Large-scale Properties of Galactic ^{26}Al Emission with SPI/INTEGRAL

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Main Contents

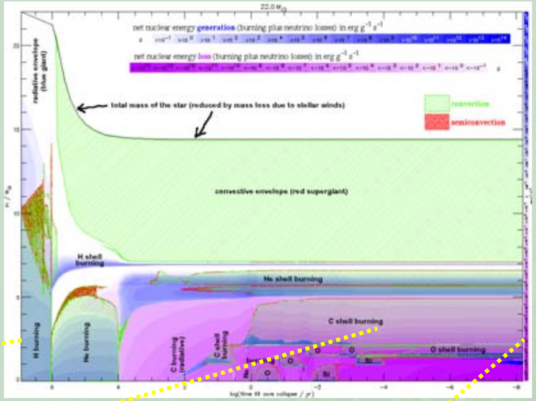
- Large-scale spectral characteristics of ^{26}Al in the inner Galaxy
- Longitude study of ^{26}Al line emission
- Latitude study of ^{26}Al line emission
- ^{26}Al emission from Cygnus, Vela and Sco-Cen

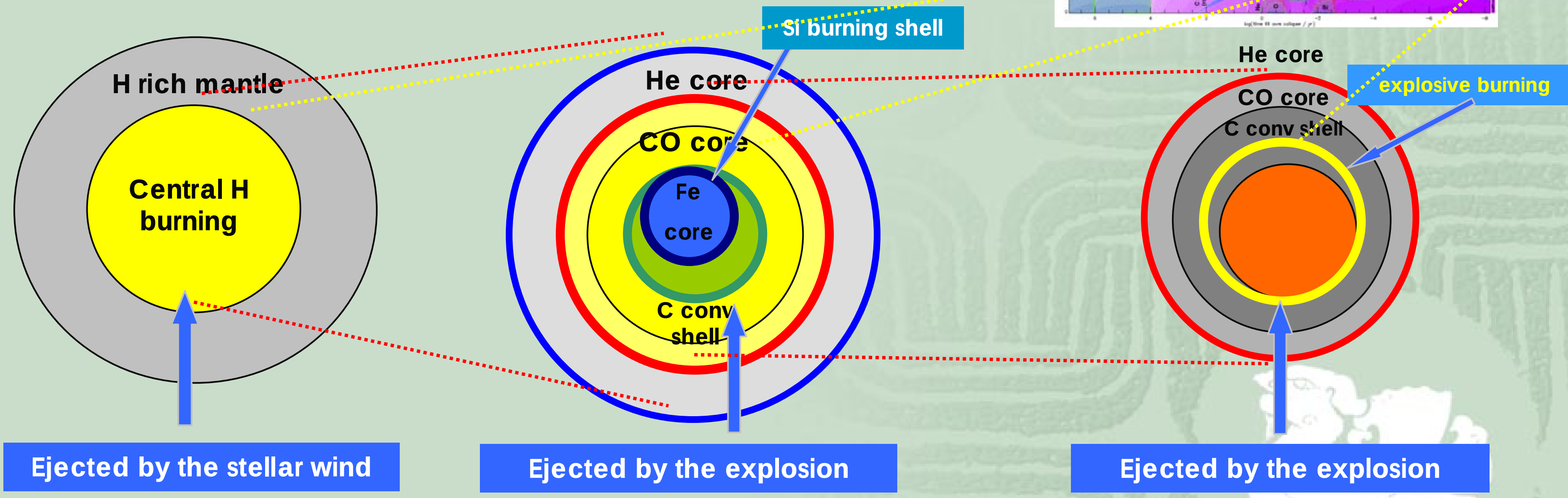
Origin of ^{26}Al in the Galaxy

^{26}Al is synthesized by proton-capture on ^{25}Mg in the hot and proton-rich environment.

Different Production Regions:

- H Convective Core
- C (Ne/C) convective Shell
  (when the star is in shell Si burning)
- Explosive Ne burning





(Limongi & Chieffi 2006)

Five possible origins of ^{26}Al in the Galaxy:

- Core collapse supernovae
- Wolf-Rayet stars (^{26}Al ejected by strong winds)
- Novae
- Asymptotic Giant Branch (AGB) stars
- Interactions of comic rays with the interstellar medium (ISM)

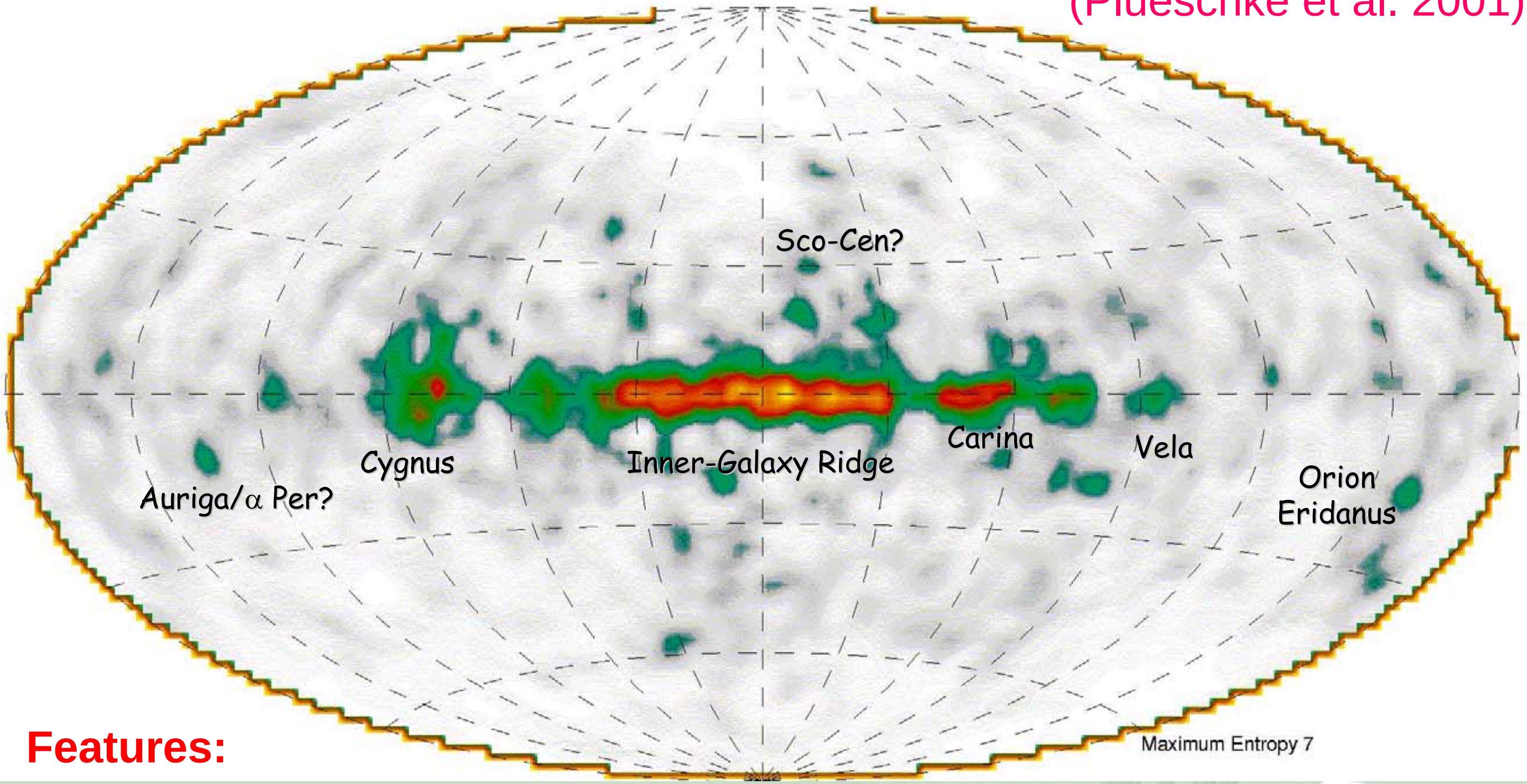
With a decay time of 1 million years, detections of ^{26}Al reflect the recent nucleosynthesis activity in the Galaxy. Yields and ejections of ^{26}Al depend on the stellar (wind) models (WRs, SNe), measurements of ^{26}Al in the Galaxy and star-formation regions have good constraints on the stellar models.

The 1809 keV gamma-ray line from radioactive ^{26}Al in the inner Galaxy was first detected by HEAO-C (Mahoney et al. 1982).

Breakthrough by COMPTEL/CGRO in ^{26}Al studies

^{26}Al Sky Map by 9-year data of COMPTEL/CGRO (1991-2000)

(Plueschke et al. 2001)



Features:

Extended Galactic ridge emission along the plane, plus Cygnus;
Low-intensity ridge toward Vela, Carina.

Implications:

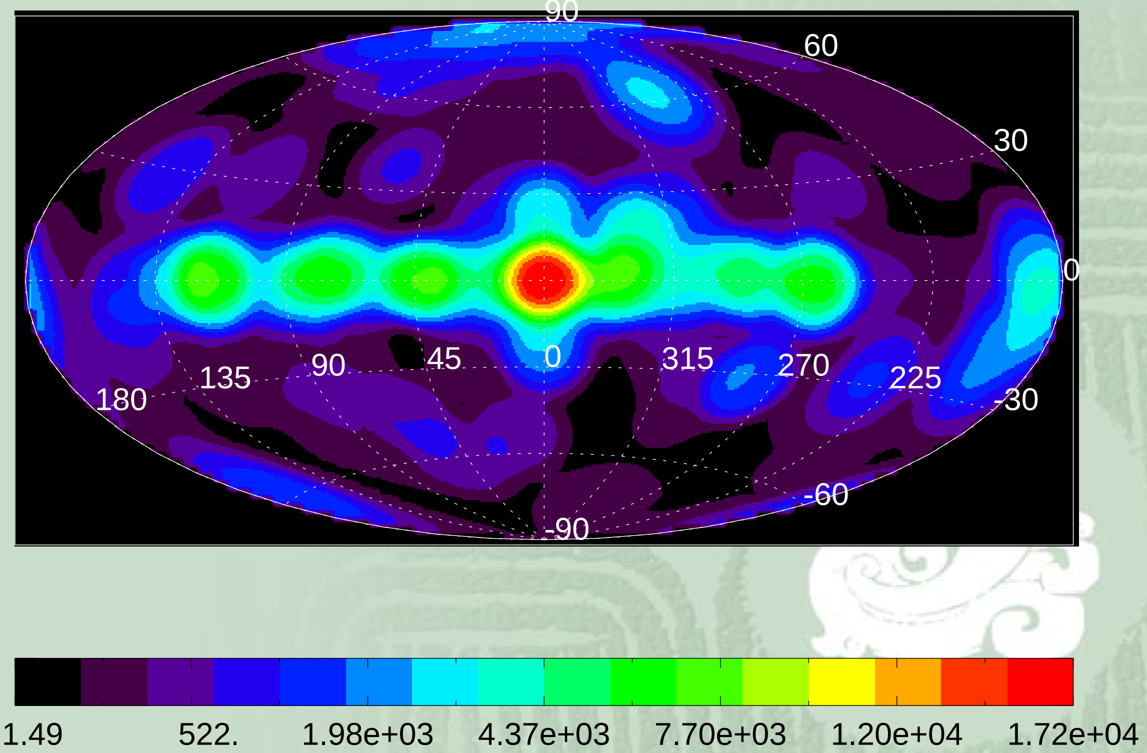
Origin of ^{26}Al is dominated by massive stars (core-collapse supernovae and Wolf-Rayet stars).

^{26}Al studies with SPI

COMPTEL has good ability on imaging, but poor on spectral information. While SPI can probe details of ^{26}Al line shapes with high spectral resolution.

Here, we used four years of SPI data (02.2003 – 02.2007) with total observation time: 47Ms

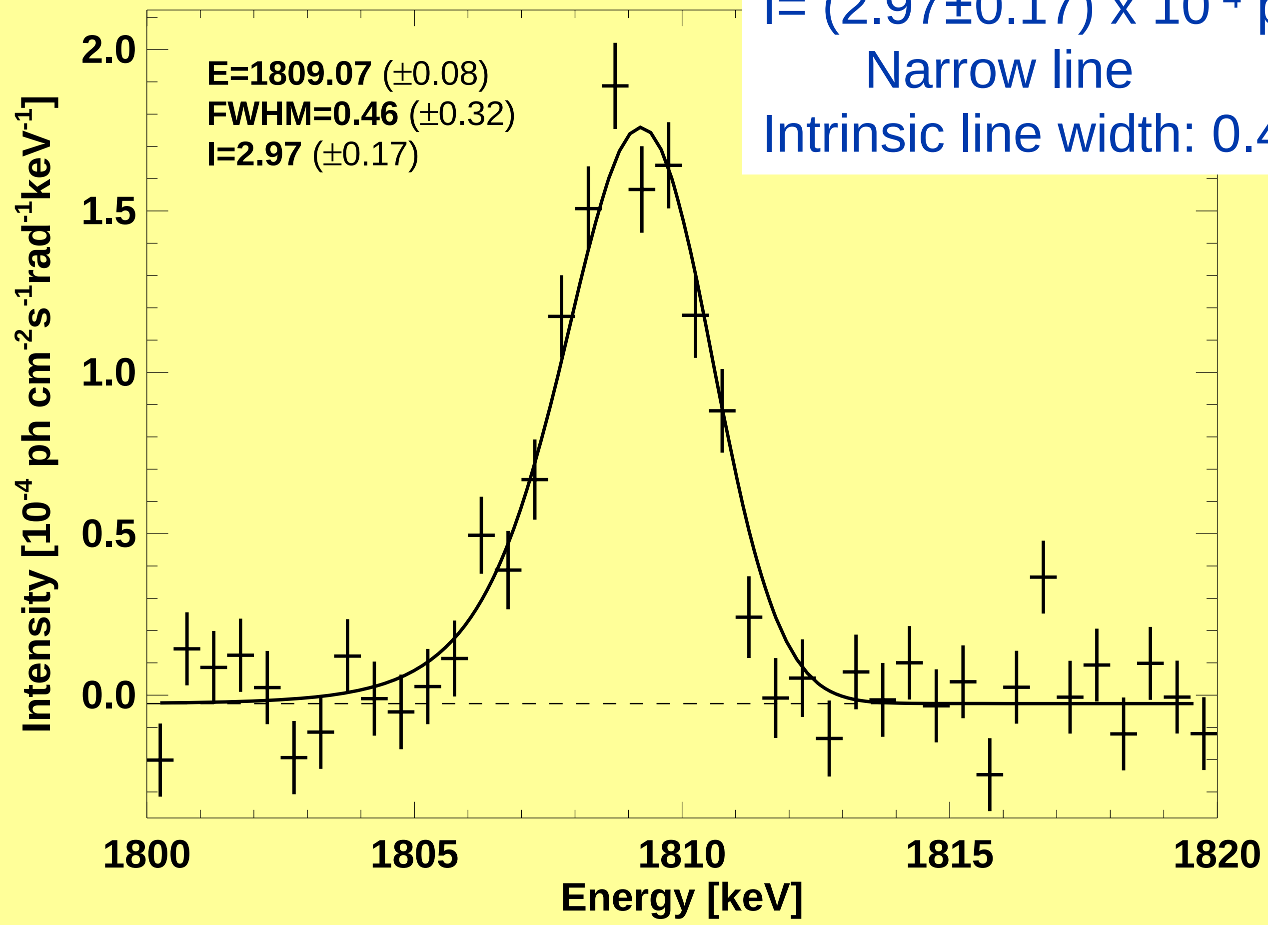
Observations concentrate on:
the Galactic center
the Inner Galaxy
Cas A
Cygnus
Carina –Vela
Crab (calibration)



^{26}Al line shape for the inner Galaxy region
(-30°<l<30°, -10°<b<10°)
large-scale spectral characteristics

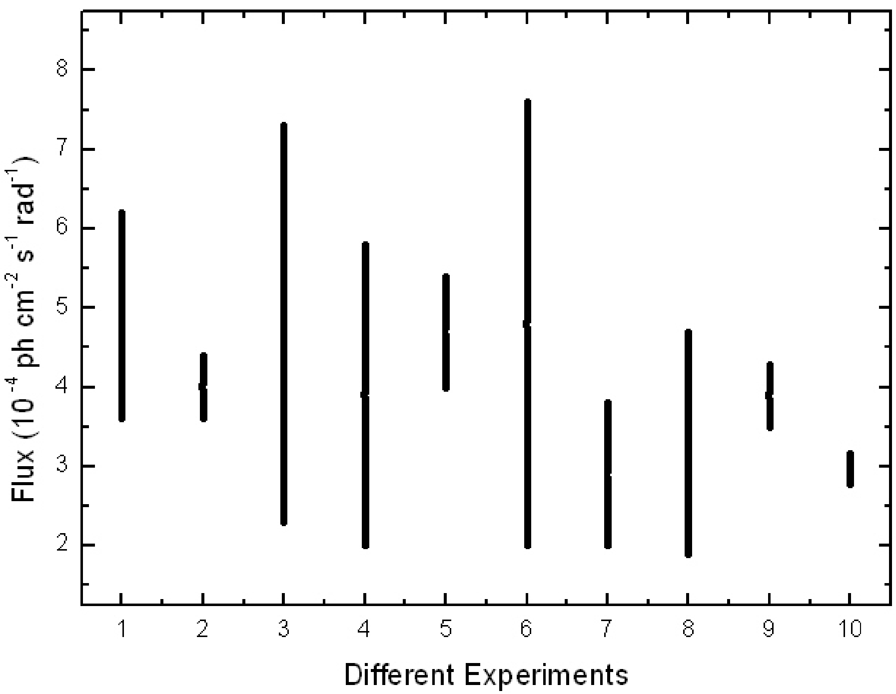
Detection significance level of ~ 30 σ

I= (2.97±0.17) x 10^{-4} ph cm^{-2} s^{-1} rad^{-1}
Narrow line
Intrinsic line width: 0.46±0.32 keV



Comparison of different experiments

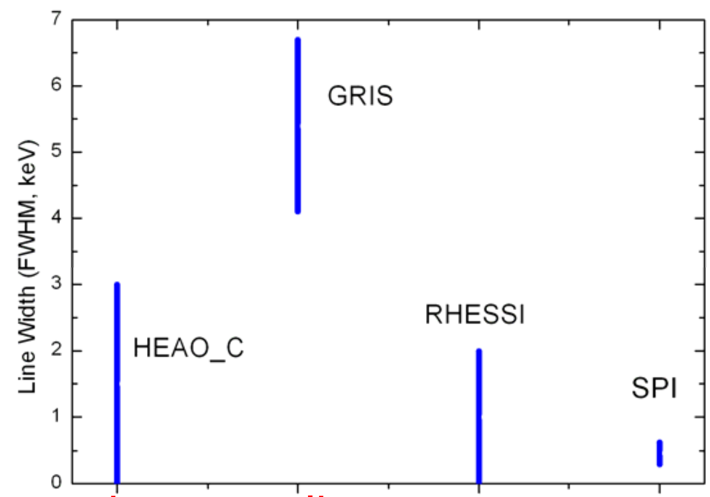
Flux



6. HEXAGONE (Durouchoux et al. 1993)
7. COMPTEL (Plueschke et al. 2001)
8. OSSE (Harris et al. 1997)
9. RHESSI (Smith 2004)
10. SPI (this work)

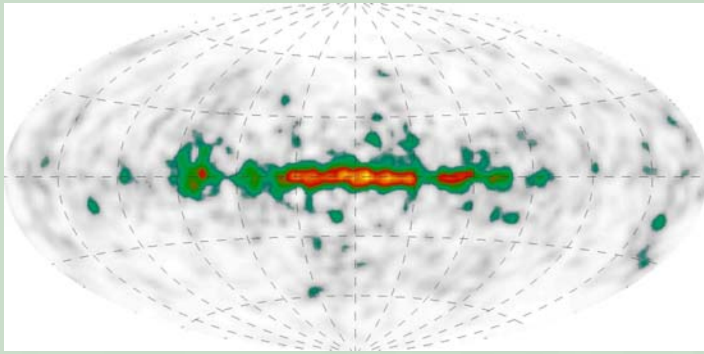
Width

1. HEAO-C (Mahoney et al. 1984)
2. SMM (Share et al. 1985)
3. MPE balloon (von Ballmoos et al. 1987)
4. Bell-Sandia (MacCallum et al. 1987)
5. GRIS (Teegarden et al. 1991)



Detailed discussion on line width in Kretschmer's talk

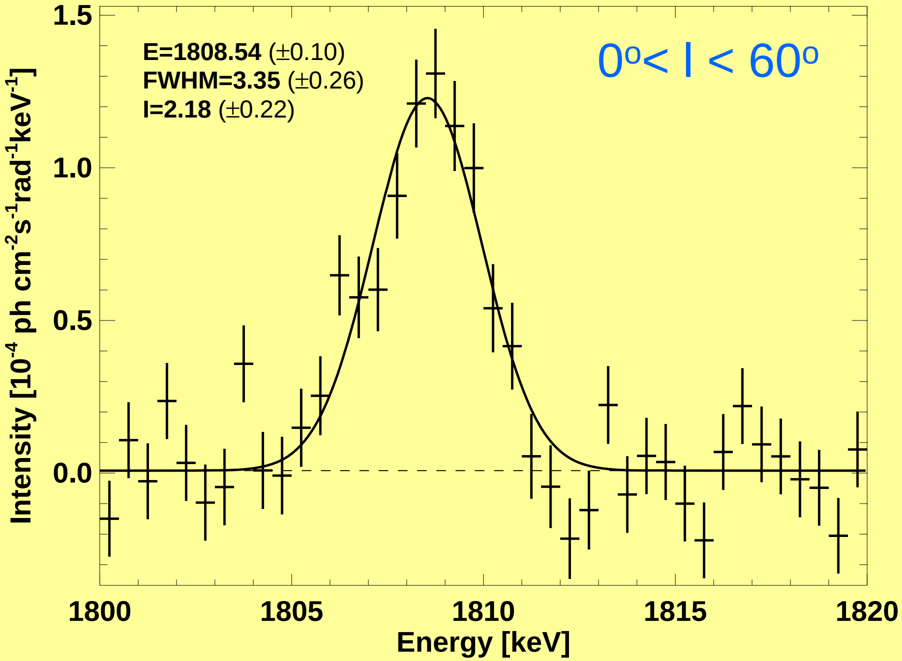
^{26}Al line shapes along Galactic Longitudes

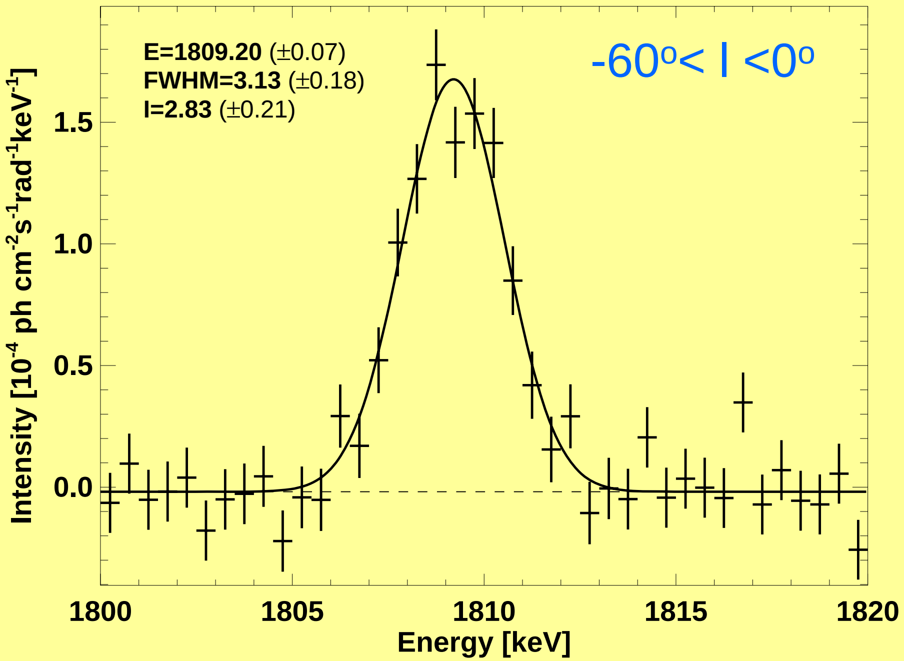


Why longitude studies?

- Asymmetry of ^{26}Al flux for 1st and 4th quadrants
- ^{26}Al line centroid energy shifts along longitudes due to Galactic rotation
- Line shapes toward different directions of the Galactic plane: dynamics of ^{26}Al sources in ISM

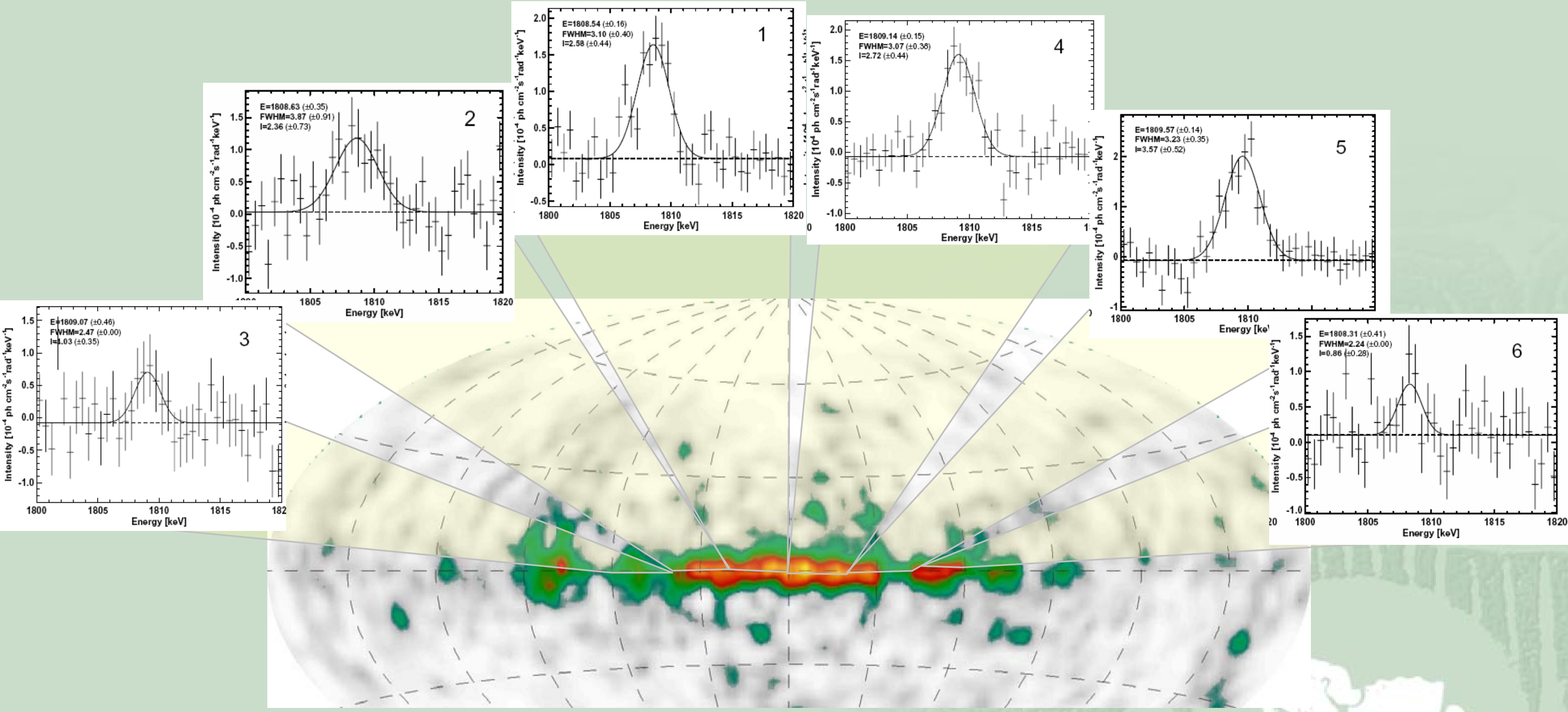
^{26}Al Intensity asymmetry: 4th is brighter than 1st, flux ratio ~ 1.3





Spectral Variation along the Plane of the Galaxy

6 segments, 20-degree longitude bin (-60º < l <60º)



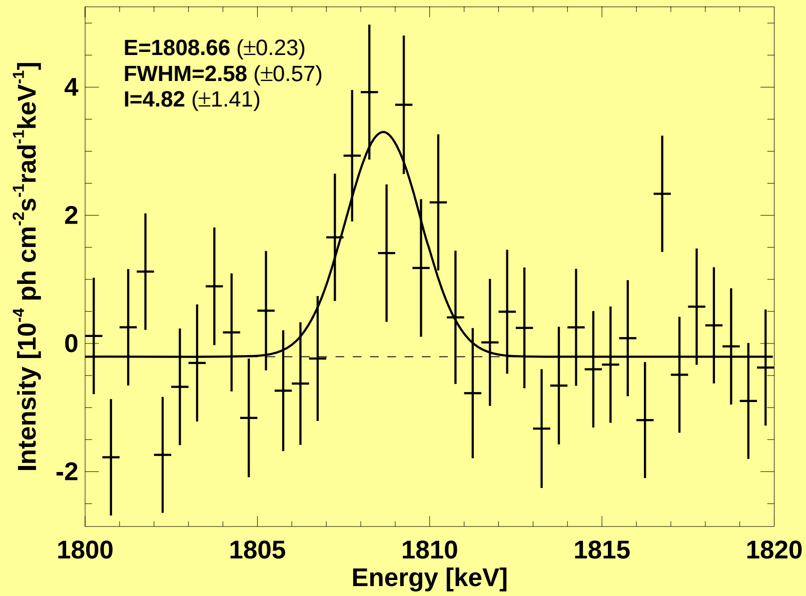
- Intensities: consistent with the COMPTEL Image
- Broad line feature toward l~20º - 40º (Sagittarius arm)

Probe the Galactic Rotation effect

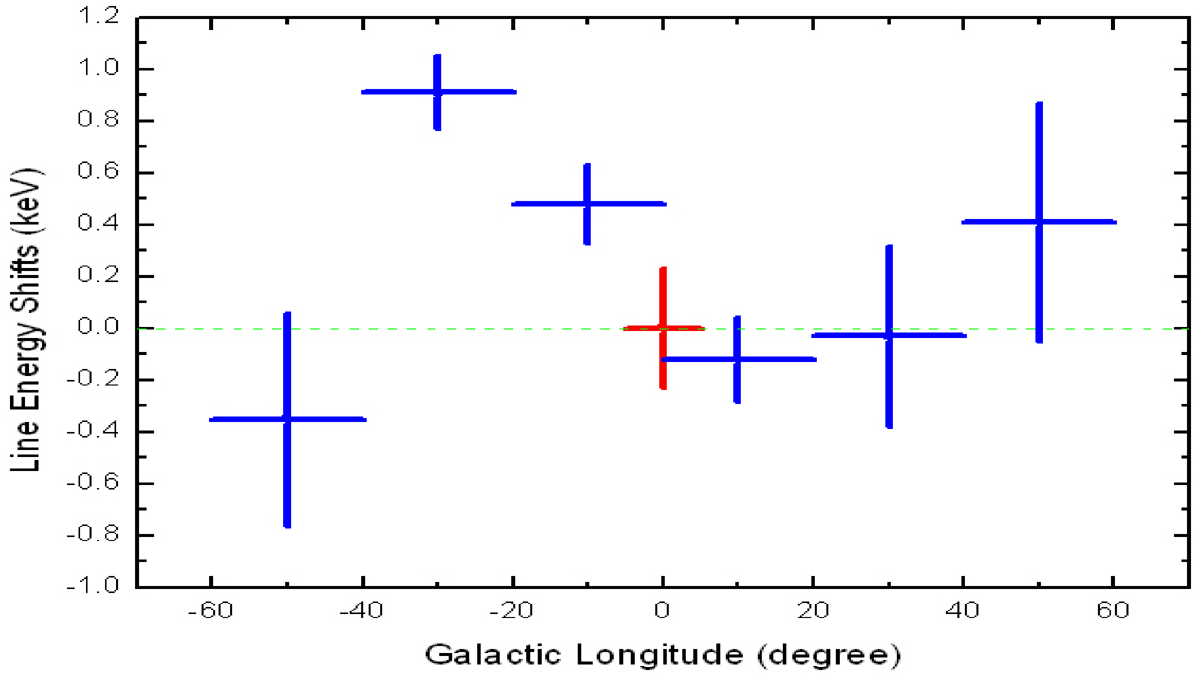
The Galactic Center (-5 < l < 5)

Line centroid: 1808.66± 0.23 keV
as a reference

Asymmetry of line energy shifts for negative and positive longitudes appears.



6 segments + Galactic center



Galactic rotation cannot explain this asymmetry.

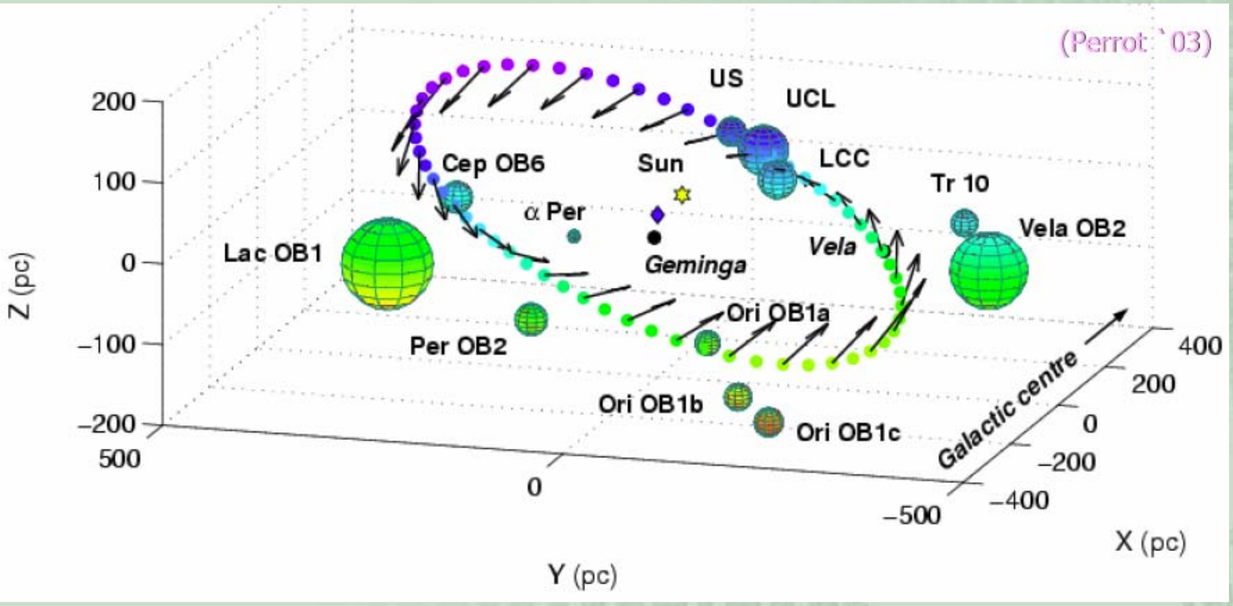
Other effects:
Galactic Bar, or local ^{26}Al sources

More details in Kretschmer's talk

Latitude study of ^{26}Al emission

Why latitude studies

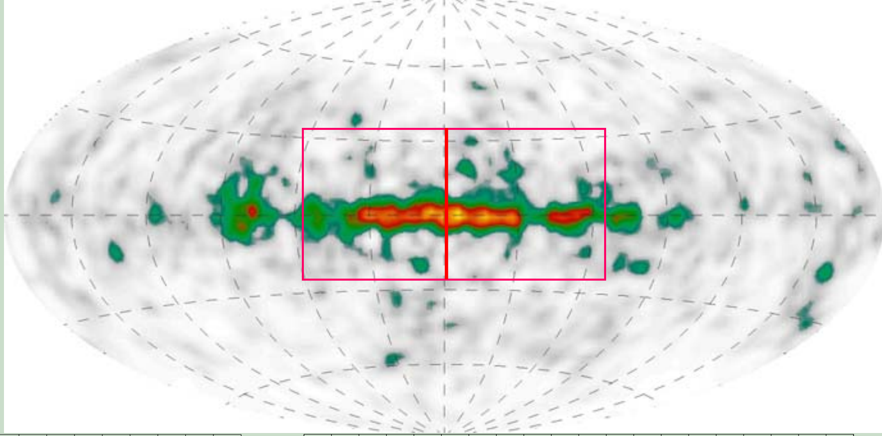
- ^{26}Al emission in the low latitudes ($|b|<5^o$) is attributed to large-scale origin (8 kpc) in the Galactic disk;
- ^{26}Al emission toward higher latitudes ($|b|>5^o$) would originate from the nearby star-formation regions (200 pc) , e.g. in the Gould Belt.



^{26}Al spectra along latitudes

(1st and 4th quadrants, separately)

^{26}Al emission is attributed to the thin disk



0<l<60

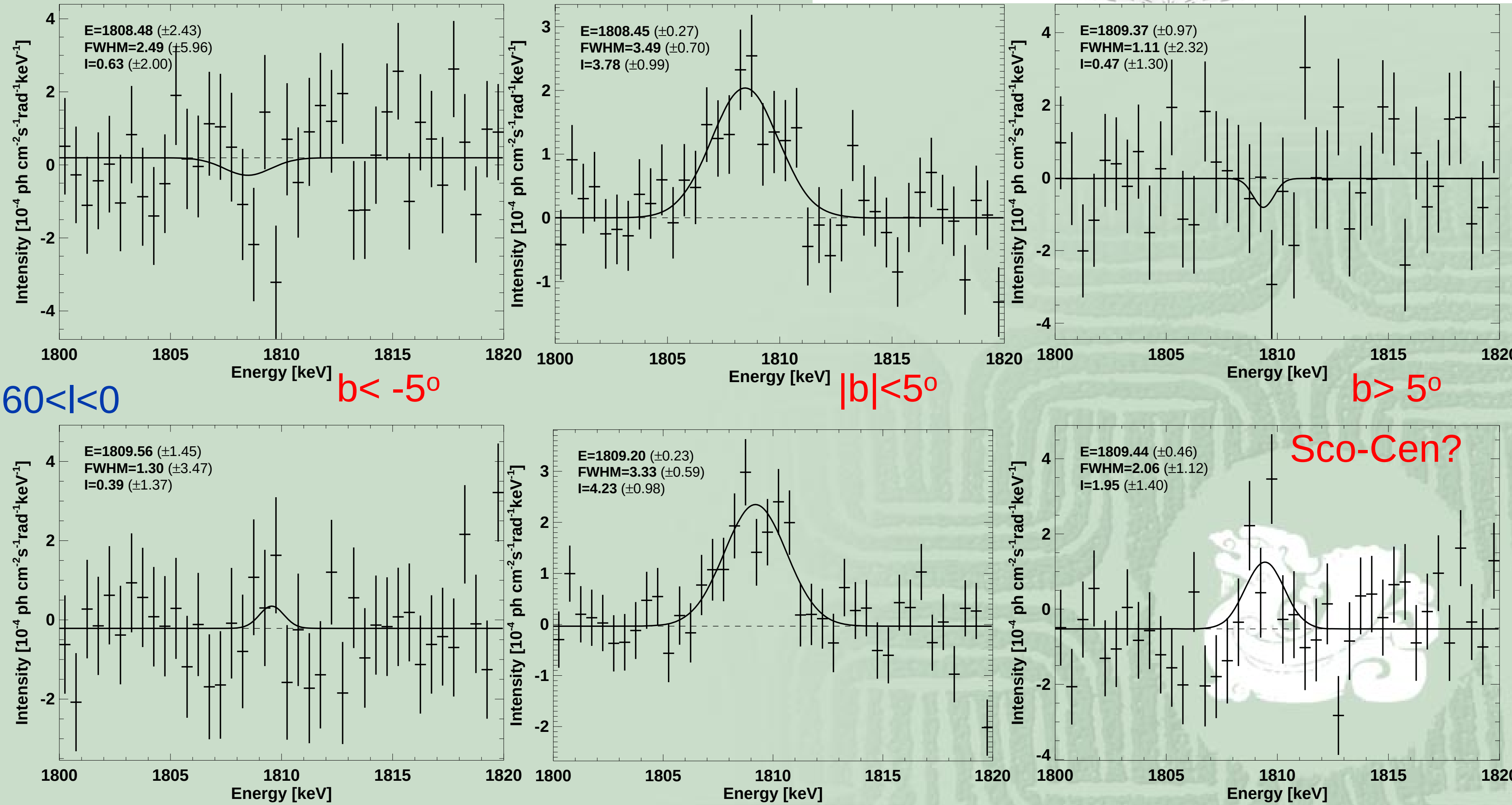
-60<l<0

b< -5o

|b|<5o

b> 5o

Sco-Cen?



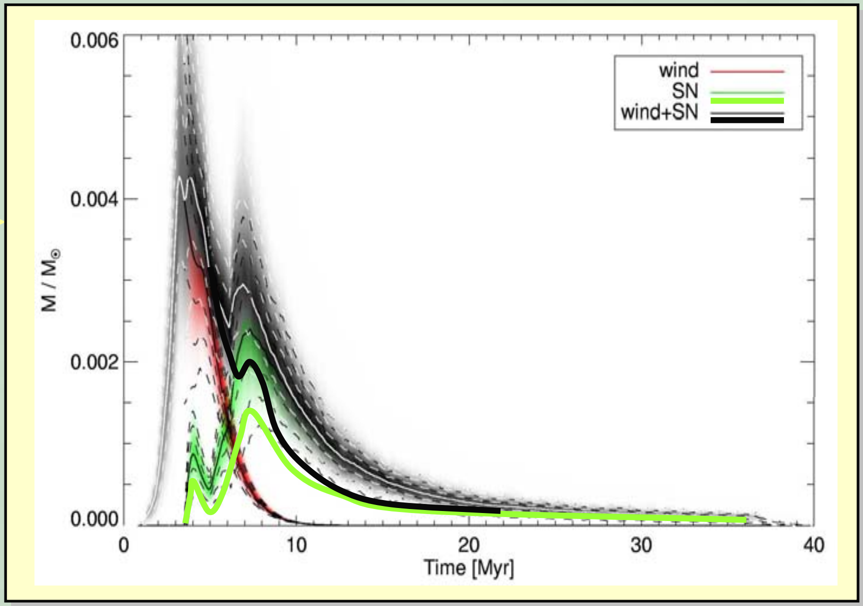
^{26}Al emission in star-formation regions

Studies of ^{26}Al emission and line shapes in nearby star-formation regions are good probe of kinematics of ^{26}Al ejecta in ISM.

^{26}Al ejection from massive star groups

^{26}Al production and ejection from a group of stars can be predicted by population synthesis models:

- stellar evolution
- stellar wind models
- Initial mass function
- nucleosynthesis yields of ^{26}Al from WR stars and SNe.



Prediction: a time-dependent ejection of ^{26}Al mass from SNe and WRs in a star group.

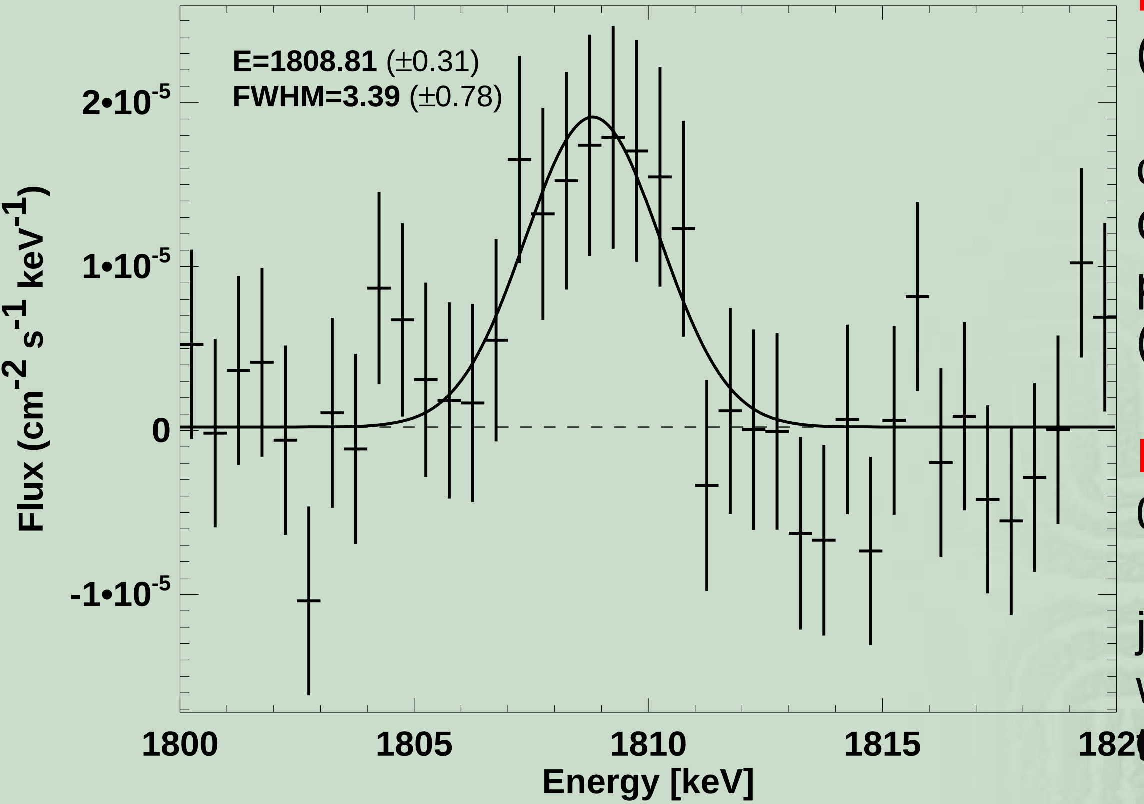
Plüschke et al., 2001, Cerviño et al. 2002

Cygnus region

A large number of OB associations, mean age of 3 Myr
Distance of 1 - 2 kpc

Studied region: $65^o < l < 95^o$
$-13^o < b < 17^o$

Detection significance level of 6 σ



Derived ^{26}Al flux:
$(7.2 \pm 1.2) \times 10^{-5}$ ph cm^{-2} s^{-1}

consistent with the results from COMPTEL, also consistent with the prediction of PopSyn models (Pluschke et al. 2001).

Intrinsic line width:
0.93±0.82 keV

just mildly broadening compared with large-scale characteristics for the inner Galaxy (0.46 keV).

Vela region

The Vela SNR, and the nearest known Wolf-Rayet star WR 11
Distance of 200-400 pc

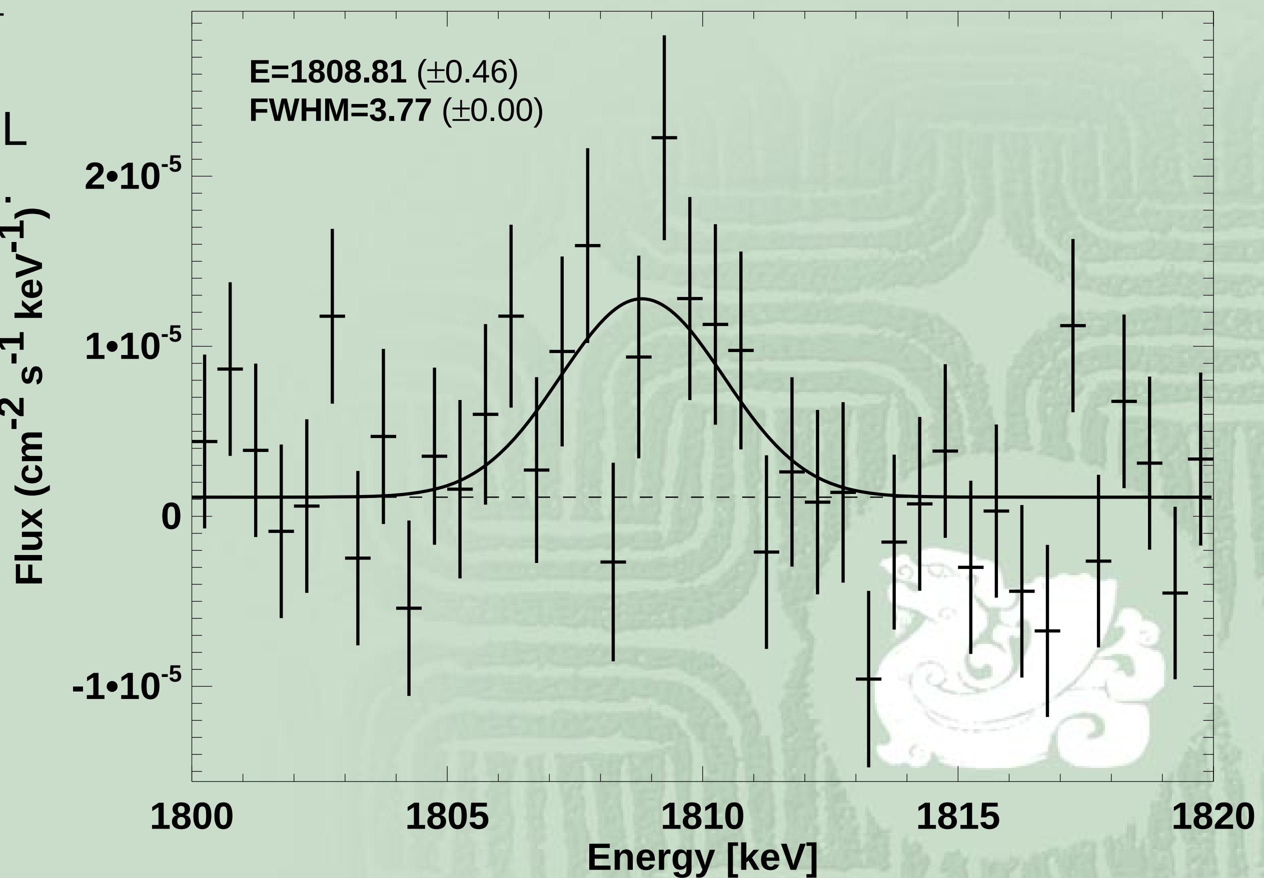
Flux:
$(4.1\pm1.2)\times10^{-5}$ ph cm^{-2} s^{-1}

consistent with COMPTEL results (Diehl et al. 1995).

Fitted intrinsic line width:
2 keV (broad?)

Significance level is still low (<3σ), need further studies

$-104^o<l<-82^o$, $-10^o<b<10^o$



Sco-Cen region

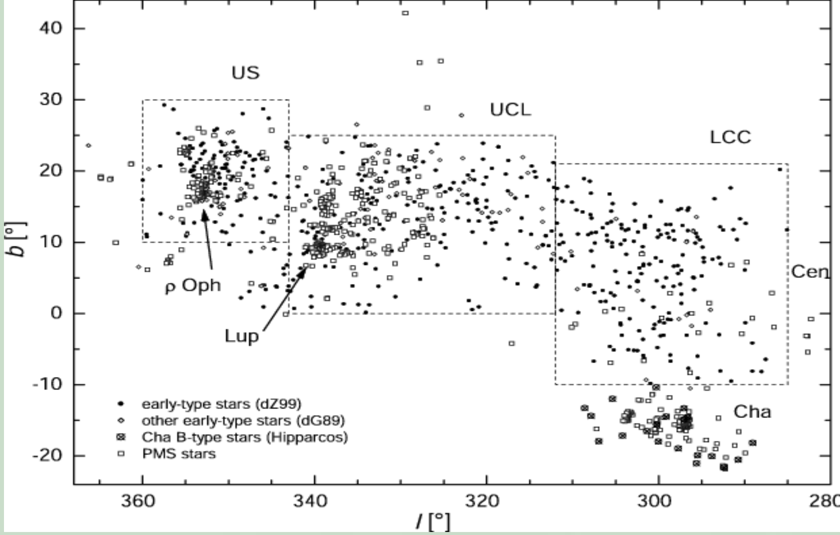
The nearest star-formation region, containing OB association
Distance of 100-200 pc

Flux:
(6.7±2.0)x10^{-5} ph cm^{-2} s^{-1}

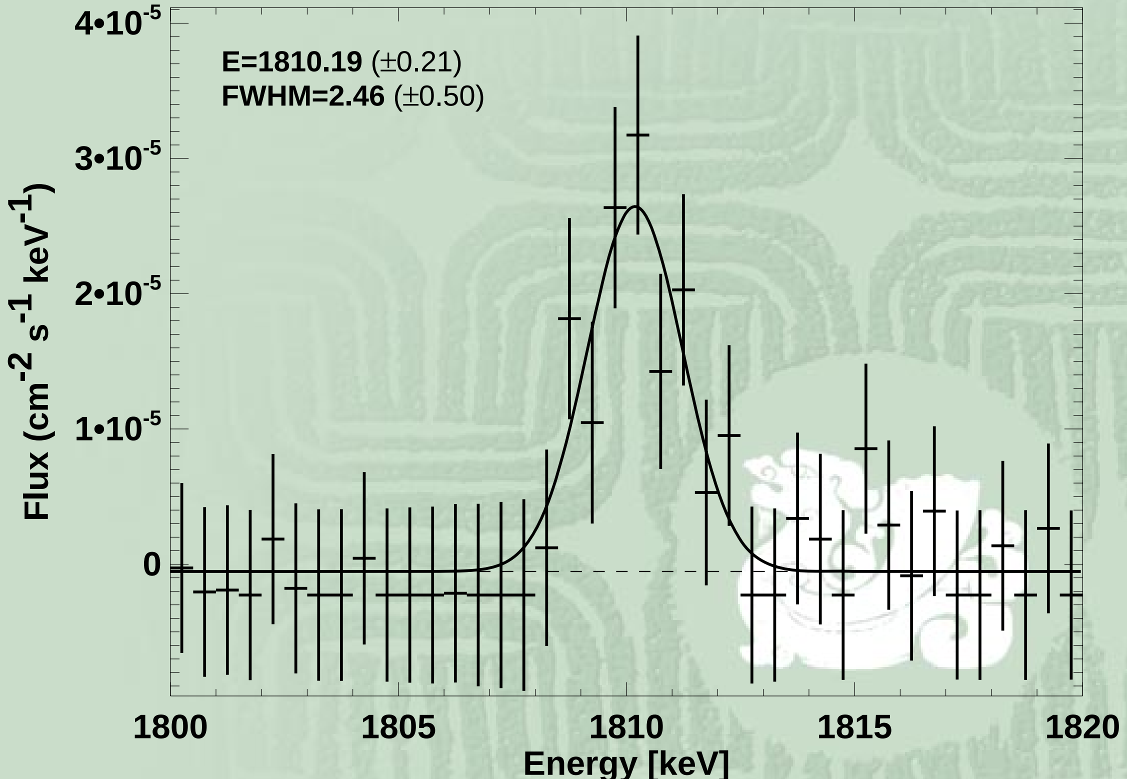
Line is narrow

Line position has a large blueshift of 1.5 keV, implying ^{26}Al ejecta have a bulk velocity of 200 km s^{-1} toward us.

Guest for environment of ^{26}Al sources in ISM: inhomogeneous in density?



-35°<l<-5°, 5°<b<30°



Summary

- Four years of SPI data obtain the ^{26}Al spectrum in the inner Galaxy region (~ 30 σ), narrow line, flux of 3×10^{-5} ph cm^{-2} s^{-1} rad^{-1}, converted to 2.7 M_o of ^{26}Al in the Galaxy;
- ^{26}Al line shapes along the Galactic longitudes are studied. 4th quadrant is brighter than 1st quadrants, with a ratio of 1.3. Line energy shifts along longitudes are discovered, as expected from Galactic rotation. The region toward the Sagittarius arm ($20^{o} < l < 40^{o}$) appears the broad line feature;
- ^{26}Al line shapes along the Galactic latitudes are probed. ^{26}Al emission is dominated by the thin disk. ^{26}Al emission toward the region of $l<0^{o}$, $b>5^{o}$ is detected, which suggests the contribution from Sco-Cen.
- ^{26}Al line shapes in three nearby star-formation regions, Cygnus, Vela and Sco-Cen are obtained with SPI. Mildly broadening for Cygnus; broad line feature for Vela; a strong blueshift of 1.5 keV for Sco-Cen.


The End
Thank you for your attention!