Towards a Study of the $^{44}Ti(\alpha,p)^{47}V$ reaction at CRYRING

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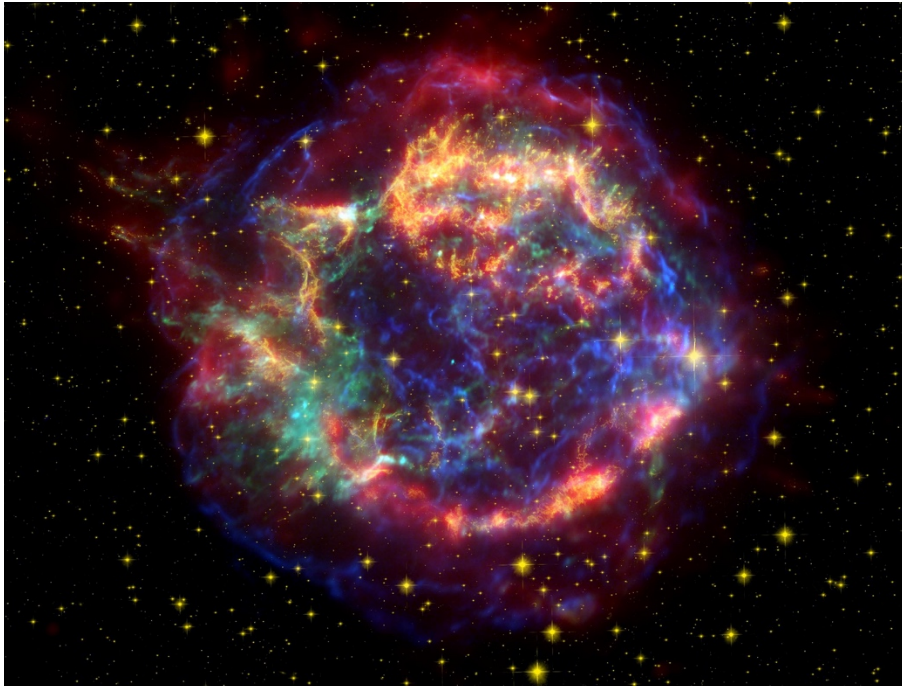


False color image of the supernova remnant Cassiopeia A (Cas A). The picture is composited of data from the Spitzer Space Telescope, the Hubble Space Telescope and the Chandra X-ray Observatory.

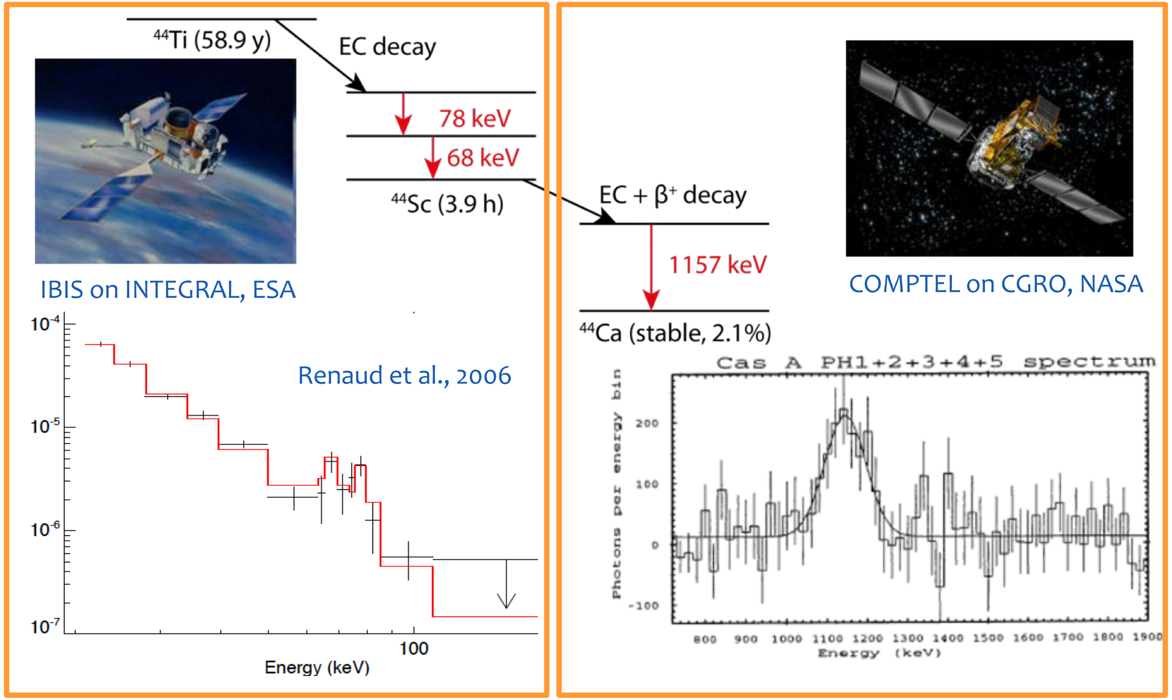
Picture: NASA/JPL-Caltech

^{44}Ti detected in SN remnants

^{44}Ti γ-emission detectable at space observatories

Dominates light curve over ^{56}Ni about 4 yrs after explosion

First detected in CasA SNR (~1667 AD, Milky Way), later in SN1987A (LMC)



^{44}Ti SN Production

Produced in α–rich freeze out of core-collapse SN

$$^{28}Si(\alpha,\gamma)^{32}S \rightarrow {}^{32}S(\alpha,\gamma)^{36}Ar \rightarrow$$
$$^{36}Ar(\alpha,\gamma)^{40}Ca \rightarrow {}^{40}Ca(\alpha,\gamma)^{44}Ti$$

Dominant consumption reaction:

$$^{44}Ti(\alpha,p)^{47}V$$

^{44}Ti amount in SNR dependent on reaction rate ratio of both reactions!

Extract from the Karlsruhe Nuclide Chart showing the region around calcium and titanium isotopes.

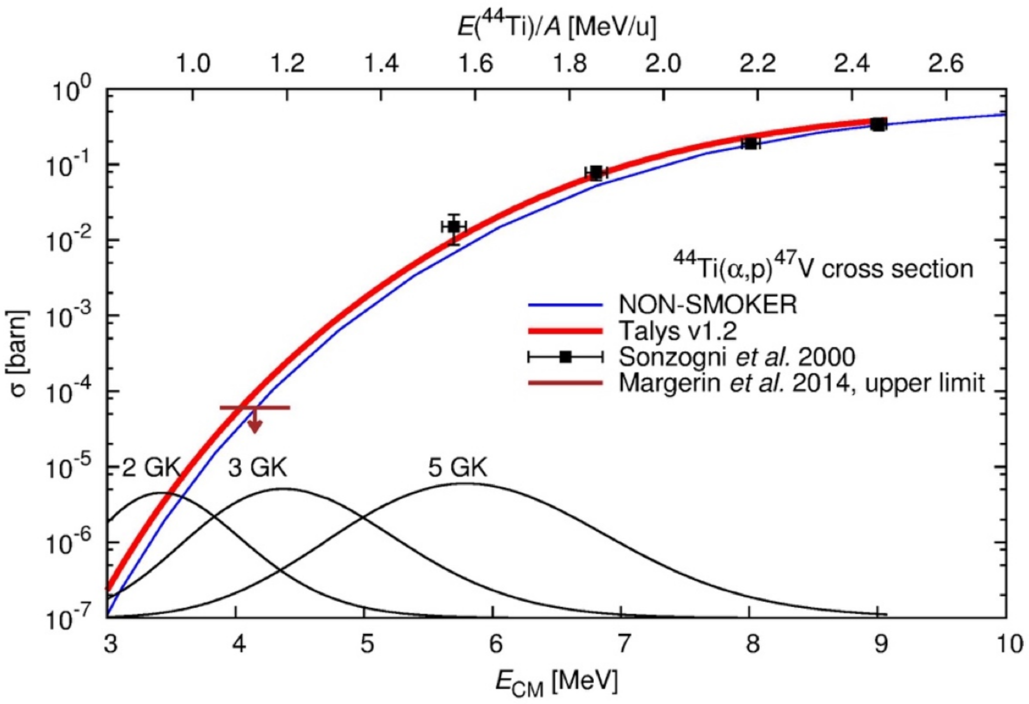
Nucleonica GmbH

Reaction Cross Section

Previous measurements above the Gamow window for core collapse SN

Margerin et al. @ ISOLDE → upper limit at 3 GK Gamow window

→ more data needed between 3 and 6 MeV E_{cm}



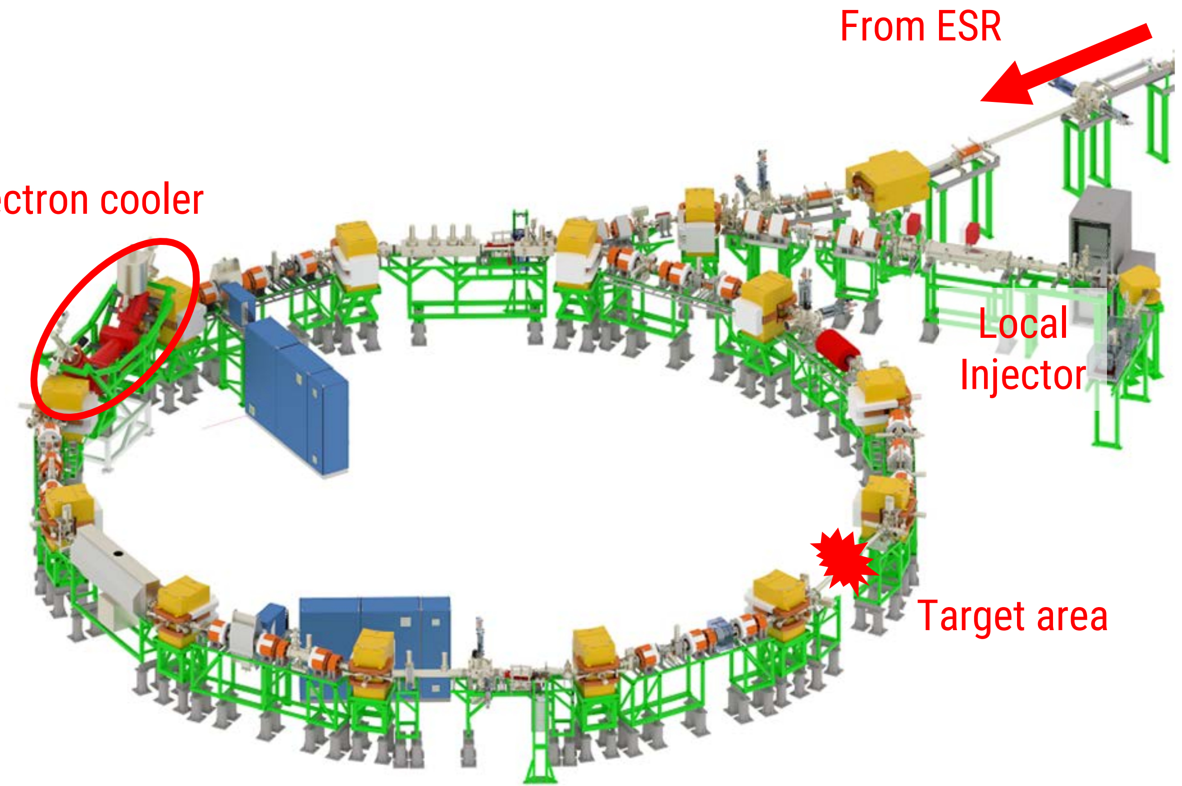
Al-Abdullah et al., Eur. Phys. J. A 50, 140 (2014)

CRYRING @ ESR

Magnetic storage ring, Bρ≤1.44 Tm

Highly-charged ions from ESR or local ion source

Limitation due to injection RFQ: $q/A > 0.35 \rightarrow Ti^{16+}$ or higher, bare (Ti^{22+}) would intrinsically remove decay products

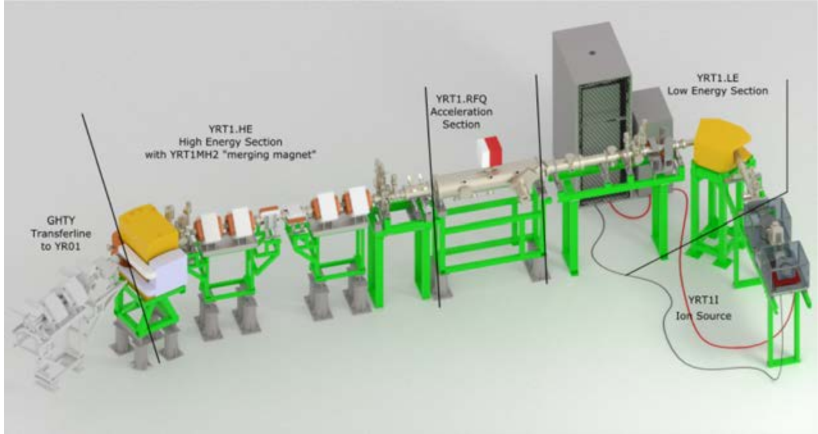


CRYRING Local Injector

Production of highly charged Ti-ions in EBIS: E.g. EBIS-A from DREEBIT GmbH, Ar^{18+} (fully ionized): 10^5 at 1Hz

Injection of Ti into EBIS: MIVOC (Metal Ions from Volatile Organic Compounds), (trimethyl)pentamethyl-cyclopentadienyl-titanium, $(CH_3)_5C_5Ti(CH_3)_3$, solid material, [Koivisto et al., NIMB 187 (2002) 111]

^{44}Ti available from PSI beam dump, up to 50 MBq (D. Schumann)



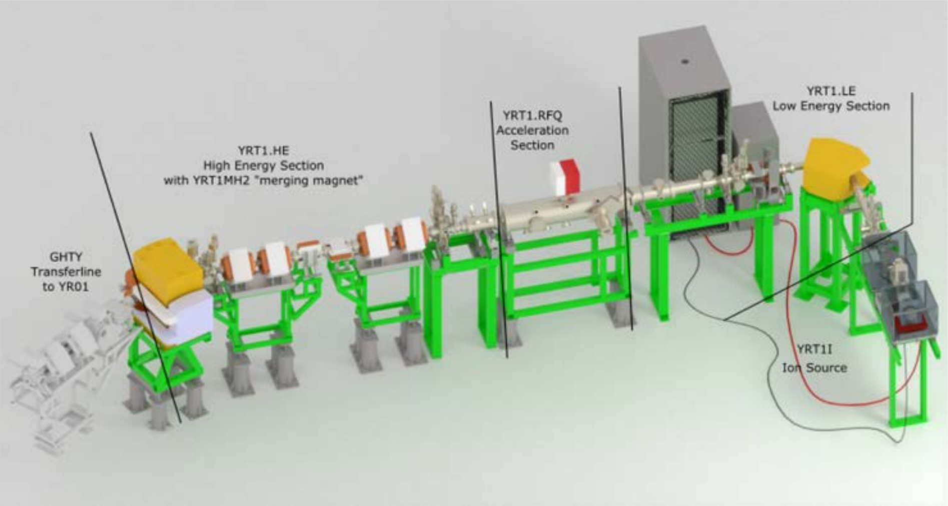
Dresden EBIS-A:
DREEBIT GmbH

CRYRING

Ions accelerated with RFQ to 300 keV/u and injected into CRYRING

Acceleration in CRYRING to required beam energy: 0.8 – 1.6 MeV/u (corresponds Gamow window of 2 – 5 GK)

Expected storage time of highly charged Ti ions: some tens of seconds
Rev. freq.: ^{44}Ti@1.1 MeV/u: 270 kHz



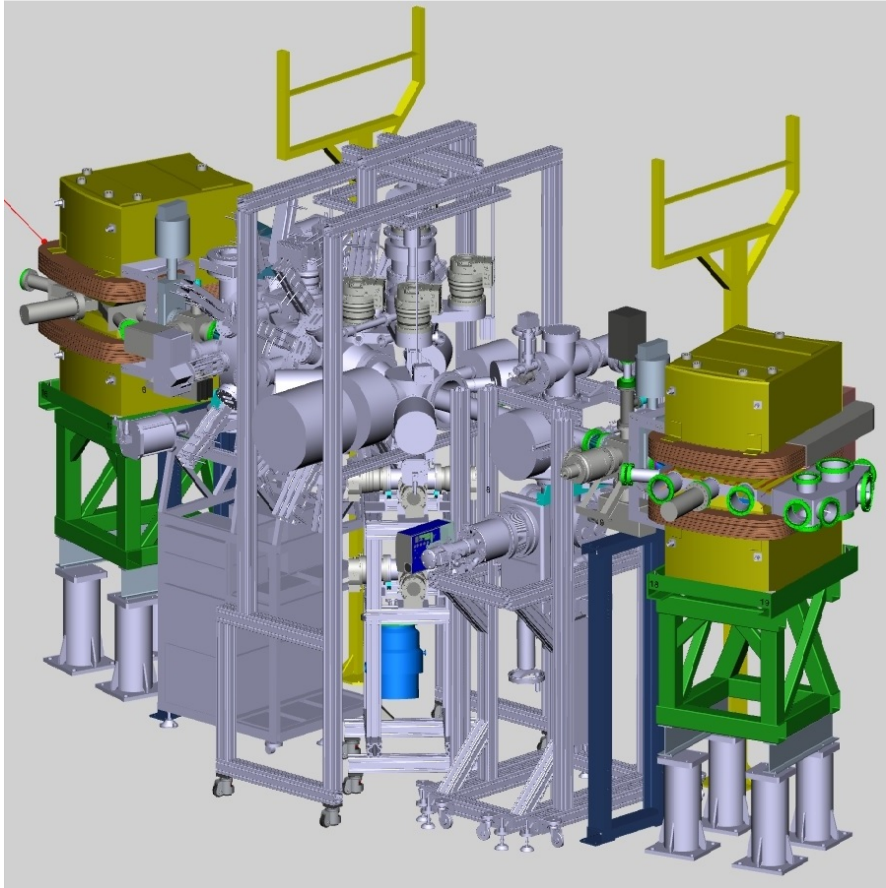
CRYRING Gas-jet Target

$^{44}Ti(\alpha,p)^{47}V$ reaction in inverse kinematics at CRYRING gas-jet target with helium

Expected jet density: up to 10^{14} at/cm^2

Detection of p with Si detectors close to target, energy ~ 7 – 9 MeV

Rate estimation: with 10^5 stored particles → ~1 event/h



Reaction Kinematics

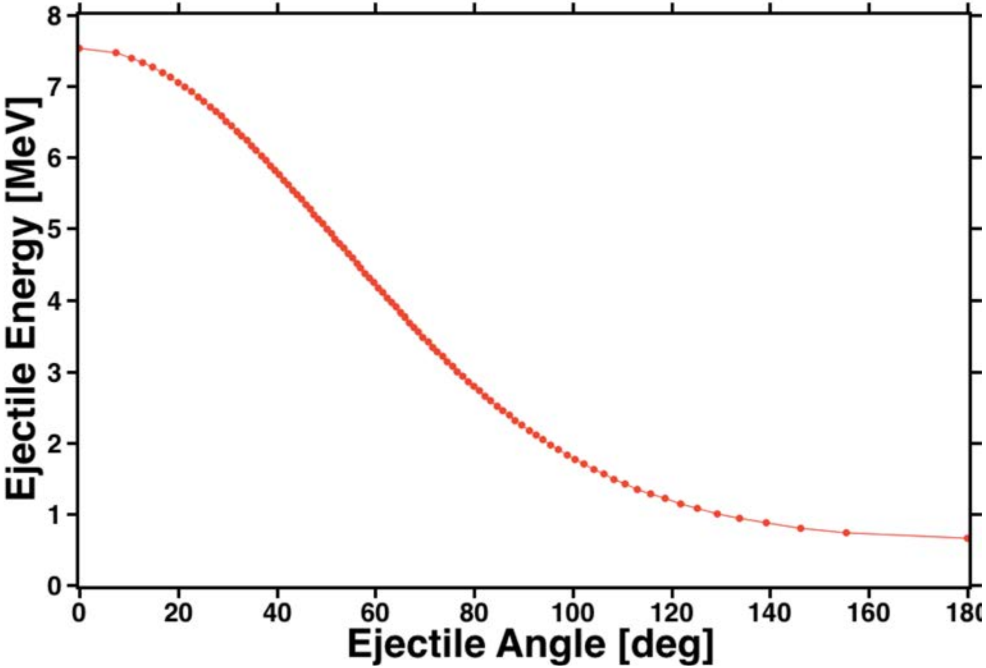
Two options because of long ^{44}Ti lifetime:

- ^{4}He-beam, ^{44}Ti target
- ^{44}Ti-beam, ^{4}He gas target

^{44}Ti beam: α-capture reaction in inverse kinematics

Maximum recoil angle in Gamow window: ~2.4°

Protons emitted in all directions



Energy distribution of the proton, E(^{44}Ti)=1.1 MeV/u

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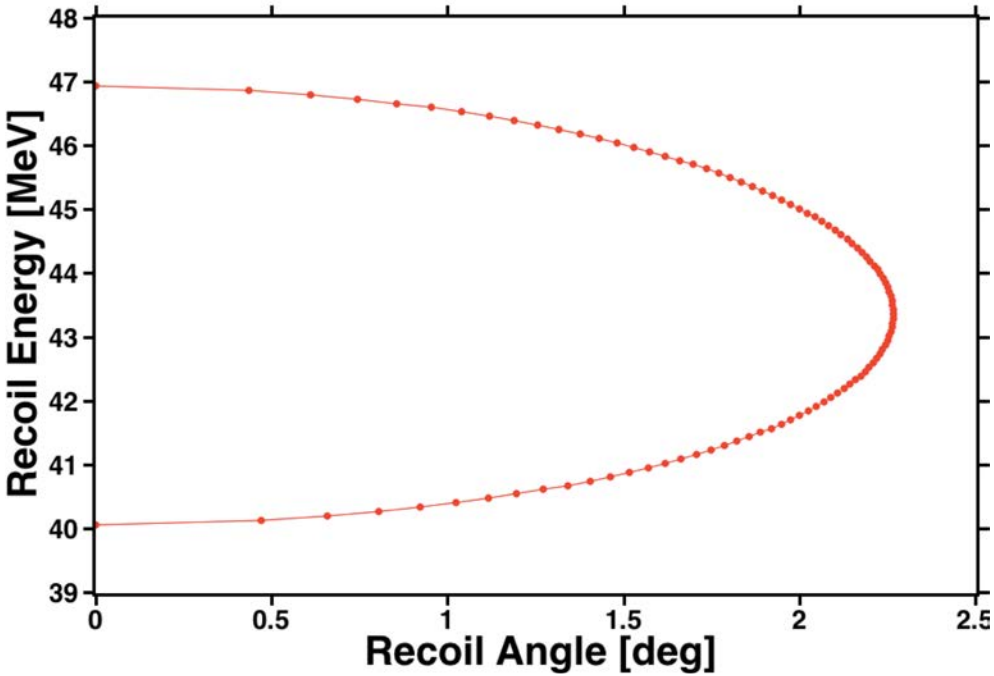

Energy distribution of the recoil, E(^{44}Ti)=1.1 MeV/u

Comparison to Previous Experiments

ATLAS / Sonzogni et al.

- ^{44}Ti beam
- ^{47}V detected with recoil mass separator

ISOLDE / Margerin et al.

- ^{44}Ti beam, single-pass
- Detection of p after reaction
  – large emission angles
- 67 mbar He gas-cell
  + high density
  – windows
  – energy loss

CRYRING

- ^{44}Ti beam, multi-pass
- Detection of p after reaction
  – large emission angles
- Gas-jet target
  – ”low” density
  + windowless
  + well defined reaction energy

Summary & Outlook

- ^{44}Ti of great interest, provides "smoking gun" for recent supernova
- Calculations and observations not in agreement → more experimental data in Gamow window needed
- Newly installed CRYRING@ESR provides excellent opportunity to measure alpha-capture reaction rate
- Accessible energies in the range of Gamow window for core-collapse SN
- Radioactive ^{44}Ti available in sufficient amounts from PSI beam dump
- More efficient use of precious ^{44}Ti material in storage ring

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