Suzaku 2011, Exploring the X-ray Universe: Suzaku and Beyond, SLAC, July 21, 2011

Progenitor Metallicity of Kepler's Supernova

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Outline

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2. Progenitor Metallicity of SNe Ia: Why Kepler?
3. Initial Suzaku Results of Kepler (100 ks, AO2)
4. **Suzaku Key Project of Kepler (AO4-5)**
   - Preliminary results

Type Ia Supernova

- Thermonuclear explosion of C/O white dwarf (WD) in a close binary: complete destruction of a star

  → Major source of Fe-group elements: galactic chemical evolution

  → "Standard candles" for cosmology

- Type Ia SNe are not homogeneous:

  Various physical mechanisms of explosion & nucleosynthesis (e.g., *Iwamoto+ 1999*): Detonations, deflagrations, delayed detonations etc.

  => yield diverse compositions of burning products.

  Various evolutionary paths or ages (prompt, delayed) related to progenitor mass, metallicity, and circumstellar structure (e.g., *Scannapieco & Bildsten 2005; Aubourg+ 2007; Matteucci+ 2009*)

  => affect SN light curve and luminosity (e.g., *Timmes+ 2003*).

  Various nature of the WD binary system: normal or WD companion.

  => accretion vs merger.

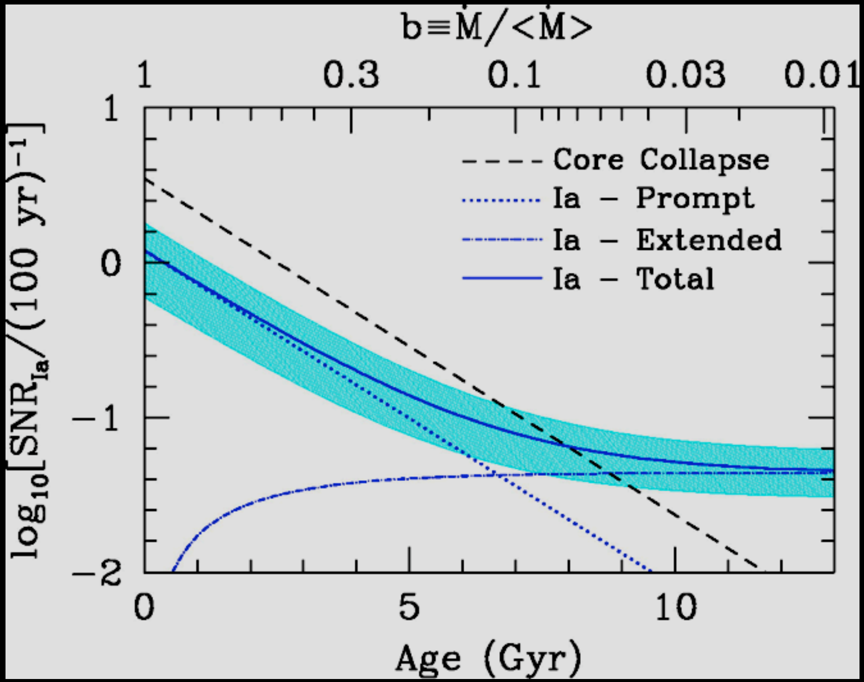
Type Ia SN Populations

Evidence for two progenitor populations:
(e.g, *Hamuy+ 1996, Howell 2001,*
van den Bergh+ 2005, Mannucci+ 2005,
Scannapieco & Bildsten 2005):

Prompt: Younger progenitors,
brighter SNe Ia (e.g., 1991T),
SN rate ∝ star-formation rate

Delayed: Older progenitors,
dimmer SNe Ia (e.g., 1991bg),
SN rate ∝ total stellar mass

Actual progenitors have *never* been identified: Tycho (SN 1572) might have been a prompt pop with a *non-subsolar* metallicity? (*Badenes+ 2008*).



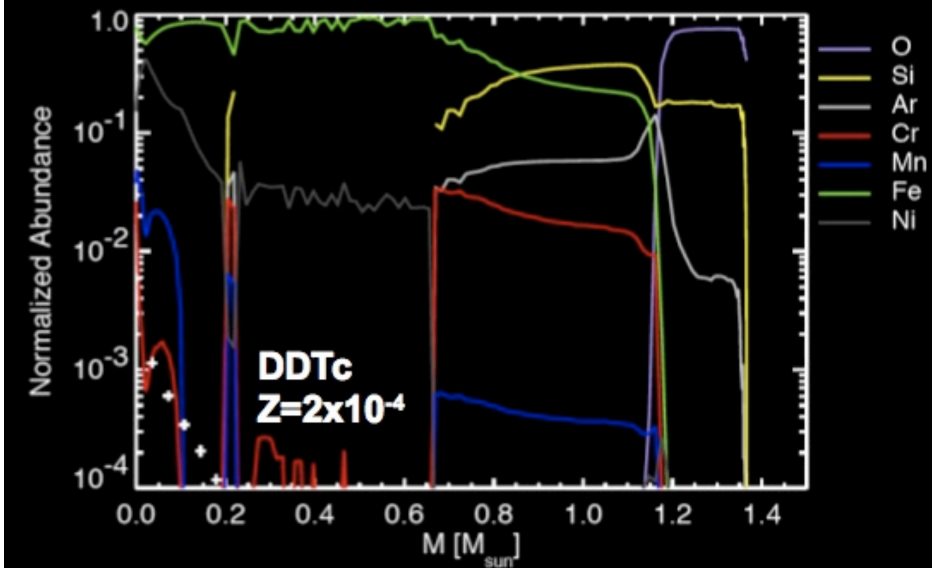
Model by *Scannapieco & Bildsten* (*2005*)

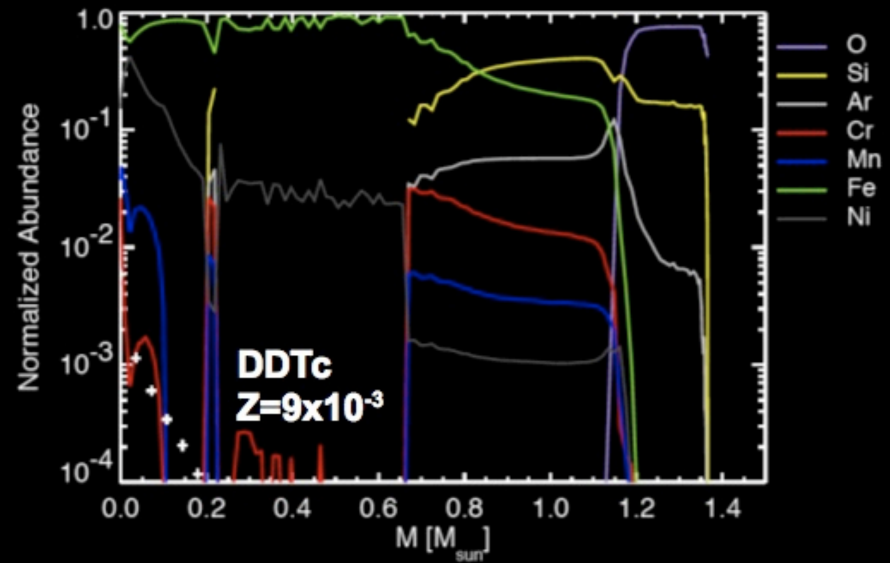
Metallicity of SN Ia Progenitor

- Metallicity (Z) of SN Ia progenitor is a key parameter to affect age/mass CSM (prompt vs delayed SN Ia populations) of the progenitor.

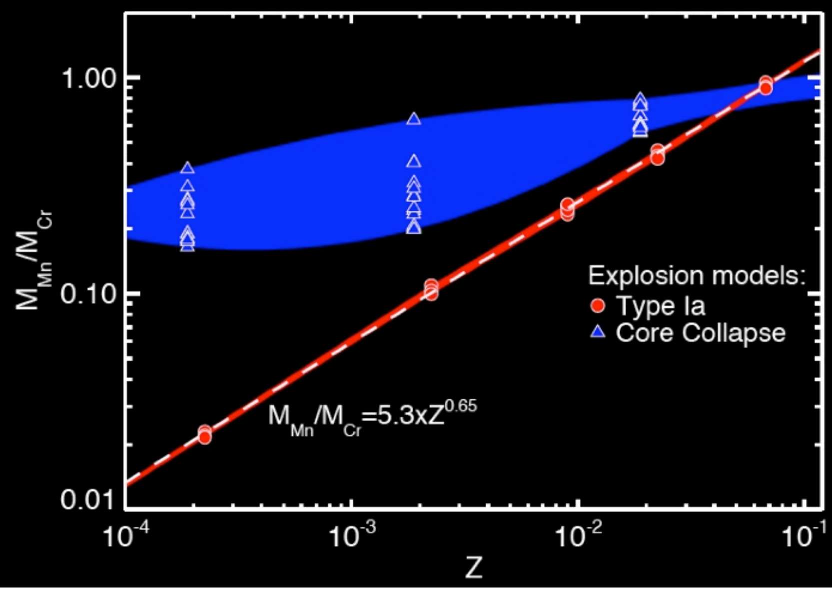
- C/O WDs born from intermediate mass stars that burn H through the CNO cycle which ends up with ^{14}N.
- Neutron excess ($\eta = 1- 2Y_e = 1 - 2[Z_A/A]$, Z_A = atomic number, A = atomic mass) is dominated by e-capture at the core ($M < 0.2\ M_\odot$) (e.g., *Brachwitz+ 2000*).
- At $M \sim 0.2$-$0.8\ M_\odot$, $^{14}N \rightarrow {}^{18}F \rightarrow {}^{18}O \rightarrow {}^{22}Ne$ (He-burning), thus η is directly related to Z: $\eta = 0.101 \times Z$ (*Timmes+ 2003*).
- η is efficiently stored in trace elements with unequal numbers of p, n ($^{55}Co \rightarrow {}^{55}Mn$).
- An abundant element Mn is useful. Cr is an ideal reference element: it is the same incomplete Si-burning product as Mn, but insensitive to η, ($^{52}Fe \rightarrow {}^{52}Cr$).

Z vs M_{Mn} / M_{Cr} in SN Ia





- Mn to Cr mass ratio is an excellent tracer of metallicity of the progenitor:
  $M_{Mn} / M_{Cr} = 5.3 \times Z^{0.65}$
  (*Badenes+ 2008*)



Measuring M_{Mn} / M_{Cr} Ratio

SN Ia nucleosynthesis study of trace elements

- X-ray data of young SNRs effectively reveal SN nucleosynthesis products directly from the stellar interior.
- Line flux measurements Cr & Mn in the X-ray spectrum of young Type Ia SNR (*Tamagawa+ 2008*).

$M_{Mn} / M_{Cr} = 1.057 \times (f_{Mn} / f_{Cr}) / (\varepsilon_{Mn} / \varepsilon_{Cr})$,

f = line flux, ε = specific emissivity per ion (*Badenes+ 2008*)

- Extragalatic SNe are not useful:

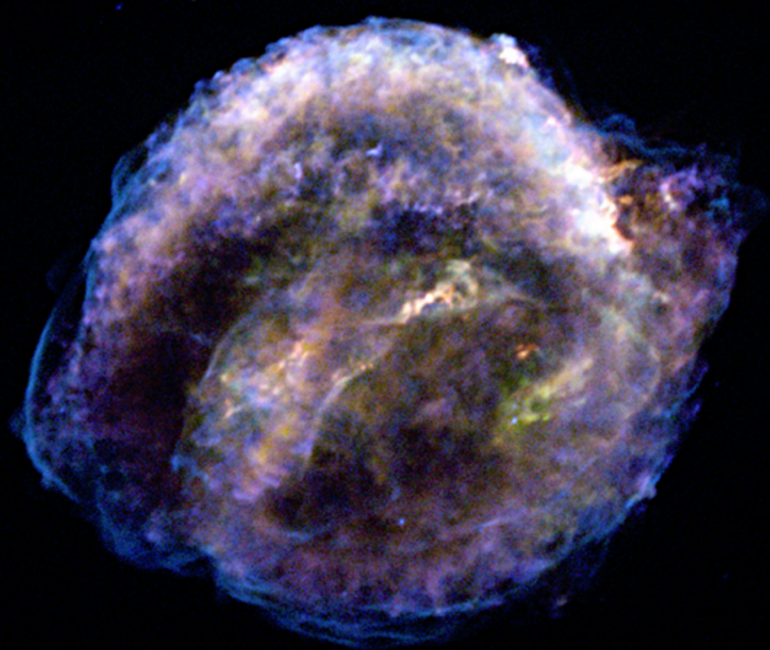
- Long half-life of ^{55}Fe (~2.7 yr): parent nucleus of ^{55}Mn

- Difficult to reveal/study CSM and ambient environment

→ Must be young Type Ia SNRs

Why Kepler?

750 ks Chandra
(*Reynolds+ 2007*)



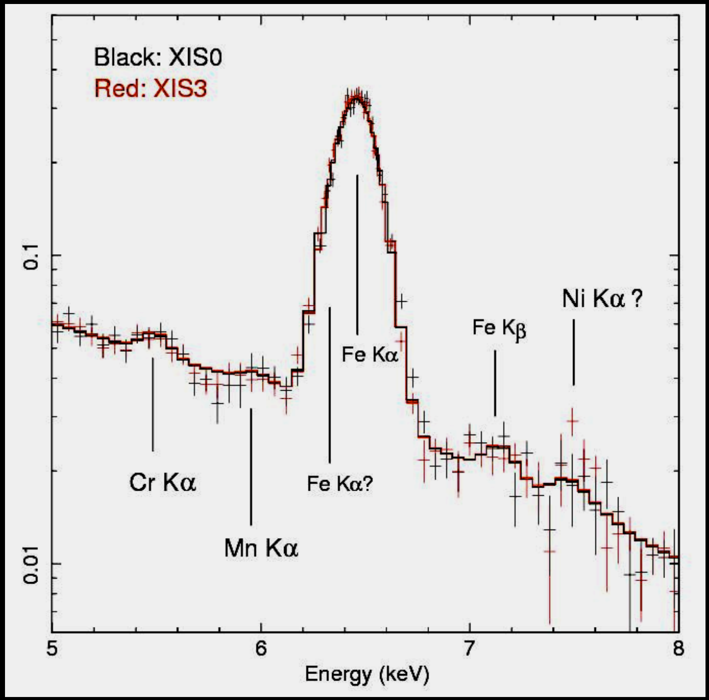
Red: 0.3-1.72 keV
Green: 0.72-1.7 keV
Blue: 1.7-8 keV

- SN 1604, Type Ia:
  Fe-rich ejecta, No O-rich ejecta
  Balmer-dominated shocks
  No central point source
- Shock-CSM interaction (e.g., *Dennefeld 1982; Reynolds+ 2007*):
  Wind-modified CSM due to progenitor (or companion) star ?
- High z ~ 500 pc, a runaway massive progenitor?

→ Unique opportunity to study nature of the progenitor with both metallicity and CSM structure!

Kepler: Initial Suzaku Results

Suzaku observation
(100 ks, AO2)

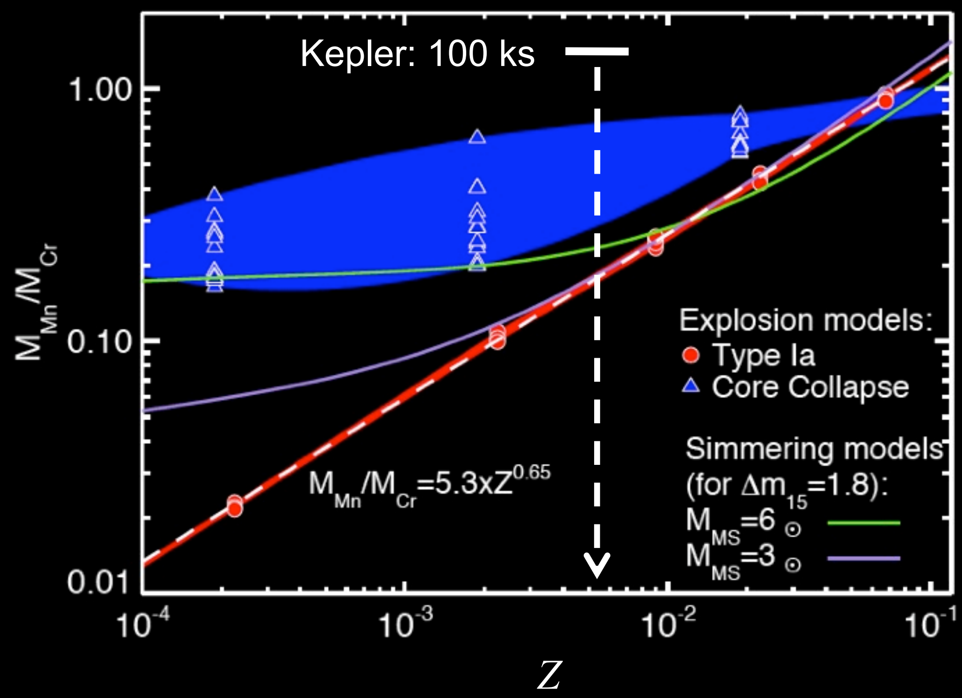


- Mn & Cr lines are detected:
  cf. It is unclear with Chandra 750 ks.
  → Suzaku XIS is uniquely efficient !
  But faint. Large statistical uncertainties.

- Due to the bright emission of Kepler, source-free regions on the same XIS are not fully reliable to estimate the background. Thus, we tested Mn and Cr line flux measurements with several background spectra.
  → Large systematic uncertainties.

Kepler: Initial Suzaku Results

$M_{Mn} / M_{Cr} < 1.5$.
Metallicity (Z) is not constrained because of poor photon statistics & systematic uncertainties in the background estimates.



Suzaku Key Project of Kepler

- The initial results are limited by poor photon statistics and uncertain background estimates => Both of a deep exposure of Kepler and a background pointing are essential to constrain the metallicity of progenitor.

- ***Suzaku*** **Key Project (AO4-5):**

620 ks source + 240 ks background observations were performed in 9/2009 – 4/2011: to minimize both statistical (due to poor photon statistics) and systematic (due to background characterization) uncertainties.

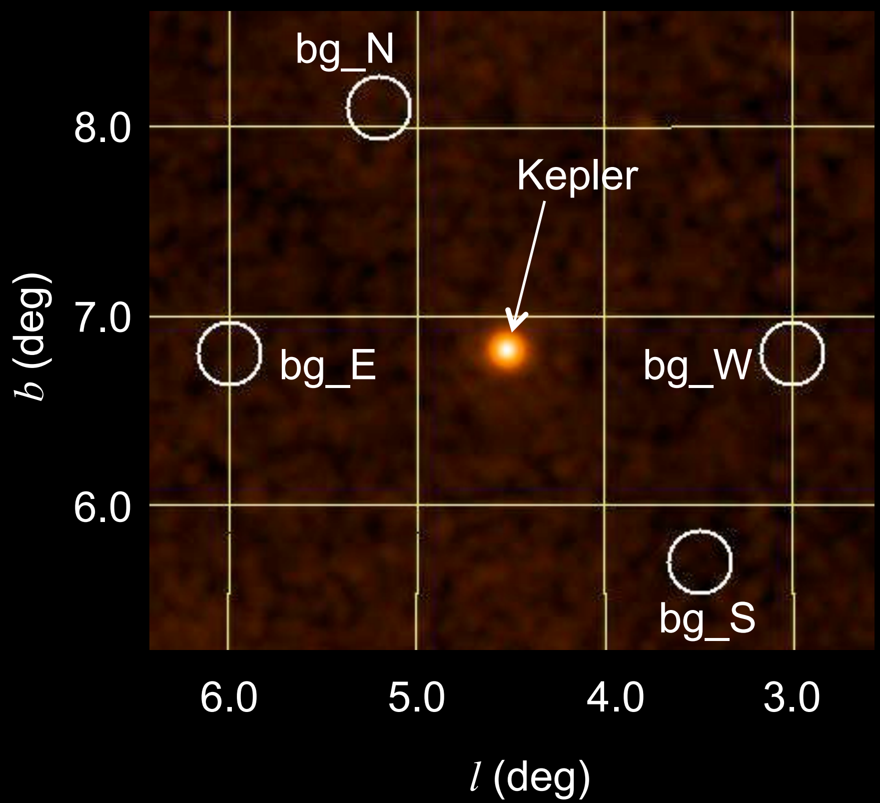
The goal was to place a tight constraint on $M_{\mathrm{Mn}} / M_{\mathrm{Cr}}$ ratio, thus on the progenitor metallicity (Z) within a factor of ~2 to distinguish solar vs supersolar abundances.

Suzaku Key Project of Kepler

- Four background pointings of nearby source-free regions within ~1.5º of Kepler were performed:

	l, b (deg)	Exp (ks)	Date
bg_N	5.2 8.1	60	2009-10
bg_S	3.5 5.7	60	2009-10
bg_E	6.0 6.8	50	2009-9
bg_W	3.0 6.8	50	2009-9

ROSAT Image of Kepler Region



Kepler KP Results: Preliminary

f_{Mn} = 4.99 ± 1.15 x 10^{-6} ph cm^{-2} s^{-1} (2σ)

f_{Cr} = 8.31 ± 1.20 x 10^{-6} ph cm^{-2} s^{-1}

[Also, Ni Kα (E = 7.53 keV, ~12σ) and Fe Kβ (E = 7.12 keV, ~16σ) lines are detected.]

M_{Mn} / M_{Cr} = 1.057 (f_{Mn} / f_{Cr}) / (ε_{Mn} / ε_{Cr})

= 0.92 $^{+0.55}_{-0.36}$

(where $\varepsilon_{Mn}/\varepsilon_{Cr}$ = 0.69 ± 0.14, for kT ~ 5 keV)

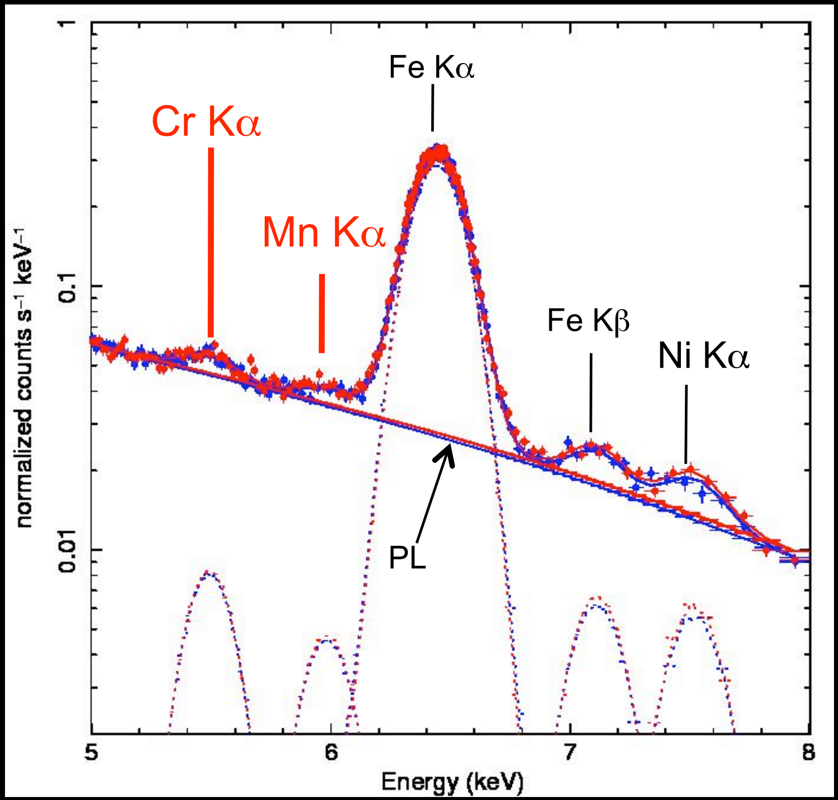
M_{Mn} / M_{Cr} = 5.3 $Z^{0.65}$ (*Badenes+ 2008*)

⇒ Z = 0.068

With $Z_\odot$ = 0.017 (*Anders & Grevesse 1989*),

=> **$Z/Z_\odot$ = 4.0 $^{+4.2}_{-2.1}$**

XIS (0,3) Spectrum of Kepler with a total of 692 ks exposure

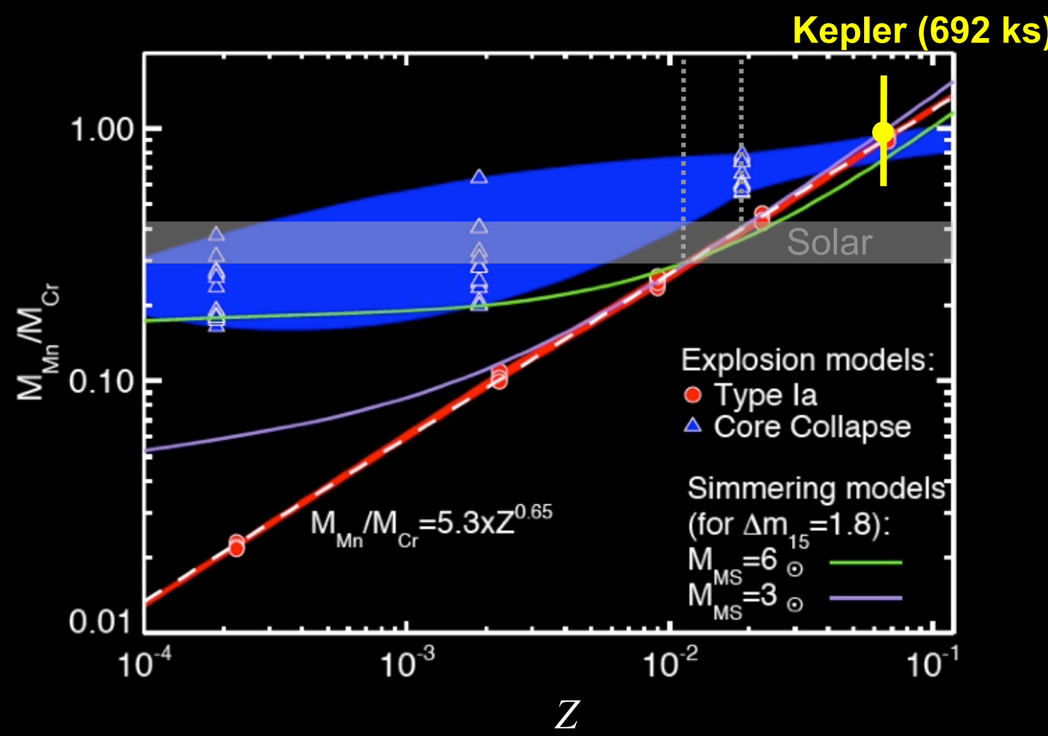


Kepler KP Results: Preliminary

M_{Mn}/M_{Cr} ratio in Kepler reveals a significantly overabundant $Z/Z_{\odot}$ **~ 4**.

→ This high metallicity of the progenitor supports a young, prompt SN Ia for Kepler.

("C-simmering" unlikely affects Kepler because it was a high-Z star with no evidence of sub-luminous SN.)



More to come: Test with other spectral models (measuring T, abundances etc)
Implications by Fe and Ni
Better constraint on ion emissivity?
Comparison with update from Tycho (400 ks XIS):
→ $Z_{Kepler} > Z_{Tycho}$?
→ Different or same population(s)?