Type Ia supernovae surveys and cosmology

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[Riess2004]

To begin with, some provocative quotations to prepare our mood

Superpessimistic:

“Cosmologists are often wrong but never in doubt.”, *L. Landau*

“… modern cosmology has strayed from the sound empirical road into a wilderness where statements can be made without fear of observational check …”, *M. Born*

“There are only 2½ facts in cosmology.”, *P. Scheuer*

X

Superoptimistic:

“Cosmology solved? Quite possibly.”, *M. Turner*

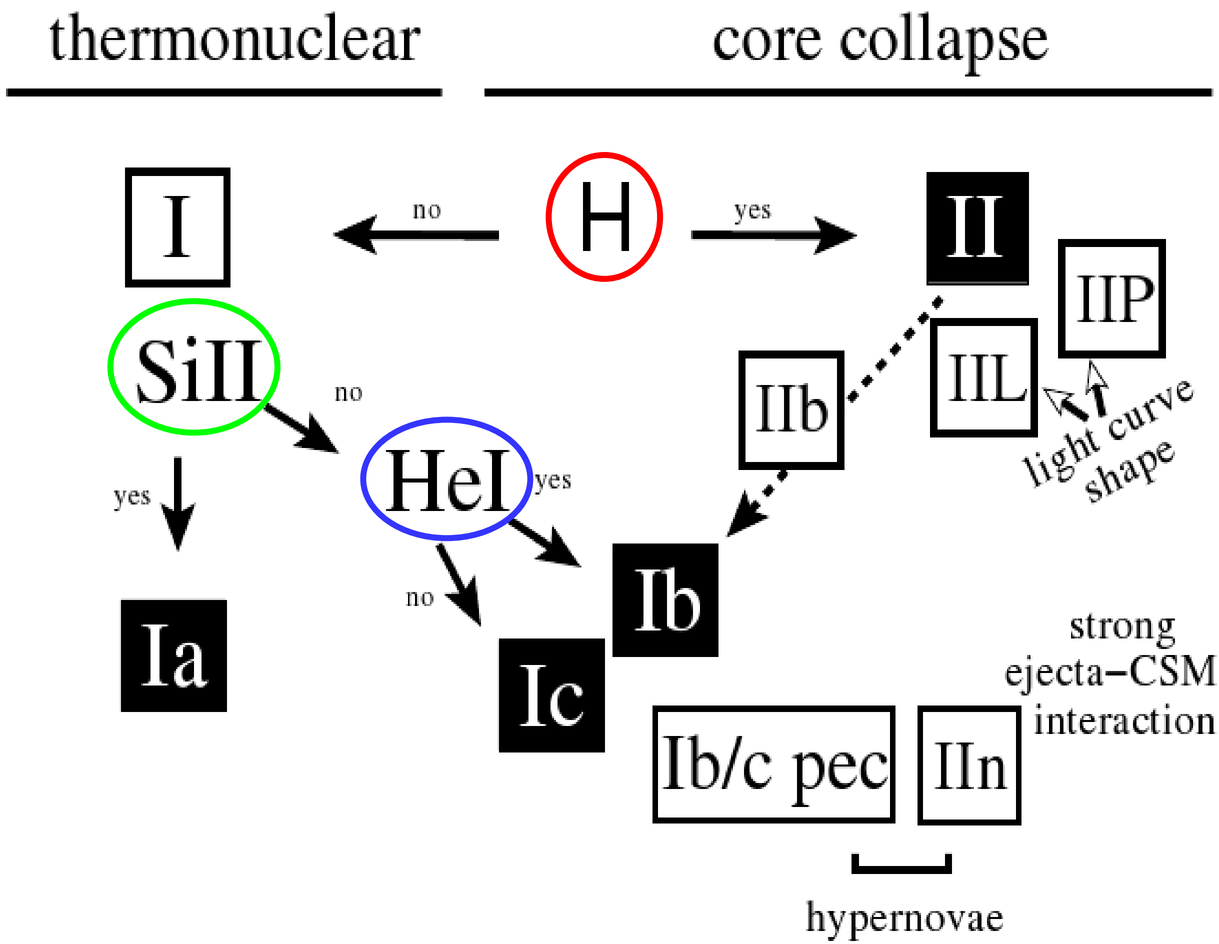
"Someday (and that day is not yet here) the physical origin and the dynamics of the entire universe will be as well understood as we now understand the stars. The existence of the universe will hold no more mystery for those who choose to understand it than the existence of the sun.", *H. Pagels*

“My goal is simple. It is a complete understanding of the universe, why it is as it is and why it exists at all.”, *S. Hawking*

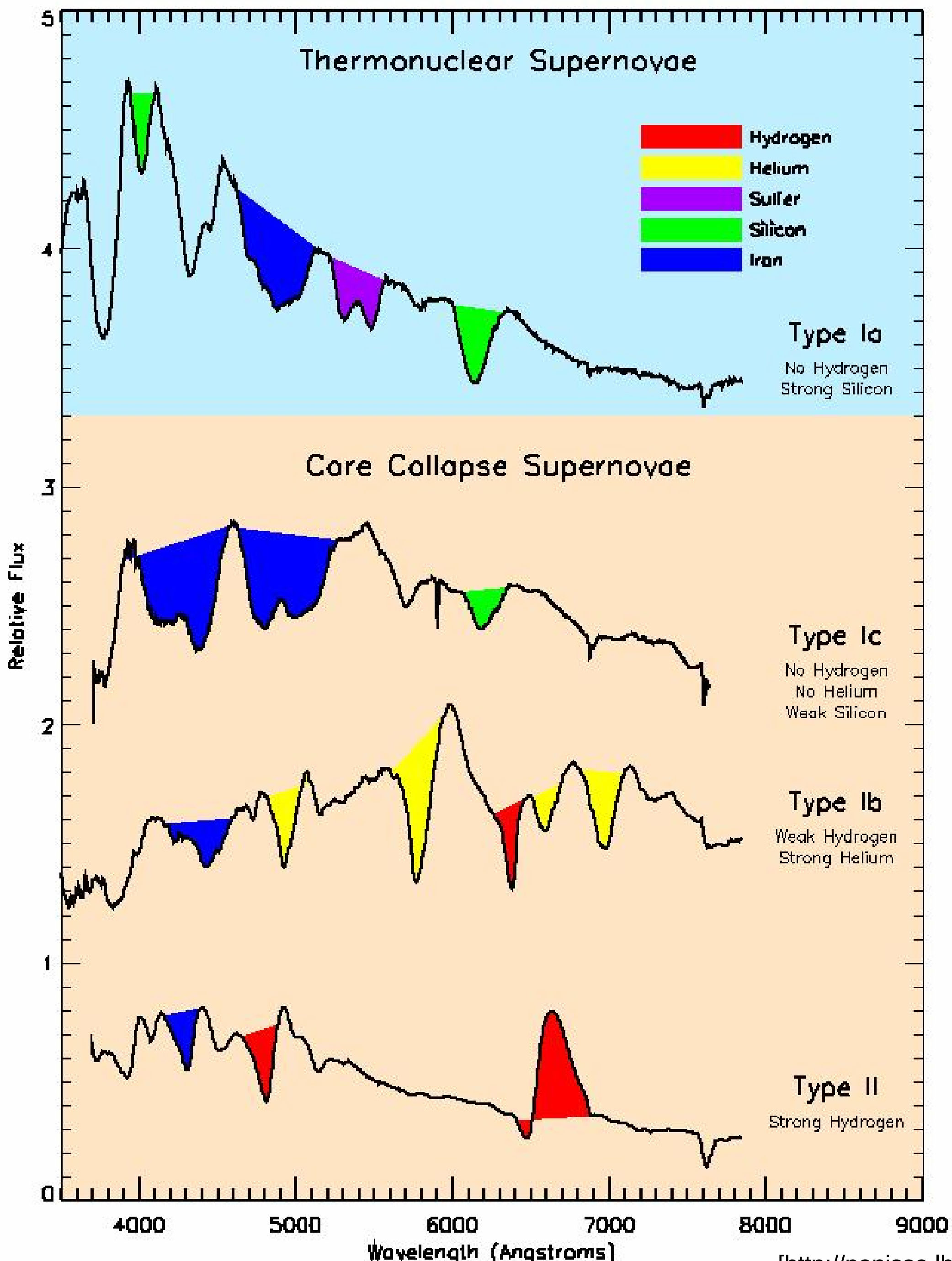
PLAN OF PRESENTATION

- GENERIC PROPERTIES OF SNe Ia
- OVERVIEW OF SURVEYS
- K CORRECTION
- FINAL REMARKS

GENERIC PROPERTIES OF SNe Ia



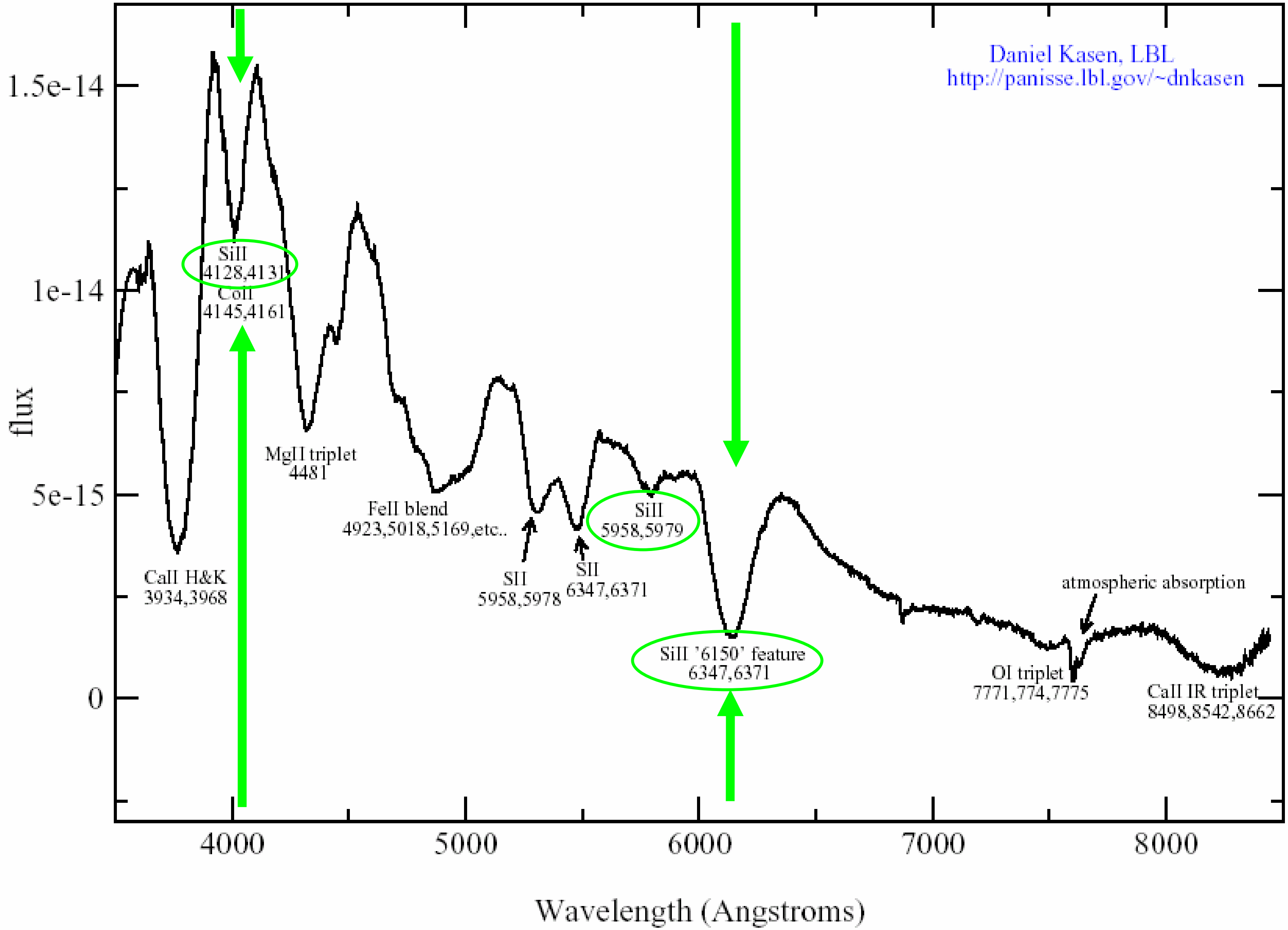
[...tto2003]

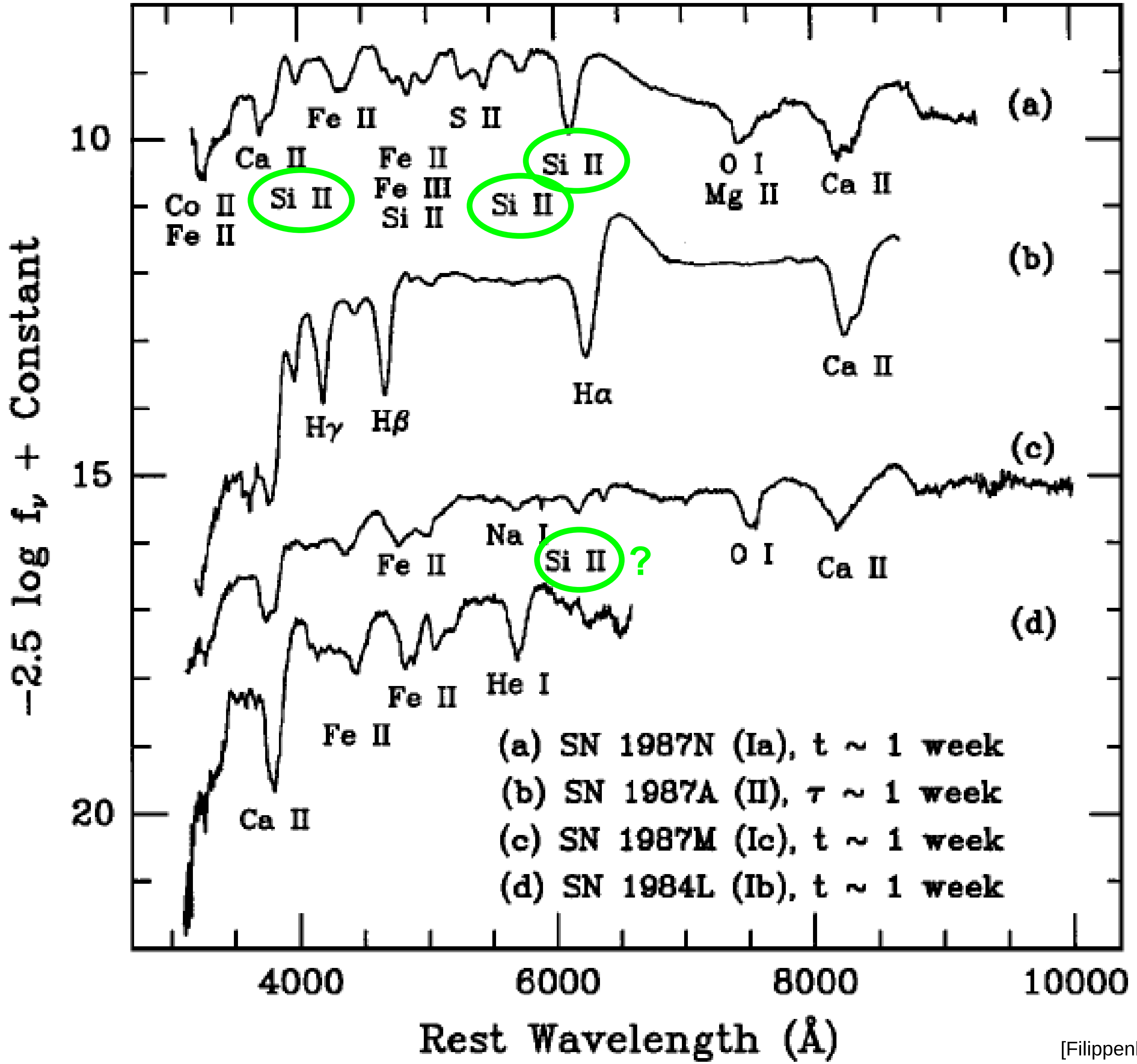


[http://panisse.lbl.gov/~dnkasen/tutorial/graphics/sn_types.jpg]

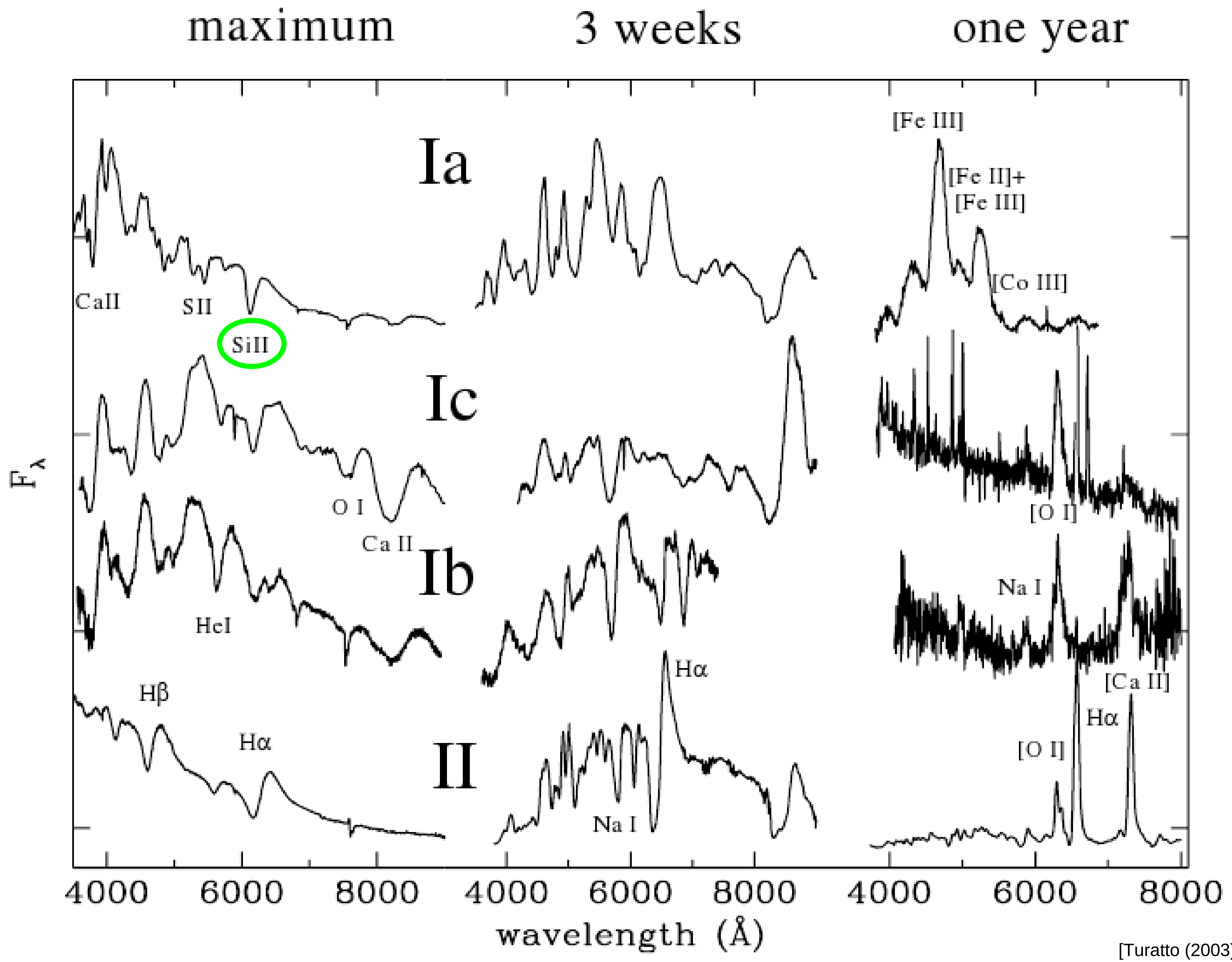
Type 1a Line Identifications

spectrum of SN1981b, a normal type1a near max

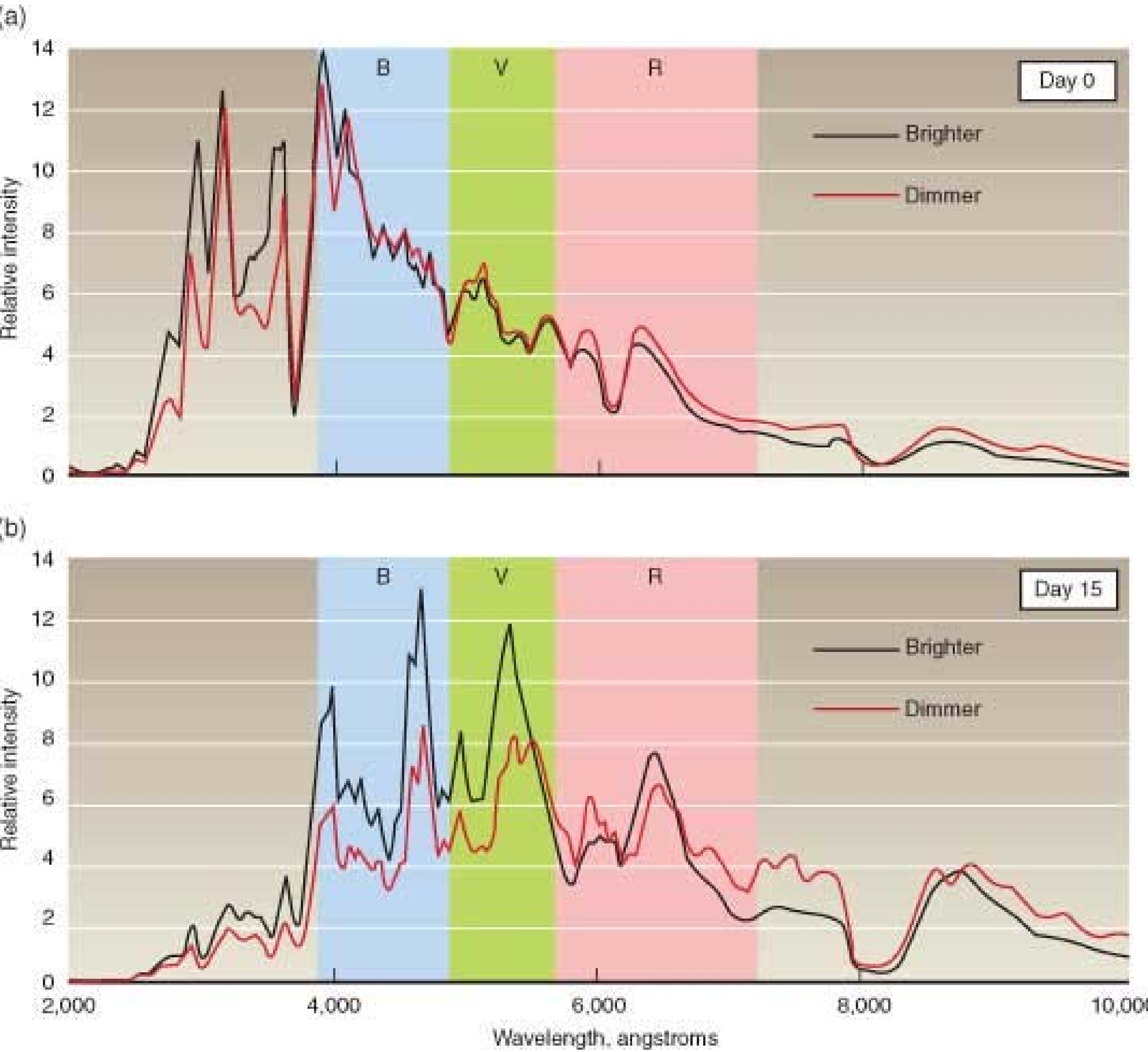




[Filippenko (1997)]

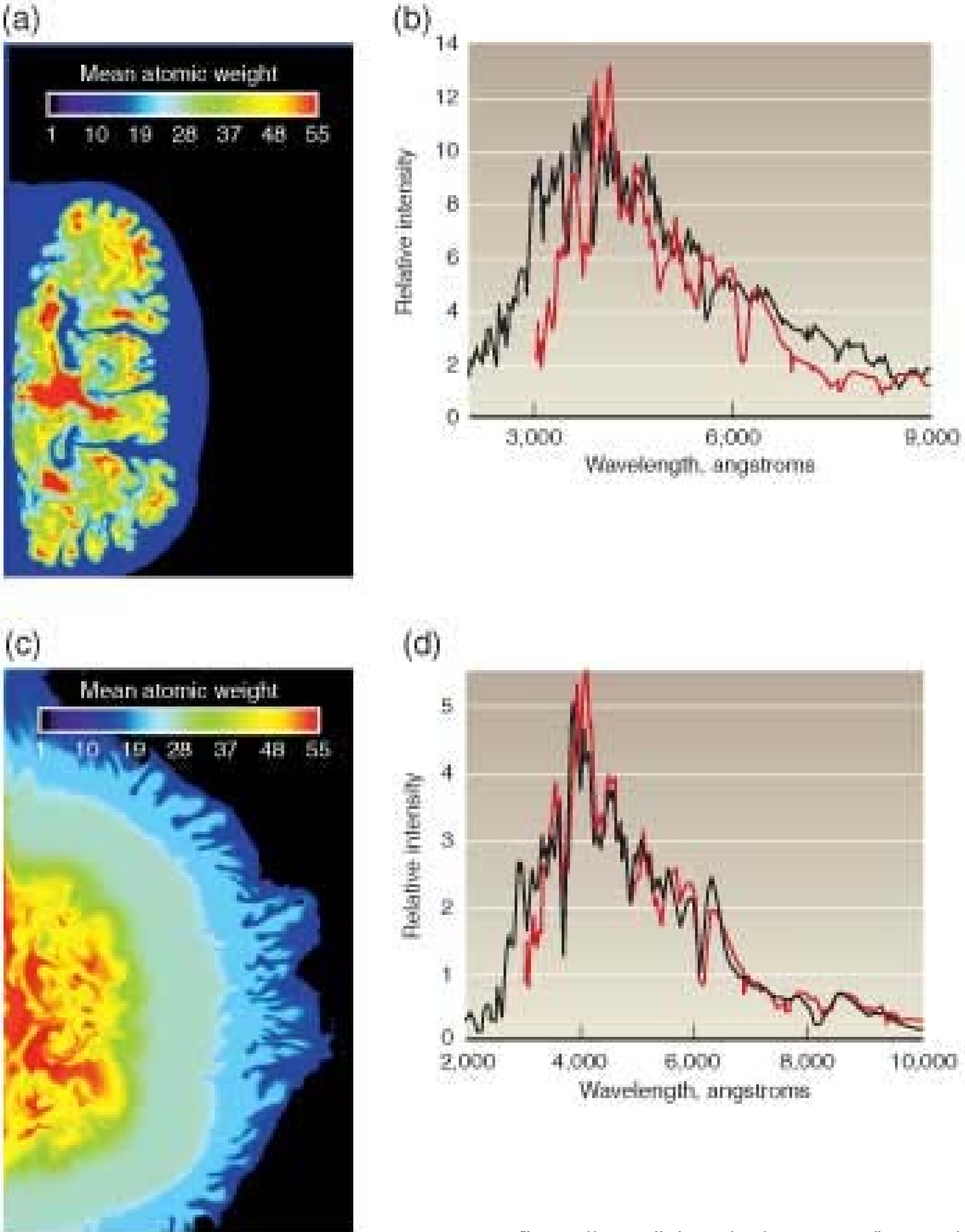


[Turatto (2003)]



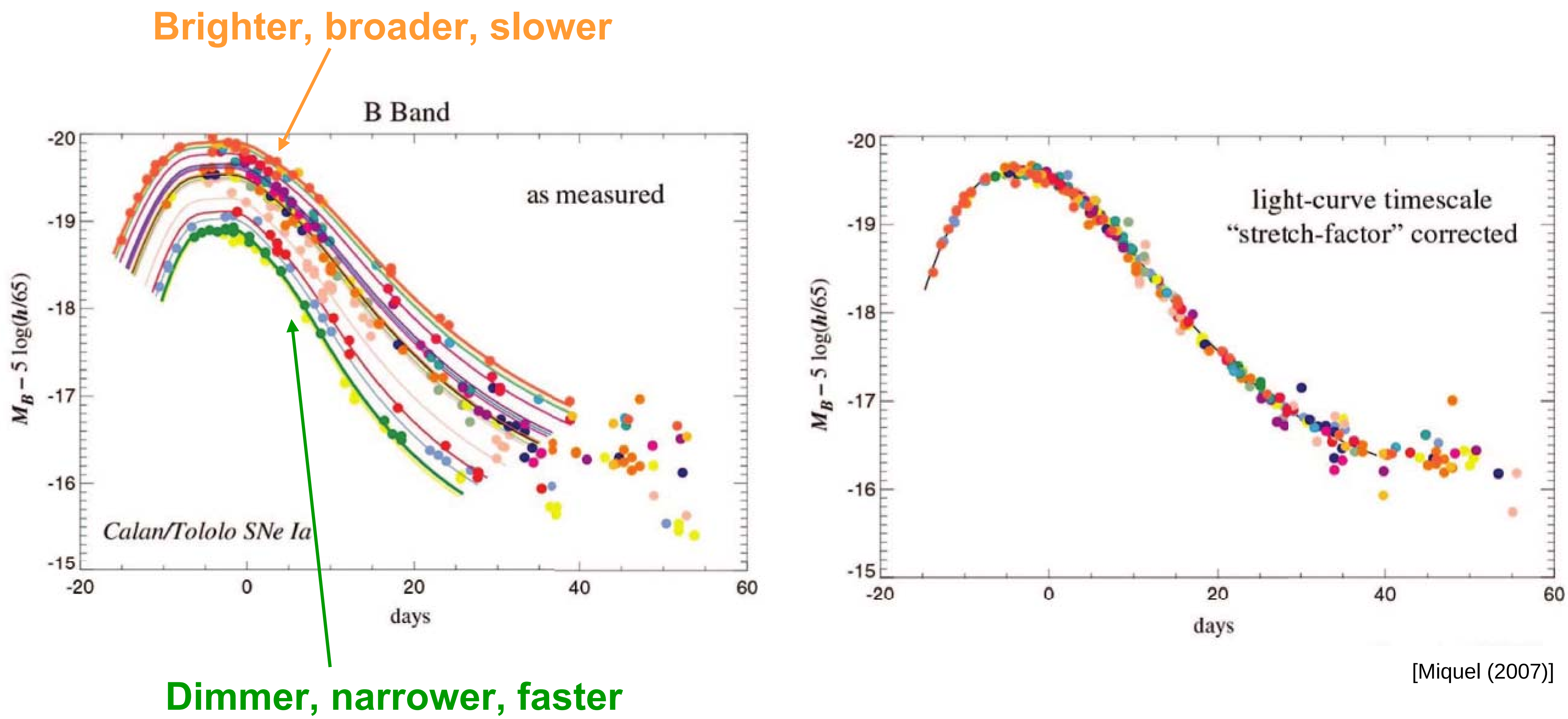
The color of supernova light evolves over time. These graphs compare the evolution of a **brighter** supernova with more nickel (**black line**) and a **dimmer** supernova with less nickel (**red line**). (a) At Day 0, both simulated supernovae have similar spectra. (b) By Day 15, light has shifted from the blue to red wavelengths as the supernovae expand and cool. In the dimmer supernova, this process happens more quickly and is responsible for the observed rapid decline of its light curve with time and hence the width–luminosity relationship.

[https://www.llnl.gov/str/SepOct08/images/supernova4.jpg]



(a) In this simulation, flames consuming a white dwarf remain **subsonic** throughout the explosion, exhibiting a dim supernova light curve. The nuclear burning produces a distribution of elements color-coded here by atomic weight (for example, blue is carbon and oxygen, green is silicon, and red is nickel). (b) The **simulated spectrum (black line)** reveals atypical features when compared with the **spectrum observed** in SN 1994D (**red line**). (c) When the **turbulence** is adjusted on the same model, the flame transitions to **supersonic** speeds after an initial subsonic explosion. This supernova produces 2.5 times more nickel, and hence, its brightness is much greater. (d) The spectrum of this **simulated** delayed detonation (**black line**) compares well to features **observed** in SN 1994D (**red line**).]

[https://www.llnl.gov/str/SepOct08/images/supernova5.jpg]



[Miquel (2007)]

Fitting (standardization) methods: Δm_{15}, stretch, MLCS, SALT, SiFTO,…

OVERVIEW OF SURVEYS

1. "CLASSICAL"

HZS (Riess1998)

- Main discovery facilities:
  * telescope: CTIO Blanco 4 m
  * detector: 2048^2 px $\simeq$ 4.2 Mpx prime focus CCD
- Time allocated to survey: 9 total nights during 1995 and 1996
- Photometric follow-up:
  * CTIO Blanco 4m, with redshited filters which best matched rest-frame B and V ones, providing a limiting magnitude $m_R < 23$
- Spectroscopic follow-up:
  * Keck I and II, 10 m, 6$\AA$ FWHM resolution, 3-5$\times$900 s (15 min)
  * MMT, then $\equiv$ 4.5 m (now 6.5 m), 3.5$\AA$ FWHM, 5-7$\times$1200 s (20 min)
  * ESO 3.6 m, 18$\AA$ FWHM, 1$\times$2700 s (45 min)
- # SNe Ia (from the survey itself): 16
- Redshift range: (0.16, 0.97)

SCP (Perlmutter1999)

- Main discovery facilities:
  * telescope: CTIO Blanco 4 m
  * detectors: 2048^2 px $\simeq$ 4.2 Mpx prime focus CCD and $4 \times 2048^2 \simeq$ 16.7 Mpx Big Throughput Camera
- Photometric follow-up:
  * CTIO 4 m, WIYN 3.6 m, ESO 3.6 m, INT 2.5 m, and WHT 4.2 m, with redshifted filters which best matched rest-frame B and V ones
- Spectroscopic follow-up:
  * Keck I and II, 10 m
  * ESO 3.6 m
- # SNe Ia (from the survey itself): 42
- Redshift range: (0.18, 0.83)

2. PRESENT

ESSENCE (Miknaitis2007, Wood-Vasey2007)

Duration: 2002-2008
Main discovery facilities:
  Telescope: CTIO Blanco 4 m
  Detector: Mosaic Imager
Photometric follow-up: V, R, I, z, J
Spectroscopic follow-up:
  Keck 10 m, MMT 6.5 m, Magellan, Gemini 8 m, VLT 8 m
 # SNe Ia observed (published): 60
Redshift range: $0.15<z<0.75$

SNLS (Astier2006)

Duration: May 2003 + 5 yr
Main discovery facilities:
    Telescope: CFHT 3.6 m
    Detector: MegaPrime/MegaCam 36 2048x4612 px (0.3 Gpx)CCDs
Photometric follow-up: r_M, i_M, g_M, z_M
Spectroscopic follow-up:
    ESO VLT (60 h/semester),
    Gemini N and S (60 h/semester),
    Keck I and II (15 nights in total)
 # SNe Ia observed (1st yr): 71
Redshift range: $0.2 < z < 1.0$

SDSS (Frieman2008)

Duration: 1 September to 30 November 2005-2007
Main discovery facilities:
- **Telescope: Apache Point Observatory 2.5 m**
- **Detector: SDSS CCD camera**

Area: 300 sq.deg.
Photometric follow-up: ugriz
Spectroscopic follow-up:
- **Hobby-Eberle Telescope 9.2 m**
- **ESO New Technology Telescope 3.6 m**
- **Apache Point Observatory Telescope 3.5 m**
- **Subaru 8.2 m**
- **Hiltner Telescope 2.4 m (MDM Observatory)**
- **William Herschel Telescope 4.2 m**
- **Kitt Peak National Observatory 4 m**
- **Keck 10 m**
- **Nordic Optical Telescope 2.6 m**
- **South African Large Telescope 11 m**

 # SNe Ia observed (first two 3-month seasons): 300 Sne Ia spectroscopically confirmed, 100 photometrically identified (and with corresponding spectra),
Redshfit range: 0.05< z < 0.35 (intermediate)

CfA (Hicken2009)

Duration: 2001-2008 (8 yr)
Main discovery facilities: 1/3 from amateur and 2/3 from professional astronomers
Photometric follow-up:
- FLWO Telescope 1.2 m (4Shooter, Minicam, Keplercam)
- PAIRITEL telescope 1.3 m (ex-2MASS instument infrared light curve)
- Bands: UBVRIr'i'; JHK (PAIRITEL robotic)

Spectroscopic follow-up:
- FLWO 1.5 m Tillinghast telescpe (FAST spectrograph)
- MMT 6.5 m telescope (Blue Channel spectrograph)
- Magellan 6.5 m telescopes (MagE, LDSS3, and IMAC spectrographs);

SNe Ia observed: 185
Redshift range: $z<0.08$

3. MISERABLE FUTURE

DES:

Duration: 5 yr
Main telescope: CTIO Blanco 4 m
Main detector: 0.5 Gpx DECam
Bands: griz,Y
SNe Ia expected:2000
Redshift range: $0.3 < z < 0.8$ (high)

Pan-STARRS:

Main telescopes: 4 x 1.8 m telescopes
Main detectors: 4 x 1.4 Gpx camera
Bands: griz, Y
SNe Ia expected: 5000 Sne Ia per year

LSST:

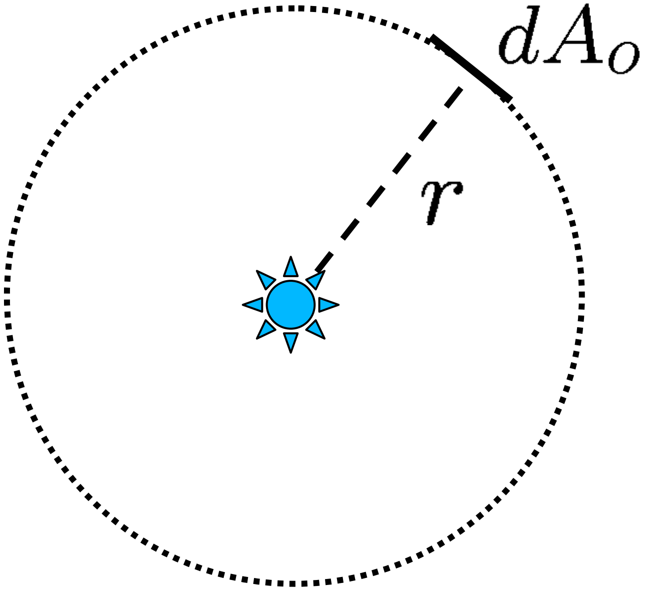
Duration: 10 yr
Main telescope: 8.4 m (Cerro Pachon)
Main detector: 3.2 Gpx camera
Bands: ugrizy (320-1050 nm)
SNe Ia expected: 10^6 per year from main survey; 10^4 from “mini-survey” with z>1

JDEM/Euclid:

Duration: 6-7 yr
Main telescope: space-borne 1.5 m
Main detector: visible CCD and NIR instrument
SNe Ia expected: 1000
Redshift range: 0.3 < z < 1.2
“Need ground data for low redshift SNe”

K CORRECTION

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1-Kr^2} + r^2 d\ell^2_{S^2}\right] \qquad 1+z = \frac{\lambda_o}{\lambda_e}$$



$$dE_e = L_\lambda(\lambda_e)\, dt_e\, d\lambda_e$$

$$dE_o = f_\lambda(\lambda_o)\, A_o\, dt_o\, d\lambda_o$$

conservation of energy

$$f_\lambda(\lambda_o) = \frac{L_\lambda(\lambda_e)}{(1+z)^2 A_o}$$

WRONG

conservation of photon number

$$f_\lambda(\lambda_o) = \frac{L_\lambda(\lambda_e)}{(1+z)^3 A_o}$$

$$f = \frac{L}{(1+z)^2 A_o} \qquad A_o = 4\pi a_o^2 r^2$$

$$D_L := \sqrt{\frac{L}{4\pi f}} = a_o(1+z)r$$

$$f_X = \frac{L_{\bar{X}}}{4\pi D_L^2}$$

$$\Updownarrow$$

$$m_X - M_X = \underbrace{5\log_{10}\left(\frac{D_L}{10\ \mathrm{pc}}\right)}_{=:\ \mu} + K_{XX}$$

Generalized K correction:

$$K_{QR} := m_R - M_Q - \mu$$

↓

$$K_{QR}(z) = -2.5\,\log_{10}\left[\frac{\int d\lambda L_\lambda(\lambda) S_\lambda^R(\lambda[1+z])}{\int d\lambda L_\lambda(\lambda) S_\lambda^Q(\lambda)} \quad \frac{g_Q}{g_R}\right]$$

PRACTICAL CONSEQUENCE (Davis2006):

"The most important feature of a complete filter set for type Ia supernova cosmology is that each bandpass be a redshifted copy of the first."

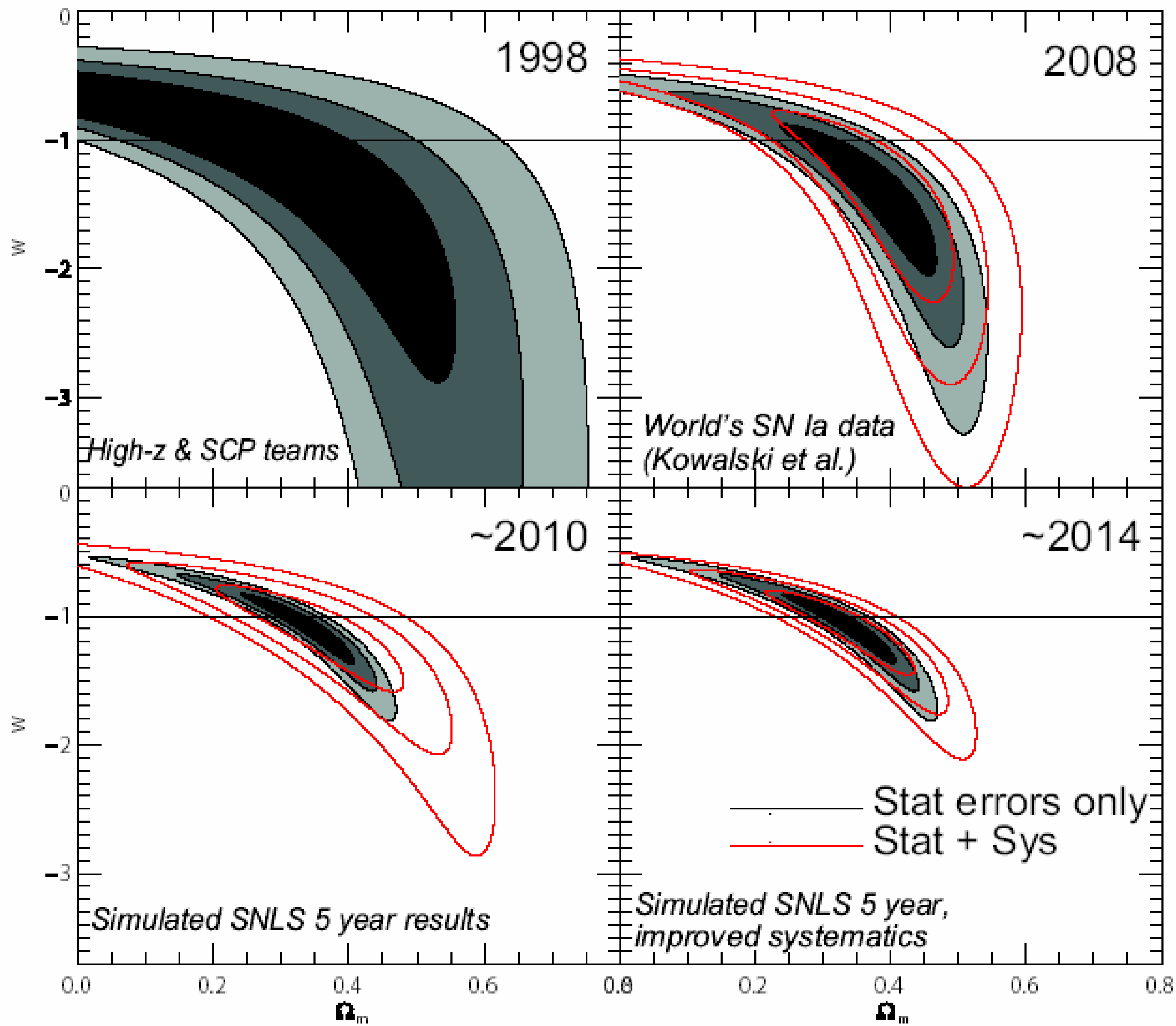
TUNABLE FILTER!!!!!!!!!

FINAL REMARKS

TABLE 1
CURRENT ESTIMATES OF SYSTEMATIC ERRORS ON W

Systematic	SNLS	ESSENCE	SDSS
Flux reference	0.053	0.02	0.037
Experiment zero points	0.01	0.04	0.014
Low-z photometry	0.02	0.005	···
Landolt bandpasses	0.01	···	0.019
Local flows	0.014	···	0.04
Experiment bandpasses	0.01	···	0.014
Malmquist bias model	0.01	0.02	0.017
Dust/Color-luminosity (β)	0.02	0.08	0.017
SN Ia Evolution	···	0.02	···
Restframe U band	···	···	0.08

[Howell2009]


1998
2008
~2010
~2014
High-z & SCP teams
World's SN Ia data
(Kowalski et al.)
Simulated SNLS 5 year results
Simulated SNLS 5 year,
improved systematics
Stat errors only
Stat + Sys
w
Ω
0
−1
−2
−3
0.0
0.2
0.4
0.6
0.8

[Howell2009]

Importance of:

- **low-redshift data**
- **follow-up resources (BTFI; robotic)**
- **small telescopes**
- **rest-frame UV and NIR studies**
- **simulation of new surveys (LSST; Euclid; JDEM)**

- **K-correction**
- **extinction/reddening**
- **reference flux/zero point calibration**
- **systematic comparison of different fitting methods**

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