ICRC 2015 - The Hague
July 30 – August 6, 2015

Type II Supernova Remnants and Cosmic-Ray Spectrum

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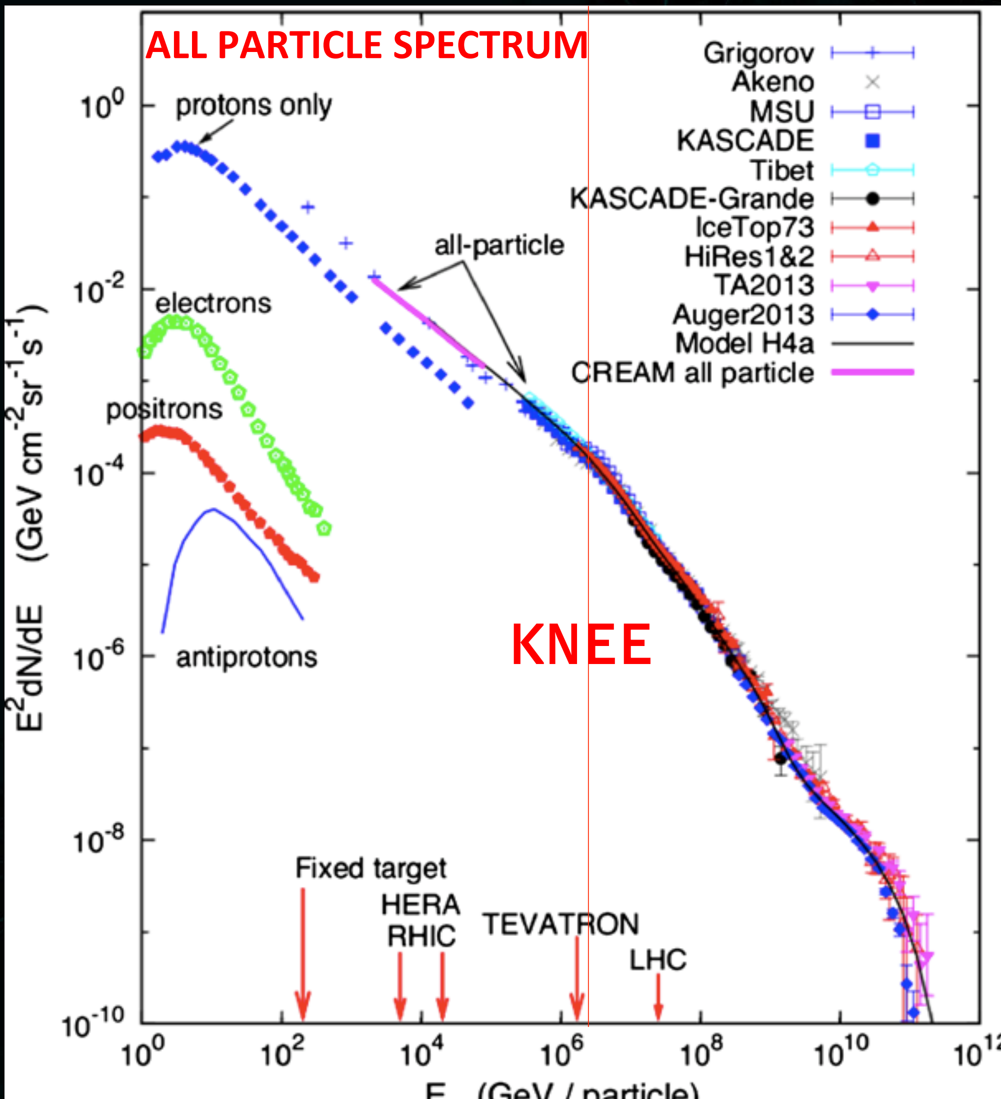
OVERVIEW



SNR accelerate Galactic Cosmic Rays

How can we reach PeV energies?

Upstream magnetic field amplification.

How?

Resonant instability ($\lambda \sim r_L$)

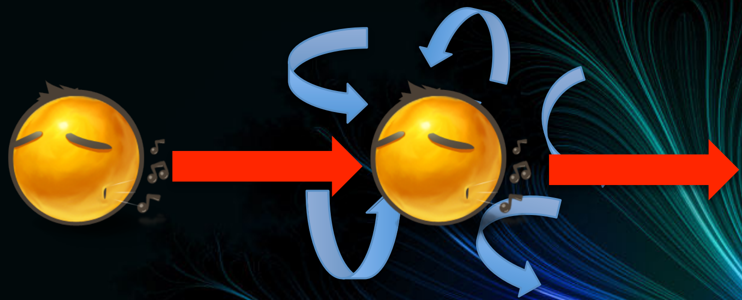
(Skilling 1975)

Not enough

(Lagage&Cesarsky83)

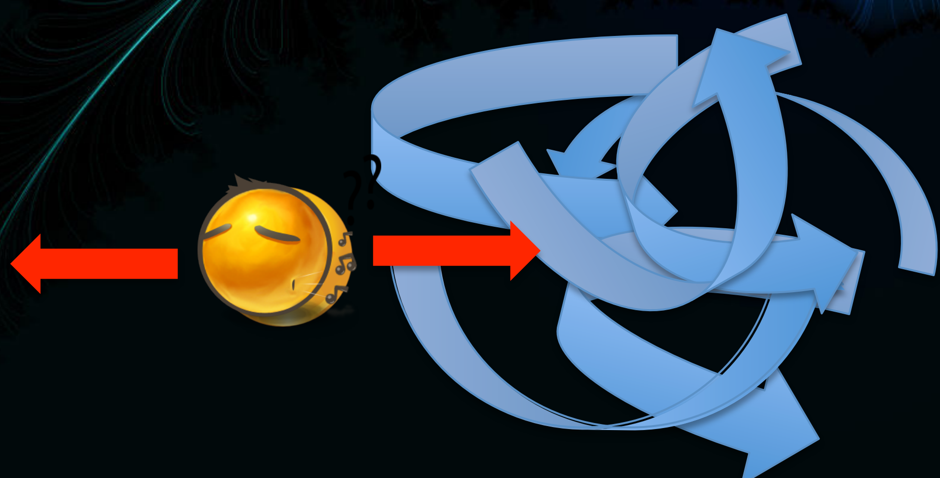
NRH INSTABILITY: HOW DOES IT WORK?

In presence of high CR acceleration efficiency, current driven regime and fast growing non-resonant modes (Bell 2004)



High energy particles escape the remnant balistically because $\lambda << r_L$

The scale of the instability is too small and there is no particle scattering
→ magnetic field perturbations grow up to resonant scales $\lambda \sim r_L$.



Particles with the same energies are scattered resonantly by perturbations towards the downstream.

Efficient acceleration

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MAXIMUM ENERGY

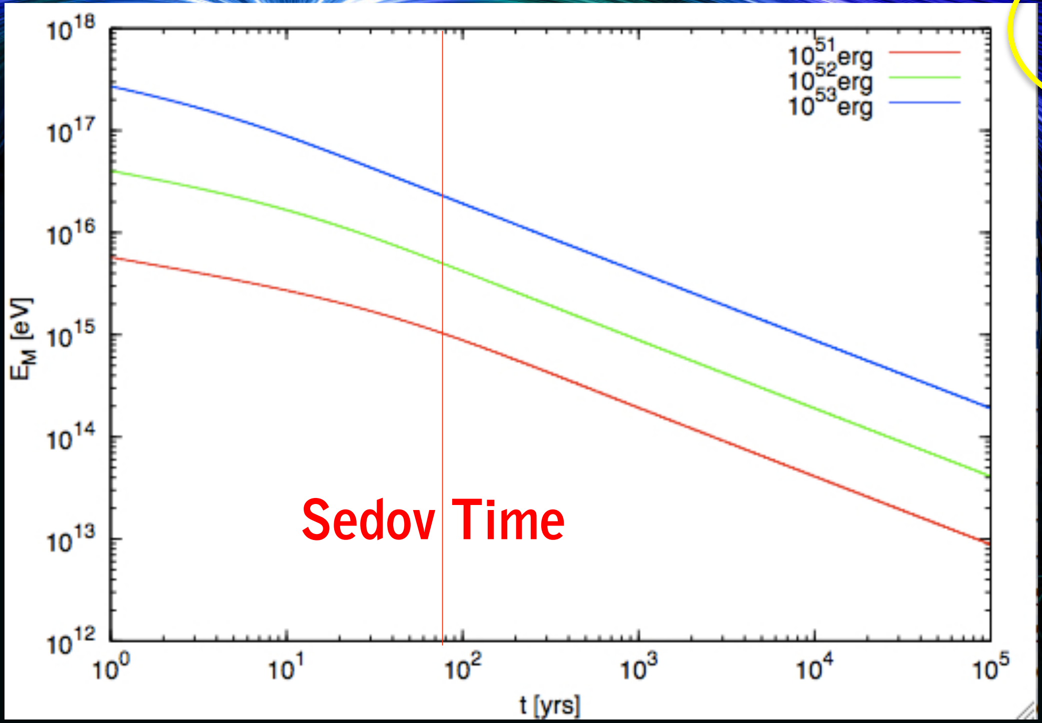
- Current driven regime
- Simulation results about growth rate (Bell,Schure 2013)
- Ejecta and Medium density profile

Type I (ISM)

$$E_M(R) \cong \frac{2Ze}{10}\sqrt{4\pi\rho R^2}\,\frac{\xi_{CR}}{c\Lambda}\,v_{sh}^2(R) = 130\left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-2/3}\left(\frac{E_{SN}}{10^{51}\,erg}\right)\left(\frac{n_{ISM}}{cm^{-3}}\right)^{1/6} TeV$$

$$E_M(R) \cong \frac{2Ze}{5}\sqrt{4\pi\rho R^2}\,\frac{\xi_{CR}}{c\Lambda}\,v_{sh}^2(R) = 1\left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-1}\left(\frac{E_{SN}}{10^{51}\,erg}\right)\left(\frac{\dot{M}}{10^{-5}\,km/yr}\right)^{1/2}\left(\frac{V_w}{10\,km/s}\right)^{-1/2} PeV$$

Type II (wind)



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ESCAPE SPECTRUM

- Power-law time dependence of the SNR radius, changing during the whole SNR evolution → $N_{esc}(E)=N_{esc}(\xi_{CR}, E_{SN})$

$$N_{esc}(E)=\begin{cases} E^{-(5+4\varepsilon)} & ED \\ E^{-(2+\varepsilon)} & ST \end{cases}$$

Type I

If injection spectral index $p \leq 2$ → $\varepsilon = 0$

$$N_{esc}(E)=\begin{cases} E^{-(4+3\varepsilon)} & ED \\ E^{-(2+\varepsilon)} & ST \end{cases}$$

Type II

If injection spectral index $p > 2$ → $\varepsilon \neq 0$

✧ The escape spectrum reproduces the injection spectrum only if $p = 2$ or steeper

✧ The spetrum is a broken power-law → There is no sharp cut-off for energies above E_M

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OBSERVED SPECTRUM

- Taking into account diffusion and spallation contributions
- Using B/C ratio in order to extimate the grammage:

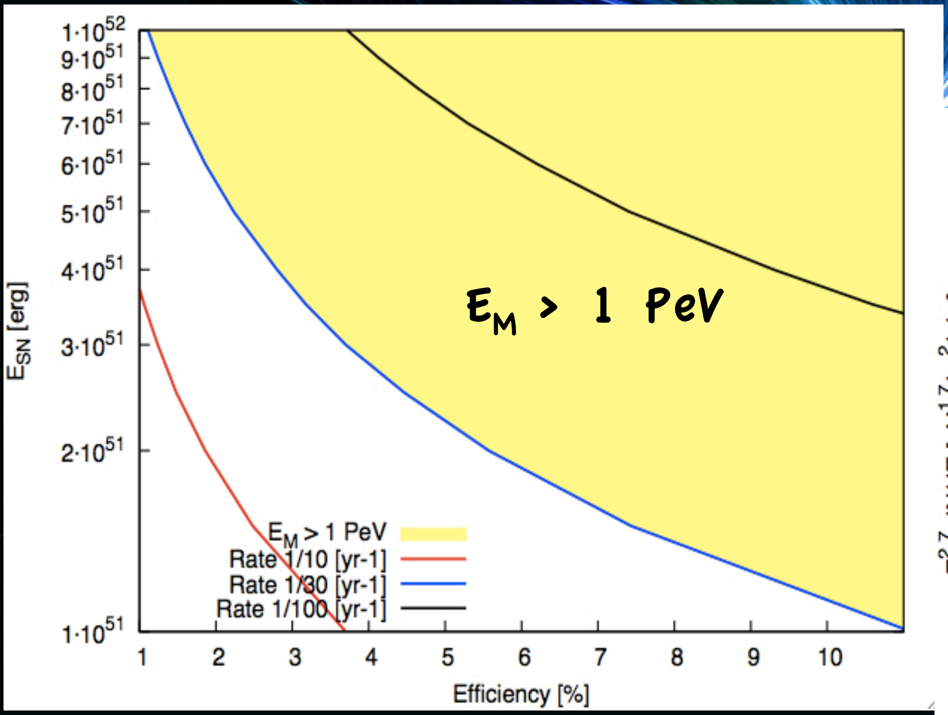
Escape — Diffusion — Spallation

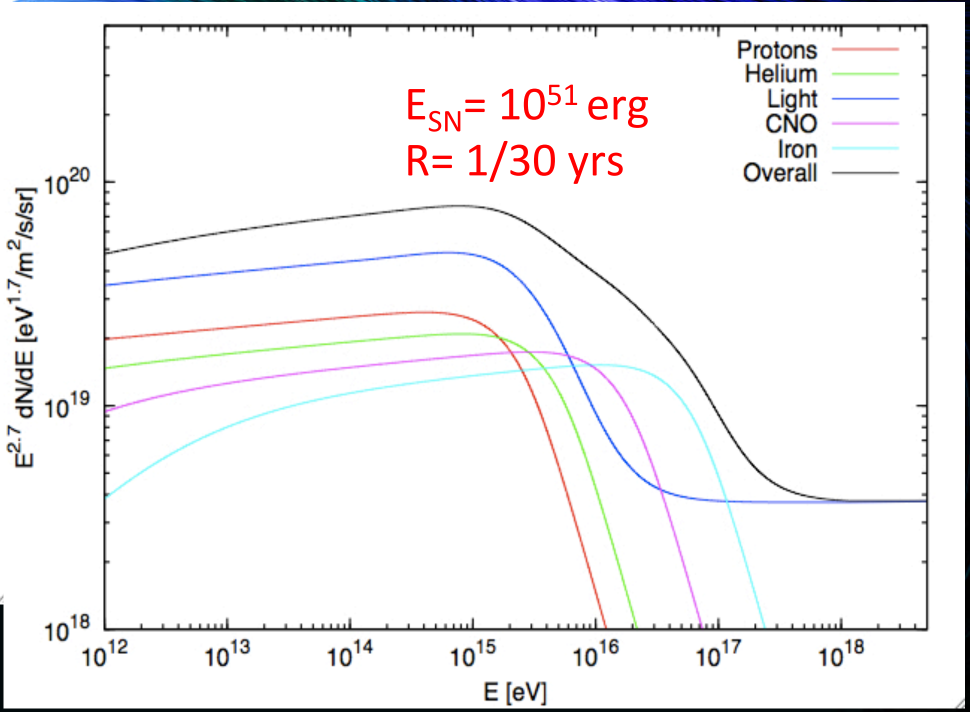
$$N_{obs}(E) = N_{esc}(E) \times \frac{\Re}{2\pi R_D^2} \frac{X(E)}{n_D h c m_p} \times \left(1 + \frac{X(E)}{m_p/\sigma_{sp}}\right)^{-1}$$

$$X(E) = n_D \frac{h}{H} c m_p \frac{H^2}{D_0} \left(\frac{E}{eZ}\right)^{-\delta}$$

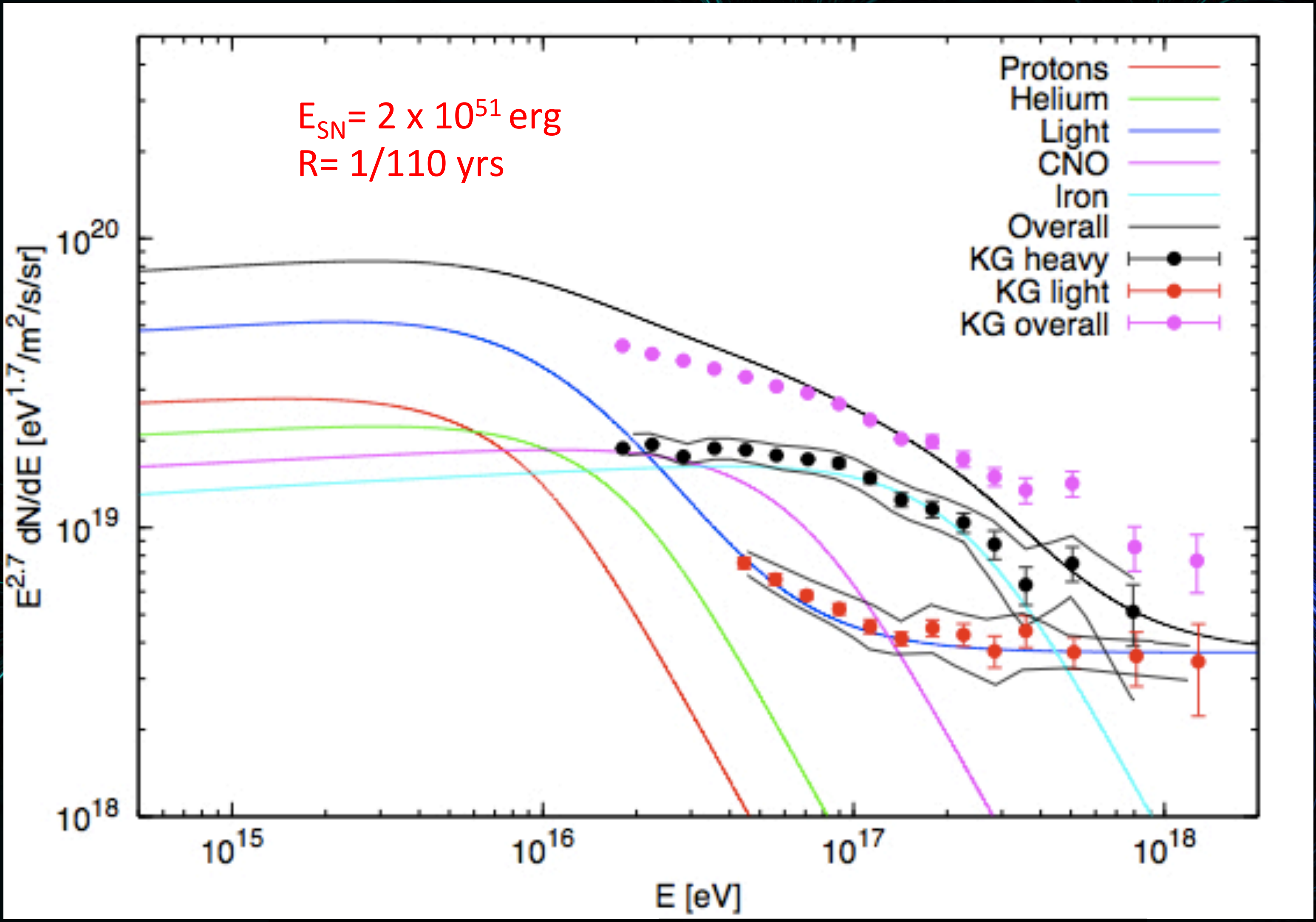
E_M= 1 PeV
ξ_{CR}= 11%

t_0= 85 yrs
v_0=15.700 km/s





KASCADE-Grande (Apel 2013)



E_M= 3.7 PeV t_0= 60 yrs

ξ_{CR}= 20% v_0=22.200 km/s

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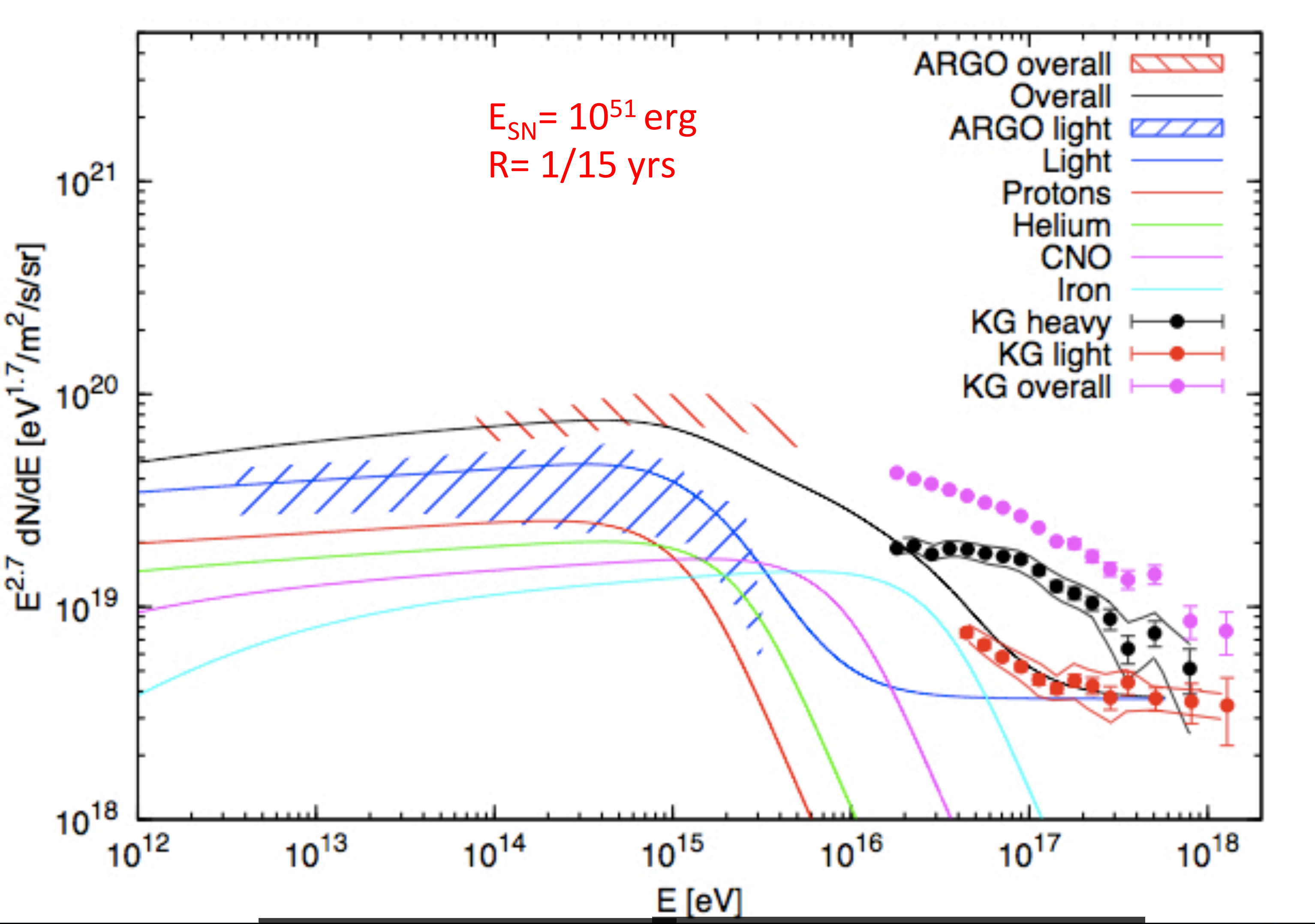
ARGO (Di Sciascio 2014)

(Dr.Shoushan, Dr De Mitri, Dr Montini, ICRC 2015)



E_M= 507 TeV t_0= 85 yrs

ξ_{CR}= 5.2% v_0=15700 km/s

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AND SO?

✧ Type II SNRs can accelerate particles up to the knee through the NRH instability

✧NHR instability leads to the release of a steep power-law spectrum in the ejecta dominated phase → no sharp cut-off!

✧ KASCADE Grande and ARGO data can be fitted with reasonable values of SN parameters.

BUT..

✧ Type II SNRs can accelerate particles up to the knee at very early time → detection problem.

✧ No model that can fit both ARGO and KASCADE-Grande data → need a better data understanding with a consequent theory improvement.


Thank you
very much!