

Ultra high energy cosmic rays from nearby starburst galaxies

Dallel Bouchachi

August 3, 2018

Badji Mokhtar University
Physics Department
Annaba, Algeria

Outline

1. Introduction
2. Current status
3. Starburst galaxy scenario
4. Conclusion

Outline

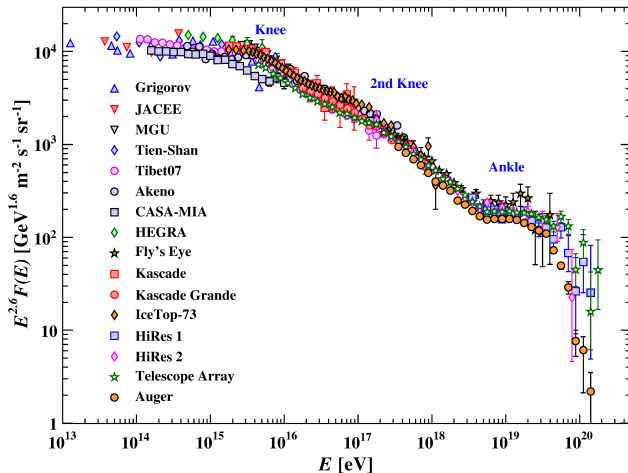
1. Introduction
2. Current status
3. Starburst galaxy scenario
4. Conclusion

Cosmic rays

- High energy particles from outer space
- Atomic nuclei (p, α , HZE)
- Mysterious origin

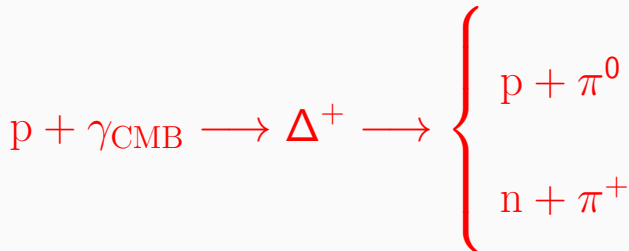
All-particle energy spectrum

[Patrignani et al. (Particle Data Group), 2016, Chin. Phys. C, 40, 100001]



GZK effect

[Greisen, 1966, PRL 16, 748; Zatsepin & Kuz'min, 1966, JETP Lett. 4, 78]



⇒ Threshold $\sim 6 \cdot 10^{19}$ eV

⇒ Mean free path ~ 10 Mpc

(1 Mpc = 3.26×10^6 y)

Outline

1. Introduction
2. Current status
3. Starburst galaxy scenario
4. Conclusion

Major underway experiments

Pierre Auger Observatory (Argentina)



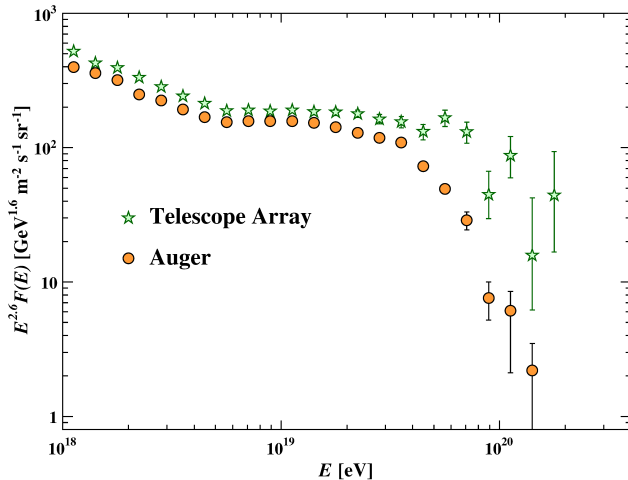
Major underway experiments

Telescope Array (TA) Experiment (USA)



All-particle energy spectrum ($> 10^{18}$ eV)

[Patrignani et al. (Particle Data Group), 2016, Chin. Phys. C, 40, 100001]



Mass composition ($> 10^{19}$ eV)

- **Auger:** heavy composition

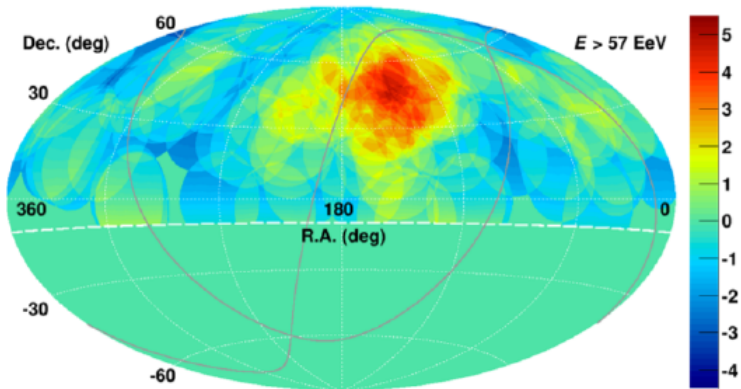
[Auger Collab., 2014, Phys. Rev. D, 90, 122006]

- **TA:** light composition

[TA Collab., 2015, Astropart. Phys., 64, 49]

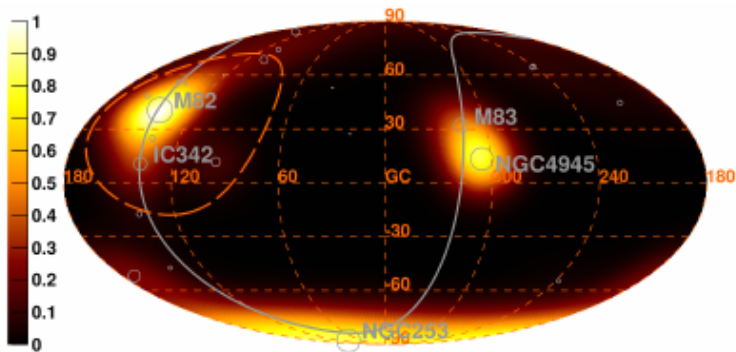
Anisotropy (Telescope Array)

[Mello Neto, 2016, J.Phys.Conf.Ser. 706(4):042009]



Anisotropy (Pierre Auger)

[Auger Collab, 2018, ApJL.10.3847/2041-8213]



Outline

1. Introduction
2. Current status
3. Starburst galaxy scenario
4. Conclusion

Source model

- Nearby starburst galaxies (redshift $z < 0.03$)

[Becker et al., 2009, arXiv:0901.1775]

- Scaling of cosmic rays with SFR

[Biermann et al., 2016, Frascati Phys. Ser., 64]

- Source weight = FIR luminosity at $60 \mu\text{m}$

[Muxlow et al., 2006, Proc. 8th European VLBI Network Symp., Torun, Poland]

Source model (cont'd)

- Injection energy spectrum:

$$\propto E^{-\gamma} e^{-E/E_{\text{cut}}}$$

- Initial mass composition:

pure proton / mixed (p, He, N, Fe)

- Reweighting factor is:

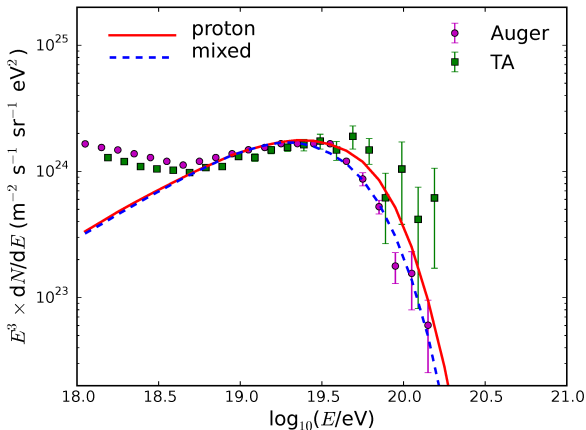
$$w(E) = E^{1-\gamma} \times \exp\left(\frac{-E}{E_{\text{cut}}}\right)$$

Propagation model: CRPropa 3

[Batista et al., 2016, J. Cosmol. Astropart. Phys. JCAP05, 038]

- Propagation of UHE cosmic-ray nuclei
- All relevant particle interactions
- 1D propagation mode (cosmological effects ...)
- 3D propagation mode (magnetic fields, sources ...)

All-particle energy spectrum (Auger, TA)



[1] Auger Collab., 2015, Proc. 34th Int. Cosmic Ray Conf., The Hague, PoS (ICRC2015) 271

[2] TA Collab., 2015, Proc. 34th Int. Cosmic Ray Conf., The Hague, PoS (ICRC2015) 349

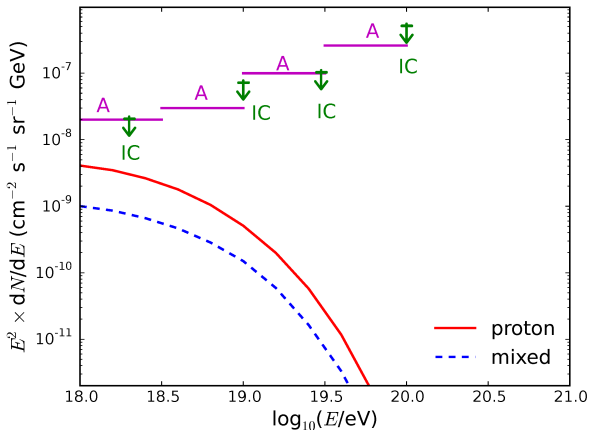
Cosmogenic neutrinos and gamma rays

- Starburst galaxies from all redshifts
- SFR function is: $(1 + z)^m$

$$m = \begin{cases} 3.4 & \text{for } z \leq 1 \\ -0.3 & \text{for } 1 < z \leq 4 \\ -3.5 & \text{for } z > 4. \end{cases}$$

[1] Yüksel, et al., 2008, *Astro. J. Lett.* L5, 683

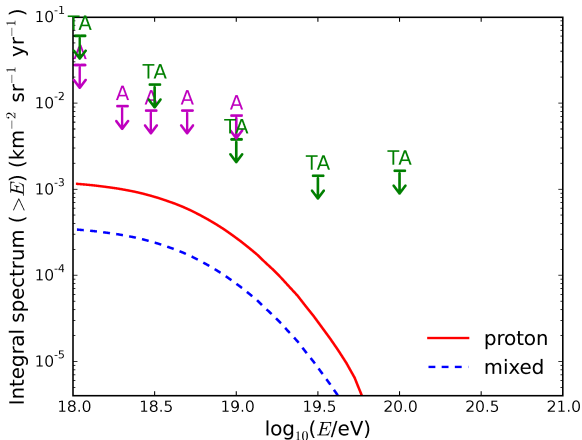
Cosmogenic neutrinos



[1] IceCube Collab., 2016, Phys. Rev. Lett., 117, 241101

[2] Auger Collab., 2017, J. Cosmol. Astropart. Phys., 04, 009

Cosmogenic gamma rays



[A] Auger Collab., 2015, Proc. 34th Int. Cosmic Ray Conf., The Hague, PoS (ICRC2015) 1103

[TA] TA Collab., 2017, Proc. 35th Int. Cosmic Ray Conf. Korea, PoS (ICRC2017) 551

Anisotropy (3D calculation)

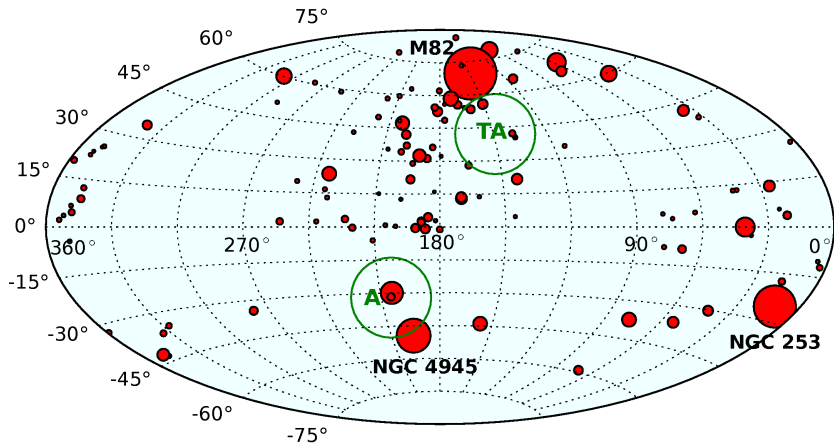
- Spatial distribution of sources
- Galactic magnetic field (JF12): lensing technique

[Jansson & Farrar, 2012, ApJ 757, 14; ApJ Lett. 761, 11]

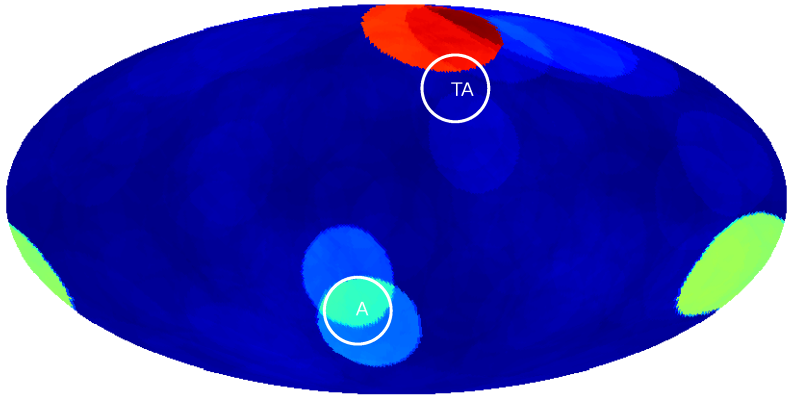
[Bretz et al., 2014, Astropart. Phys. 54, 10]

- Extragalactic magnetic field:
⇒ Kolmogorov turbulent field

Spatial distribution of sources



Deflection in magnetic fields ($E > 57$ EeV) (pure proton)



Outline

1. Introduction
2. Current status
3. Starburst galaxy scenario
4. Conclusion

Conclusion

- The observation of a hotspot near the direction of M82 puts forward the **starburst galaxy scenario**.
- The starburst galaxy scenario **reproduces well observations**.
- The flux suppression does not reflect the GZK effect but rather the depletion of power at accelerators.
- The model predicts another warm spot towards the direction of the Sculptor galaxy NGC253.
- The statistics are still not enough to draw any firm conclusion.

⇒ More data are greatly needed!

Thank you!