Introduction to the Workshop

on

"Astronomy with Radioactivities"

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Abstract

This workshop brings together scientists from the different disciplines of astronomy where radioactivities play a major role: Gamma-ray line astronomy, meteoritics and stardust astronomy, as well as solar system and cosmic ray research. The common theme of studying sources of nucleosynthesis divides into the study of explosive and stellar nucleosynthesis sources, the condensation of radioactive trace isotopes in the source environment onto particles, and gas and dust propagation studies in interstellar space, cosmic rays, and the solar system. The results from gamma-ray astronomy on a few isotopes are still sparse. On the other hand, interpretation of rich results from meteoritic studies depend on complex propagation models. In the solar system, and in cosmic rays, radioactivities are used as a tool to study such propagation effects. With this workshop, we provide an opportunity for cross-fertilization and communication among these sub-areas under the common theme of astronomy with radioactivities.

Workshop Origin and History

Workshops for gamma-ray line analysis and interpretation have been held within the COMPTEL Team since many years. The collaboration of the Max Planck Institut für extraterrestrische Physik in Garching and Don Clayton's astrophysics group at Clemson University stimulated a widening of the scope of these meetings: The commonalities of stardust aspects and meteoritics with gamma-ray line astronomy, although sparse, present interesting challenges: Why is the interstellar ^{26}Al/^{27}Al ratio so much smaller than what is measured in meteorites of the solar system? What do the (again much higher) ratios for these and other isotopes from interstellar grains, hence from specific stellar sources, tell us about the sources of ^{26}Al in the Galaxy? There are a few obvious but crude answers to these questions; modeling and understanding in detail these connections of nucleosynthesis processes and ejecta propagation and condensation however seems overly difficult.

Our first workshop along this line was "The Radioactive Galaxy", held in Clemson in 1996. In this workshop, we emphasized large-scale aspects of star formation in the Galaxy, and how this relates to nucleosynthesis byproducts which cause gamma-ray lines. The new Galactic map of ^{26}Al radioactivity and the discovery of positron annihilation emission from the Galactic disk suggested to focus on a better understanding of the distribution of sources in the Galaxy, in particular when one considers the poor spatial resolution of gamma-ray measurements, on the order of degrees. At this workshop we included aspects of nuclear-reaction cross sections and of models for nucleosynthesis source types, and discussed prospects in gamma-ray instrumentation; yet most of the discussion was focussed on star formation patterns in the Galaxy, and how they could be related to gamma-ray data. The connection to interstellar grain results was tagged as a "tough question" (Clayton), from our understanding that prominent sources of interstellar dust, AGB stars and novae, would not be major sources of ^{26}Al in interstellar space, ^{26}Al was believed to come from massive stars. At that conference, Jack Tueller had presented the GRIS results on a broadening of the ^{26}Al gamma-ray line for the first time. The connection of ^{26}Al measurements to high-velocity gas and cosmic ray acceleration was obvious, and pursued by observers and theoreticians in recent years.

Preparing now this Ringberg workshop, we decided to shift the emphasis and include more discussion of meteoritic and cosmic ray aspects. This also brings us 'closer to home', to again pose the question of why the solar system appears enriched in ^{26}Al, but now in the context of linking ^{26}Al ejected into interstellar space by its propagation aspects in the interstellar medium and to within a protostellar system. The discovery of ^{44}Ti from supernova grains in meteoritic samples (Nittler et al. 1996) highlights another link between stardust and gamma-rays: The proof of ^{44}Ti production in supernovae exists now from isotopic analyses of individual grains by the meteoritics community, and from Cas A supernova remnant studies with different telescopes by the high-energy astronomers (see contributions by Iyudin and by The). Consistency of these results should be further explored. The production and fate of the ^{44}Ti isotope is most likely determined by physical processes in the very inner region of supernova explosions, a region which is not accessible through other, more conventional branches of astronomical observations. We believe that the rather direct message told by gamma-rays is an important complement to the precise laboratory analyses of meteoritic samples which were so brightly discussed in the conference "Astrophysical Implications of the Laboratory Study of Presolar Material" in St Louis a three years ago (Bernatowicz & Zinner 1997). We take up the same theme, but now start out from the gamma-ray spectroscopy view, yet again include meteoritics and address theories of nucleosynthesis and interstellar propagation.

Gamma-Ray Line Astronomy of Radioactivities

From the many radioactive isotopes, whose decay in principle can tell us about nucleosynthesis, only a small number of isotopes turns out useful for gamma-ray astronomy: The abundance and decay time must be sufficient to create a sufficiently-bright gamma-ray source, and the decay must occur in a 'gamma-ray thin' medium. This excludes all shortlived isotopes with decay times below the material transport or ejection times, and excludes trace isotopes far beyond the iron peak. Still, we are left with a set of isotopes (see Table 1) which span an effective exposure time between the time scale of explosive events (days) and the evolution time scale of massive stars (My).

The radioactive-decay gamma-rays translate directly into isotopic abundances (less direct though for the annihilation of positrons emitted in β+ decays). In comparison, other observables such as lightcurves in optical/IR/X regimes, require a model of the deposit of radioactive energy and its transfer into other excitation channels of matter, which can be a complex tasks with associated uncertainties impacting on the result. This makes our study still worthwhile, even though building gamma-ray telescopes is a major challenge due to strong instrumental gamma-ray backgrounds caused by cosmic-ray activation, in addition to the difficulties to record directional information in the absence of focussing optics. We address the latter issues in the instrumental section of the workshop.

Isotope	**Decaytime**	**Decay Chain**	**γ -Ray Energy (keV)**
^{56}Ni	8.8 d	$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co}^*$	158, 812, 750, 480
^{7}Be	77 d	$^{7}\mathrm{Be} \rightarrow {}^{7}\mathrm{Li}^*$	478
^{56}Co	111 d	$^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}^* + e^+$	847, 1238
^{57}Ni	390 d	$^{57}\mathrm{Co} \rightarrow {}^{57}\mathrm{Fe}^*$	122
^{22}Na	3.8 y	$^{22}\mathrm{Na} \rightarrow {}^{22}\mathrm{Ne}^* + e^+$	1275
^{44}Ti	89 y	$^{44}\mathrm{Ti} \rightarrow {}^{44}\mathrm{Sc}^* \rightarrow {}^{44}\mathrm{Ca}^* + e^+$	1157, 78, 68
^{26}Al	1.04 10^6y	$^{26}\mathrm{Al} \rightarrow {}^{26}\mathrm{Mg}^* + e^+$	1809
^{60}Fe	2.0 10^6y	$^{60}\mathrm{Fe} \rightarrow {}^{60}\mathrm{Co}^*$	1173, 1332
e^+	.... 10^5y	$e^+ + e^- \rightarrow \mathrm{Ps} \rightarrow \gamma\gamma$..	511, <511

Table 1: Relevant Isotopes for Gamma-Ray Astronomy

Spectacular results have been reported in the last two decades from gamma-ray line astronomy: Shortlived radioactivities were seen from supernovae 1987A, SN1991T, and Cas A; ^{26}Al was detected in the interstellar medium and the ^{26}Al sky image showed Galactic-plane emission with hot spots along the Galactic plane, and ^{44}Ti emission revealed a supernova remnant in the solar vicinity towards the Vela direction. Possibly also related to nucleosynthesis and radioactivities, the Orion

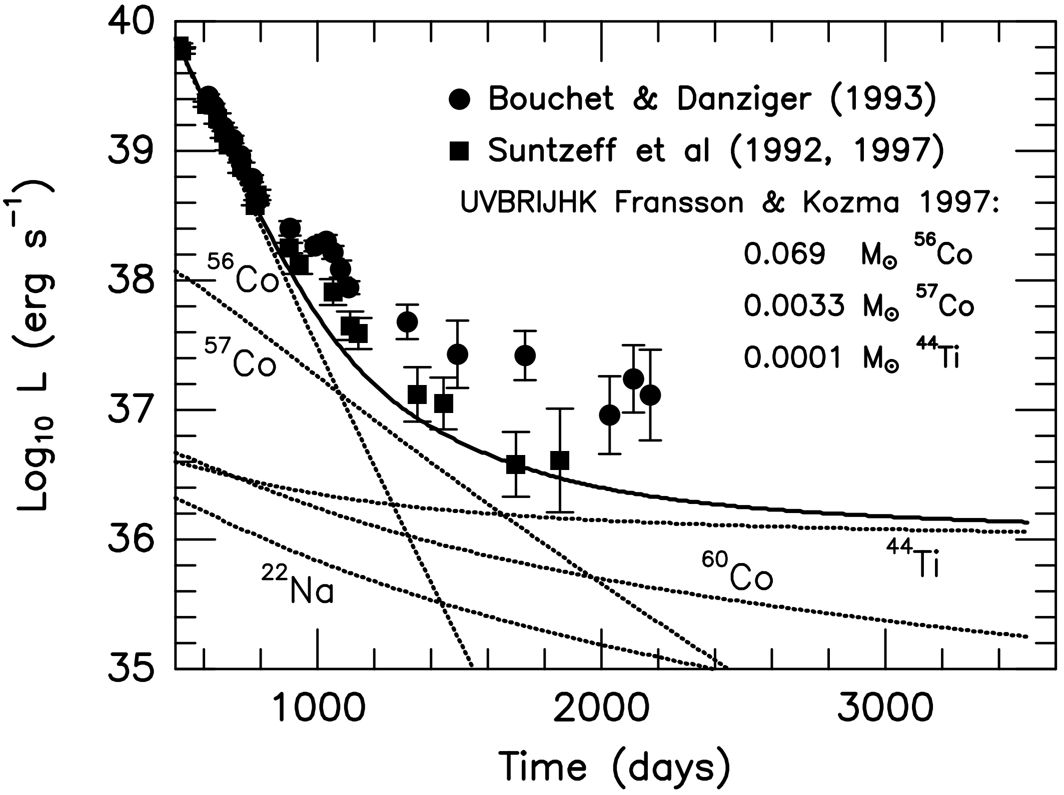


Fig. 1: The bolometric light curve of SN1987A, and its relation to energy input from radioactivities of different decay time scales (from Diehl & Timmes 1998)

region appeared to be a site of enormously-enhanced flux density in low-energy cosmic rays, as deduced from ^{12}C and ^{16}O deexcitation lines. The inner Galaxy appeared to feature a highly-variable compact source of positrons, and also produce a fountain in annihilation radiation extending far above the plane. Several of those exciting results turned out more modest and less-well constrained by gamma-ray line data as many of us wish. Yet, the remaining results illuminate several interesting astrophysical problems, as summarized here (see also Diehl & Timmes 1998).

A calibration of the nuclear energy sources of supernovae, novae, and hydrostatic burning inside stars through gamma-ray lines is crucial for models of these sites. SN1987A has been a breakthrough for supernova studies due to many complementing observations, the ^{57}Co gamma-ray measurement was one of the highlights (e.g. Clayton et al. 1992). The measurements of gamma-rays from the ^{56}Ni decay chain by SMM (Matz 1988) provided clear proof of unexpectedly large mixing of ^{56}Ni in the envelope. The UVOIR light curve model suggests that SN1987A's gamma-ray story may continue with a ^{44}Ti measurement by INTEGRAL and other next-generation telescopes (see Figure 1).

Thermonuclear supernovae (SNIa) produce 10 times or more ^{56}Ni radioactivity than core collapses (see contribution by Hillebrandt), therefore should be detectable in gamma-ray lines from much larger distances out to the Virgo cluster of galaxies, in particular in the absence of overlying envelopes. SN 1991T was at the edge of CGRO's range (14-17 Mpc), but unusually bright. The 3σ detection of the ^{56}Co lines by COMPTEL (Morris et al. 1995, 1997) was a surprise. But only weak constraints could be derived due to large systematic uncertainty, the inferred Ni mass ranges from 0.6 to (unphysical) 3.3 $M_\odot$. The CGRO user community devoted nearly four months of observing time to the second opportunity of the CGRO mission, SN1998bu in M96. Yet, neither COMPTEL (Georgii et al. 2000) nor OSSE (Leising et al. 2000) apparently see the expected radioactivity lines. In spite of the distance uncertainty (9-12 Mpc), the gamma-ray line limits from the ^{56}Ni decay chain of 2-5 10^{-5} ph cm^{-2} s^{-1} already rule out some of the brighter (because well-mixed) models for thermonuclear supernovae, in particular the 'Helium cap' models with a large amount of ^{56}Ni produced in the outer part of the supernova.

^{44}Ti and its abundance relative to co-produced Ni should be a sensitive probe of entropy and neutron excess in the inner region of supernovae, addressing current issues in supernova studies (see contributions by Thielemann and by Woosley): The location of the mass cut is essentially an unknown parameter of models, and explosion asymmetries have been suspected and are suggested e.g. by pulsar runaway or SNR jets (see also contribution by Kifonidis); the "collapsar" model for Gamma-Ray Bursts indicates far-reaching implications (MacFadyen & Woosley 1999). Gamma-ray line shape details can be resolved with Ge detectors and will encode kinematics of ejecta from regions close to the mass cut, thus being a prime target for INTEGRAL, in addition to determination of the true ^{44}Ti yield of the supernova. Such measurements are largely unaffected by processes in the overlying envelope or early supernova, exept for the possible modification of the ^{44}Ti decay time in the extreme of full ionization of ^{44}Ti (Mochizuki et al. 1999).

The ^{44}Ti decay chain emits gamma-ray lines at 1157, 68, and 78 keV. ^{44}Ti with a decay time τ=89y causes a supernova to shine brighly in gamma-rays long after its optical, X, UV, IR, and radio emission have decayed below visibility, and even until secondary emission from the blast wave interaction with circumstellar and interstellar medium may have brightened already to reveal a young supernova remnant through X-rays and radio emission from the shock. The COMPTEL 1.157 MeV gamma-ray line detection from the Cas A supernova (Iyudin et al. 1994) confirms the general picture of supernova-dominated 44Ca production through ^{44}Ti in the α-rich freeze-out. The COMPTEL survey may have shown a second source in the Vela region (Iyudin et al. 1998), although large uncertainty (Schönfelder et al. 2000) prevents meaningful interpretations of possible source parameters. ^{44}Ti appears to be an excellent tool for studying young supernova remnants (see contributions by Iyudin, by Kumagai, and by The).

There are a few striking issues in ^{44}Ti studies: The Cas A detection appeared unlikely because it is so old (319 years, hence at 2.7% of the initial ^{44}Ti luminosity), bcause it was dim as an optical supernova if historical records are correct, and because it is distant (3.4 kpc). (Circumstellar dust may be a good explanation of the brightness issue; see Hartmann et al. 1997). The second source, if confirmed, also shows up in the outer part of the Galactic disk, and not in the major star forming regions of the Galaxy. A Monte Carlo study (The et al. 2000) demonstrates that this is not in accord with expectations; the paucity of ^{44}Ti objects suggests that the ejection of ^{44}Ti is not a common characteristic of supernovae. On the other hand, the late SN1987A light curve is perfectly consistent with ^{44}Ti power input (see Figure 1) and supports ^{44}Ti to be a common supernova product. The COMPTEL flux in the ^{44}Ti line as measured from Cas A also is perfectly consistent with theoretical predictions, in particular if a possible underlying continuum (Strong et al. 2000) and the observed trend for COMPTEL of decreasing flux values with increasing signal-to-background ratio is considered. From our meteoritics colleagues, the discovery of extinct ^{44}Ti in several interstellar grains establishes independent proof of ^{44}Ti production in supernovae: from their isotopic anomalies, clearly these grains had formed within a supernova (Nittler et al. 1996). The 1-3 new source hints in COMPTEL ^{44}Ti gamma-ray surveys (Dupraz et al. 1997; Iyudin et al. 1999) will be key targets for deep searches with future experiments, in addition to detailed studies of Cas A and SN1987A.

Novae explosive nucleosynthesis (see contribution by Hernanz) should also leave traces in gamma-rays, but also in interstellar grains because novae are copious dust producers. Nova radioactive products drive a hard X-ray continuum for days, mainly from ^{13}N and ^{18}F. The candidate isotopes to be detectable for nearby (~few hundred pc) novae are ^{7}Be, τ=77d, and ^{22}Na, τ=3.75y; an additional early 511 keV flash is expected from the shortlived β^+ decays (Gomez-Gomar et al. 1998, Hernanz et al. 1999). The early ^{7}Be and 511 keV gamma-rays are brightest by far, yet observations will be serendipitous because the nova has not yet 'appeared'. None of the nova radioactivities has been detected so far (Iyudin et al. 1995, Harris et al 1991).

Nuclear burning inside stars remains largely invisible even through penetrating gamma-rays. Wolf Rayet and AGB stars mark the phases in stellar evolution, where deep convective mixing of the envelope of the star combines with material ejection through stellar winds, and thus reveals products of inner nuclear burning. Radioactivity yields could be sufficient to make nearby WR stars visible in ^{26}Al gamma-rays. For the closest WR star in the γ^2Vel binary system at 260 pc, the non-detection of ^{26}Al gamma-rays with COMPTEL (Oberlack et al. 2000) may indicate overly optimistic WR ^{26}Al yields in our present model understandings (Meynet et al 1997).

COMPTEL data could map the relatively intense ^{26}Al gamma-ray line emission over the whole sky (Figure 2; Diehl et al. 1995, Oberlack et al. 1996, Knödlseder et al. 1999a, Bloemen et al. 2000; see contributions by Knödlseder and by Oberlack). This provides a rich database for spatial distribution studies of Galactic nucleosynthesis over the past few million years. The maps show that ^{26}Al production occurs throughout the Galaxy, roughly as expected from shortlived stars formed from molecular clouds: globally CO data are not too different from the ^{26}Al map. At closer inspection, the dust emission at 240μm as mapped by the COBE DIRBE instrument, but also free-free emission derived from COBE DMR radio data at 53 GHz, provide a better correlation to ^{26}Al emission over the entire range of the Galaxy (Knödlseder et al. 1999b). Massive stars are expected to be responsible for free-free emission, as their UV luminosity ionizes the surrounding medium; similarly, winds and supernovae from massive stars inject significant turbulence into the interstellar medium, heating dust in those regions in addition to the bright stellar radiation field. It is therefore plausible, that massive stars also are the dominating sources of ^{26}Al, and 1.809 MeV emission traces their spatial distribution throughout the Galaxy. In turn, other candidate sources such as novae and AGB stars apparently are minor contributors on the Galactic scale.

A detection of decay gamma-rays from ^{60}Fe, which is co-produced with ^{26}Al in core-collapse supernovae, is still awaited, and would strenghten these conclusions (Naya et al. 1998; Diehl et al. 1998).

In our Galaxy, apparently the Cygnus, Carina, and Vela regions are regions of currently-enhanced massive star activity, from these ^{26}Al maps. For the Cygnus region, observations allow to assemble a complete census of massive stars and their associations, as well as inferences of past supernova activity from Cygnus superbubble and Loop. Modeling the expected Cygnus ^{26}Al emission from these present-day observables, one obtains ~80% of the observed 1.809 MeV flux; this appears to be a high fraction, considering that the massive stars which terminated their life a million years ago should have left not much observables exept ^{26}Al (Plüschke et al. 2000, and his contribution here). In the Vela region, the ^{26}Al-bright Molecular Ridge (VMR) is marked by signs of recent massive star formation, warm

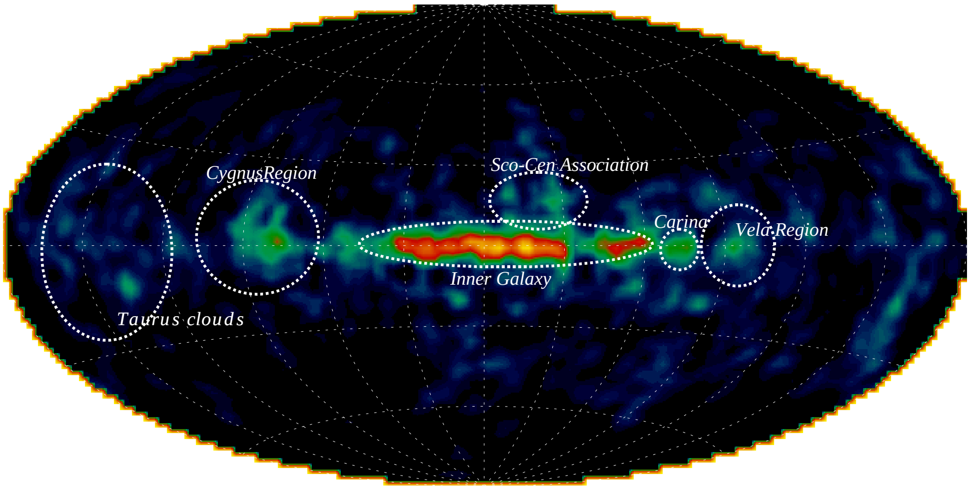


Fig. 2: The apparent distribution of ^{26}Al *sources in the Galaxy, as mapped by 1.809 MeV gamma-rays with COMPTEL*

dust and the brightest HII regions of the southern sky. Well-known foreground sources such as the 11000-year-old Vela Supernova Remnant, and the Wolf-Rayet/O-star binary system γ^2Vel are still too far away to be regognizable above this diffuse background, even though recent studies have reduced the quoted distances for these objects in both cases (Diehl et al 1999; see also contribution by Meynet). Localized astronomical studies, like those in the Cygnus and Vela regions, including application of population synthesis models, may turn out as promising laboratories for stellar nucleosynthesis study.

Observations with Ge detectors have suggested that the 1.809 MeV line from ^{26}Al is broader than shown by the original HEAO-C measurement (Naya et al. 1996). Assuming the observed broadening is of cosmic nature, a large fraction of ^{26}Al decays would occur from nuclei with velocities in the 500 km s^{-1} range. It is not easy to imagine environments which can support high velocities over the million-year decay time scale (see Chen et al. 1997). Yet, aluminium is highly refractory and may preferentially end up on dust grains, which could be a major contributor to cosmic ray nuclei if acceleration in supernova shock fronts in the environment of stellar associations is important (Ellison et al. 1997, Sturner and Naya 1999). INTEGRAL (Winkler 1996) with its high-resolution Ge detectors should clearly enlighten this issue.

^{26}Al decay is *one* of the radioactivity positron sources in the Galaxy, probably at the level of 10% of the total, others being the decay chains of 60Co, ^{44}Ti, and nova-produced ^{7}Be, ^{19}F, and ^{22}Na. The disk of the Galaxy has been shown to emit positron annihilation radiation in the 511 keV line and the 3-photon para-positronium annihilation: OSSE scans along the Galactic plane show that the 511 keV source(s) reported from earlier balloon observations are not restriced to the Galactic Center region (Purcell et al. 1997, Kinzer et al. 1999; see contribution by Milne). The supernova and nova radioactivity contributions to interstellar positrons are very uncertain, mainly because positron transport in young (age ~years) supernova remnants is unclear (Milne et al. 1997). The "annihilation fountain" inferred from earlier OSSE measurements may be another laboratory to specifically study the fate of positrons injected in interstellar space (e.g. Dermer and Skibo 1997).

In summary, gamma-ray line measurements have established several constraints for astrophysics: Direct observations of radioactivities have begun to calibrate nuclear energy sources. Maps in the lines of ^{26}Al decay and e+ annihilation provide a first astronomical database in line gamma-rays for correlation studies. Line shape and isotope ratio results indicate that the study of stellar mixing and of the sources of cosmic radiation will also employ gamma-ray line measurements.

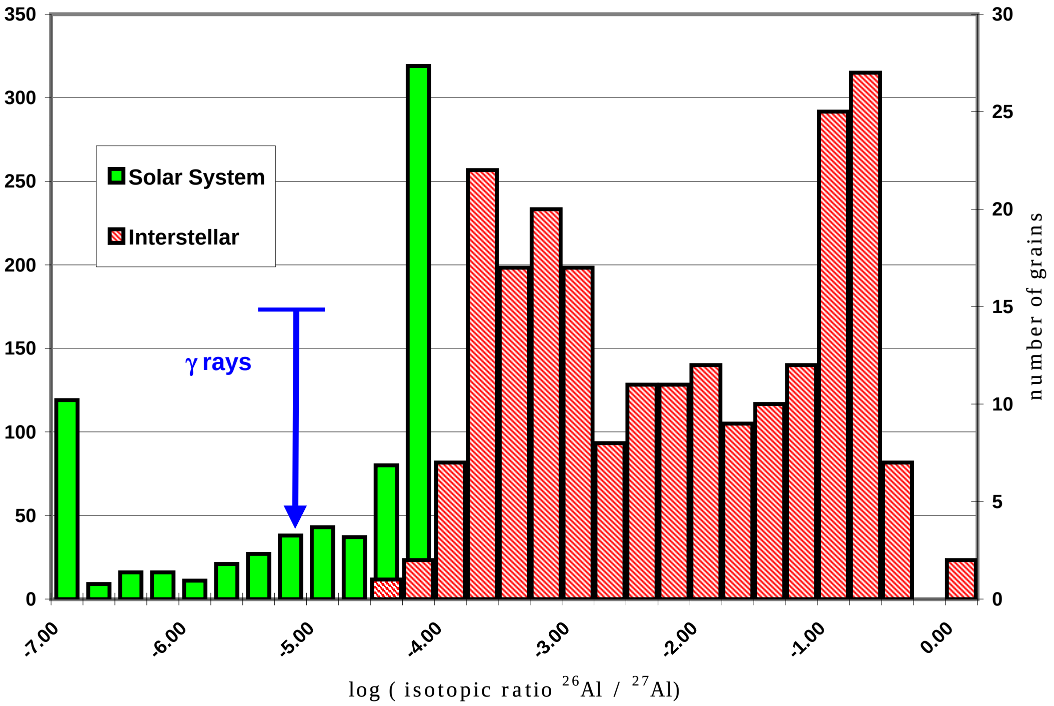
Radioactivity Research Areas and Workshop Themes

Chemical evolution of galaxies results from cycling of matter through stars forming from clouds in the ISM, nuclear processes during stellar evolution produce radioactivities, and stellar winds and explosions feed nucleosynthesis products back into this cycle. Our measurement access to the nuclear processes is limited and biased, and we need to understand in particular the transport processes back into the ISM (see contributions by Chevalier, by Woitke, and by Clayton) and towards our measurement apparatus through comparisons and consistency checks of inferred results, where possible.

Gamma-ray emission and transport is complex in dense environments such as novae, supernovae, and stellar interiors, but is rather well-understood in interstellar space. Line shape details from radioactive-decay lines allow a direct kinematic interpretation, and tell us about 3-dimensional effects of convection and mixing relativey close to the nucleosynthesis site. On the other hand, the isotopic database from the analyses of interstellar grains is of paramount precision and holds the information about those sites where these particular grains have been formed (see Bernatowicz & Zinner 1997). The regions where mixing and turbulent motions imprint a signature to gamma-ray lines are not quite the same as the regions, where those same 3-dimensional effects control condensation of ejecta into interstellar grains. It is one of the current challenges to connect our understanding of envelope dynamics to condensation models in a consistent manner, so that interstellar-grain isotopic ratios and interstellar-gas isotopic ratios can be compared and consistently evaluated for nucleosynthesis parameters (see Woitke's contribution). Spatial information remains limited, onto the solar system for meteoritic studies, and to the scale of major star forming complexes for gamma-ray measurements.

The detection of ^{44}Ti-contaminated supernova grains raises the question of how grains can be formed in the supernova envelope; the low C/O ratio would prevent grain formation according to conventional belief (see Woitke's and Clayton's contributions). Formation of ^{44}Ti-enriched supernova grains could require special conditions, occur in subclasses of supernovae only. Although the ^{44}Ti gamma-ray sources appear to be non-typical, too, the respective conditions may not be related. Alternatively, ^{44}Ti production in a supernova may imply unusual 3D processes which affect the measured gamma-ray line shape, the Ti and Ni isotopic ratios, and in turn the condensation of Ti. The relation of supernova grain isotopic ratios to spectroscopic measurements of ejecta composition in young supernova remnants is not obvious, even though Cas A appears as an excellent laboratory. Different branches of astronomy are to be exploited for an understanding of supernova-produced ^{44}Ti.

The ^{26}Al database from meteoritic studies reveals several distinct classes of samples (see Figure 3, MacPhersson et al. 1995). On one hand, there appears to be a population of interstellar grains with high ^{26}Al/^{27}Al ratios up to 1. These suggest links to supernova dust again, more plausibly though to dust formed in AGB winds, as inferred from the rich database of precisely mapped C and N isotope ratios (see contributions by Amari and by Hoppe, and the theory contributions on ABG stars by Mowlavi and by Gallino). Clearly those high ratios are very different from the interstellar average detected in gamma-rays of a few 10^{-6} (see arrow in Figure 3). The solar nebula appears to have a fairly well established average ^{26}Al/^{27}Al ratio of 5 10^{-5}, clearly above the interstellar average from gamma-rays, but well below the high interstellar-grain ratios. ^{26}Al radioactivity suggests a rather special formation history of the solar nebula, possibly involving late-time injection of fresh ejecta from a nearby event (Shu et al. 1987; see contribution by Meyer, and the interesting local ^{60}Fe measurement discussed by Korschinek). Other radioisotopes add meteoritic information on the early solar system: The Mn/Cr system may be exploited for assessment of a chemical gradient in the early solar system (see Lugmair's contribution). In protostellar systems in general, energetic particle collisions can have a significant impact on some isotopic ratios (see contributions by Ramaty & Kozlovsky, by Montmerle, and by Prantzos); this may provide an alternative to above late-time injection. Such low-energy cosmic-ray processes may even generate line gamma-rays from excited nuclei, to be searched for with future gamma-ray telescopes. In the end, we would like to connect our detailed knowledge about the solar system with the inferences of Galactic chemical evolution (see contributions by Truran, by Hartmann, and by Faestermann).



The $^{26}Al/^{27}Al$ isotopic ratio for interstellar grains, solar-system samples, and the interstellar medium (adapted from MacPhersson et al. 1995). The averaged ISM value from 1.809 MeV gamma-rays lies below the range for solar system samples, the high values from interstellar grains is attributed to sampling of individual sources.

Injection of seed material into cosmic-ray acceleration regions is a related subject of current research. Currently we believe that the high-energy (large-scale) component of cosmic rays arises from shock regions in young supernova remnants or stellar-wind bubbles; X-ray, radio, and very-high energy gamma-ray signatures from a few young supernova remnants seem to support the Fermi acceleration model, beyond the basic energy argument which led to this source hypothesis (e.g. Koyama et al. 1995). Unclear is which material will be picked up by the acceleration region: fresh and nucleosynthesis-enriched material from the same region is one candidate, while dust material which is decomposed by the interstellar shock seems a plausible alternative. The apparent correlation of cosmic-ray enrichments with the first ionization potential from material with standard composition appears to suggest that normal interstellar gas is accelerated after being ionized. But recent studies present a plausible alternative in acceleration of evaporated dust material, a.o. because gas condensation characteristics produce very similar selections as the first-ionization potential (e.g. Ellison et al. 1997; see also contribution by Ellison). Aluminium is among the refractory elements which should be relatively more enriched in such a model. Then, the shape of the ^{26}Al gamma-ray line may encode the velocity distribution of cosmic-ray source regions - an interesting connection between astronomy from radioactivity gamma-rays and cosmic-ray studies (see contributions by Duvernois and by Bykov).

These examples illustrate the range of themes of our workshop. We aim to address specifically the following astrophysical issues:

- Mixing processes in stellar interiors and envelopes
- Condensation and transport of material ejected from nucleosynthesis sites
- Chemical evolution scenarios
- Solar system peculiarities
- Energetic processes in protostellar systems and in supernova remnants / star formation regions

We hope you find the material in this Proceedings book as stimulating as we found the original contributions to our workshop.

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