Expansion opacity for SN Ia

How to survive when you need to use more than 10 million spectral lines

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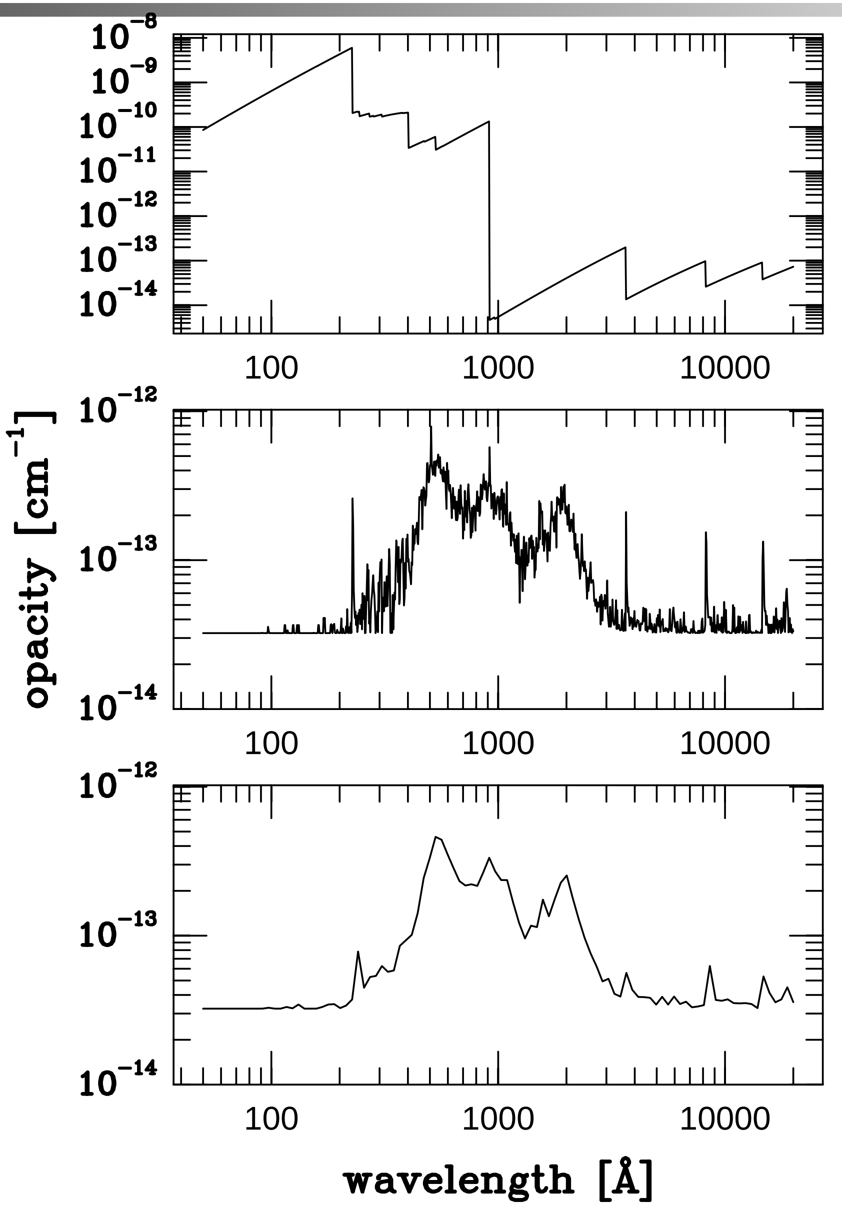
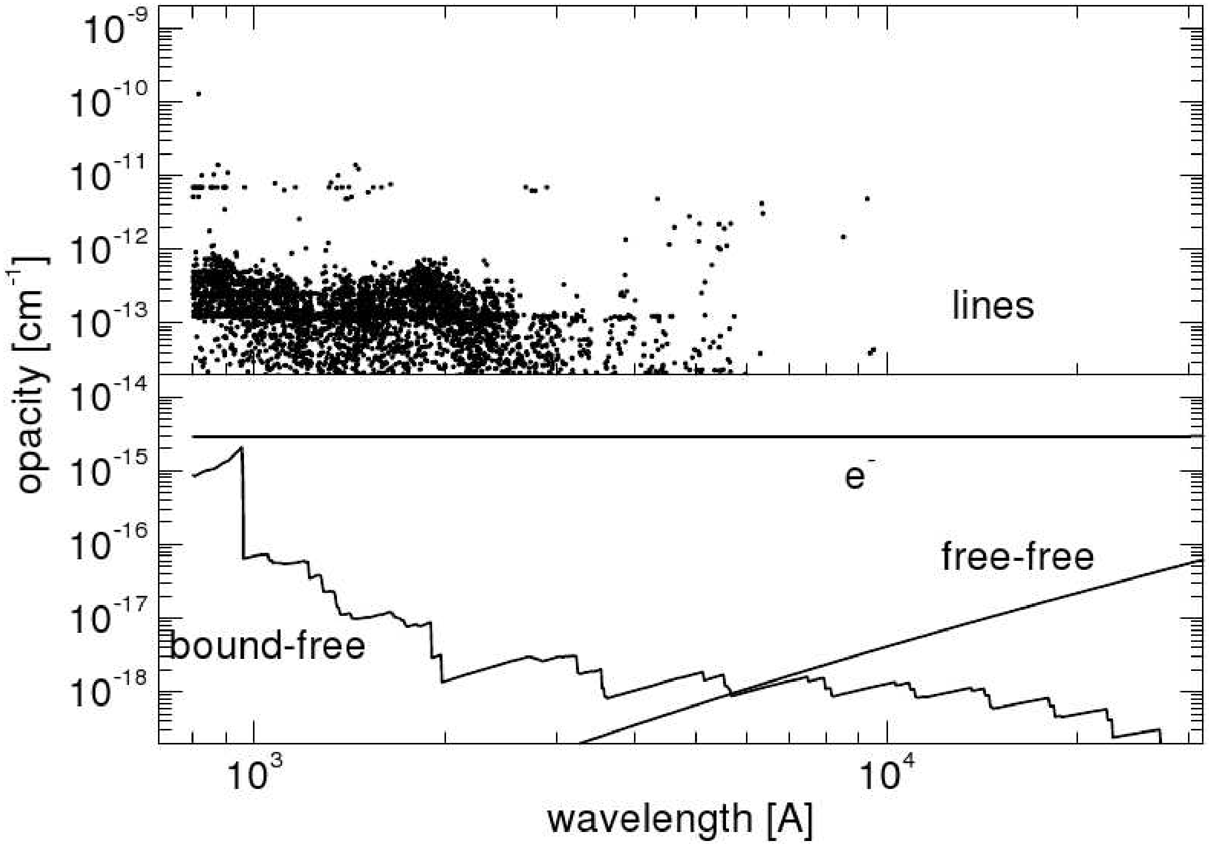
Opacity for Solar composition



Opacity for Fe–Co–Ni composition

Eastman& Pinto 2000

$\rho = 10^{-13}$ g/cm^3, $T = 2.5 \cdot 10^4$ K, $t = 14$ days

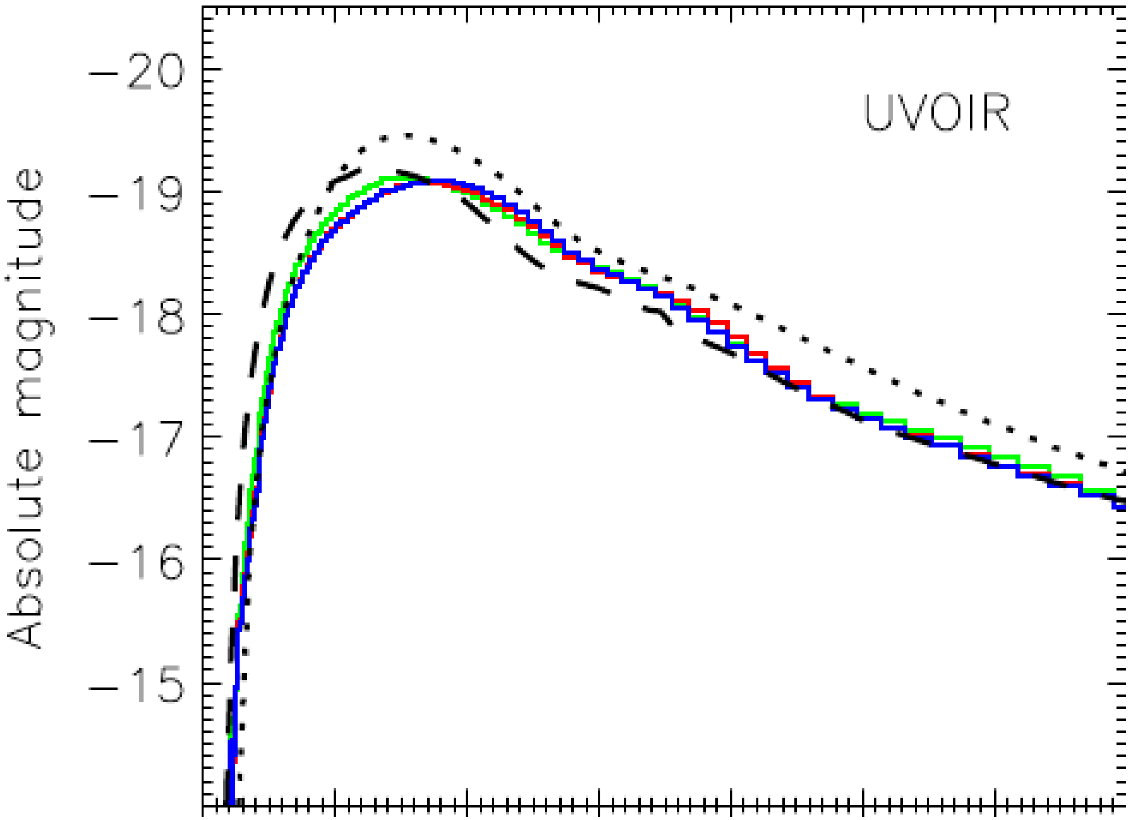


Methods for Light Curve modeling

- Monte Carlo (Lucy; SEDONA–Kasen; Sim, Kromer; Maeda)
- Monochromatic calculation of transfer equations (PHOENIX–Hauschild, Baron; EDDINGTON–Eastman, Pinto; CMFGEN–Hillier, Miller, Dessart)
- Radiative hydrodynamics (STELLA–Blinnikov+)
- Combination of hydrodynamics with MC or monochromatic radiative transport (Noebauer+MPA group)

Comparison of different codes

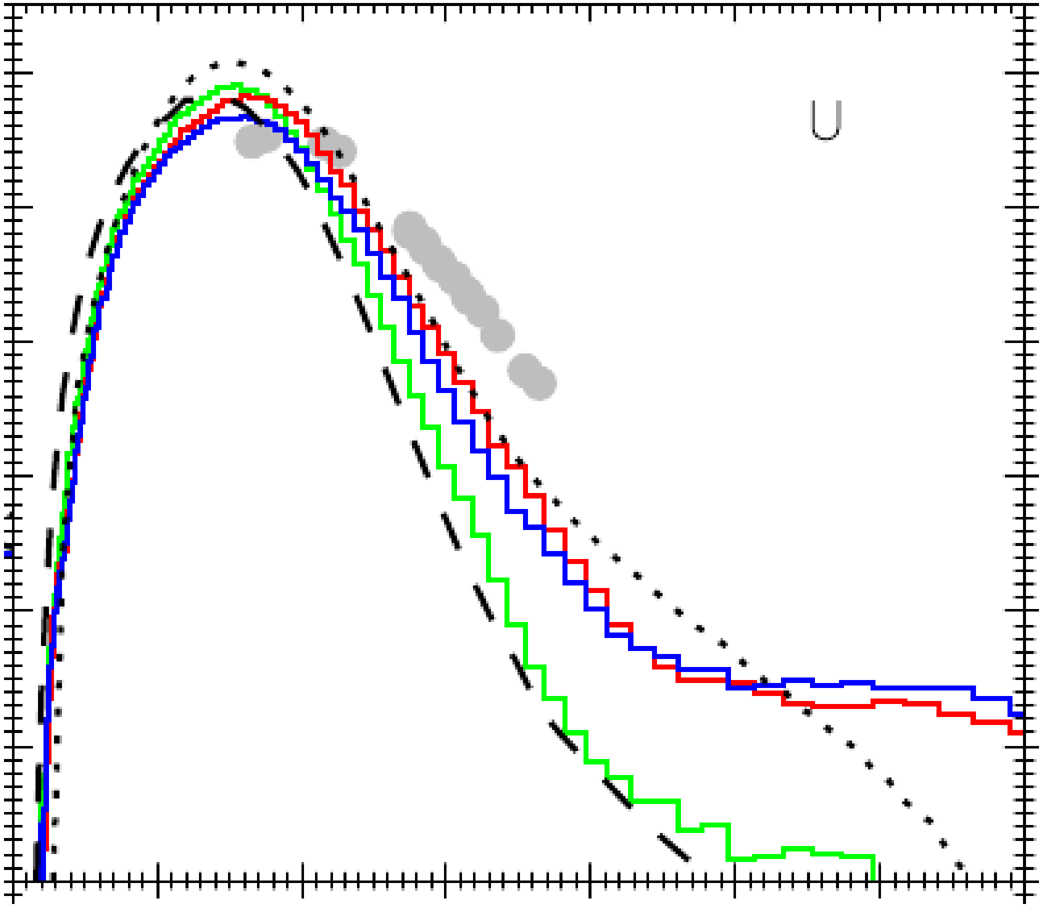
Sim / STELLA (dashes) / SEDONA (dots)



bolometric W7

Comparison of different codes

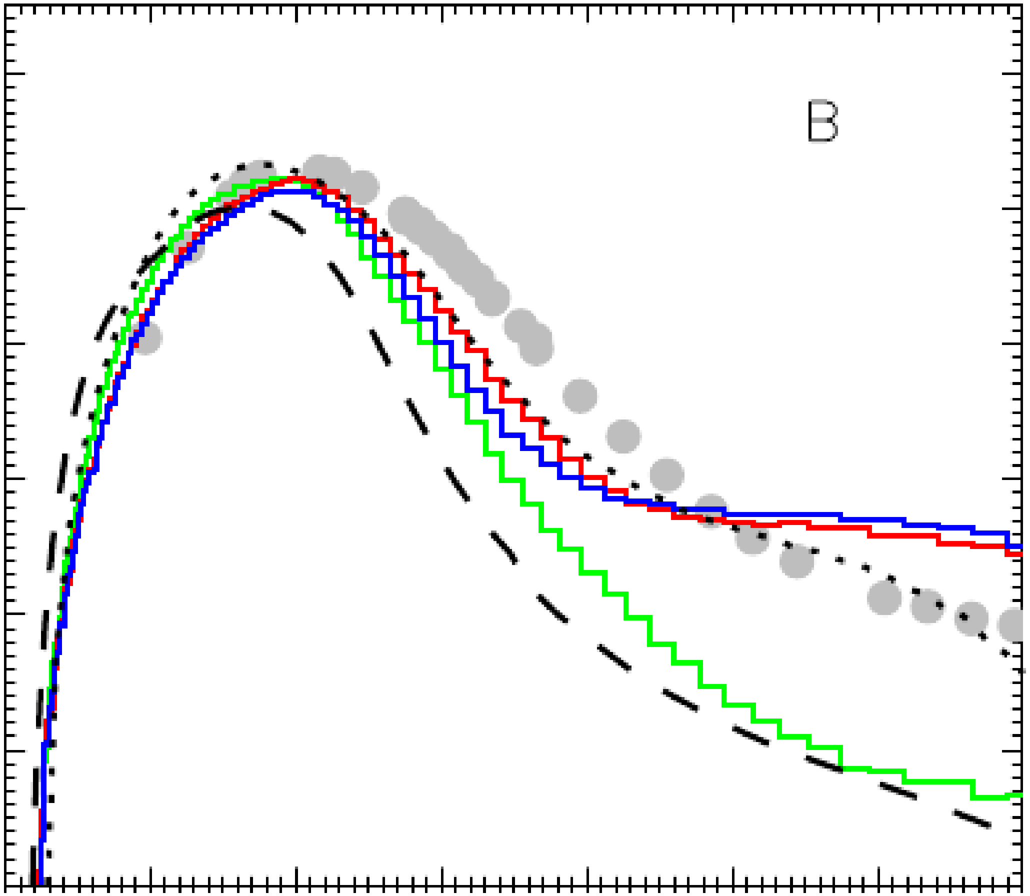
Sim / STELLA (dashes) / SEDONA (dots)



W7 in U

Comparison of different codes

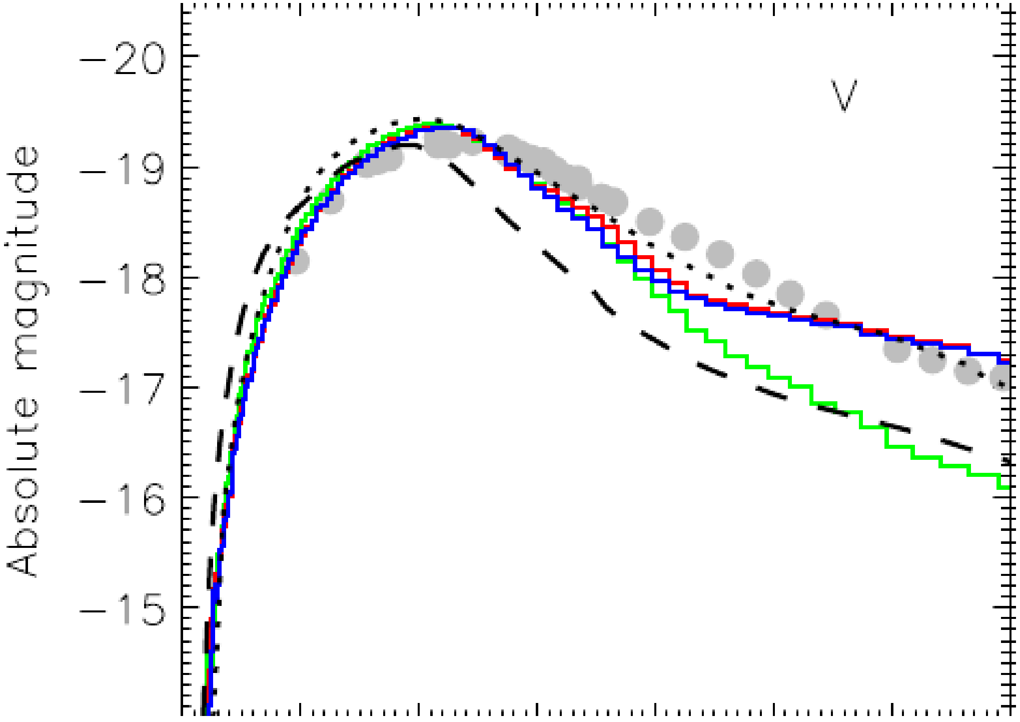
Sim / STELLA (dashes) / SEDONA (dots)



W7 in B

Comparison of different codes

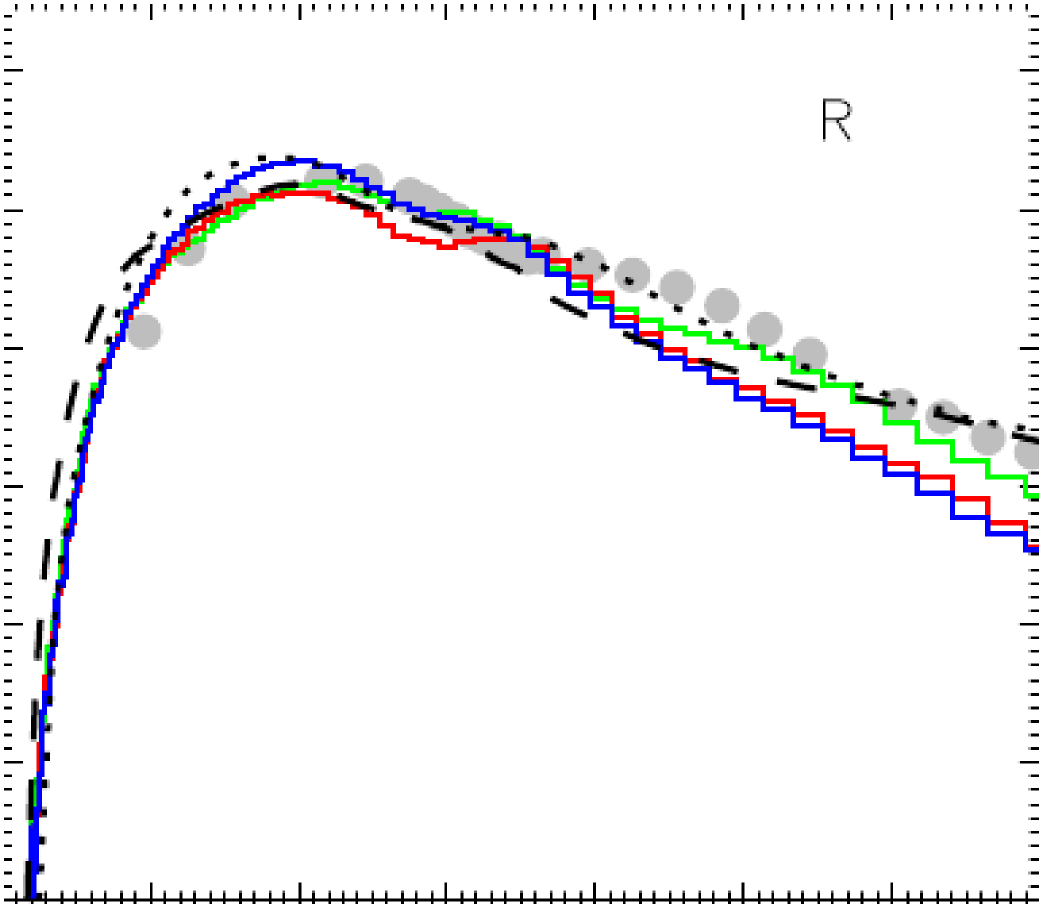
Sim / STELLA (dashes) / SEDONA (dots)



W7 in V

Comparison of different codes

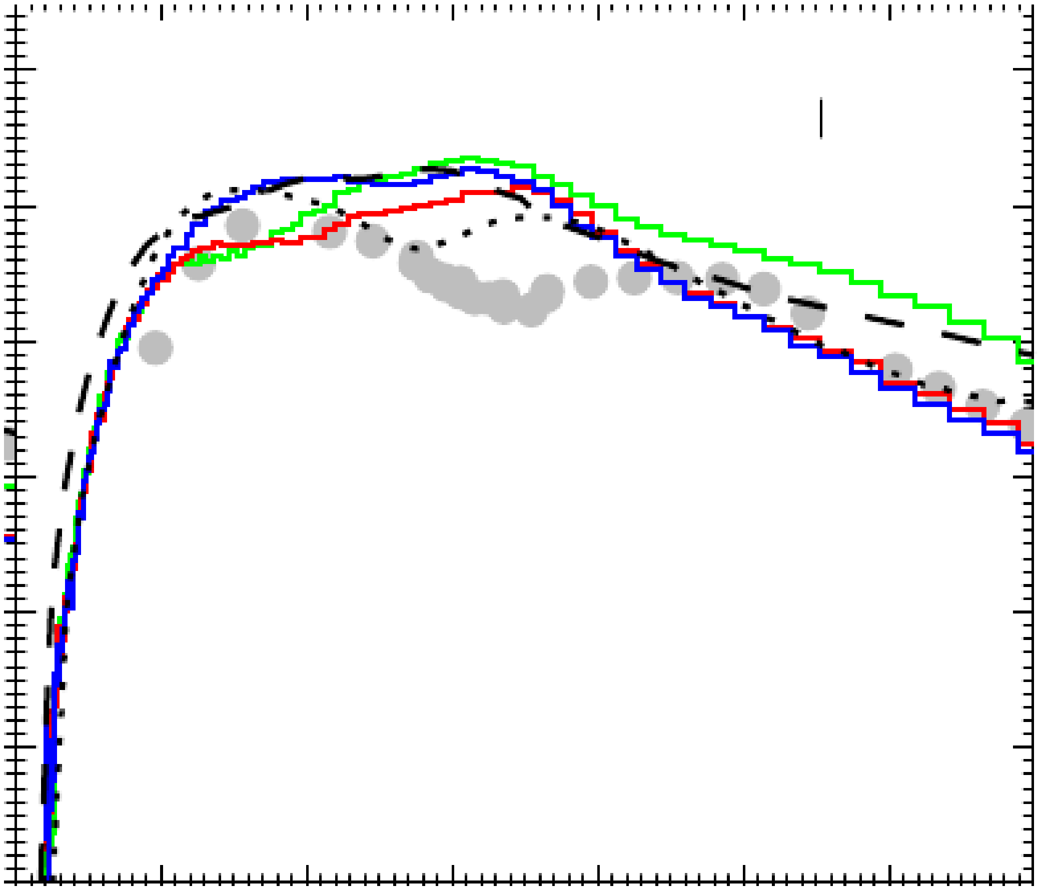
Sim / STELLA (dashes) / SEDONA (dots)



W7 in R

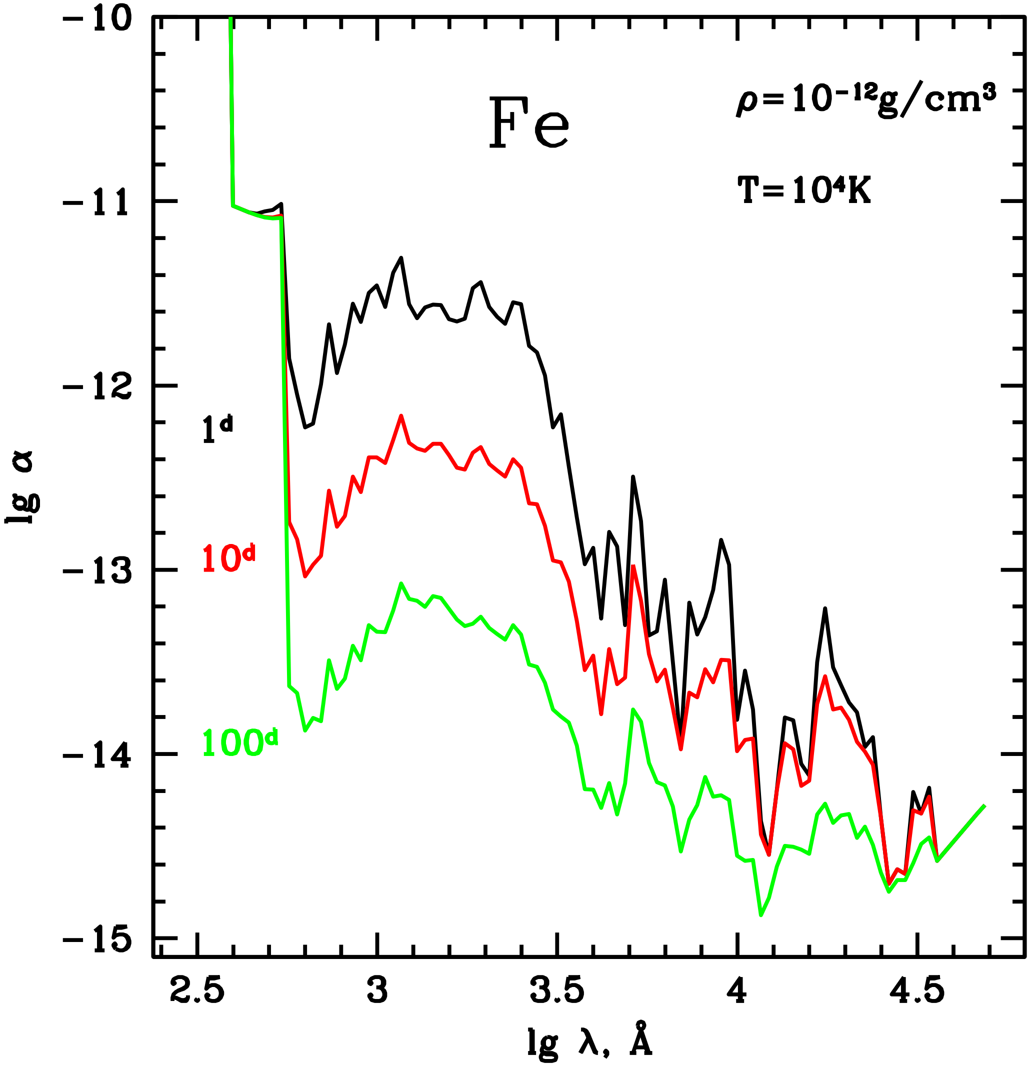
Comparison of different codes

Sim / STELLA (dashes) / SEDONA (dots)



W7 in I

Expansion opacity



Expansion opacity

For getting correct fluxes with radiative hydro codes, the correct opacity averaged over frequency bin is very important. (See Castor 2007 for references)

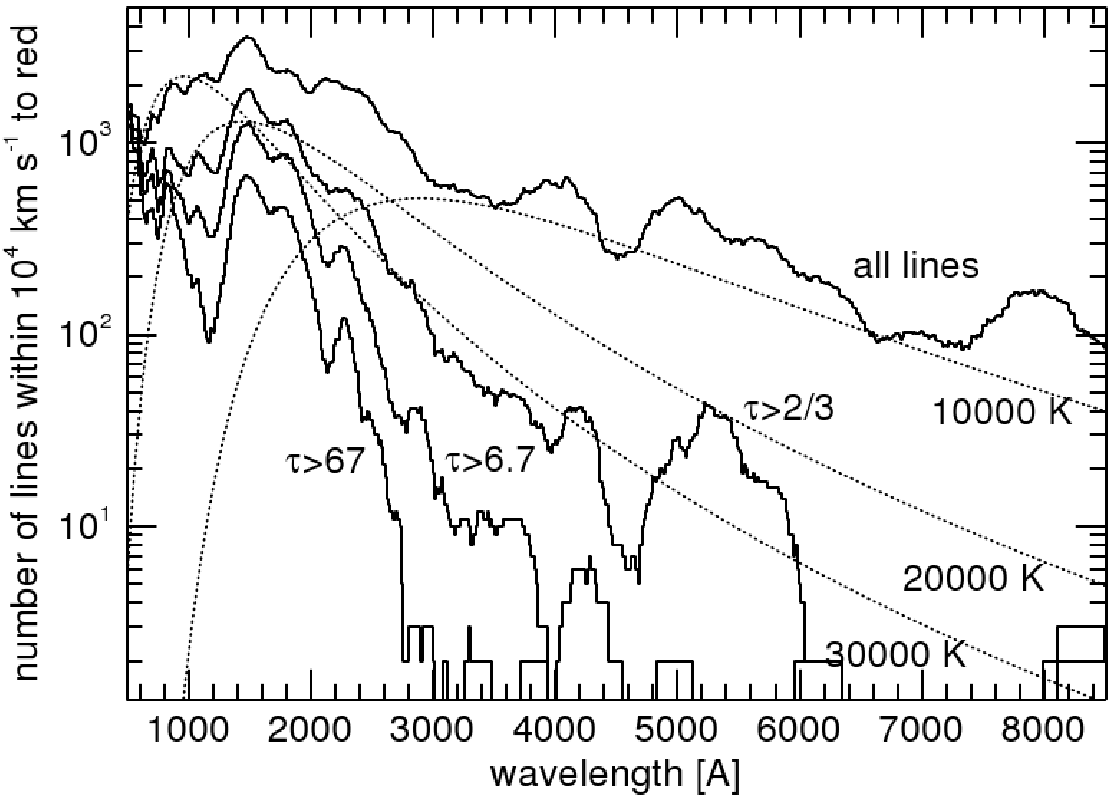
We use Eastman & Pinto approximation for $t = r/v$:

$$\chi_{\mathrm{EP}} = \frac{\nu}{\Delta\nu}\frac{1}{ct}\sum_{l}\left\{1 - \exp\left(-\tau_{\mathrm{Sob}\ l}\right)\right\}$$

$$\tau_{\mathrm{Sob}\ l} = \left(\frac{\pi e^2}{mc}\right)(fg)_l \lambda_l \frac{n_{\mathrm{ion}}}{Z_{\mathrm{part}}}\ \mathrm{e}^{-\frac{E_{\mathrm{low}}}{kT}} \bigg/ \frac{\partial v}{\partial r}$$

Number of lines

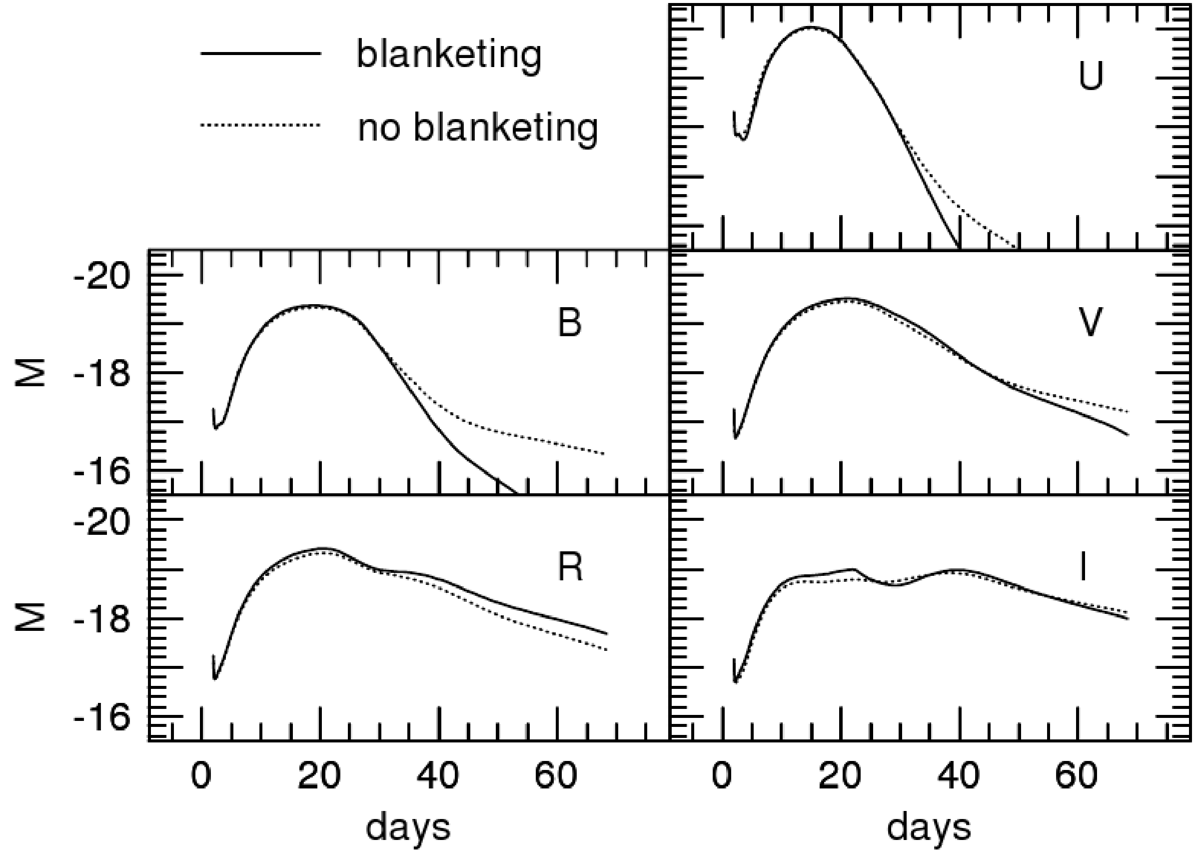
Eastman& Pinto 2000



BUT opposite direction!

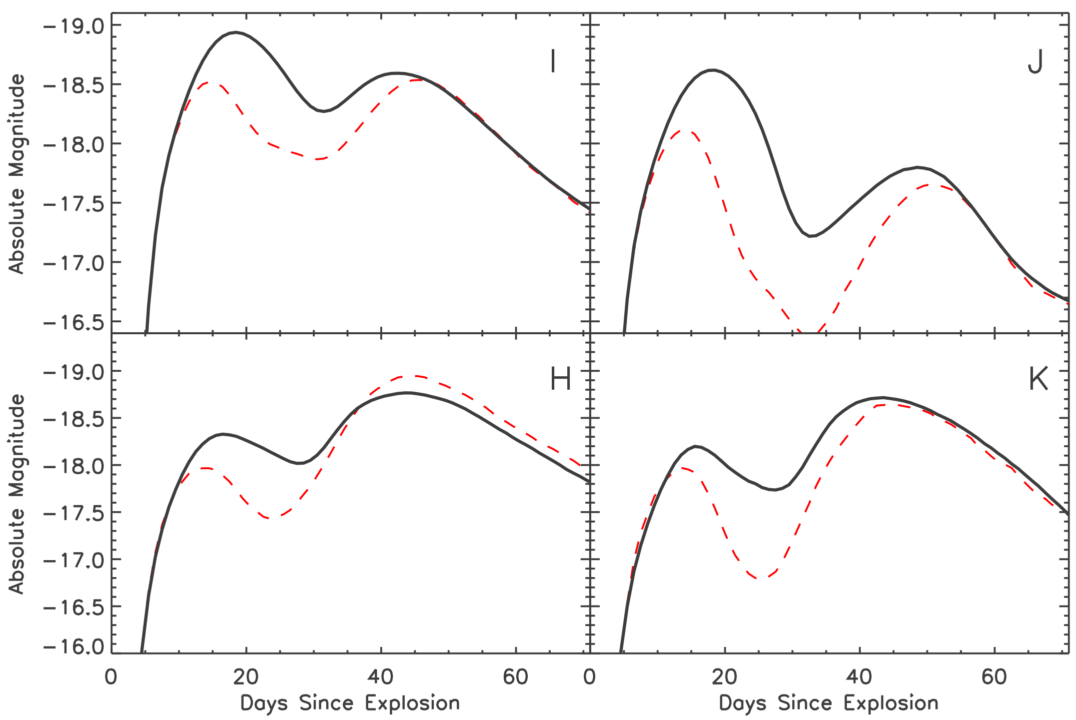
E & P Light Curves

with additional 450,000 lines



Kasen 2006

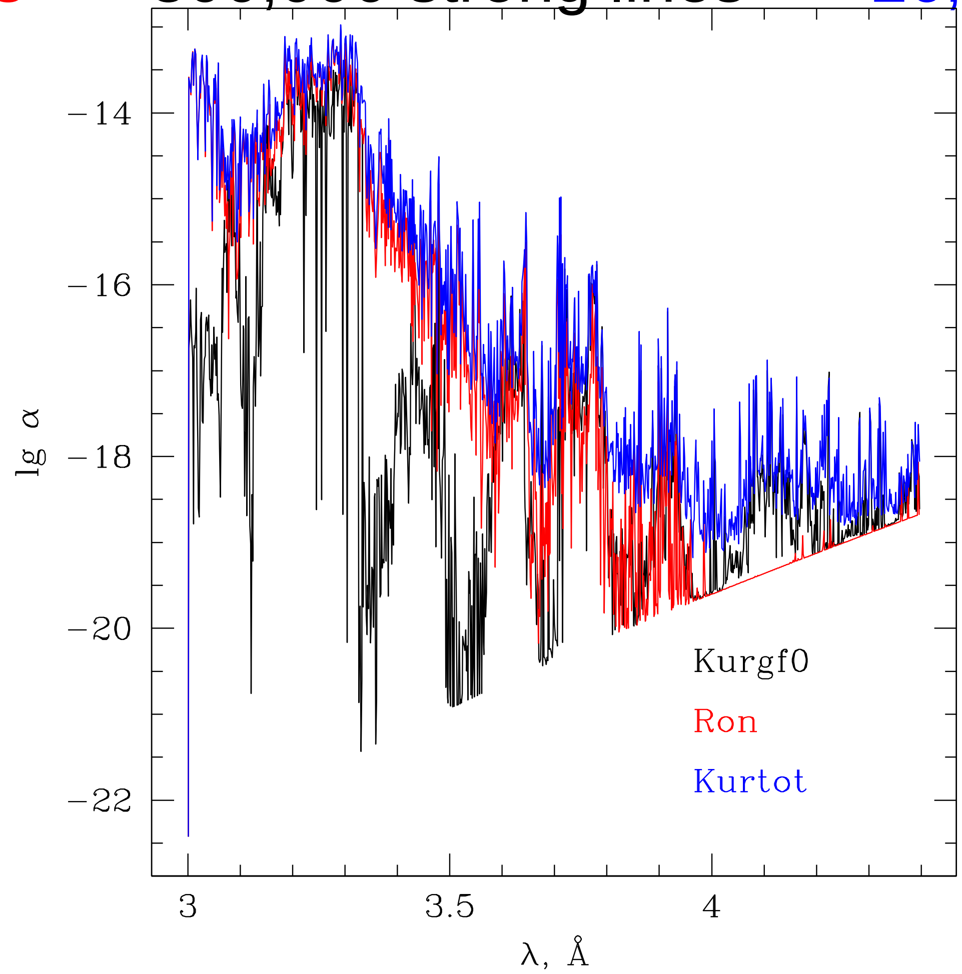
IR light curves for different line lists



Different Kurucz line lists (1000 freqs)

$\rho = 10^{-14}$ g/cm^3, $T = 15 \cdot 10^3$ K, Fe+Ni

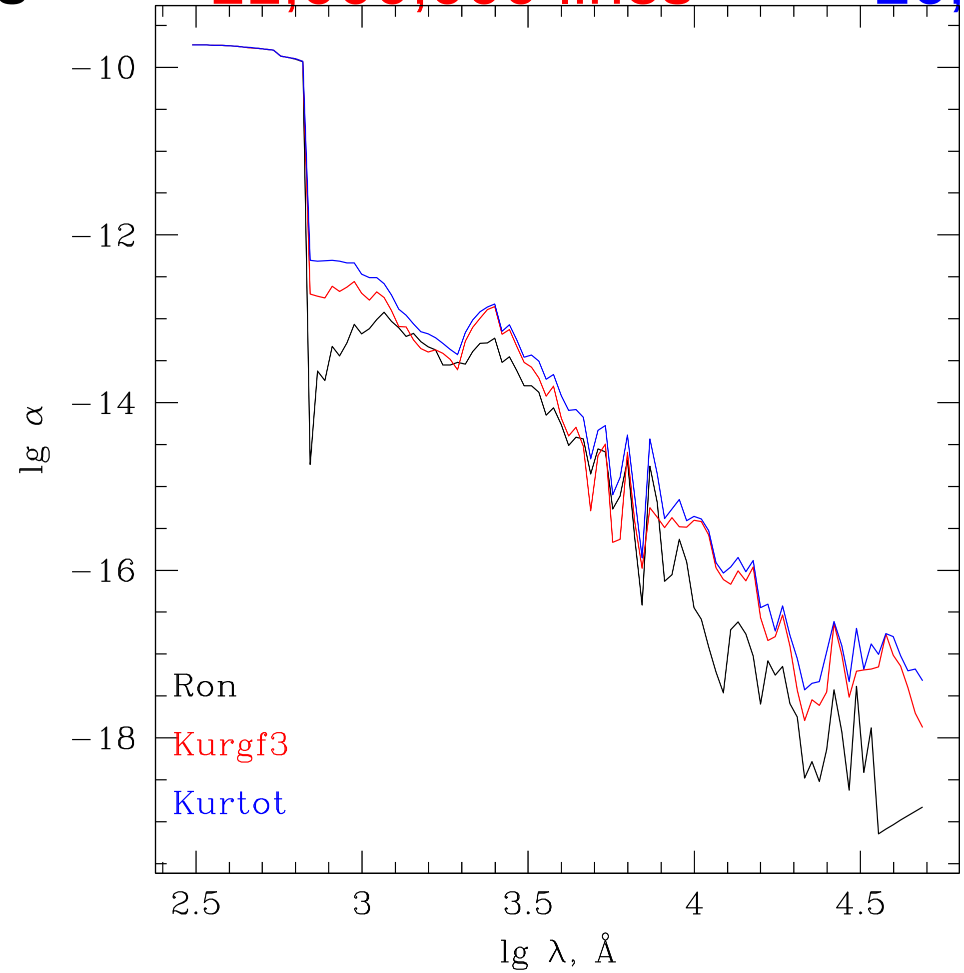
155,000 lines 300,000 strong lines 26,000,000 lines



Different Kurucz line lists (100 freqs)

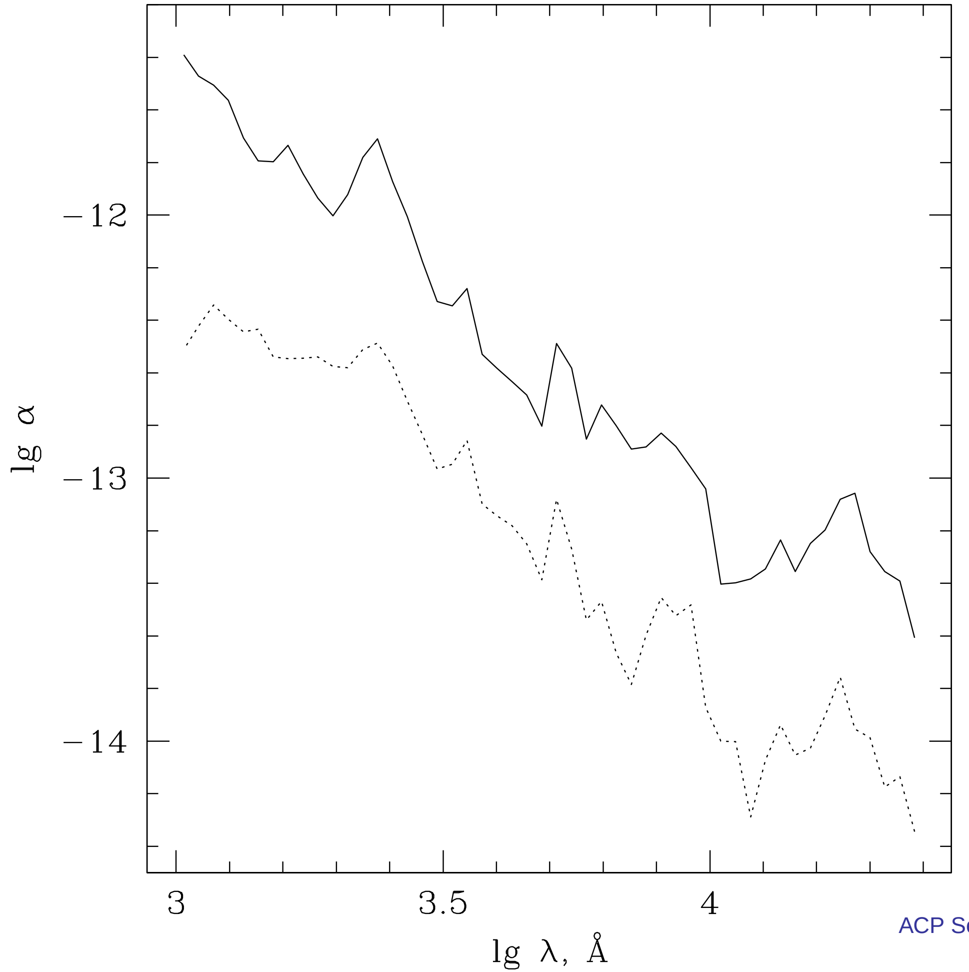
$\rho = 10^{-14}$ g/cm^3, $T = 5 \cdot 10^3$ K

155,000 lines 11,000,000 lines 26,000,000 lines



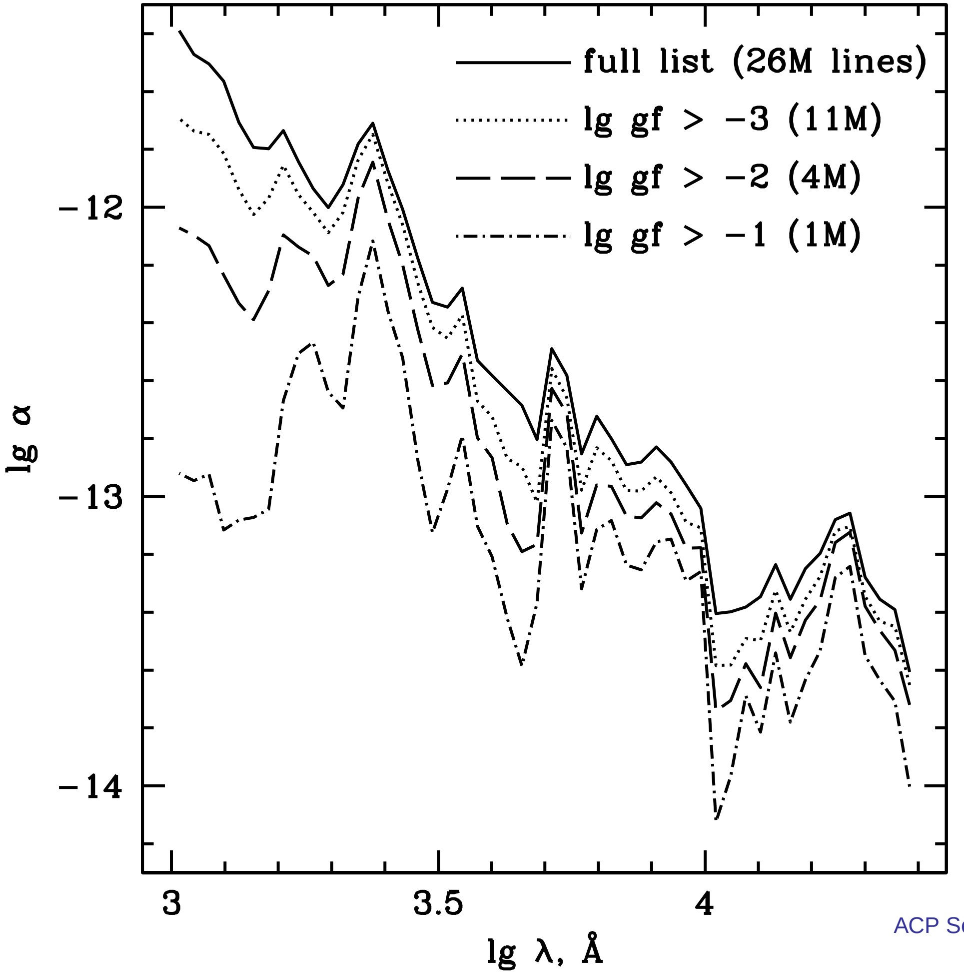
155k vs. 26M lines (50 freqs)

$\rho = 10^{-12}$ g/cm^3, $T = 7 \cdot 10^3$ K, t=20days, Fe:Co:Ni=24:75:1

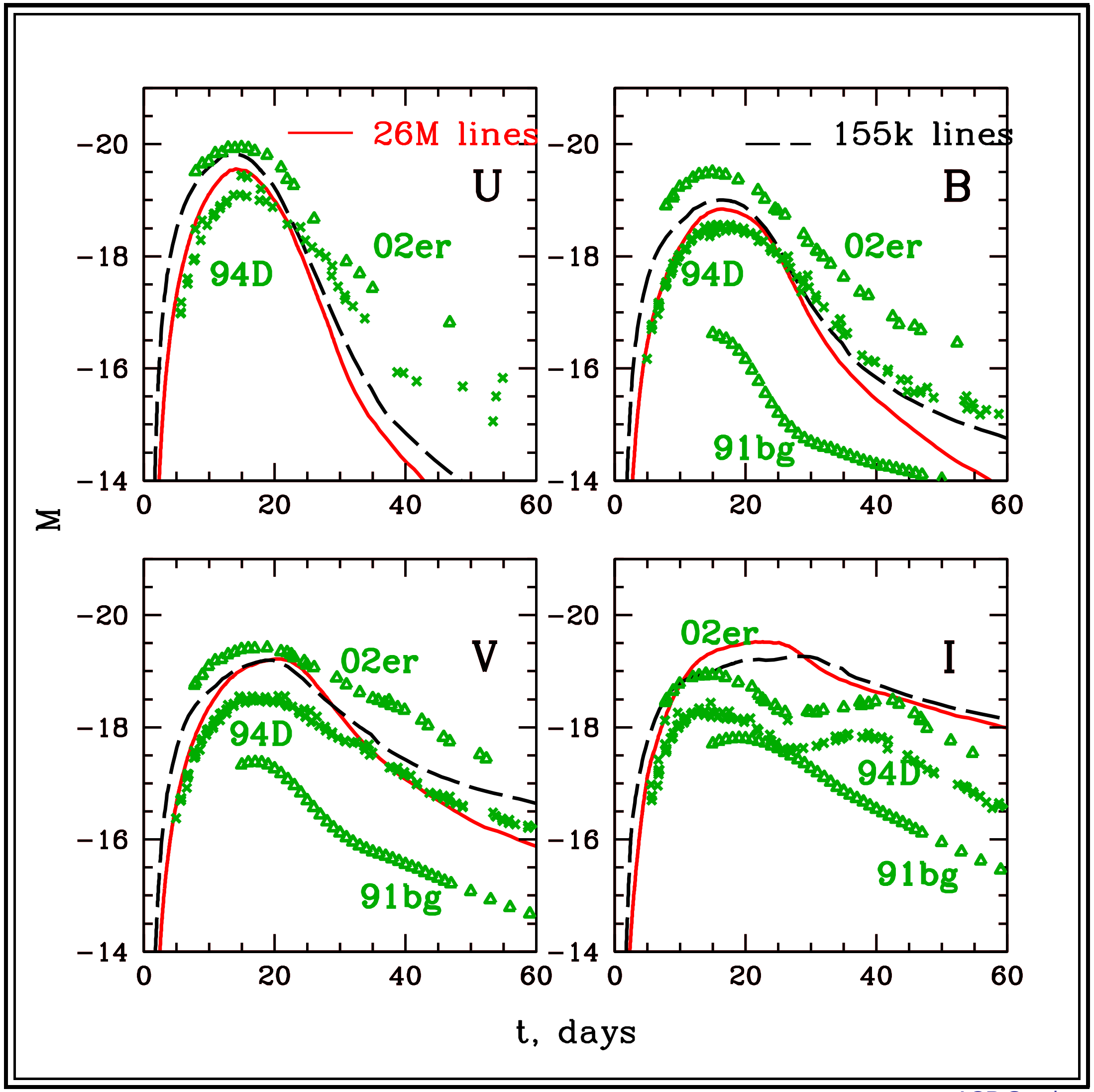


26M line list and its sublists

$\rho = 10^{-12}$ g/cm^3, $T = 7 \cdot 10^3$ K, t=20days,
Fe:Co:Ni=24:75:1



W7 light curves with different line lists



Opacity Distribution Function Method

Strom & Kurucz 1966

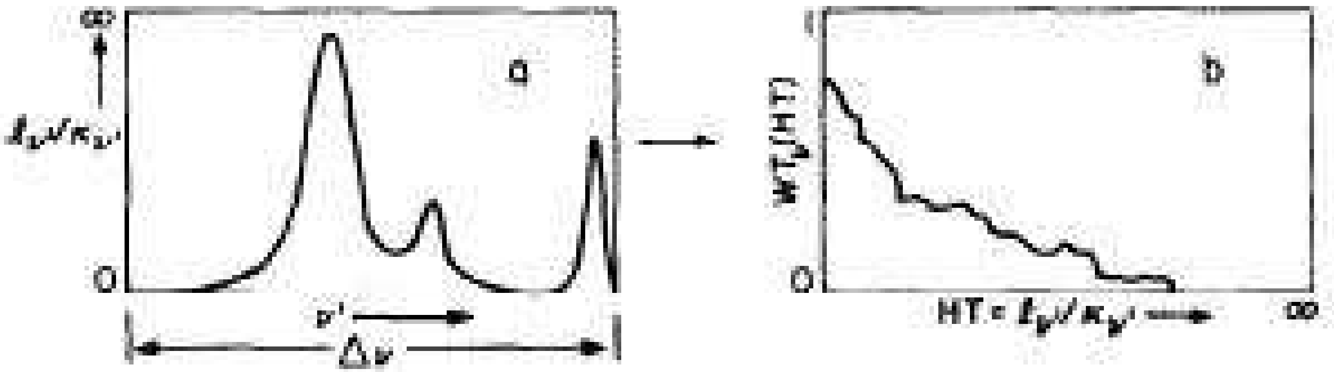
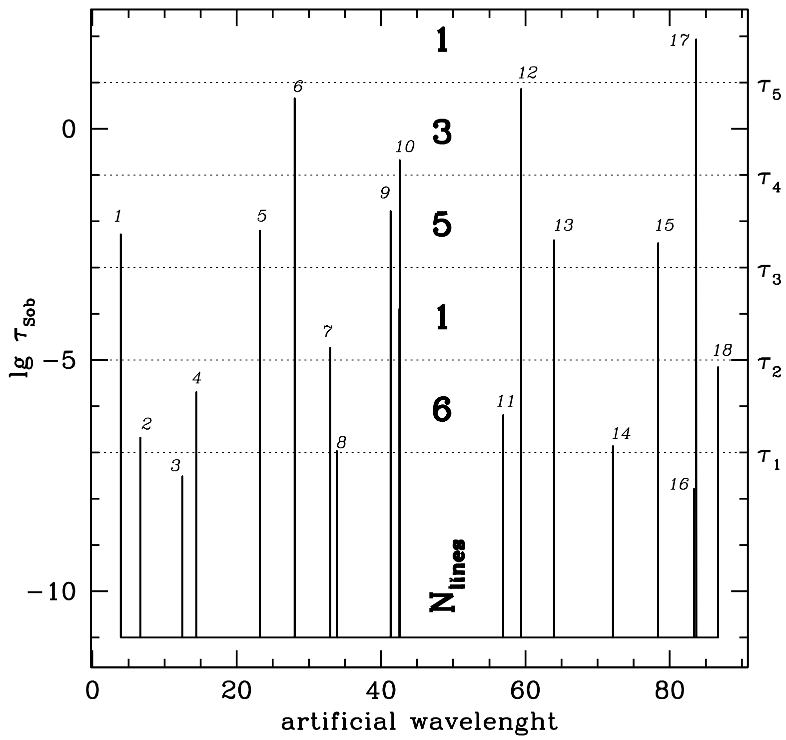


FIG. 2. A schematic representation of the procedure used in transforming the detailed opacity variation to an equivalent relation between "heights" and "weights."

Sobolev depth distribution function



$\chi_{\rm EP} \sim \sum_l \{1 - \exp\left(-\tau_{{\rm Sob}\ l}\right)\}$

Strong lines: $\chi_{\rm EP} \sim N_{\rm lines}$

Weak lines: $\chi_{\rm EP} \sim N_{\rm lines} \tau_{\rm Sob}^{\rm avg}$

Grid for the tables

It is important to choose such parameters for the tables that make the tables model-independent.

$N_{\rm lines}(\nu, \tau_{\rm Sob}/(n_{\rm ion}t, T))$ - a table for each ion is needed

$N_{\rm lines}(\nu, \tau_{\rm Sob}/(Y_i \rho t), T, n_e)$ - a table for each element

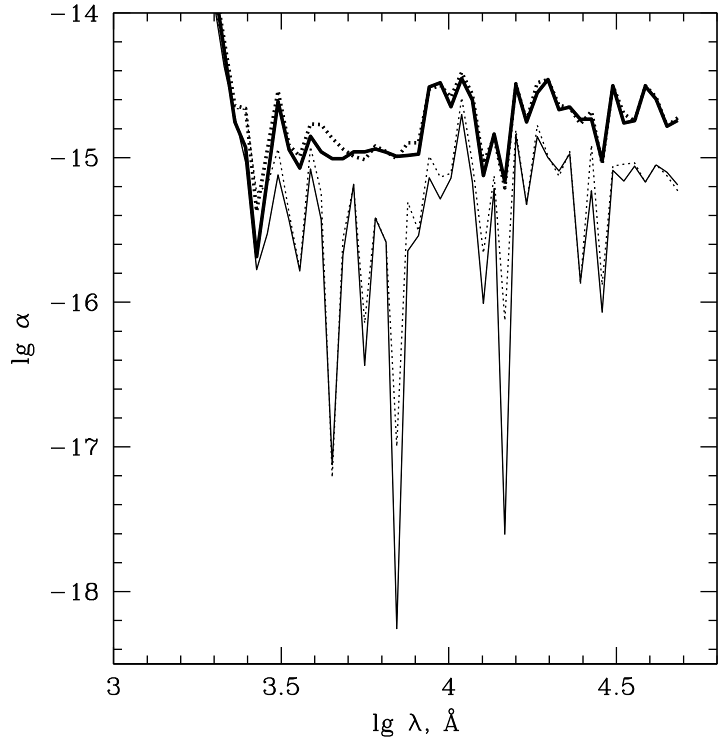
Grid for the tables

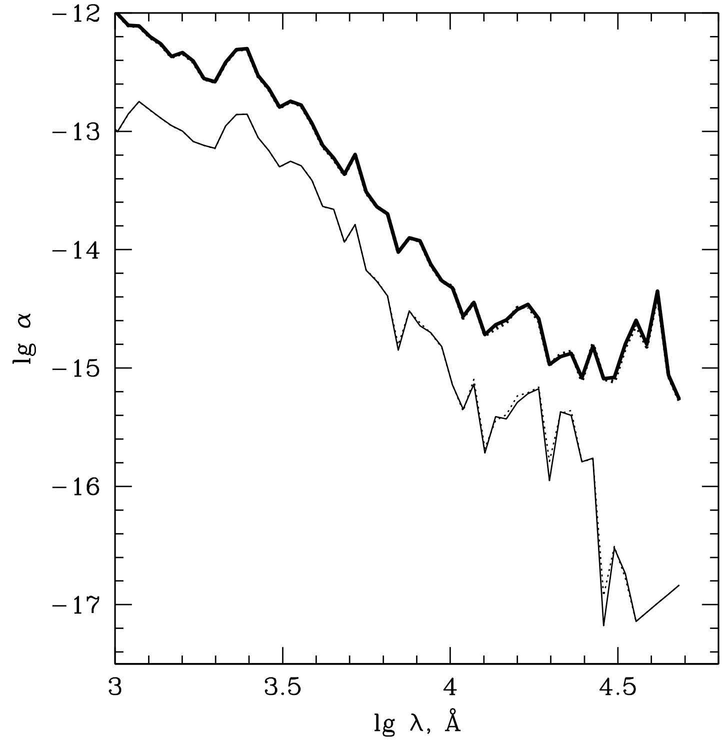
Parameter	Low limit	High limit	N bins
$\tau_{\mathrm{Sob}}/(Y_{\mathrm{at}}\rho t)$	$3.5 \cdot 10^{-2}$	$3.5 \cdot 10^{14}$	35
λ	30 Å	50 000 Å	100
T	2 500 K	150 000 K	201
n_e	$10^{4}\ \mathrm{cm}^{-3}$	$10^{16}\ \mathrm{cm}^{-3}$	49

Opacity: new method vs. LL-calculation

Si 0.64; S 0.3; Ar 0.04; Ca 0.02

Fe 0.24; Co 0.75; Ni 0.01





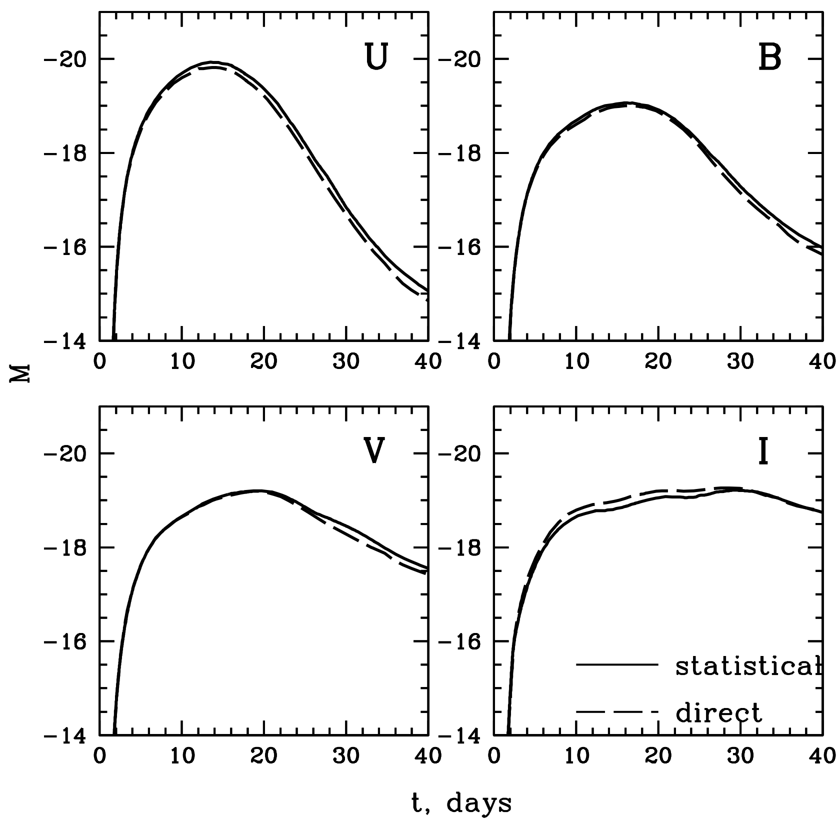
$\rho = 10^{-13}$ g/cm^3; $T = 5000$ K; t=40 days

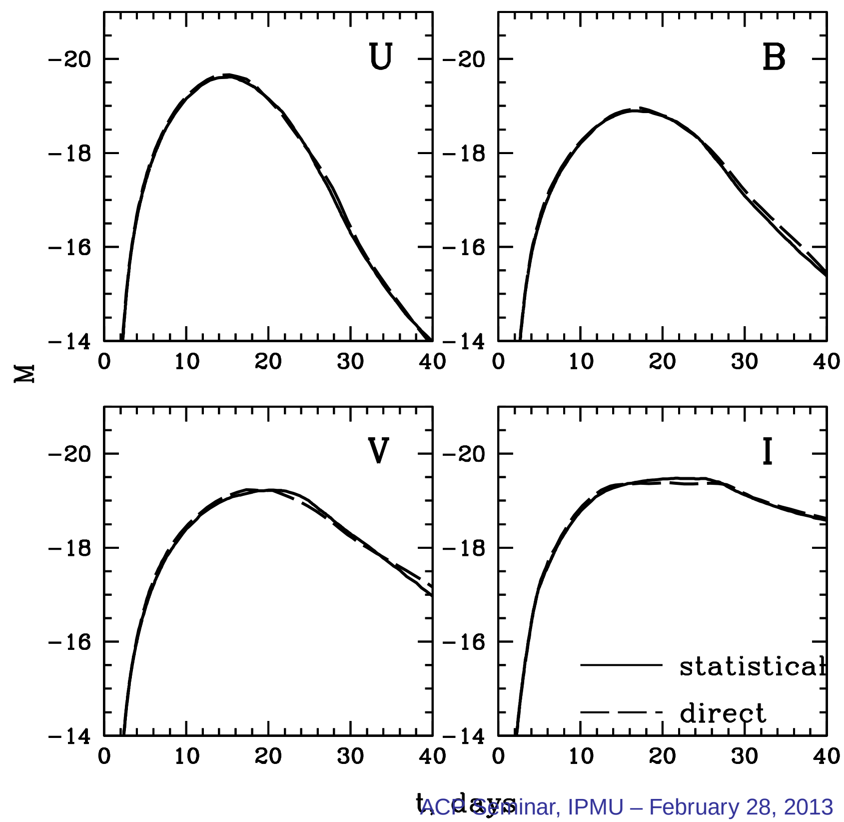
Light curves for W7

New method vs. LL-calculation

155 thousand lines

11 million lines (up to $gf = 10^{-3}$)





Conclusions

- We have developed a new method of opacity calculation for isotropically expanding medium in Sobolev approximation.
- Opacities and light curves calculated with the new method coincide rather good with the results derived with direct line-by-line integration of opacity.
- The light curve code becomes 2–3 orders of magnitude faster: now it requires 2–3 hours to produce a light curve instead of couple of months for the old version (for a line list of 26 million lines).

Conclusions

- We have checked the new method on calculation of SN Ia light curves. The applicability of this method to other types of SNe requires further investigation due to the following reasons:
  - The method is developed for a coasting stage of SN evolution ($\partial v/\partial r = v/r = 1/t$);
  - CCSNe produce mostly elements of the intermediate mass; the statistical method gives less accurate resuls for them;
  - CCSNe need wider range of temperatures and densities tabulated.