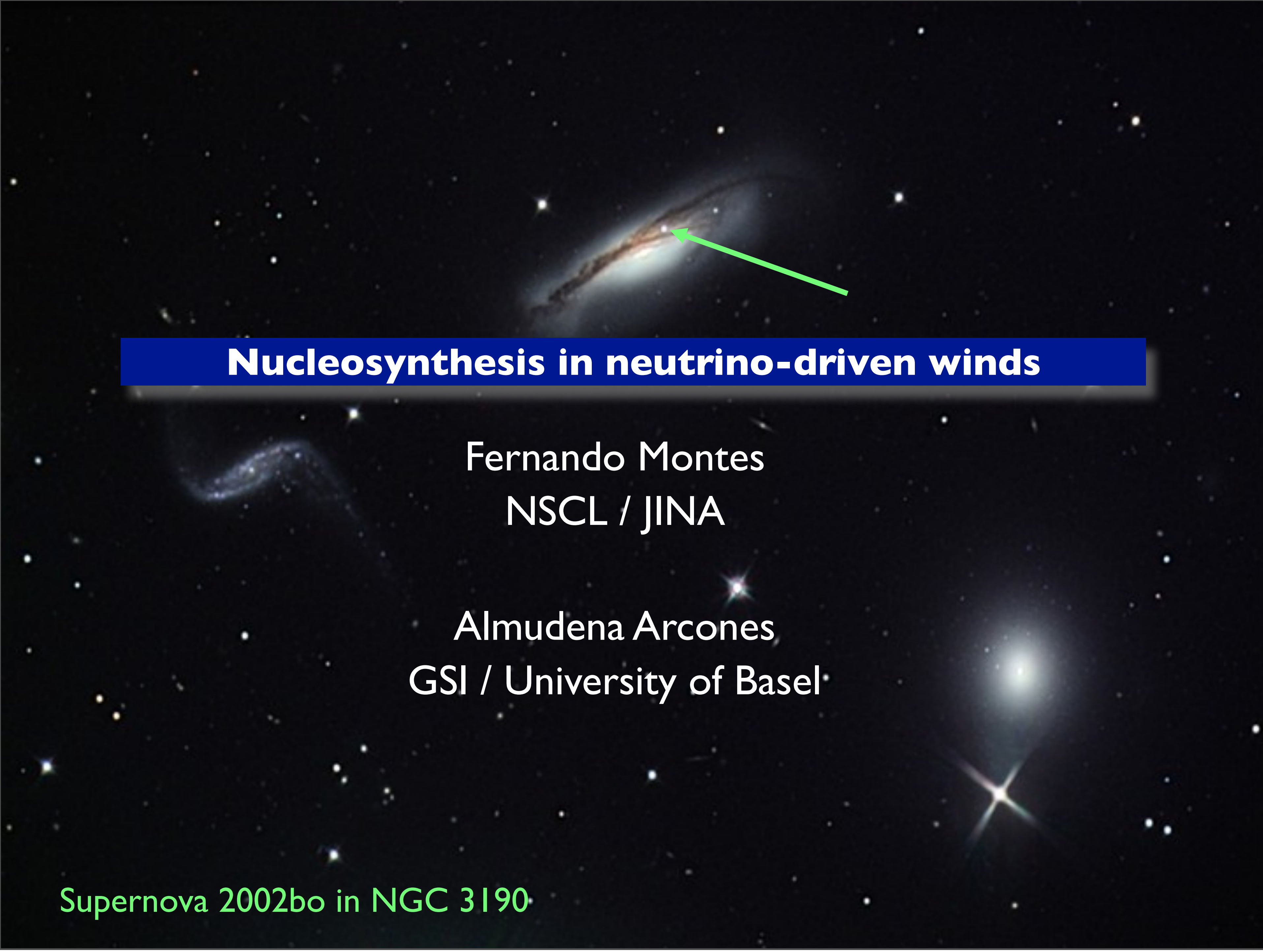
Nucleosynthesis in neutrino-driven winds

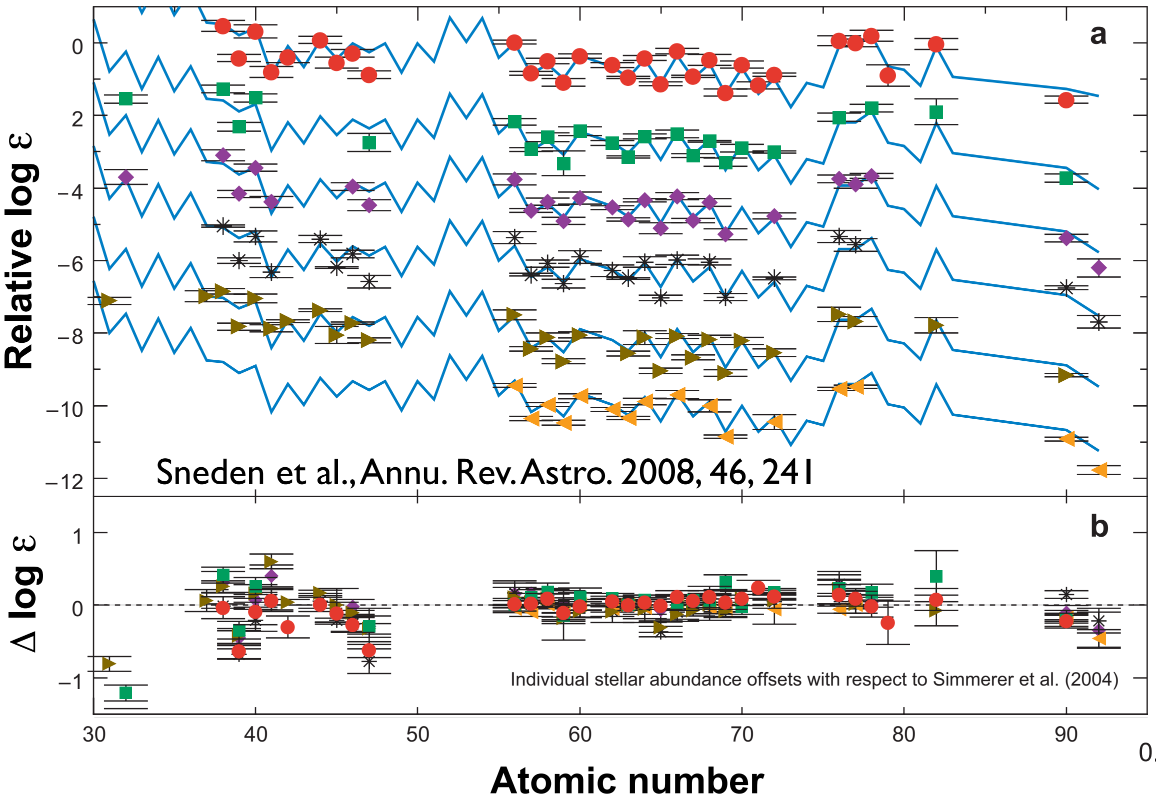
Fernando Montes
NSCL / JINA

Almudena Arcones
GSI / University of Basel



Supernova 2002bo in NGC 3190

Metal-poor stars

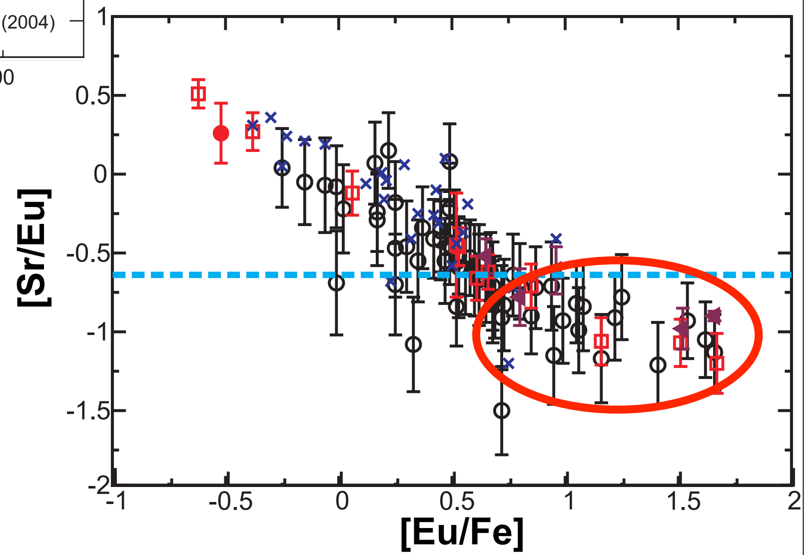


[Ba/Eu] < 0
R-process rich

[Fe/H] < -2.5
Metal poor (old stars)

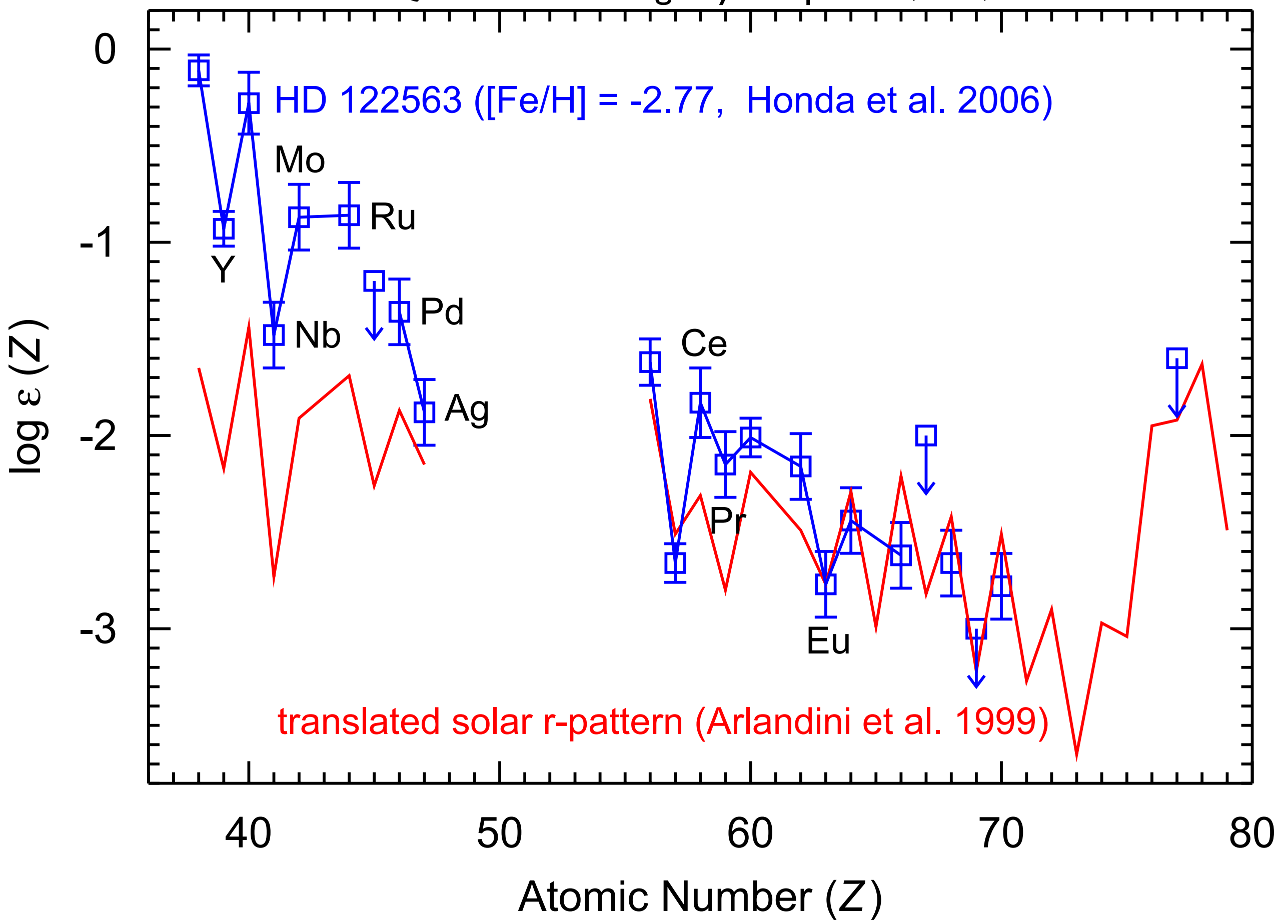
- CS 22892-052: Sneden et al. (2003)
- HD 115444: Westin et al. (2000)
- BD+17°324817: Cowan et al. (2002)
- CS 31082-001: Hill et al. (2002)
- HD 221170: Ivans et al. (2006)
- HE 1523-0901: Frebel et al. (2007)

Montes et al. ApJ 2007, 671, 1685



Metal-poor not r-process enriched stars

Qian&Wasserburg Phys. Rep. 2007, 442, 237

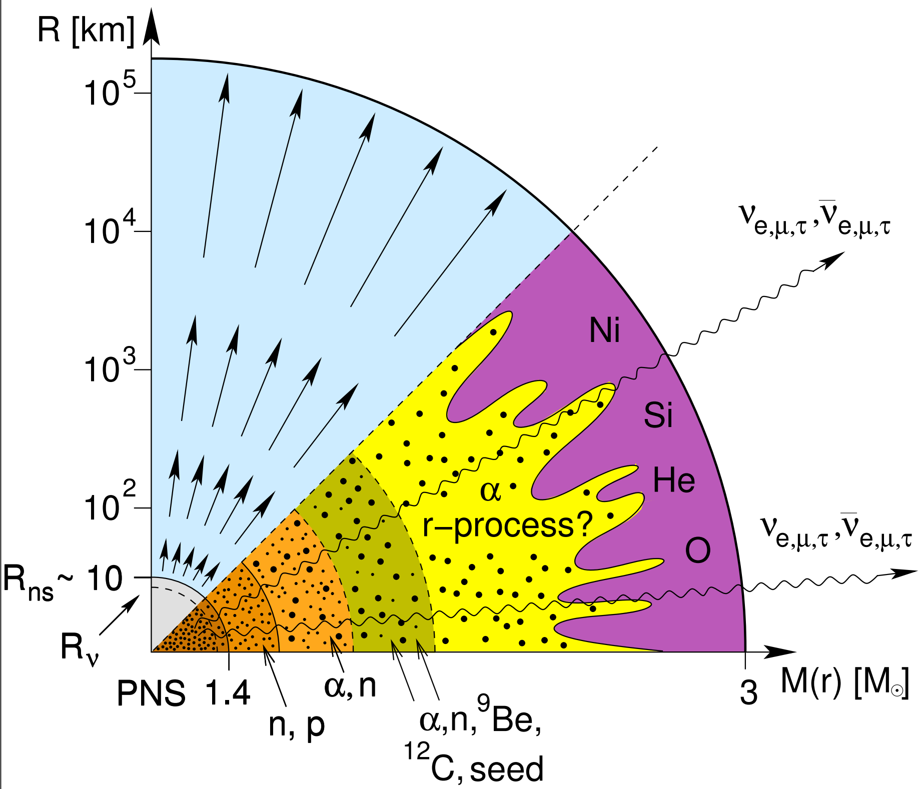


[Fe/H] = -2.8

[Ba/Eu] = -0.5

Light Element Primary Process LEPP abundance pattern

Nucleosynthesis in ν-driven winds



Qian&Woosley 1996

Entropy

$S \sim L^{-1/6}\, \epsilon^{-1/3}\, R_{ns}^{-2/3}\, M_{ns}$

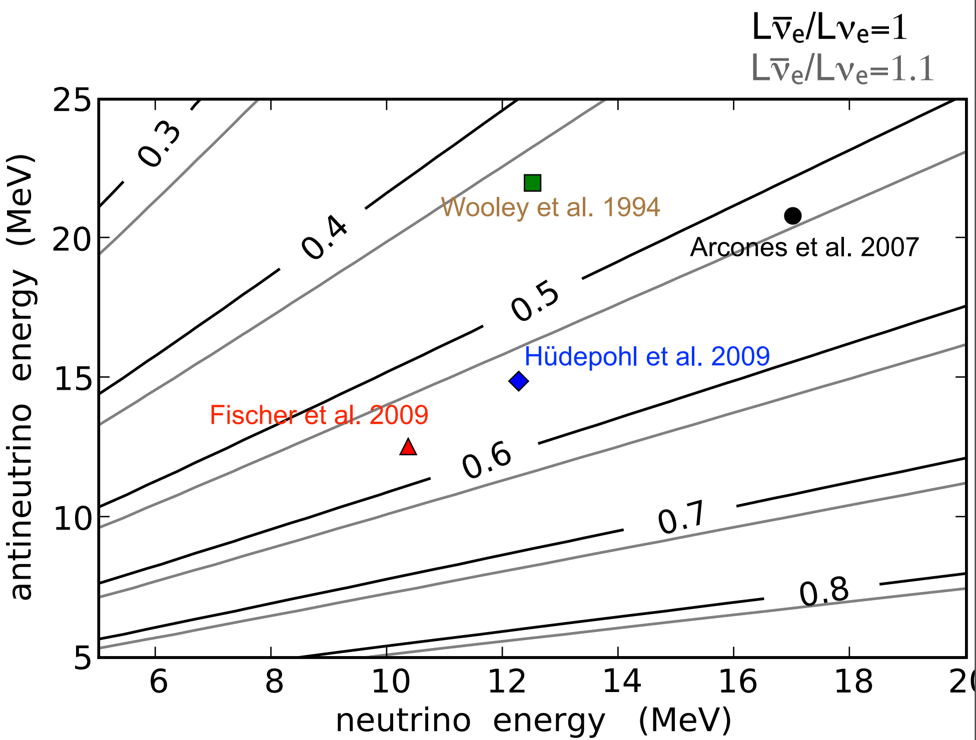
Expansion timescale

$\tau \sim L^{-1}\, \epsilon^{-2}\, R_{ns}\, M_{ns}$

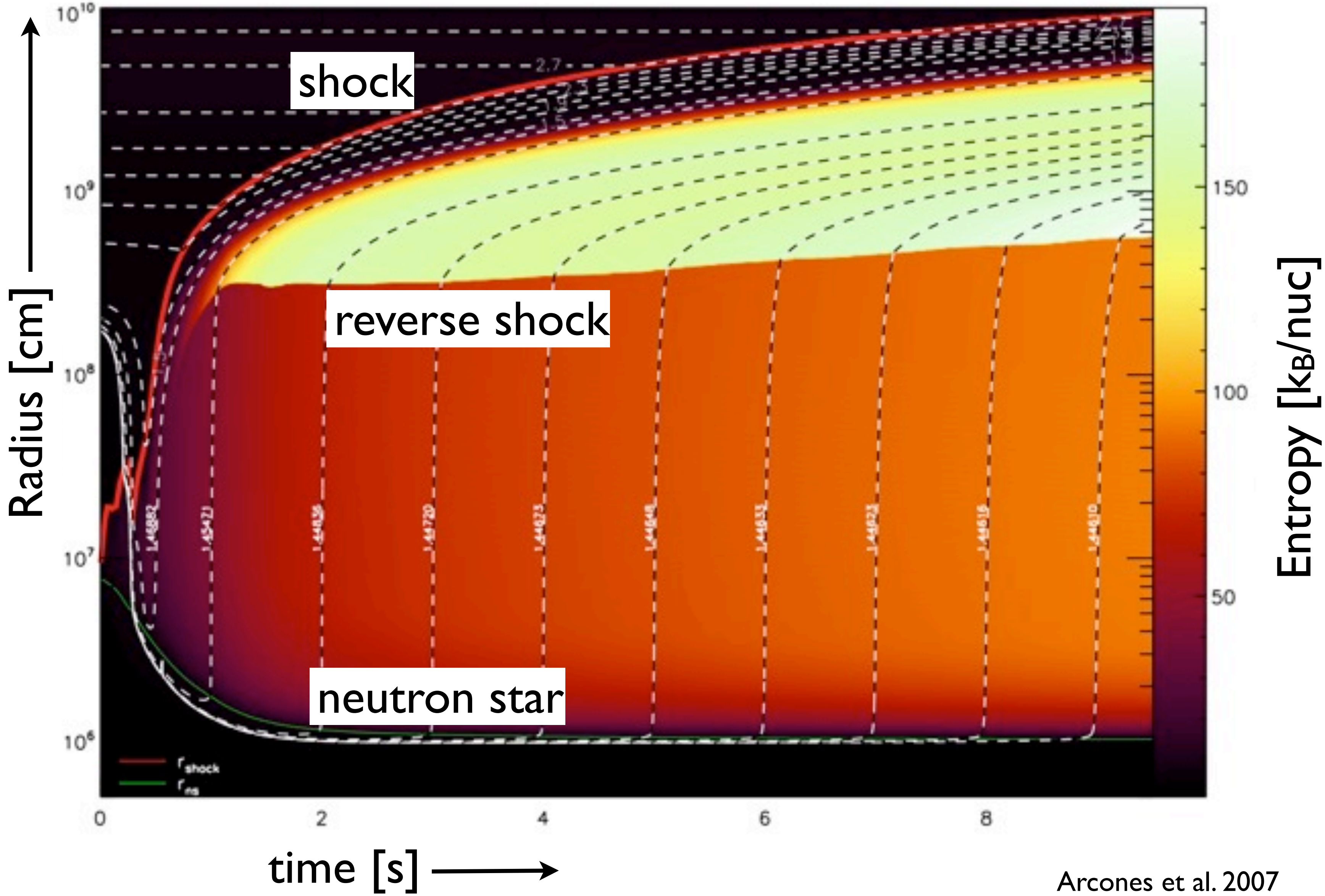
Electron fraction Y_e

$\nu_e + n \leftrightarrow p + e$

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

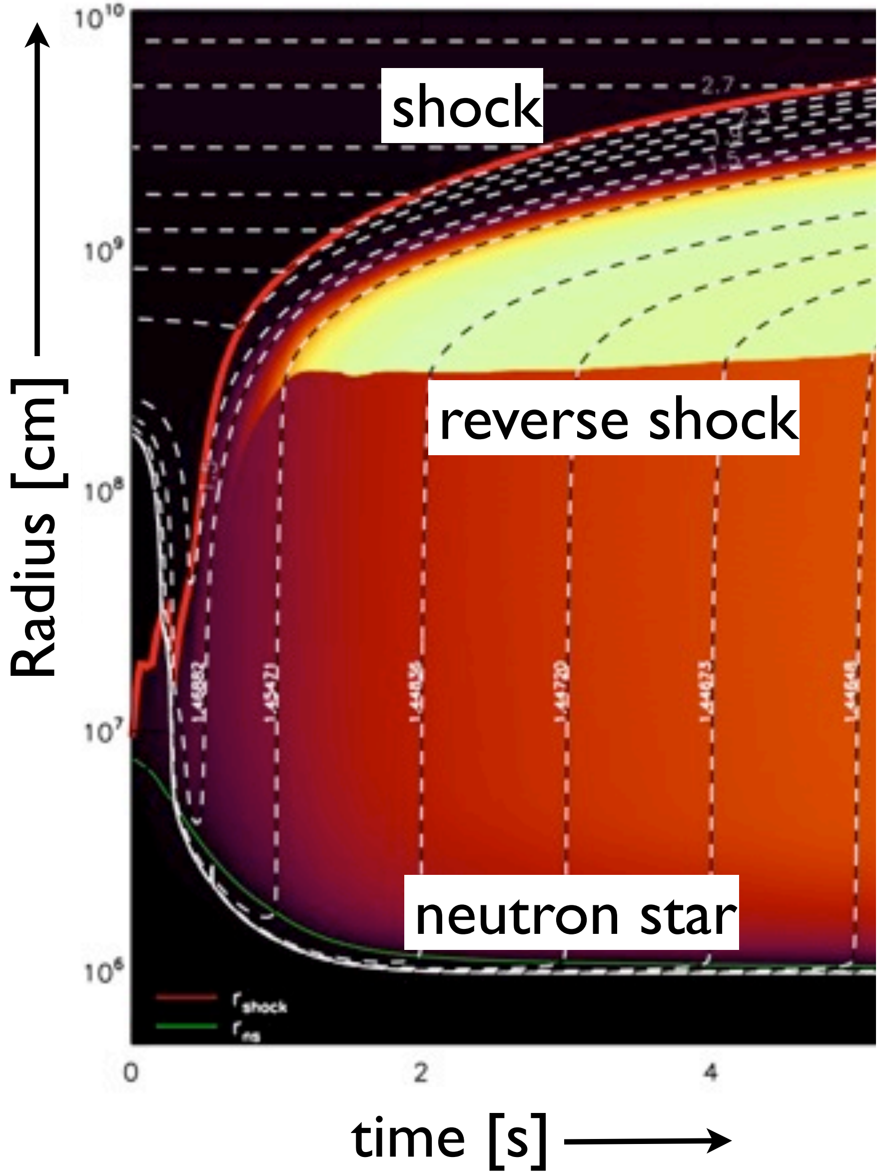


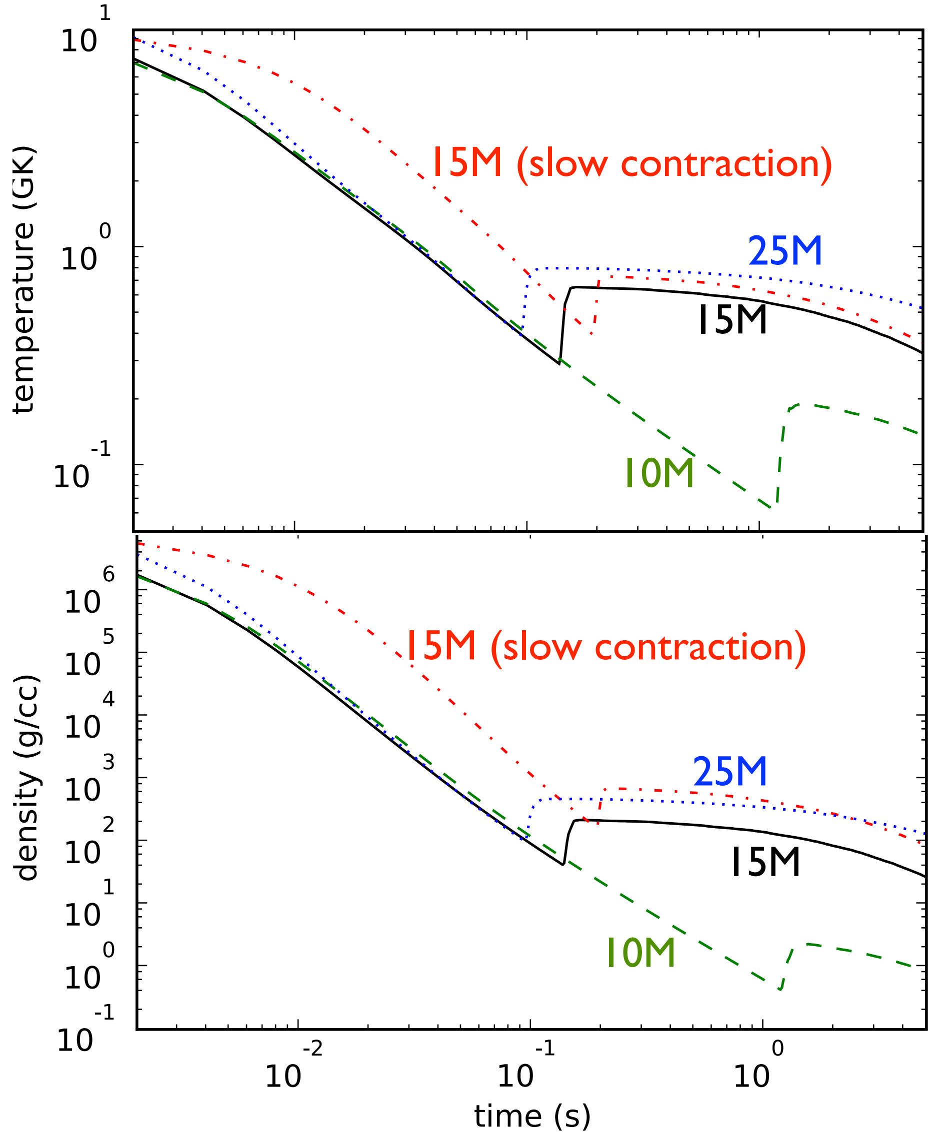
ν-driven wind simulation



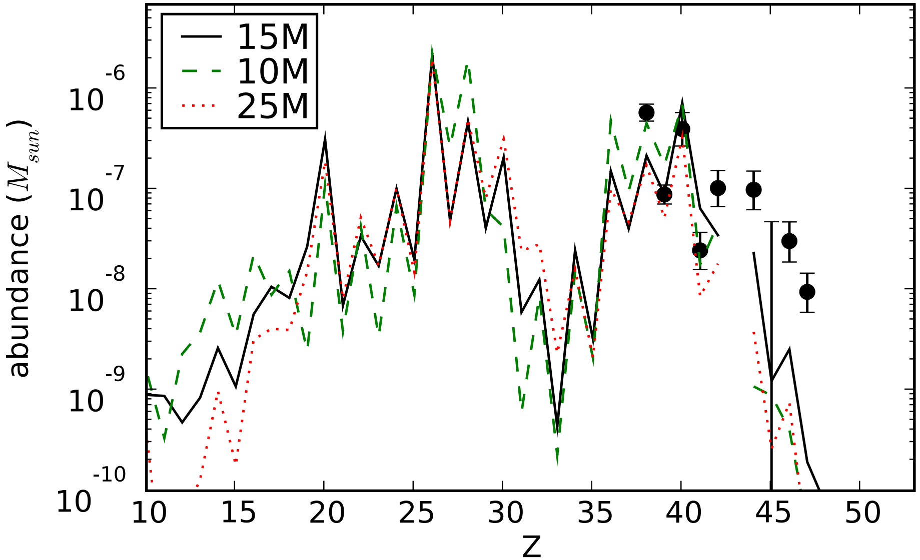
Arcones et al. 2007

ν-driven wind simulation





Nucleosynthesis in ν-driven winds

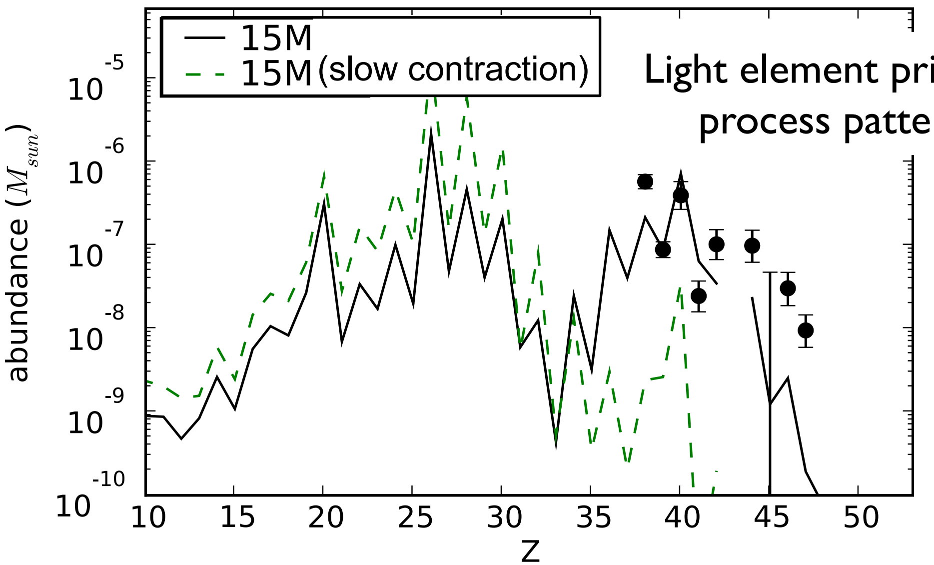


Arcones&Montes, arXiv:1007.1275

no heavy r-process nuclei
some LEPP nuclei produced

Roberts et al. NIC_XI_165

Sr-Y-Zr-Nb produced

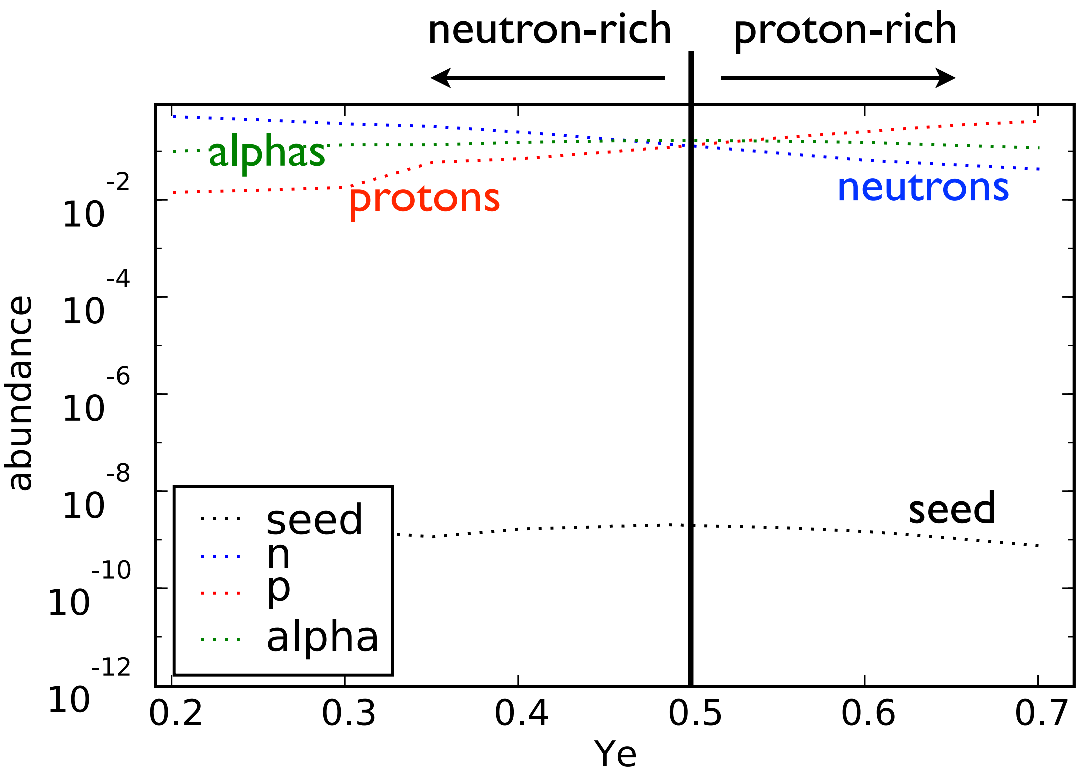


Light element primary process pattern

No major difference as a function of mass progenitor for same neutron star contraction evolution

Integrated abundances based on the neutrino-driven wind simulations

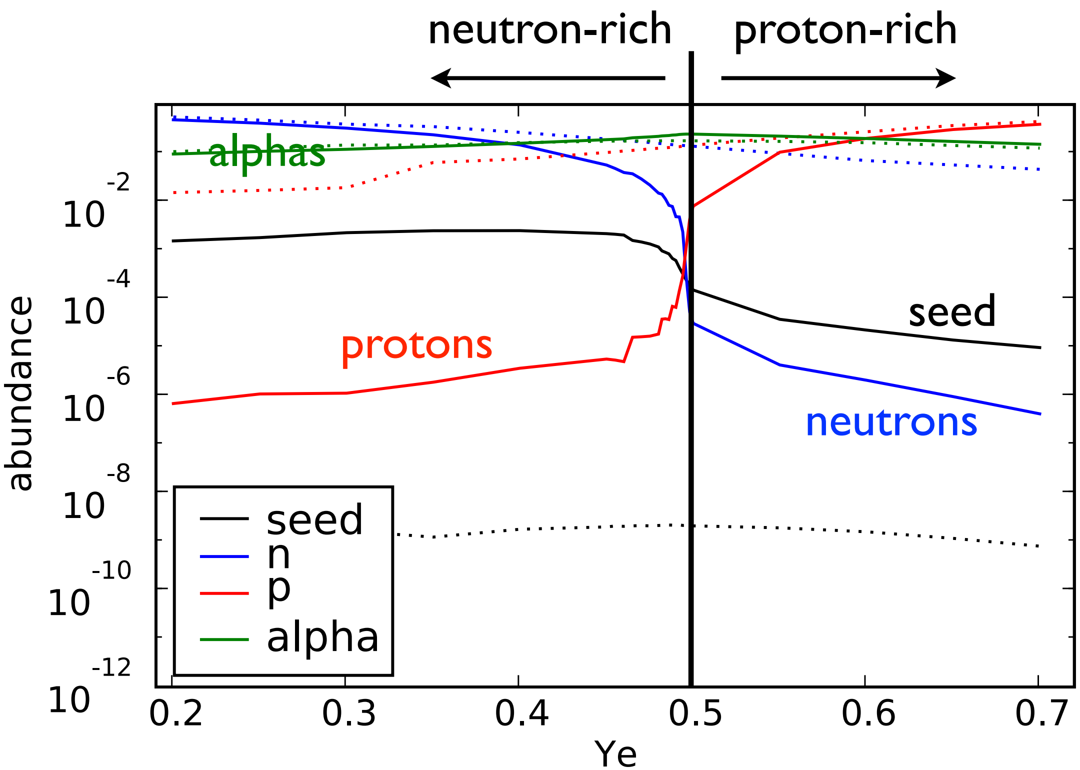
Nucleosynthesis and electron fraction



$T_9=8$

- Initial composition determined by nuclear statistical equilibrium
- At high temperatures only n, p, alphas exist

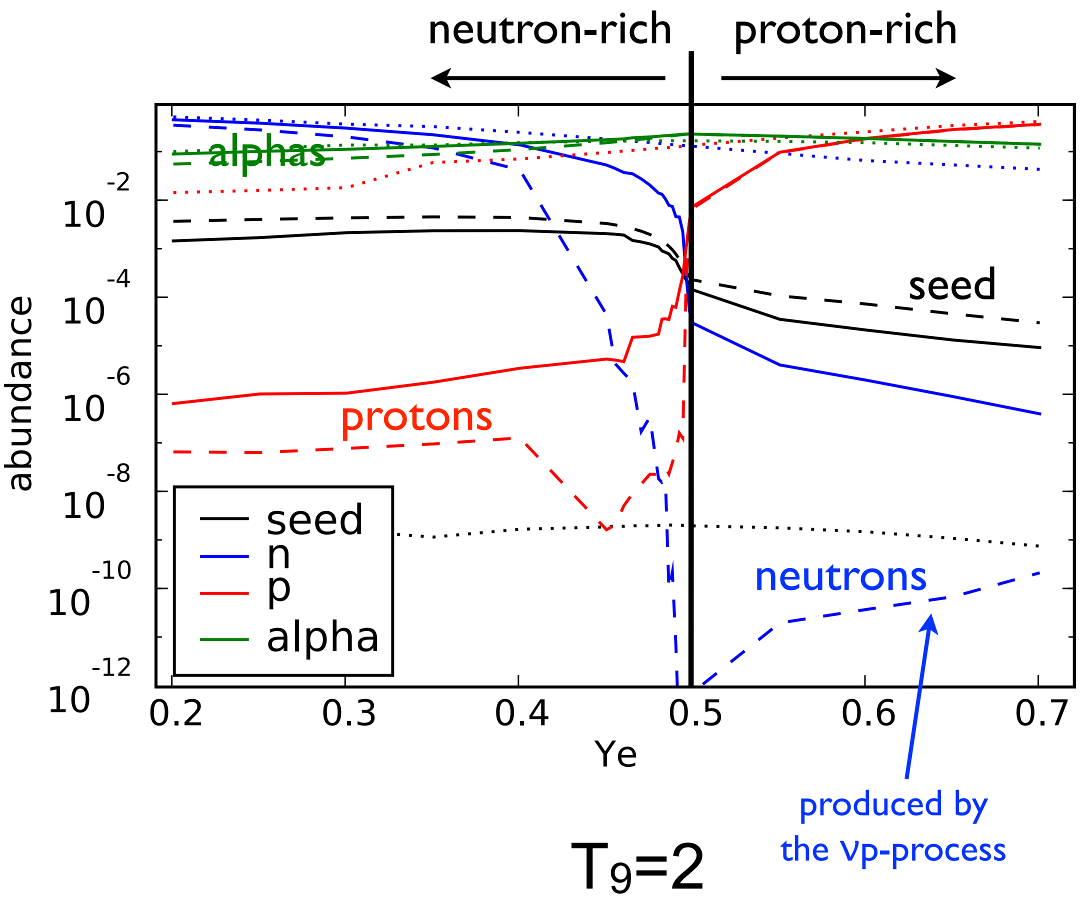
Nucleosynthesis and electron fraction



$T_9=5$

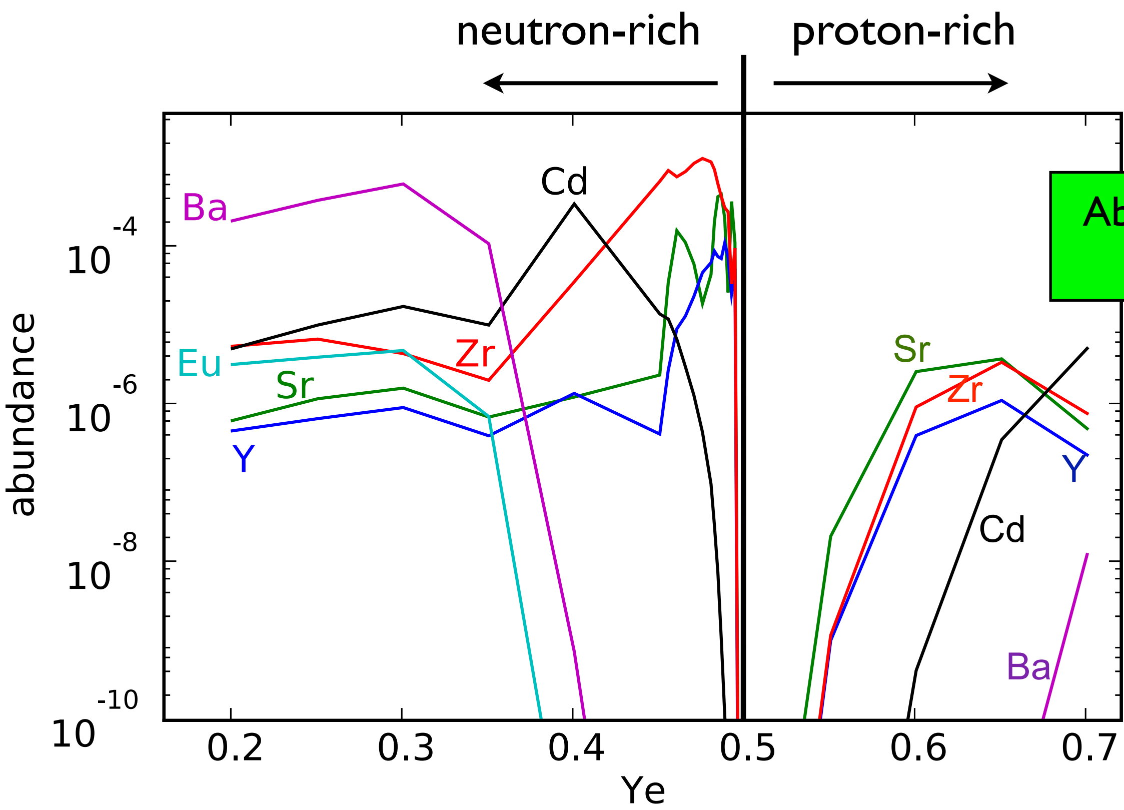
- Initial composition determined by nuclear statistical equilibrium
- At high temperatures only n, p, alphas exist
- Seed nuclei created by the time $T_9 \simeq 5$

Nucleosynthesis and electron fraction



- Initial composition determined by nuclear statistical equilibrium
- At high temperatures only n, p, alphas exist
- Seed nuclei created by the time $T_9 \simeq 5$
- Charged-particle freeze-out occurs between $T_9 \simeq 2$-3
- Formation of heavier nuclei depends on neutron-to-seed ratio and on proton-to-seed ratio after freeze-out

Nucleosynthesis and electron fraction



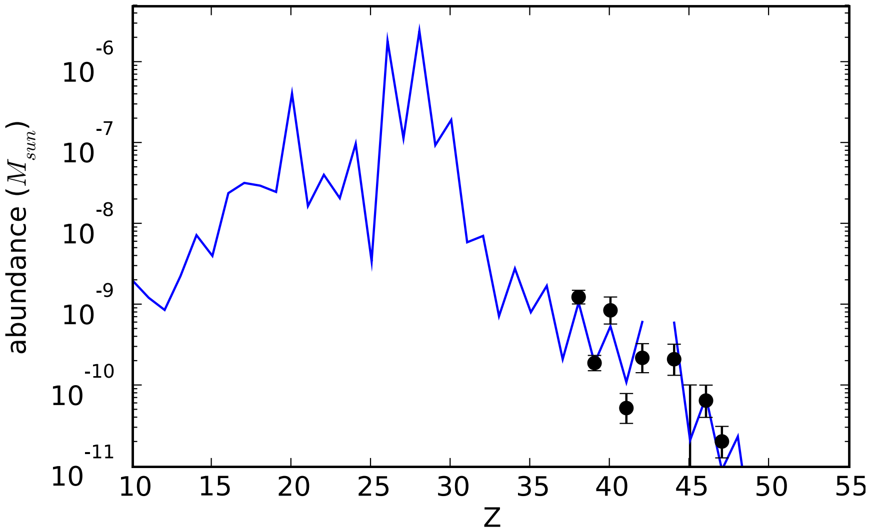
Abundance pattern is "robust" to local variations of the electron fraction

r-process elements can only be created with extreme Ye values

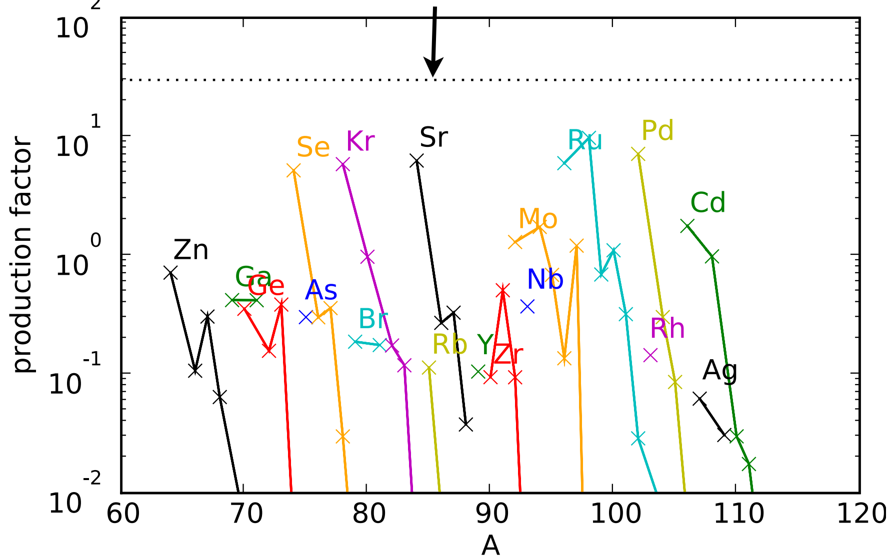
Production of heavy elements

Nucleosynthesis in proton-rich ν-driven winds

Superposition of trajectories $0.5 < Y_e < 0.65$ following Hüdepohl et al. (2009)



Limit assuming that every supernova ejects the same amount of matter with the same isotopic composition



Arcones&Montes, arXiv:1007.1275

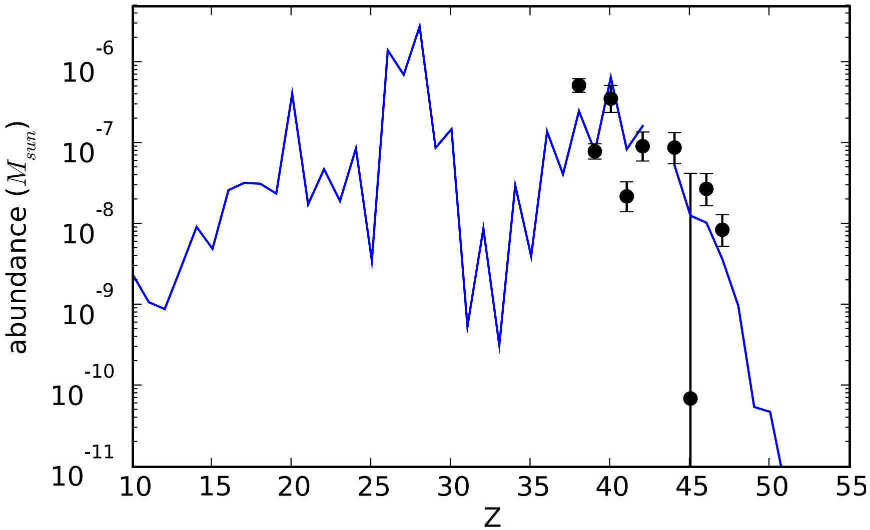
p-nuclei created

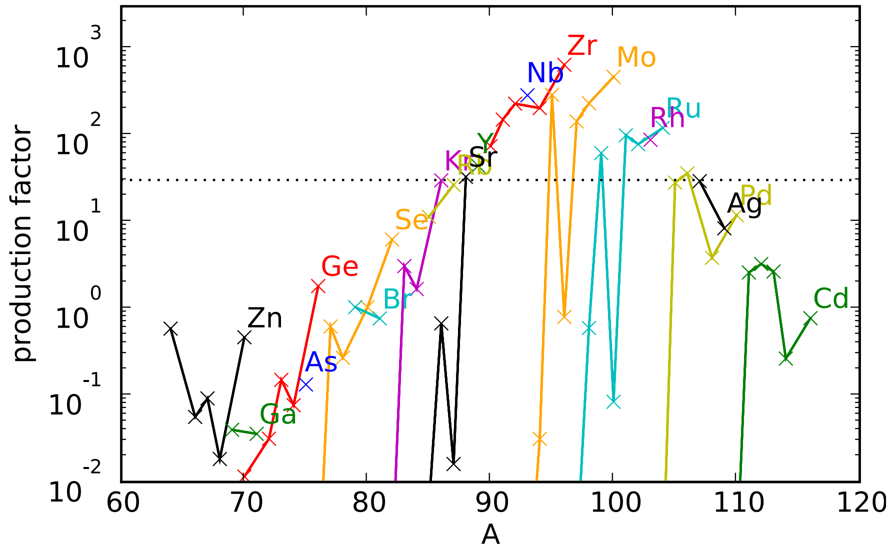
Abundance pattern is "robust" to local variations of the electron fraction
LEPP pattern observed in old metal-poor star can be explained but ....

The LEPP component of Travaglio et al. 2004 requires "s-only" isotopes

Nucleosynthesis in neutron-rich ν-driven winds

Superposition of trajectories with $0.5 > Y_e > 0.45$





LEPP pattern observed in old metal-poor stars can be explained but ....

Elemental pattern is rather sensitive to electron fraction evolution

Overproduction of A=90 nuclei (Hoffman et al. 1996)

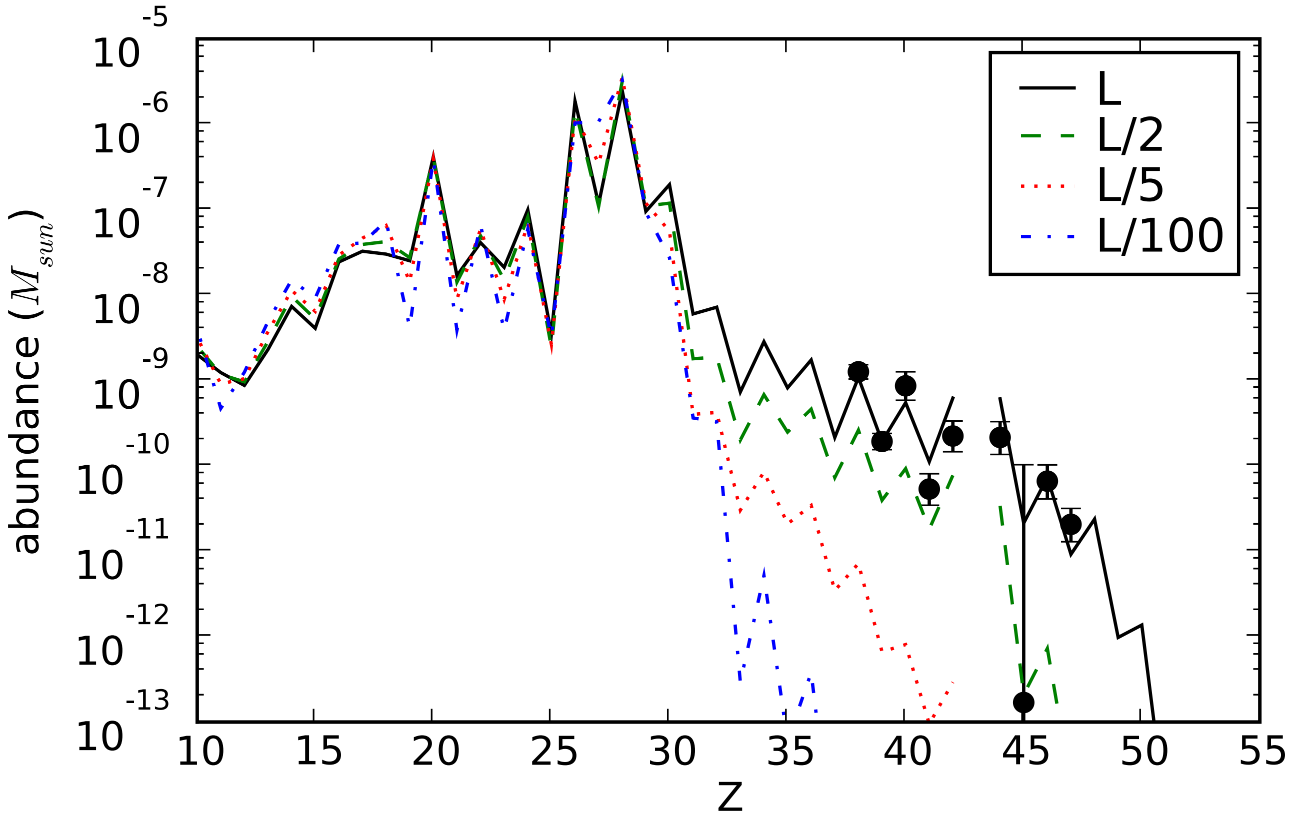
Conclusions

- First comparison of the light element primary process pattern observed in metal-poor stars and nucleosynthesis in realistic neutrino driven-wind simulations
- Electron fraction has an important effect on final abundances and depends on the uncertain composition and interaction in the outer layers of the proton-neutron star
- Abundance pattern can be reproduced by neutron and proton -rich winds
- Proton-rich winds show a rather robust pattern but produce p-nuclei and not in enough quantities
- Neutron-rich winds overproduce A=90 nuclei
- A combination of both types of winds is likely and may be able to explain the LEPP solar system contribution

Thank you

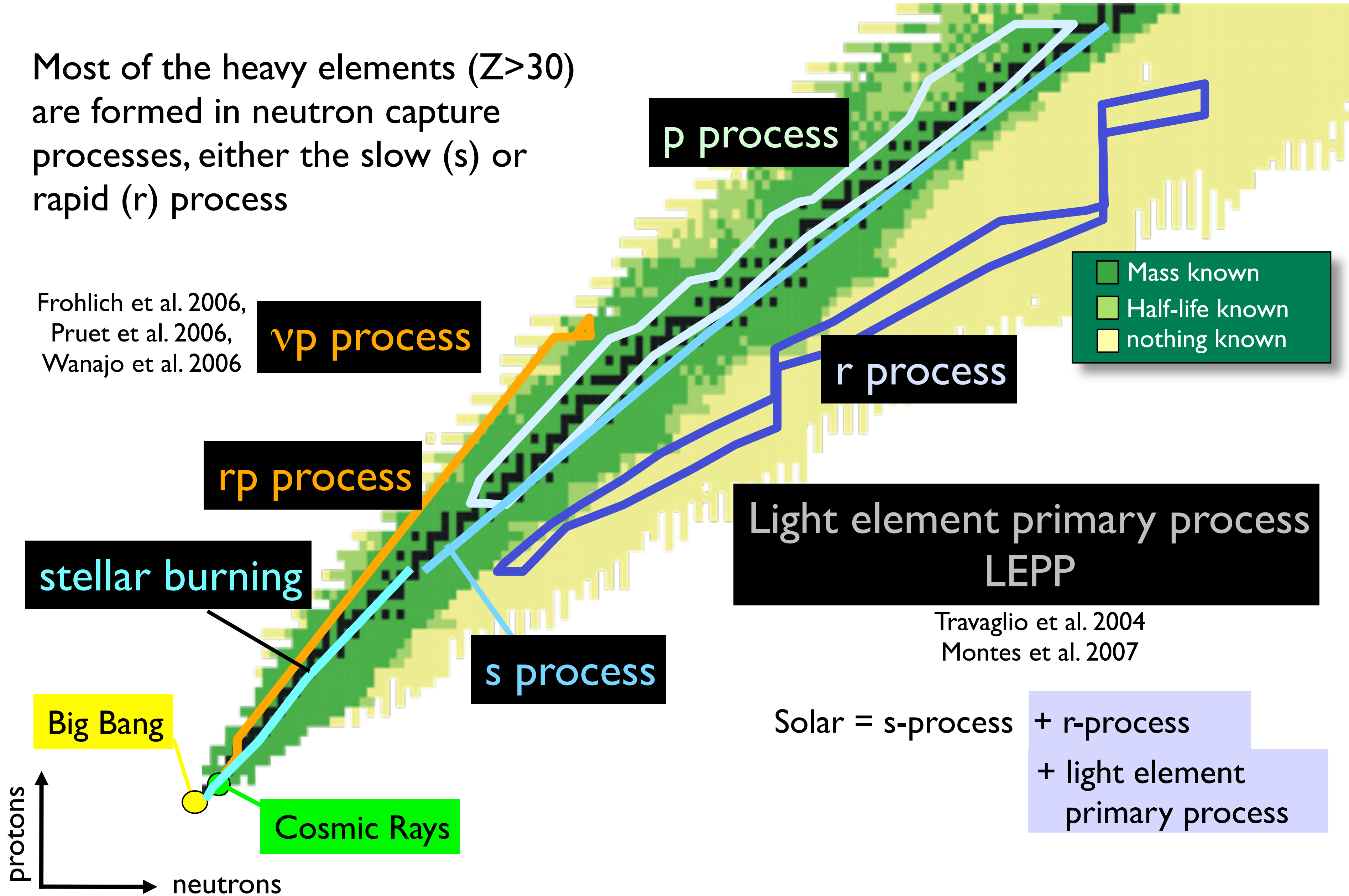
H. Th. Janka, K. Langanke, G. Martinez-Pinedo, H. Schatz, F. K. Thielemann

Nucleosynthesis and neutrino luminosity



Nucleosynthesis processes

Most of the heavy elements (Z>30) are formed in neutron capture processes, either the slow (s) or rapid (r) process



Outline

- Metal-poor star abundances
- Light Element Primary Process LEPP

Supernova 1997bs in M66

- Nucleosynthesis in neutrino-driven winds
- Uncertainties and dependance on Y_e
- Best conditions to obtain LEPP abundances
- Conclusions