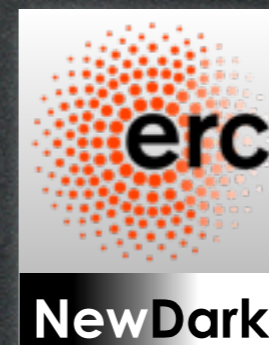


1 December 2015
Prospects in Low Mass Dark Matter
MPI Munich

Challenges of Indirect Detection of low mass DM

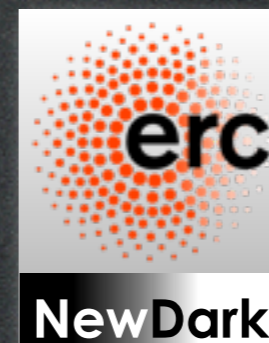
Marco Cirelli
(CNRS LPTHE Jussieu)



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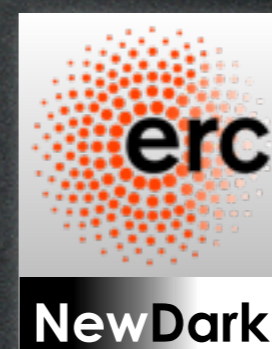


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Prospects in Low Mass Dark Matter
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Challenges of Indirect Detection of low mass DM

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(CNRS LPTHE Jussieu)

≈ 50 GeV



OUTLINE

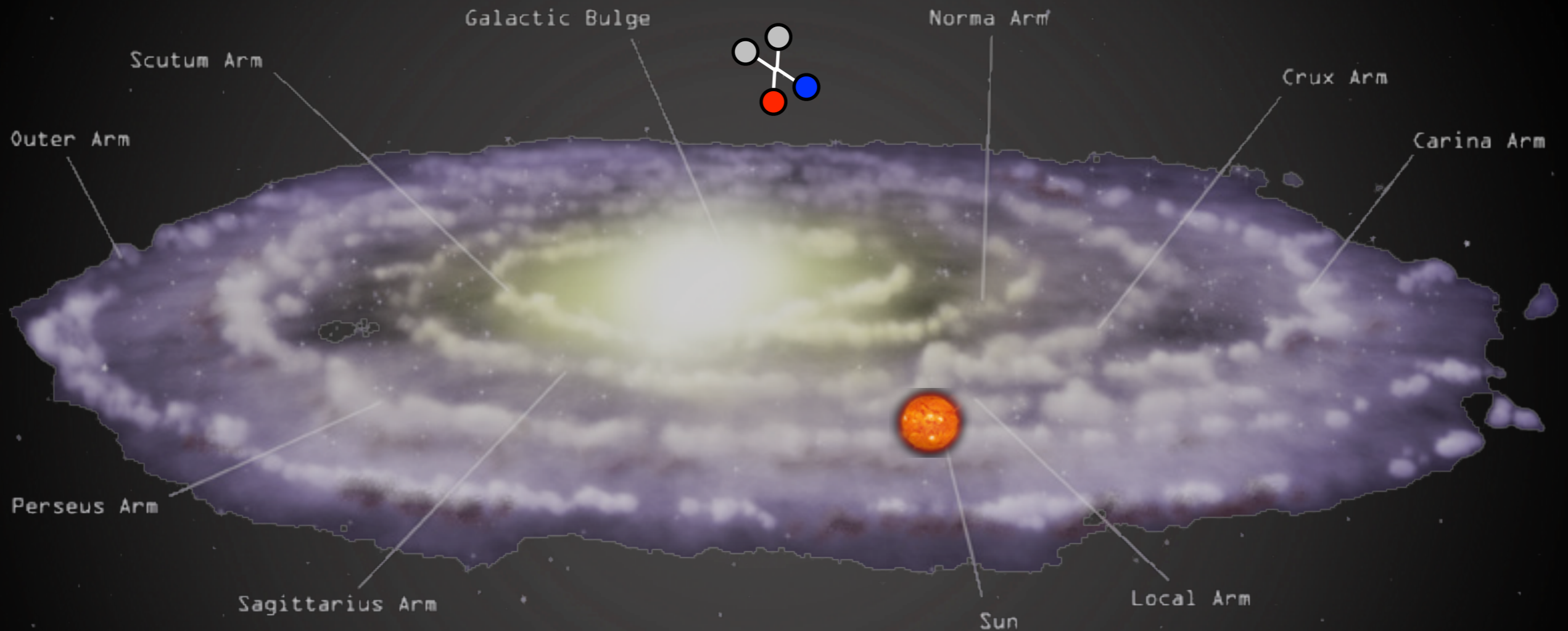
Antiprotons from
low mass DM

Gamma-rays from
low mass DM

The **GC GeV excess**
as a case study

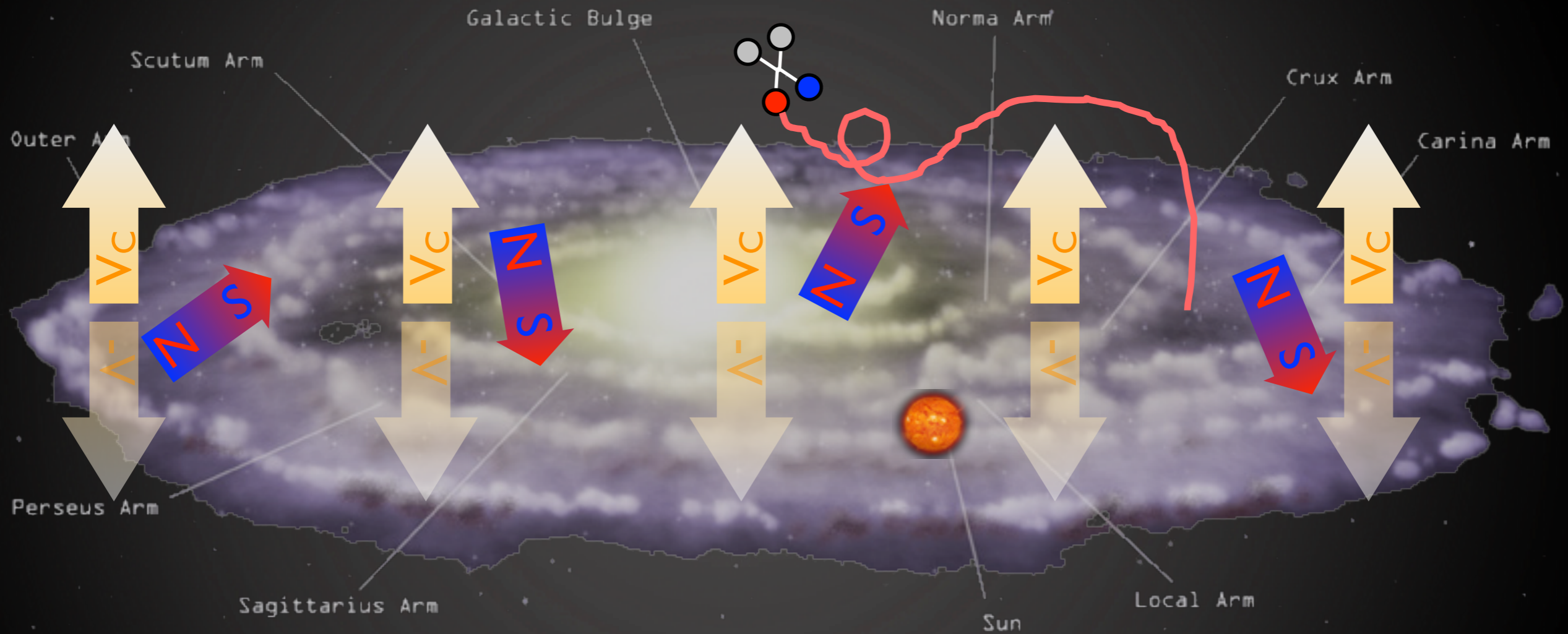
Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo



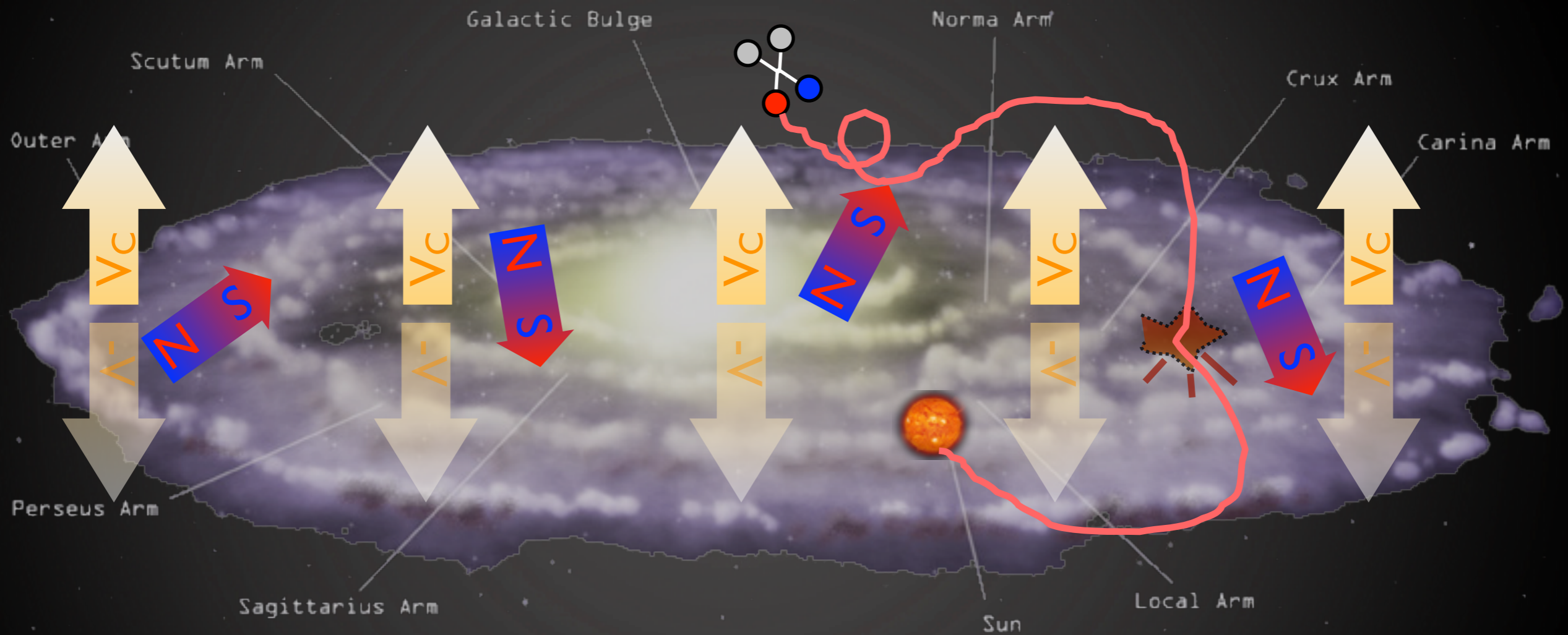
Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo



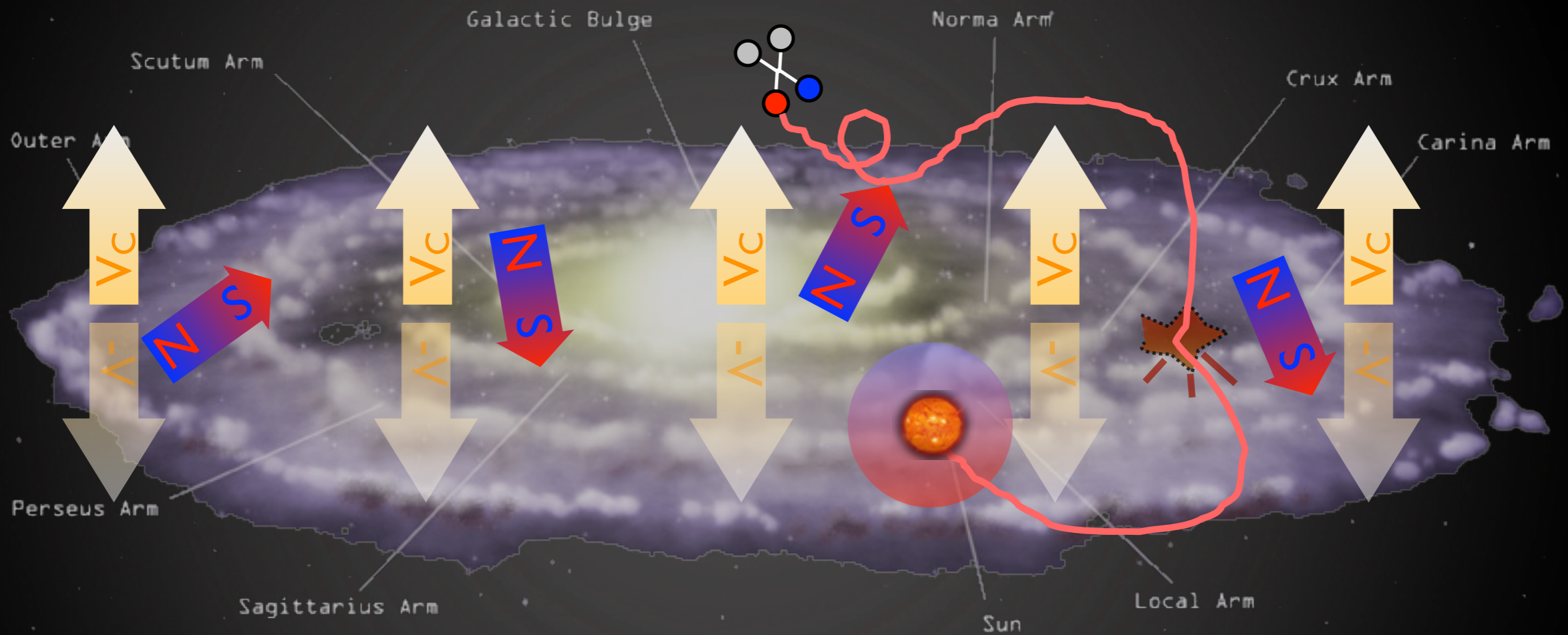
Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo



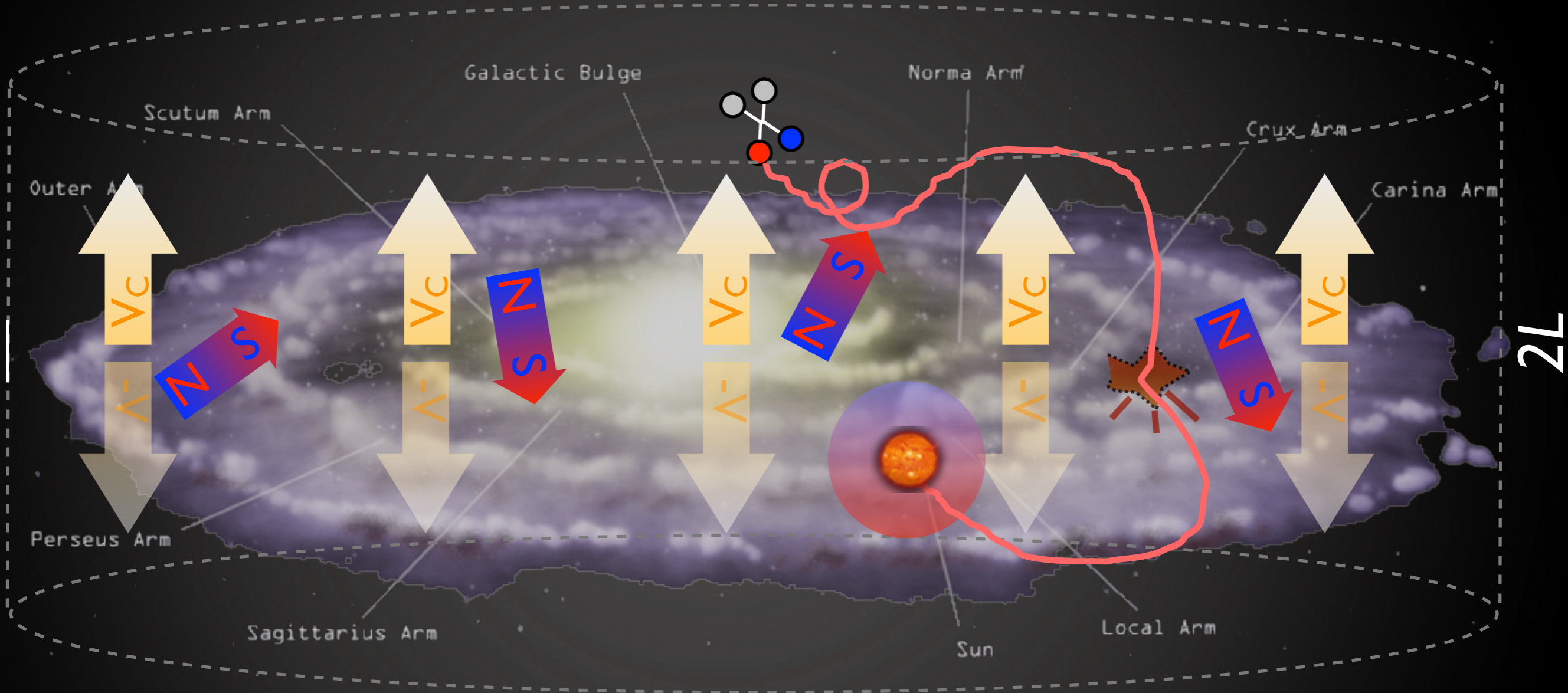
Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo



Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo



spectrum

$$\frac{\partial f}{\partial t} - K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E} (b(E)f) + \frac{\partial}{\partial z} (V_c f) = Q_{\text{inj}} - 2h\delta(z)\Gamma_{\text{spall}} f$$

diffusion

energy loss

convective wind

source

spallations

[uncert]

Salati, Chardonay, Barrau,
Donato, Taillet, Fornengo, Maur
Brun... '90s, '00s

Indirect Detection: charged CRs

\bar{p} and e^+ from DM annihilations in halo

thickness
diffusion
diff. reacc.
 p index
convection
solar mod.

	KRA	KOL	CON	THK	THN	THN2	THN3
L [kpc]	4	4	4	10	0.5	2	3
D_0 [10^{28} cm 2 s $^{-1}$]	2.64	4.46	0.97	4.75	0.31	1.35	1.98
δ	0.50	0.33	0.6	0.50	0.50	0.50	0.50
η	-0.39	1	1	-0.15	-0.27	-0.27	-0.27
v_A [km s $^{-1}$]	14.2	36	38.1	14.1	11.6	11.6	11.6
γ	2.35	1.78/2.45	1.62/2.35	2.35	2.35	2.35	2.35
dv_c/dz [km s $^{-1}$ kpc $^{-1}$]	0	0	50	0	0	0	0
ϕ_F^p [GV]	0.650	0.335	0.282	0.687	0.704	0.626	0.623
χ_{\min}^2/dof (p in [25])	0.462	0.761	1.602	0.516	0.639	0.343	0.339

Cirelli, Gaggero, Giesen, Taoso, Urbano | 407.2173
cfr. Evoli, Cholis, Grasso, Maccione, Ullio, | 108.0664

Model	Electrons or positrons		Antiprotons (and antideuterons)			
	δ	\mathcal{K}_0 [kpc 2 /Myr]	δ	\mathcal{K}_0 [kpc 2 /Myr]	V_{conv} [km/s]	L [kpc]
MIN	0.55	0.00595	0.85	0.0016	13.5	1
MED	0.70	0.0112	0.70	0.0112	12	4
MAX	0.46	0.0765	0.46	0.0765	5	15

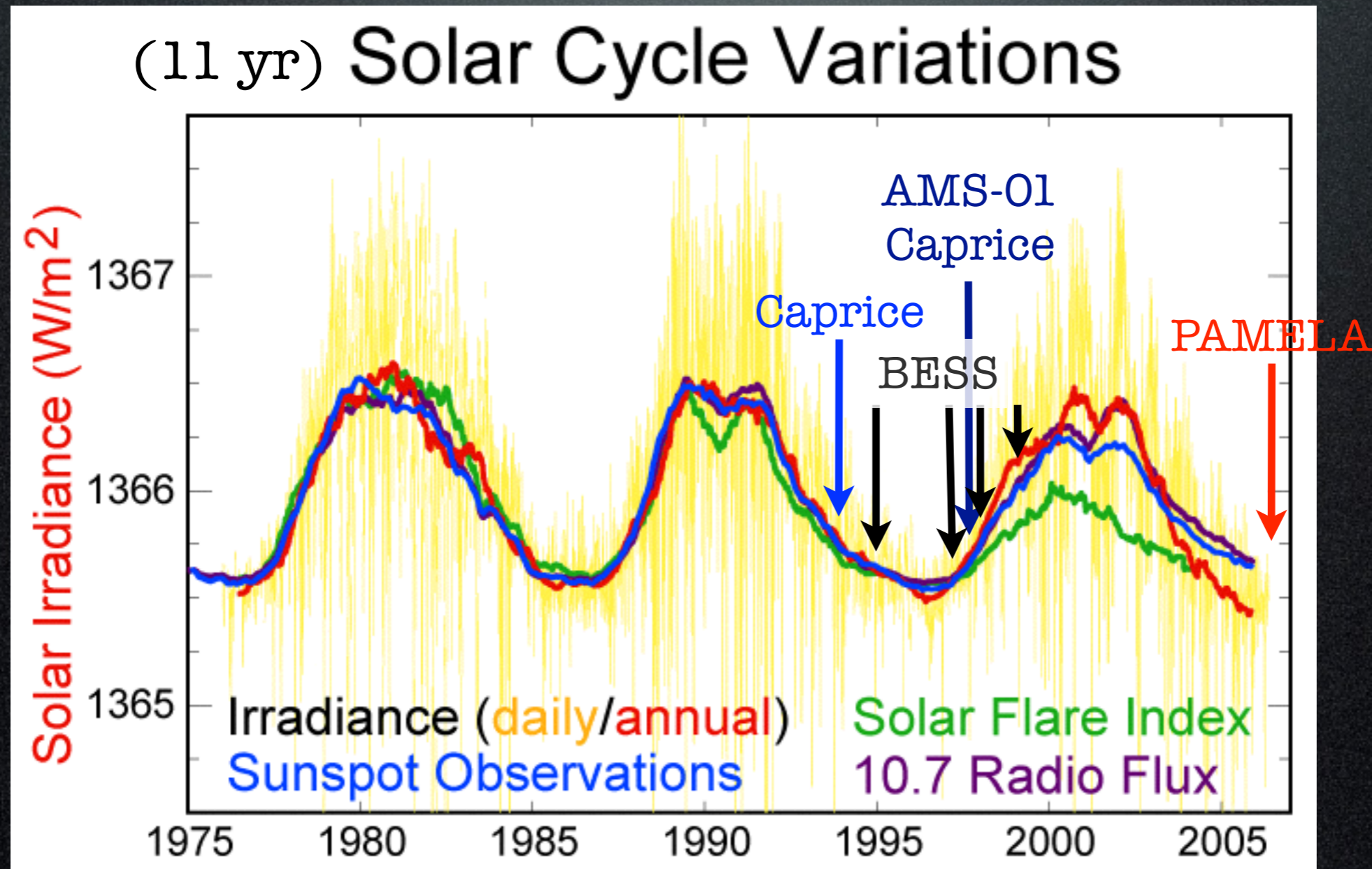
Donato et al., 2003+

Indirect Detection: charged CRs

Solar polarity Modulation of cosmic rays:

solar magnetic polarity reverses at (the max of) each cycle;
during '- polarity' state, positive particles are more deflected away

+ = rotation parallel
to magnetic field;
- = antiparallel



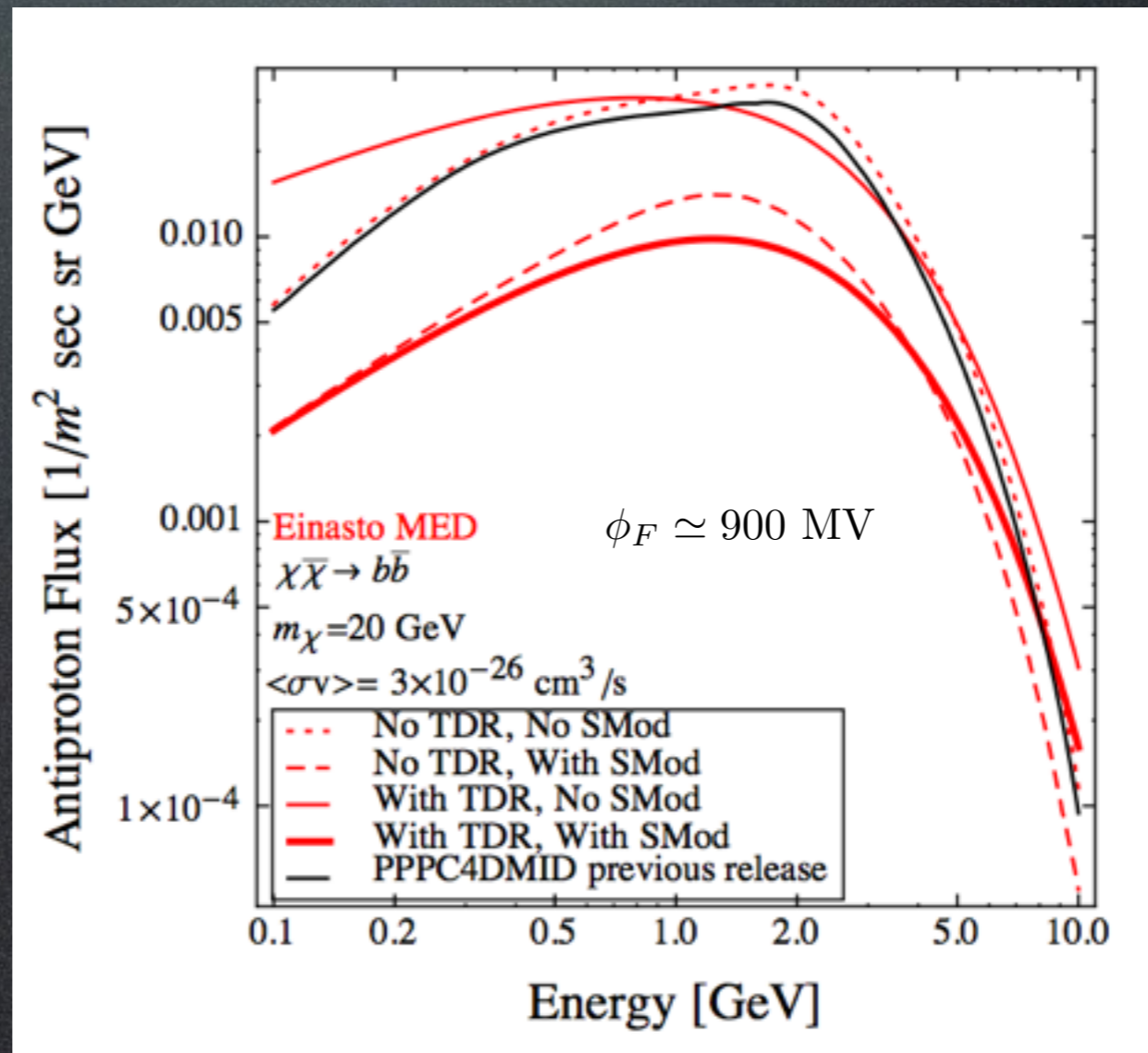
Indirect Detection: charged CRs

Solar wind Modulation of cosmic rays:

$$\frac{d\Phi_{\bar{p}\oplus}}{dT_{\oplus}} = \frac{p_{\oplus}^2}{p^2} \frac{d\Phi_{\bar{p}}}{dT}, \quad T = T_{\oplus} + |Ze|\phi_F$$

spectrum at Earth
spectrum far from Earth
Fisk potential

E.g.



Indirect Detection: charged CRs

Solar wind Modulation of cosmic rays:
which value for ϕ_F ?

Dedicated code: HelioProp

L.Maccione, 2013

polarity	tilt angle α [deg]	m.f.p. λ_0 [AU]	δ [-]	ϕ_p [GV]	$\phi_{\bar{p}}$ [GV]	rel. diff. [%]
-1.00	10.00	0.05	0.30	1.18	1.18	0.00%
-1.00	10.00	0.05	0.50	1.18	1.18	0.00%
-1.00	10.00	0.05	1.00	1.12	1.12	0.00%
-1.00	10.00	0.10	0.30	1.06	1.10	3.77%
-1.00	10.00	0.10	0.50	1.02	1.10	7.84%
-1.00	10.00	0.10	1.00	1.02	1.10	7.84%
-1.00	10.00	0.20	0.30	0.78	0.96	23.08%
-1.00	10.00	0.20	0.50	0.74	0.90	21.62%
-1.00	10.00	0.20	1.00	0.60	0.74	23.33%
-1.00	10.00	0.30	0.30	0.60	0.82	36.67%
-1.00	10.00	0.30	0.50	0.54	0.76	40.74%
-1.00	10.00	0.30	1.00	0.46	0.58	26.09%
-1.00	10.00	0.40	0.30	0.36	0.46	27.78%
-1.00	10.00	0.40	1.00	0.48	0.72	50.00%
-1.00	20.00	0.05	0.30	1.46	1.18	-19.18%
-1.00	20.00	0.05	1.00	1.28	1.12	-12.50%
-1.00	20.00	0.40	0.30	0.48	0.72	50.00%
-1.00	20.00	0.40	1.00	0.36	0.46	27.78%
-1.00	40.00	0.05	0.30	1.56	1.18	-24.36%
-1.00	40.00	0.40	0.30	0.50	0.70	40.00%
-1.00	40.00	0.40	1.00	0.38	0.44	15.79%
-1.00	60.00	0.05	0.30	1.50	1.86	24.00%
-1.00	60.00	0.05	1.00	1.18	1.34	13.56%
-1.00	60.00	0.40	0.30	0.50	0.66	32.00%
-1.00	60.00	0.40	1.00	0.40	0.42	5.00%

Neutron monitors

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1926	...	...	...	...	...	...	...	...	...	...	...	...	...
1927	401	451	516	550	566	662	557	588	546	553	492	496	528
1928	716	696	560	650	502	401	348	371	389	401	401	416	481
1929	416	509	506	599	632	509	422	365	389	389	395	363	438
1940	287	300	292	290	255	273	268	281	287	295	320	345	291
1941	389	342	371	354	323	287	303	271	359	268	273	311	316
1942	273	273	447	340	287	268	279	239	237	245	242	237	279
1943	250	255	258	271	268	271	306	309	314	292	279	273	279
1944	279	263	258	239	211	187	184	192	177	184	170	211	212
1945	250	250	334	340	258	258	255	245	234	229	242	245	261
1946	303	768	610	581	647	595	602	550	578	486	457	407	543
1947	432	413	560	685	658	1166	925	1031	1128	1001	911	827	788
1948	716	677	708	602	748	581	581	595	712	669	602	588	647
1949	696	677	613	632	585	539	486	522	479	599	526	486	568
1950	606	628	512	512	526	473	496	463	512	512	435	416	506
1951	492	647	631	618	555	510	553	587	523	514	535	513	562
1952	551	567	587	546	489	464	447	448	436	490	465	483	497
1953	515	497	506	500	500	482	495	488	483	469	472	453	488
1954	445	427	401	411	404	407	399	376	384	386	399	411	404
1955	462	413	409	409	399	406	405	417	400	429	425	476	420
1956	511	551	623	567	604	592	555	562	598	521	647	822	593
1957	955	967	929	1053	984	1033	1087	1021	1226	1149	1180	1284	1068
1958	1266	1226	1330	1308	1167	1090	1216	1120	1093	1089	1063	1125	1172
1959	1080	1139	1029	965	1072	996	1327	1269	1187	1044	1022	1056	1095
1960	1136	1080	1007	1112	1109	1042	1042	953	956	953	1024	945	1028
1961	848	815	813	822	776	783	956	836	787	749	676	698	795
1962	700	723	708	737	689	678	667	689	705	668	678	693	693
1963	612	587	592	567	603	566	562	575	613	578	561	538	579
1964	515	519	495	479	468	469	459	456	430	433	436	406	451
1965	389	394	371	348	338	386	406	413	406	394	371	376	382
1966	412	420	441	452	431	479	507	515	665	575	541	584	499
1967	632	656	597	579	630	655	625	671	658	645	690	689	643
1968	674	707	713	669	694	765	761	742	789	850	985	934	770
1969	811	799	820	823	862	1014	948	861	819	798	796	791	852
1970	810	769	784	834	835	937	934	855	780	758	834	706	818
1971	717	641	646	624	591	515	514	493	497	465	475	488	553
1972	507	520	453	427	457	528	461	636	475	461	505	476	491
1973	463	473	498	565	616	524	491	466	427	428	416	418	481
1974	420	402	438	461	527	567	630	563	605	590	565	499	520
1975	494	459	450	429	420	407	417	442	436	437	471	448	442
1976	446	440	436	461	434	426	412	408	407	408	404	411	424
1977	421	417	419	416	417	442	487	476	475	438	408	418	436
1978	478	496	510	588	669	602	591	495	495	566	528	530	544
1979	584	609	653	738	706	812	799	906	860	778	774	688	739
1980	716	743	686	762	757	886	885	855	866	960	1052	1038	845
1981	878	968	995	1055	1124	967	930	923	871	1046	1010	886	969
1982	813	982	828	798	758	1009	1258	1240	1422	1222	1150	1256	1046
1983	1086	969	877	874	1029	928	826	826	803	787	762	761	874
1984	709	736	800	846	967	880	842	778	753	751	772	746	797
1985	724	656	636	609	596	542	549	543	501	495	464	485	564
1986	486	575	507	434	416	405	403	402	401	378	433	382	434
1987	339	311	312	328	349	406	435	468	501	492	534	534	414
1988	626	593	581	602	590	610	681	697	682	714	728	819	658
1989	893	898	1183	1132	1234	1187	1022	1114	1195	1356	1470	1362	1161
1990	1232	1196	1275	1424	1452	1435	1247	1294	1187	1073	996	985	1226
1991	872	862	1257	1197	1158	2016	1938	1471	1190	1126	1115	1028	1234
1992	1019	1066	948	815	860	748	682	695	724	658	679	616	785
1993	632	634	685	621	599	580	573	571	548	545	534	541	588
1994	536	598	603	605	576	573	544	518	497	507	499	505	546
1995	484	470	494	476	468	473	423	464	459	457	451	437	467
1996	436	414	412	411	419	424	425	429	431	449	451	437	428
1997	418	400	404	413	404	405	409	394	404	424	439	424	412
1998	427	423	413	513	572	555	514	568	515	478	502	540	500
1999	602	602	589	573	589	539	513	609	691	733	751	787	629
2000	752	794	865	848	867	1073	1167	1057	992	882	1023	960	944
2001	881	774	725	995	874	832	808	904	897	959	865	833	860
2002	977	826	888	895	900	863	948	1058	963	926	1023	986	936
2003	895	892	876	909	945	1067	959	908	869	963	1281	930	954
2004	936	784	785	676	630	636	693	662	632	545	645	615	677
2005	788	642	620	589	681	610	643	676	798	596	542	540	641
2006	516	462	435	430	423	423	443	436	440	407	408	467	440
2007	391	396	376	355	351	354	357	361	352	348	353	340	361
2008	340	367	362	361	370	367	356	342	336	322	302	309	334
2009	302	285	276	267	267	270	269	274	270	260	258	255	271
2010	271	316	347	376	361	371	377	388	388	374	389	412	364
2011	398	414	426	496	453	551	518	509	513	534	488	438	478
2012	490	533	634	506	494	546	464	643	583	587	571	544	565
2013	533	530	564	559	674	679	665	640	614	571	590	625	603
2014	606	481	452	633	660	656	628	590	634	632	645	731	645

212 MV

1234 MV

http://cosmicrays oulu.fi/phi/Phi_mon.txt

$$\phi_F^{\bar{p}} = \phi_F^p \pm 50\%$$

How does DM produce γ -rays?

1. prompt emission

1a. continuum

1b. line(s)

1c. sharp features

2. secondary emission

2a. ICS

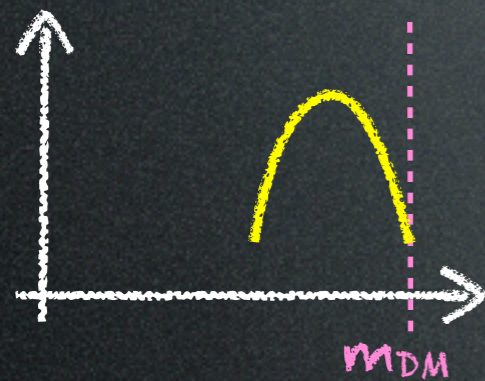
2b. bremsstrahlung

2c. synchrotron

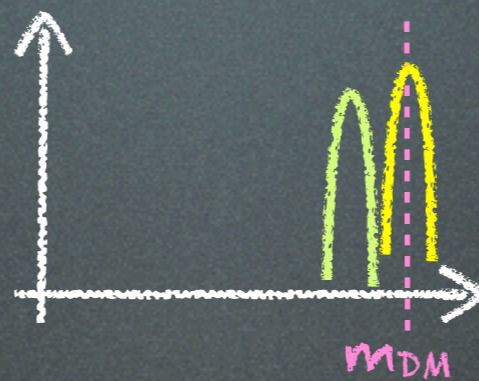
How does DM produce γ -rays?

1. prompt emission

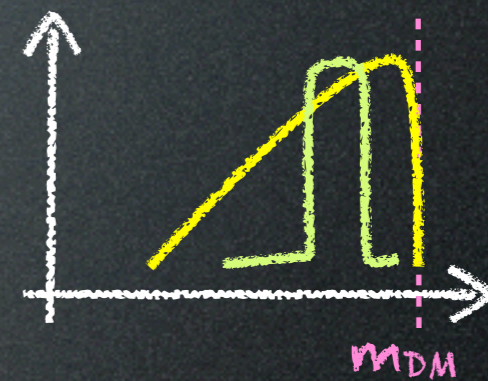
1a. continuum



1b. line(s)

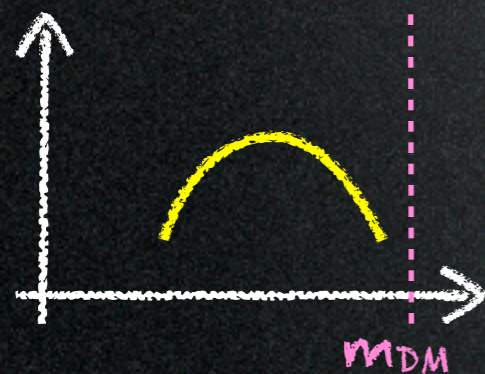


1c. sharp features

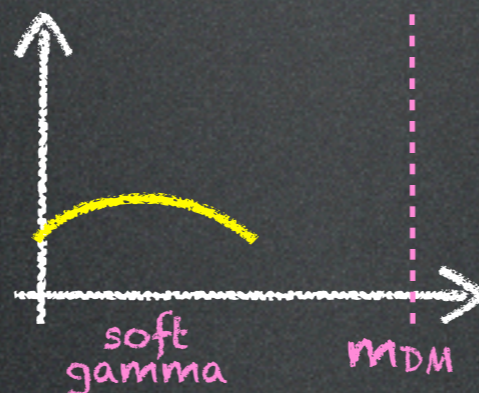


2. secondary emission

2a. ICS



2b. bremsstrahlung



2c. synchrotron

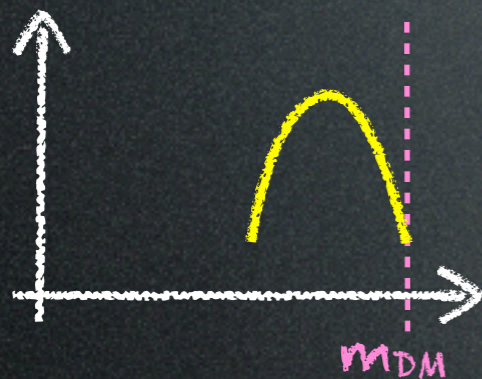


How does DM produce γ -rays?

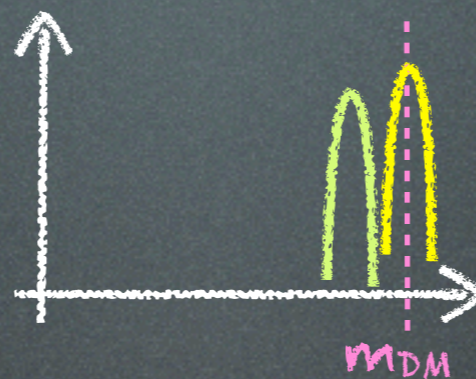
1. prompt emission

environment-independent

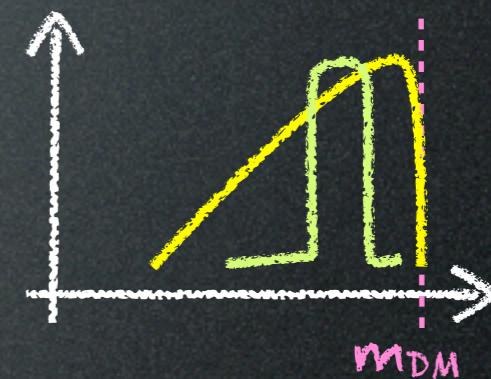
1a. continuum



1b. line(s)



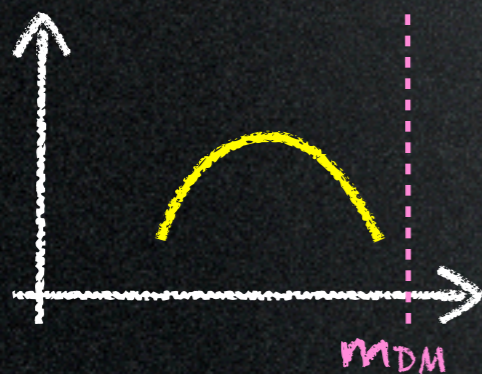
1c. sharp features



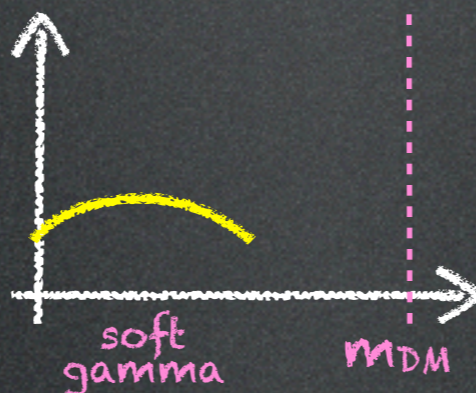
2. secondary emission

environment-dependent

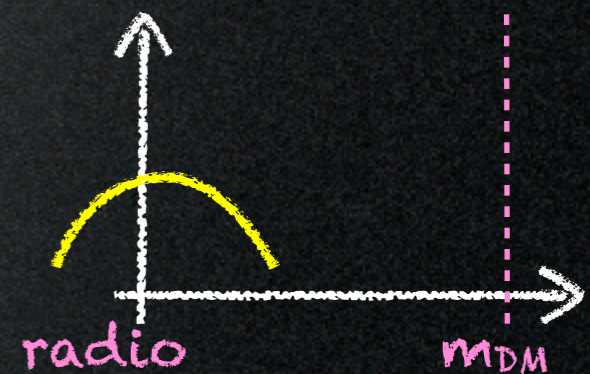
2a. ICS



2b. bremsstrahlung

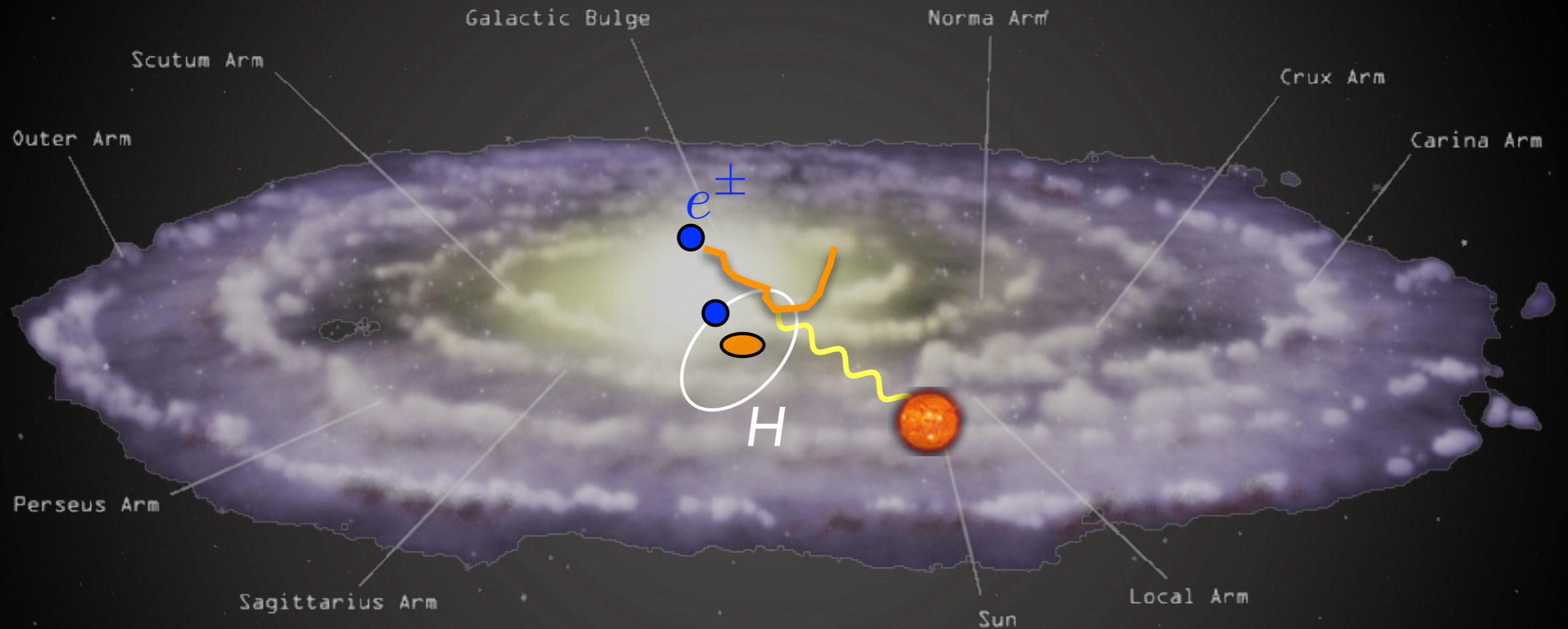


2c. synchrotron



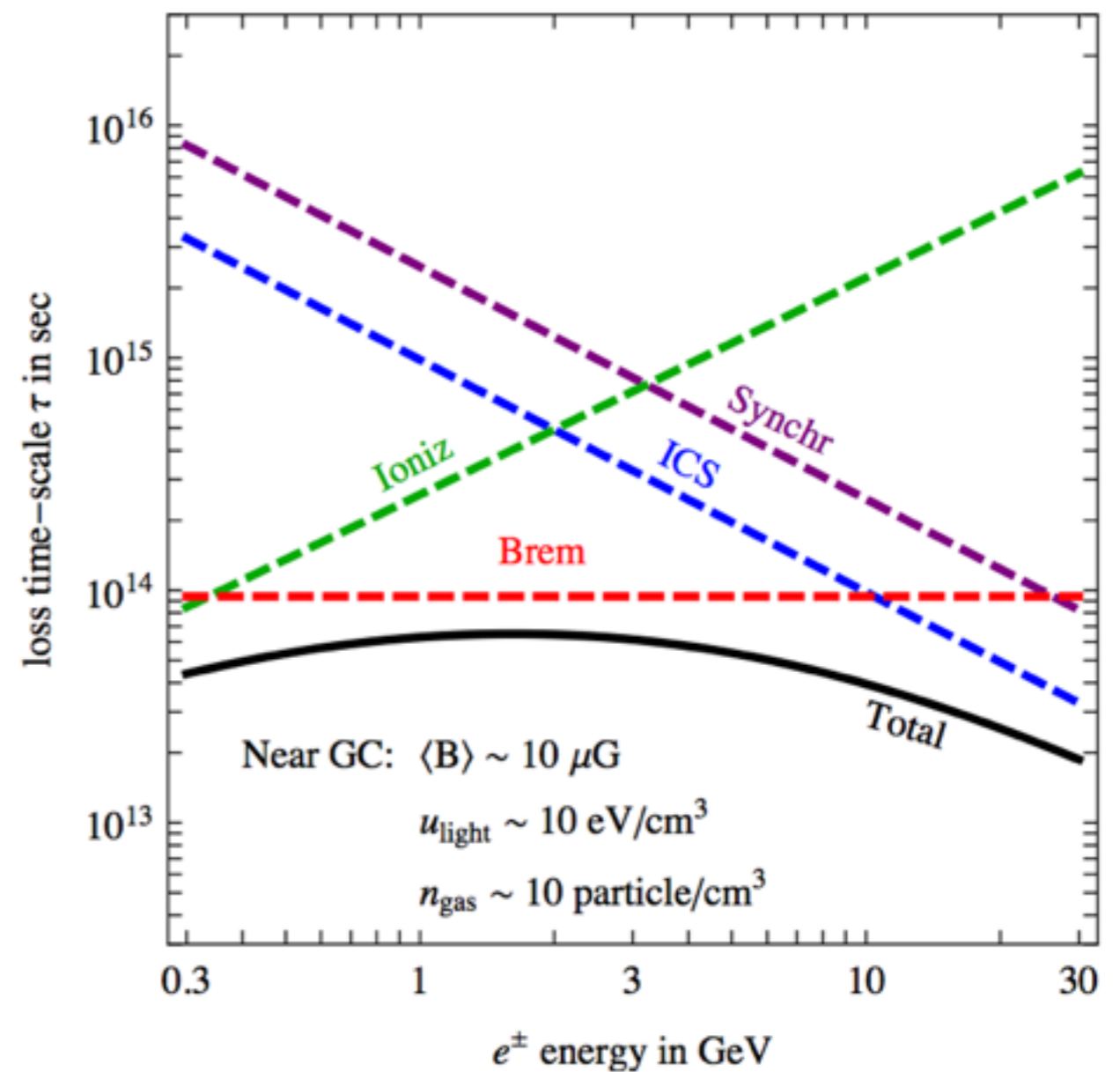
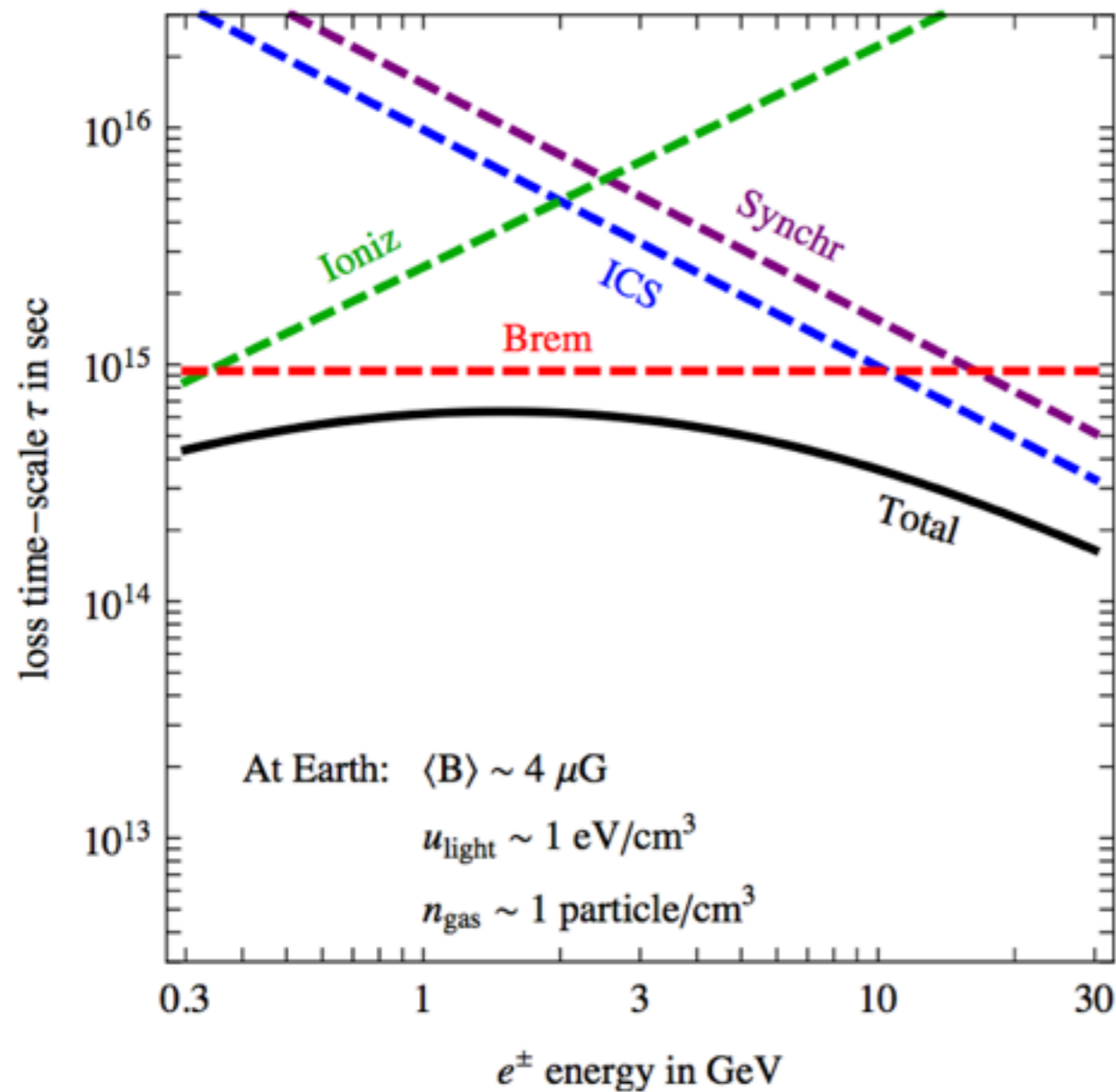
Secondary emission

b. soft gammas from bremsstrahlung of e^\pm on ISM



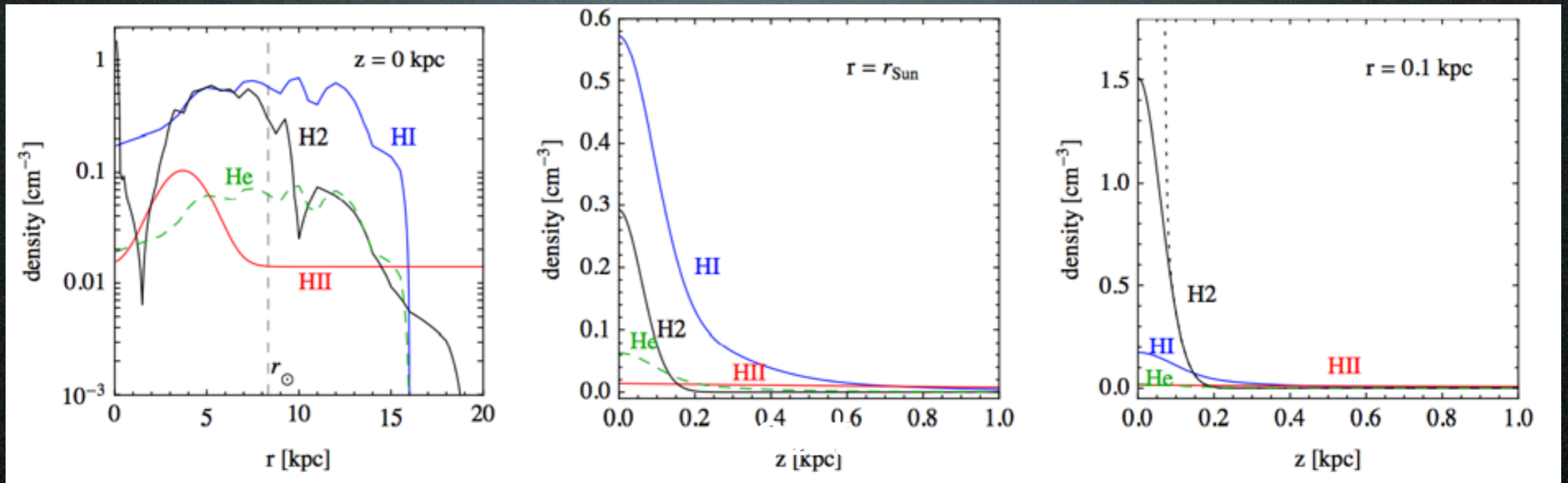
- (very) relevant at low energy, in the disk and at the GC

Relative importance of secondary emissions



\Rightarrow brem is the **dominant** energy loss for low energy e^\pm !

Gas maps



But: inner kpc of the Galaxy is denser
(and more uncertain)

SNB

Stellar Nuclear Bulge

< 1 kpc

?

CMZ

Central Molecular Zone

< 200 pc

$10^2 - 10^3 / \text{cm}^3$

CNR

Circum-Nuclear Ring

< 3 pc

$10^5 / \text{cm}^3$

Formalism

Bremsstrahlung gamma emission:

$$\frac{d\mathcal{E}_{\gamma,\text{brem}}(\vec{x})}{dE_{\gamma}} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^{\pm}} 2 \frac{d\Phi_{e^{\pm}}(\vec{x})}{dE_{e^{\pm}}} \cdot \frac{d\sigma_i}{dE_{\gamma}}$$

Formalism

Bremsstrahlung gamma emission:

$$\frac{d\mathcal{E}_{\gamma,\text{brem}}(\vec{x})}{dE_{\gamma}} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^{\pm}} 2 \frac{d\Phi_{e^{\pm}}(\vec{x})}{dE_{e^{\pm}}} \cdot \frac{d\sigma_i}{dE_{\gamma}}$$

bremsstrahlung differential cross section

$$\frac{d\sigma_i(E_{e^{\pm}}, E_{\gamma})}{dE_{\gamma}} = \frac{3 \alpha_{\text{em}} \sigma_T}{8\pi E_{\gamma}} \left\{ \left[1 + \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right)^2 \right] \phi_1^i - \frac{2}{3} \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right) \phi_2^i \right\}$$

Formalism

Bremsstrahlung gamma emission:

$$\frac{d\mathcal{E}_{\gamma,\text{brem}}(\vec{x})}{dE_{\gamma}} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^{\pm}} 2 \frac{d\Phi_{e^{\pm}}(\vec{x})}{dE_{e^{\pm}}} \cdot \frac{d\sigma_i}{dE_{\gamma}}$$

e^{\pm} population

bremsstrahlung differential cross section

$$\frac{d\sigma_i(E_{e^{\pm}}, E_{\gamma})}{dE_{\gamma}} = \frac{3 \alpha_{\text{em}} \sigma_T}{8\pi E_{\gamma}} \left\{ \left[1 + \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right)^2 \right] \phi_1^i - \frac{2}{3} \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right) \phi_2^i \right\}$$

Formalism

Bremsstrahlung gamma emission:

$$\frac{d\mathcal{E}_{\gamma,\text{brem}}(\vec{x})}{dE_{\gamma}} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^{\pm}} 2 \frac{d\Phi_{e^{\pm}}(\vec{x})}{dE_{e^{\pm}}} \cdot \frac{d\sigma_i}{dE_{\gamma}}$$

gas density

e^{\pm} population

bremsstrahlung differential cross section

$$\frac{d\sigma_i(E_{e^{\pm}}, E_{\gamma})}{dE_{\gamma}} = \frac{3 \alpha_{\text{em}} \sigma_T}{8\pi E_{\gamma}} \left\{ \left[1 + \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right)^2 \right] \phi_1^i - \frac{2}{3} \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right) \phi_2^i \right\}$$

Formalism

Bremsstrahlung gamma emission:

$$\frac{d\mathcal{E}_{\gamma,\text{brem}}(\vec{x})}{dE_{\gamma}} = \sum_i n_i(\vec{x}) \int_{E_L} dE_{e^{\pm}} 2 \frac{d\Phi_{e^{\pm}}(\vec{x})}{dE_{e^{\pm}}} \cdot \frac{d\sigma_i}{dE_{\gamma}}$$

gas density

e^{\pm} population

bremsstrahlung differential cross section

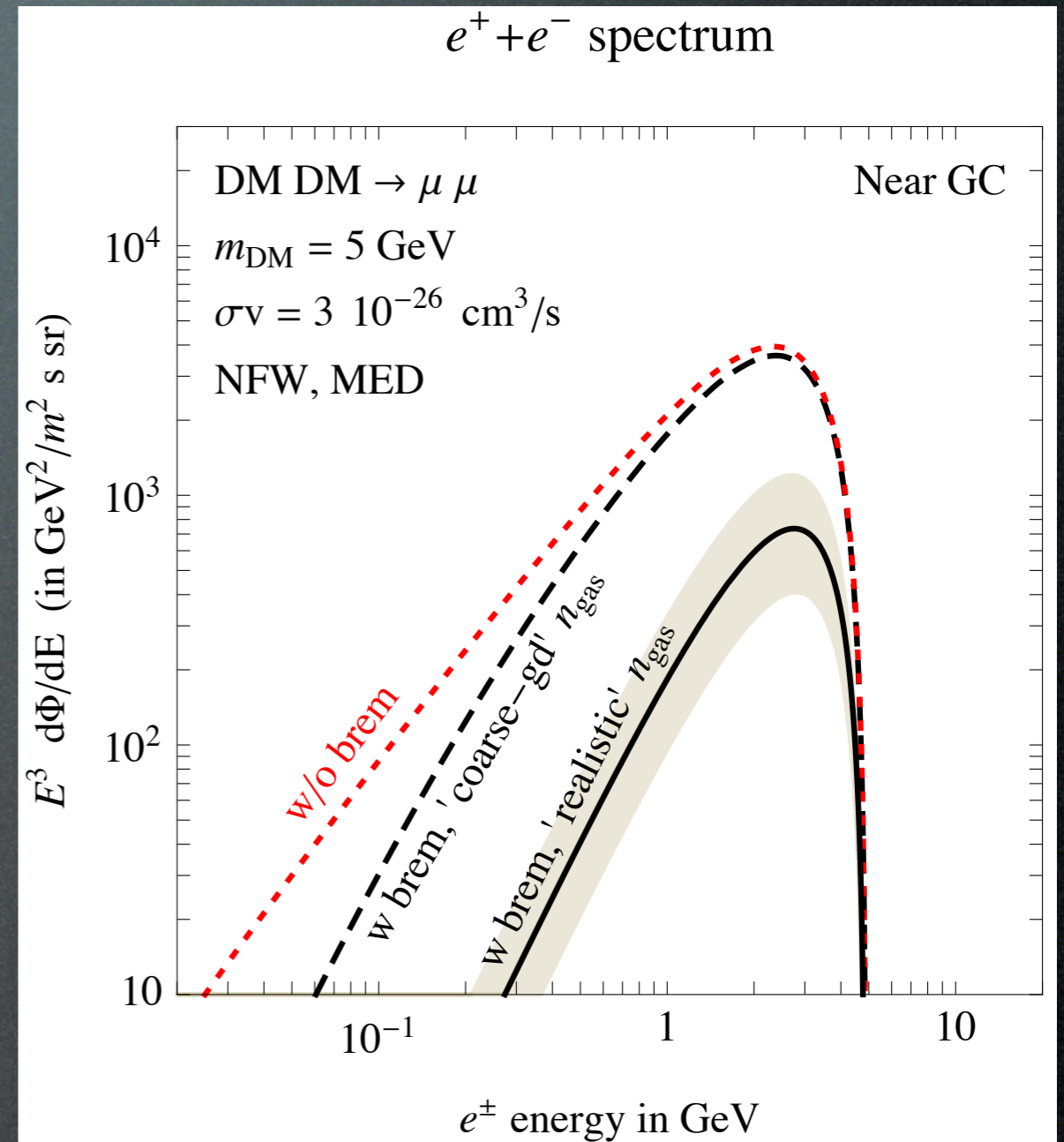
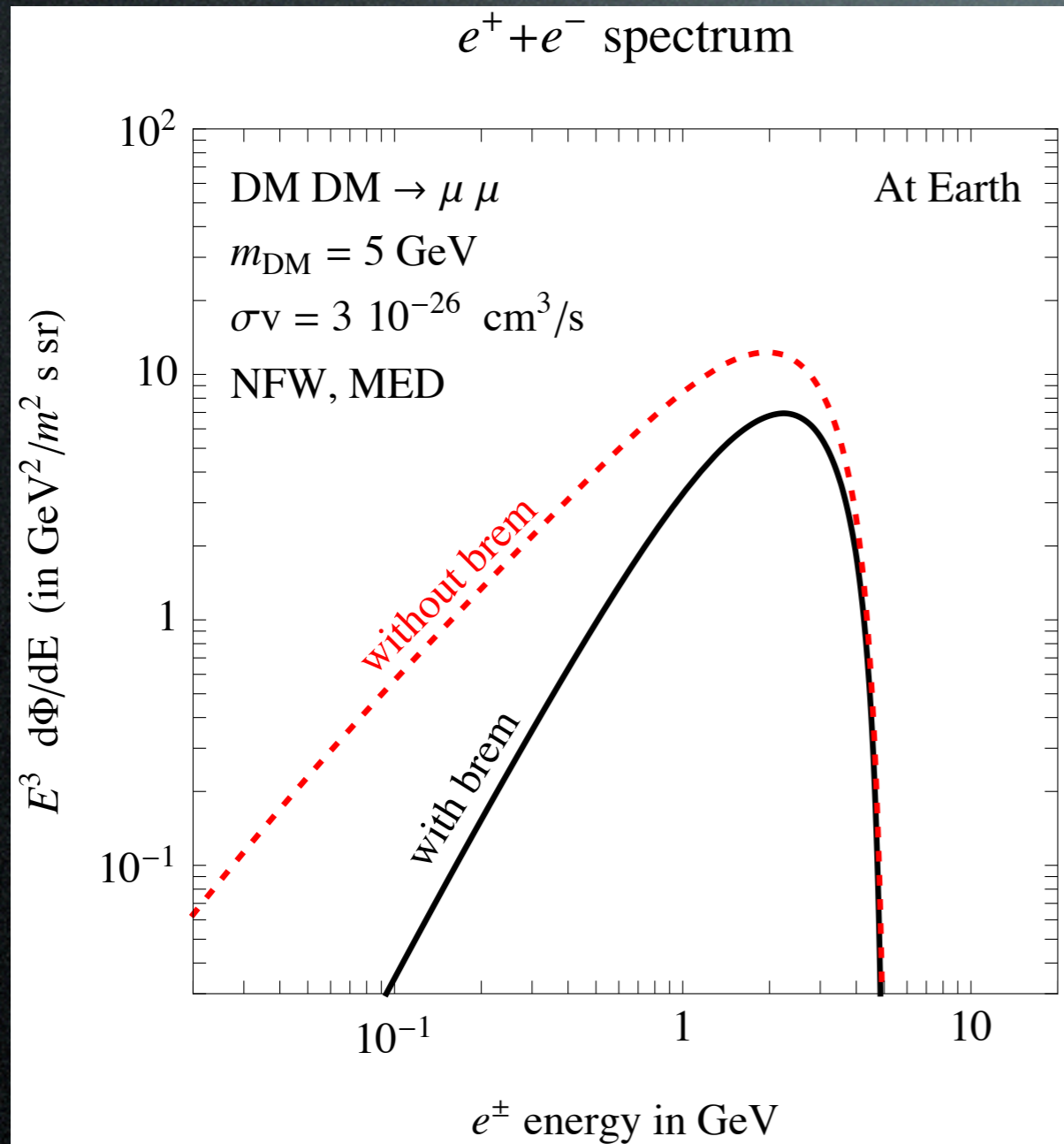
$$\frac{d\sigma_i(E_{e^{\pm}}, E_{\gamma})}{dE_{\gamma}} = \frac{3 \alpha_{\text{em}} \sigma_T}{8\pi E_{\gamma}} \left\{ \left[1 + \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right)^2 \right] \phi_1^i - \frac{2}{3} \left(1 - \frac{E_{\gamma}}{E_{e^{\pm}}} \right) \phi_2^i \right\}$$

$$\phi_1^{\text{ion}}(E_{e^{\pm}}, E_{\gamma}) = \phi_2^{\text{ion}}(E_{e^{\pm}}, E_{\gamma}) = 4(Z^2 + Z) \left\{ \log \left[\frac{2E_{e^{\pm}}}{m c^2} \left(\frac{E_{e^{\pm}} - E_{\gamma}}{E_{\gamma}} \right) \right] - \frac{1}{2} \right\}$$

$$\begin{aligned} \phi_1^{\text{H}}(\Delta = 0) &\equiv \phi_{1,\text{ss}}^{\text{H}} = 45.79, \\ \phi_2^{\text{H}}(\Delta = 0) &\equiv \phi_{2,\text{ss}}^{\text{H}} = 44.46, \\ \phi_1^{\text{He}}(\Delta = 0) &\equiv \phi_{1,\text{ss}}^{\text{He}} = 134.60, \\ \phi_2^{\text{He}}(\Delta = 0) &\equiv \phi_{2,\text{ss}}^{\text{He}} = 131.40, \\ \phi_{(1,2)}^{\text{H}_2}(\Delta = 0) &\simeq 2 \phi_{(1,2),\text{ss}}^{\text{H}} \end{aligned}$$

Results

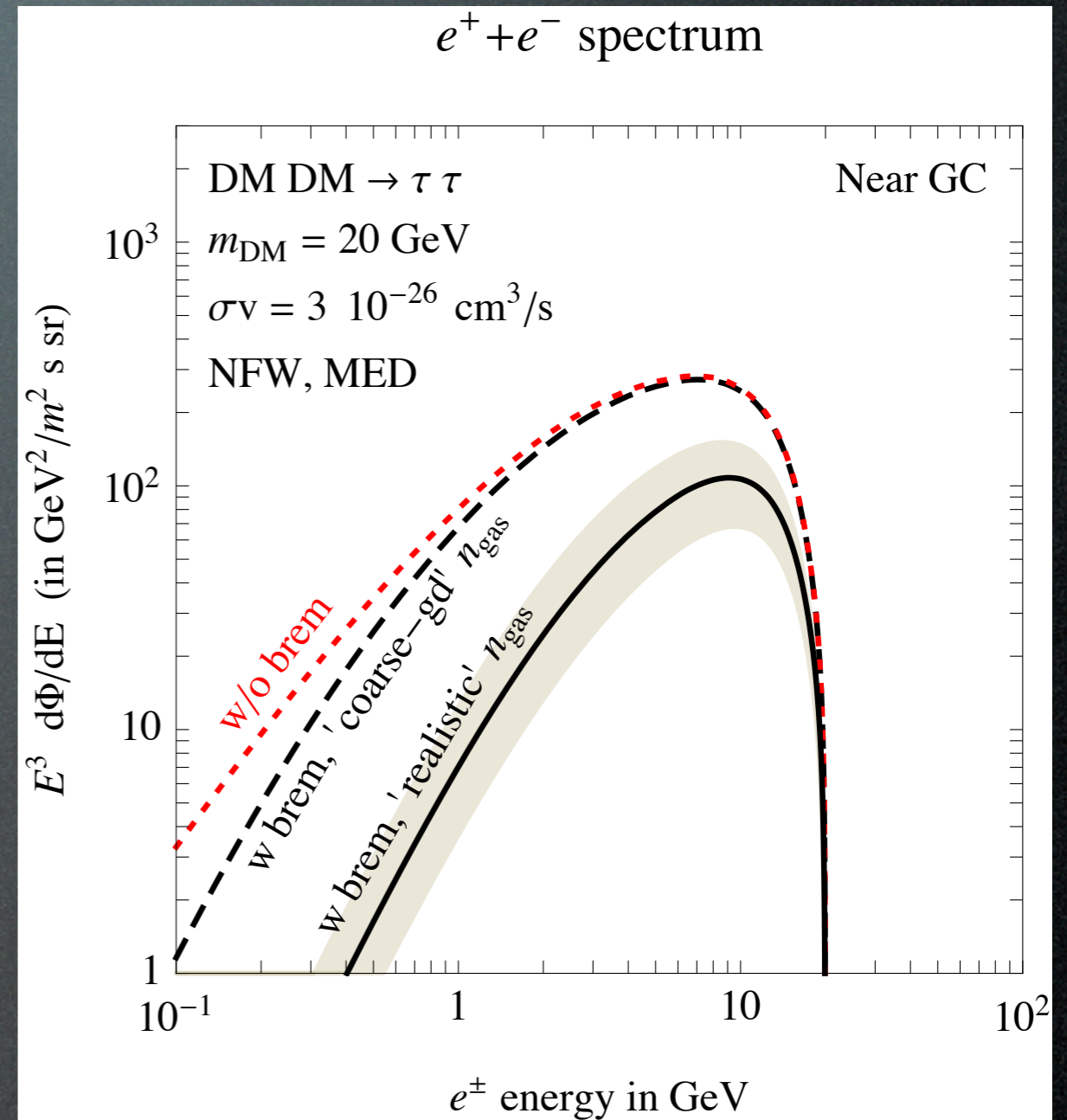
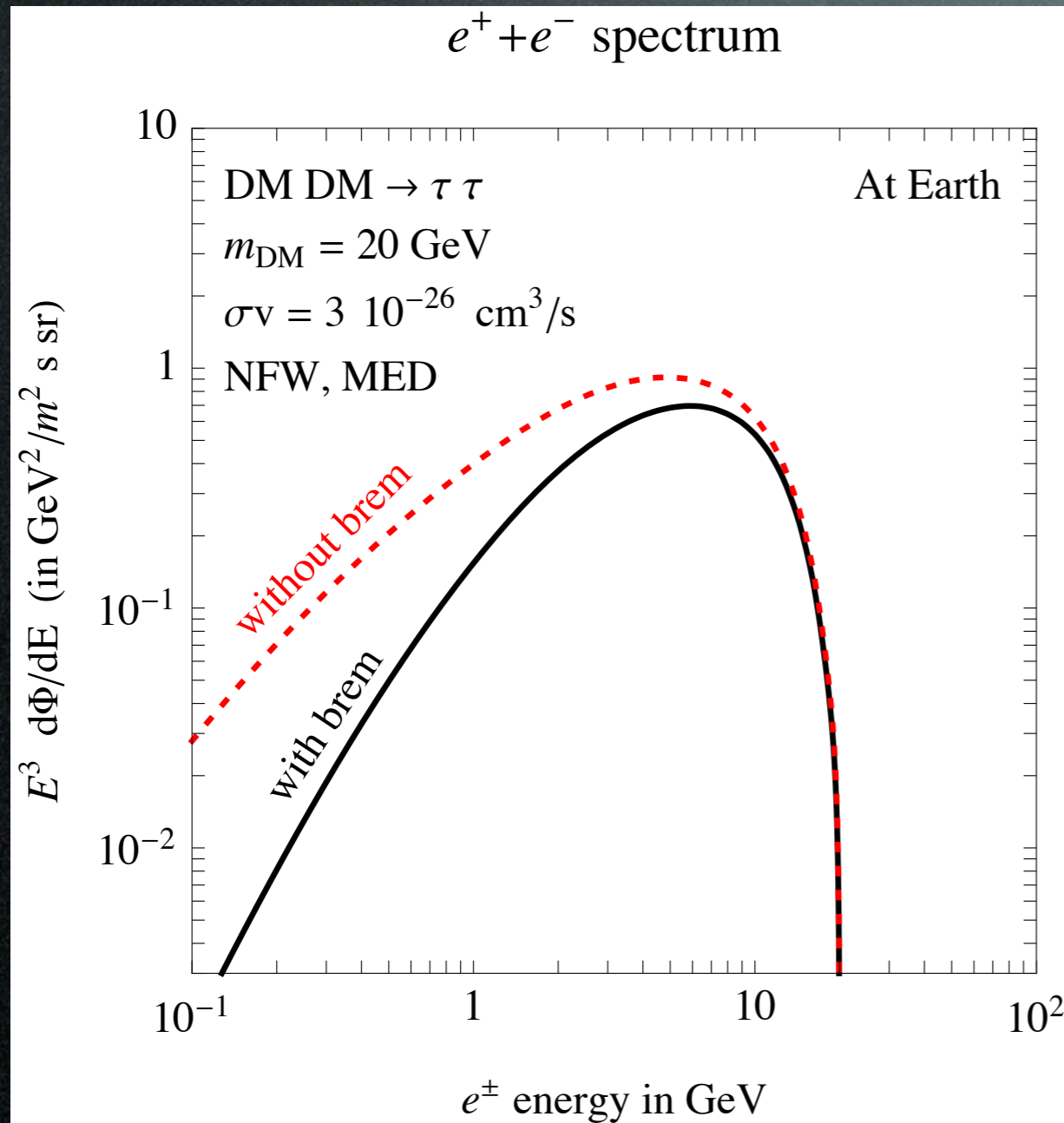
The e^\pm population is affected by bremsstrahlung

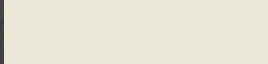


 = factor 2 uncertainty in n_{gas}

Results

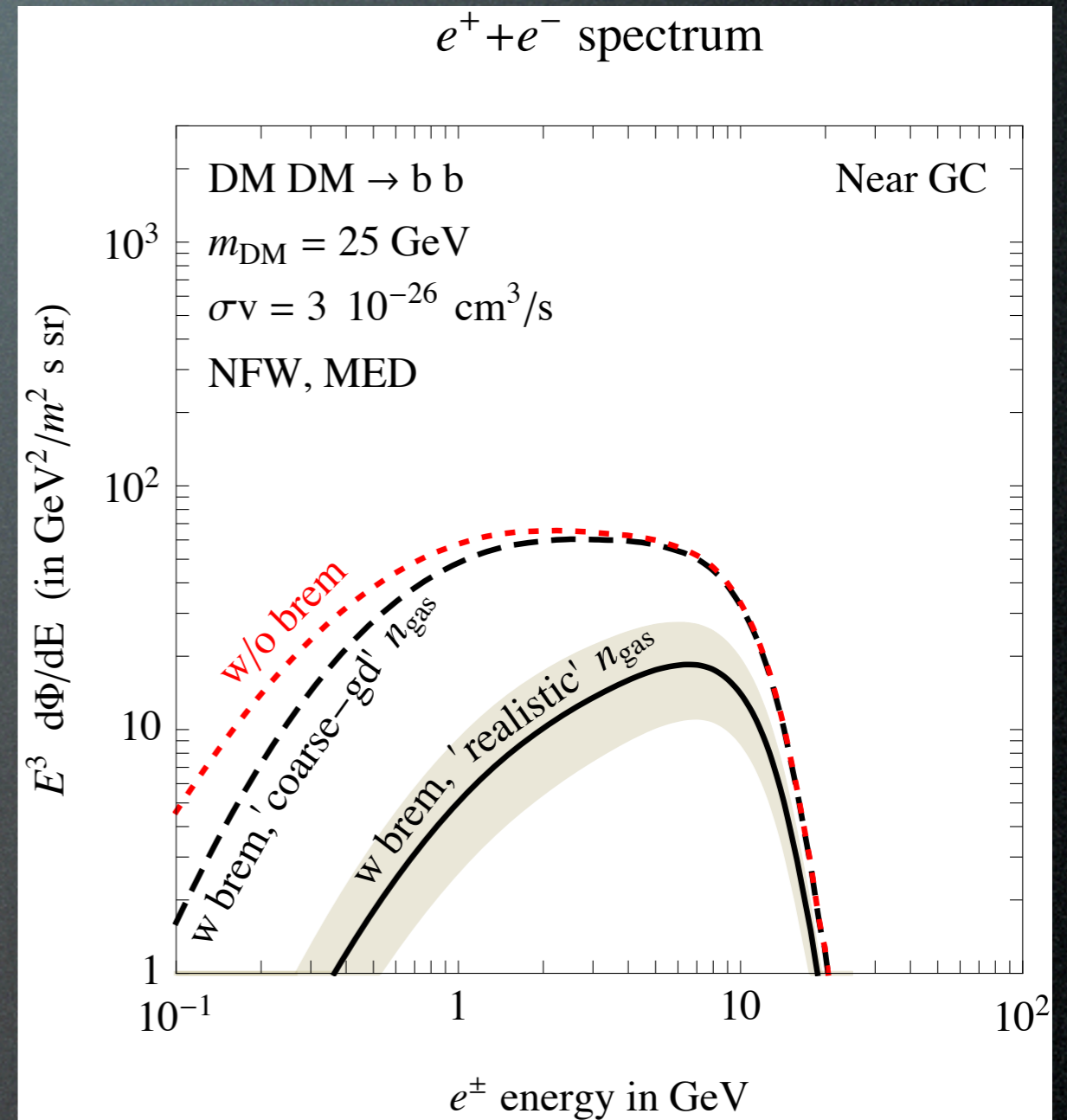
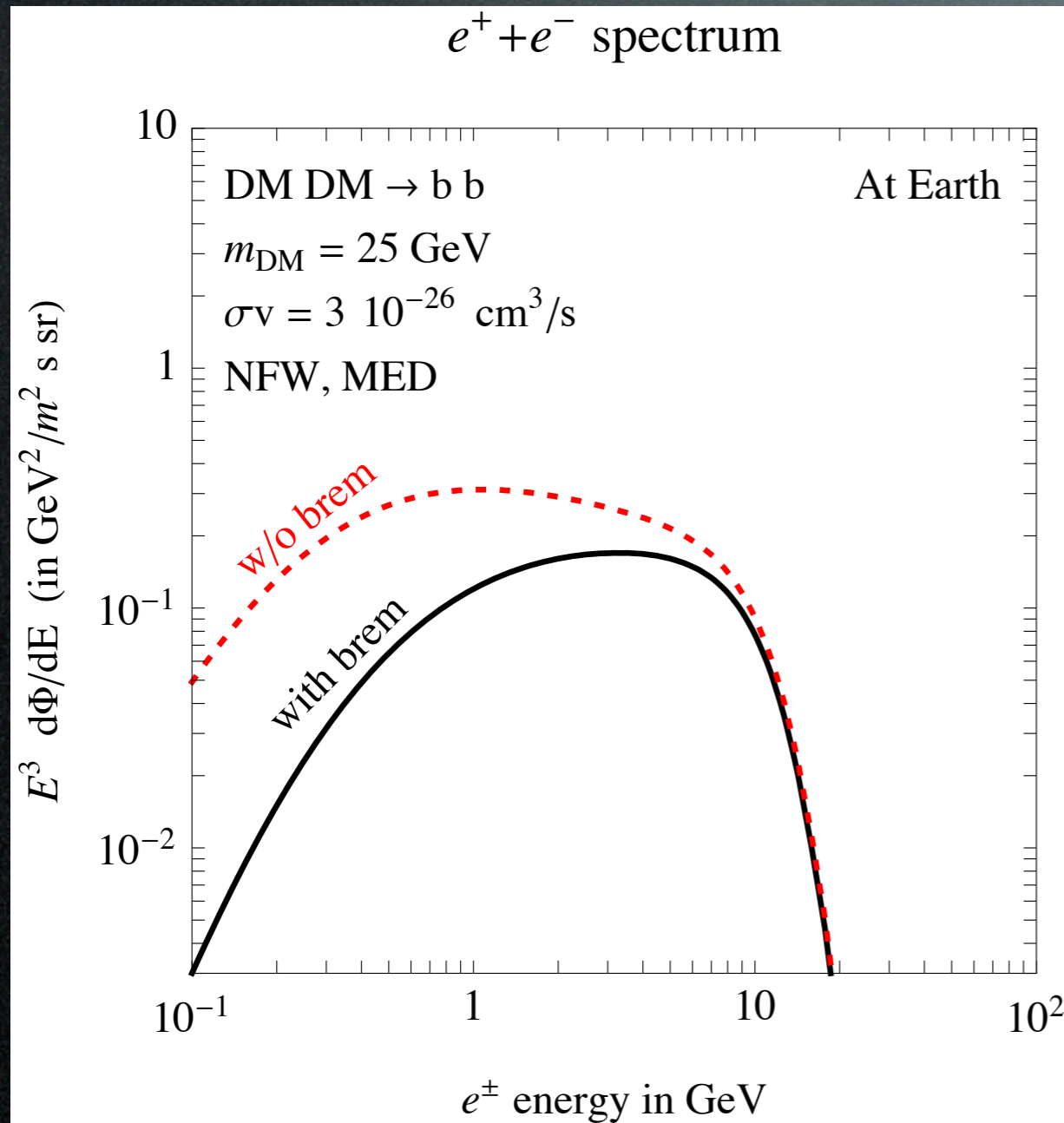
The e^\pm population is affected by bremsstrahlung



 = factor 2 uncertainty in n_{gas}

Results

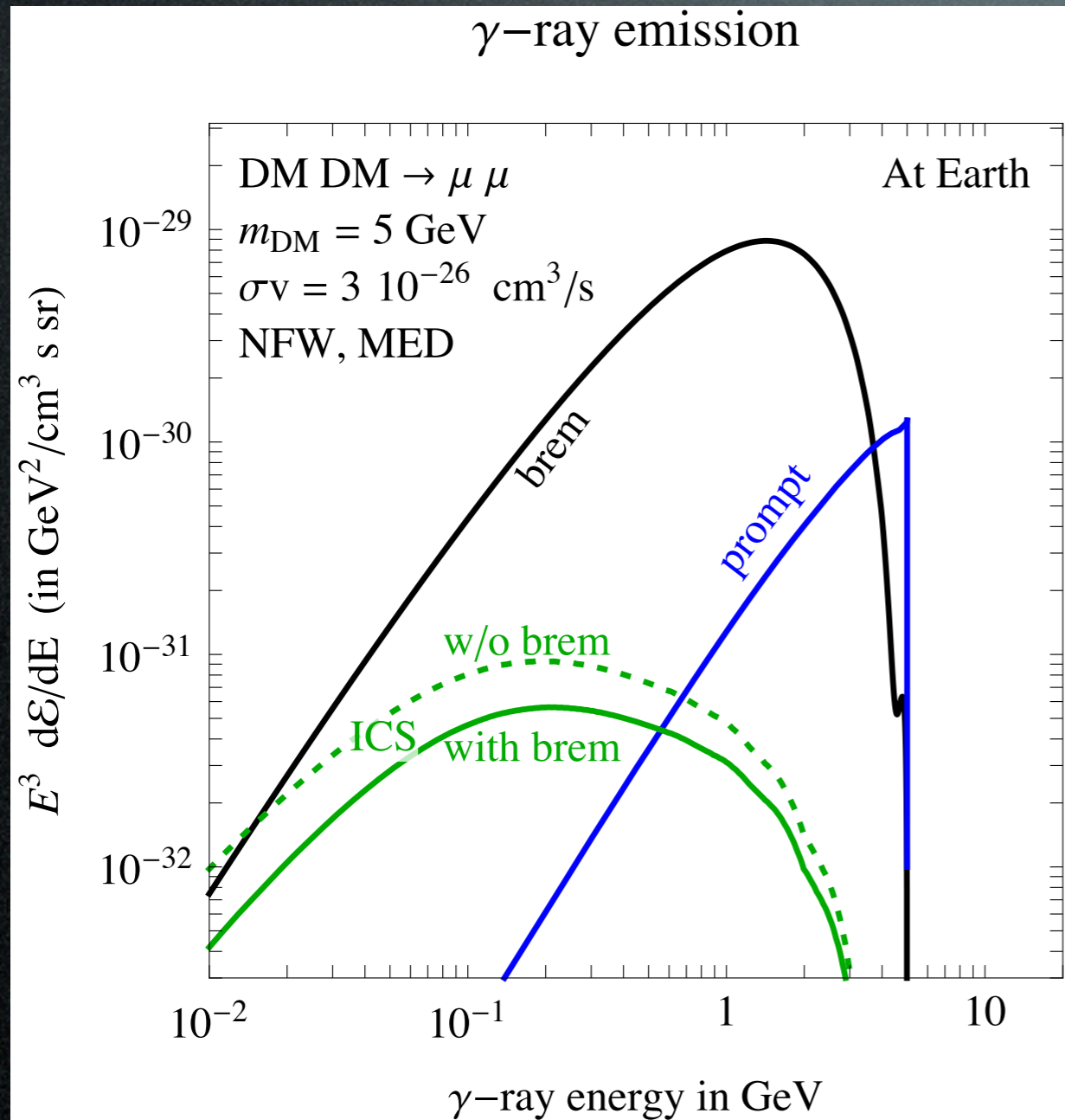
The e^\pm population is affected by bremsstrahlung



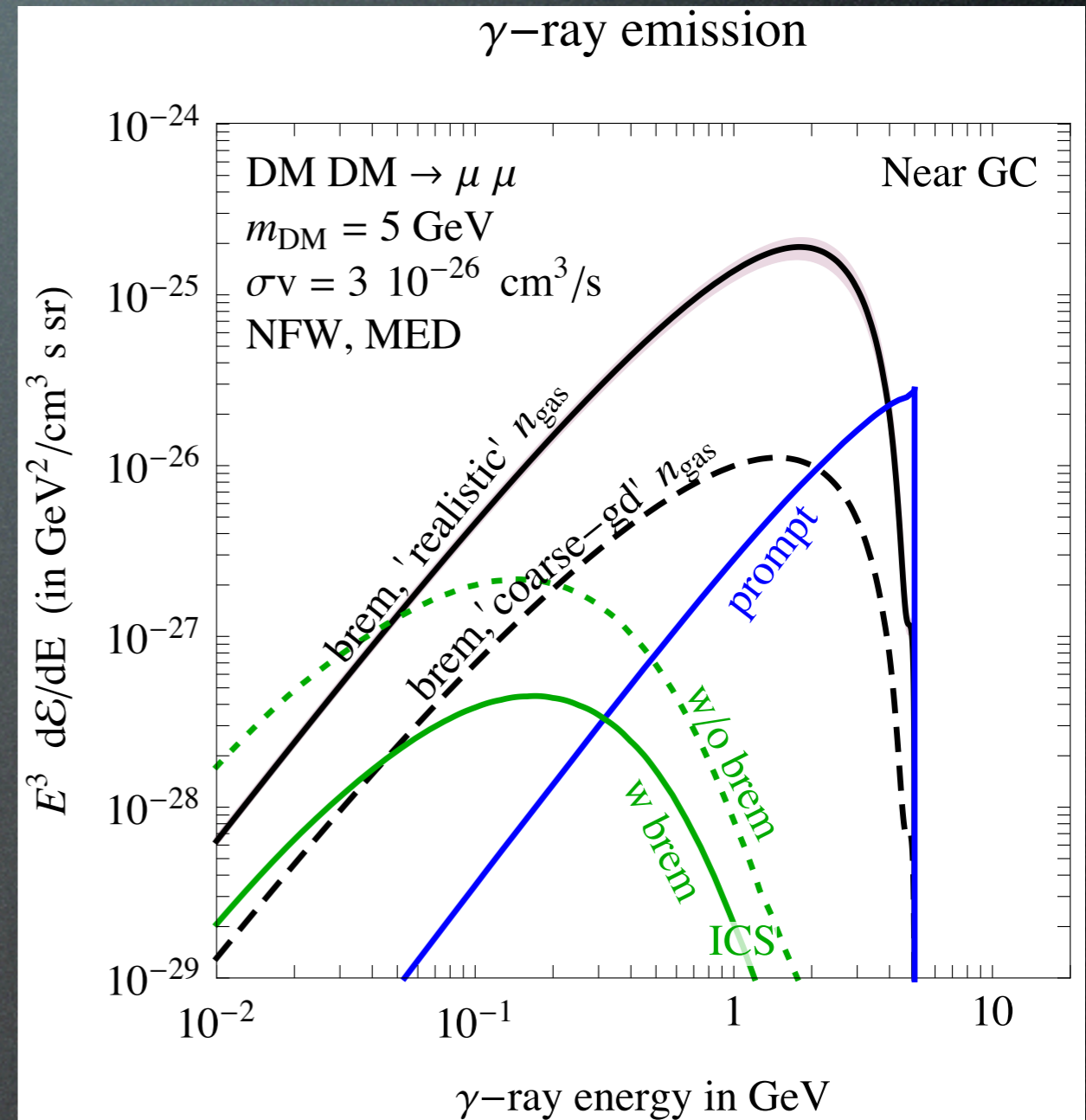
 = factor 2 uncertainty in n_{gas}

Results

The total γ ray spectrum



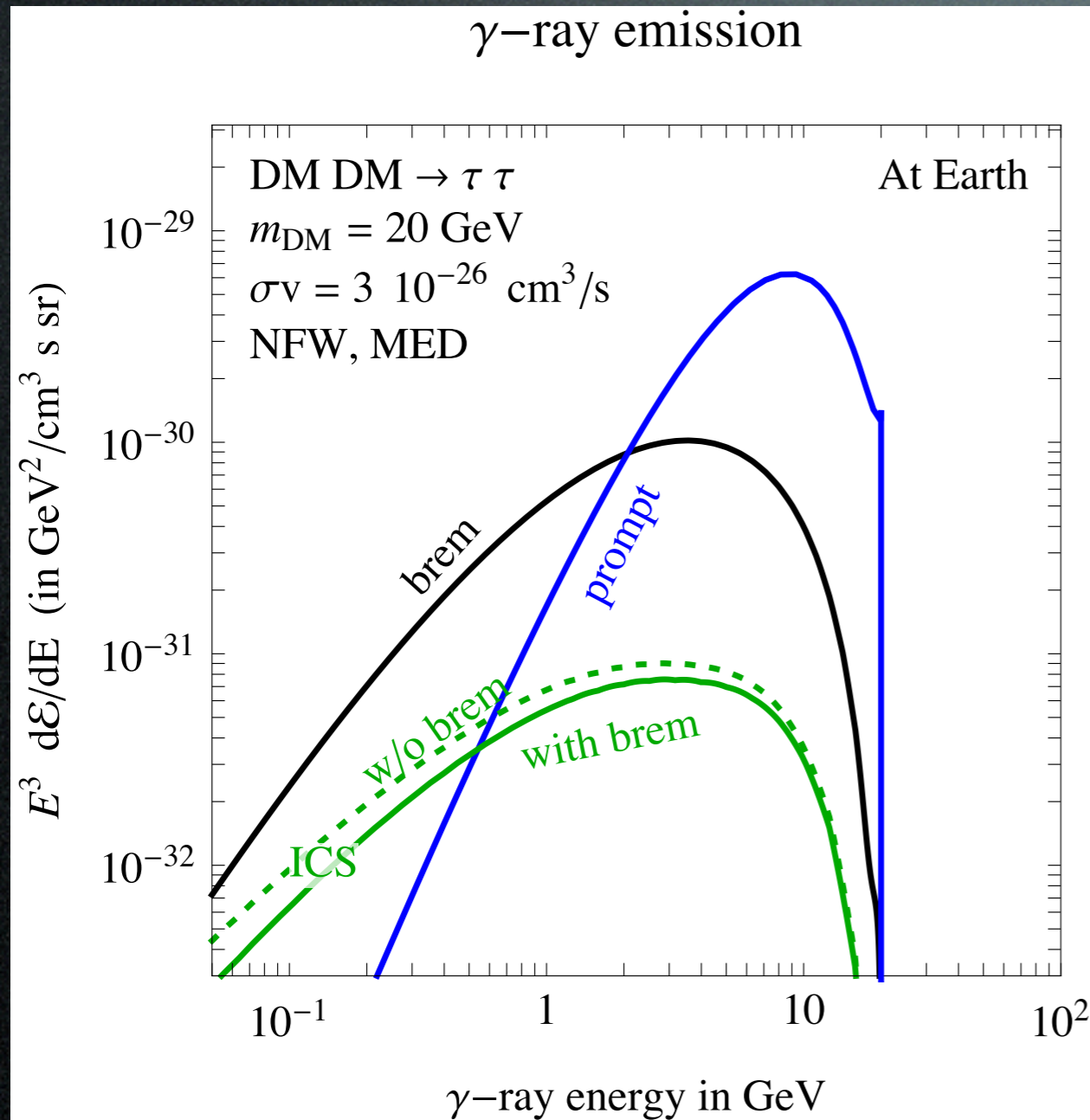
- brem is dominant
- ICS is affected



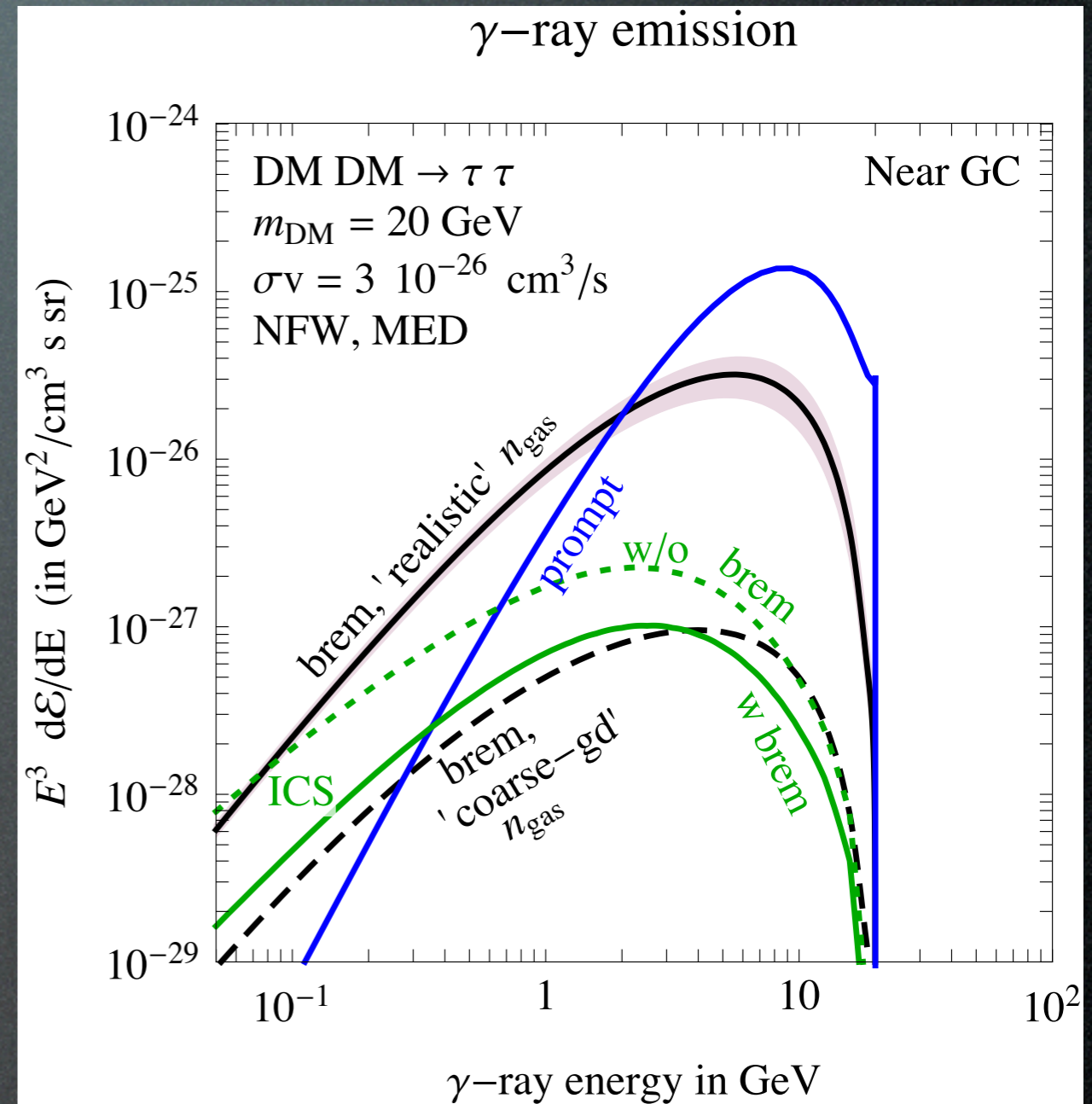
- uncertainty is somewhat reabsorbed:
- large $n_{\text{gas}} \Rightarrow$ more loss **and** more emission

Results

The total γ ray spectrum



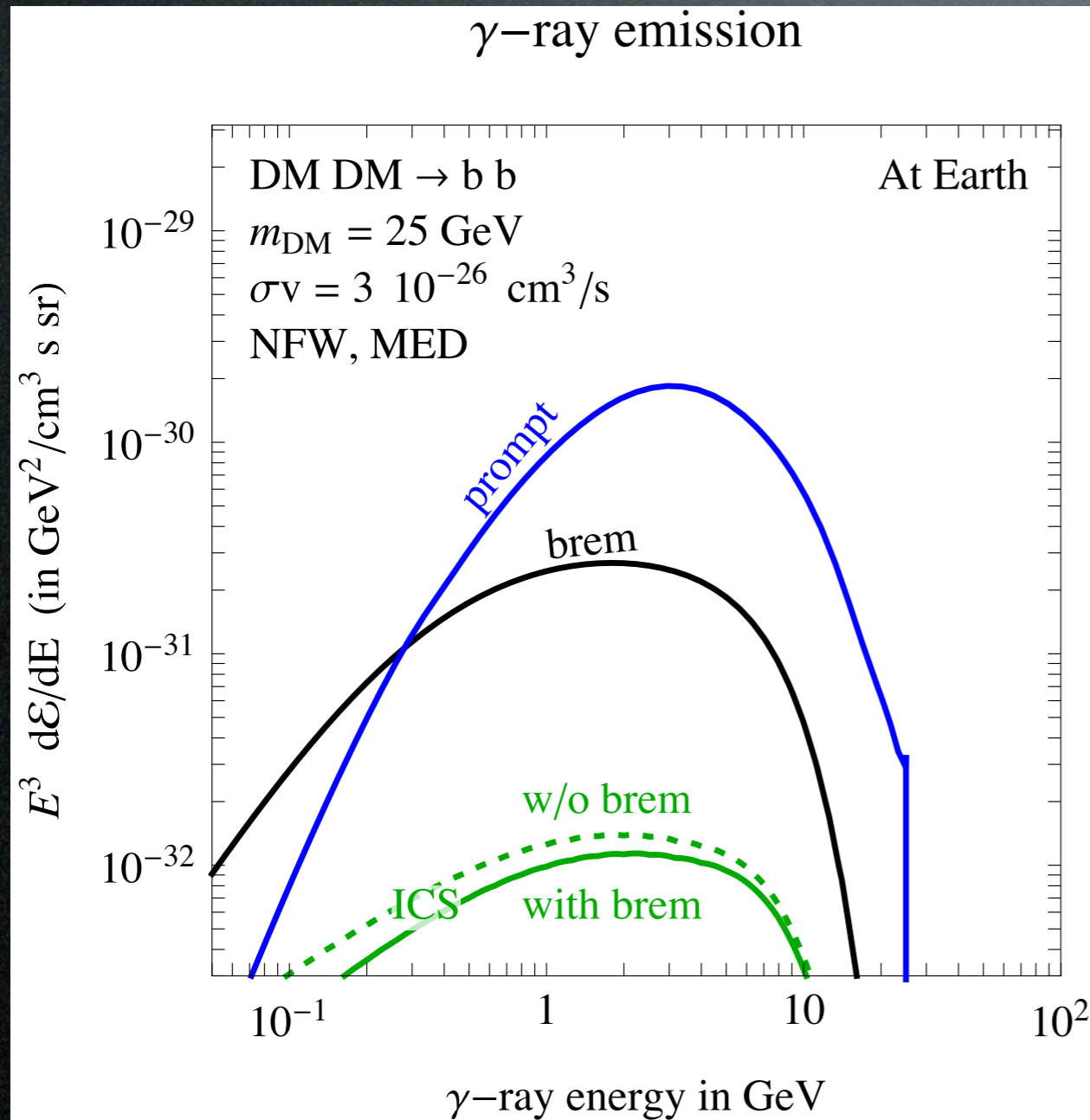
- brem is important
- ICS is affected



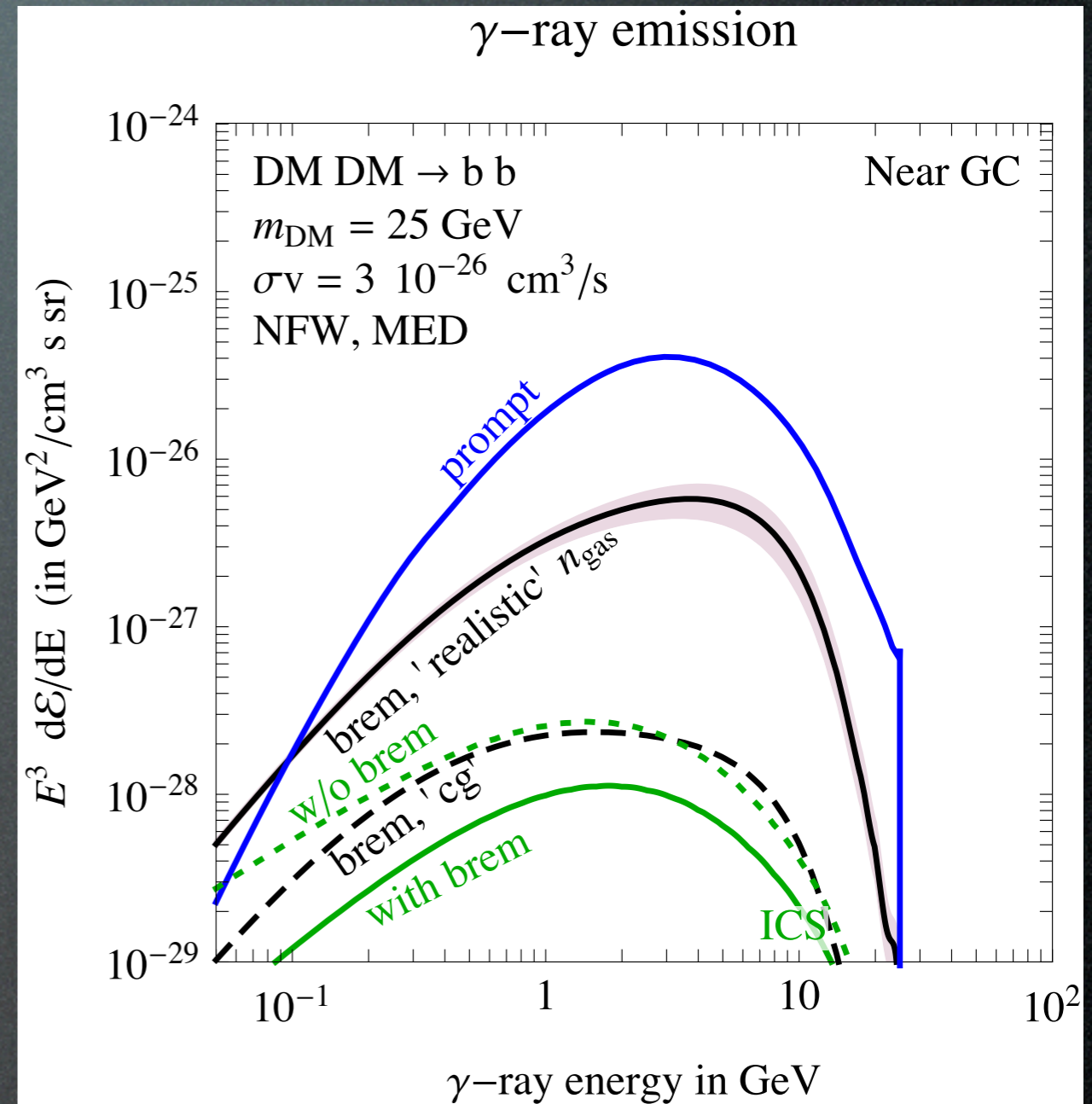
- uncertainty is somewhat reabsorbed:
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Results

The total γ ray spectrum



- brem is important
- ICS is affected



- uncertainty is somewhat reabsorbed:
- large $n_{\text{gas}} \Rightarrow$ more loss **and** more emission

GC GeV excess

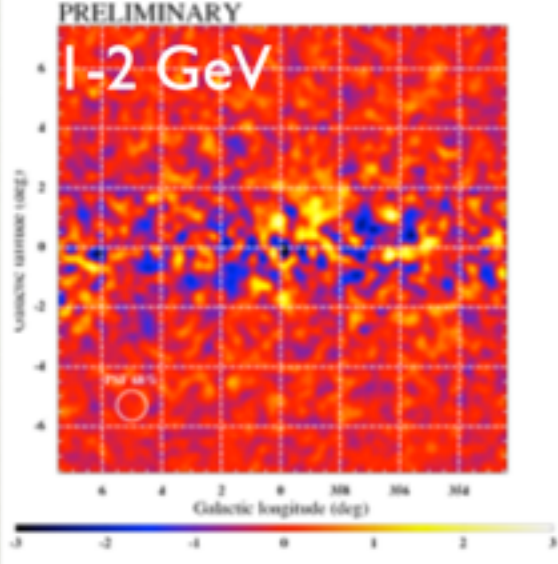
Dark Matter interpretation:

ADDITIONAL TEMPLATES

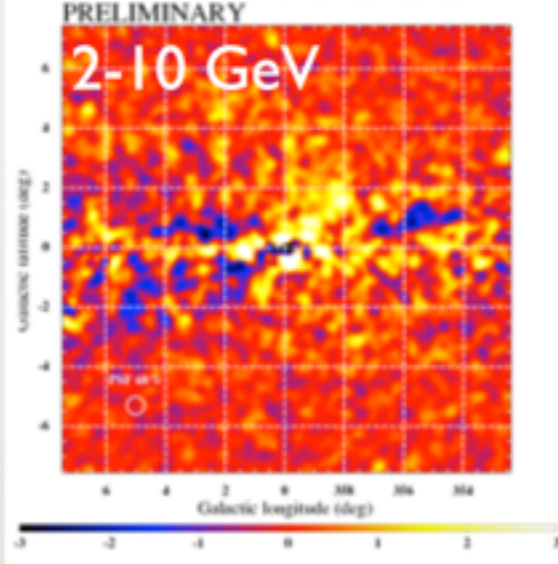
Counts in $0.1^\circ \times 0.1^\circ$ pixels
 0.3° radius gaussian smoothing

Pulsars, tuned-index

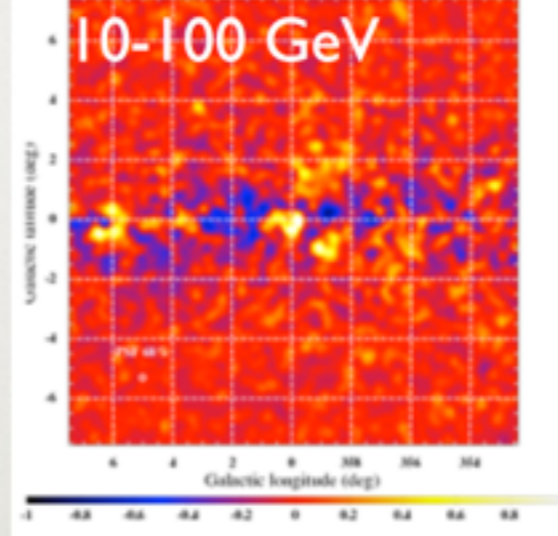
Without NFW:



DATA-MODEL

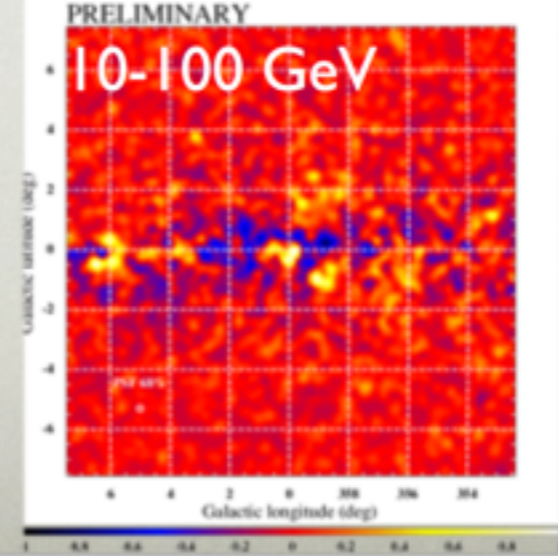
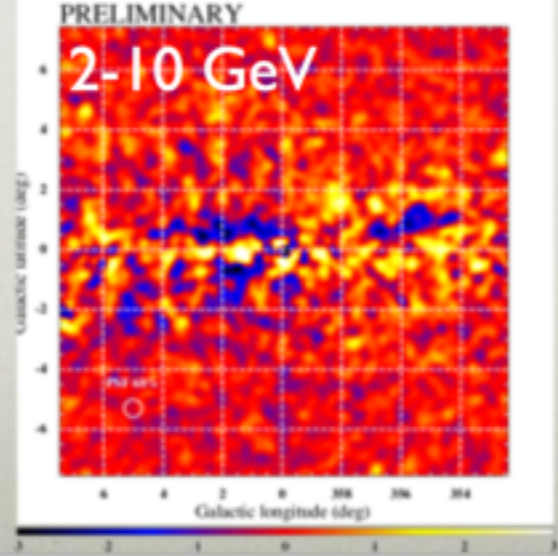
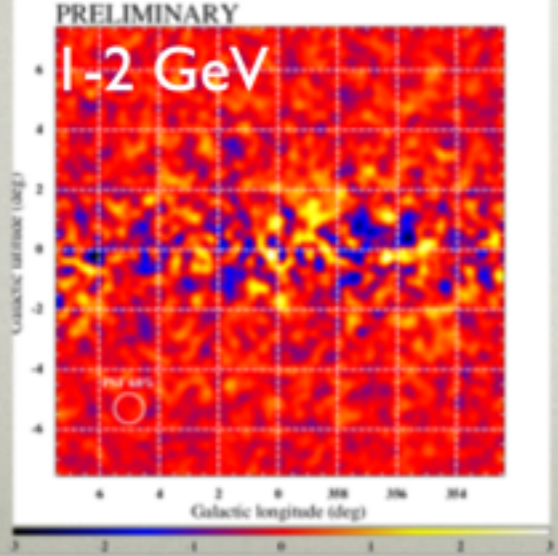


PRELIMINARY



Pulsars, tuned-index

With NFW:



S. Murgia + T. Porter for FERMI-LAT - ICRC 2015
FERMI-LAT Coll., 1511.02938

GC GeV excess

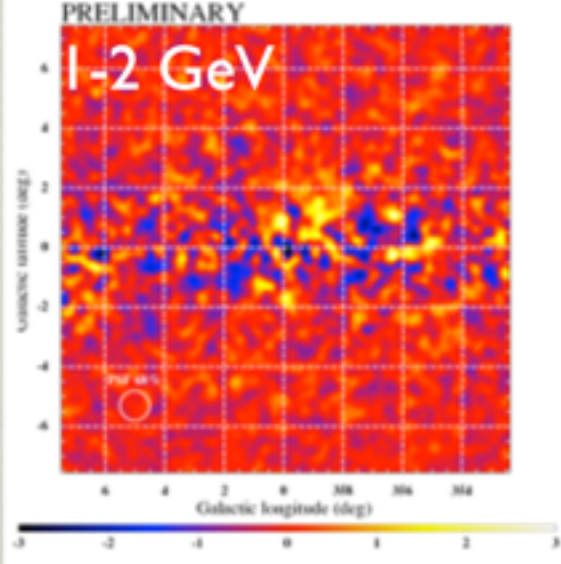
Dark Matter interpretation:

ADDITIONAL TEMPLATES

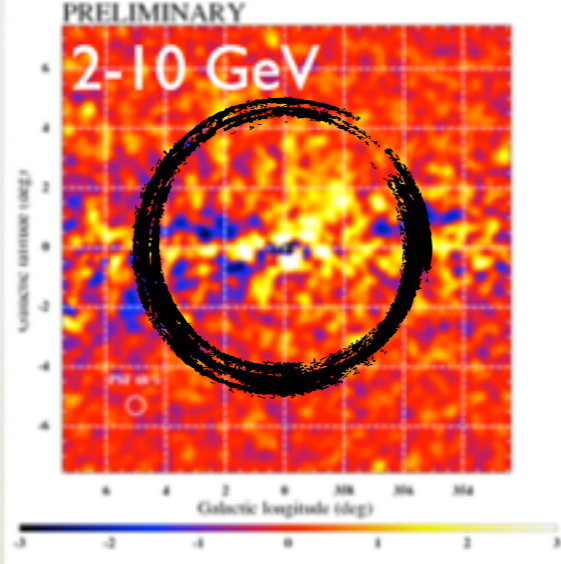
Counts in $0.1^\circ \times 0.1^\circ$ pixels
 0.3° radius gaussian smoothing

Pulsars, tuned-index

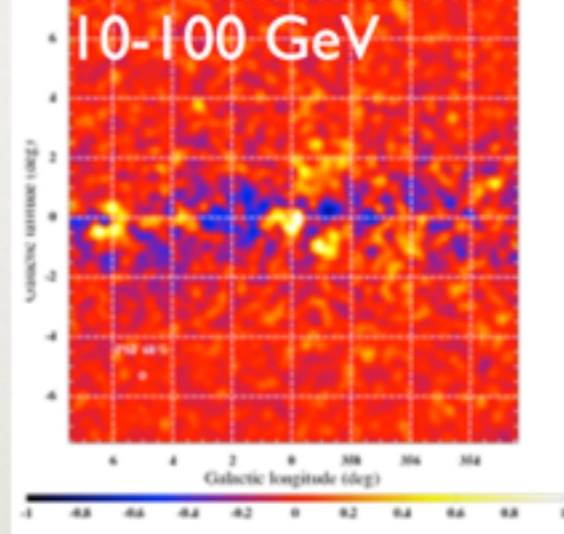
Without NFW:



DATA-MODEL

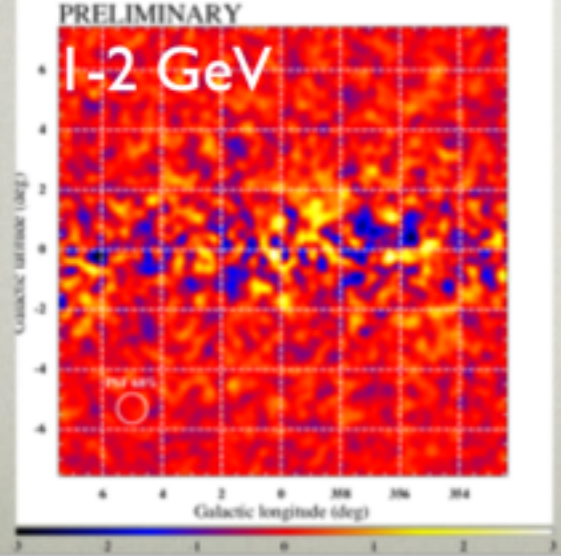


PRELIMINARY

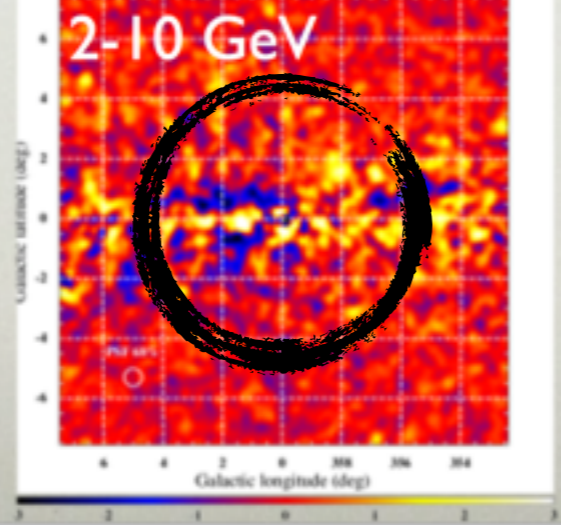


Pulsars, tuned-index

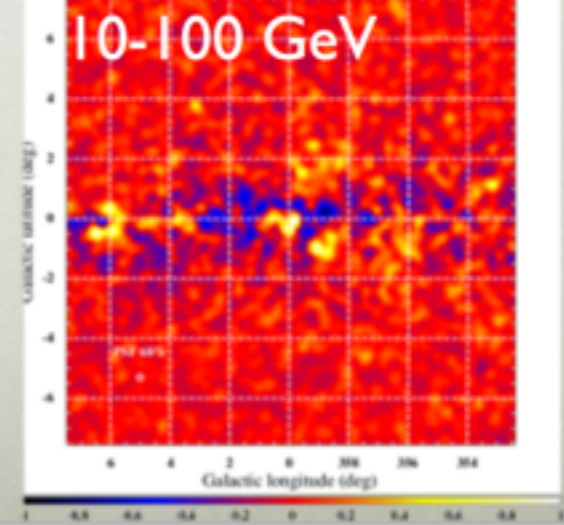
With NFW:



PRELIMINARY



PRELIMINARY



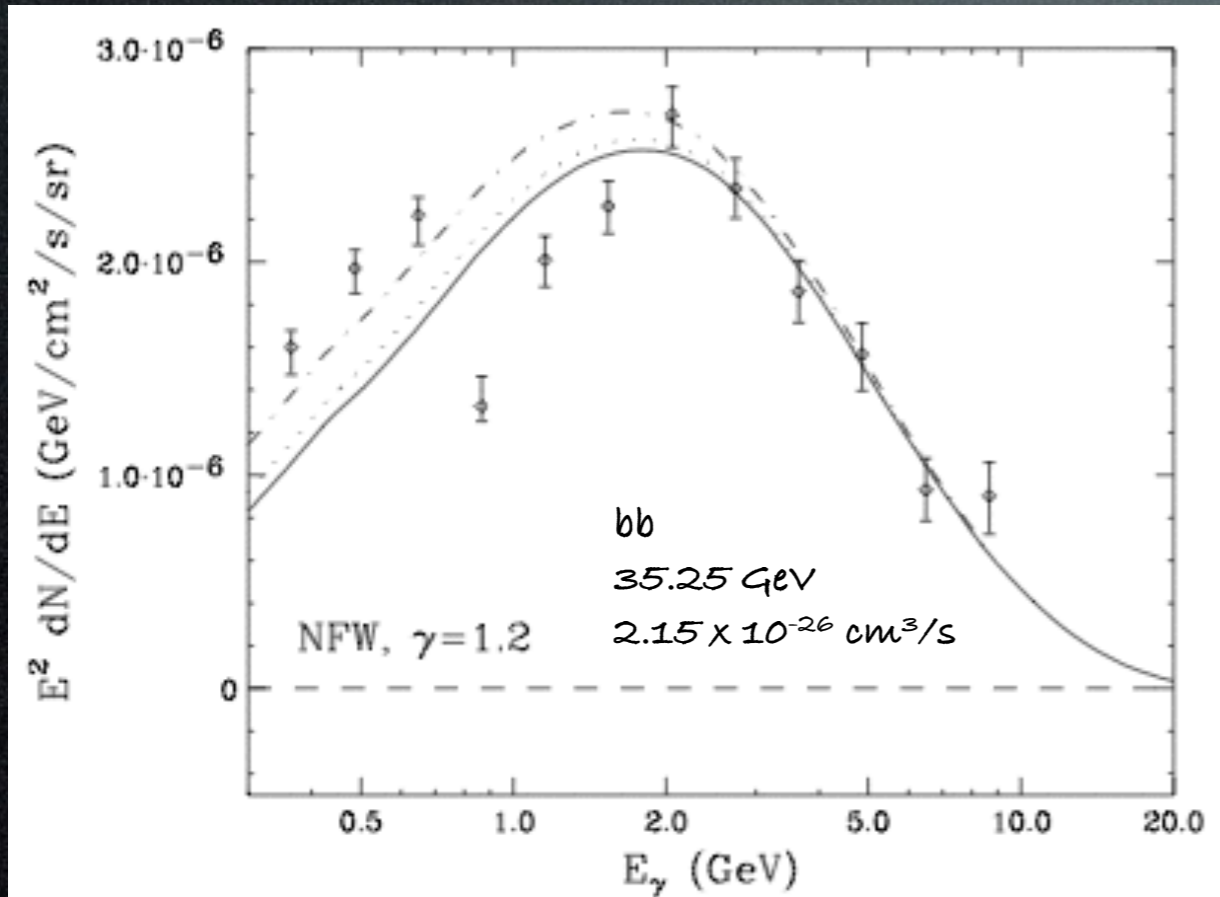
S. Murgia + T. Porter for FERMI-LAT - ICRC 2015
FERMI-LAT Coll., 1511.02938

GC GeV excess

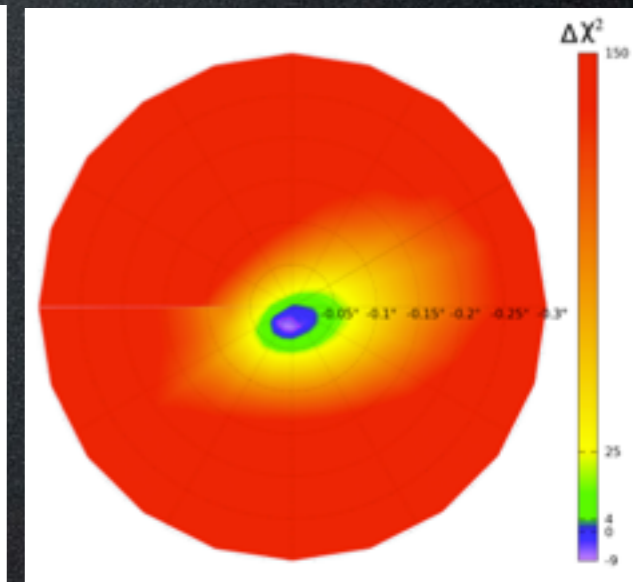
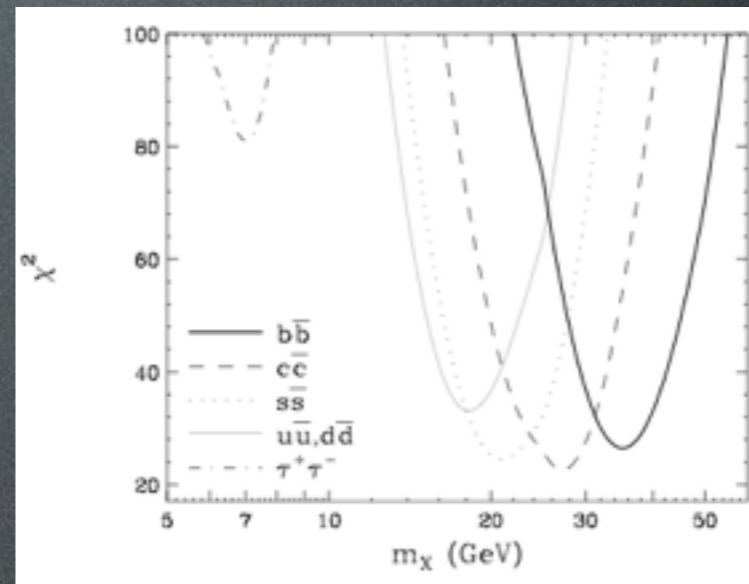
Dark Matter interpretation:

Best fit:

~35 GeV, quarks, ~thermal σ



Using events with accurate directional reconstruction



A compelling case
for annihilating DM

Daylan, Finkbeiner, Hooper, Linden,
Portillo, Rodd, Slatyer 1402.6703

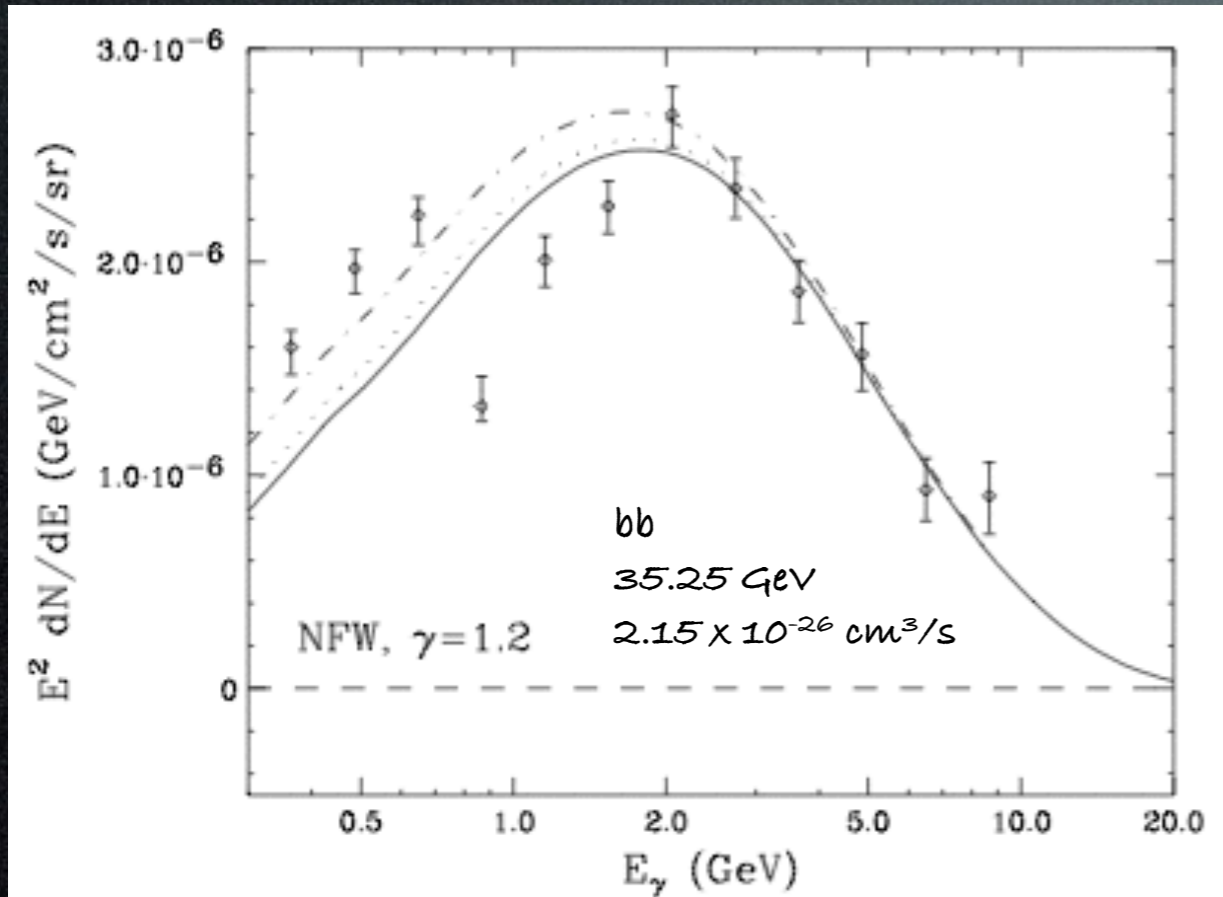
As found in previous studies [8,9], the inclusion of the dark matter template dramatically improves the quality of the fit to the *Fermi* data. For the best-fit spectrum and halo profile, we find that the inclusion of the dark matter template improves the formal fit by $\Delta\chi^2 \simeq 1672$, corresponding to a statistical preference greater than 40σ .

GC GeV excess

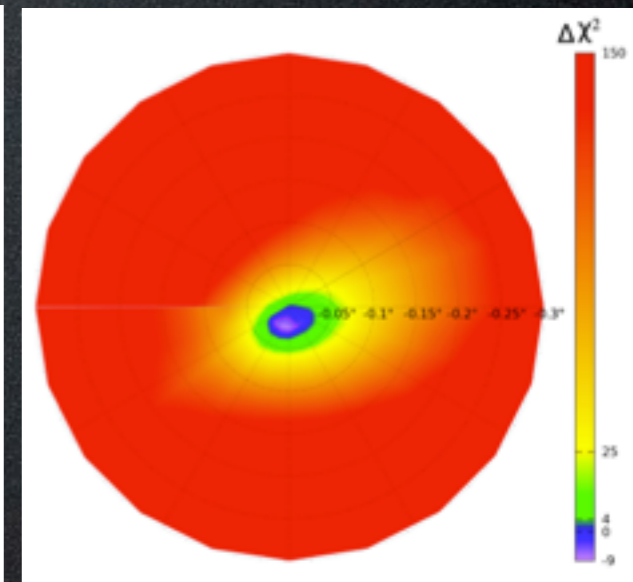
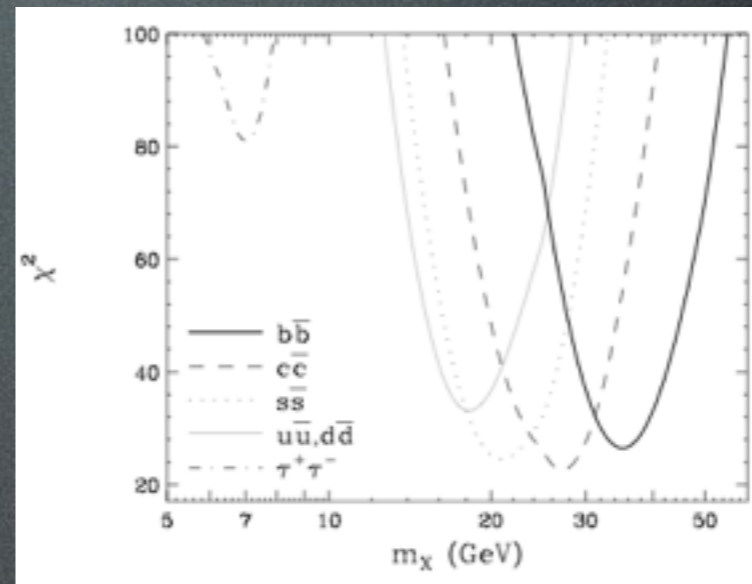
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Using events with accurate directional reconstruction



A compelling case
for annihilating DM

Daylan, Finkbeiner, Hooper, Linden,
Portillo, Rodd, Slatyer 1402.6703

...as good as it can get.

GC GeV excess

An excess with respect to **what**?

Extracting 'data points' is not trivial:

- i. choose a **ROI** (shape, extension, masking...) and harvest Fermi-LAT data
- ii. impose sensible **cuts** (Pass N, angles, CTBCORE...)
- iii. in each energy bin, fit to a sum of spatial **templates**:
 1. Fermi Coll. diffuse
 2. isotropic
 3. unresolved point sources
 4. features (bubbles...)
 5. AOB (molecular gas...)
- iv. repeat the same, adding a template for:
 6. **Dark Matter**, having chosen a certain **profile**!
- v. if iii. \rightarrow iv. improves χ^2 , there's evidence for DM
- vi. the component fitted by 6 is the residual excess to be explained

Note:

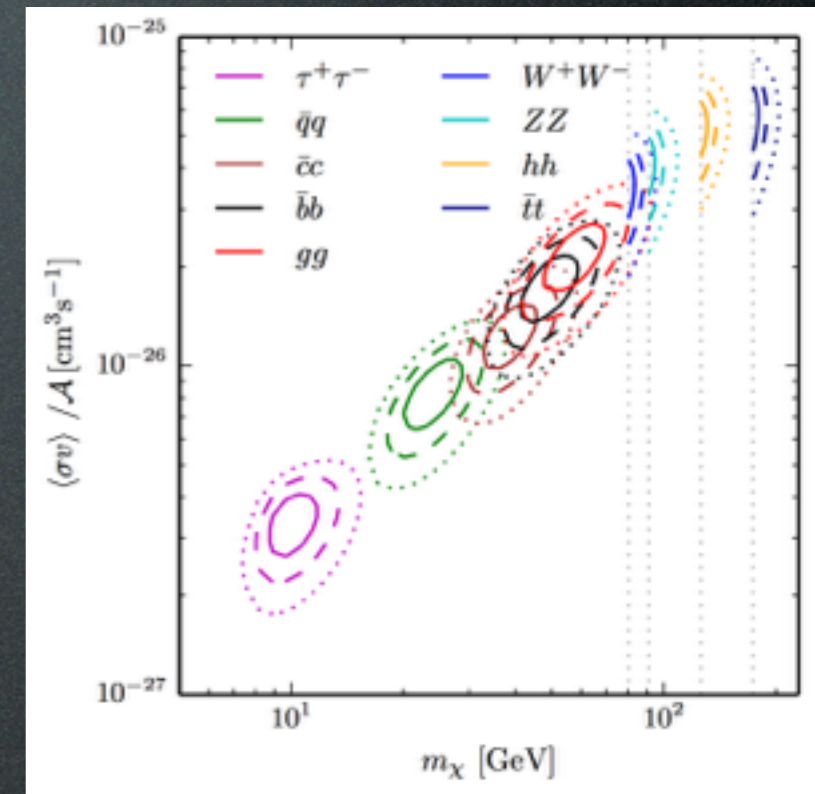
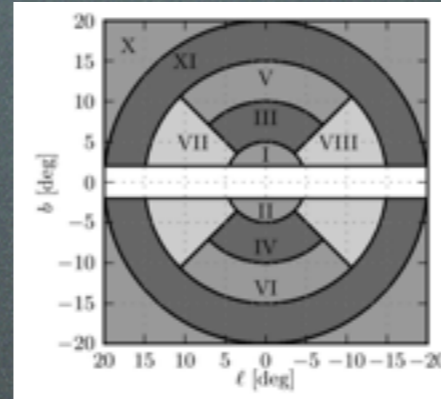
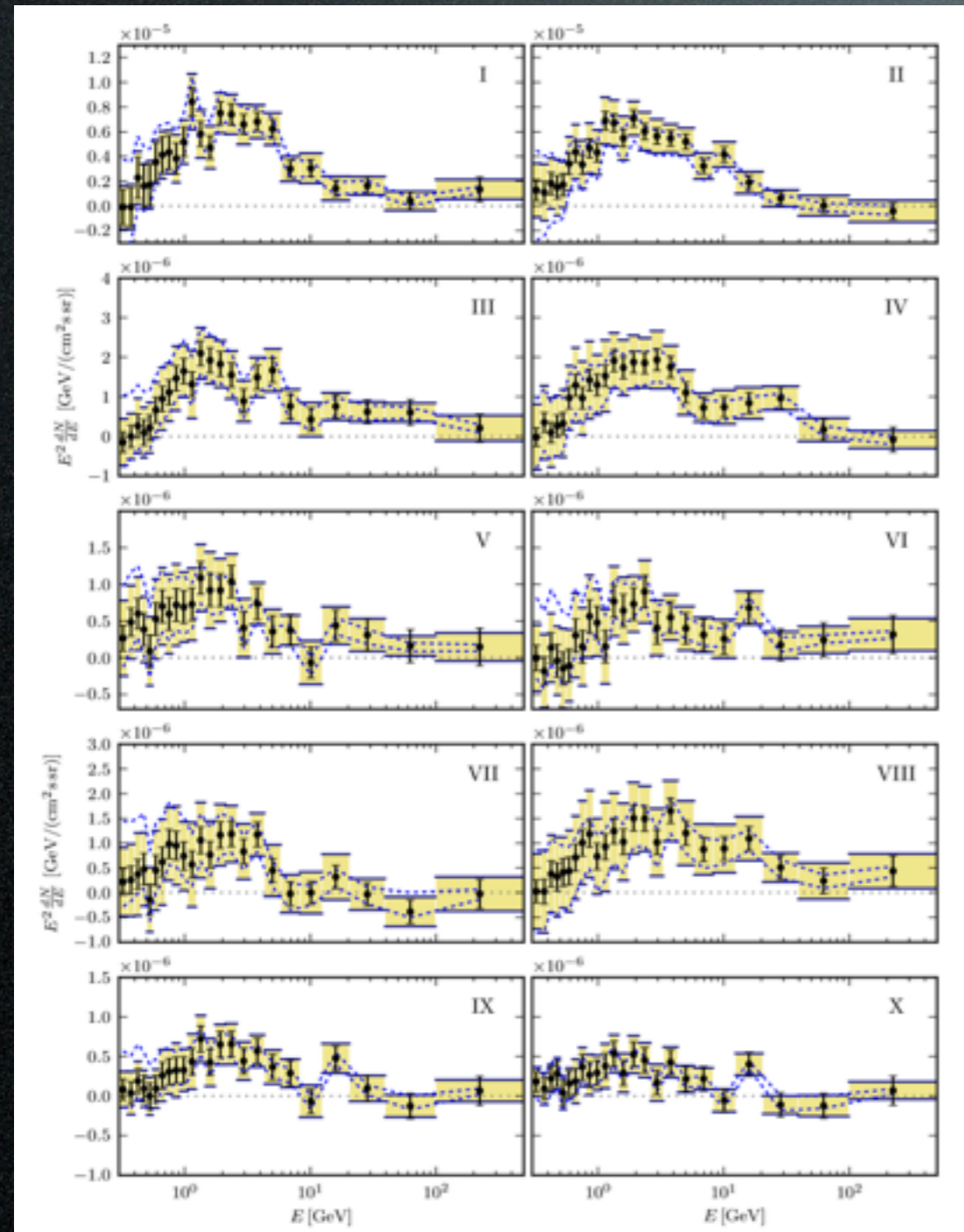
Adding 6 will in general change the recipe of 1...5 (you'll need a bit more of x here, a bit less of y there...).

Changing the profile of 6 too.

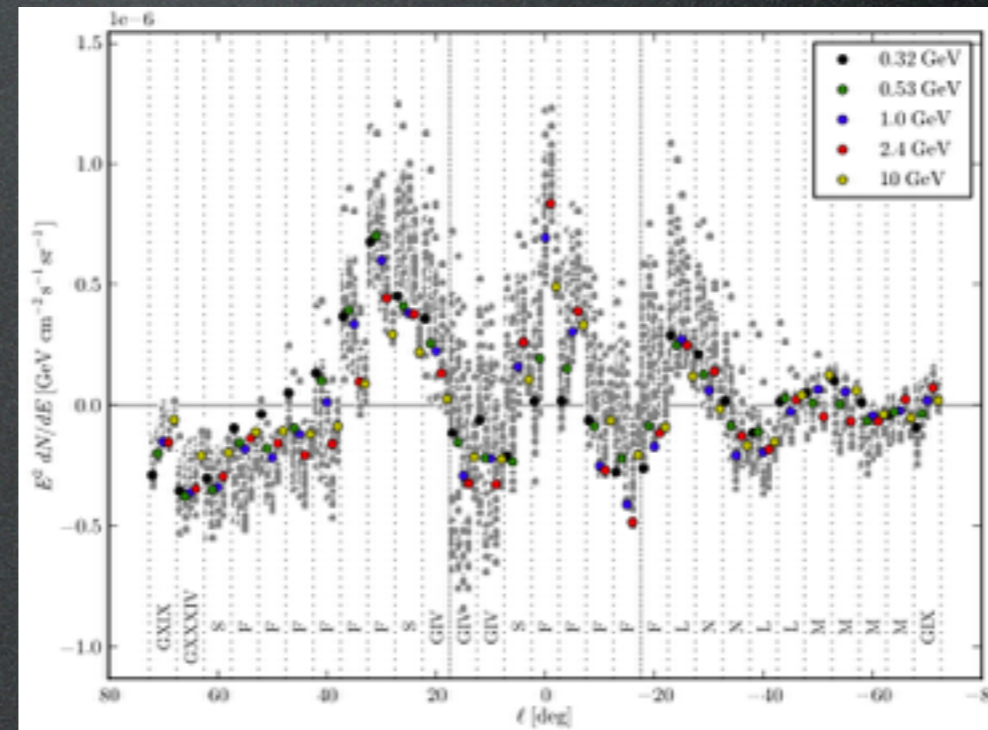
GC GeV excess

The excess is robust against **uncertainties** in foreground modelling, and it extends to $o(10^\circ)$:

More general DM good fits:



By the way, excesses exist elsewhere in the GP:

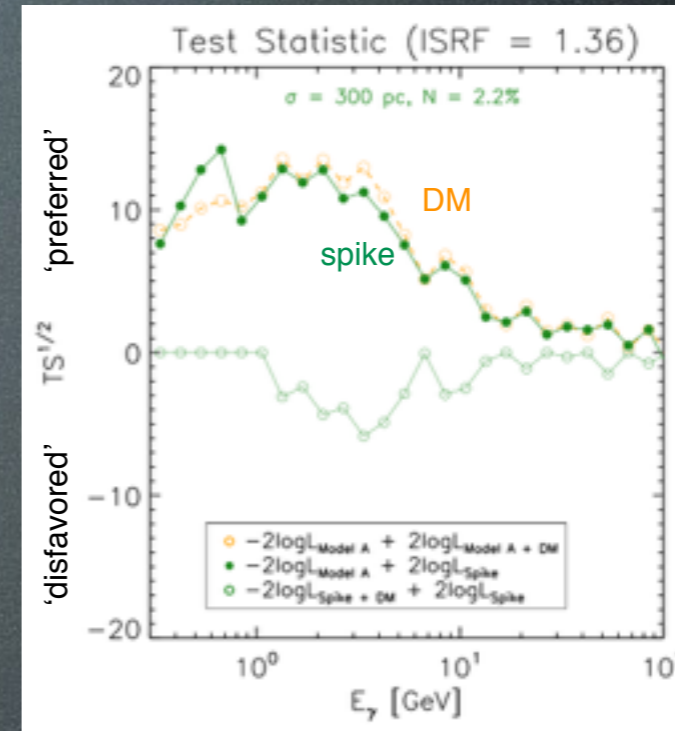
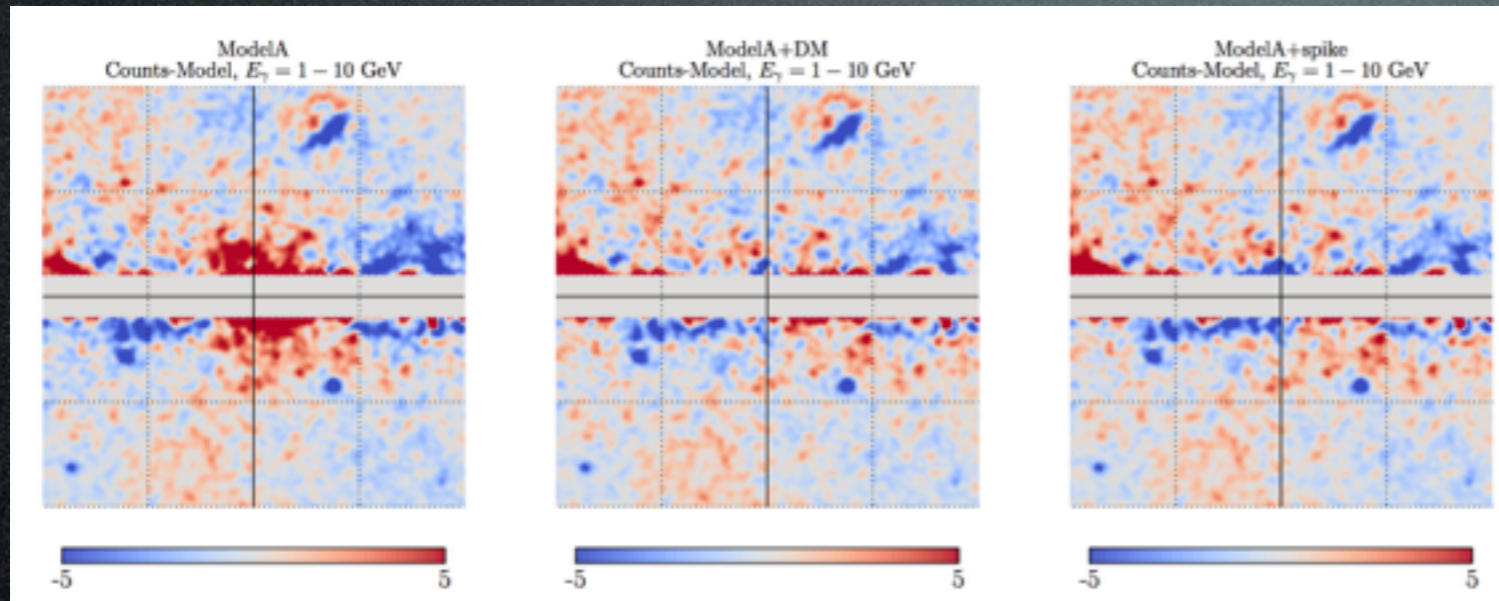


← Gal plane

Calore, Cholis, Weniger 1409.0042
Calore, Cholis, McCabe, Weniger 1411.4647

GC GeV excess

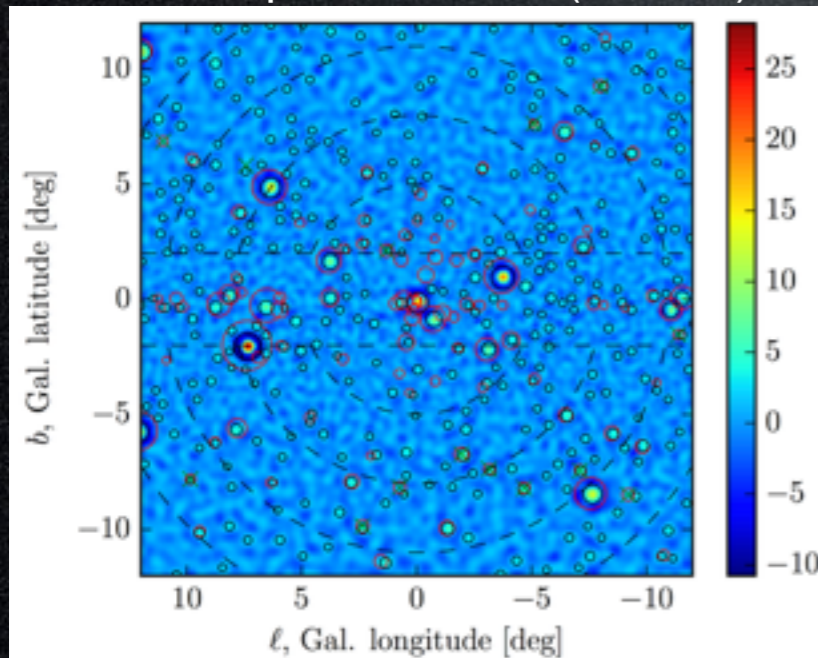
‘Astro’ interpretation(s):



An additional steady-source spike of CRs (from SNRs?) that emit via ICS

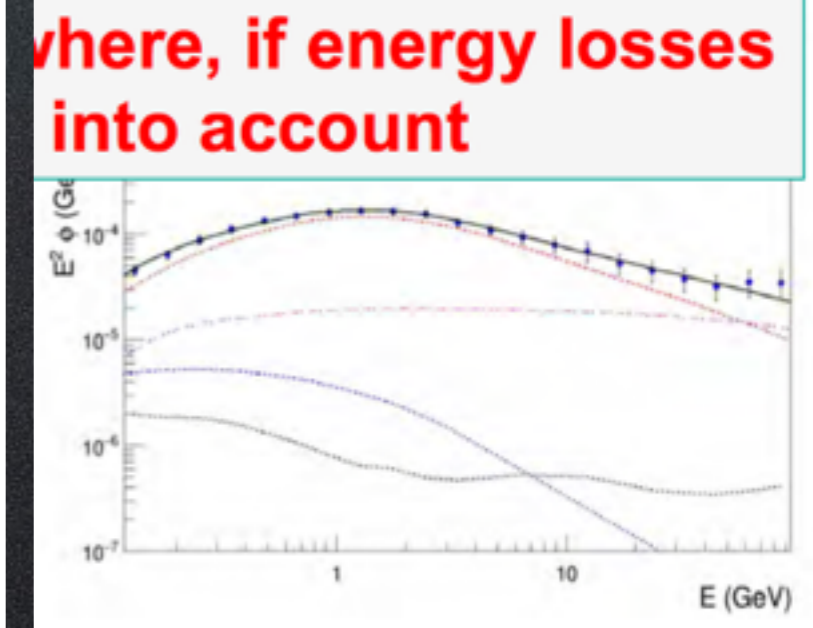
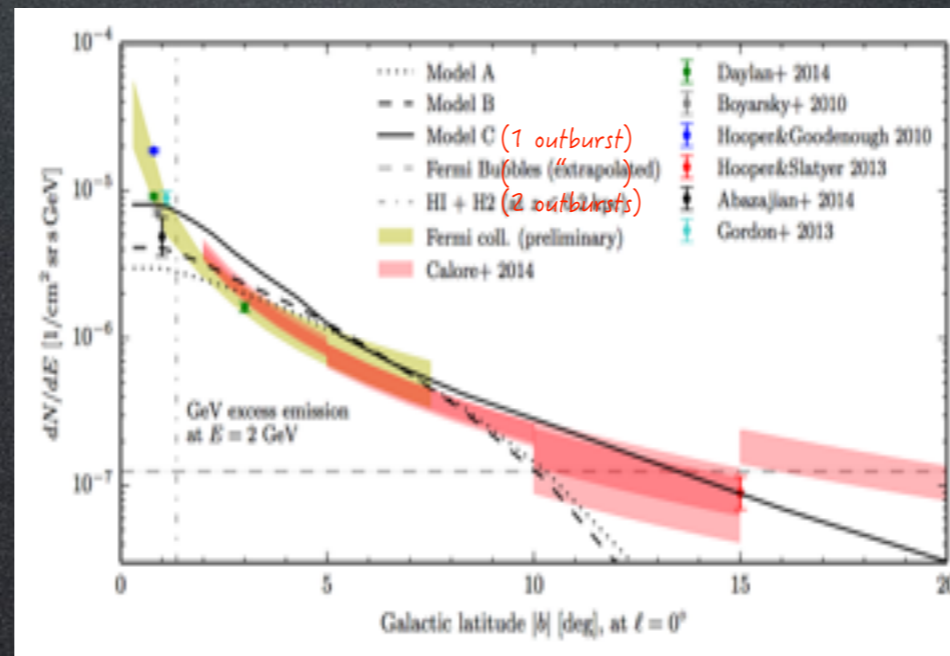
Gaggero, Taoso, Urbano, Valli, Ullio 1507.06129
 see also: Carlson, Profumo, Linden 1510.04698
 (which ‘motivates’ the spike with H2 distribution)

Unresolved point sources (MSPs?)



Leptonic outbursts: old + young (1 + 0.1 Myr)
 (but even this is not ideal)

Enhanced proton energy losses
 near the GC (?)



Lee, Lisanti, Safdi, Slatyer, Xue 1506.05124
 Bartels, Krishnamurthy, Weniger 1506.05104
 Abazajian 1011.4275
 Hooper et al. 1305.0830
 Yuan, Zhang 1404.2318
 Petrović, Serpico, Zaharijas 1411.2980

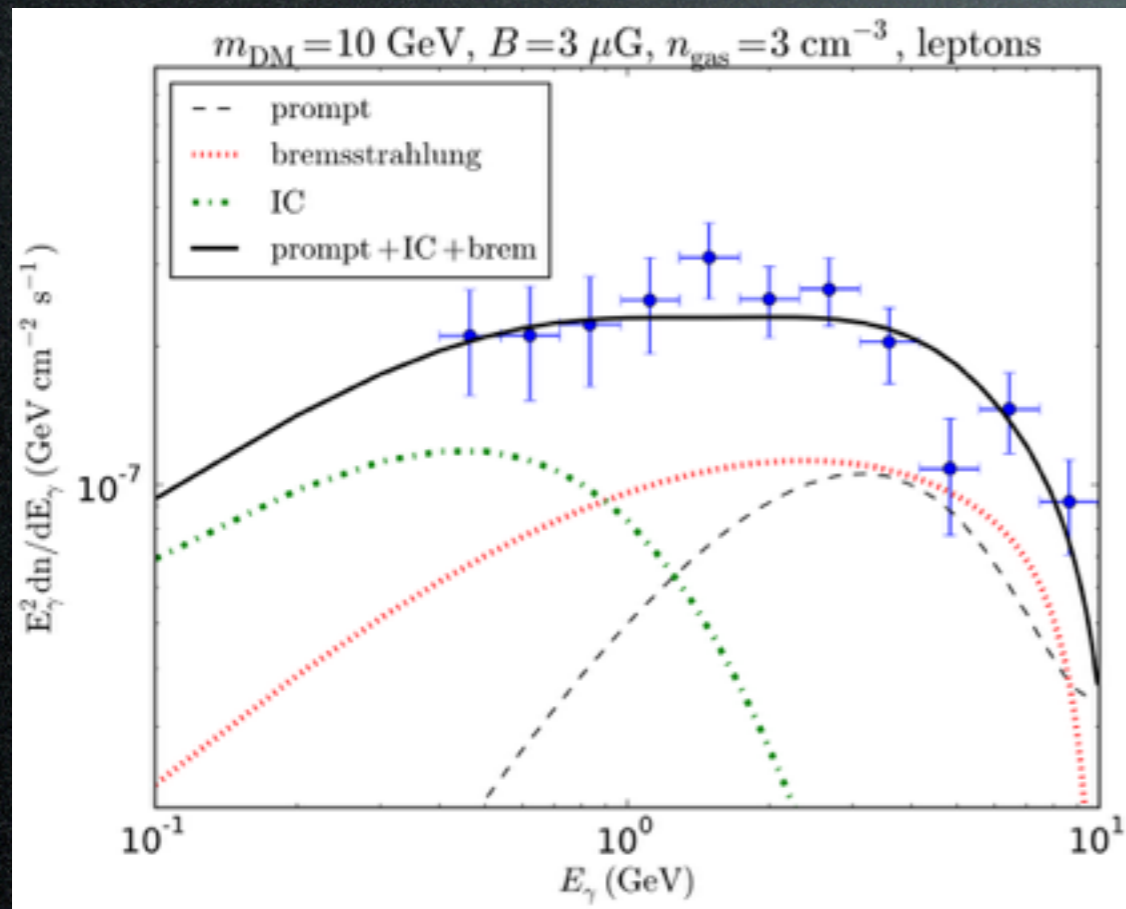
Cholis, Evoli, Calore, Linden, Weniger 1506.05119
 Petrović, Serpico, Zaharijas 1405.7928
 Carlson, Profumo 1405.7685

W. De Boer - ICRC 2015

GC GeV excess

Dark Matter interpretation:

Including secondary emission changes the conclusions



Best fit:
 $\sim 10 \text{ GeV}$, leptons, $\sim \text{thermal } \sigma v$

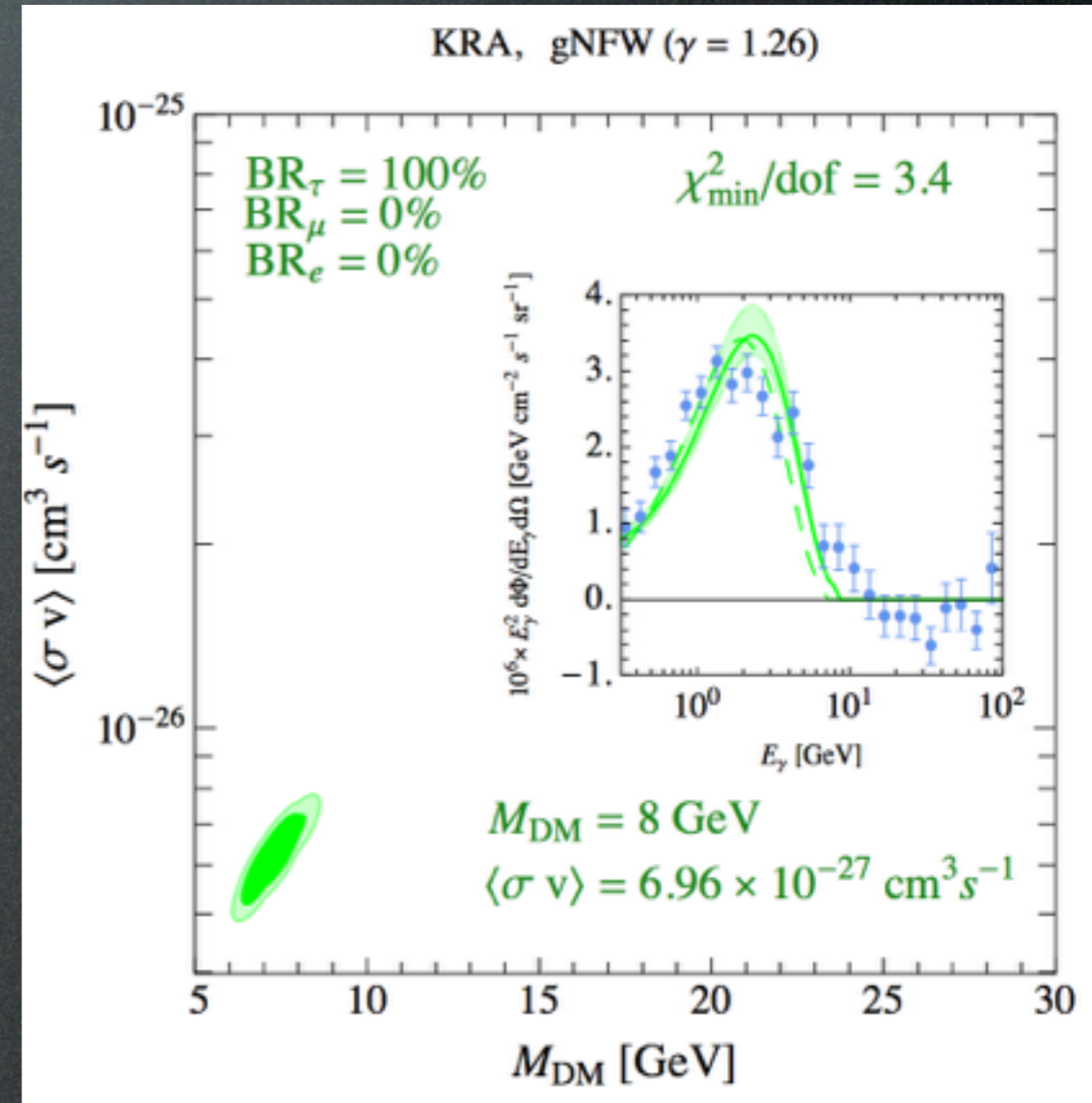
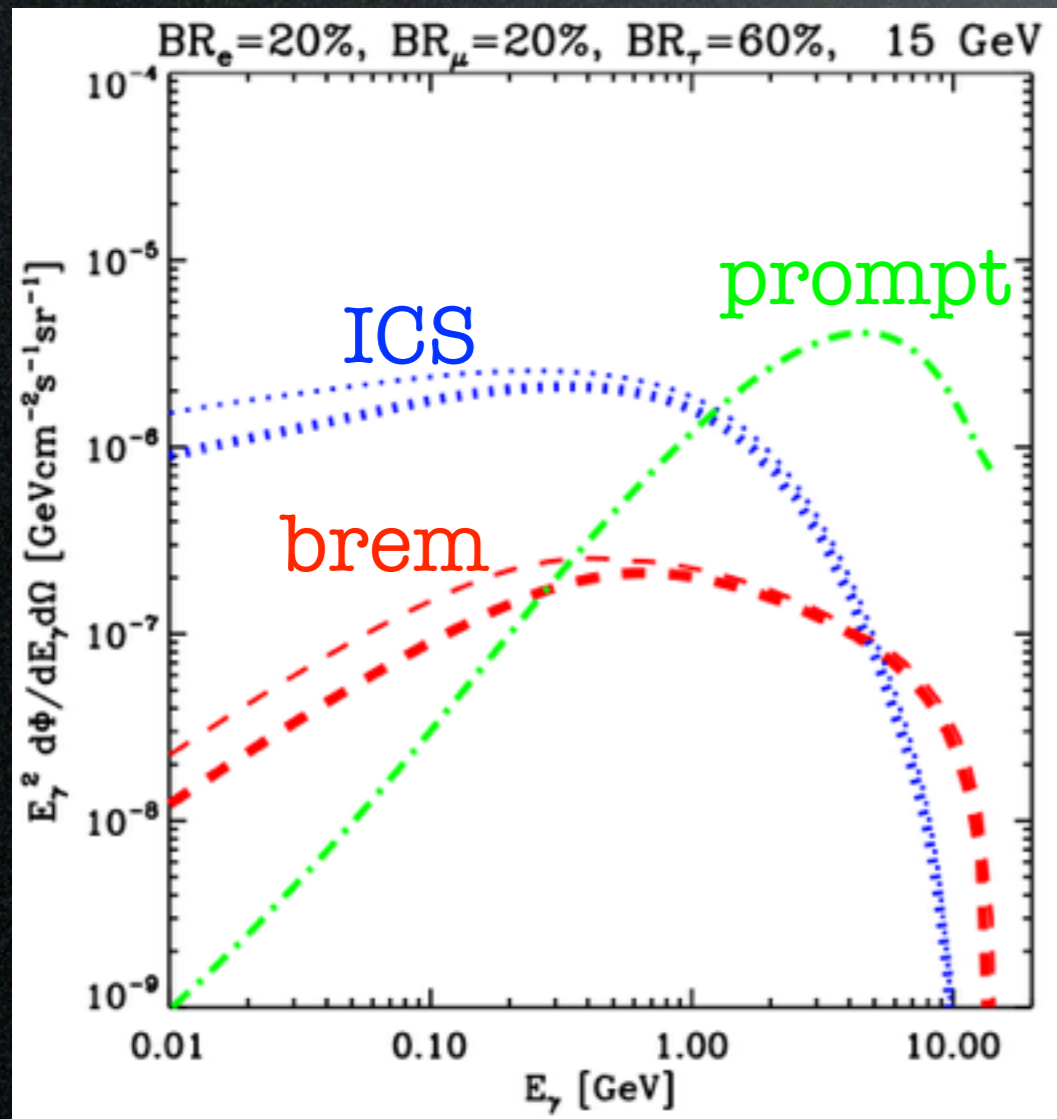
Lacroix, Boehm, Silk 1403.1987

But: propagation is approximate

GC GeV excess

Dark Matter interpretation:

Including secondary emission changes the conclusions

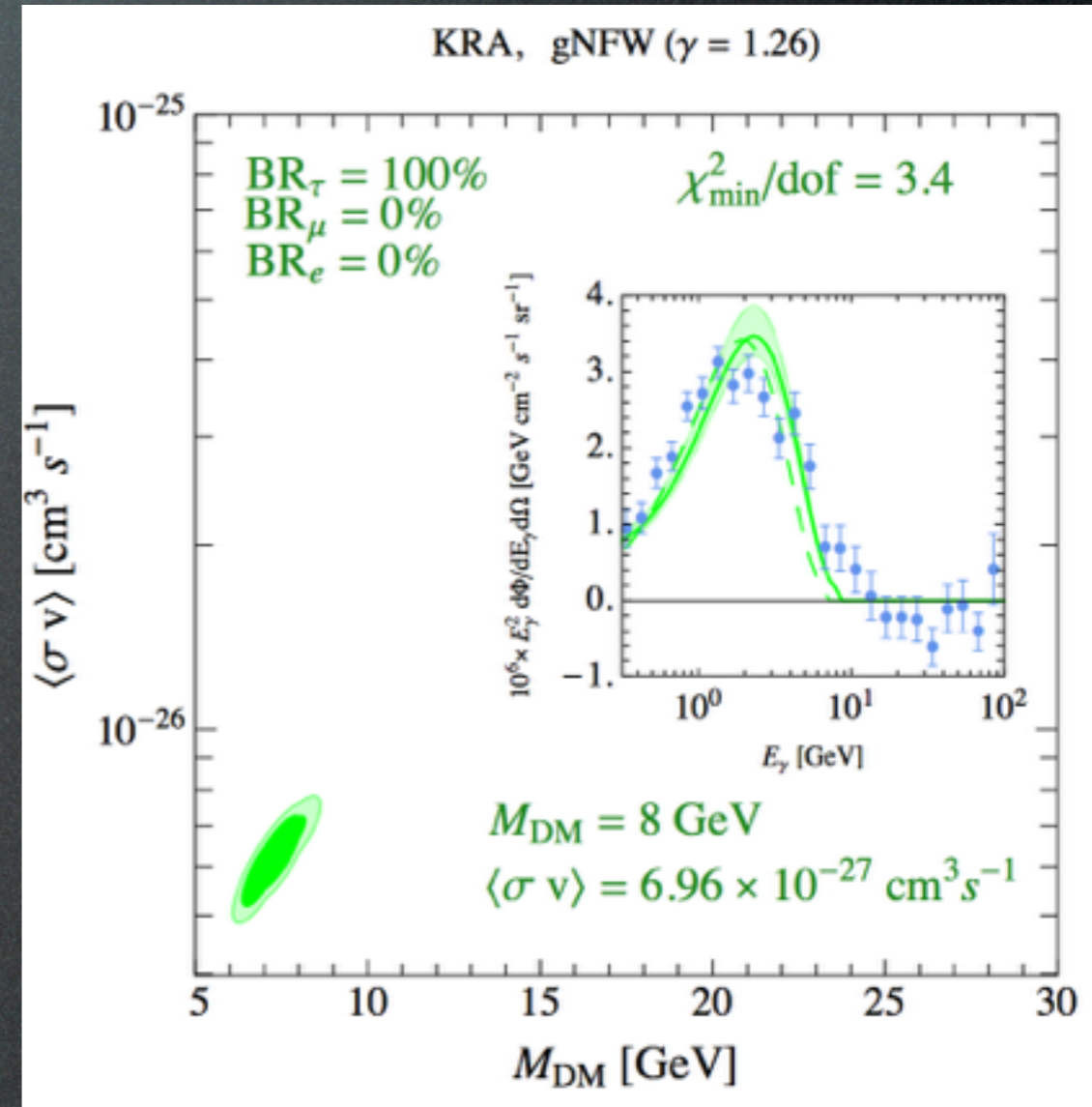
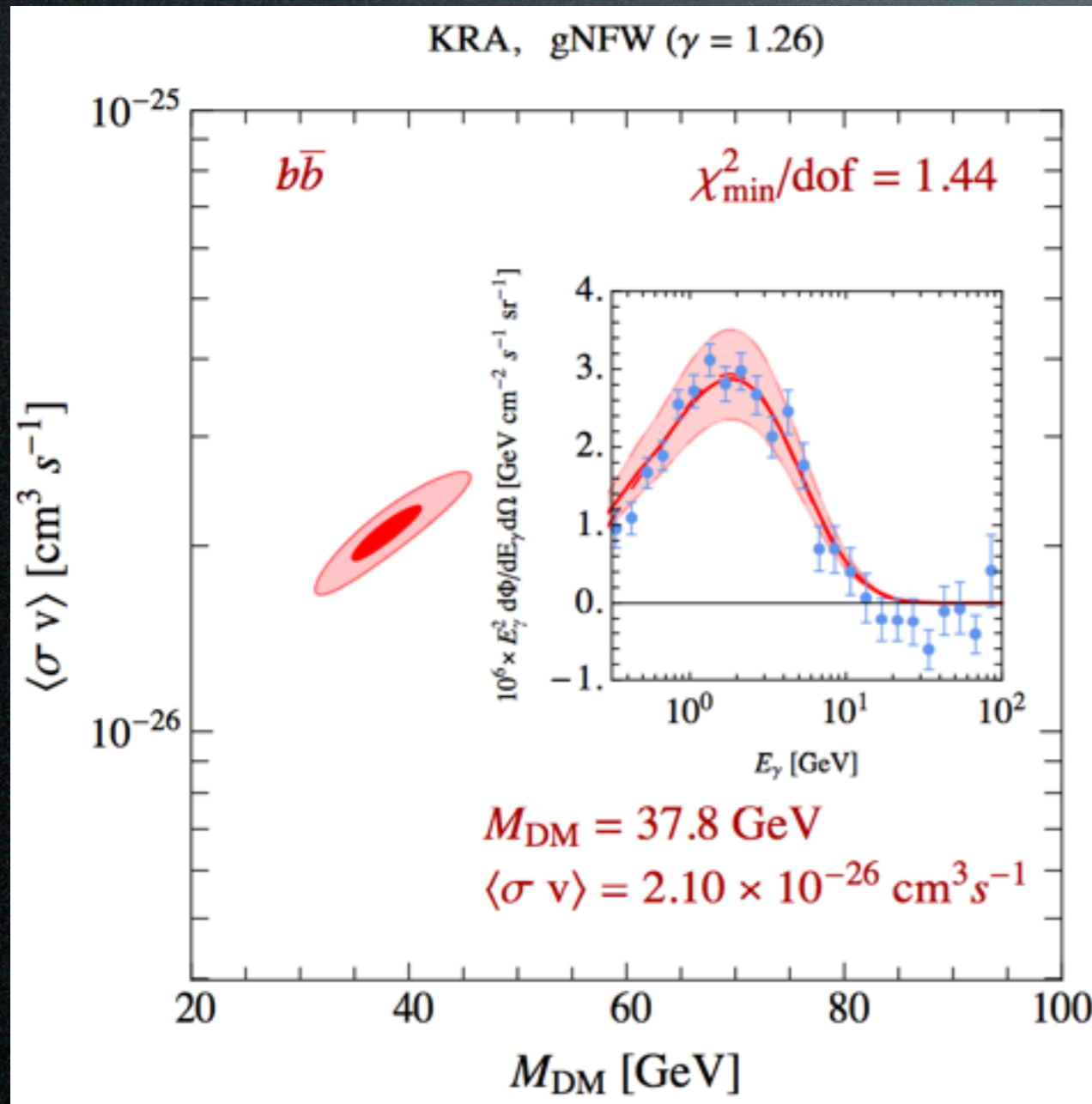


GC GeV excess

Dark Matter interpretation:

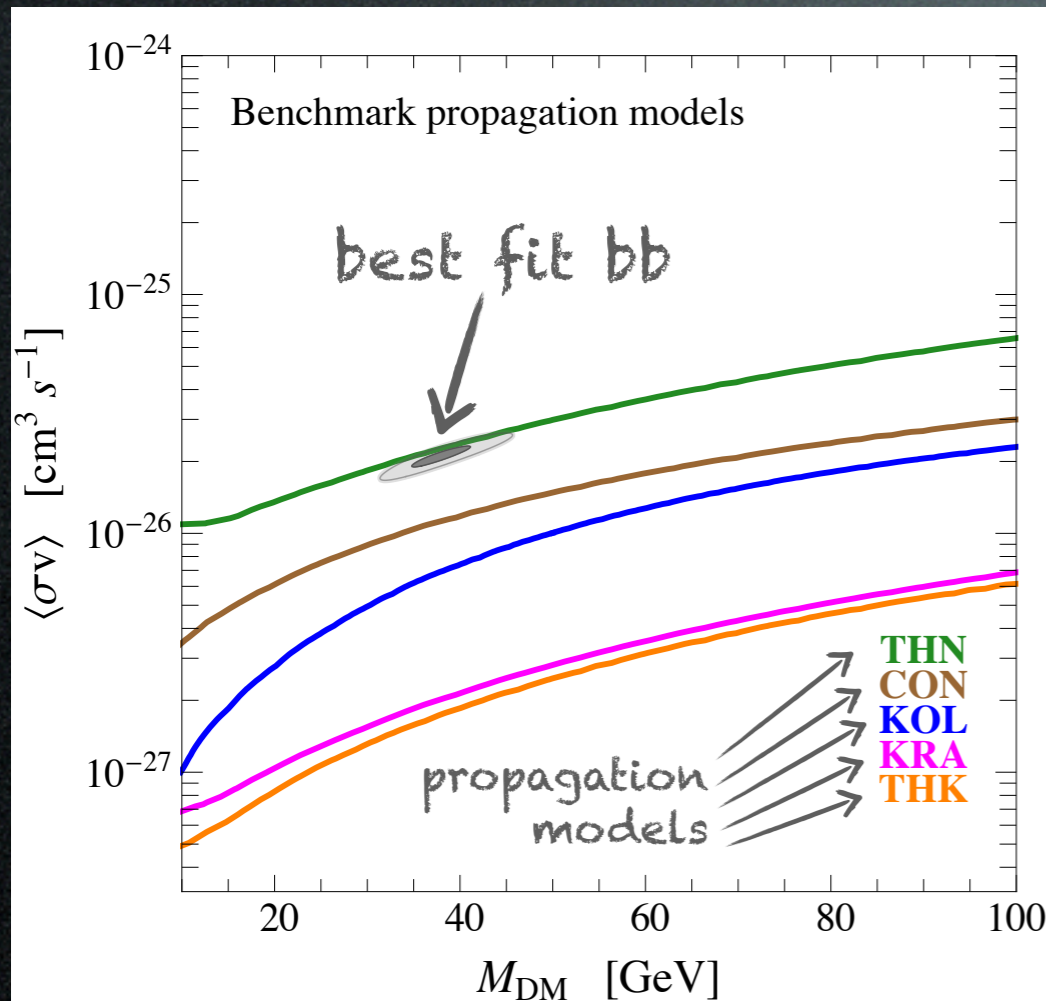
'Best' fit:

Analysis	Final State	Setup	M_{DM} [GeV]	$\langle\sigma v\rangle$ [$\text{cm}^3 \text{s}^{-1}$]	$\chi^2_{\text{min}}/\text{dof}$
'Gal Center', $\gamma = 1.2$	$b\bar{b}$	KOL	35.53	2.14×10^{-26}	12.1
	leptonic mix (*)	KOL	9.4	1.06×10^{-26}	6.3
'Inner Gal', $\gamma = 1.26$	$b\bar{b}$	KRA	37.8	2.10×10^{-26}	1.44
	$\tau^+\tau^-$	KRA	8	6.96×10^{-27}	3.4



GC GeV excess

Dark Matter interpretation:



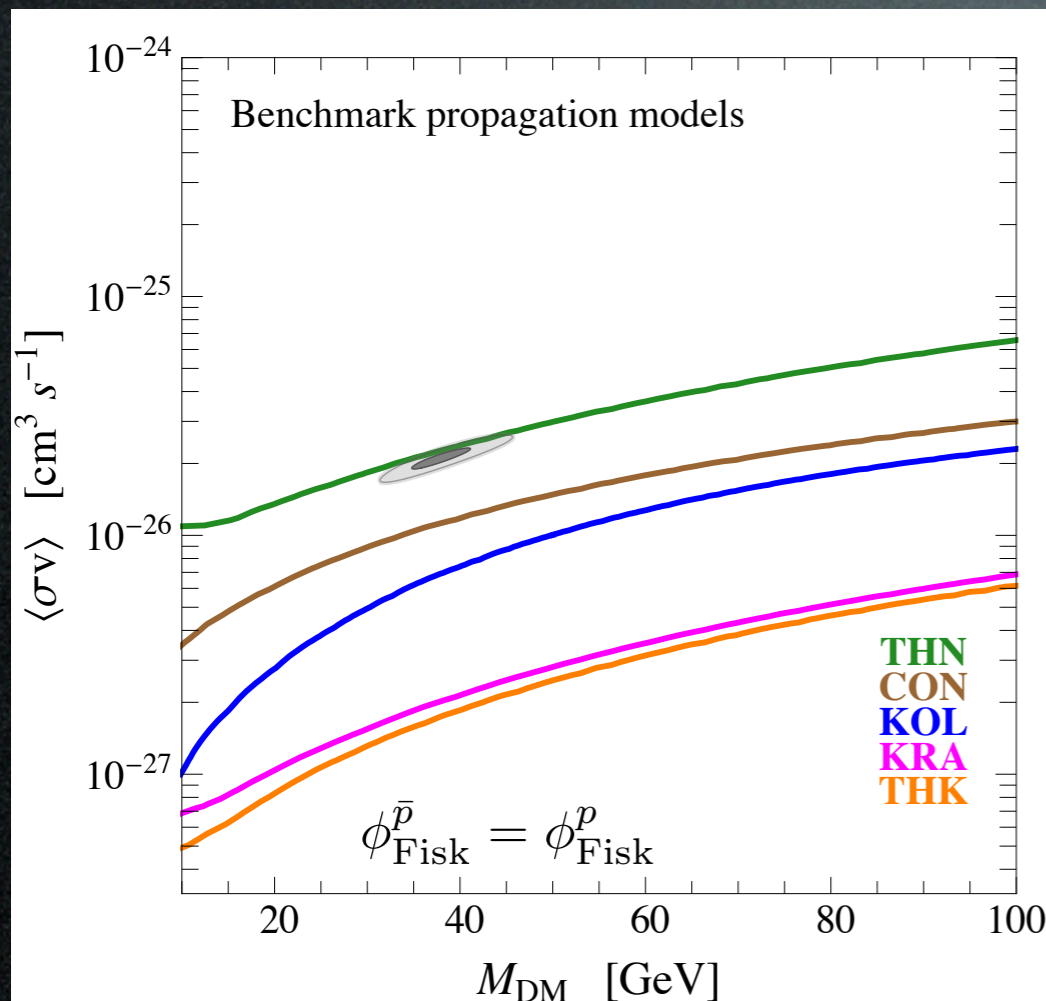
Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

Antiproton constraints may be very relevant! But not robust.

Fermi-LAT excess

GC GeV excess

Antiproton constraints:



[Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173](#)

Antiproton constraints may be very relevant! But not robust.

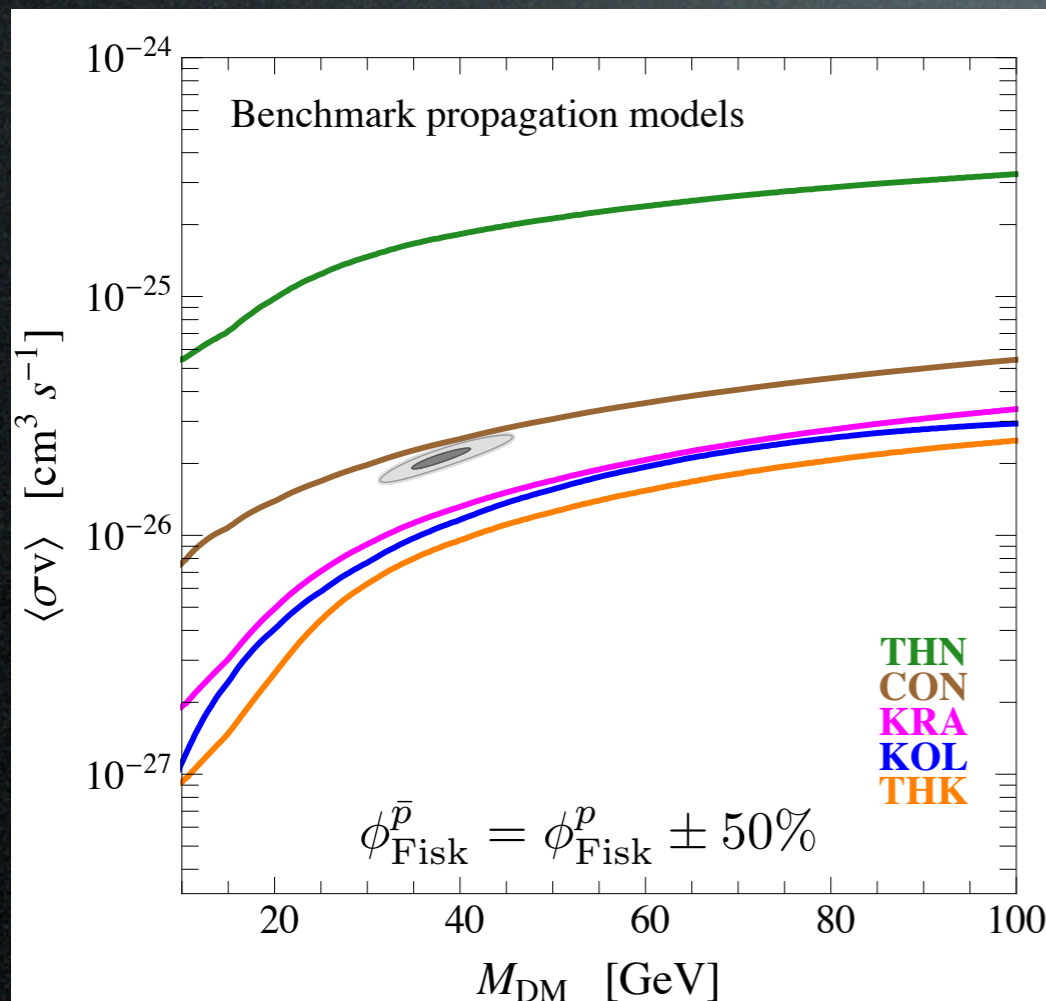
Assumption: fixed solar modulation

Result: hooperon excluded
(except unrealistic THN)

Fermi-LAT excess

GC GeV excess

Antiproton constraints:



Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

Antiproton constraints may be very relevant! But not robust.

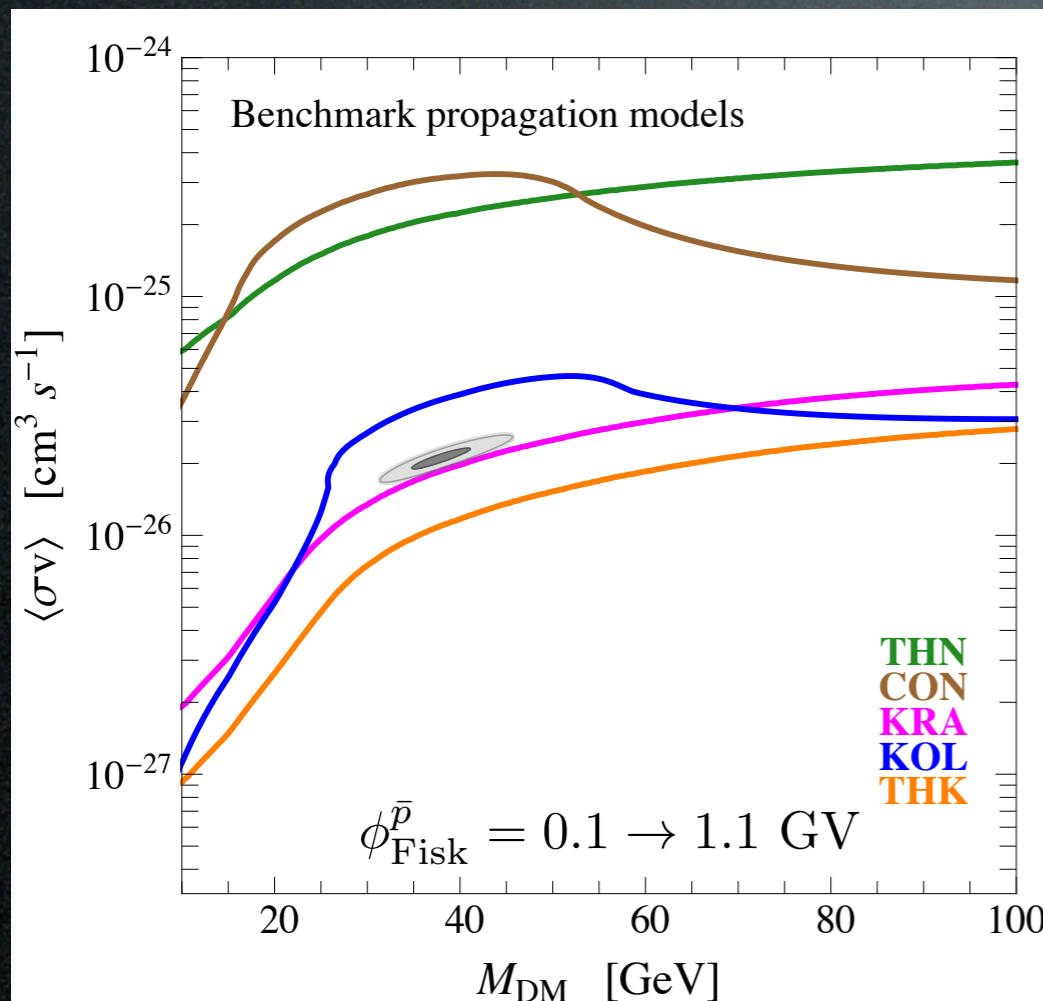
Assumption: flexible solar modulation

Result: hooperon may be excluded or not

Fermi-LAT excess

GC GeV excess

Antiproton constraints:



Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

Antiproton constraints may be very relevant! But not robust.

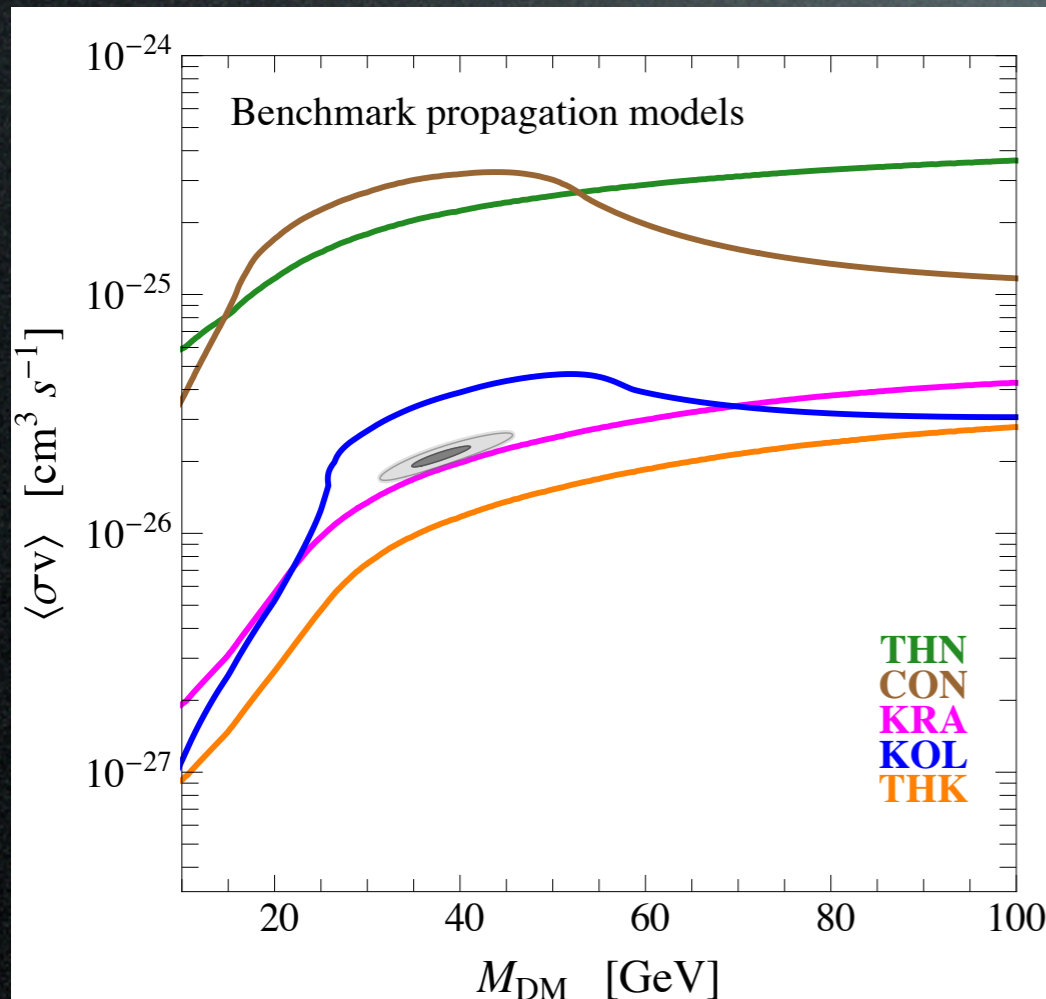
Assumption: conservative solar modulation

Result: hooperon probably reallocated (except THK models)

Fermi-LAT excess

GC GeV excess

Antiproton constraints:



[Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173](#)

Antiproton constraints may be very relevant! But not robust.

Assumption: conservative solar modulation

Result: hooperon probably reallocated (except THK models)

Fermi-LAT excess

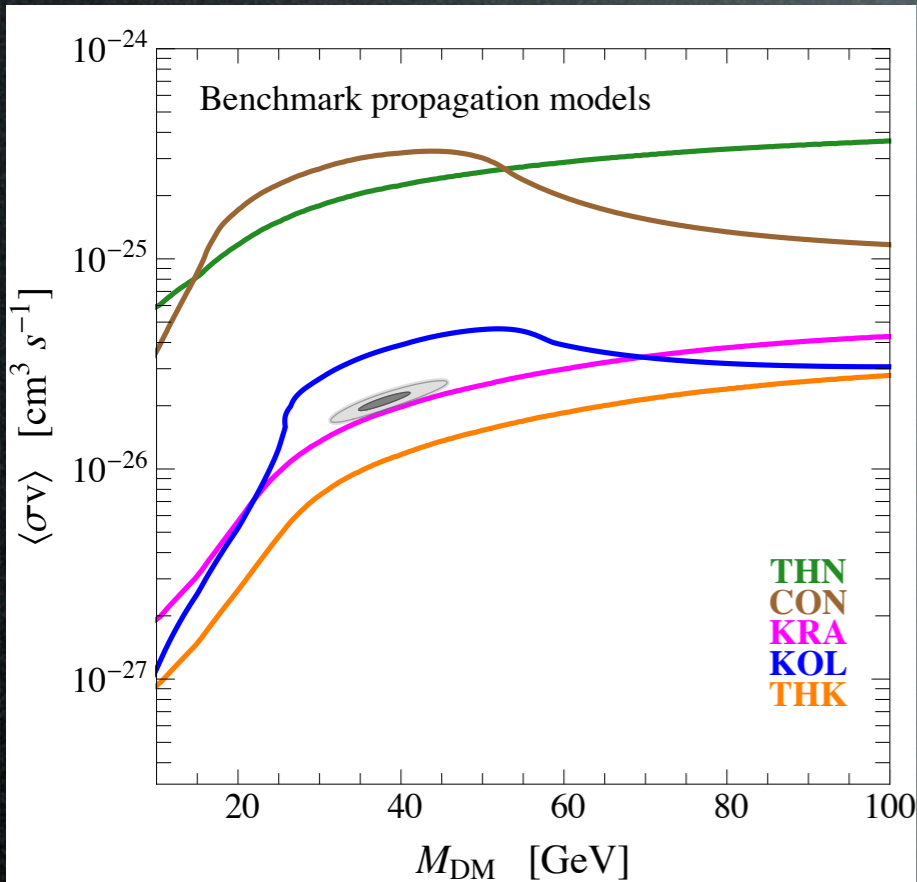
NB Conclusion differs from

[Bringmann, Vollmann, Weniger 1406.6027](#)

which finds exclusion / strong tension

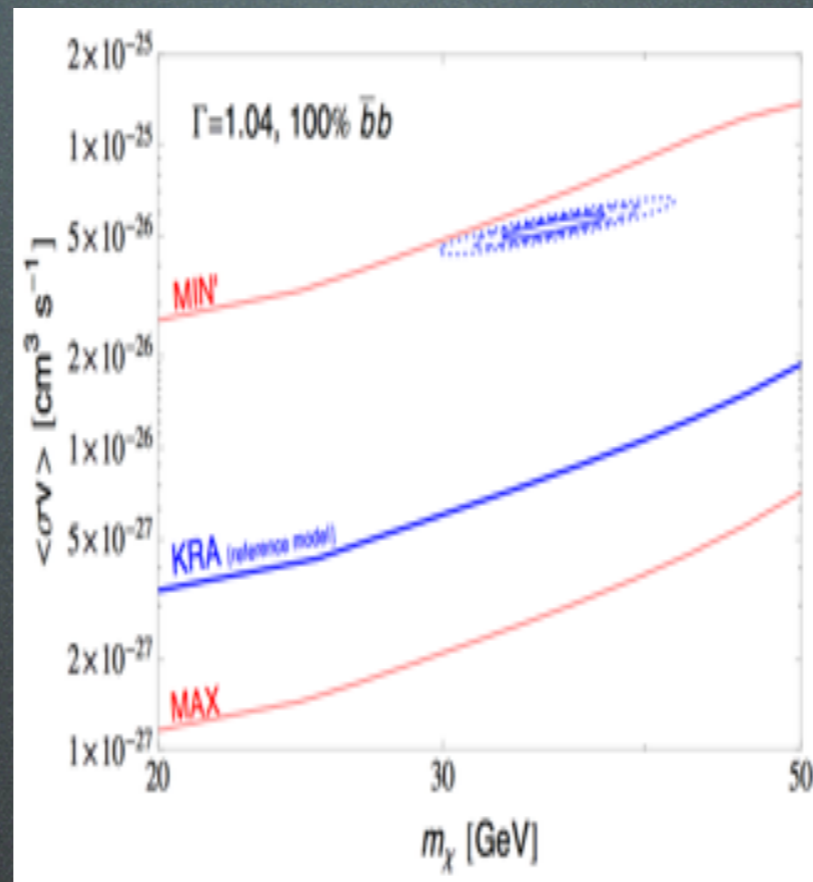
GC GeV excess

Antiproton constraints compared:



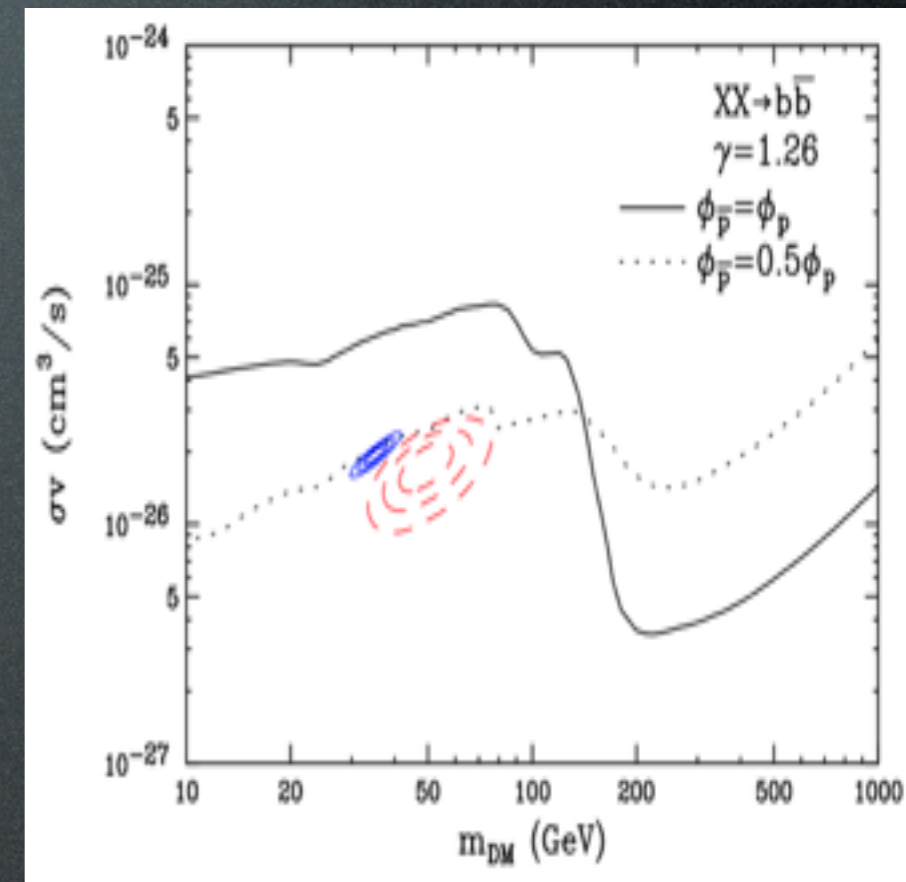
Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

May be very relevant!
But not robust.



Bringmann, Vollmann, Weniger 1406.6027

'Rule out' or
'considerable tension'.



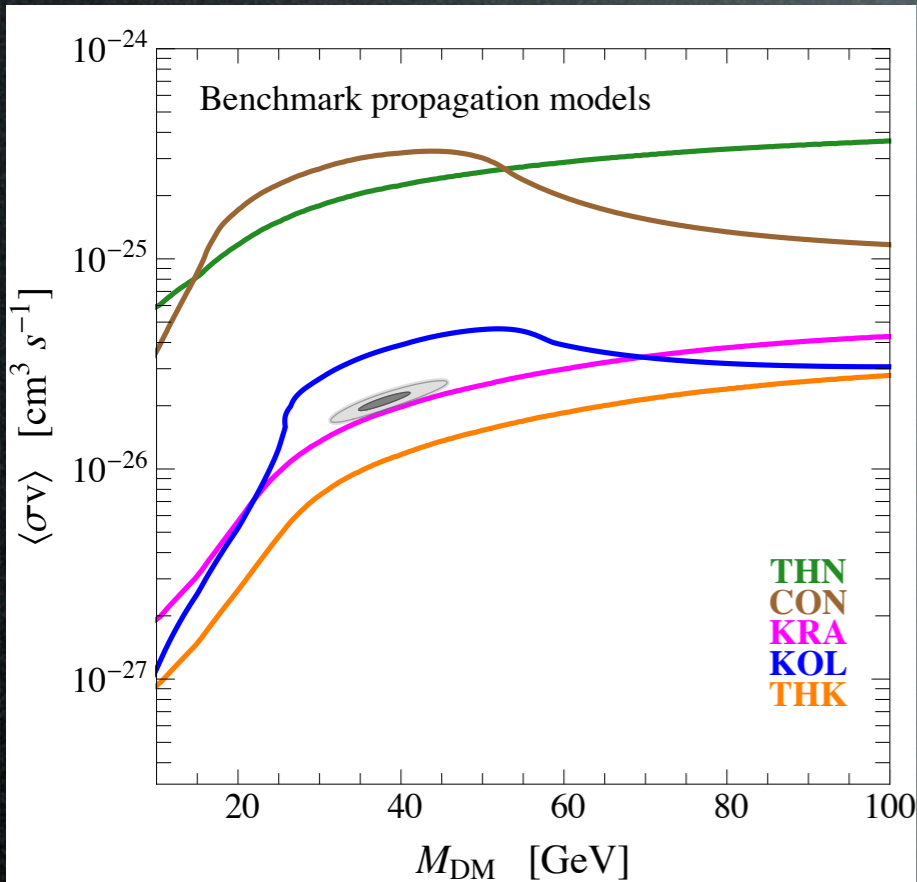
Hooper, Linden, Mertsch 1410.1527

'Significantly less stringent'.

How come?!?

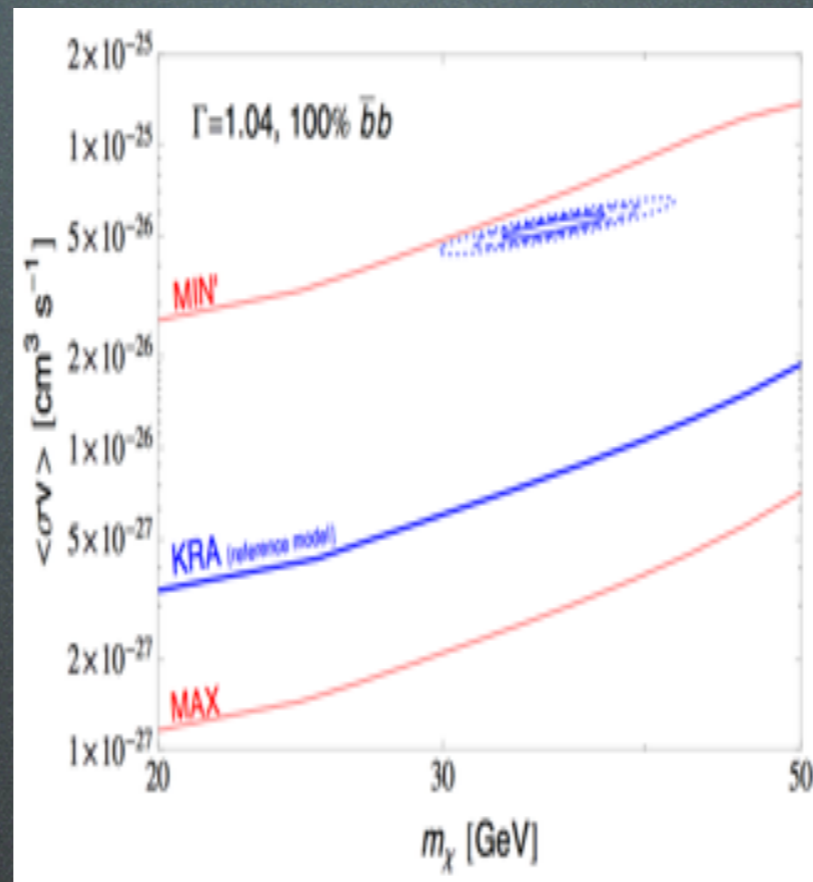
GC GeV excess

Antiproton constraints compared:



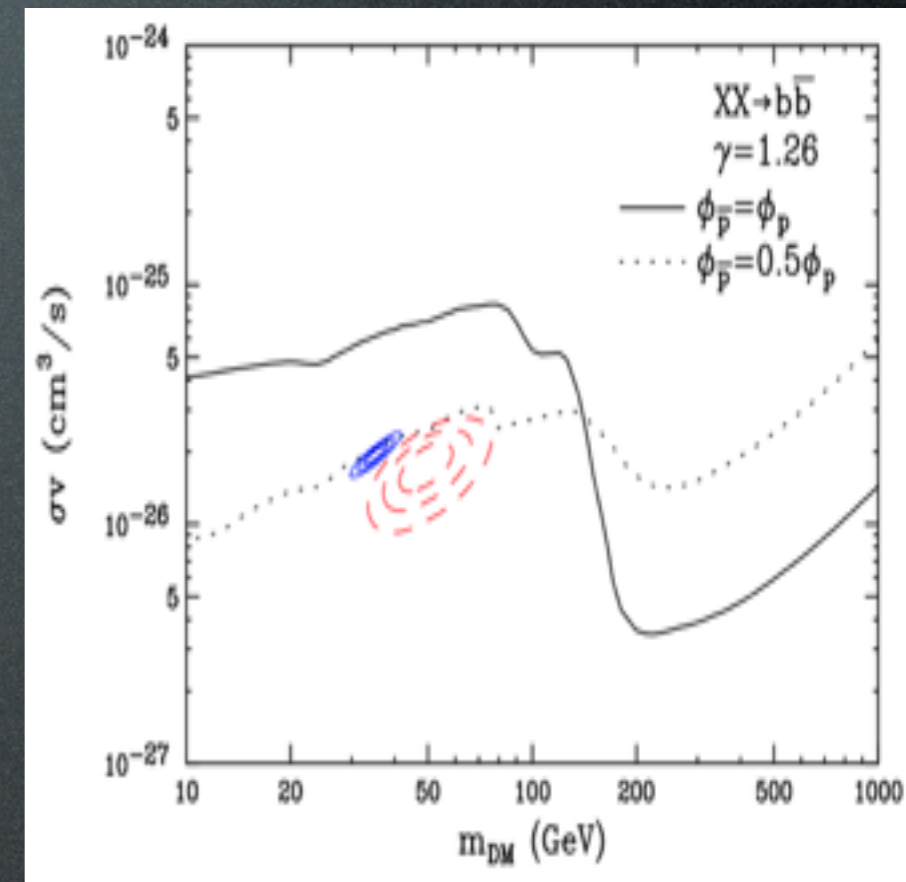
Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

May be very relevant!
But not robust.



Bringmann, Vollmann, Weniger 1406.6027

'Rule out' or
'considerable tension'.



Hooper, Linden, Mertsch 1410.1527

'Significantly less stringent'.

How come?!? The devil is in the (CR propagation) **details**:
solar modulation, convection, primary injection spectrum, tertiaries...

CONCLUSIONS

Antiprotons from
low mass DM:

*significantly affected
by solar modulation,
which is uncertain*

Gamma-rays from
low mass DM:

*environment-dependent
secondary radiation
is important, even dominant*

The **GC GeV excess**
as a case study:

- 1. secondary radiation changes
the DM interpretation,*
- 2. antiproton constraints
are inconclusive*