Global Parameters of Type Ia Supernovae

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DARK Cosmology Centre NBI

Global parameters

What do we know from observations about

- energy source, ^{56}Ni mass ?
- total mass ?
- explosion energy ?
- density ?
- element distribution ?

Stritzinger & Leibundgut, 2005, A&A, 431, 423
Stritzinger, Leibundgut, Walch & Contardo, 2006, A&A, 450, 241
Blinnikov, et al., 2006, A&A, 453, 229
Stritzinger, Mazzali, Sollerman & Benetti, 2006, A&A, 460, 793

Usual procedure

Take explosion model

density and element distribution and

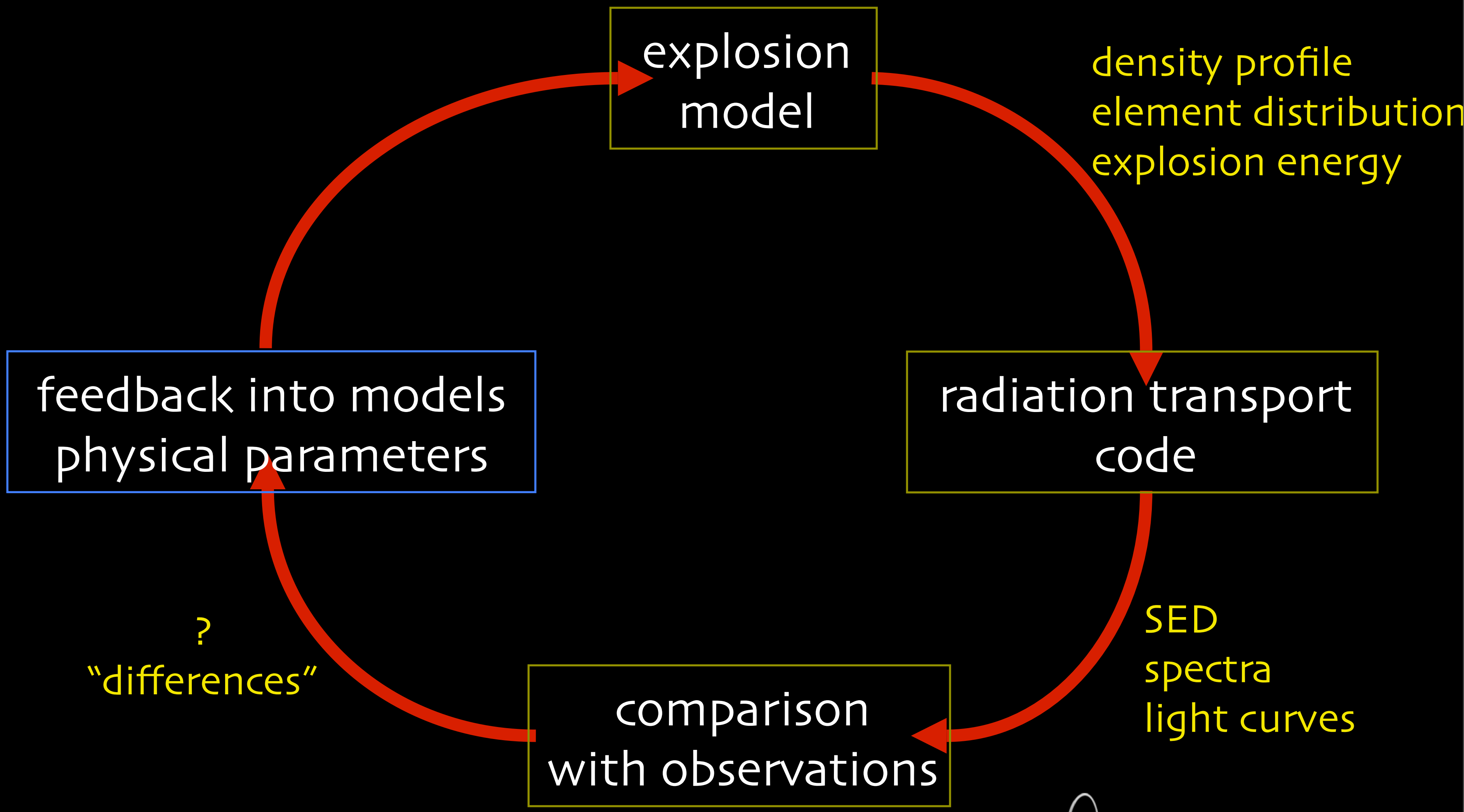
explosion energy

and calculate the emerging spectrum and SED

♣ always assume that you know the progenitor

usually Chandrasekhar mass white dwarf

Understanding SNe Ia



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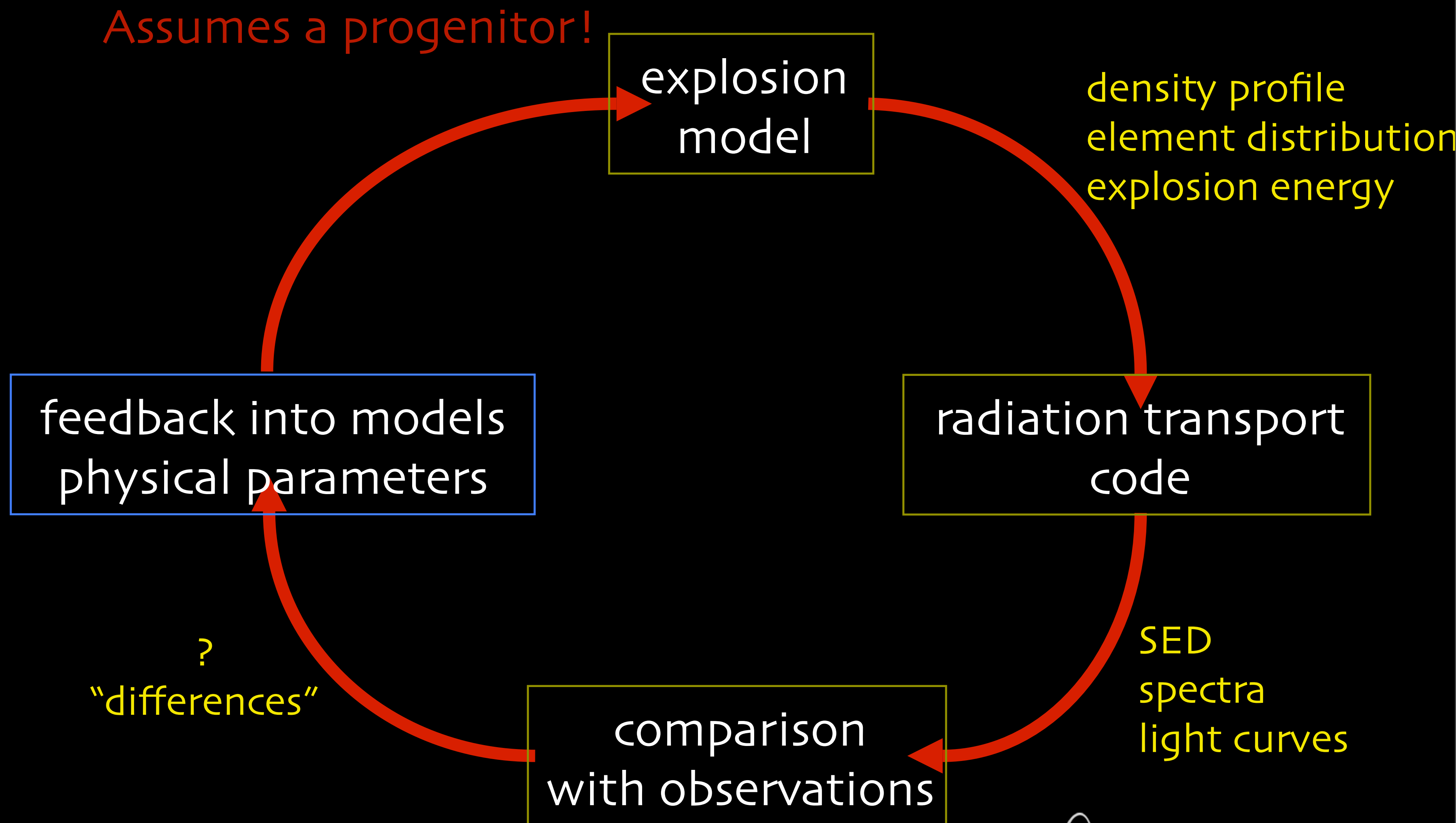
Understanding SNe Ia



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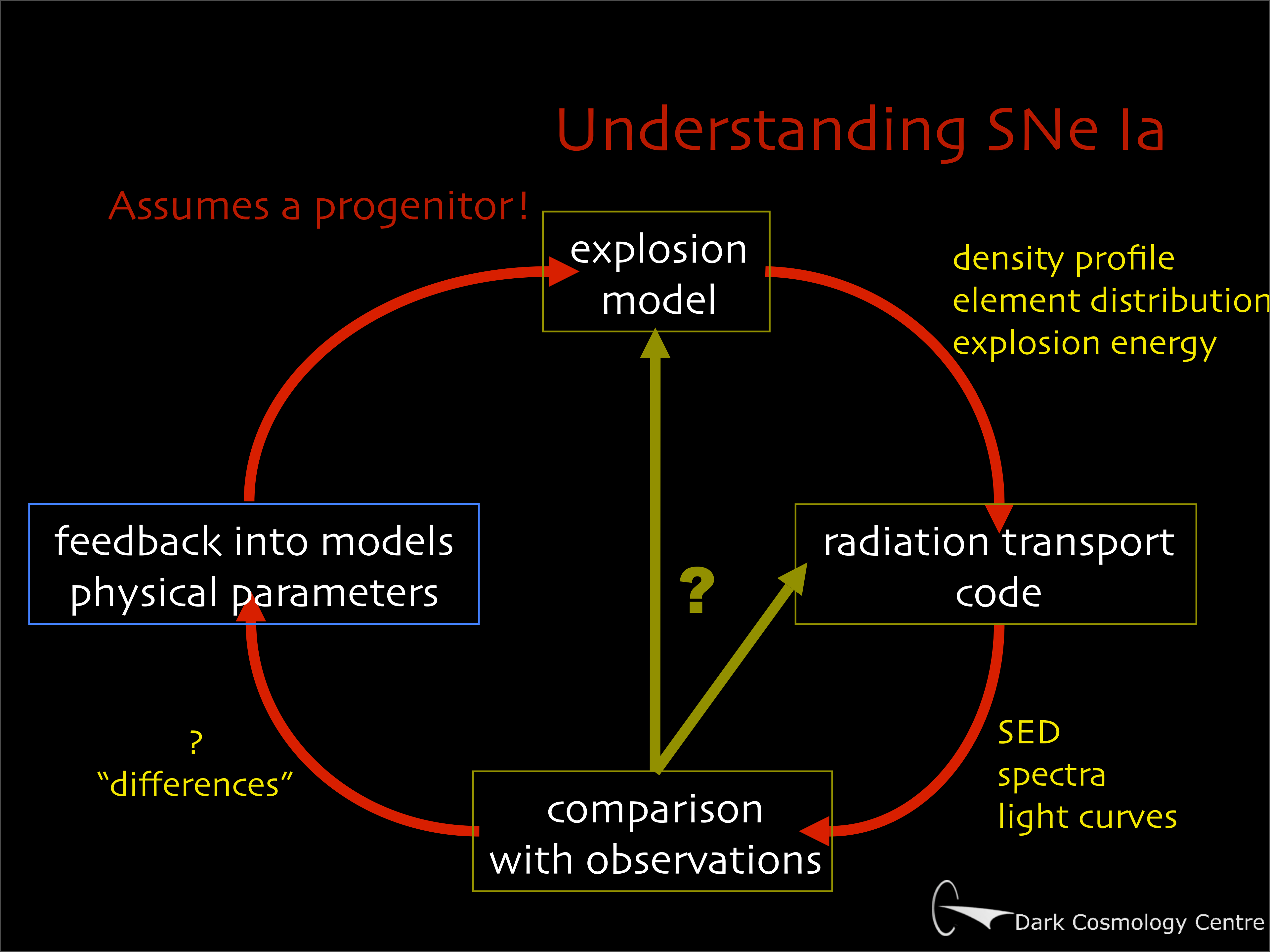
Understanding SNe Ia
Assumes a progenitor!
explosion model
density profile
element distribution
explosion energy
radiation transport code
?
SED
spectra
light curves
comparison with observations
?
"differences"
feedback into models physical parameters
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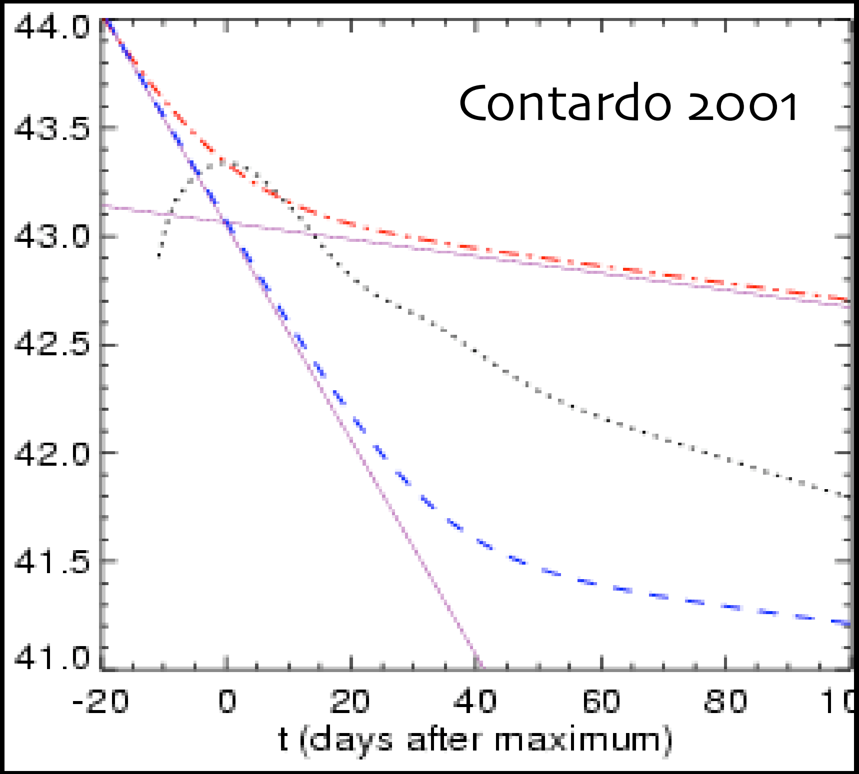
Can we do better?

Determine ^{56}Ni from the peak luminosity

Arnett`s law

Requires a bolometric luminosity

- multi filter observations
- distance



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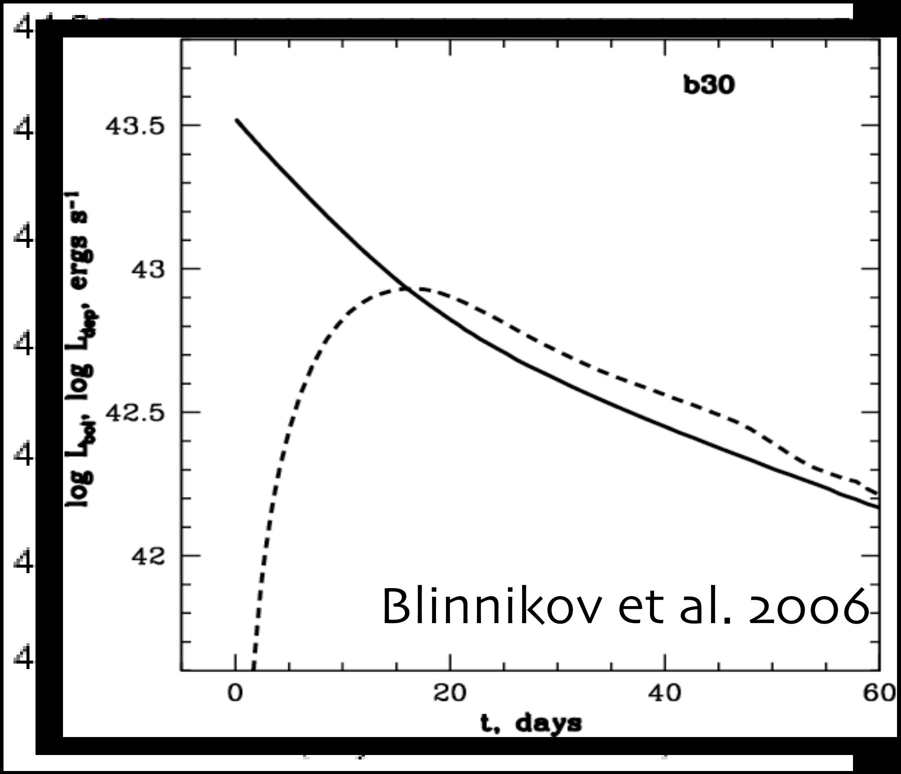

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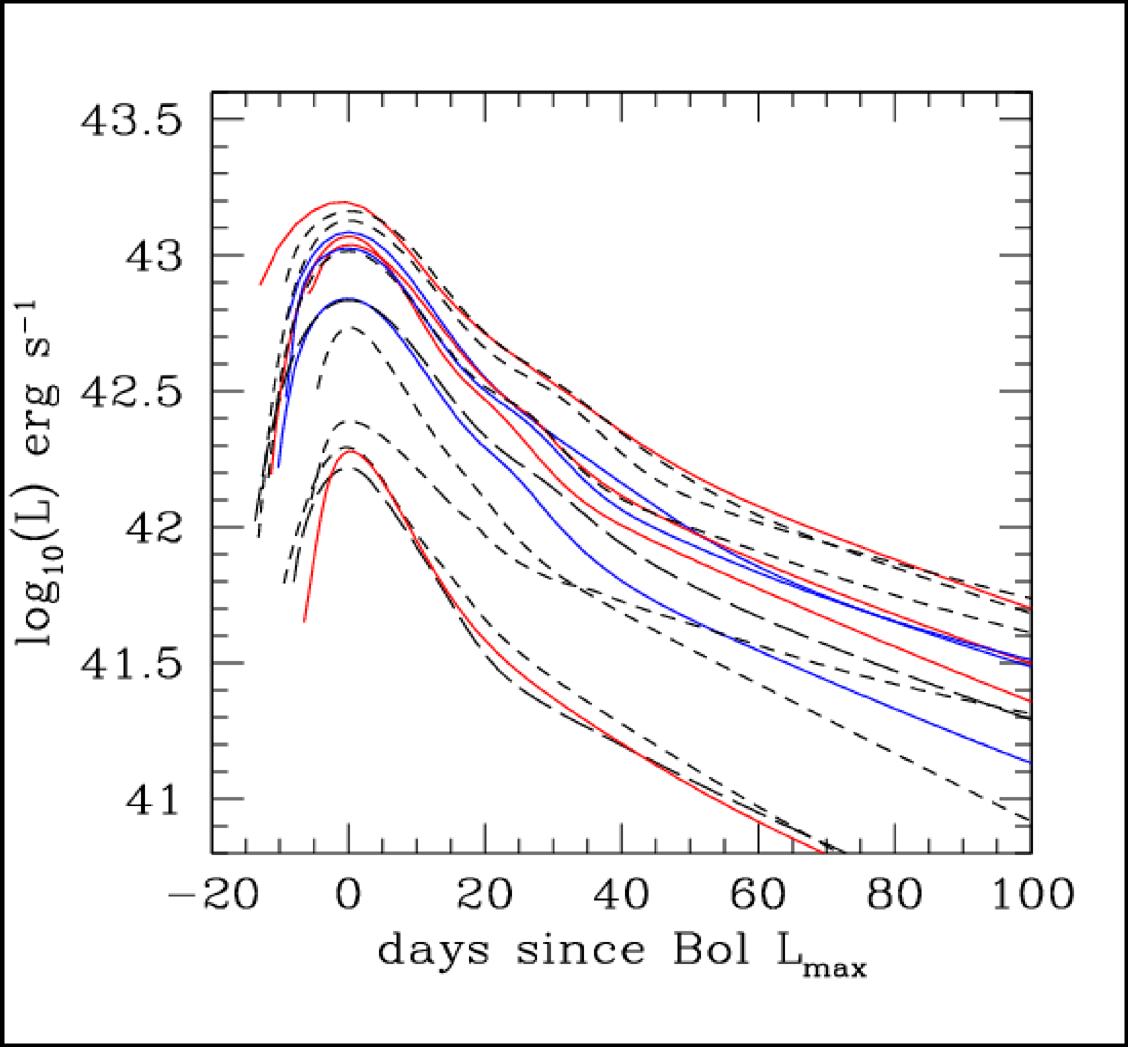
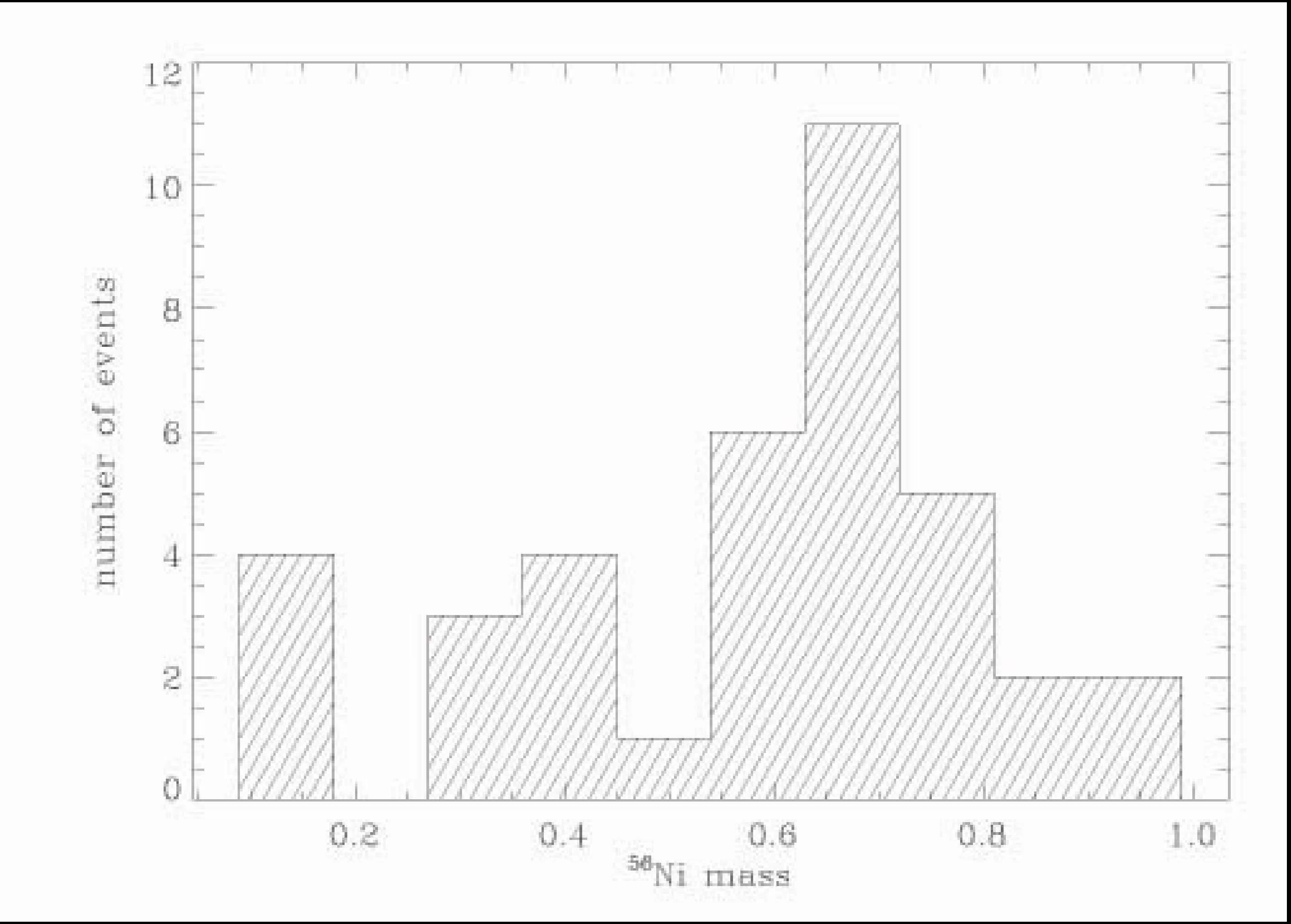
Bolometric light curves



^{56}Ni masses from light curves



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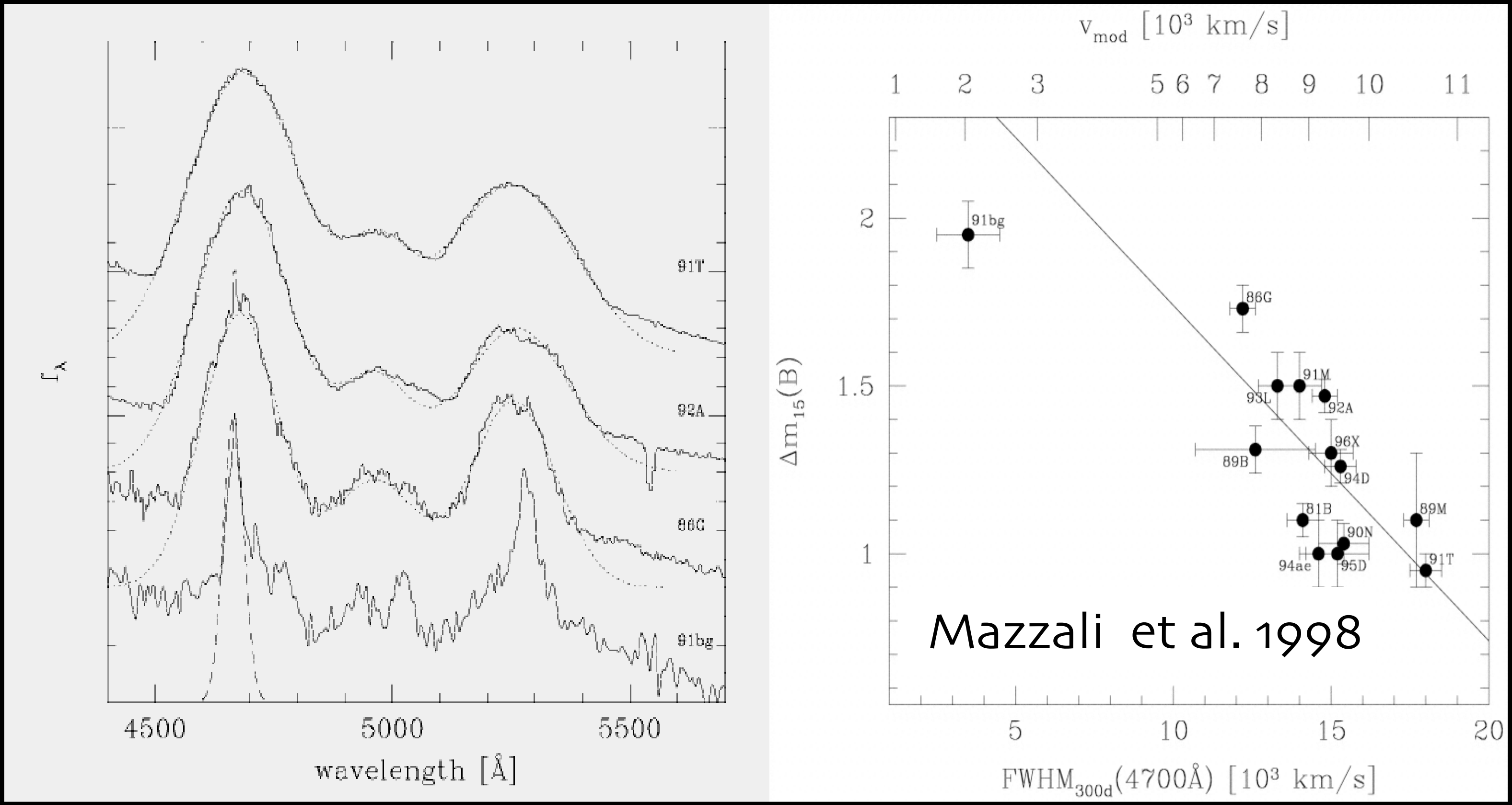
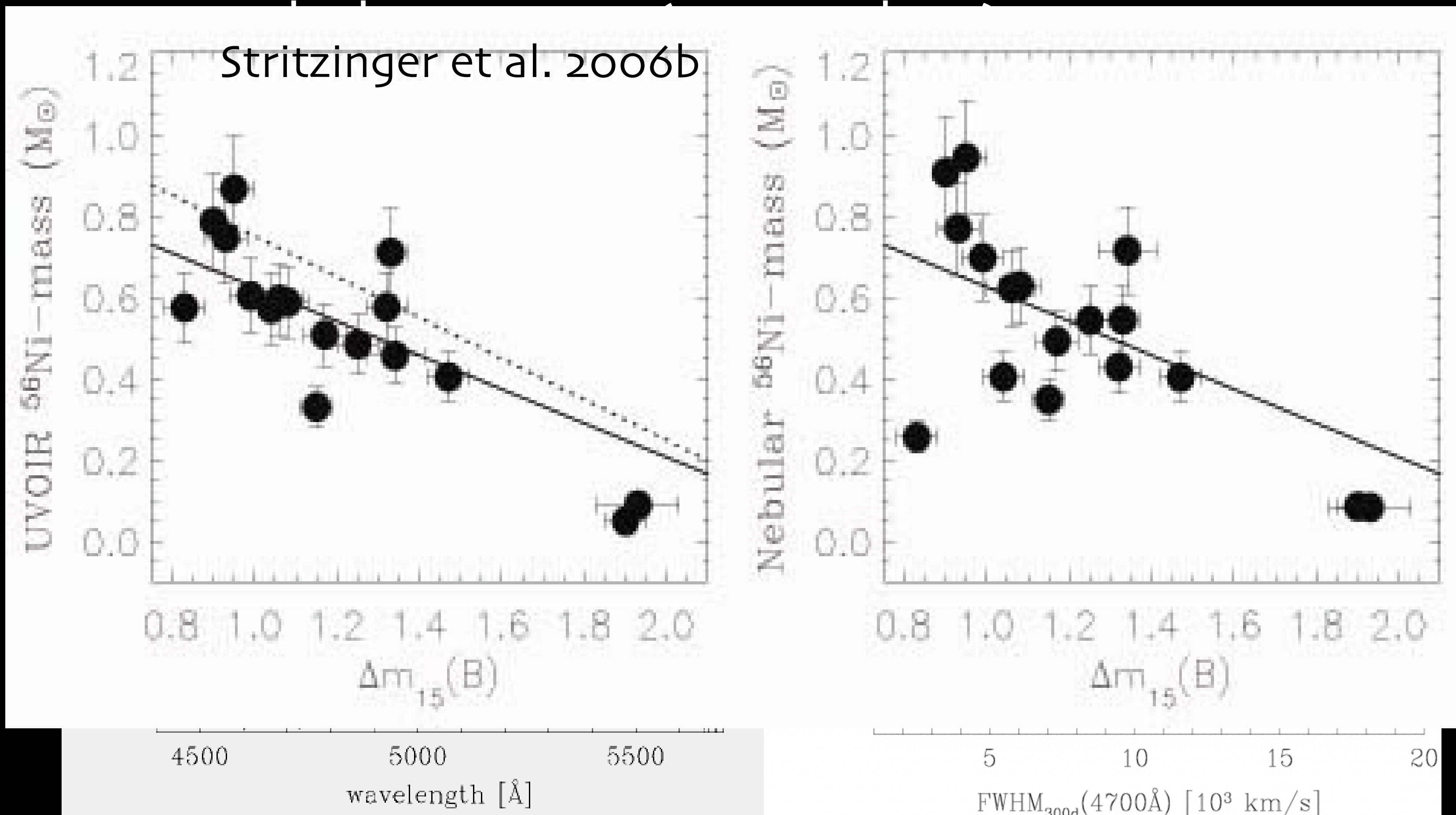
Check with a different method

Ni masses from the emission line in nebular spectra (t~300 days)



Check with a different method

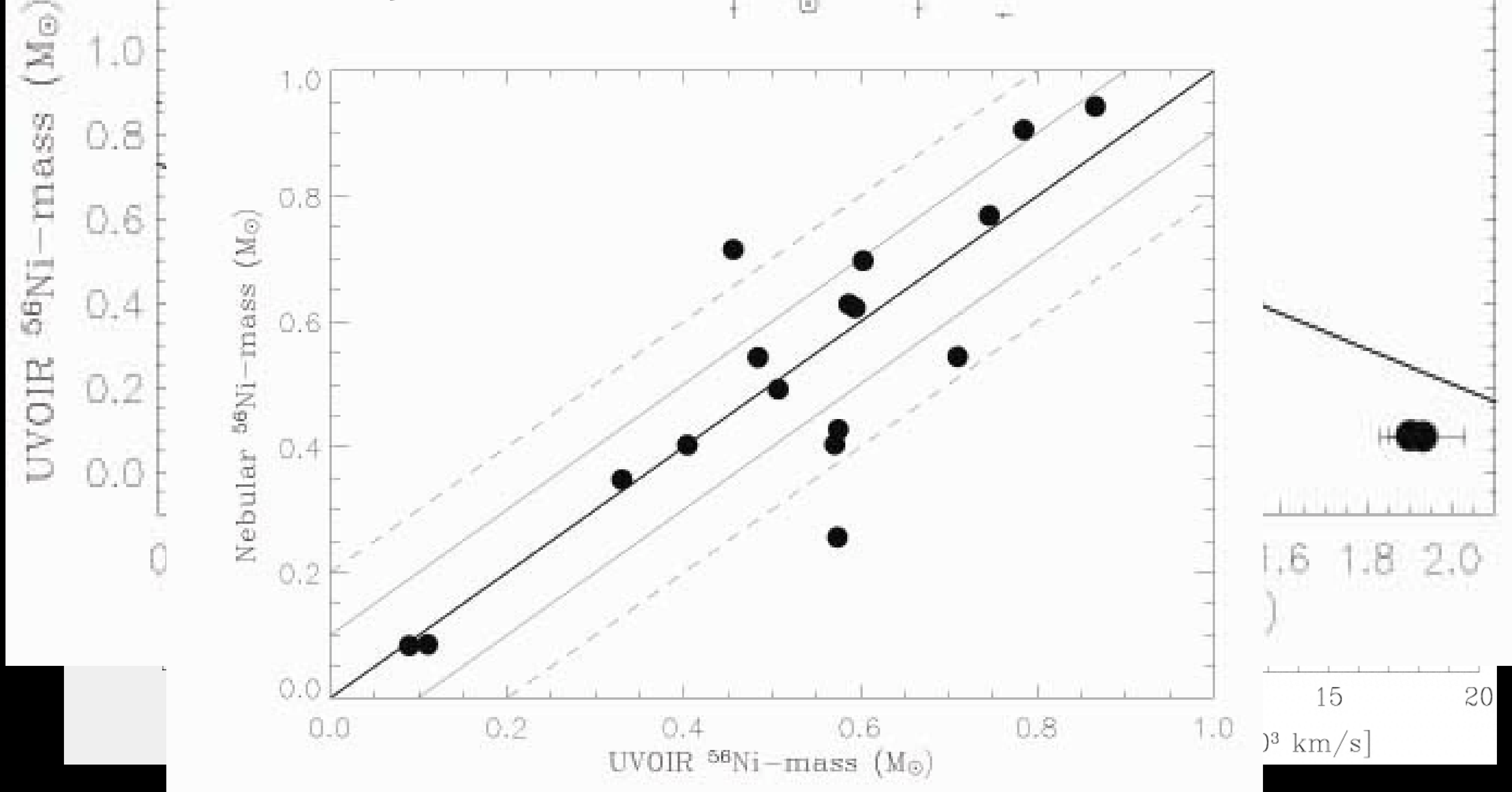
Ni masses from the emission line in



Check with a different method

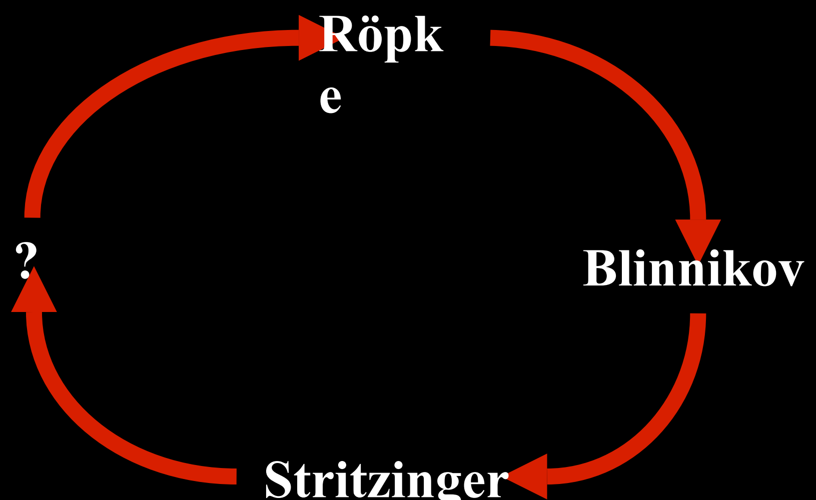
Ni masses from the emission line in

Stritzinger et al. 2006b



Check with models

Calculate the emission from explosion models (Röpke et al. 2004-2006) with a radiation transport code (STELLA – Blinnikov et al. 1998) and then derive the parameters from these "observations."



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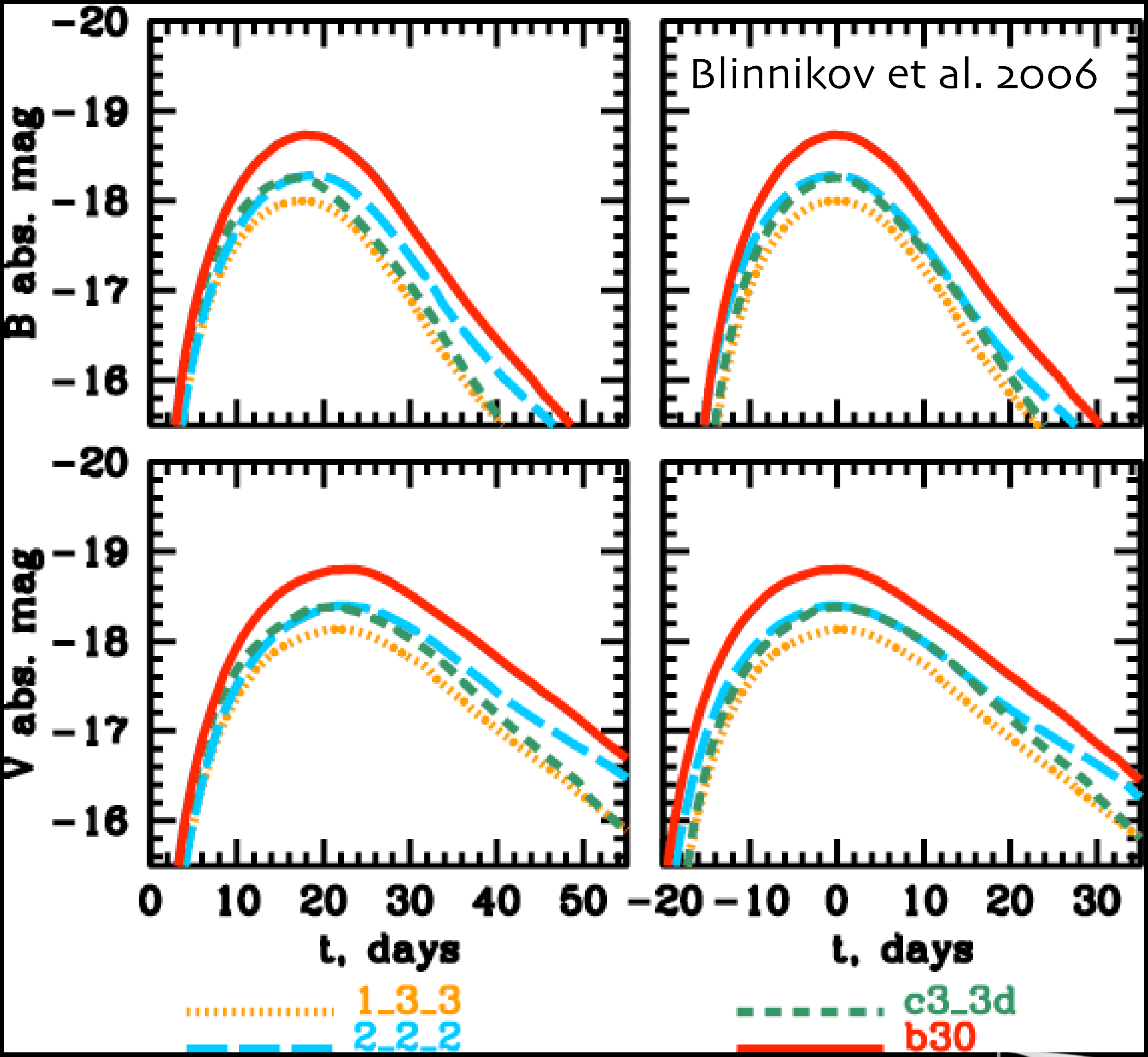
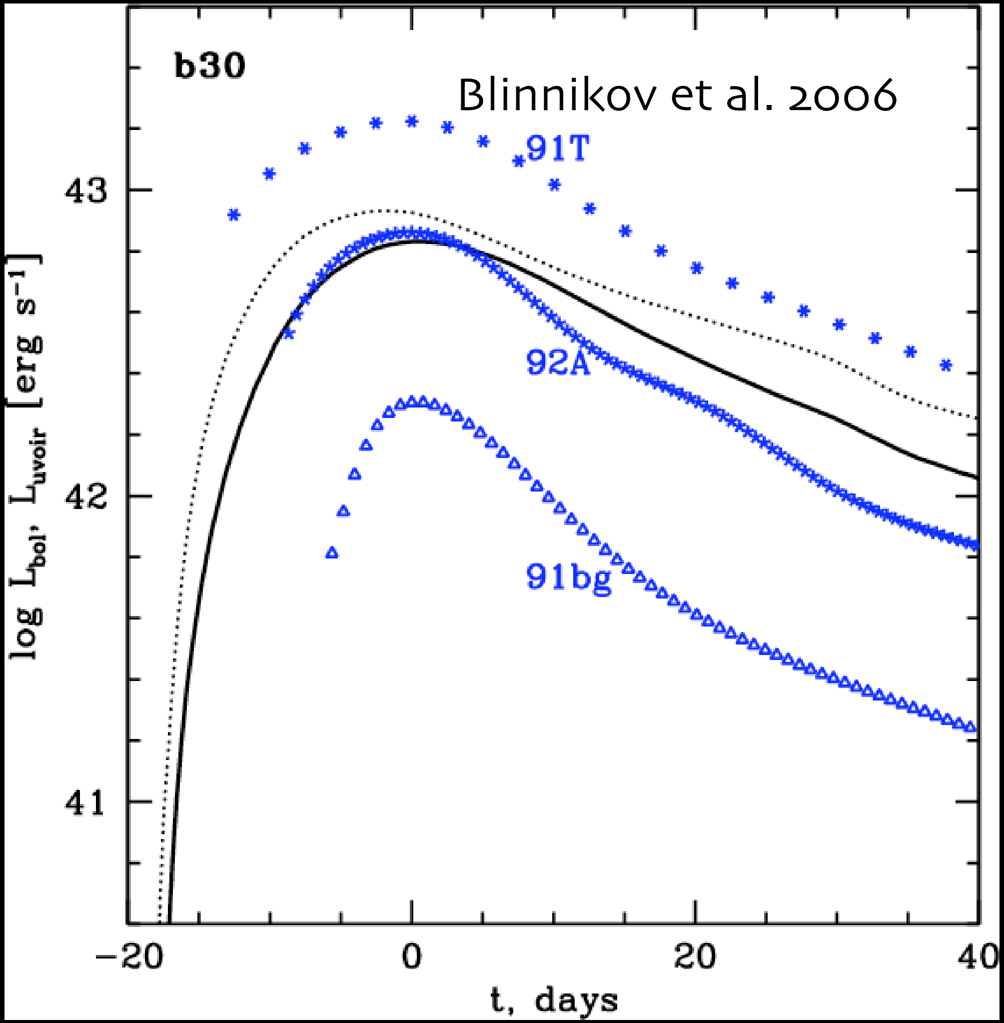


Comparison with real data

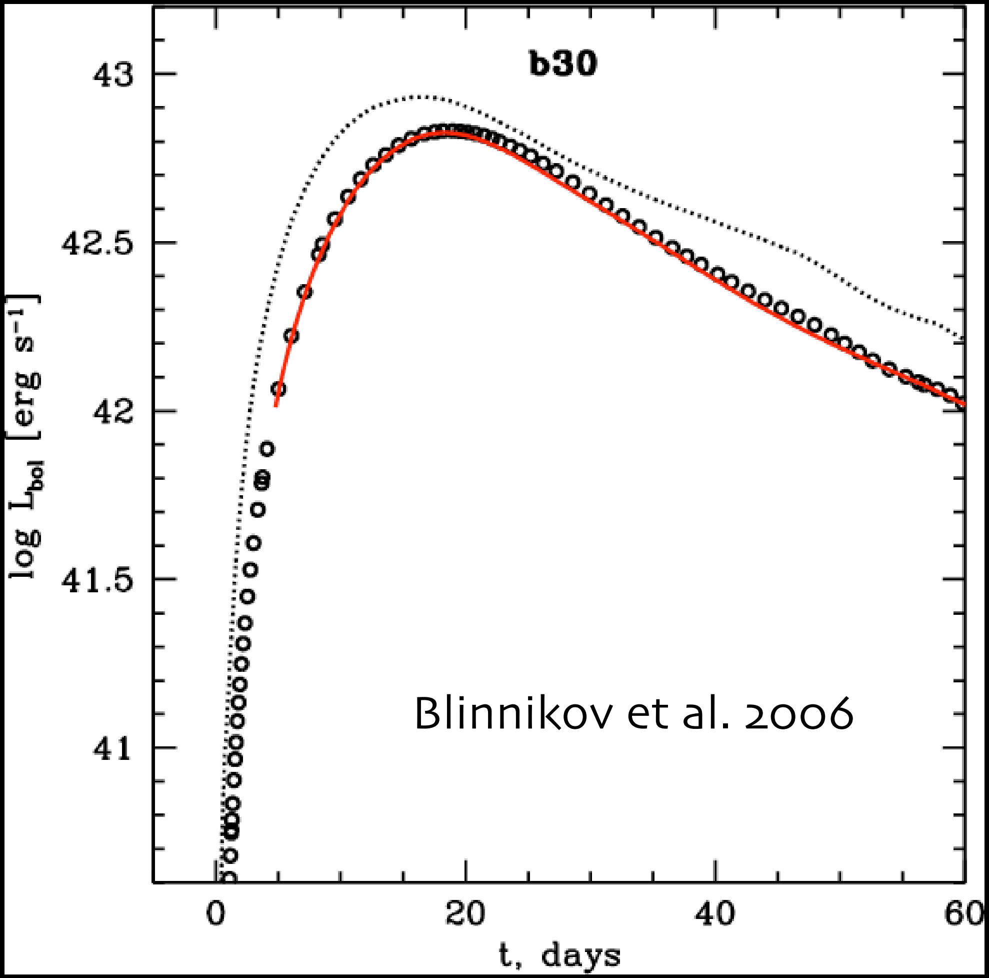


Check …

UVOIR light curve reproduced very well – validation of procedure in SL05

True bolometric light curve offset by about 15%

10% correction used is SL05 not quite right …



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Lower limits on H_0 from models of SNe Ia

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Determining H_o from models

- Hubble's law

$$D = \frac{v}{H_0} = \frac{cz}{H_0}$$

- Luminosity distance

$$D_L = \sqrt{\frac{L}{4\pi F}}$$

- Ni-Co decay

$$E_{Ni} = \frac{\lambda_{Ni}\lambda_{Co}}{\lambda_{Ni} - \lambda_{Co}} \left\{ \left[Q_{Ni} \left(\frac{\lambda_{Ni}}{\lambda_{Co}} - 1 \right) - Q_{Co} \right] e^{-\lambda_{Ni} t} + Q_{Co} e^{-\lambda_{Co} t} \right\} N_{Ni,0}$$

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H_0 from the nickel mass

$$H_0 = \frac{cz}{D} = cz\sqrt{\frac{4\pi F}{L}} = cz\sqrt{\frac{4\pi F}{\alpha E_{Ni}}} = cz\sqrt{\frac{4\pi F}{\alpha \varepsilon(t) M_{Ni}}}$$

α: conversion of nickel energy into radiation
($L=\boldsymbol{\alpha} E_{Ni}$)
ϵ (t): energy deposited in the supernova ejecta

Stritzinger & Leibundgut (2005)

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Hubble law

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Arnett's rule

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Ni-Co decay and rise time

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α: conversion of nickel energy into radiation ($L=\alpha E_{Ni}$)

ε(t): energy deposited in the supernova ejecta

Need bolometric flux at maximum F and the redshift z as observables

Stritzinger & Leibundgut (2005)

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Assumptions

Rise time (15-25 days)

→ about 10% uncertainty

Arnett's rule

energy input at maximum equals radiated energy (i.e. $\alpha \approx 1$, $\epsilon(t_{max}) \approx 1$)

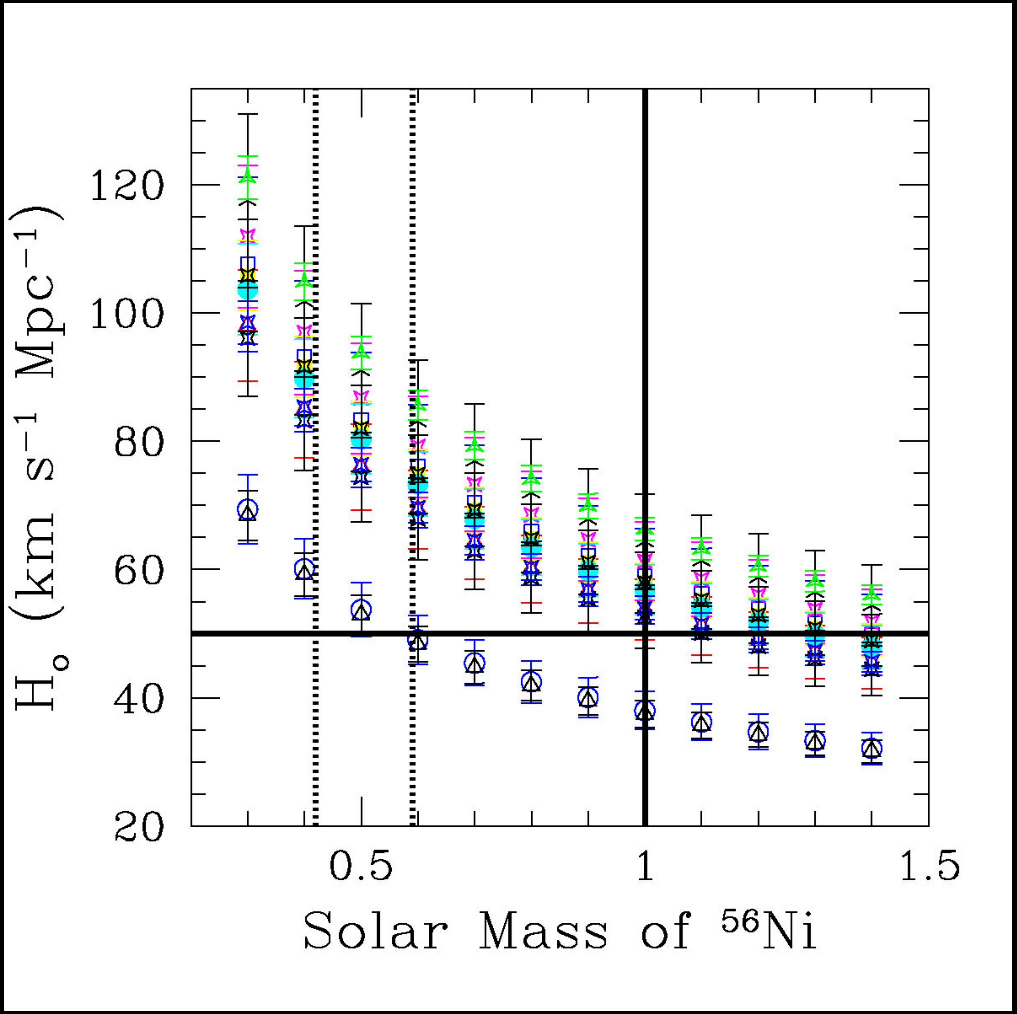
Nickel mass from models

→ uniquely defines the bolometric peak luminosity

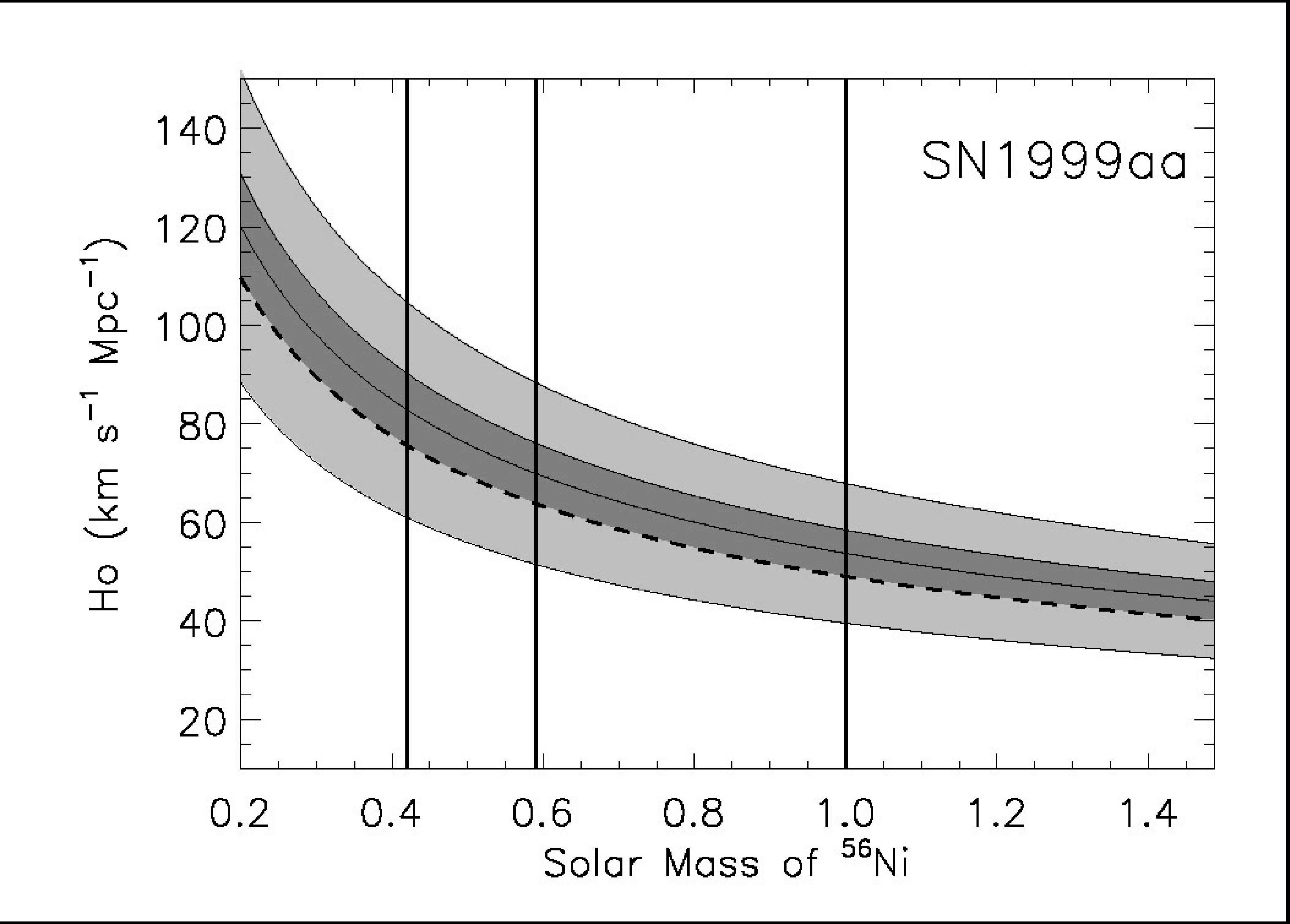
H_o and the Ni mass

Problem:

Since SNe Ia have individual Ni masses it is not clear which one to apply!



Determine a lower limit for H_o



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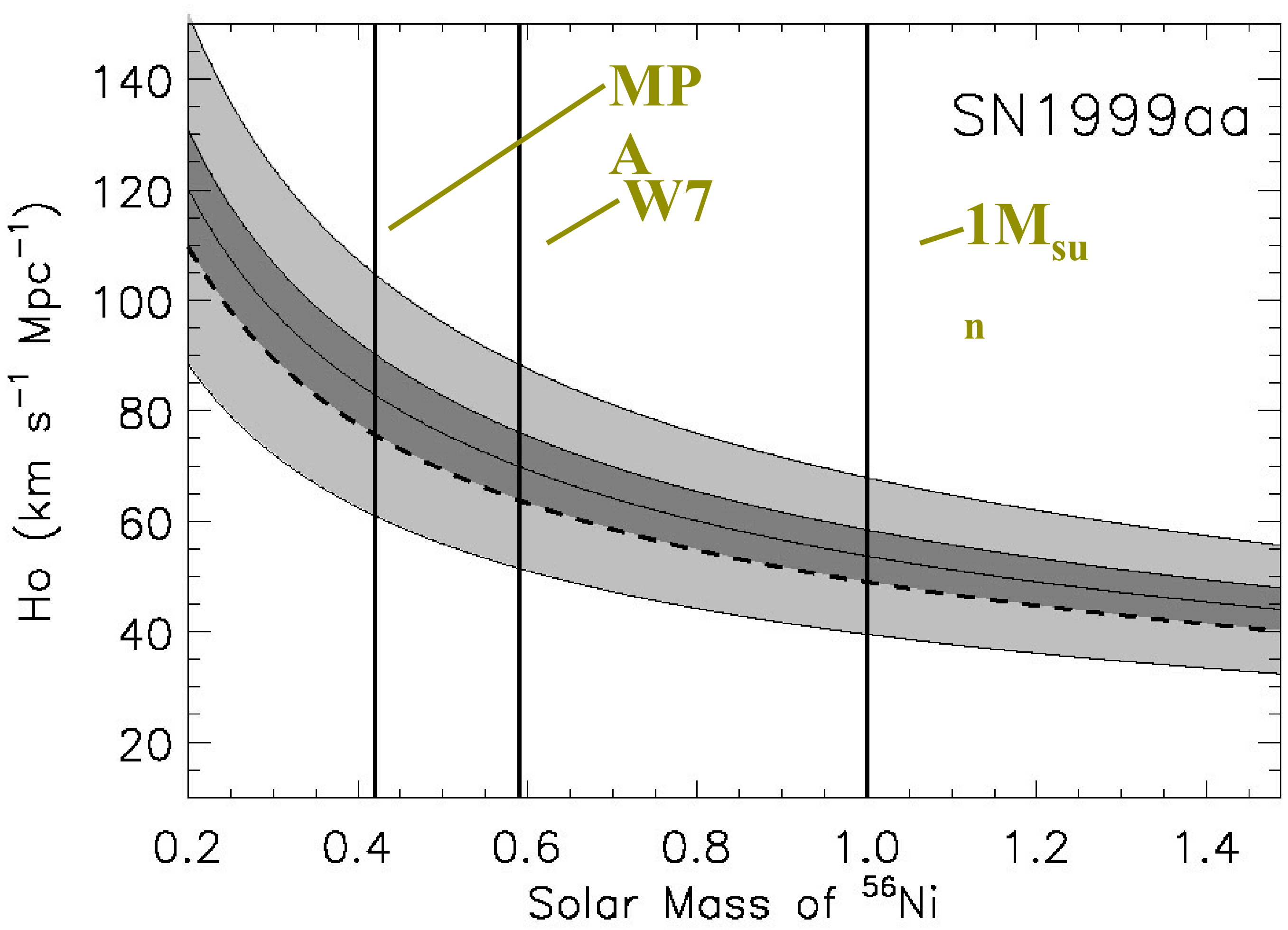

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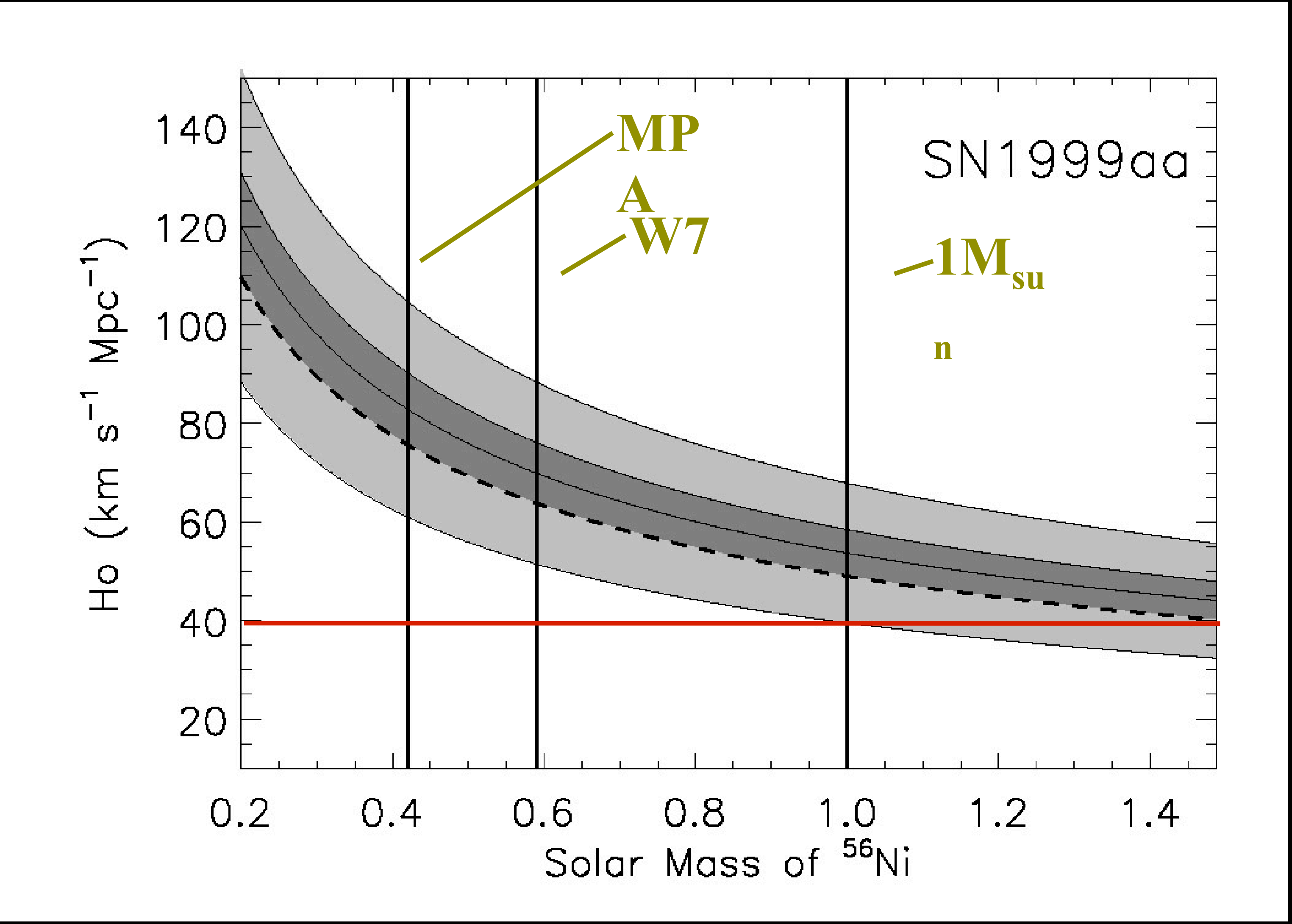

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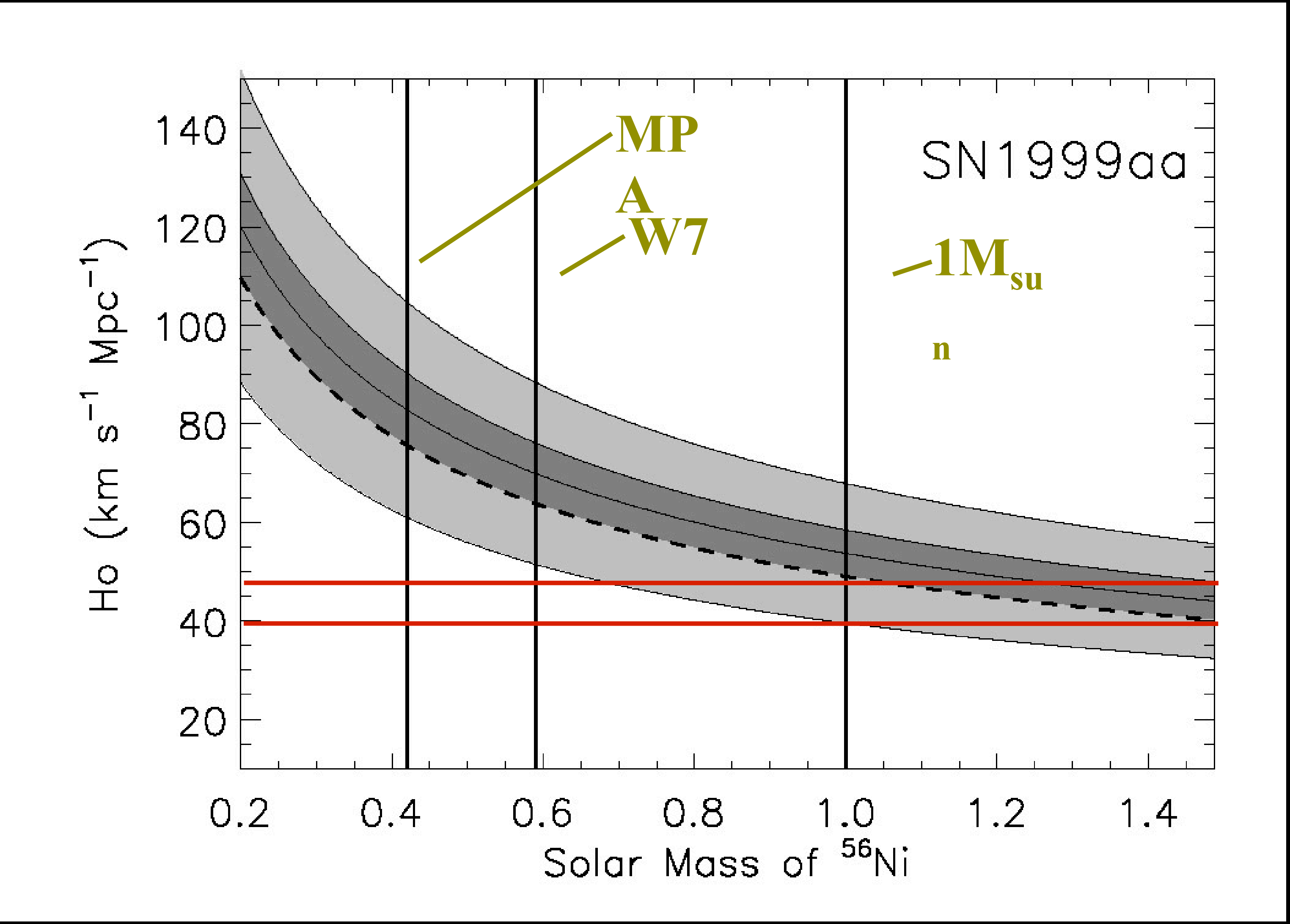

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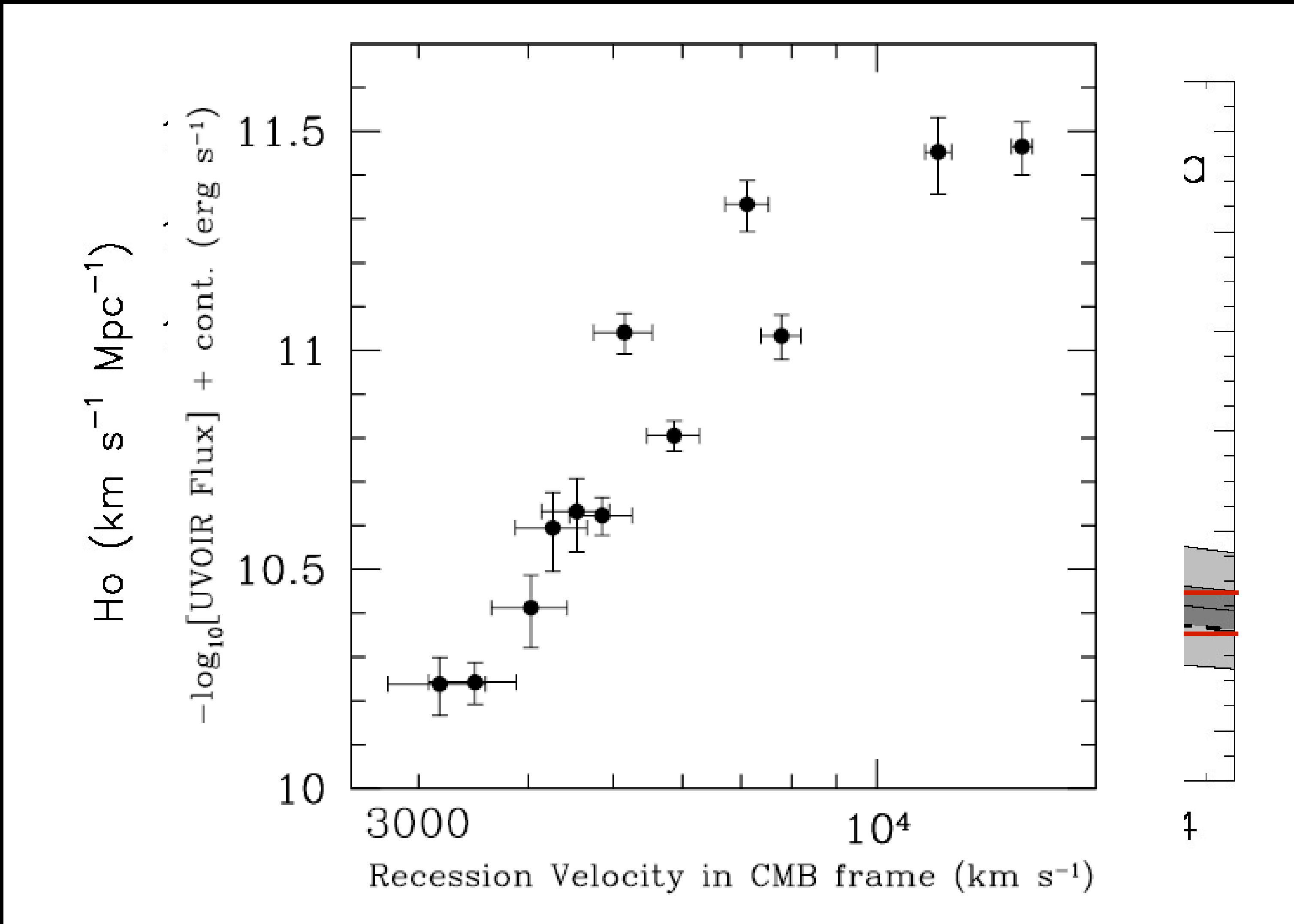
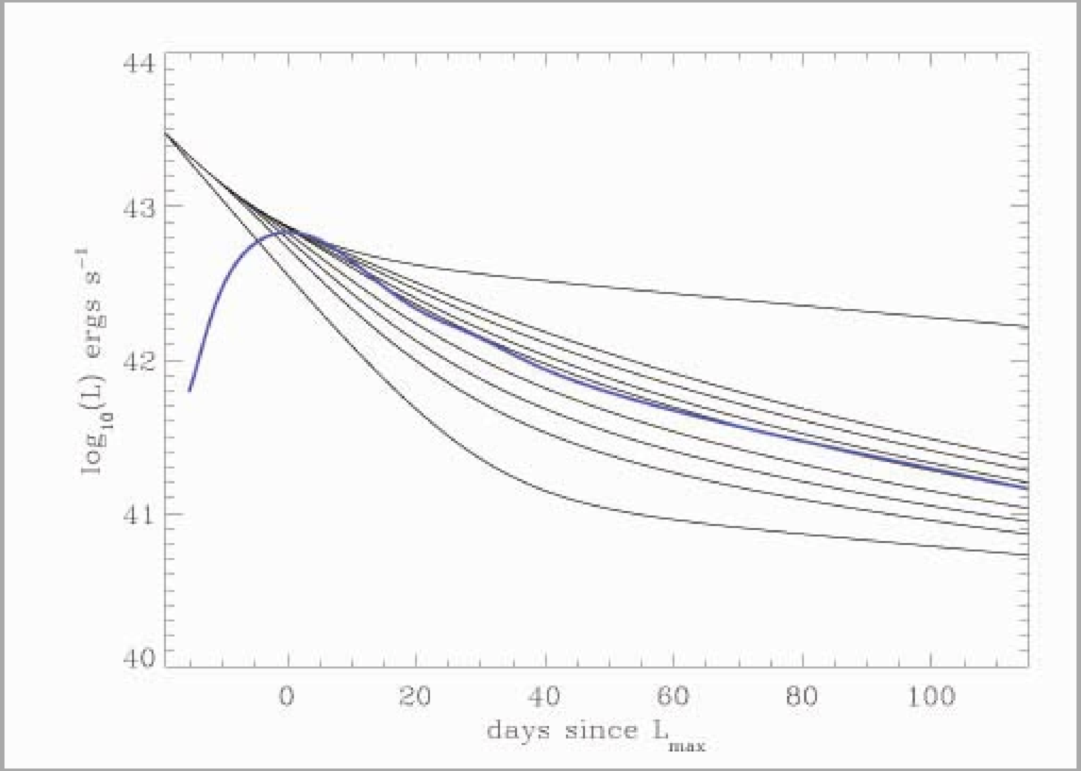


Ejecta masses from light curves

- γ-ray escape depends on the total mass of the ejecta

$$M_{ej} = \frac{8\pi}{\kappa q} t_0^2 v^2 \propto \frac{v^2}{\kappa q}$$

- v: expansion velocity
- κ: γ-ray opacity
- q: distribution of nickel



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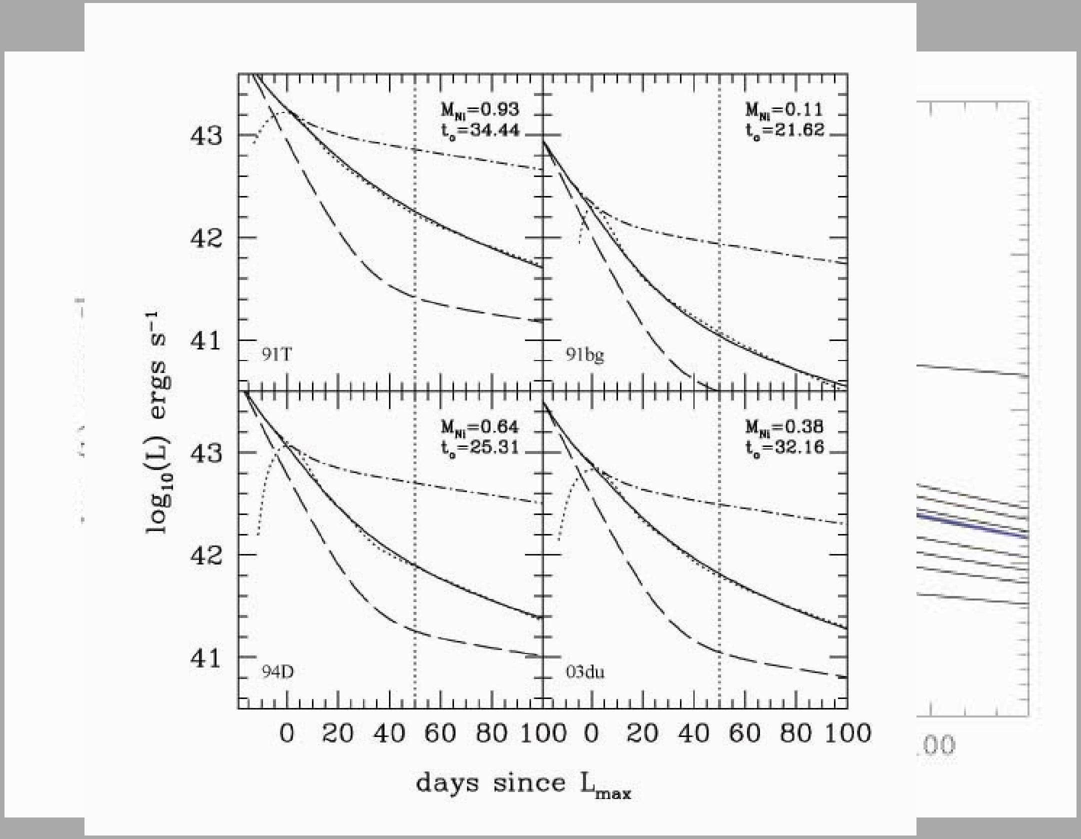
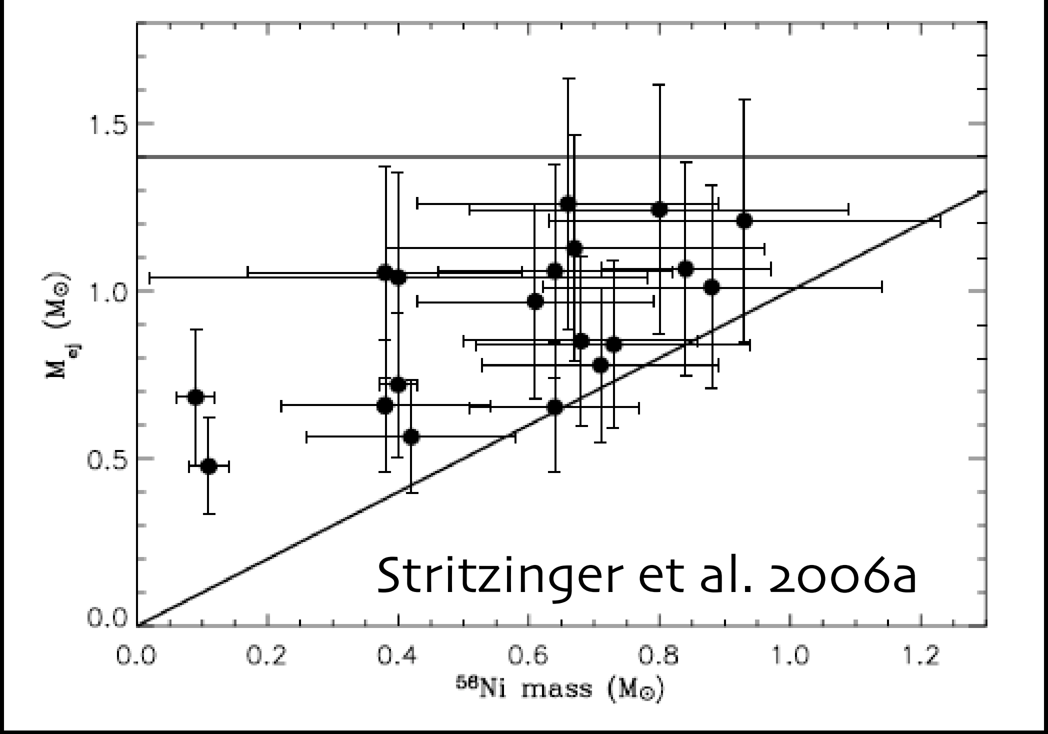


Ejecta masses

Large range in nickel and ejecta masses

- no ejecta mass at $1.4M_{sun}$
- factor of 2 in ejecta masses
- some rather small differences between nickel and ejecta mass



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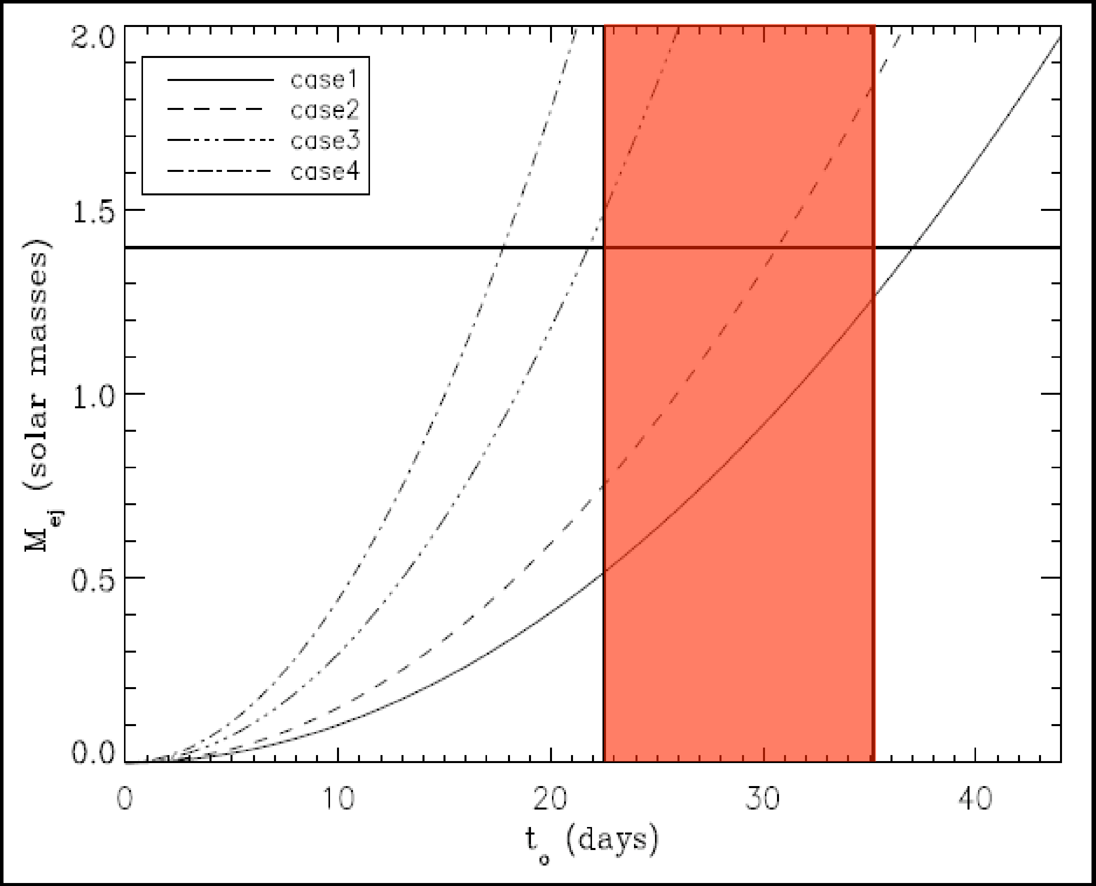
Dependence on explosion parameters

case 1: (fiducial)
- v=3000 km/s),
- κ=0.025 cm²/g and q=1/3

case 2:
- v=3625 km/s

case 3:
- v=3625 km/s,
- κ=0.0084 cm/g and
- q=1/2

case 4:
- v=3625 km/s,
- κ=0.0084 cm/g and
- q=1/3



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Summary

Arnett's rule is astonishingly good

→ determine the nickel mass in the explosion from the peak luminosity

→ large variations (up to a factor of 10)

→ lower limit on H_0 based on models: 50

Ejecta masses appear to scatter considerably

→ implications for progenitors?

→ model too simple ?

→ how can we improve?

Summary (cont.)

SNe Ia may be more varied than we like…

Differences in the explosions?

- density
- ignition
- asymmetries
- progenitor mass
- metallicity

Very Late-time Emission

◊ Nucleosynthesis of radioactive and stable elements and their distribution

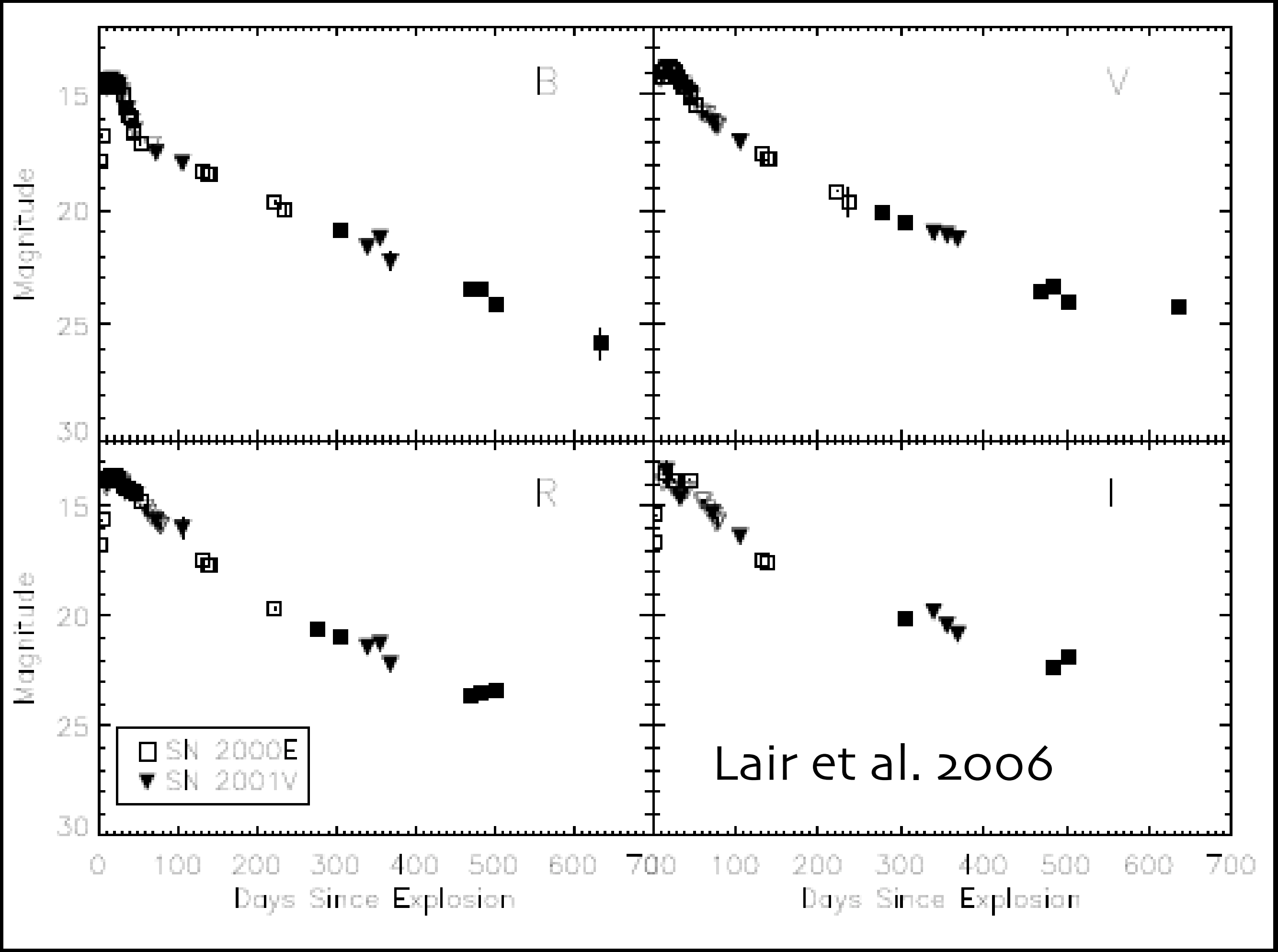
◊ Unique opportunity to probe the magnetic field structure/ configuration

- A weak/radially combed magnetic field
  ---> no deposition of positrons
- A strong/tangled magnetic field
  --> depostion of positrons

◊ Constrain positron's contribution to the Galactic 511 KeV line

◊ Study physics of freeze-out and the IR-catastrophe

Late-time optical light curves



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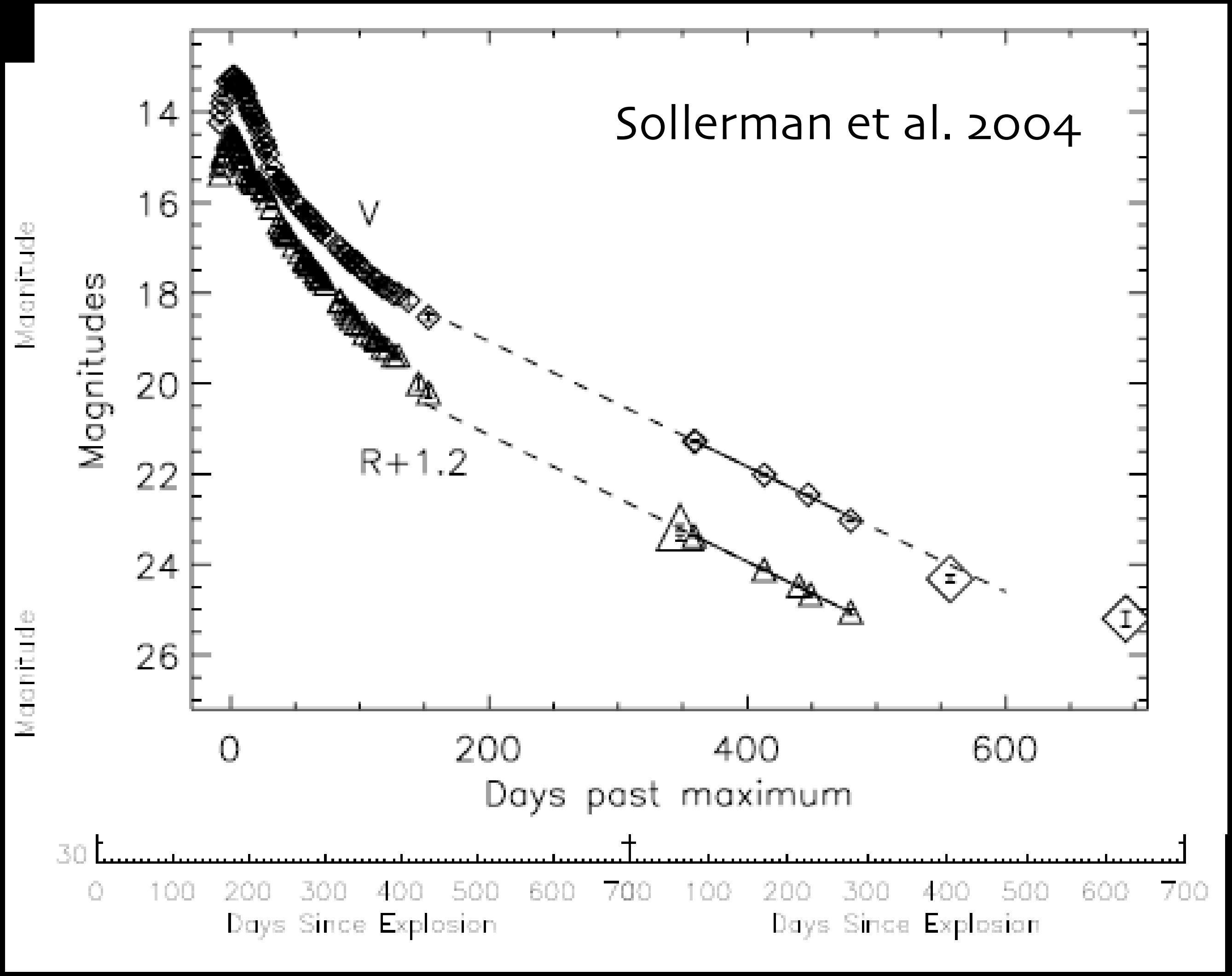

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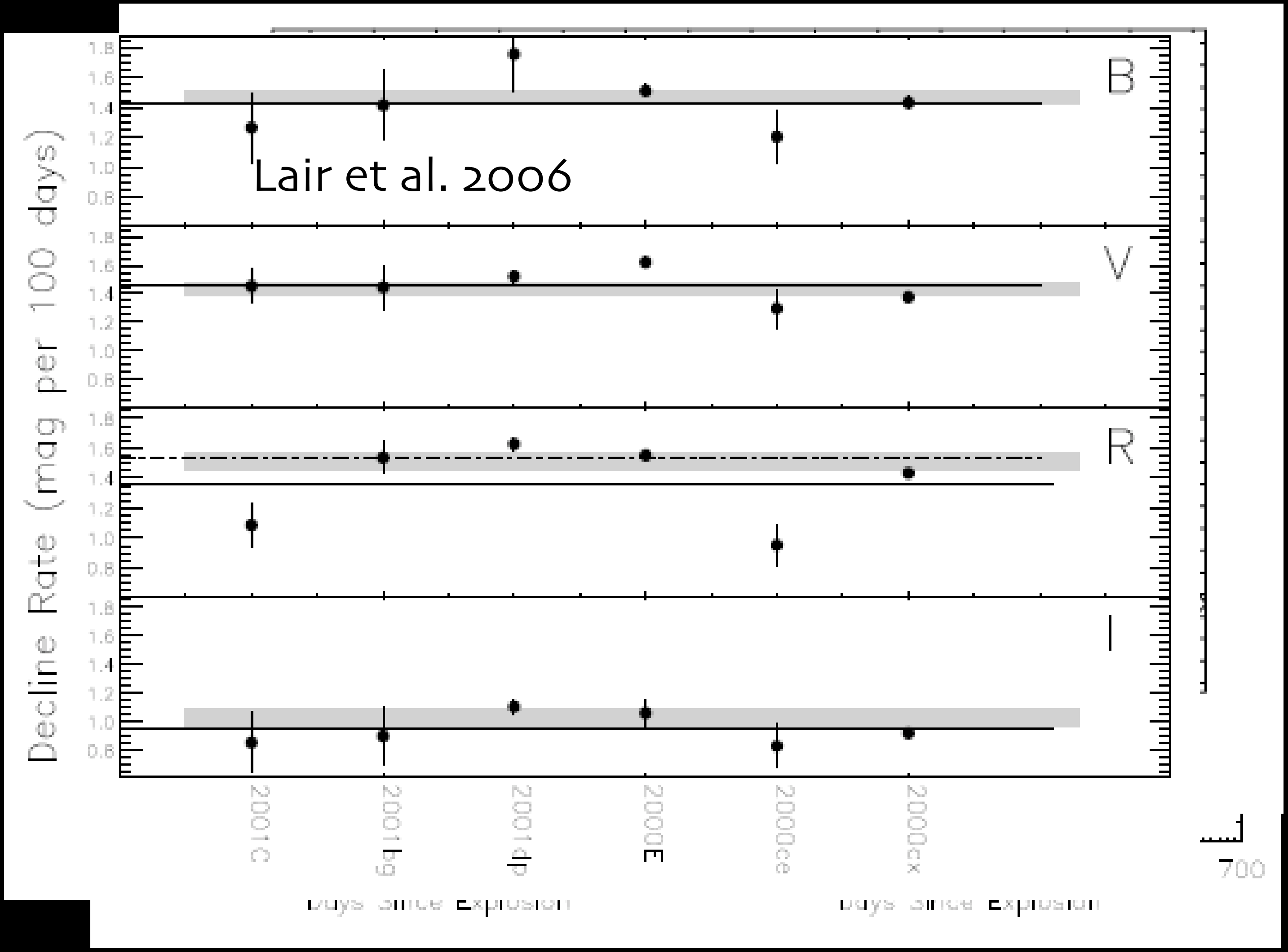

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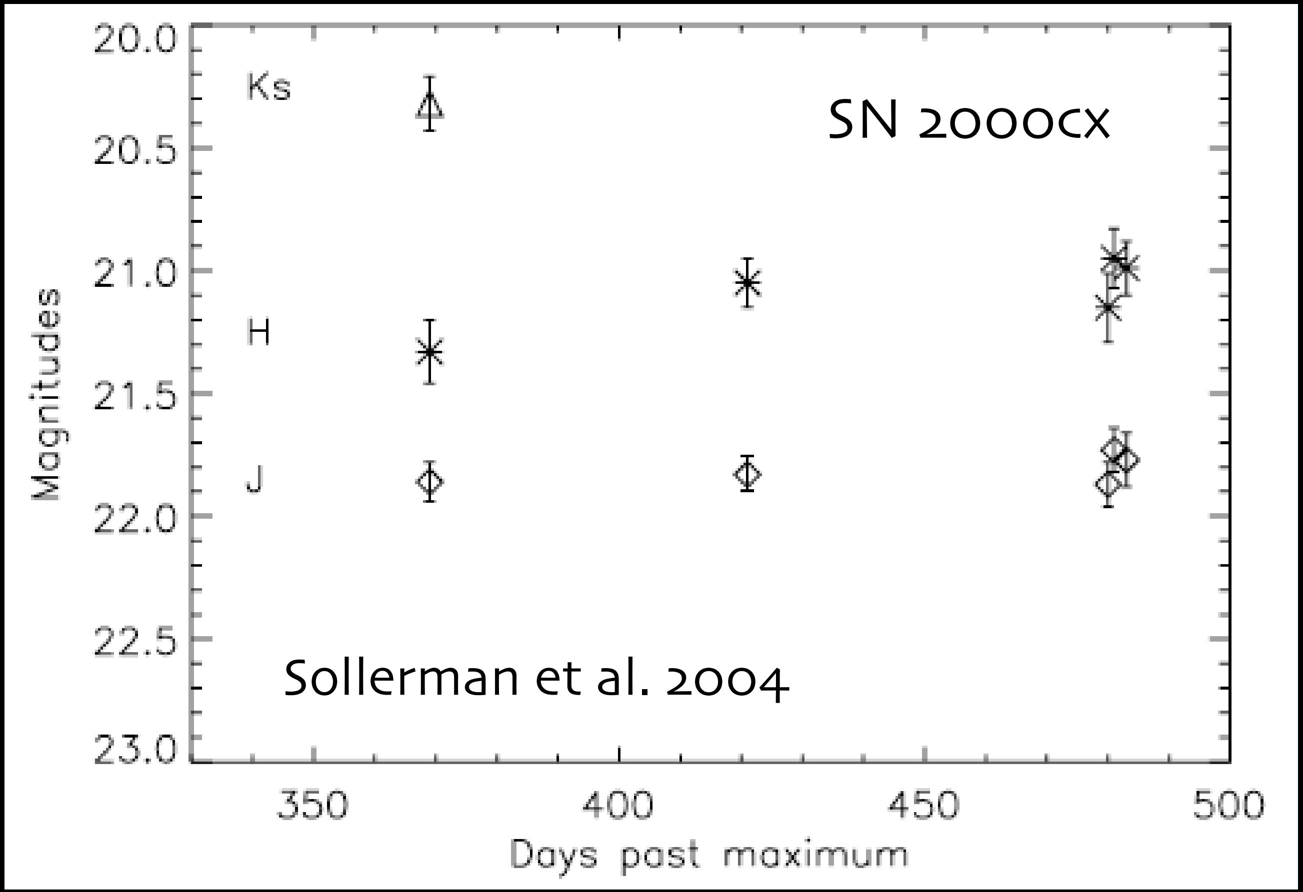
Late-time emission in IR



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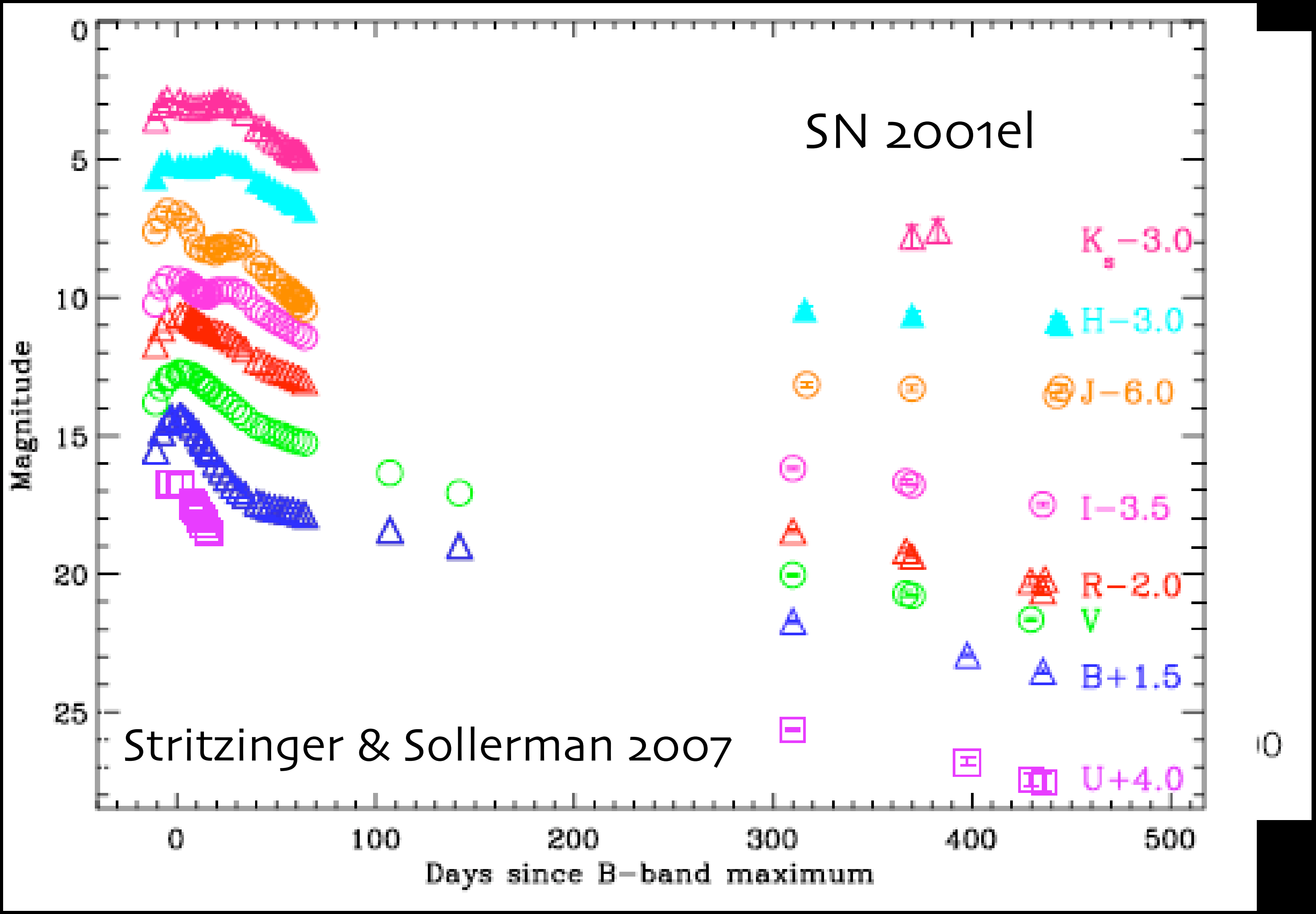

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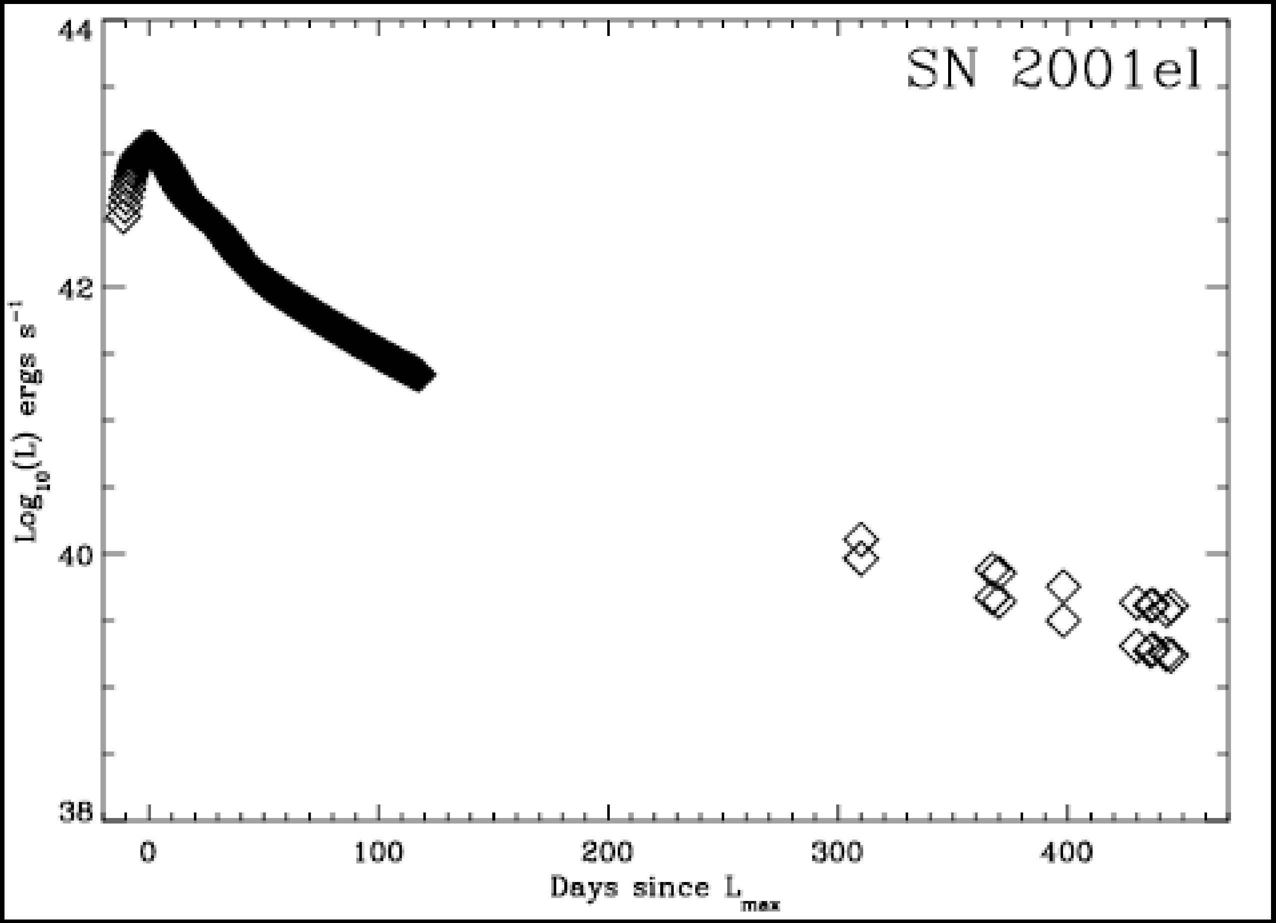
Late-time energetics



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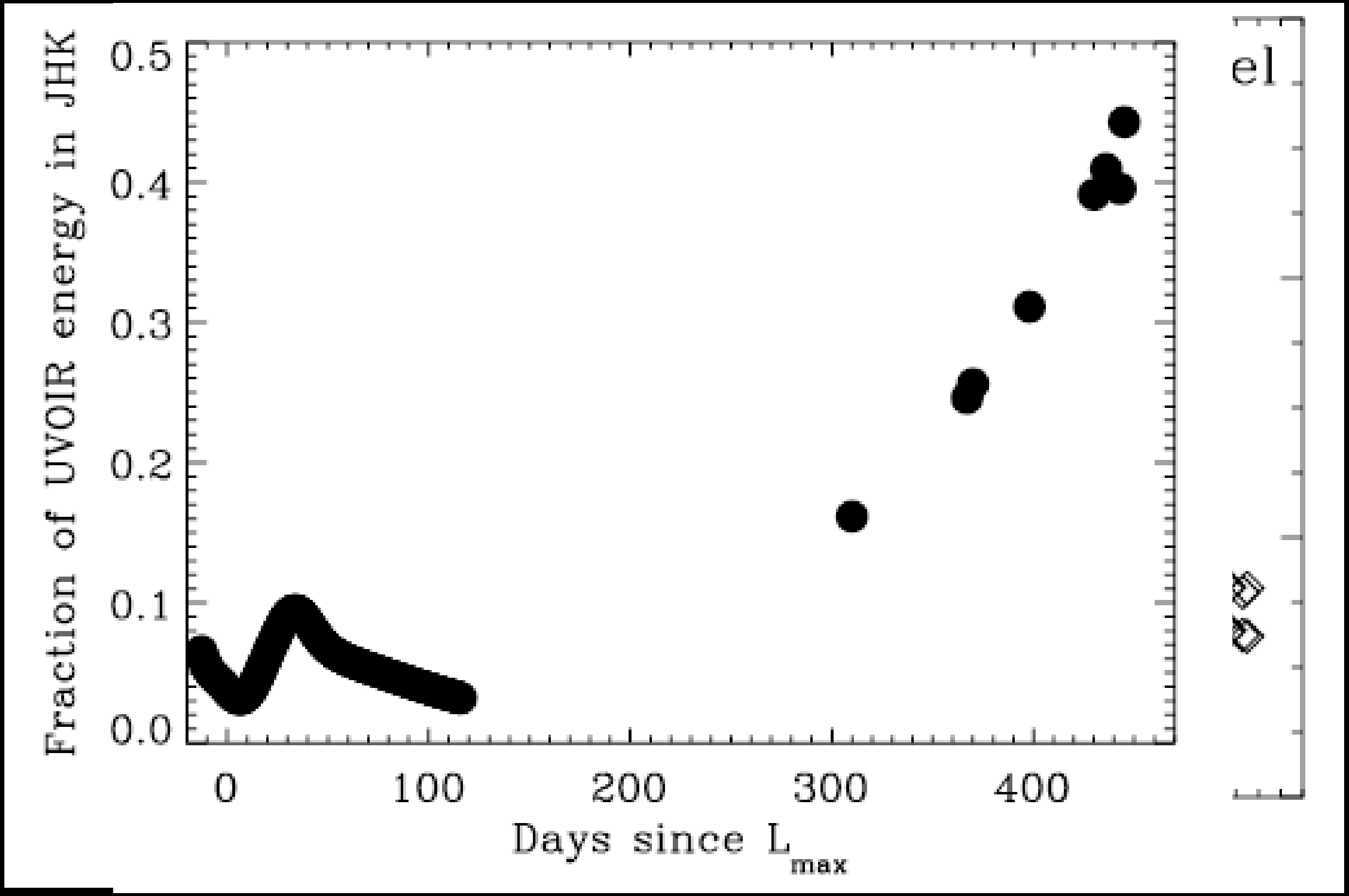

Summary

- increase importance of the IR during late-times is a generic feature of normal Ia's
- pervious conclusions of positron escape based on optical photometry alone are incorrect