ORIGIN OF COSMIC RAYS

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OUTLINE

- **Common wisdom**
- **Recent data**
  - *Positron excess*
  - *Antiprotons*
  - *Secondary nuclei*
- **What does it all mean?**
- **Very high energy regime and transition to UHECR**

THE COMMON WISDOM

- COSMIC RAYS ARE ACCELERATED AT SNR THROUGH DSA
- PROPAGATION IN THE GALAXY IS DIFFUSIVE/ADVECTIVE
- SECONDARY/PRIMARY PROVIDE INFORMATION ON TRANSPORT
- THE KNEE IS CAUSED BY
  - *Emax WITH CHANGE OF MASS*
  - *CHANGE FROM PITCH ANGLE TO SMALL DEFLECTION*
- TRANSITION TO EXTRA-GALACTIC CR OCCURS SOMEWHERE BETWEEN 10^{17} AND 10^{19} eV

COSMIC RAY ACCELERATION

DIFFUSIVE SHOCK ACCELERATION
TEST PARTICLE APPROACH

- Diffusion of charged particles back and forth across the shock leads to:

$$\frac{\Delta E}{E} = \frac{4}{3}(U_1 - U_2)$$

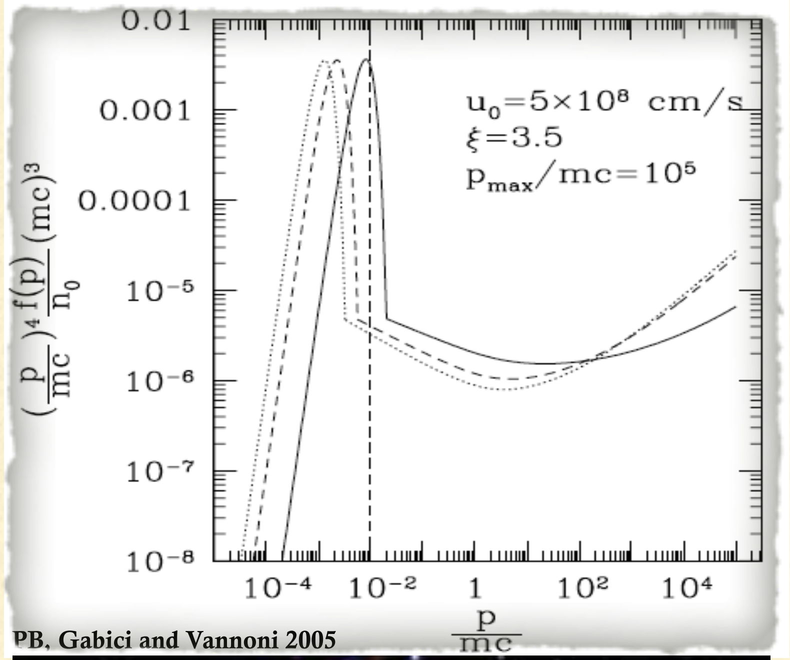
- POWER LAW SPECTRUM (only depends on compression factor)
- FOR STRONG SHOCKS (Mach>>1): E^{-2}
- INDEPENDENT OF MICRO-PHYSICS (e.g. THE DIFFUSION COEFFICIENT)

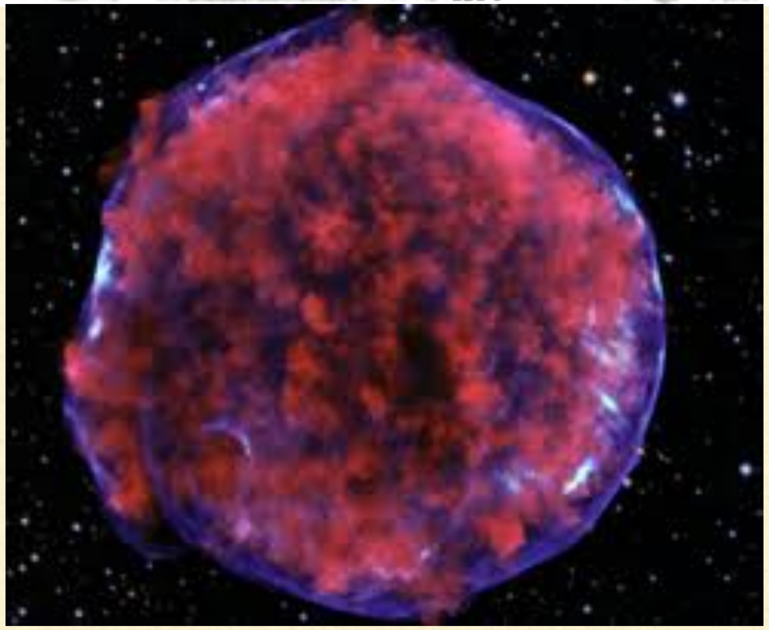
THE EFFICIENCY REQUIRED PER SNR ~10%: TEST PARTICLES?
MAXIMUM ENERGY TYPICALLY BELOW TeV: NOT ENOUGH FOR CR

NON-LINEAR DSA

HIGH EFFICIENCY WITH RESPECT TO ρV_{Shock}^2 ➜ *DYNAMICAL REACTION OF ACCELERATED PARTICLES*

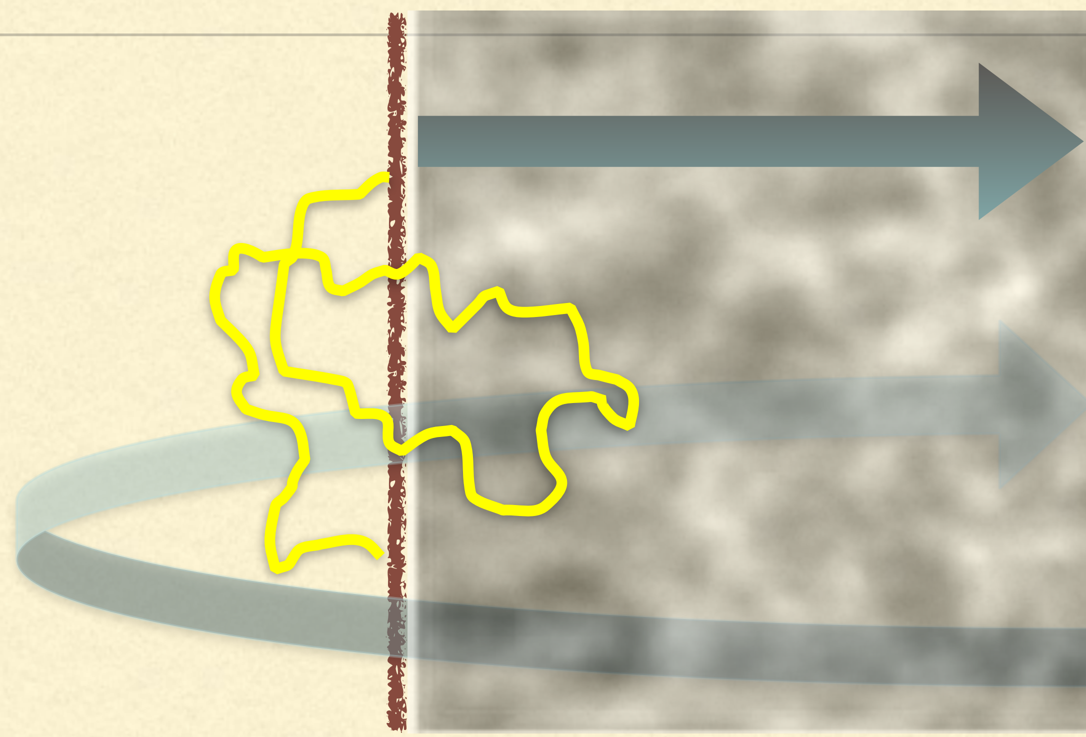
EFFICIENT ACCELERATION ➜ PLASMA INSTABILITIES ➜ B-FIELD AMPLIFICATION ➜ *HIGHER Emax*



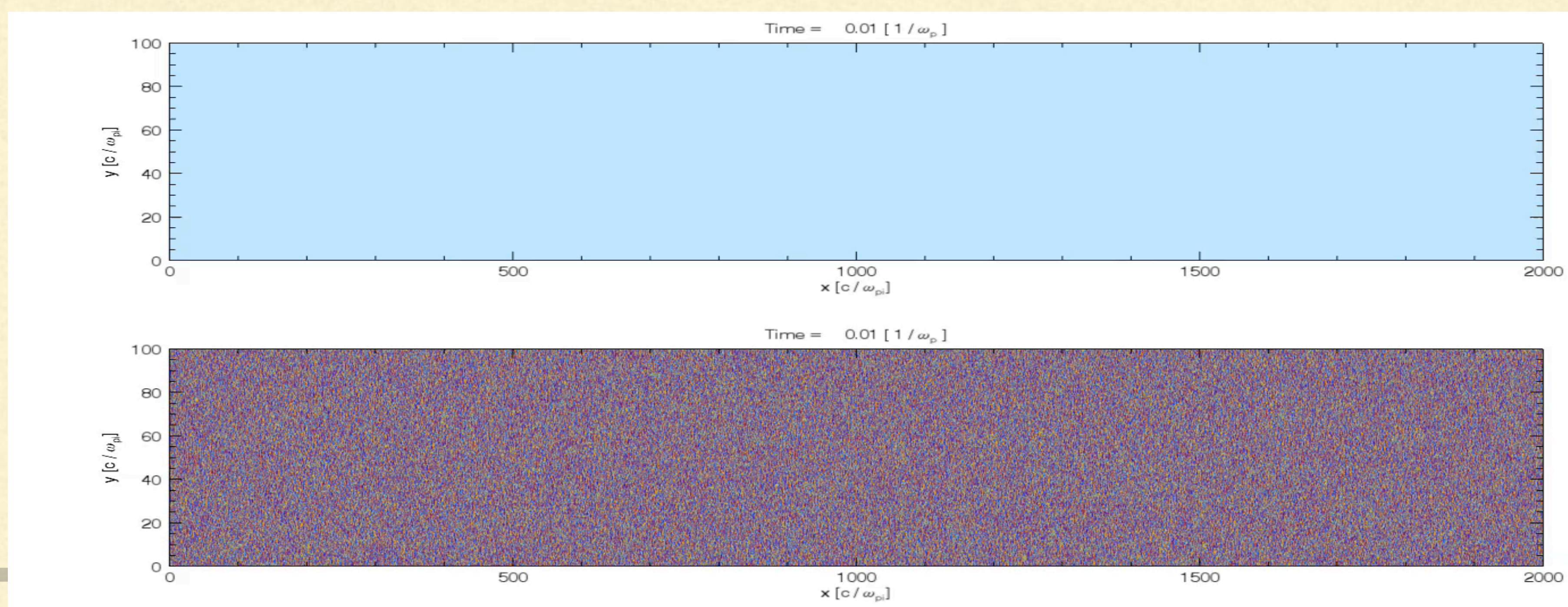


BOOTSTRAPPING…

DOWNSTREAM UPSTREAM



Bell & Schure 2013



Caprioli & Spitkovsky 2013

THE FASTEST GROWING MODES

QUASI PURELY GROWING NON-RESONANT MODES

Bell (2004): for parameters of a young SNR - new instability when

$$n_{CR}(>E)E\frac{v_s}{c} > \frac{B_0^2}{4\pi} = U_{mag}$$

Energy density of escaping CRs

$$\gamma_{max} = k_{max} v_A \qquad k_{max} B_0 = \frac{4\pi}{c} J_{CR}^{esc}$$

Growth rate $\qquad k_{max} \gg 1/r_L(E)$

The instability grows on non-resonant scales -> current not affected

Force on fluid element -> scale of the field increases

$$\rho \frac{dv}{dt} \approx J_{CR}\,\delta B(t) \rightarrow \frac{\delta B^2}{4\pi} \approx n_{CR}(>E)E\frac{v_s}{c}$$

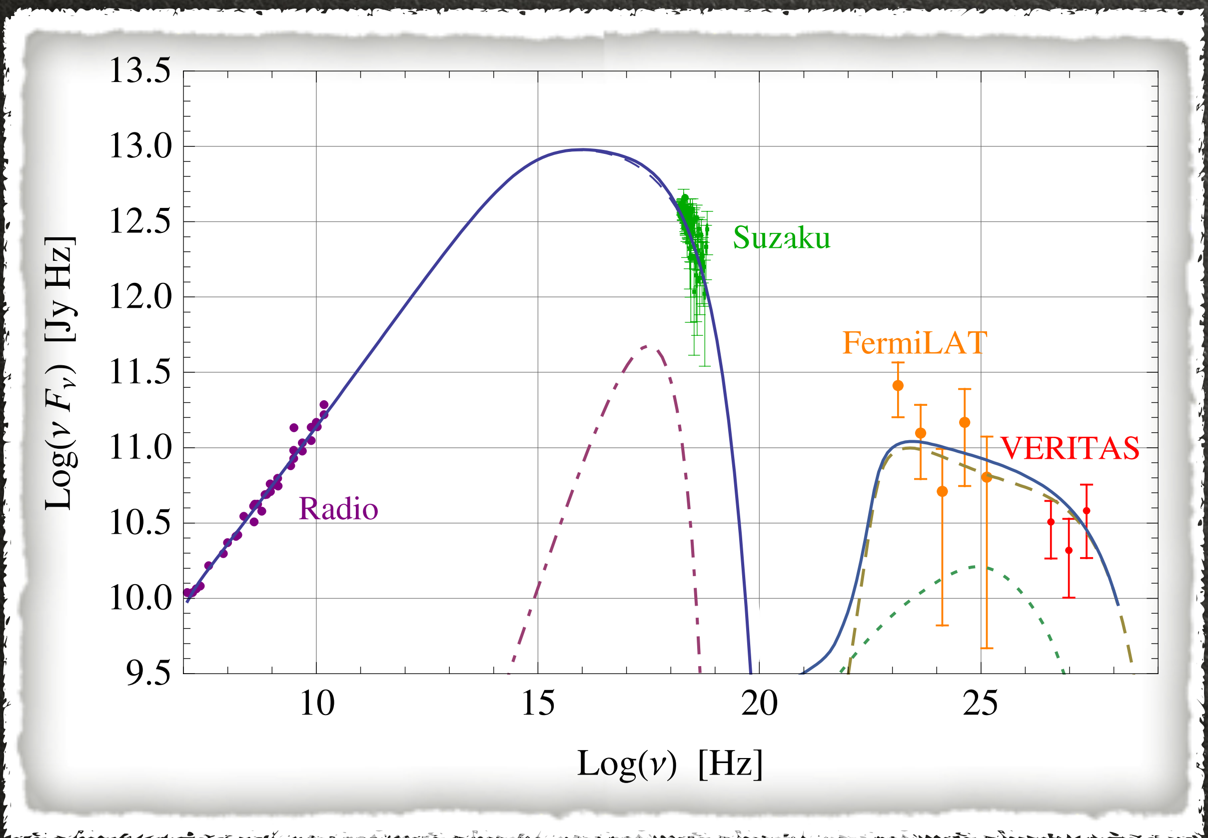
THE FIELD SATURATION —> EQUIPARTITION BETWEEN MAGNETIC ENERGY AND ENERGY OF ESCAPING CR —> TYPICALLY SEVERAL HUNDRED MICROGAUSS AFTER COMPRESSION, FOR A YOUNG SNR

IMPLICATIONS FOR MAXIMUM ENERGY

Supernovae of type Ia

Explosion takes place in the ISM with spatially constant density

$$E_{max} \approx 130\ TeV \left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-2/3}\left(\frac{E_{SN}}{10^{51} erg}\right)\left(\frac{n_{ISM}}{cm^{-3}}\right)^{1/6}$$



Supernovae of type II

In most cases the explosion takes place in the dense wind of the red super-giant progenitor

$$\rho(r) = \frac{\dot{M}}{4\pi r^2 v_W}$$

The Sedov phase reached while the shock expands inside the wind

$$R = M_{ej} v_W / \dot{M}$$

This corresponds to typical times of few tens of years after the SN explosion !!!

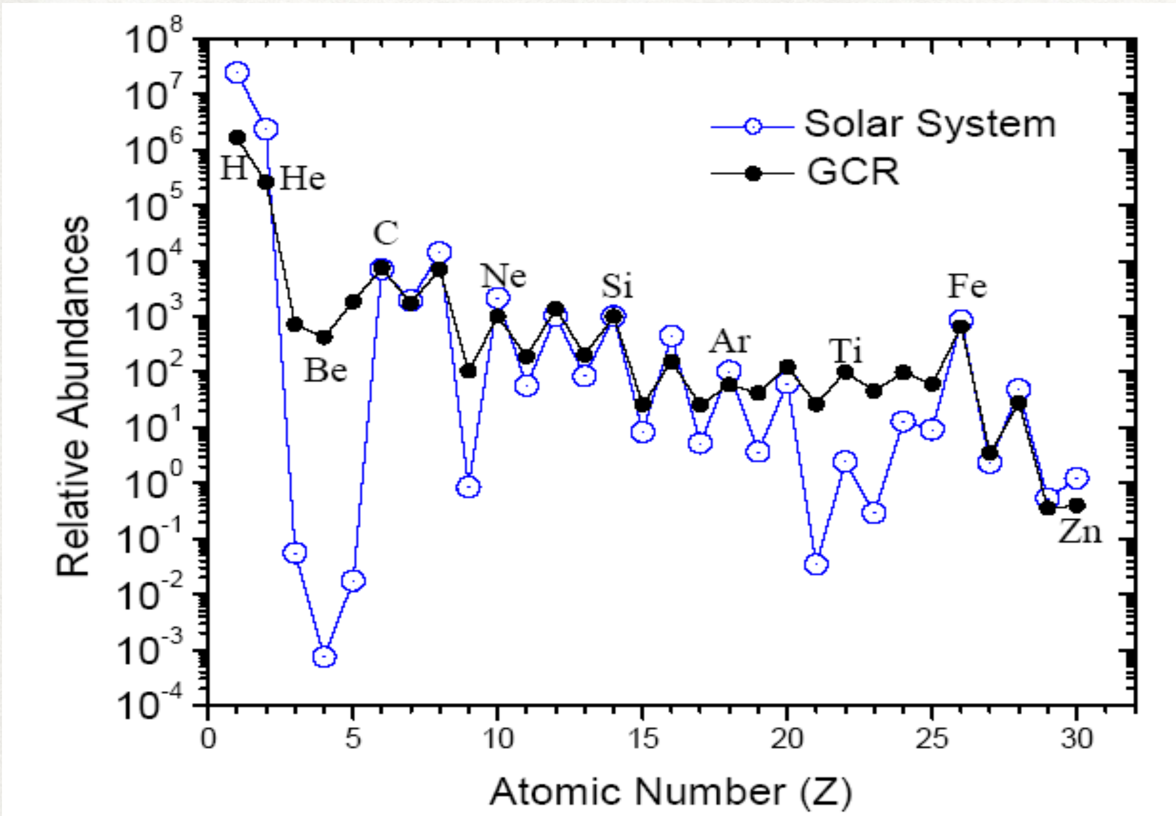
$$E_{max} \approx 1\ PeV \left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-1}\left(\frac{E_{SN}}{10^{51} erg}\right) \times \left(\frac{\dot{M}}{10^{-5} M_\odot yr^{-1}}\right)^{1/2}\left(\frac{v_{wind}}{10 km/s}\right)^{-1/2}$$

SUCCESS AND FAILURE

- EVEN IN THE PRESENCE OF STRONG INSTABILITIES ONE CAN BARELY REACH THE PeV AND ONLY IN SOME EXTREME CASES
- THE SPECTRUM OF ACCELERATED PARTICLES IS E^{-2} OR HARDER WHILE SIGNIFICANTLY STEEPER IS REQUIRED BY OBSERVATIONS…
- …BUT RECALL THAT WE STILL DO NOT REALLY KNOW HOW TO CONNECT ACCELERATED SPECTRA WITH ESCAPING ONES (worse for electrons!)
- SEVERAL INDICATIONS, THOUGH NOT CONCLUSIVE, OF EFFICIENT CR ACCELERATION FROM GAMMA AND BALMER OBSERVATIONS
- NO EVIDENCE FOR E_{MAX} HIGHER THAN 100 TeV… NOT TERRIBLY SURPRISING, BUT…
- THE ONLY YOUNG REMNANT IN WHICH IT SEEMS SAFE TO SAY WE GOT HADRONS IS TYCHO

FROM *THERE* TO *HERE*...

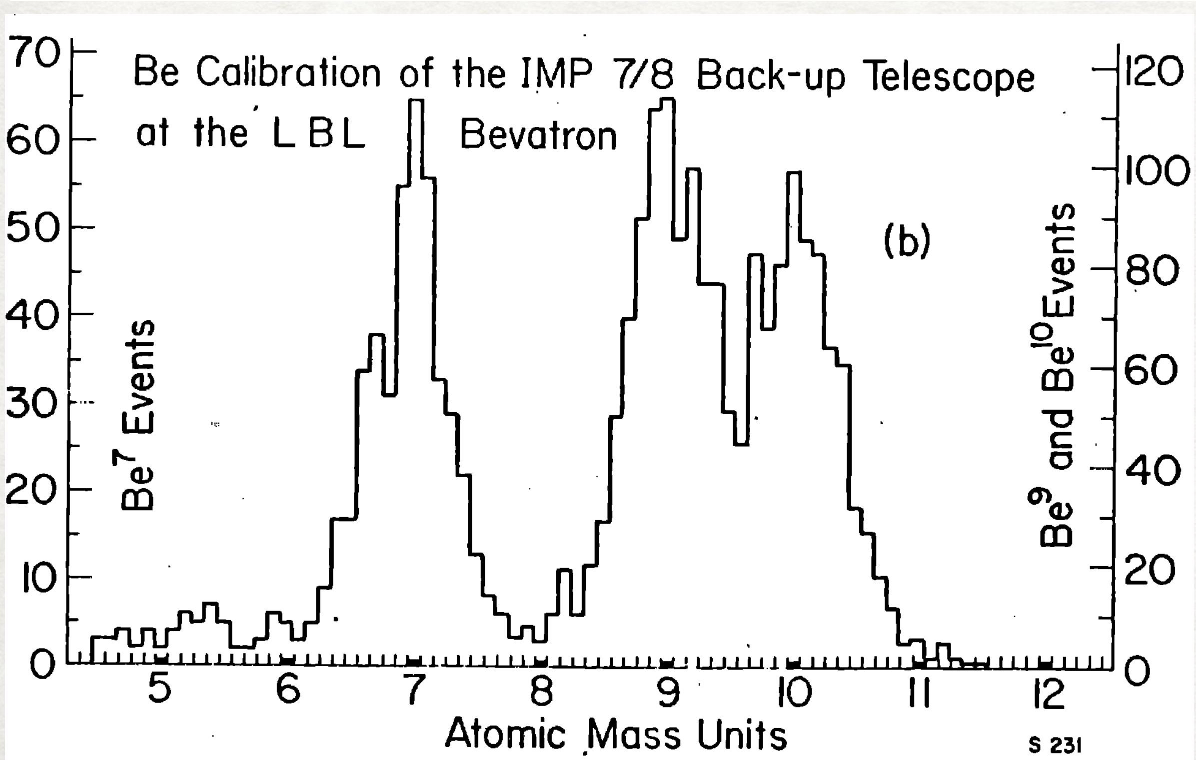
Basics of CR Physics

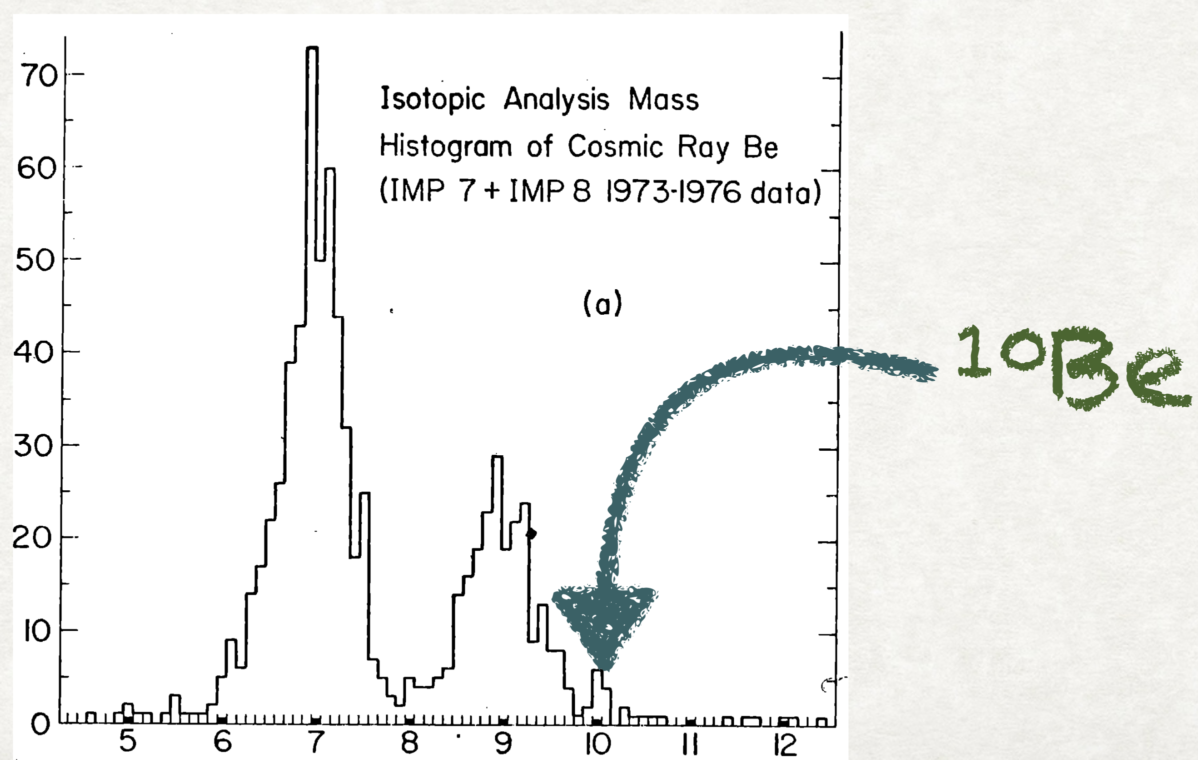


Measurements of the B-Li-Be in CRs show that CR live for tens of million years in the Galaxy

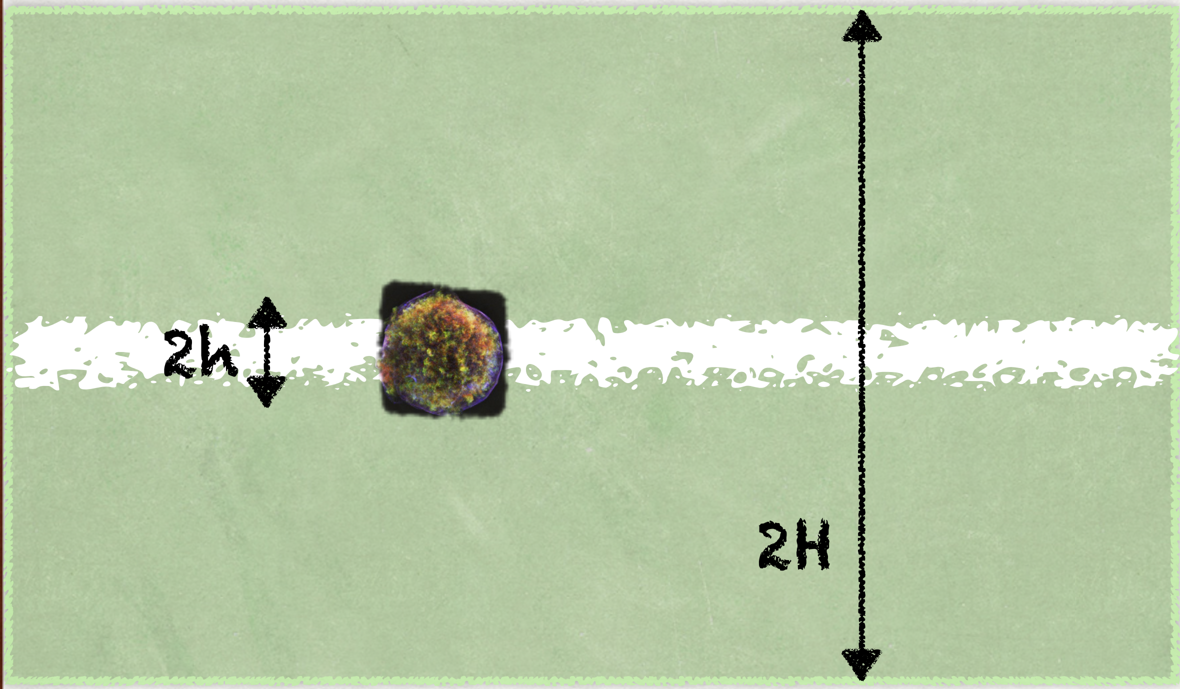
DIFFUSIVE TRANSPORT

Garcia-Munoz et al. 1977





BASICS OF CR PHYSICS: A TOY MODEL



$$-\frac{\partial}{\partial z}\left[D\frac{\partial f}{\partial z}\right] = Q_0(p)\delta(z)$$

DIFFUSION — SNR as SOURCES

$p^{-\gamma}$ — p^{δ}

$$f_0(p) = \frac{N_{inj}(p) R_{SN}}{\pi R^2_{disc}\; 2H}\frac{H^2}{D(p)} \sim p^{-\gamma-\delta}$$

$$D\frac{\partial f}{\partial z} = Constant \rightarrow f(z) = f_0\left(1 - \frac{z}{H}\right)$$

PARTICLES ESCAPE AT |Z|=H —> FREE ESCAPE BOUNDARY !

A SIMPLE GENERALIZATION OF CR TRANSPORT

$$-\frac{\partial}{\partial z}\left[D_\alpha \frac{\partial I_\alpha(E_k)}{\partial z}\right] + 2h_d n_d v(E_k)\sigma_\alpha \delta(z) I_\alpha(E_k) =$$

DIFFUSION

SPALLATION OF NUCLEI **α**

$$= 2Ap^2 h_d q_{0,\alpha}(p)\delta(z) + \sum_{\alpha'>\alpha} 2h_d n_d\, v(E_k)\sigma_{\alpha'\to\alpha}\delta(z) I_{\alpha'}(E_k)$$

INJECTION OF NUCLEI **α**

CONTRIBUTION TO NUCLEI **α** FROM SPALLATION OF NUCLEI **α'>α**

FOR SIMPLICITY THIS EQUATION DOES NOT CONTAIN SOME LOSS TERMS (IONIZATION), ADVECTION AND SECOND ORDER FERMI ACCELERATION IN ISM

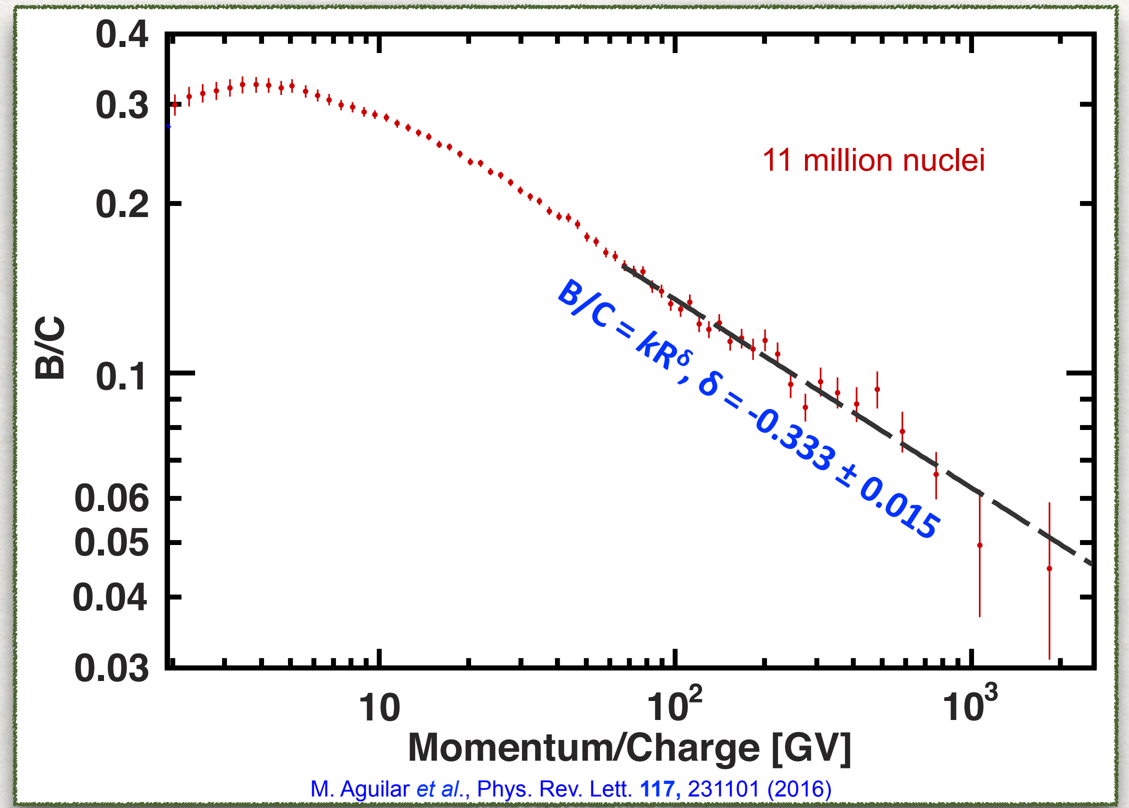
ALL THESE EFFECTS MAY BECOME IMPORTANT AT E<10 GeV/nucleon

A FEW GENERAL CONSIDERATIONS

- ☑ THE SPECTRA OF NUCLEI BEHAVE AS PROTONS, $E^{-\gamma-\delta}$, AT HIGH ENERGIES, WHERE SPALLATION IS WEAK
- ☑ AT LOW ENERGIES, WHERE SPALLATION DOMINATES, NUCLEI HAVE THE SAME SPECTRUM AS INJECTION
- ☑ THE INJECTION SPECTRA OF SECONDARY NUCLEI, POSITRONS AND ANTIPROTONS REFLECT THIS TREND

SECONDARY/PRIMARY: B/C

Evidence for CR diffusive transport



primary equilibrium

$$n_{pr}(E/n) \propto Q(E/n)\tau_{diff}(E/n)$$

secondary injection

$$q_{sec}(E/n) \approx n_{pr}(E/n)\sigma v n_{gas}$$

secondary equilibrium

$$n_{sec}(E/n) \approx q_{sec}(E/n)\tau_{diff}(E/n)$$

$$\frac{n_{sec}}{n_{pr}} \approx \frac{\sigma}{m_p}\left[v n_{gas} m_p \tau_{diff}\right]$$

GRAMMAGE: $X(E/n) \propto \tau_{diff}(E/n) \sim 1/D(E/n)$

POSITRONS

FOR TYPICAL PARAMETERS OF CR PROPAGATION, FOR ELECTRONS ENERGY LOSSES KICK IN ABOVE ~10 GeV

equilibrium primary electrons:

$$n_e(E) \sim \frac{Q(E)\tau_{loss}(E)}{2\pi R_d^2\sqrt{D(E)\tau_{loss}(E)}} \sim E^{-\gamma-\frac{1}{2}-\frac{\delta}{2}}$$

injection secondary e^-e^+:

$$q_{sec}(E)dE \sim n_p(E')dE'\sigma_{pp}n_{gas}c \sim E^{-\gamma-\delta'}$$

equilibrium secondary pairs:

$$n_{sec}(E) \sim \frac{q_{sec}(E)\tau_{loss}(E)}{2\pi R_d^2\sqrt{D(E)\tau_{loss}(E)}} \sim E^{-\gamma-\delta'-\frac{1}{2}-\frac{\delta}{2}}$$

RATIO:

$$\frac{n_{e^+}(E)}{n_e(E)} \sim E^{-\delta'}$$

It reflects the slope of the proton spectrum at E'~20E

ANTIPROTONS

injection pbar: $q_{\bar{p}}(E)dE \sim n_p(E')dE'\sigma_{pp\to\bar{p}}(E')n_{gas}c \sim E^{-\gamma-\delta'+s}$

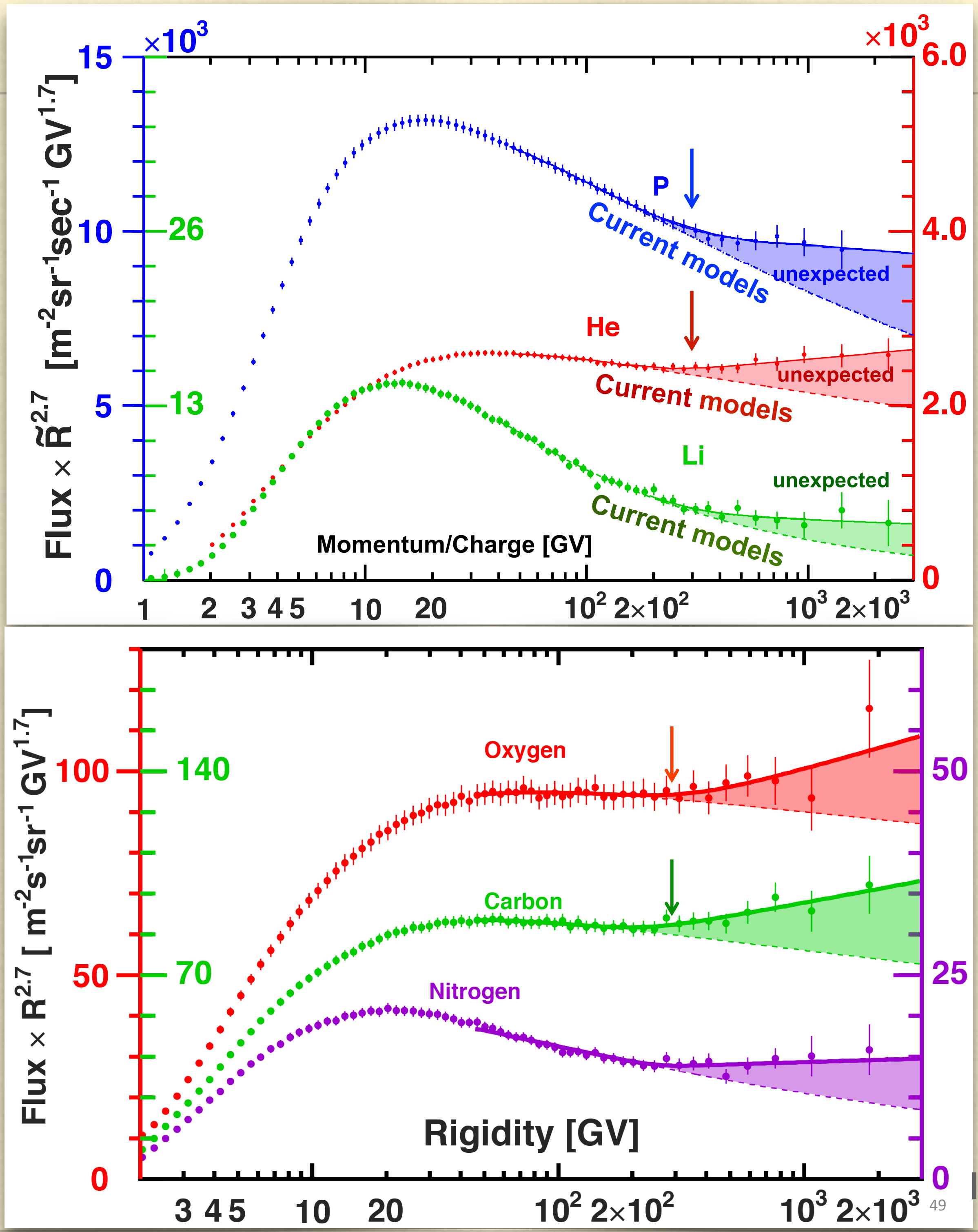
equilibrium pbar: $n_{\bar{p}}(E) \sim q_{\bar{p}}(E)\tau_{diff}(E) \sim E^{-\gamma-\delta'+s-\delta}$

RATIO 1: $\frac{n_{\bar{p}}}{n_p} \sim E^{-\delta'+s}$

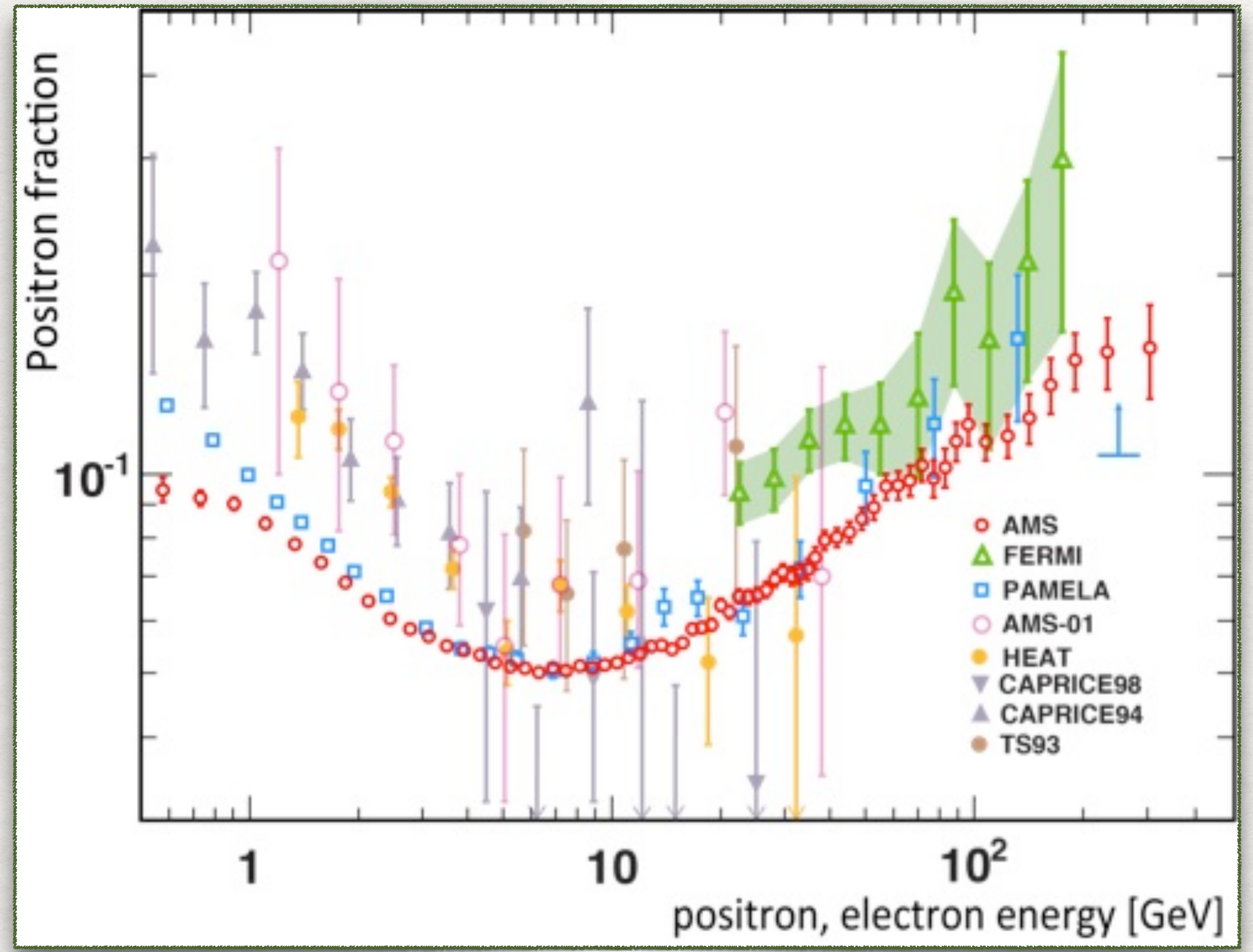
RATIO 2: $\frac{n_{\bar{p}}}{n_{e^+}} \sim E^{s-\frac{\delta}{2}+\frac{1}{2}}$

SURPRISES: SPECTRA OF PROTONS, HELIUM AND HEAVIER PRIMARY NUCLEI

- **Both protons and helium spectra show a break @~200-300 GV (PAMELA and AMS-02) -** ***Some Physics kicking in?***
- **The He spectrum is slightly harder than that of protons -** ***Acceleration or propagation?***
- **There is some indication that a similar break exists for heavier nuclei (CREAM)**



SECONDARY/PRIMARY: POSITRON FRACTION



AMS-02 Coll. 2013

Reacceleration of secondary Pairs in old SNRs

PB 2009, PB & Serpico 2009; Mertsch & Sarkar 2009

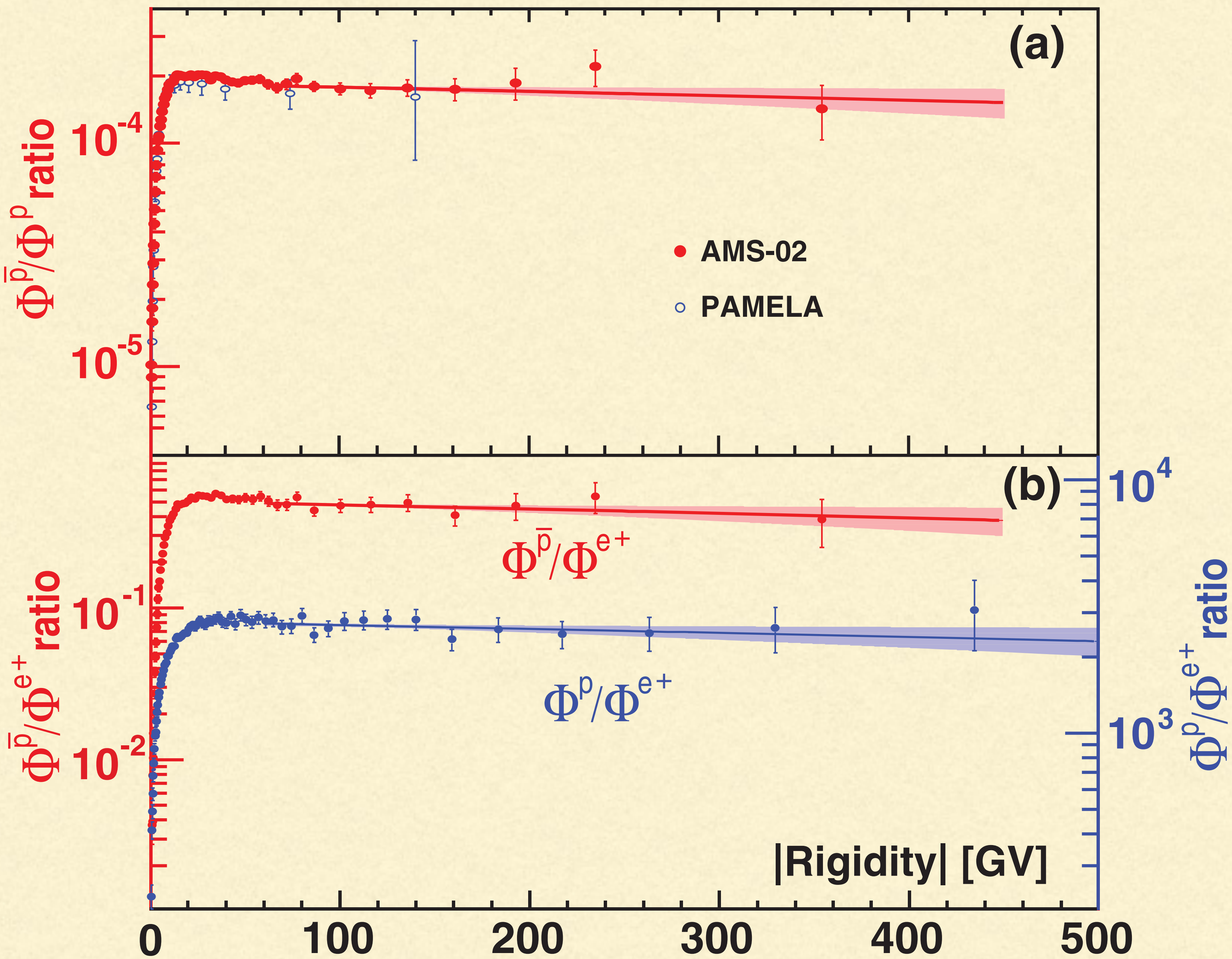
Pulsar Wind Nebulae

Hooper, PB & Serpico (2009); PB & Amato 2010

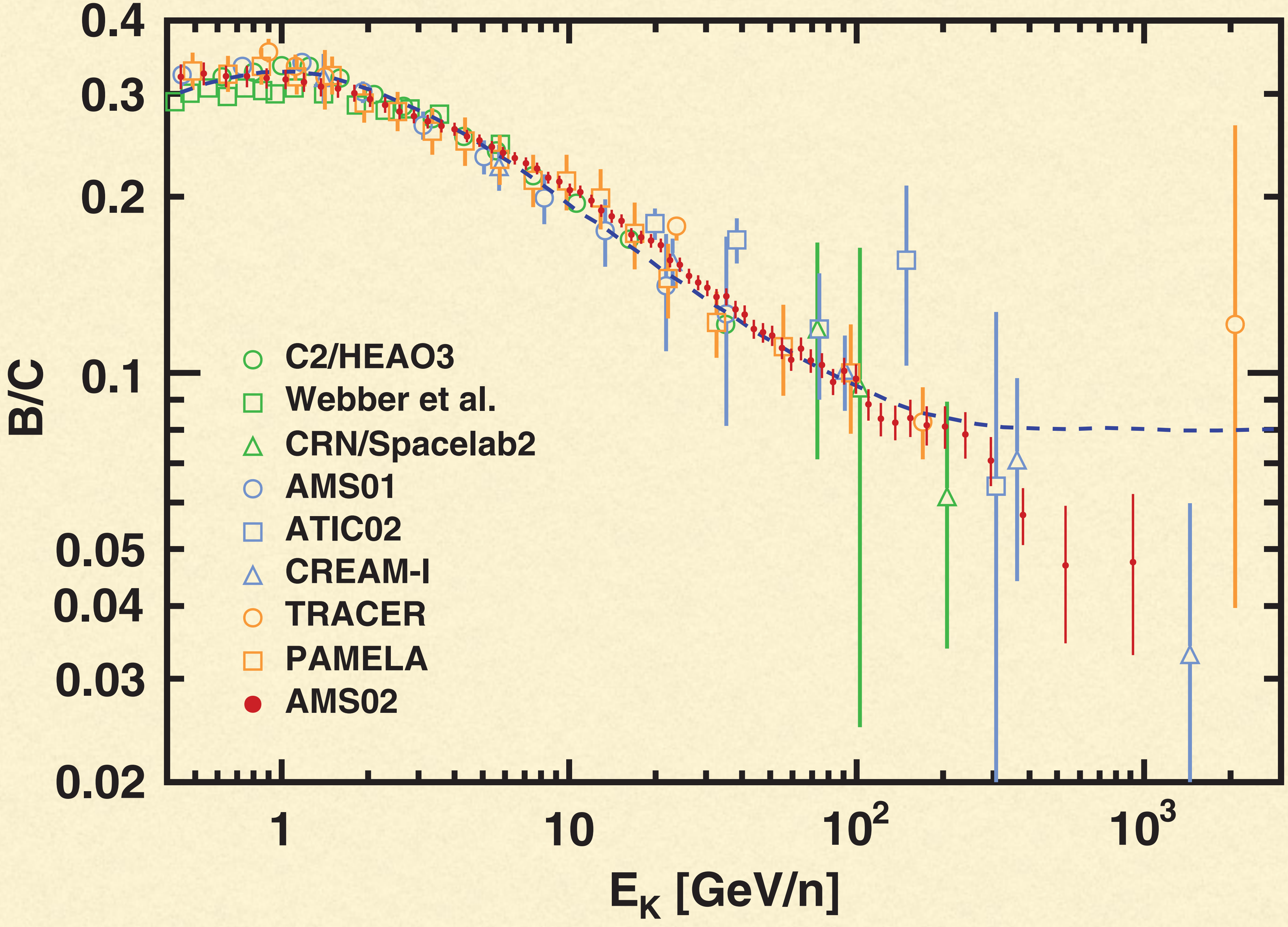
Dark Matter Annihilation

Difficult: high annihilation, Cross section, leptophilia, Boosting factor [Serpico (2012)]

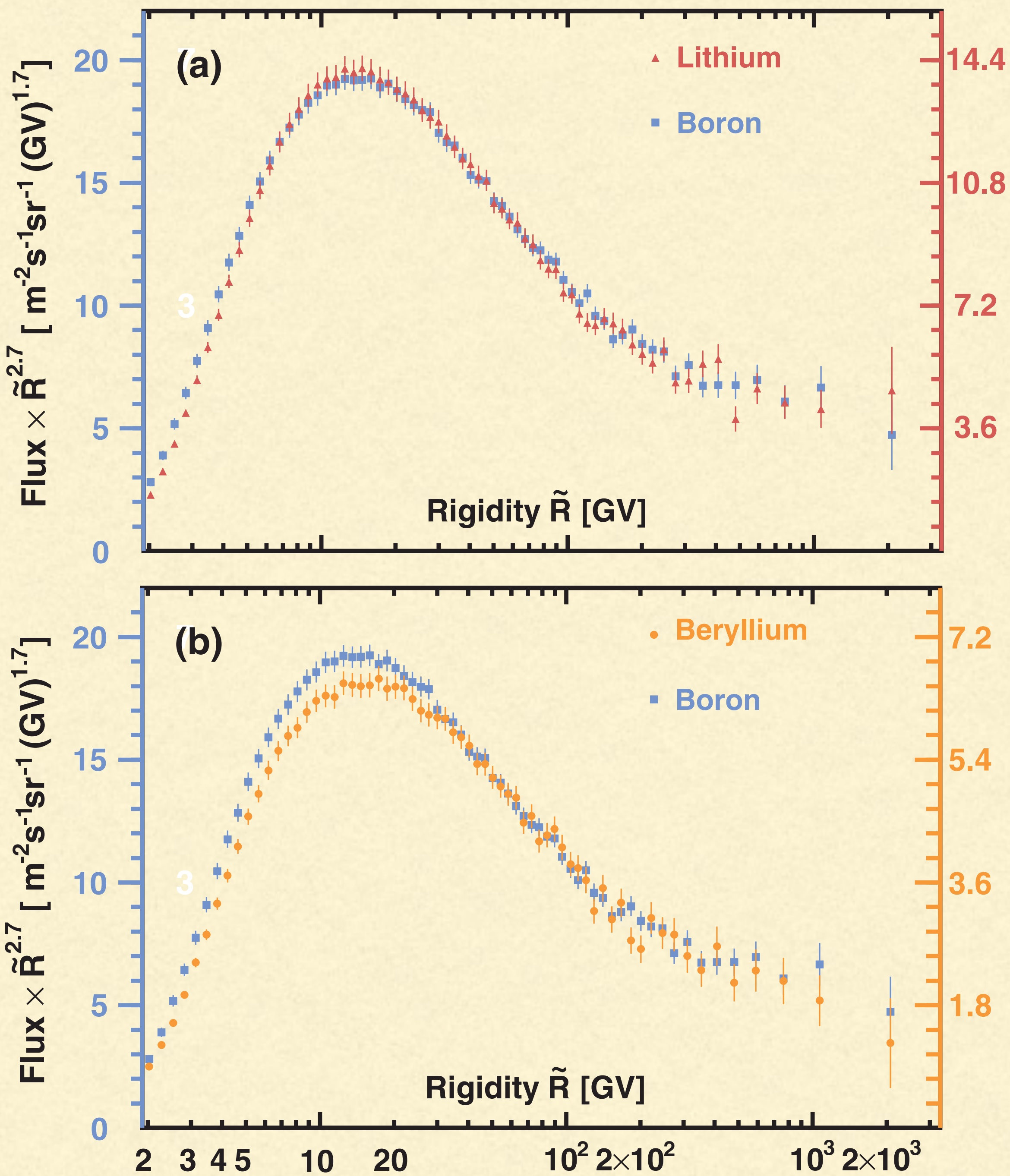
A GLOBAL PICTURE - AMS02

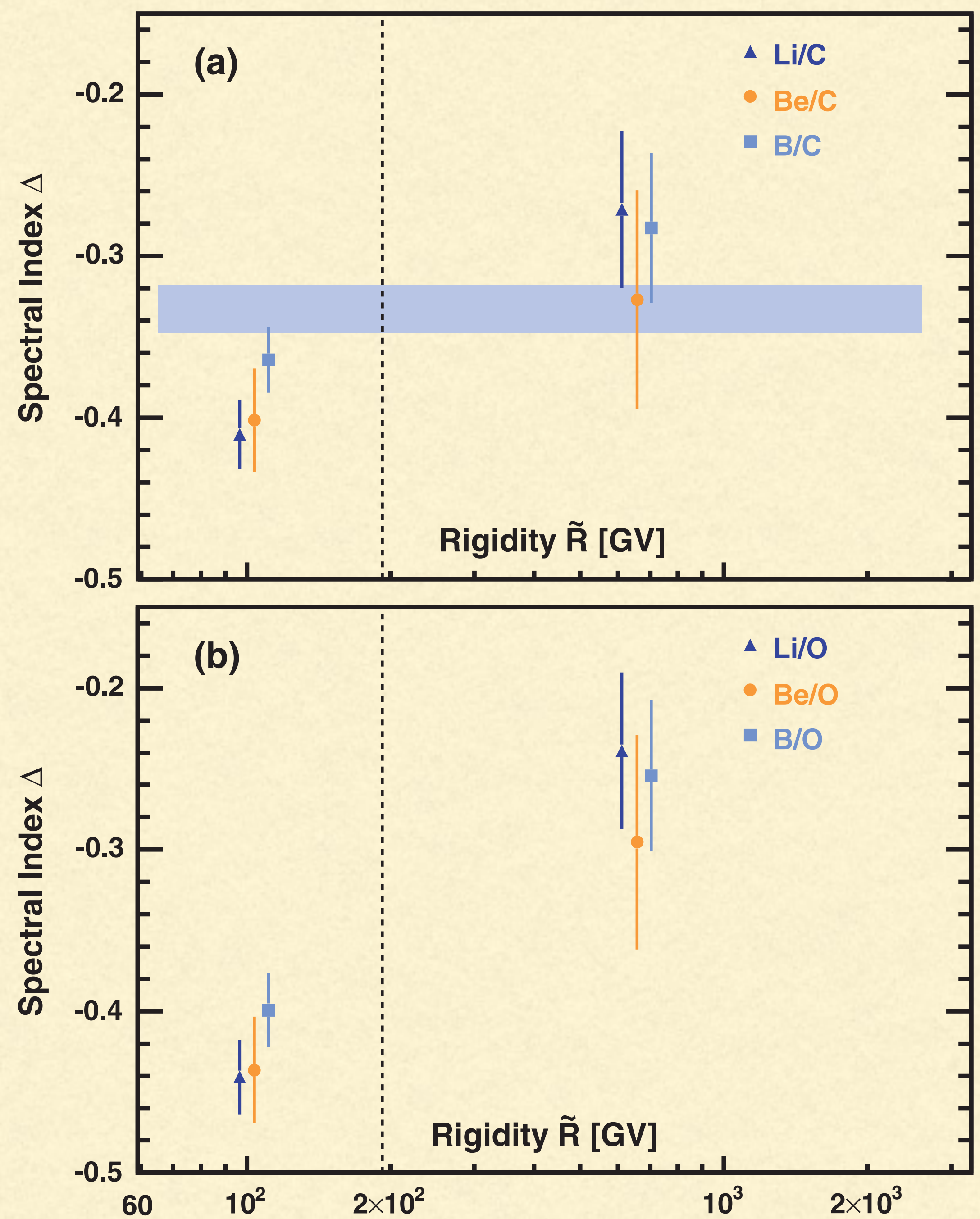


THE B/C RATIO - AMS02



SECONDARY NUCLEI - AMS02



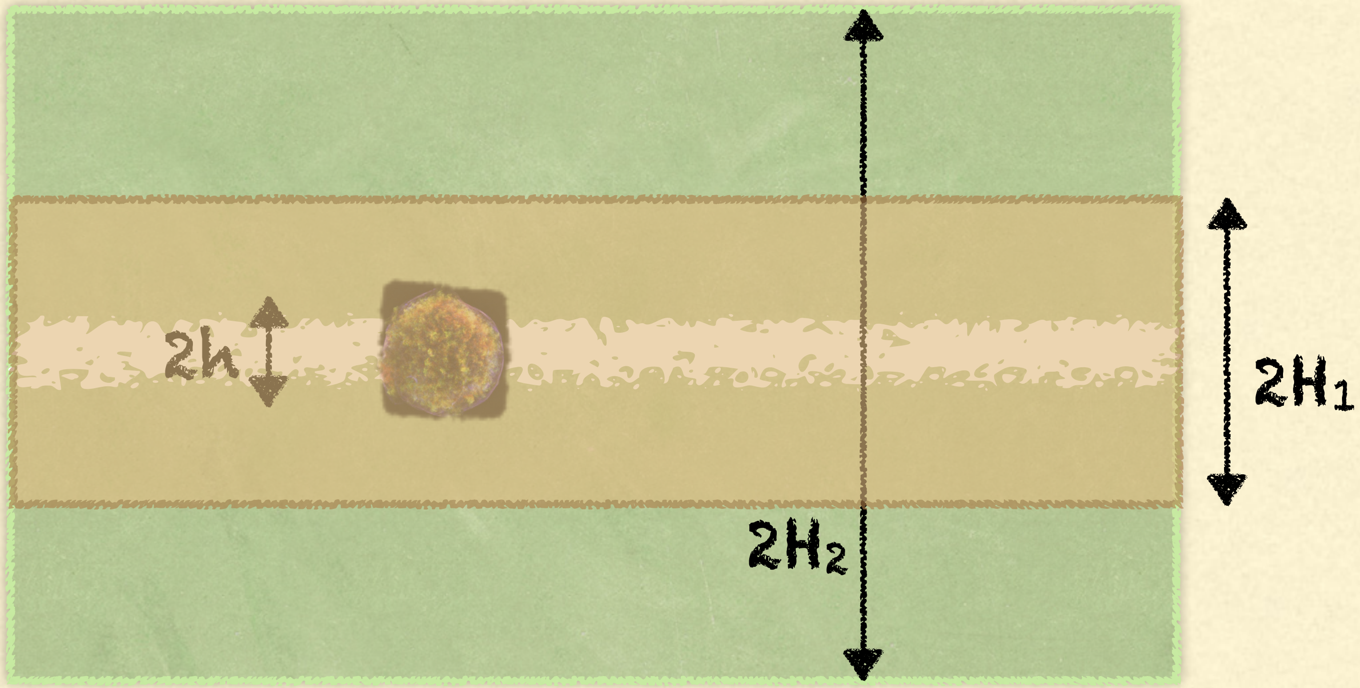


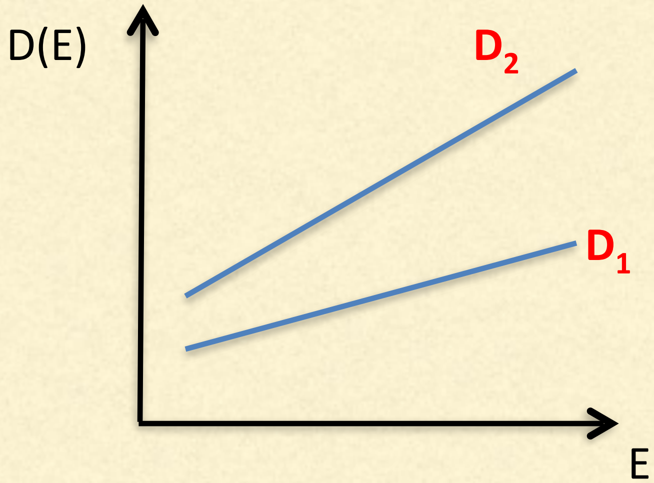
BREAKS IN PRIMARY SPECTRA

- IN PRINCIPLE THEY COULD REFLECT THE ACCIDENTAL PROXIMITY OF A LOCAL SOURCE, BUT UNLIKELY (Genolini et al. 2017)
- MOST LIKELY IT REFLECTS A NEW PHENOMENON CONNECTED TO TRANSPORT
- TRANSPORT IN A D(P,Z) WOULD WORK (Tomassetti, 2012 and following work)
- ONSET OF NON LINEAR CR TRANSPORT EFFECTS WOULD WORK (PB+, 2012 and following work)

SPACE DEPENDENT DIFFUSION

Tomassetti 2012



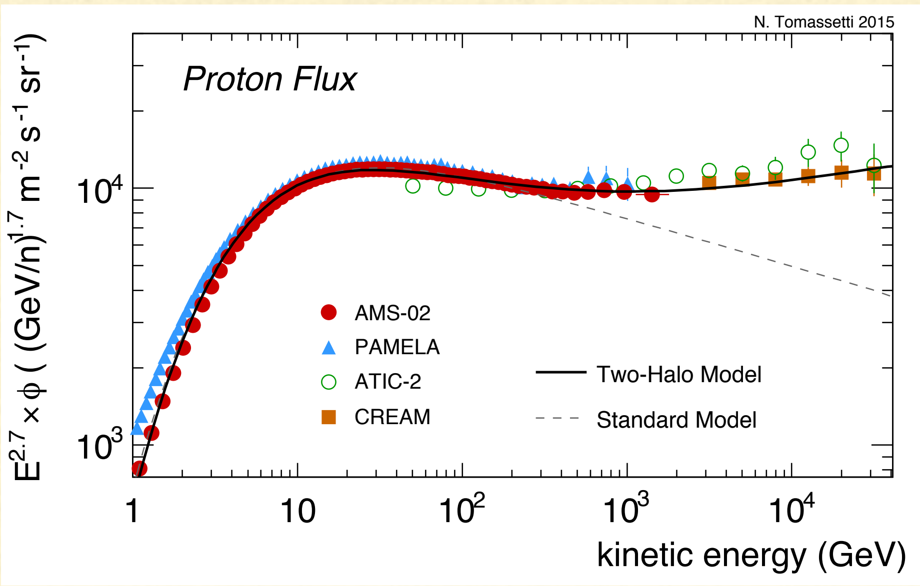


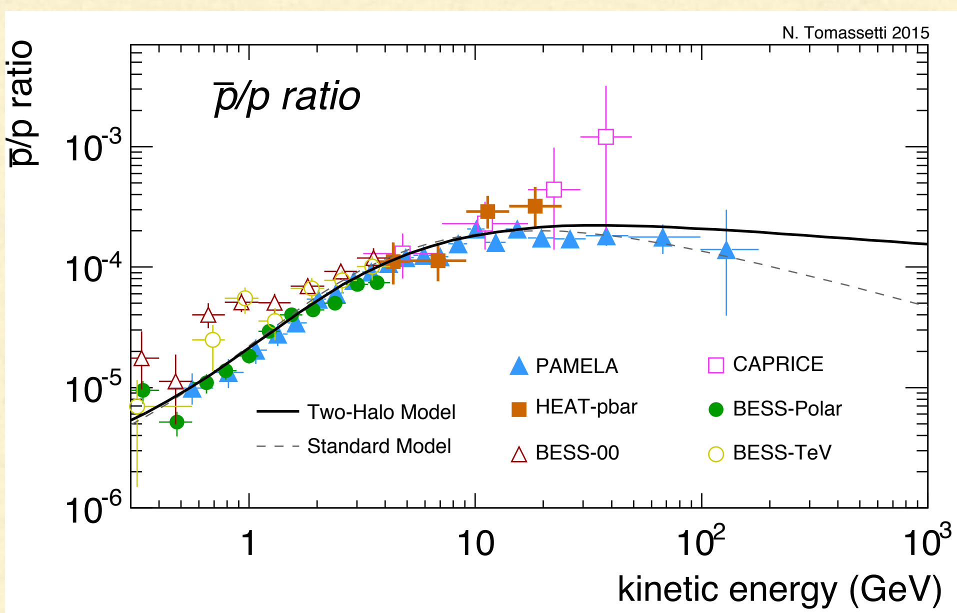
$$f_0(p) = \frac{N(p)\mathcal{R}}{2\pi R_d^2}\left[\frac{H_1}{D_1} + \frac{H_2 - H_1}{D_2}\right] \propto \begin{array}{ll} E^{-\gamma-\delta_2} & E \ll E_{cr} \\ E^{-\gamma-\delta_1} & E \gg E_{cr} \end{array}$$

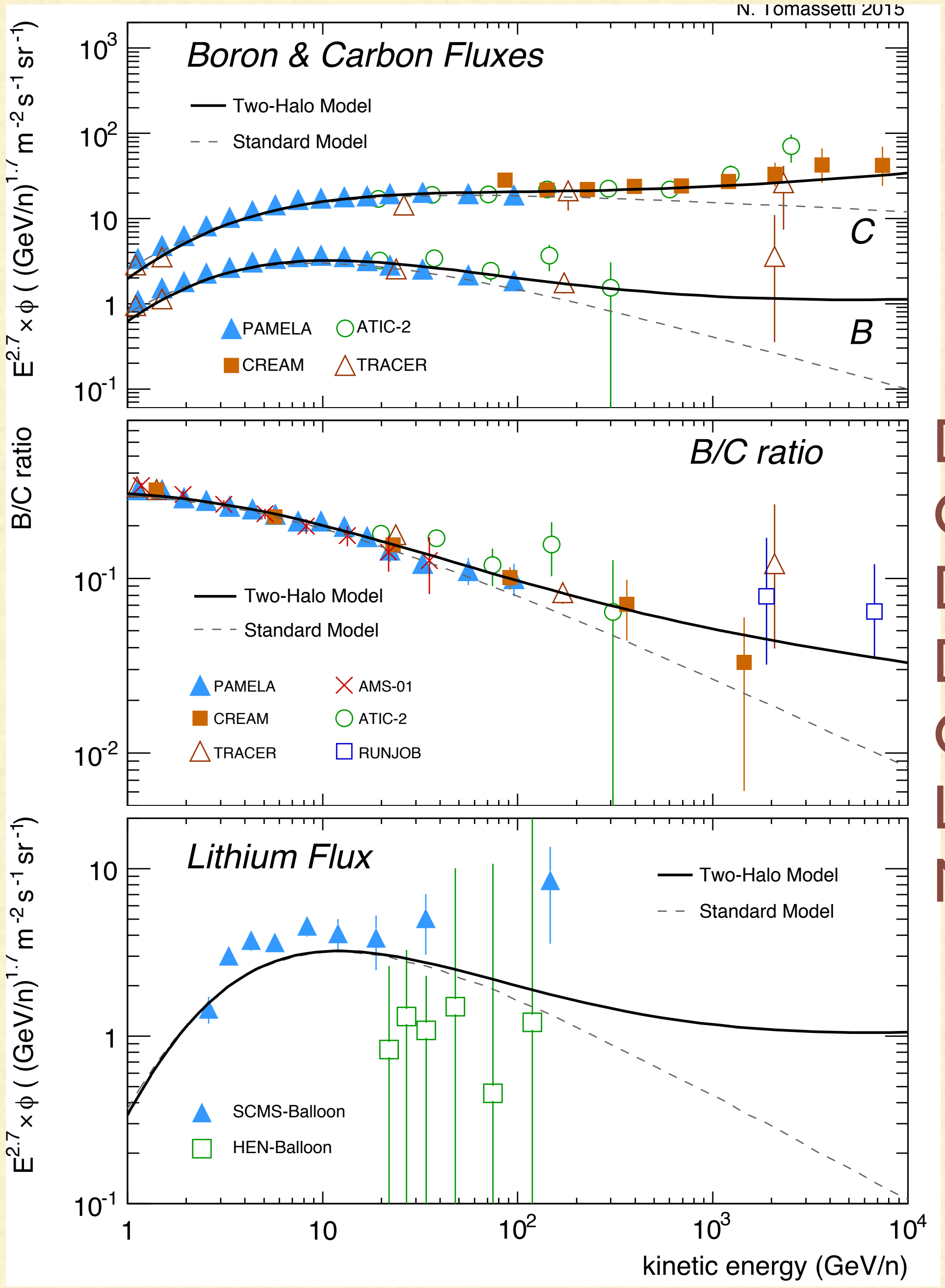
$$E_{cr} = \left[\frac{K_1}{K_2}\,\frac{H_2 - H_1}{H_1}\right]^{\frac{1}{\delta_2 - \delta_1}}$$

SPACE DEPENDENT DIFFUSION

Tomassetti 2015







δ1=0.15

δ2=0.75

DESPITE THE SIMPLICITY OF THE IDEA THE SPACE DEPENDENCE OF THE DIFFUSION COEFFICIENT REMAINS LACKS A PHYSICAL MOTIVATION

NON-LINEAR TRANSPORT

- DIFFUSING CR EXCITE A STREAMING INSTABILITY ➠ ENHANCED SCATTERING
- TURBULENCE MAY ALSO BE INJECTED, FOR INSTANCE BY SN EXPLOSIONS, AT LARGE SCALES AND CASCADE DOWN
- THESE PROCESSES NATURALLY LEAD TO SPATIALLY DEPENDENT DIFFUSION

NON-LINEAR TRANSPORT

PB, AMATO&SERPICO 2012, ALOISIO&PB 2013, ALOISIO, PB & SERPICO 2015

THE TRANSPORT EQUATION FOR EACH NUCLEAR SPECIE IS SOLVED WITH A DIFFUSION COEFFICIENT

$$D_\alpha(p) = \frac{1}{3}\frac{p\,c}{Z_\alpha e B_0} v(p) \left[\frac{1}{k\,W(k)}\right]_{k=Z_\alpha e B_0/\mathrm{pc}}$$

WHERE THE DENSITY OF WAVES RESPONSIBLE FOR SCATTERING SATISFIES THE QUASI LINEAR EXPRESSION:

$$D_\alpha(p) = \frac{1}{3}\frac{p\,c}{Z_\alpha e B_0} v(p) \left[\frac{1}{k\,W(k)}\right]_{k=Z_\alpha e B_0/\mathrm{pc}}$$

NON-LINEAR TRANSPORT

PB, AMATO&SERPICO 2012, ALOISIO&PB 2013, ALOISIO, PB & SERPICO 2015

THE WAVES ARE INJECTED AT SOME LARGE SCALE $1/K_0$, CASCADE IN K-SPACE (DAMPING) AND ARE AMPLIFIED BY STREAMING INSTABILITY INDUCED BY CR

$$\frac{\partial}{\partial k}\left[D_{kk}\frac{\partial W}{\partial k}\right] + \Gamma_{CR} W = q_W(k)$$

$$D_{kk} = C_K v_A k^{7/2} W(k)^{1/2}$$

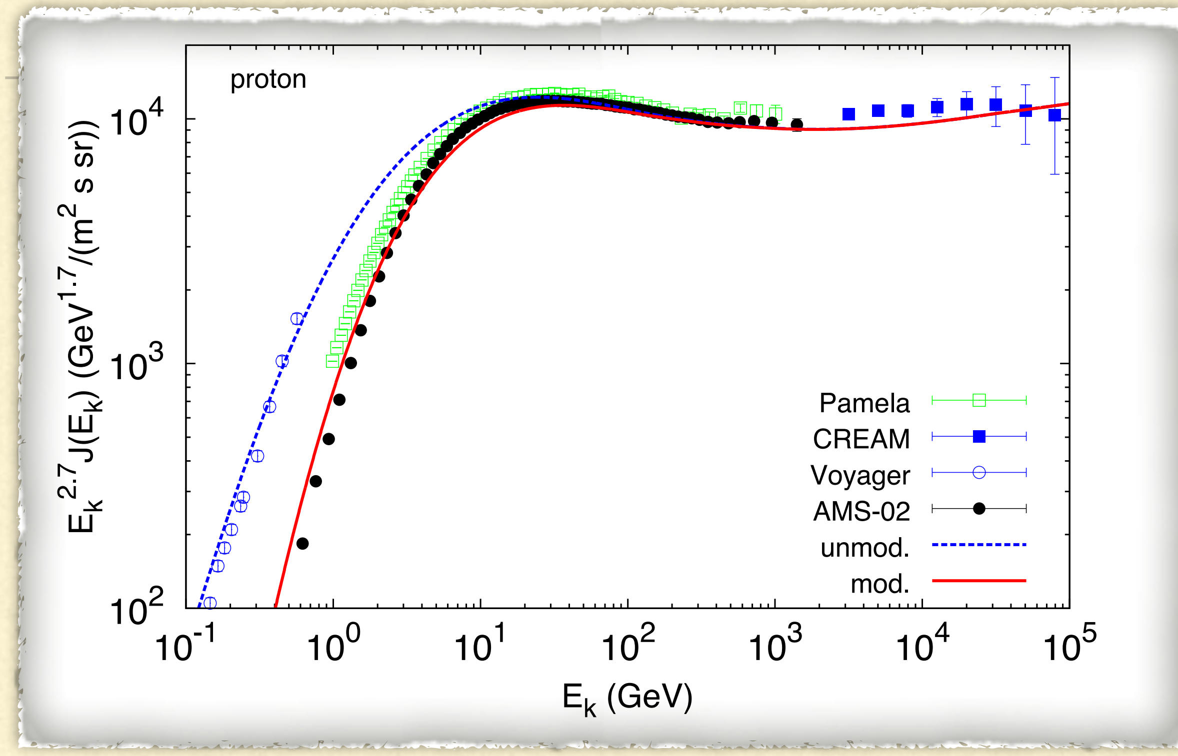
INJECTION

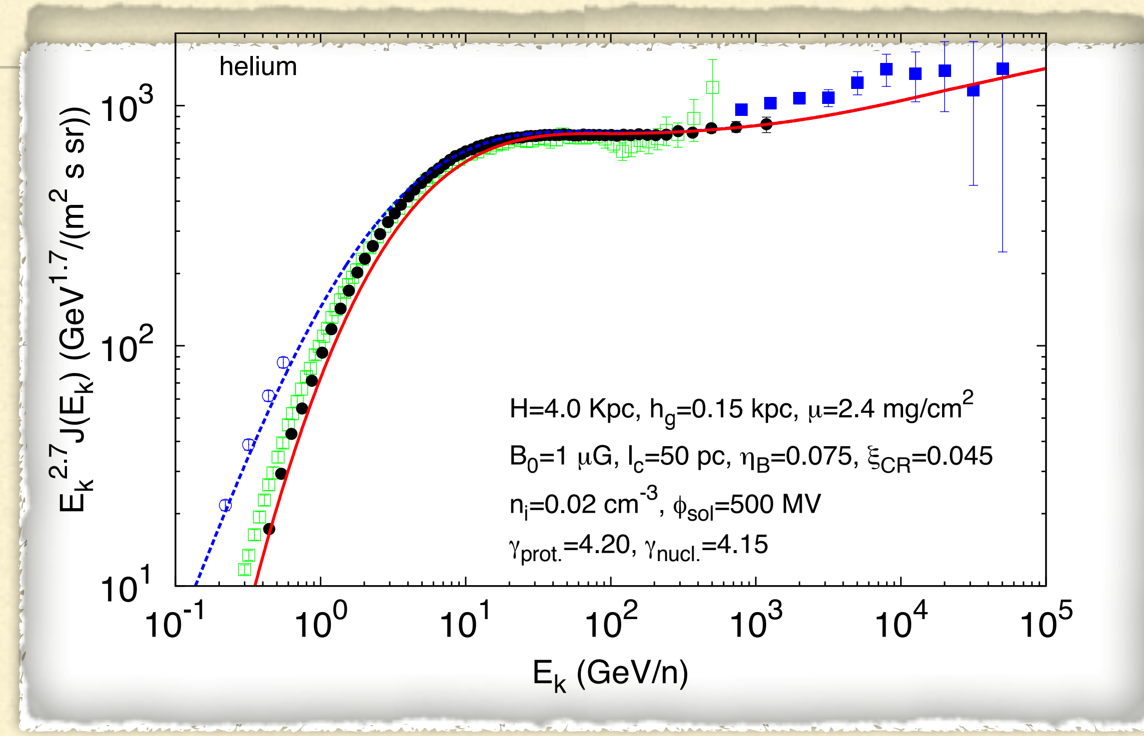
$$\delta(k - 1/l_c)$$

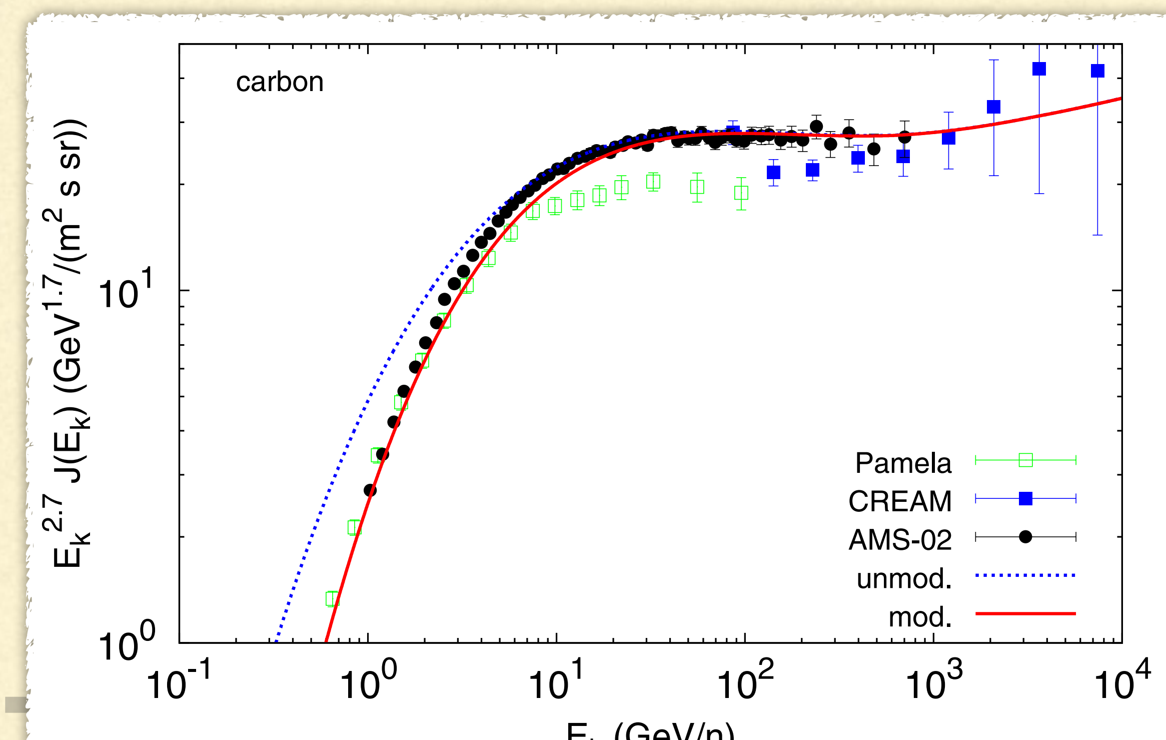
$$\Gamma_{cr}(k) = \frac{16\pi^2}{3}\frac{v_A}{k\,W(k)B_0^2}\sum_\alpha\left[p^4 v(p)\frac{\partial f_\alpha}{\partial z}\right]_{p=Z_\alpha e B_0/kc}$$

Spectral Breaks:
self-generation vs previous turbulence

Aloisio, PB & Serpico 2015

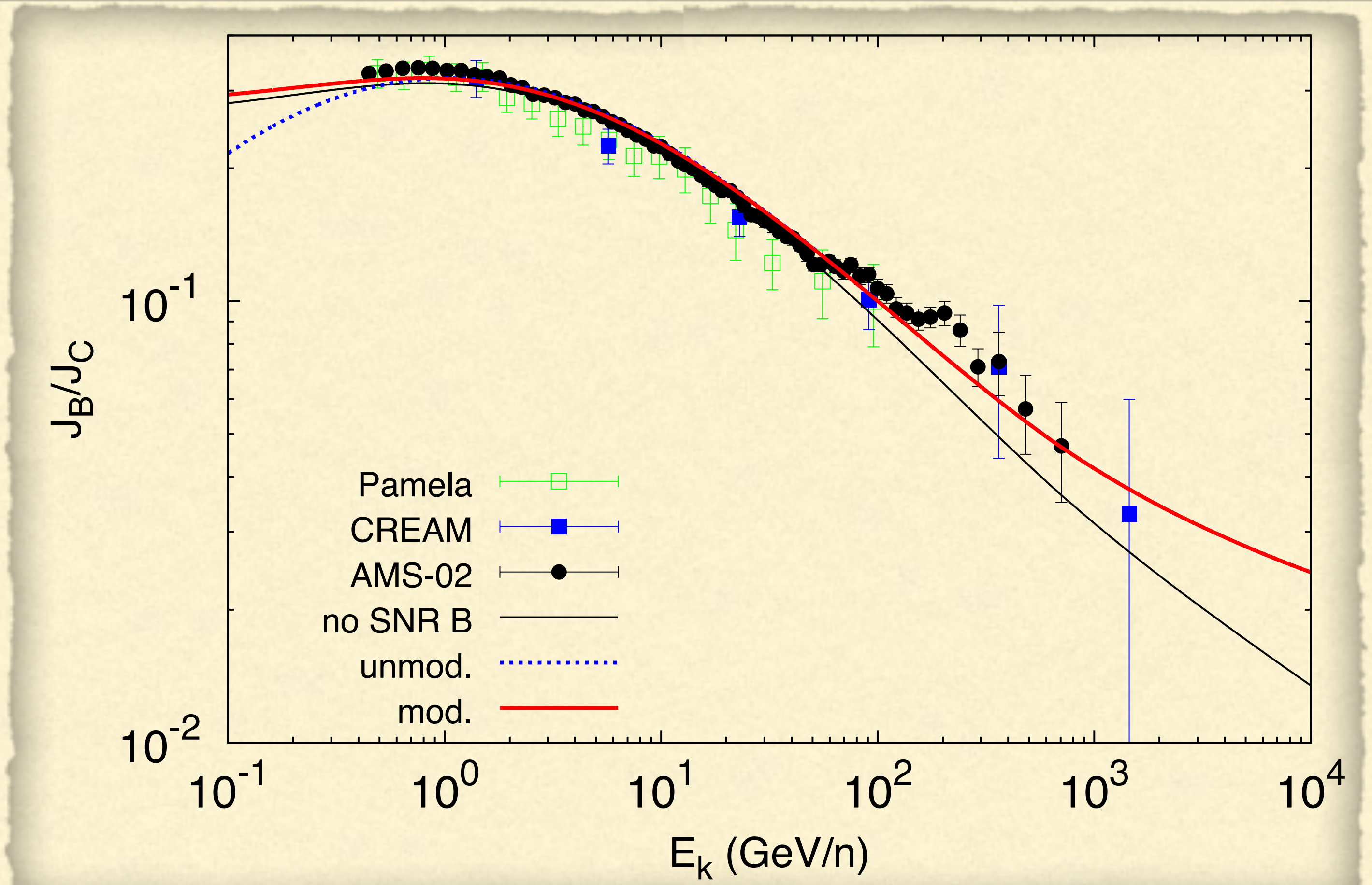






Voyager data are automatically fitted with no additional breaks… advection with self-generated waves at E<10 GeV?

B/C: self-generation vs previous turbulence



Aloisio, PB & Serpico 2015

AMS-02 B/C shows an excess at E>100GeV, compatible with the grammage inside sources:

$$X_{\rm SNR} \approx 1.4 r_s m_p n_{\rm ISM} c T_{\rm SNR} \approx 0.17\,{\rm g\,cm^{-2}} \frac{n_{\rm ISM}}{\rm cm^{-3}} \frac{T_{\rm SNR}}{2\times 10^4 {\rm yr}}$$

SHOCK ACCELERATION OF SECONDARY NUCLEI

SHOCKS ARE BLIND TO THE NATURE OF CHARGED PARTICLES THAT TAKE PART IN ACCELERATION

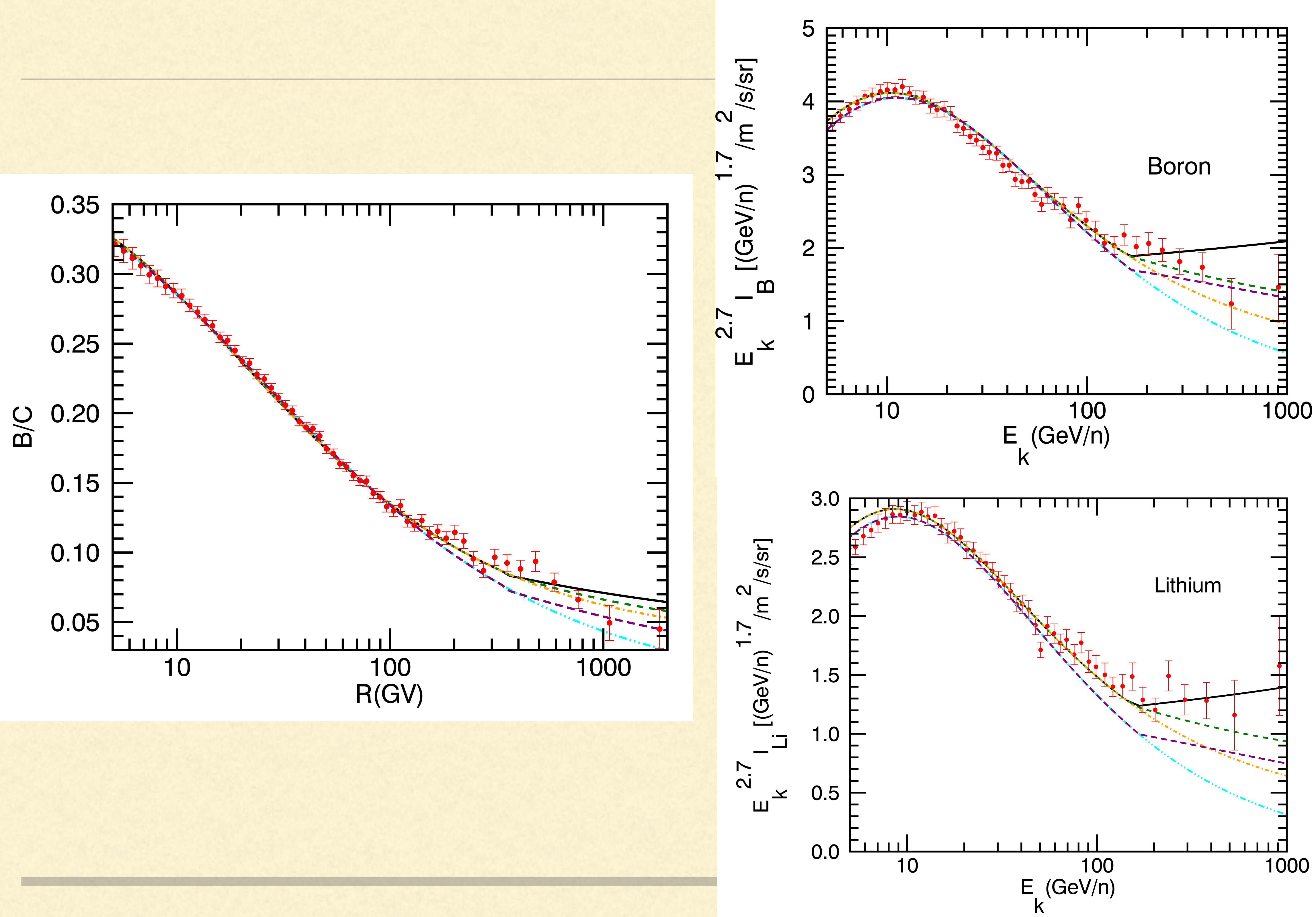
HENCE SECONDARY PARTICLES WORK AS SEEDS AS WELL…

PRIMARY NUCLEI
thermal seeds —> $E^{-\gamma}$

SECONDARY NUCLEI
$E^{-\gamma-\delta}$ —> $E^{-\gamma}$

IT IS CLEAR THAT THE OCCASIONAL ACCELERATION OF SECONDARY NUCLEI MUST BE THE MAIN CONTRIBUTION AT SUFFICIENTLY HIGH E, TYPICALLY ABOVE TeV (PB 2017)

SHOCK ACCELERATION OF SECONDARY NUCLEI

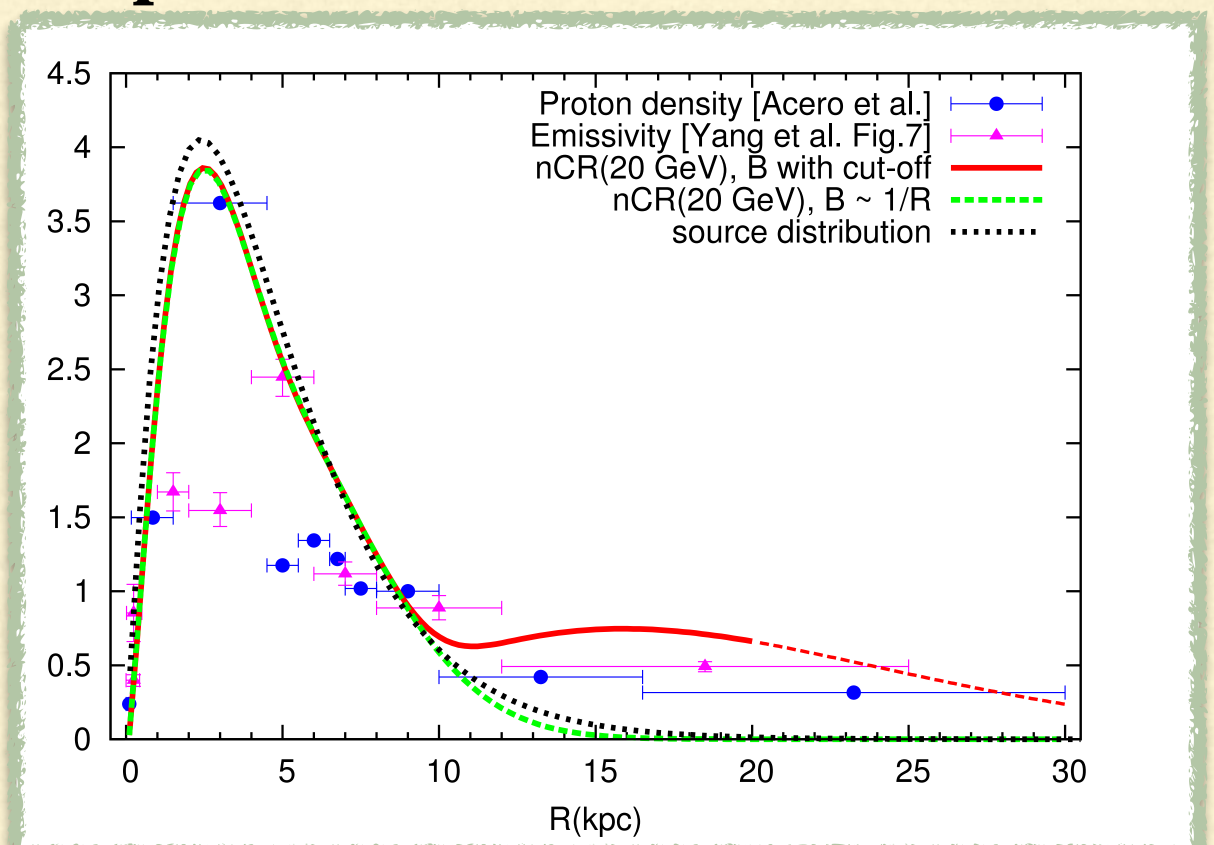


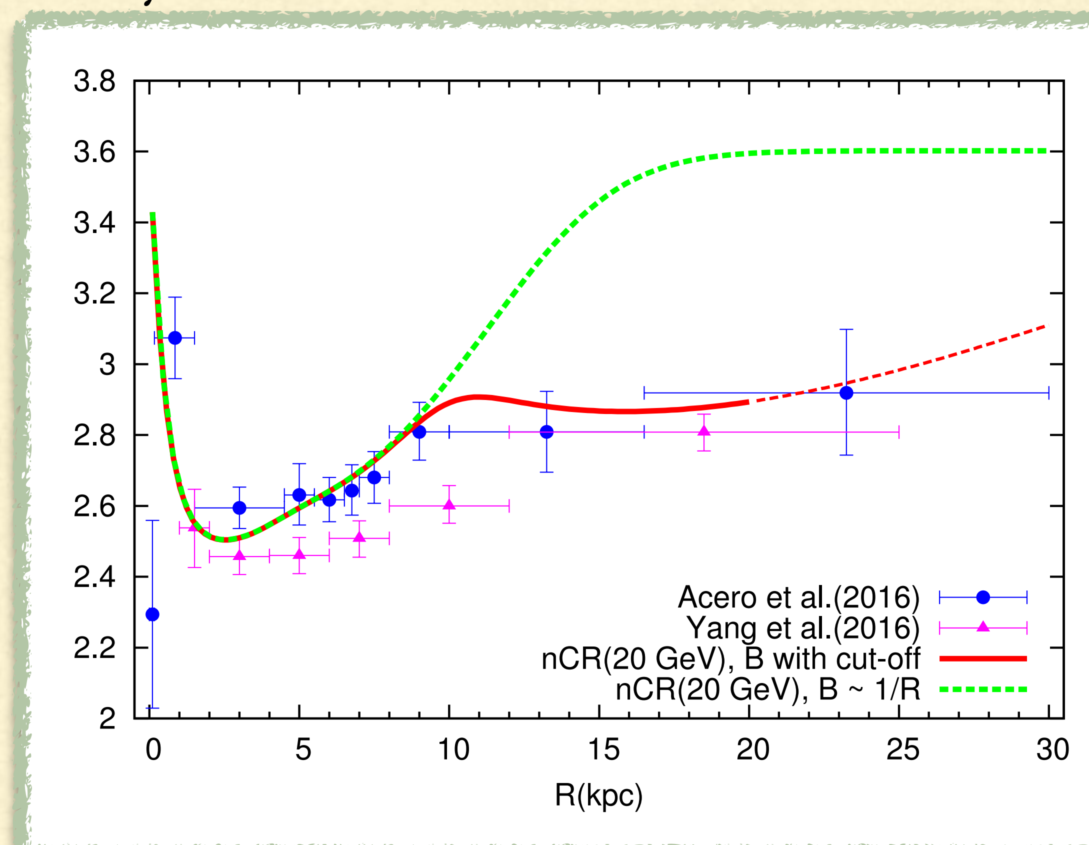
THE CR GRADIENT

The CR density as a function of the Galactocentric distance R is flatter than expected based upon source density, for large R

…But it has a peak in the central region of the Galaxy…

The **spectrum is also harder** in the central Galaxy than it is in the outskirt

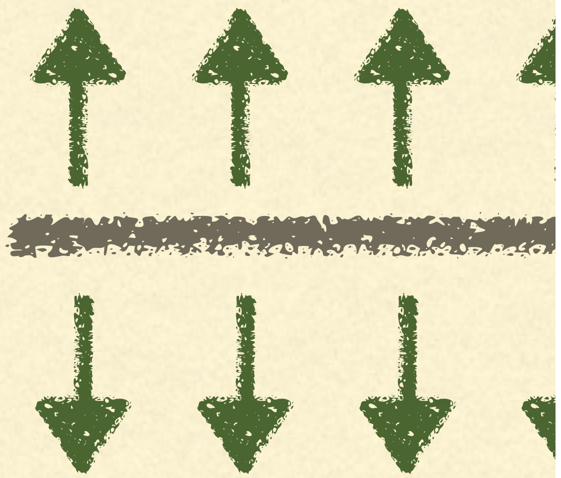




Recchia, PB & Morlino 2016 [arXiv:1604.07682]

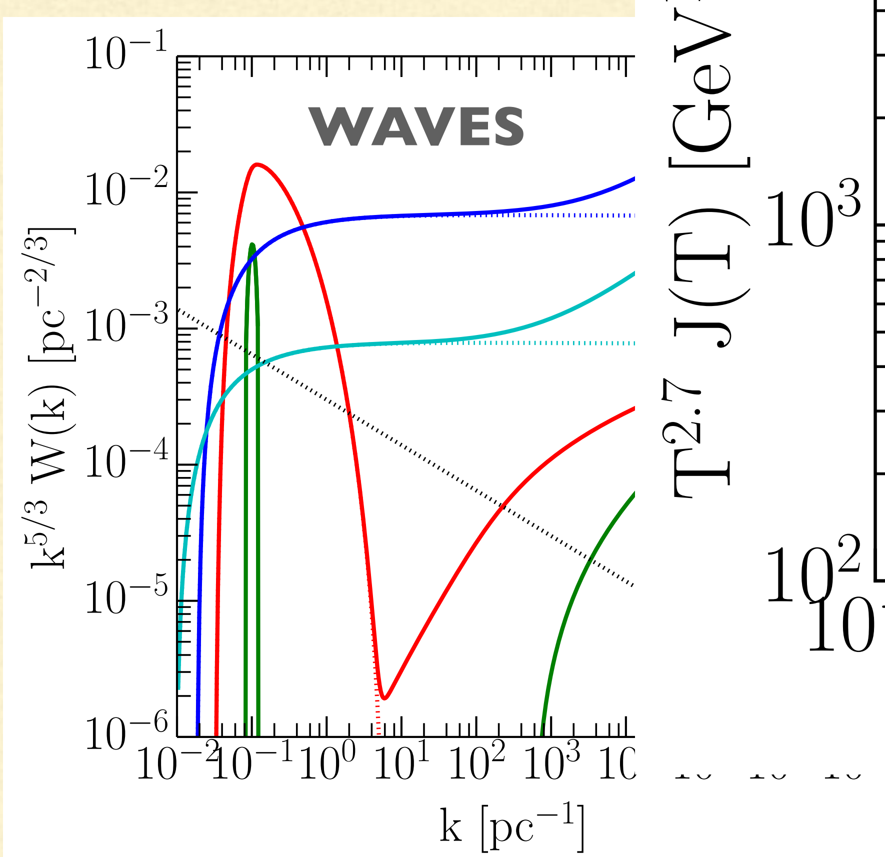
TURBULENCE ADVECTED FROM THE DISC

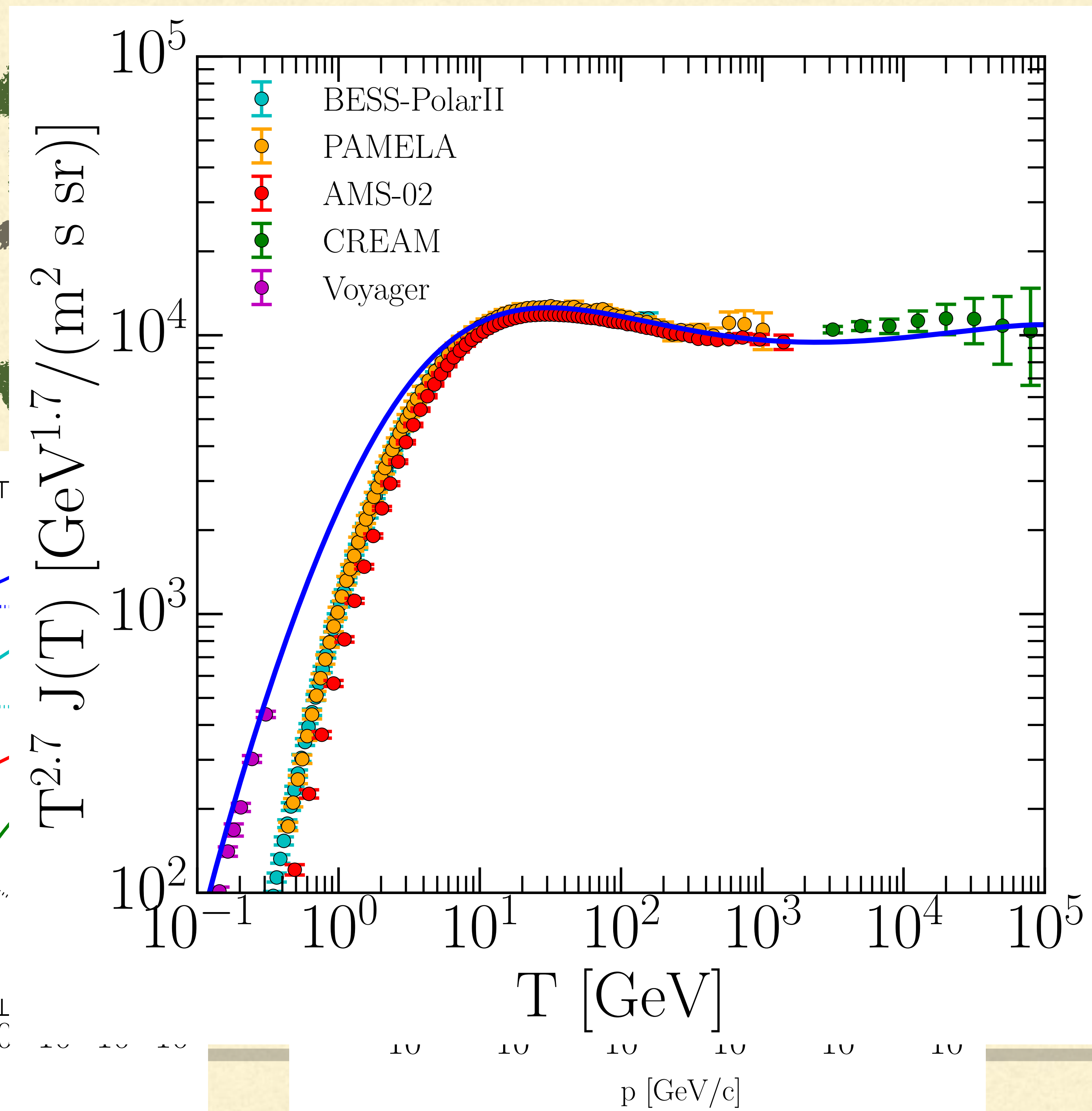
Evoli, Aloisio, PB & Morlino 2018



N THE DISC IS
AND CASCADES
ME ~K_0^2/D_{KK}

ELF-GENERATED

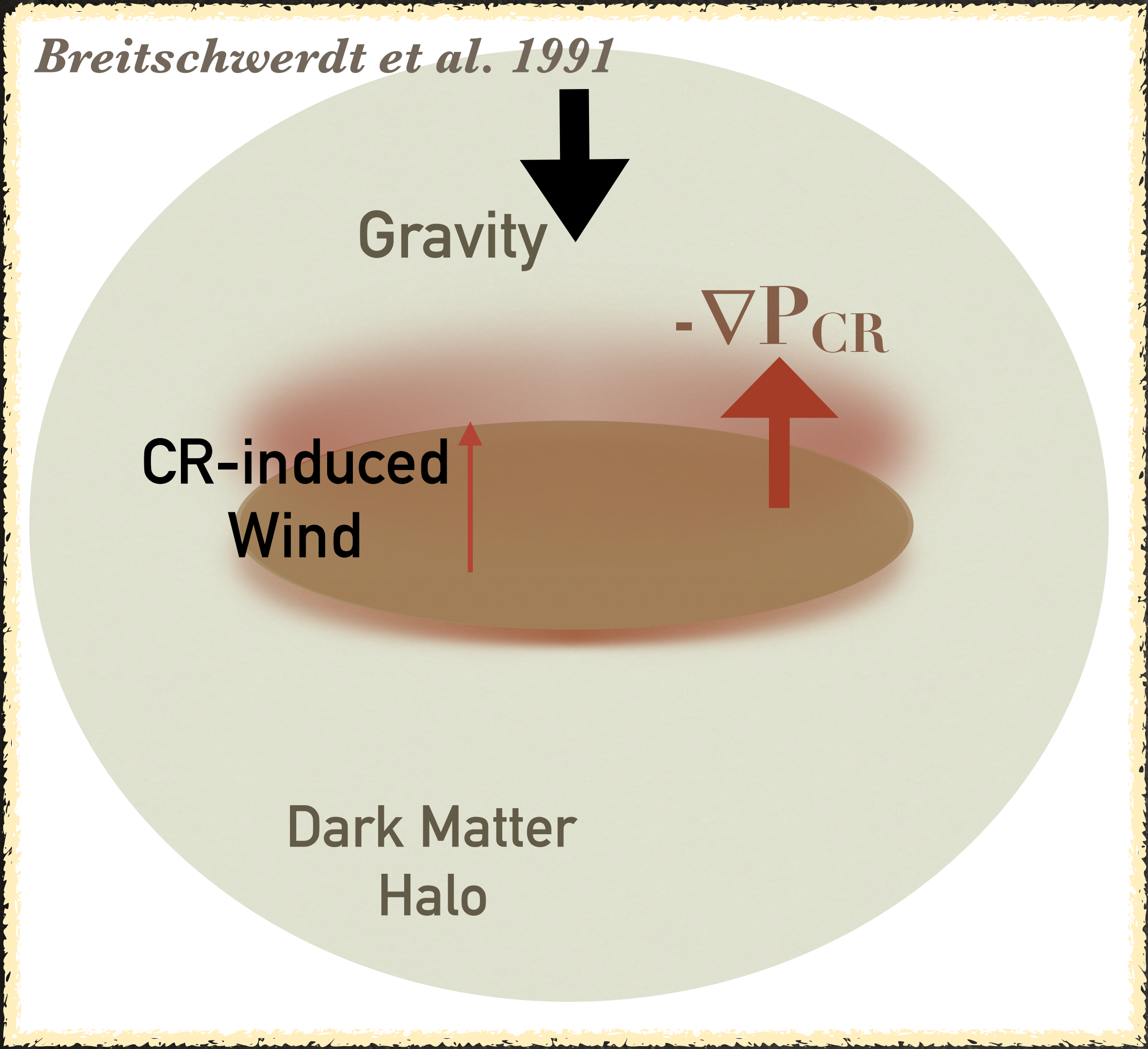




THE HALO IS ELF-GENERATED.

IO NEED FOR AN ARTIFICIAL BOUNDARY CONDITION

Cosmic Rays vs Gravity



The force exerted by CR may wins over gravity and a wind may be launched

$$\vec{\nabla}\cdot(\rho\vec{u}) = 0,$$

$$\rho(\vec{u}\cdot\vec{\nabla})\vec{u} = -\vec{\nabla}(P_g + P_c) - \rho\vec{\nabla}\Phi,$$

$$\vec{u}\cdot\vec{\nabla}P_g = \frac{\gamma_g P_g}{\rho}\vec{u}\cdot\vec{\nabla}\rho - (\gamma_g - 1)\vec{v}_A\cdot\vec{\nabla}P_c,$$

$$\vec{\nabla}\cdot\left[\rho\vec{u}\left(\frac{u^2}{2} + \frac{\gamma_g}{\gamma_g - 1}\frac{P_g}{\rho} + \Phi\right)\right] = -(\vec{u}+\vec{v}_A)\cdot\vec{\nabla}P_c,$$

$$\vec{\nabla}\cdot\left[(\vec{u}+\vec{v}_A)\frac{\gamma_c P_c}{\gamma_c - 1} - \frac{\overline{D}\vec{\nabla}P_c}{\gamma_c - 1}\right] = (\vec{u}+\vec{v}_A)\cdot\vec{\nabla}P_c,$$

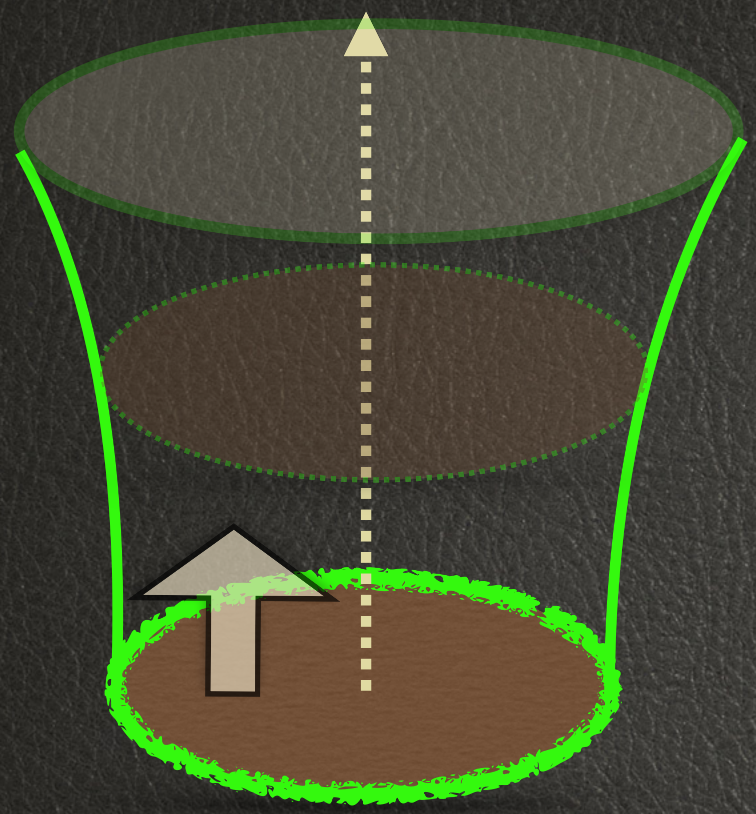
$$\vec{\nabla}\cdot\vec{B} = 0$$

$$\vec{\nabla}\cdot\left[D\vec{\nabla}f\right] - (\vec{u}+\vec{v}_A)\cdot\vec{\nabla}f + \vec{\nabla}\cdot(\vec{u}+\vec{v}_A)\frac{1}{3}\frac{\partial f}{\partial \ln p} + Q = 0$$

Diffusion determined by self-generation at CR gradients balanced by local damping of the same waves

No pre-established diffusion coefficient and no pre-fixed halo size

Cosmic Rays vs Gravity: CR driven winds



Aside from math, the Physics of the problem can be understood easily: There is a critical distance above (and below) the disc (which depends on particle energy) where diffusion turns into advection:

$$\frac{z^2}{D(p)} \simeq \frac{z}{u(z)} \to z_*(p) \propto p^{\delta/2} \qquad D(p) \sim p^\delta$$

Ptuskin et al. 1997

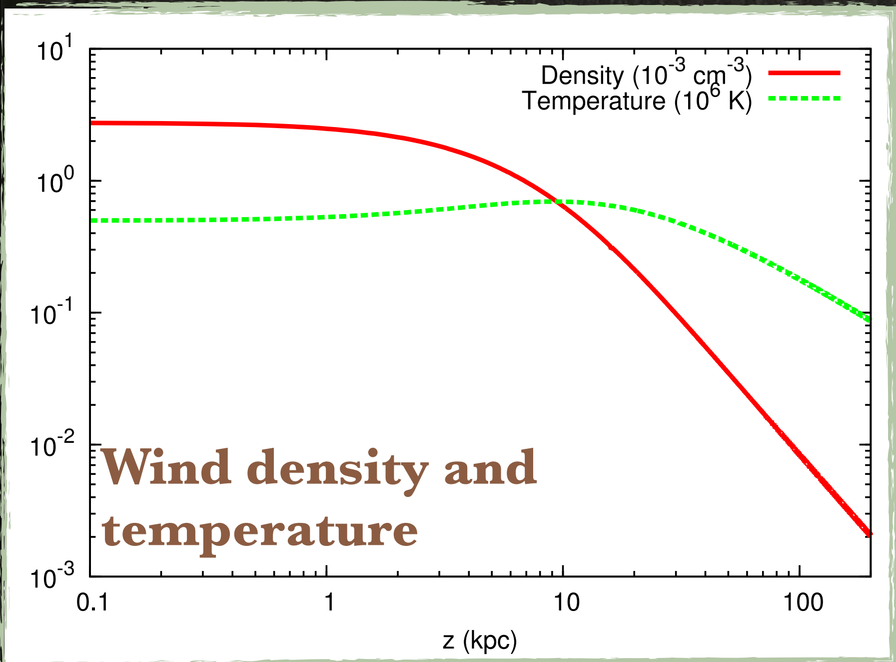
No fixed halo size H

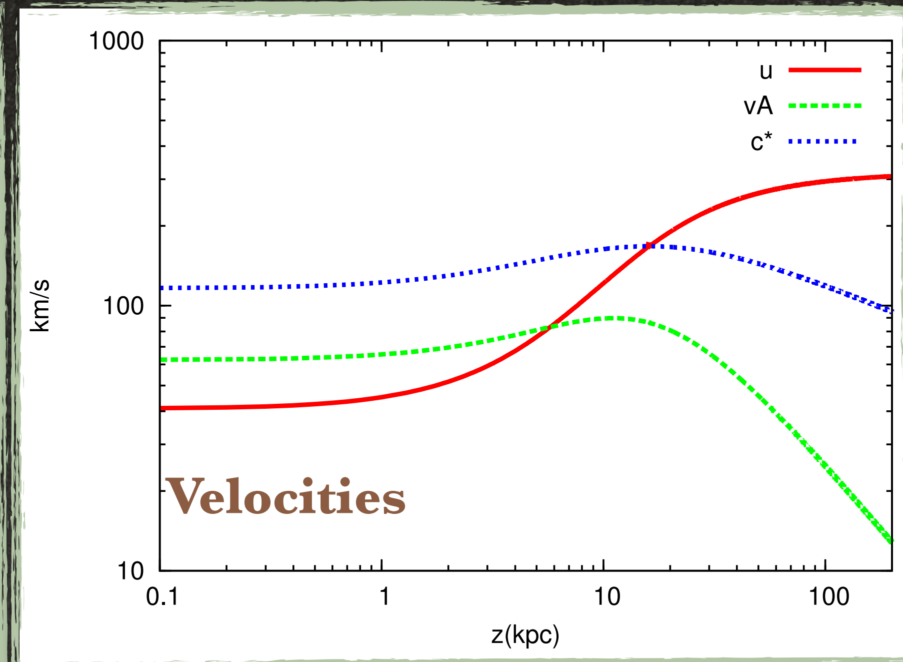
$$f_0(p) = \frac{Q(p)}{2A_{disc}} \frac{H}{D(p)} \sim E^{-\gamma-\delta} \qquad f_0(p) = \frac{Q(p)}{2A_{disc}} \frac{z_*(p)}{D(p)} \sim E^{-\gamma-\delta/2}$$

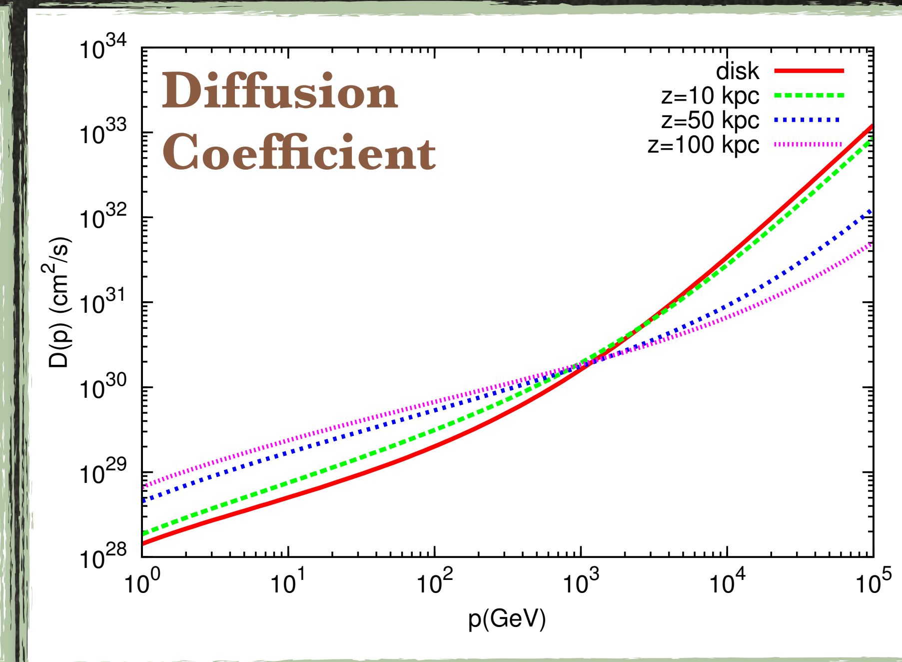
STANDARD CASE | **CR-INDUCED WIND WITH SELF-GENERATION**

At high energy, the critical scale becomes larger than the size of the region where the geometry of the wind remains cylindrical, and a steepening of the spectrum should be expected

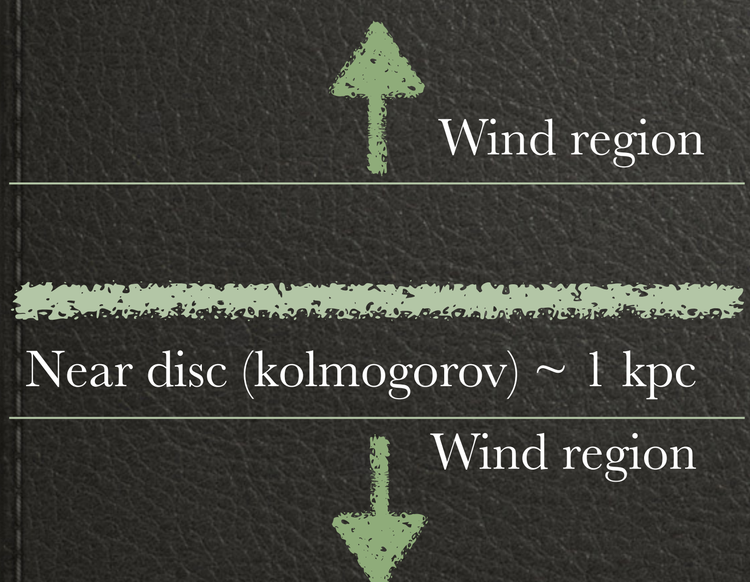
Recchia, PB & Morlino 2016 [arXiv:1603.06746]

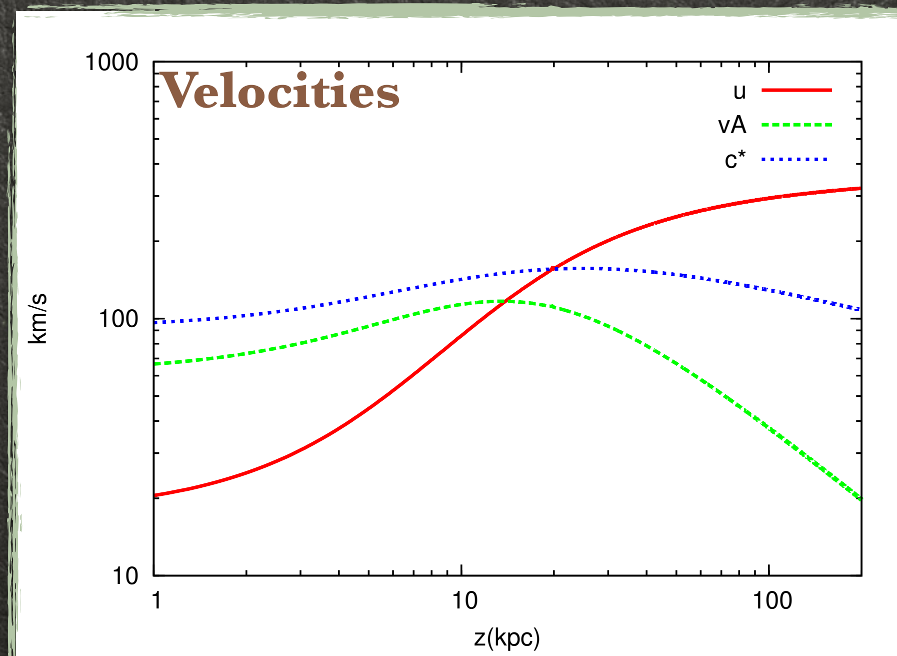


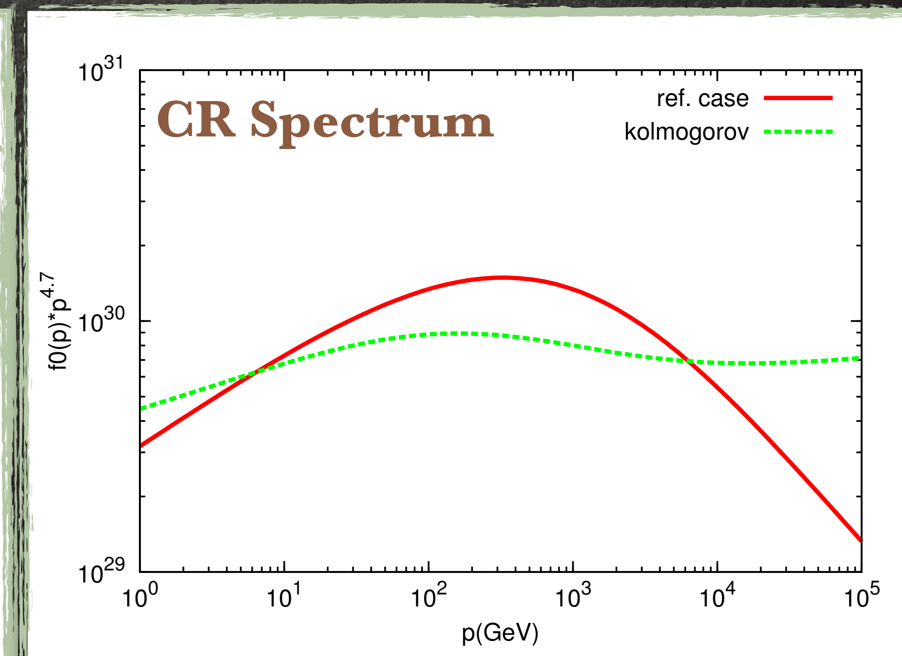




Wind solutions can be found, but they typically lead to CR spectra at the Earth that are quite unlike the observed ones… unless there is a transition region close to the Galactic disc where diffusion is due to other processes…



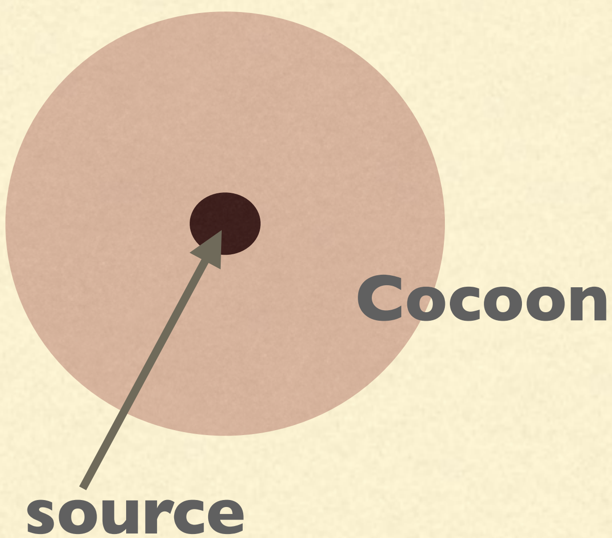




A RADICALLY NEW VIEW?

- IT HAS BEEN NOTED THAT THE FLAT PBAR/P AND RISING POSITRON FRACTION MIGHT SUGGEST A NEW VIEW (***COWSIK 2014, LIPARI 2016, WAXMAN 2014***)
- THE GRAMMAGE WE SEE MIGHT BE ACCUMULATED CLOSE TO SOURCES AND TRANSPORT IN THE GALAXY MIGHT BE E-INDEPENDENT
- SEVERAL IMPLICATIONS:
  - *The injection spectrum of p and e is different*
  - *The injection spectra of nuclei are the same as observed (steep)*
  - *Electrons do not lose energy appreciably during transport (short confinement time)*
  - *Positrons and antiprotons are both pure products of pp collisions*
  - *B/C should flatten (rigidity independent) at R>1 TV*

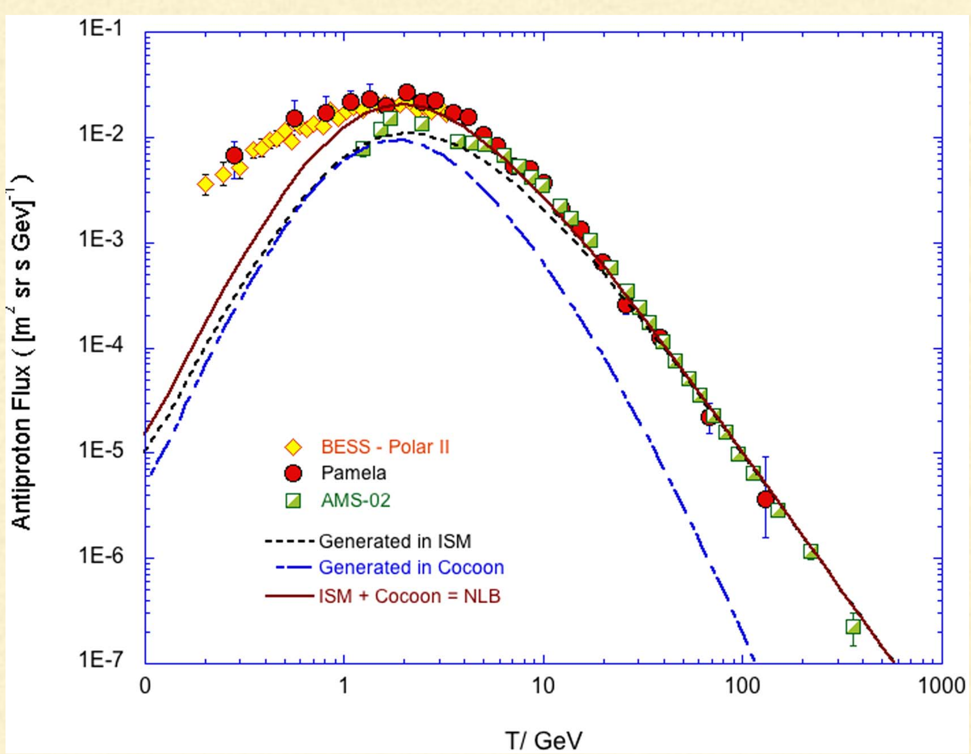
THE NESTED-LEAKY-BOX MODEL

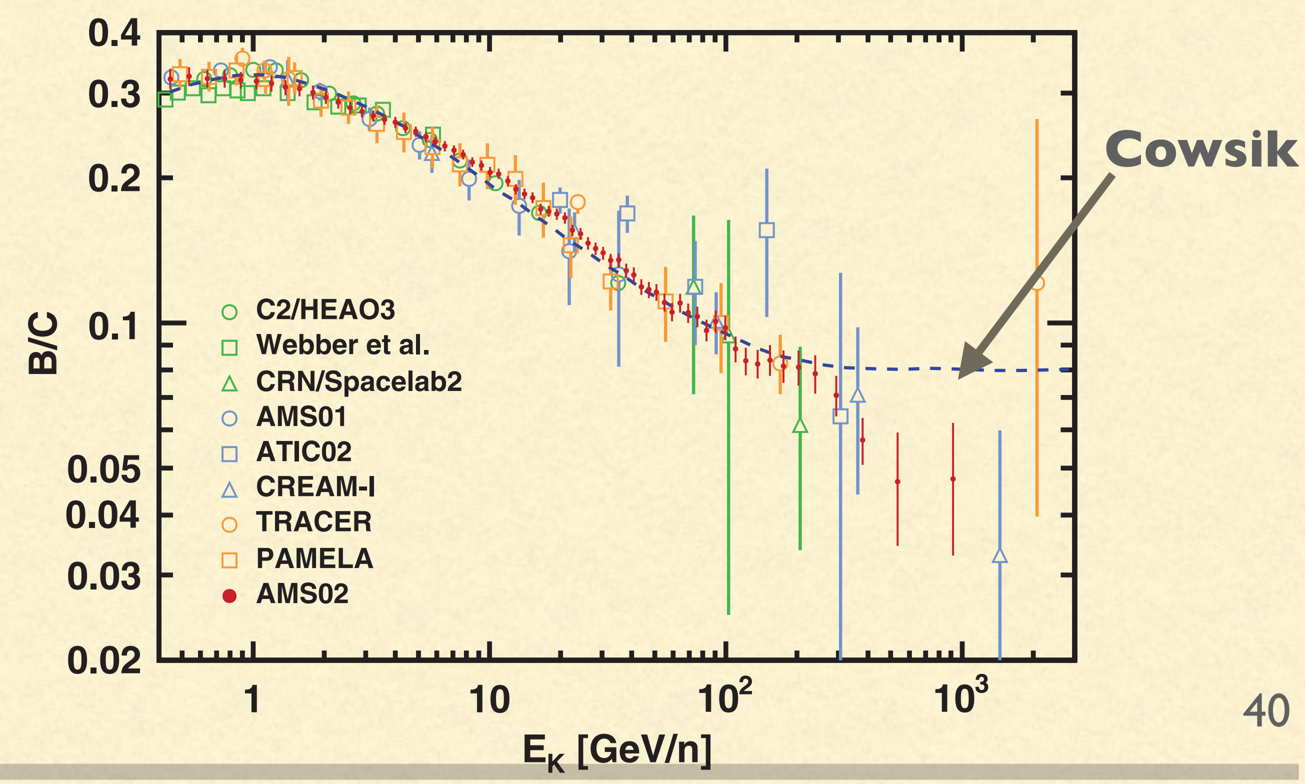


THE MODEL IS BASED ON THE ASSUMPTION THAT ***THERE ARE COCOONS*** *AROUND CR SOURCES WHERE GRAMMAGE (FIT TO THE DATA) IS ACCUMULATED. NO PHYSICAL JUSTIFICATION FOR IT.*

THE GRAMMAGE IN THE GALAXY IS ***RIGIDITY INDEPENDENT*** *BY ASSUMPTION.*

THESE TWO ASSUMPTIONS CAN BE TUNED TO FIT THE DATA



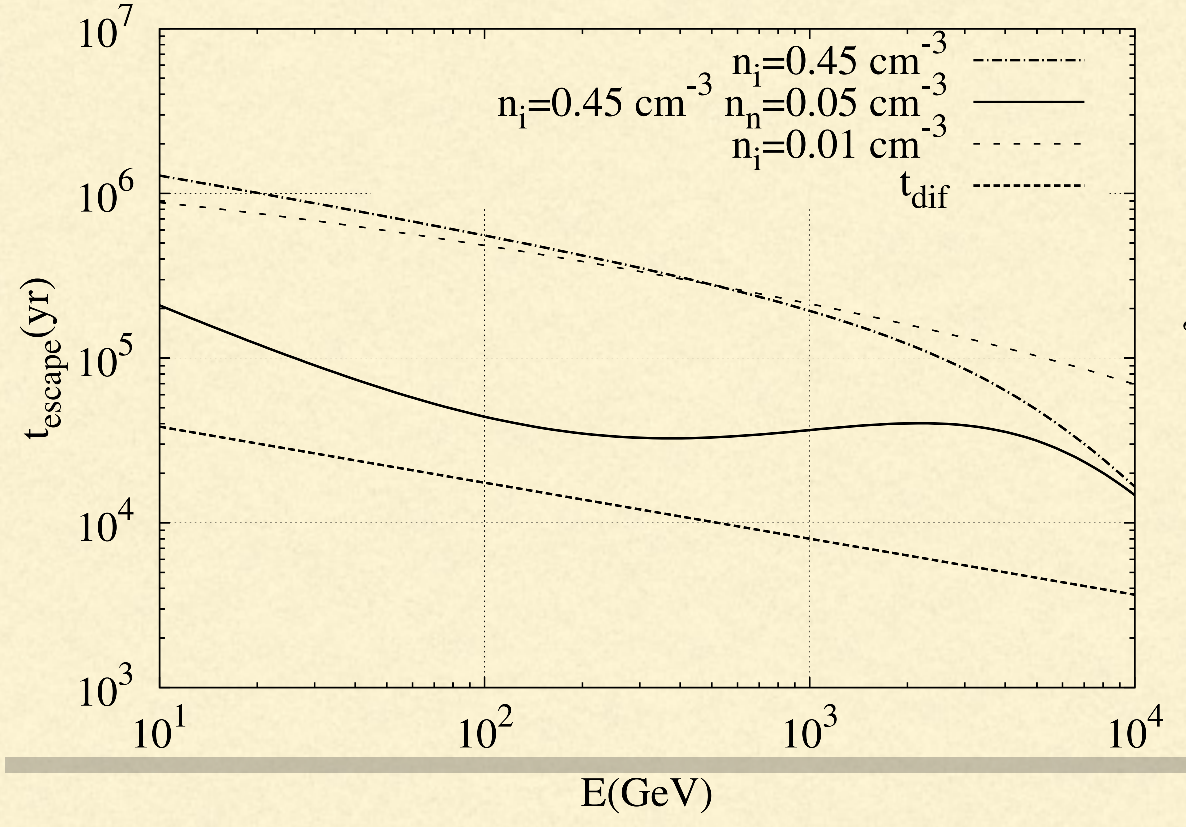


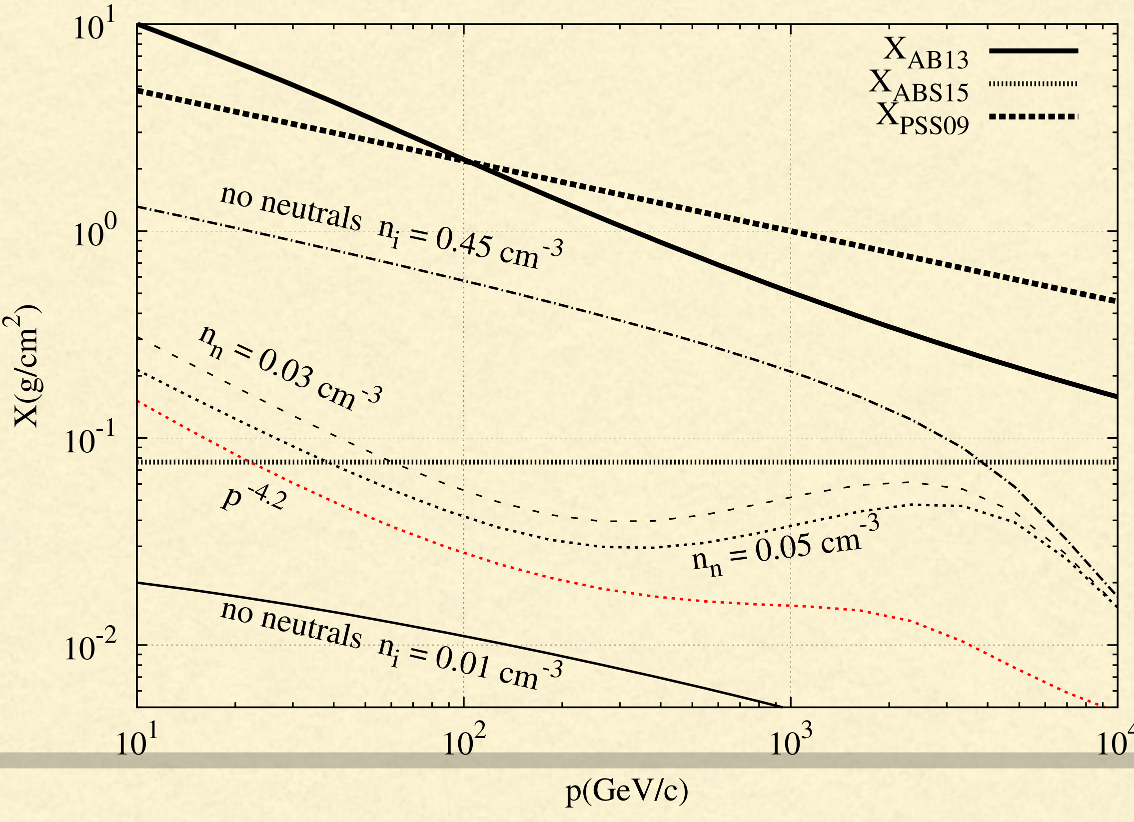
GRAMMAGE AROUND SOURCES

IN NORMAL CONDITIONS THE ISM IS INSUFFICIENT TO GUARANTEE ANY DECENT NEAR-SOURCE GRAMMAGE

THE ONLY CHANCE TO DO SO IS IF THE CR TRANSPORT NEAR SOURCES IS STRONGLY NON-LINEAR (large CR density and density gradients) WHICH MAKES CONFINEMENT TIME LONGER (COCOON)

FOR A STANDARD SN THIS MAY IN FACT BE THE CASE (**D'ANGELO, PB & AMATO 2017**)





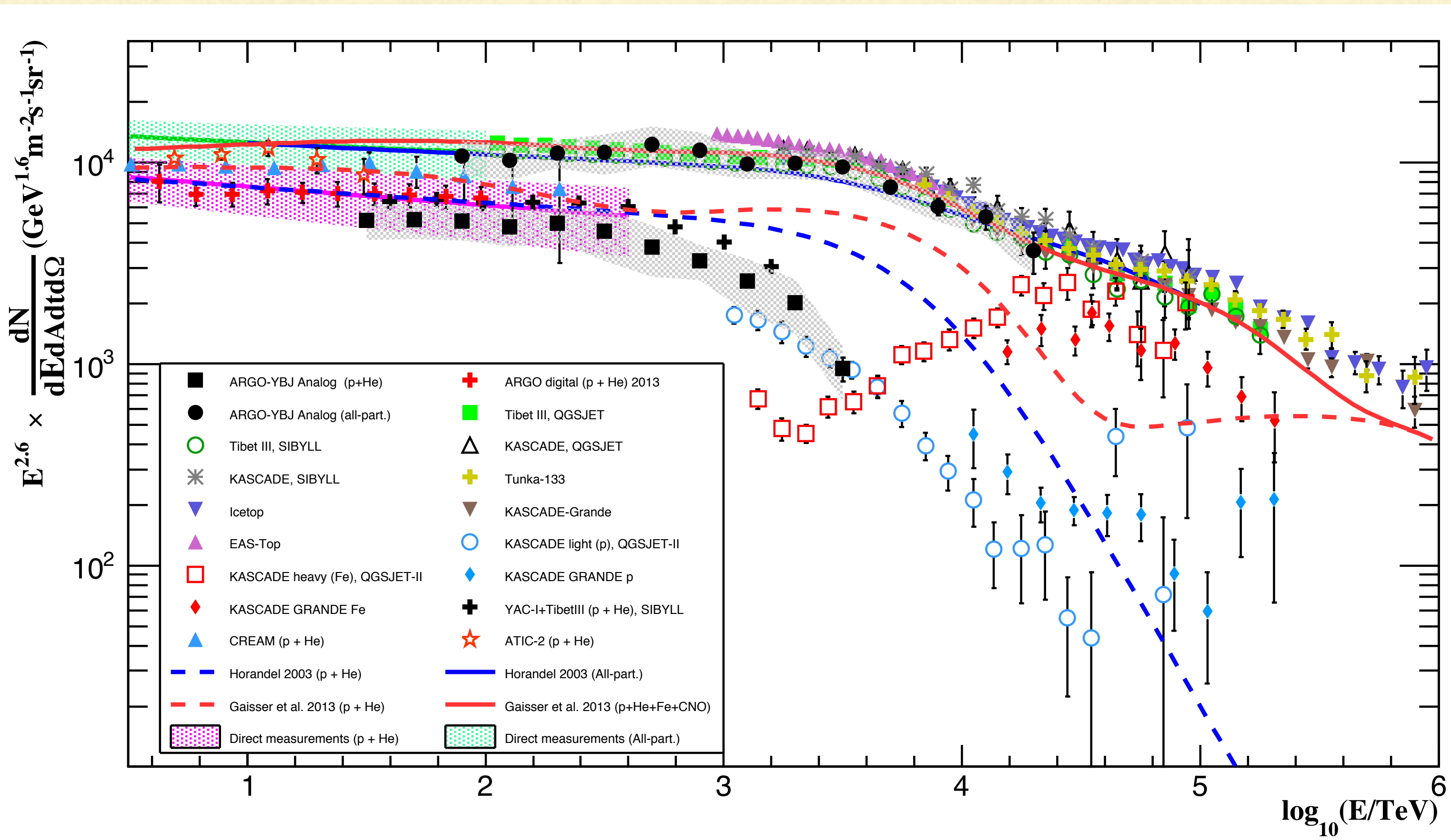
GRAMMAGE AROUND SOURCES

- THE FEASIBILITY IF THIS SCENARIO DEPENDS STRONGLY ON THE AMOUNT OF NEUTRAL GAS
- THE PROXIMITY OF A CLOUD INCREASES THE GRAMMAGE IN THE NEAR SOURCE REGION
- THE EMISSIVITY INTEGRATED ALONG A LINE OF SIGHT IS SENSITIVE TO WHETHER THIS PHENOMENON IS TAKING PLACE (*MORLINO ET AL. 2017*)
- WHEN PRESENT IT STOPS BEING IMPORTANT FOR E>1 TeV, AS WOULD BE REQUIRED TO BE A "COCOON"
- **THERE ARE SEVERAL INDICATIONS ALREADY THAT THE DIFFUSION COEFFICIENT CLOSE TO SOURCES IS MUCH SMALLER THAN AVERAGE (SEE FERMI OBSERVATIONS OF MOLECULAR CLOUDS, HAWC EVIDENCE FOR DIFFUSE EMISSION, ...)**

IS IT POSSIBLE TO HAVE ENERGY INDEPENDENT DIFFUSION?

- RECALL THAT THE D(E) THAT ARE USUALLY QUOTED ARE, STRICTLY SPEAKING, PARALLEL D
- THIS NEEDS RESONANCES! IT HAS TO BE ENERGY DEPENDENT…
- …UNLESS THERE ARE PECULIAR TURBULENCE SPECTRA (e.g. k^{-2}) WHICH WOULD IMPLY D(E)=CONST

CONSIDERATIONS ON THE END OF GALACTIC CR - TRANSITION



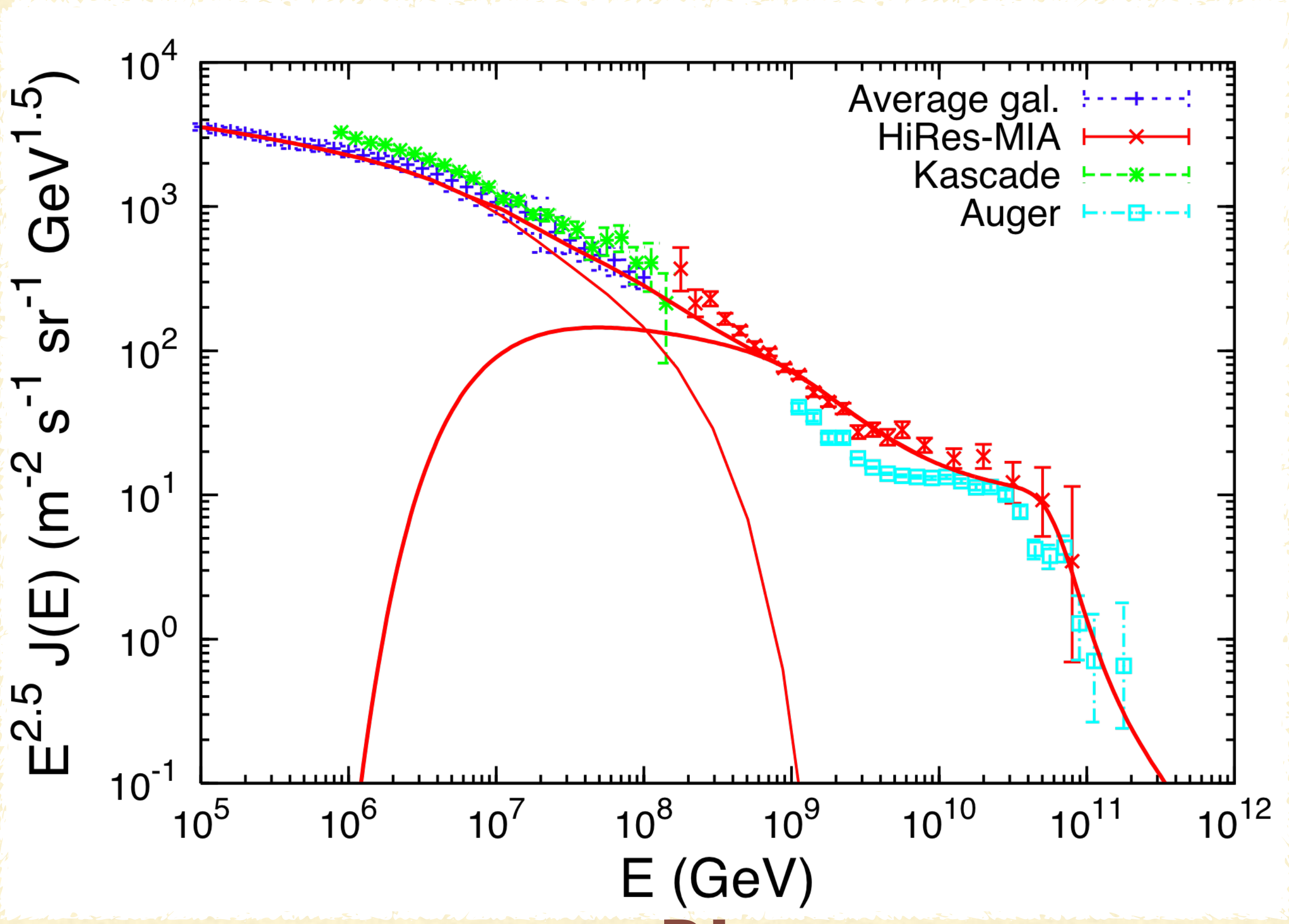
UNDERSTANDING WHAT IS GOING ON AROUND THE KNEE REMAINS CRUCIAL TO FIGURE OUT WHERE GALACTIC CR END

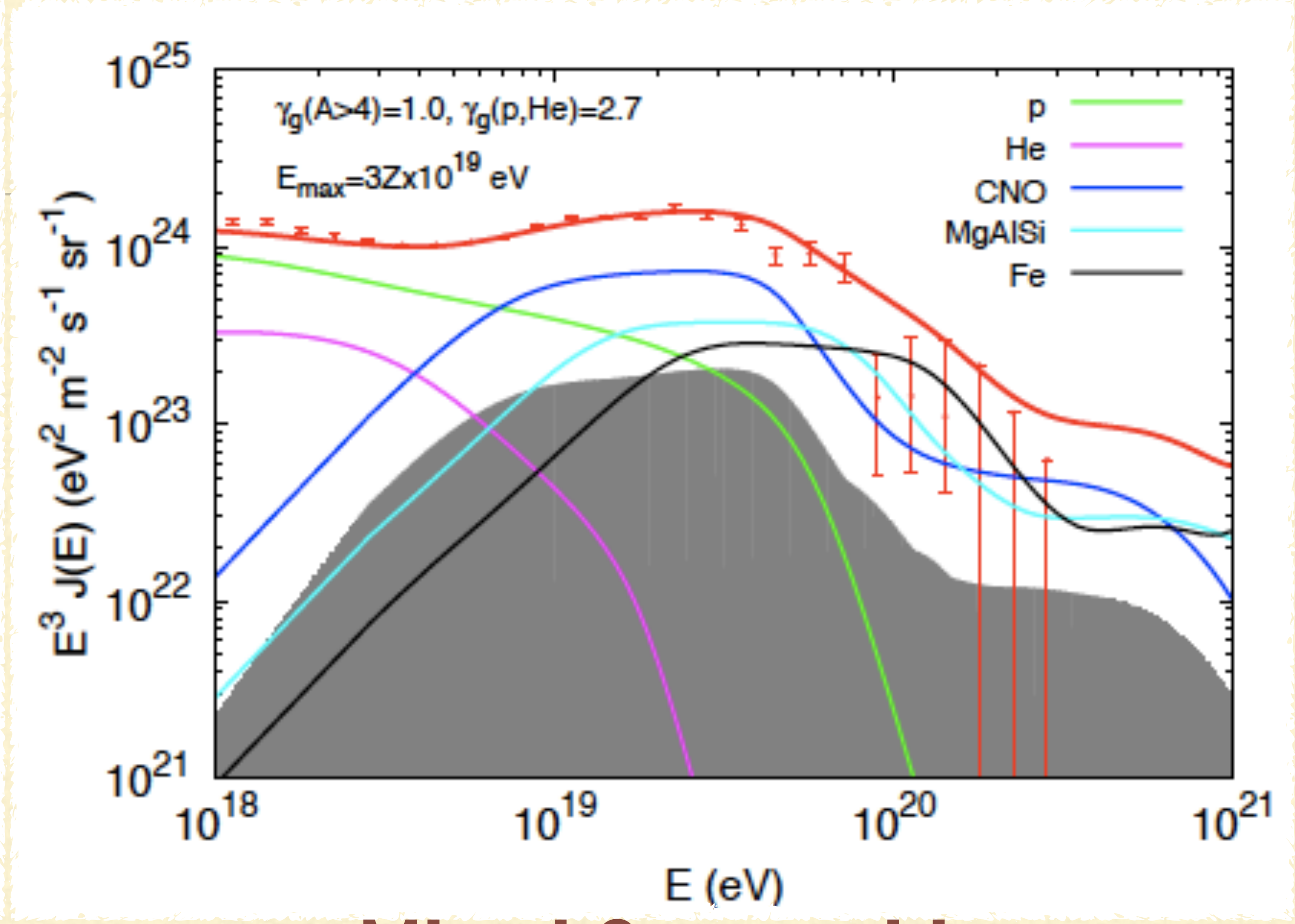
IF THE KNEE IS MADE BY LIGHTER ELEMENTS ➟ GALACTIC CR END WITH HEAVY ELEMENTS AROUND A FEW 10^{17} eV

IF THE KNEE IS MADE BY INTERMEDIATE ELEMENTS (ARGO-YBJ) THE ISSUE OF THE OVERALL SPECTRUM HAS TO BE DEBATED

THE ISSUE OF THE TRANSITION TO EXTRAGALACTIC CR IS TIGHTLY CONNECTED WITH THE ORIGIN OF THE KNEE AND THE END OF GALACTIC CR

TRANSITIONS





Dip

Berezinsky et al.

chemical composition not immediately compatible with Auger data

Mixed Composition

Allard et al.; Aloisio et al.

Mixed composition with $E_{max} \sim 5\ 10^{18}$ eV

Additional extra-gal protons

CONCLUSIONS

- DATA FORCE US TO A CONTINUOUS REVISITATION OF OUR IDEAS (DYNAMIC FIELD)
- THE STANDARD MODEL CERTAINLY NEEDS MODIFICATIONS
- WHETHER SUCH MODIFICATIONS ARE A SYMPTOM THAT A MAJOR REVISITATION OF THE PARADIGM IS NEEDED REMAINS TO BE SEEN