From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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^{3}He and ^{4}He in the local interstellar gas as observed with the COLLISA foil experiment on the Mir space station

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Abstract. With the COLLISA foil experiment onboard the Mir space station we have collected samples of interstellar helium, which have been returned to the Earth and investigated by mass spectrometric analysis. Recently, we have been able to reduce the experimental uncertainties as given earlier (Salerno *et al.* 2003). Our improved estimate of the helium isotopic ratio in the local interstellar medium is now $(^3\text{He}/^4\text{He})_{LISM} = (1.62 \pm 0.29) \times 10^{-4}$ (Busemann *et al.* 2005).

Keywords. ISM: abundances, Galaxy: abundances, Galaxy: evolution

1. Introduction

Together with D, and ^{7}Li, the helium isotopes are produced in the Big Bang. For some time the abundance of ^{3}He has been used as a tracer of Big Bang nucleosynthesis, and for the determination of the present-day baryon/photon number ratio in the universe. During the last decade it has, however, become clear that the value of some of these monitors is questionable because stellar evolution of low- and high-mass stars and the way how matter is recycled in galactic evolution is more complicated than anticipated. Nevertheless, all light isotopes – including ^{3}He – have remained valuable tools to test and constrain models of stellar and galactic evolution. In this context, we briefly discuss our new value for the ^{3}He/^{4}He isotopic ratio in the Local Interstellar Medium (LISM) derived from the COLLISA foil experiment on Mir (cf. Busemann *et al.* 2005).

2. Experiment

Among various ways to determine the abundance of ^{3}He in the galactic interstellar medium, the in-situ determination of the isotopic abundances of helium in the neutral interstellar gas, which penetrates into the inner solar system, is the most direct method. The Sun moves at 25 km/s through the LISM. The solar wind and solar UV radiation produce the heliospheric cavity, which is bounded in the upwind direction at about 100 AU with a termination shock, the heliopause, and the heliospheric bow shock. Interstellar neutral helium, which passes through the heliospheric boundary, penetrates deep into the inner solar system, where it is ionized inside the Earth's orbit after having been accelerated to approximately 60 km/s by the solar gravity field. Combined with the orbital motion of the Earth, the relative velocity between neutral interstellar helium and a collecting

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experiment in the vicinity of the Earth can add up to almost 80 km/s, which is sufficient to implant helium particles into a Be target. This can be used to detect the isotopic composition of interstellar helium without interference from ambiguities due to line-of-sight- or discrimination-effects. The isotopic ratio of trapped interstellar helium can then be analysed mass-spectrometrically under well controlled laboratory conditions. We have exposed several CuBe foils in a special particle camera “COLLISA” on the Russian Mir space station for a total exposure period of 60 hours. The foils have been analyzed using the laboratory facilities of the University of Bern and of the ETH Zürich by two different techniques: Salerno *et al.* (2003) have successfully applied the stepwise heating technique to disentangle possible contaminations of interstellar helium from other sources. More recently, Busemann *et al.* (2005) have used the Closed System Stepped Etching (CSSE) technique to improve the distinction from non-interstellar sources, thereby considerably reducing the experimental background and the uncertainties.

3. Results

The results of the two investigations with COLLISA are summarized in Table 1. The quoted errors cover 2 σ uncertainties and include counting statistics and mass discrimination for the mass-spectrometric analysis, background uncertainties, and discrimination for different trapping efficiencies for the two isotopes.

Table 1. Results of COLLISA foil investigations

COLLISA Sample foil	^{3}He/^{4}He ($\times 10^4$)	Extraction Method	Reference
L-461-2-1	1.7 ± 0.8	Stepwise heating	Salerno *et al.* (2003)
L-431-2-1-6	1.62 ± 0.29	Closed system etching	Busemann *et al.* (2005)

4. Discussion and Conclusions

We have determined the isotopic composition in the contemporary interstellar gas and find that $(^3\mathrm{He}/^4\mathrm{He})_{LISM}=(1.62 \pm 0.29)\times 10^{-4}$. Together with the presolar value derived from Jupiter's atmosphere (Mahaffy *et al.* 2000), which is $(1.66 \pm 0.05)\times 10^{-4}$, this can be used as benchmark for the nuclear evolution of light elements within the galaxy during the past 4.6 Gy. Although ^{3}He is built up in considerable amounts as an intermediate product of the pp-chain at the boundary of the nuclear burning zones during the life of low-mass stars, apparently little ^{3}He is ejected during the final phases of the evolution of low-mass stars. Bania *et al.* (2002) find no sign of systematic variation of ^{3}He/H in HII regions with galactocentric distance. Their average value $(^3\mathrm{He/H})=(1.9 \pm 0.6) \times 10^{-5}$ is consistent with our best estimate of the local interstellar medium of $(^3\mathrm{He/H})_{LISM}=(1.58 \pm 0.29) \times 10^{-5}$ (based on $Y_\odot=0.27 \pm 0.01$). The lack of spatial variation in regions of different degree of nucleosynthetic evolution is consistent with the now clearly appearing lack of temporal variation during the last 4.6 Gy in the solar neighbourhood. We attribute the spread in the observations of HII regions (Bania *et al.*, 2002) to different rotational histories, and different degrees of mixing of the envelopes of the progenitors. Considering the short evolution time scales of active star forming regions, it appears unlikely that ^{3}He can serve as a reliable tracer for Big Bang nucleosynthesis.

Acknowledgements

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Monique and François Spite with their first astronomy professor, Vladimir Kourganov, at the welcome reception.

Monique Spite, entertaining Alan Alves Brito, Beatriz Barbuy and Bruno Castilho at the welcome reception.

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