Title: The Contributions (and Limitations) of Type Ia Supernovae to Cosmology

Date: Sep 13, 2007 09:30 AM

URL: http://pirsa.org/07090047

Abstract: The cosmological power of Type Ia Supernovae depends on their ability to determine distances. The astrophysical limitations, like reddening, local velocity inhomogeneities and intrinsic variations, are a severe impediment for the cosmological applications of these cosmic explosions. Overcoming these systematic restrictions must be the goal of any future supernova projects.

Contributions (and Limitations) of Type Ia Supernovae to Cosmology

Bruno Leibundgut

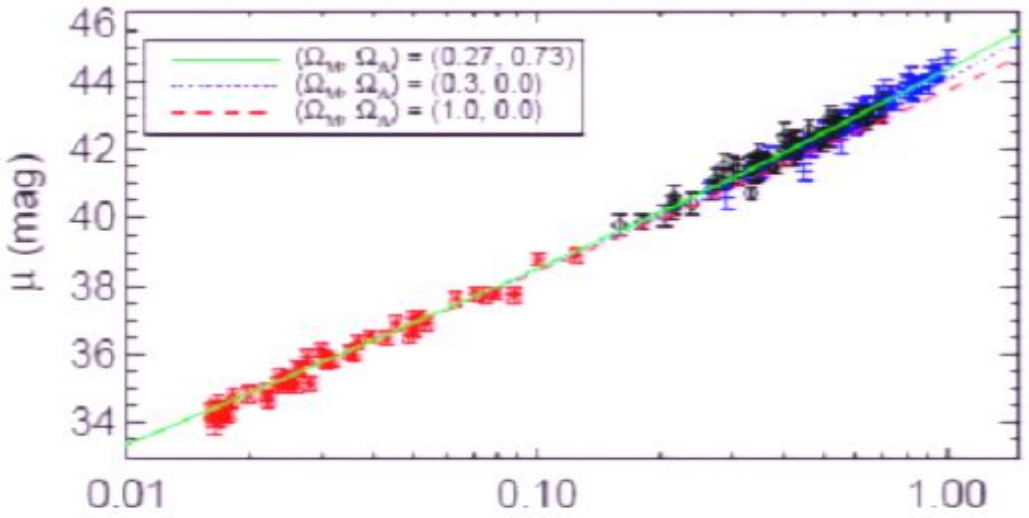
European Southern Observatory

The Astrophysics of Type Ia Supernova Cosmology

Bruno Leibundgut

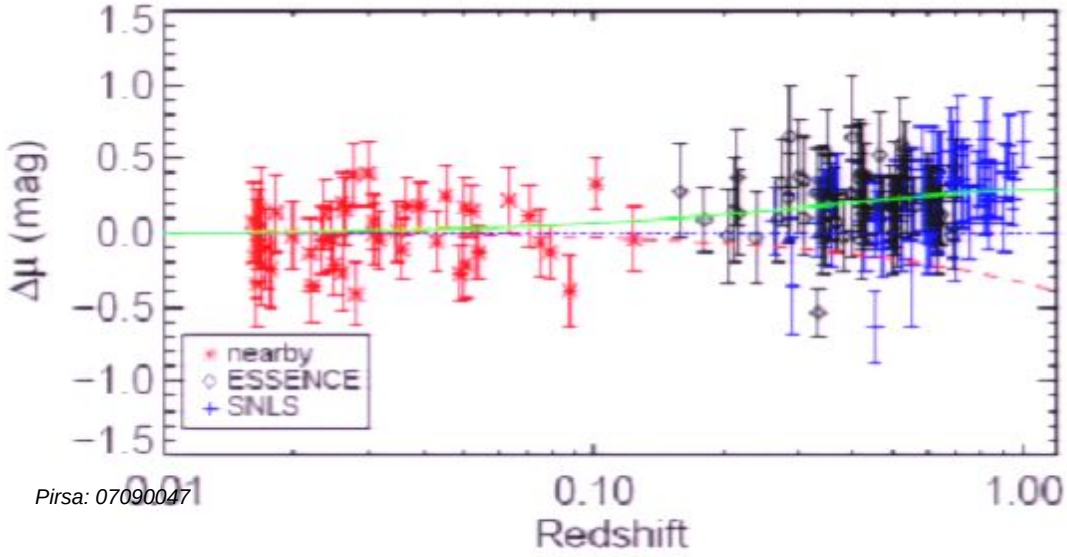
European Southern Observatory

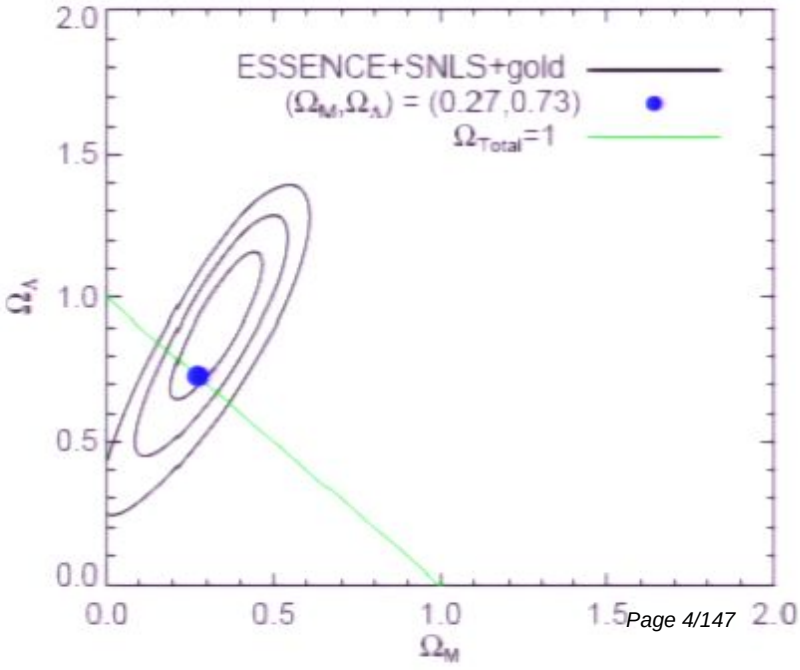
The SN Ia Hubble Diagram



Combination of ESSENCE, SNLS and nearby SNe Ia

Wood-Vasey et al. 2007





Current surveys

SNLS

- Astier et al. 2006 – 71 distant SNe Ia
- various papers describing spectroscopy (Lidman et al. 2006, Hook et al. 2006, Bronder et al. 2008), rise time (Conley et al. 2006) and individual SNe (Howell et al. 2006)

ESSENCE

- Wood-Vasey et al. 2007 – 60 distant SNe Ia
- Miknaitis et al. 2007 – description of the survey
- Davis et al. 2007 – comparison to exotic dark energy proposals
- spectroscopy (Matheson et al. 2005, Blondin et al. 2006)

Cosmology results

SNLS 1st year (Astier et al. 2006)

- **71 distant SNe Ia**
  - flat geometry and combined with BAO results

Ω_M = 0.271 ± 0.021 *(stat)* ± 0.007 *(sys)*

w* = -1.02 ± 0.09 *(stat)* ± 0.054 *(sys)

ESSENCE 3 years (Wood-Vasey et al. 2007)

- **60 distant SNe Ia**
  - plus 45 nearby SNe Ia, plus 57 SNe Ia from SNLS 1st year
  - flat geometry and combined with BAO

w = -1.07 ± 0.09 (*stat*) ± 0.13 (*sys*)

Ω_M = 0.27 ± 0.03

Systematics table

Wood-Vasey et al. 2007

Table 5. Potential Sources of Systematic Error on the Measurement of w

Source	dw/dx	Δx	Δ_w	Notes
Phot. errors from astrometric uncertainties of faint objects	1/mag	0.005 mag	0.005	
Bias in differential image photometry	0.5 / mag	0.002 mag	0.001	
CCD linearity	1 / mag	0.005 mag	0.005	
Photometric zeropoint differences in R, I	2 / mag	0.02 mag	0.04	
Zeropoint offset between low and high z	1 / mag	0.02 mag	0.02	
K-corrections	0.5 / mag	0.01 mag	0.005	
Filter passband structure	0 / mag	0.001 mag	0	
Galactic extinction	1 / mag	0.01 mag	0.01	
Host-galaxy R_V	0.02 / R_V	0.5	0.01	"glosz"
Host-galaxy extinction treatment	0.08	prior choice	0.08	different priors
Intrinsic color of SNe Ia	3 / mag	0.02 mag	0.06	interacts strongly with prior
Malmquist bias/selection effects	0.7 / mag	0.03 mag	0.02	"glosz"
SN Ia evolution	1 / mag	0.02 mag	0.02	
Hubble bubble	$3/\delta H_{\rm effective}$	0.02	0.06	
Gravitational lensing	$1/\sqrt{N}$ / mag	0.01 mag	< 0.001	Holz & Linder (2005)
Grey dust	1 / mag	0.01 mag	0.01	
Subtotal w/o extinction+color	...	...	0.082	
Total	...	...	0.13	
Joint ESSENCE+SNLS comparison	...	...	0.02	photometric system
Joint ESSENCE + SNLS total	...	...	0.13	

Systematics table

Wood-Vasey et al. 2007

Table 5. Potential Sources of Systematic Error on the Measurement of w

Source	dw/dx	Δx	Δ_w	Notes
Phot. errors from astrometric uncertainties of faint objects	1/mag	0.005 mag	0.005	
Bias in differential image photometry	0.5 / mag	0.002 mag	0.001	
CCD linearity	1 / mag	0.005 mag	0.005	
Photometric zeropoint differences in R, I	2 / mag	0.02 mag	0.04	
Zeropoint offset between low and high z	1 / mag	0.02 mag	0.02	
K-corrections	0.5 / mag	0.01 mag	0.005	
Filter passband structure	0 / mag	0.001 mag	0	
Galactic extinction	1 / mag	0.01 mag	0.01	
Host-galaxy R_V	0.02 / R_V	0.5	0.01	"glosz"
Host-galaxy extinction treatment	0.08	prior choice	0.08	different priors
Intrinsic color of SNe Ia	3 / mag	0.02 mag	0.06	interacts strongly with prior
Malmquist bias/selection effects	0.7 / mag	0.03 mag	0.02	"glosz"
SN Ia evolution	1 / mag	0.02 mag	0.02	
Hubble bubble	$3/\delta H_{\text{effective}}$	0.02	0.06	
Gravitational lensing	$1/\sqrt{N}$ / mag	0.01 mag	< 0.001	Holz & Linder (2005)
Grey dust	1 / mag	0.01 mag	0.01	
Subtotal w/o extinction+color	...	...	0.082	
Total	...	...	0.13	
Joint ESSENCE+SNLS comparison	...	...	0.02	photometric system
Joint ESSENCE + SNLS total	...	...	0.13	

The currently most complete SN Ia sample

(Riess et al. 2007)

Collected all available distant SNe Ia

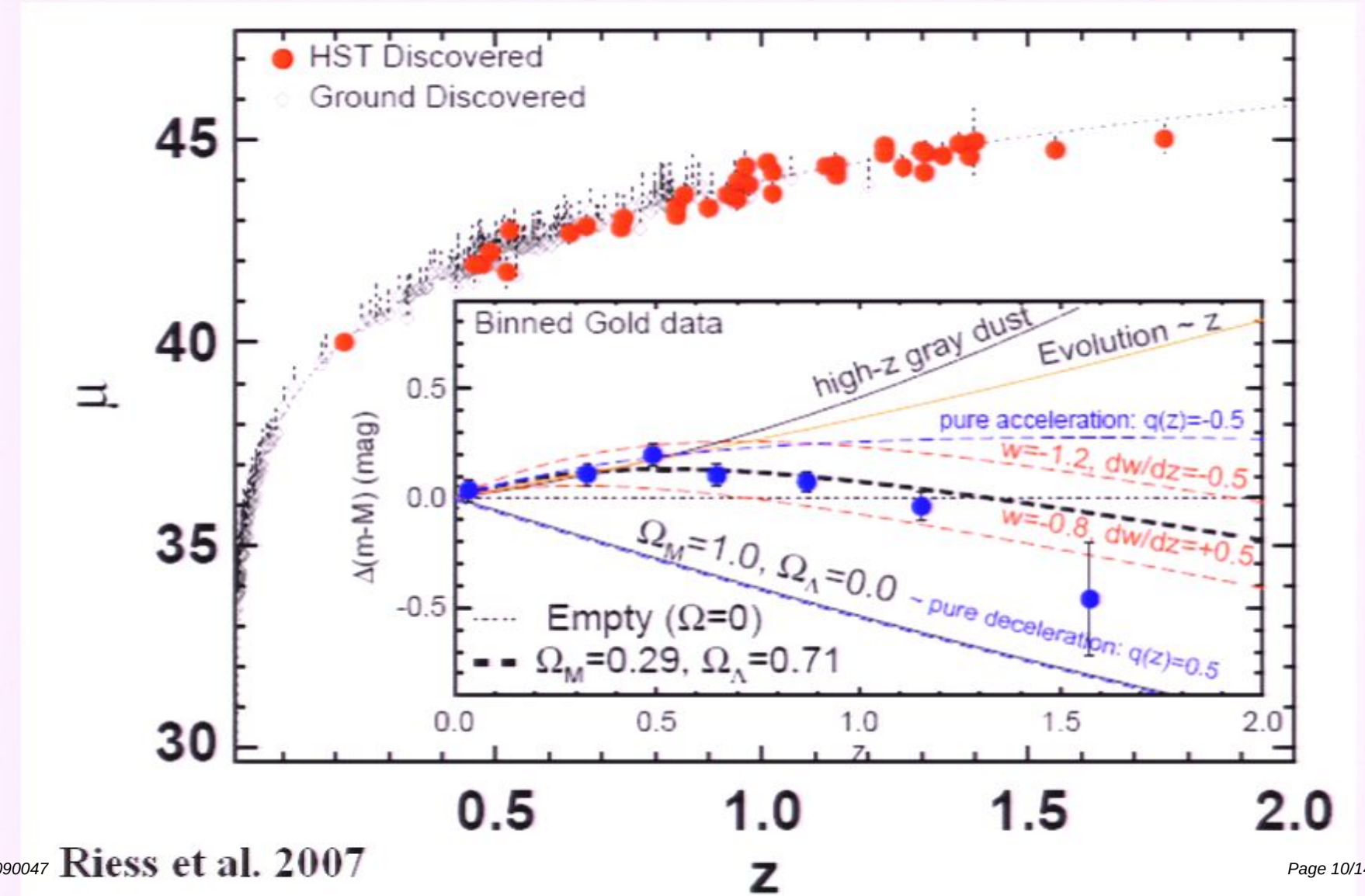
- Riess et al. (2004)
- Astier et al. (2006)
- Wood-Vasey et al. (2007)

→ 23 SNe Ia with z>1

→ total of 182 SNe Ia with z>0.0233 (v=7000 km/s)

lower redshift limit to avoid any local effects

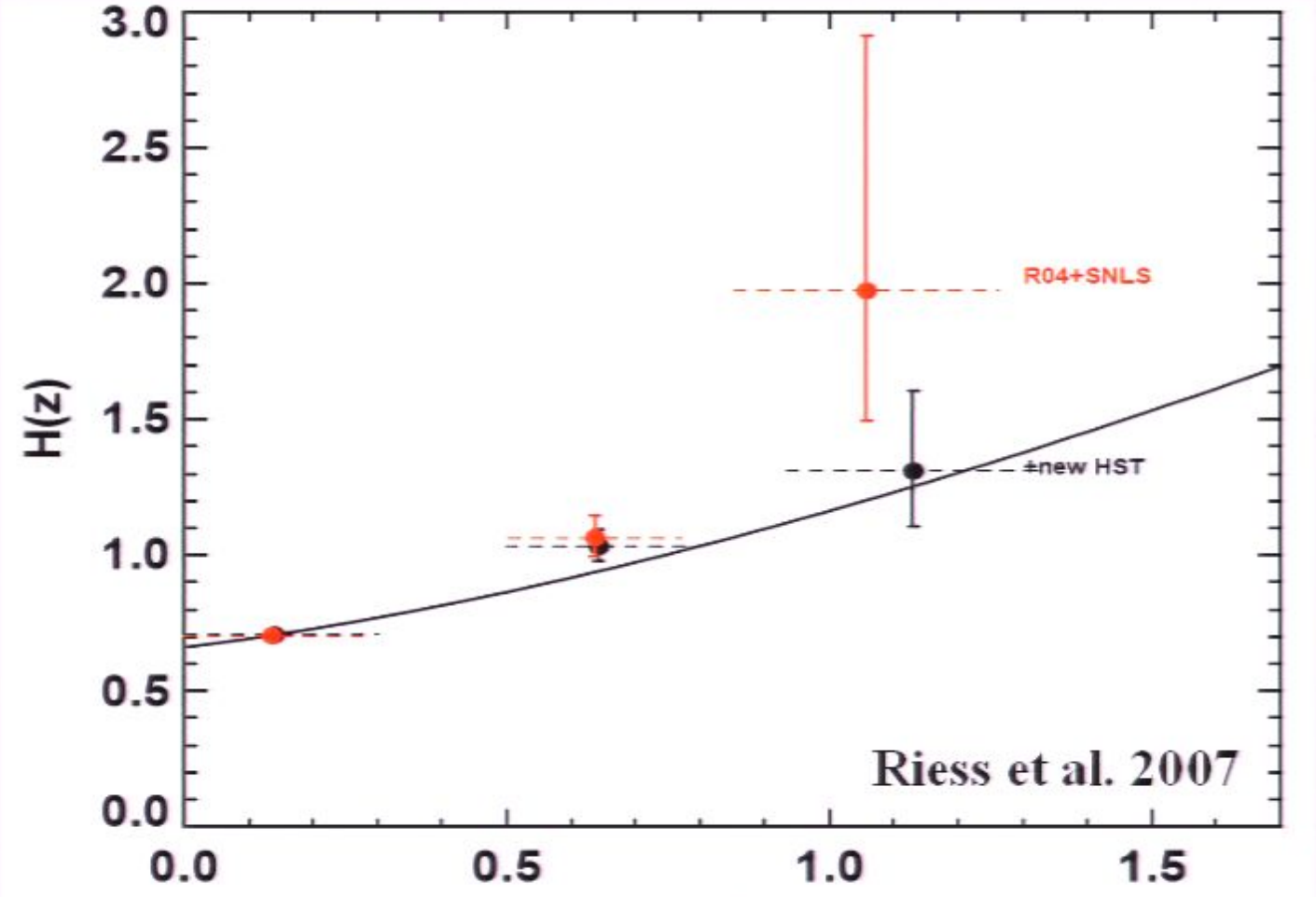
SN Ia Hubble Diagram



Riess et al. 2007

Analysis

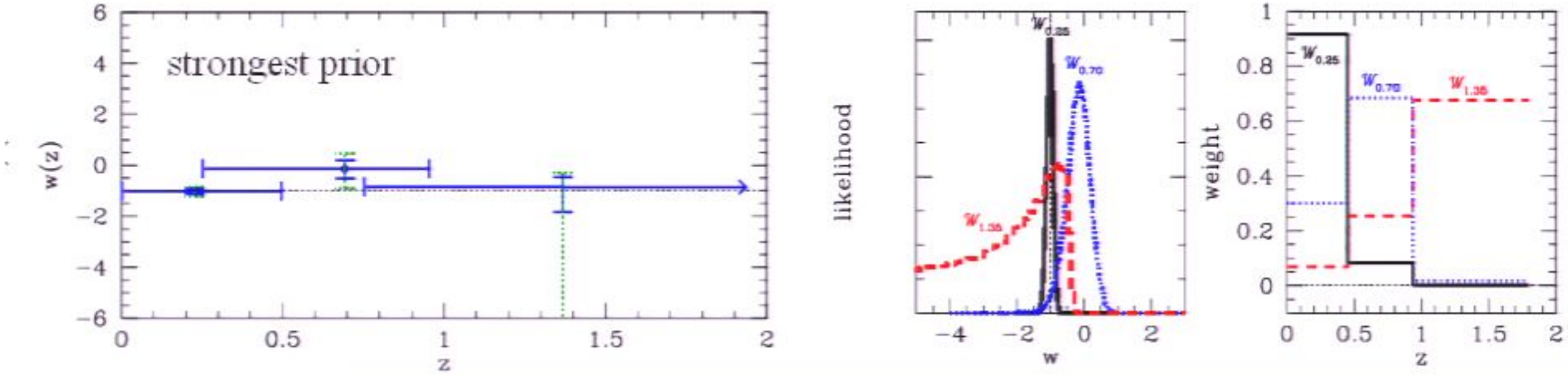
Check for acceleration, i.e. H(z) (model independent!)



Analysis

Reconstruct *w(z)* from the data following Huterer & Cooray (2005):

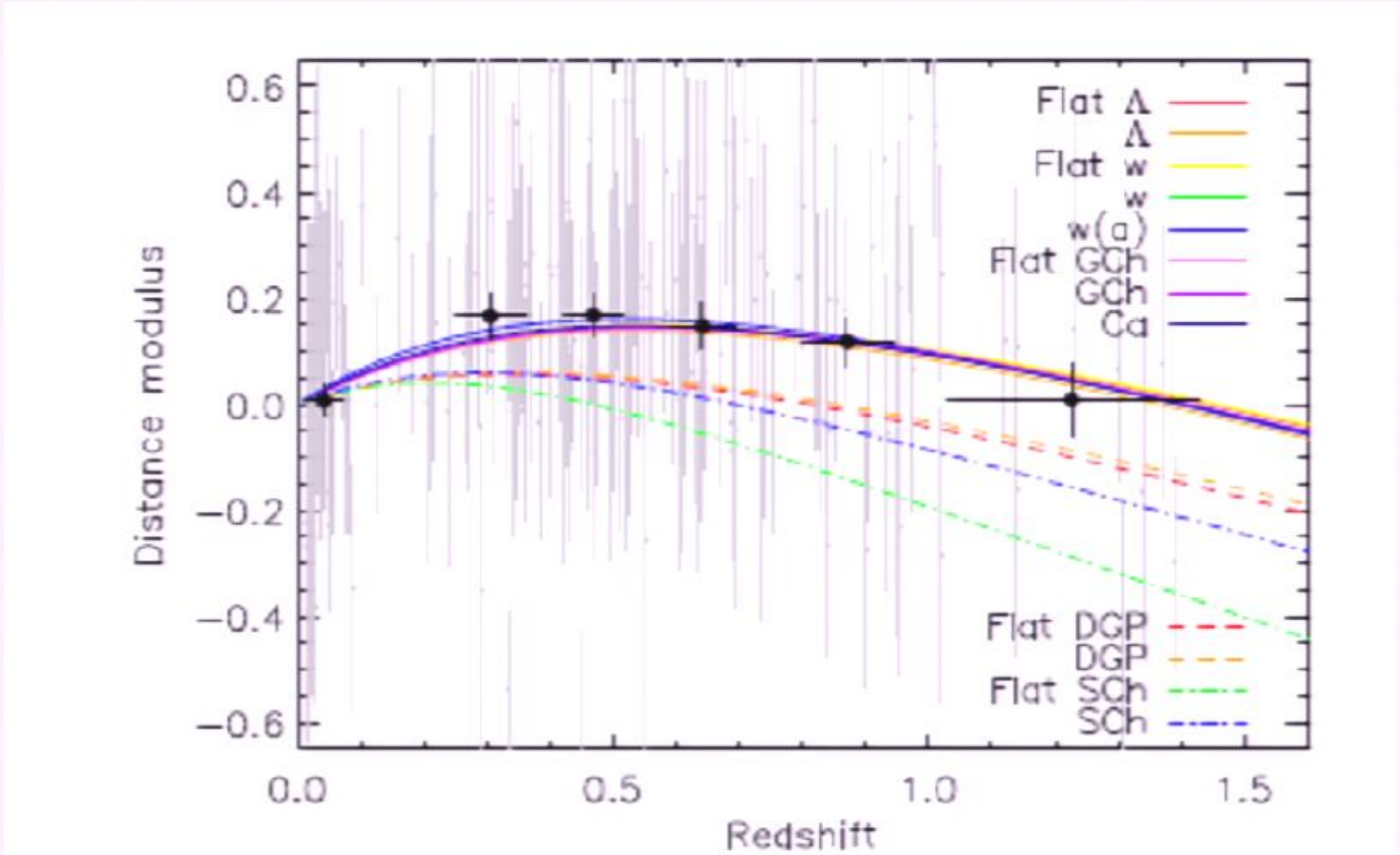
Construct 'independent' redshift bins at 0.25, 0.70 and 1.35 and compare *w(z)*



Riess et al. 2007

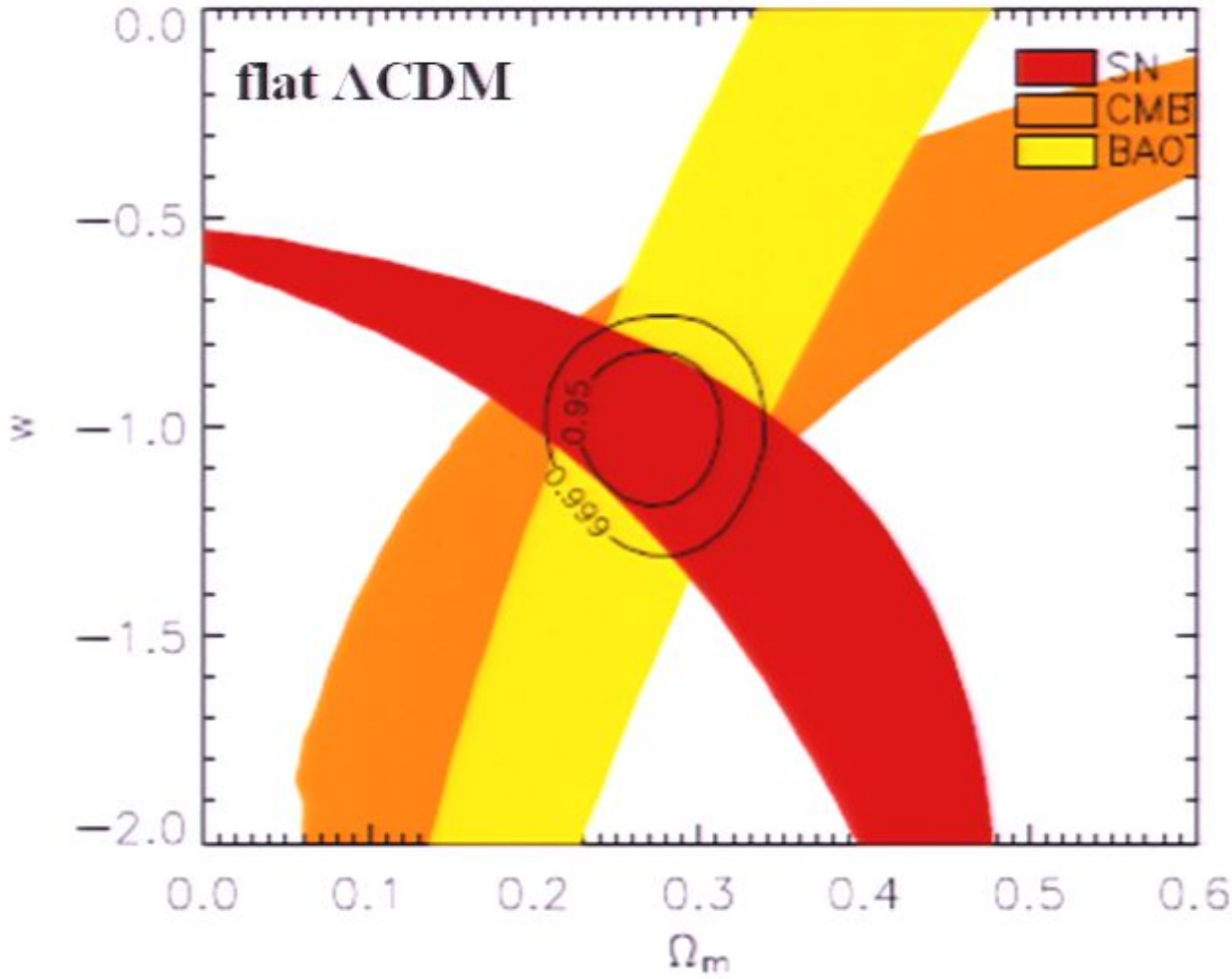
Comparison to other models

Davis et al. 2007



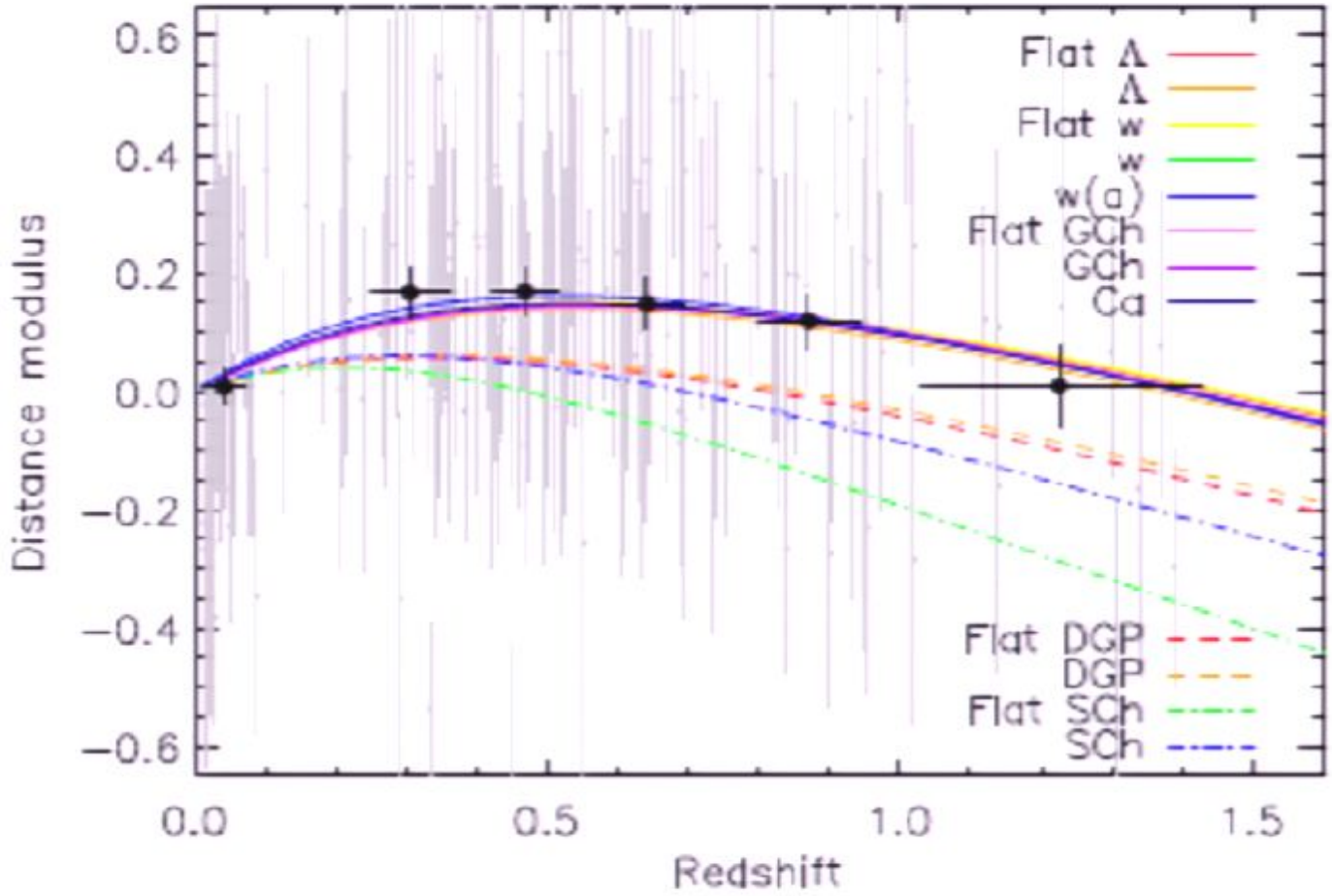
Comparison to other models

Davis et al. 2007



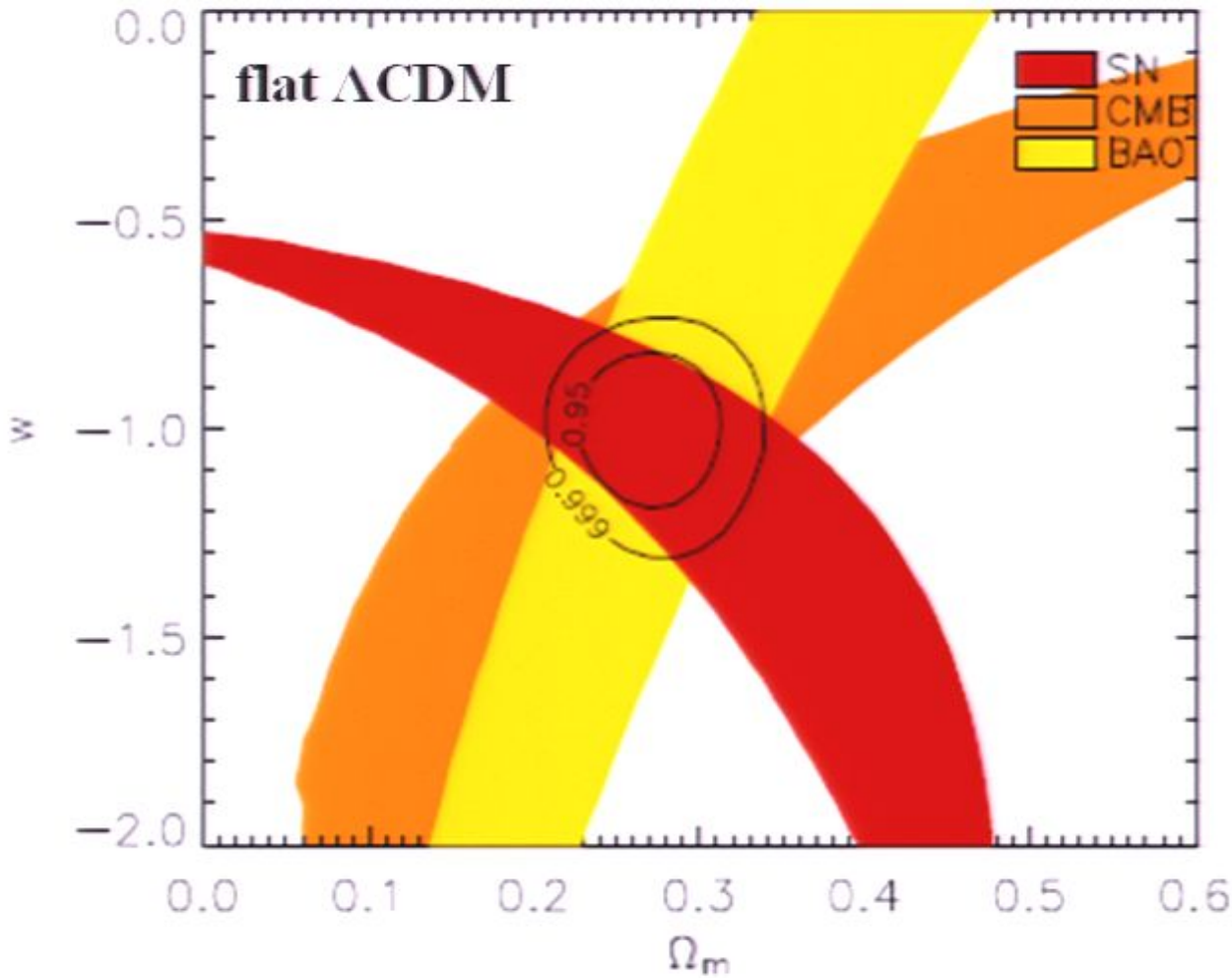
Comparison to other models

Davis et al. 2007



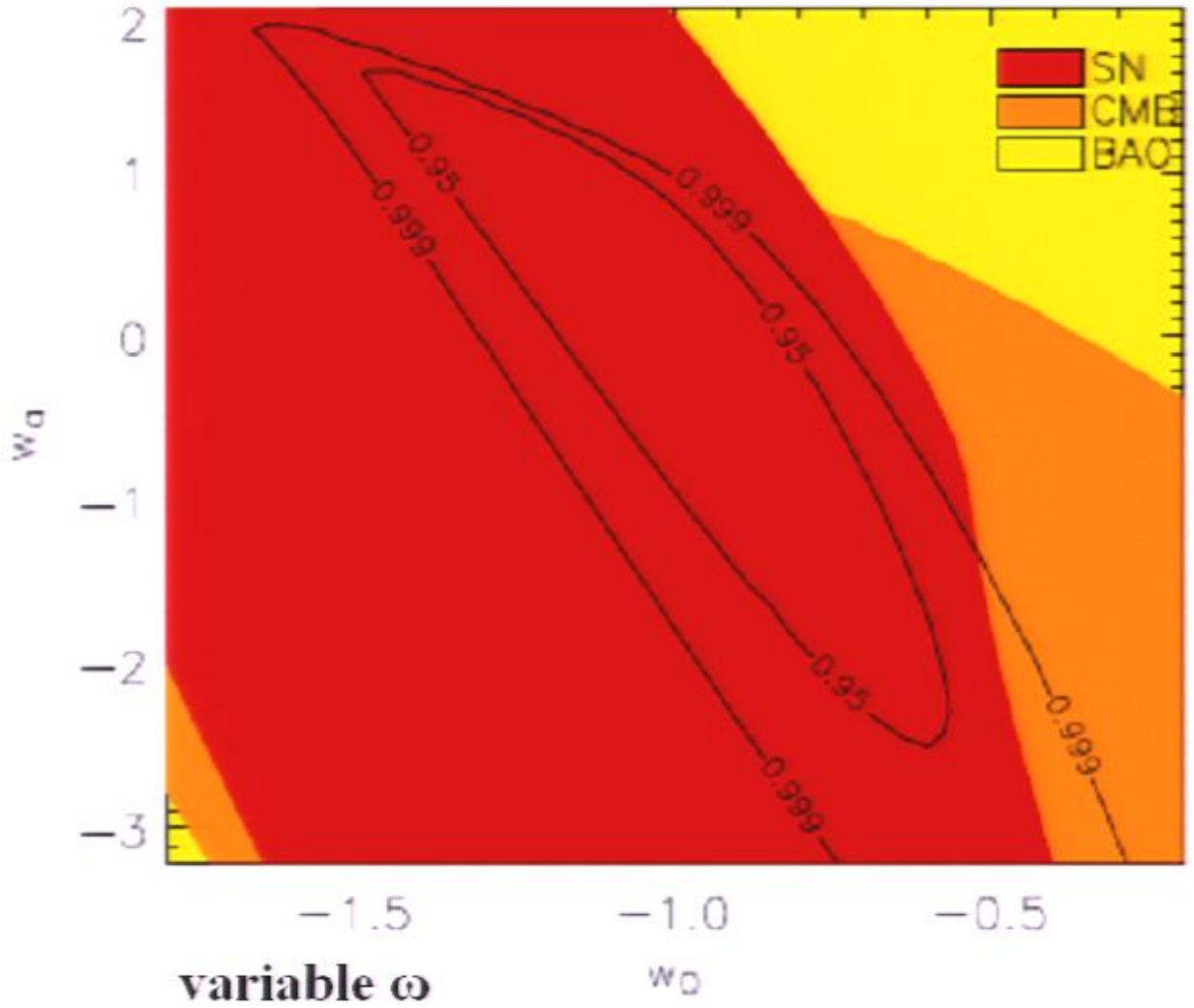
Comparison to other models

Davis et al. 2007



Comparison to other models

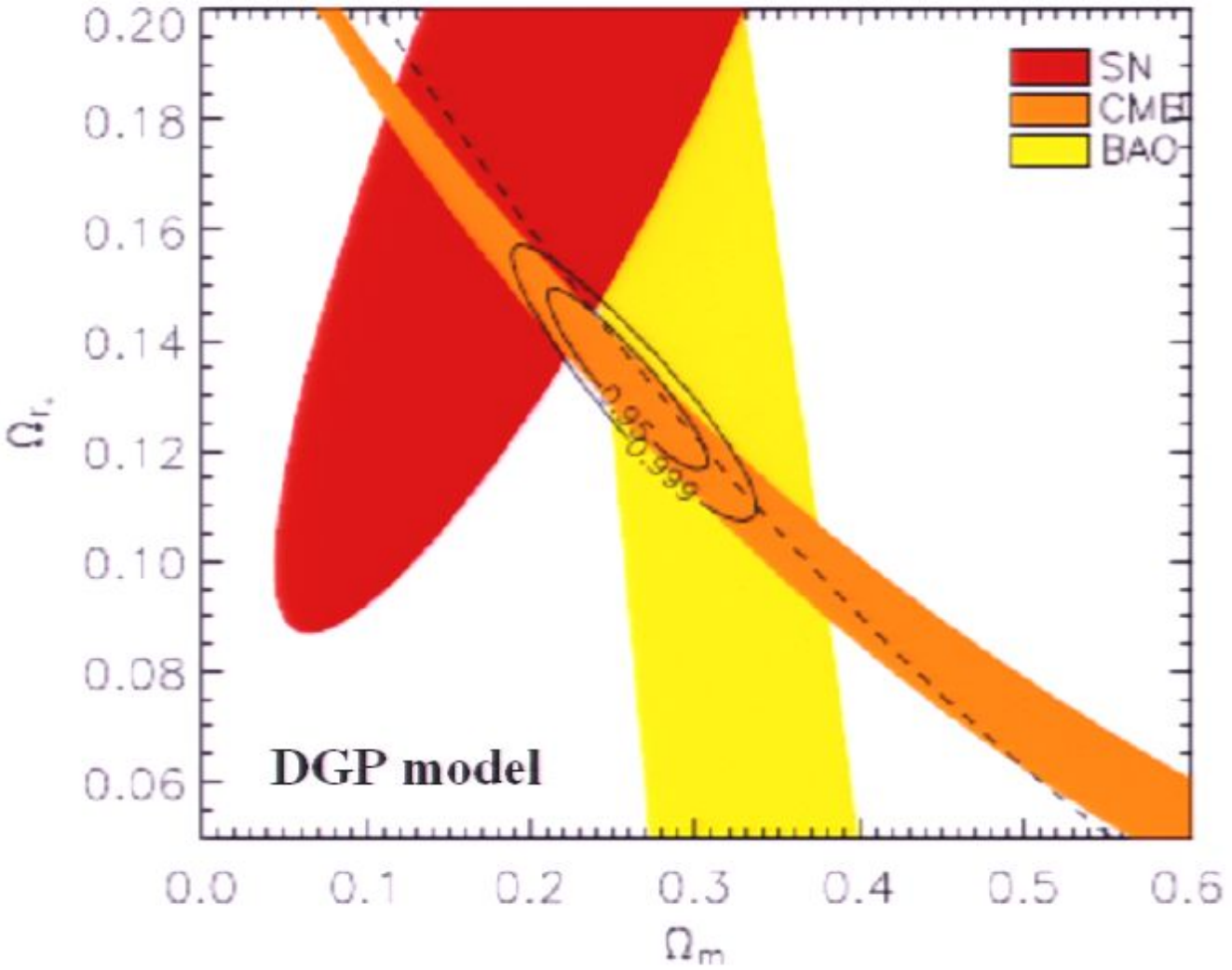
Davis et al. 2007



variable ω

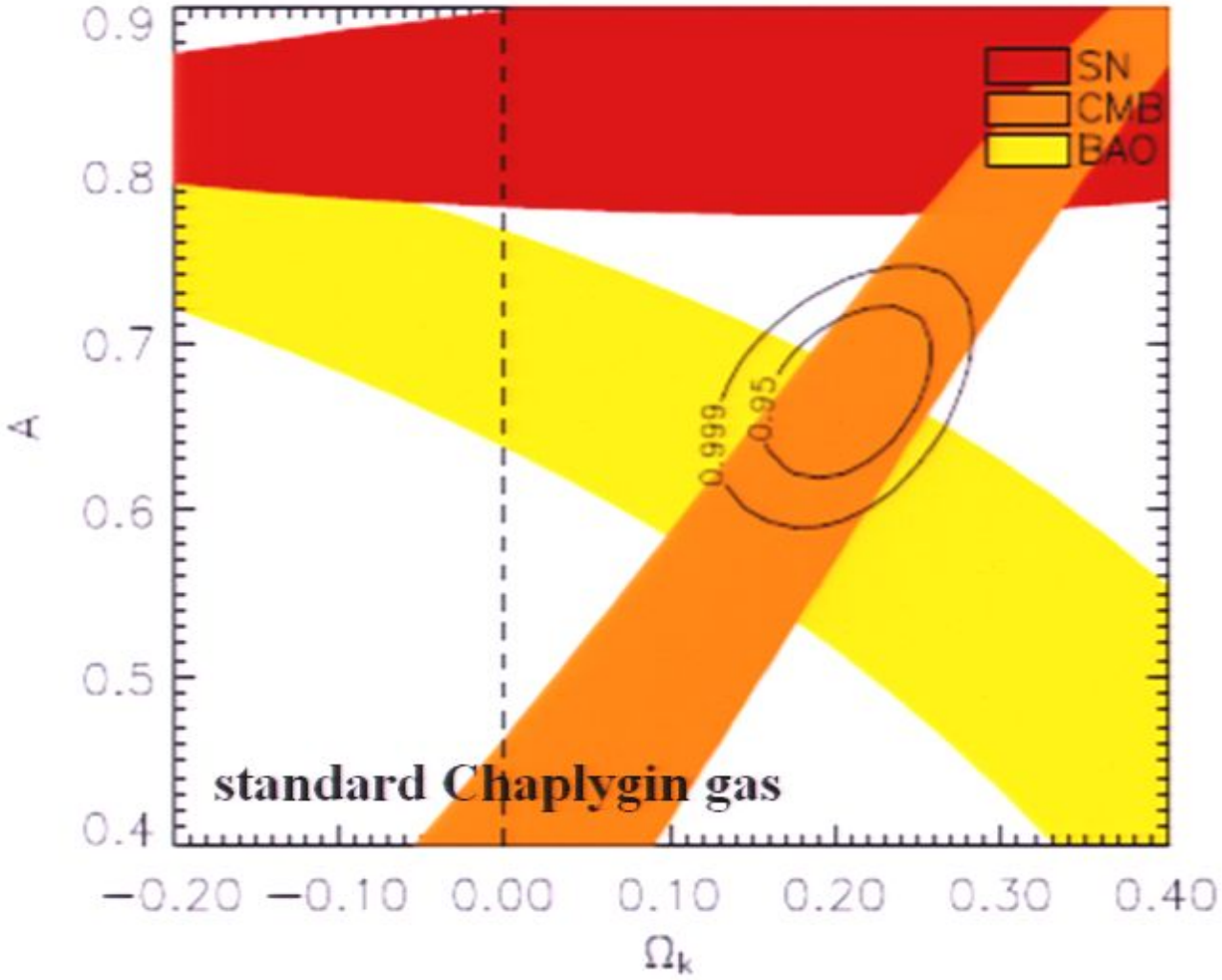
Comparison to other models

Davis et al. 2007



Comparison to other models

Davis et al. 2007



Astrophysics

To measure cosmological parameters (distances) you need to

- understand your source
- understand what can affect the light on its path to the observer ('foregrounds')
- know your local environment


Supernova!
© Anglo-Australian Telescope


2003aj
2003ak
HST04Kur
HST04Mcg
HST04Gre
2002fw
2002hp
HST04Omb
2002fx
HST05Zwi
2002kd
HST04Rak
2002hr
2002kc
2003be
HST04Sas
HST05Dic
HST05Str
2003lv
2003dy
HST04Haw
HST05Gab
HST04Cay
HST04Yow
HST05Red
HST05Lan
HST04Tha
2003es
2003bd
2003eb
2003eq
HST04Eag
HST05Spo
HST05Fer
HST04Man
N
E
Supernovae!
Riess et al. 2007

Systematics

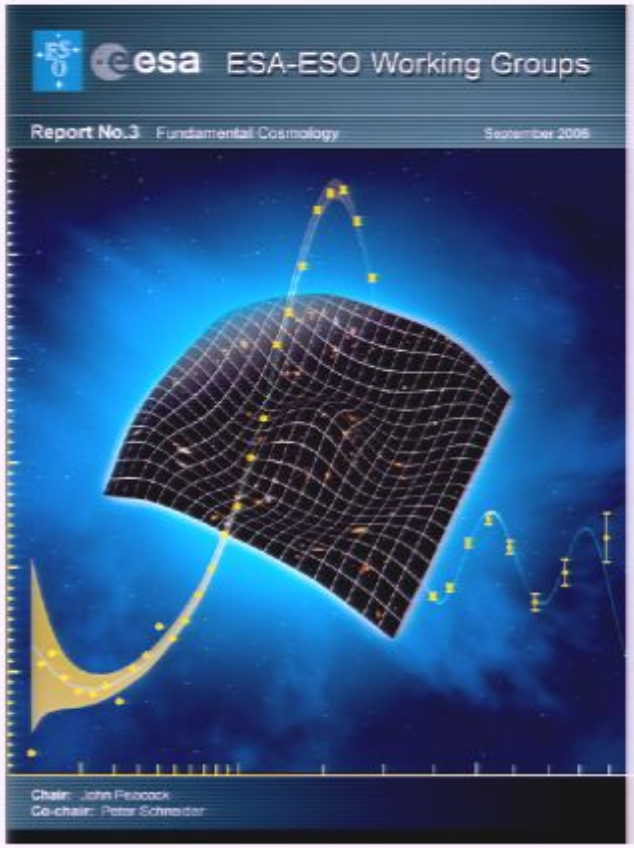
Contamination
Photometry
K-corrections
Malmquist bias
Normalisation
Evolution
Absorption
Local expansion field

Systematics

Contamination	
Photometry	measurement
K-corrections	
Malmquist bias	
Normalisation	source
Evolution	
Absorption	path
Local expansion field	local environment

Systematics of SNe Ia

[T]he length of the list indicates the maturity of the field, and is the result of more than a decade of careful study.

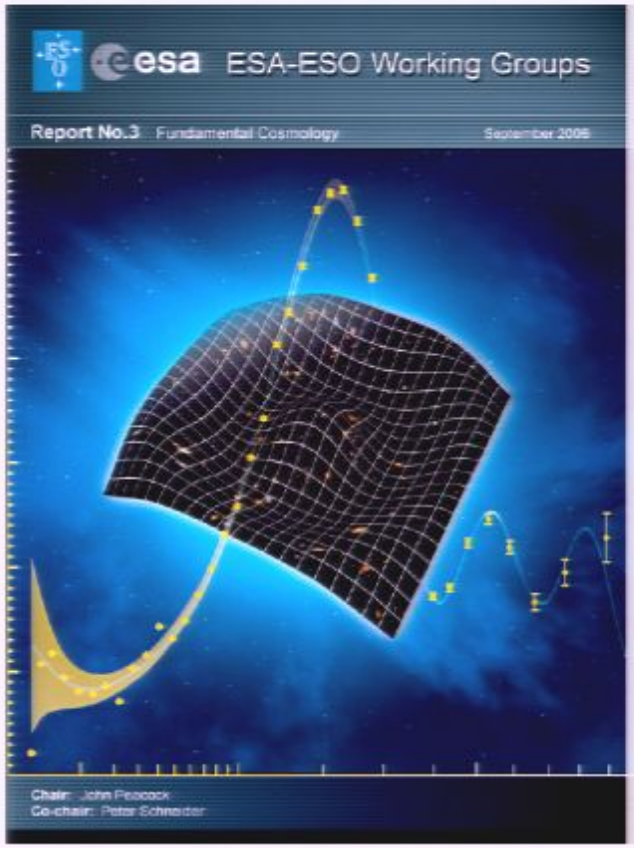


Systematics

Contamination	
Photometry	measurement
K-corrections	
Malmquist bias	
Normalisation	source
Evolution	
Absorption	path
Local expansion field	local environment

Systematics of SNe Ia

[T]he length of the list indicates the maturity of the field, and is the result of more than a decade of careful study.



Know your source

Type Ia Supernovae

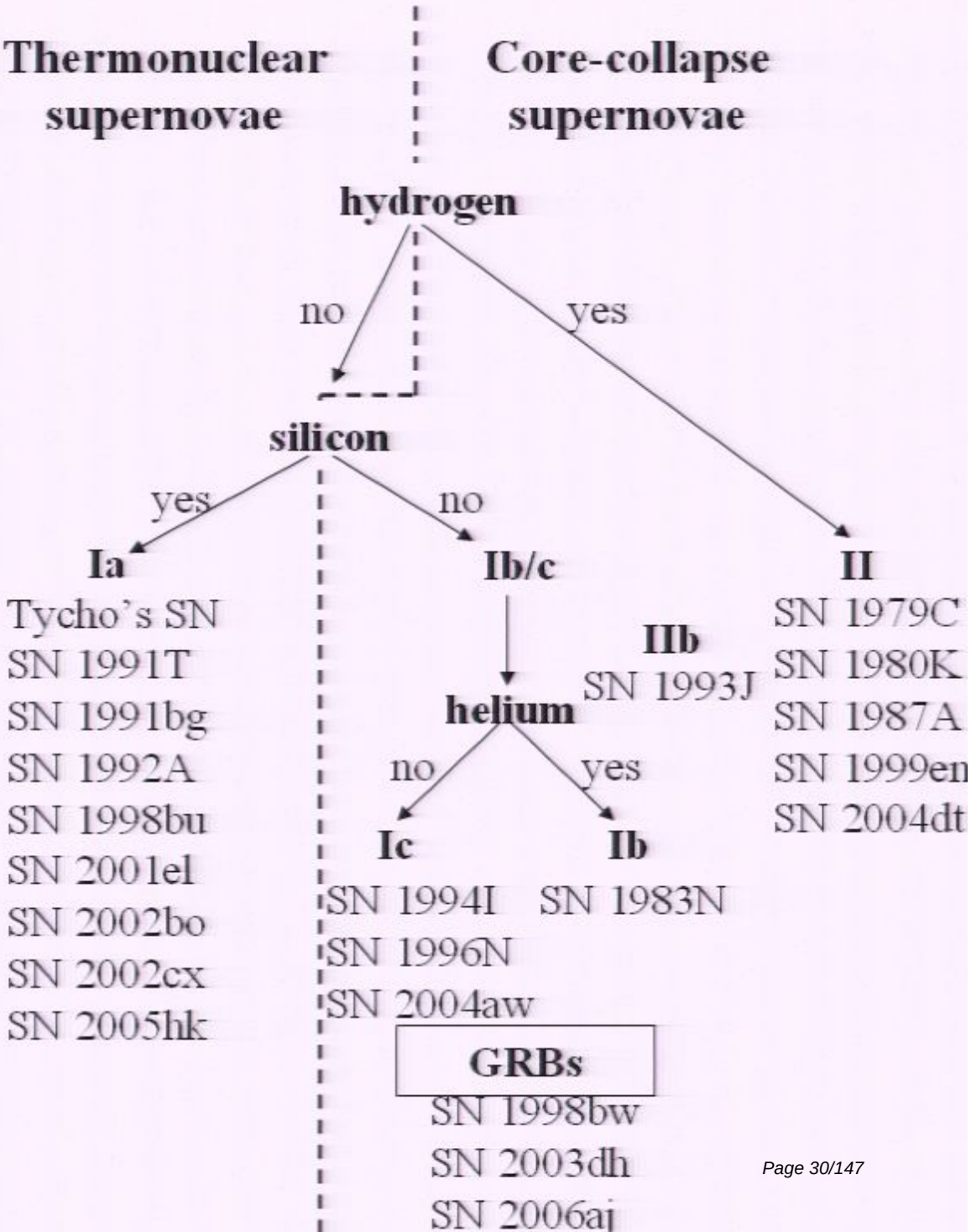
- **complicated source**
- **interesting physics**
- **progenitor systems**

→ determine the global parameters of the explosions

- fuel → nickel mass → distribution in the ejecta
- total mass
- explosion energy

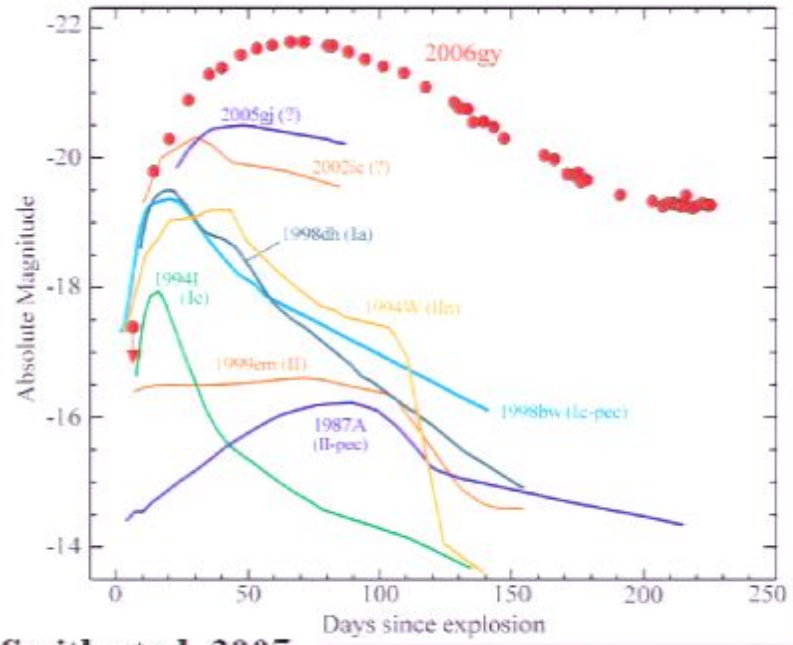
Supernova classification

based on maximum light spectroscopy



Supernova classification

based on maximum light spectroscopy



Smith et al. 2007

Thermonuclear supernovae | **Core-collapse supernovae**

hydrogen

no → **silicon**

yes → **II**

SN 1979C
SN 1980K
SN 1987A
SN 1999em
SN 2004dt

silicon

yes → **Ia**

Tycho's SN
SN 1991T
SN 1991bg
SN 1992A
SN 1998bu
SN 2001el
SN 2002bo
SN 2002cx
SN 2005hk

no → **Ib/c**

IIb
SN 1993J

Ib/c

helium

no → **Ic**

SN 1994I
SN 1996N
SN 2004aw

yes → **Ib**

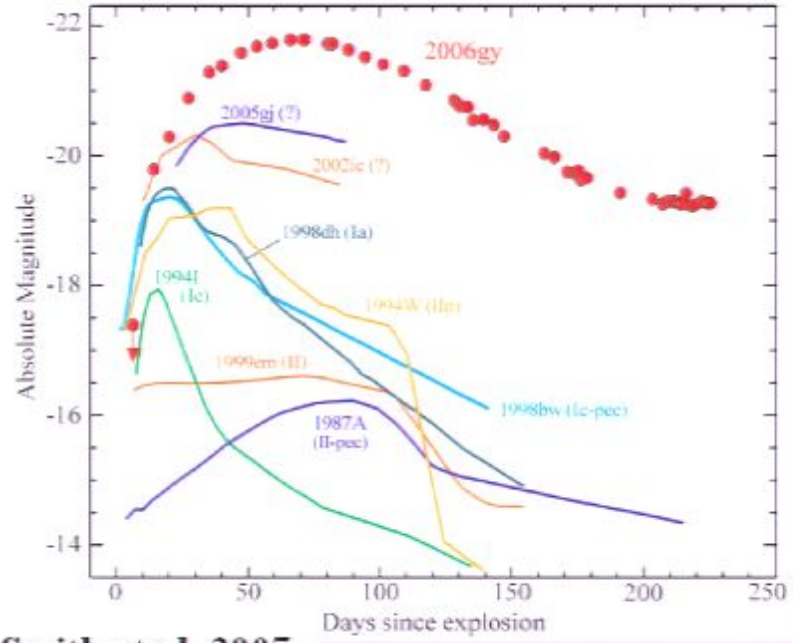
SN 1983N

GRBs

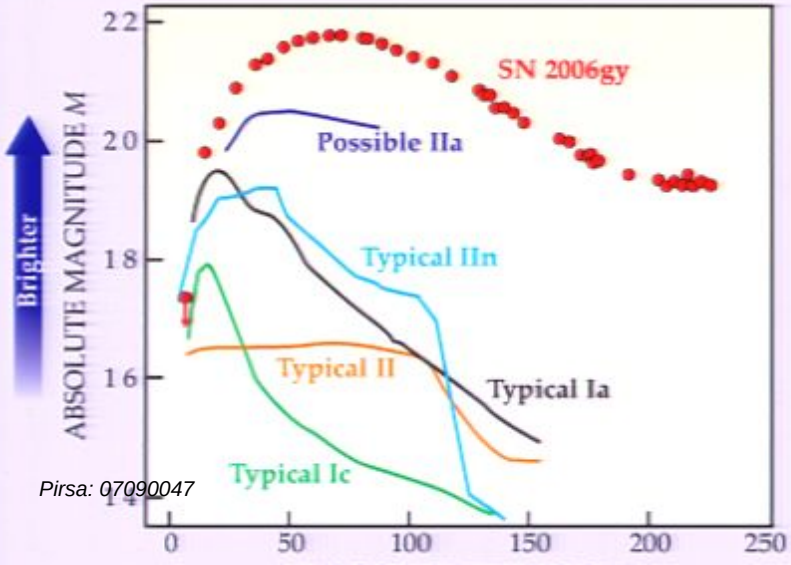
SN 1998bw
SN 2003dh
SN 2006aj

Supernova classification

based on maximum light spectroscopy



Smith et al. 2007



Thermonuclear supernovae | **Core-collapse supernovae**

hydrogen

no → **silicon**

yes → **II**

SN 1979C
SN 1980K
SN 1987A
SN 1999em
SN 2004dt

silicon

yes → **Ia**

Tycho's SN
SN 1991T
SN 1991bg
SN 1992A
SN 1998bu
SN 2001el
SN 2002bo
SN 2002cx
SN 2005hk

no → **Ib/c**

IIb
SN 1993J

Ib/c

helium

no → **Ic**

SN 1994I
SN 1996N
SN 2004aw

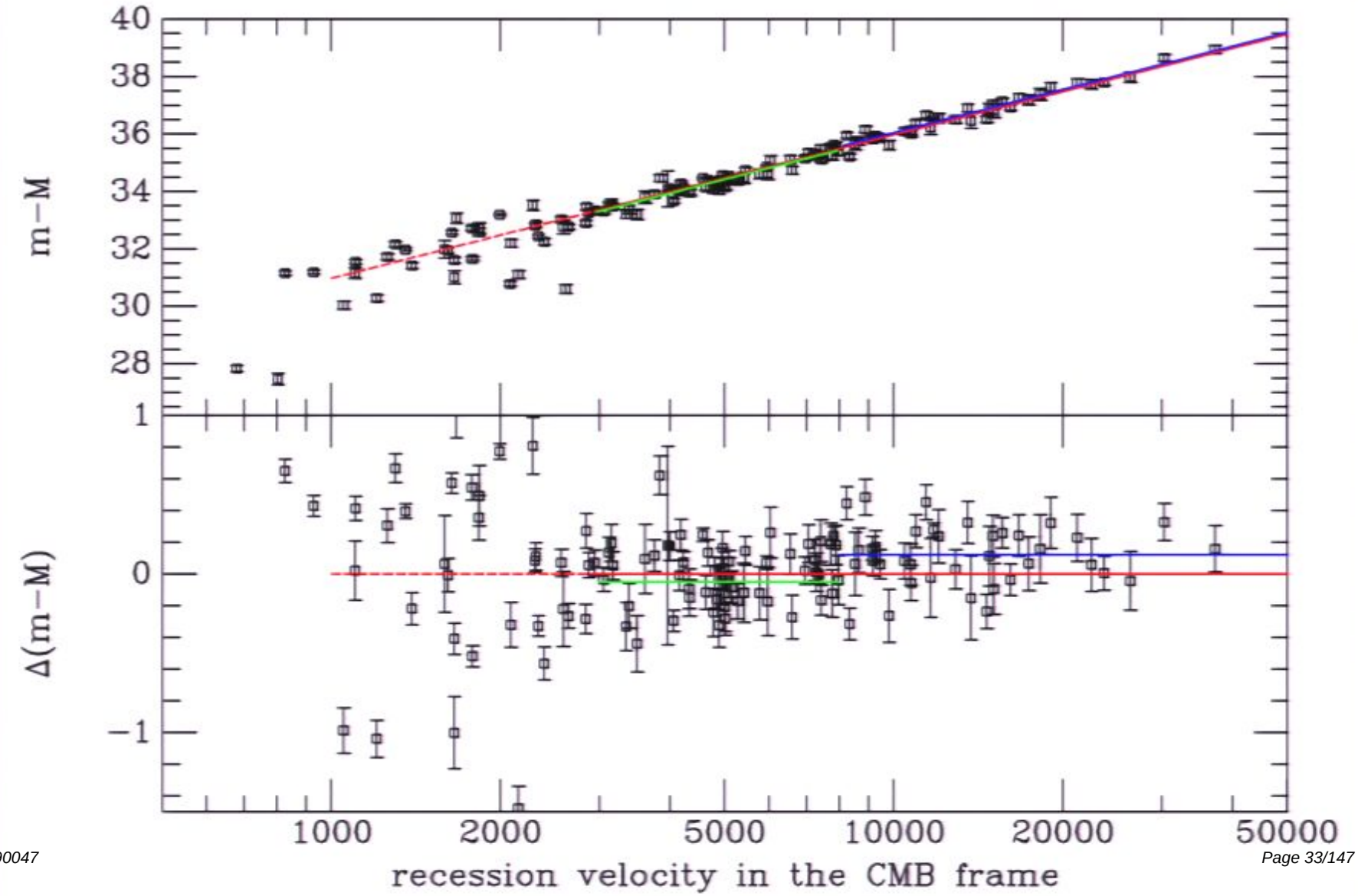
yes → **Ib**

SN 1983N

GRBs

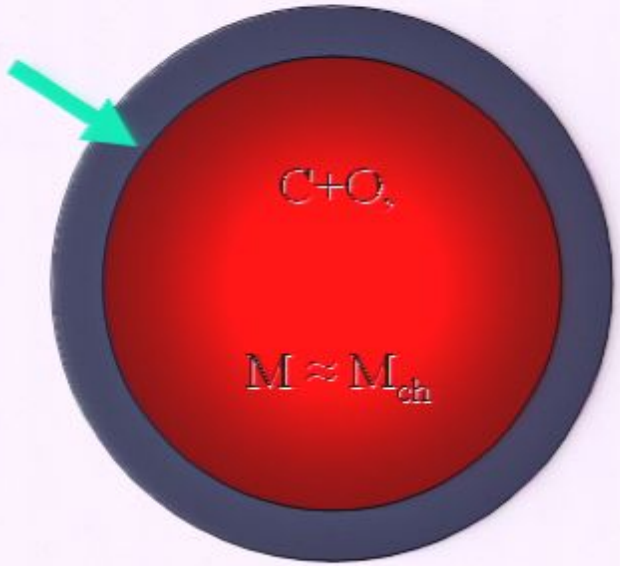
SN 1998bw
SN 2003dh
SN 2006aj

Distance indicator!



The "standard model"

He (+H)
from binary
companion



Density ~ 10^9 - 10^{10} g/cm

Temperature: a few 10^9 K

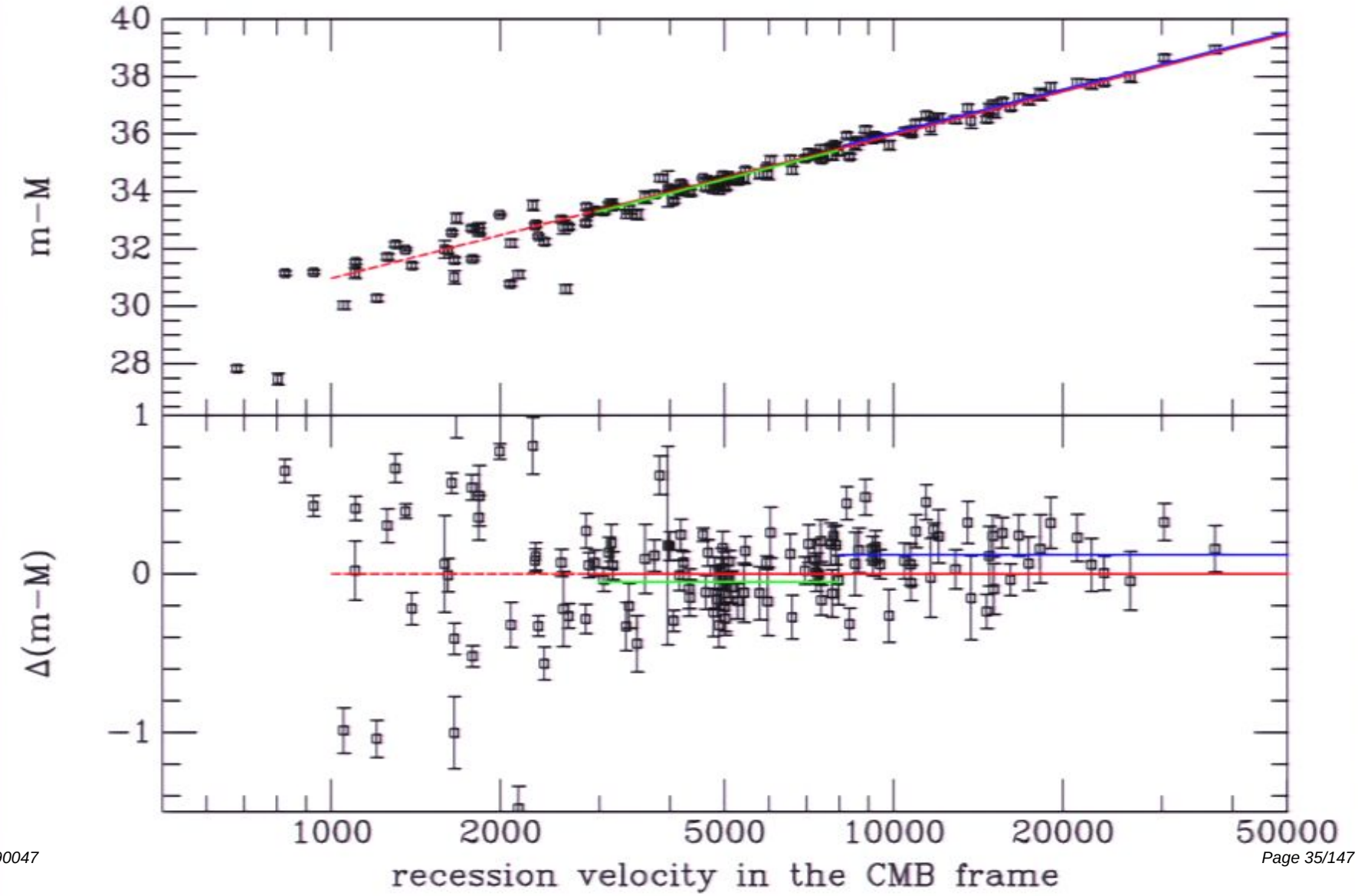
Radii: a few 1000 km

Explosion energy:

Fusion of
C+C, C+O, O+O
⇒ "Fe"

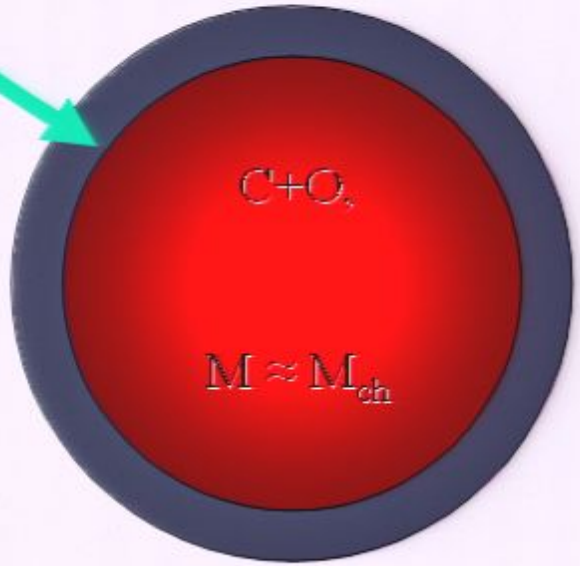
There is a lot more to this – you need to contact your explosive theory friends

Distance indicator!



The "standard model"

He (+H)
from binary
companion



Explosion energy:

Fusion of

C+C, C+O, O+O

⇒ "Fe"

Density ~ 10^9 - 10^{10} g/cm

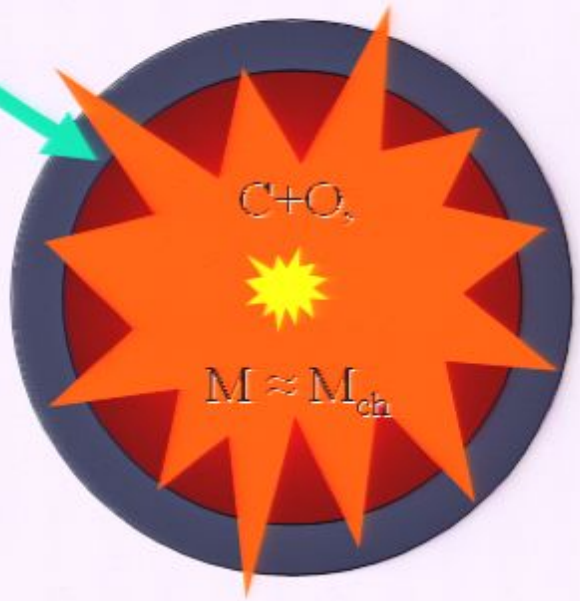
Temperature: a few 10^9 K

Radii: a few 1000 km

There is a lot more to this – you need to contact your explosive theory friends

The "standard model"

He (+H)
from binary
companion



Density ~ 10^9 - 10^{10} g/cm

Temperature: a few 10^9 K

Radii: a few 1000 km

Explosion energy:

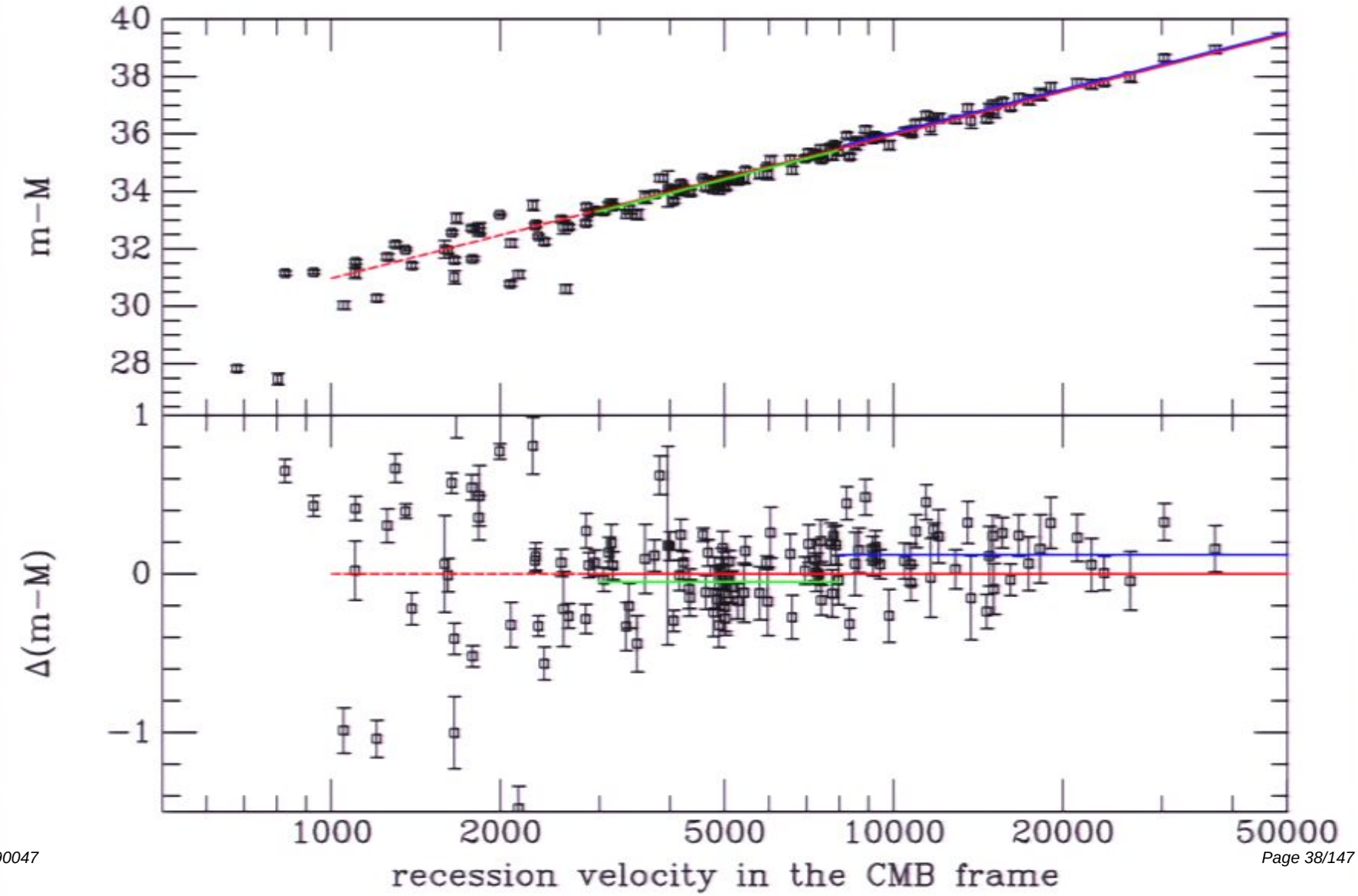
Fusion of

C+C, C+O, O+O

⇒ "Fe"

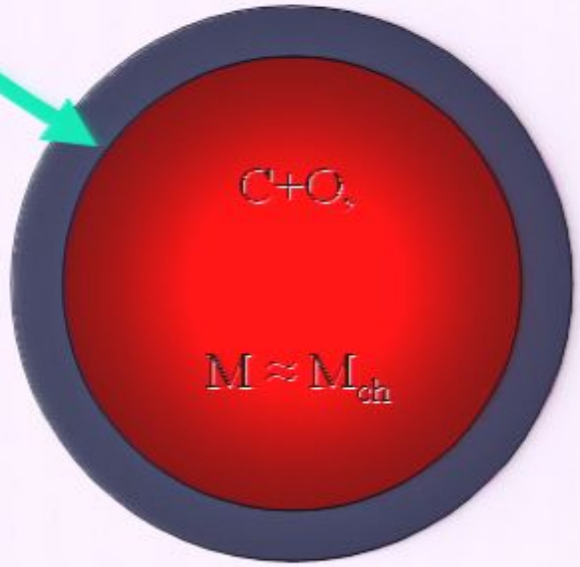
There is a lot more to this – you need to contact your explosive theory friends

Distance indicator!



The "standard model"

He (+H)
from binary
companion



Density ~ 10^9 - 10^{10} g/cm

Temperature: a few 10^9 K

Radii: a few 1000 km

Explosion energy:

Fusion of

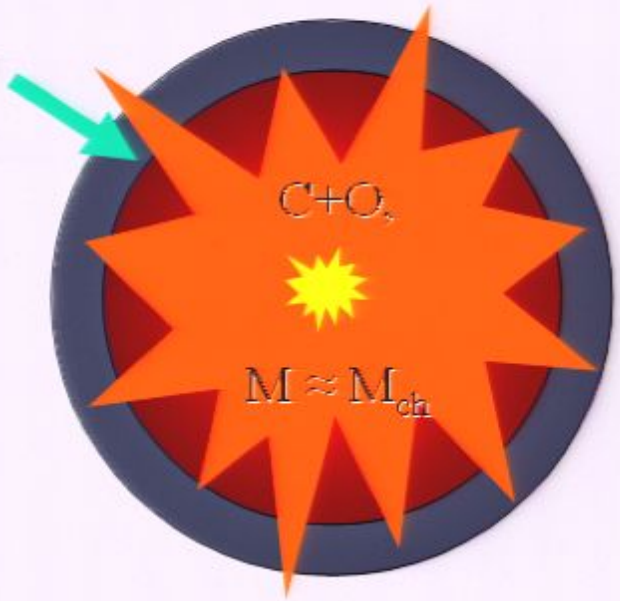
C+C, C+O, O+O

⇒ "Fe"

There is a lot more to this – you need to contact your explosive theory friends

The "standard model"

He (+H)
from binary
companion



Density ~ 10^9 - 10^{10} g/cm

Temperature: a few 10^9 K

Radii: a few 1000 km

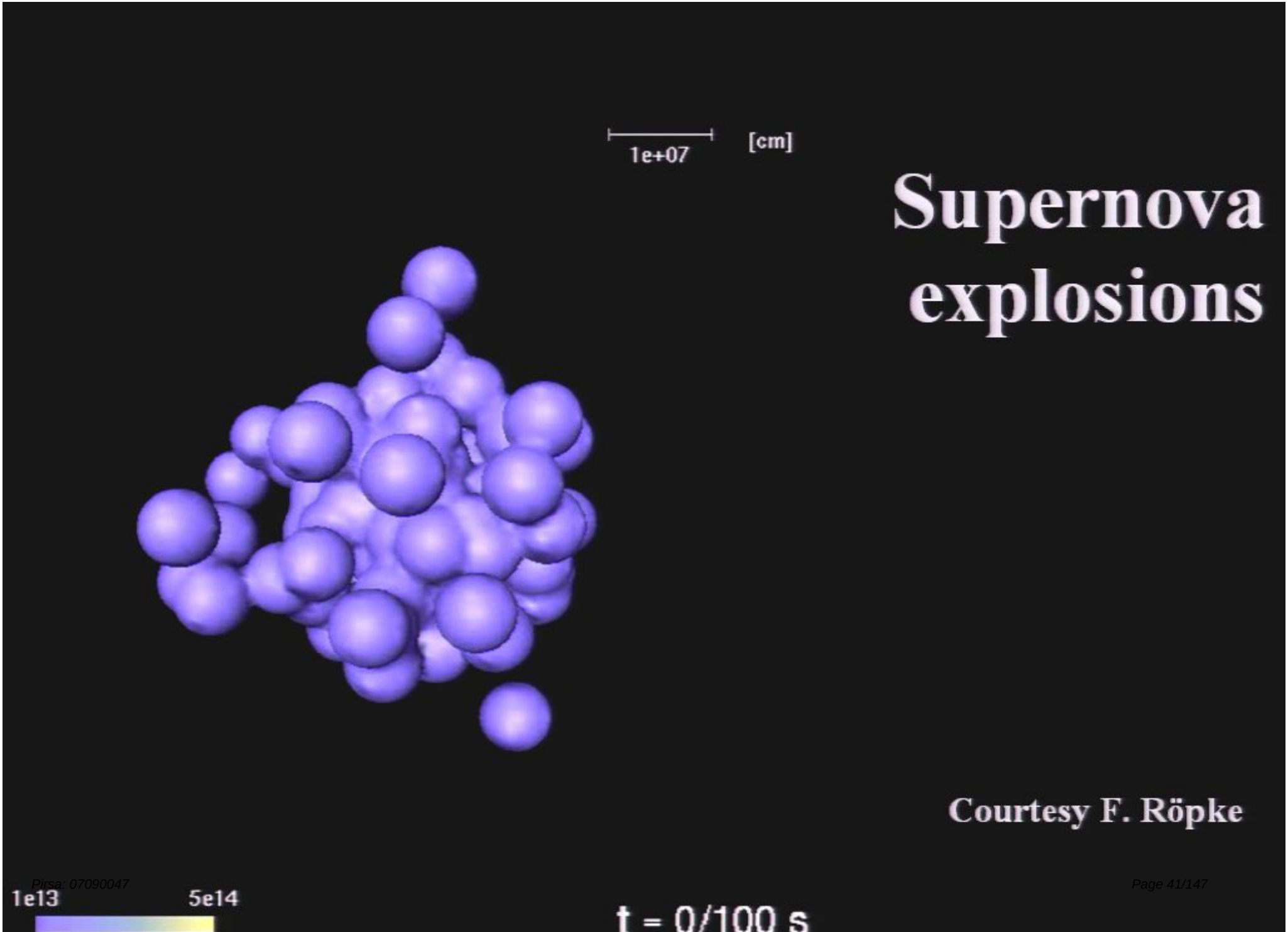
Explosion energy:

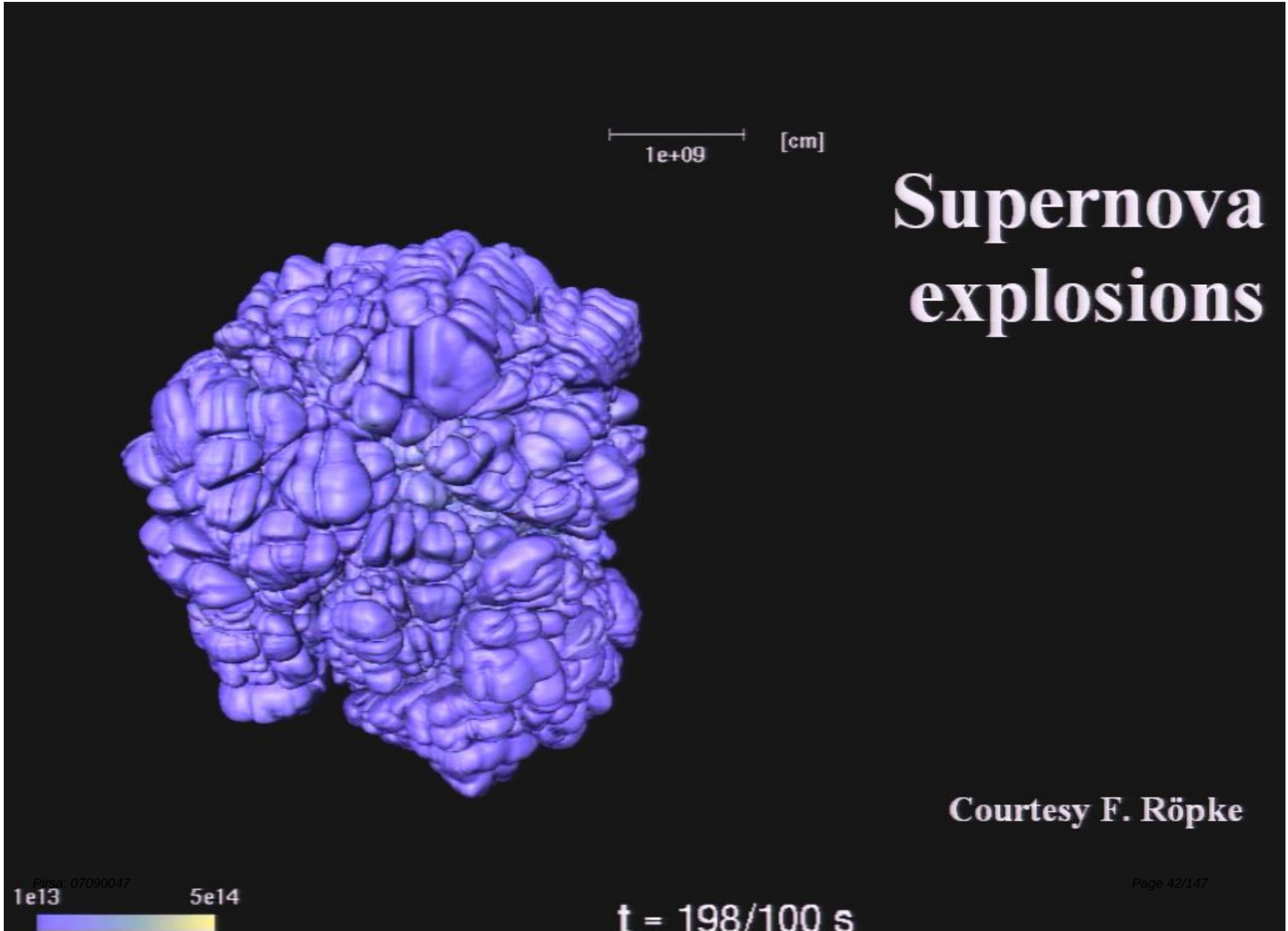
Fusion of

C+C, C+O, O+O

⇒ "Fe"

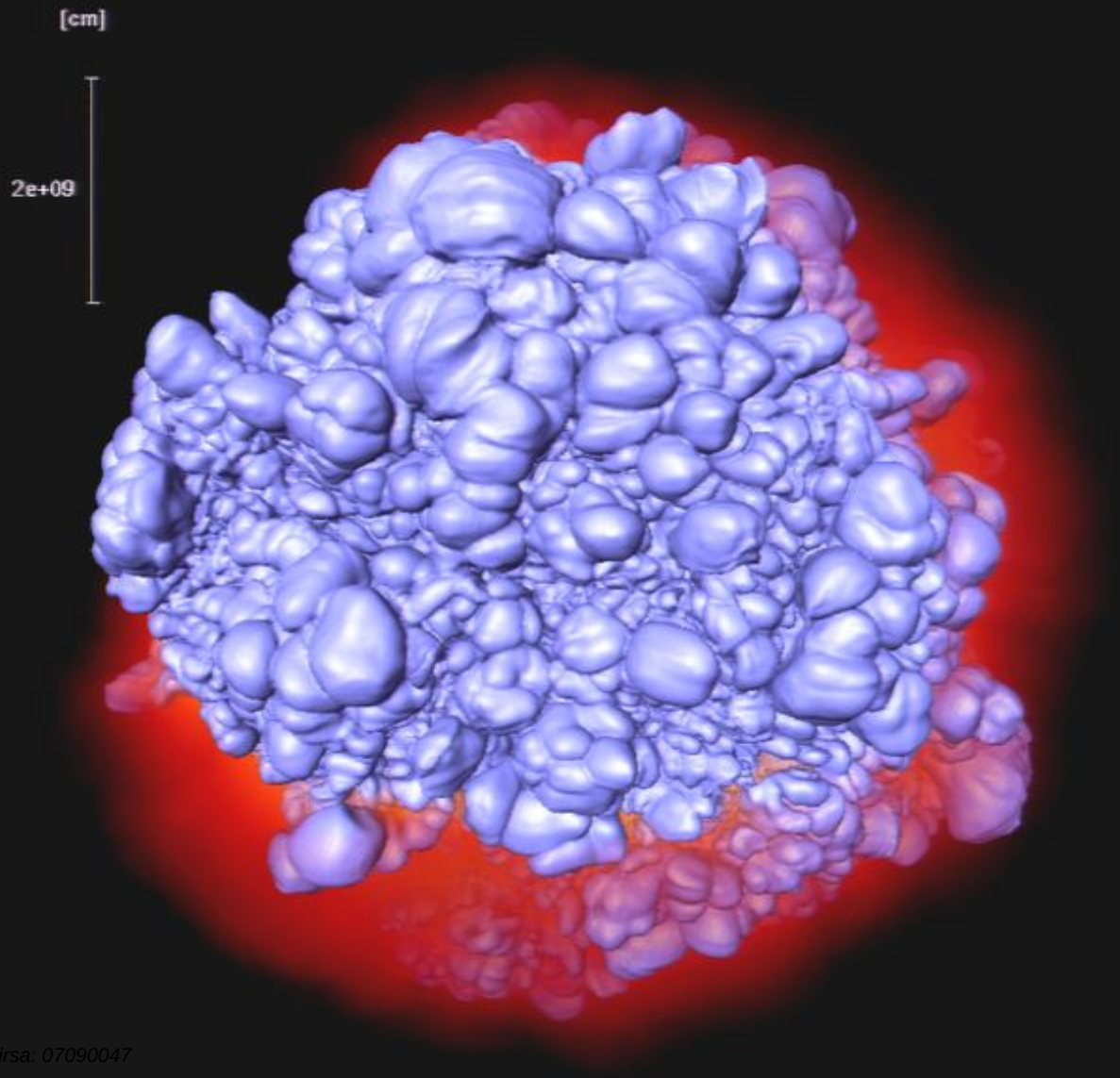
There is a lot more to this – you need to contact your explosive theory friends





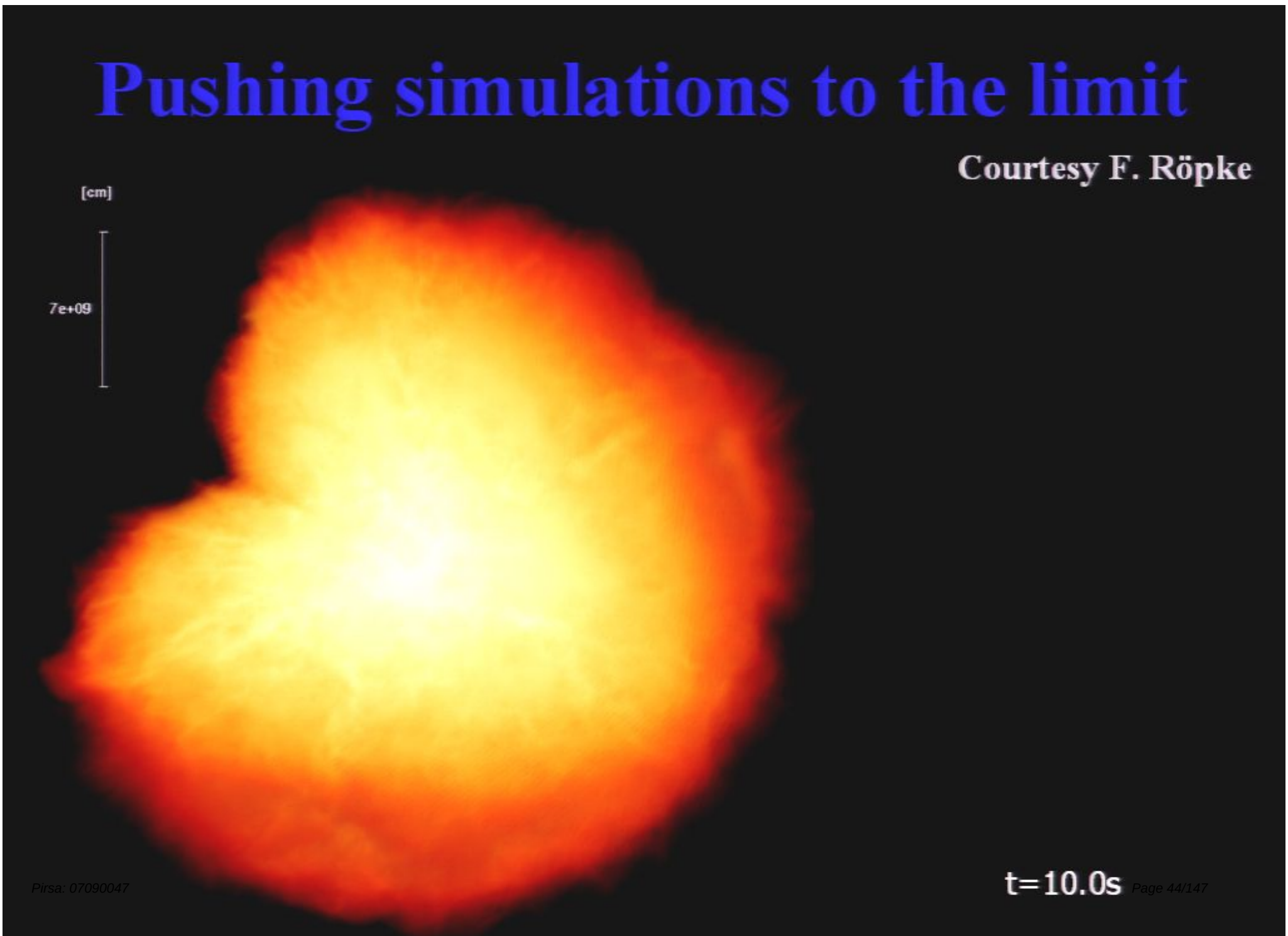
Pushing simulations to the limit

Courtesy F. Röpke



Pushing simulations to the limit

Courtesy F. Röpke



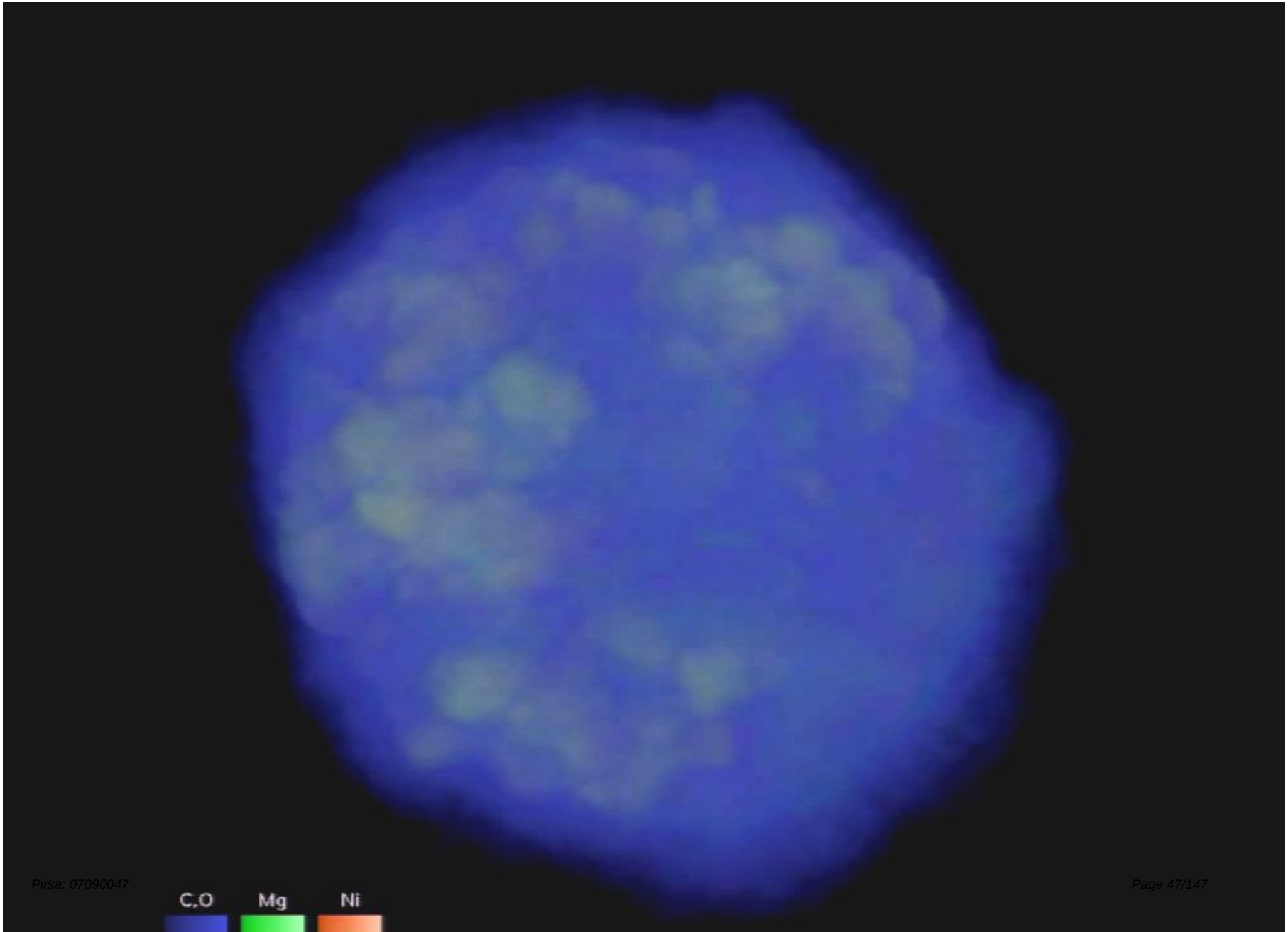
Thermonuclear Supernova Explosion Model

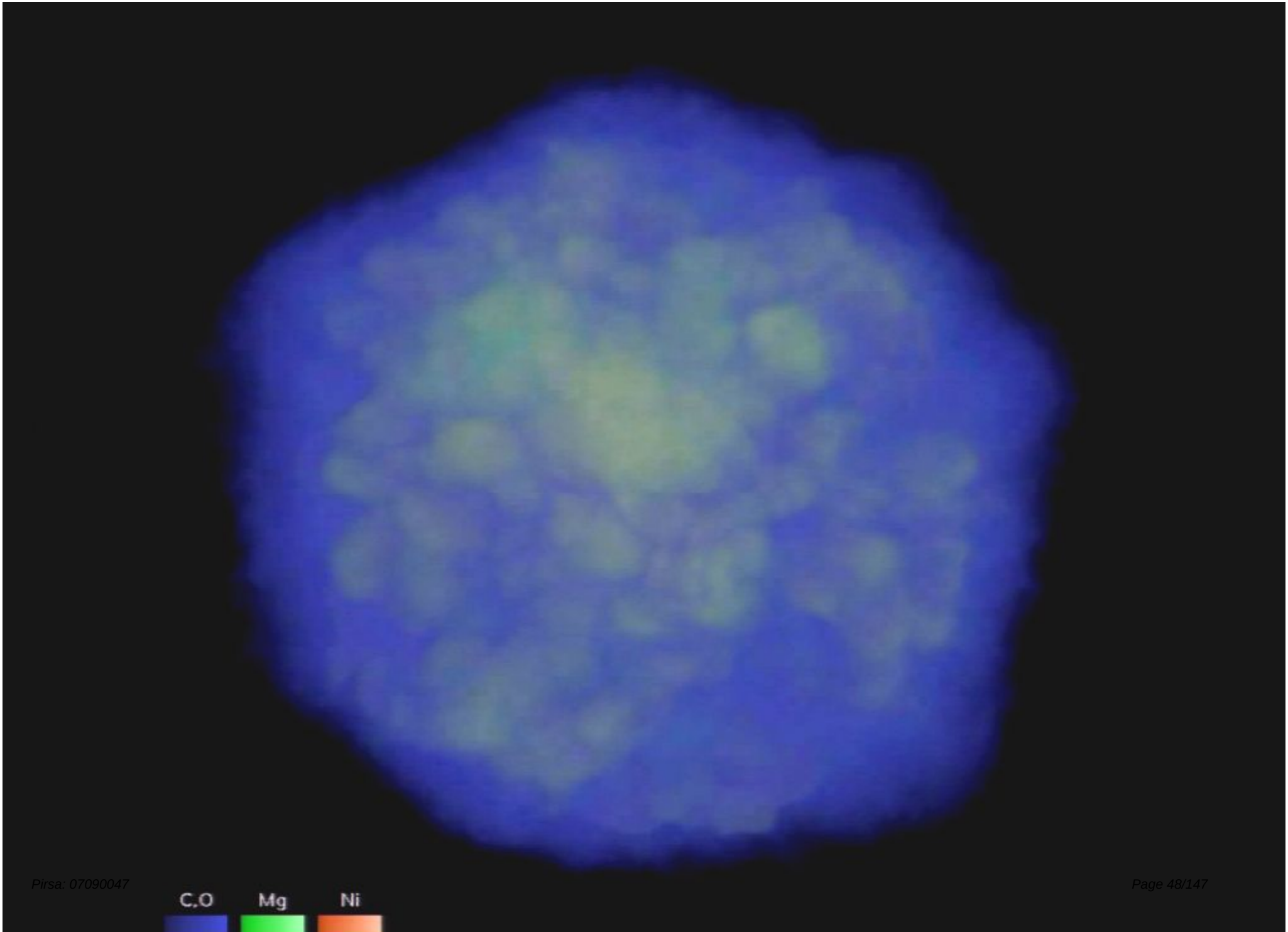
composition 10 s after ignition

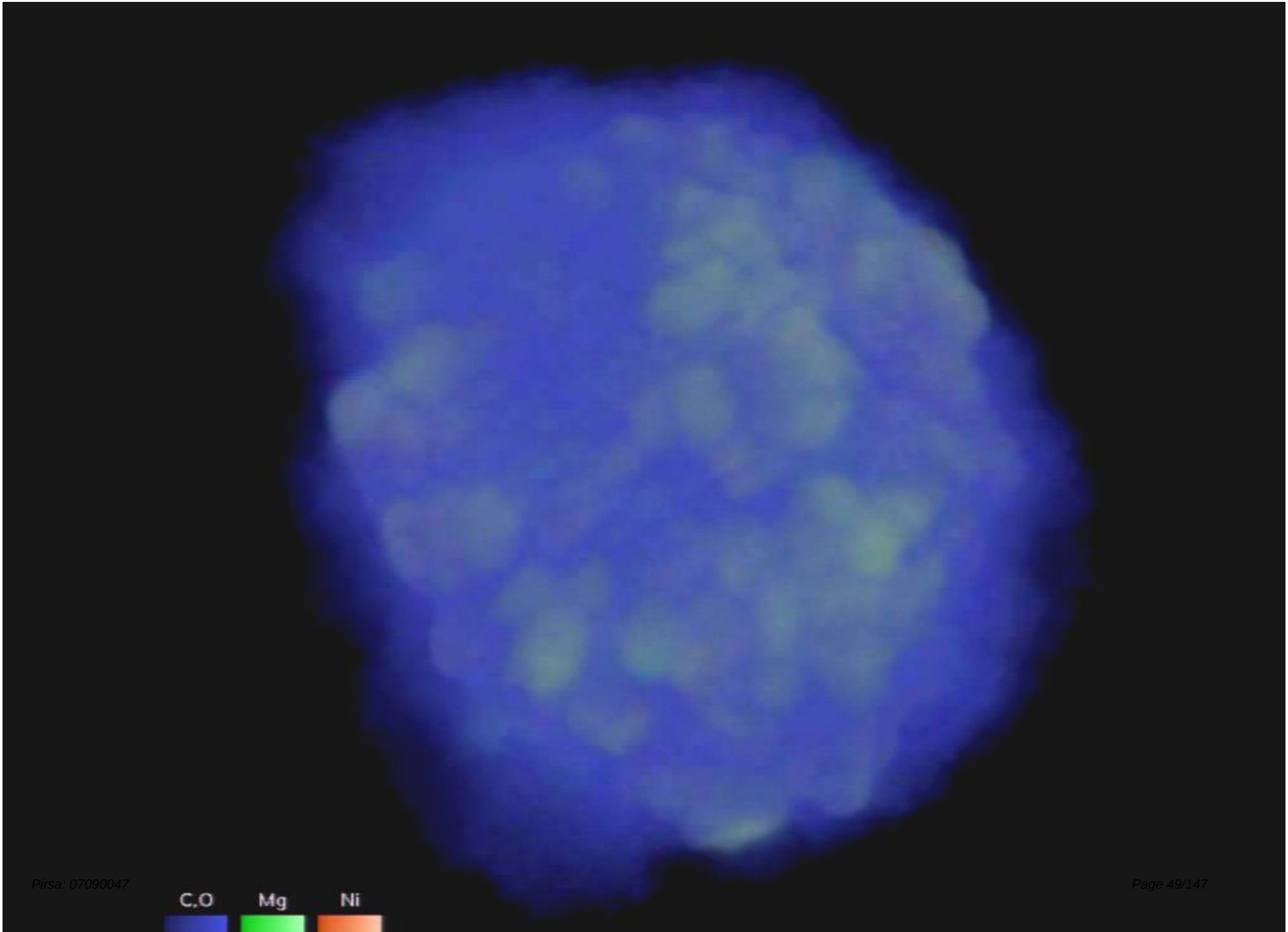
(c) Friedrich Röpke, MPA, 2005

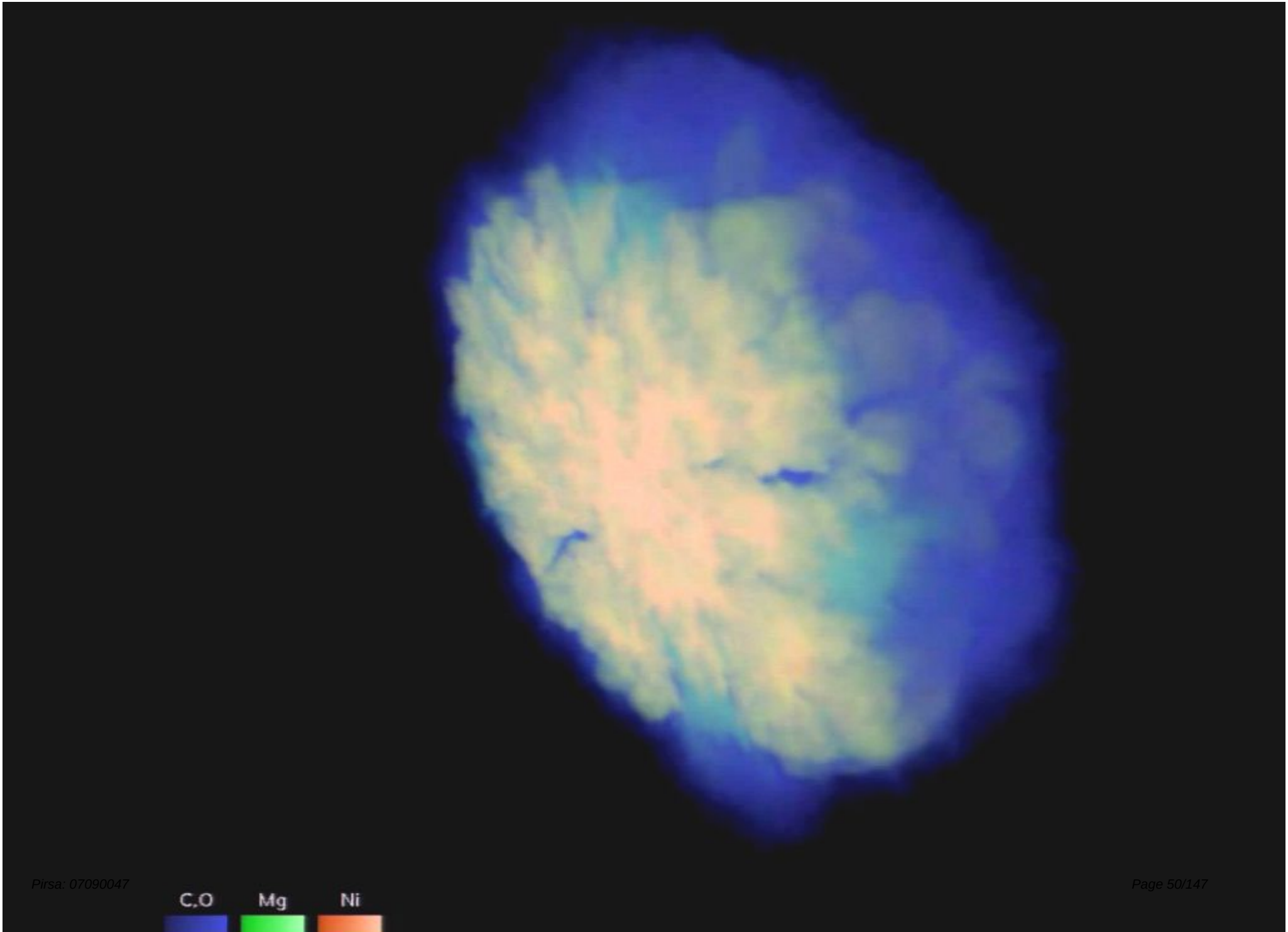
Thermonuclear Supernova Explosion Model

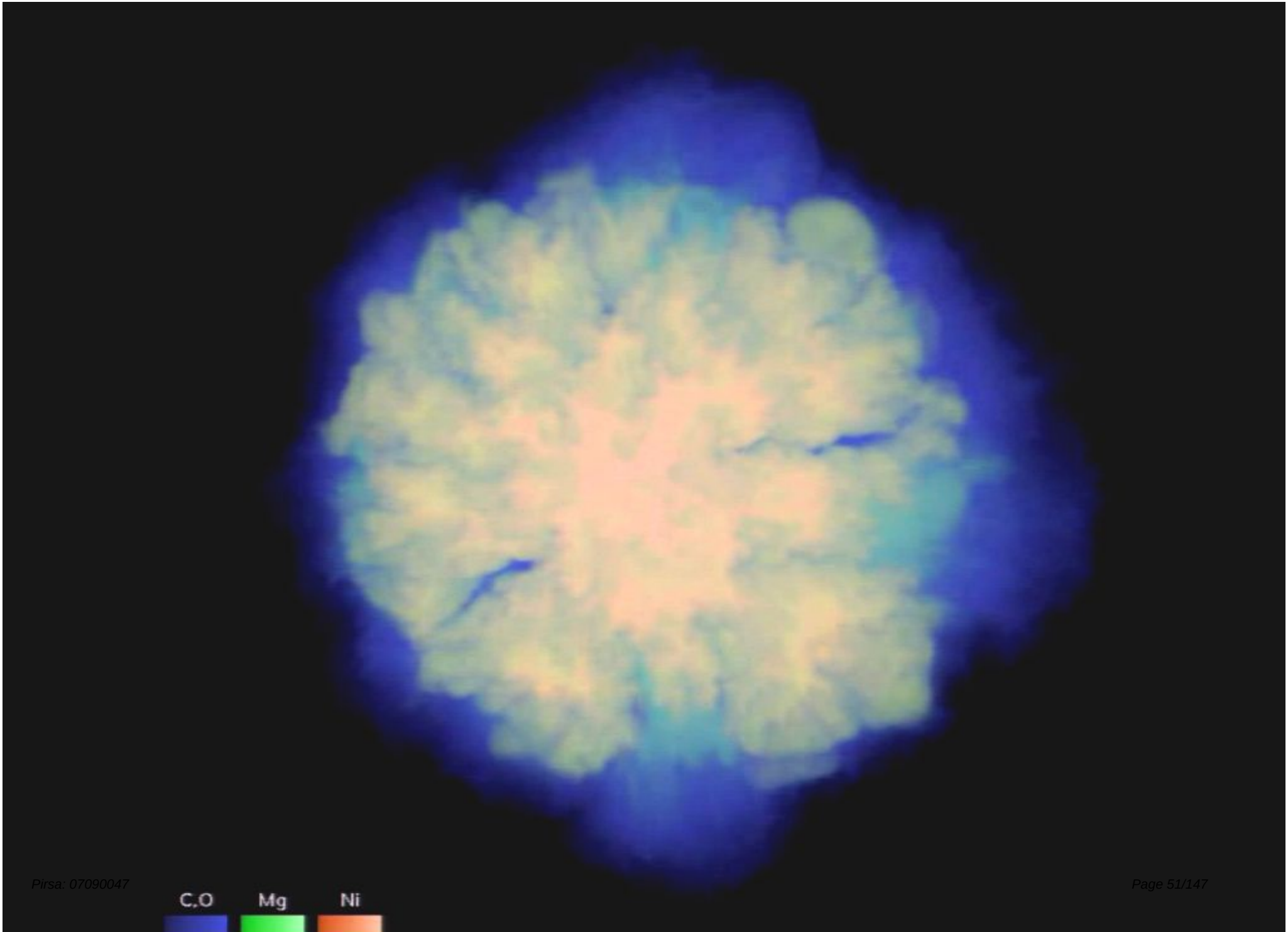
composition 10 s after ignition


C,O
Mg
Ni


C,O
Mg
Ni

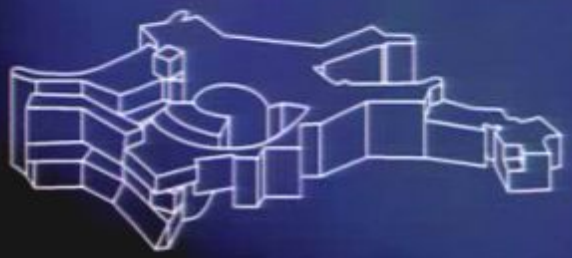

C,O
Mg
Ni


C,O
Mg
Ni


C,O
Mg
Ni

Thermonuclear Supernova Explosion Model

composition 10 s after ignition

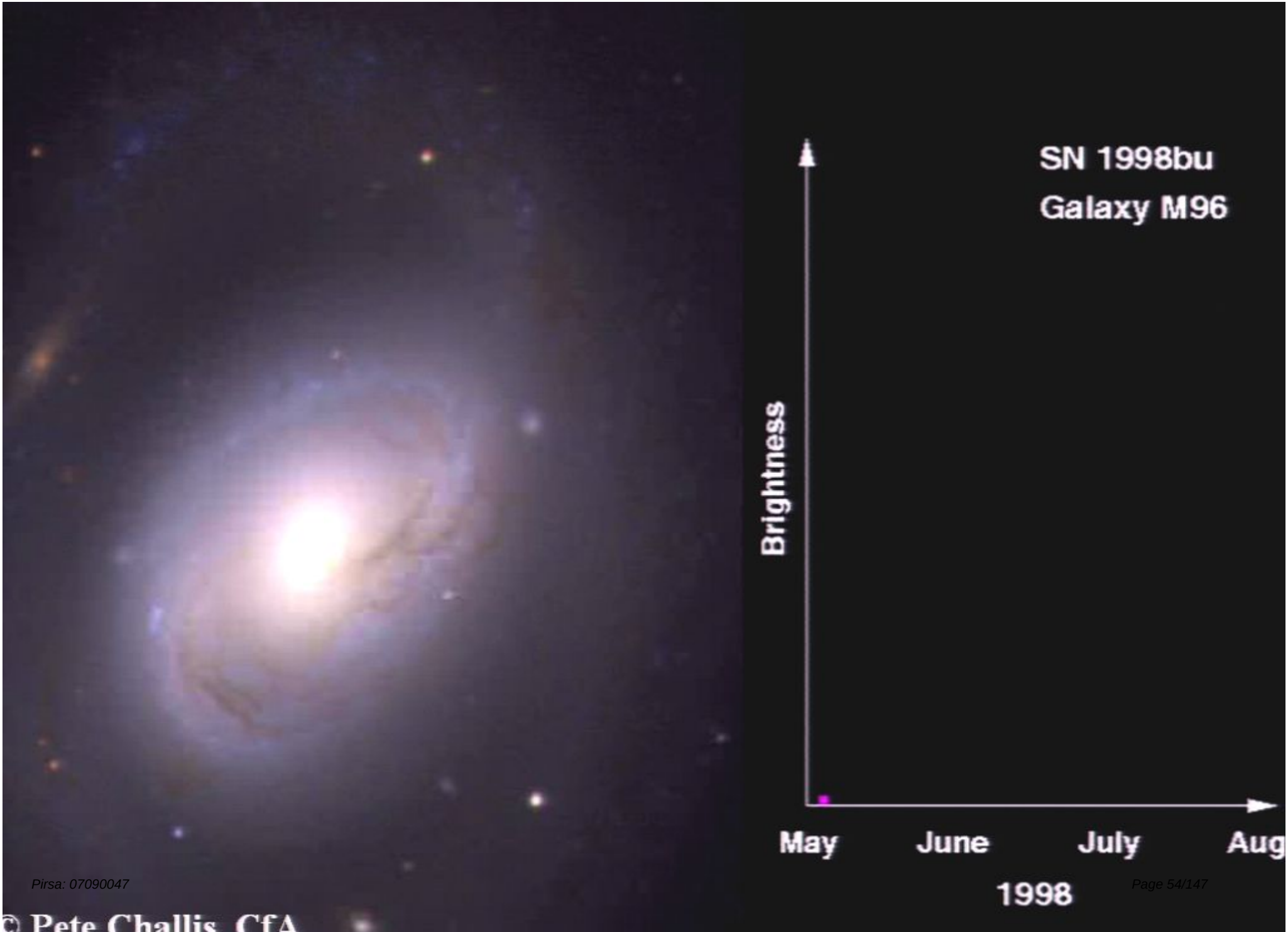


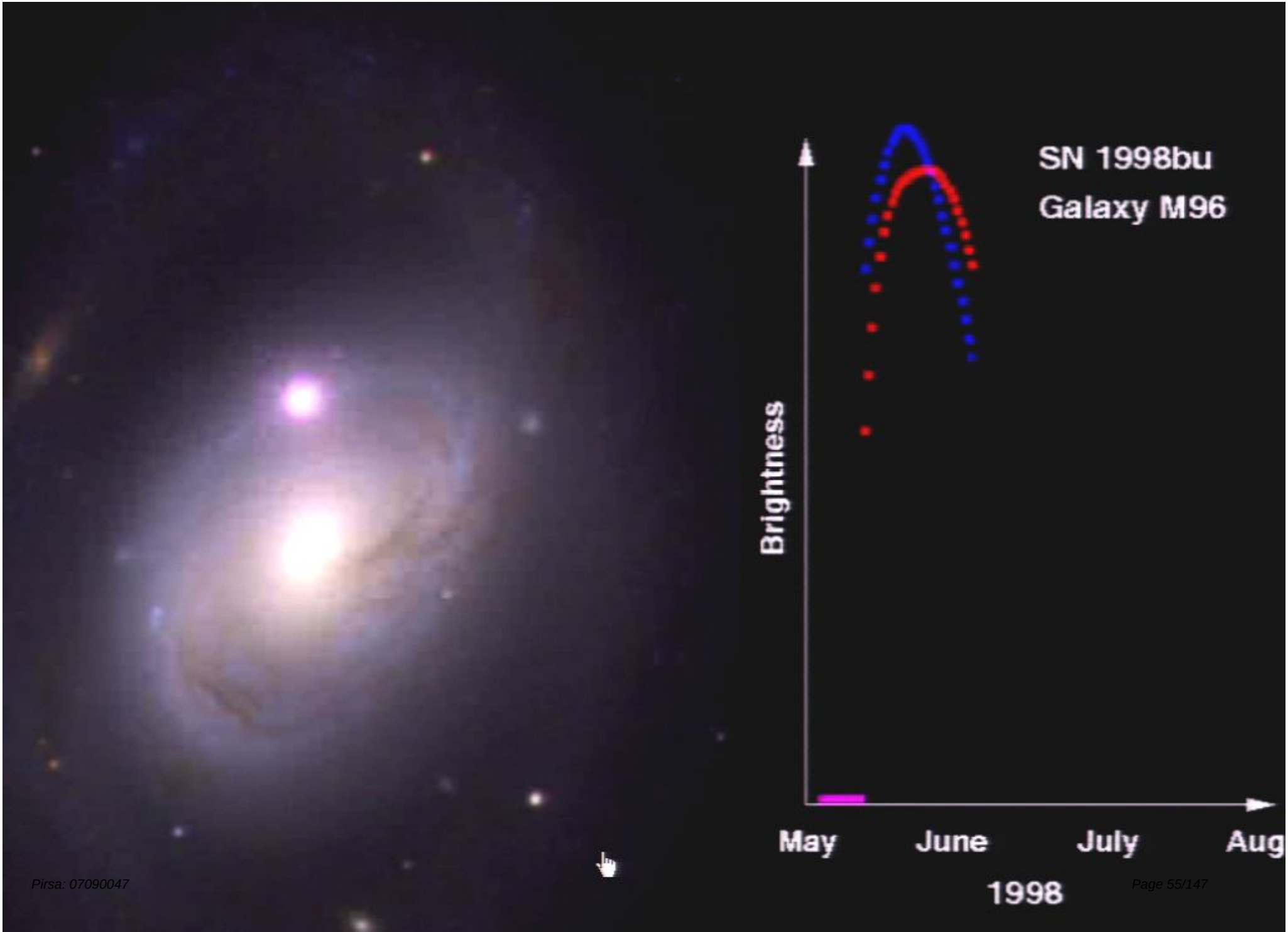
(c) Friedrich Röpke, MPA, 2005

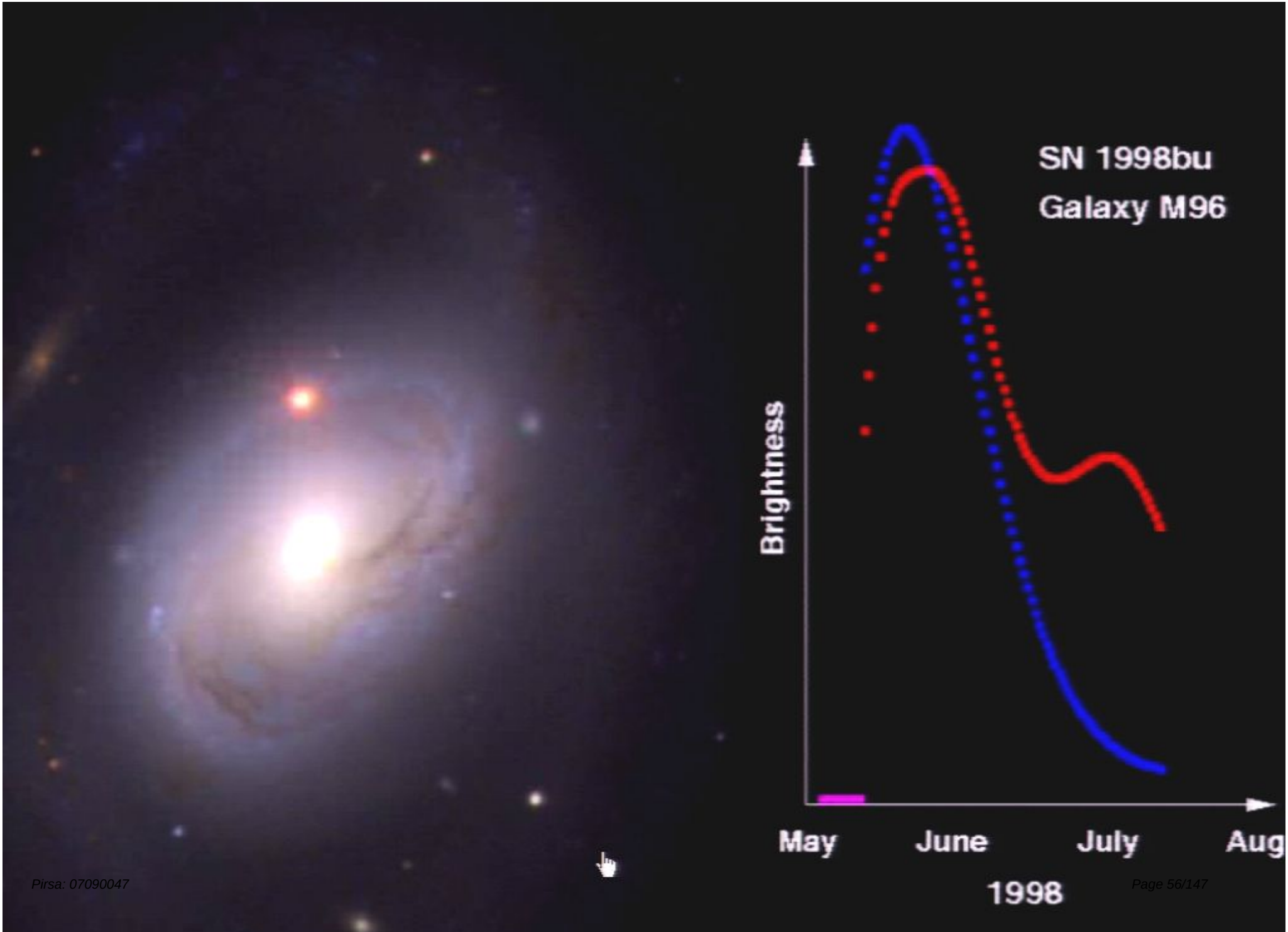
There is more after 10 seconds …

Radiation hydrodynamics

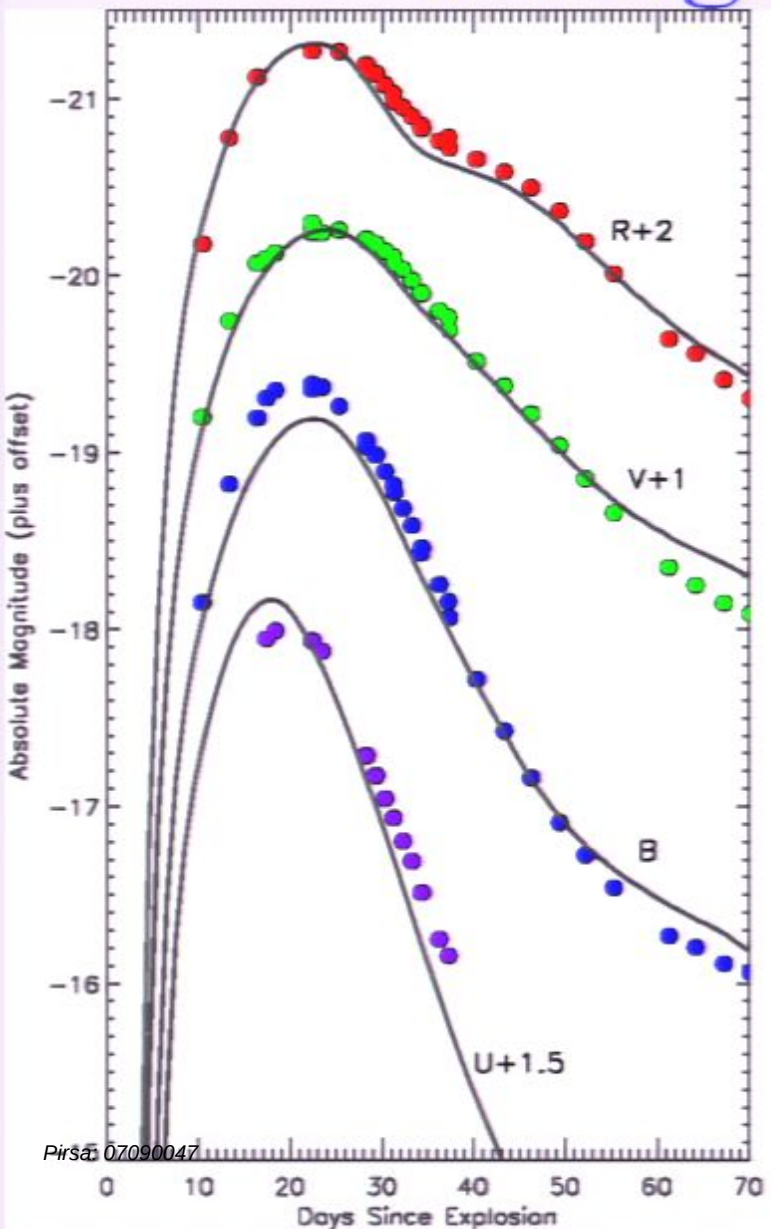
- how do the photons escape the supernova
- the observational fun starts here
- (and the explosion calculations stop)

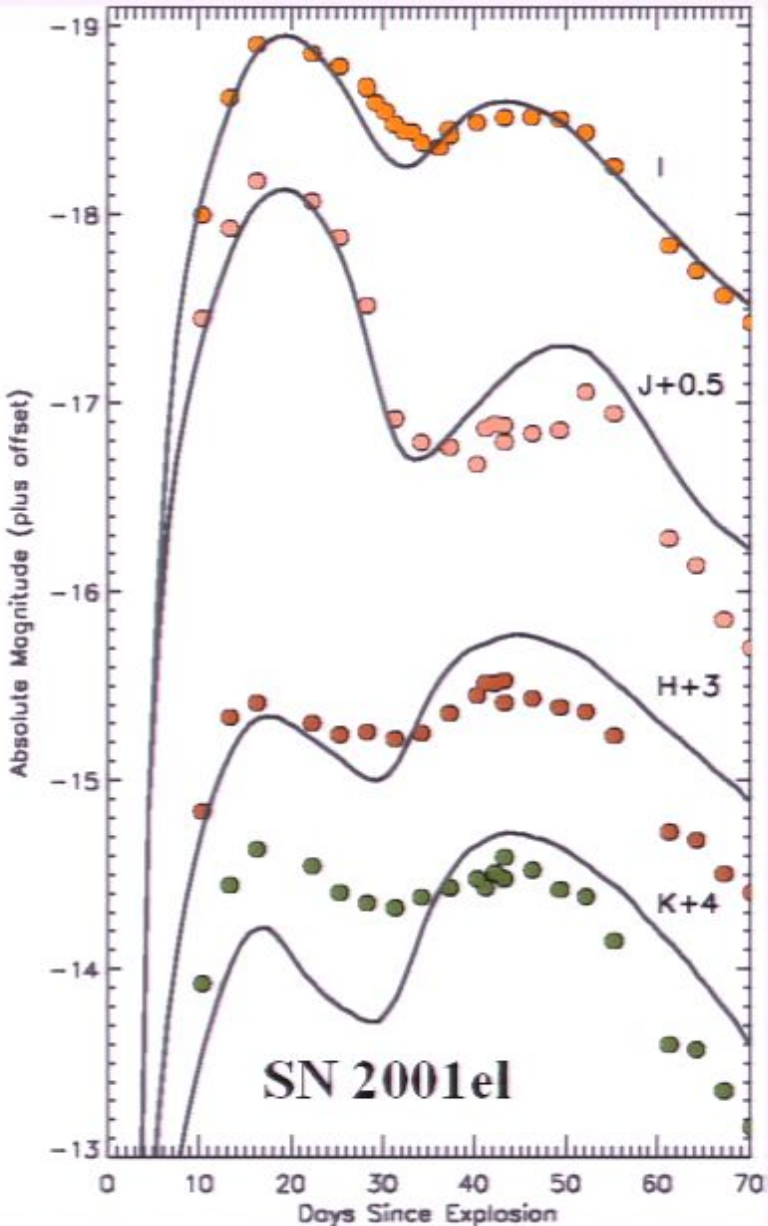

SN 1998bu
Galaxy M96
Brightness
May
June
July
Aug
1998
© Pete Challis, CfA


SN 1998bu
Galaxy M96
Brightness
May
June
July
Aug
1998


SN 1998bu
Galaxy M96
Brightness
May
June
July
Aug
1998

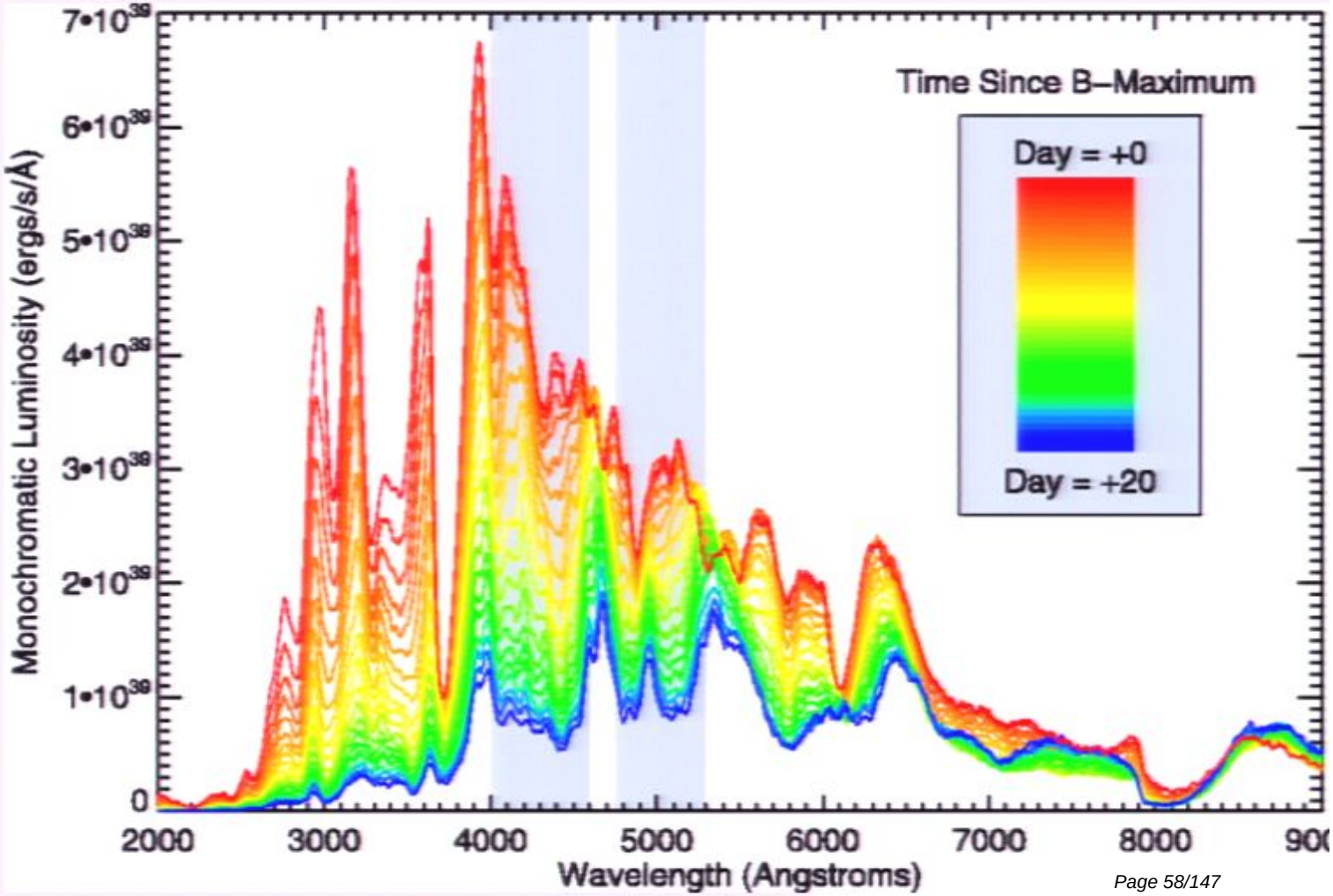
SN light curve calculations





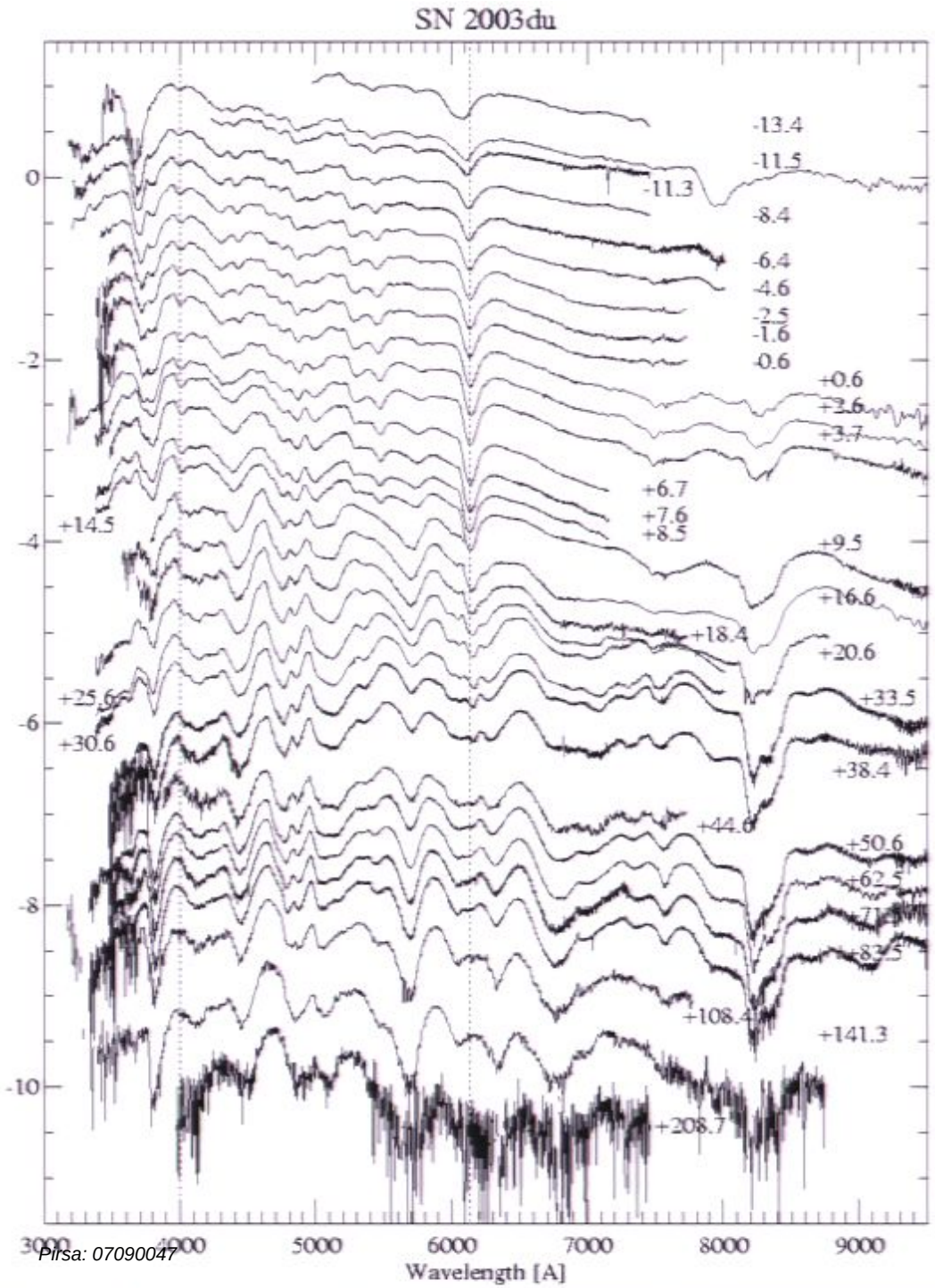
Kasen 2006

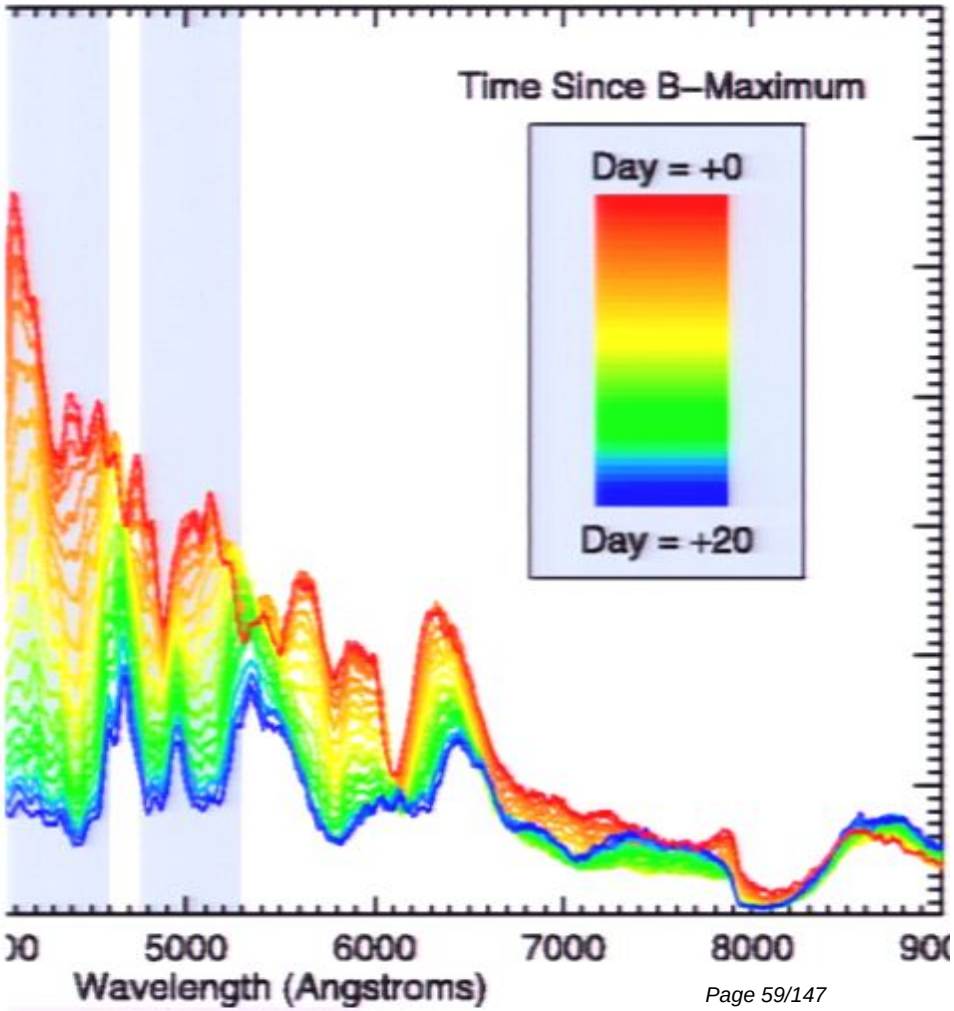
Spectral evolution



Kasen & Woosley 2007

ctral evolution





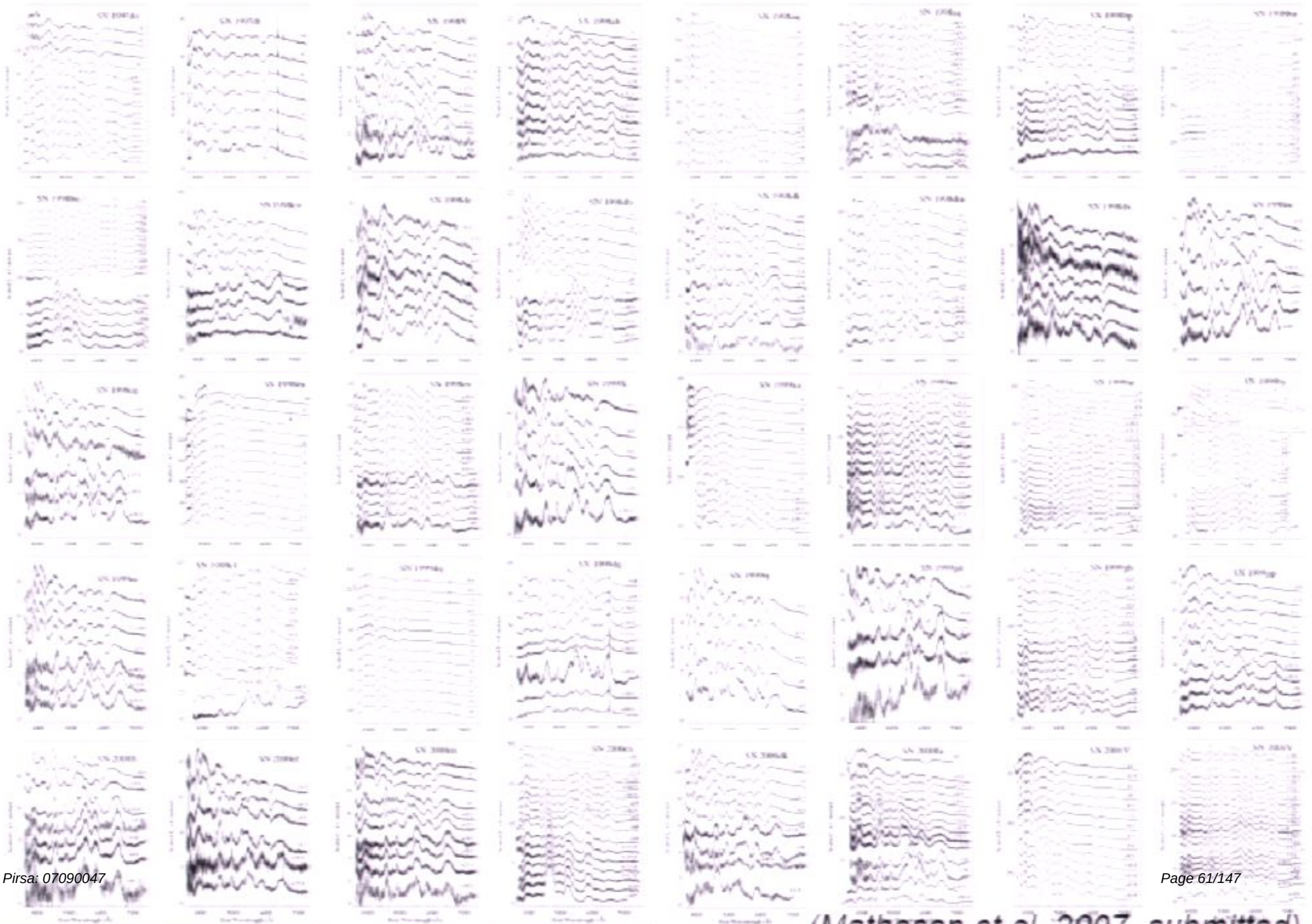
Stanishev et al. 2007

Kasen & Woosley 2007

Are SNe Ia standard candles?

No!

- **large variations in**
  - light curve shapes
  - colours
  - spectral evolution
  - polarimetry
- **some clear outliers**
  - what is a type Ia supernova?
- **differences in physical parameters**
  - Ni mass
  - ejecta mass



(Matheson et al. 2007, submitted)

Are SNe Ia standard candles?

No!

- **large variations in**
  - light curve shapes
  - colours
  - spectral evolution
  - polarimetry
- **some clear outliers**
  - what is a type Ia supernova?
- **differences in physical parameters**
  - Ni mass
  - ejecta mass

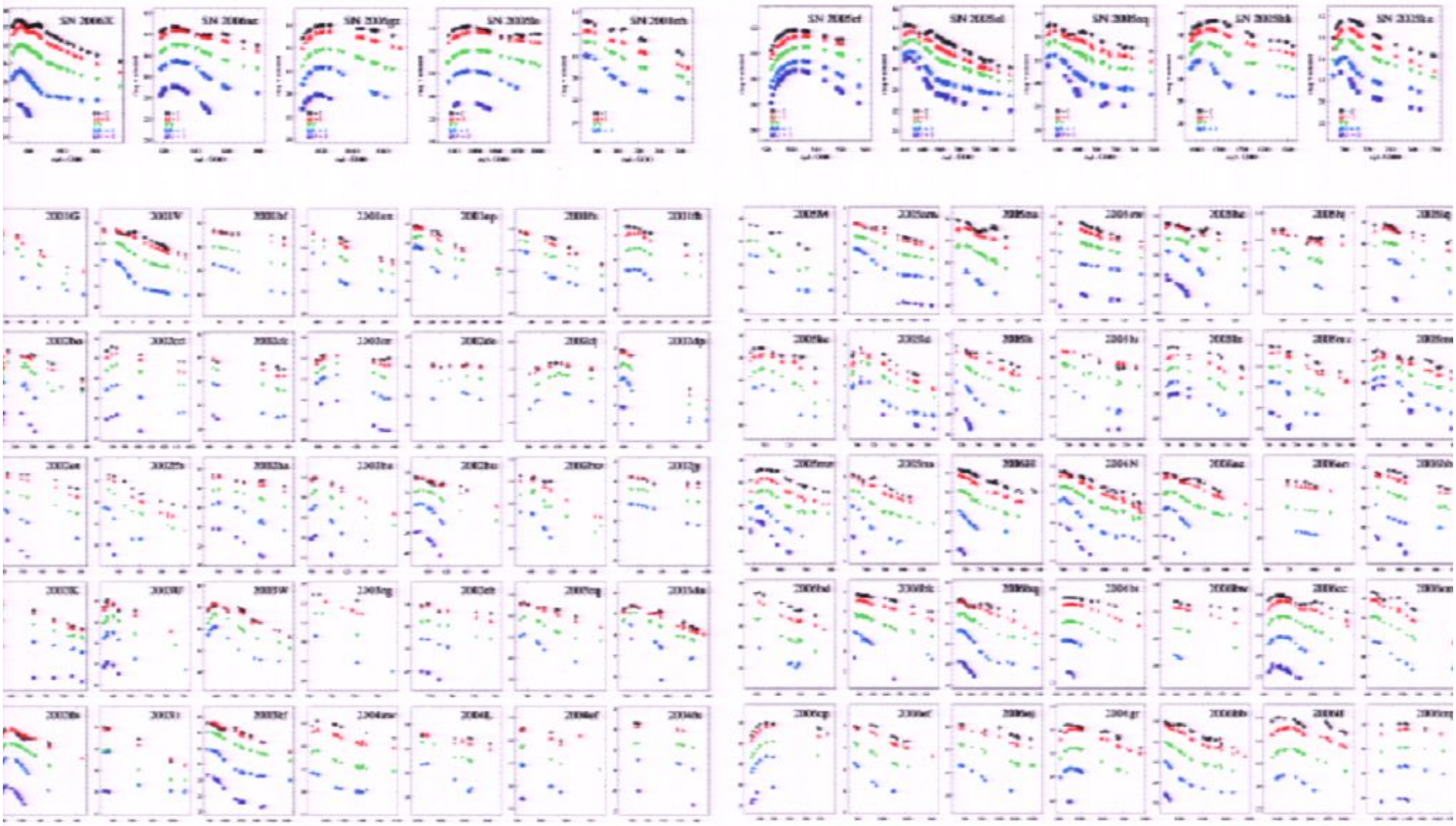


Figure 1: 80 CfA light curves from 2000-2001 (*UBVRI*) and 2004-2006 (*UBVri*)

80 SN Ia light curves *(Malcolm Hicken)*

The diversity of SNe Ia

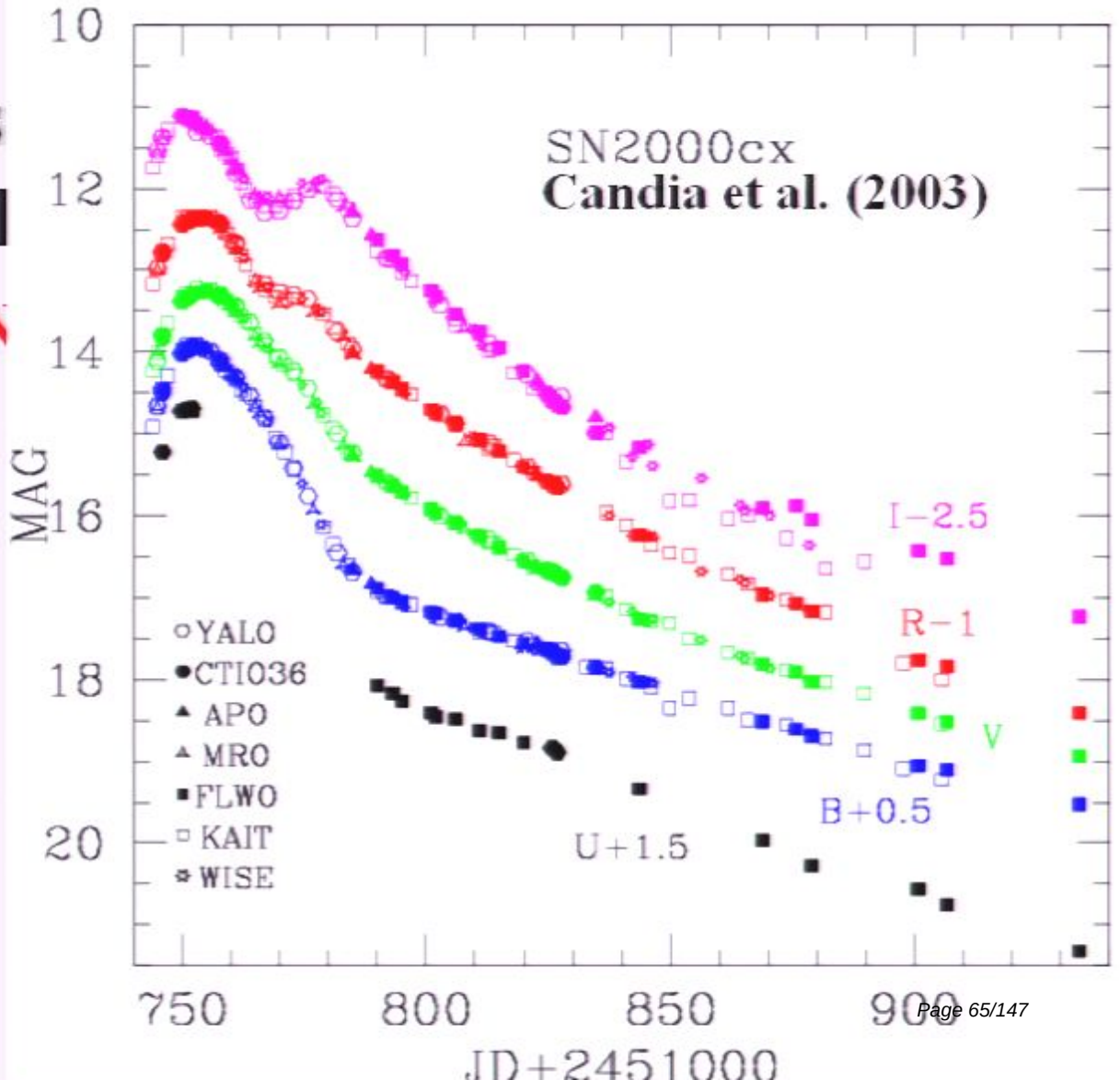
Recent examples have destroyed the standard candle picture

- **SN 2000cx, SN 2002cx**

The diversity of SNe Ia

Recent examples
standard candl

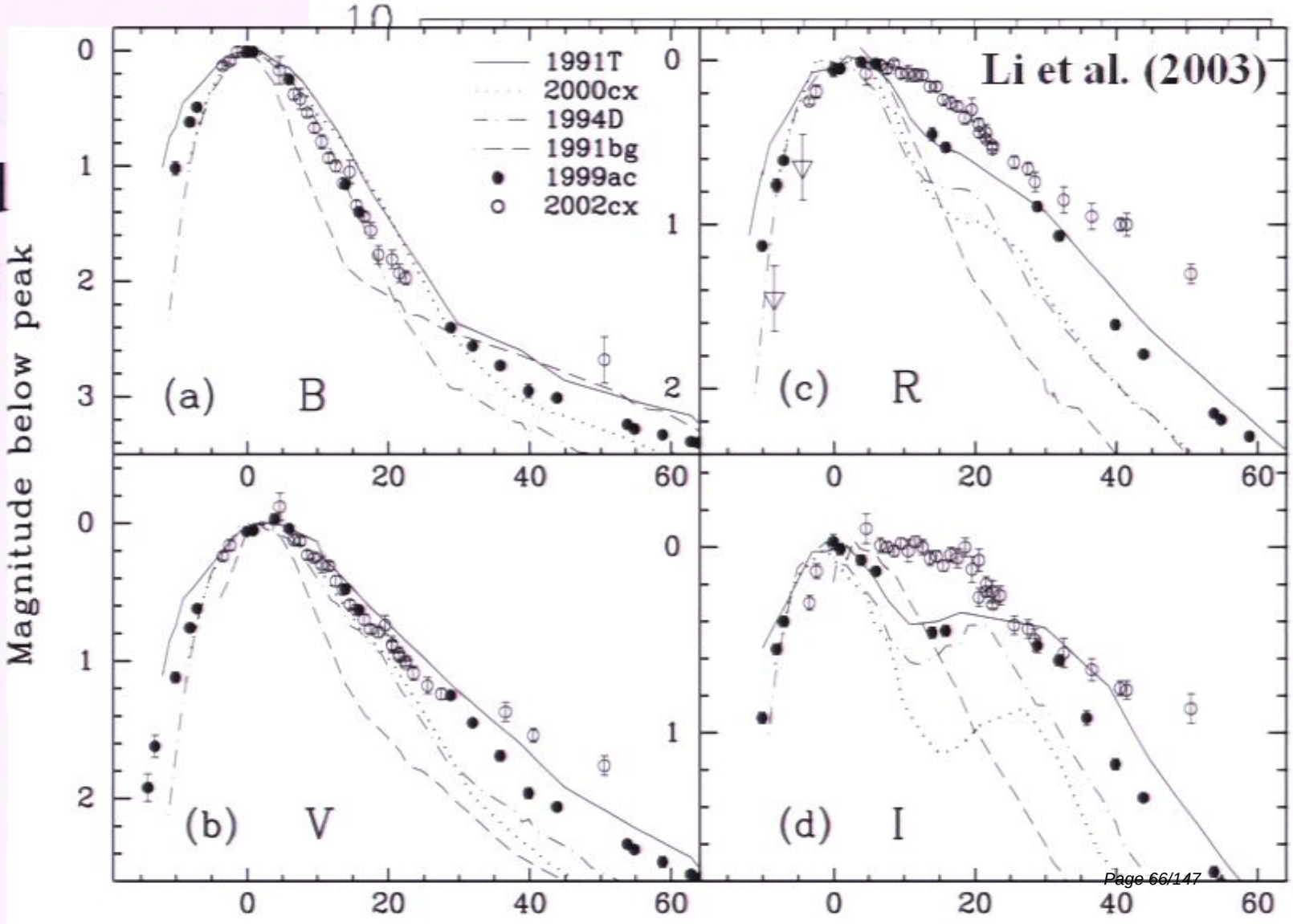
- **SN 2000cx, SN**



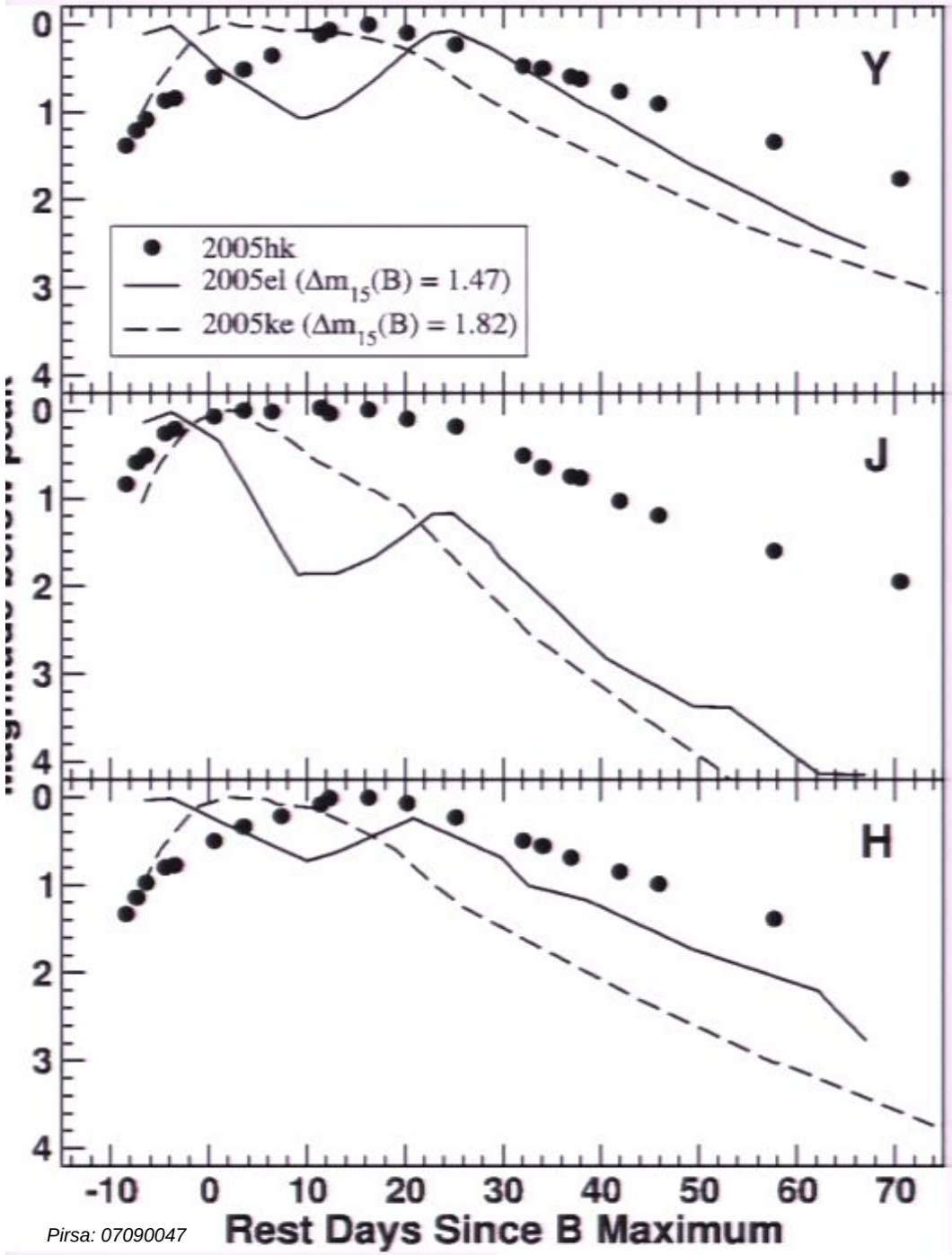
The diversity of SNe Ia

Recent stand

- **SN**

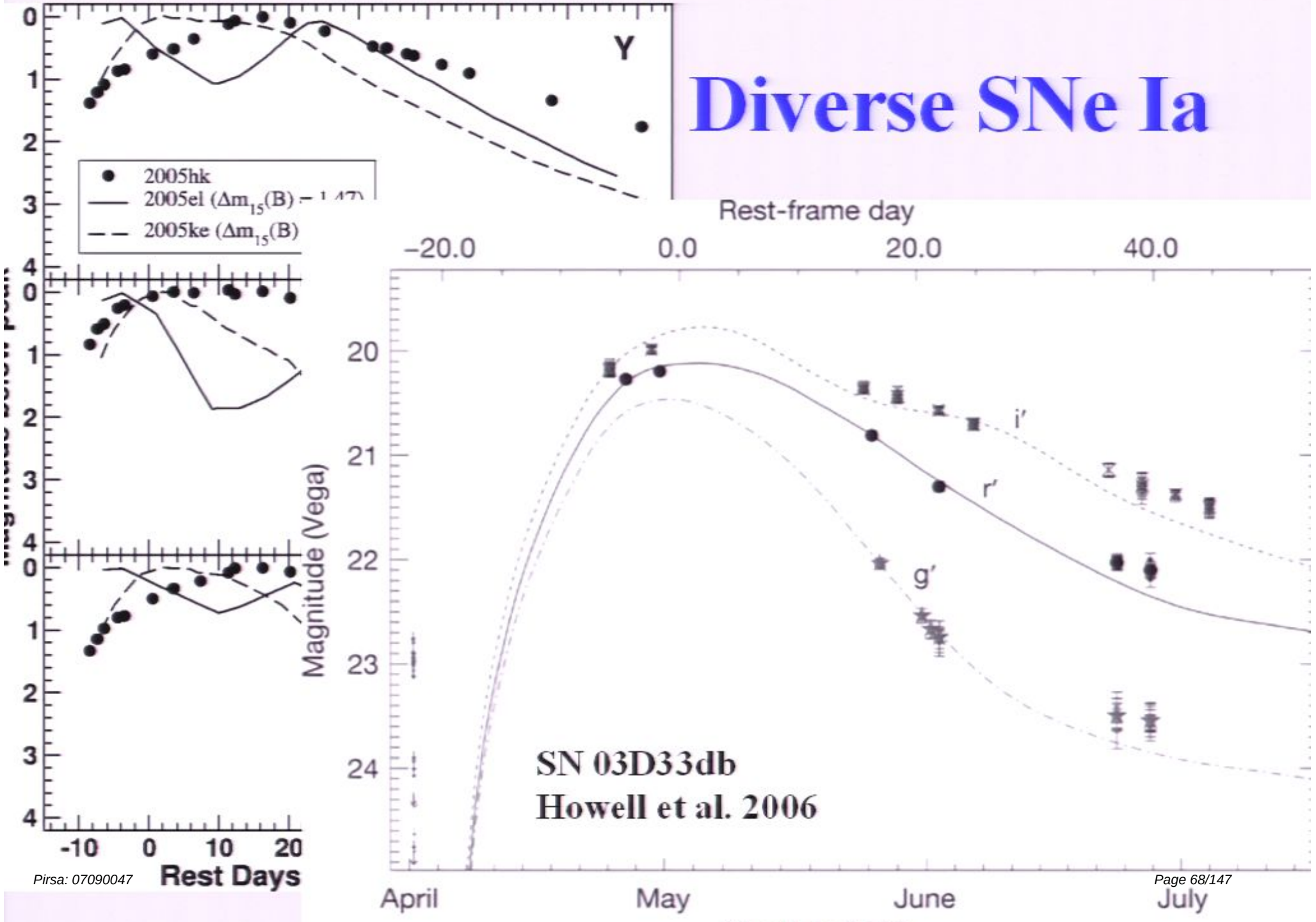


Diverse SNe Ia

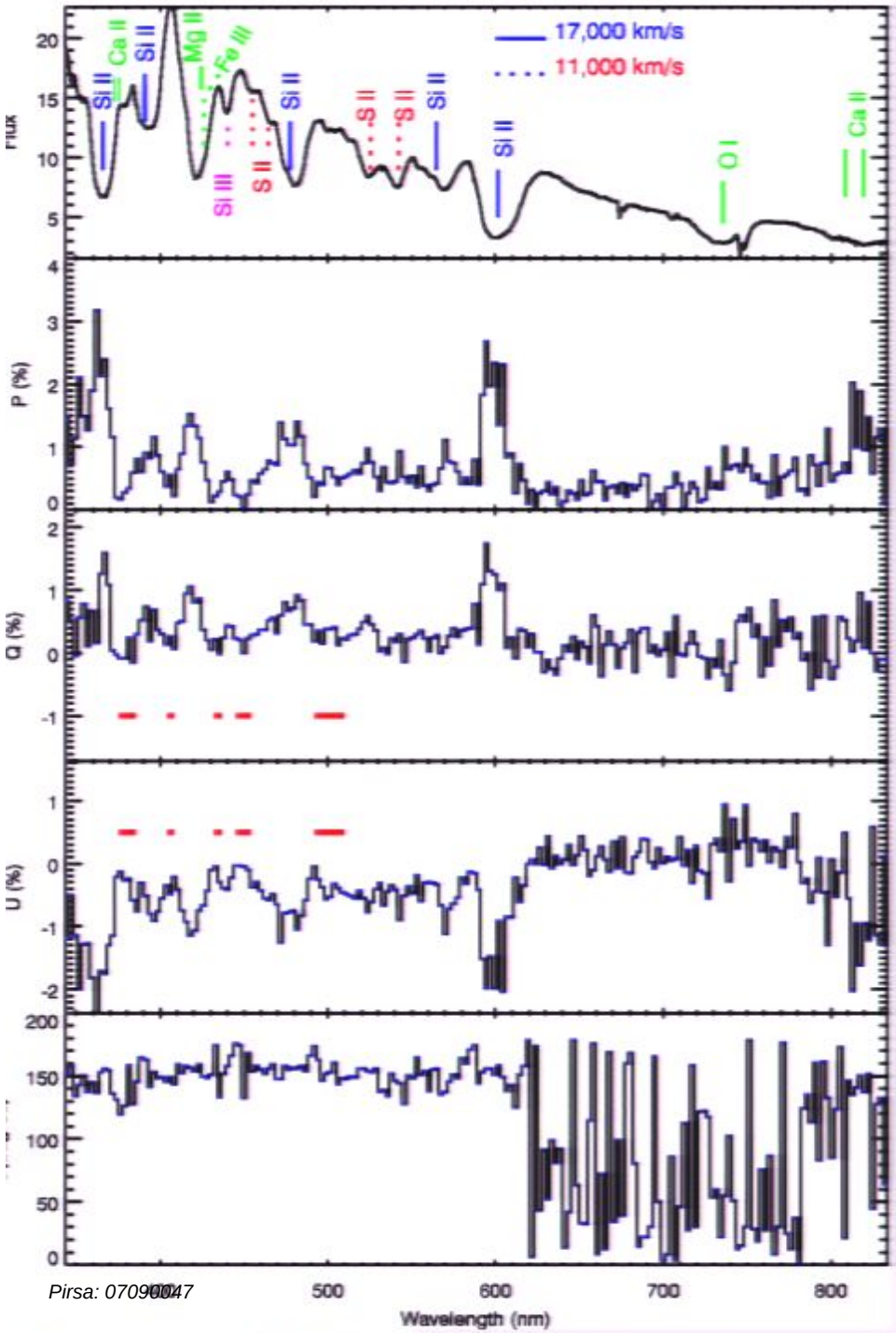


Phillips et al. 2007

Diverse SNe Ia

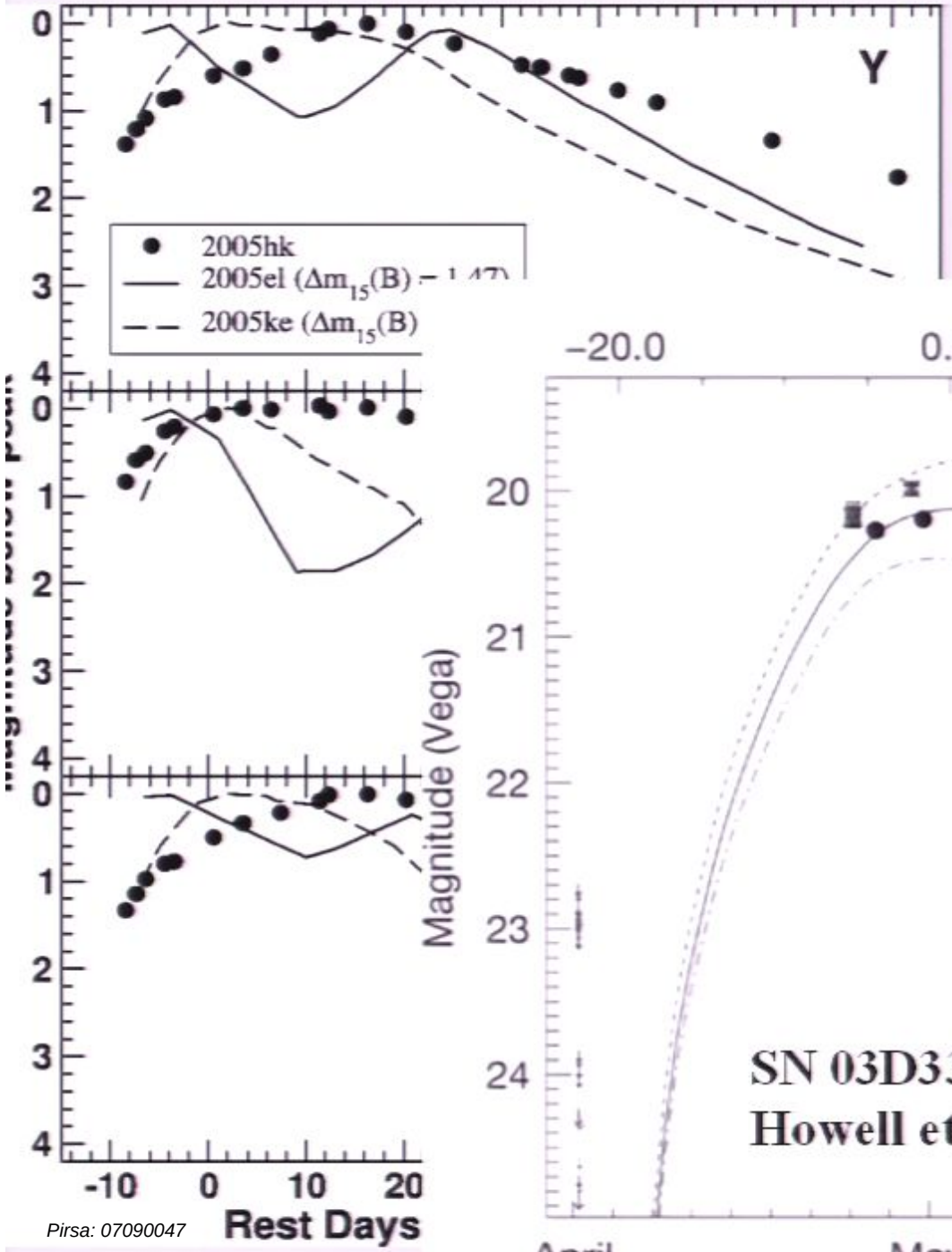


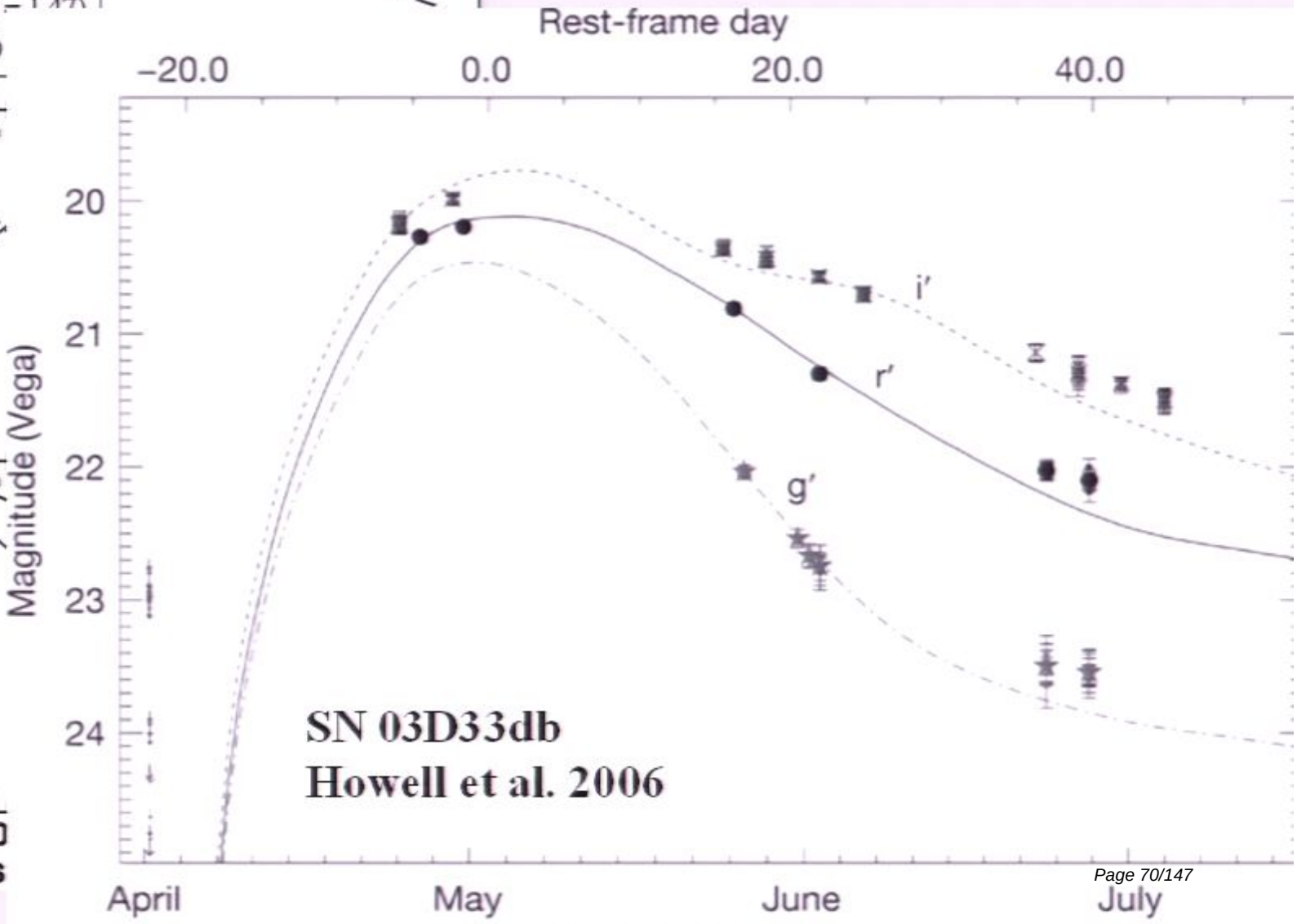
Polarimetry



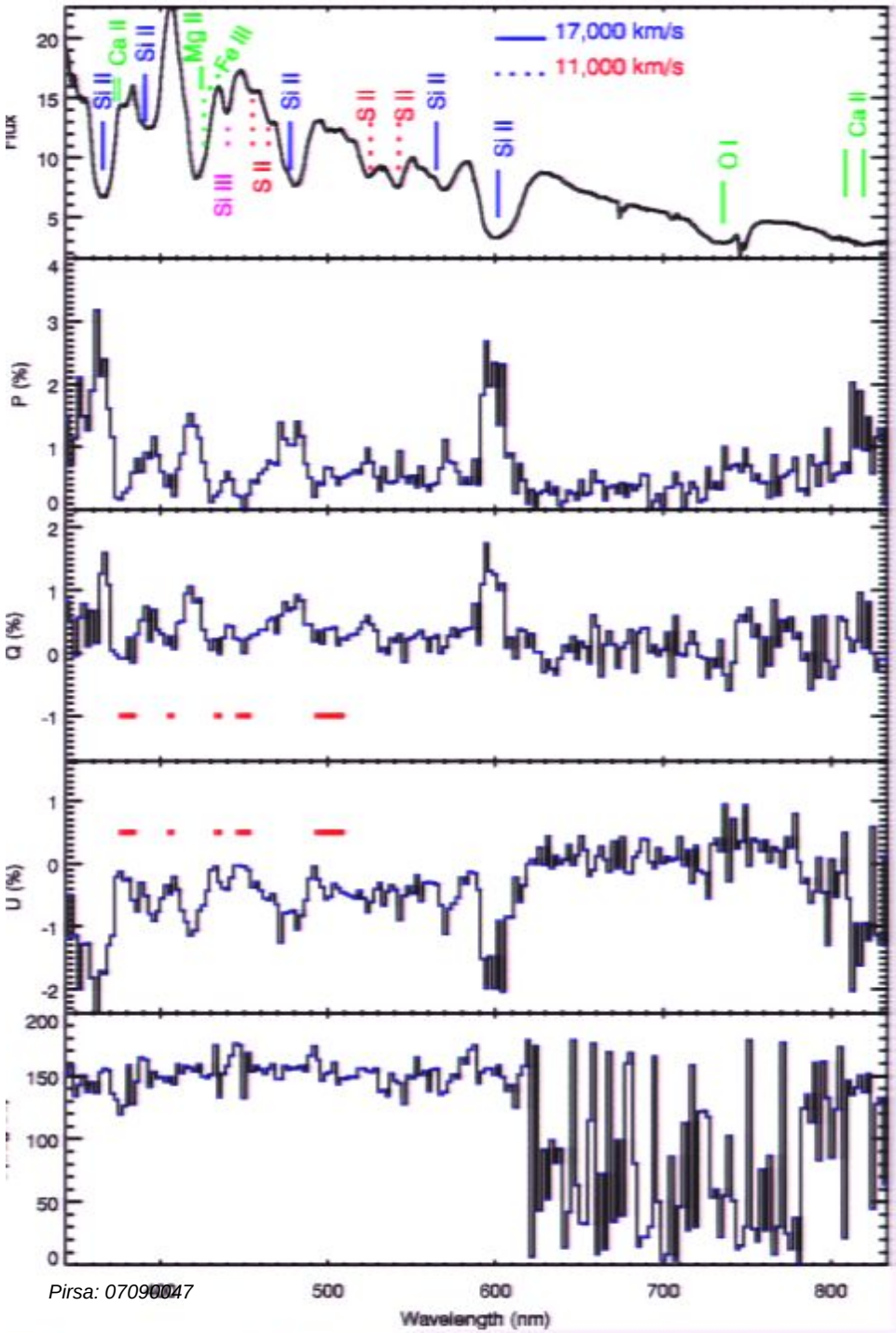
Wang et al. 2006

Diverse SNe Ia



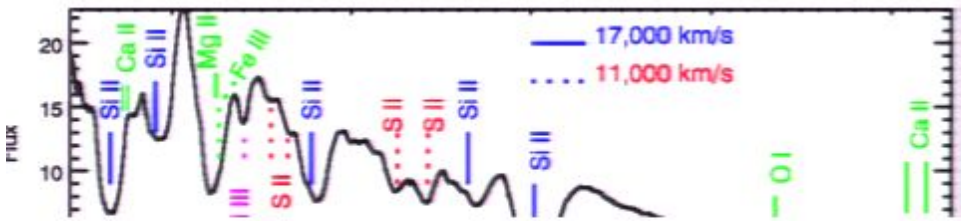


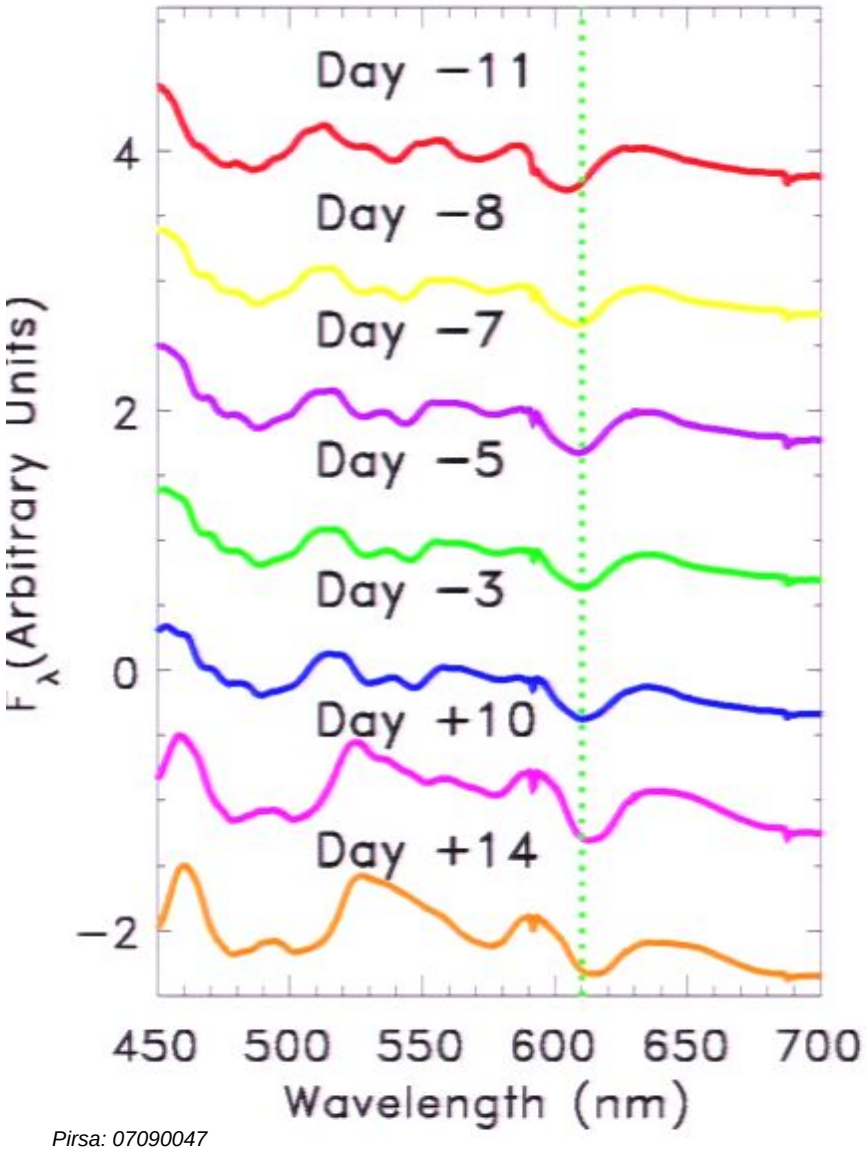
Polarimetry

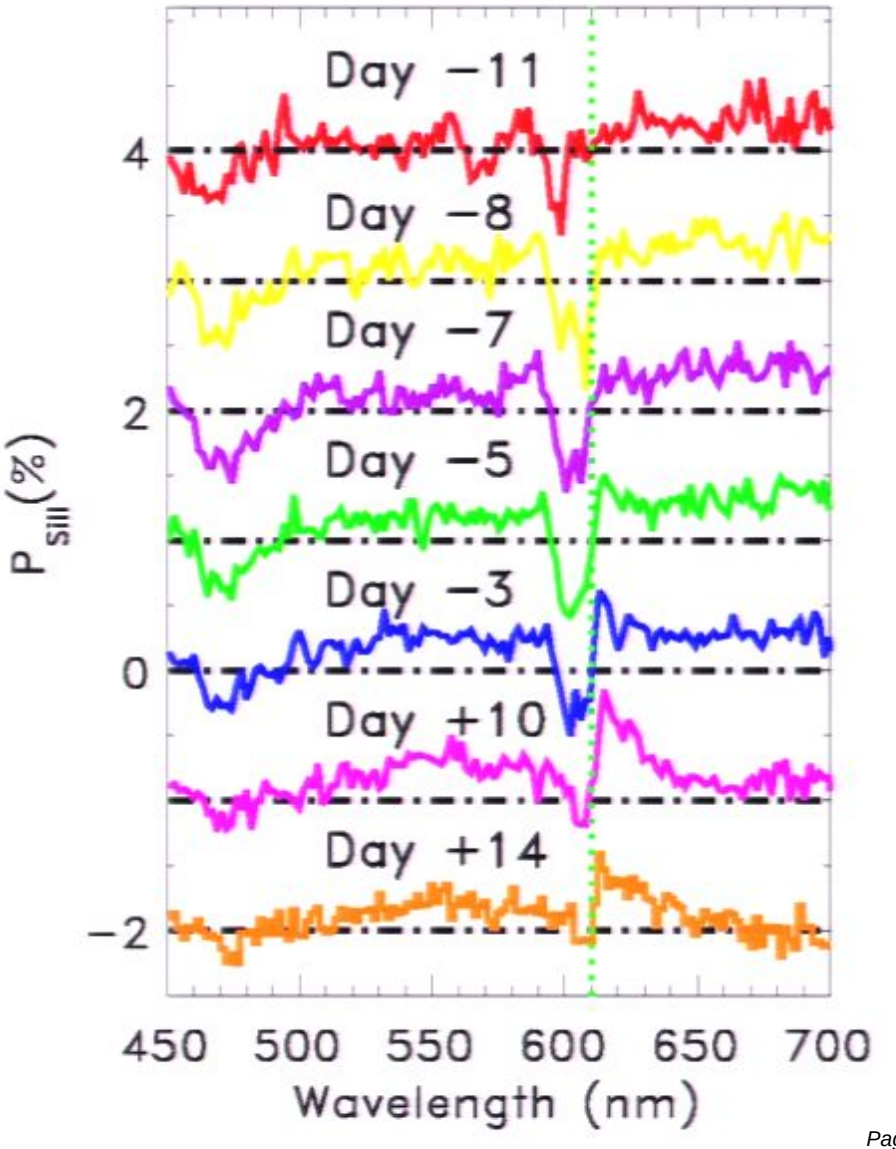


Wang et al. 2006

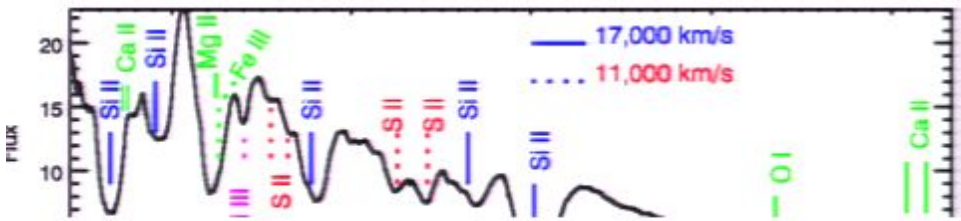
Polarimetry







Wang et al. 2007



Polarimetry

Spectropolarimetry of SNe Ia

(Leonard et al. 2005)

Polarimetry results

Very small continuum polarisation

→overall shape appears fairly round

Partially strong line polarisation

→distribution of individual elements could be clumped

→inhomogeneous explosion mechanism?

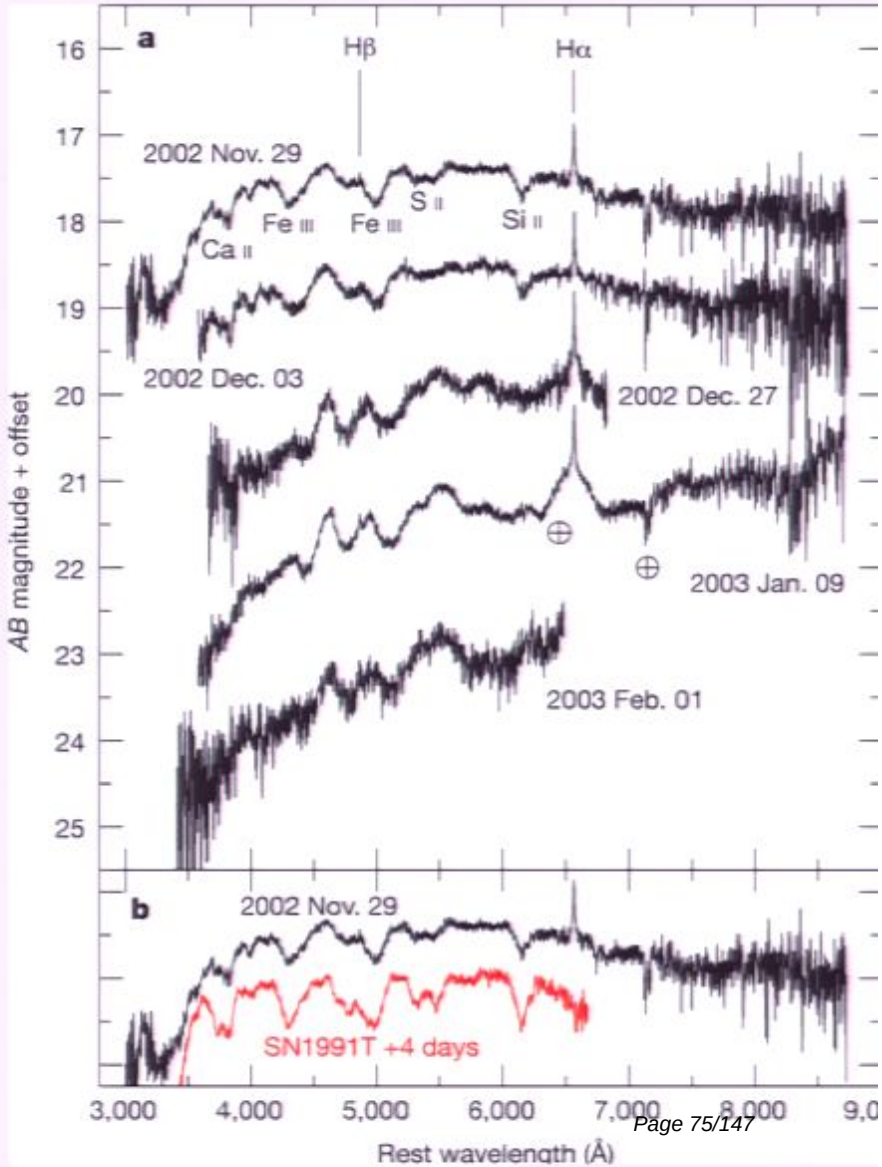
→dependence on viewing angle?

Possible correlation with light curve shape parameter (Wang et al. 2007)

What is a SN Ia?

Peculiar cases abound …

- SN 1991T, SN 1991bg
- SN 1999aa, SN 1999ac
- SN 2000cx, SN 2002cx
- SN 2002ic
- SN 03D3bb
- SN 2005hk
- and more

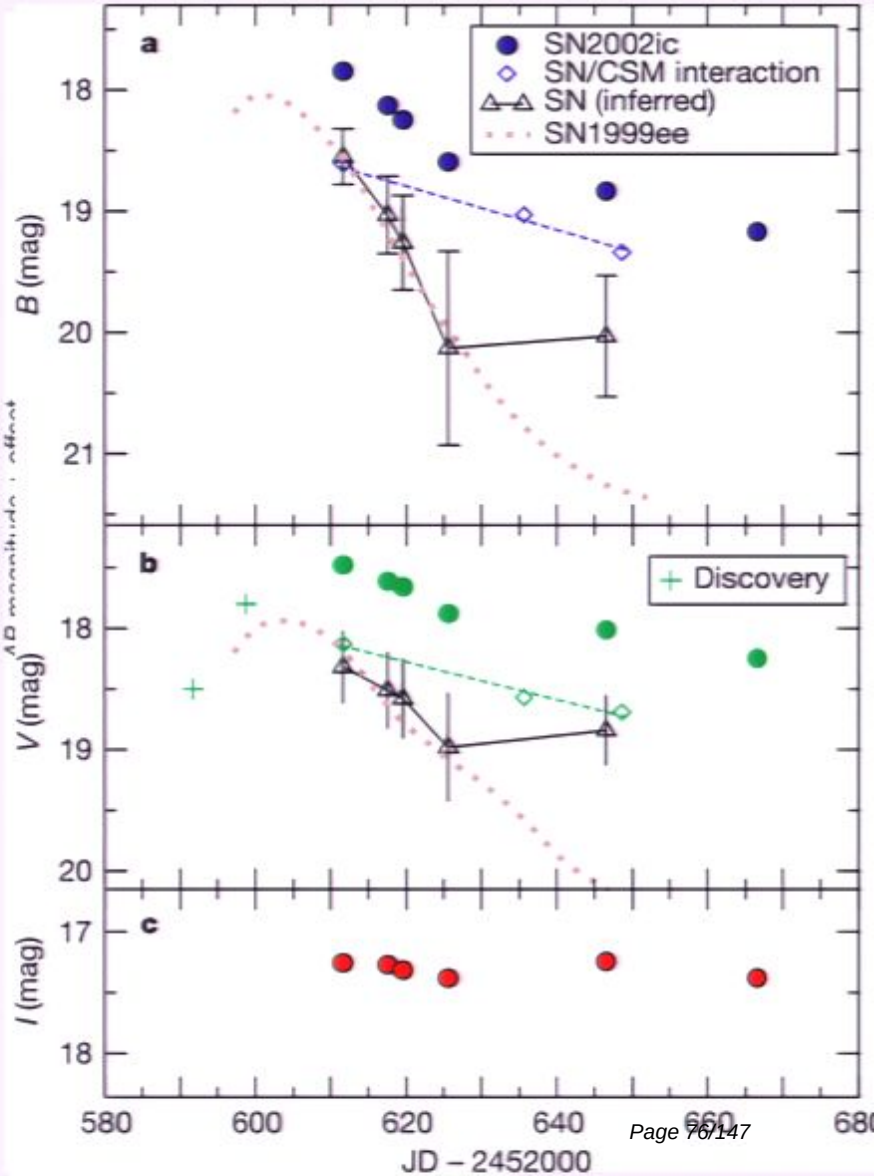


Hamuy et al. 2003

What is a SN Ia?

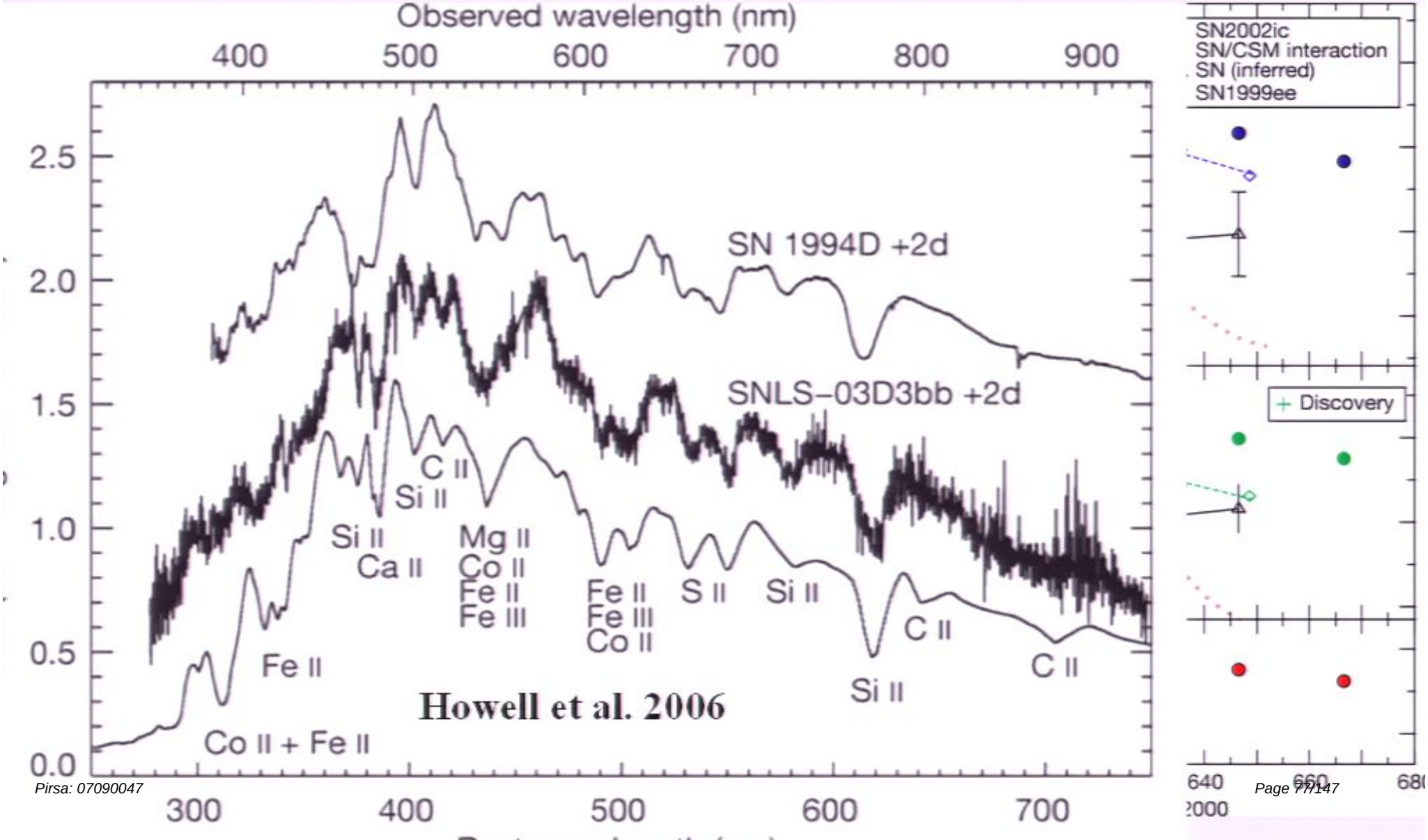
Peculiar cases abound …

- SN 1991T, SN 1991bg
- SN 1999aa, SN 1999ac
- SN 2000cx, SN 2002cx
- SN 2002ic
- SN 03D3bb
- SN 2005hk
- and more

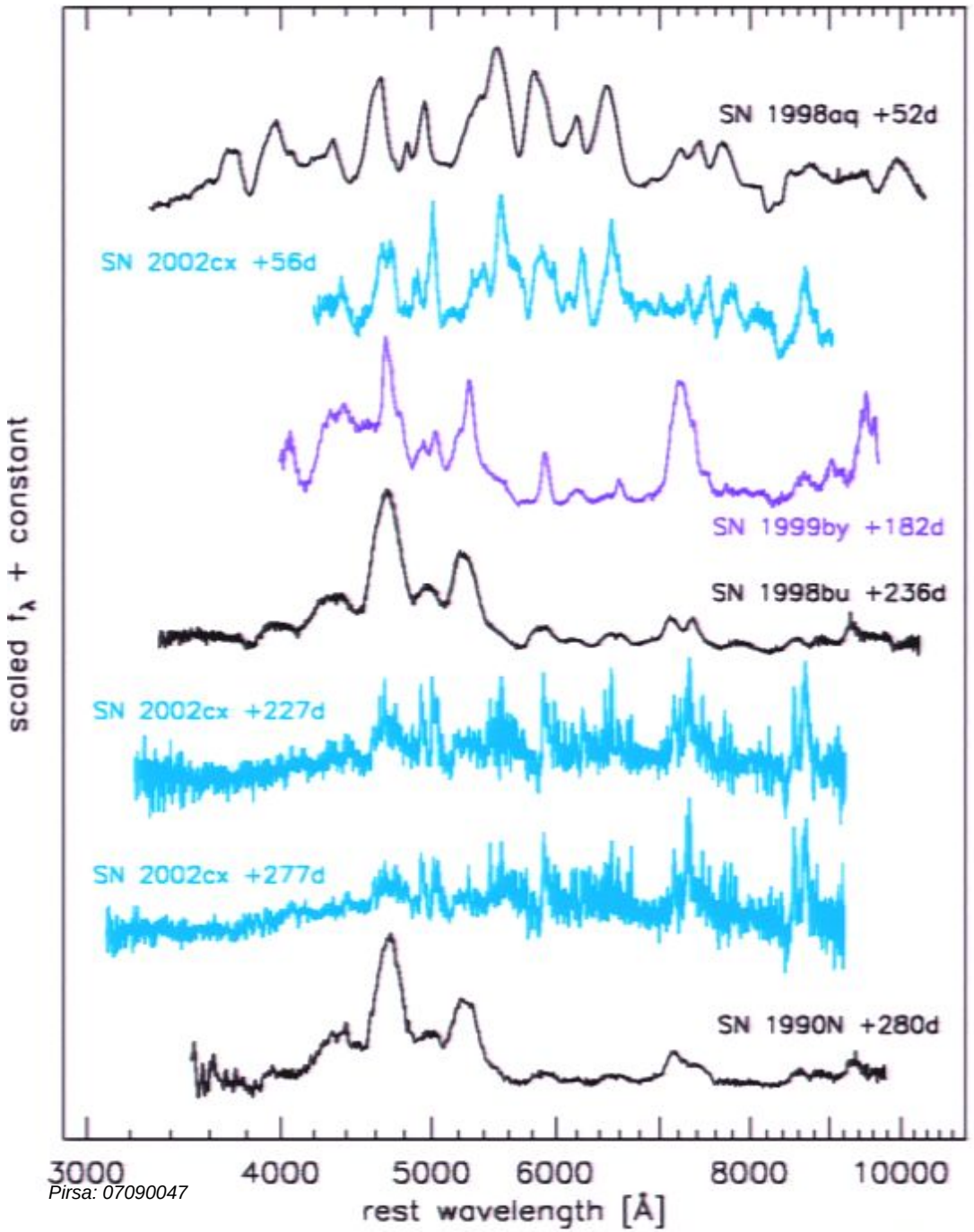


Hamuy et al. 2003

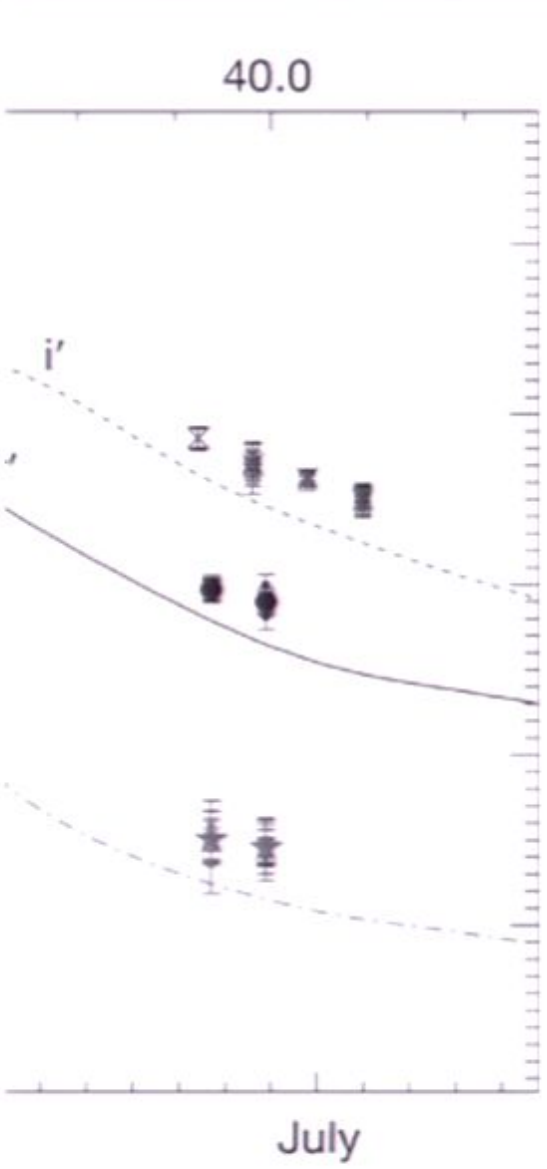
What is a SN Ia?

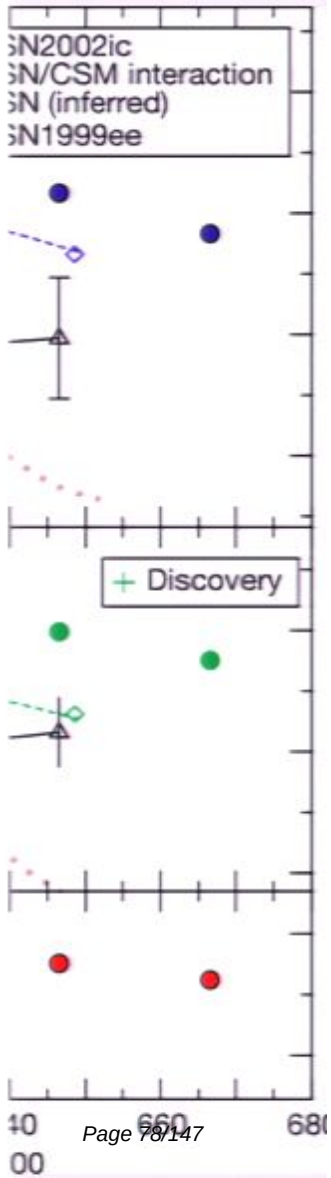


hat is a SN Ia?

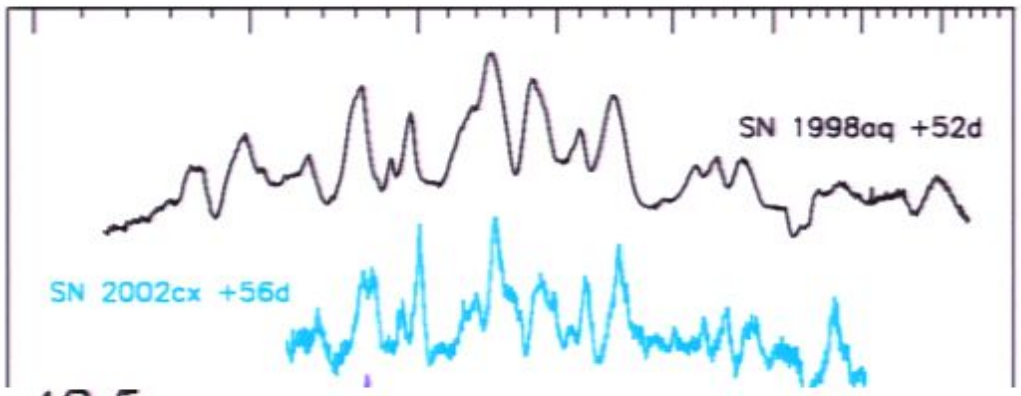


Jha et al. 2006

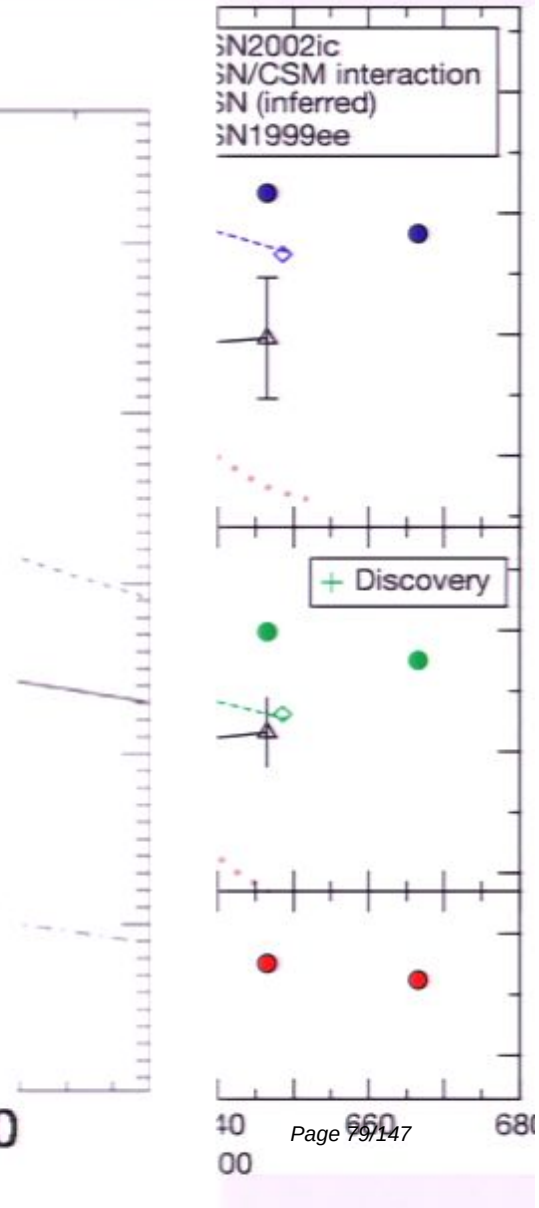




hat is a SN Ia?


SN 1998aq +52d
SN 2002cx +56d

Phillips et al. 2007
SN 2001el
SN 2006hk
SN 1999by
Model lc_1_3_3
log L_bol [erg s^-1]
Days Since Explosion
43.5
43
42.5
42
41.5
41
0
20
40
60
80


40.0
SN2002ic
SN/CSM interaction
SN (inferred)
SN1999ee
Discovery

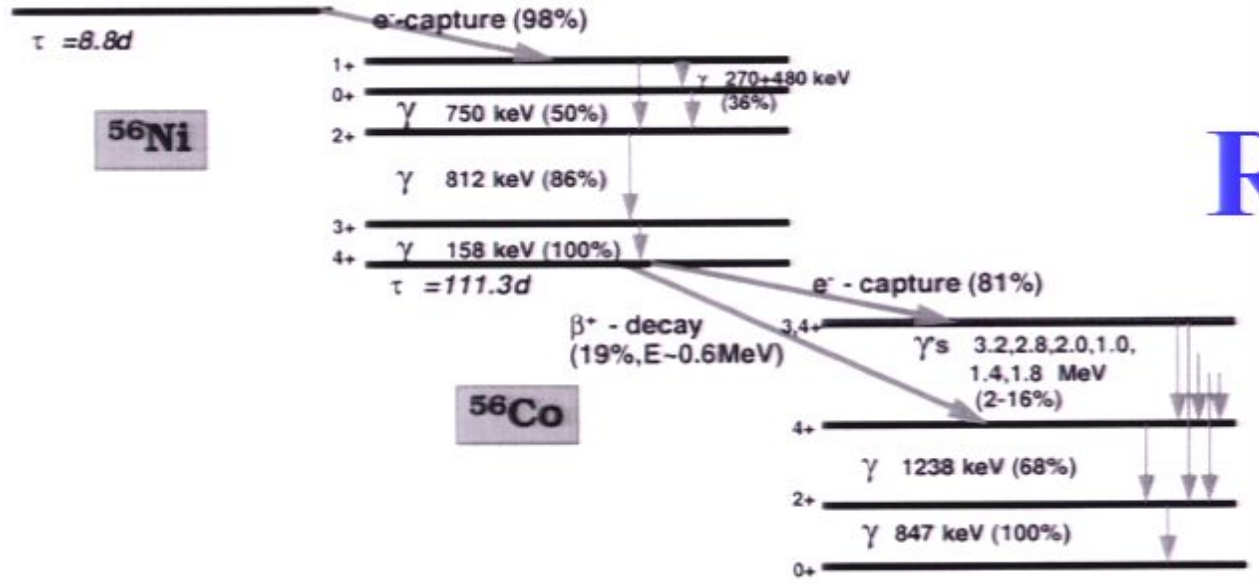
Global explosion parameters

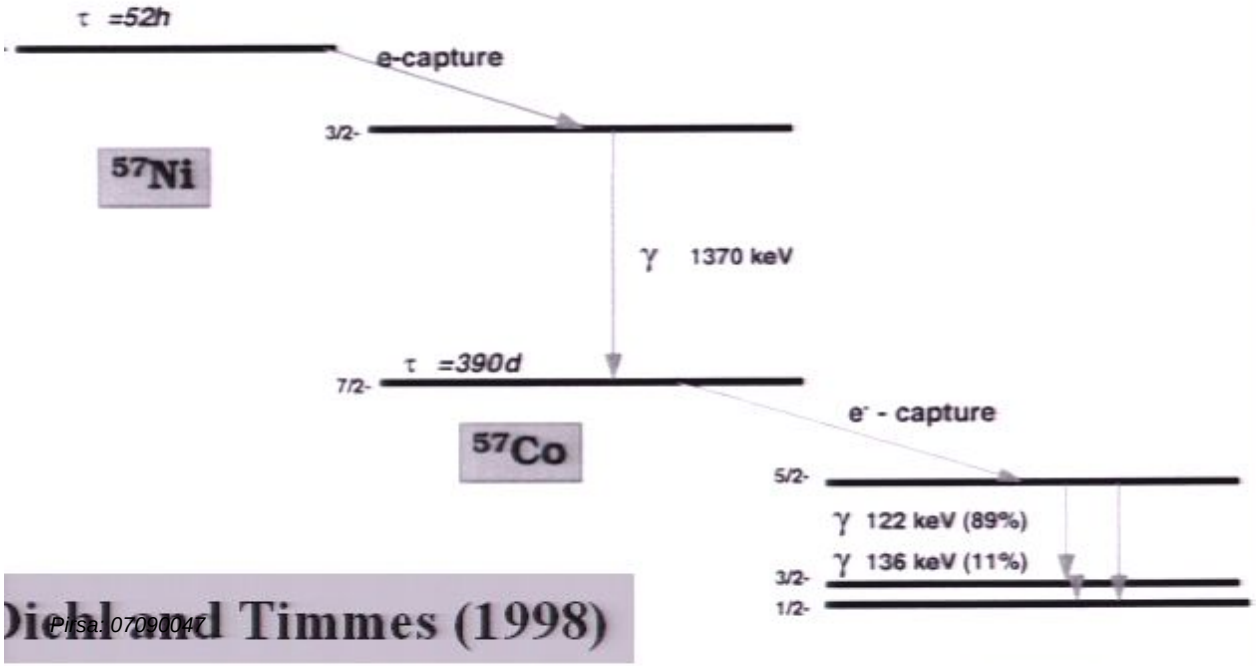
Determine the nickel mass in the explosion from the peak luminosity

- large variations (up to a factor of 10)

Possibly determine

- total mass of the explosion or
- differences distribution of the nickel, i.e. the ashes of the explosion or
- differences in the explosion energies





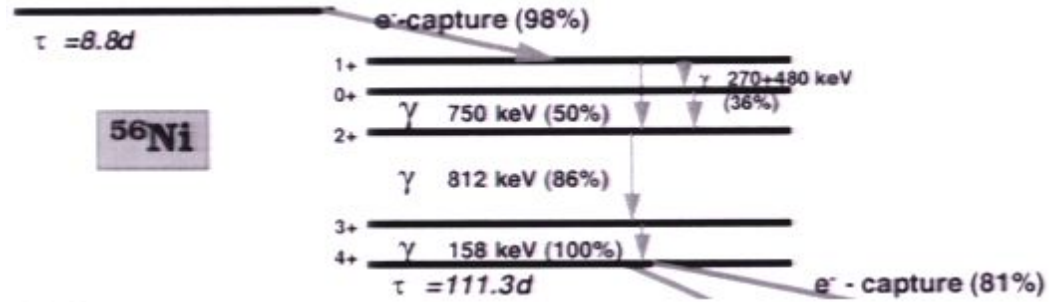
Diehl and Timmes (1998)

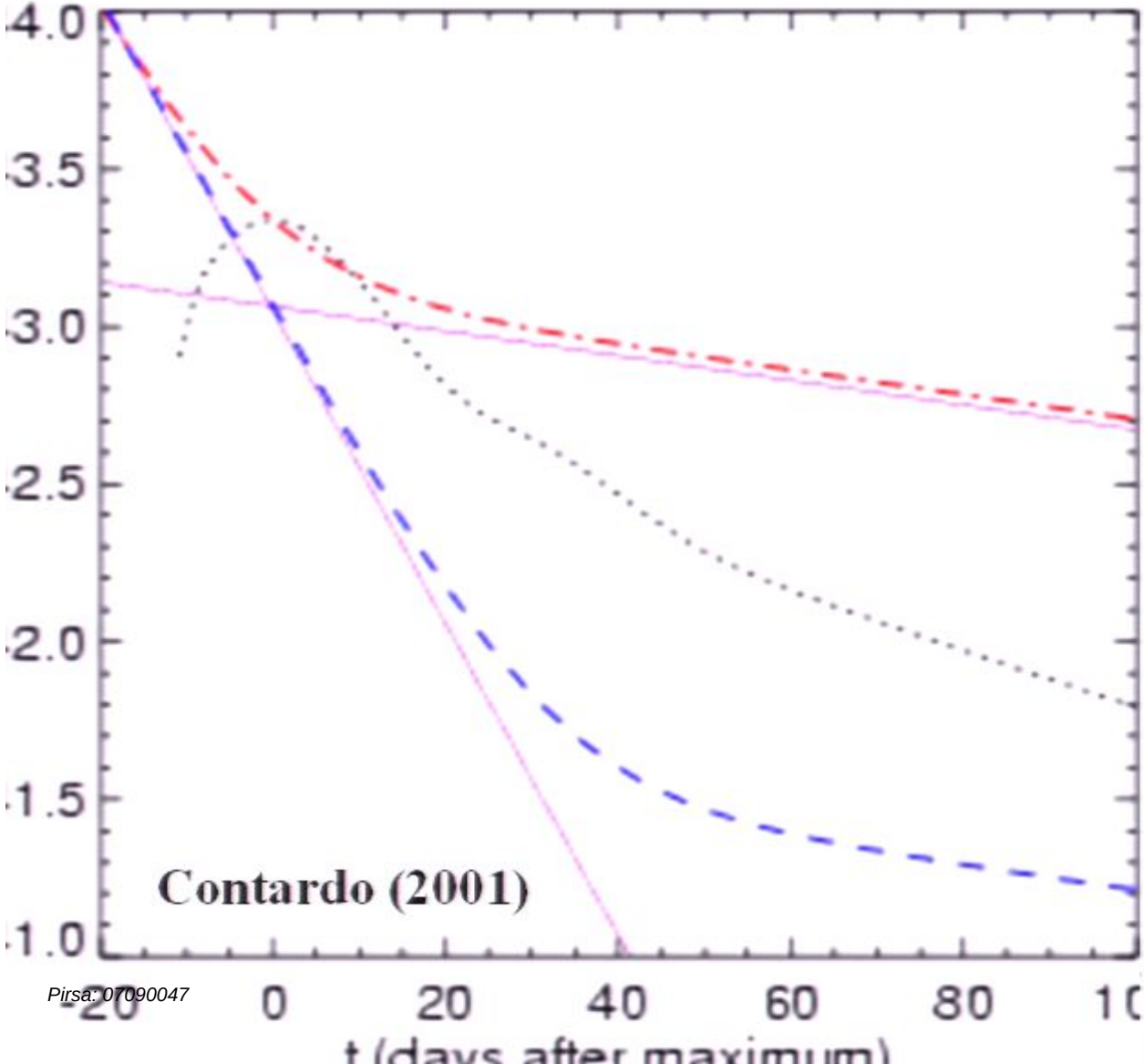
Radioactivity

Isotopes of Ni and other elements

- **conversion of γ-rays and positrons into heat and optical photons**

Radioactivity

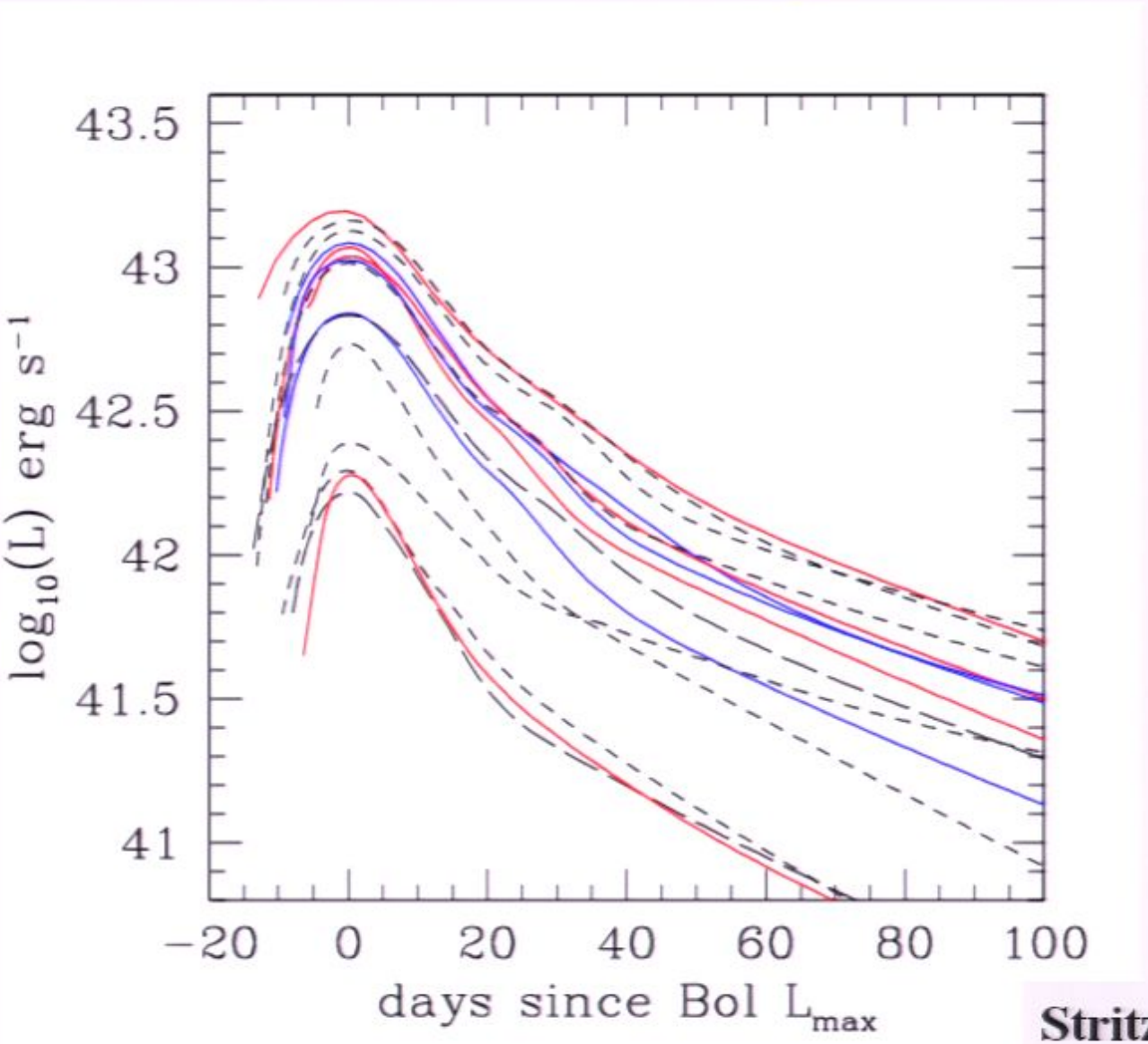




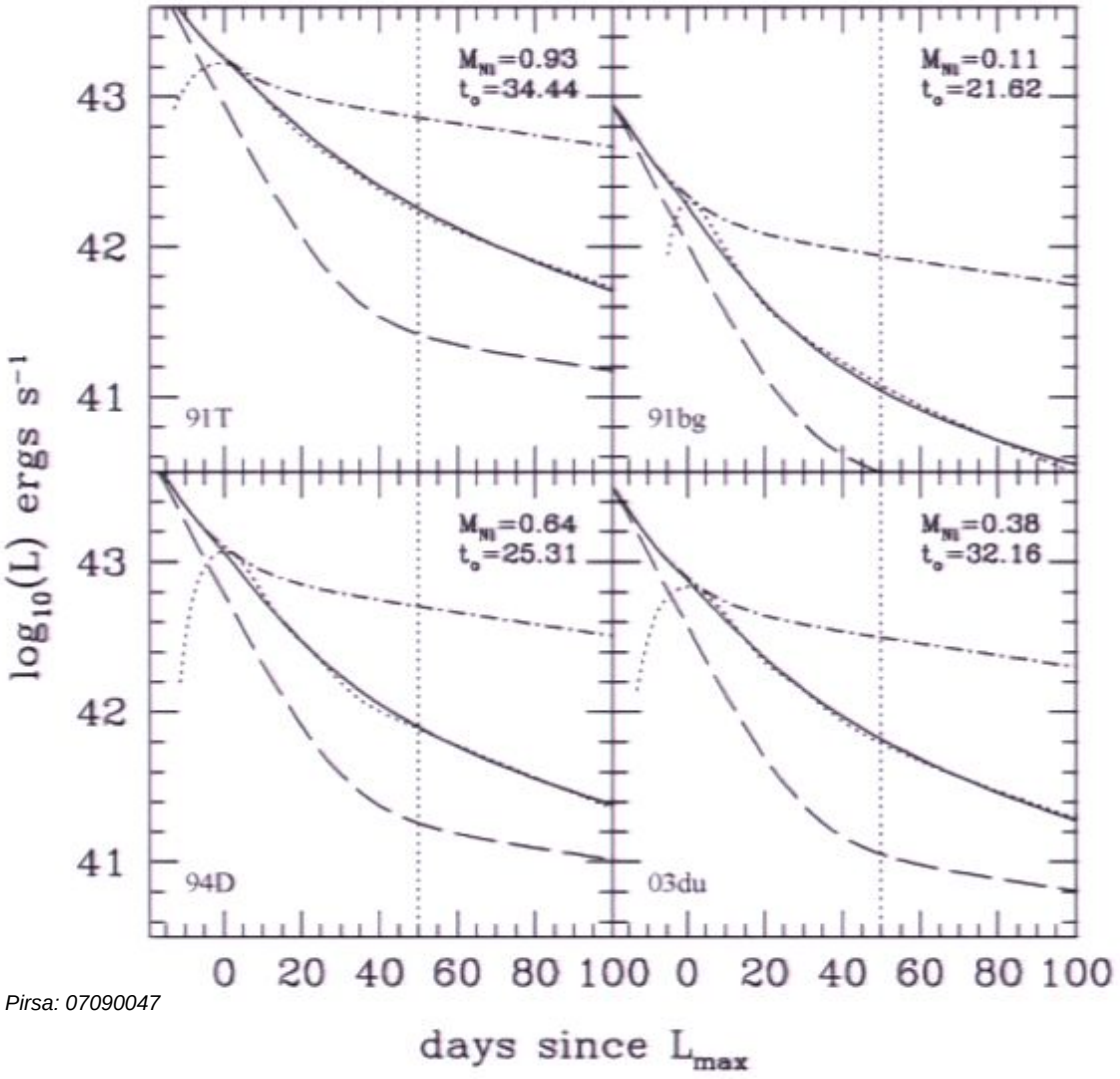
Isotopes of Ni and other elements

- conversion of γ-rays and positrons into heat and optical photons

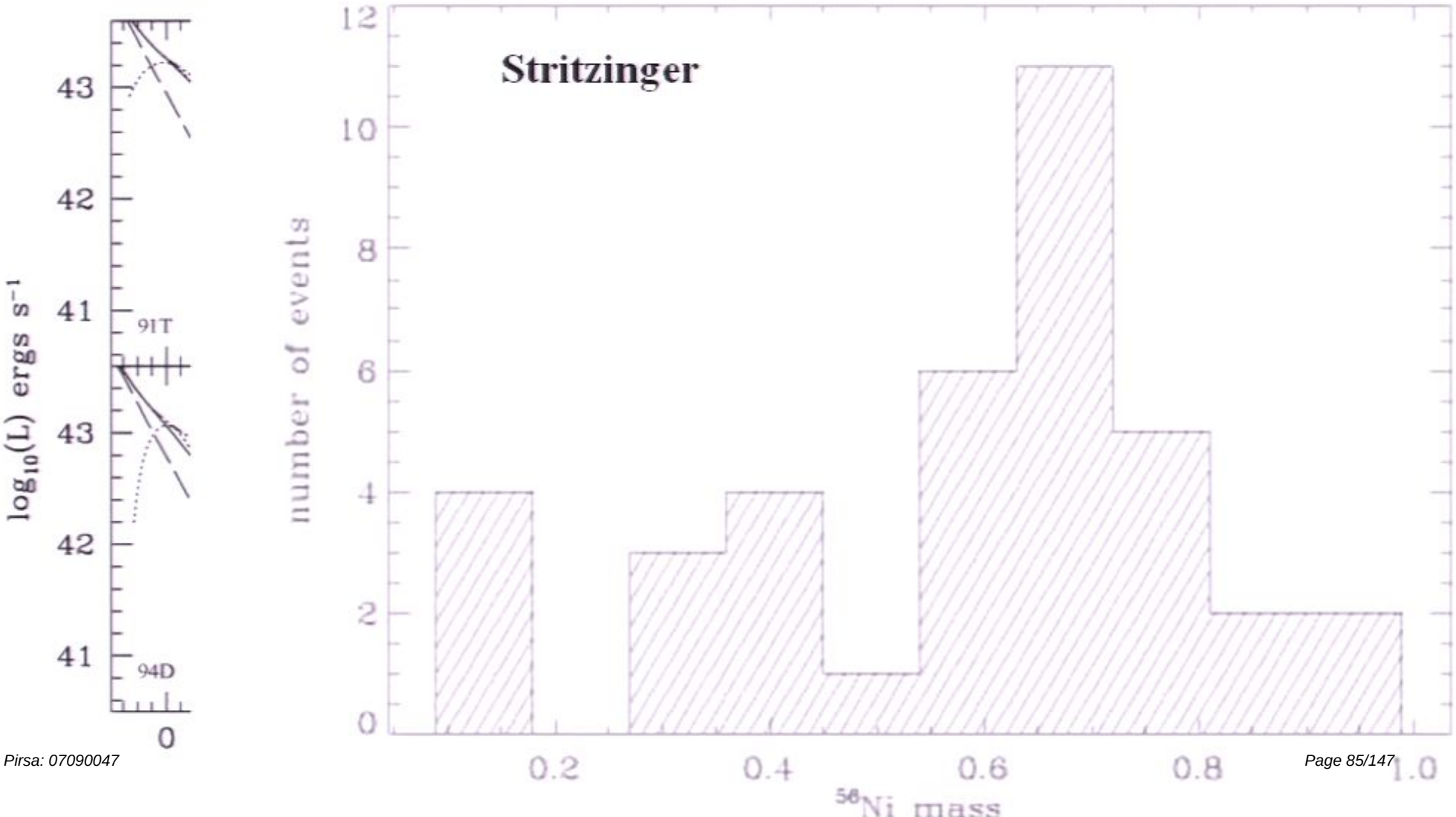
Bolometric light curves



Ni masses from light curves



Ni masses from light curves



Determining H_0 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

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

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 ($L=\alpha E_{Ni}$)

$\varepsilon(t)$: energy deposited in the supernova ejecta

Stritzinger & Leibundgut (2005)

H_0 from the nickel mass

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

Hubble law

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

Stritzinger & Leibundgut (2005)

H_0 from the nickel mass

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

Luminosity distance

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

Stritzinger & Leibundgut (2005)

H_0 from the nickel mass

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

Arnett's rule

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

Stritzinger & Leibundgut (2005)

H_0 from the nickel mass

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

Ni-Co decay and rise time

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

$\varepsilon(t)$: energy deposited in the supernova ejecta

Stritzinger & Leibundgut (2005)

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 ($L=\alpha E_{Ni}$)

$\varepsilon(t)$: energy deposited in the supernova ejecta

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

Stritzinger & Leibundgut (2005)

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 ($L=\alpha E_{Ni}$)

$\varepsilon(t)$: energy deposited in the supernova ejecta

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

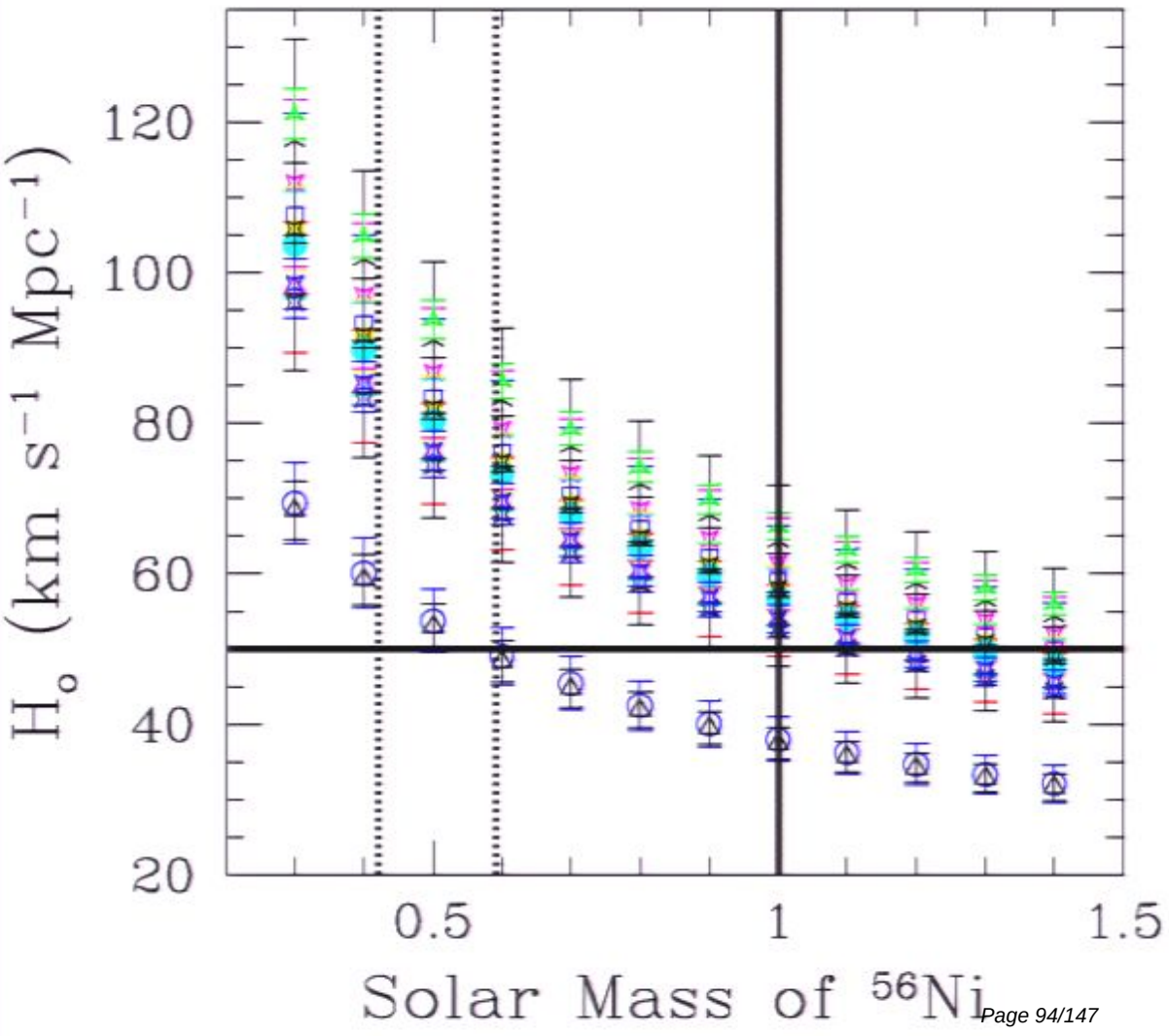
Stritzinger & Leibundgut (2005)

H_0 and the Ni mass

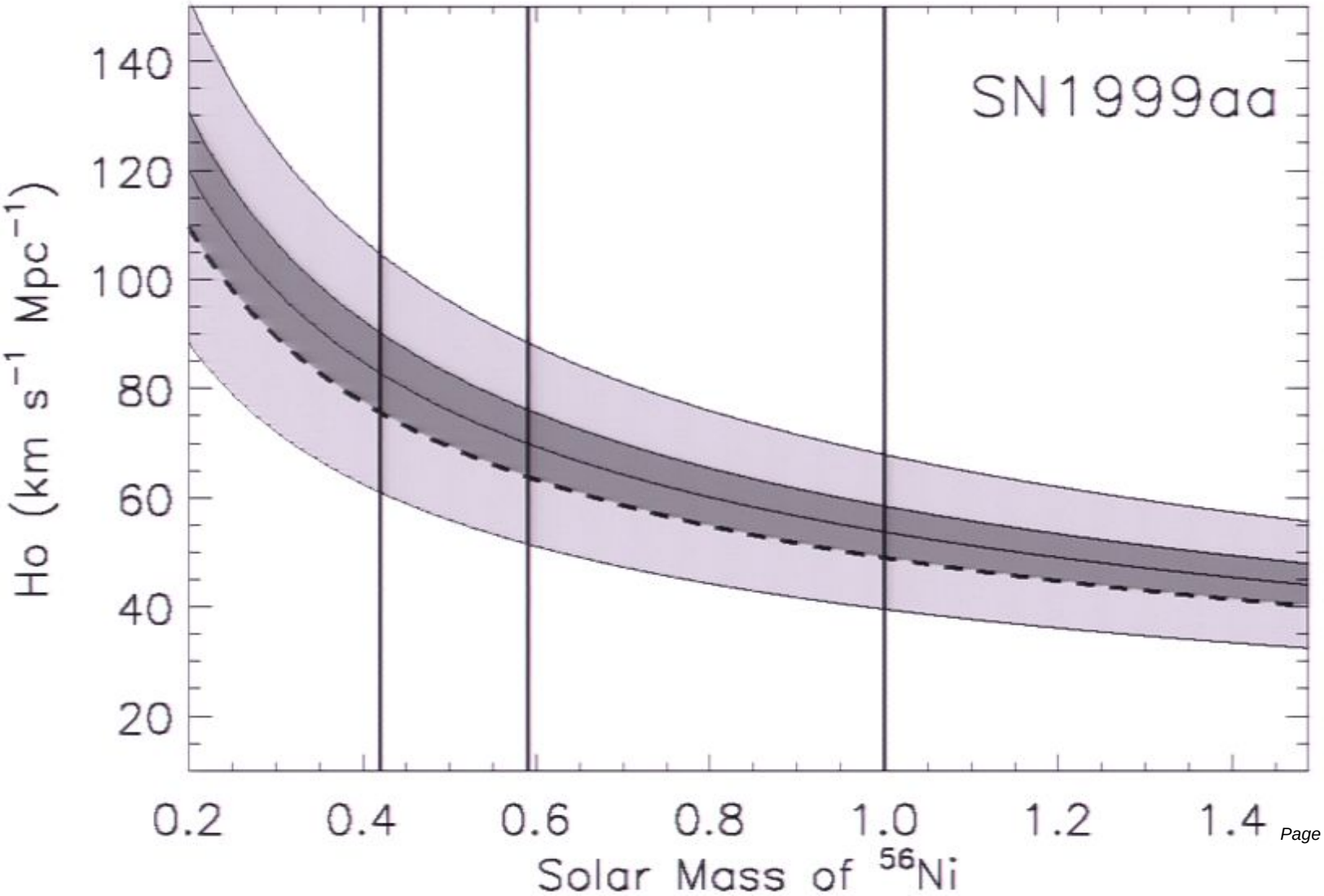
Individual SNe follow the $M^{-½}$ dependency.

Problem:

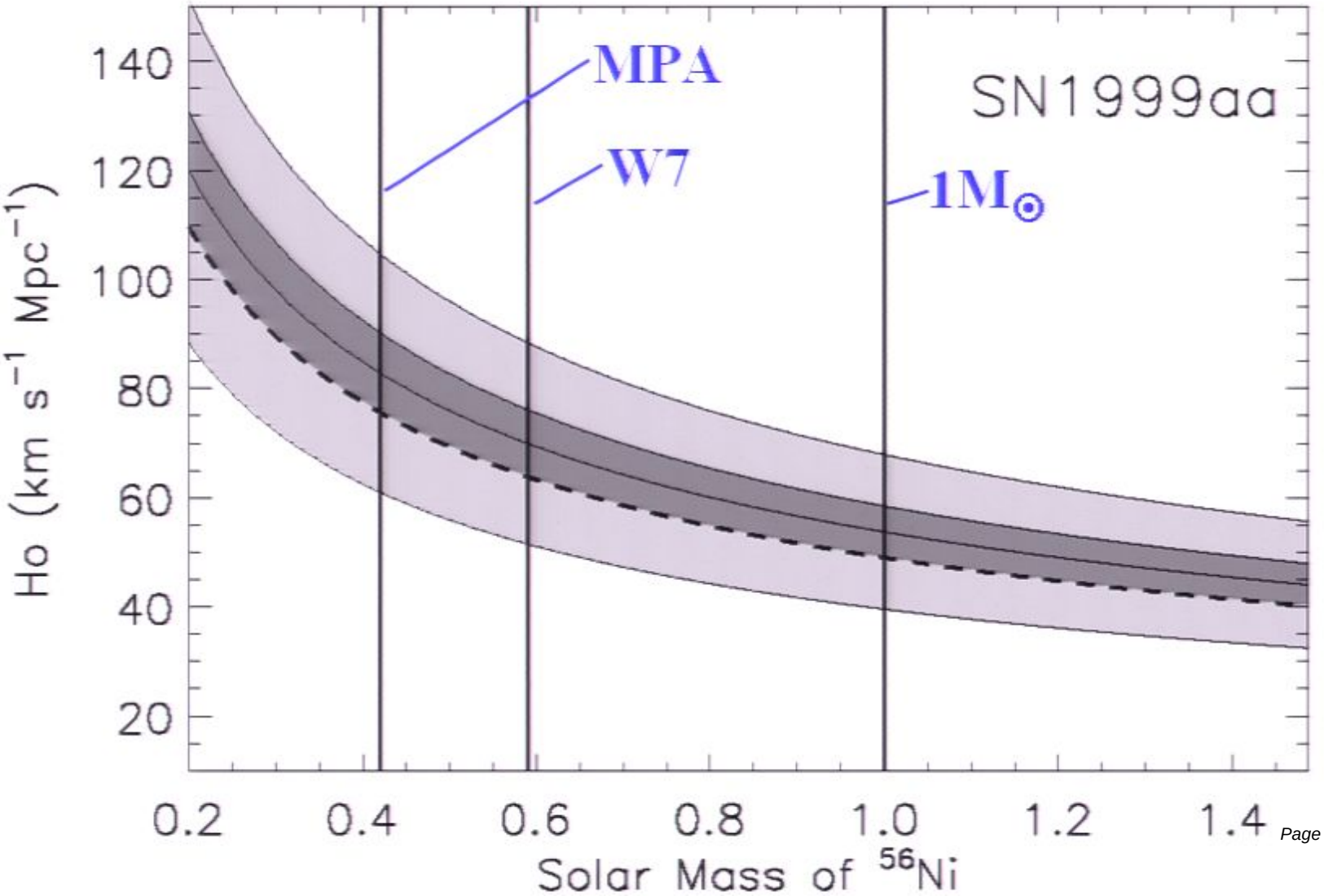
Since they have individual Ni masses it is not clear which one to apply!



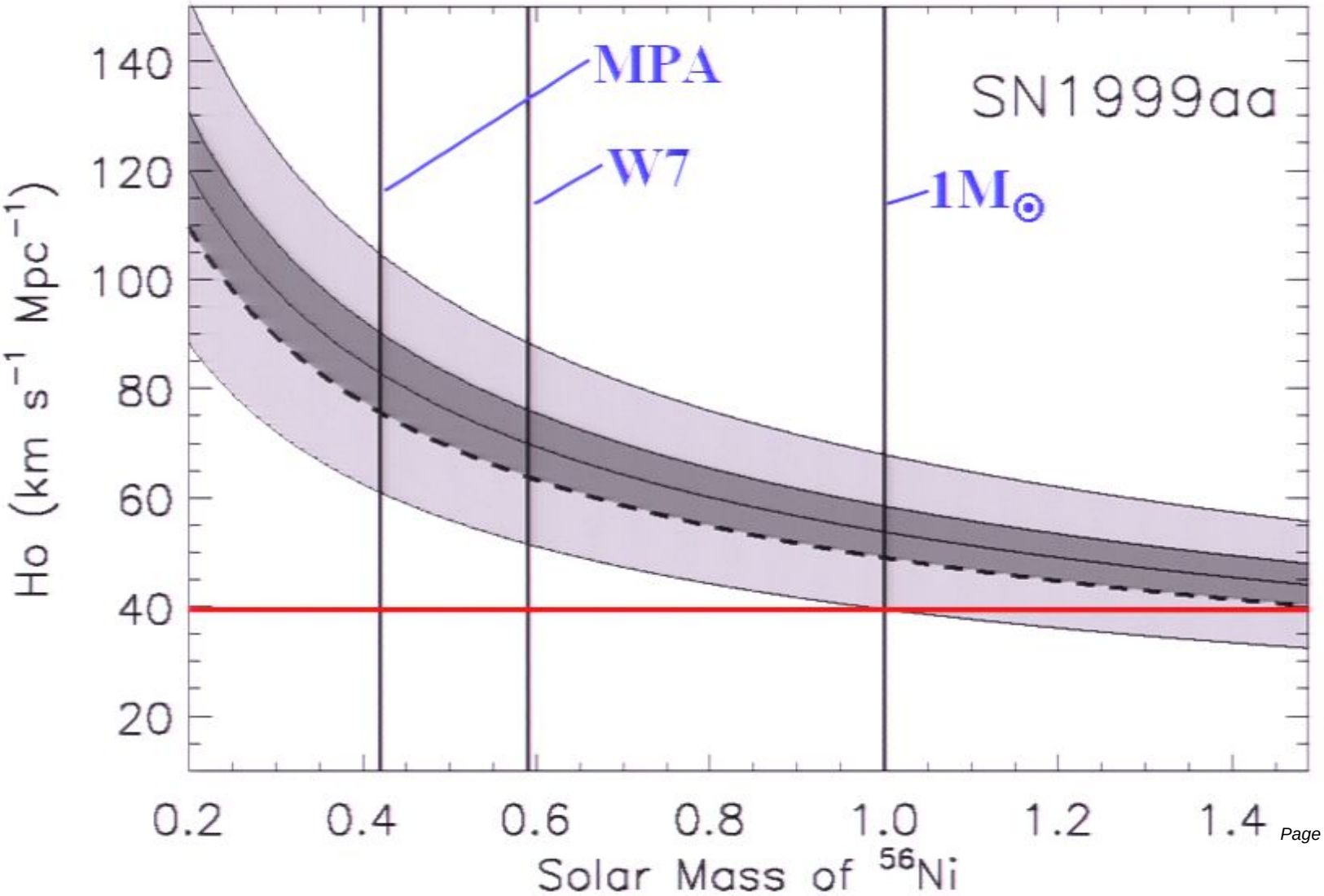
Determine a lower limit for H_0



Determine a lower limit for H_0



Determine a lower limit for H_0



Ejecta masses from light curves

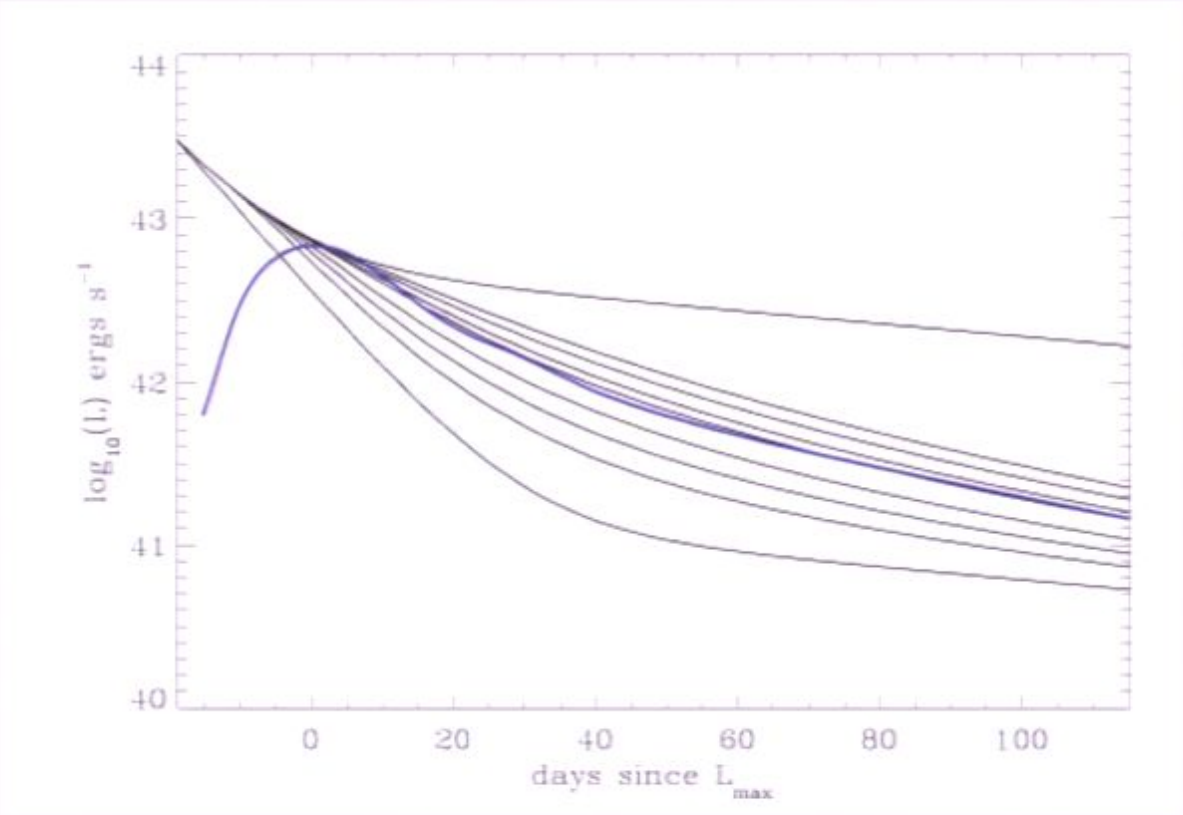
γ-ray escape depends on the total mass of the ejecta

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

v: expansion velocity

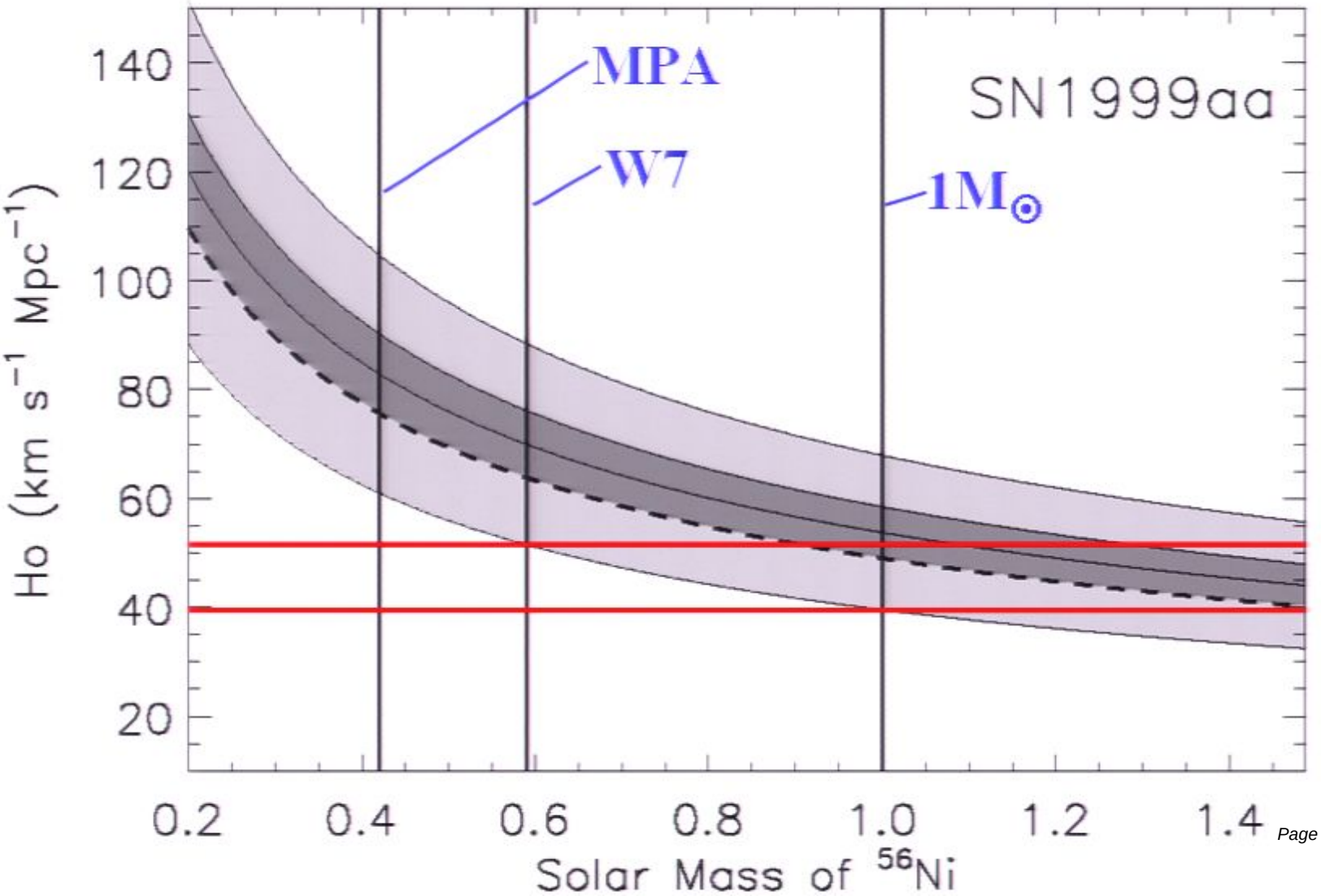
κ: γ-ray opacity

q: distribution of nickel



Stritzinger et al. 2006

Determine a lower limit for H_0



Ejecta masses from light curves

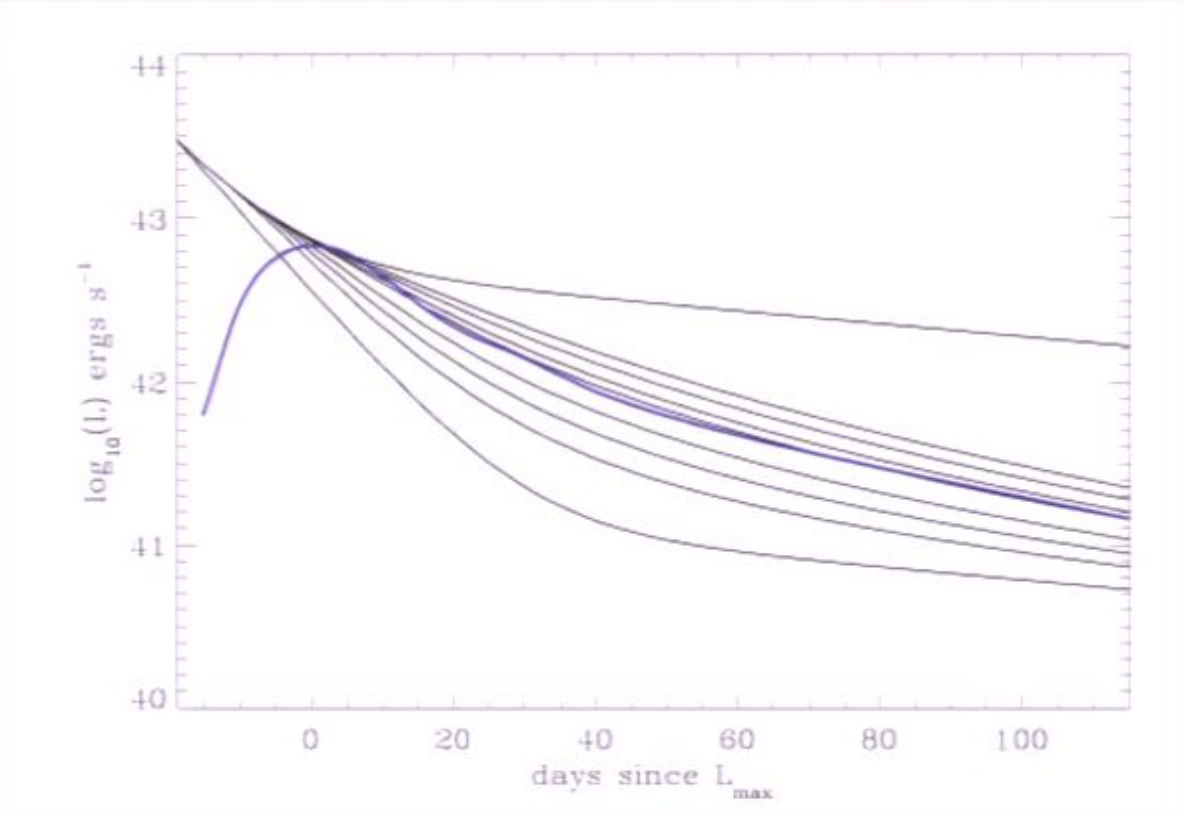
γ-ray escape depends on the total mass of the ejecta

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

v: expansion velocity

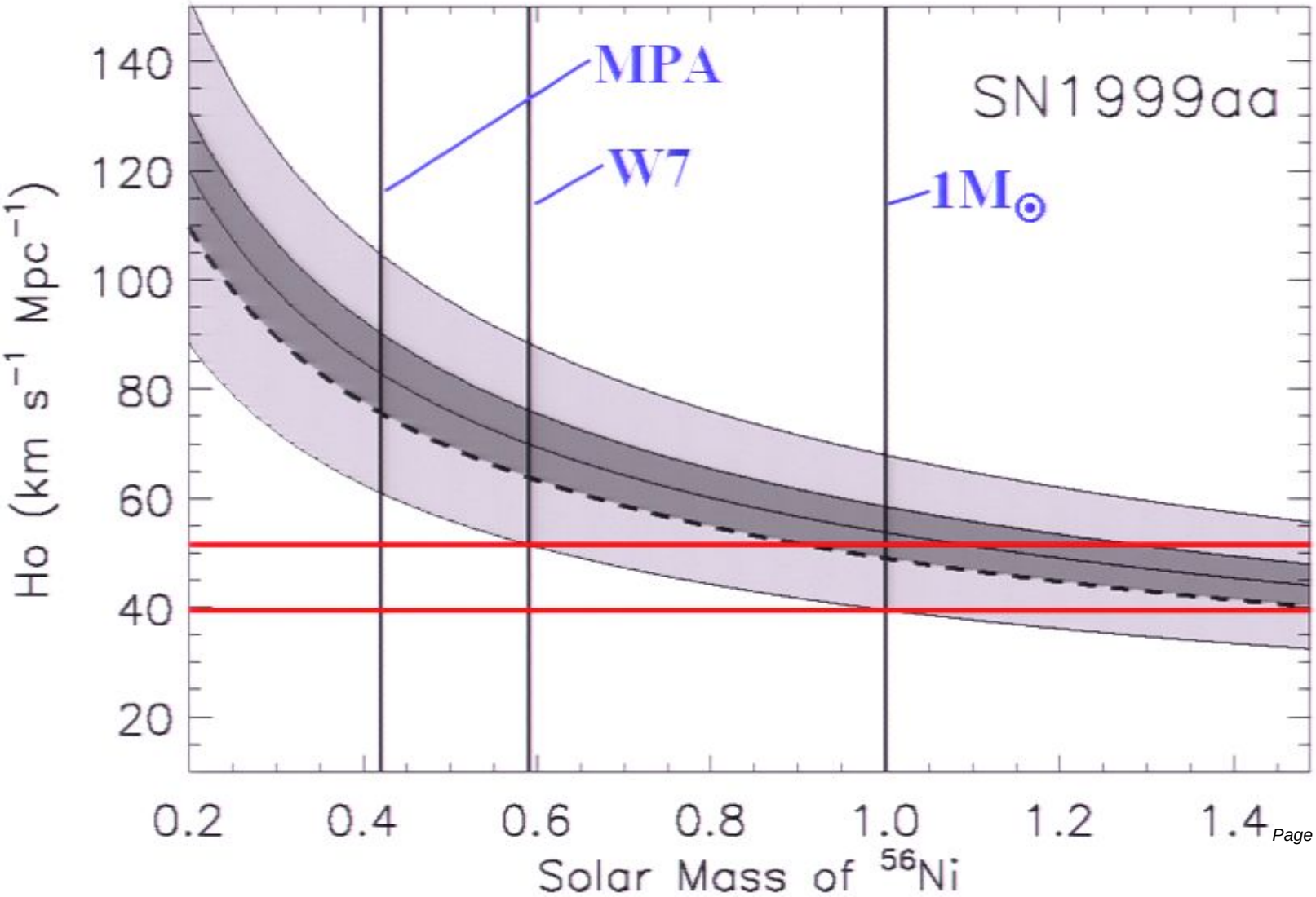
κ: γ-ray opacity

q: distribution of nickel



Stritzinger et al. 2006

Determine a lower limit for H_0



Ejecta masses from light curves

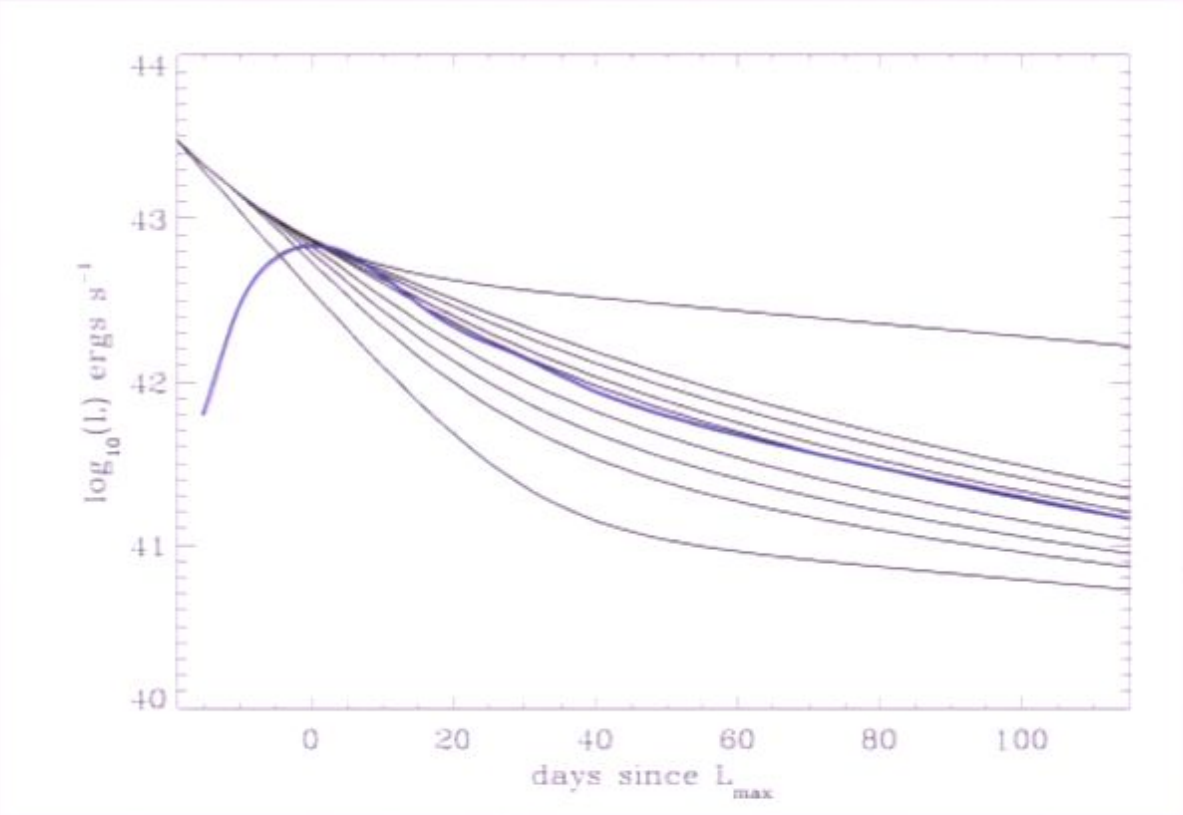
γ-ray escape depends on the total mass of the ejecta

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

v: expansion velocity

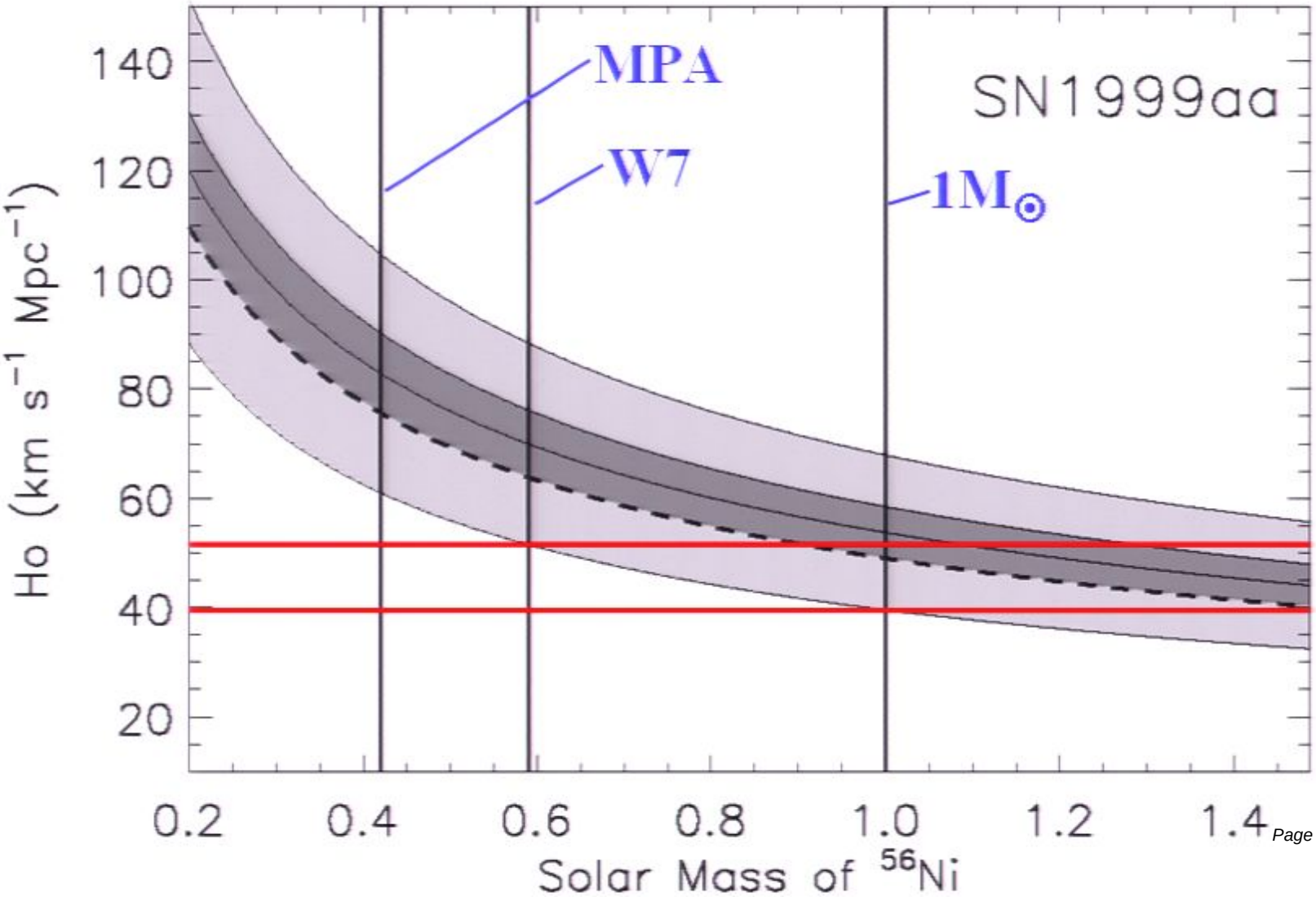
κ: γ-ray opacity

q: distribution of nickel



Stritzinger et al. 2006

Determine a lower limit for H_0



Ejecta masses from light curves

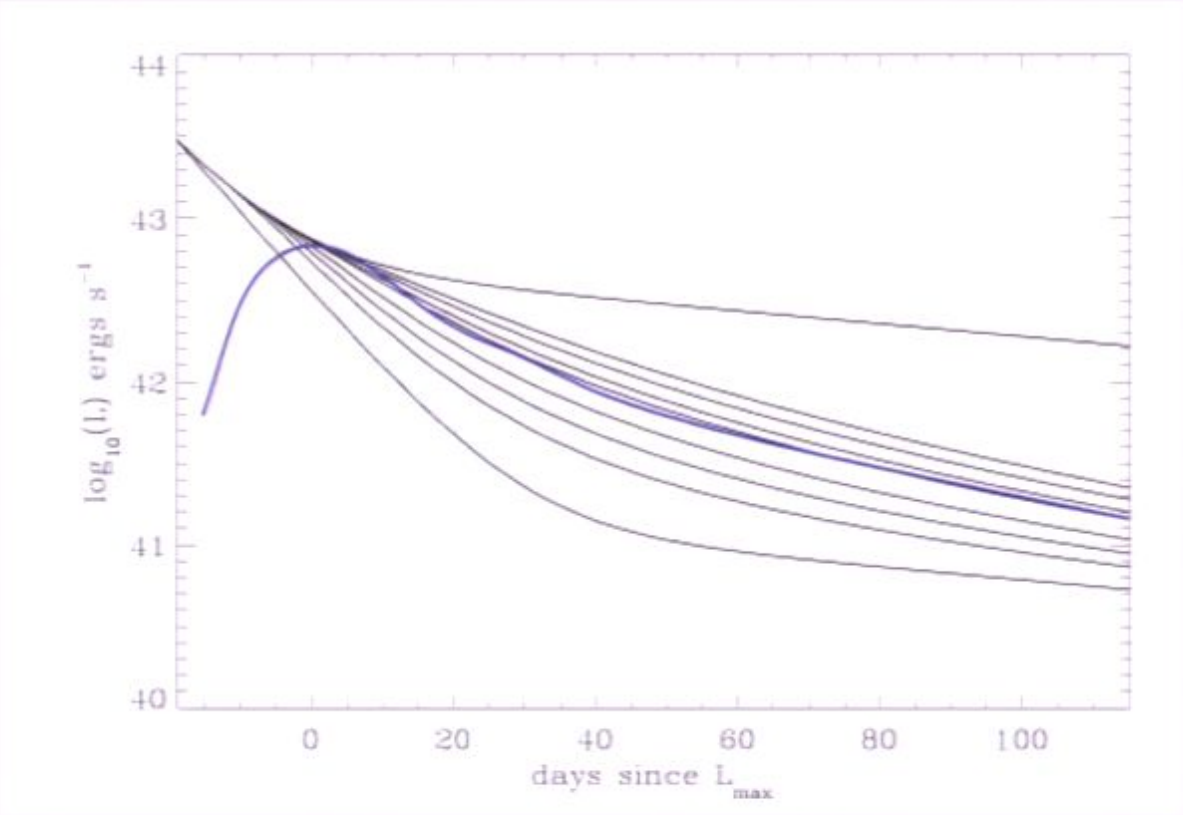
γ-ray escape depends on the total mass of the ejecta

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

v: expansion velocity

κ: γ-ray opacity

q: distribution of nickel

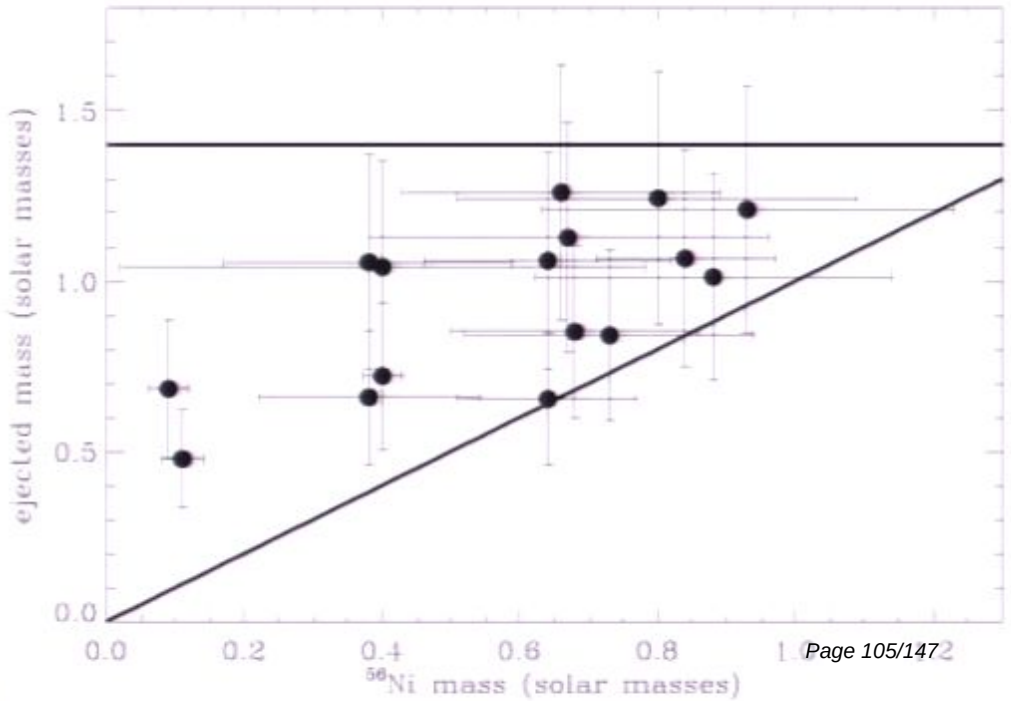


Stritzinger et al. 2006

Ejecta masses

Large range in nickel and ejecta masses

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



Stritzinger et al. 2006

Type Ia Supernovae

Individual explosions

- **differences in explosion mechanism**
  - deflagration *vs.* delayed detonations
- **3-dimensional structures**
  - distribution of elements in the ejecta
  - high velocity material in the ejecta
- **explosion energies**
  - different expansion velocities
- **fuel**
  - amounts of nickel mass synthesised
- **progenitors**
  - ejecta masses?

Standard SNe Ia?

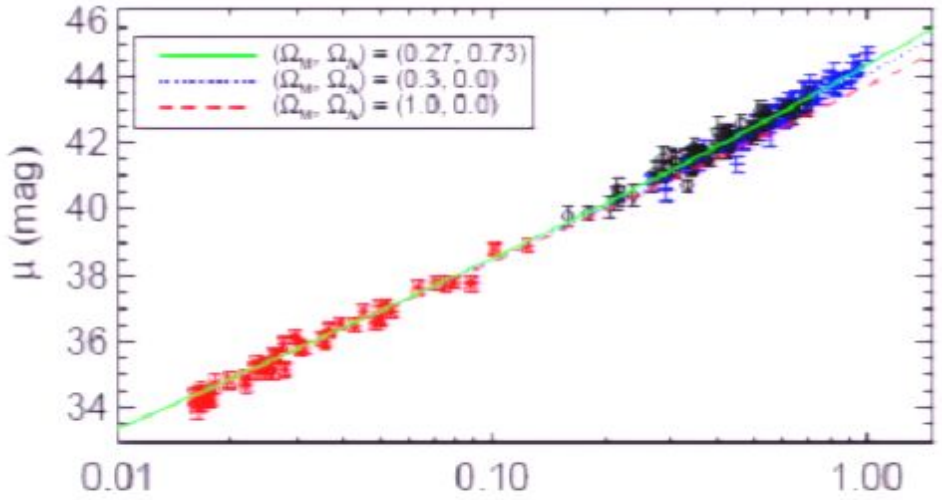
What is the definition of a normal SN Ia?

- **light curves**
  - already used to normalise the peak luminosity
  - second parameter
    - SALT2 → Guy et al.
    - CMAGIC → Wang et al.
- **expansion velocities**
  - observational coverage (spectroscopy!)
- **spectral twins**
  - observational coverage (spectroscopy!)

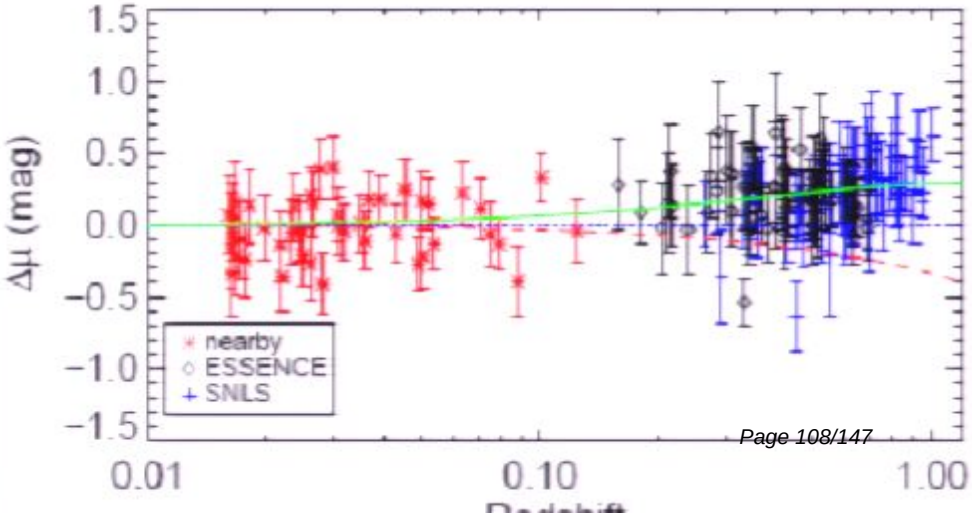
Reddening? K-corrections? Local velocity field? Evolution?

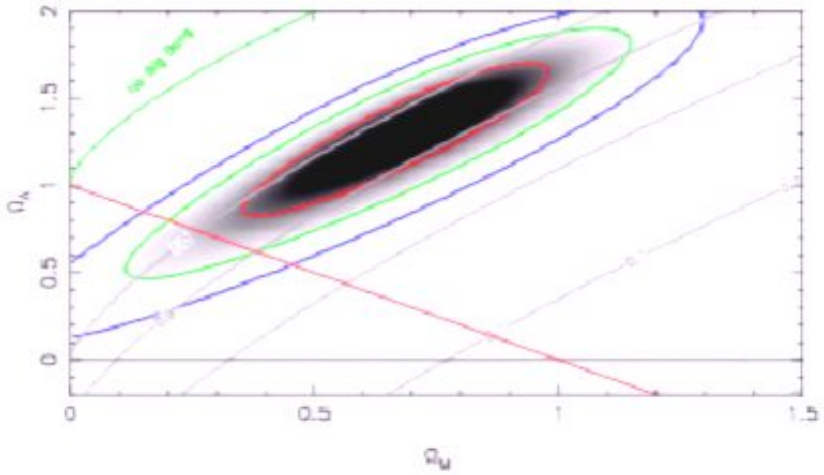
Know where you are

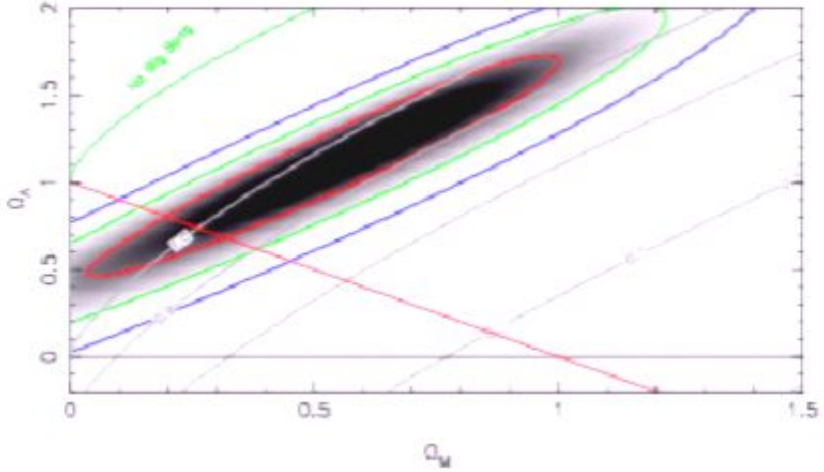
All cosmological interpretations make use of the same local sample!

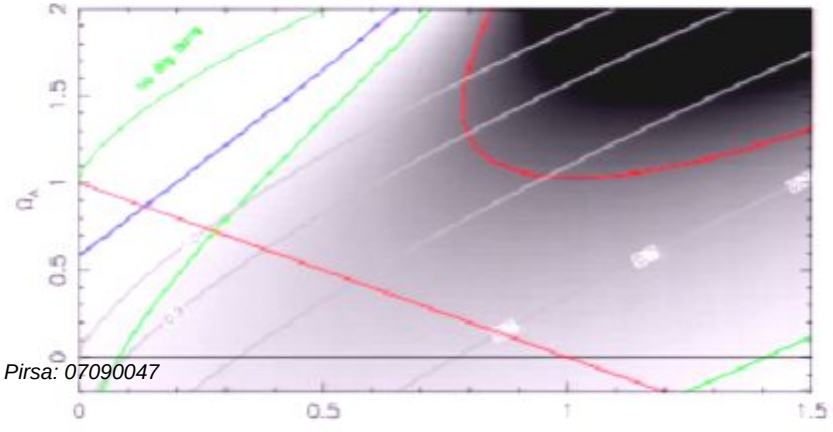


Wood-Vasey et al. 2007









All SNe Ia from Tonry et al. 2003

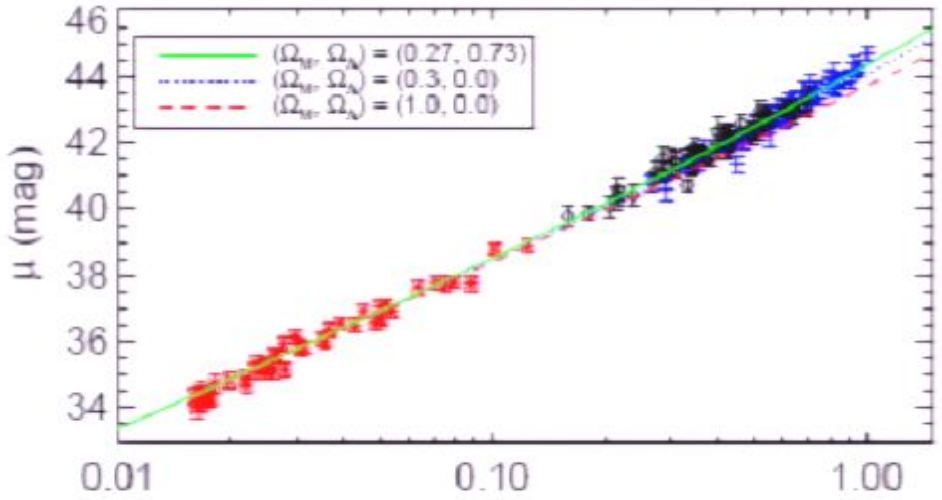
Three highest-z objects removed

Only objects with 0.2<z<0.8

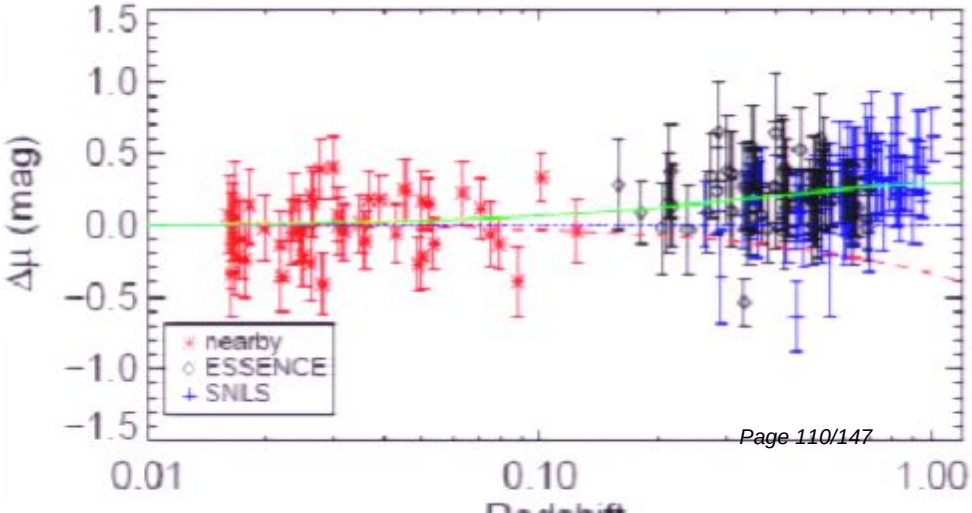
Blondin 2005

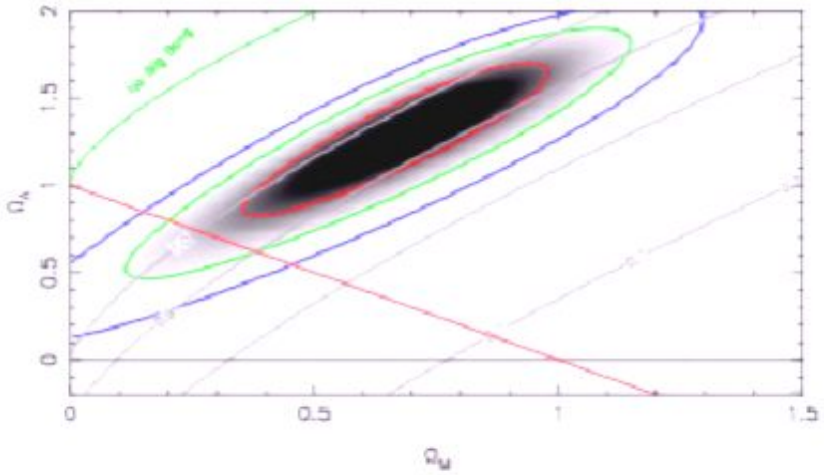
Know where you are

All cosmological interpretations make use of the same local sample!

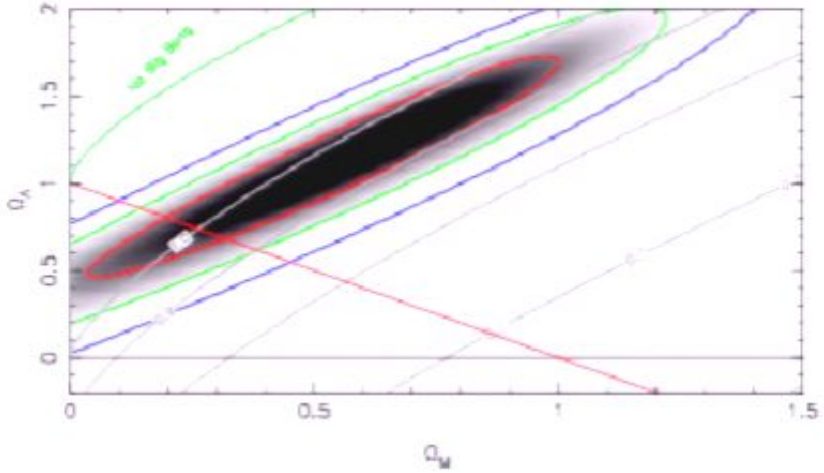


Wood-Vasey et al. 2007

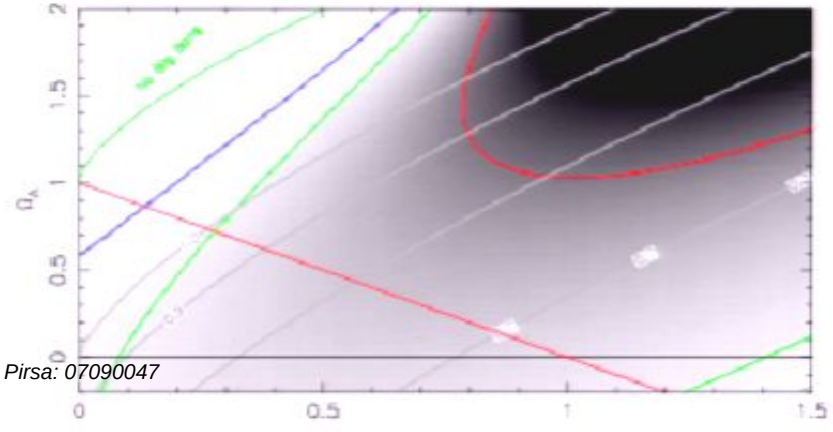




All SNe Ia from Tonry et al. 2003



Three highest-z objects removed

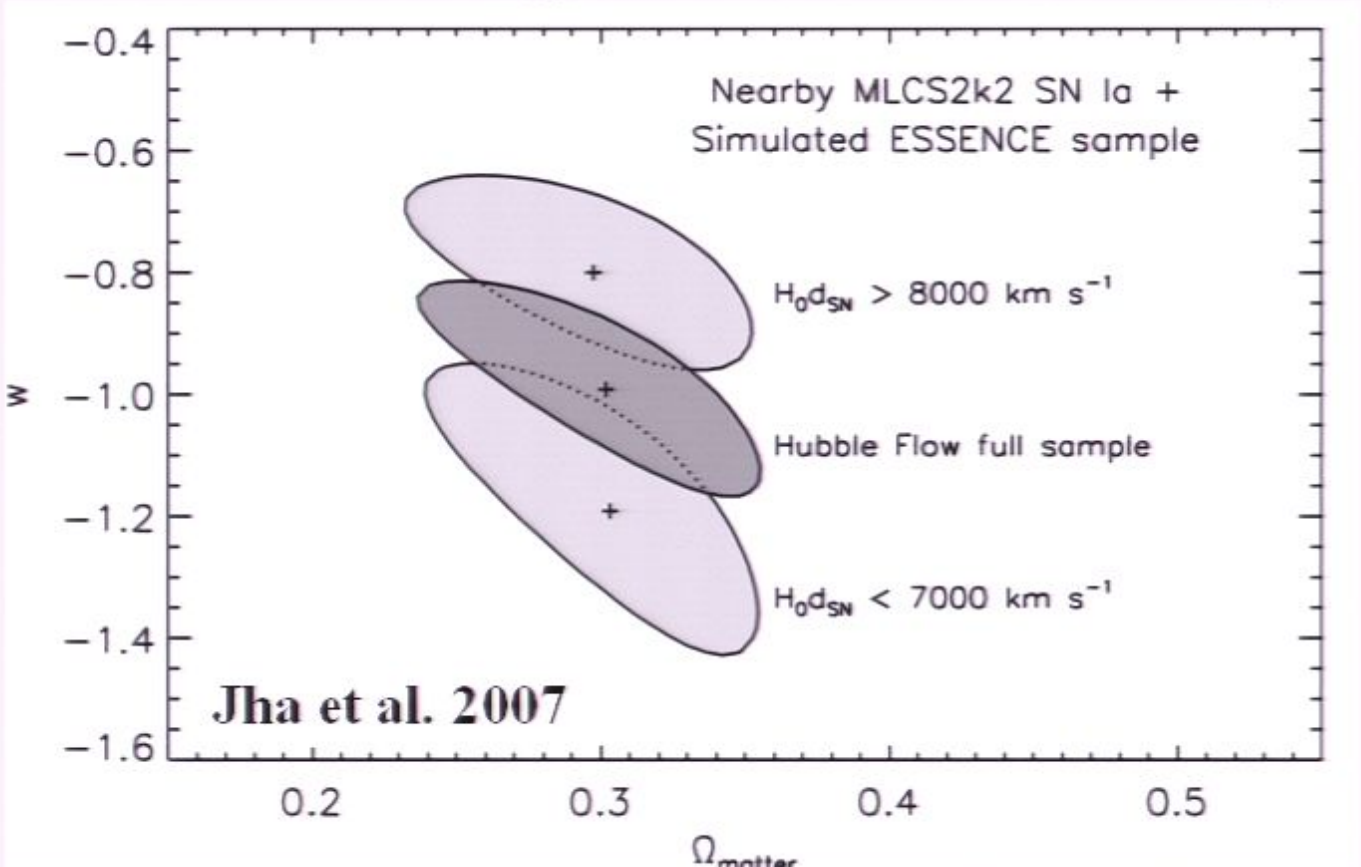


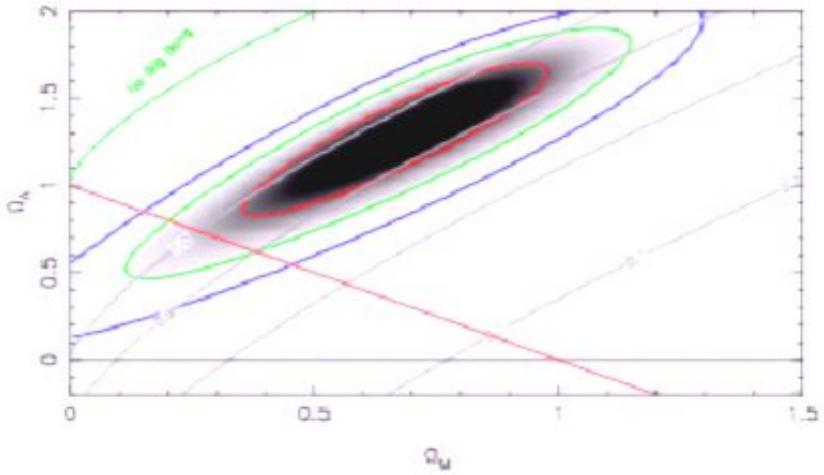
Only objects with 0.2<z<0.8

Blondin 2005

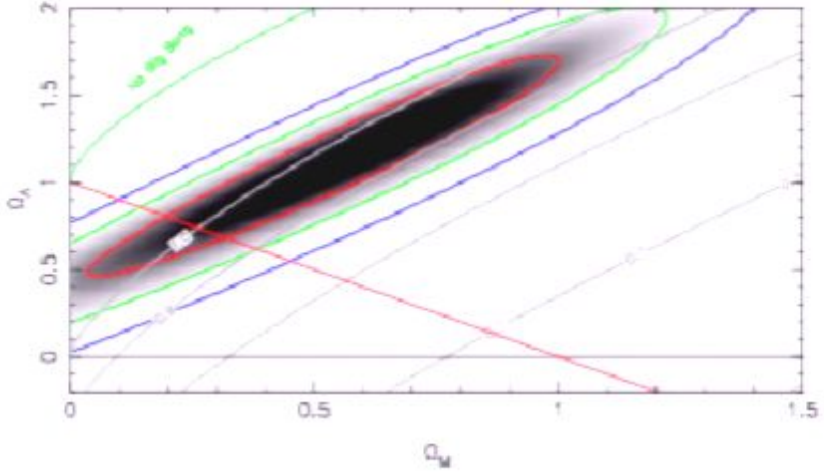
The importance of the local sample

Systematics of the local sample could be a problem (local impurities in the expansion field, e.g. 'Hubble bubble')

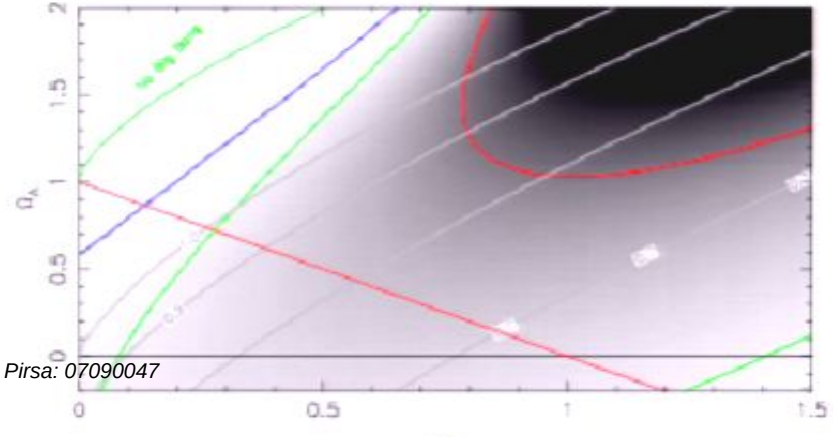




All SNe Ia from Tonry et al. 2003



Three highest-z objects removed

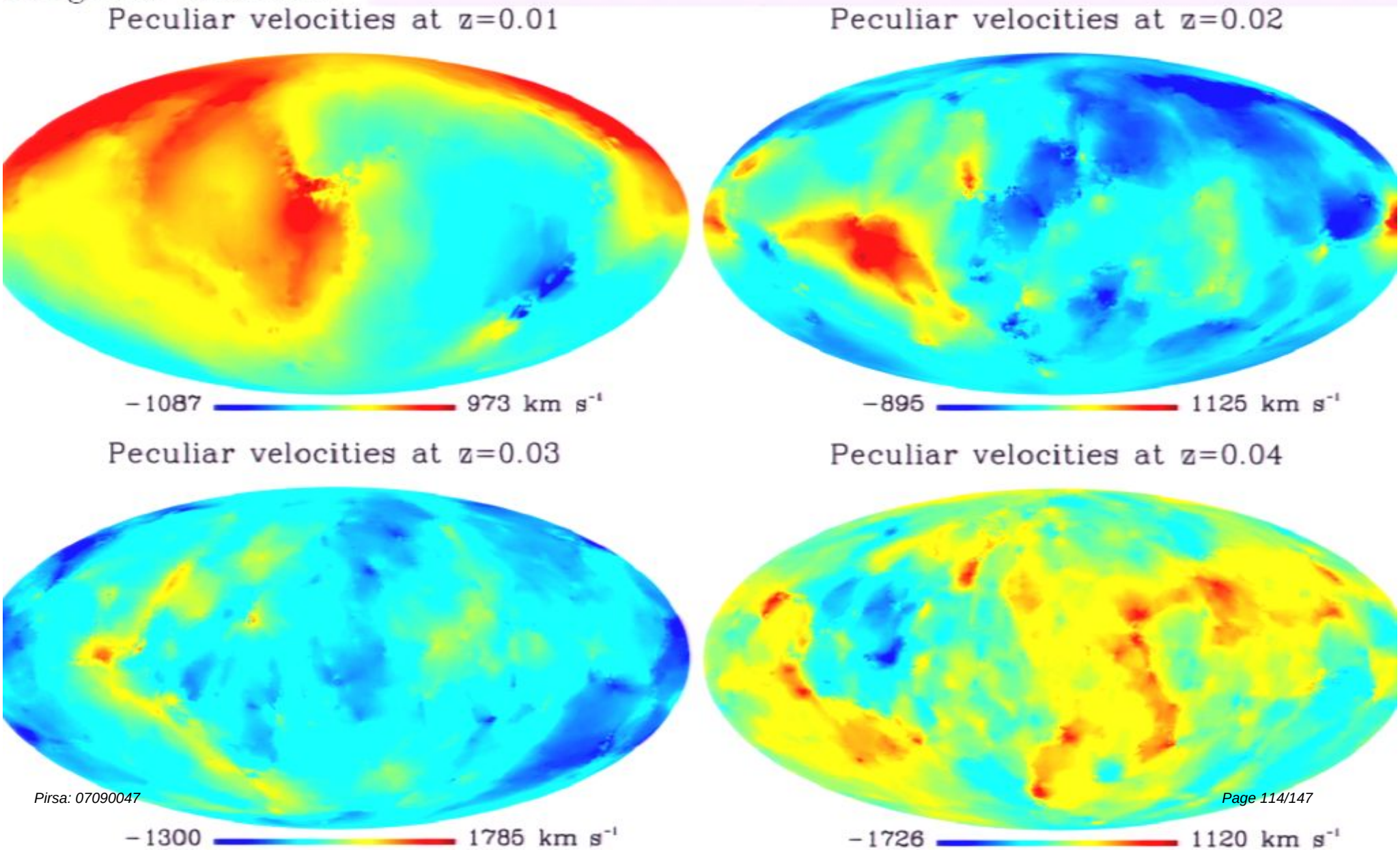


Only objects with $0.2<z<0.8$

Blondin 2005

Where does the Hubble flow begin?

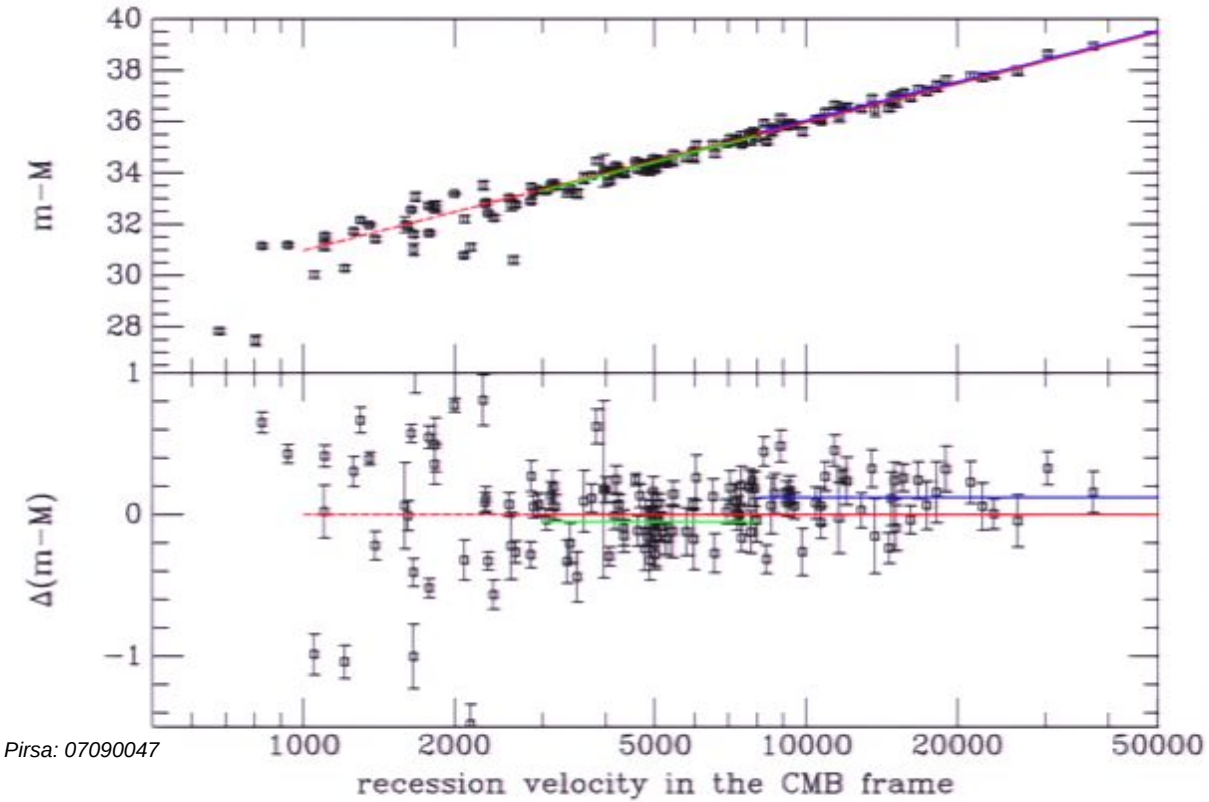
Haugbølle et al. 2007



Is the Hubble Bubble real?

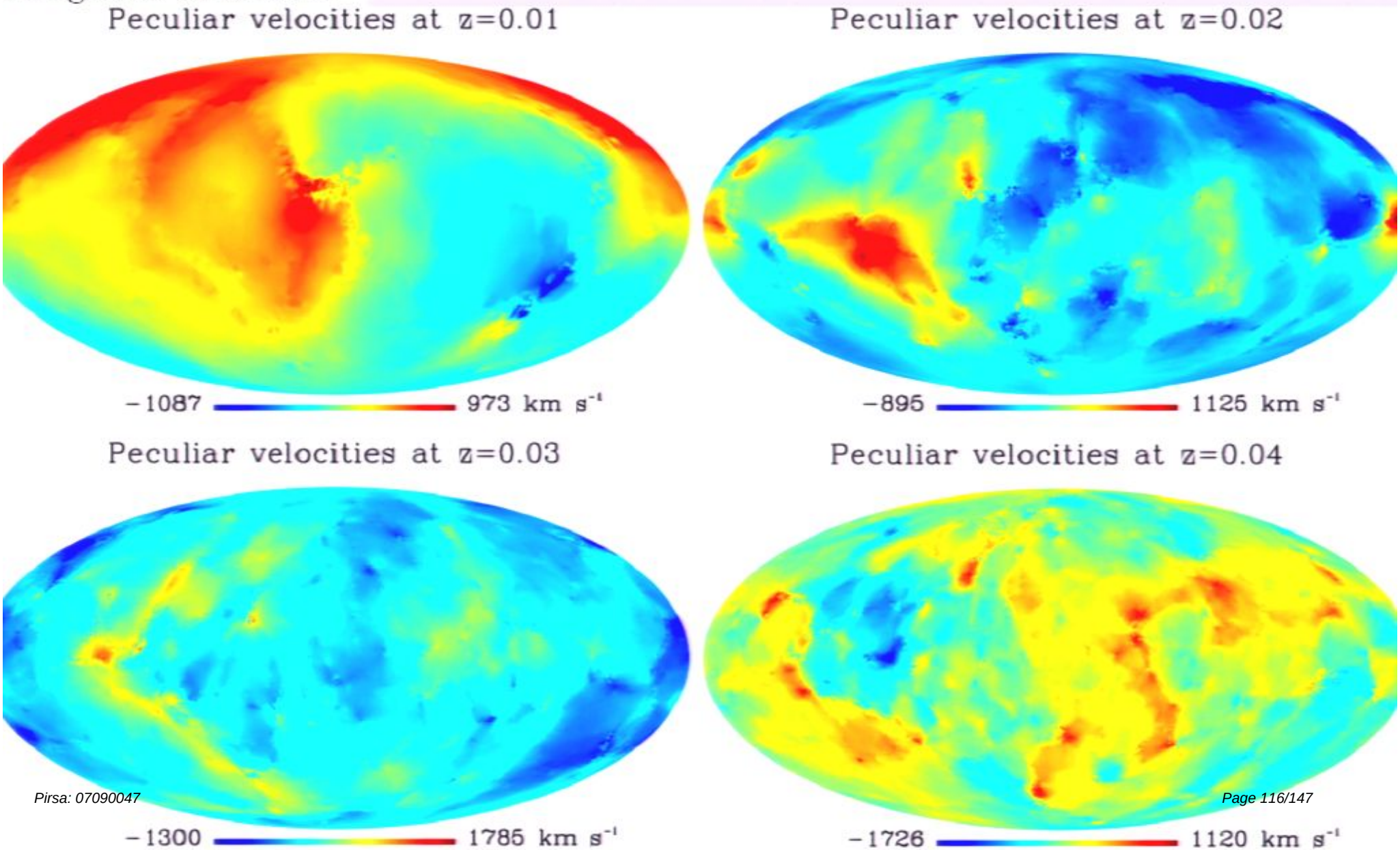
Jha et al. (2007) confirm earlier results

- **Riess et al. (1996), Zehavi et al. (1998)**



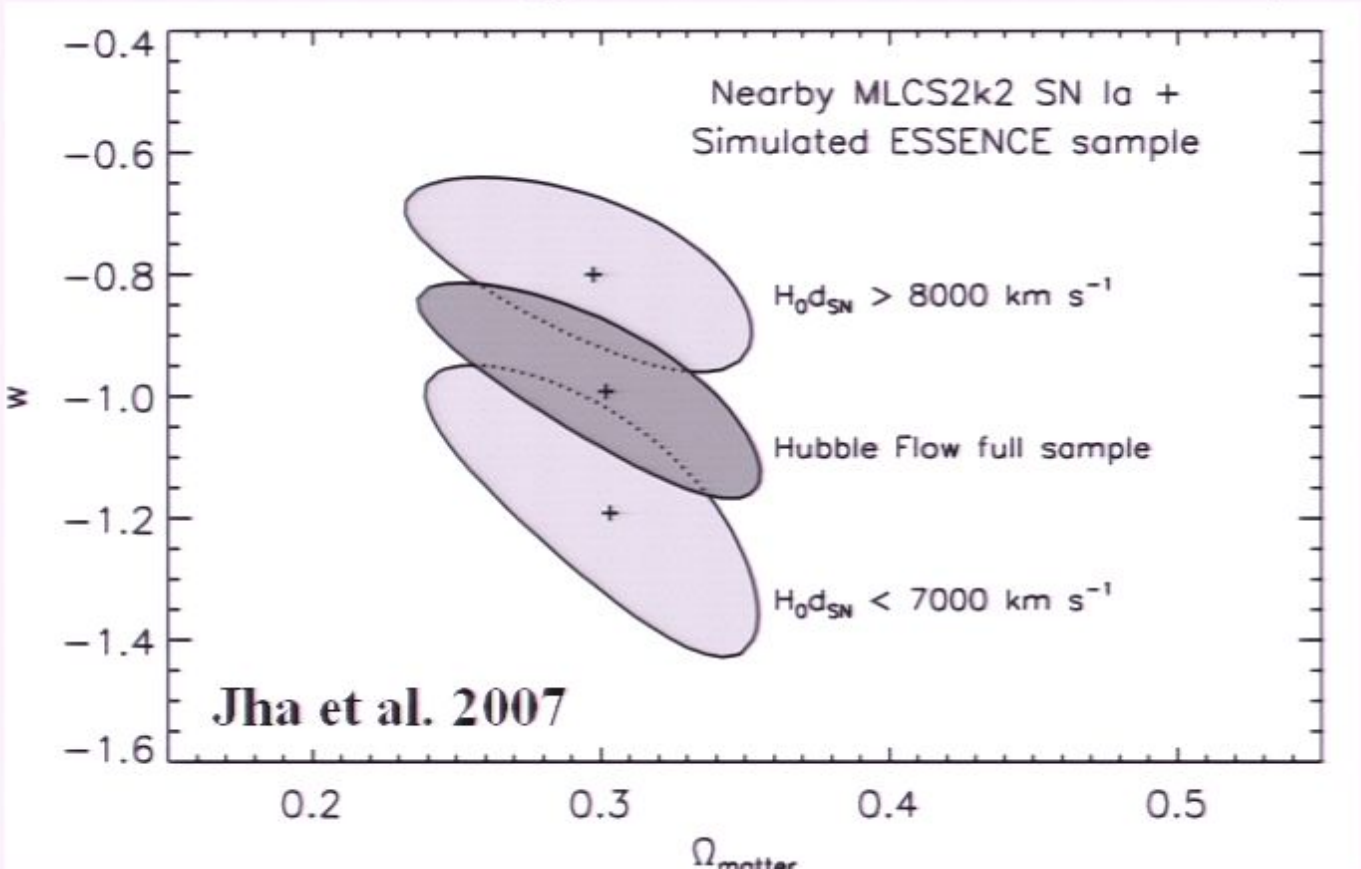
Where does the Hubble flow begin?

Haugbølle et al. 2007



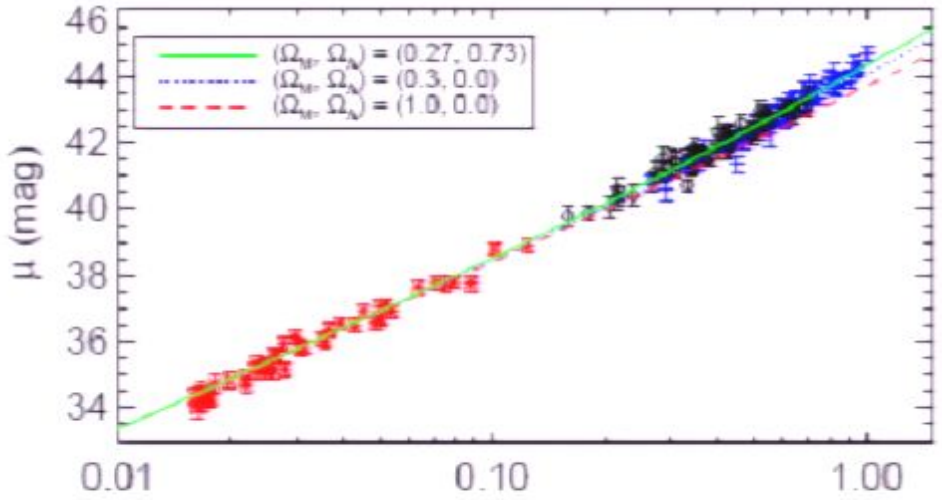
The importance of the local sample

Systematics of the local sample could be a problem (local impurities in the expansion field, e.g. 'Hubble bubble')

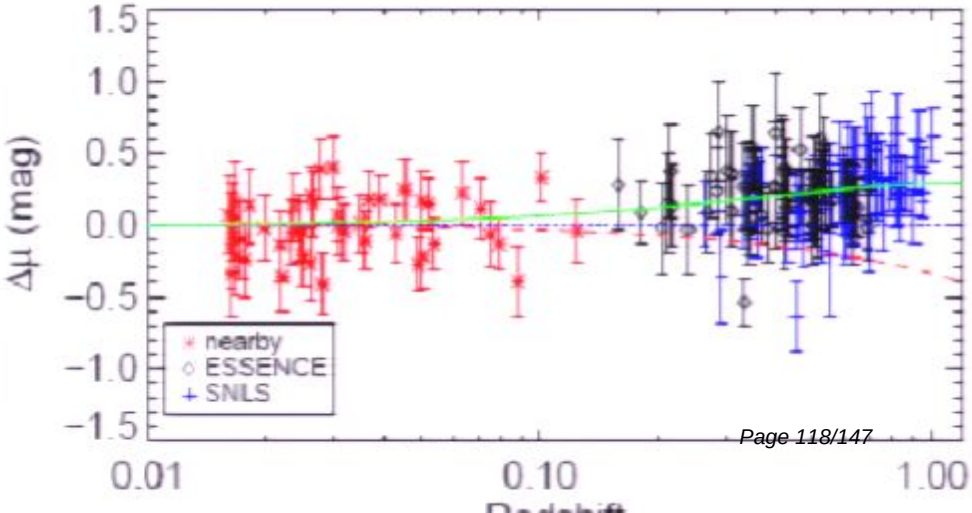


Know where you are

All cosmological interpretations make use of the same local sample!



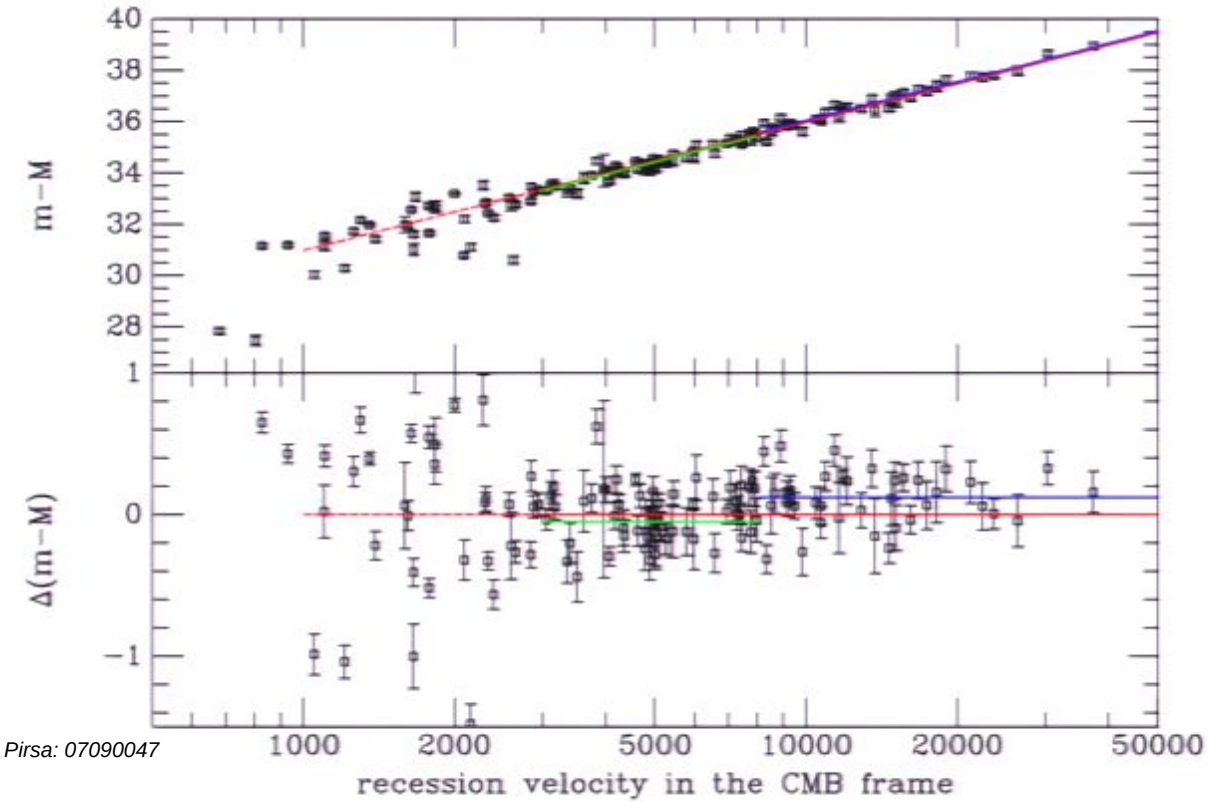
Wood-Vasey et al. 2007



Is the Hubble Bubble real?

Jha et al. (2007) confirm earlier results

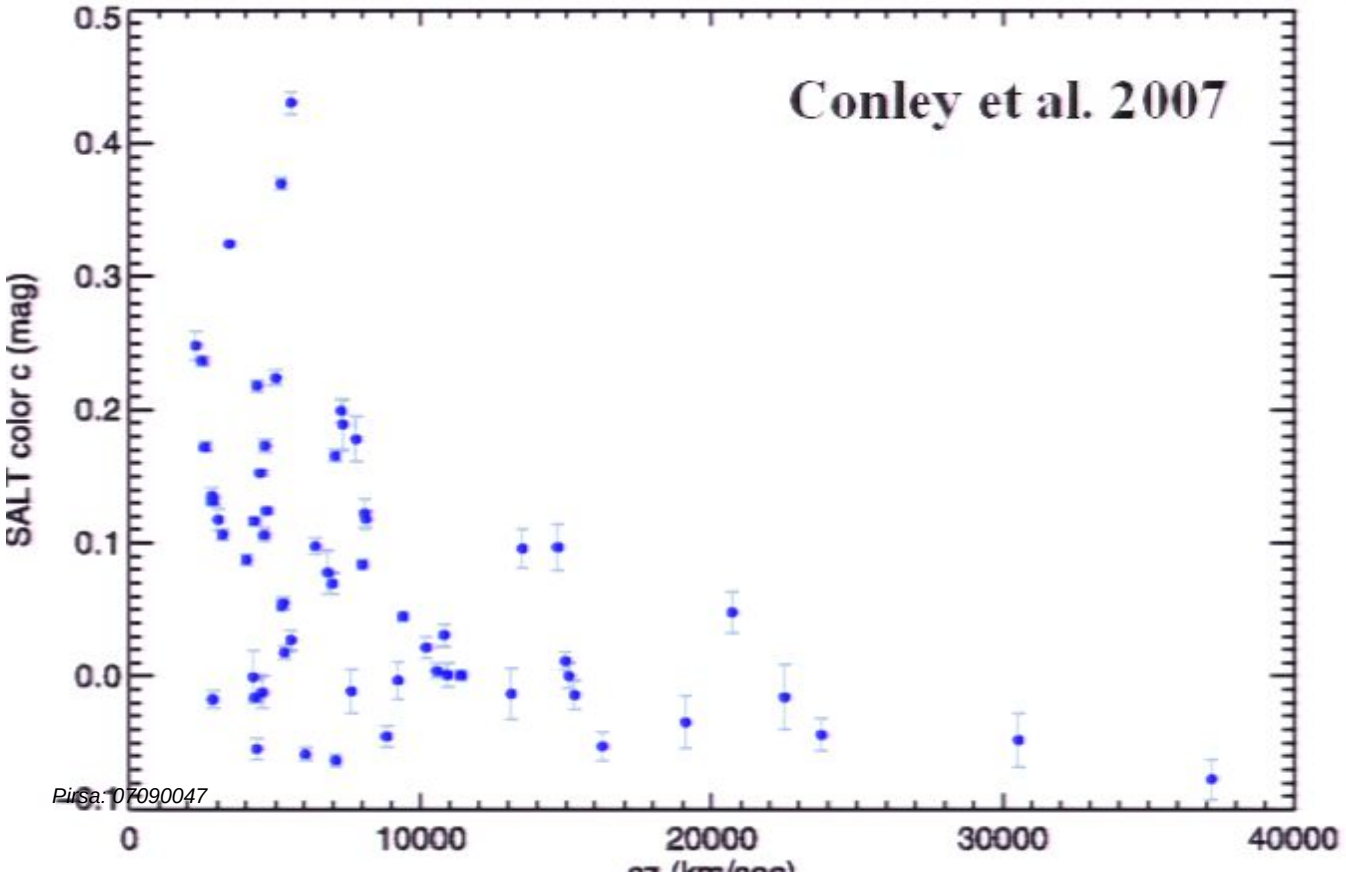
- **Riess et al. (1996), Zehavi et al. (1998)**



Is the Hubble Bubble real?

Jha et al. (2007) confirm earlier results

- **Riess et al. (1996), Zehavi et al. (1998)**



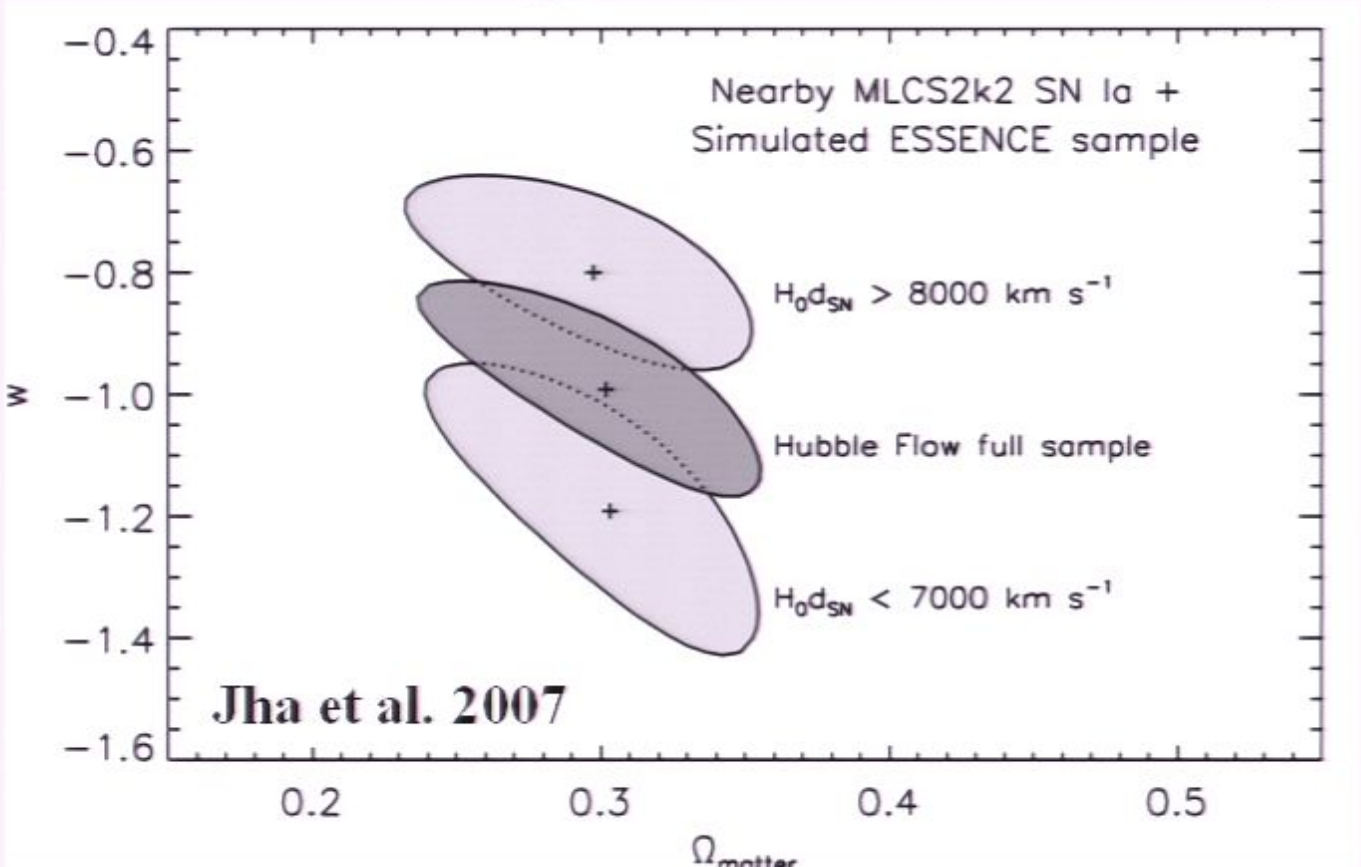
Claimed to be a colour effect

Conley et al. (2007), Wang (2008)

use of a non-standard reddening law 'removes' the Hubble Bubble

The importance of the local sample

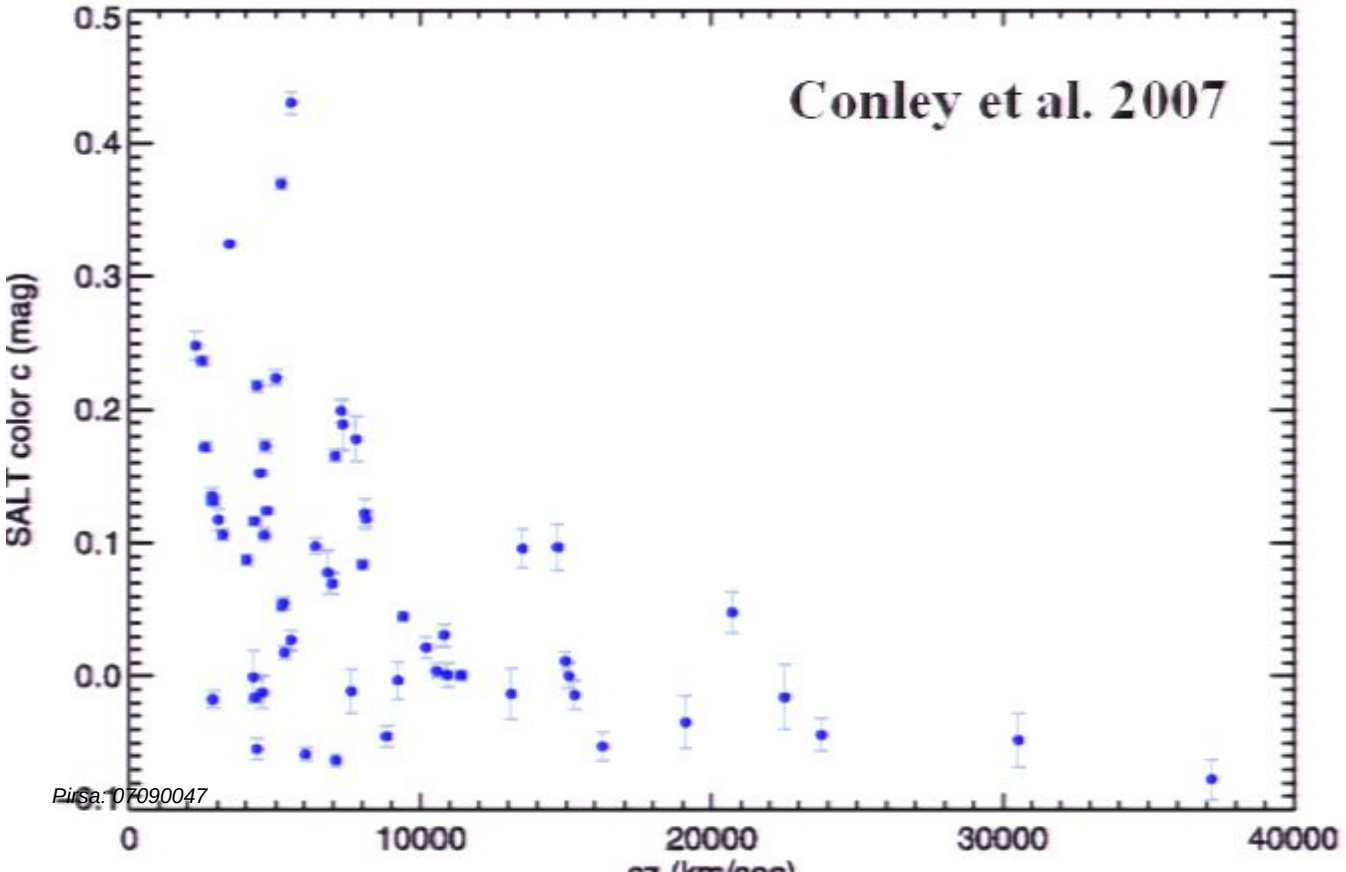
Systematics of the local sample could be a problem (local impurities in the expansion field, e.g. 'Hubble bubble')



Is the Hubble Bubble real?

Jha et al. (2007) confirm earlier results

- **Riess et al. (1996), Zehavi et al. (1998)**



Claimed to be a colour effect

Conley et al. (2007), Wang (2008)

use of a non-standard reddening law 'removes' the Hubble Bubble

Know what happens on the way

Standard reddening?

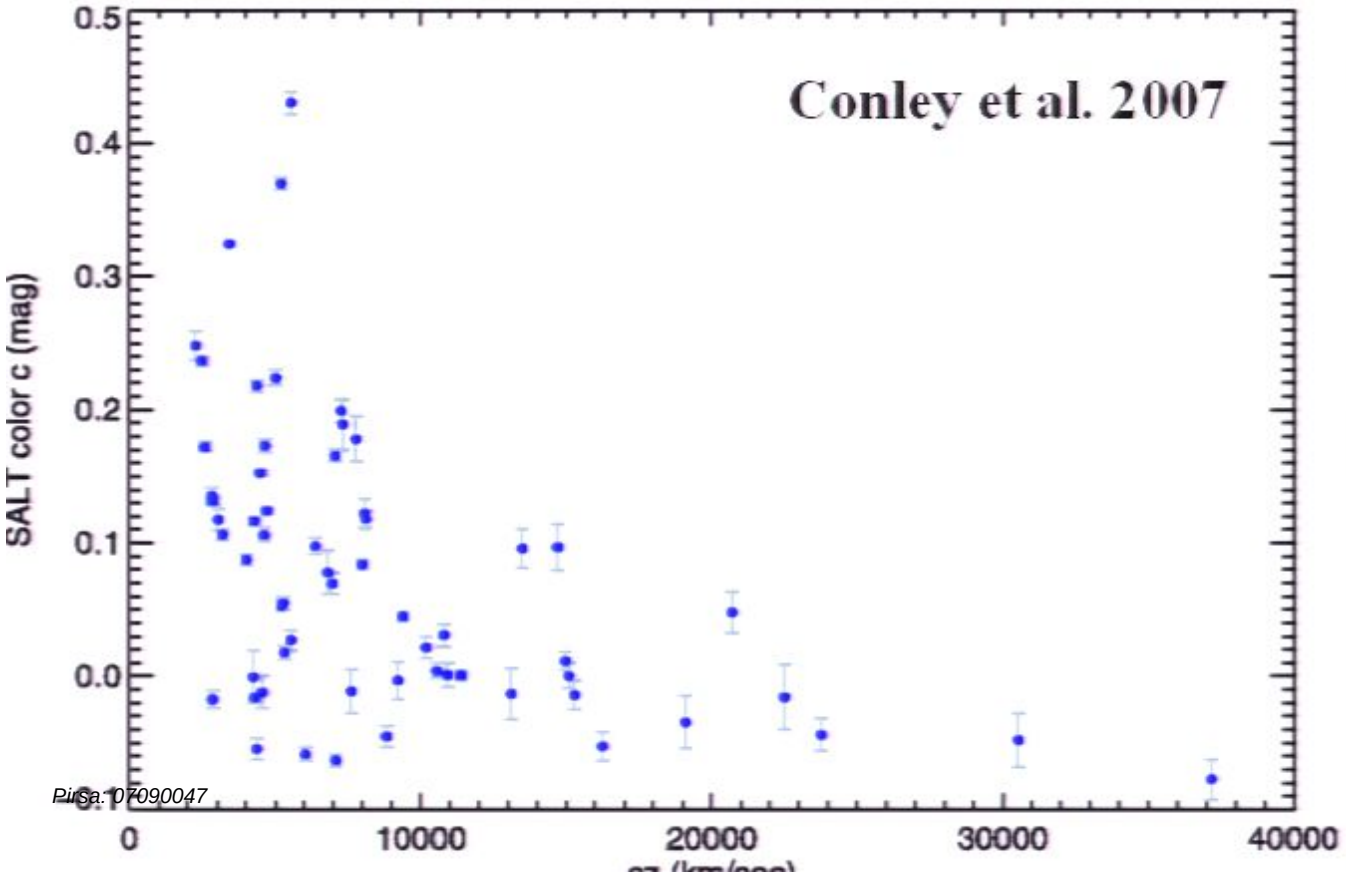
- **indications from many SNe Ia that $R_V<3.1$**
  - e.g. Krisciunas et al., Elias-Rosa et al.
- **free fit to distant SNe Ia gives $R_V\approx2$**
  - Guy et al., Astier et al.
- **Hubble bubble disappears with $R_V\approx2$**
  - Conley et al., Wang

Need good physical understanding for this!

Is the Hubble Bubble real?

Jha et al. (2007) confirm earlier results

- **Riess et al. (1996), Zehavi et al. (1998)**



Claimed to be a colour effect

Conley et al. (2007), Wang (2008)

use of a non-standard reddening law 'removes' the Hubble Bubble

Know what happens on the way

Standard reddening?

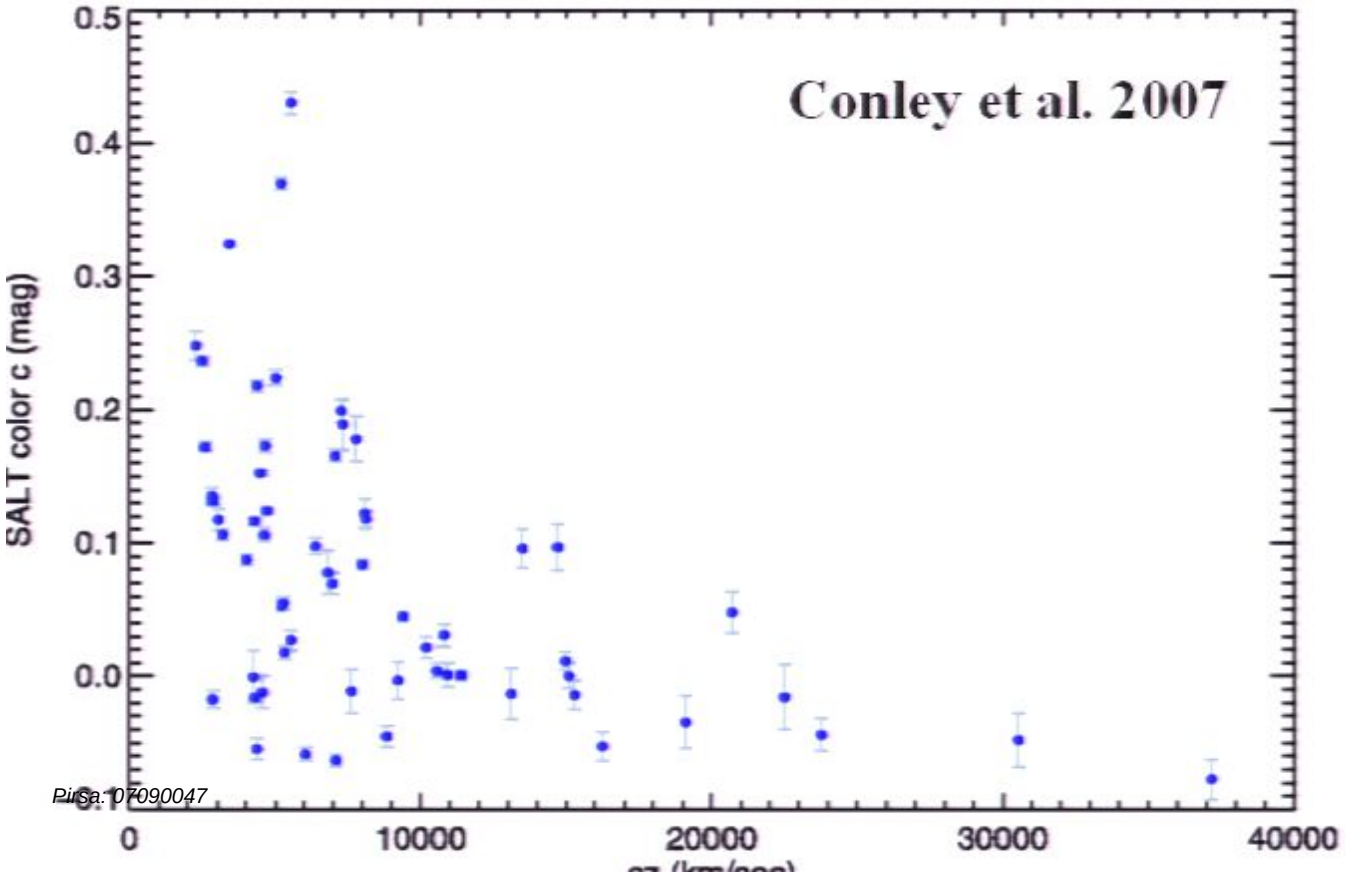
- **indications from many SNe Ia that $R_V<3.1$**
  - e.g. Krisciunas et al., Elias-Rosa et al.
- **free fit to distant SNe Ia gives $R_V\approx2$**
  - Guy et al., Astier et al.
- **Hubble bubble disappears with $R_V\approx2$**
  - Conley et al., Wang

Need good physical understanding for this!

Is the Hubble Bubble real?

Jha et al. (2007) confirm earlier results

- **Riess et al. (1996), Zehavi et al. (1998)**



Claimed to be a colour effect

Conley et al. (2007), Wang (2008)

use of a non-standard reddening law 'removes' the Hubble Bubble

Know what happens on the way

Standard reddening?

- **indications from many SNe Ia that $R_V<3.1$**
  - e.g. Krisciunas et al., Elias-Rosa et al.
- **free fit to distant SNe Ia gives $R_V\approx2$**
  - Guy et al., Astier et al.
- **Hubble bubble disappears with $R_V\approx2$**
  - Conley et al., Wang

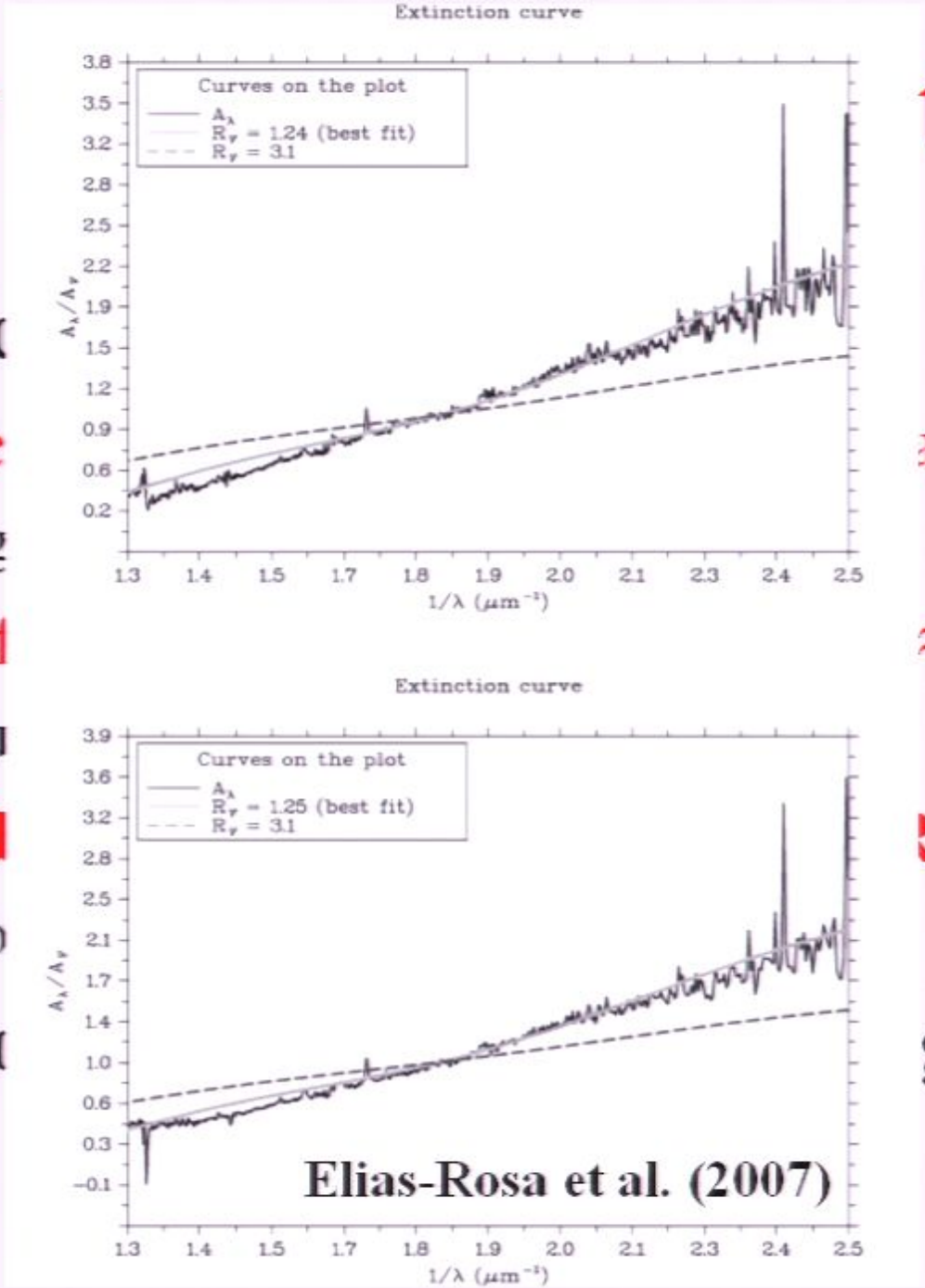
Need good physical understanding for this!

Know … the way

Standard …

- indic … at R_V<3.1
  - e.g …
- free f … ≈2
  - Gu …
- Hubl … R_V≈2
  - Co …

Need goo … g for this!



Know what happens on the way

Standard reddening?

- **indications from many SNe Ia that $R_V<3.1$**
  - e.g. Krisciunas et al., Elias-Rosa et al.
- **free fit to distant SNe Ia gives $R_V\approx2$**
  - Guy et al., Astier et al.
- **Hubble bubble disappears with $R_V\approx2$**
  - Conley et al., Wang

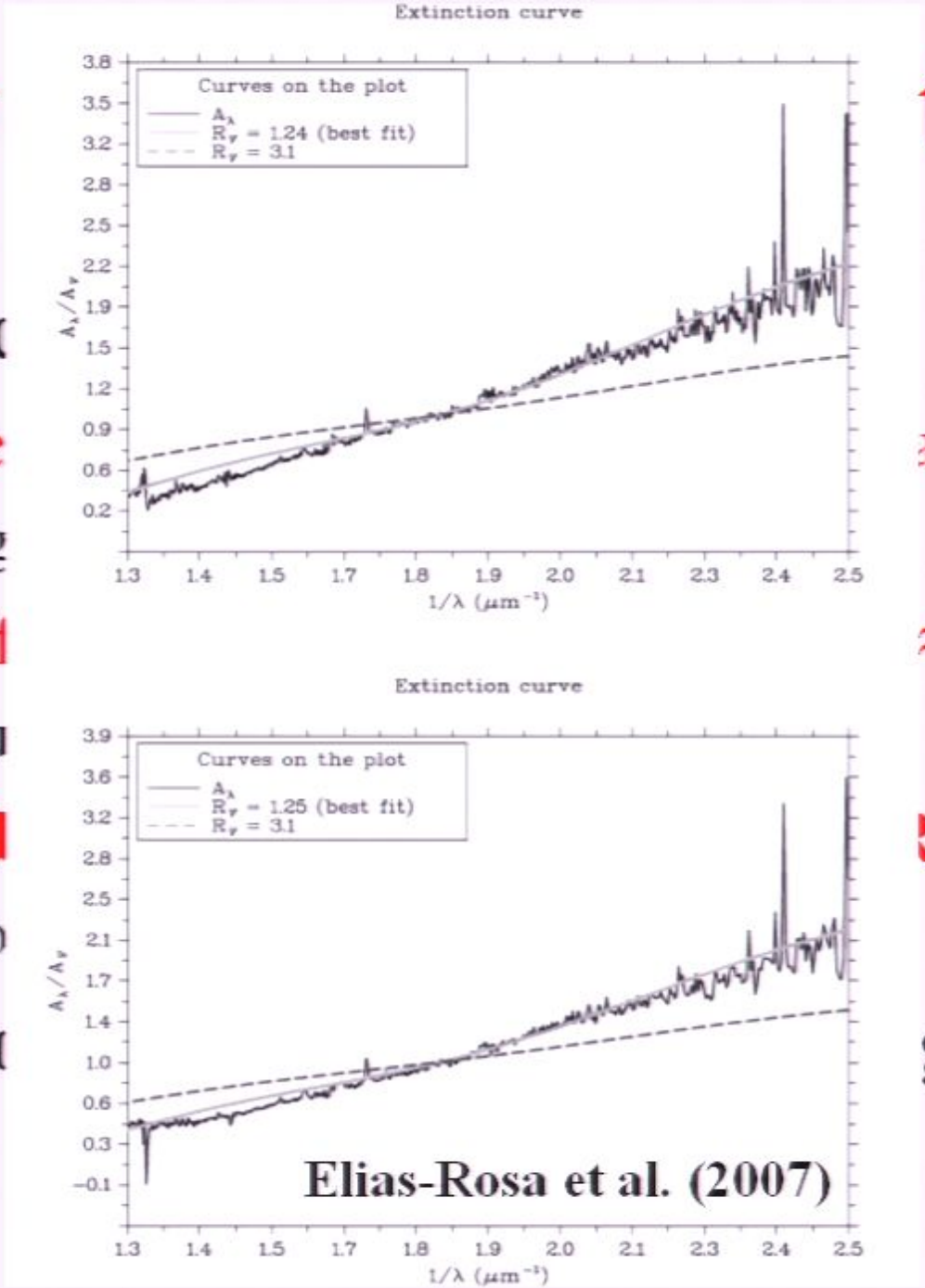
Need good physical understanding for this!

Know … the way

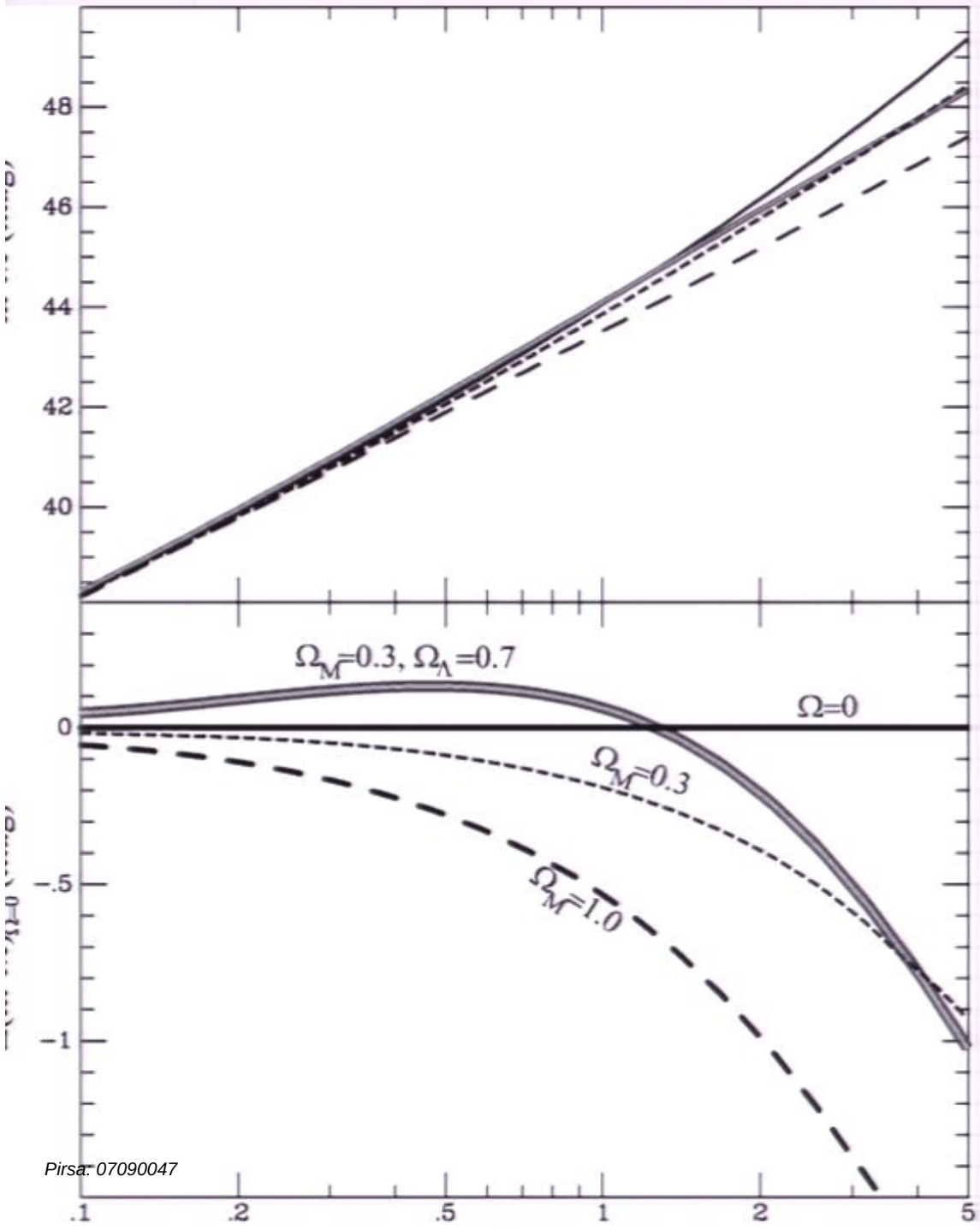
Standard …

- indic … at R_V<3.1
  - e.g …
- free f … ≈2
  - Gu …
- Hubl … R_V≈2
  - Co …

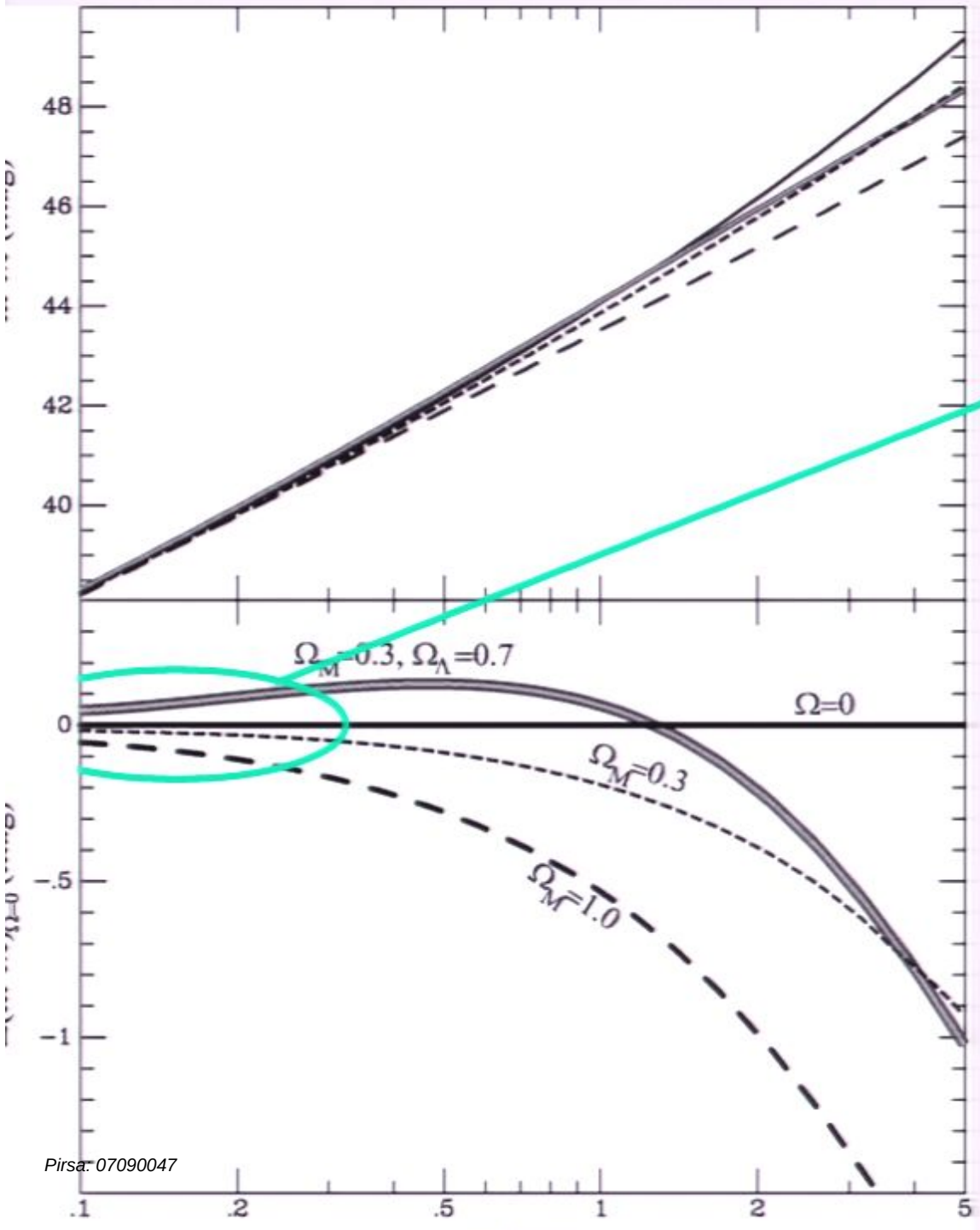
Need goo … g for this!



Where are we …

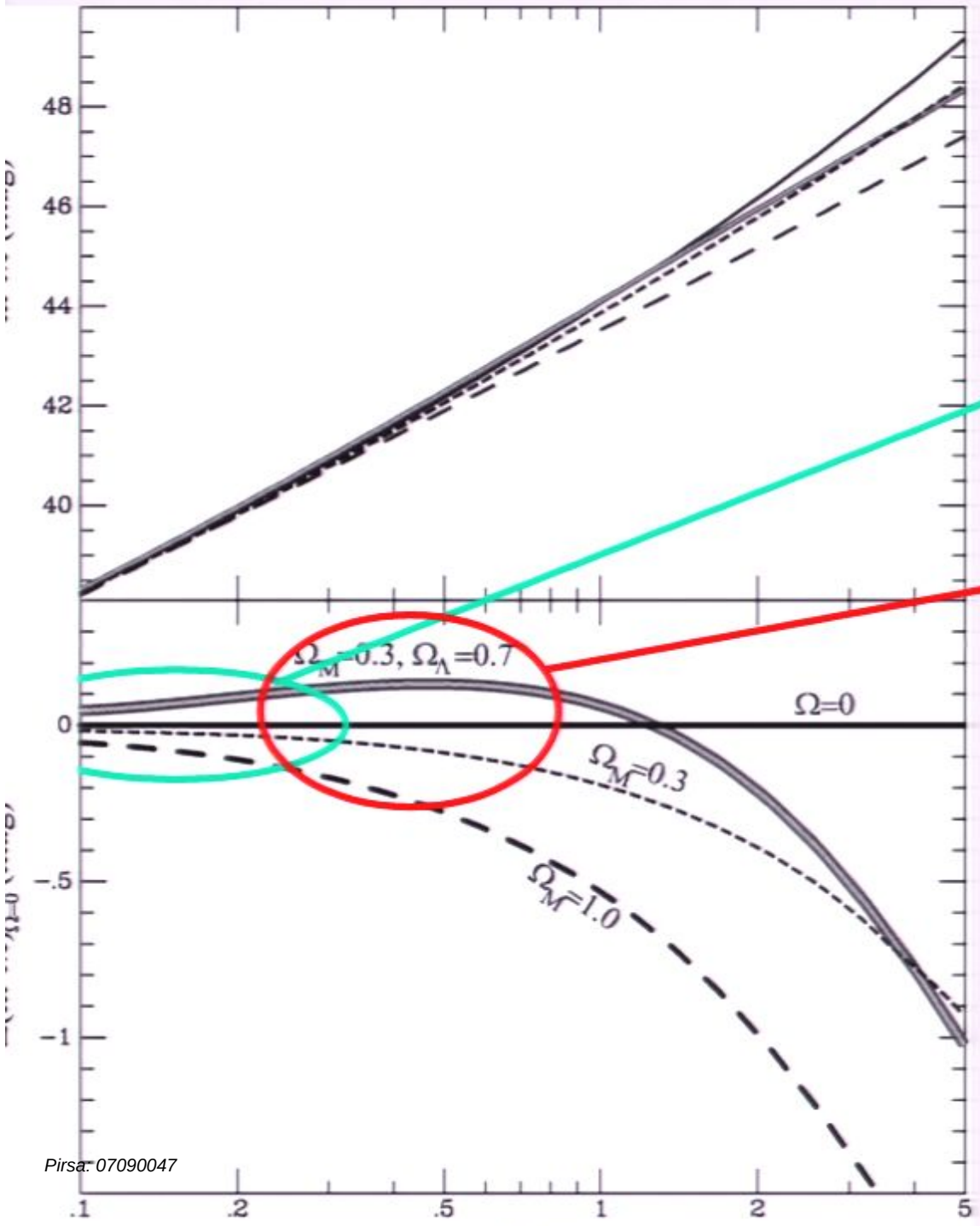

48
46
44
42
40
0
−.5
−1
.1
.2
.5
1
2
5
Ω_M=0.3, Ω_Λ=0.7
Ω=0
Ω_M=0.3
Ω_M=1.0

Where are we …



SN Factory
Carnegie SN Project
SDSSII

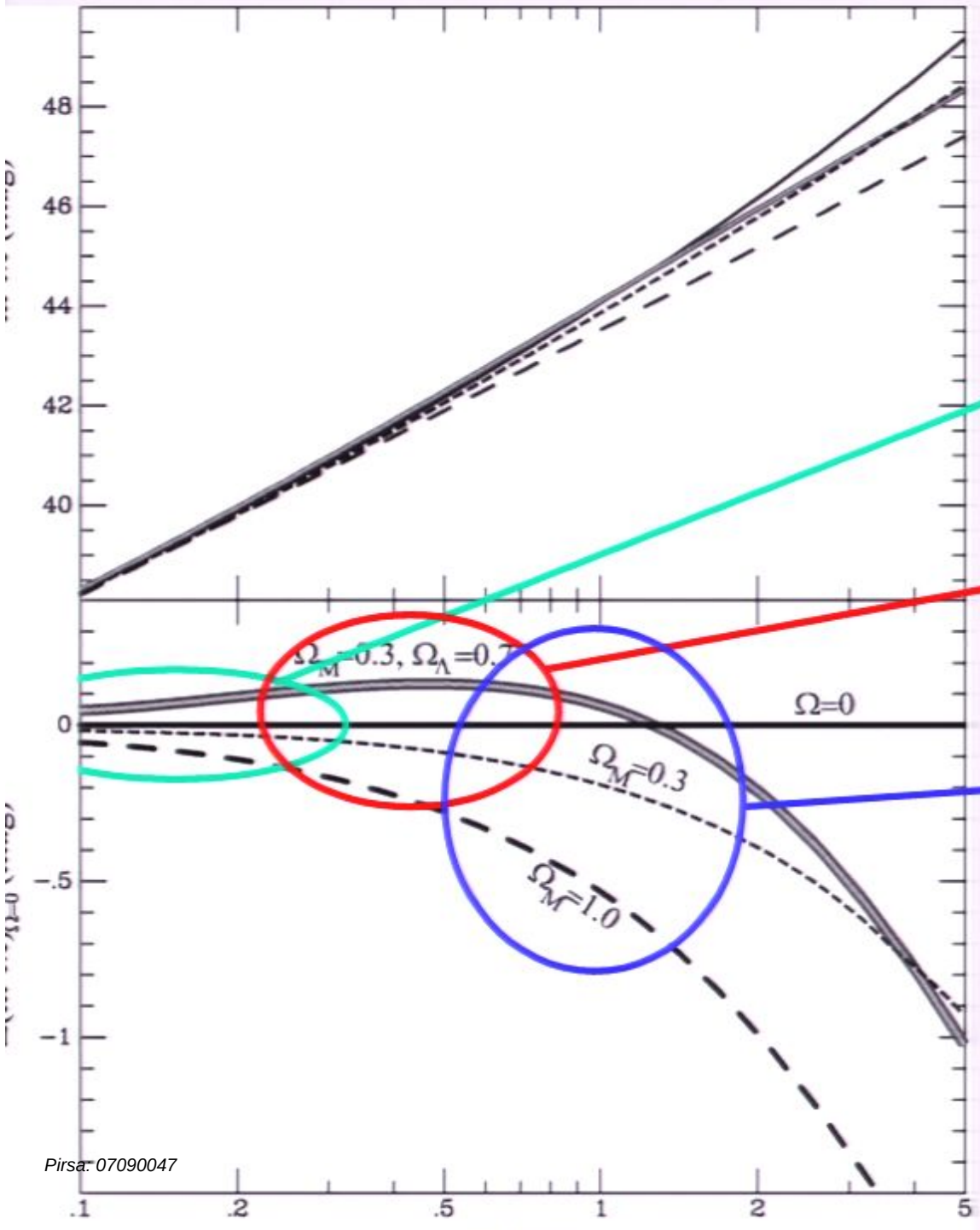
Where are we …



SN Factory
Carnegie SN Project
SDSSII

ESSENCE
CFHT Legacy Survey

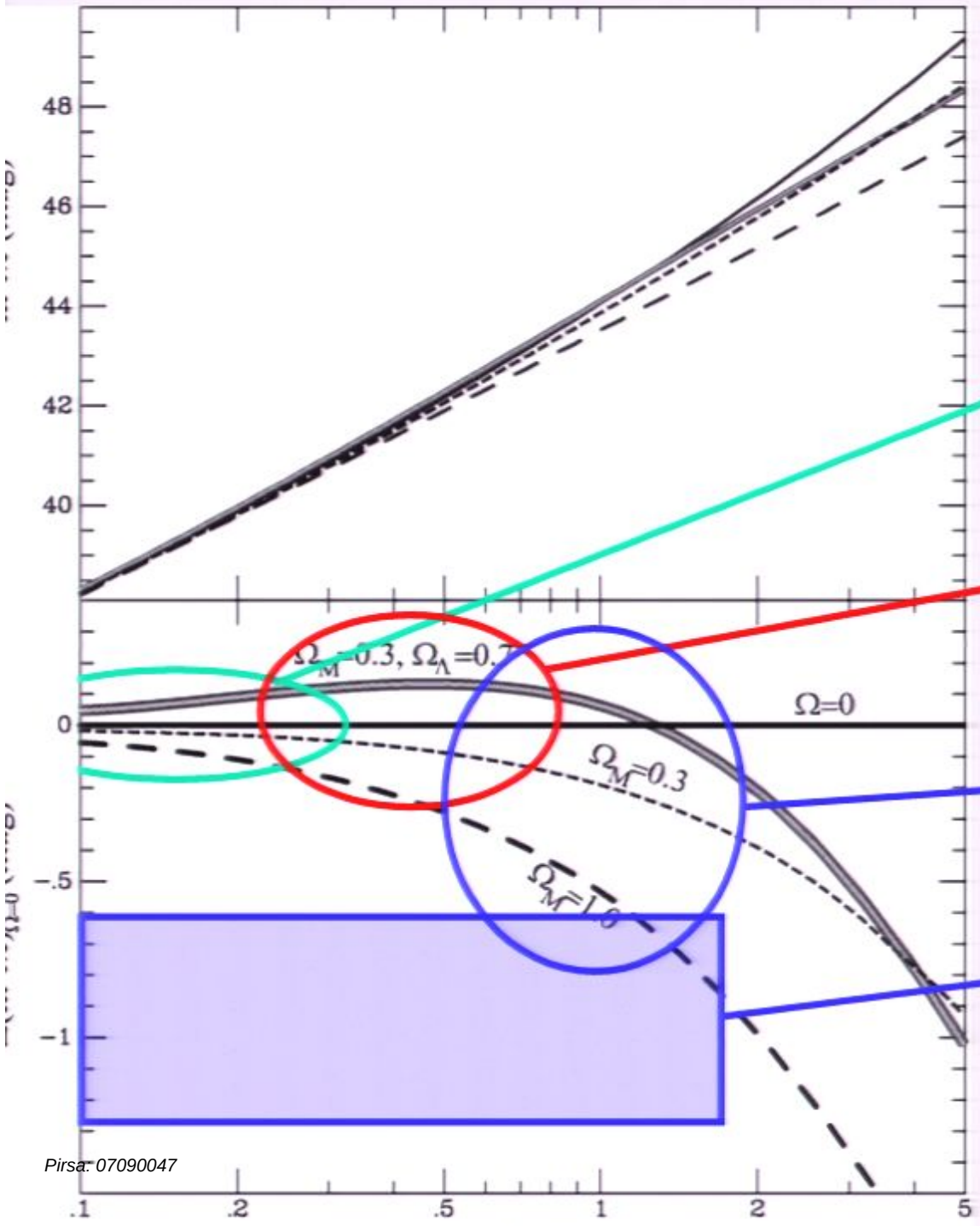
Where are we …



SN Factory
Carnegie SN Project
SDSSII

ESSENCE
CFHT Legacy Survey

Higher-z SN Search
(GOODS)



Where are we …

SN Factory
Carnegie SN Project
SDSSII

ESSENCE
CFHT Legacy Survey

Higher-z SN Search
(GOODS)

SNAP/LSST

Plus the local searches:
LOTOSS, CfA, ESC

The next steps

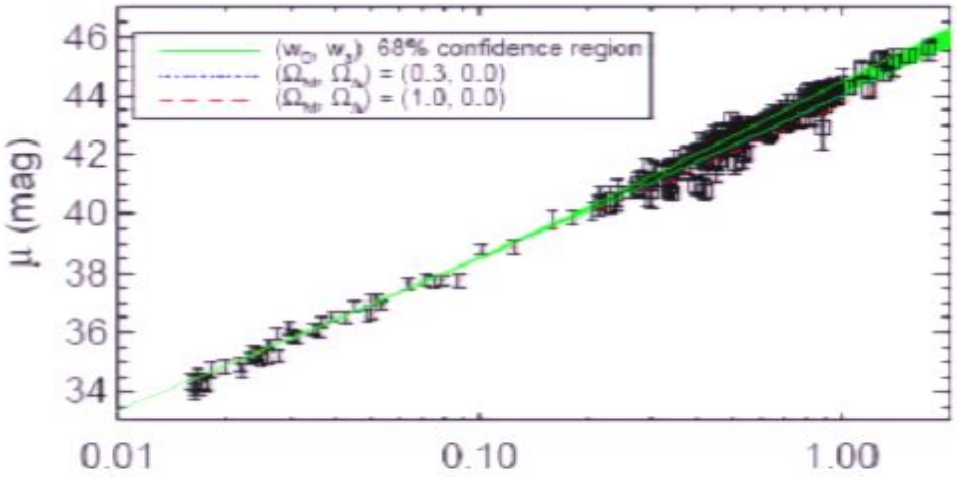
At the end of 2008

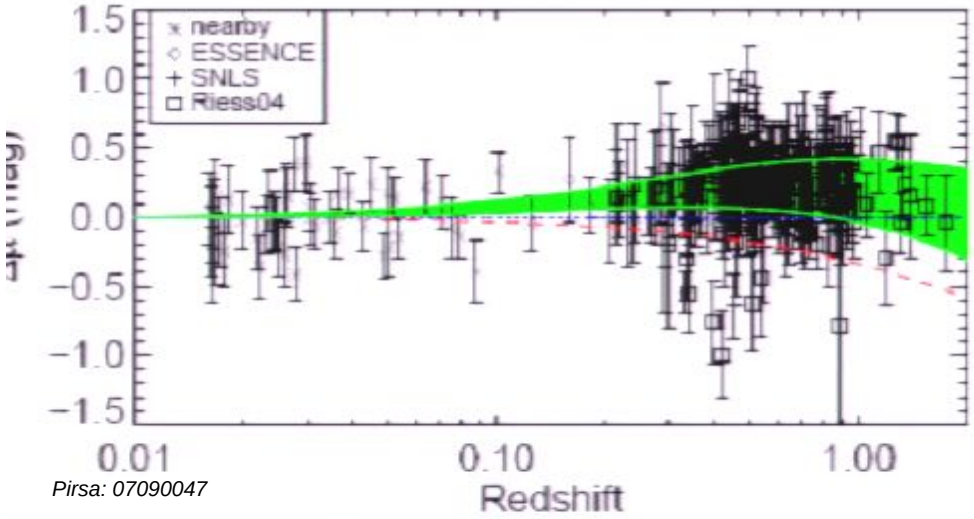
- **about 1000 SNe Ia for cosmology**
- **constant ω determined to 5%**
- **accuracy dominated by systematic effects**
  - reddening, correlations, local field, evolution

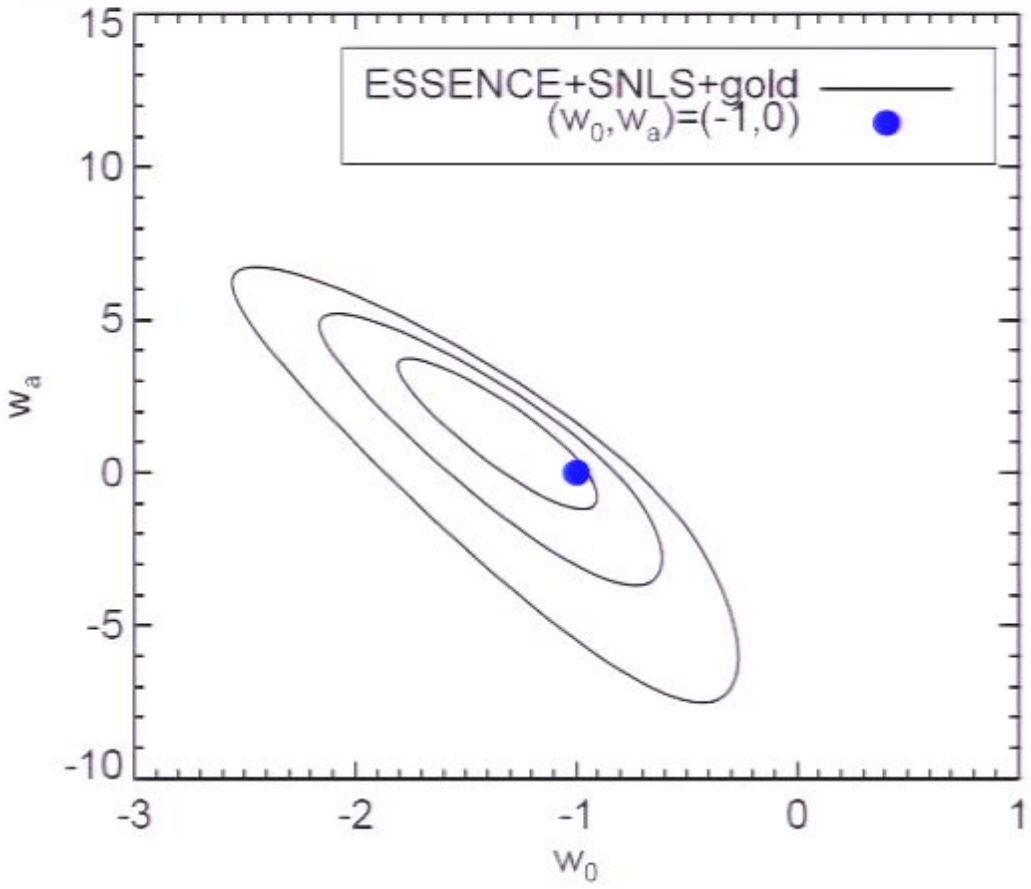
Test for variable ω

- **required accuracy ~2% in *individual* distances**
- **can SNe Ia provide this?**
  - can the systematics be reduced to this level?
  - homogeneous photometry?
  - handle 10000 SNe Ia?

Time variable ω?







Wood-Vasey et al. 2007

Requirements

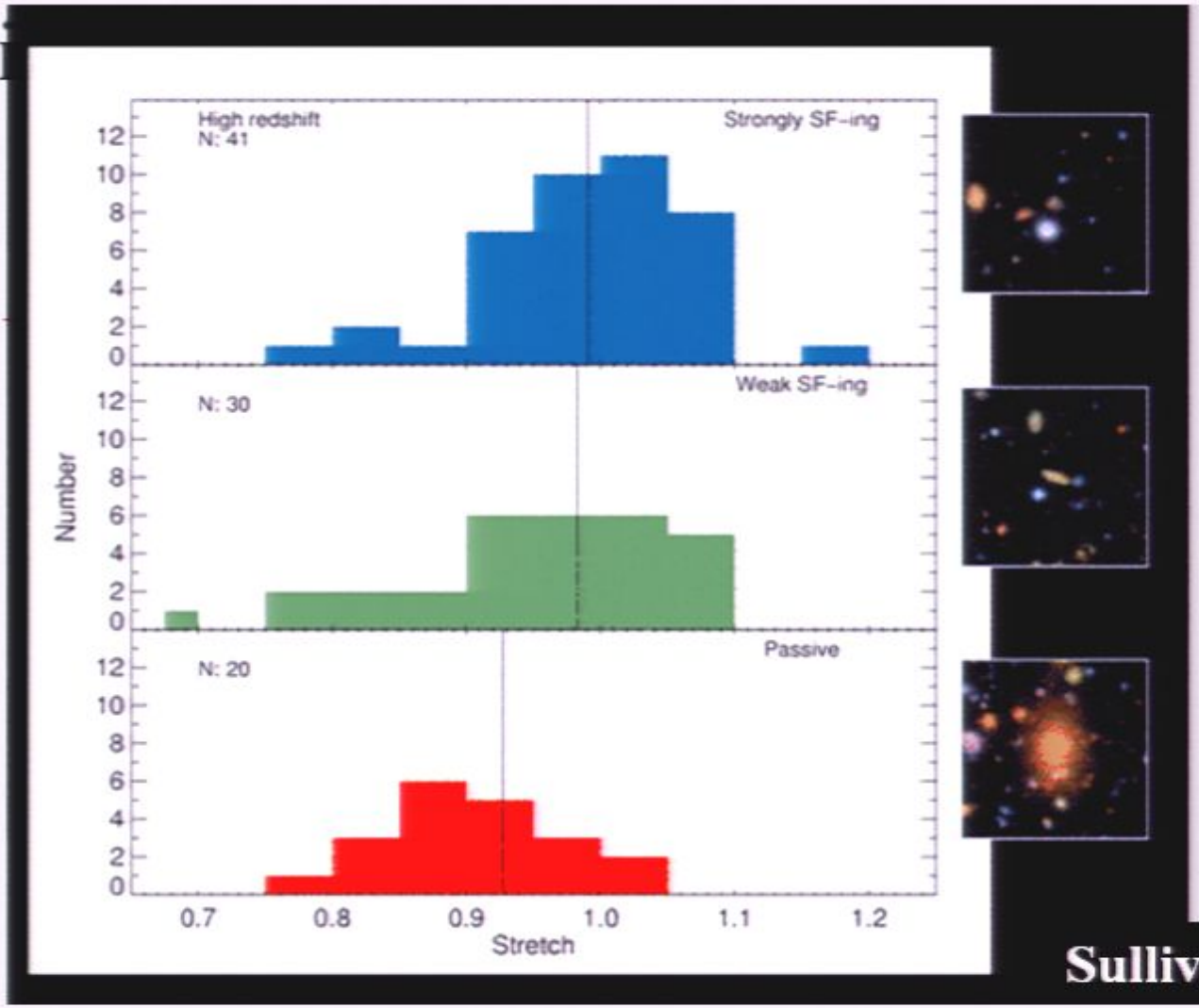
Limit uncertainties to below 2%

- **solve the local field problem**
- **solve reddening problem**
- **understand evolution**
  - amongst SNe Ia (e.g. metallicity effects)
  - within the sample (e.g. correlations)

Requirements

Limi

-
-
-



Sullivan et al. 2006

Requirements

Limit uncertainties to below 2%

- **solve the local field problem**
- **solve reddening problem**
- **understand evolution**
  - amongst SNe Ia (e.g. metallicity effects)
  - within the sample (e.g. correlations)
- **understand SN Ia physics**
  - progenitors
  - explosion mechanism(s)
  - 3-dimensional

End of slide show, click to exit.

Requirements

Limit uncertainties to below 2%

- **solve the local field problem**
- **solve reddening problem**
- **understand evolution**
  - amongst SNe Ia (e.g. metallicity effects)
  - within the sample (e.g. correlations)
- **understand SN Ia physics**
  - progenitors
  - explosion mechanism(s)
  - 3-dimensional

Microsoft PowerPoint - [Perimeter07]

File Edit View Insert Format Tools Slide Show Window Help Adobe PDF

Type a question for help

75% Notes... Transition Design

46

47

48

49

50

Determine a lower limit for H_0

51

Ejecta masses from light curves

52

Ejecta masses

53

Type Ia Supernovae

54

Standard SNe Ia?

55

Know where you are

56

57

The importance of the local sample

58

Where does the Hubble flow begin?

59

Is the Hubble Bubble real?

60

Know the way

61

Where are we ...

62

The next steps

63

Time variable ω?

64

Requirements

65

Slide Sorter Default Design

Microsoft PowerPoint - [Perimeter07]

File Edit View Insert Format Tools Slide Show Window Help Adobe PDF

Type a question for help

75% Notes... Transition Design

The Astrophysics of Type Ia Supernova Cosmology

Bruno Leibundgut
European Southern Observatory

1

The SN Ia Hubble Diagram

Combination of ESSENCE, SNLS and nearby SNe Ia

2

Current surveys

SNLS:

ESSENCE:

3

Cosmology results

SNLS 1st year (Astier et al. 2006)

- 71 distant SNe Ia

ESSENCE 3 years (Wood-Vasey et al. 2007)

- 60 distant SNe Ia

4

Systematics table

5

The currently most complete SN Ia sample

(Riess et al. 2007)

Collected all available distant SNe Ia

- Riess et al. (2004)
- Astier et al. (2006)
- Wood-Vasey et al. (2007)

→ 23 SNe Ia with $z>1$

→ total of 182 SNe Ia with $z>0.0233$ ($v=7000$ km/s)

lower redshift limit to avoid any local effects

6

SN Ia Hubble Diagram

7

Analysis

Check for acceleration, i.e. $\ddot{a}(z)$ (model independent!)

8

Analysis

Reconstruct $w(z)$ from the data following Huterer & Cooray (2005):

Construct independent redshift bins: σ=0.25, 0.70 and 1.25 and compress only

9

Comparison to other models

10

Astrophysics

To measure cosmological parameters (distances) you need to

- understand your source
- understand what can affect the light on its path or the observer (foregrounds)
- know your local environment

11

Supernova!

12

Supernovae!

13

14

Systematics

Contamination
Photometry
K-corrections
Malmquist bias
Normalisation
Evolution
Absorption
Local expansion field

15

Systematics

Contamination
Photometry — measurement
K-corrections
Malmquist bias
Normalisation — source
Evolution
Absorption — path

Systematics of SNe Ia

[T]he length of the list indicates the maturity of the field, and is the result of more than a decade of careful study.

Know your source

Type Ia Supernovae

- complicated source
- interesting physics
- progenitor systems
- determine the global parameters of the explosions

Supernovae as 'standard candles'

Uniform appearance

- light curves
- colour curves
- spectral evolution

Slide Sorter Default Design

Microsoft PowerPoint - [Perimeter07]

File Edit View Insert Format Tools Slide Show Window Help Adobe PDF

Type a question for help

75% Notes... Transition Design

The Astrophysics of Type Ia Supernova Cosmology

Bruno Leibundgut
European Southern Observatory

1

The SN Ia Hubble Diagram

Combination of ESSENCE, SNLS and nearby SNe Ia

2

Current surveys

SNLS

ESSENCE

3

Cosmology results

SNLS 1st year (Astier et al. 2006)

- 71 distant SNe Ia

ESSENCE 3 years (Wood-Vasey et al. 2007)

- 60 distant SNe Ia

4

Systematics table

5

The currently most complete SN Ia sample

(Riess et al. 2007)

Collected all available distant SNe Ia

- Riess et al. (2004)
- Astier et al. (2006)
- Wood-Vasey et al. (2007)

→ 23 SNe Ia with $z>1$

→ total of 182 SNe Ia with $z>0.0233$ ($v=7000$ km/s)

lower redshift limit to avoid any local effects

6

SN Ia Hubble Diagram

7

Analysis

Check for acceleration, i.e. $\ddot{R}(z)$ (model independent)

8

Analysis

Reconstruct $w(z)$ from the data following Huterer & Cooray(2005)

Construct independent redshift bins at 0.25, 0.70 and 1.25 and compare only

9

Comparison to other models

10

Astrophysics

To measure cosmological parameters (distances) you need to

- understand your source
- understand what can affect the light on its path or the observer (foregrounds)
- know your local environment

11

Supernova!

12

Supernovae!

13

14

Systematics

Contamination
Photometry
K-corrections
Malmquist bias
Normalisation
Evolution
Absorption
Local expansion field

15

Systematics

Contamination — measurement
Photometry
K-corrections
Malmquist bias
Normalisation — source
Evolution
Absorption — path

Systematics of SNe Ia

[T]he length of the list indicates the maturity of the field, and is the result of more than a decade of carefully tidy

Know your source

Type Ia Supernovae

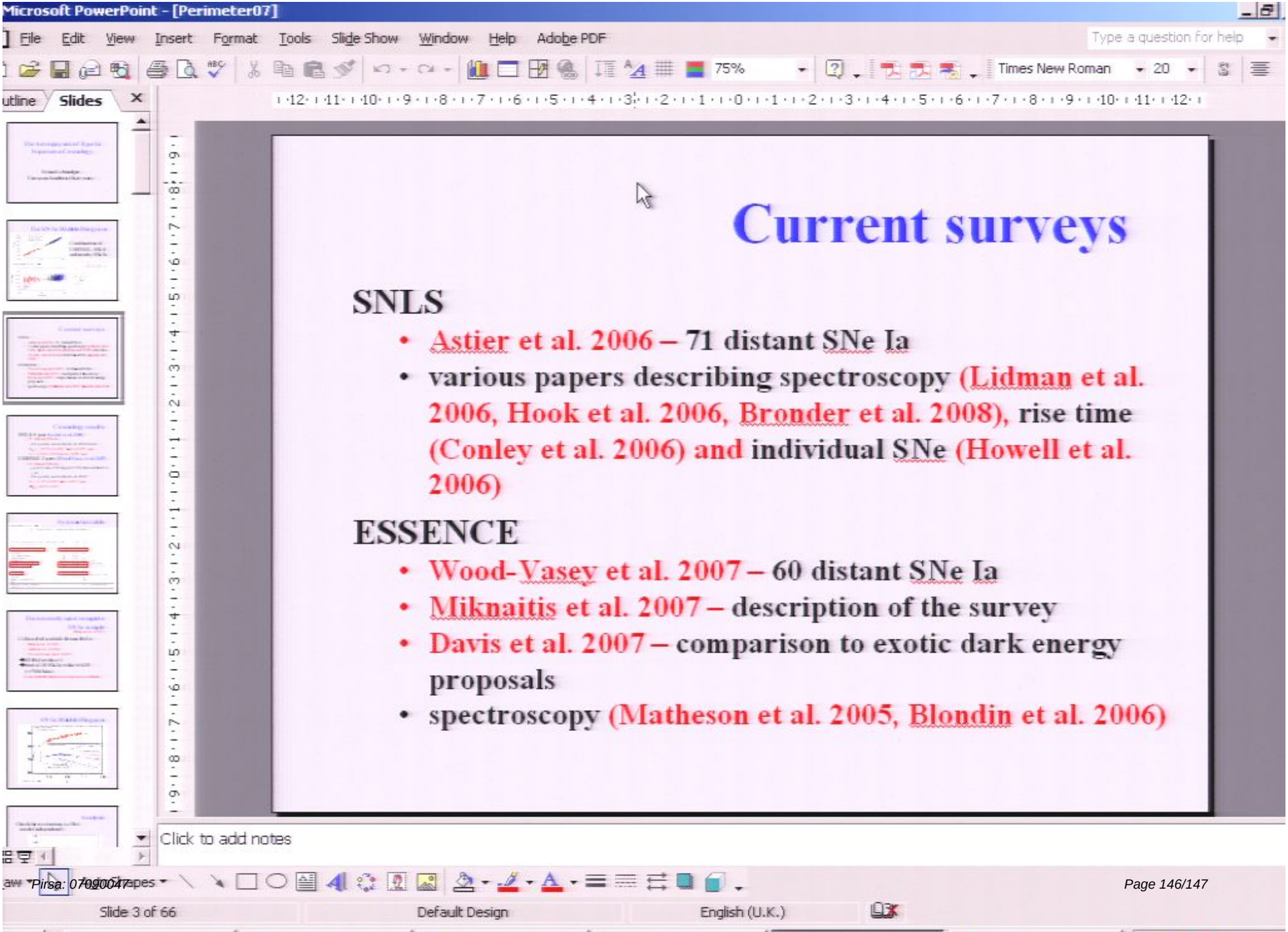
- complicated source
- interesting physics
- progenitor systems
- determine the global parameters of the explosions

Supernovae as 'standard candles'

Uniform appearance

- light curves
- colour curves
- spectral evolution

Slide Sorter Default Design


Microsoft PowerPoint - [Perimeter07]
File Edit View Insert Format Tools Slide Show Window Help Adobe PDF
Type a question for help
75%
Times New Roman
20
Outline
Slides
Current surveys
SNLS
Astier et al. 2006 – 71 distant SNe Ia
various papers describing spectroscopy (Lidman et al. 2006, Hook et al. 2006, Bronder et al. 2008), rise time (Conley et al. 2006) and individual SNe (Howell et al. 2006)
ESSENCE
Wood-Vasey et al. 2007 – 60 distant SNe Ia
Miknaitis et al. 2007 – description of the survey
Davis et al. 2007 – comparison to exotic dark energy proposals
spectroscopy (Matheson et al. 2005, Blondin et al. 2006)
Click to add notes
Slide 3 of 66
Default Design
English (U.K.)

Current surveys

SNLS

- Astier et al. 2006 – 71 distant SNe Ia
- various papers describing spectroscopy (Lidman et al. 2006, Hook et al. 2006, Bronder et al. 2008), rise time (Conley et al. 2006) and individual SNe (Howell et al. 2006)

ESSENCE

- Wood-Vasey et al. 2007 – 60 distant SNe Ia
- Miknaitis et al. 2007 – description of the survey
- Davis et al. 2007 – comparison to exotic dark energy proposals
- spectroscopy (Matheson et al. 2005, Blondin et al. 2006)