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

NIC 2006

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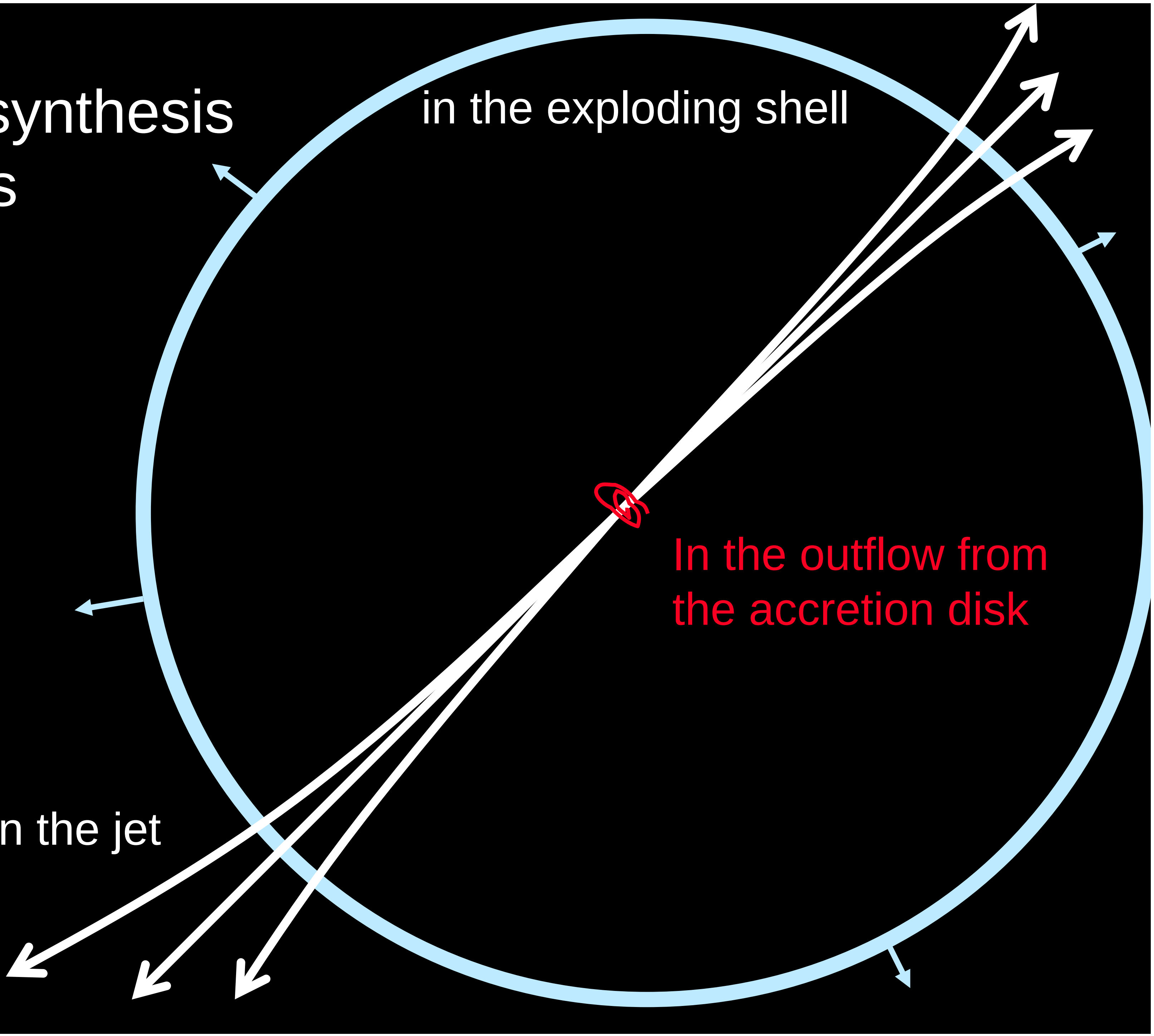
Union College

Nucleosynthesis in GRBs

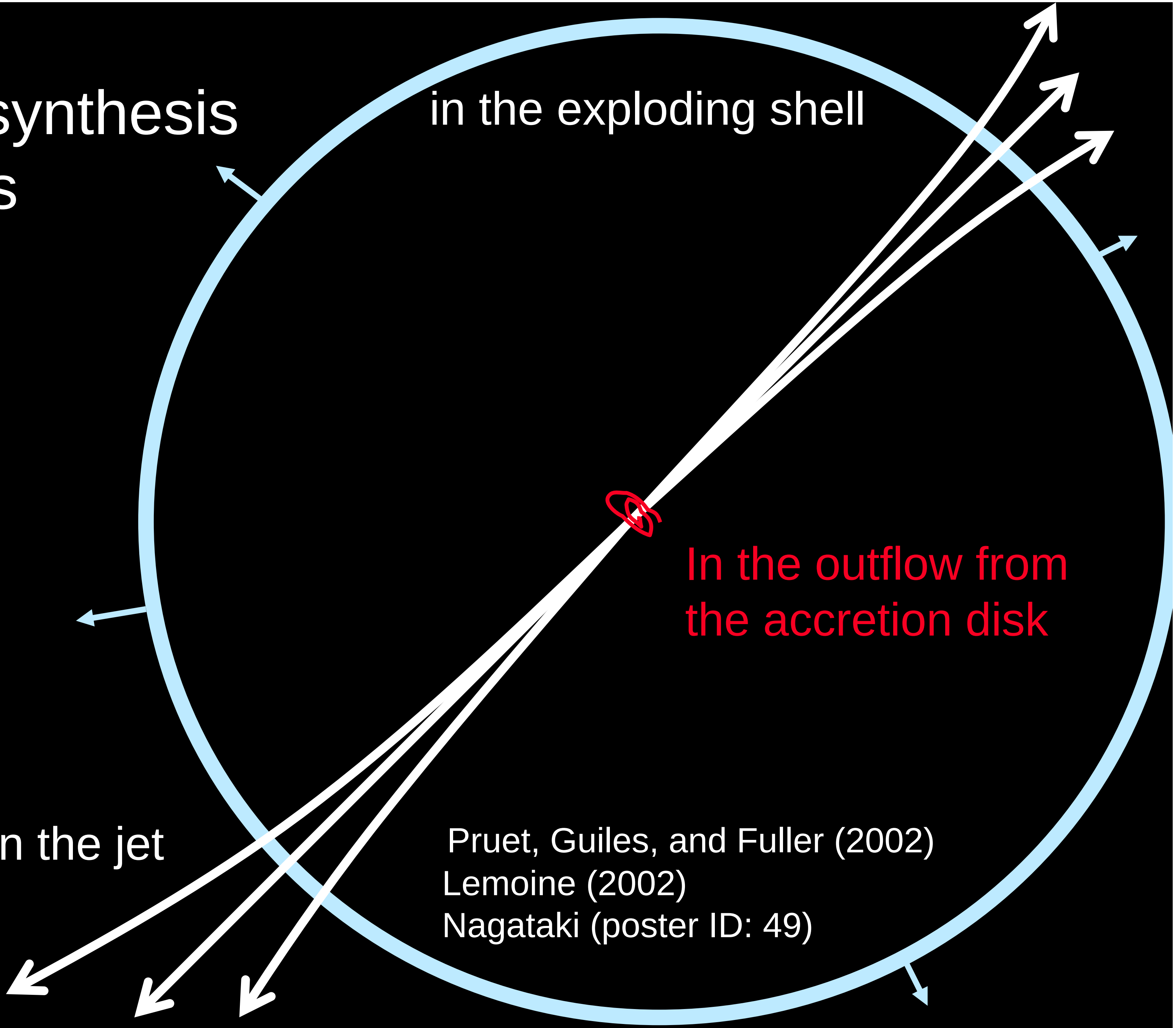


in the exploding shell

In the outflow from the accretion disk

in the jet

Nucleosynthesis in GRBs



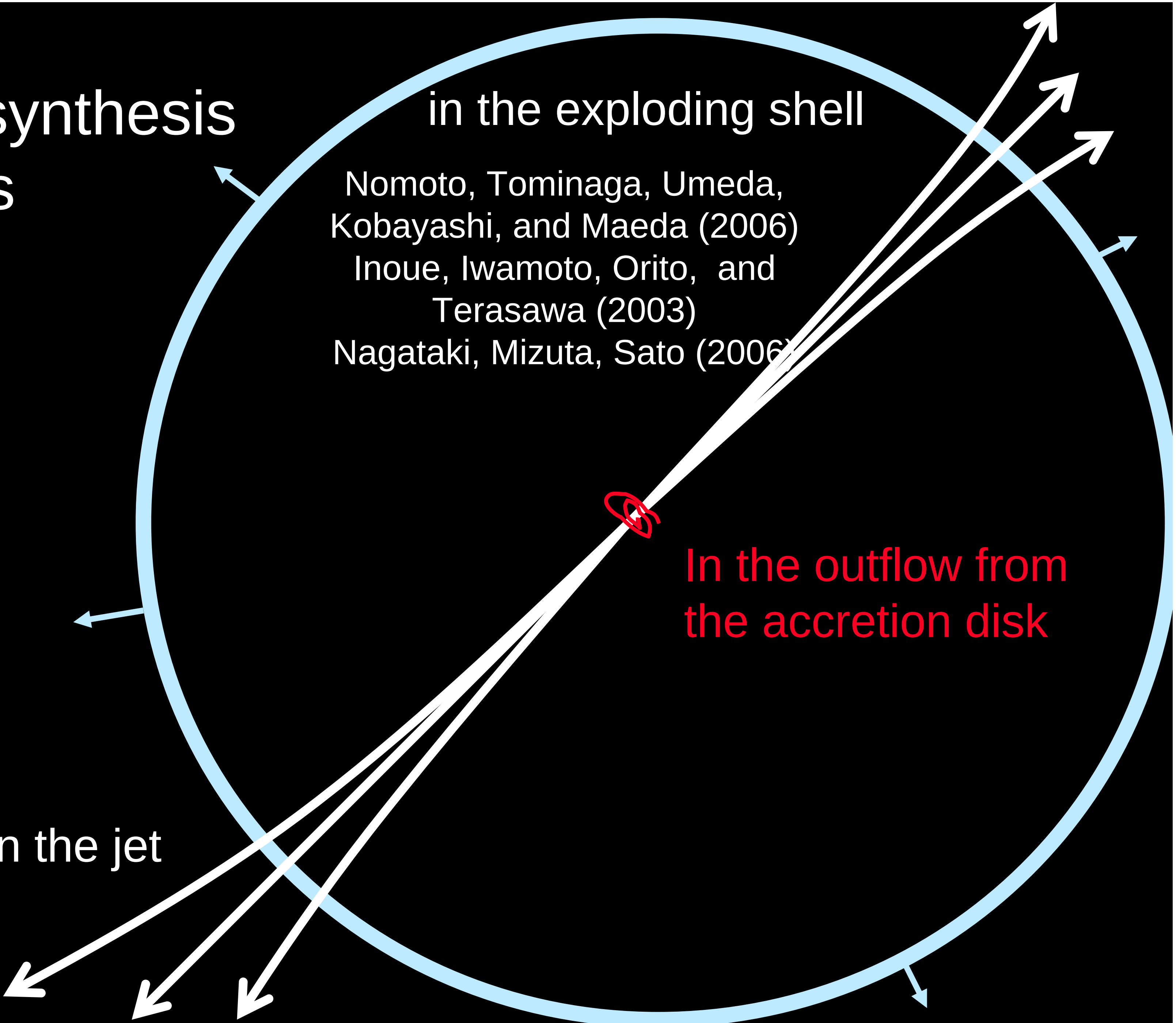
in the exploding shell

In the outflow from the accretion disk

in the jet

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

Nucleosynthesis in GRBs



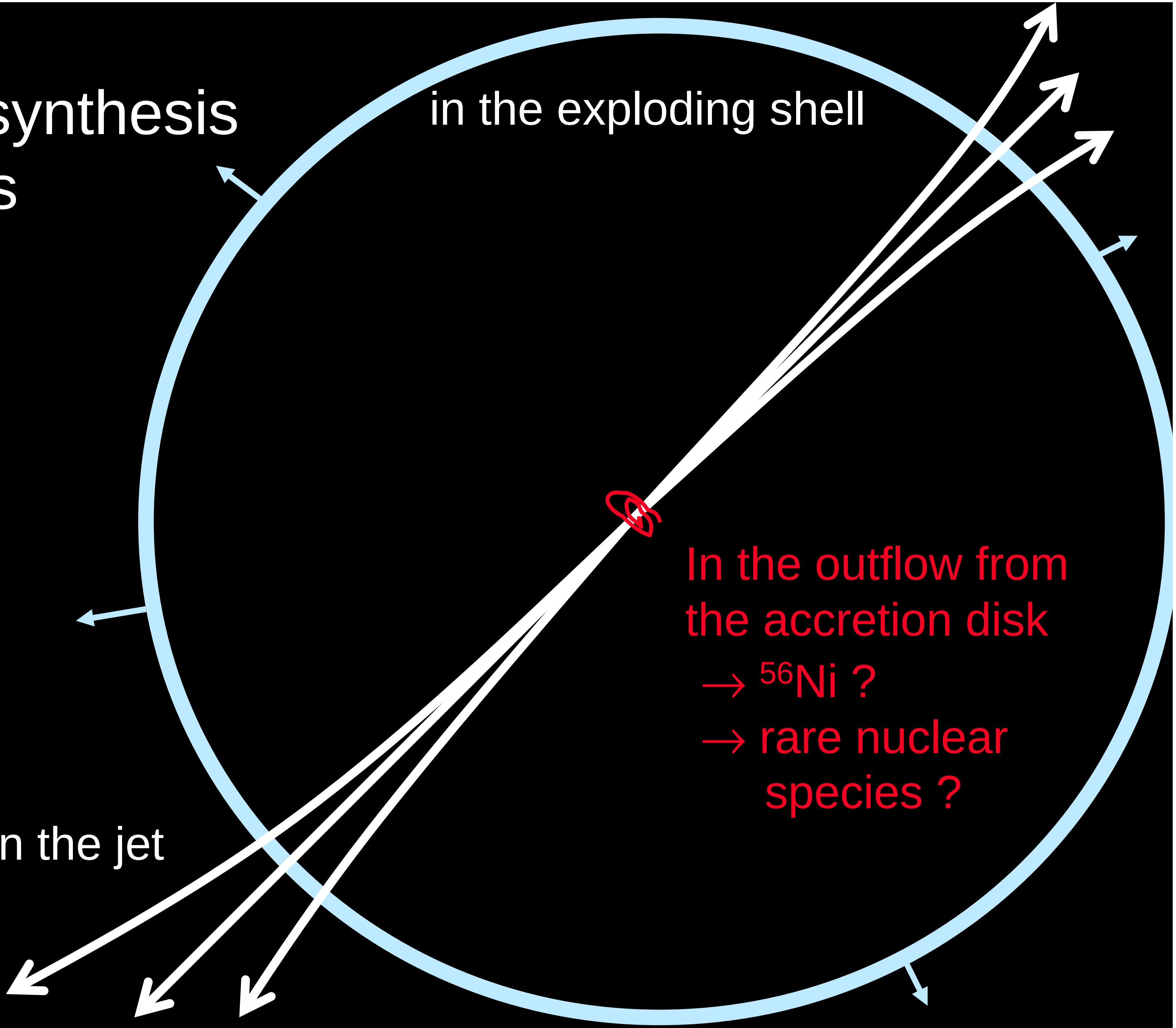
in the exploding shell

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

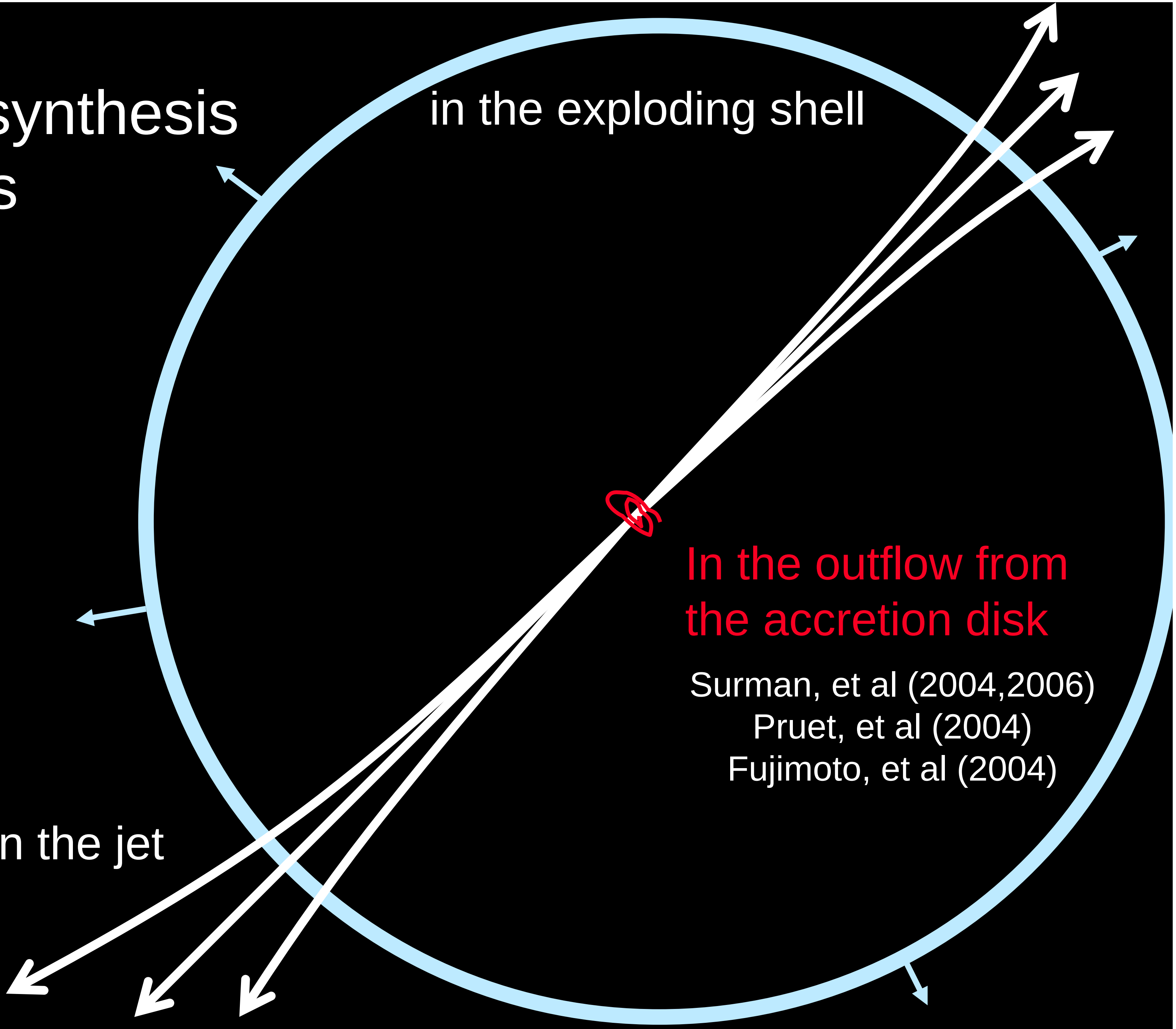
In the outflow from the accretion disk

→ ^{56}Ni ?

→ rare nuclear species ?

in the jet

Nucleosynthesis in GRBs



in the exploding shell

In the outflow from the accretion disk

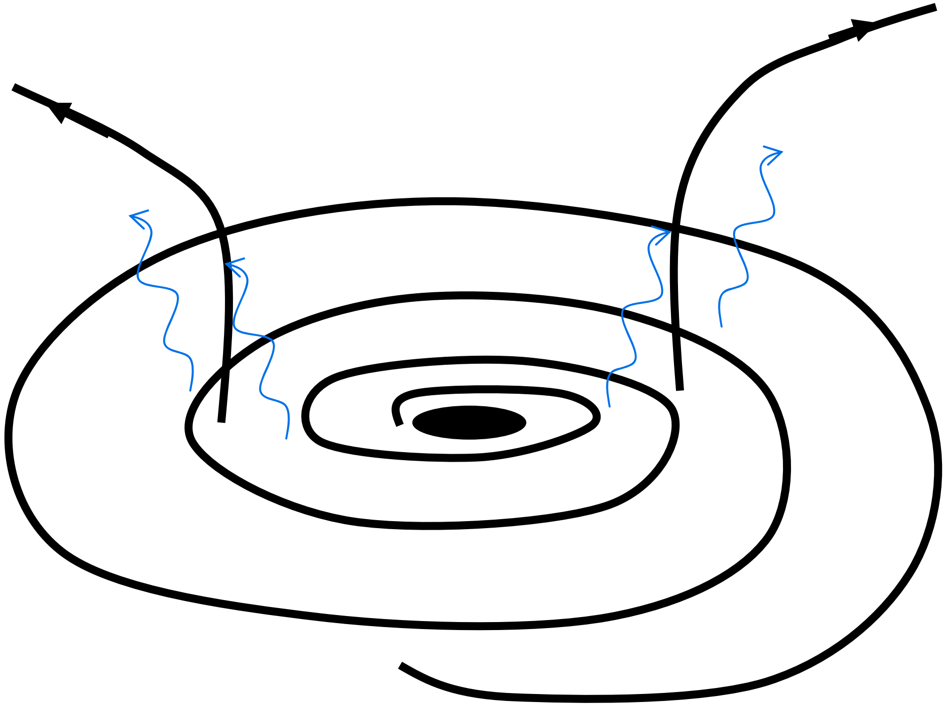
Surman, et al (2004,2006)
Pruet, et al (2004)
Fujimoto, et al (2004)

in the jet

Nucleosynthesis in the Outflow

Follow material

- through disk
- as ejected in outflow



Electron fraction set by:

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

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

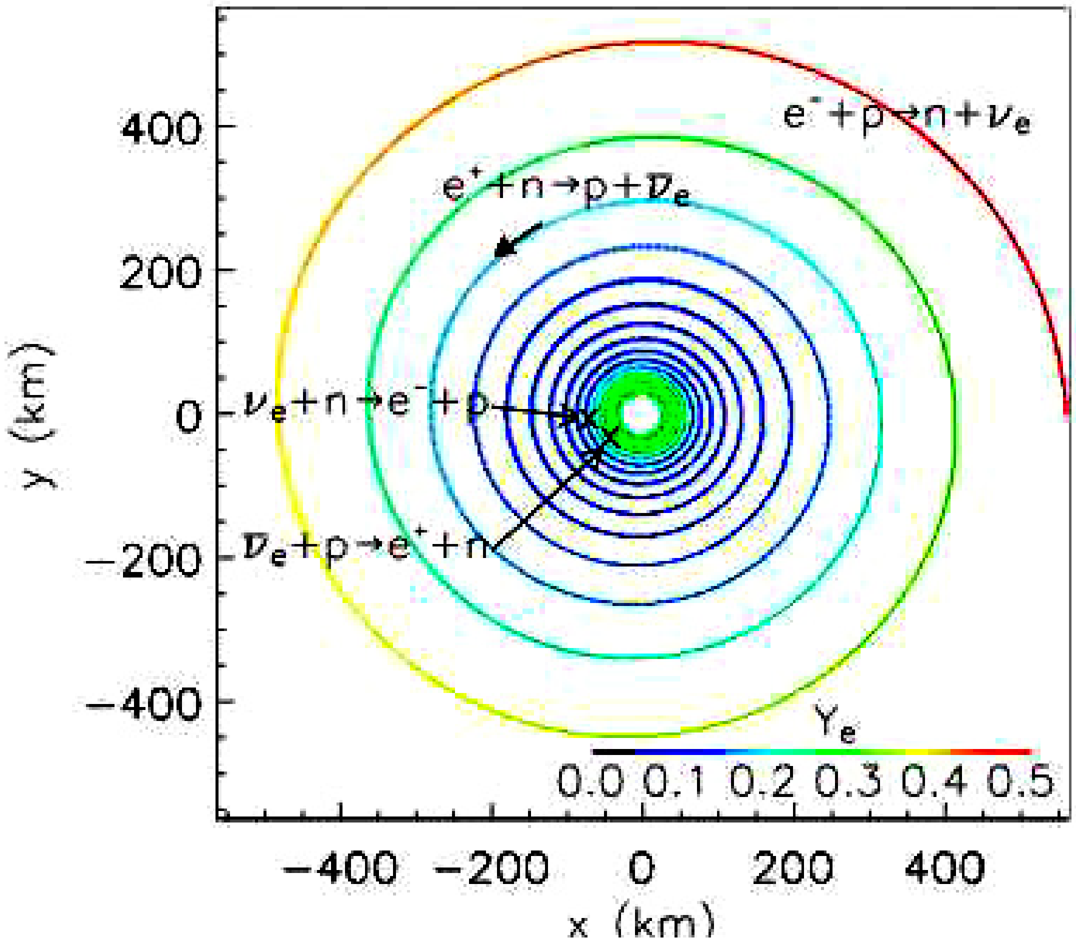
Disk models:

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

Popham, Woosley, and Fryer (1999)

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

DiMatteo, Perna, and Narayan (2002)



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

Evolution of Y_e in the disk

DPN $\dot{m} = 1.0$

Outflow Parameterization

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

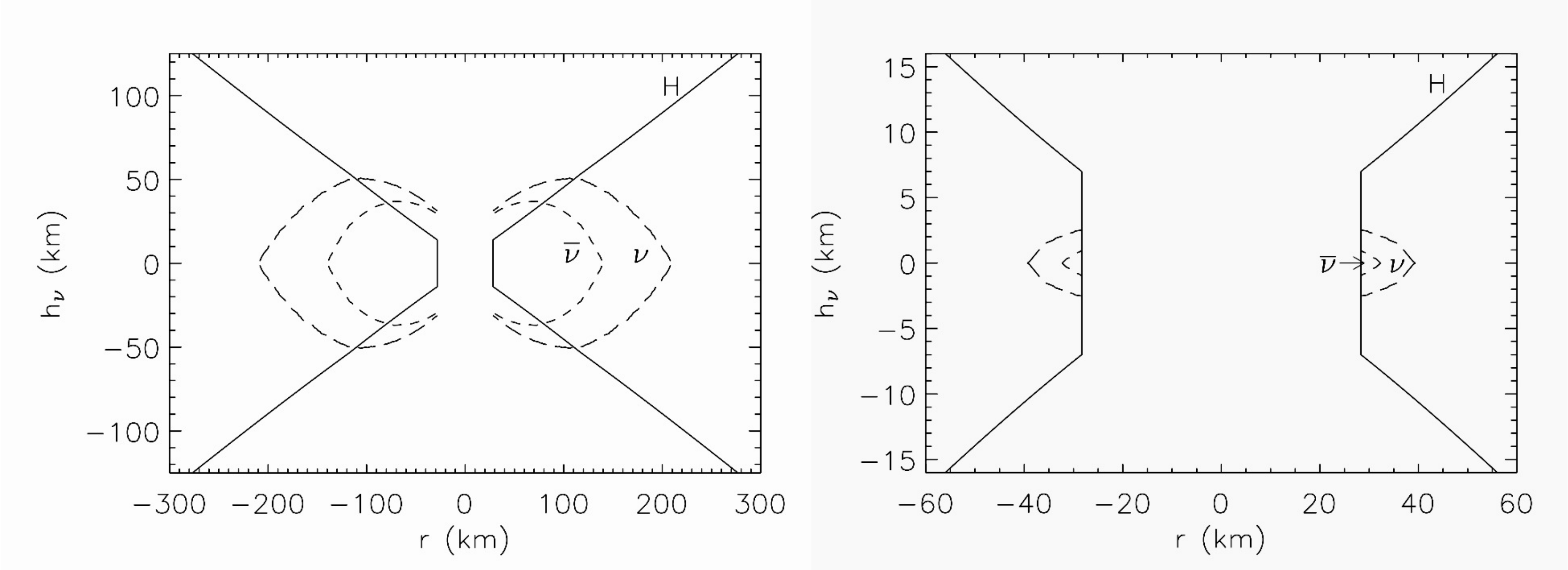
$$u = v_\infty \left(1 - \frac{R_o}{R}\right)^\beta$$

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_ν)

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

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

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

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

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	

^{56}Ni mass fraction

Lines indicate Ye

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

Moderate accretion rates => Nickel Synthesis

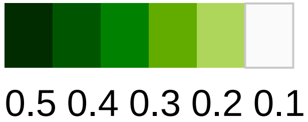
DPN

$\dot{m} = 1.0$

$r_o = 250 \text{ km}$

$v_\infty = 0.1c$

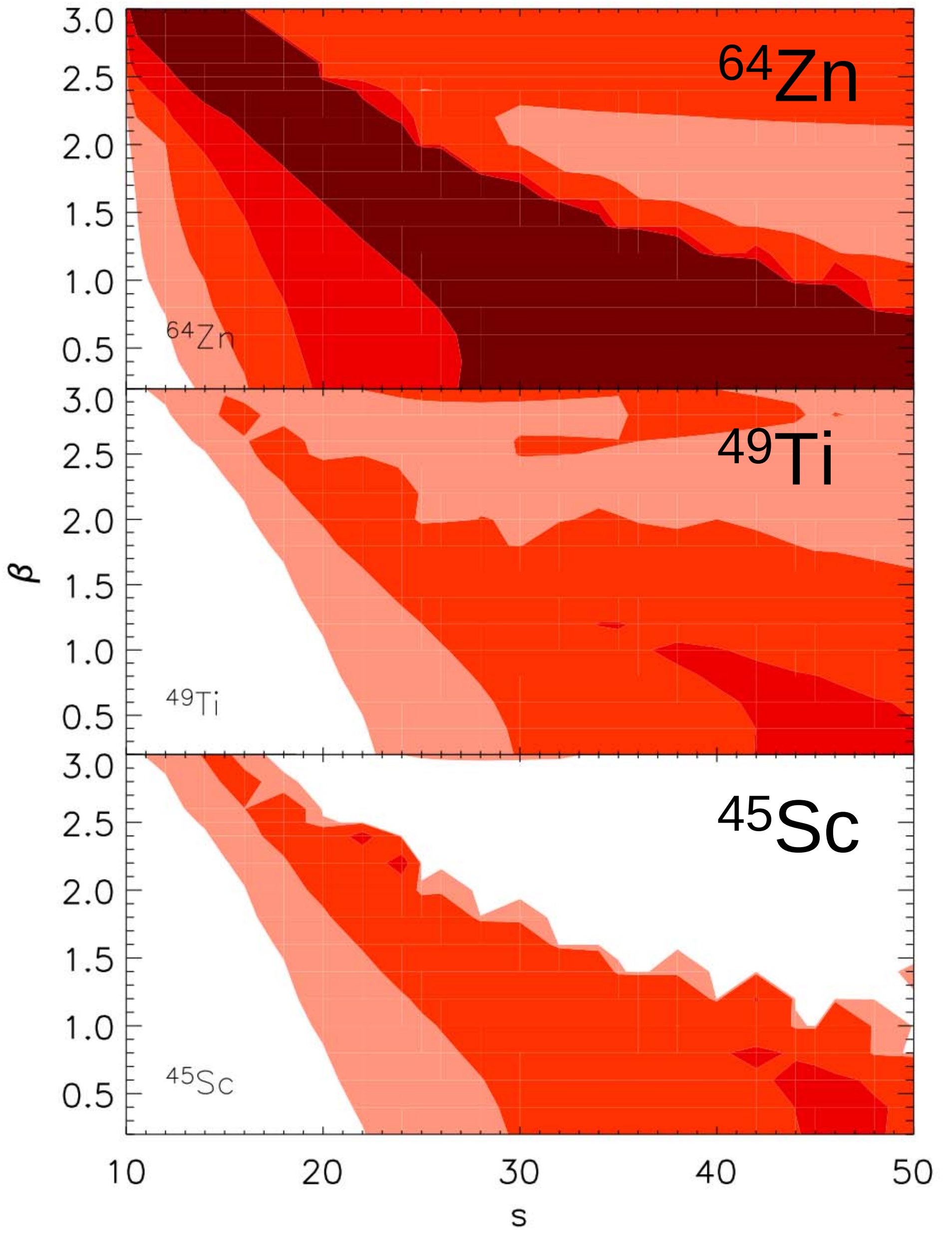
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



^{56}Ni mass fraction

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

Overproduction Factors



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

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

O(j) >

1000	100	10	1
🟥	🟥	🟥	🟥

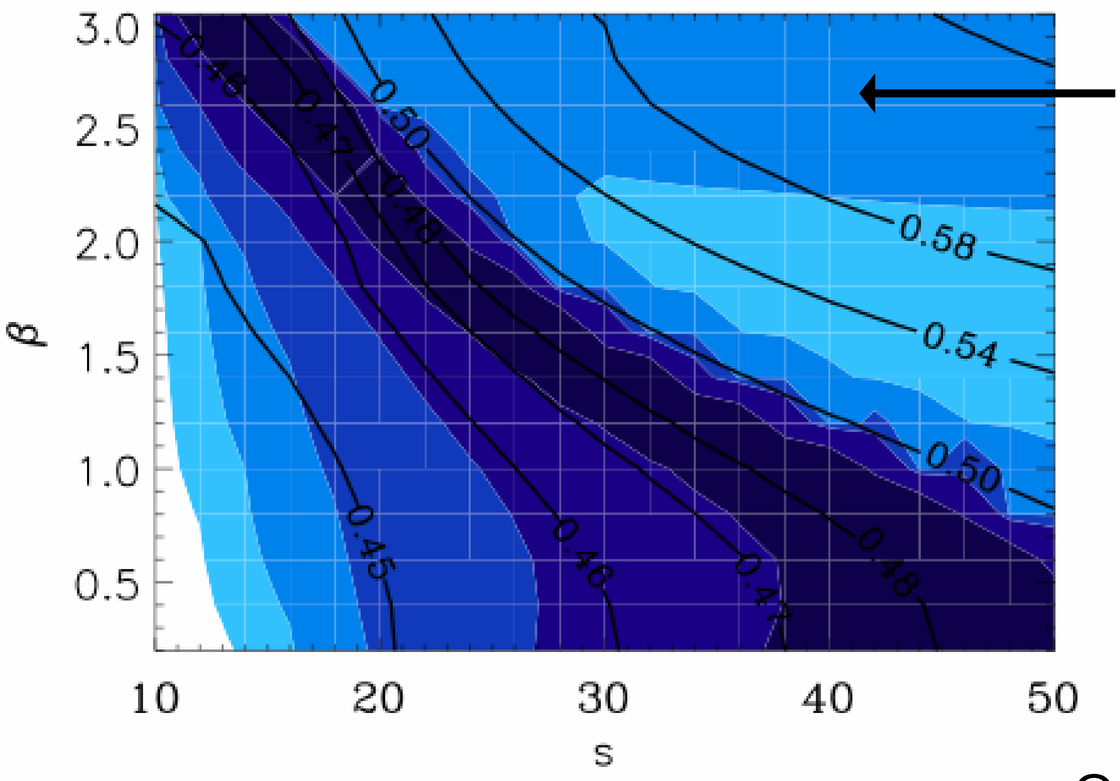
PWF

$\dot{m} = 0.1$

$r_o = 100\ \mathrm{km}$

$v_\infty = 0.1c$

^{64}Zn



Slow outflow - enhancement due to neutrino interactions

PWF

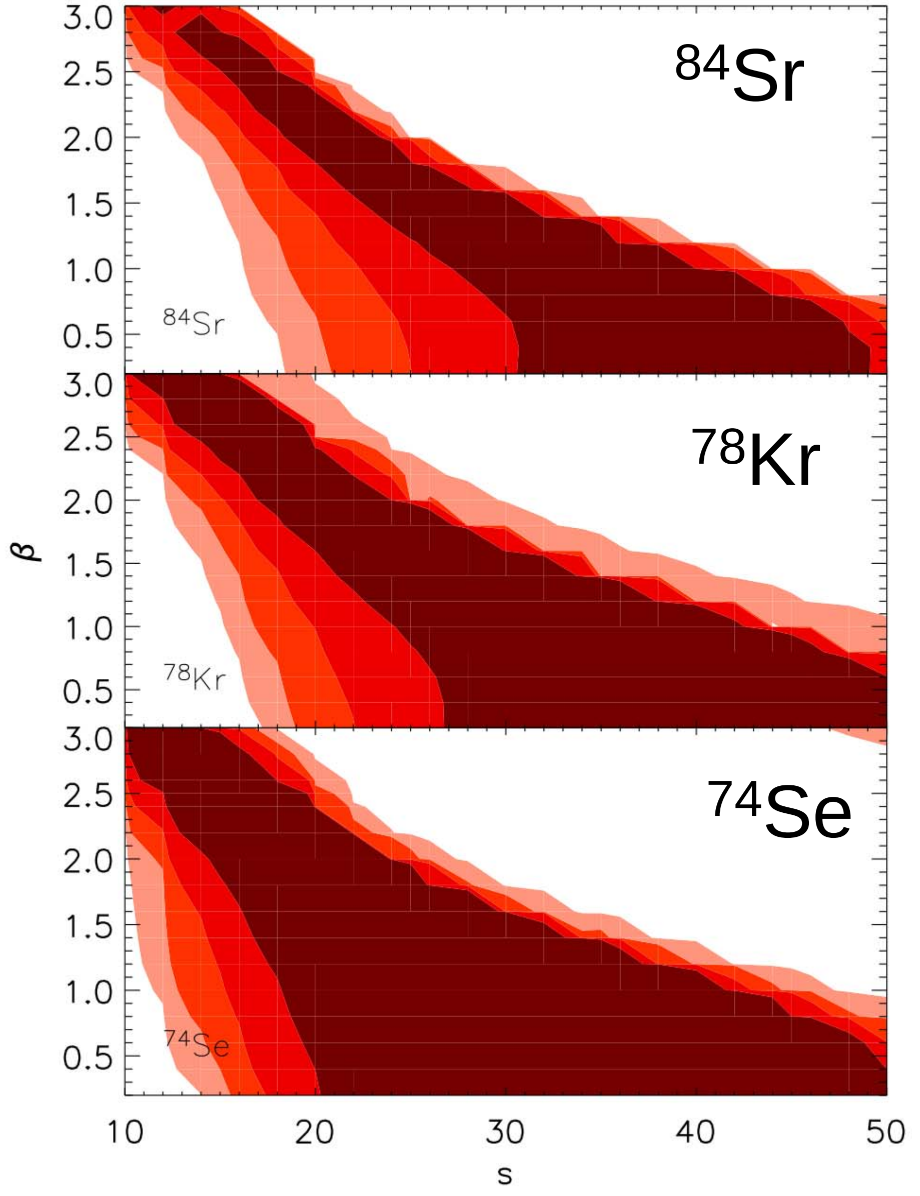
$\dot{m} = 0.1$

$r_o = 100$ km

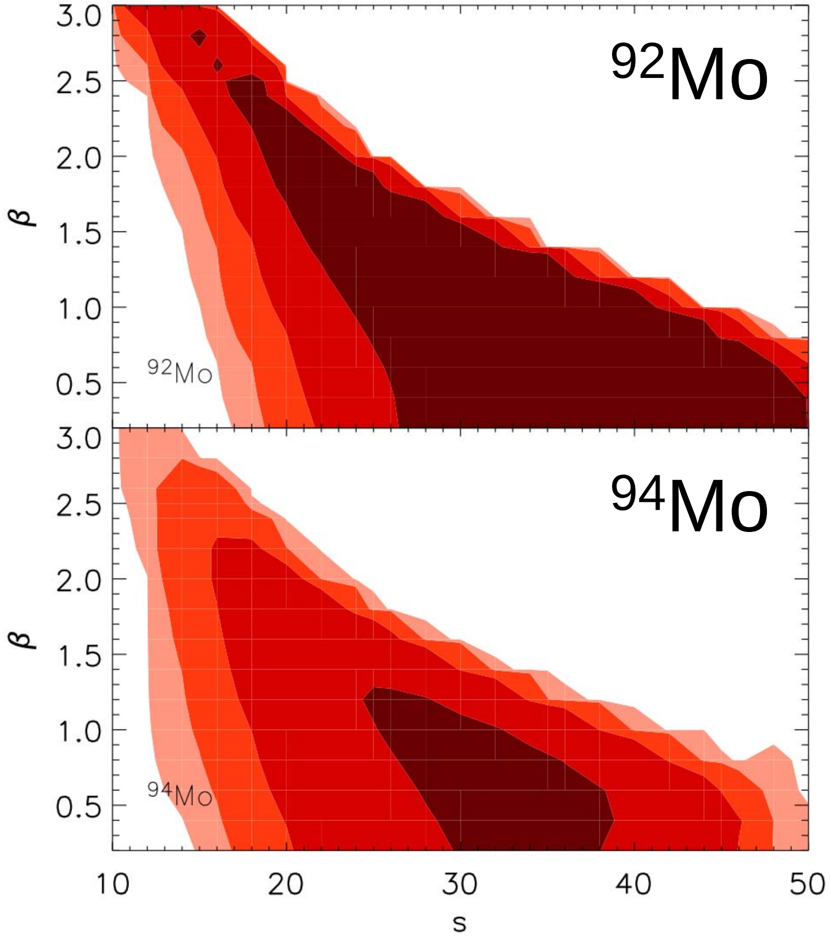
$v_\infty = 0.1c$

O(j) >

5000	1000	100	10	1
🟦	🟦	🟦	🟦	🟦

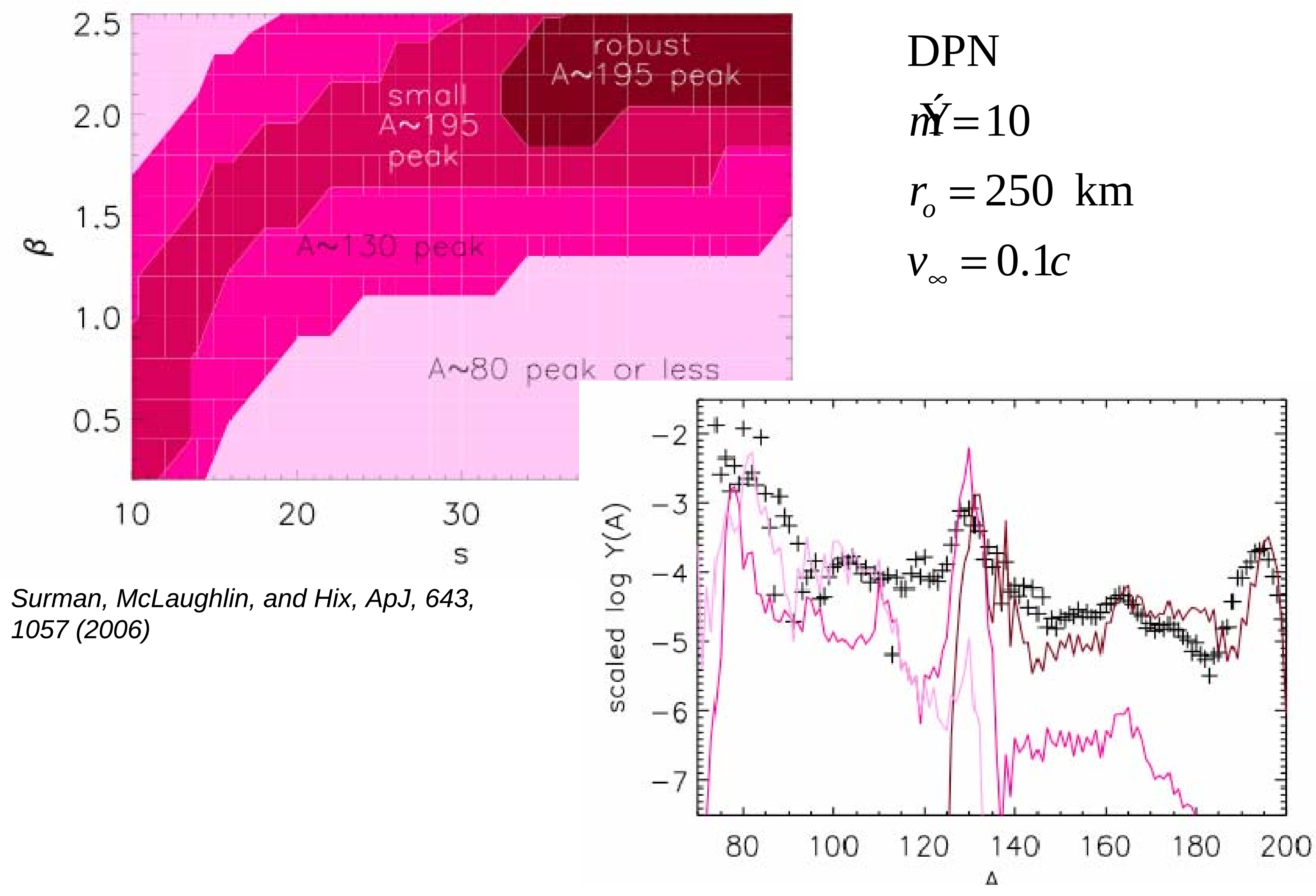


Surman, McLaughlin, & Hix, ApJ, 643, 1057 (2006)



p-process nuclei

High accretion rate => *r*-Process Nucleosynthesis



DPN

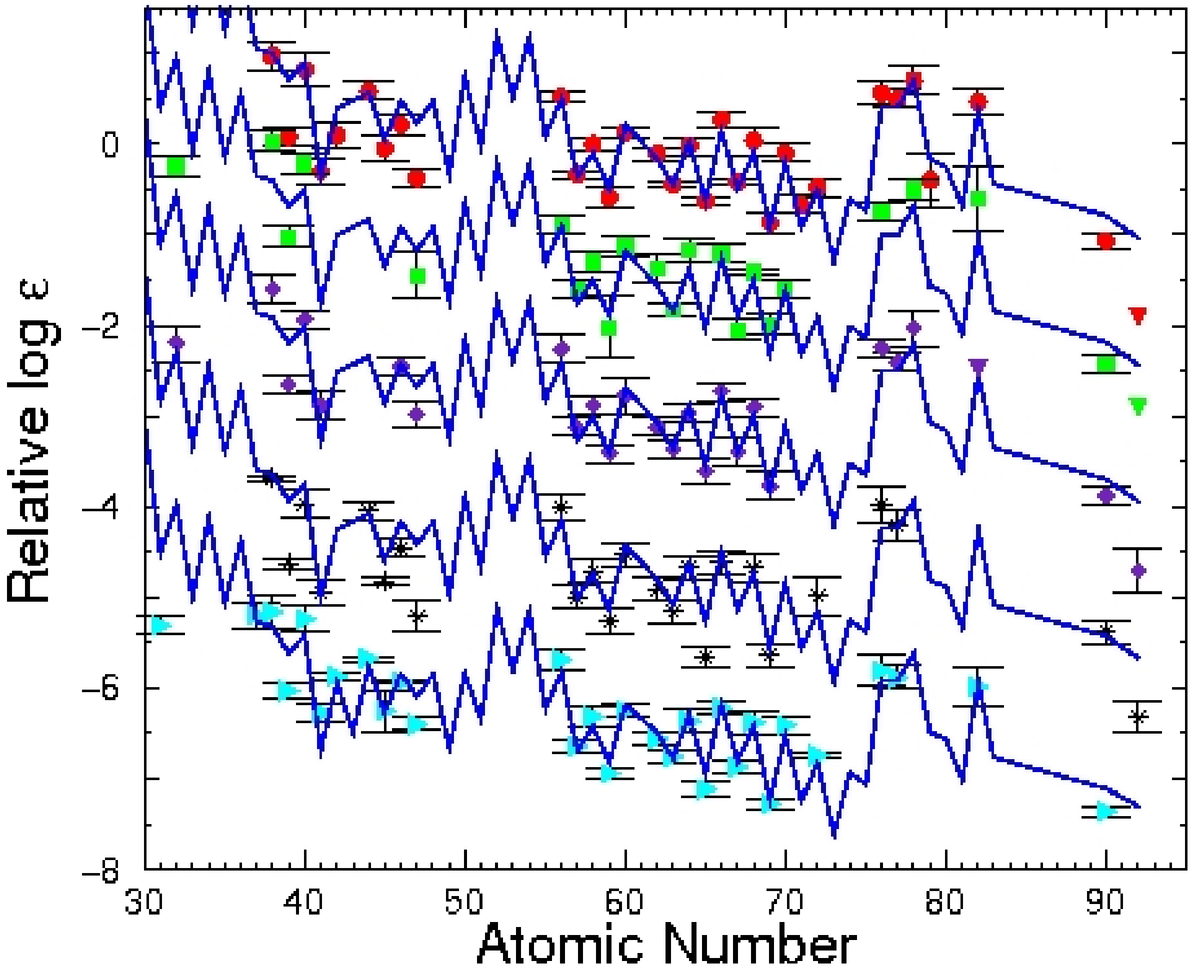
$\dot{m} = 10$

$r_o = 250\ \text{km}$

$v_\infty = 0.1c$

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}Zn, ^{45}Sc, and ^{92}Mo