

SCHOOL OF ADVANCED STUDIES Scuola Universitaria Superiore

ORIGIN OF COSMIC RAYS

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OUTLINE

Common wisdom

Recent data

- *Positron excess*
- *Antiprotons* \bullet
- *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 10¹⁷ AND 10¹⁹ eV

COSMIC RAY **ACCELERATION**

4

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 *p*V_{Shock}² *DYNAMICAL REACTION OF ACCELERATED PARTICLES*

EFFICIENT ACCELERATION \rightarrow PLASMA INSTABILITIES \rightarrow B-FIELD AMPLIFICATION \rightarrow *HIGHER Emax*

BOOTSTRAPPING…

DOWNSTREAM UPSTREAM

Bell & Schure 2013

Caprioli & Spitkovsky 2013

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THE FASTEST GROWING MODES *QUASI PURELY GROWING NON-RESONANT MODES*

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

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 8**HUNDRED MICROGAUSS AFTER COMPRESSION, FOR A YOUNG SNR**

IMPLICATIONS FOR MAXIMUM ENERGY

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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

> RED GIANT WIND

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

The Sedov phase reached while the shock expands inside the wind

SN EXPLOSION

$$
R = M_{\rm ej} v_{\rm W}/\dot{M}
$$

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

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

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
- **M** NO EVIDENCE FOR E_{MAX} HIGHER THAN 100 TeV... NOT TERRIBLY SURPRISING, BUT...
- **M** THE ONLY YOUNG REMNANT IN WHICH IT SEEMS SAFE TO SAY WE GOT HADRONS IS TYCHO

FROM *THERE* **TO** *HERE***…**

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Basics of CR Physics

BASICS OF CR PHYSICS: A TOY MODEL

A SIMPLE GENERALIZATION OF CR TRANSPORT

F↵(*p*)*.* (8)

I↵(*Ek*) = *Ap*²

$$
-\frac{\partial}{\partial z}\left[D_{\alpha}\frac{\partial I_{\alpha}(E_{k})}{\partial z}\right] + 2h_{d}n_{d}v(E_{k})\sigma_{\alpha}\delta(z)I_{\alpha}(E_{k}) =
$$
\n**SPALLATION OF NUCLEI** α
\n
$$
= 2Ap^{2}h_{d}q_{0,\alpha}(p)\delta(z) + \sum_{\alpha'\geq \alpha} 2h_{d}n_{d}v(E_{k})\sigma_{\alpha'\to\alpha}\delta(z)I_{\alpha'}(E_{k})
$$
\nINJECTION OF NUCLEI α
\n**CONTRIBUTION TO NUCLEI** α FROM SPALLATION OF NUCLEI $\alpha'\geq \alpha$

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, Ε-γ-δ, ΑΤ HIGH ENERGIES, WHERE SPALLATION IS WEAK

M AT LOW ENERGIES, WHERE SPALLATION DOMINATES, NUCLEI HAVE THE SAME SPECTRUM AS INJECTION

Ø THE INJECTION SPECTRA OF SECONDARY NUCLEI, POSITRONS AND ANTIPROTONS REFLECT THIS TREND

SECONDARY/PRIMARY: B/C

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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

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

 n_{sec} n_{pr} \approx σ $m_{\mathrm{\textit{\tiny{\j}}}}$ $|vn_{gas}m_p\tau_{diff}$

POSITRONS

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

equilibrium \mathbf{p} rimary electrons: $n_e(E) \sim$

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

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:

RATIO:

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

 $n_{e^+}(E)$ $n_e(E)$

 $\sim E^{-\delta'}$ It reflects the slope of the proton spectrum at the proton spectrum at $E' \sim 20E$

ANTIPROTONS

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

equilibrium pbar:

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

RATIO 1: RATIO 2:

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

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

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

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)]

AMS-02 Coll. 2013

A GLOBAL PICTURE - AMS02

to the proton flux (blue, left axis) [16], the electron flux (purple,

THE B/C RATIO - AMS02 $T = D / C \cdot D A T / Q$

charge Z in the ith rigidity bin ðRi; Ri þ ΔRiÞ is given by

In this Letter the B=C ratio was measured in 67 bins from

 $T_{\rm eff}=T_{\rm eff}=C_{\rm eff}$ as systematic error on the B $=C_{\rm eff}$

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

M TRANSPORT IN A D(P,Z) WOULD WORK (Tomassetti, 2012 and following work)

Ø ONSET OF NON LINEAR CR TRANSPORT EFFECTS WOULD WORK (PB+, 2012 and following work)

SPACE DEPENDENT DIFFUSION

Tomassetti 2012

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

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

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SPACE DEPENDENT DIFFUSION

2 *Tomassetti 2015* ³

FIG. 2. Top to bottom: Energy spectra of B and C, B/C

FIG. 3. The ¯p/p ratio as function of kinetic energy. The

To match the data, a diffusion coefficient with δ ≈ 0.15 is

NON-LINEAR TRANSPORT

Ø DIFFUSING CR EXCITE A STREAMING INSTABILITY ENHANCED SCATTERING

Ø TURBULENCE MAY ALSO BE INJECTED, FOR INSTANCE BY SN EXPLOSIONS, AT LARGE SCALES AND CASCADE DOWN

Ø THESE PROCESSES NATURALLY LEAD TO SPATIALLY DEPENDENT DIFFUSION

NON-LINEAR TRANSPORT *PB, AMATO&SERPICO 2012, ALOISIO&PB 2013, ALOISIO, PB & SERPICO 2015* $\overline{}$ ² **E**(*E* $\frac{1}{2}$ **E**(*i* $\frac{1}{2}$ **E**(**i** $\frac{1}{2}$ N N N implications for the nuclear spectra and for the B/C ratio. We where *I*α(*E*) is the flux of nuclei with kinetic energy per nu- $\sqrt{2}$ **for a** for the clean of the clean of the v *p*² *f f f f*⁰, *f f f*² *f*² *f*

+

m

mass number of the quantity α

σα′→^α, (3)

µ v

THE TRANSPORT EQUATION FOR EACH NUCLEAR SPECIE IS SOLVED WITH A DIFFUSION COEFFICIENT is the rate of adiabatic energy losses due to advection. ANSPURT EQUATIUN FUR EAUN NUCLEAR SPECIE HA DIFFI **2. Self-generated versus pre-existing waves** $EQUAT$ $\ddot{}$ UN
LIC FOR EACH *D*^α *H* UCLEAR SPECIE IS SOLVED which represents the grammage for nuclei of type α with kinetic of type α with kinetic of type α

$$
D_{\alpha}(p) = \frac{1}{3} \frac{pc}{Z_{\alpha}eB_0} v(p) \left[\frac{1}{k W(k)} \right]_{k = Z_{\alpha}eB_0/pc}
$$

d*x*

The paper is structured as follows: in Sect. 2 we summarize

ad

3µ *c*

2*h* ^d

WHERE THE DENSITY OF WAVES RESPONSIBLE FOR SCATTERING SATISFIES THE QUASI LINEAR EXPRESSION: ⁺ µv(*p*)σα *m* **JERE THE DENSITY** ISI LINEAR EXPRESSION. The diffusion coefficient relevant for a nucleus α

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

NON-LINEAR TRANSPORT through the wave power in the spectra are in the waves are in the spectra are in the spe mined by the relevant diffusion coefficient. The problem can be in *k* space for a Kolmogorov phenomenology and *C*^K ≈ 0.052 NON-LINEAR TRANSPORT for instance, by supernova explosions. This means that *q ^W*(*k*) ∝ PB, AMATO&SERPICO 2012, ALOISIO&PB 2013, ALOISIO, PB & SERPICO 2015

E INJECTED AT SOME LARGE SCALE 1/K₀, CASCADE DAMPING) AND ARE AMPLIFIED BY STREAMING **INSTABILITY INDUCED BY CR ECTED AND ARE AMPLIFIED BY STI** $EAMING$ \overline{I} the mass in the one in this formalism is the one in the one the direction parallel to the direction parallel to the ordered magnetic field. In additional to the order of
The ordered magnetic field magnetic field. In addition to the order of the order or the order of the order of THE WAVES ARE INIECTED AT SOME LARGE SCALE LIKA CASCADE IN K-SPACE (DAMPING) AND ARE AMPLIFIED BY STREAMING " THE WAVES ARE INJECTED AT SOME LARGE SCALE 1/K₀, CASCADE ∂*k* ∂*k*

and *Dkk* = *C*KvA*k*⁷/²*W*(*k*)

through the wave power *W*(*k*), but the spectra are in turn deter-

The nonlinearity of the problem is evident here. The diffusion

 $\mathcal{M}(\mathcal{M})$ is the index labeling nuclei of different types. All nuclei of different types. All nu-linear $\mathcal{M}(\mathcal{M})$

¹/² is the diffusion coefficient of waves

transport equation for each nucleus, Eq. (3), and writing the evo-

$$
\frac{\partial}{\partial k} \left[D_{kk} \frac{\partial W}{\partial k} \right] + \Gamma_{CR} W = q_W(k)
$$
\n
$$
D_{kk} = C_K v_A k^{7/2} W(k)^{1/2}
$$
\n
$$
\Gamma_{cr}(k) = \frac{16\pi^2}{3} \frac{v_A}{k W(k) B_0^2} \sum_{\alpha} \left[p^4 v(p) \frac{\partial f_{\alpha}}{\partial z} \right]_{p = Z_{\alpha} e B_0 / kc}
$$

for instance, by supernova explosions. This means that *q ^W*(*k*) ∝

Spectral Breaks: self-generation vs previous turbulence Shectral Breaks: The Shectral stable isotopes for a given value of charge. are included in the calculations. seli-generation vs brev flux spectra and secondary to primary ratios, notably B/C. The $\mathcal{H}(\mathcal{X})$ and $\mathcal{H}(\mathcal{X})$ is a compared with the prediction of our calculations of our calculations of our calculations of $\mathcal{H}(\mathcal{X})$ \sim The solid line is the flux at the flux at the flux at the Earth and Correction due to Earth and Correction due to Earth and Correction and Correction due to Earth and Correction due to Earth and Correction due to Ear sus tul pulefice **Aloisio, PB & Serpico 2015**

p=*Z*α*eB*0/*kc*

k W(*k*)*B*²

0

α

 10^{1} $\frac{17}{10^{-1}}$ 10^2 $10³$ 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} $\mathsf{E}_\mathsf{k}{}^{2.7}$ J (E_k) (GeV $^{1.7}$ /(m 2 s sr)) E_k (GeV/n) helium H=4.0 Kpc, h_a=0.15 kpc, μ =2.4 mg/cm² $B_0=1 \mu G$, $I_c=50 \text{ pc}$, $η_B=0.075$, $\xi_{CR}=0.045$ n_i=0.02 cm⁻³, φ_{sol}=500 MV $γ_{prot.} = 4.20, γ_{nucl.} = 4.15$

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

spectra and later confirmed by AMS-02, although at the time

B/C: self-generation vs previous turbulence weak energy dependence of the propagated spectra that is ex- $B/C \cdot$ se low energies, the agreement of the predicted spectra with those conoration ve provious turbu correction and the data correction is the data of the spectrum of the spectrum of the spectrum of the spectrum o in the ISM. $\mathsf{D}\mathsf{I}\mathsf{C}$ **1.5**

Fig. 3. Spectrum of C nuclei as measured by CREAM (blue squares),

transport is dominated by advection (at the Alfén speed) with

tion are somewhat oversimplified, either when applied to data

ited dynamical range at high energy. Note that a break would

 \overline{a} AMS-02 B/C shows an excess at E>100GeV, compatible with the grammage inside sources: ζ , and according to preliminary measurements of preliminary measurements of ζ AMS-02 (black circles). The black/bottom solid line is the prediction of confinement in the state of the configuration and

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

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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-^γ

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 \mathbb{R}^n fails, because in $\frac{1}{2}$ (20) also causes the low energy the low energy $\frac{1}{2}$

Figure 5. Preliminary spectrum of lithium as measured by AMS-

ening of the lithium spectrum, with no apparent need for

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

...But it has a peak in the central region of the Galaxy... But it has a pear in the central region of t dicted CR density at E α density at E α at E α and α as a dashed α raday...

The **spectrum is also harder** in the central Galaxy than it is in the outskirt *f***c spectrum is also harder** in the cent. \mathbf{C}

TURBULENCE ADVECTED FROM THE DISC

Evoli, Aloisio, PB & Morlino 2018 waves for different values of *z*. Right: Diffusion coefficient as a function of the Galactic height at different energies.

Cosmic Rays vs Gravity

r

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⇢(*z*), *u*

where *Q0¹ is the injection* spectrum, and the coefficients cient (assumed to be seen the galactic be seen to be galactic constant) and *R* the galactic constant of galactic con CR gradients balanced by local damping of the same waves ϵ Γ constant Γ or Γ and Γ and Γ and Γ Diffusion determined by self-generation at of the same waves propagation problem, and is usually taken to be of order ' 4

 N o pre-established diffusion coefficient a kpc. Instead in the fixed halo size is momentum-dependent and does not need to be artificially $k \rightarrow \frac{1}{2}$ No pre-established diffusion coefficient and no pre-fixed halo size

The force exerted by CR may wins over gravity and a wind may be launched de la see Sec. 4 and appendix A) tum and energy conservation (see Sec. 4 and appendix A)):

$$
\vec{\nabla} \cdot (\rho \vec{u}) = 0,
$$
\n
$$
\rho (\vec{u} \cdot \vec{\nabla}) \vec{u} = -\vec{\nabla} (P_g + P_c) - \rho \vec{\nabla} \Phi,
$$
\n
$$
\vec{u} \cdot \vec{\nabla} P_g = \frac{\gamma_g P_g}{\rho} \vec{u} \cdot \vec{\nabla} \rho - (\gamma_g - 1) \vec{v_A} \cdot \vec{\nabla} P_c,
$$
\n
$$
\vec{\nabla} \cdot \left[\rho \vec{u} \left(\frac{u^2}{2} + \frac{\gamma_g}{\gamma_g - 1} \frac{P_g}{\rho} + \Phi \right) \right] = -(\vec{u} + \vec{v_A}) \cdot \vec{\nabla} P_c,
$$
\n
$$
\vec{\nabla} \cdot \left[(\vec{u} + \vec{v_A}) \frac{\gamma_c P_c}{\gamma_c - 1} - \frac{\overline{D} \vec{\nabla} P_c}{\gamma_c - 1} \right] = (\vec{u} + \vec{v_A}) \cdot \vec{\nabla} P_c,
$$
\n
$$
\vec{\nabla} \cdot \vec{B} = 0
$$

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

f (*z*, *p*), *D*(*z*, *p*), *P*c (*z*) and *D*(*z*) are the CR distribution func-

3

~(*z*), *P*g (*z*) are the gas density, velocity and pressure.

@ ln *p*

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:

No fixed halo size H

 $\frac{z}{u(z)} \rightarrow z_*(p) \propto p^{\delta/2} \qquad D(p) \sim p^{\delta}$ Ptuskin et al. 1997

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

*z*2

 $\overline{D(p)} \cong$

z

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

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 37

reference case. *Recchia, PB & Morlino 2016 [arXiv:1603.06746]*

Using the approach described in *§*2, *§*3 and *§*4, we also calculated the spectrum of Galactic CRS: in the upper panel of Galactic CRS: in the upper part of Galactic CRS

temperature (greed dashed line) in units of 106 K for the wind

fixed while iterating upon the distribution function *f* ^j.

I Wind solutions can be fou temperature (greed wind dashed in units of 106 K for the wind variable wind variable that are quite unlike the 1000 u the fact that ion-neutral damping is expected to damp any type Wind solutions can be t_{max} because of the presence of $\frac{1}{2}$ ettur die quite attitud d \log \mathbb{F}_{q} but that timinally load to aga, but they typically icau to ch above density and ch and ch and ch and ch and ch ch ch ch ch where alitusion is aue to othe \sim \pm 0.¹⁸ set $^{-10.5}$ coefficient, $^{-1}$ ϵ case case can be divided in the Earth locations in the ϵ Wind solutions can be found, but they typically lead to CR spectra at the Earth \diagdown that are quite unlike the observed ones… unless there is a transition region \mathbb{I}^3 close to the Galactic disc where diffusion is due to other processes... $f(\mathbf{R})$ temperature (greed dashed line) in units of 106 K limited to the 10-18 0.01 , 0.1 , 0.1 , 0.1 , 0.1 , 0.01 , 0.01 , 0.01 $\mathbf{A}(\mathbf{p}_c)$ $JIOUCS 8...$

A RADICALLY NEW VIEW?

- IT HAS BEEN NOTED THAT THE FLAT PBAR/P AND RISING POSITRON FRACTION MIGHT \triangledown SUGGEST A NEW VIEW (*COWSIK 2014, LIPARI 2016, WAXMAN 2014*)
- THE GRAMMAGE WE SEE MIGHT BE ACCUMULATED CLOSE TO SOURCES AND \triangledown TRANSPORT IN THE GALAXY MIGHT BE E-INDEPENDENT

Ø SEVERAL IMPLICATIONS:

- *The injection spectrum of p and e is different* \overline{M}
- *The injection spectra of nuclei are the same as observed (steep)* \blacksquare
- *Electrons do not lose energy appreciably during transport (short confinement time)* \blacksquare
- *Positrons and antiprotons are both pure products of pp collisions* $\overline{\mathbf{z}}$
- *B/C should flatten (rigidity independent) at R>1 TV*

THE NESTED-LEAKY-BOX MODEL made by carbon fiber and aluminum honeycomb estimated from simulation, using MC samples generated T include the uncertainties in the uncertainties in the two back- A KI-BUXIVIUIDE ciency, in the acceptance calculation, in the rigidity of

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. shown in Fig. 3 of the Supplemental Material [31]. The background from interactions above L1 in the boron interactions above L1 in the boron in the ASED ON THE ASSUMPTION THAT THERE △10 UN THE ASSUMITION THAT <u>THEN</u> D CN SOUNCES WHENE GNAWWAGE (FIT TO THE

at 2 Gv, −0.5% at 200 GV, and −13% at 200 GV, and

Cocoon THE GRAMMAGE IN THE GALAXY IS **RIGIDITY INDEPENDENT** BY *ASSUMPTION.* −7% au 2000 com After background subset of the sample contains the sample contains the sample contains of the sample contai

source

and L3–L8. This residual background is < 3% for the

rigidity range. The total correction to the B=C ratio from

SOURCE THESE TWO ASSUMPTIONS CAN BE TUNED TO FIT THE DATA 2.3

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**) 4

GRAMMAGE AROUND SOURCES

- **EX THE FEASIBILITY IF THIS SCENARIO DEPENDS STRONGLY ON THE AMOUNT OF NEUTRAL** GAS
- **M THE PROXIMITY OF A CLOUD INCREASES THE GRAMMAGE IN THE NEAR SOURCE REGION**
- **Ø THE EMISSIVITY INTEGRATED ALONG A LINE OF SIGHT IS SENSITIVE TO WHETHER THIS** PHENOMENON IS TAKING PLACE (*MORLINO ET AL. 2017*)
- **M 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?

EX RECALL THAT THE D(E) THAT ARE USUALLY QUOTED ARE, STRICTLY SPEAKING, PARALLEL D

EX THIS NEEDS RESONANCES! IT HAS TO BE ENERGY DEPENDENT…

Ø …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 1017 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 E THE ISSUE OF THE TRANSITION TO EXTRAGALACTIC CR AND THE END OF GALACTIC CR IS TIGHTLY CONNECTED WITH THE ORIGIN OF THE KNEE

TRANSITIONS

Additional extra-gal protons 45

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