GALACTIC COSMIC RAYS

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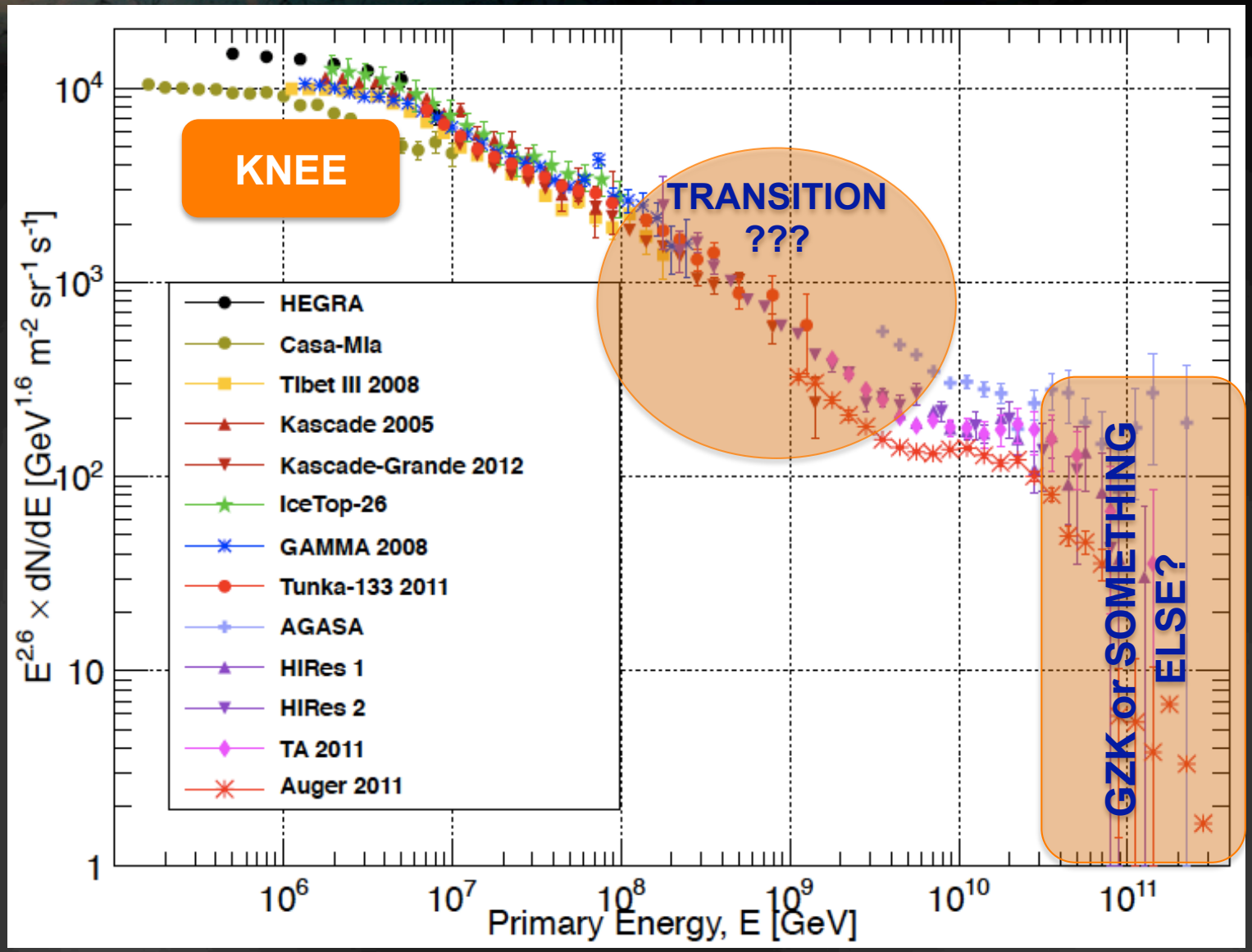
Future DM Astro-Particle Physics, Trieste, October 2013

(Some) RECENT RESULTS

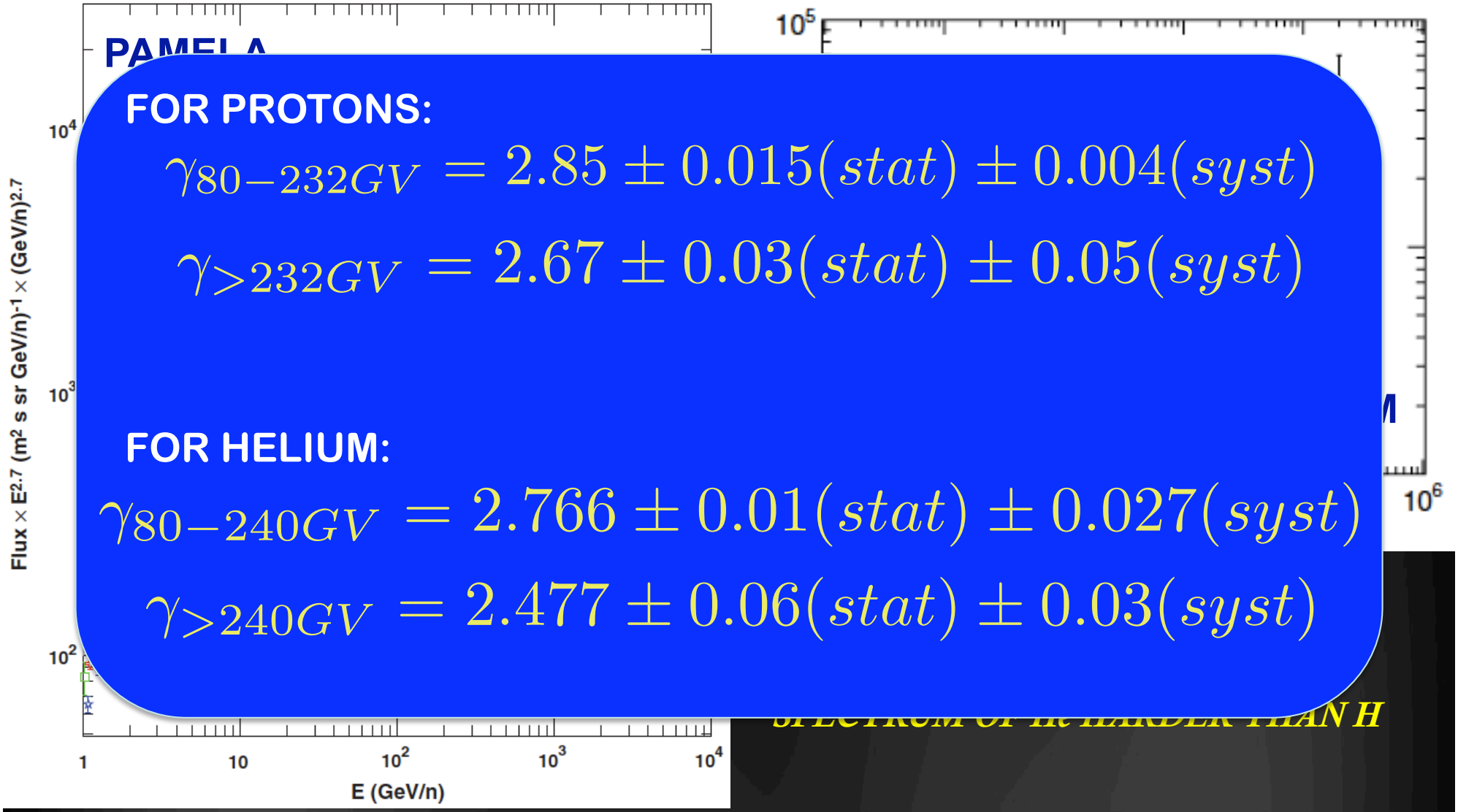
- PROTON AND HELIUM HARDENINGS AT LOW AND HIGH E (PAMELA, but AMS?)
- GAMMA RAYS FROM CLOUDS IN GOULD BELT AND DIFFUSE GAMMA RAY BACKGROUND
- POSITRON RATIO
- SMALL/LARGE SCALE ANISOTROPIES
- PeV NEUTRINOS
- CR ACCELERATION IN SNR AND B-FIELD AMPLIFICATION
- CR ACCELERATION IN SNR AND GAMMA RAY SPECTRA
- OBSERVATIONS OF BALMER LINES AND CR ACCELERATION
- TRANSITION GALACTIC → EXTRAGALACTIC (KASCADE-GRANDE, ICETOP)
- CHEMICAL COMPOSITION OF UHECR

THE SPECTRUM OF COSMIC RAYS



From Gaisser et al. 2013

HYDROGEN AND HELIUM



FOR PROTONS:

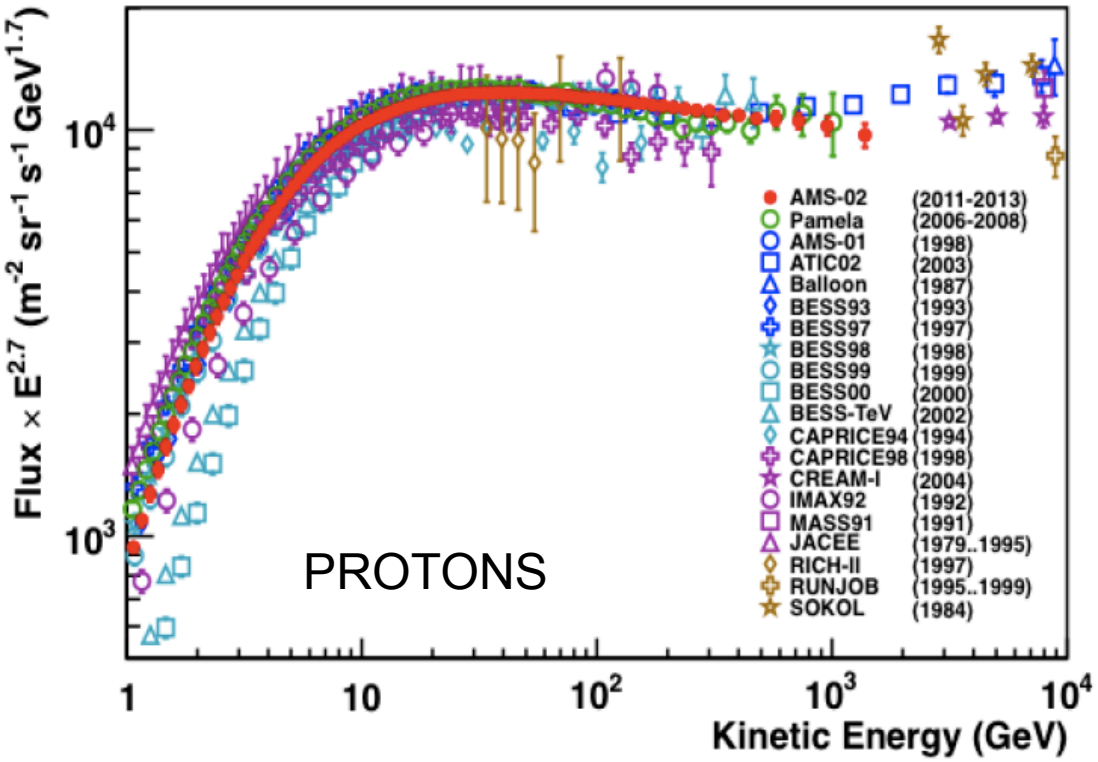
$$\gamma_{80-232GV} = 2.85 \pm 0.015(stat) \pm 0.004(syst)$$

$$\gamma_{>232GV} = 2.67 \pm 0.03(stat) \pm 0.05(syst)$$

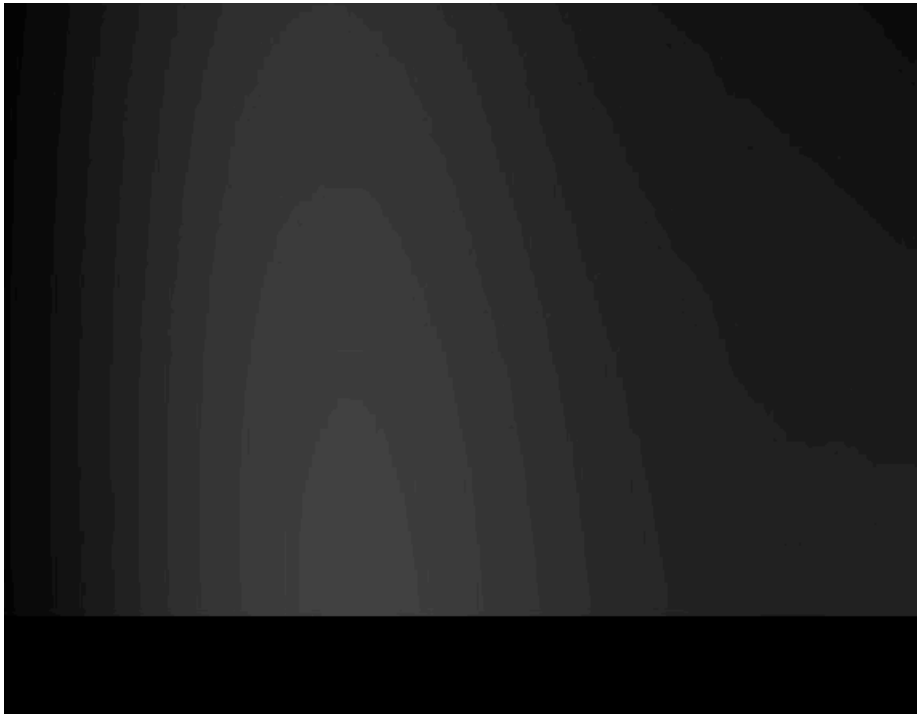
FOR HELIUM:

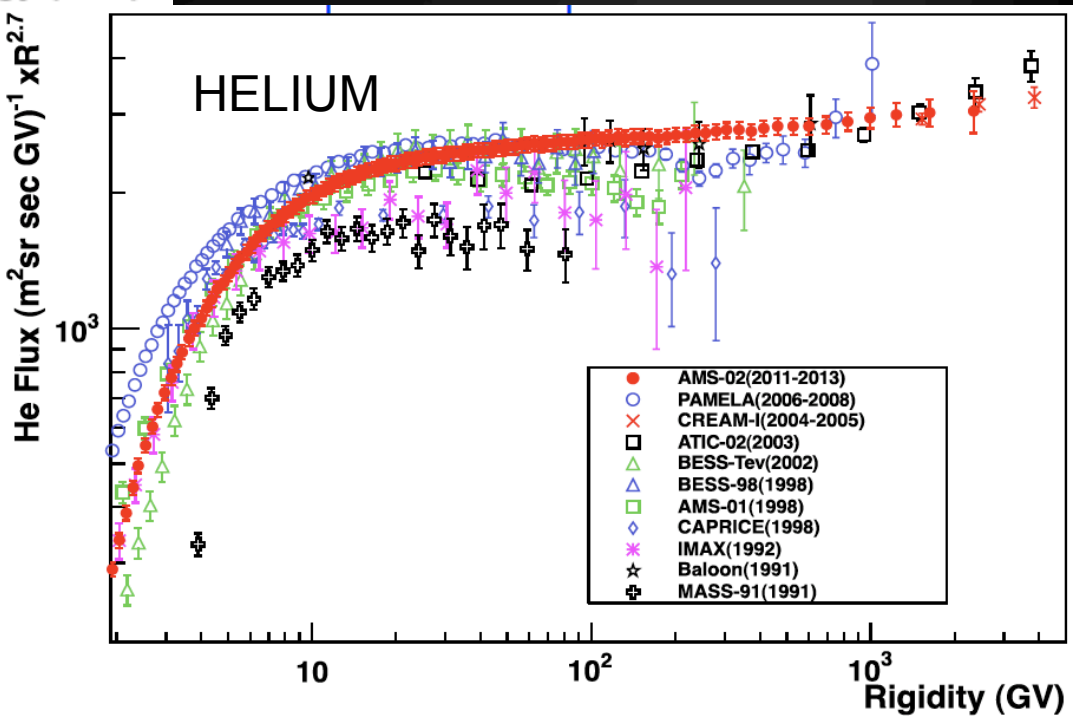
$$\gamma_{80-240GV} = 2.766 \pm 0.01(stat) \pm 0.027(syst)$$

$$\gamma_{>240GV} = 2.477 \pm 0.06(stat) \pm 0.03(syst)$$

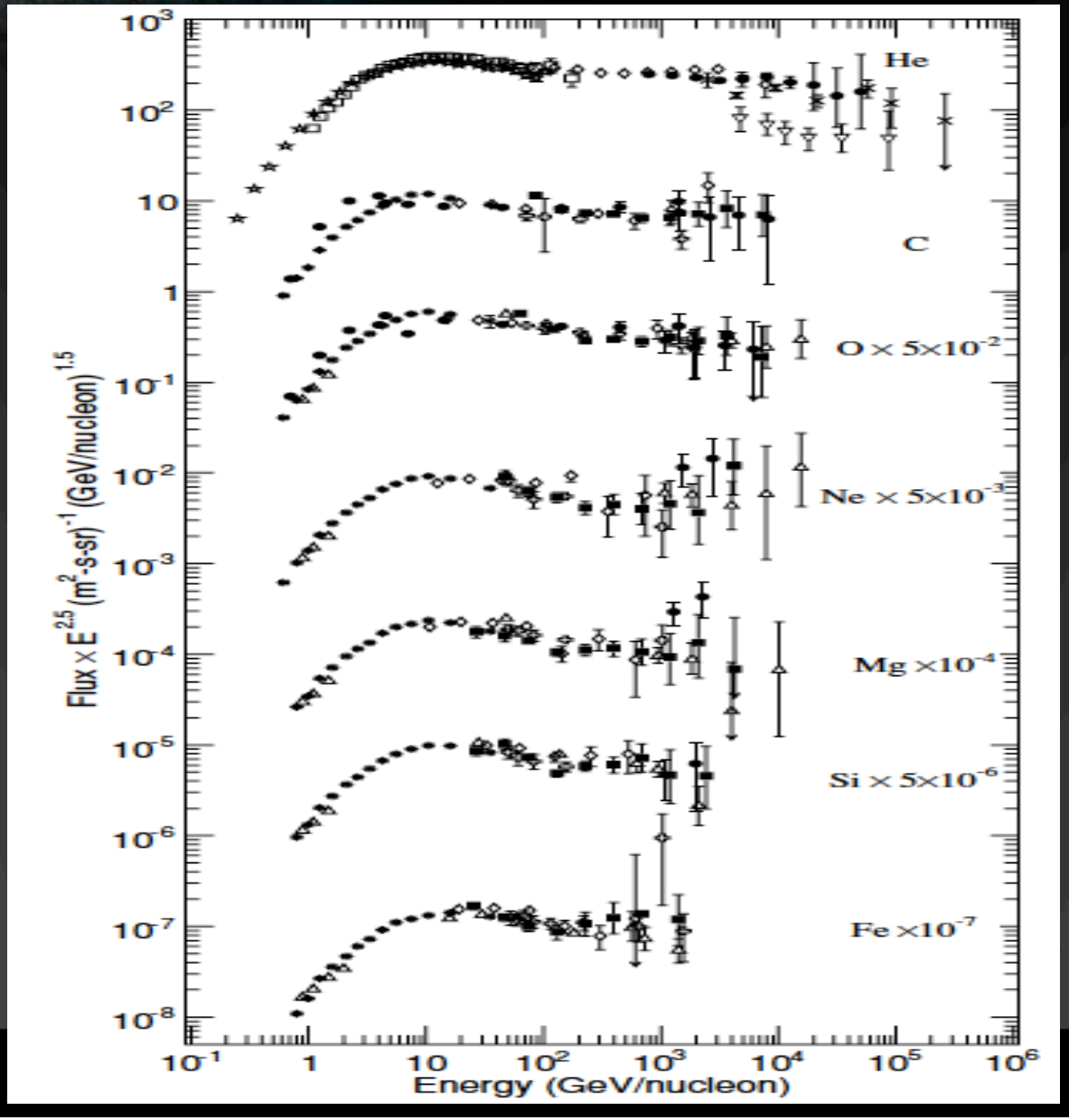


AMS unpublished results as presented at the ICRC in Rio de Janeiro (2013)





HEAVIER PRIMARY NUCLEI



Ahn et al. 2010

DIFFUSIVE TRANSPORT

THE DIFFUSIVE TRANSPORT OF CR IN THE GALAXY IS THE WEAKEST LINK IN THE THEORY

- ***PERPENDICULAR vs PARALLEL DIFFUSION***
- ***D(E) INDEPENDENT OF POSITION. SLOPE FROM B/C***
- ***ORIGIN OF DIFFUSION ? (Alfven, Magnetosonic, cascades, dampings, …)***
- ***EFFECT OF COSMIC RAYS ON THEIR OWN TRANSPORT !!!***

DIFFUSIVE TRANSPORT

I DELIBERATELY SUMMARIZE HERE ONLY THE VERY ESSENTIAL POINTS…

1) PROPAGATION MAINLY MODELED BY USING GALPPROP AND DRAGON

2) WE ARE STILL STUCK WITH TWO MAIN POSSIBILITIES:

a. REACCELERATION

$D(p) \sim p^{1/3}$ WITH NO LOW ENERGY BREAKS

INJECTION SPECTRUM WITH A FLATTENING BELOW ~2 GV

INJECTION SPECTRUM ~$p^{-2.4}$ STEEPER THAN PREDICTIONS FROM DSA

b. NO REACCELERATION (Diffusion Models)

$D(p) \sim p^{0.6}$ WITH A LOW ENERGY BREAK BELOW FEW GV

POWER LAW IN INJECTION ~$p^{-2.1}$

IT HAS SEVERE PROBLEMS WITH ANISOTROPY

NEITHER REACCELERATION MODELS NOR DIFFUSION MODELS MAY ACCOUNT FOR THE SPECTRAL BREAKS

NON SEPARABLE D(E,z)

THE STANDARD RULE OF THUMB THAT

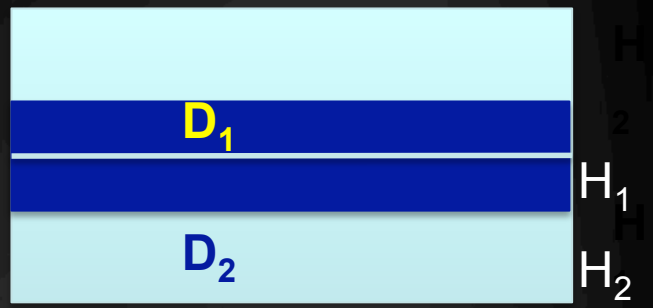
$$n(E) \sim Q(E)\,\tau(E) \sim Q(E)/D(E) \sim E^{-\gamma-\delta}$$

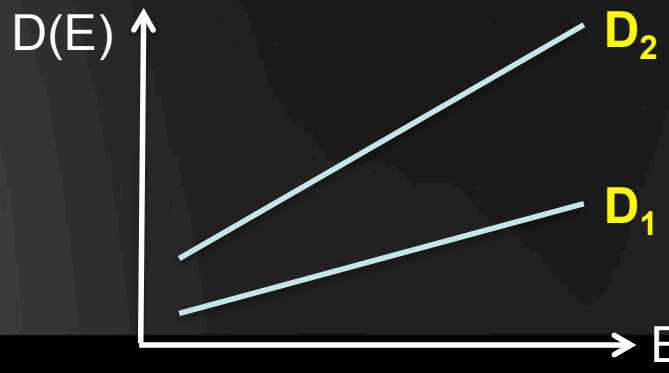
IS ONLY VALID FOR SPATIALLY CONSTANT DIFFUSION OR FOR SEPARABLE D(E,z)=F(E)G(z)

EASIEST INSTANCE OF NON-SEPARABILITY:

$$D(E,z) = D_1(p) = K_1 \left(\frac{E}{E_0}\right)^{\delta_1} \qquad for\ |z| < H_1$$

$$D(E,z) = D_2(p) = K_2 \left(\frac{E}{E_0}\right)^{\delta_2} \qquad for\ H_1 < |z| < H_2$$





NON SEPARABLE D(E,z)

THE SIMPLEST FORM OF THE TRANSPORT EQUATION CAN BE WRITTEN AS:

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

$$q(p,z) = 2hq_0(p)\delta(z)$$

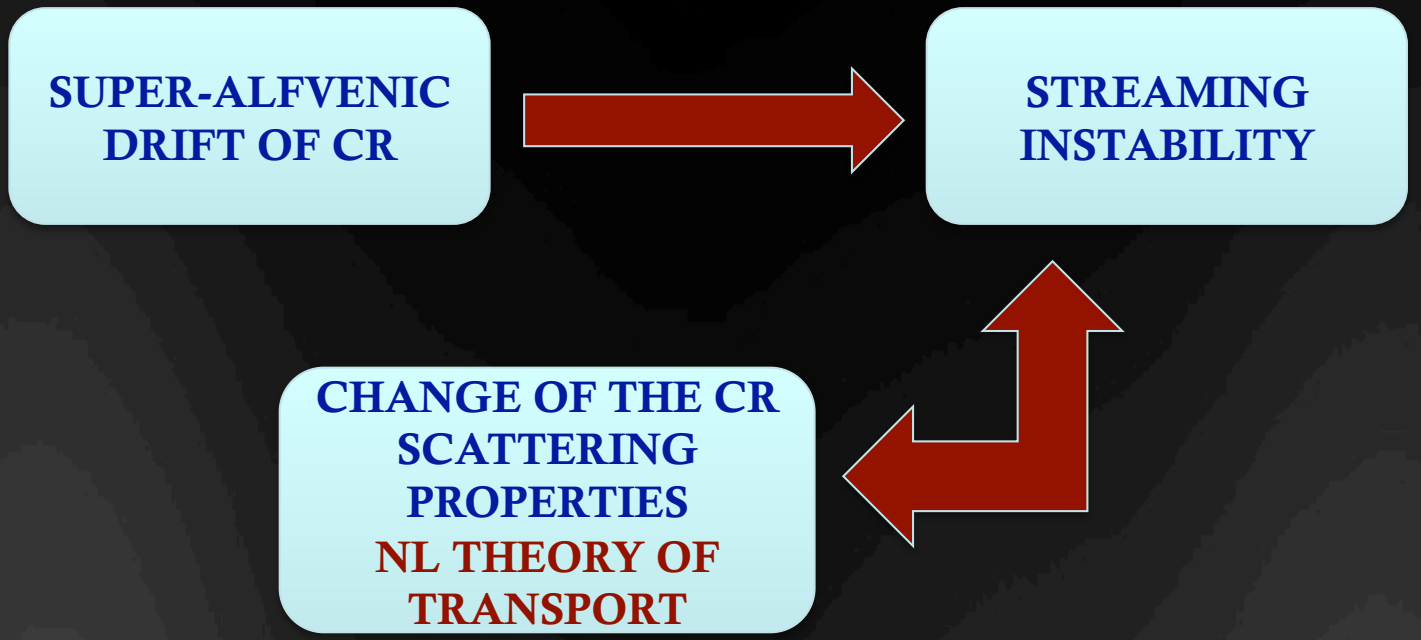
$$q_0(p) = \frac{N(p)\mathcal{R}}{2h\pi R_d^2}$$

WHERE THE CR DENSITY IN THE DISC IS (e.g. Dogiel 2001, Tomassetti 2012***):***

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

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

THE ROLE OF CR ON THEIR OWN TRANSPORT



THIS NON LINEAR TRANSPORT IS CRUCIAL IN ACCELERATION !!!

IN THE CONTEXT OF THE GALAXY, STUDIED BY *Skilling (1975). Holmes (1975)*
AND MORE RECENTLY BY *PB, Aloisio & Serpico (2012)*

AROUND THE SOURCES *Ptuskin, Zirakashvili & Plesser (2008), Malkov et al. (2013)*

THE ROLE OF CR ON THEIR OWN TRANSPORT

THE GROWTH RATE OF THE UNSTABLE MODES INDUCED BY CR IS PROPORTIONAL TO THEIR SPATIAL GRADIENT

$$\Gamma_{CR} = \frac{16\pi^2}{3} \frac{v_A}{B_0^2 \mathcal{F}(k_{res})} \left[p^4 v(p) \frac{\partial f}{\partial z} \right]_{p_{res}(k)}$$

WHERE THE DISTRIBUTION FUNCTION OF CR IS FOUND FROM THE DIFFUSION EQUATION WITH:

$$D(p) \approx \frac{1}{3} r_L v(p) \frac{1}{\mathcal{F}(k_{res})} \qquad k_{res}(p) = 1/r_L(p)$$

$$\Gamma_{CR}(k) = \frac{\tau_A}{\tau_{diff}(p)} \Omega_{cyc} \frac{n_{CR}(>p_{res})}{n_i} \qquad \tau_A = \frac{H}{v_A} \qquad \tau_{diff} = \frac{H^2}{D(p)}$$

$$\Gamma_{CR}(k) \approx 2 \times 10^{-10} \left(\frac{E}{5GeV} \right)^{-1.2} \; s^{-1}$$

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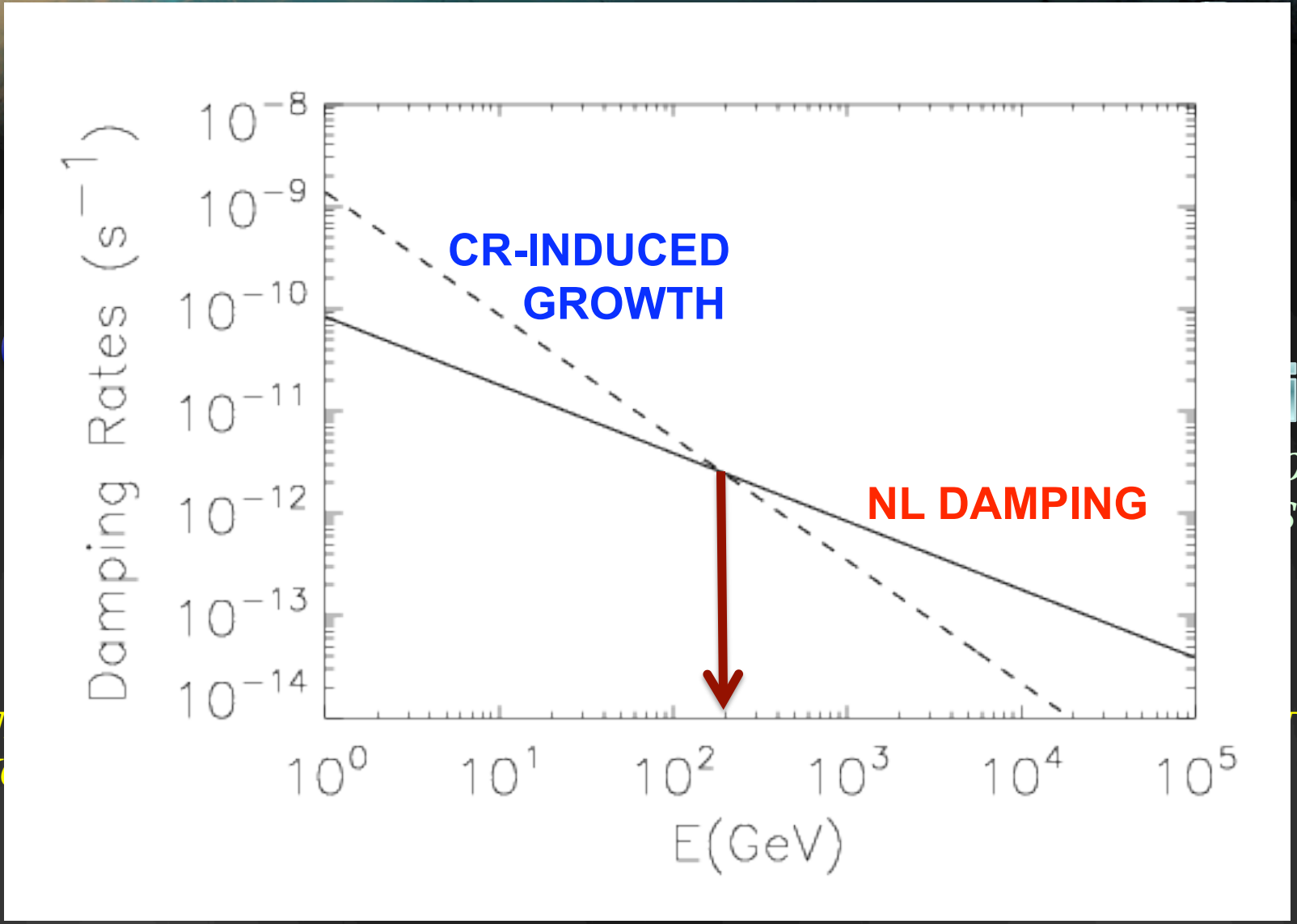


CR TRANSPORT IN SELF-GENERATED WAVES

PB, Amato & Serpico 2012, Aloisio & PB 2013

$$-\frac{\partial}{\partial z}\left[D_\alpha(E)\frac{\partial f_\alpha}{\partial z}\right]+v_A\frac{\partial f_\alpha}{\partial z}+\frac{f_\alpha}{\tau_{sp,\alpha}}-\frac{dv_A}{dz}\frac{p}{3}\frac{\partial f_\alpha}{\partial p}+\frac{1}{p^2}\frac{\partial}{\partial p}\left[p^2\left(\frac{dp}{dt}f_\alpha\right)_{ion}\right]=$$

$$q_{inj}(p)+\sum_{\alpha'>\alpha}\frac{f_{\alpha'}}{\tau_{sp,\alpha'\to\alpha}}$$

α DENOTES THE TYPE OF NUCLEUS (BOTH PRIMARIES AND SECONDARIES ARE INCLUDED)

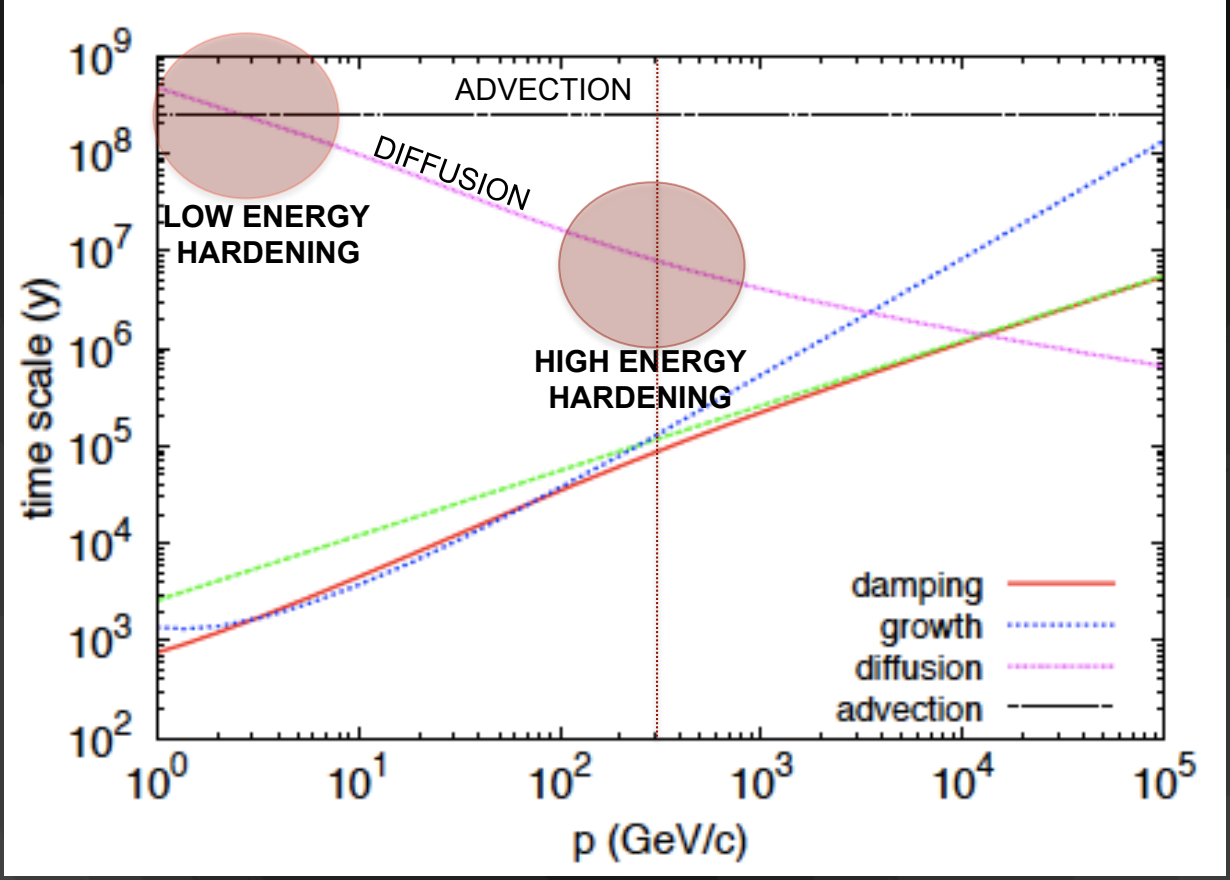
$$\frac{\partial}{\partial k}\left[D_{kk}\frac{\partial W}{\partial k}\right]+\Gamma_{CR}W=q_W(k)$$

TRANSPORT EQUATION FOR WAVES

DIFFUSION COEFFICIENT OUTPUT OF THE CALCULATIONS

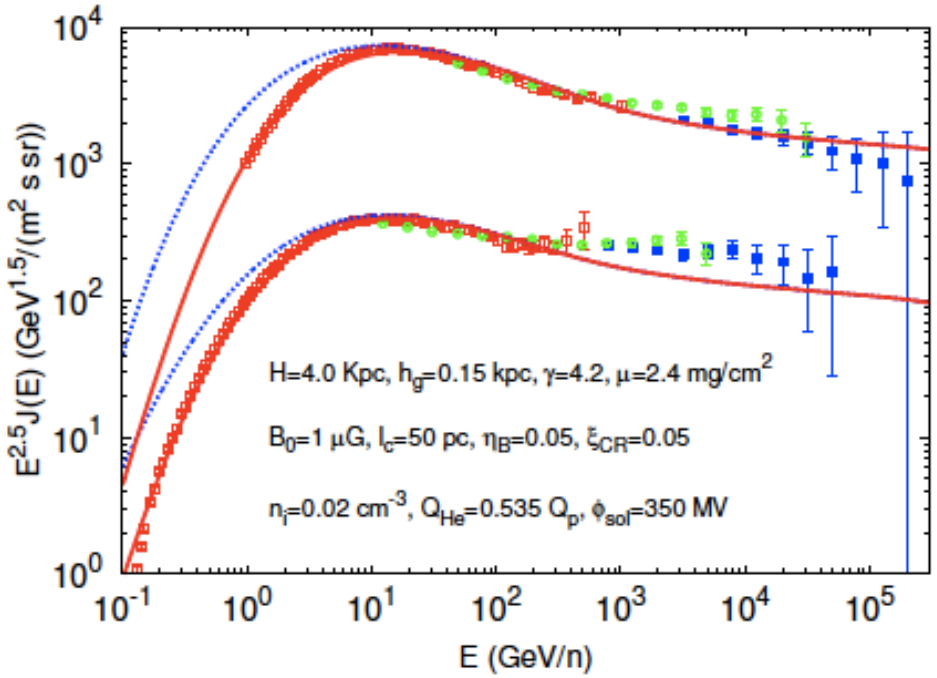
CHANGE OF SLOPE OF D(E) → CHANGE OF SLOPE IN SPECTRA WHERE TRANSPORT SWITCHES FROM SELF-GENERATED TO PRE-EXISTING δB

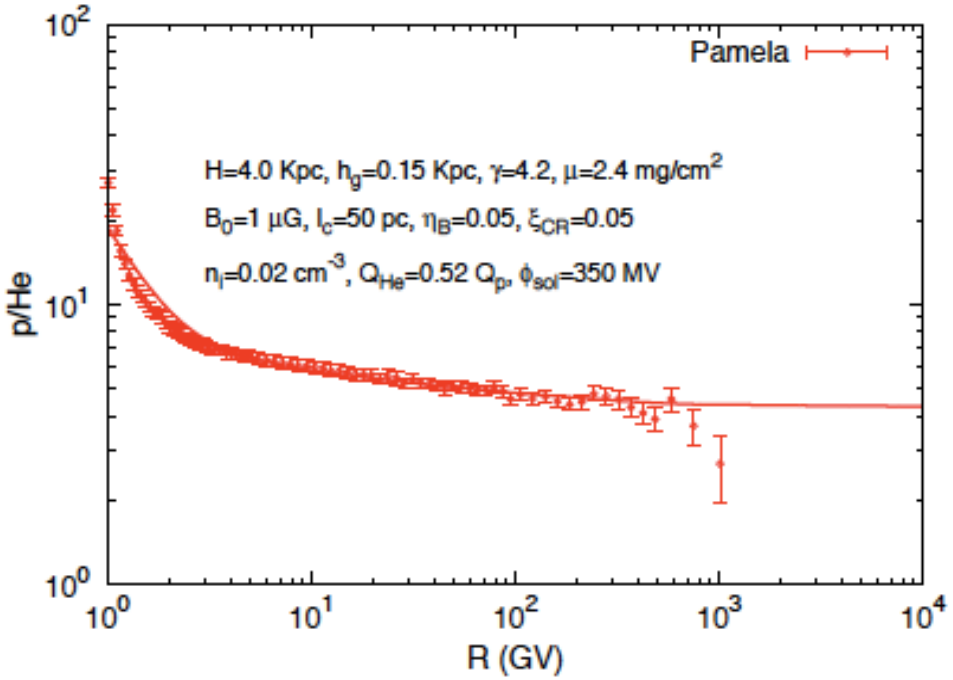
GENERAL TRENDS



Aloisio & PB 2013

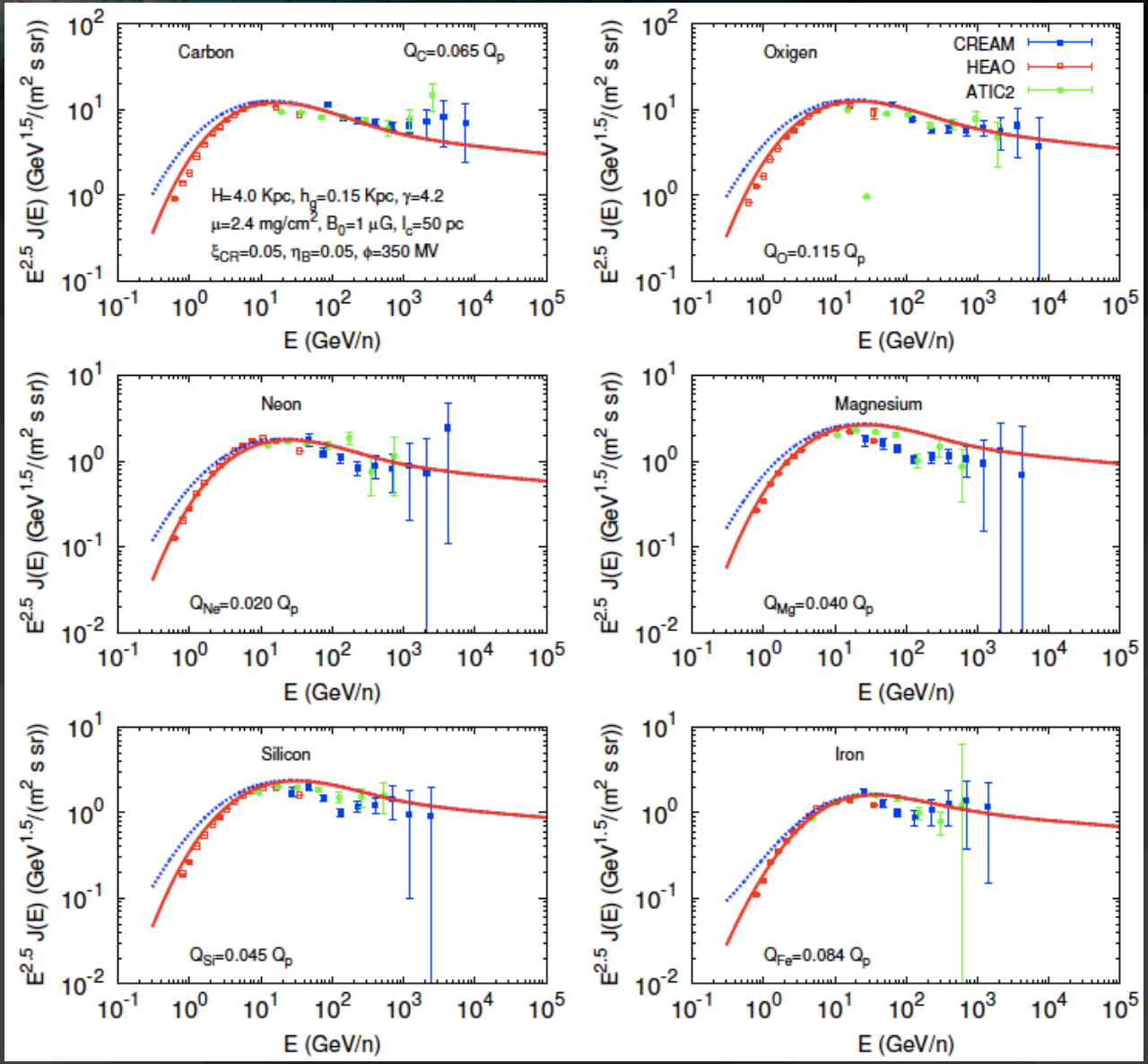
HYDROGEN AND HELIUM





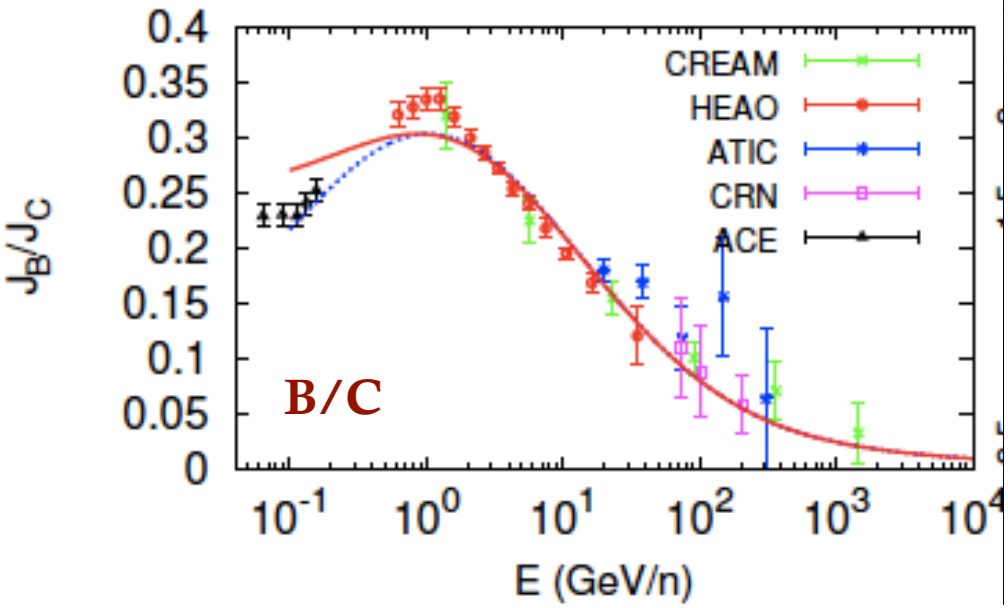
Aloisio & PB 2013

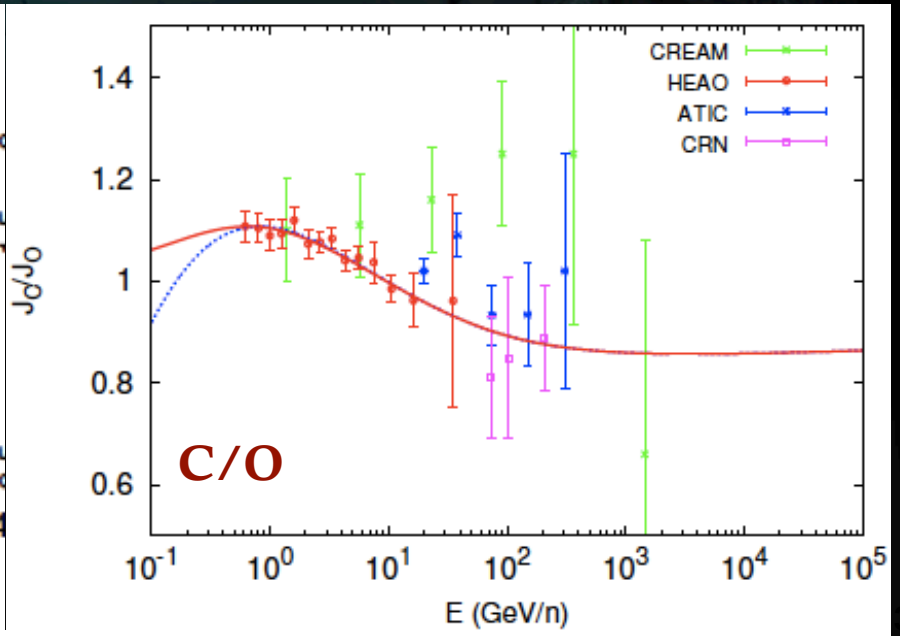
SPECTRA OF HEAVIER NUCLEI

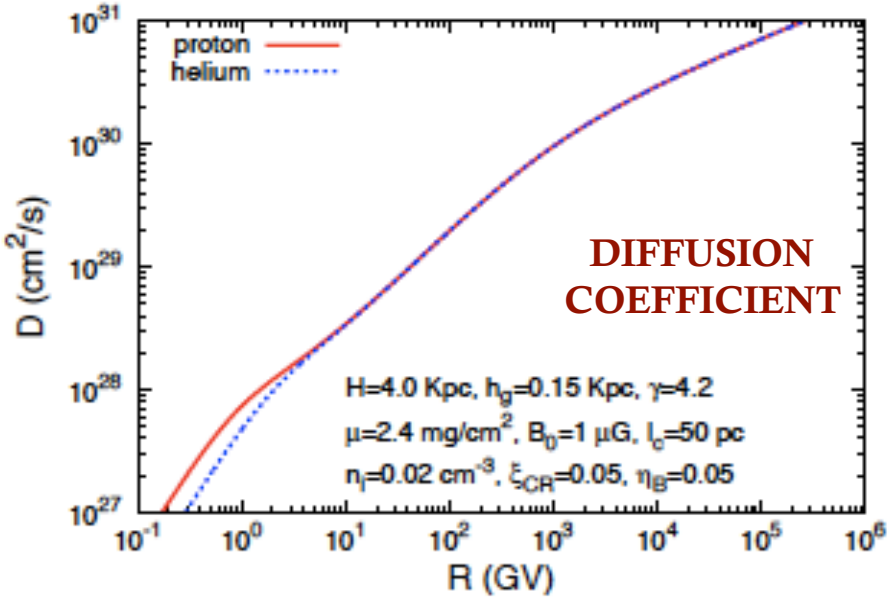


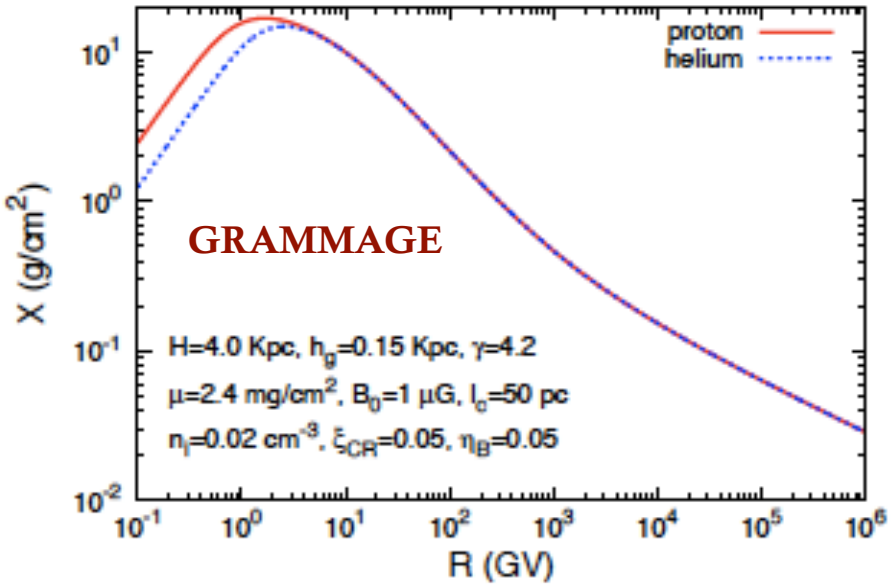
Aloisio & PB 2013

SECONDARY/PRIMARY



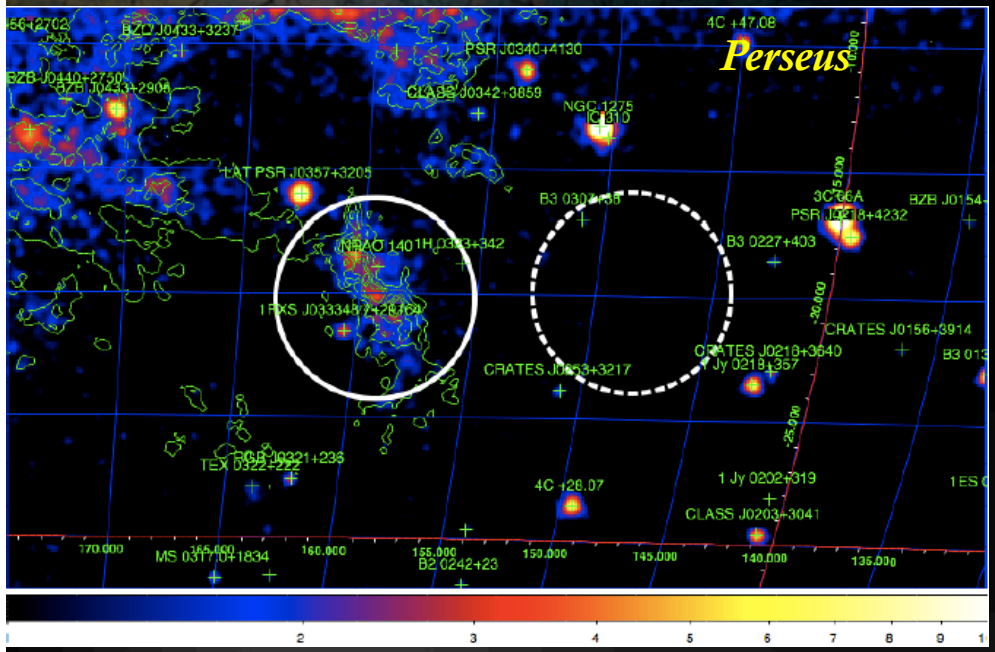


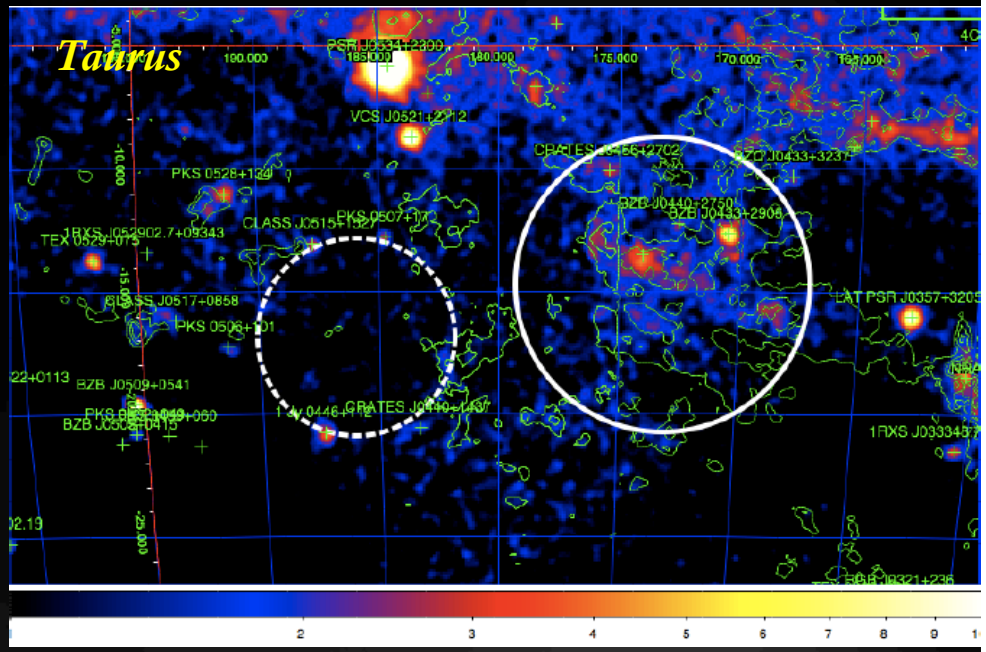




CLOUDS IN THE GOULD'S BELT

Neronov et al. 2012 (see also Kachelriess & Ostapchenko 2012)

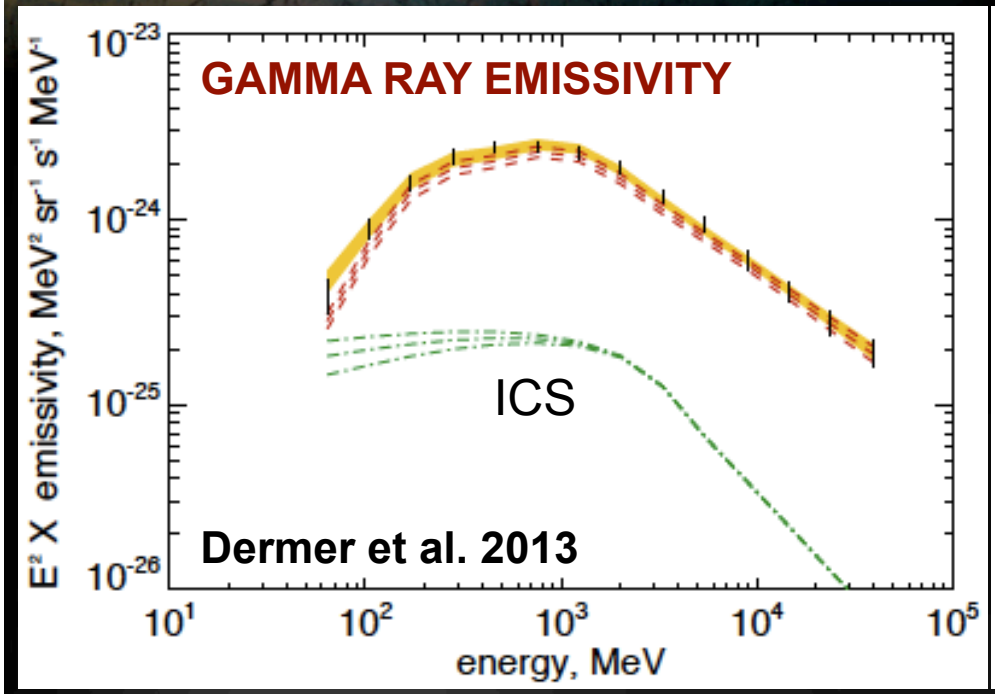


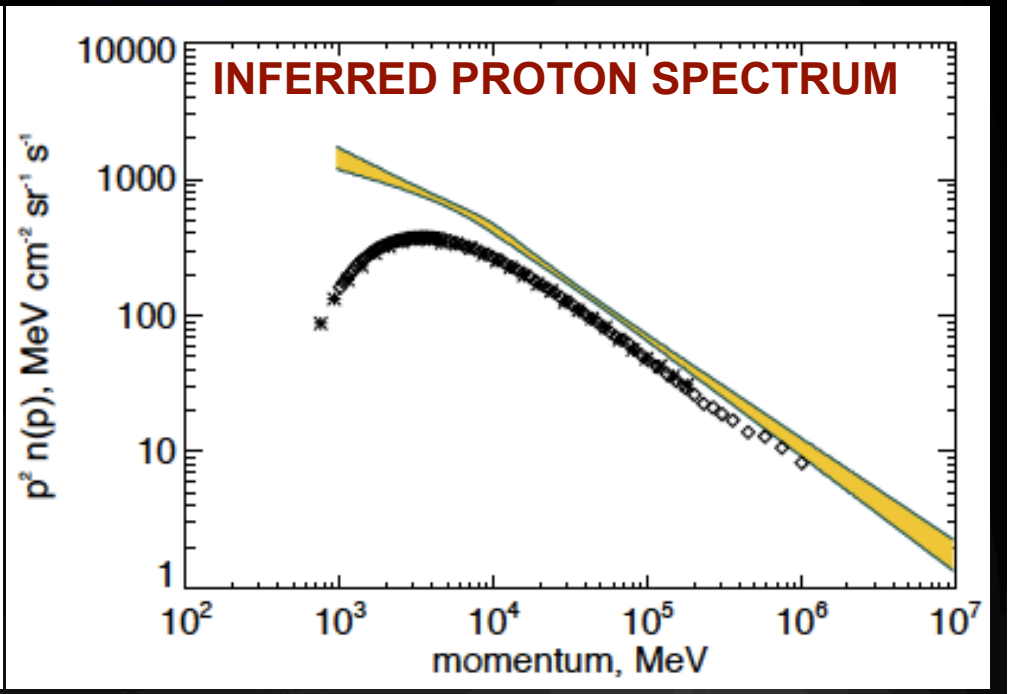


FERMI-LAT DATA HAVE BEEN USED TO MEASURE THE CR SPECTRUM IN SELECTED CLOUDS OFF THE GALACTIC DISC, IN THE GOULD BELT

THE INFERRED CR SPECTRUM SHOWS A LOW ENERGY BREAK AND A SPECTRUM FOR E>10 GEV WITH SLOPE ~ 2.9 SIMILAR TO PAMELA SLOPE IN THE RANGE 80 - 200 GV

DIFFUSE GAMMA RAY EMISSIVITY

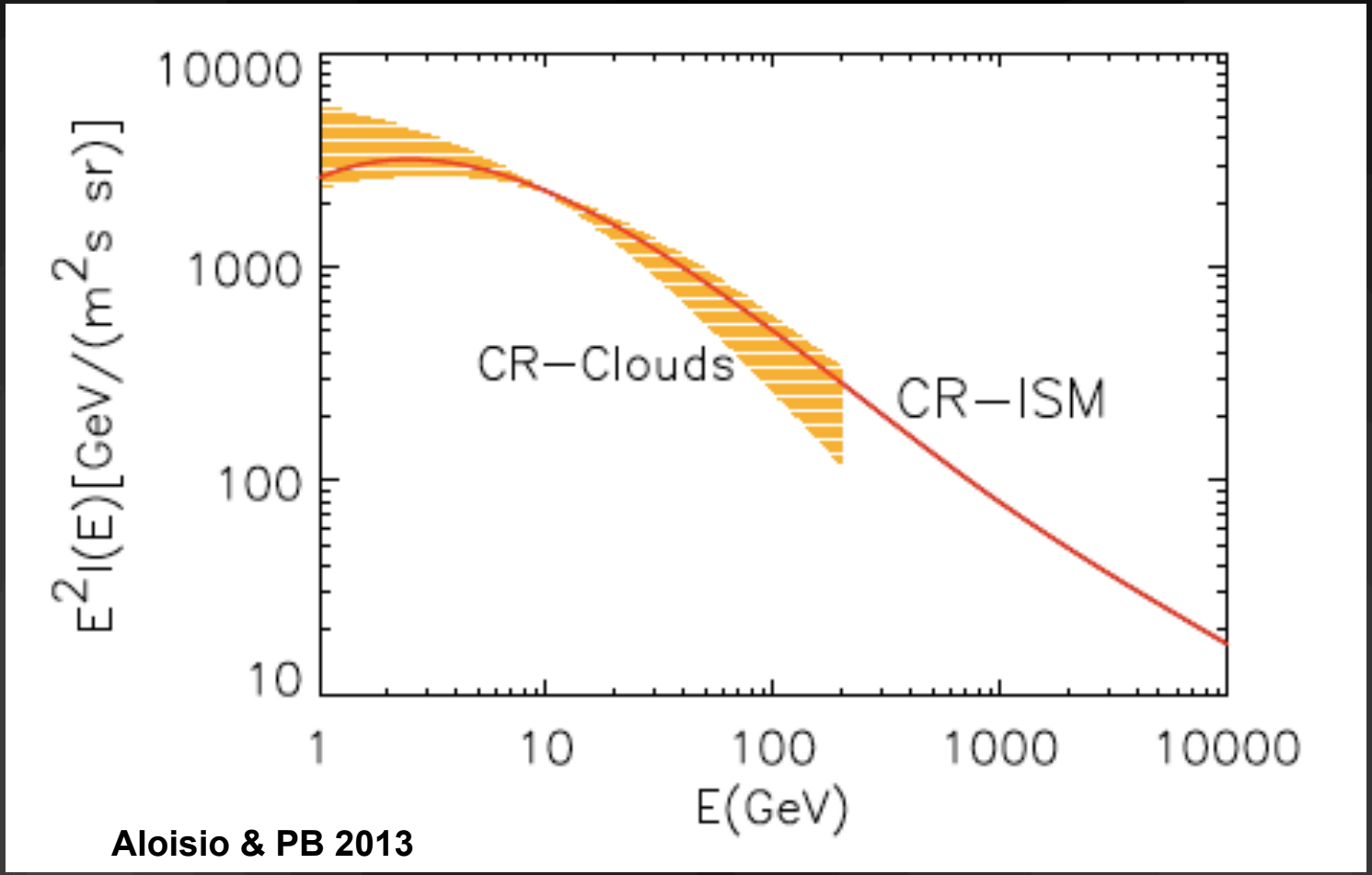




THE INFERRED PROTON SPECTRUM AT E>10 GeV HAS THE SAME SLOPE AS THE PAMELA SPECTRUM, BUT IT IS A FACTOR ~1.4 LARGER (PROBABLY THIS IS JUST GEOMETRY)

CLEARLY AT E>200 GeV THE INFERRED SPECTRUM DOES NOT SHOW THE HARDENING SEEN IN PAMELA DATA

PREDICTED PROTON SPECTRUM vs CLOUDS



Aloisio & PB 2013

NEW PHENOMENA IN CR ACCELERATION

FOUR NEW PIECES OF OBSERVATIONS HAVE CONSIDERABLY AFFECTED OUR UNDERSTANDING OF CR ACCELERATION

- ***NARROW FILAMENTS OF NON-THERMAL X-RAY SYNCHROTRON EMISSION***

- ***DETECTION OF THE PION PEAK IN THE GAMMA RAY EMISSION OF SOME SNRs CLOSE TO MOLECULAR CLOUDS***

- ***DETECTION OF GAMMA RAY EMISSION FROM GeV to ~50 TeV FROM THE TYCHO SNR***

- ***HINTS OF EFFICIENT CR ACCELERATION FROM THE BALMER LINE EMISSION OF SOME SNR***

X-RAY FILAMENTS IN YOUNG SNR

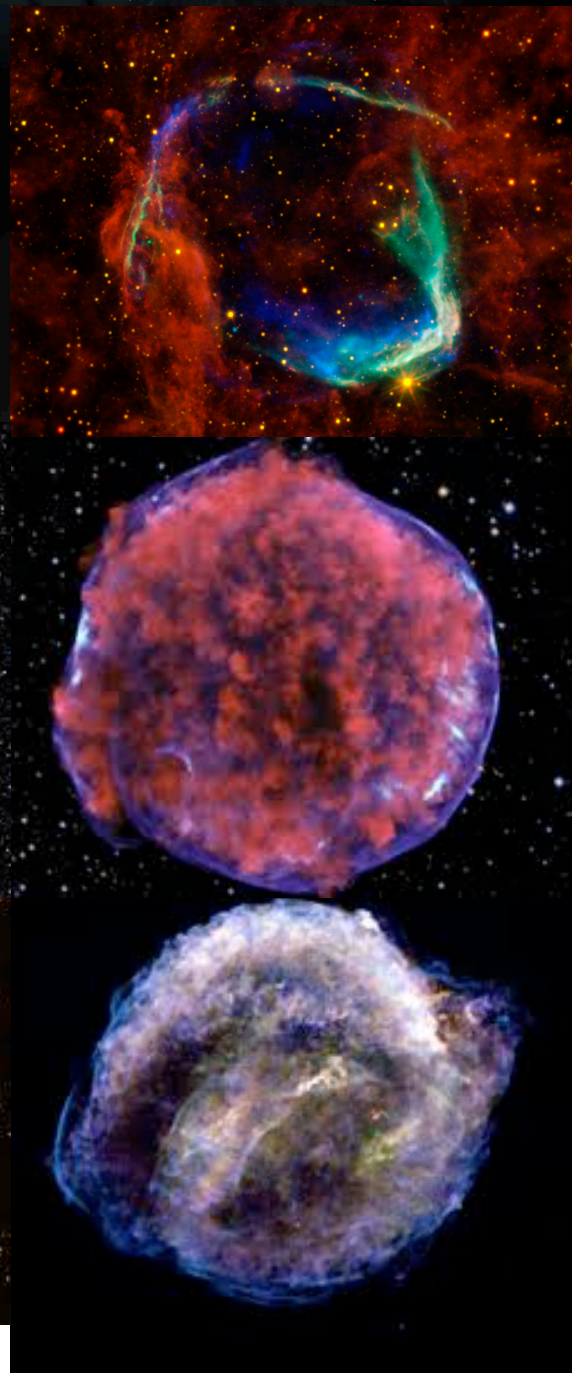
TYPICAL SIZE OF THE FILAMENTS ~ 10^{-2} parsec

The emission in the filaments is non-thermal synchrotron of the highest energy electrons in the accelerator

$$\Delta x \approx \sqrt{D(E_{max})\tau_{loss}(E_{max})} \approx 0.04\ B_{100}^{-3/2}\ \mathrm{pc}$$

Comparison with the observed thickness leads to an estimate for the local field

$$B \approx 100\ \mu\mathrm{Gauss}$$



MAGNETIC FIELD AMPLIFICATION AND P_{MAX}

THE EVIDENCE FOR B-FIELD AMPLIFICATION IS CRUCIAL FOR AT LEAST TWO REASONS:

- ***IN THE ABSENCE OF THIS PHENOMENON THE MAXIMUM ENERGY OF ACCELERATED PARTICLES IS ~1-10 GeV ONLY***

- ***MAGNETIC FIELD AMPLIFICATION HAS LONG BEEN EXPECTED AS A BY-PRODUCT OF CR ACCELERATION (STREAMING INSTABILITY)***

IN THE BOHM ASSUMPTION FOR THE TURBULENT COMPONENT:

$$D(E) = \frac{1}{3}\frac{pc^2}{eB_{ampl}} = 3.3 \times 10^{26} cm^2/s \; B_{100\mu G}^{-1} \left(\frac{E}{10^{15} eV}\right)$$

$$\tau_{acc} = \frac{D(E)}{V_{sh}^2} \approx 50 \left(\frac{E}{10^{15} eV}\right) \left(\frac{V_{sh}}{5000 km/s}\right)^2 B_{100\mu G}^{-1} \; years$$

CLOSE TO THE TIME OF BEGINNING OF THE SEDOV PHASE…

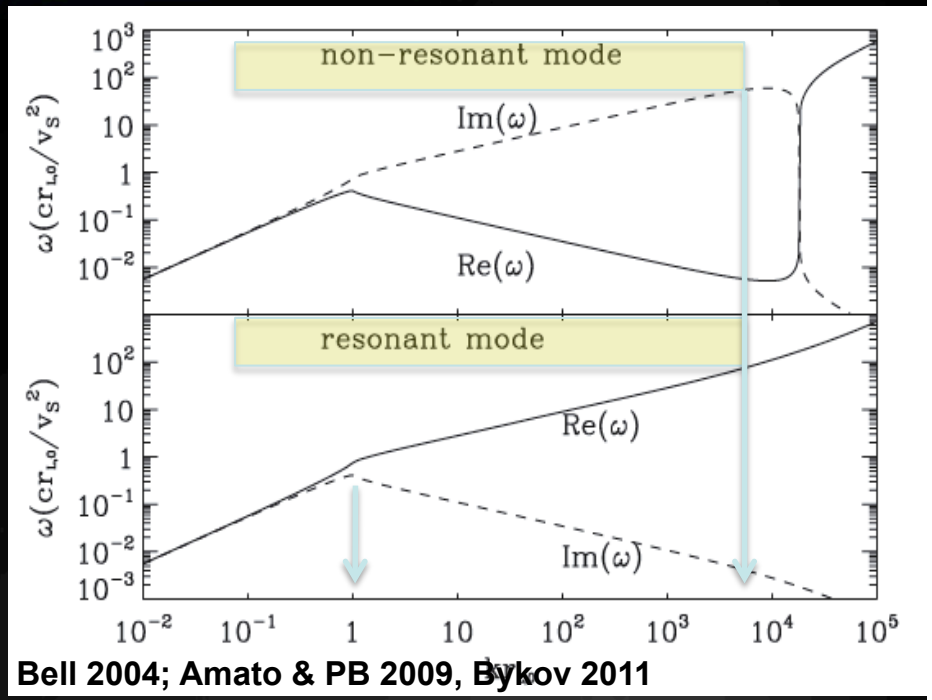
SCALES AND PeV CR

PARTICLE SCATTERING ONLY TAKES PLACE AT THE RESONANCE:

$$k \approx \frac{1}{r_L(E)}$$

POWER IS NEEDED AT THE RESONANT SCALE

DIFFERENT INSTABILITIES GENERATE POWER ON DIFFERENT SCALES



Bell 2004; Amato & PB 2009, Bykov 2011

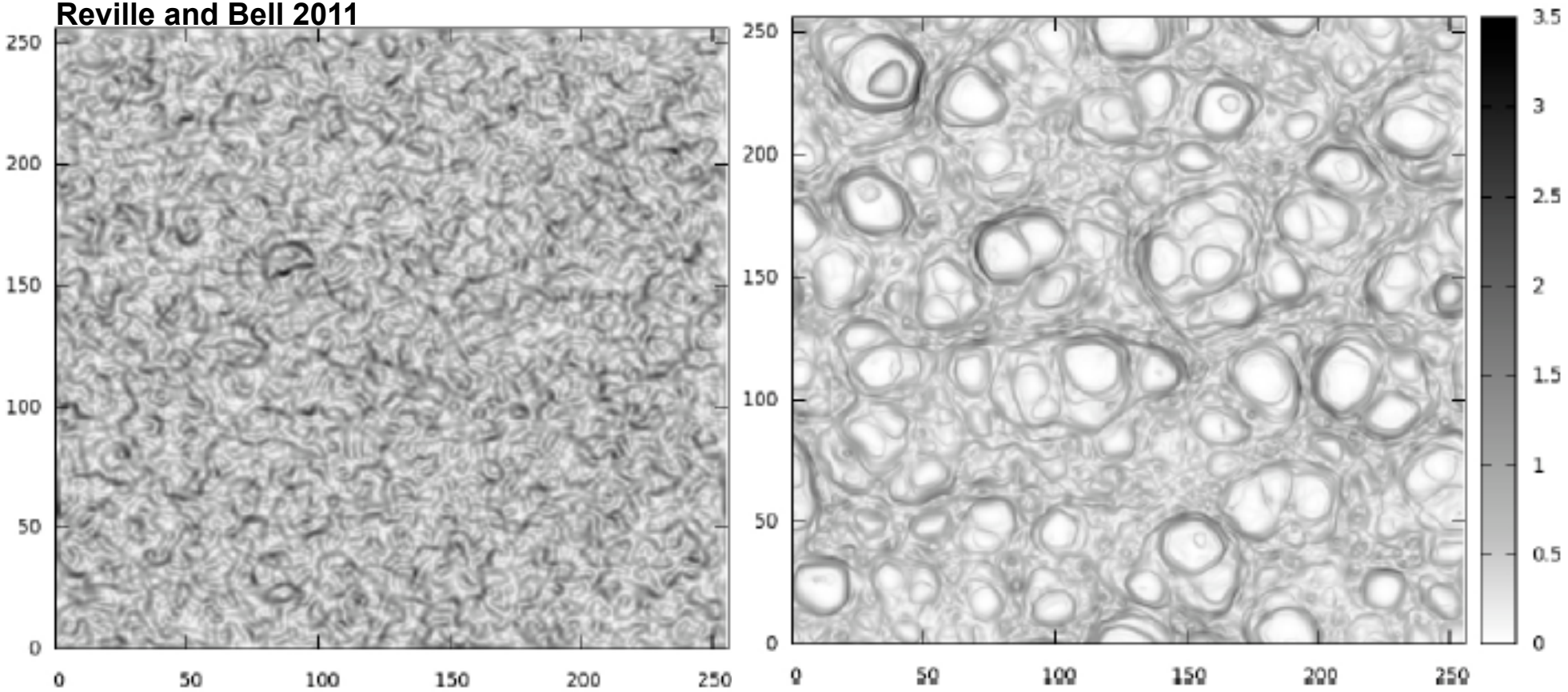
THE NON RESONANT MODE (Bell 2004, 2005) GROWS THE FASTEST BUT ON VERY SMALL SCALES… IN ORDER FOR THIS MODE TO BE IMPORTANT FOR E_{MAX}~PeV, ITS SATURATION MUST LEAD TO LARGER SCALES BY A FACTOR OF ~MILLIONS (Inverse cascade?) –

ROLE OF ESCAPING PARTICLES VERY IMPORTANT

THE PROBLEM OF REACHING THE KNEE (PROTONS) IS STILL NOT QUANTITATIVELY UNDERSTOOD… EVEN WORSE IF IT WERE NEEDED TO REACH HIGHER E_{MAX}

FILAMENTATION INSTABILITY

Reville and Bell 2011



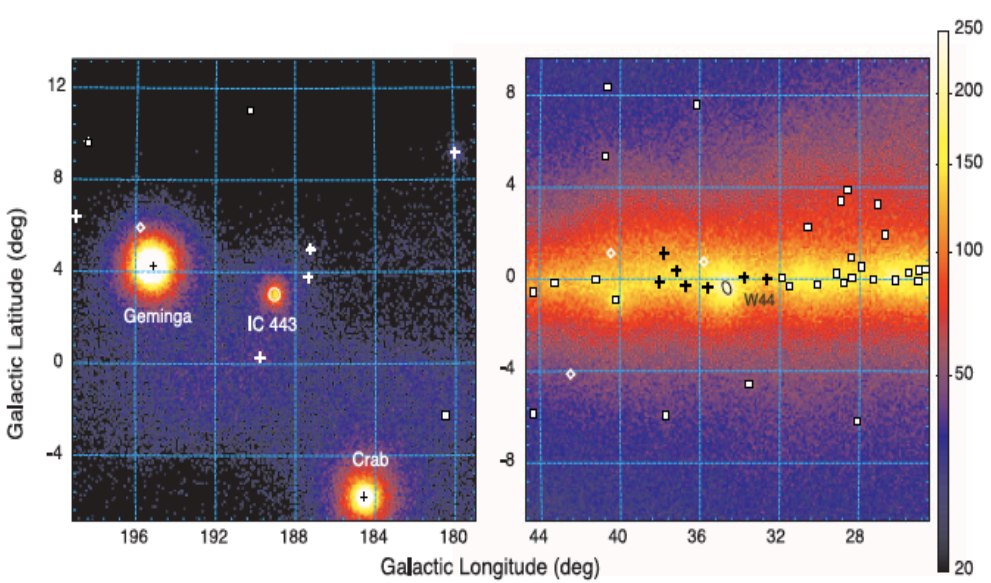
THE IDEA IS THAT THE SMALL SCALE INSTABILITY INCREASES B BY A FEW…

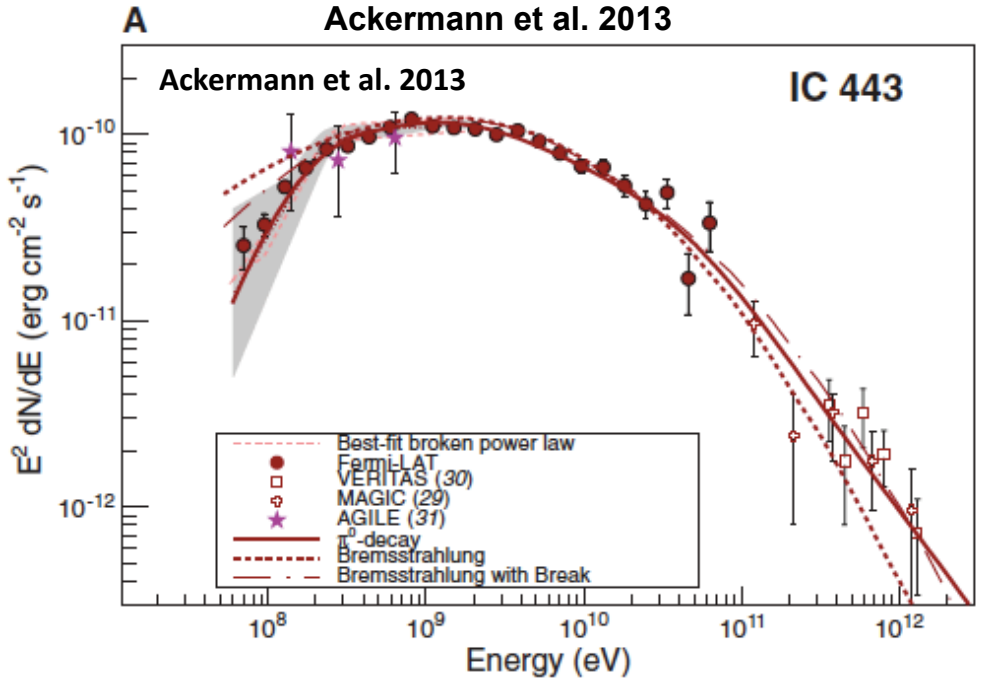
THE CURRENT TUBES THAT DEVELOP INCREASE THE SCALE TO THE LARMOR RADIUS OF THE ESCAPING PARTICLES

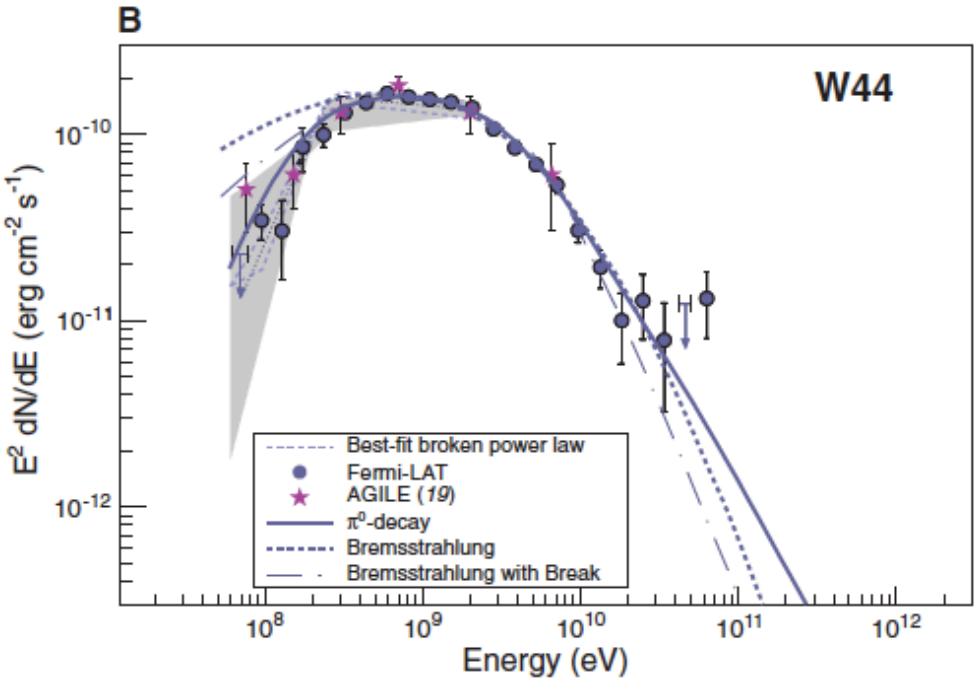
PION BUMPS AND MC

BOTH FERMI-LAT AND AGILE FOUND EVIDENCE FOR THE PION BUMP IN THE SPECTRUM OF TWO SNR CLOSE TO MOLECULAR CLOUDS

ASIDE FROM CONFIRMING THAT HADRONS ARE BEING ACCELERATED, THIS IS PROBABLY GOING TO TELL US MORE ON PROPAGATION THAN PARTICLE ACCELERATION *(Nava & Gabici 2013; Malkov et al. 2013, Giacinti & Kachelriess 2013)*

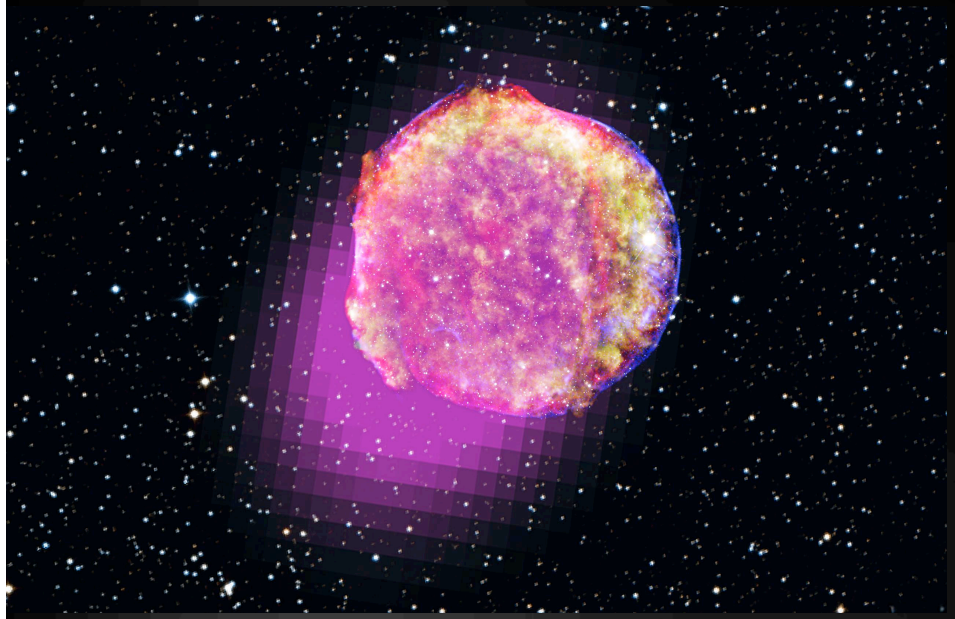


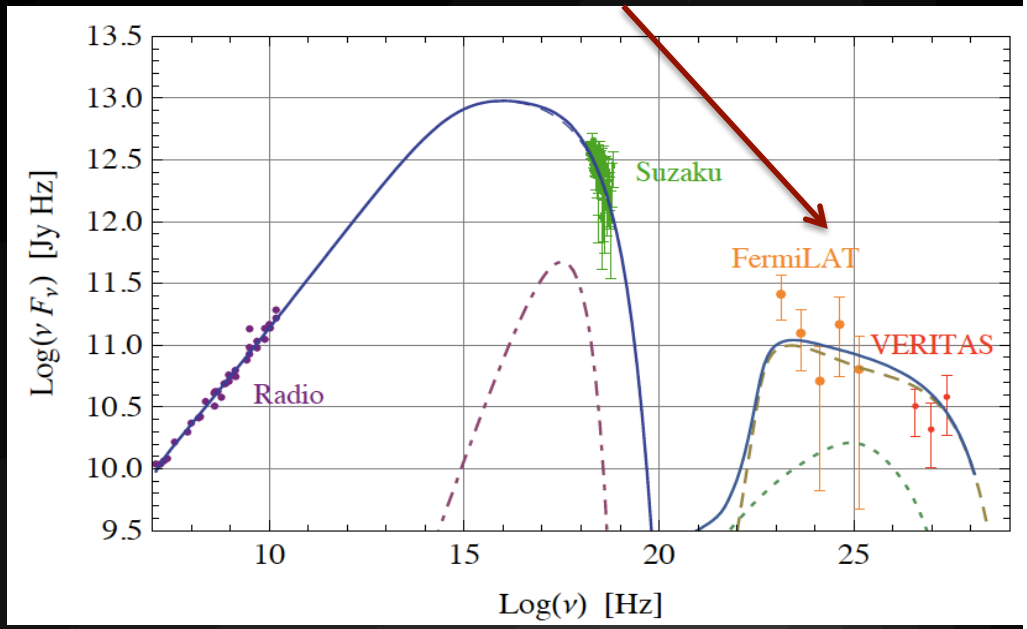




THE TYCHO LHC

STEEP SPECTRUM HARD TO EXPLAIN WITH LEPTONS





Morlino & Caprioli 2011

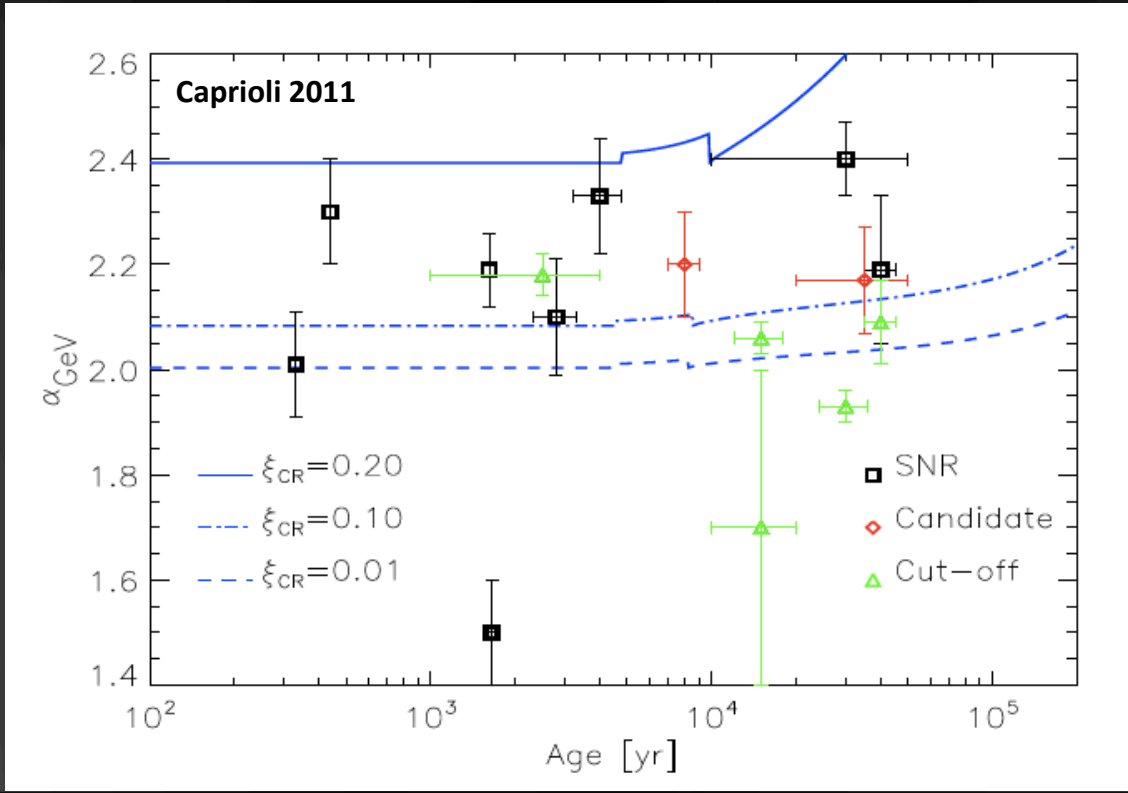
E_{max}~500 TeV

PROBLEMATIC SPECTRA

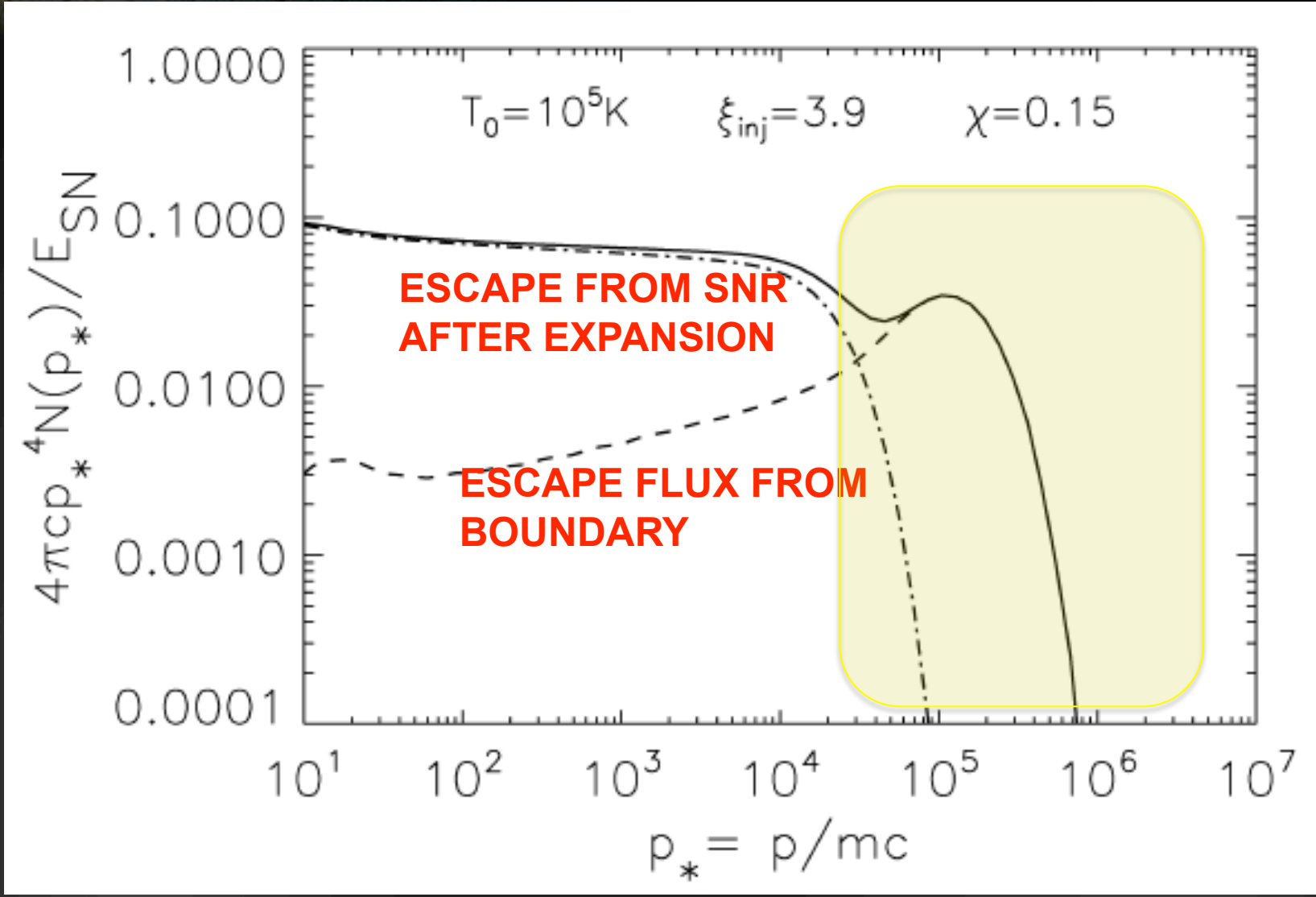
The non linear theory of DSA (as well as the test particle theory) all predict CR spectra close to E^{-2} and even harder than E^{-2} at E>10 GeV

This finding does not sit well with:

1) ***CR ANISOTROPY (THE REQUIRED D(E) HAS TO SCALE AS $E^{0.75}$)***
2) ***GAMMA RAY SPECTRA FROM SELECTED SNRS***



ESCAPE FROM SNR IN NLDSA



Caprioli et al. 2009

NOTES ON ANISOTROPY

$$\delta_{\vec{x}} = \frac{3D(E)}{c}\frac{\nabla_{\vec{x}} n_{CR}(E,\vec{r},t)}{n_{CR}}$$

$$\vec{J}_{CR}(\vec{r},t) = -D\vec{\nabla} n_{CR}(\vec{r},t)$$

CR CURRENT

ONE CAN DEFINE THE FIRST TWO MOMENTS:

$$\delta_{A1} = \frac{\langle \vec{J}_{CR} \rangle}{\frac{1}{3} c n_{CR}(E)}$$

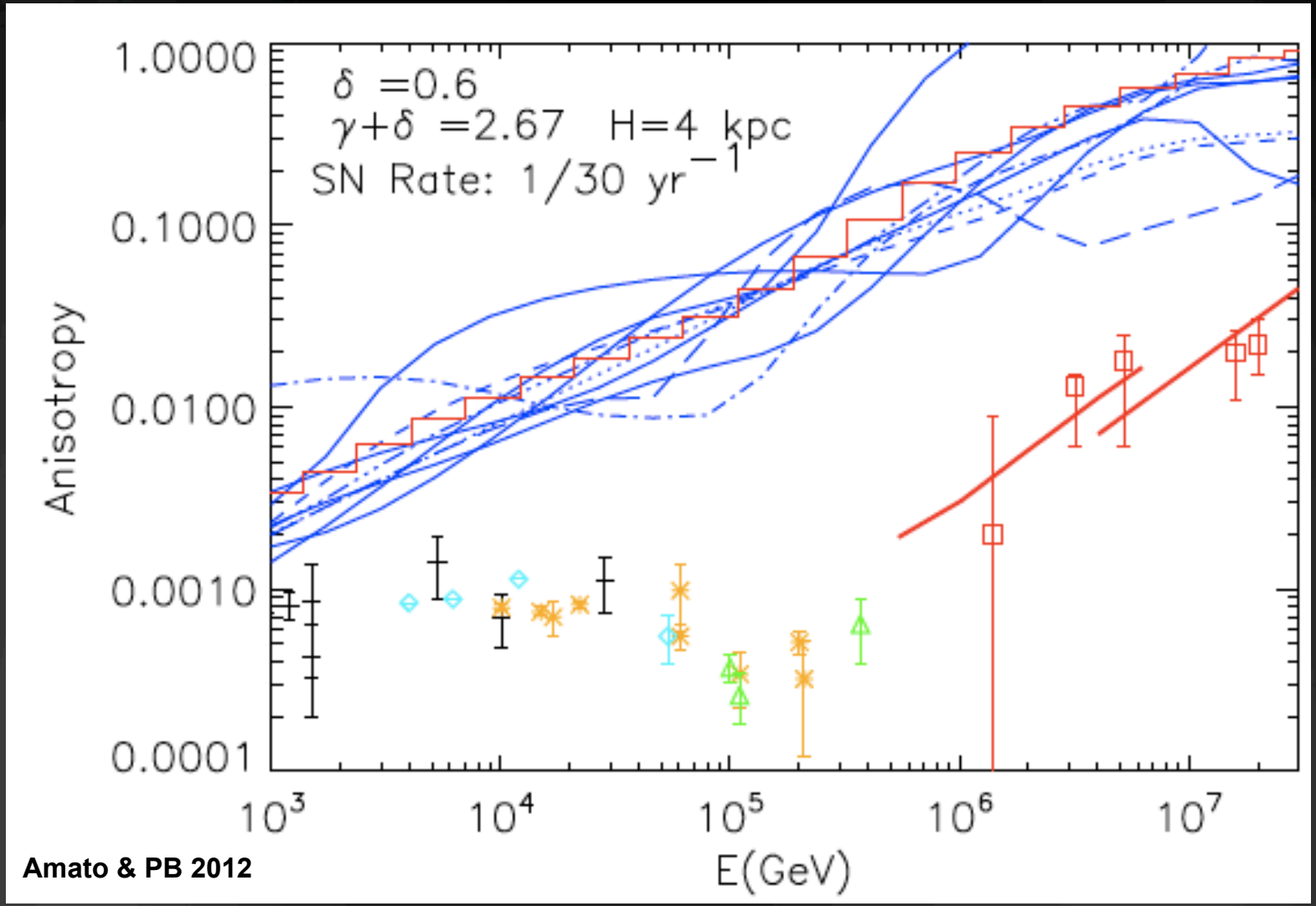
$$\delta_{A2} = \frac{\langle \delta\vec{J}_{CR} \cdot \delta\vec{J}_{CR} \rangle^{1/2}}{\frac{1}{3} c n_{CR}(E)}$$

ANISOTROPY DUE TO THE OVERALL INHOMOGENEOUS DISTRIBUTION OF SOURCES (this is zero for a homogeneous disc)

ANISOTROPY DUE TO INDIVIDUAL SOURCES. THIS TERM IS ALWAYS NON ZERO AND ACTUALLY (IN PRINCIPLE) DIVERGING

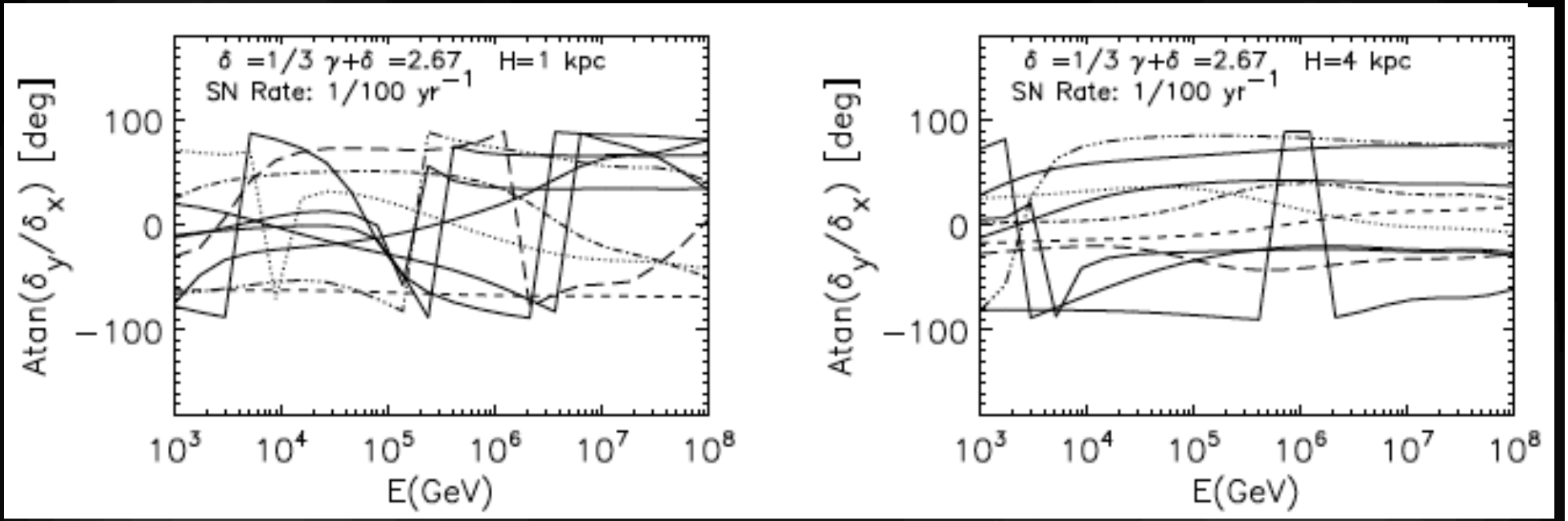
BOTH CONTRIBUTIONS OR SUMS OF THE TWO ONLY GIVE RISE TO A DIPOLE ANISOTROPY… THE PHASE OF THE LATTER IS LIKELY TO CHANGE ERRATICALLY AS A FUNCTION OF ENERGY

ANISOTROPY



Amato & PB 2012

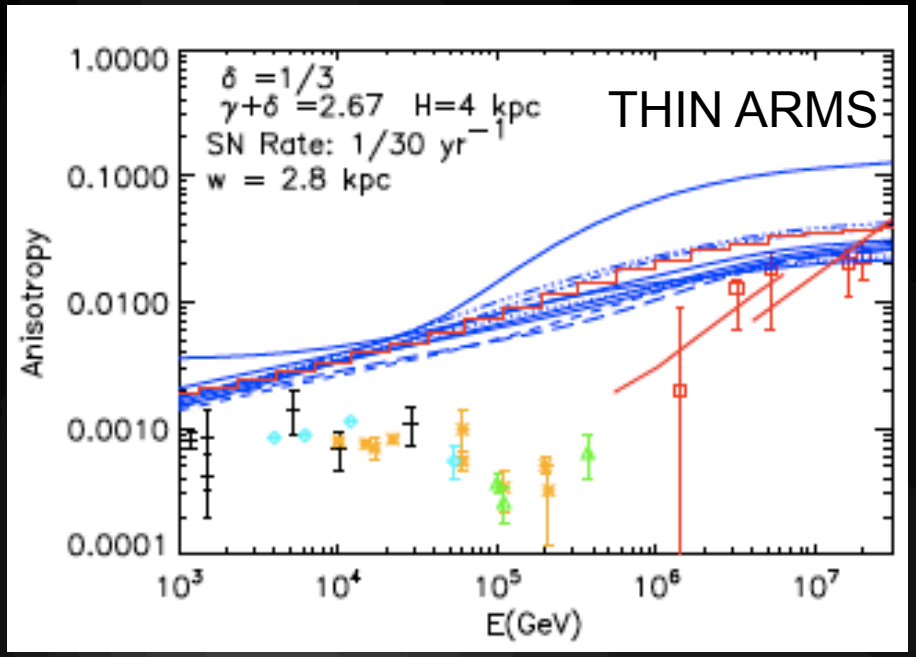
ANISOTROPY

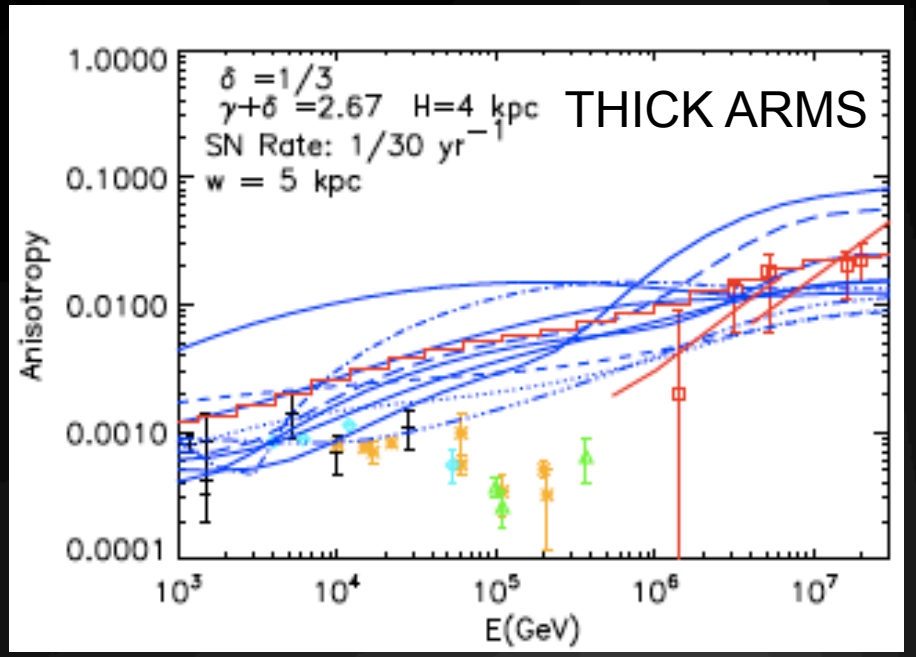


Amato & PB 2012

BUT δ=1/3 IS NOT COMPATIBLE WITH THE SNR SPECTRA WE GET !

ANISOTROPY: Spiral Arms



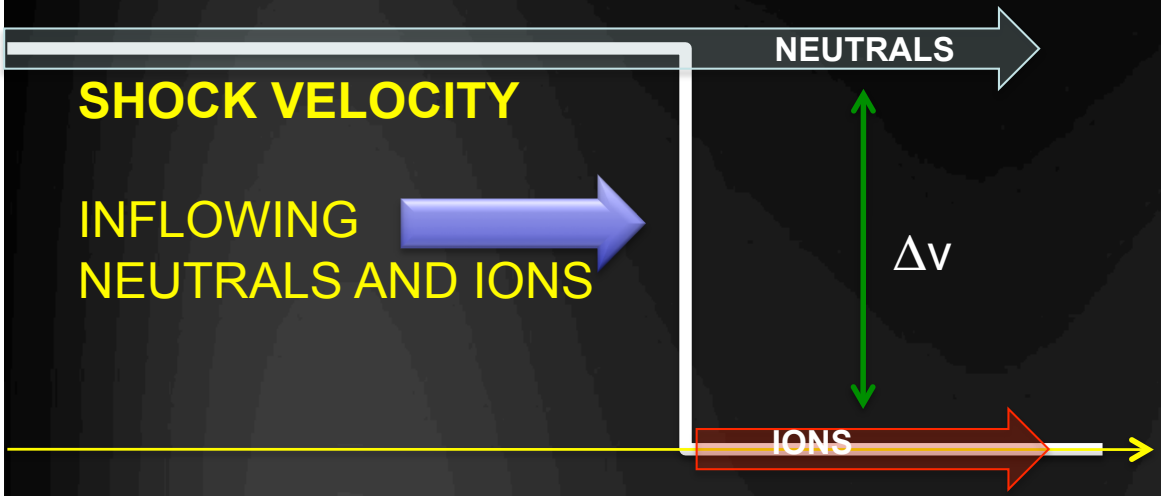


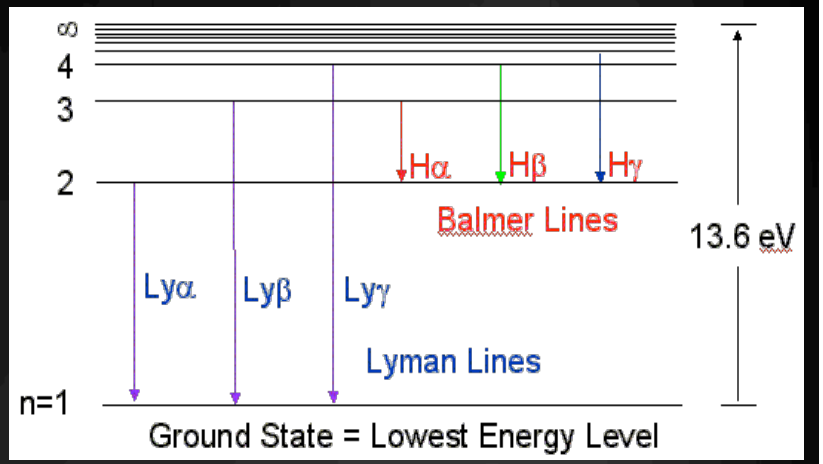
Amato & PB 2012

OBSERVATION OF ANOMALOUS BALMER LINES

THIS FIELD IS STILL YOUNG, BUT IT HAS A HUGE POTENTIAL IN TERMS OF 'MEASURING' THE AMOUNT OF COSMIC RAYS CLOSE TO SNR SHOCKS

THE PHYSICS QUESTION IS: "WHAT HAPPENS WHEN A COLLISIONLESS SHOCK CROSSES A PARTIALLY IONIZED MEDIUM?"





THE WIDTH OF THE BALMER LINE(S) PROVIDES POWERFUL INFORMATION ON THE IONS TEMPERATURE DOWNSTREAM OF THE SHOCK → CR CALORIMETRY !!!

BROAD AND NARROW Hα LINE

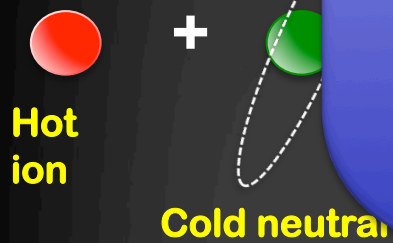
TWO PROCESSES GET ACTIVATED:

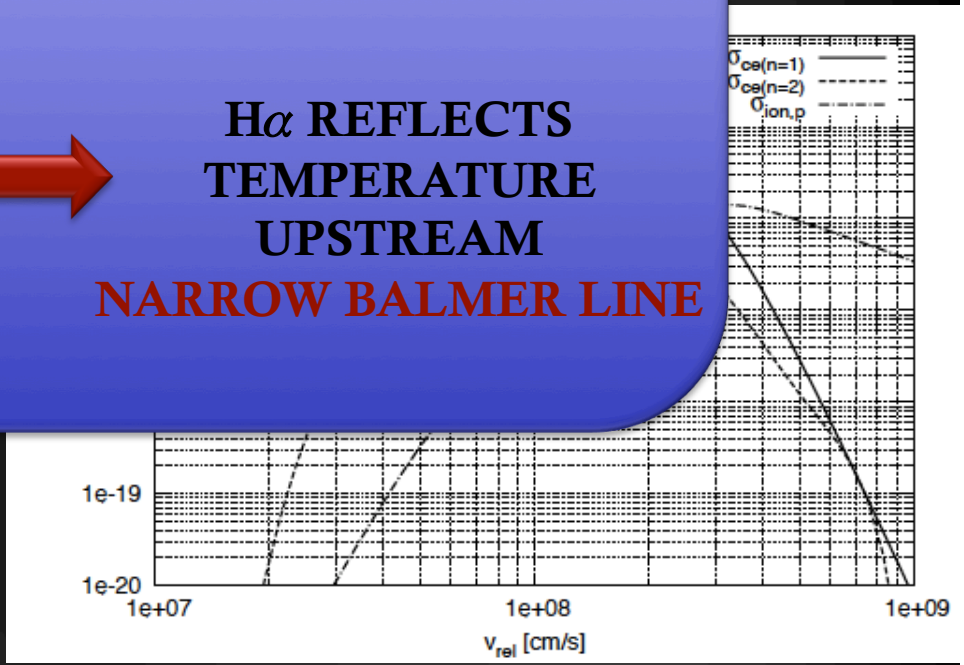
CHARG

IONIZA

BALMER LINE FROM ATOMS WITH CE DOWNSTREAM → **Hα REFLECTS TEMPERATURE OF IONS DOWNSTREAM**
BROAD BALMER LINE

BALMER LINE FROM ATOMS WITH NO CE DOWNSTREAM → **Hα REFLECTS TEMPERATURE UPSTREAM**
NARROW BALMER LINE



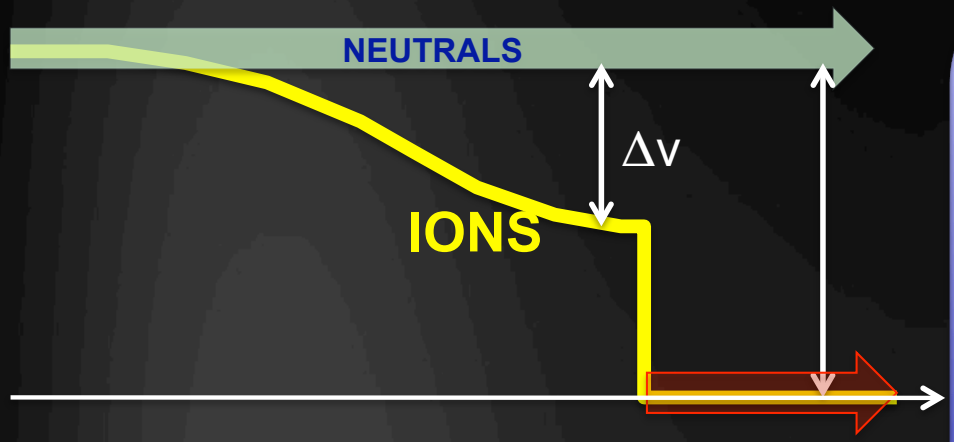


ANOMALOUS Hα LINE WIDTHS

IN THE PRESENCE OF PARTICLE ACCELERATION TWO THINGS HAPPEN:

LOWER TEMPERATURE DOWNSTREAM

A PRECURSOR APPEARS UPSTREAM

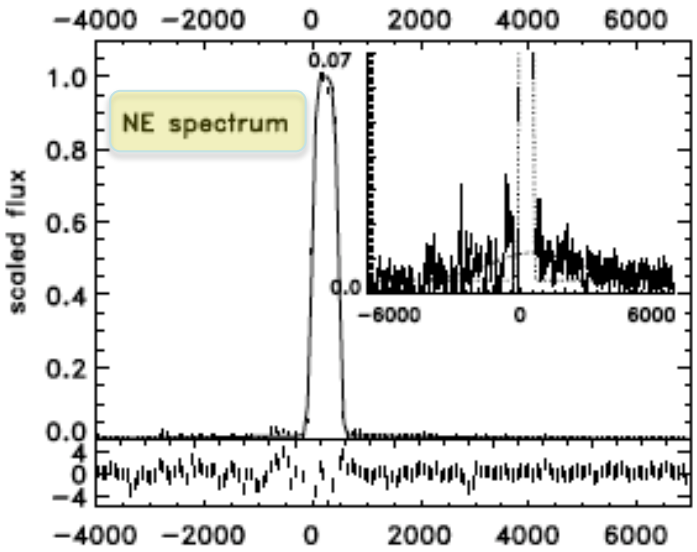


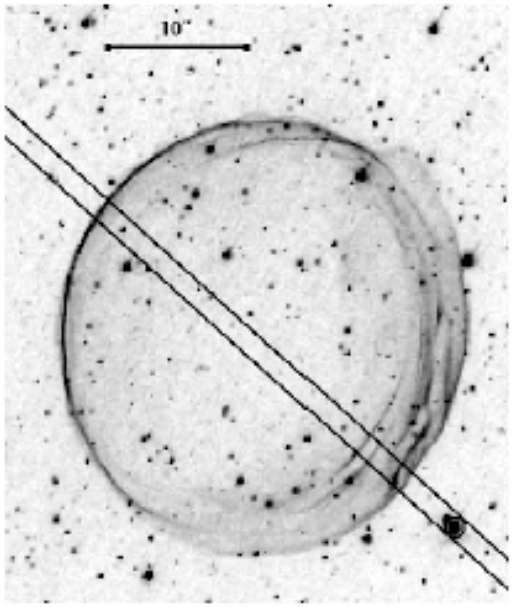
BROAD BALMER LINE GETS NARROWER

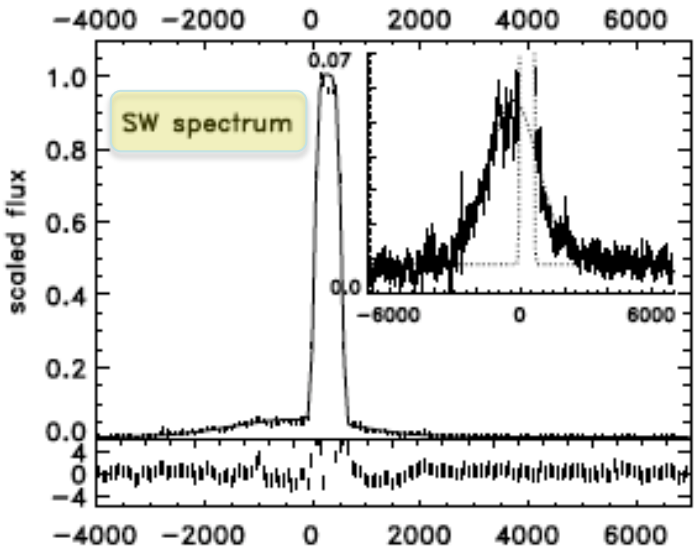
NARROW BALMER LINE GETS BROADER

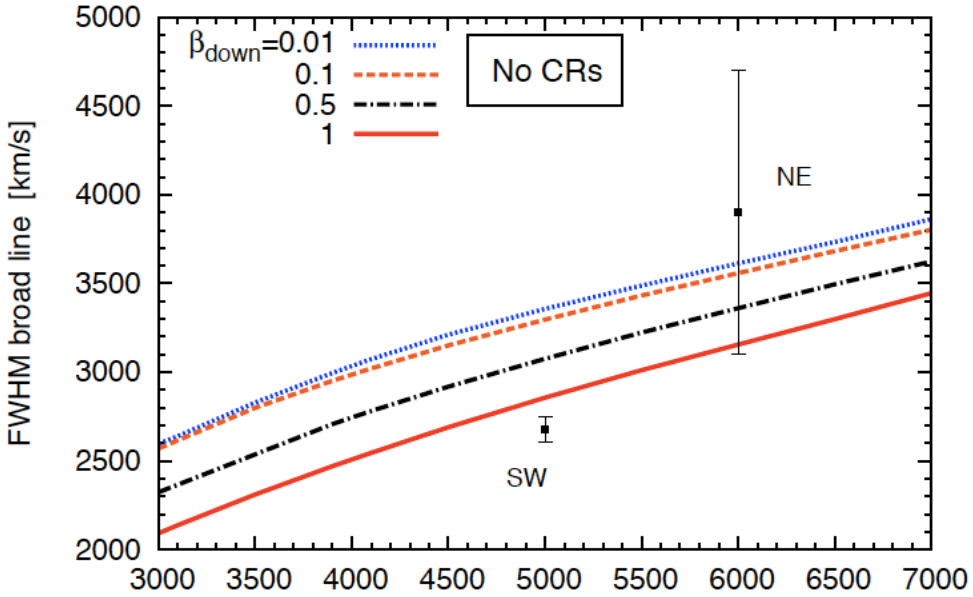
SNR 0509-67.5

Helder et al. 2009

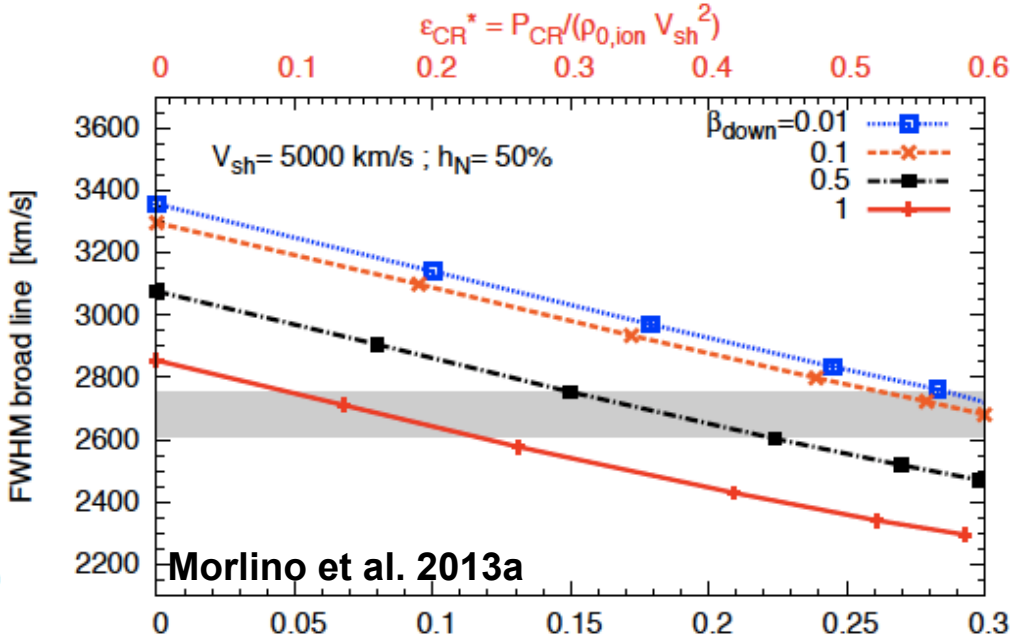




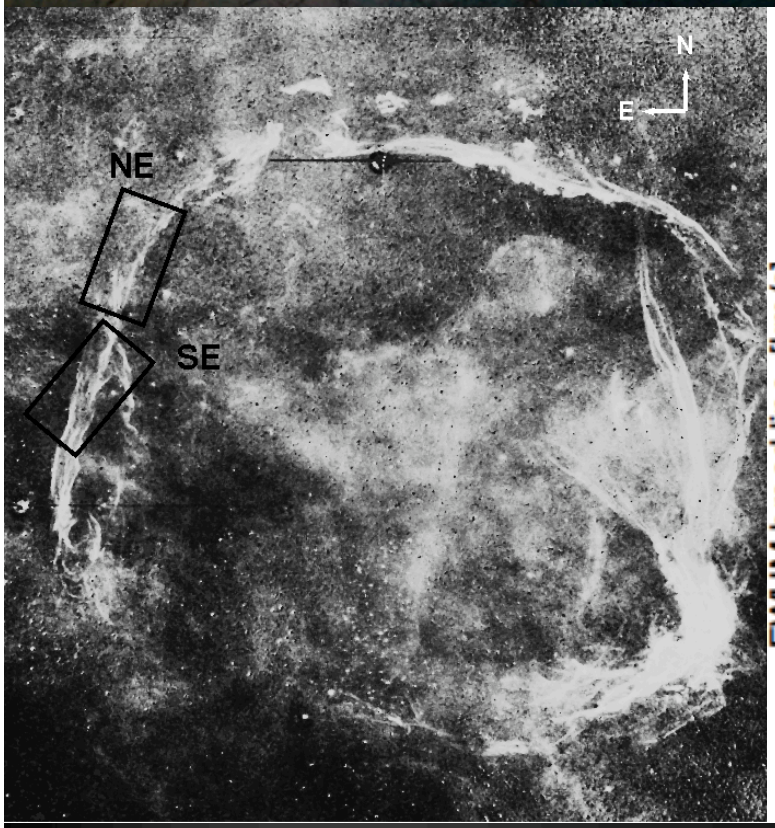


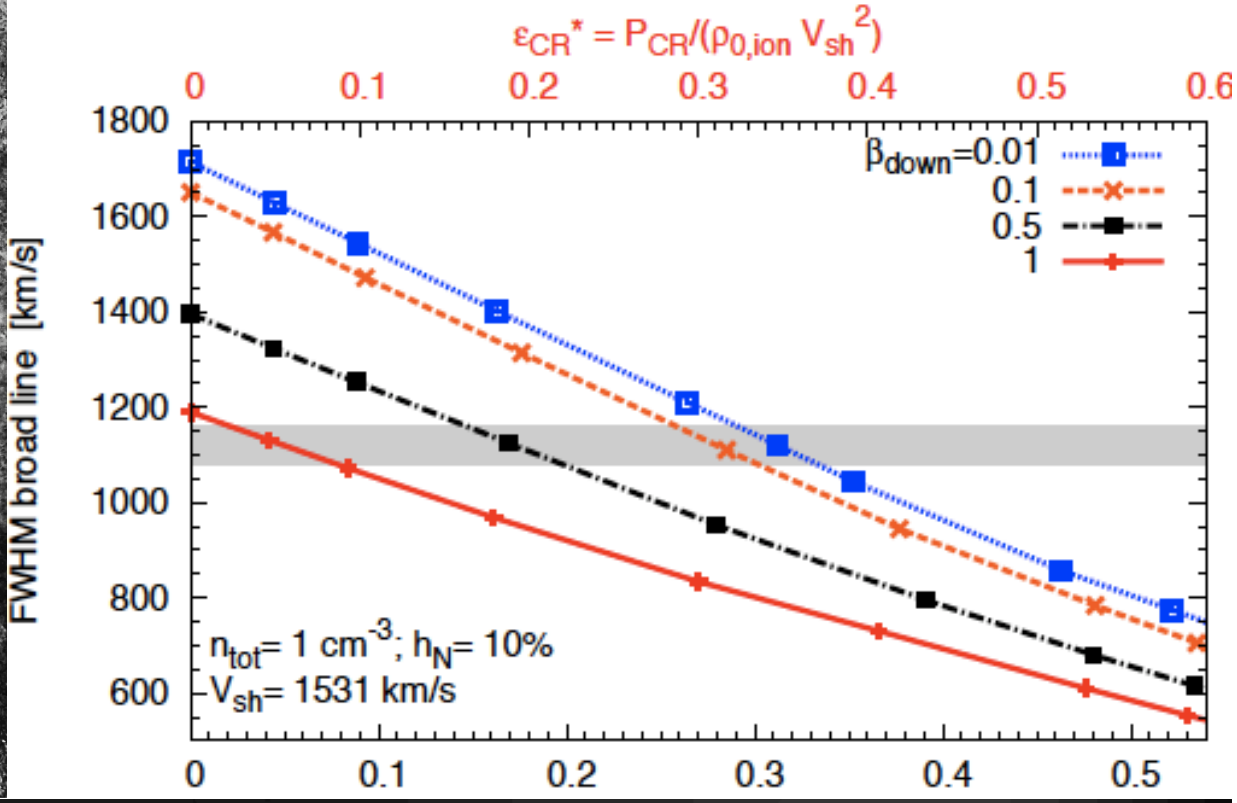


Morlino et al. 2013a



RCW86





Helder et al. 2013

Morlino et al. 2013

SOME THOUGHTS ON THE END OF THE GALACTIC CR SPECTRUM

THE DIFFICULTY IN REACHING E_{MAX}^{PR}~1-10 PeV SUGGESTS THAT THE GALACTIC CR SPECTRUM MAY END WITH IRON AT ~few 10^{17}eV

BUT WE HAVE NO EVIDENCE AS YET OF SNR AT THE KNEE (OR ABOVE OF COURSE) – NOT SURPRISING SINCE E_{MAX} LAST FOR SHORT TIME AROUND T_{SEDOV}

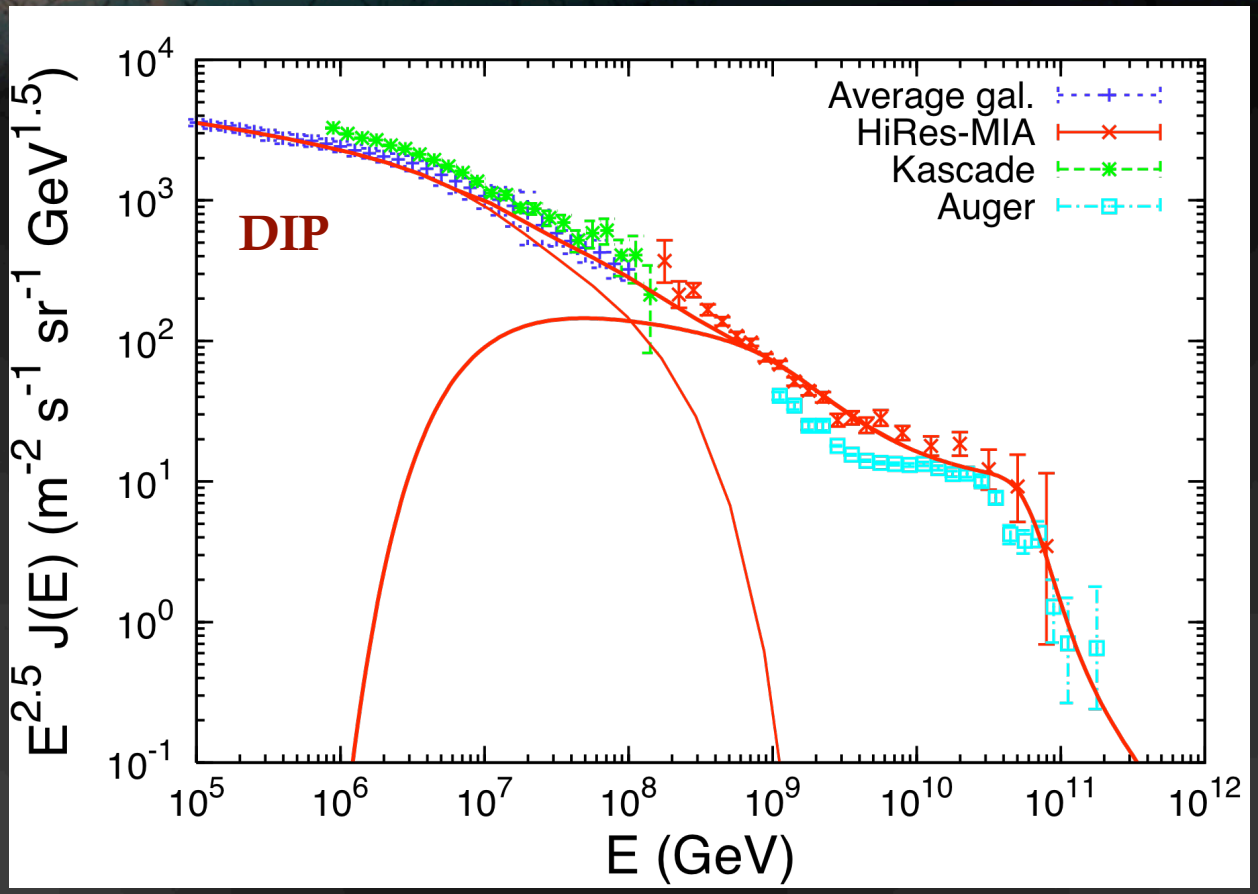
SPECTRUM AND COMPOSITION AT 10^{17}-10^{19} eV CRUCIAL TO UNDERSTAND TRANSITION

STANDARD SNR PARADIGM ONLY CONSISTENT WITH THE DIP MODEL FOR THE TRANSITION

A MIXED COMPOSITION OF UHECR REQUIRES A THIRD CR COMPONENT (EITHER GALACTIC, IN THE FORM OF A POPULATION OF SUPERENERGETIC SNR) OR EXTRA-GALACTIC – EXTRAGALACTIC INJECTION SPEXTRA REQUIRED TO BE VERY HARD!!!

ONLY A PROPER UNDERSTANDING OF THE ORIGIN OF GALACTIC CR CAN ALLOW US TO SAY SOMETHING MEANINGFUL ON UHECR

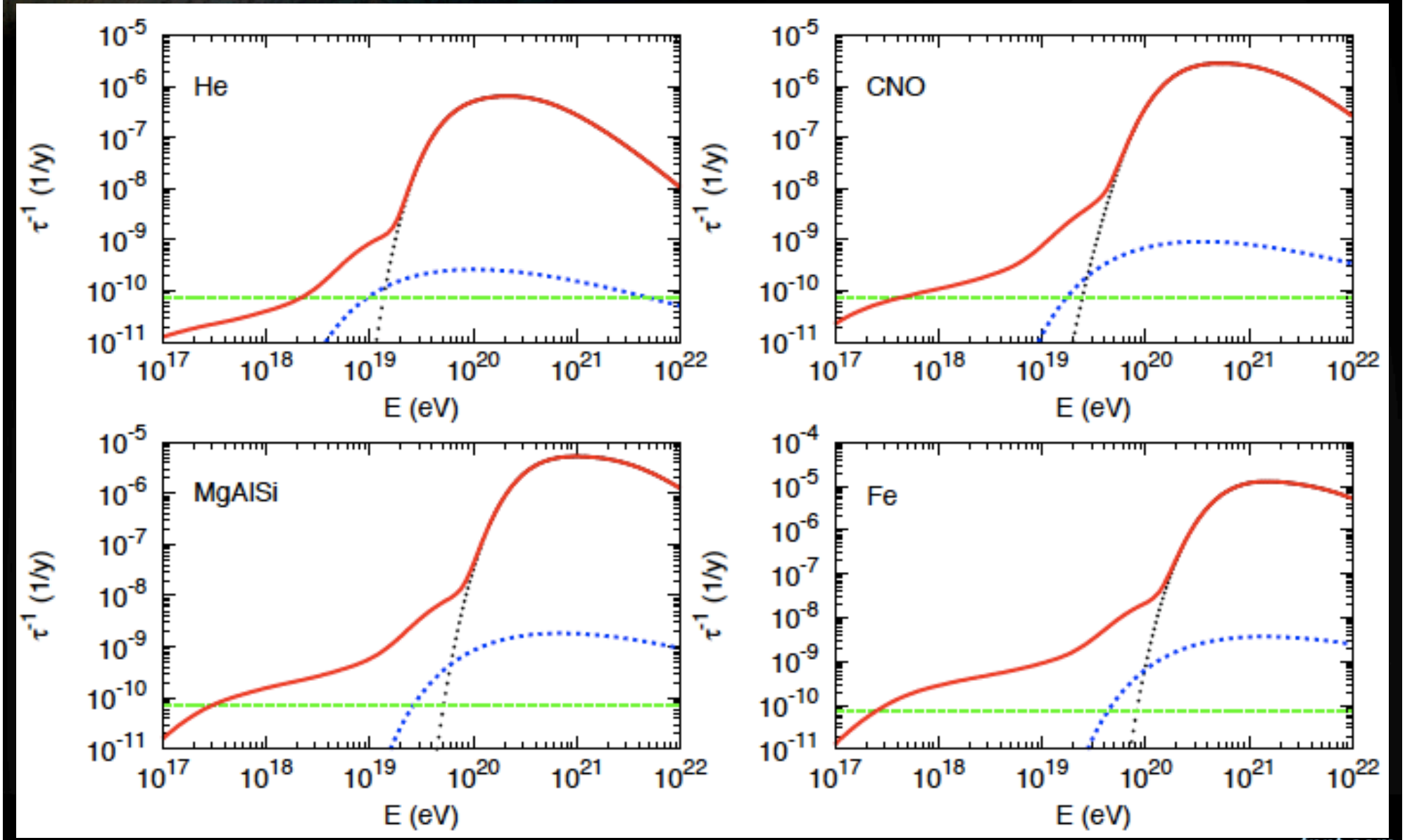
TRANSITION AND UHECR



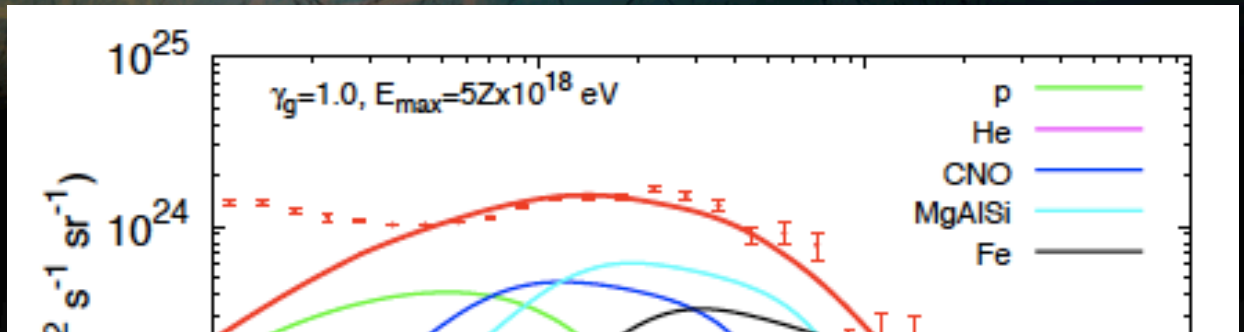
THE DIP IS THE ONLY EXPLANATION OF THE TRANSITION THAT IS COMPATIBLE WITH THE BASIC PREDICTIONS OF THE SNR PARADIGM FOR GALACTIC COSMIC RAYS

BUT IT IS INCOMPATIBLE WITH THE OBSERVED COMPOSITION

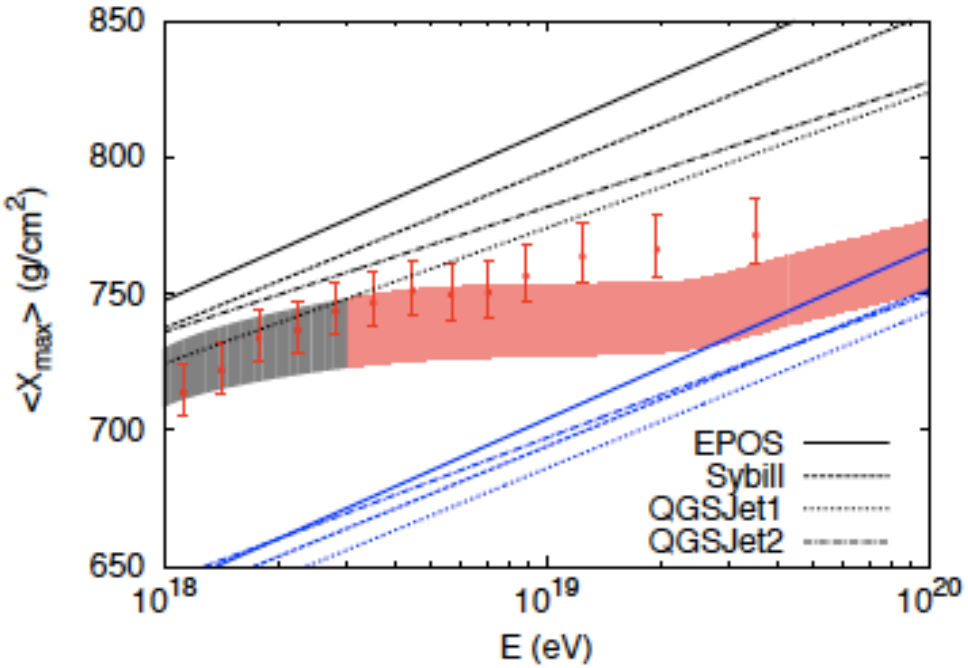
LOSSES FOR NUCLEI

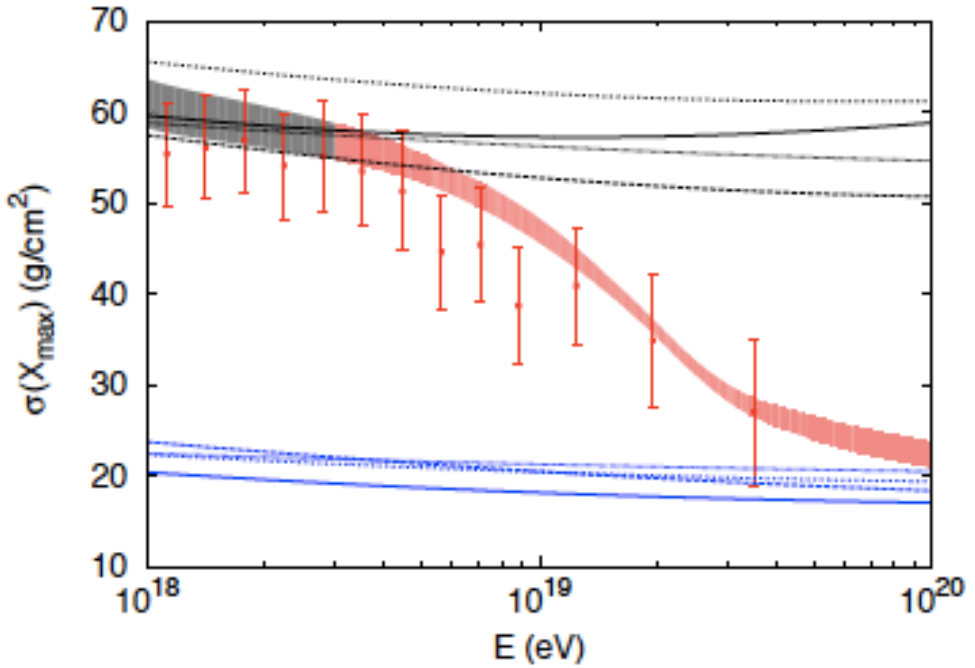


TRANSITION AND UHECR



VERY HARD INJECTION SPECTRA REQUIRED IF SOURCES GENERATE NUCLEI

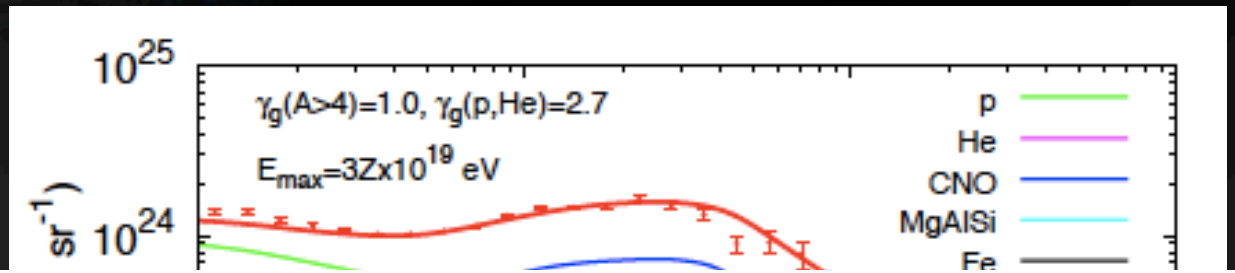


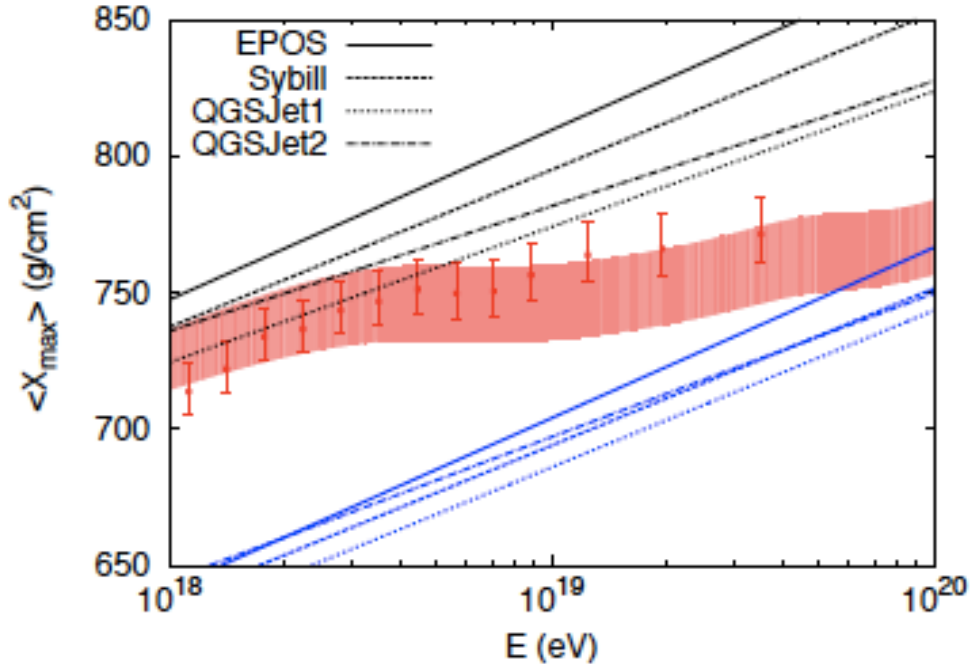


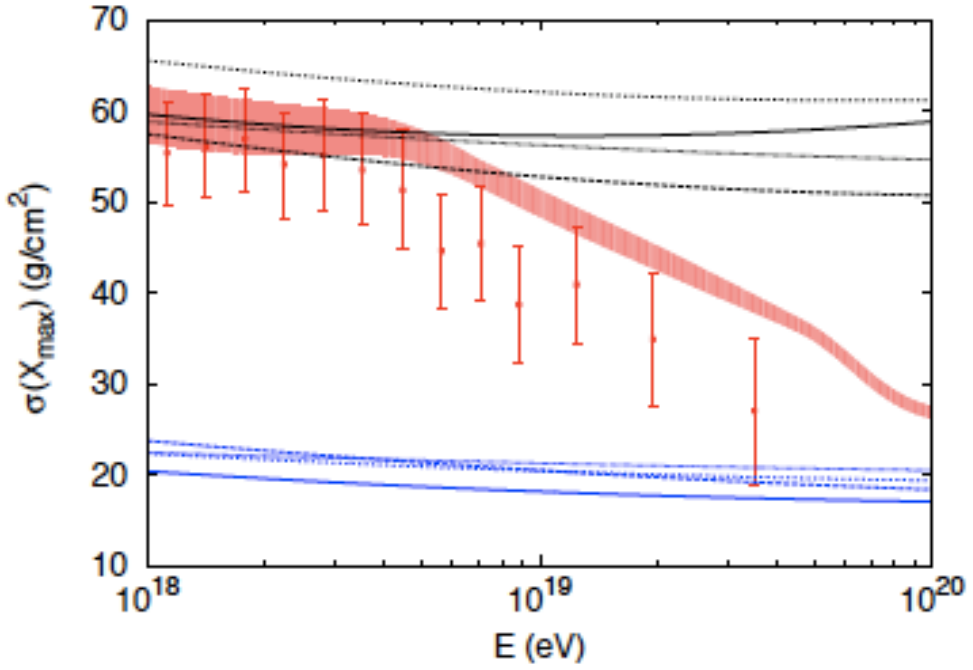
Aloisio, Berezinsky & PB 2013

TRANSITION AND UHECR

Additional Extragalactic Component

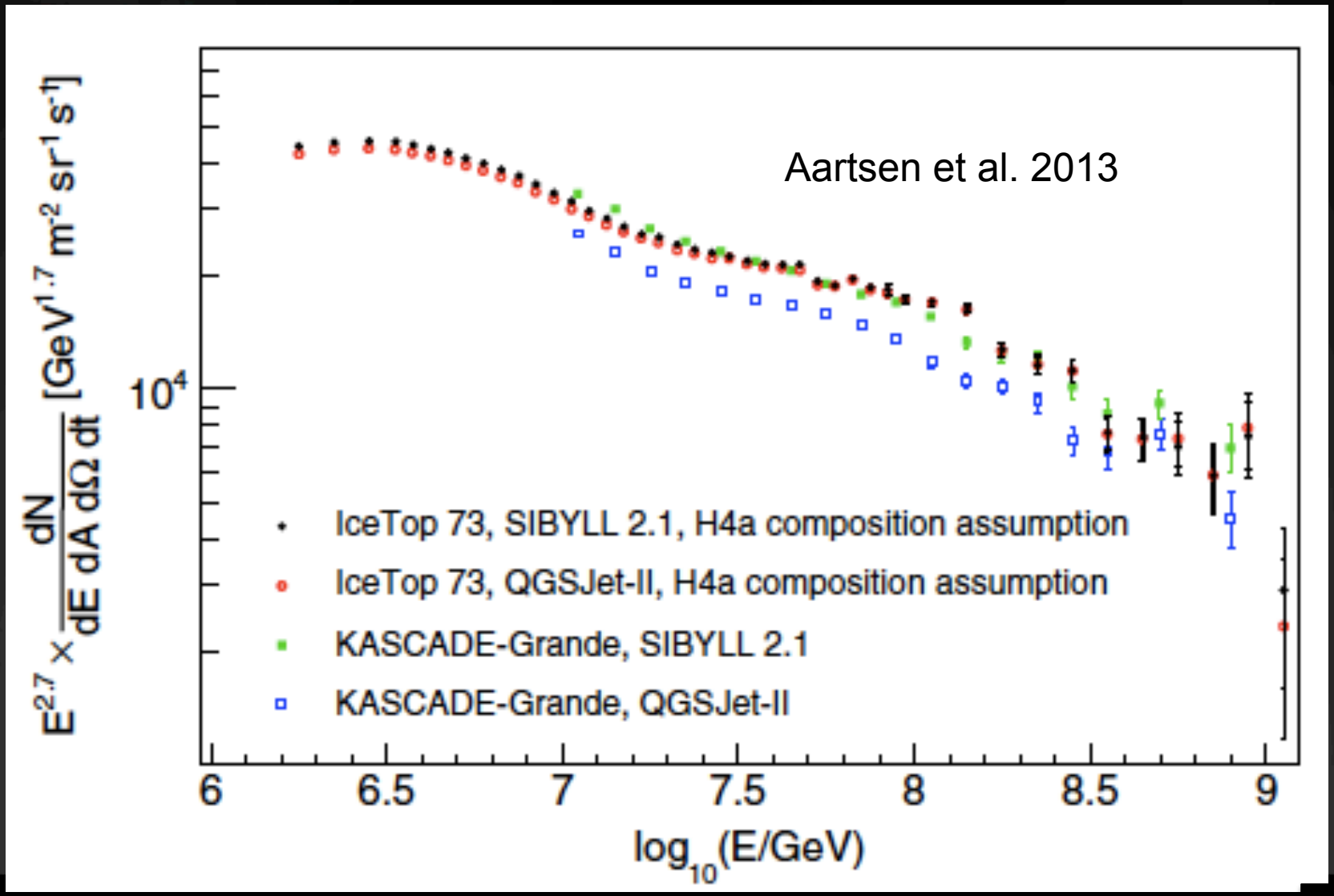


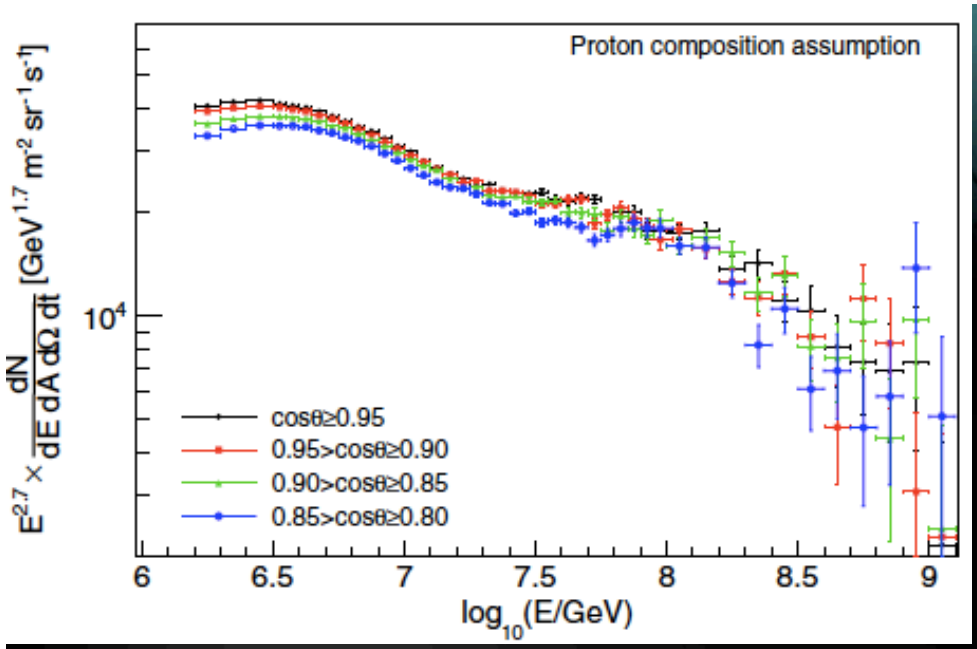


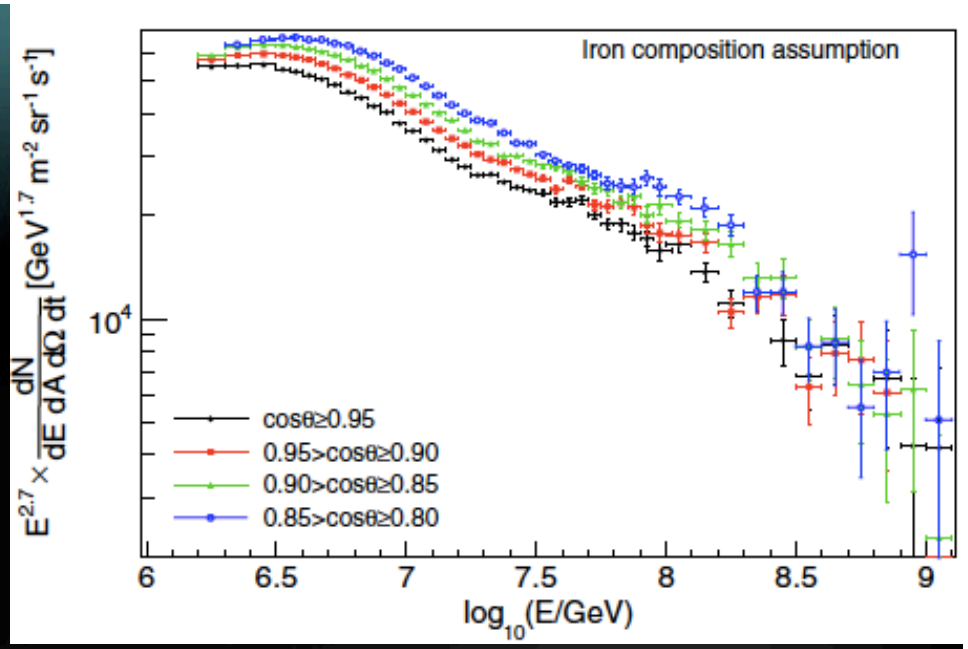


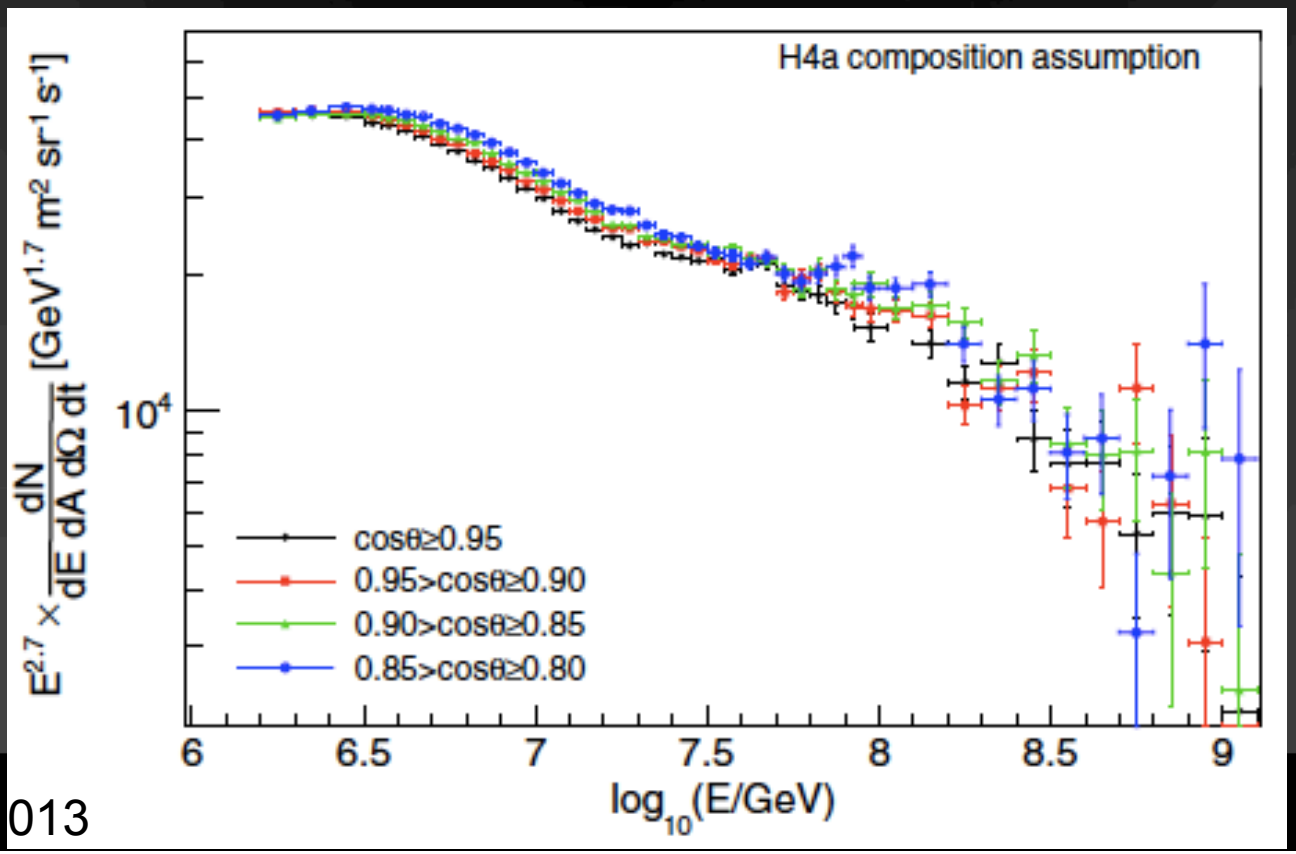
Aloisio, Berezinsky & PB 2013

NEW ICETOP RESULTS

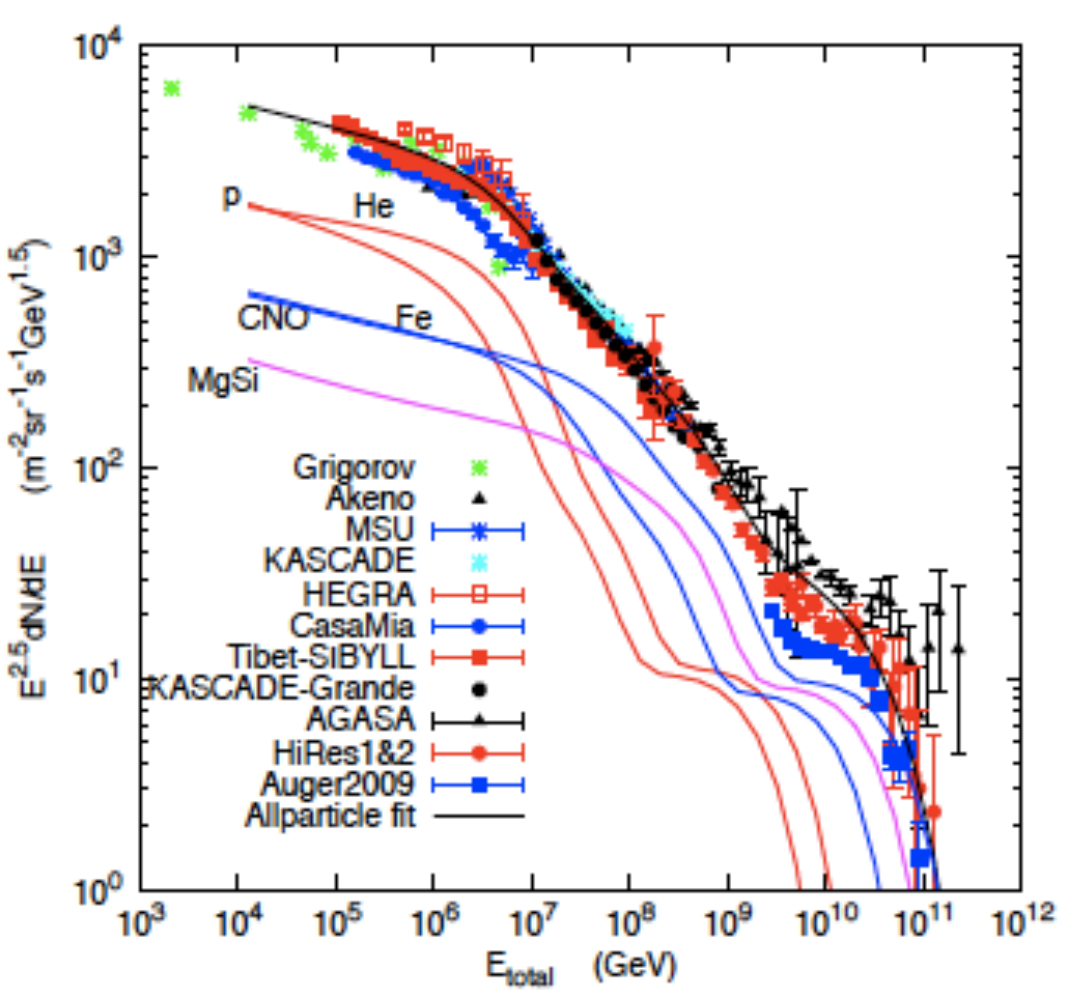



Proton composition assumption
$E^{2.7} \times \frac{dN}{dE\, dA\, d\Omega\, dt}$ [GeV$^{1.7}$ m^{-2} sr^{-1} s^{-1}]
10^4
cosθ≥0.95
0.95>cosθ≥0.90
0.90>cosθ≥0.85
0.85>cosθ≥0.80
6
6.5
7
7.5
8
8.5
9
$\log_{10}$(E/GeV)


Iron composition assumption
$E^{2.7} \times \frac{dN}{dE\, dA\, d\Omega\, dt}$ [GeV$^{1.7}$ m^{-2} sr^{-1} s^{-1}]
10^4
cosθ≥0.95
0.95>cosθ≥0.90
0.90>cosθ≥0.85
0.85>cosθ≥0.80
6
6.5
7
7.5
8
8.5
9
$\log_{10}$(E/GeV)


H4a composition assumption
$E^{2.7} \times \frac{dN}{dE\, dA\, d\Omega\, dt}$ [GeV$^{1.7}$ m^{2} sr^{-1} s^{-1}]
10^4
cosθ≥0.95
0.95>cosθ≥0.90
0.90>cosθ≥0.85
0.85>cosθ≥0.80
6
6.5
7
7.5
8
8.5
9
$\log_{10}$(E/GeV)

THEIR BEST FIT MODEL



Gaisser 2012

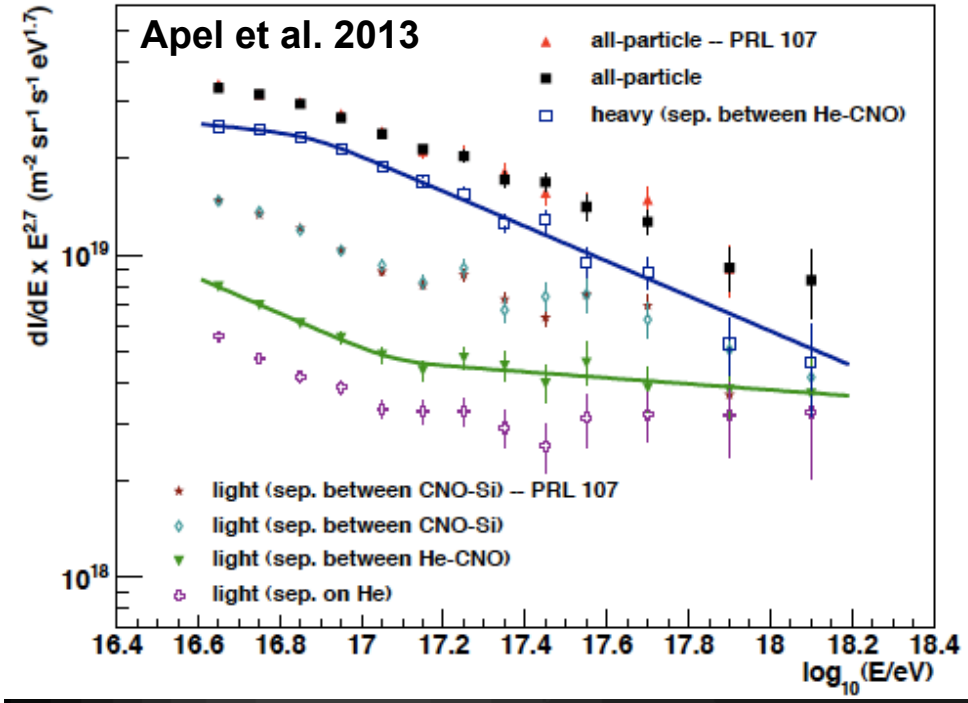
THREE COMPONENTS:

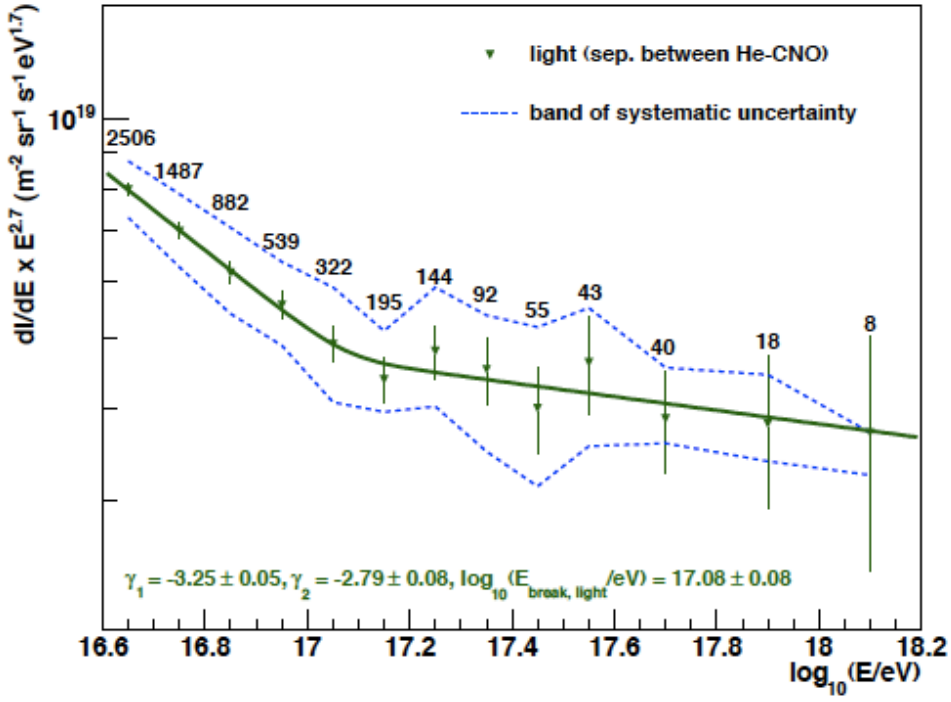
1) **GALACTIC COMPONENT WITH MAX RIGIDITY 4 PeV**

2) **GALACTIC COMPONENT WITH HARDER SPECTRUM AND MAX RIGIDITY 30 PeV**

3) **EXTRAGALACTIC COMPONENT**

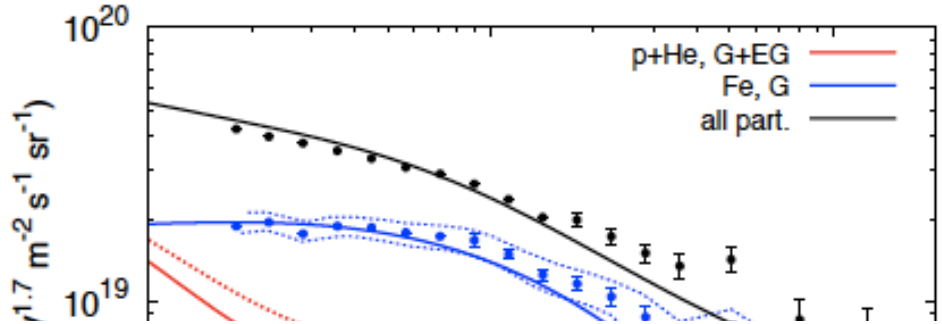
CHEMICAL COMPOSITION AND TRANSITION TO ULTRA HIGH ENERGY COSMIC RAYS

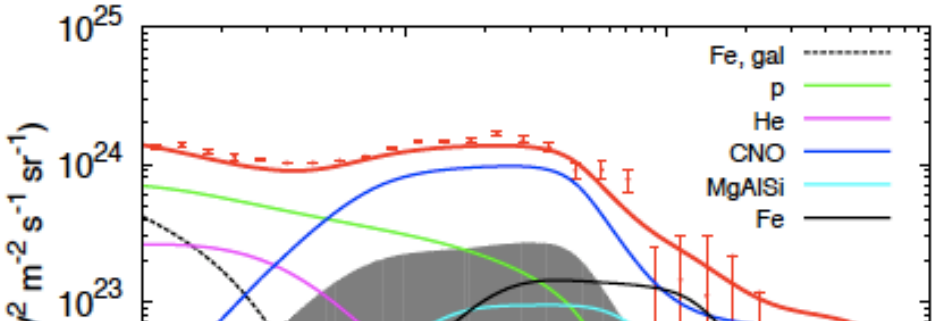


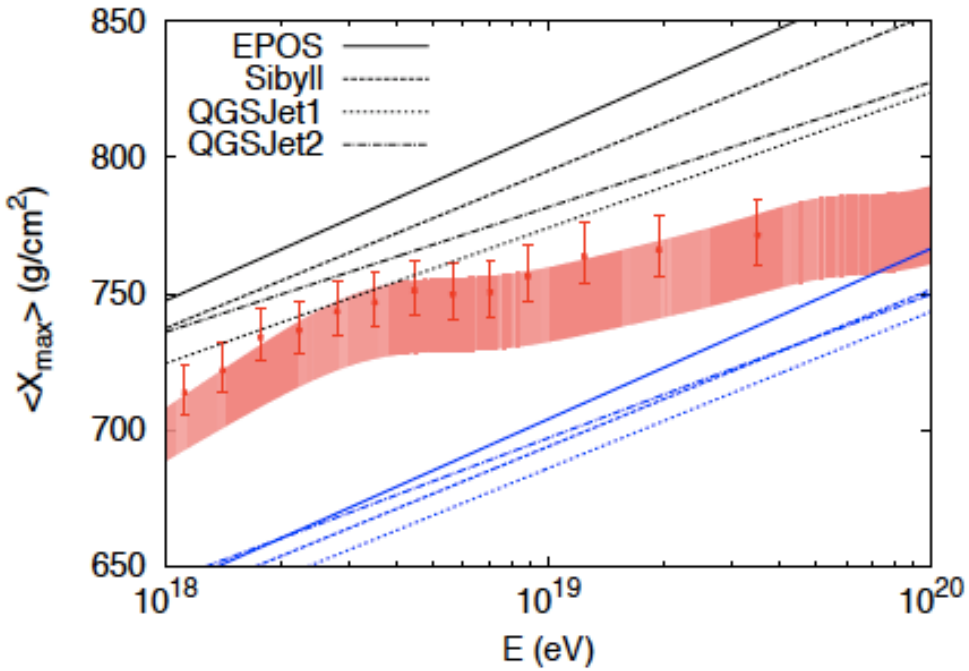


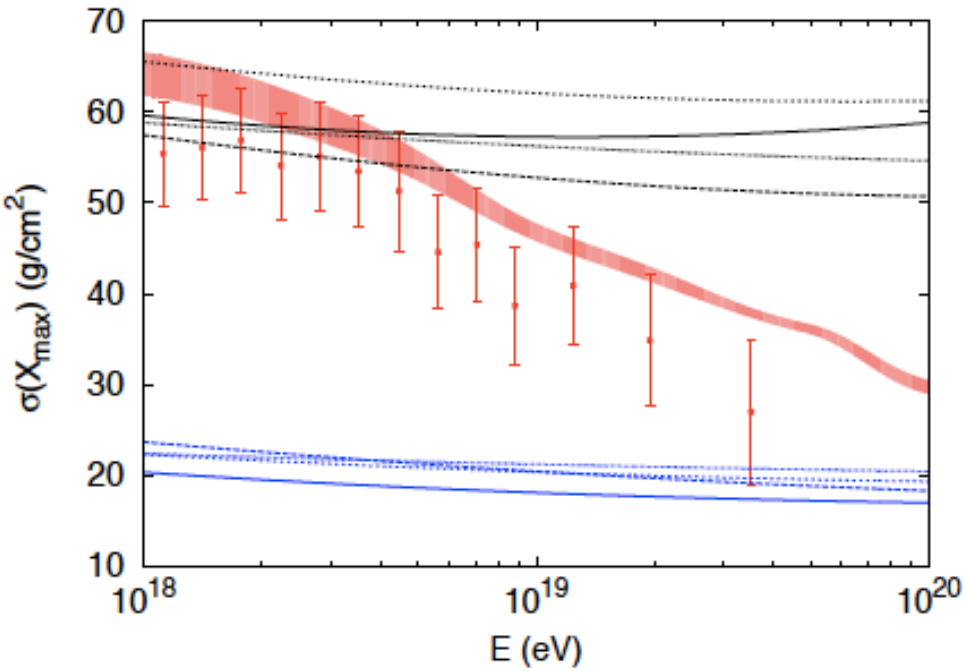
Proliferation of components

Aloisio, Berezinsky & PB 2013









SUMMARY

- *ALTHOUGH THE GENERAL PICTURE OF THE ORIGIN OF CR APPEARS TO BE OUTLINED, THERE ARE MANY LOOSE ENDS*
- *A COHERENT PICTURE IS STILL MISSING - AMBIGUITY IN THE RESULTS OF MEASUREMENTS OF SPECTRA, COMPOSITION AND ANISOTROPY*
- *IN TERMS OF CR ACCELERATION, THE PROBLEM OF REACHING VERY HIGH ENERGIES APPEARS TO HAVE BECOME A PLASMA PHYSICS PROBLEM*
- *BUT STILL THERE ARE ISSUES WITH ANISOTROPY VS SPECTRA*
- *PROPAGATION IS ALL BUT TRIVIAL (PERP/PAR, SPACE DEPENDENCE, SELF-SCATTERING, …)*
- *IN THE STANDARD PICTURE THE GALACTIC CR SPECTRUM SHOULD END AT AROUND THE SECOND KNEE, BUT CHEMICAL COMPOSITION OF UHECR???*
- *NOT ONLY WE COULD USE BETTER THEORETICAL TOOLS, ALSO ALTERNATIVE OBSERVATIONS WOULD HELP… BALMER OBSERVATIONS MAY BE WHAT WE ARE ARE AFTER… UNFORTUNATELY NOT MUCH AFTER HUBBLE SPACE TELESCOPE*