Nucleosynthesis from Black Hole Accretion Disks

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Union College

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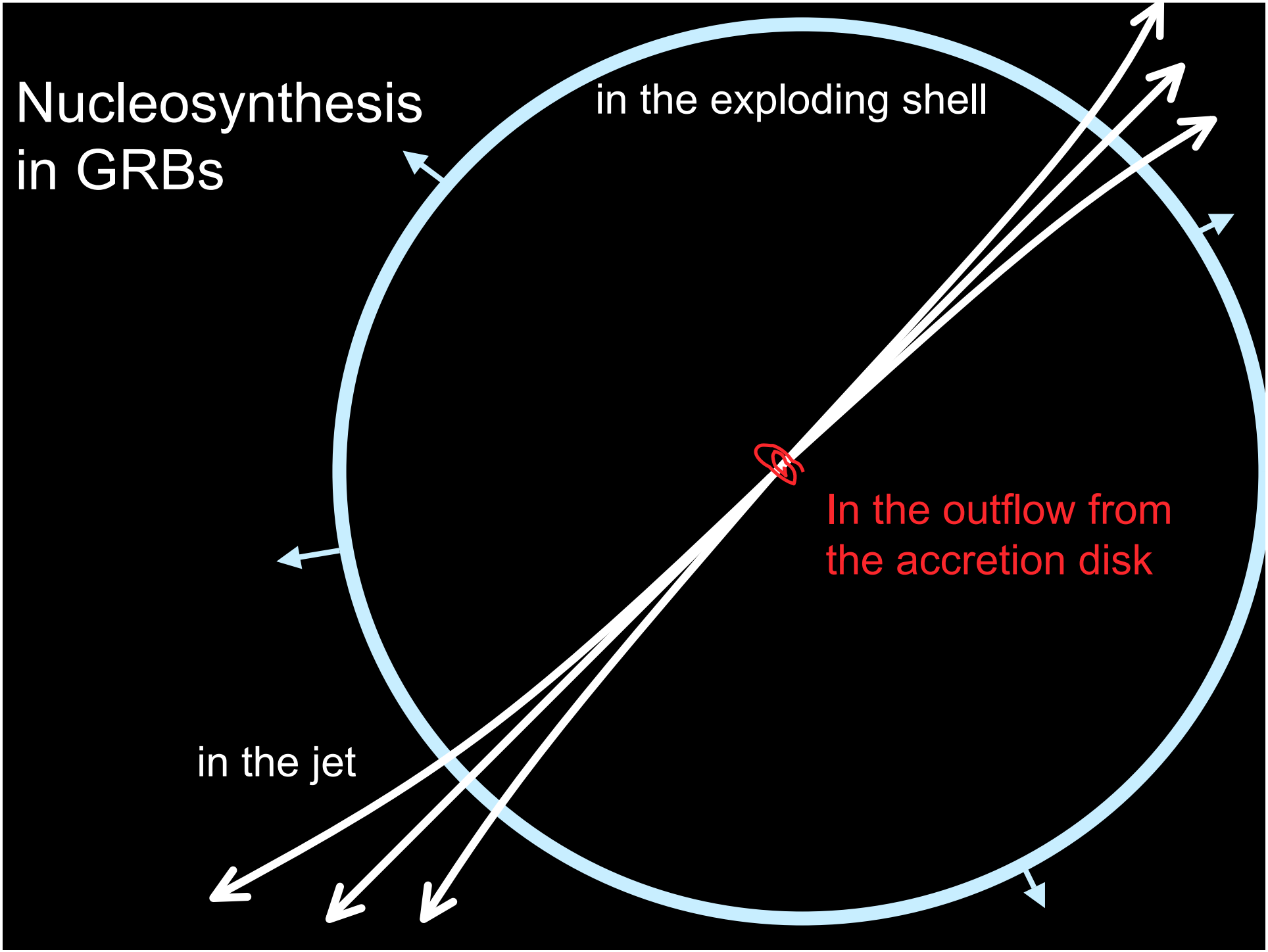
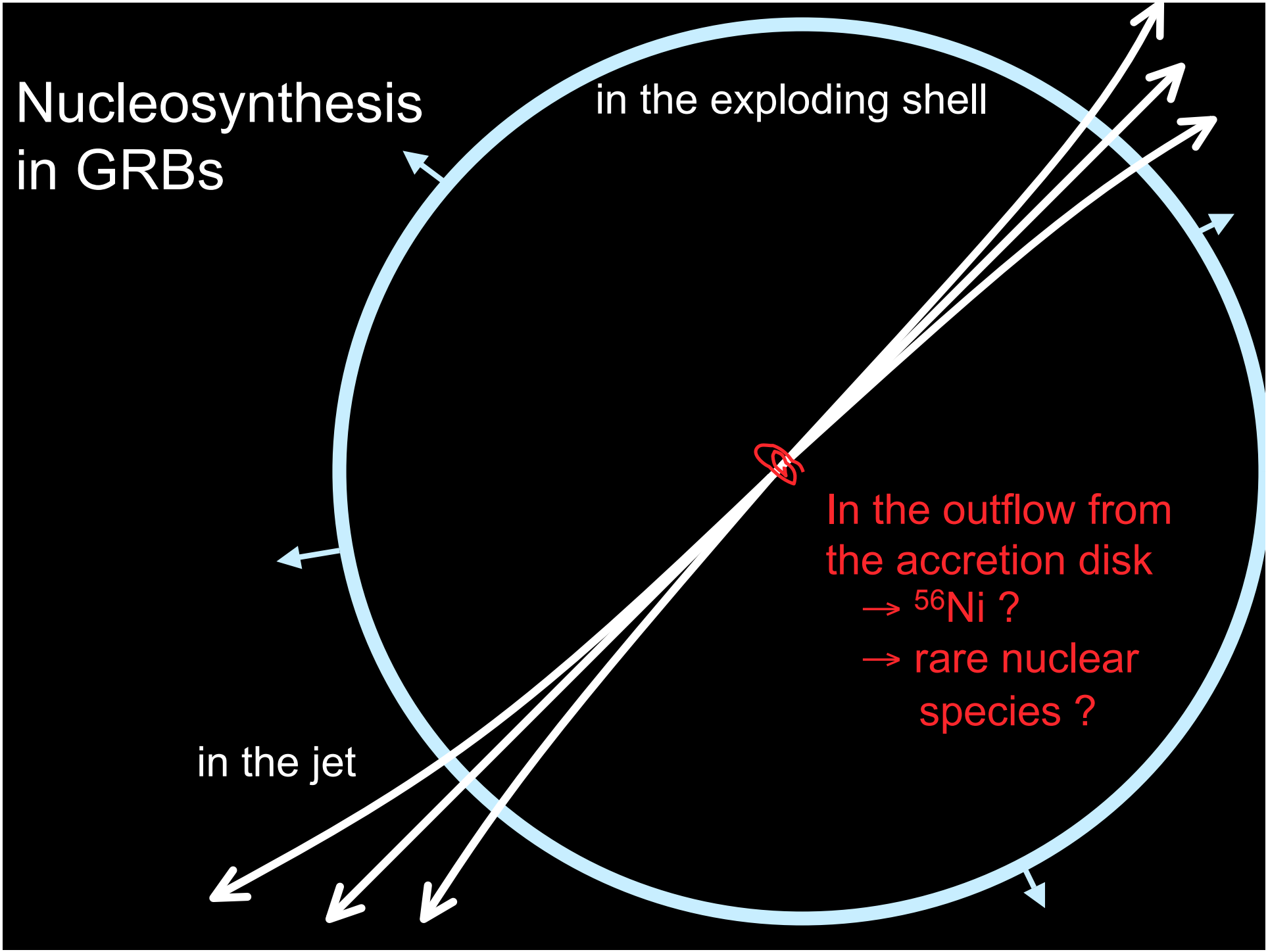
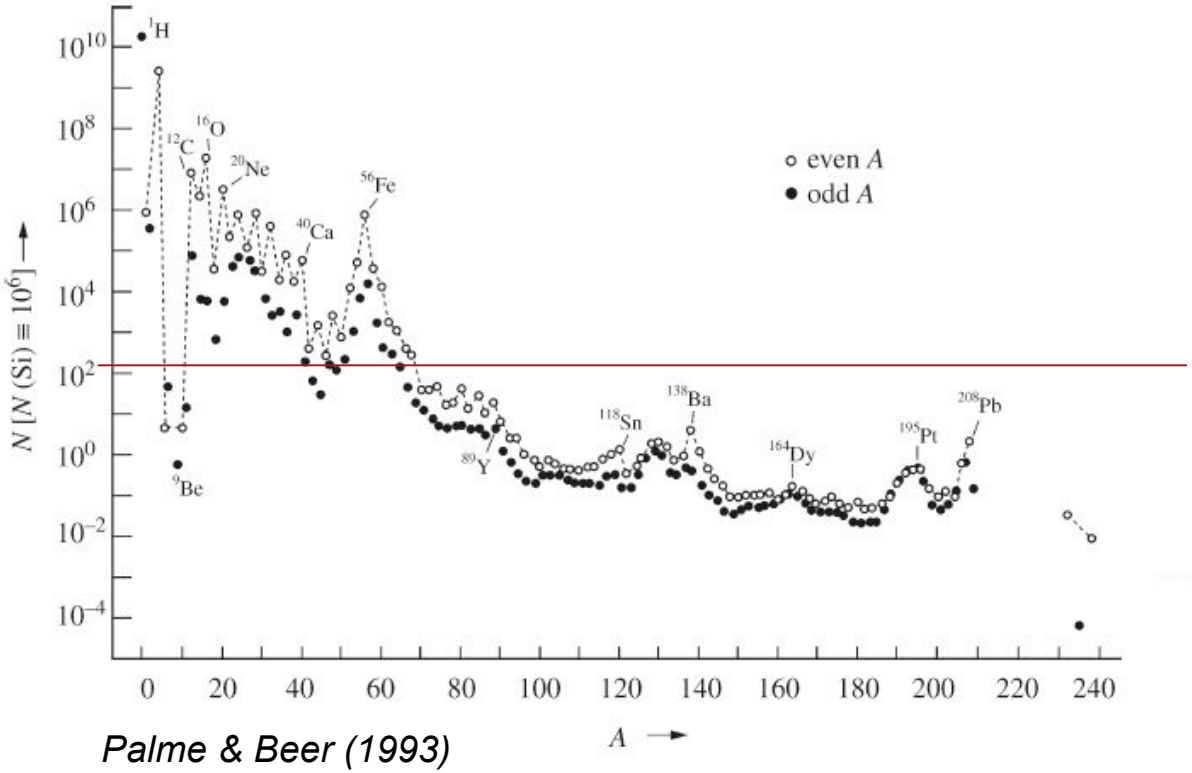

Nucleosynthesis
in GRBs
in the exploding shell
In the outflow from
the accretion disk
in the jet

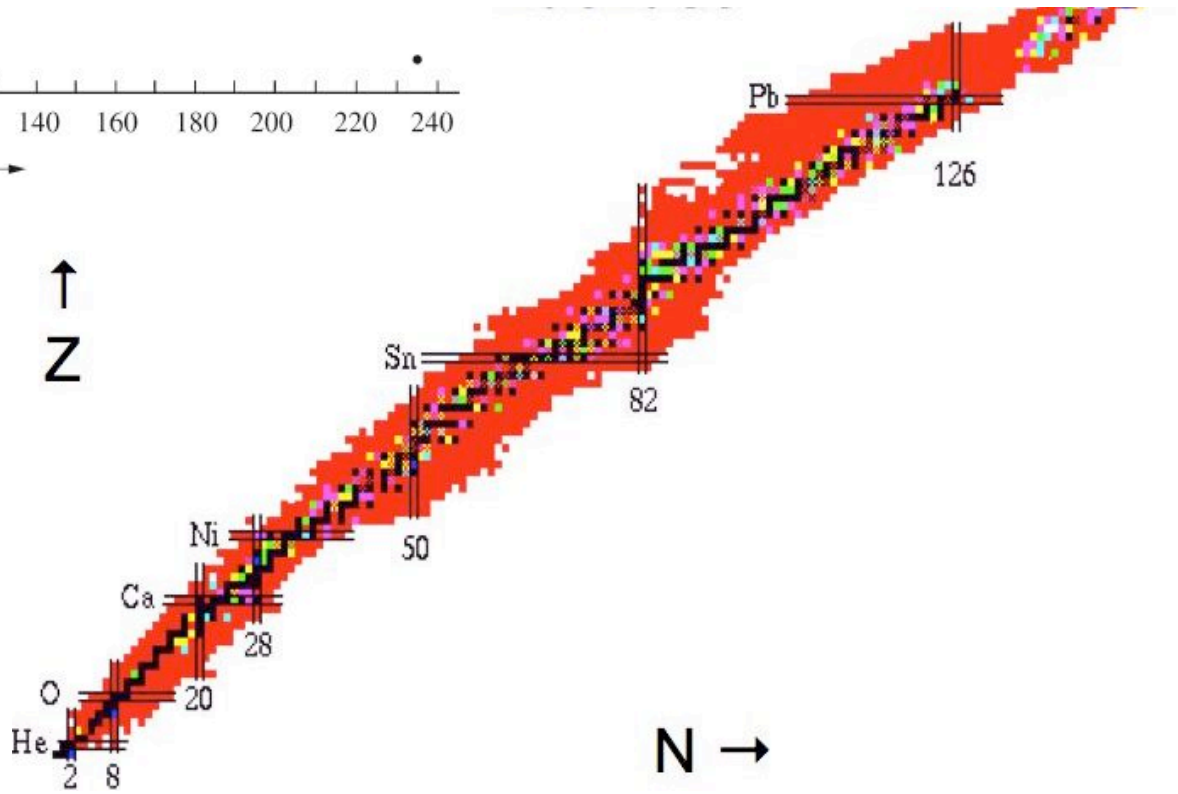

Nucleosynthesis
in GRBs
in the exploding shell
In the outflow from
the accretion disk
→ ^{56}Ni ?
→ rare nuclear
species ?
in the jet

Rare nuclear species



Palme & Beer (1993)

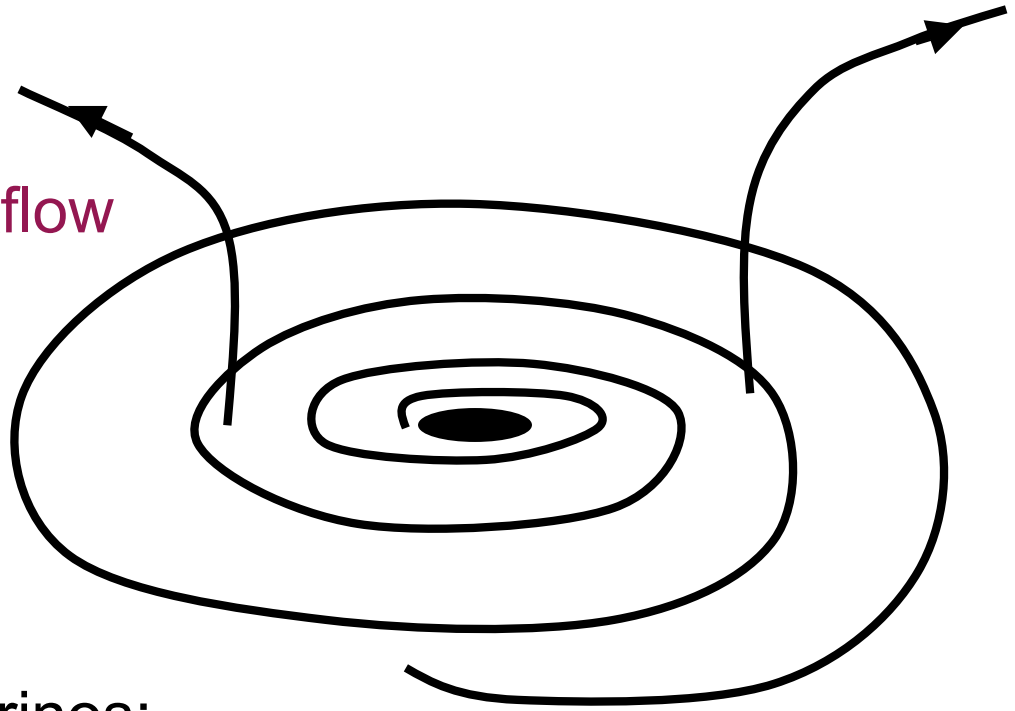
r, *s*, and *p* processes



Neutrinos and Nucleosynthesis in the Outflow

Follow material

- through disk
- as ejected in outflow



Importance of neutrinos:

Weak reactions set neutron-to-proton ratio,
which determines subsequent nucleosynthesis

Y_e in the Outflow

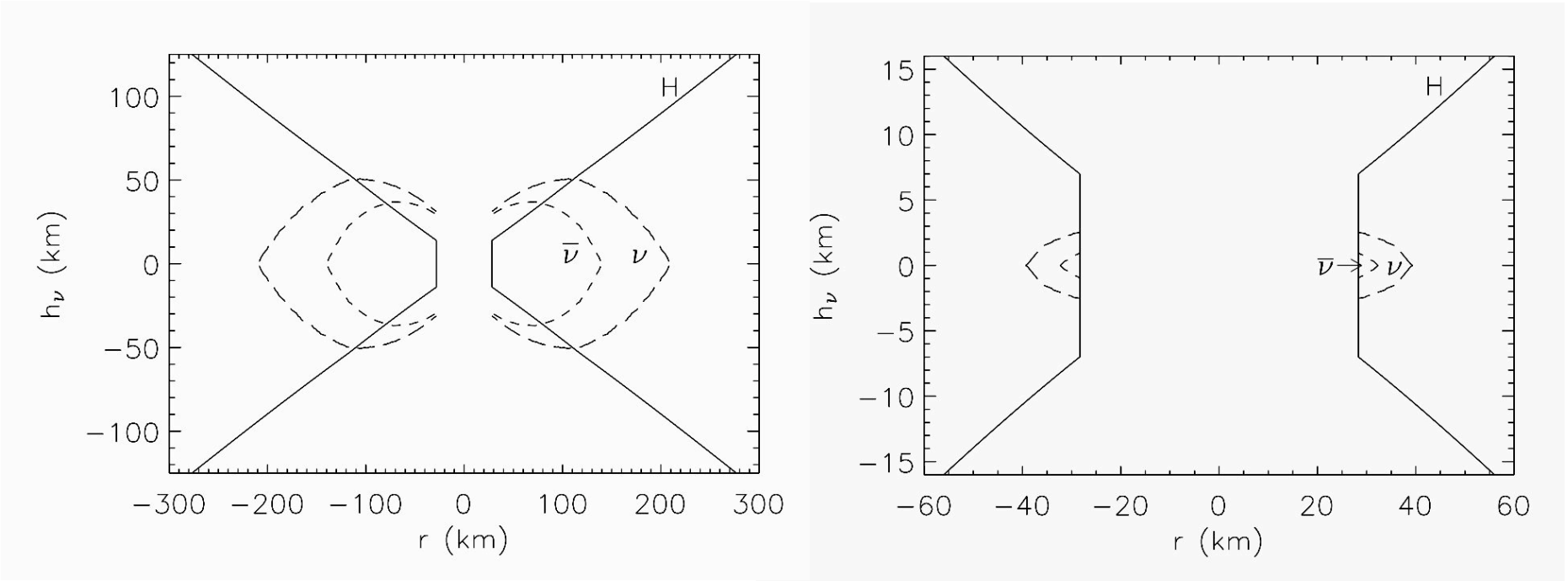
The neutron to proton ratio of the material is the crucial factor that determines the resulting nucleosynthesis

Electron fraction $Y_e = p/(p+n)$ set by

$$e^- + p \leftrightarrow n + \nu_e$$

$$e^+ + n \leftrightarrow p + \bar{\nu}_e$$

Y_e = 0.5 $\rightarrow$ n/p = 1



Surman & McLaughlin, ApJ, 603, 611 (2004)

Neutrino flux coming from disk is dominated by contribution from optically thick region

⇒ When antineutrino surface is large, the antineutrinos tend to dominate (higher T_ν) $\quad \bar{\nu}_e + p \rightarrow n + e^+$

⇒ If antineutrino surface is small or nonexistent, neutrino flux dominates $\quad \nu_e + n \rightarrow p + e^-$

Outflow Parameterization

Take velocity as a function of radial distance from the black hole to be

$$u = v_\infty \left(1 - \frac{R_o}{R}\right)^\beta$$

where 5,000 $< v_\infty <$ 50,000 km/s, 0.2 $< \beta <$ 2.5

Take flow to be vertical at first, then radial

Consider adiabatic flows with entropy $10 < s < 50$

Evolution of Ye in the outflow

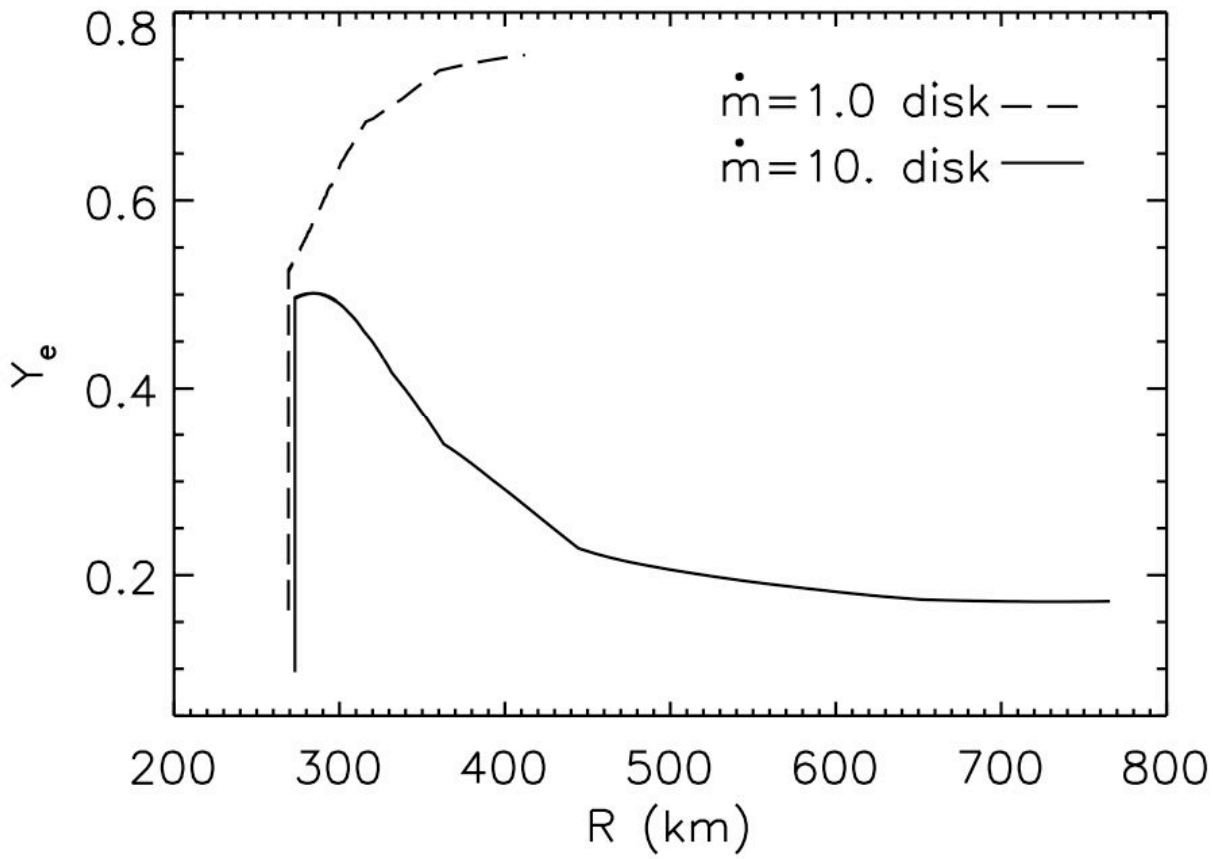
DPN

$r_o = 250$ km

$v_\infty = 0.1c$

$S = 50$

$\beta = 2.5$



Nuclear Recombination in the Outflow

Full nuclear network code:

W. R. Hix, *J. Comp. Appl. Math*., 109, 321 (1999)
(J. Beun, R. Surman)

r-process nucleosynthesis code:

J. Walsh, B.S. Meyer, R. Surman

Look for: * ^{56}Ni

* rare nuclear species:

p process

r process

High Y_e => Nickel Synthesis

PWF

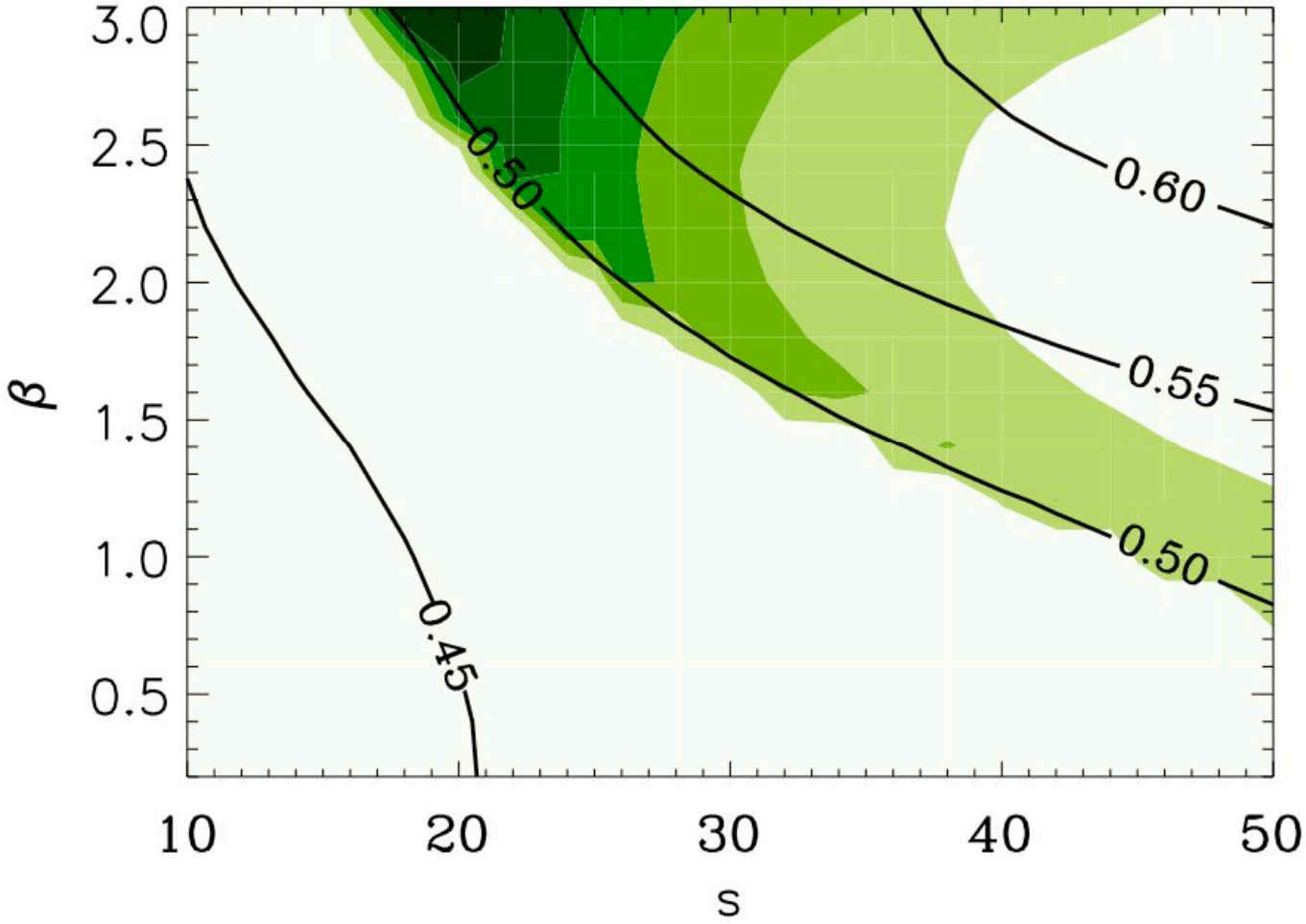
$\dot{m} = 0.1$

$r_o = 100 \text{ km}$

$v_\infty = 0.1c$

0.5 0.4 0.3 0.2 0.1

^{56}Ni mass fraction



Surman & McLaughlin, astro-ph0509365, ApJ in press

High Y_e => Nickel Synthesis

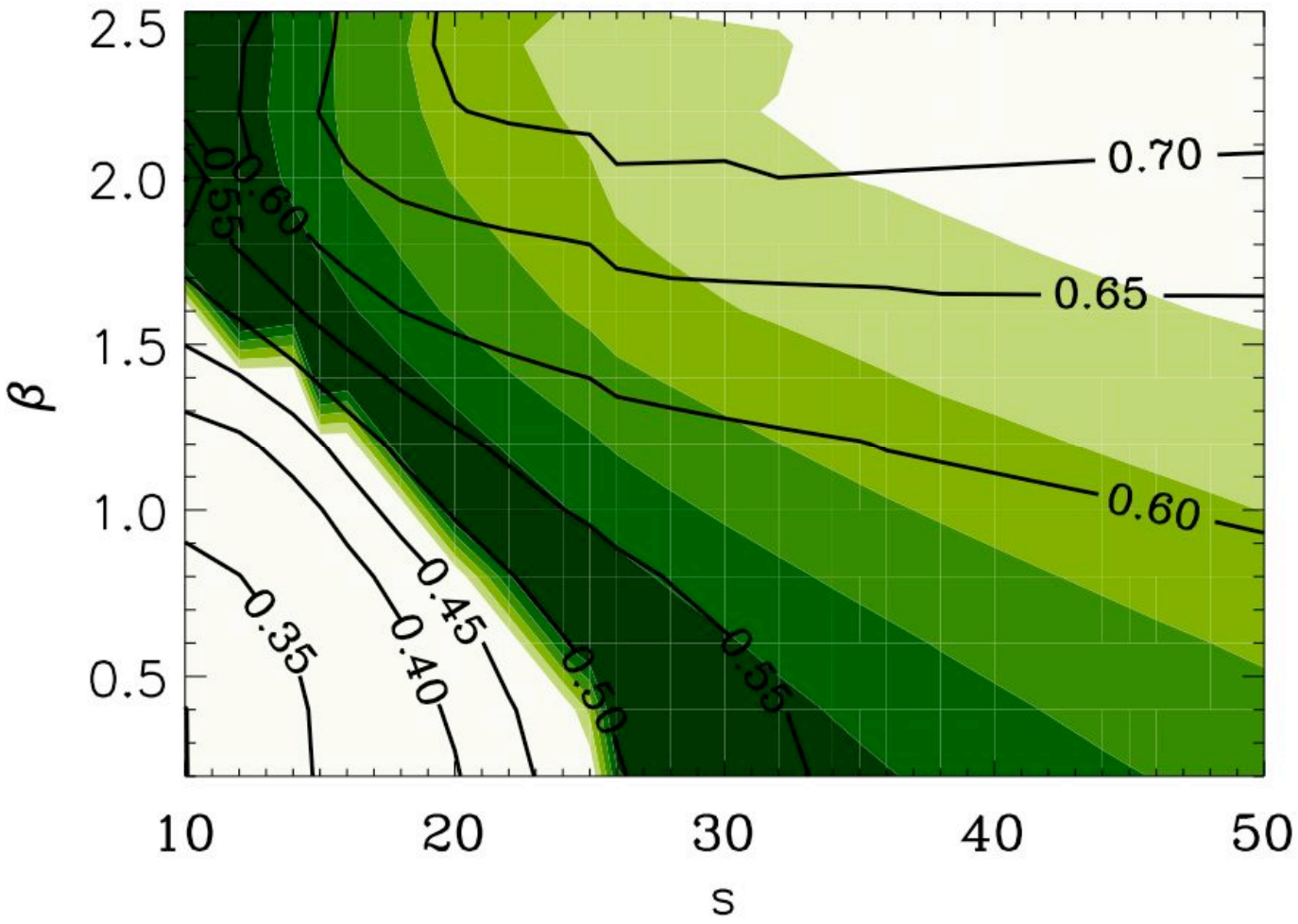
DPN

$\dot{m} = 1.0$

$r_o = 250 \text{ km}$

$v_\infty = 0.1c$

^{56}Ni mass fraction



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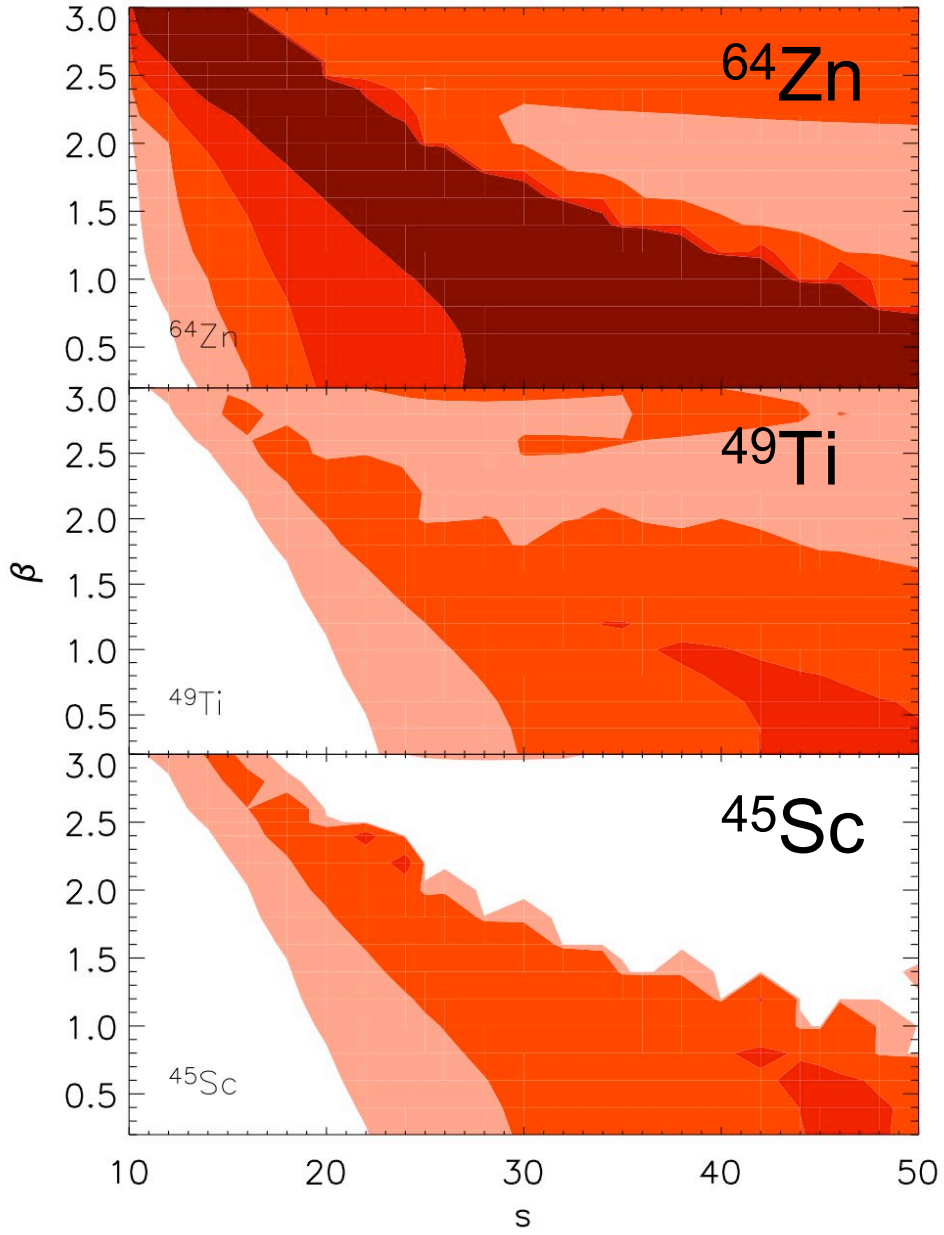

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Overproduction Factors

$$O(j) = \left(\frac{M_{wind}}{M_{SN\ ejecta}} \right) \times \left(\frac{X_{wind}}{X_{solar}} \right)$$

O(j) >

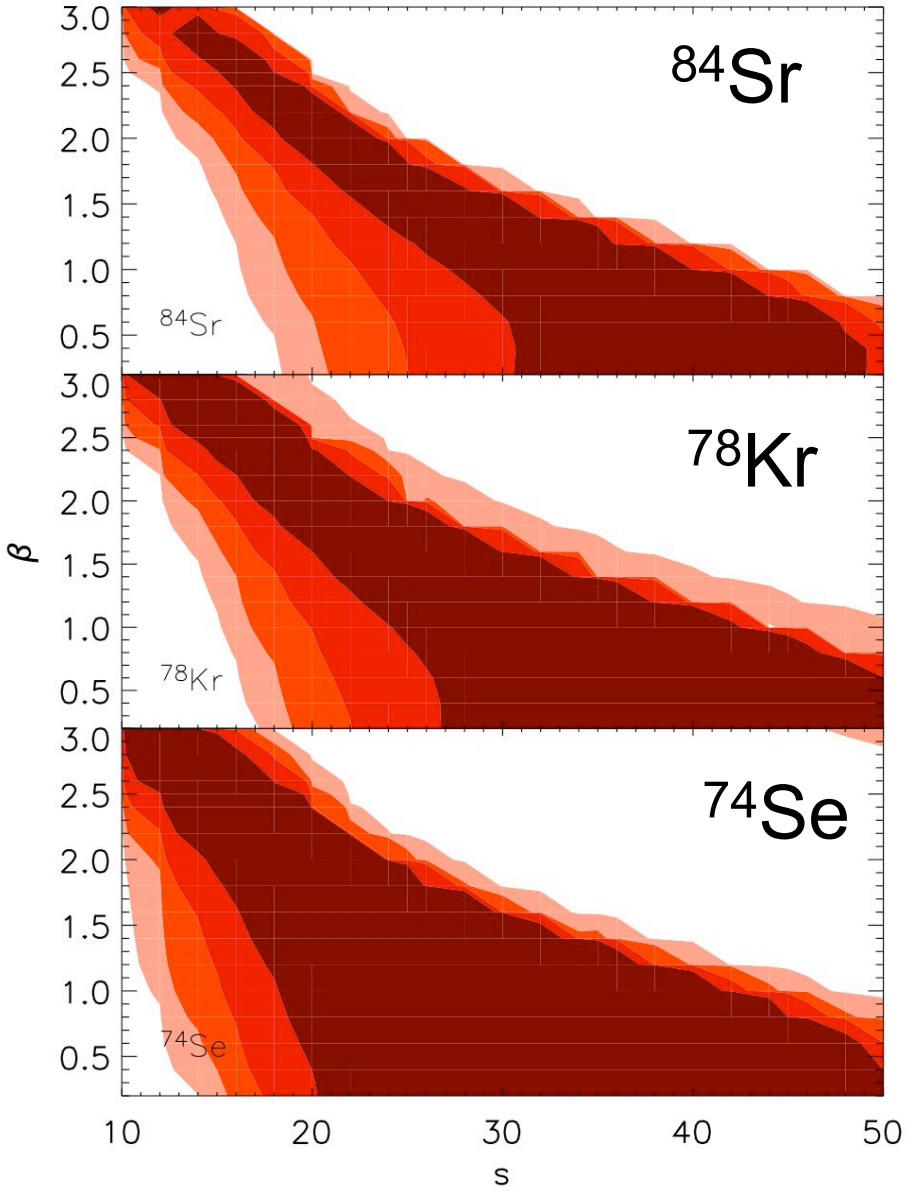
1000 100 10 1

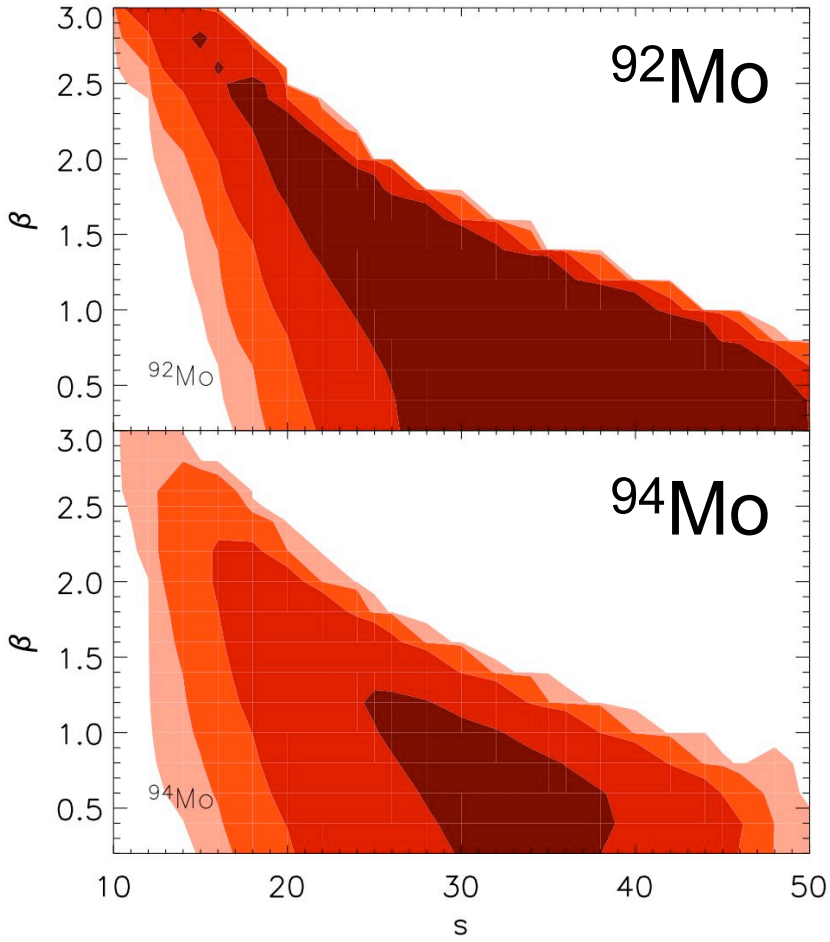
PWF

$\dot{m} = 0.1$

$r_o = 100$ km

$v_\infty = 0.1c$





Surman & McLaughlin, astro-ph0509365, ApJ in press

p-process nuclei

p-process nuclei

A > 100 (ex: ^{174}Hf, ^{168}Yb, ^{190}Pt)

produced via (γ,*n*) & (γ,α) reactions on heavy nuclei in supernovae

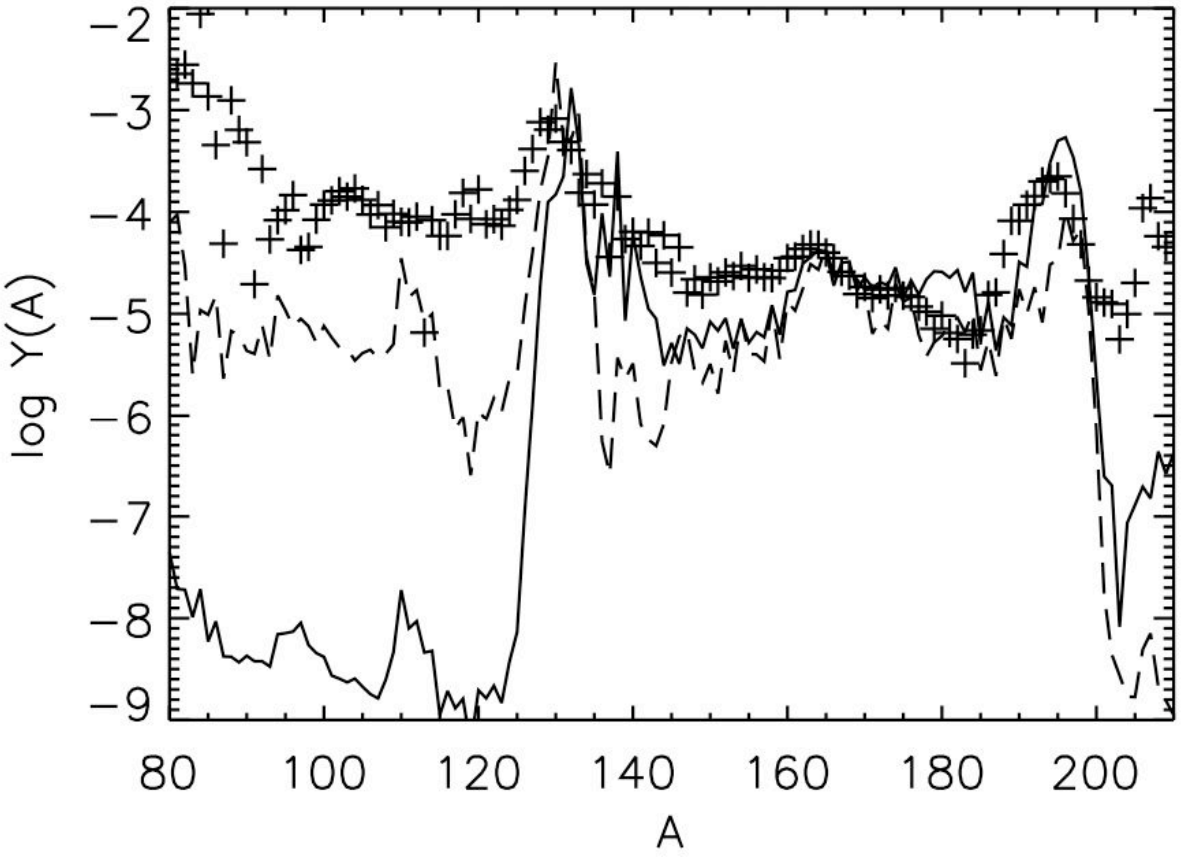
A < 100 (ex: ^{74}Se, ^{78}Kr, ^{84}Sr, ^{92,94}Mo)

factor of ~100 more abundant than A > 100 *p*-process nuclei

produced via explosive proton capture

site and method of production unclear

Low Y_e => *r*-Process Nucleosynthesis



DPN

$\dot{m} = 10$

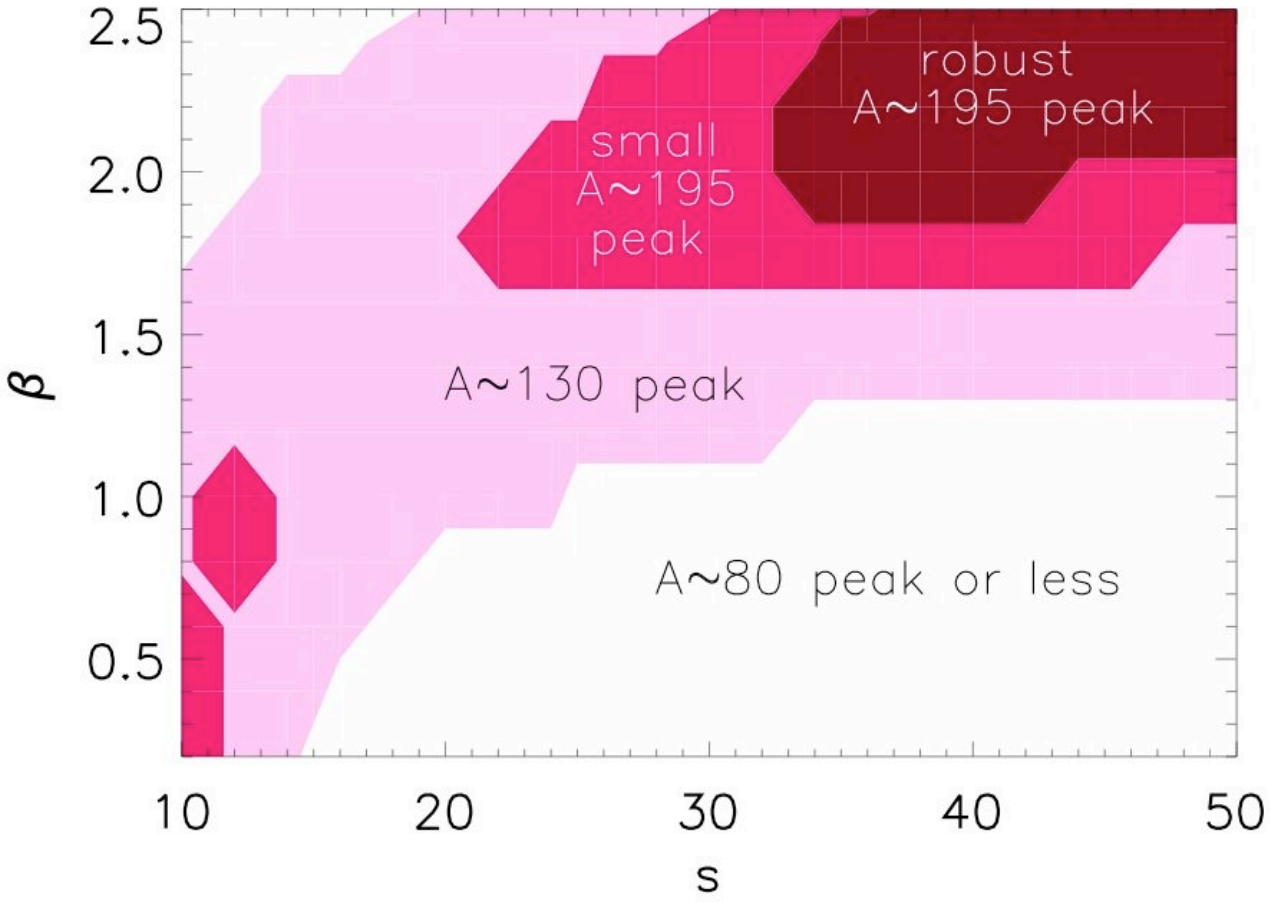
$r_o = 250$ km

$v_\infty = 0.1c$

$s = 10, \quad \beta = 0.4$

$s = 50, \quad \beta = 2.2$

Surman & McLaughlin, astro-ph0509365, ApJ in press



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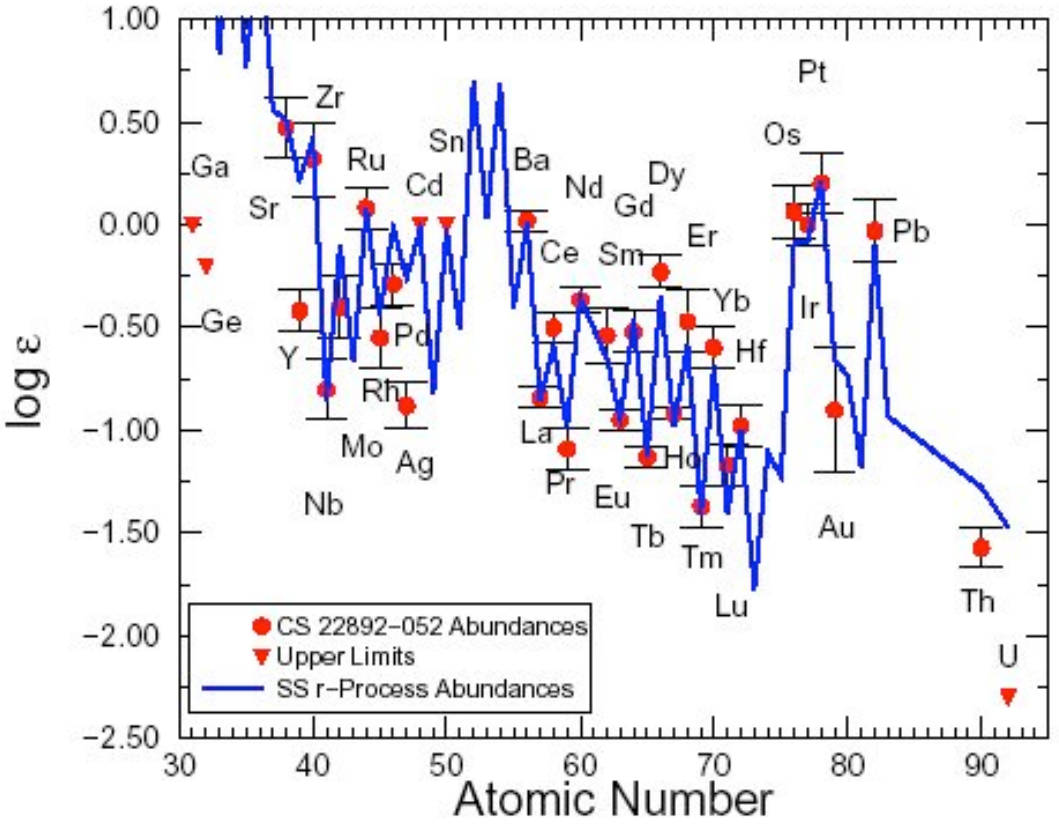
r-process nuclei



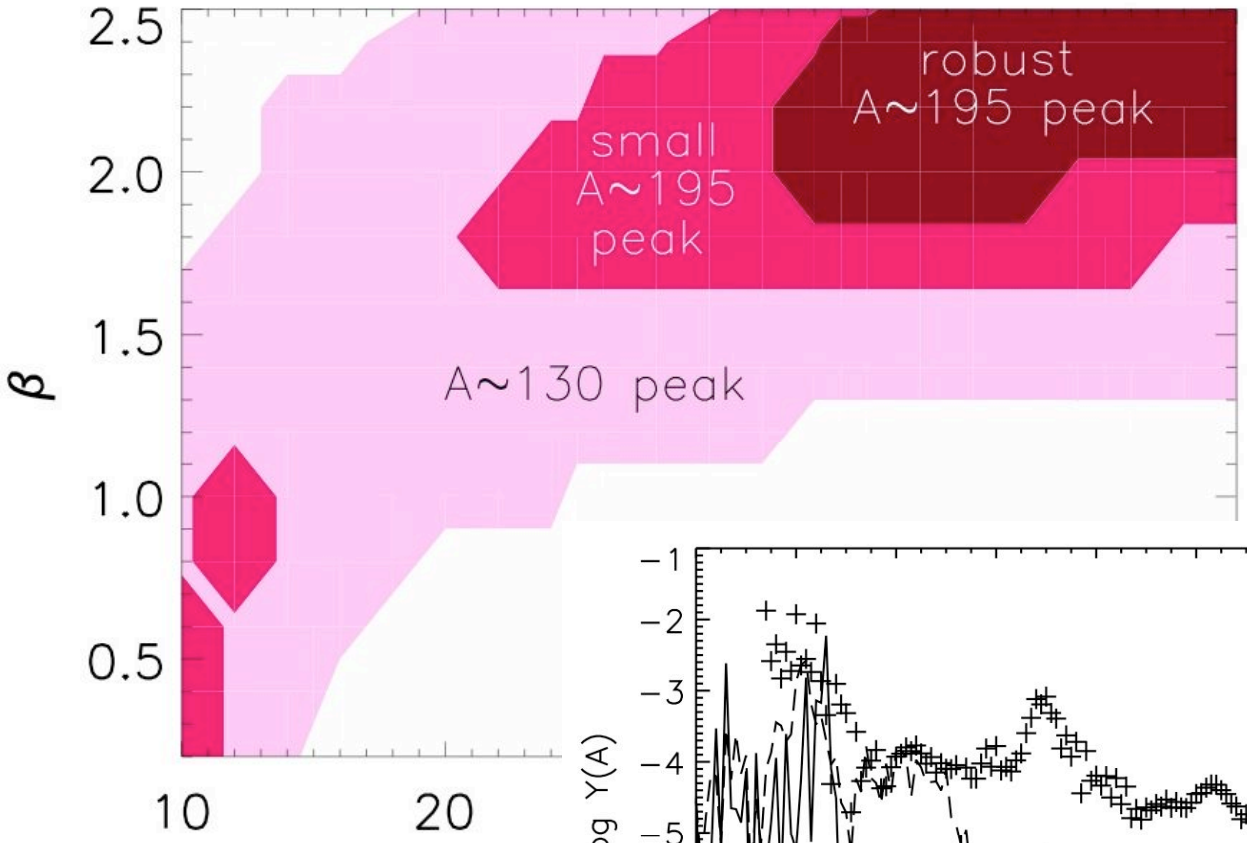
Cowan and Sneden (2004)

Possible astrophysical sites ⇒

neutron star mergers

core-collapse supernovae

Halo star observations appear to be most consistent with this site



DPN

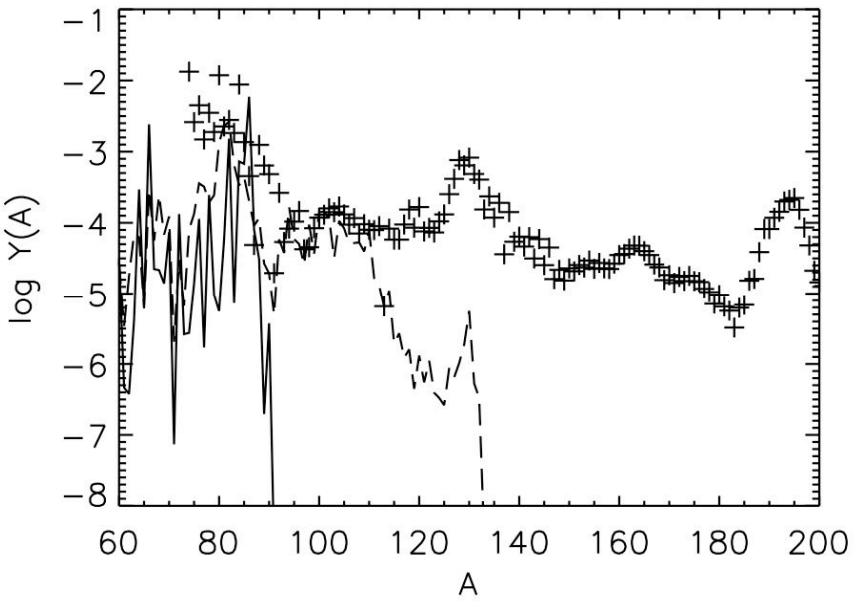
$\dot{m} = 10$

$r_o = 250$ km

$v_\infty = 0.1c$

$s = 30, \quad \beta = 1.0$

$s = 45, \quad \beta = 1.0$



Surman & McLaughlin, astro-ph0509365, ApJ in press

Conclusions

Given disk and outflow parameters, we can determine what nucleosynthesis will result from an understanding of the neutrinos

Nucleosynthesis in accretion disk outflows provides a promising mechanism for GRB nickel production

Additionally, GRBs may contribute to the galactic abundances of certain rare nuclear species, such as *r*-process nuclei or light/intermediate mass proton-rich nuclei