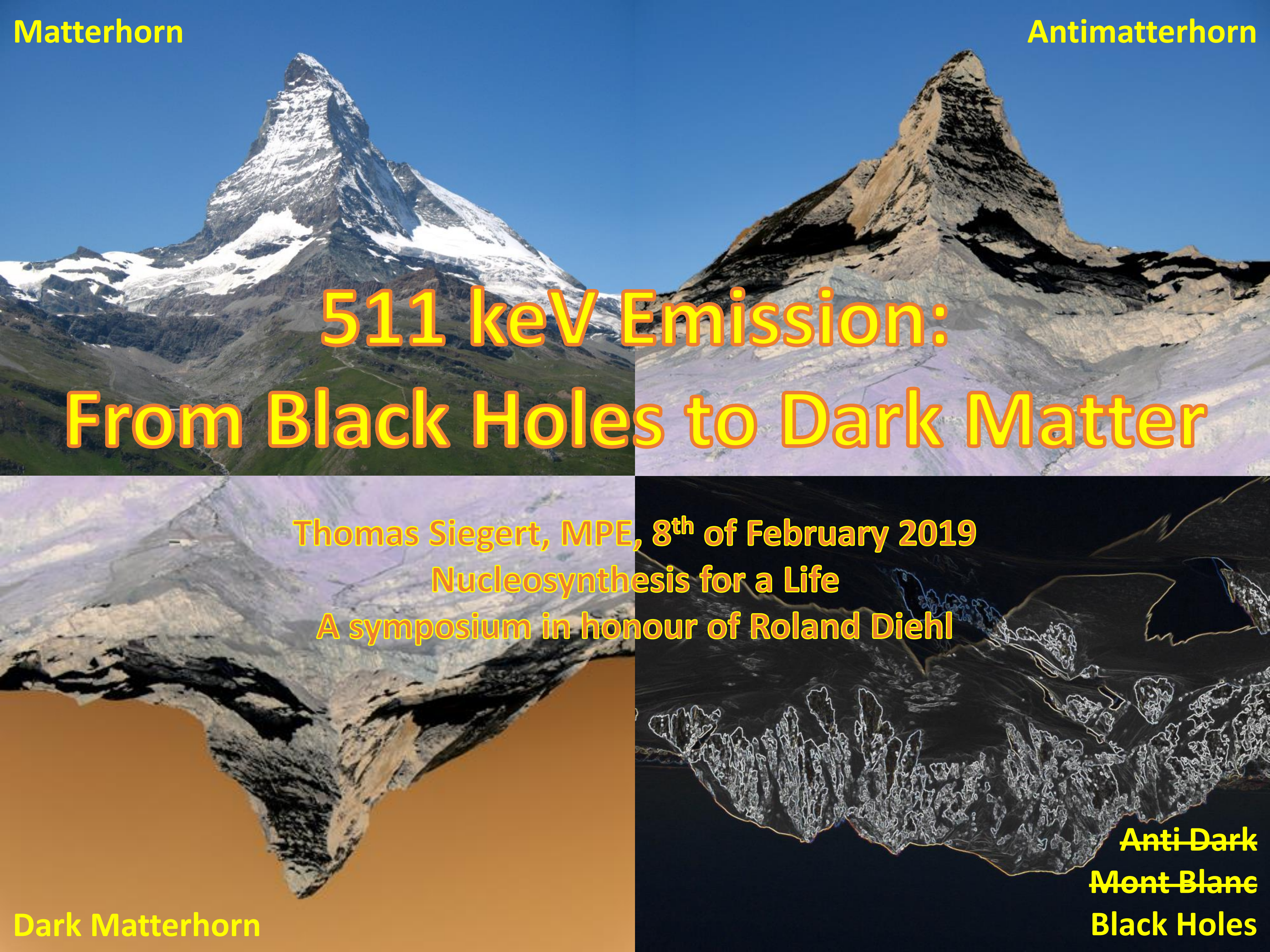


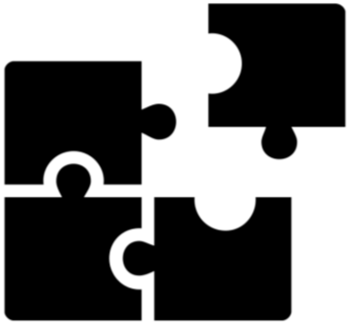
511 keV Emission: From Black Holes to Dark Matter

Thomas Siegert, MPE, 8th of February 2019

Nucleosynthesis for a Life

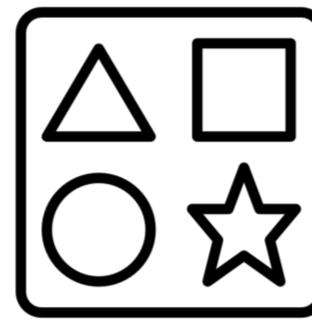
A symposium in honour of Roland Diehl

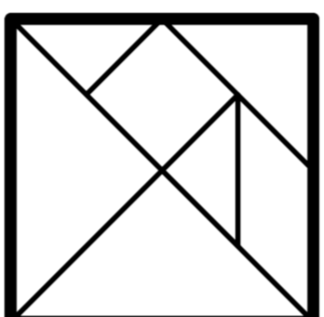
The Positron Puzzle



What do we see?

Where do the positrons come from?





Why does it look like that?

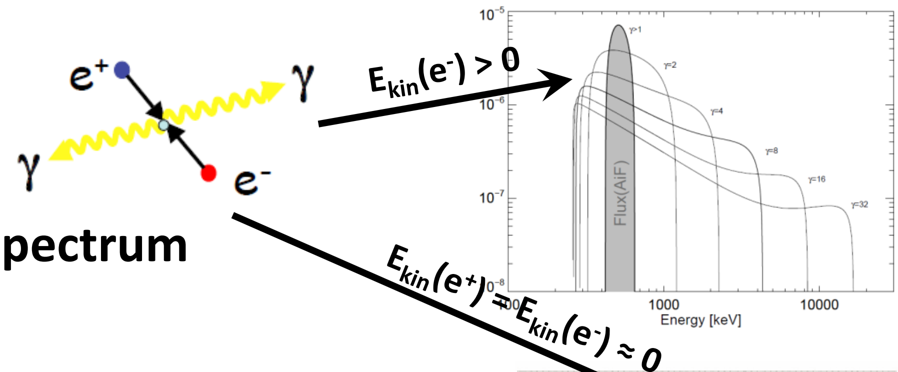
What Do We See?

- <u>Annihilation in Flight:</u>

  → Direct annihilation with $E_{kin}(e^{\pm}) \geq 0$

  → $E_{kin}(e^{+}) = E_{kin}(e^{-}) \approx 0$: **511 keV line**

  → $E_{kin}(e^{+}) \neq/= E_{kin}(e^{-}) > 0$: **continuous spectrum**

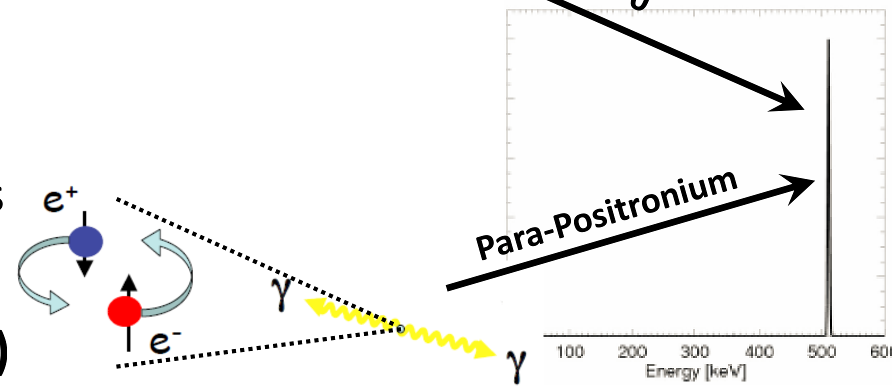


- <u>Formation of Positronium Atom (Ps):</u>

  → Singlet state (S=0): antiparallel spins

  “Para-Positronium” p-Ps

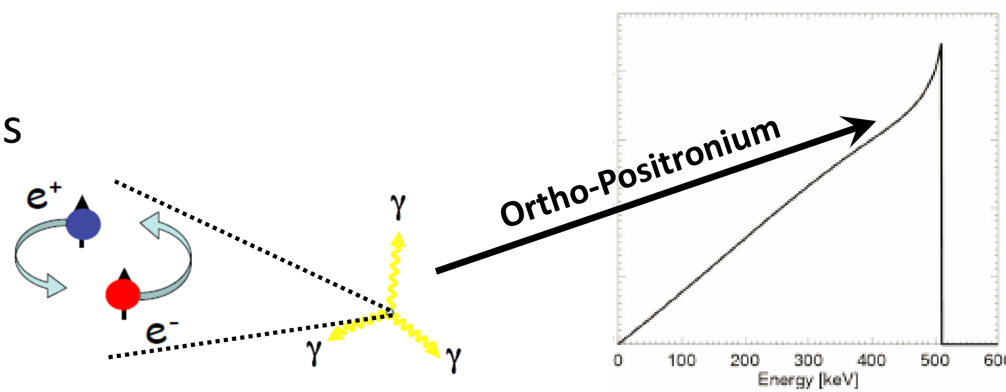
  2γ: monoenergetic γ-ray line (511 keV)



  → Triplet state (S=1): parallel spins

  “Ortho-Positronium” o-Ps

  3γ: continuous spectrum

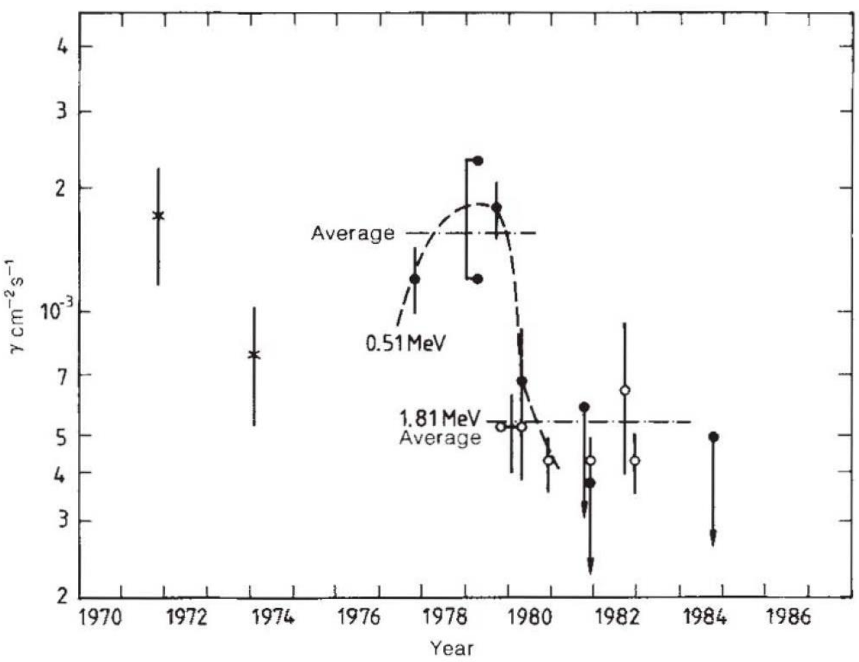


Where Do The Positrons Come From?
Of Course: ^{26}Al!

Webber, Schönfelder, Diehl 1986

LETTERS TO NATURE

Is there a common origin for the cosmic γ-ray lines at 0.51 and 1.81 MeV near the galactic centre?



"Here we discuss the possibility that the 0.51- and 1.81-MeV lines have a common origin [...] and we show that this is not contradicted by the existing data."

Okay, lets go!

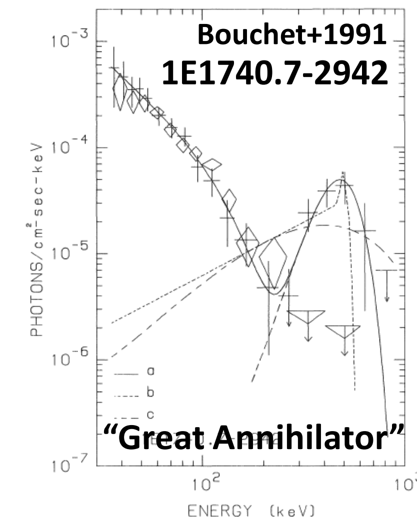
"The ^{26}Al line requires that 5±2 M_{Sun} of ^{26}Al was synthesized within this timescale of ~10^6 yr."

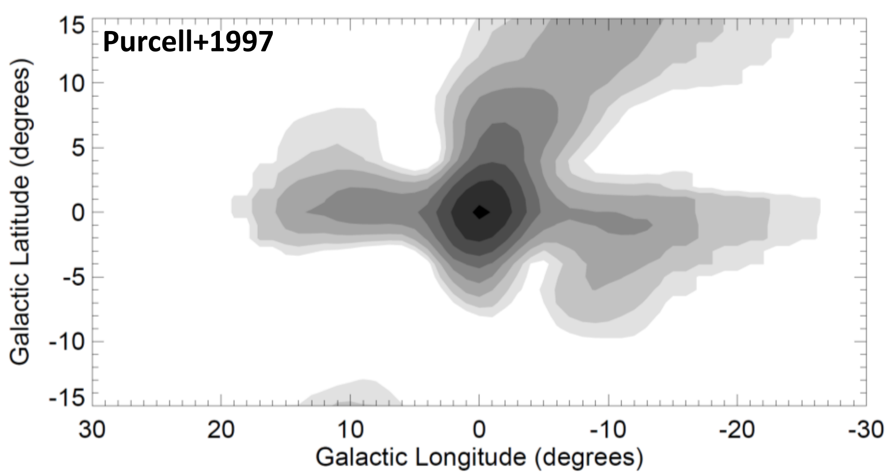
Sounds plausible.

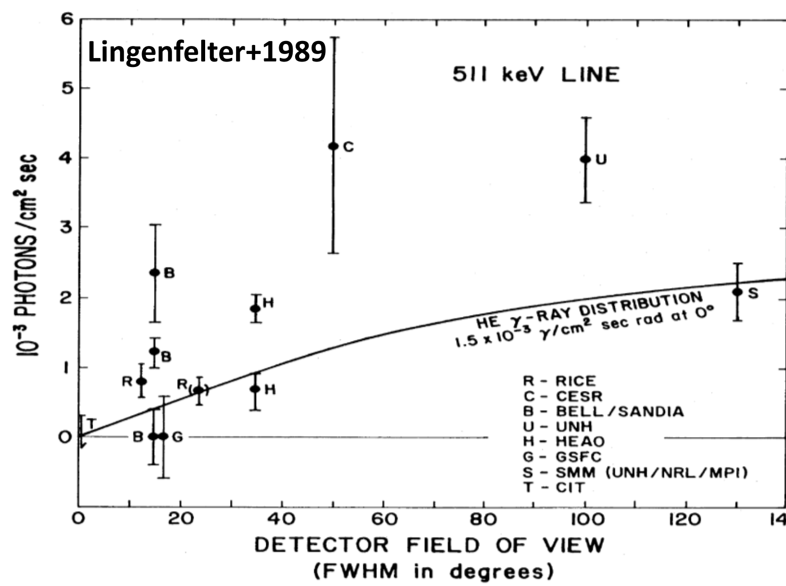
"To produce the observed increase of the 0.51-MeV line of 2.5 times the steady 1.8-MeV line [...] a spherical region containing the ^{26}Al of 3 pc is required."

Well, errr ...

Variability Of The 511 keV Line?

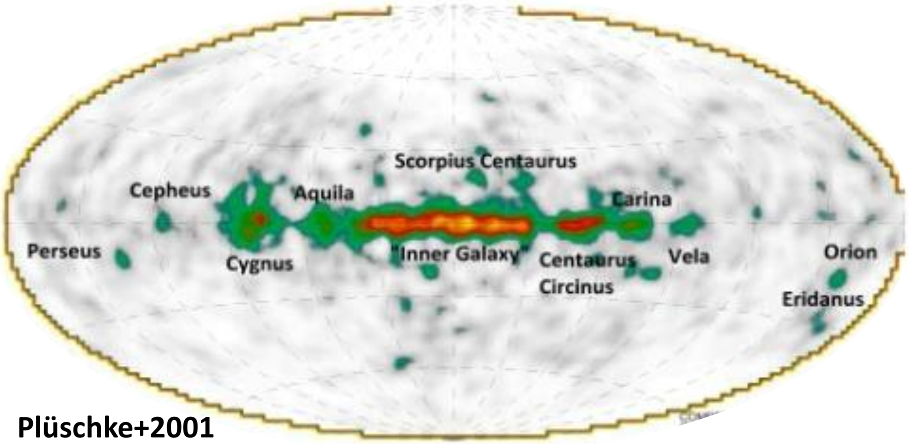




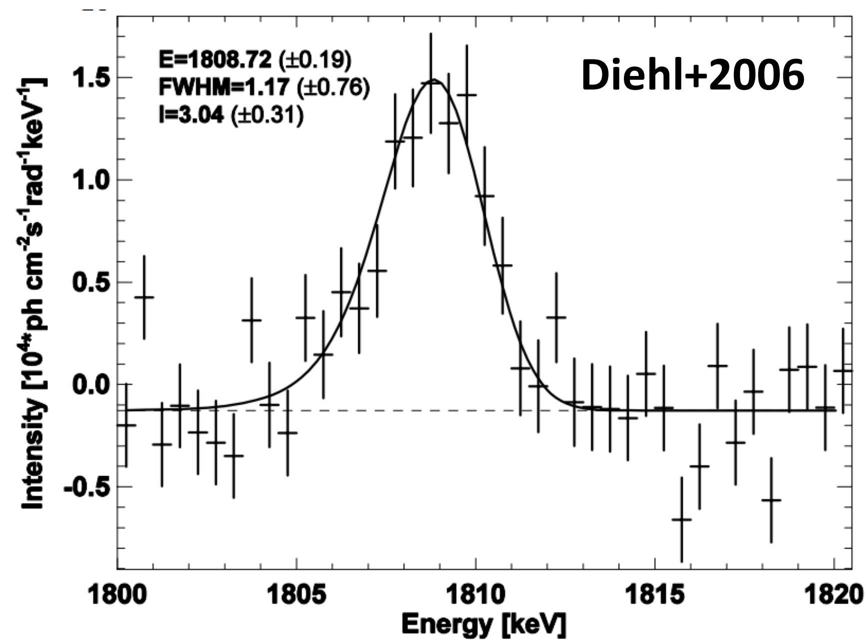


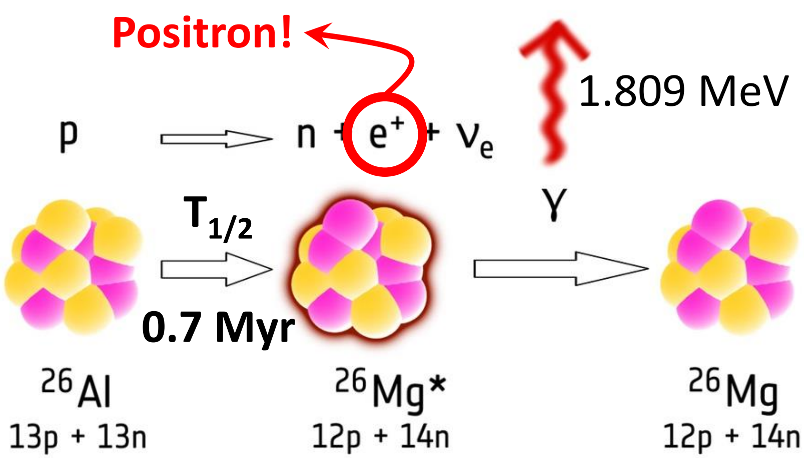
^{26}Al – Of Course!

Milky Way in ^{26}Al (1.809 MeV)



Plüschke+2001

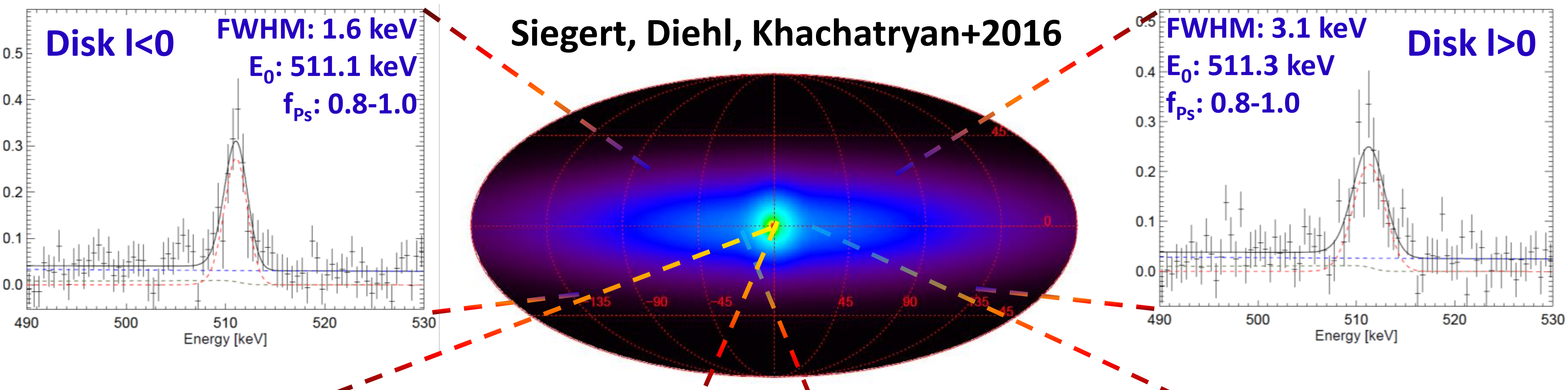




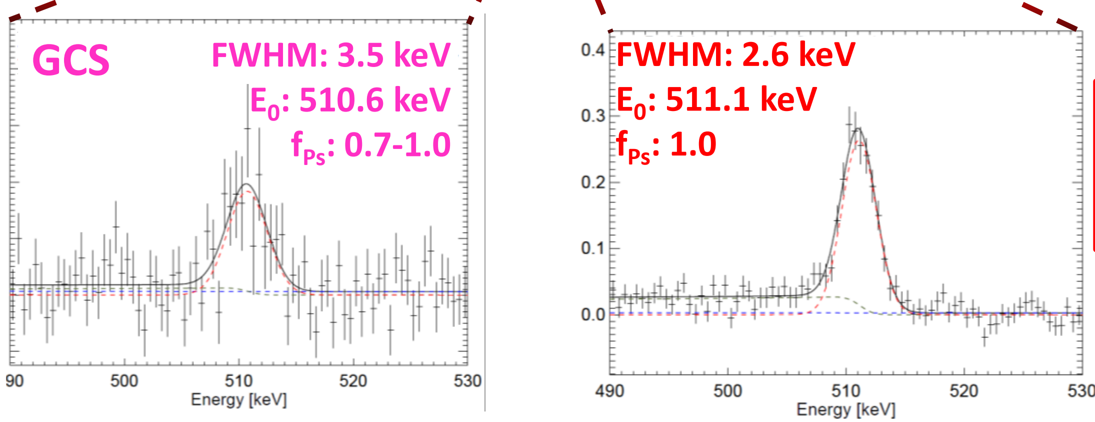
- There are ≈ 2.8 M_{Sun} of ^{26}Al in the Galaxy
- That makes 0.3×10^{43} e^+ s^{-1} along the Galactic plane
- **Is that enough?**

How Many Positrons Are There?

Disk Annihilation budget: 3.1×10^{43} e^{+} s^{-1}



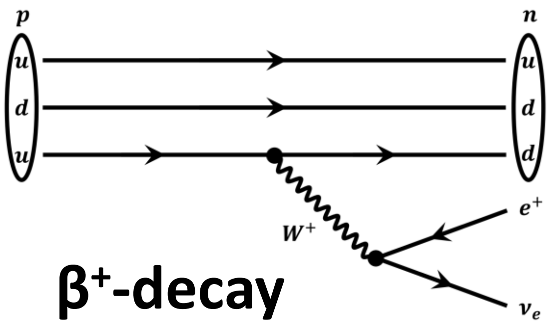
Galactic centre: 0.1×10^{43} e^{+} s^{-1}



Bulge: 1.7×10^{43} e^{+} s^{-1}

Total Milky Way: $(4.9\pm1.7)\times10^{43}$ e^{+} s^{-1}

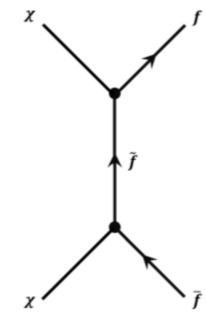
Positron Production Mechanisms



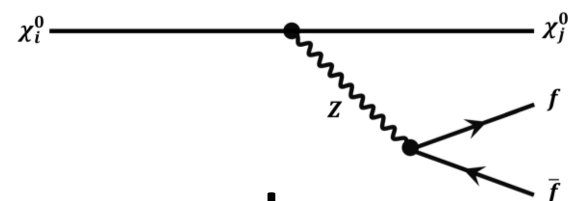
β⁺-decay

High-energy processes!

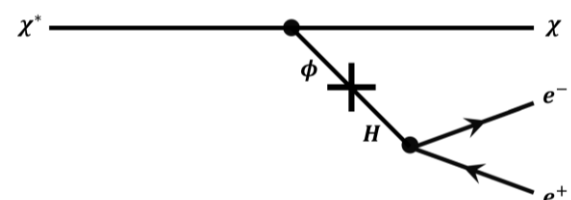
Dark matter …



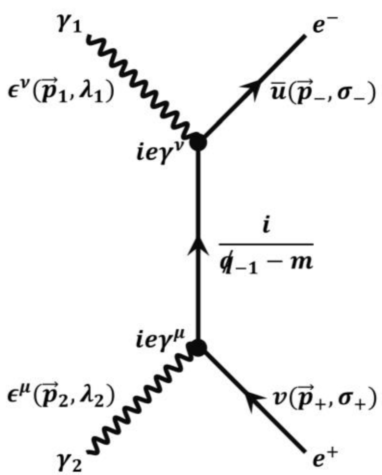
… annihilation



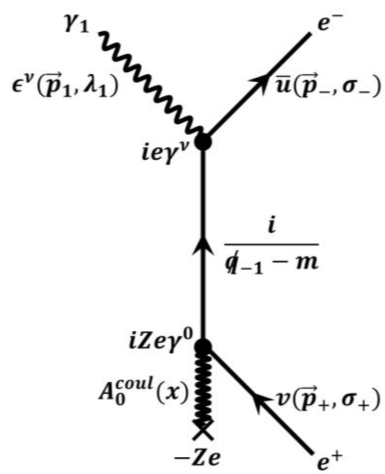
… decay



… deexcitation



γγ pair production



γ/EM-field pair production

Candidate Positron Sources

Ummmm …

- **Massive stars / Novae / SNe Ia&II**

→ Radioactivity from β⁺-decay

- **XRBs / Microquasars**

→ "Compact γ-ray source"; Jets; Corona

- **Sgr A***

→ Past AGN activity; Accretion disk

- **Cosmic rays**

→ p-p collisions: Secondary positrons

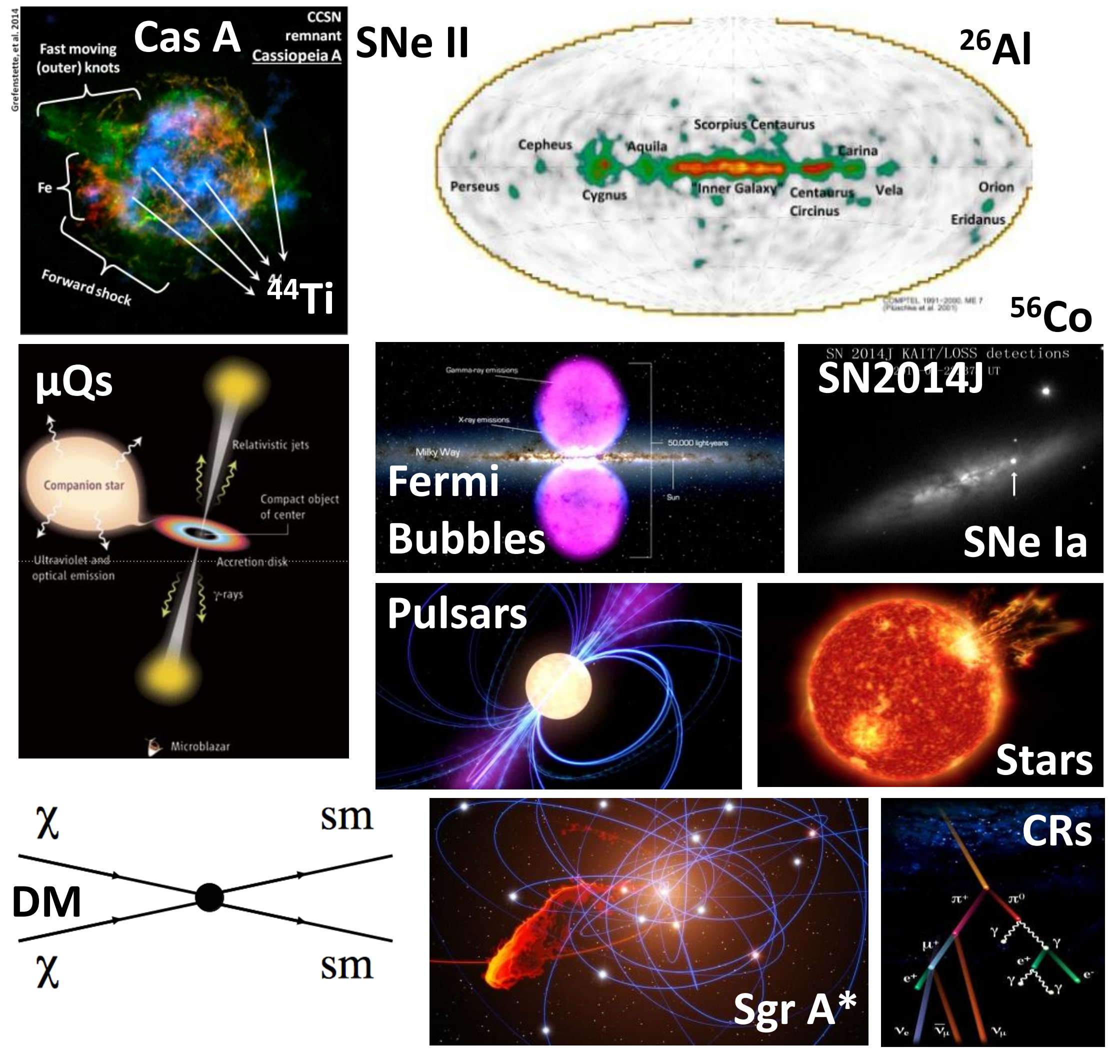
- **Pulsars**

→ Magnetic field interactions

- **Dark Matter**

→ Decay; Annihilation; Excitation

- **Stars / stellar flares**



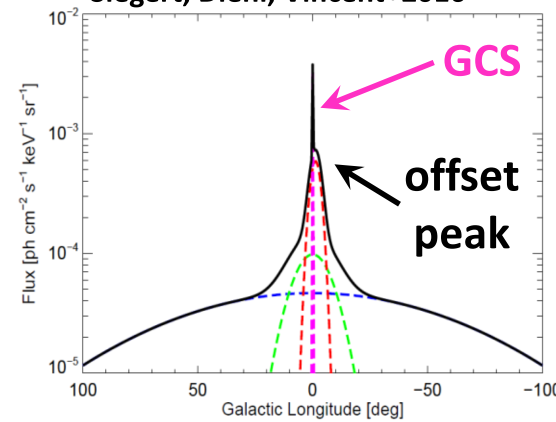
Let's Try Dark Matter: A Bulge Component On Its Own

Decay, Annihilation, De-excitation?

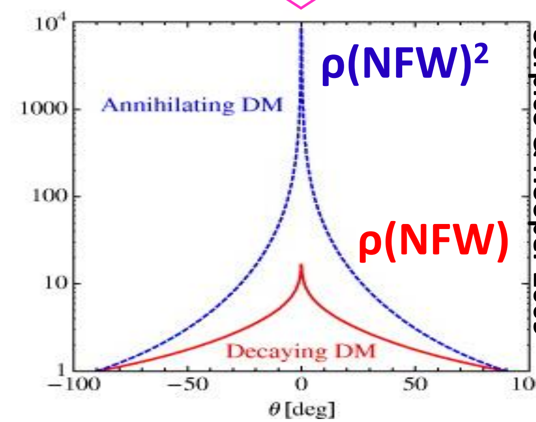
$$F_{511} \propto (\rho_{DM})^n\ ?$$

Skinner+2014: Dark matter profile with n=2 fits

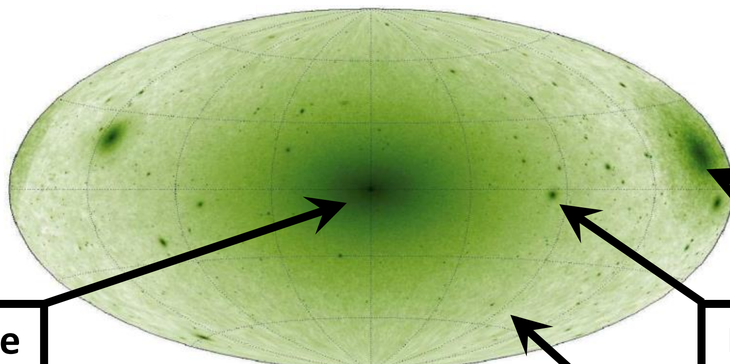
Siegert, Diehl, Vincent+2016



?



Serpico & Hooper 2009



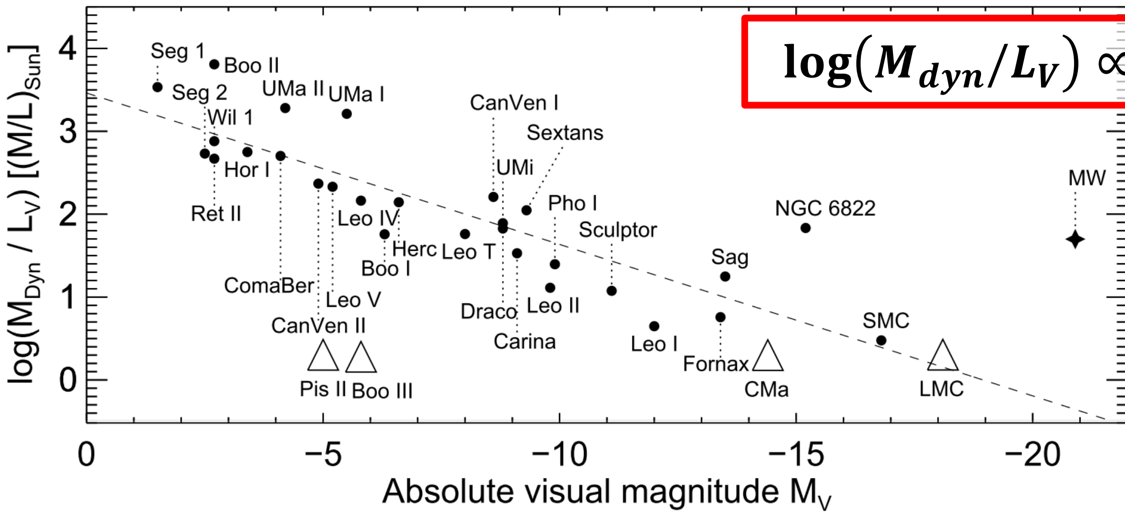
Galactic centre ⇕ DM main halo

Dark matter simulation
Kuhlen+2008

Dwarf galaxies ⇕ DM sub-haloes

The Dark Matter Scenario With SPI

Dwarf galaxies are believed to be DM-dominated



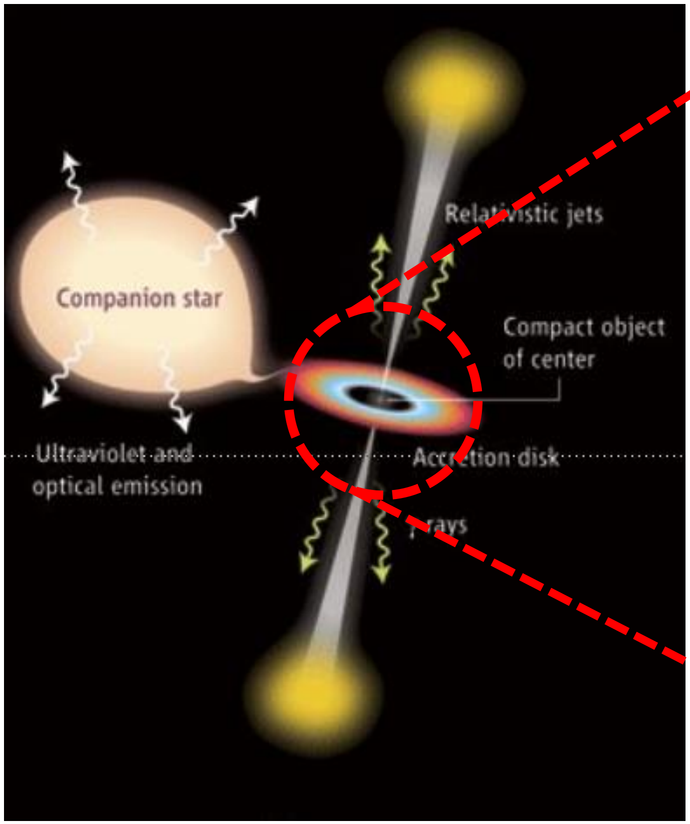
$$\log\left(M_{dyn}/L_V\right) \propto +(0.22 \pm 0.02)M_V$$

DM in dwarf galaxies?

Maybe, yes.

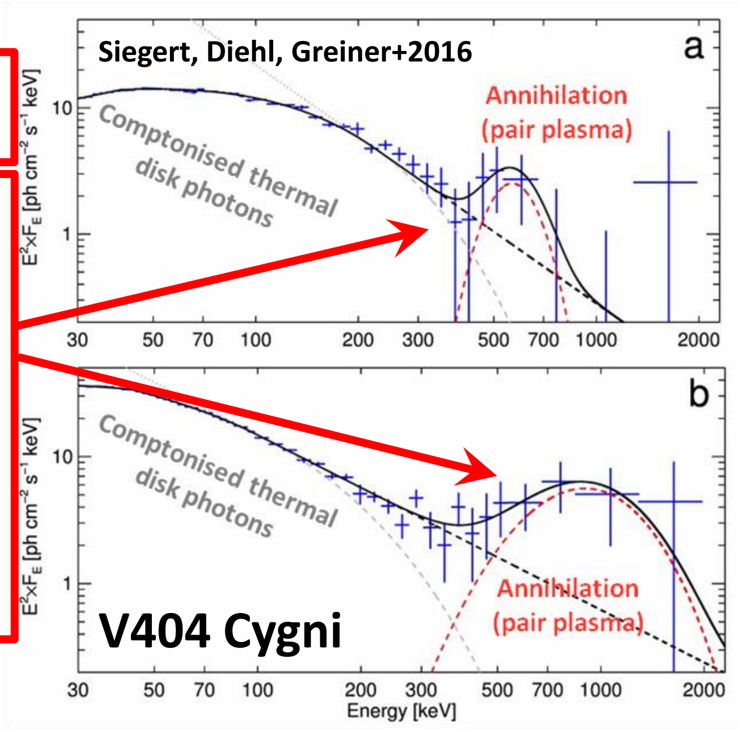
A Bulge Component: Microquasars

Microquasars identified as galactic positron sources!



$\gamma + \gamma \rightarrow e^+ + e^-$

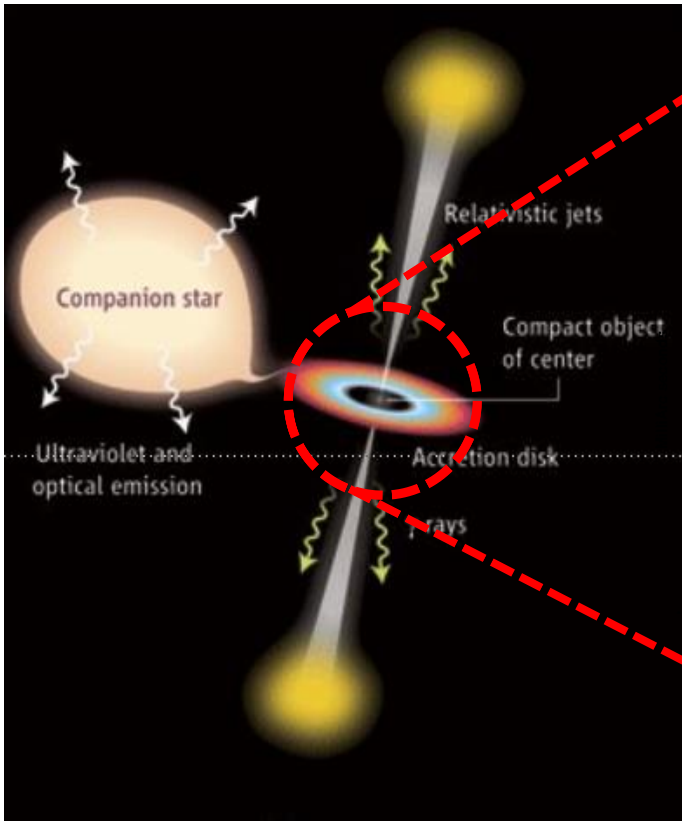
- e^+ annihilated: $\approx 10^{42}\ s^{-1}$
- Duty cycle: $\approx 10^{-3}$
- Escape fraction: $\approx 20\%$

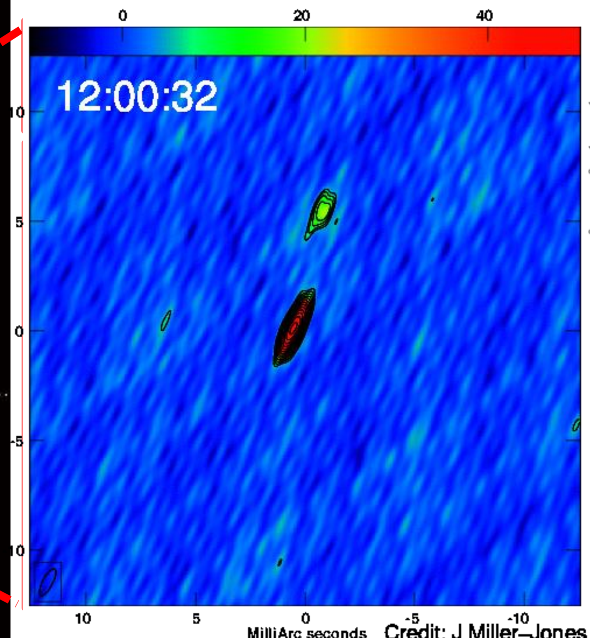


$10^3 - 10^8$ μQs expected in the Milky Way: contribution tens of %!

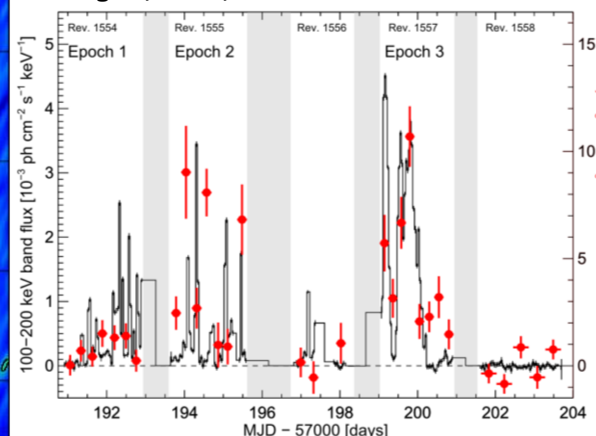
A Bulge Component: Microquasars

Microquasars identified as galactic positron sources!





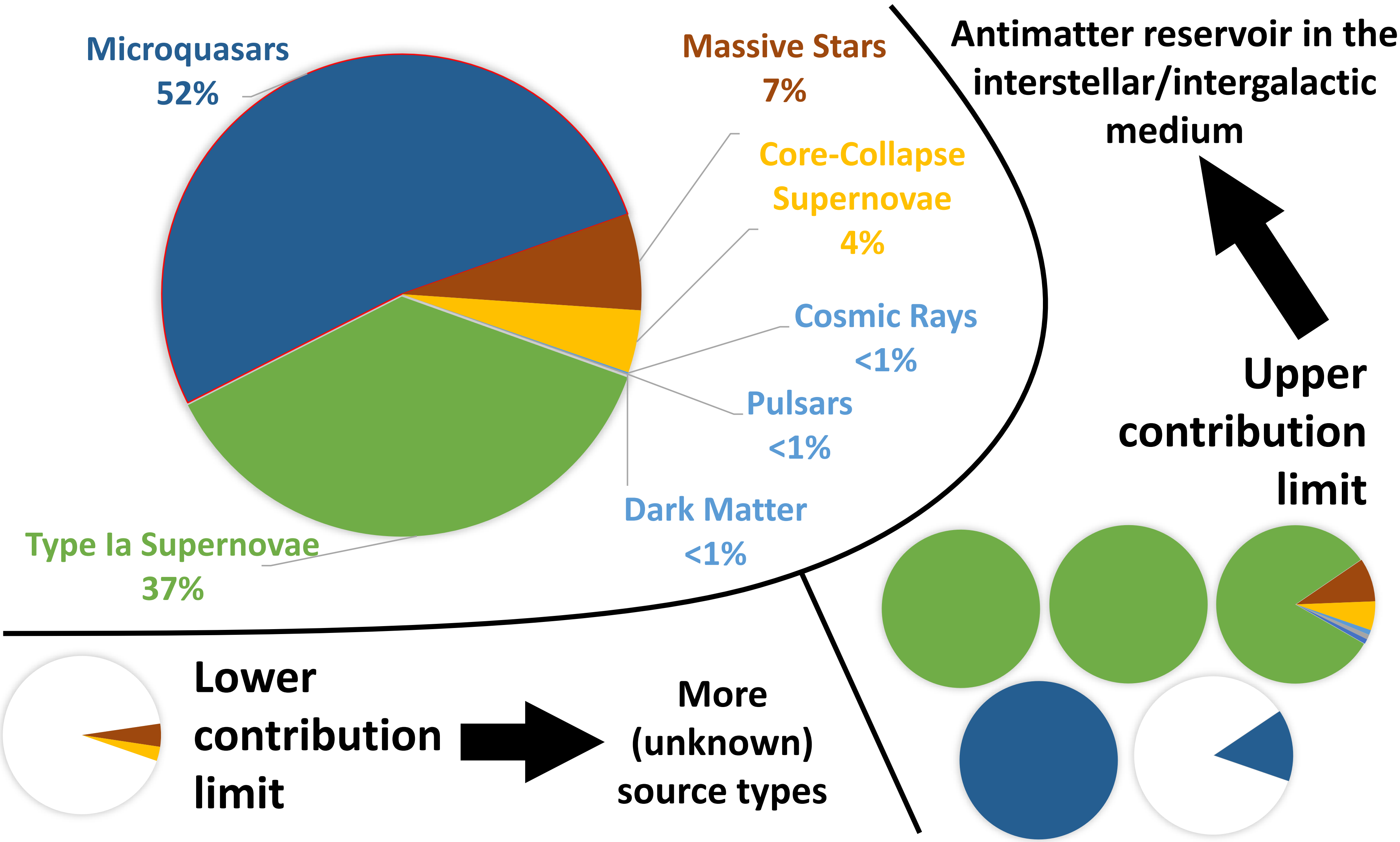
Siegert, Diehl, Greiner+2016



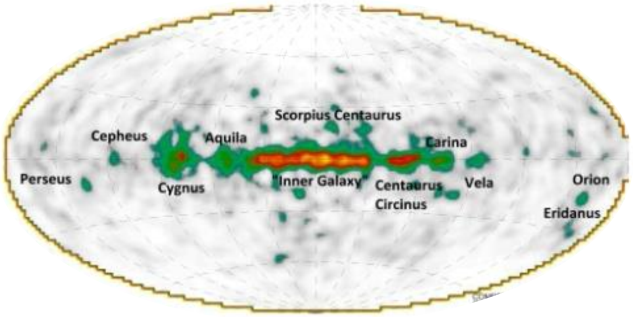
Pair-plasma annihilation light curve in V404 Cygni

$10^3 - 10^8$ µQs expected in the Milky Way: contribution tens of %!

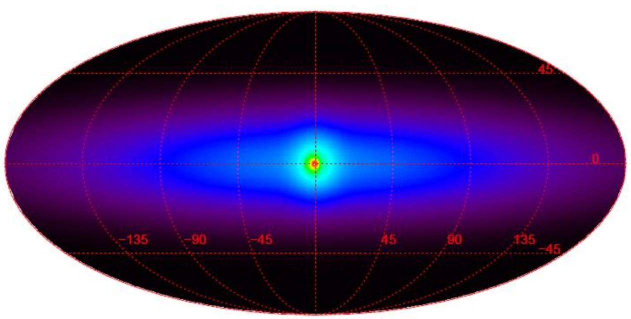
Budgeting Galactic Positrons



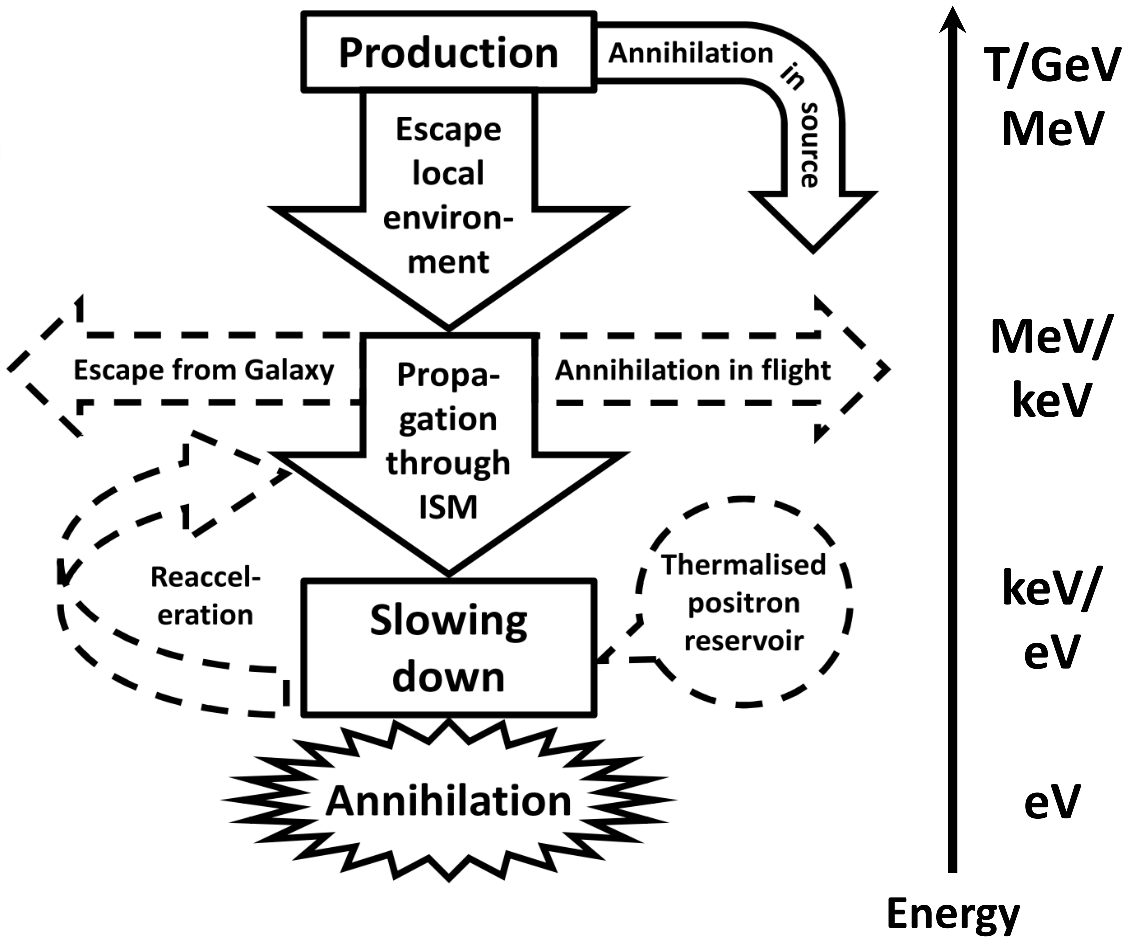
Why Does It Look Like This?



Source distribution



Sink distribution



Positron propagation required!

Summary And Outlook

Microquasars

Maybe just ask the aliens …

an

reservoir

Is it the matrix?

Su

pro

Is it an optical (gamma) illusion?

The Ultimate Roland Quiz