New Insights from Massive Star Groups?

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with
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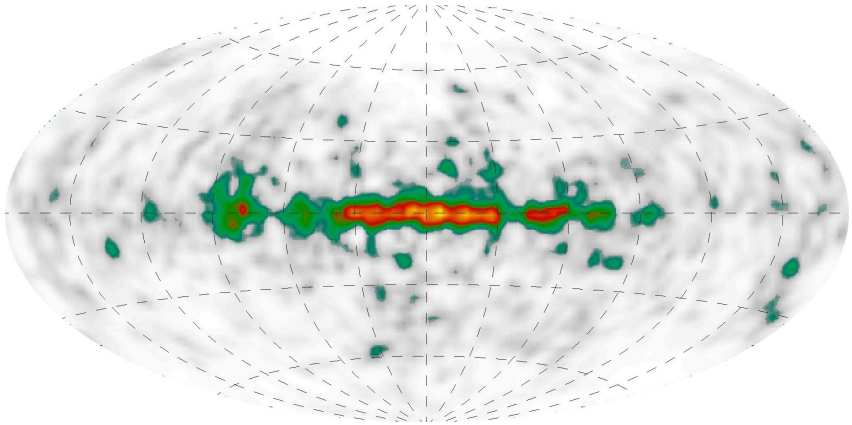
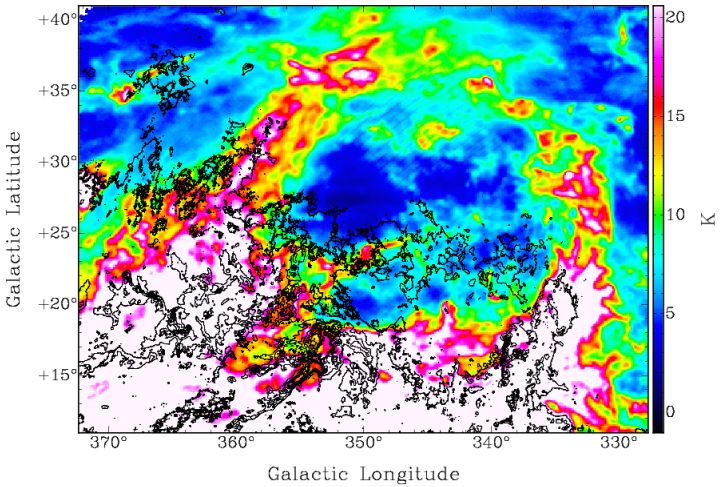
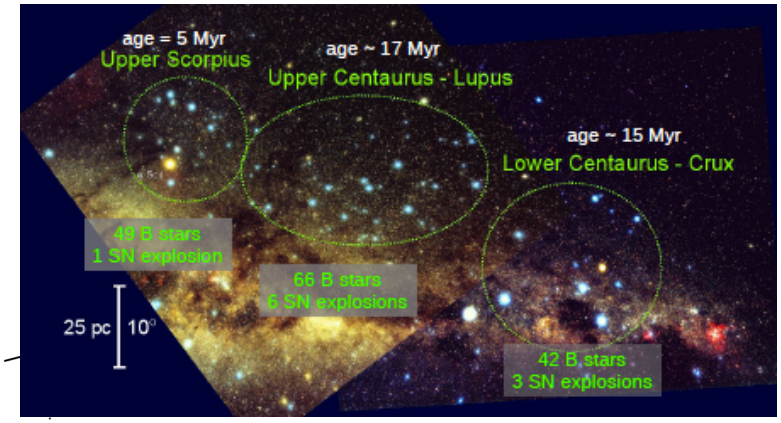
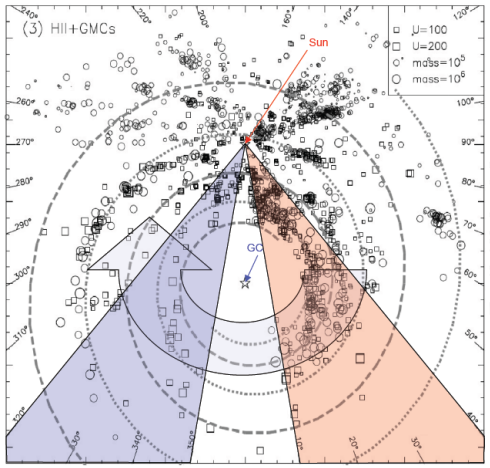
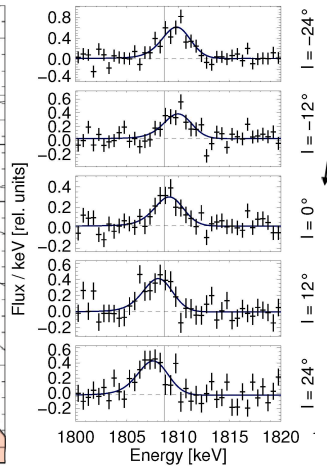
Jochen Greiner, Xiaoling Zhang (MPE),
Gerry Skinner, Wei Wang, Wolfgang Hillebrandt, Keiichi Maeda,
and many others at other institutions

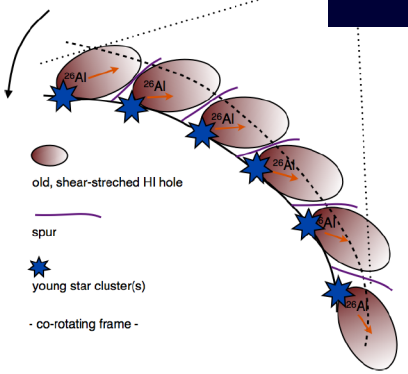










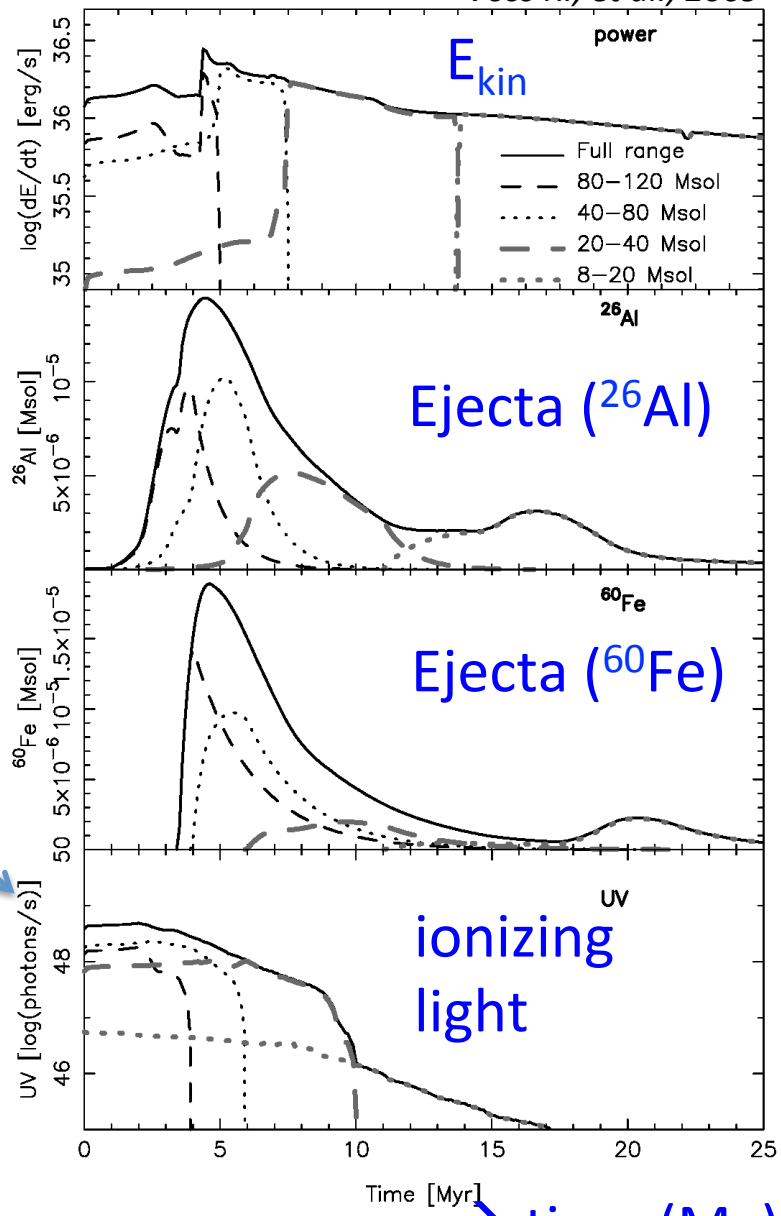


Massive Star & Supernovae and the ISM

Massive-Star Groups

- We study the "outputs" of massive stars and their supernovae
  - Winds and Explosions
  - Nucleosynthesis Ejecta
  - Ionizing Radiation
- We get observational constraints from
  - Star Counts
  - ISM Cavities
  - Free-Electron Emission
  - Radioactive Ejecta

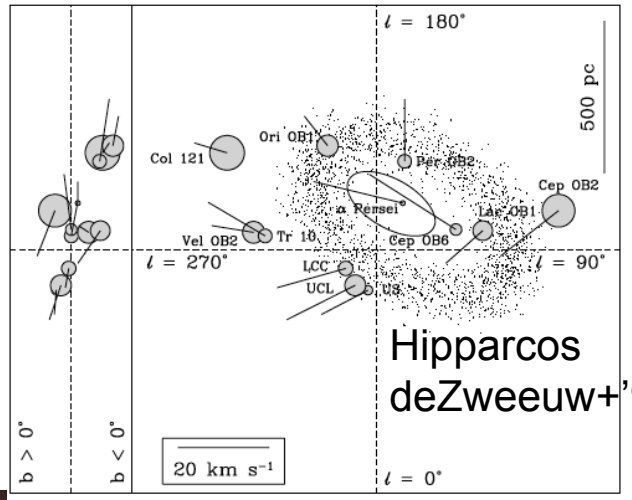
Voss R., et al., 2009



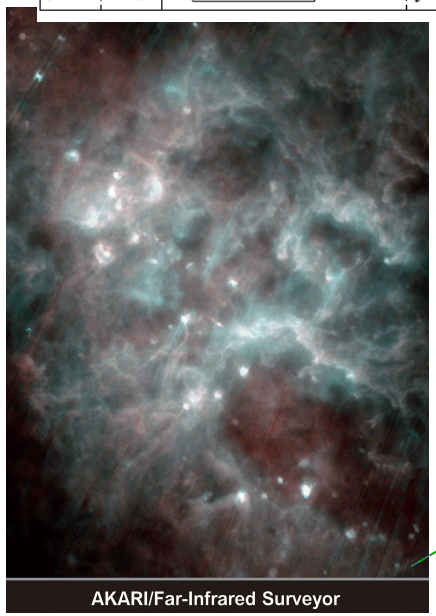
Studying Specific Groups of Stars

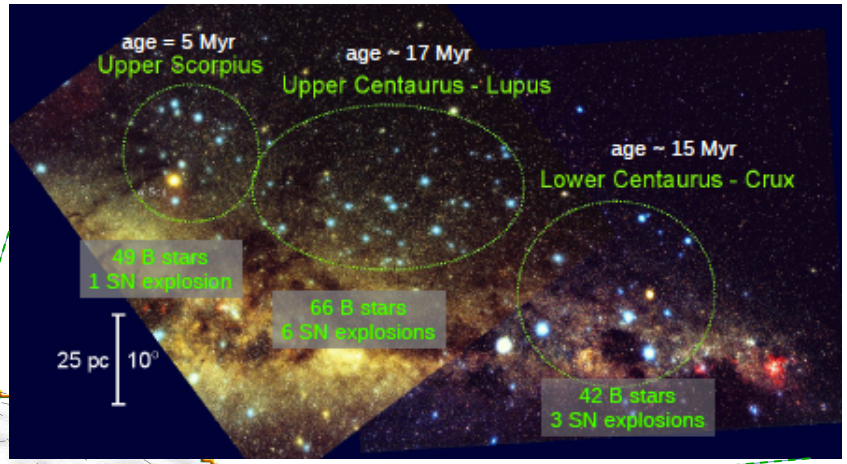
Nearby and/or rich Groups of Stars:

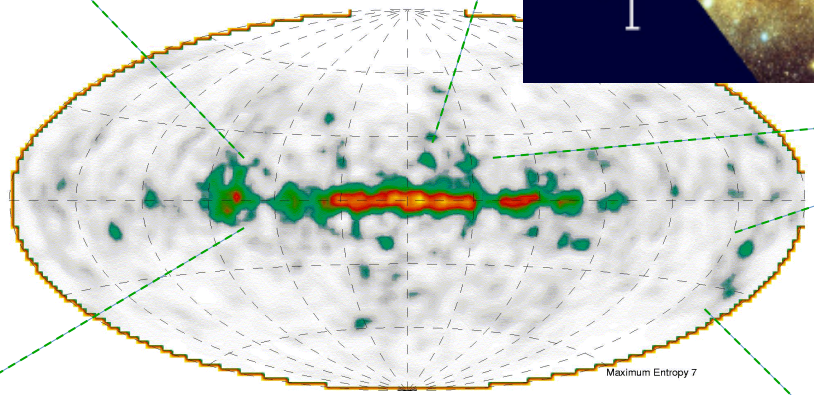
Test our Models for Consistency

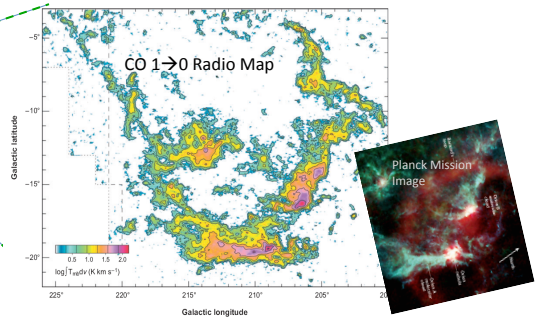


Hipparcos
deZweeuw+'99



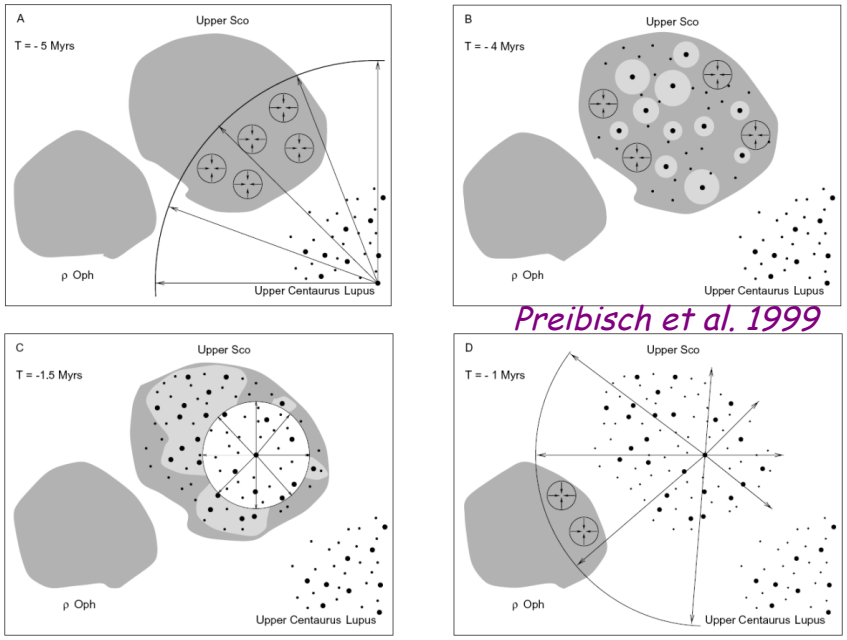




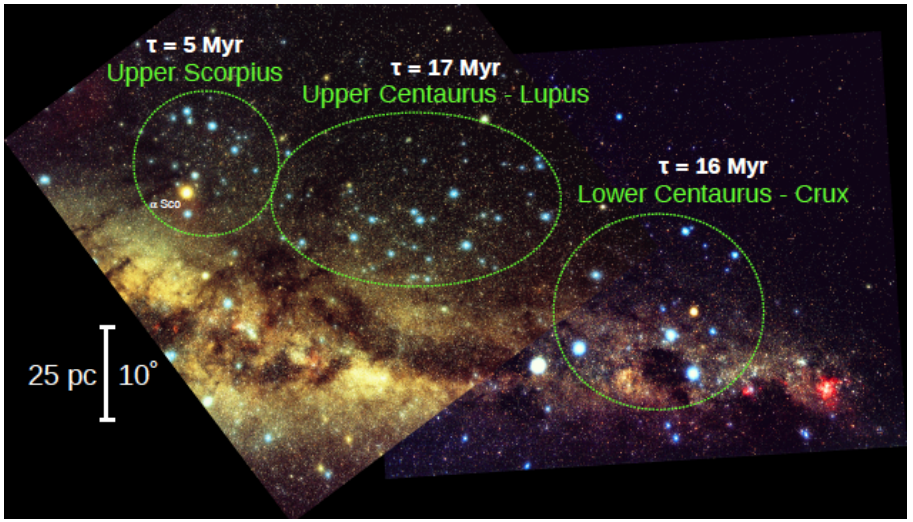


The Sco-Cen Association: Triggered Star Formation?

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



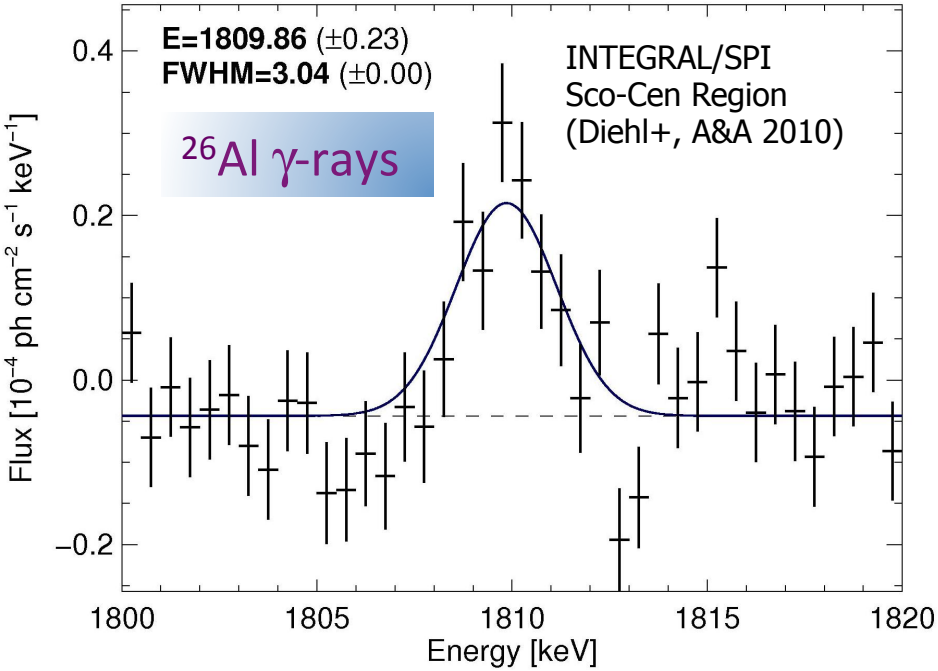
Preibisch et al. 1999



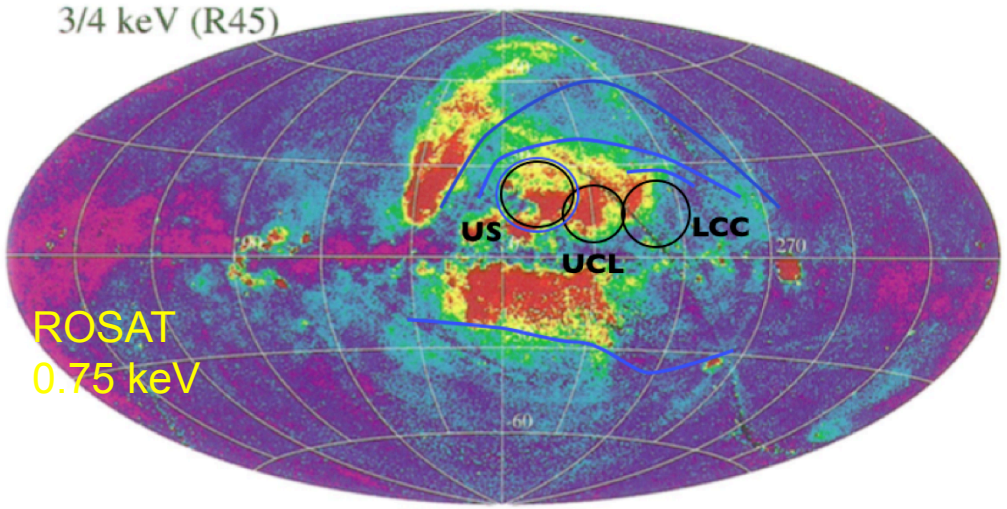
☆ **Compare Data with Population Synthesis**

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

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

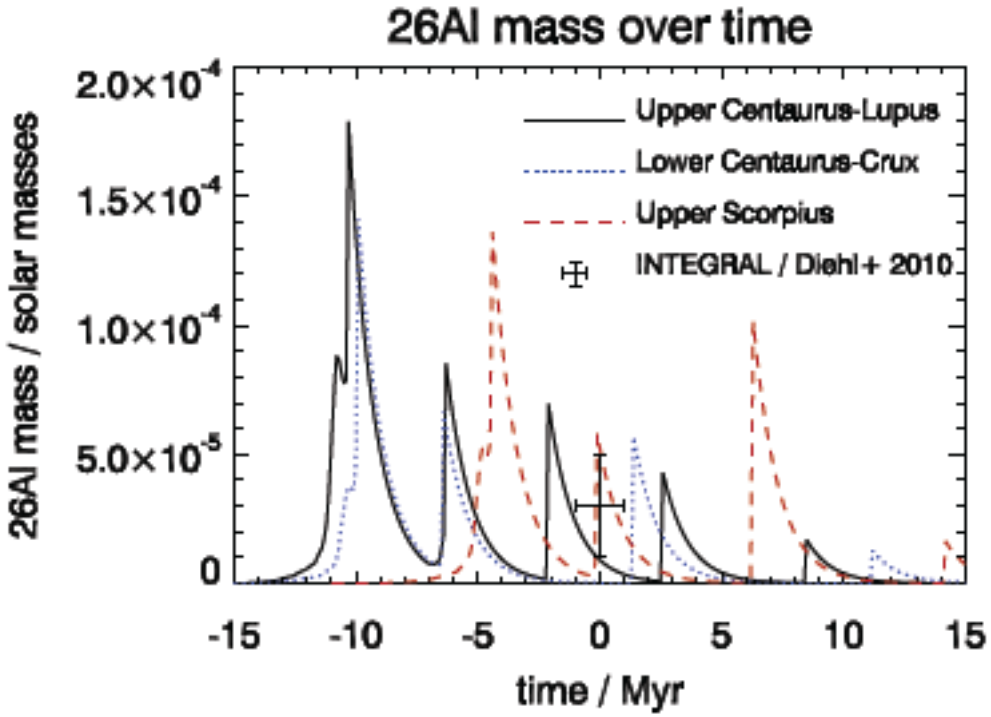


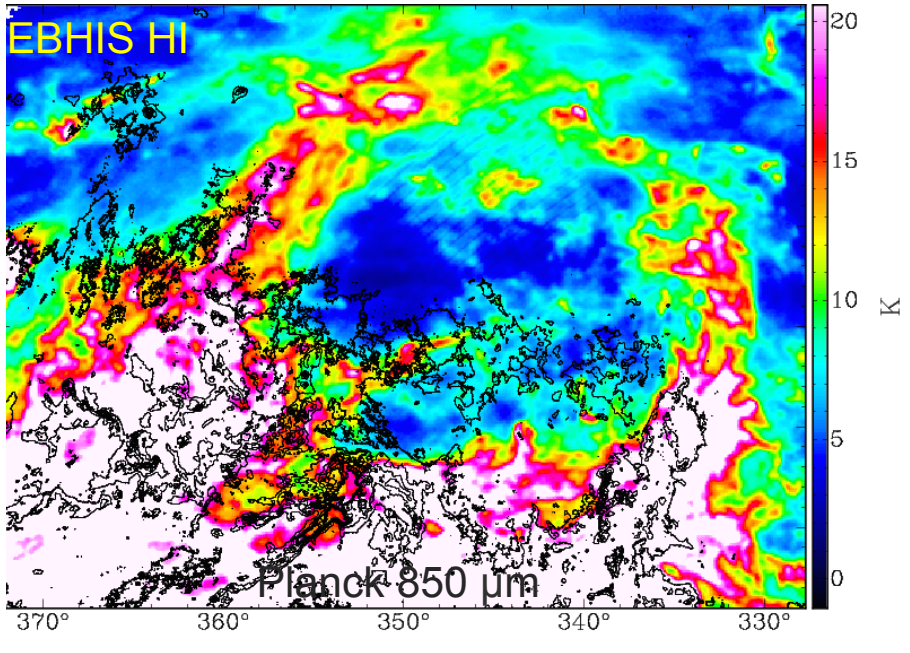
Scorpius-Centaurus Groups



- Studies at different wavelengths and observables…X-rays dust, HI

Using new ages, star counts, and the cluster-mass/most-massive-star relation →

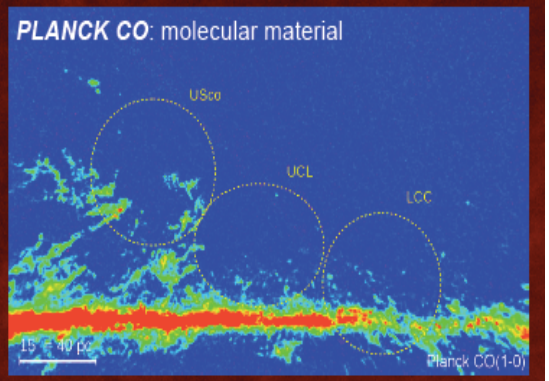




Multi-wavelength Study

Planck 850µ map of the entire ScoCen OB association

The Planck all-sky maps provide a unique opportunity to study the cloud emission over the full spatial extent of the Sco-Cen cloud complex. We retrieved all-sky maps for the FIR and sub-mm wavelengths of 850, 550, and 350 µm from the Planck legacy archive. This revealed, for the first time, the cold gas and dust distribution in the entire Sco-Cen region with an unprecedented spatial resolution of 5' (corresponding to physical scales of ~ 0.2 pc at a distance of 140 pc). In the same way we extracted a temperature map of Sco-Cen and calculated a column density map from the available Planck extinction map E(B-V). *We will use this for clump identification and mass determinations.*



Mass of shell from dust:
$M \approx 4 \times 10^4 M_\odot$

Upper Centaurus-Lupus = UCL

Lower Centaurus-Crux = LCC

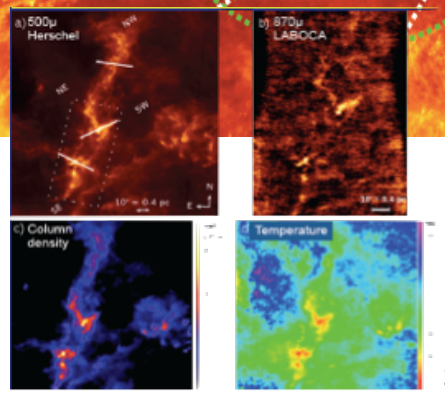
Upper Scorpius = USco

Ophiuchus cloud

≈ 20 deg

Lupus I cloud

$M \approx 10^3 M_\odot$



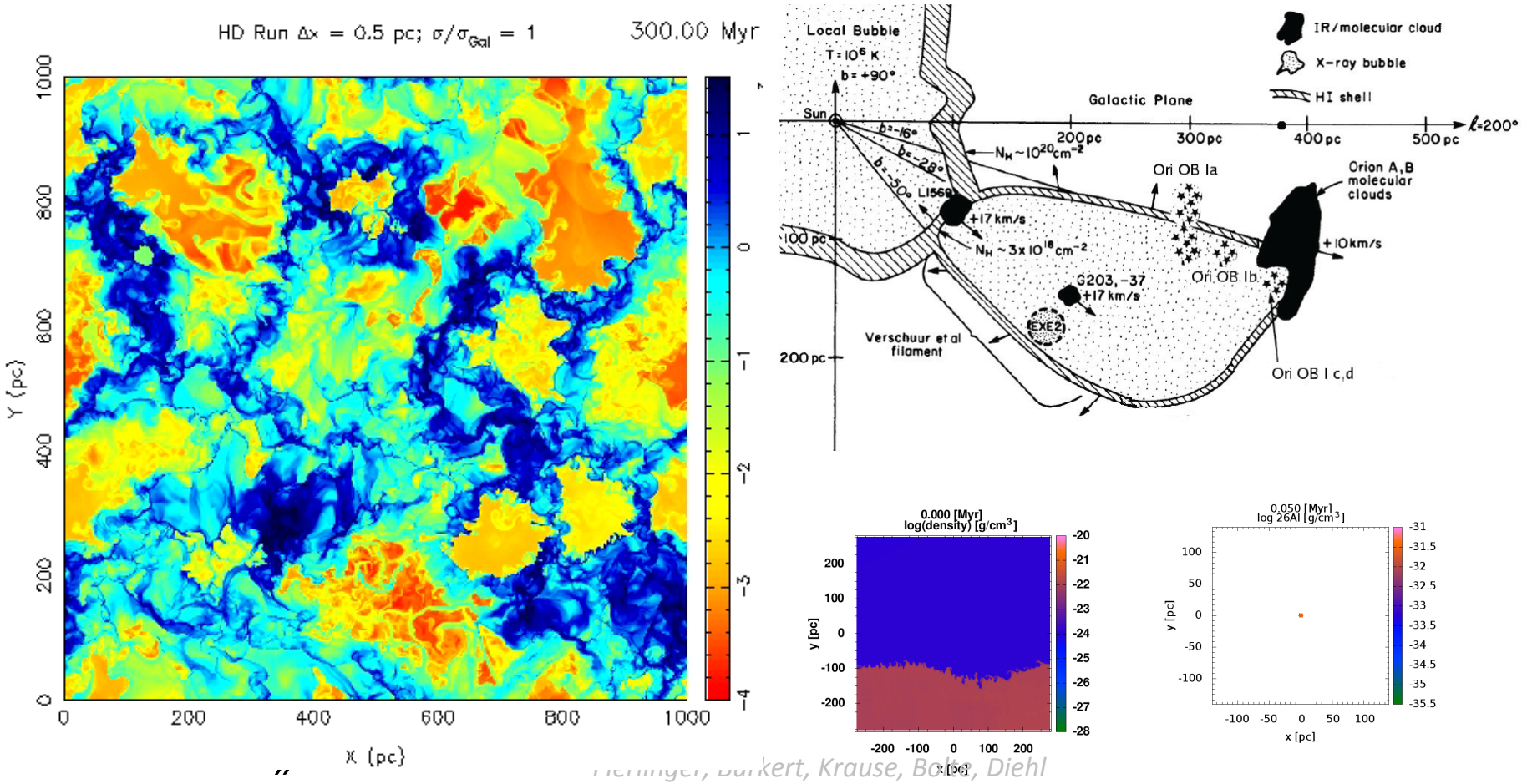
850µ Planck

Gaczkowski, Preibisch, RD, Krause, et al.

Orion: Nucleosynthesis Ejecta and Dynamics of Interstellar Medium

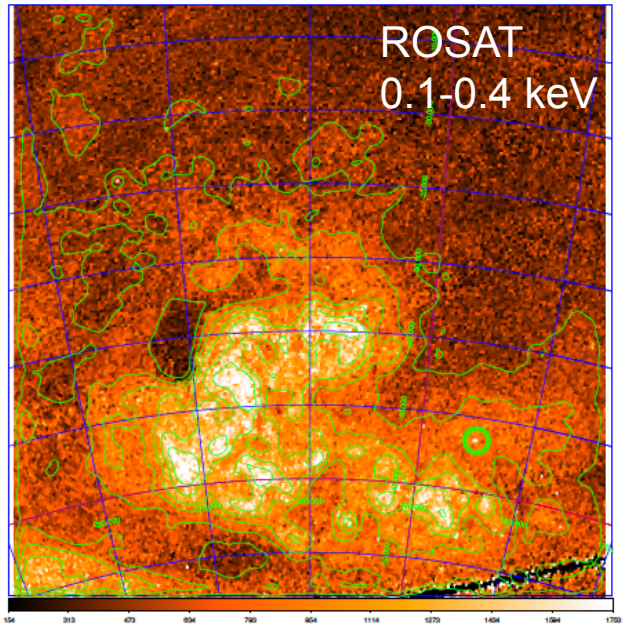
INTEGRAL Data are being collected!

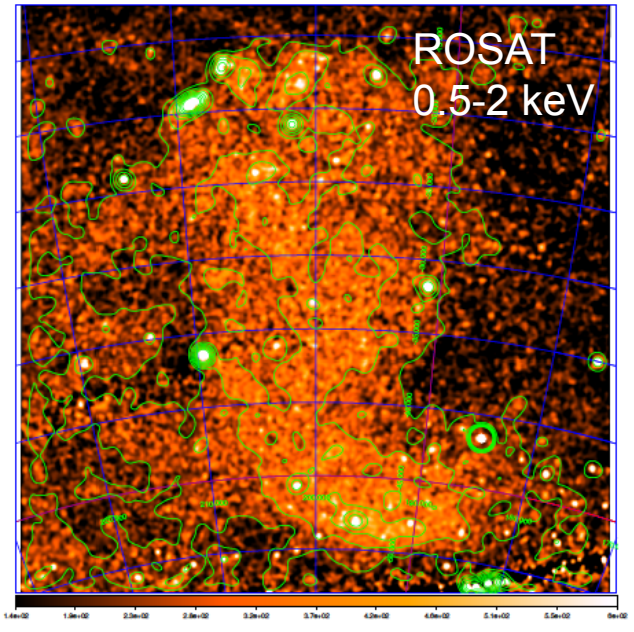
- ISM is Highly-Dynamic → Ejecta in (Super-)Bubbles
  - Study Specific Regions in Detail (Cygnus, Orion, Scorpius-Centaurus, Carina)

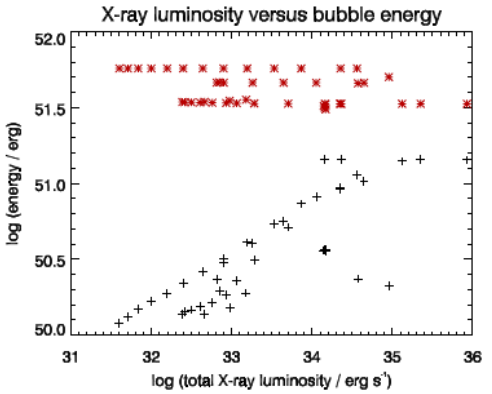


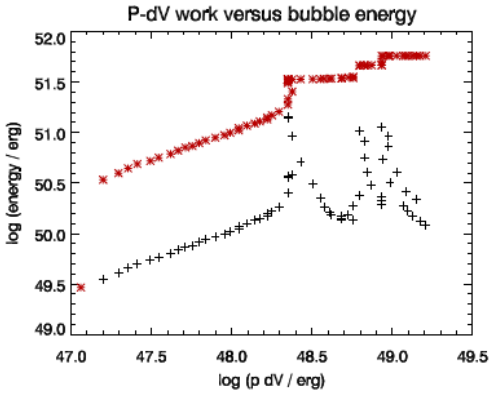
Understanding the Eridanus Superbubble

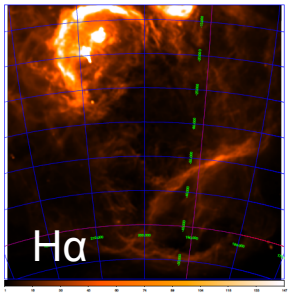
- X-ray Emission, size, ^{26}Al

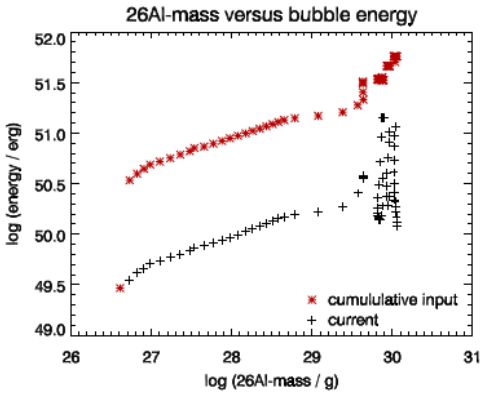




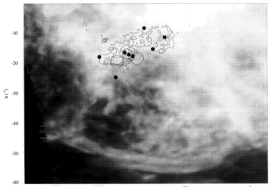








- Temporal X-ray brightenings after SN energy injections
- spatial oscillations



SN Ejecta Nearby: Transport in ISM

- ^{60}Fe Clearly Seen in Oceanfloor (and Lunar) Samples
  from SN ~2.2-2.8 My ago

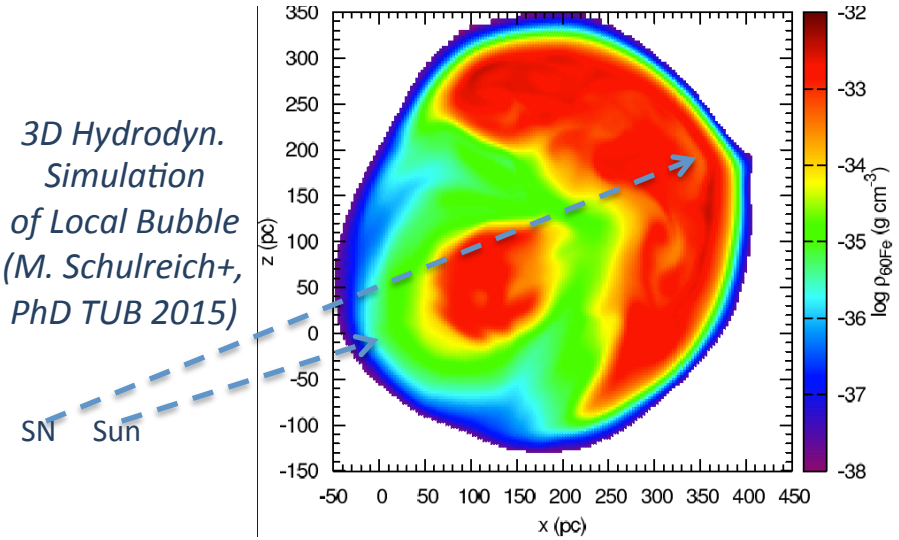
Knie et al. 2004; Fitousi et al. 2008; Feige et al. 2015; Fimiani et al. 2015

- ^{26}Al → Study ISM Dynamics

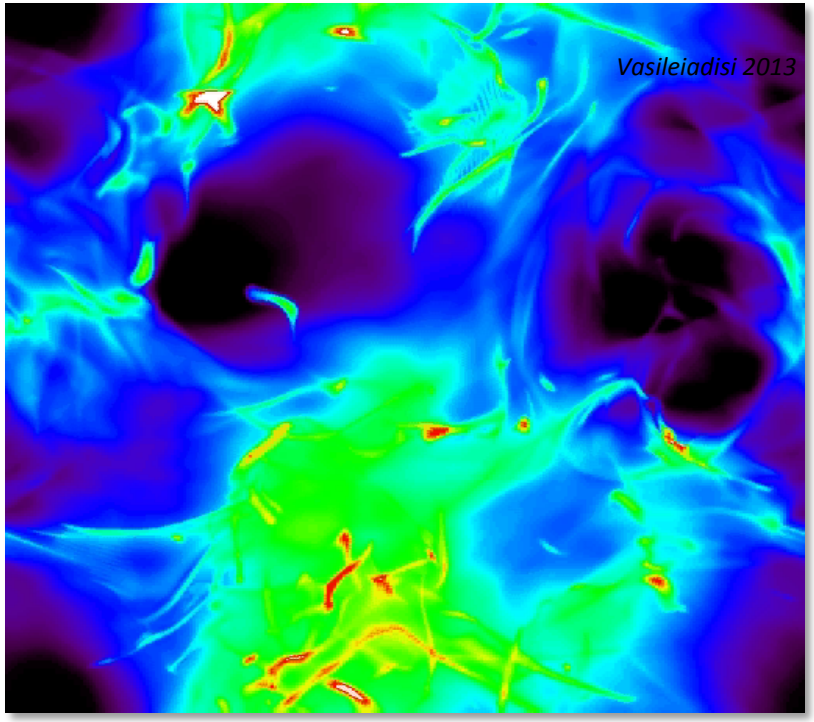
→

  – SN Ejecta Transport at ~10pc Scale??

3D Hydrodyn. Simulation of Local Bubble (M. Schulreich+, PhD TUB 2015)

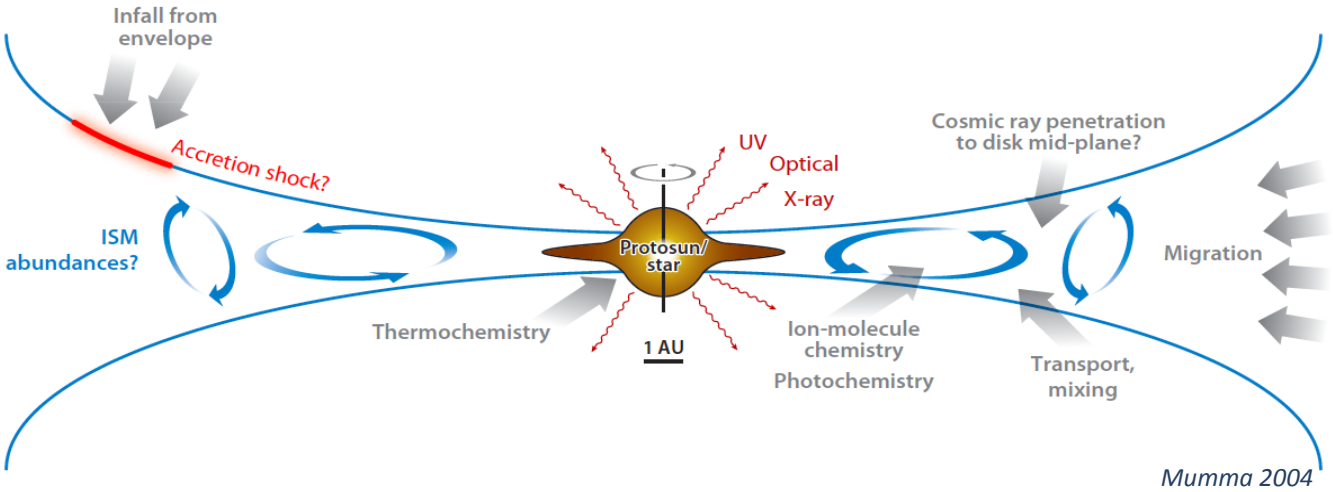


ISM transport towards a newly-forming star/Sun

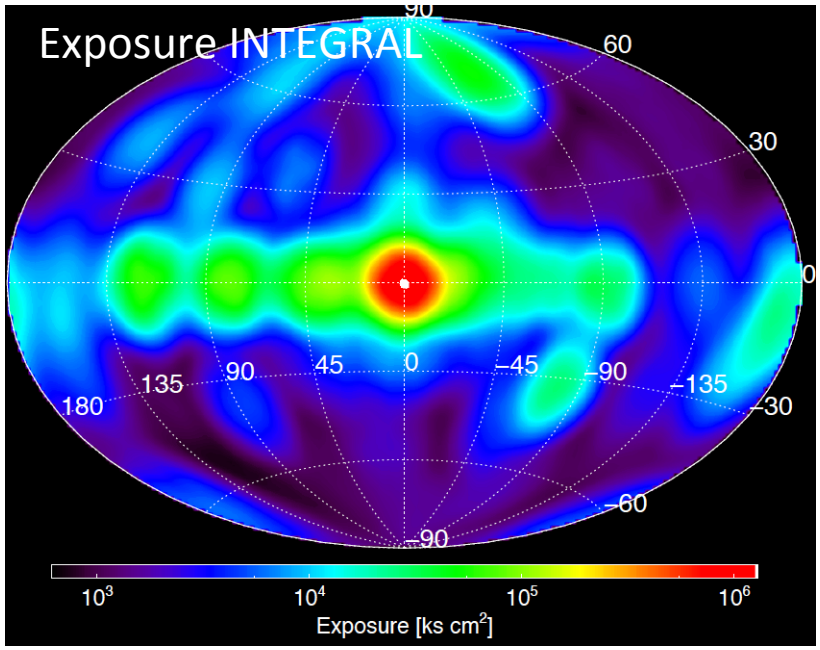


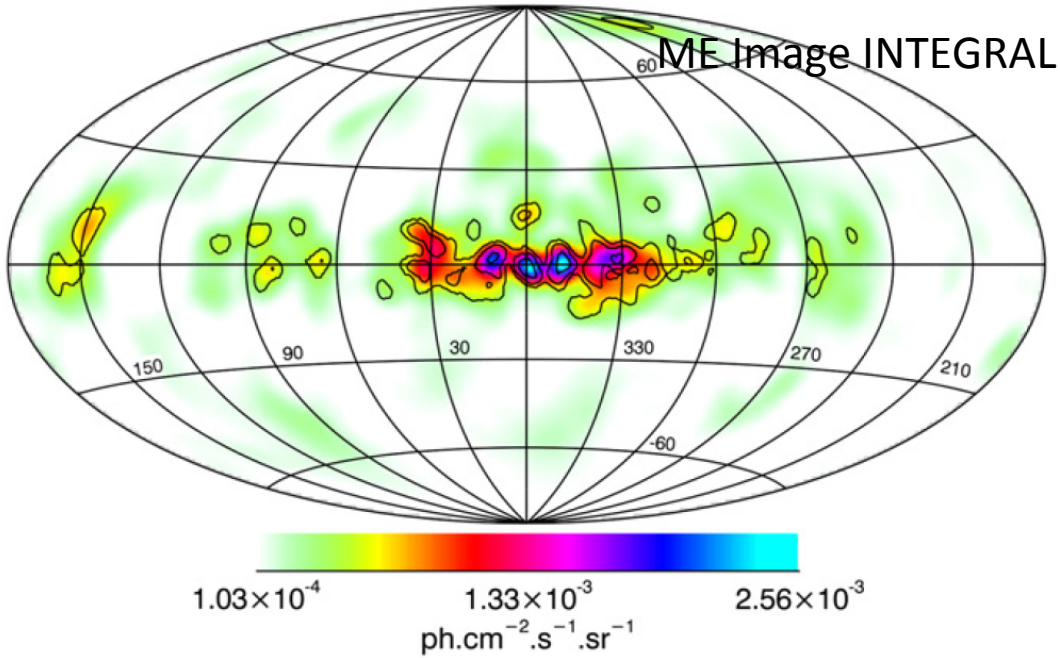
- From the dynamic ISM a concentration of gas cools → protostar
- ISM ingestion through rapid disk flow
- Accreting ISM partly forms solids at inner disk edge

→ESS enrichment with ^{26}Al from a nearby WR star???

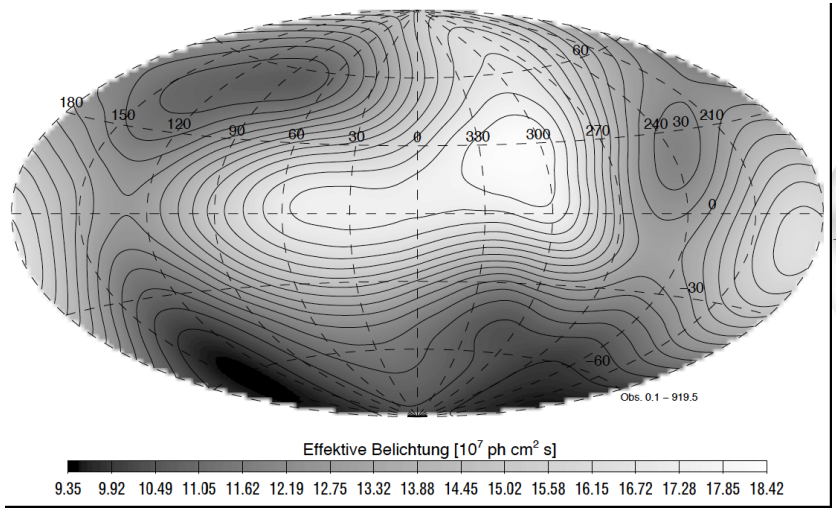


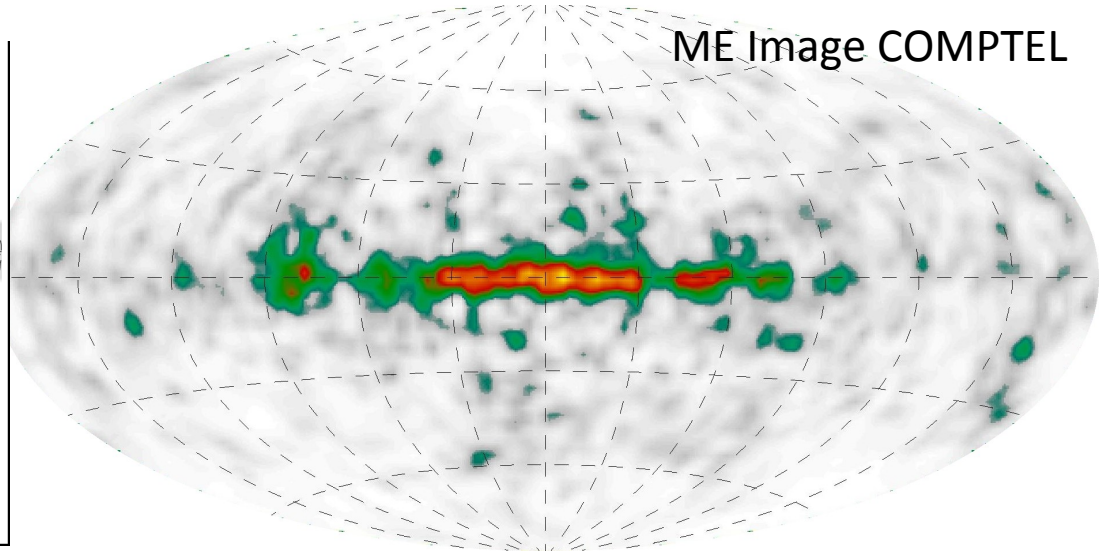
Imaging Galactic ^{26}Al with COMPTEL & SPI



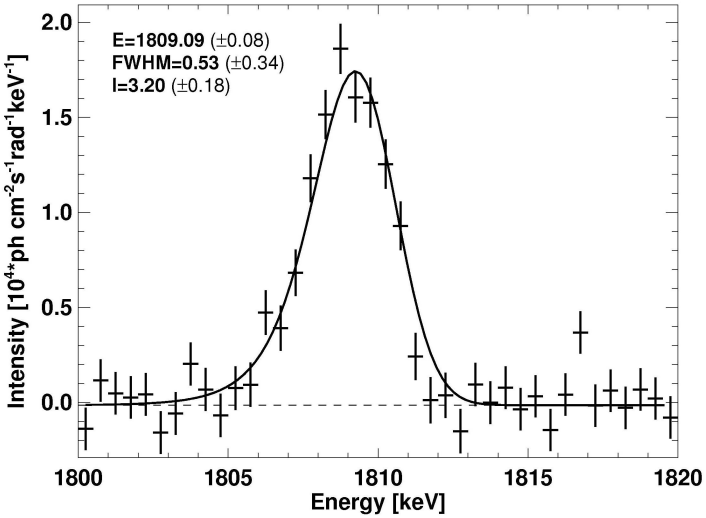


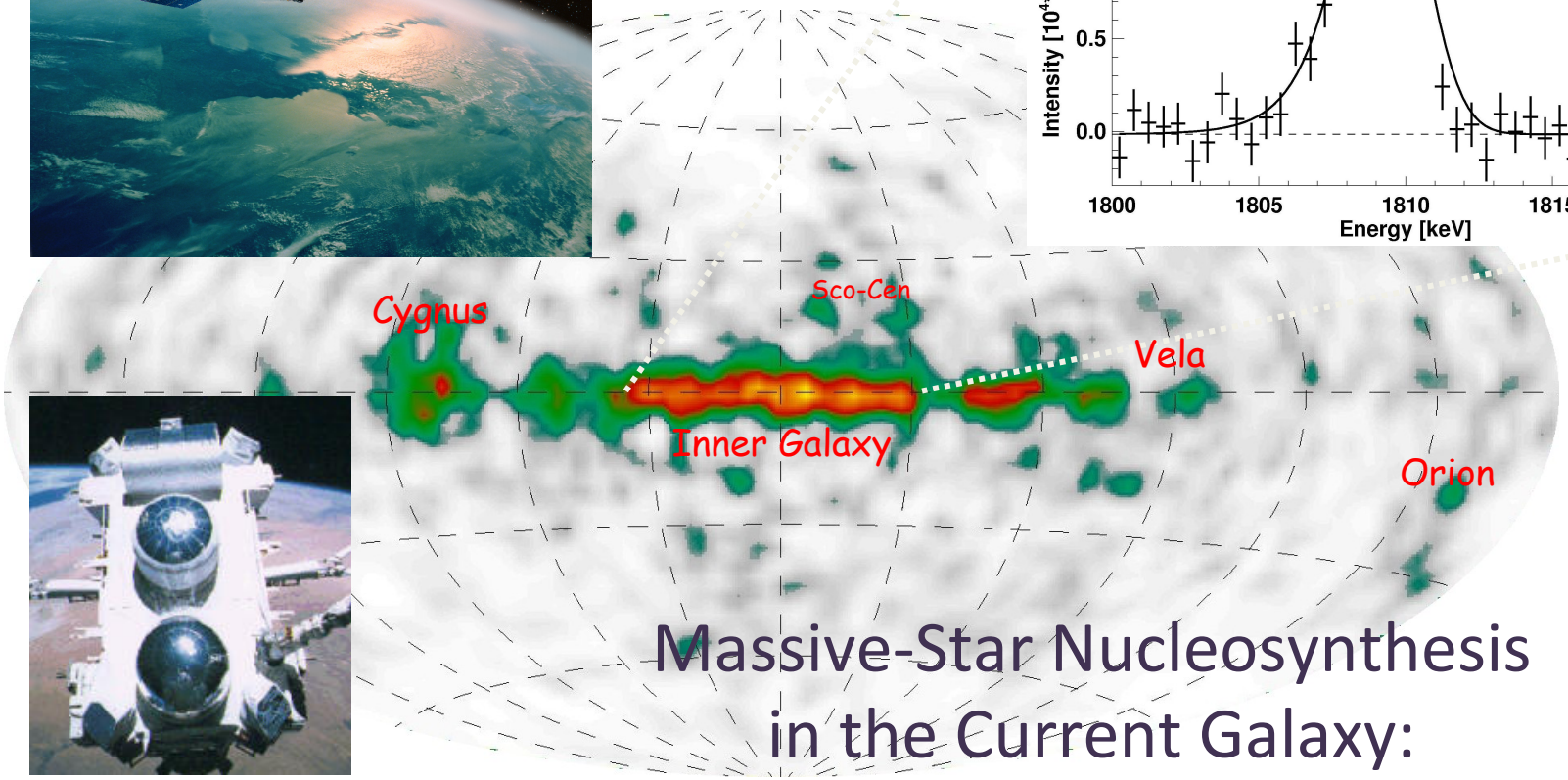
Exposure COMPTEL





^{26}Al in our Galaxy: γ-rays Show Massive-Star Groups



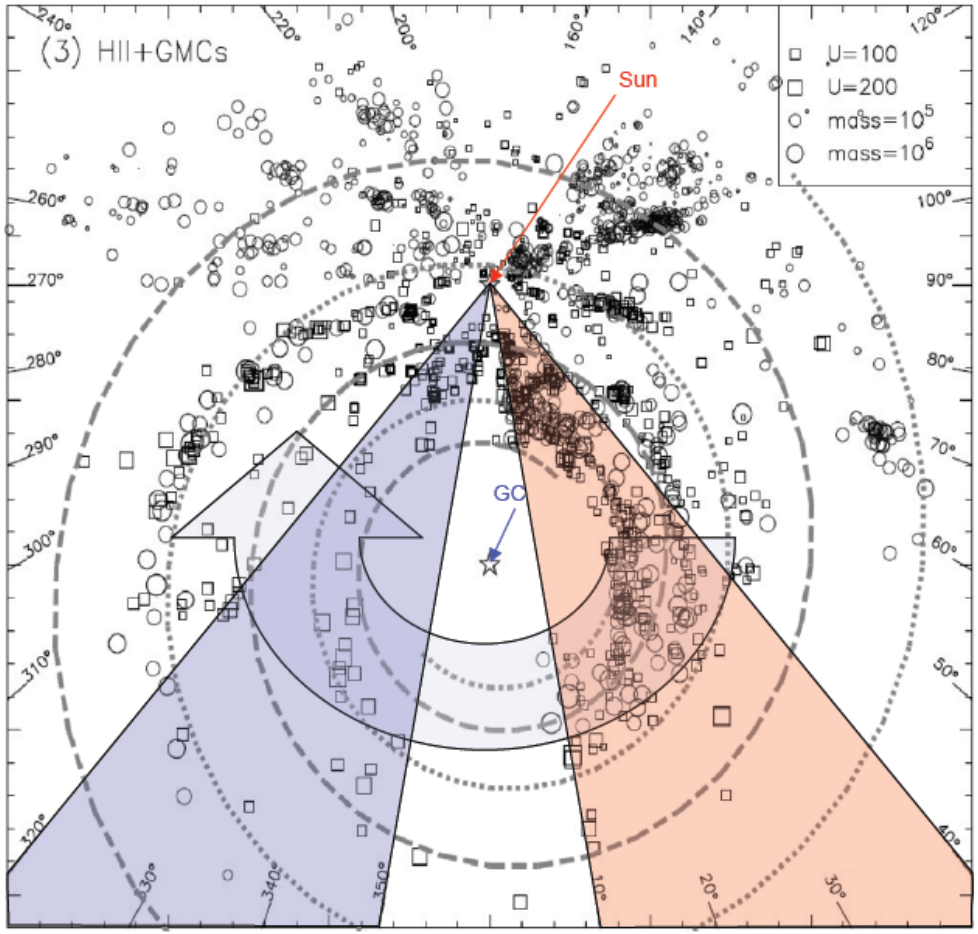


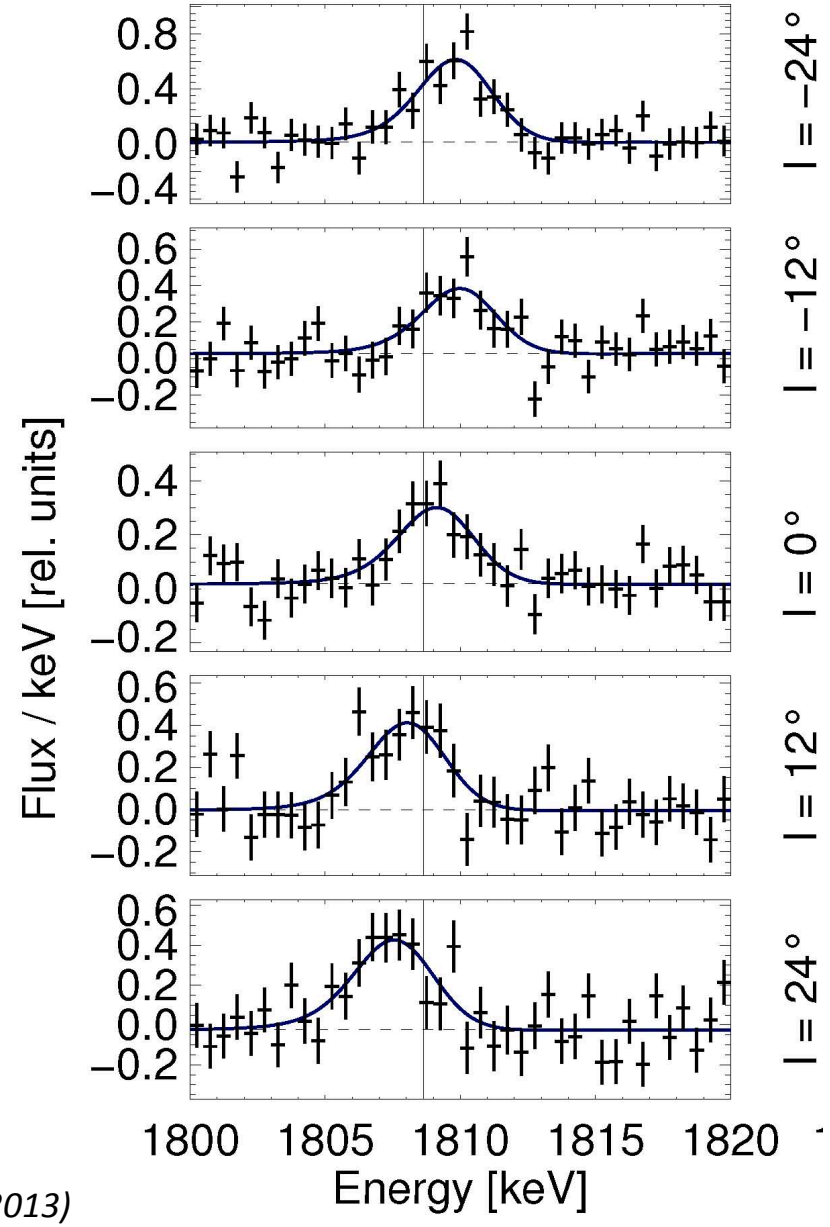
Massive-Star Nucleosynthesis in the Current Galaxy:

Current Enrichment (~My) from ^{26}Al γ-rays

Views of Objects in our Galaxy: ^{26}Al γ-rays

- Large-scale Galactic rotation

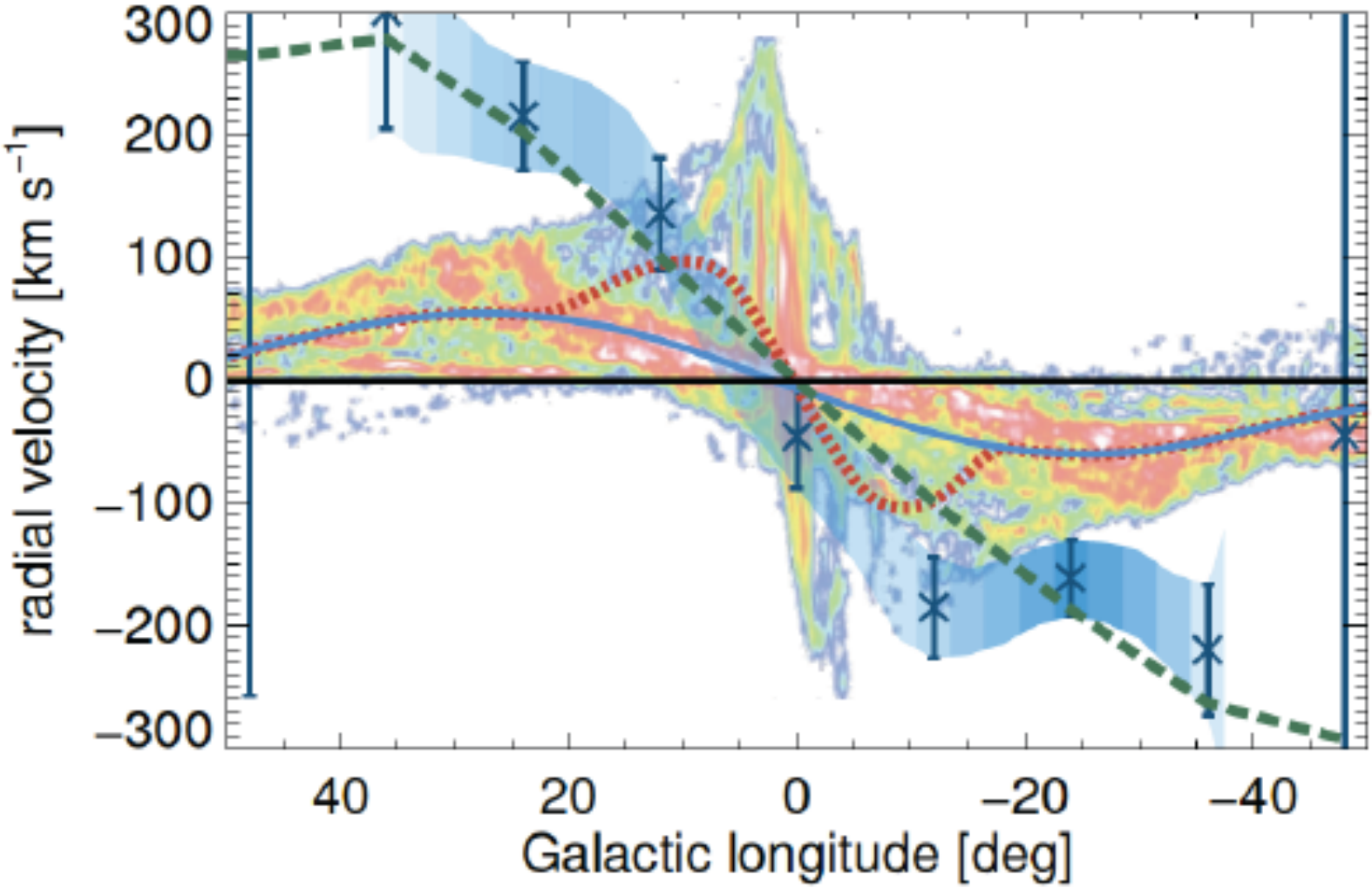




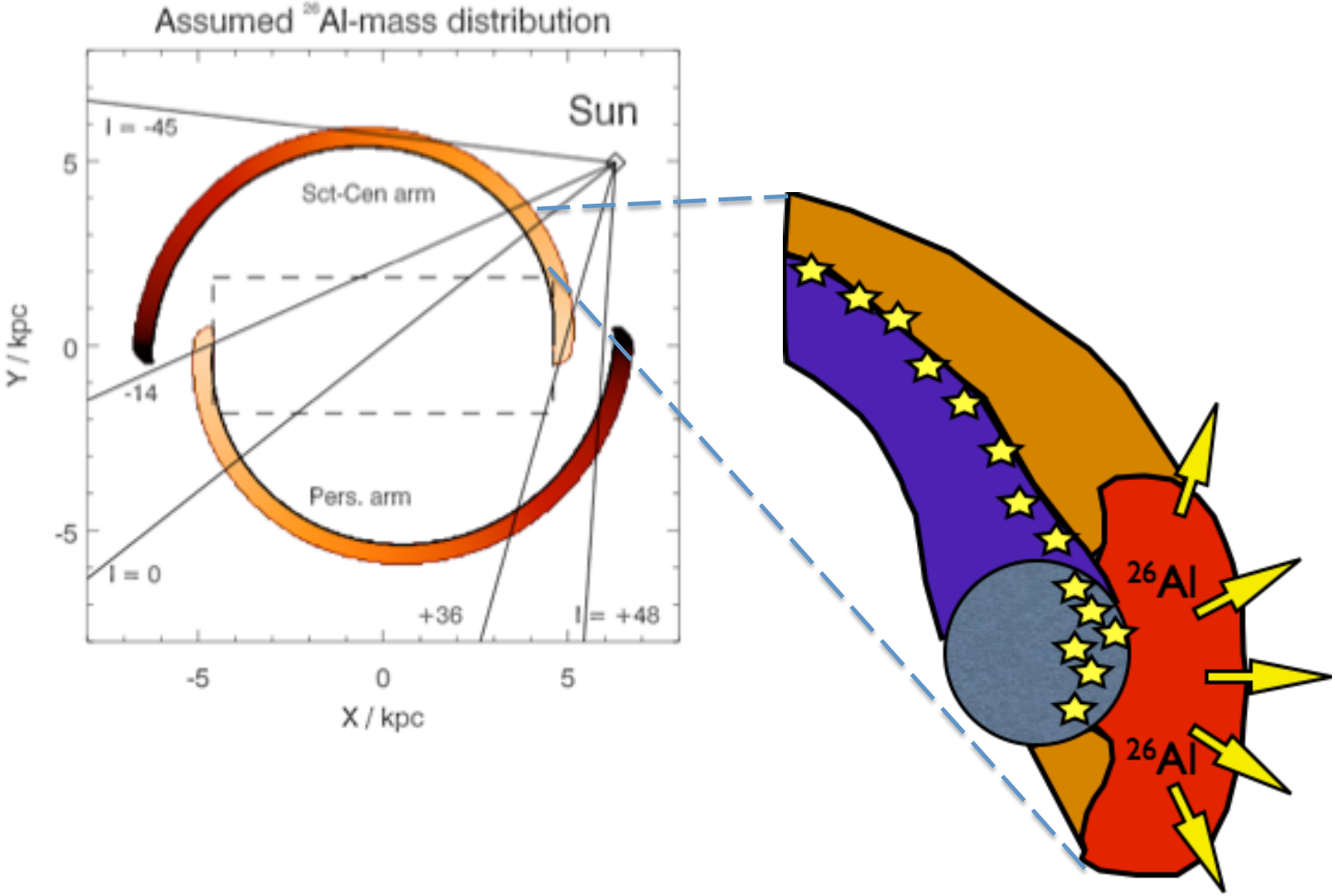
Kretschmer et al., A&A (2013)

The Galactic View: longitude-velocity diagrams

- excess velocity seen for massive-star ejecta!

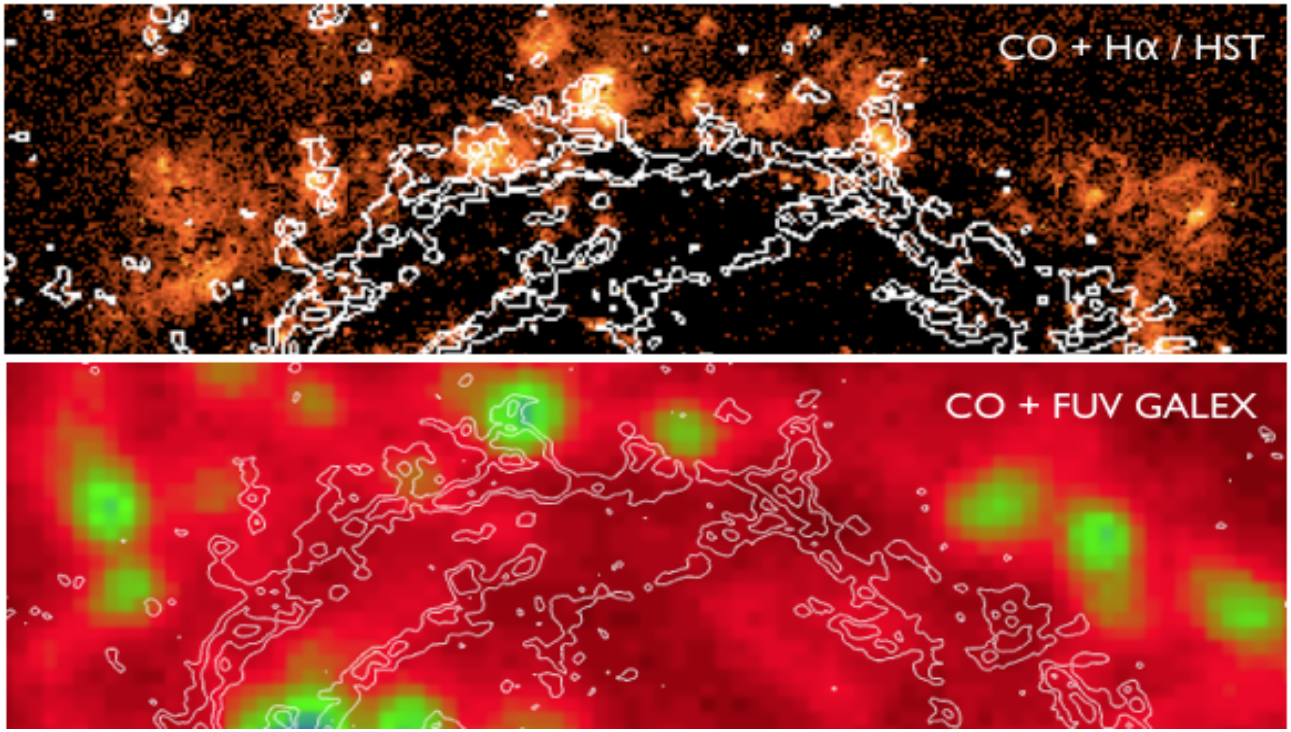


How Massive-Star Feedback Occurs…



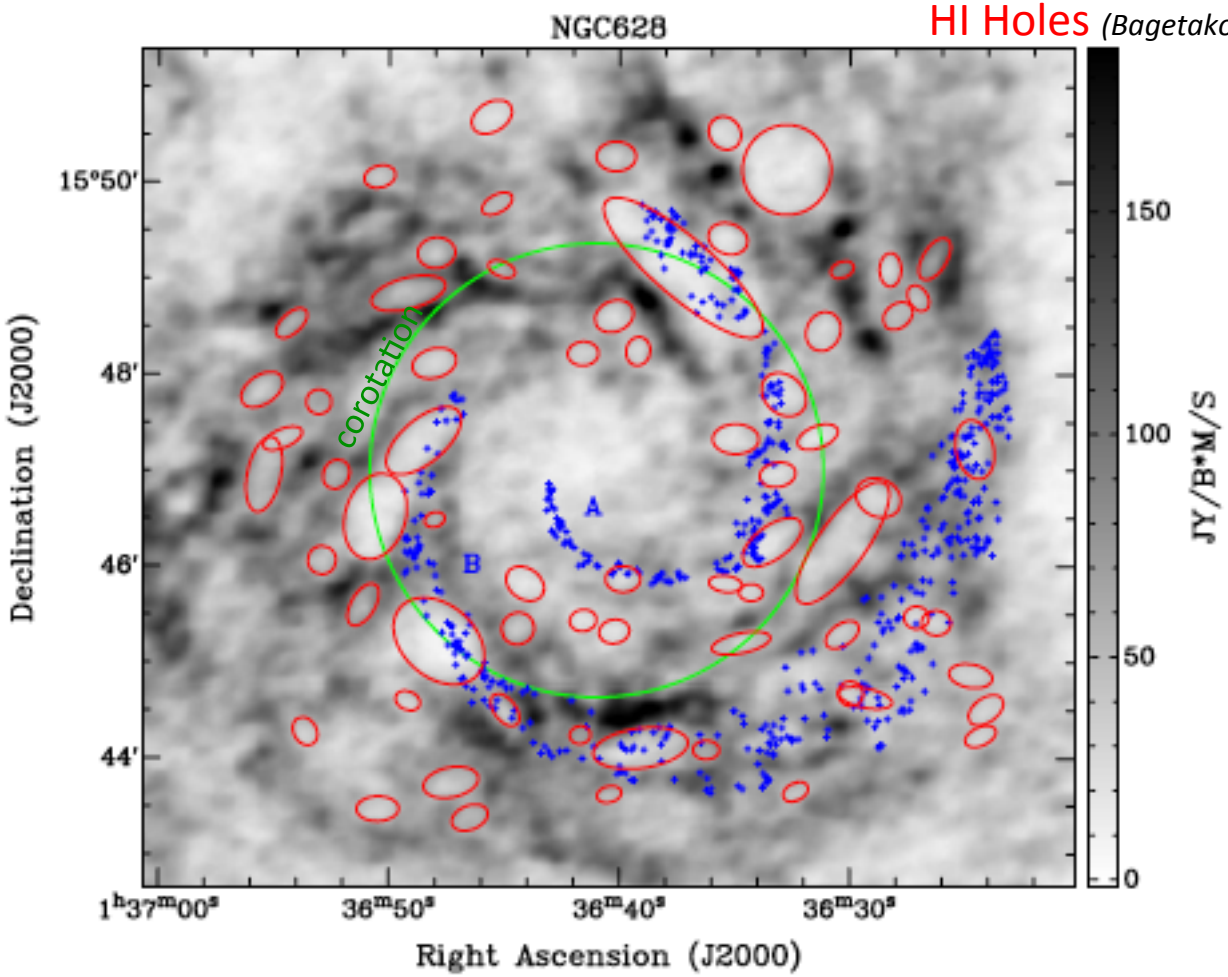
Spiral Arm Details

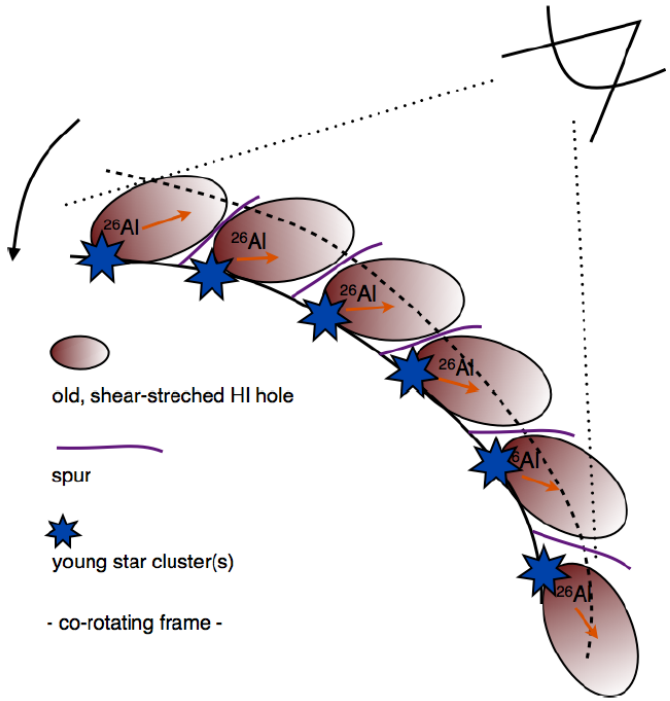
- M51: suitable aspect for spiral-arm studies
  - *Schinnerer et al. 2013*
- Massive-star groups at leading edges of spiral arms



Superbubbles and HI Holes

- ^{26}Al Ejecta Streaming into HI Holes Between Arms

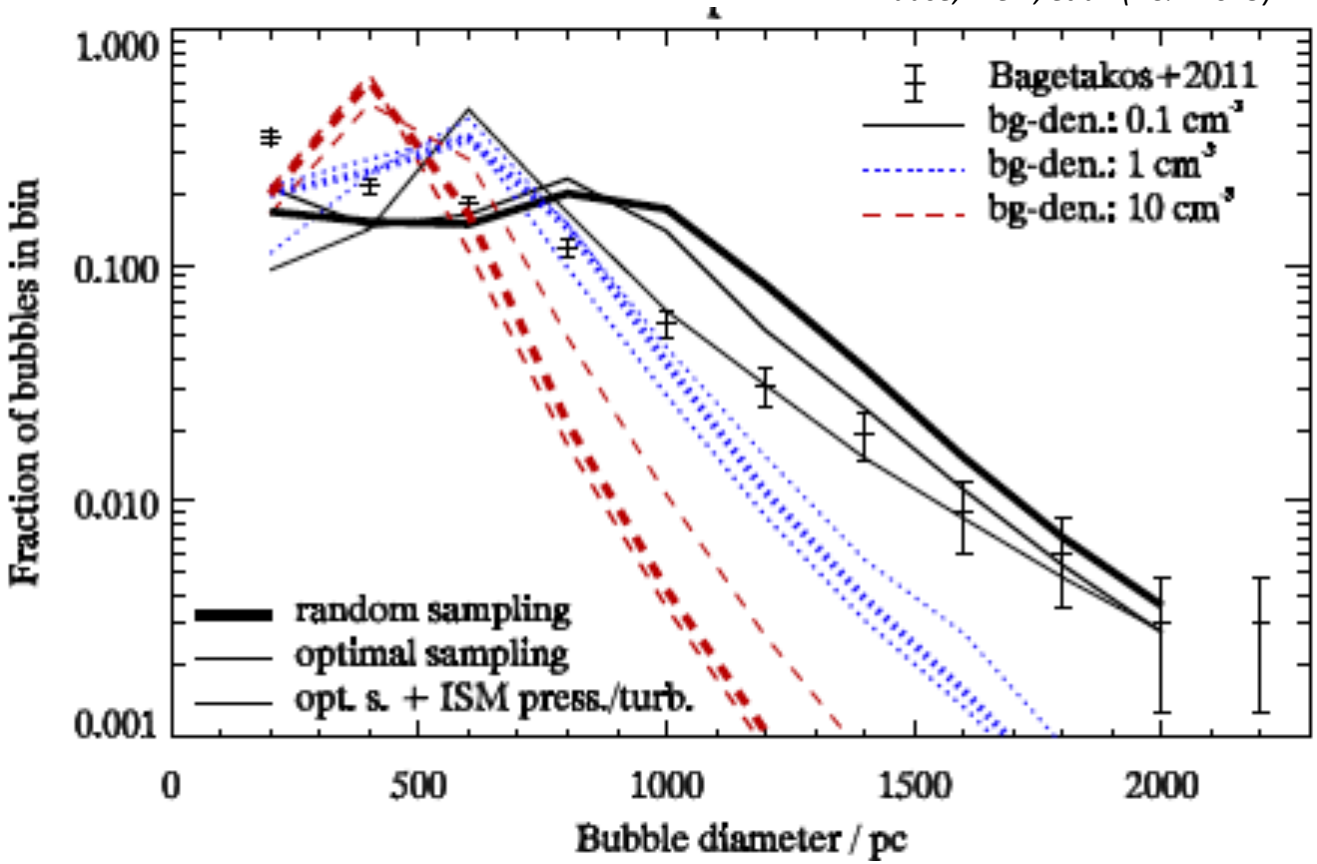




How do HI "holes" (~SB's) compare with this?

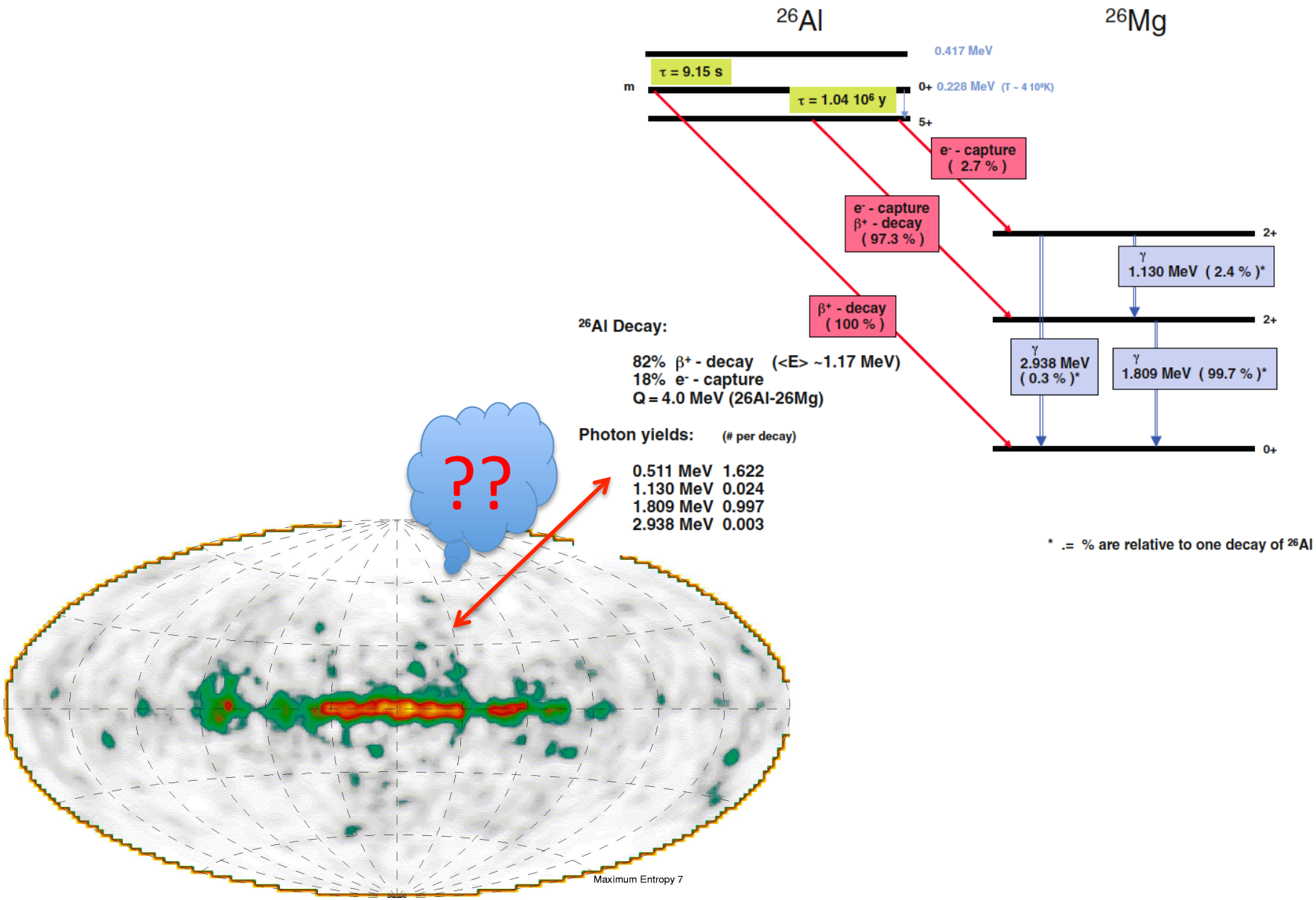
- PopSyn → Ejected E_{kin} from Star Clusters → SB size
  - Depends on ambient ISM density

Krause, Diehl, et al. (A&A 2015)



– Low-density environments are required to make large SBs

^{26}Al


26Al
26Mg
0.417 MeV
τ = 9.15 s
m
0+ 0.228 MeV (T ~ 4 10⁹K)
τ = 1.04 10⁶ y
5+
e⁻ - capture
(2.7 %)
e⁻ - capture
β⁺ - decay
(97.3 %)
2+
γ
1.130 MeV (2.4 %)*
β⁺ - decay
(100 %)
2+
γ
2.938 MeV
(0.3 %)*
γ
1.809 MeV (99.7 %)*
0+
26Al Decay:
82% β⁺ - decay (<E> ~1.17 MeV)
18% e⁻ - capture
Q = 4.0 MeV (26Al-26Mg)
Photon yields: (# per decay)
0.511 MeV 1.622
1.130 MeV 0.024
1.809 MeV 0.997
2.938 MeV 0.003
* .= % are relative to one decay of 26Al
??
Maximum Entropy 7

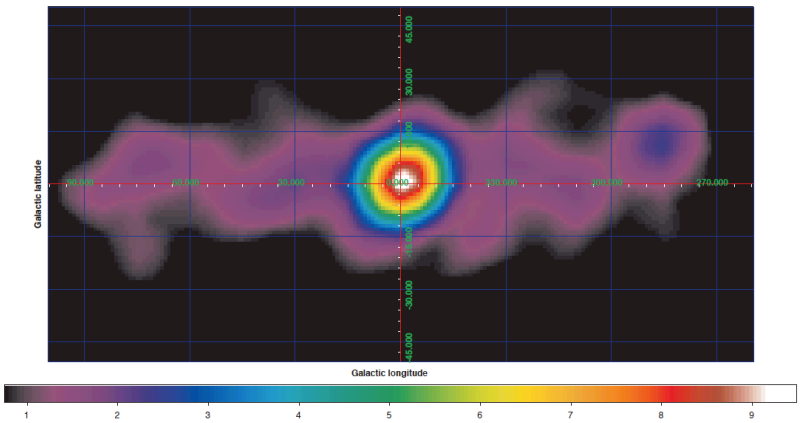
Understanding the 511 keV Line Emission

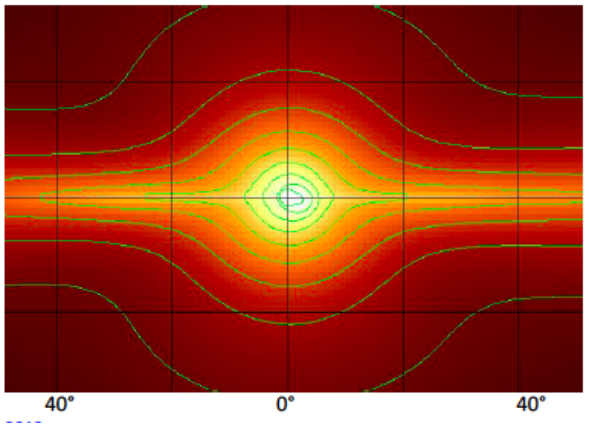
After 10 y of measurements and various different analyses

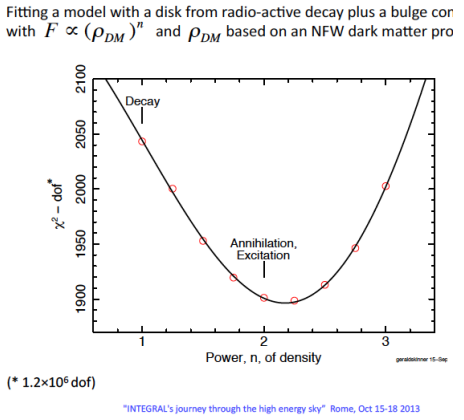
- *Knödlseder+ 2005, Jean+ 2005, Weidenspointner+ 2008, Churazov+ 2011, Bouchet+ 2011, Skinner et al. 2013, 2015a,b*

– Surprisingly-bright extended “bulge-like” emission

- None of the plausible candidate sources would produce this
- The centroid appears offset by ~1 deg towards 4th quadrant
- Sgr A*(?) appears to contribute ‘point-like’ emission, but cannot explain the extended bulge
- Dark matter annihilation matches observed “bulge” emission (but why??? There are pulsars, microquasars, SNe, …)







Discussion: Ejecta Recycling

- How do massive star photons/wind/SNe act to shape ISM around massive star groups?
  - Superbubbles; sweeping up ISM (enriched or not?)
  - How quickly is gas ejected? (→ GCs?)
- Can we use ISM morphology insights towards constraining the recycling time?
  - How and where do ejecta cool towards GMC cores?
- How may star formation be "triggered"?
  - Sco-Cen, Lupus cloud
- How may star forming gas be biased/enriched
  - e.g. making GC stellar populations / ESS enrichment / oceancrust ^{60}Fe?