Kepler Center for Astro and Particle Physics

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

"Space based research of the High and Ultra-High Energy Universe"

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What do we mean with:

High, Very High and Ultra High Energy Astrophysics?

High-Ultra High Energy Astrophysics

High Energy Photons: X-rays and more

$$X-rays \qquad 0.1\,keV < h\nu < 500\,keV$$

$$Gamma-rays \qquad 500\,keV < h\nu$$

- LE or MeV : 0.1 -100 MeV *Open (But…)*
- HE or GeV : 0.1 -100 GeV *Open! (GLAST)*
- VHE or TeV : 0.1 -100 TeV *Open! (HESS +)*
- PeV (10^{15} eV) → EeV (10^{18} eV) ***Unexplored***
- at 10^{20}-10^{21} ZeV **Frontiers of the Universe!**

15 Orders of Magnitudes!

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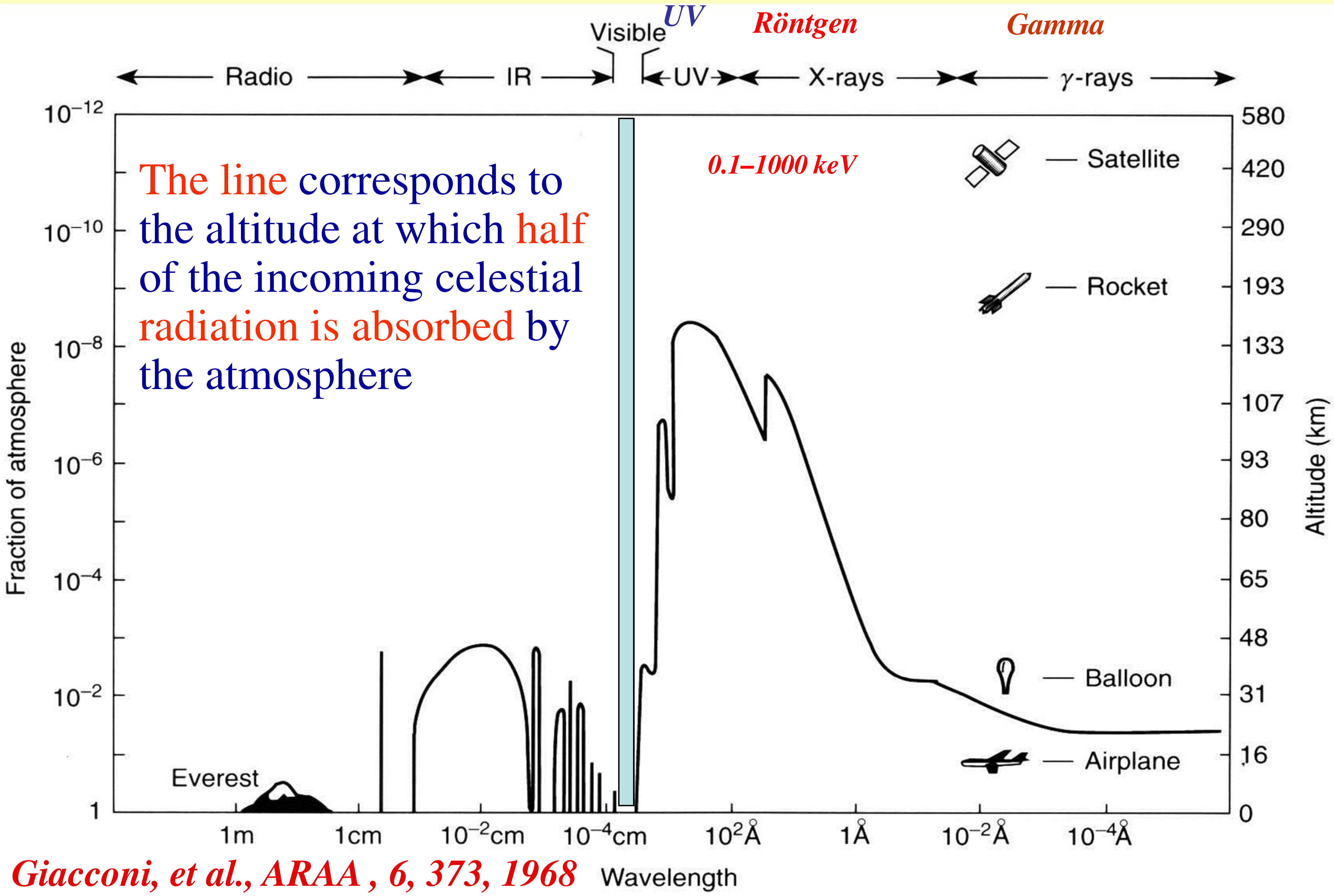
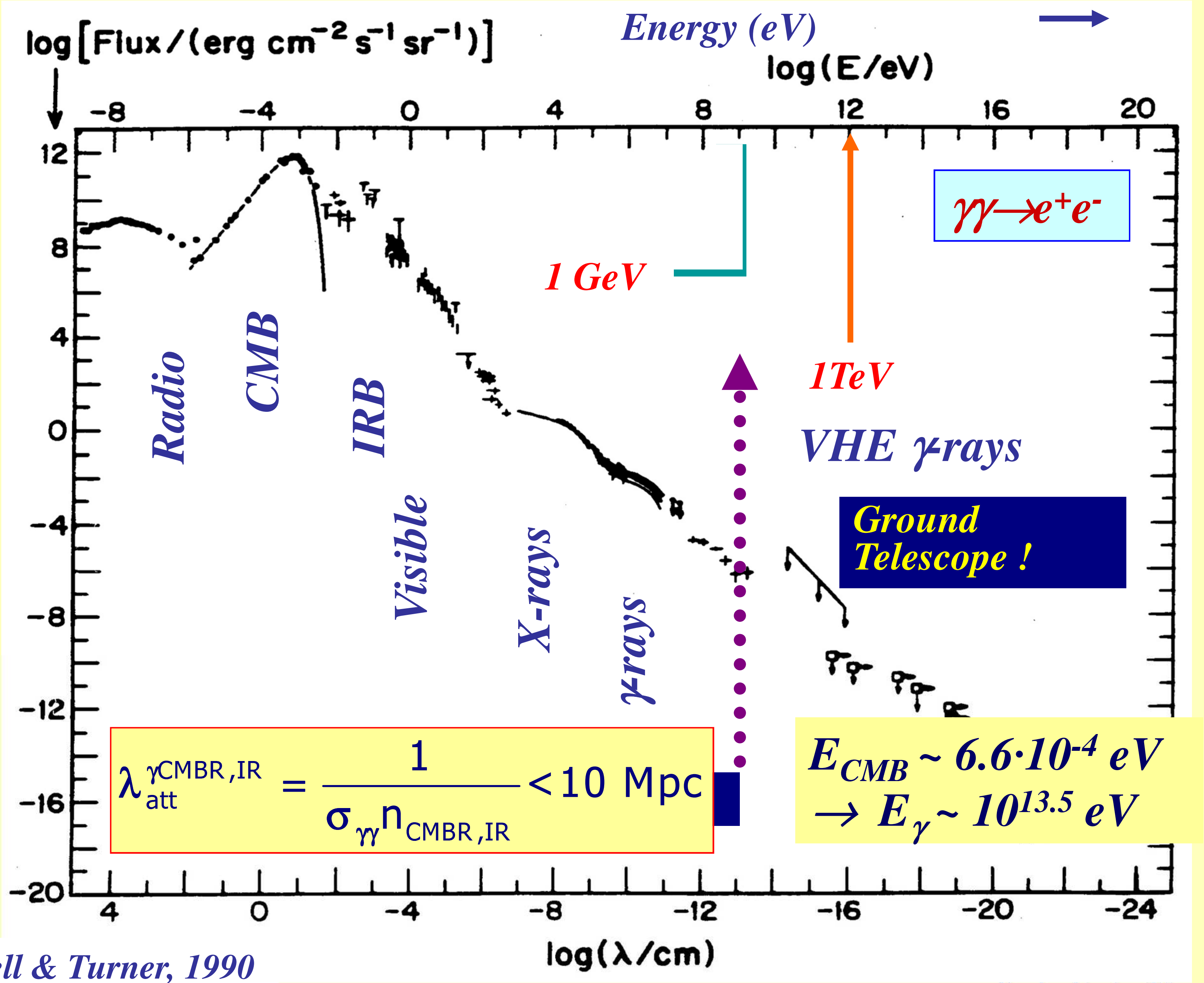
Electromagnetic Radiation through the atmosphere

The line corresponds to the altitude at which half of the incoming celestial radiation is absorbed by the atmosphere



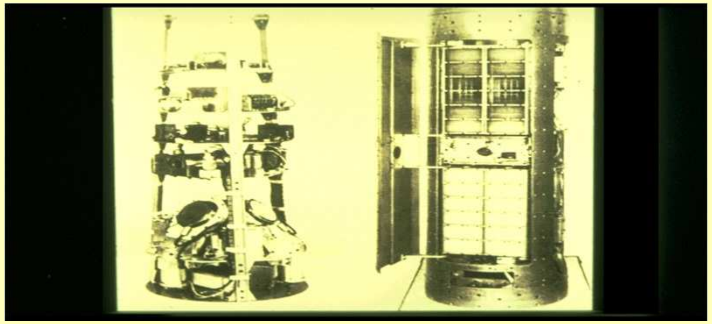
Giacconi, et al., ARAA , 6, 373, 1968



Ressell & Turner, 1990

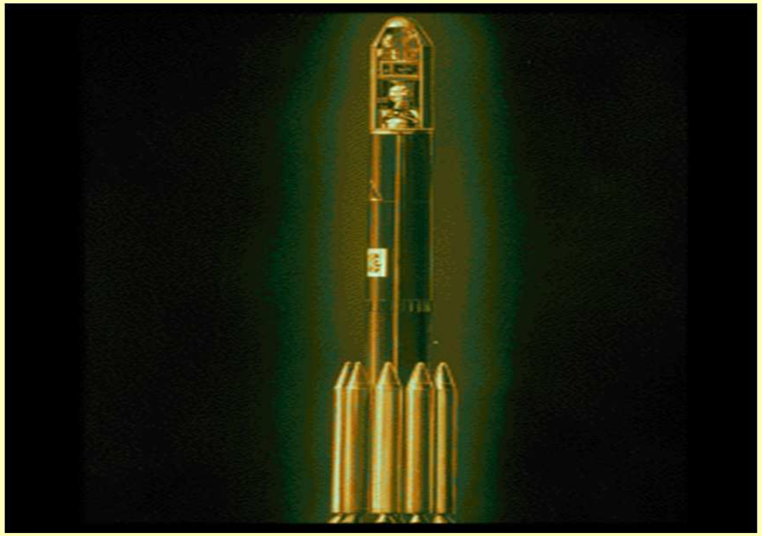
Part I:
Let's then focus on X-ray Astrophysics

The Birth of modern High Energy Astrophysics 1962



On June 18 1962, on an Airforce Aerobee rocket an ASE-MIT proportional counter was launched by Rossi, Giacconi, Paolini e Gursky

SCO X-1



Giacconi et al., Physical Review Letters, vol. 9, p. 439 (1962) (Nobel 2002)

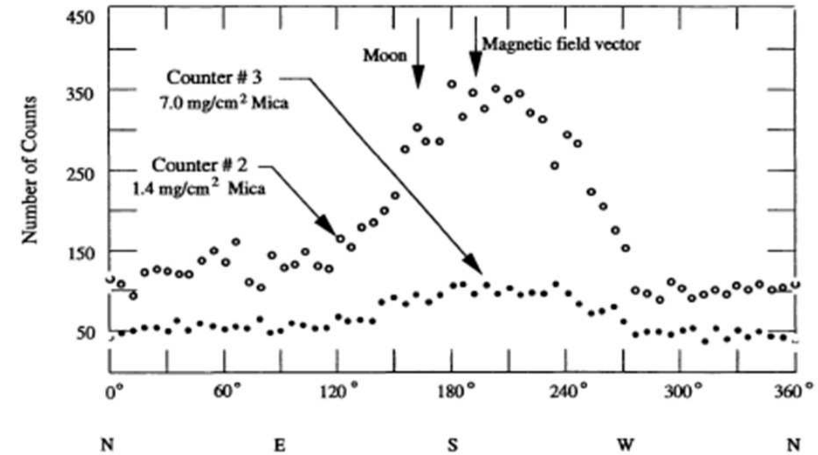
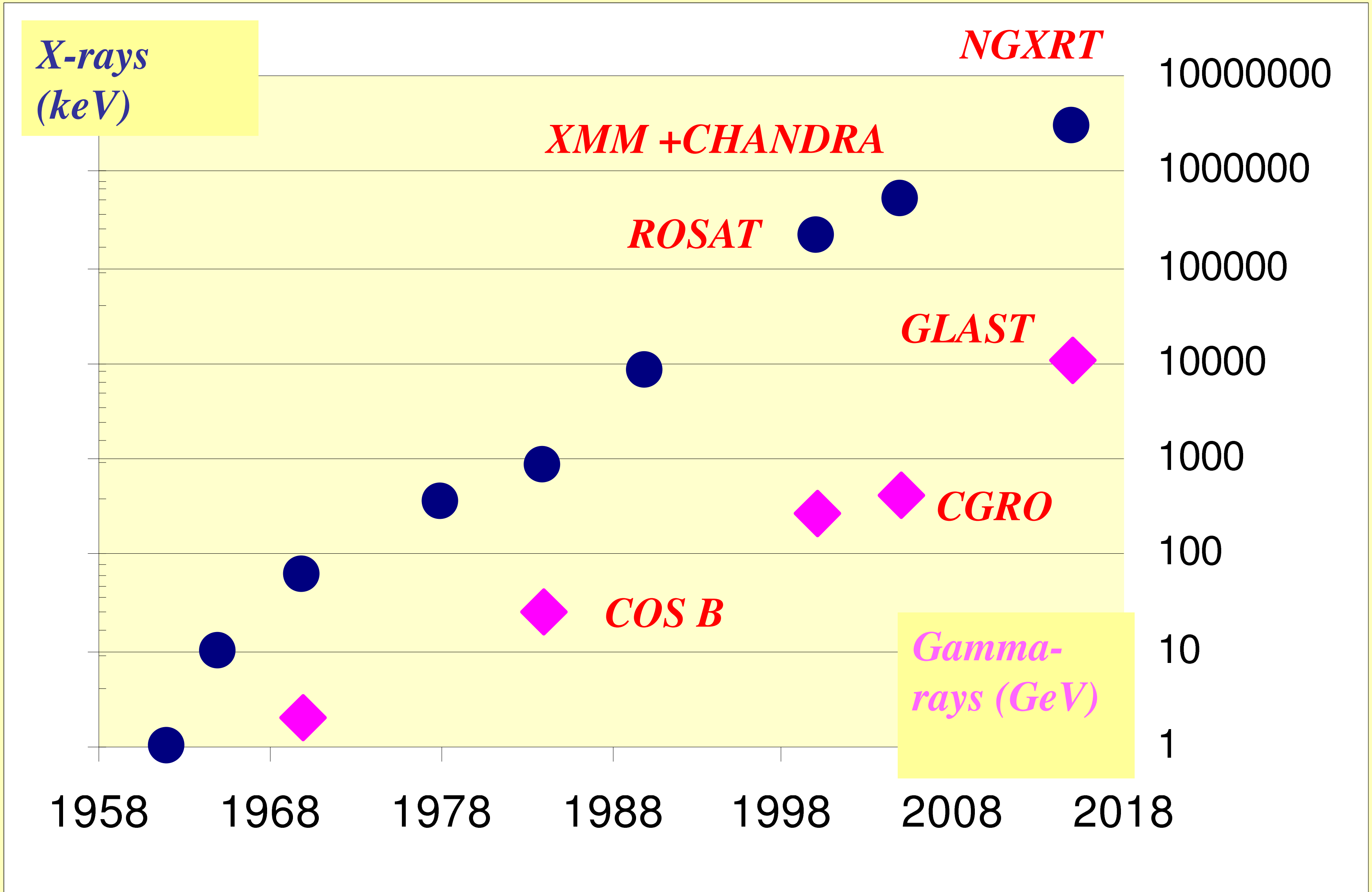
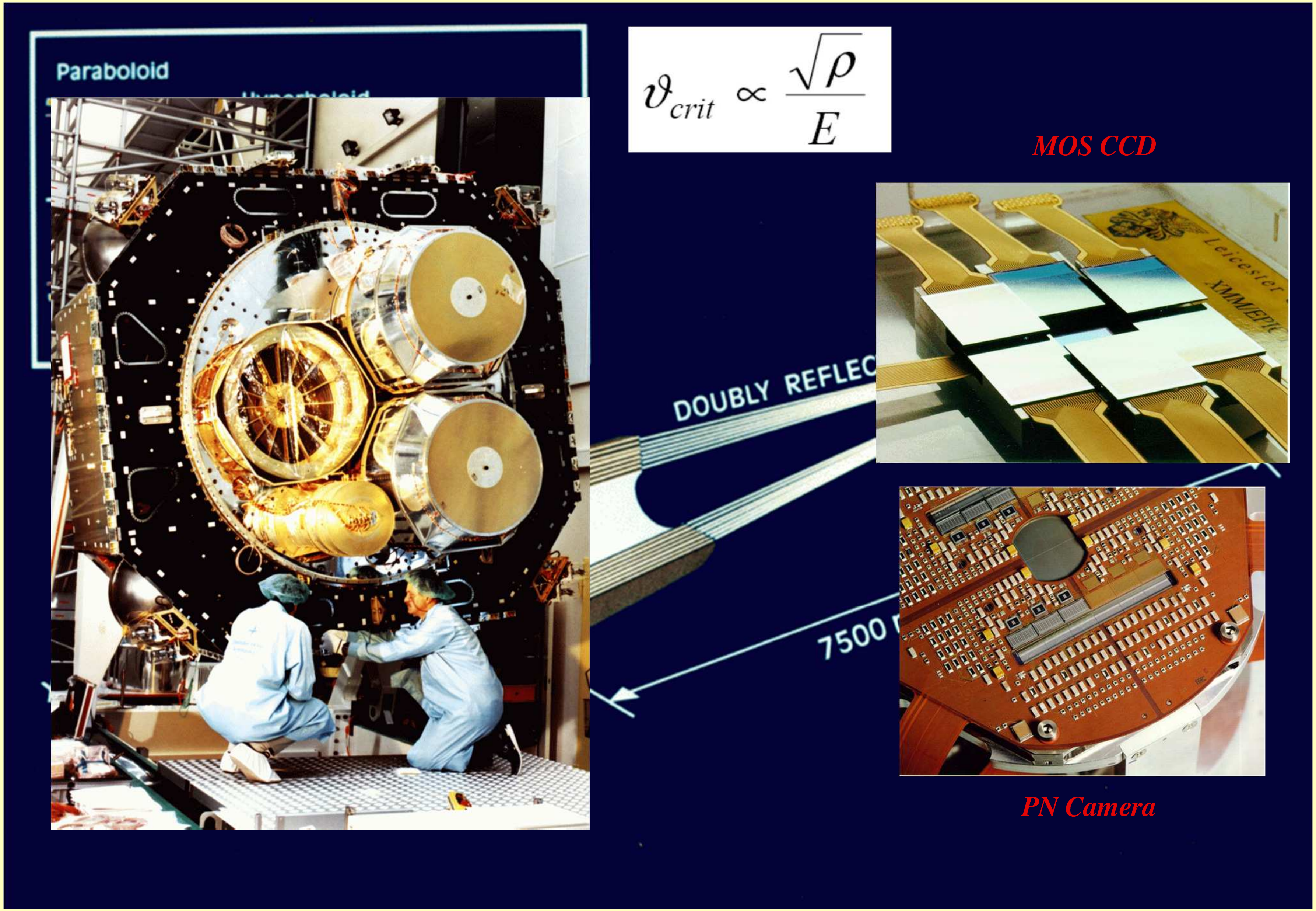


Figure 1 Azimuthal distribution of X rays from the photon (Geiger) counters (two different window thicknesses) on a sounding rocket in June 1962. These data revealed the existence of a discrete celestial X-ray source (Sco X-1) at azimuth ∼195° and the diffuse X-ray background. (From Giacconi et al 1962; redrawn for this work.)

Number of X and Gamma ray sources



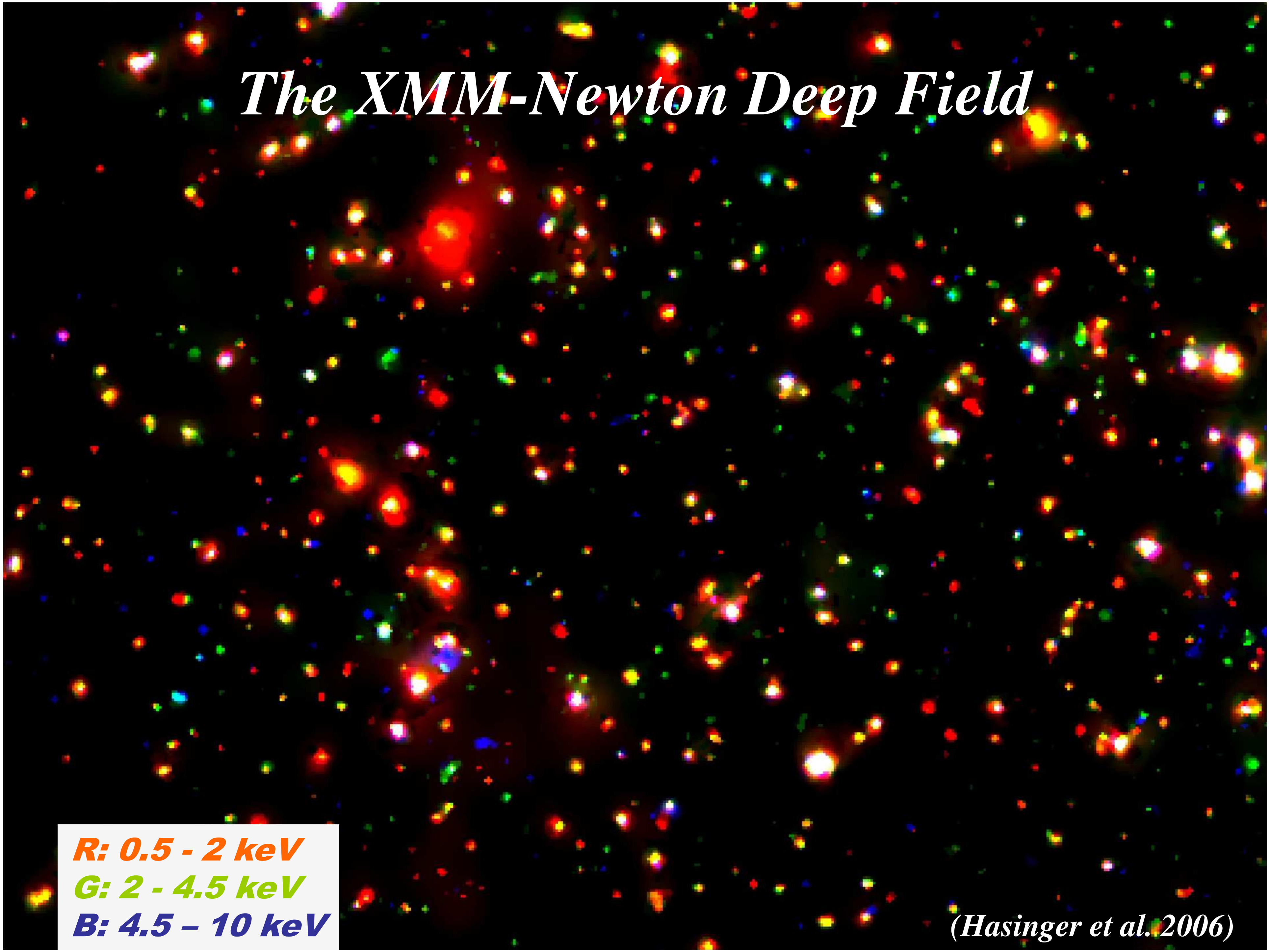
How does it work an X-ray telescope?



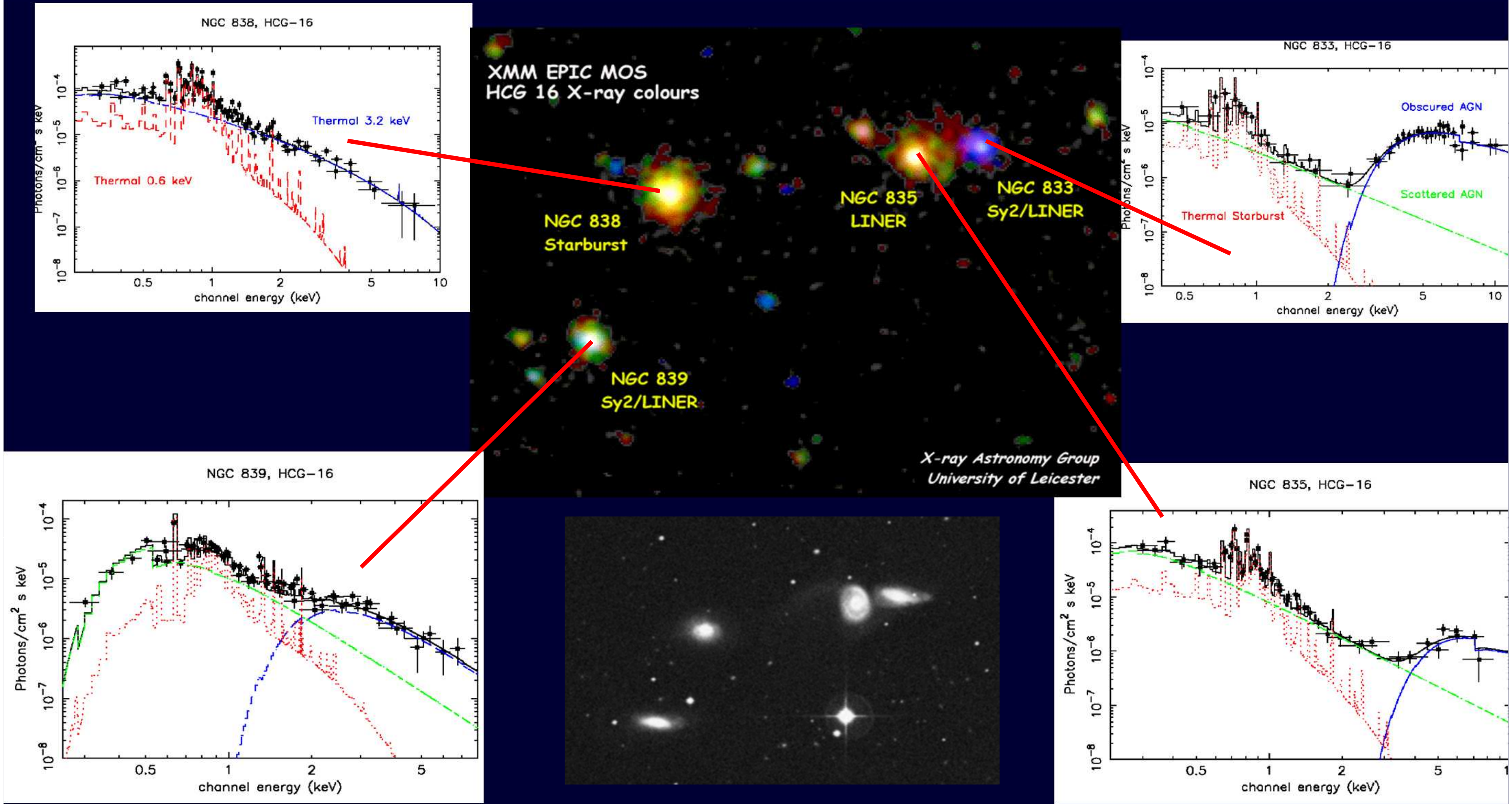
$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$

XMM-Newton	Chandra
	
Mirror area 0.4 m^2	*Mirror area 0.08 m^2*
Spatial resolution 15'' HEW	*Spatial resolution 0.5'' HEW*
Sensitivity: 10^{-15} erg cm^{-2} s^{-1}	*Sensitivity: 10^{-16} erg cm^{-2} s^{-1}*

Limited Performances for bright sources! (already a 100 mCrb)


The XMM-Newton Deep Field
R: 0.5 - 2 keV
G: 2 - 4.5 keV
B: 4.5 – 10 keV
(Hasinger et al. 2006)

XMM spectral capabilities…



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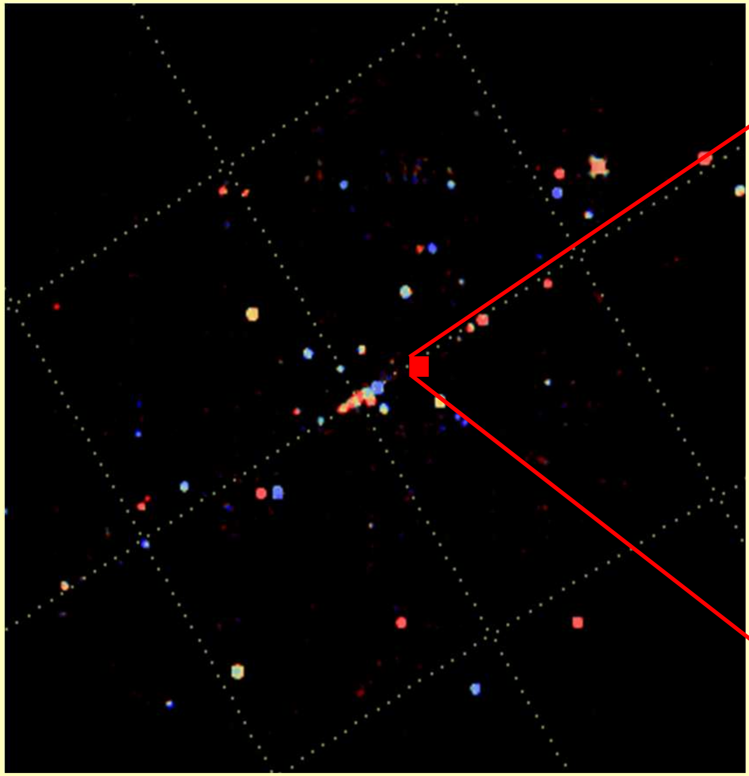
Key questions of X-ray astrophysics

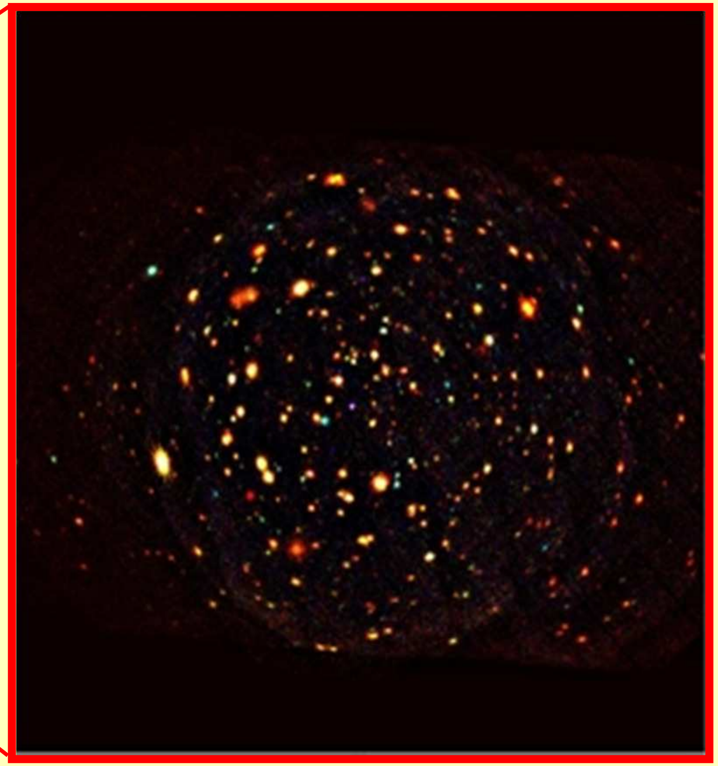
- *Contribution to Cosmology*
  - *Co-evolution AGN and Galaxies*
  - *Cosmic Hard X-ray Background*
  - *Clusters of Galaxy as probe for Dark Energy*
  - *Search for the missing Baryons*
- *Contribution to Physics*
  - *Probing Gravity around Black Holes and Neutron Star*
  - *Matter under extreme condition: EOS of Neutron Stars*
  - *The physics of accretion in both galactic and extragalactic sources*
  - *Understanding the acceleration mechanisms*

What comes next (observational requirements)?

Requirement 1: Focusing at Hard X-ray

A pointed telescope with the XMM-Newton angular resolution and sensitivity in the INTEGRAL/ISGRI energy range





30 degrees

30 arcmin

INTEGRAL, Coded Masks

XMM, Focusing Optics

Hard X–rays at "XMM" level

Hard X–rays

IGR/ISGRI (2002, coded mask)

- 15 keV – 1 MeV
- sensitivity: ~ 0.3 mCrab
- angular resol. (FWHM): 0.2 °
- catalogue of 421 sources

Hard X- (2015, focusing)

- 0.5 – 80 keV
- sensitivity: ~ 1 μCrab
- angular resol. (FWHM): 8"

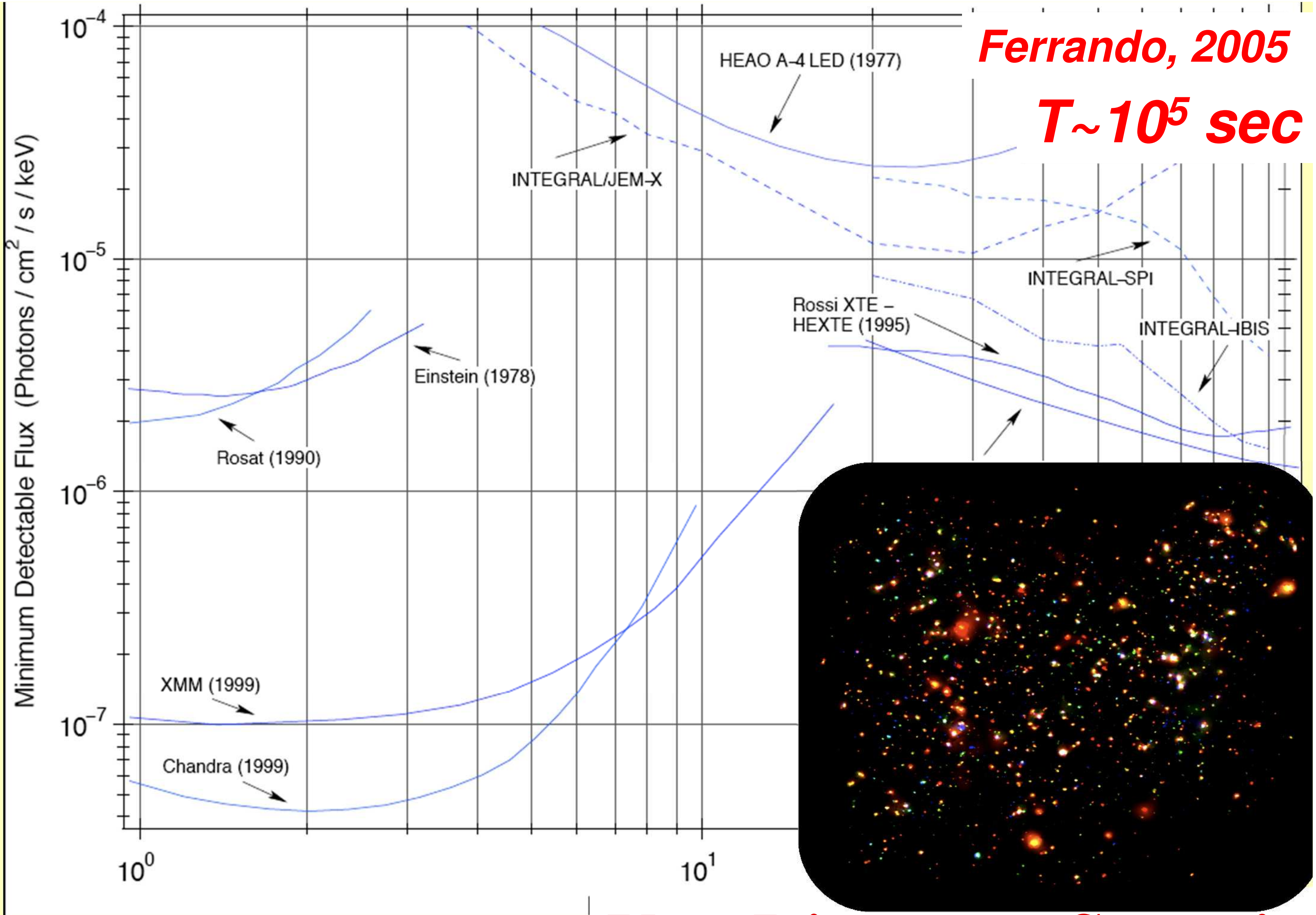
Soft X–rays

UHURU (1970, collimator)

- 2 – 20 keV
- sensitivity : ~ 1 mCrab
- angular resol. (FWHM) : 0.5 °
- catalogue of 339 sources

XMM–Newton (1999, focusing)

- 0.1 – 15 keV
- sensitivity: ~ 1 μCrab
- angular resol. (FWHM): 6"
- catalogue of ~ 125,000 sources



Ferrando, 2005

T~10^5 sec

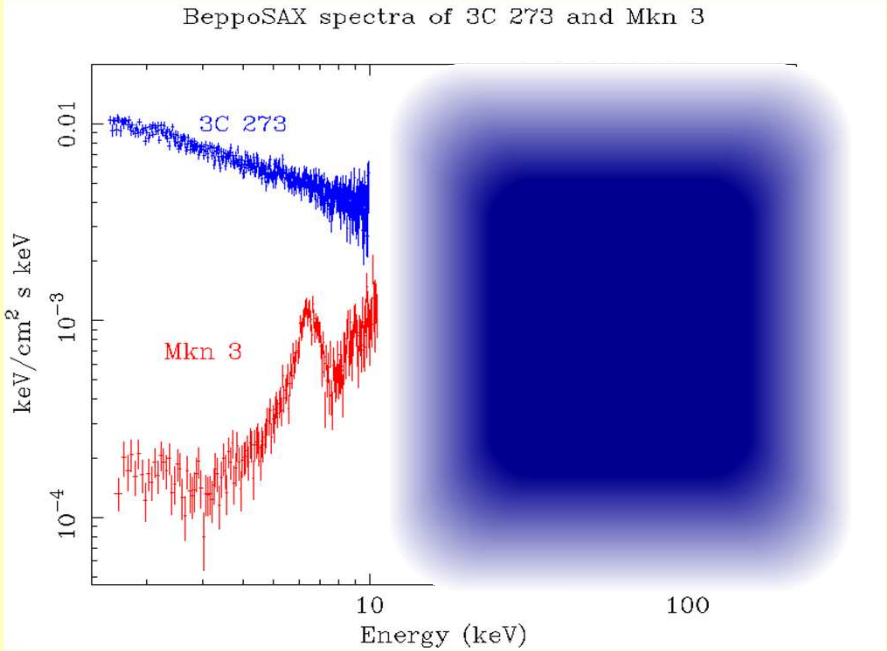
Tenzer+, 2008

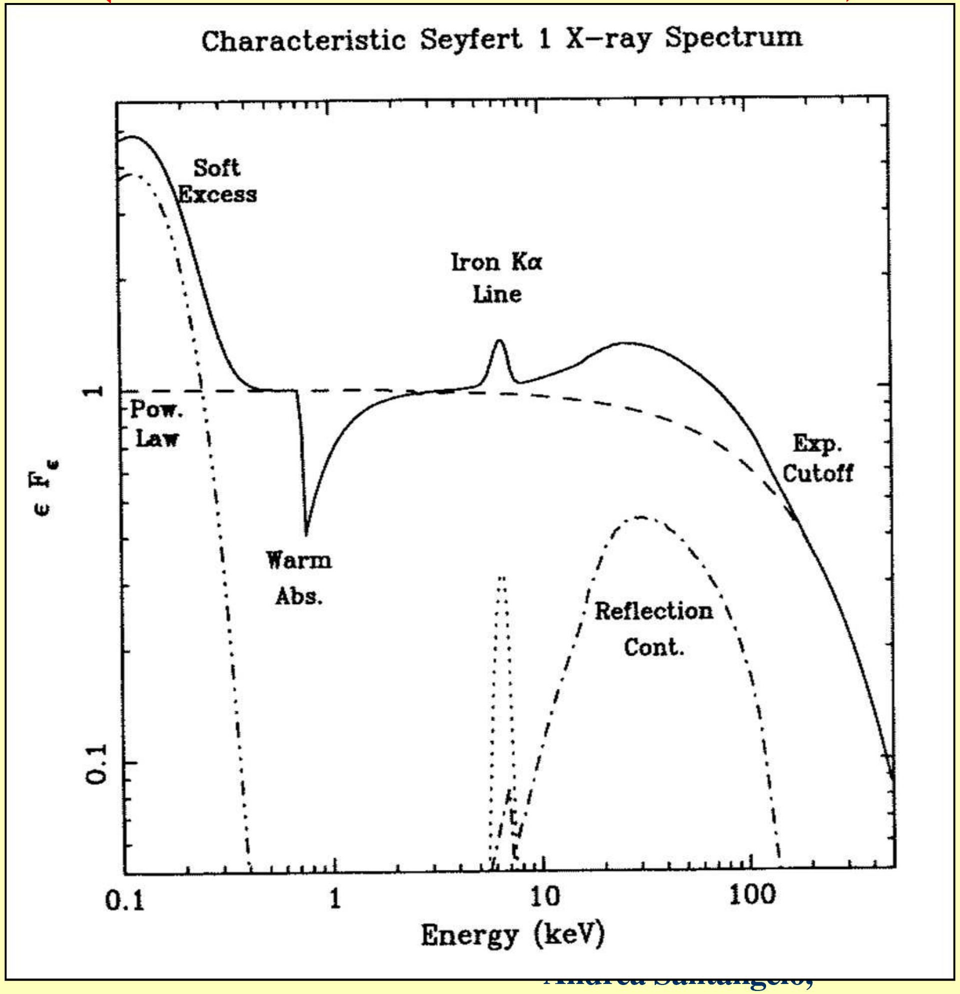
Vast Discovery Space!

Requirement 2: Broad band (0.1-100 keV)

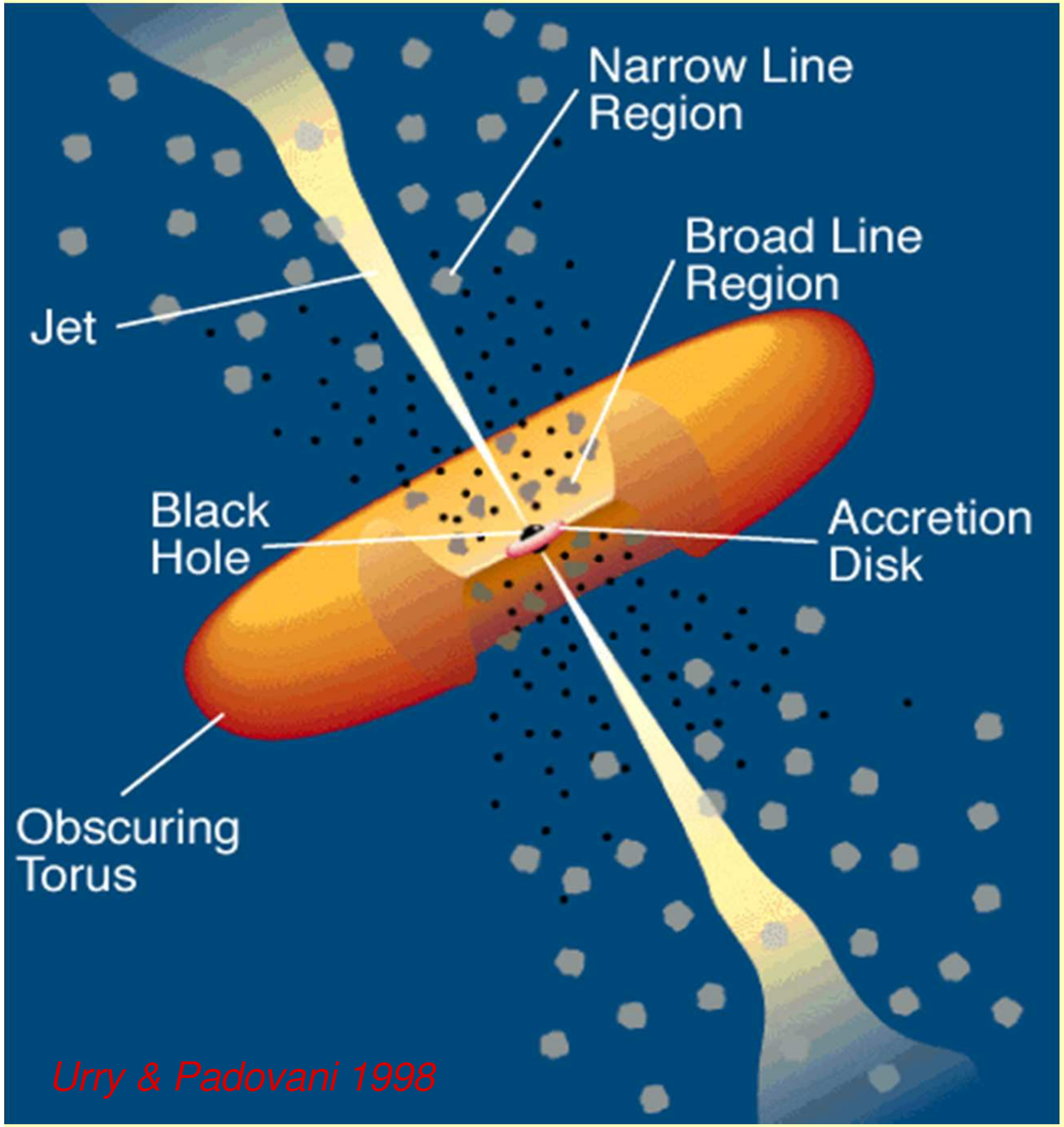
Many spectral features

Limited band of XMM and Chandra





Active Galactic Nuclei



Urry & Padovani 1998

Supermassive Black Holes

$$M \approx 10^6 - 10^9 M_{Sun}$$

Accretion Powered:

$$L \approx \eta \dot{M} c^2$$

Efficiency **Accretion rate**

$$\dot{M} = \frac{L}{\eta c^2} \approx 10 M_{Sun} / year$$

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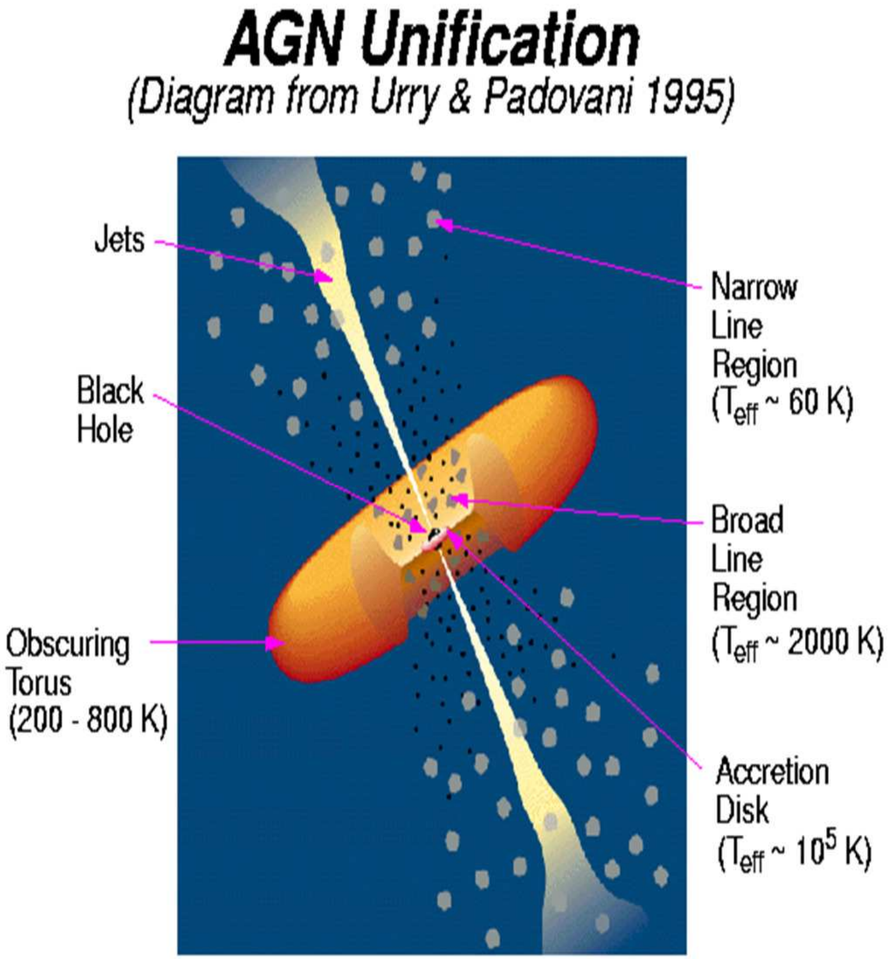
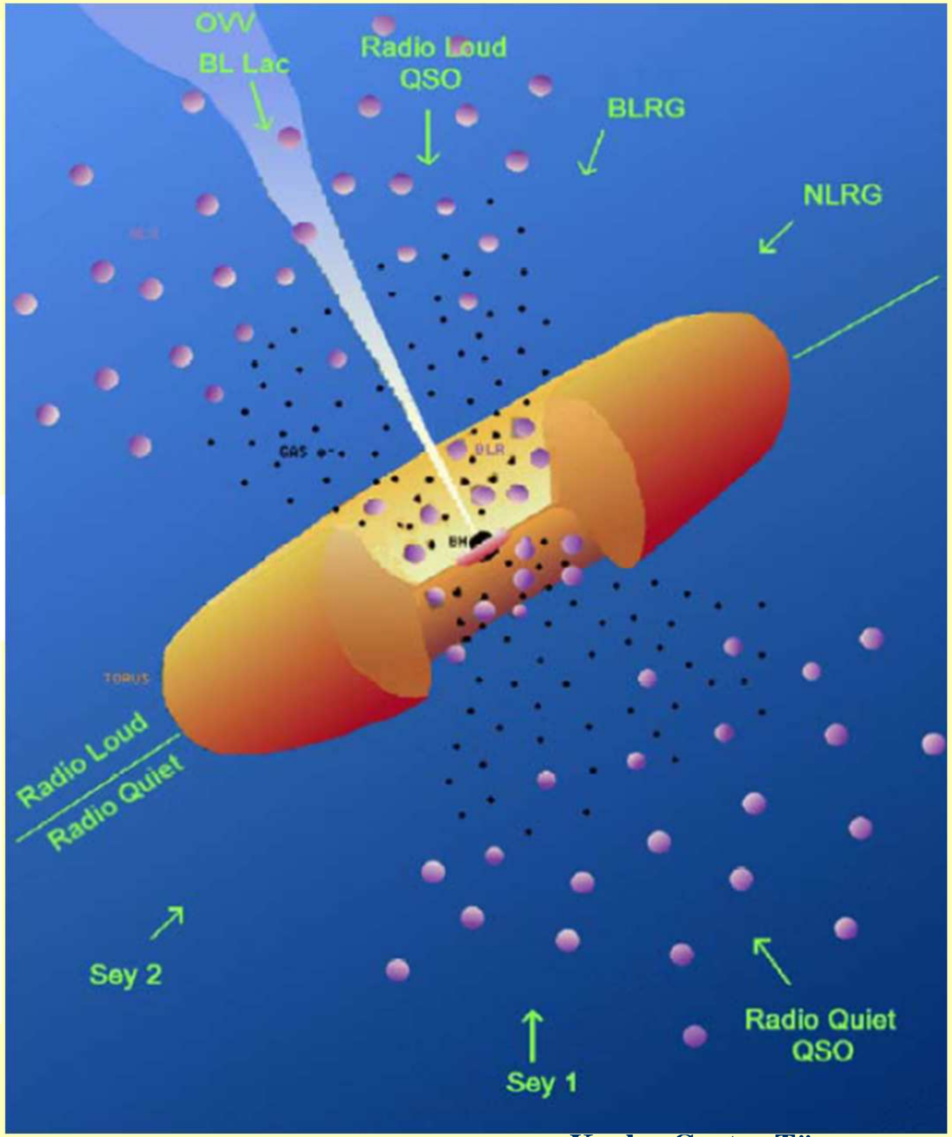
Schematic: AGN Unified Source Model





Focusing and Broad Band
Two Core Science Objectives

Increasing by 3 orders of magnitude
the discovery space at E~10-70 keV

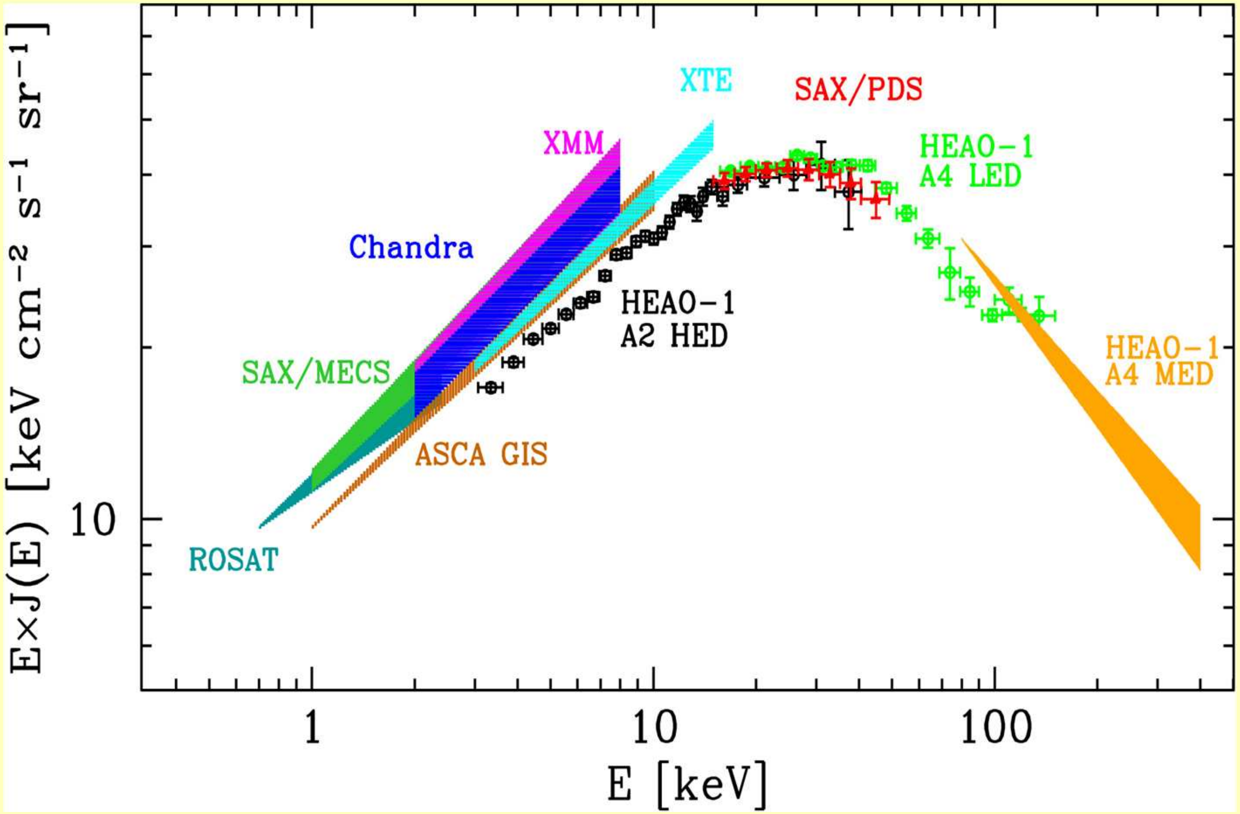
I – Census and Physics of Black Holes

II - Particle Acceleration Mechanisms
(Not in this talk)

The Quest for Black Holes

Resolve > 50% of the Hard CXB**, thus determining the fraction and evolution of obscured sources and providing a more **complete census of SMBH

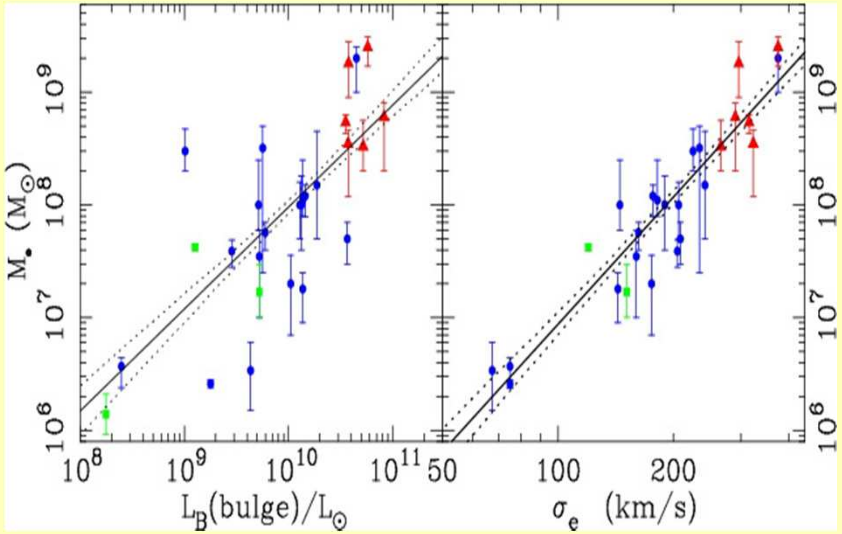
About 50 % resolved in sources in the 7–10 keV band



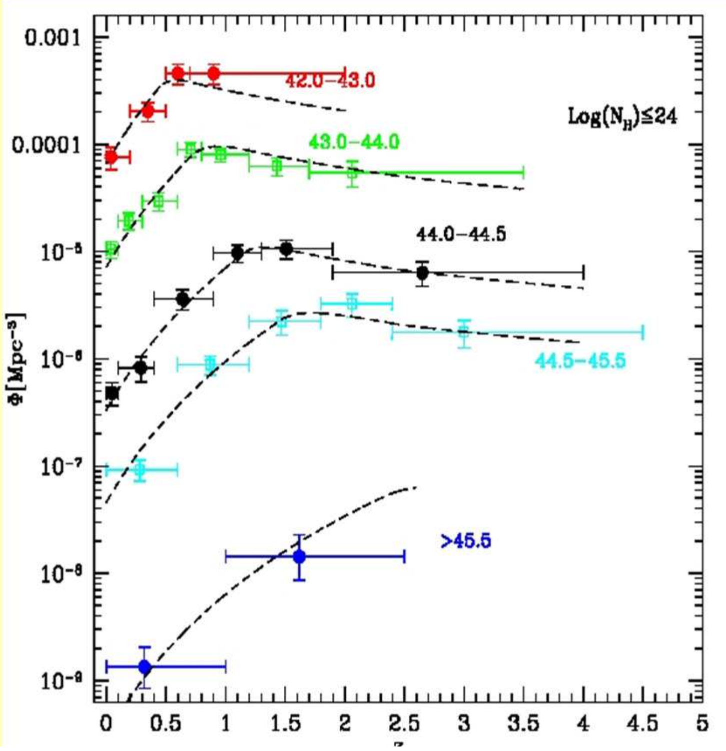
But less than a few % resolved beyond 10 keV, at the emission peak!

SMBH and Galaxies: tight Correlation

tight correlation between M_{BH} and bulge properties.



The low luminosity AGN peak recently between (0.5-2 z) which is the golden epoch of AGN and Galaxy Activity



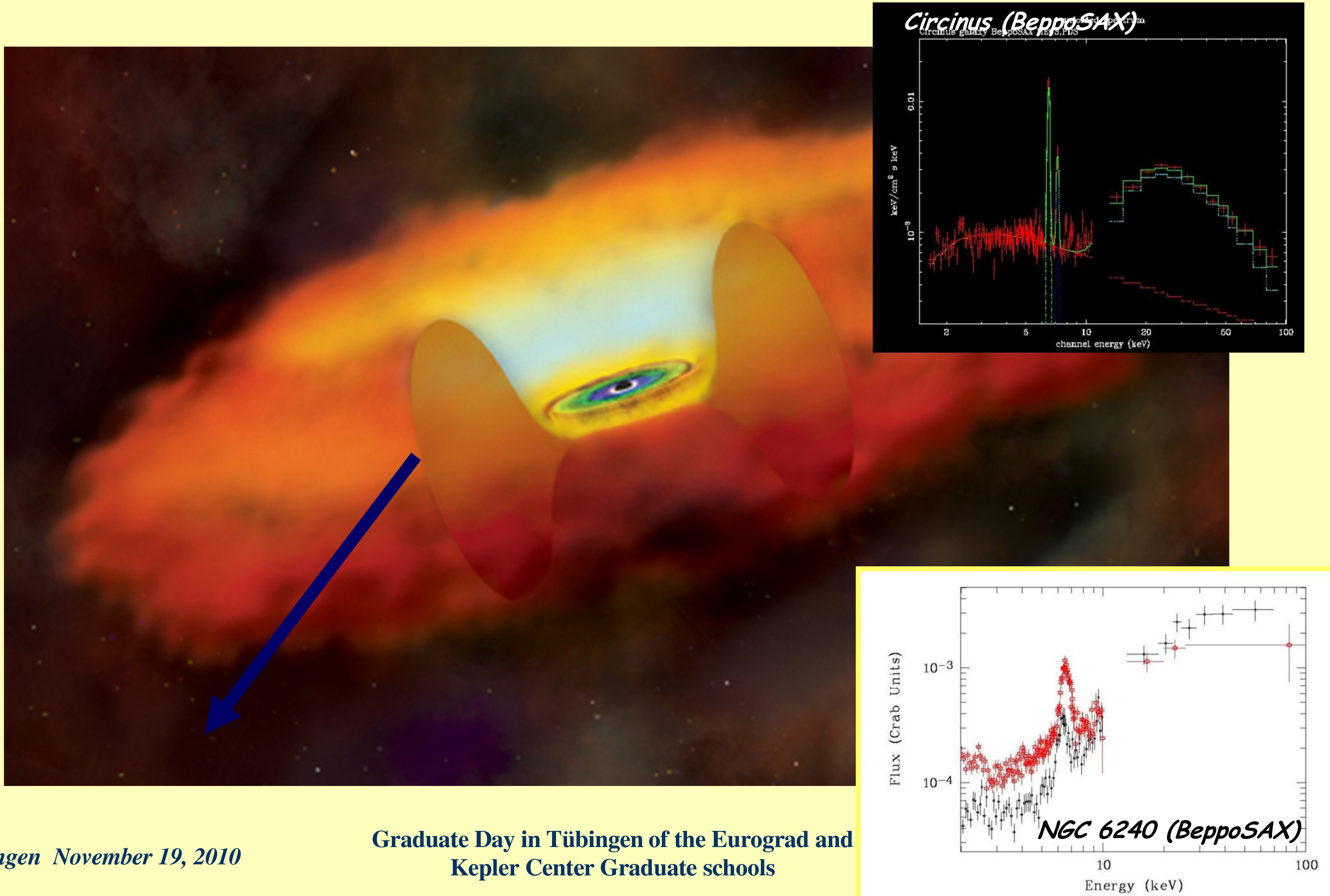
Hasinger +, 2005

→ most BH mass accreted during luminous AGN phases! Most bulges passed a phase of activity:

Co-evolution of AGN and Galaxies

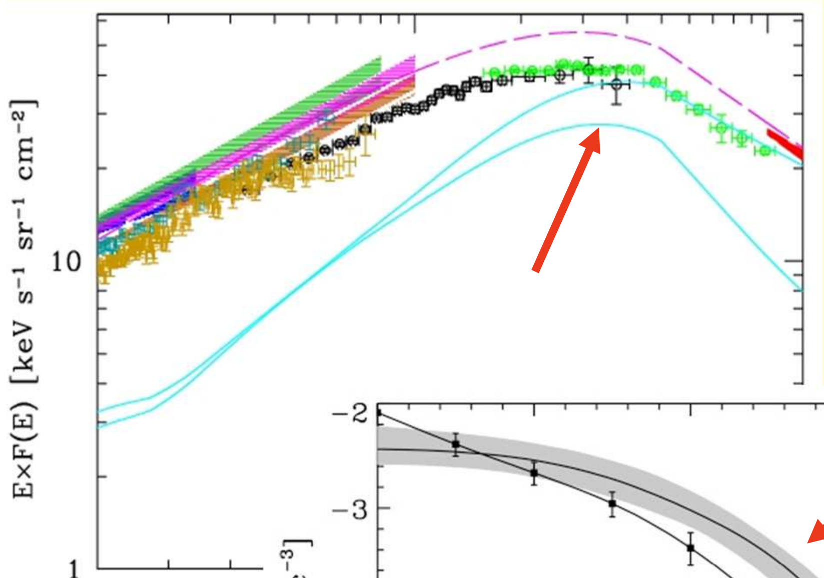
Complete SMBH census to understand AGN evolution linked to galaxy evolution

Where are the obscured AGN?

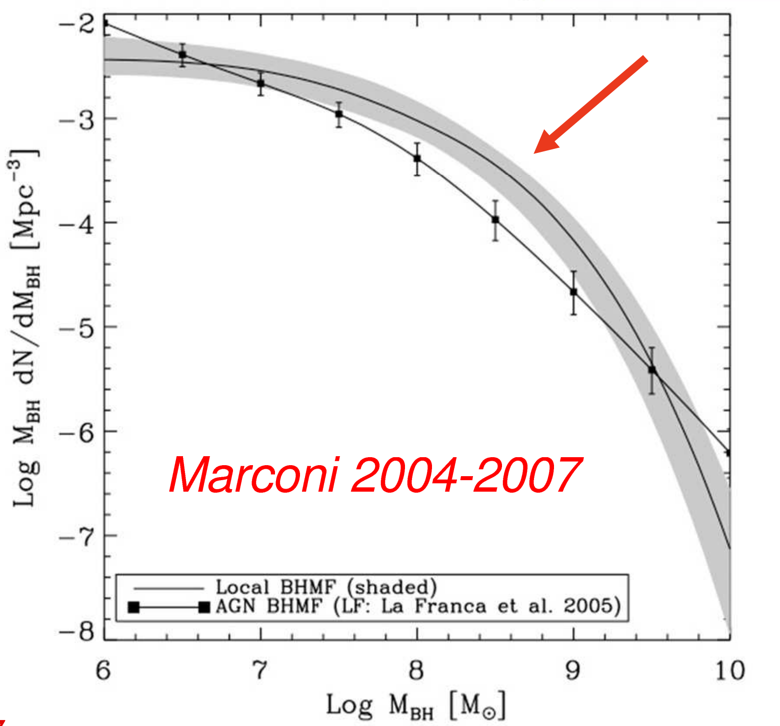


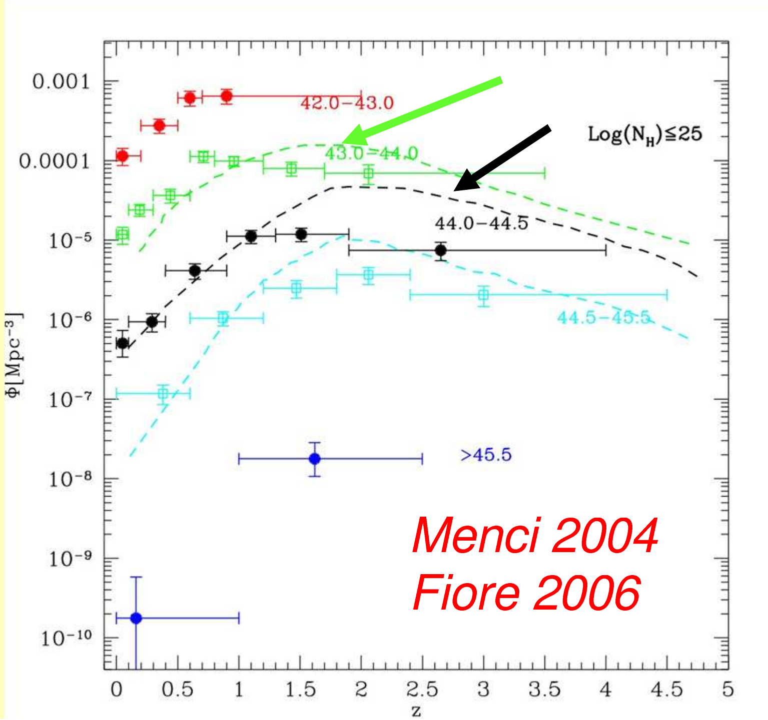
Evidences for missing SMBH

Comastri, 2004



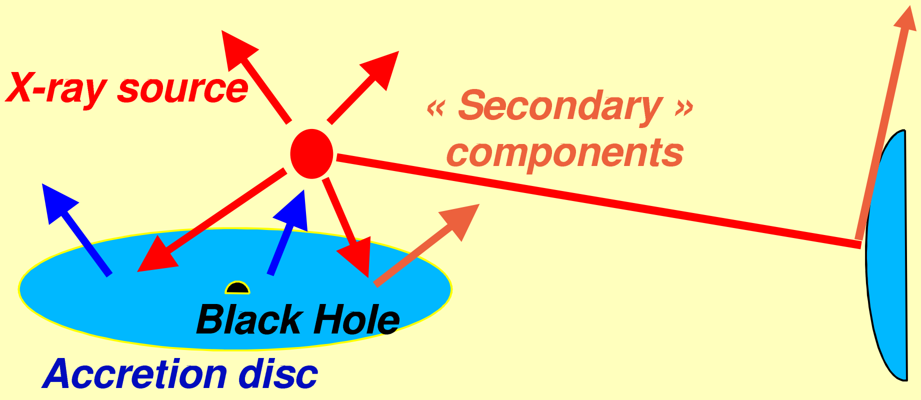
While the CXB energy density provides a statistical estimate of SMBH growth, the lack, so far, of focusing instrument above 10 keV (where the CXB energy density peaks), frustrates our effort to obtain a comprehensive picture of the SMBH evolutionary properties.

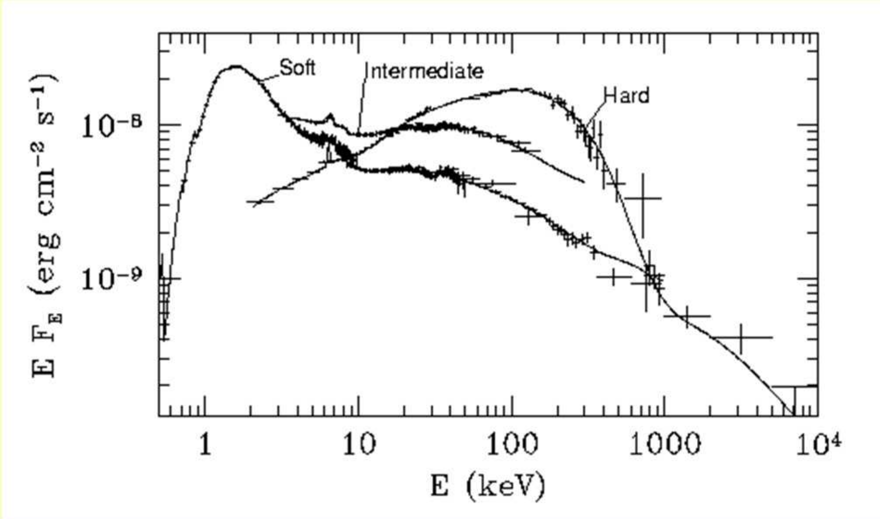


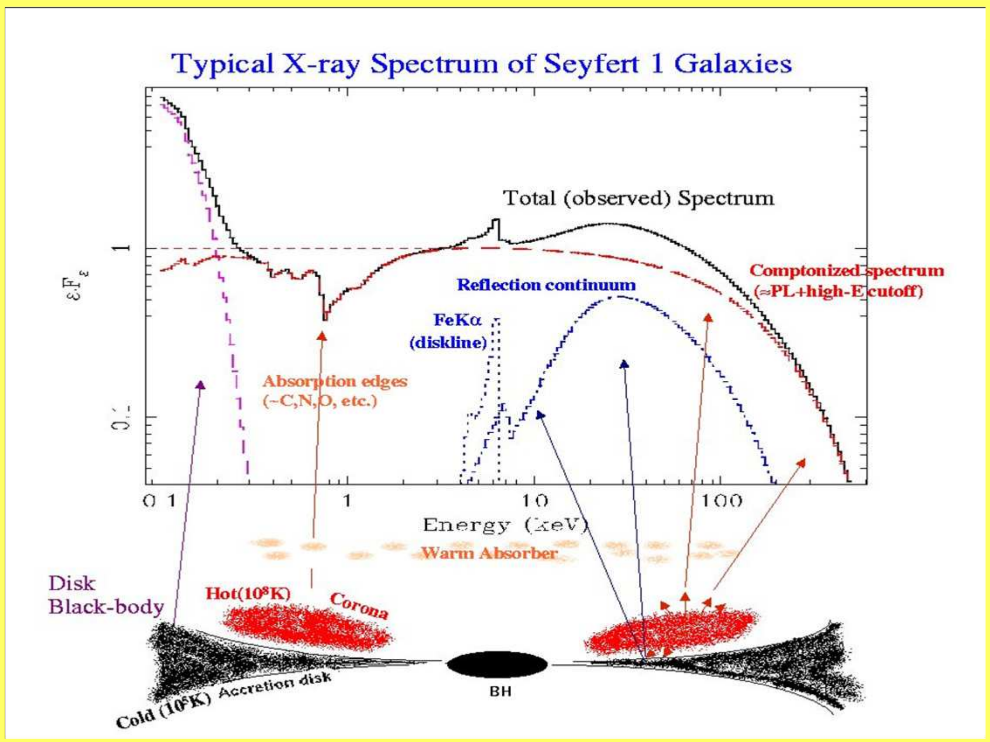


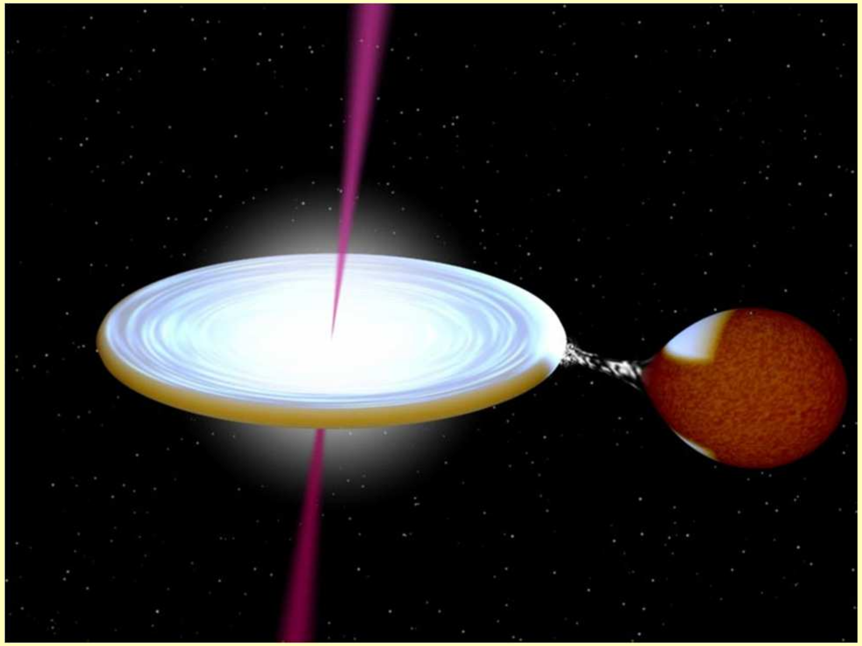
Fiore, 2007

Constrain physics of the accretion flow onto both Super Massive BH and solar mass (tens of solar masses) BH







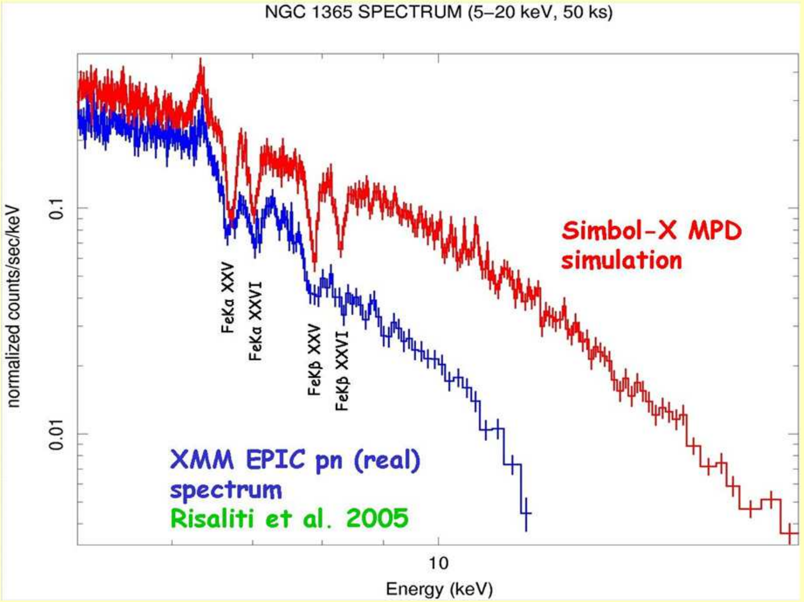


Going to lower Energies

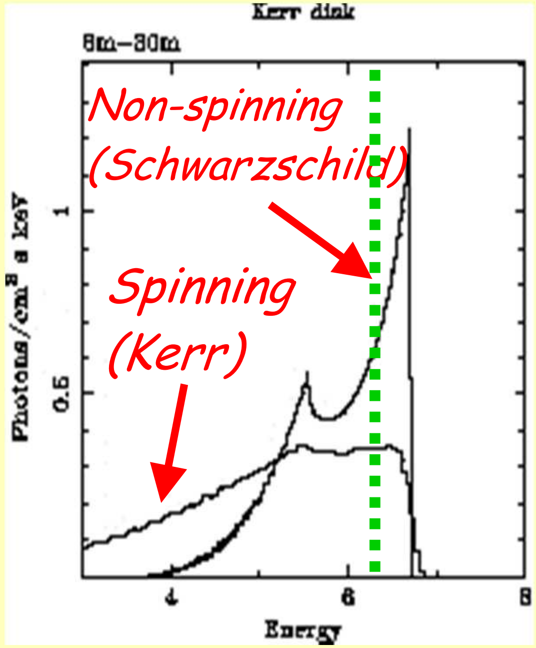
Low Energy coverage is essential:

a) Massive Outflows: connection SMBH - Galaxy

b) Iron Line (6.4 keV) studies → probe General Relativity



Absorption lines : massive outflows



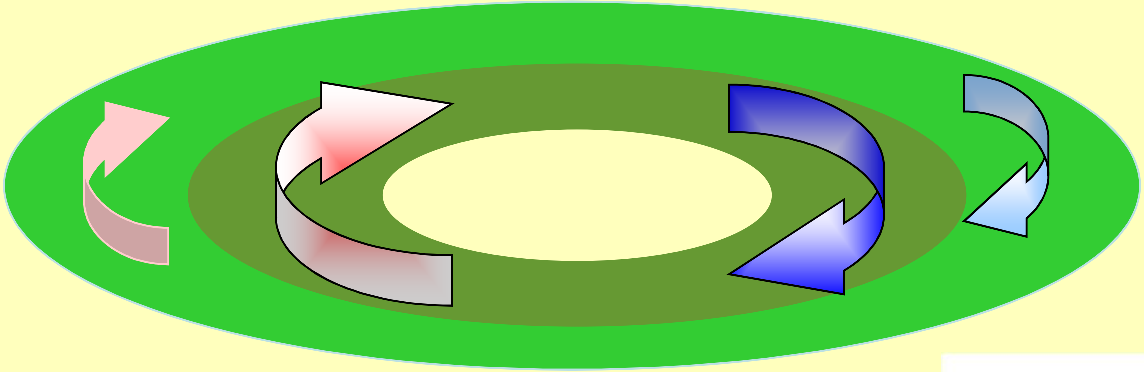
Using the Fluorescence iron line to probe fundamental physics

Requirement 3: Improve of a factor of 10 the sensitivity at the Iron line (6.4 keV)

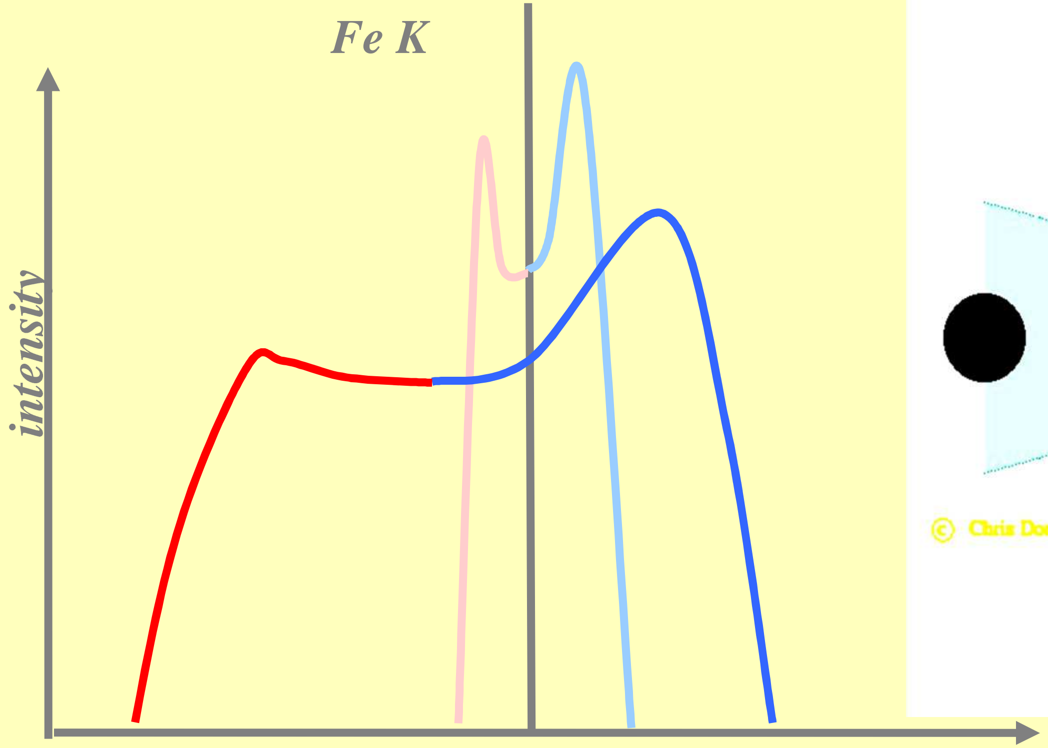
Requirement 4: High Throughput missions (High Time Resolution Spectrometer, capability of processing 10^6 events)

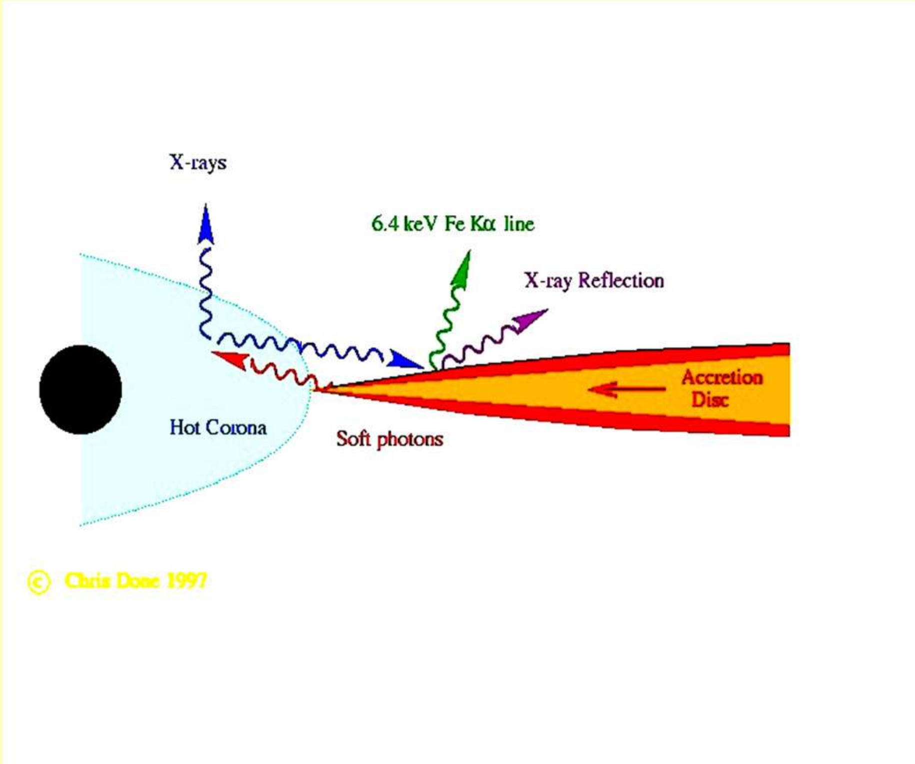
The Iron line comes from the disk…

Newtonian + Relativistic Doppler



Relativistic Boosting

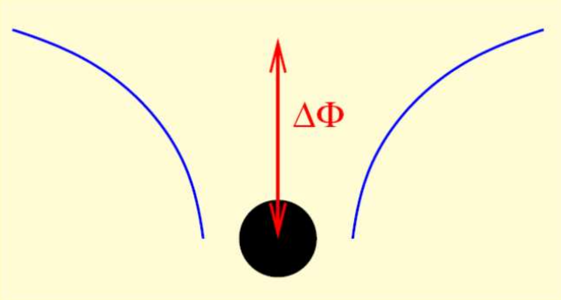


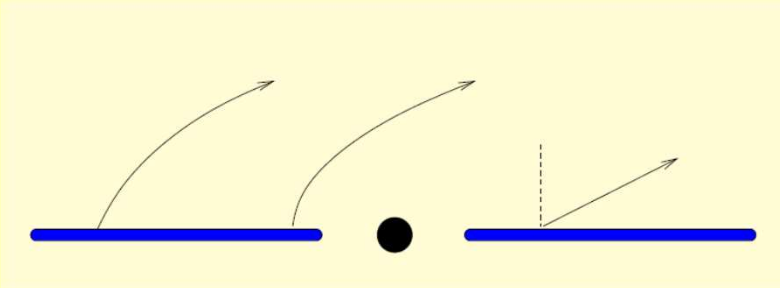


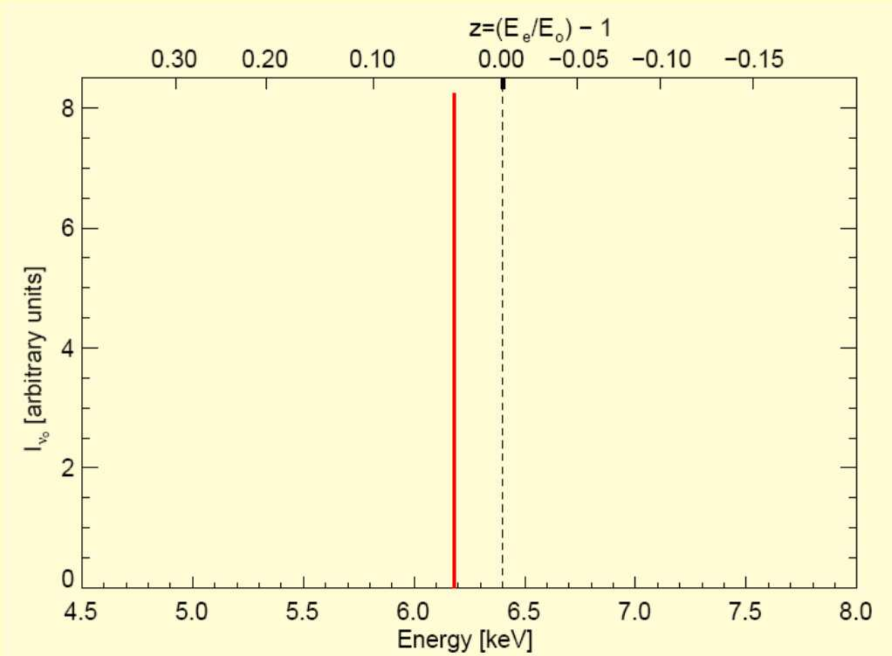
Complex Phenomenon…

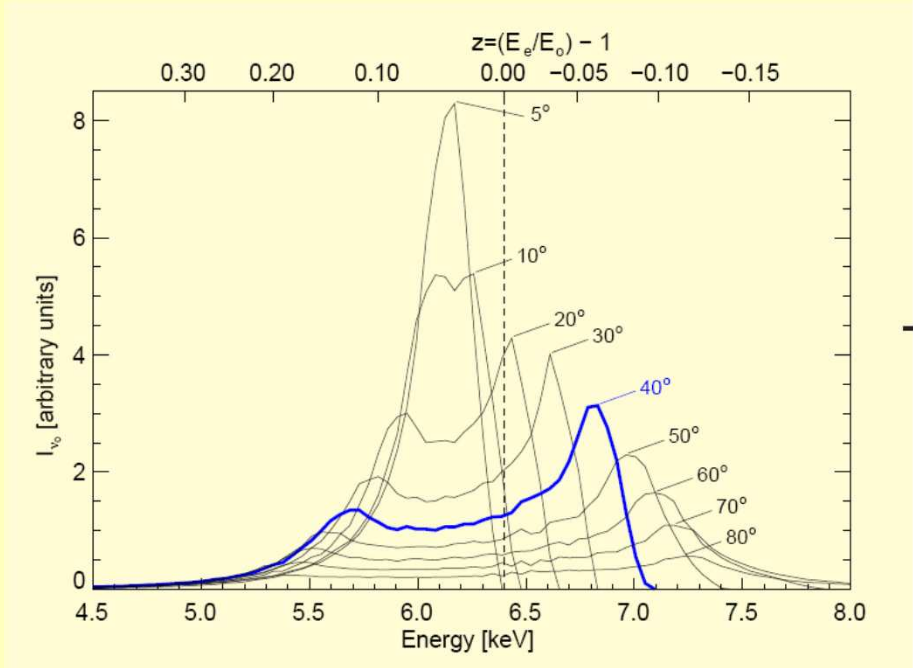
$$1+z=\frac{\lambda_o}{\lambda_e}\approx\left(1-\frac{2GM}{c^2 r}\right)$$

Potential Well + Light Bending

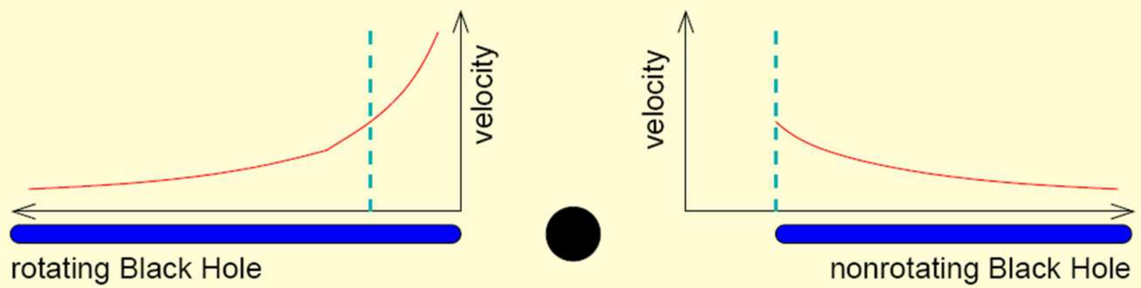






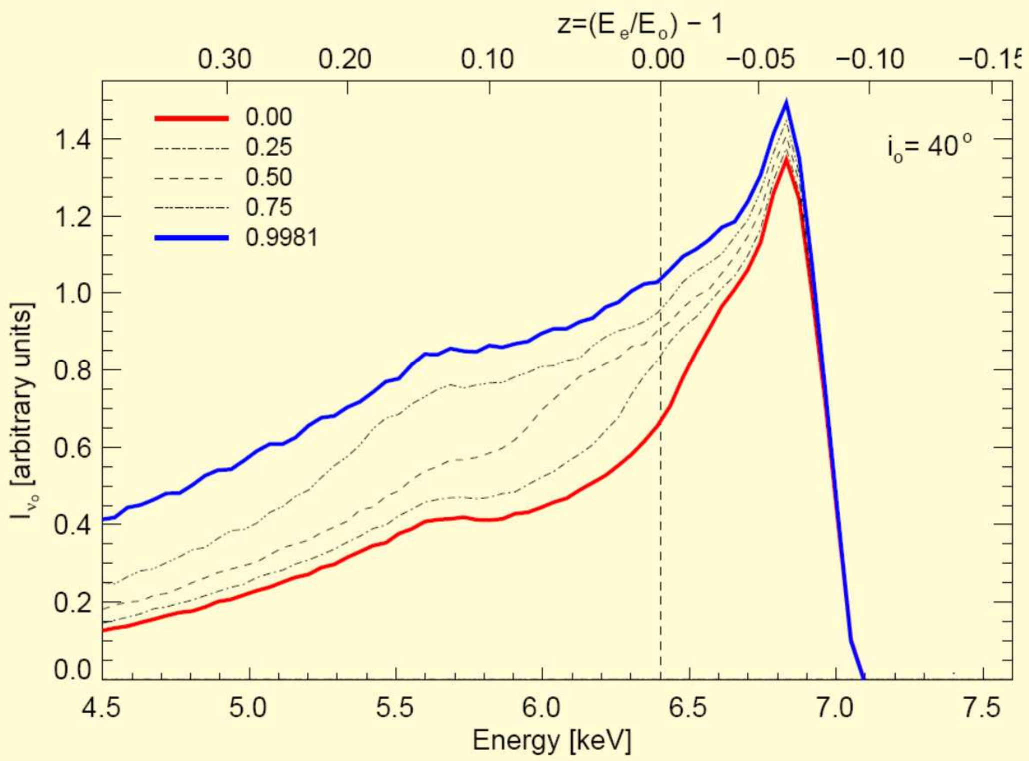


Black Hole rotation

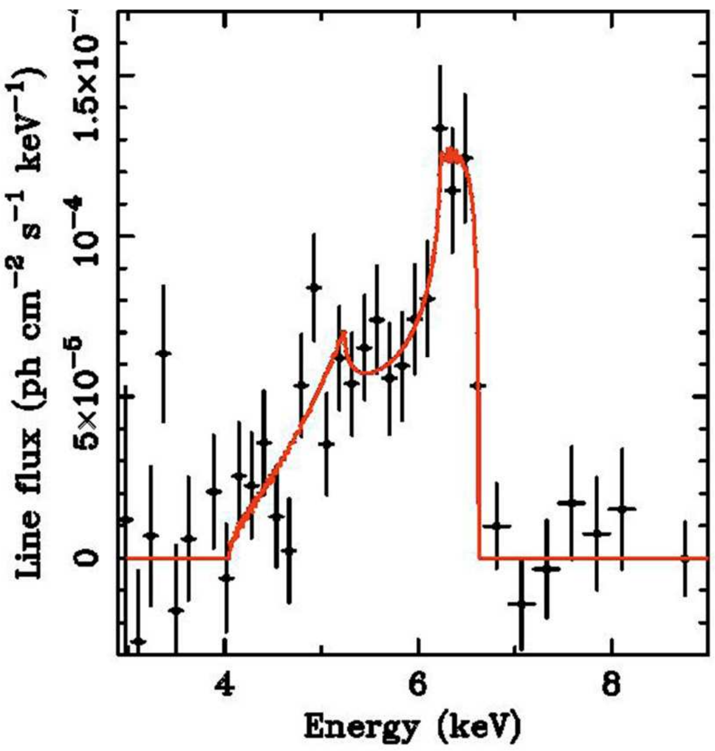


Important diagnostic tool:

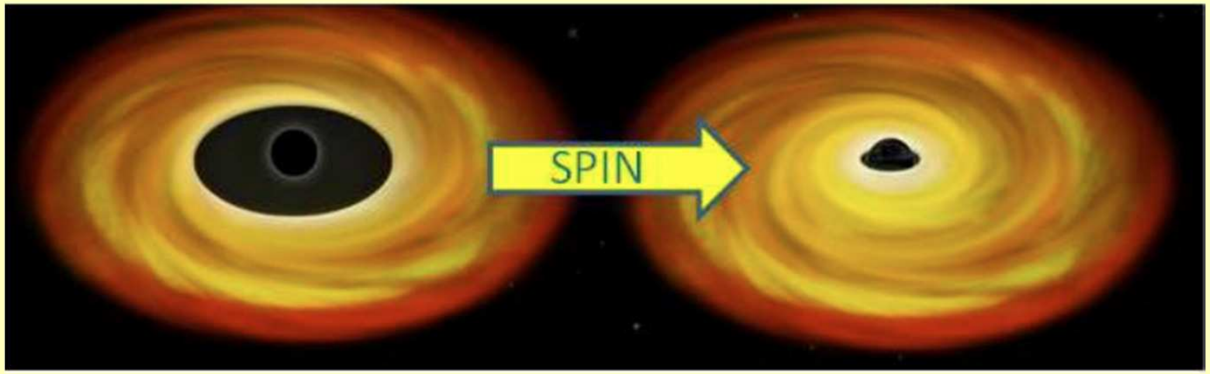
- ***Inner radius***
- ***Inclination angle***
- ***Ionization state***
- ***Spin of the Black Hole***

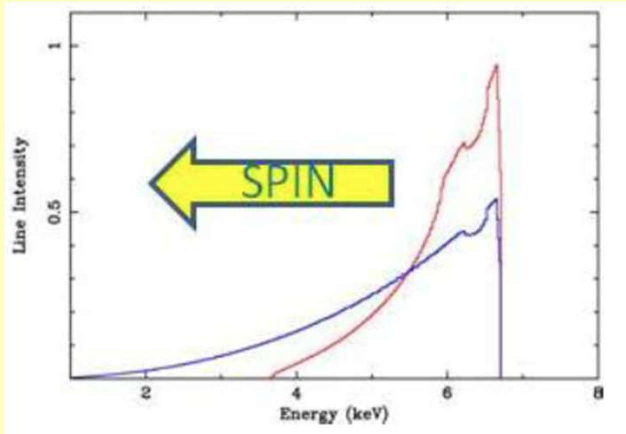


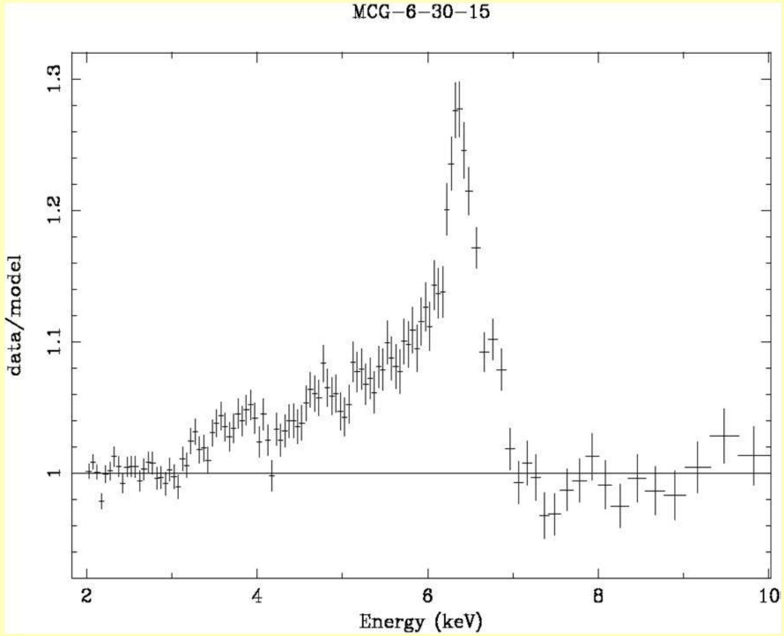
Tanaka +, 1995 (MGC 6-30-15)



The Spin of Black Holes







XMM observation of the iron line in MCG-6-30-15. The red wing extends to less than 4 keV, indicating an inner radius of less than 6 G M / C²

Spinning black hole?
(a > 0.93)

Wilms +, 2001; Fabian +, 2002

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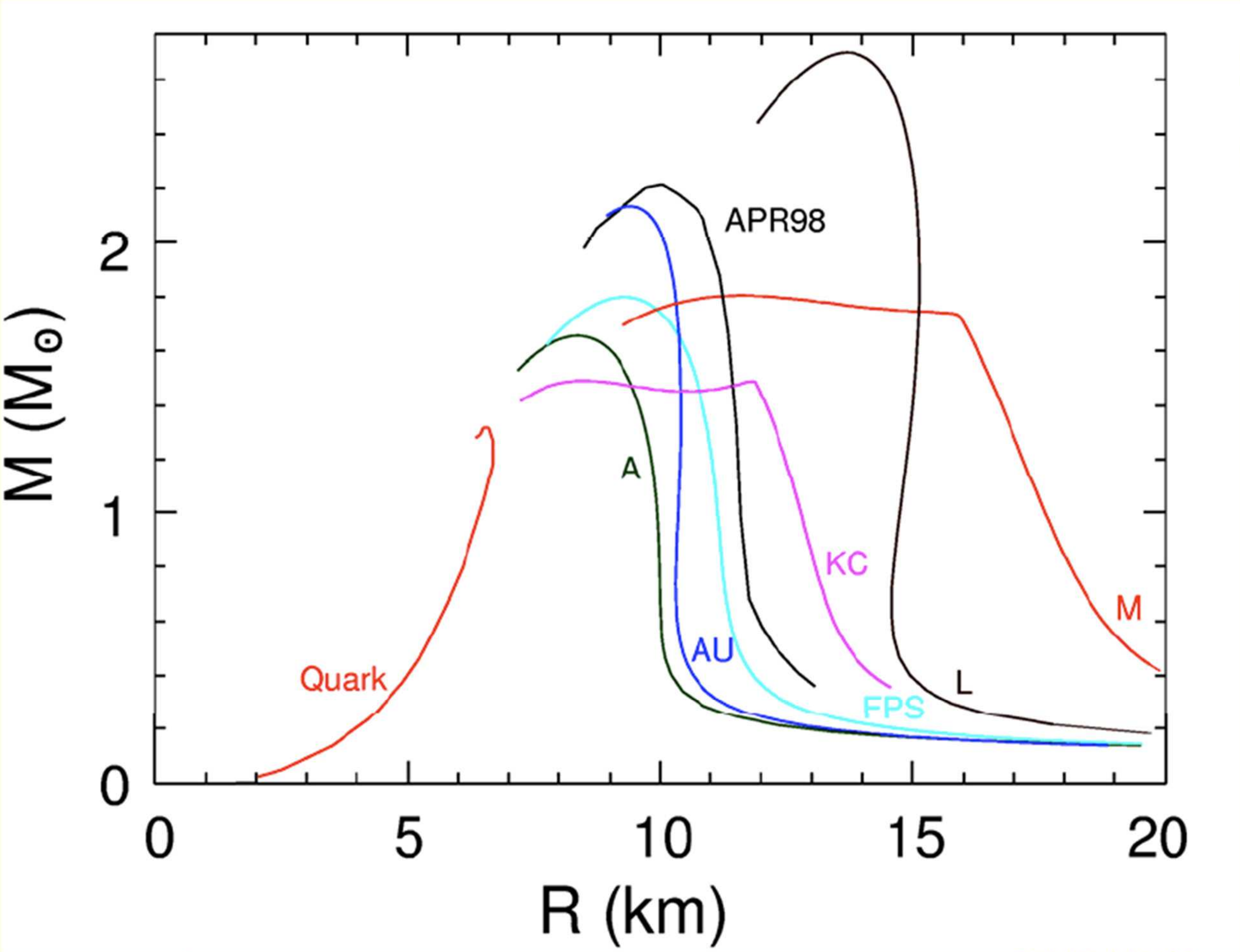
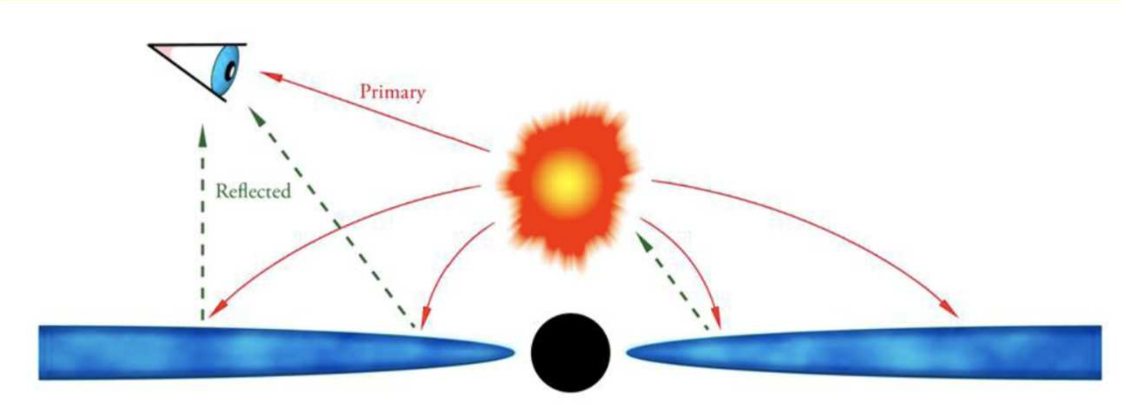
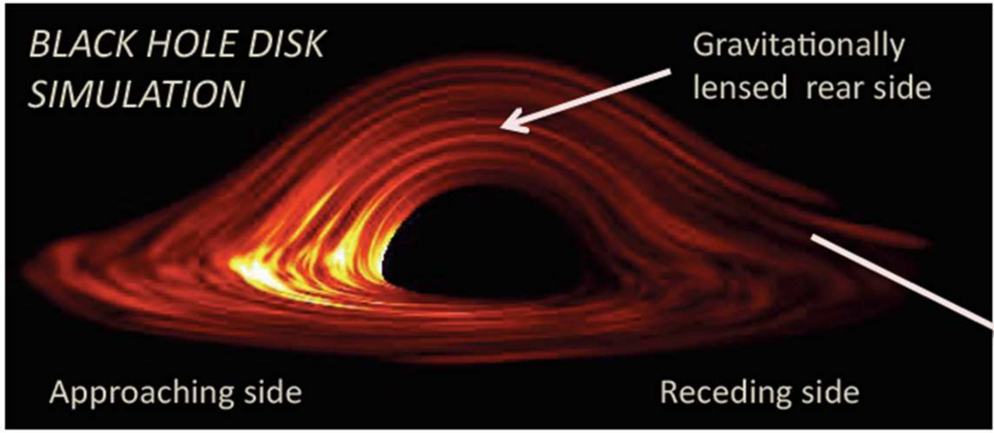
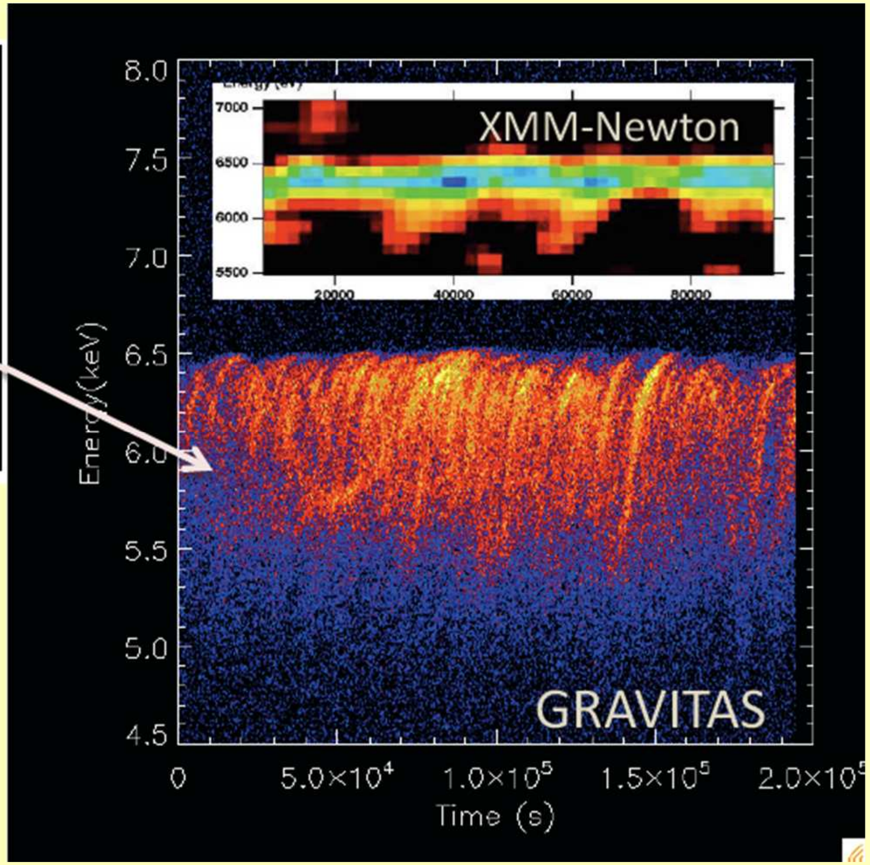


M (M$_\odot$)
R (km)
0
1
2
0
5
10
15
20
APR98
A
AU
FPS
KC
L
M
Quark



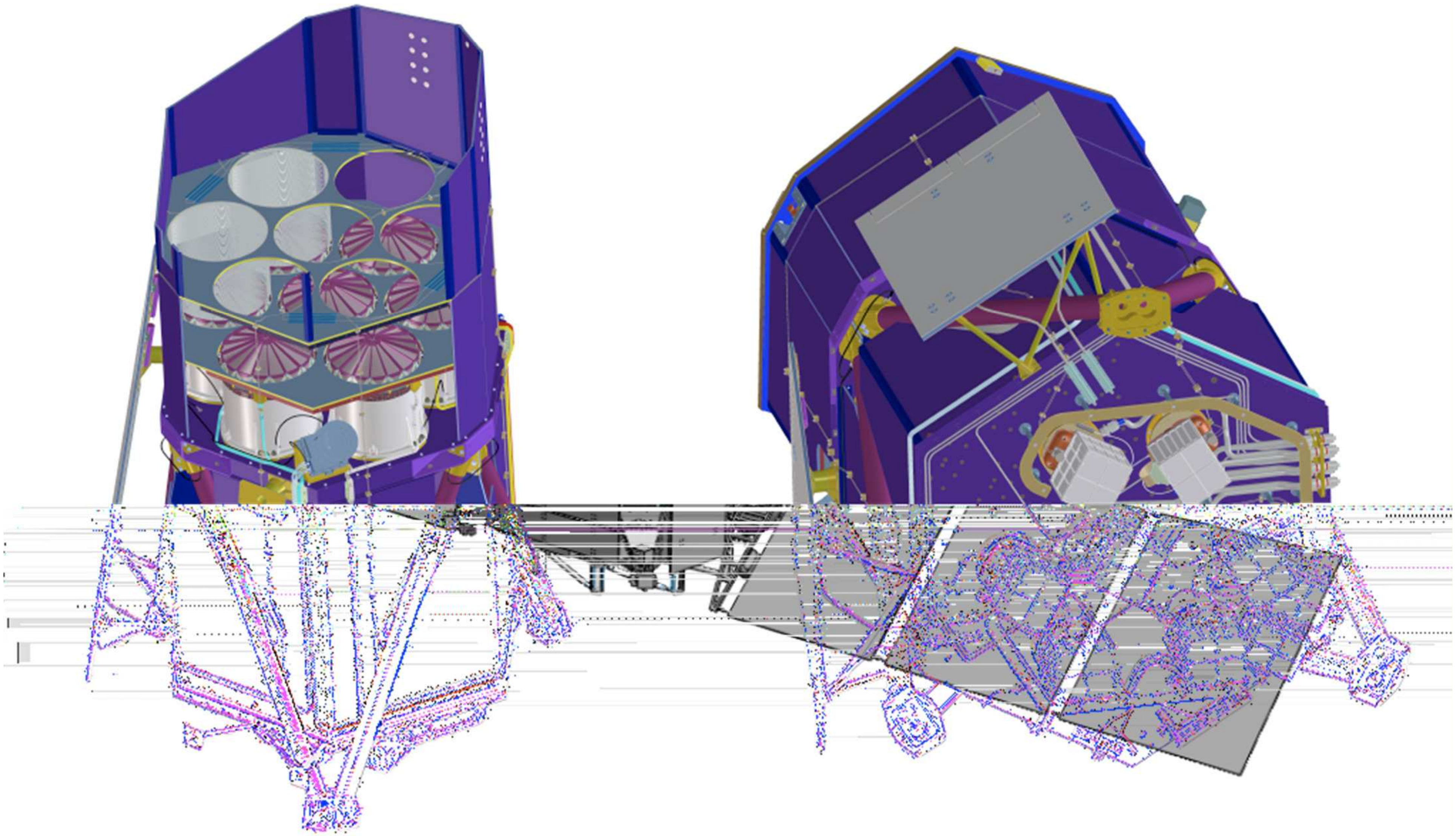
Because the features are variable in both flux and energy the disk can be mapped in the time-energy plan





Effect of "Riverberation": Rings and Hot Spots are seen due to turbolence and their emission is modulated with the orbits

eROSITA Telescope

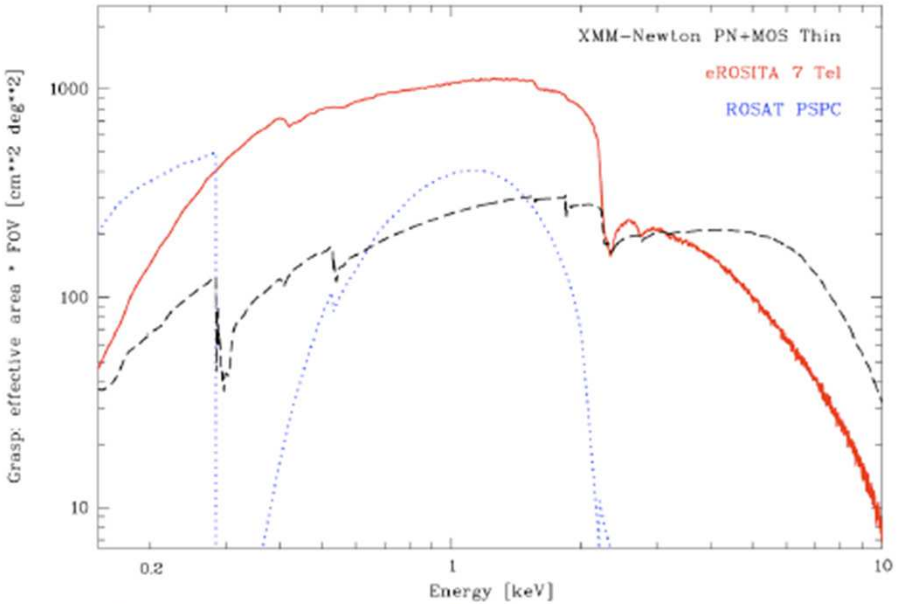


Performances

GRASP

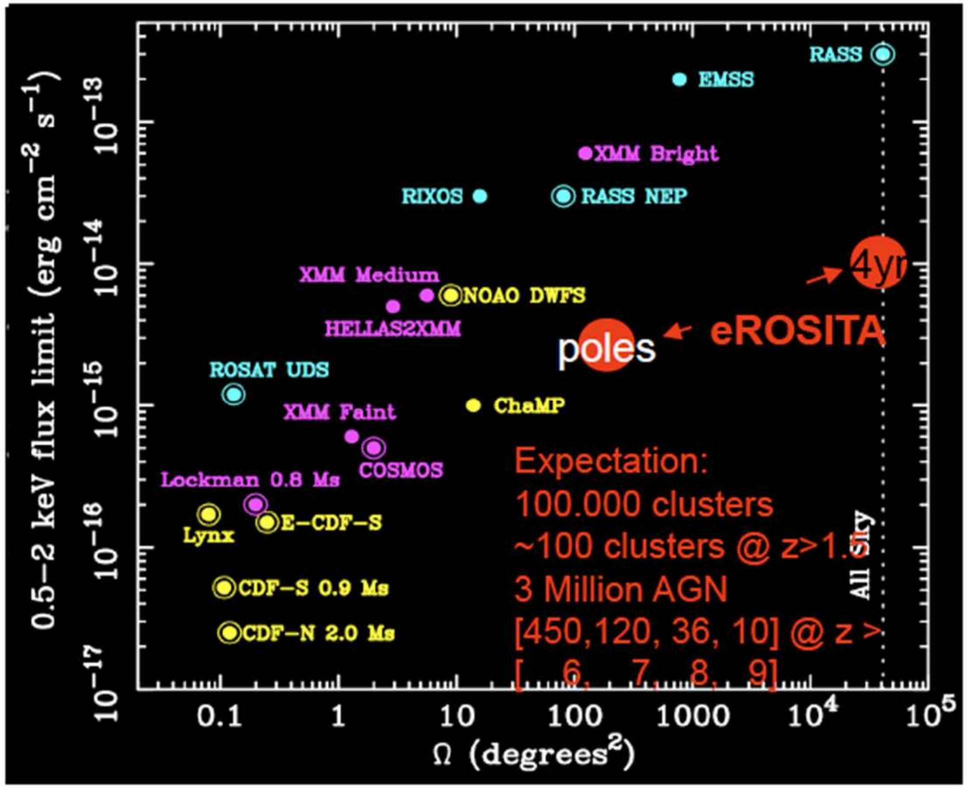
Expected Sources

- ***10^5 Clusters***
- ***10^2 Clusters at z>1***
- ***$3x10^6$ AGN***
- ***~ 700 AGN at z>6***



7 telescopes, 350 cm² each
large field of view (61 arcmin Ø)

~ 2 × XMM-Newton (MOS+PN)



- ***Energy Range 0.3-10 keV***
- ***Angular resolution pointed <15"***
- ***Angular resolution average <28"***

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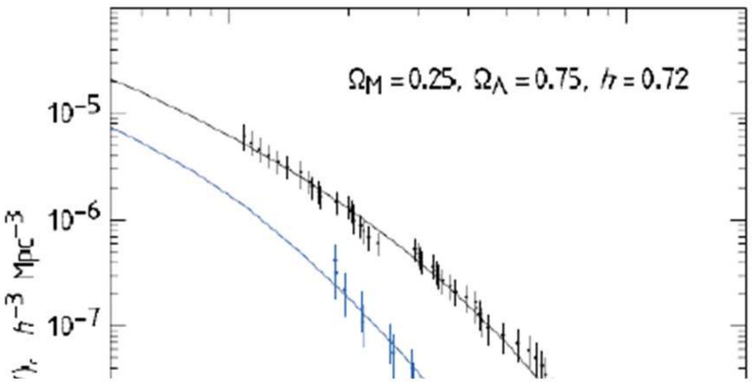
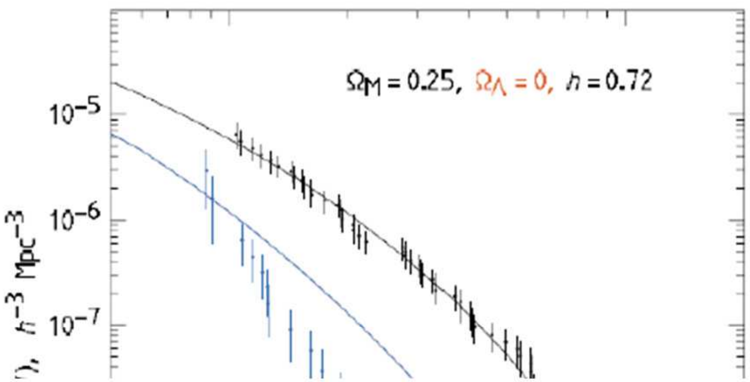
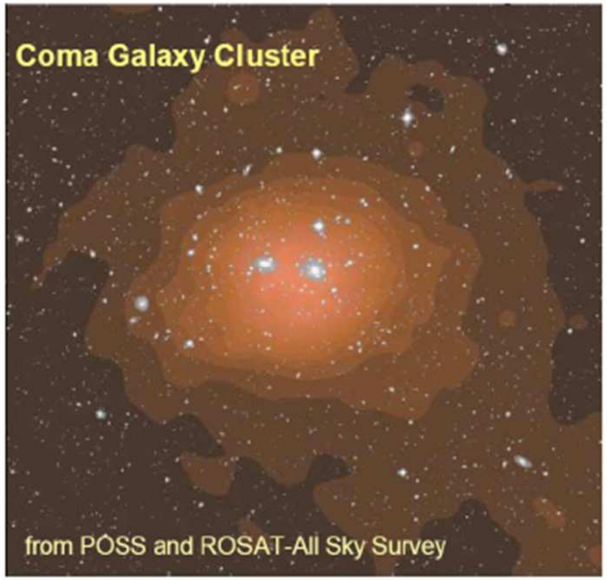
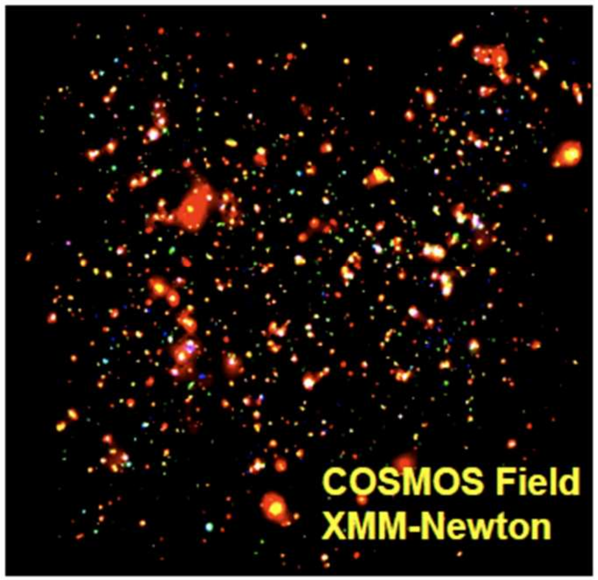
Distribution and Mass of Clusters vs. Cosmological Parameters





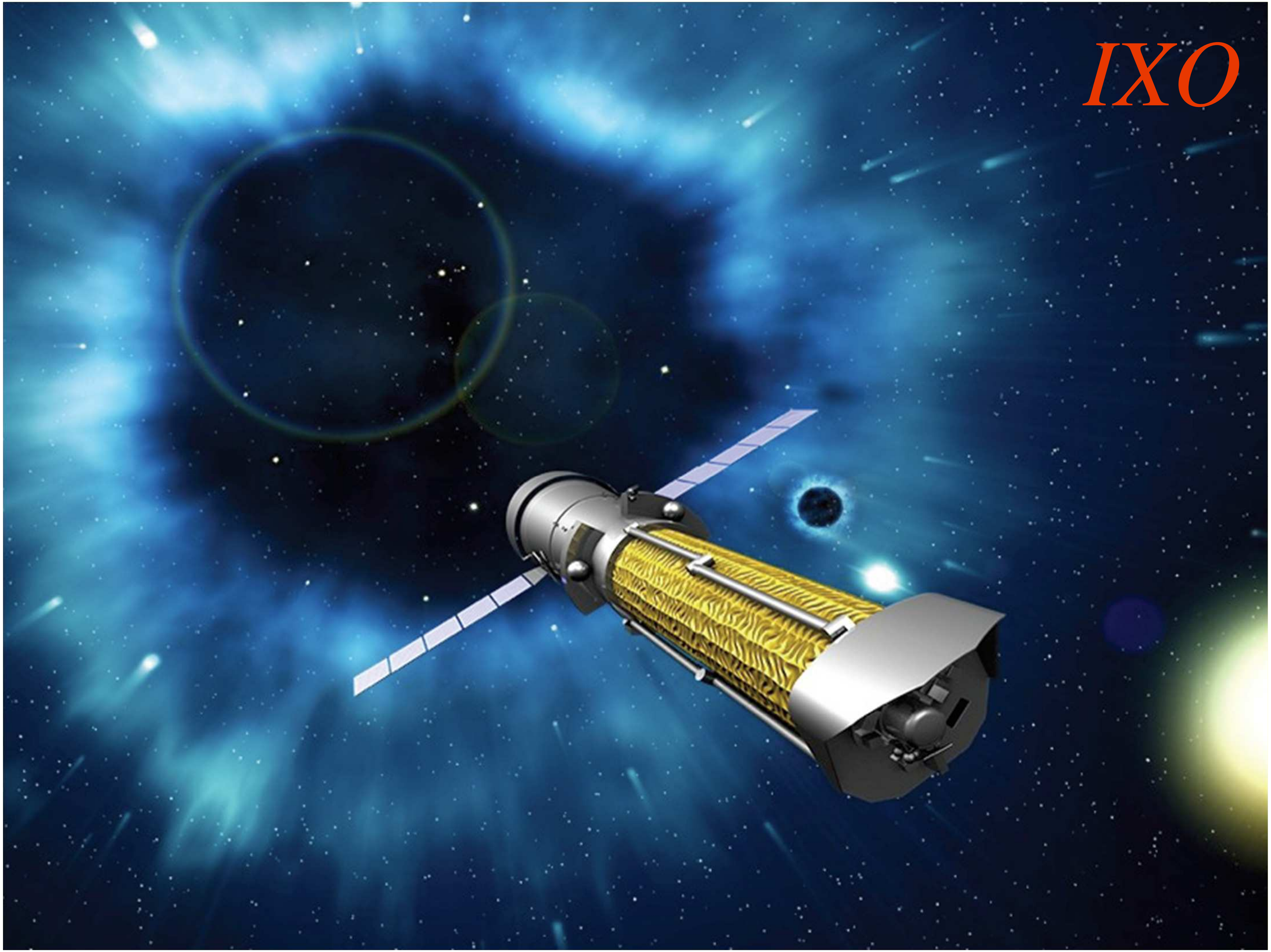




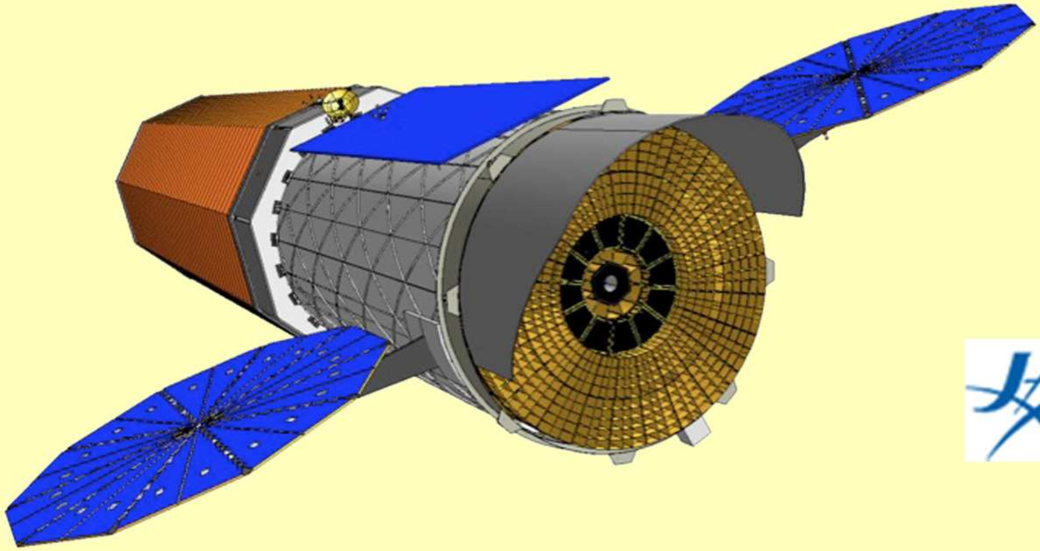
In X-rays we see clusters as one continuous entity

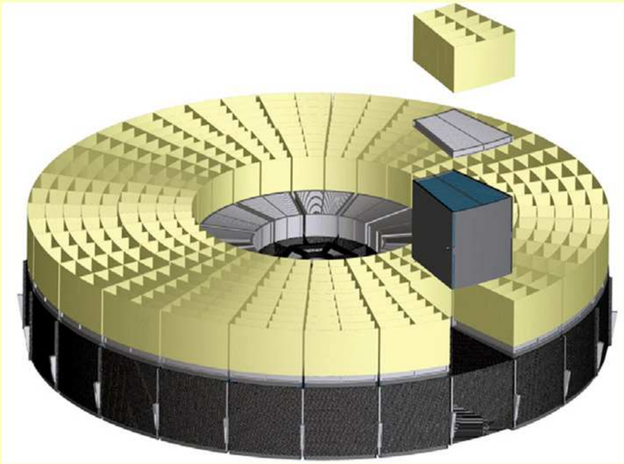
Clusters of galaxies are the largest gravitationally bound entities in the universe

Most cosmological studies involving galaxy clusters are based on X-ray surveys


IXO

International X-ray Observatory (IXO)





Launch in 2021 (?)

Mission Life
- 5 years required, 10 years goal

Launch
- December 2021
- Atlas V 551 or Ariane 5
- Max Liftoff Mass: 6425 kg

Orbit
- L2 800,000 km semi-major axis halo orbit

IXO Payload

- *Flight Mirror Assembly (FMA)*

– Highly nested grazing incidence optics

– 3 m^2 @ 1.25 keV with a 5” PSF

- *Instruments*

– X-ray Micro-calorimeter Spectrometer (XMS)

2.5 eV with 5 arc min FOV

– X-ray Grating Spectrometer (XGS)

R = 3000 with 1,000 sq cm

– Wide Field Imager (WFI) and Hard X-ray Imager (HXI)

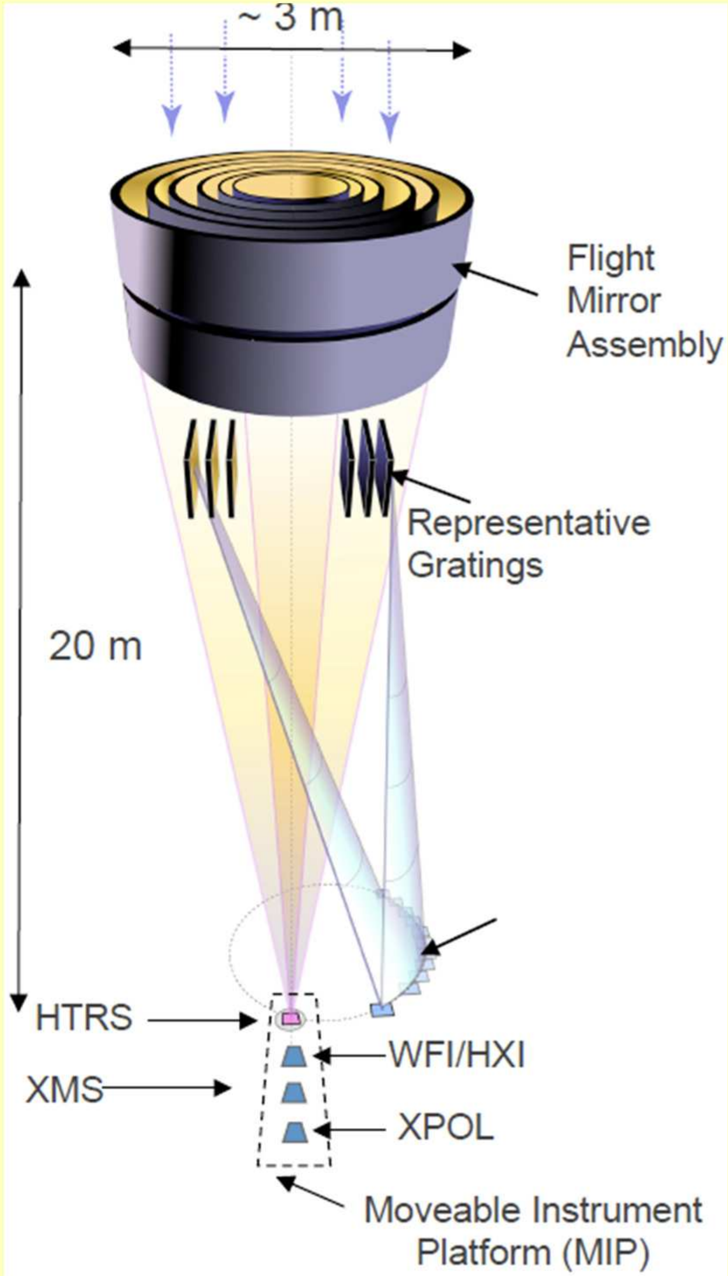
18 arc min FOV with CCD-like resolution

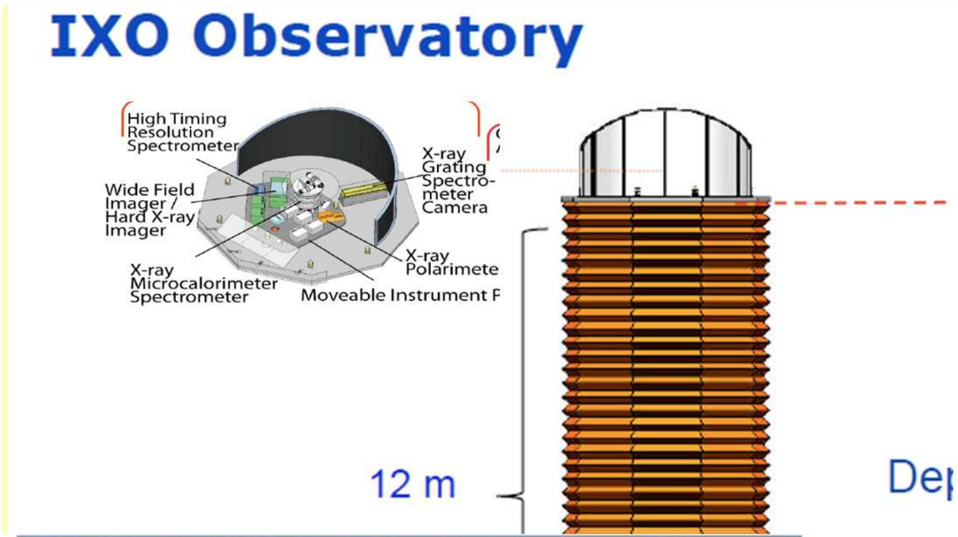
0.3 to 40 keV

– X-ray Polarimeter (X-POL)

– High Time Resolution Spectrometer

Fluxes up to 10^6 events in the 0.3-10 keV range (5 Crab) with 150 eV FWHM @6 keV





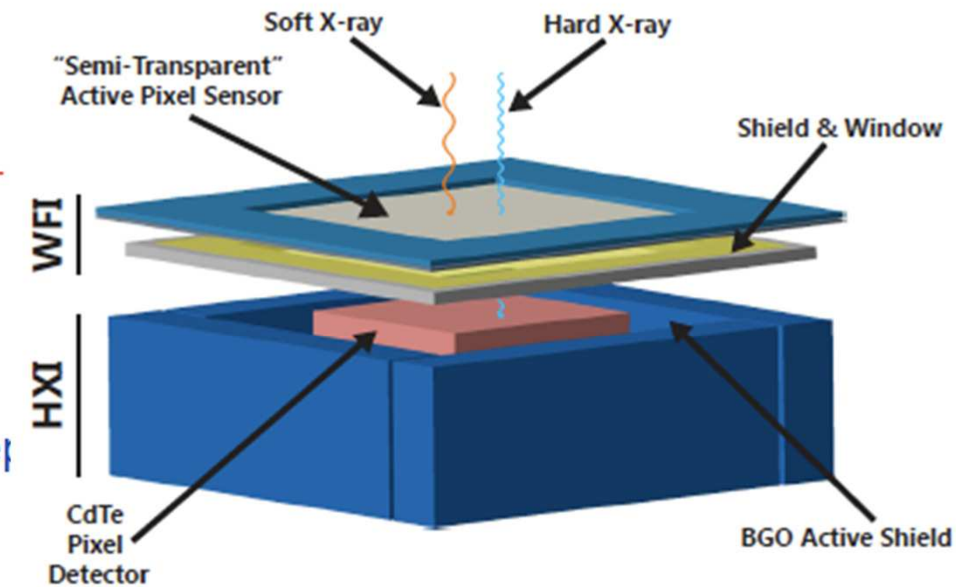


Figure 2-6. WFI/HXI Schematic: The WFI soft X-ray Active Pixel Sensor (APS) is in front of the HXI CdTe detector.

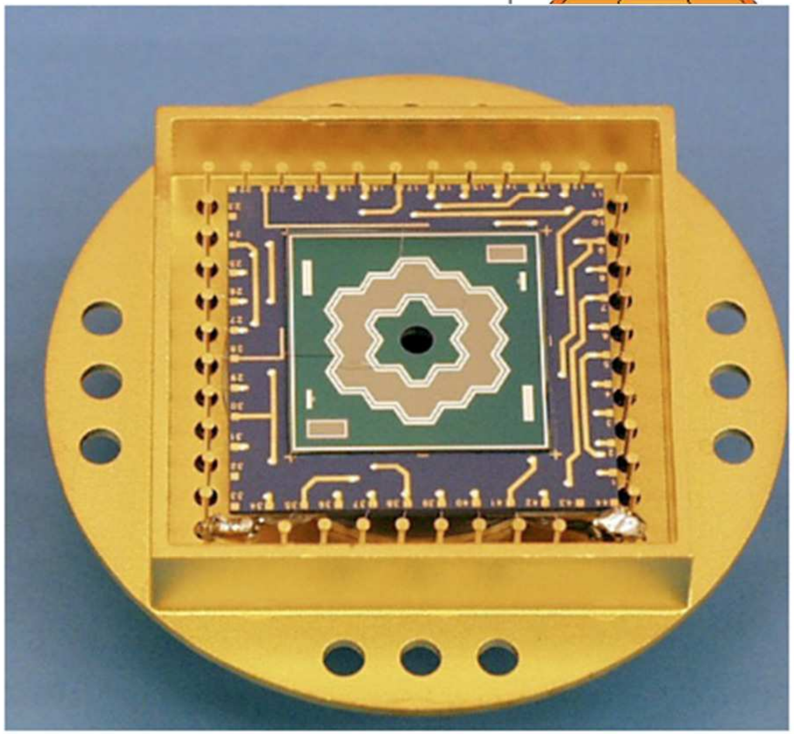
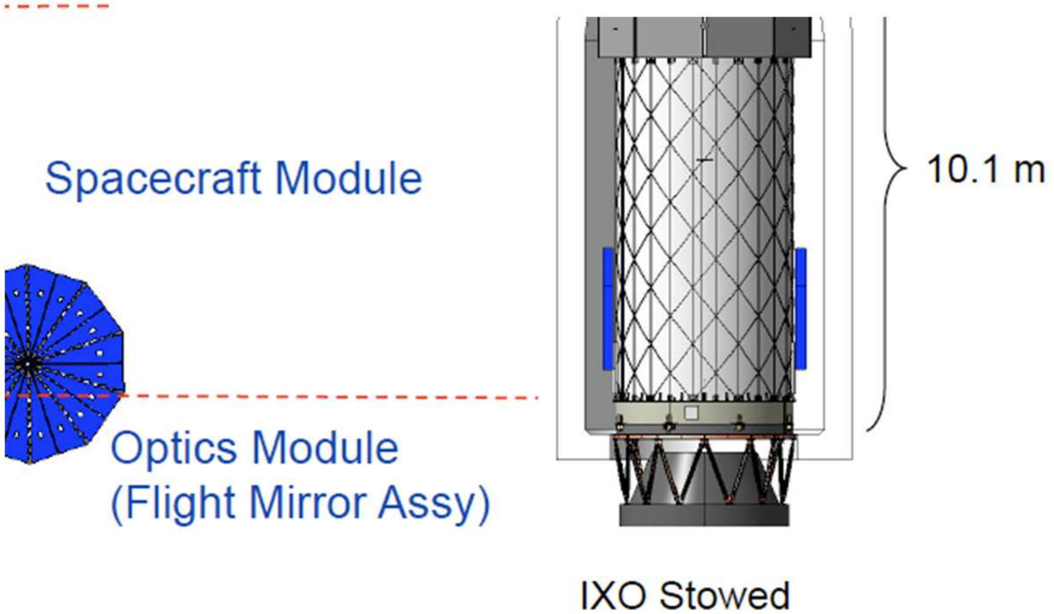
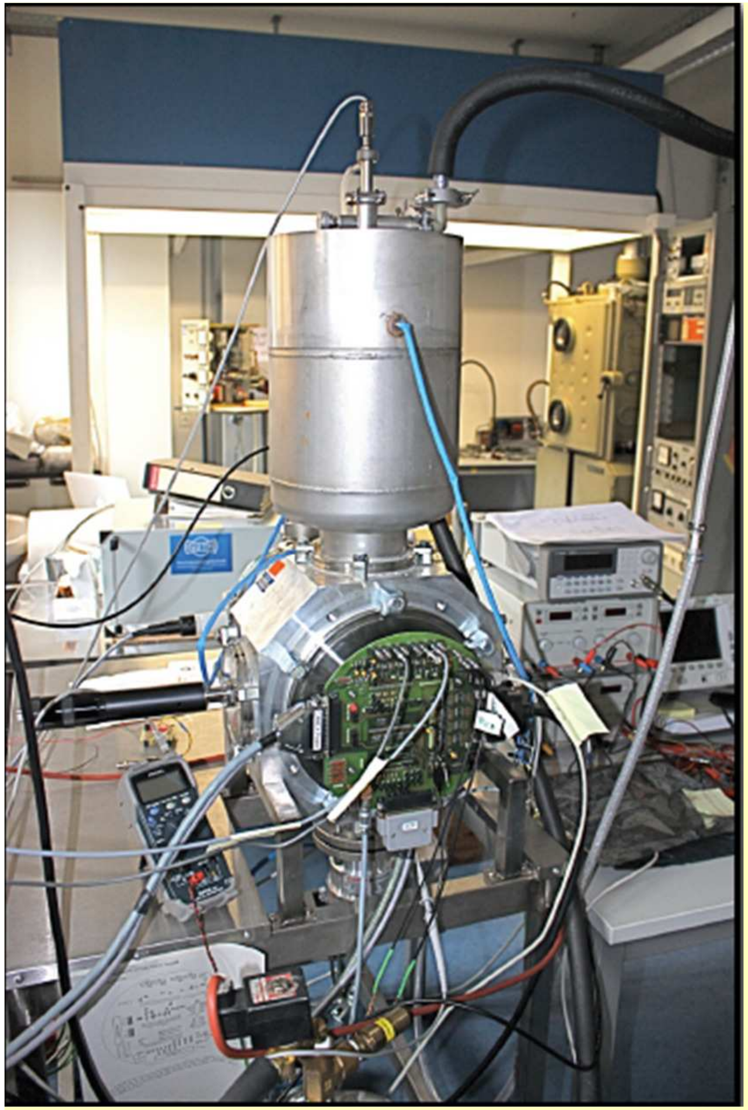


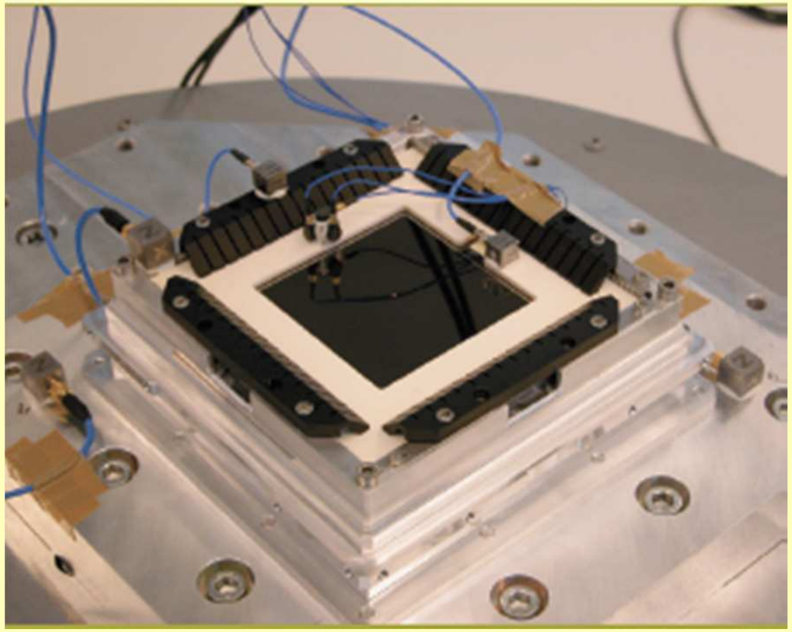
Figure 2-8. Photograph of 12 hexagonal Silicon Drift Detectors (the 7 central SDDs are removed). The layout/design is the same as for the HTRS detector.



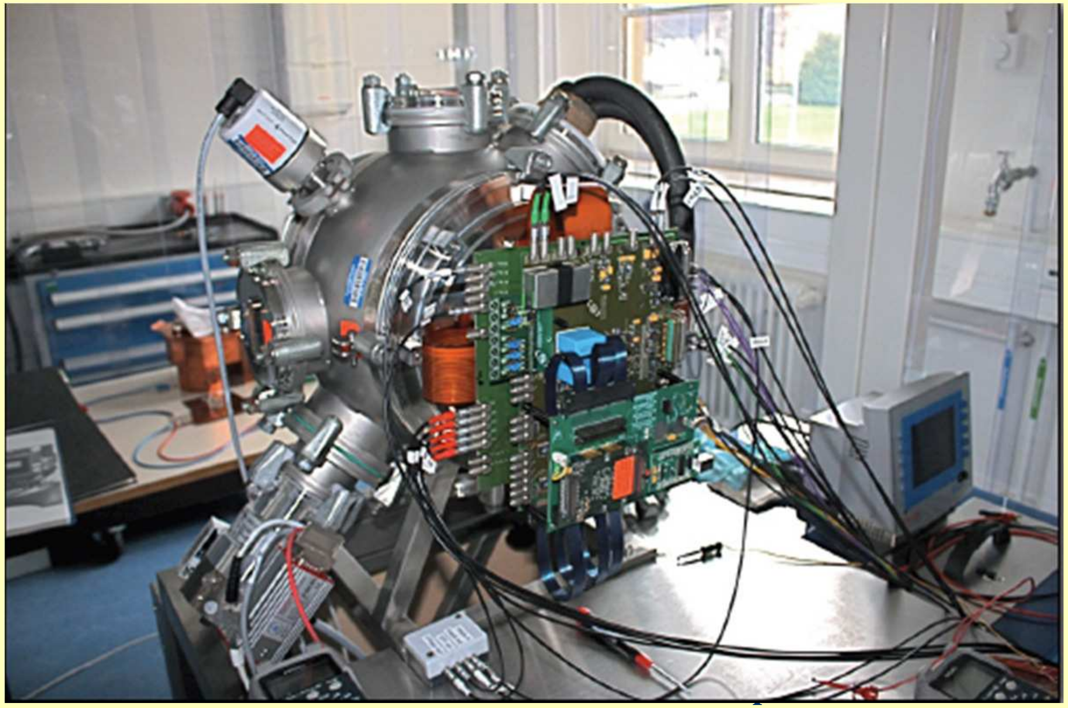
KEY PERFORMANCE REQUIREMENTS

Mirror Effective Area	3 m^2 @ 1.25 keV 0.65 m^2 @ 6 keV with a goal of 1 m^2 150 cm^2 @ 30 keV with a goal of 350 cm^2	Black hole evolution, large scale structure, cosmic feedback, Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution (FWHM)	ΔE = 2.5 eV within 2 x 2 arc min (0.3 – 7 keV) . ΔE = 10 eV within 5 x 5 arc min (0.3 - 7 keV) ΔE =150 eV at 6 keV within 18 arc min diameter (0.1 - 15 keV) $E/\Delta E$ = 3000 with an average area of 1,000 cm^2 between 0.3 -1.0 keV and a goal of 3000 cm^2 for point sources ΔE = 1 keV within 8 x 8 arc min (10 – 40 keV)	Black Hole evolution, Large scale structure Missing baryons using tens of background AGN
Angular Resolution	≤5 arc sec HPD (0.1 – 7 keV) 30 arc sec HPD (7 - 40 keV); goal of 5 arc sec	Large scale structure, cosmic feedback, black hole evolution, missing baryons
Count Rate	1 Crab with >90% throughput. ΔE < 150 eV @ 6 keV (0.1 – 15 keV)	Strong gravity, EOS
Polarimetry	1% MDP on 1 mCrab in 100 ksec, 3σ, 2 - 6 keV,2.6 x 2.6 arc min FOV with 7 arc sec HPD.	AGN geometry, strong gravity
Astrometry	1 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	100 μsec	Neutron star studies





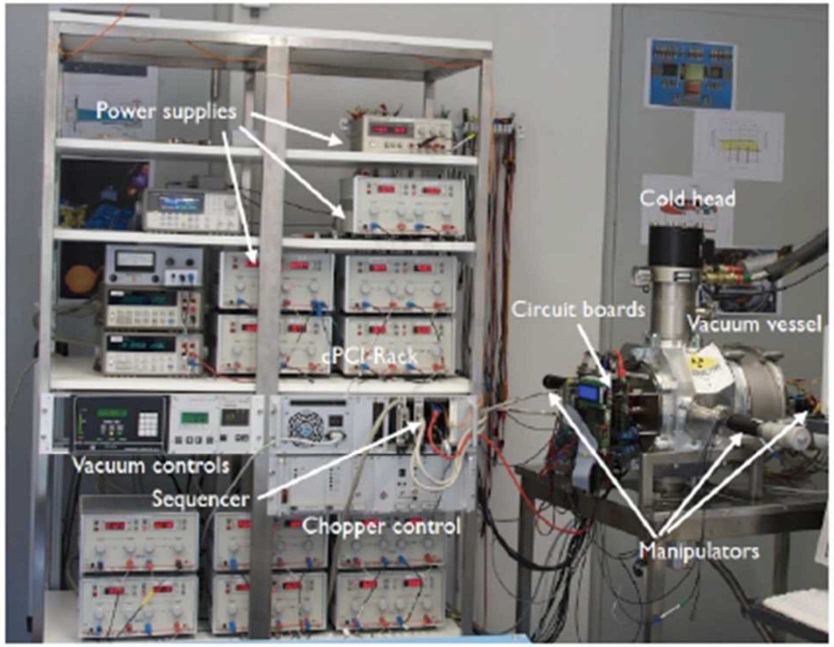
Stacked detector (LED+HED) Simbol-X: SVM



eRosita Framestore CCD testing set-up

IXO-WFI lab setup at IAAT

Courtesy of Chris Tenzer

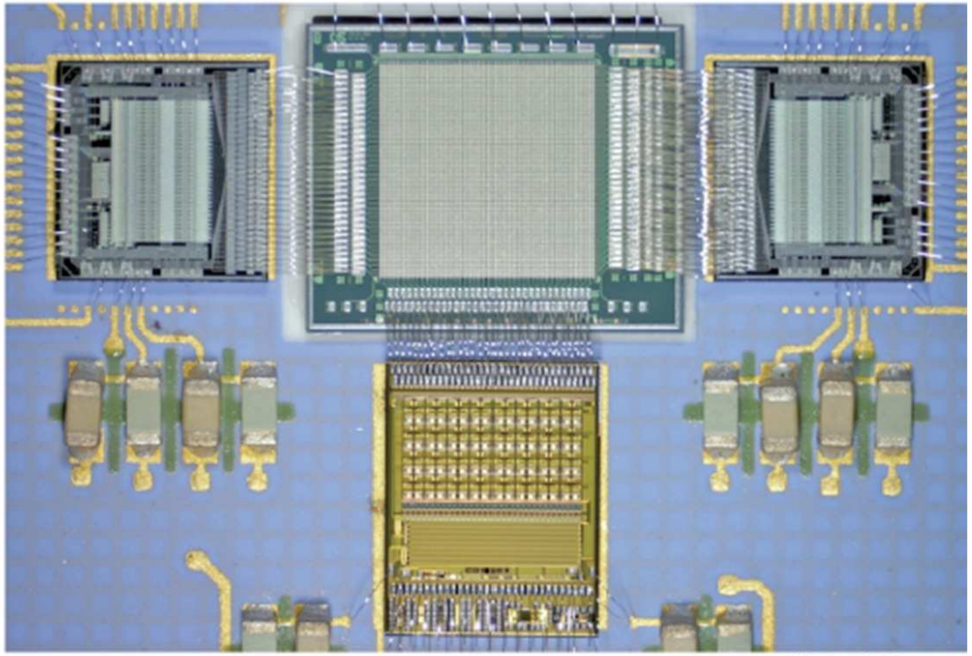


Goal of this setup:

- operate a 64 x 64 Pixel prototype
- test electronics components developed for detector readout and event-preprocessing

Performance measurements:

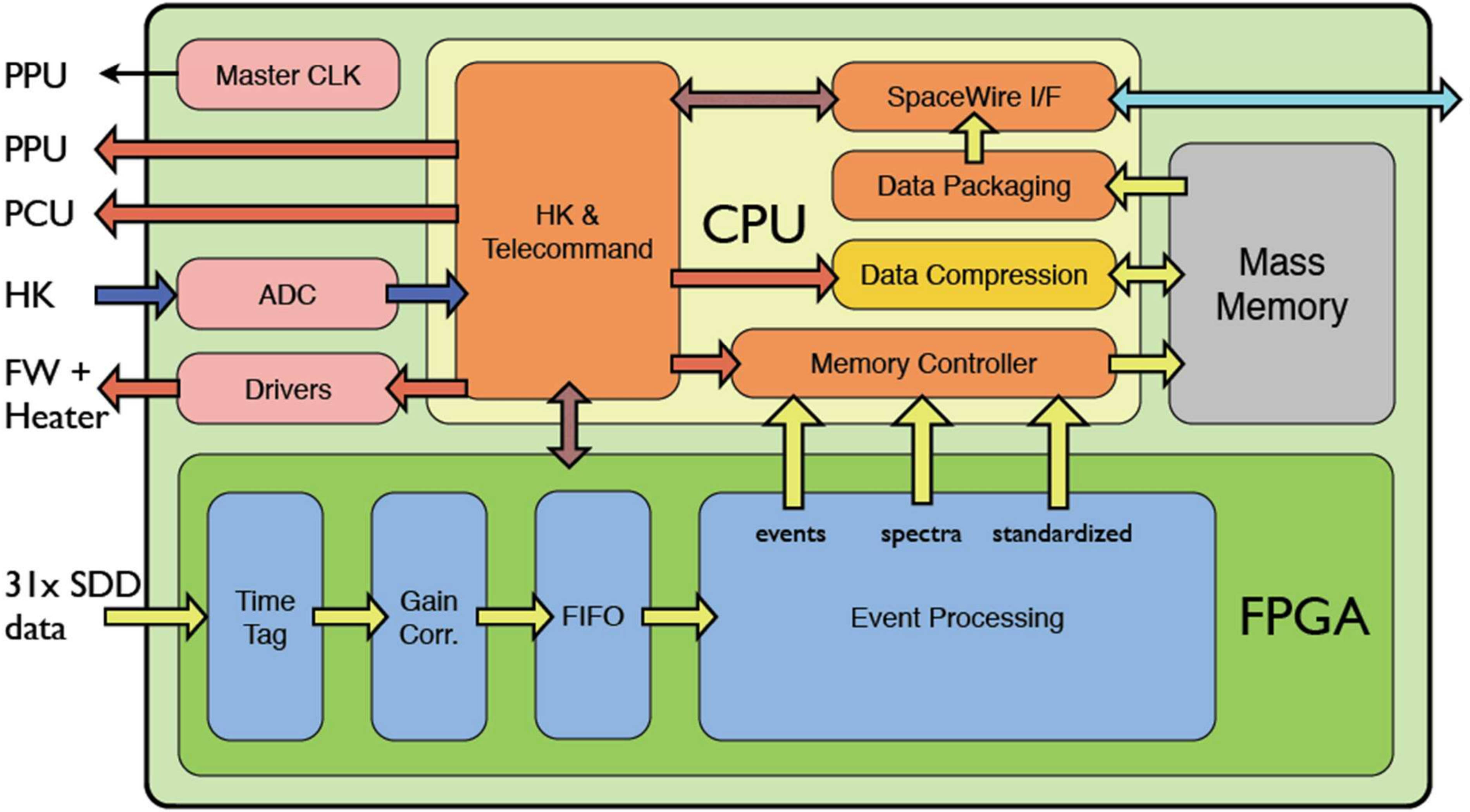
- energy resolution
- split event distribution
- noise and offset stability as a function of temperature



images: Michael Martin, I

Courtesy of Chris Tenzer

IAAT hardware contribution for IXO-HTRS

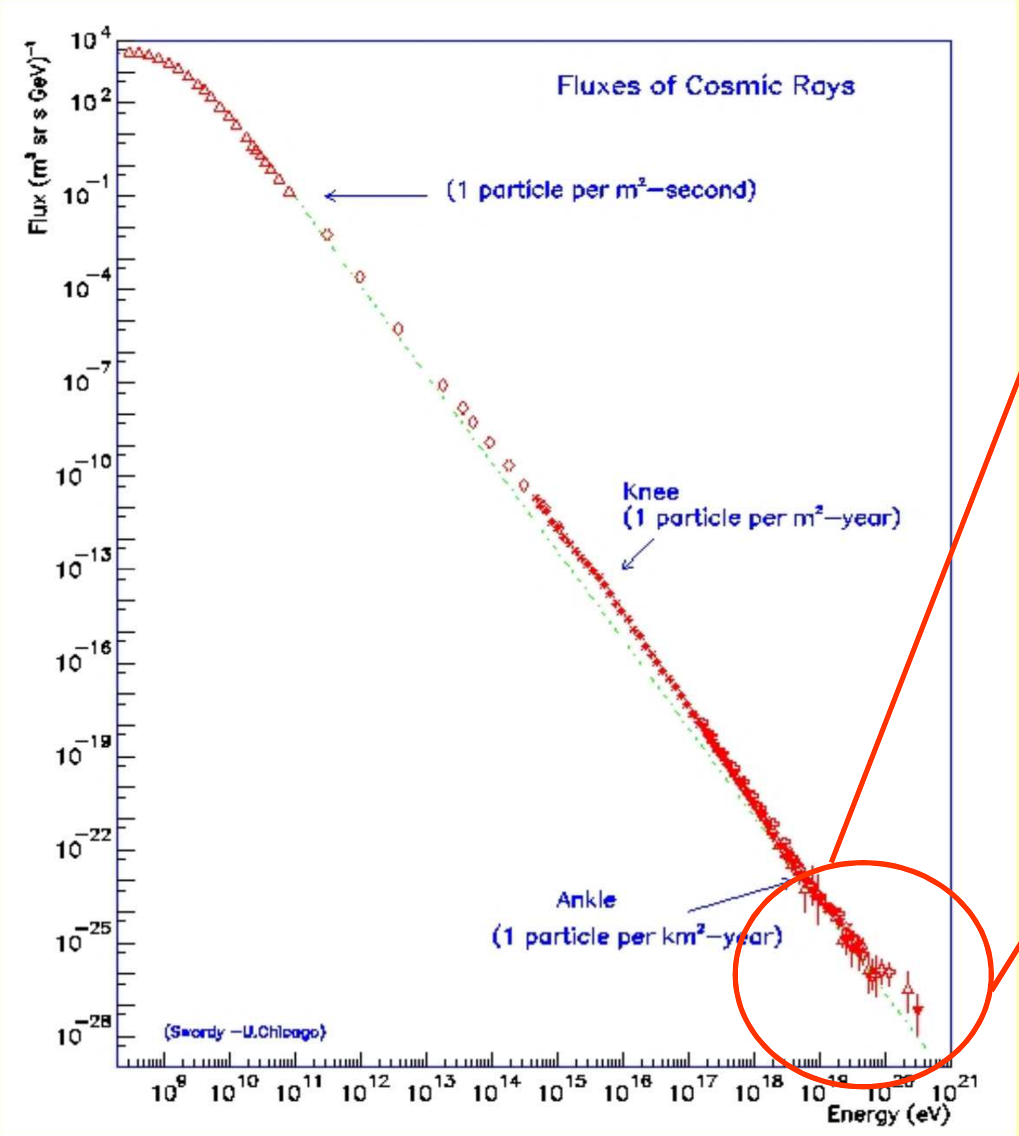


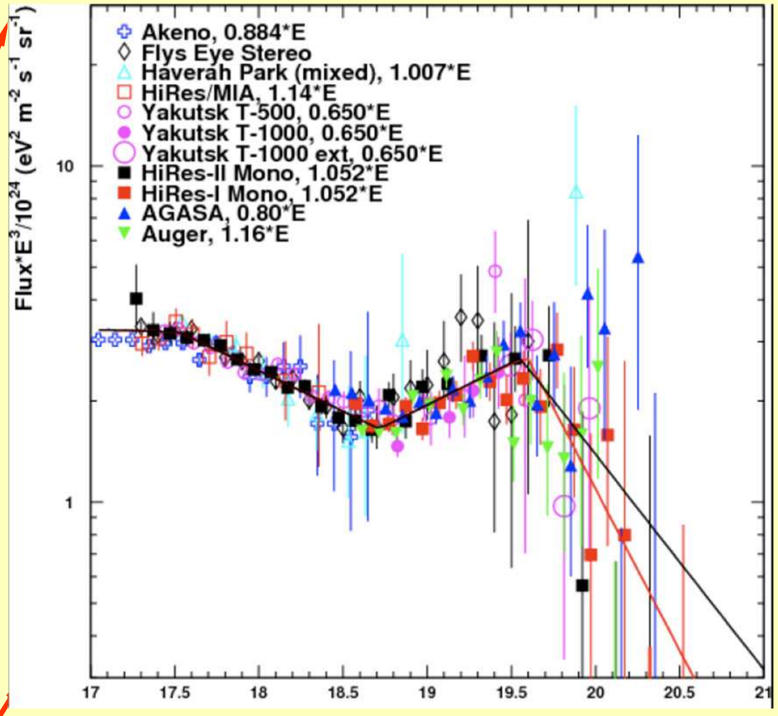
Digital Data Processing Unit

Part II: The exploration from space of the UHE Universe

(I know quite a jump…)

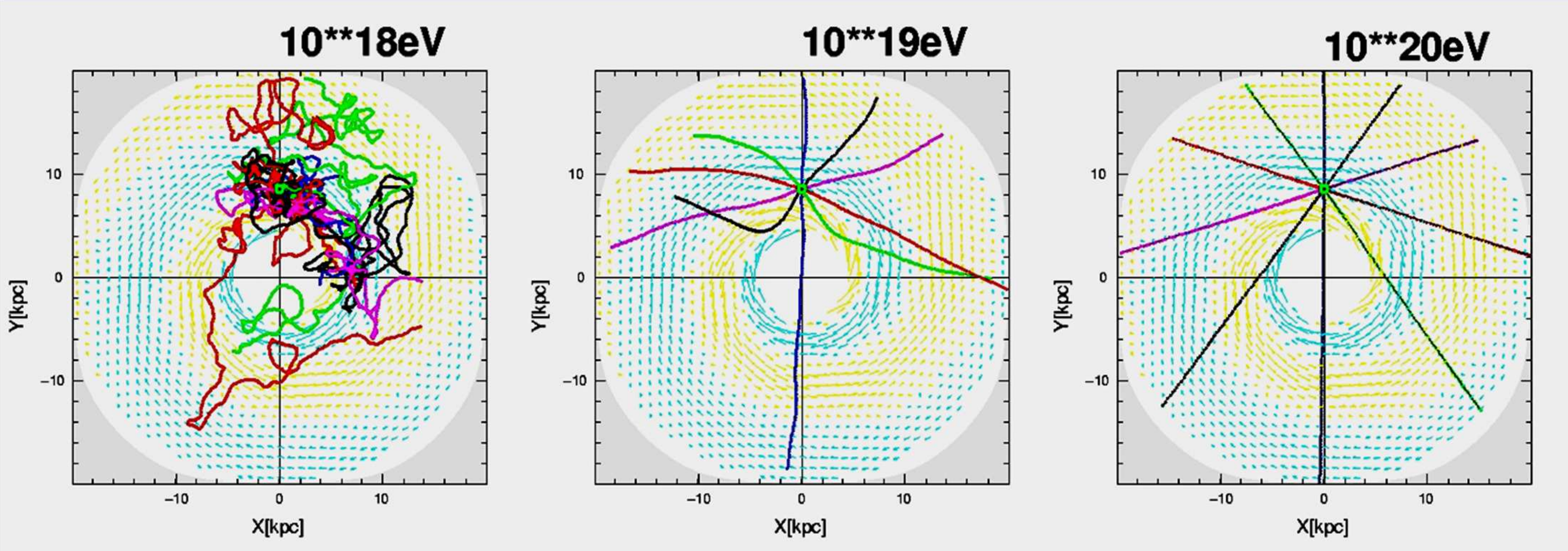
UHE → $E > (5\text{-}6)\times10^{19}$ eV (~10^{16} keV)





Their origin, nature and even their route to Earth presents an extraordinary puzzle

Astrophysics: two problems
1. Cosmic Ray propagation in our Galaxy



Largely unknown local extragalactic and galactic magnetic field limits proton astronomy to higher energies

Gyroradius...

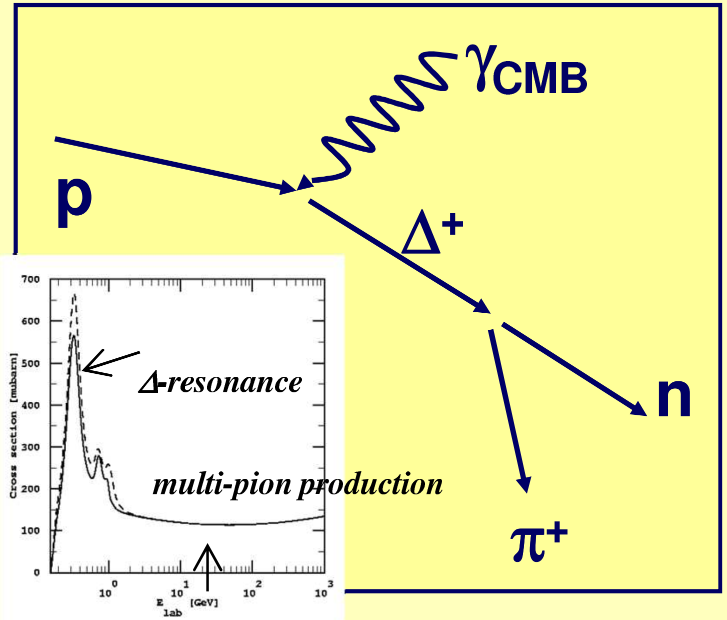
$$r = \frac{\gamma m_0 v \sin\theta}{ZeB} = \left(\frac{pc}{Ze}\right)\frac{\sin\theta}{Bc}$$

2. The GZK Effekt



Greisen (1966) and, independently Zatsepin & Kuz'min (1966)

Kenneth Greisen ***George Zatsepin*** ***Vadim Kuzmin***



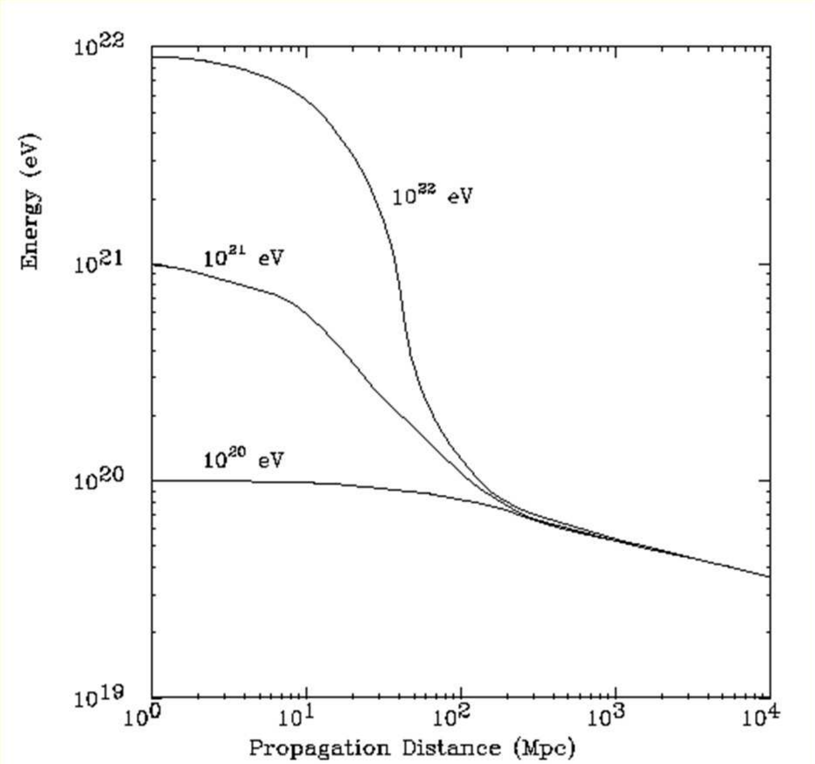
$$E_{th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \approx 5 \cdot 10^{19} \text{eV}$$

$$p + \gamma \rightarrow n + \pi^+$$

$$p + \gamma \rightarrow p + \pi^0$$

$$p + \gamma \rightarrow p + e^+ + e^-$$

Attenuation length, a limited horizon



$$\Delta E_p \approx 20\% E_p$$

$$\lambda_{int} \approx 10 \text{ Mpc}$$

$$L_{Hor}^{GZK} \approx 100 \text{ Mpc}$$

Nagano & Watson, Rev. Mod. Phys, Vol. 72, N° 3 (2000)

$A + h\nu \rightarrow (A\text{-}1) + N$

$A + h\nu \rightarrow (A\text{-}2) + 2N$

$A + h\nu \rightarrow A + e^+ + e^-$

Photodisintegration (Puget et al., 1976)

Pair production (Blumenthal, 1970)

E ~ 2×10^{20} eV (nuclei)

GZK effect ?

Viewed from a distance, an EAS appears as a ***luminous disc moving at the speed of light***. Its luminosity increases up to a maximum and gradually fades

The number of charged particles (mainly e+ and e-) can be well parametrized by the Gaisser-Hillas function

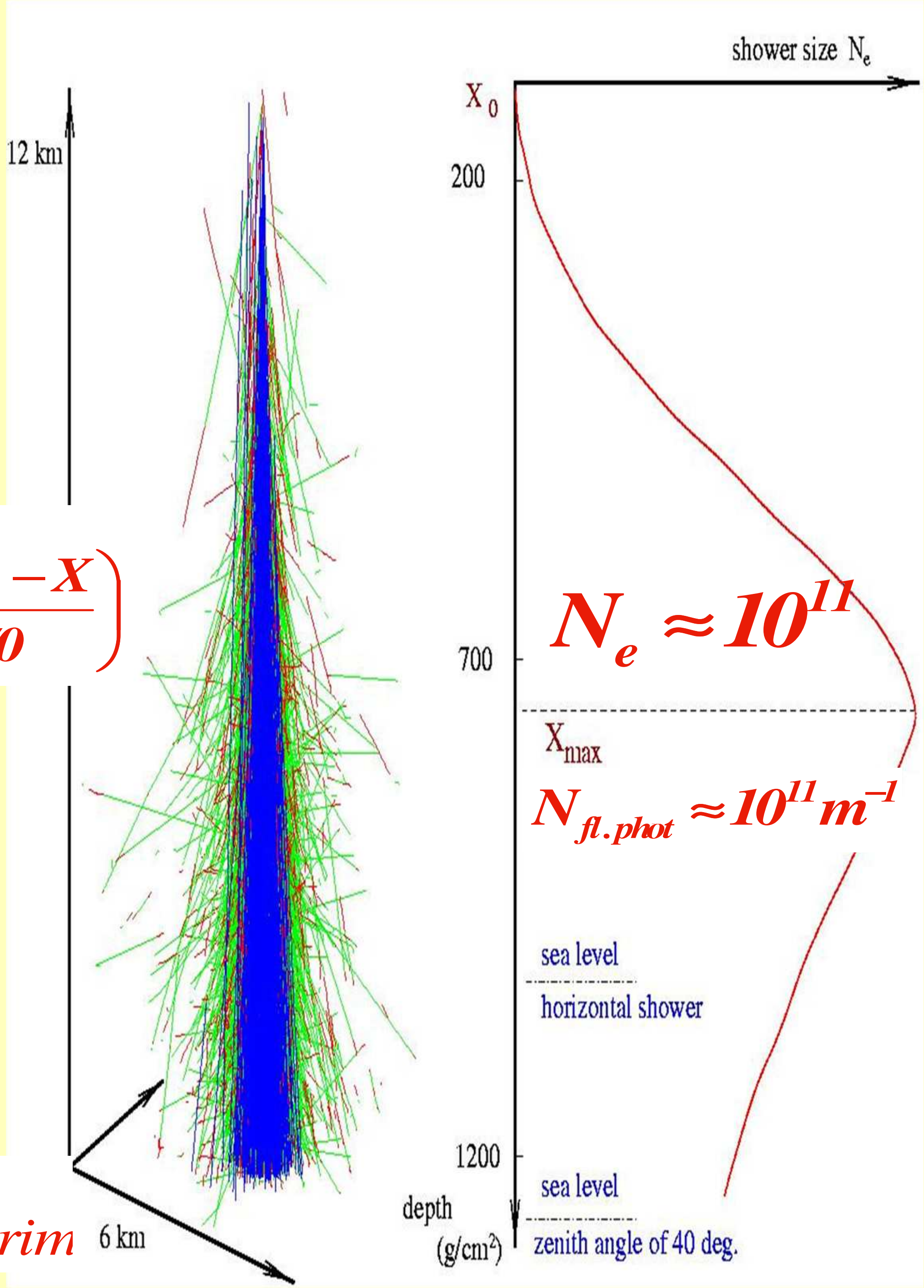
$$N_e = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X_0}{70}} exp\left(\frac{X_{max} - X}{70}\right)$$

X_0 is the depth of the first interaction

X_{max} is the depth of the maximum

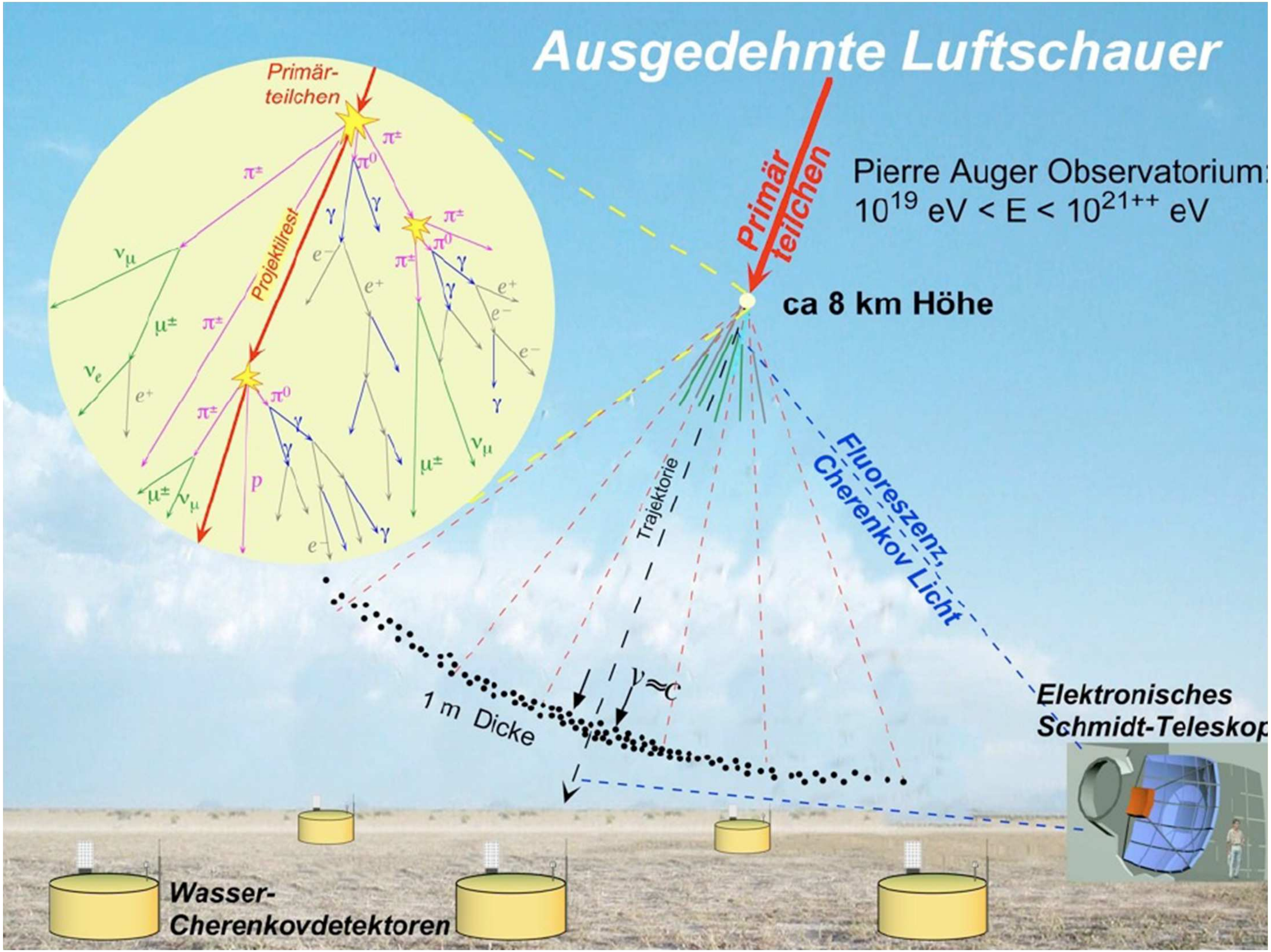
X is the cumulate slant depth, in g/cm² (thickness of air traversed)

$$X_{max} = X_0 + 55\log_{10} E_{prim}$$



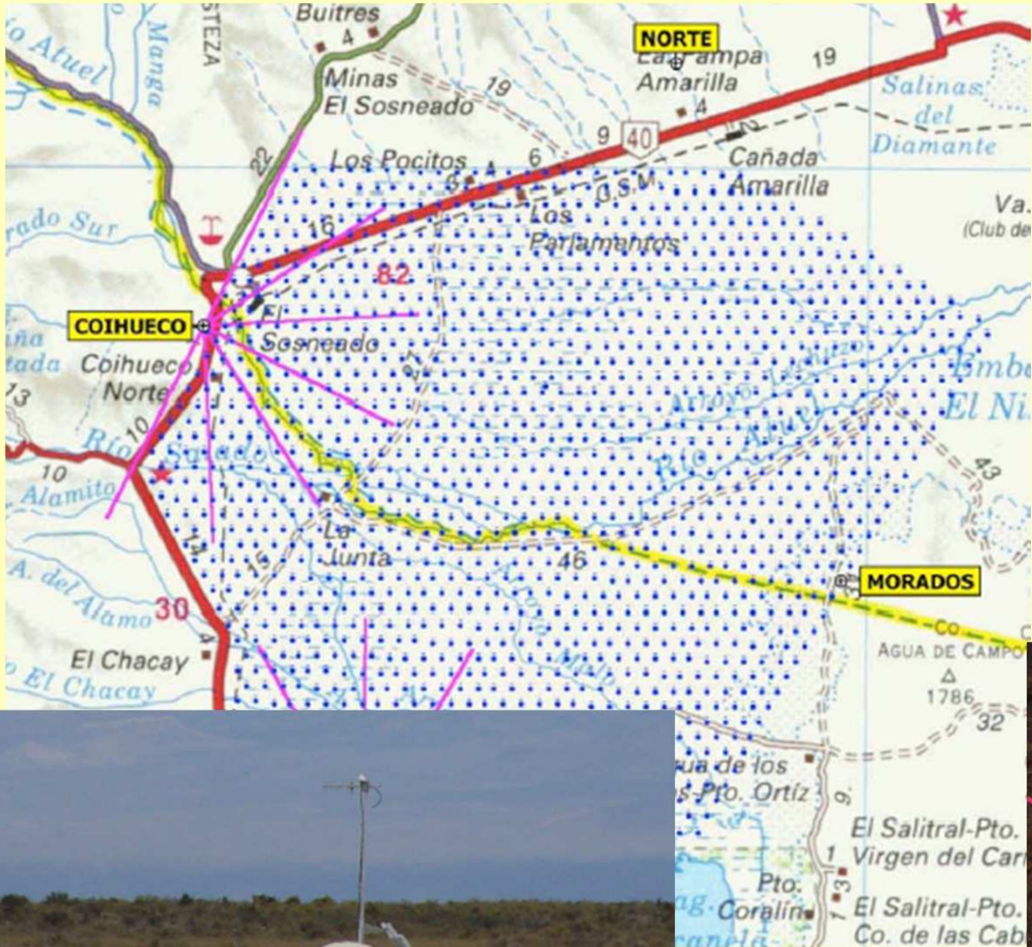
$$N_e \approx 10^{11}$$

$$N_{fl.phot} \approx 10^{11} m^{-1}$$



Ausgedehnte Luftschauer
Primär-teilchen
Pierre Auger Observatorium:
10^19 eV < E < 10^21++ eV
ca 8 km Höhe
Projektilrest
Trajektorie
Fluoreszenz, Cherenkov Licht
v≈c
1 m Dicke
Elektronisches Schmidt-Teleskop
Wasser-Cherenkovdetektoren

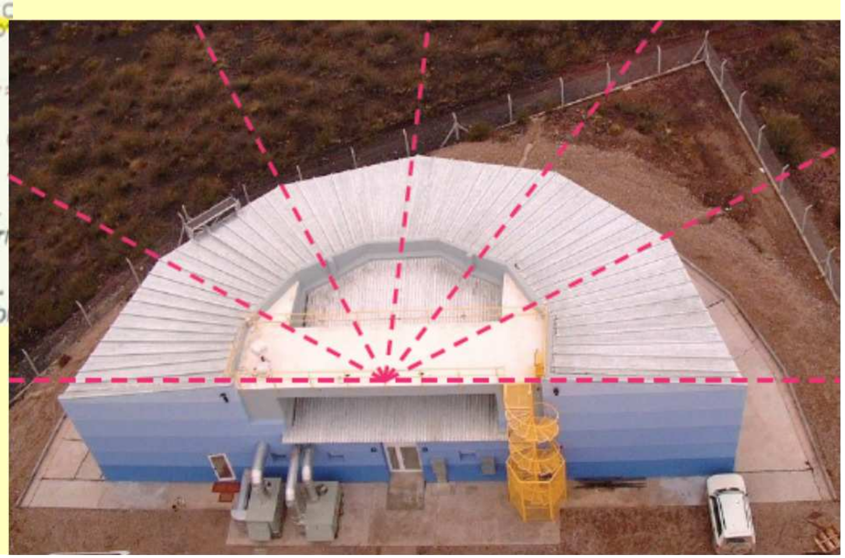
The Pierre Auger Observatory (South…)



1600 water Cherenkov detectors
4 stations with 24 fluorescence telescope

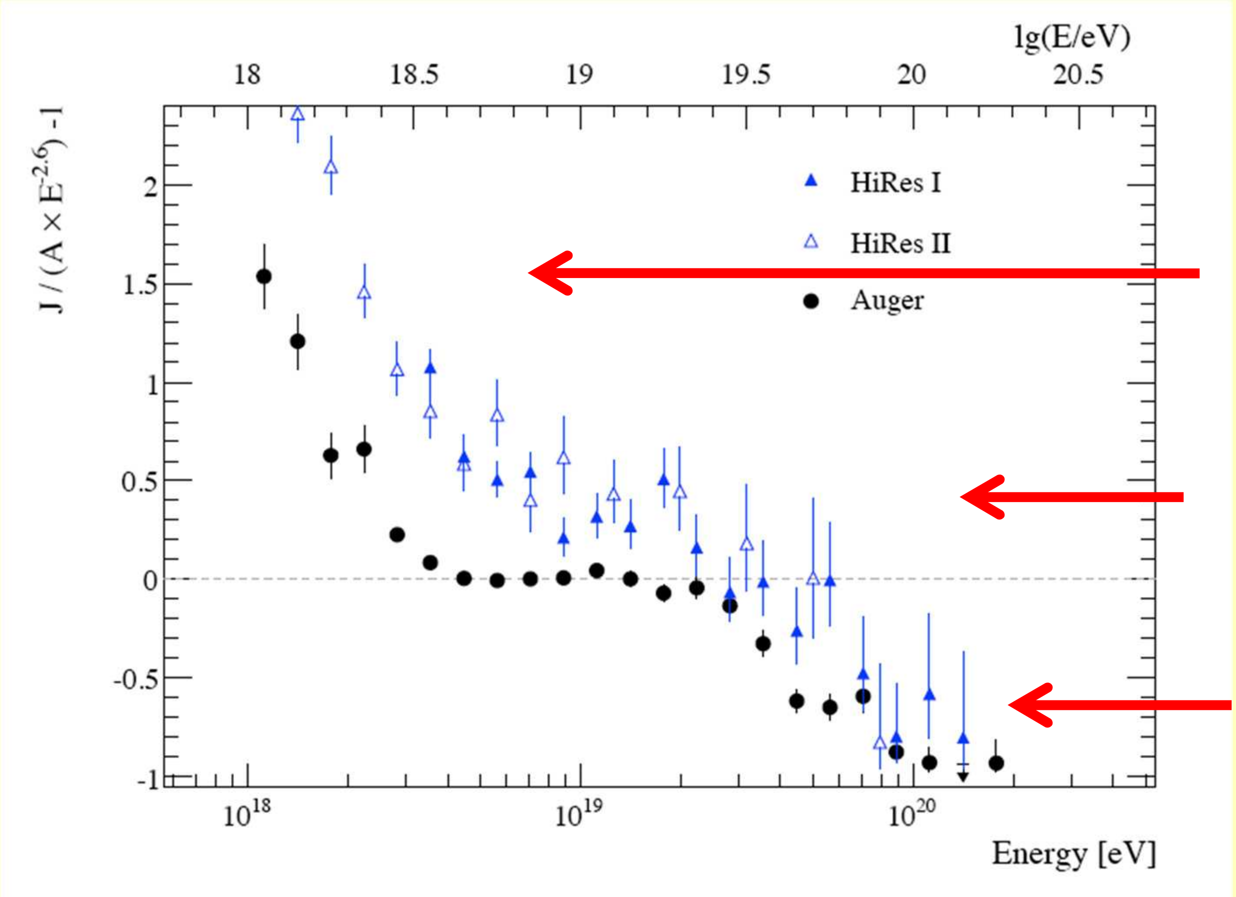
$$A^{eff}_{Auger} \approx 7\times10^{3}\ km^{2}\cdot sr$$

$$1\ particle \Big/ km^{2}\ century$$



A key result of Auger South and HiRes

The Auger Collaboration (2008a), Abbasi et al. (2008), Bergman (2008)



$\gamma_1 = 3.26 \pm 0.04$

$\gamma_2 = 2.59 \pm 0.02$

$\gamma_3 = 4.3 \pm 0.2$

Observation of a "flux suppression" in the spectrum:
GZK feature (? Or Sources running out of fuel)

Relevance of Auger's result:

- (Bad news for current observatories) it implies *a very low flux:*

$$1 particle / km^2 / sr / century \quad E > 6 \times 10^{19} eV$$

$$1 particle / km^2 / sr / millennium? \quad E > 10^{20} eV$$

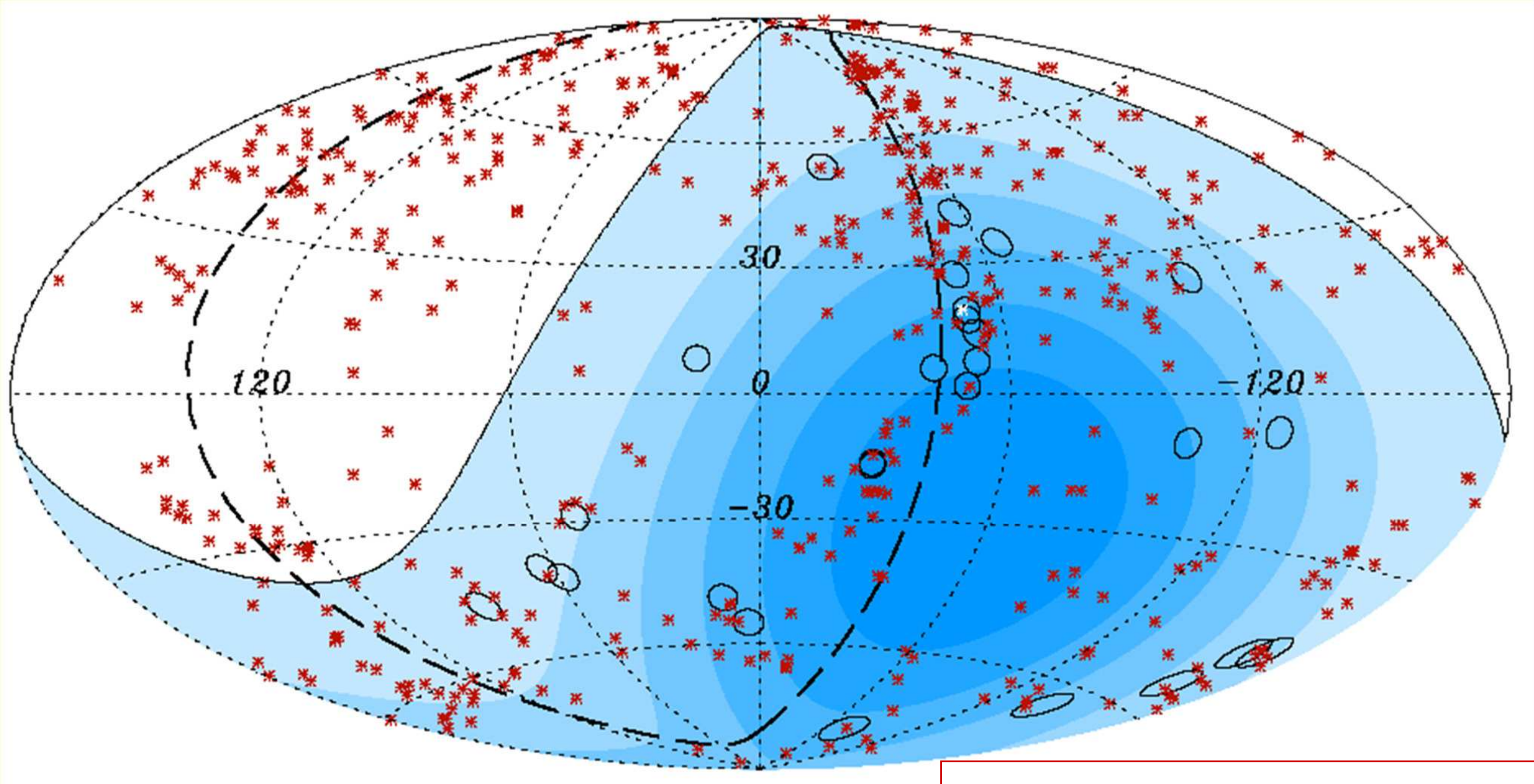
- (Good news) It *limits the horizon* and gives us the possibility to find local sources:
  - *Large angular separation*
  - *Smaller magnetic deflections*

Sources?

A second key result from Auger

The Auger Collaboration (2007)

Ang. Sep. $\psi < 3.1°$, $z < 0.018$ (75 Mpc) and $E > 56$ EeV

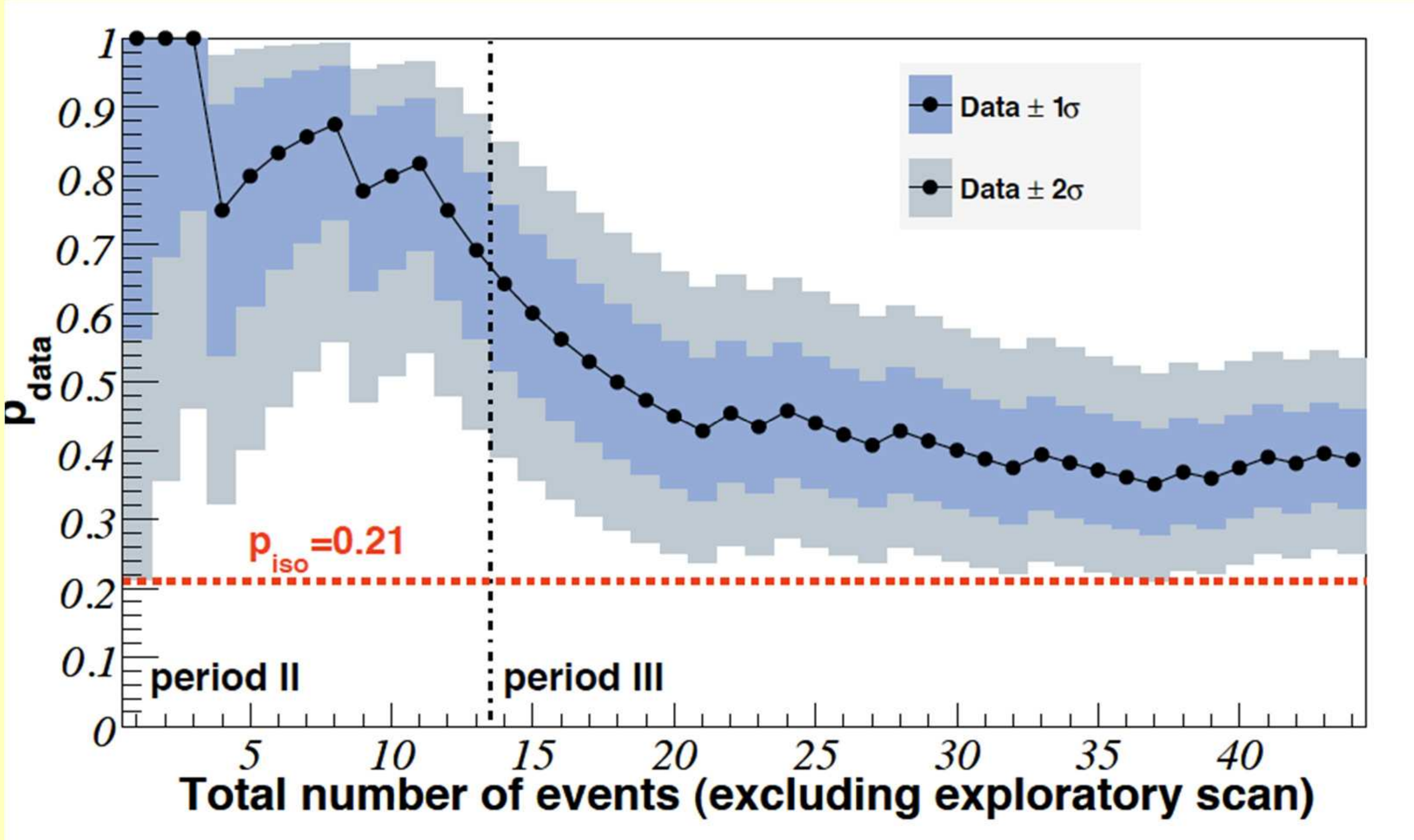


Observation of anisotropy of UHE particles at $E>5x10^{19}$ eV (1%)

Enables Particle Astronomy

Hague & PAO collaboration, 2009

Auger South latest results



2004-2009

58 events for E> 55 EeV

Cen A interesting region

P_{data} =k/N binomial parameter
It indicates the degree of correlation
For isotropy P_{iso}=0.21

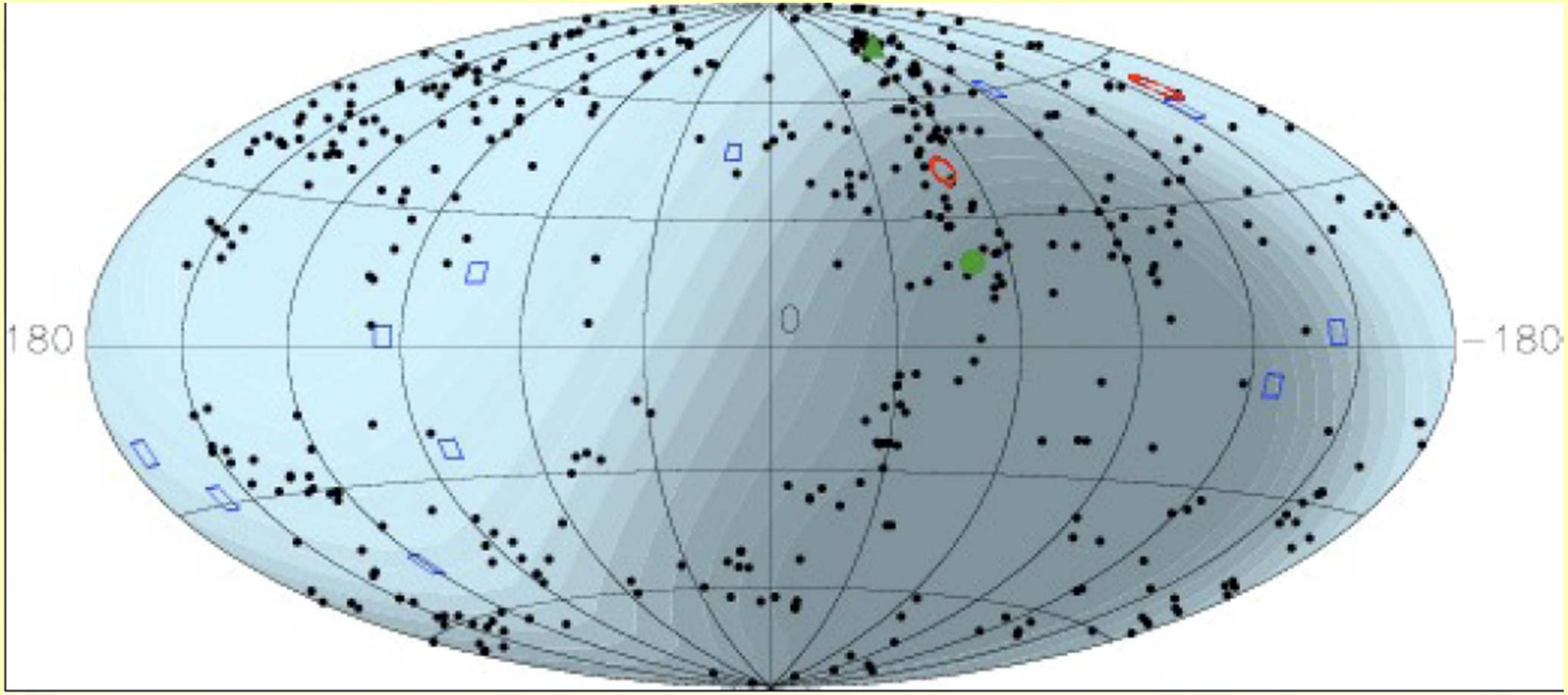
$P_{Auger09}$=0.38 ±0.07
More than 2σ

And HiRes? No clear evidence…

Andrea Santangelo, Kepler Center-Tü

Abbasi et al. (2010) arXiv:1002.1444v1

HiRes no correlation



Black dots = 457 AGNs + 14 QSOs from the Veron Cetty catalogue for z < 0.018
red circles = 2 correlated events above 56 EeV within 3.1°,
blue squares = 11 uncorrelated events

test

Evidence for GZK suppression?

Auger: Yes → Protons

HiRes: Yes → Protons

Evidence for Anysotropy/correlation, sources?

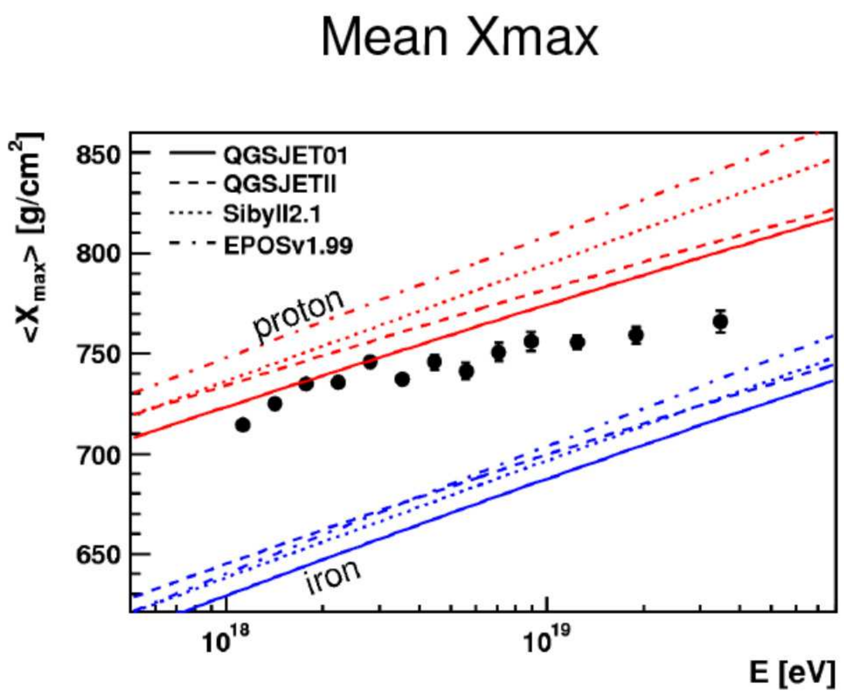
Auger: Yes → Protons, not isotropizing deflection

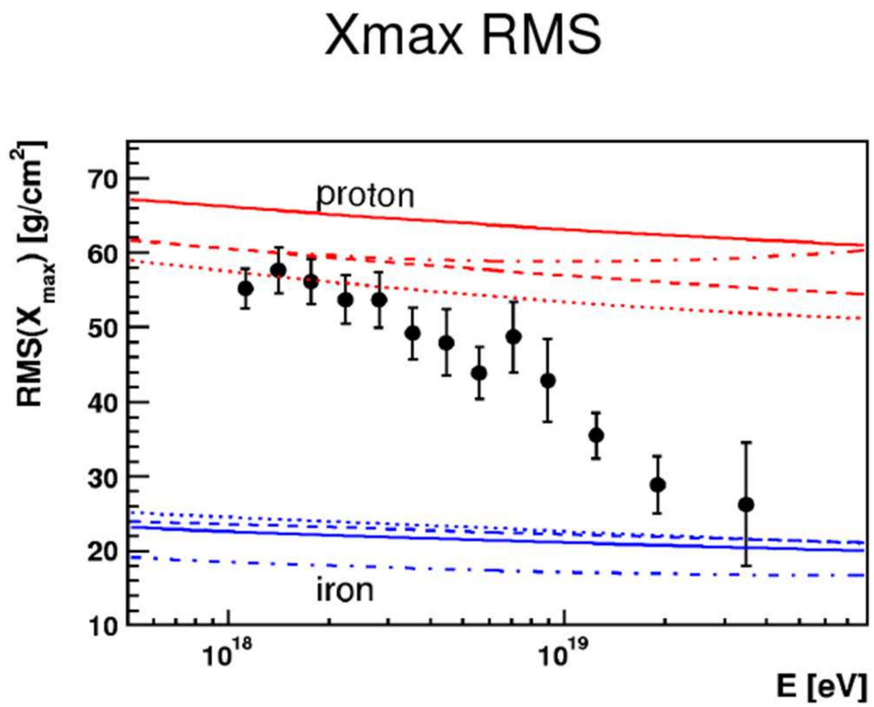
HiRes: NO → Nuclei? Protons and strong deflections?

Andrea Santangelo,
Kepler Center-Tü

Protons or Nuclei: Composition?

Mean X_{max} and RMS from 3754 events

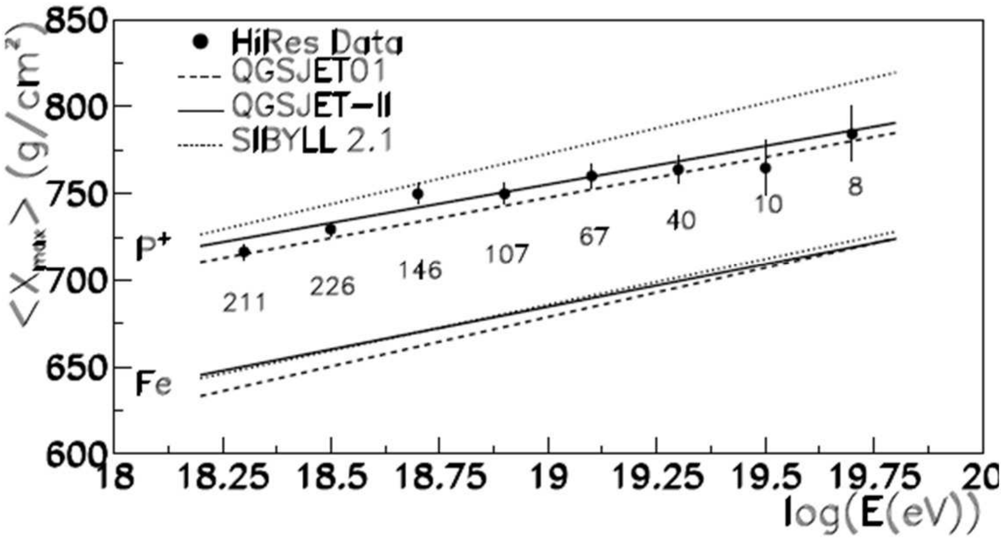


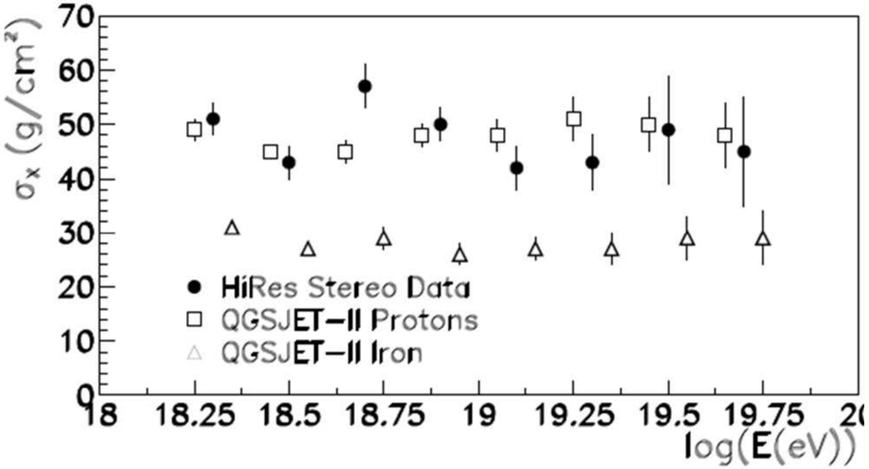


Auger: iron nuclei?

Composition?

HiRes, 2010, mean X_{max} and RMS





HiRes: Protons?

Abbasi et al., PRL (2010)

Evidence for GZK suppression?

Auger: Yes

HiRes: Yes → Protons

↘ Protons

Evidence for Anysotropy/correlation, sources?

Auger: Yes

HiRes: NO → Nuclei? Protons and strong deflections?

↓

Protons, not isotropizing deflection

Composition...

Auger: Iron

HiRes: Protons

Andrea Santangelo,
Kepler Center-Tü

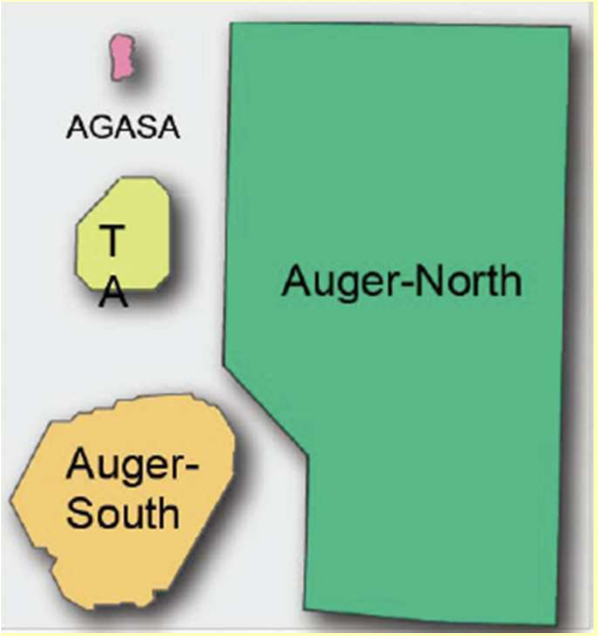
Nature cannot be contradictory...

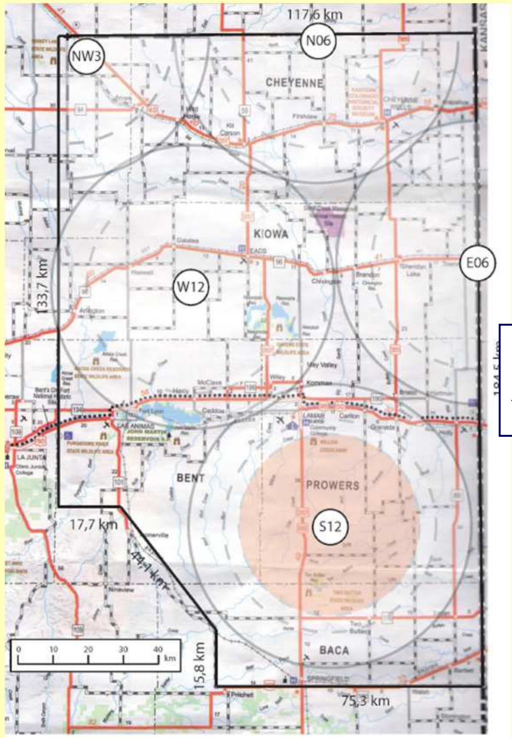
Experiments can!
A crisis in UHE research?

The ways to go... try to understand what are the reasons of the discrepancies!

The ways to go (2) ... Design and build the next generation of UHE observatories

The ways to go... Ground (Auger North) vs. Space



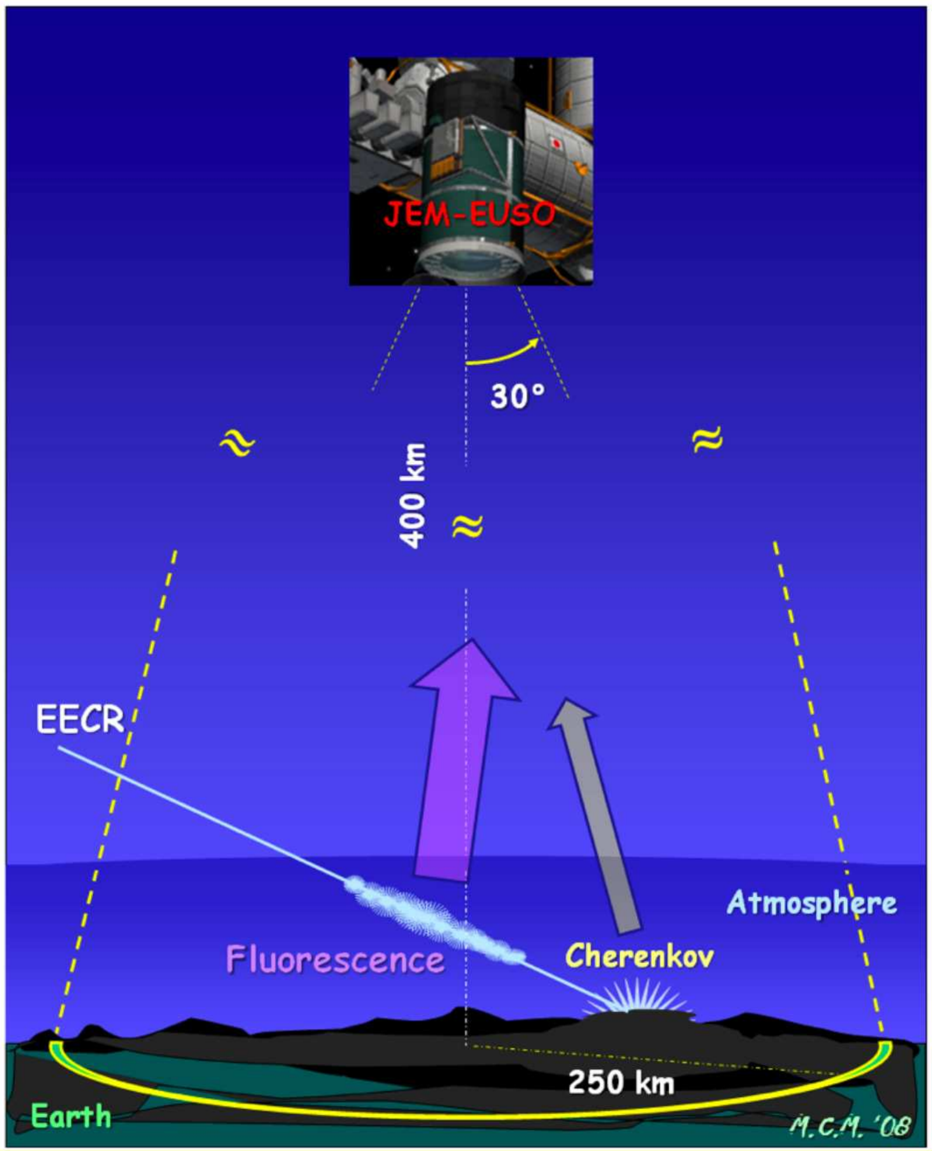


>4000 Surface Detectors
~40 Fluorescence Telescopes

$$A^{geom}_{Auger North} \approx 2\times10^{4}\ \mathrm{km}^{2}$$

Why "from space"?
How "from space"?

Observational Technique

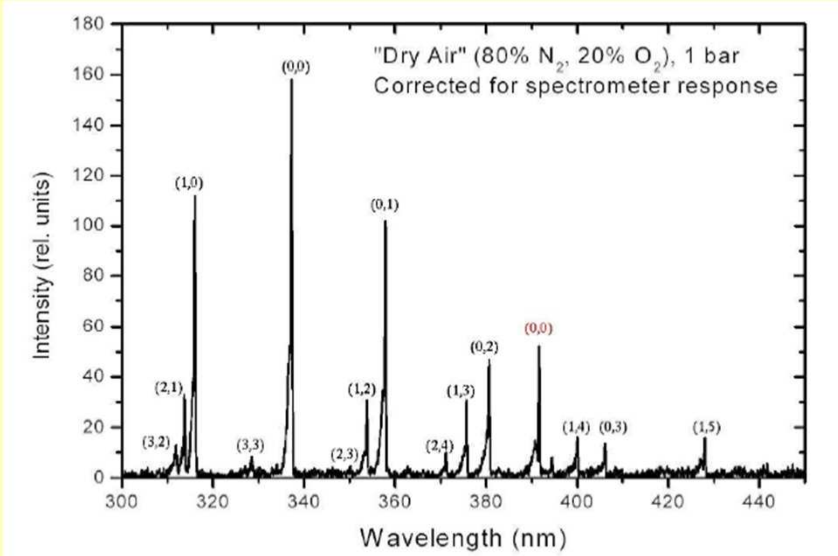


$$e^- + N_2 \longrightarrow N_2^{*+} + e^- \ (+e^-)$$

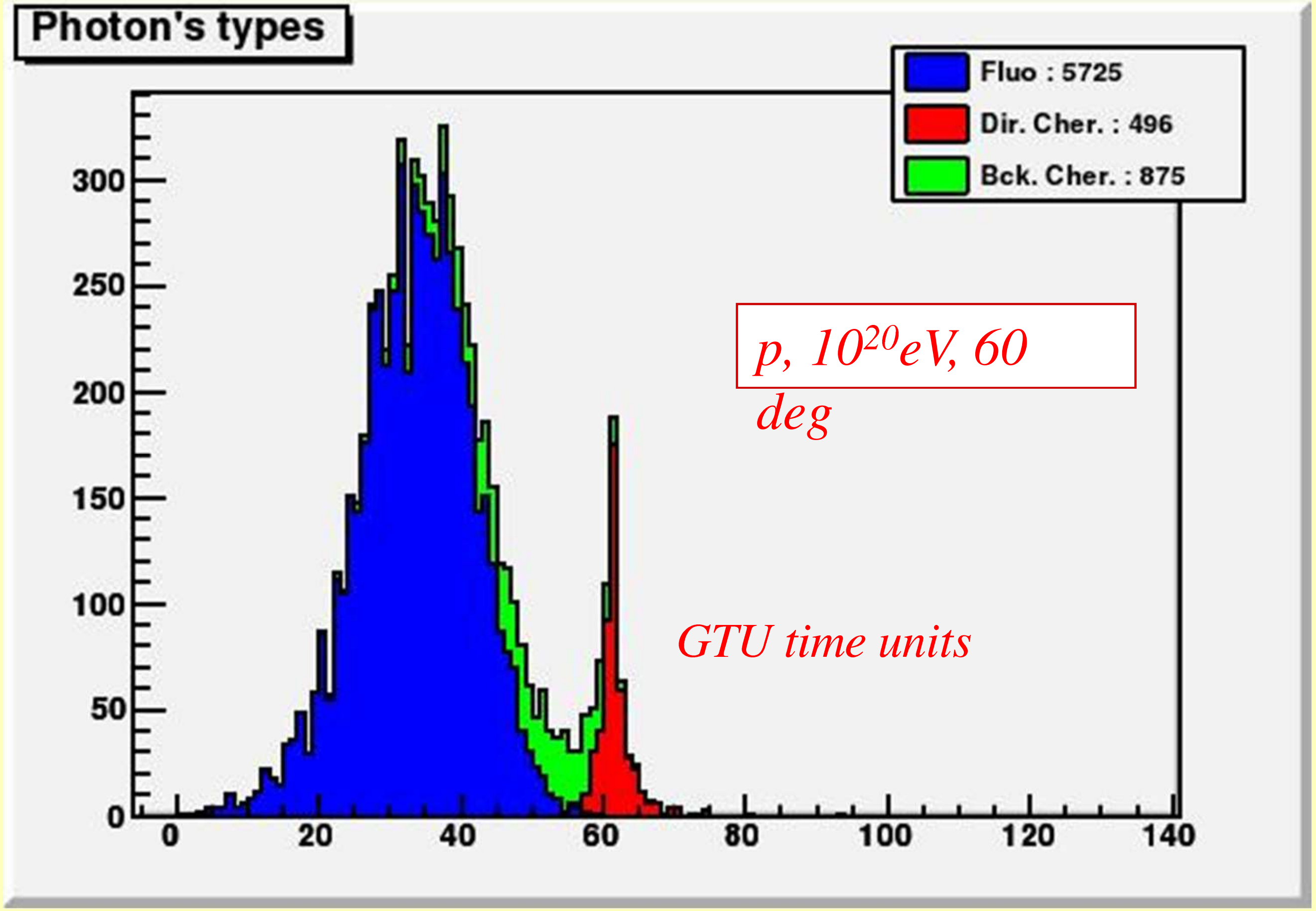
$$e^- + N_2 \longrightarrow N_2^{*+} + e^- \ (+e^-)$$
$$N_2^{*+} + e^- \longrightarrow N_2^{*}$$

A. Bunner, 1967; Kakimoto et al., 1996

Nagano, 2009;



$$330 - 400\ nm,\ \text{UV}$$



a) Fluorescence

b) Scattered Cherenkov

c) Direct (diffusively reflected Cherenkov)

$$1\ GTU = 2.5\ \mu\text{sec}$$

FAST SIGNAL

$$duration \sim 150\ \mu\text{sec}$$

Simulation of the light profile observed at the entrance pupil of JEM-EUSO, using the ESAF code

Andrea Santangelo,
Kepler Center-Tü

JEM-EUSO

The Extreme Universe Space Observatory (EUSO) onboard the Japan Experiment Module (JEM) of the International Space Station

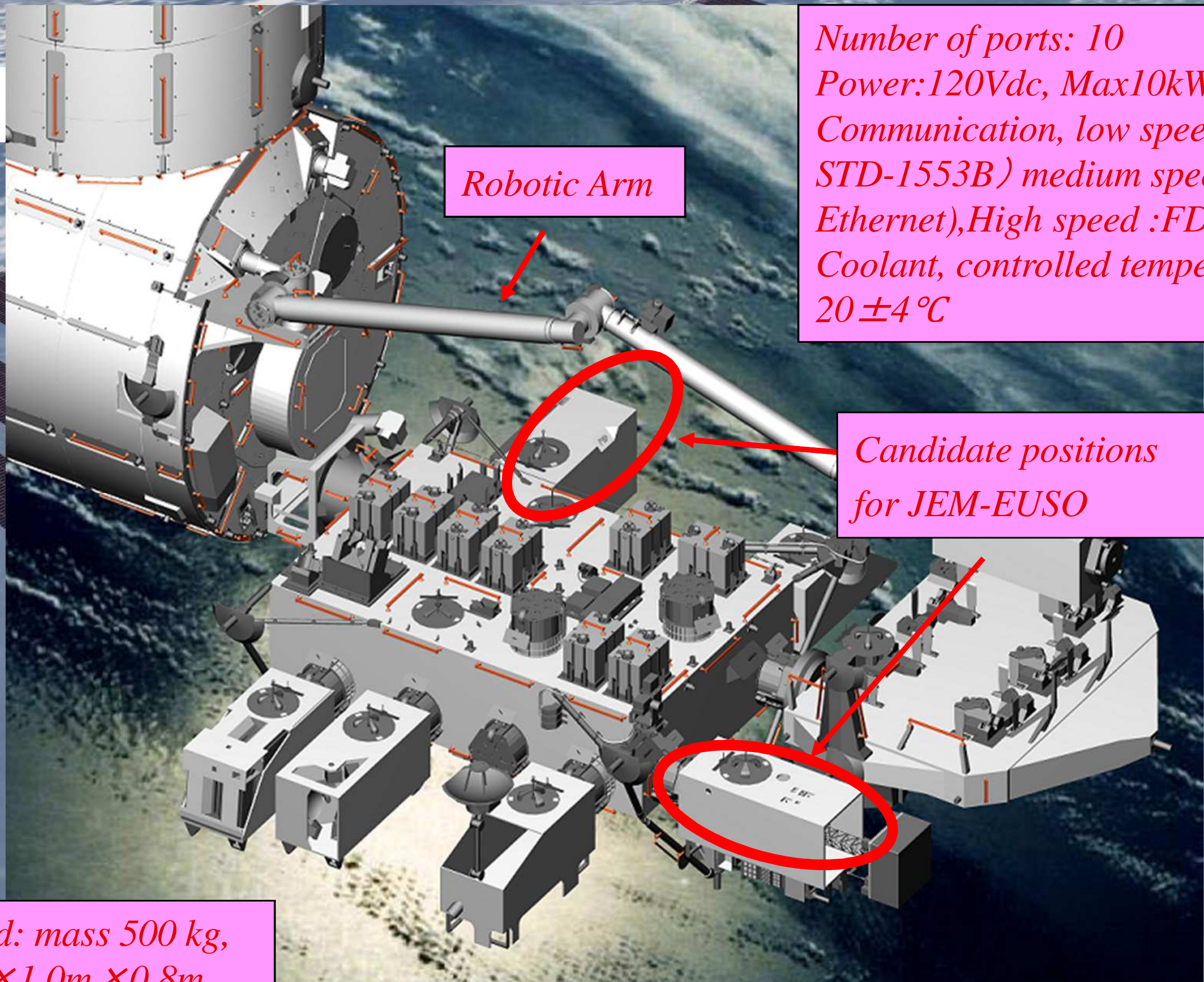
The JEM-EUSO Collaboration, led by RIKEN-Japan, brings together 170 scientists from 12 Countries: Japan, Europe, US, Korea, Mexico and Russia

Andrea Santangelo,
Kepler Center-Tü

The Mission


Japanese Experiment Module
"Kibo" July 2009

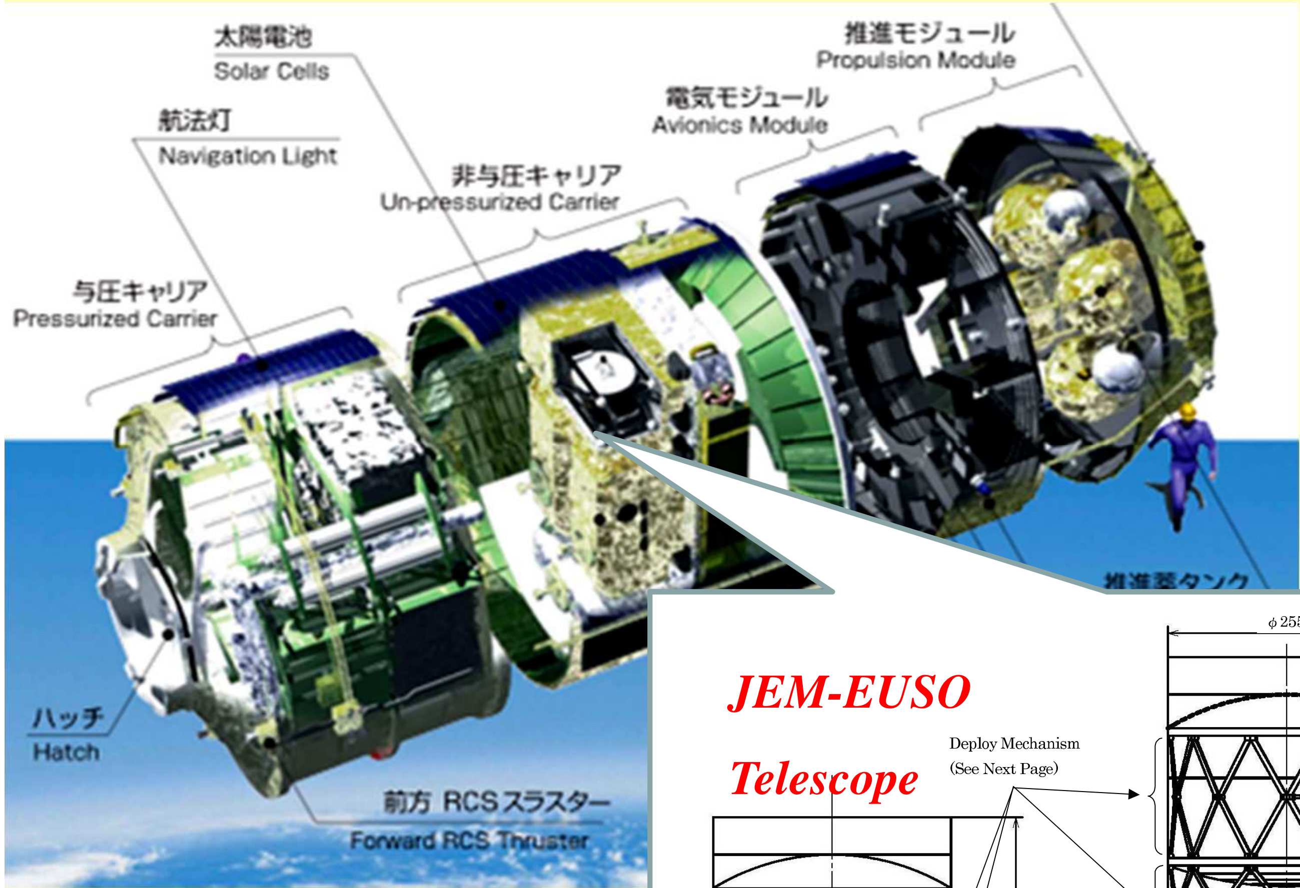
Japanese Experiment Module (KIBO) onboard the International Space Station

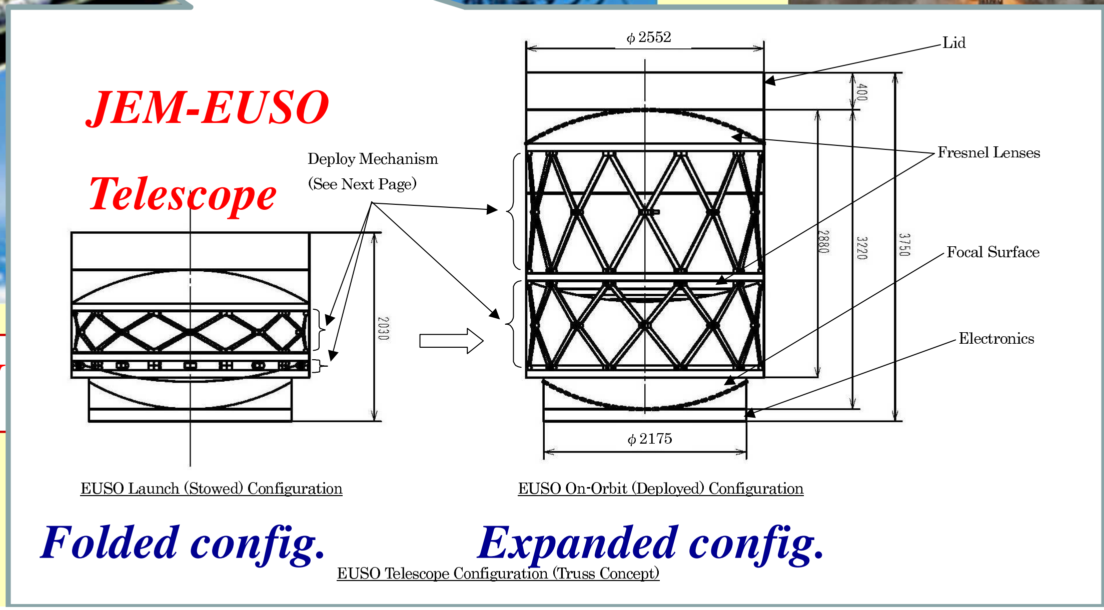


Number of ports: 10
Power:120Vdc, Max10kW
Communication, low speed (MIL-STD-1553B) medium speed (Ethernet),High speed :FDDI)
Coolant, controlled temperature 20±4℃

Standard Payload: mass 500 kg, envelope:1.85m ×1.0m ×0.8m

Transfer to the ISS:
H-IIB Transfer Vehicle (HTV)



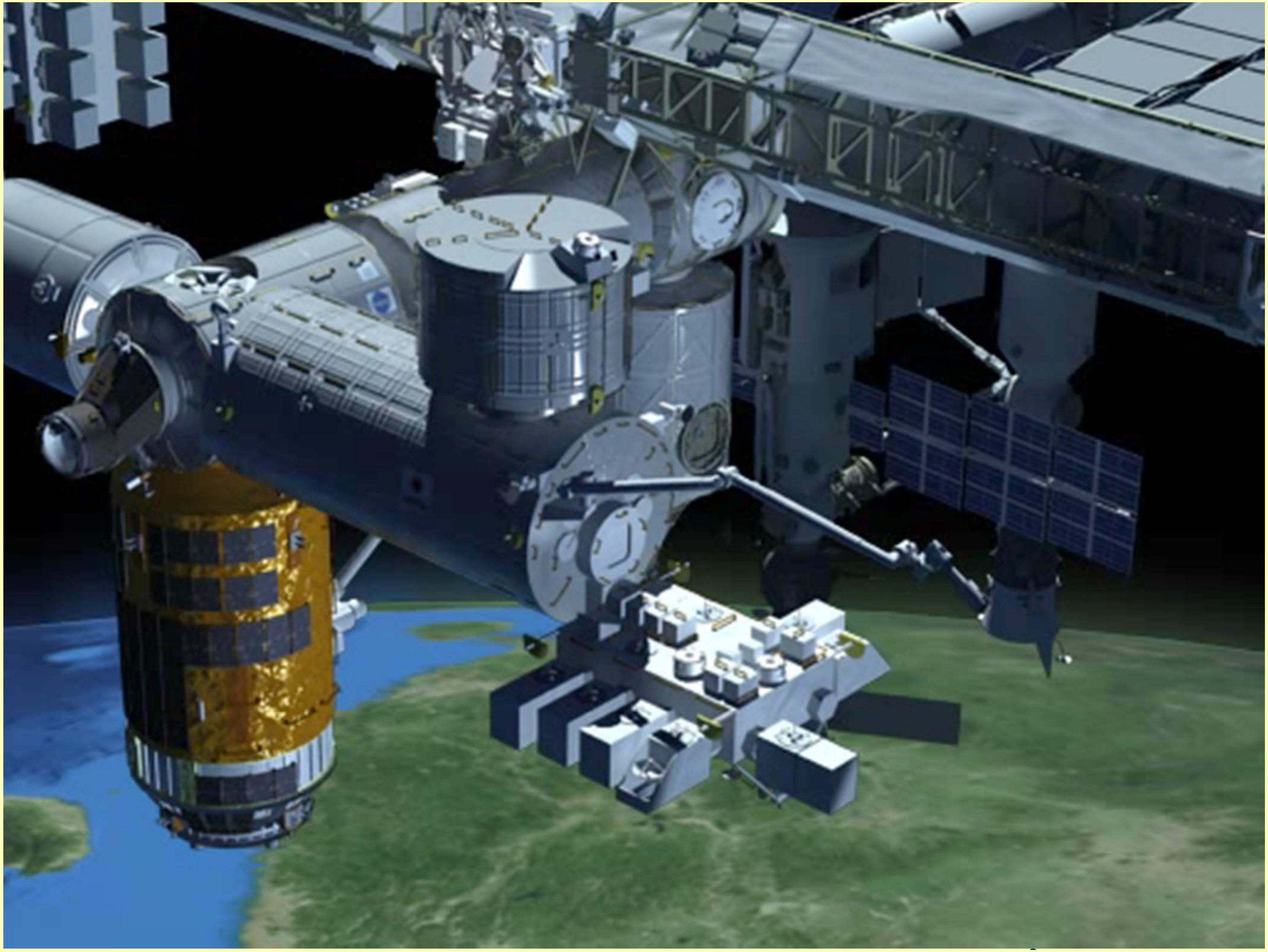


Successfull Launch of H

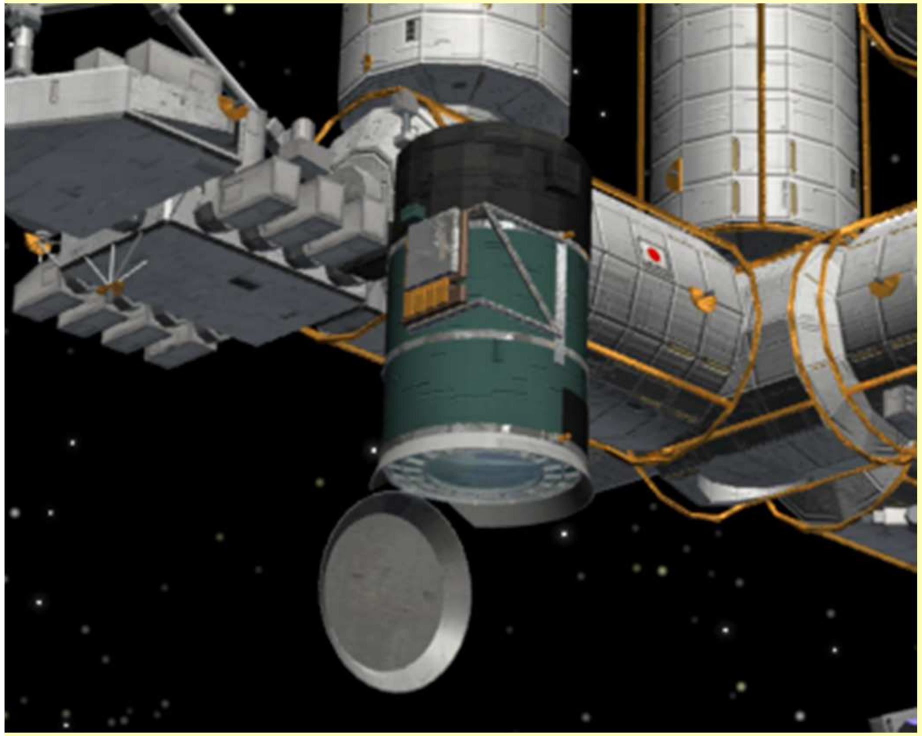
4 m across, 10 m long

Mission aspects have been successfully studies by JAXA and RIKEN

• Time of launch:	year 2015
• Operation Period:	3 years (+ 2 years)
• Launching Rocket :	H2B
• Transportation to ISS:	un-pressurized Carrier of H2 Transfer Vehicle (HTV)
• Site to Attach:	Japanese Experiment Module/ Exposure Facility #2
• Height of the Orbit:	~400km
• Inclination of the Orbit:	51.64°
• Mass:	1983 kg
• Power:	926 W (operative), 352 W (non-operative)
• Data Transfer Rate:	285 kpbs



JEM-EUSO Telescope on ISS

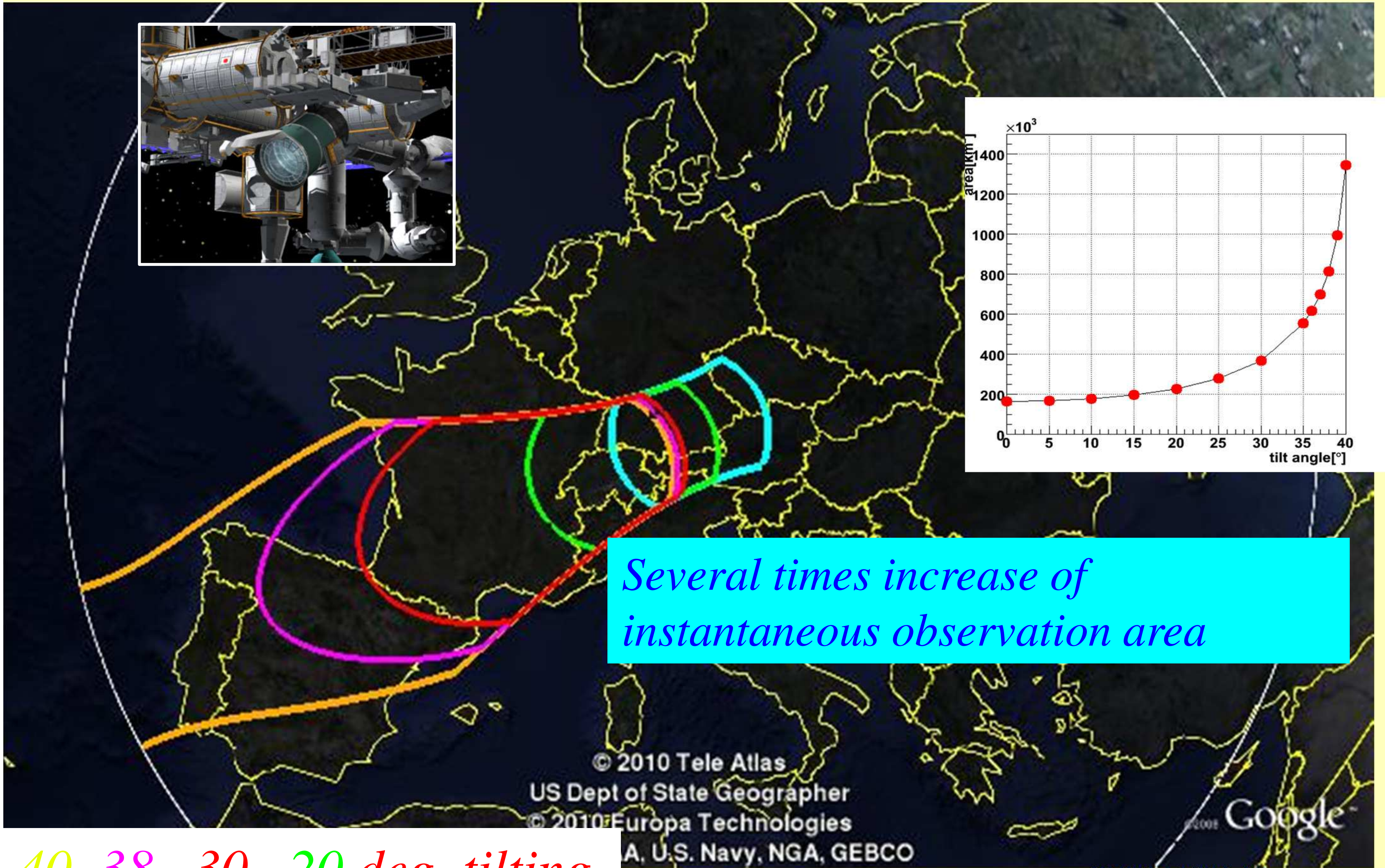


Vertical Mode (2 years)

Tilted Mode (3 years)

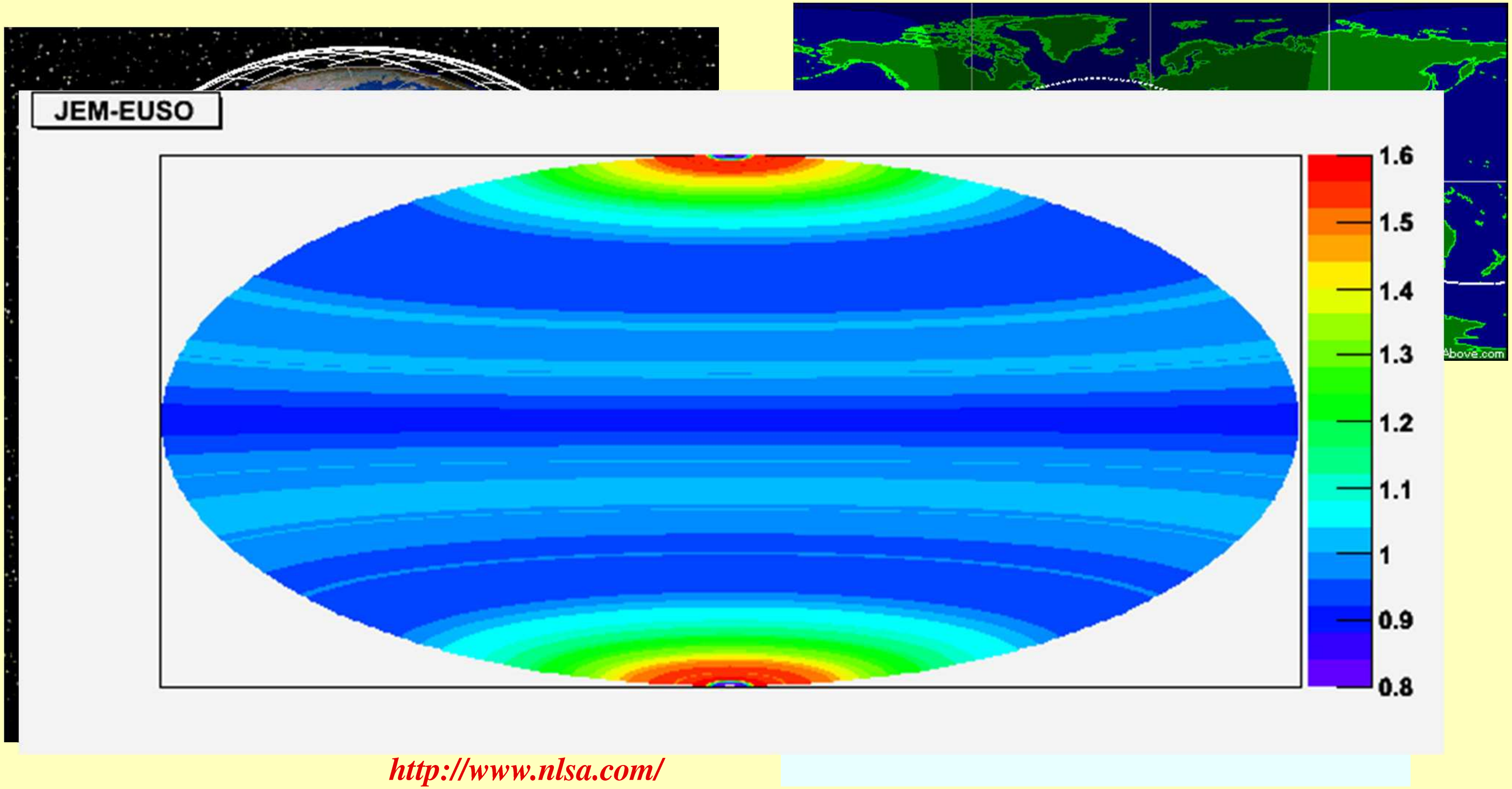
Larger effective area (×3) with ~35° tilt

Field of view (Nadir vs. tilting)



40 38 30 20 deg. tilting

ISS Orbit → Uniform Exposure



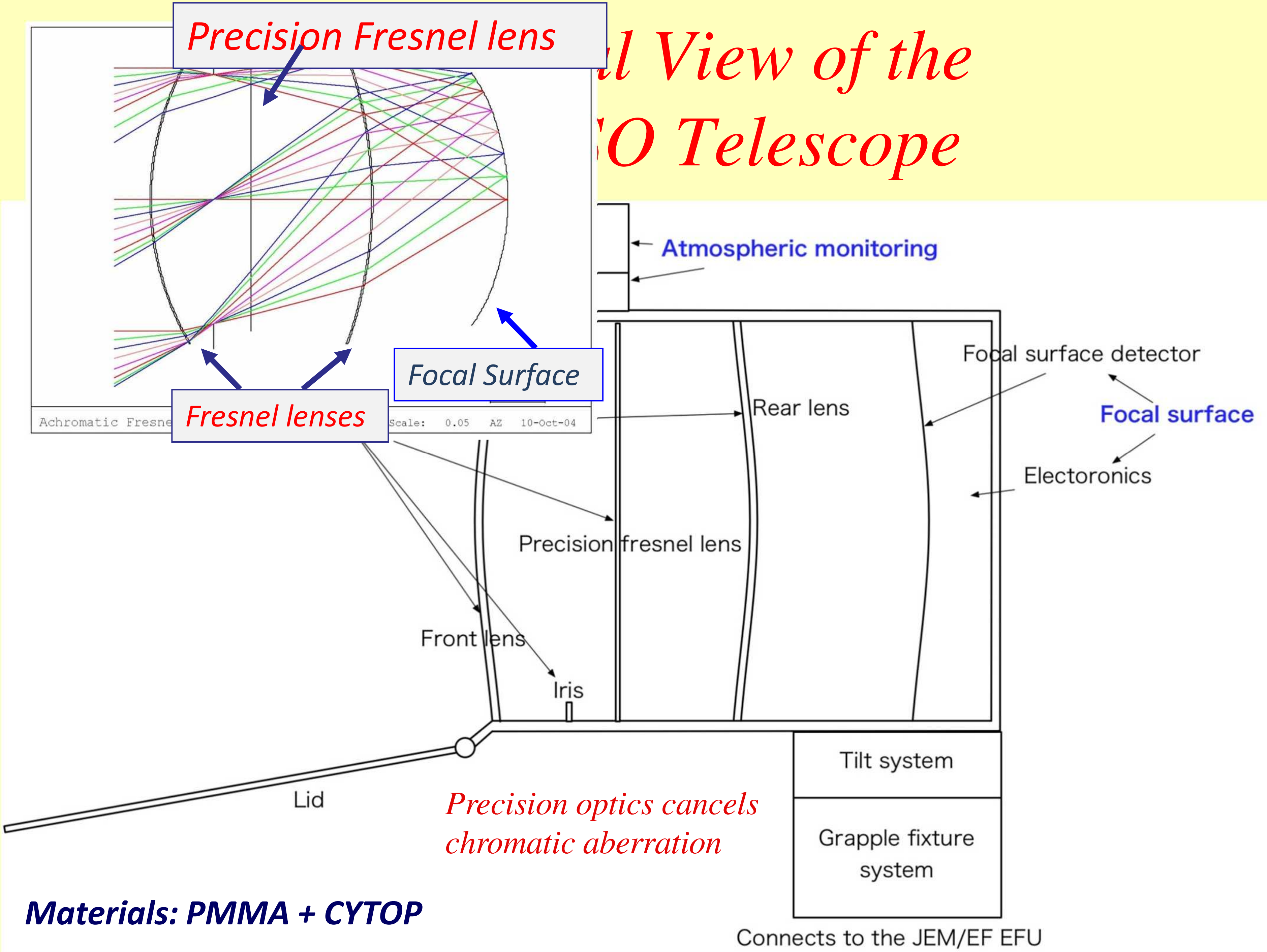
http://www.nlsa.com/

Full-Sky Coverage

Andrea Santangelo,
Kepler Center-Tü

The Main Instrument
(… the UV Telescope)

l View of the O Telescope



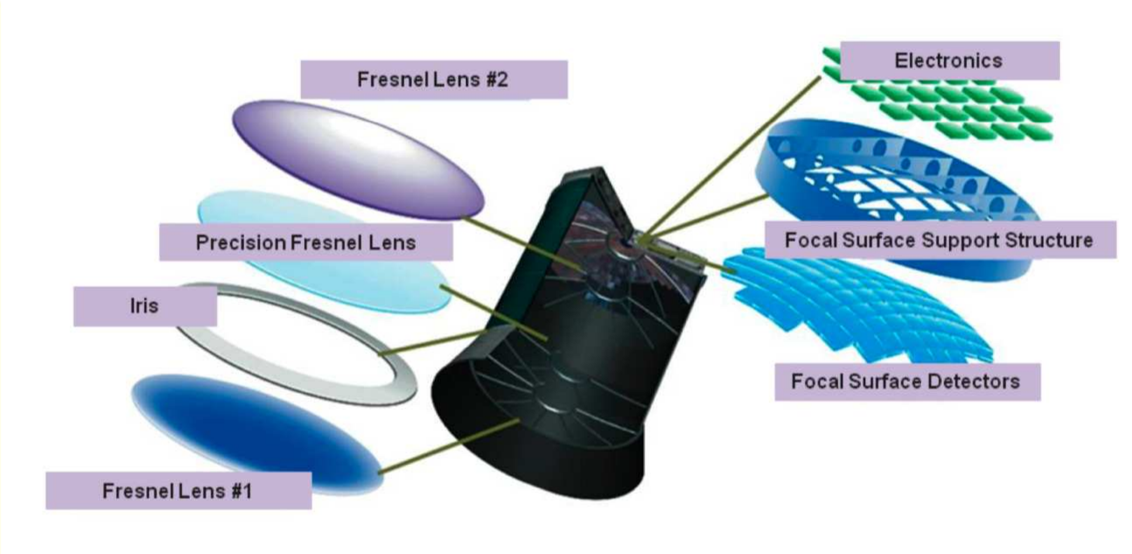
Precision optics cancels chromatic aberration

Materials: PMMA + CYTOP

The UV Telescope

Table 1. *Main parameter of the JEM-EUSO instrument*

Field of View	±30°
Aperture Diameter	2.5m
Optical bandwidth	330 - 400nm
Angular granularity	0.1°
Pixel Size	4.5mm
Number of Pixels	~2.0×10^5
Pixel Size at the ground	750m
Duty Cycle	~20 - 25%
Observational Area	~2×10^5 km^2



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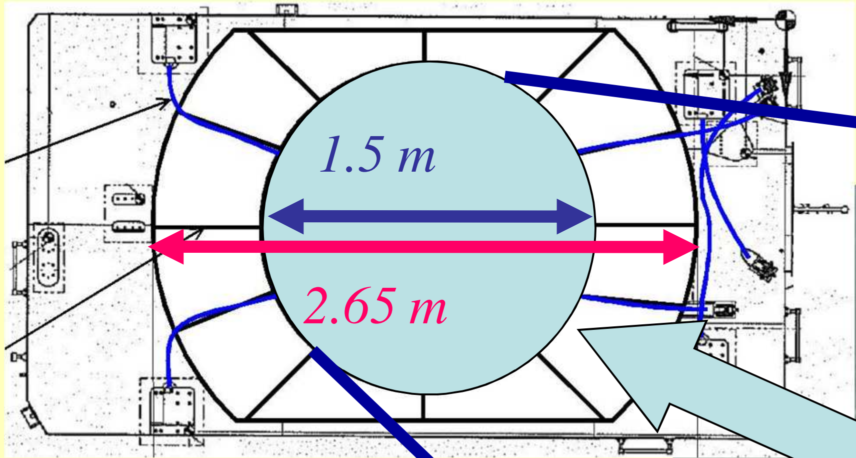
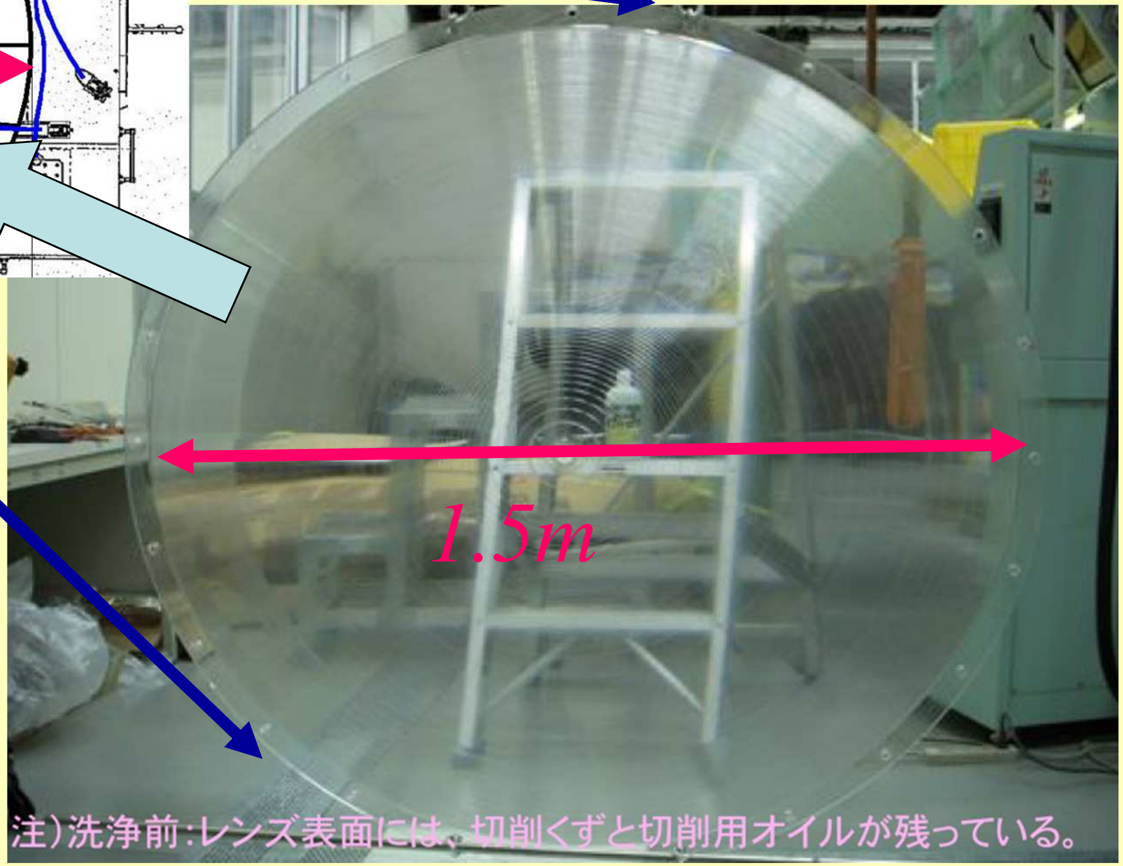
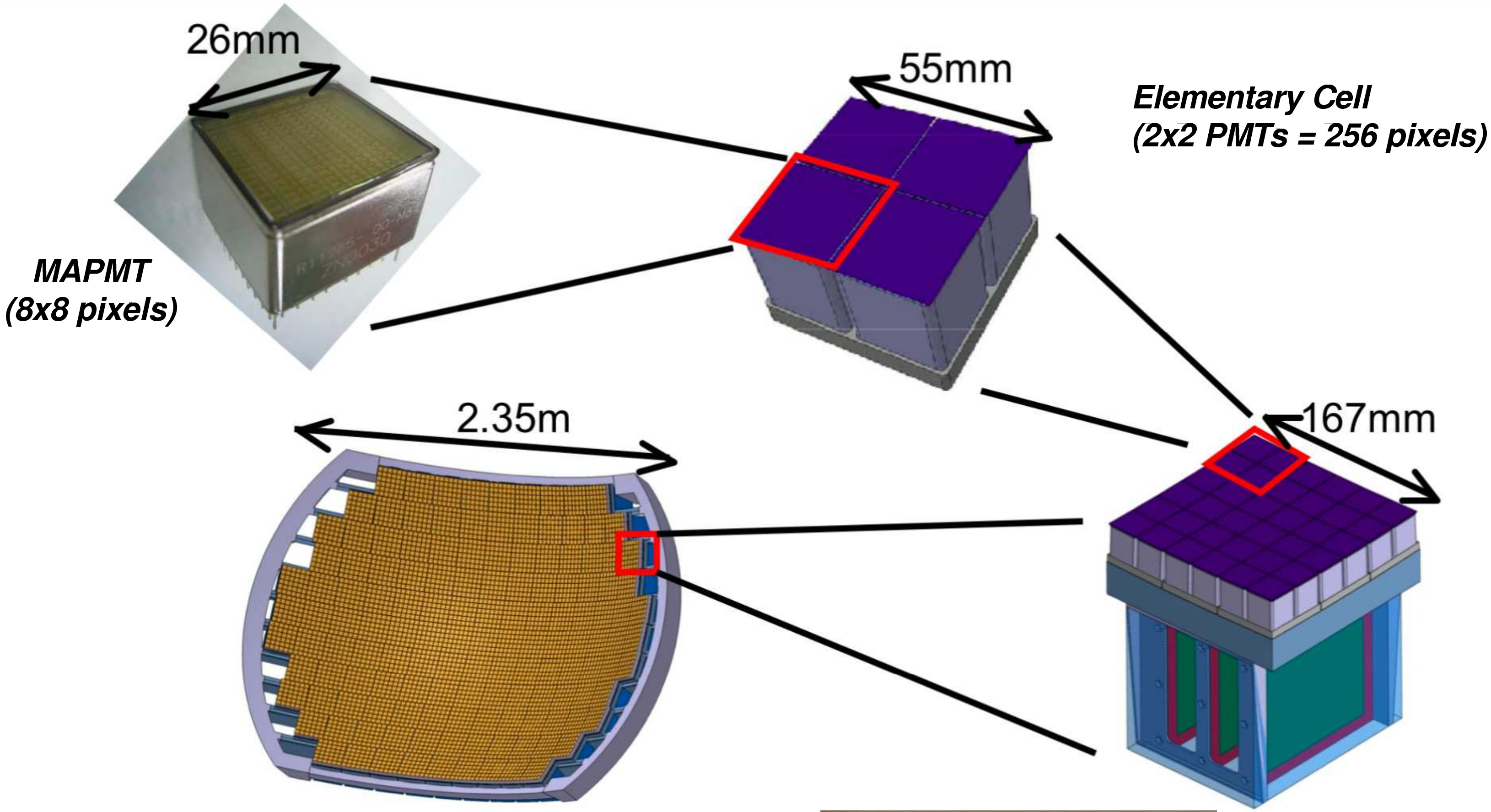
Recent progress in Optics

Manufacturing large diameter Fresnel lens



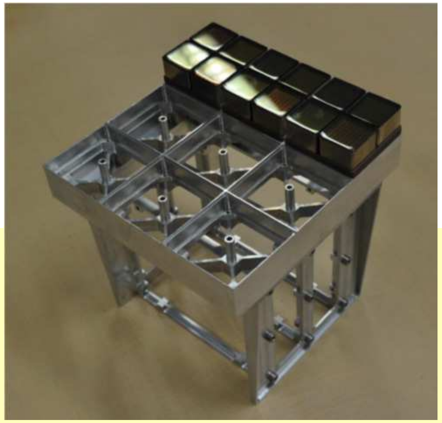


We obtained a cutting machine with a 3.4m dia. turn table to make a 2.65m dia. Fresnel Lens.



Focal Surface detector
137 PDMs = 0.3M Pixels

Photo-Detector Module
(3x3 ECs = 2,304 pixels)



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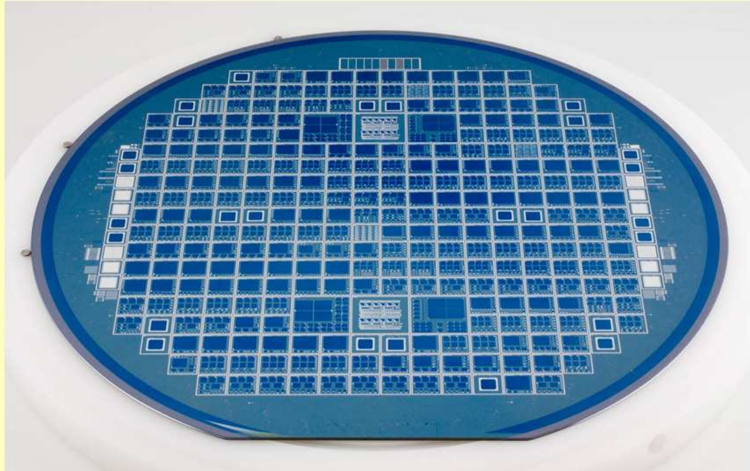
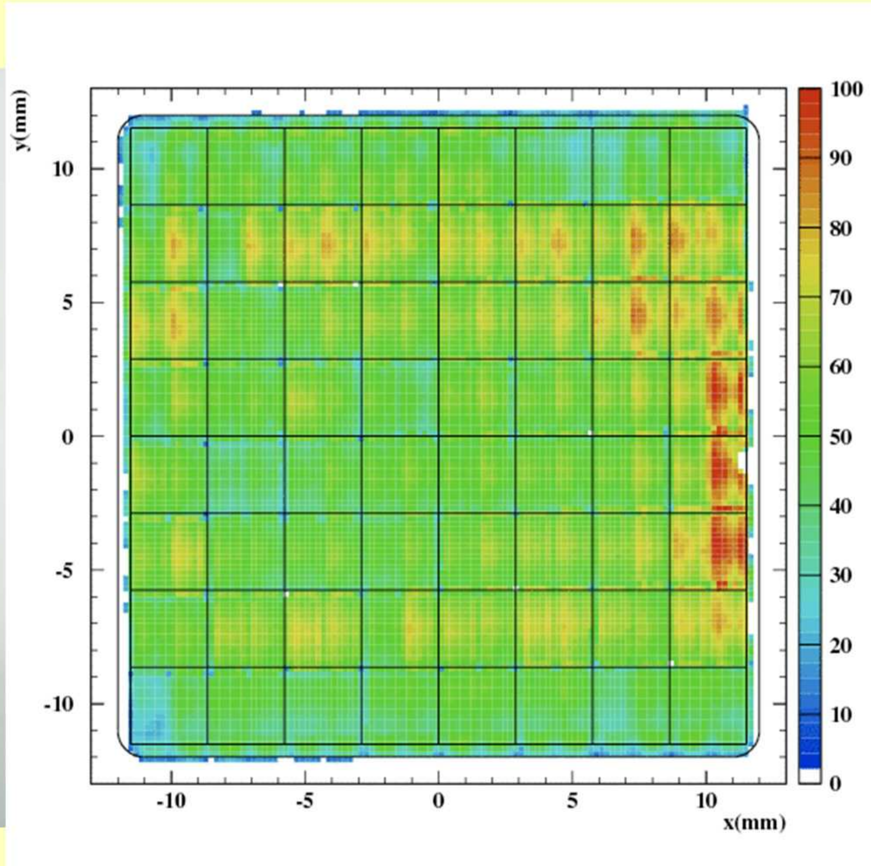
Baseline: M64 (Hamamatsu), Tested last August, Excellent Performances!

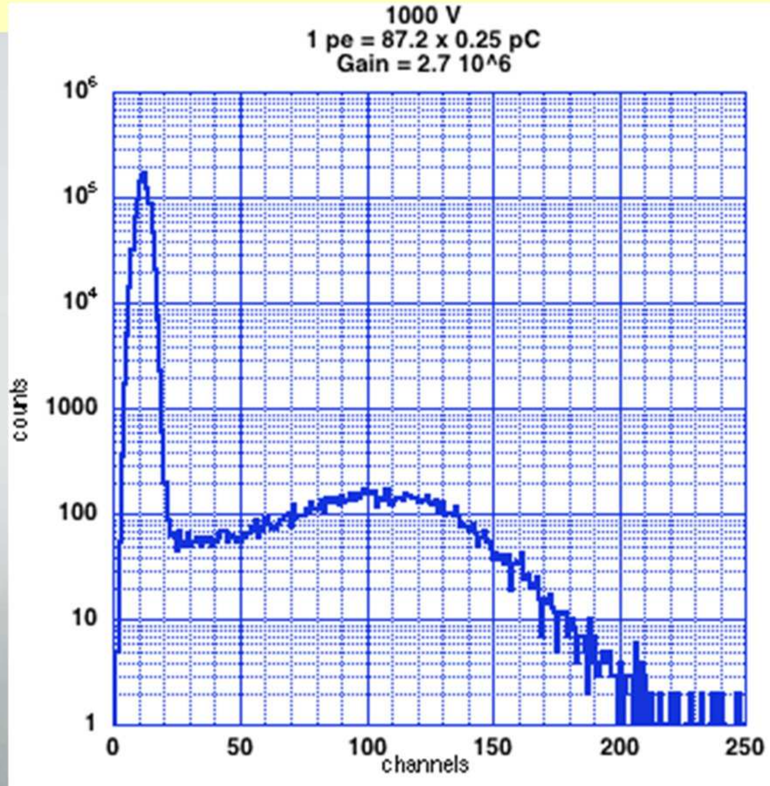
Advanced Options:

SiPM (Germany…)

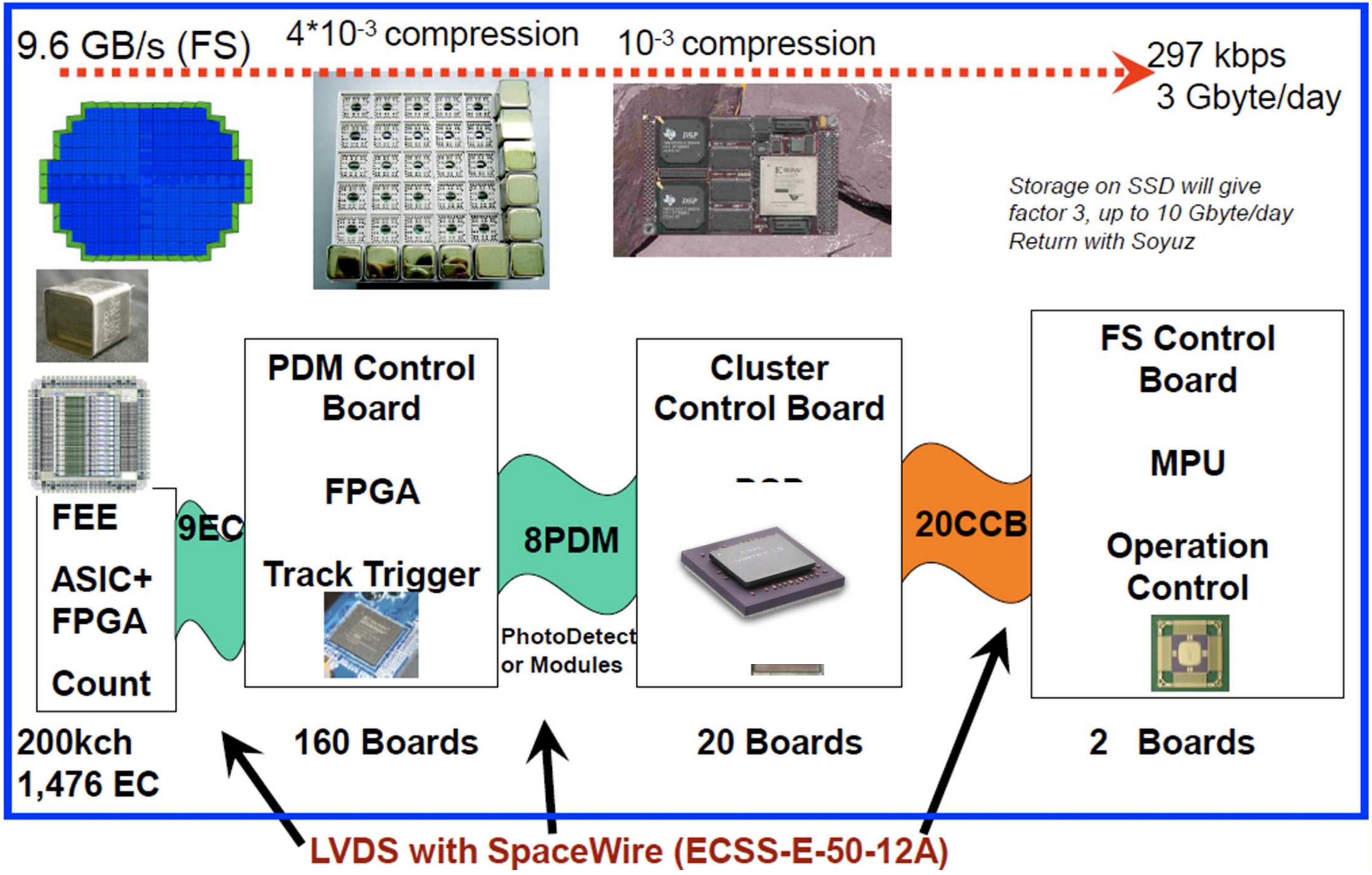


Alternative: SiPM (MPI-HLL)

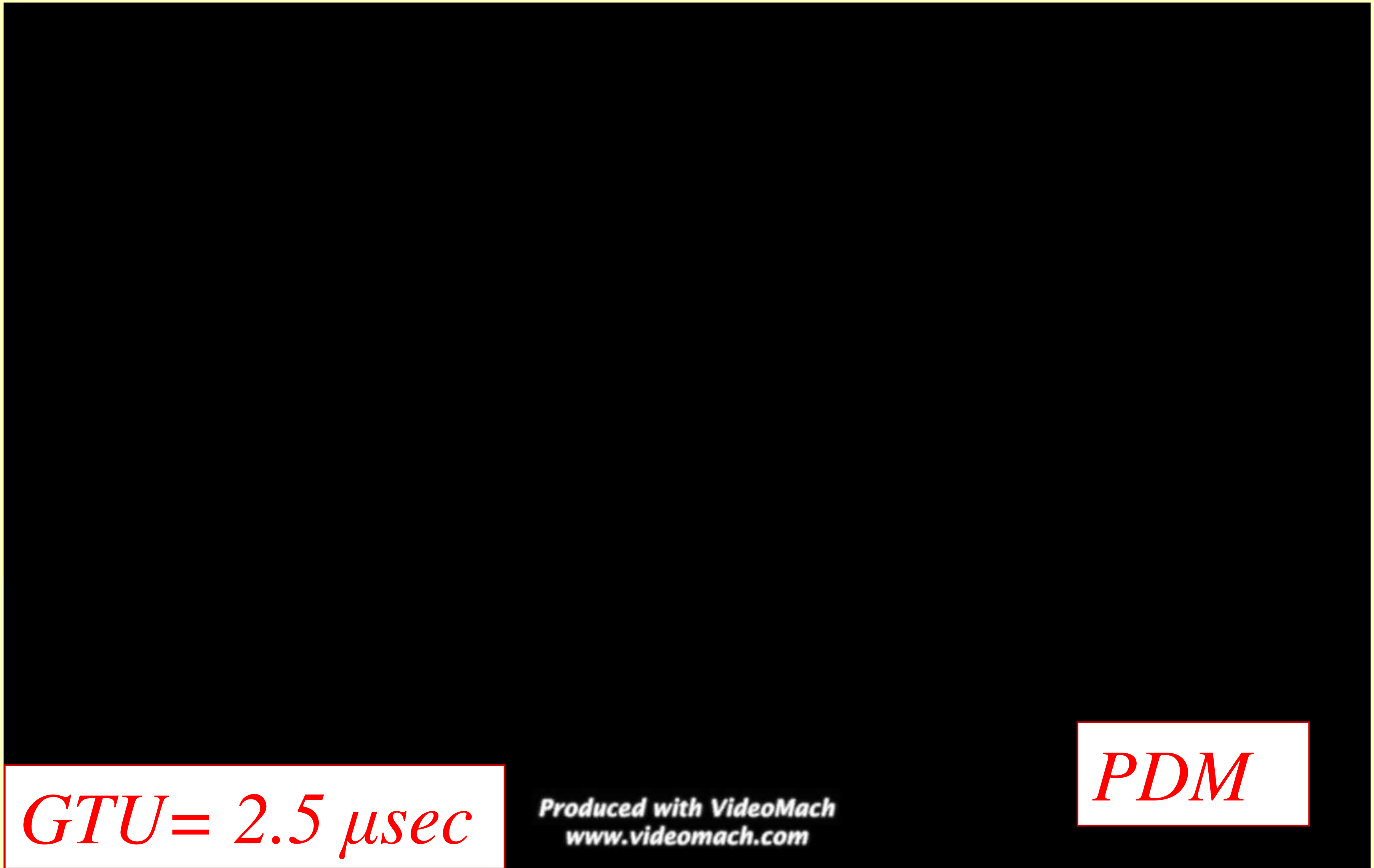




JEM-EUSO DAQ – Data reduction block scheme



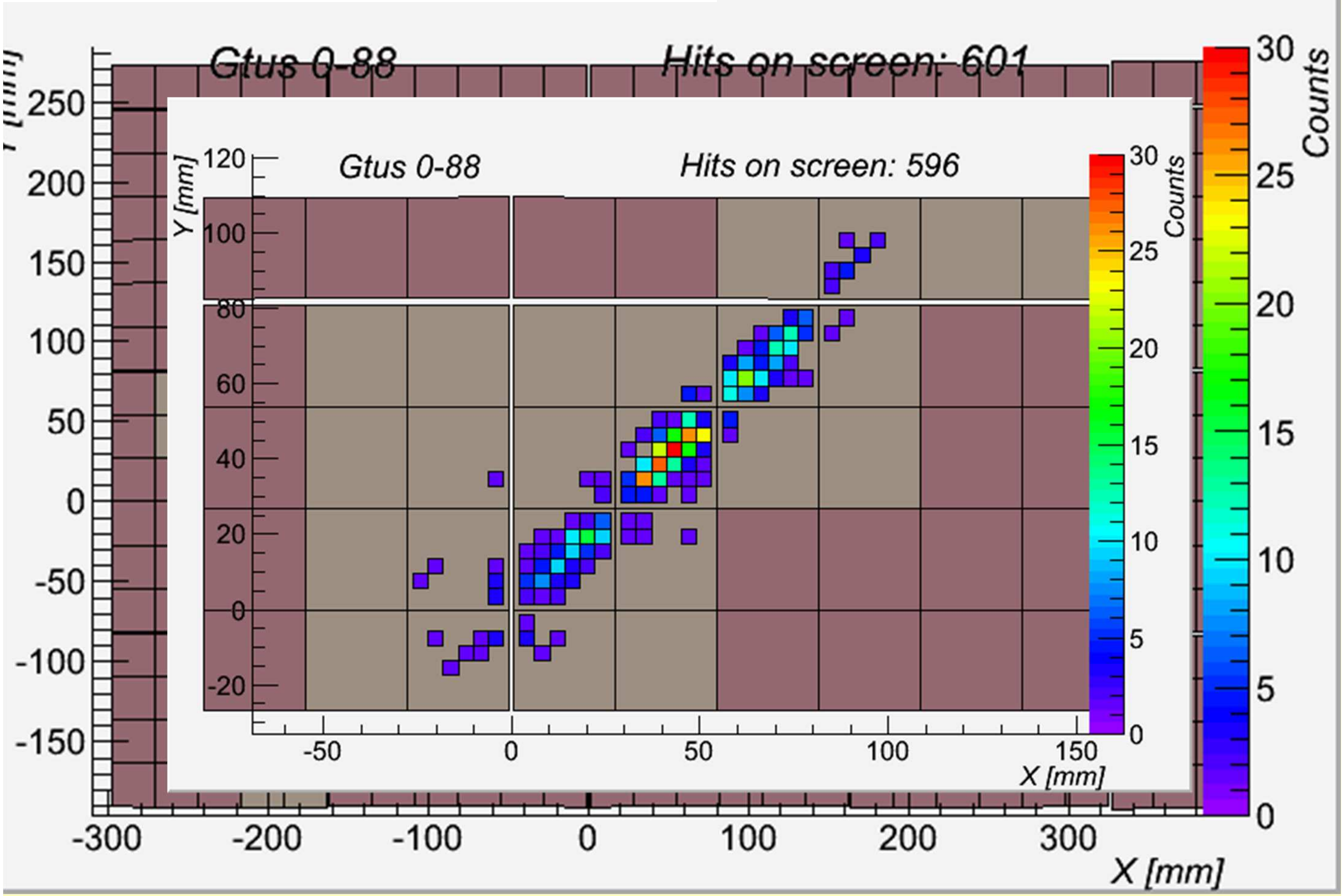
Proton Shower (60 deg, 10^{20}eV)



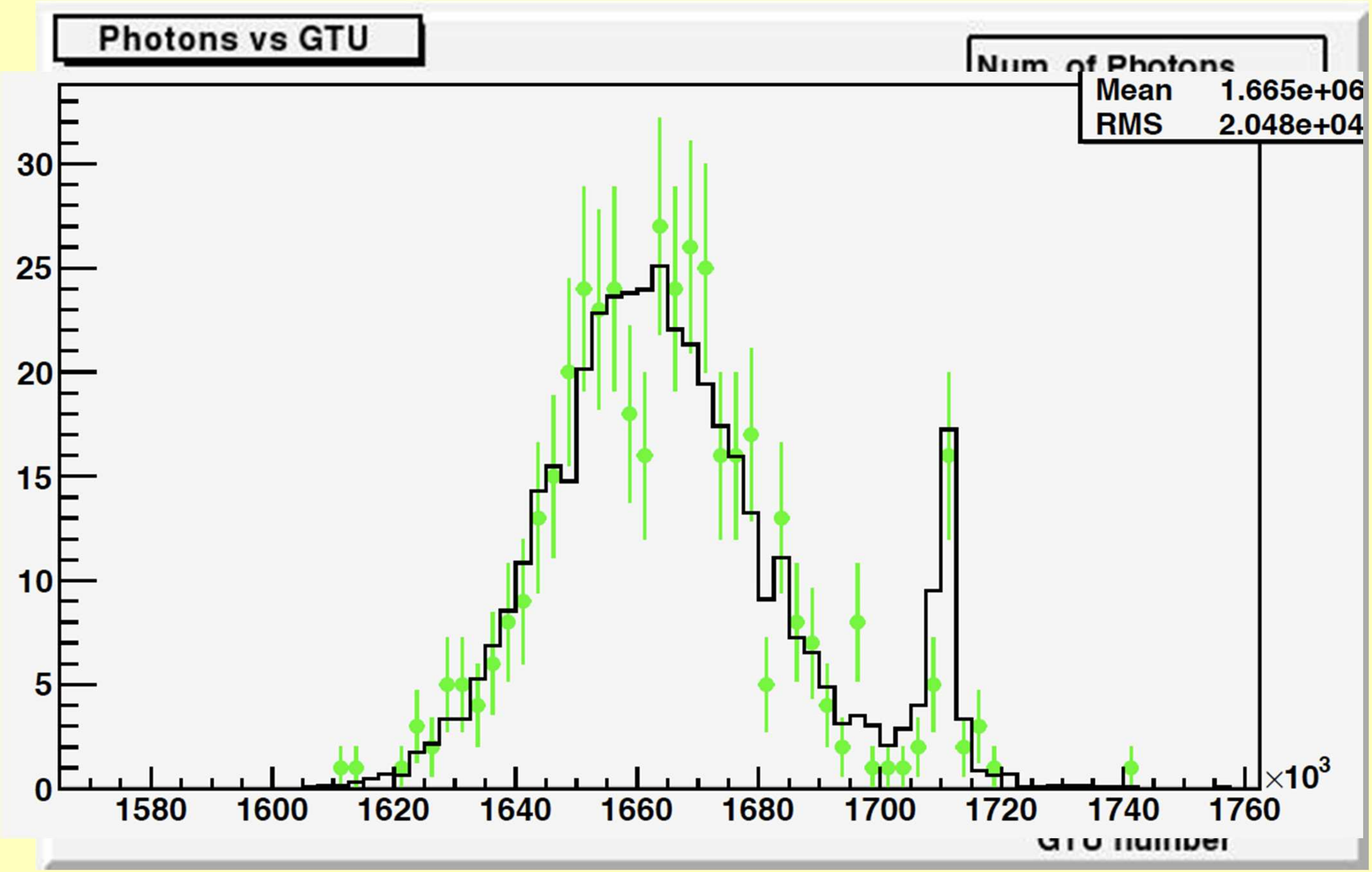
GTU= 2.5 μsec

PDM

Result of end-to-end simulation



Signal for a p shower (60 deg, 10^{20}eV)



Performances

Large distance > 400 km

Large FOV $\gamma \pm 30^\circ$

$$A^{inst} \approx 6\times10^5\ km^2 \cdot sr$$

$$\eta_{cycle} \approx 10 \div 25\%$$

$$A_{Euso}^{eff} \approx (6 \div 9)\times10^4\ km^2 \cdot sr$$

Large Target Mass of the atmosphere

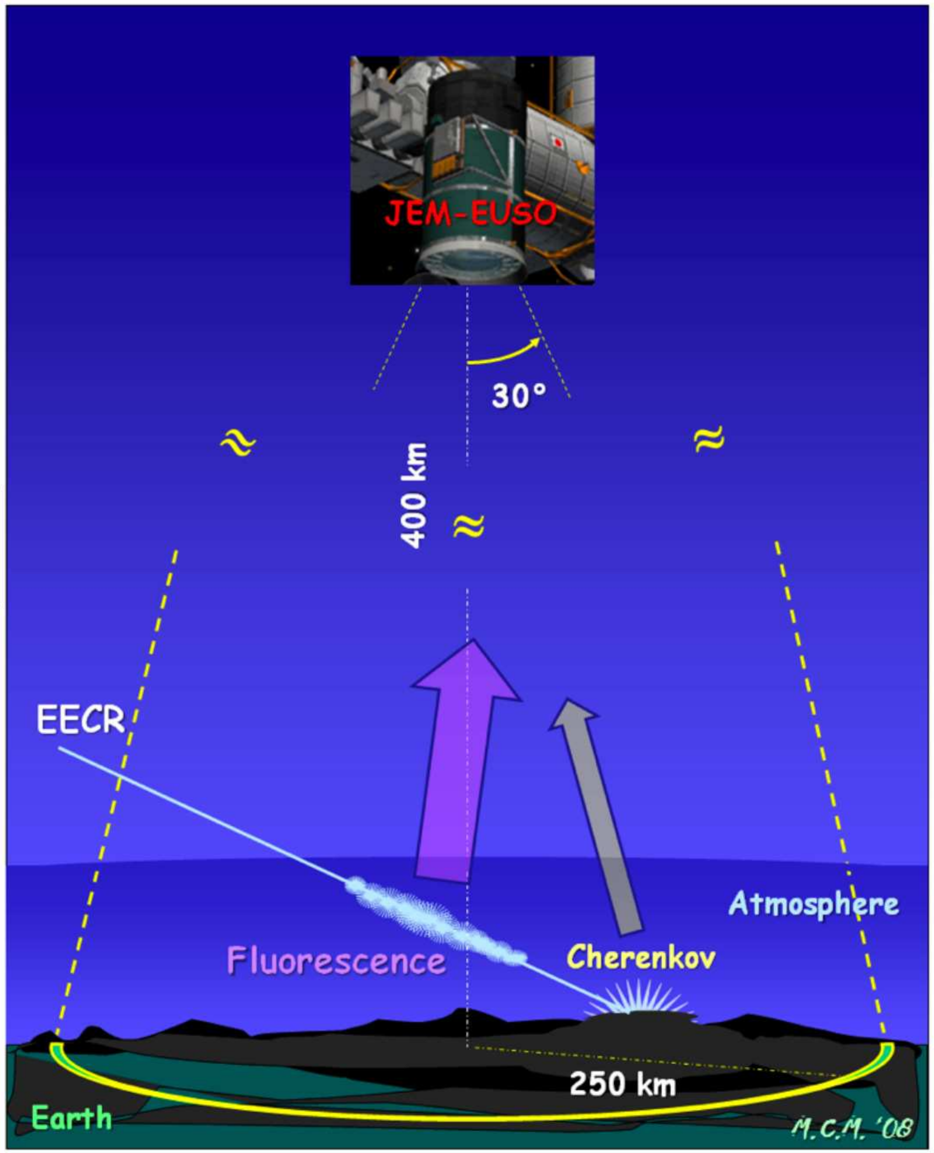
$$\approx few \times 10^{12}\ tons$$

Full sky coverage looking at both North and South sky

$$4\pi\ coverage$$

Large Distance R but small proximity effect

$$\Delta R / R in \%$$



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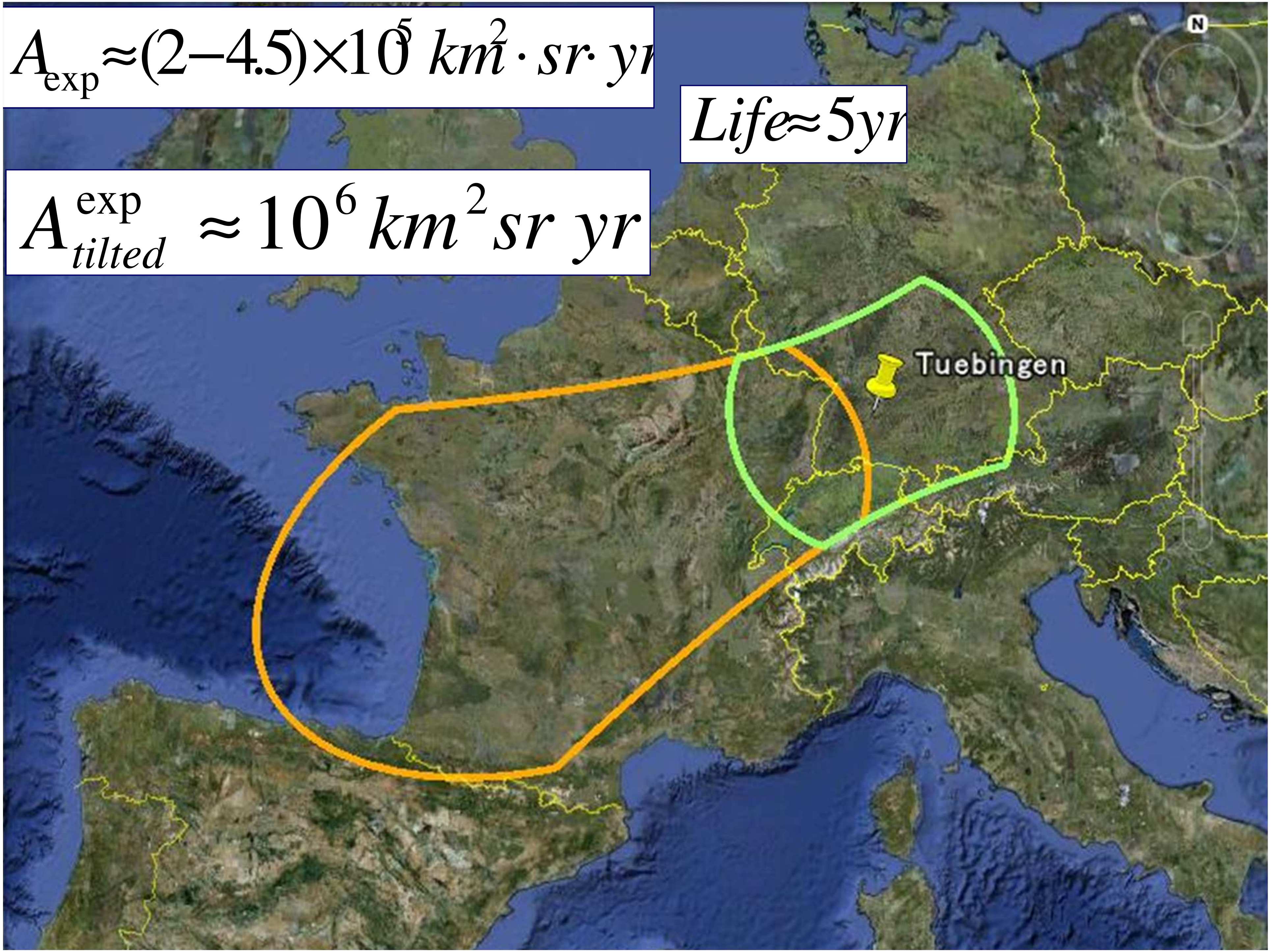
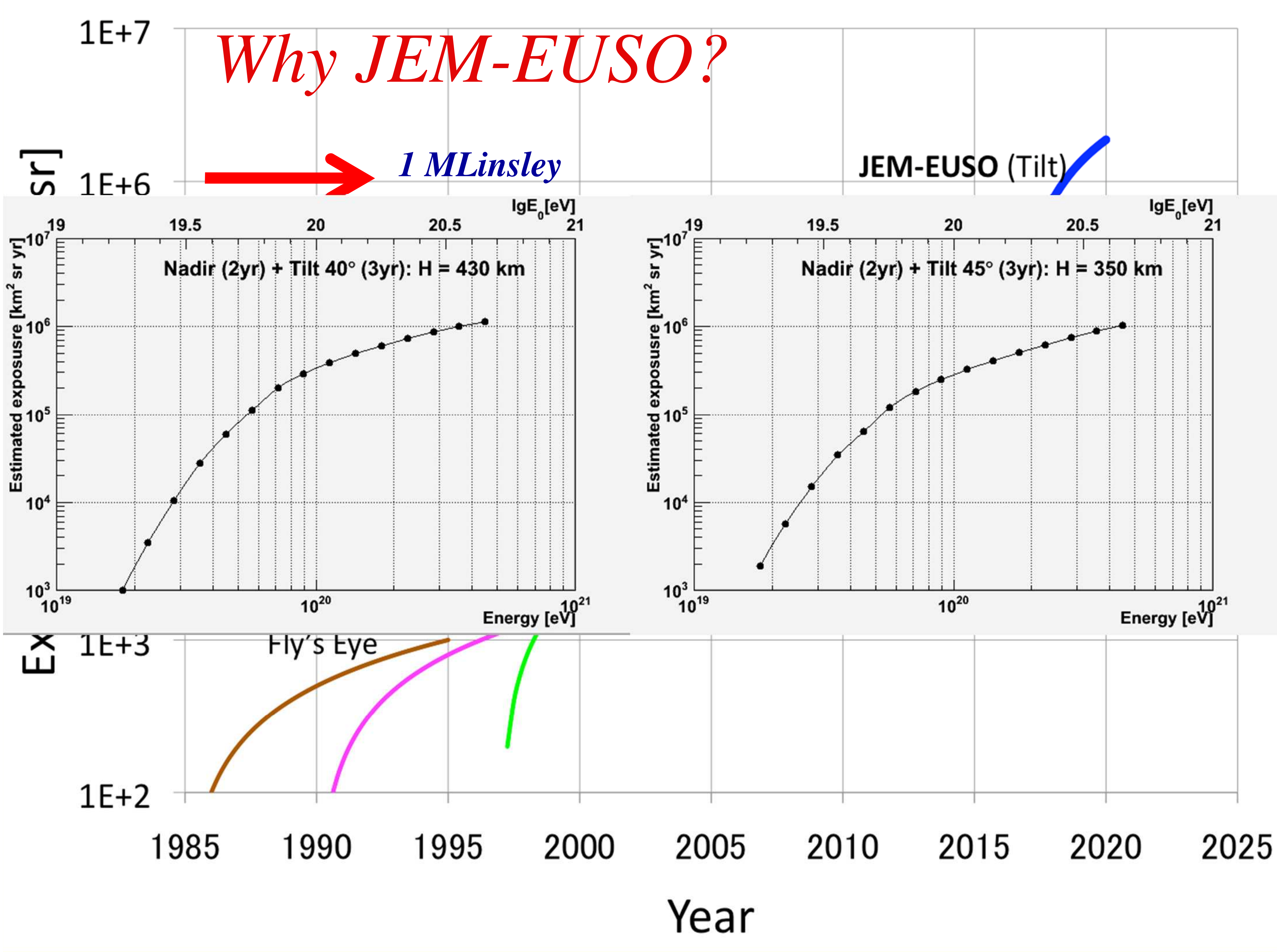
$$A_{\exp} \approx (2-4.5)\times 10^{5}\ km^{2}\cdot sr\cdot yr$$

$$Life \approx 5yr$$

$$A_{tilted}^{\exp} \approx 10^{6}\ km^{2} sr\ yr$$

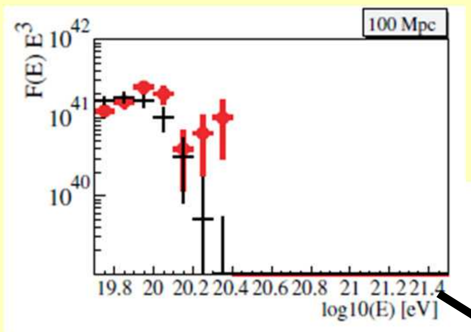


Why JEM-EUSO?



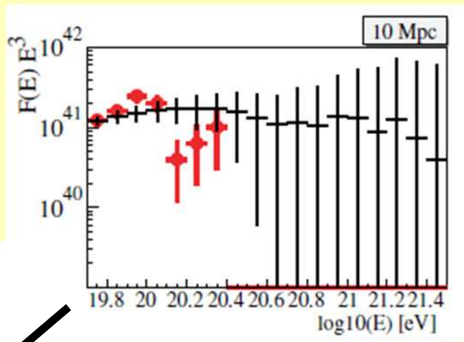
1 MLinsley
JEM-EUSO (Tilt)
Fly's Eye
1E+7
1E+6
1E+3
1E+2
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
Nadir (2yr) + Tilt 40° (3yr): H = 430 km
Nadir (2yr) + Tilt 45° (3yr): H = 350 km
lgE0[eV]
Estimated exposusre [km2 sr yr]
Energy [eV]

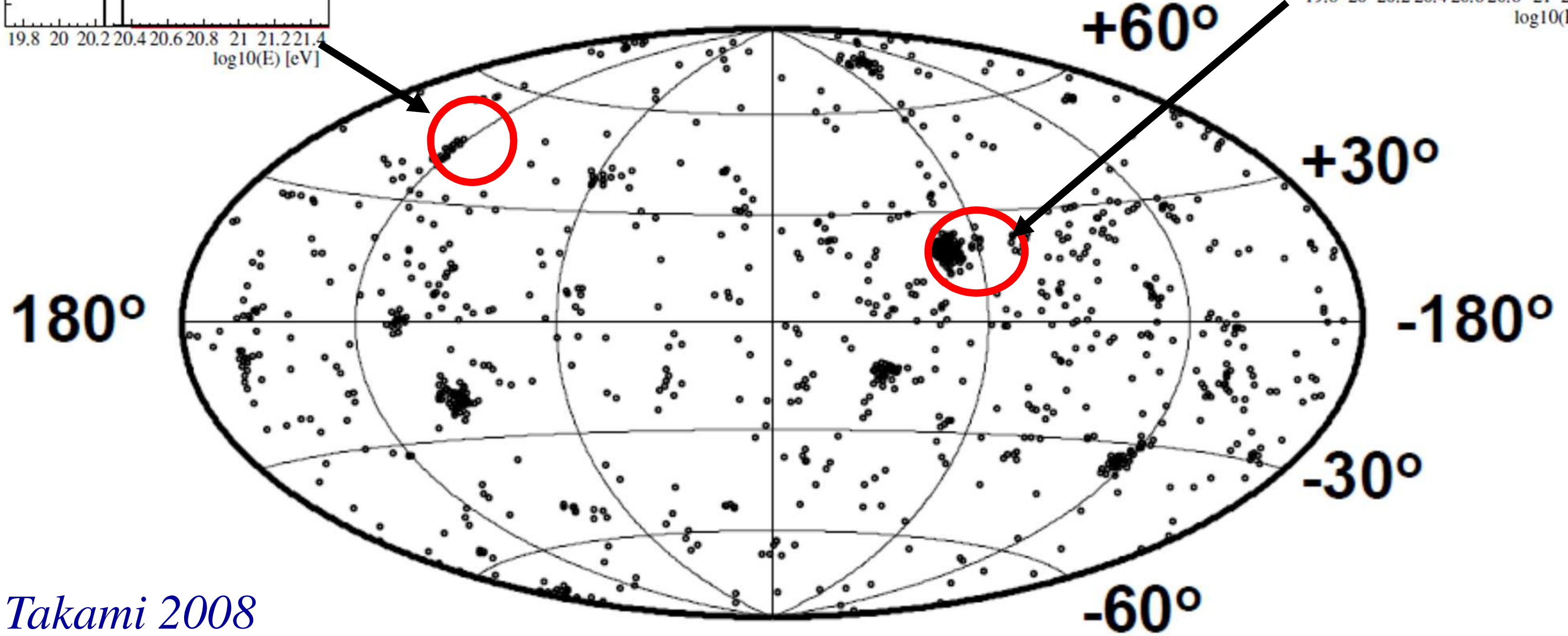
JEM-EUSO sky



Forecast in case of 1,000 events

Brightness of particles ∝ X ray（AGN）





Takami 2008

- ***More than 1,000 events: E>7x10^19eV***
- ***We expect to discover several dozens of clusters***
- ***Can observe the whole sky***

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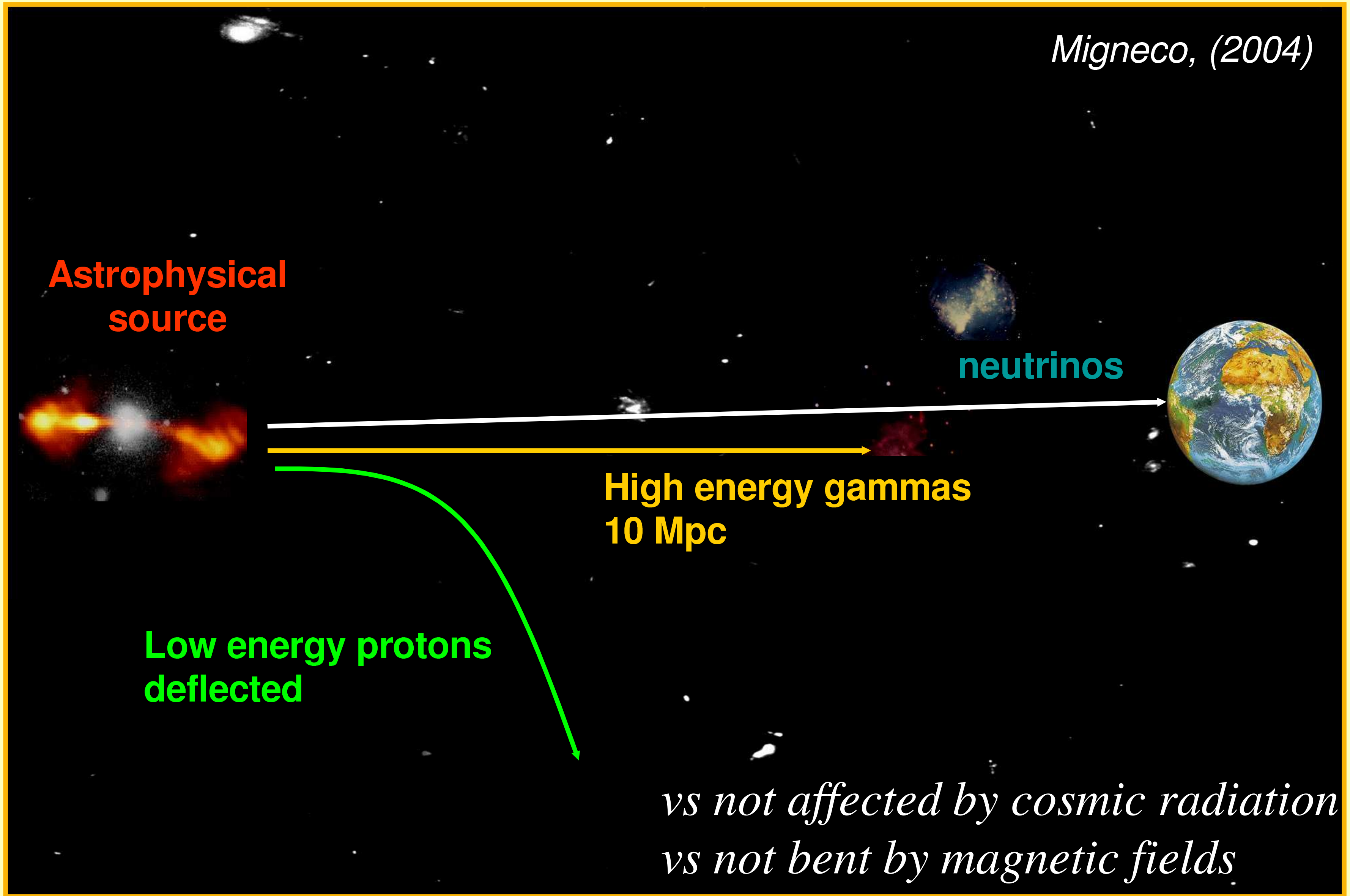
Exploratory Science Objectives:

- Neutrinos at UHE

- Photons at UHE

- Fundamental Physics

Astrophysical Neutrinos... (at UHE)



Production: Decay chains of mesons

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu})$$

$$\hookrightarrow e^{\pm} + \nu_{e}(\bar{\nu}_{e}) + \nu_{\mu}(\bar{\nu}_{\mu})$$

$\nu_e : \nu_\mu : \nu_\tau$

1 : 2 : 0 **(at generic source)**

pp→ π → μ ν_μ→ e $\nu_e \nu_\mu \nu_\mu$

1 : 1 : 1 **(at earth) max.mixing**

Other mesons like Kaons are also involved to certain degree and all decay chains are very well known → But HOW the mesons are produced ?

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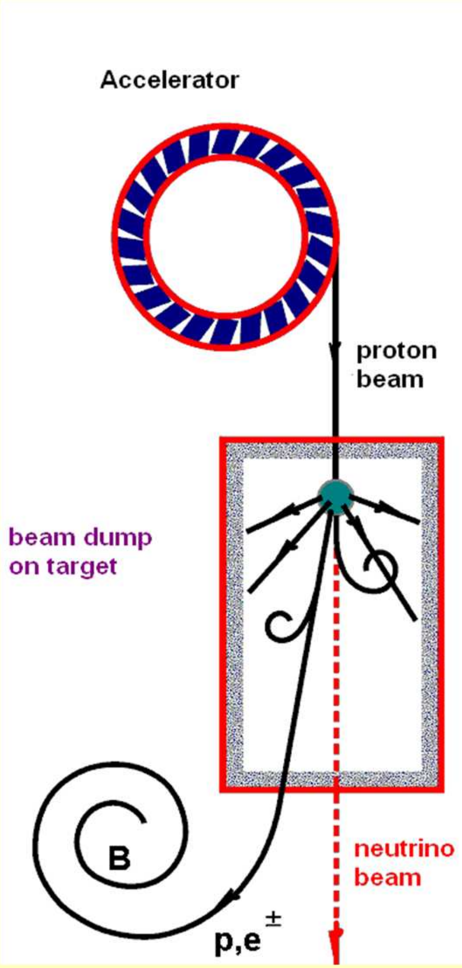
Sources of Neutrinos?

$$p + Nuclei \rightarrow \pi^{\pm,0} + \ldots$$

$$p\gamma \rightarrow n\pi^{+}$$

$$p\gamma \rightarrow p\pi^{0} \qquad \frac{\sigma_{p\gamma}}{\sigma_{pp}} = 0.01$$

$$p\gamma \rightarrow p\pi^{+}\pi^{-}$$



We have an accelerator of protons to generate a proton beam

Fermi mechanisms can accelerate protons

$$\propto E^{-2}$$

We need a gas (well nuclei) or ambient photons target

- Supernova ejecta
- Accretion disks
- Galactic disk
- Molecular clouds
- …

- Jets in AGN
- Microquasars, Binaries
- GRB
- CMB

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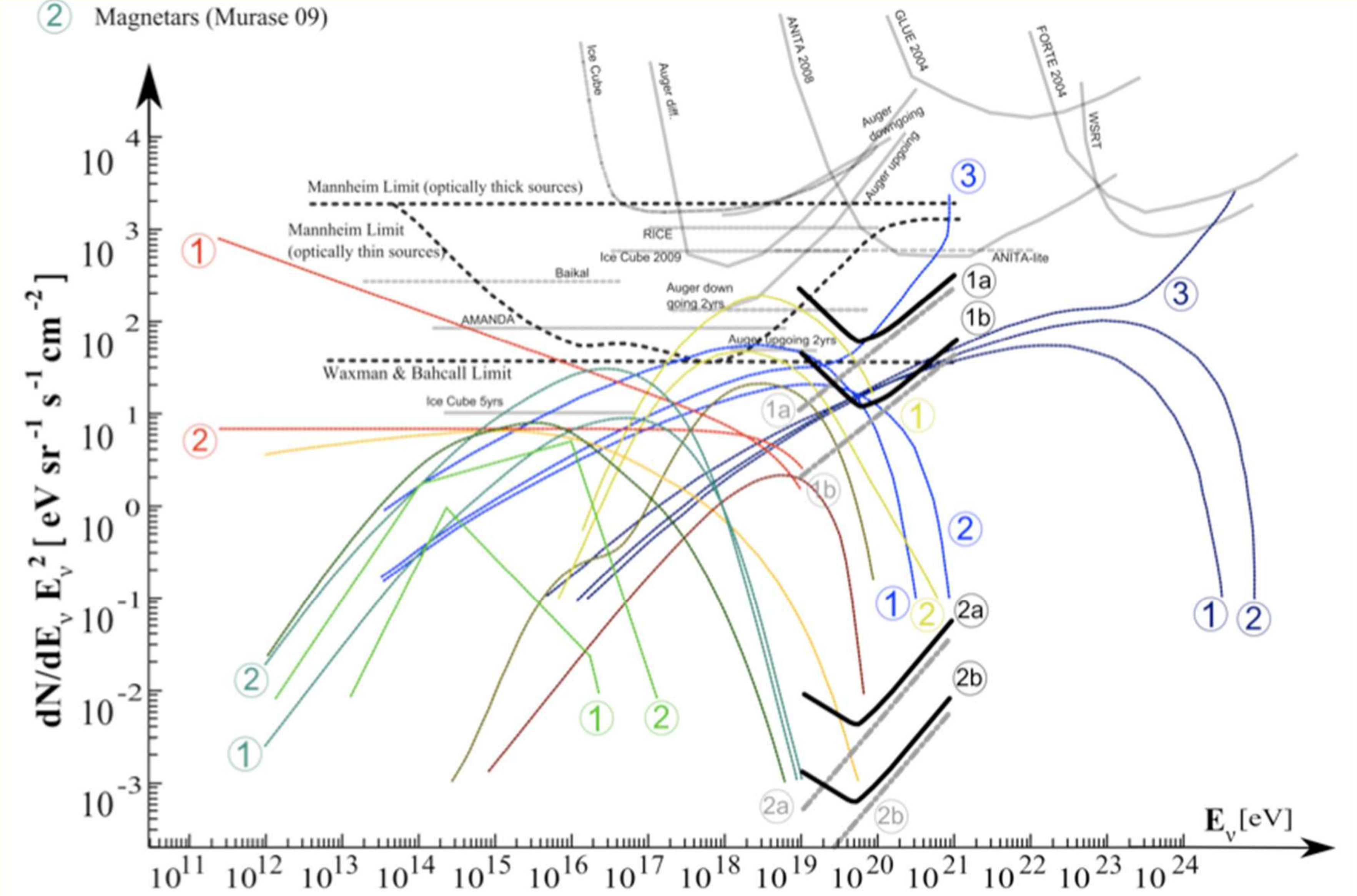
Bittermann, 2010

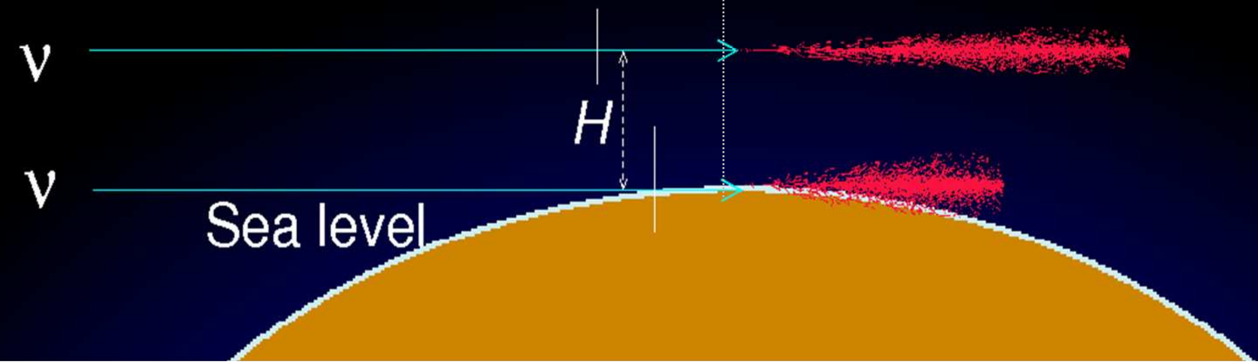
The Zoo of neutrino models



Neutrino shower simulation

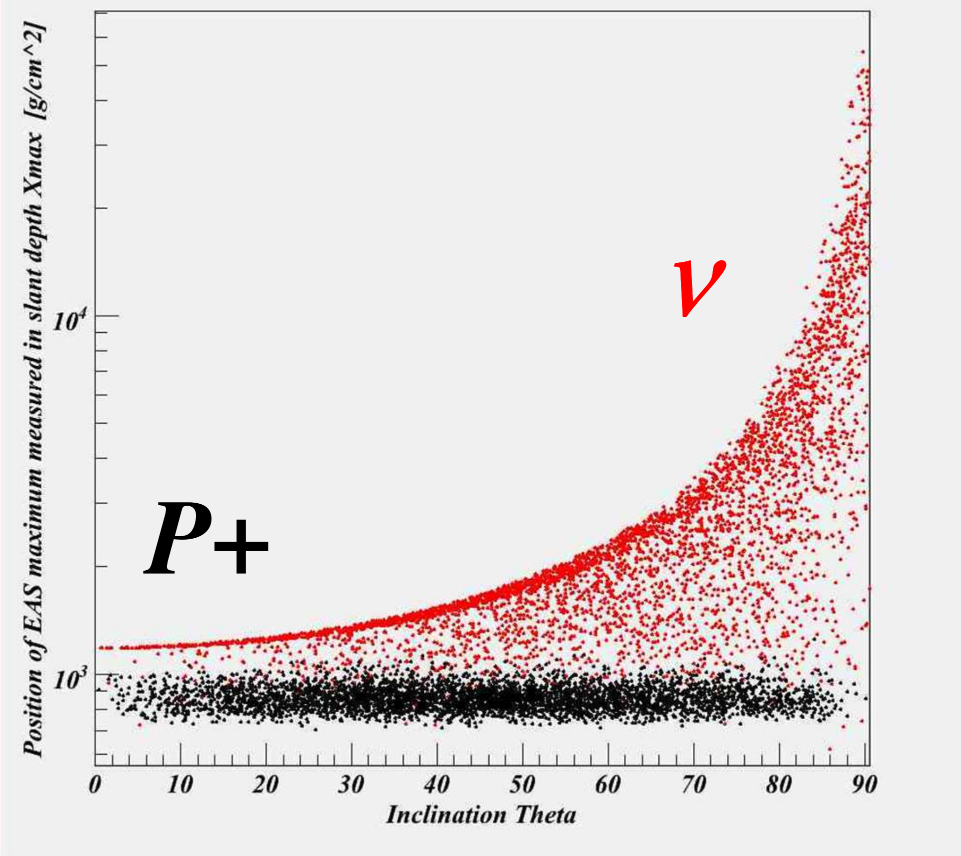
- *Horizontally incident neutrinos*
  - *Survival prob. to come in FOV*
    - *Neutrino: ~exp(-0.001)*
    - *Proton: ~exp(-1000) for 10^{20} eV*

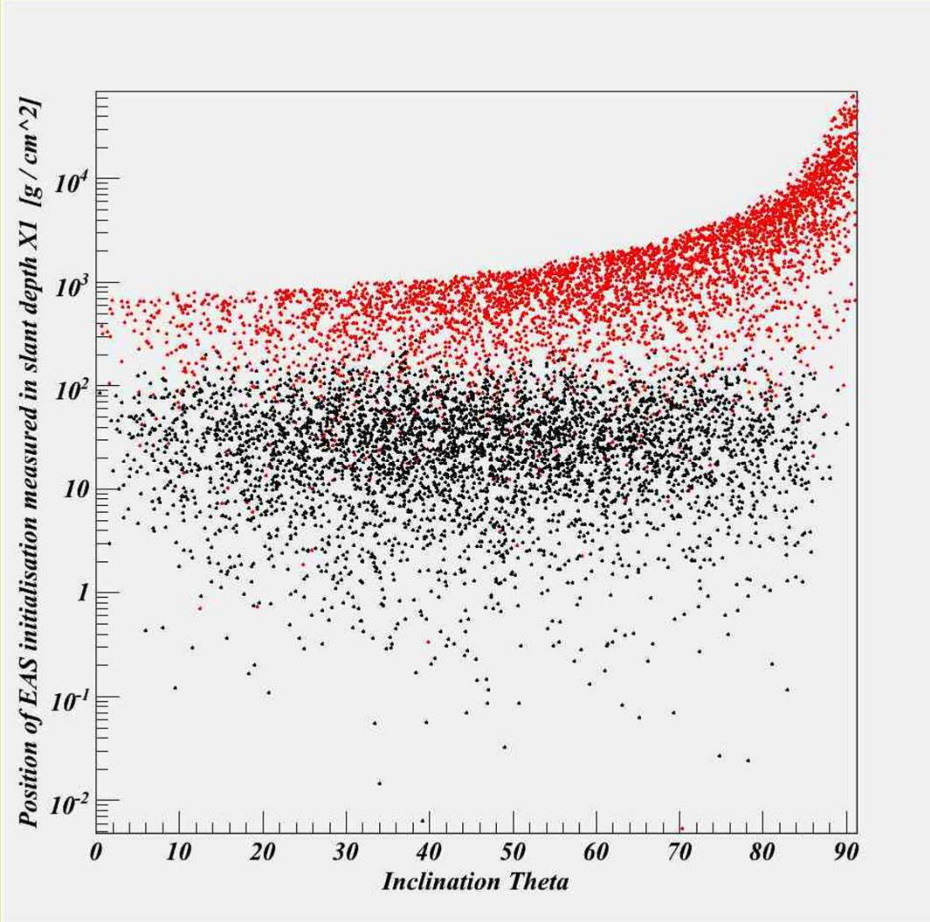
- *CONEX code used for shower simulation in atmosphere*



Discrimination of Neutrinos vs Protons

Rejection > 10^{-5}





Xmax

X1 initial point

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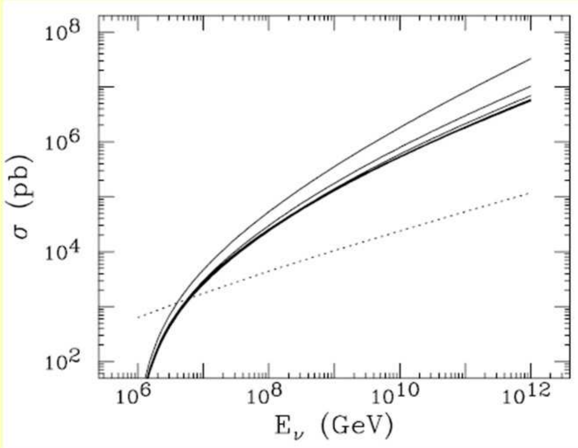
New Physics?

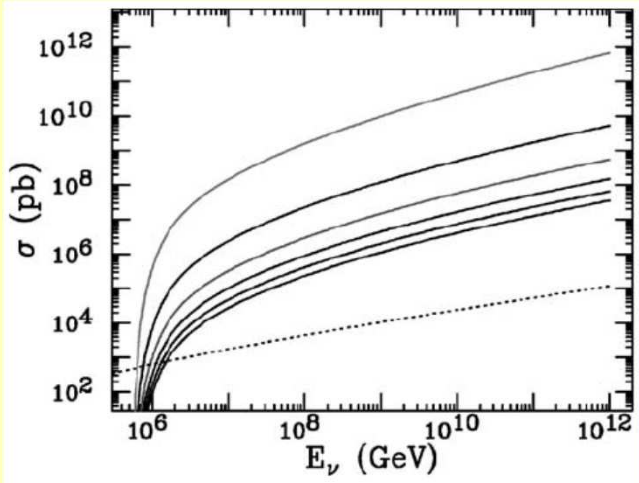
Neutrino cross sections

Black Hole production



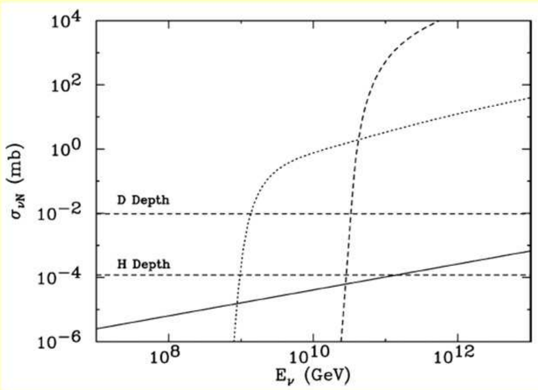
Feng & Shapere, 2002

p-brane production



Anchordoqui, Feng and Goldberg, 2002

EW instanton effects

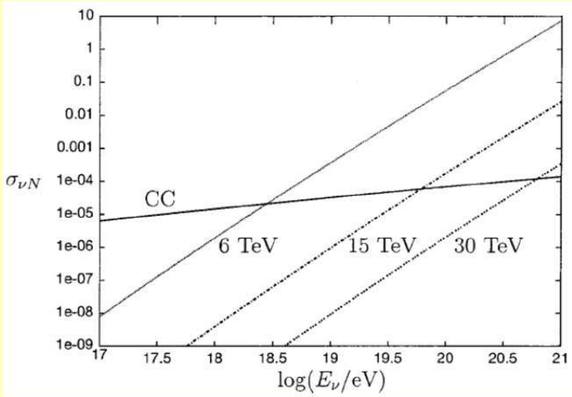


Bezrukov et al., 2003a, 2003b

Ringwald, 2003

Han & Hooper, 2004

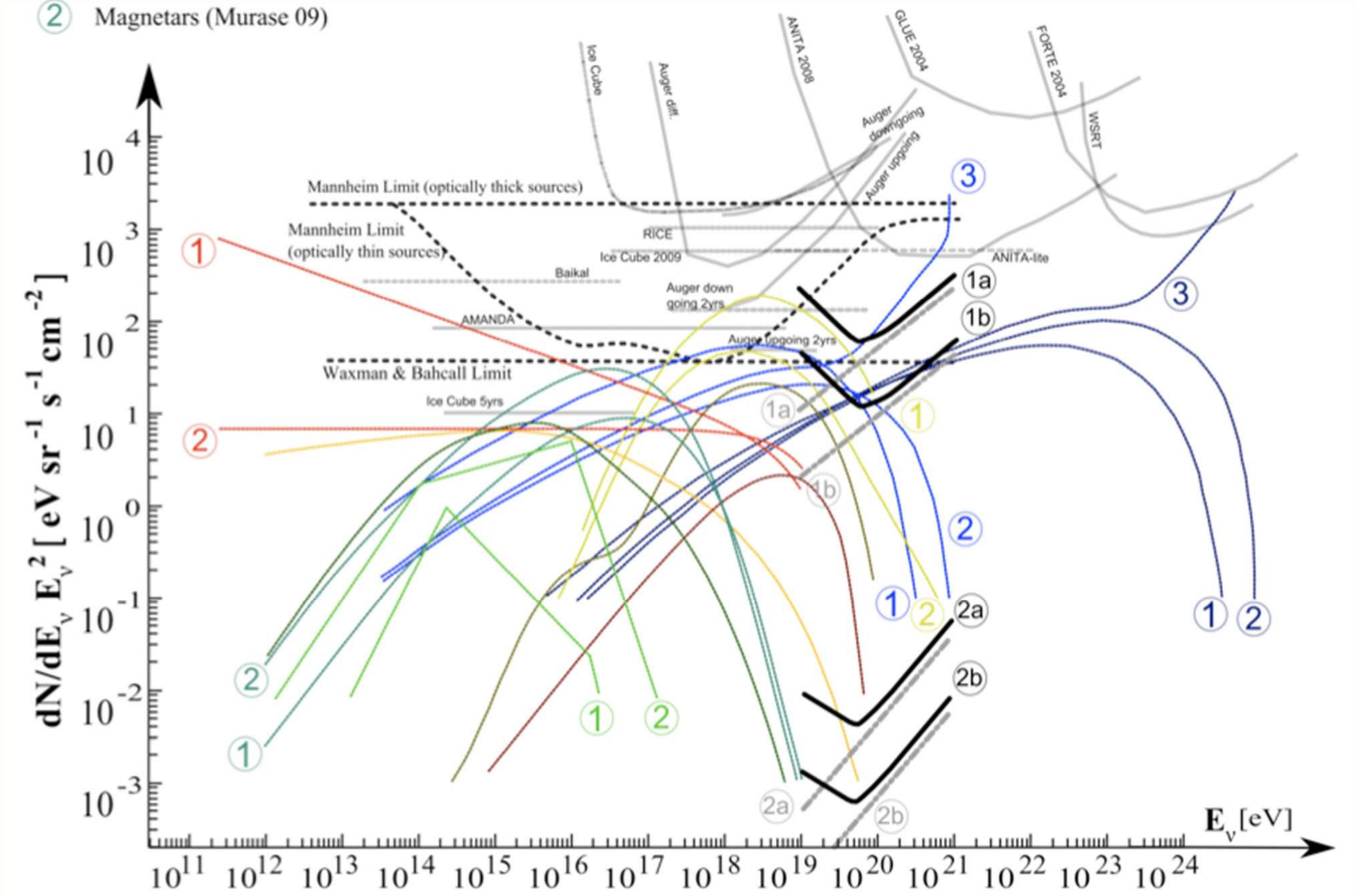
Exchange of KK modes



Kachelriess & Plümacher, 2000

Bittermann, 2010

The Zoo of neutrino models



Scientific Requirements

Number of Events: > 1000 (at E> $7x10^{19}$eV)
Arrival direction: < 2.5° → **Point Source**
Energy determination: < 30% → **Energy spectrum**
Xmax determination: < 120 g/cm^2 → **LPM EAS**
Neutrino EAS

They have been confirmed by end to end simulations performed with two independent Frameworks (ESAF in Europe)

Conclusion (I)

HESS was right: we need a lot of money for all these fascinating projects!

Updated from

F. Halzen, 2002

Conclusion II: Serendipity or Vision?

« The Eye »	User	date	Intended Use	The breakthrough
Optical	Galileo	1608	Navigation	Moons of Jupiter
Optical	Hubble	1929	Nebulae	Expanding Universe
Radio	Jansky	1932	Noise	Radio galaxies
Micro-wave	Penzias, Wilson	1965	Radio-galaxies, noise	3K cosmic background
X-ray	Giacconi, Rossi	1965	Sun, moon	neutron stars accreting binaries
Radio	Hewish, Bell	1967	Ionosphere	Pulsars
γ-rays	military	1960?	Thermonuclear explosions	Gamma ray bursts
UHECR	*JEM-EUSO ?*	*2015?*	*UHE CR and ν sources*	*????*

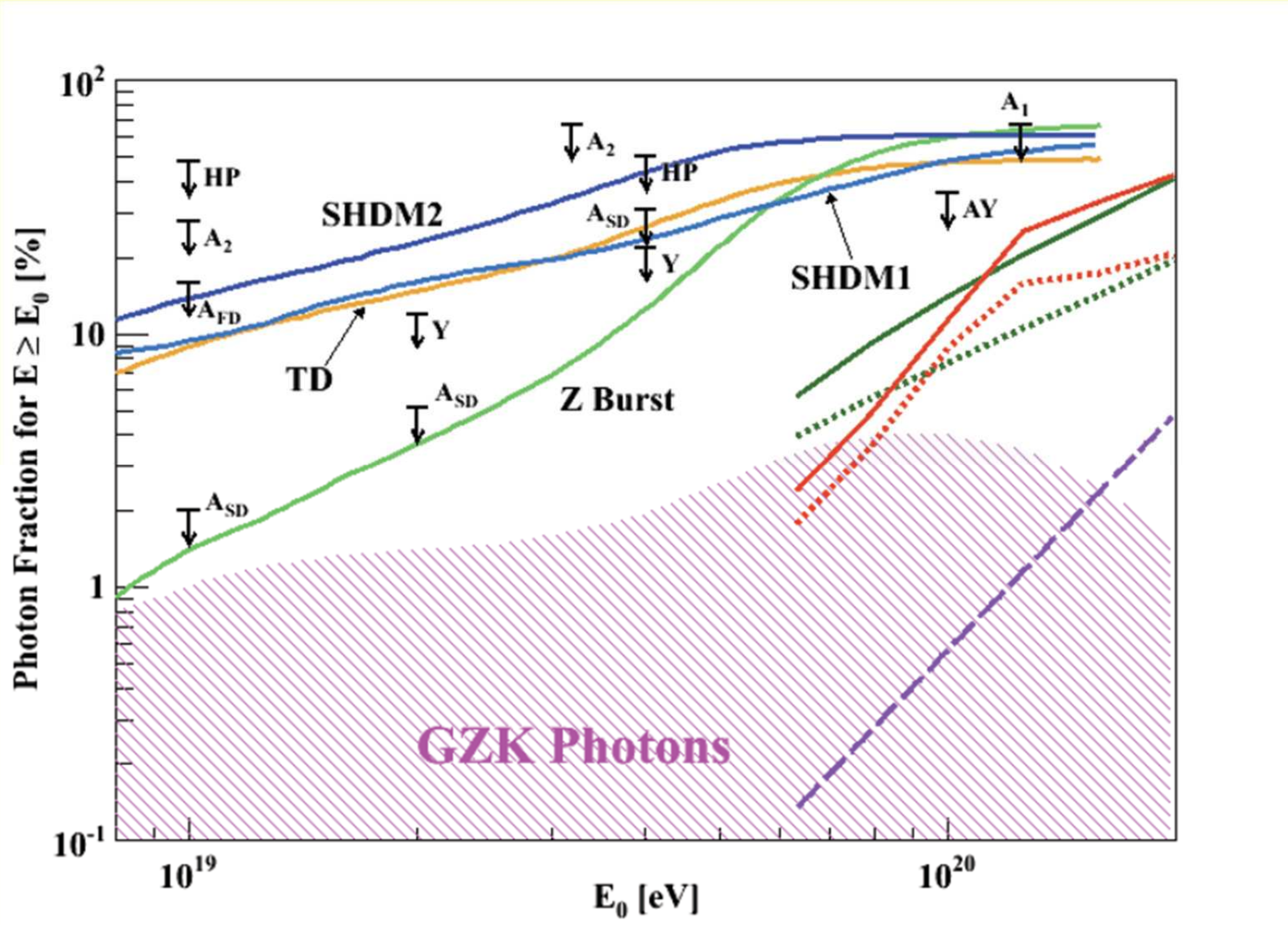
What will be the impact of clouds in the efficiency of the mission?

- In rough numbers:
  - 1/3 of the time the sky is clear,
  - 1/3 of the time there are only low altitude clouds (<1 km), and
  - 1/3 of the time there clouds at higher altitudes, interfering with measurements.
- The cloud interference will be assessed by:
  - IR imagery calibrated by nadir-pointing LIDAR measurements
  - Auto-detection using the forward directed Cherenkov emission from the EAS events themselves.

Constrains from Auger

Auger Collaboration, 2009

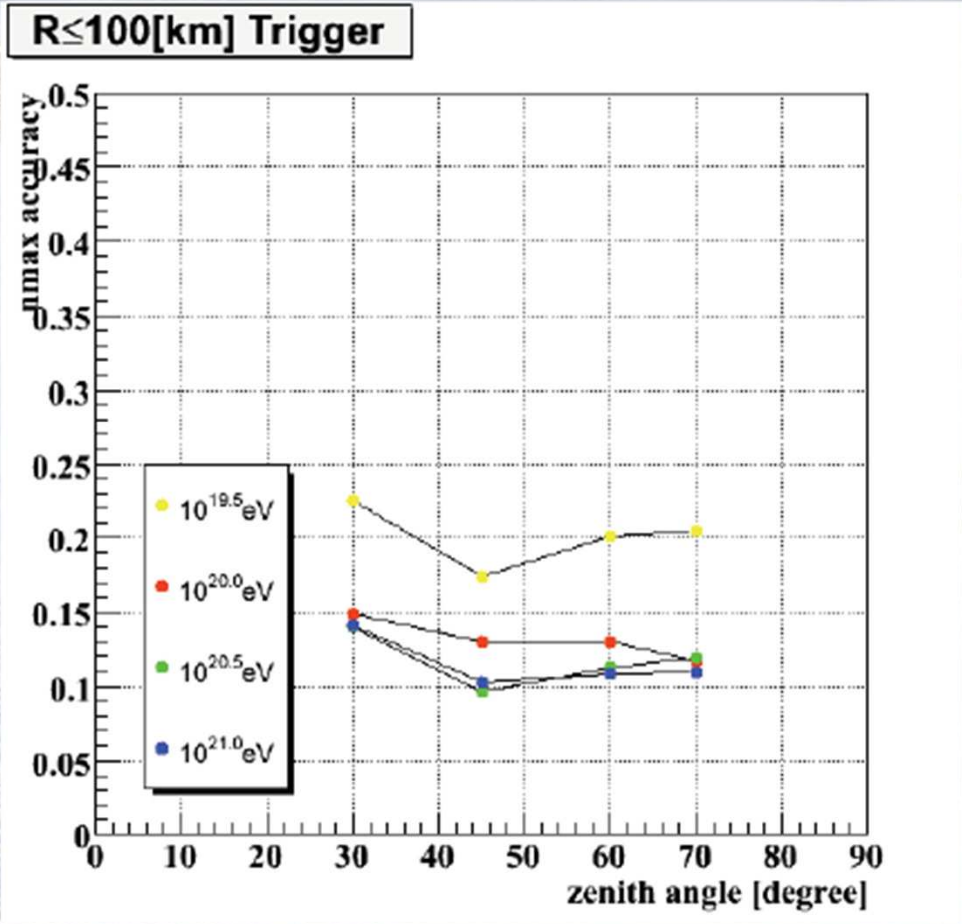
SHDM models ***are strongly constrained by the absence of identified photon candidates*** **in the Auger data**

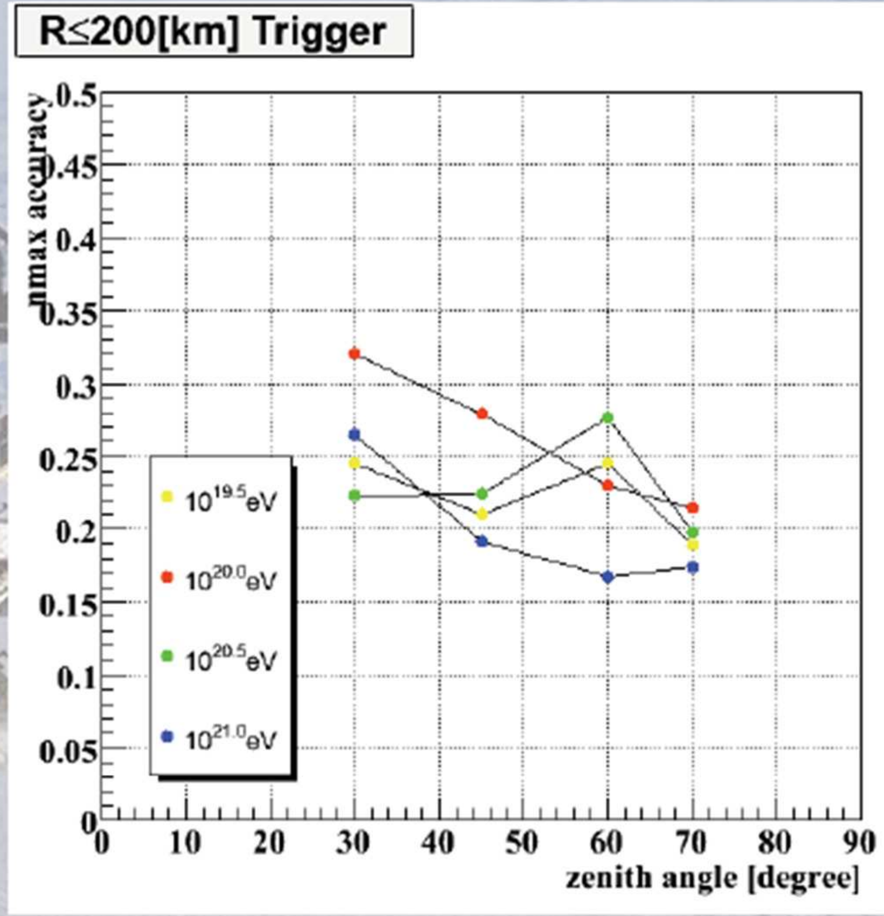


ngelo,
Kepler Center-Tü

Performances

Energy resolution

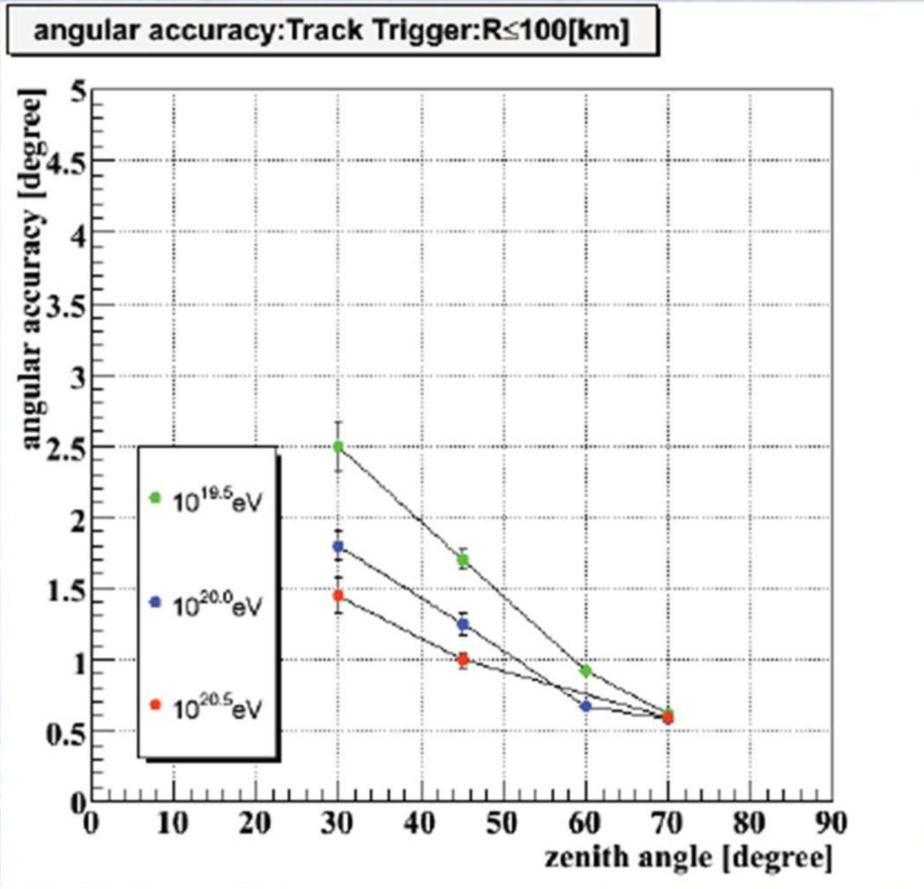


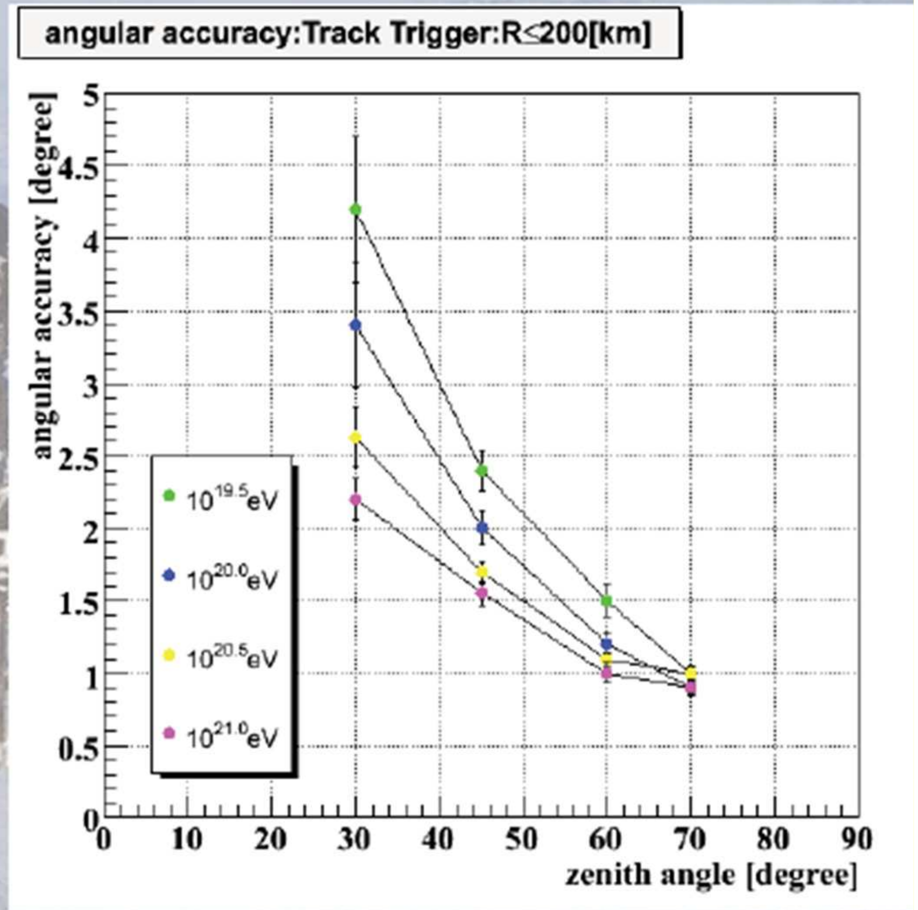


OK

Performances

Angular resolution

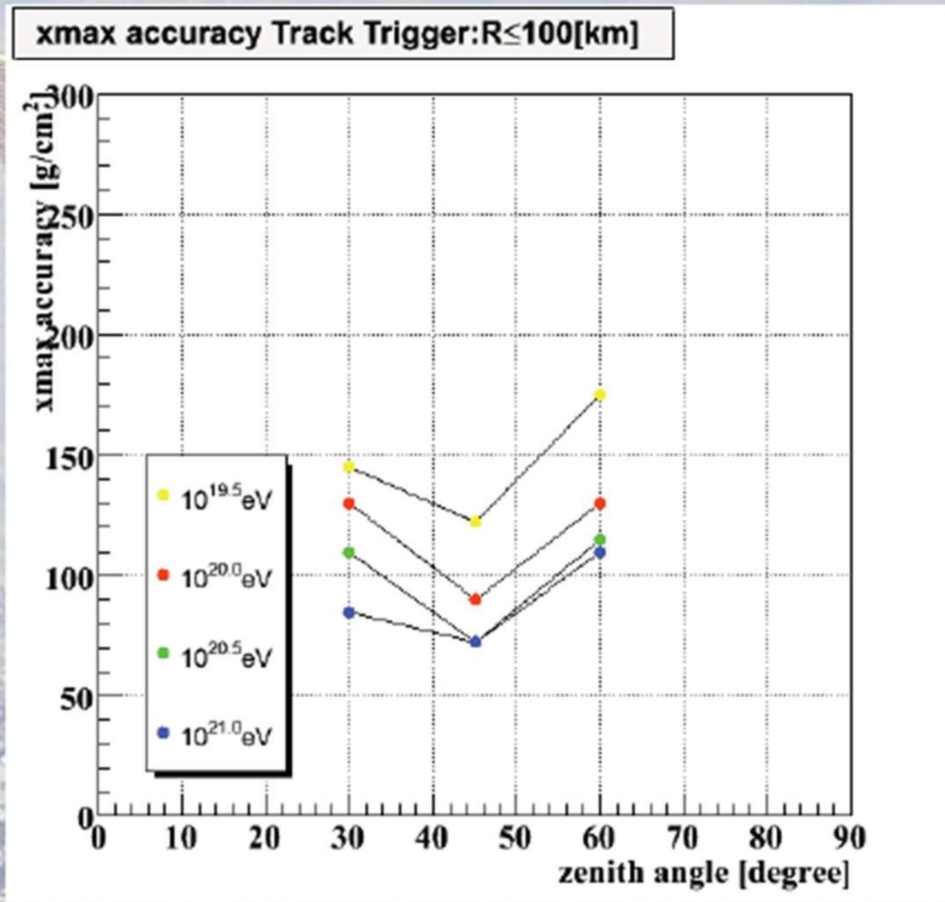


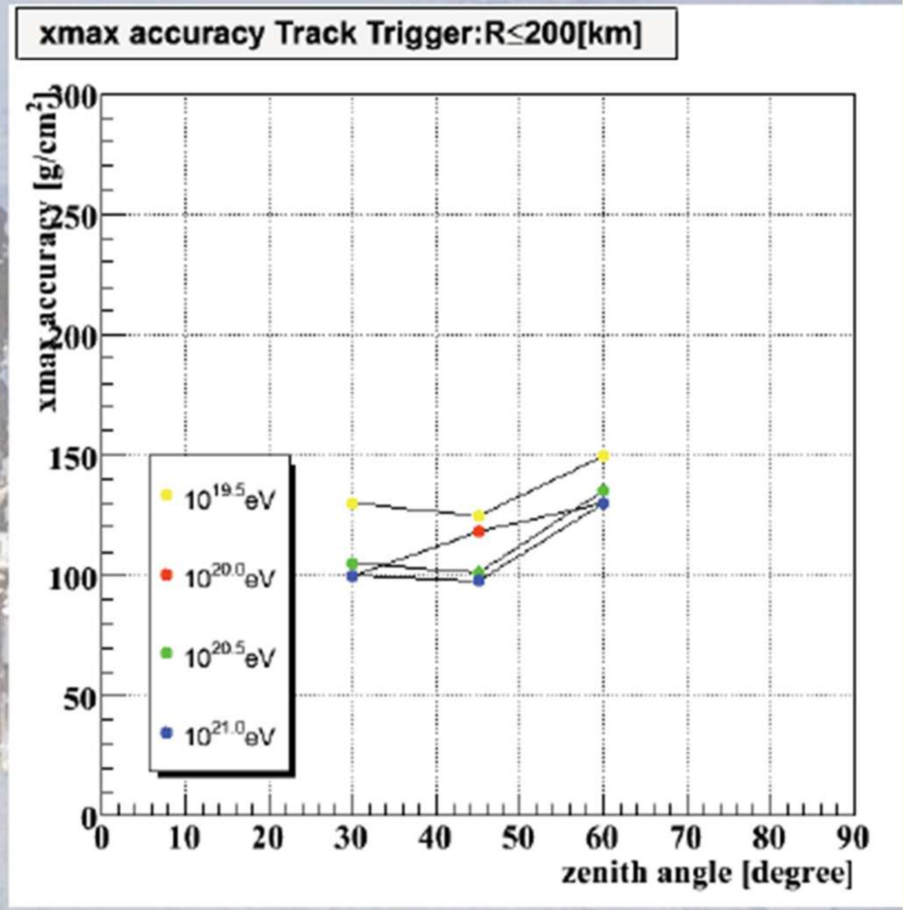


OK

Performances

Xmax resolution





OK

Atmospheric Monitoring System

- ***IR Camera***

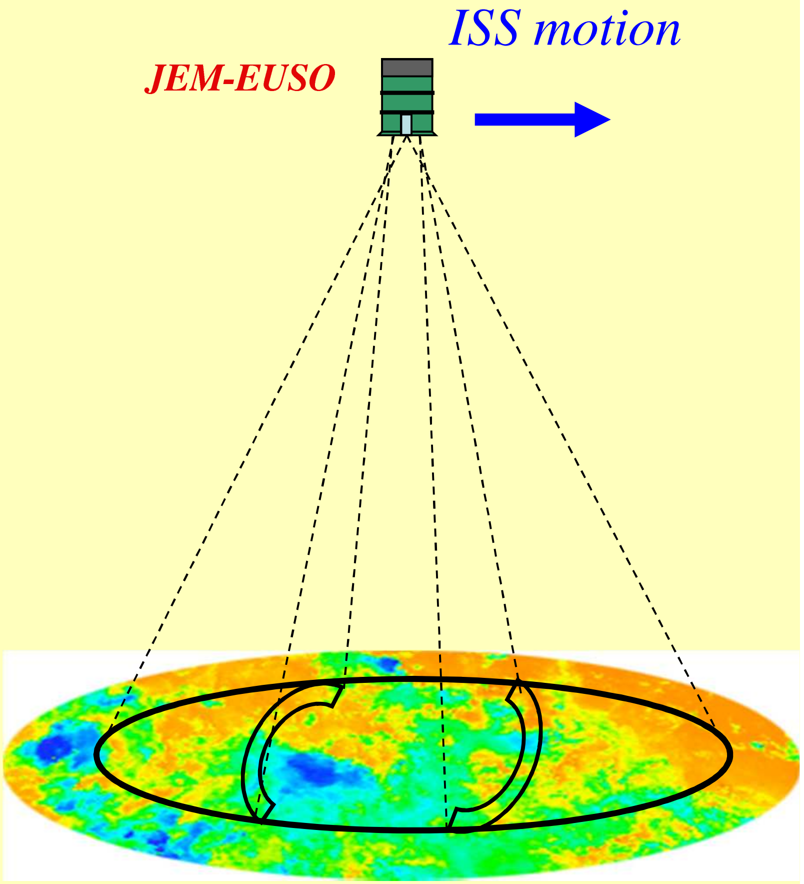
  Imaging observation of cloud temperature inside FOV of JEM-EUSO

- ***Lidar***

  Ranging observation using UV laser

- ***JEM-EUSO "slow-data"***

  Continuous background photon counting



- *Cloud amount, cloud top altitude: (IR cam., Lidar, slow-data)*
- *Airglow : (slow-data)*
- *Calibration of telescope : (Lidar)*

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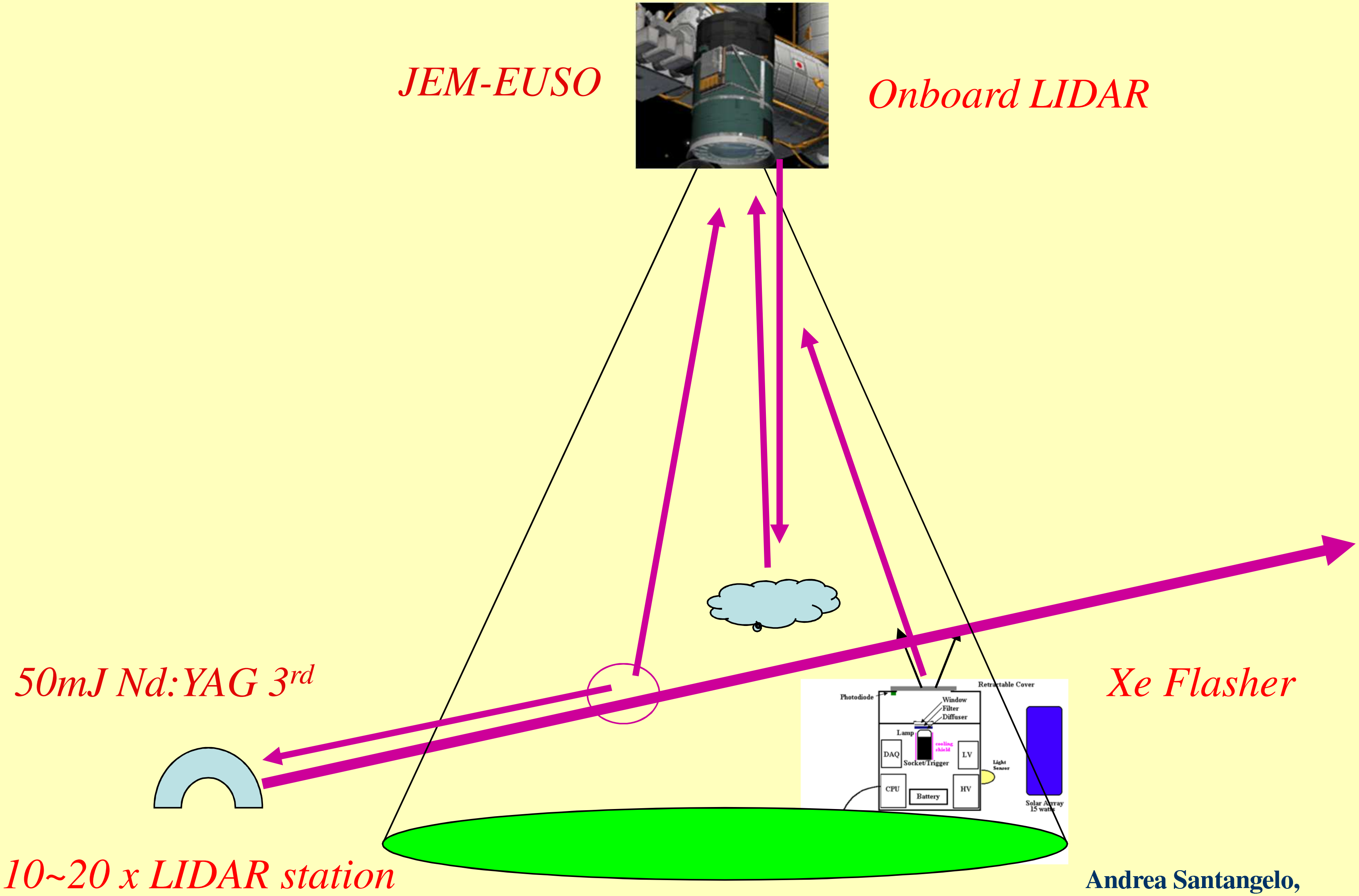
Kepler Center-Tü

Calibration and Monitor by Onboard LIDAR, Ground LIDAR & Xe flasher



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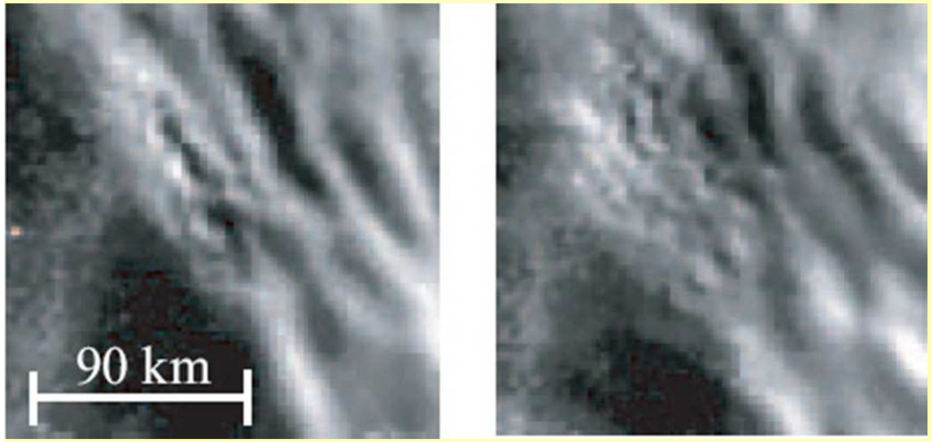
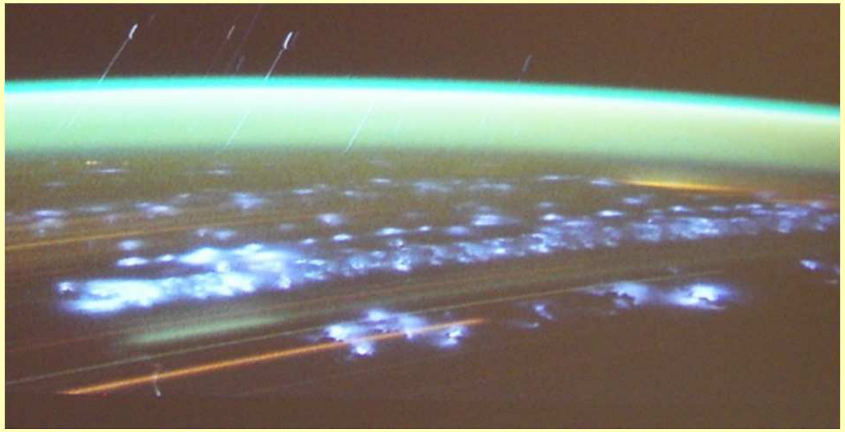
Atmospheric Luminous Phenomena

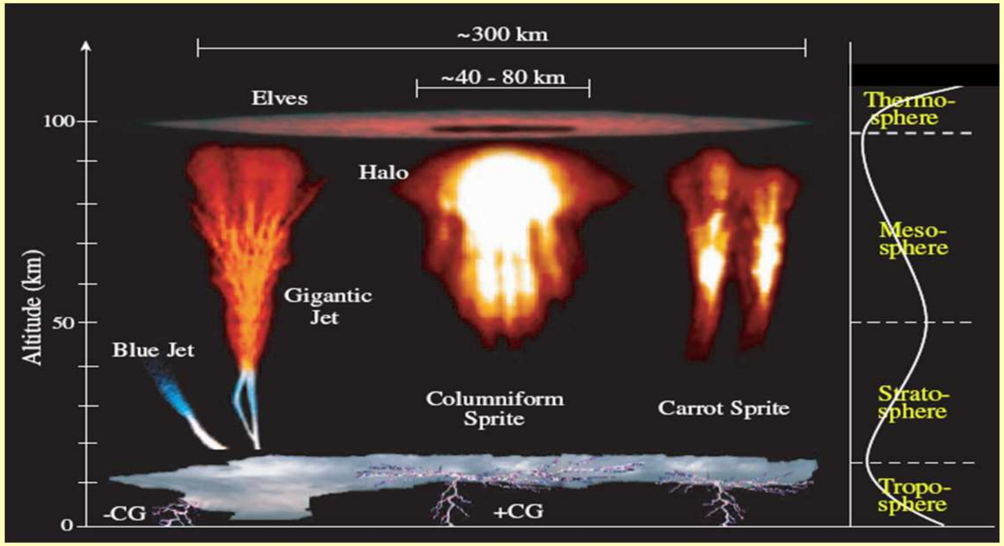


OH airglow observed from ground



Lightning picture observed from ISS

Leonid meteor swarm in 2001 taken by Hivison camera



Various transient events

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Transient Luminous events

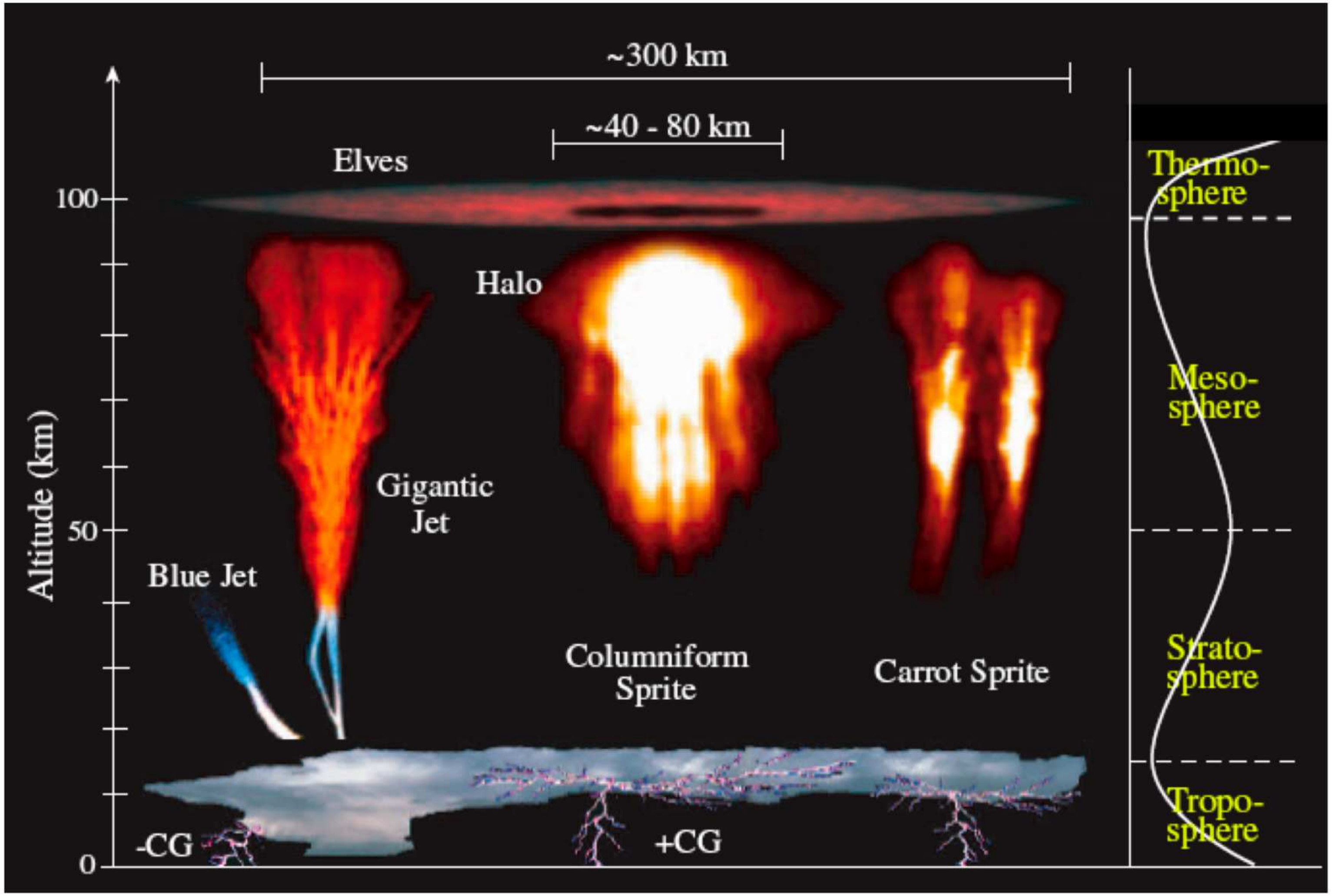

Figure 2.2.5-2. *Various transient luminous events associated with lightning.*

From the JEM-EUSO phase A report

A naïve science objective: exploration of the Unknown!

Updated from

F. Halzen, 2002

Serendipity or Vision?

« The Eye »	User	date	Intended Use	The breakthrough
Optical	Galileo	1608	Navigation	Moons of Jupiter
Optical	Hubble	1929	Nebulae	Expanding Universe
Radio	Jansky	1932	Noise	Radio galaxies
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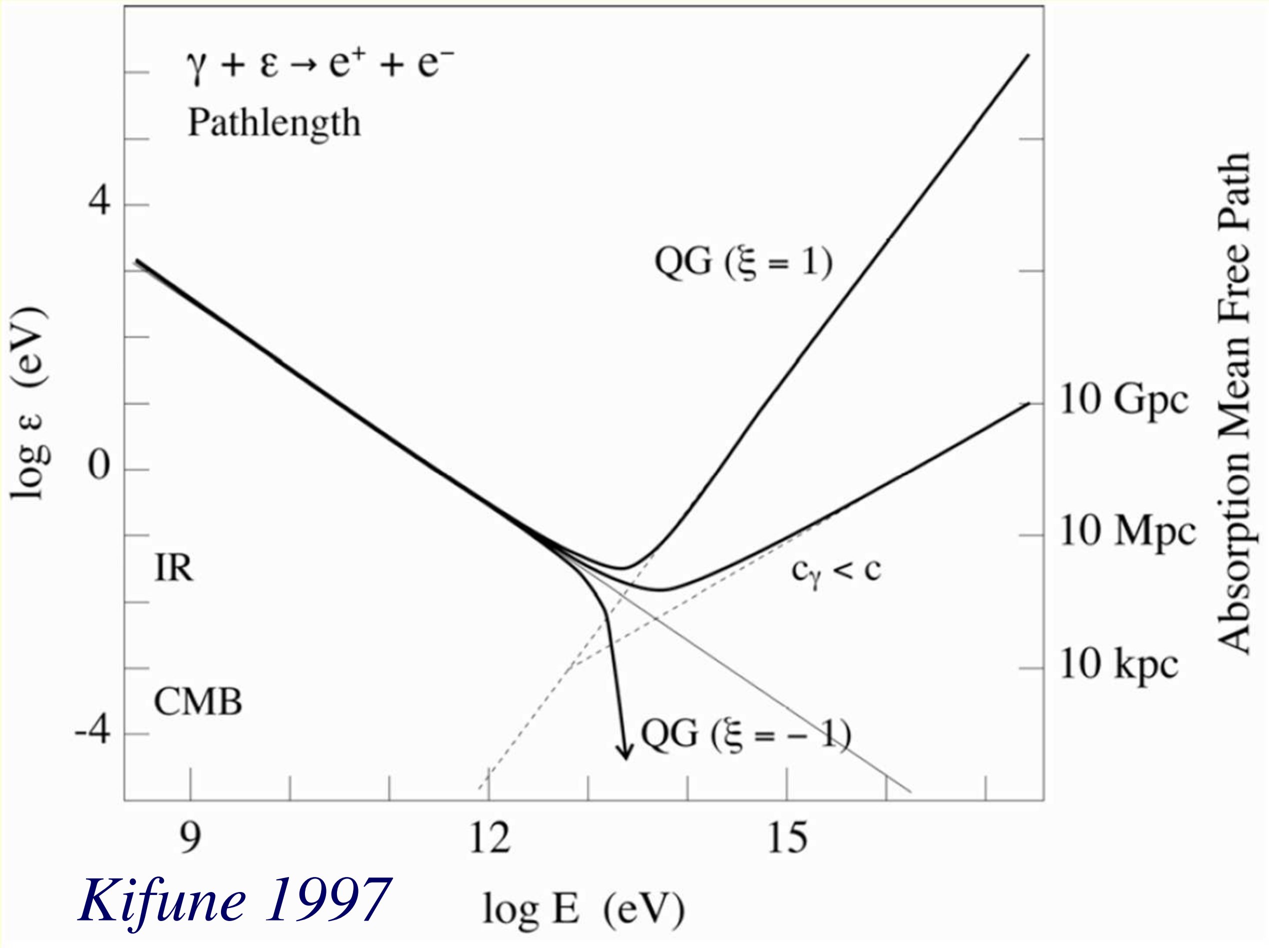
Radio	Hewish, Bell	1967	Ionosphere	Pulsars
γ-rays	military	1960?	Thermonuclear explosions	Gamma ray bursts
UHECR	*JEM-EUSO ?*	*2015?*	*UHE CR and ν sources*	*????*

Back-up slides

Atmospheric Sciences

- Lightning and TLEs by CR data
  - Nadir Observation of Lightning and TLEs
  - Global Survey of TLEs
  - Narrow Bipolar Events
- Night Grow, Plasma Bubbles by slow data
  - Global Imaging of O_2 Hertzburg I night grow
  - Formation Mechanism of Plasma Bubbles
  - Energy, Momentum, and Material transfers in upper atmosphere
- Clouds and atmospheric condition by Lidar and IR cam
  - Global survey of cloud top height
  - Aerosol distribution in troposphere and lower stratosphere(<25km): Mie Lidar
  - Density and temperature distribution (25-60 km): Rayleigh Lidar
- Meteors by slow data



Kifune 1997

EHE γ-rays travel > Gpc only in Quantum Gavity or C-G vacuum

- E (γ) ⟿ ← - - - ε (10^{-3}K)
- $4\varepsilon E - \xi \geq 4 m_e c^4$

Andrea Santangelo,
Kepler Center-Tü

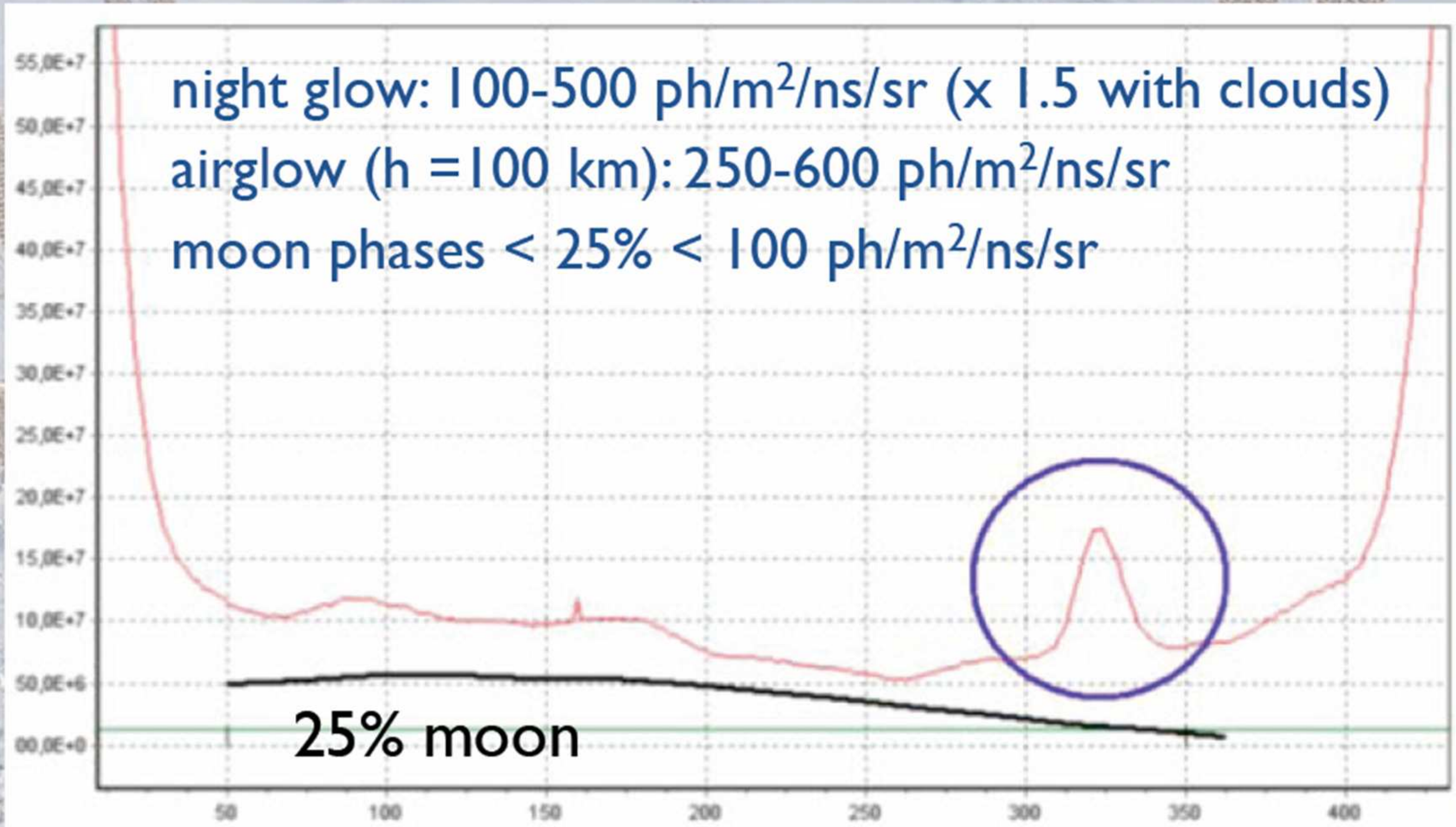
What is the expected background of the mission?

- Dark Sky Background
  - Estimated from balloon flight data collected by Italian and US balloon experiments and from Russian satellite measurements (Tatiana). The additional light seen from space was checked against upper atmosphere models for the Hertzberg emission in the UV. Simulations show that the EAS signals an be seen above this background.
- The Moon
  - We have used measurements of lunar emissions in the UV to determine the addition of reflected moonlight to the dark sky background. Since the moon is very non-Lambertian, it adds little below half-moon. Nearer full moon the threshold must be raised to accommodate the background.
- Background light from Cities
  - This was measured by balloon flights and satellites. Extrapolations were made to cities not measured, scaling by population. Avoiding cities results in a rather small reduction in collection time.
- Auroral light:
  - This was estimated from satellite measurements and estimated from historical patterns of auroral activity. Aurora will cause a small decrease in collection time.
- Other Sources:
  - Lightening: We have found that all known forms of lightening longer duration pulses of light. These should not be confused with the EAS signal.
  - Xenon flash lamps on aircraft, tall towers, etc. These are too fast to satisfy the EAS trigger criterion.

Background

Measured by Tatiana
flown in 2005

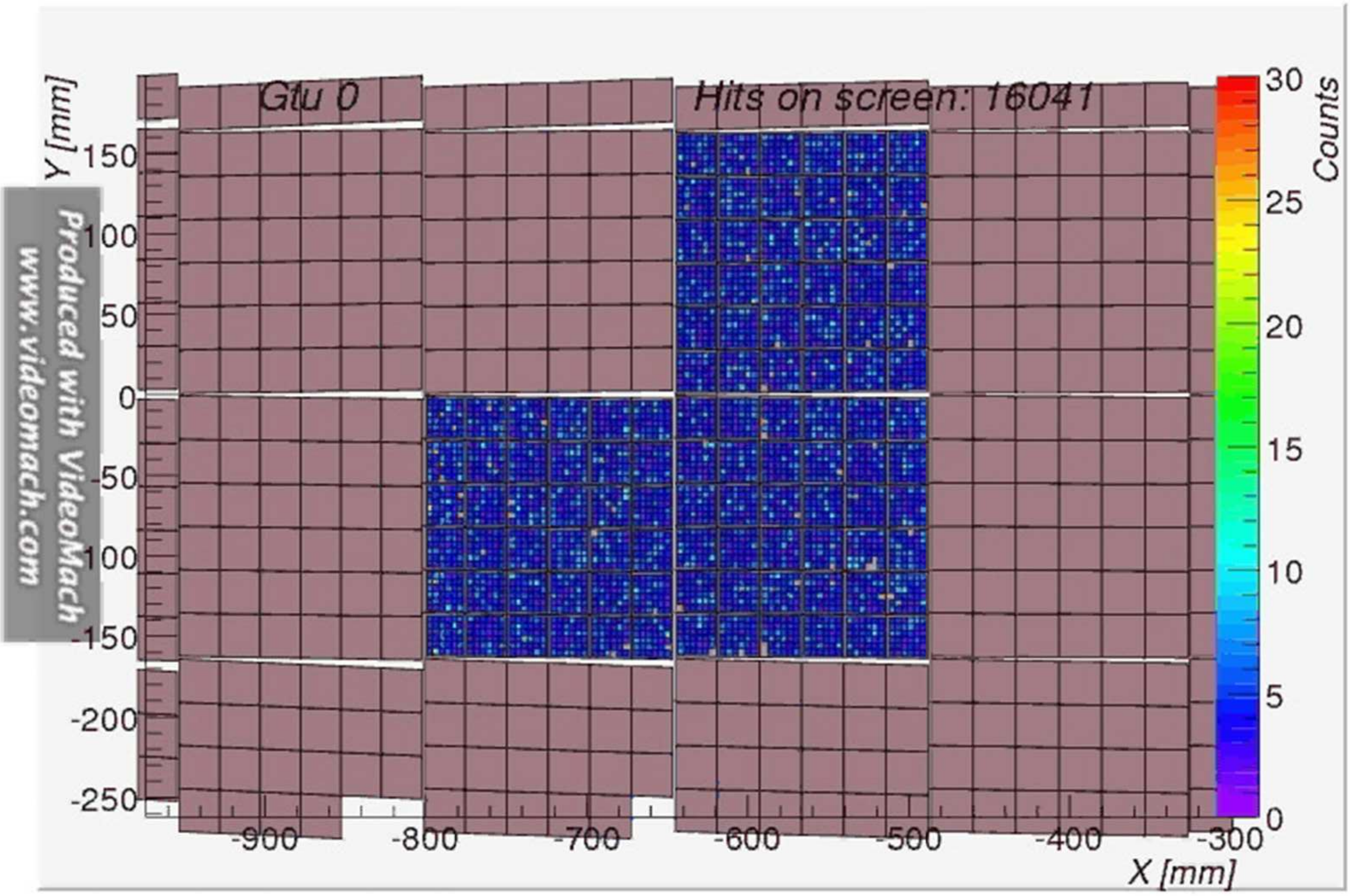
Further studies with TUS
launch in 2011 (funded & scheduled)

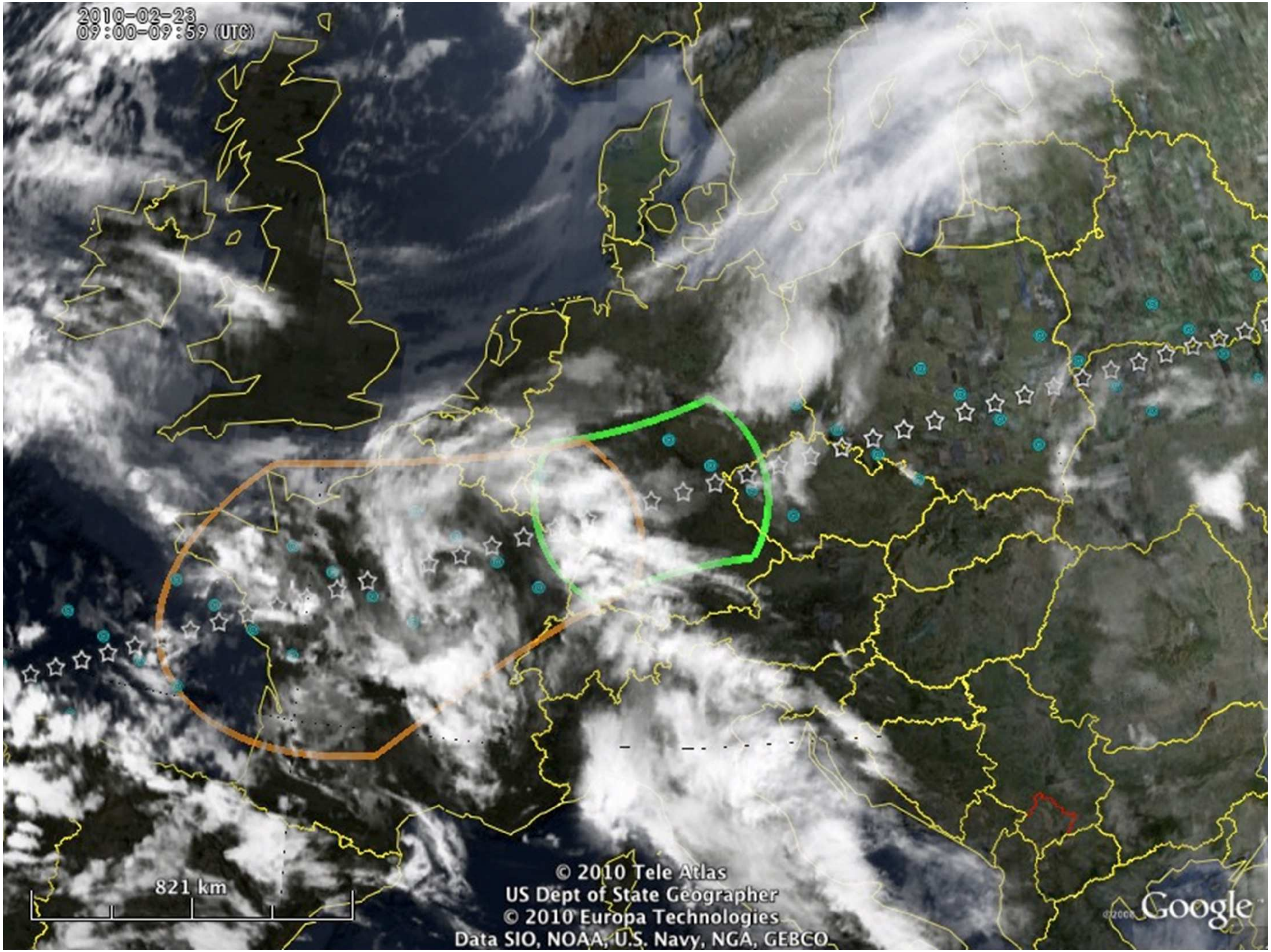


How is JEM-EUSO calibrated?

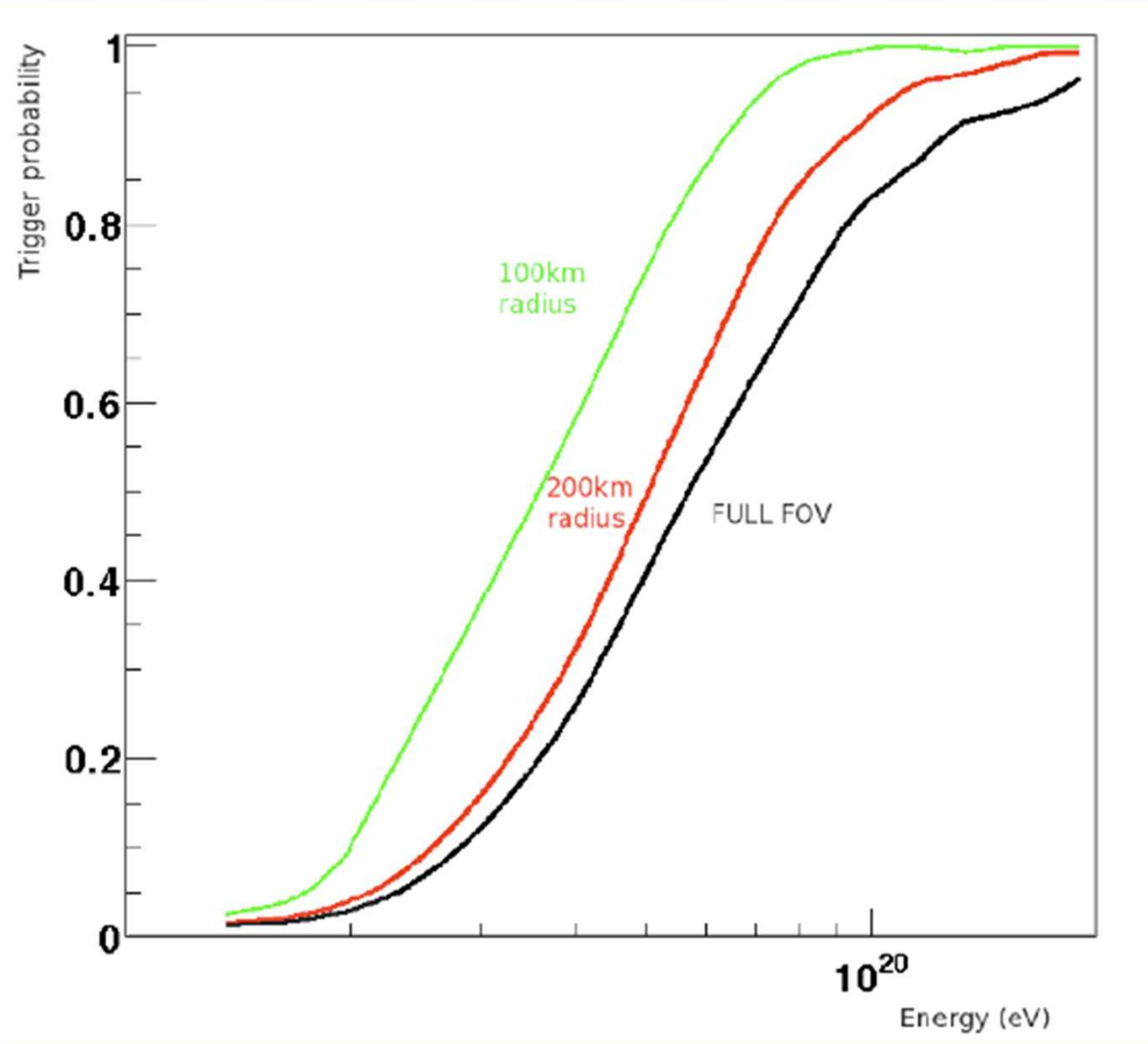
- Ground based calibration:
  - MAPMTs and front-end electronics are calibrated before integration in focal plane
  - Throughput of optics as a function of incident angle and wavelength is measured using a large collimator (USA)
  - Spot-size as a function of incident angle and wavelength is measured using a large collimator (USA)
  - Scattered light as a function of incident angle and wavelength is measured using a large collimator (needed due to background sources in the FOV near candidate EAS events) (USA)
  - Performance test of fully integrated instrument (Japan)
  - Potentially a full performance test in the flight thermal/vacuum environment (Japan or USA)
- On-orbit calibration/performance monitoring:
  - Electronics performance monitored with built-in testing capabilities
  - *MAPMT/EM performance monitored during day-light time with strategically placed LEDS within the telescope volume or on the lid*
  - Ground Light Sources (GLS)
    - *~30 GLS units strategically placed around the world, candidate sites are remote areas with little manmade background, over-flights occur once per day on average,*
    - GLS are calibrated before deployment, monitored during operations and re-calibrated/replaced as warranted
    - During over-flight, the GLS flashes repeatedly and triggers the telescope and the atmospheric monitoring system (AMS).
    - The captured image and AMS data are used to reconstruct the luminosity of the GLS signal and compared with the known luminosity of the GLS. This validates the data analysis of the EAS
    - The GLS enables monitoring the spot-size of the optics because it is a point source
    - The GLS includes an air-borne unit that is flown at different altitudes on a monthly basis Altitudes will cover the range of shower maximum depths

$500\ counts/(ns\ sr\ m^2)$




2010-02-23
09:00-09:59 (UTC)
821 km
© 2010 Tele Atlas
US Dept of State Geographer
© 2010 Europa Technologies
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google

Trigger efficiency in the inner part: important for Cross-Calibration



$3\times10^{19} < E < 5\times10^{19}$

$R_{FOV}\ N \sim 25\%$

$R < 200\ km\, N \sim 32\%$

$R < 100\ km\, N \sim 58\%$

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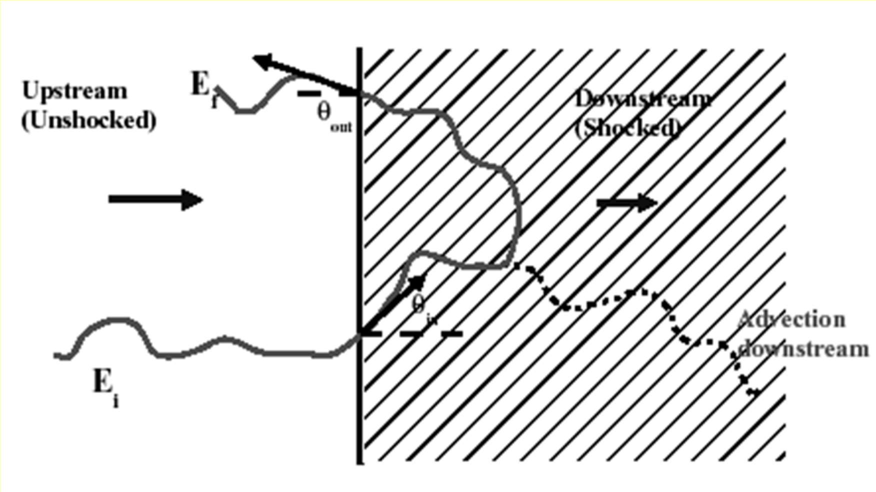
Bottom-up: Acceleration Mechanisms?

1st Order Fermi Shock Acceleration: Basic Ingredient Shocks!



The fractional energy gain per shock crossing depends on the velocity jump at the shock. Spectrum E^{-q} with $q > 2$ typically

When the gyroradius becomes comparable to the region size, the spectrum cuts off

Hillas' limit

To accelerate a particle efficiently it must cross the shocks several times.

$$R_g = \frac{E}{ZeB_{acc}} \approx L_{acc}$$

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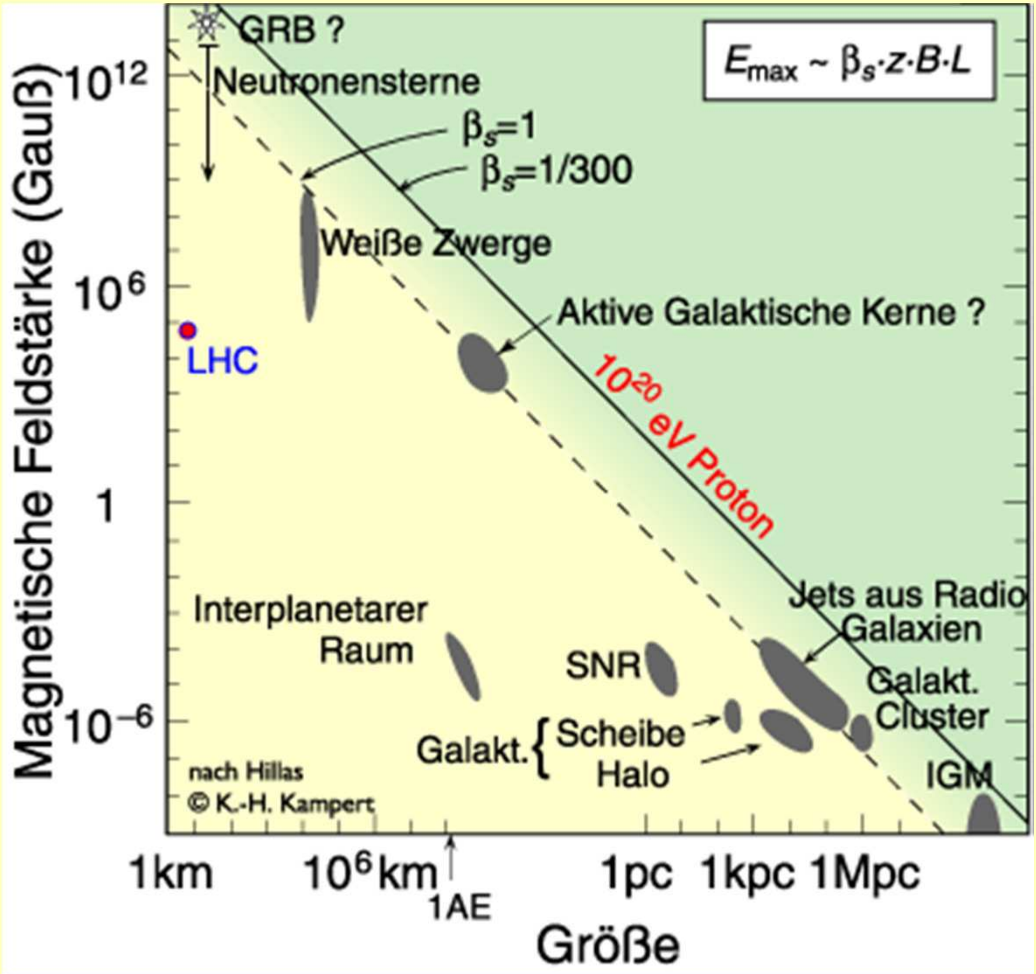
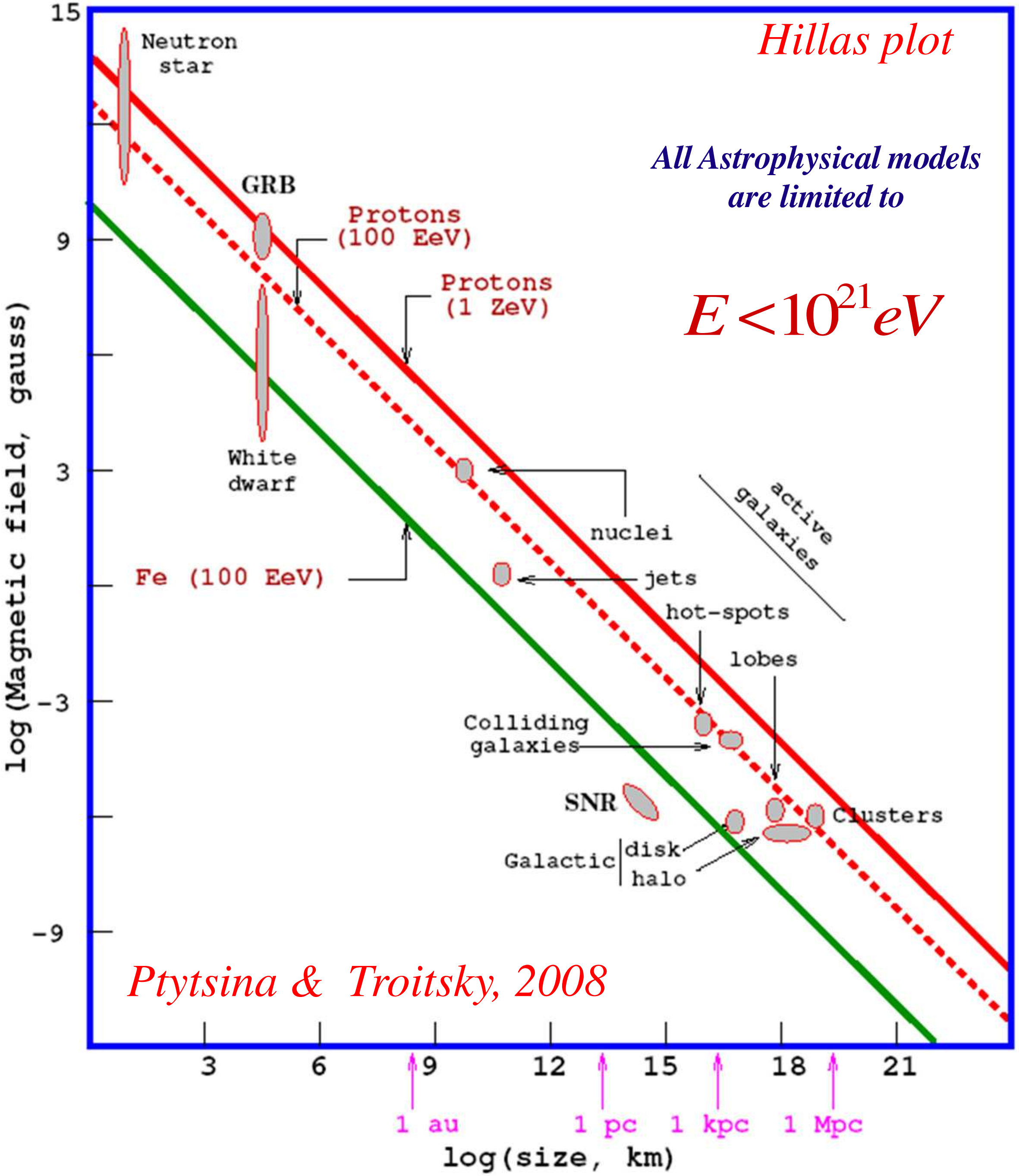
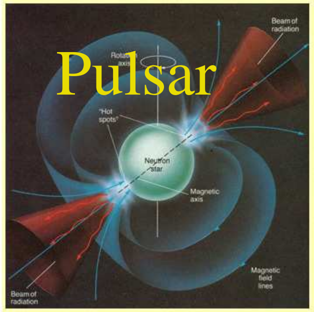
Possible Sources:

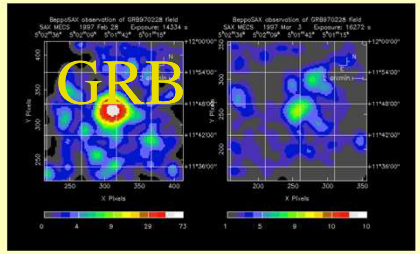
Hillas plot

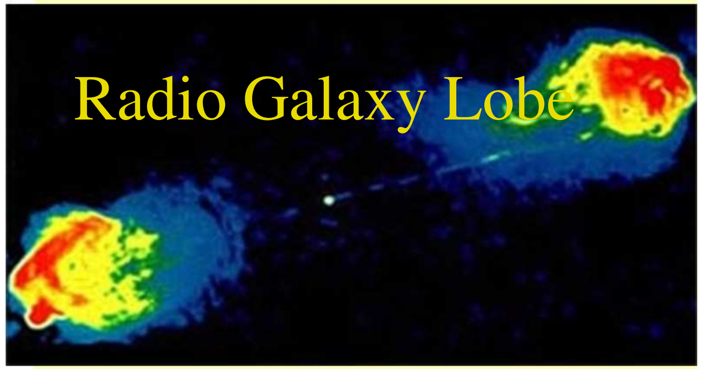


$$E_{max} \approx \beta_{shock} Z \cdot B[\mu G] \cdot L[kpc] \cdot 10^{18} eV$$

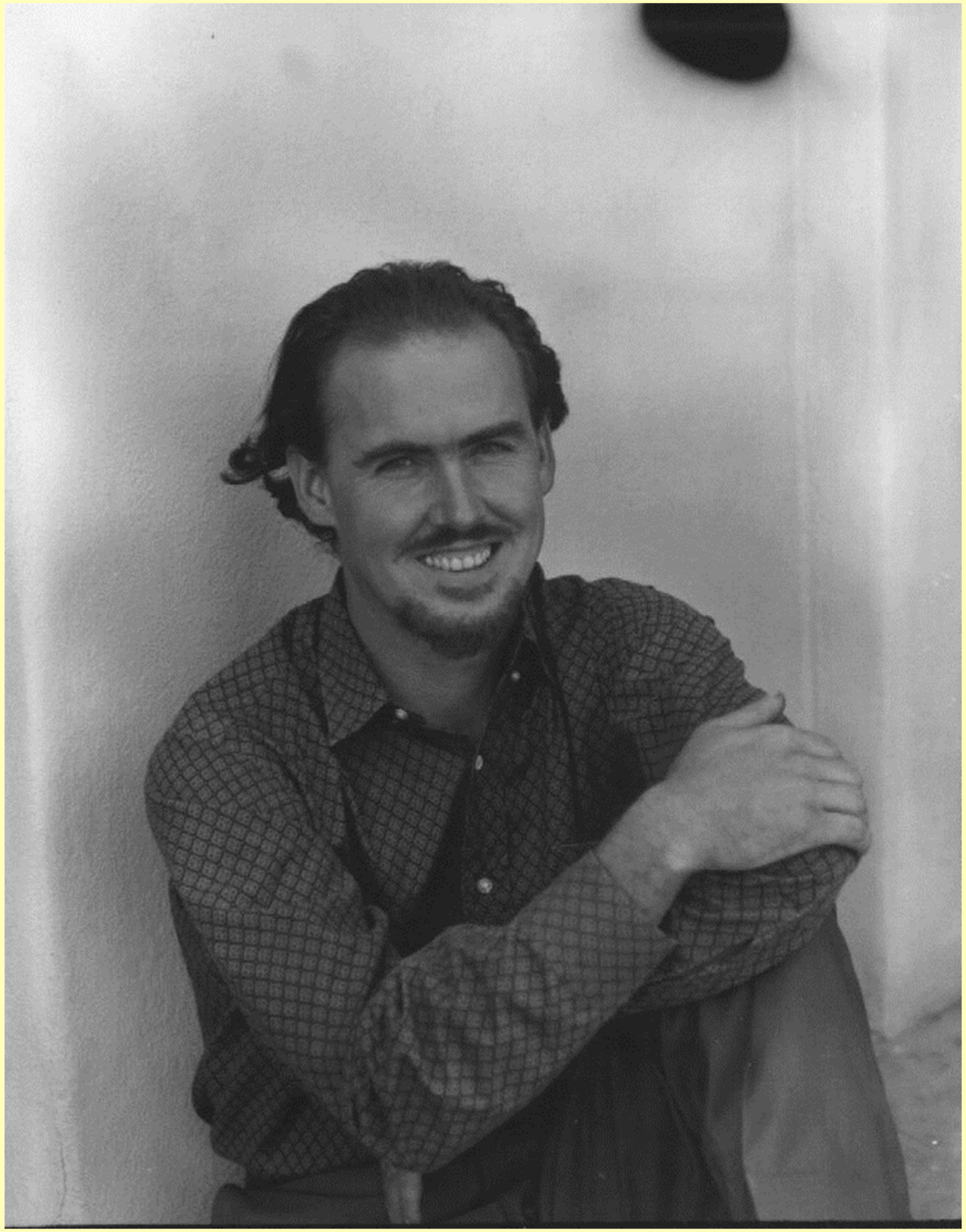








Torres & Anchordoqui, 2004



John Linsley at Volcano Ranch in the 60's

John Linsley in 1979 in the Field Committee Report of NASA "Call for Projects and Ideas in High Energy Astrophysics for the 1980s"

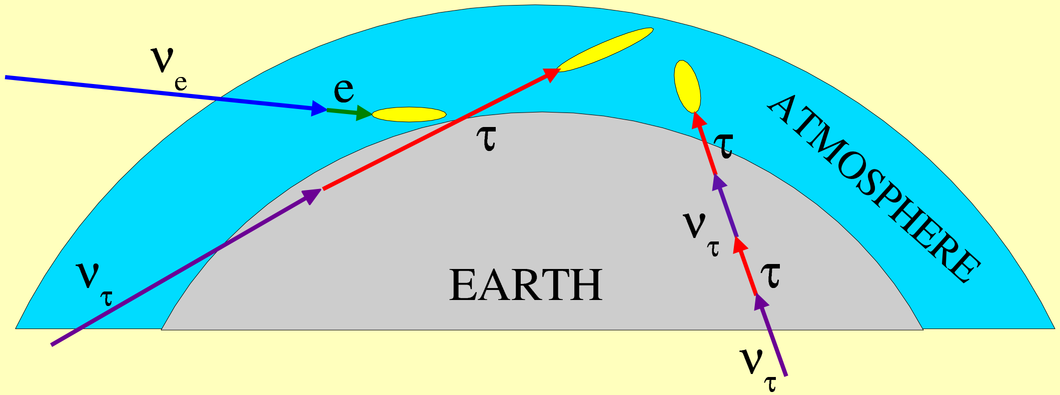
The concept to observe, by means of Space Based devices looking at Nadir during the night, the fluorescence light produced by an EAS proceeding in the atmosphere

In 1995 Yoshi Takahashi of UHA rediscovered the original idea and proposed the MASS program wich later became a reality with the OWL and EUSO studies

Neutrino Cross sections

Fargion et al., 1999

Bottai & Giurgola, 2003

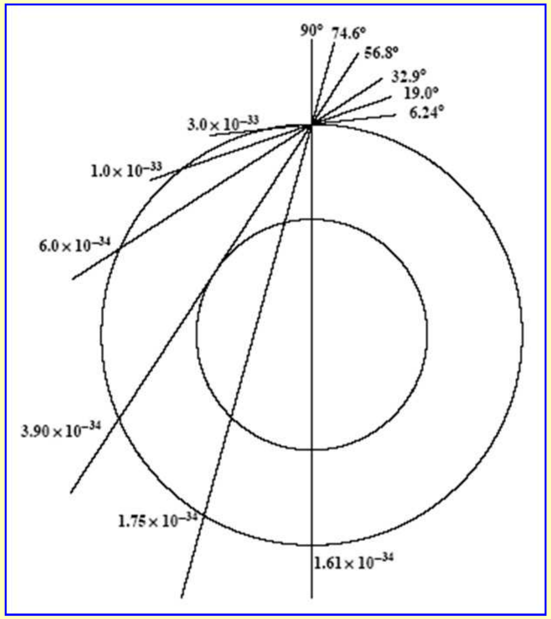


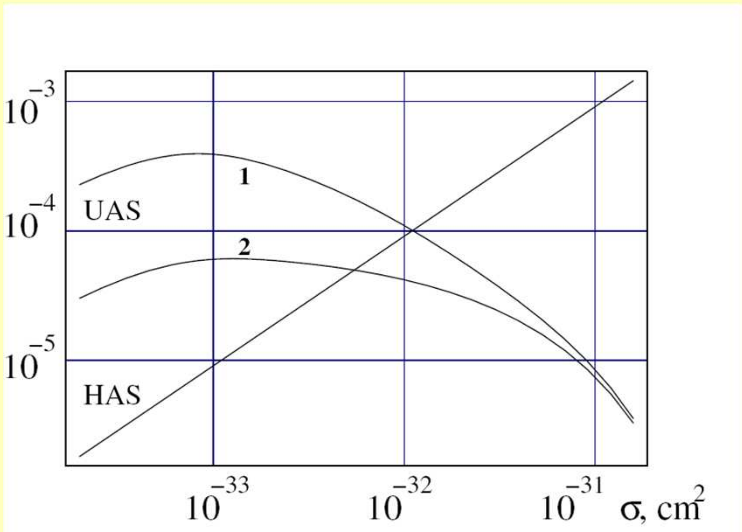
Fargion, 1997, 2002, 2004

Yoshida et al., 2004

Neutrino Cross Sections can be measured from the ratio of Horizonthal to Upward showers

Palomarez-Ruiz, Irimia and Weiler, 2006





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Top-down models

Bhatacharjee & Sigl, 2000

Particles are produced from the top, from the top, from the decay of some supermassive unstable particle

1.) particles released from topological defects, left over from the cosmological phase transitions (cosmic strings, magnetic monopoles, domain walls…)
2.) long-lived massive free particles ("WIMPZILLA" dark matter, mirror matter)

Berezinsly, Blasi, Vilenkin 1999

$$X \rightarrow q + q \, , m_X > 10^{12} \, GeV$$

The X particle decay into quarks that hadronize, generating pions and a small fraction of protons and neutrons. At the production most of UHE particles are γ-rays and Neutrinos.

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} (\bar{\nu}_{\mu})$$

$$\pi^{0} \rightarrow \gamma\gamma$$

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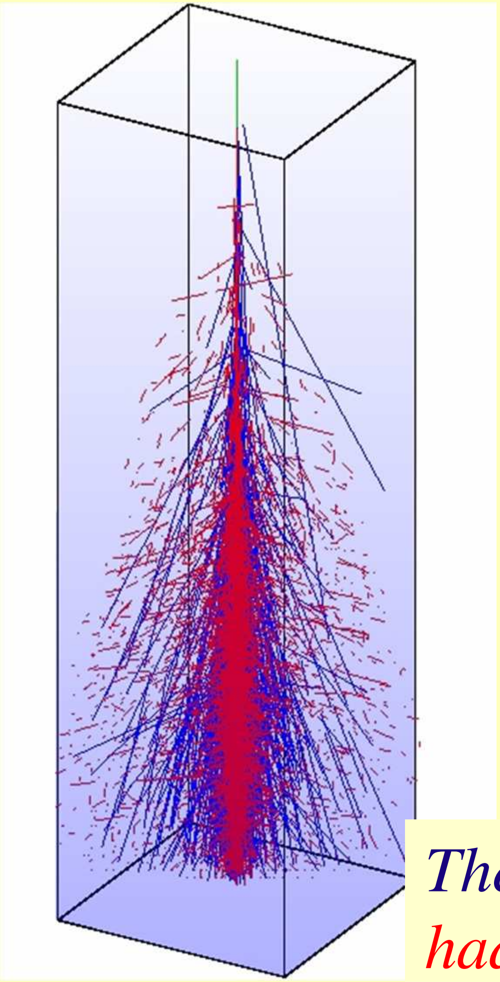
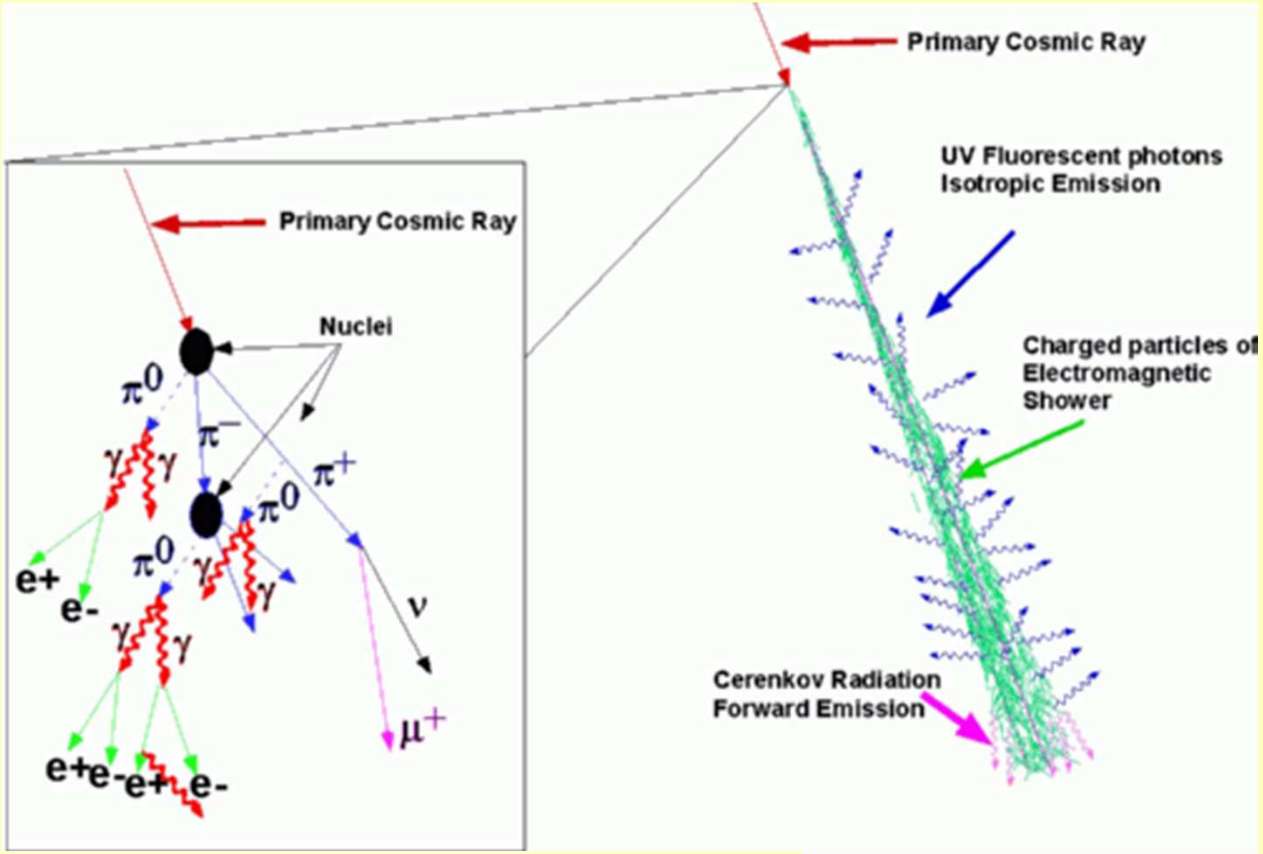
Extend Air Shower





10-100 km
30-300 μs

The primary interaction can be hadronic. A number of secondaries mainly pions are generated. These give rise to further hadronic interactions

Hadronic Cascade
Charged pions→muons

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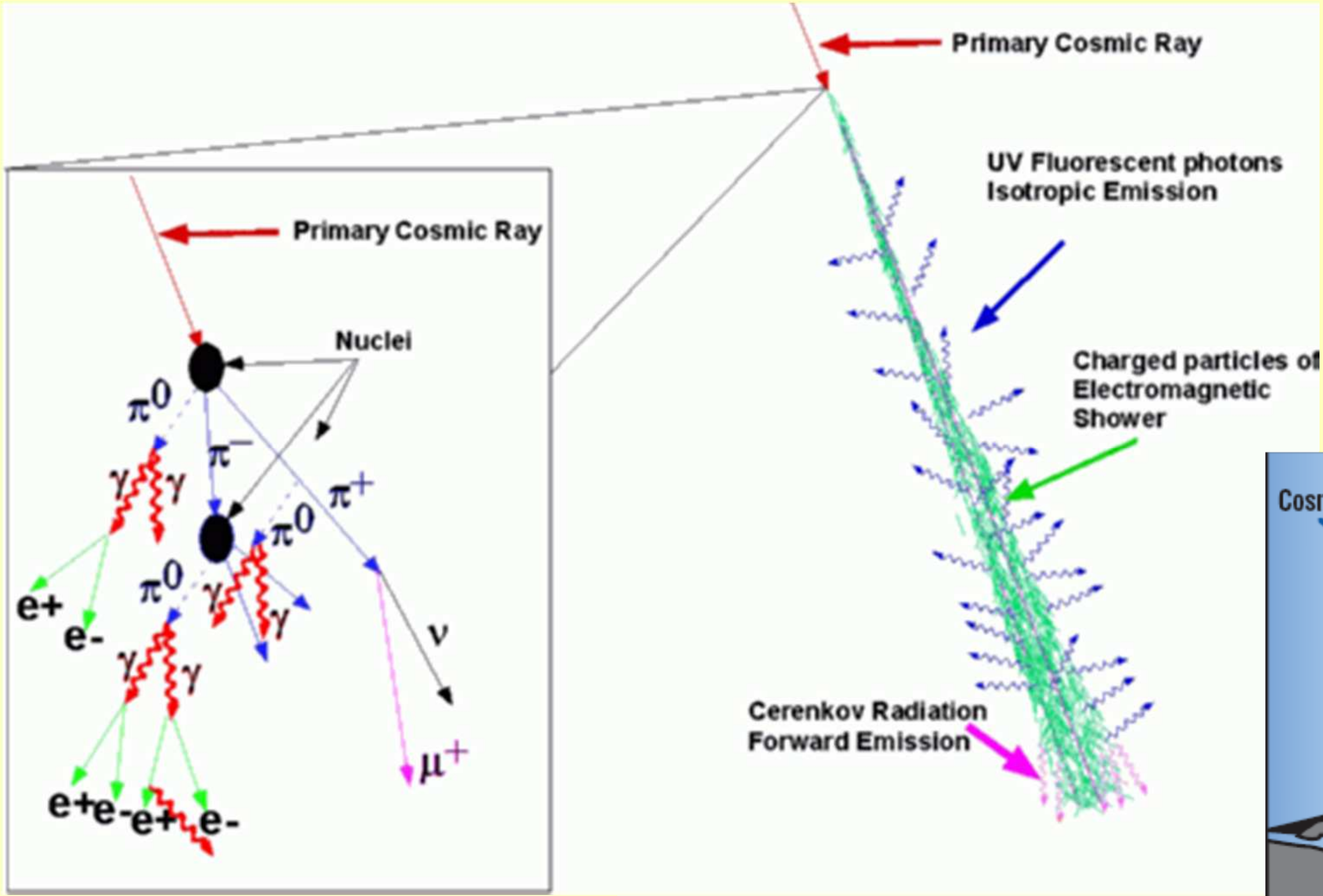
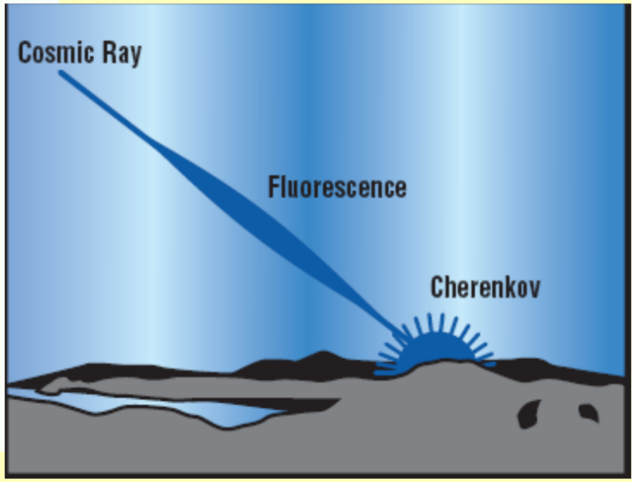
Electromagnetic Component in the Extend Air Shower



At each step 1/3 of the energy is given to neutral pions which decay into gamma photons



Photons produce e-pairs and Compton electrons which produce photons via bremsstrahlung

Two types of light are produced:

- **Fluorescence photons** (isotropic)
- **Cherenkov photons** (beamed)

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