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Creation and transmutation of magnetized nuclei at explosively dense matter

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Abstract. Synthesis of iron group chemical elements is considered for the ultra-magnetized astrophysical plasma in supernovae. Maximum of nucleosynthesis products is shown to shift towards smaller mass numbers approaching titanium due to magnetic modification of nuclear structure. The results are corroborated with an excess of ^{44}Ti revealed from the INTEGRAL mission data.

1 Introduction

Nuclear densities exceeding normal values arise at core-collapse supernovae and can be achieved in heavy ion collisions. Nuclides produced in such processes contain an information on matter structure and explosion mechanisms. In this contribution we analyze possibilities for using radionuclides to probe internal regions of respective sites. Supernovae (SN) represent promising candidates for synthesis of heavy atomic nuclei and renewing other nuclear components. Magnetization of hot dense plasma makes plausible explosion mechanism and can leave its trace at nucleosynthesis [1]. We reveal radiatioactivity and volume of ^{44}Ti in SN remnant (SNR) Cassiopeia A (CAS A) from the INTEGRAL data.. The observational data are compared to theoretical predictions while accounting for an influence of astrophysical environment on creation and decay of ^{44}Ti in SNR.

2 Nuclide radioactivity probing the explosive burning region

Radioactive nuclides synthesized at nuclear processes provide an opportunity to probe the active reaction regions. Created at the SN explosions radioisotopes can be observed by registration of characteristic gamma-lines, accompanying their radioactive transitions. The decay chain ^{44}Ti→ ^{44}Sc→ ^{44}Ca gives rise to the emission of lines with energies 67.9 keV and 78.4 keV (from ^{44}Sc*) and 1157 keV (from ^{44}Ca*) of approximately the same intensity. The ^{44}Ti half-life period of about 52 years allows to evaluate the mass of this isotope in SNR.
We analyze the data, obtained by the Integral IBIS/ISGRI and SPI detector systems. As is described in ref. [1] we analyze the Sciences Windows (scw) of type pointing from catalog [2]. Here we discuss further results from processing of extended data sets accumulated during a period from 2002 to 2009. The total effective exposure time is about 1.2 Ms. Respective image-mosaics for vicinity of SNR CAS A in various energy ranges of registered photons are presented in figure 1. The color (brightness) is proportional to the gamma-quanta flux: the larger the flux the brighter the color of a pixel. For the first range the confidence level (i.e., ratio signal/noise) reaches the level of 40, for other energy intervals it exceeds 5 indicating reliable registration. As discussed in [1, 3] (see references therein) the respective energy spectra display peaks at energies 67.9 keV and 78.3 keV, i.e. characteristic lines of ^{44}Sc, with total flux equals to 10^{-4} photons/cm^2/s.

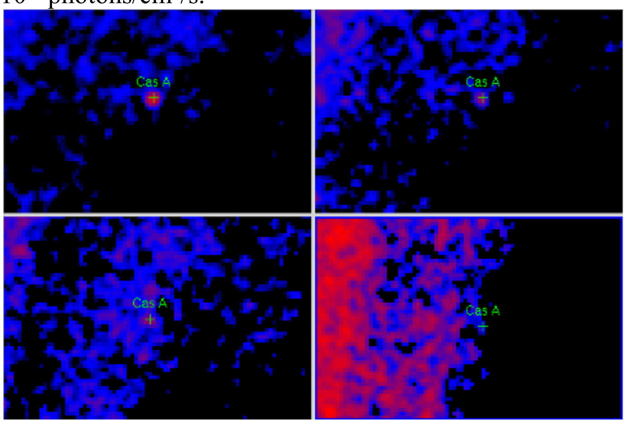

Fig. 1. Direction (pixel number) dependence of the registered gamma-ray flux at different energy ranges. Top: left - 20–62 keV, right - 62–72 keV. Bottom: left - 72–82 keV; right – 82-100 keV; for the vicinity of SNR CAS A, (J2000) R.A. 350.86°, decl. 58.81°, indicated by cross.

The corresponding spectrum of INTEGRAL SPI detector system is displayed in figure 2. The ^{44}Ca characteristic line is shown in an insert and well fitted by Gaussian function with center 1.157 MeV and FWHM 3 keV confirming, thereby, respective signal. The count rate yields a flux (5.2 ± 1.1[stat]- 2.3[syst]) $\times 10^{-5}$ photons/cm^2/s.

Accounting for a distance to SN CAS A and a half-life time of the isotope, for an averaged over lines isotropic emission of gamma-radiation we get the mass value $(4 \pm 1) \times 10^{-4}$ M_{Sun} of initially synthesized ^{44}Ti at SN explosion. This value exceeds considerably predictions of SN models without magnetic effects.

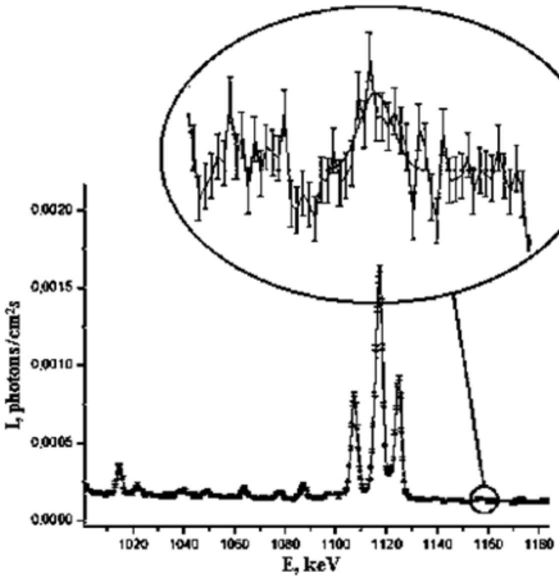

Fig. 2. Energy spectrum in the vicinity of SNR CAS A.

3 Nucleosynthesis in SN magnetic field

The nuclear statistical equilibrium (NSE) approach is used very successfully to describe abundance of iron group and nearby nuclides for over half a century, cf. [1, 4-6]. We briefly recall that at NSE conditions abundance of *i*th nuclear particle Y_i (e.g., nucleons, nuclei, electrons) at temperature T is determined by the respective chemical potential from the extremum condition for entropy S. At considered parameters of SN plasma, i.e. magnetic field strengths $H < 100$ teratesla, the yield Y_i of atomic nucleus i is mainly determined by corresponding binding energy B_i as: $Y_i \sim \exp\{-B_{ii}/kT\}$, see [1, 4-6]. Respectively, the dependence of relative output for nucleosynthesis products $y=Y(H)/Y(0)$ on magnetic field strength H is determined by a change of binding energy $\Delta B(H)$ in the field. The normalized yield ratio $[i/j] = y_i/y_j$ with exponential accuracy can be written as

$$[i/j]\,(H) \sim \exp\{(\Delta B_j - \Delta B_i)/kT\}. \quad (1)$$

Since magnetic effects are determined by nuclear shell structure [1, 4-6] we identify magnetic field dependence of binding energy $\Delta B(H)$ with a change of shell correction energy C (i.e. $\Delta B(H) = C(H) - C(0)$) and use Eq. (1) to examine features of nuclide composition in ultra-magnetized astrophysical plasmas. As is seen in figure 3 the often considered yield ratio [Ti/Ni] displays oscillations as a function of the field strength due to magic-antimagic switching in nuclear structure. At weak fields the portion of Ti grows in conjunction with observations.

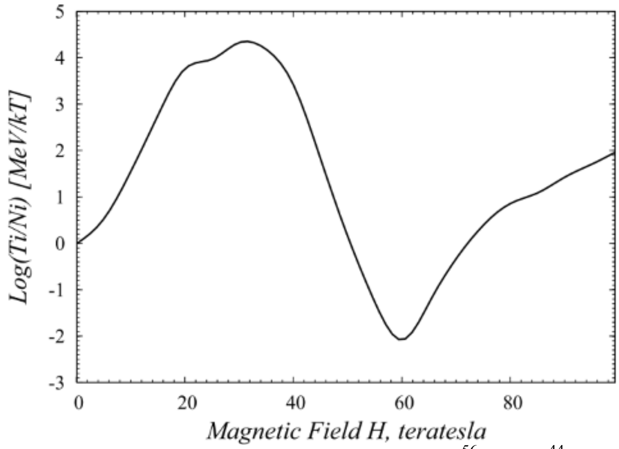

Fig. 3. Magnetic field dependence of yield ratio ^{56}Ni and ^{44}Ti.

4 Conclusion

Synthesis of chemical elements at conditions of nuclear statistical equilibrium is investigated for the ultra-magnetized astrophysical plasma in supernovae. For iron group nuclides the magnetic modification of nuclear structure shifts a maximum of nucleosynthesis products towards smaller mass numbers approaching titanium. Signals of ^{44}Ti radioactive decay in the gamma-spectra of the supernova remnant Cassiopeia A are revealed from the Integral IBIS/ISGRI and SPI observational data. The gamma-ray flux for ^{44}Ca* line with energy 1.157 MeV is determined. Magnetic effects in nucleosynthesis are favorably compared to observational data.

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References

1. V.N. Kondratyev, Phys. At. Nucl., **75**, 1368 (2012)
2. http://virgo.bitp.kiev.ua
3. M. Renaud, *et al*., New Astron. Rev., **50**, 540 (2006)
4. V.N. Kondratyev, I.M. Kadenko, MNRAS **359**, 927 (2005)
5. V.N. Kondratyev, Bull. Univ. Kiev, **No 3**, 31 (2010)
6. V.N. Kondratyev, Phys. Rev. Lett. **88**, 221101 (2002)