

# **Cosmic Ray Observations around and above the knee**

Karl-Heinz Kampert, University of Wuppertal e-mail: kampert@uni-wuppertal.de









- Astrophysical Relevance of Energy Range
- Experimental Data
  - connecting direct and EAS experiments
  - the knee region
  - the second knee and ankle region
- Experiments in the near Future
- Concluding Remarks

# **SNRs: The galactic CR accelerators ?**

#### HESS Collaboration: Nature 432 (2005) 75; Nature 439 (2006) 695



Morphology of RX J1713.7-3946



Diffuse TeV  $\gamma\text{-emission}$  from galactic centre region

#### **Experimental proof ?**

- Still no evidence for hadronic accelerators
- TeV γs can (still) be interpreted by Inverse Compton (IC)
- Diffuse γs suggest nearby sources with a hard spectrum
- Why are most SNRs not seen in TeV light ?



# Knee by SNRs ?



### Knee by diffusion losses ?



TeV Particle Astrophysics 2007, August 2007, Venice

# Knee by change of hadronic interaction ?



TeV Particle Astrophysics 2007, August 2007, Venice

# **Energy Spectra** & Composition

### **Direct Measurements: RUNJOB, JACEE, ATIC...**



- proton above 10<sup>15</sup> eV detected !
- p-spectra agree
- He spectra almost a factor of 2 lower in RUNJOB
- slopes are almost parallel: E<sup>-2.7-2.8</sup>
- all-particle in RUNJOB ~ 40-50% less than in JACEE & SOKOL

### **Energy & Mass from EAS by KASCADE**

#### **CORSIKA Simulations**

Data



### **E-spectra from KASCADE**

# Unfolding with QGSJet01

GHEISHA 2002 for low energy interactions



### **E-spectra from KASCADE**

### **Unfolding with SIBYLL 2.1**

GHEISHA 2002 for low energy interactions



#### More CNO & Iron with Sybill based unfolding

### **E-spectra from KASCADE**

### **Unfolding with EPOS**

#### GHEISHA 2002 for low energy interactions



#### Very proton dominant, no Iron (too many muons in EPOS at high energies)

# **Effect of low-energy Model**

#### Unfolding with QGSJet01 GHEISHA 2002 and Fluka for low energy interactions

QGSJet 01, 0°-18°



**Minor Effect only** 

# **? E/Z or E/A ?**



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# **? E/Z or E/A ?**



# EAS-TOP & MACRO (TeV µs)



EAS-TOP Collaboration; Astrop. Phys., 20 (2004) 641

# GAMMA @ Mt. Aragats





Fit to N<sub>ch</sub>, N<sub>µ</sub>, s assuming rigidity effect and power law  $\gamma_1$ ,  $\gamma_2$ 

enormous differences between SIBYLL and QGSJET ? problem of detector MC ?

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arXiv:0704.3200

# GAMMA @ Mt. Aragats



arXiv:0704.3200

# **The CR Energy Spectrum**



### **Proton Primaries: direct and EAS data**



#### direct and EAS data are of similar uncertainties in which they agree well

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### **Proton Primaries vs Acceleration Models**



### **Proton Primaries vs Propagation Models**



### **Helium Primaries: direct and EAS data**



Uncertainties are significantly larger than for protons
KASCADE (with QGSJET) may be a little high

### **Helium Primaries vs Acceleration Models**



### **Helium Primaries vs Propagation Models**



### **Iron Primaries: direct and EAS data**



### **Iron Primaries vs Acceleration Models**



### **Iron Primaries vs Propagation Models**



# **All-Particle Spec. & Composition**



# 2 Is there a 2<sup>nd</sup> Knee ?



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# New & better data to come...



**KASCADE-Grande** @ FZ-Karlsruhe  $\sim 0.5$  km2 coverage electron & muon counting muon production height



#### IceTop/IceCube

@ South Pole ~ 1 km2 coverage charged particles at ground 500 GeV muons in ice

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Karl-Heinz Kampert

### **KASCADE-Grande LDFs**



$$\rho_{ch} = N_{ch} \cdot C(s) \cdot \left(\frac{r}{40\mathrm{m}}\right)^{s-1.5} \left(1 + \frac{r}{40\mathrm{m}}\right)^{s-2.3}$$

### **KASCADE-Grande** N<sub>ch</sub>-Spectrum



### 3 The Ankle Region Galactic → Extragalactic ?



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### **Ankle:** composition helps to discriminate models?



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20.5

# **Xmax distribution**



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### **Cosmogenic Neutrinos to probe p-dip model ?**



# **Expts under Construction / Proposed**

High Elevation Auger Telescopes (HEAT) 30° - 60° elevation





TALE @ Telescope Array prototype up to 72° elevation

# **Concluding Remarks**

- Vast progress on experimental data from knee to GZKregion ! ... still more to come in near future
- Quality of data from EAS arrays suffer from interaction models. ... LHC-forward expts will help here
- Progress also in acceleration & propagation models
   ... but present uncertainties still too large
   ... how to improve, what data is needed ?
- Second knee suggestive but remains to be proven
- Ankle clearly oberved, but origin to be verified by composition studies, ... again very model dependent
- HEAT & TALE will address this question

### Knee & Ankle region is now a target of high resolution studies Need to know their origin for a convincing picture of CR origin