PANIC 2008
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NGC 2300

Cosmic Rays from Thermal Sources

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and

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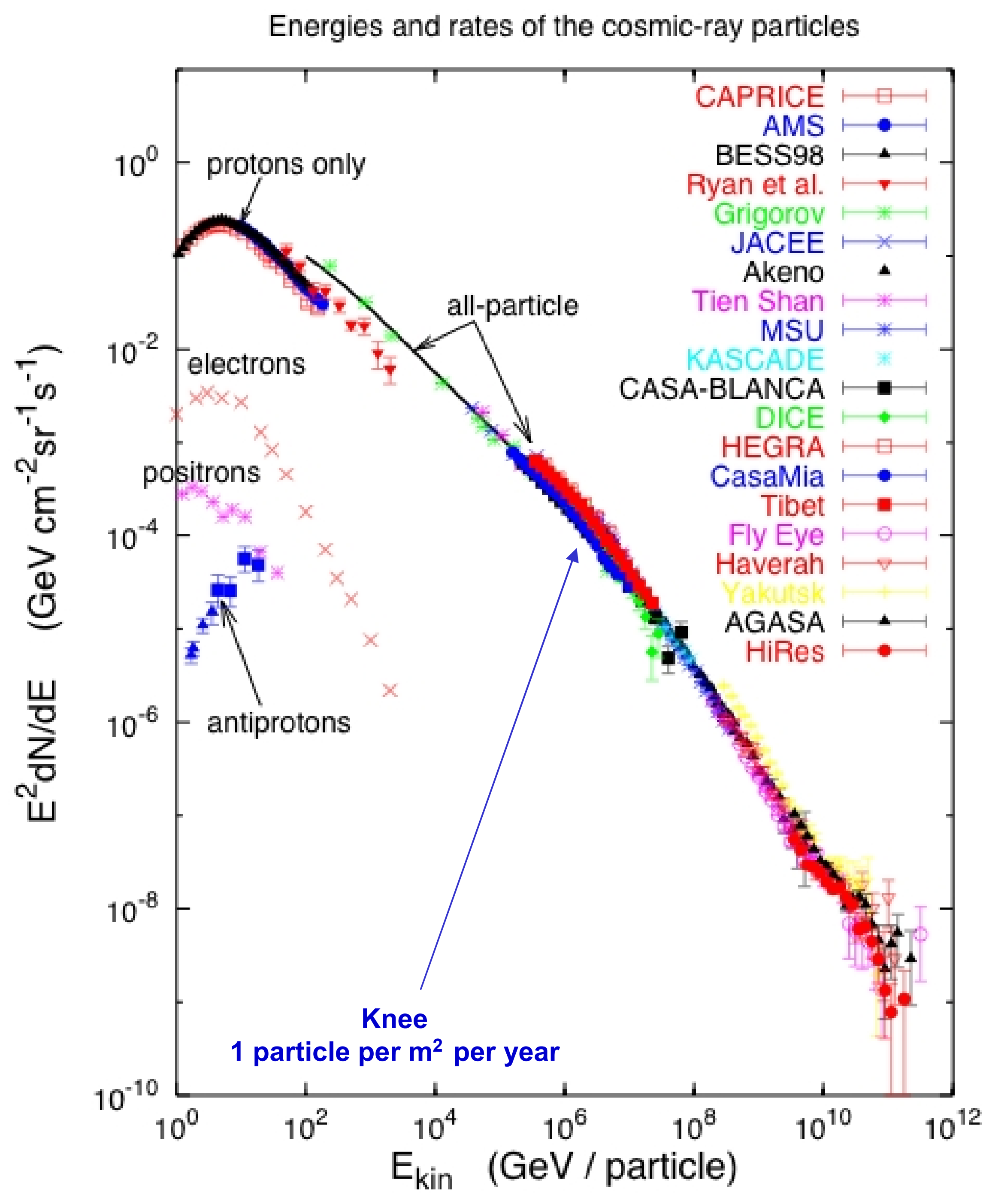
Cosmic rays

Energy spectrum spans more than 12 orders of magnitude in energy and 24 in intensity

- The accelerators?

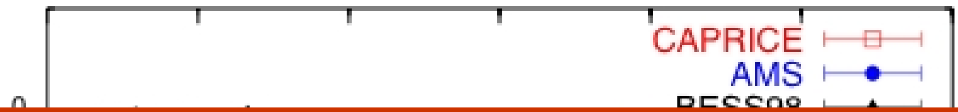
Nature accelerates particles 10^7 times the energy of LHC!

What are the sources?



Cosmic rays

Energies and rates of the cosmic-ray particles



The *knee*: different regimes of the diffusive propagation of CR ?

or: some property of the source of CR itself?

if so: what it is?

Perhaps: some change in the characteristic of the source of CR resulting in the abrupt change of distribution.

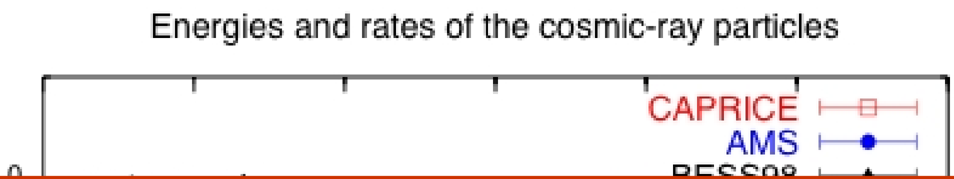
Our proposition: it is the change in the pattern of temperature fluctuations existing in the otherwise thermal source.
It can be described using a generalized statistical model in which:

$$\exp(-E/T) \;\longrightarrow\; \exp_q(-E/T)=[1-(1-q)E/T]^{1/(1-q)}$$

where $q = 1 + \langle(1/T)^2\rangle/\langle(1/T)\rangle^2 = 1 + 1/C$

is the measure of fluctuations (C is the heat capacity of the source)

Cosmic rays



The *knee*: different regimes of the diffusive propagation of CR ?

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Our proposition: it is the change in the pattern of temperature fluctuations existing in the otherwise thermal source.

The temperature fluctuations in astrophysics is much discussed problem nowadays, see K.Klai et al., *Astrophys. J. 644 (2006) 61* and references therein

is the measure of fluctuations (C is the heat capacity of the source)

Our proposition

is therefore

to replace picture

like this

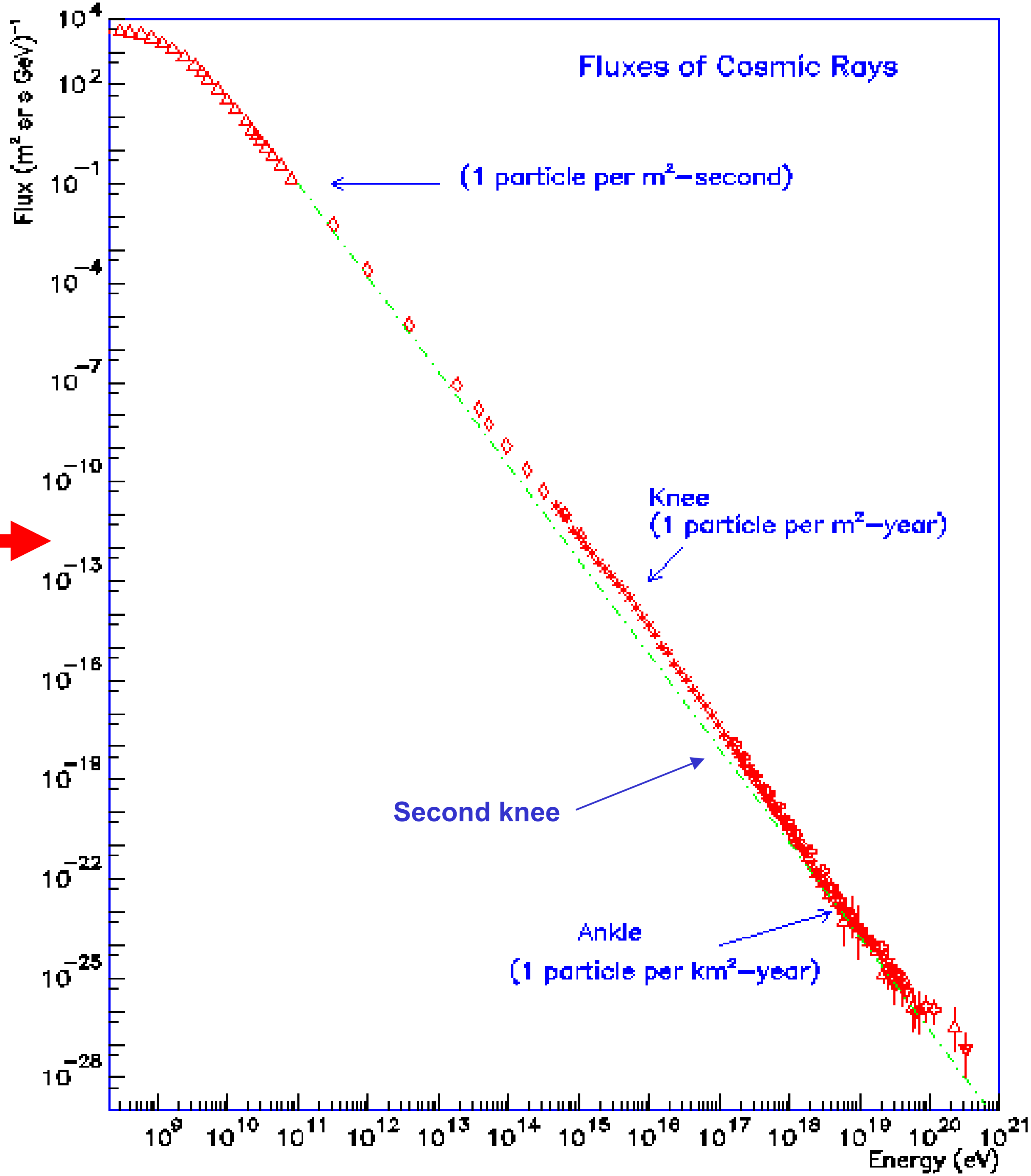
by another one

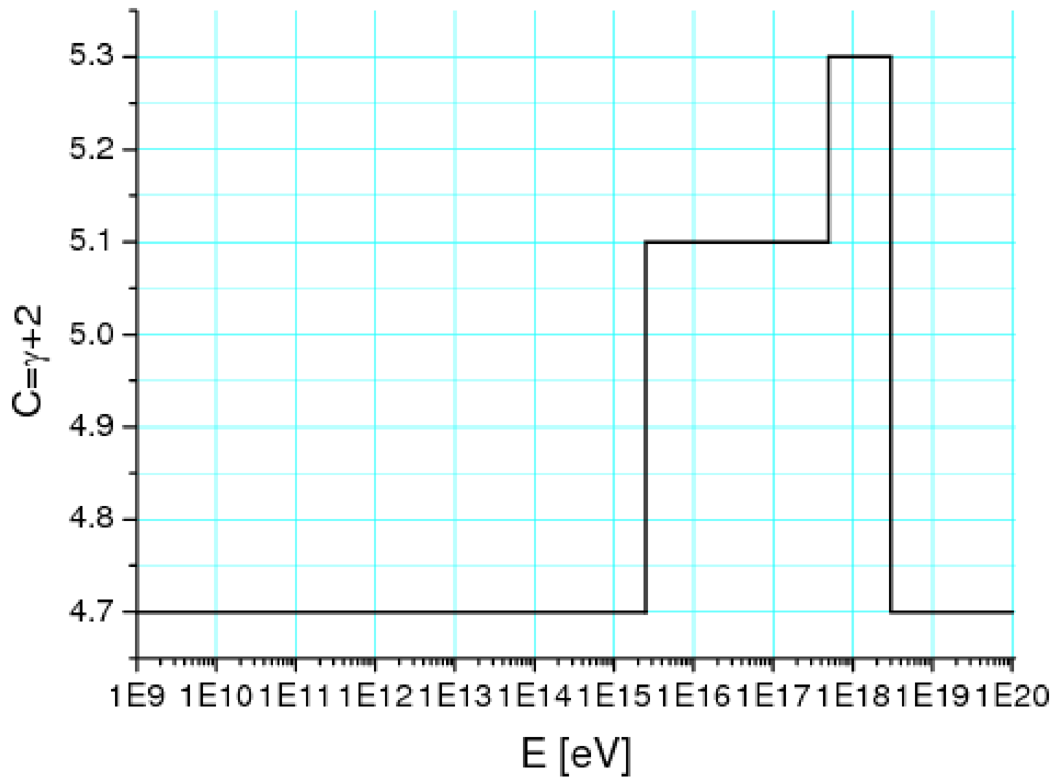
in which the visible

energy spectrum

structure would be

more visible





$$\Phi(E) \propto E^{-\gamma}$$

$$\gamma = \frac{3-2q}{q-1}$$

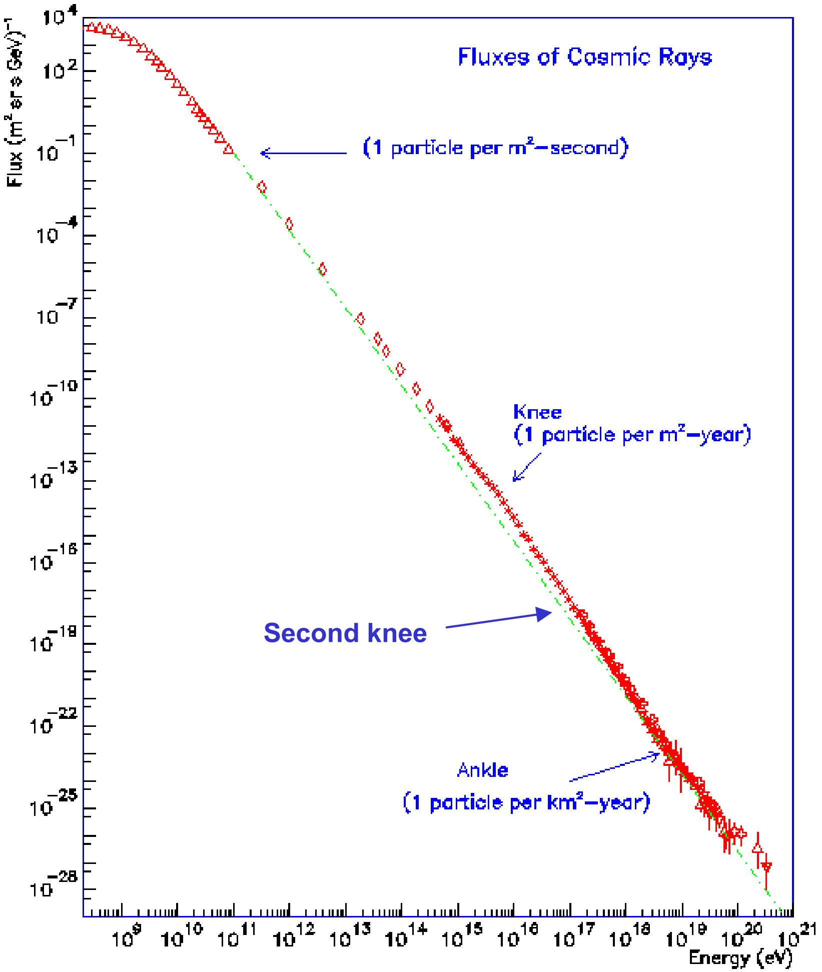
Energy dependence of the heat capacity defined as,

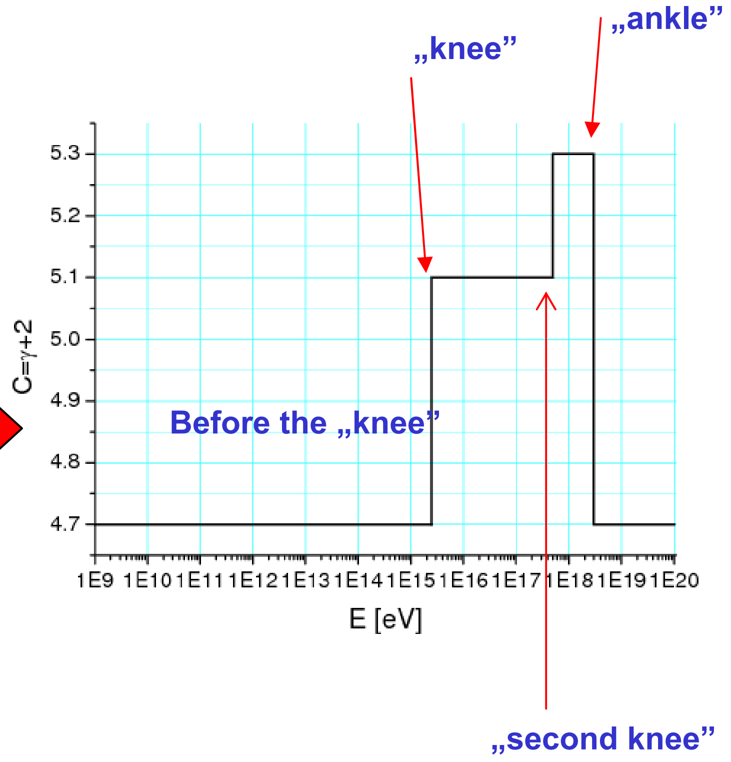
C=1/(q-1),

resulting from the measured CR energy spectrum.

The features of the energy spectrum of CR are now dramatically amplified forming an isolated, structured bump.

we propose to investigate such conjecture





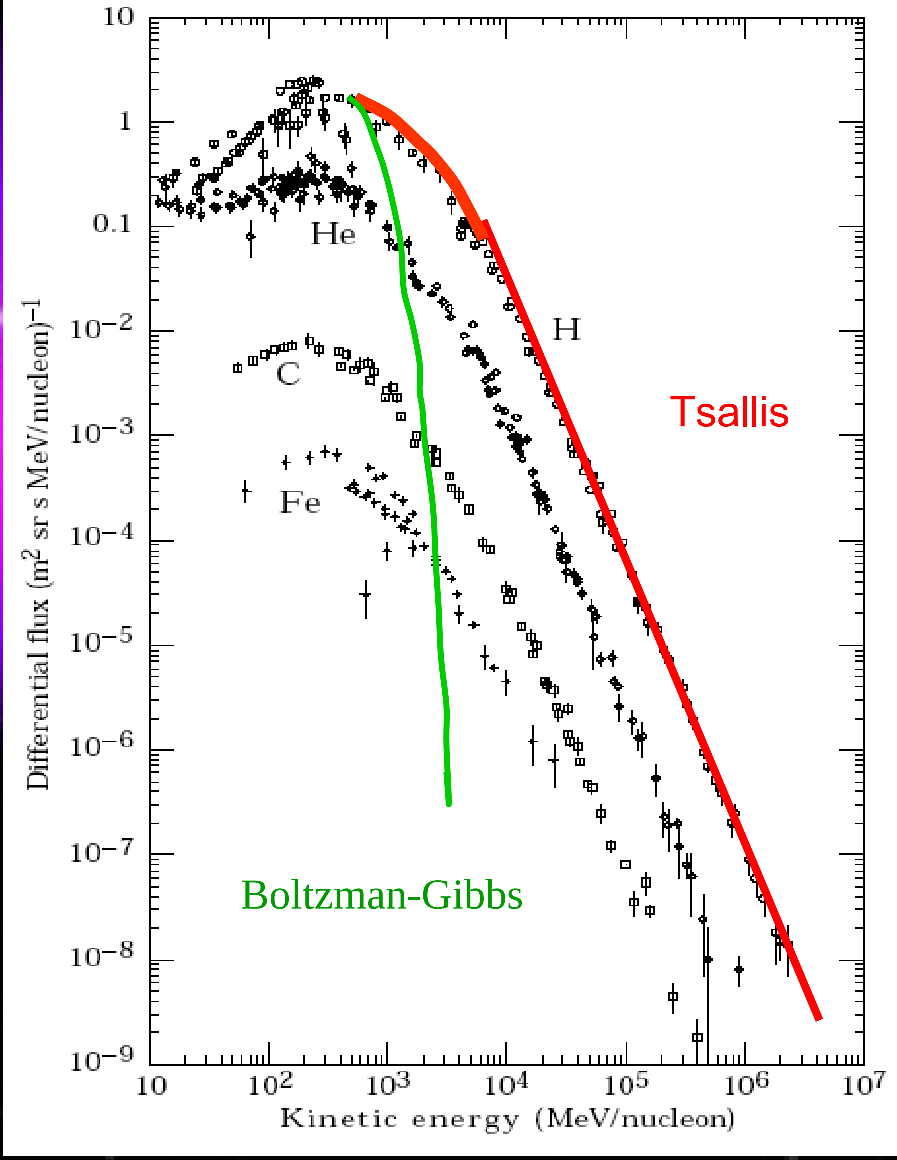
Energy spectrum in thermal models

$$\Phi(E) = N_0 E^2 P(E)$$

$$E >> T$$

$$\Phi(E) \propto E^{-\gamma}$$

$$\gamma = \frac{3-2q}{q-1}$$



So far we have:

(*) **C.Tsallis, J.C.Anjos, E.P.Borges, Pl A310 (2003) 372,** ***Fluxes of cosmic rays: a delicately balanced stationary state.***

(*) **C.Beck, Physica A331 (2004) 173,** ***Generalized statistical mechanics of cosmic rays.***

C.Tsallis, J.C.Anjos, E.P.Borges, Pl A310 (2003) 372, ***Fluxes of cosmic rays: a delicately balanced stationary state.***

… We propose a phenomenological approach along the lines of nonextensive mechanics, a formalism which contains Boltzmann-Gibbs statistical meachnics as a particular case …………….

… The knee then appears as a crossover between two fractal-like thermal regimes … characterized by (T,q) and (T',q')………

… Since the entropic index q is known to reflect (multi) fractality, the present results strongly suggest that either the generation or the transport (or both) of cosmic rays occur in the scale invariant media ……..

Problem: the „temperatures" obtained are very large, of the order of 100-1000 Mev → where from could they come?

C.Beck, Physica A331 (2004) 173, ***Generalized statistical mechanics of cosmic rays.***

…. We consider a generalized statistical mechanics model for the creation process of cosmic rays which takes into account the temperature fluctuations ….

... q=11/9 and $T=(5/9)T_H$ where $T_H \approx 180$ MeV is Hagedorn temperature measured in collider experiments…..

This temperature seems to be overestimated because it is based on the fit to small enery region and therefore is of limited value only.

As before – it seems to bee too large.

(G.W, Z.W., PRL 84 (2000) 2770)

$$\left[1-(1-q)\beta_0 E\right]^{1/(1-q)} = \int_0^\infty d\beta\, f(\beta)\, \exp(-\beta E); \quad \beta = \frac{1}{T}$$

Now, if f(β) is such:

$$f(\beta) = \frac{1}{\Gamma(\alpha)}\left(\frac{\alpha}{\beta_0}\right)^{\alpha} \beta^{\alpha-1} \exp\left(-\frac{\alpha}{\beta_0}\beta\right); \quad \alpha = \frac{1}{q-1}; \quad \beta_0 = \langle\beta\rangle$$

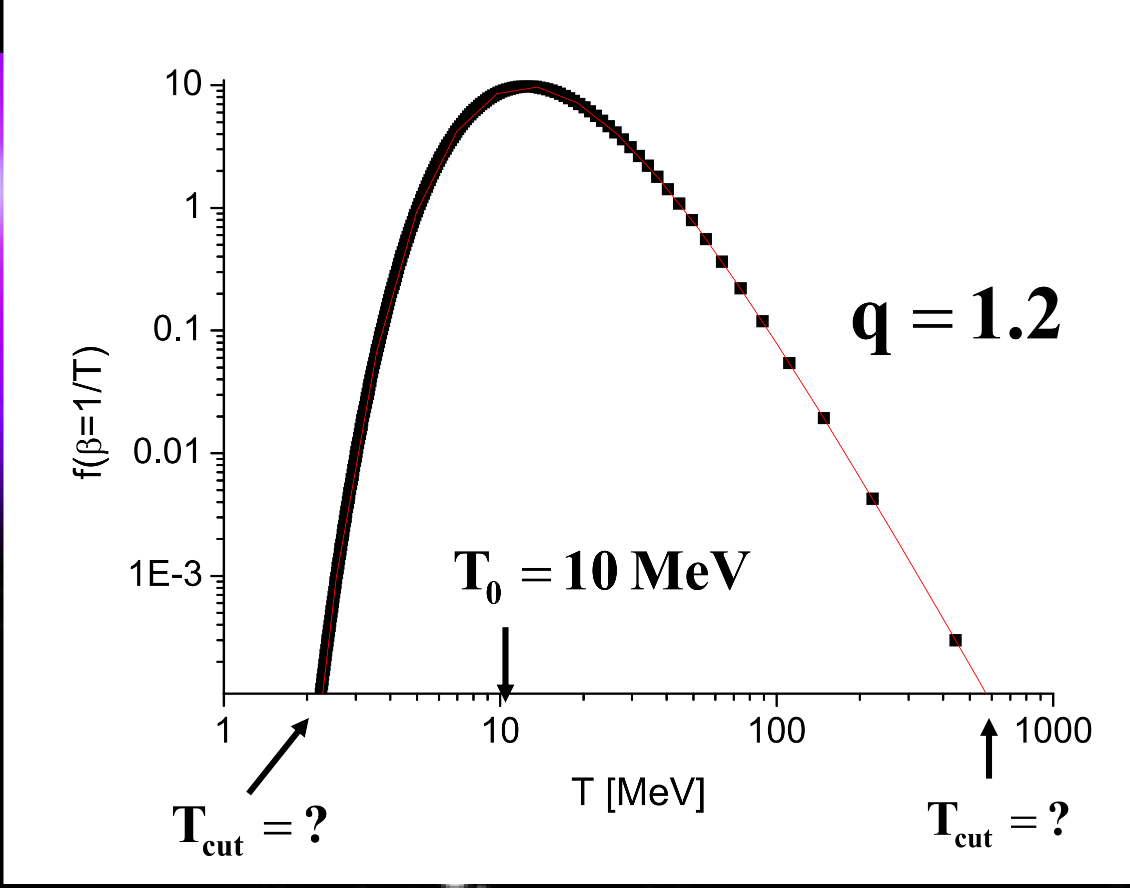
then

$$q = 1 + \frac{\langle\beta^2\rangle - \langle\beta\rangle^2}{\langle\beta\rangle^2} = 1 + \frac{1}{C}$$

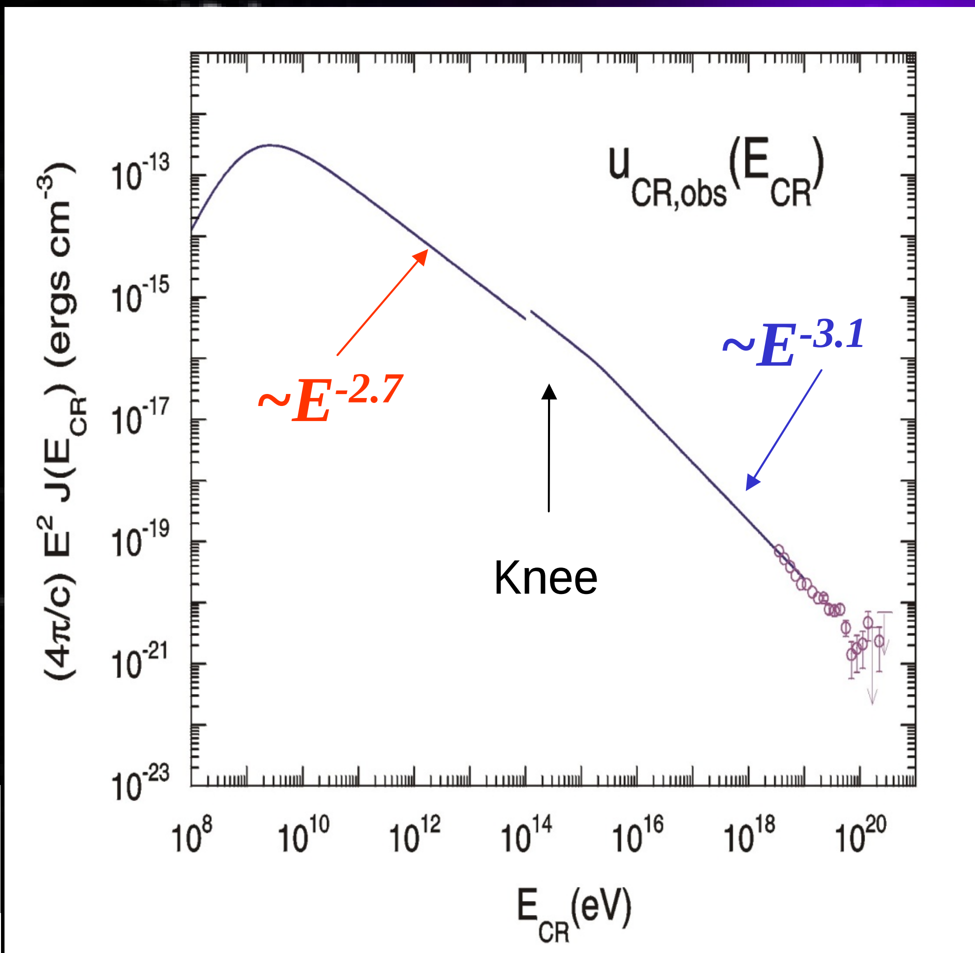
We assume now that the possible origin of such f(β) is temperature fluctuation in the source of CR , a possibility which is is much discussed at present (K.Klai et al., *Astrophys. J. 644 (2006) 61* and references therein)

$$f(\beta)=\frac{1}{\Gamma(\alpha)}\left(\frac{\alpha}{\beta_0}\right)^{\alpha}\beta^{\alpha-1}\exp\left(-\frac{\alpha}{\beta_0}\beta\right)$$

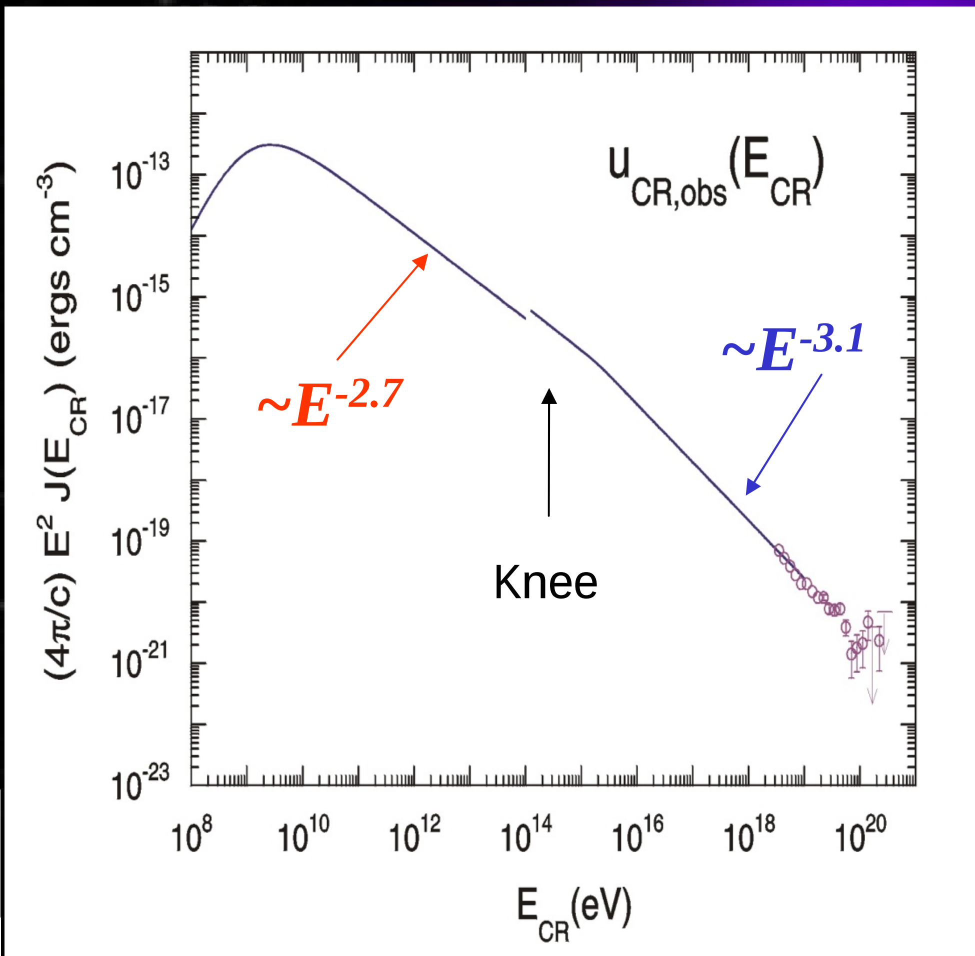
We would like to have something like this, with such small value of temperature T_0

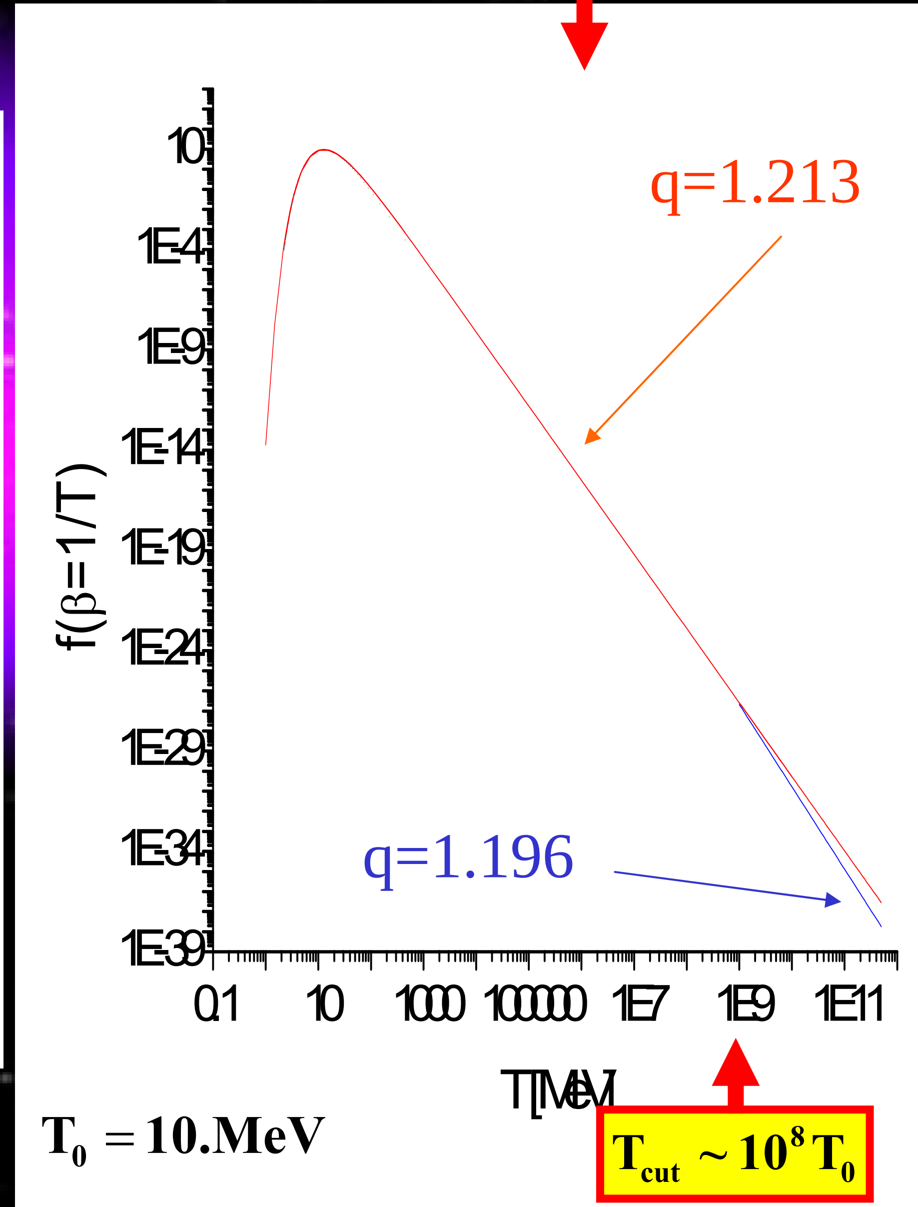


To reproduce what is observed



To reproduce what is observed one needs something like this





To reproduce what is observed

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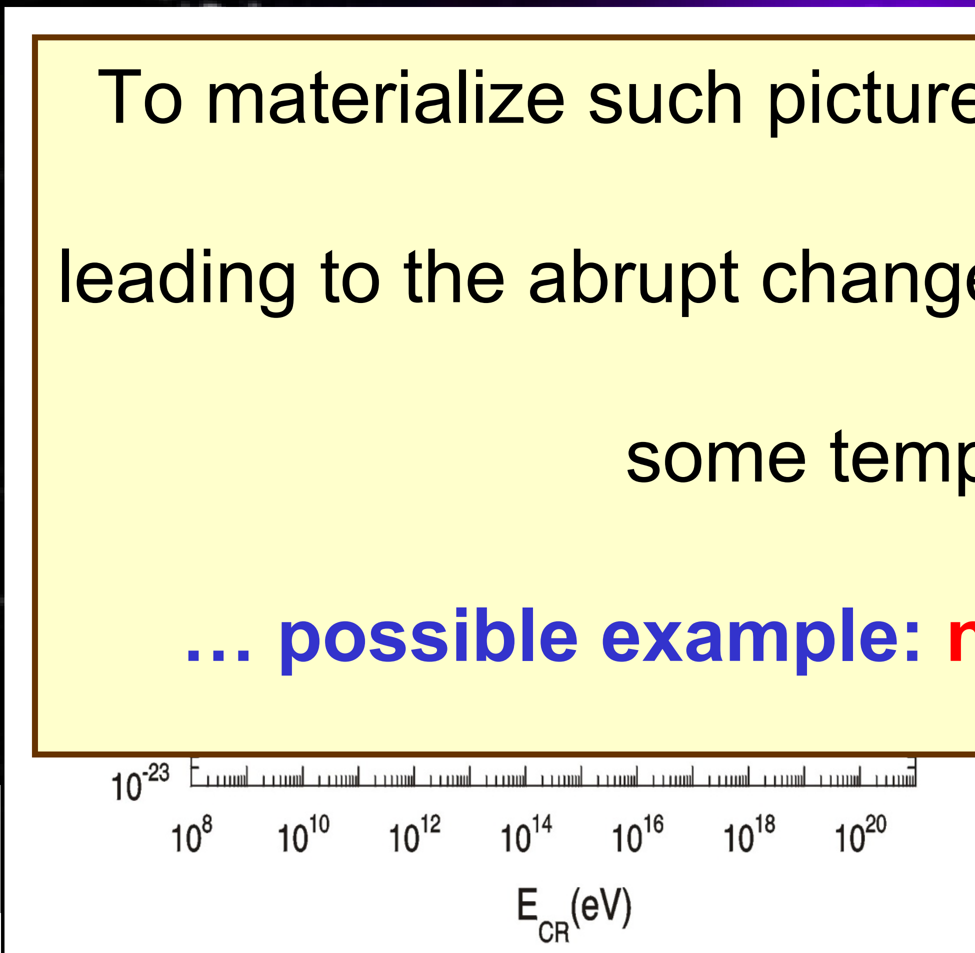
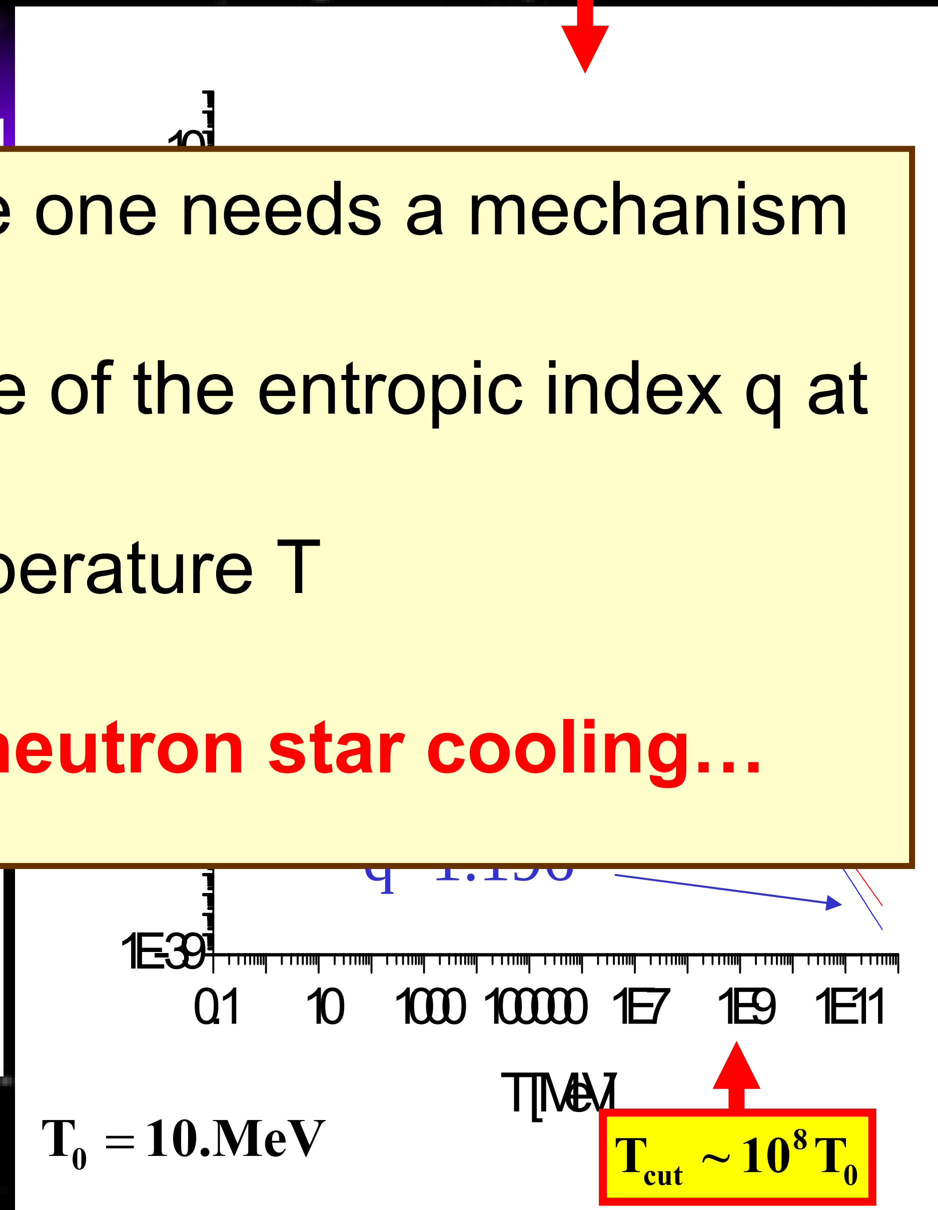


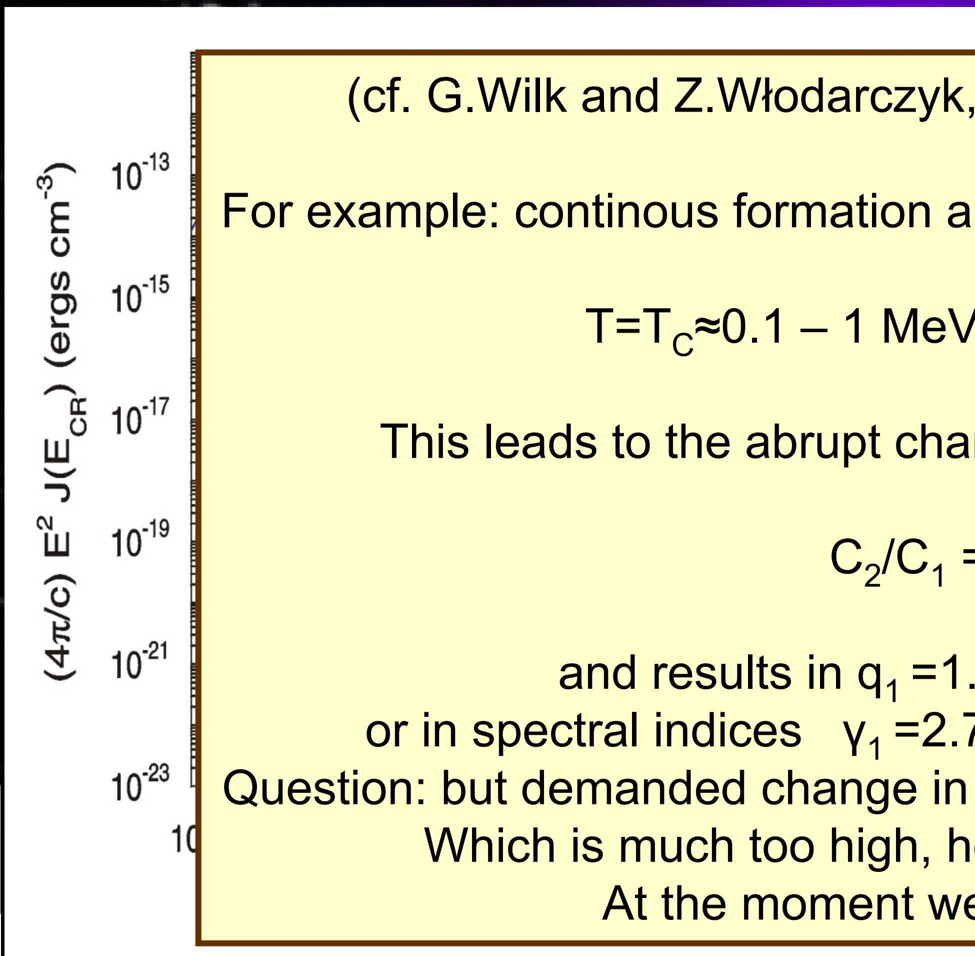


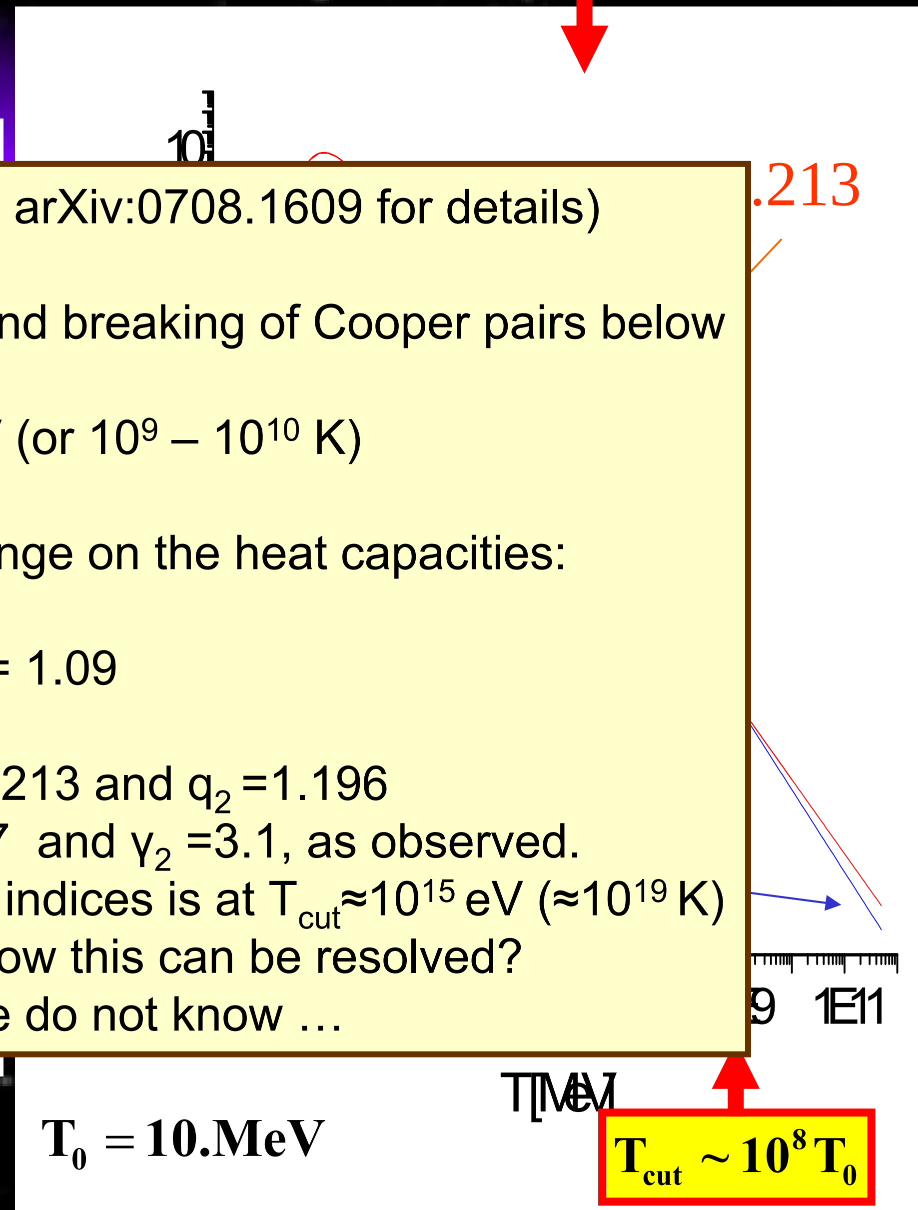
To materialize such picture one needs a mechanism leading to the abrupt change of the entropic index q at some temperature T

… possible example: neutron star cooling…

To reproduce what is observed

one needs something like this





(cf. G.Wilk and Z.Włodarczyk, arXiv:0708.1609 for details)

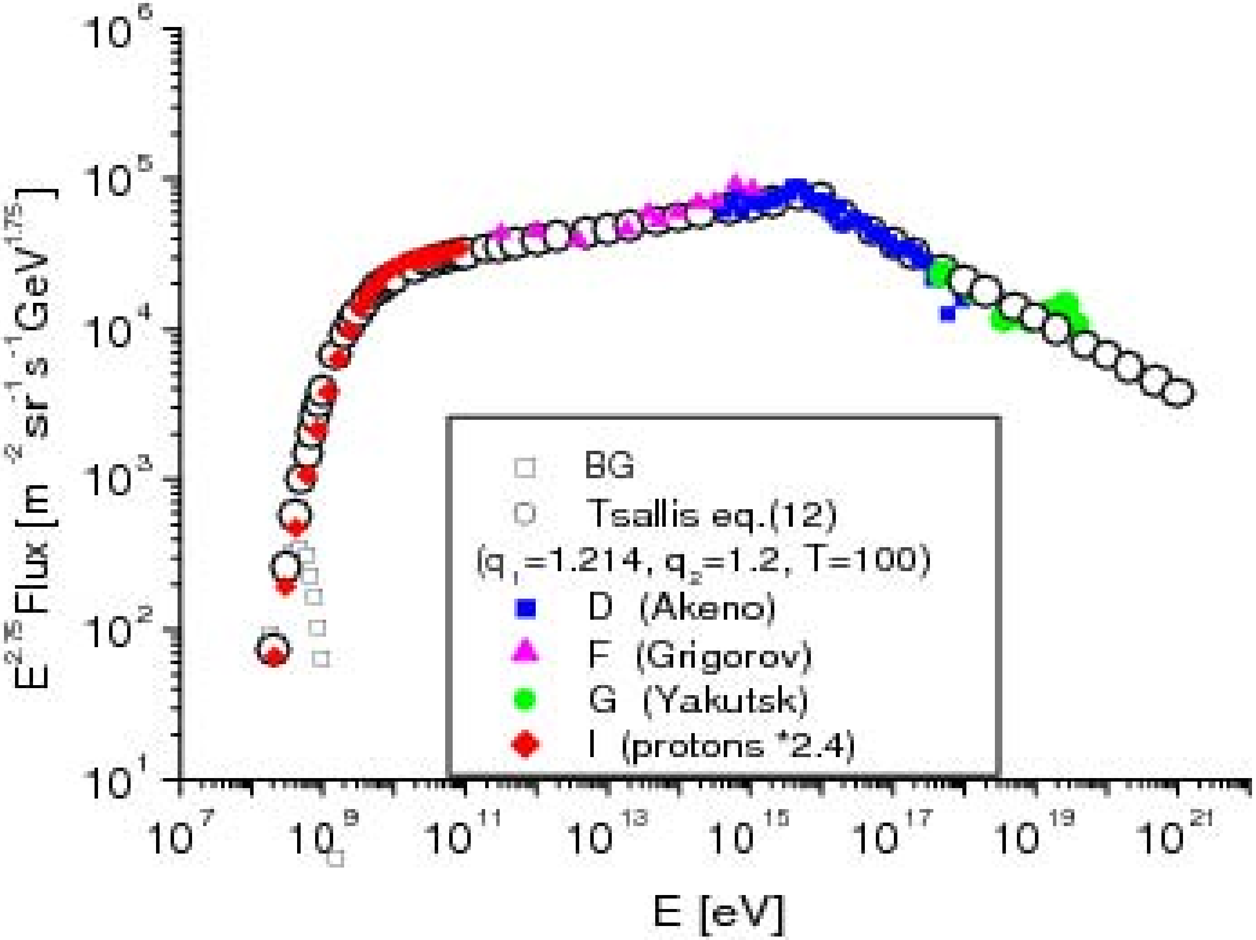
For example: continous formation and breaking of Cooper pairs below

$T=T_C \approx 0.1 - 1$ MeV (or $10^9 - 10^{10}$ K)

This leads to the abrupt change on the heat capacities:

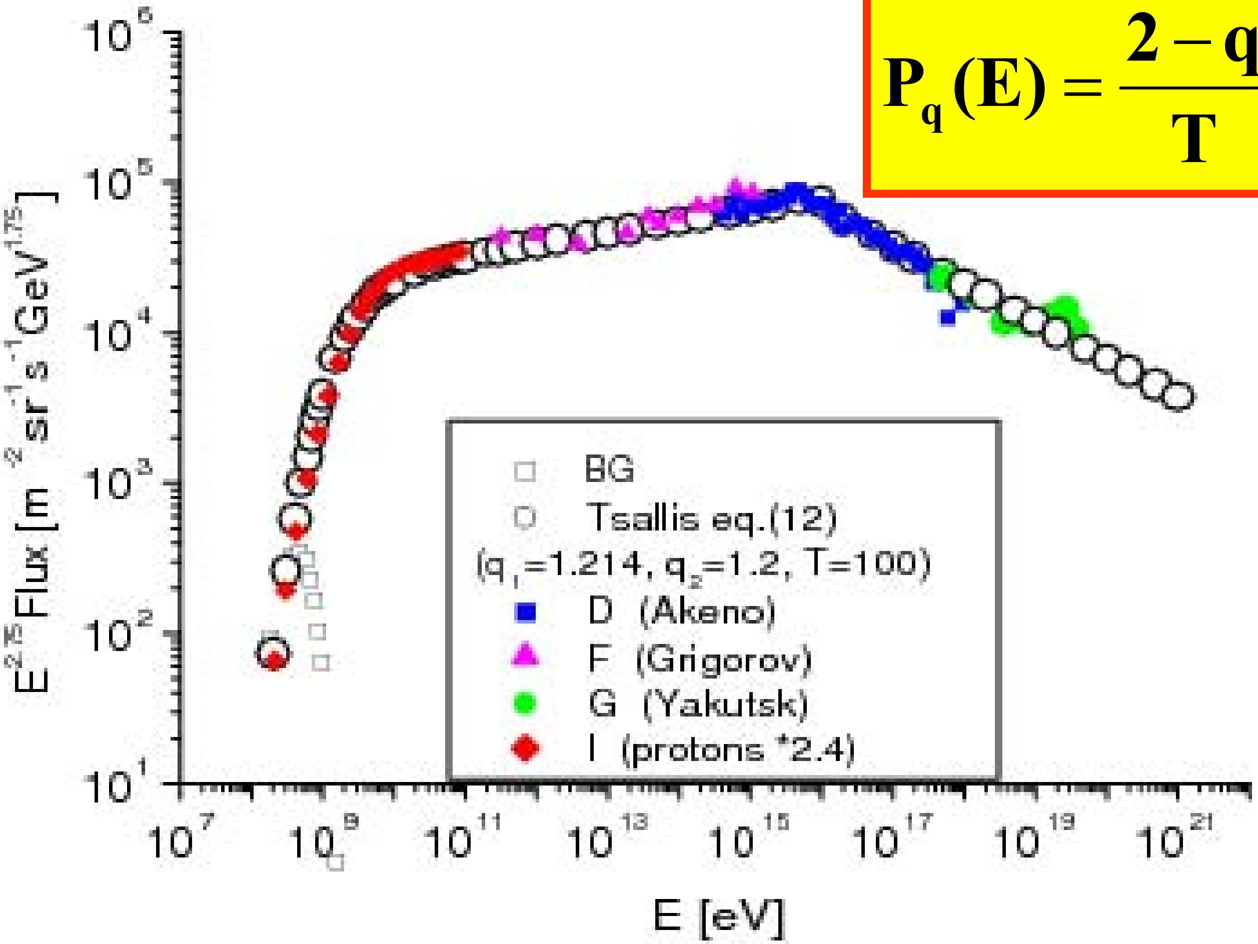
$C_2/C_1 = 1.09$

and results in $q_1 = 1.213$ and $q_2 = 1.196$
or in spectral indices $\gamma_1 = 2.7$ and $\gamma_2 = 3.1$, as observed.
Question: but demanded change in indices is at $T_{cut} \approx 10^{15}$ eV ($\approx 10^{19}$ K)
Which is much too high, how this can be resolved?
At the moment we do not know …



The CR energy spectrum fitted to the doubleTsallis distributions, which accounts for the whole region of energy. It was obtained assuming that fluctuations of the temperature change abruptly at some energy corresponding to $T_{cut} \approx 10^{15}$ eV ≈ 10^{19} K .

$$P_q(E) = \frac{2-q}{T}\left(1-(1-q)\frac{E}{T}\right)^{1/(1-q)}$$



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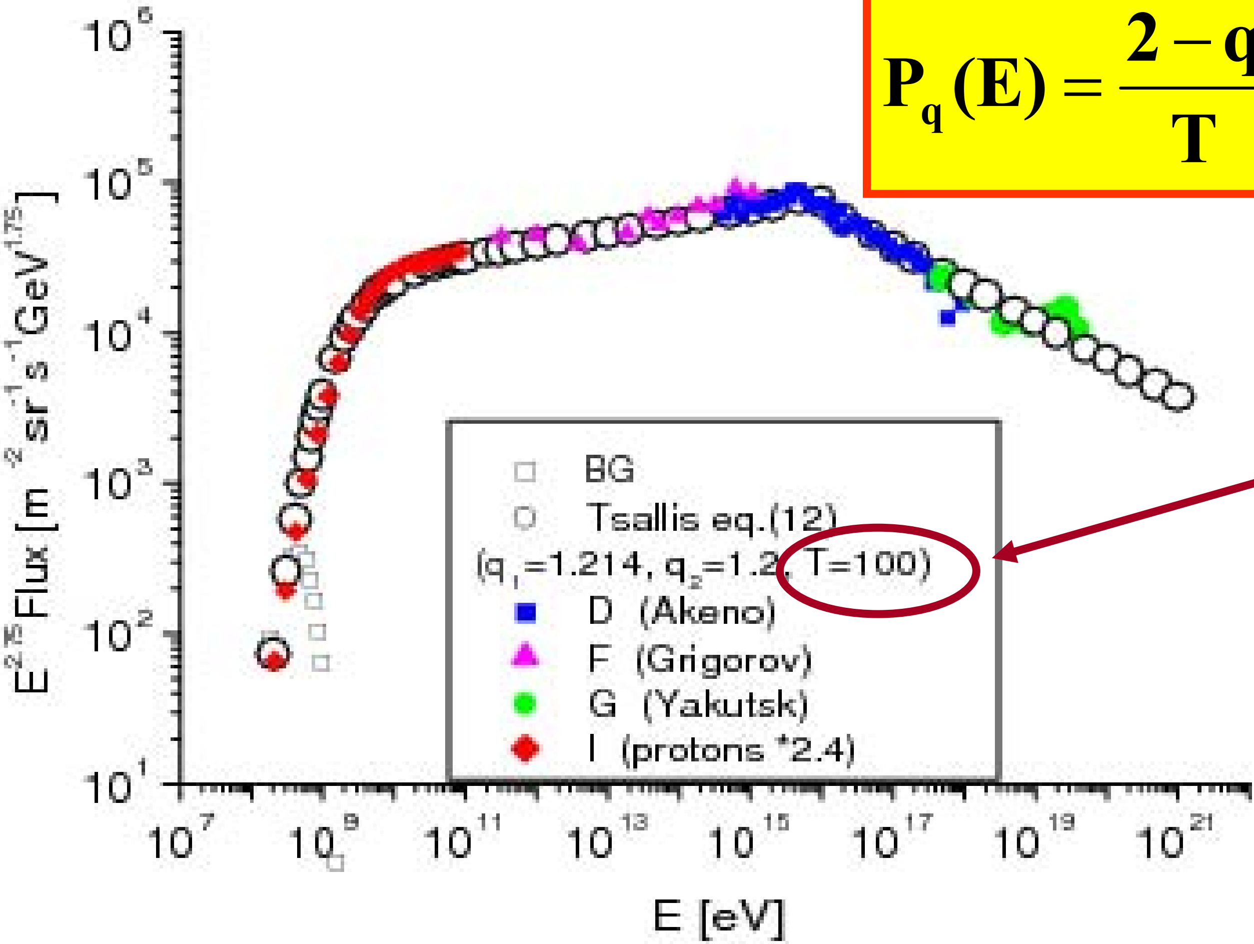
$$P_q(E) = \frac{2-q}{T}\left(1-(1-q)\frac{E}{T}\right)^{1/(1-q)}$$

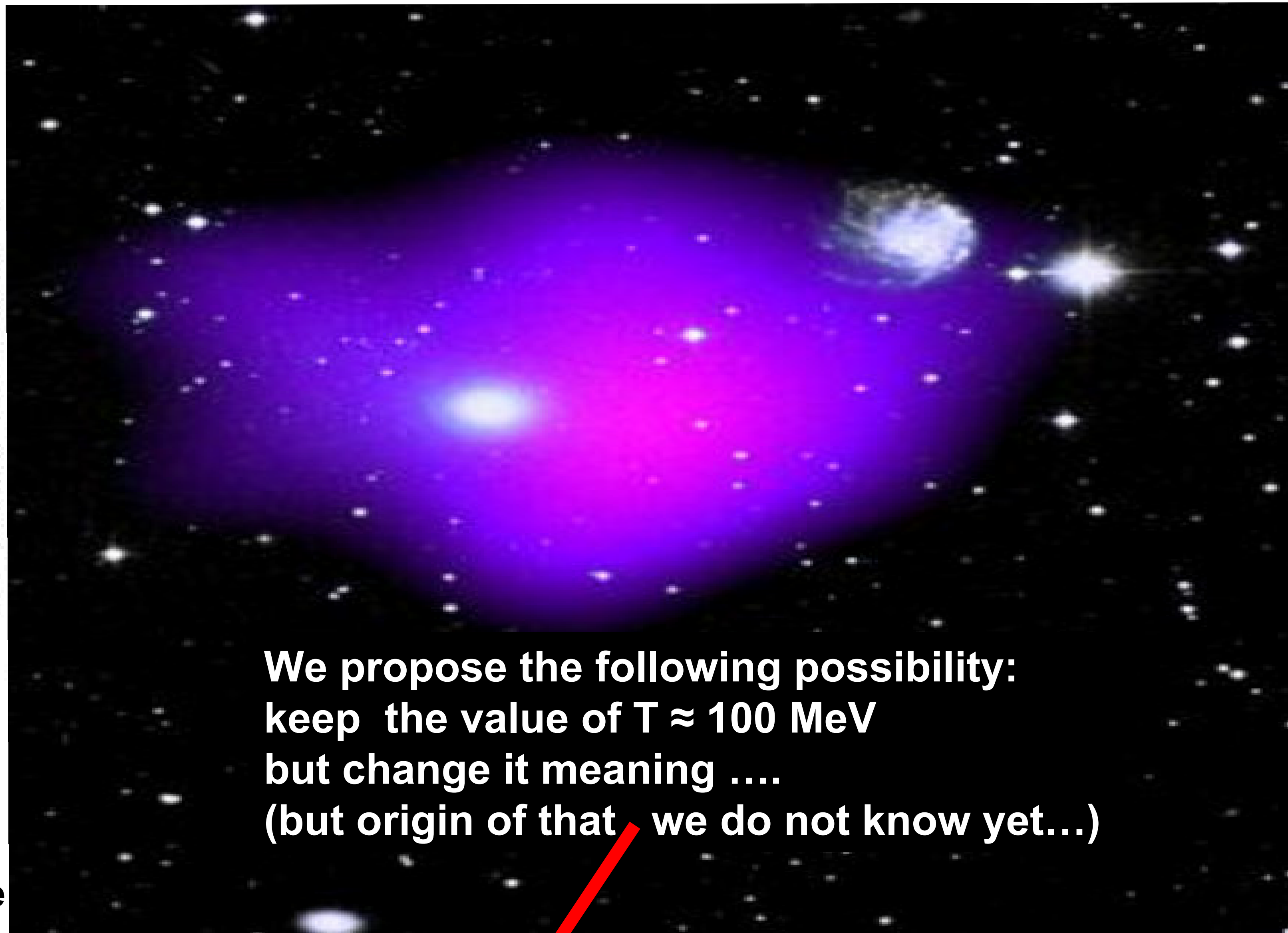
Too big

(again…)



The CR energy spectrum fitted to the doubleTsallis distributions, which accounts for the whole region of energy. It was obtained assuming that fluctuations of the temperature change abruptly at some energy corresponding to $T_{cut} \approx 10^{15}$ eV ≈ 10^{19} K .

$E^{2.75}$ Flux [m^{-2} sr^{-1} s^{-1} $GeV^{1.75}$]



We propose the following possibility:
keep the value of $T \approx 100$ MeV
but change it meaning ….
(but origin of that we do not know yet…)

The

accounts for the whole region of energy. It was obtained assuming that fluctuations of the temperature change abruptly at some energy corresponding to $T_{cut} \approx 10^{15}$ eV $\approx 10^{19}$ K .

Proposed way out of this dillemma:

Add to what was proposed in our paper PRL84(2000)2770
(which was accounting only for the possible fluctuations of T)
also effect of the possible viscosity (*) .

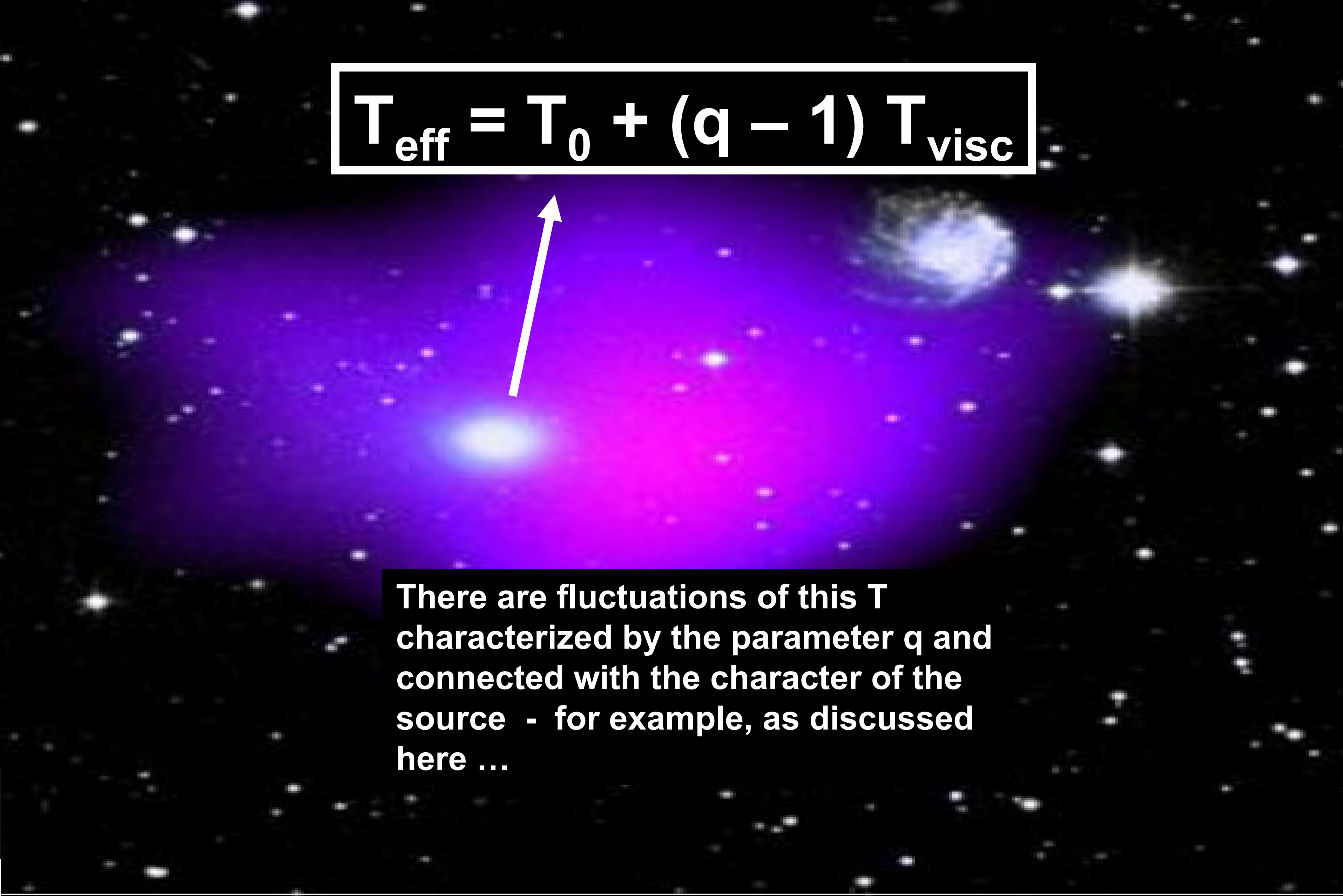
As a result one gets:

- **the same power-like distribution as before**
- **but with the previous $T_0=<T>$ replaced by some effective T_{eff} :**

$$T_{eff} = T_0 + (q - 1)\, T_{visc}$$

where T_{visc} is some new parameter depending on the transport properties of the space through which CR propagates.

(*) G.Wilk, Z.Włodarczyk, arXiv 0810.2939[hep-ph], *Power laws in elementary and heavy-ion collisions - A story of fluctuations and nonextensivity?*



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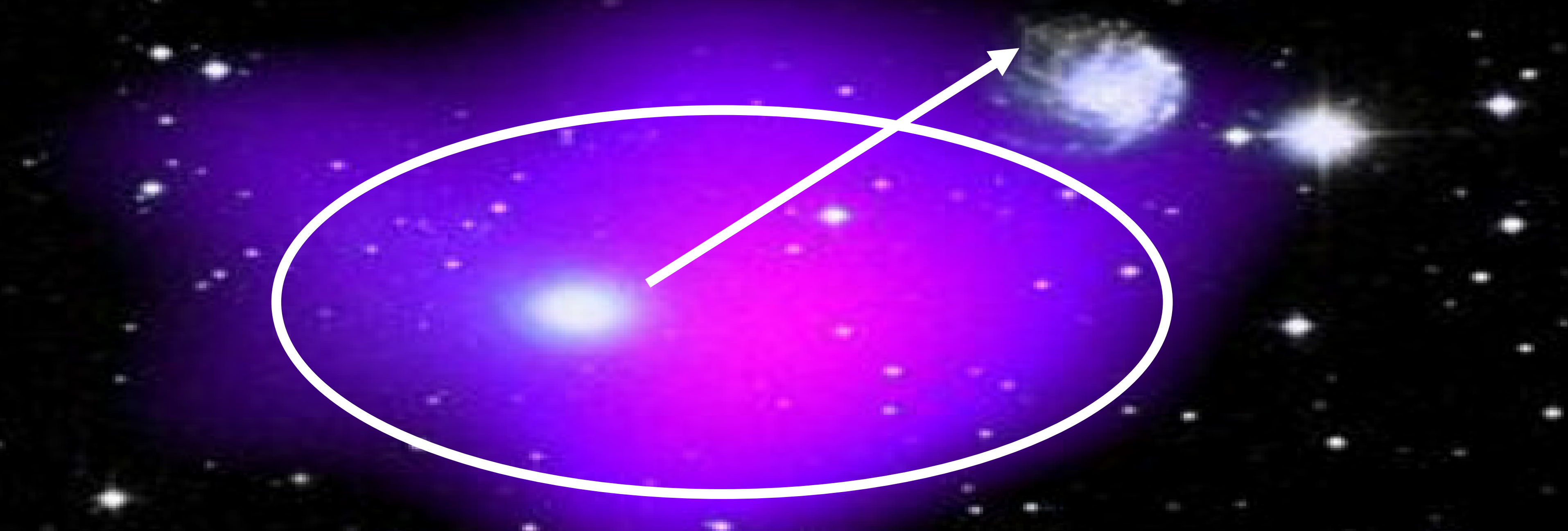

But there is also a surrounding space around the emission point, which can pump energy into some selected region from which a CR particle is emitted, it is described by the positive parameter T_{visc}

→ - the total T_{eff} grows therefore with q .

(*) G.Wilk, Z.Włodarczyk, arXiv 0810.2939[hep-ph], *Power laws in elementary and heavy-ion collisions - A story of fluctuations and nonextensivity? -*

$$T_{eff} = T_0 + (q - 1)\, T_{visc}$$

Actually, this situation is opposite to what one has in the heavy ion collisions (*). There, in the AA collisions, one has

- **region of collision in which particles are produced and which is hot and**
- **cold surroundings (spectators).**

Here the energy proceeds from the region of the production to the surroundings and therefore T diminishes with q.

(*) G.Wilk, Z.Włodarczyk, arXiv 0810.2939[hep-ph], *Power laws in elementary and heavy-ion collisions - A story of fluctuations and nonextensivity? -*

To summarize this point:

(*) In a star we have small T_0 (of the order of MeV) with some fluctuations given by $q>1$

(*) But if we have a flow, then in the corresponding Tsallis distribution one has T_{eff} , which can be quite large (of the order of 100 MeV)

(*) In the spectrum of CR one observes Tsallis distribution with $T_{eff} \sim 100$ MeV (as in the previous works by Tsallis et al.. and Beck) but now it does not mean that the temperature of the star has such a value because T_{eff} is composed from:

- the temperature of the star itself, T_0 , and
- the effect of the surrounding space given by the T_{visc} .

As results now T_0 can be as small as desired.

(*) Notice: such an effect appears **ONLY** in the case of **Tsallis distribution**. For $q \rightarrow 1$ one has $T_{eff} \rightarrow T_0$.

⇒ if there is no fluctuations of T one always has only T_0 .

Notice:

The temperature T which one needs seems to be of the order of MeV, i.e., of the order of the stars interior temperature. If stars are born extremaly hot in supernova explosions, with interior temperature around $T \approx 100$ MeV, already within a day the temperature in the central region of the star will drope to something like 0.1–10 MeV (10^9–10^{10} K) and reach the value of 1 keV in about 100 years. The critical temperature corresponding to the nucleon superfluidity is around 1 MeV.

It means that the origing of changes of nonextensivity parameters at $T_{cut} \approx 10^{15}$ eV $\approx 10^{19}$ K required to fit data is still open question.

Notice:

Perhaps this can be explained by the same mechanism which leads to large T_{eff} because, when one considers viscosity effects in stars, one observes very large abrupt changes of the viscosity coefficient which can result in effective T_{cut} of the desired order…(?)… , see, for example:

N. Andersson, *Modelling the dynamics of superfluid neutron stars,* Astrophys Space Sci (2007) 308: 395–402

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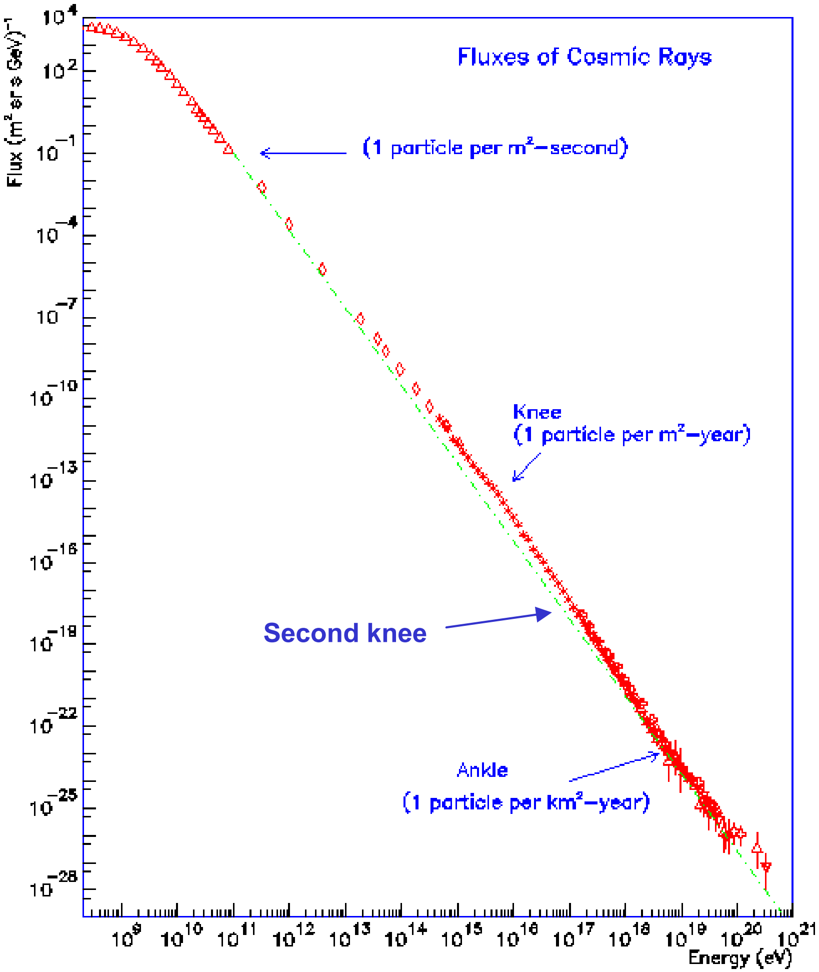
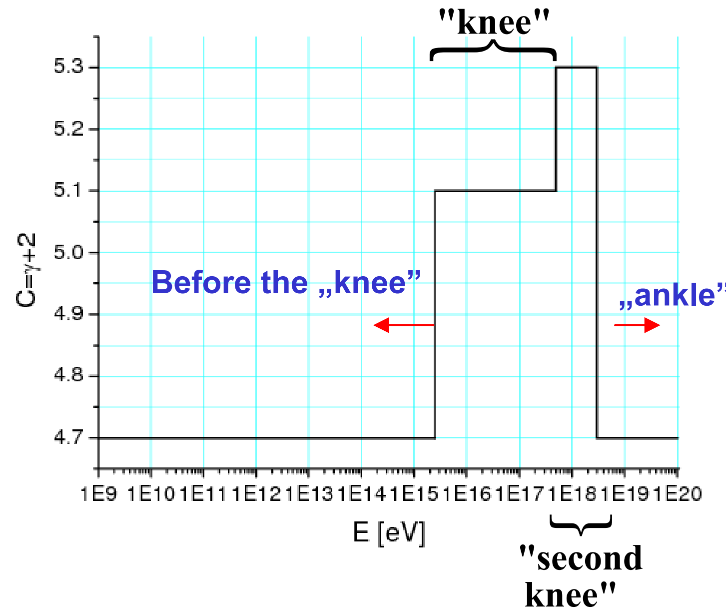
To summarize: we propose to investigate such idea





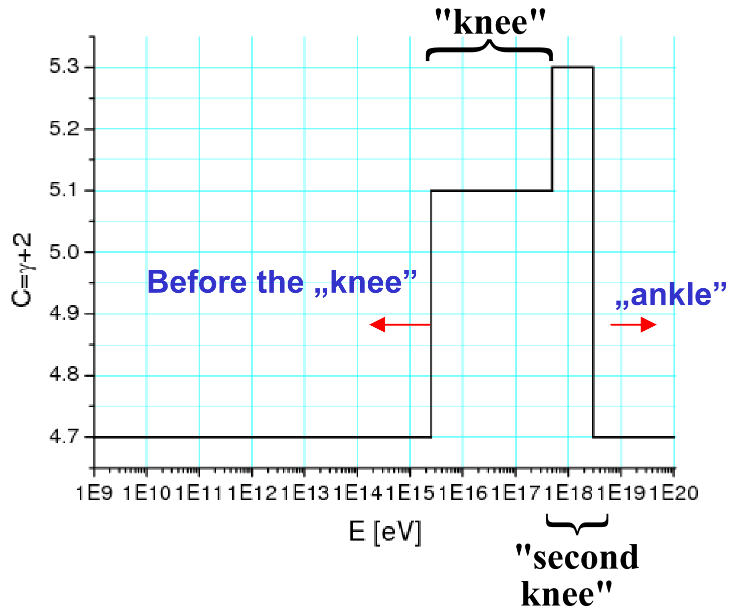
To summarize: we propose to investigate such idea

Use nonextensive thermal approach in which parameter q is connected with the heat capacity C=1/(q-1)

C acts as a kind of magnifying glass converting all subtleties of the shape of the energy flux of CR into a much more pronounced and structured bump.

Its importance would parallel long-standing discussion of the origin of the knee-like structure of the CR energy spectrum, but exposed in much more dramatic and visible way.

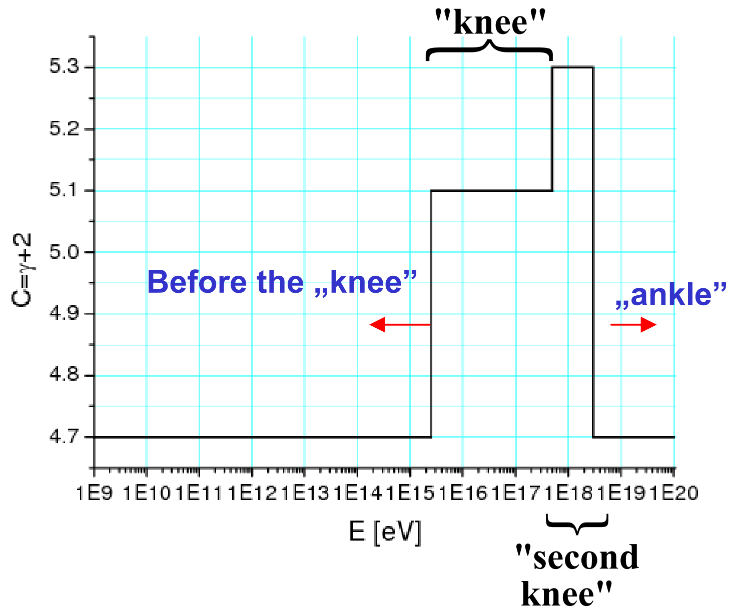
At the moment we can only offer two examples of the possible explanation of this feature.



Examples of the possible explanation of this feature: (I)

(I) This effect is due to the change of the effective number of degrees of freedom in the incoming projectiles with energy.

Assuming that most of CR consist of protons, which are build from three quarks, one could speculate that consecutive bumps correspond to excitations from single proton to proton plus one quark and two quark structure, after exciting all three quarks one comes back to the original situation (*).

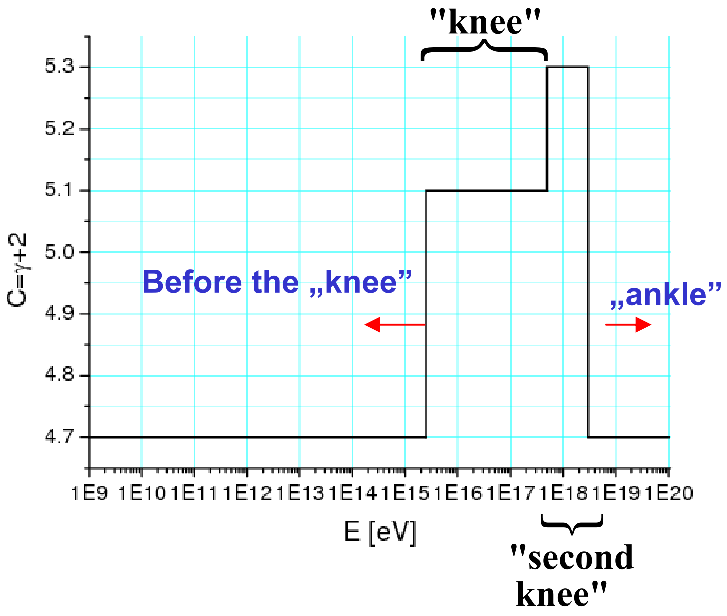


(*) Much in the spirit of the changes observed when ice becomes water and this becomes steam – there the corresponding C's also show characteristic jump, see P.Fraundorf, *Am.J.Phys.* **71** (2003) 1142.

Examples of the possible explanation of this feature: (II)

(II) This effect reflects the behavior of heat capacity in Fermi liquids.

O.V.Maxwell, *Astrophys. J.* 231 (1979) 201.



Examples of the possible explanation of this feature: (II)

(II) This effect reflects the behavior of the heat capacity in Fermi liquids (*).

The proton's heat capacity it is proportional to the ratio of the effective mass of the proton in the neutron fuid to the mass of the free proton: $C \sim m^*/m$

In the case of a mixture of Fermi liquids the proton effective mass m^* is affected by the interactions with neutrons and other protons and is given by

$$\frac{m^*}{m} = 1 + \frac{1}{3} D_p \left[f_1^{pp} + \left(\frac{k_{F_n}}{k_{F_p}} \right)^2 f_1^{pn} \right]$$

where D_p denotes the density of quasiparticle states at Fermi surface given bythe wave vectors k_{Fn} and k_{Fp} for the, respectively, neutrons and protons whereas f_1^{pp} and f_1^{pn} are Landau parameters (**).

(*) O.V.Maxwell, *Astrophys. J.* 231 (1979) 201.

(**) M.Borumand, R.Joynt and W.Kluźniak, *Phys. Rev.* C54 (1996) 2745.

Examples of the possible explanation of this feature: (II)

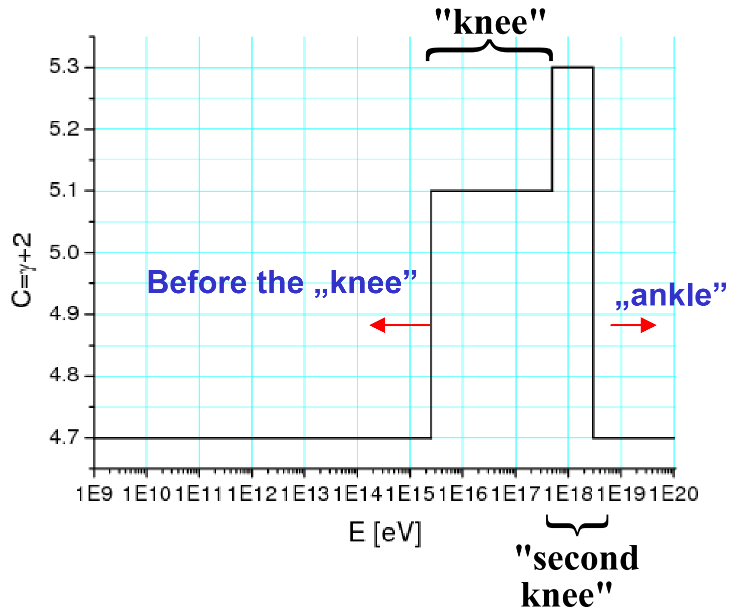
(II) This effect reflects the behavior of heat capacity in Fermi liquids (*).

We start with the superfuid liquid with (here *m represents the effective mass for the *pp* and *pn* interactions),.** **$C_1 = 4.7$**

When energy increases we stop to see nuclear interactions and (with *m representing *pp* interactions only).** **$C_2 = 5.1$**

Finally, for larger *T*, we have Fermi gas with **$C_3 = 5.3$**

and, still further, we return again to the usual Fermi liquid .



(*) O.V.Maxwell, *Astrophys. J.* 231 (1979) 201.

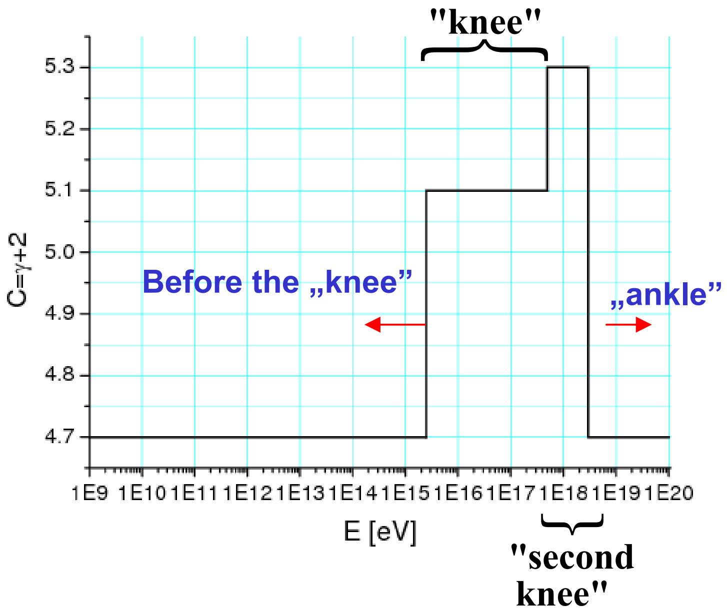
Examples of the possible explanation of this feature: (II)

(II) This effect reflects the behavior of heat capacity in Fermi liquids (*).

It is worth to remember that fuctuations of temperature we are talking about here refer to fuctuations in the small region *V* .

For Fermi liquid the heat capacity expressed in units of Boltzmann constant k_B (i.e., for $k_B = 1$) is of the order $C \approx 3 \cdot 10^{35}$ cm^{-3} (**).

Therefore, taking values of *C* estimated from the slope of the primary CR spectra one gets that the size of the region of fuctuations is $V \sim 10^4$ fm^3.



(*) O.V.Maxwell, *Astrophys. J.* 231 (1979) 201.
(**) D.G.Yakovlev and V.A.Urpin, *Sov. Astron. Lett.* 7 (2) (1981) 88.

Summary

- Nonextensive statistics succesfully describes the smooth power-like spectrum

- We propose to place the origin of the proposed temperature fluctuations in a source of CR (rather than in the temperature distribution of CR sources) . Actually, one needs a composed pattern of fluctuations with an abrupt change in the q-parameter at T ~ PeV in order to reproduce region of ”knee”; its origin remains at the moment unknown…

- The observed temperatures <T> seem to be of the order of ~ MeV (i.e., of the order of the T in the interior of stars), which is much smaller than values obtained by Tsallis and al., and by Beck.

- To get <T> ~ 100 MeV (as required by data on the CR spectra) one has to allow for the action of the surroundings of the source resulting in T_{eff} of that order.


NGC 23
The
End