Study of the ^{44}Ti(α,p)^{47}V reaction at CRYRING

O. Forstner[1,2,3,†], M. Lestinsky[2], D. Bemmerer[4], S. Merchel[4], K. Zuber[5], and T. Stöhlker[1,2,3]

[1]Helmholtz-Institut Jena, 07743 Jena, Germany
[2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[3]Friedrich-Schiller-Universität Jena, 07743 Jena, Germany
[4]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany
[5]Technische Universität Dresden, 01062 Dresden, Germany

[†]Contact: o.forstner@gsi.de

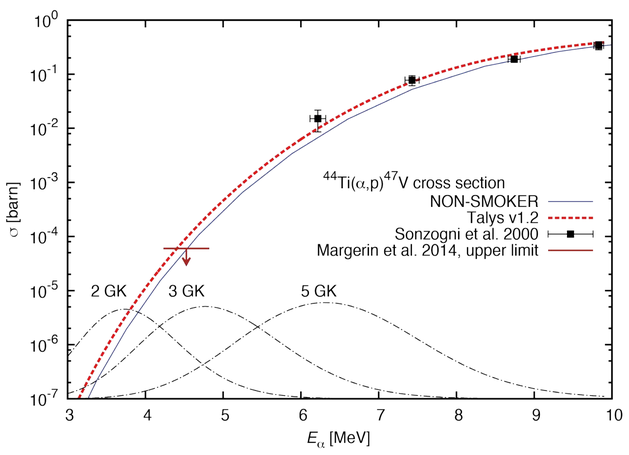
Motivation

The radionuclide ^{44}Ti is one of the few cosmogenic nuclei that were directly observed by satellite based gamma-ray observatories. It is produced in core collapse supernovae by α-capture reactions. The main reaction consuming ^{44}Ti is ^{44}Ti(α,p)^{47}V. The precise knowledge of both production and consumption reaction rates is therefore crucial for the determination of the final amount of ^{44}Ti produced in the supernova. Here we present the idea of measuring the reaction rate of the reaction ^{44}Ti(α,p)^{47}V at CRYRING in inverse kinematics at the Gamow window for core collapse supernovae.

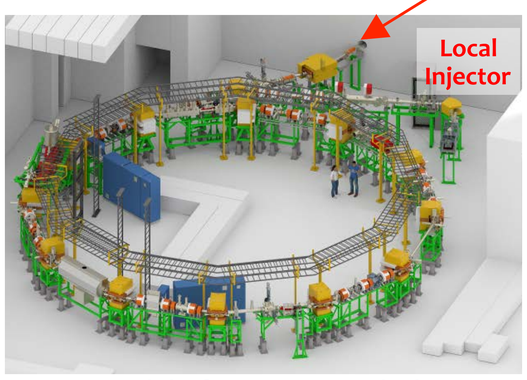
Extract from the Karlsruhe Nuclide Chart showing the region around calcium and titanium isotopes.
Picture: Nucleonica GmbH

Proposed Measurement at CRYRING

- Due to current restrictions of the injection RFQ of CRYRING (q/A > 0.35) minimum charge state of 16$^+$ has to be used for injection
- Enriched ^{44}Ti will be charge bred in an EBIT ion source to charge state 20$^+$ and injected into CRYRING at 300 keV/u.
  Desired beam intensity: minimum 10^5 stored particles
- Acceleration of ions up to energies for the relevant Gamow windows energies ($E_{c.m.}$ < 6 MeV) up to 2.2 MeV/u (0.47 Tm at charge state 20$^+$)



Compilation of theoretical predictions and experimental values for the cross section of the reaction ^{44}Ti(α,p)^{47}V. The indicated Gamow peaks show that data for $E_{c.m.}$ below 6 MeV is needed. [2]



CAD model of CRYRING with the local injector.

- After reaching desired energy interaction of stored ^{44}Ti ions with helium atoms from the CRYRING gasjet target.
- Detection of the protons resulting from the reaction downstream of the gasjet target with particle detectors. ⇒ ΔE-E detection required to distinguish reaction protons from elastically scattered alpha particles.

Conclusion

The newly installed CRYRING together with a local ion source producing highly charged ions for injection is ideally suited to study the astrophysical relevant reactions. The available energy at CRYRING allows performing the reactions directly at the Gamow window. The long storage time (up to 10^3 s in some cases) allows efficient use of the precious enriched material.

References

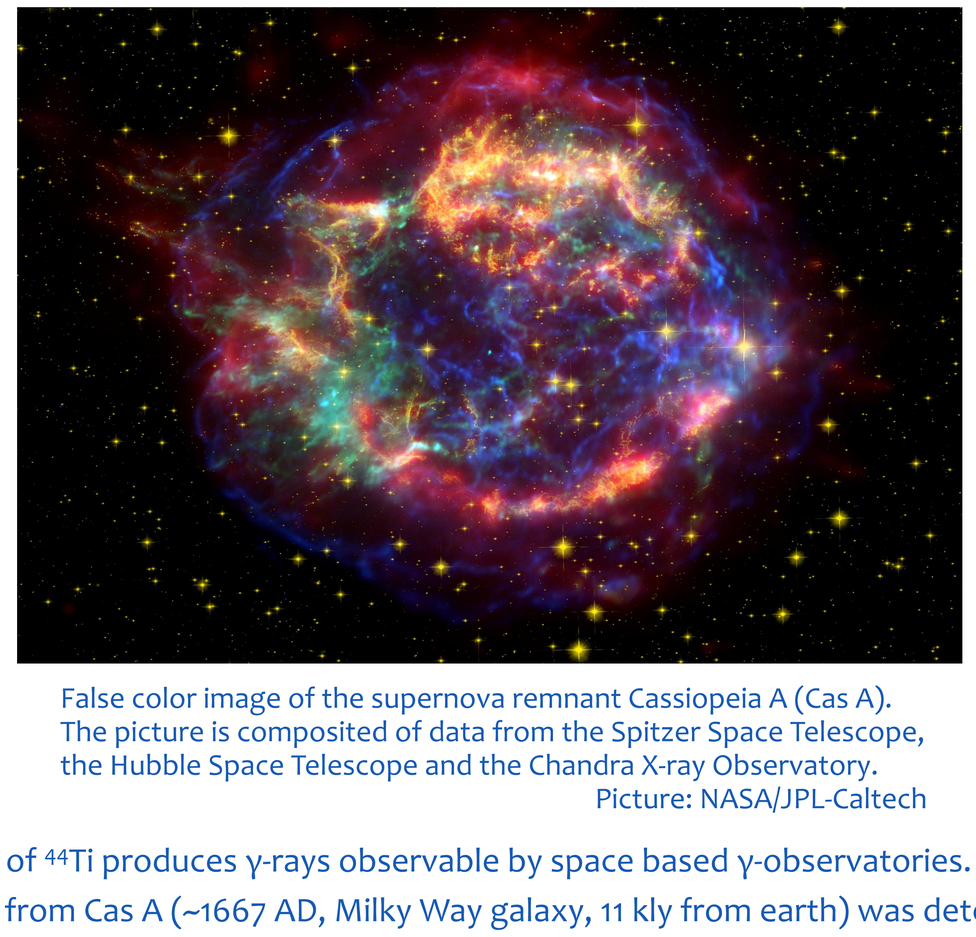
[1] V. Margerin, Physics Letters B 731 (2014) 358-361
[2] T. Al-Abdullah et al., The European Physical Journal A 50 (2014) 140
[3] H. Koivisto et al., Nucl. Instr. and Meth. In Phys. Res. B 187 (2002) 111-116
[4] A.F. Iyudin et al., Astronomy & Astrophysics 284 (1994) L1
[5] M. Renaud et al., Astrophysical Journal 647 (2006) L41

^{44}Ti in core collapse supernovae

^{44}Ti ($T_{1/2}$=58.9±0.3 years) is produced in core collapse supernovae during alpha-rich freeze-out near the mass cut by successive α-capture reactions on ^{28}Si:

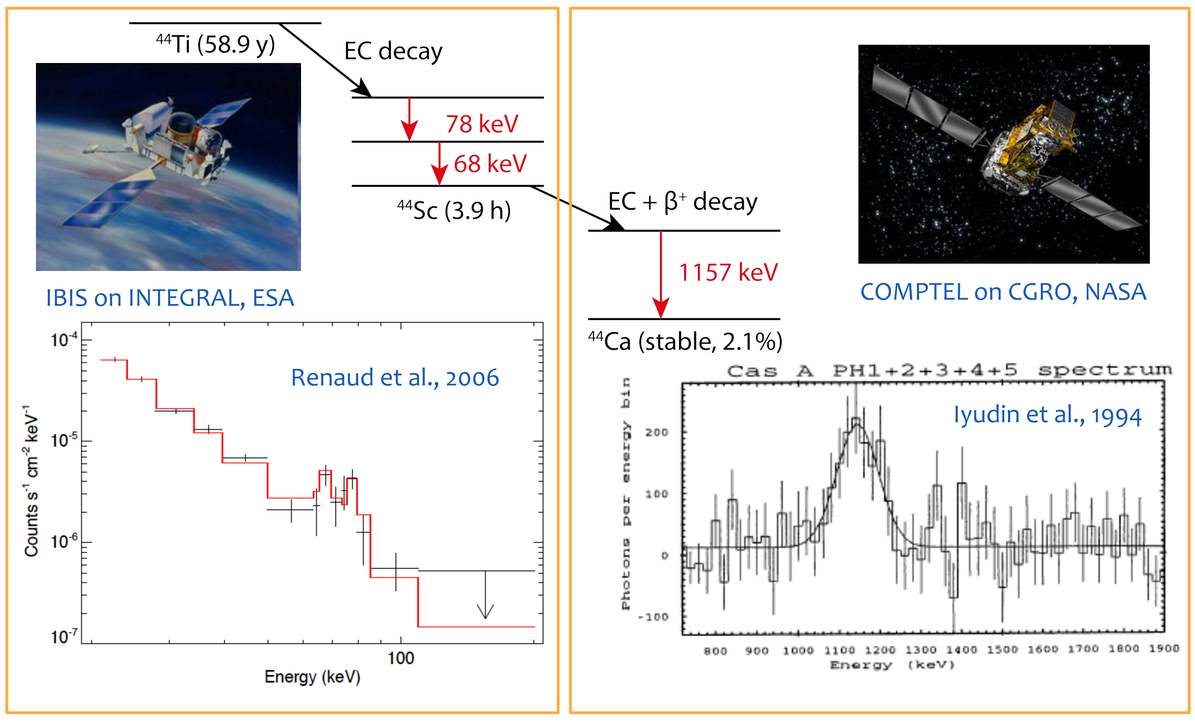
^{28}Si(α,γ)^{32}S→^{32}S(α,γ)^{36}Ar→^{36}Ar(α,γ)^{40}Ca→^{40}Ca(α,γ)^{44}Ti…

Half-life of about 60 years provides "smoking gun" for supernova explosion



False color image of the supernova remnant Cassiopeia A (Cas A).
The picture is composited of data from the Spitzer Space Telescope, the Hubble Space Telescope and the Chandra X-ray Observatory.
Picture: NASA/JPL-Caltech

Decay of ^{44}Ti produces γ-rays observable by space based γ-observatories.
Signal from Cas A (~1667 AD, Milky Way galaxy, 11 kly from earth) was detected by COMPTEL, BeppoSAX and INTEGRAL telescopes.
^{44}Ti dominates light curve over ^{56}Ni and ^{56}Co about four years after explosion ⇒ recently ^{44}Ti detected in the remnants of SN1987A (Large Magellanic Cloud)



Further evidence from excess of ^{44}Ca in presolar grains (up to 100 times solar).
Amount of ^{44}Ti in supernova remnant is not well produced by astrophysical models → more input about reaction rates necessary

Dominant production reaction: ^{40}Ca(α,γ)^{44}Ti
⇒ currently under investigation at HZDR: direct production of ^{44}Ti with α-beam impinging on ^{40}Ca target, measurement of produced ^{44}Ti with AMS (Accelerator Mass Spectrometry)

Dominant consumption reaction: ^{44}Ti(α,p)^{47}V
⇒ to be measured at CRYRING

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
seit 1558
TECHNISCHE UNIVERSITÄT DRESDEN
HELMHOLTZ GEMEINSCHAFT
GSI
Helmholtz-Institut Jena