Radioactive ^{30}S Beam to Study XRBs

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Astrophysical Motivation

X-Ray Bursts observed with multiple peaks in their bolometric luminosity are explained by Fisker *et al.* as multiple releases of nuclear energy, separated by a nuclear waiting point. [1]

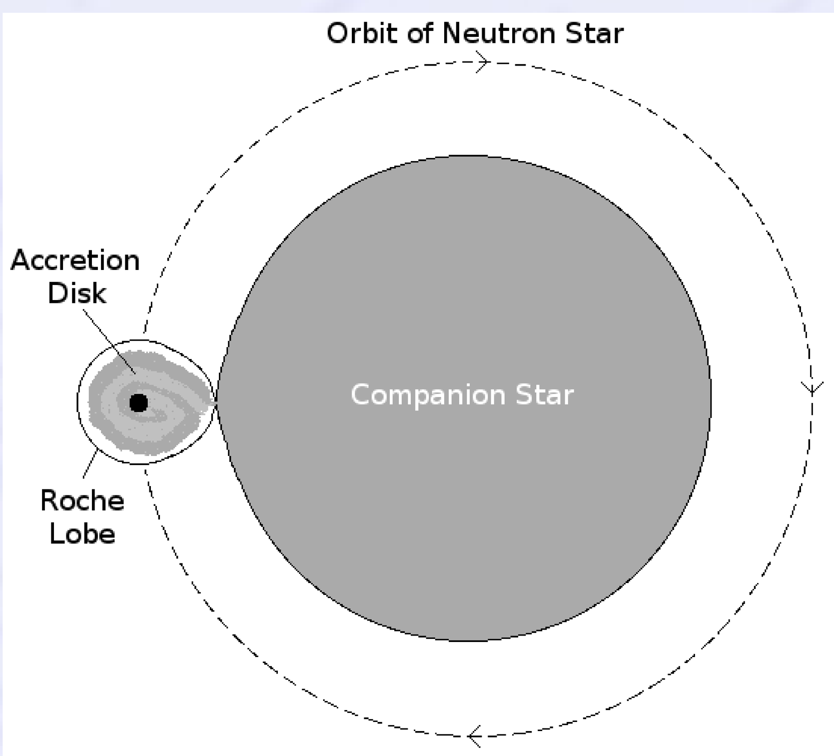

Figure 1: Schematic drawing of accreting neutron star binary where the companion has filled the Roche lobe.

- Low mass accreting neutron star binaries
- Accreted material assumed to be solar[2]
  - 90.99% H, 8.87% He
  - .03% C, .01% N, .08% O
- β-limited hot CNO pre-burst
  - (T_9 = .1 – .2 K)
- Thermal instabilities → explosion
  - *rp-process* (T_9 = 1 – 2 K)
  - CNO seed nuclei
- Recurrent bursts, ~ 100 known XRBs

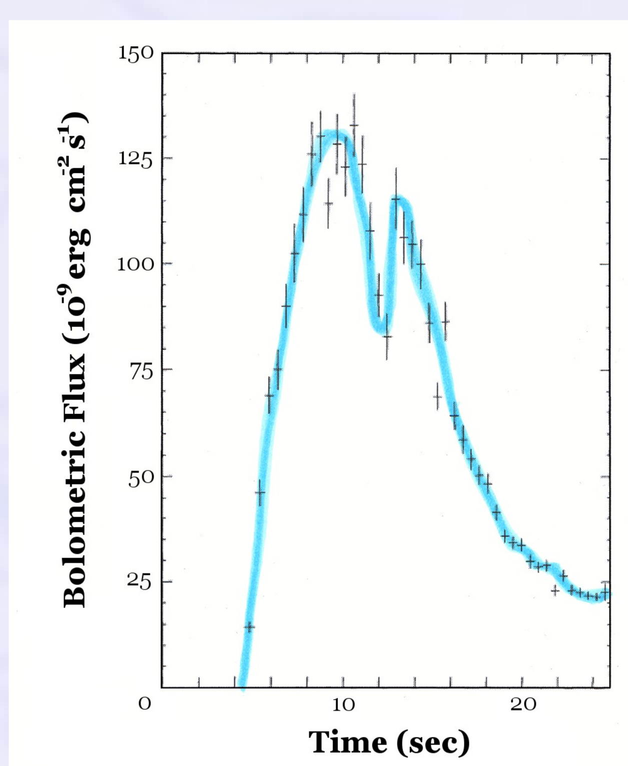

Figure 2: Double-peaked XRB 4U 1608-52 spectrum, plotted as time versus bolometric flux (10^{-9} in cgs). Notice 25% decrease in luminosity after first peak.[6]

- 4 observed multi-peaked bursts [3,4,5,6]
  - These constrain XRB models
  - Many proposed explanations
- Fisker *et al.* propose nuclear waiting point
  - Explains peaks with only nuclear physics
  - Infer bottleneck at ^{30}S
  - β^+-deacy on order of burst rise-times
  - Burning inhibited by photodisintegration
- ^{30}S(α,p)^{33}Cl cross section affects light curve
  - By changing *theoretical reaction rate* by factor of 100, the model by Fisker *et al.* shows a different profile shape.
- We will experimentally measure ^{30}S(α,p)^{33}Cl
  - To do this, we need a radioactive ^{30}S beam

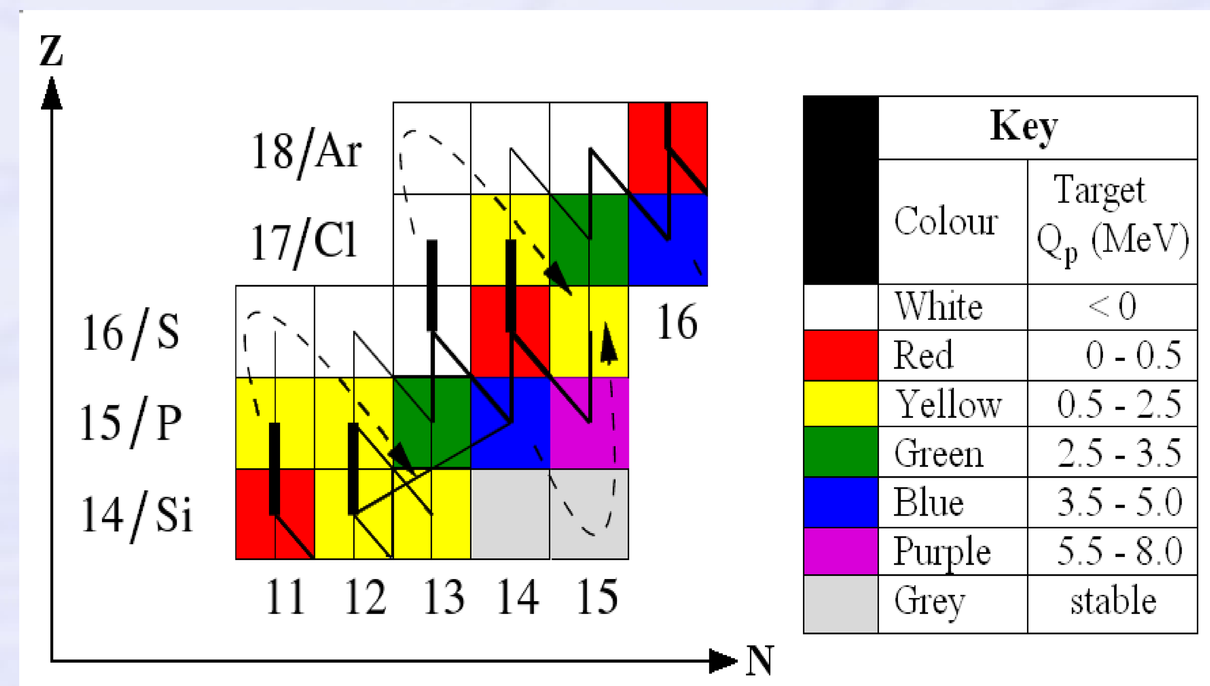

Figure 3: N vs. Z diagram near ^{30}S (Z=16, N=14). Colour indicates energy released during proton-capture (Q_p). Black lines indicate strength of the reaction path for (p,γ), β^+, (α,p), except for thick vertical lines indicating (p,γ)-(γ,p) equilibrium. XRB nucleosynthesis must pass through ^{30}S($t_{1/2}$=1.178 s). ^{30}S(α,p) not shown – no experimental data. [1]

^{30}S Beam Development

We successfully separated out the proton-rich isotope ^{30}S, after bombarding a ^{3}He gas cell with a stable ^{28}Si beam using the ^{3}He(^{28}Si,n)^{30}S reaction. [7]

- 2 days of ^{30}S beam development in December 2006
- Work performed at CRIB [8]
  - CRIB is operated by the University of Tokyo and located at the RIKEN laboratory (Wako, Japan).

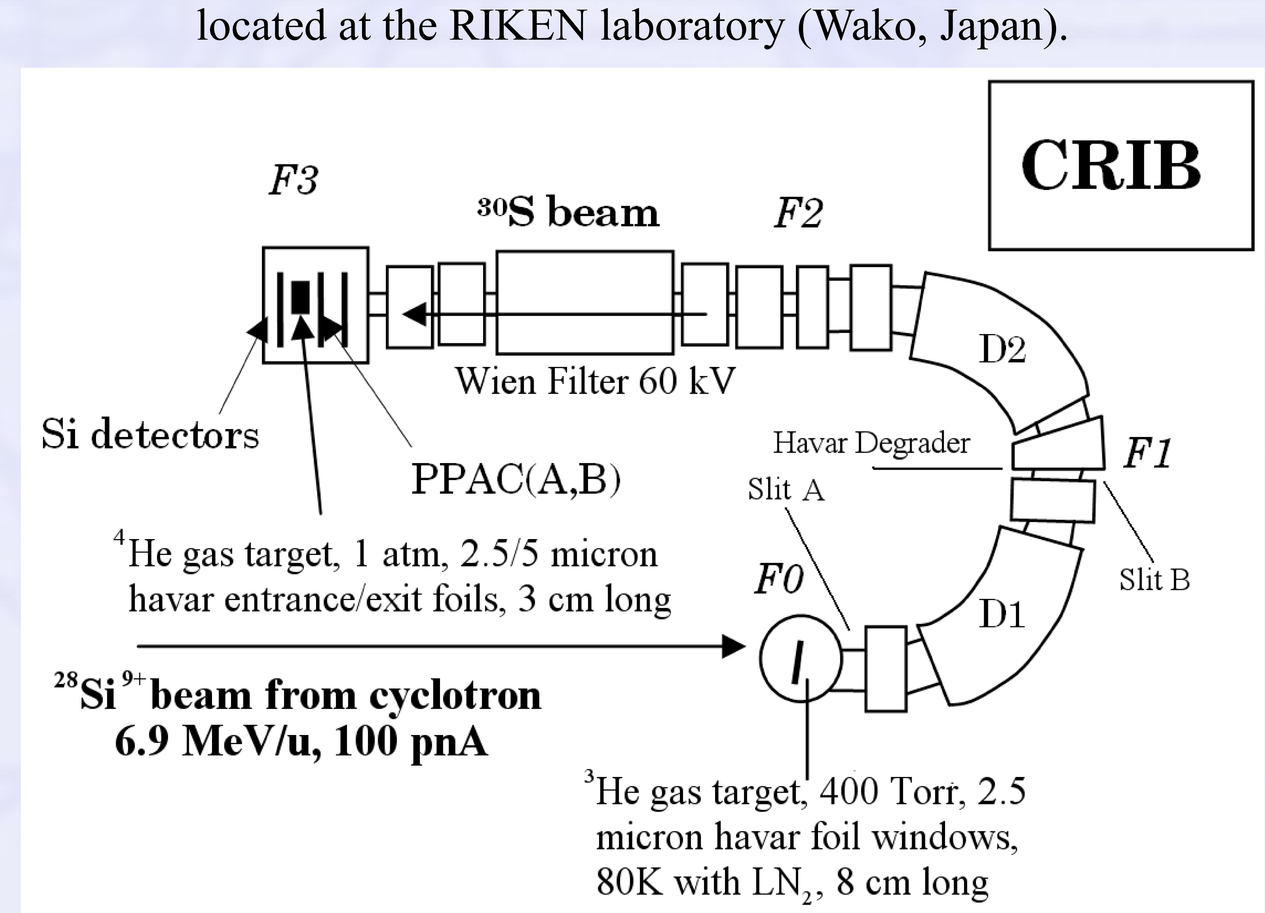

Figure 4: Schematic of CNS radioactive ion beam separator (CRIB) facility, showing experimental parameters of interest for ^{30}S beam development run.

Experimental Setup

To measure the ^{30}S(α,p)^{33}Cl cross section, we will bombard a He gas cell with ^{30}S, looking for reaction protons in coincidence with incident ^{30}S beam particles. [9]

- Scan Gamow window for T_9 = 1 – 2 K
  - Equivalent E_{beam} = 12 – 33 MeV
- Thick target method to scan Gamow window
  - Set He pressure based on $\langle E_{beam} \rangle$
  - Expected to be ~ 1 atmosphere

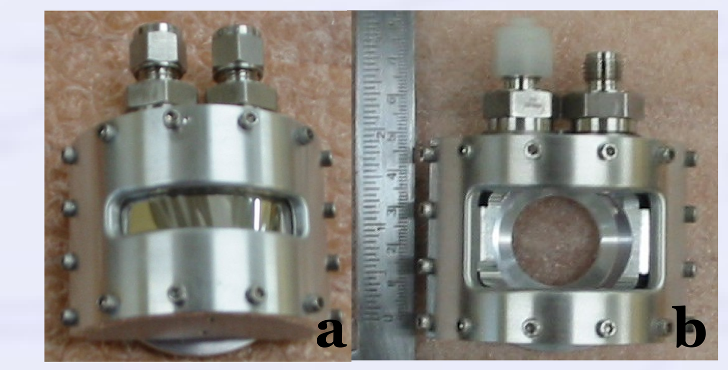

Figure 5: (**a**) Gas cell with havar window with 1 cm windows and (**b**) modified gas cell (foil windows absent) with 2 cm windows. Picture shows rear perspective of gas cell. ^{30}S beam diameter found to be ~ 1.5 cm.

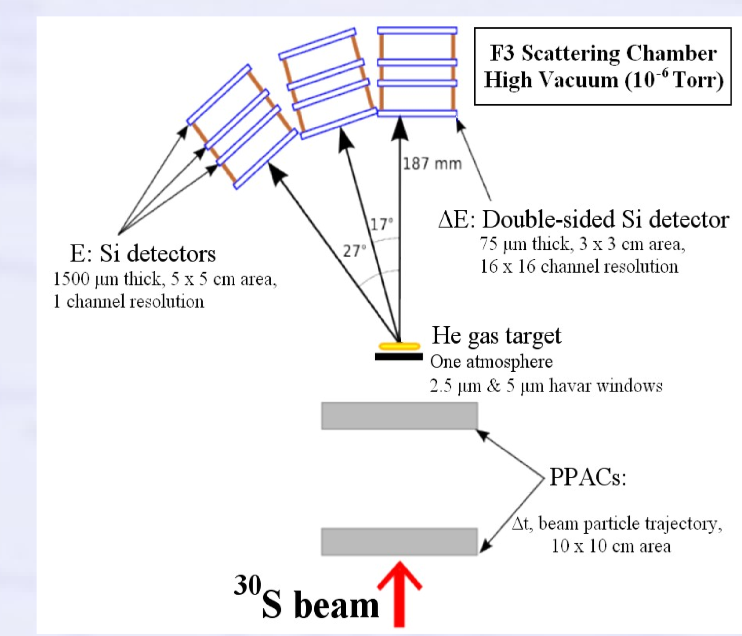

Figure 6: Schematic view of scattering chamber (F3 on *Figure 4*) detector setup.

- Detect protons at three angles
  - ΔE-E Silicon telescopes
  - Distinguish scattered α's from protons
- Parallel plate avalanche counters (PPAC)
  - Correlate beam particles with protons [10]
- Find efficiency using known (α,p) reaction [11]
  - Use ^{28}Si beam, like RIB production
  - α(^{28}Si,p)^{32}S previously measured [12,13]

Results

We developed a number of ^{30}S beams optimized to different parameters: one with 56% purity, another with 11.3 ± 1.8 MeV, and a third with 3 × 10^3 particles per second (pps). [14]

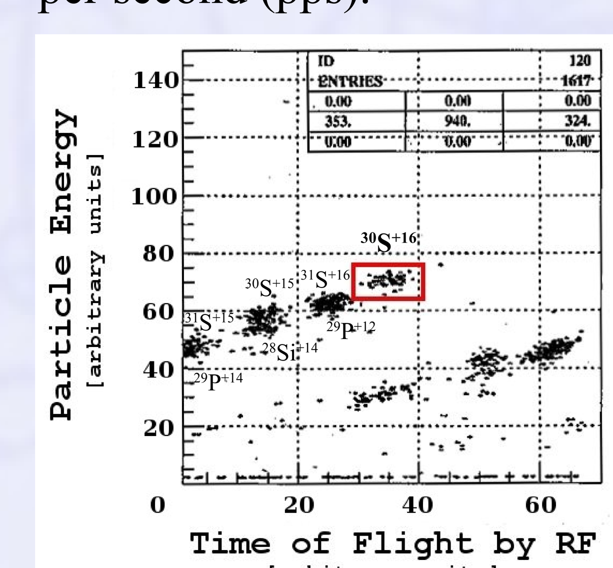

Figure 7: Sample on-line particle identification spectrum. Red box encloses ^{30}S^{+16} ions. Notice charge state contamination of ^{30}S ions with similar A/Q values to other reaction products.

- Fully ionized ^{30}S yielded the best results
  - ^{30}S^{+16}, E_{beam} = 14 ± 1.5 MeV
  - 3 x 10^3 pps / 100 pnA
  - 4.3% purity for lower intensities
- Second beam development run planned
  - Early 2008
  - 10^5 pps needed based on theoretical rate
  - Increase E_{beam} to Gamow window
- Measure ^{30}S(α,p) cross section spring 2008
  - Worst case: set lower limit
  - If rate is 10^2 above theoretical value, it's inconsistent with Fisker's waiting point theory, which we can measure with 10^3 pps.

McMaster University

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References and Works Cited

[1] J. L. Fisker, F.-K. Thielemann, M. Wiescher, ApJ **608** (2004) L61.
[2] E. Anders & M. Grevesse, Geochim. Cosmochim. Acta **53** (1989) 197.
[3] E. Kuulkers *et al.*, A&A **382** (2002) 947
[4] M. Sztajno *et al.*, ApJ **299** (1985) 487.
[5] J. van Paradijs *et al.*, MNRAS **221** (1986) 617.
[6] W. Penninx *et al.*, A&A **208** (1989) 146.
[7] W. Bohne *et al.*, Nucl. Phys. A **378** (1982) 525.
[8] S. Kubono *et al.*, Eur. Phys. J. A **13** (2002) 217.
[9] W. Bradfield-Smith *et al.*, Nuc. Inst. and Meth. A **425** (1999) 1.
[10] H. Kumagai *et al.*, Nuc. Inst. and Meth. A **470** (2001) 562.
[11] C. Wrede, private communication (2007).
[12] M. A. Buckby & J. D. King, Can. J. Phys. **62** (1984) 134.
[13] S. K. Das *et al.*, Phys. Rev. C **62** (2000) 054606.
[14] D. Kahl *et al.*, CNS Annual Report 2006.