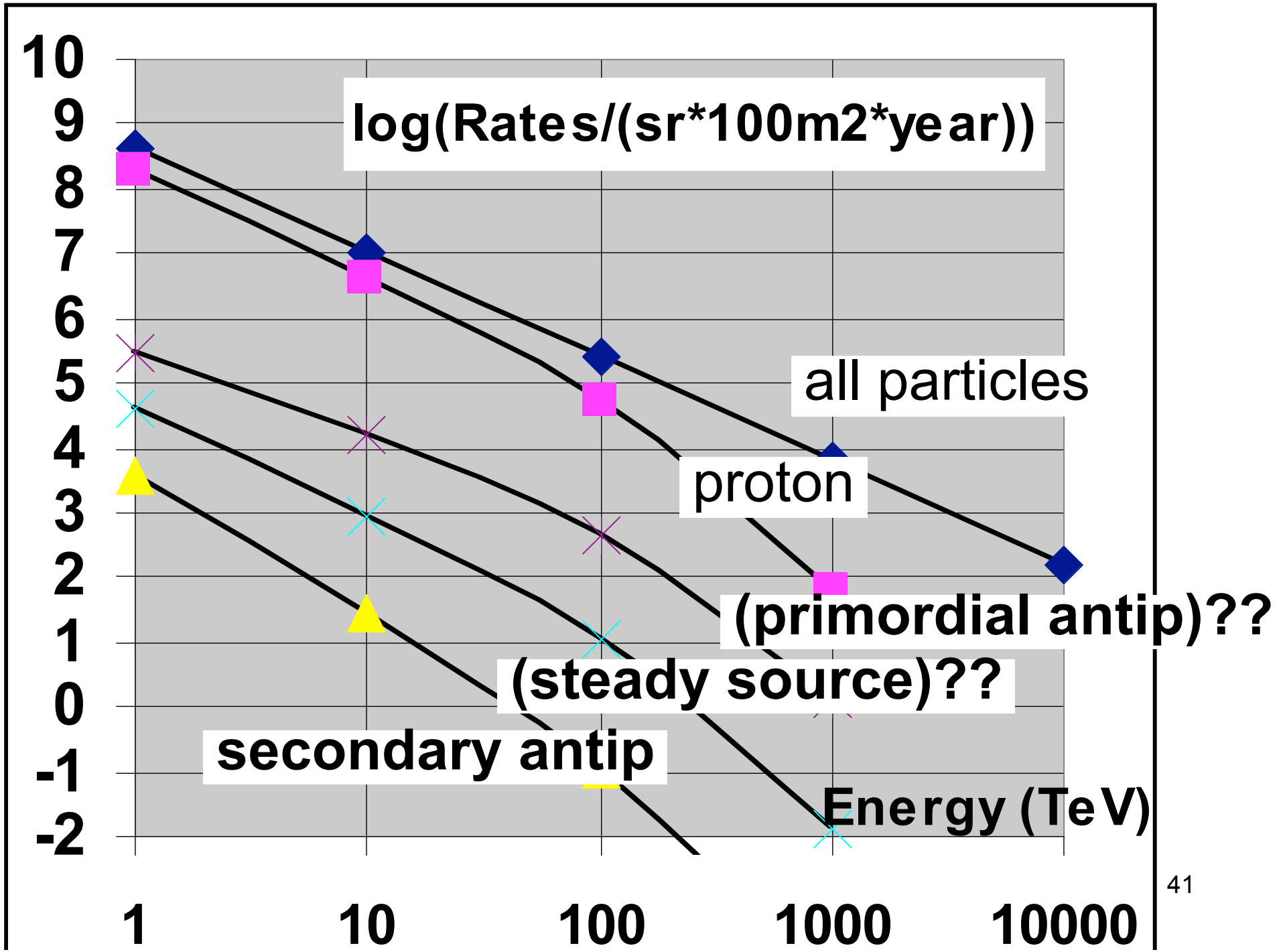

"IDEAL" SCHEME FOR HUNTING ANTIMATTER
(p)
MAGNETIC
SPECTROMETER
(E)
IMAGING
CALORIMETER

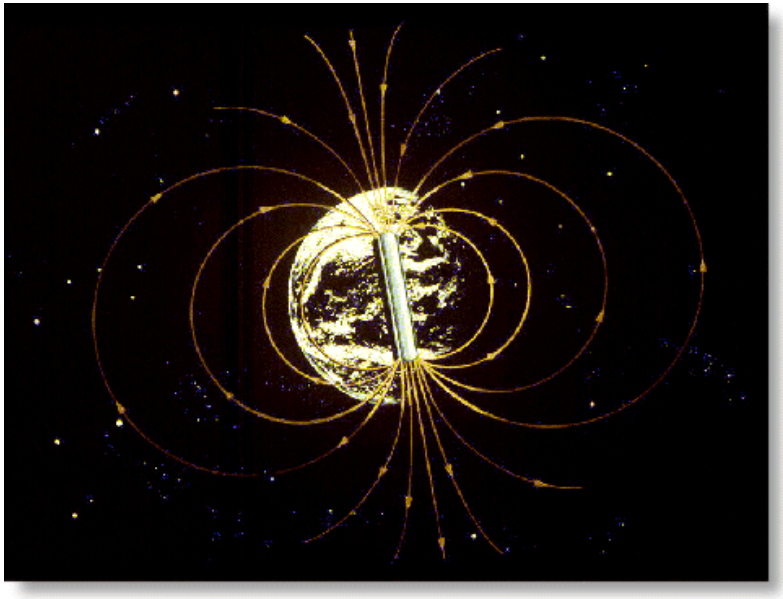

IMAGING CALORIMETER
Σ
E
HIT ELEMENTS
PATTERN
PARTICLE IDENTIFICATION

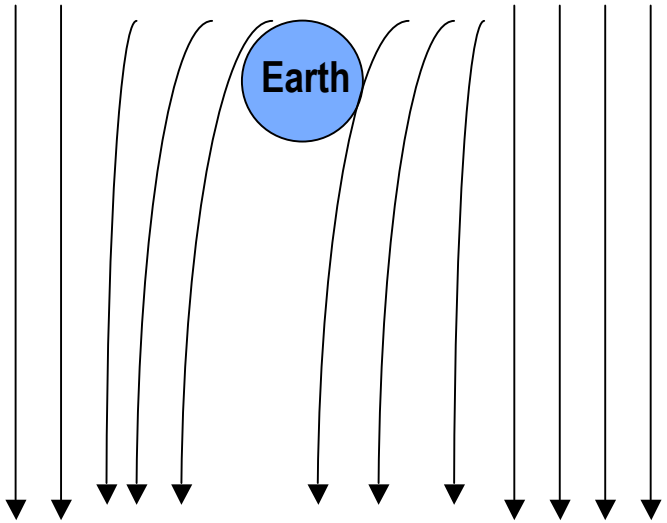
To go up in Energy needed to improve the precision of the Magnetic Spectrometer

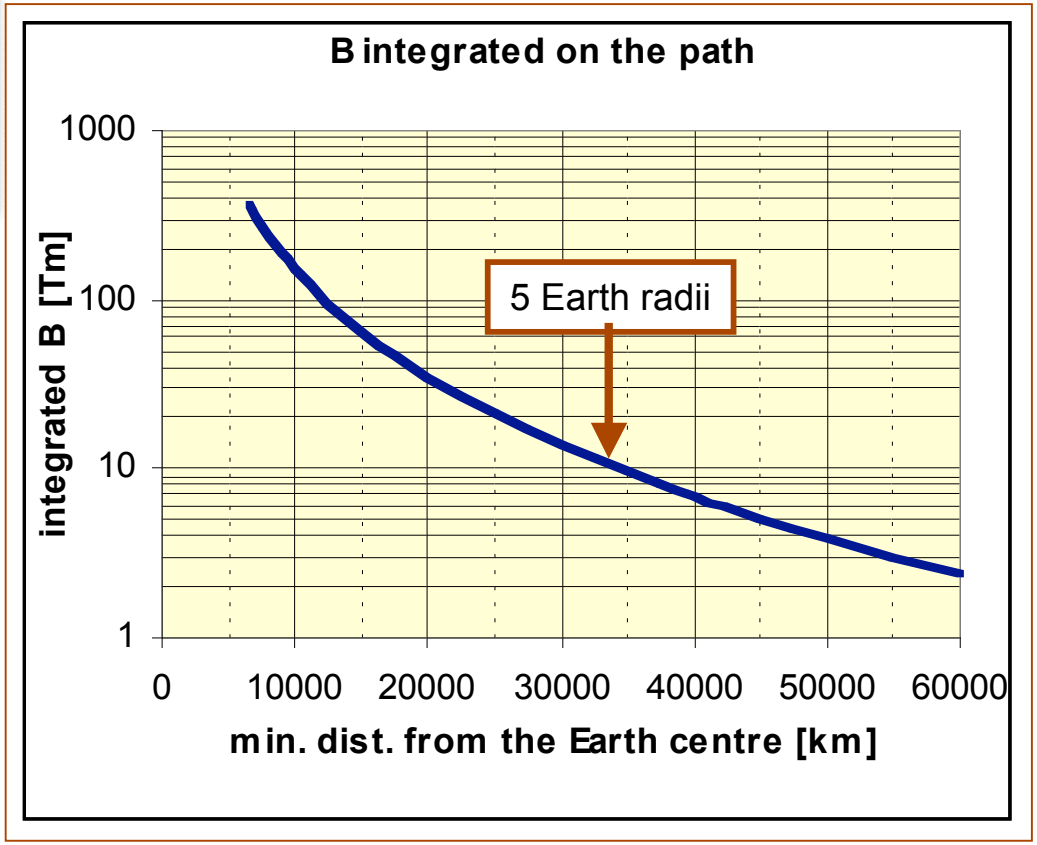
Spillover of p on antip = 0.2 of the antip flux

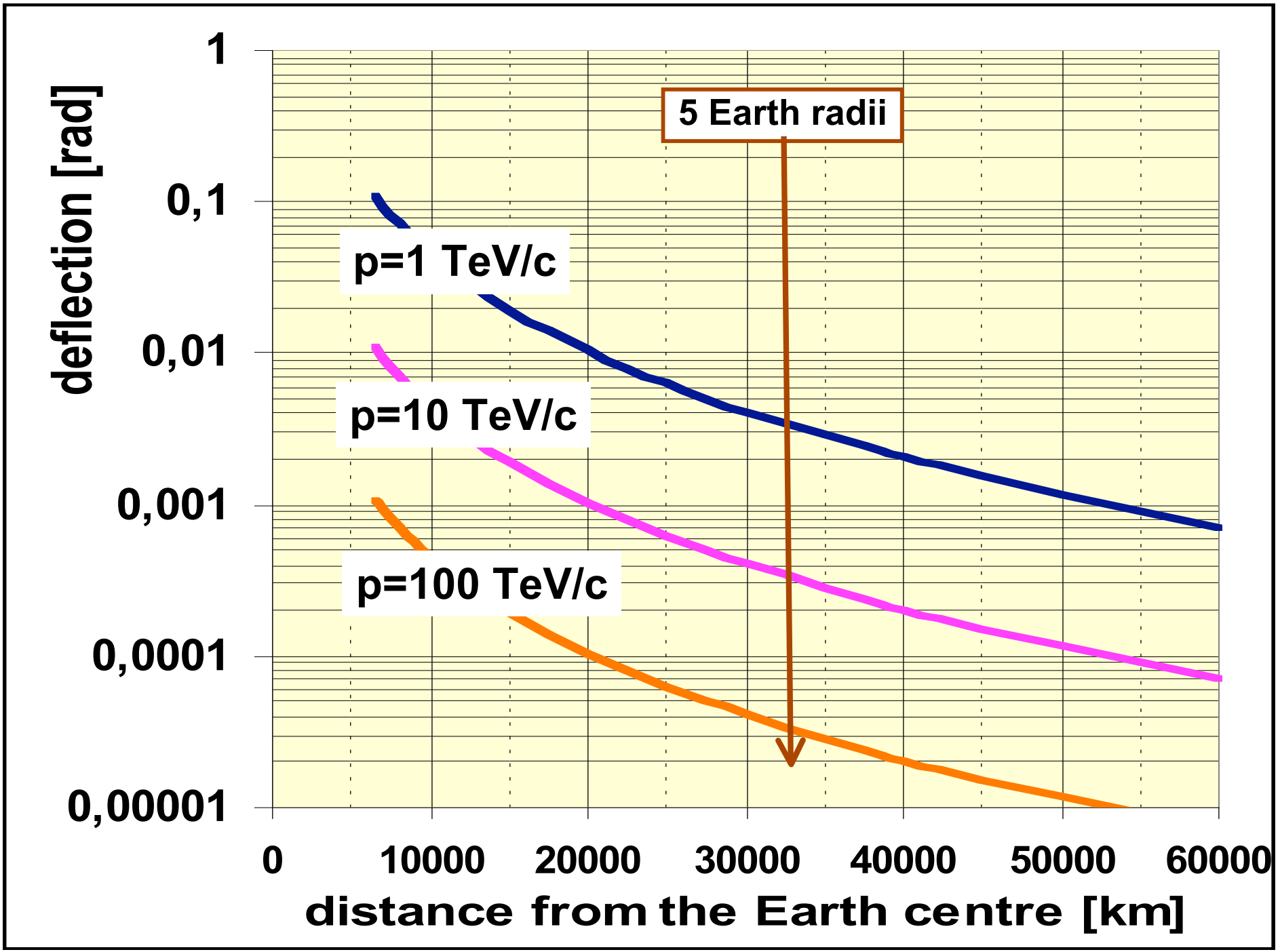


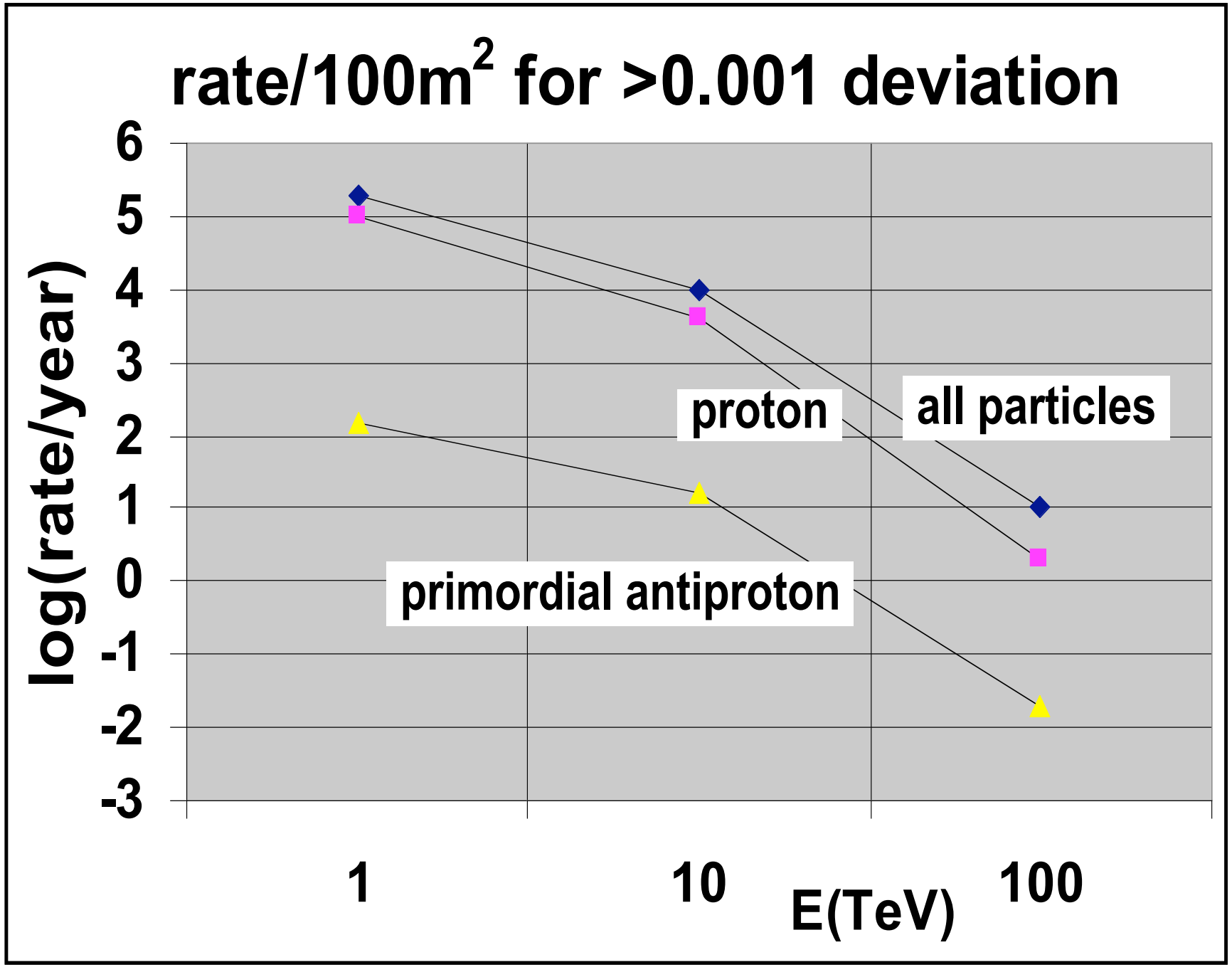

log(Rates/(sr*100m2*year))
all particles
proton
(primordial antip)??
(steady source)??
secondary antip
Energy (TeV)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
1
10
100
1000
10000

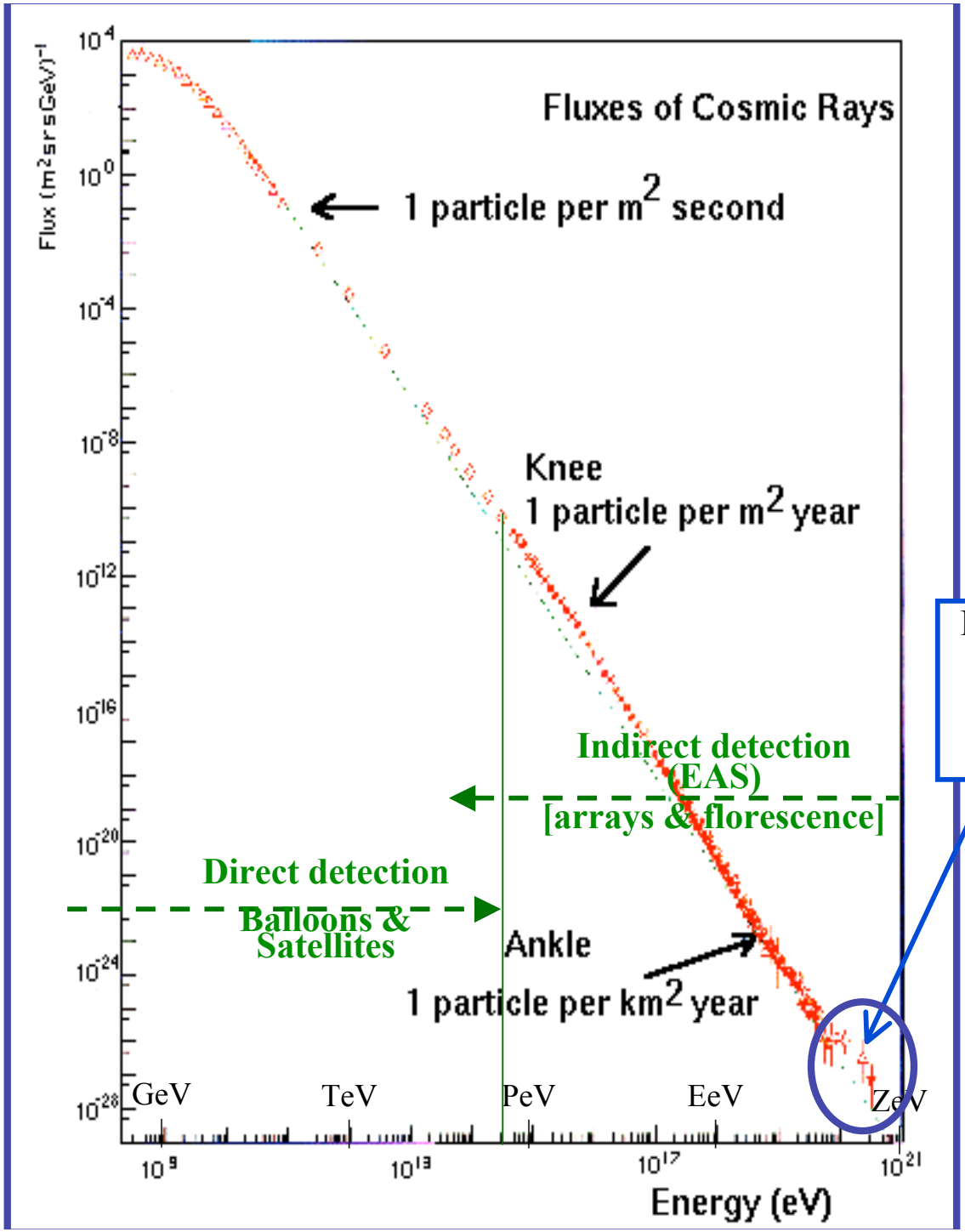



Earth


B integrated on the path
1000
100
10
1
integrated B [Tm]
5 Earth radii
0
10000
20000
30000
40000
50000
60000
min. dist. from the Earth centre [km]

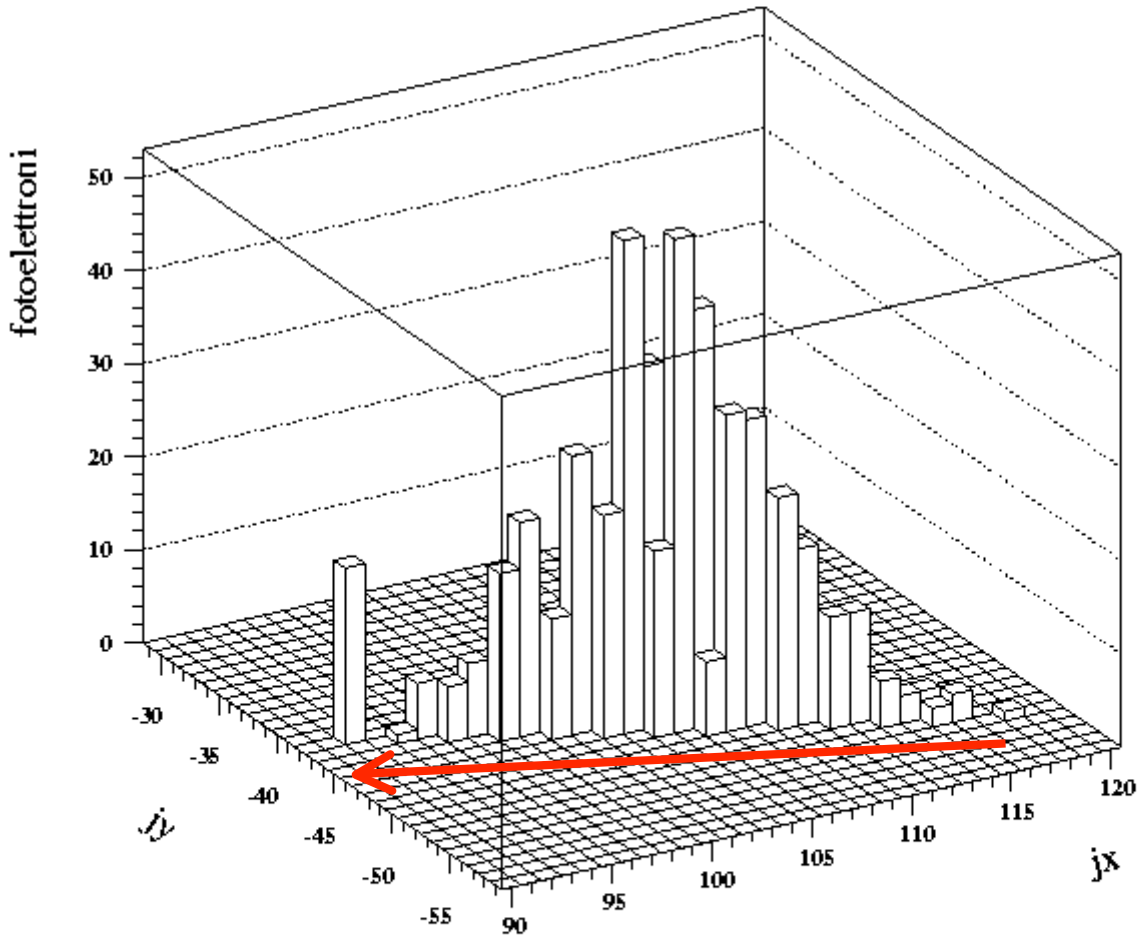

deflection [rad]
1
0,1
0,01
0,001
0,0001
0,00001
5 Earth radii
p=1 TeV/c
p=10 TeV/c
p=100 TeV/c
0
10000
20000
30000
40000
50000
60000
distance from the Earth centre [km]


rate/100m^2 for >0.001 deviation
log(rate/year)
6
5
4
3
2
1
0
-1
-2
-3
proton
all particles
primordial antiproton
1
10
100
E(TeV)

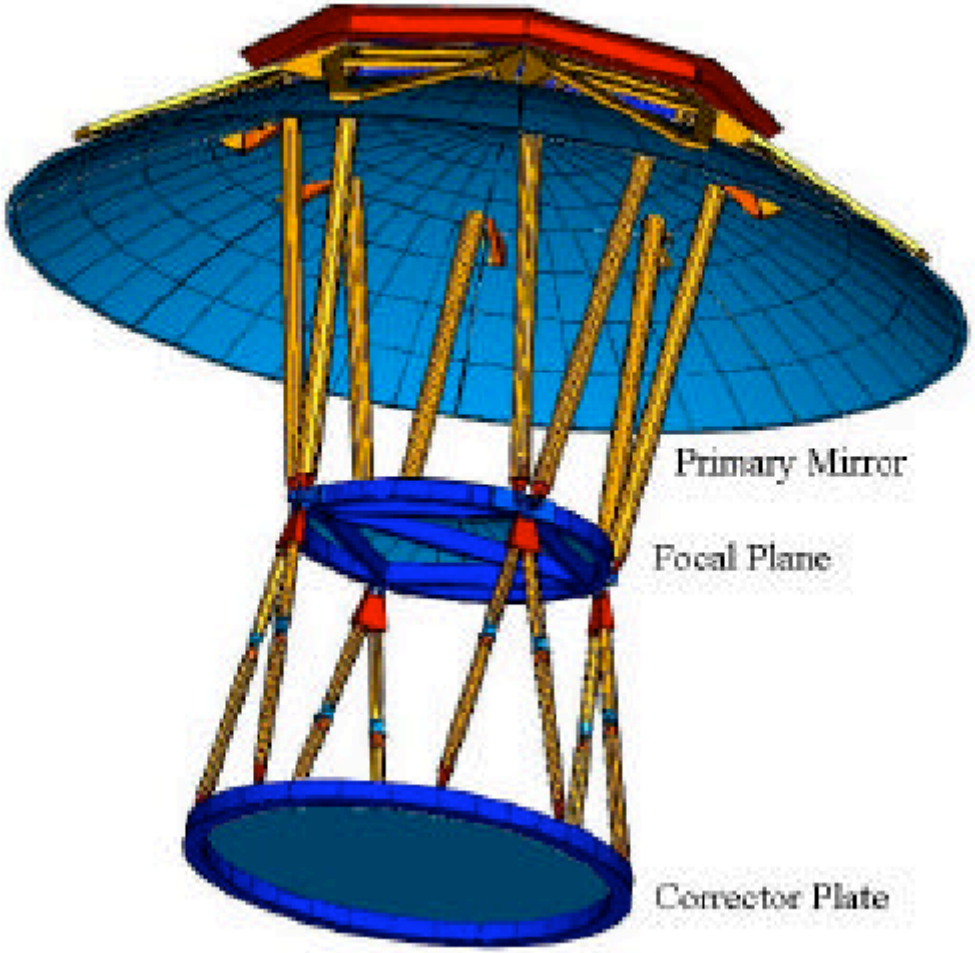


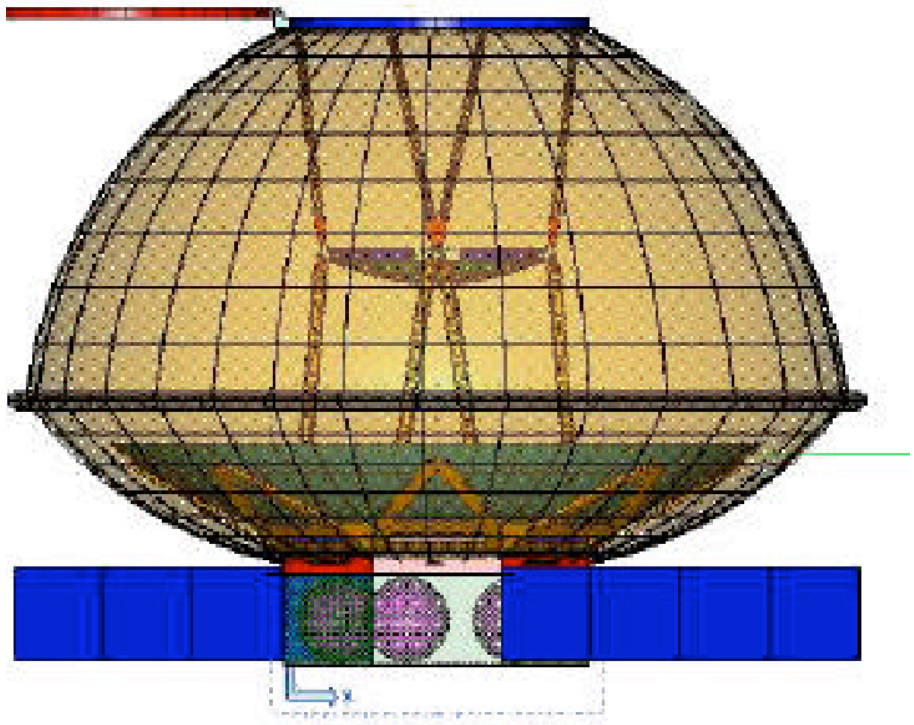
Extreme Energy CR

[AUGER, EUSO, TUS, KLYPVE?, OWL??]

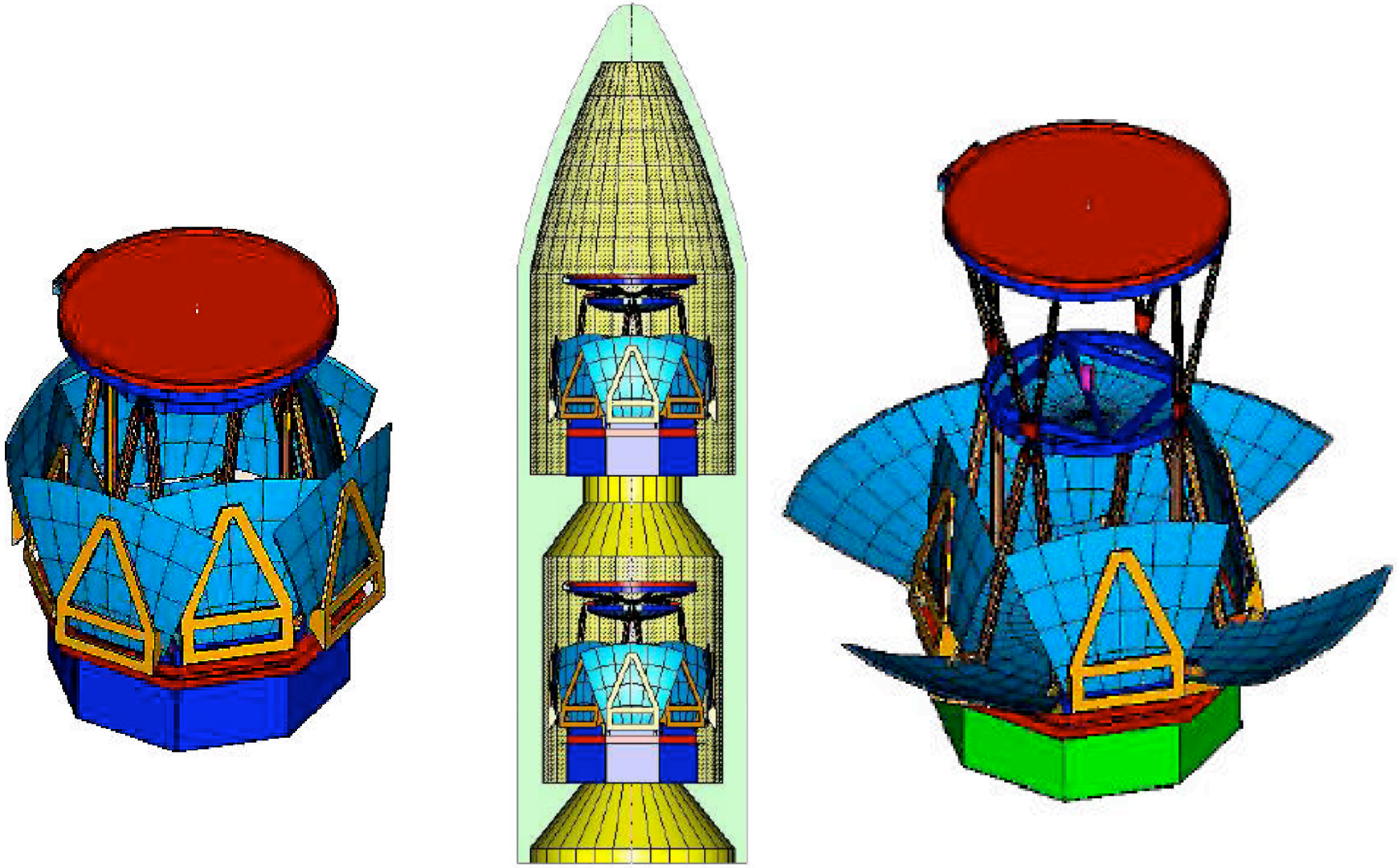

fotoelettroni
50
40
30
20
10
0
-30
-35
-40
-45
-50
-55
jy
90
95
100
105
110
115
120
jx

A proposal from NASA: OWL





Deployment of OWL from a Delta 4050-H-19

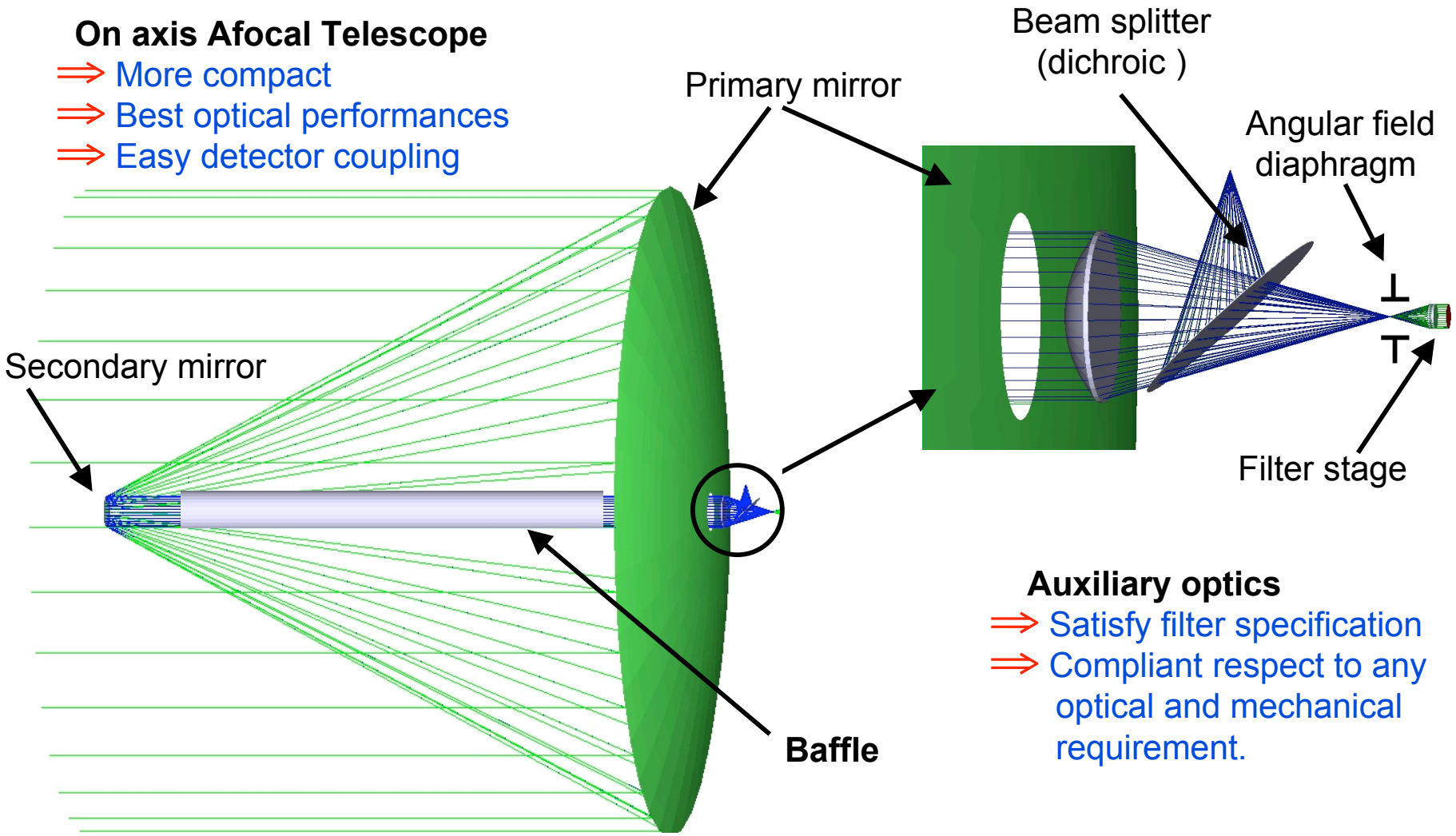


Moon Base: candidate optical configurations

INOA

On axis Afocal Telescope

⇒ More compact
⇒ Best optical performances
⇒ Easy detector coupling



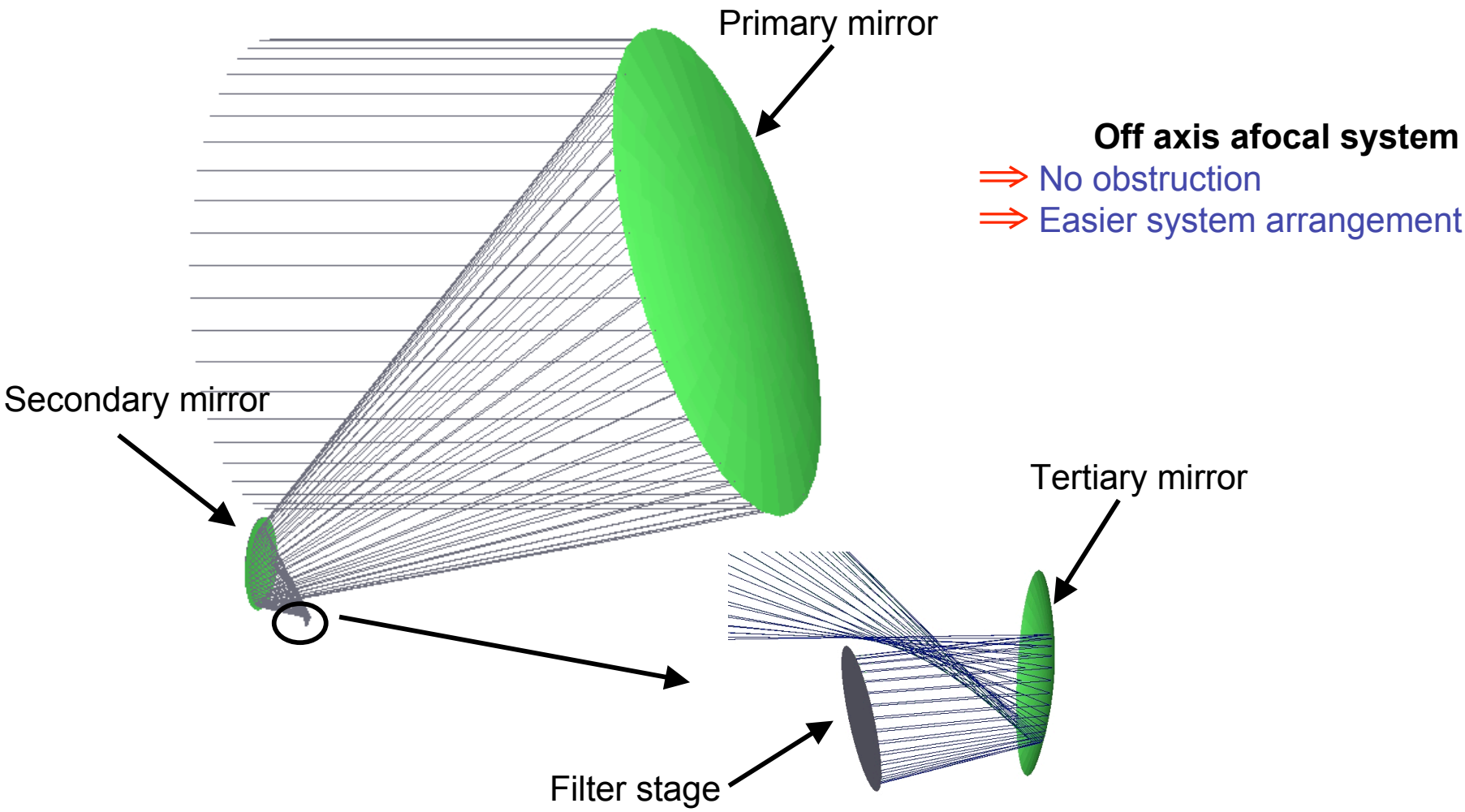
Auxiliary optics

⇒ Satisfy filter specification
⇒ Compliant respect to any optical and mechanical requirement.

Mechanical tolerances **Can be solved with active control of mirror surface**

Moon Base: candidate optical configurations

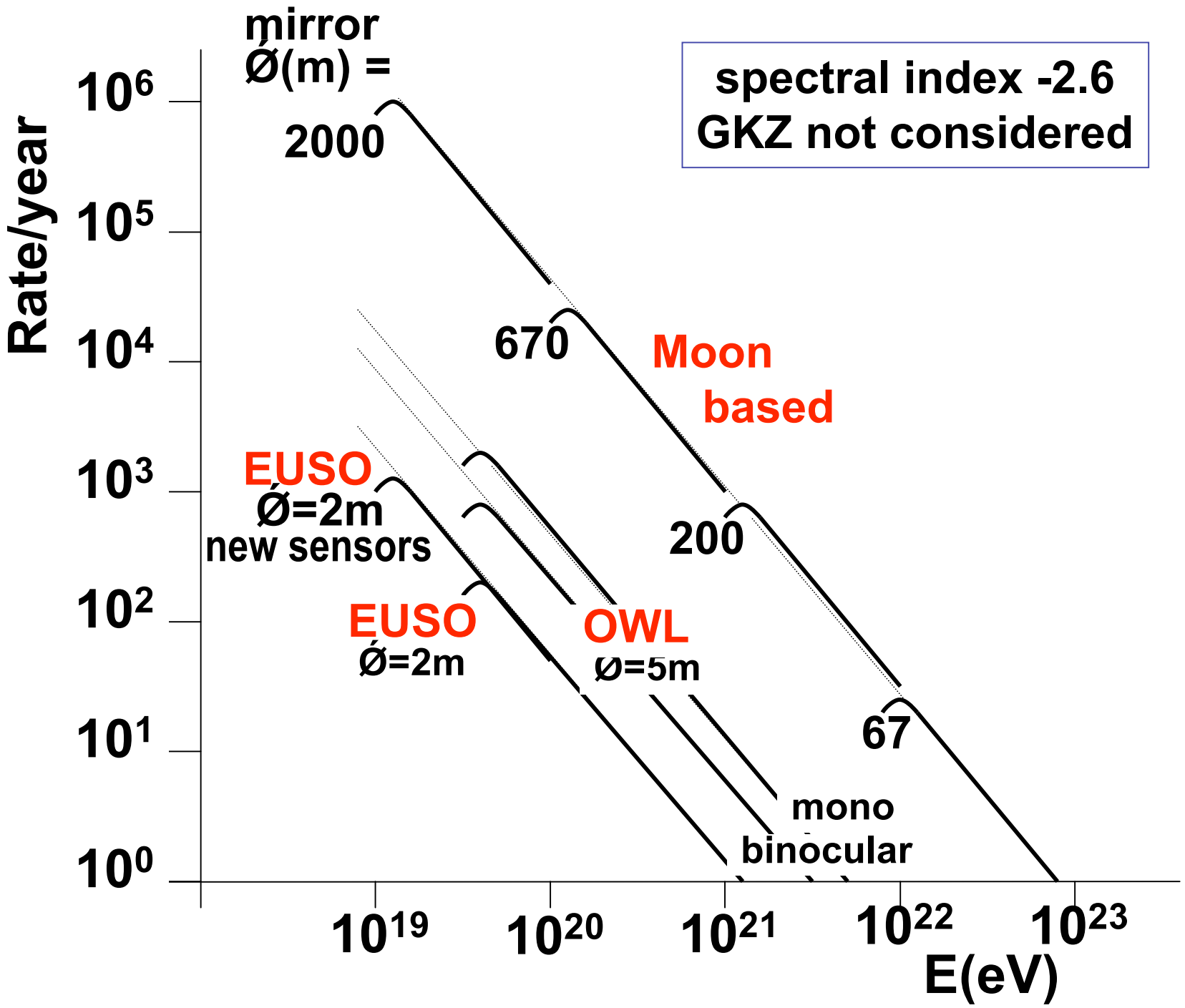
INOA



Off axis afocal system

⇒ No obstruction

⇒ Easier system arrangement


mirror
Ø(m) =
2000
670
200
67
Moon
based
EUSO
Ø=2m
new sensors
EUSO
Ø=2m
OWL
ø=5m
mono
binocular
spectral index -2.6
GKZ not considered
Rate/year
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^19
10^20
10^21
10^22
10^23
E(eV)

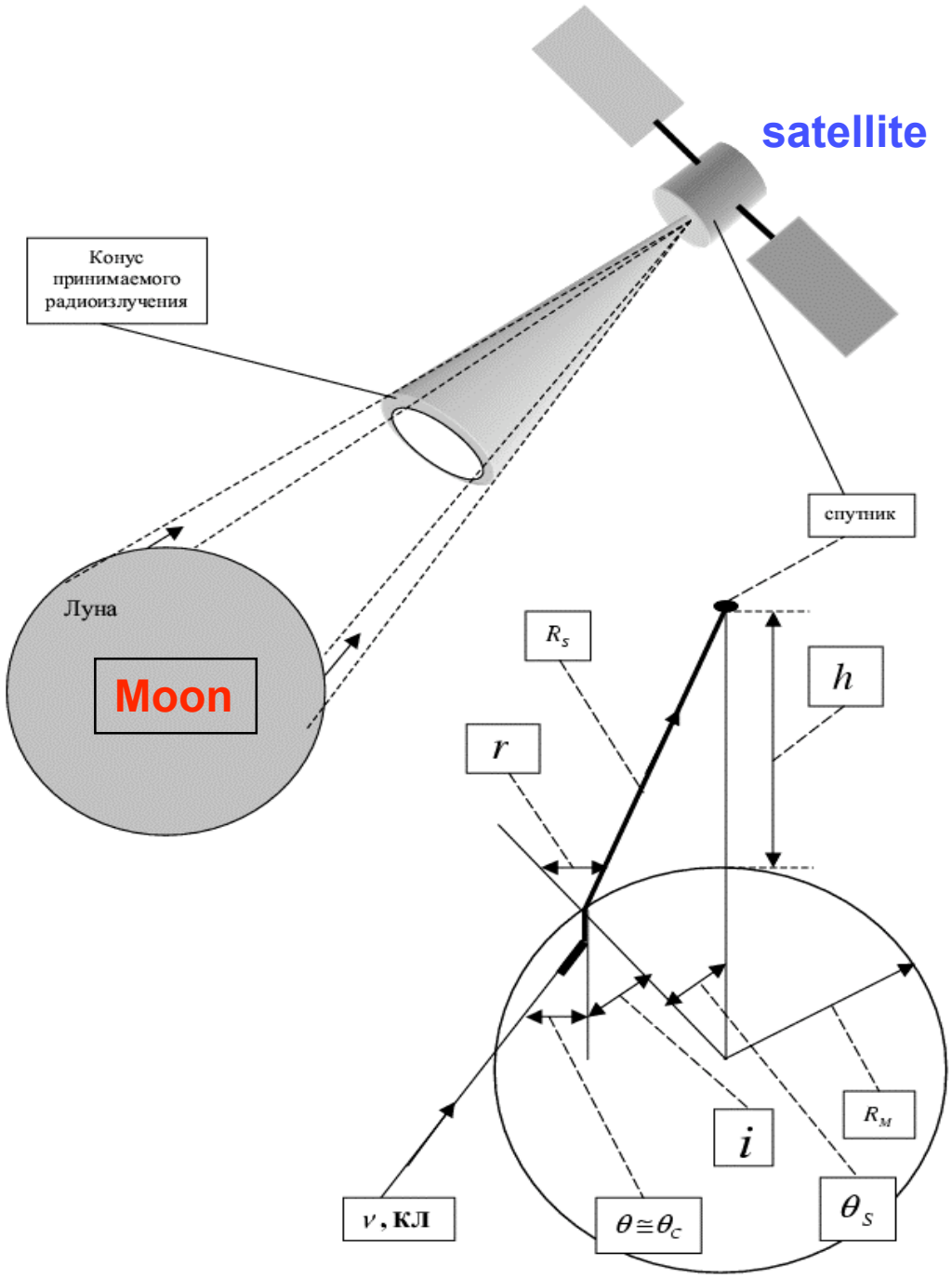
Geometry

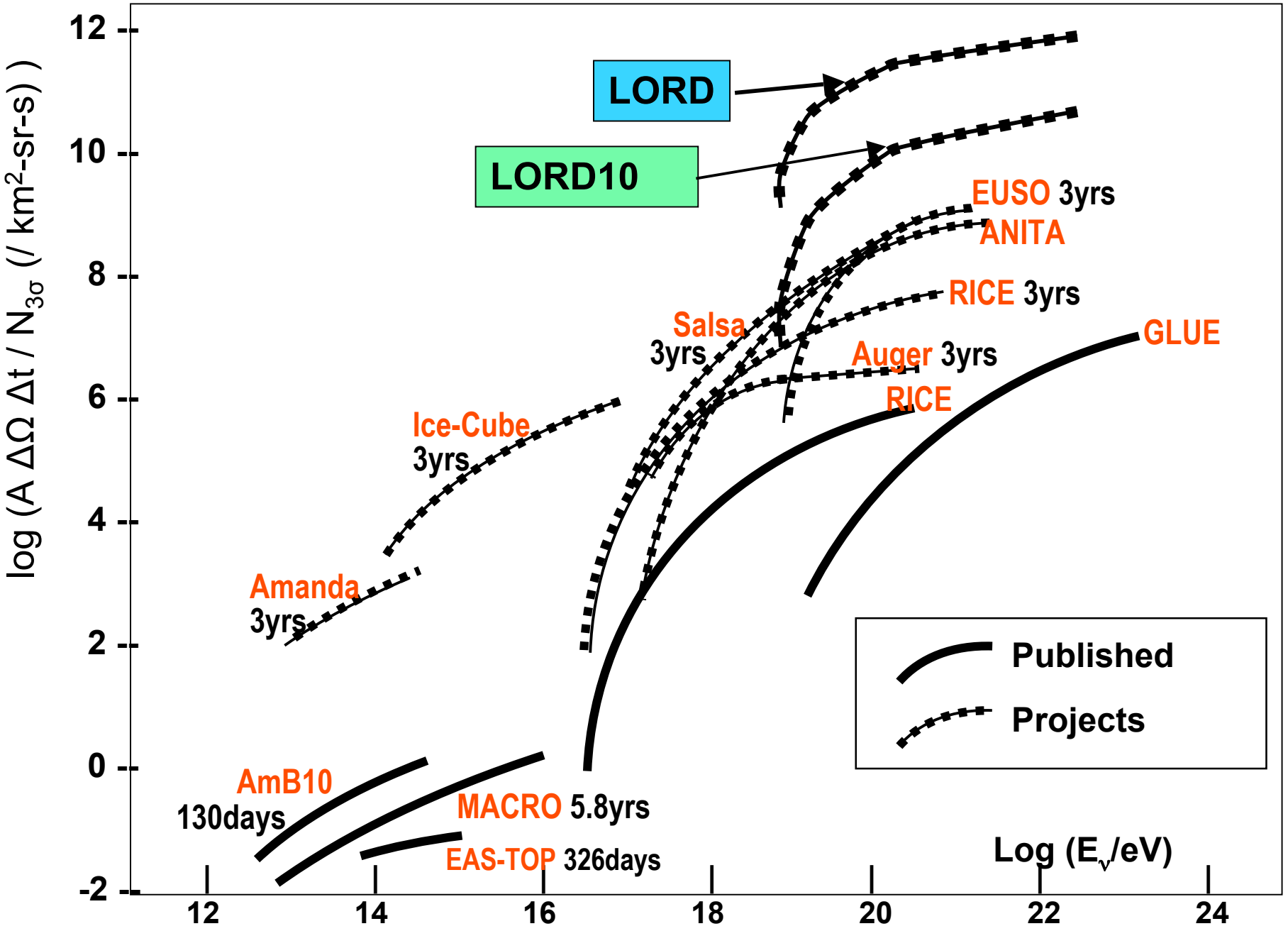
of the LORD

experiment

h: from a few tens to a few thousands of km

R_m ~ 1740 km

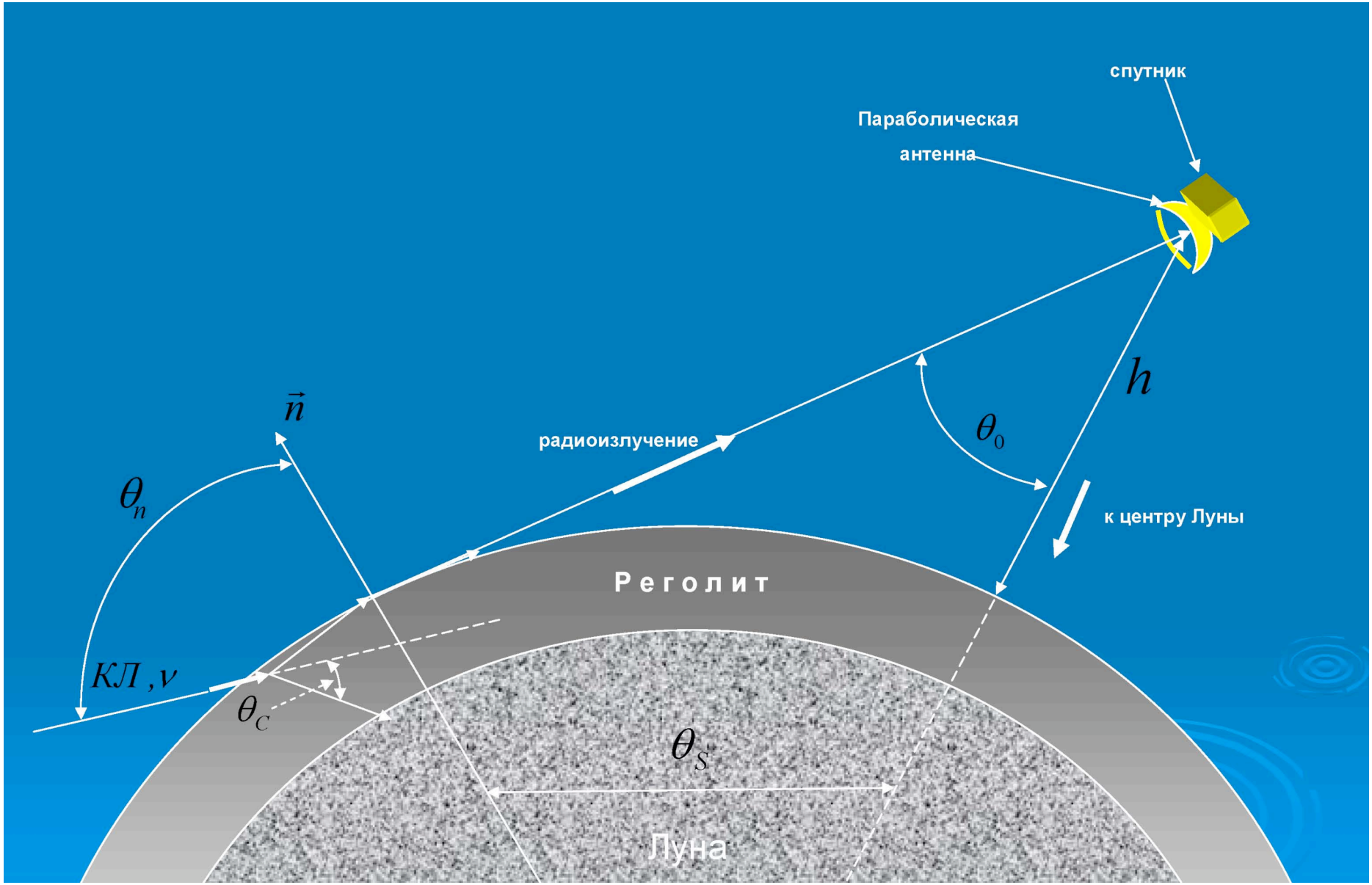


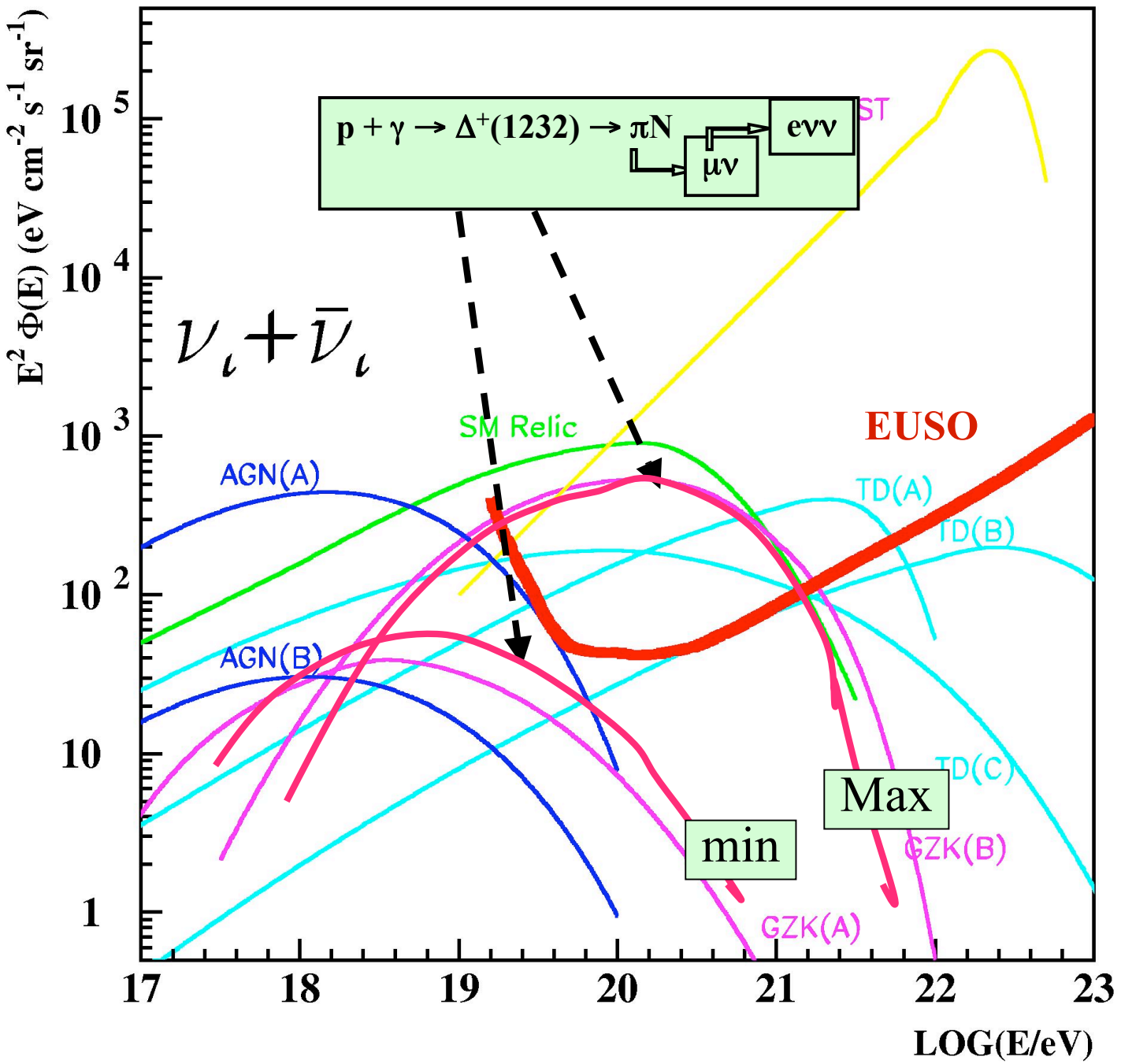

log (A ΔΩ Δt / N3σ (/ km2-sr-s))
12
10
8
6
4
2
0
-2
12
14
16
18
20
22
24
Log (Eν/eV)
LORD
LORD10
EUSO 3yrs
ANITA
RICE 3yrs
Salsa
3yrs
Auger 3yrs
RICE
GLUE
Ice-Cube
3yrs
Amanda
3yrs
AmB10
130days
MACRO 5.8yrs
EAS-TOP 326days
Published
Projects

A new actor on the scene of CR from space?

neutrino

new instrument for
Astrophysics,
Cosmology,
Particle Physics

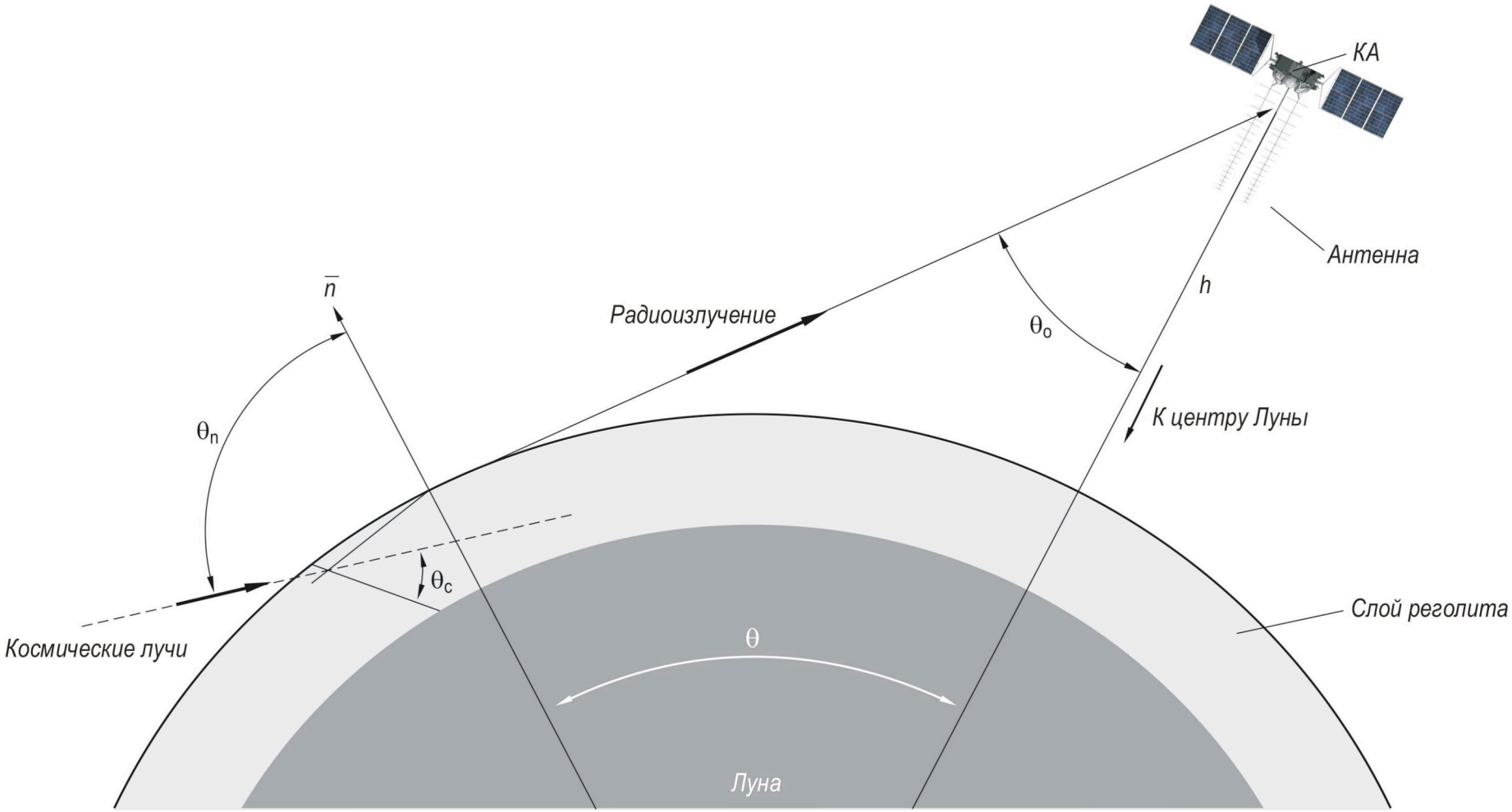

спутник
Параболическая
антенна
$\vec{n}$
радиоизлучение
θ_0
h
θ_n
к центру Луны
Реголит
$КЛ, \nu$
θ_C
θ_S
Луна

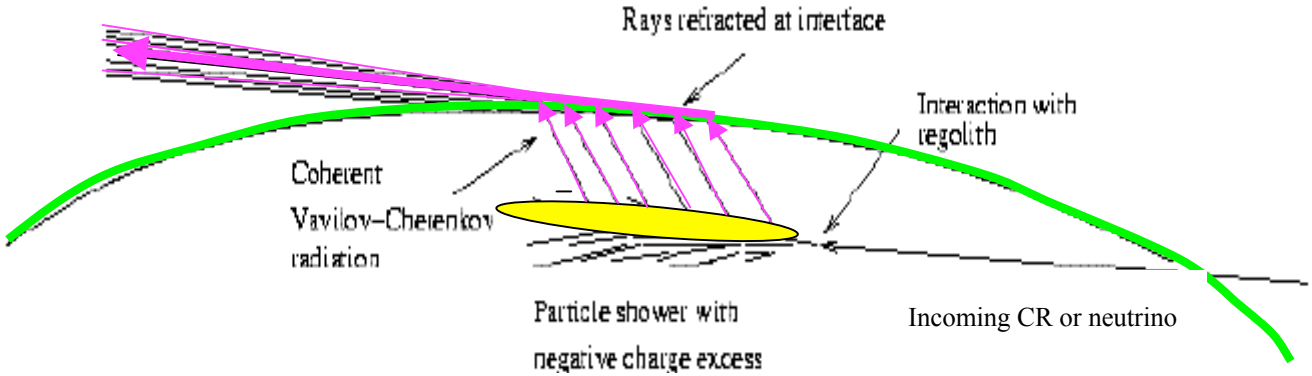

$E^2\,\Phi(E)$ (eV cm^{-2} s^{-1} sr^{-1})
10^5
10^4
10^3
10^2
10
1
17
18
19
20
21
22
23
LOG(E/eV)
$p + \gamma \rightarrow \Delta^+(1232) \rightarrow \pi N$
$e\nu\nu$
$\mu\nu$
ST
$\nu_i + \bar{\nu}_i$
SM Relic
EUSO
AGN(A)
AGN(B)
TD(A)
TD(B)
TD(C)
Max
min
GZK(B)
GZK(A)

Huge target mass $V_{eff} \sim 10^5$ (km.w.e.)^3

Lunar satellite:

- **Very favorable background conditions**
- **Short (and variable) distance – high signal**


КА
Антенна
h
$\bar{n}$
Радиоизлучение
θ_o
К центру Луны
θ_n
θ_c
Космические лучи
Слой реголита
θ
Луна


Rays refracted at interface
Interaction with regolith
Coherent Vavilov–Cherenkov radiation
Particle shower with negative charge excess
Incoming CR or neutrino

ЛУННЫЙ ОРБИТАЛЬНЫЙ РАДИО ДЕТЕКТОР

в рамках программы ЛУНА-ГЛОБ

V.Tsarev, e-mail
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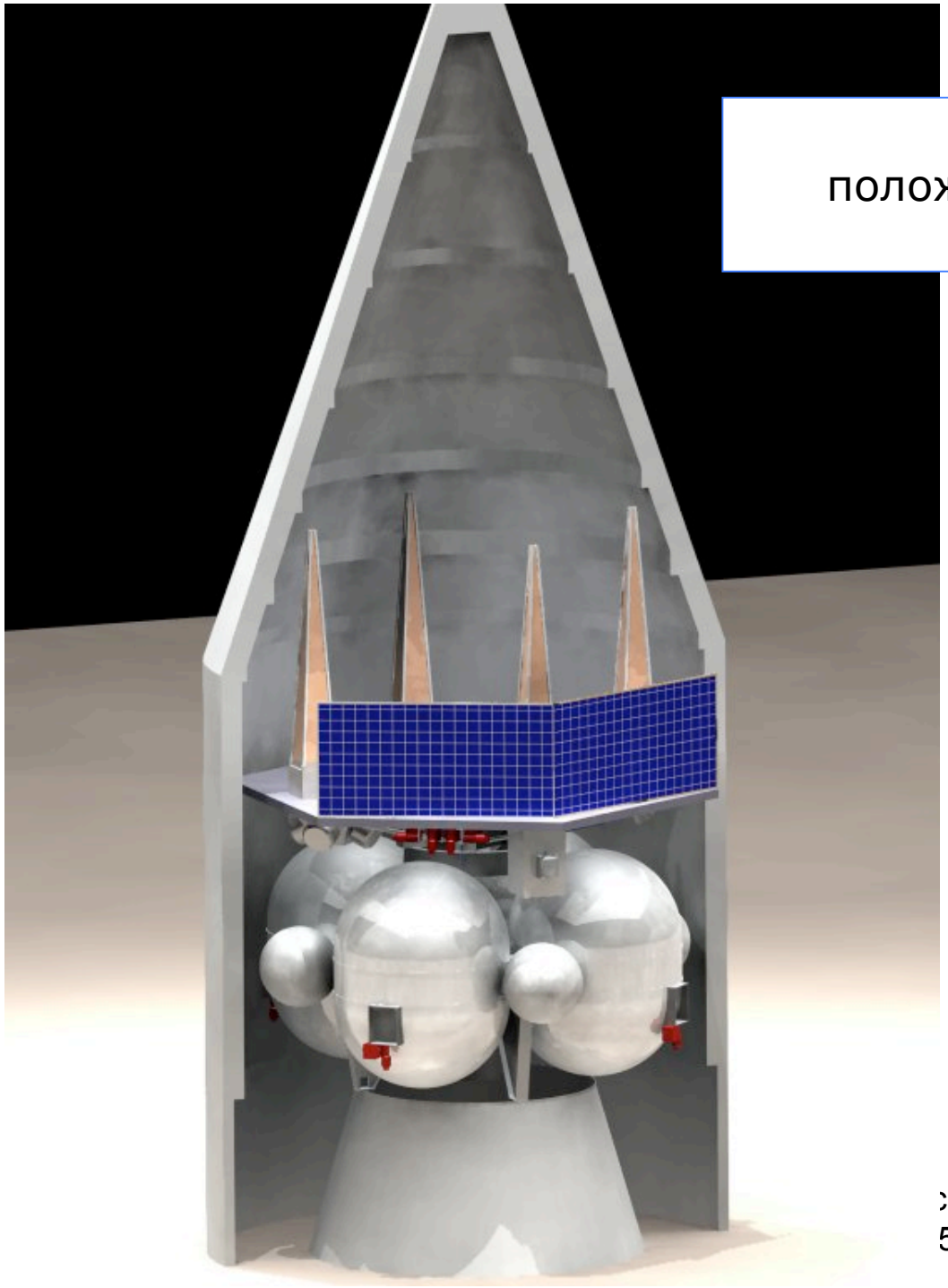
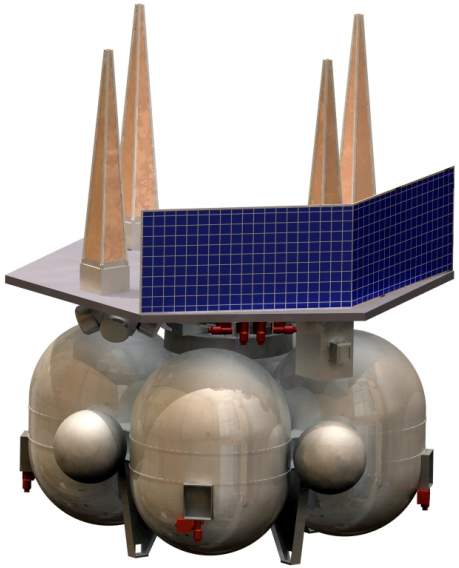
Россия: ФИАН, НПО им. Лавочкина, НИИЯФ МГУ,

Швеция (ISP), США, Голландия, Индия

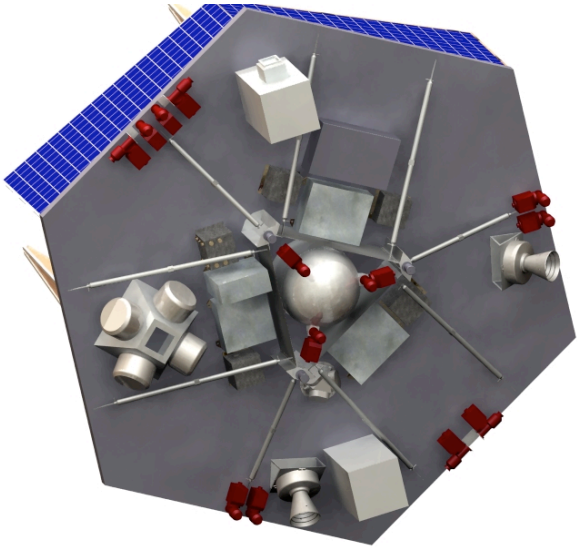


КА в транспортном положении под обтекателем РН «Космос-3М»

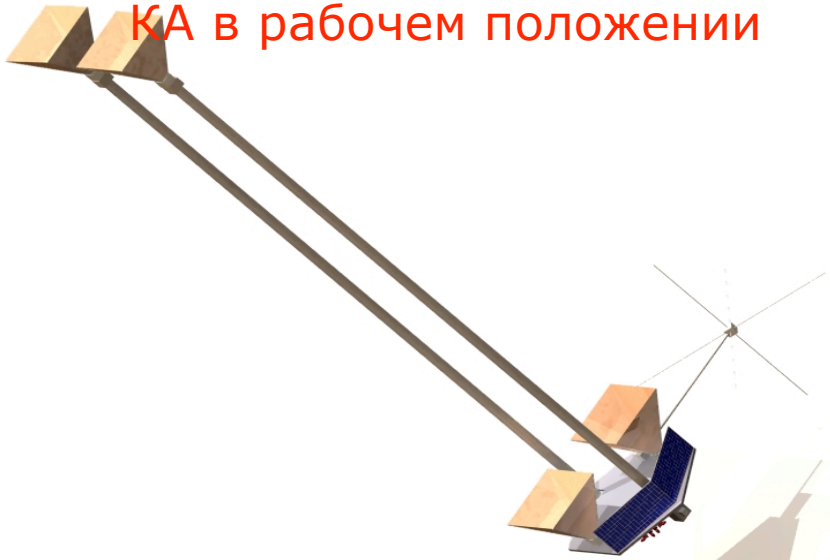
КА в транспортном положении с разгонным блоком



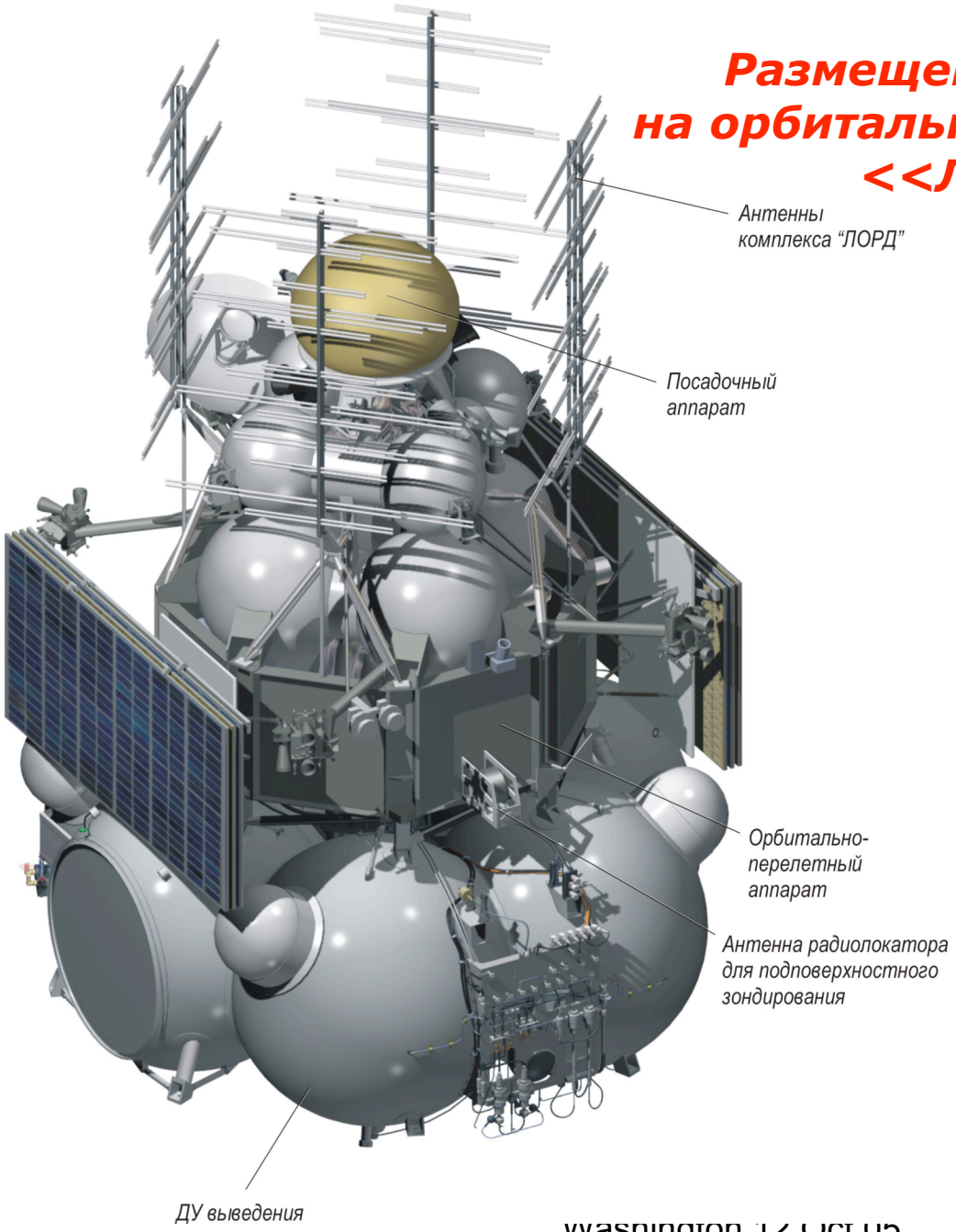
КА в транспортном положении (вид снизу)

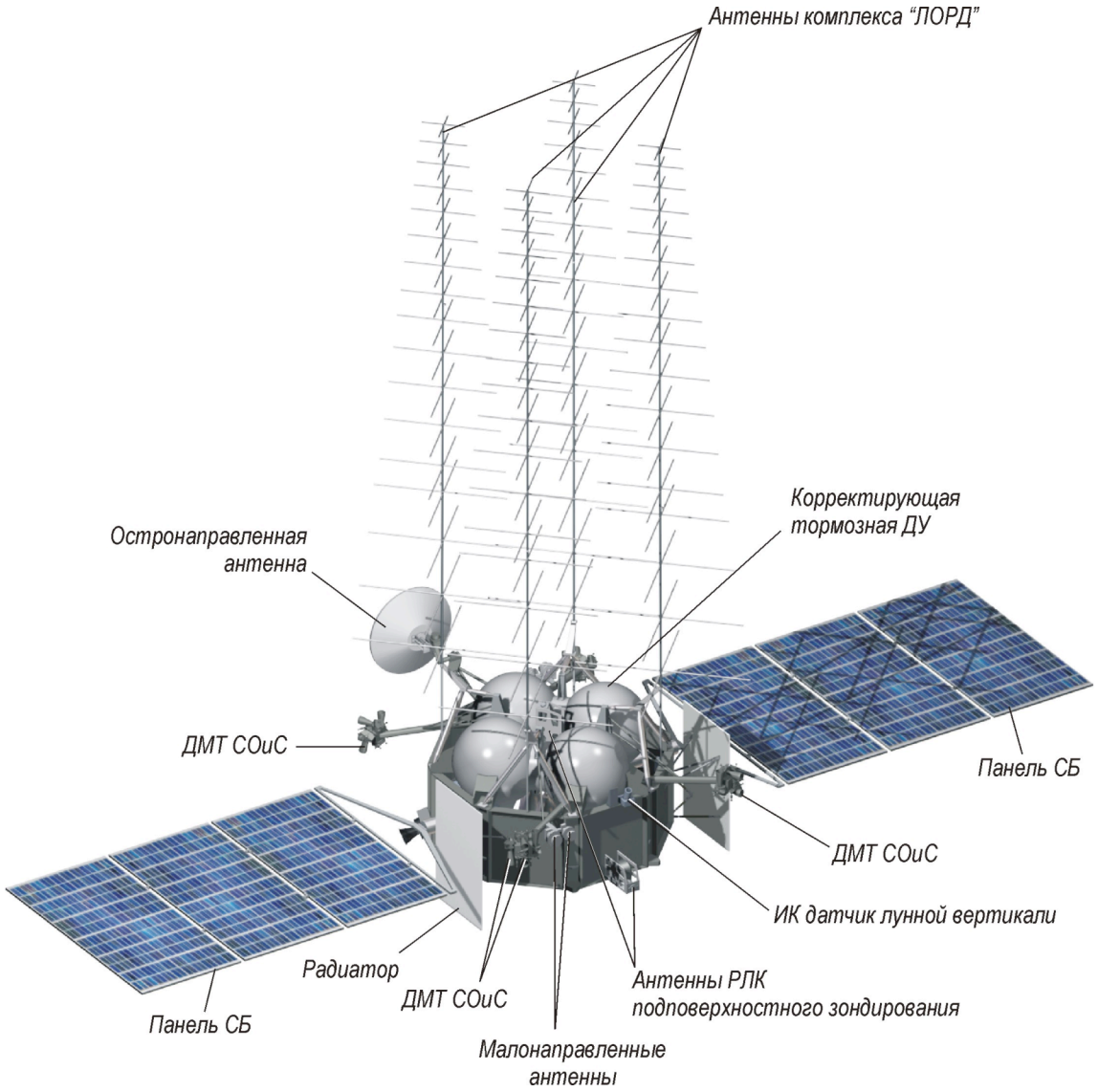


КА в рабочем положении



Размещение комплекса ЛОРД на орбитально-перелетном аппарате <<Луна-Глоб>>





Размещение комплекса ЛОРД на орбитально-перелетном аппарате <<Луна-Глоб>> (в рабочем положении)

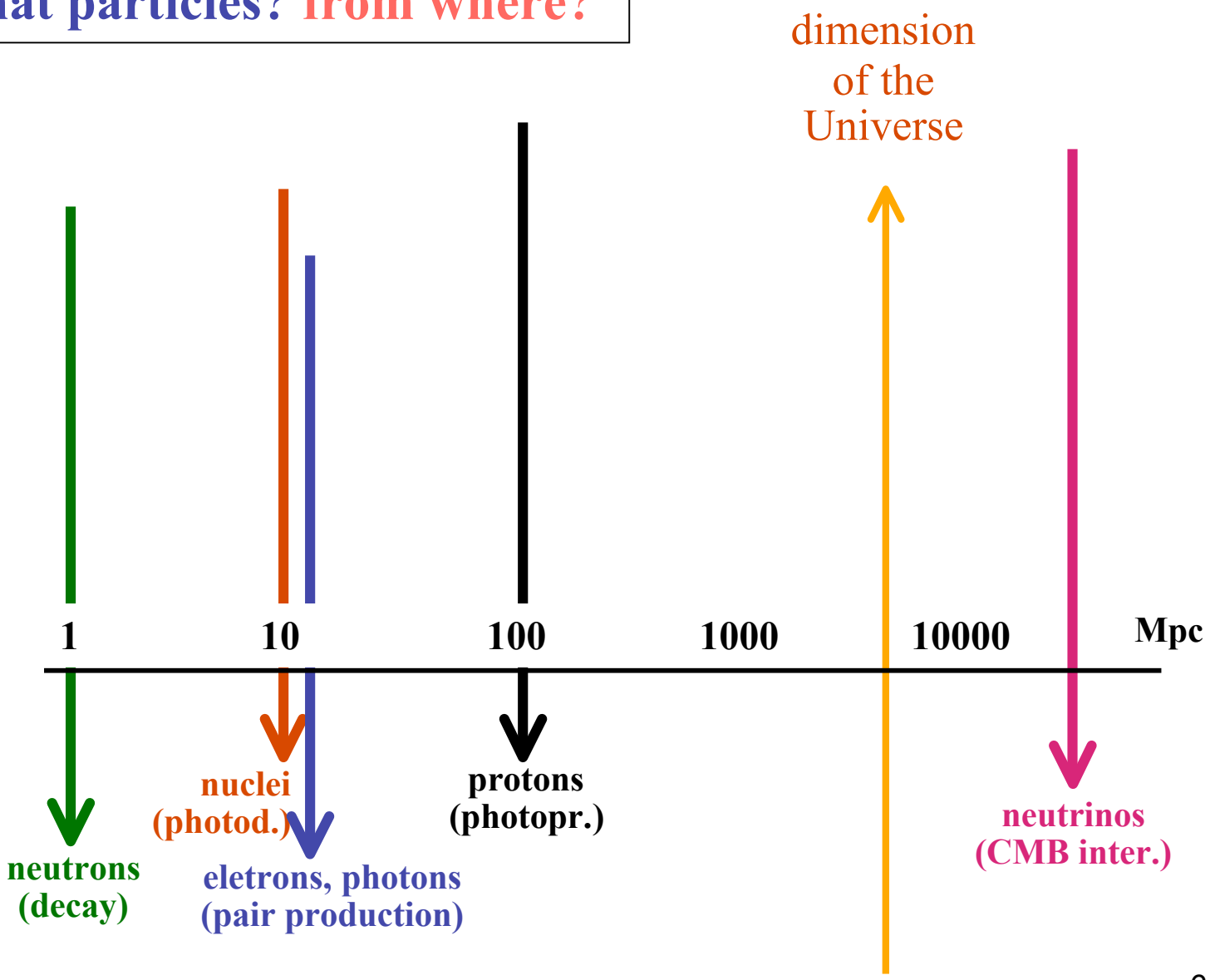
A new actor on the scene of CR from space?

neutrino

new instrument for
Astrophysics,
Cosmology,
Particle Physics

$E_{particle} = 10^{20}$ eV

what particles? from where?



By products (or basic services, or (zero -1) generation experiments)

Monitor of **sun activity** (em, charged particle (identified), neutrons)

Direction of **high energy SCR** from CME (for radiation protection)

Unbiased **monitor of GCR flux and composition** (climate long range change)

Global **Earth scanning** (pixel < 50x50 km^2 possible) in UV, optical, infrared (many uses, including continuous forecasting of fast phenomena formation)