The *'Nucleosynthesis'* Field

by Roland Diehl
MPE Garching

Contents

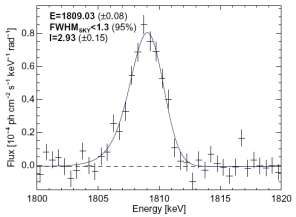
- *Review & Update on*
  Science Results and Discussion Status
- *Forecast wrt. Mission Extension Request*

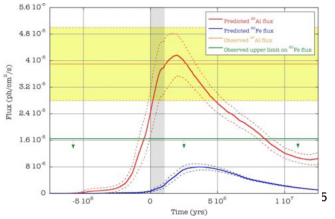
Status of the *Nucleosynthesis* Field - Overview

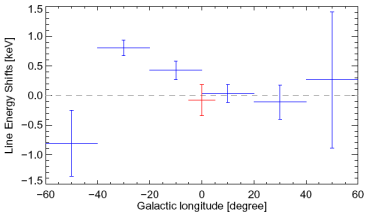
Status Jun 2009

☆ ^{26}Al in the Galaxy

- ☞ Spatially-Resolved Spectra
- ☞ Line Width Constraint
- ☞ Galactic ^{26}Al versus Models
- ☞ Cygnus-Region ^{26}Al versus Models

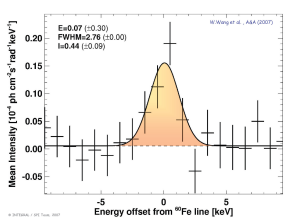


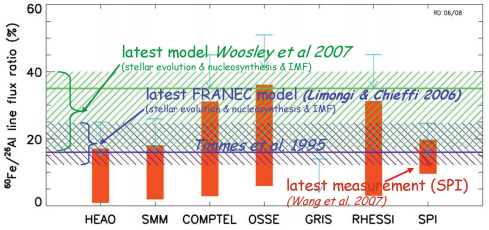




☆ ^{60}Fe in the Galaxy

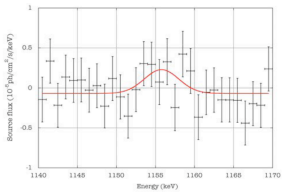
- ☞ Clear Detection
- ☞ ^{60}Fe/^{26}Al Ratio: New Models & Theory
- ☞ ^{60}Fe Lifetime Re-Determined/Revised

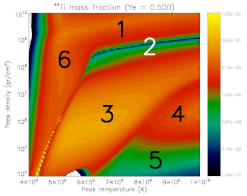




☆ ^{44}Ti from Supernovae

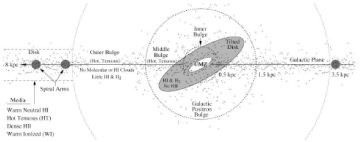
- ☞ Cas A Constraints from all 3 ^{44}Ti Lines
- ☞ New Models for cc-SNe

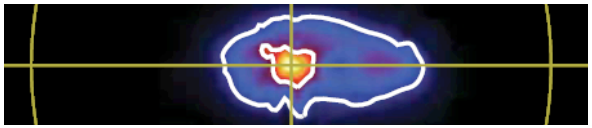


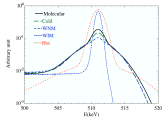


☆ Positrons in the Galaxy

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





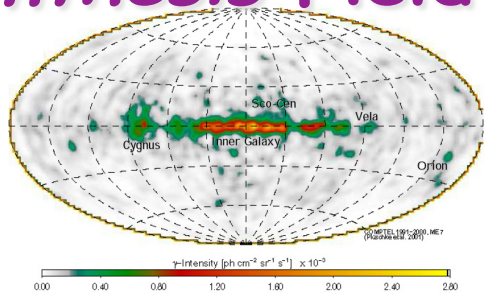


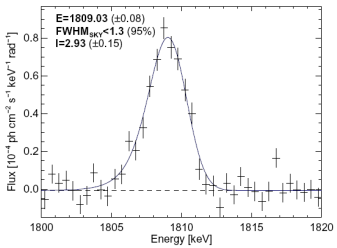
Status of the *Nucleosynthesis* Field - ^{26}Al

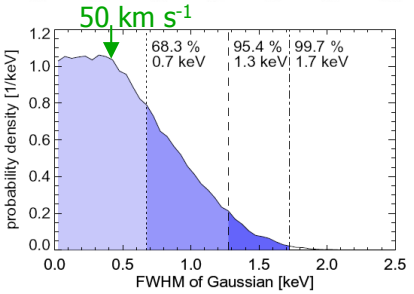
Status Jun 2009

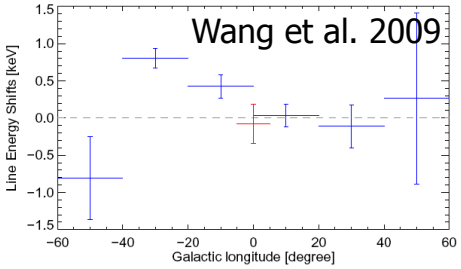
☆ ^{26}Al Observation Results

- ☞ Spatially-Resolved Spectra
- ☞ Line Width Constraint
- ☞ Galactic ^{26}Al versus Models
  - **Wang et al., A&A (2009)**
- ☞ Cygnus-Region ^{26}Al versus Models
  - **Martin et al., submitted to A&A**



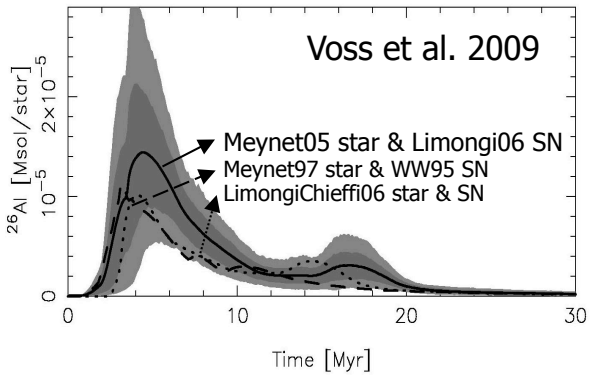






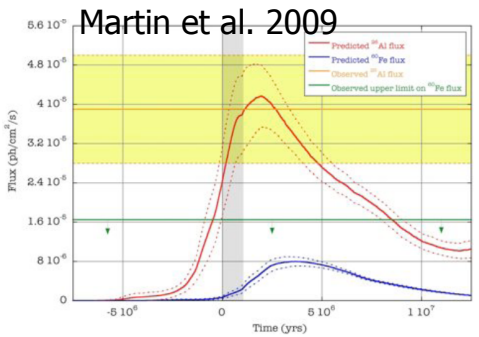
☆ ^{26}Al Nucleosynthesis Models

- ☞ Stellar Evolution from MS through Collapse
  - **Limongi & Chieffi, A&A (2006)**
- ☞ Stellar Evolution Including Effects of Stellar Rotation
  - **Palacios et al., A&A (2005)**
- ☞ Updates of WW95 Model with new Nuclear Physics
  - **Woosley & Heger, PhysRep (2007)**



☆ ^{26}Al in Massive-Star Regions: Predictions

- ☞ Population Synthesis for Massive-Star Groups
  - **Voss et al., submitted to A&A**
- ☞ Massive-Star Groups in the Cygnus Region
  - **Martin et al., submitted to A&A**



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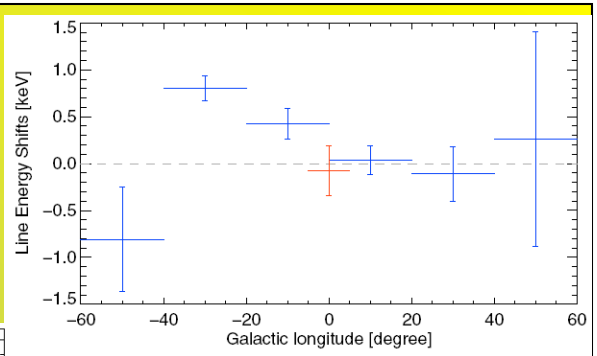
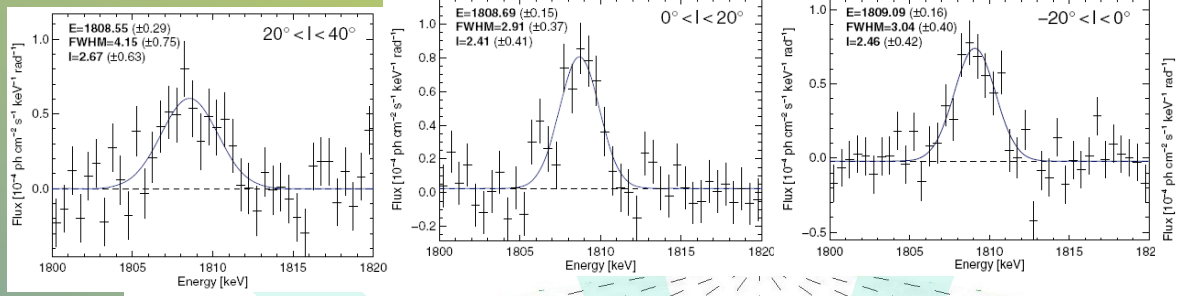
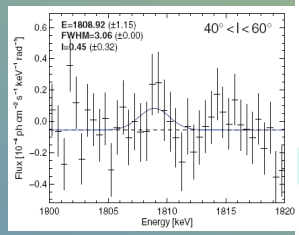
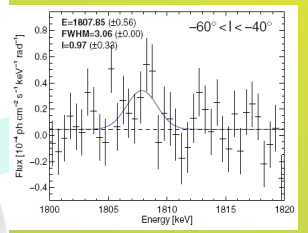
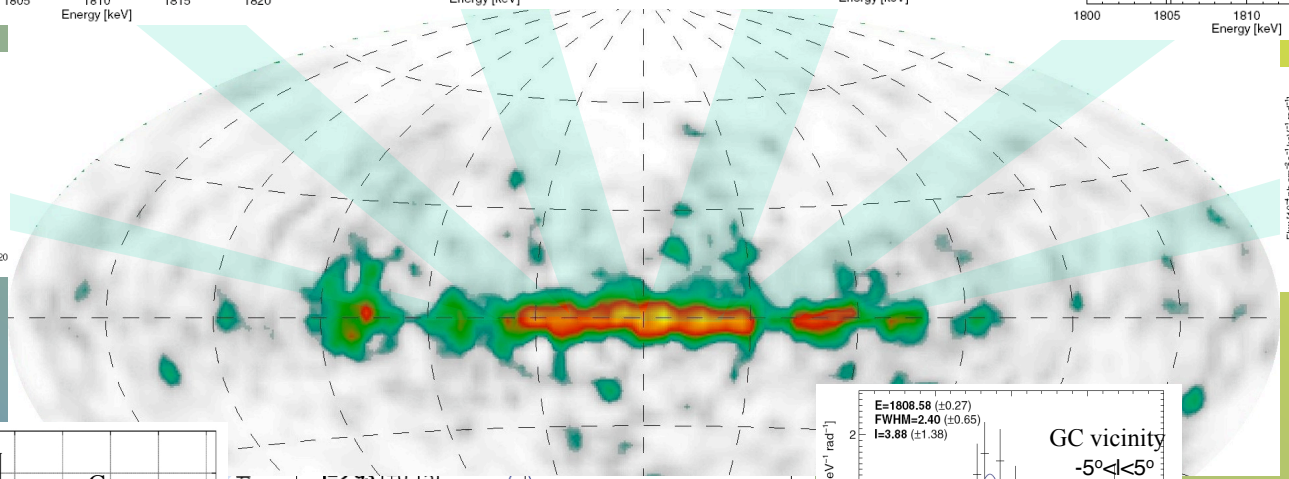
^{26}Al Spectra along the Plane of the Galaxy

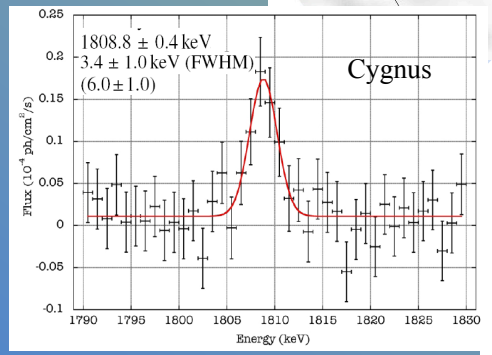


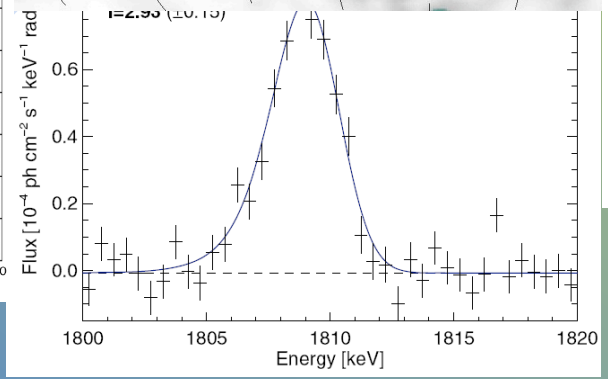


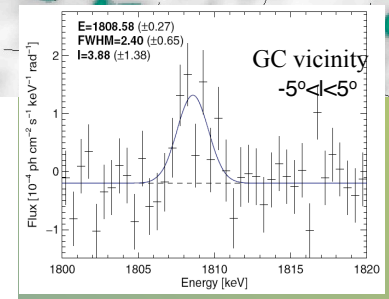












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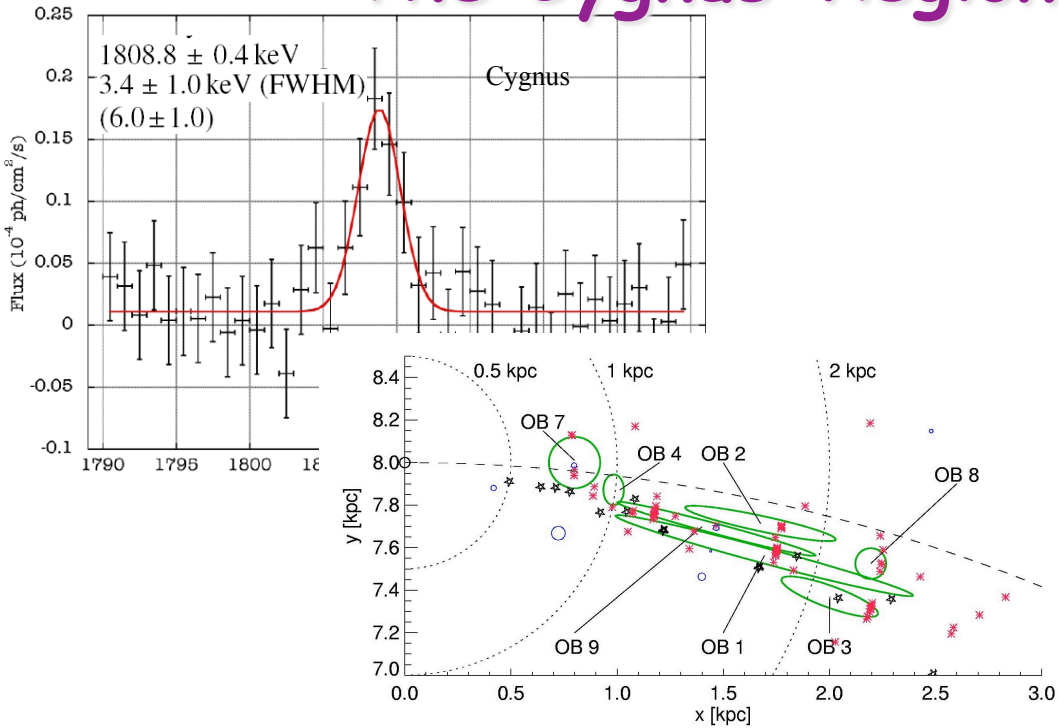
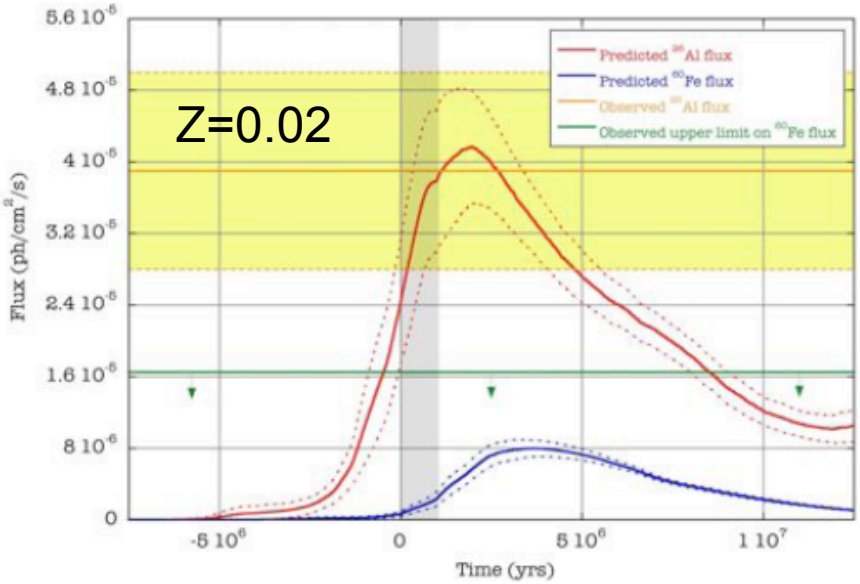
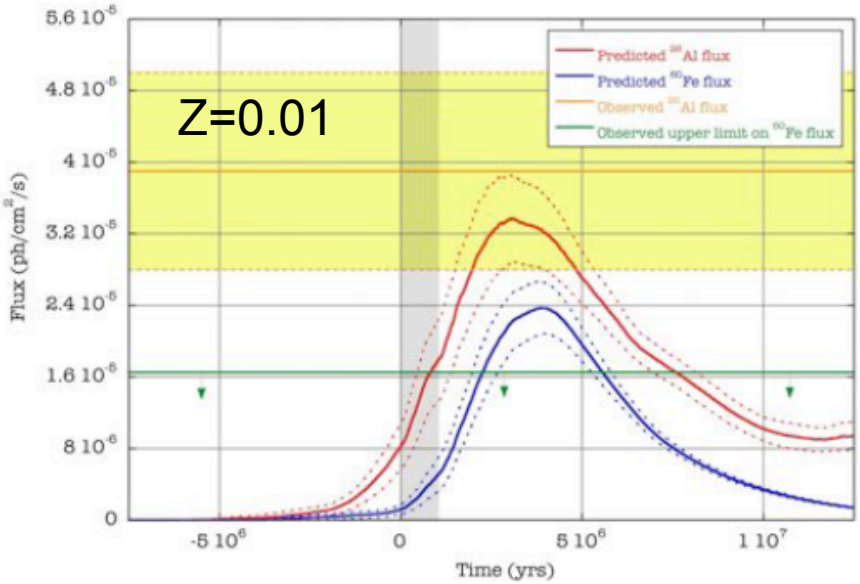
- Wang et al., A&A Vol. 496 (2009)
- Martin et al., A&A Vol. tbd (2009)

The Cygnus-Region Massive Stars



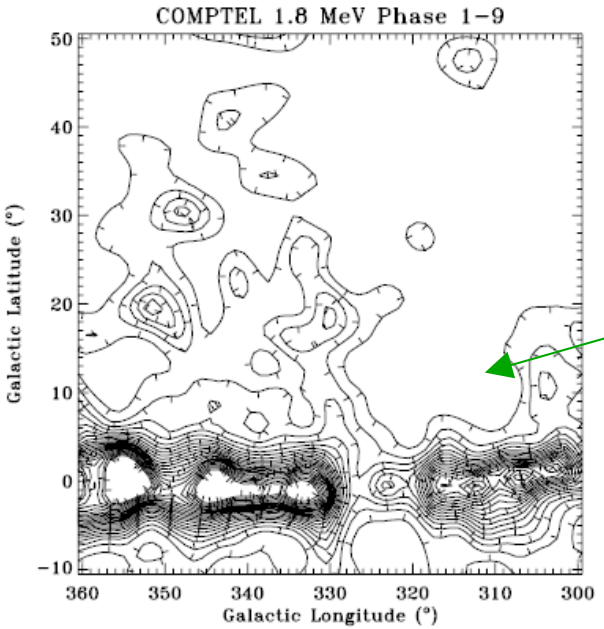


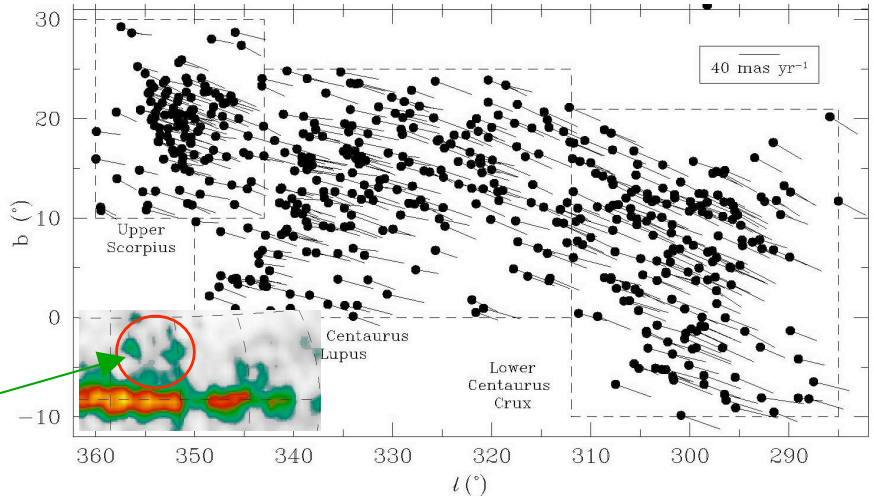


- ☆ **Compare Predictions from Latest Massive-Star Models to SPI Measurements**
  - ☞ Use Only Cygnus-Region Associations (exclude foreground&background)
  - ☞ ^{26}Al Yields Consistent for $Z_\odot$=0.02, While Low for Updated $Z_\odot$=0.01
  - ☞ ^{60}Fe and 511 keV Upper Limits Consistent with Predictions
  - ☞ ***P. Martin+ 2009 a,b***

The Sco-Cen Association and ^{26}Al γ-rays

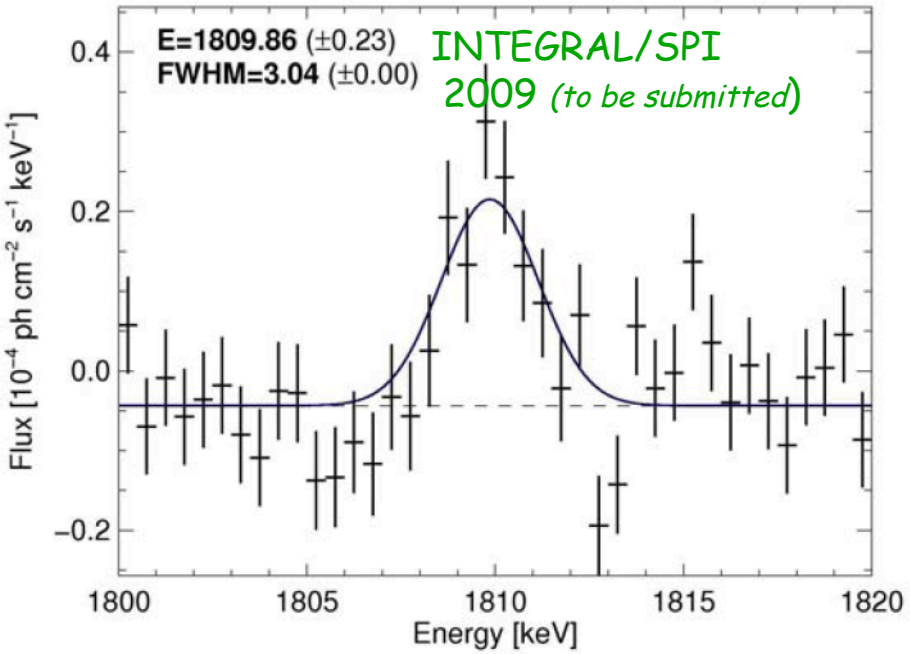
- Nearest OB Association (~120pc)
- Extended, low Surface-Brightness





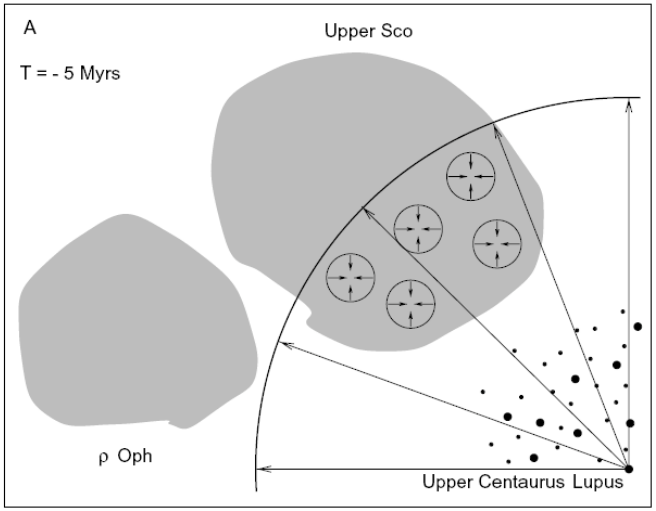
☆ ^{26}Al Emission from the Sco-Cen Group Seen with SPI (5σ)

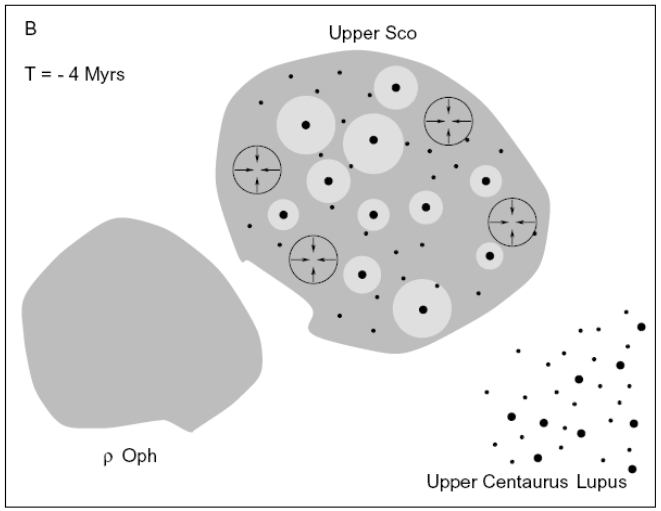
- Nearby Recent (My) Star Formation
- Independent Age Constraints
- Morphology?

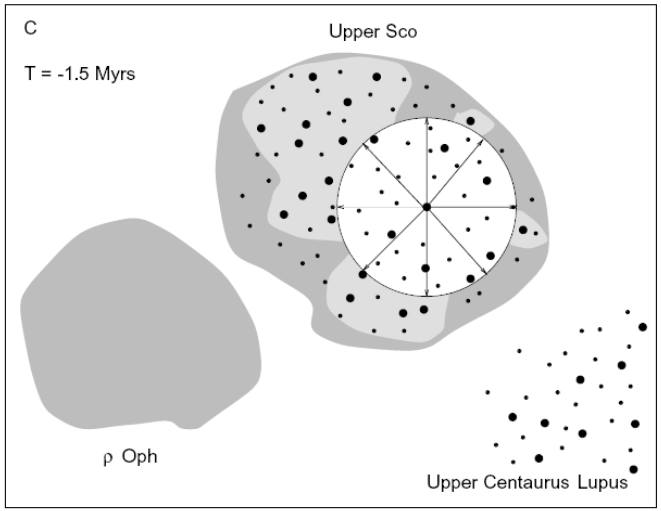


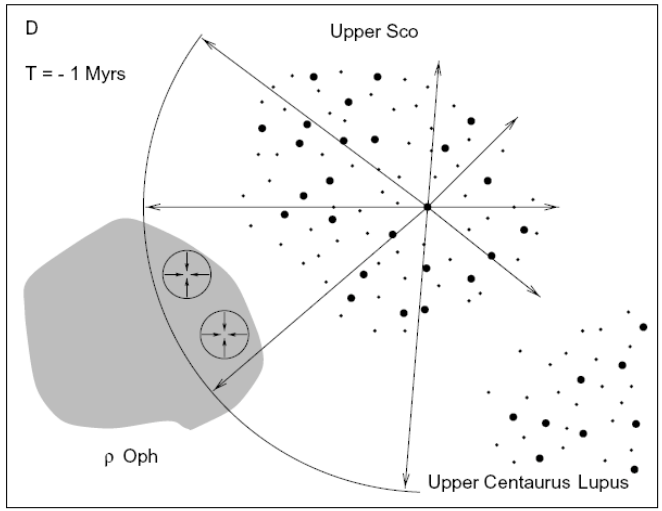
Astrophysics Issues of the Upper Sco Region

Preibisch et al. 1999







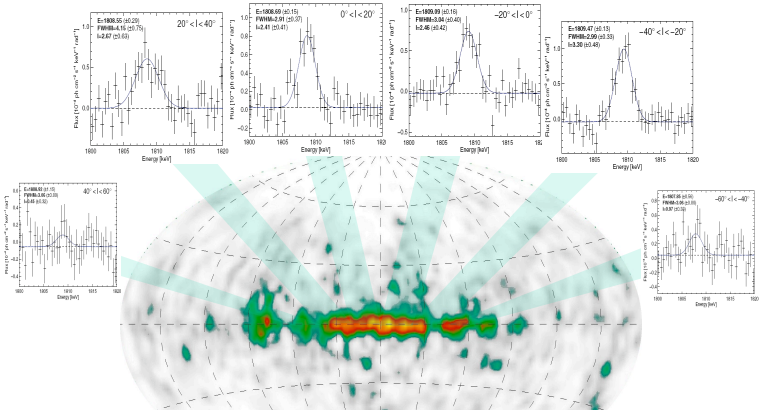


☆ **Triggered Star Formation** ("Standard" Case; Contentious)

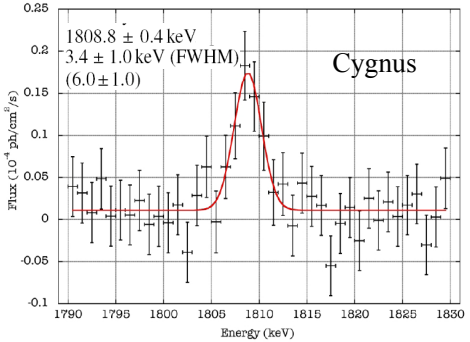
- ☞ UCL Massive-Star Action Triggers SF in USco ~5 Myrs ago
- ☞ ρ Oph Molecular Cloud Hit by USco Massive-Star Action ~1 Myrs ago

2009/2010: Specific Regions "Astrophysics" Now!

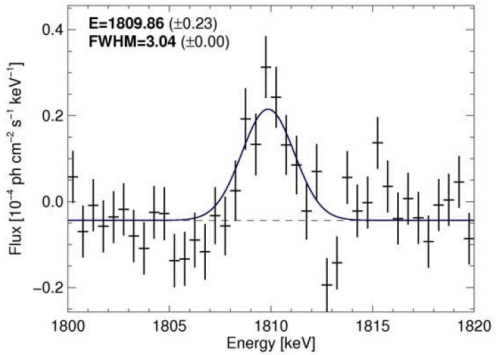
☆ Spectra for Different Regions along Galactic Plane *(Wang+'09)*



☆ Cygnus Region Assessment *(Martin+'09)*



☆ Scorpius-Centaurus Association Detection *(Diehl+'10)*



☆ Nearby Massive-Star Group Constraints *(Ohlendorf+'10)*

☆ Inner Galaxy Hot-ISM Kinematics *(Kretschmer+'10)*

Status of the *Nucleosynthesis* Field - ^{60}Fe

Status Jun 2009

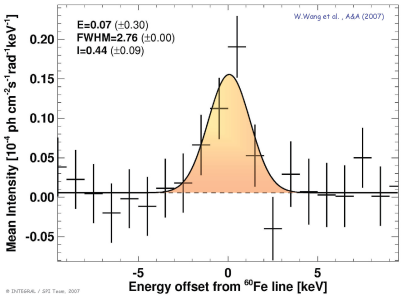
☆ ^{60}Fe in the Galaxy

☞ Clear Detection

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

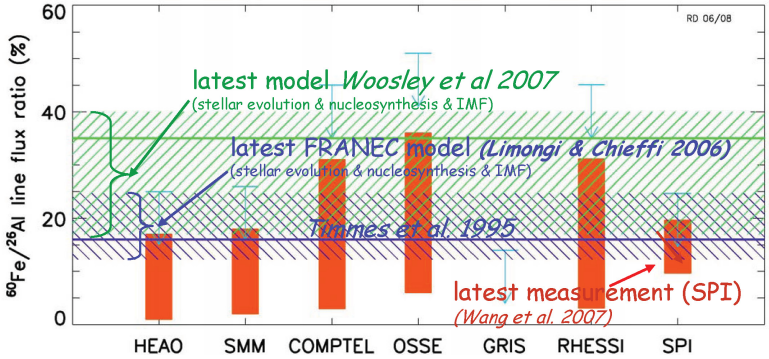
☞ Limits for Cygnus, Vela

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

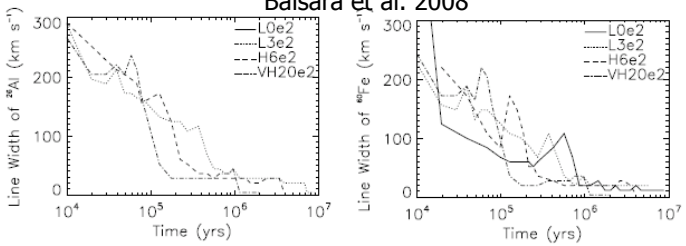


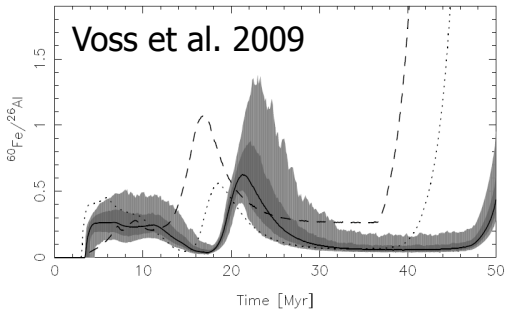
☞ ^{60}Fe/^{26}Al Ratio: New Models & Theory

- 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



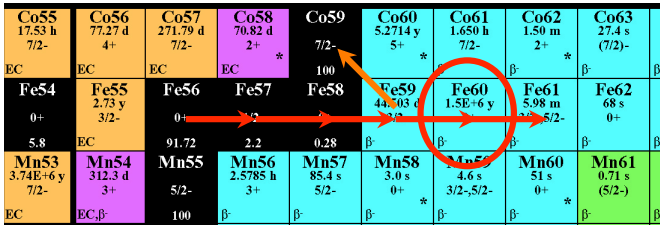
Balsara et al. 2008





☞ ^{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')



Roland Diehl

^{60}Fe Study 2009: Addressing "Systematics"

☆ Issues:

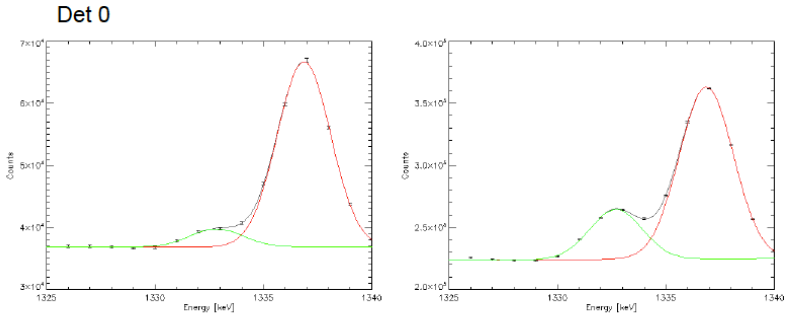
- ☞ Instrumental Ge Line at 1337 keV
- ☞ ^{60}Co Build-up

☆ Methods:

- ☞ Build a Spectral/Temporal/Detector-Pattern Model of Bgd

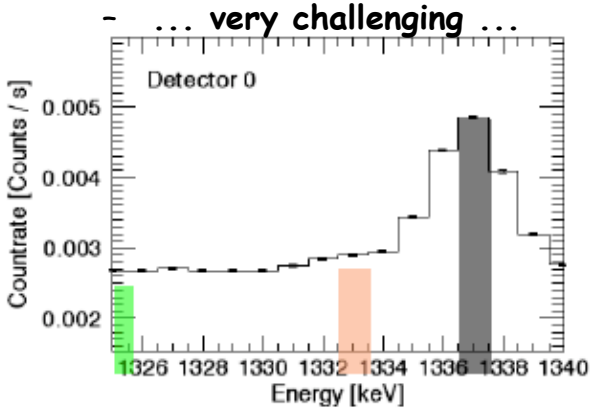
☆ Status:

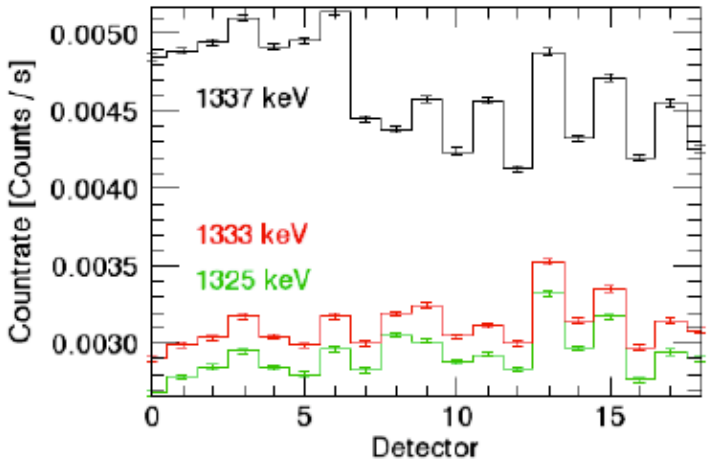
- ... very challenging ...

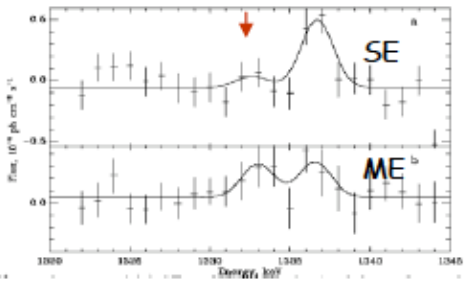


- 1435.4 IJD

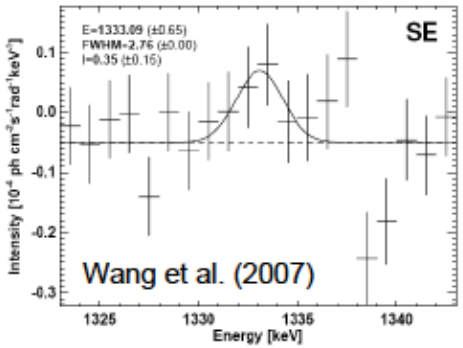
1659.4 IJD -







Harris et al. (2005)



→ Reduces systematics

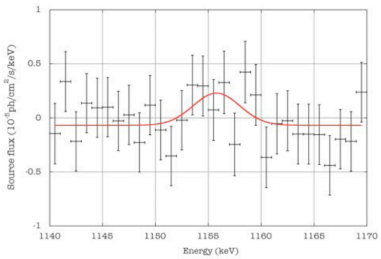
→ Improve sensitivity

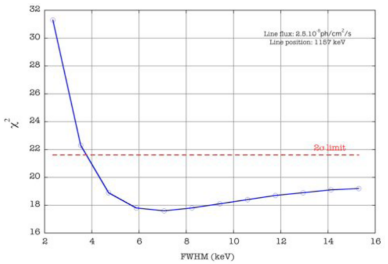
→ How to use these signatures in our analysis?

Status of the *Nucleosynthesis* Field - ^{44}Ti

Status Jun 2009

☆ ^{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

☆ New Radioactivity Constraints for SNe

- ☞ Cas A Echo Spectrum, Krause+ 2008
- ☞ Cas A ^{56}Ni Yield from Reddening, Ericson+ 2008
- ☞ New SNR G1.9+0.3 with ~100 yrs age
  - Reynolds+ 2008
  - No Hint for ^{44}Ti Emission found in SPI nor IBIS

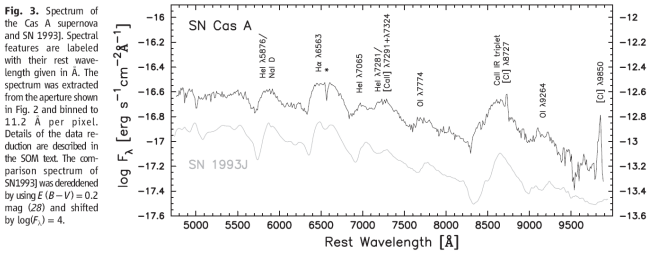
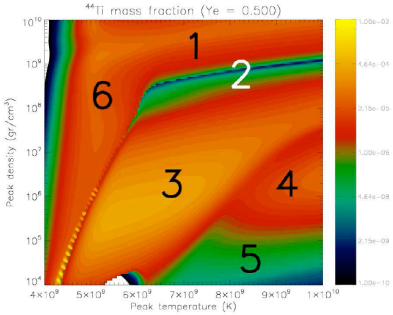


Fig. 3. Spectrum of the Cas A supernova and SN 1993J. Spectral features are labeled with their rest wavelength given in Å. The spectrum was extracted from the aperture shown in Fig. 2 and binned to 11.2 Å per pixel. Details of the data reduction are described in the SOM text. The comparison spectrum of SN1993J was dereddened by using $E(B-V) = 0.2$ mag (28) and shifted by $\log(F_\lambda) = 4$.

☆ New Model Yields & their Variabilities

- ☞ First 2.x-dimensional Parametrized Simulations
  - Strong Y_e Dependency; Fryer+ 2008, Magkotsios+ 2008
- ☞ 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?
- ☞ Nuclear-Network Studies
  - e.g. NARF, Parikh+ in prep.



Model Name and citation	Model Charact. E_{exp} 10^{51} erg	Model Charact. M_{rem} $M_\odot$	Yields ^{28}Si $M_\odot$	Yields ^{45}Sc 10^{-5} $M_\odot$	Yields ^{44}Ti 10^{-5} $M_\odot$	Yields ^{60}Co 10^{-5} $M_\odot$	Yields ^{56}Ni $M_\odot$
WW-S22A[8]	1.47	2.02	0.356	1.20	6.15	2.43	0.205
WW-S25A[8]	1.18	2.07	0.315	0.228	3.04	5.36	0.129
23e-1.5[7]	3.2	1.5	0.303	0.082	0.513	1.03	0.0013
23e-2.0[7]	2.6	2.0	0.461	0.080	6.95	1.04	0.283
d0.2-1.5[7]	2.6	1.5	0.463	0.081	2.62	0.99	0.240
d0.7-1.5[7]	2.3	1.5	0.482	0.091	10.0	1.01	0.216
23p-1.2[7]	3.2	1.2	0.362	0.080	0.655	0.992	0.0066
23p-1.6[7]	2.4	1.6	0.439	0.079	23.5	0.996	0.613
CL-20[9]	1.6	-	0.156	0.542	4.03	1.13	0.10
CL-25[9]	1.8	-	0.245	1.26	2.19	2.44	0.10

Roland Diehl

Status of the *Nucleosynthesis* Field: e^+ Annihilation

Status Jun 2009

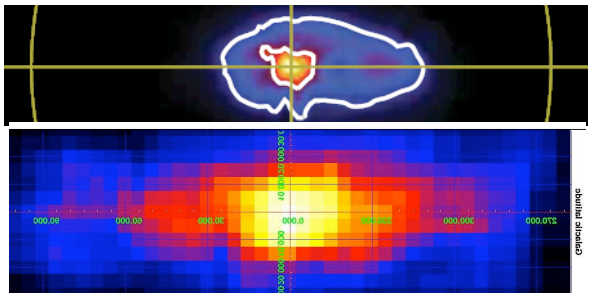
☆ Positrons in the Galaxy

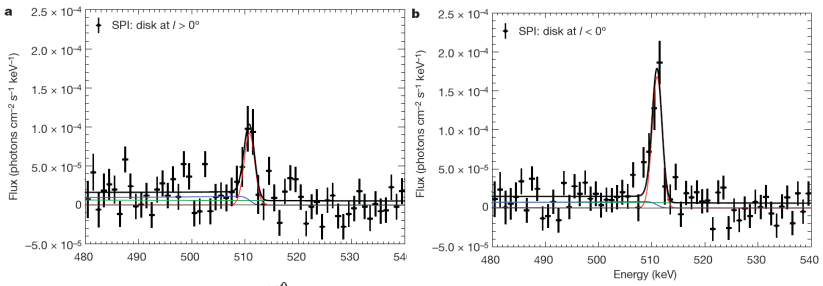
☞ Imaging Studies -> Asymmetry

- Weidenspointner et al., Nat 2008
- Bouchet et al., ApJ 2008
- Skinner et al., PoS 2009 -> $1.60\ ^{+0.49}_{-0.16}$

☞ Spatially-Resolved Spectra

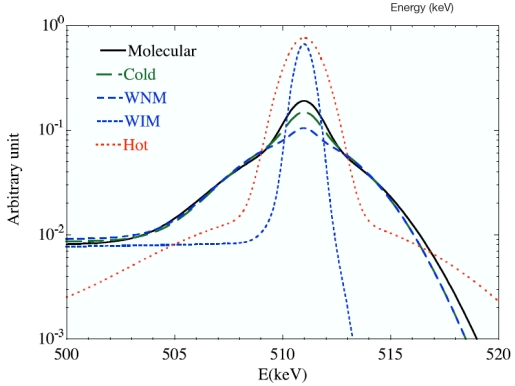
- Weidenspointner et al., Nat 2009





☆ Models and Simulations

- Prantzos et al., in prep for RevModPhys (from 2007/2008 ISSI workshops)
- Studies & Discussion on Cosmic-Ray Propagation, on Positron Production by Different Sources, on Positron Annihilation Physics, on Dark Matter



☞ Annihilation Physics and Site

- Guessoum et al., A&A 2006

☞ Sources: SgrA; Pulsars; Binaries; DM; ...

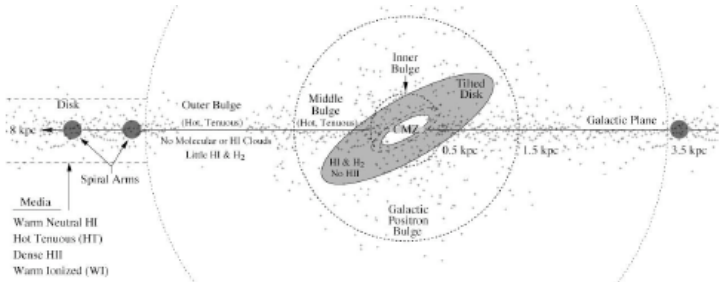
- Cheng; Wang; Guessoum, Skinner; Boehm, Hooper;...

☞ Positron Propagation in ISM

- Gillard et al., ESA-SP 2007; Jean+ A&A '09

☞ Bulge/Disk Ratio: New Models & Theory

- Higdon et al.; Lingenfelter, ApJ



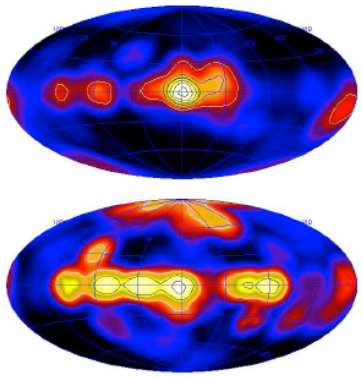
☞ Reviews

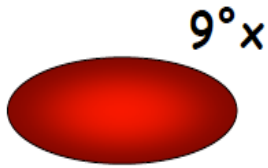
- Diehl & Leising '09; Prantzos+ '10

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
- ☞ ...





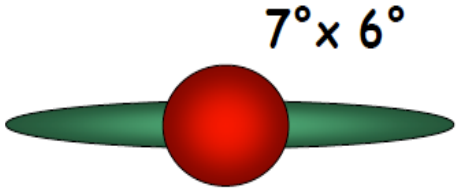
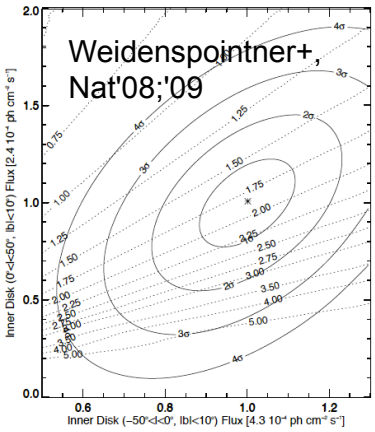
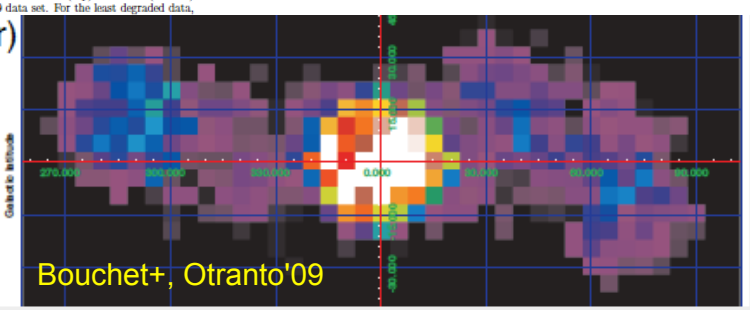


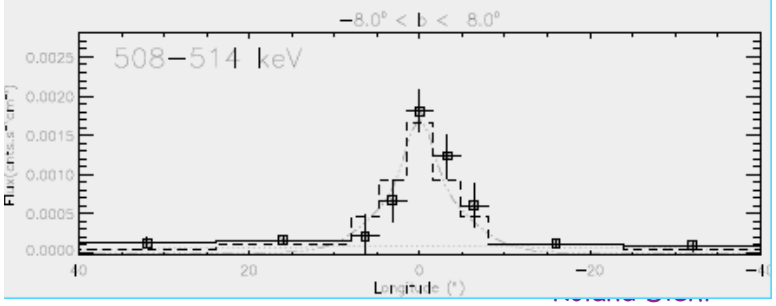
Figure 2: The exposure to the sky for the least (top) and most (bottom) degraded subsets of the Mar. 3, 2009 data set. For the least degraded data, the contours are at exposure level
degraded data, the contours are at

☆ 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?



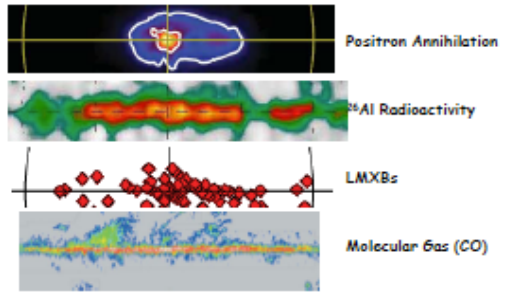


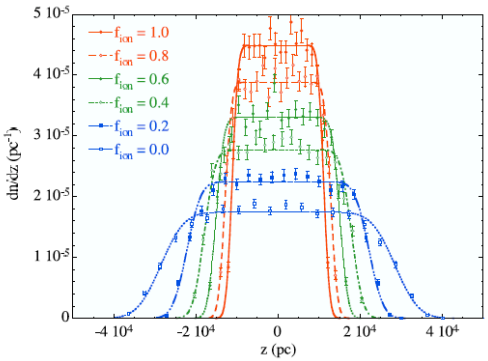


Positron Annihilation: Interpretational Efforts

☆ Study Contributions from Different Candidate Sources

- ☞ Millisecond Pulsars
  - » Wang
- ☞ Microquasars
  - » Guessoum
- ☞ LMXBs
  - » Bandyopadhay
- ☞ Sgr A Environment and Magnetic-Field Configuration
  - » Chernyshov et al.



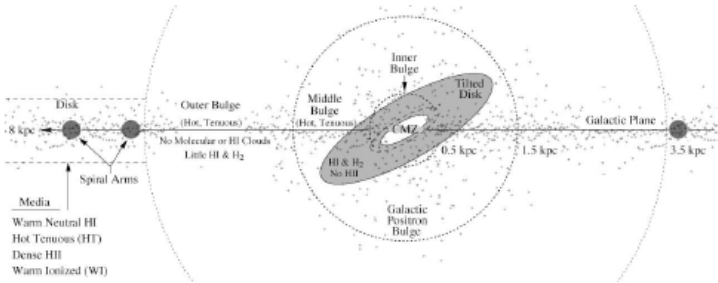


☆ Study Positron Annihilation and Propagation

- ☞ Annihilation on PAHs
  - » Guessoum
- ☞ Positron Propagation in Complex ISM
  - » Jean & Gillard

☆ Wholistic Models and Reviews

- ☞ Just Normal OB Associations and Sources
  - » Higdon & Lingenfelter
- ☞ RMP Review from 2 ISSI Worksessions
  - » Prantzos et al., RMP Submission Dec'09



☆ Many Interpretational Papers

- ☞ Cosmic Rays and its Positron Component
- ☞ Dark Matter Particle Models

Candidate Results to Support 2010 Request for Extension

(a subjective extrapolation)

☆ ^{26}Al – based Astrophysics Studies

- ☞ The inner Galaxy's Doppler-Shifted Line -> l-v Diagram
- ☞ The ^{26}Al Yields for Several Known Groups of Stars
- ☞ The ^{60}Fe/^{26}Al Ratio Constraints on Massive-Star Structure
- ☞ *2012+: Demonstrate Variety -> "^{26}Al Astronomy"*

☆ Positron Annihilation

- ☞ Morphology Constraints for Bulge and Disk (Latitude Extent, ...)
- ☞ The Bulge-to-Disk Emission Ratio and Candidate Source Constraints
- ☞ The Line Shape Inferences for Bulge versus Disk
- ☞ *2012+: Clarify if Source or Propagation Puzzle*

☆ ^{44}Ti

- ☞ The Velocity Contraints on ^{44}Ti Ejecta from Cas A
- ☞ Re-Analysis of Galactic-Plane Survey -> new hints for expected ~5 SNR?