On the importance of analyzing very-high and ultra-high energy data together - towards a new working group for UHECR symposia







Light and Heavy Knees, Ankles, and Transition

Hillas model 5.5 log₁₀(E^{2.75} x Flux / m ⁻²s⁻¹sr⁻¹GeV^{1.75}) O Tunka **o** HaverahPk Tibet 0 5.25 🛧 Akeno/AGASA KASCADE Stereo FlysEye HiRes All 💁 💁 🌺 📩 5 4.75 A-component 4.5 rigiditv 4.25 3.75 **B-component** 3.5 A.M.Hillas, J. Phys. G: Nucl. Part. Phys. 31 (2005) R95 3.25 17 20 14 15 16 18 19 $\log_{10}(E/eV)$ E ^{2.5} J(E) (m⁻² sec ⁻¹ sr ⁻¹ eV ^{1.5}) 1013 10¹⁶ light particles heavy particles 10¹⁵ **KASCADE, KASCADE-Grande** 10¹⁴ 10¹⁹ 10²⁰ 10¹⁴ 10¹⁵ 10^{16} 1017 10^{18} (eV/particle) Energy

rigidity dependent knees (A component)

(galactic) B-component needed to explain allparticle spectrum

Highest energy is extragalactic



Questions to the knee-to-ankle energy range



Overlap direct-indirect measurements? Hadronic interaction models? **Rigidity dependent knee? Fine-structures in spectrum? Composition at knee? Spectra of individual masses?** Iron knee? **End of Galactic Spectrum?** Second knee? **Transition galactic – xgalactic? Anisotropy?**

Engel, Blümer, Hörandel: Progress in Particle and Nuclear Physics 63 (2009) 293



Current Experiments 10¹⁶-10¹⁸eV







HECR 2018 Ukra Had Law

Andreas Haungs



- Structures of all-particle spectra similar (in the level of 15%)
- first composition results are in agreement with KASCADE-Grande





UHECR experiments









KASCADE: the rigidity knee

- same unfolding but based on different hadronic interaction models embedded in CORSIKA



- all-particle spectrum similar
- general structure similar: knee by light component
- -relative abundances very different for different high-energy hadronic interaction models but for many models: proton not the most dominant component!

KASCADE collaboration, Astrop.Phys. 24 (2005) 1 , Astrop.Phys. 31 (2009) 86





KASCADE-Grande energy spectra of mass groups



• steepening due to heavy primaries (3.5σ)

hardening at 10^{17.08} eV
(5.8σ) in light spectrum

• slope change from $\gamma = -3.25$ to $\gamma = -2.79!$

Phys.Rev.Lett. 107 (2011) 171104 Phys.Rev.D (R) 87 (2013) 081101





Tunka-133 Composition



- The heavy component (N+Fe) has a break at 10¹⁷ eV, reaching a fraction value of 80%
- The light component starts to rise again above 10¹⁷ eV
- Up to now we cannot confirm the sharp decrease of <In A> seen by KASCADE and the high <In A> at 10¹⁷ eV

S.Epimahkov Tunka-133 (2015)





IceTop+IceCube: Composition



- Combined
 IceTop IceCube
 analysis by a
 neural net
- Confirms structures seen before
- Differences in mass scale





HEAT (2015) Auger Collaboration, ICRC2015, arXiv:1509.03732



QGSJetII-04 (Mean of ln A) **Syst**. Auger @ ICRC 2015 50% p - $\langle \ln A \rangle$ ------p-dominated, but 50% Fe mixed compos. 85% p -15% He 19.5 18.5 19.0 17.0 17.5 18.0 20.0 $\log_{10}(\mathbf{E}/\mathbf{eV})$

> Auger; arXiv:1509.03732, subm. to PRD Correlations of Xmax and shower-size ⇒ mixed composition at ankle, i.e. no pure p-beam

 \Rightarrow dip-model (e+e- pair prod. in CMB) ruled out

Kampert, 2016 Auger Collaboration





Xmax / Composition by Radio

A lot of (promising) progress in Xmax determination by radio Experiments



- published already by LOPES PhysRevD 90(2014)062001
 Tunka-Rex PRD 97, 122004 (2018)
 LOFAR Nature 531(2016)70
 - Auger/AERA promising
- Higher energy
- More accurate EAS
- Calibration
- Various methods

Certainly important contribution by the radio experiments High threshold? (see IceTop radio enhancement)



experiments in the knee energy range

• (Tibet, ARGO) LHAASO

CR around knee with multi-detector installation China - with participation of France. Italv

• TAIGA/ Tunka/HiSCORE/Tunka-Taiga-Rex

CR around knee and up to ankle with multi-detector installation Russia - with participation of Germany, more?

IceCube/IceTop – (Gen2)

Ice-Cherenkov array on top of IceCube USA – with important European contribution Enhancement plans for surface (veto) array

• GRAPES

KASCADE-like operating array at 2300m altitude India - with participation from Japan

• HAWC

High-Altitude Gamma-ray Observatory in Mexico Extension with outer trigger for better CR detector

• NEVOD

Nevod / Decor complex now with air shower array

• NICHE

Cherenkov array at TA for low energies





Transition working group

Target:

- Energy spectrum and composition from knee to ankle
- Systematics by hadronic interaction models
- Comparison with astrophysical models

First steps:

- Formation of the working group (end of 2018?)
- Comparison and compilation of all currently available results
- Agreement on a defined set of simulations which will be reconstructed
 - First report next UHECR??



