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A possibility of interpretation of the cosmic ray knee near 10 TV as a contribution of a single close source

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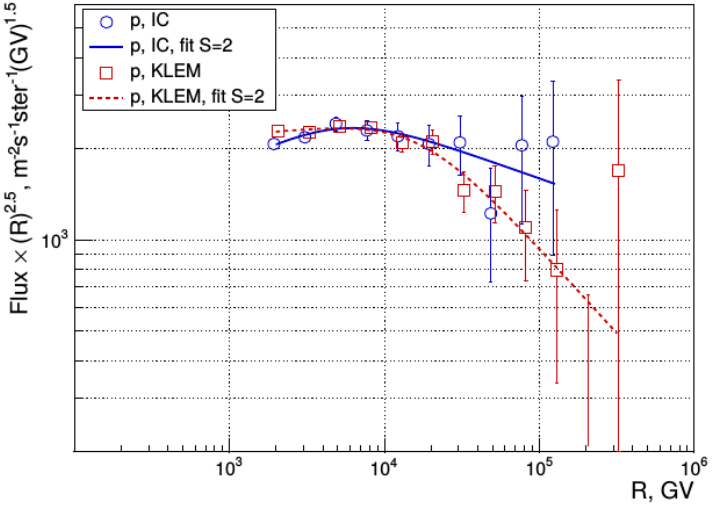
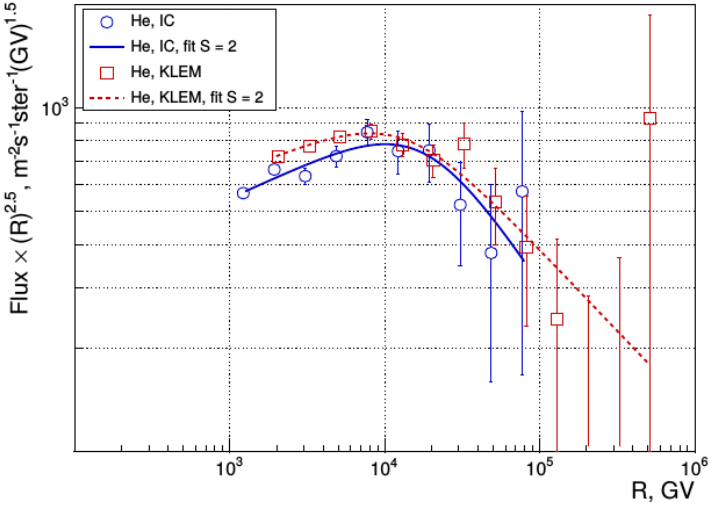
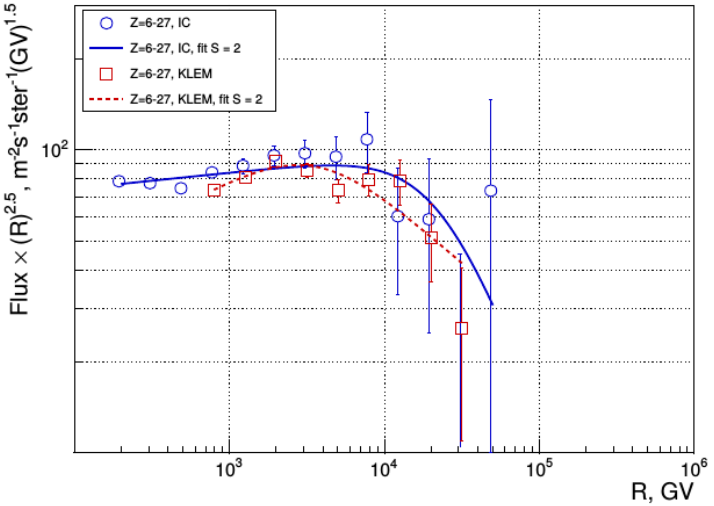
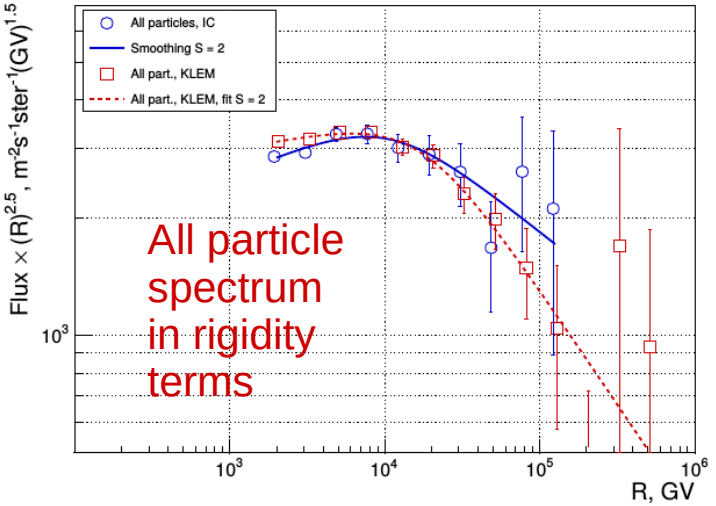
ISCRA-2019, June 27

The NUCLEON space experiment:
A new universal cosmic-ray knee near the magnetic rigidity 10 TV





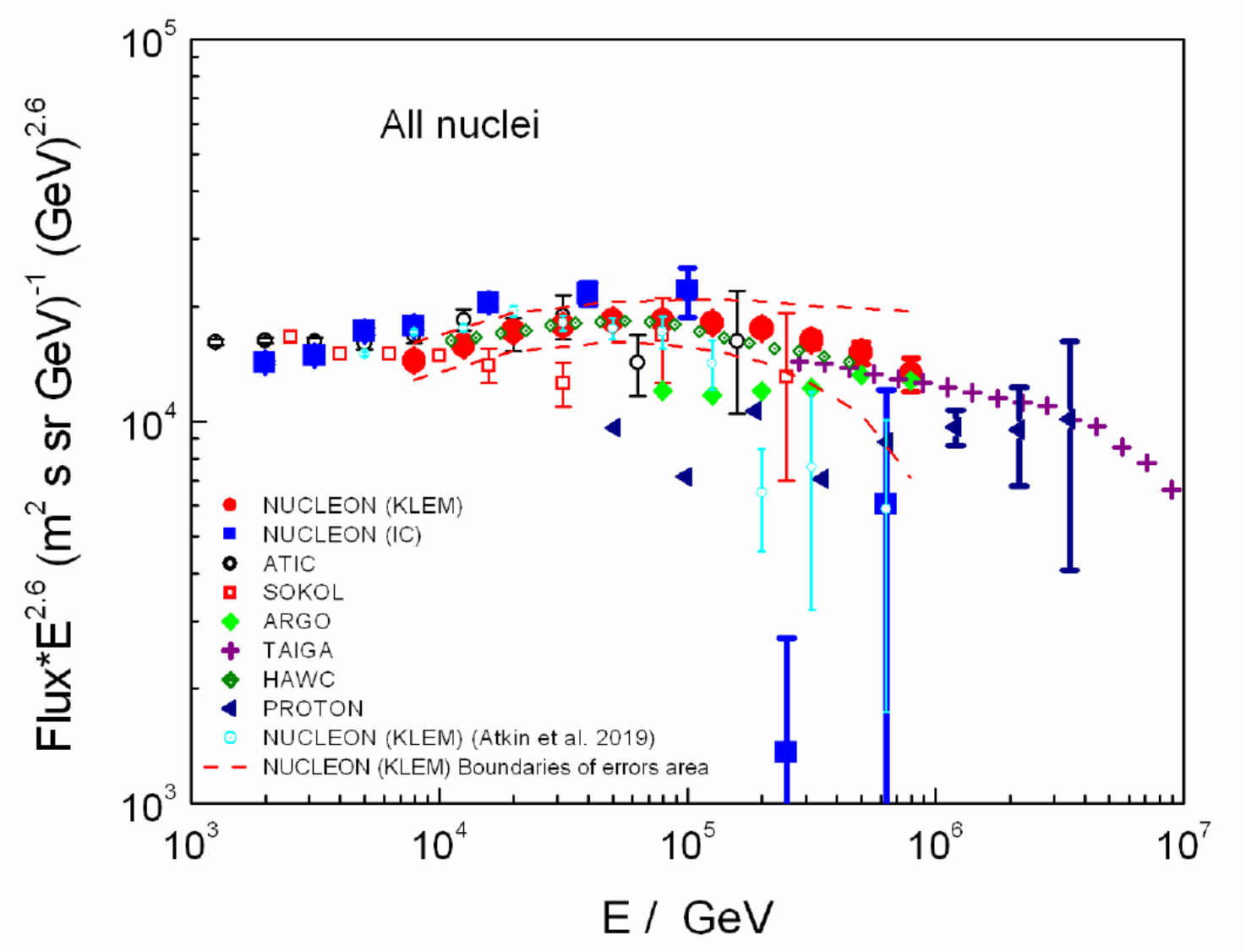




JETP Lett. V.108, No 1, P. 5 (2018) [arXiv:1805:07119].

Statistical significance > 3.9σ in all nuclear groups (4.2σ-4.4σ - the last data)

10TV-knee transforms to ~50GeV knee in usual terms of E/particle (HAWC, NUCLEON)

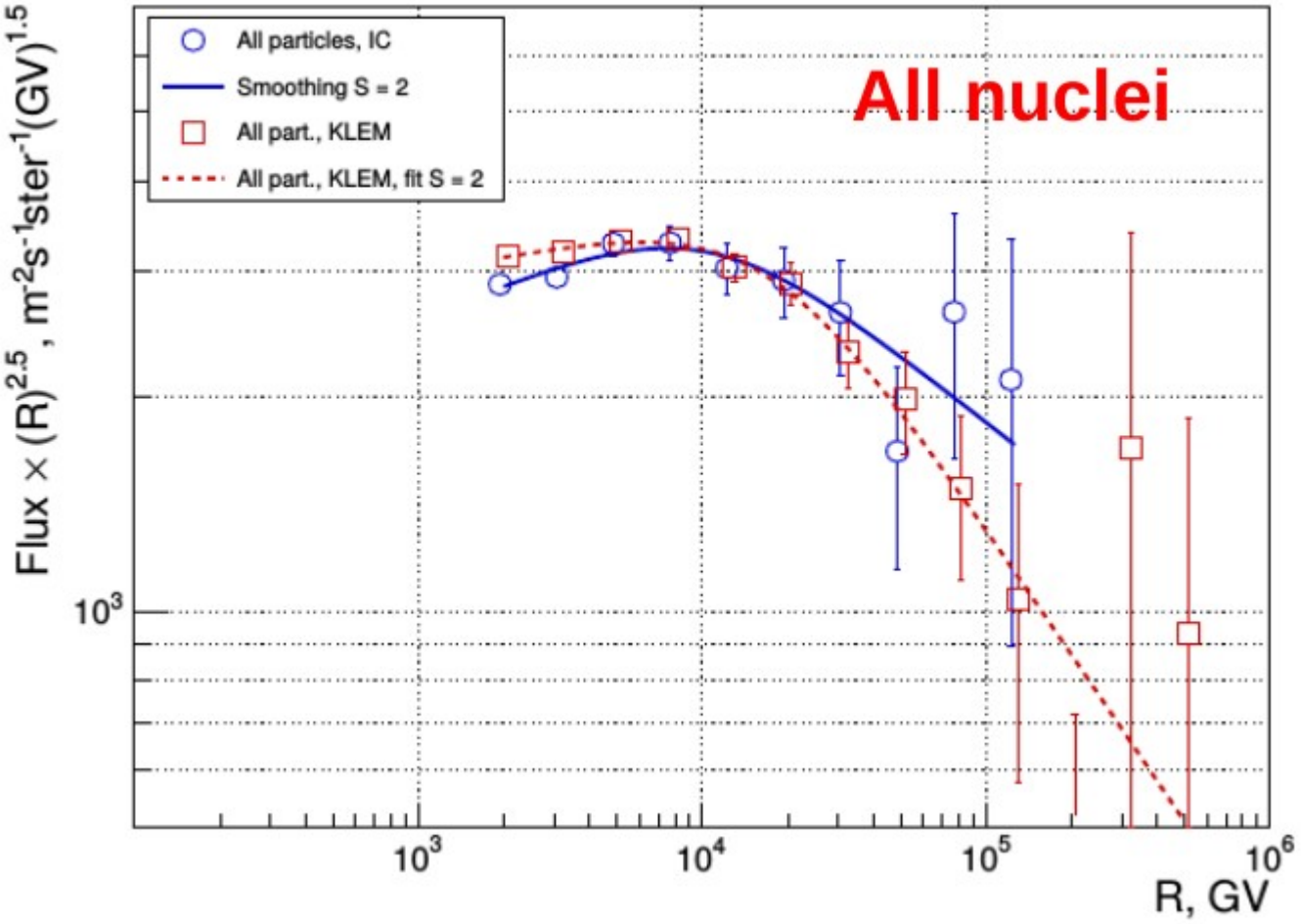


The simplest possible explanation of 10 TV-knee:

10TV is a limit of acceleration of some kind
of CR source - a single nearby one (?) or generic (?)

Argument No 1 for a single source :

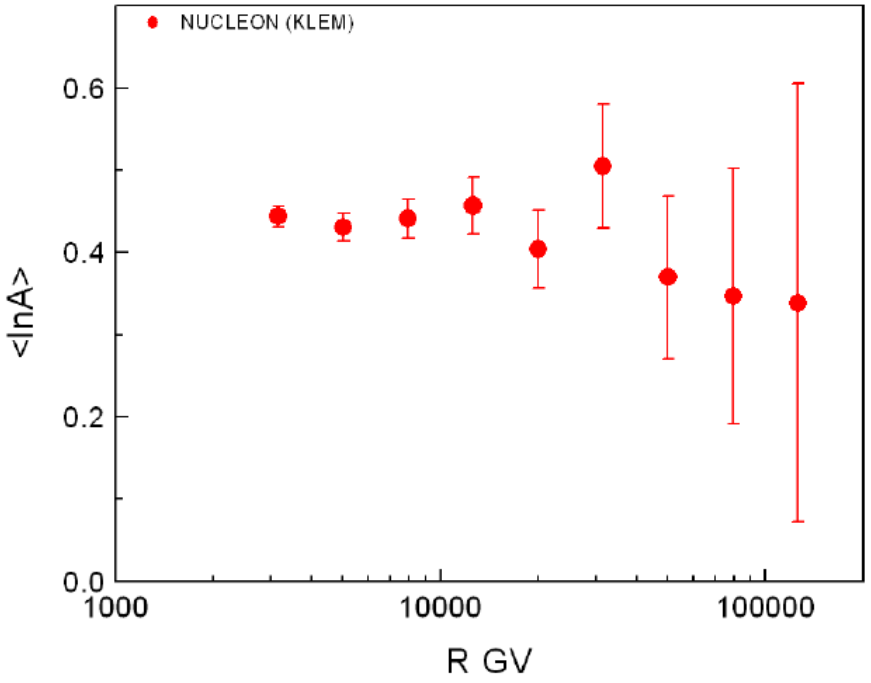
The knee is very sharp to be from multiple sources

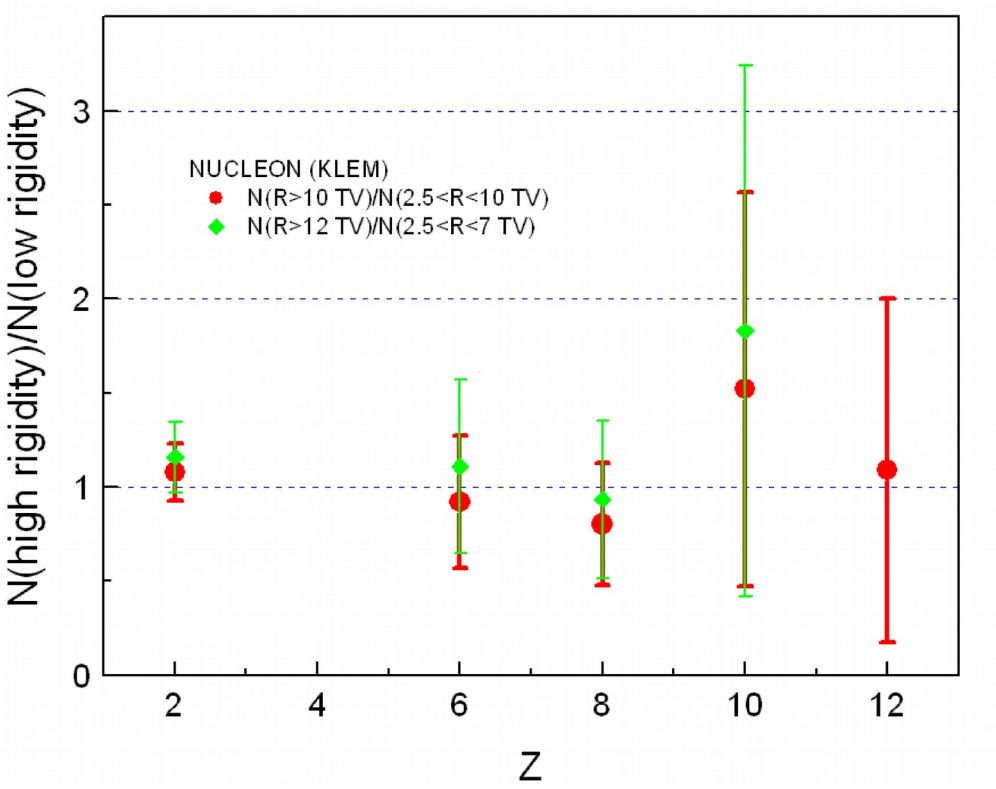


Argument No 2 for a single source:

The chemical composition is approximately constant around the knee

N – nucleus flux / protons flux





Is it actually possible to fit the data by a single reasonable CR source?

General problem formulation

CR diffusion equation:

$$\frac{\partial N(R,t,\mathbf{r})}{\partial t} - \nabla[D(R)\nabla N(R,t,\mathbf{r})] = Q(R,t,\mathbf{r})$$

$$D(R) = D_0 \left(\frac{R}{R_{ref}}\right)^{-\delta}$$

“Flash lamp” approximation:

$$F_Z(R,r,T) = \frac{C}{4\pi} G(R,T,r) Q_Z(R)$$

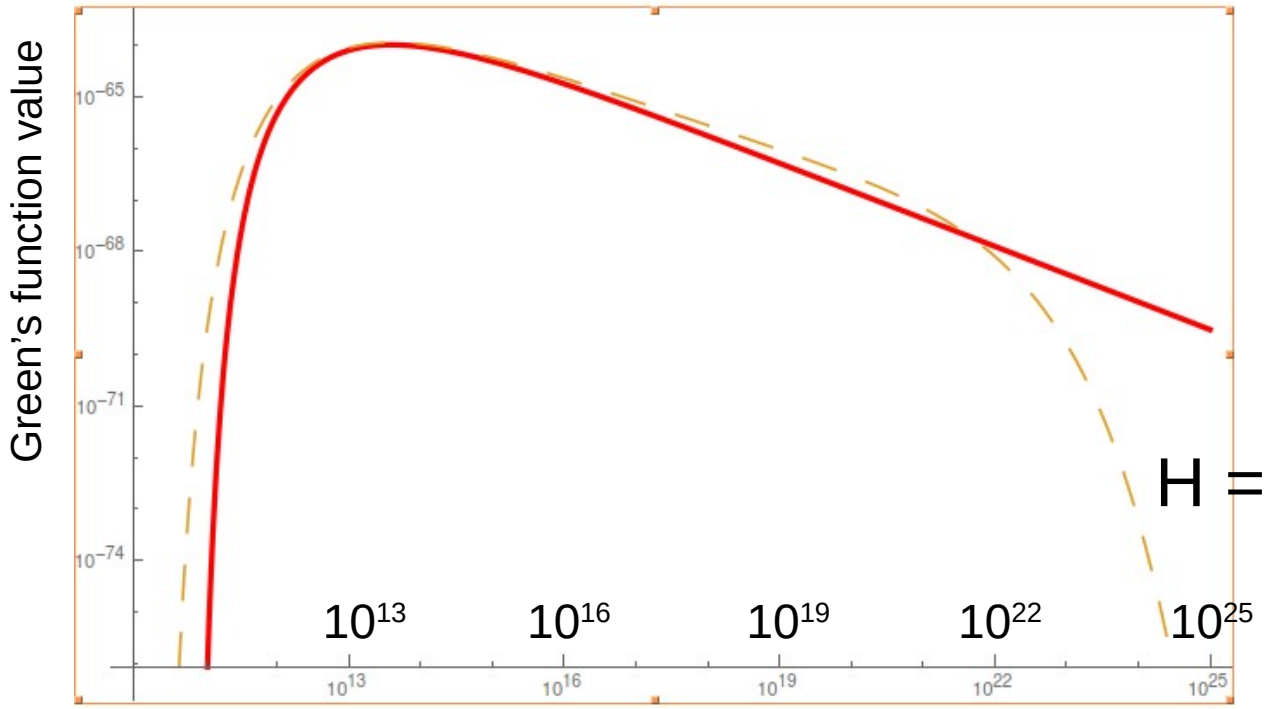
$F_Z(R, r, t)$ – local flux
$G(R, t, r)$ – Green function
R – rigidity,
r – the distance to the source,
t – age of the source

Green's function

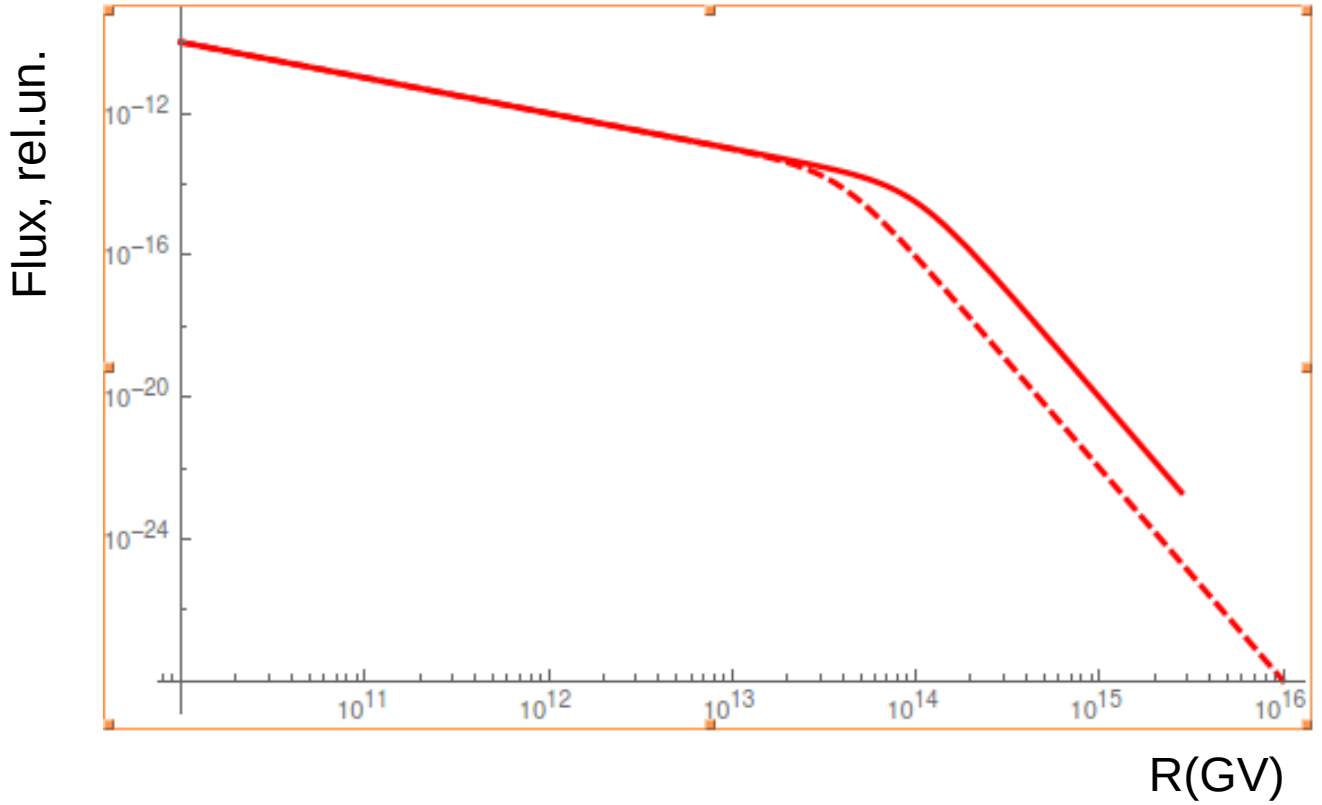
Spectrum and Anisotropy of Cosmic Rays at TeV-PeV-energies and Contribution of Nearby Sources

Classical Green's function in 3d space: $G(R, r, T) = \left[\frac{1}{4\pi D(R)T}\right]^{3/2} e^{-\frac{r^2}{4D(R)T}}$

G (r = 0.3kpc, T = 30 ky)



Spectrum and chemical composition of the source



Example parameters:

$\gamma = 2$

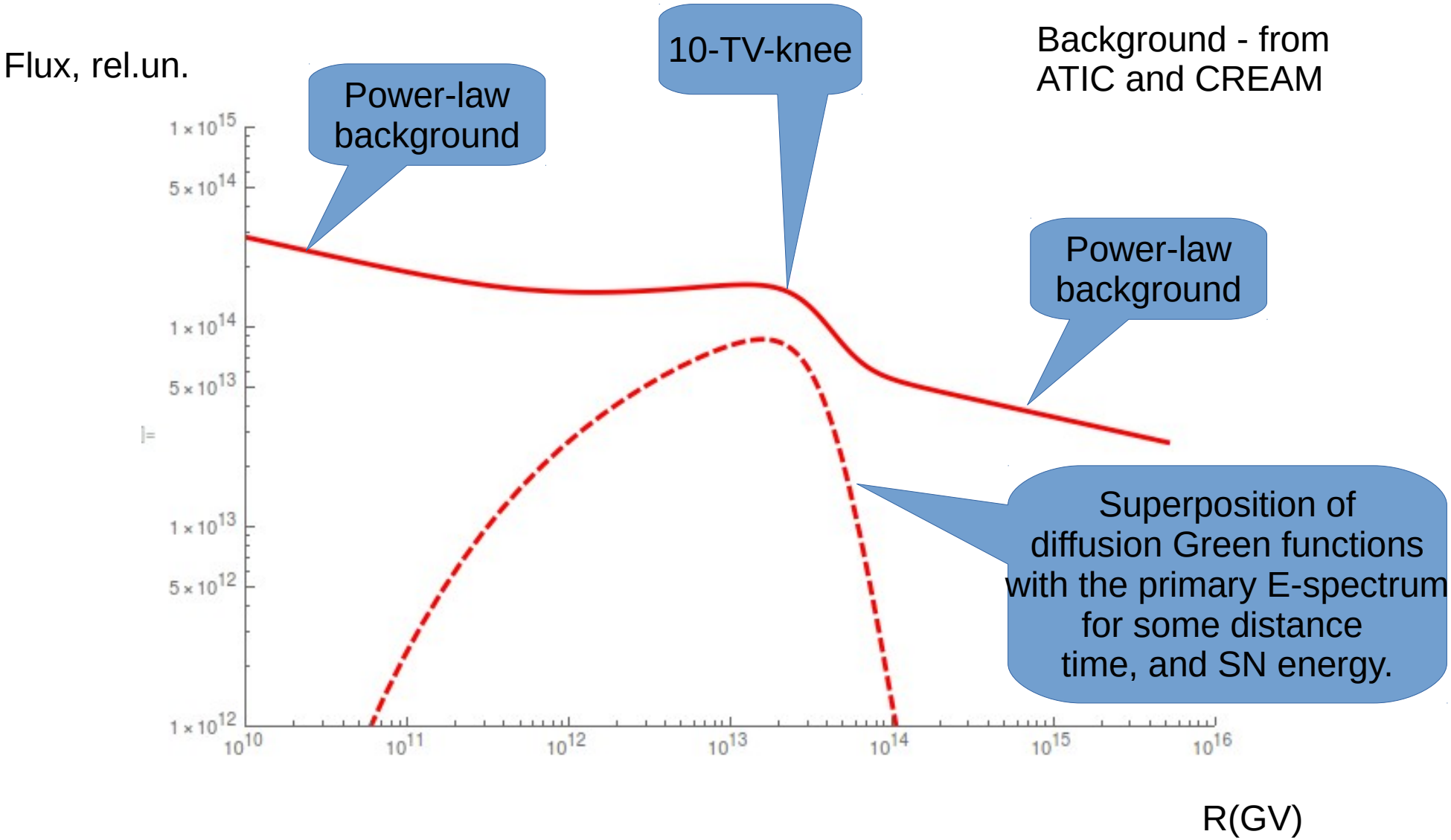
$\Delta\gamma = 2$

$\omega = 3$

$$Q_z = \frac{C}{4\pi} Z_i * NormalCoefficient * R^{-\gamma}\left(1+\left(\frac{R}{R_{ref}}\right)^{\omega}\right)^{-d\,\gamma/\omega}$$

$$NormalCoefficient = \frac{W\,k}{\int_{10^9}^{\infty}\left[R * R^{-\gamma}\left(1+\left(\frac{R}{R_{ref}}\right)^{\omega}\right)^{(-d\,\gamma/\omega)}\right]dR * \sum_{i=1}^{28}\left(Z_i\,Ab_i\right)}$$

A single source model:
Background + knee in the “Flash lamp” approximation



Multivariable fit

Minimized function:

$$\chi^2 = \sum_{Z=1,2,6,8} \sum_i \left\{ \frac{F_i^Z - M_i^Z(T, r, W, He_{abu}, C_{abu}, O_{abu})}{\sigma_i^Z} \right\}^2$$

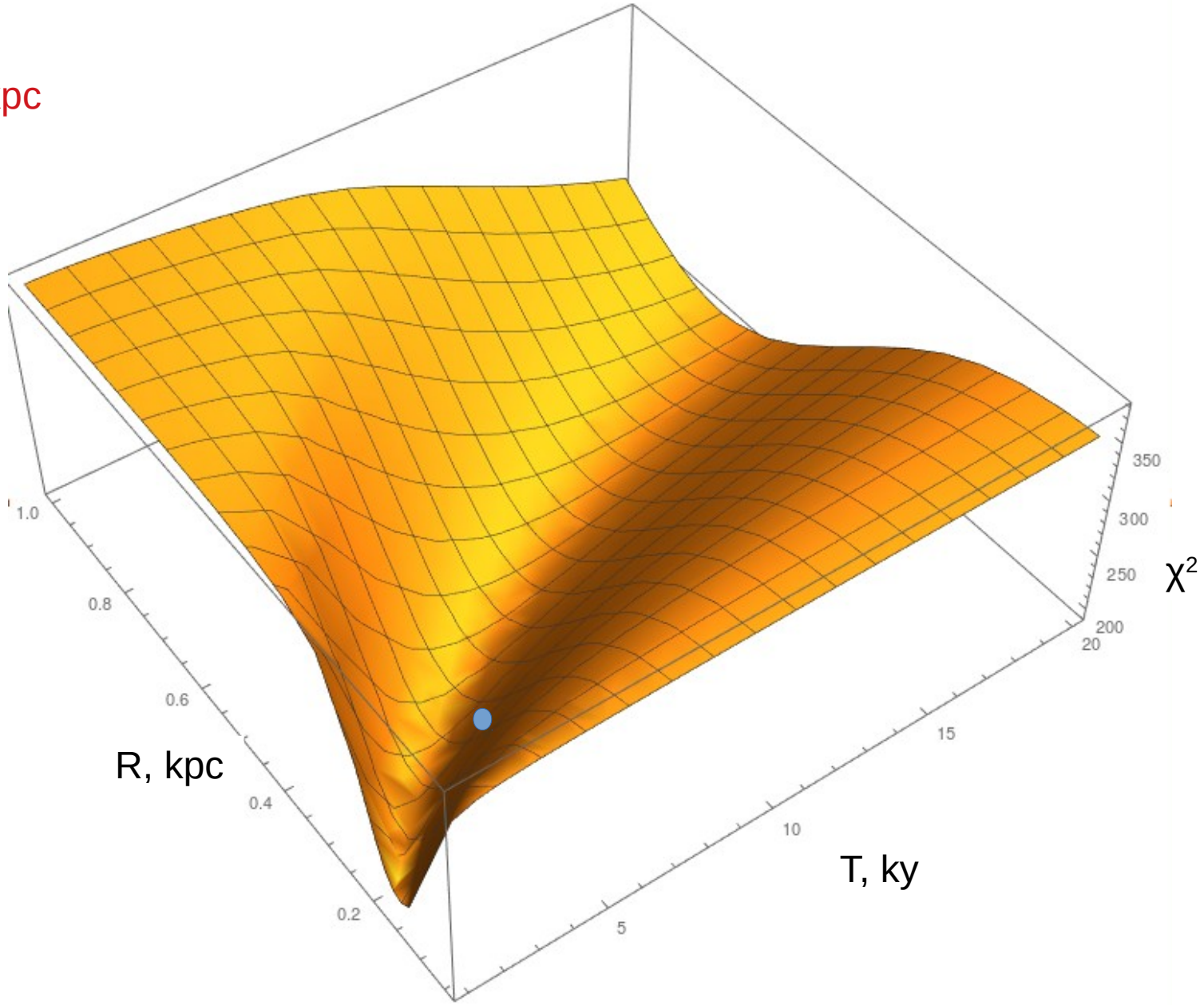
W - SN explosion energy (erg), CR fraction *k* = 0.1;
$He_{abu} = I_p / I_{He}$ etc;
i – number of point in the spectrum

In every point of the phase space (T < 20 ky, r < 1 kpc) this function is minimized for free parameters *W*, He_{abu}, C_{abu}, O_{abu}
{40 < lg*W* < 60}, {0 < He_{abu} < 1}, {0 < C_{abu} < 1}, {0 < O_{abu} < 1}

In total 45 experimental points are being fitted in 4D phase space of free parameters for each point of {T, r} space.

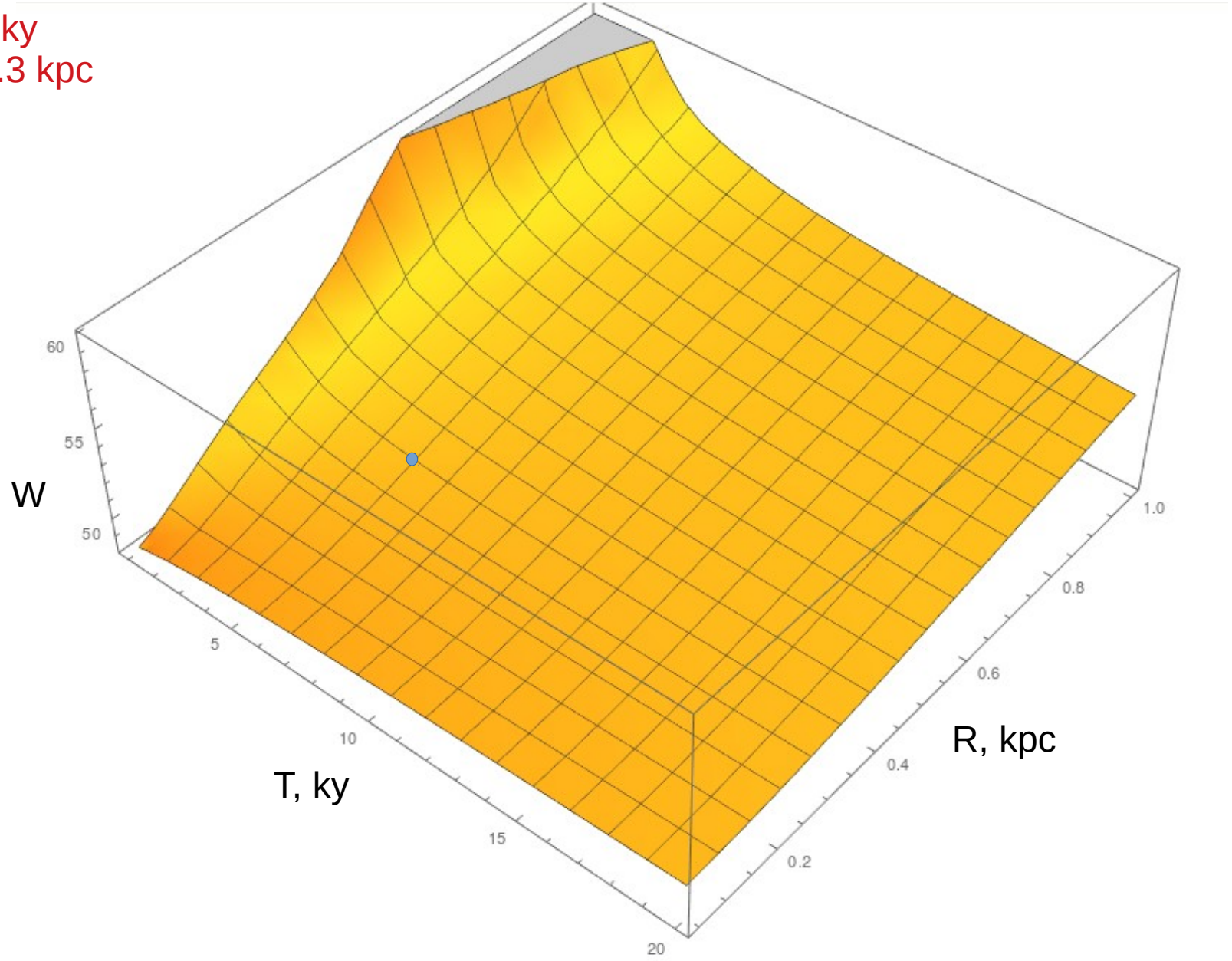
χ^2 of the approximation

Reasonable values:
T ~ 5 ky
R ~ 0.3 kpc



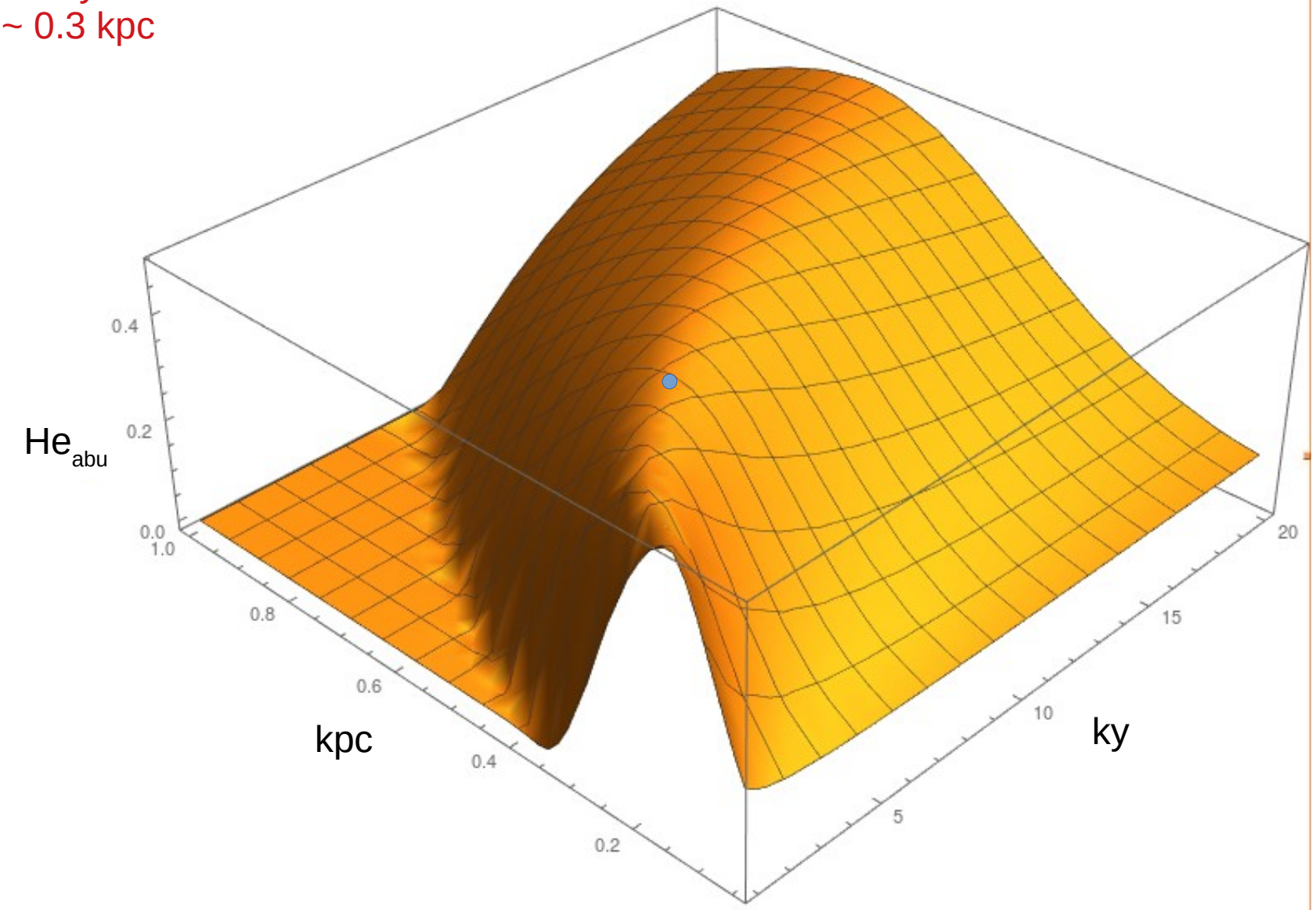
Reasonable values:
T ~ 5 ky
R ~ 0.3 kpc

Logarithm of source power, W



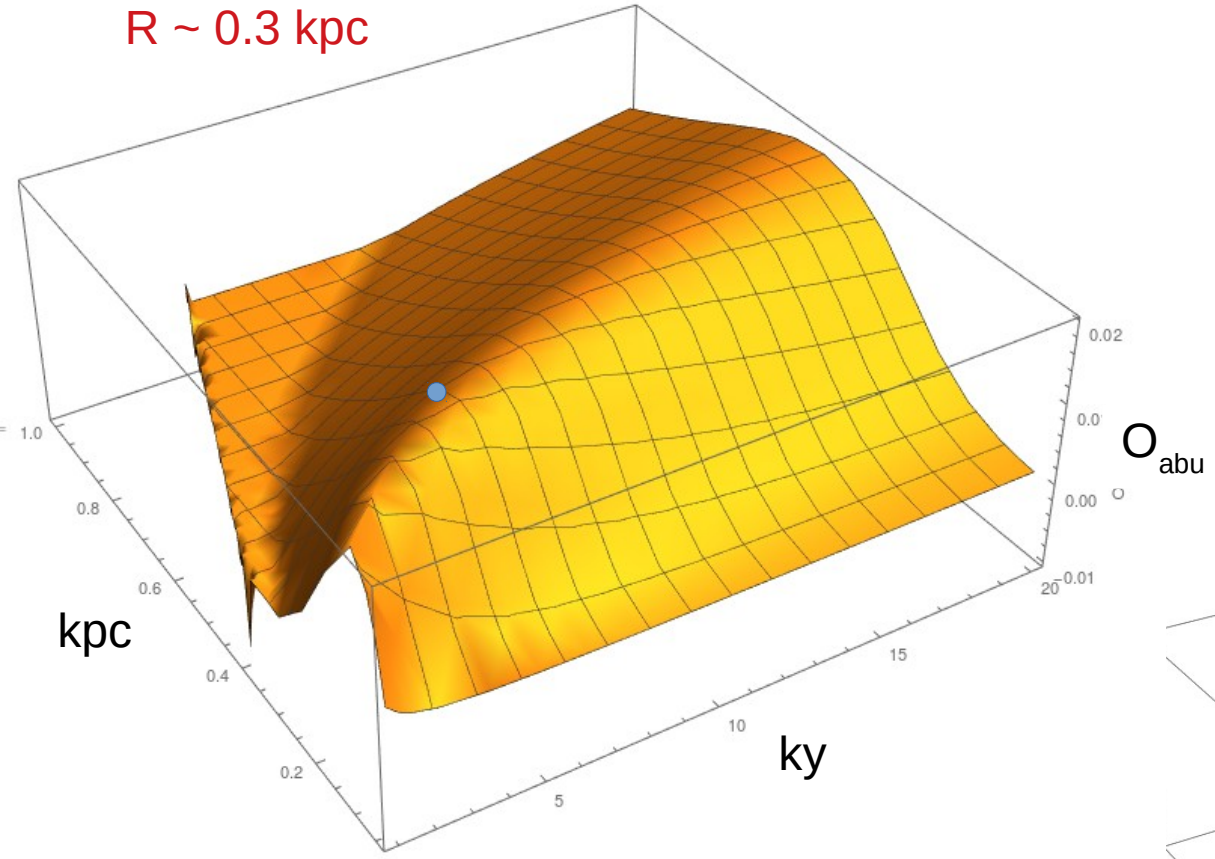
He/H ratio in the source

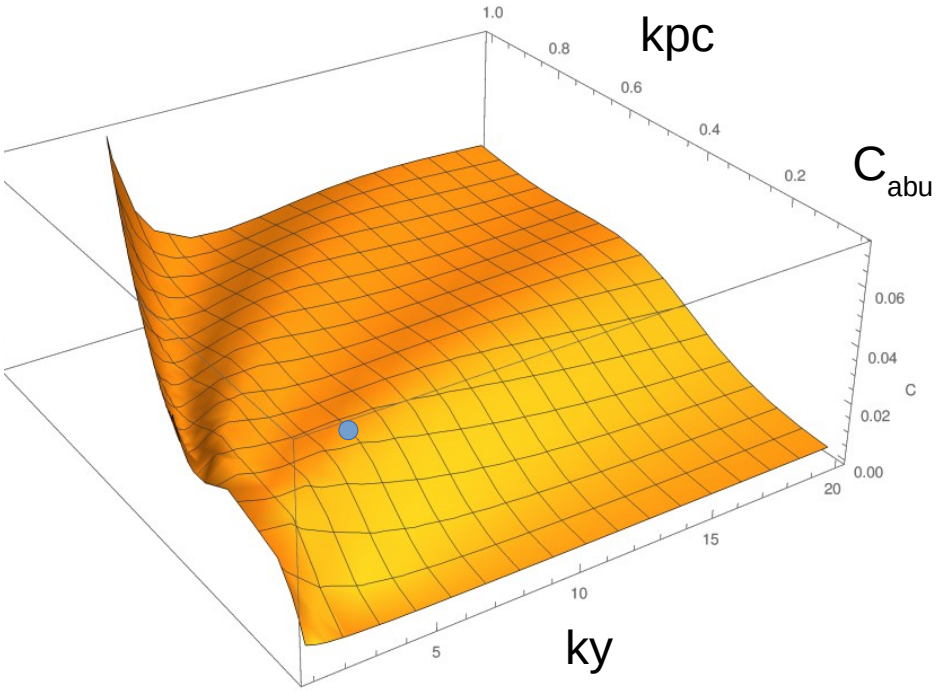
Reasonable values:
T ~ 5 ky
R ~ 0.3 kpc



C/H and O/H in the source

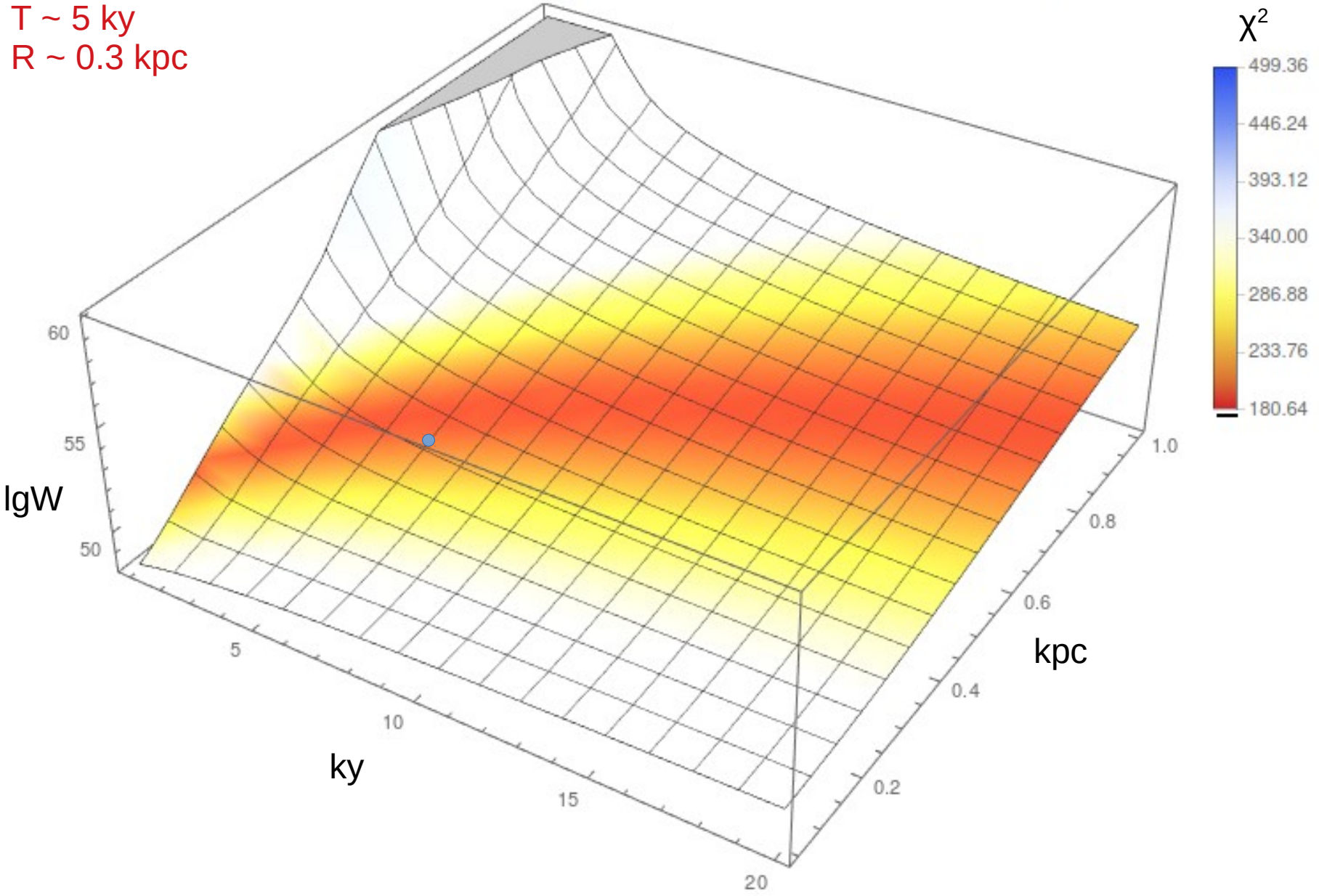
Reasonable values:
T ~ 5 ky
R ~ 0.3 kpc



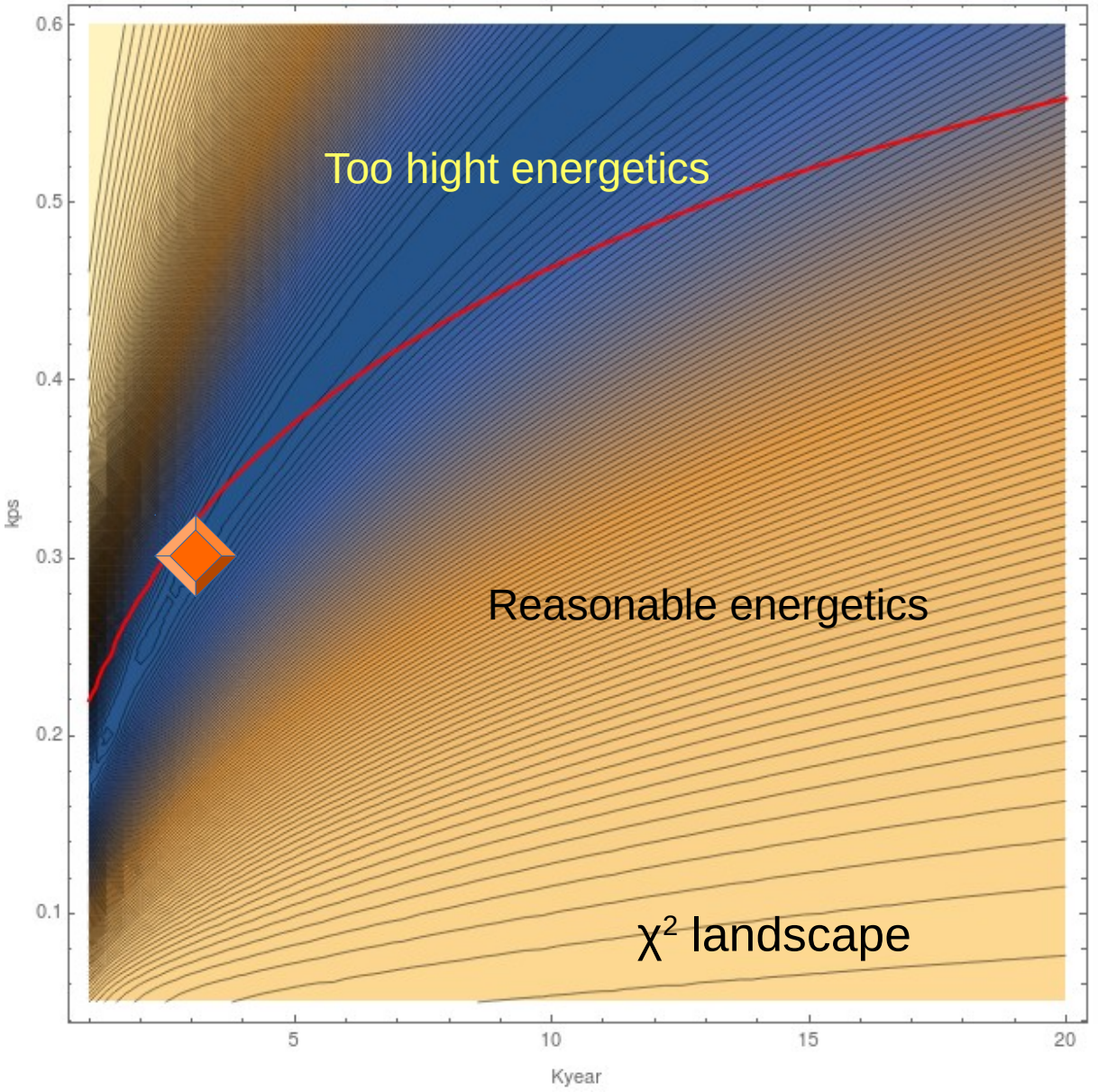


Possible source existence region

Reasonable values:
T ~ 5 ky
R ~ 0.3 kpc

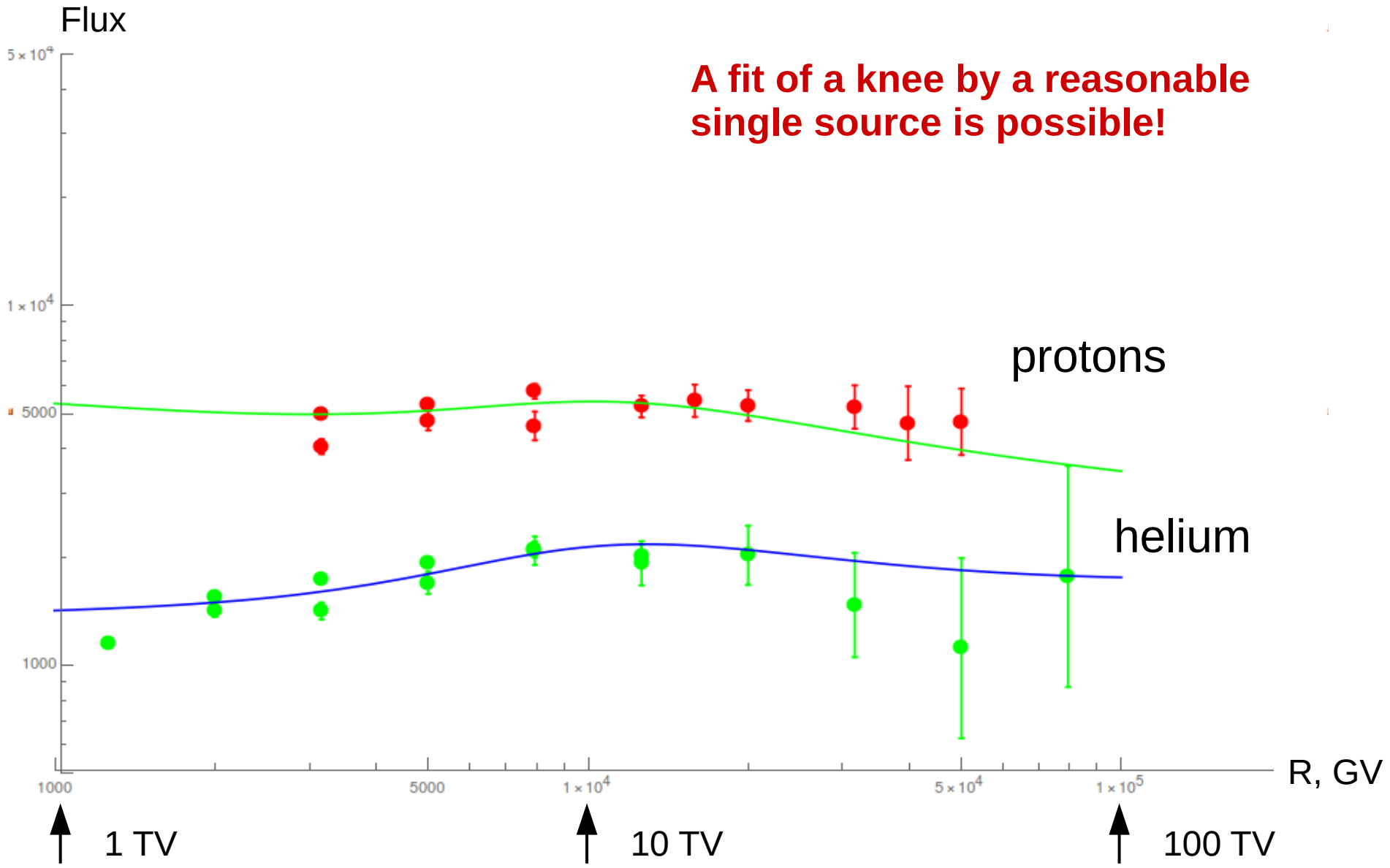


The best fit:
T = 3 ky, L = 0.3 kpc, W = 1.6 10^{51} erg (10% in the cosmic rays)



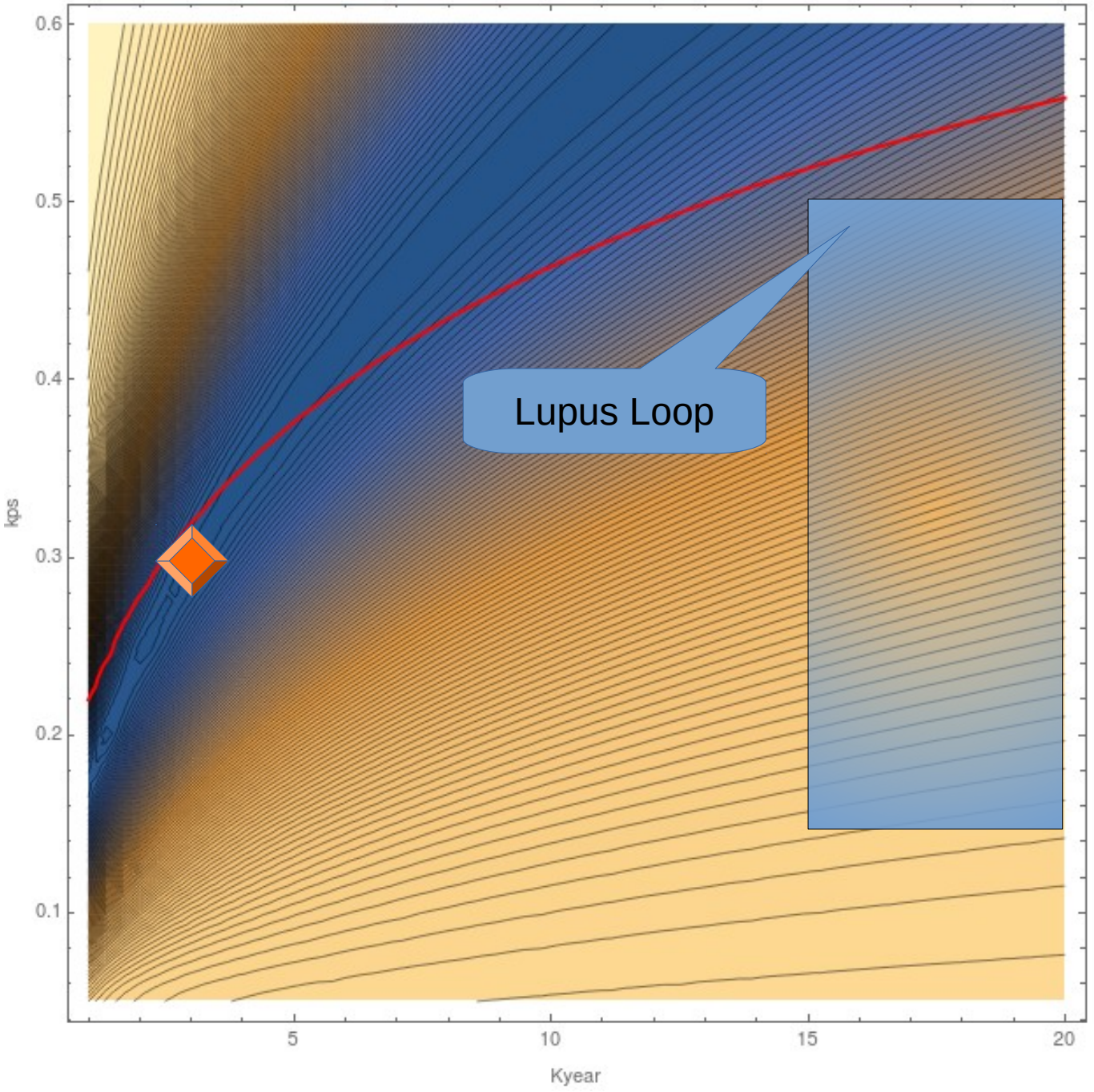
3 10^{51} erg

All nuclei groups are fitted by the same single source separately

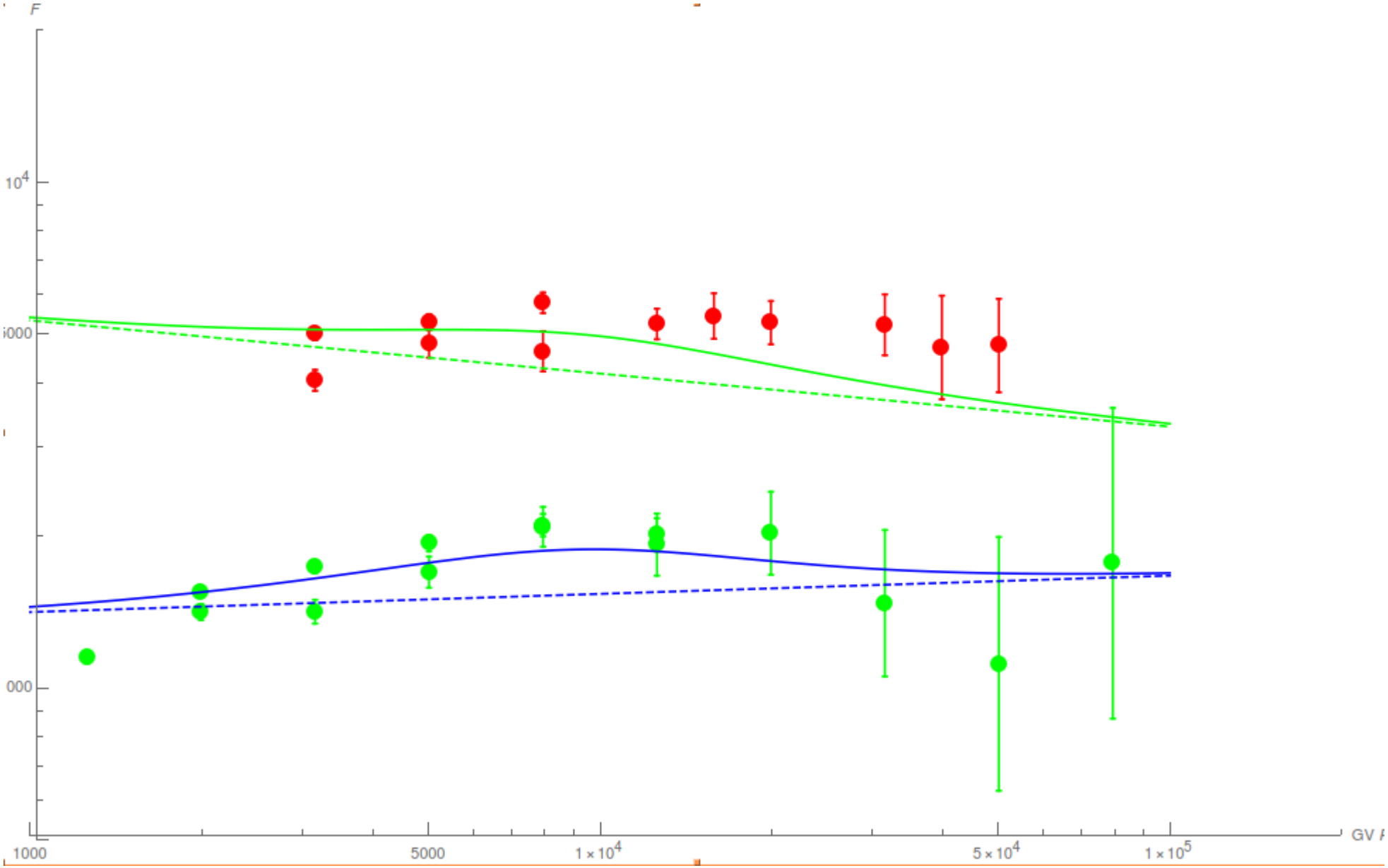


Lupus Loop:

L = 0.15 – 0.5 kpc
T = 15 – 30 ky



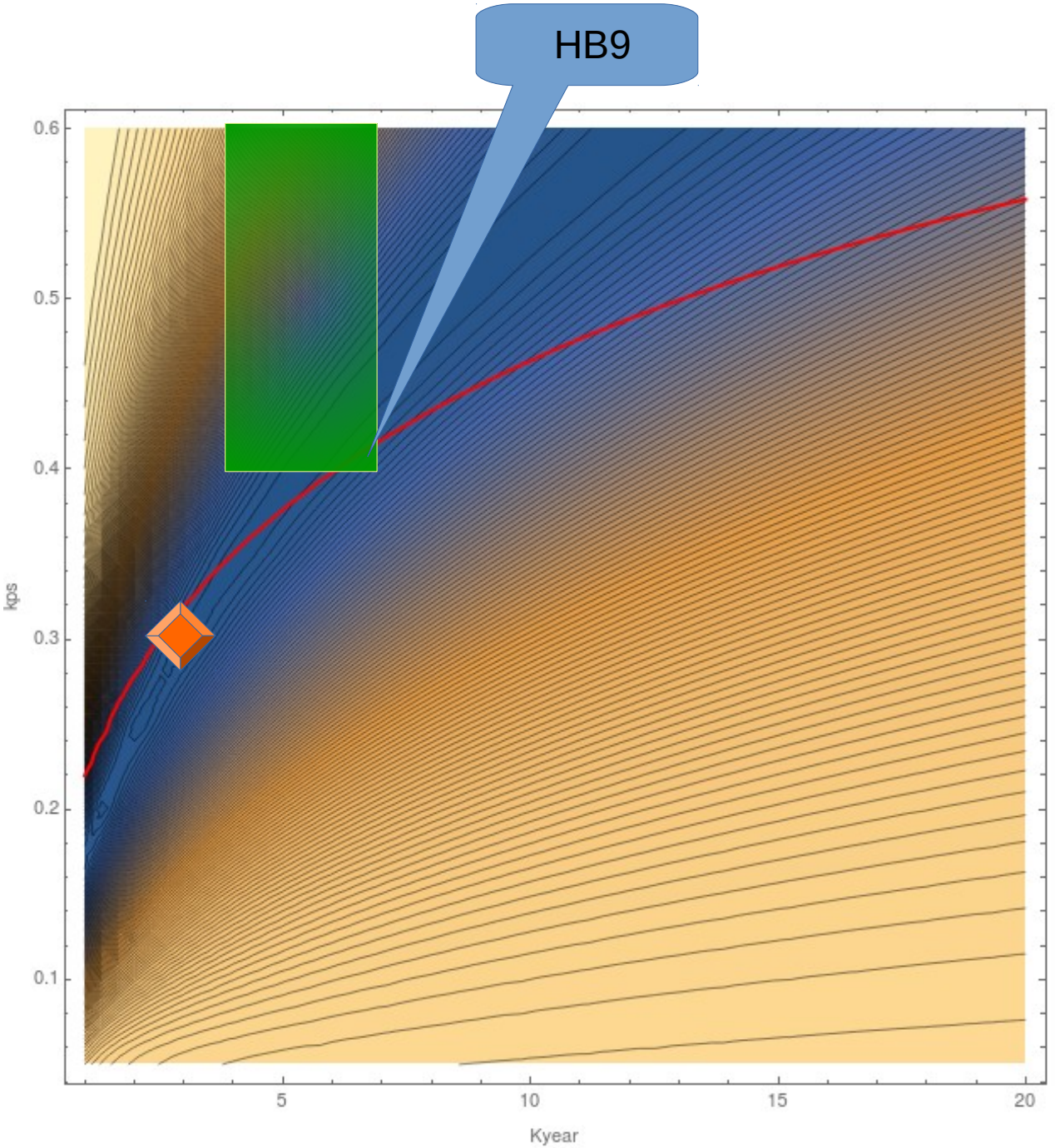
Lupus Loop



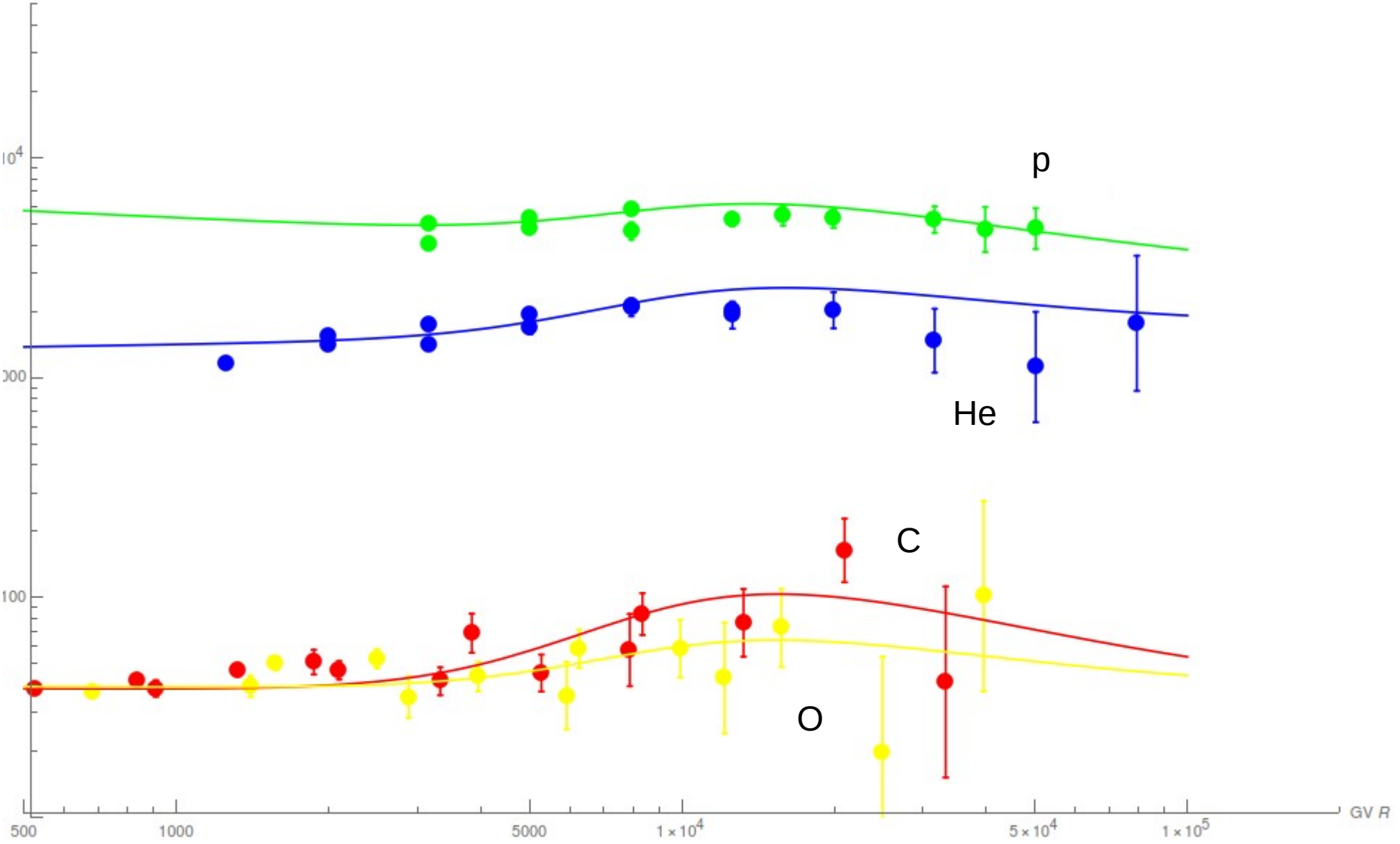
HB9 - Good real candidate

D. A. Leahy and W. W. Tian
A&A, V.461, 1013 (2007)

L = 0.4 – 1.2 kpc
T = 4 – 7 ky



HB9



Conclusions

- A fit of a 10TV-knee by a reasonable single source is possible.
- There are several of SNR candidates to fit 10TV-knee.
- There may be several SNR that are invisible to us

Further development of the model

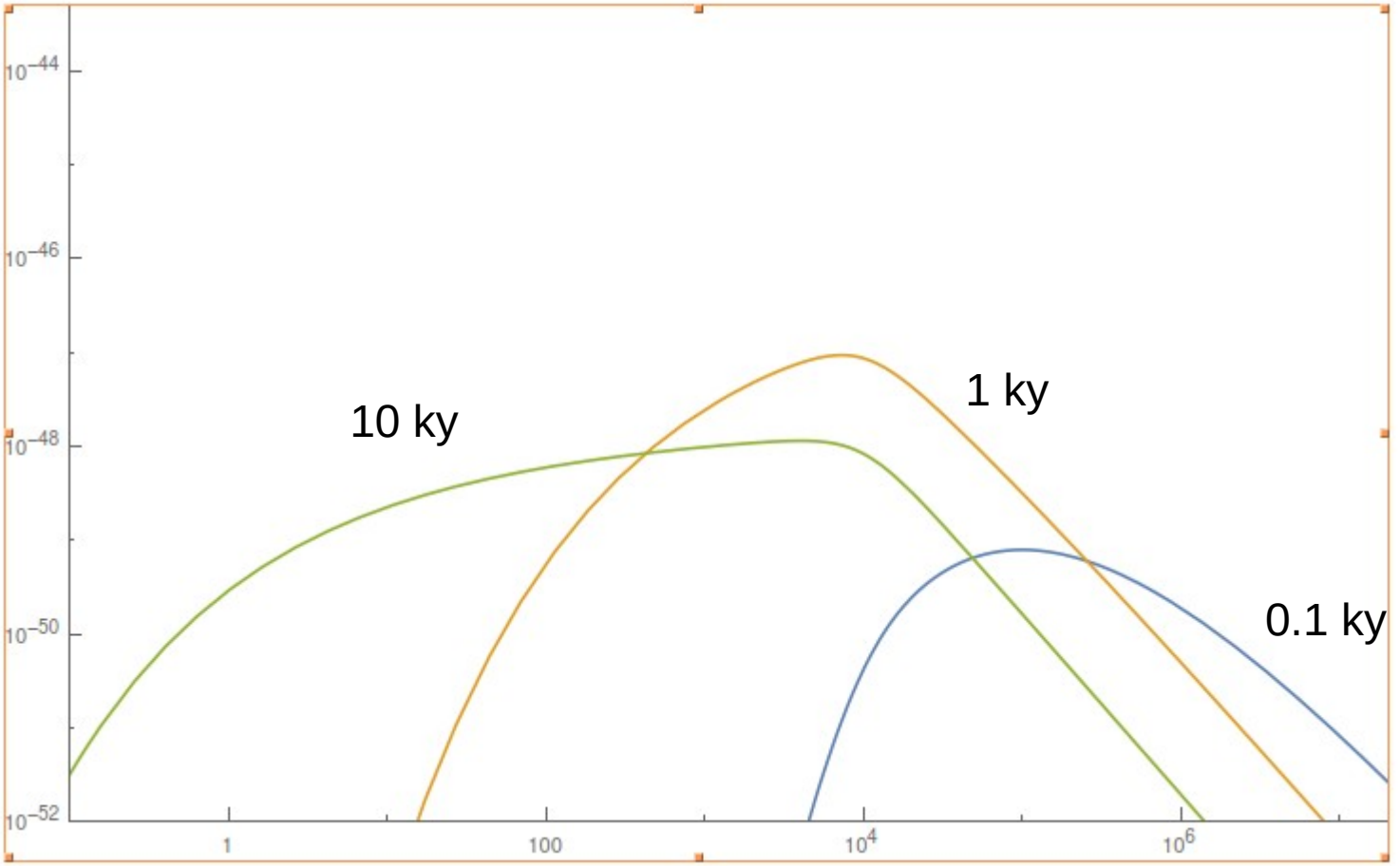
- Inclusion of EAS experiments (VERITAS, HAWC) to get a better fit for the source
- Transition from the “flash lamp” approximation to models with source spectrum dependence on age of the SNR
- Inclusion of gamma astronomy data to construct source models

Back ups

Point-like source contribution age dependence

Distance r = 0.1 kpc

Flux, rel.un.



R(GV)