How Standard is the Candle?: A Theoretical Look at Metallicity Effects in Type Ia Supernovae

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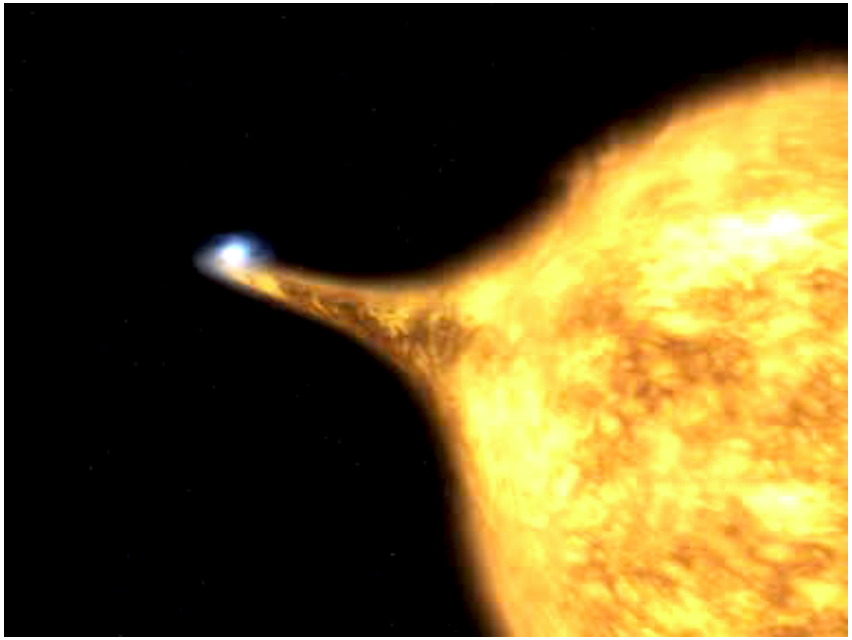
Type Ia Supernovae



[NASA]

Stars with a main sequence mass between 0.85 and 8 solar masses form C/O white dwarf.

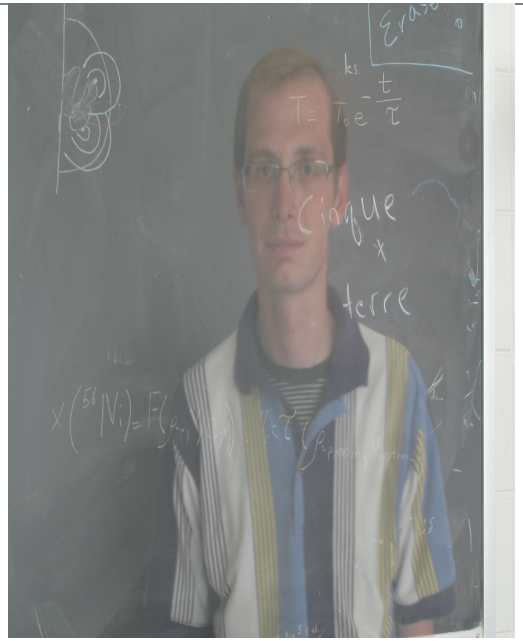
A single degenerate binary system where the non-degenerate star accretes onto the white dwarf.

Thermonuclear incineration of a C/O white dwarf near the Chandrasekhar limit (1.4 Solar Masses). [see Hillebrandt & Niemeyer 2000]

BRIGHT

Luminosity:
Set by the abundance of ^{56}Ni

WIDTH



Opacity:

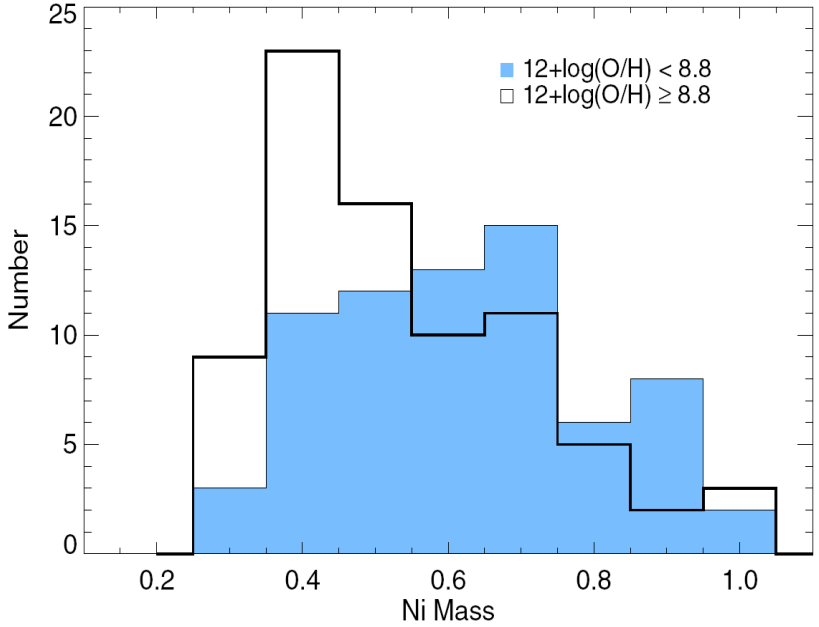
Set by the abundance of Fe group elements The principal component of which is ^{56}Ni

Kinetic Energy:

Set by how much C\O burned. Related to how much ^{56}Ni produced.

Why Metallicity

- Surveys have shown that SNe Ia have some knowledge of the galaxy that they are in.
- Composition is determined from host galaxy photometry.
- Ni mass is determined from Luminosity



[Howell et al. 2009]

For Example

$$2\,^{12}C + 2\,^{16}O = {}^{56}Ni$$

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$$\cdots = 2\,^{58}Ni$$

The formal approach

Lets pretend that ^{56}Ni and ^{58}Ni are the only species in the burned fuel. The equations for mass and charge conservation imply that

$$M(^{56}Ni) \approx 0.6(1 - 0.057\, Z/Z_{sun})$$

This results in a scatter of about 0.1 M in peak brightness, assuming no other metallicity dependent effects.

[Timmes, Brown, Truran 2003]

Flames

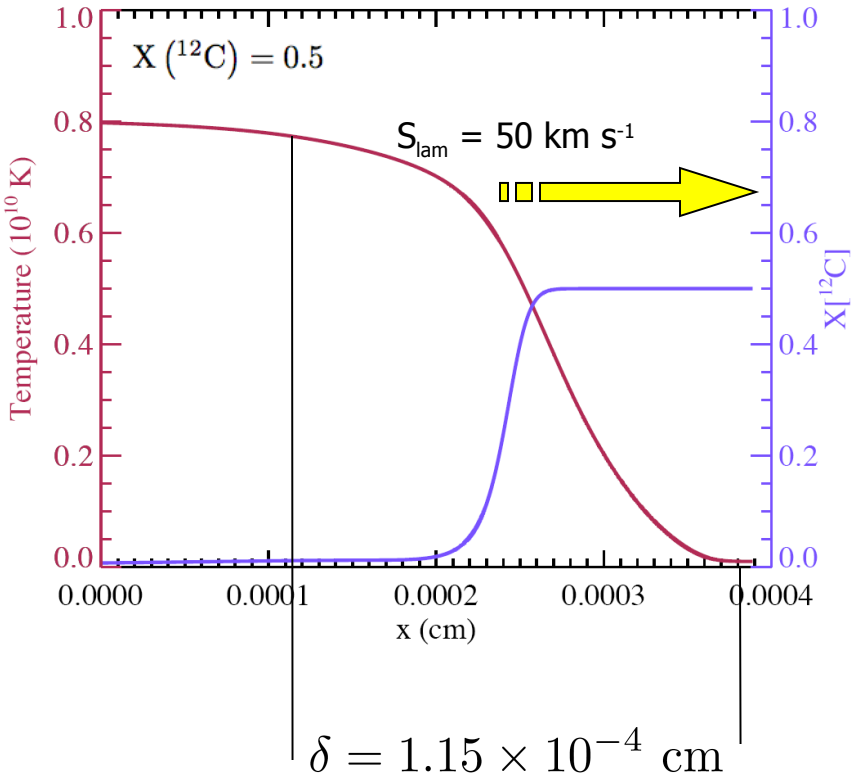
$$S_{lam}\left[\frac{dE}{dx}+P\frac{d(1/\rho)}{dx}\right]=\frac{1}{\rho}\frac{d}{dx}\left(K\frac{dT}{dx}\right)+\varepsilon$$

$$\varepsilon = N_A\sum_i B_i\frac{dY_i}{dt}$$

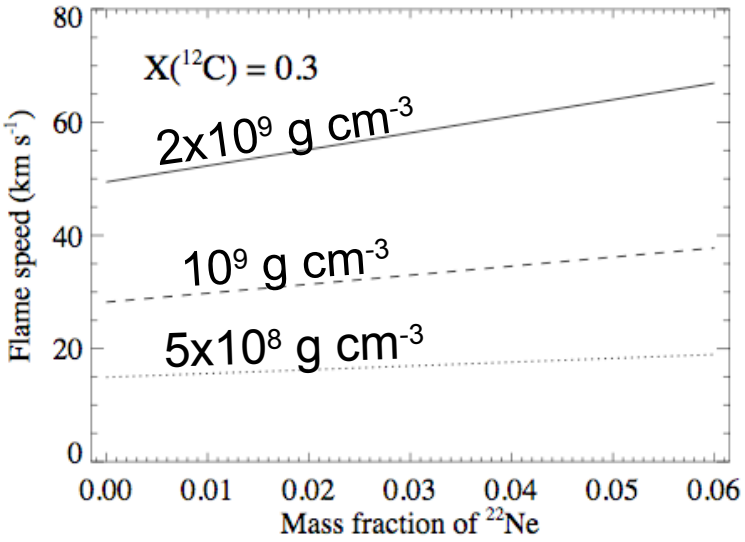
PdV work

heat flux

Nuclear flame is just like any other flame except instead of being powered chemical reactions, nuclear reactions provide the energy source.



Flame Speedup



[Chamulak et al. 2007]

Increasing the metallicity increases the flame speed linearly.

A 3 times solar metallicity increases the flame speed by 30%!

The extra neutrons are able to allow for more reactions to take place in the flame front resulting in greater energy release

Flash

- Developed by the ASC Flash center at the University of Chicago
- Eulerian compressible hydrodynamics code
- Capable of doing hydrodynamics in 1-D, 2-D or even 3-D
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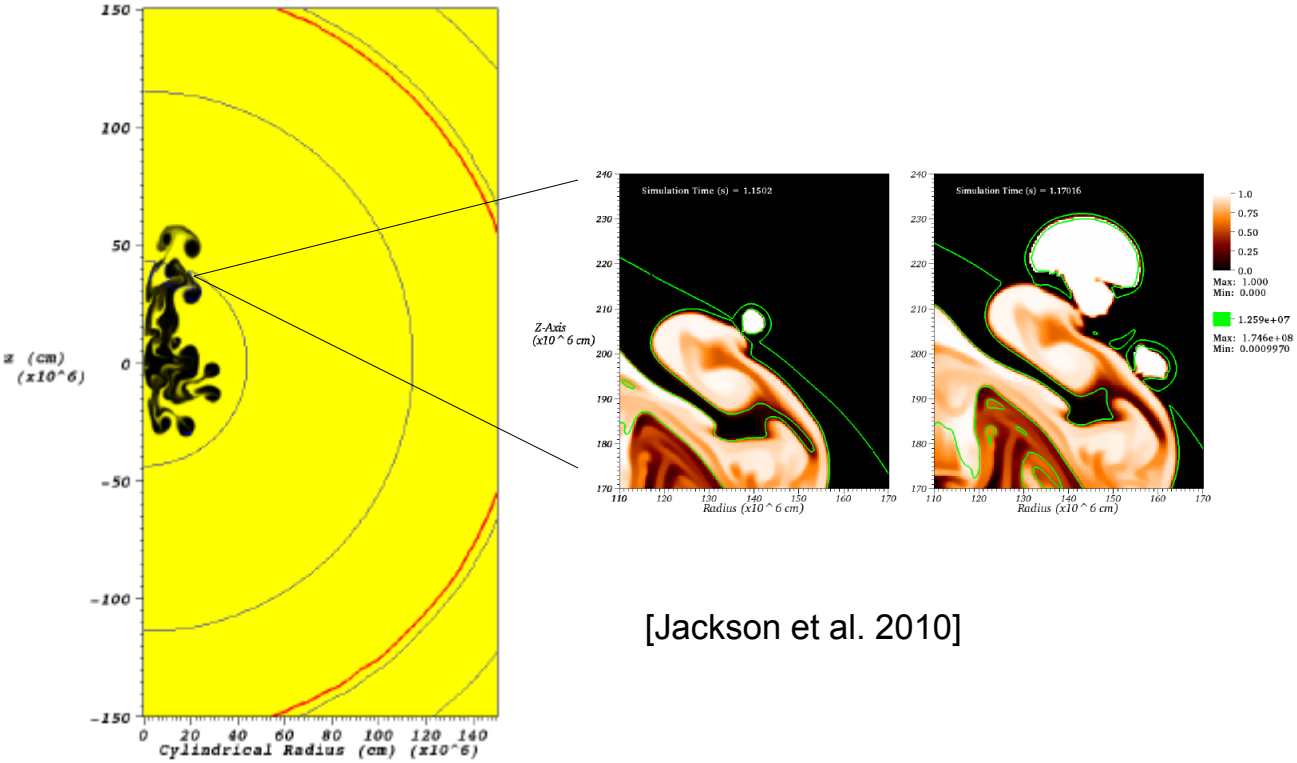
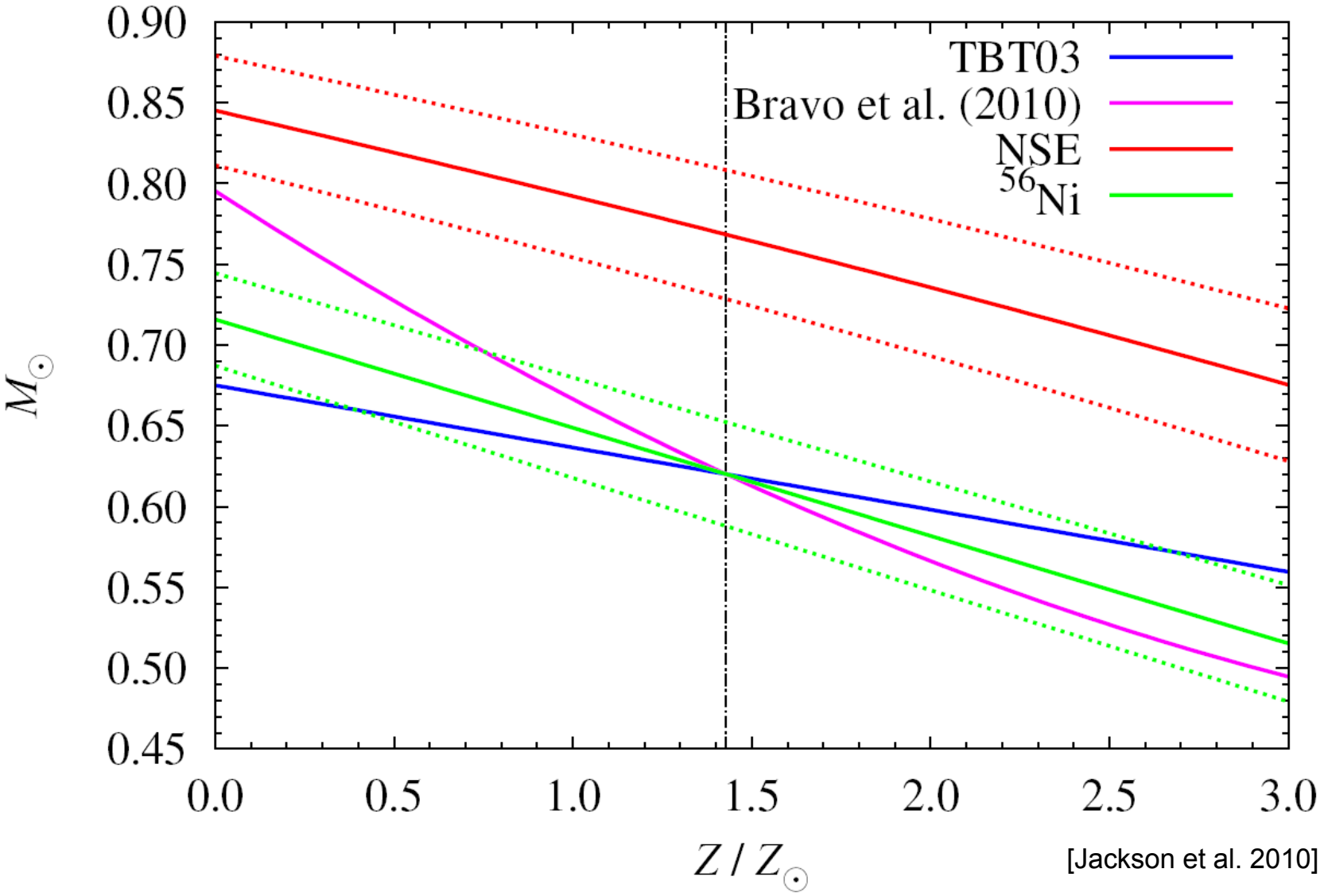
The Model Considered

Deflagration to detonation transition (DDT)

Transition is dependent on flame speed and width



[Jackson et al. 2010]



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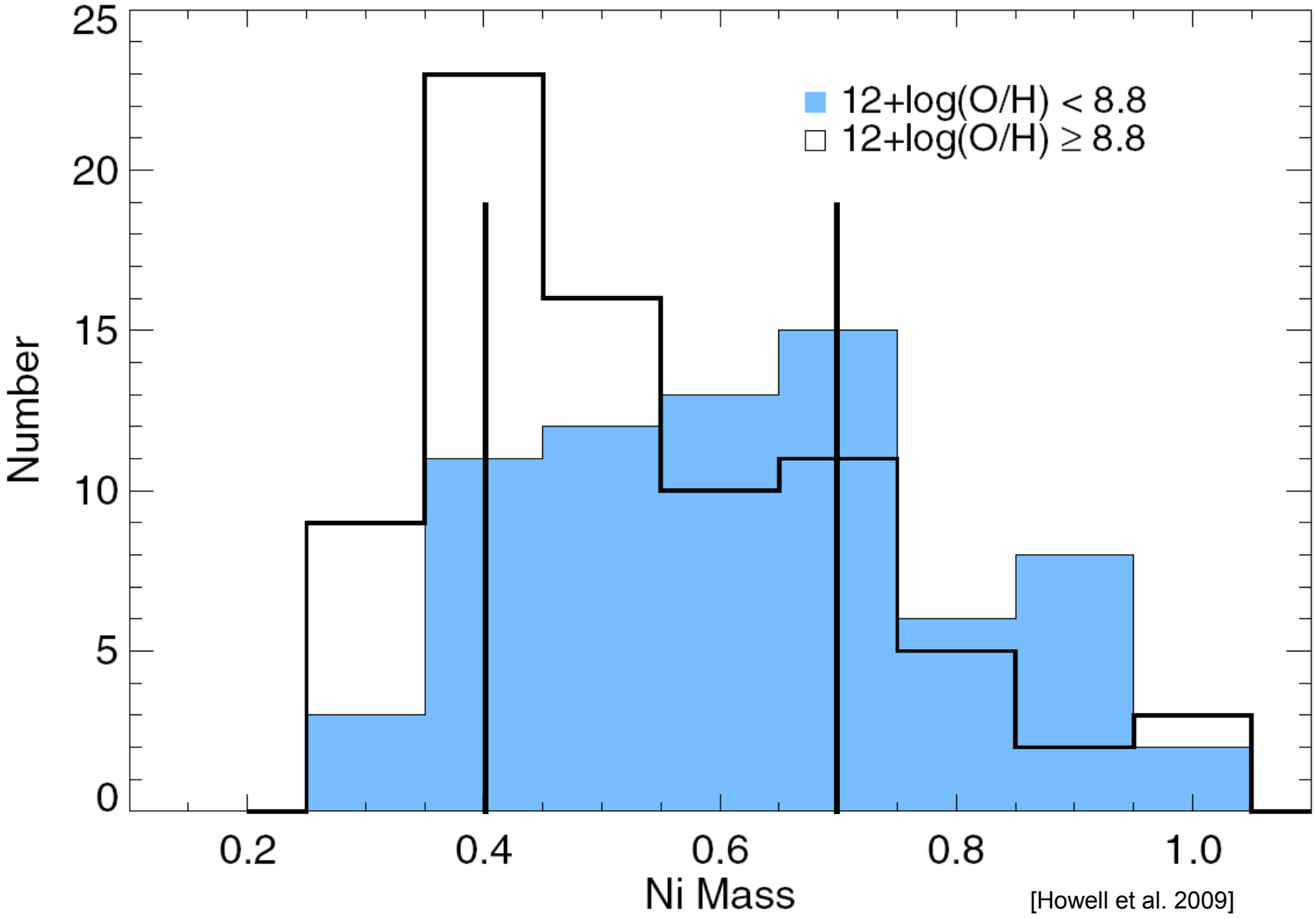

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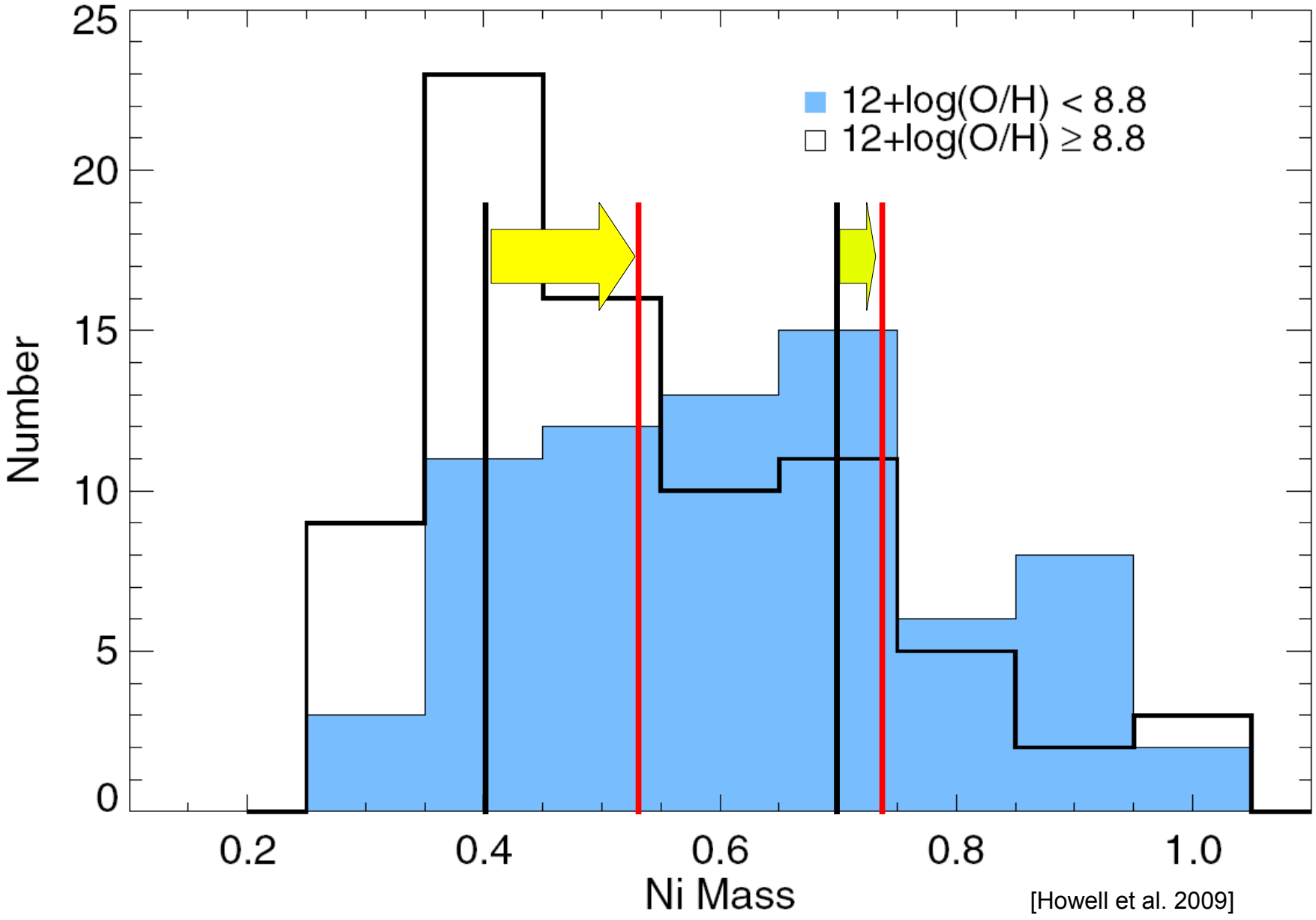

[Howell et al. 2009]

Conclusions & Collaborators

SNe Ia seam to know something about the type of galaxy they are in.

Metallicity affects the nucleosynthesis taking place in SNe Ia.

While metallicity may contribute to some of the observed scatter in luminosities it probably is not the only thing.

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