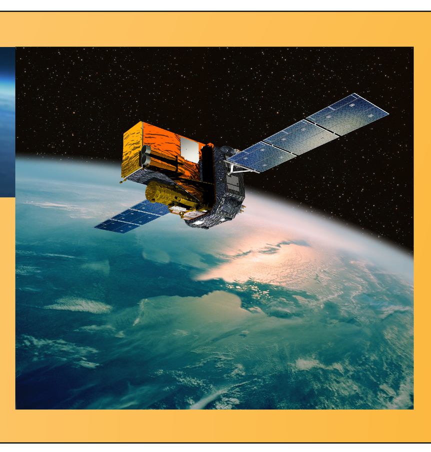


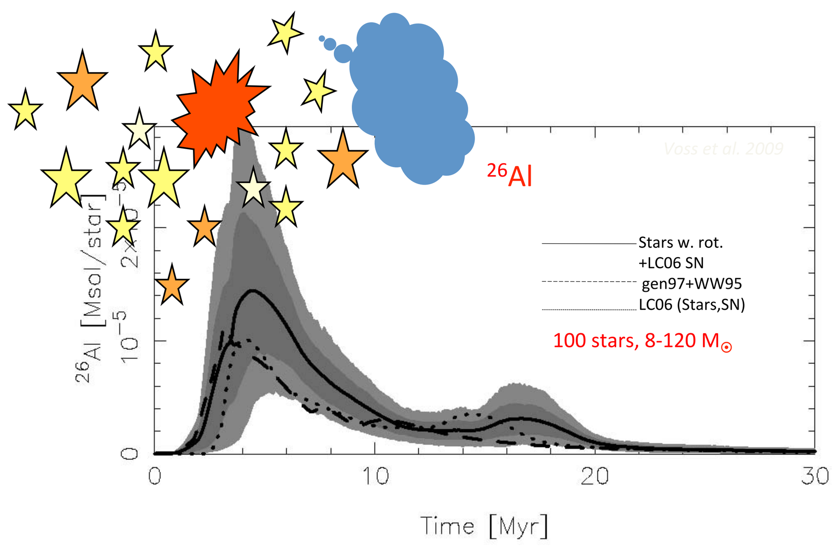
Nucleosynthesis Ejecta in the Interstellar Medium

Roland Diehl[1,2], Martin Krause[1], Karsten Kretschmer, Andreas Burkert[1,2,3], Ortwin Gerhard[1], Jochen Greiner[1], Thomas Siegert[1], & Wei Wang[4]

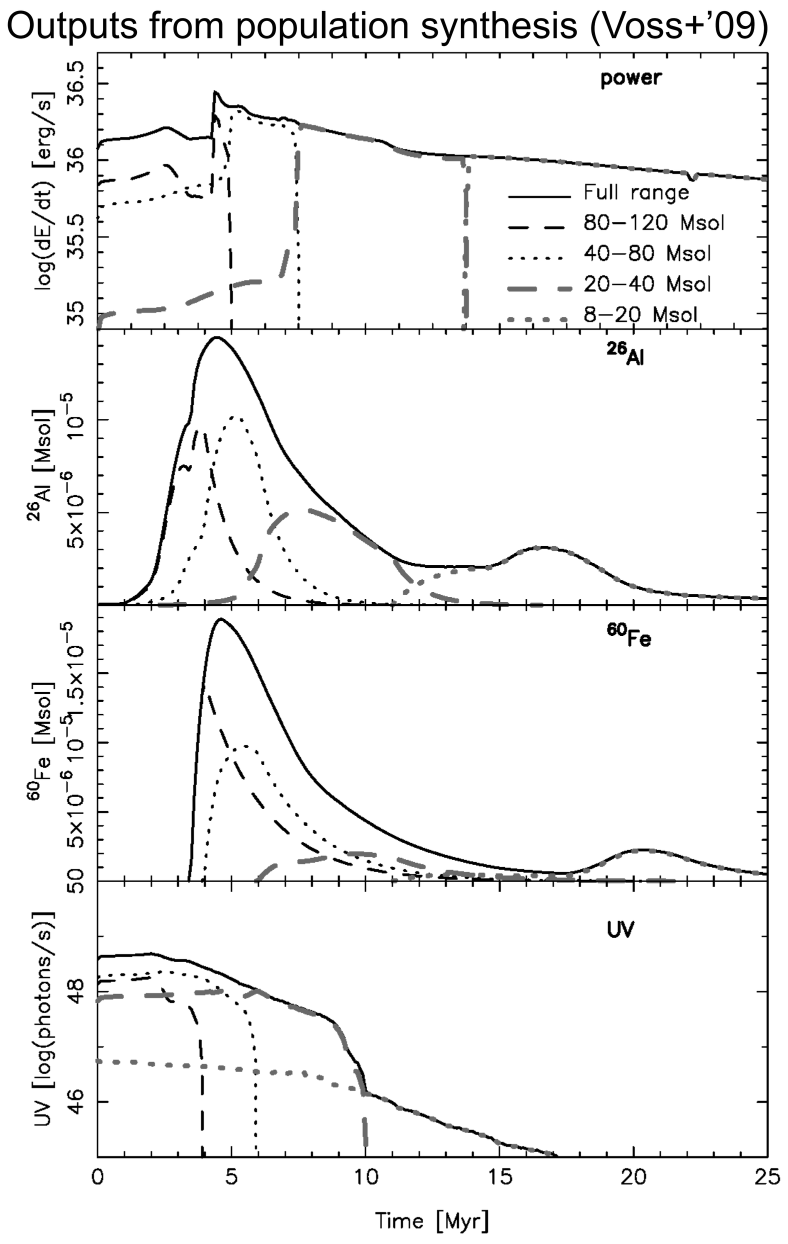
Abstract: Massive stars occur in groups, and shape their surroundings by their emissions of ionizing radiation, wind and supernova explosion energy, and ejecta containing freshly-produced isotopes. Gamma-ray observations can measure trace isotopes of the nucleosynthesis ejecta directly, and thus provide a new astronomical tool to reveal the otherwise nearly unaccessible hot and teneous phase of the ISM. We find new aspects of this „feedback“ of matter enriched with new isotopes into the ISM, in that ejecta flows into large cavities (superbubbles) extending into inter-arm regions and the halo of our Galaxy. We compare these results with hydrodynamic simulations and other astronomical data from IR through optical to X-rays and gamma-rays, to learn about massive-star group impacts on the time scale of millions of years.

Winds and Supernovae, New Isotopes, ...

Massive star groups can be modeled using a Monte-Carlo sampled standard initial-mass distribution and detailed stellar-evolution models, cluster richness being constrained by star counts (Voss et al. 2009). Thus the expected time histories of outputs from a coeval group of stars can be predicted (see plots), consistently modeling ionizing and kinetic energy imparted on their surroundings, plus nucleosynthesis ejecta, over ~30 My.

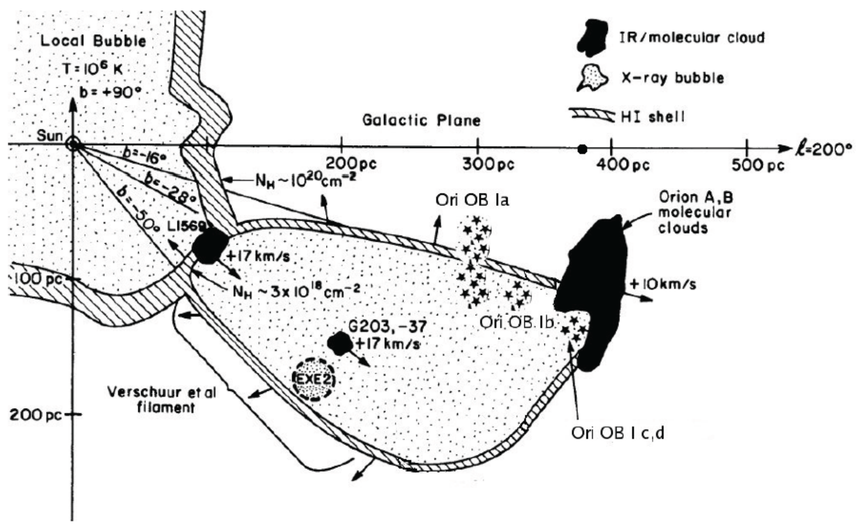


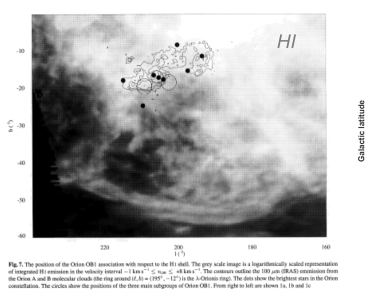
Outputs from population synthesis (Voss+'09)

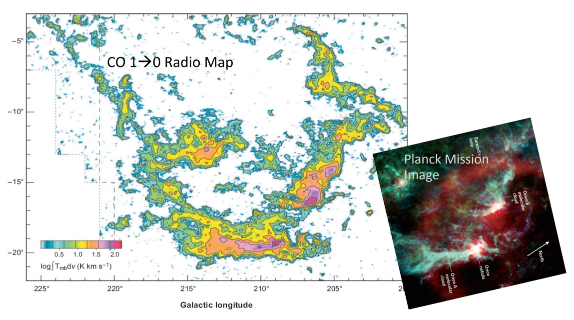


Orion OB1 / Eridanus ...Sco-Cen ....

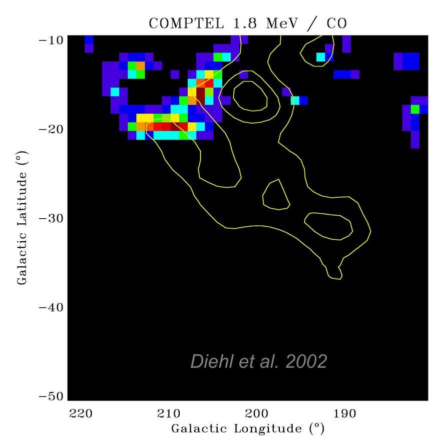
Orion OB1 subgroups a-d span ~12 My in age, and are one such example. Current nucleosynthesis ejecta are attributed to subgroup c, while subgroups a,b have created the Eridanus cavity, which extends towards the Sun. Cavity walls are seen in HI, the hot gas of the inner cavity in X-rays, and the radioactive afterglow in ^{26}Al gamma-rays demonstrates that ejecta flows are very asymmetric, extending from sources into pre-blown cavities. Offsets between massive-star groups and superbubbles may be a rather typical characteristic of feedback. The formation and evolution of the superbubbles thus may be the key to understanding feedback.

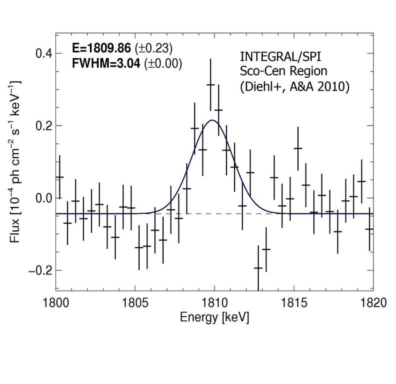


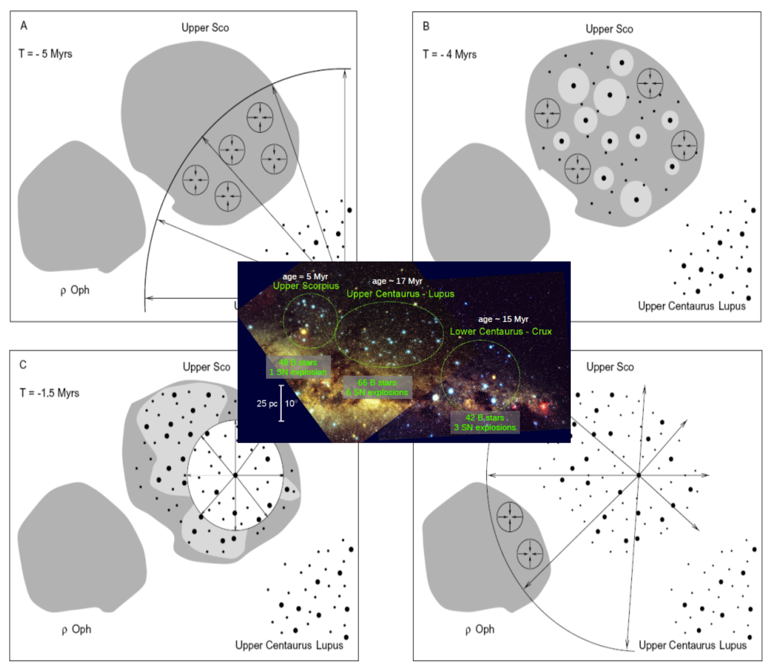




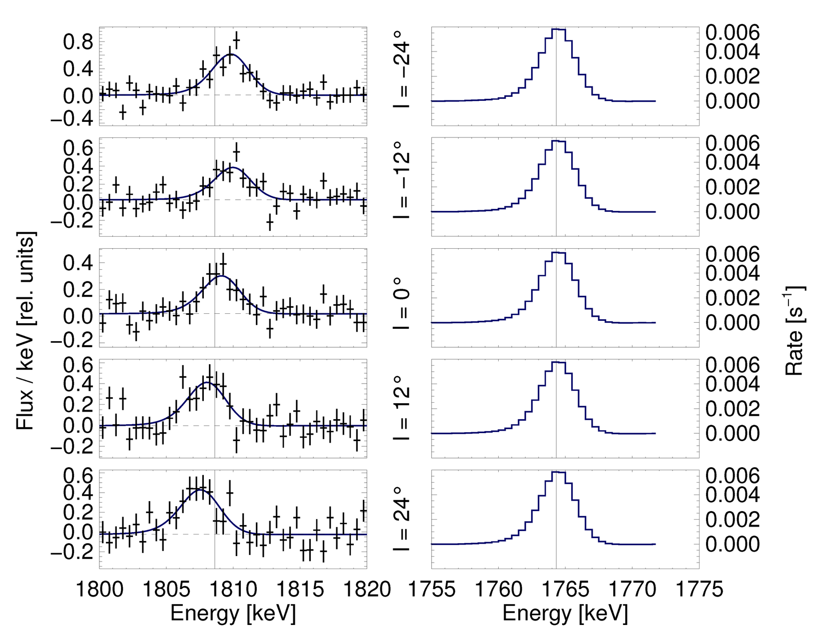
The nearby (~120 pc) Scorpius-Centaurus association includes 3 well-separated groups, with ages 5...17 My, which suggest successive triggering of star formation as the superbubble shocks from one group's late evolution reach neighboring molecular clouds (Preibisch & Zinnecker 1999). Detection of radioactive afterglow of ^{26}Al from near Upper Sco (Diehl et al. 2010) is consistent with this subgroup's most-recent activity, and another nearby test case of such feedback, sufficiently constrained from data.



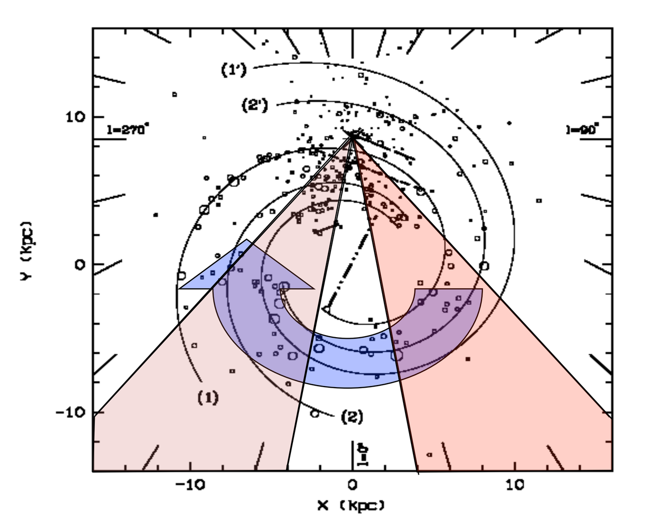


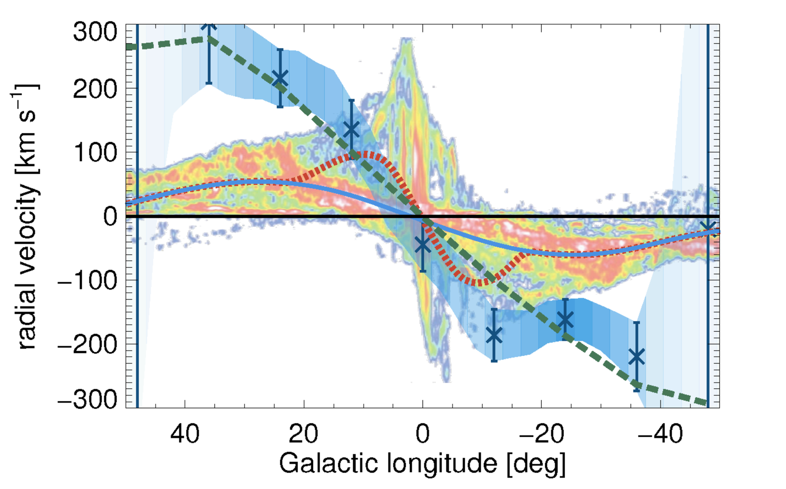


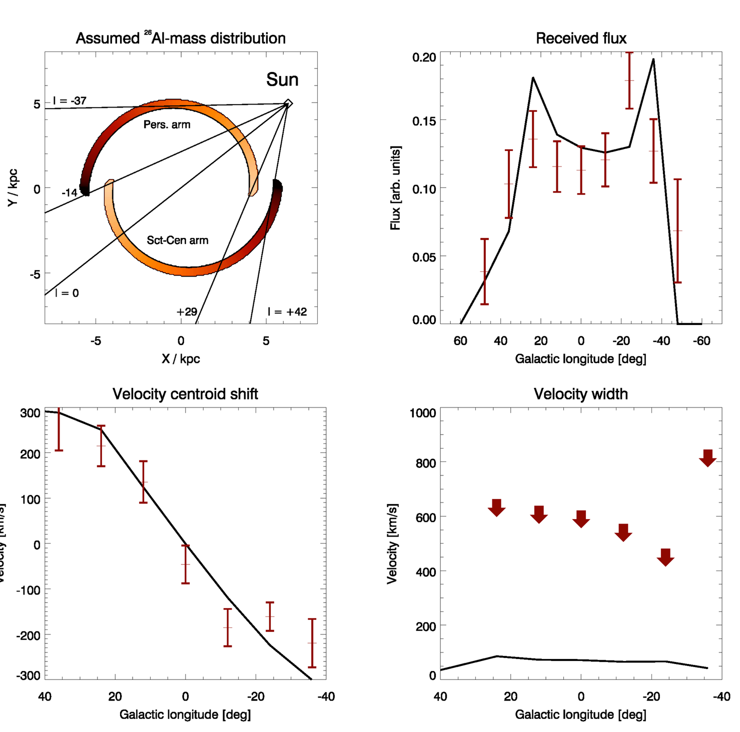
Asymmetric Superbubble Blow-Outs from Spiral Arms?



The ^{26}Al gamma-ray line can be seen to shift in position when viewing along the plane of the Galaxy (left), such as expected from large-scale rotation in the Galaxy. Now with ten years of INTEGRAL observations we are able to trace these line shifts and determine a longitude-velocity description for ejecta-enriched, hot, and teneous interstellar gas. Comparison (top right) shows that the ^{26}Al-enriched gas shows significant velocity excess of order 100-200 km s^{-1}. We interpret this as resulting from systematic offsets of massive-star groups at times where ^{26}Al ejection reaches its peak (3-5 My after birth), so that the superbubbles into which ^{26}Al is injected develop asymetric extents into the inter-arm regions. This geometry has been modeled by coarse assumptions (lower right figures): adopting ^{26}Al sources dominantly populating inner spiral arms, we add such a velocity offset towards the leading edge by 200 km s^{-1}, and reproduce our observations. The latitude extent of the Galactic disk as seen in ^{26}Al matches such superbubble-dominated kinematics, with ~150 pc scale height. This has implications from transport of angular momentum from the Galaxy's disk to its halo, and for escape of ionizing radiation into the IGM.







References

Roland Diehl

Astrophysical background:
Burkert A., Bodenheimer P,, MNRAS, 280, 1190 (1996)
Oey S., M. S. & Clarke, C. J., MNRAS, 289, 570 (1997)
Preibisch T., Zinnecker H., AJ, 117, 2381 (1999)
Zinnecker H., Yorke H.W., ARAA, 45, 481 (2007)

Our own recent work:
Diehl R. et al., A&A, 522, A51 (2010)
Diehl R. et al., Springer LNP 812 (2011)
Krause M., et al., MNRAS, 411, 580 (2011)
Martin P., et al., A&A, 506, 703 (2009)
Voss R., et al., A&A, 504, 531 (2009)
Voss R. et al., A&A, 520, 51 (2010)
Diehl R. et al., Proc.of Sci, INTEGRAL, 107 (2013)
Krause M. et al., A&A, 550, A49 (2013)
Kretschmer K. et al., A&A, submitted (2013)

Specific Region Literature:
Bally J., et al.; in : Handbook of SFRs ; ASP (2008)
De Geus E.J., et al., A&A, 262, 258 (1992)
De Zeeuw P.T., et al., AJ, 117, 354 (1999)
Pöppel W.G.L., et al., A&A, 512, A83 (2010)

Affiliations:
(2) Excellence Cluster „Origin and Evolution of the Universe“, D-85748 Garching, www.universe-cluster.de
(1) Max-Planck-Institut für extraterrestrische Physik, D-85741 Garching, www.mpe.mpg.de
(3) Universitätssternwarte München, of LMU, D-81679 München. www.usm.lmu.de
(4) National Astronomical Observatories, Chinese Acad. of Sci., Beijing 100012, China