# Nebular Phase NIR Spectroscopy of SNe Ia

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CSP Team Meeting

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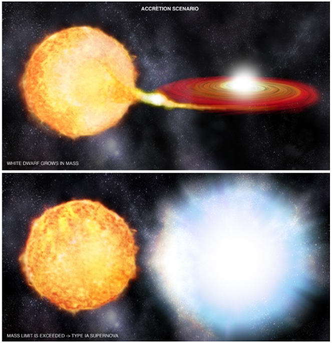
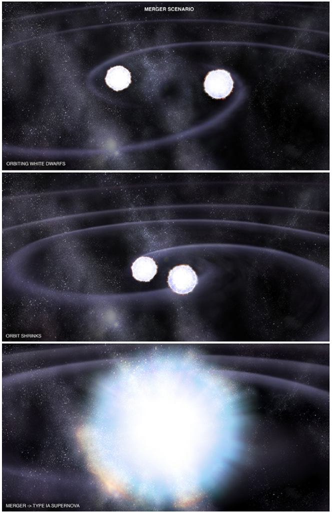
# SNe Ia Progenitor Systems and Explosion Scenarios

## Accretion to a $M_{Ch}$ Explosion




Chandra Media Telecon Feb. 17, 2010
(artist interpretation)

## Merger

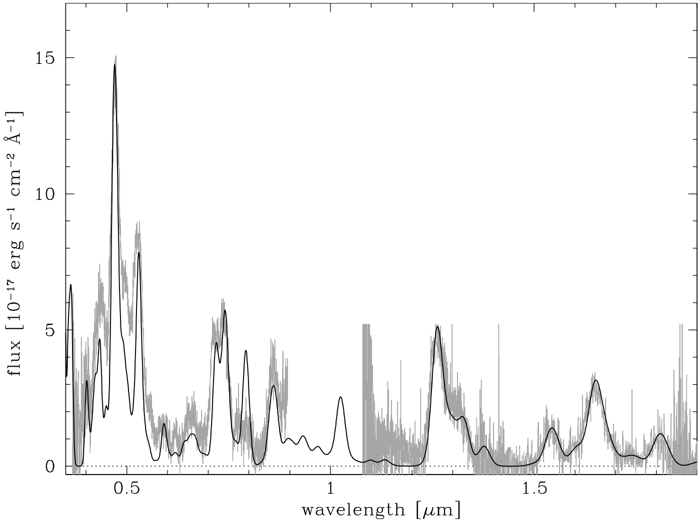


# Radioactive Decay and Products

$$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}$$

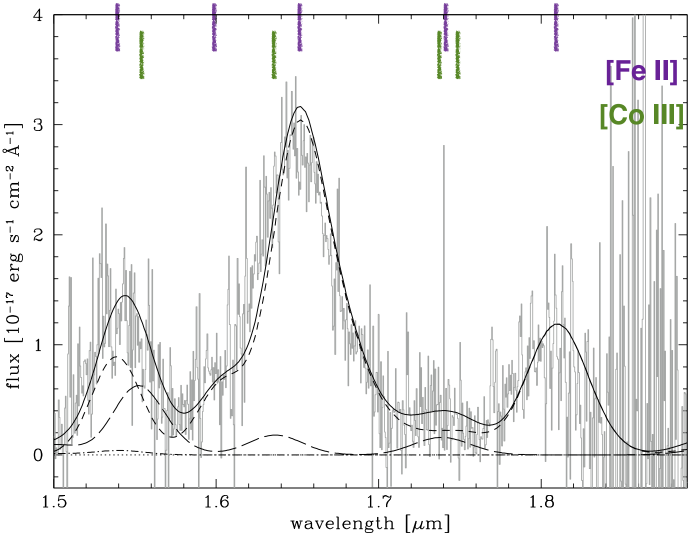
| | |
|---|---|
| $^{56}\mathrm{Ni} \longrightarrow {}^{56}\mathrm{Co} + \gamma + \nu_e$ | $t_{1/2}({}^{56}\mathrm{Ni}) = 8.80\,\mathrm{days}$ |
| $^{56}\mathrm{Co} \longrightarrow {}^{56}\mathrm{Fe} + \gamma + \nu_e$<br>$^{56}\mathrm{Co} \longrightarrow {}^{56}\mathrm{Fe} + e^+ + \gamma + \nu_e$ | $t_{1/2}({}^{56}\mathrm{Co}) = 77.12\,\mathrm{days}$ |
| $e^+ + e^- \longrightarrow \text{p-Ps} \longrightarrow 2\gamma$<br>$e^+ + e^- \longrightarrow \text{o-Ps} \longrightarrow 3\gamma$ | $t_{1/2}(\text{p-Ps}) = 125\,\mathrm{ps}$<br>$t_{1/2}(\text{o-Ps}) = 142\,\mathrm{ns}$ |

# Late-Time Optical and NIR Spectra




Spyromilio et al. 2004

# Late-Time Optical and NIR Spectra




Spyromilio et al. 2004

# Comparison with Models by P. Hoeflich

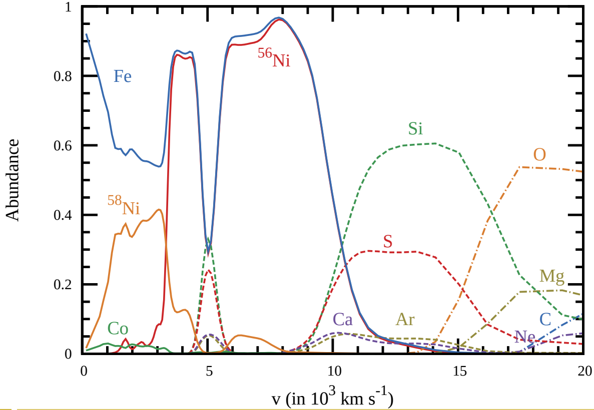
- used previously for normal bright and subluminous SNe Ia
- spherically symmetric DDT models
- free parameters
  - progenitor system conditions
    - $\rho_c$ – based on accretion history and material
    - $M_{\mathrm{MS}}$ and $Z$ – WD structure
  - explosion conditions
    - $\rho_{\mathrm{tr}}$ – extent of $^{56}$Ni production

Reference Model used with SN 2005df:
"7p0z22..."

$\rho_c$ is varied from $0.5 - 4.0 \times 10^9\,\mathrm{g\,cm^{-3}}$
$M_{\mathrm{MS}} = 7\,\mathrm{M_{\odot}}$
solar metallically
$\rho_{\mathrm{tr}} \approx 2.7 \times 10^7\,\mathrm{g\,cm^{-3}}$

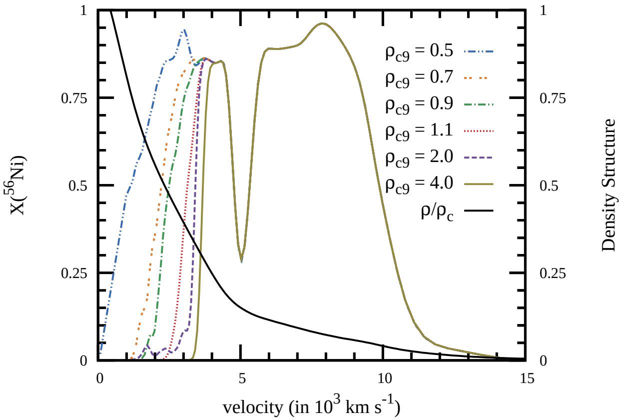
# The Chemical Distribution in the Ejecta

| Isotopes | Process | Temperature (in $10^9$ K) | Density (in g cm$^{-3}$) |
|---|---|---|---|
| $^{58}$Ni/$^{54}$Fe/$^{57}$Co | electron capture | $> 5$ | $10^9$ |
| $^{56}$Ni | explosive Si-burning | $> 5$ | $2 \times 10^7$ |
| Si/S | explosive O-burning | $> 3$ | $> 4 \times 10^6$ |
| Ne/Mg/O | explosive C-burning | $> 1$ | $> 10^6$ |
| C/O | unburned material | $< 0.5$ | $< 10^6$ |

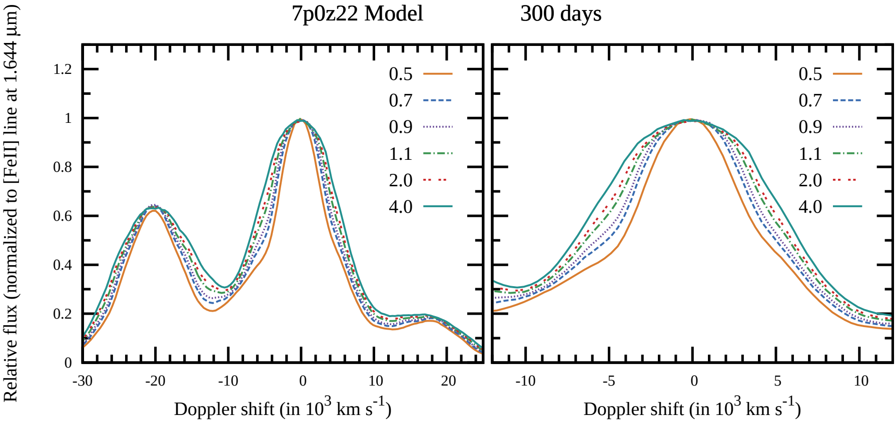


# The $^{56}$Ni Abundance Depends on $\rho_c$

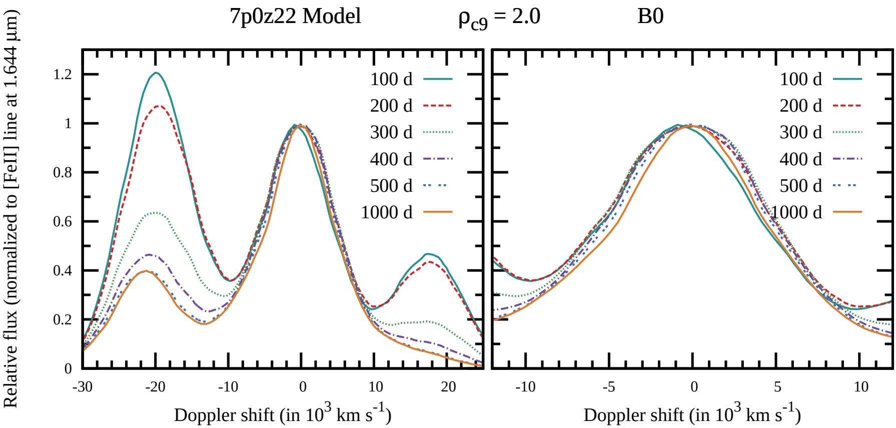
These models have been created so that they have nearly identical outer layers of $^{56}$Ni! The abundances in the inner region is increasingly affected by electron capture as $\rho_c$ increases.



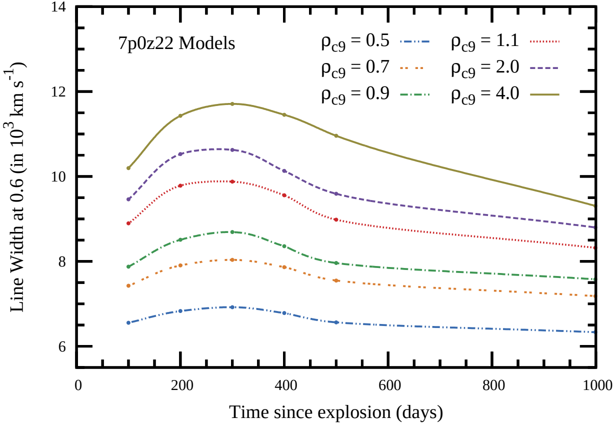
# The Effect of $\rho_c$ on the Line Profile



# The Evolution of the 1.644 $\mu$m Line Profile



# Observable: Line Width of the 1.644 $\mu m$ Emission Line




Our method gives a lower limit!

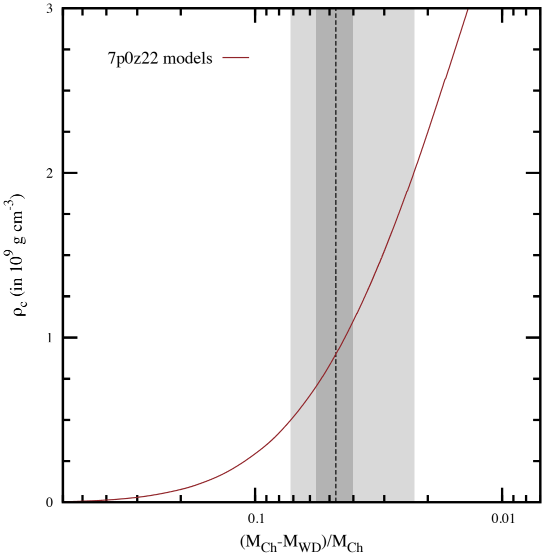
Mixing or continuum oversubtraction will mimic a narrower line and, therefore, lower $\rho_c$ and $M_{\rm WD}$.

# The $M_{\rm WD}$ and $\rho_c$ Relationship for $\rm M_{Ch}$ Models

best fit:
$\rho_c = 0.9 \times 10^9\,\rm g\,cm^{-3}$
$\rightarrow M_{\rm WD} = 1.31\,\rm M_\odot$

$1\sigma$ ($\rho_{c9} = 0.7 - 1.1$)
$\rightarrow M_{\rm WD} = 1.30 - 1.32\,\rm M_\odot$

$2\sigma$ ($\rho_{c9} = 0.5 - 2.0$)
$\rightarrow M_{\rm WD} = 1.28 - 1.35\,\rm M_\odot$



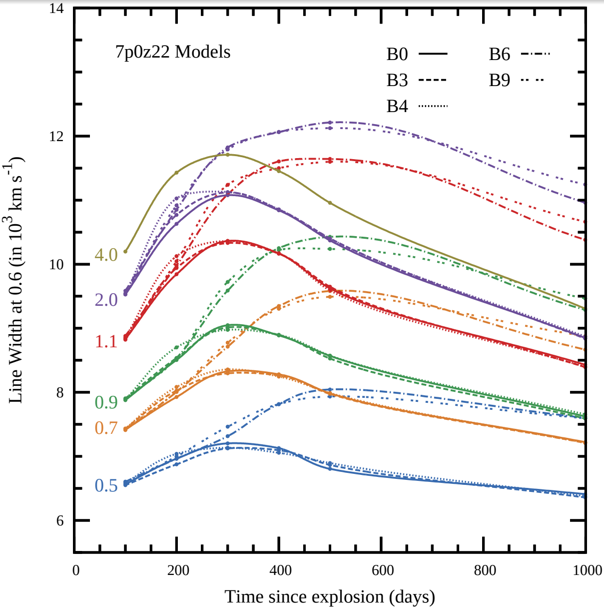
# The Effect of $B$ Fields in the Expanding Ejecta

Most current SNe Ia models completely ignore magnetic fields during the explosion and for radiation transport.

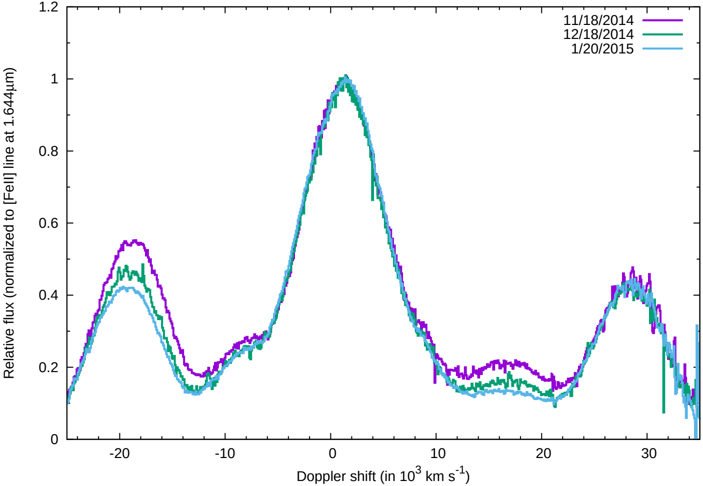
- $B$ fields might be the key to suppressing hydro-instabilities!
  - not important when $\gamma$-photons dominate ($< 100\,\mathrm{days}$)
  - become important when positrons dominate ($200 + \mathrm{days}$)
- evolution of the line profile will be affected by:
  - $B$ field strength
  - morphology
  - size scale

    $\longrightarrow$ shed light on origins

# The Effect of a Turbulent $B$ Field



# Late-Time SN 2014J Spectra




Look at that S/N!

# Questions?