– UHECR 2012 –

"**Future Directions in UHECR Physics**"

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On the astrophysical value of larger, yet achievable UHECR detectors

Etienne Parizot

Carl Blaksley, Guillaume Decerprit, Denis Allard

APC – University Paris Diderot (Paris 7)

The field is in crisis.

Should we try to overcome it? Can we?

Arguably, yes!

Don't let UHECRs speak unheard!

Past directions in UHECR physics

- We wanted to do particle astronomy.
- We thought that by going to very high energies we could succeed

  → see multiplets on small angular scales, associations with sources, etc.

- We knew the flux was low, up there → + GZK effect!
- So we needed very large detectors → Auger…

- We've built large detectors and look at the highest energies
- But we found no sources → deflexions are too large

- And quite probably a large contribution of high-Z nuclei
- And there is a cutoff!

  → we have to fight against the GZK effect, indeed!

Past directions in UHECR physics

- It was definitely worth doing and we did learn a lot!
- And there is still a lot to learn about particle physics, shower structure, etc.

  → But it is much better to do it a lower energies, where statistics can be high!

- So what about UHECRs?
- Shouldn't we just stop now?
- NO! → we can and will "isolate" a source of UHECRs on the sky in a near future with a MegaLinsley-scale detector (~10^6 km^2 sr yr)
- The key is the GZK effect! → not our enemy, but our ally!

Dive into the GZK cut-off!

- We will make progress not by increasing the number of events, but by reducing the number of sources!

- At 10^{20} eV, most events come from a handful of sources

  ⟹ there, astronomy can start

- Very special situation: multi-messenger astrophysics
- Charged particles ≠ photons

  ⟹ Change our way of thinking: fewer sources is better!

- If we isolate just the one brightest UHECR source on the sky, we've made a huge progress, of great astrophysical value!

The GZK benediction:

- **Claim**: at the highest energies, the CR sky is dominated by the contribution of only a few sources

  → Even with large deflections, the hottest spots will be identified!

- **Proof**: simulations!

- So what? What do we learn from the few hottest spots?

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- So what? What do we learn from the few hottest spots?

→ density of sources

→ source power

→ fraction of global source power that goes into UHECRs

→ acceleration efficiency?

→ Individual source spectrum

→ maximum energy?

→ spectral index?

→ deflection pattern and size

→ magnetic fields

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High-Energy Astrophysics!

Hot spots statistics…

- Method

→ Assume a given source density

→ Build a particular realization of the source configuration with that density

→ Build a random data set (with a very large number of events to avoid large Poissonian fluctuations) from that particular source distribution (implementing propagation effects)

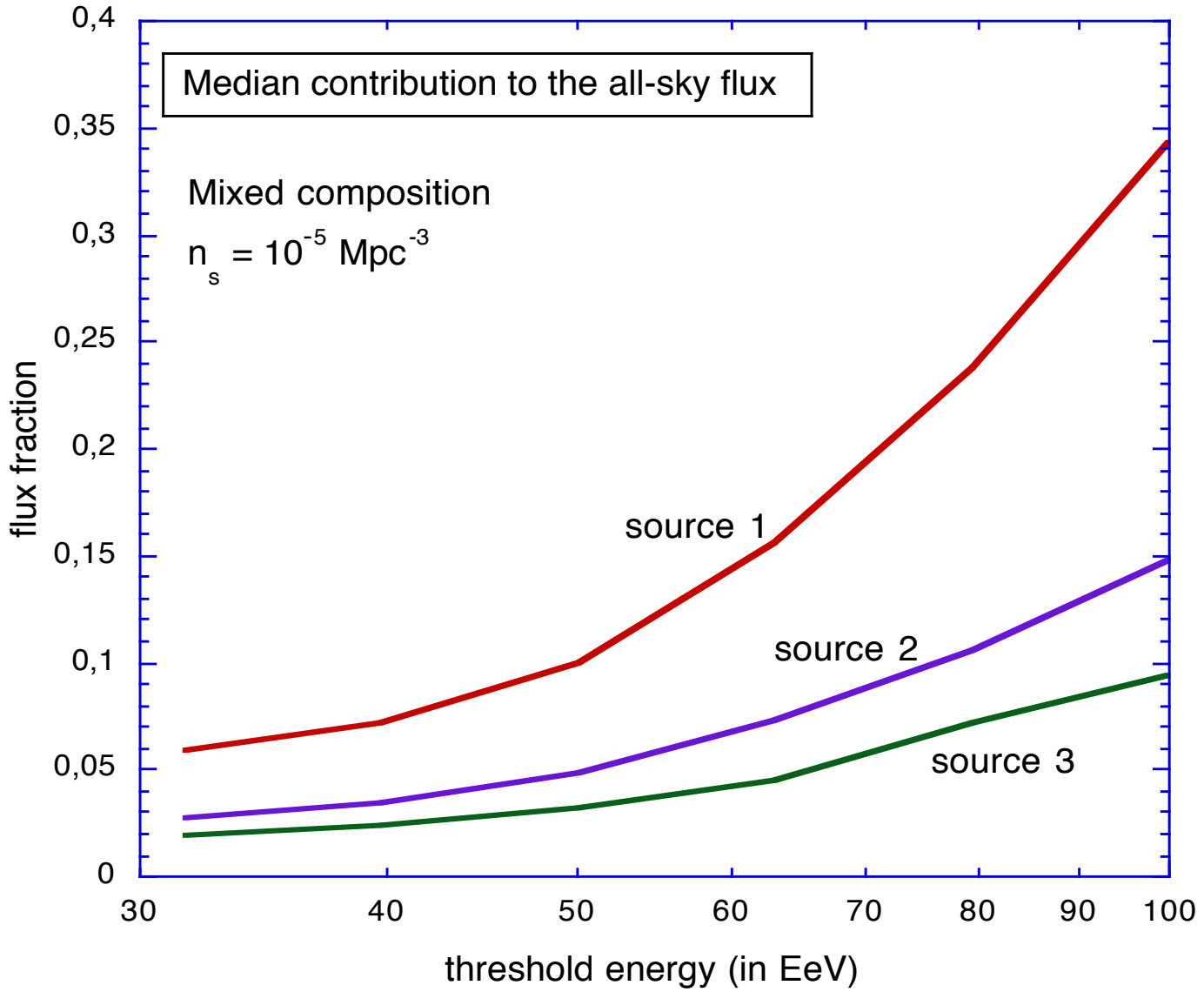
→ Determine the fraction of events that come from what turned out to be the brightest source for that source configuration

→ Do the same for the second brightest source, third brightest source, etc.

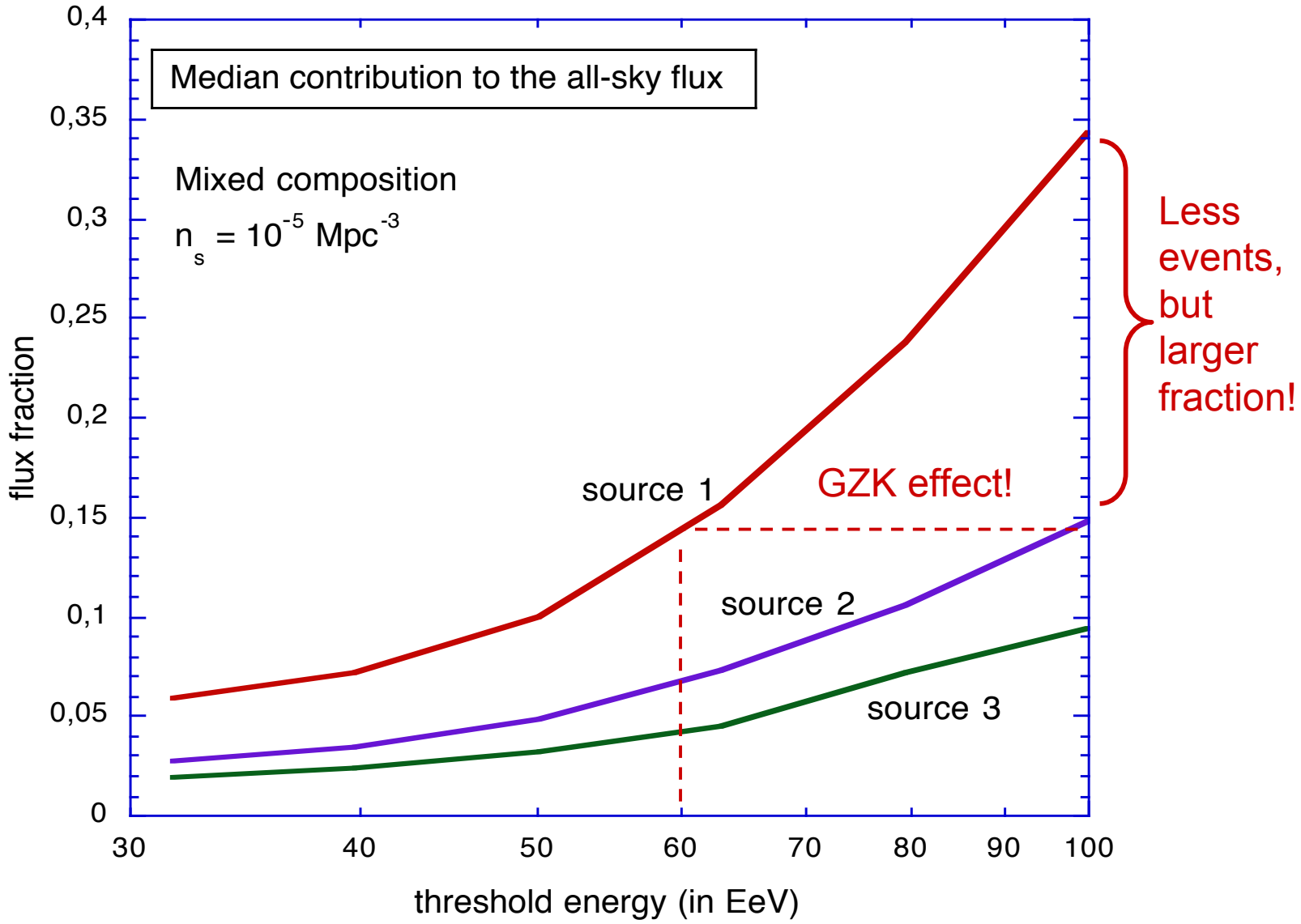
→ Repeat all this for another source configuration with the same density, to explore cosmic variance

→ Repeat all the above for a different source density, luminosity distribution, composition, source spectrum…

Single source contribution



Single source contribution



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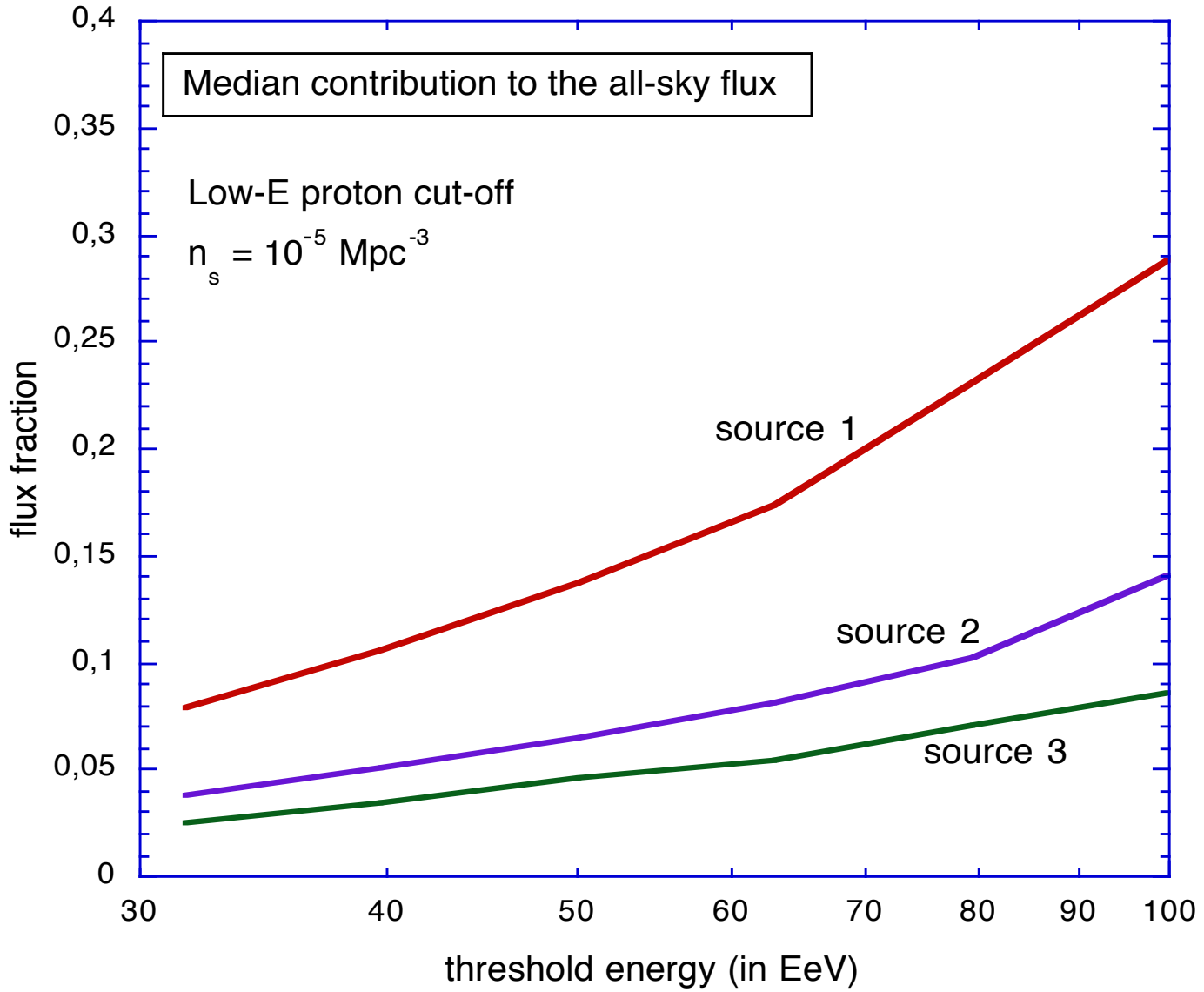

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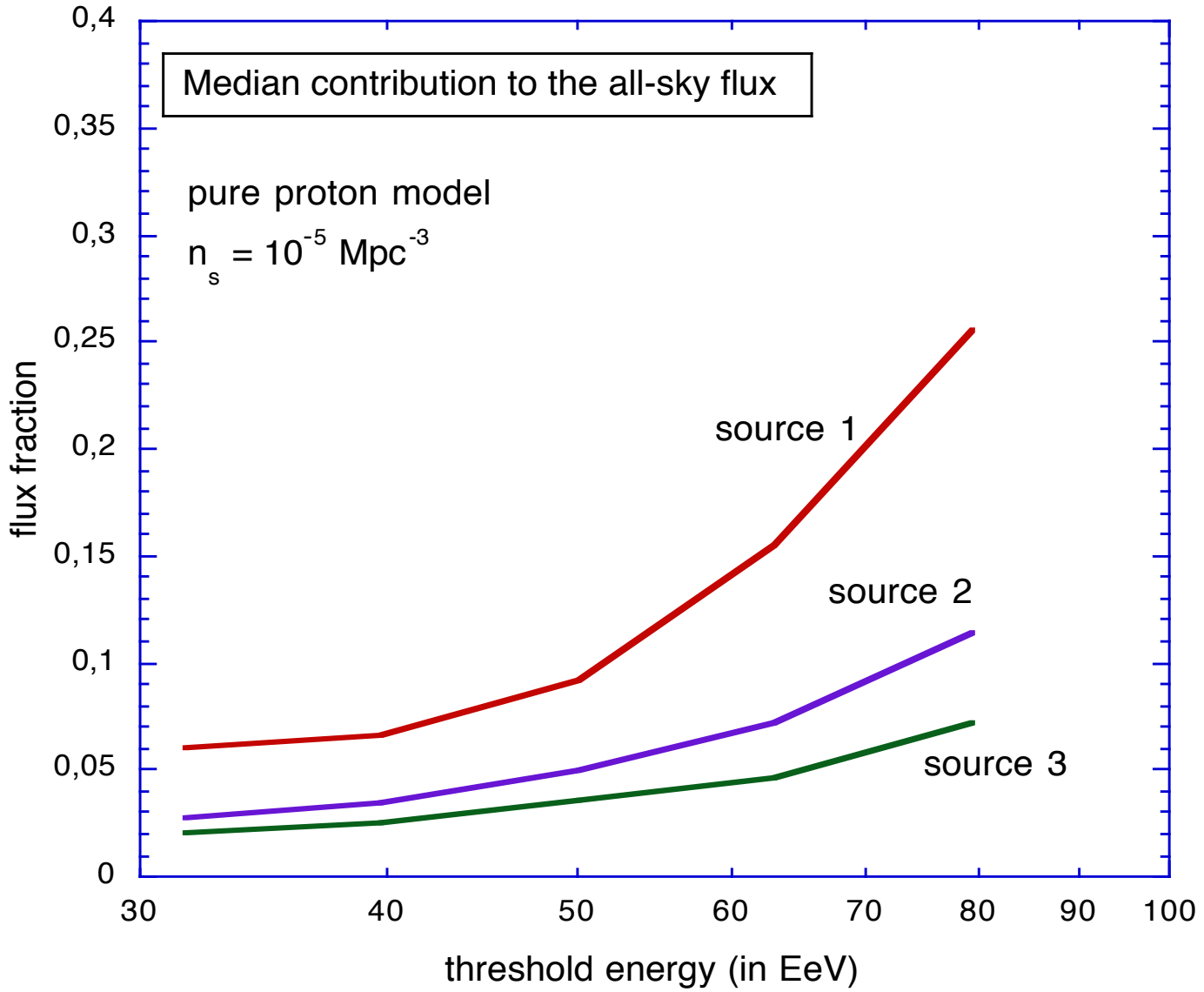

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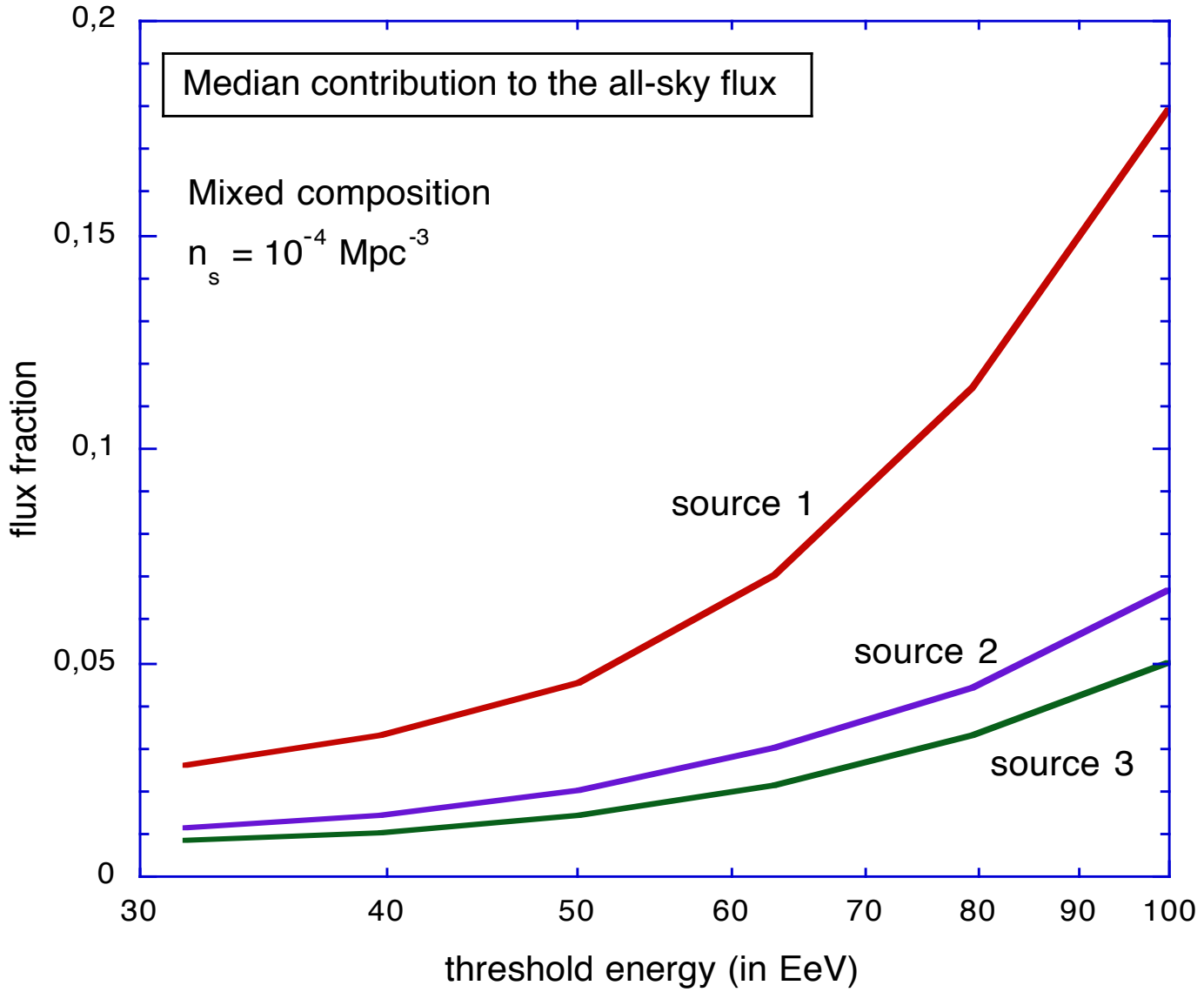

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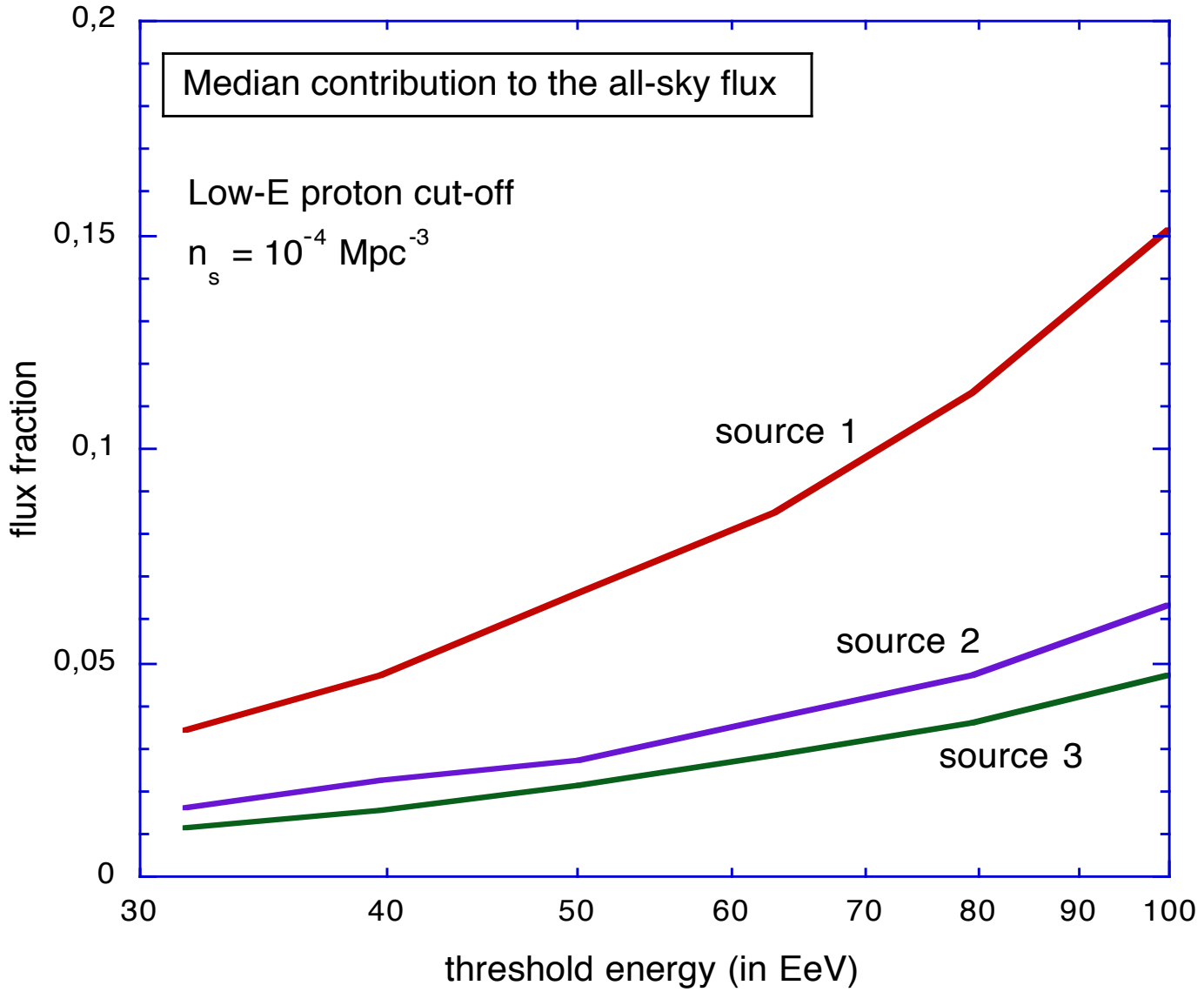

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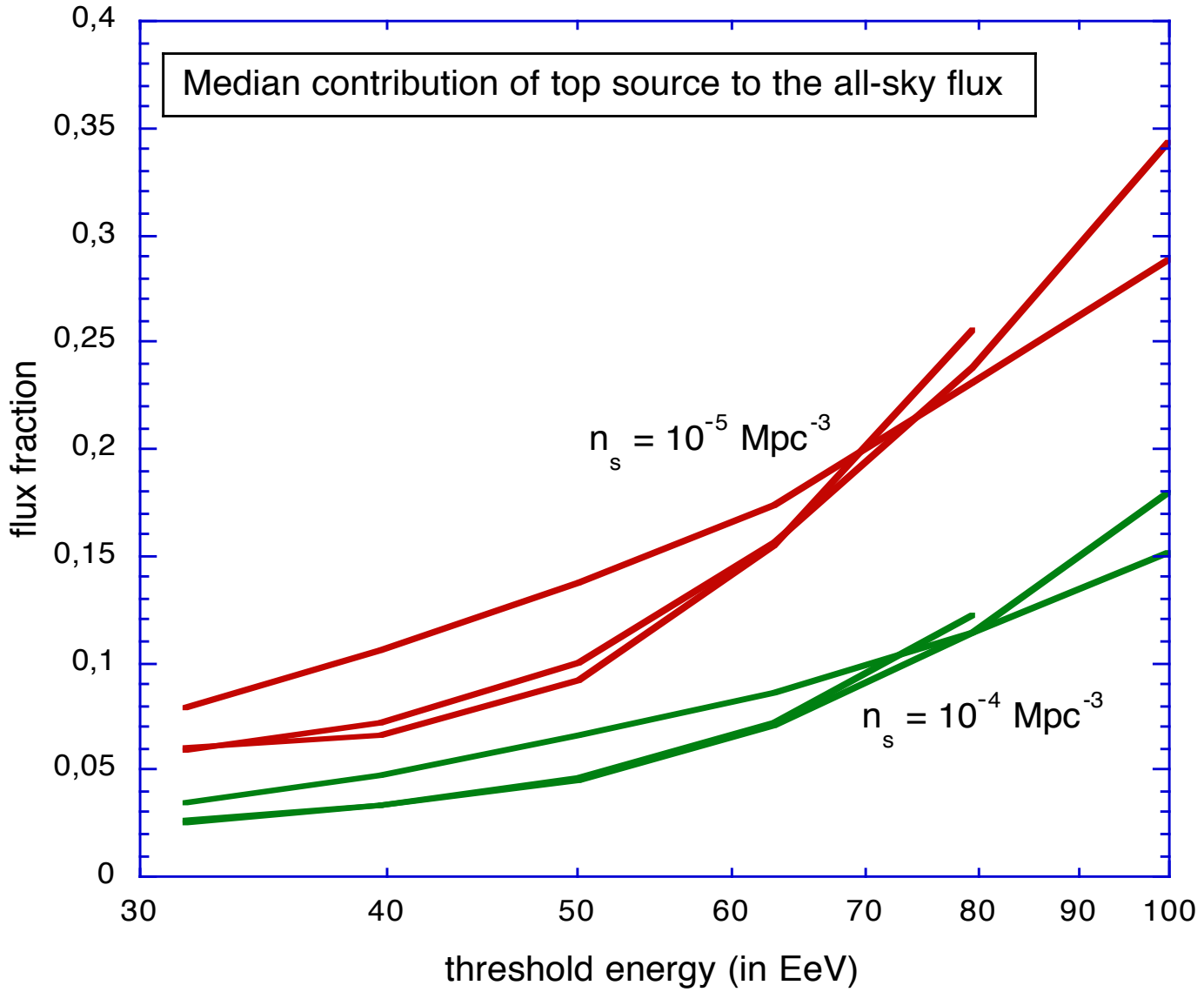
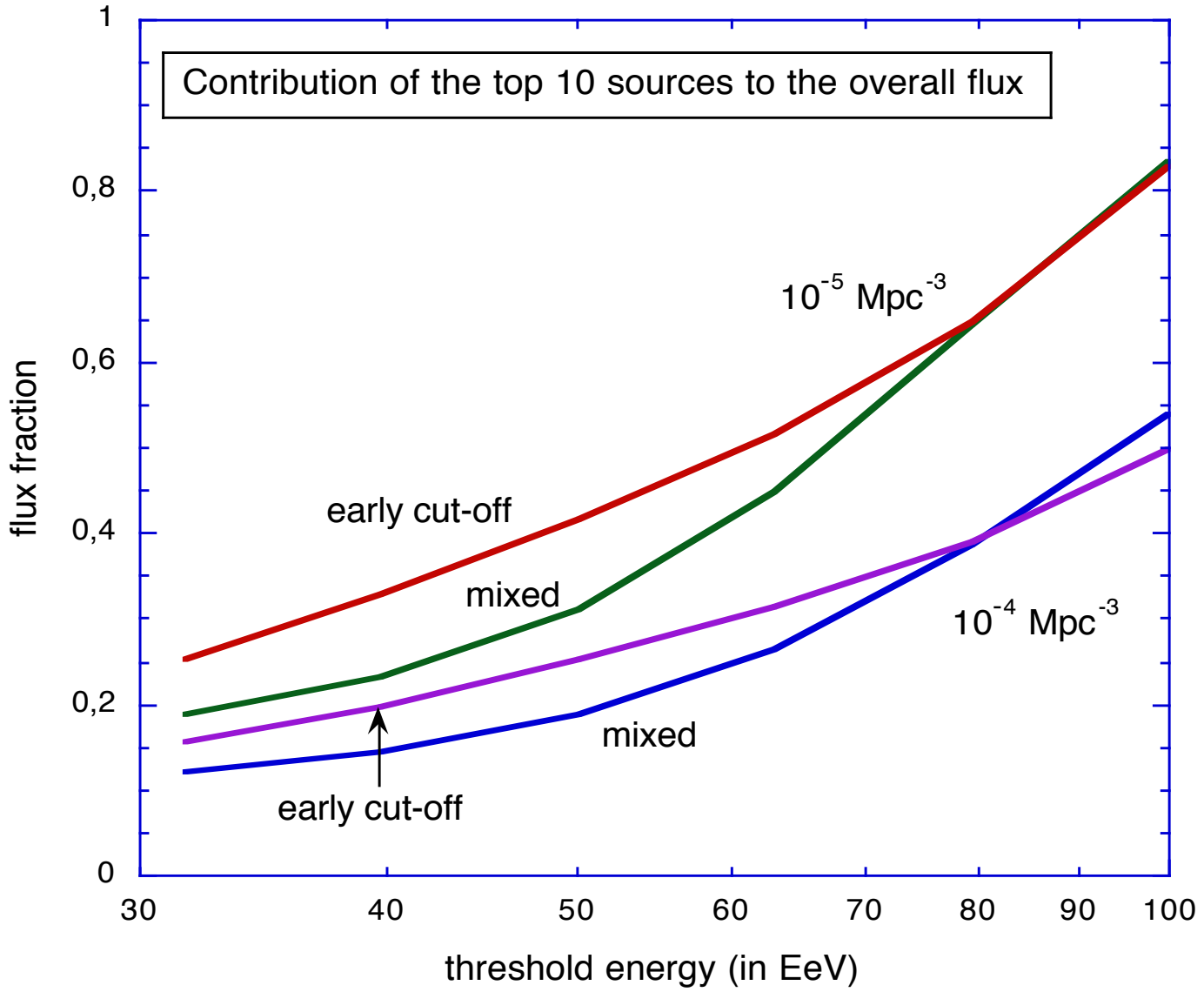


Contribution of top 10 sources



Looking for the hot spot(s)

- What if we accumulate 10^6 km^2 sr yr of exposure?
- This is 40-50 times more than Auger today!

  → 150 – 200 events above 10^{20} eV (or more?, depending on energy scale)

- → ~ 50 events above 10^{20} eV from the brightest source is a reasonable estimate!

  NB: such multiplets may be present in the data already, at lower E, but drowned in the background of overlapping sources…

  → reduce the horizon, and isolate the brightest source!

- Can we "isolate" the brightest source(s) on the sky?

  → yes, if deflections are ≤ 60 degrees at 10^{20} eV !

Looking for the hot spot(s)

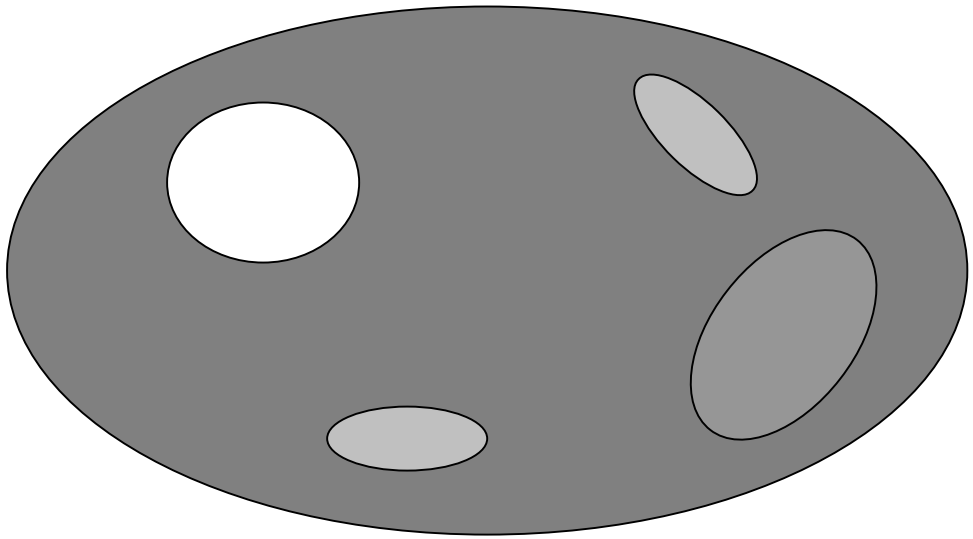
- Simple example:

$1/4^{th}$ of the events in the hottest source

$3/4^{th}$ of the events in the rest

Fraction of sky within ± 30° of a source : ~$1/15^{th}$

$\Omega/4\pi = (1-\cos 30°)/2 = 6.7\%$



Most events in a hot spot come from the same source!

We must find these hot spots – individual sources! – and study them.

- Main goal for the field: draw the UHECR sky map at 10^{20} eV!

Draw the UHECR sky map!

- High angular resolution is not crucial

  Individual deflection may be up to 20 degrees or more anyway!

- We don't need particularly high quality data.
- We don't need a huge number of events.
- We need as much events as possible from as few sources as possible!
- This can be a valuable "future direction" in **truly**-UHECR physics
- The GZK energy range is where there is more value in reducing the number of sources than in increasing the number of events.

Future directions in UHECR physics

- For decades we said:

"UHECRs are great because deflections decrease as energy increases, and we can point back to the sources. Unfortunately, there is a GZK cutoff and the flux is extremely low."

- Now we can say:

"UHECRs are great *because the GZK effect is there*! Of course, E/Z may not be large enough for deflections to be very small, but that's not really a problem:

Let's reduce the number of sources, and we will isolate them on the sky!"

- Once we have isolated a source, astrophysics can start!

  Source density, source power, acceleration efficiency, individual spectrum, E_{max}, spectral index, deflections, magnetic fields…

- Do not forget astrophysics! It can start with $\leq 10^6$ km^2 sr yr !

Future directions in UHECR physics

- Particle physics is OK (understanding cross sections, hadronic physics, muons, shower physics…)

  But we shall not do that at 10^{20} eV!

  Whatever is interesting there is already interesting at 10^{19} eV, with much much higher flux!

- Do not forget astrophysics and astroparticle physics!

  Real UHECRs are GZK-CRs !

  There are key questions about acceleration and sources that are accessible, even with heavy UHECRs!

- Very high precision measurement is not crucial

  A few degrees in angular resolution and 25%–30% in energy resolution is good enough at this stage!

  JEM-EUSO can do a tremendous job! Very credible way forward!

Future directions in UHECR physics

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Thank you very much