Models for SUPERNOVAE Ia: True and Apparent Diversity

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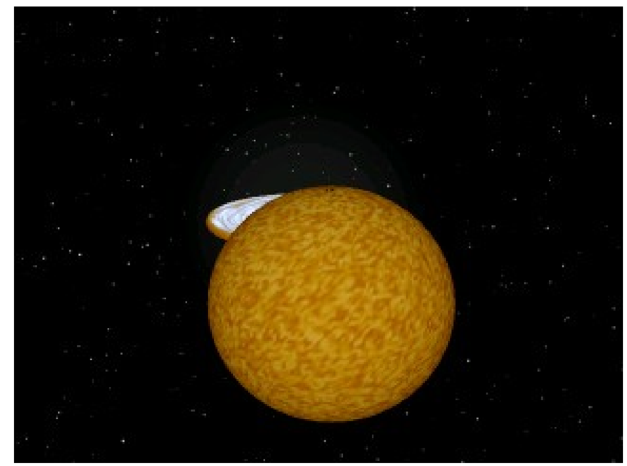
VLT: Baade,Justin,Patat(ESO &Co), Wang(TAM),Wheeler(UT), …
PLUS: Gerardy (FSU), Quimby (CT), ...

I) Introduction

- SNe Ia appear homogeneous
- SNe Ia appear almost spherical
- SNe Ia are useful for cosmology



R.Hines

II) SNe Ia are Diverse & 3-D by Nature

- nuclear burning fronts
- progenitors (MS masses, rotation, ...)
- progenitor systems (accretion disks, separation …)
- different classes of SNeIa

=> SNe Ia are a threat to cosmology

Cooking of a Supernova

A) Stellar evolution of a low mass star (M< 7Mo, 1E9 years) + mass-loss

=> initial structure of the WD

Method: Spherical stellar evolution code (Chieffi, Limongi & Straniero 1998, ApJ 502, 737)

B) **Quasi-static evolution of the progenitor (1E6...8 yrs) + accretion**

=> initial structure of the WD at the time of the explosion (SS-X-ray sources)

Method: Spherical accretion code (H et al. 2000, 528, 590)

C) **The thermonuclear runaway (few hours)**

=> preconditioning of the explosive phase   Method: B) or 2D-hydro code (H & Stein, 2001, ApJ)

D) **Hydrodynamical phase of explosion (1 to 60 sec)**

=> nucleosynthesis + release of explosion energy

Methods: Spherical rad. hydro including nuclear network (H et al. 2000, ApJ 528, 589 +refs.)

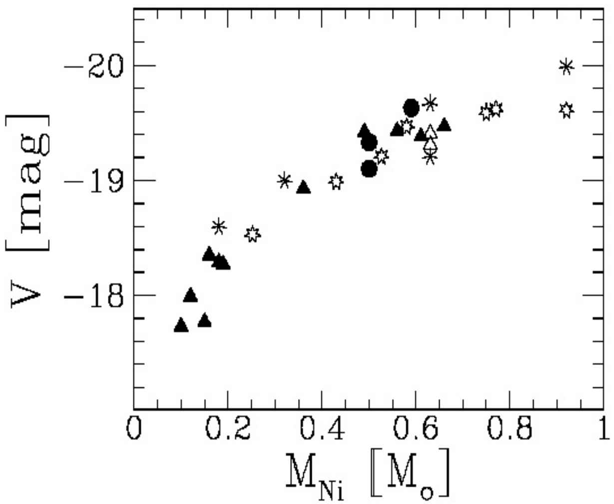
+ 3-D hydro for deflagration (Khokhlov 1998, J. Comp. Phys. 143, 519)

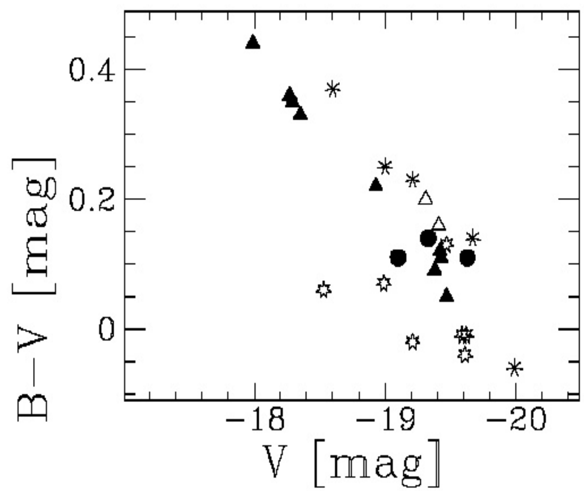
E) Flux and polarization spectra & LCs in 1-3D (month to years) => time evolution Of expanding envelopes

(Methods: D1)1 + NLTE/LTE occupation numbers (see D1), var-eddington factor in 1-3D (H 1995, 2001, 2009)

The Brightness Decline and Color Relations (H etal 96)

a) M(V) and B-V as a function of M(56Ni)



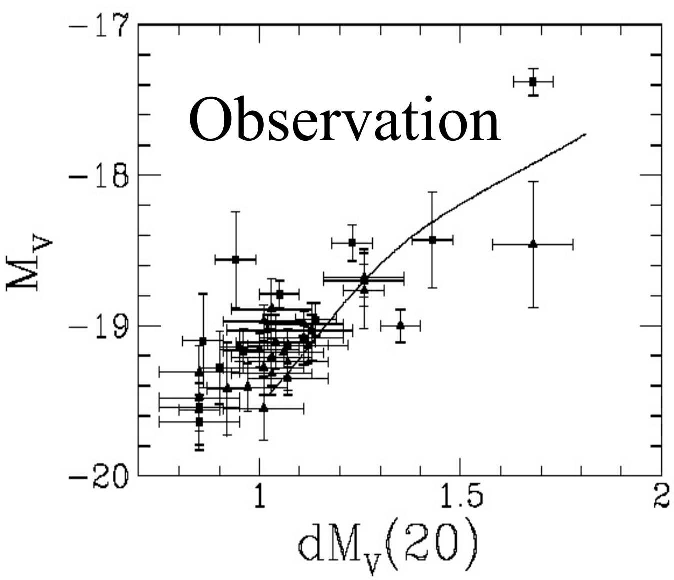


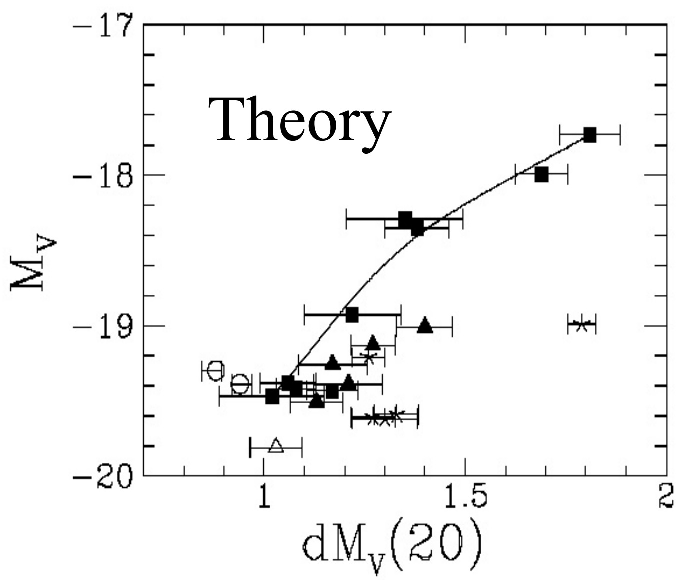
- SNeIa become dimmer & redder with decreasing M(56Ni)

Symbols are various scenarios Including DD, DF, DET, PDD, Mergers Star-> HeD

b) Maximum brightness decline relation M(V)=f(dM20) Hetal96

(black line corresponds to a change in rho(tr) for a specific PDD-model)





- **qualitative agreement but large spread**
- **most of SN scenarios give dm15 but with larger spread**

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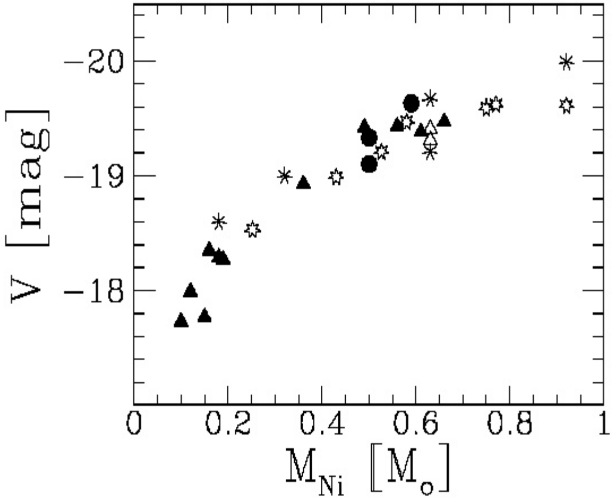

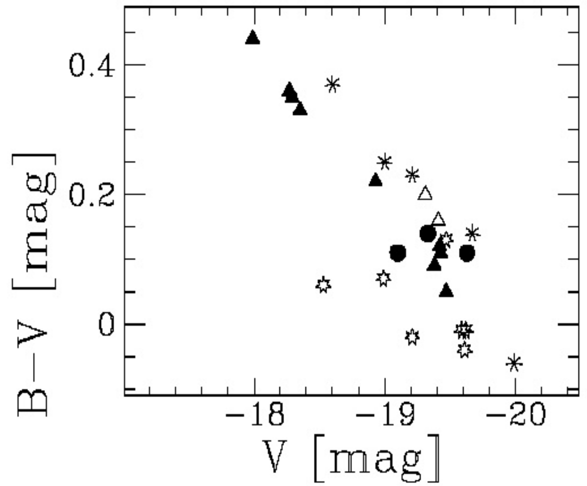

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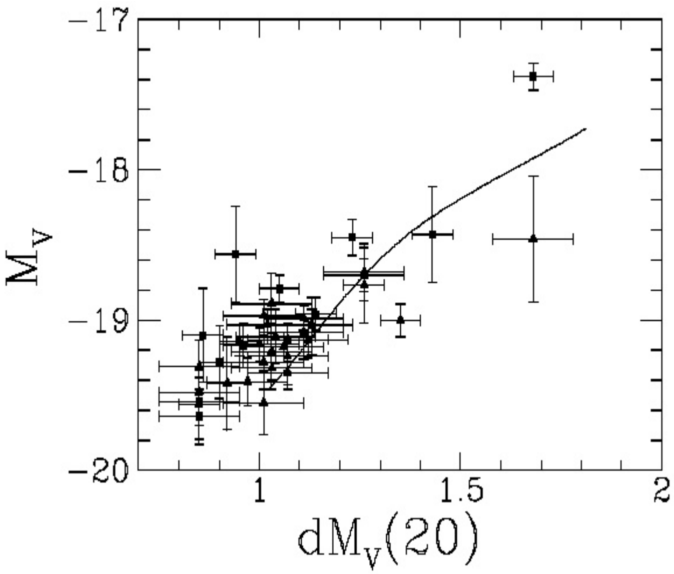

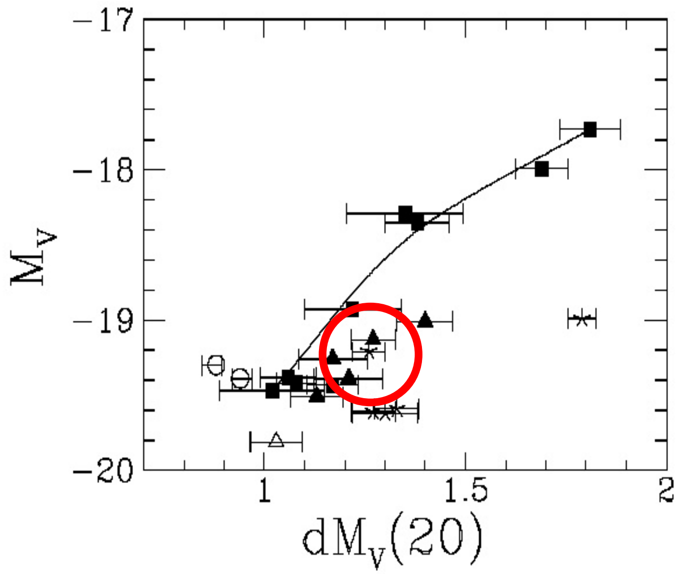

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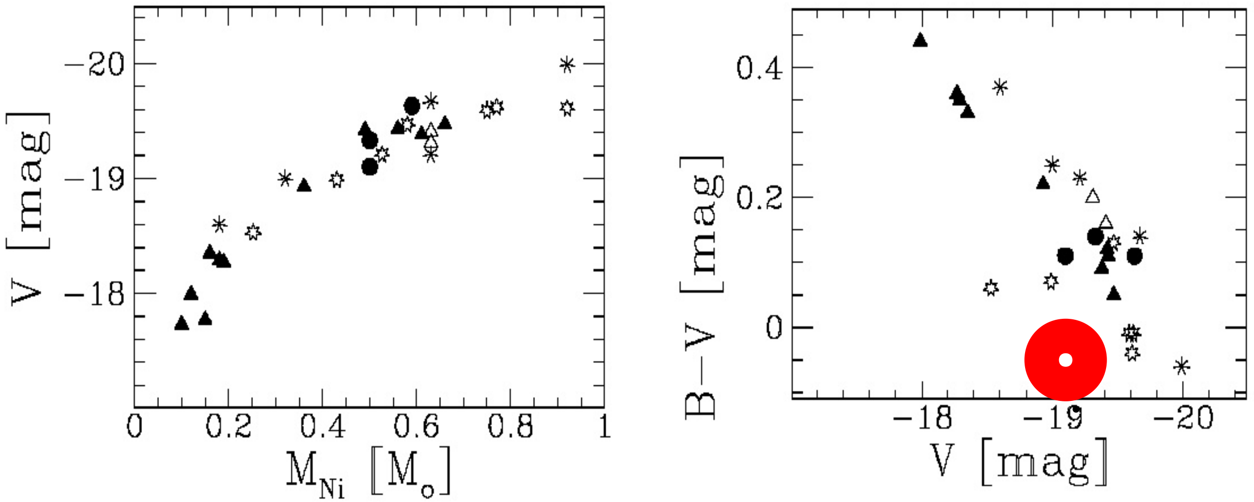

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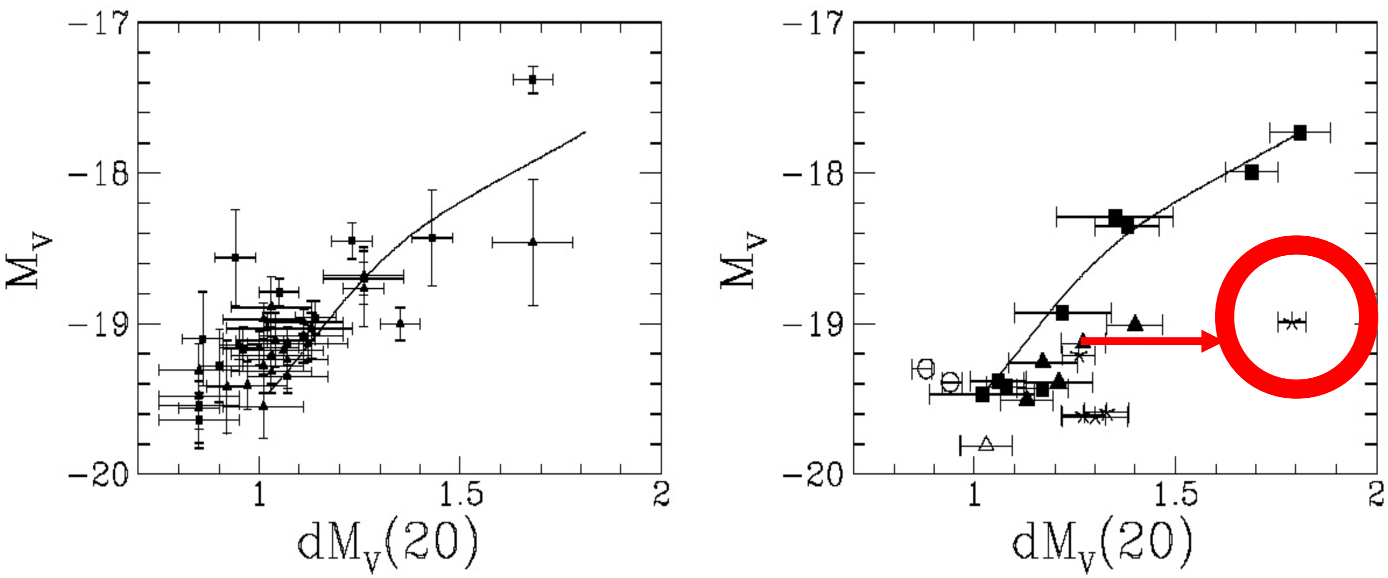
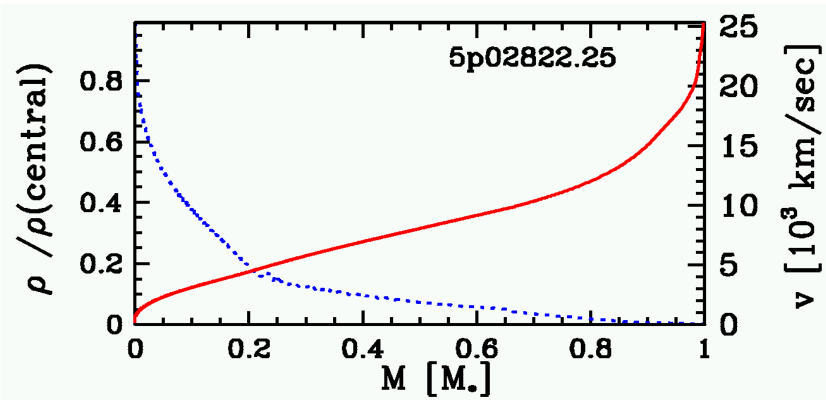


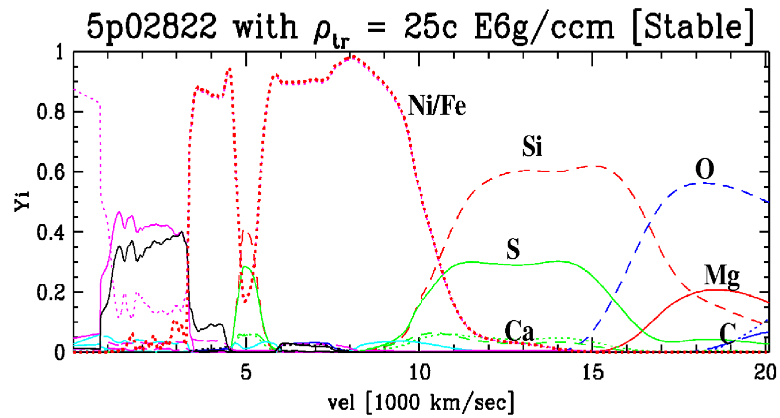
- qualitative agreement but large spread

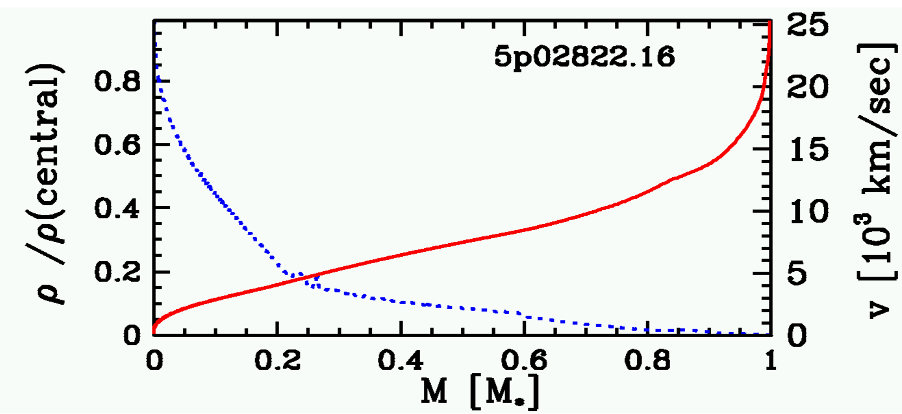
Trouble with mixing anti-correlation

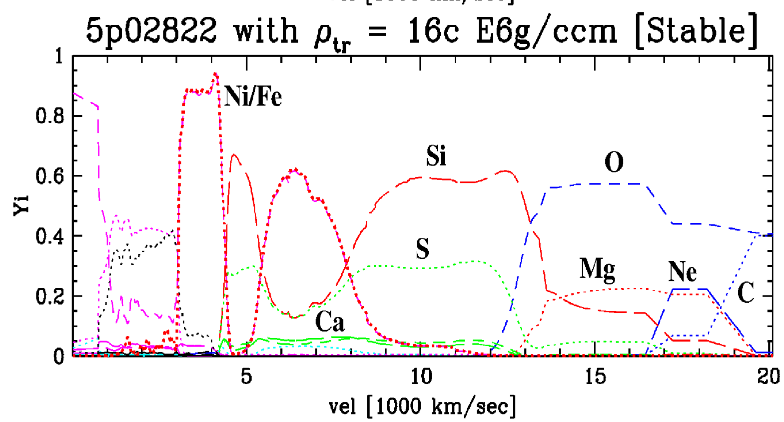
Delayed detonation models for various transition densities rho(tr)

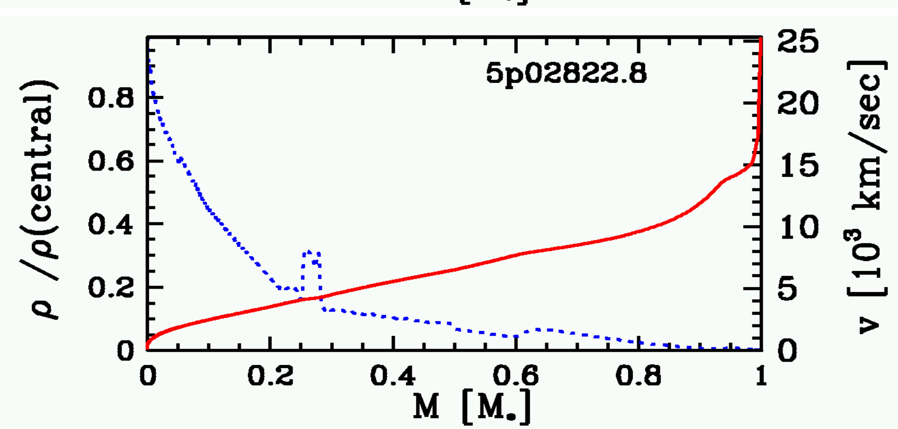
[M(MS)= 3 Mo; Z = 1.E-3 solar; rho(c)= 2E9 g/ccm with rho(tr)=8, 16, 25 g/ccm]

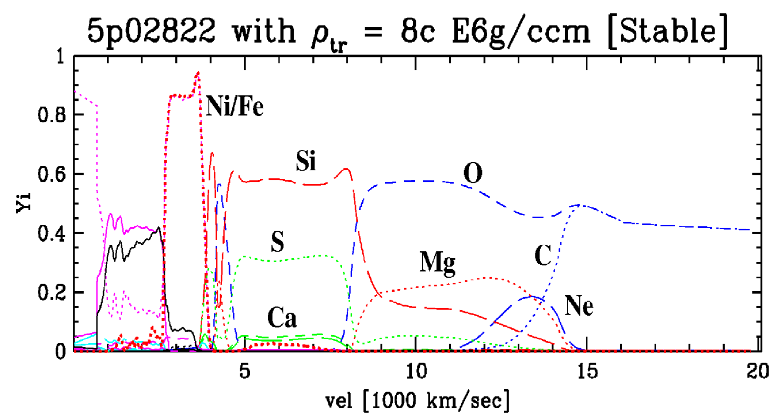




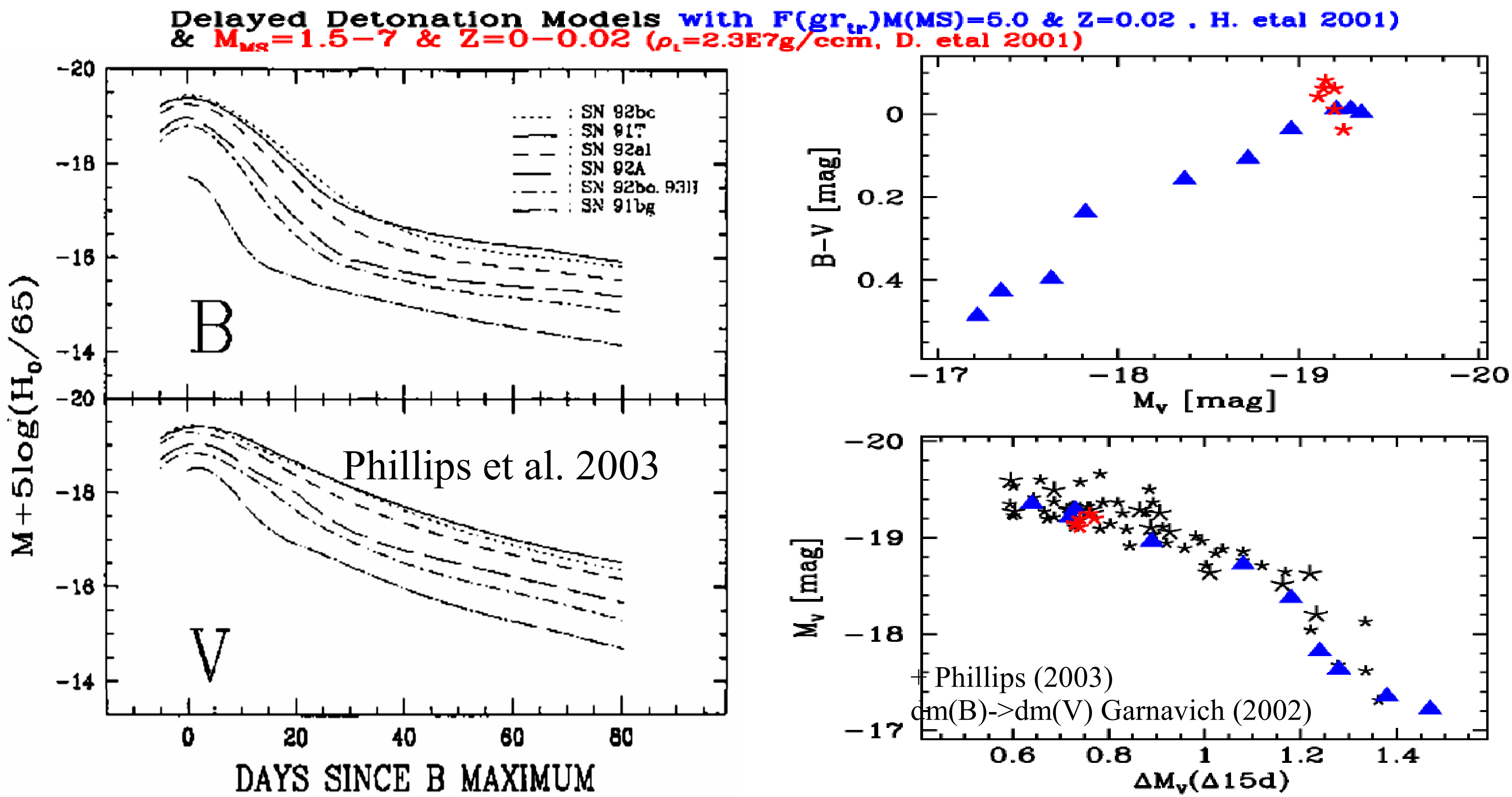








The Brightness-Decline Relation for DDTs

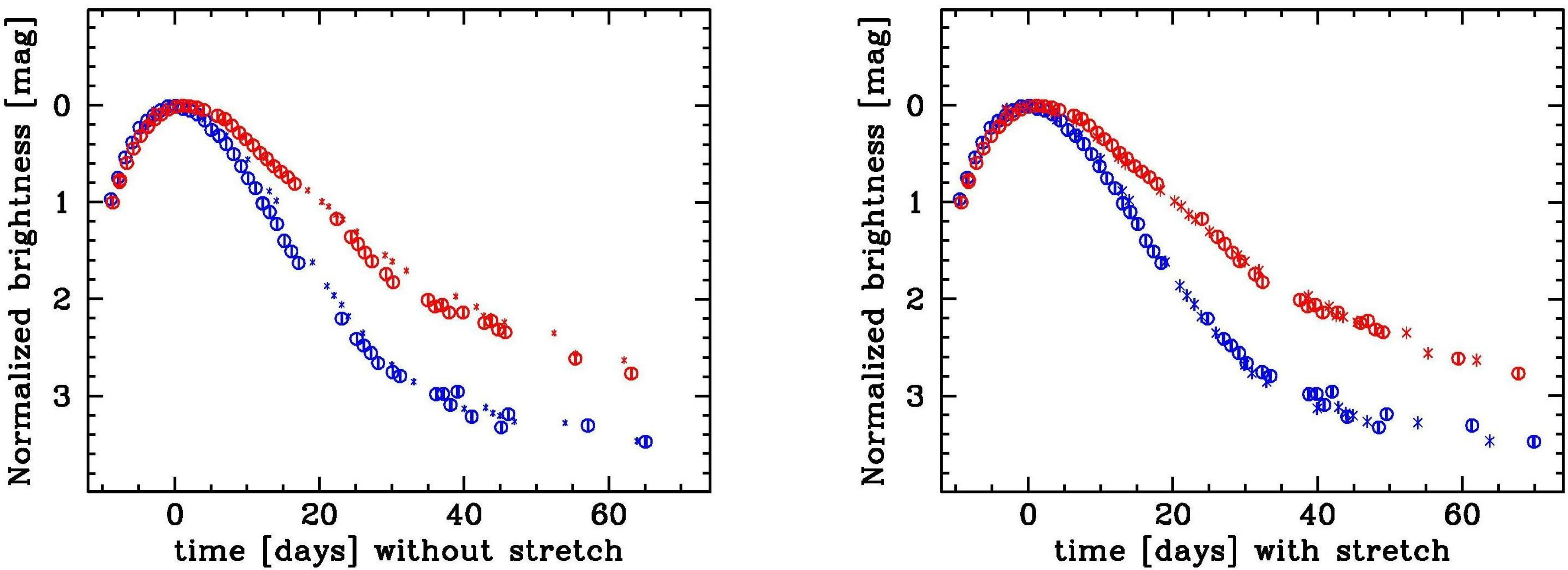


- **Generic: Brightness decline relation is an opacity effect** (Hoeflich etal 96,Mazzali et al. 2001)
- **Small spread requires similar explosion energies** *(±0.5mag for all scenarios H. et al. 96)*
- **Within DD models, relation can be understood as change of burning before DDT**

Differential Analysis, or Comparing 'Equals' by Construction

SN2005ef vs. SN2005el

(from CSP)

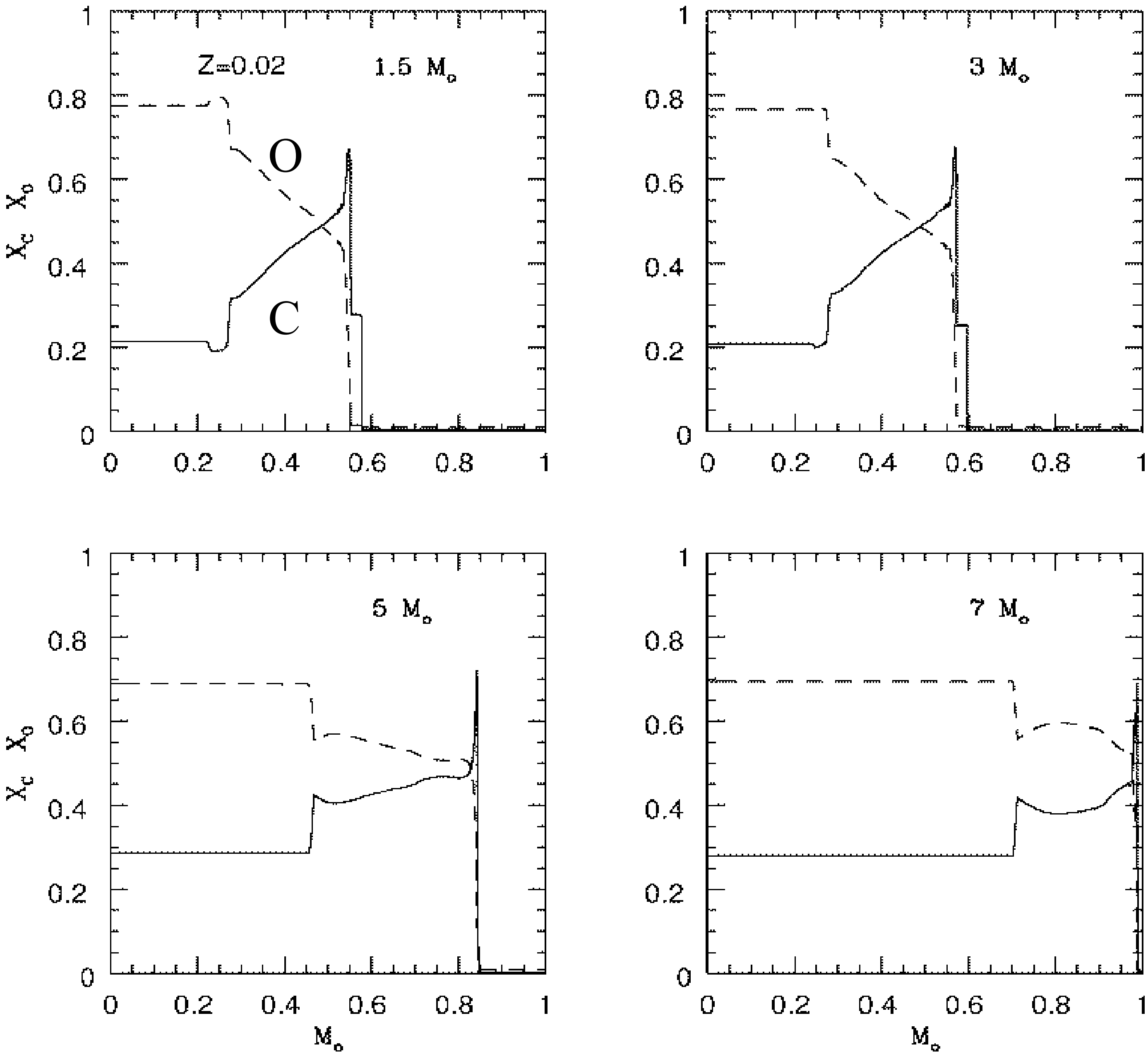


Without and with

normalization to the same brightness decline ratio

Influence of the MS mass and Z

(Dominguez, H, Straniero 2001, ApJ 557, 279)



- Size of C-depleted core depends on central He burning during the stellar evolution

=> f(MS)

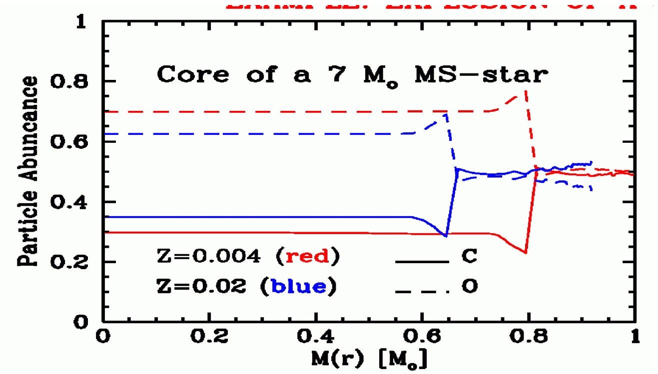
=> Explosion energy f(MS)

Progenitor Signatures on SNIa Light Curves

C/O profile of the WD

depends on MS mass
and metallicity of WD

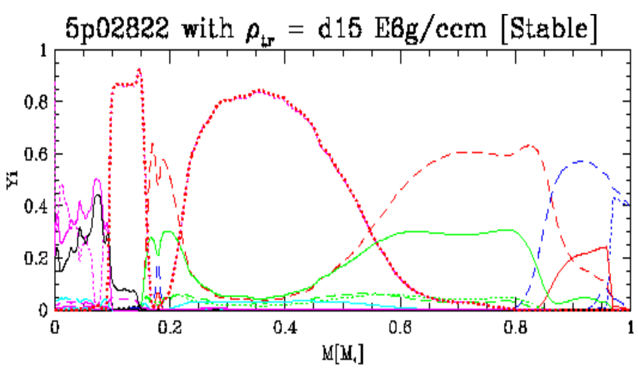
Theory (predicted)



Accretion Rate =>

Central density at explosion
changes electron capture

:1&6E9g/cm3



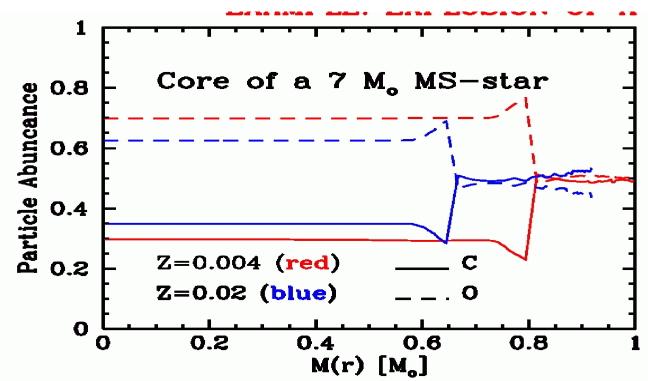
Progenitor Signatures on SNIa Light Curves

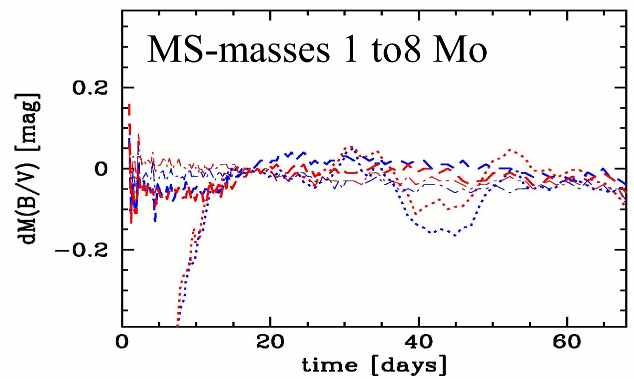
Differential change in B and V light-curves

Observations (CTIO)

C/O profile of the WD
depends on MS mass
and metallicity of WD

Theory (predicted)

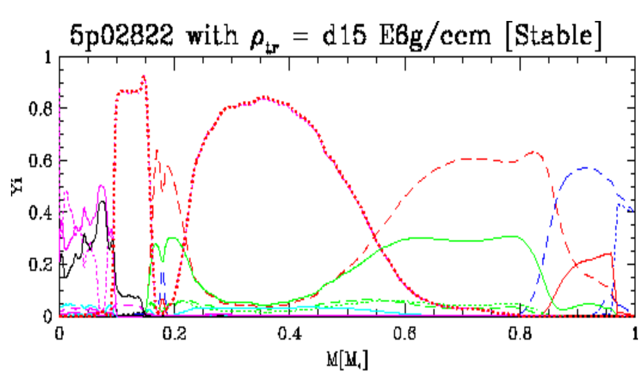


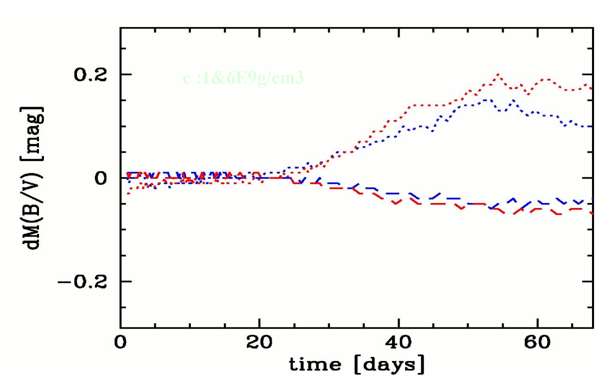


Accretion Rate =>

Central density at explosion
changes electron capture

rho





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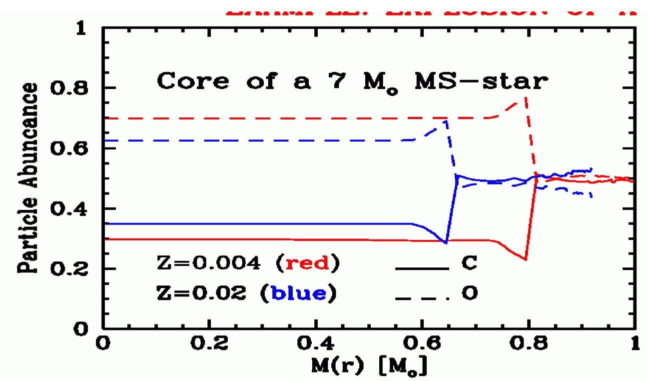

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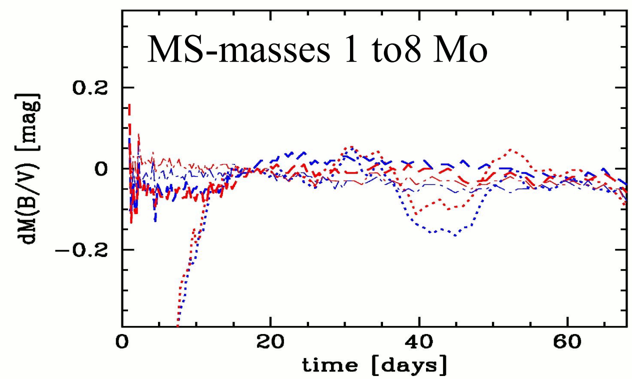
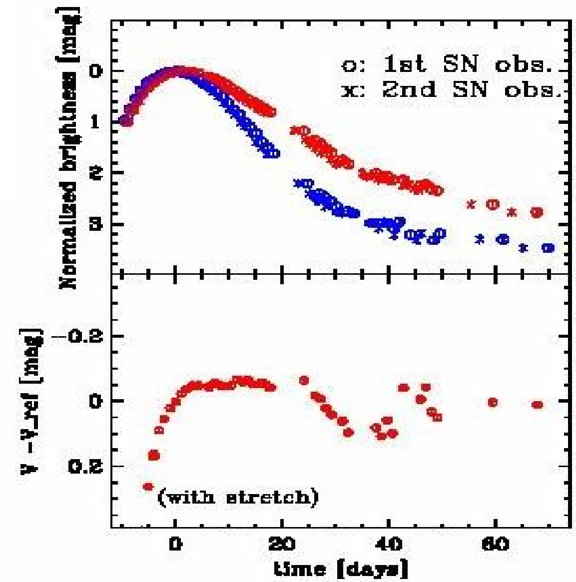


Observations (CSP)



Accretion Rate =>

Central density at explosion
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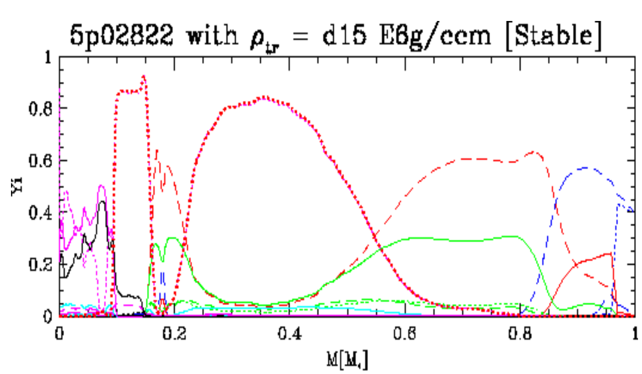
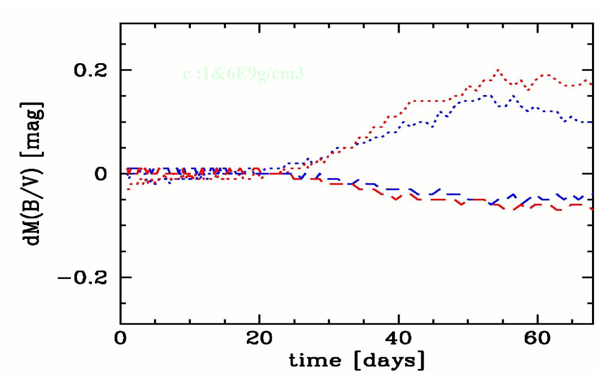
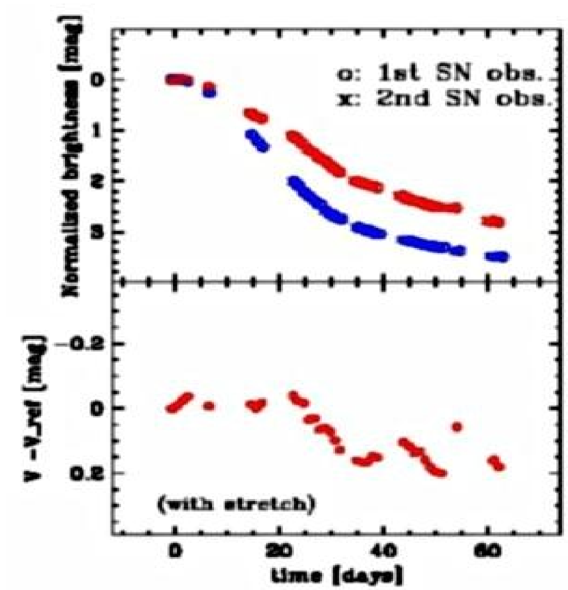
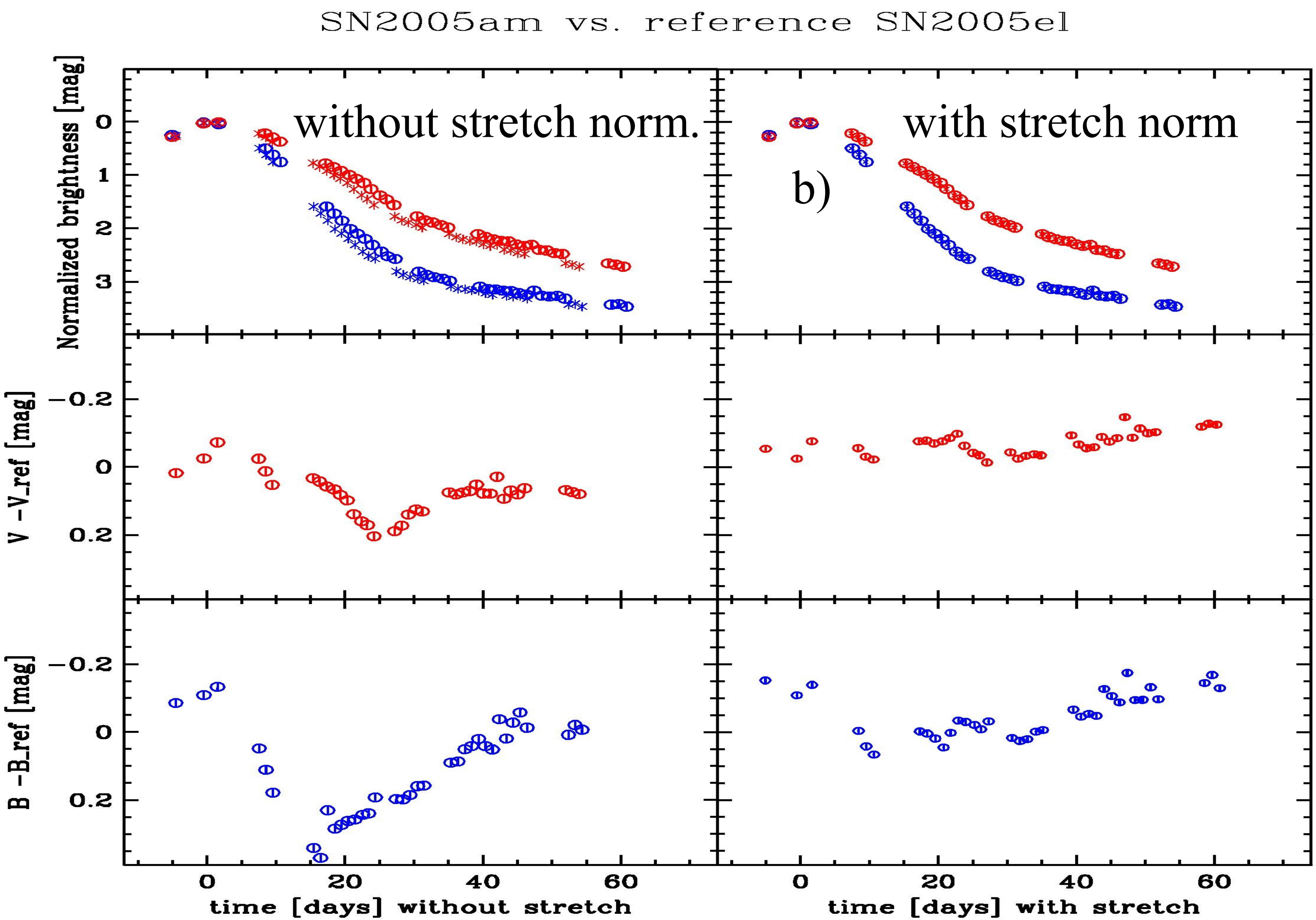


rho





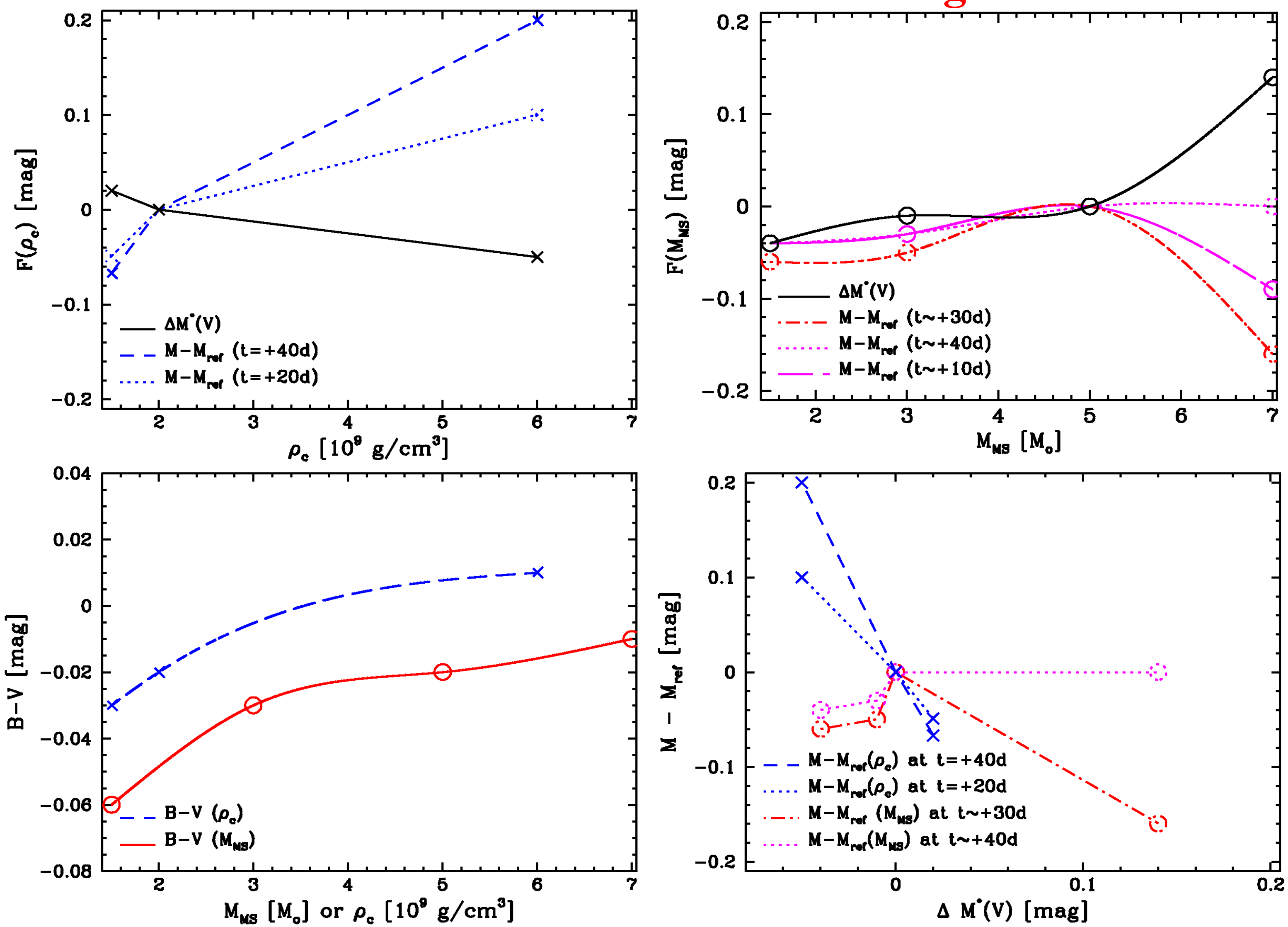
Two SN with different dm15 (1.23 &1.39)
(but similar progenitors and accretion)



Theoretical Relations of Model-Properties and Observables

Players: Peak/Tail ratios and Colors & Offset in Brightness

Blue: Accetion effects **Red: Progenitor Effect**



How to Probe the 3-D Nature?

I) Direct imaging

Problem: too far -> Remnants only -> Interaction with environment

II) Line Profiles

Problems: large velocity fields (10000 km/sec) -> line blending, unresolved

III) Polarization

Problems: $P \approx 0.1\ \%$; far away-> dim, object unresolved

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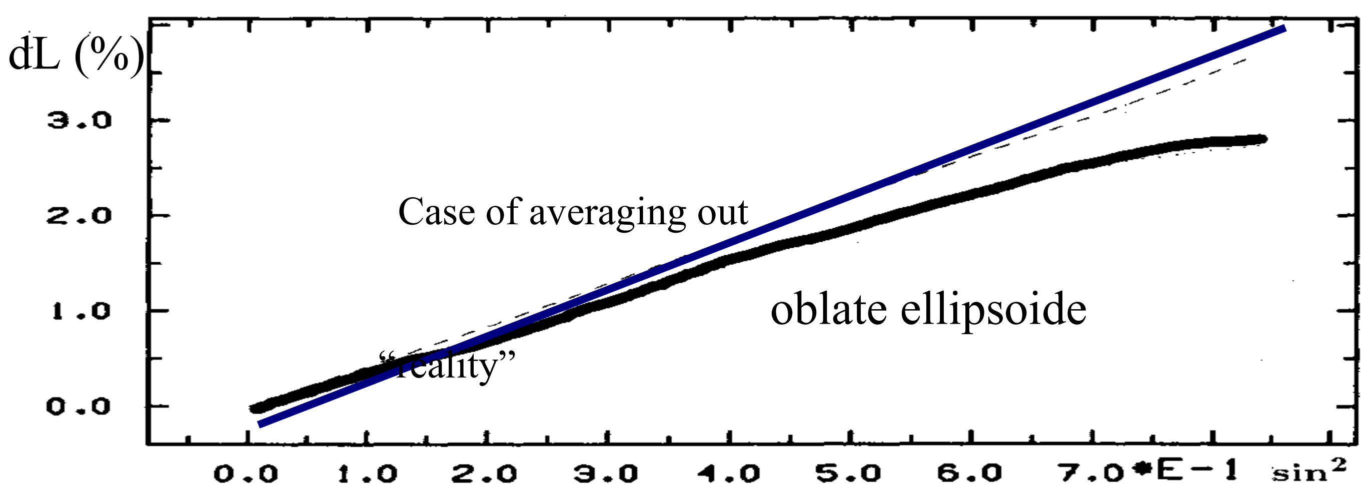
III) Polarization

Problems: P ≈ 0.1... 0.2 %; far away-> dim, object unresolved

Why care if you don't like Supernovae? Cosmology

Example: Scattering dominated atmosphere for SN of 10% asphericity (Hoeflich 1991)

P (Thomson) =0.1 % => 3 % directional dependence of luminosity

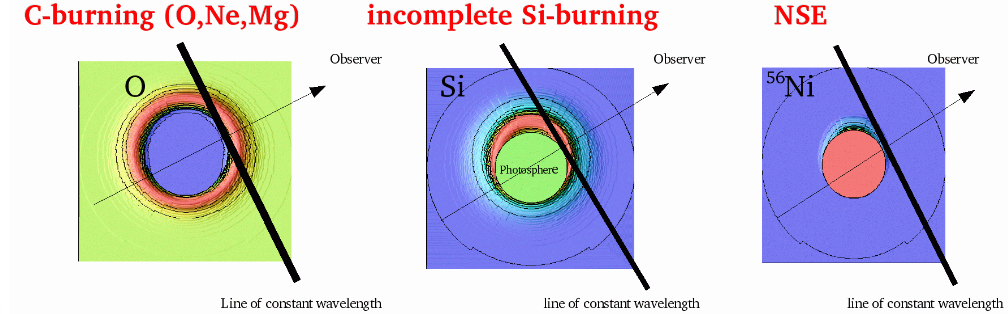


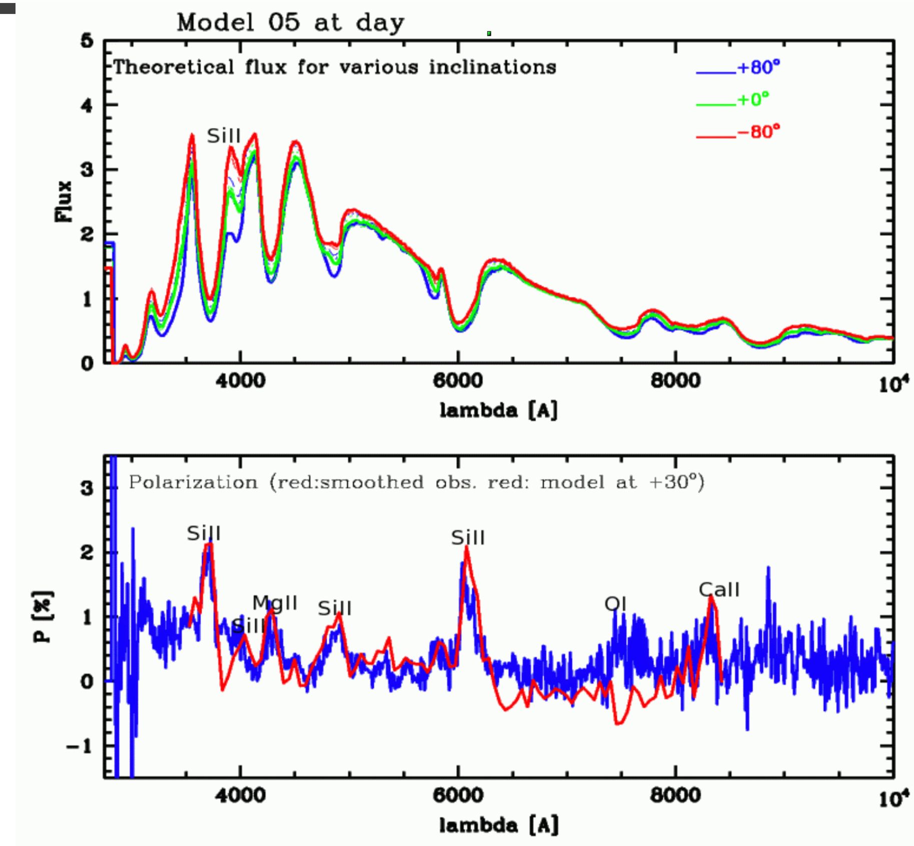
=> Systematic shift in averaged brightness for average over sample of SN

Θ

Polarization as Tool to Decipher the 3D Structure of Type Ia SNe

SN2004dt 12 days after the explosion with VLT
VLT vs. Model





Electromagnetic wave : $\psi(z,t) = Ee^{i(kz-\omega t)}$

$\underline{E} = (E_x, E_y)$

Intensity is defined as the time average over many waves

$I = I_0 + I_{90} = \overline{E_x\ E_x^* + E_y\ E_y^*} = \overline{E_x^2 + E_y^2}$

Degree of polarization P

$P = (I_0 - I_{90})/(I_0 + I_{90})$

with position angle χ

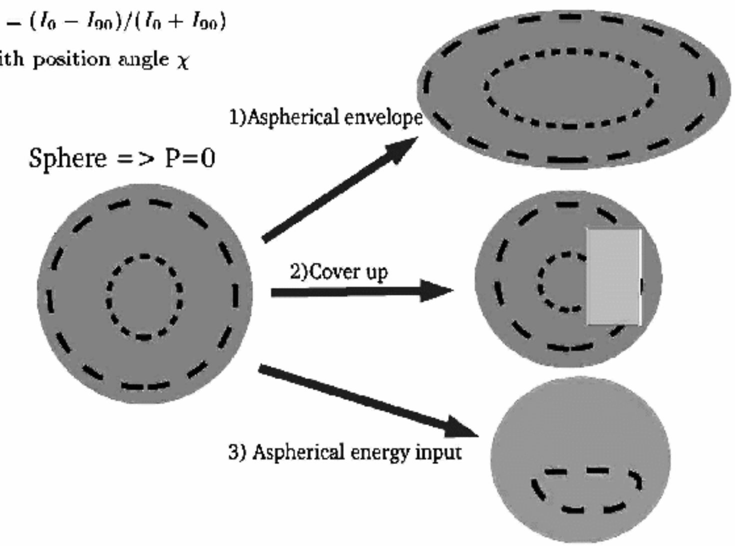
Stokes Parameter (equivalent)

$Q = I_0 - I_{90}$

$U = I_{45} - I_{-45}$

$V = 0$ for linear polarization

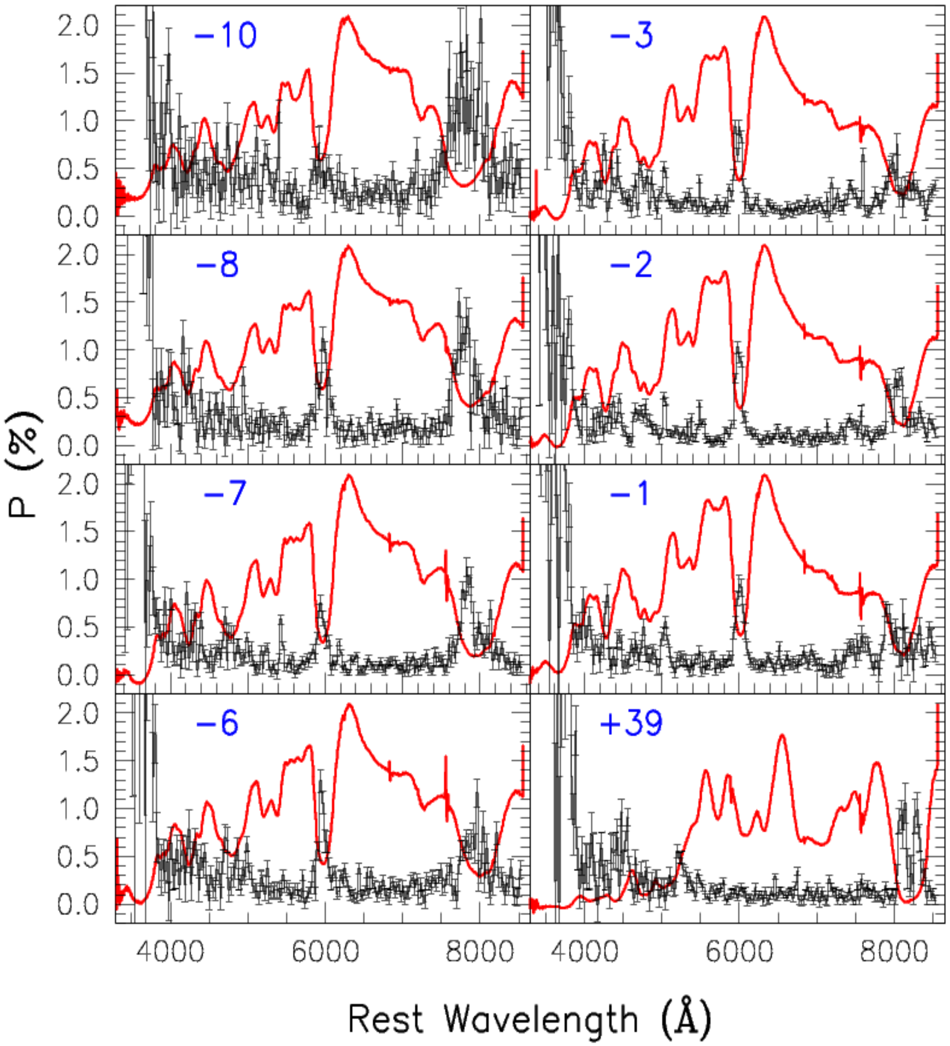
Rem.: $\tan 2\chi = U/Q$ and $P = \sqrt{Q^2 + U^2}$

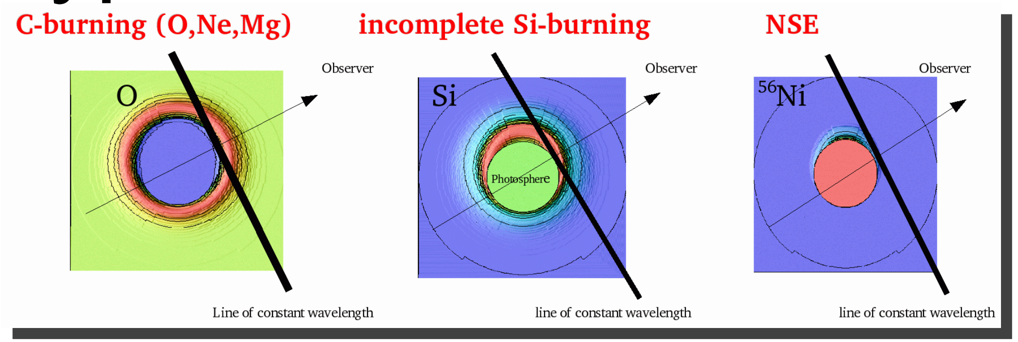


(Hoeflich, 1995)

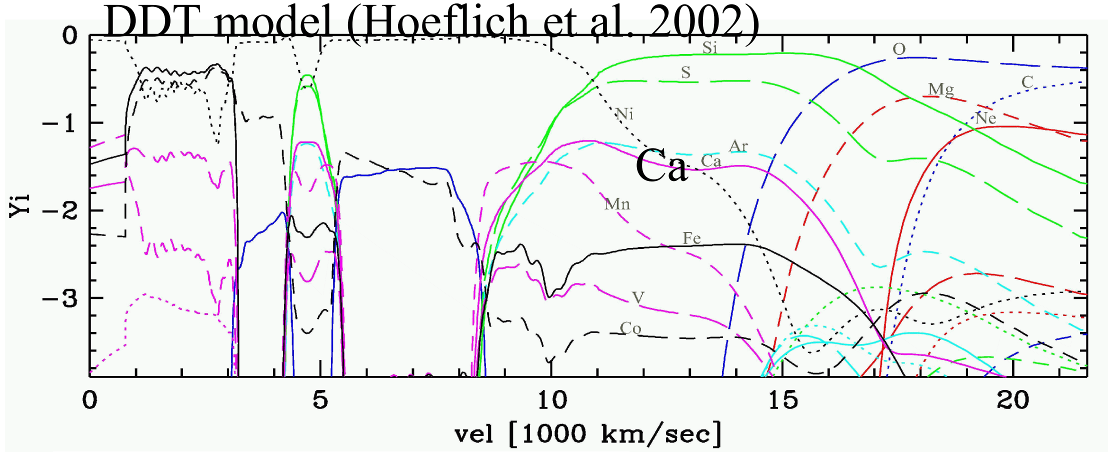
Polarization as Tool to Decipher the 3D Structure of Type Ia SNe

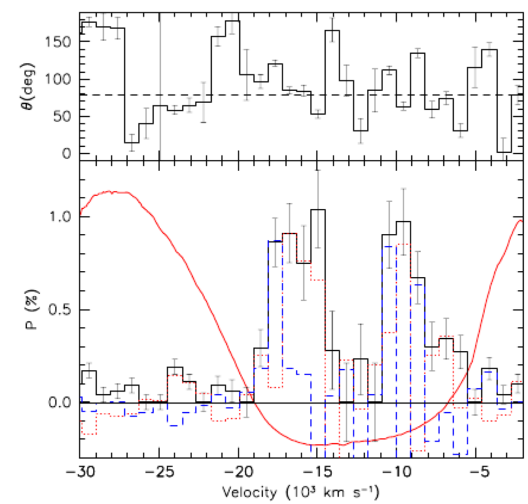
SN2006X (Patat et al.)
(times are relative to maximum)

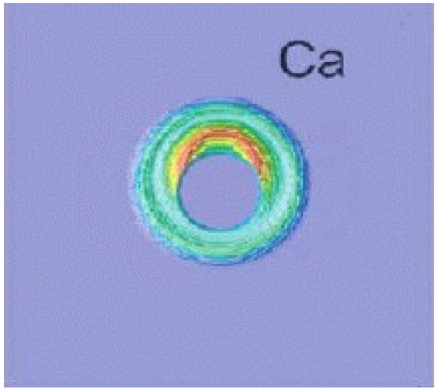




DDT model (Hoeflich et al. 2002)







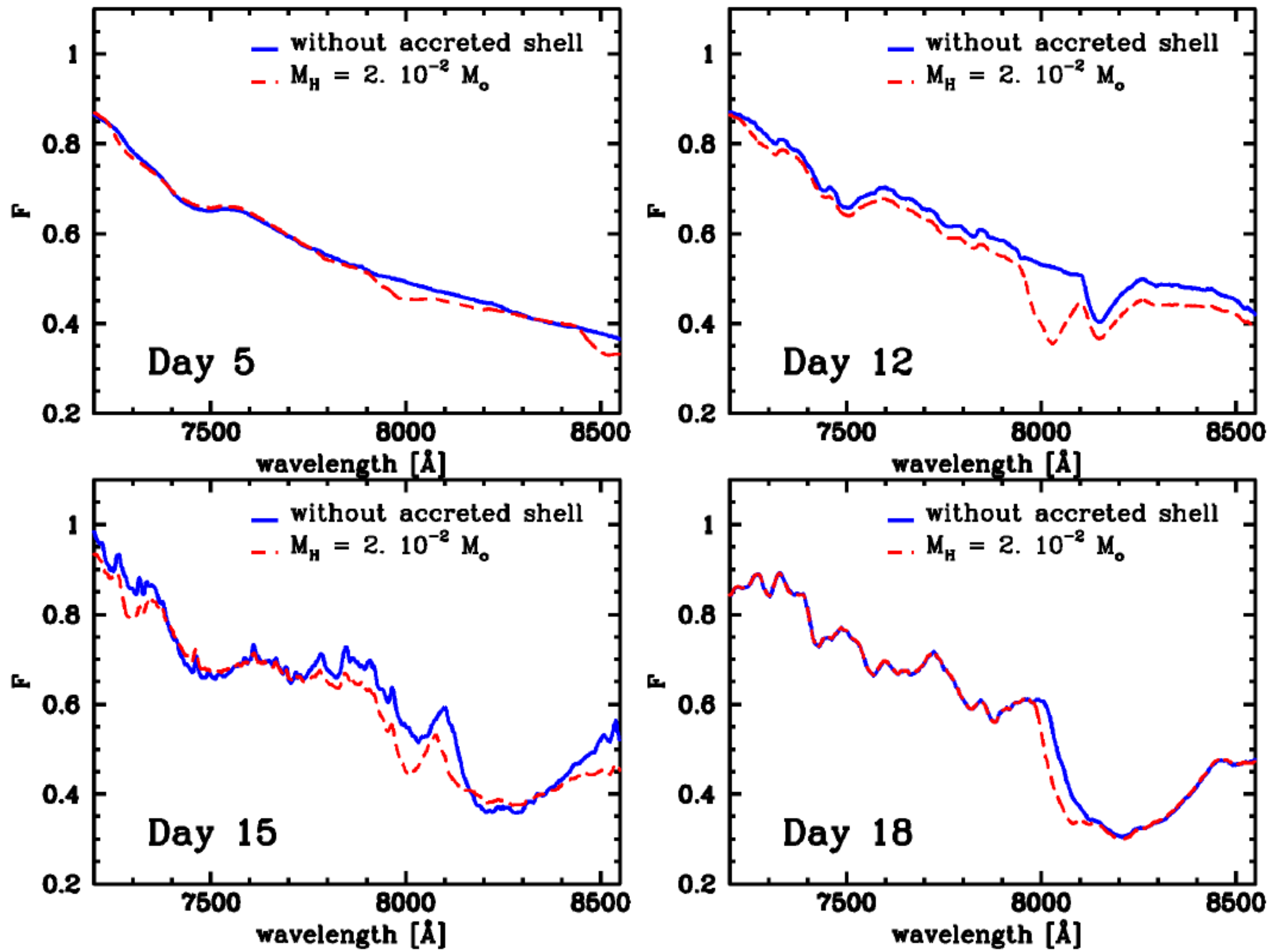
+ 39 days

Possible Signatures of the Progenitor System: Evolution of the high velocity Ca II feature

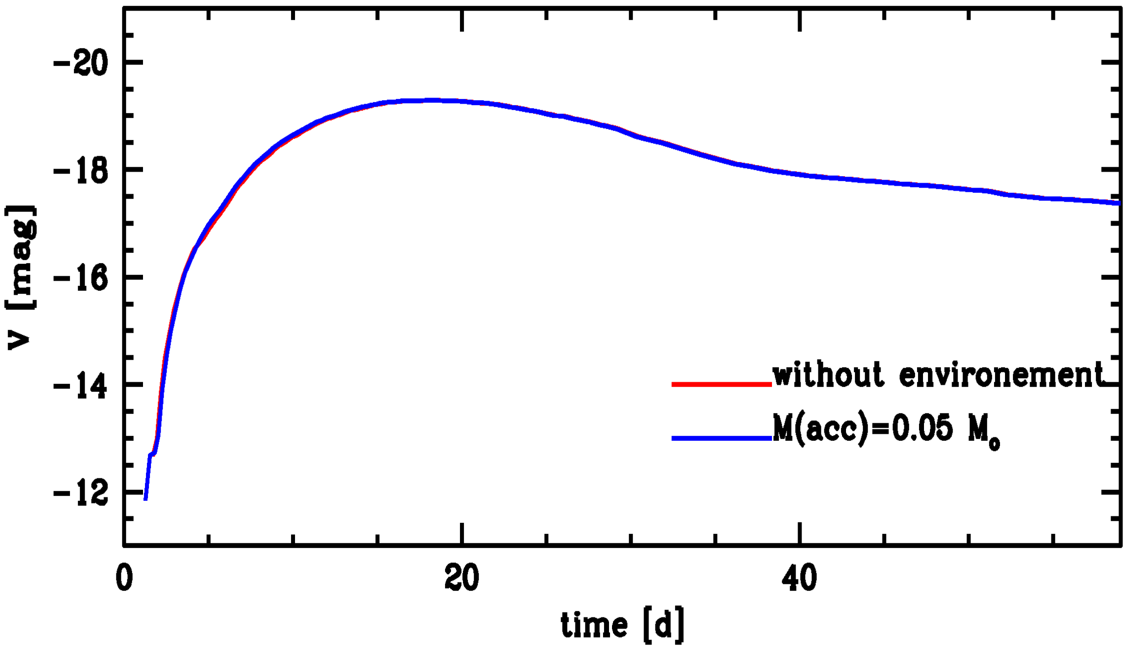
Signature of

Ionization front:
- very transient (2...3 days)
- changing Doppler shift

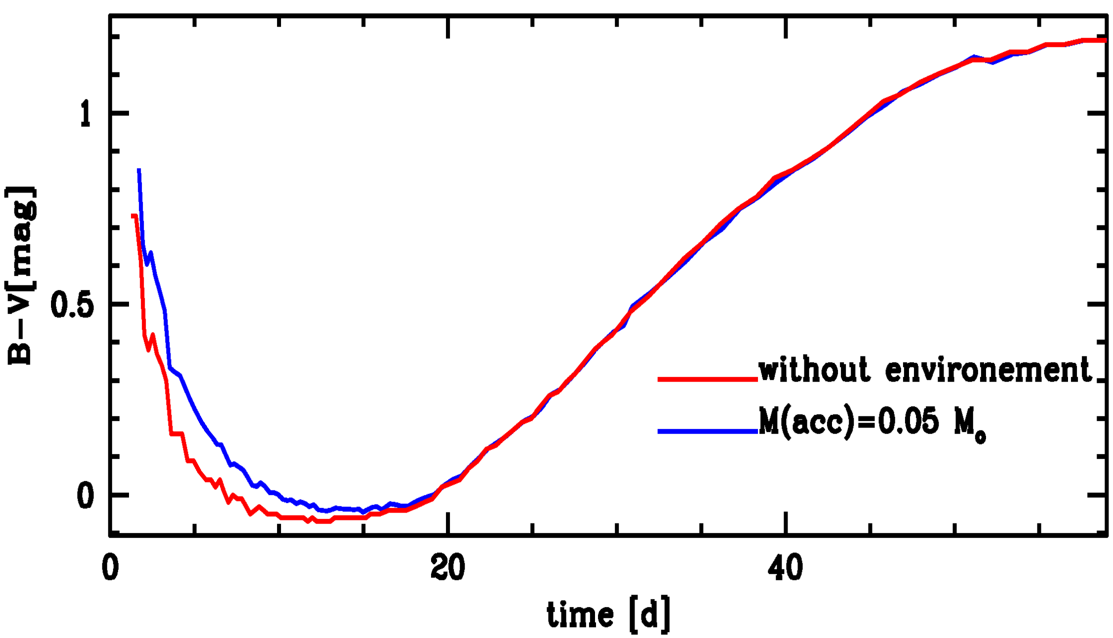
Shell:
- persistent (>10 ...14 days)
- almost constant velocity



What else? Light Curves



- little changes in LC
- early colors are redder by 0.1 to 0.2 mag

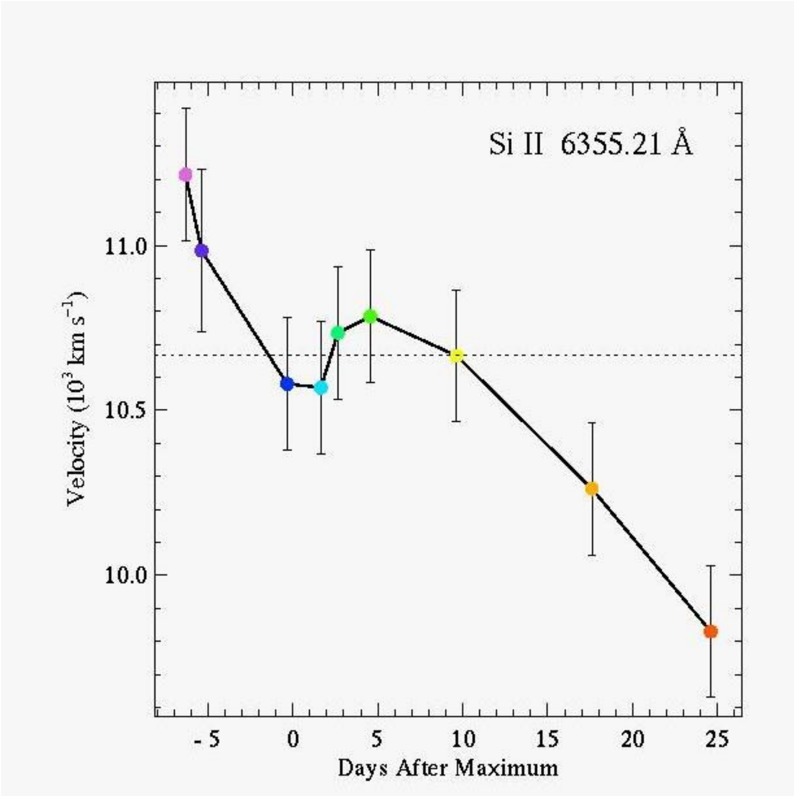


Rem.: Change due to optical thickness of shell for electron scattering

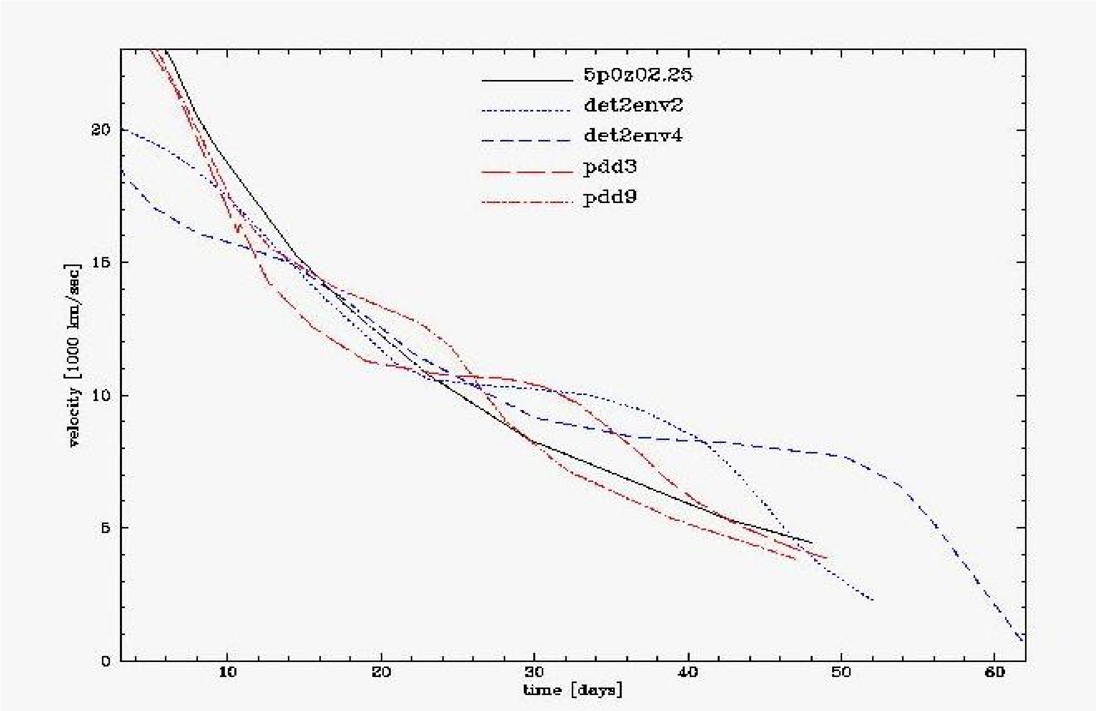
We need spectra to detangle rise time and shell !!!

Two Classes of SNIA???
(QHW06,HKW93, 2005cj et al., with HET)

Si velocity of 2005cj



HKW93,HK96

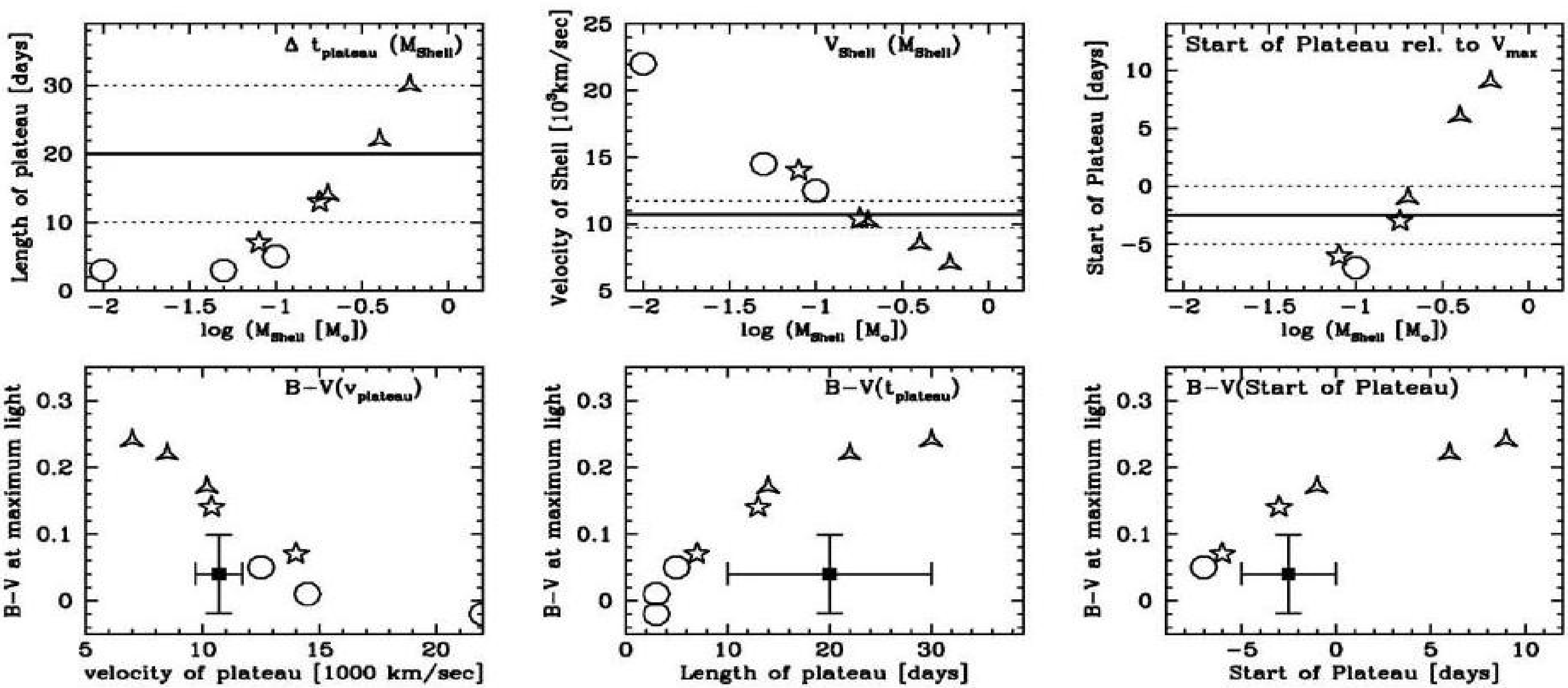


Plateau described by on-set, length and color

Two Classes of SNIA???

(QHW06,HKW93, 2005cj et al., with HET)

Take two (photometry with 1 sigma error bars and standard reddening)



Maybe, the color is intrinsically red ?

Conclusions

- SN Ia evolve
  all the same→1 parameter→multi-parameter

- current accuracy 0.2 mag

- potentially 0.02...3 mag accuracy

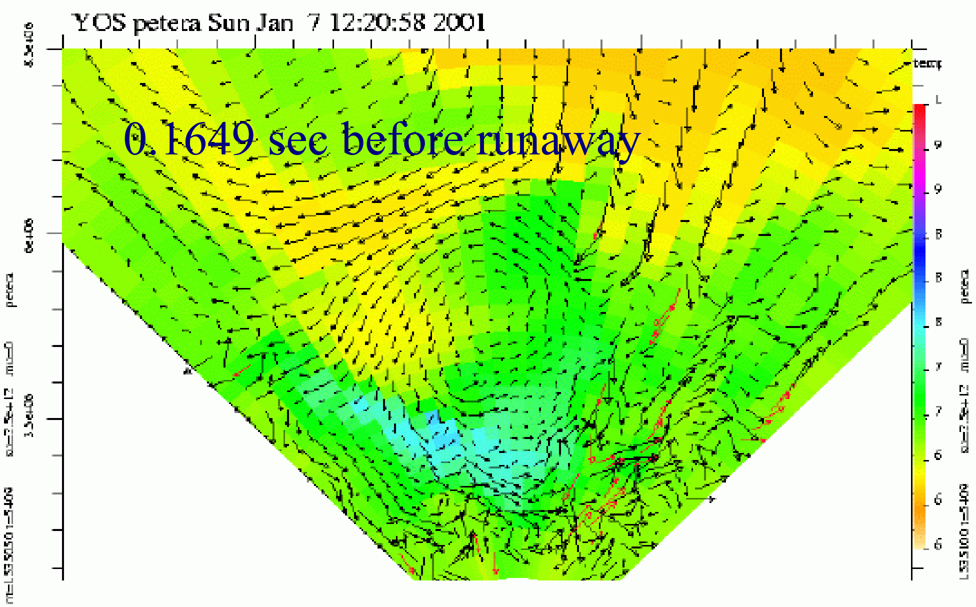
- asphericity puts the limit if not corrected

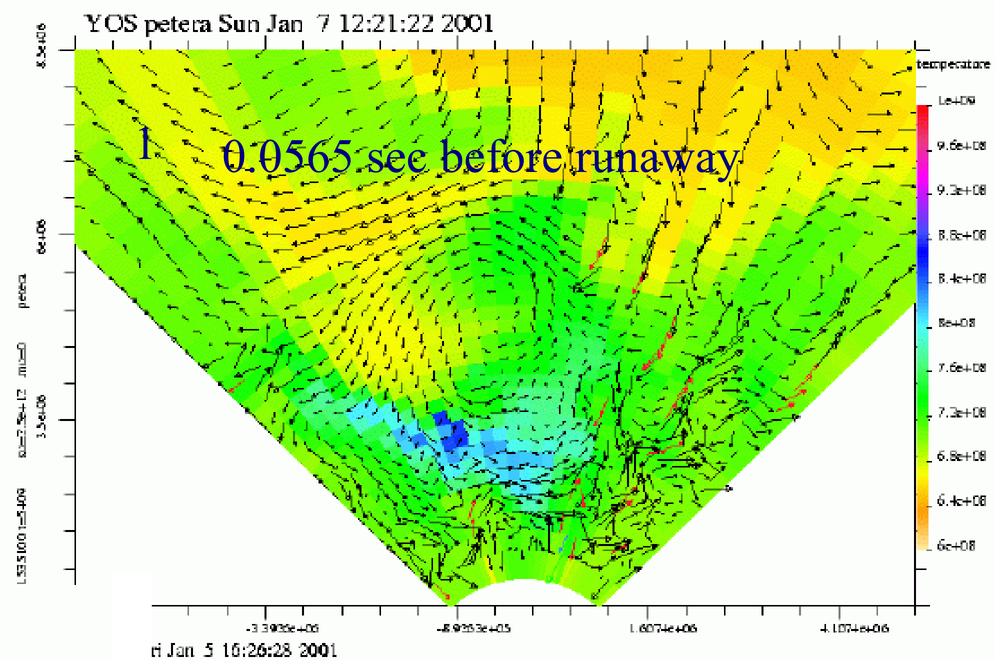
- likely, more than one class

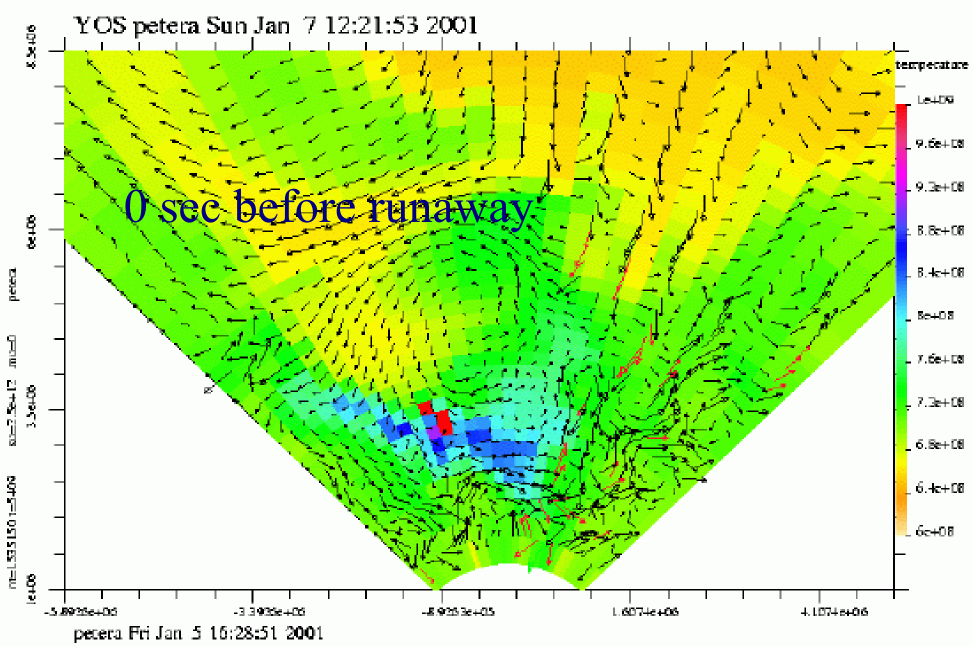
PROBELM: Reconditioning & Run away

Temperature and velocity before the explosion (Hoeflich & Stein 2002, ApJ 568, 791)

Longest velocity vector in black = 50 km/sec ; 600E8 K< T < 1E9 K







- size of shown domain: 100 km
- size of inner boundary: 13.7 km
  evolution followed over 5 hours

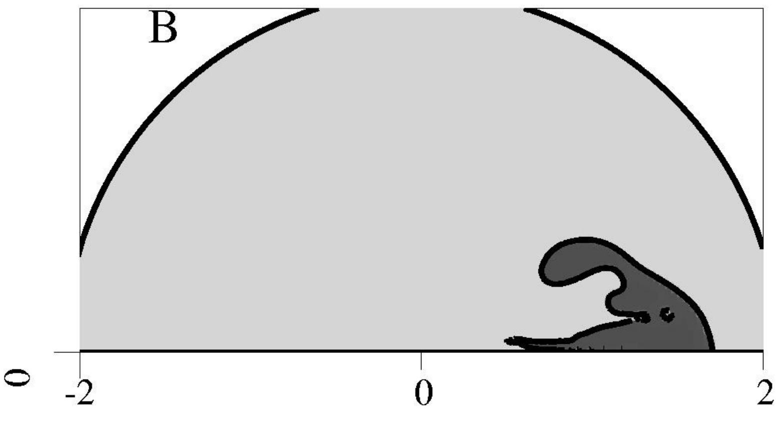
- ignition close to the center at within one cell (about 35 km)
- ignition occurs due to compression of an element due to circulation.
- v(turb) >> v (RT close to center)
  -> early phase of nuclear burning is governed by preconditioning of WD

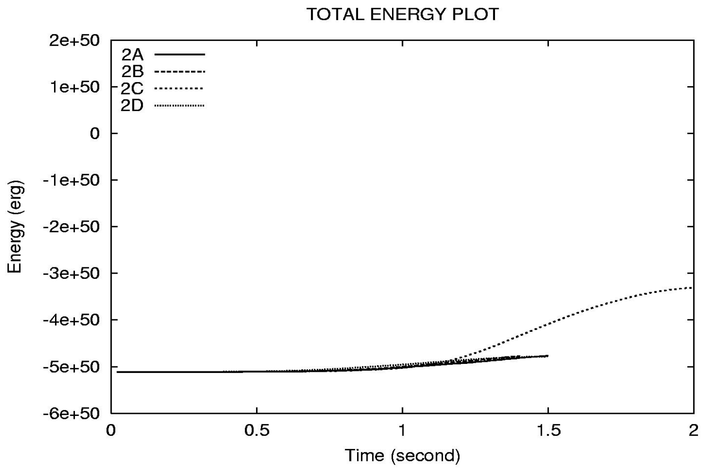
Influence of the Initial Condition on Deflagrations

(from Livne, Asiaga & Hoeflich 2005, ApJ)

Jelly-fish

M(burn)=0.05Mo

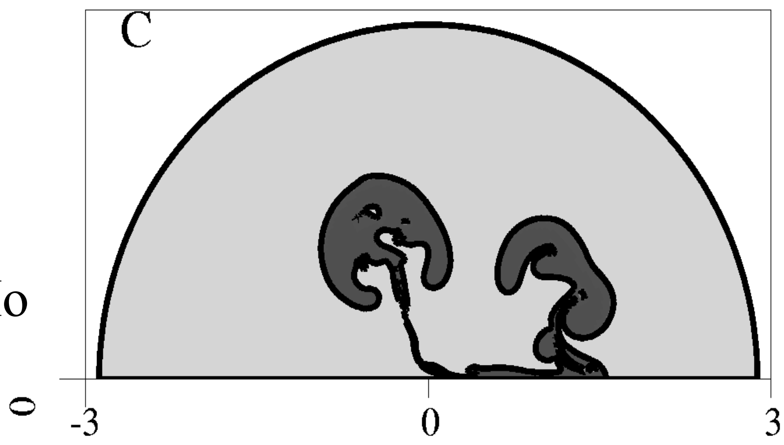


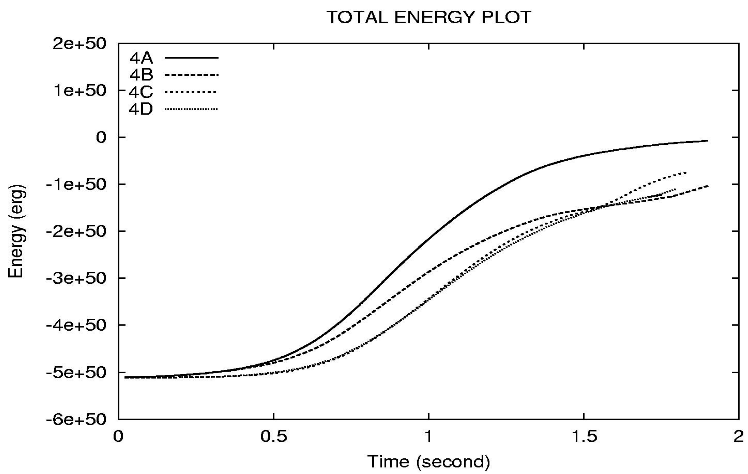


Fissle solution:

Few spot-ignition, non-simultaneous

M(burn)=0.2...0.3Mo





- WD is loosely bound for Fissle solutions. Amount of deflagration burning consistent with 1D LC and spectra !
- PDD models are back (pulsational DDT as mechanism) (Khokhlov et al. 1993, Hoeflich et al. 1995)