Exposing the Nuclear Burning Ashes of Radius Expansion Type I X-ray Bursts

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Introduction

I. X-ray Bursts and Convection

- X-ray bursts produced by unstable nuclear burning of freshly accreted H- and/or He-rich material on the surface of a neutron star in a low-mass X-ray binary.
- Burning confined to a thin layer at base of accreted atmosphere.
- Most of the atmosphere is convective during the early stages of a burst.
- Ashes of nuclear burning well-mixed throughout convective region.

II. Radius Expansion Bursts

- He-rich burning layers produce very energetic bursts due to sensitivity of 3α energy generation rate to He abundance.
- He-rich layers occur in systems that accrete H & He at low accretion rates or those with a He white dwarf donor.
- These systems have peak luminosities that exceed Eddington, $L > L_{Edd}$, and therefore have radiative winds that eject the upper layers of the atmosphere.

The Question

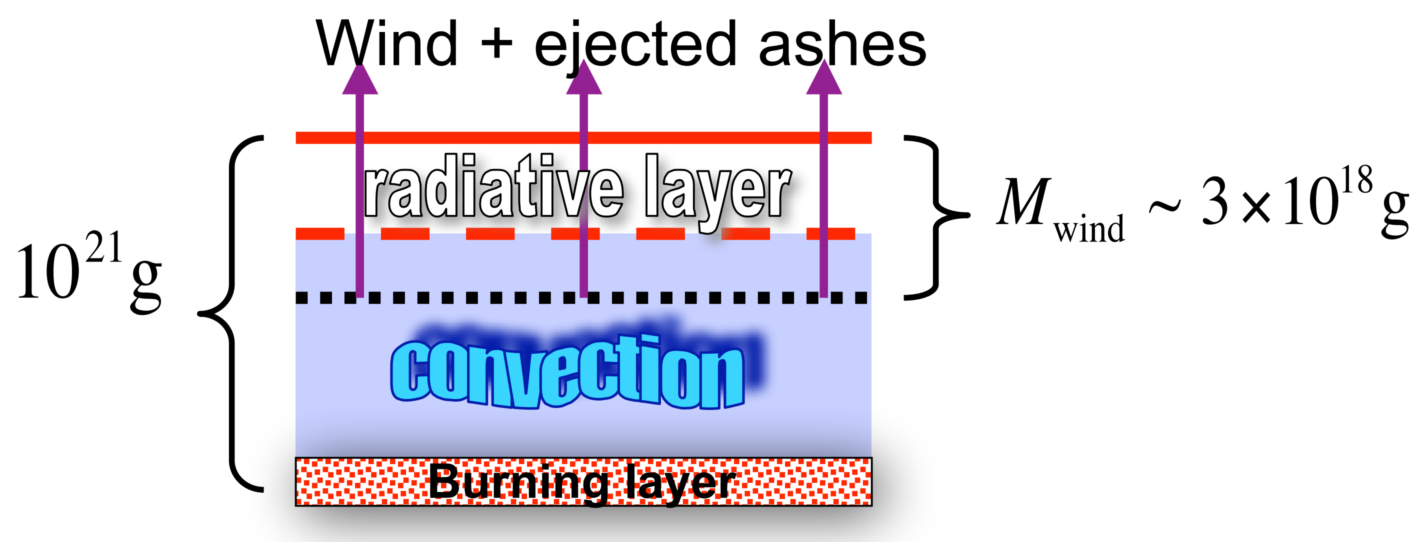
<u>**Given that**</u>:

1. Ashes of burning mixed throughout convective region and
2. Winds during radius expansion bursts eject layers lying above column depth $y_{wind.}$

Q: Do radius expansion bursts eject ashes of burning?

A: Yes, if $y_{c,min} < y_{wind}$

$y_{c,min}$ = minimum column depth ($-\int\rho dr$) reached by convective zone



The Convective Zone

<u>Goal</u>: calculate evolution of convective zone and determine if/when convection extends beyond y_{wind}

1. Before burst entire atmosphere is radiative:

$$T_{rad}(y) \propto y^{1/4}$$

2. As energy generation ε_{nuc} from burning increases, a convective zone forms with an adiabatic temperature structure:

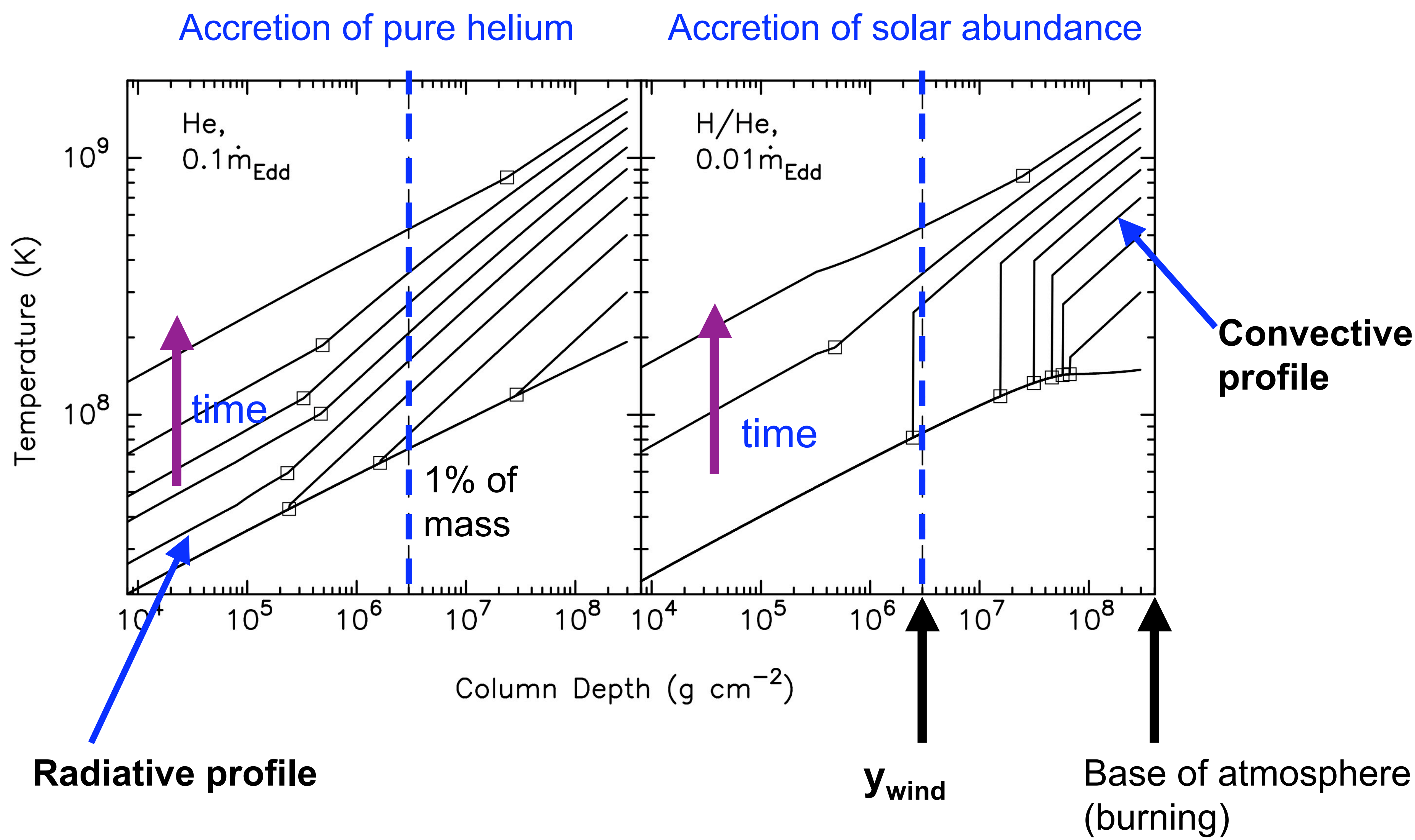
$$T_{conv}(y) \propto y^{n} \quad n \approx 2/5$$

3. Initially convective zone moves to lower y because atmosphere is cold and ε_{nuc} high.

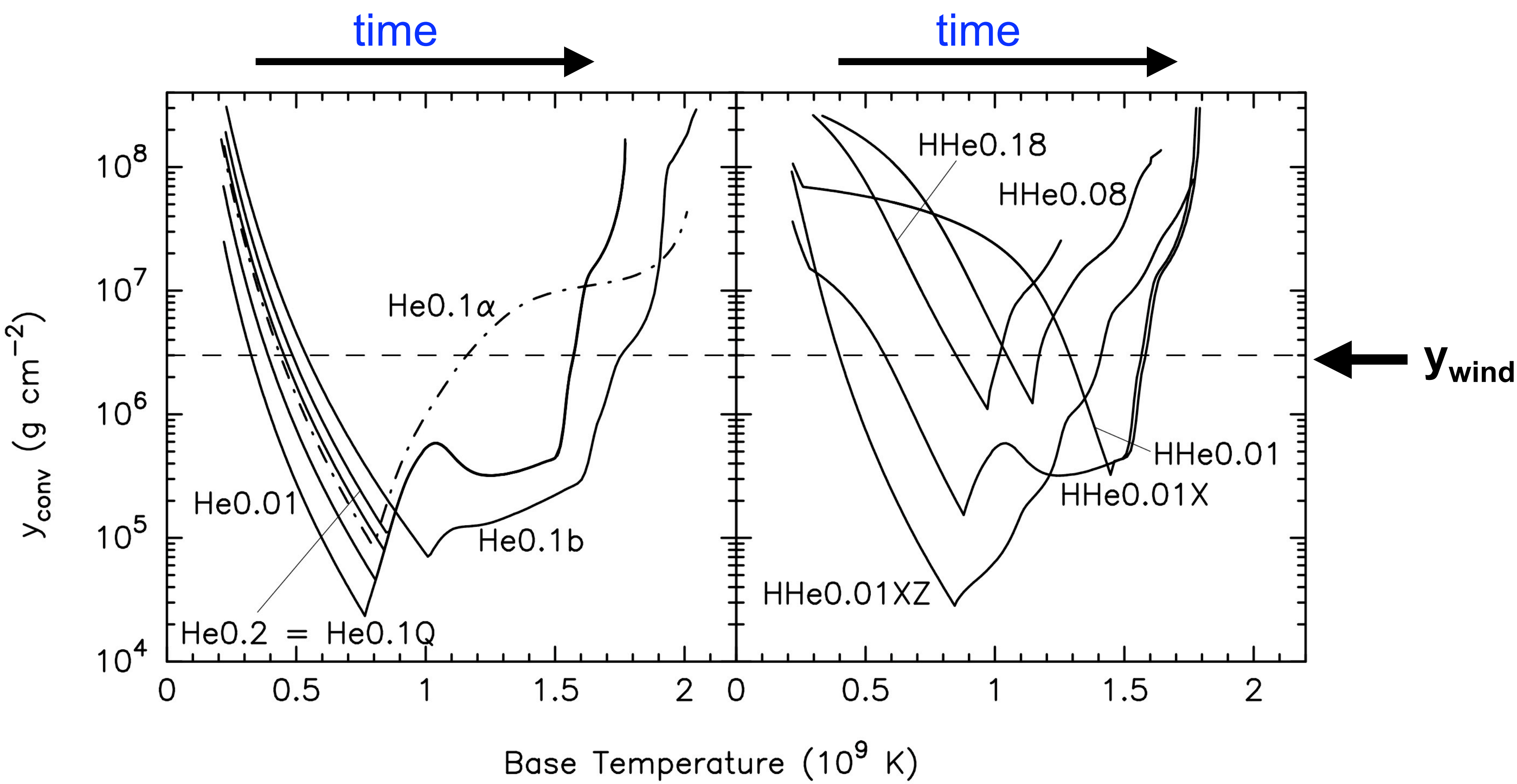
4. Eventually convective zone recedes back down to the base because: radiative zone has heated up and ε_{nuc} has decreased

Use full reaction network to calculate ε_{nuc} and nucleosynthesis

Evolution of temperature profile for two different models

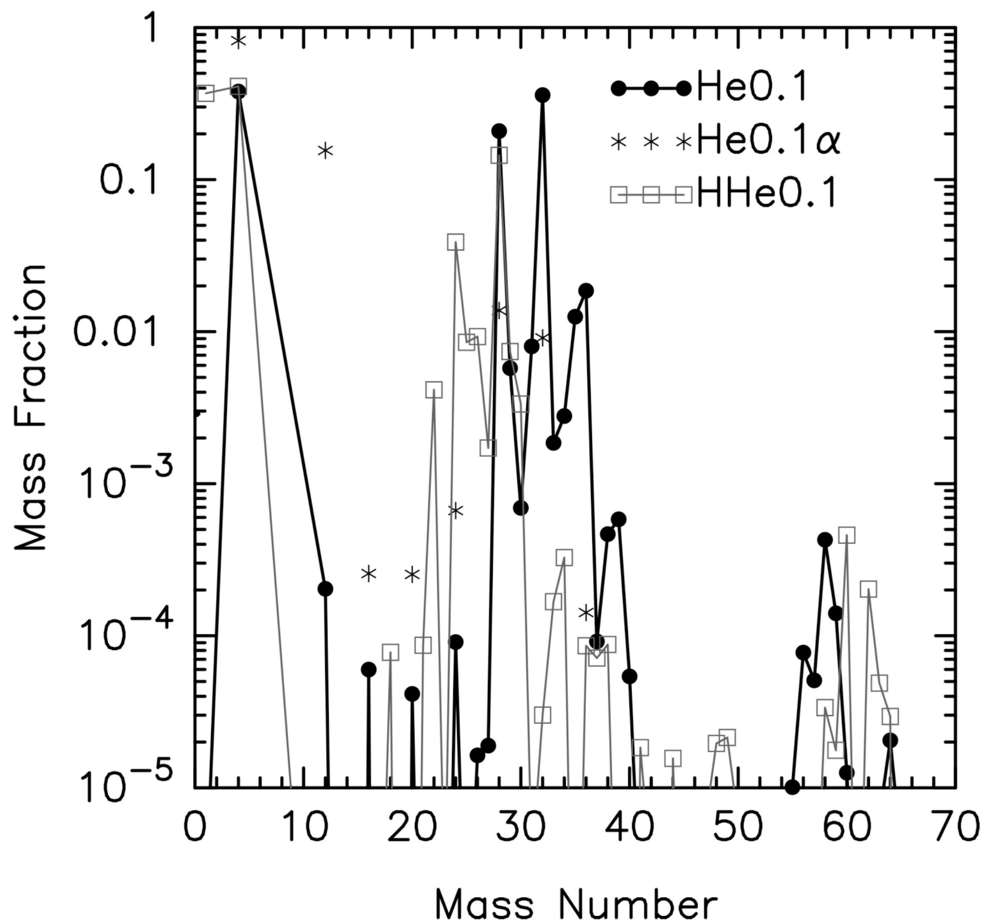


Evolution of convective zone for a range of different models

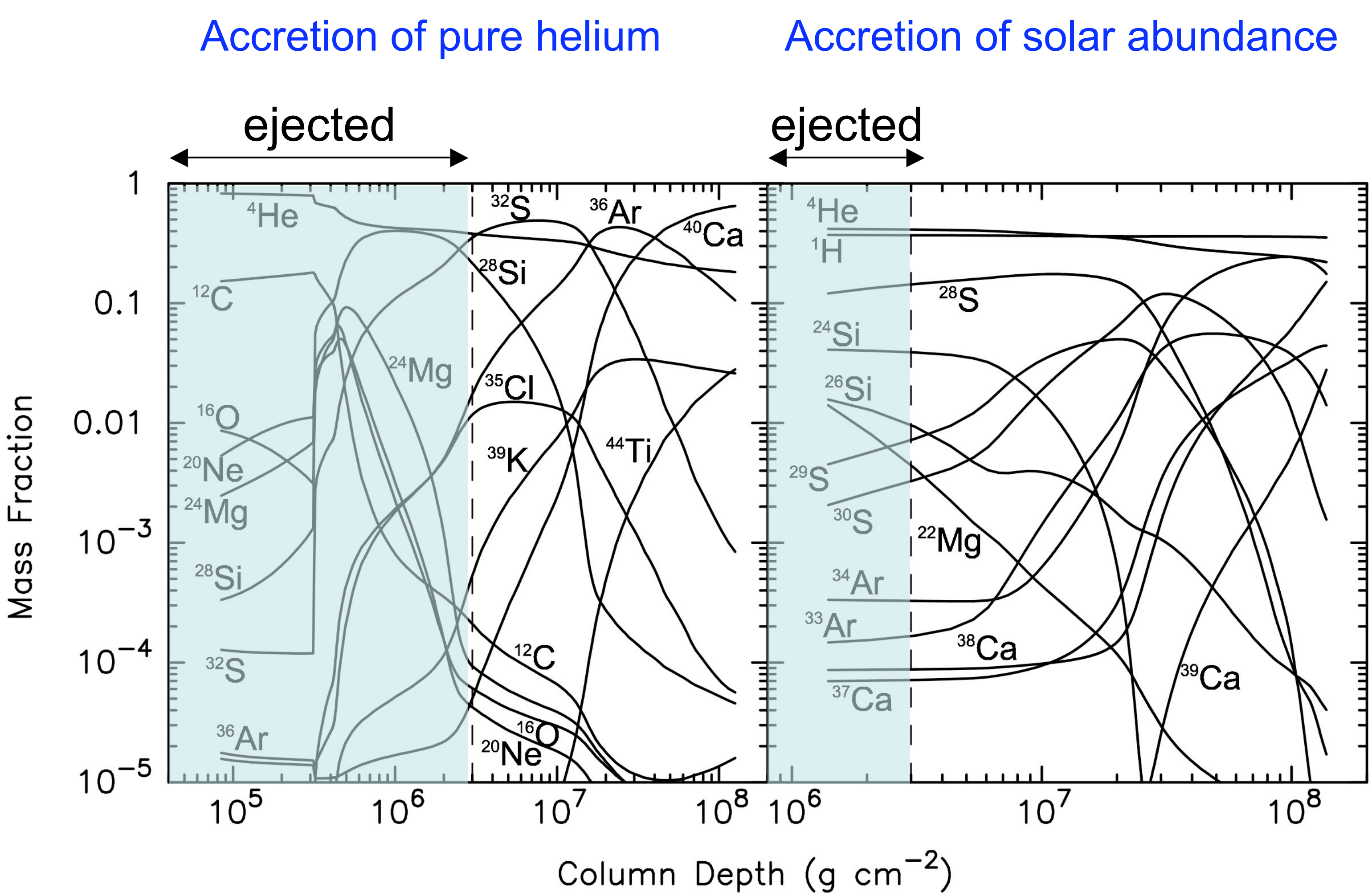


<u>Conclusion</u>: $y_{c,min} < y_{wind}$ during radius expansion bursts
ashes ejected by wind

Composition of Ejected Ashes



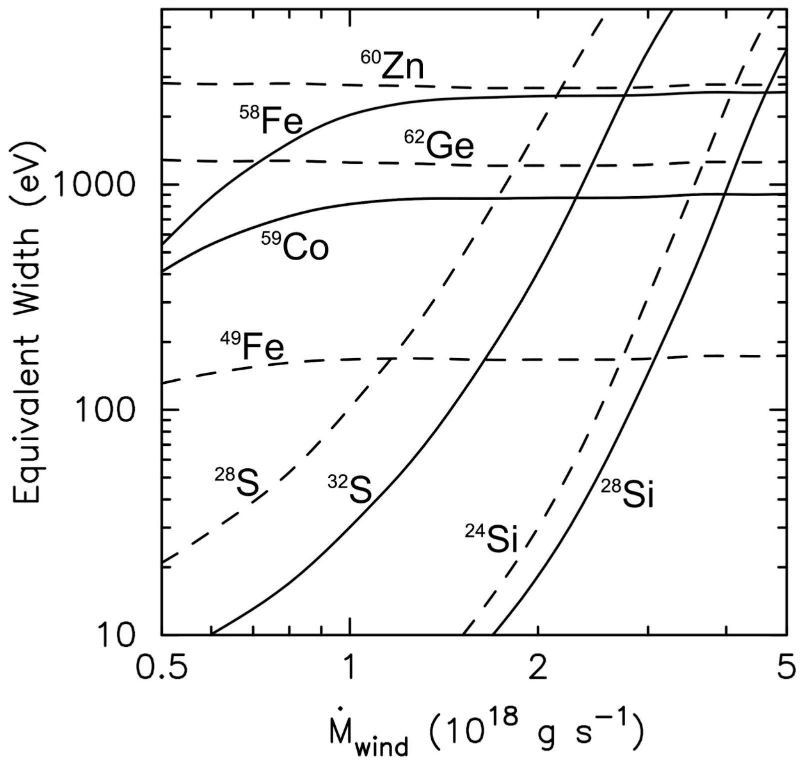
Final composition profile of ashes



Detecting the Ashes

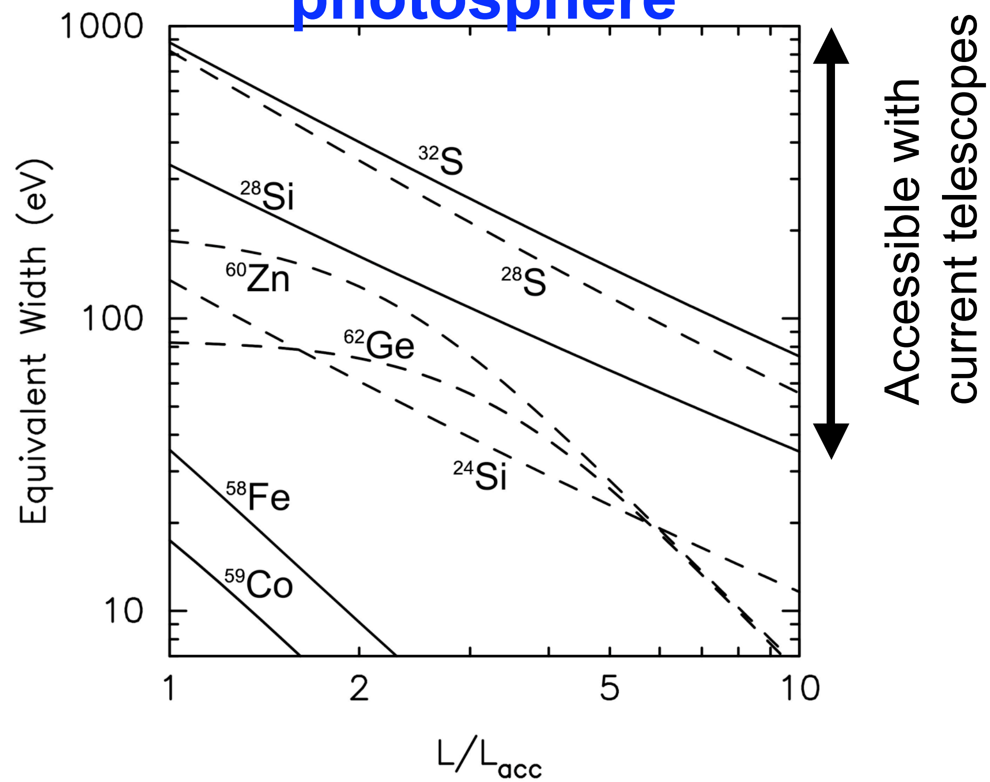
Calculated equivalent width of photoionization edge of H-like ashes in wind and those in photosphere after wind turns off

wind



wind mass loss rate

photosphere



post-RE luminosity relative to accretion luminosity

Conclusions

1. Our calculations of the convective zone evolution suggest that radius expansion bursts will eject ashes of nuclear burning.
2. The ejected ashes have mass number in the range $A = 30 – 60$.
3. The column density of ashes in hydrogen-like states is high enough that current high resolution X-ray telescopes should be able to detect spectral features of ashes.
4. A detection would probe nuclear burning processes during bursts.
5. Ashes detected in photosphere may enable a measurement of the gravitational redshift of the neutron star.