



POSITRON ANNIHILATION IN THE MILKY WAY:

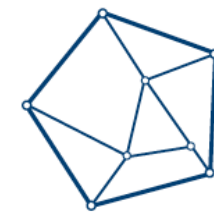
The 511 keV excess

Fiona H. Panther

with Roland Crocker, Yuval
Birnboim, Ivo Seitenzahl and
Ashley Ruitter



Australian
National
University



CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

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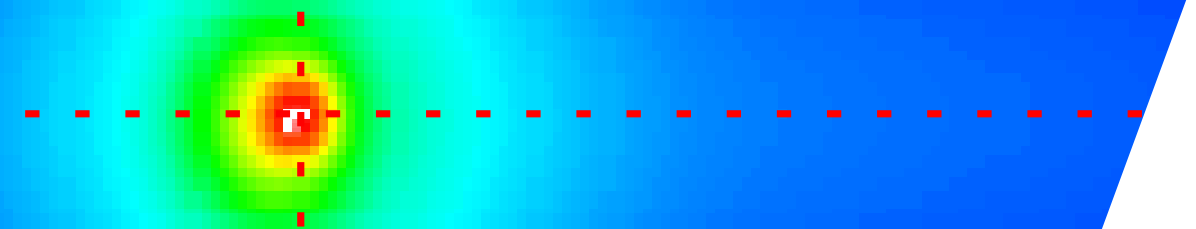
Three Elephants in the Gamma Ray Sky
October 21-24, Garmisch-Partenkirchen

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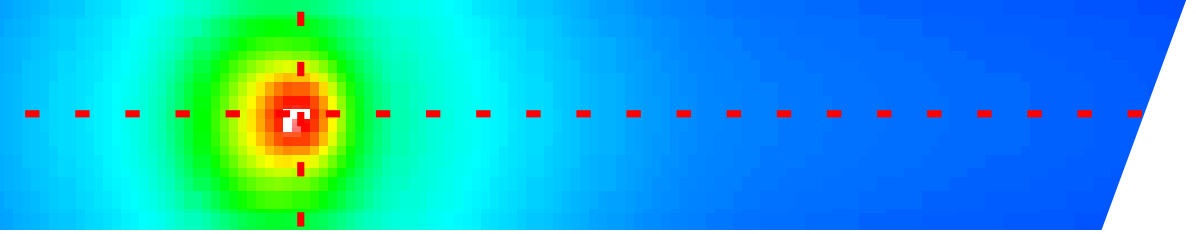


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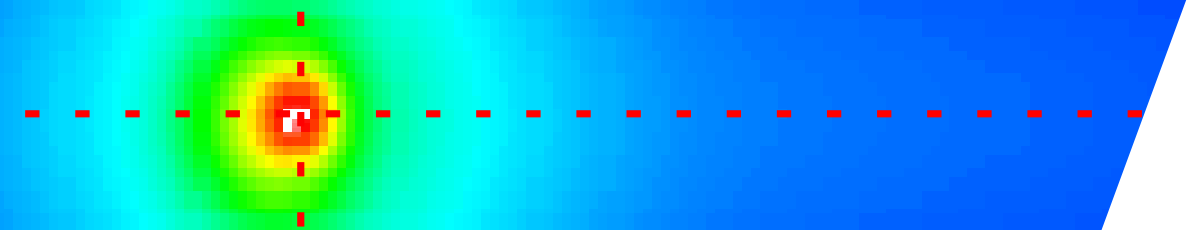
Overview

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$\sim 5 \times 10^{43}$ positrons annihilate each second

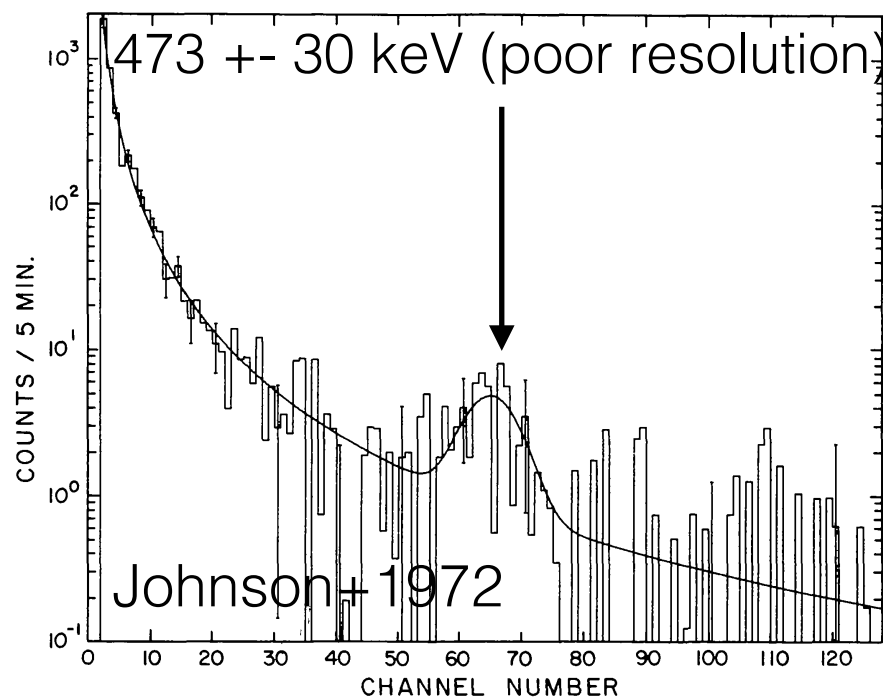
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Second detection -
balloon spectrometer

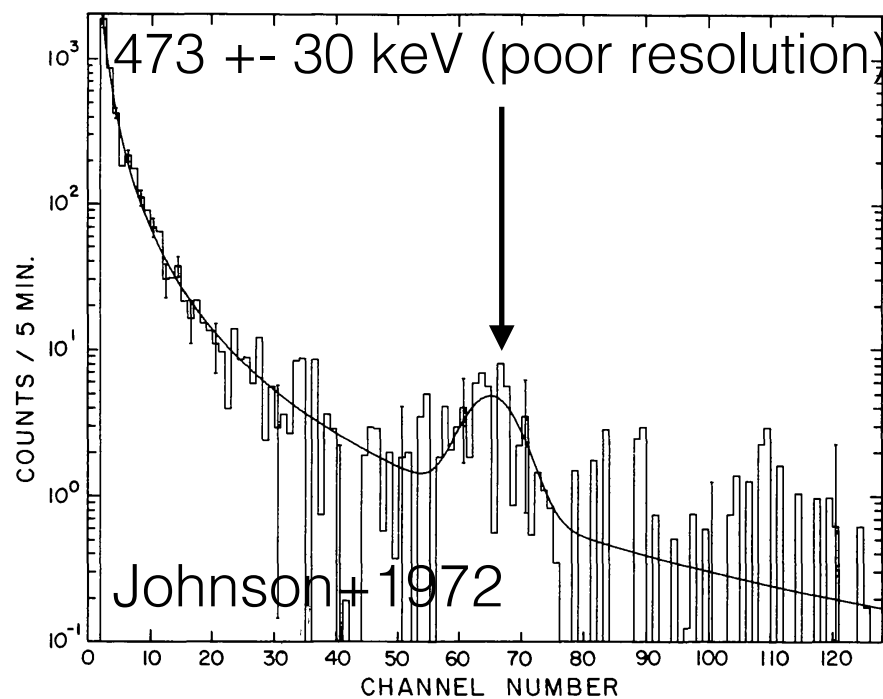
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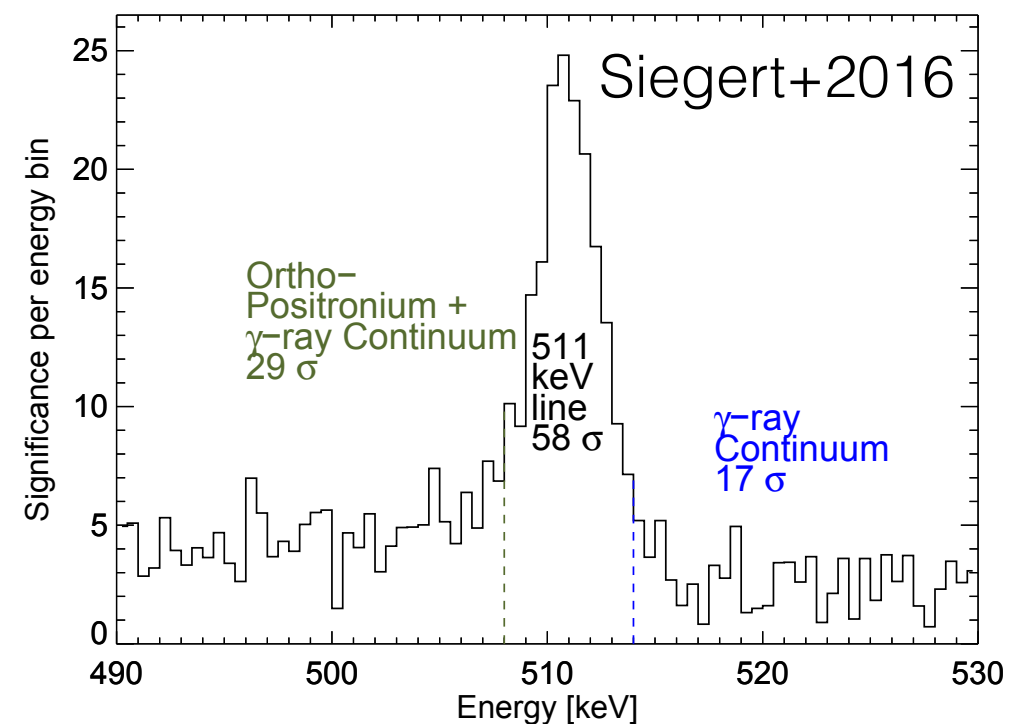
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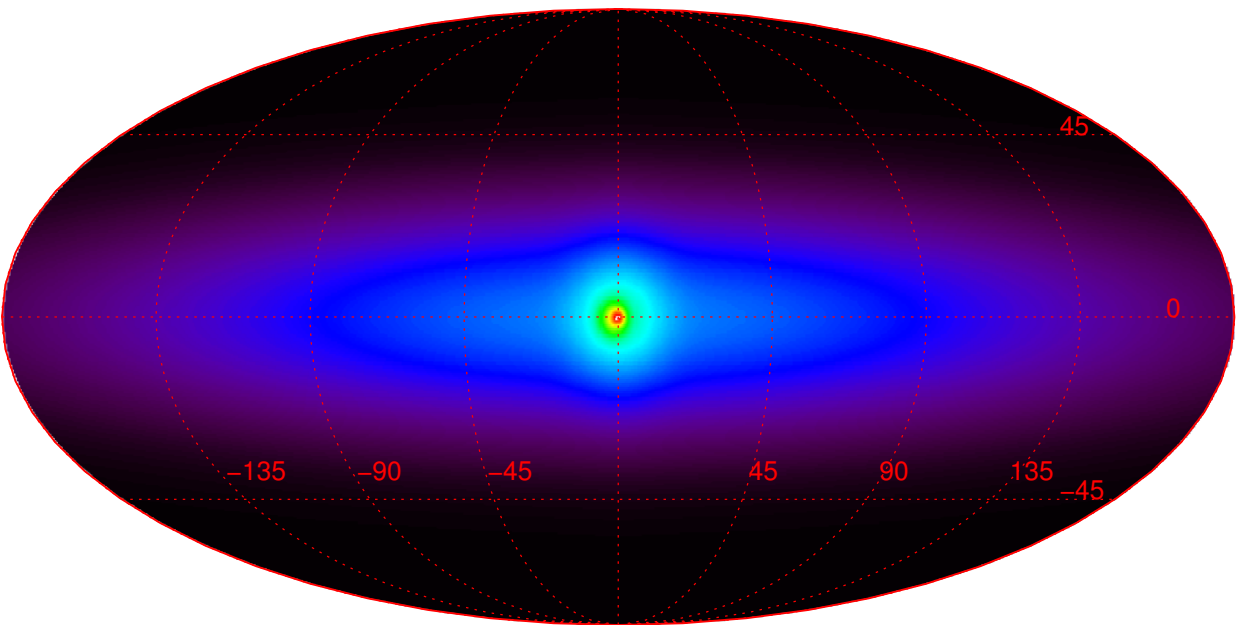
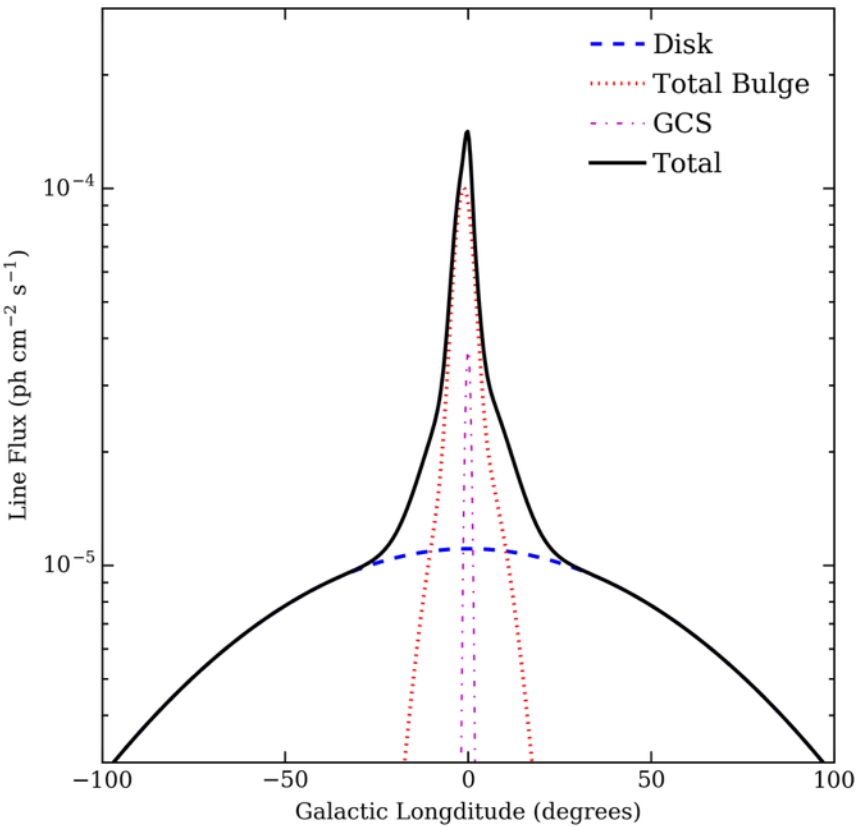
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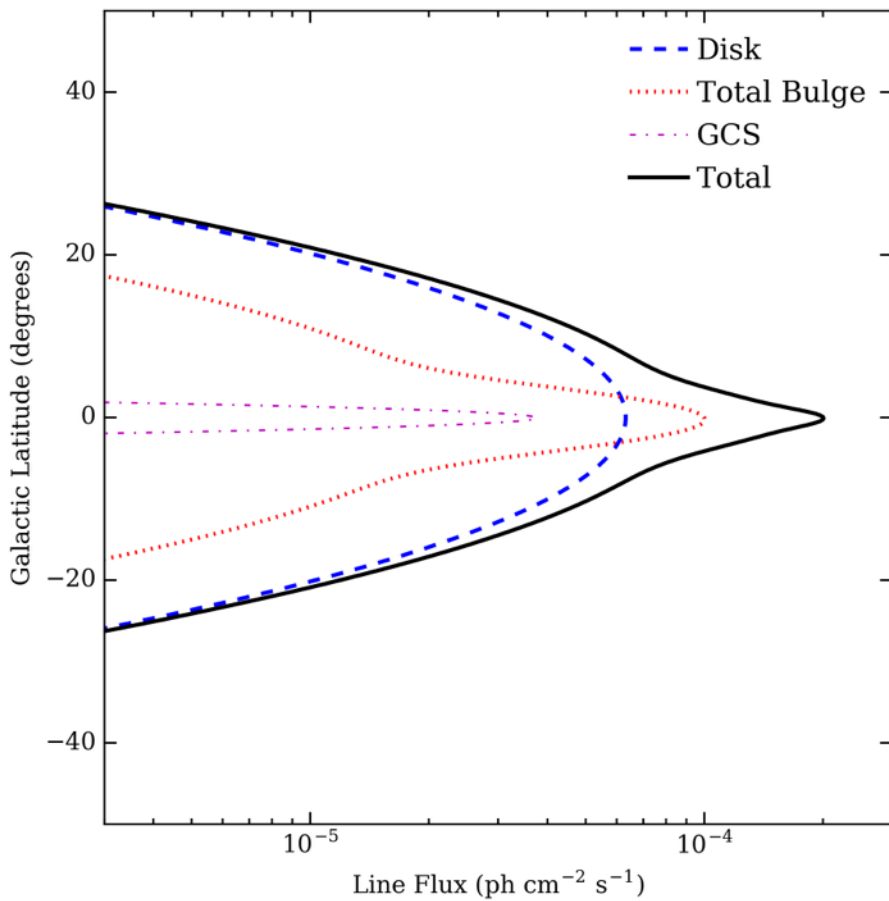
Current observations -
INTEGRAL/SPI

Current Observations

Sky maps:



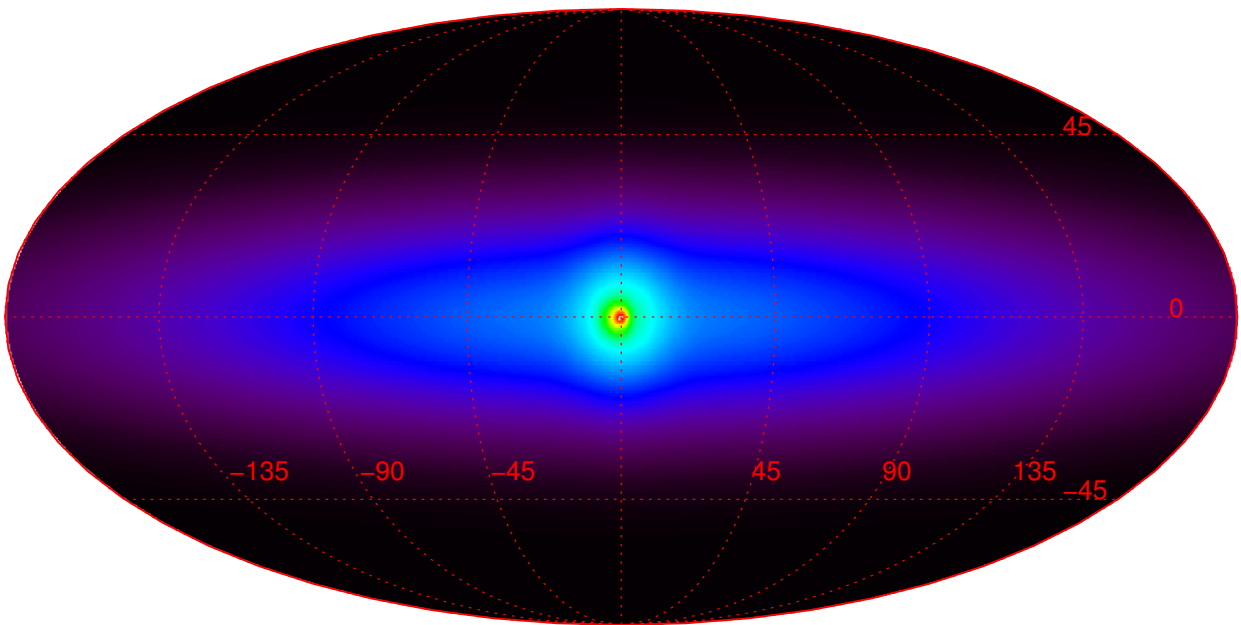
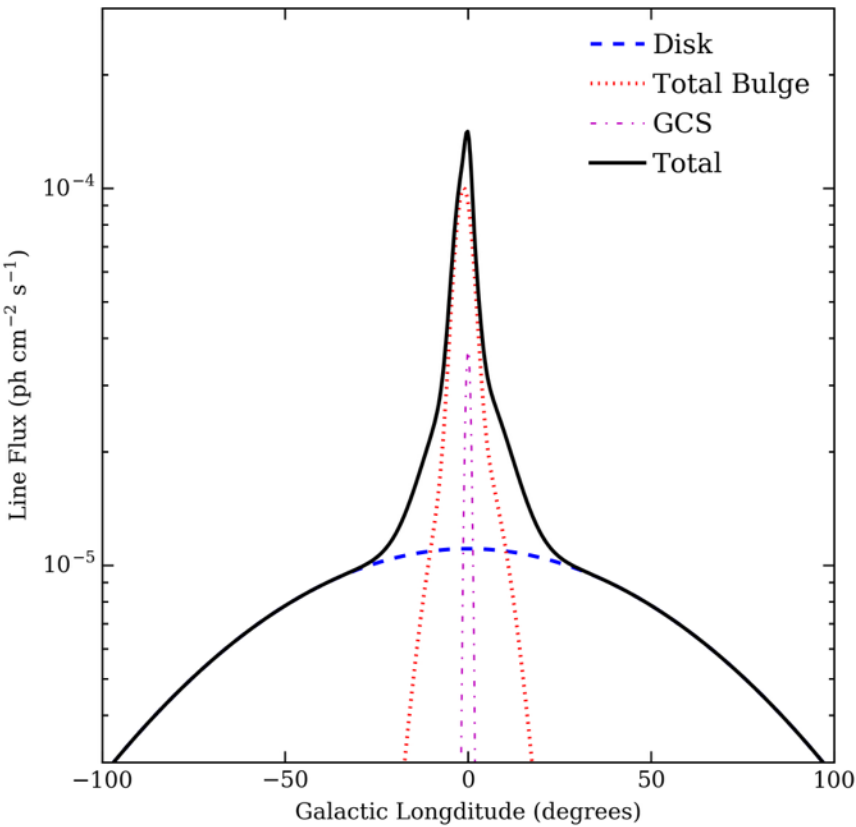
Siegert+2016



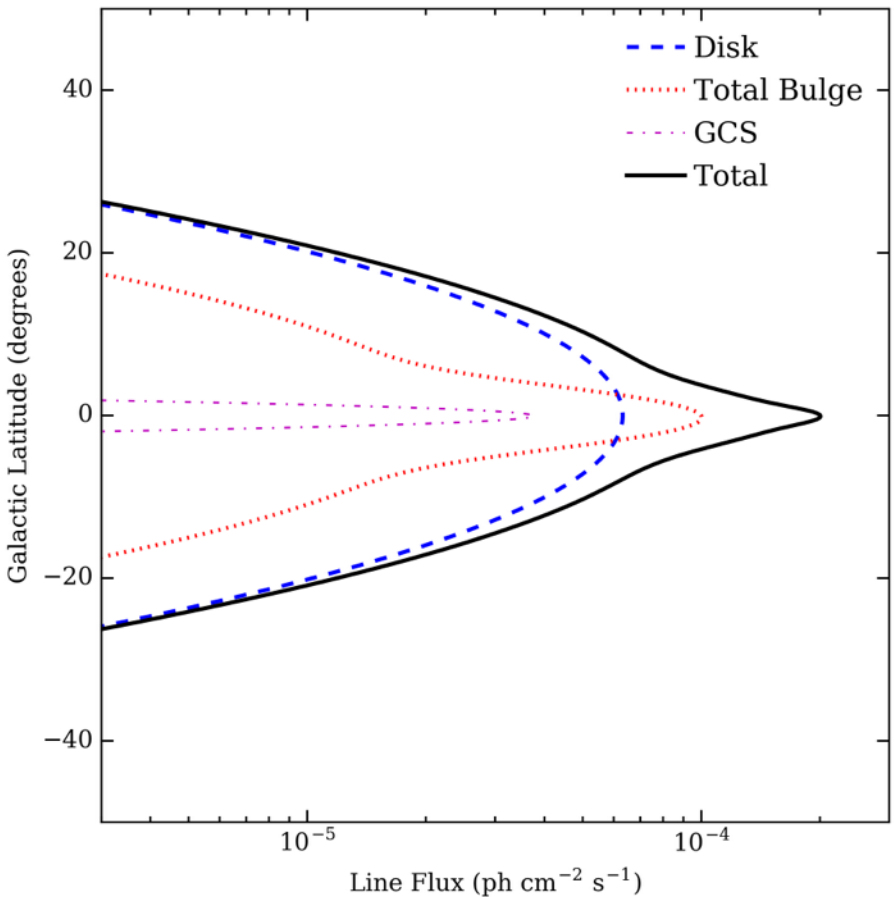
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- **Best fit models** to emission based on specific sky backgrounds



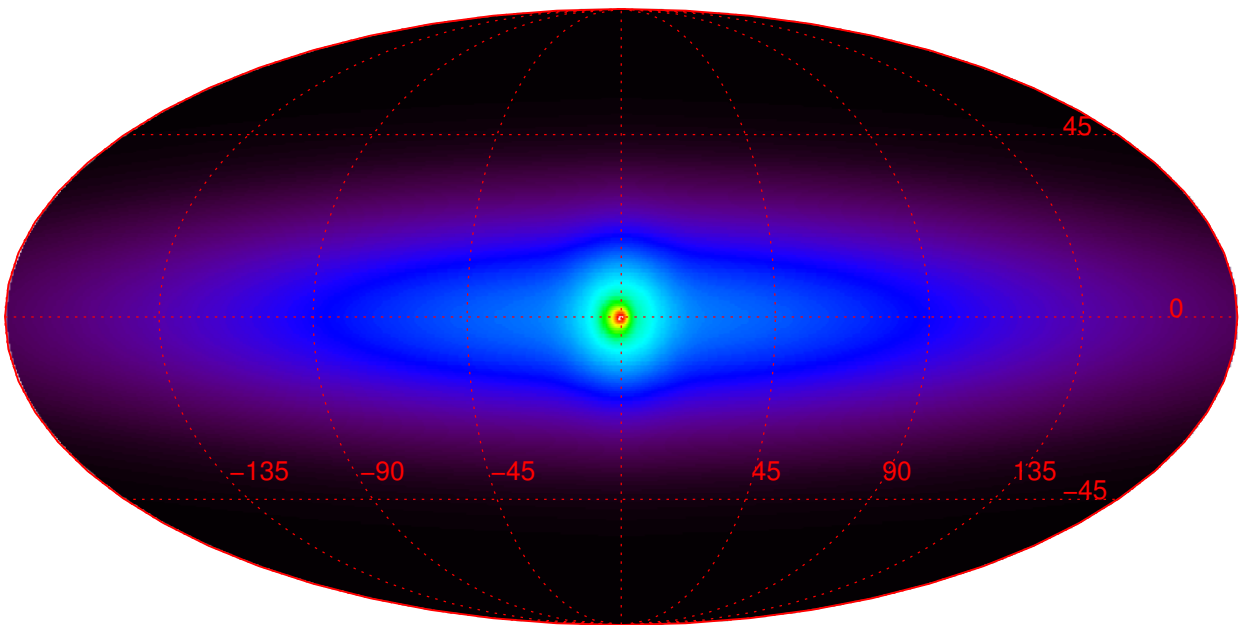
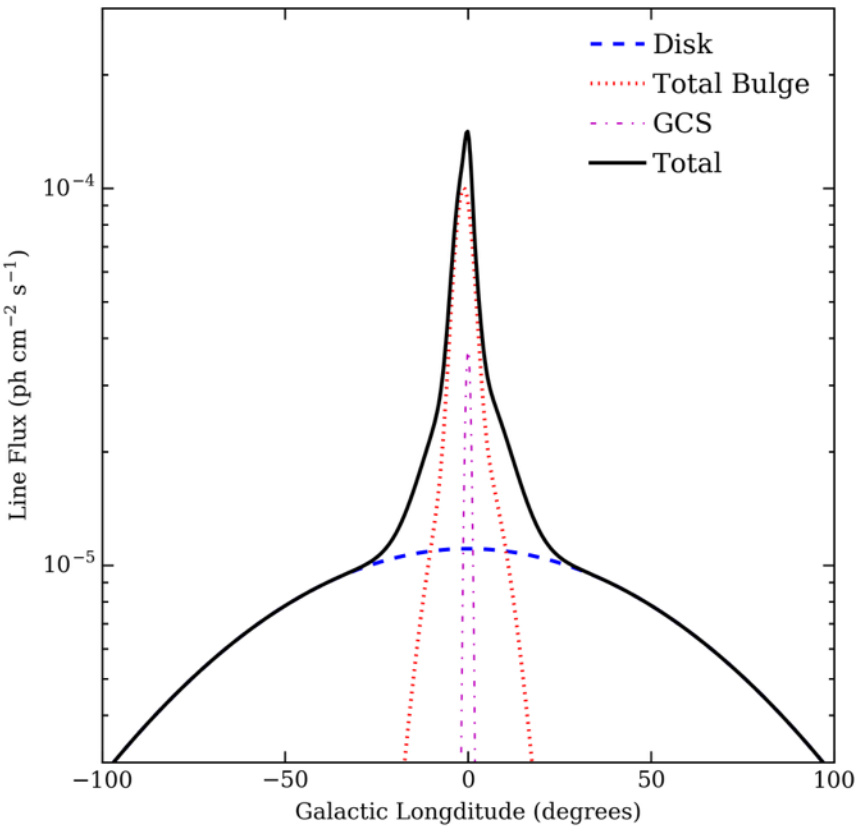
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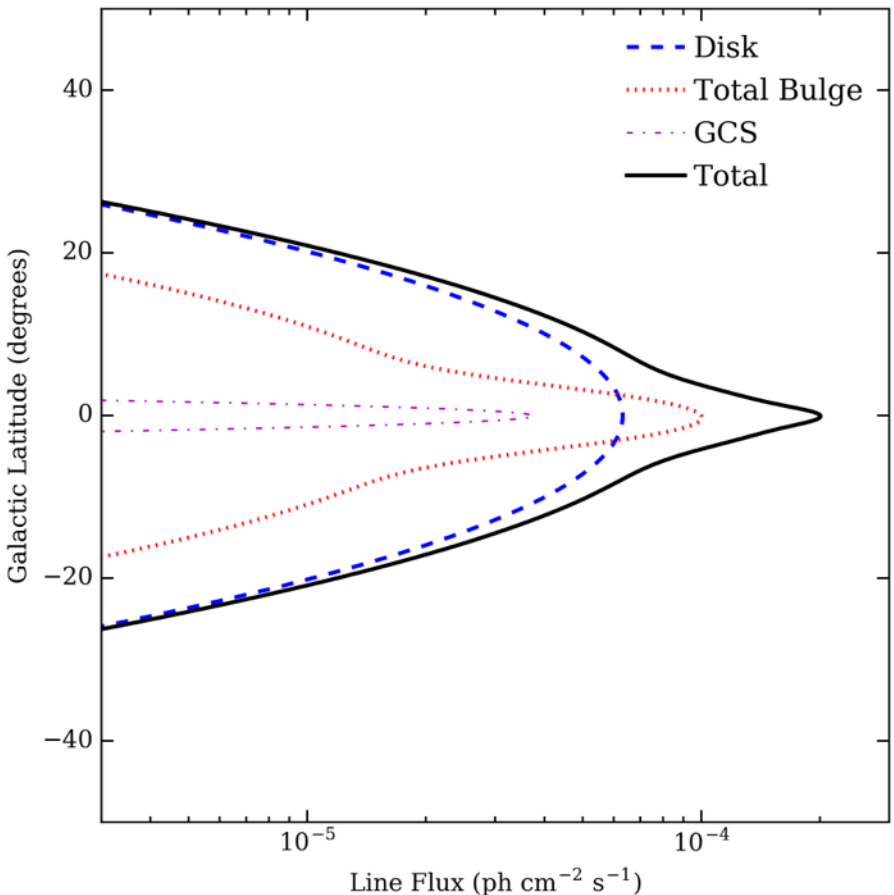
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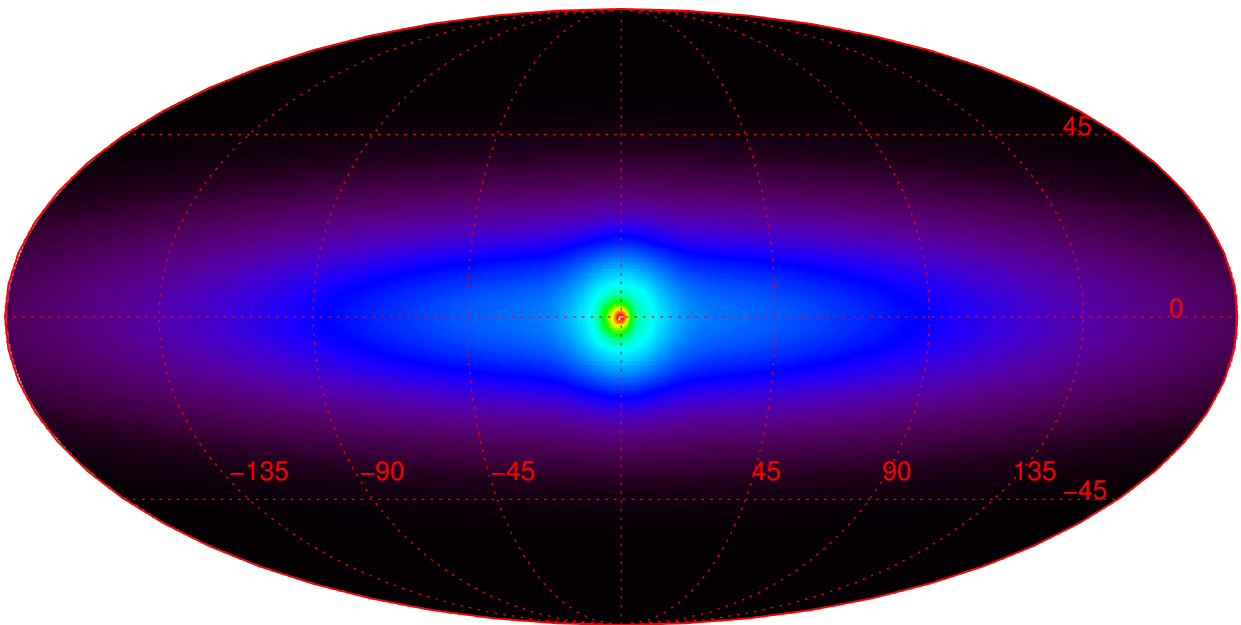
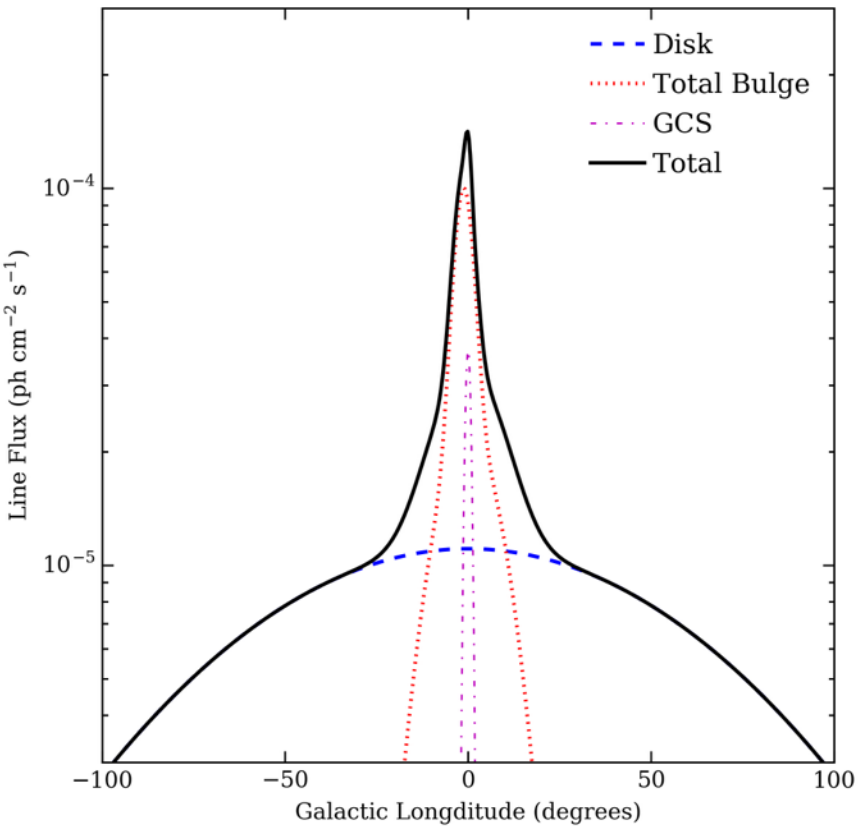
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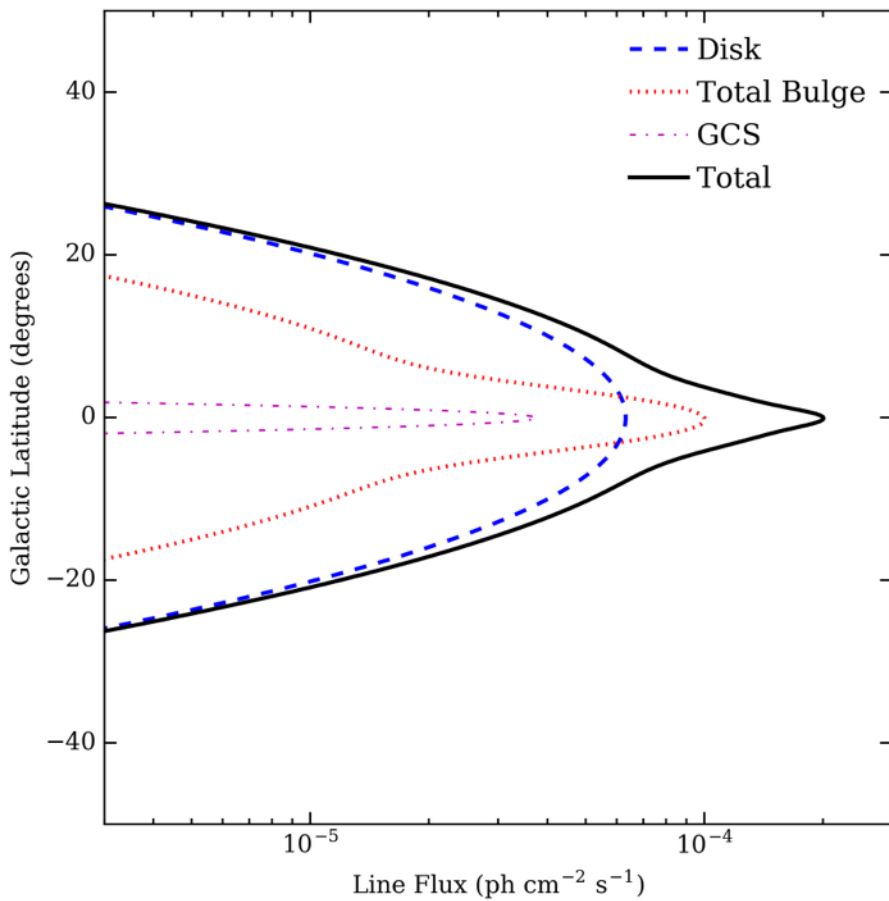
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- Apparent detection of “**Galactic Center Source**” - point source or distributed?



Siegert+2016

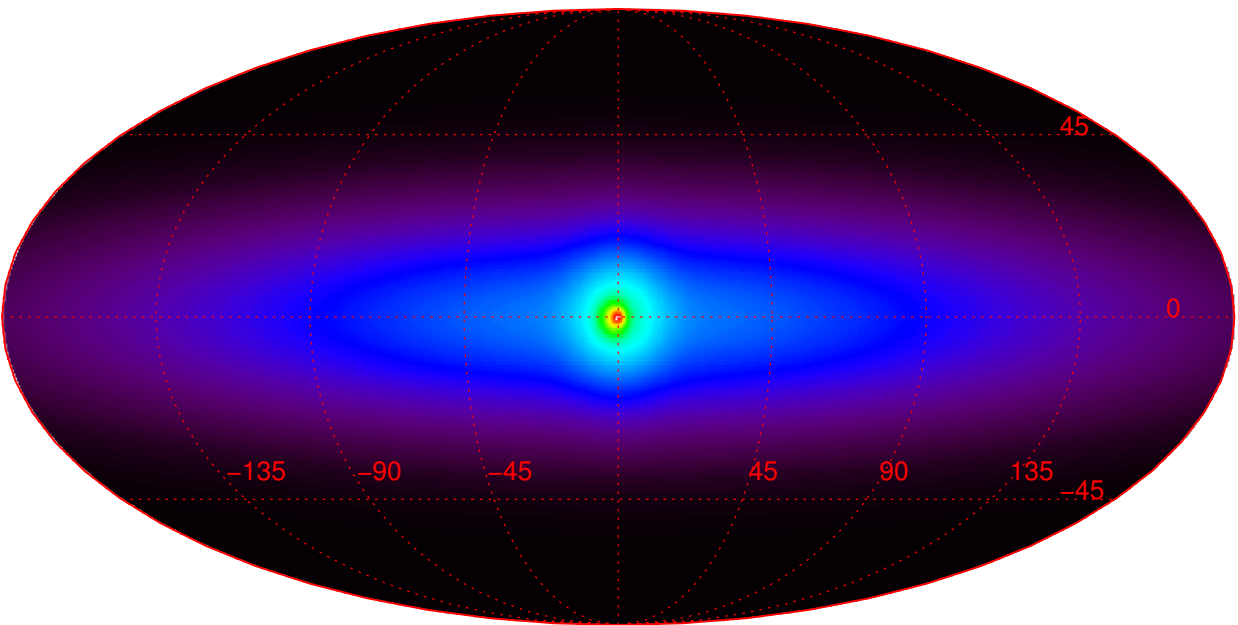
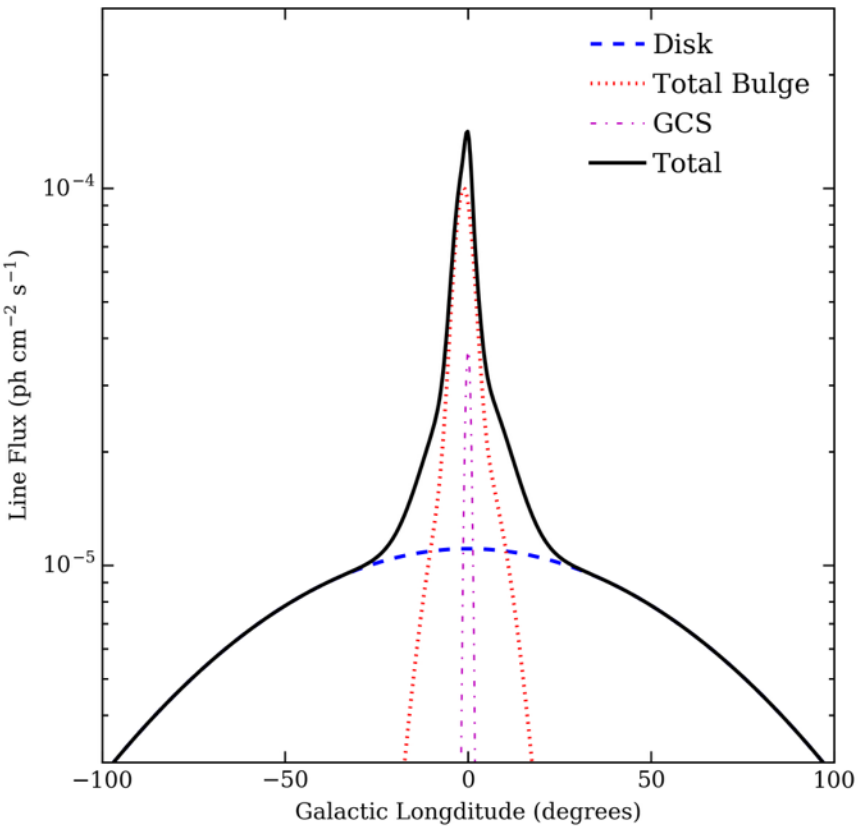


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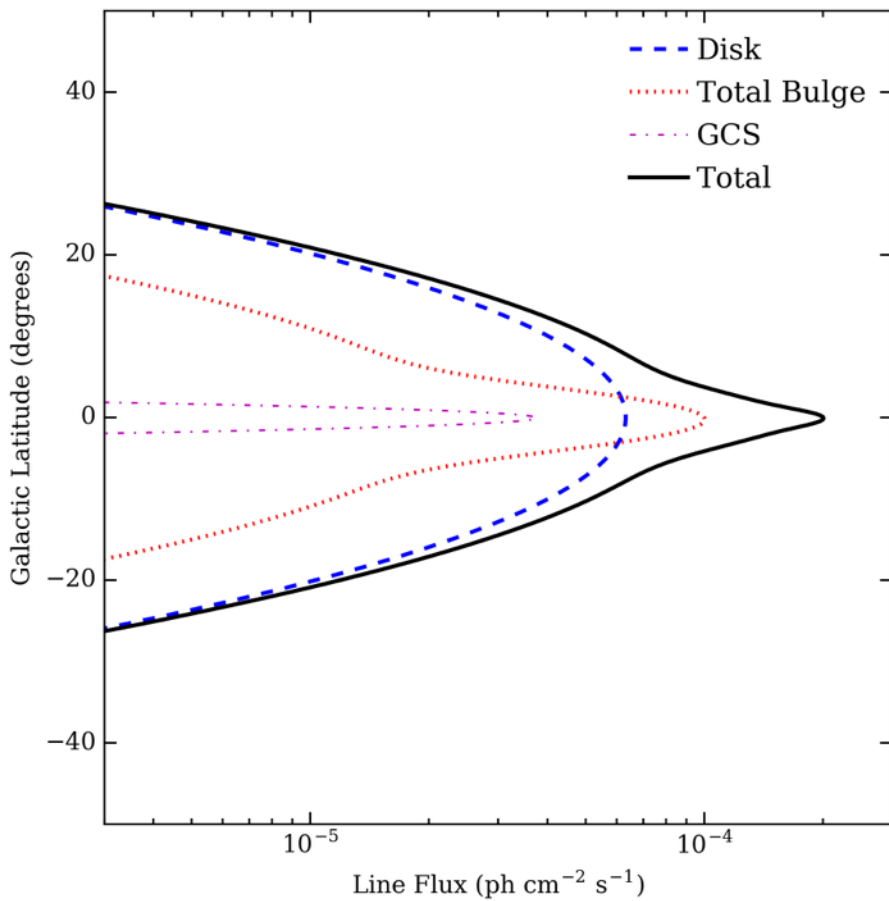
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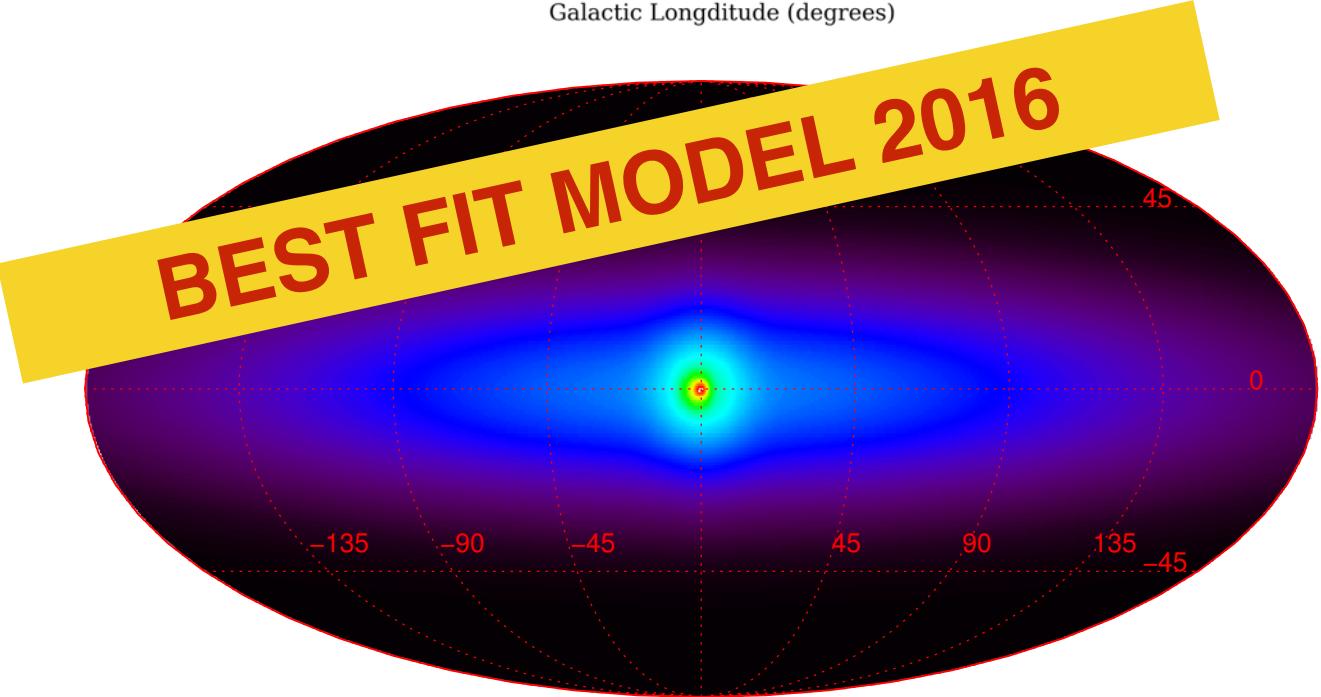
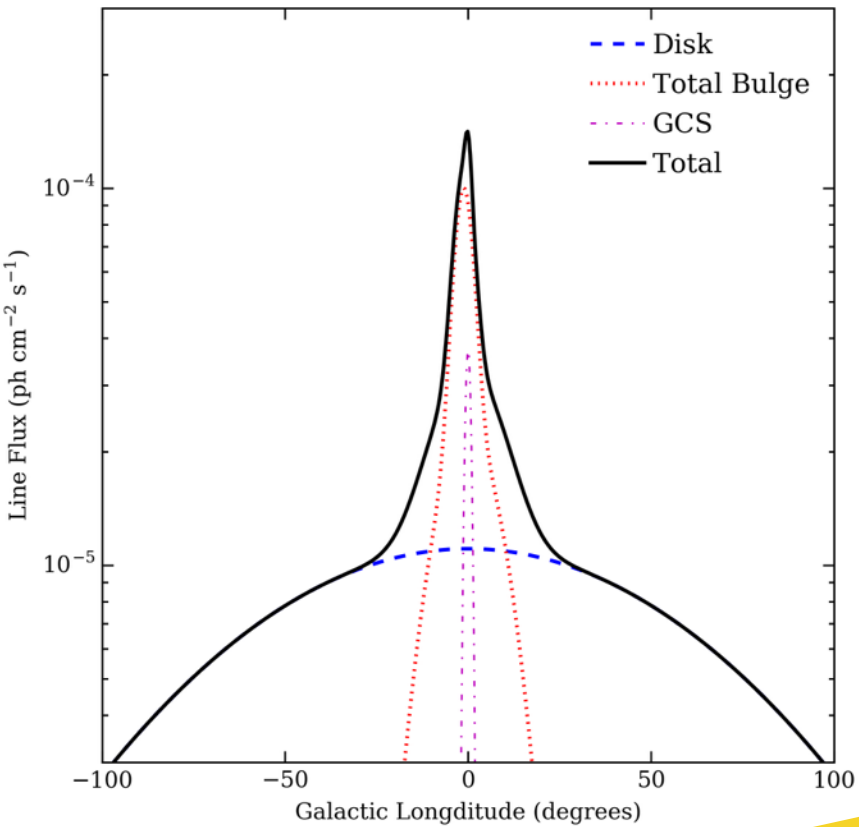


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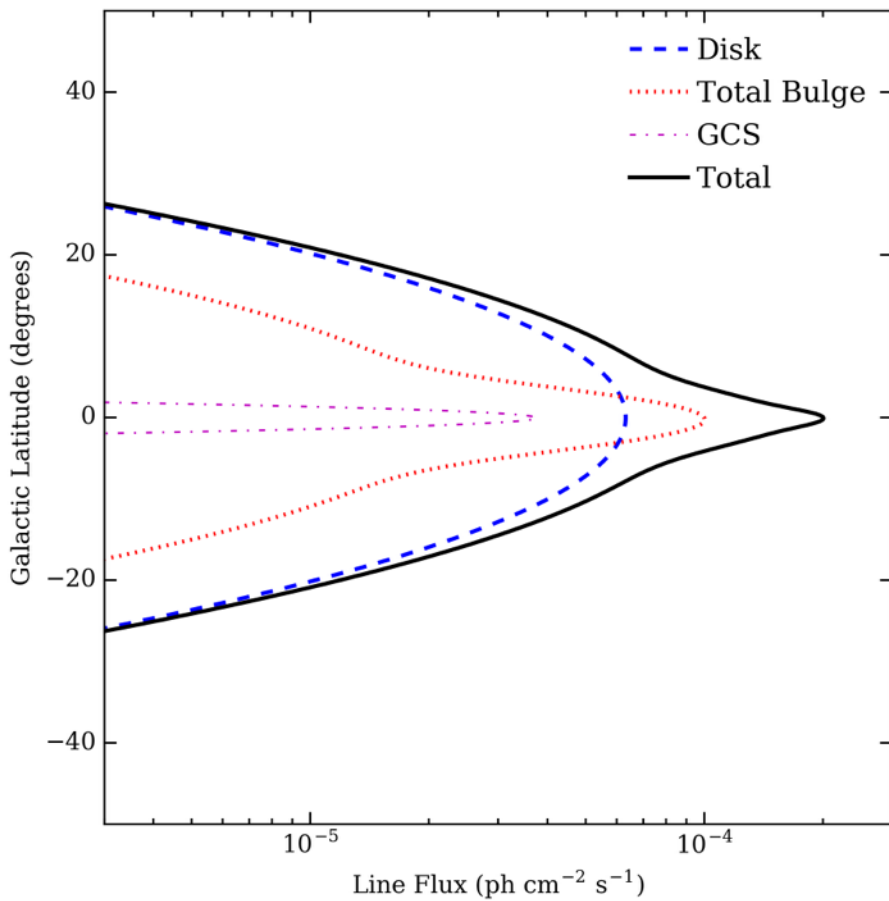
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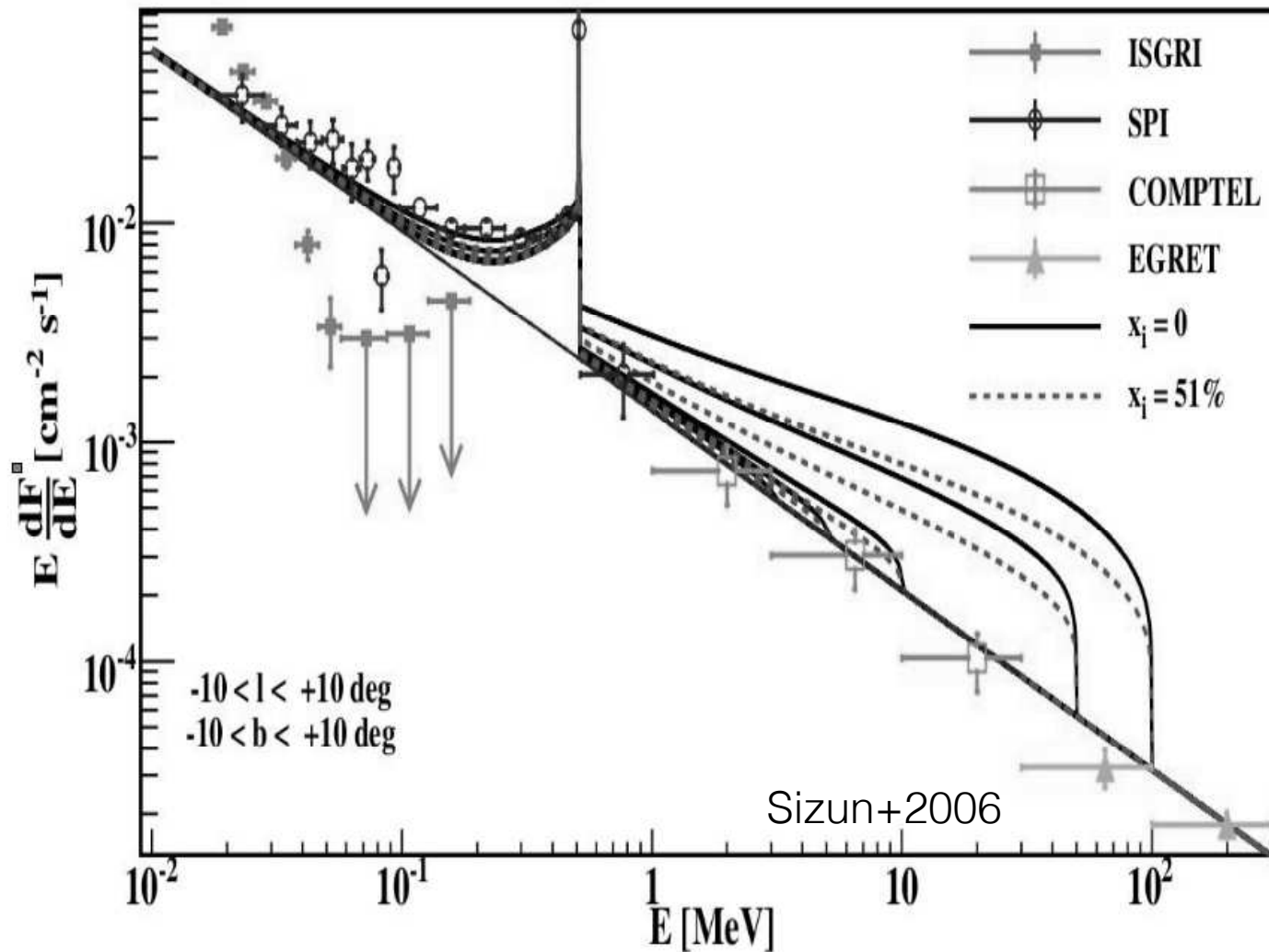


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Spectra:

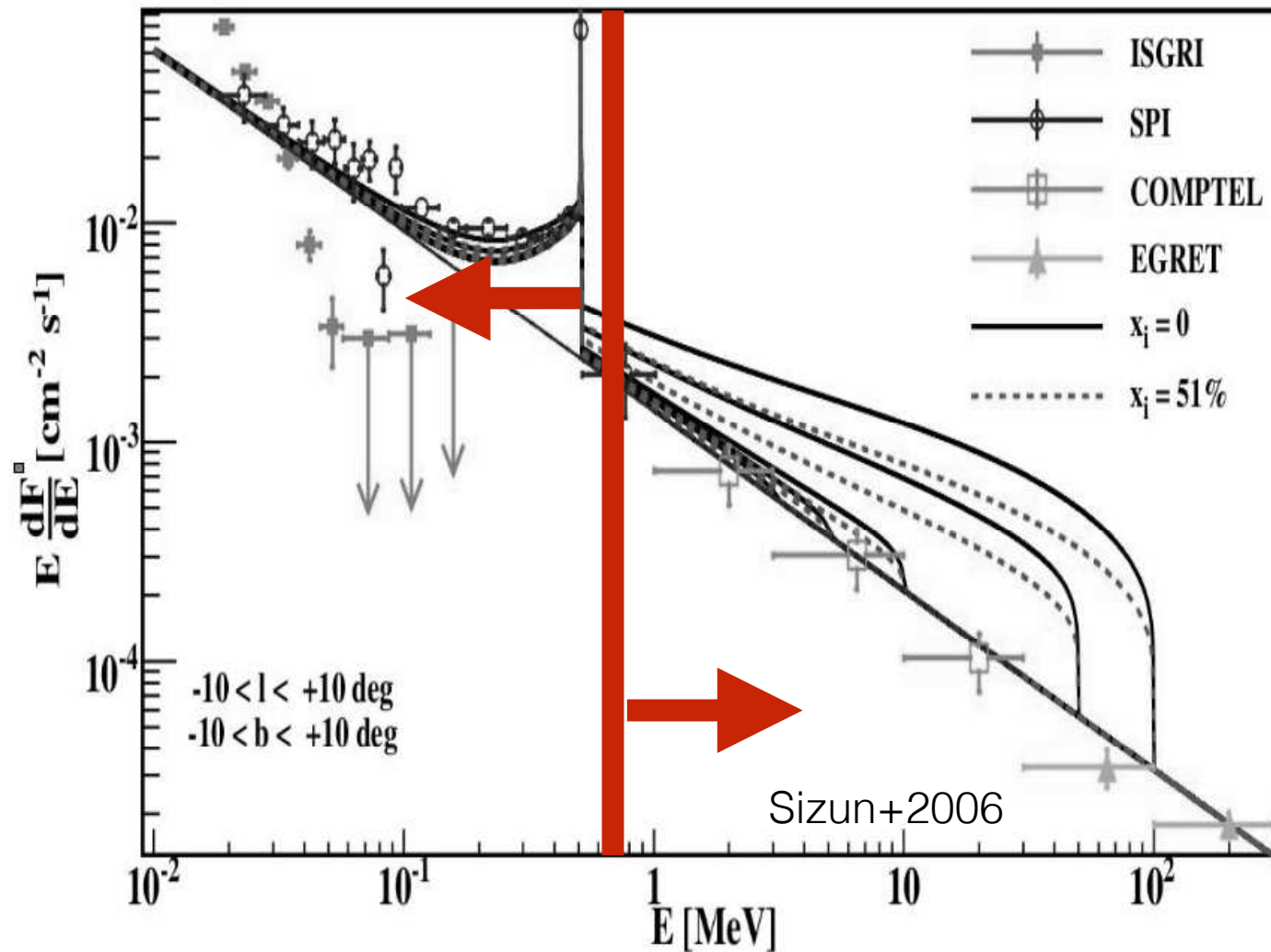
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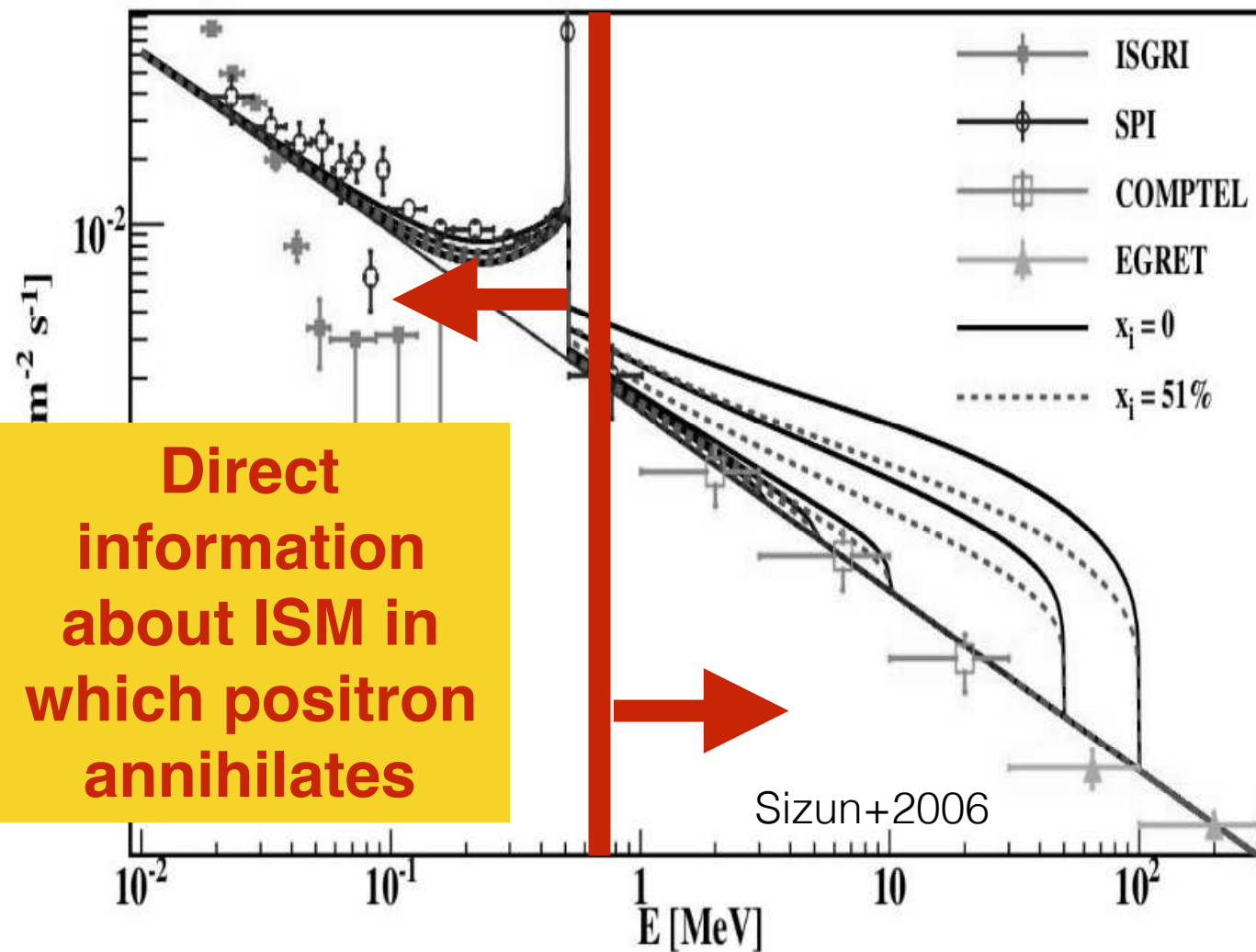
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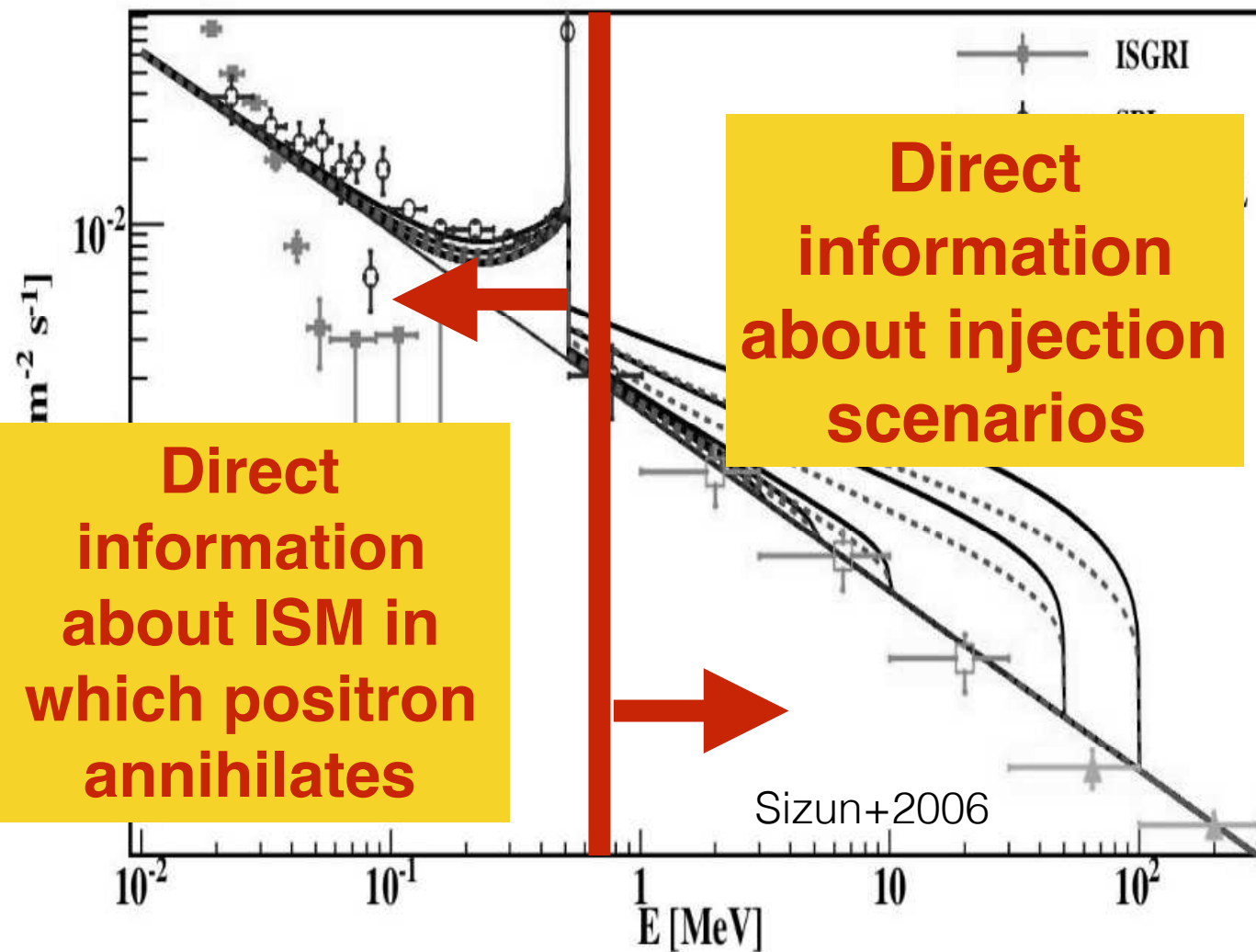
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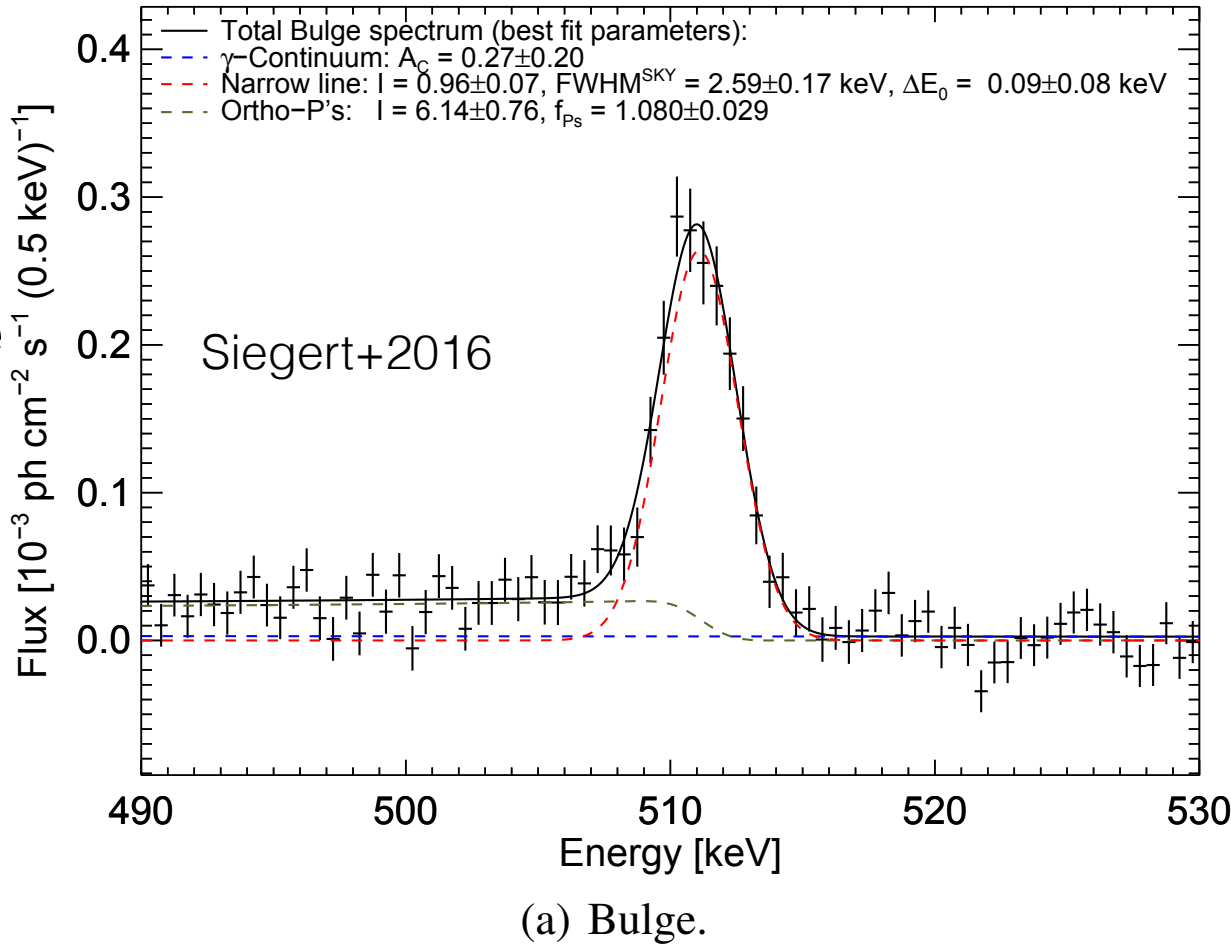
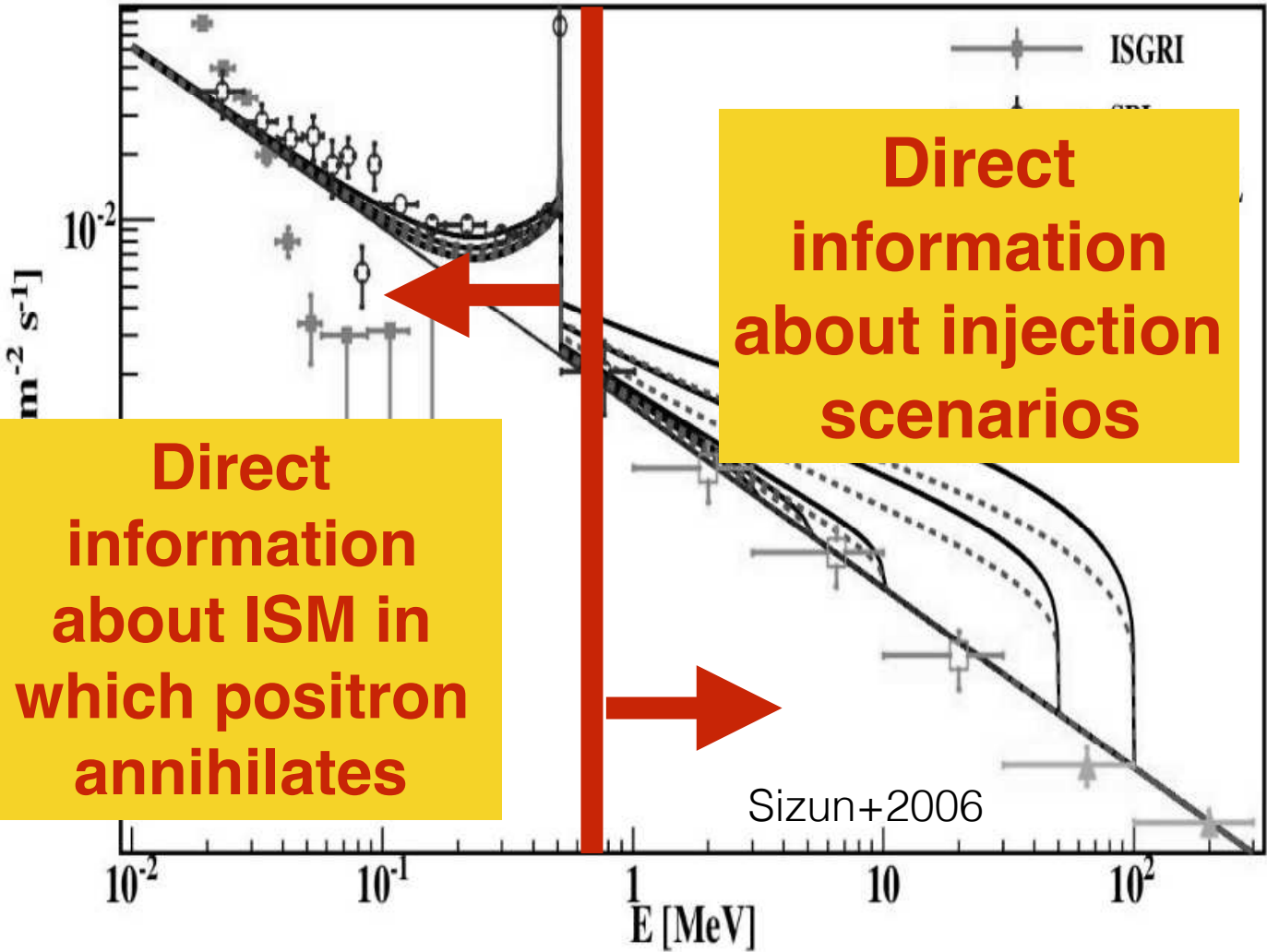
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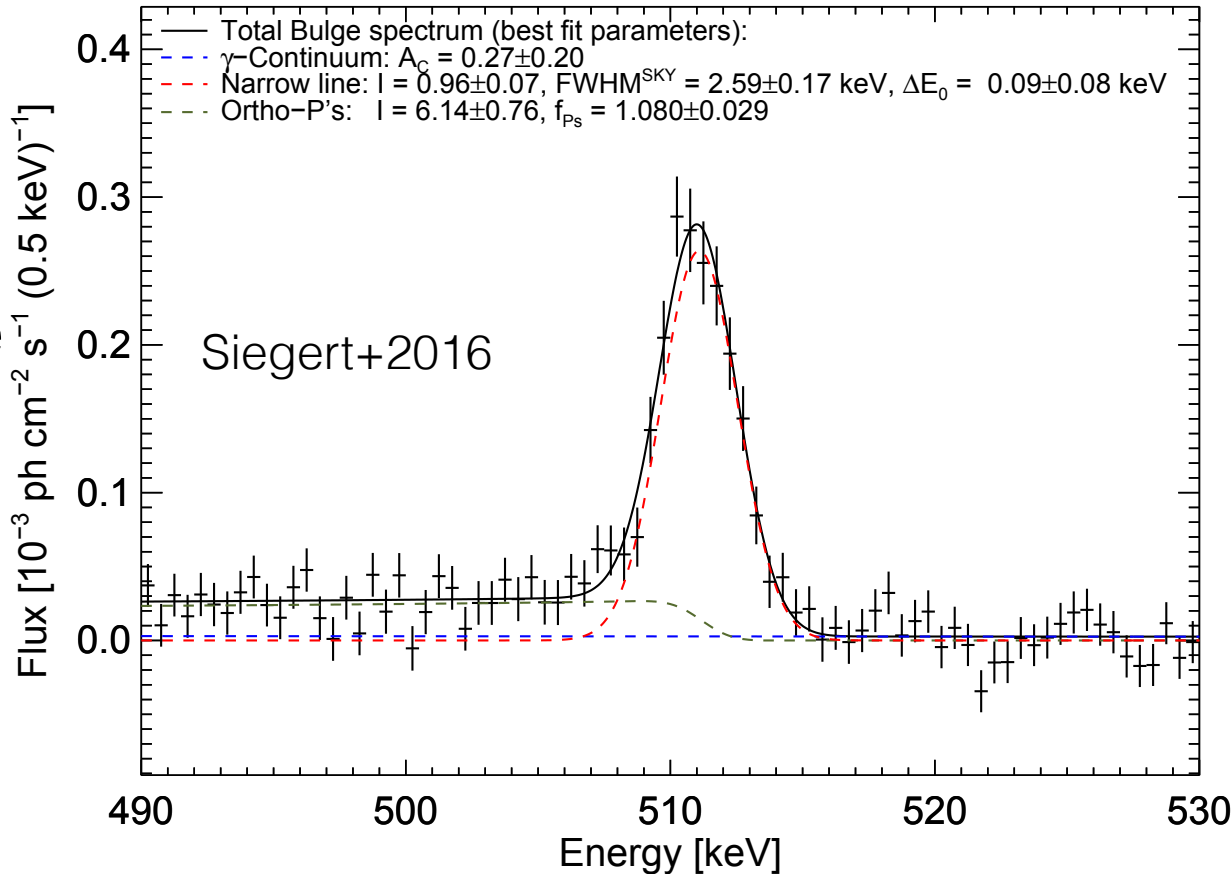
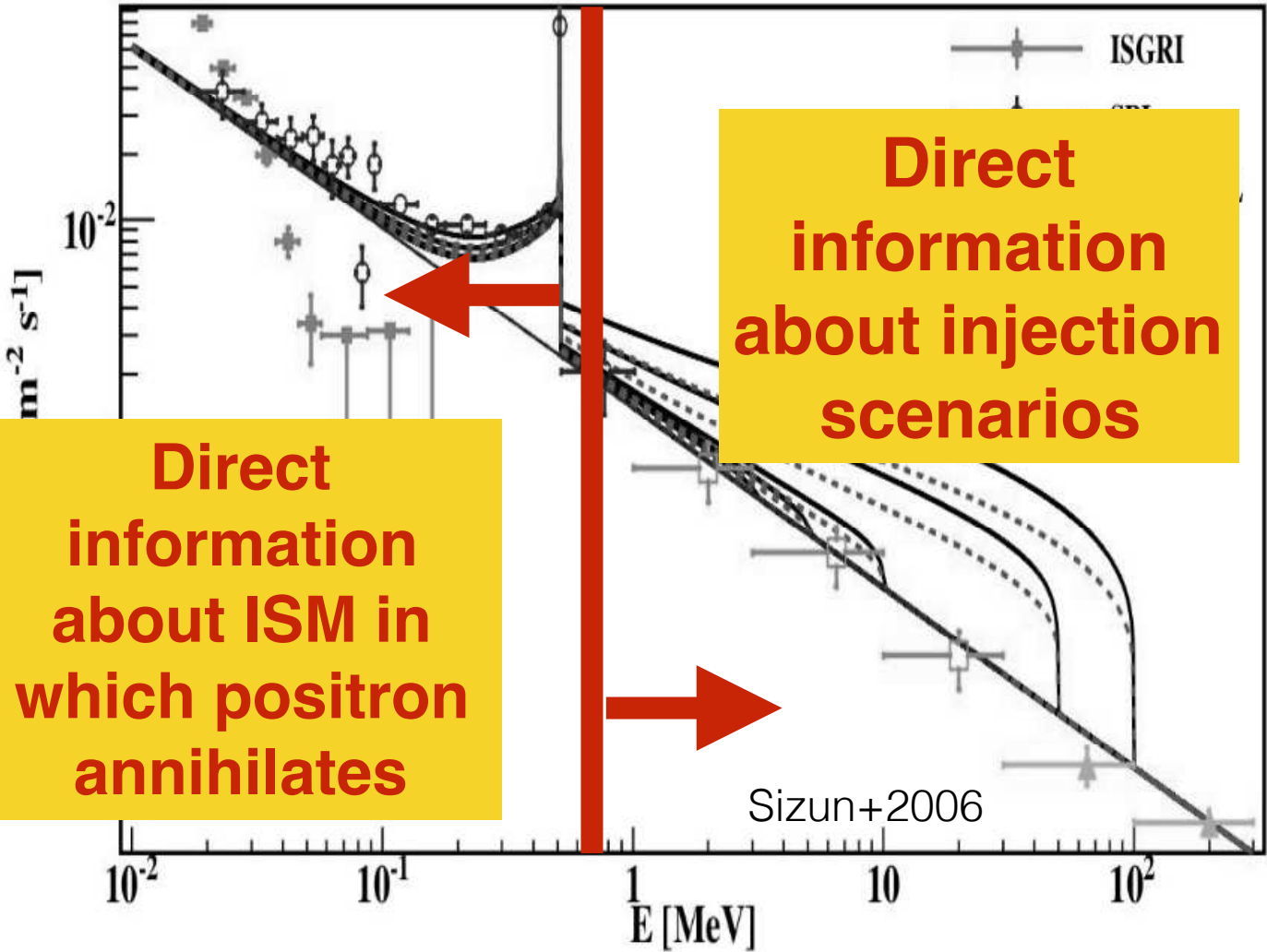
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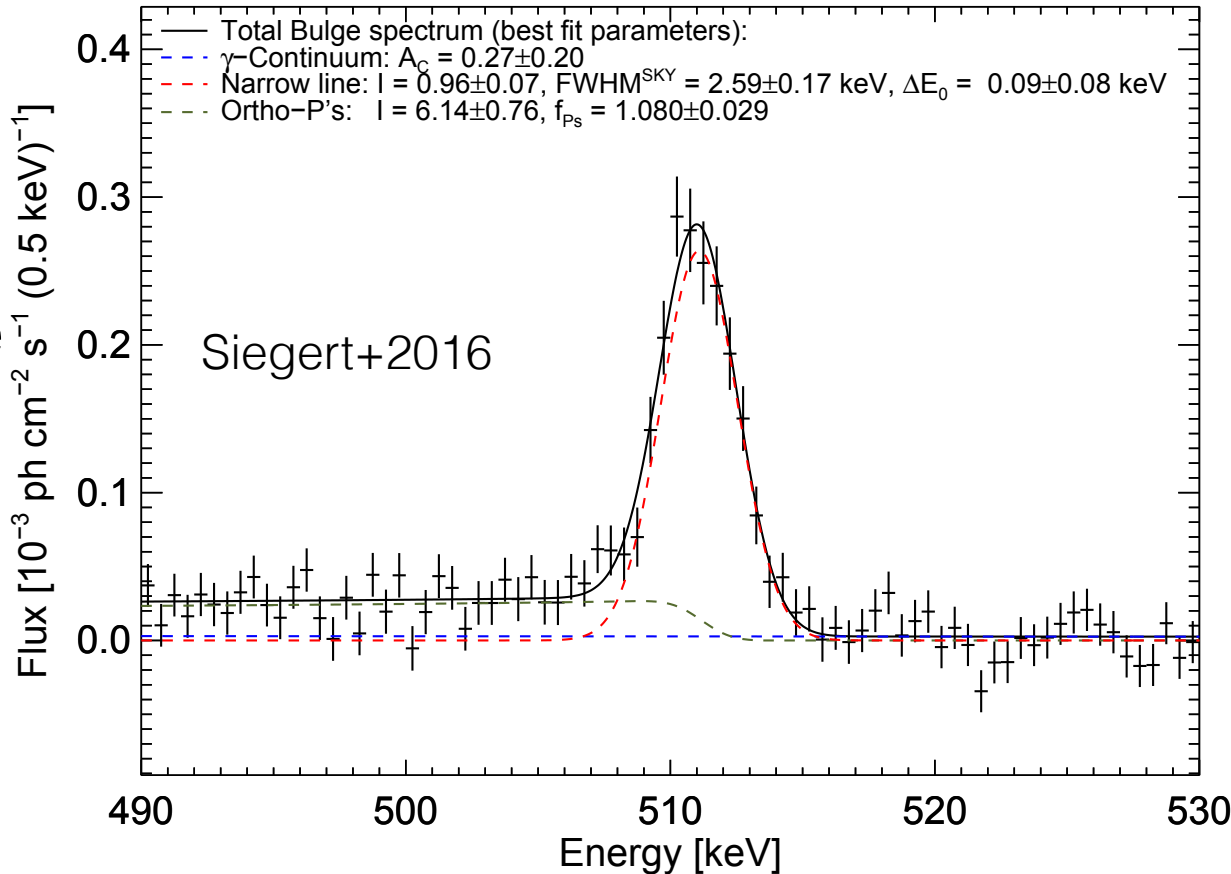
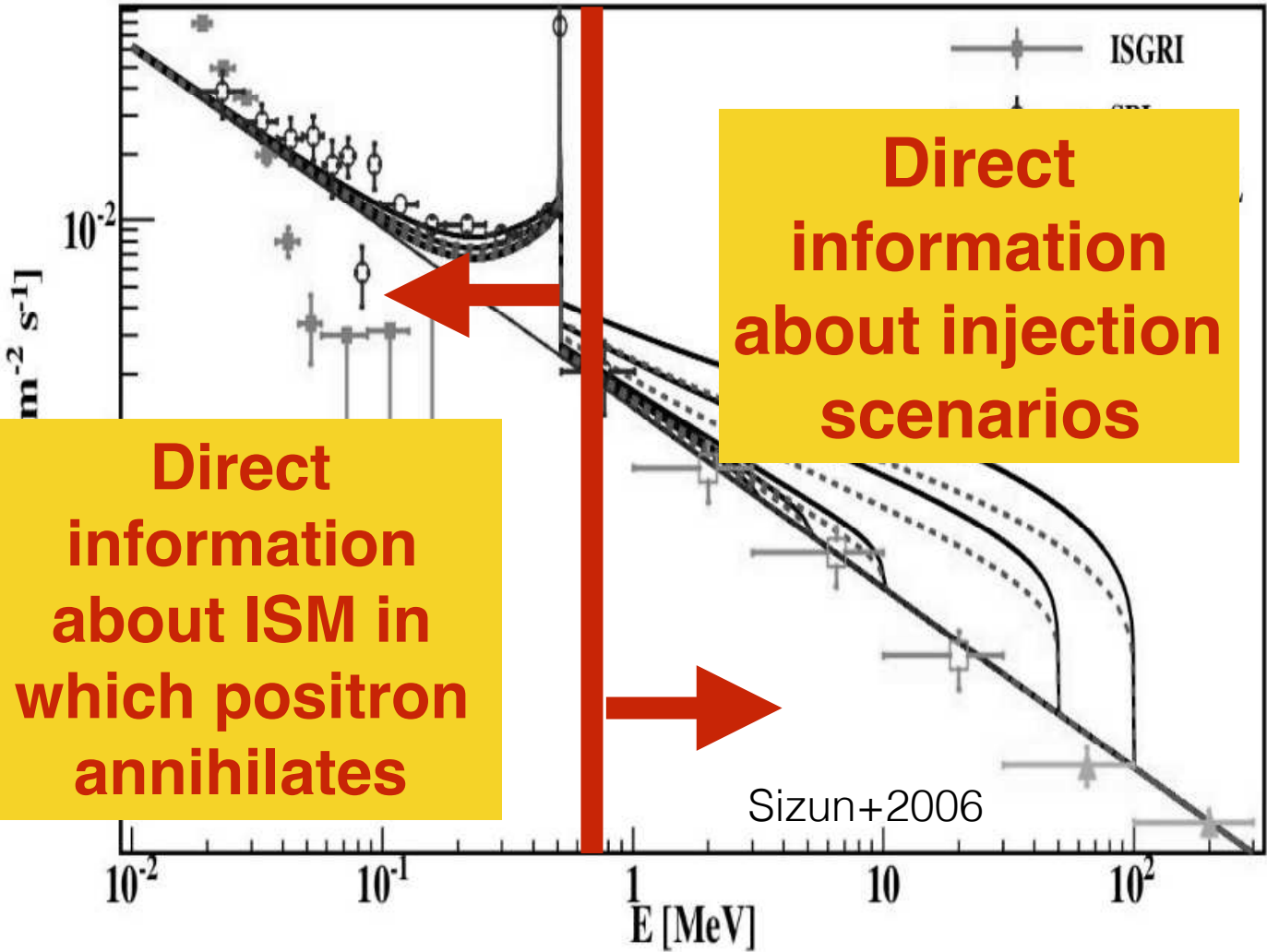
(a) Bulge.

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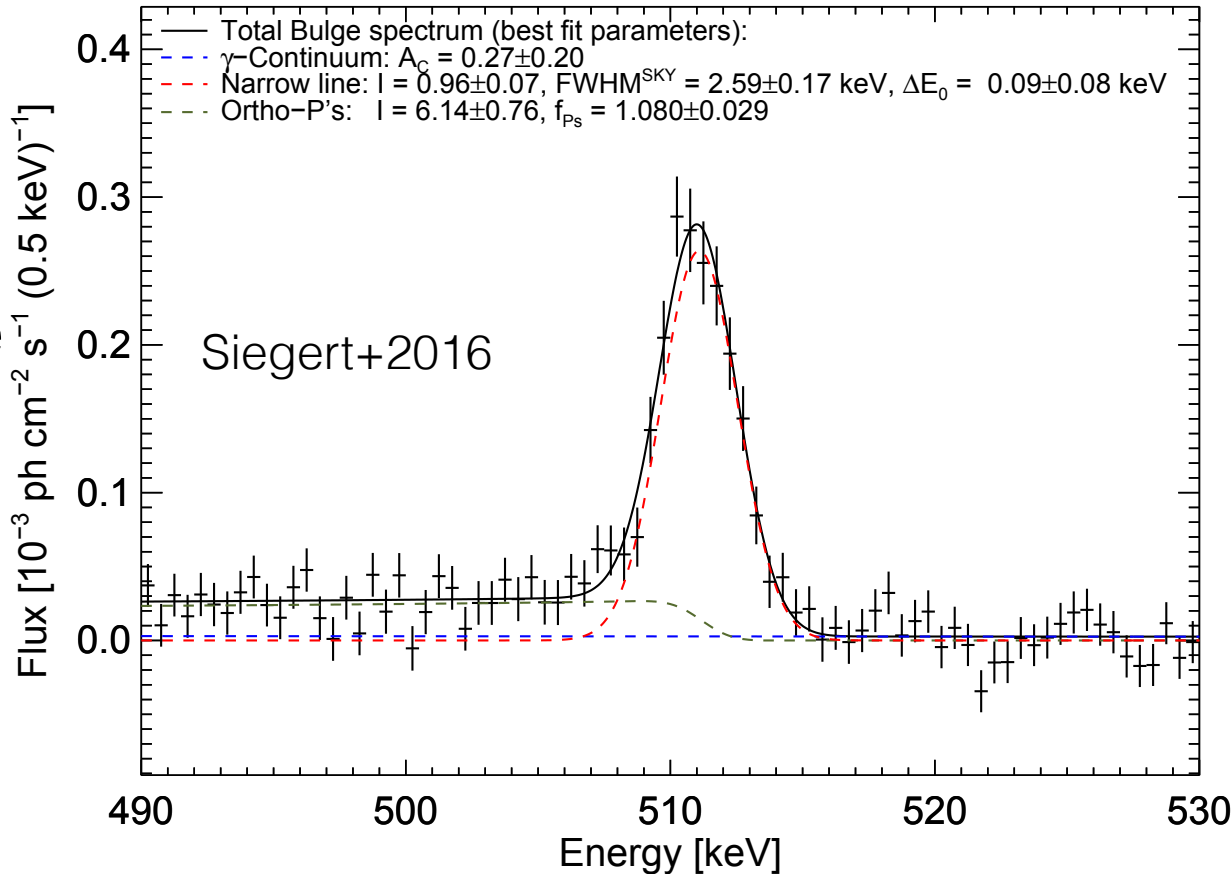
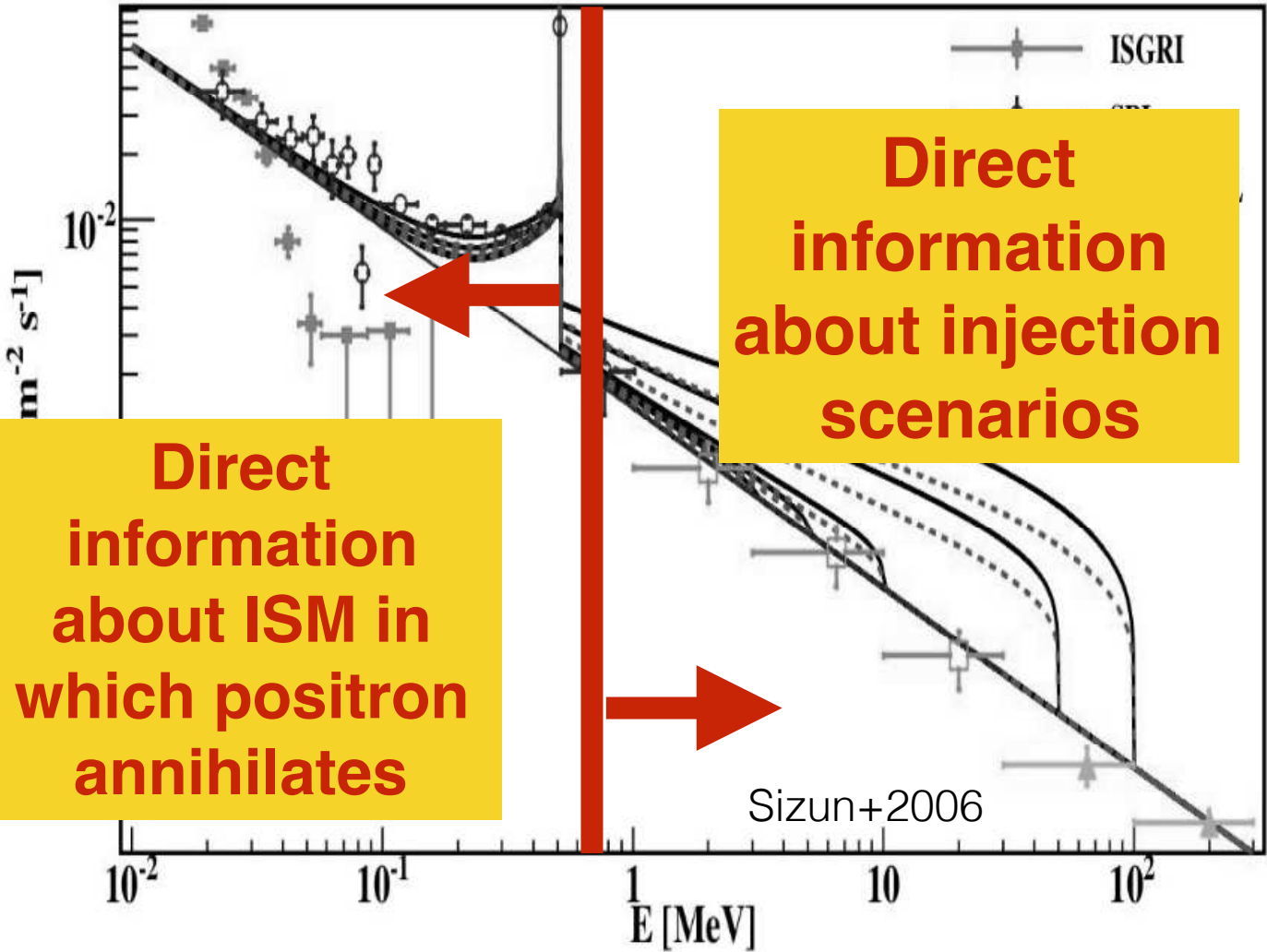
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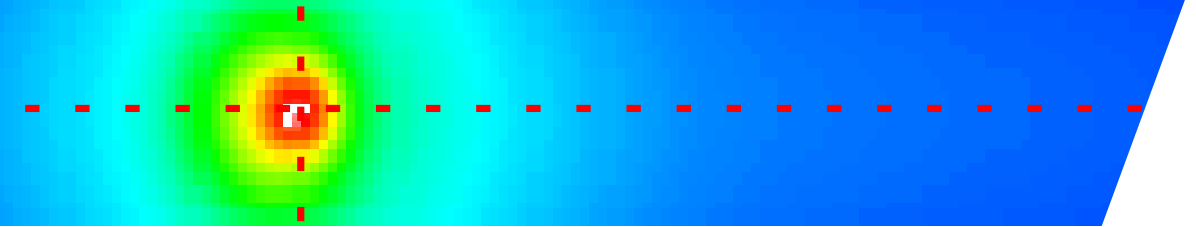
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- Absence of excess >511 keV: Positrons injected at **less than a few MeV** (Aharonian & Atoyan 1981, Beacom & Yüksel 2007)



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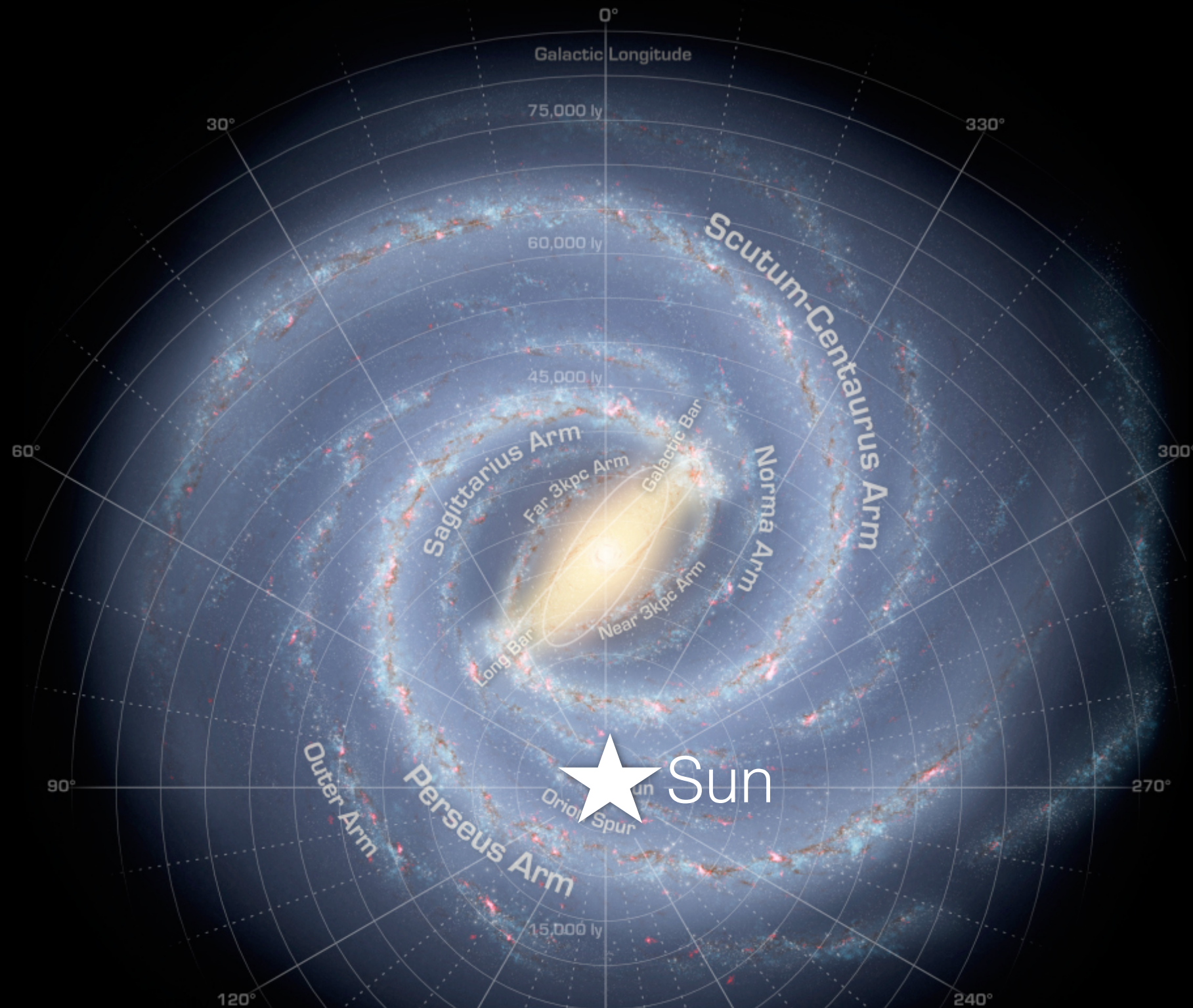
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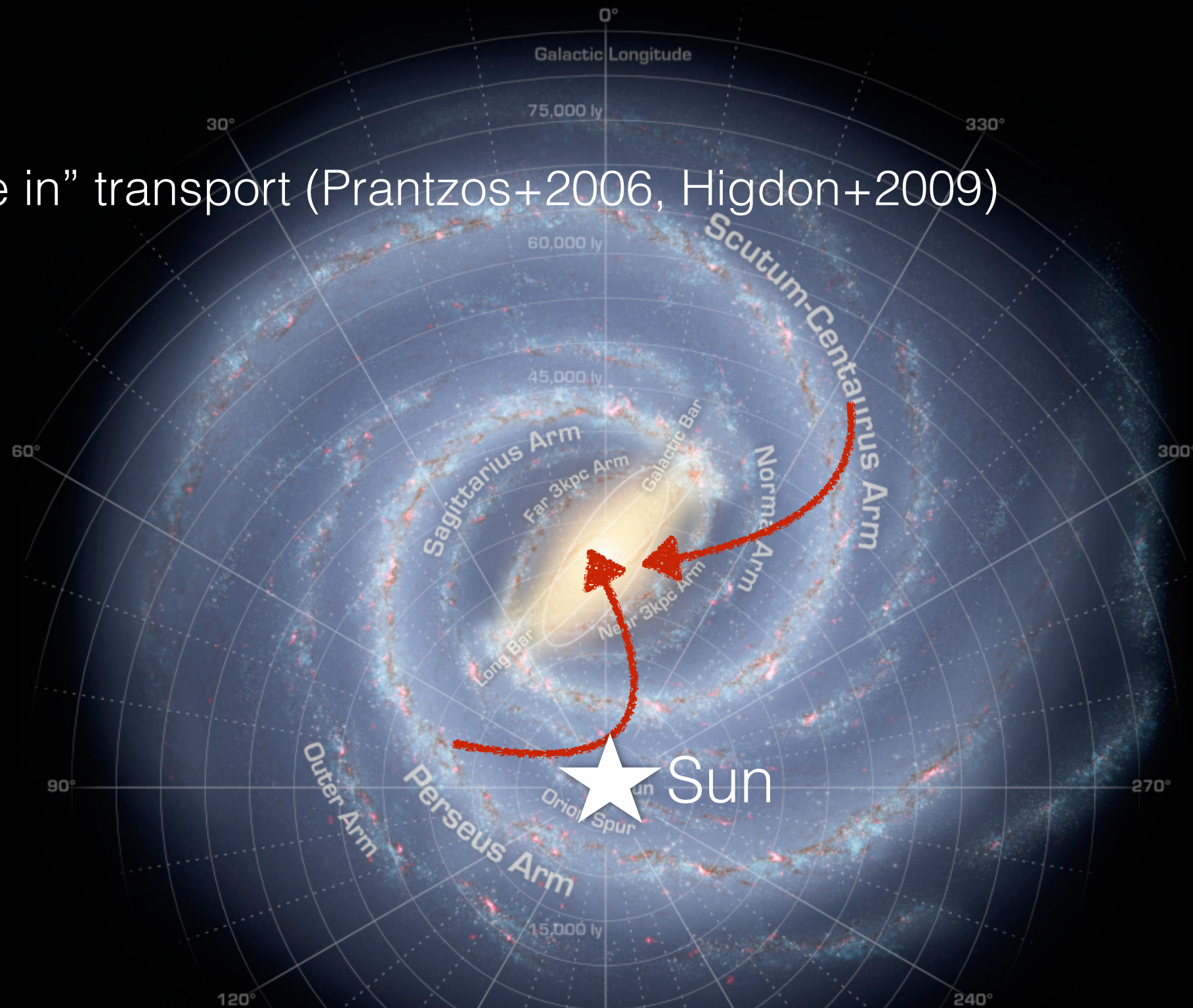
Common production/transport scenarios in literature



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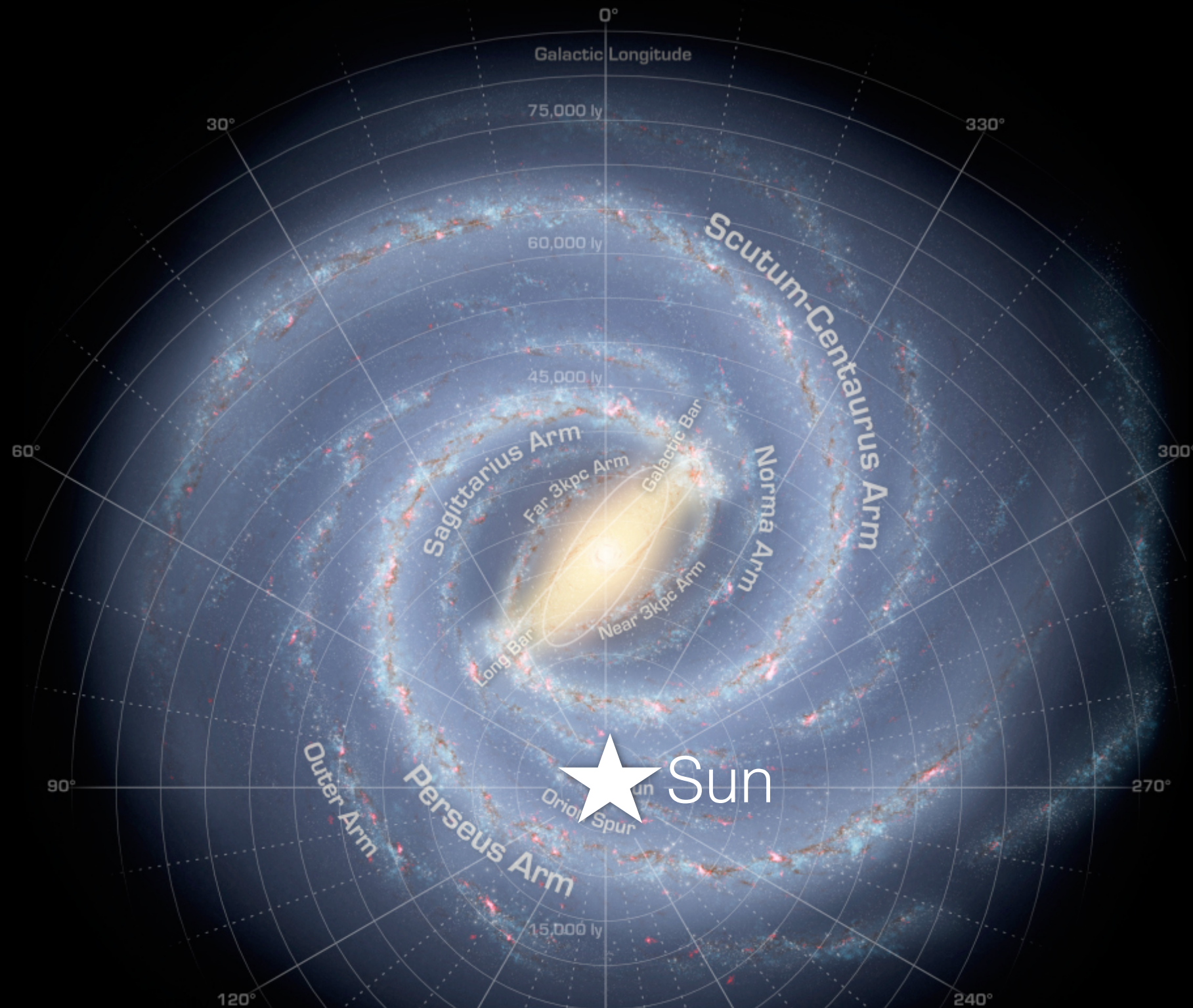
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1. "Outside in" transport (Prantzos+2006, Higdon+2009)



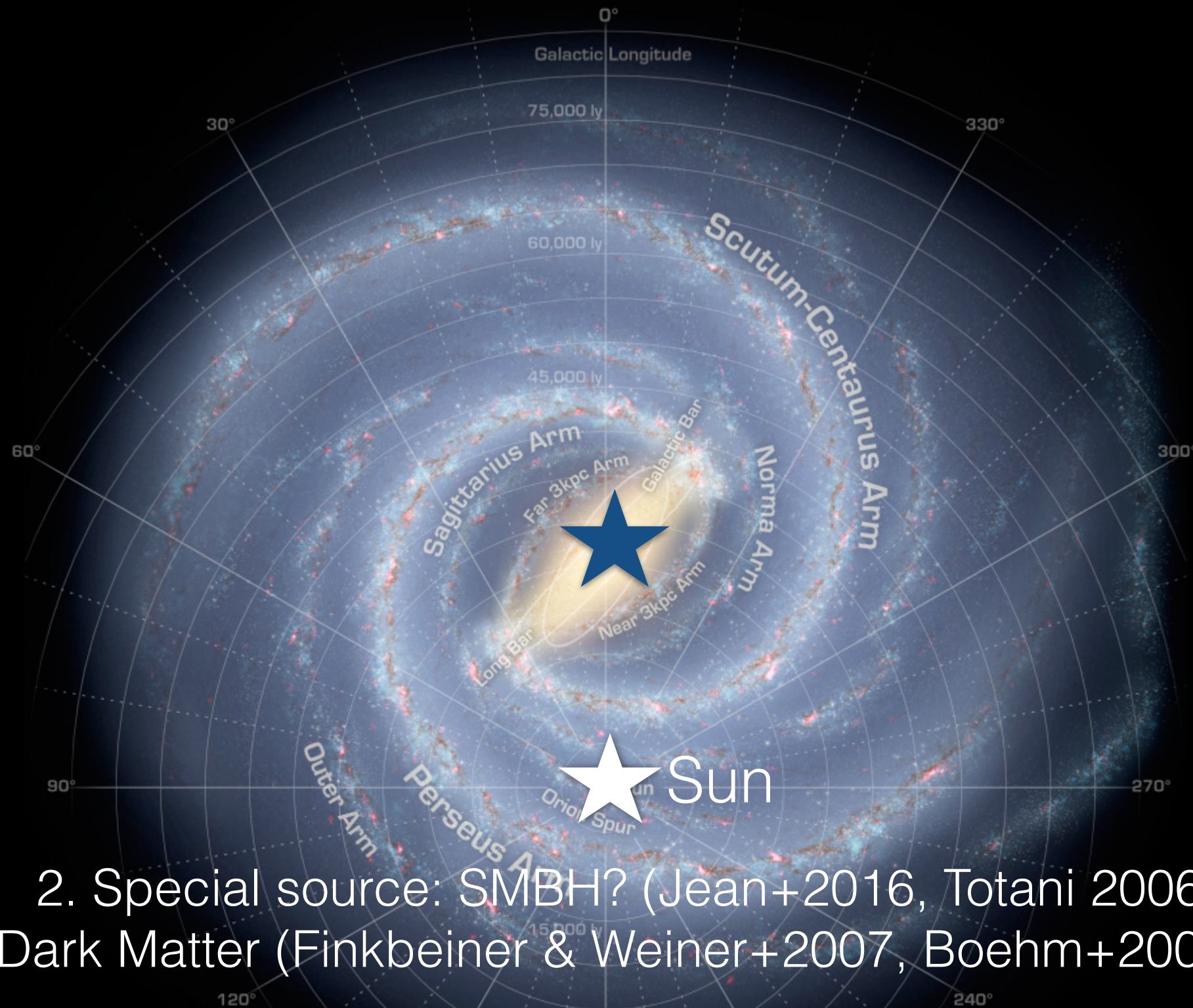
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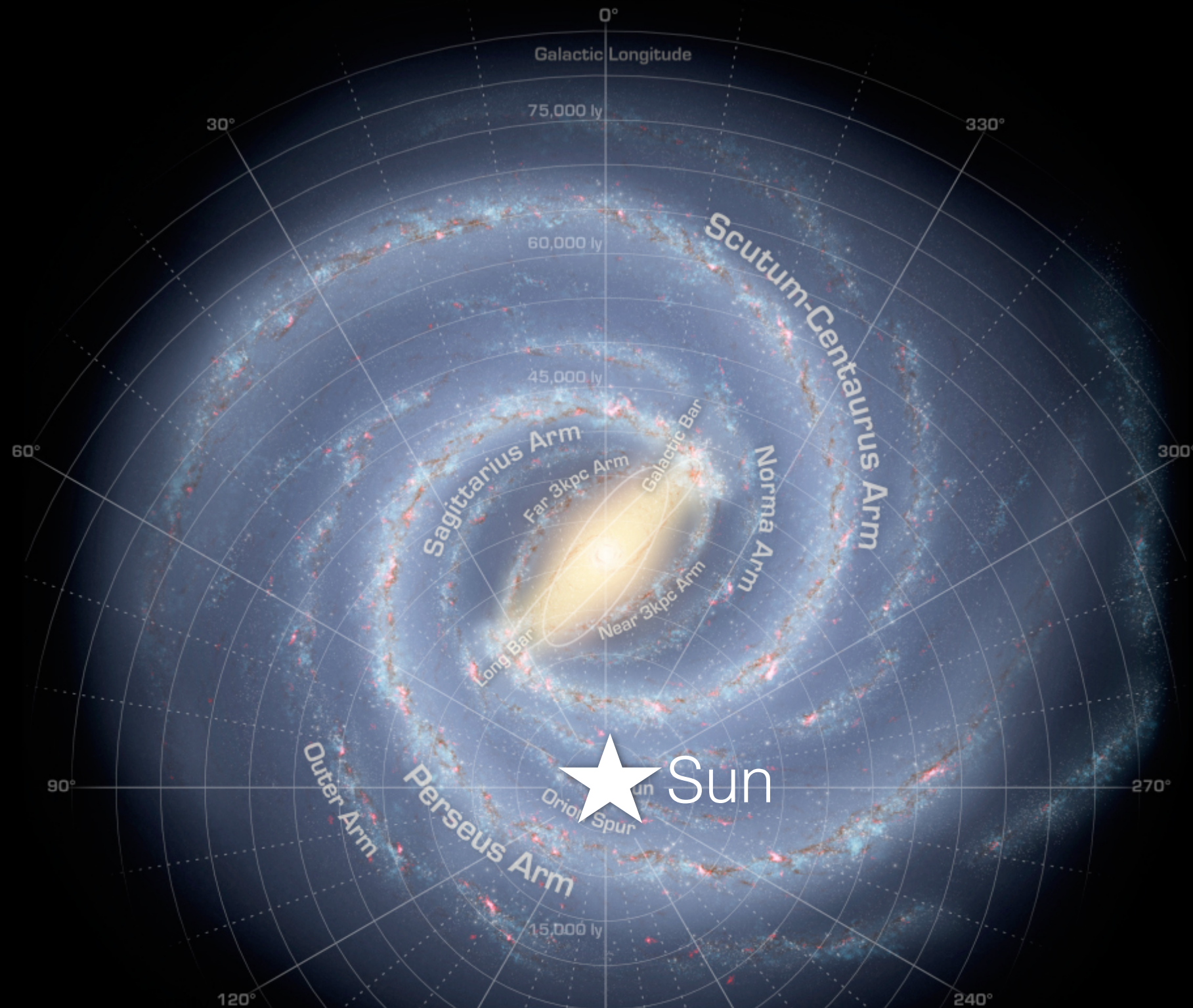
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2. Special source: SMBH? (Jean+2016, Totani 2006),
Dark Matter (Finkbeiner & Weiner+2007, Boehm+2009)?

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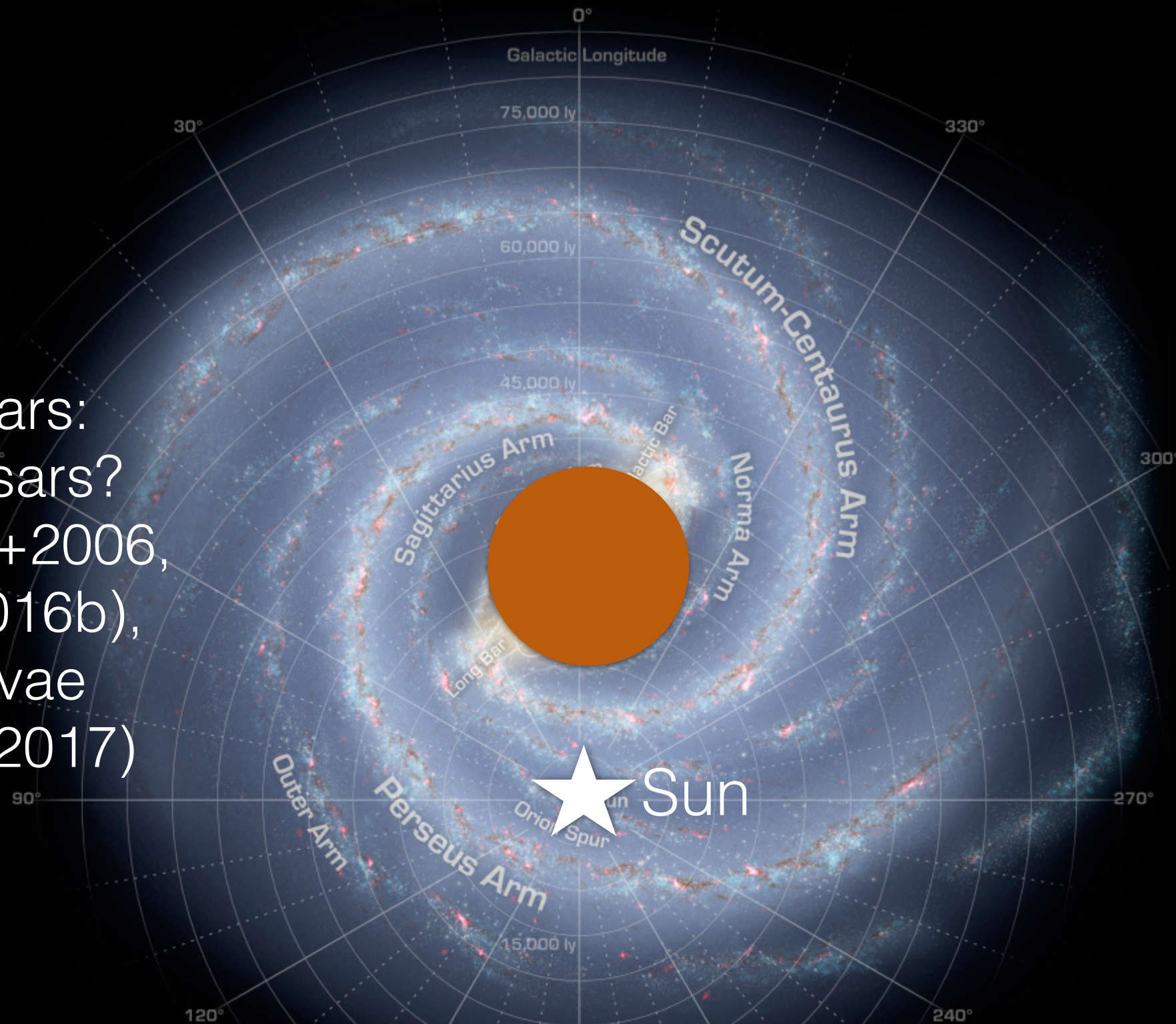
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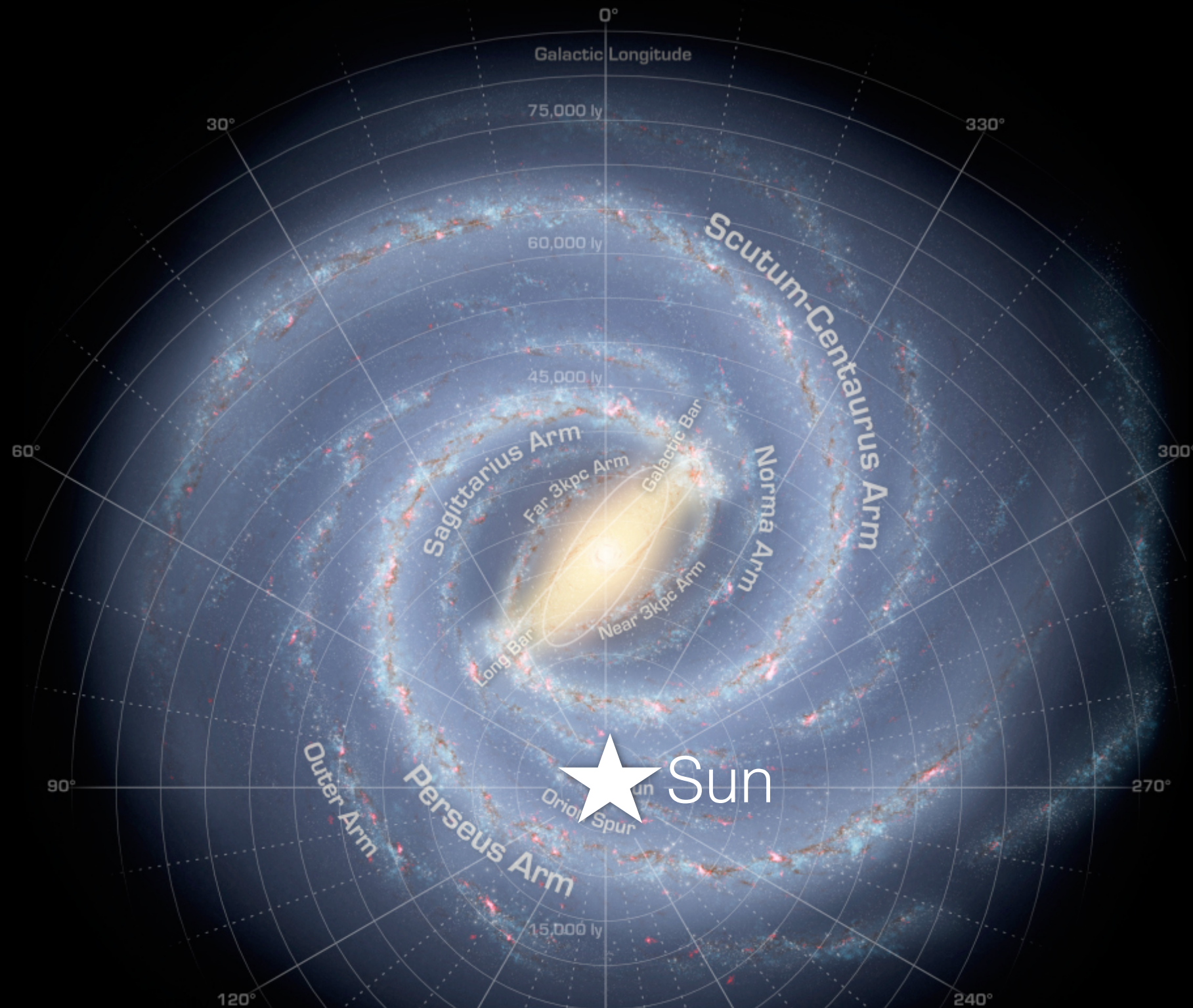
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3. Old stars:
Microquasars?
(Guessoum+2006,
Siegert+2016b),
supernovae
(Crocker+2017)



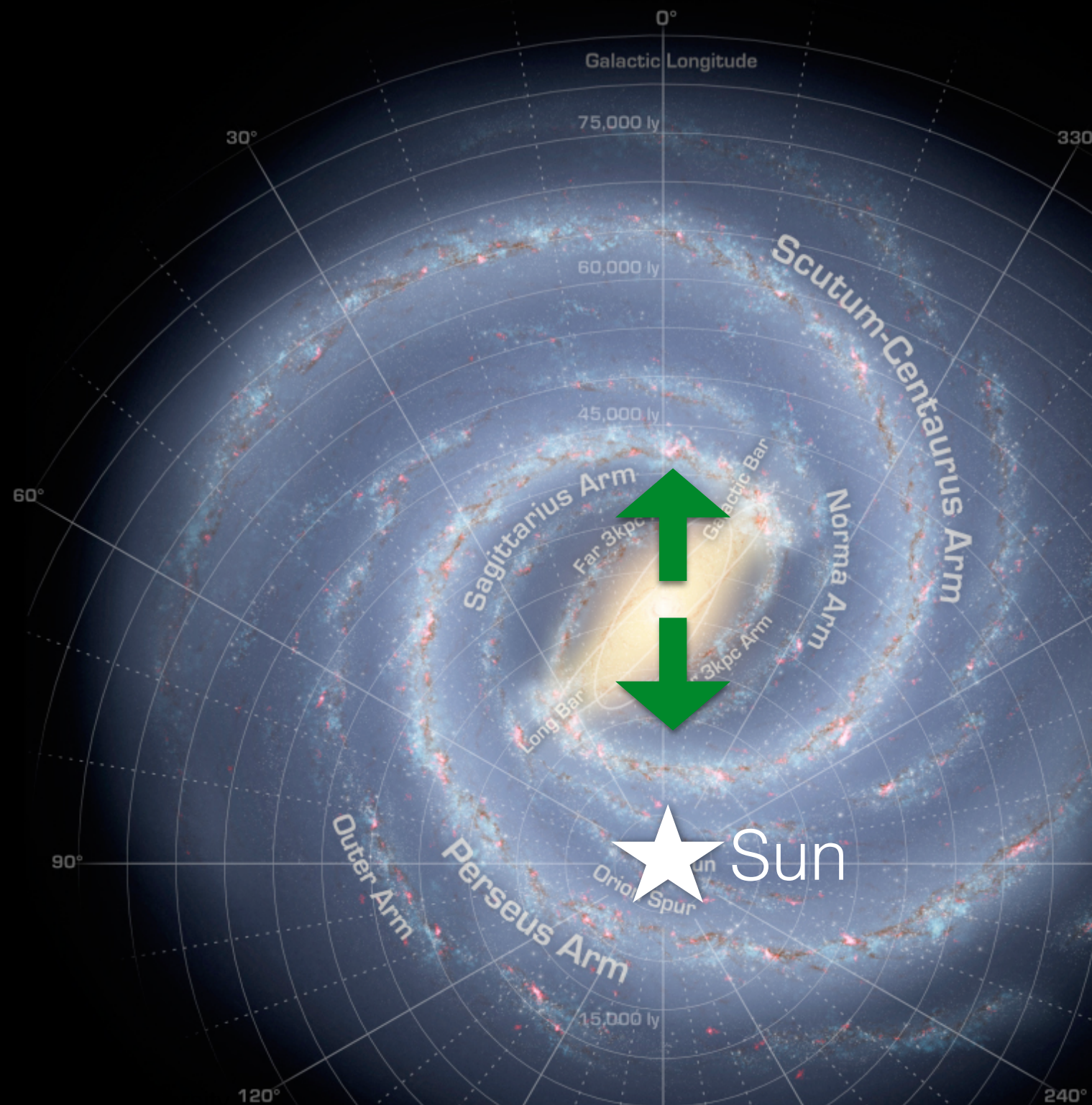
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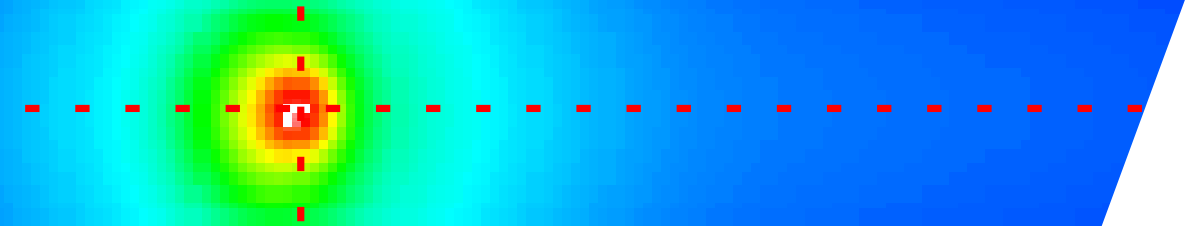


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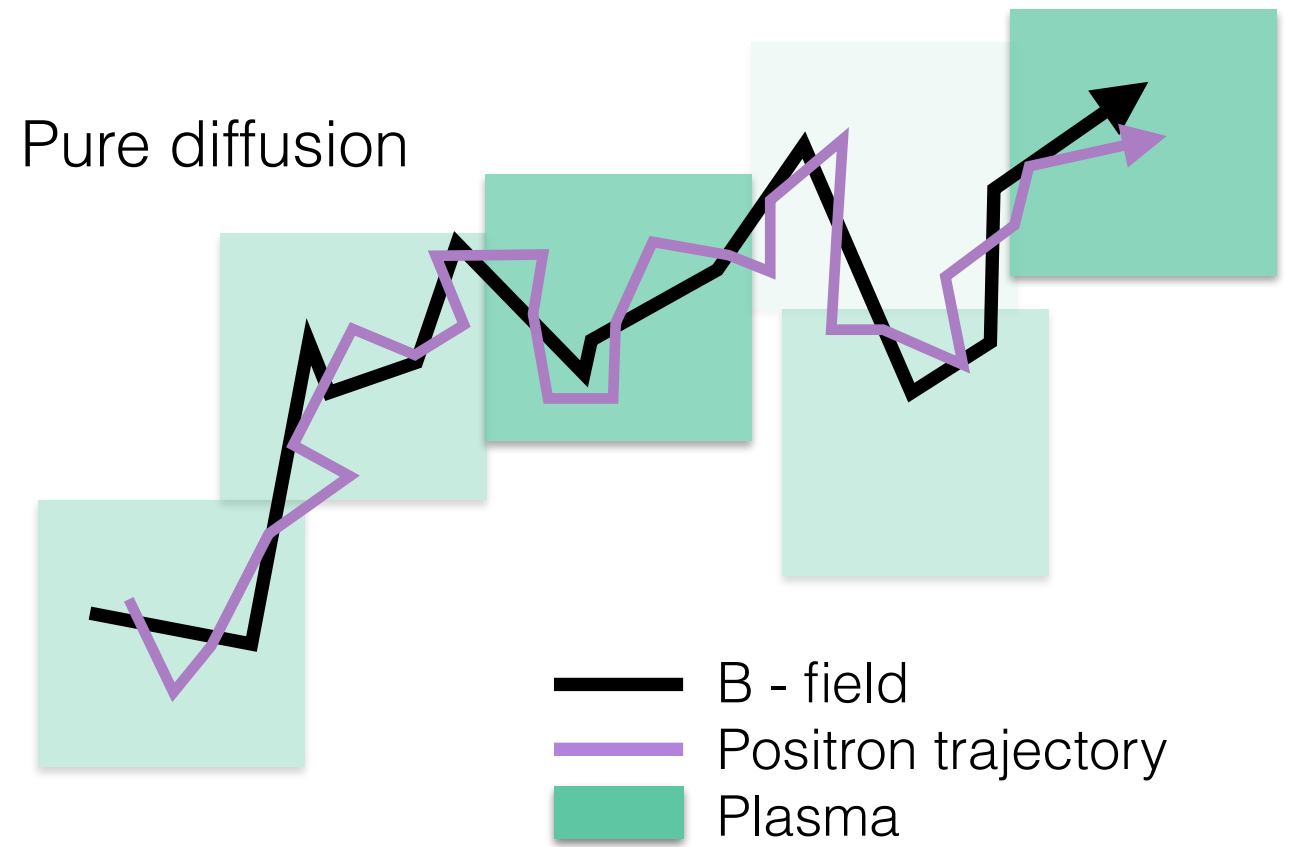
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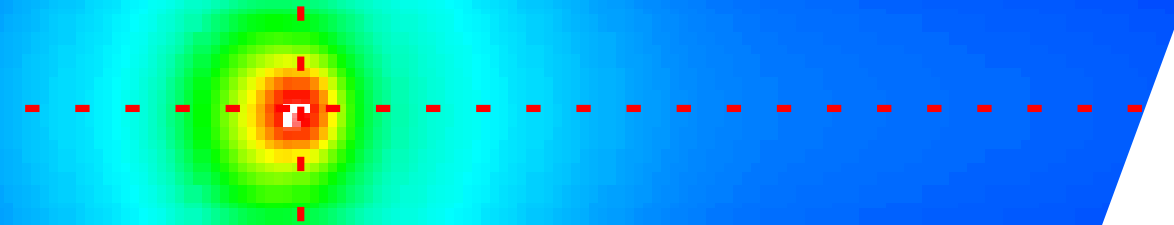


4. “Inside out”
Transport:
Diffusion (Jean
+2009, Alexis
+2012).
Advection
(Panther+2017a,
submitted to
MNRAS Letters)



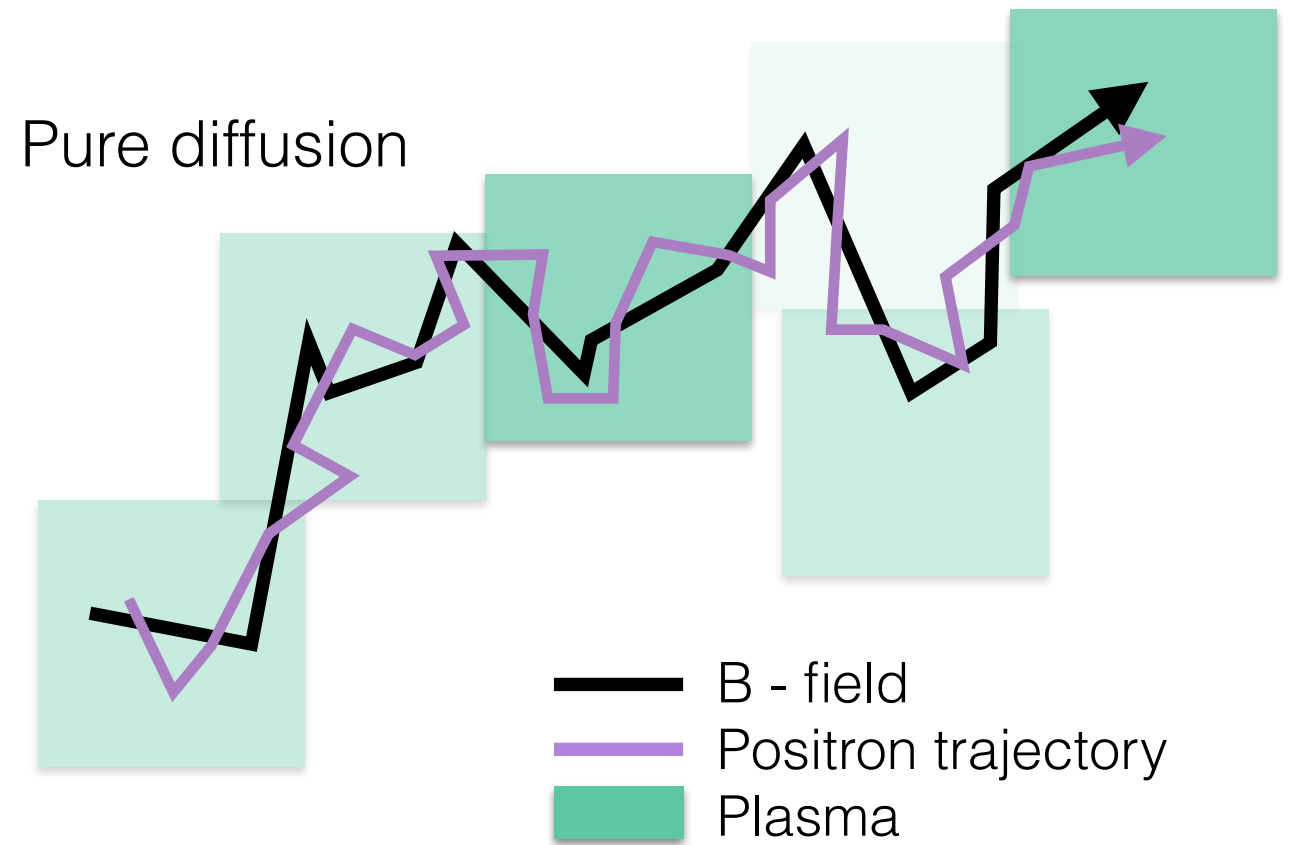
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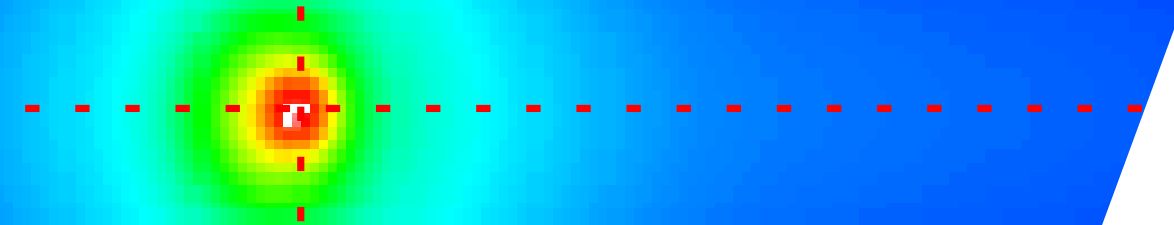




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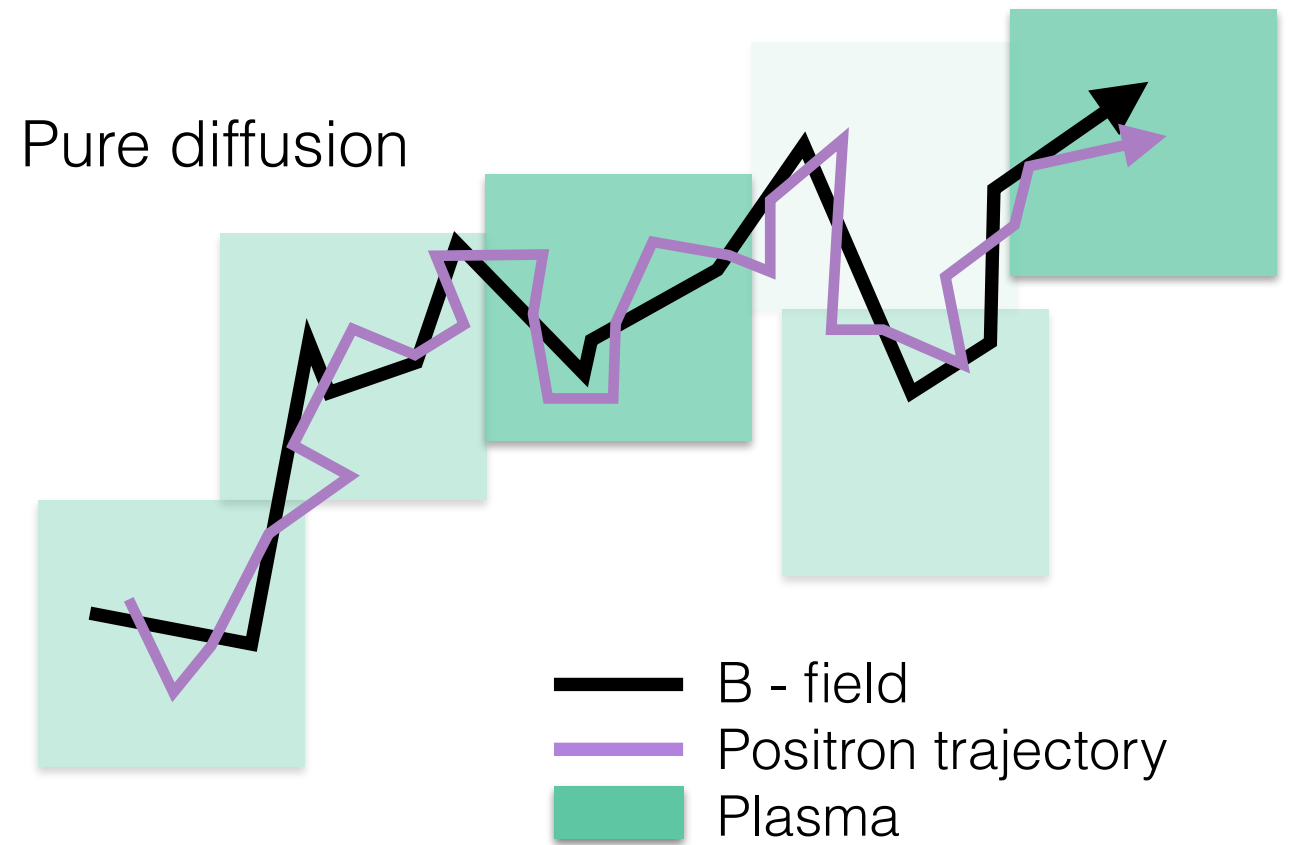
In diffusive transport scenarios, **positrons are confined close to their sources (within ~ 200pc) (Jean+2009)**

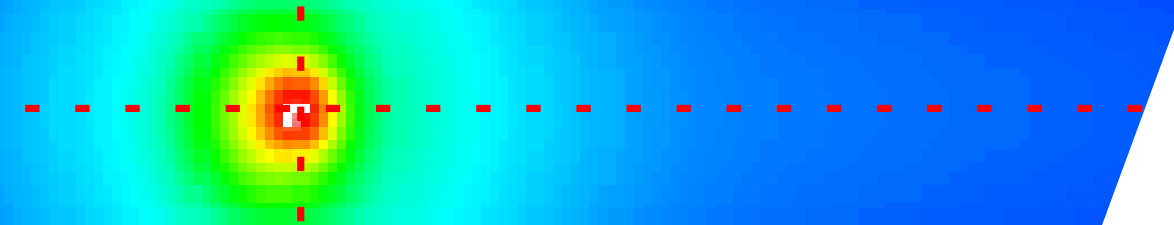




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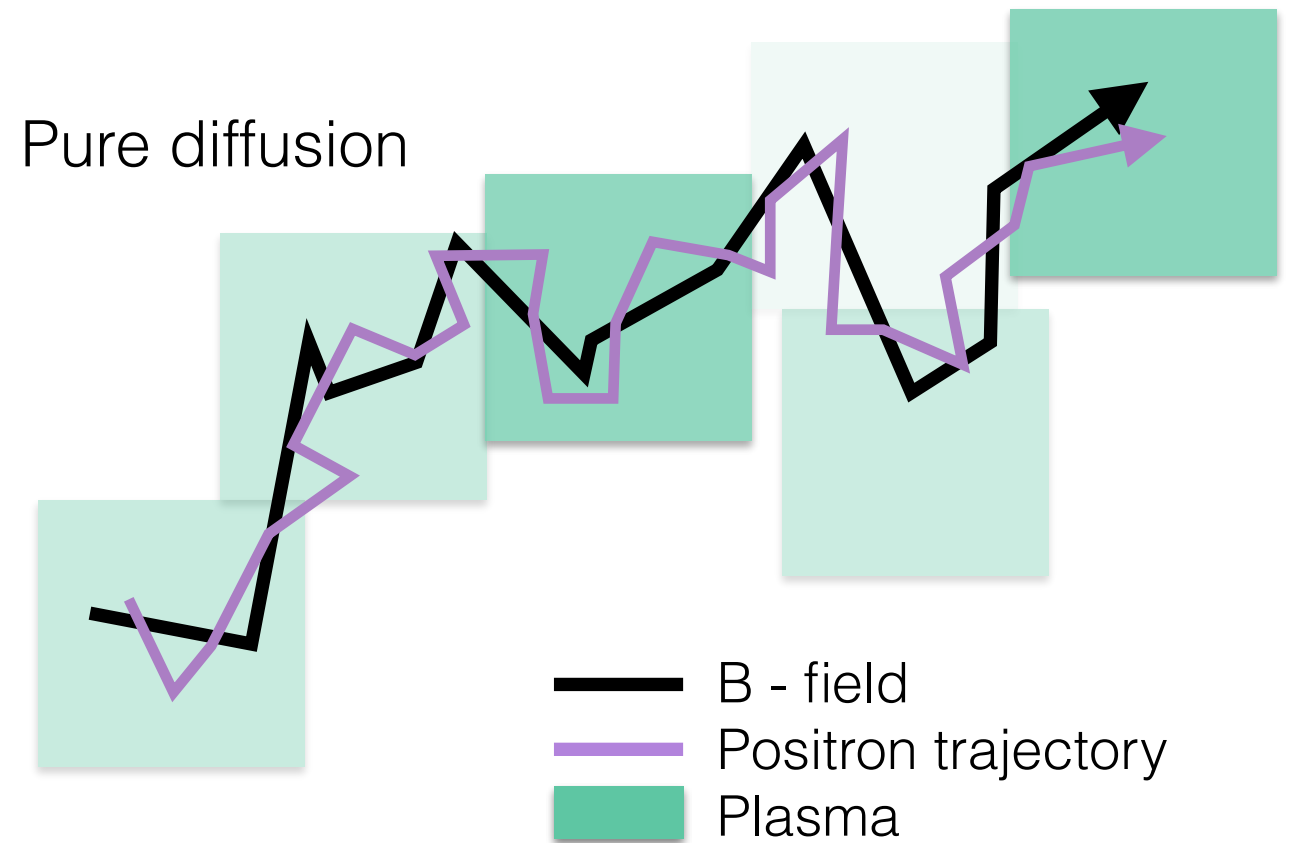


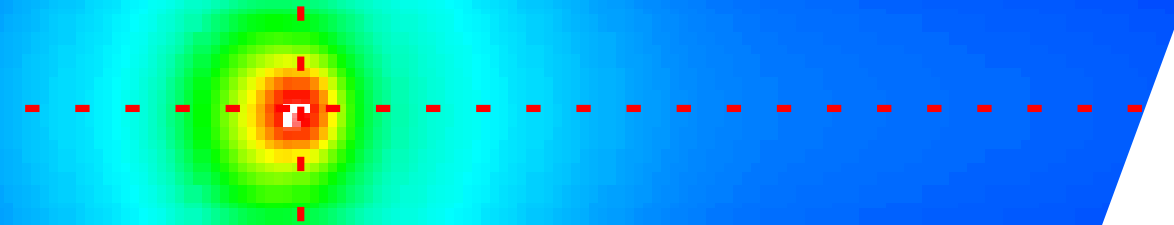


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Low energy positrons - like those responsible for the 511 keV signal - are **coupled to plasma** via B-field.

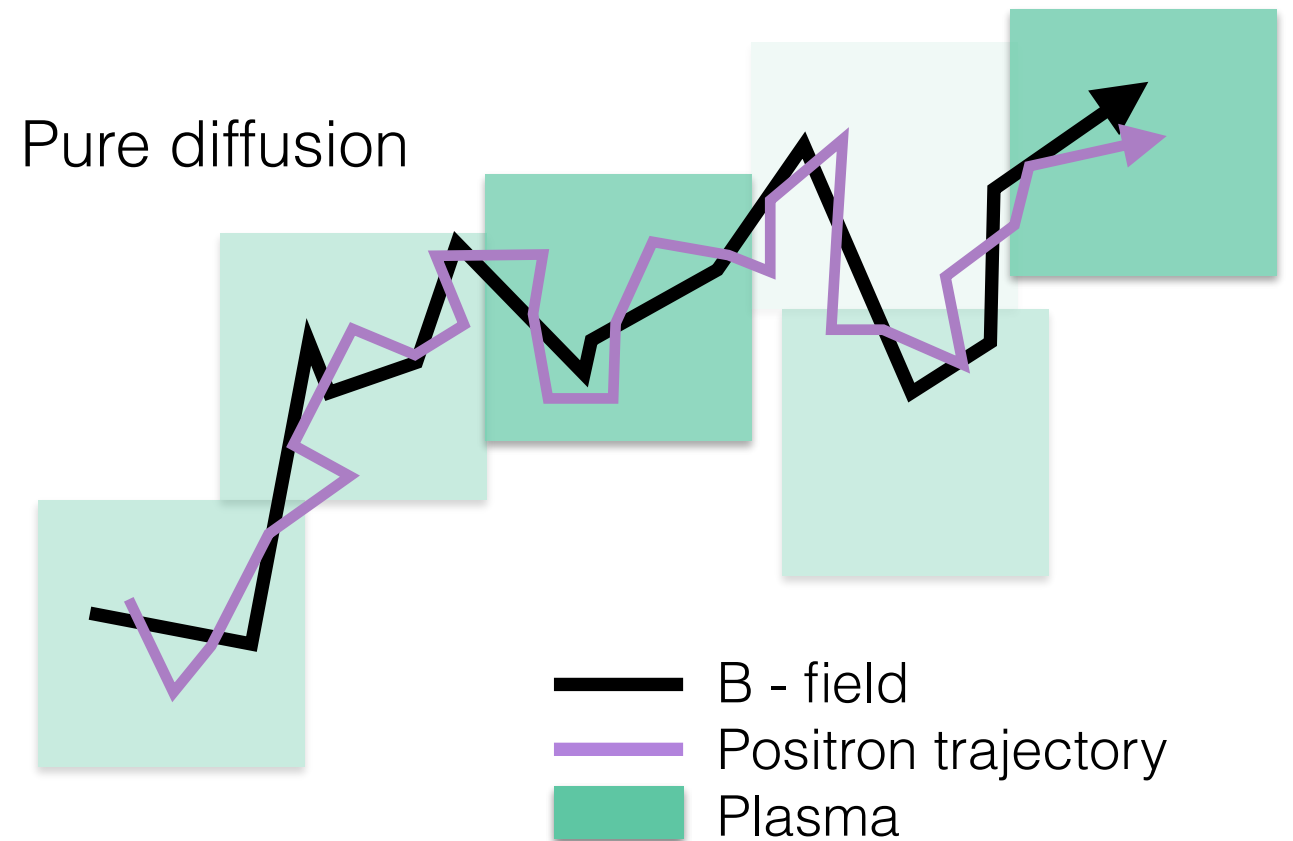




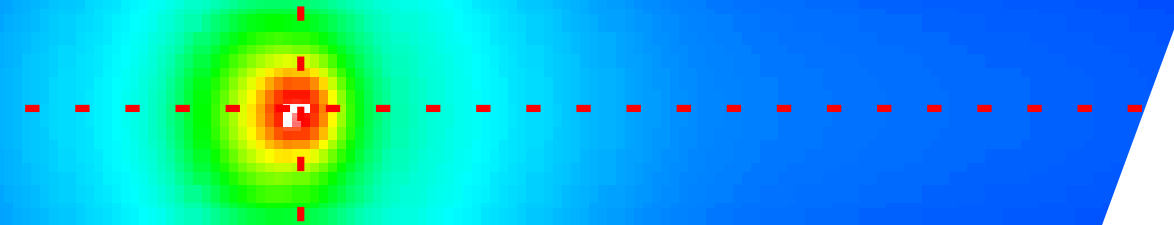
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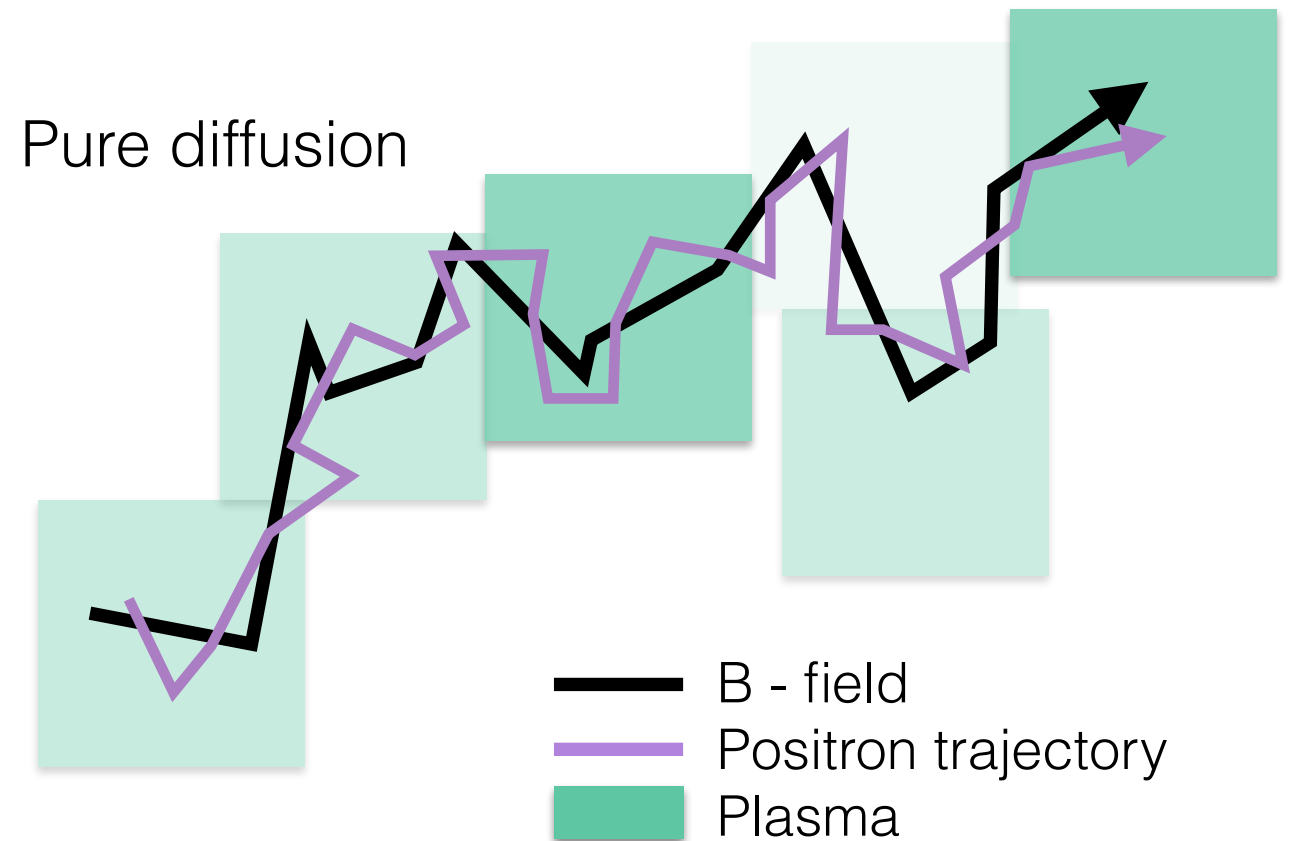
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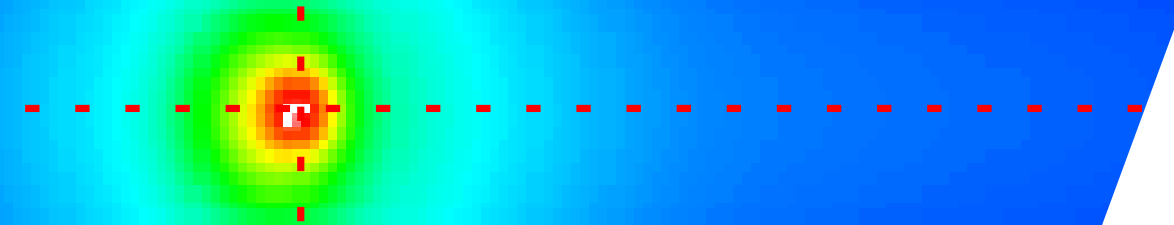


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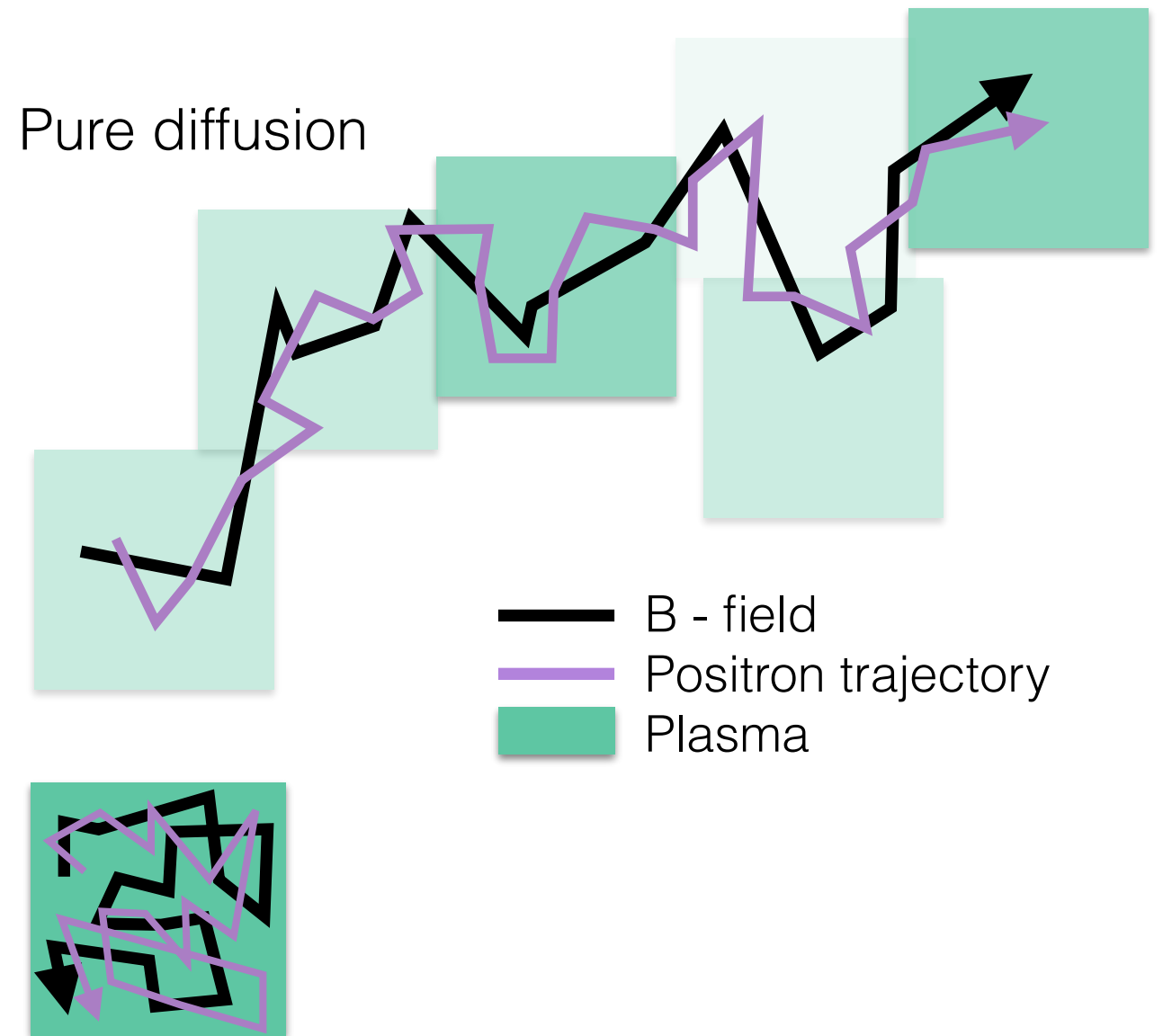


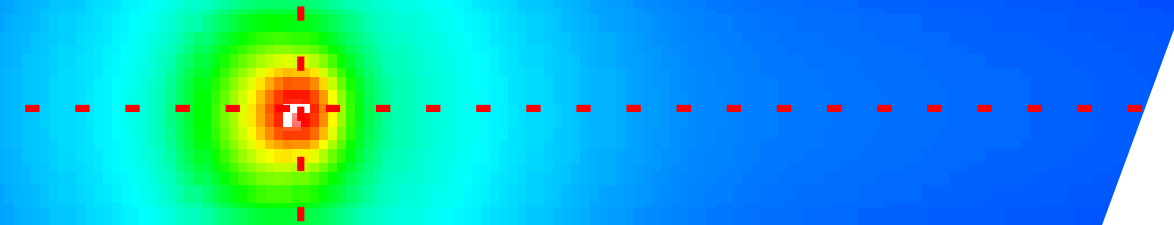
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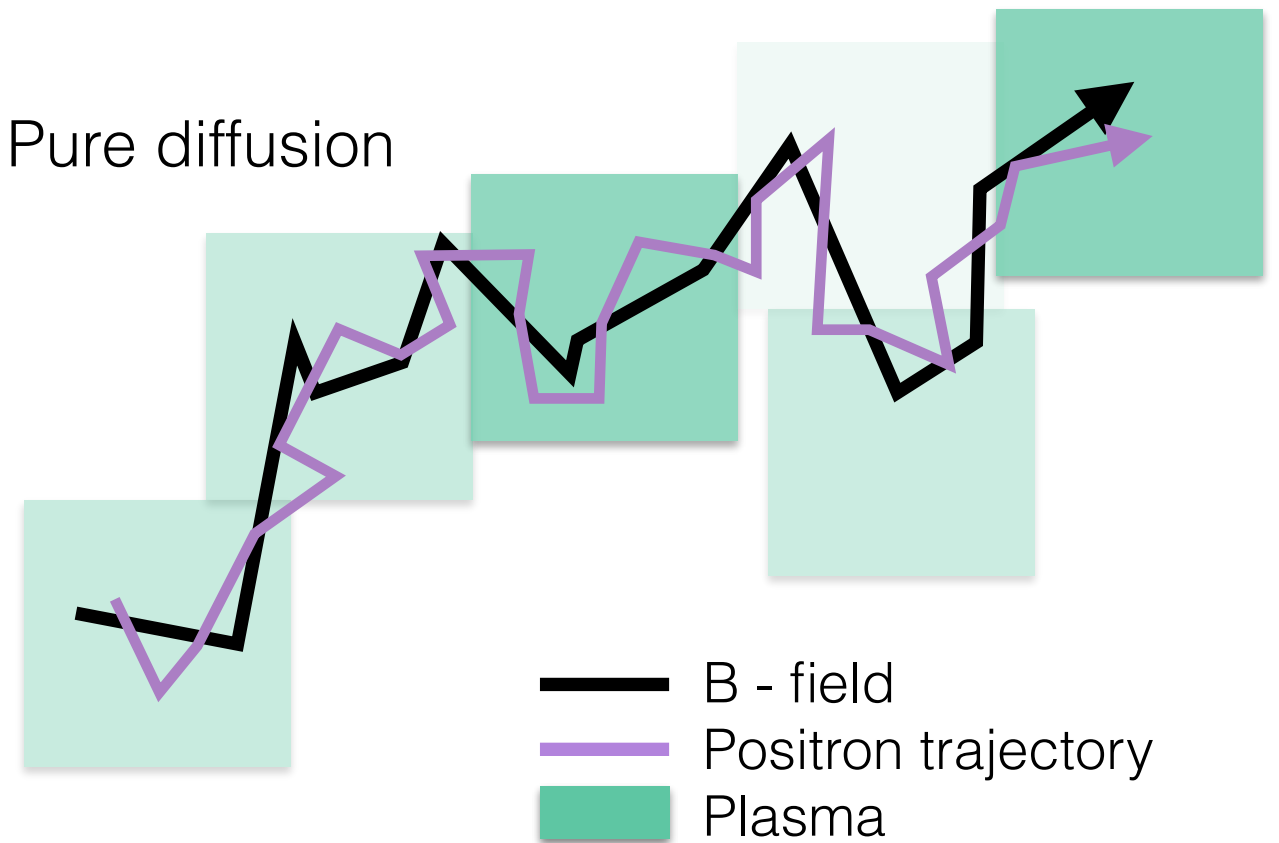
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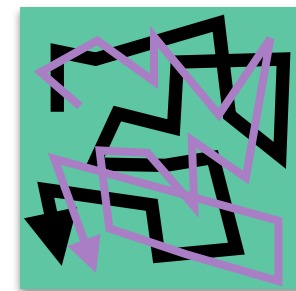
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Jean+2009 imply that if a plasma has some ordered large scale motion, **positrons get “taken along for the ride”** but do not simulate this scenario.

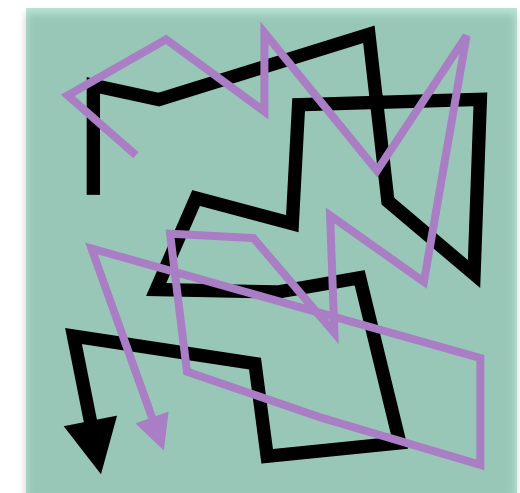
Pure diffusion



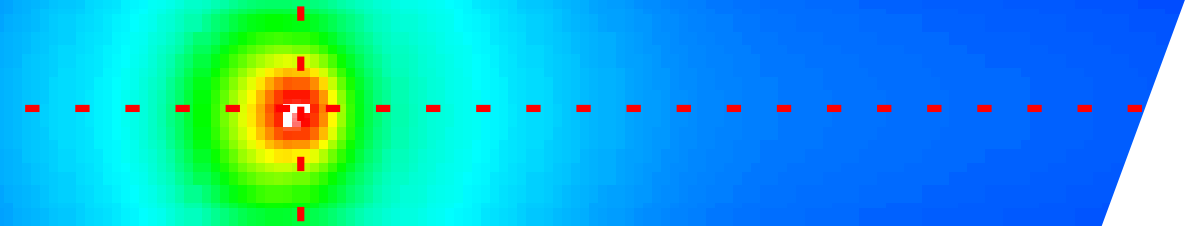
-  B - field
-  Positron trajectory
-  Plasma



Diffusion on small scales, gas motion on large scales



Explaining the GB 511 keV line



Explaining the GB 511 keV line

Annihilation spectrum only encodes information about the ISM conditions when the positron annihilates

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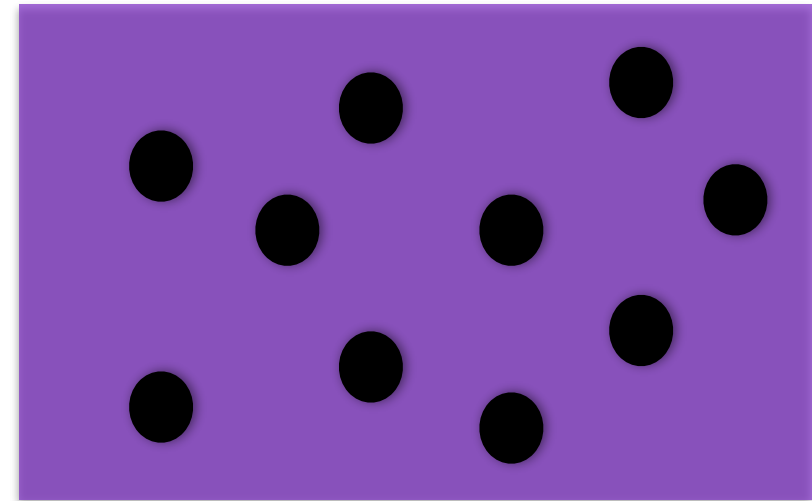
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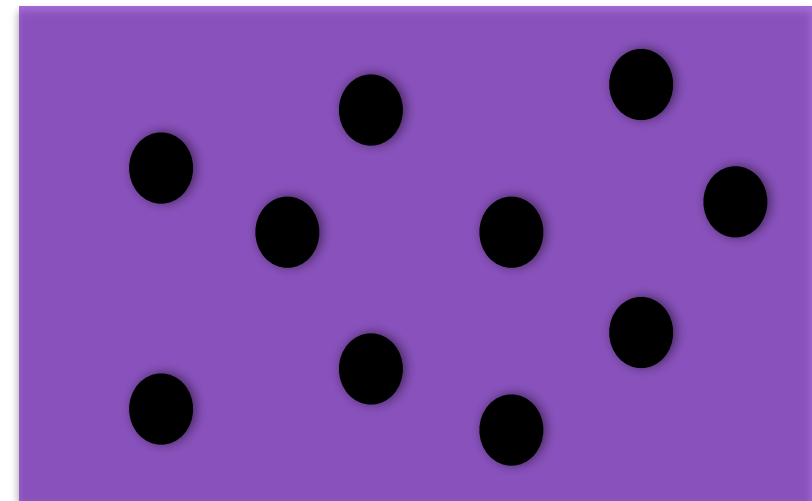
Allow plasma to cool around static positron

Explaining the GB 511 keV line

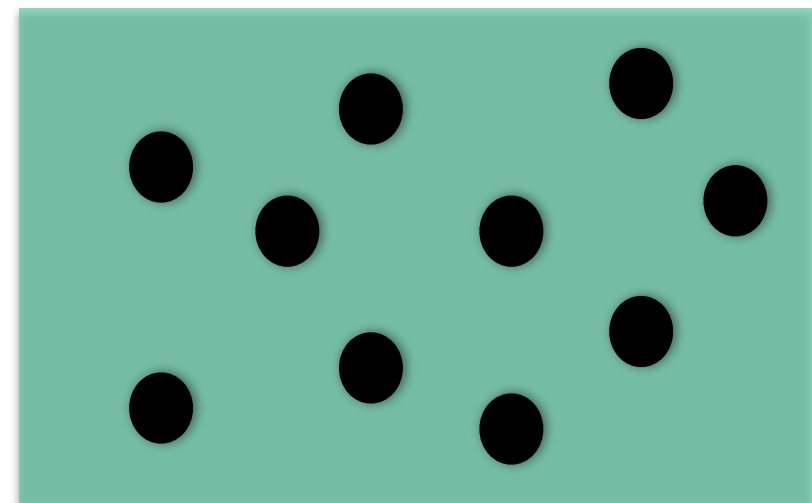
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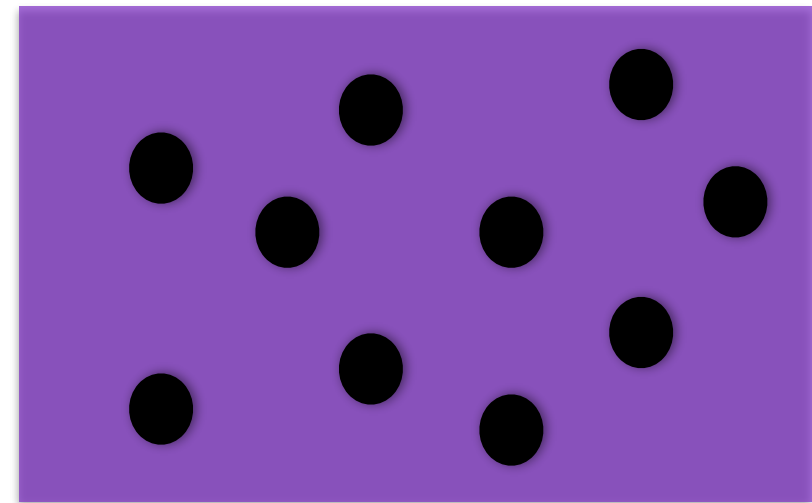
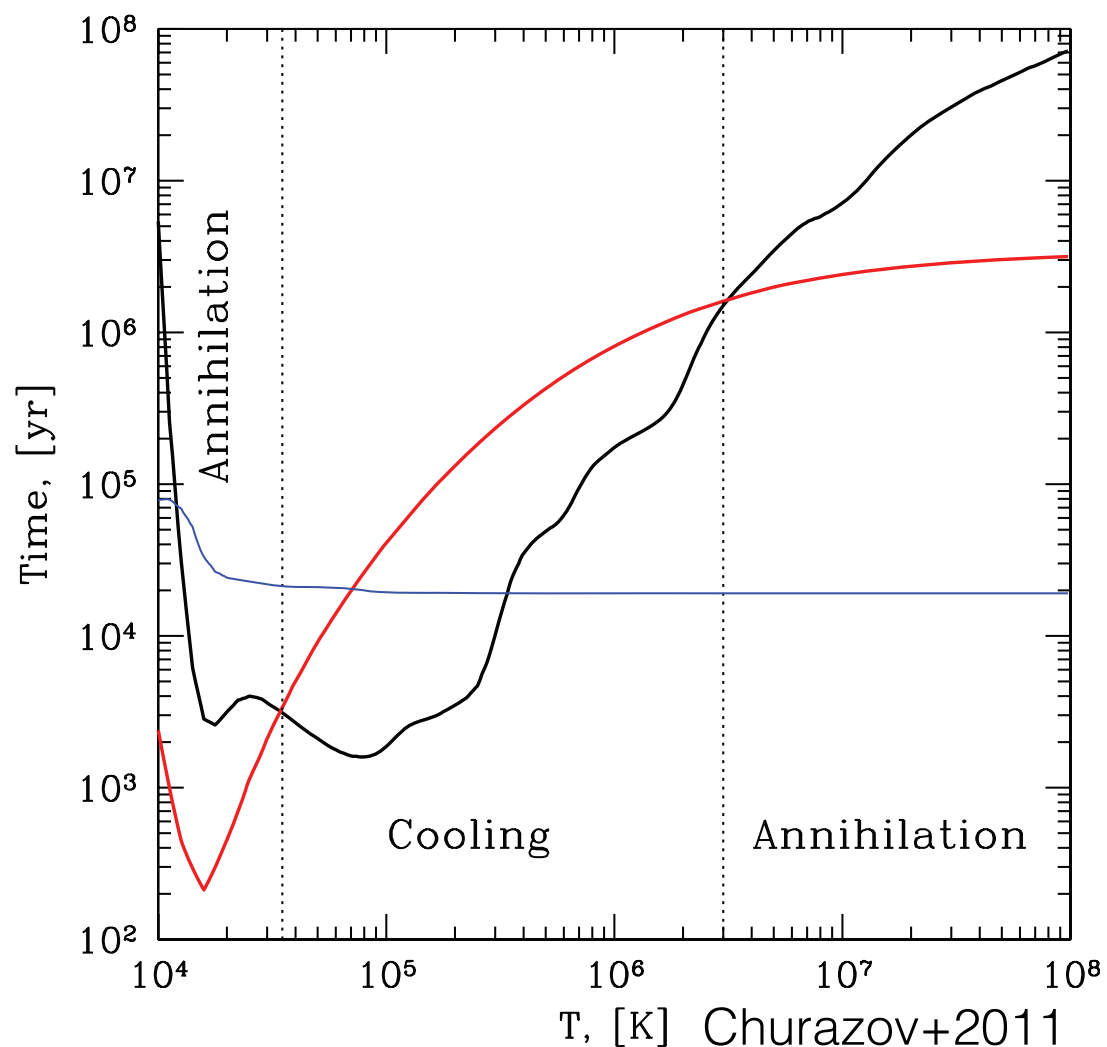


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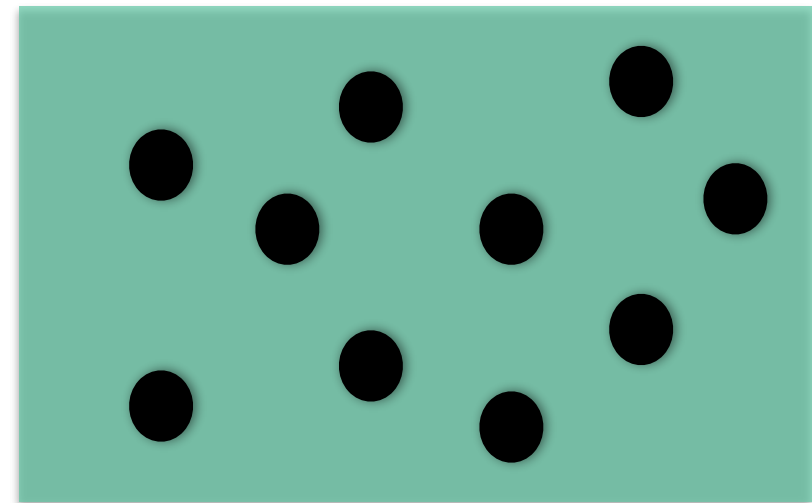
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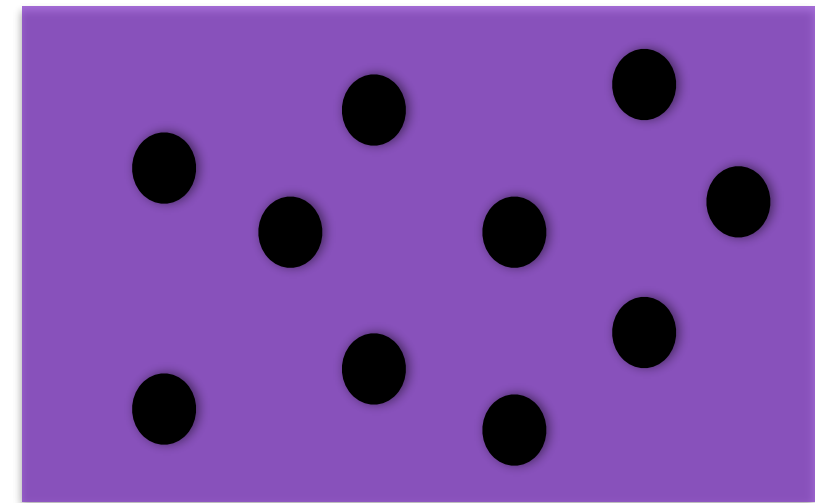
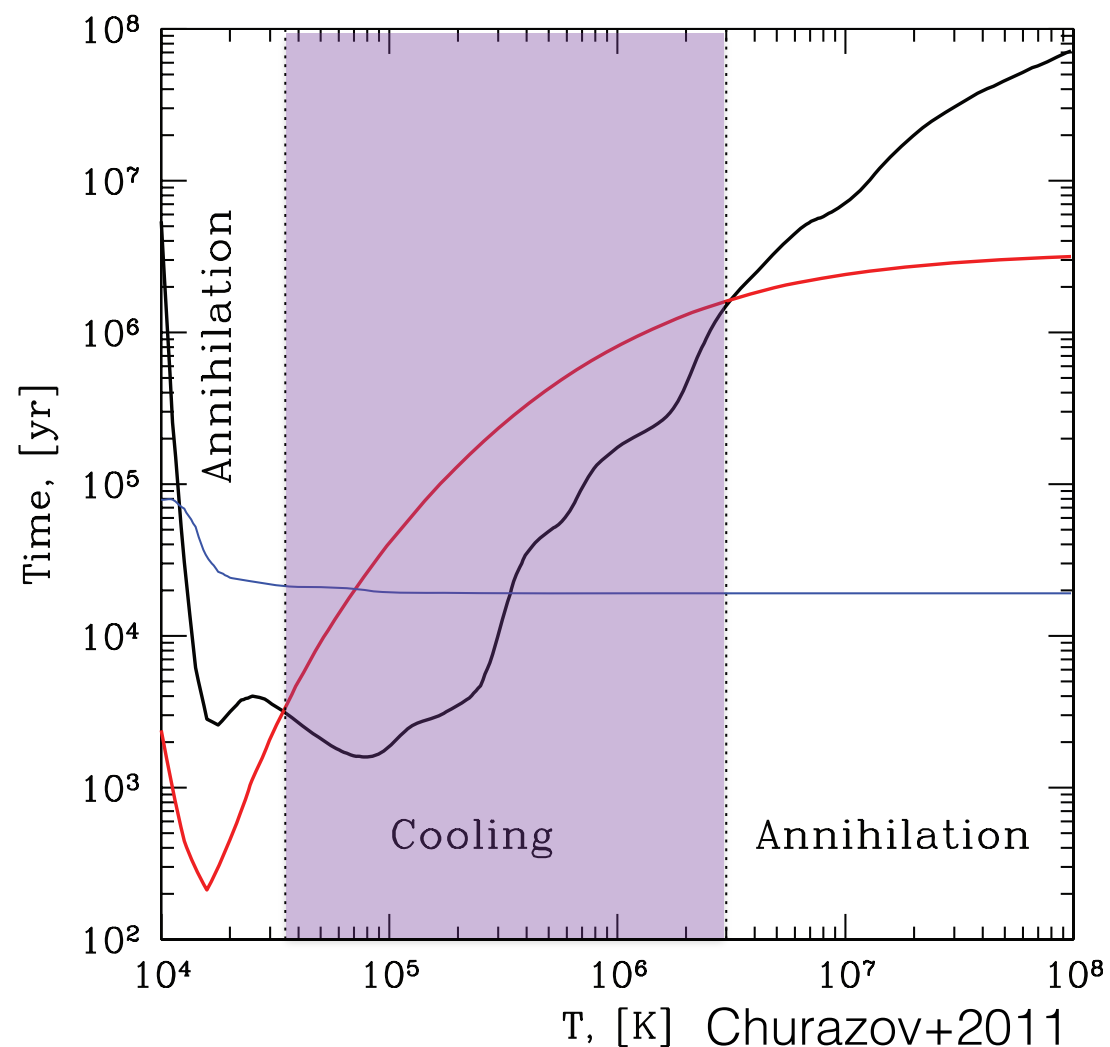


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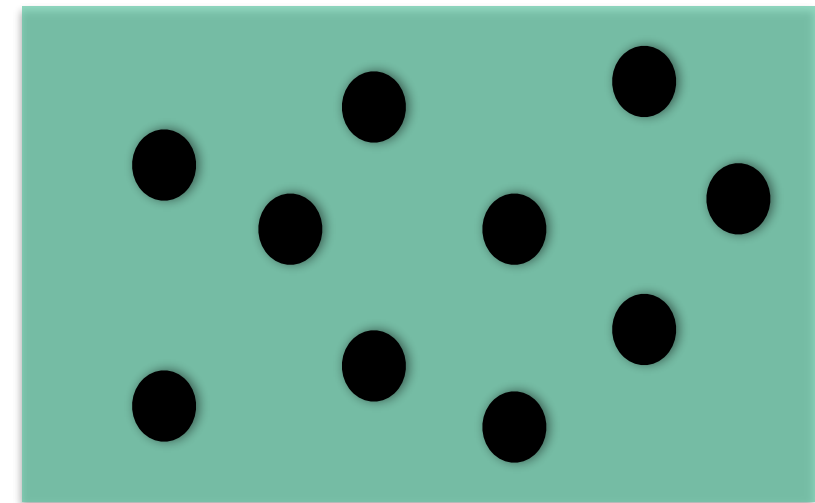
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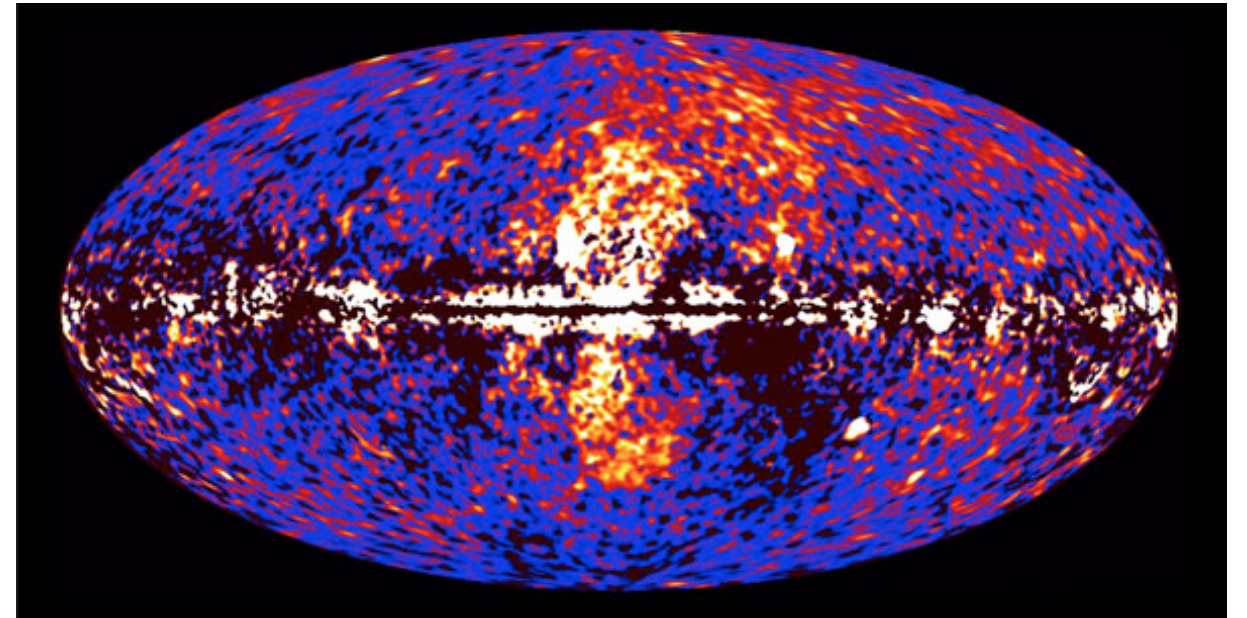
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The GB 511 keV line and the FBs

Evidence for a bipolar nuclear outflow in the Milky Way originated in 2003 (Bland-Hawthorn & Cohen)

The 2010 discovery of the Fermi Bubbles (Su+2010, Dobler+2010) provide additional **evidence of an outflow from the Galactic nuclear region**, casting doubts on the model of a static ISM in this region

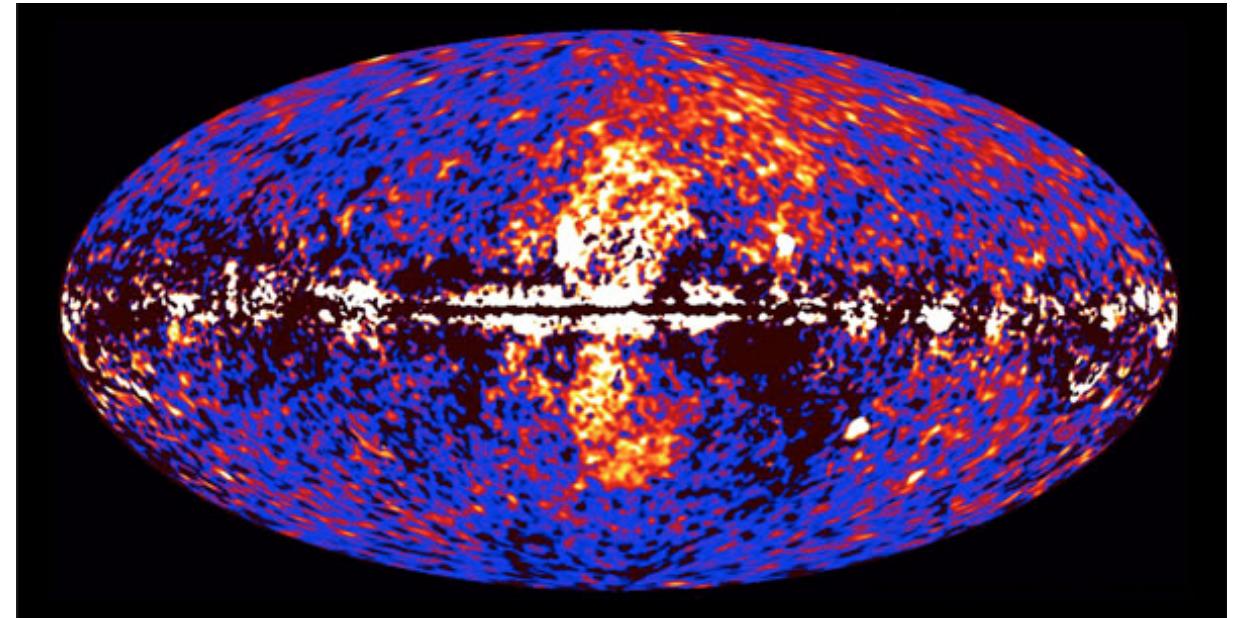


FERMI collaboration

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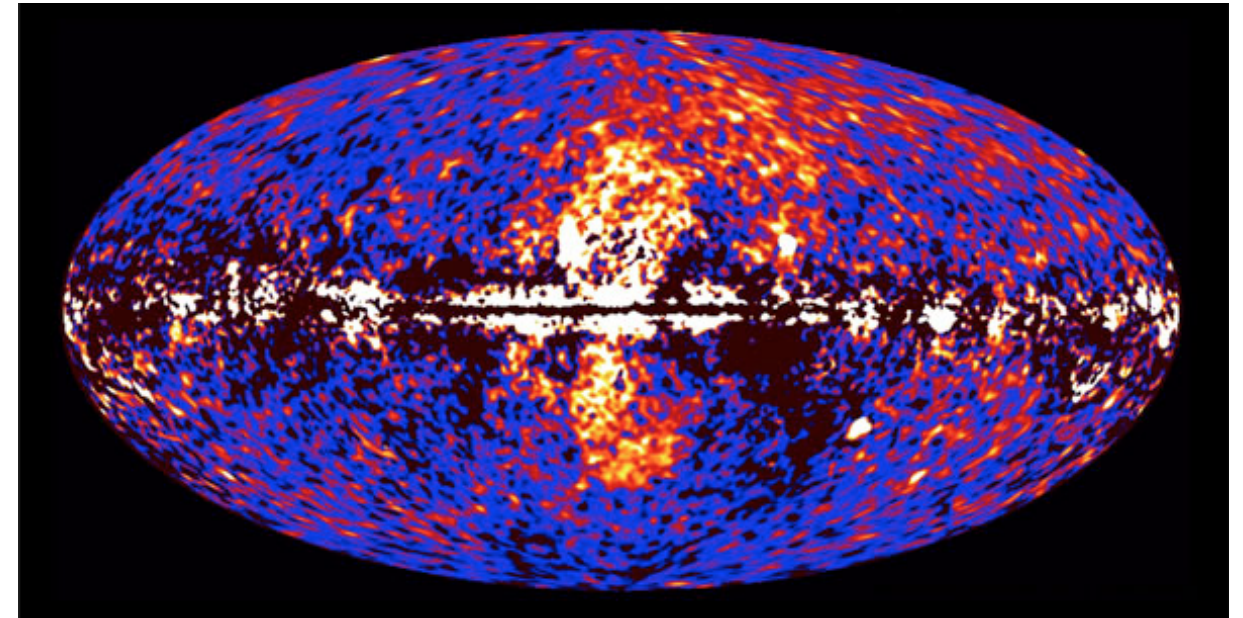


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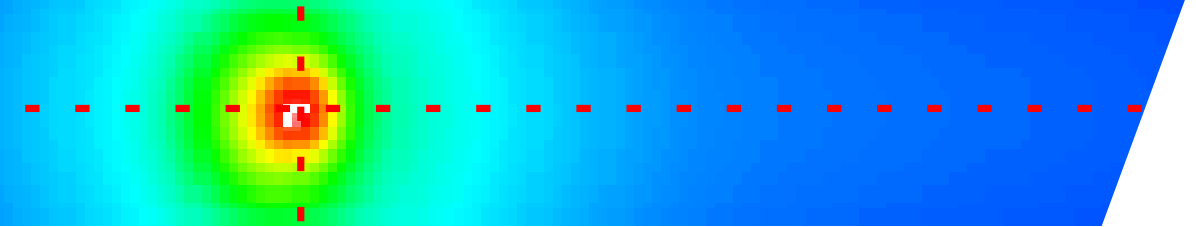
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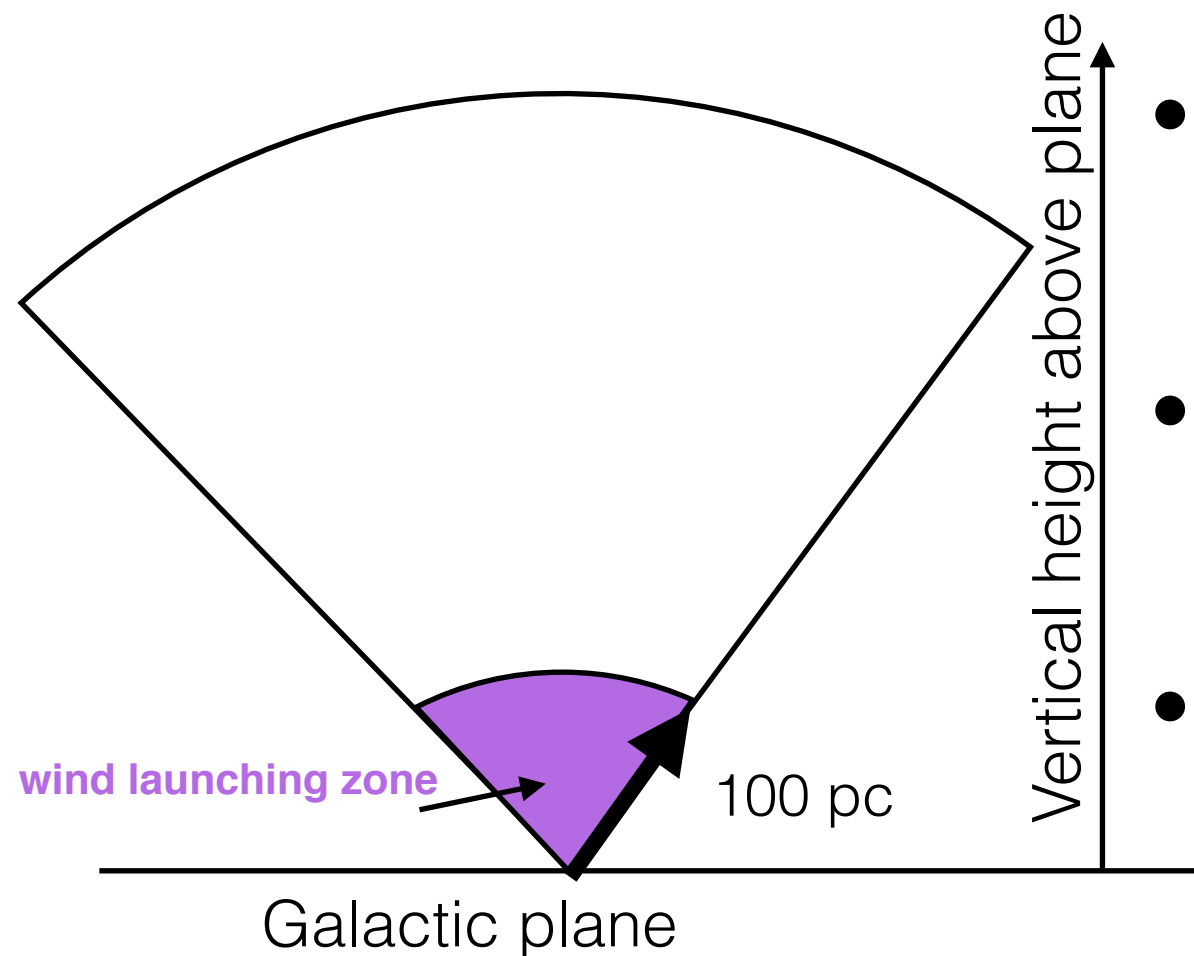
Are positrons “catching a ride” in the outflow that inflates the Fermi Bubbles, and cools as it does so (e.g. Crocker+2011)? Can they explain the annihilation in the Galactic bulge?

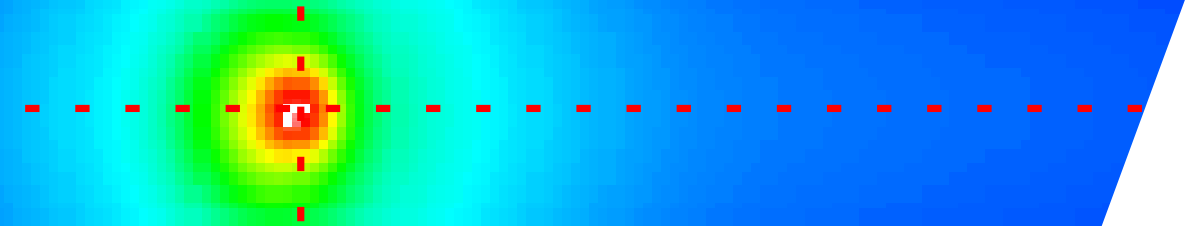
Modelling the nuclear outflow



Wind launching zone:

- $r_0 \sim r(\text{Central Molecular Zone}) \sim 100 \text{ pc}$
- mass and energy injected by CMZ star formation ($\sim 0.1 M_{\text{sun}}/\text{yr}$)
- wind accelerated to v_0 at r_0 ($v_0 \sim 200 - 1500 \text{ km s}^{-1}$)
- Initial temperature \rightarrow kinetic power \sim thermal component ($T_0 \sim 10^5 - 10^8 \text{ K}$)
- Opening angle $\rightarrow \pi \text{ Str}$ (results insensitive to choice of opening angle)





Modelling the nuclear outflow

Free expanding wind zone

- Explore properties of steady-state wind for range of parameter space:

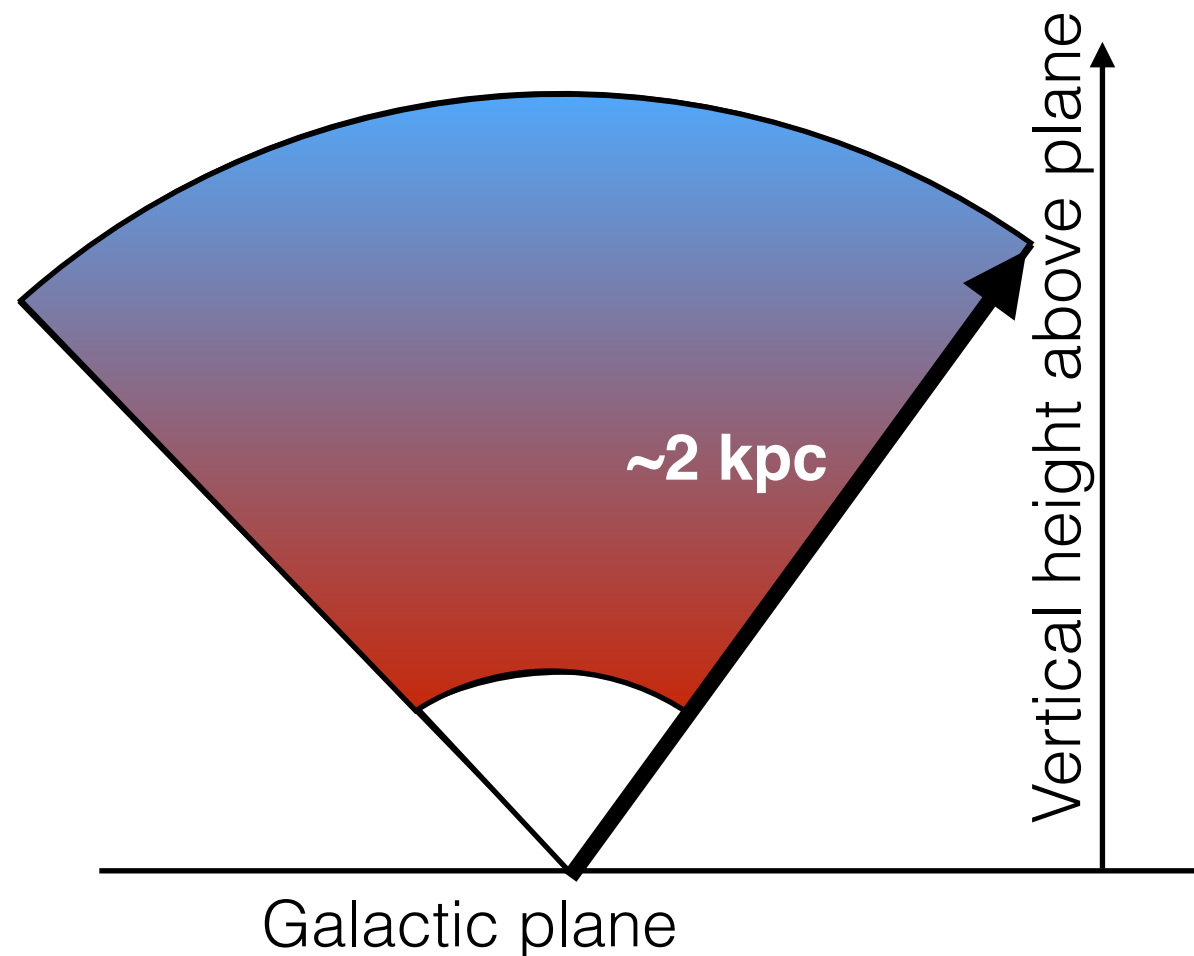
Energy flux -> $10^{38} - 10^{40} \text{ erg s}^{-1}$

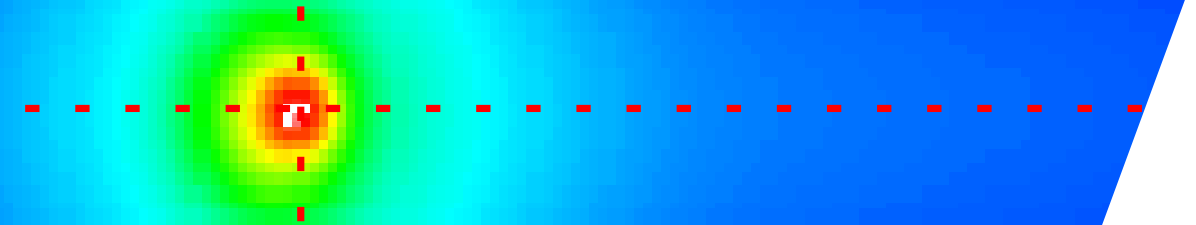
Mass flux -> $10^{-3} - 10^0 M_{\text{sun}} \text{ yr}^{-1}$

- Wind density evolves due to mass conservation

- Wind decelerates due to gravitational potential (Breitschwerdt+)

- Wind cools due to radiative and adiabatic cooling

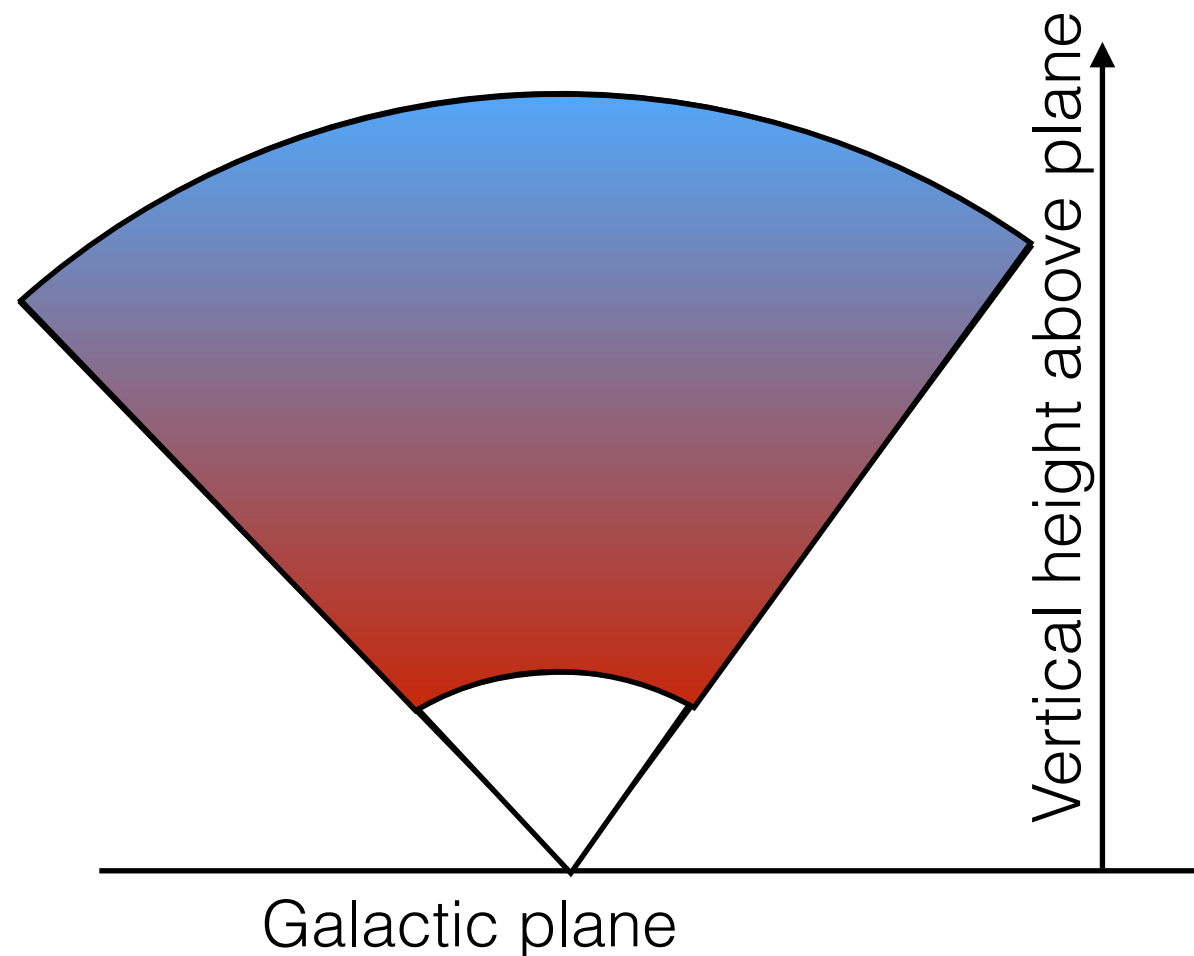




Calculating positron trajectories

For a given point in parameter space calculate trajectories as a function of galactocentric radius:

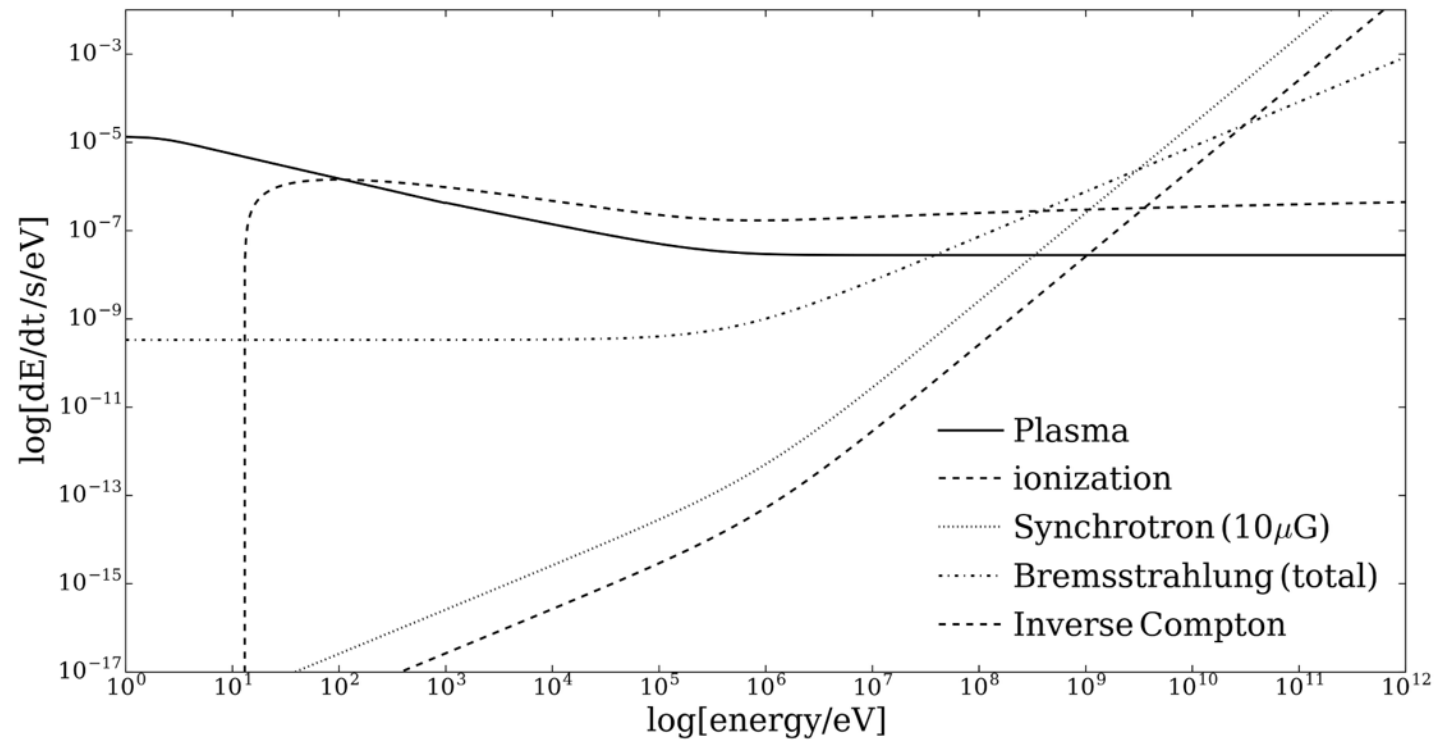
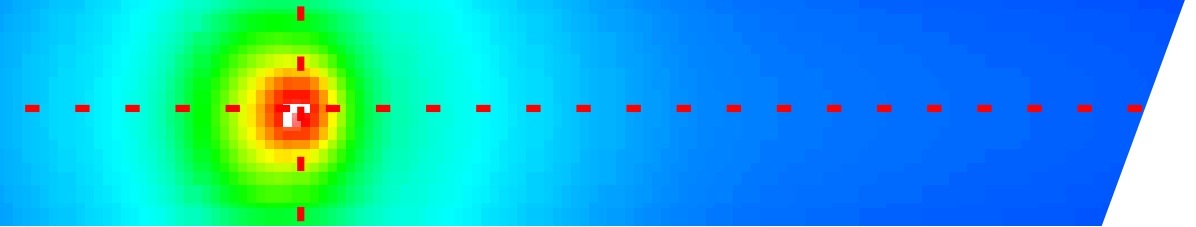
- Mass density
 - Temperature
 - Wind velocity
 - Ionization fraction of hydrogen based on CIE (Sutherland & Dopita 1993)
- Each trajectory represents the trajectory of a positron in the model.



Positrons travel outwards **at wind velocity v**

Positrons are injected at the wind launching radius with initial energy w_0 and followed until they thermalize (reach ~ 10 eV)

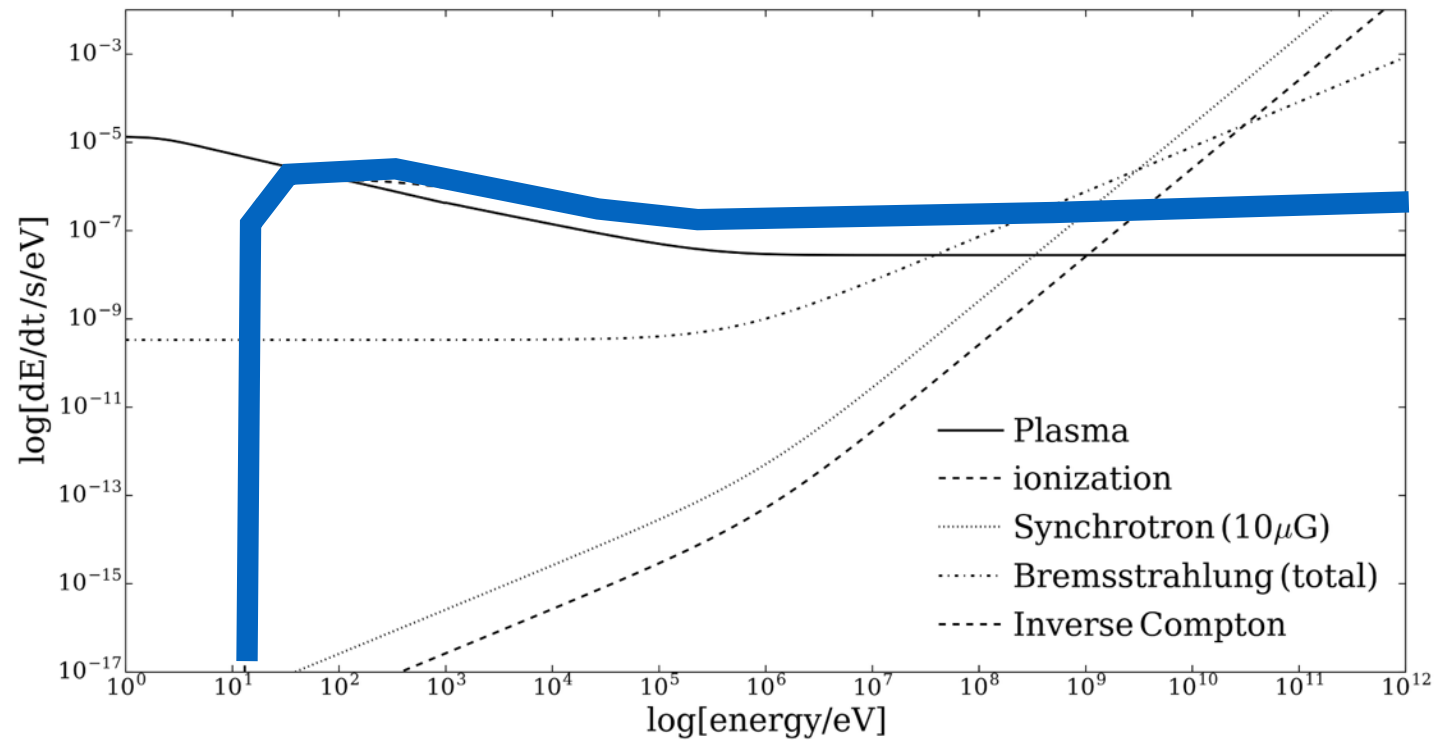
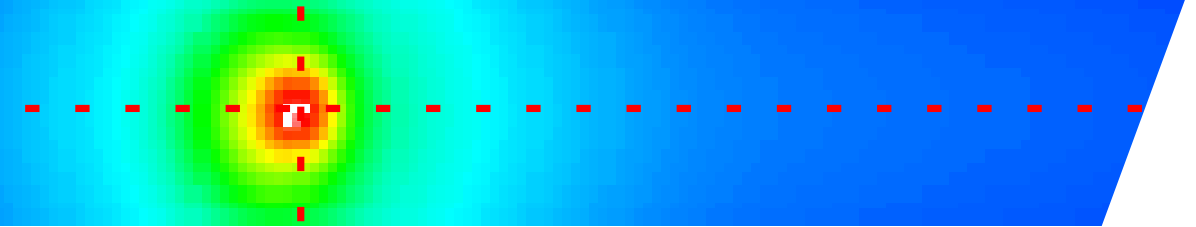
Calculating positron trajectories



Positrons are mildly relativistic:

Radiative losses through ionisation and coulomb losses. Other processes make negligible contribution

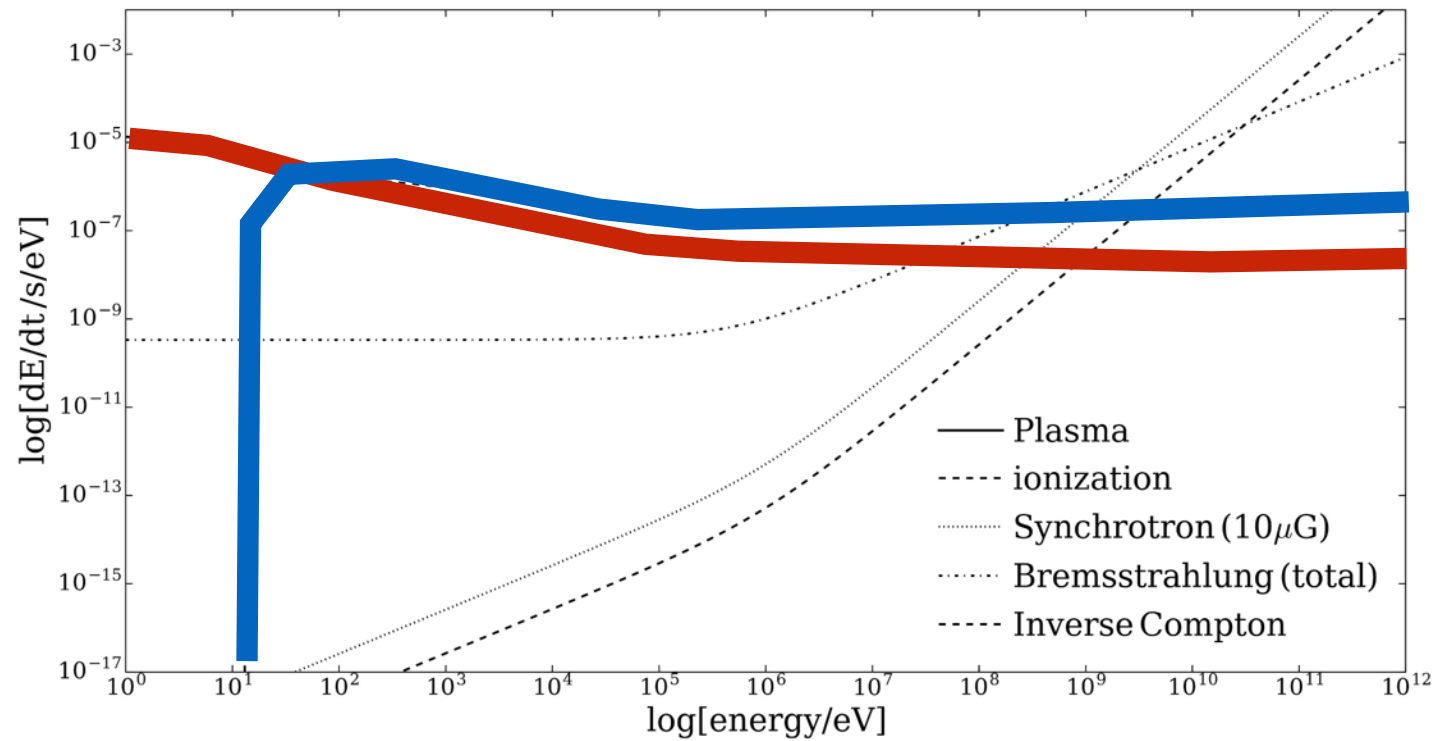
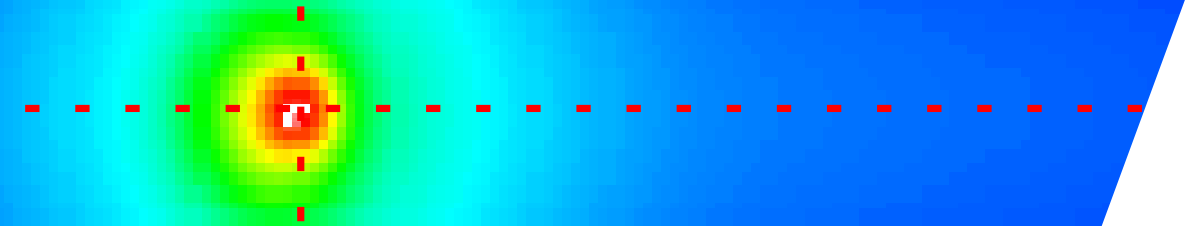
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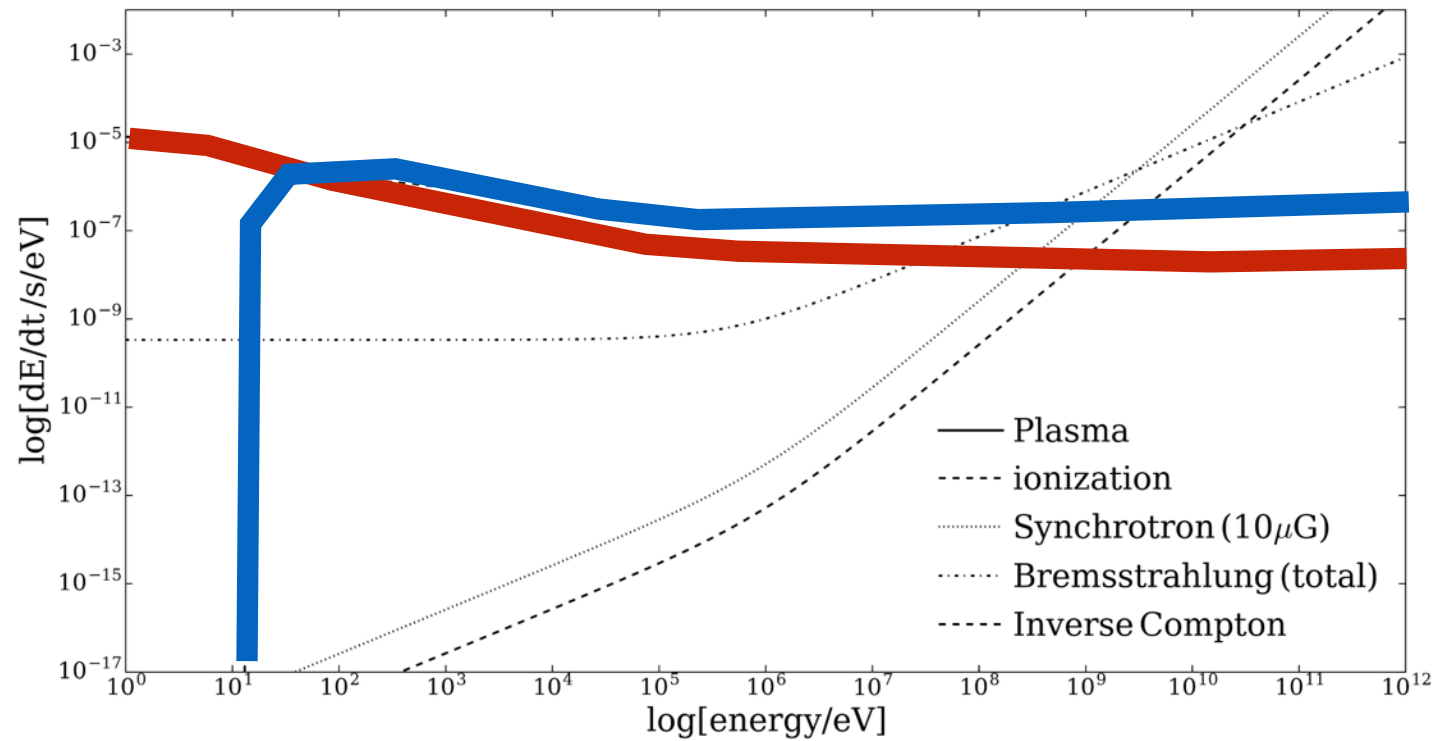
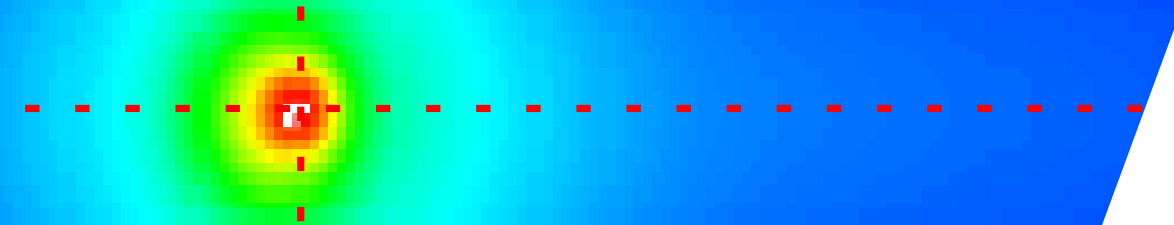
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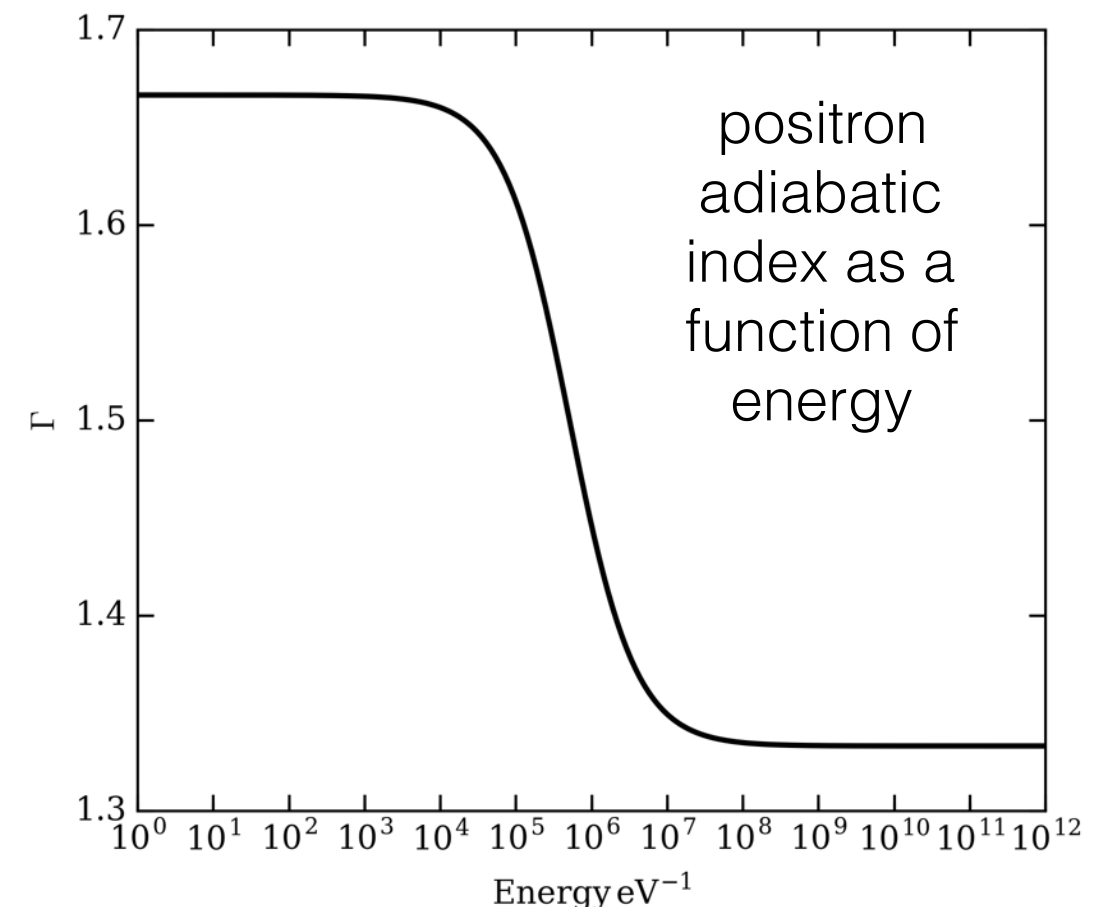
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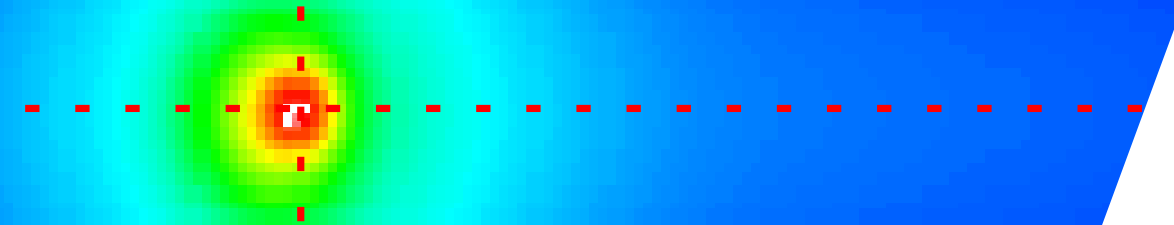


$$\left. \frac{dw}{dt} \right|_{\text{ad}} = -2 \frac{(\Gamma - 1)v[t]w_0}{(r_0 + v[t]t)} \left(\frac{\rho[t]}{\rho_0} \right)^{\Gamma-1}.$$

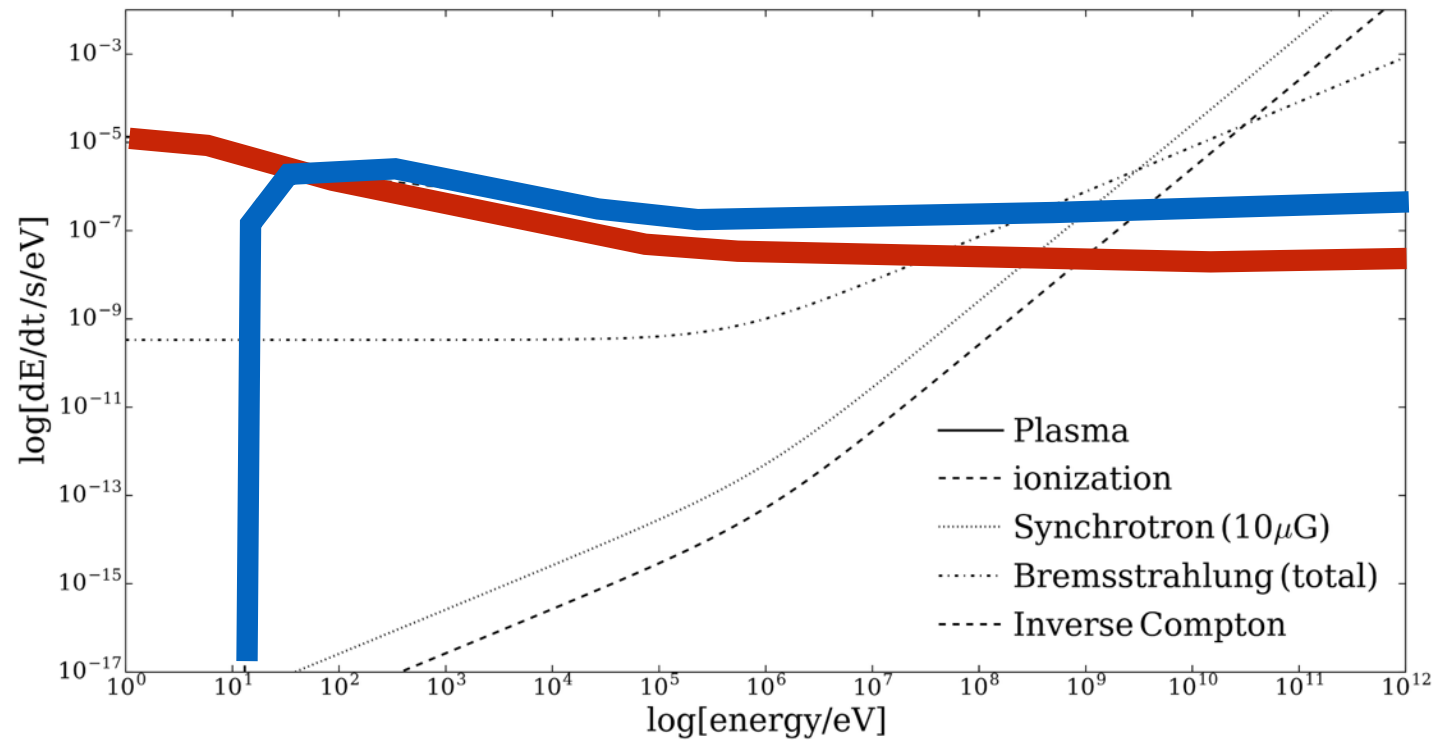
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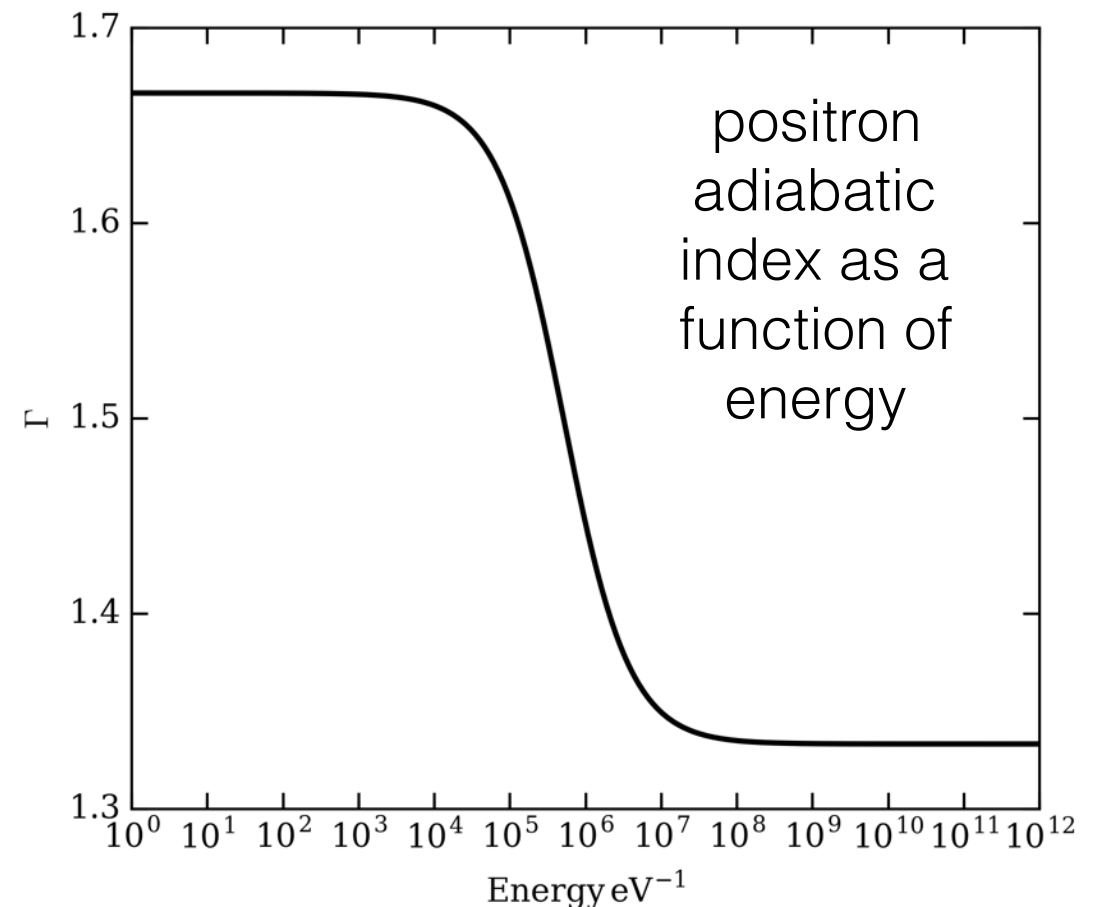


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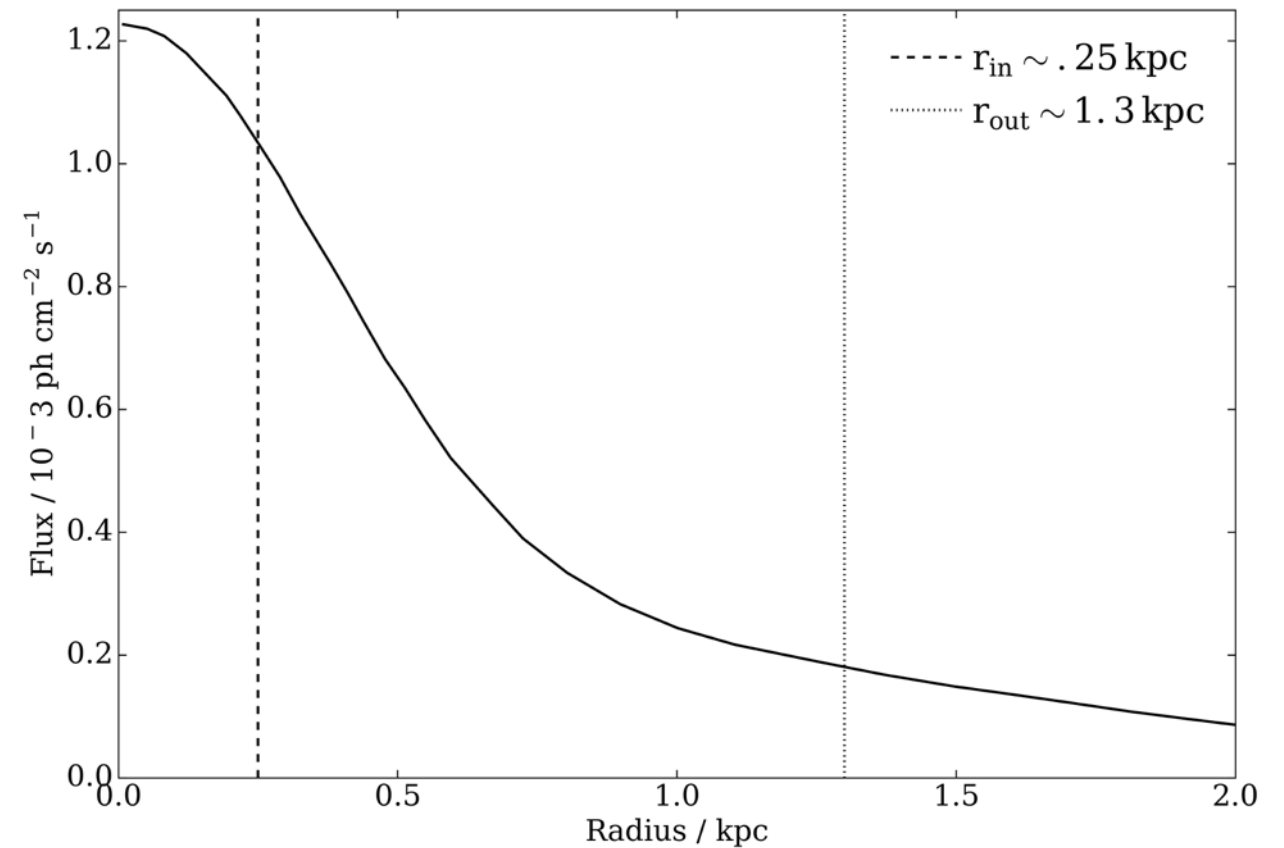
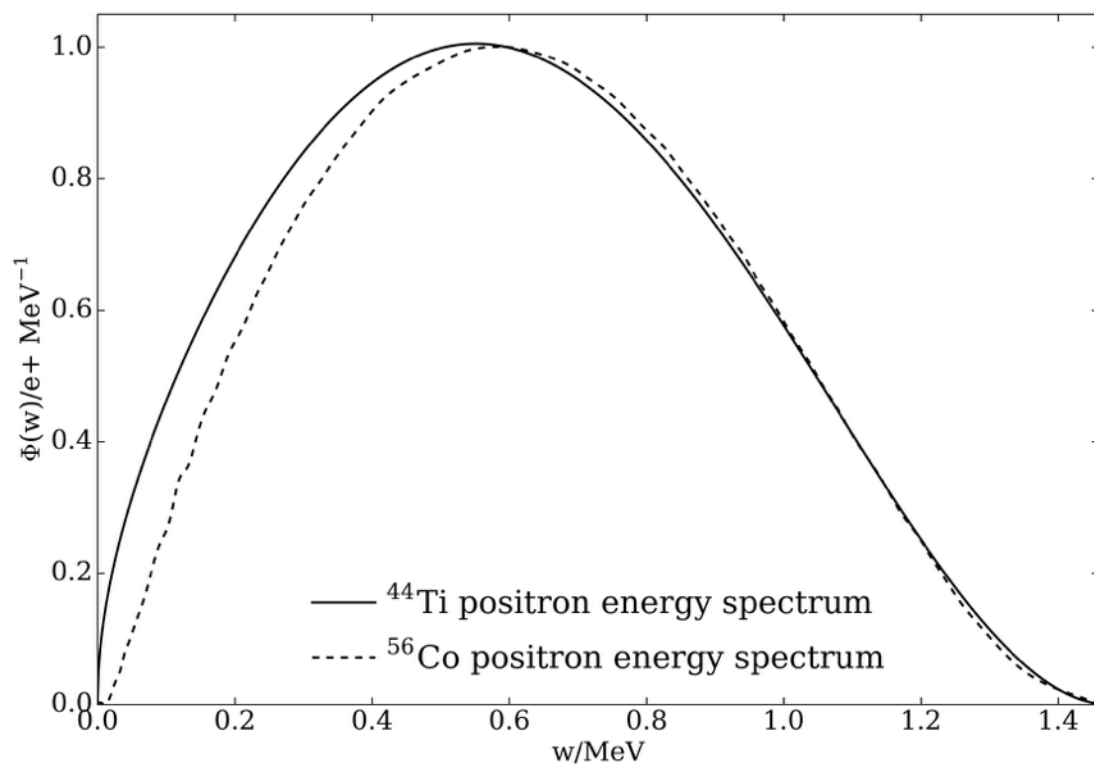
Adiabatic losses dominate over radiative processes:

Adiabatic index allowed to vary (w/ assumption of ideal EoS)



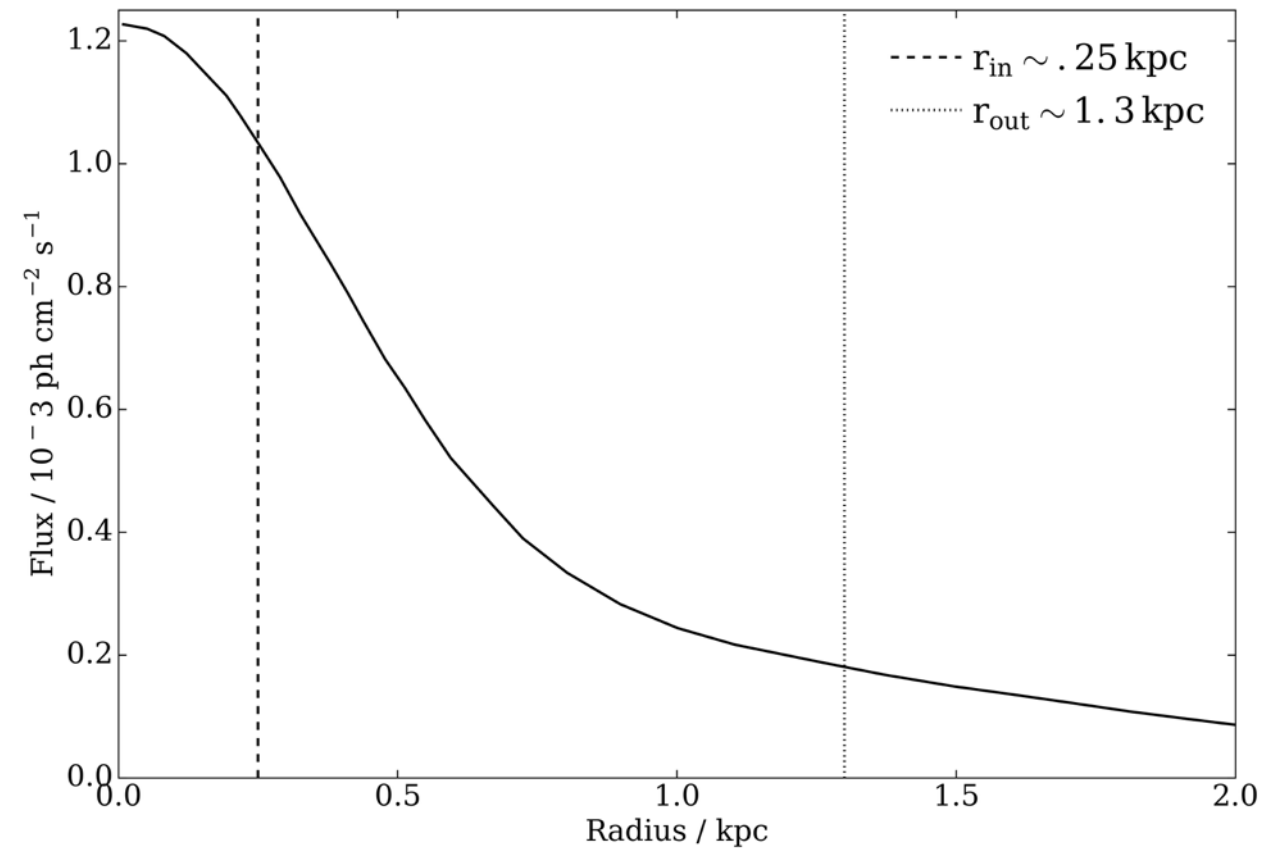
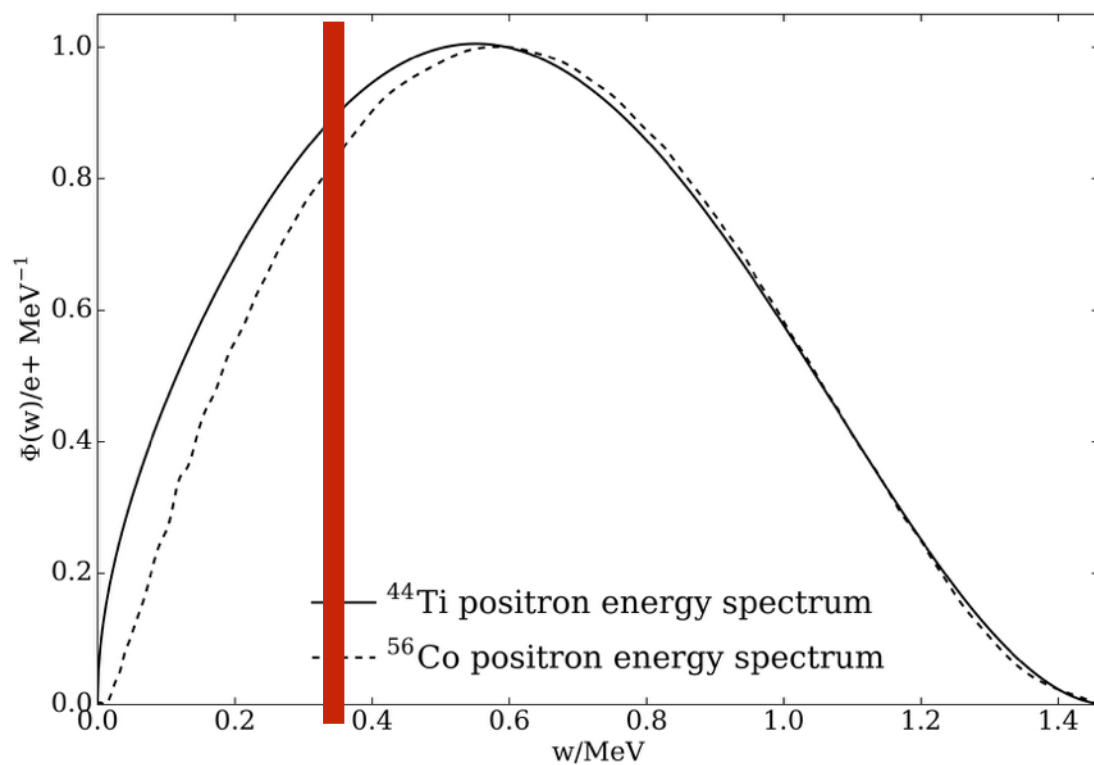
Calculating positron trajectories

Introduce a parameterisation of the Galactic bulge model intensity profile, and the positron injection energy spectrum



Calculating positron trajectories

Introduce a parameterisation of the Galactic bulge model intensity profile, and the
 $W_{\text{low}} \sim 0.4 \text{ MeV}$ positron injection energy spectrum

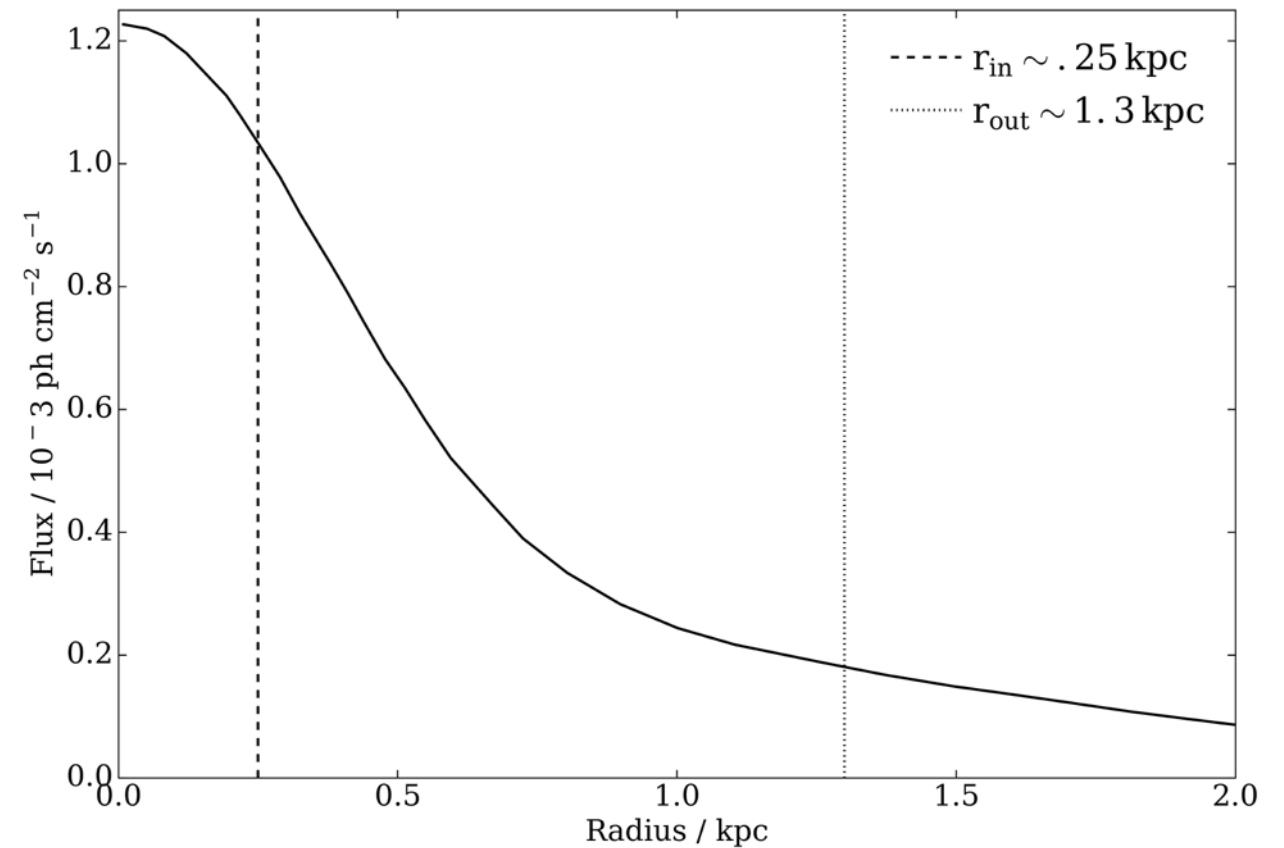
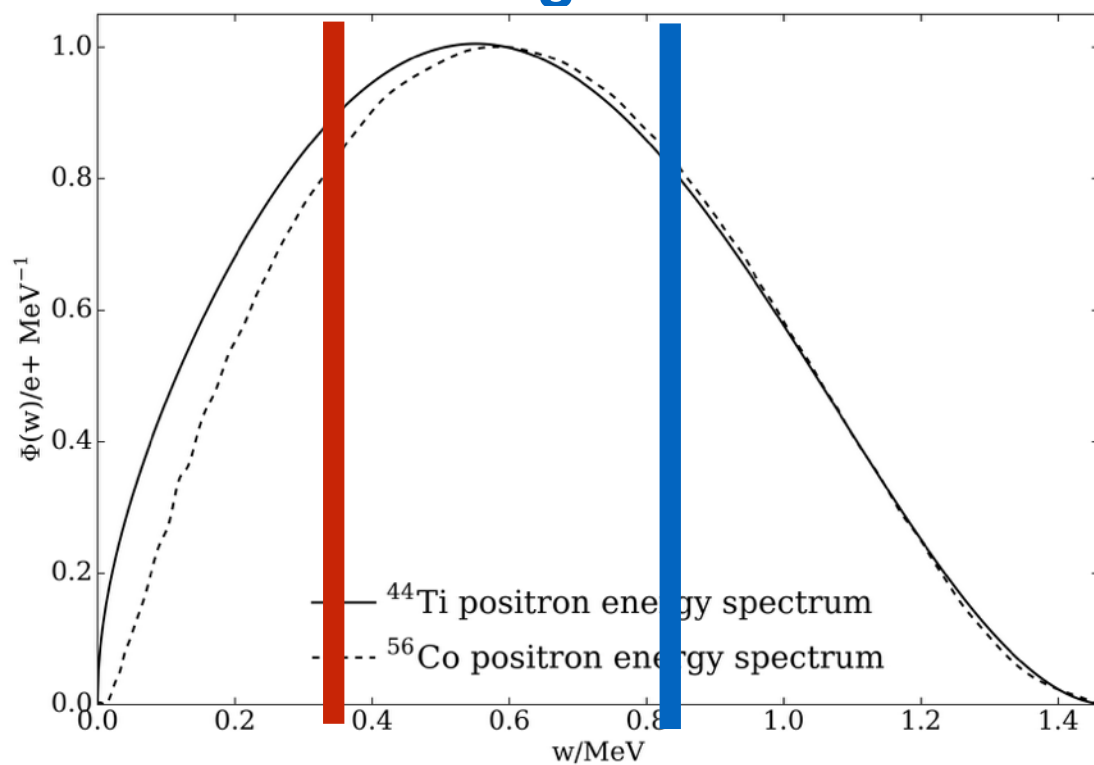


Calculating positron trajectories

Introduce a parameterisation of the Galactic bulge model intensity profile, and the positron injection energy spectrum

$W_{\text{low}} \sim 0.4 \text{ MeV}$

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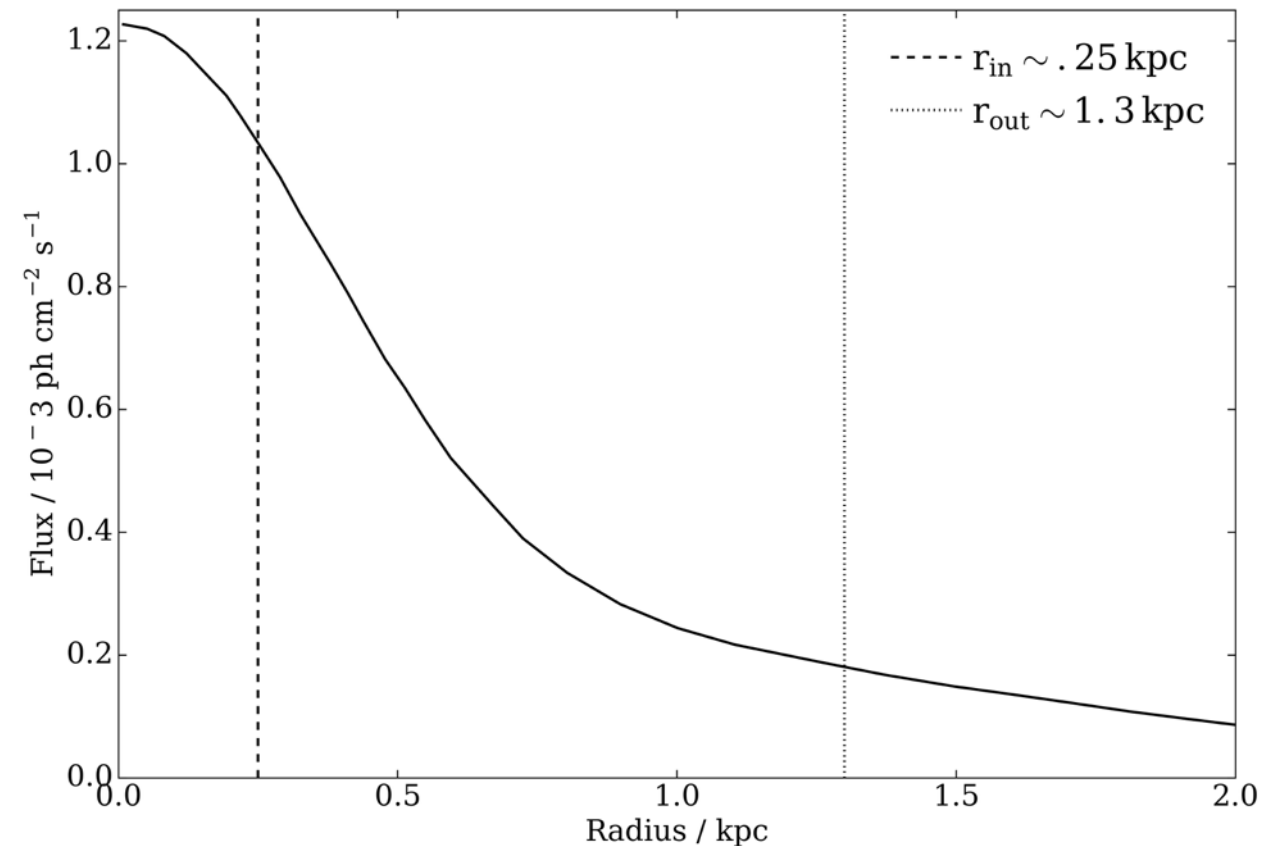
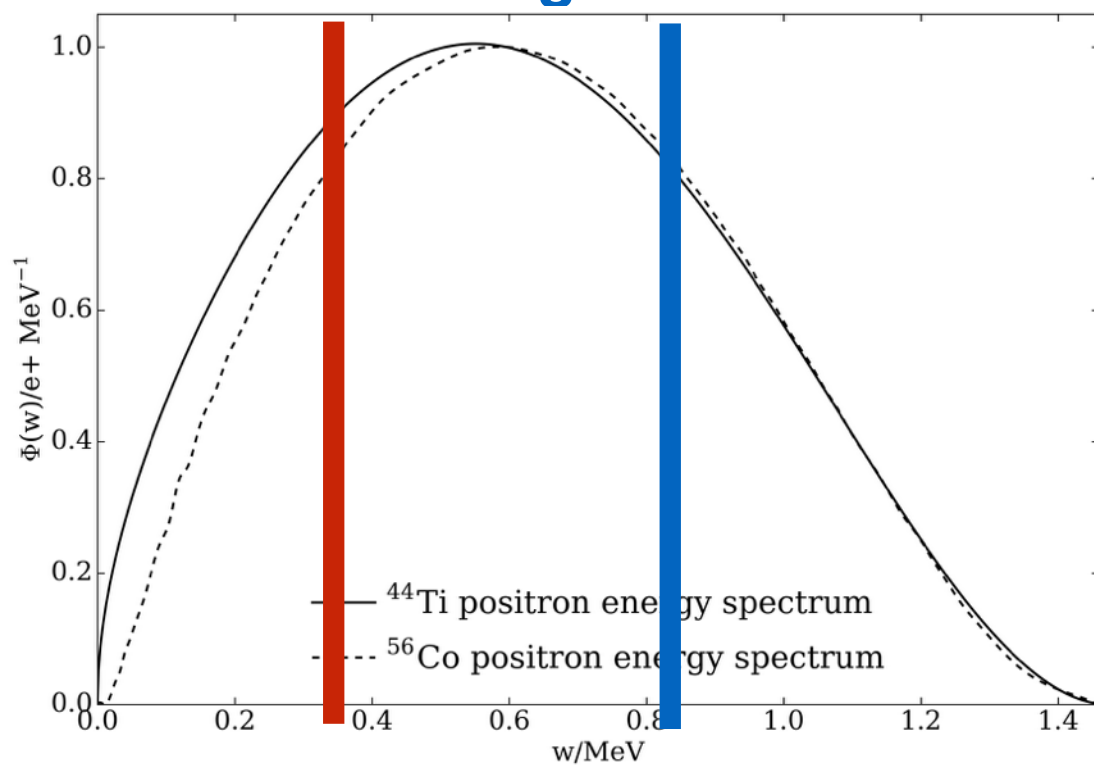


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W_{low} , W_{high} : mean energy at which 50% of positrons are injected into the ISM

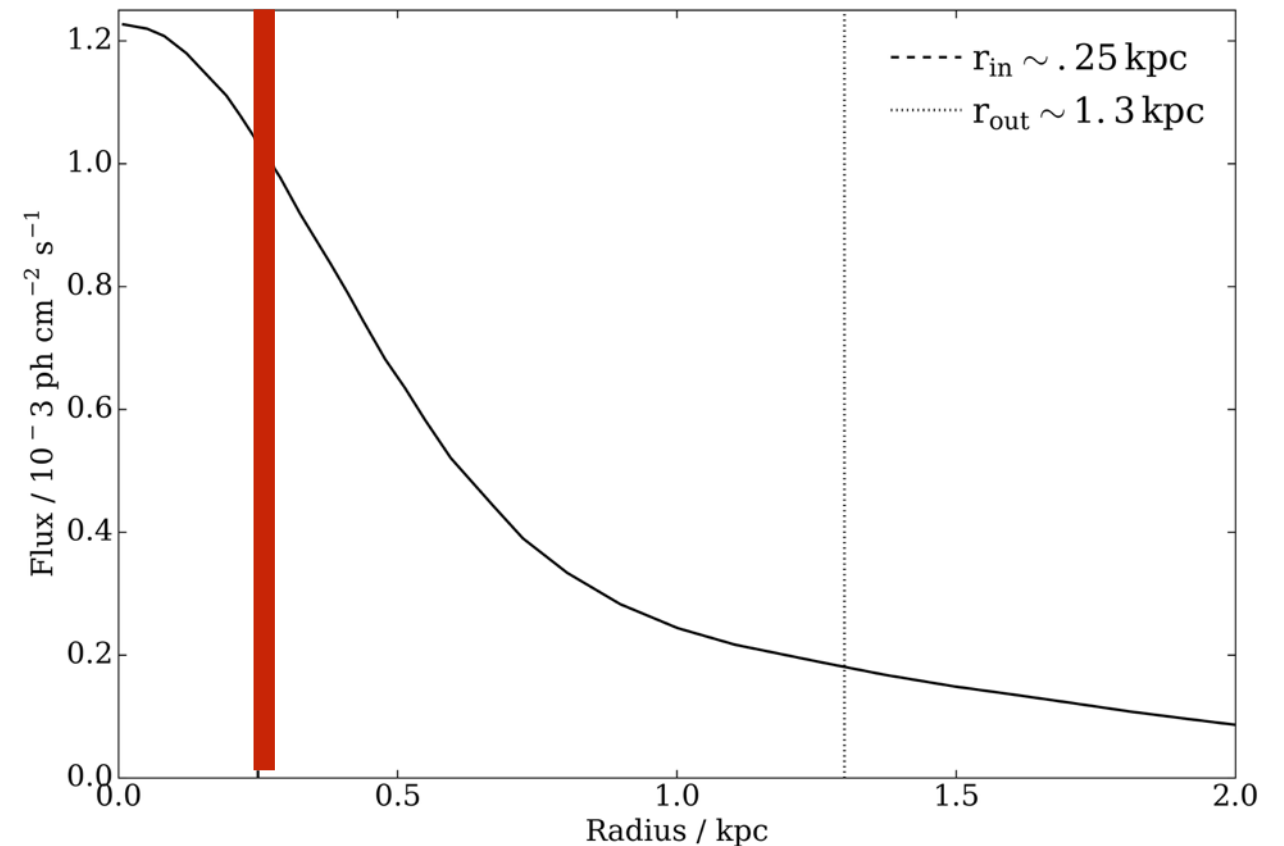
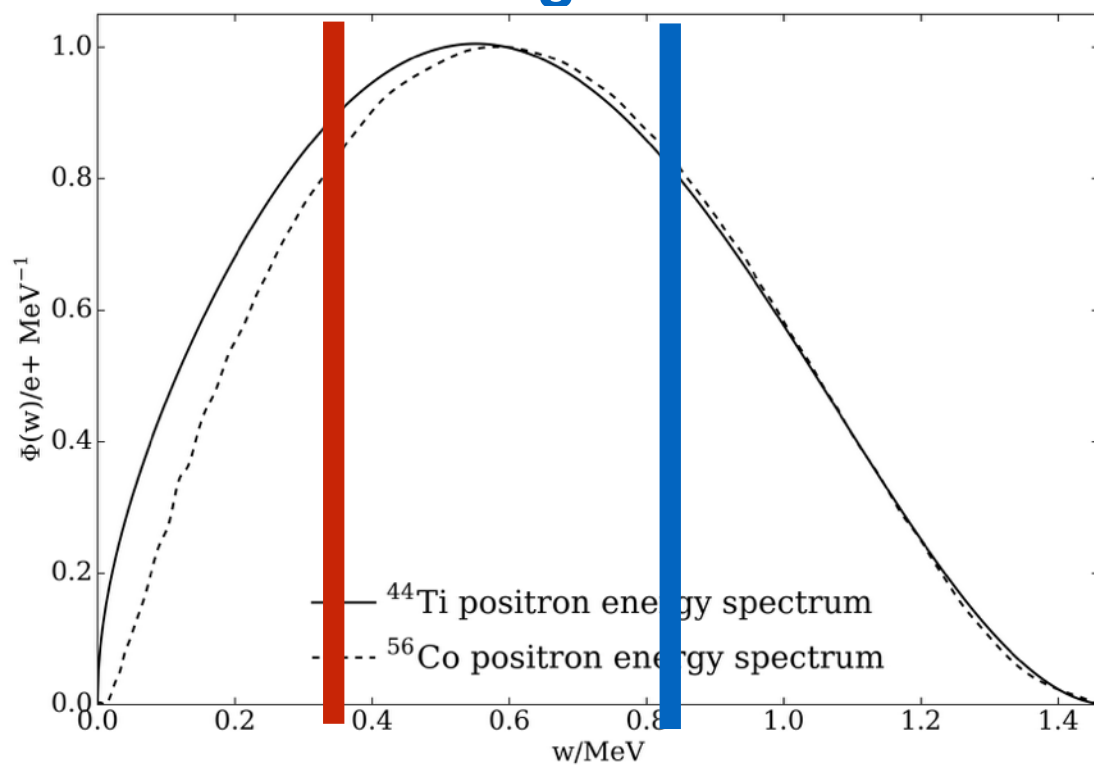
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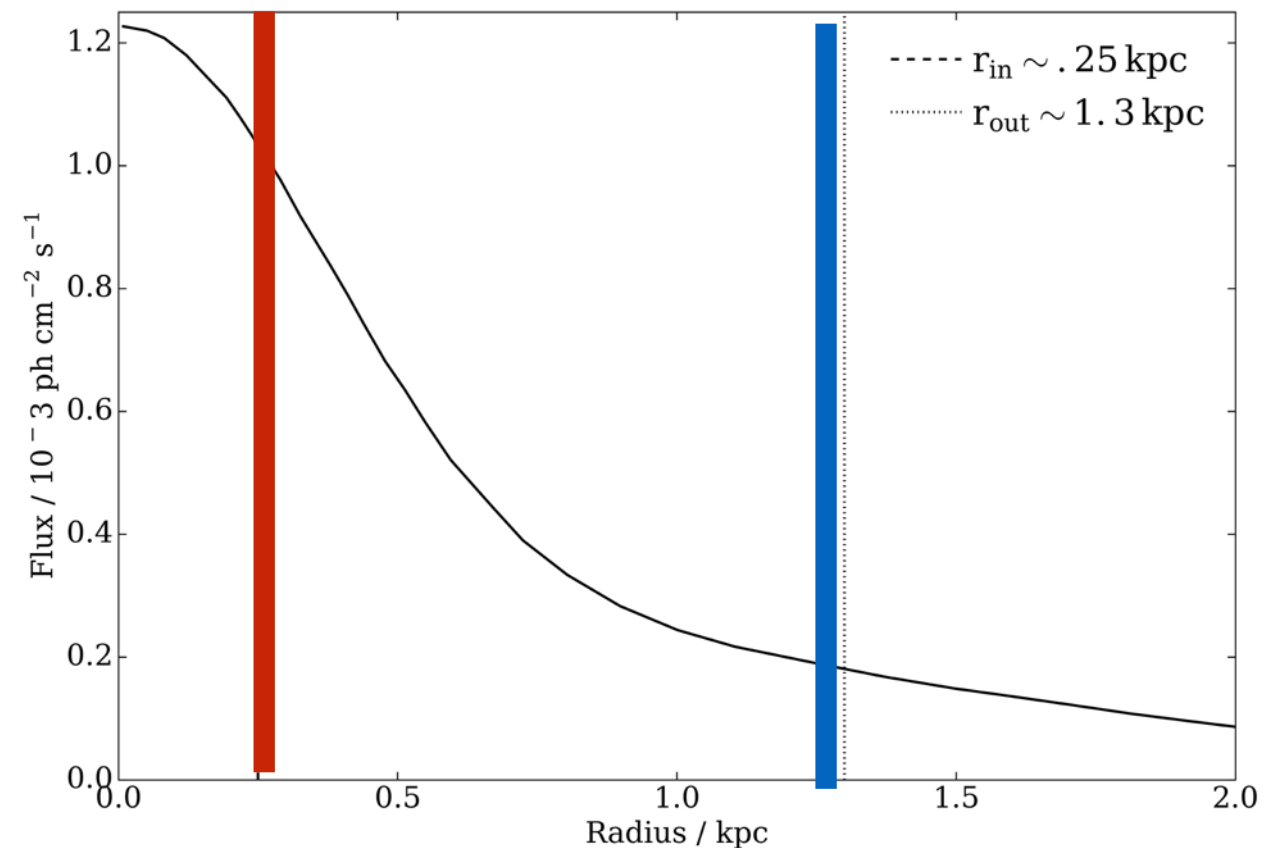
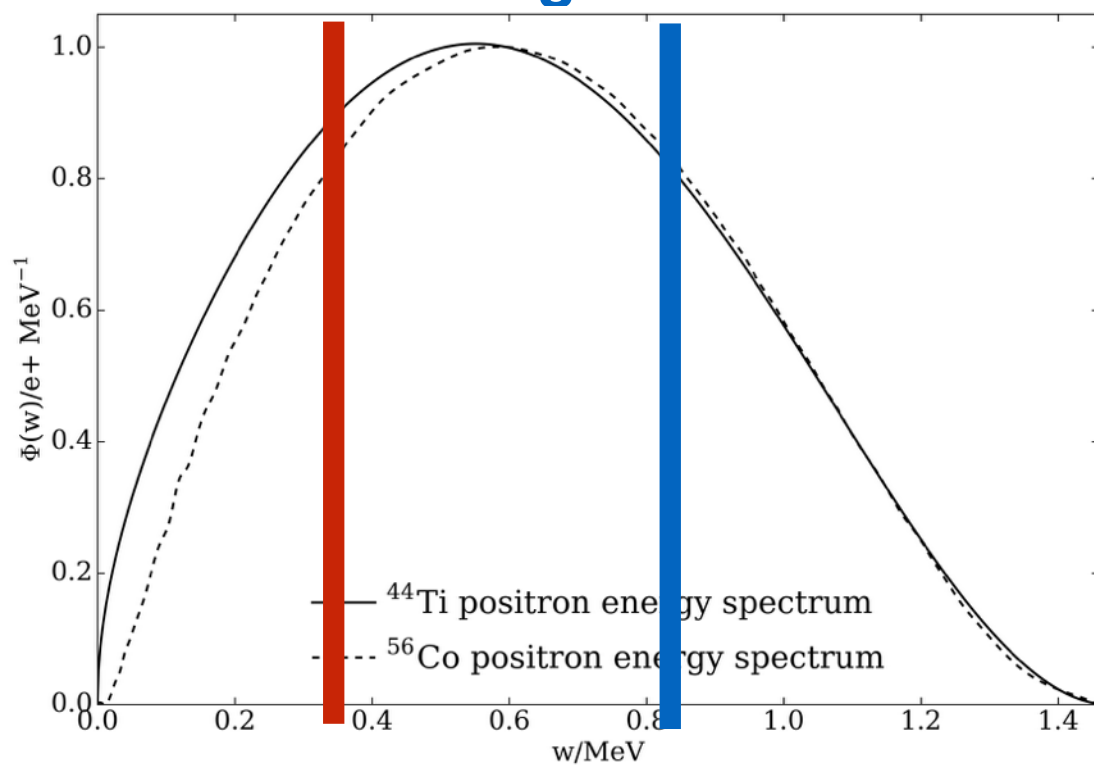
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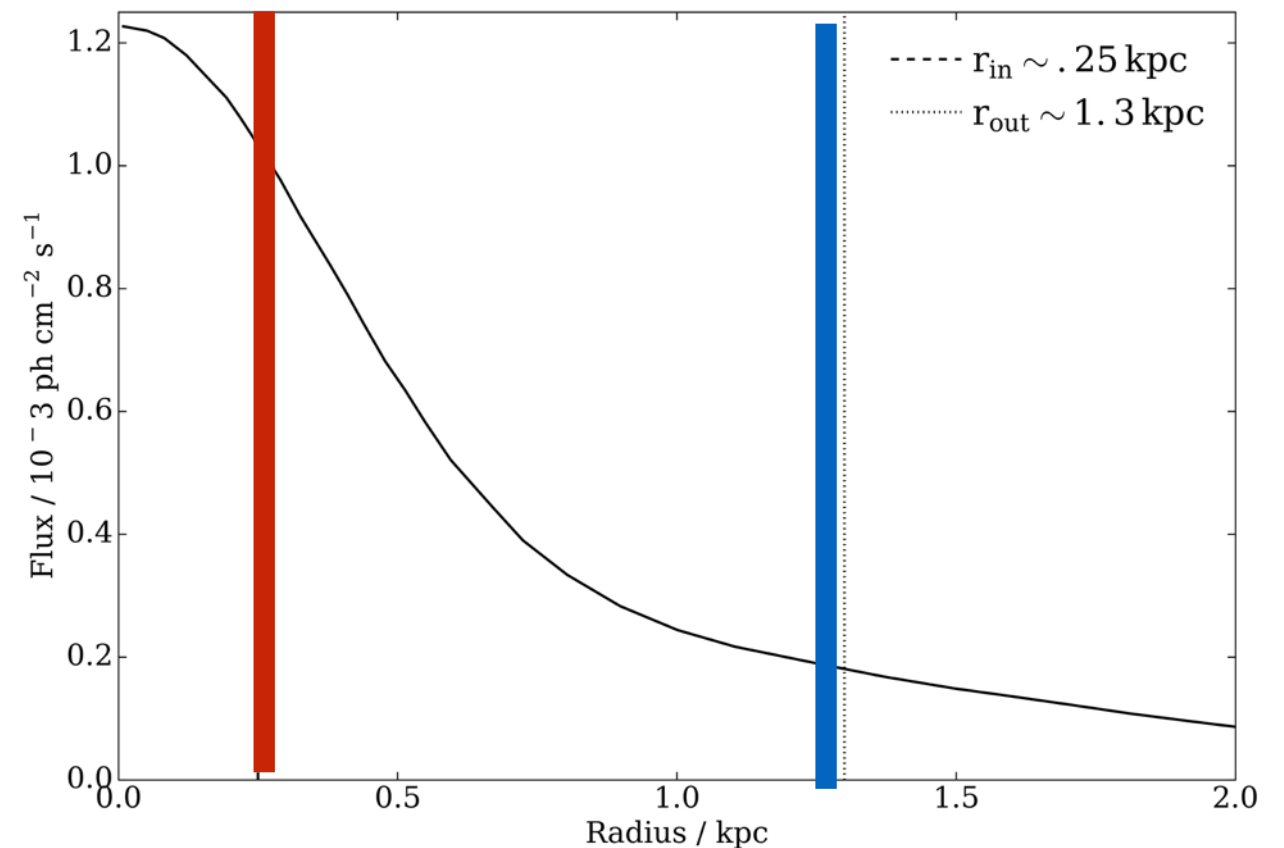
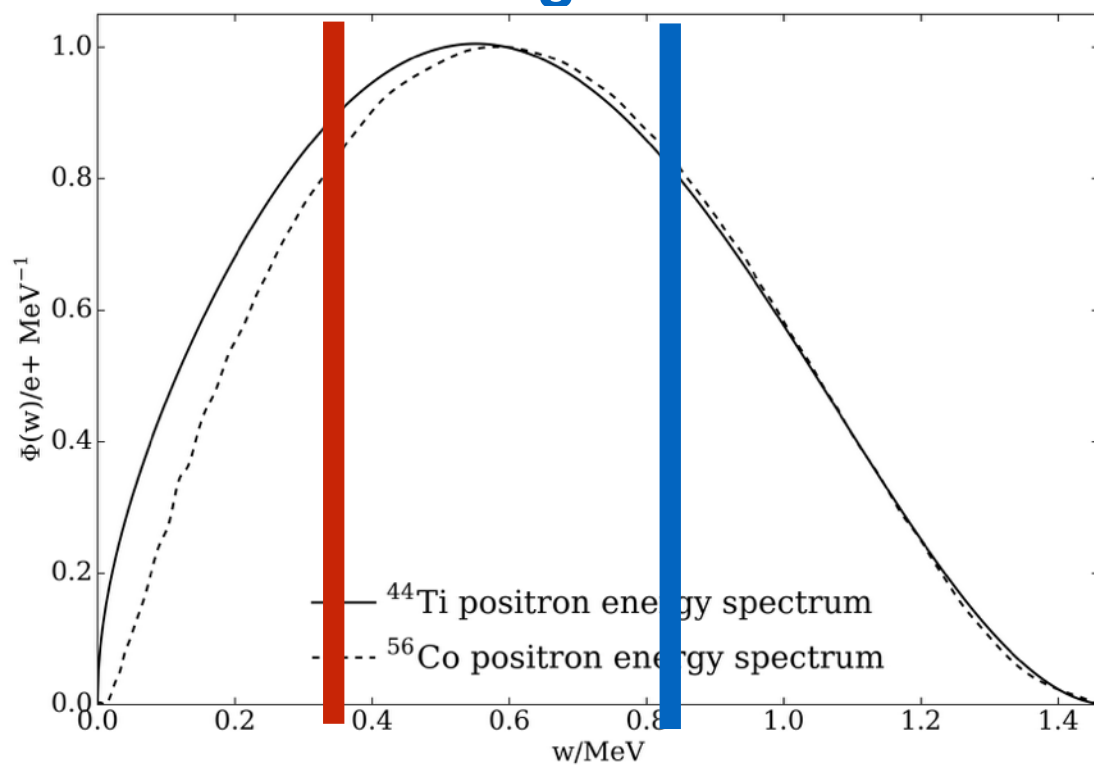
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Calculating positron trajectories

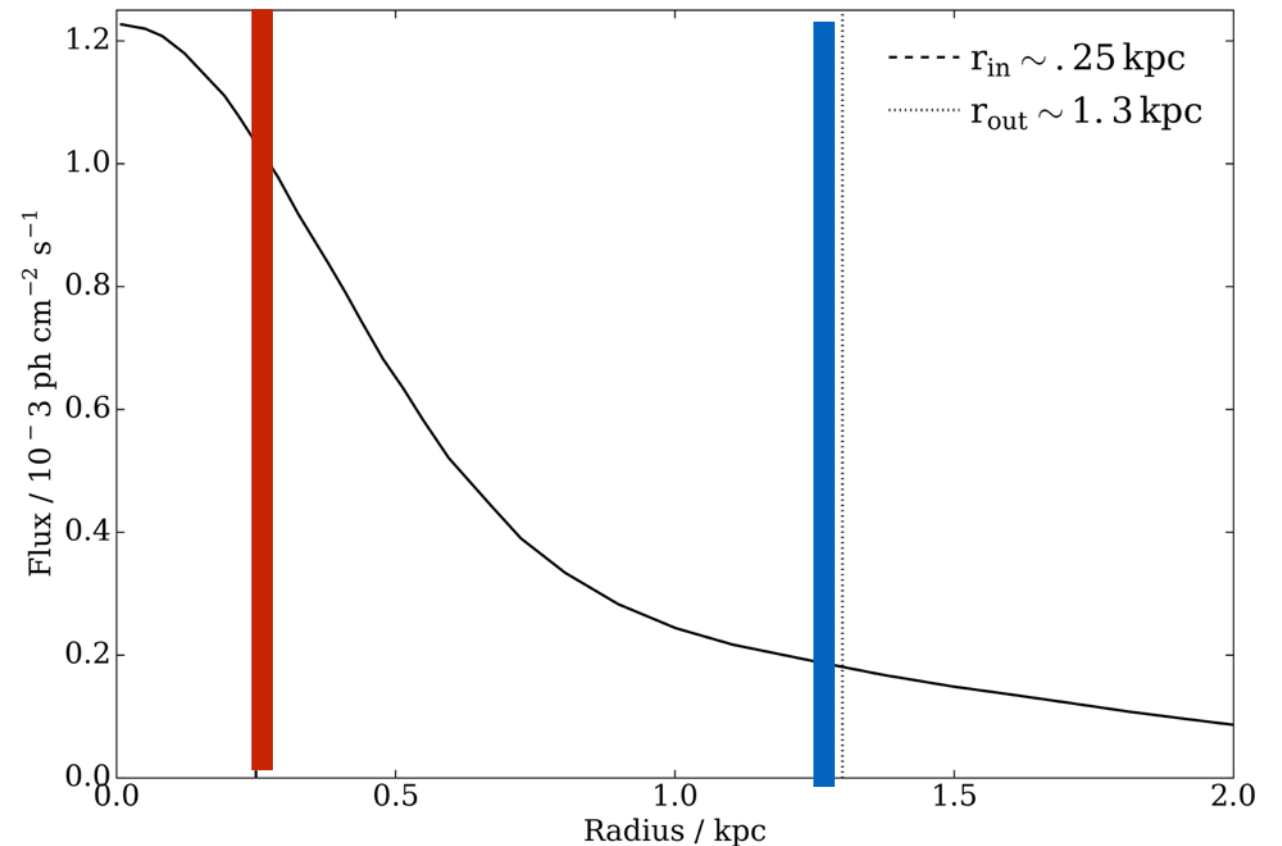
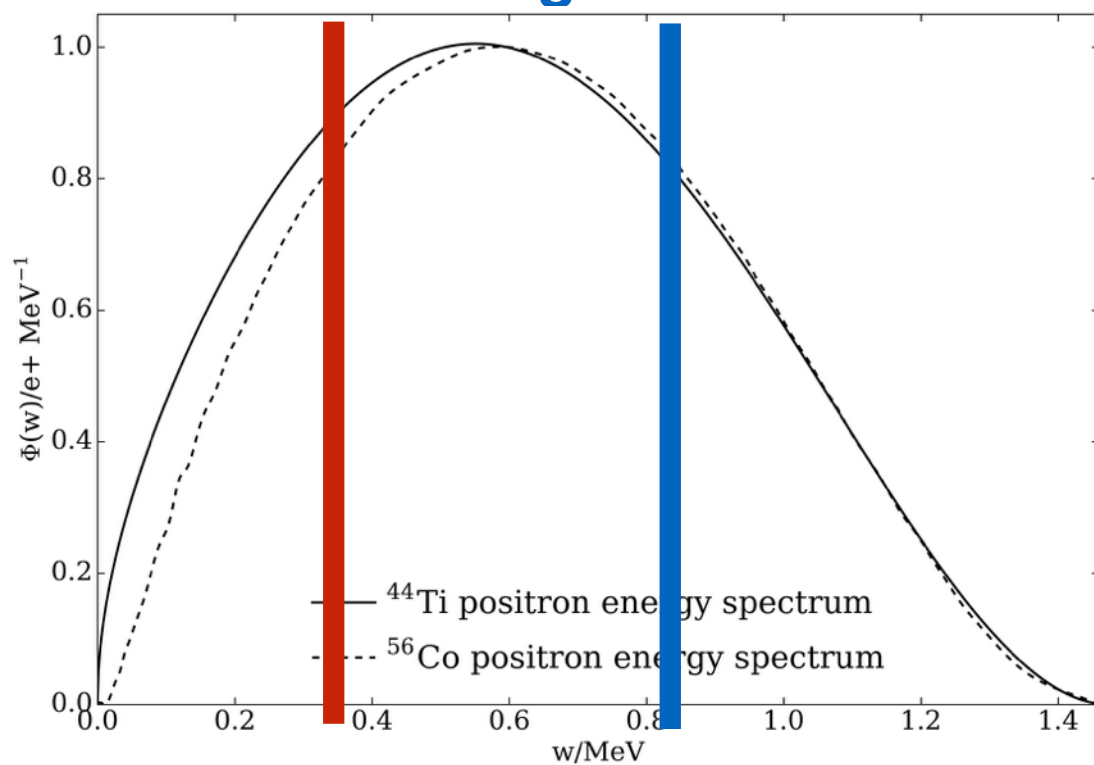
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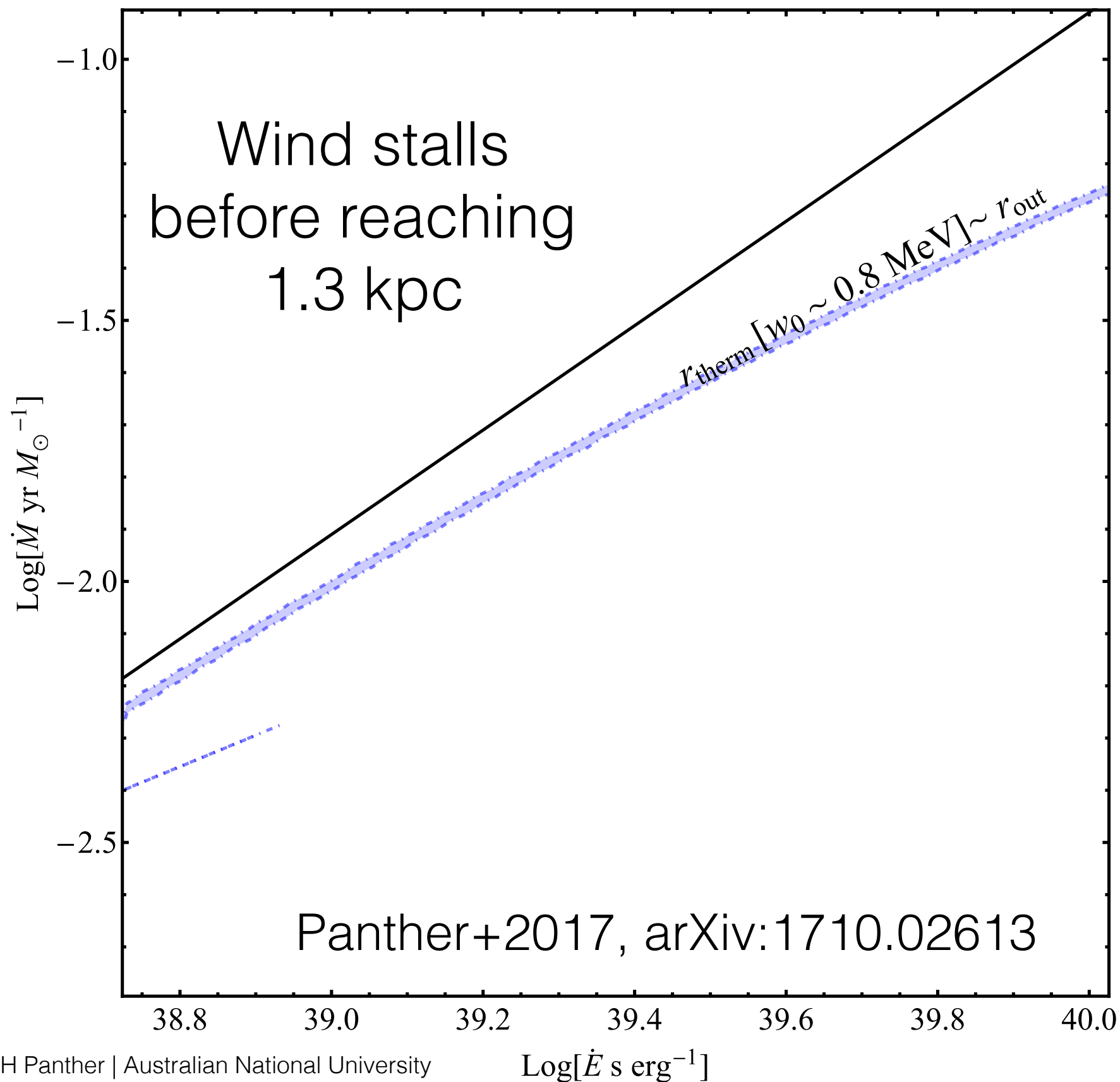
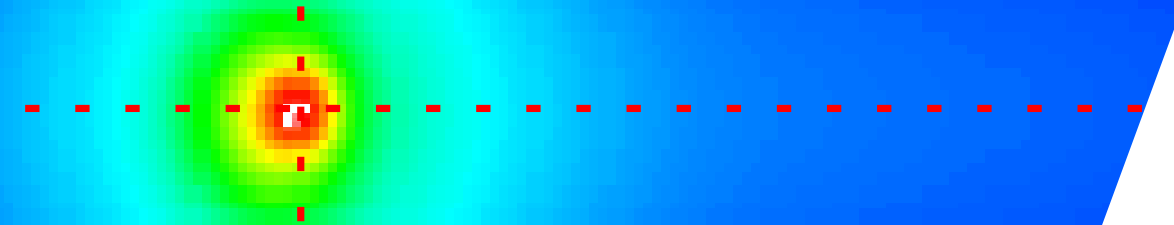


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Remember: smooth Gaussian profile is a property of the best fit model, not necessarily the signal itself

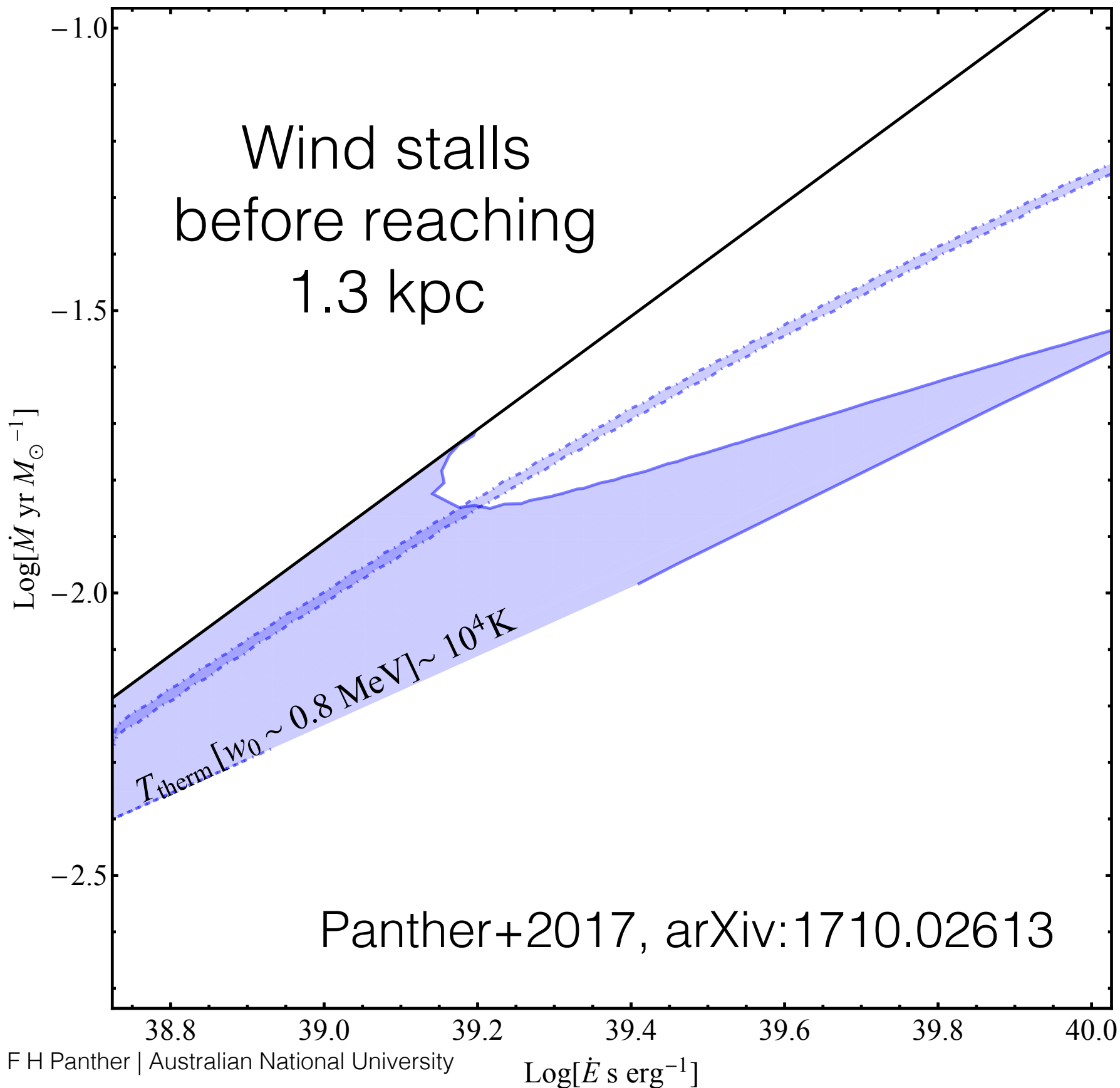
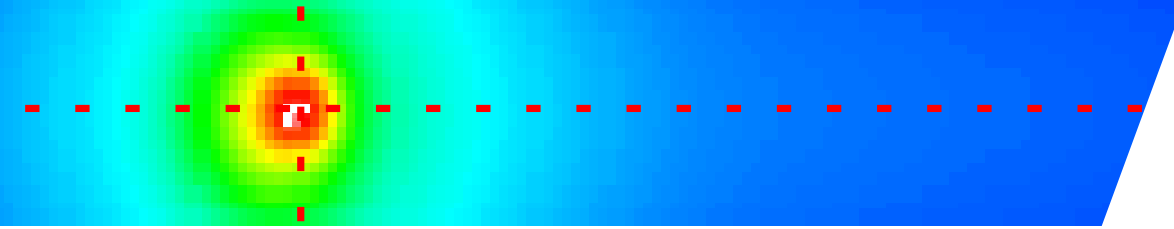
Results



Positrons with initial kinetic energies **W**high advect to **r**out

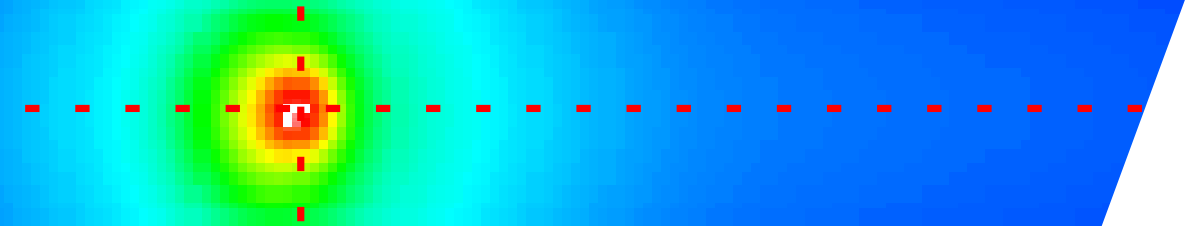
For annihilation spectra to be consistent with observations, these positrons must annihilate in a 10^4 K ISM

Results

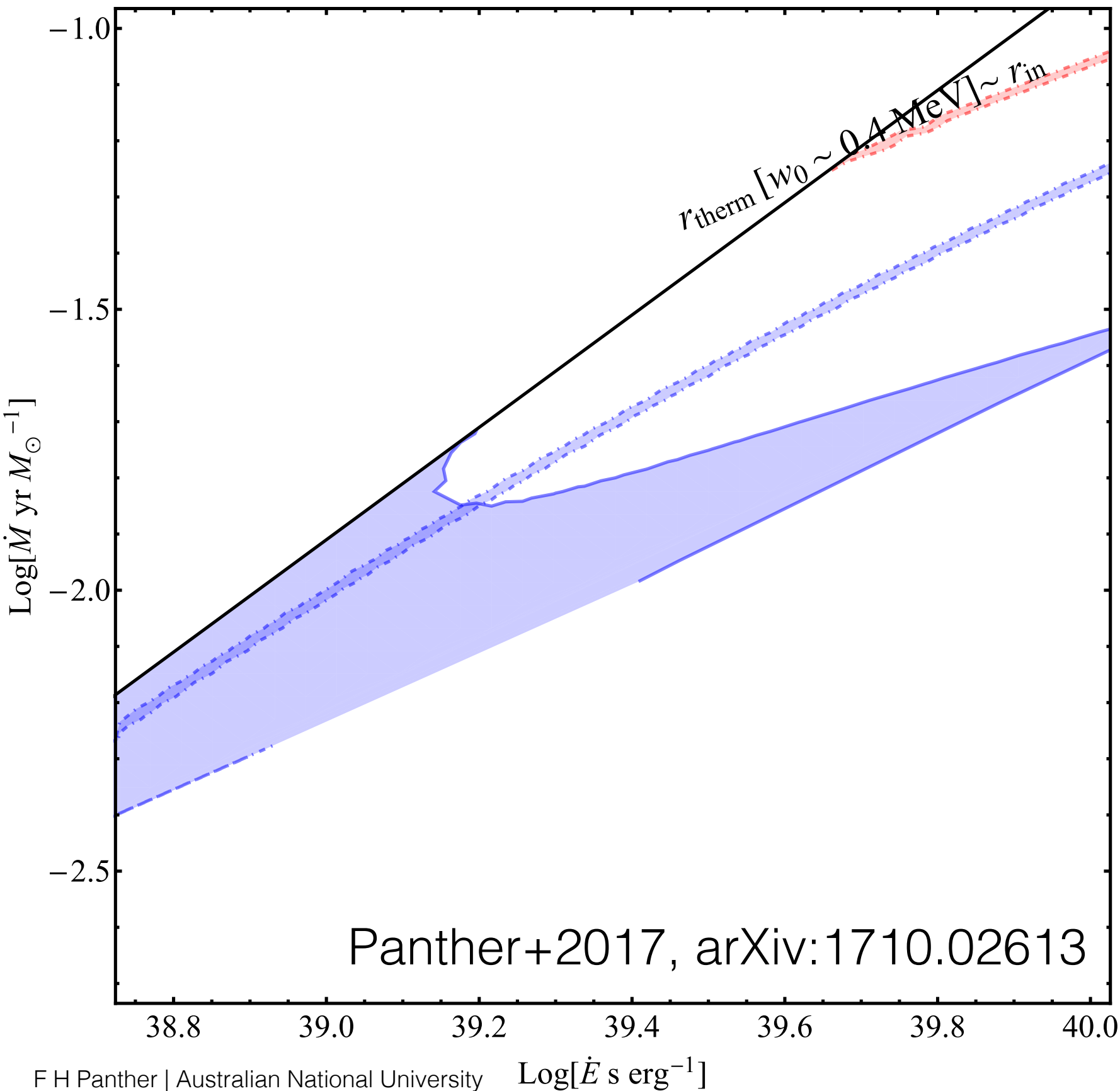


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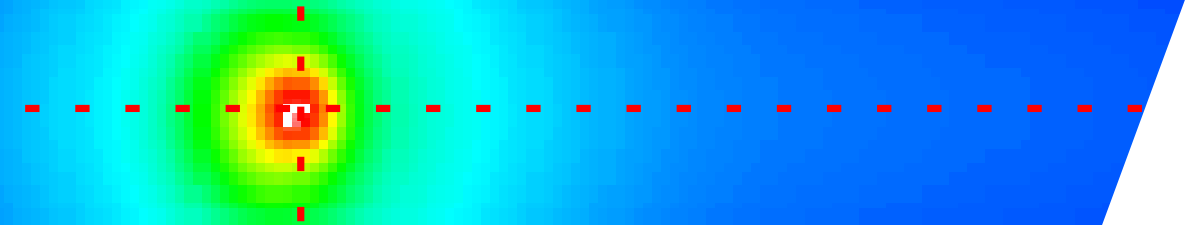


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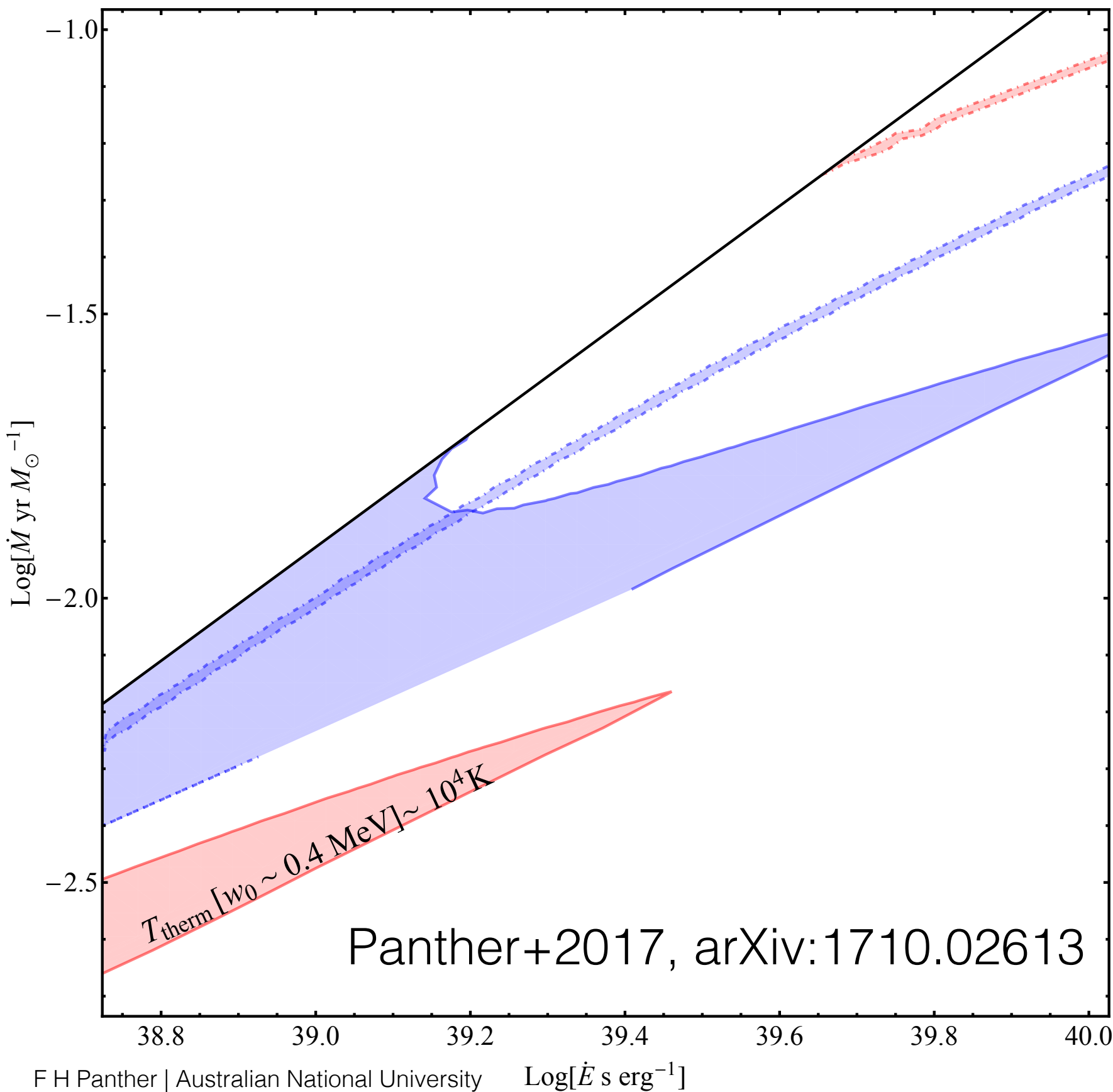


Positrons with initial kinetic energies w_{low} advect to r_{in}

For annihilation spectra to be consistent with observations, these positrons must also annihilate in a 10^4 K ISM

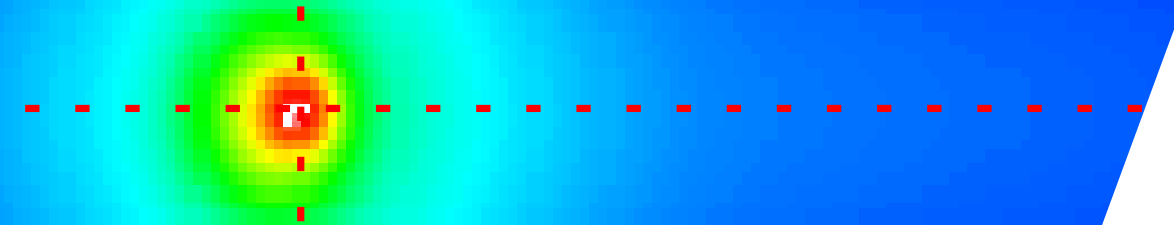


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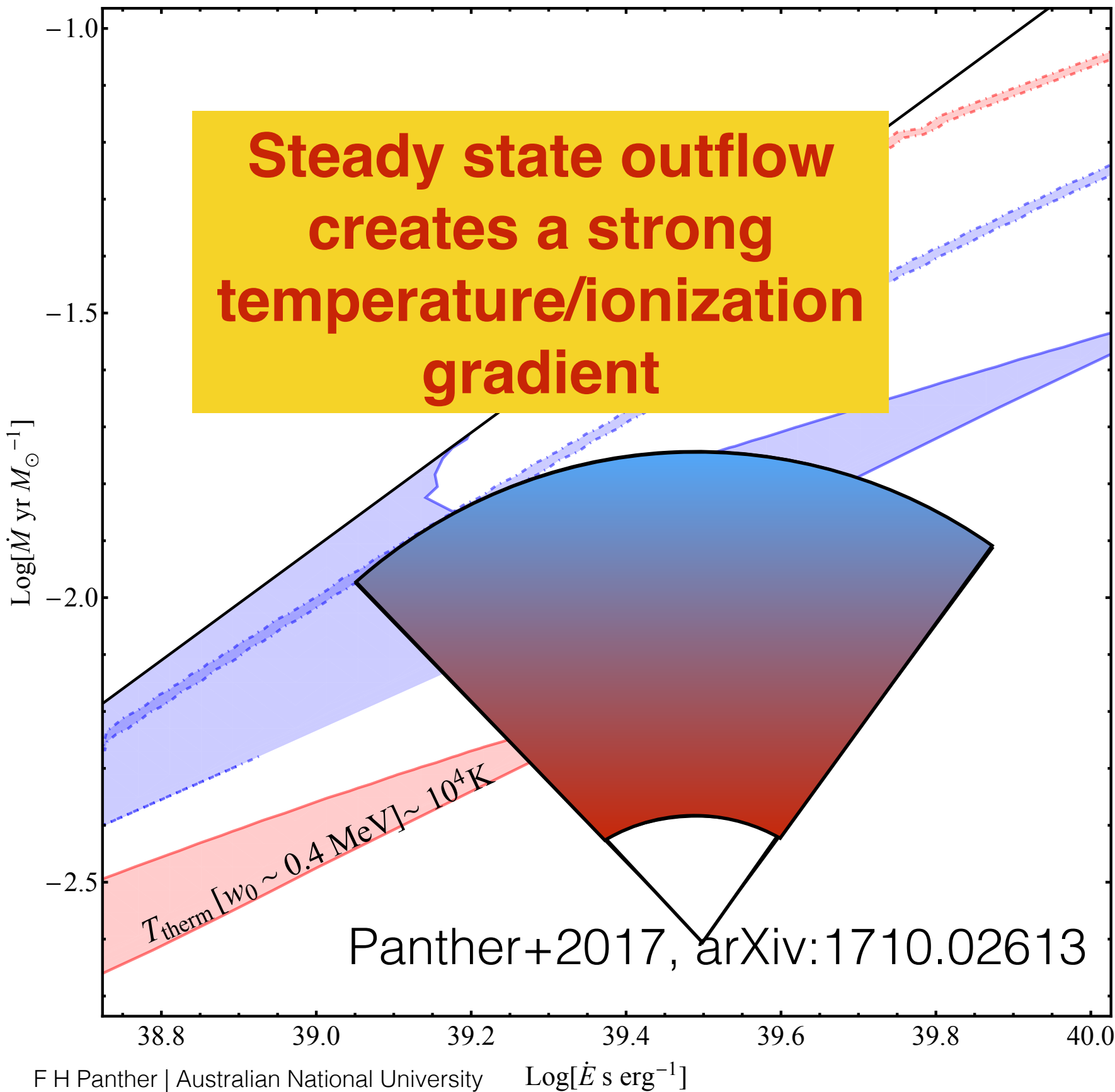


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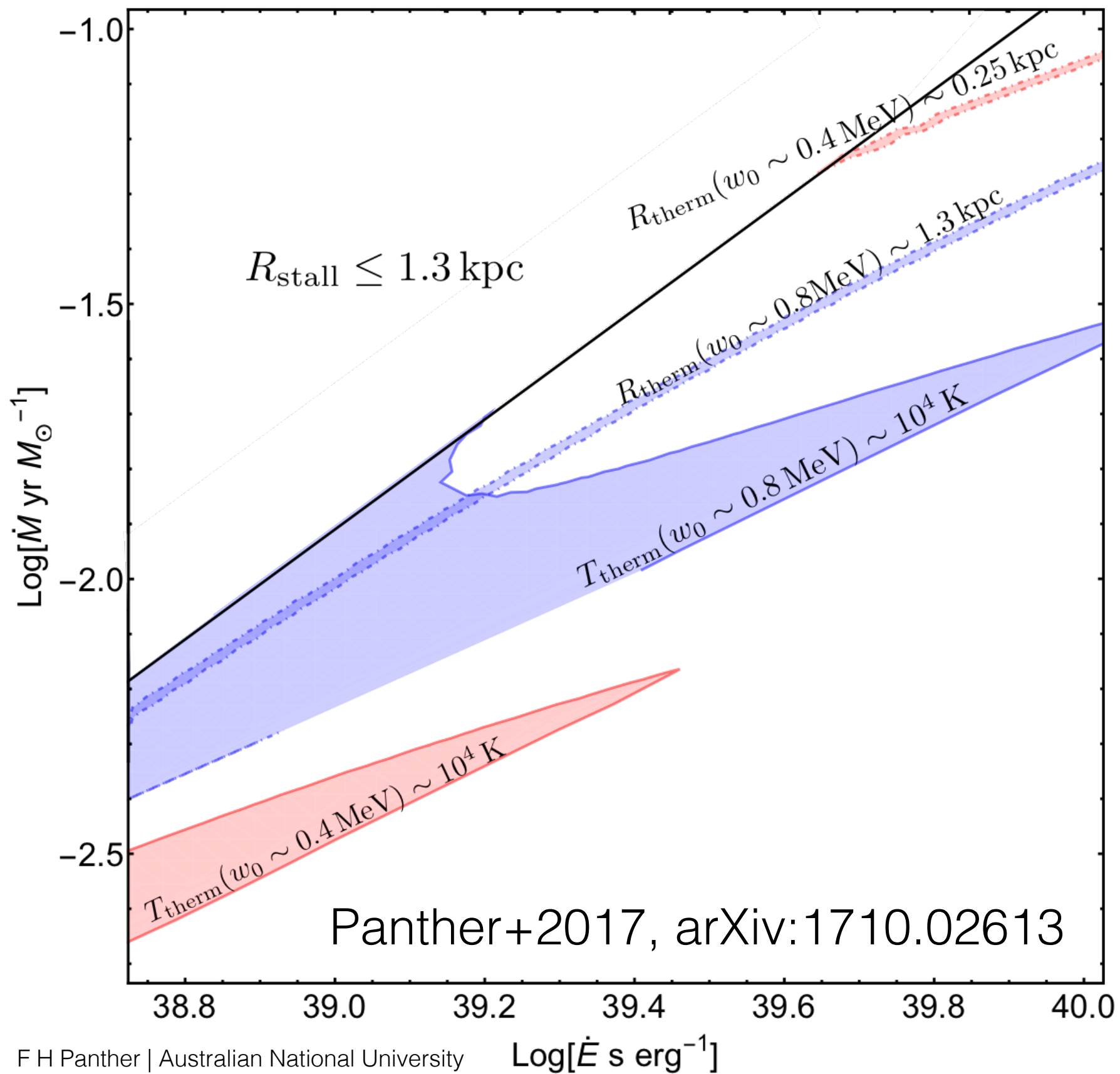
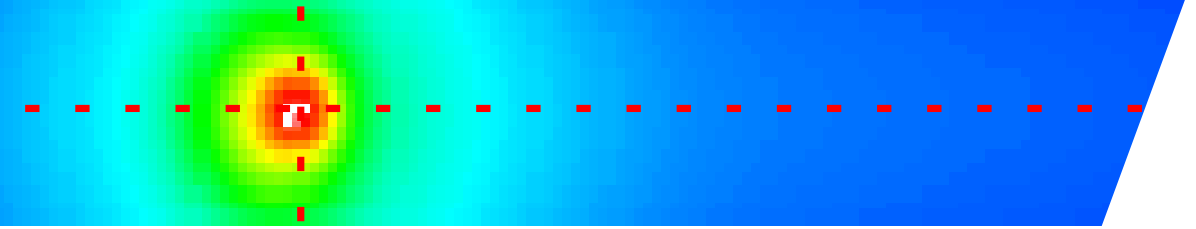
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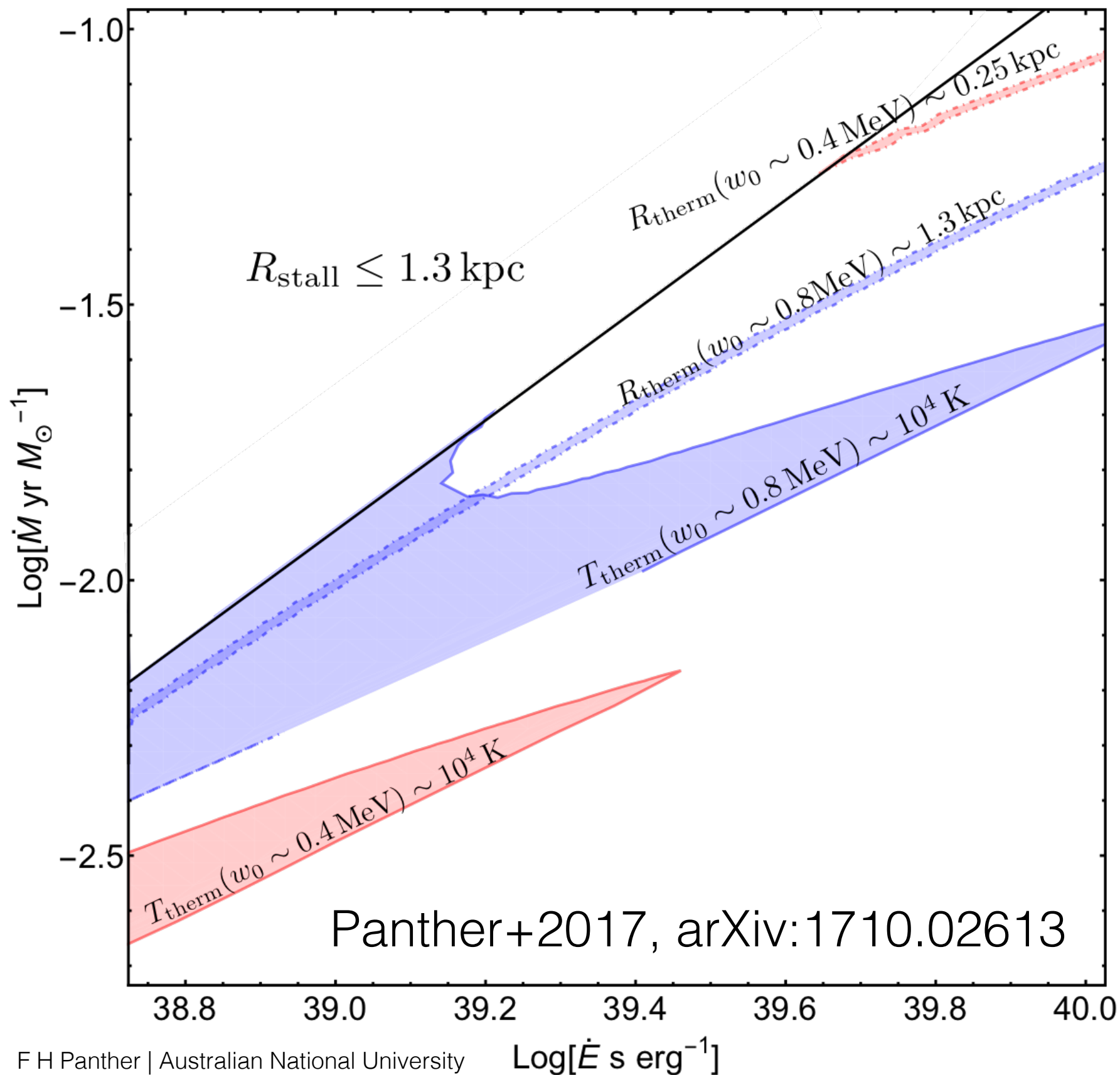
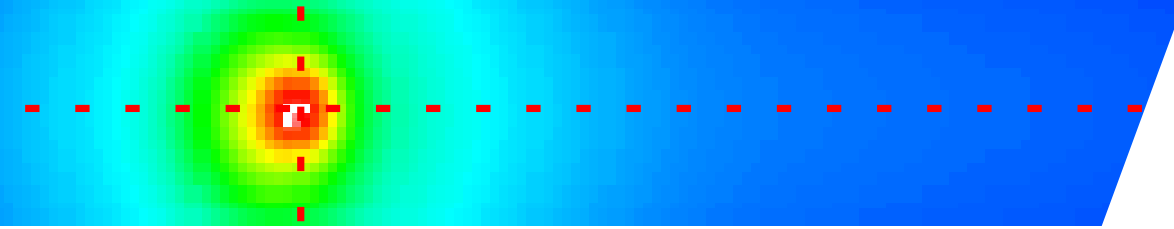
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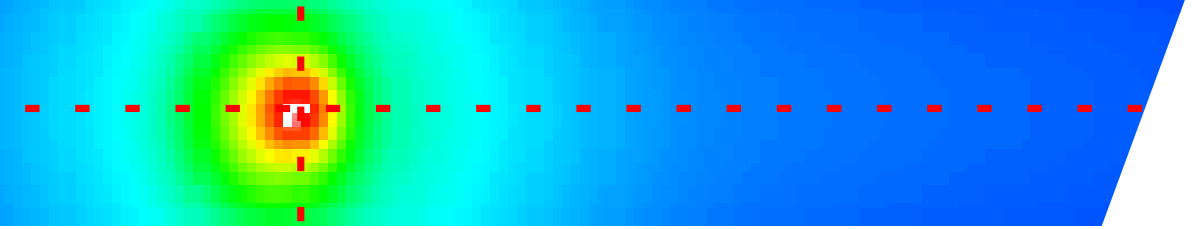


Results



No part of the parameter space describing the nuclear outflow can consistently reproduce the positron annihilation morphology or spectra

Summary





Summary

Steady state advective transport of positrons cannot explain the positron annihilation spectrum and morphology in the Galactic bulge (**Panther+2017, arXiv:1710.02613**)



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