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Conference Highlights

Astronomy with Radioactivities. III.[1]

Astronomy of γ-ray lines, cosmic rays, and meteoritic inclusions uses radioactive nuclei for the study of cosmic nucleosynthesis and its associated astrophysical issues. The third international workshop on this theme, hosted by the Max Planck Society, brought together theoreticians from many fields, including stellar evolution, nuclear and particle astrophysics, interstellar medium, and cosmic-ray physics, with experimentalists who use γ-ray telescopes, cosmic-ray detectors, and laboratory mass spectrometers. The experimental or observational foundations of research on this theme have experienced major advances in recent years, in particular in the areas of γ-ray line studies with the *Compton Gamma Ray Observatory*, q1 the rapidly improving isotopic diagnostic of interstellar grains since their discovery in 1987, and new isotopic data for cosmic rays in near-Earth space. These unique observational windows, opened up with the discovery of interstellar ^{26}Al by *HEAO-C* 20 years ago, have established a new "astronomy with radioactivities" in the last decade, with a variety of observations of radioactive γ-rays and detailed isotopic analyses of a diversity of presolar grains.

The workshop assessed spatial and temporal distributions of nucleosynthesis in the Galaxy through γ-ray lines from ^{26}Al, ^{44}Ti, ^{22}Na, positron annihilation, and warm dust (talks by Miguel Cervino, Stefan Plüschke, Roland Diehl, Anatoli Iyudin, Peter Milne, and Ronald Drimmel). The Cygnus region is now used as a laboratory to test the consistency of models and observed yields for stellar groups with rather well constrained stellar contents. It appears that some inconsistencies are encountered, which point to deficiencies in either nucleosynthetic yields or the stellar census. Grains in the interstellar medium preserved an isotopic memory of the production sites. Peter Hoppe reviewed the various types of grains found in meteorites, and their possible origins, based on their isotopic signatures, q2 which are clearly different from solar system material; most grains are most likely the result of nuclear processing in q3 asymptotic giant branch stars, while the SiC X-grains appear to originate in supernovae and diagnose the complexity of the *r*-process with probably two different sites/sources (Uli Ott). Sachiko Amari showed that for a few grains observed abundance patterns (C, N, and Si isotopes) suggest a nova origin, finally adding this long-expected source to the menu of presolar-grain astronomy. Large ^{26}Al enrichments and ^{22}Na excesses are associated with these peculiar grains, as expected for explosive hydrogen burning. Mike DuVernois reviewed several recent isotopic measurements on cosmic rays with the *Advanced Composition Explorer*; analyses have used the radio- q4 active decay of Ni isotopes to measure the time delay between production of the cosmic-ray seed material and its acceleration to high energies. Closer to home, Klaus Knie demonstrated that the ocean floor contains radioactive isotopes, which strongly q5 suggests that a supernova exploded very nearby only a few million years ago and may have shaped the local interstellar environment.

All these measurements have confirmed the global picture of nucleosynthesis in stars and explosion sites and have answered many of the early questions. However, already the red giant phase of stellar evolution shows a large diversity and complexity in the models, with many open questions about convection and mixing, which prevent any straightforward pre- q6 diction of isotopic abundance patterns that emerge from these sites (John Lattanzio). Yet, these stars are expected to produce rich varieties of radioactive envelope material, some of which is predicted to eject Al only in the form of radioactive ^{26}Al.

Models for massive stars were shown to generally produce isotopic signatures that are expected traditionally. Present generations of models now include rotational mixing and also include large nuclear networks that co-evolve with the stellar models, opposed to the postprocessing treatment used in the past (Alessandro Chieffi, Alex Heger). However, the yields still depend critically on many poorly known nuclear cross sections; Alex Heger showed that presupernova core sizes vary by as much as 30% because of these uncertainties, with a correspondingly large impact on predicted isotopic yields. Inverting the point of view, even with a few precise isotopic measurements one is able to significantly constrain stellar structure models and prescriptions of the mixing processes in the presence of chemical gradients, rotation, and mass loss from the surface.

Developing a better understanding of the core collapse supernova mechanism could benefit greatly from direct Ni isotope γ-ray line measurements. For thermonuclear (Type Ia) supernovae, Jens Niemeyer showed that numerical modeling of the physical processes is now approaching the relevant scales in space and time. Finger-like Ni bubbles emerge naturally without invoking an artificial transition from deflagration to detonation. For novae, Margarida Hernanz showed the great potential of electron-positron annihilation γ-ray observations for studying issues related to the envelope mass and velocity. She again reminded us that the optical nova light appears much later than the signal in the γ-ray band, so that monitoring

[1] The conference was held at Ringberg Castle, Germany in 2001 May. Proceedings will be edited by Roland Diehl, Dieter Hartmann, Peter Hoppe, and Nikos Prantzos and published in *New Astronomy Reviews*.

instruments of the γ-ray sky are needed to alert the community rapidly and thus allow follow-up observations of the early light curve with large-aperture telescopes on the ground. The physics of explosive nuclear burning in nova environments is still very poorly understood. Early detection in the γ-ray regime could facilitate a much needed breakthrough in this area.

The fate of radioactive products after they leave their production site remains a rather challenging astrophysical problem. The sophistication of present-day models of the energy transport in supernovae, including radioactive γ-rays and electrons as well as atomic, molecular, and dust emission, was vividly demonstrated by Peter Höflich, Claes Fransson, and Jesper Sollerman. The supernova light curve of SN 1987A is well reproduced over a large range of wavelengths out to 1500 days after the explosion. After that time, the energy input from the decay of radioactive ^{44}Ti does not seem sufficient to produce the observed flux. Peter Milne discussed the effects of positron transport and energy deposition on the evolution of SNIa light curves.

Early stages of supernova remnant evolution appear less homogeneous than present-day models often assume: Jean Ballet presented X-ray spectroscopy data that reveal major variations in Fe abundance for different single clumps in the Tycho super-
q7 nova remnant (SNR). Roger Chevalier led a critical discussion of the interpretation of X-ray emission, using the Vela SNR as an example. Nonthermal particle energy distributions can produce ambiguous effects in a clumped medium at the interface of the supernova blast wave and swept-up interstellar matter. The nonthermal distribution is a result of conditions in the shocked region, which can efficiently produce a high-energy component (cosmic rays). Don Ellison reported on an SNR where about 50% of the kinetic ram energy might have been converted to cosmic rays. Youssaf Butt discussed situations in which a nearby molecular cloud may form a suitable target for the nucleonic component of cosmic rays to produce large fluxes of GeV γ-rays. The observation of this signal would constitute proof of nonelectronic cosmic-ray production in supernova remnants. This is an established paradigm, but reliable data supporting this hypothesis are lacking. Nikos Prantzos and Thierry Montmerle discussed some interesting new scenarios for particle acceleration to high energies in advection-dominated accretion flows through disks around stellar black holes, as well as pre–main-sequence stars. Conditions could be favorable for nuclear processing with the accompanying production of new radioactivities and detectable nuclear γ-ray signals from their decay.

The future holds exciting opportunities for more precise measurements of the traces left behind by new nuclei just after their birth: In the laboratory, the "nano scale" will be explored with mass spectrometry on individual interstellar grains, with two new experiments in Mainz, Germany, and St. Louis, US (Peter Hoppe). From space, high-resolution spectroscopy of γ-ray lines will give us access to line shape details that encode information on the kinematics of newly born nuclei; the ESA
International Gamma-Ray Astrophysics Laboratory mission is q8
scheduled to be launched in 2002 October (Volker Schönfelder, Nikos Prantzos, Stephan Schanne). These new instruments will enlighten us about new aspects of nucleosynthesis, explosions, and interstellar processes yet do not provide the desirable and often demanded "orders-of-magnitude improvement." Groups around the world are developing new experiments of unprecedented capabilities, characterized by an ambitious tracking of the details of the interaction between MeV photons and material in multisegment detectors (Peter Bloser, Peter Milne). Many components of these next-generation experiments present technological challenges as well as new data processing and analysis challenges (Georg Weidenspointner).

Opinions expressed by many of the participants during the discussion sessions also echo in Don Clayton's workshop summary. While not presently heading for "front-page discoveries," the excitement provided by insights gained from this year's instruments and the anticipation of discoveries with the instruments of the next decade continue to consolidate, question, and stimulate our everyday research. The scientific accomplishments and challenges of this field seem somewhat underexposed in the science community interest, especially in comparison to observational cosmology or planetary science themes. However, our community is confident that the pursuit of new nuclei will provide fertile grounds for deep insights into the origin of the elements and on the means by which these species eventually found their way to Earth and Homo sapiens.

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QUERIES TO THE AUTHOR

1 Au: “Compton Observatory”: refers to the Compton Gamma Ray Observatory?

2 Au: “signatures which”: “which” changed to “that” or comma added before “which” throughout to conform to American usage for restrictive and nonrestrictive clauses, respectively; changes are marked “which/that.”

3 Au: have I expanded AGB correctly?

4 Au: have I expanded ACE correctly?

5 Au: that/which

6 Au: that/which

7 Au: have I expanded SNR correctly?

8 Au: have I expanded “INTEGRAL” correctly?

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