e-ASTROGAM WB - Nucleosynthesis

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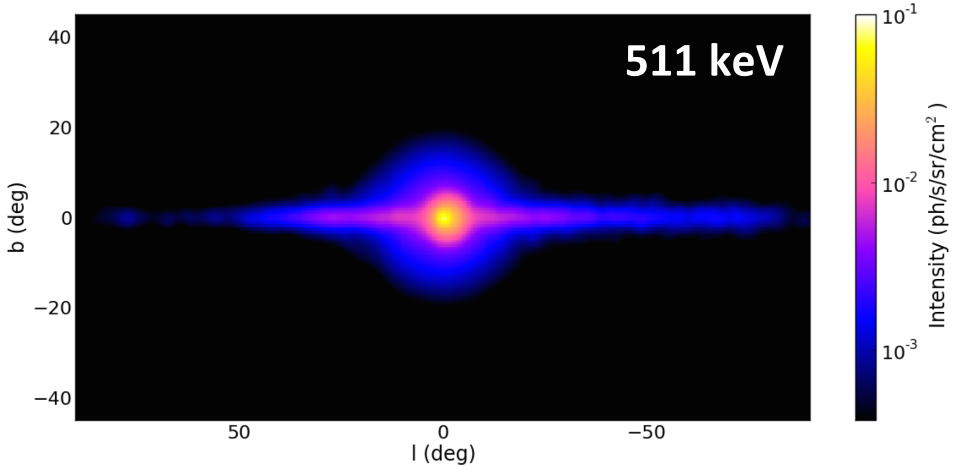
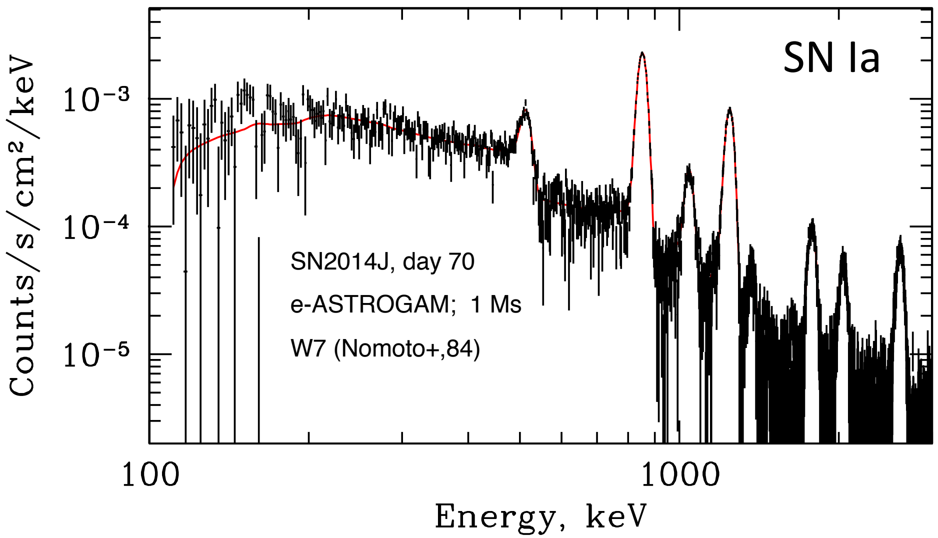
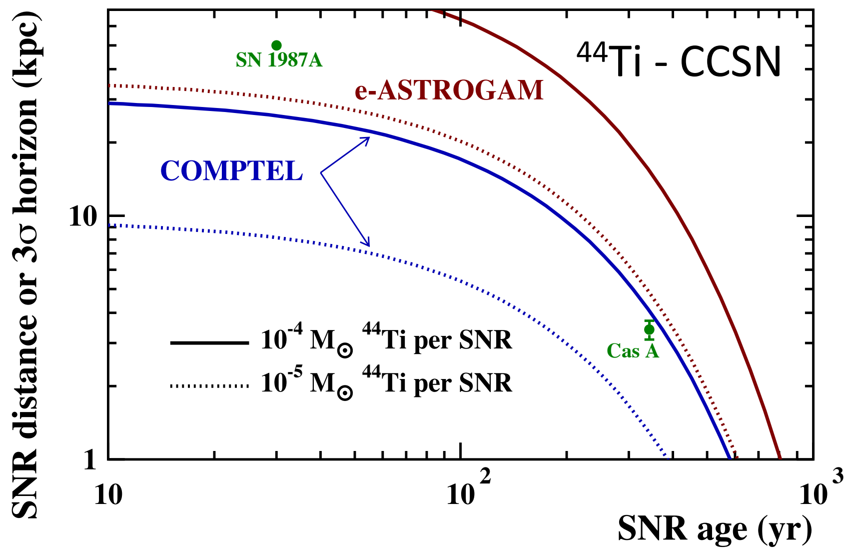






e-ASTROGAM Radioactivities

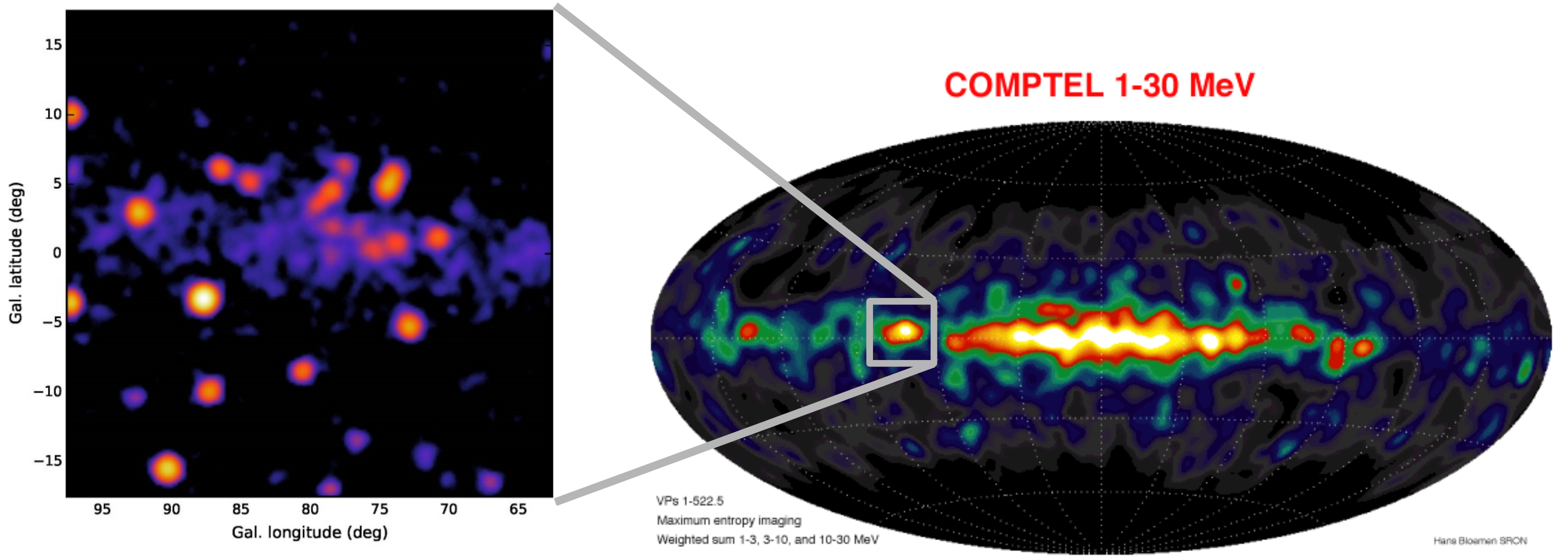
Isotope	Production site	Decay chain	Half-life	γ-ray energy (keV) and intensity
^{7}Be	Nova	$^{7}\mathrm{Be} \xrightarrow{\epsilon} {}^{7}\mathrm{Li}^{*}$	53.3 d	478 (0.11)
^{56}Ni	SNIa, CCSN	$^{56}\mathrm{Ni} \xrightarrow{\epsilon} {}^{56}\mathrm{Co}^{*}$ $^{56}\mathrm{Co} \xrightarrow{\epsilon(0.81)} {}^{56}\mathrm{Fe}^{*}$	6.075 d 77.2 d	158 (0.99), 812 (0.86) 847 (1), 1238 (0.67)
^{57}Ni	SNIa, CCSN	$^{57}\mathrm{Ni} \xrightarrow{\epsilon(0.56)} {}^{57}\mathrm{Co}^{*}$ $^{57}\mathrm{Co} \xrightarrow{\epsilon} {}^{57}\mathrm{Fe}^{*}$	1.48 d 272 d	1378 (0.82) 122 (0.86), 136 (0.11)
^{22}Na	Nova	$^{22}\mathrm{Na} \xrightarrow{\beta^{+}(0.90)} {}^{22}\mathrm{Ne}^{*}$	2.61 y	1275 (1)
^{44}Ti	CCSN, SNIa	$^{44}\mathrm{Ti} \xrightarrow{\epsilon} {}^{44}\mathrm{Sc}^{*}$ $^{44}\mathrm{Sc} \xrightarrow{\beta^{+}(0.94)} {}^{44}\mathrm{Ca}^{*}$	60.0 y 3.97 h	68 (0.93), 78 (0.96) 1157 (1)
^{26}Al	CCSN, WR AGB, Nova	$^{26}\mathrm{Al} \xrightarrow{\beta^{+}(0.82)} {}^{26}\mathrm{Mg}^{*}$	$7.4{\cdot}10^{5}$ y	1809 (1)
^{60}Fe	CCSN	$^{60}\mathrm{Fe} \xrightarrow{\beta^{-}} {}^{60}\mathrm{Co}^{*}$ $^{60}\mathrm{Co} \xrightarrow{\beta^{-}} {}^{60}\mathrm{Ni}^{*}$	$1.5{\cdot}10^{6}$ y 5.27 y	59 (0.02) 1173 (1), 1332 (1)

Highlights:

- ^{56}Ni decay chain detected from SN 1987A (core-collapse) and SN 2014J (thermonuclear) => new insights on the (asymmetric) explosion mechanisms (see Diehl 2017)
- ^{44}Ti detected from 2 SNRs, Cas A and SN 1987A, no other source found in γ-ray surveys (Tsygankov et al. 2016) => synthesis in a rare class of SNe (see also Crocker et al. 2017)?
- ^{26}Al and ^{60}Fe diffuse radioactivities (flux ratio of 15%) => hot ISM properties (Krause et al. 2015)

Key performances

E (keV)	FWHM (keV)	Origin	SPI sensitivity (ph cm^{-2} s^{-1})	e-ASTROGAM sensitivity (ph cm^{-2} s^{-1})	Improvement factor
511	1.3	Narrow line component of the e+/e- annihilation radiation from the Galactic center region	5.2×10^{-5}	4.1×10^{-6}	13
847	35	^{56}Co line from thermonuclear SN	2.3×10^{-4}	3.5×10^{-6}	66
1157	15	^{44}Ti line from core-collapse SN remnants	9.6×10^{-5}	3.6×10^{-6}	27
1275	20	^{22}Na line from classical novae of the ONe type	1.1×10^{-4}	3.8×10^{-6}	29
2223	20	Neutron capture line from accreting neutron stars	1.1×10^{-4}	2.1×10^{-6}	52
4438	100	^{12}C line produced by low-energy Galactic cosmic-ray in the interstellar medium	1.1×10^{-4}	1.7×10^{-6}	65



Contributions on nucleosynthesis

1. Thermonuclear supernovae (SN Ia): *Eugene Churazov, Roland Diehl, Jordi Isern, and Vincent Tatischeff*

2. Core collapse supernovae: *Jordi Isern, Mark Leising, Roland Diehl, and Vincent Tatischeff*

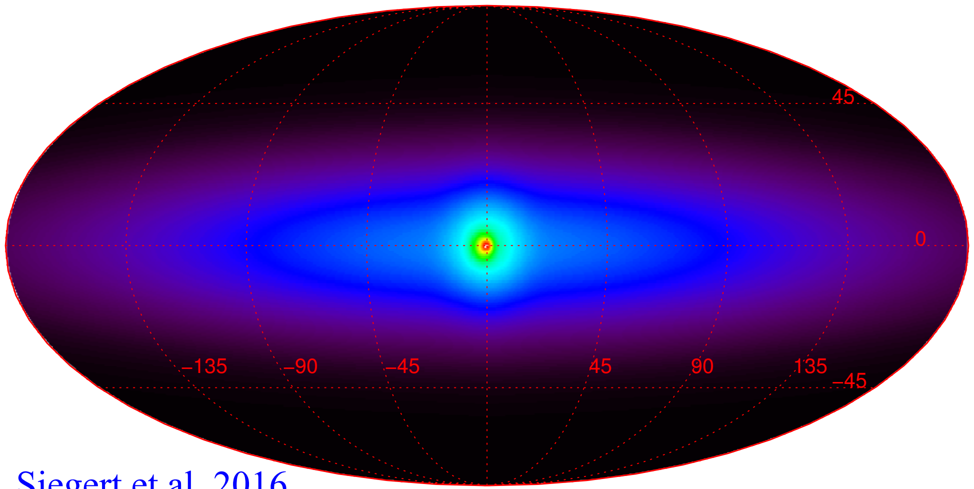
3. Nova explosions: *Margarita Hernanz, Jordi José, Pierre Jean, et al.*

4. Diffuse gamma-ray line emissions: *Roland Diehl, Nikos Prantzos, and Vincent Tatischeff*

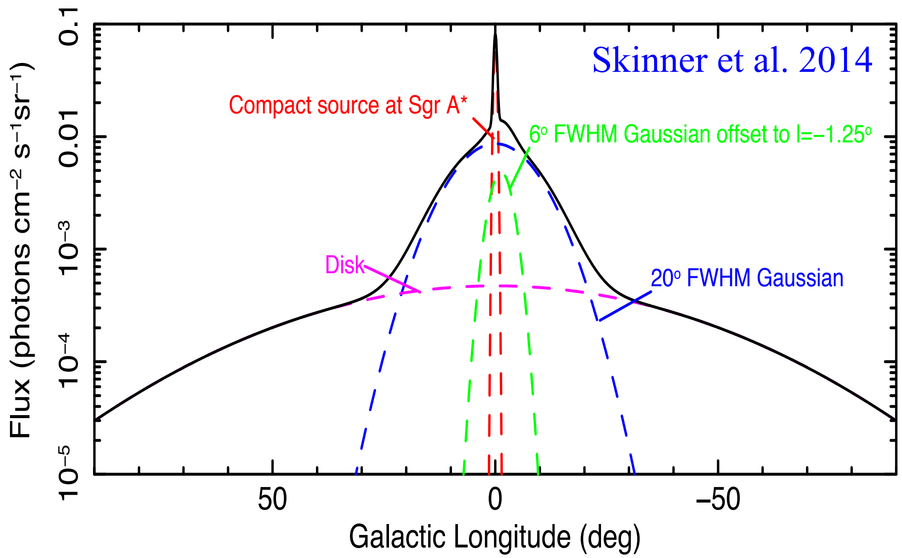
5. Galactic positron annihilation radiation: *Nikos Prantzos, Pierre Jean, Jordi Isern, and Vincent Tatischeff*

Positron annihilation radiation

- First (and brightest) gamma-ray line detected from outside the solar system (Johnson et al. 1972; Leventhal et al. 1978)
- F_{511} = 2.7 × 10^{-3} ph cm^{-2} s^{-1} => Galactic positron annihilation rate of ~ 5 × 10^{43} s^{-1}
- Three distinct annihilation regions in the Galaxy: disc, bulge and center (nucleus) (Skinner et al. 2014)
- Bulge/disk ratio of ~ 1.4 (Weidenspointer et al. 2008) now reduced to 0.58 ± 0.13 with the detection of more low surface brightness emission (Siegert et al. 2016)

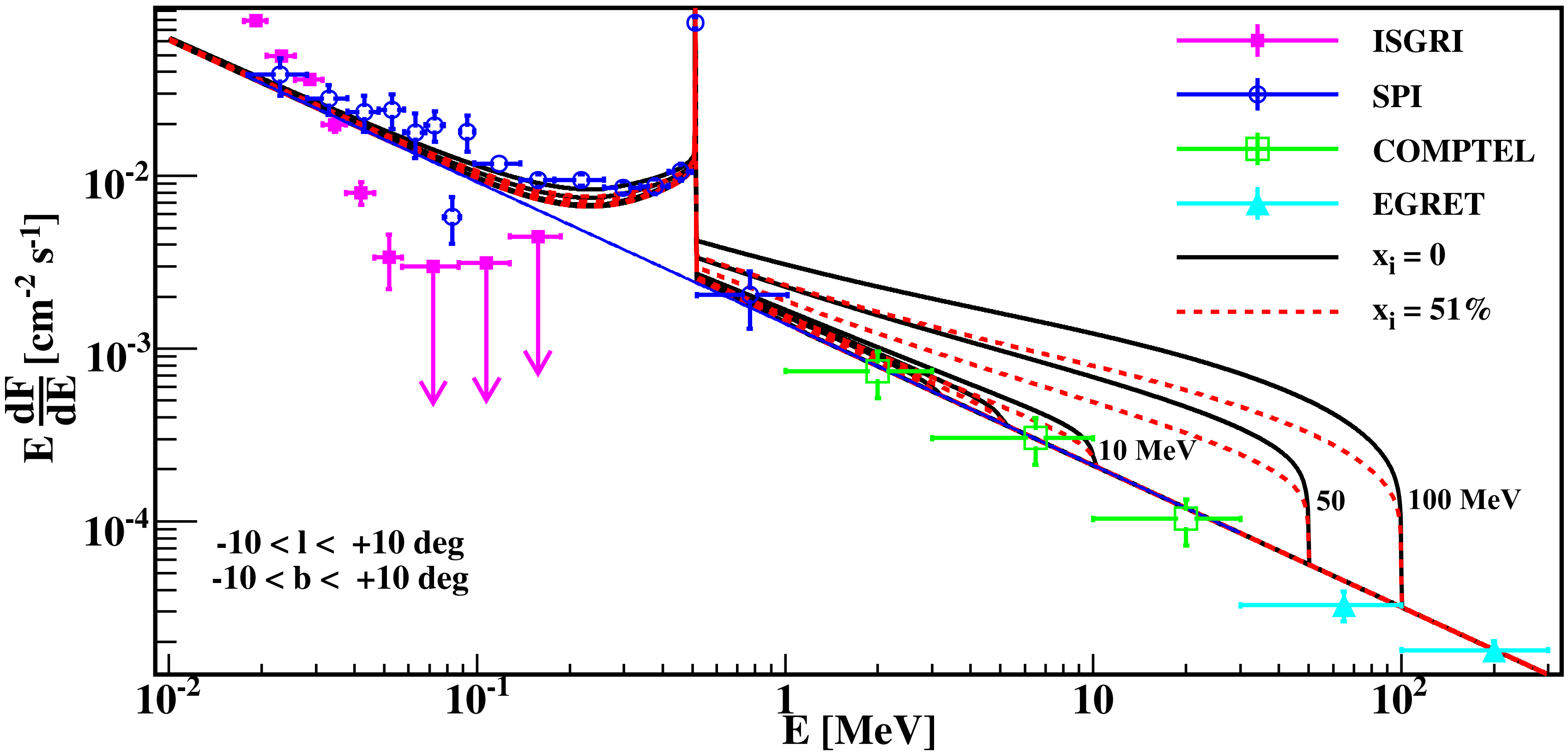


Siegert et al. 2016



e-ASTROGAM Annihilation in flight

- Diffuse emission in the 1 - 100 MeV range constraints the energy of the released positrons, because of the continuum radiation from in-flight annihilation, E_{e+} < 3 MeV (Beacom & Yuksel 2005), E_{e+} < 7.5 MeV (Sizun et al. 2006)
- Rules out e$^+$ production in cosmic-ray interactions (p + p), in pulsars and magnetars (γ + γ, γ + B), as well as from "canonical" (i.e. GeV) dark matter annihilation/decay



Candidate positron sources

From Prantzos et al. 2011, Rev. Mod. Phys.

Source	Process	$E(e^+)$[a] (MeV)	e^+ rate[b] $\dot{N}_{e^+}$ (10^{43} s^{-1})	Bulge/disk[c] B/D		Comments
Massive stars: ^{26}Al	β^+ decay	$\sim$1	0.4	<0.2	✔	$\dot{N}$, B/D: Observationally inferred
Supernovae: ^{24}Ti	β^+ decay	$\sim$1	0.3	<0.2		$\dot{N}$: Robust estimate
SNIa: ^{56}Ni	β^+ decay	$\sim$1	2	<0.5	?	Assuming $f_{e^+,esc} = 0.04$
~~Novae~~	~~β^+ decay~~	~~$\sim$1~~	~~*0.02*~~	~~<0.5~~		Insufficient e^+ production
~~Hypernovae/GRB: ^{56}Ni~~	~~β^+ decay~~	~~$\sim$1~~	~~?~~	~~<0.2~~		Improbable in inner MW
~~Cosmic rays~~	~~p-p~~	~~$\sim$30~~	~~0.1~~	~~<0.2~~		Too high e^+ energy
LMXRBs	γ-γ	$\sim$1	*2*	<0.5	?	Assuming $L_{e^+} \sim 0.01\ L_{obs,X}$
Microquasars (μQs)	γ-γ	$\sim$1	*1*	<0.5		e^+ load of jets uncertain
~~Pulsars~~	~~γ-γ/γ-γ_B~~	~~>30~~	~~*0.5*~~	~~<0.2~~		Too high e^+ energy
~~ms pulsars~~	~~γ-γ/γ-γ_B~~	~~>30~~	~~*0.15*~~	~~<0.5~~		Too high e^+ energy
~~Magnetars~~	~~γ-γ/γ-γ_B~~	~~>30~~	~~*0.16*~~	~~<0.2~~		Too high e^+ energy
Central black hole	p-p	High	?			Too high e^+ energy, unless $B > 0.4$ mG
	γ-γ	1	?		?	Requires e^+ diffusion to $\sim$1 kpc
Dark matter	Annihilation	1 (?)	?			Requires light scalar particle, cuspy DM profile
	Deexcitation	1	?			Only cuspy DM profiles allowed
	~~Decay~~	~~1~~	~~?~~			Ruled out for all DM profiles
Observational constraints		<7	2	>1.4		

Positrons from a rare class of SN Ia?

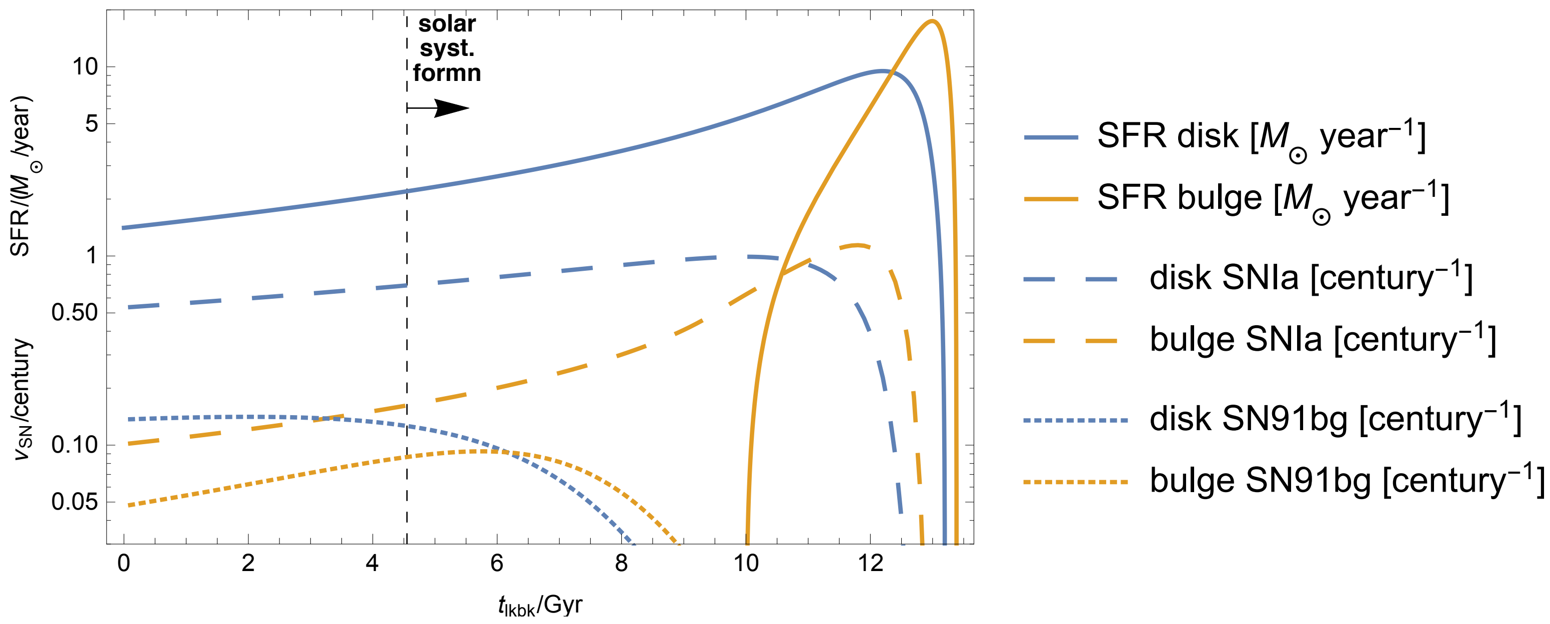
Crocker et al. 2017, Nature Astronomy, vol. 1, id. 0135

- With the revised upwards disk contribution (Siegert et al. 2016), both the bulge/disk and nucleus/bulge luminosity ratios are consistent with the stellar mass ratios

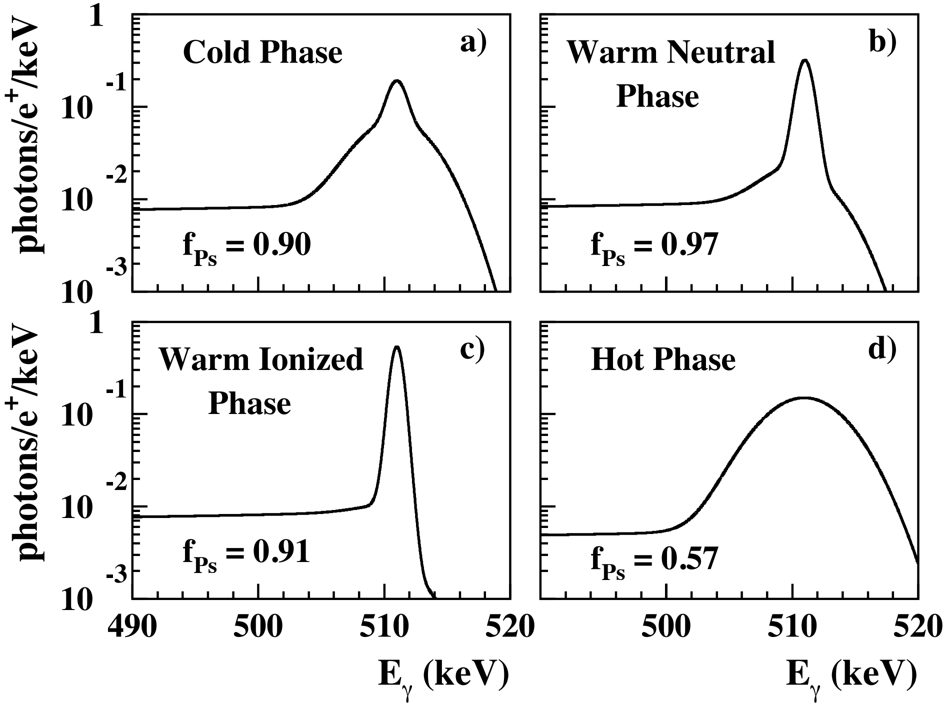
$\Rightarrow$ A single β^+ source connected to old stars could explain the global distribution

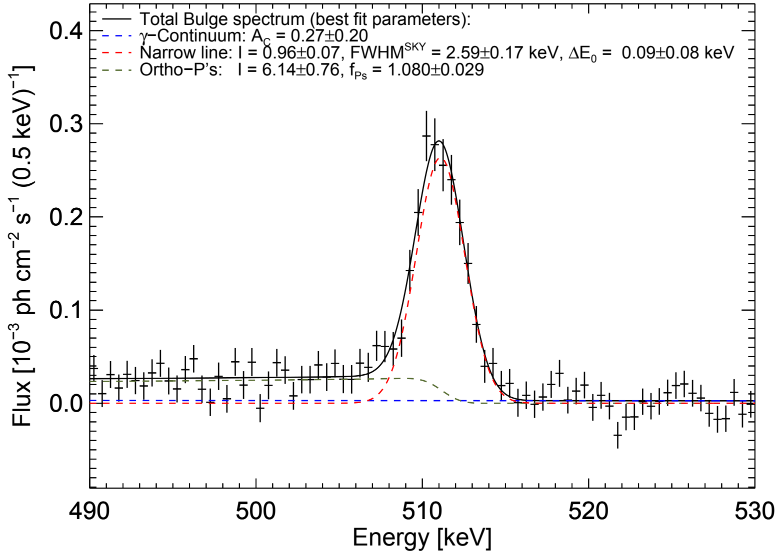
- Proposed source: SN1991bg-like thermonuclear SNe producing ~ 0.03 M_{sol} of ^{44}Ti via detonation of CO-He WD binary mergers with a recurrence time of ~ 530 years

$\Rightarrow$ May also explain the lack of ^{44}Ti-emitting SNRs and the solar system abund. of ^{44}Ca

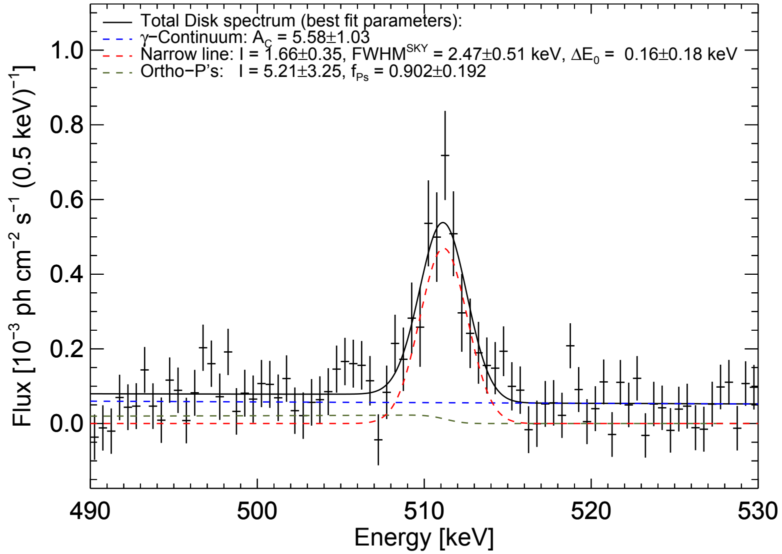


- 511 keV line shape and Ps fraction in the bulge consistent with annihilation in a mixture of warm (T ~ 8000 K) neutral and ionized phases of ISM (Jean et al. 2006)
- Very little is known on the propagation of the positrons from their sources to the region of annihilation





(a) Bulge.



(b) Disk.

e-ASTROGAM Expected results

- e-ASTROGAM will perform a deep Galactic survey of the positron annihilation radiation

⇒ Detailed morphology of the various components (disk, wide bulge, narrow bulge, central source)

⇒ Possible detection of individual star forming regions (e.g. Cygnus)

⇒ Point sources (e.g. microquasars)?

⇒ A single β^+ source (which one?) to explain the global distribution (together with ^{26}Al)?