#### EBERHARD KARLS UNIVERSITÄT TÜBINGEN



#### Mathematisch-Naturwissenschaftliche Fakultät

Institut f. Astronomie u. Astrophysik





"Doing astronomy by looking downward"

### The JEM-EUSO mission (or better "Status of ... ")

### Andrea Santangelo\*

\* Global Coordinator of the JEM-EUSO Collaboration

Frontiers Objects in Astrophysics and Particle Physics May 18-24 2014, Vulcano (Italy)



### Preamble

The Extreme Energy Frontier: The end of the Cosmic Ray Spectrum



### **UHE and EE region**



 $\blacktriangleright$  E > (5-6)×10<sup>19</sup> eV (~10<sup>16</sup> keV)



### Part I What is JEM-EUSO?



The Extreme Universe Space Observatory onboard the Japan Experiment Module (JEM) of the ISS





2001-2004

### Heritage of the ESA EUSO study



Japanese Experiment Module "Kibo" (Also NASA)

きぼう, Hope

K. K. R. MI

51.6°

01075011100





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





### **Science Instrument on HTV**



The Telescope has to be deployed after it is attached at the ISS



### New study: the SpaceX Dragon option





SpaceX Dragon attached to the ISS Remote Manipulator Arm on May 25, 2012 (Credit: NASA)

### JEM-EUSO accommodated in the Space X- Dragon launcher





Cont



Circular optics: Same perf.

The JEM-EUSO Collaboration "The JEM-EUSO Instrument" (Exp. Astr. 2014)

# Mission aspects have been successfully studied $\rightarrow$ improvements

Parameter	Value	
Mission Lifetime	5 years	
Rocket	H2B or Falcon 9	
Transport Vehicle	HTV or Dragon	
Accommodation on JEM	EF#2 or EF#9	
Mass	1770 kg → 1153 kg	
Envelope	290 cm(x) x 270 (y) cm x 160 (z)	
Power	926 W (op.) 352 W (non op.)	
Data rate	300 kB/s (+ on board storage 10 GB/s)	
Orbit	400 km	
Inclination of the Orbit	<b>51.6°</b>	
Operation Temperature	-10° to 50°	



### Science Instrument *deployed* (Schematic)







## UNIVERSITAT TUBINGEN The UV Telescope Parameters

Parameter	Value	
Field of View	<b>±30°</b>	
Monitored Area	>1.3×10 <sup>5</sup> km <sup>2</sup>	
Telescope aperture	≥2.5 m	
Operational wavelength	300-400 nm	
Resolution in angle	0.075°	
Focal Plane Area	4.5 m <sup>2</sup>	
Pixel Size	<3 mm	
Number of Pixels	≈3×10⁵	
Pixel size on ground	≈560 m	
Time Resolution	2.5 µs	
Dead Time	<3%	
Detection Efficiency	≥20%	



### Part II How does JEM-EUSO observe?



### Technique: fluorescence from space





J. Linsley

Y. Takahashi



330 – 400 *nm*, UV

 $e^- + N_2 \longrightarrow N_2^*$ (+e⁻) \* + e⁻ (+e⁻)  $N_2^*$ 



b) Scattered Cherenkov c) Direct (diffusively reflected Cherenkov) Back. = 500 / (m<sup>2</sup> sr ns) FAST SIGNAL

a) Fluorescence

### duration $\approx 50 - 150 \ \mu s$

Simulation of the light profile observed at the entrance pupil (above) and throught the instrument using the ESAF code



θ=30°, 60°, 75°

**Shower development** 



The granularity of the recorded track is shown



- Far and almost constant distance of the shower (no proximity effect)
- Shower is contained in the FOV: *observation of the entire profile*
- Possibility of *observing in cloudy conditions* (in most cases  $X_{max}$  above the cloud-top)
- Less contamination by Cherenkov
- Efficient gamma/hadron separation using different geographical areas
- Measurement of neutrino showers at high altitude *with less LPM effect*

Telemetry constrains!!! → Be careful in comparing reduction from trigger to "reconstruction" efficiency

### Two advantages: 1. Monitored Area



JEM-EUSO







-30







Declination [°]

+60 + 90

+30

#### 

0



 $4\pi$  coverage

-90 -60



### Part III Why JEM-EUSO?



### The cut-off: open questions remain



- Is this the GZK suppression? Or are the sources running out of fuel...
- Do we see a recovery of the spectrum ?
- Has the spectrum an end? Which is the maximum energy

• Cut-off implies a very low flux:

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

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

• (Good news) It limits the horizon and gives us the possibility to find local sources



**Again Auger South** 



Hague & PAO collaboration, 2009



#### AGN data TA vs. Auger



• 17 events correlate out of 42 (0.40)  $\implies p = 1.4\%$ 

K. H. Kampert, presented at VHEPA 2014 (Kashiwa, Japan)

#### UNIVERSITAT TÜBINGEN A tantalizing result: TA hotspot

#### Oversampling with a 20° radius for 72 events above 57 EeV



- Statistical significance 5.1σ (before correction)
- Chance probability: 3.6σ (1.4x10<sup>-4</sup>)

H. Sagawa presented at VHEPA 2014 (Kashiwa, Japan)



EBERHARD KARLS

- *Identification of sources* by high-statistics arrival direction analysis (+multi-wavelength!)
- *Measurement of the energy spectra* of individual sources (spectral shape, flux, power)

Understand and constrain acceleration and emission mechanisms

**JEM-EUSO** Main Scientific Objectives (1)

Physics and Astrophysics at E>5.×10<sup>19</sup>eV or better



- Exploratory Objectives: new messengers
  - Discovery of UHE neutrinos by neutrino
     discrimination and identification via X<sub>0</sub> and X<sub>max</sub>
     Discovery of UHE Gammas by discrimination of
    - $X_{max}$  due to geomagnetic and LPM effect
  - Other Exploratory Objectives:

EBERHARD KARLS

- Constrains on the galactic and local extragalactic fields
- Limits on monopoles
- Search for "nuclearites"
- Test of Lorentz Invariance



Old EUSO plot by Bottai et al., 2003



#### The key concept



(CC)  $v_1 N \rightarrow l + hadrons$ (NC)  $v_1 N \rightarrow v_1 + hadrons$ 



### Neutrinos vs. Protons: X<sub>max</sub>



Distribution of  $X_{max}$  for protons and neutrinos for E=10<sup>20</sup> eV and  $\theta$ =85° (First Peak of the shower profile)



### Physics and Astrophysics at E>5.×10<sup>19</sup> eV

But also... Explore new physics in the energy range *E*≈10<sup>20</sup>-10<sup>21</sup>eV

Highest statistics and therefore largest exposures at extreme energies

$$E \approx 10^{20-21} eV$$

Lower Energies are important for overlapping with current generation observatories with significant statistics...  $E < 5 \times 10^{19} eV$ 



### Part IV Technical progress...



### **BBM of the Optics (Protypes)**



Performances meet already the requirements (or very close)

large diameter Fresnel lenses manufactured in Japan and tested in the US at the University of Alabama (Huntsville) and at MSFC (NASA)







Focal Surface detector 137 PDMs = 0.3M Pixels





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



### Two EM of the PDM integrated APC

**ASIC Board** 



### *Elementary Cell*

Integration: 4 MAPMTs, filters, and the EC boards







#### JEM-EUSO France, Germany, Korea, Italy and Japan





#### **EM of the Electronics**





### Part V What can JEM-EUSO do?



### Annual exposure in nadir



Annual exposure at highest energy ~9 times of Auger SD

Bertaina et al. (The JEM-EUSO Coll.) Adv. Sp. Res. 2014



### Geometrical aperture in nadir mode



Adams, Jr. et al., Astroparticle Physics, 44 (2013) 76–93 for details.





The JEM-EUSO collaboration "Performances of JEM-EUSO: angular reconstruction" (Exp. Astr.) 2014



#### **Energy reconstruction**



All sky events

Diamond events In the center + Cherenkov stamp

The JEM-EUSO collaboration "Performances of JEM-EUSO: energy and  $X_{max}$  reconstruction" (Exp. Astr.) 2014



### Anisotropy studies with JEM-EUSO



1) Establish the first consistent, highsensitivity,  $4\pi$ -steradian map of the UHECR sky

2) Study signatures of the cosmic variance / constrain source density

3) Study large scale anisotropies (dipole and quadrupole) (~uniform fullsky coverage!)

4) Constrain source density / deflections / magnetic fields → study of extended multiplets (energy/deflection)
- close multiplets => protons !

Auger energy scale:1100 / 250 / 100 events above 50 / 80 / 100 EeV HiRes/TA energy scale: 2100 / 580 / 260 events above 50 / 80 / 100 EeV

#### 300 000 km<sup>2</sup> sr yr



"JEM-EUSO statistics": 1100 events above 50 EeV (Auger energy scale)



300 000 km<sup>2</sup> sr yr

d'Orfeuil et al., 2014



### **JEM-EUSO Extreme Energy Universe**

"JEM-EUSO statistics": 250 events above 80 EeV (Auger energy scale)



300 000 km<sup>2</sup> sr yr



#### Sky-map above 80 EeV (Auger energy scale)



### Proton Dominated... fantastic but...



EBERHARD KARLS UNIVERSITÄT

TÜBINGEN

\_\_\_\_\_



#### The Zoo of neutrino models



The JEM-EUSO collaboration "Ultra High Energy Photons and Neutrinos with JEM-EUSO" (Exp. Astr.) 2014



### Part VI Pathfinders



- Japan, USA, Korea, Mexico, Russia
- Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland
- 15 Countries, 80 Institutions, more than 285 researchers
- RIKEN, Japan: leading institution







### • The Pathifinders: TA-EUSO

TA-EUSO: Cross-Calibration Tests at the Telescope Array site in Utah in collaboration with the ICRR, Institute Cosmic Ray Research in Tokyo and the TA collaboration  $\rightarrow$  (going on at APC); installation early end of July 2014



The JEM-EUSO Collaboration "Ground-based tests of JEM-EUSO components at the Telescope Array site, EUSO-TA" (Exp. Astr. 2014)



Test of the prototype at the Telescope Array (TA) site in Utah

TA site, UTAH, Black Mesa



- TA-EUSO will be located at Black Rock Mesa FD Station
  - Electron Light Source at 100m
  - Most nearby SD is at ~3.5 km
  - Central Laser Facility ~21km





Lens have been installed, Focal Surface integration on going at APC

### **EUSO-Balloon**

 Test the key technologies and techniques for JEM-EUSO

Test the JEM-EUSO EM

Measure the background UV levels

 Search for background events that mimic air showers

 Detect the fluorescent signals of air showers from above for the first time

### Second Pathfinder: EUSO Balloon

- Look down from the balloon with an UV telescope (PDM EM + 3 lenses system)
- Engineering test
- Background test
- Airshower from 40 km altitude



#### Rescaling JEM-EUSO

	JEM-EUSO	EUSO-Balloon	
Height(km)	420	40	
Diameter(m)	2.5	1	
FoV/pix(deg)	0.08	0.25	
Pixel@ground(km)	0.580	0.175	
FoV/PDM(deg)	3.8	12	
PDM@ground(km)	28.2	8.4	
Signal Ratio	1	17.6	
BG Ratio	1	0.9-1.8	
S/√N	1	20-10	
E <sub>thr</sub> (eV)	3x10 <sup>19</sup>	1.5-3x10 <sup>18</sup>	
Number of PDM	143	1	







### EUSO-Balloon: Will be *launched in Summer* 2014 from Timmins, (Canada); → Integration and Testing Phase at IRAP in Toulouse



Von Ballmoos et al. (The JEM-EUSO collab.) Adv. Sp. Res. 53 (2014)



### **EUSO Balloon: PDM and IR Camera**





EUSO Balloon PDM: 36 MAPMTs 64 anodes) Total 2304 pixels

- Frame Rate: 0.1 Hz
- Wavelength: 10-12.5µm
- **FoV**: 75°

### **Helicopter Under-flight for Calibration**

A helicopter carrying a UV flasher and a UV laser will be flown under EUSO-BALLOON on a helicopter to:
Provide an absolute reference for the intrinsic luminosity of light flashes
Check on the trigger efficiency

Check on the trigger efficiency
Check the accuracy of cosmic ray arrival direction reconstruction from the air shower images

The helicopter will fly under the balloon at altitudes up to 10,000 ft. The balloon will transmit its GPS position directly to the helicopter.

Spring APS Meeting



### **Recently: KLYPVE-EUSO**





### **Different Configurations under study**

	KLYPVE	K-EUSO Baseline	Advanced Optics
Optics type	Mirror	Mirror + corrective lens	Mirror + objective lens
FOV	$\pm 7^{\circ}$	$\pm 14^{\circ}$	$\pm 25^{\circ}$
Mirror diameter	3.6 m Aspherical	3.4 m Aspherical	4m Aspherical (Mangin)
Mirror area	$10 \text{ m}^2$	$9 \text{ m}^2$	$12 \text{ m}^2$
Focal distance	3 m	4 m	4 m
Lens diameter	none	2.64  m (Fresnel + Diff)	3.6  m (Fresnel + Diff)
FS diameter	1.2 m	1.4 m	1.9 m
Number of pixels	2500	$\sim 119808$	$\sim 223488$
Pixel angular size	$0.016^{\circ}$	$0.058^{\circ}$	$0.076^{\circ}$
Pixel FOV in atm.	2000 m	400 m	530 m
Orbit height	400 km	400 km	400 km

### KLYPVE is an approved mission in ROSCOSMOS



- In the last two years the JEM-EUSO missions has been tremendously progressed:
  - Solid Science case → emerging of the sources and the discovery potential
  - **Solid estimates of the observational figures** (via end-to end simulations)
  - Solid technology and production of the EM models
  - **Test observational technique and background** with pathfinders

Solid mission profile in a programmatic context that is turbolent! 1) In the NASA ISS roadmap; 2) ESA topical team renewed; 3) Being actively studied by ROSCOSMOS



# Thank you.

Contact:

Andrea Santangelo Abteilung Hochenergieastrophysik Sand 1, 72076 Tübingen · Germany Phone: +49 7071 29-76128 Andrea.Santangelo@uni-tuebingen.de







### **Exploring the frontiers**

### $\longrightarrow$ E > (5-6)×10<sup>19</sup> eV (~10<sup>16</sup> keV)

