New cosmic ray MIN-MED-MAX benchmark models for dark matter indirect signatures

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Outline

1) Dark matter and antimatter cosmic rays

2) Measuring the height L of the magnetic halo

3) Defining the new MIN, MED and MAX models

4) New MIN-MED-MAX fluxes on selected examples

5) Bracketing down uncertainties

Based on Weinrich et al., A&A **639** (2020) A131 [2002.11406]
Weinrich et al., A&A **639** (2020) A74 [2004.00441]
Génolini et al., [2103.04108]

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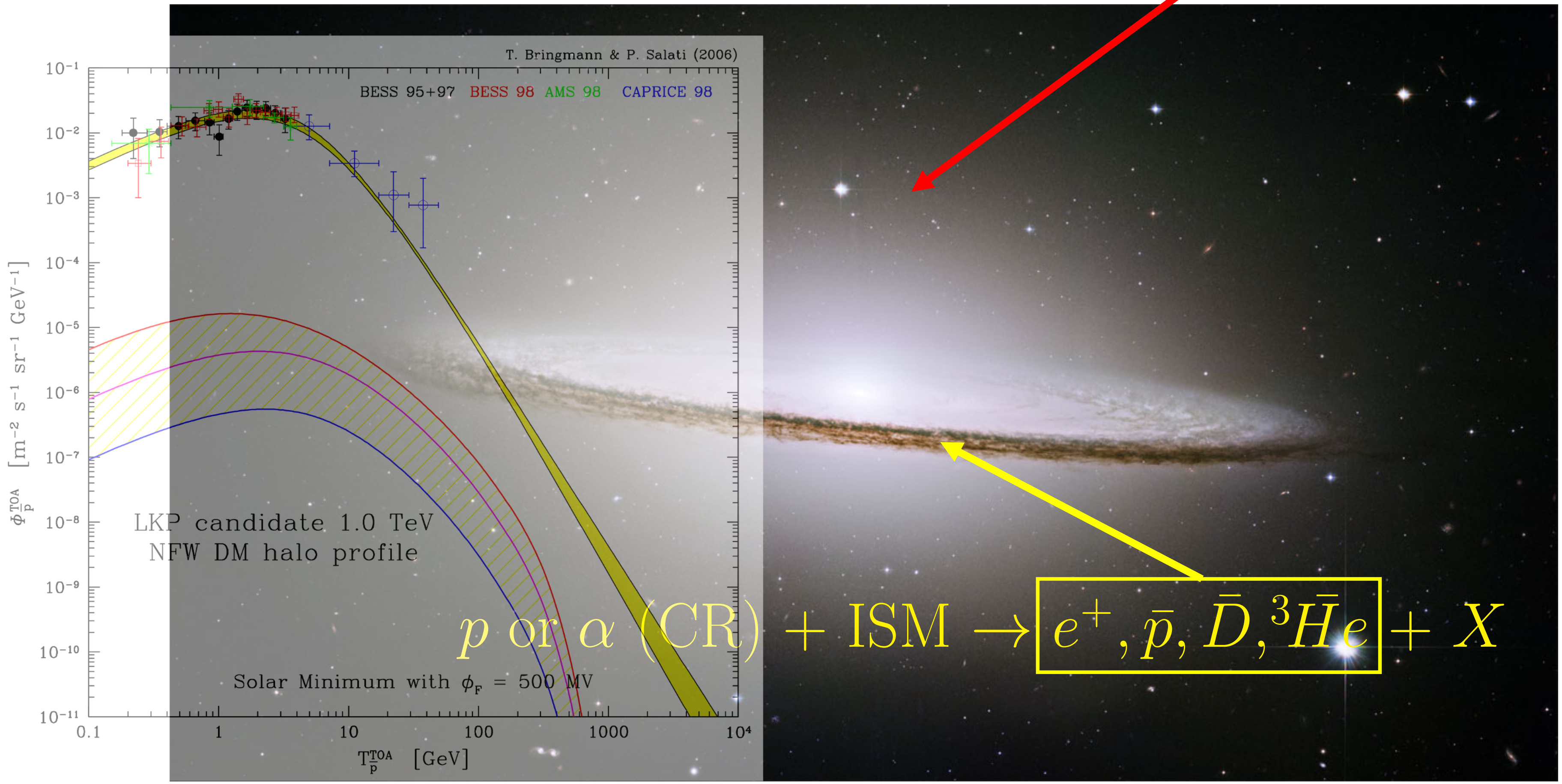
1) Dark matter and antimatter cosmic rays

Dark Matter particles could be the major component of the haloes of galaxies. Their mutual annihilations or decays would produce an **indirect signature** under the form of high-energy **cosmic rays**.

$$\chi + \chi \;\rightarrow\; q\bar{q}, W^{+}W^{-}, \ldots \rightarrow\; \gamma, \boxed{e^{+}, \bar{p}, \bar{D}, {}^{3}\bar{He}} \,\&\, \nu' s$$



Uncertainties from **cosmic ray propagation** need to be ascertained.
MIN-MED-MAX benchmark configurations allow to bracket them.

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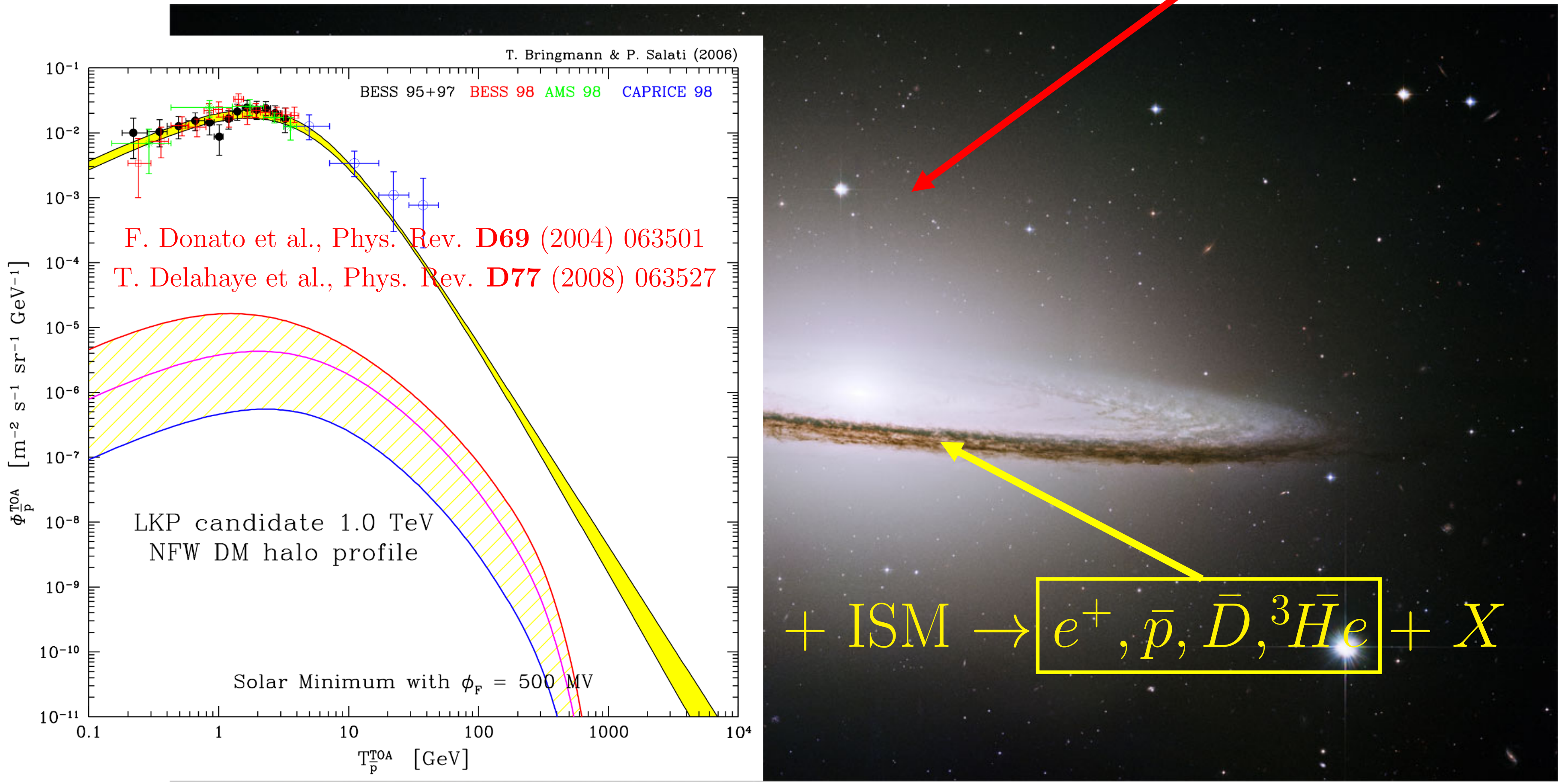

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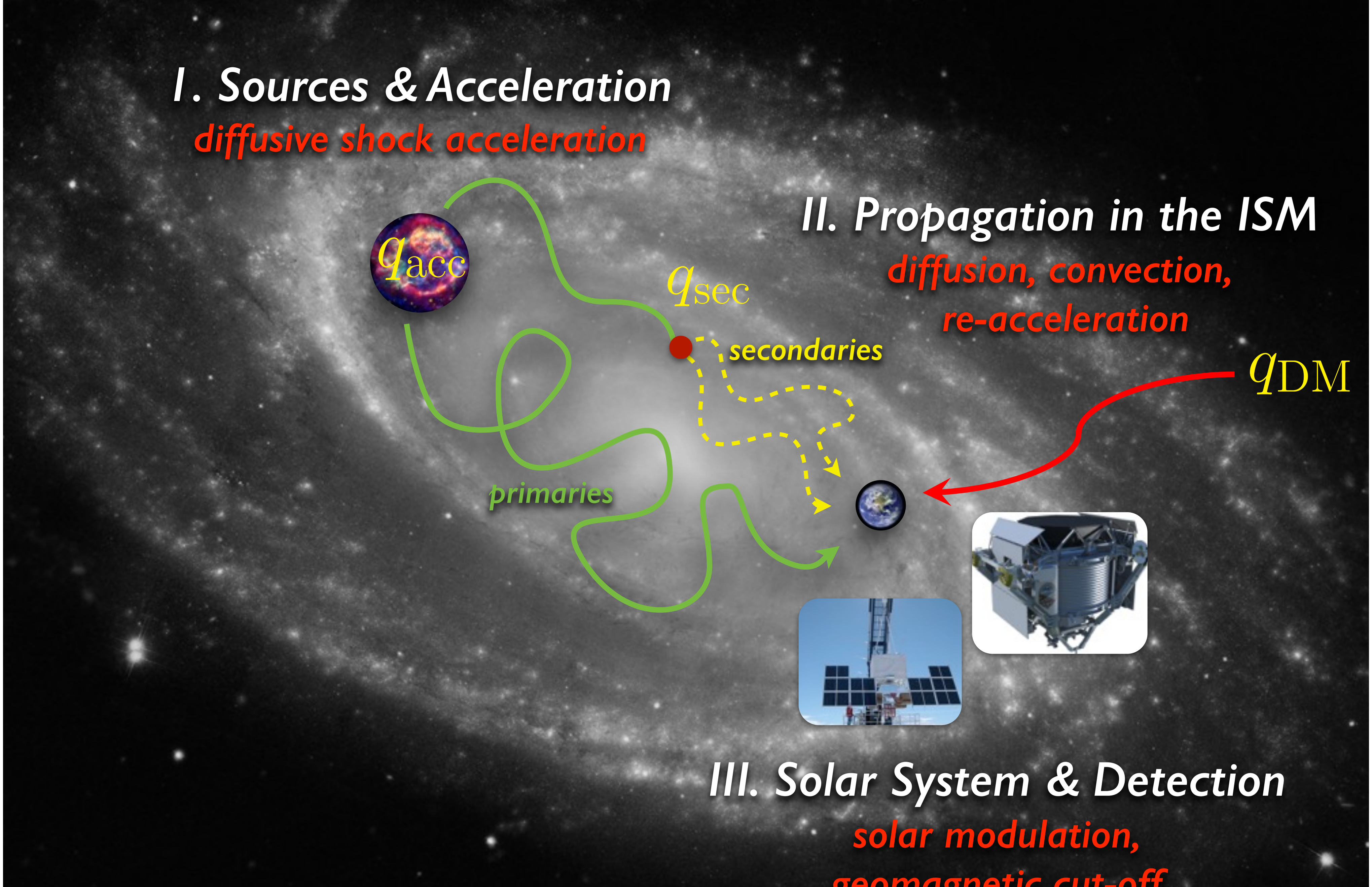
2) Measuring the height L of the magnetic halo



Courtesy Antje Putze, TeVPA 2015

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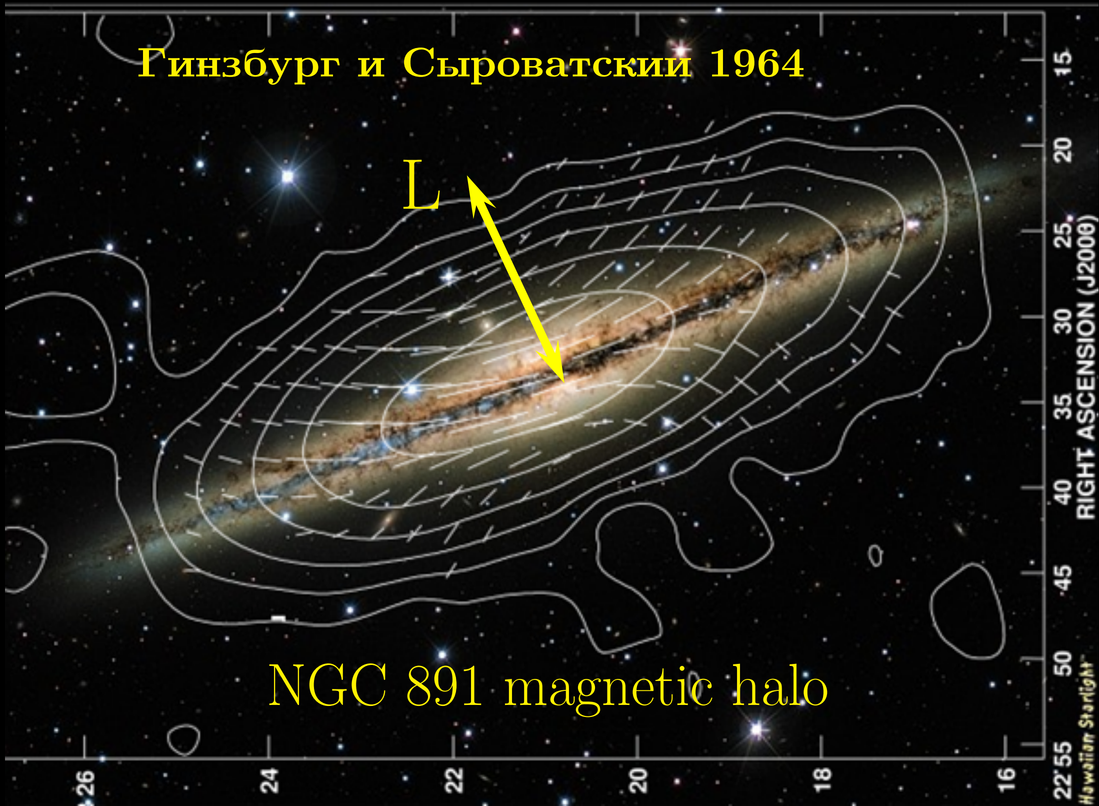
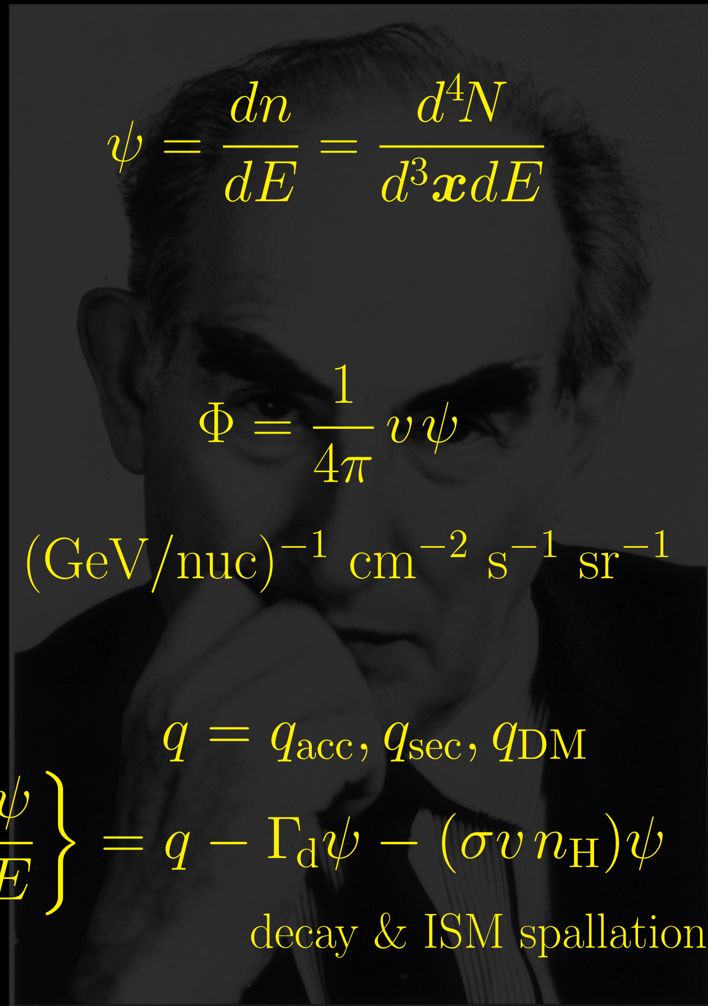




$$\psi = \frac{dn}{dE} = \frac{d^4N}{d^3\boldsymbol{x}\,dE}$$

$$\Phi = \frac{1}{4\pi} v\,\psi$$

$(\mathrm{GeV/nuc})^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$

$$q = q_{\mathrm{acc}},\, q_{\mathrm{sec}},\, q_{\mathrm{DM}}$$

$$\dot{\psi} + \boldsymbol{\nabla}\cdot\{-K\,\boldsymbol{\nabla}\psi + \psi \boldsymbol{V}_C\} + \frac{\partial}{\partial E}\left\{b\,\psi - D_{EE}\frac{\partial \psi}{\partial E}\right\} = q - \Gamma_{\mathrm{d}}\psi - (\sigma v\, n_{\mathrm{H}})\psi$$

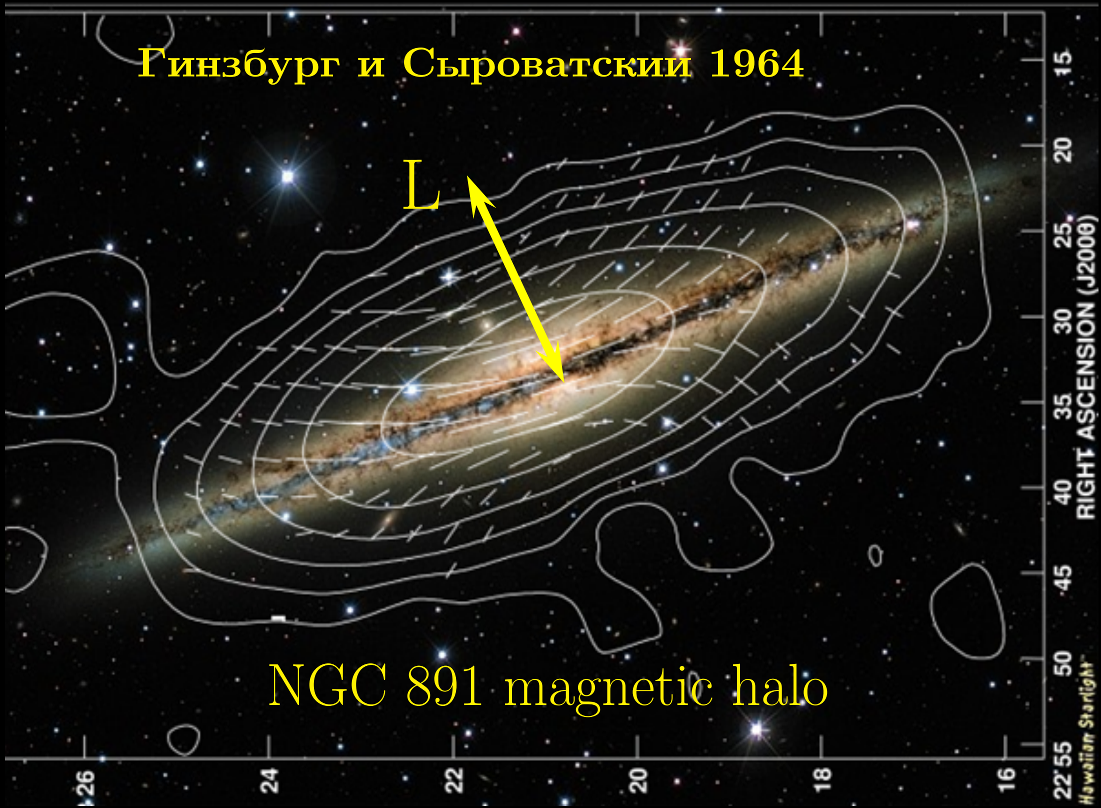
convection — E losses — decay & ISM spallation

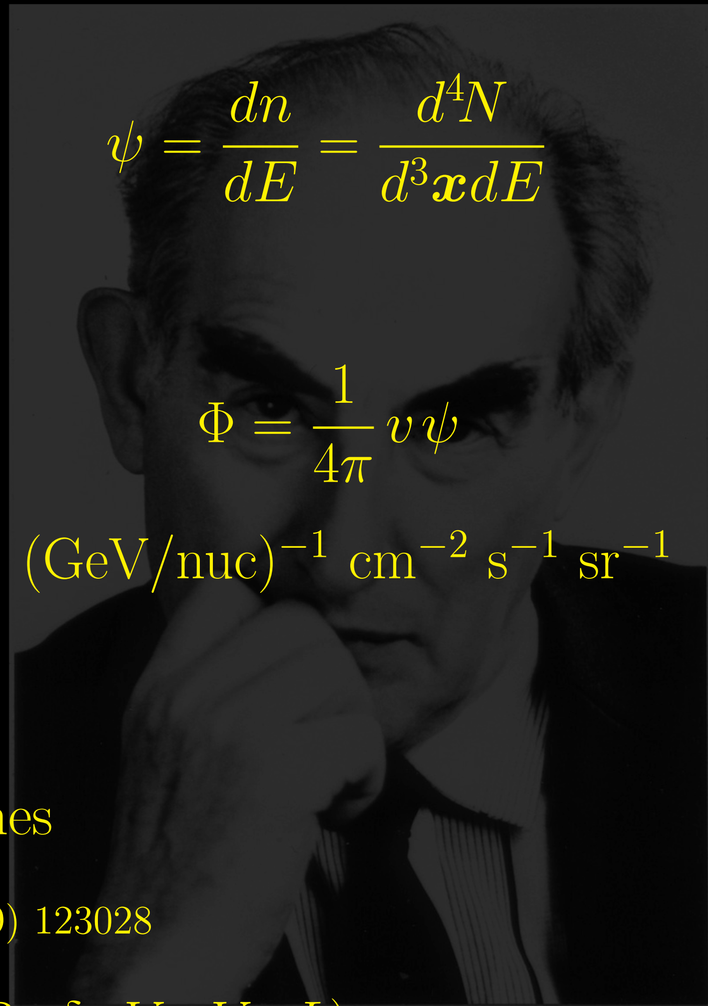
$\boldsymbol{x}$ diffusion — E diffusion

$$K = \beta^{\eta} K_0 \left\{1 + \left(\frac{R_{\mathrm{l}}}{R}\right)^{\frac{\delta-\delta_{\mathrm{l}}}{s_{\mathrm{l}}}}\right\}^{s_{\mathrm{l}}} \left(\frac{R}{1\,\mathrm{GV}}\right)^{\delta} \left\{1 + \left(\frac{R}{R_{\mathrm{h}}}\right)^{\frac{\delta-\delta_{\mathrm{h}}}{s_{\mathrm{h}}}}\right\}^{-s_{\mathrm{h}}}$$

$$D_{EE} = \frac{4}{3}\frac{\beta^2}{\delta(4-\delta^2)(4-\delta)}\frac{{V_a}^2 p^2}{K}$$

2) Measuring the height L of the magnetic halo





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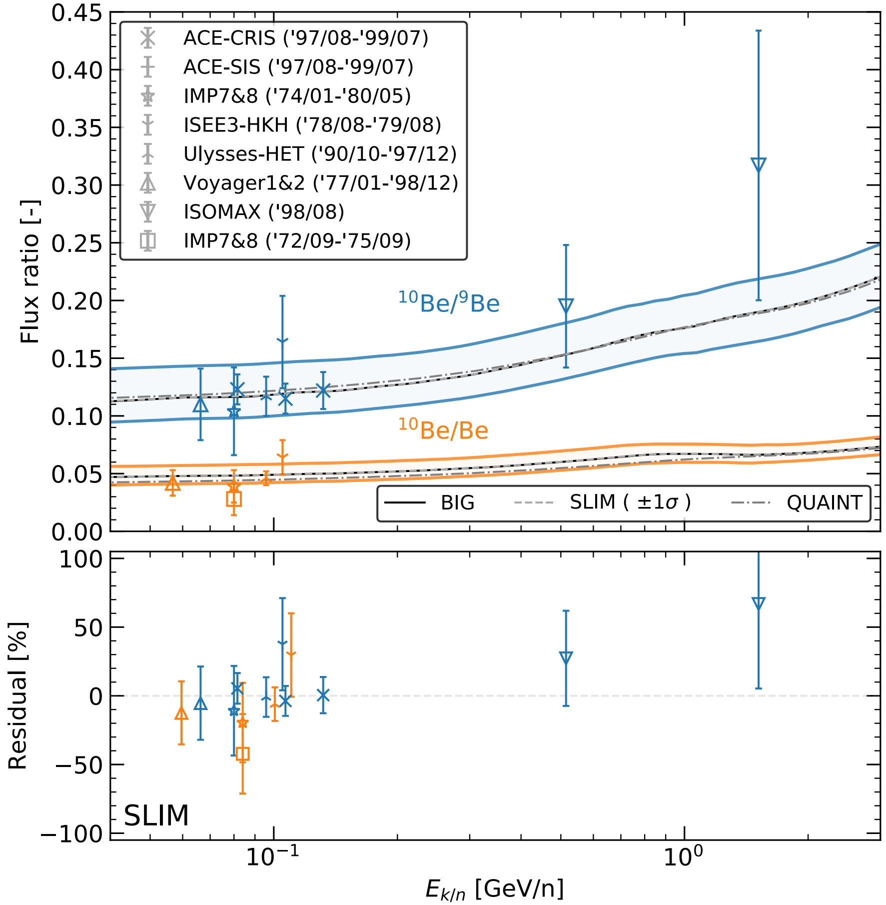
Three CR transport schemes

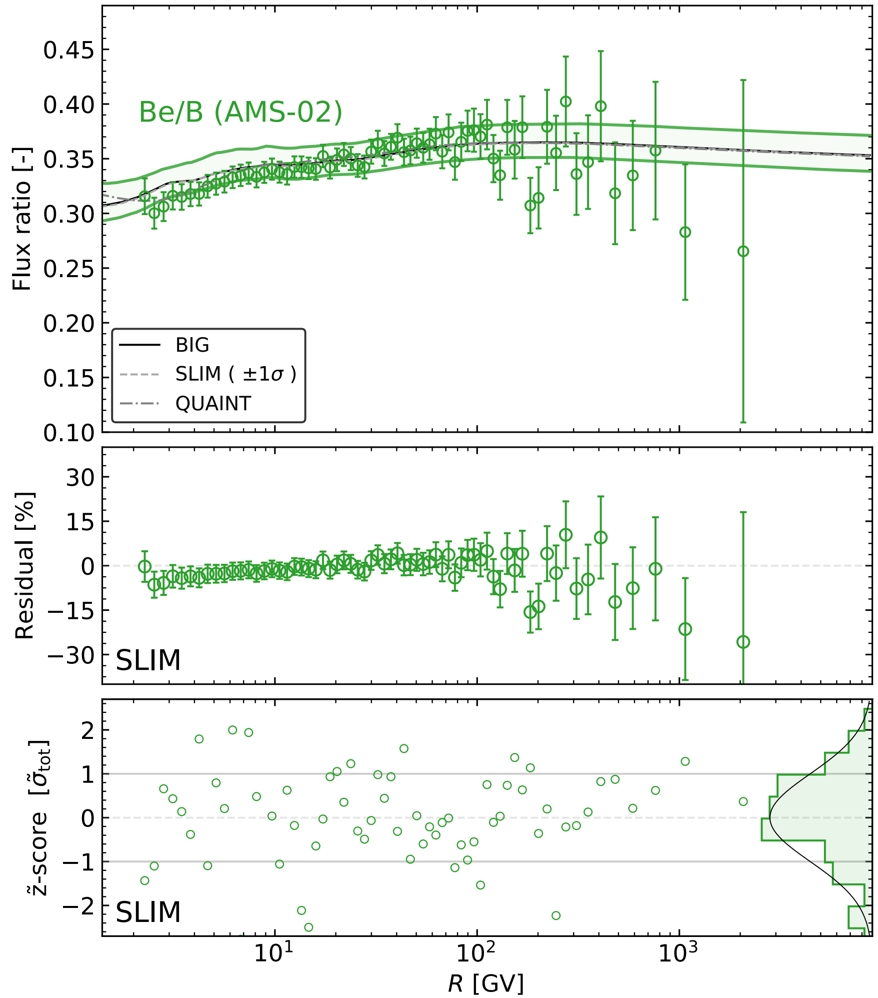
Y. Génolini et al., Phys. Rev. **D99** (2019) 123028

- BIG is the most comprehensive (K_0, δ, R_l, δ_l, V_C, V_a, L)
- QUAINT $\subset$ BIG is the old scheme (K_0, δ, η, V_C, V_a, L)
- SLIM $\subset$ BIG is for the Gifted Amateur (K_0, δ, R_l, δ_l, L)

2) Measuring the height L of the magnetic halo

- ^{10}**Be** used as a CR clock with half-lifetime $t_{1/2}$ of 1.387 Myr
- But isotopic data at low energies and with improvable precision
- Trade-off between isotopic data ^{10}**Be/Be** & ^{10}**Be/^{9}Be** and elemental ratio ^{10}**Be/B**





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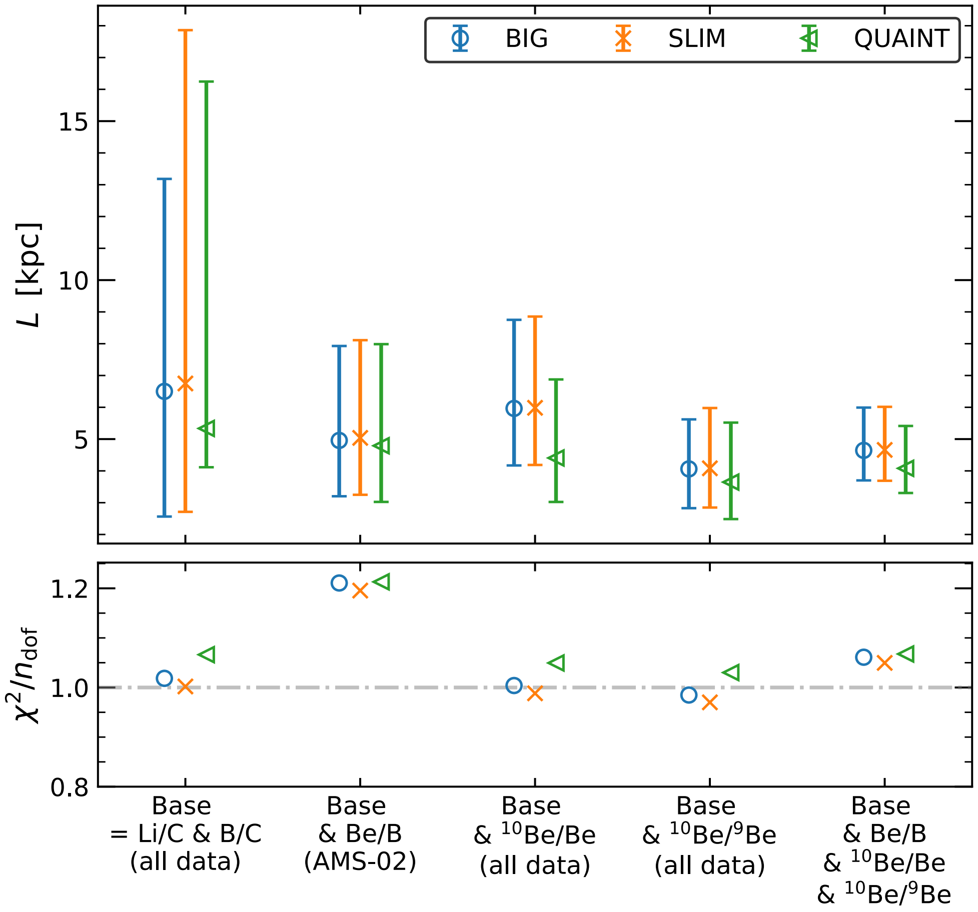


	BIG	SLIM	QUAINT
Base & Be/B (AMS-02)			
L [kpc]	$4.96^{+2.97}_{-1.76}$	$5.04^{+3.07}_{-1.79}$	$4.79^{+3.19}_{-1.77}$
$\chi^2 / n_{\rm dof}$	233.7 / 193	233.1 / 195	235.3 / 194
$\chi^2_{\rm nui} / n_{\rm nui}$	17.4 / 20	17.4 / 20	15.8 / 20
Base & Be/B & ^{10}Be/Be & ^{10}Be/^{9}Be (all data)			
L [kpc]	$4.64^{+1.35}_{-0.94}$	$4.66^{+1.35}_{-0.97}$	$4.08^{+1.33}_{-0.78}$
$\chi^2 / n_{\rm dof}$	266.3 / 251	265.6 / 253	269.0 / 252
$\chi^2_{\rm nui} / n_{\rm nui}$	25.6 / 35	25.4 / 35	25.6 / 35

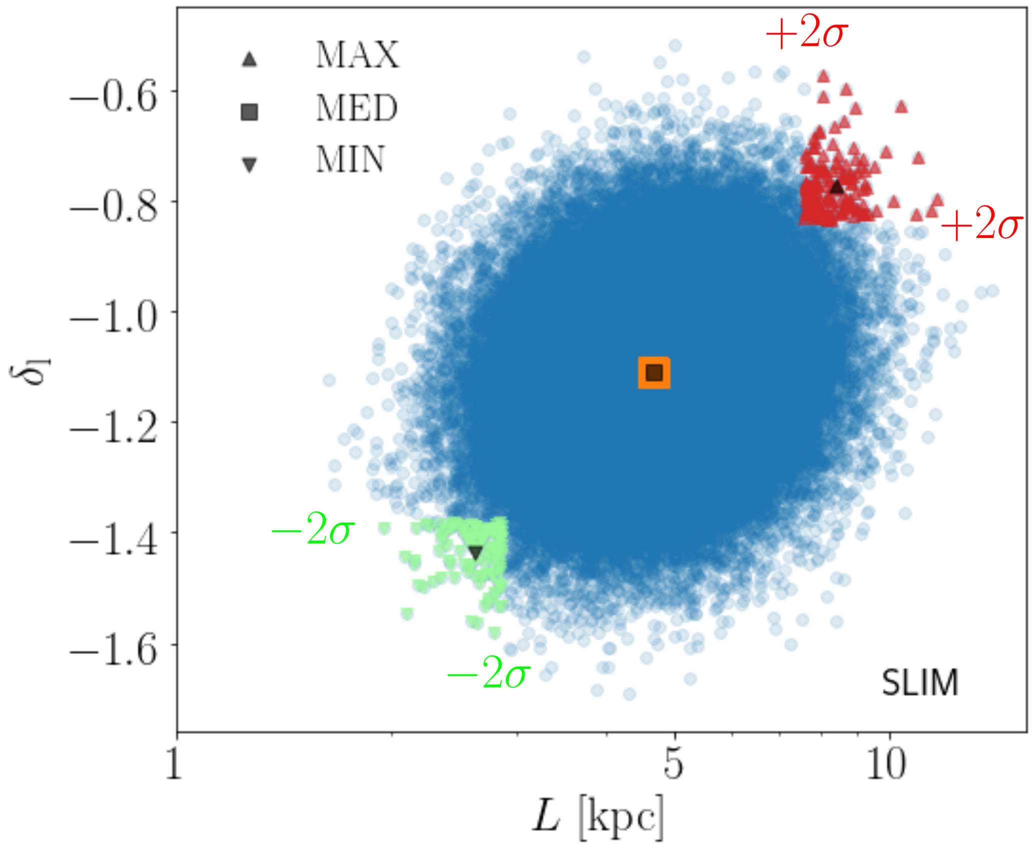
$\log_{10} L$ [kpc]	δ	$\log_{10} K_0$ [kpc^2 Myr^{-1}]	R_l [GV]	δ_l
0.668	0.499	−1.444	4.482	−1.110

$$
\begin{pmatrix}
+1.13\text{e-}2 & -2.05\text{e-}4 & +1.10\text{e-}2 & +1.96\text{e-}3 & +2.41\text{e-}3 \\
-2.05\text{e-}4 & +1.06\text{e-}4 & -3.91\text{e-}4 & +1.03\text{e-}6 & -3.38\text{e-}4 \\
+1.10\text{e-}2 & -3.91\text{e-}4 & +1.12\text{e-}2 & +1.79\text{e-}3 & +3.28\text{e-}3 \\
+1.96\text{e-}3 & +1.03\text{e-}6 & +1.79\text{e-}3 & +2.80\text{e-}2 & +1.42\text{e-}2 \\
+2.41\text{e-}3 & -3.38\text{e-}4 & +3.28\text{e-}3 & +1.42\text{e-}2 & +1.88\text{e-}2
\end{pmatrix}
$$

The precision on L improves as more data sets are combined

Cosmic ray parameter values and associated covariance matrix for SLIM

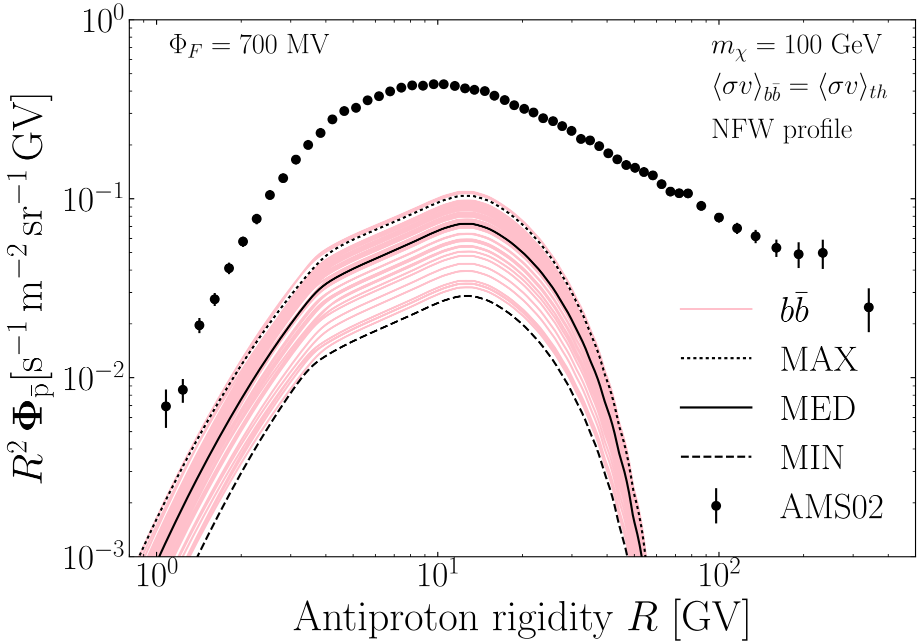
3) Defining the new MIN, MED and MAX models



SLIM	L [kpc]	δ	$\log_{10} K_0$ [$\mathrm{kpc^2\,Myr^{-1}}$]	R_l [GV]	δ_l
MAX	8.40	0.490	-1.18	4.74	-0.776
MED	4.67	0.499	-1.44	4.48	-1.11
MIN	2.56	0.509	-1.71	4.21	-1.45

- B/C is proportional to L/K
- $\Phi_{\bar{p}} \propto \dfrac{L^2}{K}$ while $\Phi_{e^+} \propto \left\{\dfrac{L^2}{K}\right\}^{3/2}$
- B/C data set L/K above a few GV
- $\Phi_{\bar{p}} \propto L$ and $\Phi_{e^+} \propto L^{3/2}$ above a few GV
- Below a few GeV, additional information is required since L and K are not correlated
- The larger δ_l, the smaller K at low rigidity and the larger $\Phi_{\bar{p}}$ and Φ_{e^+}
- for SLIM the relevant CR parameters which control DM signals are L and δ_l

4) New MIN-MED-MAX fluxes on selected examples

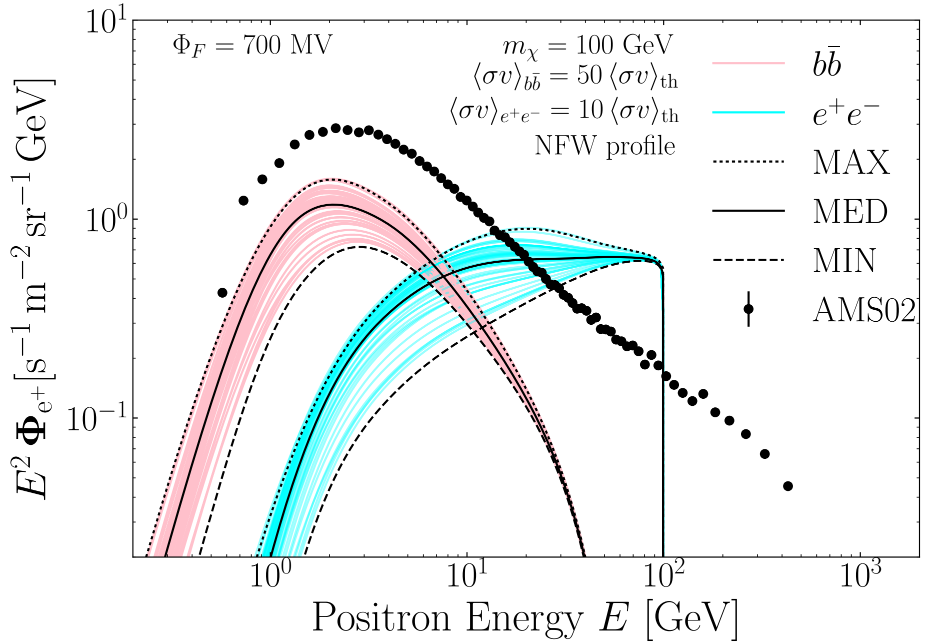


- $\Phi_{\bar{p}}$ calculated with USINE public code

D. Maurin, Comp. Phys. Com. **247** (2020) 106942

- $\Phi_{\bar{p}} \propto \dfrac{L^2}{K} \propto L$ above a few GV while below curves are intertwined with one another

- All $\Phi_{\bar{p}}$ inside the band from MIN to MAX whose width corresponds to a factor ~ 4



- Φ_{e^+} calculated with the pinching method

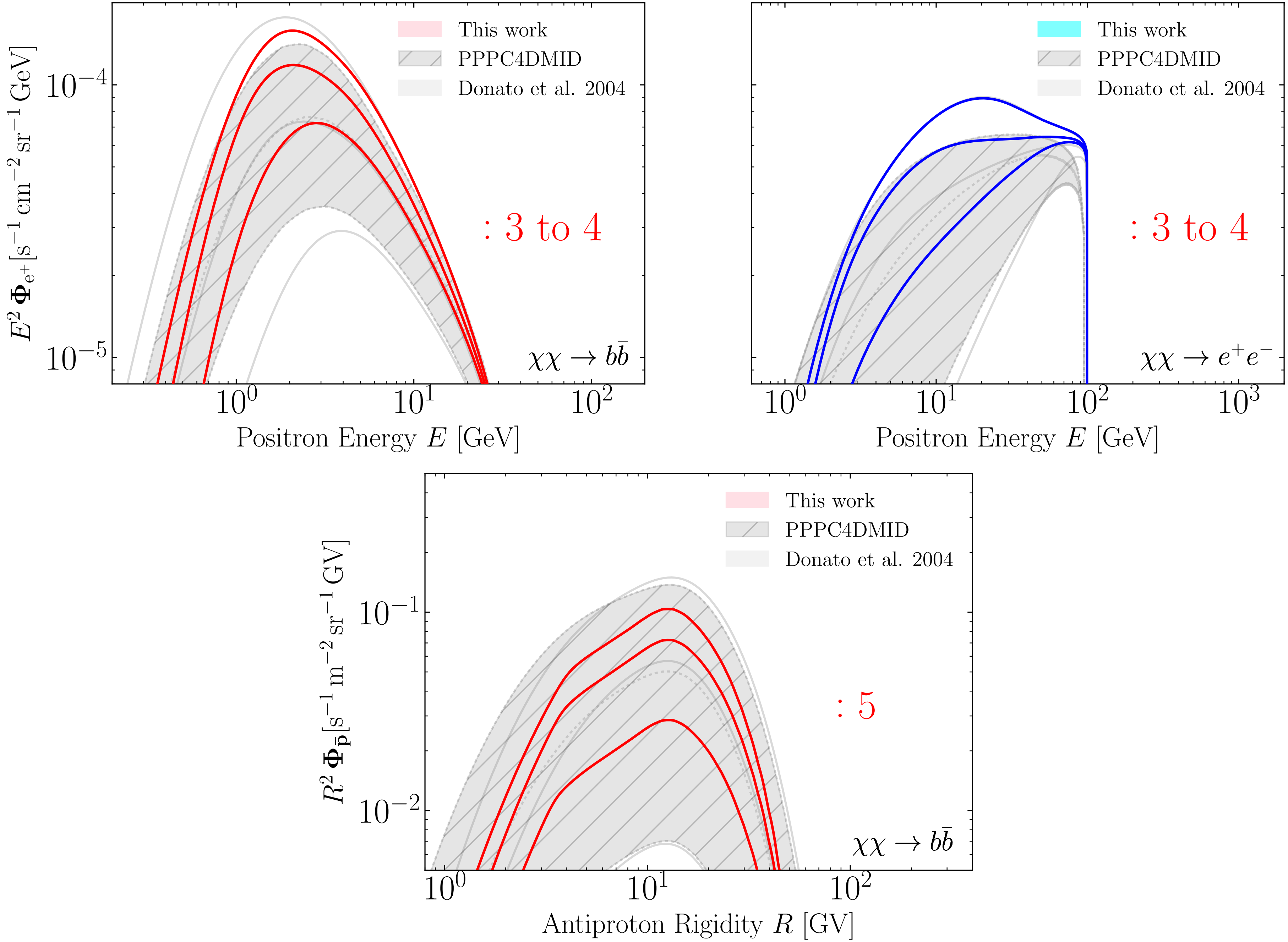
M. Boudaud et al., A&A **605** (2017) A17

- Φ_{e^+} has a local origin for $E \to m_\chi$ and no longer depends on CR parameters $\Leftarrow E$ losses vs diffusion

- $\Phi_{e^+} \propto \left\{\dfrac{L^2}{K}\right\}^{3/2} \propto L^{3/2}$ down to $\sim$ GeV while below curves are intertwined with one another

- All Φ_{e^+} inside the band from MIN to MAX with width increasing @ low E (factor ~ 4 @ 1 GeV)

5) Bracketing down uncertainties



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Pierre Salati,[a,*] Mathieu Boudaud,[b] Marco Cirelli,[c] Laurent Derome,[d] Yoann Génolini,[e] Julien Lavalle,[f] David Maurin[d] and Pasquale Dario Serpico[a]

Takeaway

• This contribution is about the Galactic propagation models called MIN, MED and MAX that yield minimal, median and maximal fluxes of primary antimatter particles produced by dark matter annihilation or decay.

• These configurations have been extensively used in the astroparticle community to bracket the uncertainties on dark matter indirect signatures that arise from cosmic-ray propagation. As cosmic-ray data have considerably improved in the past decade, a revision was mandatory.

• Using the latest measurements of cosmic-ray nuclei, we have revised the parameters driving the propagation of charged species throughout the Galaxy. We have derived in particular the height L of the magnetic halo, a crucial quantity driving the intensity of primary antiprotons and positrons fluxes produced by dark matter.

• We obtain the new MIN-MED-MAX benchmarks for the BIG, QUAINT and SLIM schemes, reducing theoretical uncertainties by a factor of 3-4 (positrons) and 5 (antiprotons) with respect to their initial version.

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