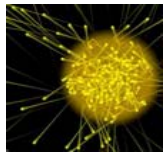
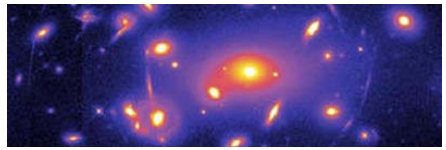
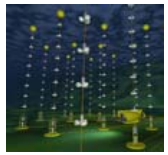





ASPERA

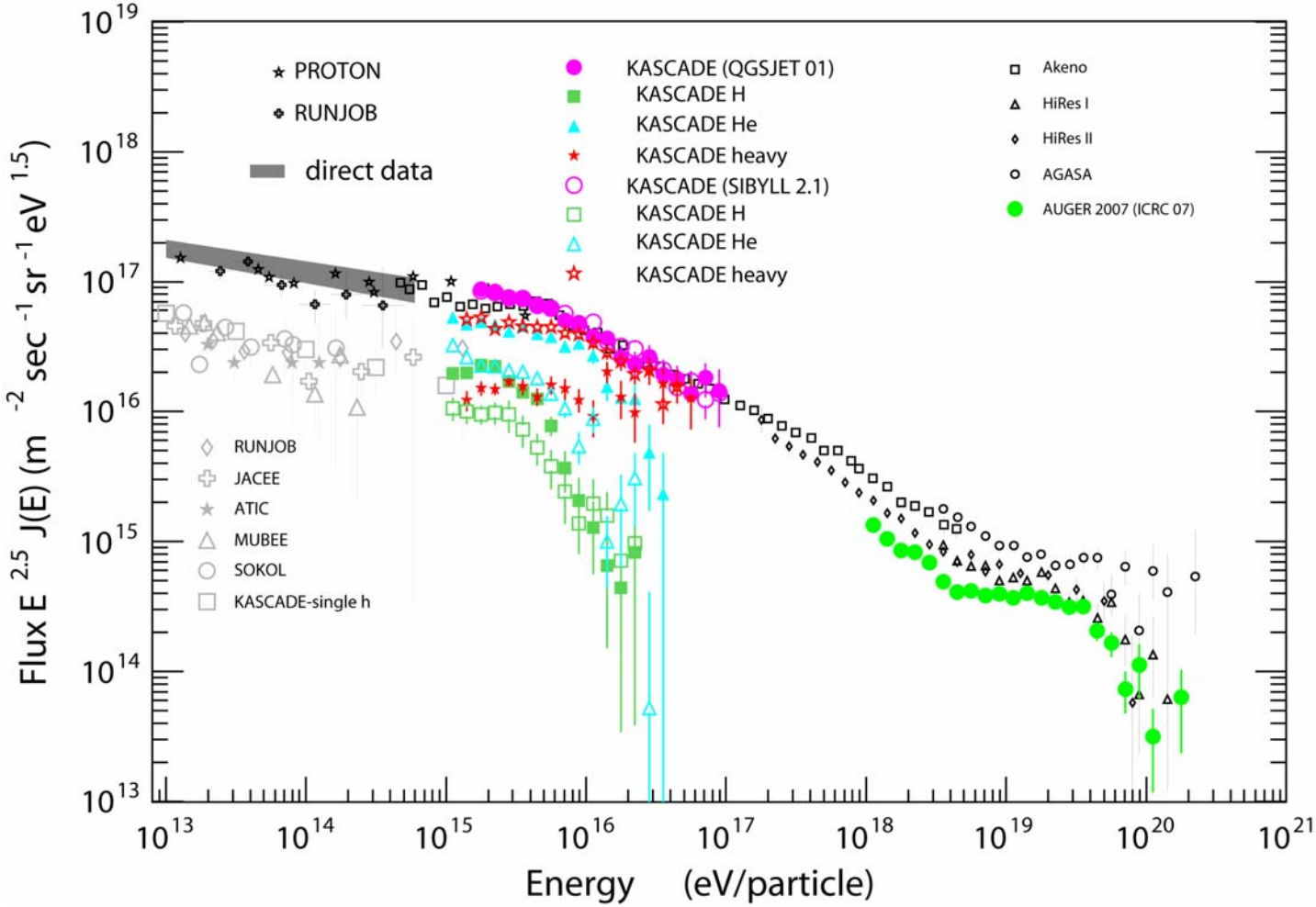
AStroparticle Physics European Coordination ERAnet

working group 3

HIGH ENERGY COSMIC RAYS

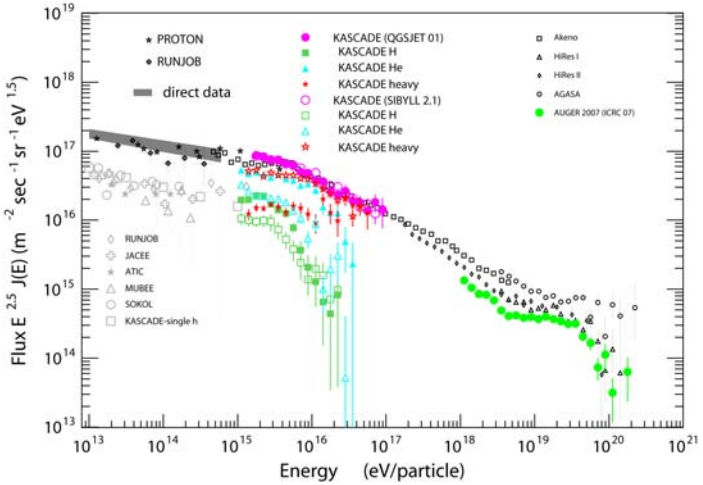
Status July 2007

High Energy Cosmic Rays



Do we understand the spectrum?
I.e. Sources ? Acceleration ? Propagation ? of the cosmic particles?

High Energy Cosmic Rays

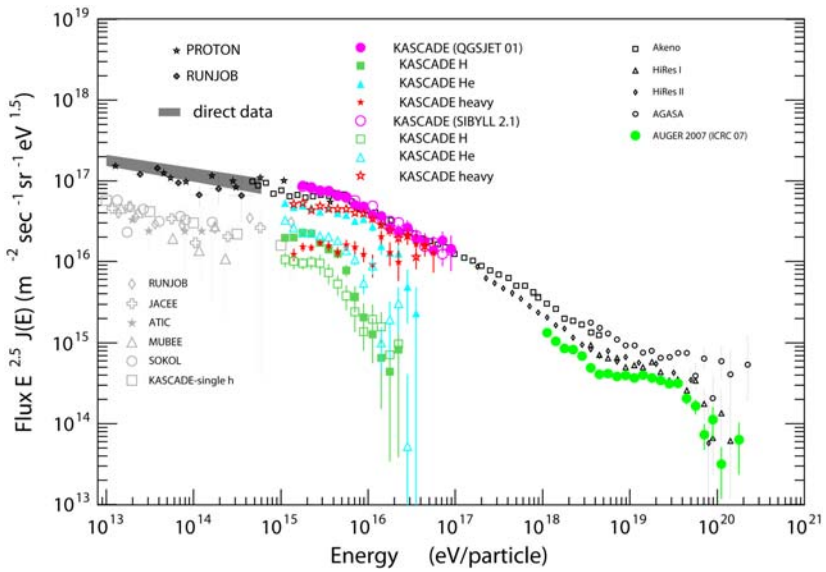


Astrophysical questions to understand the spectrum, more in detail:

- **How can cosmic accelerators boost particles to these energies?**
- **What is the maximum energy achievable by galactic sources such as supernova remnants or microquasars?**
- **What is the nature of the particles?**
- **How do they propagate through the Universe?**
- **Does the cosmic ray energy spectrum extend beyond the maximum energy a proton can maintain when traveling over large cosmic distances, as they would eventually collide with the omnipresent CMB?**
- **What is the view of the sky at extreme energies?**

From: Roadmap Phase I

High Energy Cosmic Rays



Last decade ~(1993-2005):

Big step forward by sophisticated experiments:
(AMS01, ATIC, TRACER, PAMELA, KASCADE, AUGER,…)

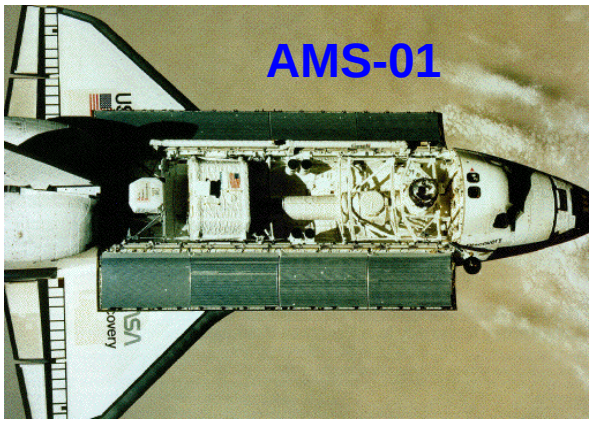
By multi-detector and hybrid measurements of cosmic rays and air showers with high accuracy.

next decade ~(2008-2018):

- **Covering with same quality the whole spectrum.**
- **Energy spectra of individual particles over whole energy range.**
- **At highest energies: sources? and source spectra?**
- **Start with particle astronomy.**

High Energy Cosmic Rays

Last decade and present:



High Energy Cosmic Rays

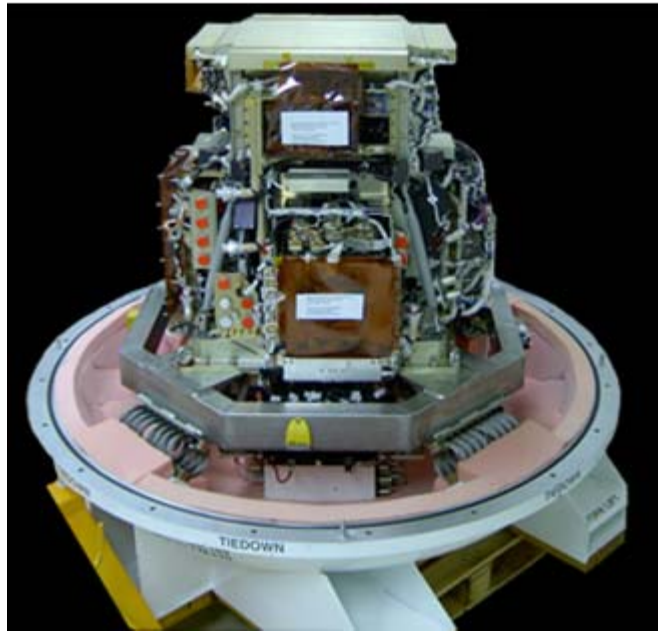
Working group 3

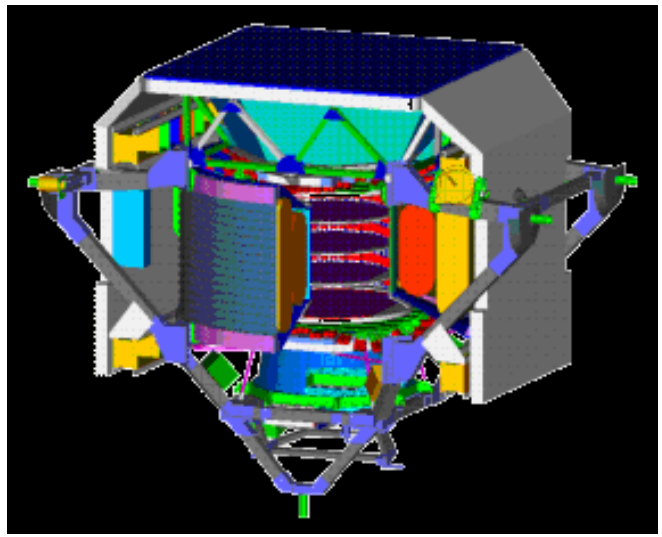
Experiments asked for questionnaires:

Auger (south):	**ground based**	**GZK**
Auger (north):	**ground based**	**GZK+beyond**
JEM-EUSO:	**space based**	**GZK+beyond**
SUPER-EUSO:	**space based**	**GZK+beyond**
LOFAR:	**ground based**	**ankle,GZK+beyond (CR+ν)**
SKA:	**ground based**	**GZK + beyond (moon, only)**
Emma:	**ground based**	**knee**
NUCLEON/L-NUC:	**space based**	**direct knee**
AMS-02:	**space based**	**direct GeV-TeV**

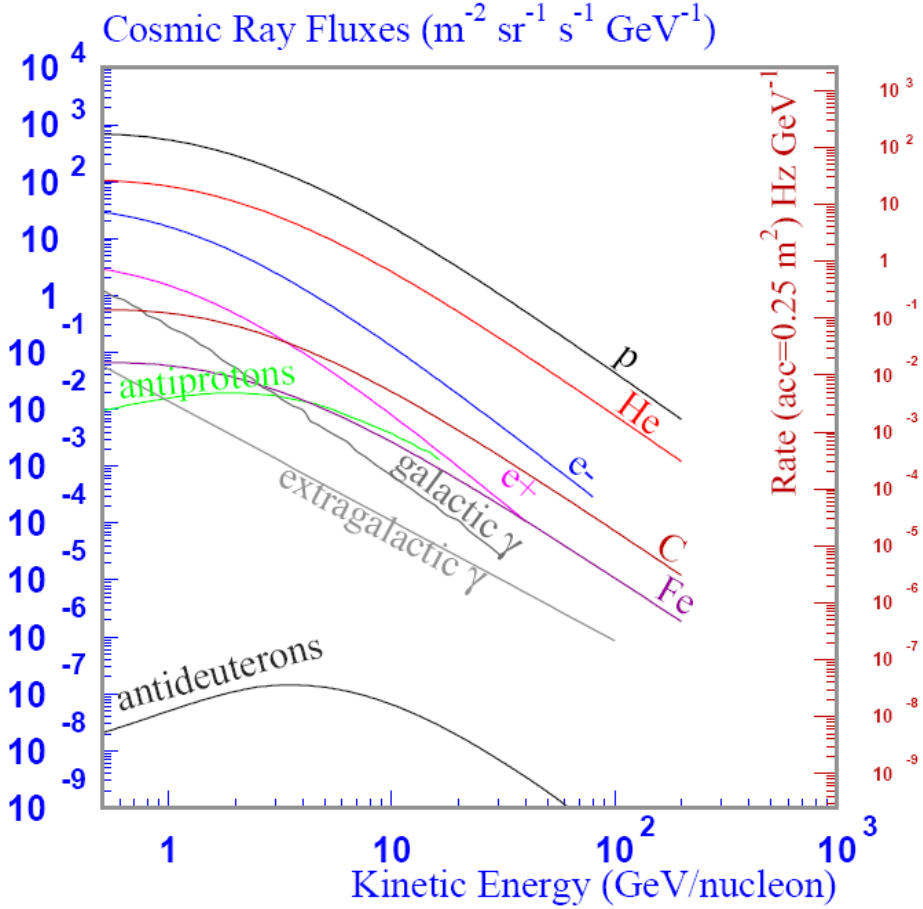
Also important for understanding cosmic rays:
H.E.S.S. / MAGIC / CTA ➔ working group gamma rays
ICECUBE ➔ working group neutrinos
…..

Direct measurements:





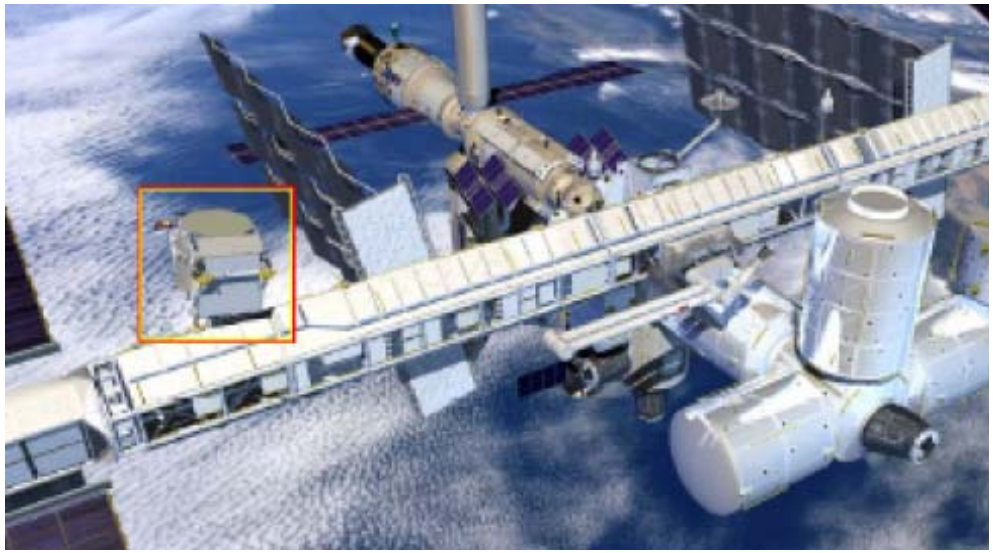
Direct measurements in the GeV-TeV range:

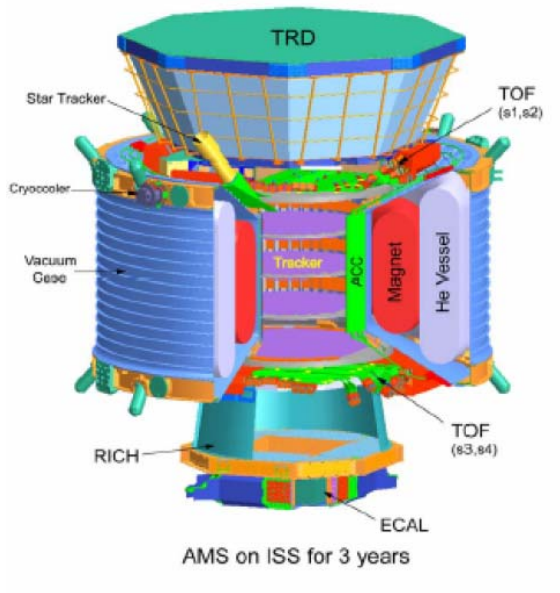


Open questions :

- **Details on production, acceleration and propagation of cosmic rays**
- **Details of solar modulation**
- **Dark matter signals**
- **Antimatter in cosmic rays**

AMS-02
Alpha Magnetic Spectrometer





AMS on ISS for 3 years

- An experiment to search in space for dark matter, missing matter and antimatter on the international space station.

- High precision direct measurement of CR composition and spectrum.

- **Hadronic cosmic rays:**
  - **Secondary/primary ratios (propagation models)**
  - **Confinement times (galactic halo)**
  - **Solar cycle effects**
- **Antimatter (direct detection of anti-nuclei)**
- **Dark matter signals (antiprotons, electrons/positrons)**

AMS-02 - STATUS

- **Status**
  - **Final constructed – launch with space shuttle not yet approved**
- **Collaboration:**
  - **exists**
  - **600 scientists ~70% EU ~60% ASPERA**
  - **9 European countries: CH,DE,ES,FI,FR,IT,NL,P,RO**
- **Obstacles:**
  - **Shuttle manifest**
- **R&D required:**
  - **Operation in space; data transfer**
- **Funding by EU call? ➔ data transfer**
- **Linking? ➔ through agreements with collaborators**
- **Computing? ➔ regional computing power, storage, GRID**

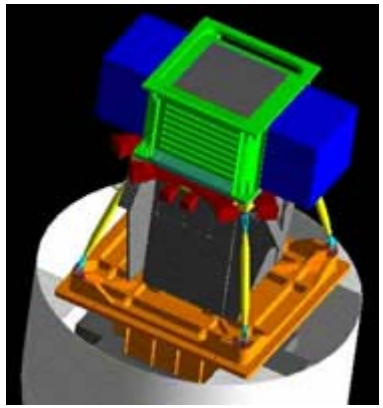
AMS-02: 2008-2018

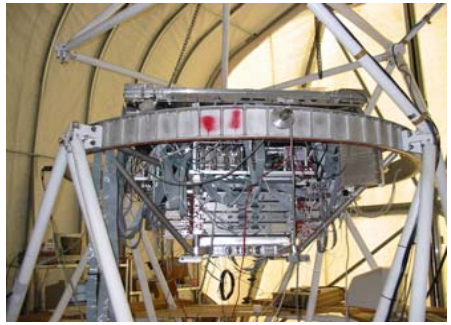
- **Timetable:**
  - Commissioning 2008 Operation 2009-2015
- **Risks:**
  - Shuttle manifest
- **Resources:**
  - 3.000 k€ 600 FTE 70% Europe 30% Others
  - Operation costs ~500 k€ per year
  - INFN, DLR, ASI, IN2P3, SNF, CIEMAT, TEKES
- **ASPERA:**
  - 2.100 k€ 420 FTE per year (2008-13): 350 k€ and 70 FTE
- **Compiled by**
  - Roberto Battiston r.battiston@tiscali.it

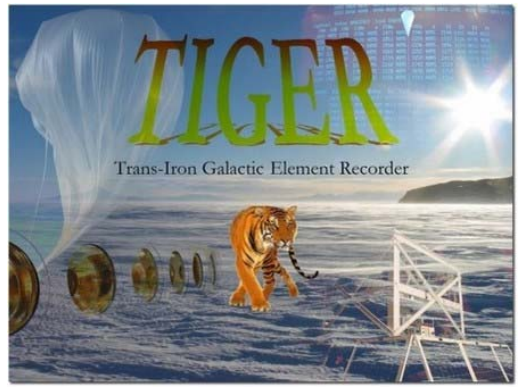
Direct measurements in the GeV-TeV range:

Further experiments (non ASPERA or too small) :

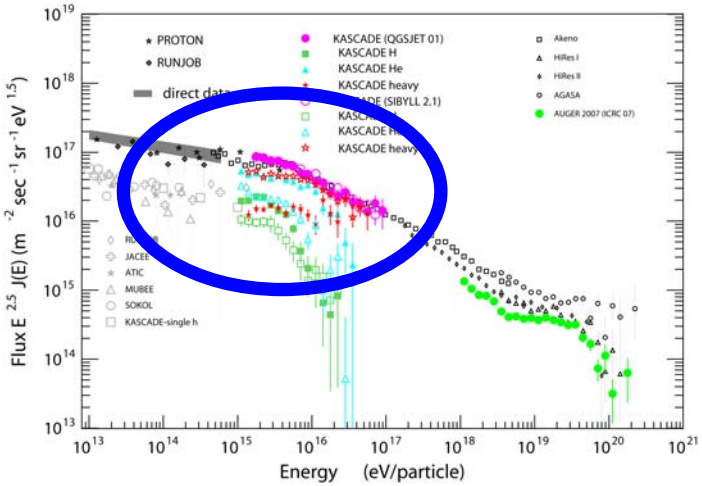
- **PAMELA**
  - Antiprotons, Protons, Electrons, Positrons 0,25 - 100 GeV
- **CREAM**
  - 10^{12} to > 5 x 10^{14} eV cosmic rays
- **BESS**
  - Antiprotons and Antihelium 0,25 - 100 GeV
- **ATIC**
  - Proton- and Heliumspectra 10 - 10000 GeV
- **TRACER**
  - spectra 8 < Z < 26 <10 TeV/nuc
- **TIGER**
  - Elemente 30 < Z < 40 >0,5 GeV/n
- …







Reaching the Knee:

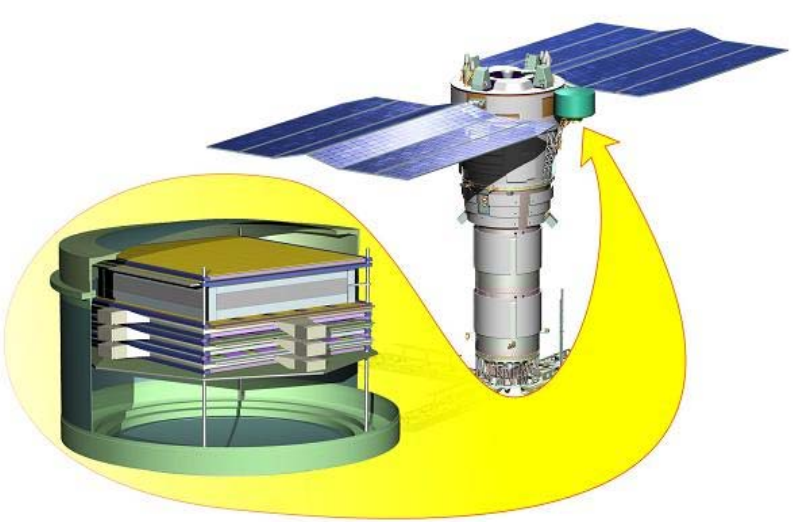


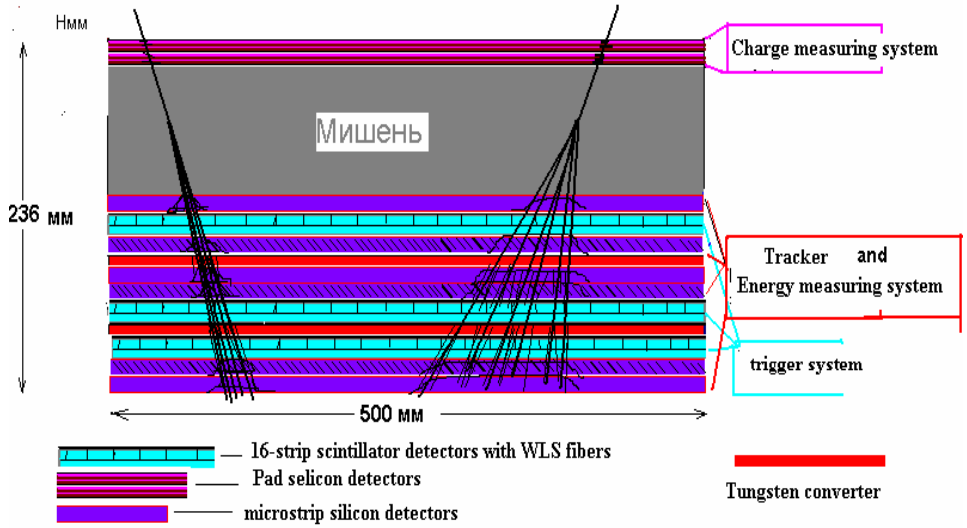
2007:
Origin of the knee still unknown!

Tasks, experimentally to be solved:

- **differences in slopes of different nuclear components (below the knee);**
- **CR anisotropy in time and space (propagation in Galaxy, nearby source?);**
- **electrons and gammas;**
- **isotopes after iron;**
- **Knee position(s)**
- **composition at the knee**
- **anisotropy around the knee**
- **structure of spectrum (below, around, and above the knee)**
- **overlap direct with air-shower measurements (hadronic interaction models)**

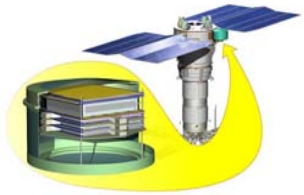
NUCLEON





- **Satellite experiment (included in Russian Space Program 2005-2010)**
- **Measurements of charged particles of 10^{12}-10^{16} eV to clarify:**
  - **the Cosmic Rays origin**
    - **differences in slopes of different nuclear components (changing a type of sources in this energy region?)**
  - **propagation of CR in Galaxy**
    - **secondary to primary ratio (diffusion coefficient?)**
  - **CR anisotropy (nearby source ?)**

NUCLEON - STATUS



- **Status**
  - **prototype flight approved**
  - **R&D phase B (L-NUCLEON) design study**

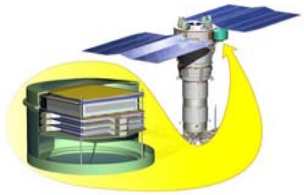
- **Collaboration:**
  - **exists**
  - **40 scientists ~100% EU ~40% ASPERA**
  - **2 European countries: Italy + Russia**

- **Obstacles:**
  - **Funding**

- **R&D required:**
  - **Particle detectors, low power electronic, lightweight mechanics**

- **Funding by EU call? ➔ detector development**
- **Linking? ➔ further collaborating institutes**
- **Computing? ➔ need computing power, GRID**

NUCLEON: 2008-2018



- **Timetable:**
  - **R&D 2008-10** — **Construction 2011-14**
  - **Commissioning 2014-15** — **Operation 2015-16**
  - **Conceptional Design Study 2008/09** — **Technical DS 2008-2015**
  - **Decision for Construction 2011** — **Launch 2015?**

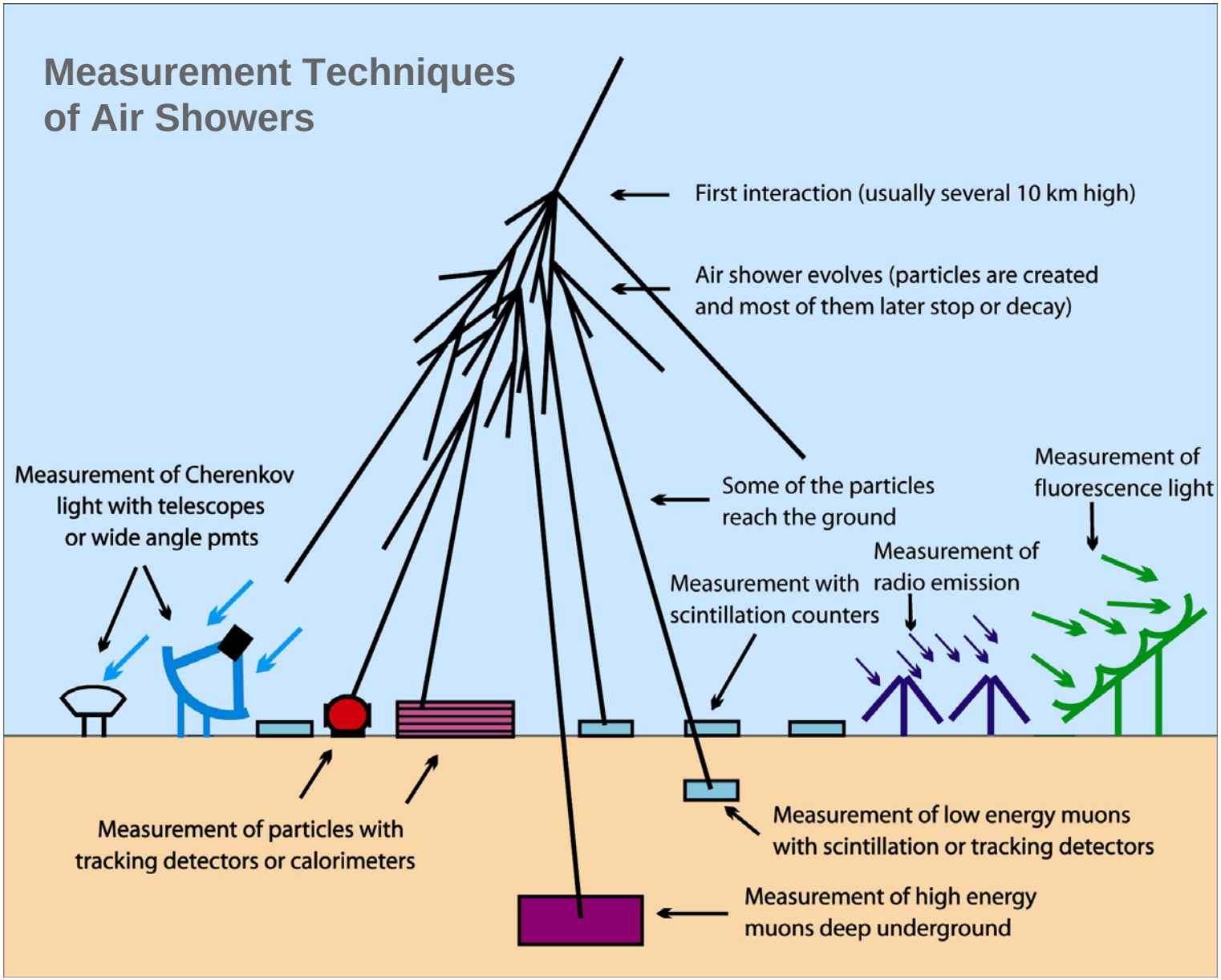
- **Risks:**
  - **Funding**

- **Resources:**
  - **40.150 k€ 600FTE 40% Europe 60% Others**
  - **+ 30.000 k€ for launching (Russia)**
  - **INFN - ASI , SINP ARSENAL**

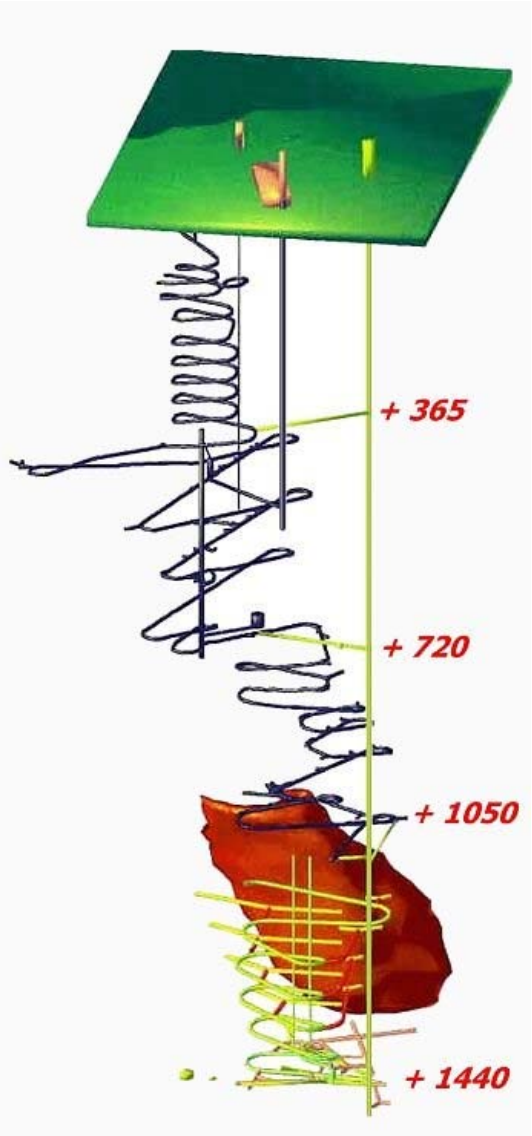
- **ASPERA:**
  - **10.000 k€ 240 FTE per year (2011-15): 4.000 k€ and ~25 FTE**

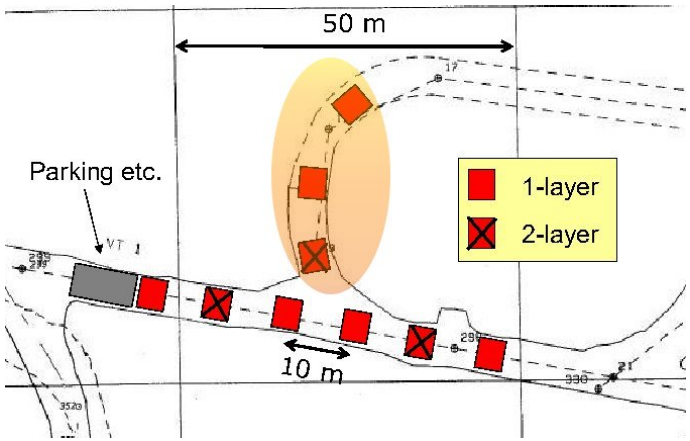
- **Compiled by**
  - **Andrea Vacchi vacchi@ts.infn.it**

Indirect measurements:



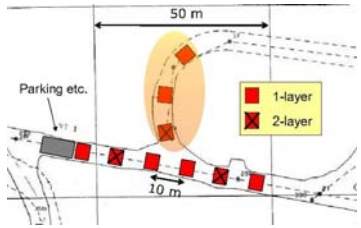
EMMA





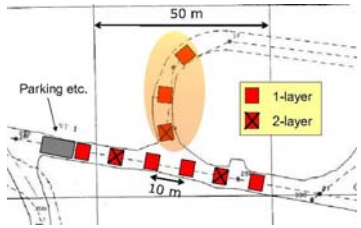
- **Multimuon experiment located at Pyhäsalmi Mine, Finland (CUPP: centre of Underground Physics in Pyhäsalmi)**
- **Air shower measurements (around the knee) aiming**
  - **New information on the composition at the knee**
  - **Study of high muon-multiplicity events**

EMMA - STATUS



- **Status**
  - **construction**
- **Collaboration:**
  - **exists**
  - **20 scientists ~70% EU ~0% ASPERA**
  - **3 European countries: Finland, Demark, Russia**
- **Obstacles:**
  - **-**
- **R&D required:**
  - **-**
- **Funding by EU call? ➔ -**
- **Linking? ➔ further collaborating institutes?**
- **Computing? ➔sufficient**

EMMA: 2008-2018



- **Timetable:**
  - **Construction + parallel operation 2008-18**
  - **In 2008-09: surface array**
- **Risks:**
  - **-**
- **Resources:**
  - **Finland, Denmark, Russia**
- **ASPERA:**
  - **Presently no request to ASPERA funding agencies**
- **Compiled by**
  - **Timo Enqvist** timo.enqvist@oulu.fi
  - **Jan Ridky** ridky@cern.ch

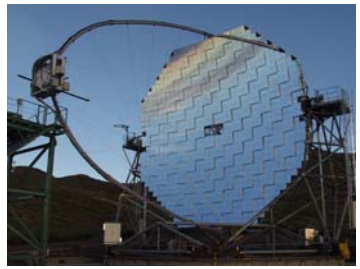
Around the knee:

Further experiments (non ASPERA or too small or no further investments) :

- **KASCADE**
  - data analysis
- **TUNKA**
  - Cherenkov-array, data analysis
- **TIBET AS-γ**
  - 4300m asl, scintillator array
- **ARGO-YBJ**
  - 4300 m asl, gammas ~100GeV
- **MILAGRO➔HAWC**
  - Water cherenkov pool, Gammas (TeV)
- **HESS / MAGIC / CTA**
  - Chrenkov telescopes
- **…**

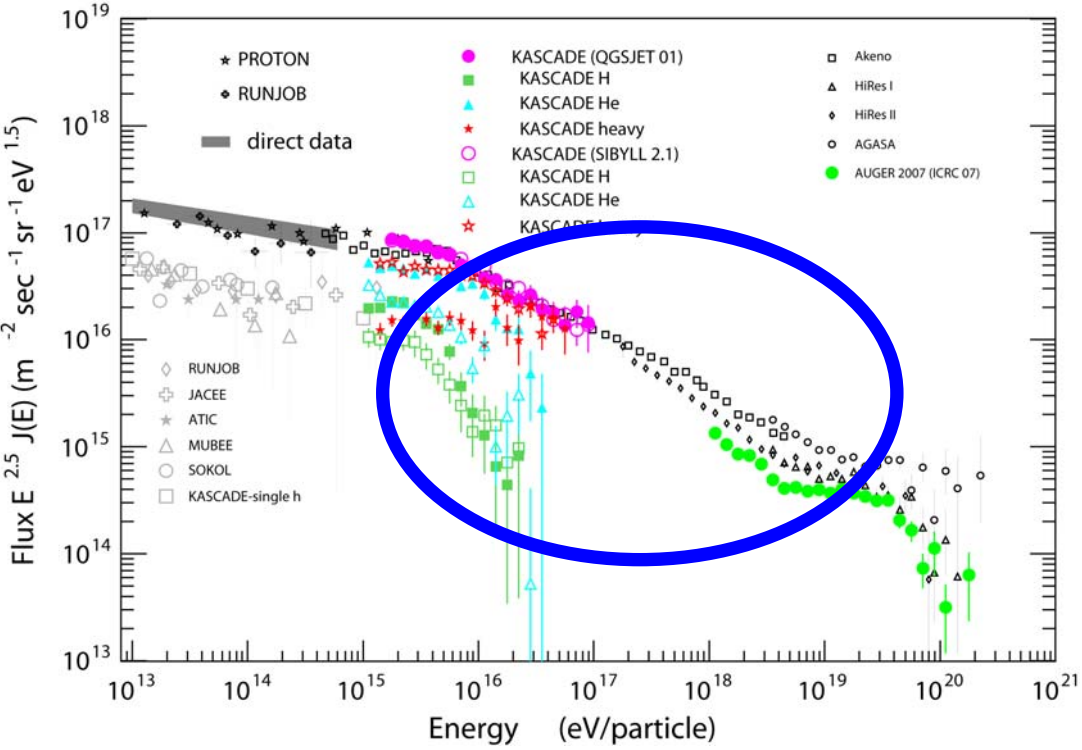







- **No dedicated air-shower experiment planed for the overlap region of direct and air shower measurements (high-altitude KASCADE-like detector)**

Between Second Knee and Ankle



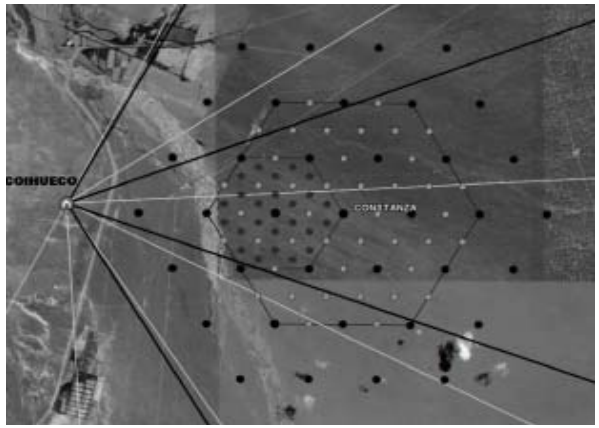
2007:
Least explored energy range !

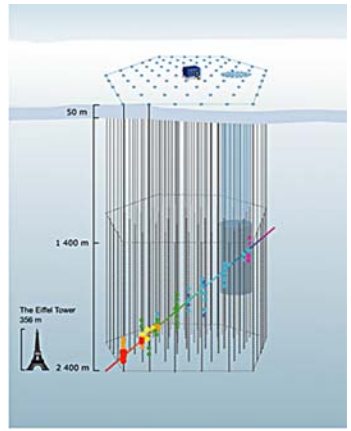
- **The iron knee?**
- **Transition to extragalactic CR?**
- **Composition**
- **Anisotropies, Point Sources?**

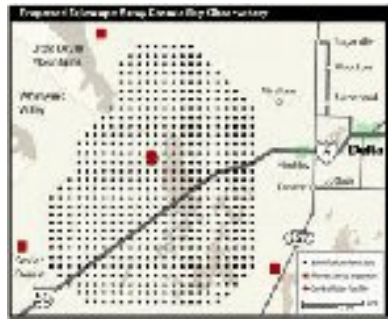
Between Second Knee and Ankle :

Experiments (non ASPERA or in other working groups or different main task):

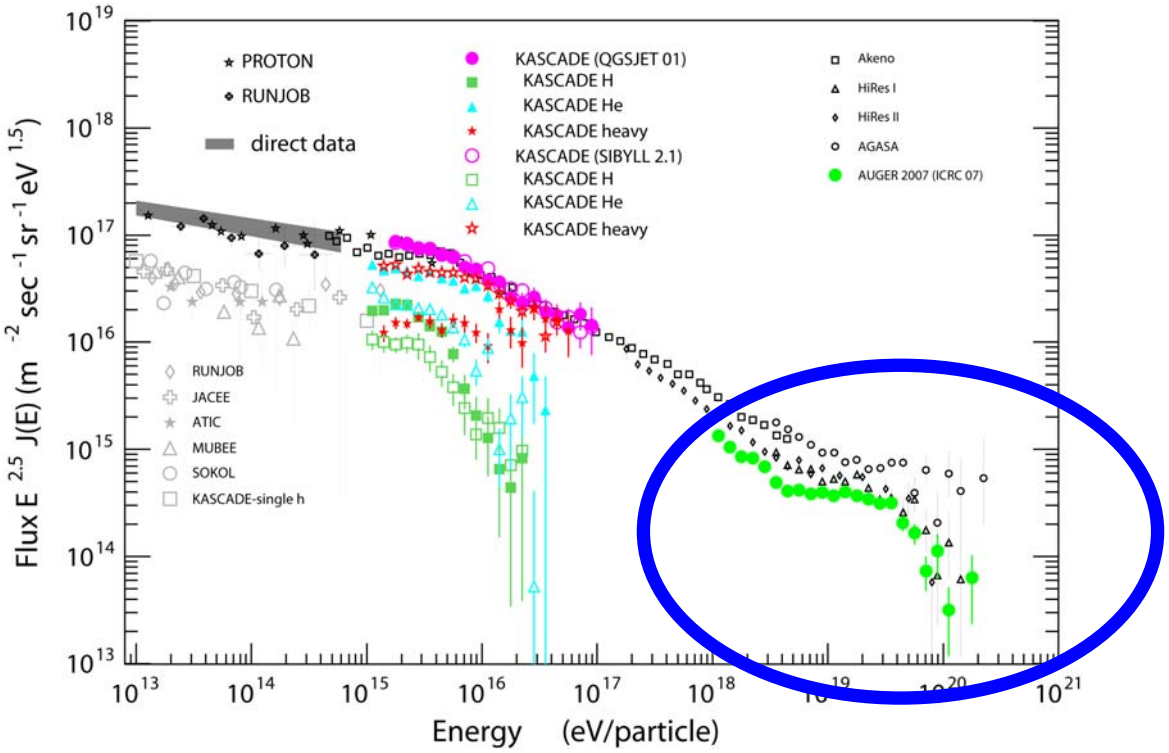
- **KASCADE-Grande**
  - 10^{16}-10^{18}eV (finish in 2009)
- **AUGER South Enhancements**
  - HEAT, AMIGA
- **ICETOP / ICECUBE**
  - See neutrino wg
- **TALE** (Telescope Array Low Energy Extension)
  - American-Japanese proposal
- **LOFAR**
  - Radio astronomy (see later)
- **…**







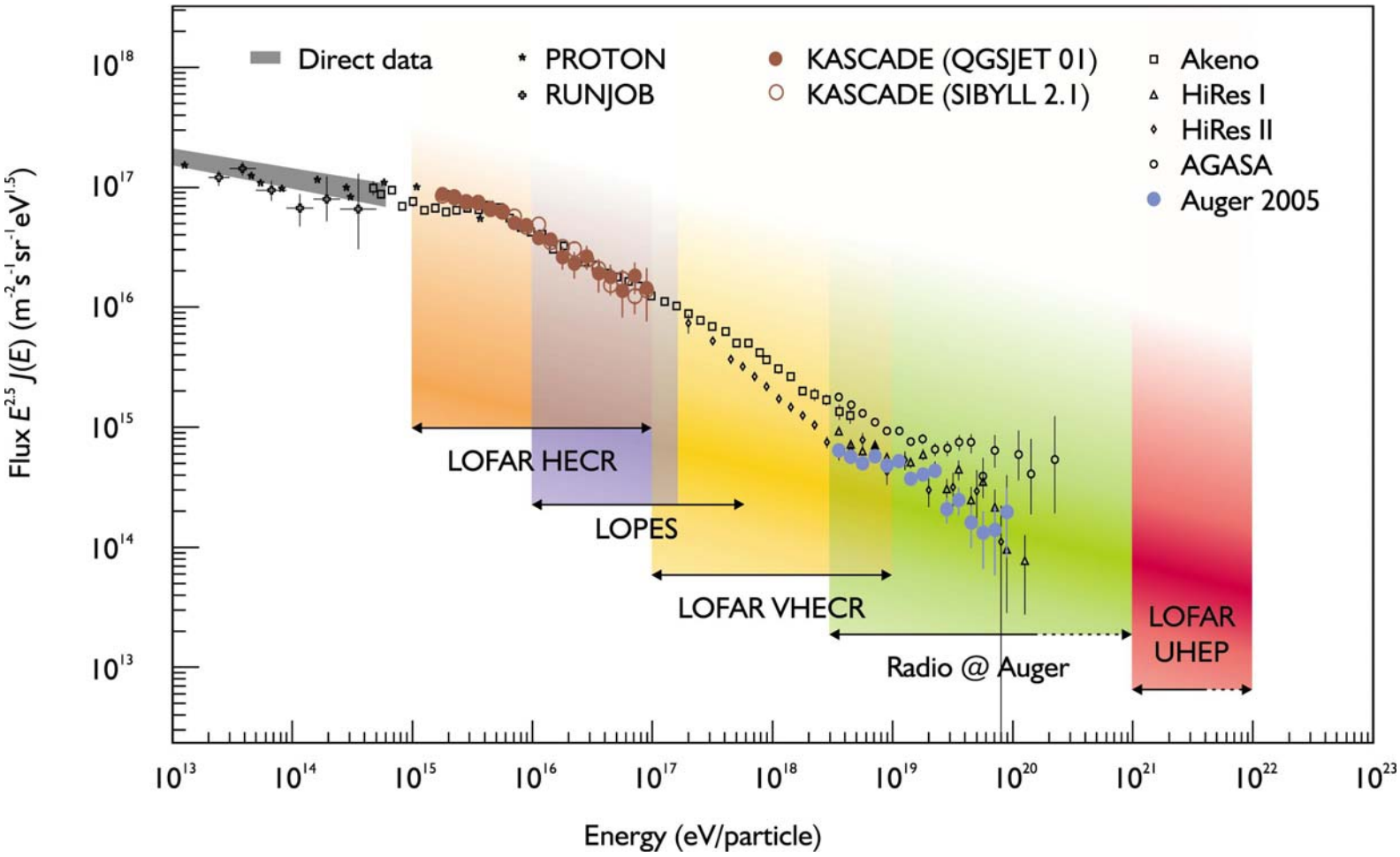
Ankle and GZK range



2007:
There is the GZK cutoff!

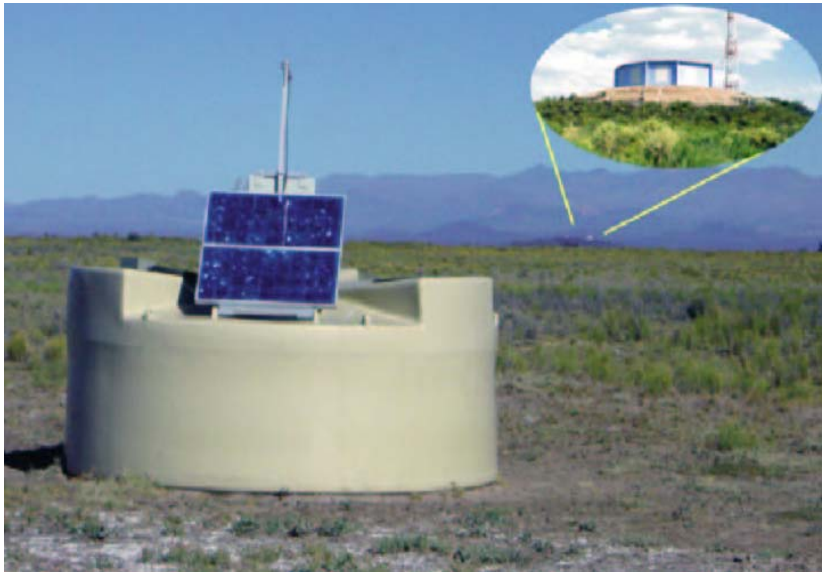
- **How can cosmic accelerators boost particles to these energies?**
- **What is the maximum energy achievable?**
- **What is the nature of the particles?**
- **How do they propagate through the Universe?**
- **What is the view of the sky at extreme energies?**
- **New techniques for detecting?**

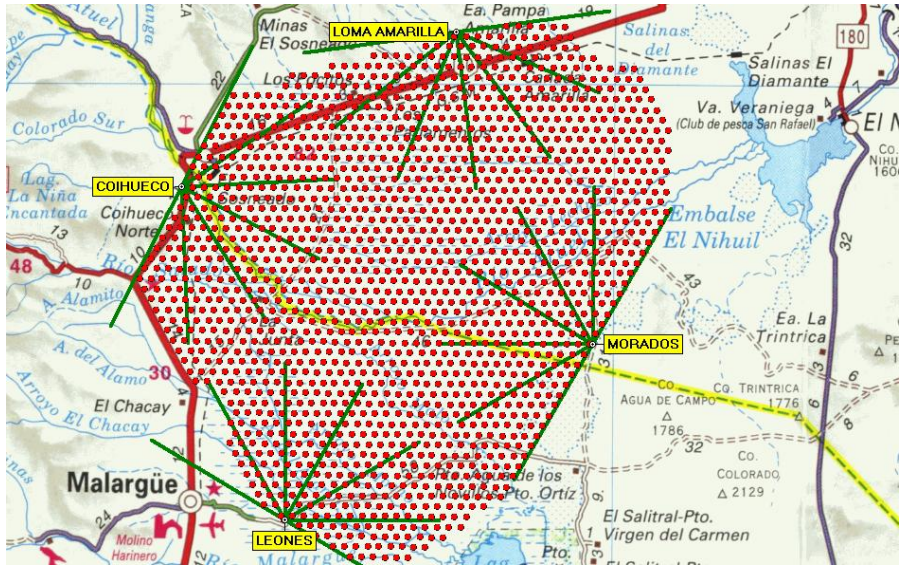
Radio Detection of Cosmic Rays



- **Promising technique for high-energy cosmic rays and neutrinos !!**

Pierre Auger Observatory – South

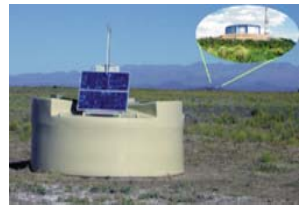




Giant air shower array in the Argentinean Pampas!

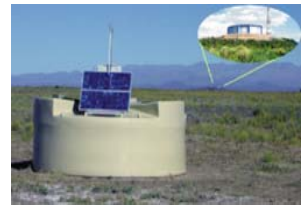
- **Where does the spectrum end ?**
  - **Is there a GZK cutoff ?**
- **Primary nature (composition) ?**
  - **Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?**
- **What is the source of UHECR ?**
  - **Bottom-Up or Top-Down scenario ?**
- **Arrival direction distribution**
  - **Search for departure from isotropy – point sources**

Pierre Auger Observatory – South: STATUS



- **Status**
  - operational
  - commissioning phase of enhancements
- **Collaboration:**
  - exists
  - 400 scientists ~50% EU ~45% ASPERA
  - 10 European countries: CZ,DE,ES,FR,IT, NL,PL,PT,SI,UK
- **Obstacles:**
  - Funding of the operation
- **R&D required:**
  - -
- **Funding by EU call? ➔ -**
- **Linking? ➔ no access to site, but public data?**
- **Computing? ➔ need moderate increase and compensation**

Pierre Auger Observatory – South : 2008-2018



- **Timetable:**
  - Construction (+enhancements) until 2010
  - Operation 2018+
- **Risks:**
  - -
- **Resources:**
  - 15.000 k€ ? FTE 50% Europe 50% Others
  - Operation costs ~800 k€/year
  - MEYS, BMBF, PT-DESY, FECYT, CNRS, INFN, FOM, FCT, PPARC
- **ASPERA:**
  - 7.500 k€ existing FTE per year (2008-18): 400 k€ operation costs
- **Compiled by**
  - Johannes Knapp j.knapp@leeds.ac.uk

LOFAR

Large radio telescope (10 – 240 MHz) 100s of antennas at an area of > 100 000 km^2

Key science programmes:

- **Cosmology:** Epoch of Reionization
- **All-Sky Surveys:** Star forming galaxies, AGN, Clusters, etc.
- **Transient detection:** Everything that bursts and varies
- **Astroparticle Physics:** Direct detection of cosmic rays
  Cosmic rays & neutrinos impacting the moon
- **Solar physics:** solar radio bursts

LOFAR : STATUS

- **Status**
  - Approved (astronomy community)
  - Commissioning (first core station in operation)

- **Collaboration:**
  - Exists / expand
  - ?? scientists ~100% EU ~100% ASPERA?
  - 7 European countries: DE,FR,IT,NL,PL,SE,UK

- **Obstacles:**
  - Funding of the operation

- **R&D required:**
  - Data transfer, Short pulse radio trigger (for CR)

- **Funding by EU call? ➔ HEAPNET FP7 JRA**
- **Linking? ➔ data are public after 1 year (established)**
- **Computing? ➔ need moderate increase and compensation**

LOFAR : 2008-2018

- **Timetable:**
  - R&D until 2010 Construction until 2011
  - Commissioning and operation until 2018+
- **Risks:**
  - Manpower operation key science program CR, radio trigger
- **Ressources:**
  - 104.000 k€ 77 FTE (CR) 100% Europe 0% Others
  - Ca. 1.000 k€ for CR programme
  - ASTRONOMY --- FOM
- **ASPERA:**
  - 1.000 k€ 77 FTE for CR key science program (~80k€/year 2008-2018)
- **Compiled by**
  - Olaf Scholten scholten@kvi.nl

SKA

TIMELINE

Concept

1994
International Working Group

1995
Start of Prototyping

2000
Signing of first Memorandum of Agreement

2005
Signing of extended Memorundum of Agreement

2006
Site Ranking Decision

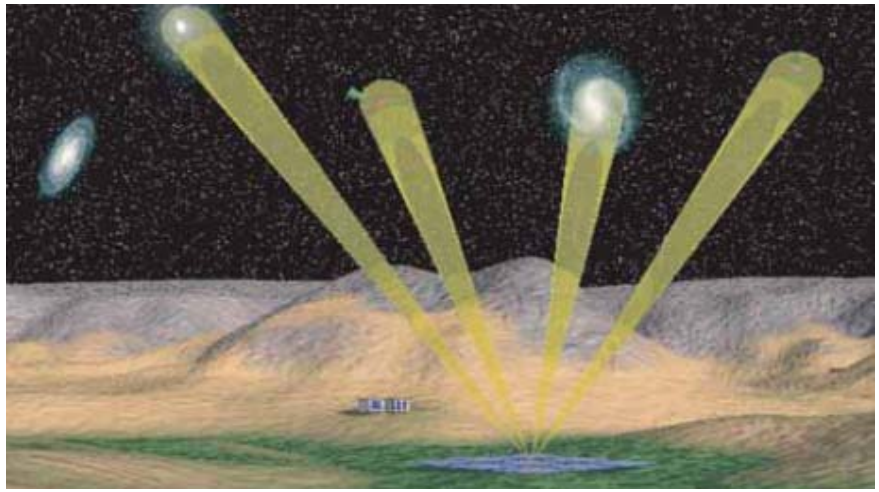
2009
Final Technology Decision

2010
Construction of pathfinder on site

2013
Early Science

2014
Construction of full array

2020
Full SKA operational!

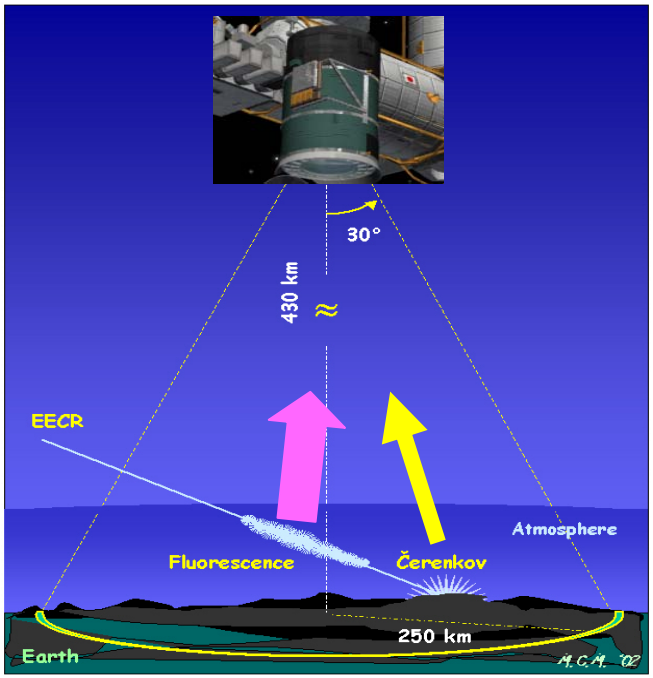


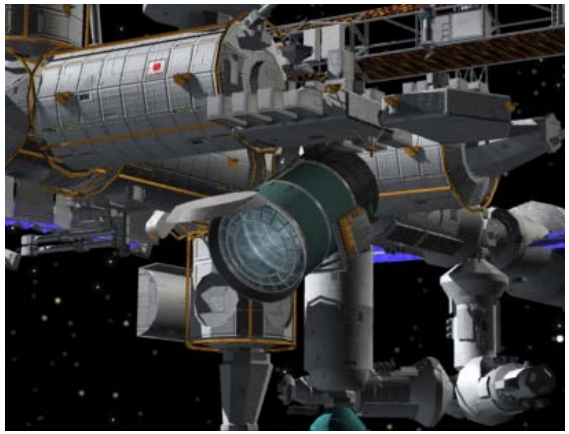
Square Kilometer Array (SKA) = Follow-up of LOFAR

to be built between 2014 and 2020 at the Southern hemisphere (South-Africa or Australia)
Included in the ESFRI list

•Cosmic rays as science program?

JEM-EUSO





H-II Transfer Vehicle (HTV)

An ISS based air-fluorescence experiment aiming for extreme energy astronomy by particle channel.

- **Cosmic ray measurements for energies > 5 10^{19}eV**
- **Detection of extreme energy neutrinos to examine extra dimensions in super-gravity/string theory**
- **Examination of quantum gravity, dark matter and quantum limit at super-LHC energies to m > 300 TeV/c2**
- **Global observations of night-glows, plasma discharges and lightings**

JEM-EUSO: STATUS

- **Status**
  - approved phase A+B 2007-2009 in Japan
  - launch possible (30%) 2013
- **Collaboration:**
  - exists
  - 139 scientists ~35% EU ~35% ASPERA
  - 4 European countries: France, Germany, Italy, Switzerland
- **Obstacles:**
  - start up funds in Europe
- **R&D required:**
  - high quantum efficiency detectors (SiPMT array)
- **Funding by EU call? ➔ HEAPNET FP7**
- **Linking? ➔ TBD**
- **Computing? ➔ not applicable?**

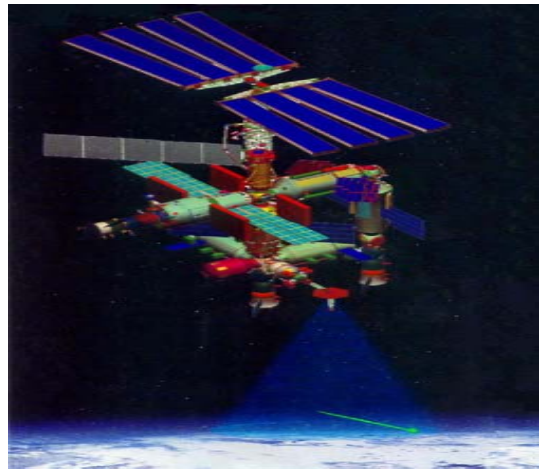
JEM-EUSO : 2008-2018

- **Timetable:**
  - CDR 2008 TDR 2009 Decision for construction 2012
  - R&D 2008-09 Construction 2010-12
  - Commissioning 2013 Operation 2013-17
- **Risks:**
  - ISS programmatic profile, European funds critical
- **Resources:**
  - 26.000 k€ 0 FTE 25% Europe 75% Others
  - Operation costs ~1.000 k€/year
  - BMBF, CNRS, SNF, INFN,
- **ASPERA:**
  - 6.500 k€ 0 FTE per year: 125k€/08-09 1.500k€/10-12 250k€/13-17
- **Compiled by**
  - Andrea Santangelo andrea.santangelo@uni-tuebingen.de

Ankle and GZK range

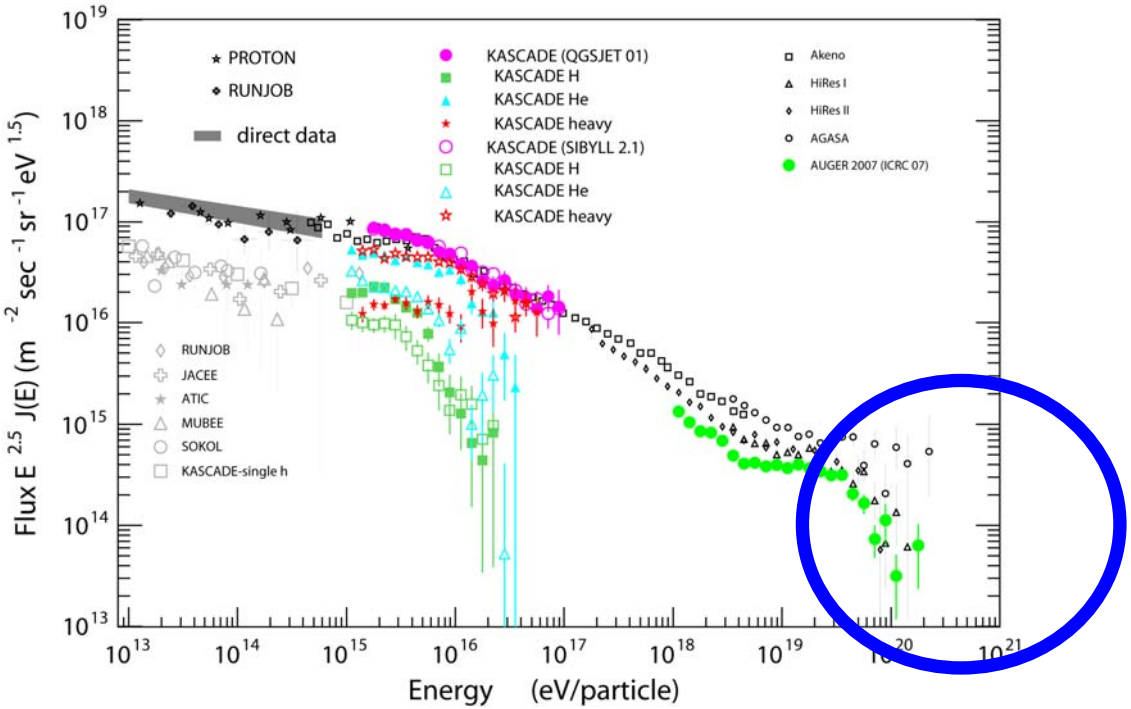
Further experiments (non ASPERA) :

- **TUS-KLYPVE**
  - Russian fluorescence experiment at ISS or as free flyer
- **Telescope Array TA**
  - American-Japanese hybrid experiment
- **LORD**
  - Lunar orbiter radio detector (Russia)
- **…?**



- **All these experiments are also looking for high-energy cosmological neutrinos!!**

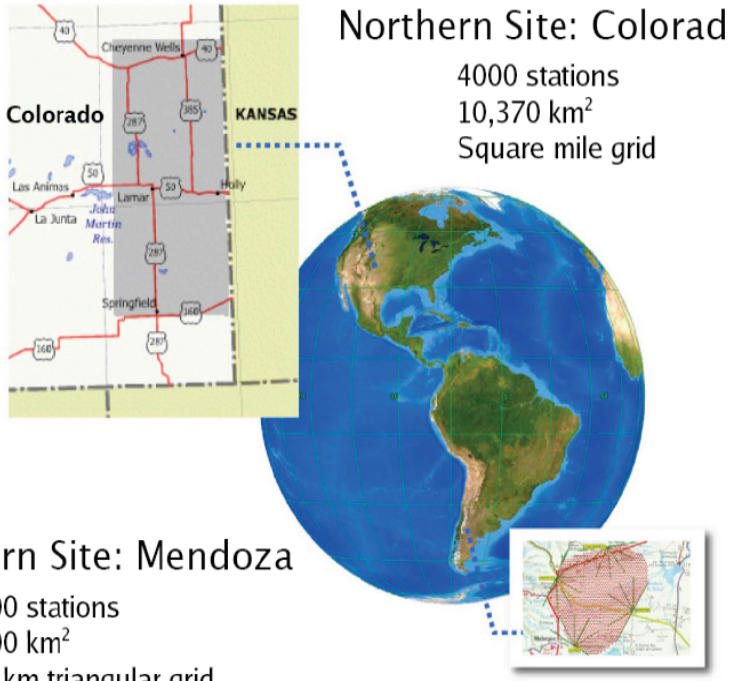
Beyond GZK : Particle Astronomy

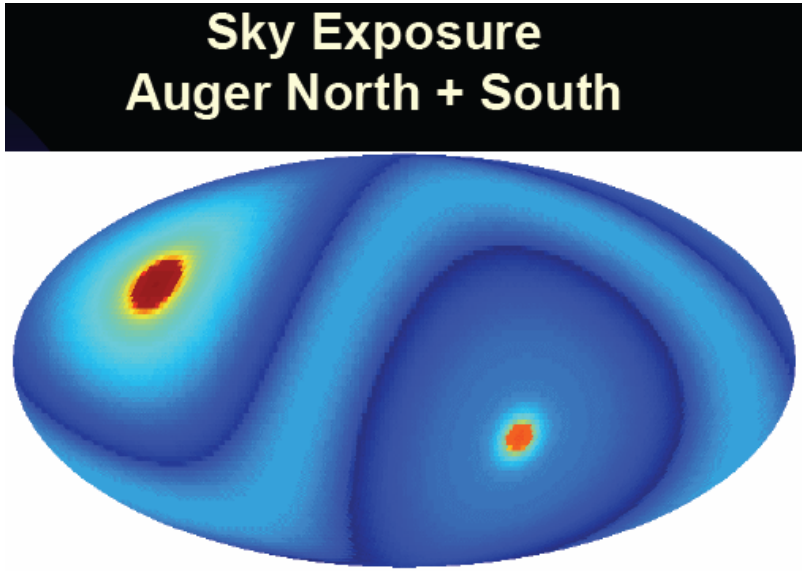


Task next decade:
Towards
Particle Astronomy !!

- **Window of Opportunity: 10^{19} - 10^{21} eV**
- **Maximize Statistics in this energy range**
- **Identify Sources**
- **Towards Source Spectra**
- **Multi-Messenger Source Observations**
- **Photon Observations**
- **High Energy Neutrino Detection via air-showers**

Pierre Auger Observatory – North





Giant air shower arrays in Southern and Northern Hemisphere for Full Sky Coverage

- **Sources in the sky ?**
  - **Near sources: source spectra - Far sources: spectral cutoff**
- **Primary nature (composition) ?**
  - **Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?**
- **Source spectra ?**
- **Multimessenger astronomy**

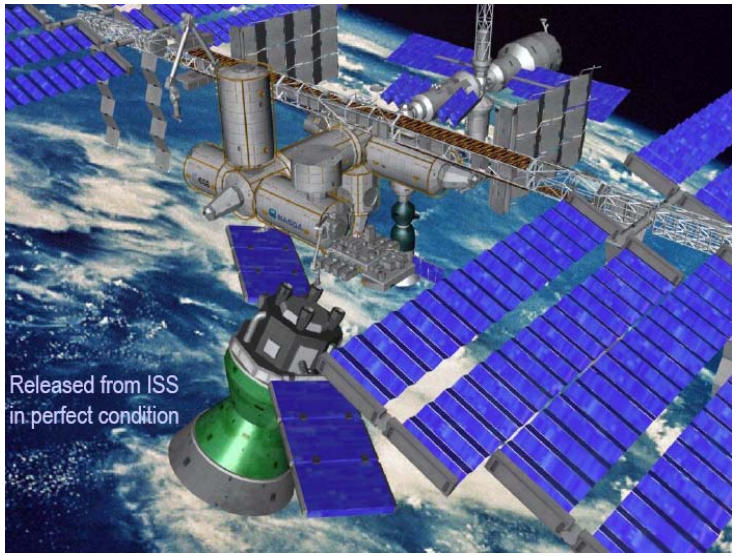
Pierre Auger Observatory – North: STATUS

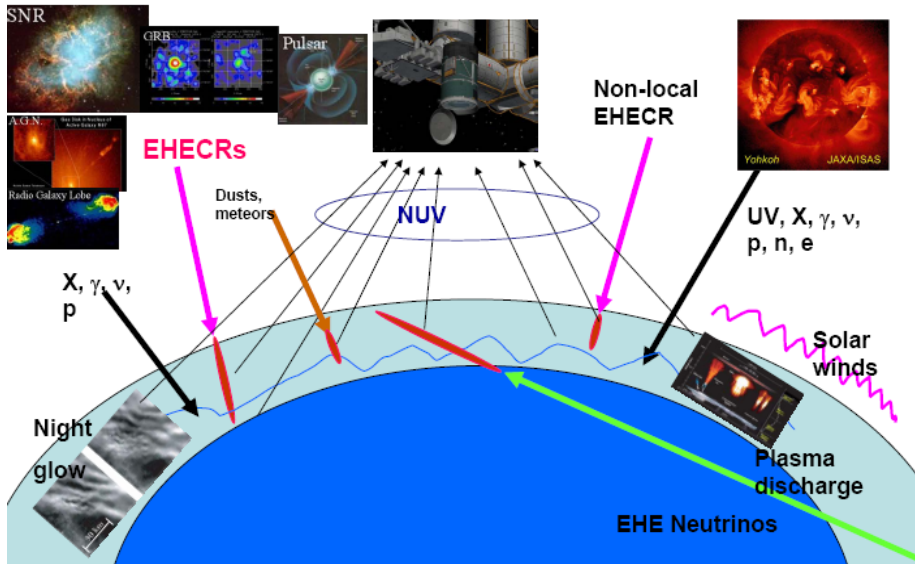
- **Status**
  - conceptual – R&D
- **Collaboration:**
  - exists (Auger south + more?)
  - 400+ scientists ~50% EU ~45% ASPERA
  - 10 European countries: CZ,DE,ES,FR,IT, NL,PL,PT,SI,UK
- **Obstacles:**
  - funding construction, R&D for enlargement
- **R&D required:**
  - Cheaper detectors
  - radio array
- **Funding by EU call? ➔ HEAPNET FP 7**
- **Linking? ➔ no access to site, but public data?**
- **Computing? ➔ TBD**

Pierre Auger Observatory – North : 2008-2018

- **Timetable:**
  - **R&D 2008-10 Construction 2008-12**
  - **Operation 2010-2018+**
- **Risks:**
  - **Detector quality vs. costs**
- **Resources:**
  - **70.000 k€ 655 FTE ~50% Europe ~50% Others**
  - **Construction costs ~60.000 k€**
  - **MEYS, BMBF, PT-DESY, FECYT, CNRS, INFN, FOM, FCT, PPARC**
- **ASPERA:**
  - **35.000 k€ 330 FTE peak 2009-11: 10.000 k€ per year**
- **Compiled by**
  - **Johannes Knapp** j.knapp@leeds.ac.uk

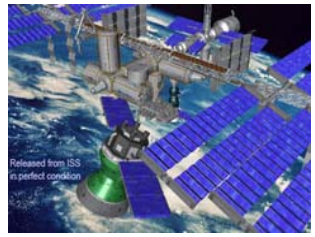
SUPER-EUSO





- **conception and design of a space-based experiment for observation of UHE Cosmic Particles from space (in the post Pierre Auger Observatory era)**
- **Studies within the ESA Cosmic Vision (2015-2025) program**
  - **Cosmic ray measurements for energies > 10^{20} – 10^{22} eV**
  - **Where does the spectrum end ?**
    - **Is there a GZK cutoff ? Are the sources local (<100 Mpc) ?**
  - **Primary nature (composition) ?**
    - **Nuclei ? Protons ? Gamma rays ? Neutrinos ? Or……?**
  - **Global sky observations**
    - **night-glows, plasma discharges and lightings**

SUPER-EUSO: STATUS



- **Status**
  - **Conceptual, technology is in R&D**
  - **proposal for ESA cosmic vision**

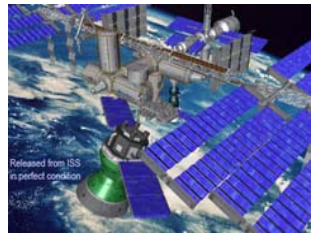
- **Collaboration:**
  - **just formed**
  - **~130 scientists 80% Eu 75%ASPERA**
  - **> 7 European countries: CH,ES,FR,IT,DE,PL,PT,SE,UK**

- **Obstacles:**
  - **funding start-up, competition with other space missions**

- **R&D required:**
  - **Optics, photo sensors, electronic of next generation, atmosphere**

- **Funding by EU call? ➔ HEAPNET FP7**
- **Linking? ➔ TBD**
- **Computing? ➔ seems sufficient**

SUPER-EUSO : 2008-2018



- **Timetable:**
  - CDR 2008-09 TDR 2010-11 TUS and JEM_EUSO as “pathfinder”
  - Critical Reviews and Decision for construction 2012-?
  - R&D 2008-11 Construction 2012-15 Commissioning 2015-18
  - launching >2018

- **Risks:**
  - schedule, funding, manpower

- **Resources:**
  - 155.000 k€ 335 FTE 60% Europe 40% Others

- **ASPERA+ESA:**
  - 93.000 k€ 200 FTE peak 2014-15: ~25.000 k€ per year

- **Compiled by**
  - Alessandro Petrolini Alessandro.Petrolini@ge.infn.it

Conclusions

Plans for next decade (2008-2018):
(Recommendations from Roadmap Phase 1):

- **Present efforts (focused in Auger South with 50% European contribution) pursued with vigor**
- **Establish scientific case and make significant contribution to Auger North ➔ Towards particle astronomy**
- **Support of R&D of new detection techniques**
- **Inclusion of high-energy cosmic rays in the ESA Cosmic Vision 2015 program**
- **Close cooperation with accelerator physics (LHC) ➔ hadronic interaction models**
- **Bridge gap of direct to shower measurements**

Summary: total costs

Experiments	k€	FTE milestones
•Auger (south):	15.000	-
	operation 2018++; construction<2011	
•Auger (north):	70.000	655
	R&D<2011; construc<2014; operat.2018++	
•JEM-EUSO:	26.000	-
	2009 A+B report JAXA, launch 2013	
•SUPER-EUSO:	155.000	335
	R&D<2012, constr.<2016 commis.<2019	
•LOFAR:	104.000	77
	R&D+construction CR-KSP <2012 (1M€)	
•NUCLEON:	70.000	600
	operation >2014 construction<2011	
•AMS-02:	3.000	600
	operation >2008 end 2015	

Summary: ASPERA

Experiment	k€	scientists (present)	FTE (required in 10 yrs)
•Auger (south):	7.500	400	-
•Auger (north):	35.000	400	330
•JEM-EUSO:	6.500	140	-
•SUPER-EUSO:	93.000	130	200 (ESA)
•LOFAR(CR):	1.000	10	77
•NUCLEON:	10.000	40	240
•AMS-02:	2.100	600	420

Conclusions

Plans for next decade (2008-2018):

- **For the whole range of high-energy cosmic rays still detailed experimental investigations are necessary**
- **New generation of experiments is on the way**
- **most important (largest investments) is the investigation of the highest energy particles**

➔ Towards particle astronomy

ASPERA working group 3

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+ recently interest from Spain (Oscar Blanch, Dolores Frias)