Positron annihilation spectrum from the inner Galaxy

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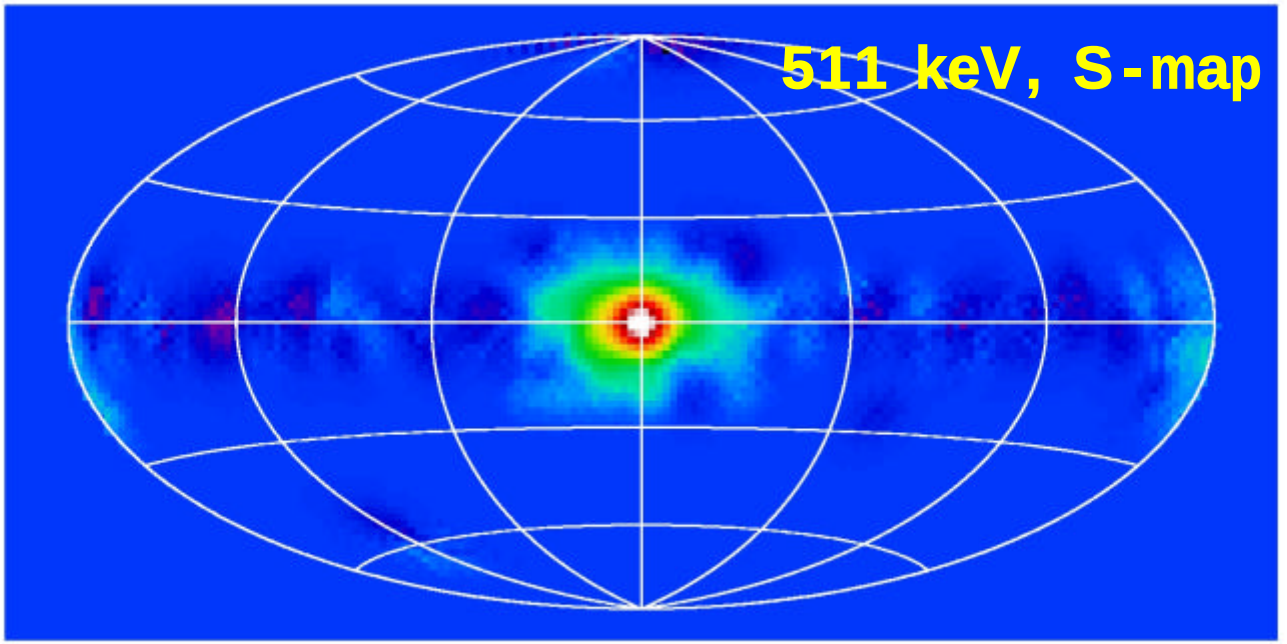


MNRAS, in press

see also Jean et al, Knödlseder et al,

e^+e^- Line @ 511 keV from Galactic Center regio

Discovered in 1972 as ~ 476 keV feature (Rice U, NaI)

Johnson, Harden & Haymes, 1972; Johnson & Haymes, 1973

Identified with a narrow 511 keV line in 1978 (Bell-Sandia, Ge)

Leventhal, MacCallum & Stang, 1978

Observed by e.g. SMM, OSSE, TGRS ...

The brightest ?-line in the Galaxy **(few 10^{-3} phot/s/cm^2)**

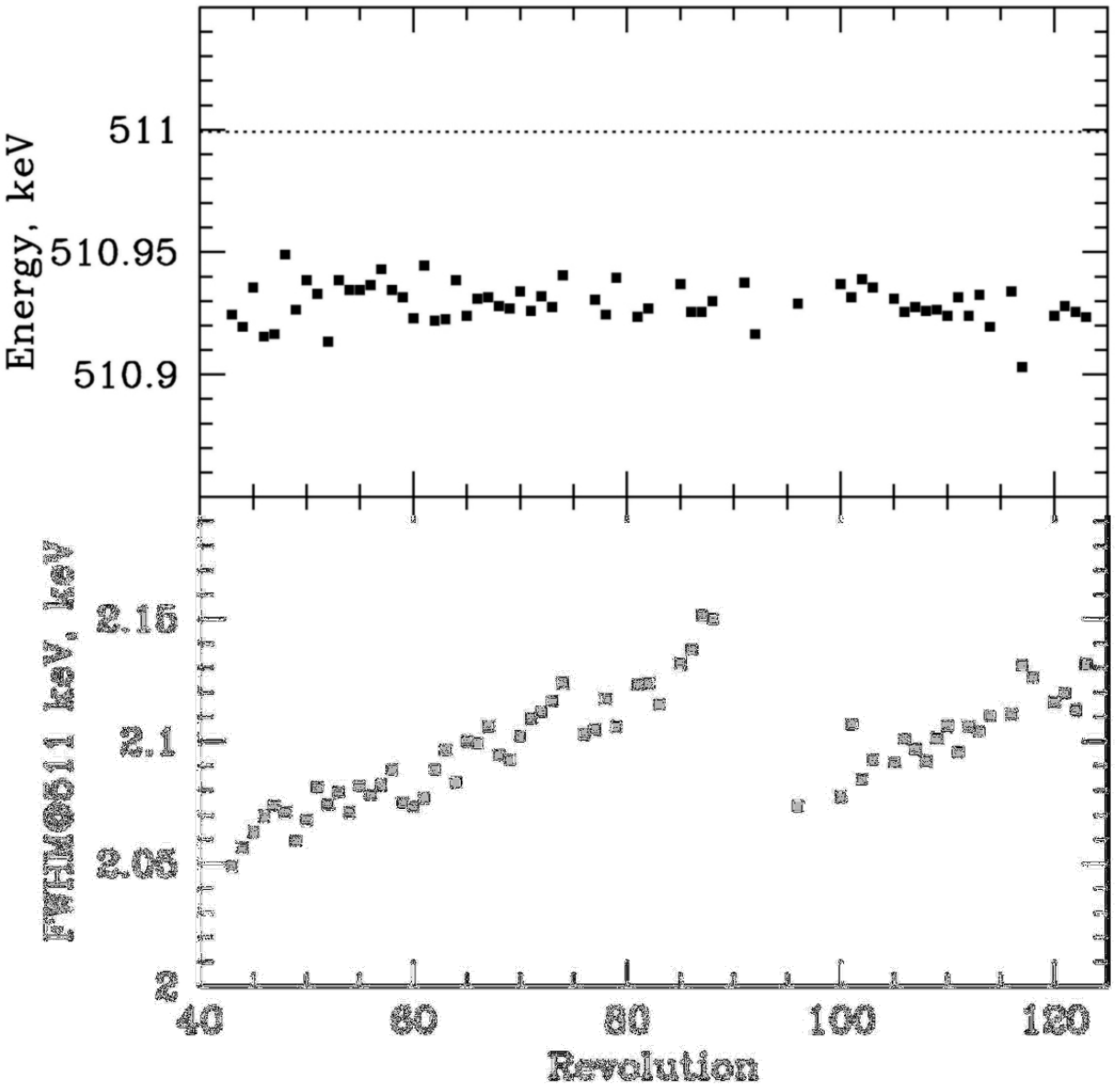
Many channels for positron production:

- ?Nucleosynthesis (SNe, Novae, WR, AGB): (e.g. Ni56, Ti44, Al26)
- ?Cosmic rays interaction
- ?BH and pulsars (pair production, jets)
- ?Dark matter annihilation

Analysis standard steps:

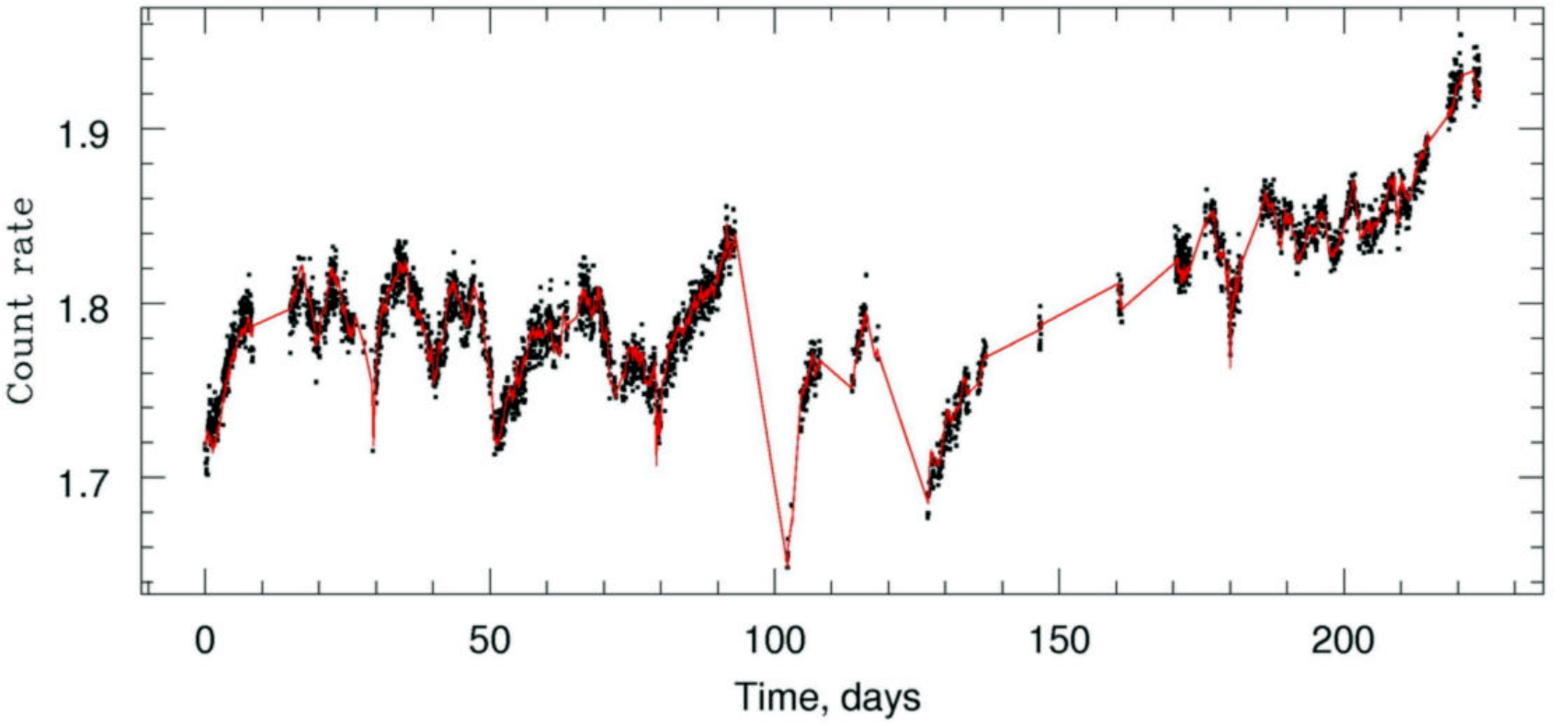
- Energy Calibration
- Background modeling
- Spectra extraction for selected spatial model

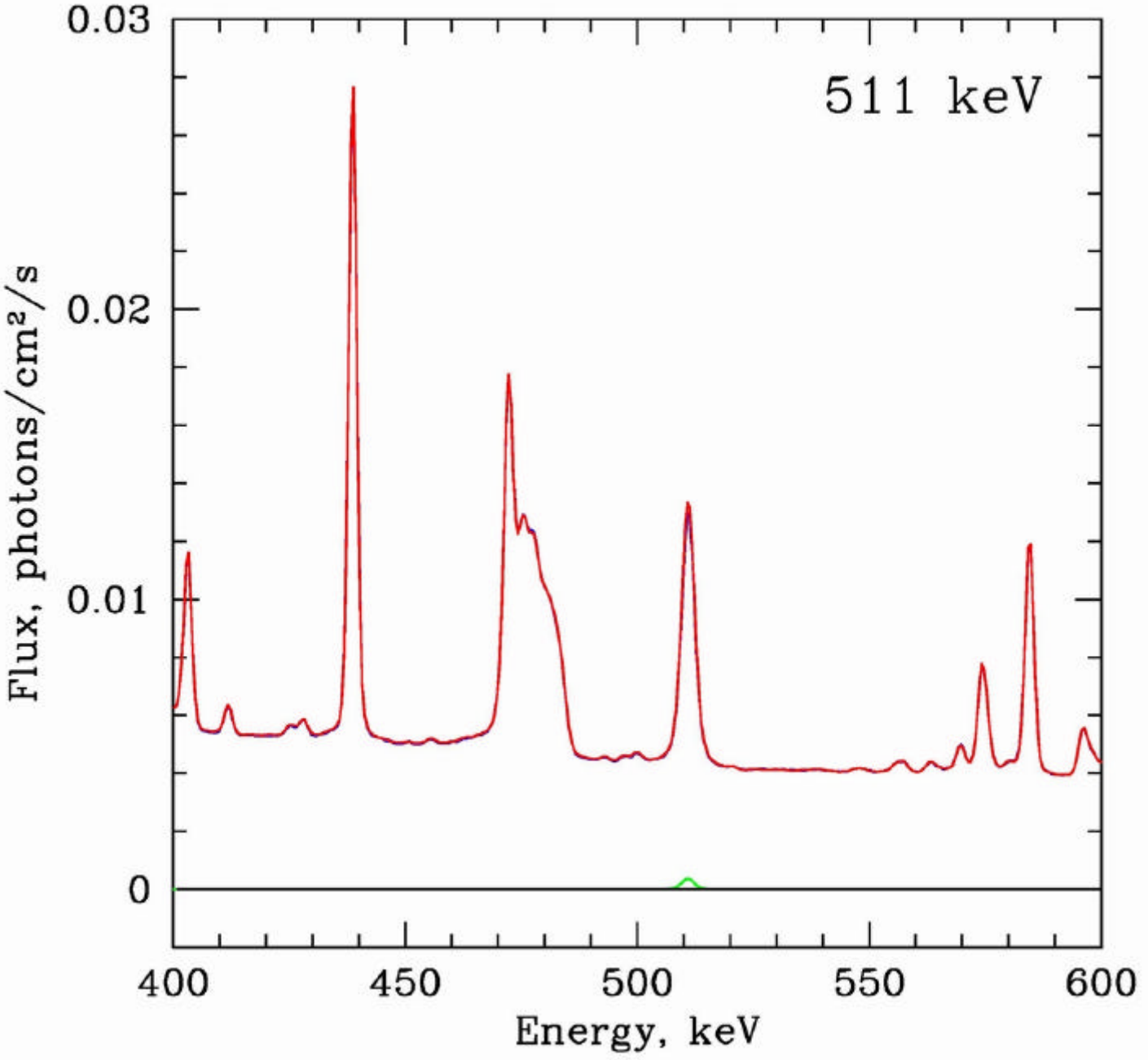
Energy calibration



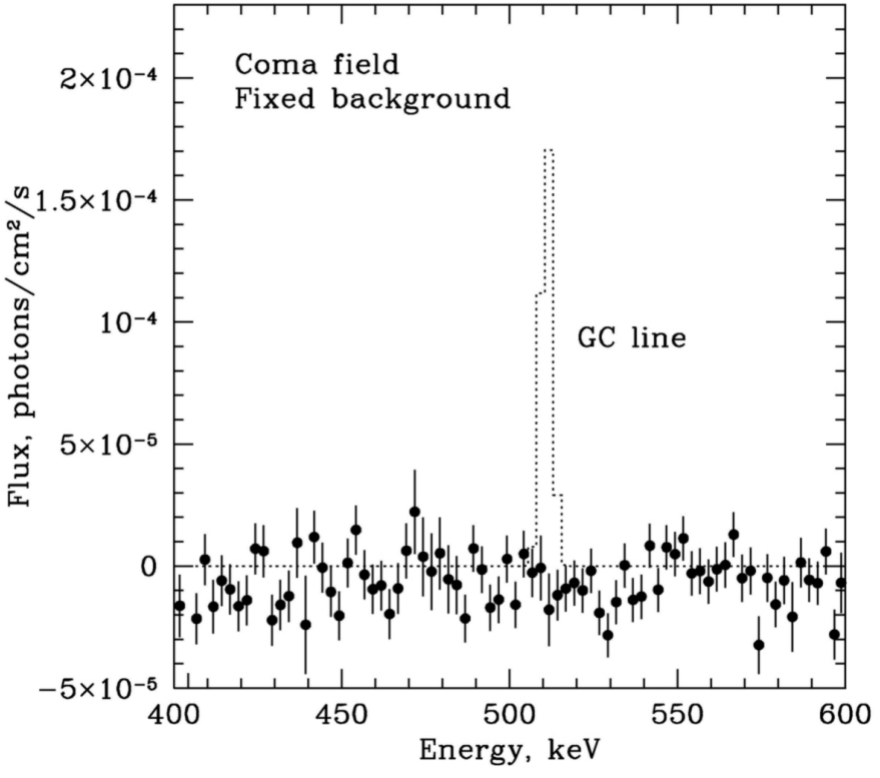
RMS~0.01 keV

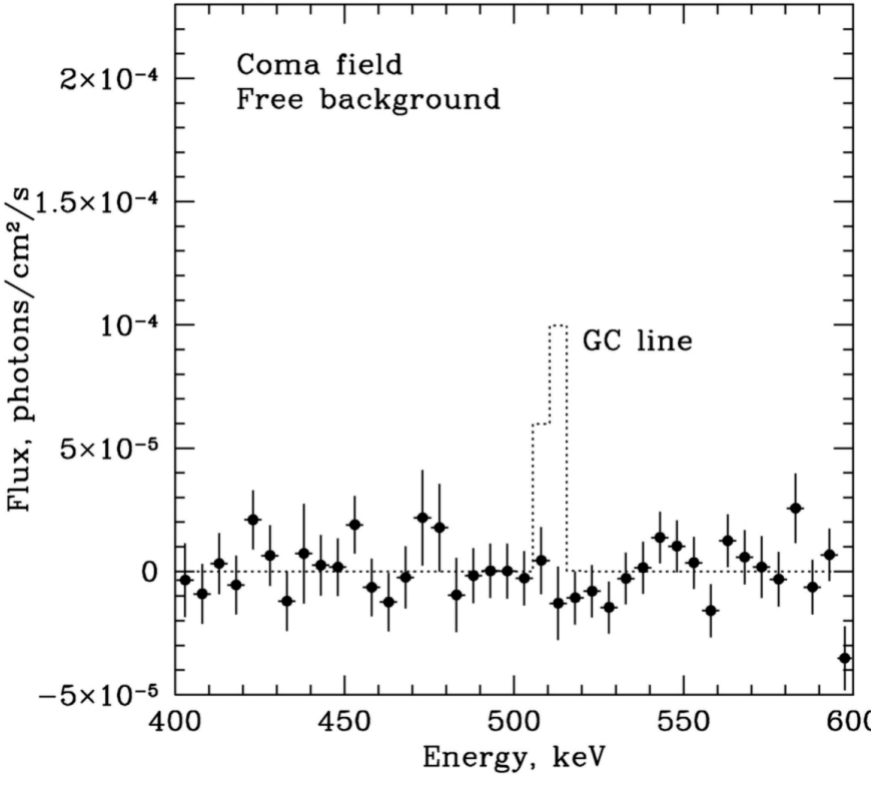
Background modeling

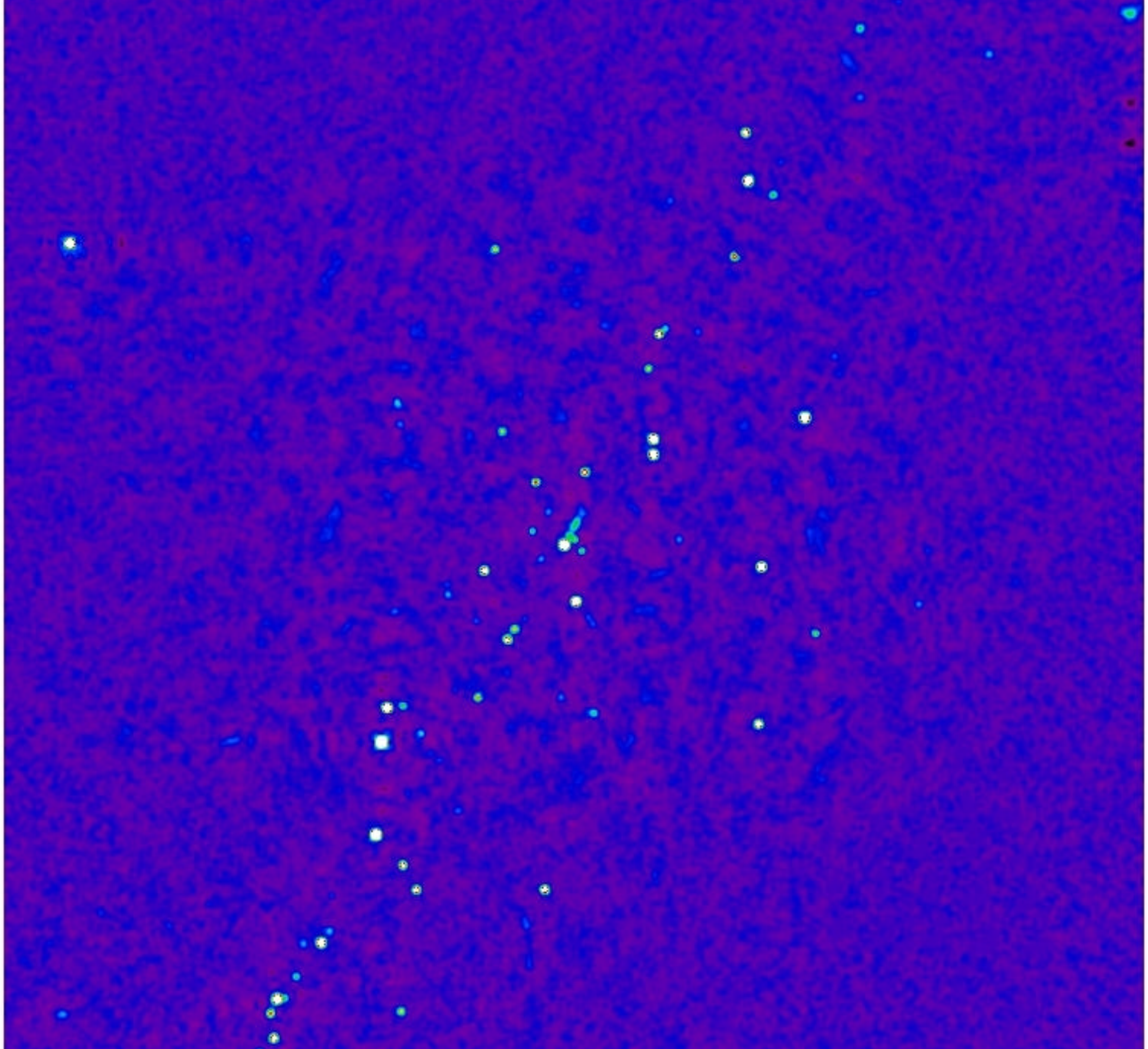


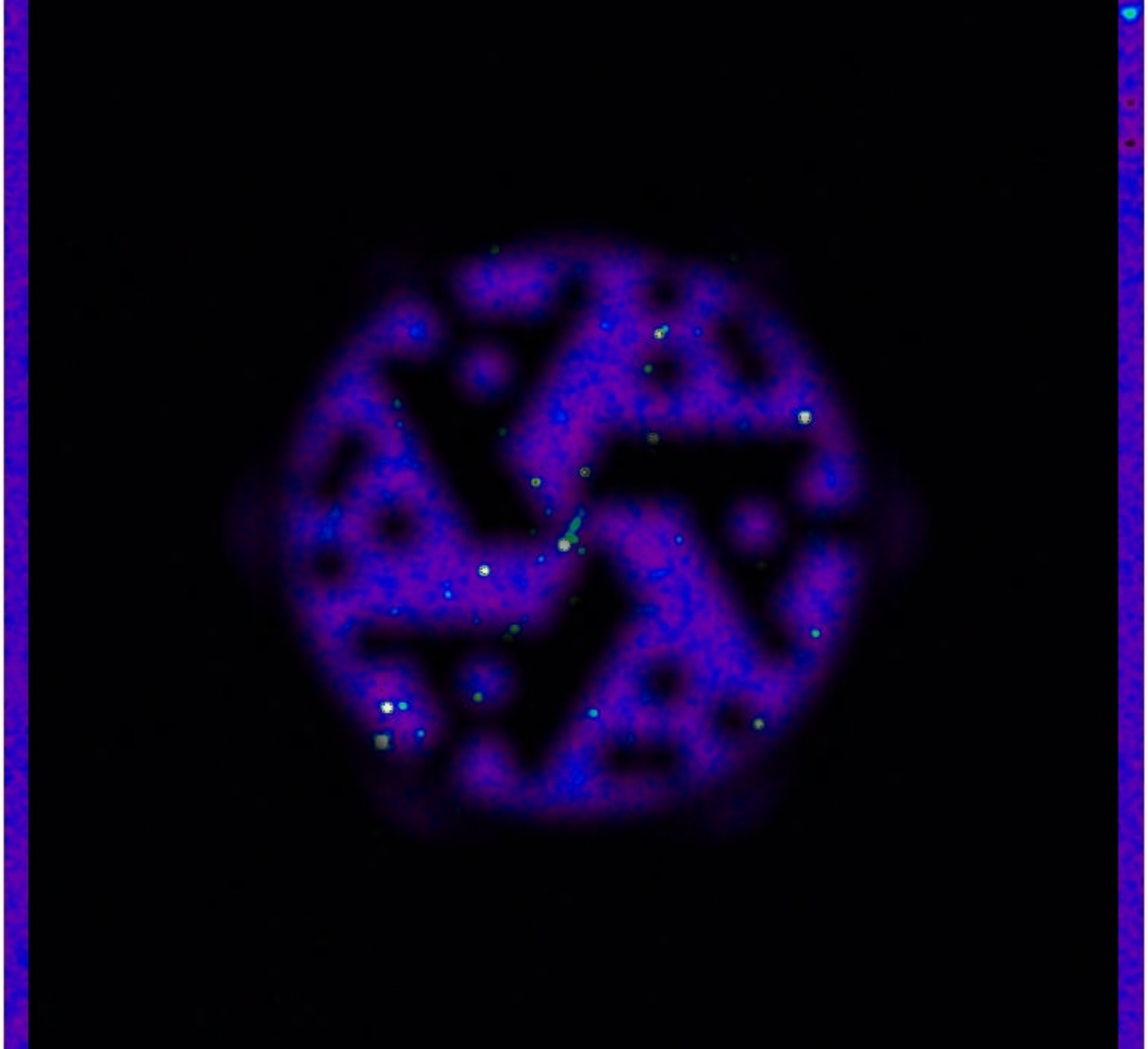

511 keV
0.03
0.02
0.01
0
Flux, photons/cm²/s
400
450
500
550
600
Energy, keV

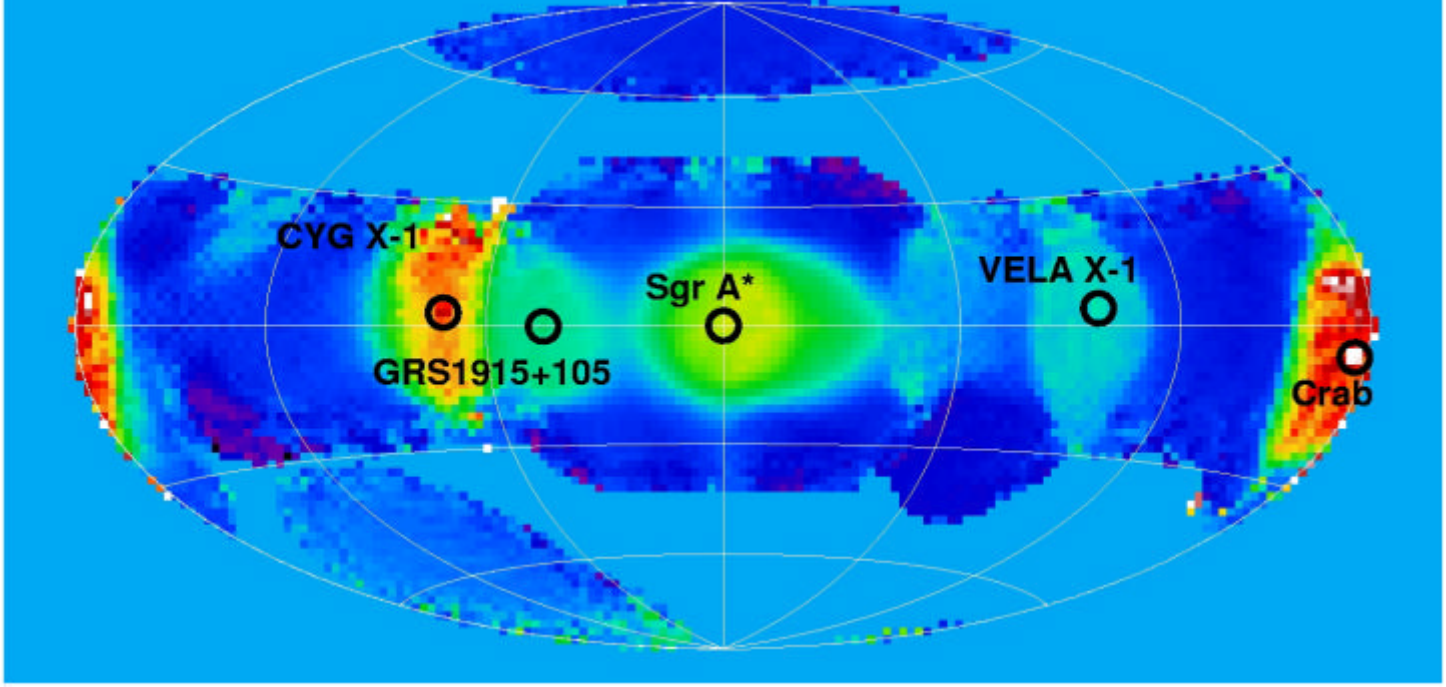
Background verification



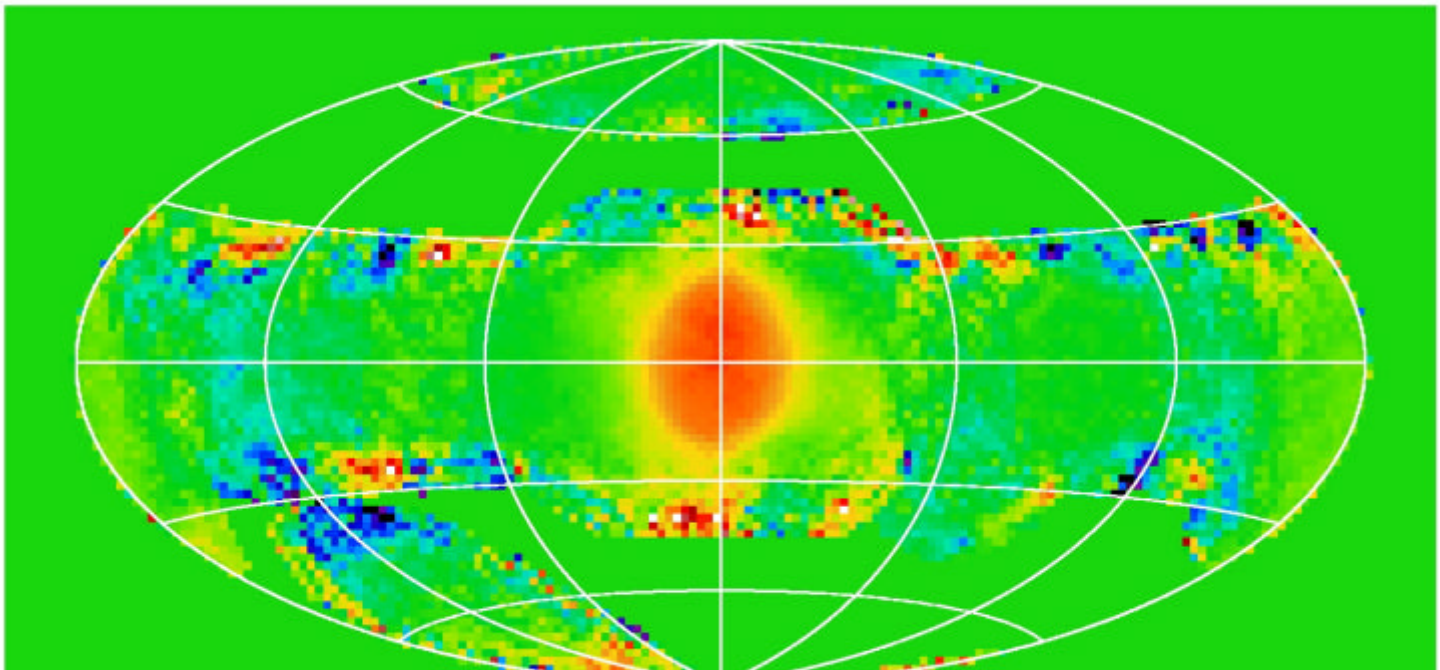




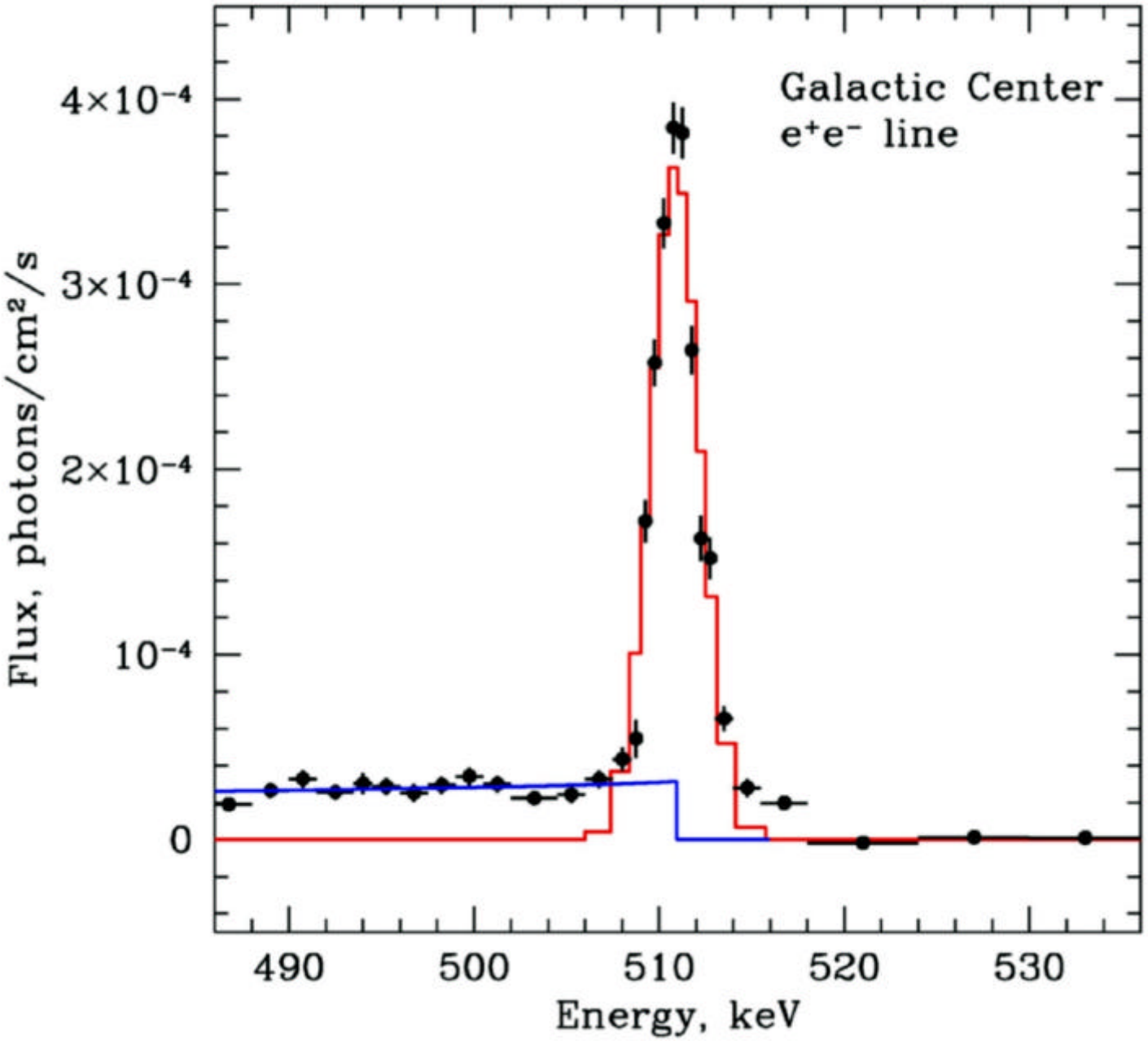




50 keV



511 keV


Galactic Center
e+e− line
Flux, photons/cm²/s
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
10⁻⁴
0
490
500
510
520
530
Energy, keV

Fixed background:

Energy 510.988 ± 0.035 keV
FWHM 2.47 ± 0.11 keV

Free background:

Energy 510.954 ± 0.075 keV
FWHM 2.37 ± 0.25 keV

$$m_e c^2 = 510.999\,\mathrm{keV}$$

Bulk velocity < 20-40 km/s (Earth motion
Differential velocity < 800 km/s

Processes in hydrogen plasma (dust free)

- **Deceleration of positrons:**

  Ionization (E>13.6 eV)

  Excitation (E>10.2 eV)

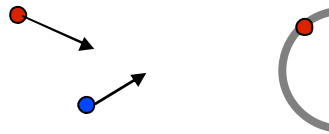
  Coulomb losses (if ionized)

- **Direct annihilation**

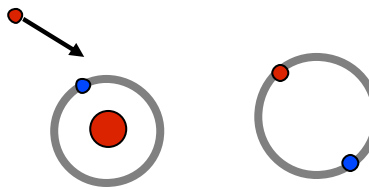
  Bound electrons: $\sim \sigma_T \, \mathrm{v}$

  Free electrons: $\sim \sigma_T \, \mathrm{c} \quad (E \gg 13.6\,\mathrm{eV})$

- **Radiative recombination (if ionized, T - low)**

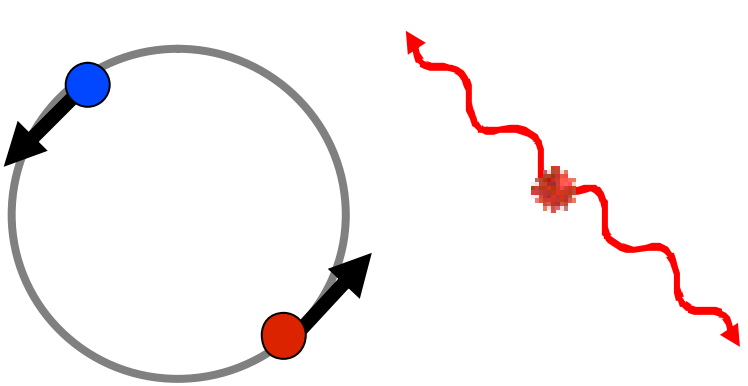


- **Charge exchange (if neutral, E>6.8 eV)**

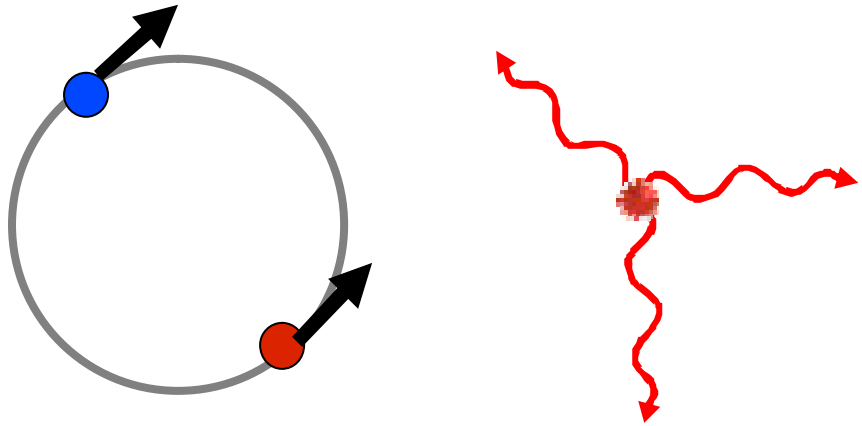


Bussard, Ramaty & Drachman 197

$$\text{CE + RR} = \left\{ \begin{array}{lll} \text{Para-positronium,} & \frac{1}{4} & 2\gamma \\ \text{Ortho-positronium,} & \frac{3}{4} & 3\gamma \end{array} \right.$$



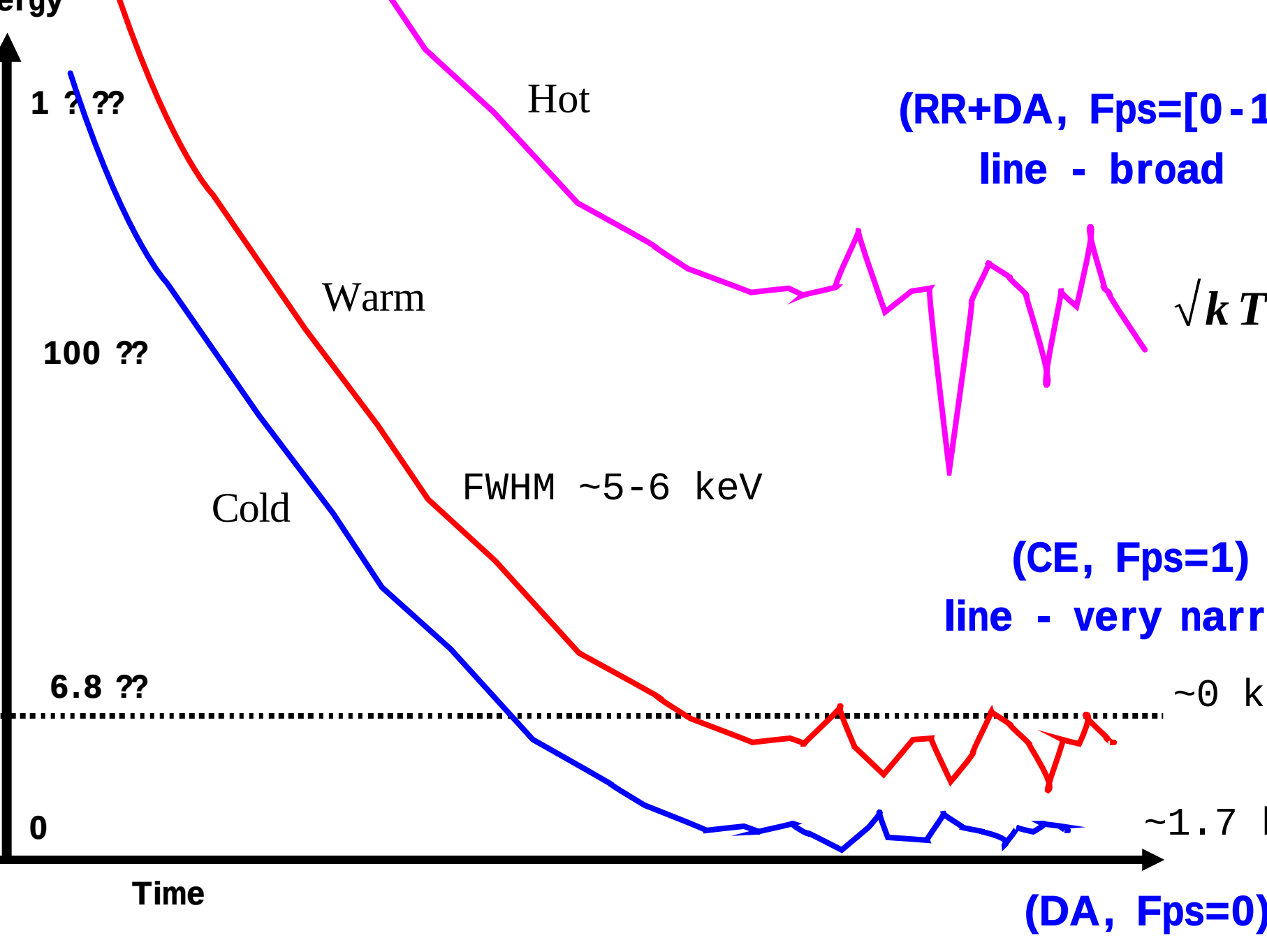
10^{-10} s

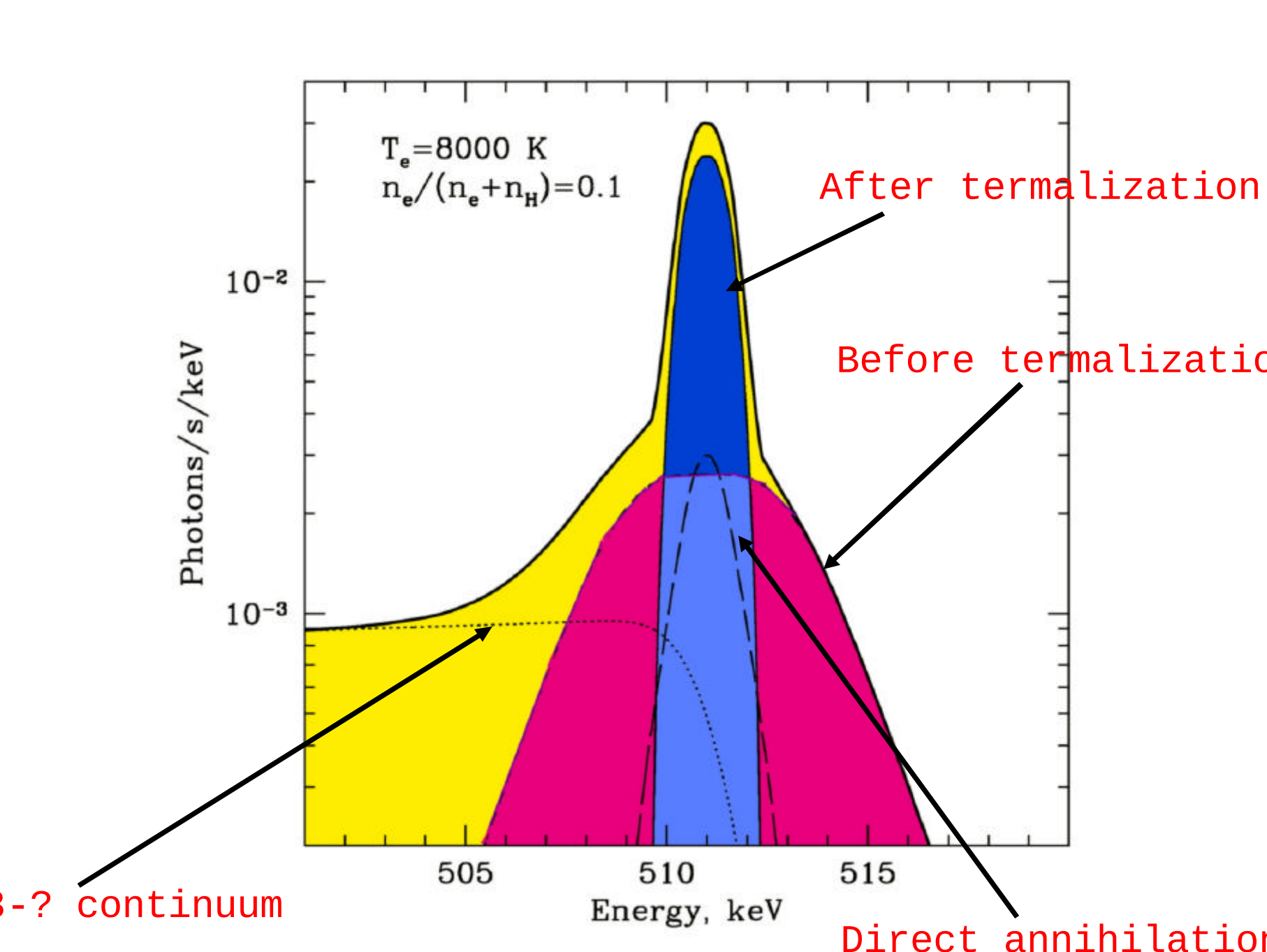


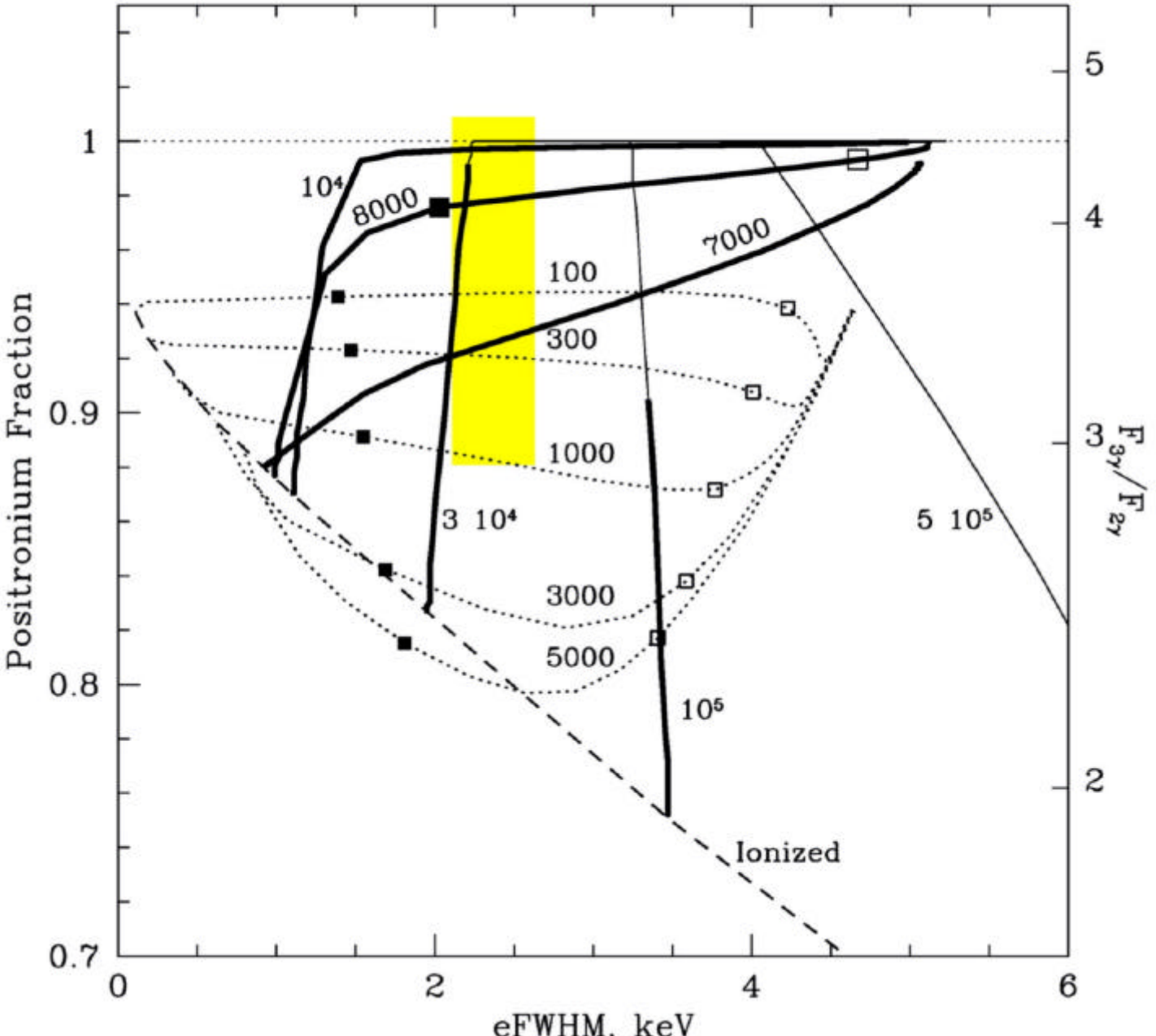
10^{-7} s

$$F_{\frac{3\gamma}{2\gamma}} = \frac{\frac{3}{4}\times 3}{\frac{1}{4}\times 2} = 4.5$$

Deviations from 4.5 → Direct annihilation / CE+RR


ergy
1 ? ??
100 ??
6.8 ??
0
Time
Hot
Warm
Cold
FWHM ~5-6 keV
(RR+DA, Fps=[0-1
line - broad
√kT
(CE, Fps=1)
line - very narr
~0 k
~1.7
(DA, Fps=0)


T_e=8000 K
$n_e/(n_e+n_H)$=0.1
After termalization
Before termalizatio
10^{-2}
10^{-3}
Photons/s/keV
505
510
515
Energy, keV
3-? continuum
Direct annihilation


Positronium Fraction
eFWHM, keV
$F_{3\gamma}/F_{2\gamma}$
1
0.9
0.8
0.7
0
2
4
6
5
4
3
2
10^4
8000
7000
100
300
1000
3 10^4
5 10^5
3000
5000
10^5
Ionized

Phase	T_e K	n, cm^{-3}	χ	T_s, years	T_a, years
Cold	80	30	0	10^3	10^4
WN	8000	0.3	0.1	10^5	$7\,10^4$
WI	8000	0.3	0.5	10^5	$7\,10^4$
Hot	$8\,10^5$	0.003	1	10^7	$3\,10^8$

WN – OK

old+WN+WI – OK

lot < 8 %, but ...

Positrons: production ? annihilation

DM annihilation ? volume ? hot phase

- **Migration between phases?**
- **Positrons locked to phase?**
- **Life time of hot phase** $2\,10^7$ **year**

Conclusions

- Most precise line parameters
- Line is unshifted (v < ~30 km/s)
- No fast expansion (v < 800 km/s)
- WNM – OK
- Neither pure Cold nor Hot (<8%)
- Dark matter annihilation is still an option