Top-Down Models and UHECRs

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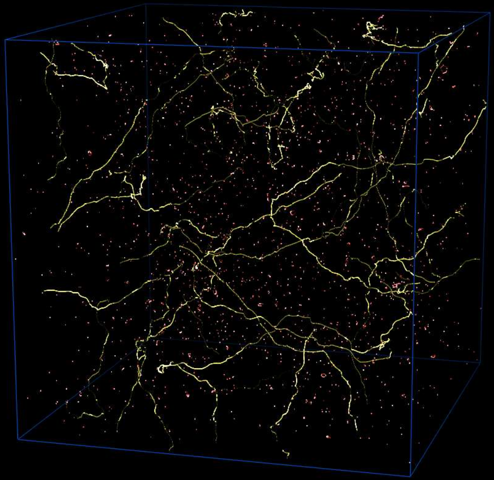

Bottom-up versus top-down models

Bottom-up models

- acceleration in electromagnetic fields

$\Rightarrow$ charged particles: protons, nuclei, electrons

- photons and neutrinos as secondaries

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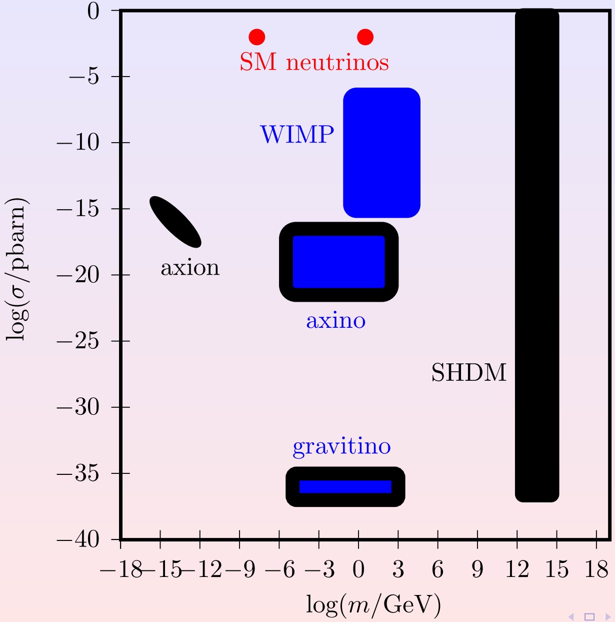
Top-down models

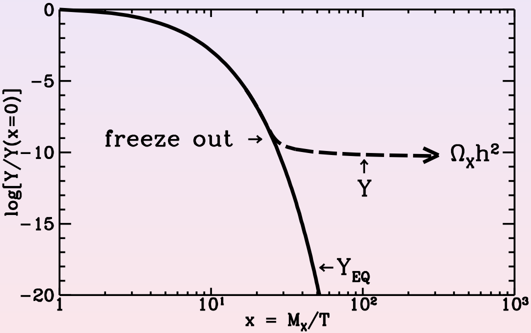
- relics from early universe $\leftrightarrow$ DM
  - non-thermal or thermal
  - point particle or non-perturbative solutions
  - stable or decaying
- fragmentation products: mainly photons, neutrinos

Dark matter candidates



The standard candidate: WIMP

- inflation suggested $\Omega = 1$, CMB shows that $\Omega \approx 1$
- BBN constrains baryon content, $\Omega_b h^2 = 0.019 \pm 0.001$
- LSS requires that DM is dissipation-less and "cold"
- thermal production of CDM,



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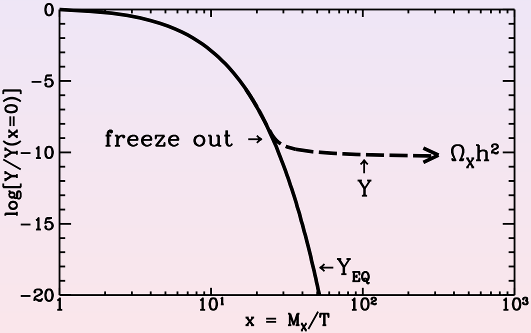

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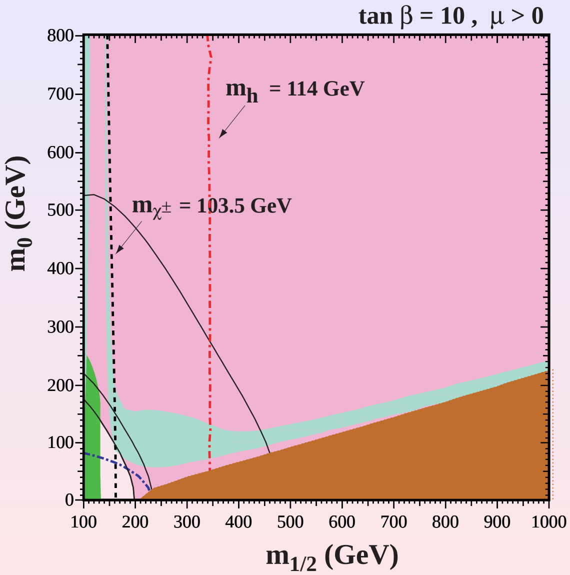
unitarity limit: $m \lesssim 100$ TeV

Status of neutralino DM after LEPII:



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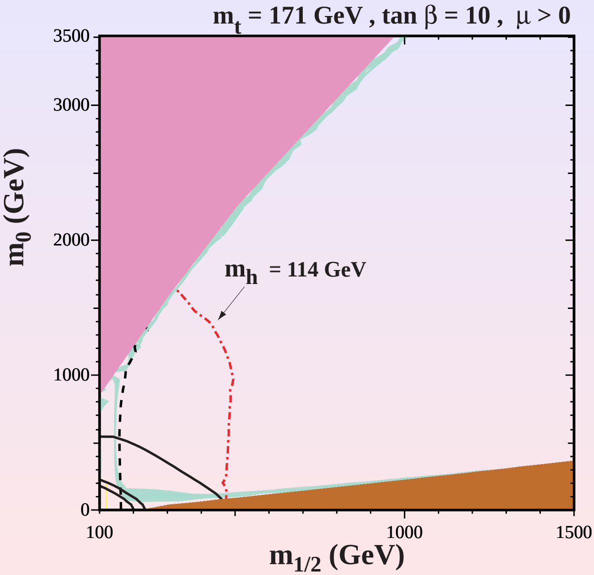
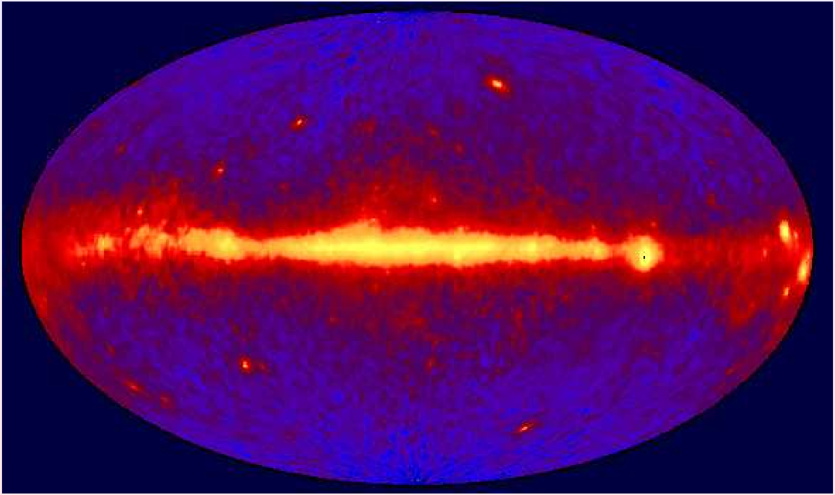


Indirect detection claims:

- Signal from
  $\chi\chi$ annihilations in the diffuse extragalactic photon background:



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[*Elsässer, Mannheim '04*]

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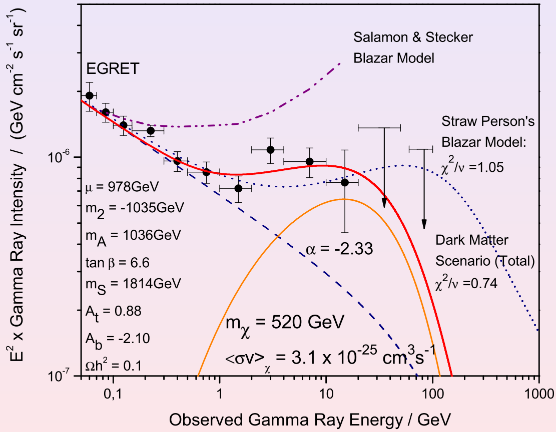

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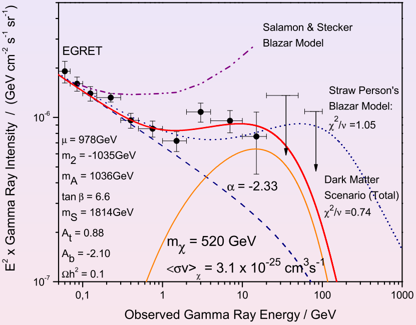

problem:

- search for small excess on top of “astrophysical background”

Reminder: GZK puzzle as motivation for top-down models

- no obvious counter-parts for 10^{20}eV events

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- no obvious counter-parts for 10^{20}eV events
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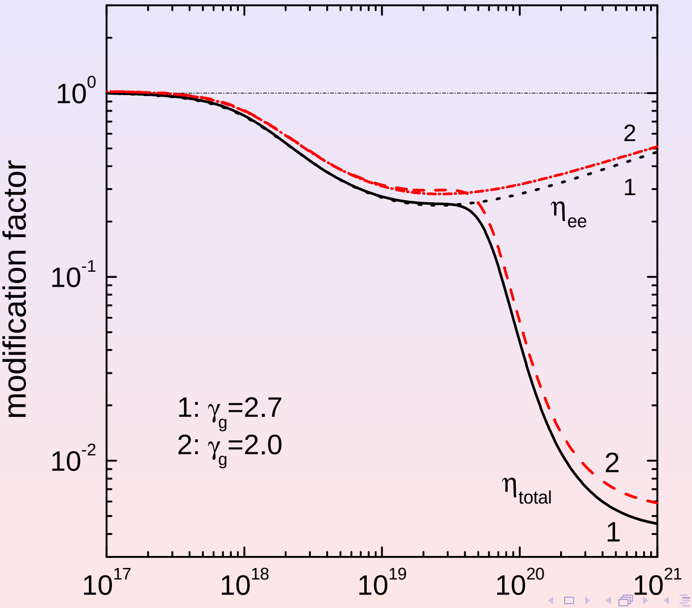
- AGASA excess
- misinterpretation of GZK suppression as GZK cutoff

Modification factor:

[Berezinsky, Gazizov, Grigorieva '03]



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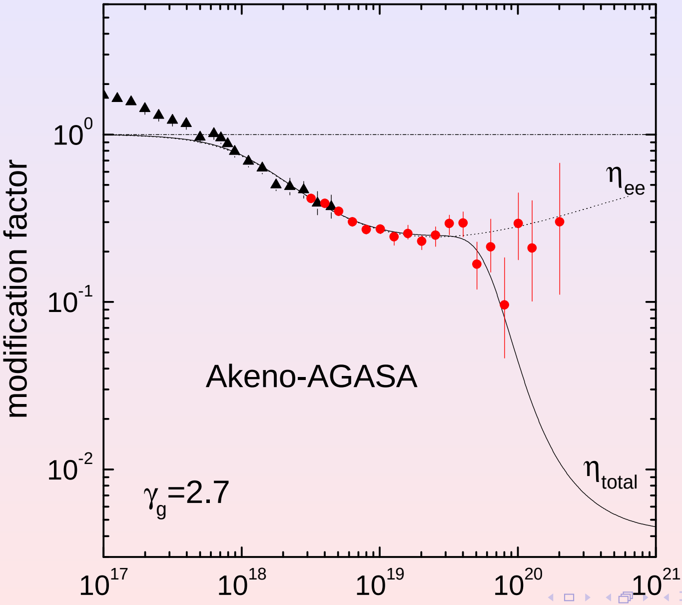
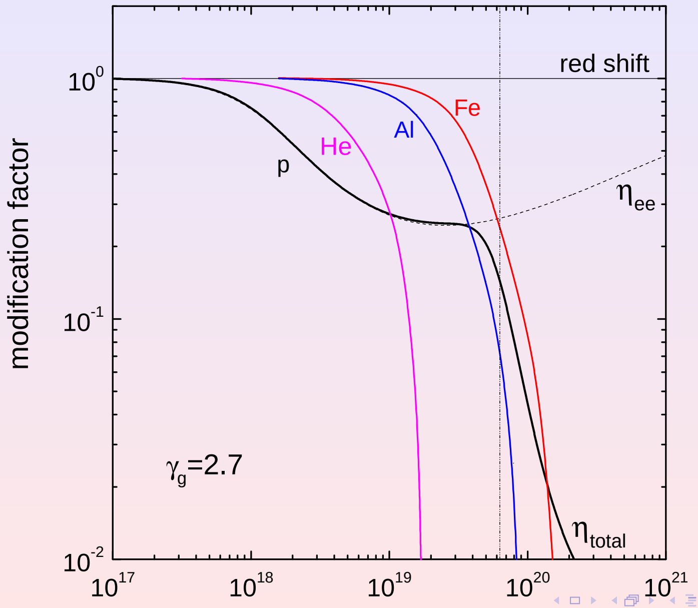
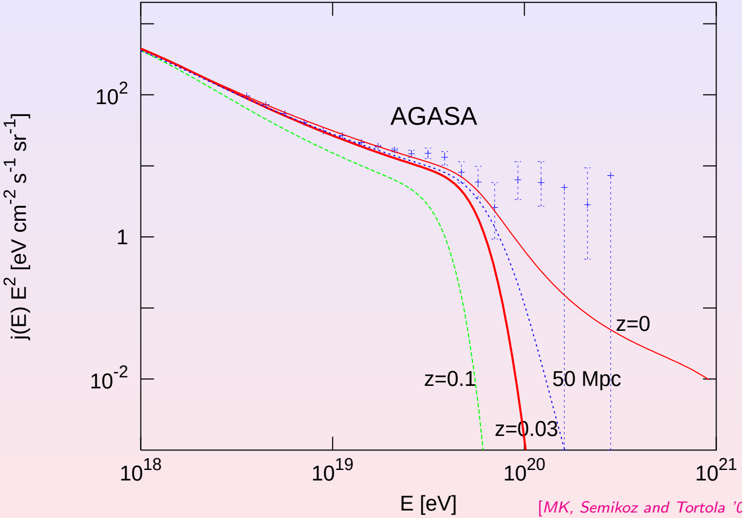


Modification factor: Nuclei



GZK suppression – dependence on n_s



[*MK, Semikoz and Tortola '03*]

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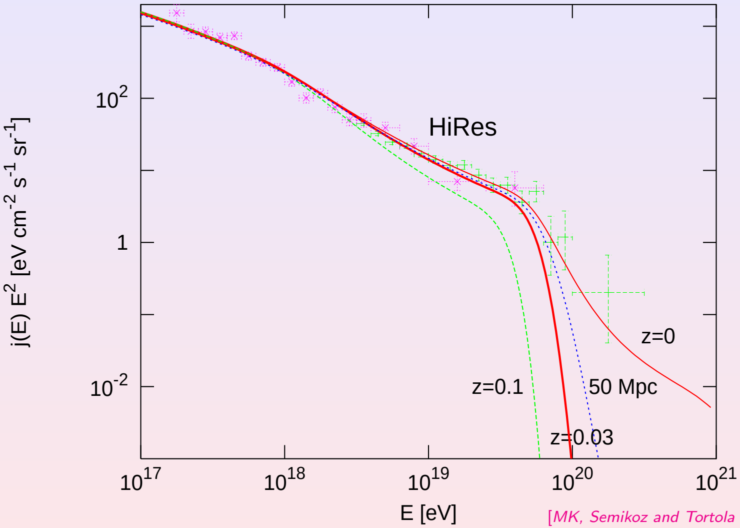

[MK, Semikoz and Tortola '03]

Top-Down Models

UHECR primaries are produced by decays of supermassive particle X with $M_X \gtrsim 10^{12}$ GeV.

- topological defects: monopoles, strings, ...

  [Hill '83; Ostriker, Thompson, Witten '86]

- superheavy metastable particles

  [Berezinsky, MK, Vilenkin '97; Kuzmin, Rubakov '97]

Advantages:

- no acceleration problem
- no visible sources
- if $X \in$ CDM, no GZK-cutoff
- theoretically motivated; testable predictions

Gravitational creation of superheavy matter

- Small fluctuations of field Φ obey

$$\ddot{\phi}_k + \left[k^2 + m_{\rm eff}^2(\tau)\right]\phi_k = 0$$

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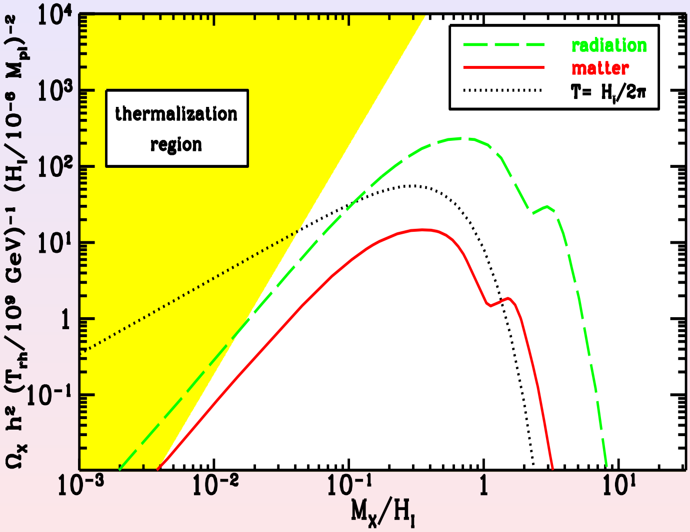
- In inflationary cosmology

$$\Omega_X h^2 \sim \left(\frac{M_X}{10^{12}\mathrm{GeV}}\right)^2 \frac{T_{RH}}{10^9\mathrm{GeV}}$$

dependent only on cosmology, for $M_X \lesssim H_I$

[*Kuzmin, Tkachev '98; Chung, Kolb, Riotto '98*]

Gravitational creation of superheavy matter:



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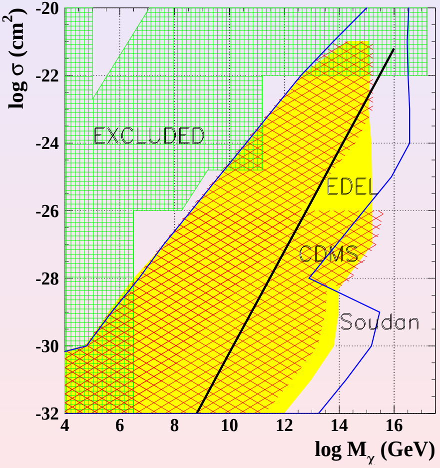
lifetime:

- metastable or stable due to some (gauged) R symmetry

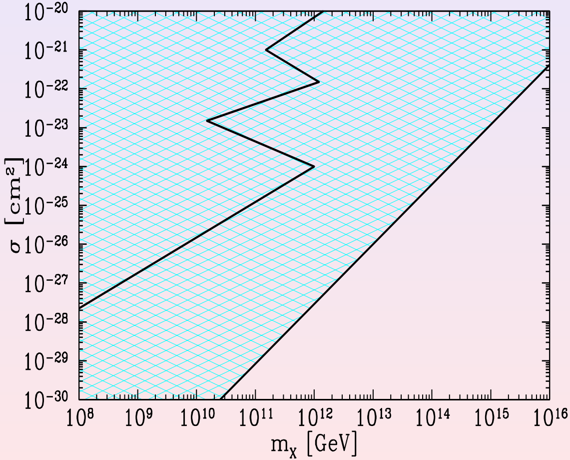
Detection of superheavy matter:

- direct detection: density $1/M_X$, recoil energy is constant
  $\Rightarrow$ large σ_{XN} required



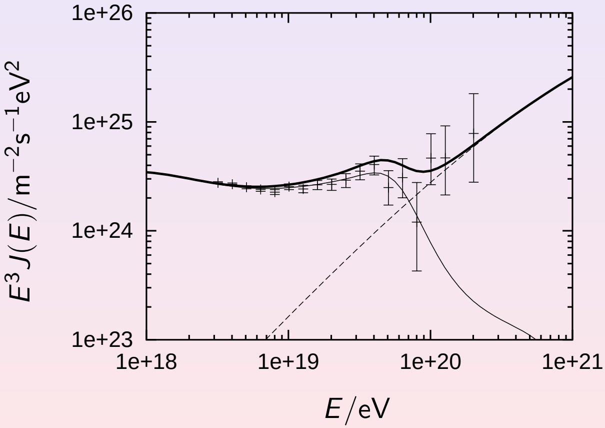
Detection of superheavy matter:

- indirect detection via neutrinos from the Sun:
  signal should compete with usual fluxes
  $\Rightarrow \langle \sigma v \rangle \sim 10^{-26}$ cm^2 needed



Detection of superheavy matter:

- UHECR above the GZK cutoff via nucleon, photon secondaries



Lifetime:

- stable: annihilation gives too small flux
- decay: too fast?
  For $M_X \gtrsim 10^{10}$ GeV even gravitational interactions result in cosmological short lifetimes, $\tau_X \ll t_0$.
- global symmetry broken by wormhole effects, $\tau_X \propto \exp(S)$
- symmetry broken by instanton effects,
  $\tau_X \propto \exp(-4\pi^2/g^2)$
- discrete symmetries forbid operators with $d < 9$
- crypton or fractionally charged and confined particle of superstring theories

Fragmentation of heavy particles

- consider Bremsstrahlung, $X \to \bar{f} f V$:

  soft and collinear singularities generate terms $\ln^2(m_V^2/m_X^2)$ for $m_X^2 \gg m_V^2$ $\Rightarrow$ compensate the small couplings g^2,

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- (modified) DGLAP description possible

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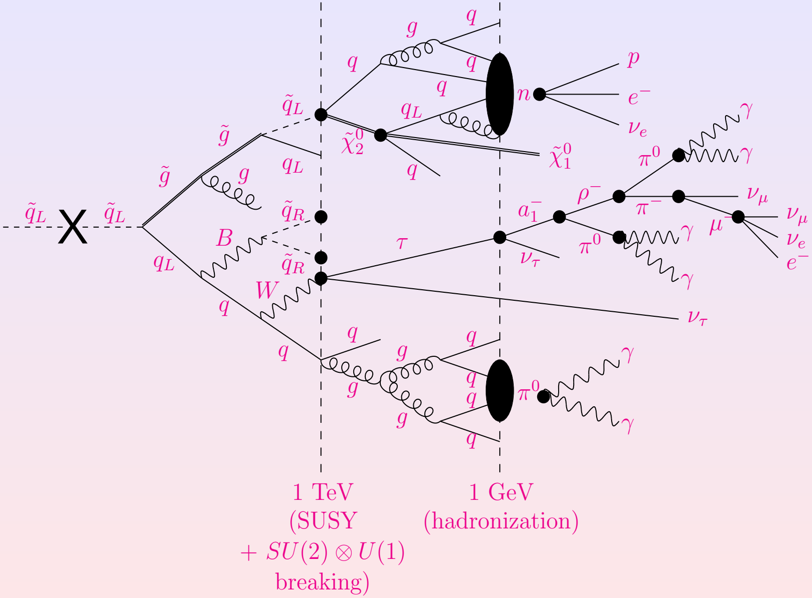
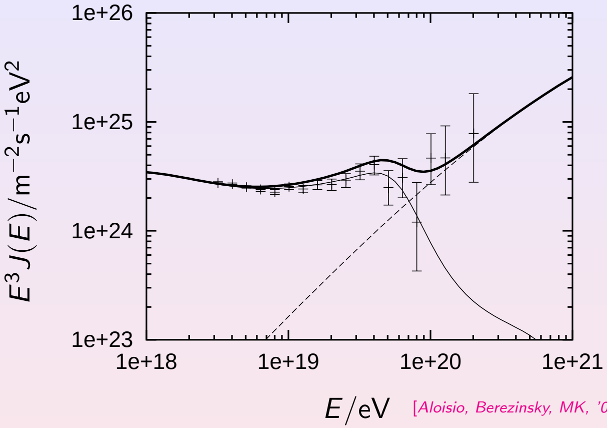


Signatures of SHDM decays

- flat spectra $dE/E^{1.9}$ up to $m_X/2$

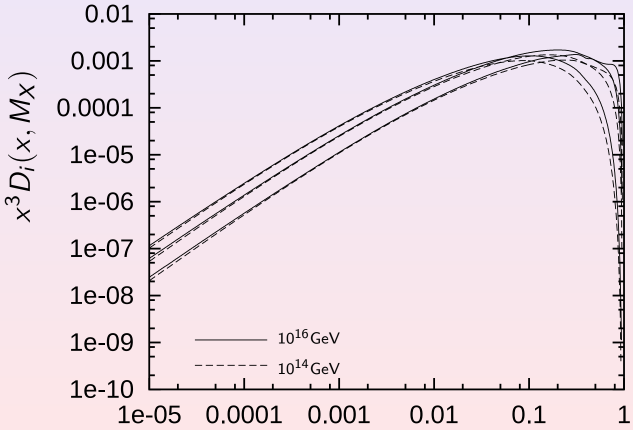


[Aloisio, Berezinsky, MK, '03]

$\Rightarrow$ SHDM dominates UHECR flux only above $\sim 8 \times 10^{19}$ eV

Signatures of SHDM decays

- flat spectra $dE/E^{1.9}$ up to $m_X/2$
- composition:
  - $\gamma/p \gg 1$, large neutrino fluxes, no nuclei
  - LSPs, if R parity conserved



Sig

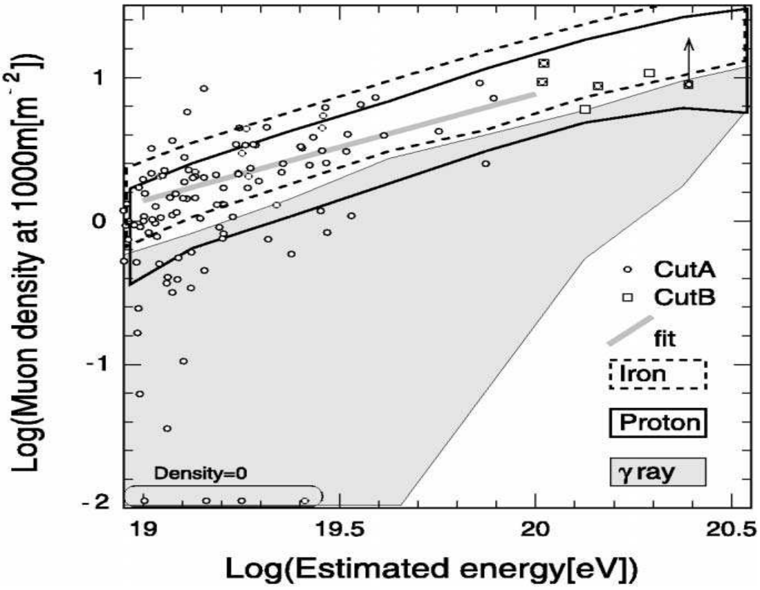


FIG. 2.—The $\rho_{\mu}(1000)$ vs. E_0 relation for observed events (*circles and*

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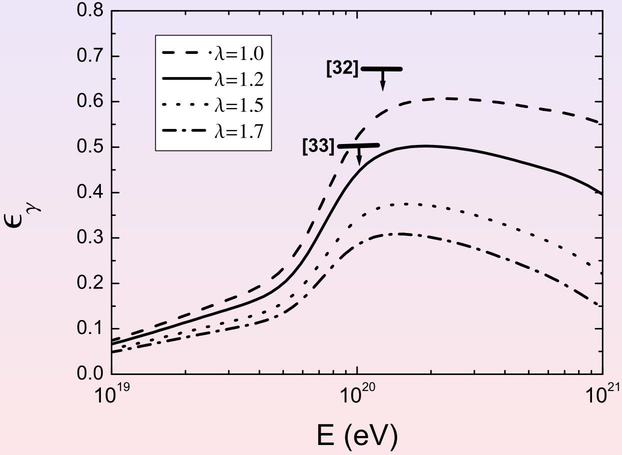
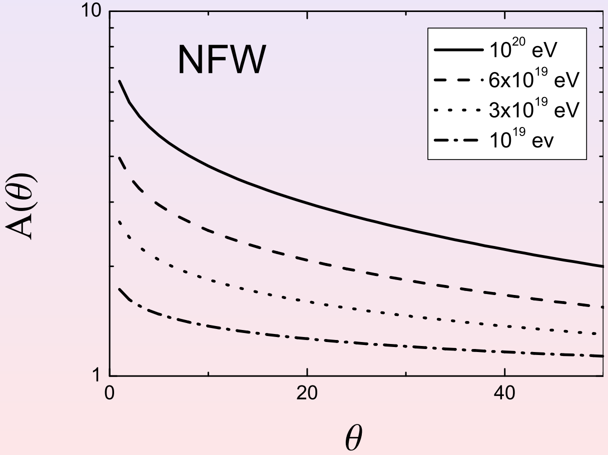


Signatures of SHDM decays

- flat spectra $dE/E^{1.9}$ up to $m_X/2$
- composition:
- galactic anisotropy:

[*Dubovsky, Tinyakov '98*]



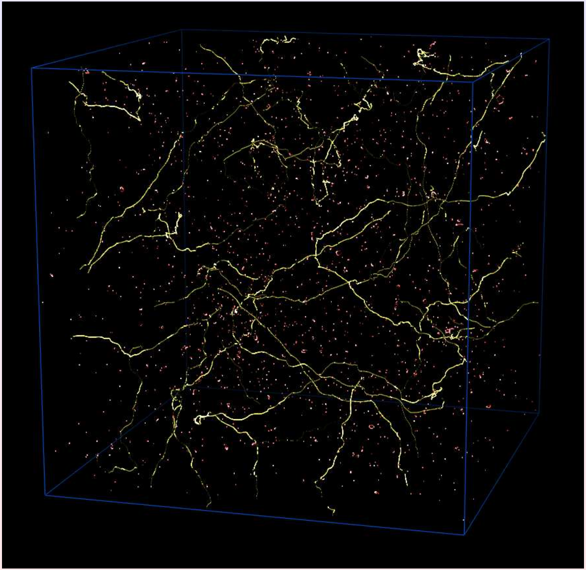
Topological defect models

+ "generic" in SUSY-GUTs
+ produced during reheating

- typical density: one per horizon/correlation length
- main energy loss low-energy radiation?

Topological defect models

[Allen, Shellard '06]



- box $2ct$
- matter epoch
- scaling regime

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favourable models for UHECRs:

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- hybrid defects: cosmic necklaces

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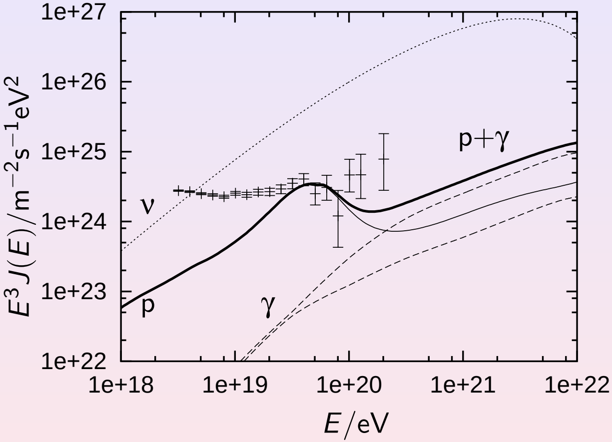
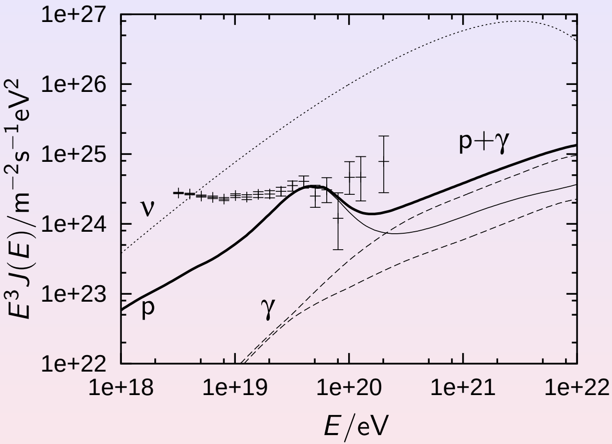
favourable models for UHECRs:

- monopole-antimonopole pairs
- hybrid defects: cosmic necklaces
  - $G \to H \otimes U(1) \to H \otimes Z_2$
  - monopoles $M \sim \eta_m/e$ connected by strings $\mu_s \sim \eta_s^2$
  - parameter $r = M/(\mu d)$:
  - $r \ll 1$ normal string dynamics
  - $r \gg 1$ non-rel. string network



[*Aloisio, Berezinsky, MK, '03*]

Status of topological defect models – necklaces:

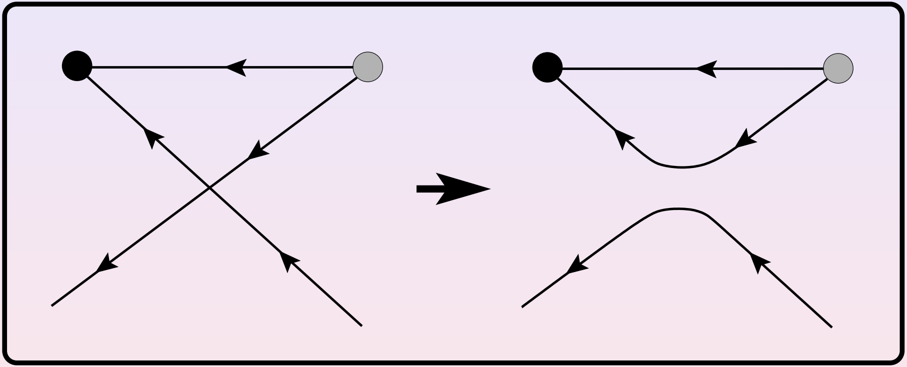


⇒ shape of spectrum allows only sub-dominant contribution

- UHE photon fraction reduced

Cosmic necklaces:

[*Blanco-Pillado, Olum '07*]

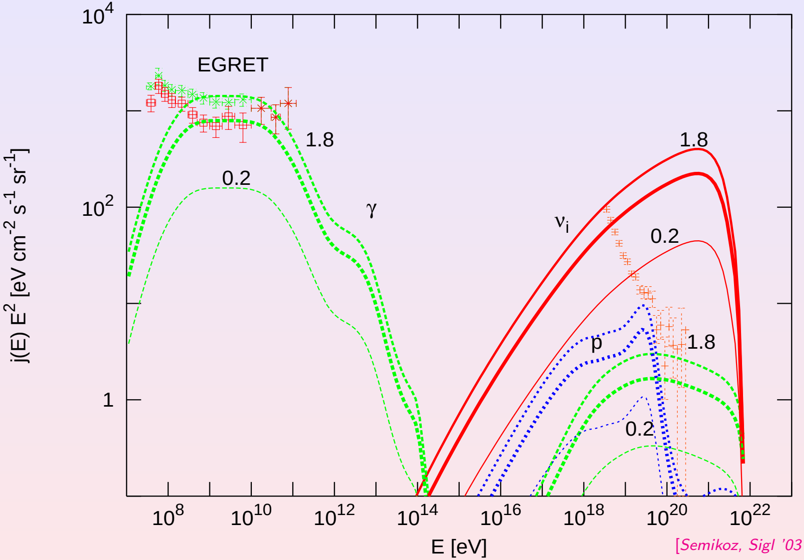


Idea of EGRET limit

all energy in γ and $e^{\pm}$ cascades down to GeV–TeV range, bounded by observations:

$$\begin{aligned}\omega_{\rm cas} &= f_{\rm em}\, m_X \int_0^{t_0} dt\, (1+z)^{-4}\, \dot{n}_X(t) \\ &\lesssim 2\cdot 10^{-6}\,{\rm eV/cm^3}\end{aligned}$$

Elmag. cascades and EGRET limit:

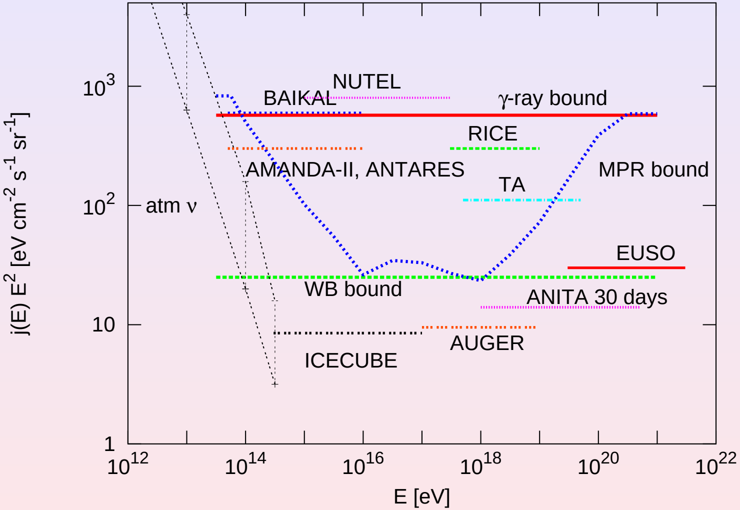


[Semikoz, Sigl '03]

Summary

- AGASA excess as main motivation for top-down models is gone
- no positive evidence for superheavy dark matter from its two key signatures:
  - photons
  - galactic anisotropy
- SHDM remains an interesting DM candidate
- topological defects are generic prediction of (SUSY-) GUTs
- should be searched for as subdominant sources of UHECR

Sensitivity of neutrino detectors



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