# The *'Nucleosynthesis'* Field

*by Roland Diehl*
*MPE Garching*

## Contents

- *Review & Update on Science Results and Discussion Status*
- *"Legend" Assessment*

# INTEGRAL's Legacy
## in Nucleosynthesis

☆ **Science Goals:** *(from 2010 Extension Request)*

**Key science areas of *INTEGRAL* are:**

- **Studies of nucleosynthesis through gamma-ray lines from elements formed in supernovae,**
- **Studies of the physics of emission mechanisms of white dwarfs, neutron stars, and black holes,**
- **Deep surveys for supermassive black holes in Active Galactic Nuclei, and**
- **Observations of gamma-ray bursts.**

**A key asset of *INTEGRAL* is its high resolution gamma-ray line spectroscopy, which will remain a unique capability for more than a decade to come.**

☞ *Annihilation Emission:*

- *Origin of Positrons* → *DM and Exotic Sources?*
- *Annihilation Site* → *Positron Transport*

☞ *Diffuse Radioactivities ($^{26}$Al, $^{60}$Fe):*

- *Massive-Star Groups / Clusters* → *Nucleosynthesis Yields*
- *Dynamics of Hot ISM* → *Nucleosynthesis Recycling*

☞ *Supernova Mechanisms ($^{44}$Ti, $^{56}$Ni):*

- *ccSN Interiors ($^{44}$Ti/$^{56}$Ni)* → *Asymmetries*
- *SNIa Yields ($^{56}$Ni)* → *Brightness Calibration*

*INTEGRAL* will be able to measure possible offsets [4], [5], relative to the Galactic Centre as well as spatial structures in the galactic distribution of the 511 keV emission (Fig. 2). Precision measurements of the line shape and positronium fraction will identify the gas properties of the annihilation site [71]. This will be key information for the determination of the origin of the positrons [72].

*INTEGRAL* will be able to disentangle $^{26}$Al source regions along the line of sight, and thus measure $^{26}$Al yields from massive stars in associations (e.g. the Cygnus region [6]).

*INTEGRAL* will be able to test if the spatial distribution of the $^{60}$Fe line emission is consistent with that of $^{26}$Al emission and will constrain the dynamics of the hot interstellar medium in the inner Galaxy (as demonstrated through a longitude-velocity diagram for $^{26}$Al, [7], see Fig. 4).

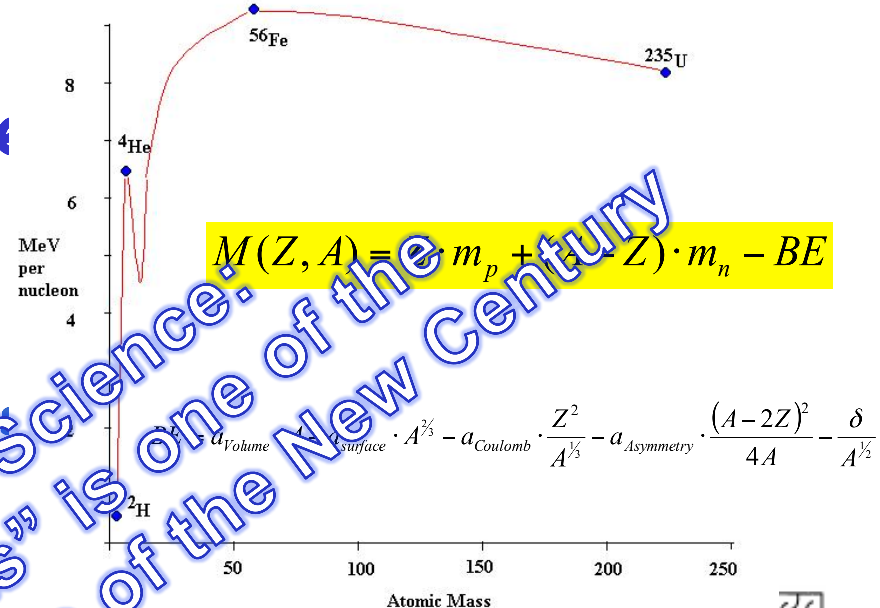
*INTEGRAL* will be able to study in greater detail the inner regions of core-collapse supernovae through the $^{44}$Ti gamma-ray line emission (e.g. Cas A). In addition, the homogeneous exposure of the galactic plane is likely to reveal other $^{44}$Ti candidates. These results will guide future *NuSTAR* observations of $^{44}$Ti, and constrain core-collapse supernova yield models. Similarly, tighter limits on $^{22}$Na and $^{7}$Be line gamma-rays will establish *INTEGRAL*'s legacy on nova nucleosynthesis.

*INTEGRAL* will also provide a unique diagnostic to probe the black holes in X-ray transient outbursts through the red-shifted 511 keV line emission.

***INTEGRAL* will be the premier mission to study nucleosynthesis in an exploding star in case of a nearby supernova event, either type Ia at a few Mpc, or a core collapse supernova, like SN 1987A in the LMC (Fig. 6).** Only gamma-rays **directly** measure the radioactivity which powers SN light. Given that there is a chance of such an event during the extended mission operations phase, the opportunity to observe gamma-rays from $^{56}$Ni decay (Fig. 6) provides a unique potential for nuclear-line astronomy. Gamma-ray measurements are able to probe dynamics of radioactive ejecta most directly. With *INTEGRAL*, we might well learn more about supernova physics from one such object than from all previous ones combined.

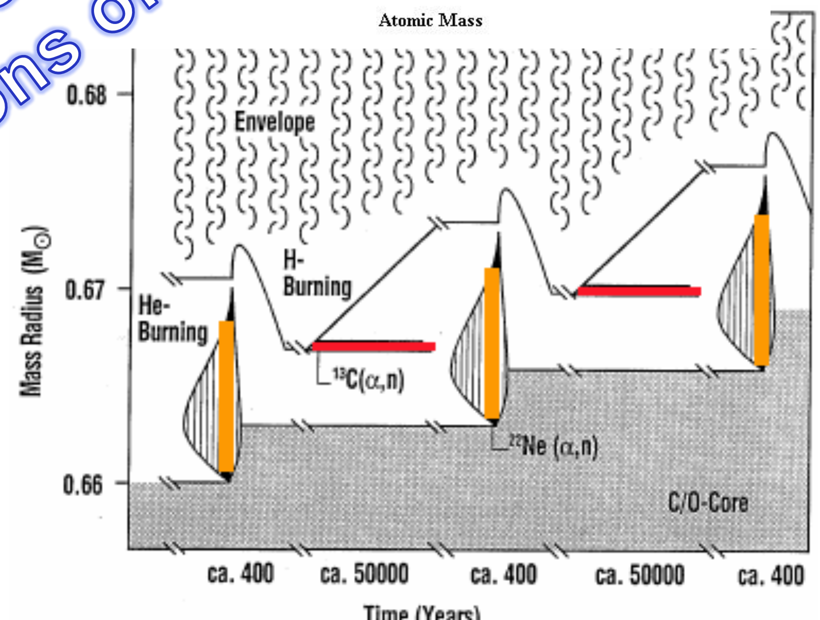
# Nuclear Reactions in Cosmic Sites

- **Nuclear Reaction Paths and their Efficiencies are driven by:**
  - ☆ The Binding Energies / Stabilities of Isotopes (mostly unstable!)
  - ☆ The Abundance & Energies of Isotopes as set within the Cosmic Sites




$$M(Z,A) = Z \cdot m_p + (A-Z) \cdot m_n - BE$$

$$BE = a_{Volume} \cdot A - a_{surface} \cdot A^{2/3} - a_{Coulomb} \cdot \frac{Z^2}{A^{1/3}} - a_{Asymmetry} \cdot \frac{(A-2Z)^2}{4A} - \frac{\delta}{A^{1/2}}$$



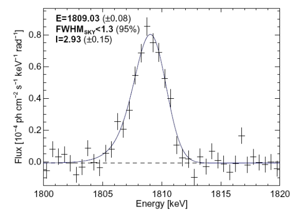

US Academy of Science: "Origin of Elements" is one of the Eleven Science Questions of the New Century

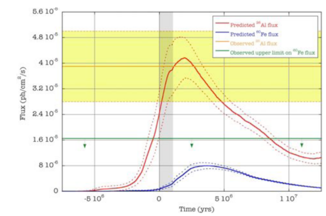
# Status of the *Nucleosynthesis* Field - Overview

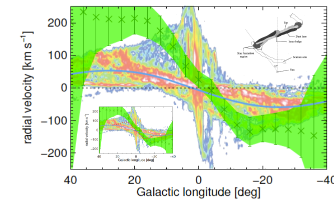
Status Jan 2012

## ☆ $^{26}$Al in the Galaxy

- ☞ Spatially-Resolved Spectra
- ☞ Constraints $^{26}$Al versus Models
- ☞ ISM Dynamics Studies started

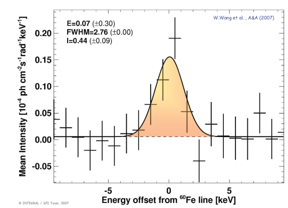


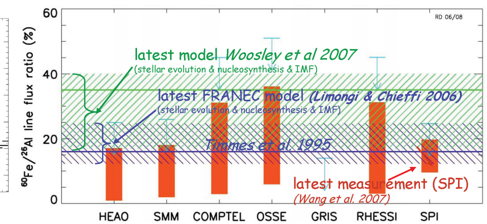





## ☆ $^{60}$Fe in the Galaxy

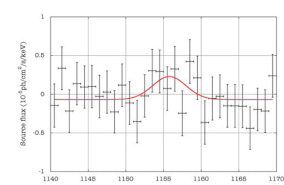
- ☞ Clear Detection; no Imaging (yet?)
- ☞ $^{60}$Fe/$^{26}$Al Ratio and
  $^{60}$Fe Nucl.Physics Being Revised

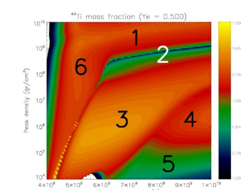





## ☆ Supernovae

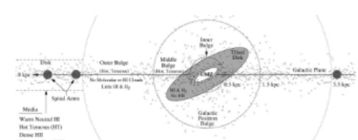
- ☞ $^{44}$Ti: Cas A Constraints from all 3 $^{44}$Ti Lines;
  SN1987 Detection
- ☞ Model Variety for cc-SNe and SNIa
- ☞ SN2011fe Limits on $^{56}$Ni



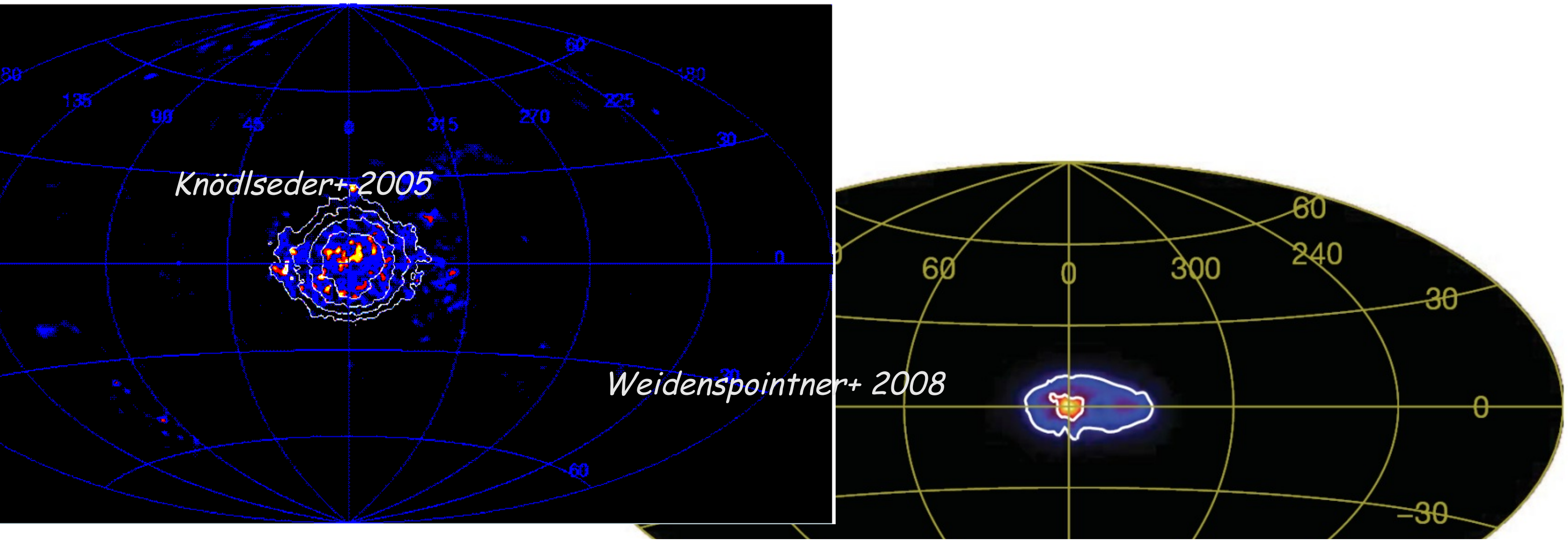


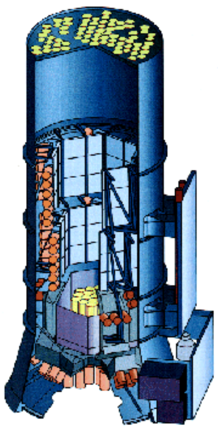

## ☆ Positrons in the Galaxy

- ☞ Spatially-Resolved Spectra
- ☞ Line Shape Constraints
- ☞ Bulge/Disk Ratio: New Models & Theory

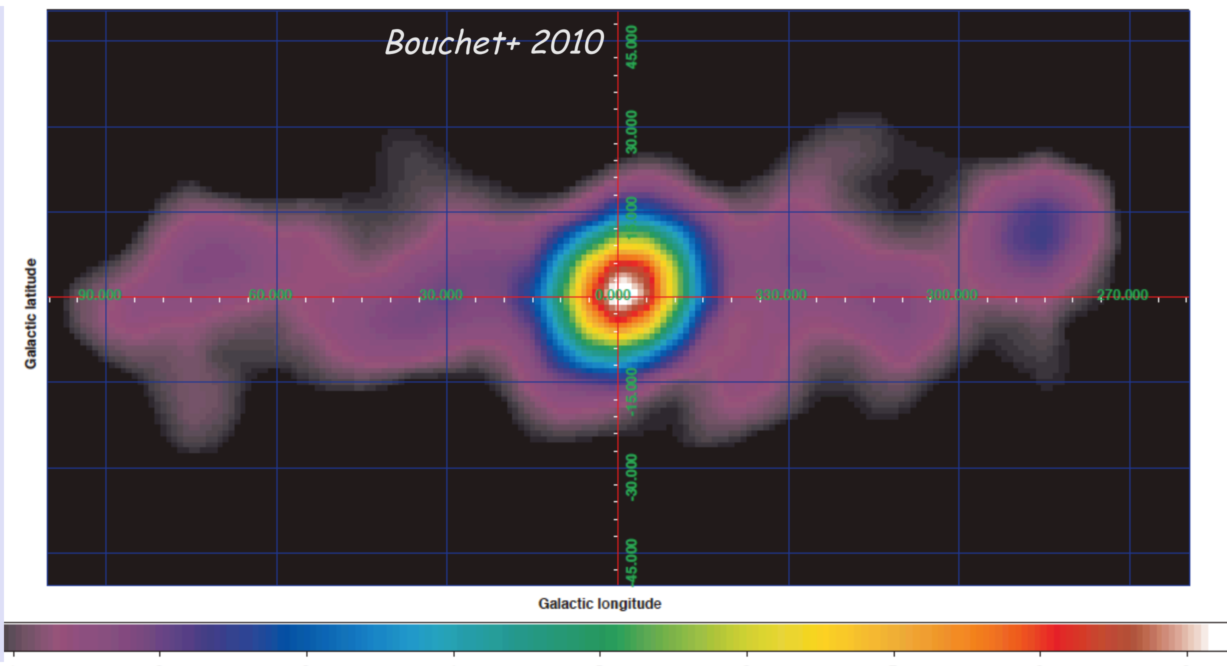



# The Signature of Annihilating Positrons



- ☆ Annihilation γ-rays are dominated by a Bright Inner-Galaxy Component
- ☆ The $^{26}$Al e+ Produced in the Disk (82%) are a Minor Contribution
- ☆ Annihilation γ-ray Emission Presents a Puzzle:
  - ☞ e+ Sources ?
  - ☞ **Propagation !!**
  - ☞ Annihilation Environments



# Locations of Candidate Positron Sources

Prantzos et al., RMP 83 (2011)

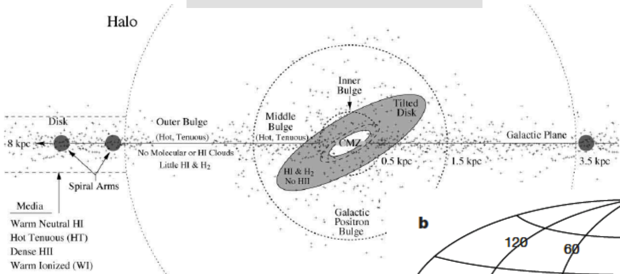
- ☆ Nucleosynthesis
- ☆ Accreting Binaries
- ☆ Pulsars
- ☆ SMBH?
- ☆ Dark Matter?

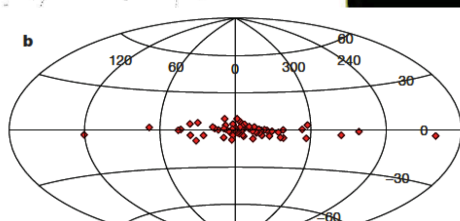
☞ Only Gamma-Rays Can Tell

| 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 | $\beta^+$ decay | ~1 | 0.4 | <0.2 | $\dot{N}$, $B/D$: Observationally inferred |
| Supernovae: $^{44}$Ti | $\beta^+$ decay | ~1 | 0.3 | <0.2 | $\dot{N}$: Robust estimate |
| SNIa: $^{56}$Ni | $\beta^+$ decay | ~1 | *2* | <0.5 | Assuming $f_{e^+,\mathrm{esc}} = 0.04$ |
| Novae | $\beta^+$ decay | ~1 | *0.02* | <0.5 | Insufficient $e^+$ production |
| Hypernovae/GRB: $^{56}$Ni | $\beta^+$ decay | ~1 | ? | <0.2 | Improbable in inner MW |
| Cosmic rays | *p-p* | ~30 | 0.1 | <0.2 | Too high $e^+$ energy |
| LMXRBs | $\gamma$-$\gamma$ | ~1 | *2* | <0.5 | Assuming $L_{e^+} \sim 0.01\ L_{\mathrm{obs},X}$ |
| Microquasars ($\mu$Qs) | $\gamma$-$\gamma$ | ~1 | *1* | <0.5 | $e^+$ load of jets uncertain |
| Pulsars | $\gamma$-$\gamma$/$\gamma$-$\gamma_B$ | >30 | *0.5* | <0.2 | Too high $e^+$ energy |
| ms pulsars | $\gamma$-$\gamma$/$\gamma$-$\gamma_B$ | >30 | *0.15* | <0.5 | Too high $e^+$ energy |
| Magnetars | $\gamma$-$\gamma$/$\gamma$-$\gamma_B$ | >30 | *0.16* | <0.2 | Too high $e^+$ energy |
| Central black hole | *p-p* | High | ? | | Too high $e^+$ energy, unless $B > 0.4$ mG |
| | $\gamma$-$\gamma$ | 1 | ? | | Requires $e^+$ diffusion to ~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 | |

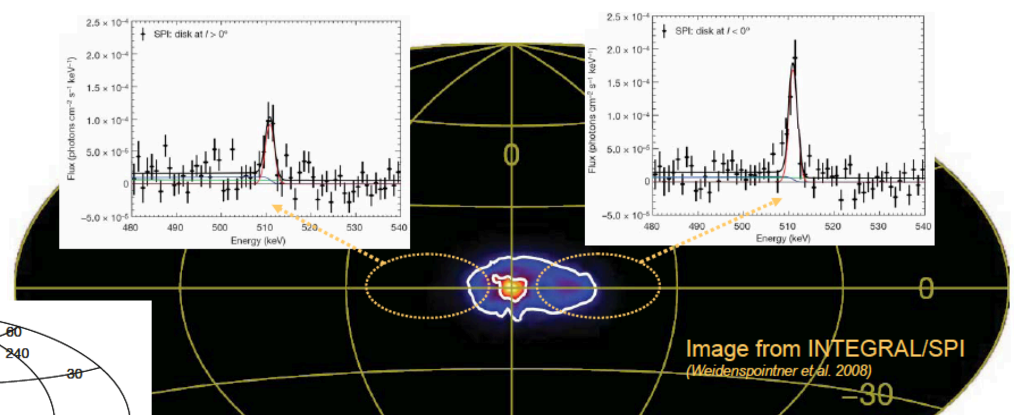
[a]Typical values are given.
[b]$e^+$ rates: in roman: observationally deduced or reasonable estimates; in italic: speculative (and rather close to upper limits).
[c]Sources are simply classified as belonging to either young ($B/D < 0.2$) or old ($< 0.5$) stellar populations.

Higdon et al., ApJ 2009




Weidenspointner et al., 2008



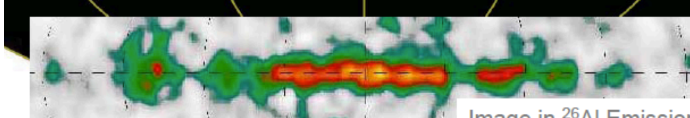



Image in $^{26}$Al Emission from CGRO
(Plüschke et al. 2001);
$^{26}$Al is responsible for ~30% of e+ in the Galactic Disk

X-ray Binaries show a similarly asymmetric distribution - are those the sources?

 Roland Diehl

# 2009 Analysis Efforts: Different Groups & Methods

## ☆ Systematics??

- ☞ Analysis Method?
  - Which Sky Model is Fitted?
    - » Sky Pixels / Few Different Shapes
  - How is Bgd Defined and Determined?
    - » On/Off versus Longterm Models
    - » Parametrizations and their Solutions
- ☞ Pointing Pattern?
- ☞ Instrumental Longterm Changes
  - Detector Degradation
    - » Least/Most Degraded Exposure: →
  - Background Changes
- ☞ ...

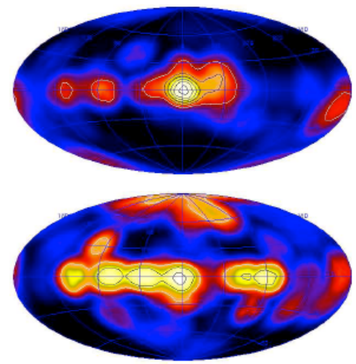
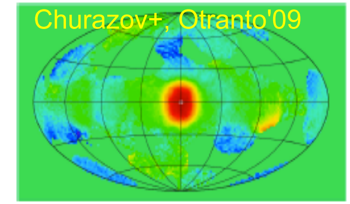
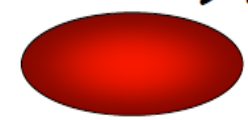
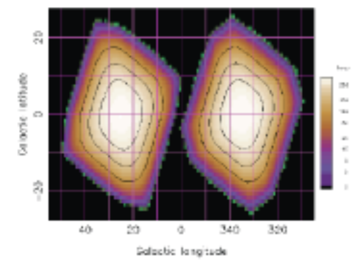


Figure 2: The exposure to the sky for the least (top) and most (bottom) degraded subsets of the Mar. 3, 2009 data set. For the least degraded data, the contours are at exposure levels of 1, 2, ..., 6 × $10^8$ $cm^2$ s. For the most degraded data, the contours are at exposure levels of 1, 2, and 3 × $10^8$ $cm^2$ s.

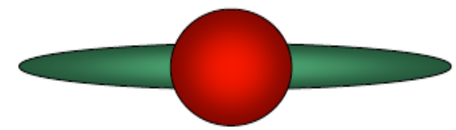



9°x 6°



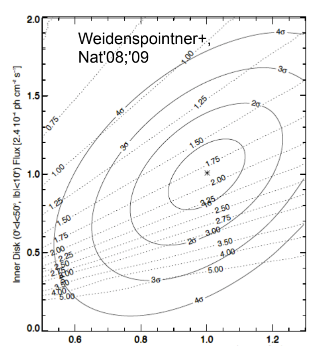



7°x 6°

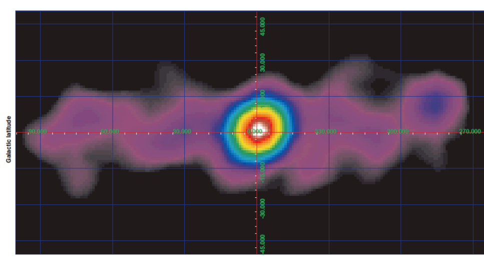


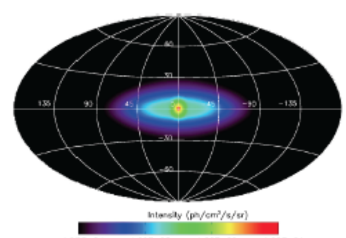
## ☆ Asymmetry of inner Disk Debated

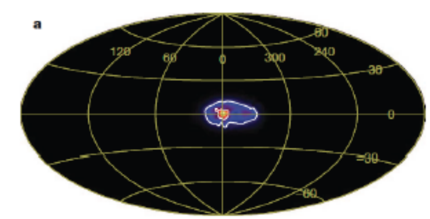
- ☞ "Evidence" at 3...4 σ by one Group
  - rejecting "equal-flux" hypothesis
- ☞ Consistency with Symmetric Models by other Groups
  - less sensitive?
  - more conservative?




Bouch

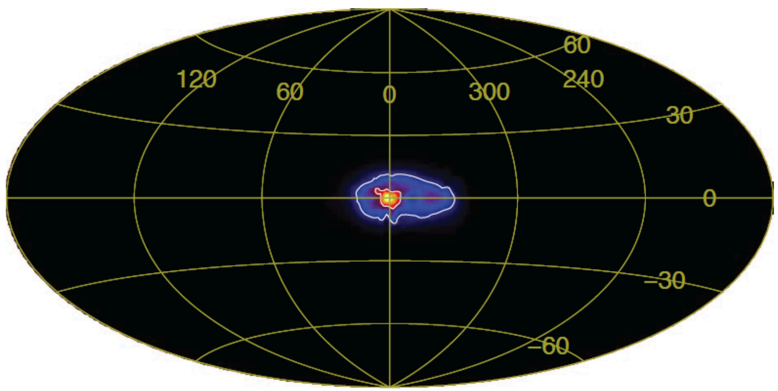


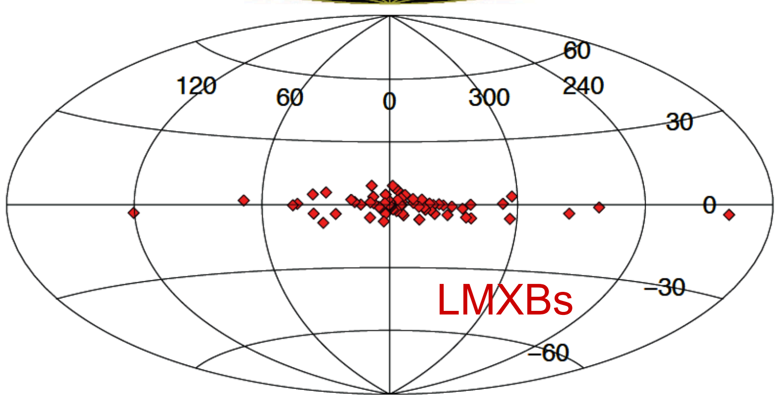


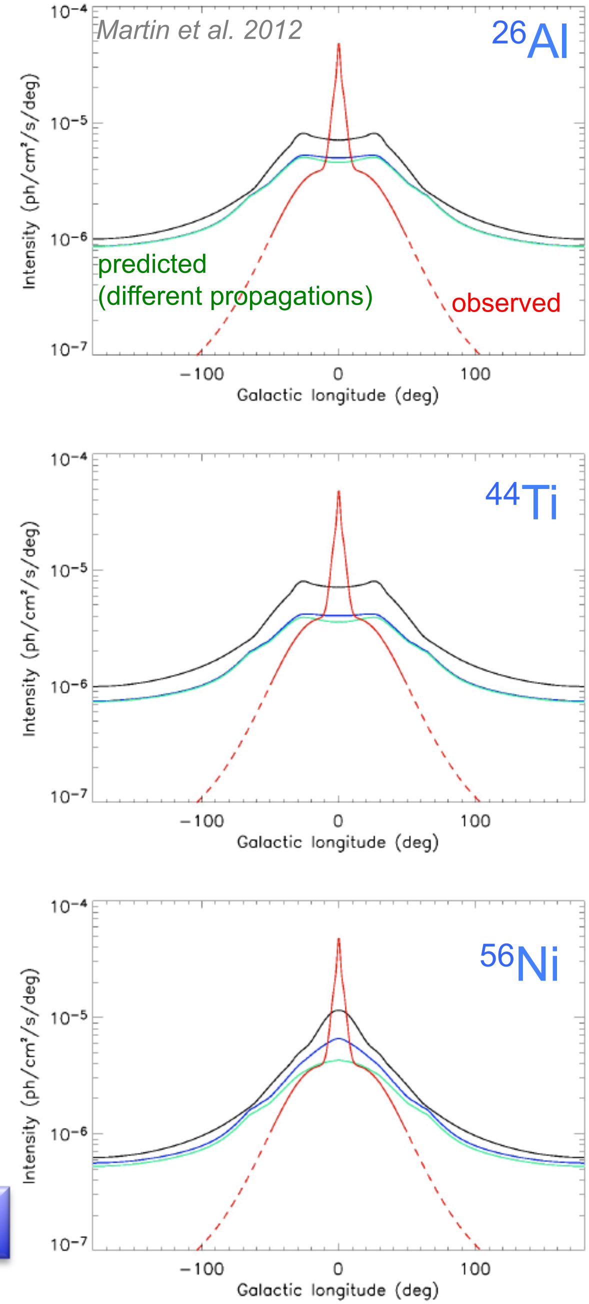



# Morphology of Positron Annihilation Emission

- **Trying to Discriminate Different Sources...**



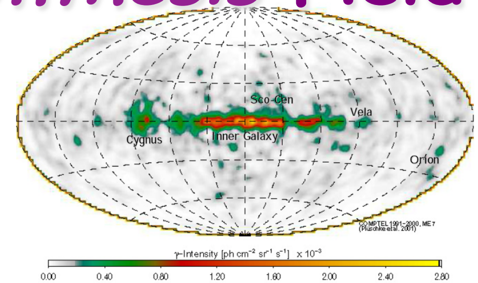

**How much Exposure is Needed to Obtain an Answer?**

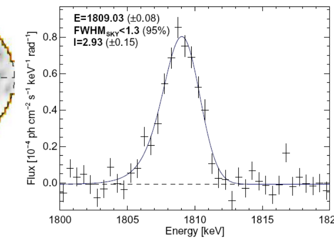
# Status of the *Nucleosynthesis* Field - $^{26}$Al

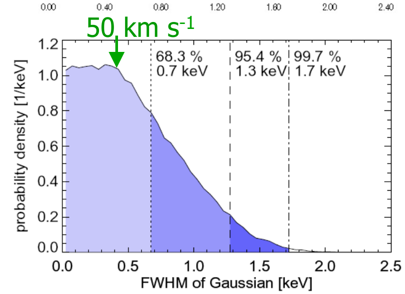


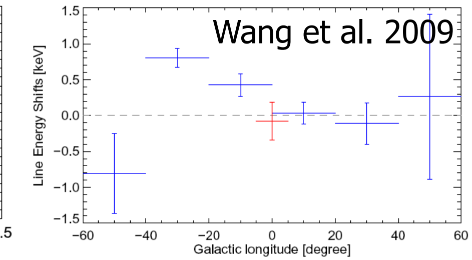
## ☆ $^{26}$Al Observation Results

- ☞ Spatially-Resolved Spectra
- ☞ Line Width Constraint
- ☞ Galactic $^{26}$Al versus Models
  - **Wang et al., A&A (2009)**
- ☞ Regional $^{26}$Al versus Models
  - **Cygnus (Martin et al., A&A (2010)**
  - **Sco-Cen (Diehl et al., A&A (2010)**
  - **Carina (Voss et al., A&A (2011)**
- ☞ Population Synthesis for Massive-Star Groups
  - **Voss et al., A&A (2009; 2010)**



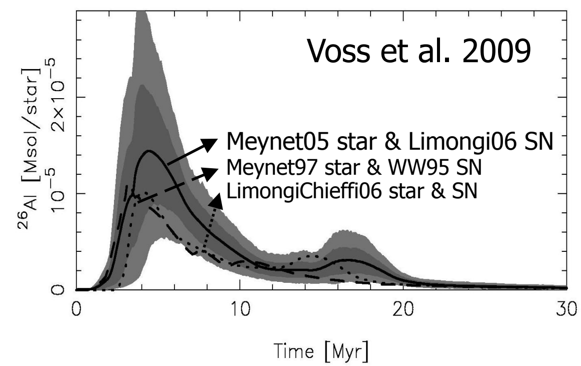



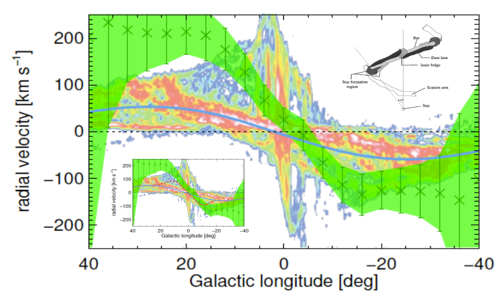

## ☆ $^{26}$Al Nucleosynthesis Models

- ☞ Stellar Evolution from MS through Collapse, with Effects of Stellar Rotation, Winds, Reaction Rate Updates...

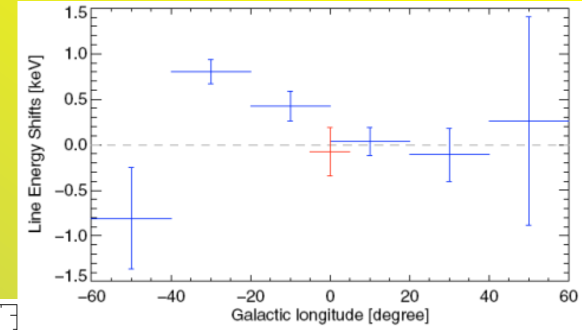


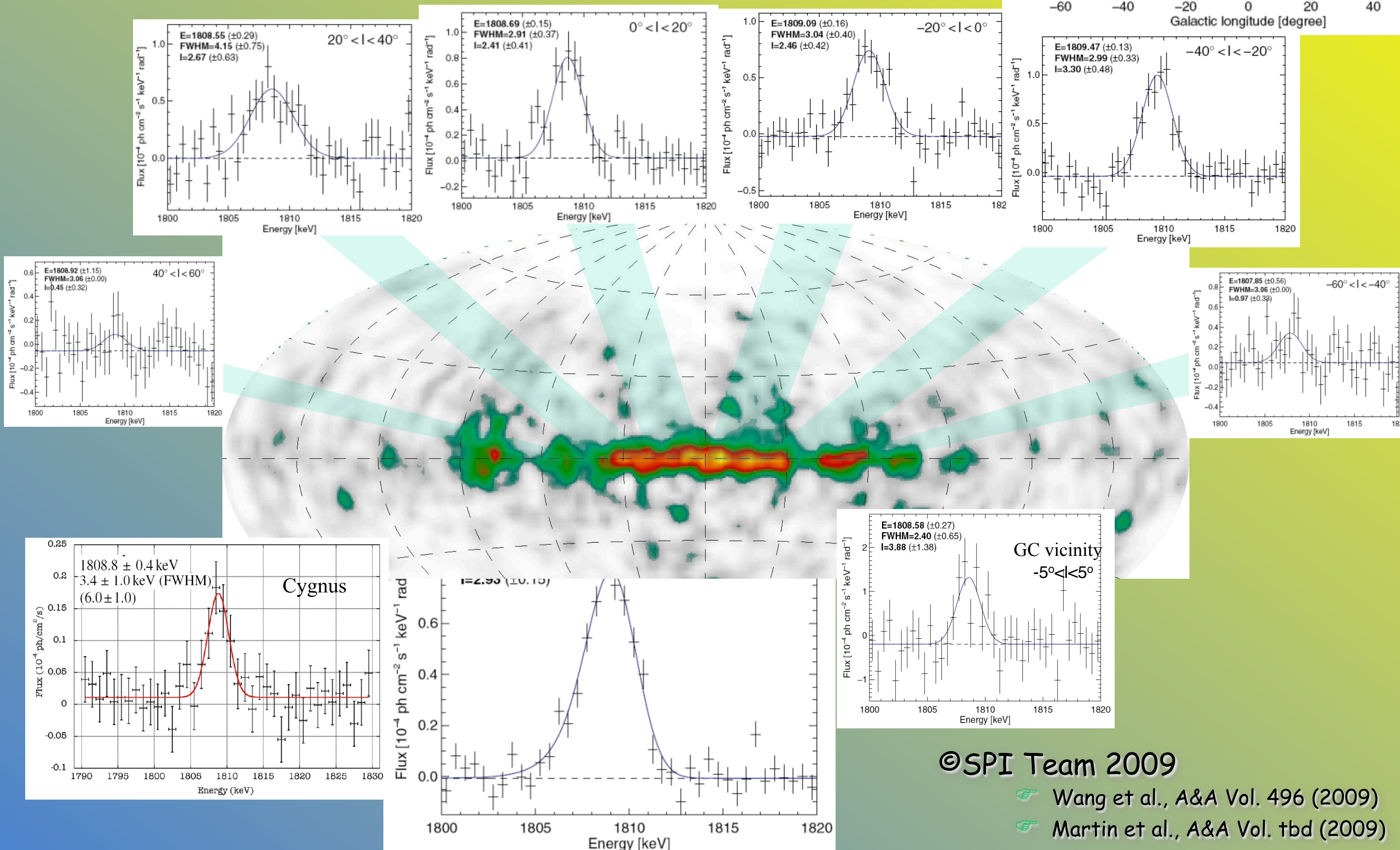

## ☆ $^{26}$Al Astronomy

- ☞ Inner-Galaxy Line Centroid Variations
  - **Kretschmer et al., in preparation for A&A**
- ☞ Massive-Star Groups in Orion
  - **Krause et al., in preparation for A&A**



# $^{26}$Al Spectra along the Plane of the Galaxy



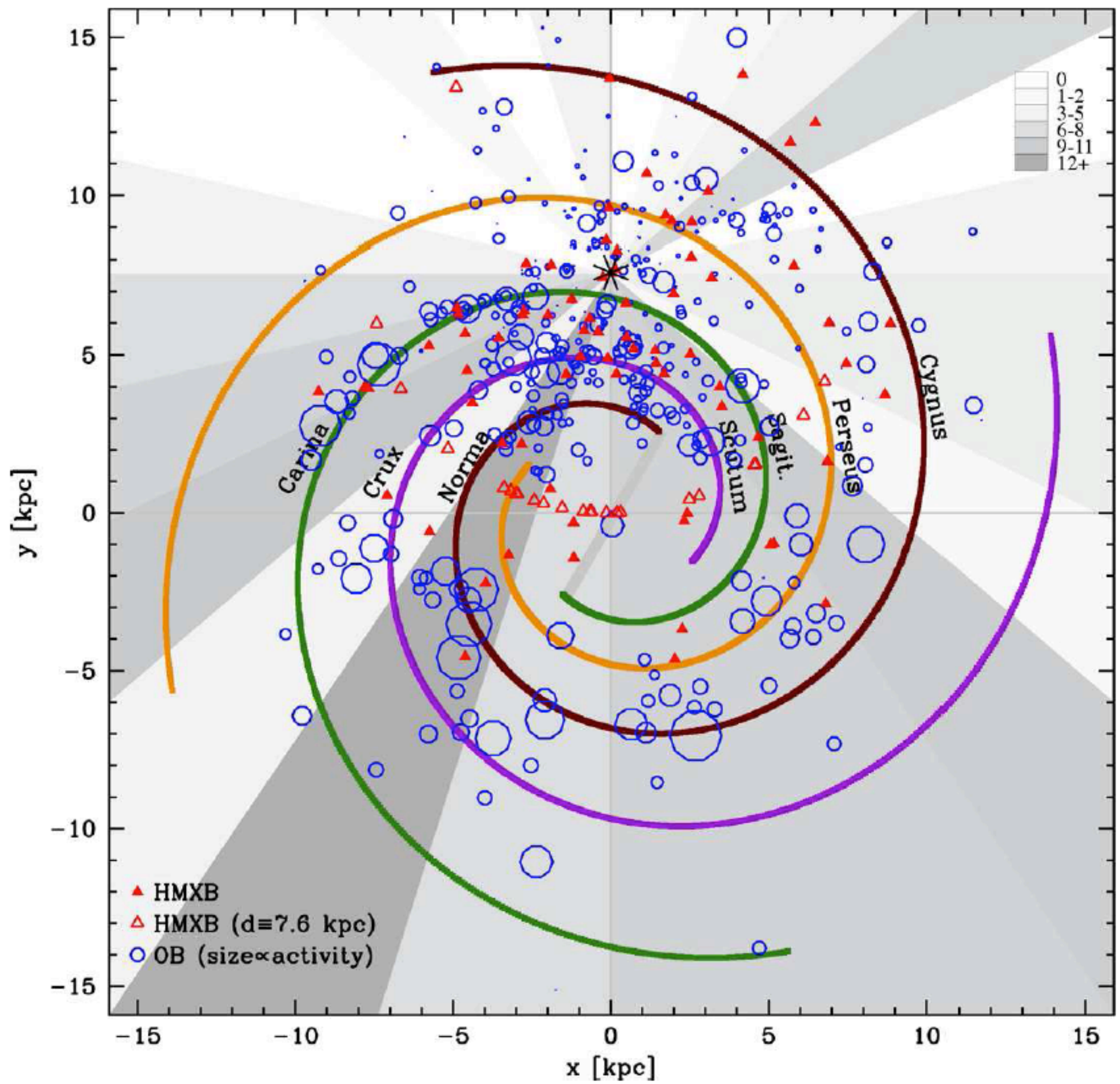

©SPI Team 2009

- Wang et al., A&A Vol. 496 (2009)
- Martin et al., A&A Vol. tbd (2009)

# Locations of Candidate Nucleosynthesis Sources

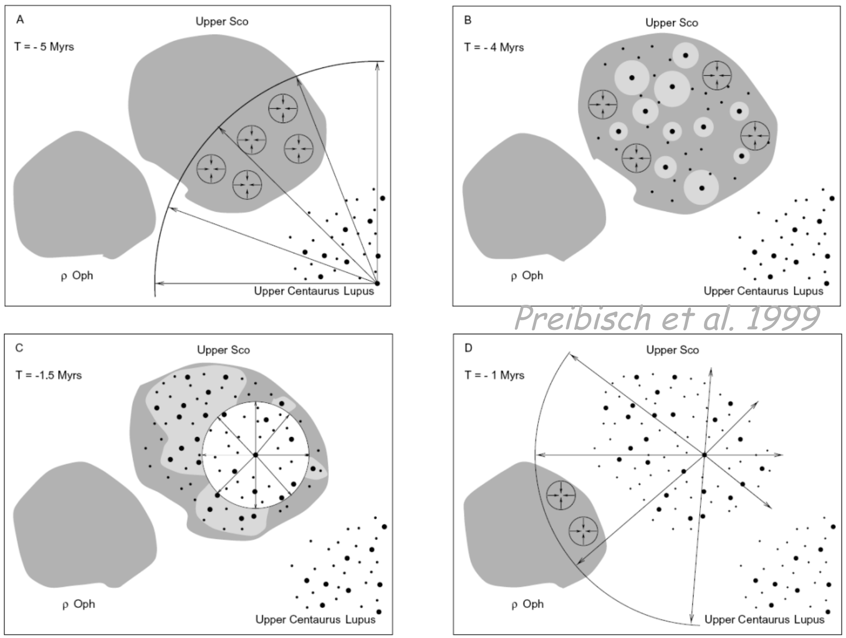
- ☆ OB Associations, Massive Binaries, ... Spiral-Arm Regions, ...

  - ☞ Gamma-Rays May Complement Incomplete Knowledge

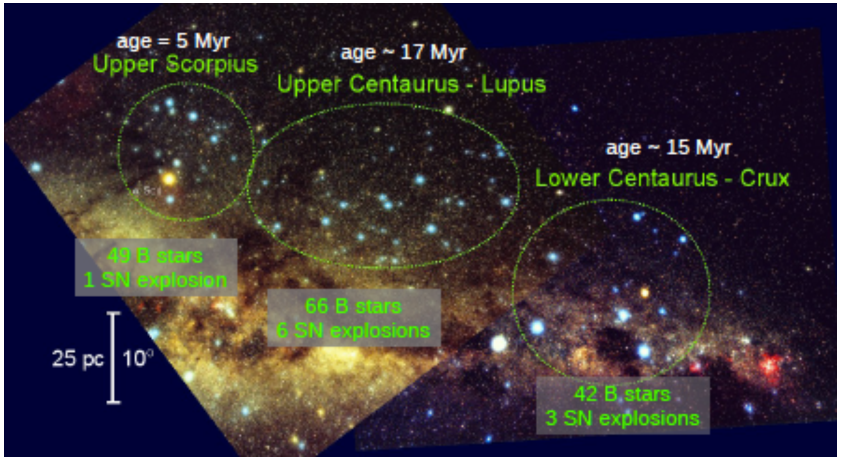


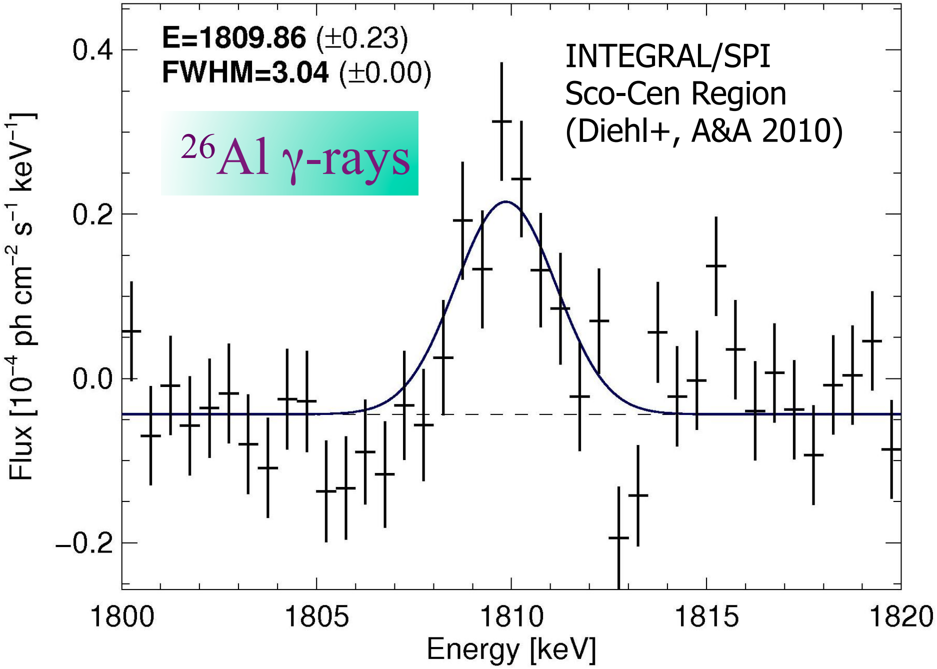
# The Sco-Cen Association: Triggered Star Formation?

- Nearest OB Association (~120pc)
  - subgroups of ages 5, 16, 17 My
- **Extended, Triggered Star Formation?**




*Preibisch et al. 1999*



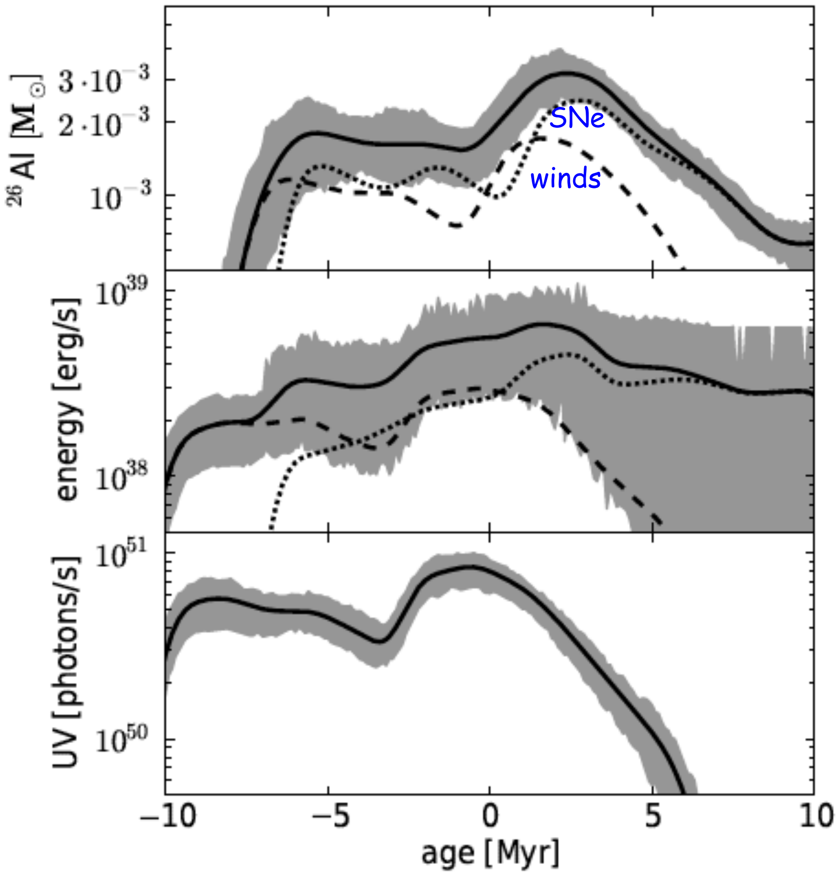

- **Compare Data with Population Synthesis**

  *R. Voss, RD, et al., 2009, 2010, 2011*

  - **Observed $^{26}$Al Emission**
  - **Stellar Groups Ages & Richness**
  - **ISM Shell/Cavity Observables**

# The Carina Region

- Comparing Model Predictions to Observations:
  - *Voss et al. 2011*




*Plüschke+2001; Martin+ 2011:*

$^{26}$Al Gamma-Rays 1-2 $10^{-5}$ ph cm$^{-2}$ s$^{-1}$
→ 4…9 $10^{-3}$ $M_\odot$ of $^{26}$Al

*Smith & Brooks 2007:*

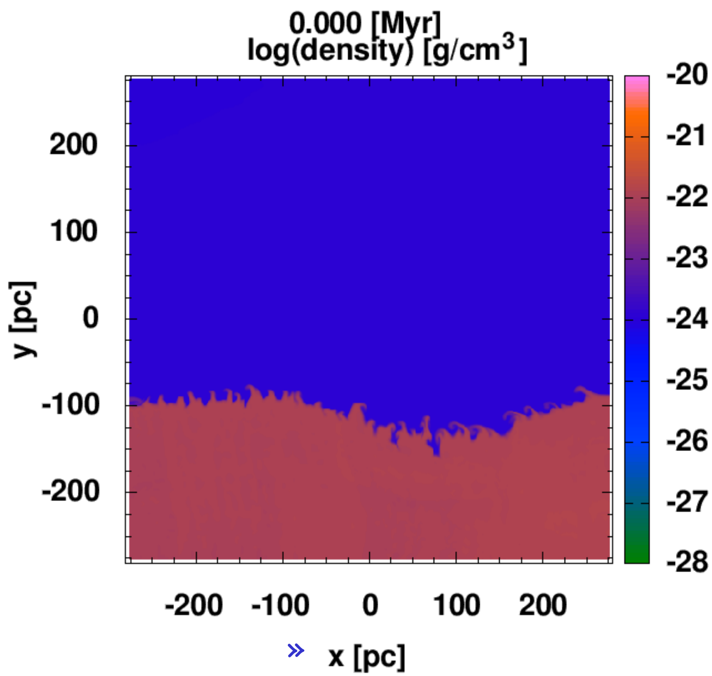
Stellar-Wind Energy ~ 2 $10^{38}$ erg s$^{-1}$
No SNe

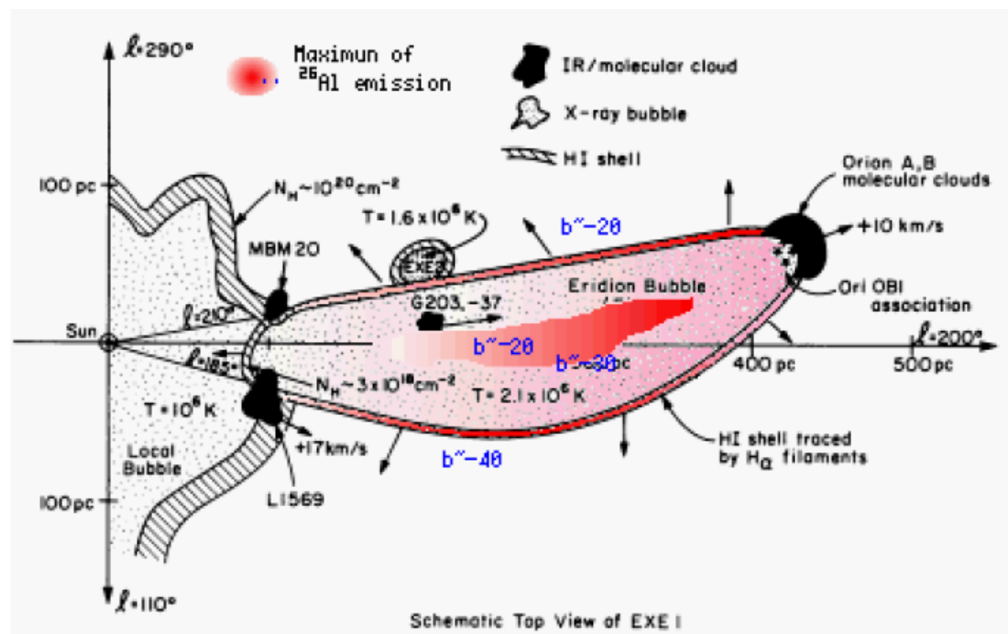
*Smith & Brooks 2007:*

Ionizing Photons → Rate ~ 2 $10^{51}$ s$^{-1}$

# Dynamics of the Interstellar Medium

- ISM is Highly-Dynamic → Formation of (Super-)Bubbles
  - ☆ Mixing of SN Ejecta into Disk and Halo?
- Simulations:
  - ☆ Trace Evolution of Massive-Star Activity in Parental Cloud



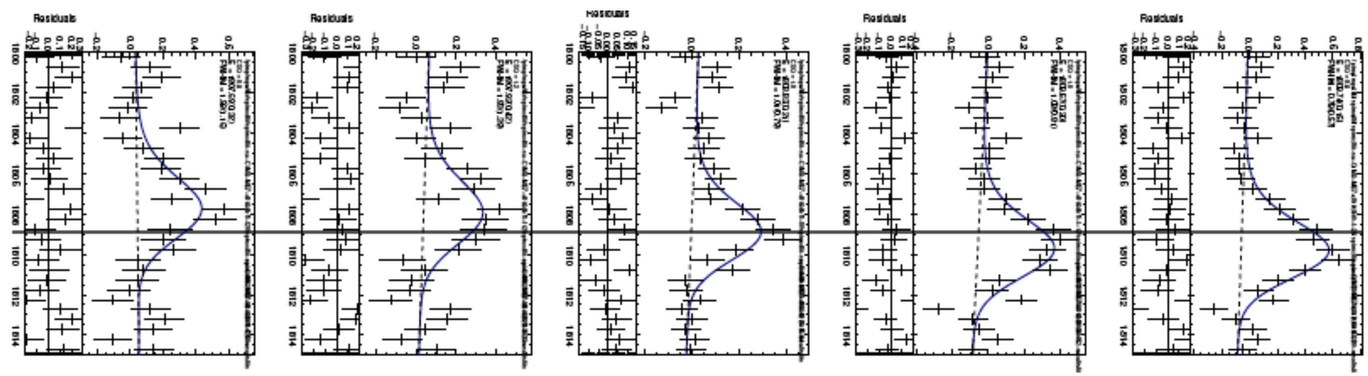



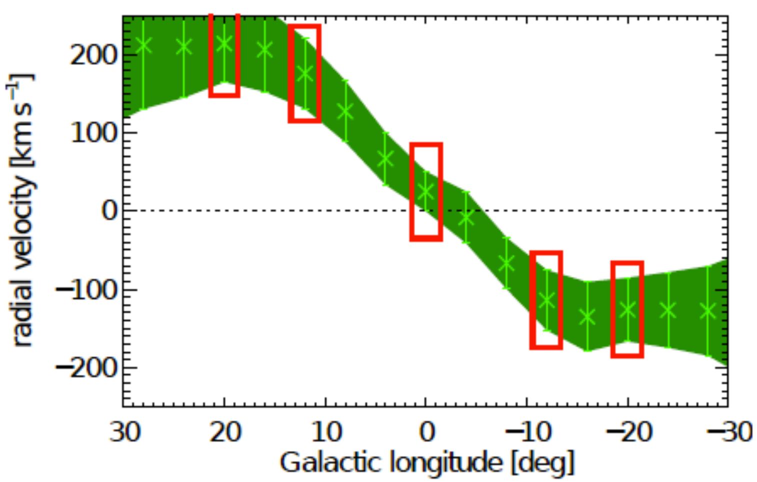

» Burkert, Krause, Diehl, et al.

# $^{26}$Al Kinematics

- **Mapping $^{26}$Al-enriched gas in inner Galaxy with INTEGRAL:**
  - **2.7° FWHM 'Beam'**

☆ **Integrate $^{26}$Al Line in Δl Bins → Centroid → Galactic Rotation**



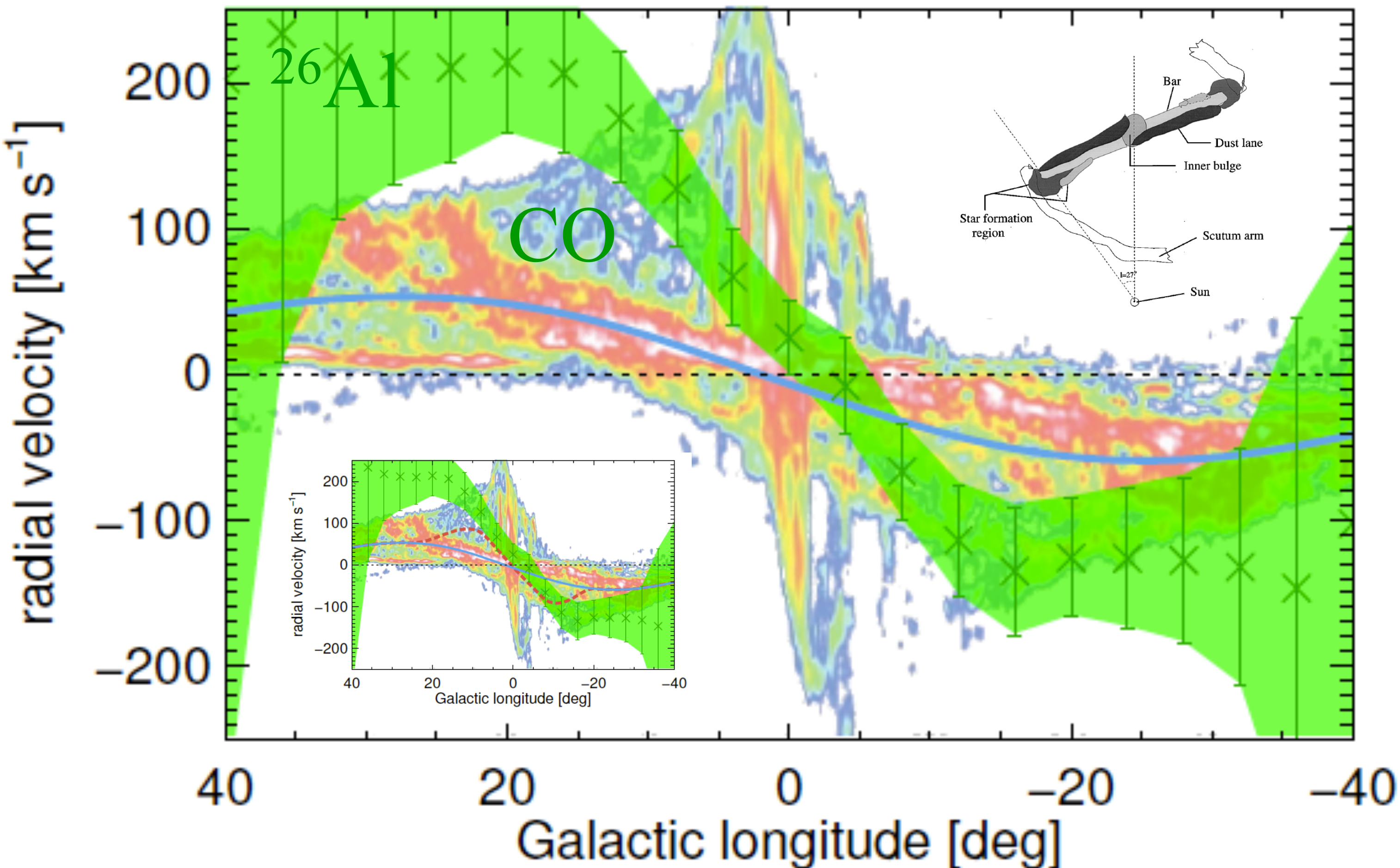




- fit sky maps to INTEGRAL data → spectrum
- spectral fit → line centroid
- scan region of interest along Galactic plane

# ISM Kinematics along the Galactic Bar

☆ Hot ISM as Traced by $^{26}$Al Appears at Higher Velocities

*Kretschmer et al., in prep. / 2012*




an example,
where gamma-rays complement other bands

# Status of the *Nucleosynthesis* Field – $^{60}$Fe

Status Jun 2009

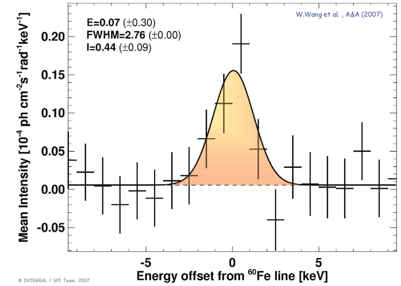
## ☆ $^{60}$Fe in the Galaxy

☞ Clear Detection

- Wang et al., A&A 2007; Lang et al., in prep.

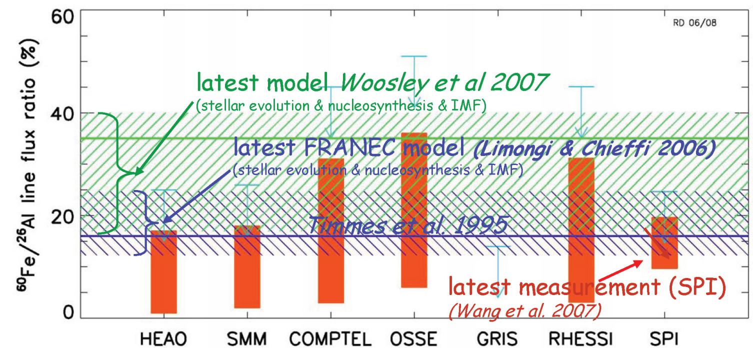
☞ Limits for Cygnus, Vela

- Wang et al., A&A 2007; Martin et al., submitted to A&A

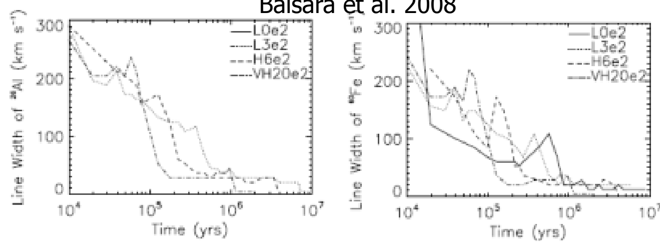


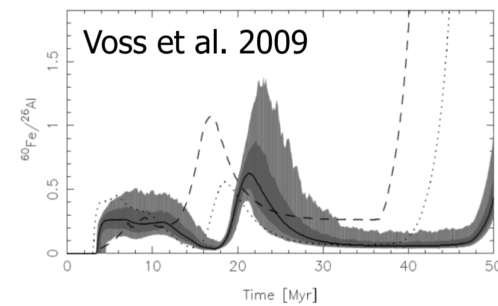

☞ $^{60}$Fe/$^{26}$Al Ratio: New Models & Theory

- Updates & Variants on Stellar & SN Models
  - » Limongi & Chieffi, A&A 2006
- Review/Re-Measurements of Nuclear Rates
  - » First-Ever Measurement of $^{60}$Fe (n,γ)$^{61}$Fe (10.2 ±3 mb) (Reifarth et al. 2009)
  - » First Measurements of $^{59}$Fe (n,γ)$^{60}$Fe in preparation
- Simulations for ISM-Massive-Star Groups
  - » Balsara et al. 2008
  - » Voss et al. 2009



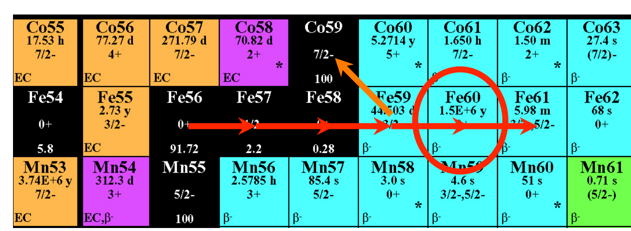

Balsara et al. 2008




☞ $^{60}$Fe Lifetime Re-Determined/Revised

- » 'old' value: τ=(2.15 ±0.3) My (Kutschera et al 1984)
- » 'new' value: τ=(3.78 ±0.06) My (Rugel et al 2009) based on $^{60}$Fe from PSI beam dump and AMS
- » Implications for Young Regions (not 'steady-state')



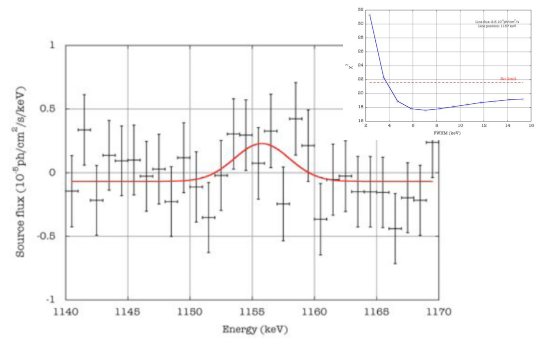
Status Jan 2012

# Status of the *Nucleosynthesis* Field – $^{44}$Ti

## ☆ $^{44}$Ti from Supernovae

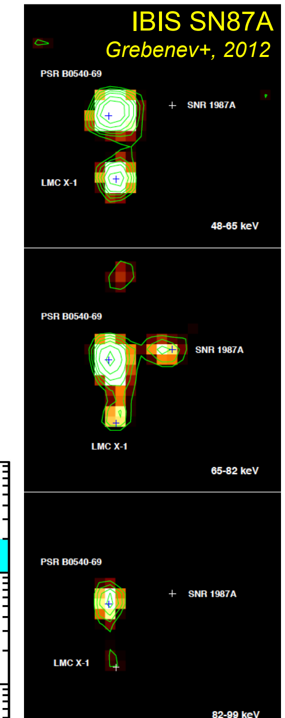
☞ Cas A Constraints from 3 Lines

- IBIS provided best total-flux measurement (2.5 ±0.3) $10^{-5}$ ph $cm^{-2}$ $s^{-1}$ (Renaud+ 2006)
- Compatible Velocities >500 km/s (SPI 1157 keV line limit); Martin+ 2009




☞ SN1987A Discovery with IBIS:

- Grebenev+, submitted to Nature / Chia Laguna Sep 2011
  $^{44}$Ti flux on high side, but convincing detection exclusively in 60-80 keV band



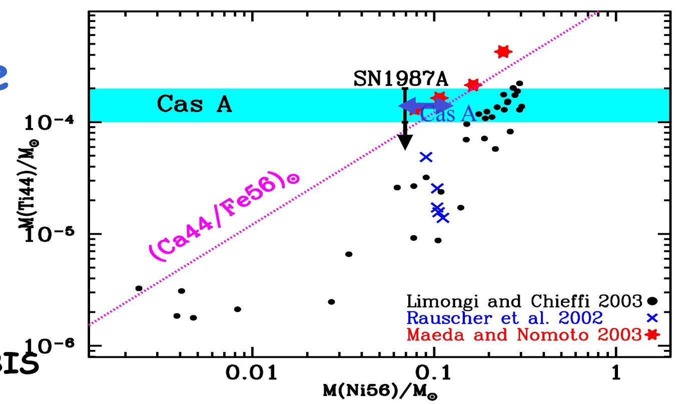

## ☆ Radioactivity Constraints for SNe

☞ Cas A Echo Spectrum, Krause+ 2008

☞ Cas A $^{56}$Ni Yield from Reddening, Ericson+ 2008

☞ SNR G1.9+0.3 with ~100 yrs age

- Reynolds+ 2008
- No Hint for $^{44}$Ti Emission found in SPI/IBIS



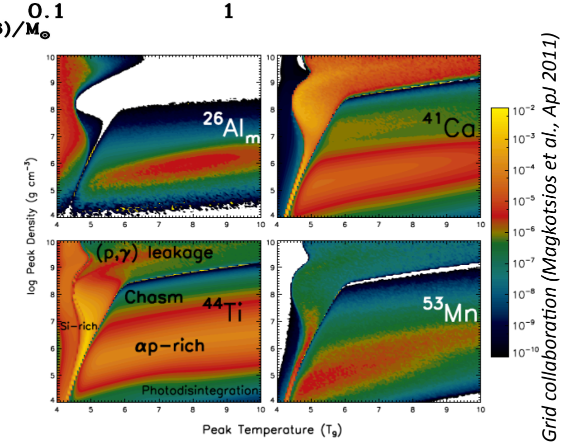

## ☆ New Model Yields & their Variabilities

☞ 2.x-dimensional Parametrized Simulations of Extremes

- Strong $Y_e$ Dependency; Fryer+ 2008, Magkotsios+ 2008, 2011
- Nuclear-Network Studies (Parikh+, in prep.)

☞ Re-Measurements of Key Nuclear Reaction Rates

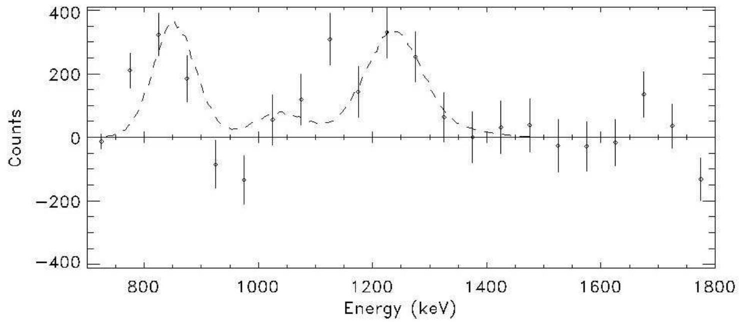
- $^{40}$Ca(α,γ)$^{44}$Ti being measured; $^{44}$Ti(α,p)$^{47}$V to be done (RIB); others?






Roland Diehl

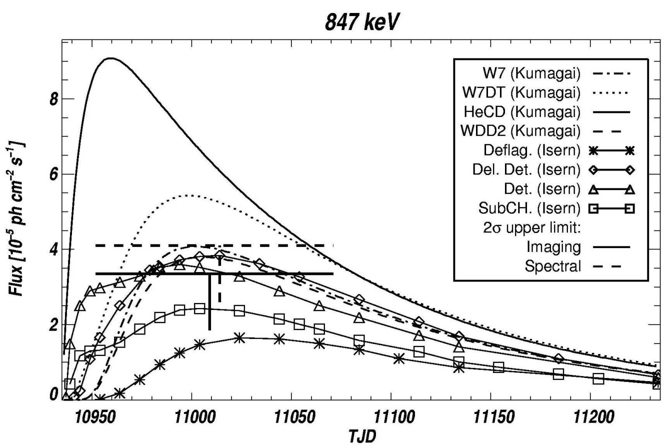
# "Calibration" of Thermonuclear Supernovae




(Morris et al. 1995;1997)

## ❍ SN 1991T

- Peculiar & Super-Bright; d~17Mpc
- Indication of $^{56}$Co Lines (COMPTEL)
  -> $M_{Ni}$~0.6-3.3 $M_o$




(Georgii et al. 1999)

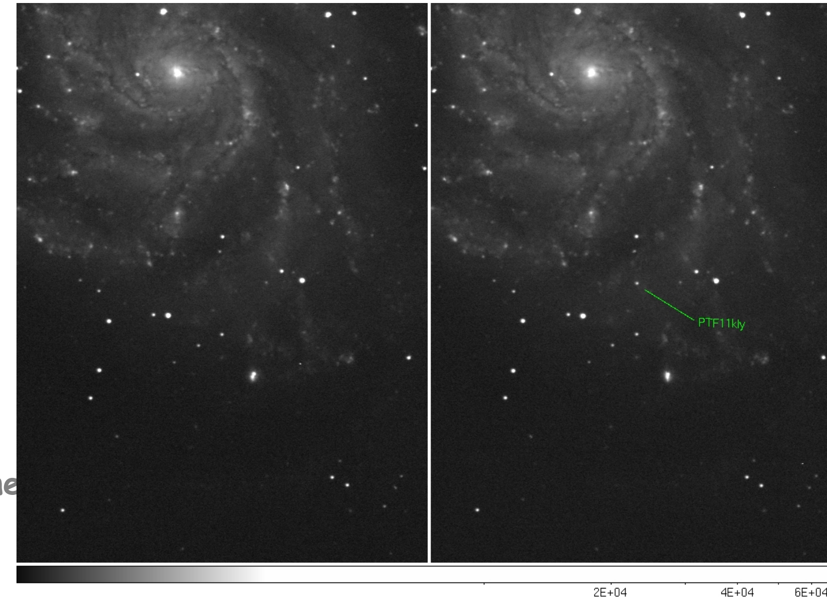
## ❍ SN1998bu

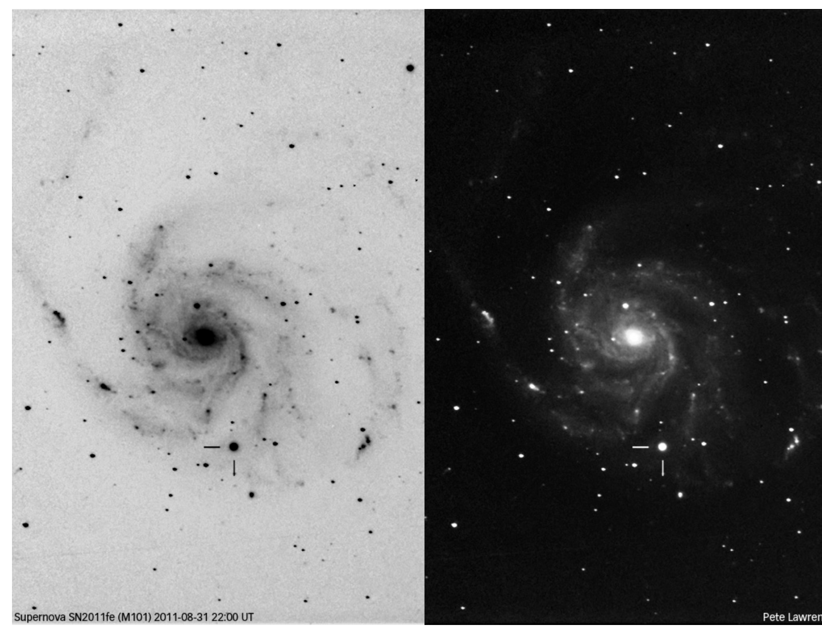
- Unusually-high Reddening; d~8-12 Mpc
- Limits on Lines (OSSE; COMPTEL)
  Constrain Models:
  No He Cap Detonator(s)

- **Instrumental Sensitivity Requires d < 10 Mpc**
- **Two "Opportunities" Both "Unusual"**
- **Accuracy Insufficient for Real $^{56}$Ni Mass Constraints**

# SN 2011fe (PTF11kly) in M101

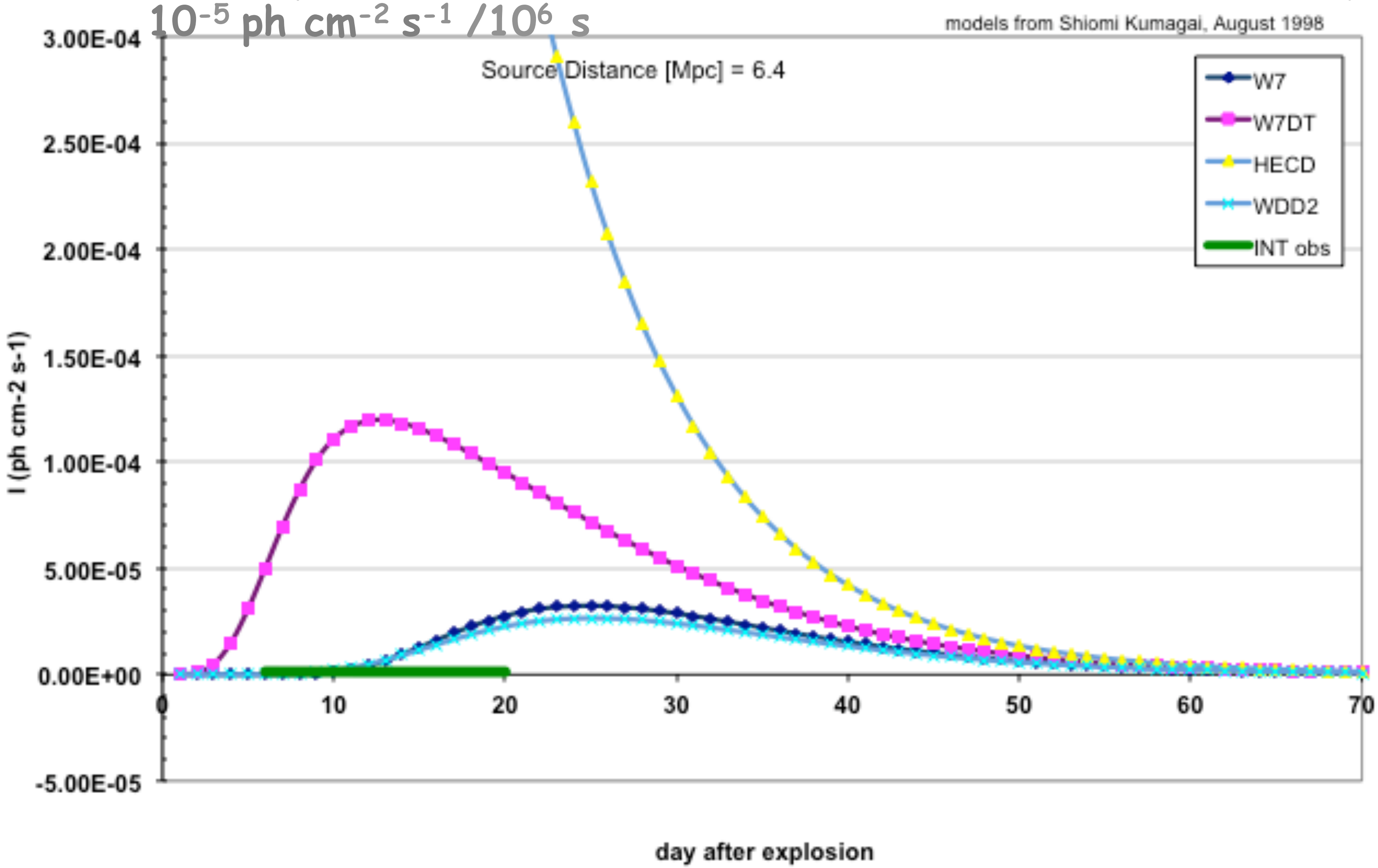
- **SN Observables:**
  - Coordinates:
    - RA 14:03:05.81, Dec +54:16:25.4
    - l=101.983168, b=59.843299
  - Discovered 24 Aug 2011 by Palomar Transient Facility
  - Distance to M101: 6.4 Mpc (±0.2 stat ± 0.5 sys; Shappee & Stane ApJ 2011)
  - Galactocentric Distance of SN: ~8.9 ±0.9 kpc
  - Metallicity at SN Location: ~0.39 solar
  - Inferred Explosion Date: 23 Aug 2011



# SNIa Models and Gamma-Rays

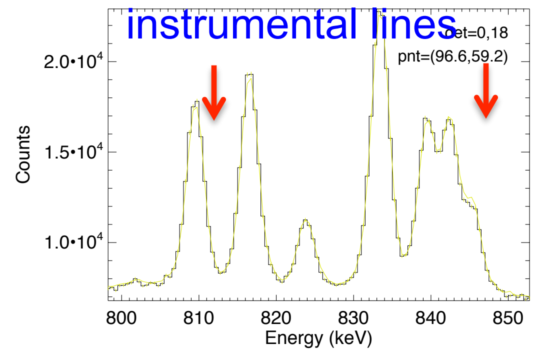
- Early Observations Could Rule Out He Cap Models, for SN 2011fe in M101
  - ☞ 4 $10^{-5}$ ph $cm^{-2}$ $s^{-1}$ in 812 keV Ni line @7Mpc → SPI sensitivity is 3 $10^{-5}$ ph $cm^{-2}$ $s^{-1}$ /$10^{6}$ s



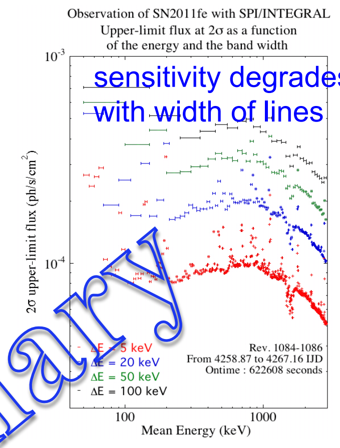
# ...working on analysis of the observations

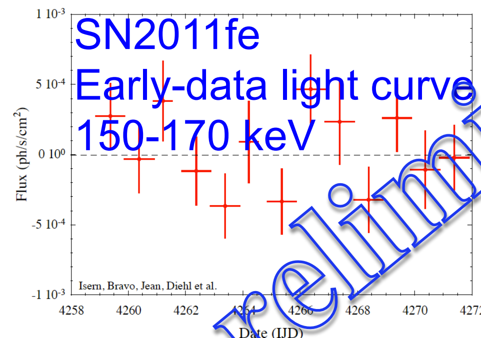
- **Analysis Requires**
  - Filtering of Data
    - » Contamination by Intense Solar Flare
  - Building & Verifying a Background Model
  - Celestial-Source Analysis
  - ... time...
- **Quick-Look Results**
  - ☆ Confirmation of Methods and Sensitivities
  - ☆ No Indications of any (plausible) SNIa Gamma-Ray Line from SN2011fe
    - Limits ~$10^{-4}$ ph $cm^{-2}$ $s^{-1}$

raw spectra:



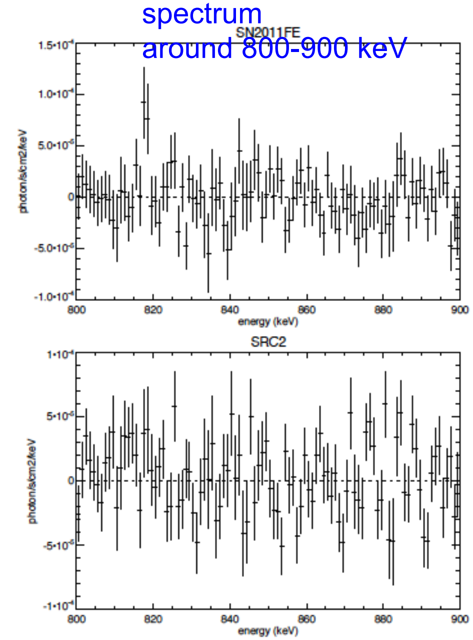

*Isern, Jean, RD, et al.; others...*

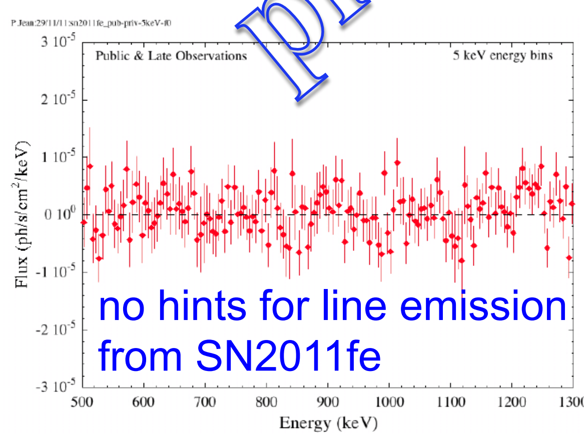



preliminary

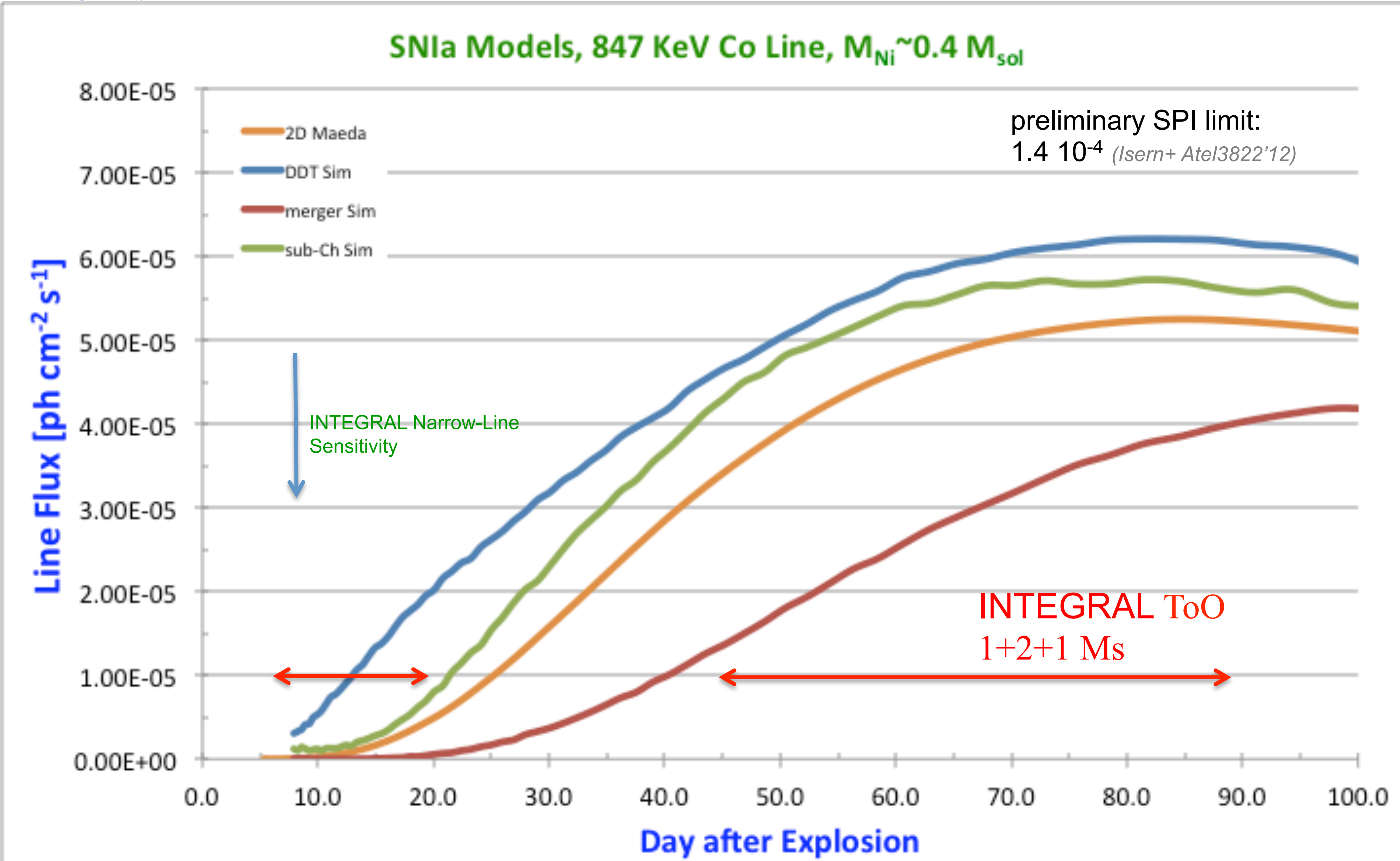
SN2011fe vs reference region spectrum around 800-900 keV



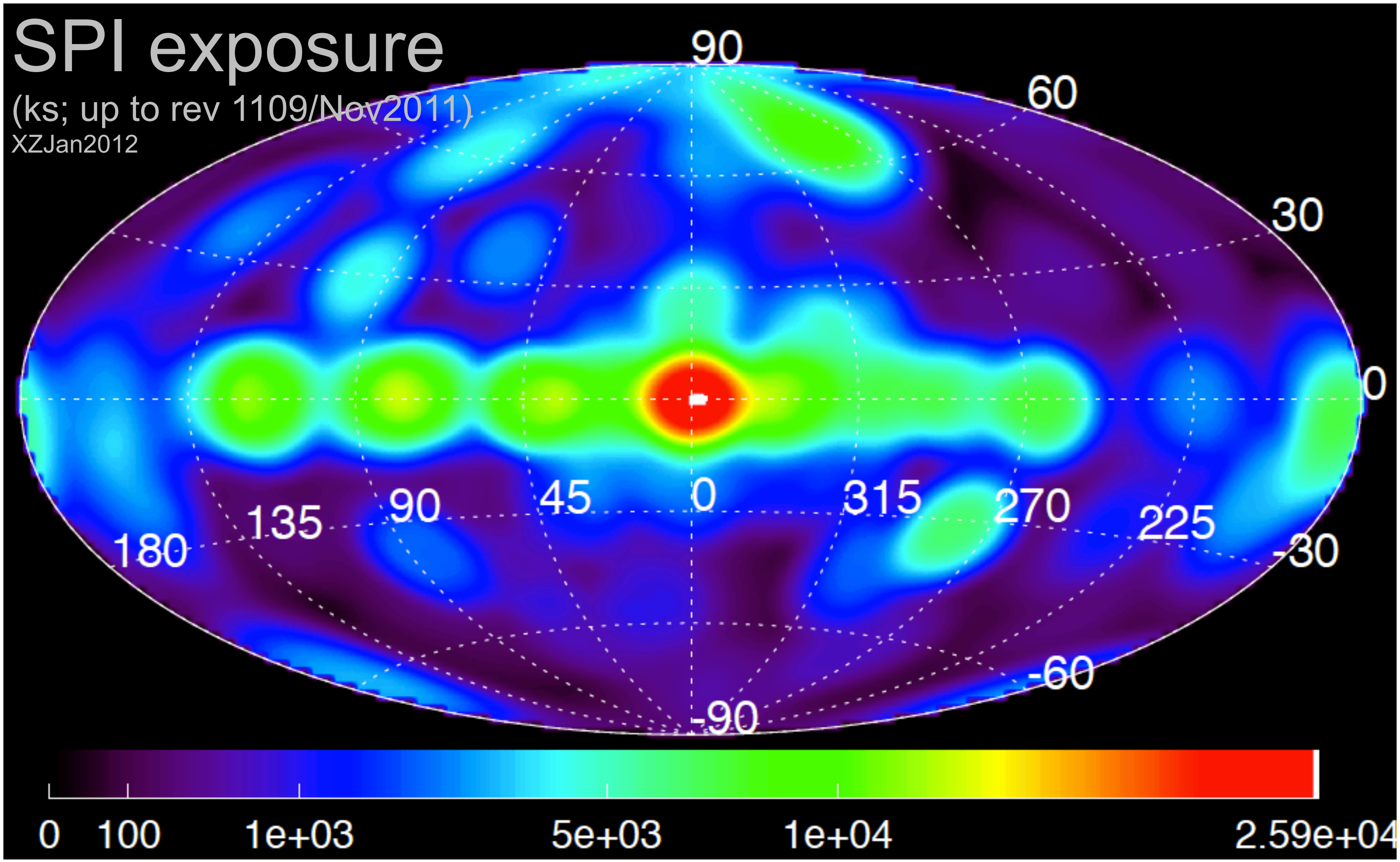
# SNIa Models and Gamma-Rays: SN2011fe @6.4 Mpc

- The $^{60}$Co Gamma-Ray Intensity Peaks at ~50...90 Days after



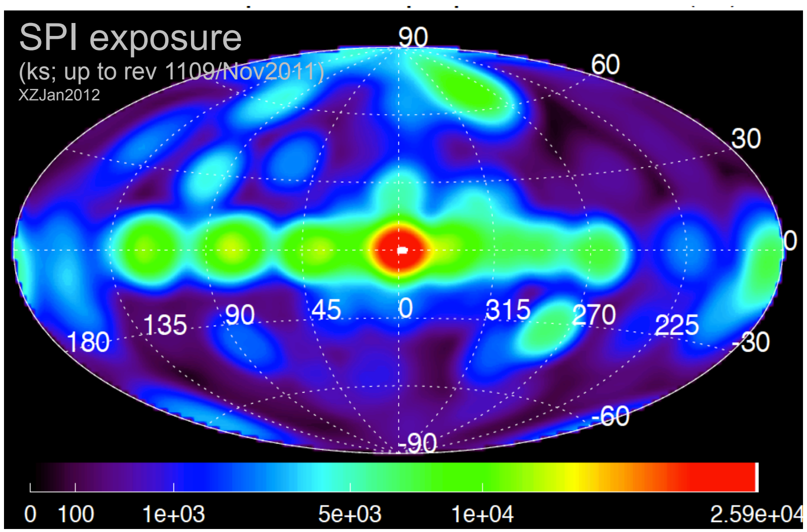
# INTEGRAL Legacy: Sky Survey

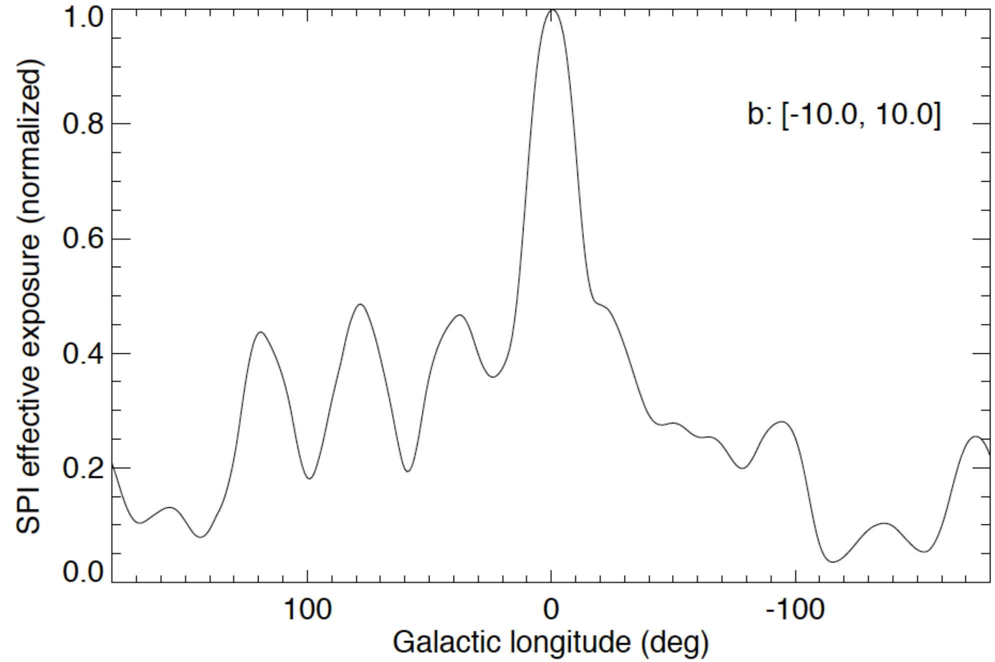
- INTEGRAL's Sky Exposure will be 'Legacy' in the Domain of Nucleosynthesis Lines (0.1-5 MeV) for a Long Time to come

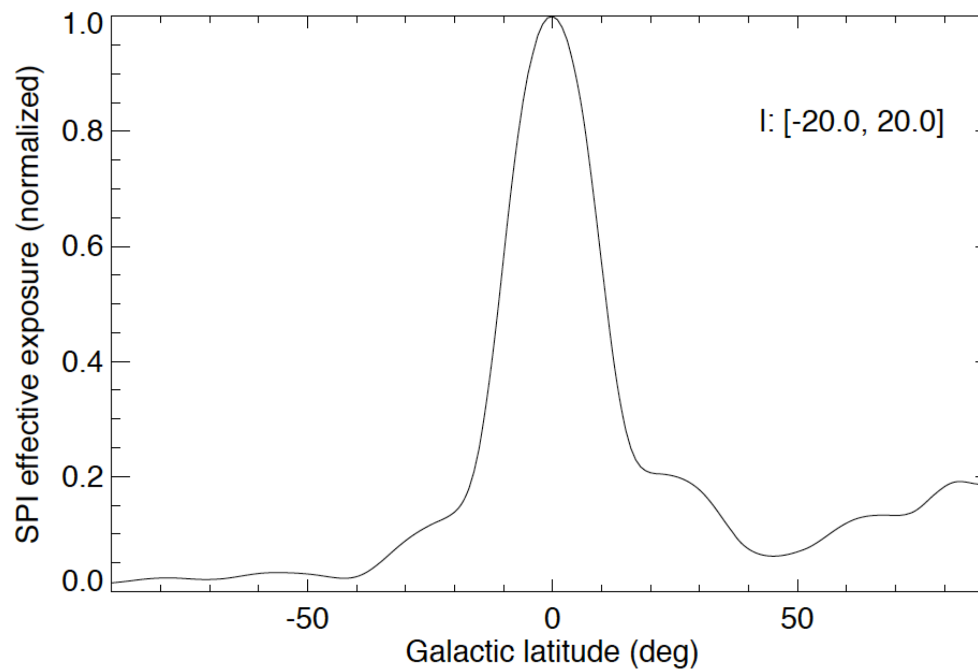


# INTEGRAL Legacy: MeV Sky Survey

- **Coverages in Longitude and Latitude:**
  - ☆ Are Biases Acceptable for a 'Legacy Survey'?
  - ☆ Which "Nucleosynthesis Regions" may be missed?
    - ☞ Inner Galaxy... Molecular Ring
    - ☞ Spiral-Arm Regions
    - ☞ Cygnus, Carina, Orion, ...
    - ☞ LMC



# INTEGRAL's Legacy
## in Nucleosynthesis

## ☆ Science Goals: *(from 2010 Extension Request)*

☞ *Annihilation Emission:*
- *Origin of Positrons* → *DM and Exotic Sources?*
- *Annihilation Site* → *Positron Transport*

☞ *Diffuse Radioactivities ($^{26}Al$, $^{60}Fe$):*
- *Massive-Star Groups / Clusters* → *Nucleosynthesis Yields*
- *Dynamics of Hot ISM* → *Nucleosynthesis Recycling*

☞ *Supernova Mechanisms ($^{44}Ti$, $^{56}Ni$):*
- *ccSN Interiors ($^{44}Ti/^{56}Ni$)* → *Asymmetries*
- *SNIa Yields ($^{56}Ni$)* → *Brightness Calibration*

## ☆ Legacy / INTEGRAL

☞ *e+:*
- *Inner-Galaxy Map → unique*
- *Plane, Regions, Sources → unique*

☞ *$^{26}Al$, $^{60}Fe$:*
- *Massive-Star Groups / Clusters → unique*
- *Dynamics of Hot ISM → unique*

☞ *Supernova Mechanisms ($^{44}Ti$, $^{56}Ni$):*
- *ccSN Interiors ($^{44}Ti/^{56}Ni$) → NUSTAR*
- *SNIa Yields ($^{56}Ni$) → unique*

## ☆ Observations as Legacy for:

☞ The Galaxy, i.e.
- Inner Galaxy and Bulge ✔
- Entire Galactic Plane O
- Spiral-Arm Tangential Views ✔...O
- Outer Galaxy O
- Cygnus, Cas A, Vela, Orion ✔✔✔O

☞ LMC ✔?

☞ Virgo Cluster Galaxies ✔...

☞ Nearby Dwarf Spheroidals ✔?

## ☆ Priorities:

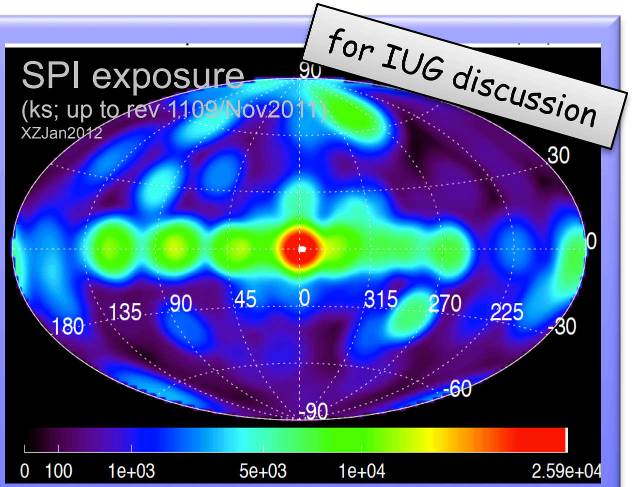
☞ Galaxy Survey
- Morphology Studies
  in Longitude
  Bulge/Disk Ratio
  Spiral Structure and Bar Region
  Inner/Outer Galaxy
  SFRs versus Large-Scale

☞ Specific Sources
- Massive Clusters in Galaxy
- Nearby Stars and Binaries (e+, $^{26}Al$, WW
- LMC/SN1987A

☞ Nova and SNIa Opportunities

# Requirements to Establish the Legacy

- Which INTEGRAL data will remain unique?
  - Line Spectroscopy
  - MW-Galaxy Survey at >100 keV → few MeV
  - All-Sky AGN Survey
- Which Science Issues make up the Legacy?
  - Transients Monitoring
  - Polarization
  - Line Spectroscopy >100 keV




- Estimate the needs versus INTEGRAL's potential
  - How much exposure in mid latitudes would be needed to change any of the 511 bulge extent results significantly (DM origin/SMBH)?
  - How much GPlane exposure is needed to get the 511 brightness of the disk sufficiently well? (what is the requirement?)
  - How much inhomogeneity in the GPlane exposure can be tolerated without harming the astrophysics conclusions, eg on search for $^{44}$Ti sources?
  - How much Orion exposure is be needed to obtain a meaningful lines result?
  - How much LMC exposure is needed to consolidate the SN1987A $^{44}$Ti result?