

# Neutrinos and Nucleosynthesis in Gamma Ray Bursts (black hole accretion disks)

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NIC 2006

Rebecca Surman

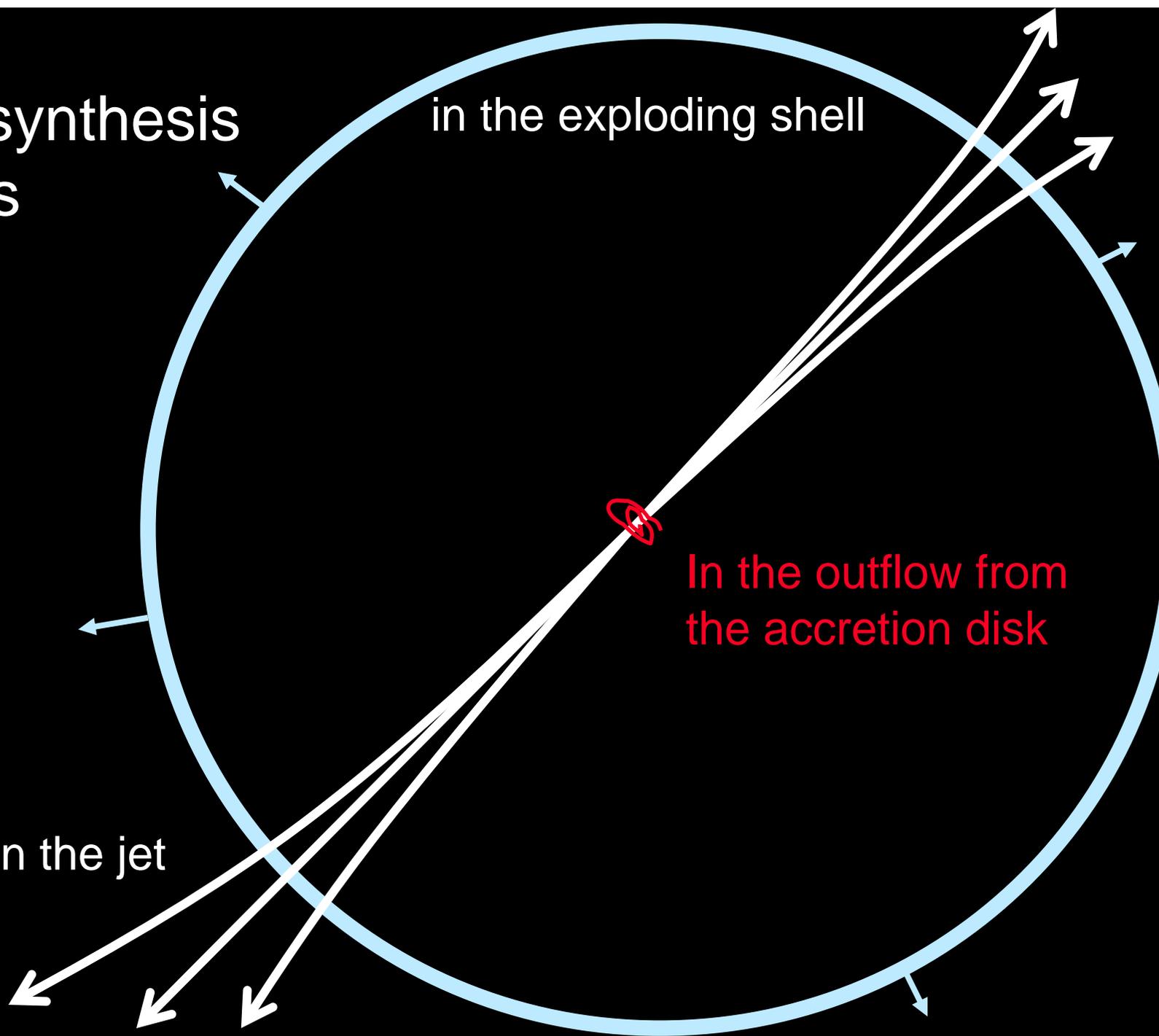
Union College

# Nucleosynthesis in GRBs

in the exploding shell

In the outflow from  
the accretion disk

in the jet



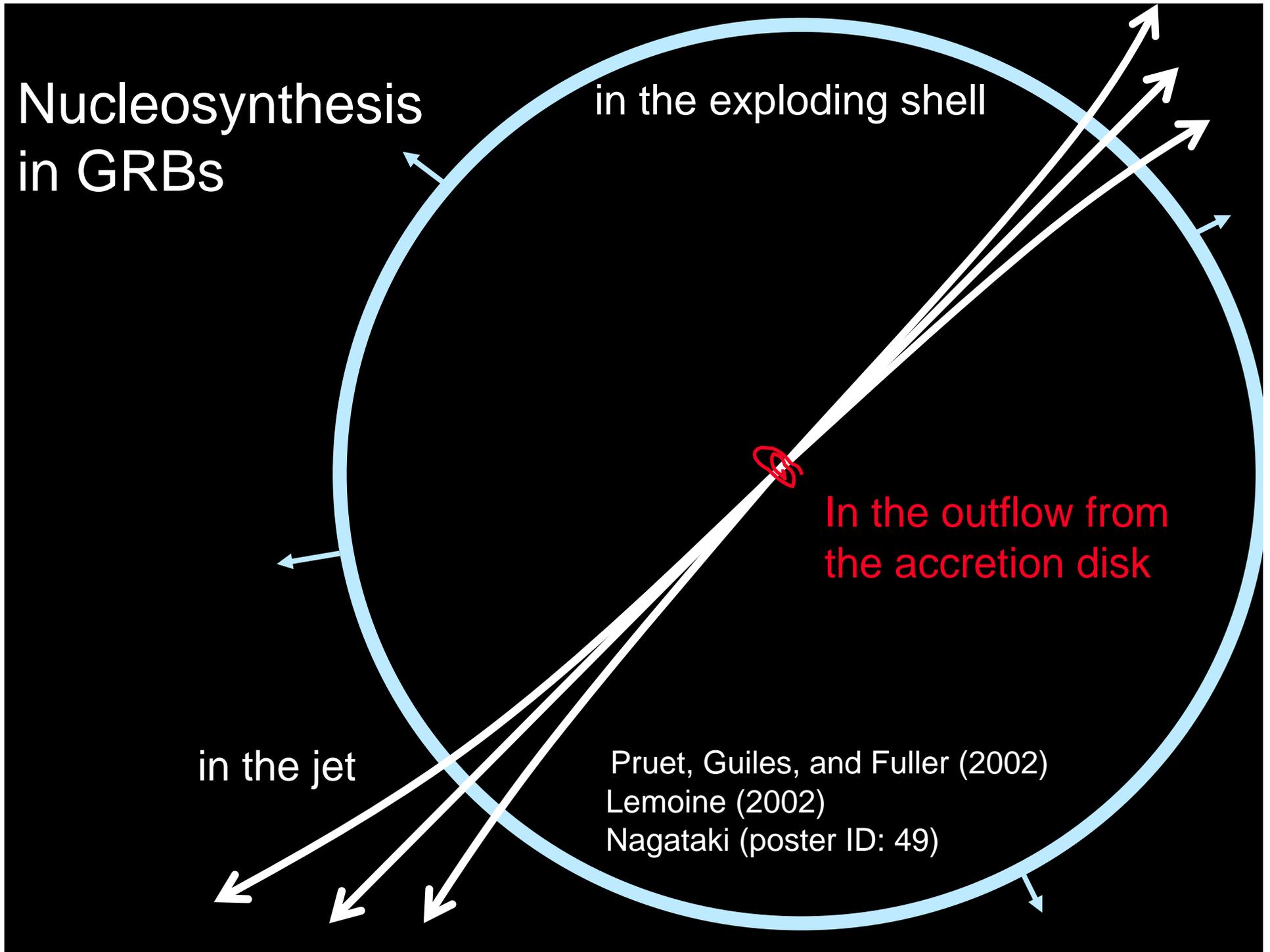
# Nucleosynthesis in GRBs

in the exploding shell

In the outflow from  
the accretion disk

in the jet

Pruet, Guiles, and Fuller (2002)  
Lemoine (2002)  
Nagataki (poster ID: 49)



# Nucleosynthesis in GRBs

in the exploding shell

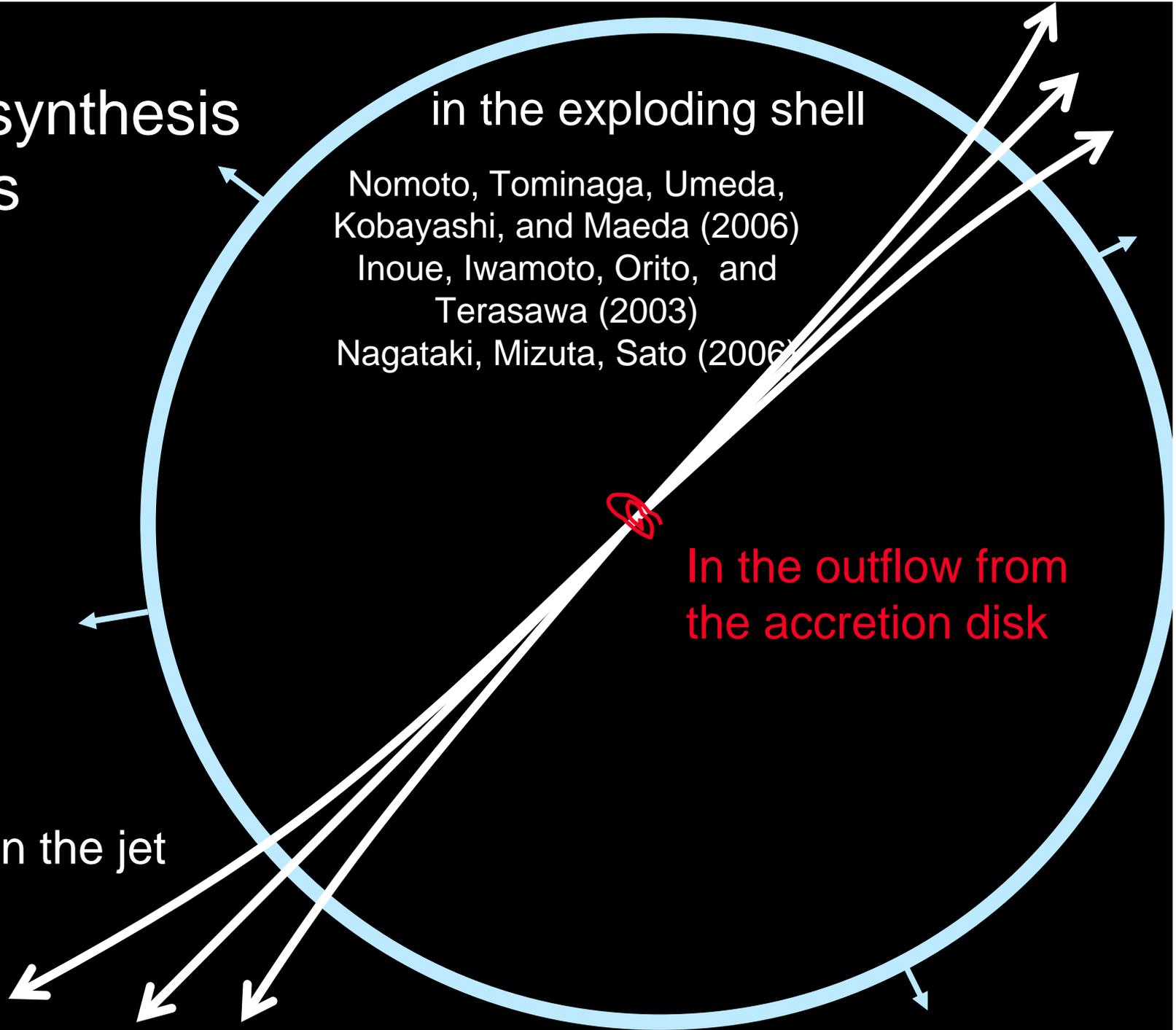
Nomoto, Tominaga, Umeda,  
Kobayashi, and Maeda (2006)

Inoue, Iwamoto, Orito, and  
Terasawa (2003)

Nagataki, Mizuta, Sato (2006)

In the outflow from  
the accretion disk

in the jet



# Nucleosynthesis in GRBs

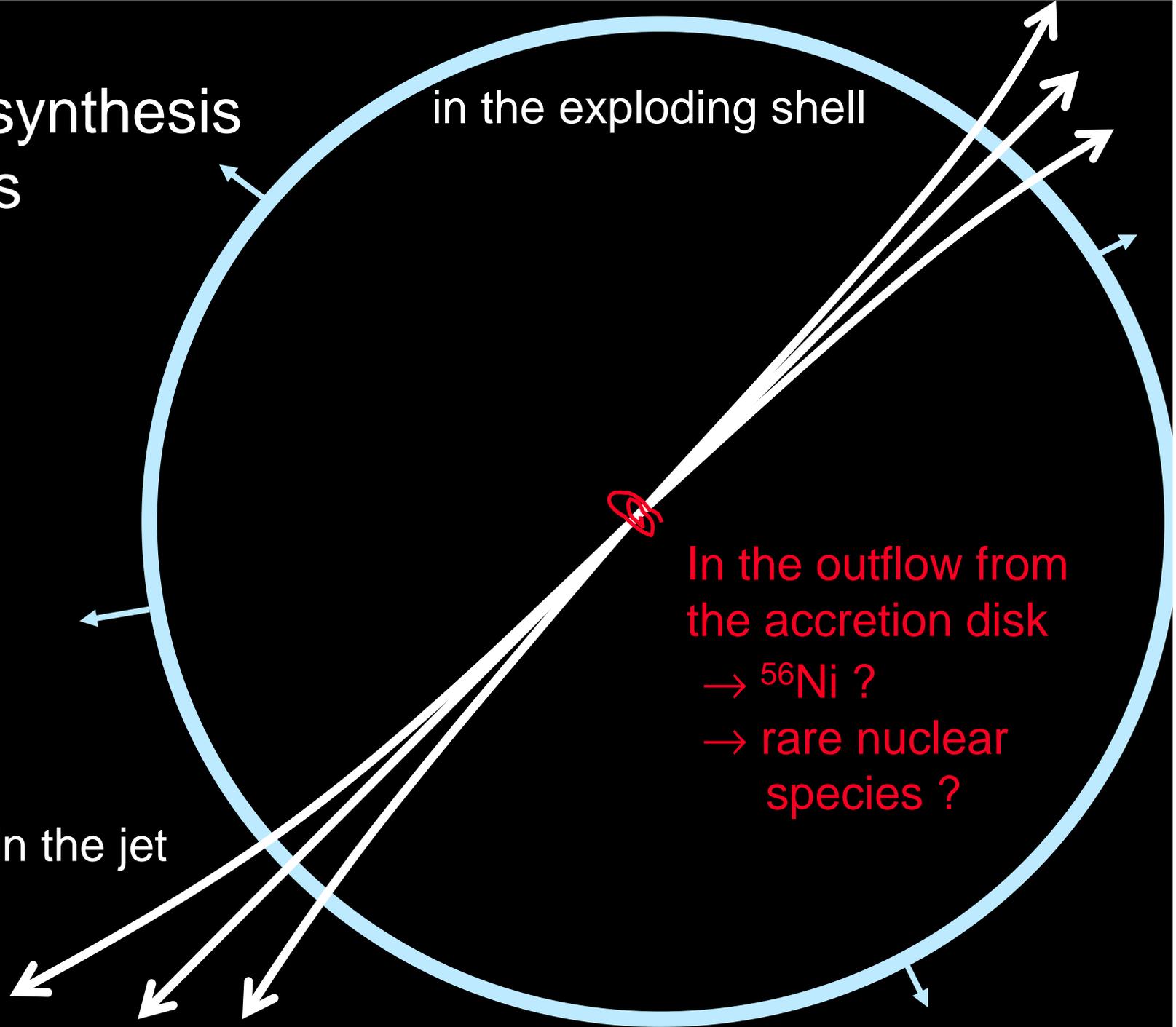
in the exploding shell

In the outflow from  
the accretion disk

→  $^{56}\text{Ni}$  ?

→ rare nuclear  
species ?

in the jet



# Nucleosynthesis in GRBs

in the exploding shell

In the outflow from  
the accretion disk

Surman, et al (2004,2006)

Pruet, et al (2004)

Fujimoto, et al (2004)

in the jet

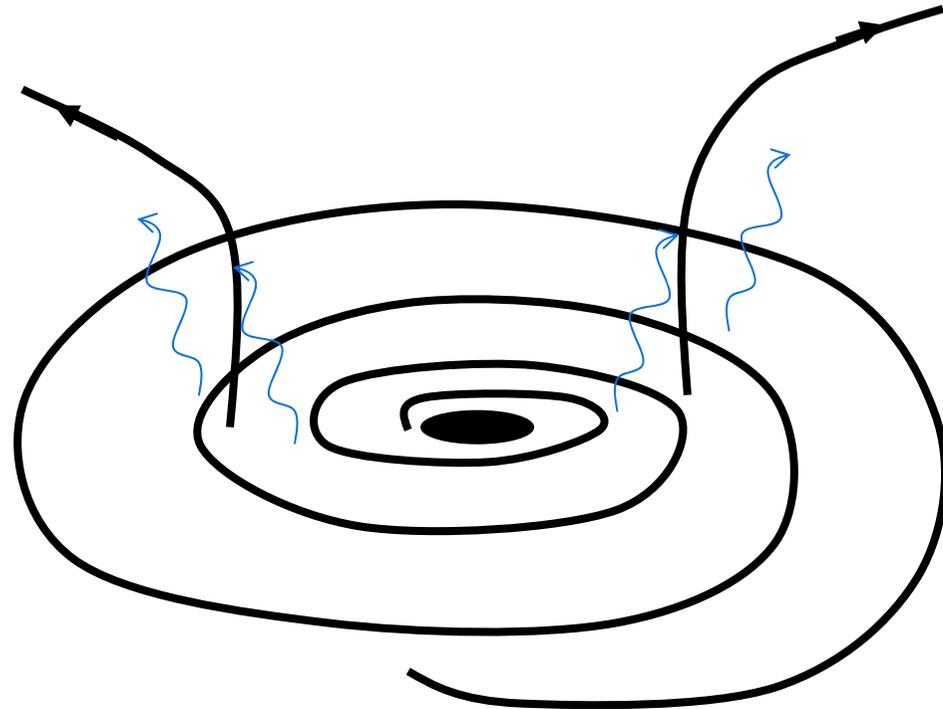
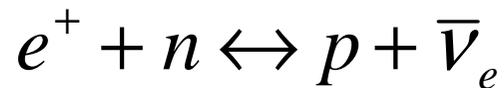
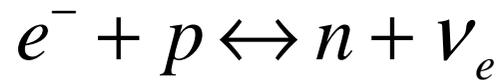


# Nucleosynthesis in the Outflow

Follow material

- through disk
- as ejected in outflow

Electron fraction set by:



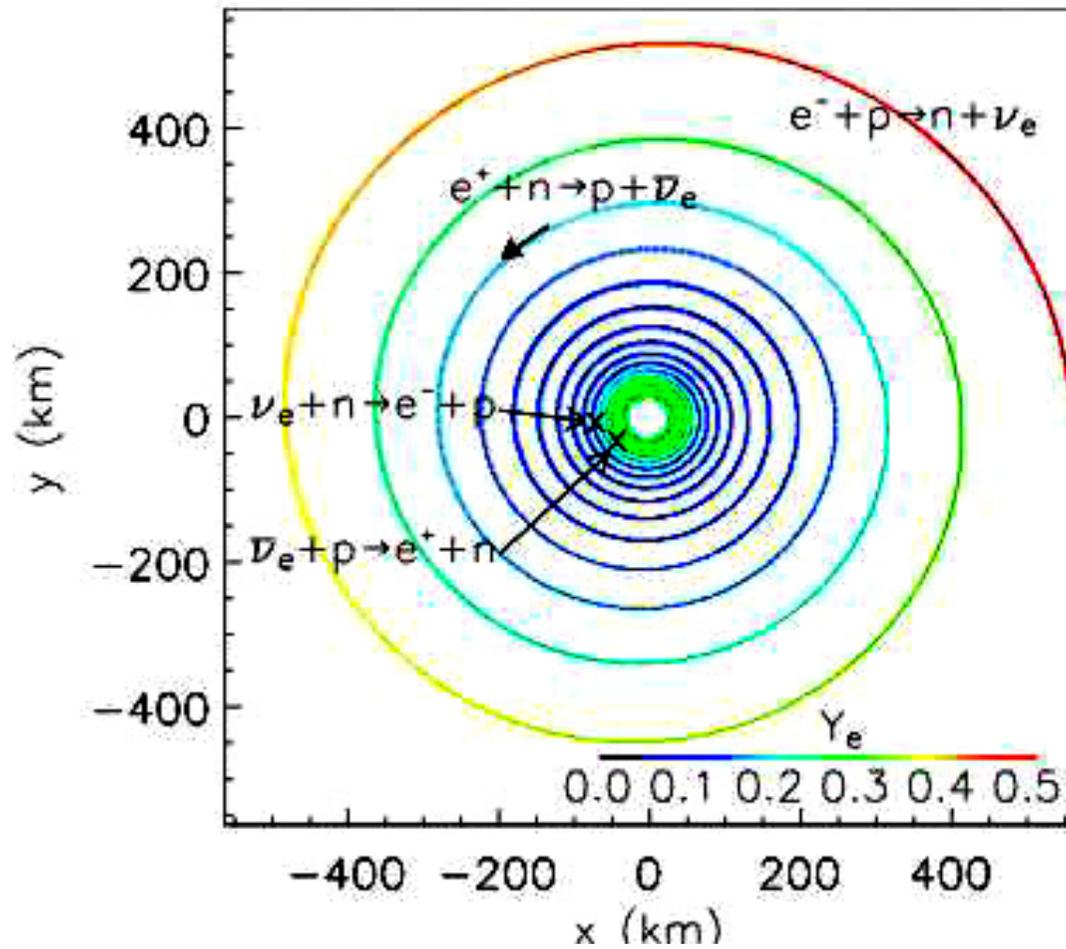
Disk models:

Low accretion rate disks -  $\dot{m} < 1$ , where  $\dot{m} = 1$  is 1 solar mass/second

Popham, Woosley, and Fryer (1999)

High accretion rate disks -  $\dot{m} \geq 1$

DiMatteo, Perna, and Narayan (2002)



Evolution of  $Y_e$   
in the disk

DPN  $\dot{m} = 1.0$

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

# Outflow Parameterization

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

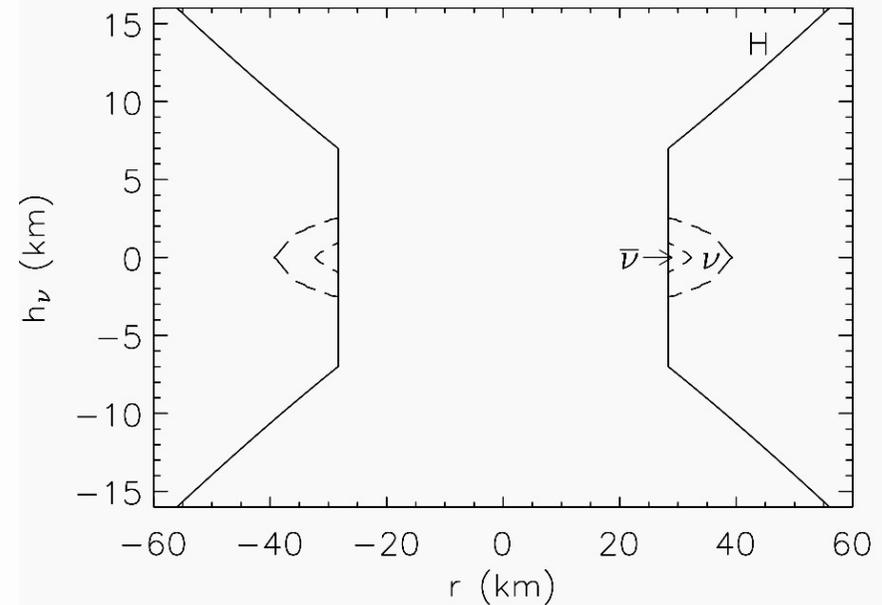
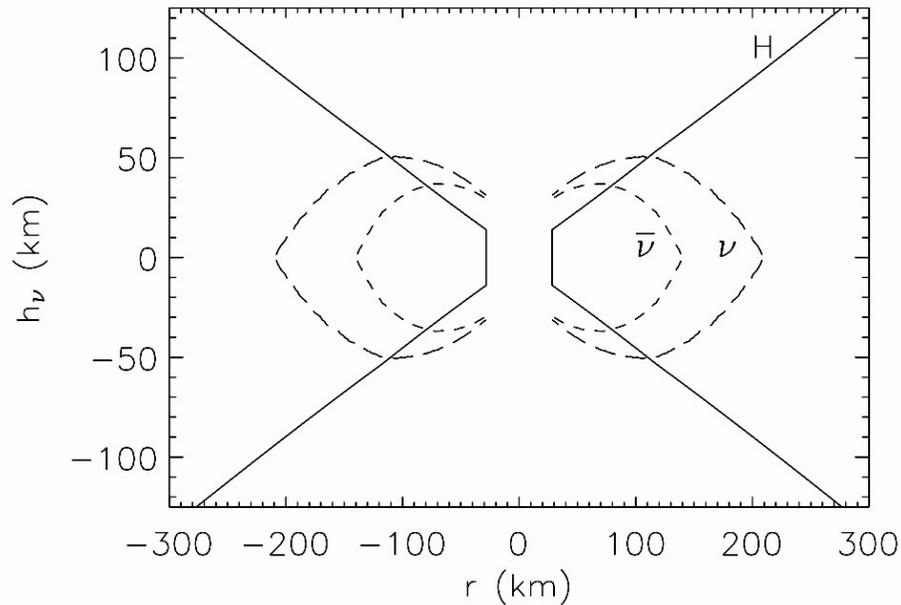
$$u = v_{\infty} \left( 1 - \frac{R_o}{R} \right)^{\beta}$$

where  $5,000 < v_{\infty} < 50,000$  km/s,  $0.2 < \beta < 3.0$

Take flow to be vertical at first, then radial

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

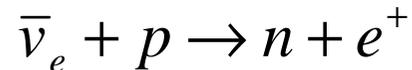
# Neutrino Decoupling Surfaces



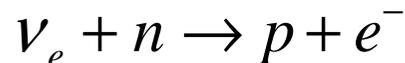
Surman & McLaughlin, *ApJ*, 603, 611 (2004)

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

⇒ When antineutrino surface is large, the antineutrinos tend to dominate (higher  $T_\nu$ )



⇒ If antineutrino surface is small or nonexistent, neutrino flux dominates



# 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: \*  $^{56}\text{Ni}$

\* rare nuclear species:

*p* process

*r* process

# Low accretion rate => Nickel Synthesis

PWF

$$\dot{m} = 0.1$$

$$r_o = 100 \text{ km}$$

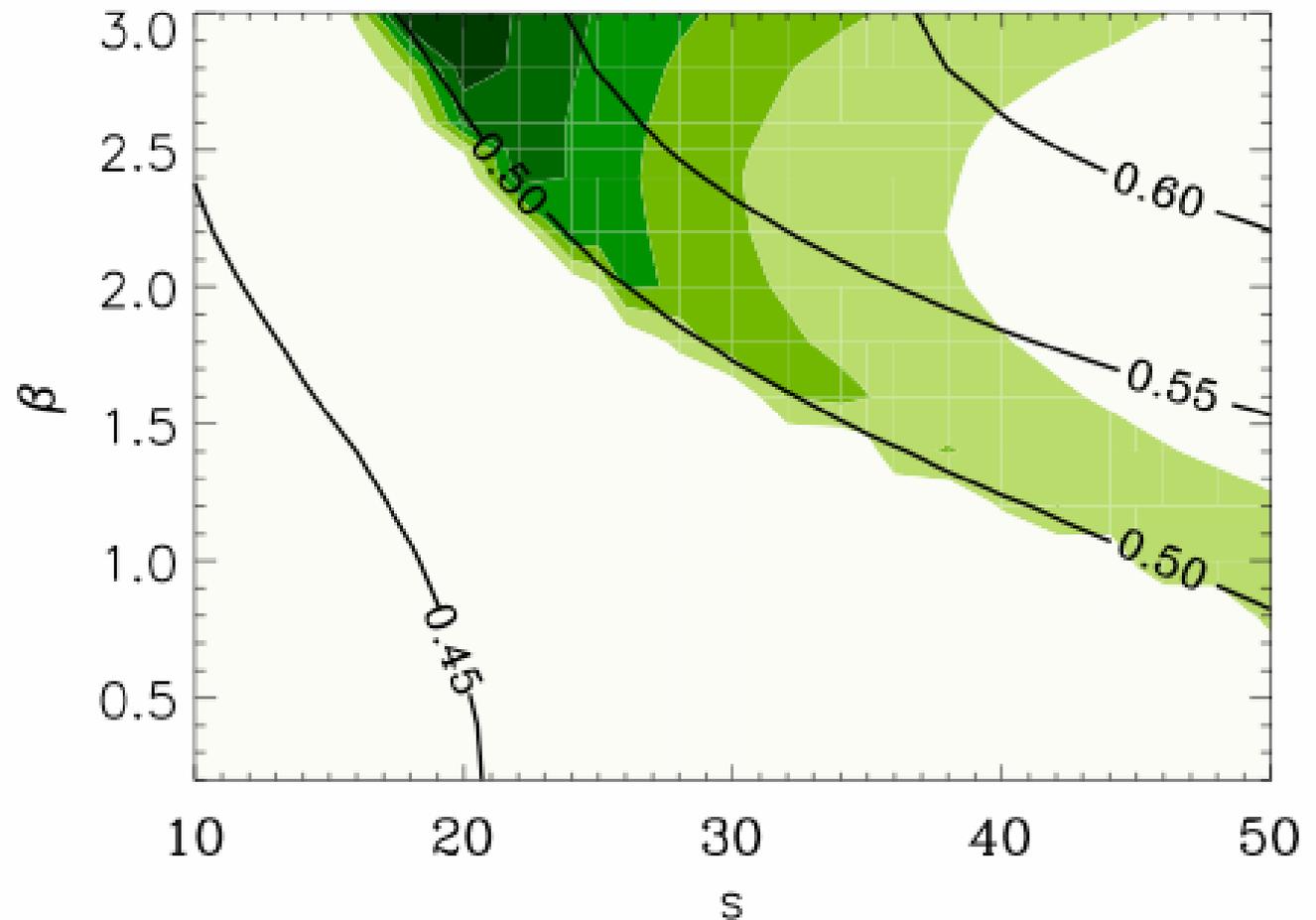
$$v_\infty = 0.1c$$



0.5 0.4 0.3 0.2 0.1

<sup>56</sup>Ni mass  
fraction

Lines indicate  
Ye



Surman, McLaughlin & Hix, *ApJ*, 643, 1057 (2006)

# Moderate accretion rates => Nickel Synthesis

DPN

$$\dot{m} = 1.0$$

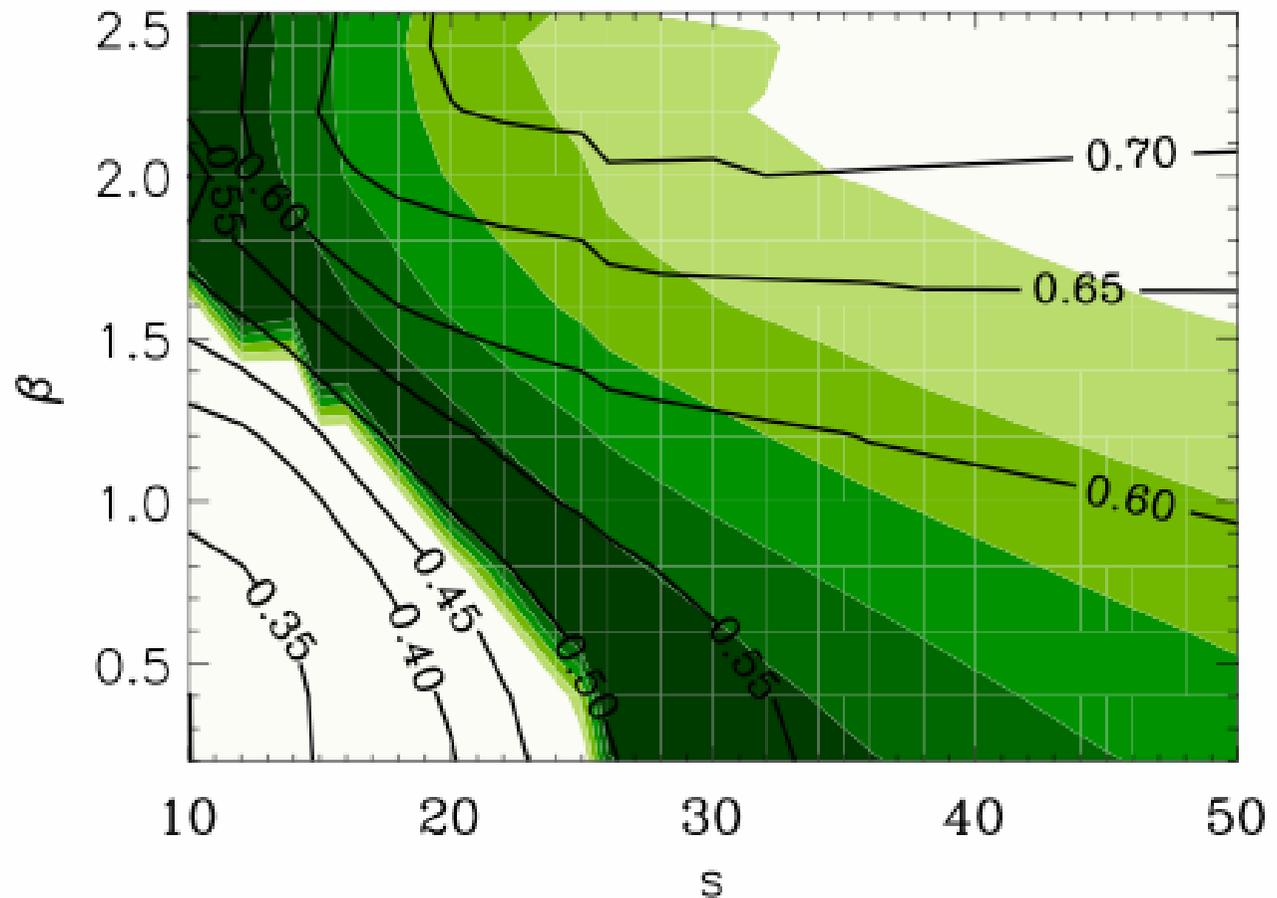
$$r_o = 250 \text{ km}$$

$$v_\infty = 0.1c$$



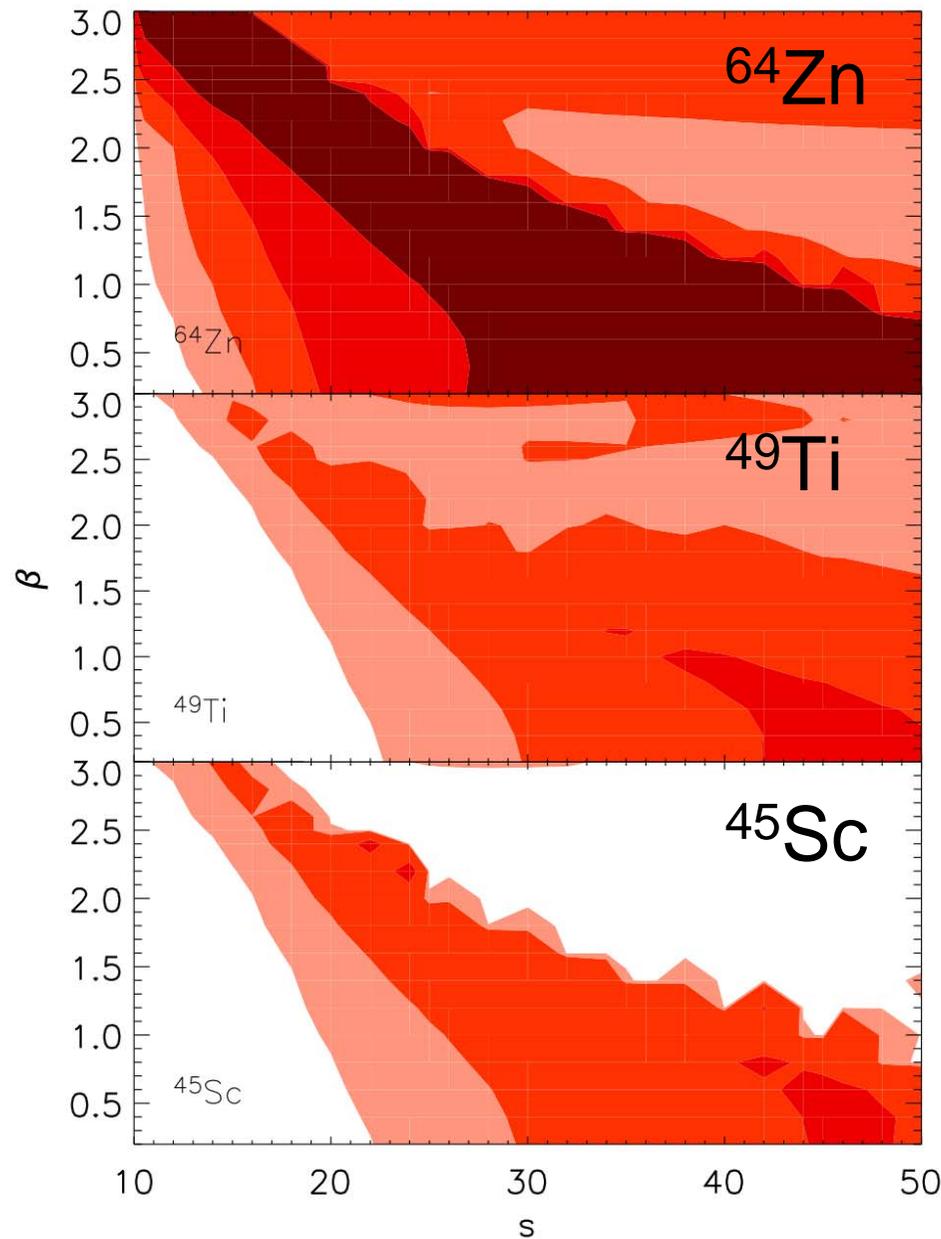
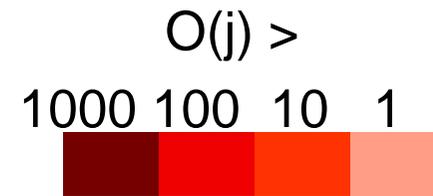
0.5 0.4 0.3 0.2 0.1

<sup>56</sup>Ni mass  
fraction



# Overproduction Factors

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



PWF

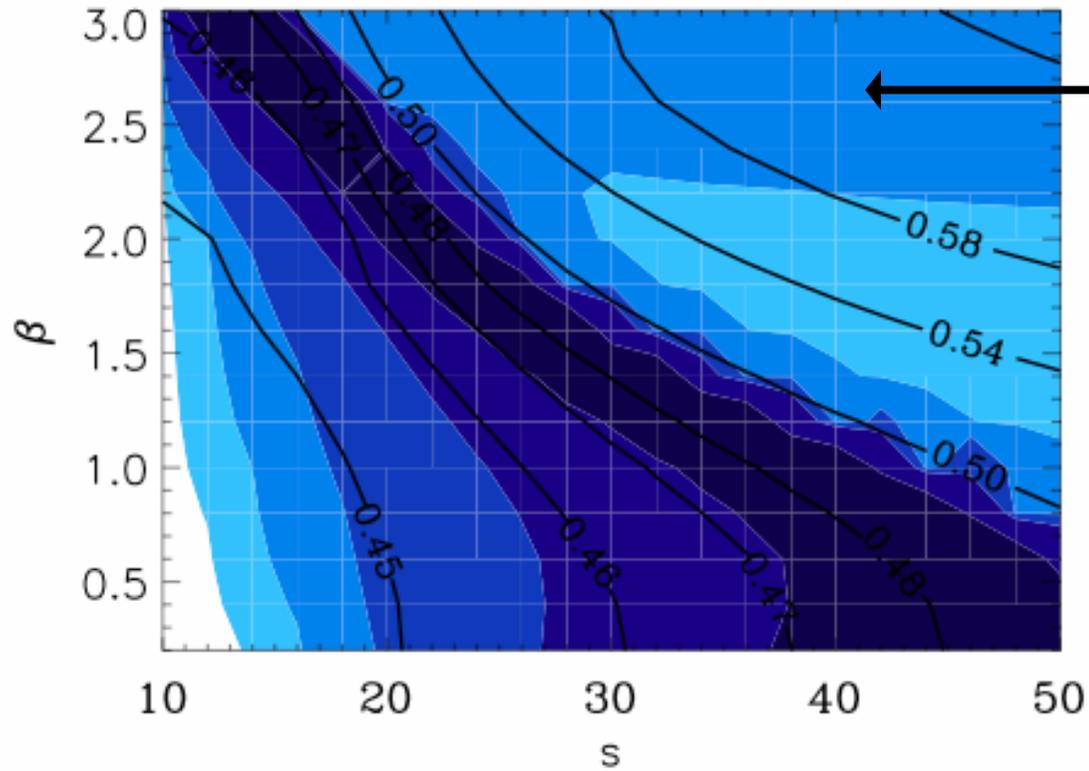
$$\dot{m} = 0.1$$

$$r_o = 100 \text{ km}$$

$$v_\infty = 0.1c$$

Surman, McLaughlin, & Hix, *ApJ*, 643, 1057 (2006)

$^{64}\text{Zn}$



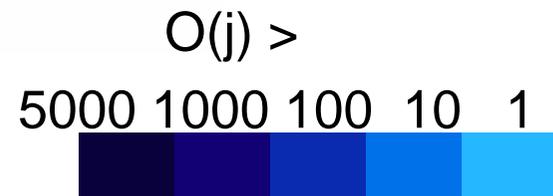
Slow outflow -  
enhancement due to  
neutrino interactions

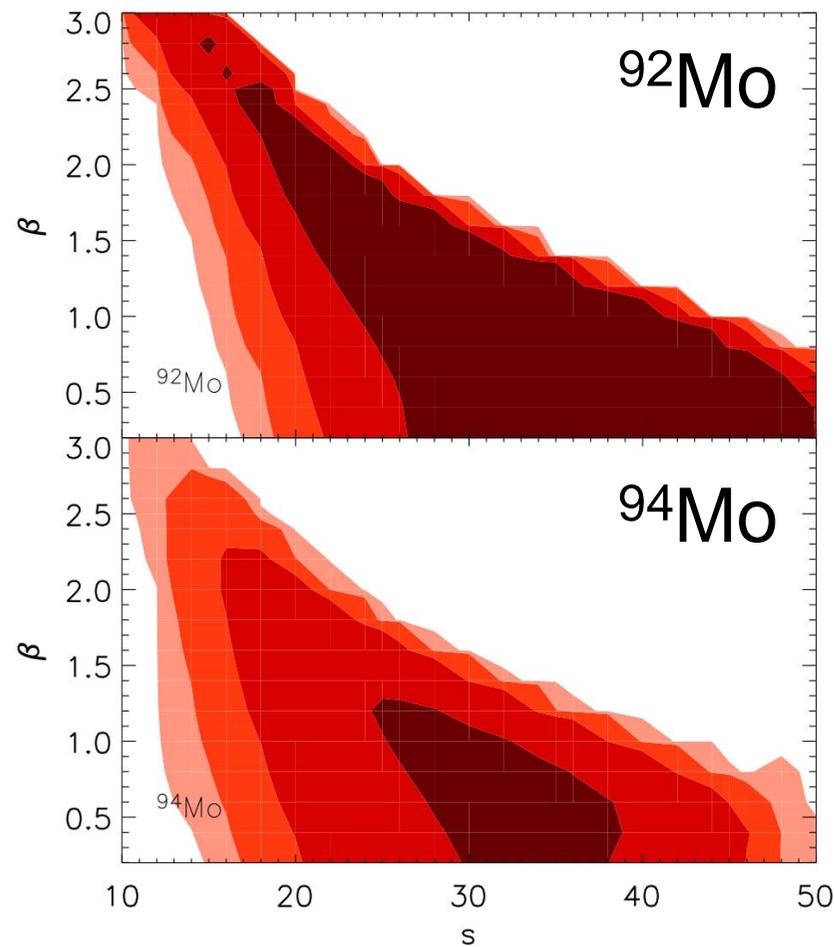
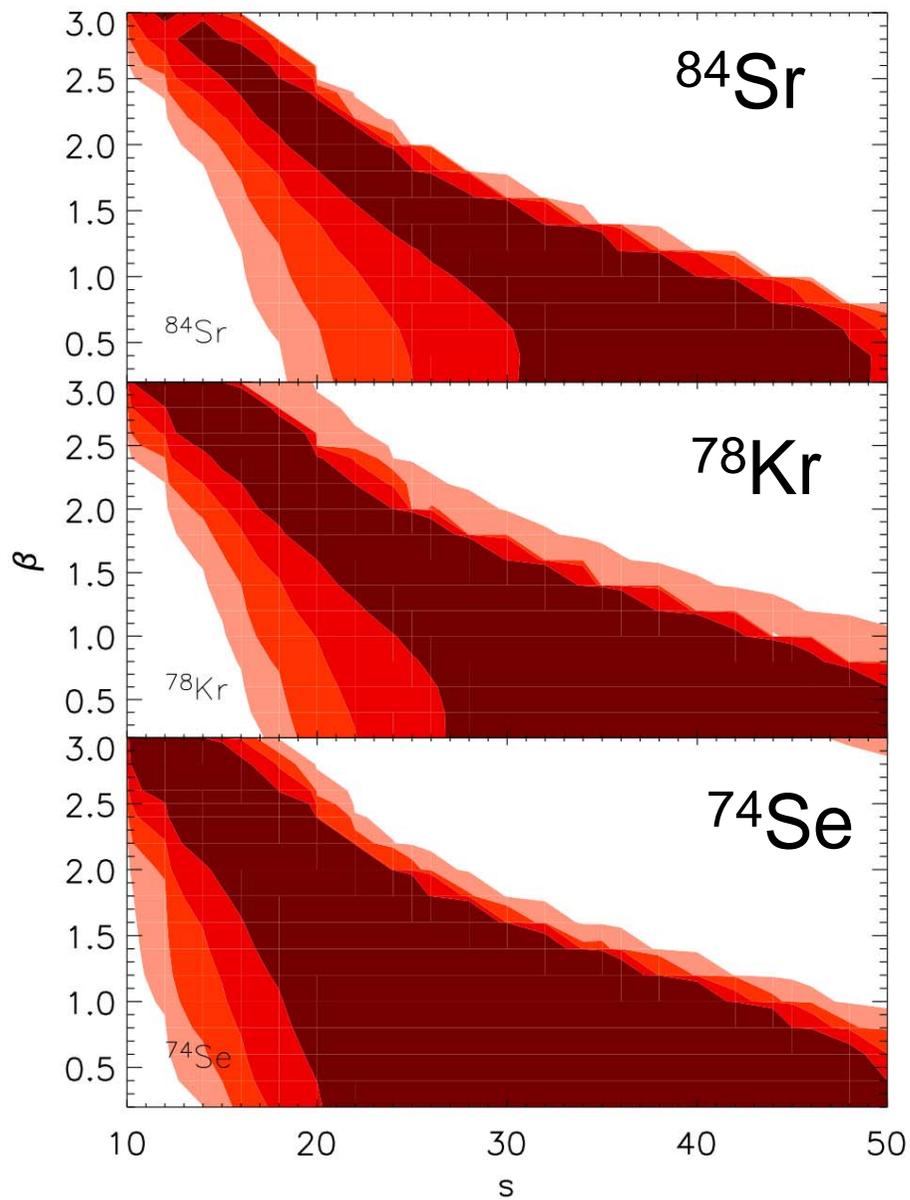
PWF

$$\dot{m} = 0.1$$

$$r_o = 100 \text{ km}$$

$$v_\infty = 0.1c$$

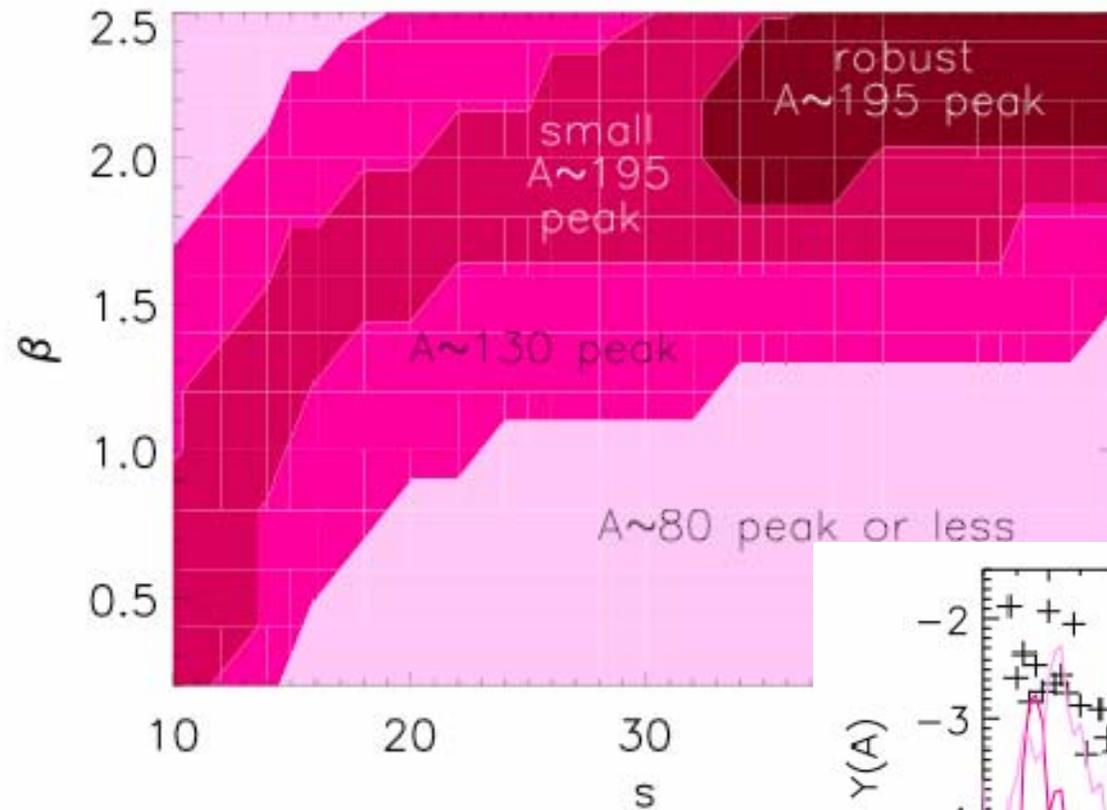




*p*-process nuclei

Surman, McLaughlin, & Hix, *ApJ*, 643, 1057 (2006)

# High accretion rate => *r*-Process Nucleosynthesis



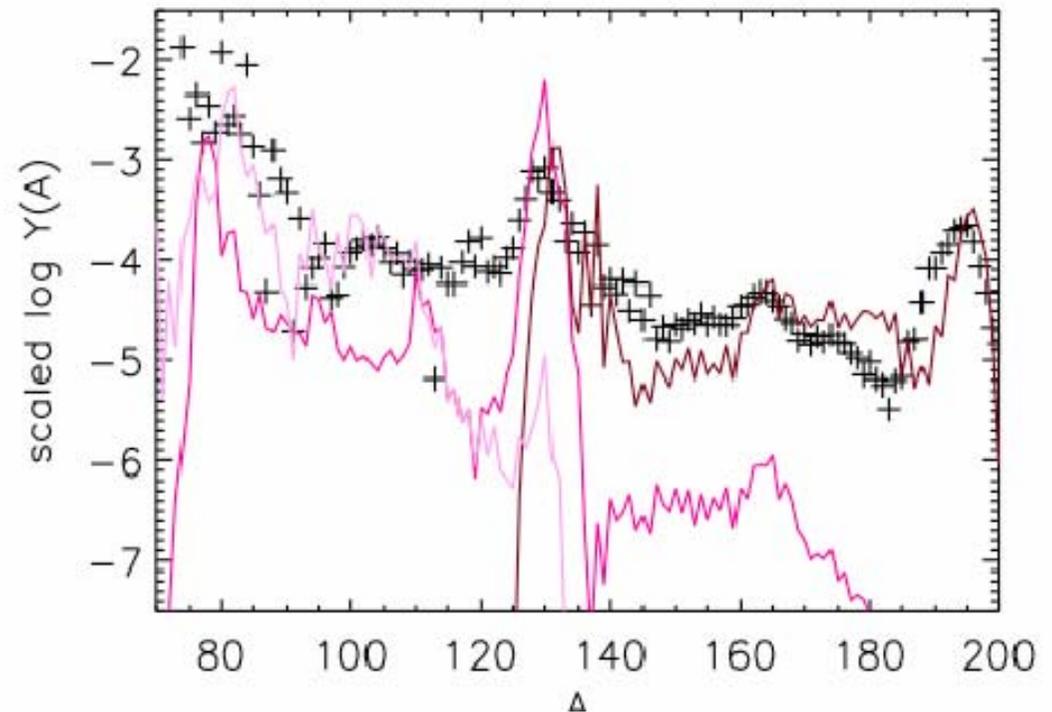
DPN

$$\dot{m} = 10$$

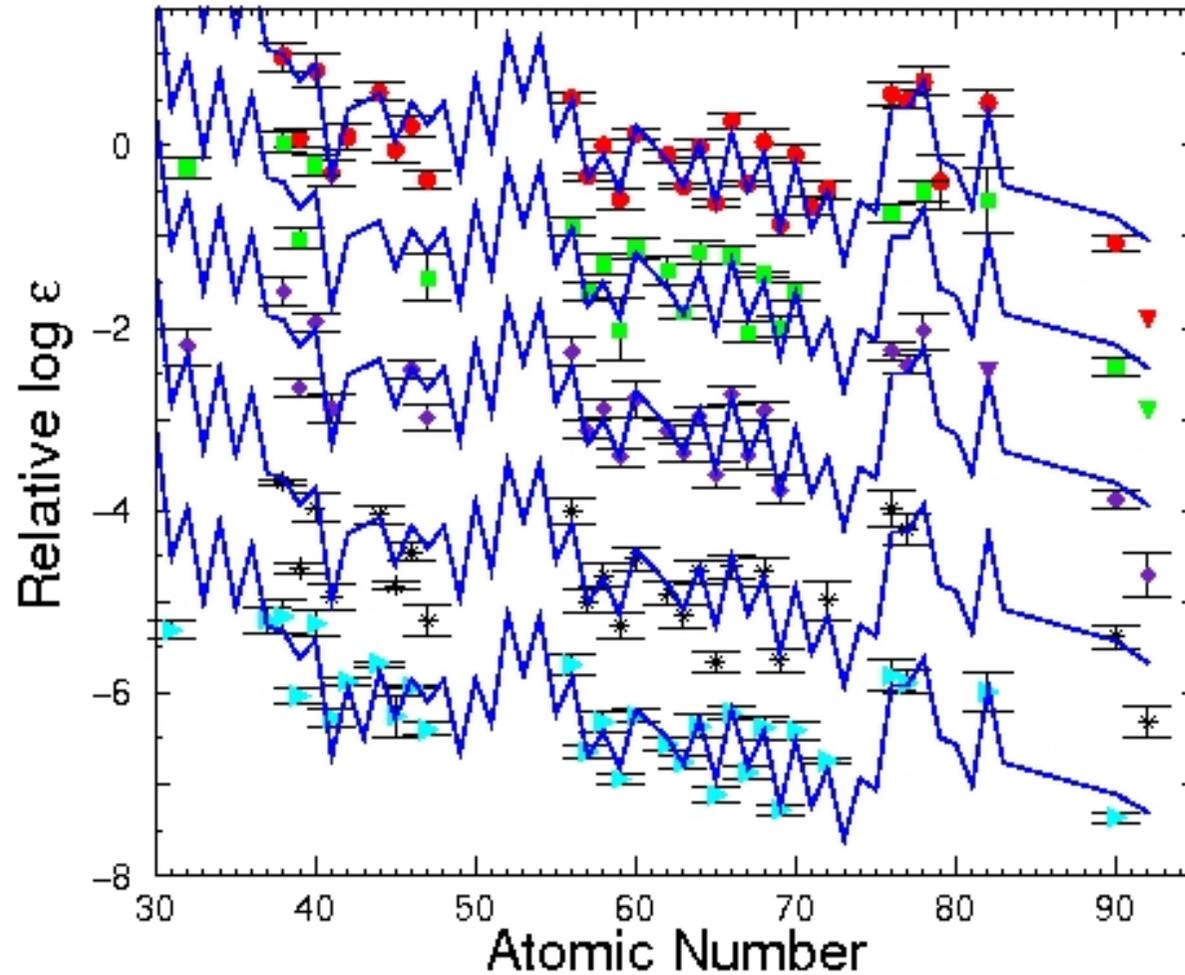
$$r_o = 250 \text{ km}$$

$$v_\infty = 0.1c$$

Surman, McLaughlin, and Hix, *ApJ*, 643, 1057 (2006)



# Metal-poor Halo Star data



From J. Cowan's talk, 6/27/06

# 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 such as  $^{64}\text{Zn}$ ,  $^{45}\text{Sc}$ , and  $^{92}\text{Mo}$