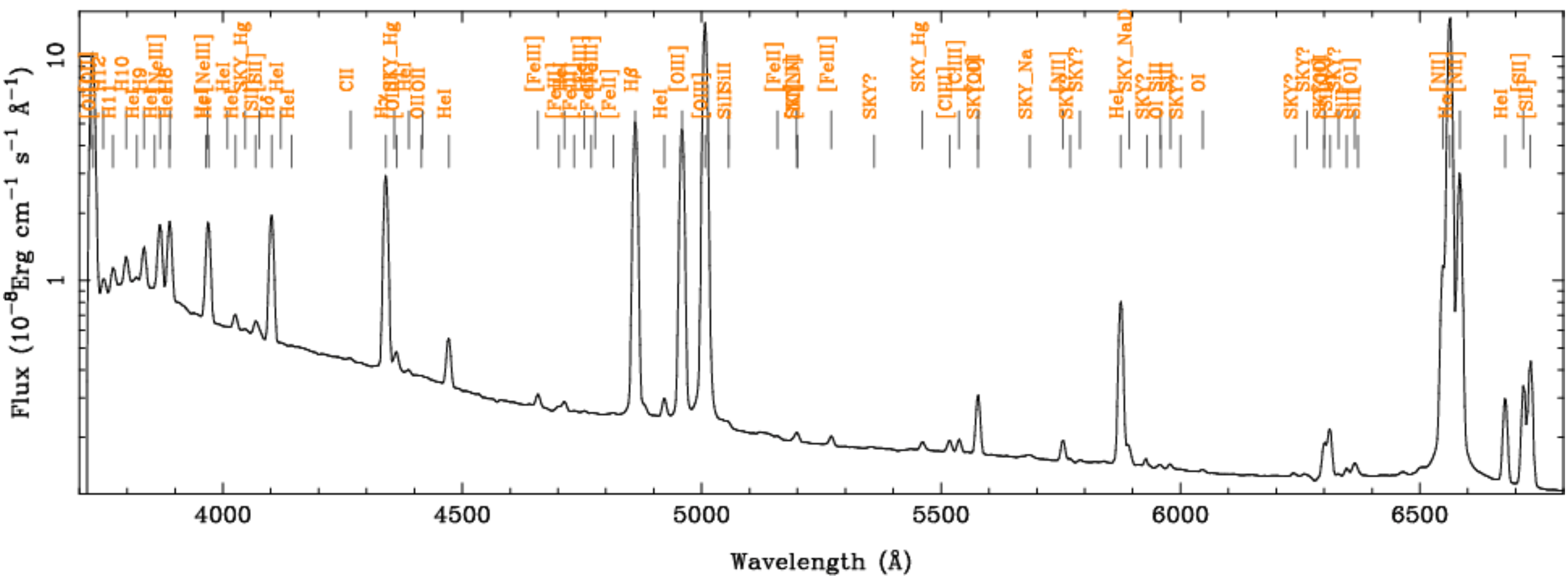
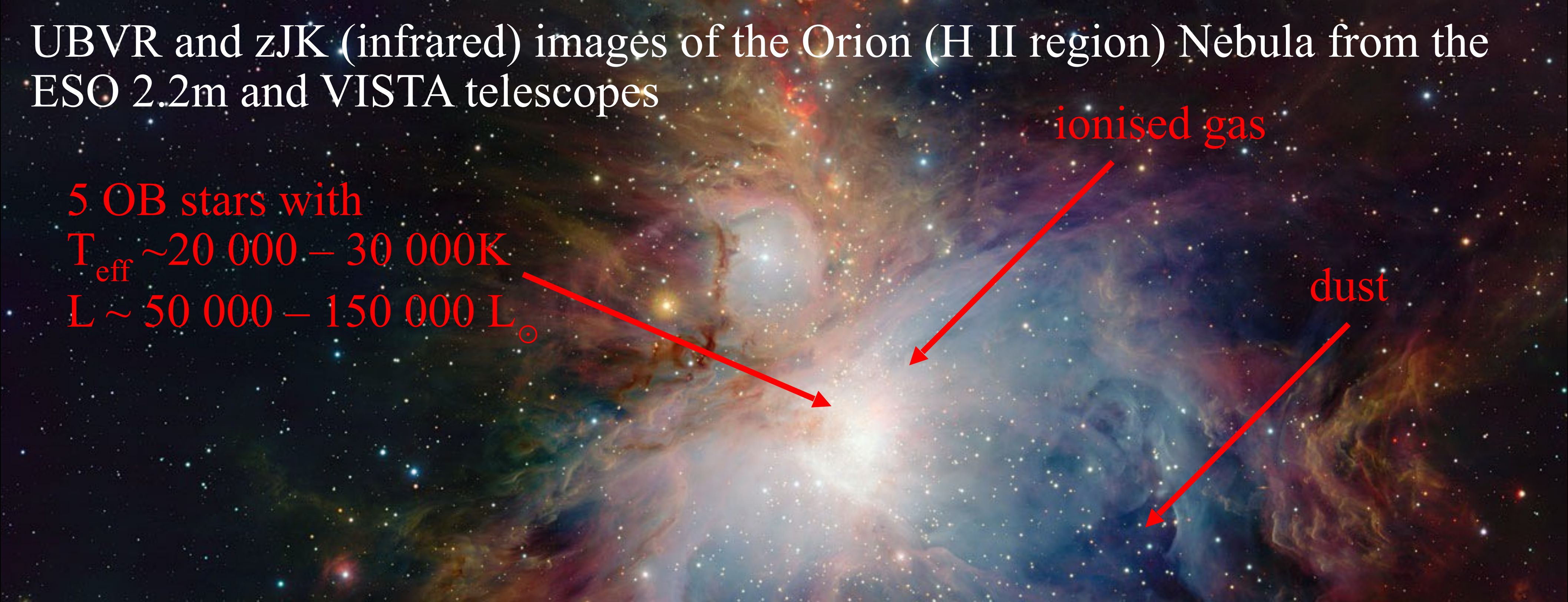
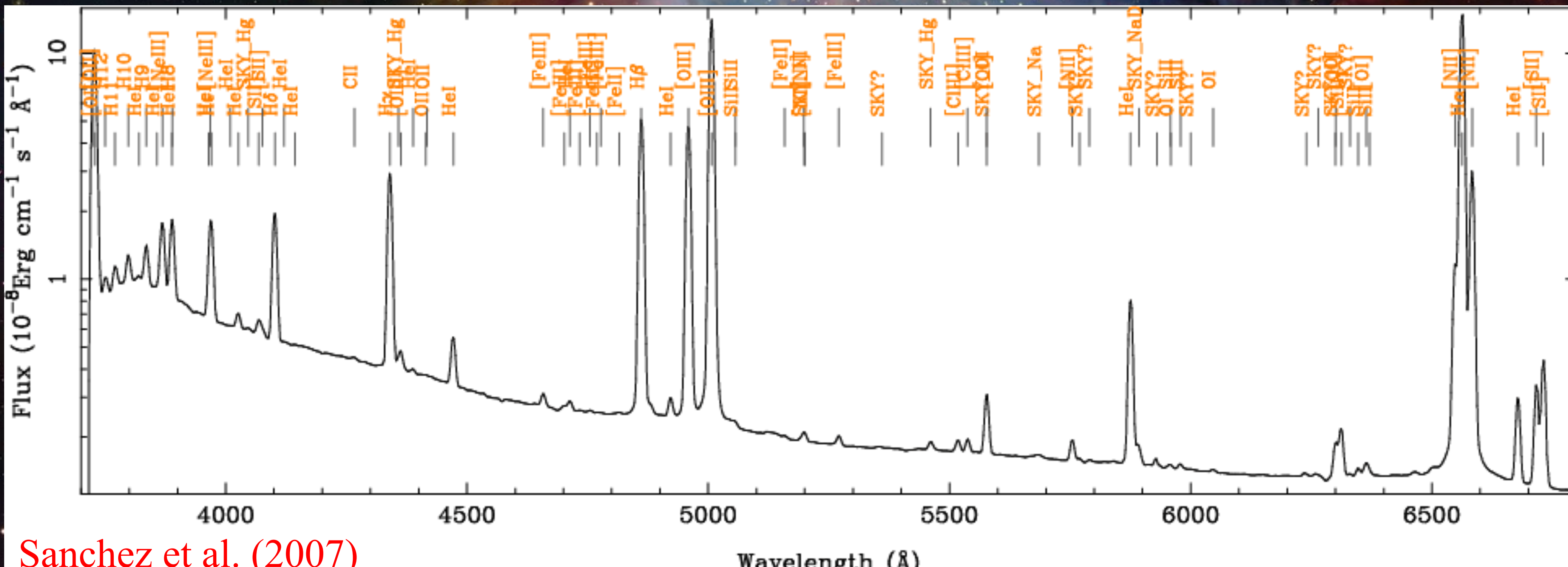
Astronomical spectroscopy

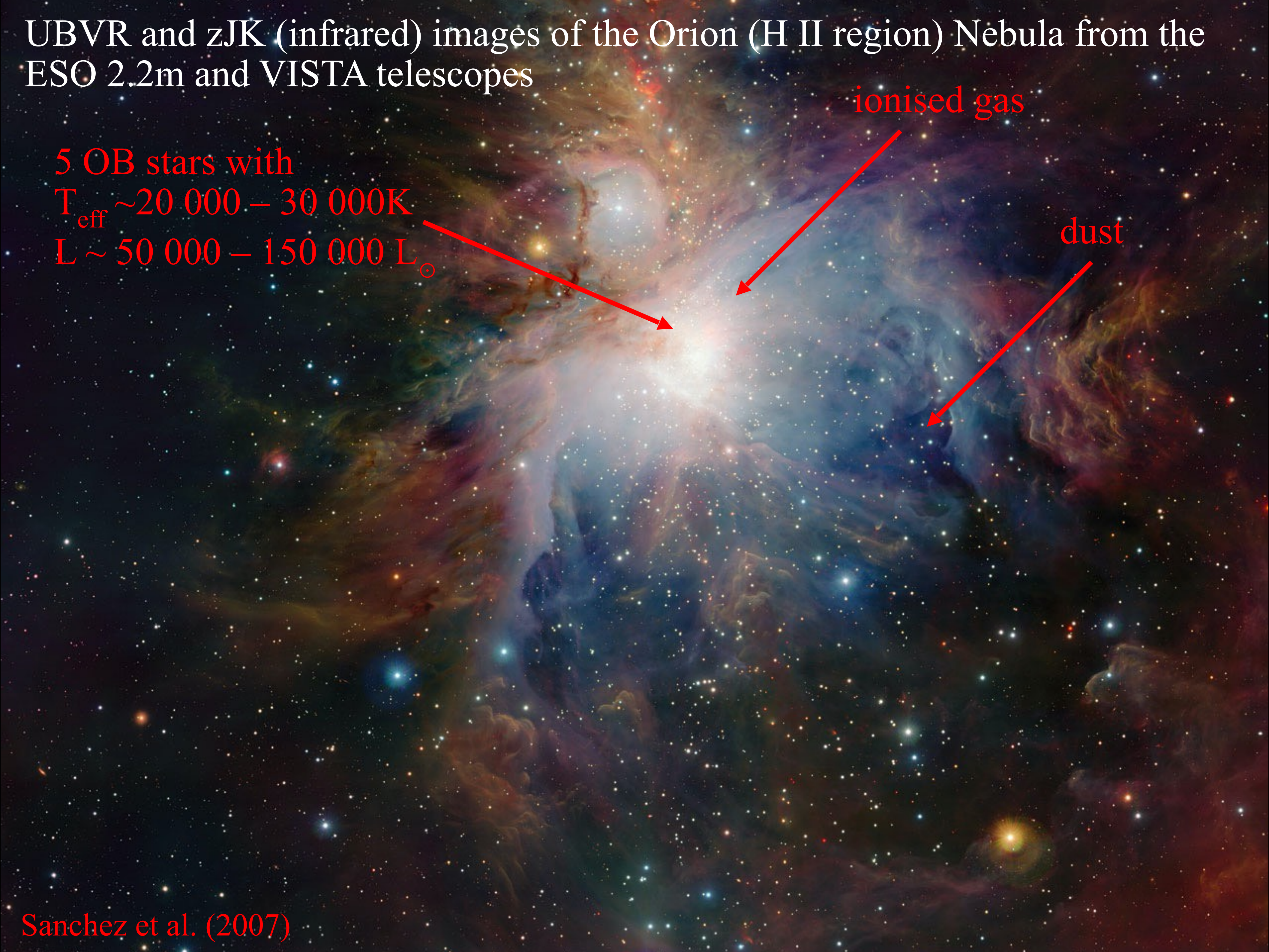
Seppo Mattila







Sanchez et al. (2007)



UBVR and zJK (infrared) images of the Orion (H II region) Nebula from the ESO 2.2m and VISTA telescopes
ionised gas
5 OB stars with
T_{eff} ~20 000 – 30 000K
L ~ 50 000 – 150 000 $L_\odot$
dust
Sanchez et al. (2007)

Wavelength Lab. (Å)	Wavelength Obs. (Å)	Flux[1]	Line Id.	Wavelength Lab. (Å)	Wavelength Obs. (Å)	Flux	Line Id.
3726.03*	3724.94	35219.70	[OII]	5006.84*	5006.99	143002.31	[OIII]
3728.82*	3730.08	40670.09	[OII]	5056.02	5055.80	35.09	SiII
3750.15	3751.09	676.63	H12	5056.35	5056.35	39.79	SiII
3770.63	3771.25	1574.32	H11	5158.81	5157.92	52.29	[FeII]
3797.90	3798.18	2550.31	H10	5197.90	5195.79	25.86	[NI]
3819.64	3819.54	876.94	HeI3819	5199.00	5199.49	76.77	SKY_NI
3835.39	3835.15	3391.71	H9	5200.26	5201.02	142.51	[NI]
3857.53	3853.55	561.27	HeI	5270.40	5270.64	171.06	[FeIII]
3868.75	3868.59	8266.59	[NeIII]	5360.00	5359.94	6.06	SKY?
3888.65	3887.97	4416.27	HeI	5461.00	5461.07	215.29	SKY_HgI
3889.05	3890.22	3957.53	H8	5517.71	5517.71	284.96	[ClIII]
3964.73	3967.69	3634.16	HeI	5537.88	5537.89	281.24	[ClIII]
3967.46	3968.09	642.14	[NeIII]	5577.00	5576.40	789.97	SKY_OI
3970.07	3969.20	5478.41	$H\epsilon$	5577.31	5578.10	791.73	[OI]
4009.27	4007.41	318.24	HeI	5685.00	5684.97	118.17	SKY_NaI
4026.21	4026.00	722.02	HeI	5754.64*	5754.66	400.01	[NII]
4046.00	4046.02	32.09	SKY_HgI	5770.00	5769.91	15.66	SKY?
4068.60	4068.39	458.02	[SII]	5790.00	5790.04	1.16	SKY?
4076.35	4074.88	159.72	[SII]	5875.62	5875.56	7538.90	HeI
4101.74	4101.56	12021.26	$H\delta$	5893.00	5892.61	348.91	SKY_NaI D
4120.86	4121.23	53.23	HeI	5930.00	5927.95	123.02	SKY?
4143.76	4148.23	23.02	HeI	5957.61	5957.11	41.97	SiII
4267.15	4265.12	85.48	CII	5958.58	5957.49	12.78	OI
4340.47	4340.32	23860.65	$H\gamma$	5978.97	5978.80	81.35	SiII
4358.00	4364.15	113.00	SKY_HgI	6000.00	6000.26	12.91	SKY?
4363.21*	4366.76	831.27	[OIII]	6046.40	6046.57	41.92	OI
4387.93	4379.43	125.13	HeI	6240.00	6239.95	60.97	SKY?
4414.91	4471.37	1937.47	OII	6265.00	6264.91	30.67	SKY?
4416.98	4418.47	62.93	OII	6300.00	6299.33	297.01	SKY_OI
4471.50	4412.41	97.99	HeI	6300.30	6301.39	362.98	[OI]
4658.10	4658.22	379.59	[FeIII]	6312.10	6312.27	950.13	[SIII]
4701.62	4701.26	123.43	[FeIII]	6330.00	6329.99	46.28	SKY?
4713.20	4713.36	279.38	HeI	6347.09	6347.30	141.11	SiII
4733.93	4735.80	40.15	[FeIII]	6363.78	6363.72	208.24	[OI]
4754.83	4755.52	62.28	[FeIII]	6370.36	6370.53	107.90	SiII
4769.60	4775.10	62.48	[FeIII]	6548.03*	6547.63	10743.11	[NII]
4777.88	4783.04	29.99	[FeIII]	6562.82*	6562.87	171573.70	$H\alpha$
4815.55	4815.82	82.38	[FeII]	6583.41*	6583.52	32494.66	[NII]
4861.33*	4861.41	50768.69	$H\beta$	6678.15*	6678.37	1907.79	HeI6678
4921.93	4922.20	201.94	HeI	6716.39	6716.47*	2354.08	[SII]
4958.91*	4959.02	47337.07	[OIII]	6730.85*	6731.27	3447.13	[SII]

[1] 10^{-11} Erg cm^{-2} s^{-1}

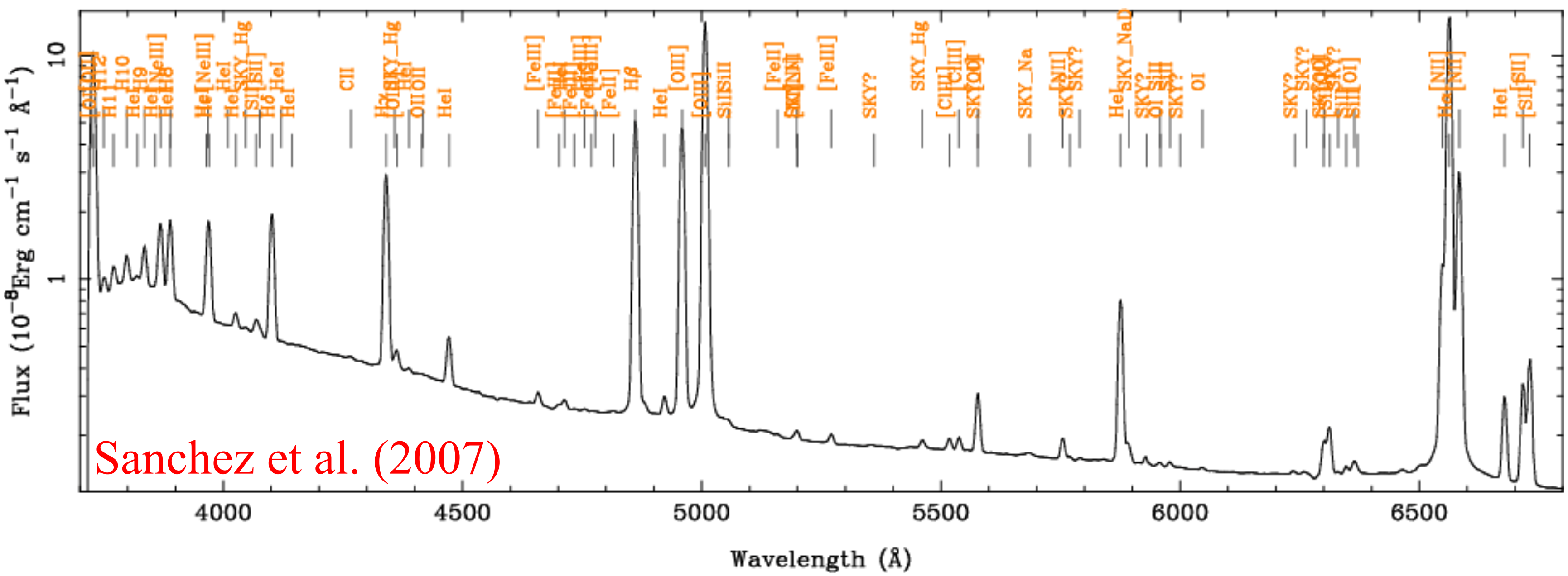
Sanchez et al. (2007)

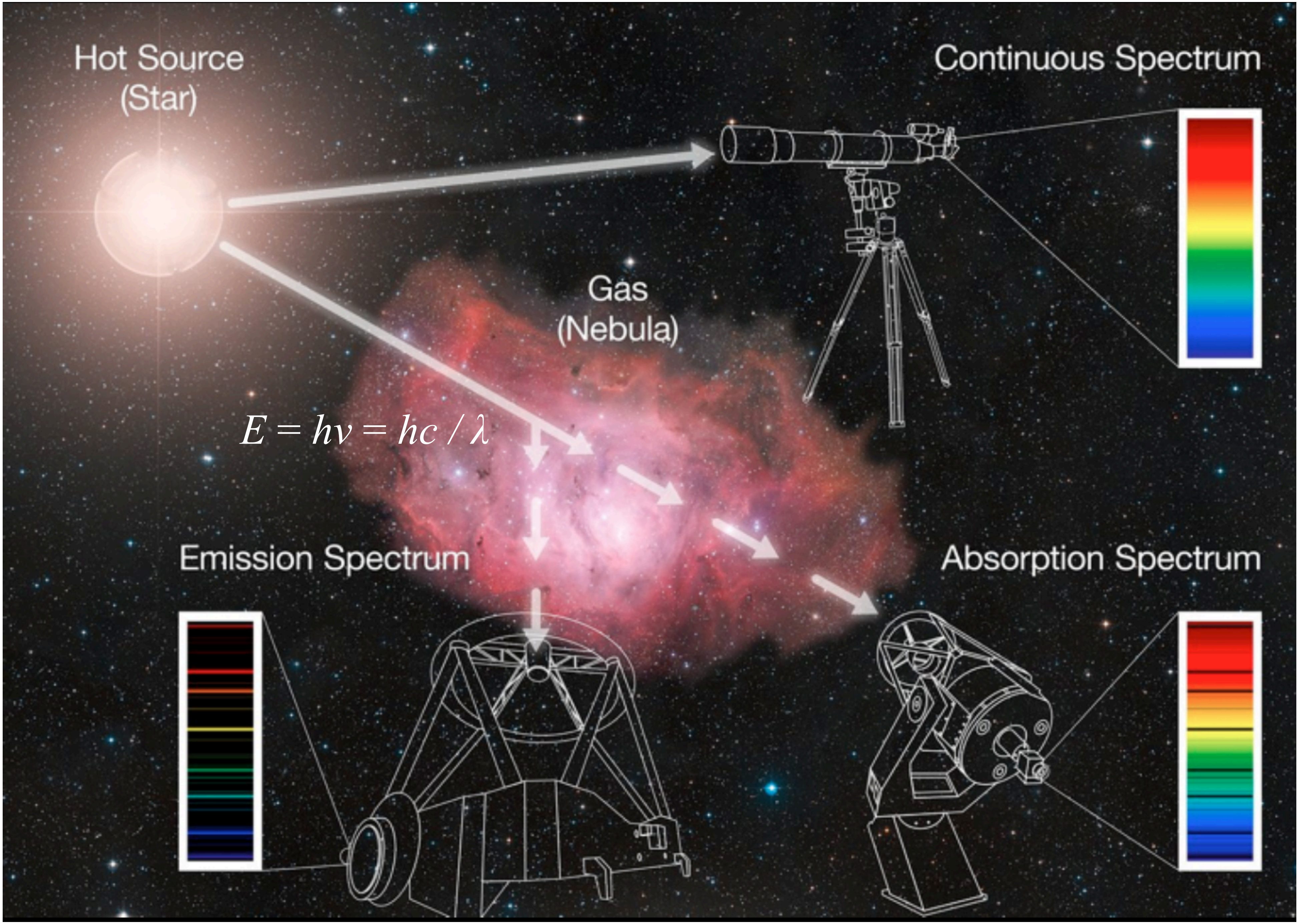
1 Å = 10^{-10} m

Introduction

"A spectrum is worth a thousand images"

- Spectroscopy probably the most important method for learning about the physics of astrophysical objects:
  - Densities, temperature, elemental abundances, motions, magnetic fields, geometry of the emitting region ...
- To interpret a spectrum one needs considerable knowledge of atomic and molecular physics (available from quantum mechanics and lab. studies):
  - The energy levels, intrinsic line strengths and rest wavelengths of the transitions for each atom, ion or molecule, ionisation energies etc.

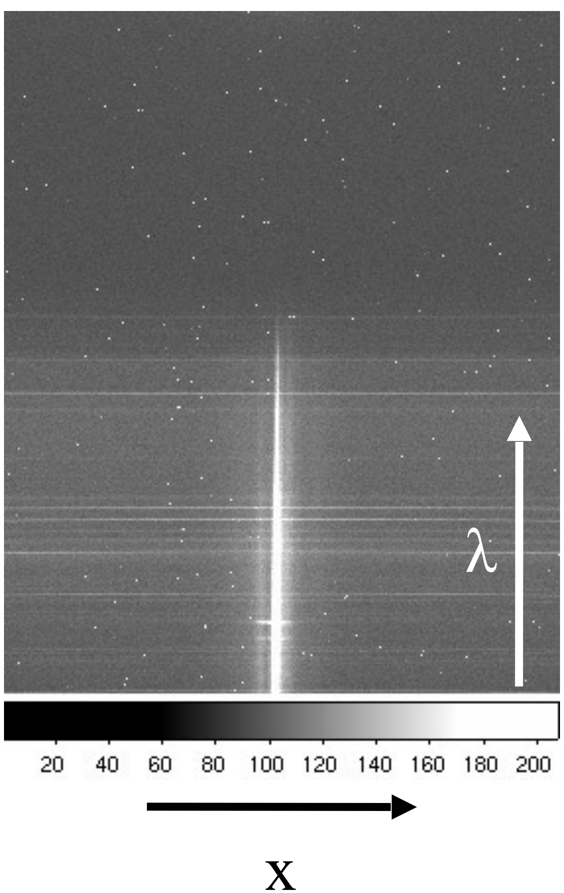


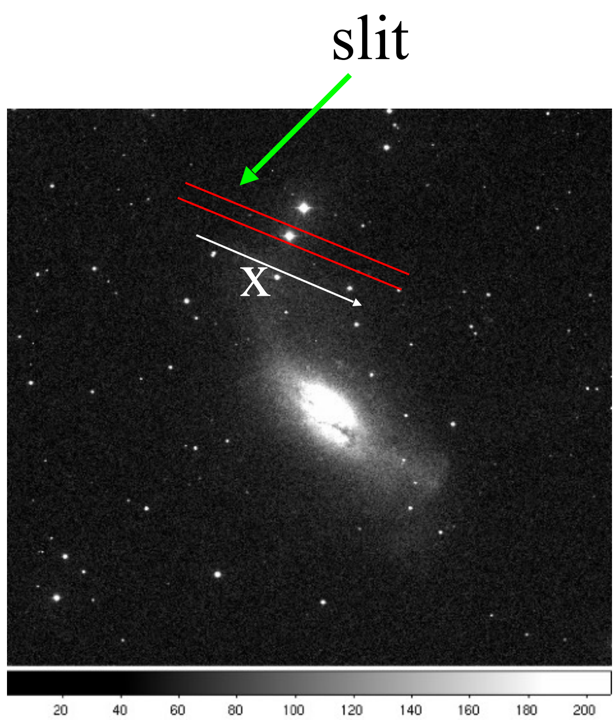


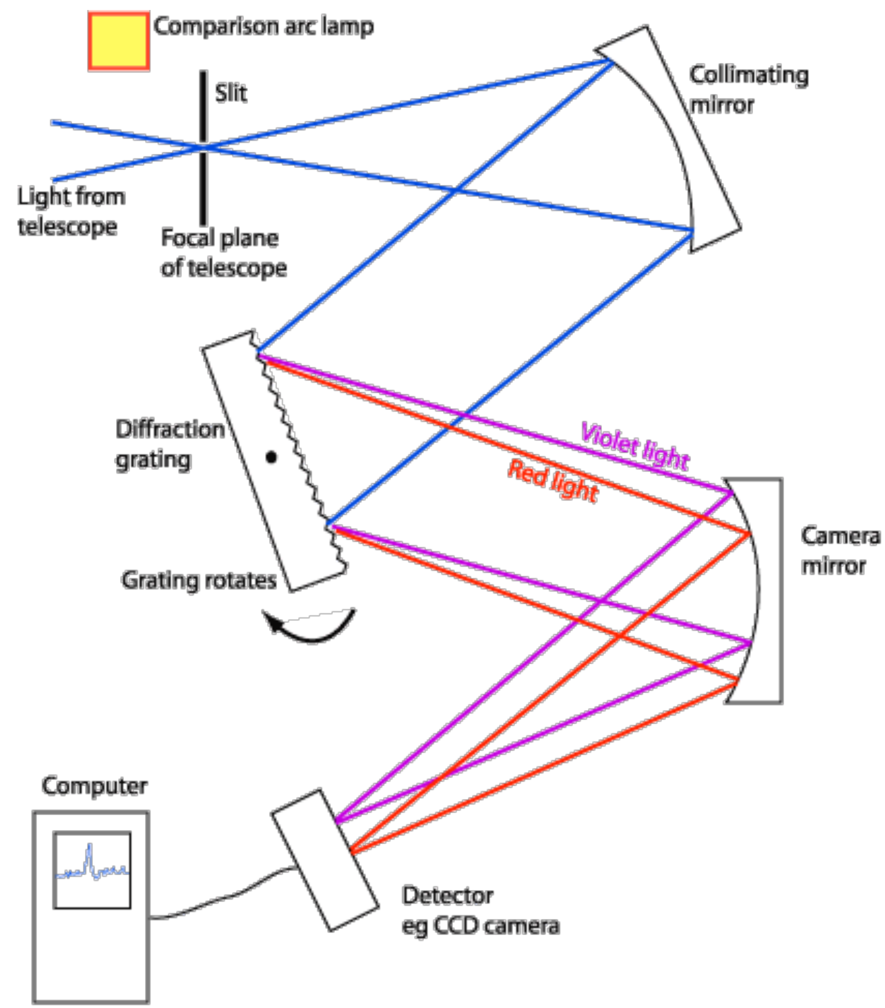
Hot Source
(Star)
Continuous Spectrum
Gas
(Nebula)
$E = h\nu = hc / \lambda$
Emission Spectrum
Absorption Spectrum

Spectroscopic observations

• Determine the flux density as a function of wavelength (spectral energy distribution, spectral lines, physical conditions, velocities etc.)
• Use a mask with a narrow aperture (slit) to cut the 2D image to 1D
• Use a diffraction grating (or a grism) to disperse the incident light beam into spectrum
• Spectrographs use an imaging device (CCD) to record the dispersed light







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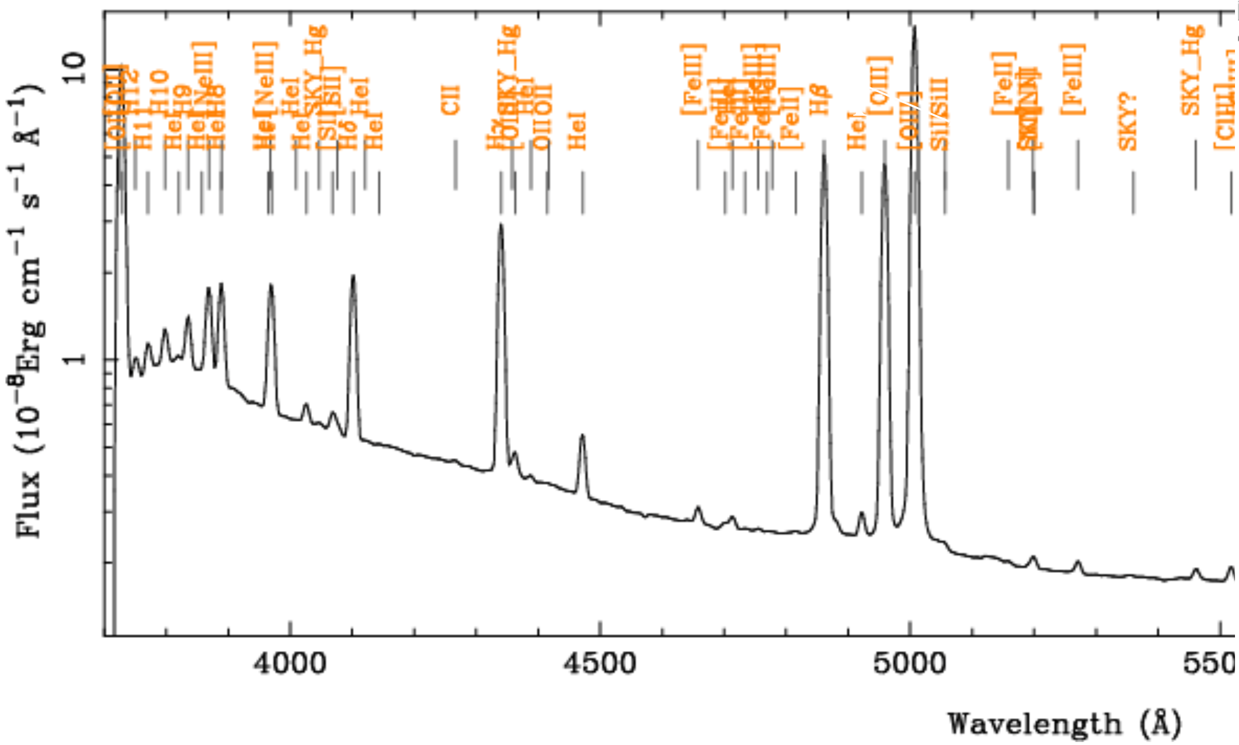
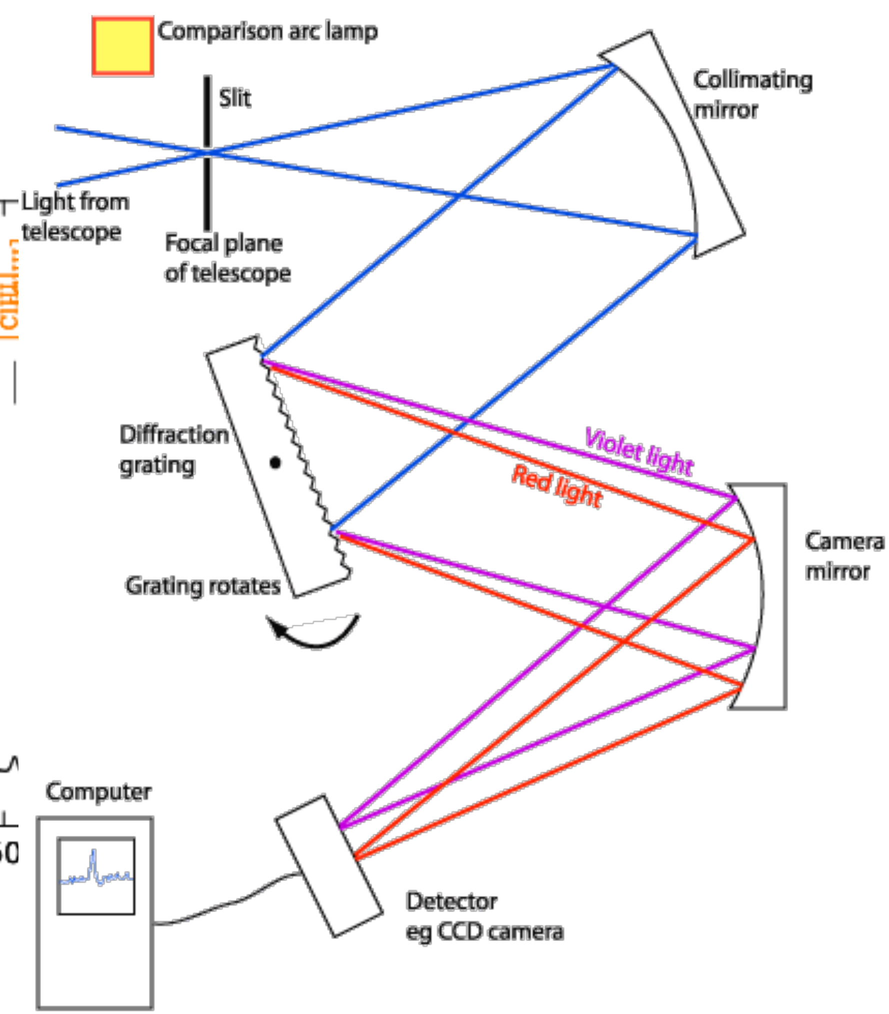
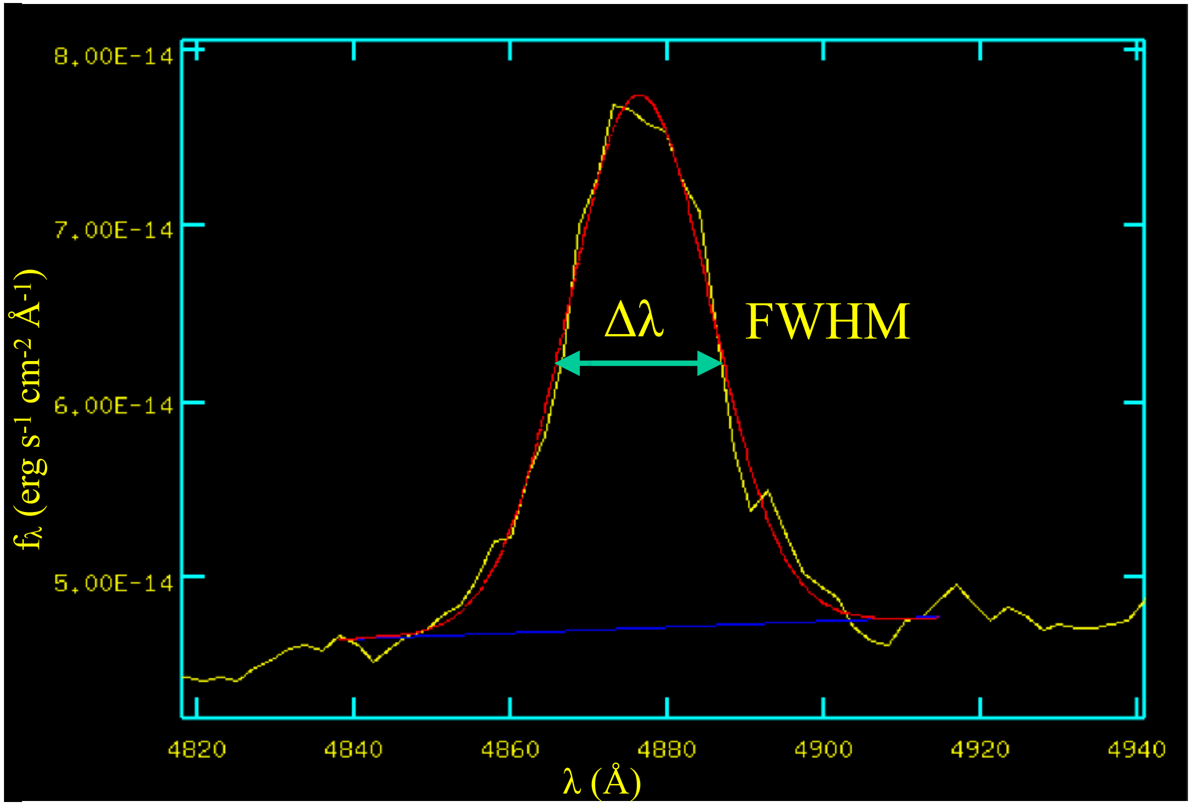




Spectroscopic observations

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

- Resolving power of a spectrograph R = λ/Δλ
  - Low resolution R = 500, at 650 nm Δλ = 1.3 nm (600 km/s)
  - Medium resolution R = 5000, at 650 nm Δλ = 0.13 nm (60 km/s)
  - High resolution R = 50 000, at 650 nm Δλ = 0.013nm (6 km/s)



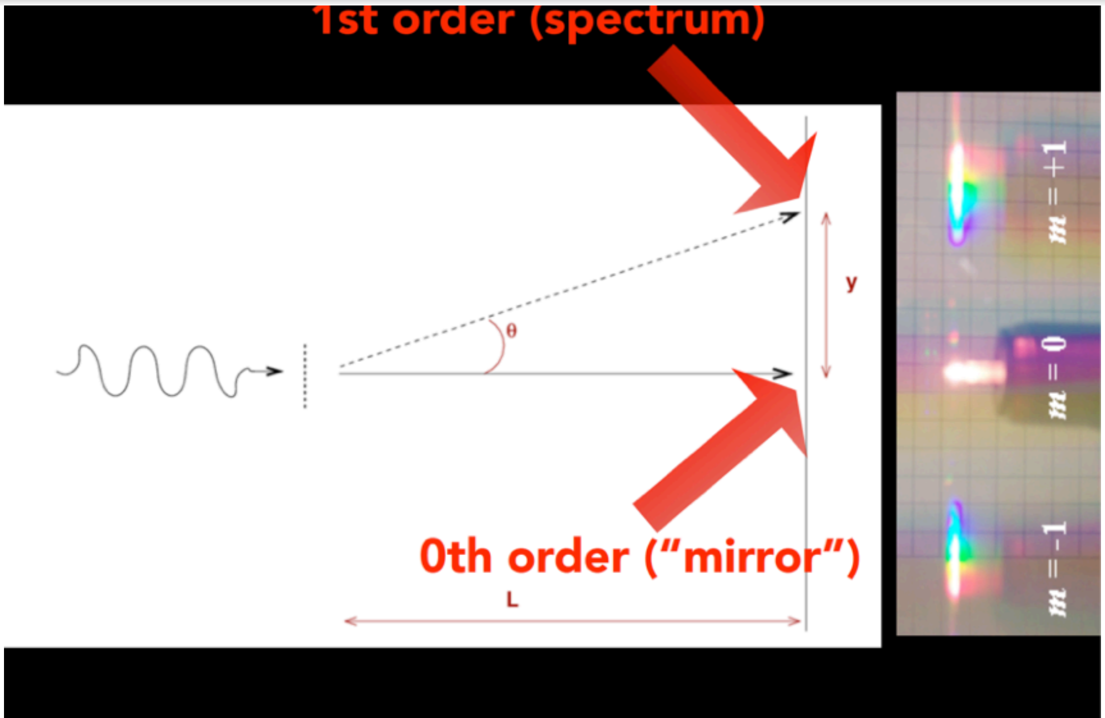
Spectroscopic observations

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

- Resolving power of a spectrograph R = $\lambda/\Delta\lambda$
  - Low resolution R = 500, at 650 nm $\Delta\lambda$ = 1.3 nm (600 km/s)
  - Medium resolution R = 5000, at 650 nm $\Delta\lambda$ = 0.13 nm (60 km/s)
  - High resolution R = 50 000, at 650 nm $\Delta\lambda$ = 0.013nm (6 km/s)
- Dispersion of a spectrograph given by the grating equation in nm/mm in the focal plane or in nm/pixel for the CCD detector

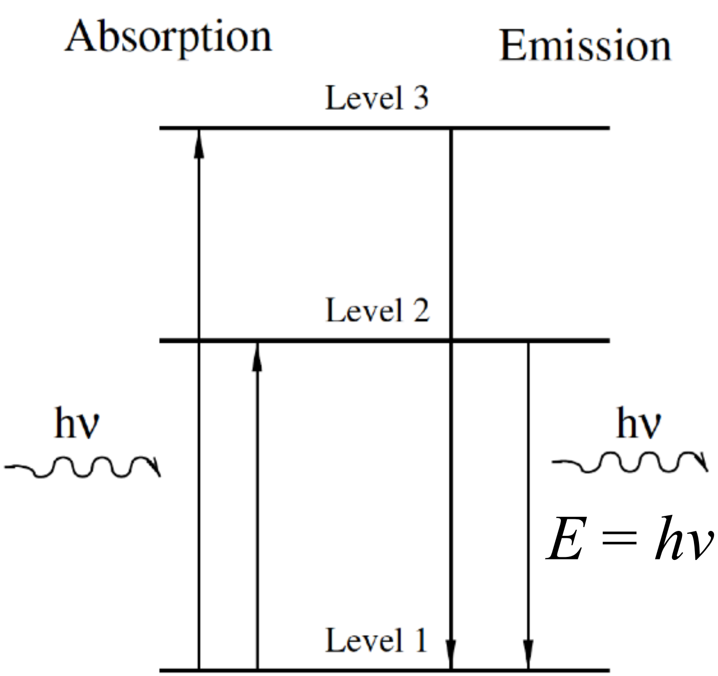
THE GRATING EQUATION

$$d\sin(\theta) \quad = \quad m\lambda \qquad , \qquad m = 1, 2, 3, \ldots$$

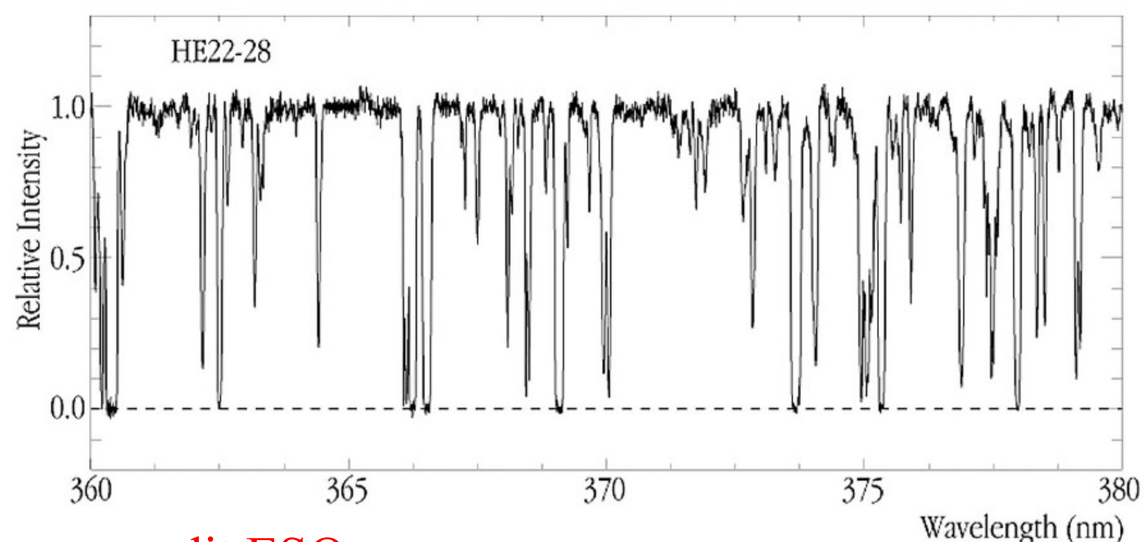


Spectral lines

- Spectral lines observed in either **emission or absorption**
- **Allowed transitions** the 'strongest' (most probable) transitions
  - Satisfy the electric dipole selection rules
  - e.g. recombination lines of hydrogen (Hα, Hβ, Hγ, Hδ etc.)
- **Forbidden transitions** $10^{8\text{-}12}$ times 'weaker' than allowed transitions
  - e.g. the forbidden lines [O II], [O III], [N II], [S II]



$$E = h\nu = hc / \lambda$$



credit ESO

Astronomical redshift

redshift

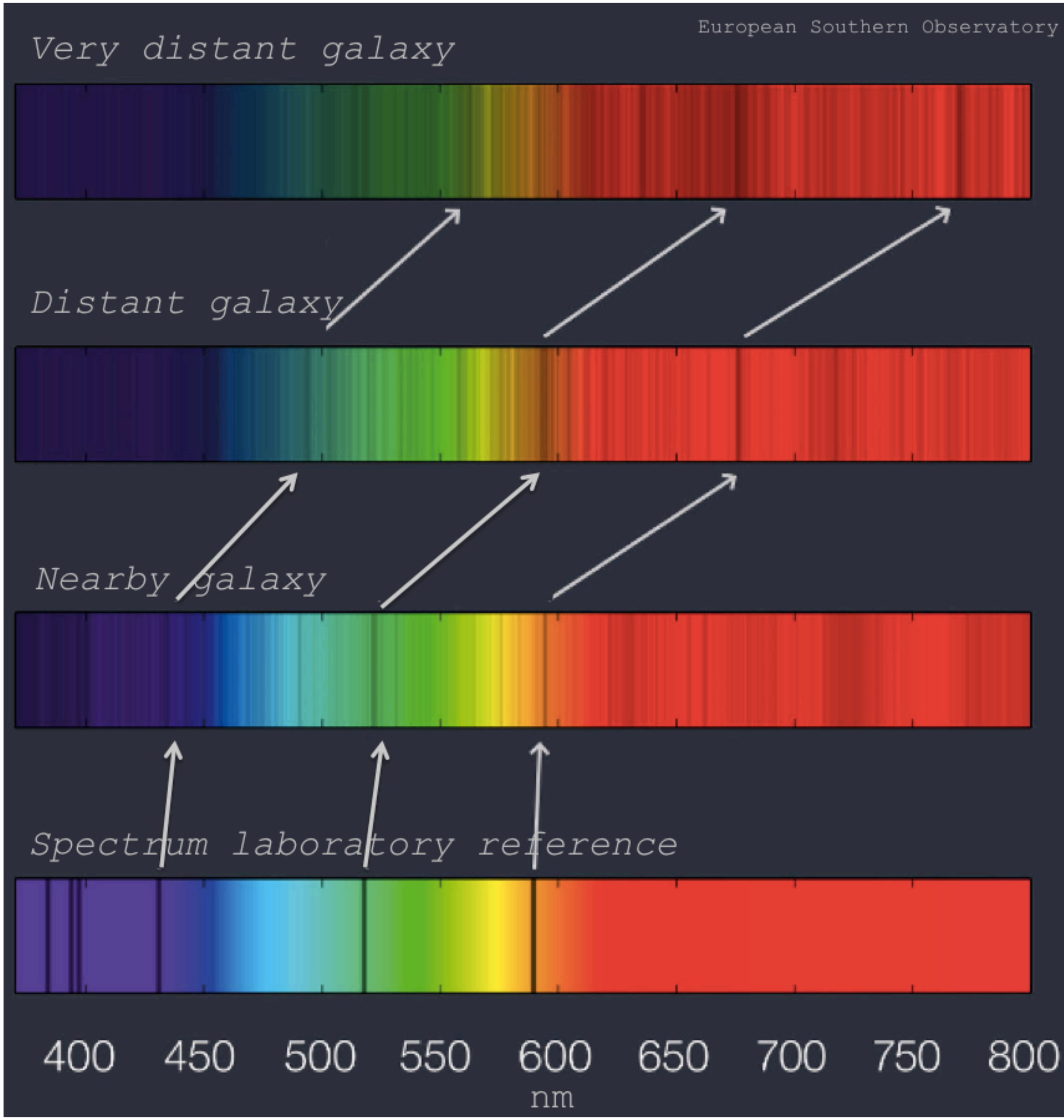
$$z = \frac{\Delta\lambda}{\lambda_{rest}} = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{v}{c}$$

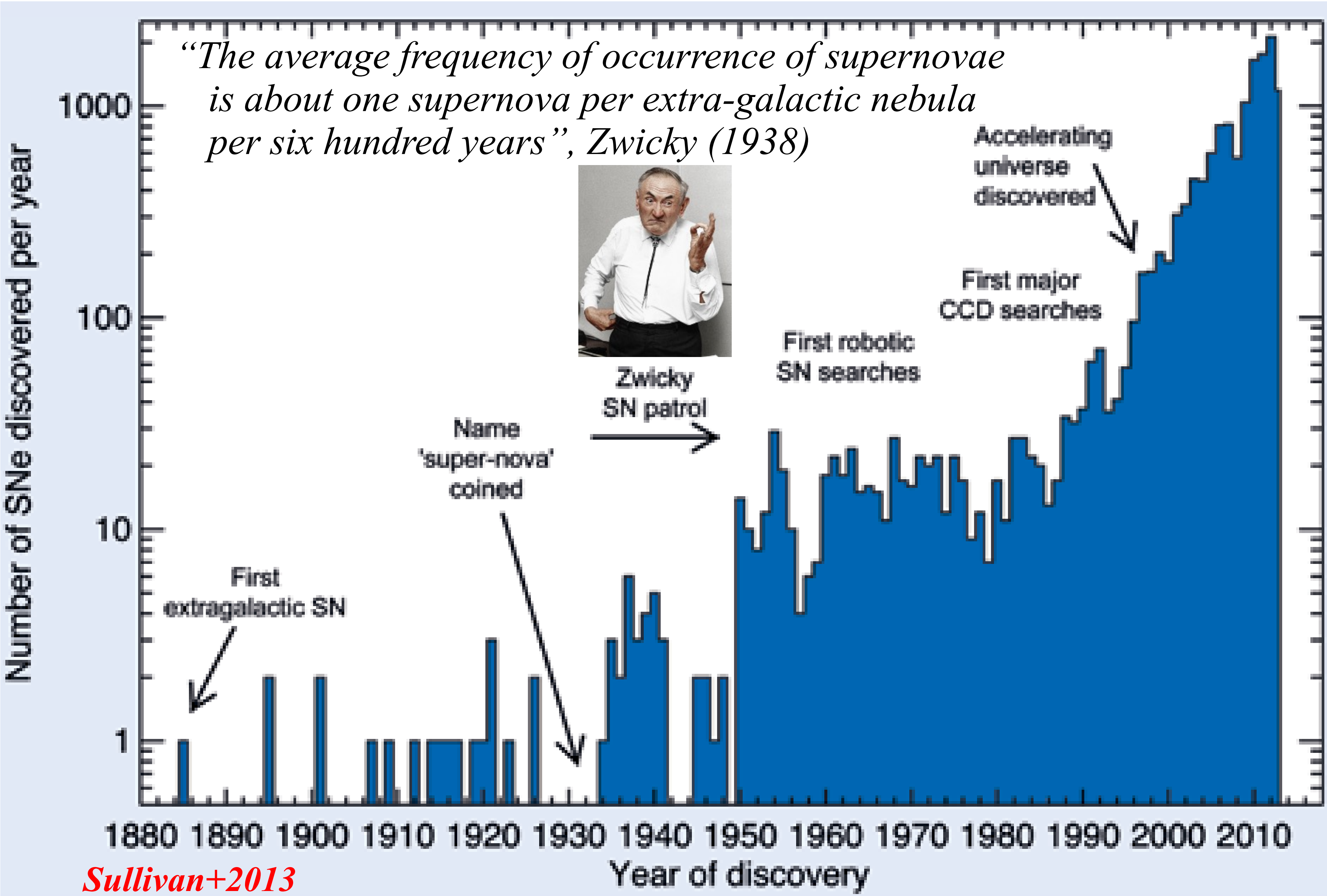
Hubble's law

$v = H_0\, d$

where $H_0 \sim 70$ km s^{-1}/Mpc

z = 0.05 corresponds
to ~214 Mpc ~ 700 Mly





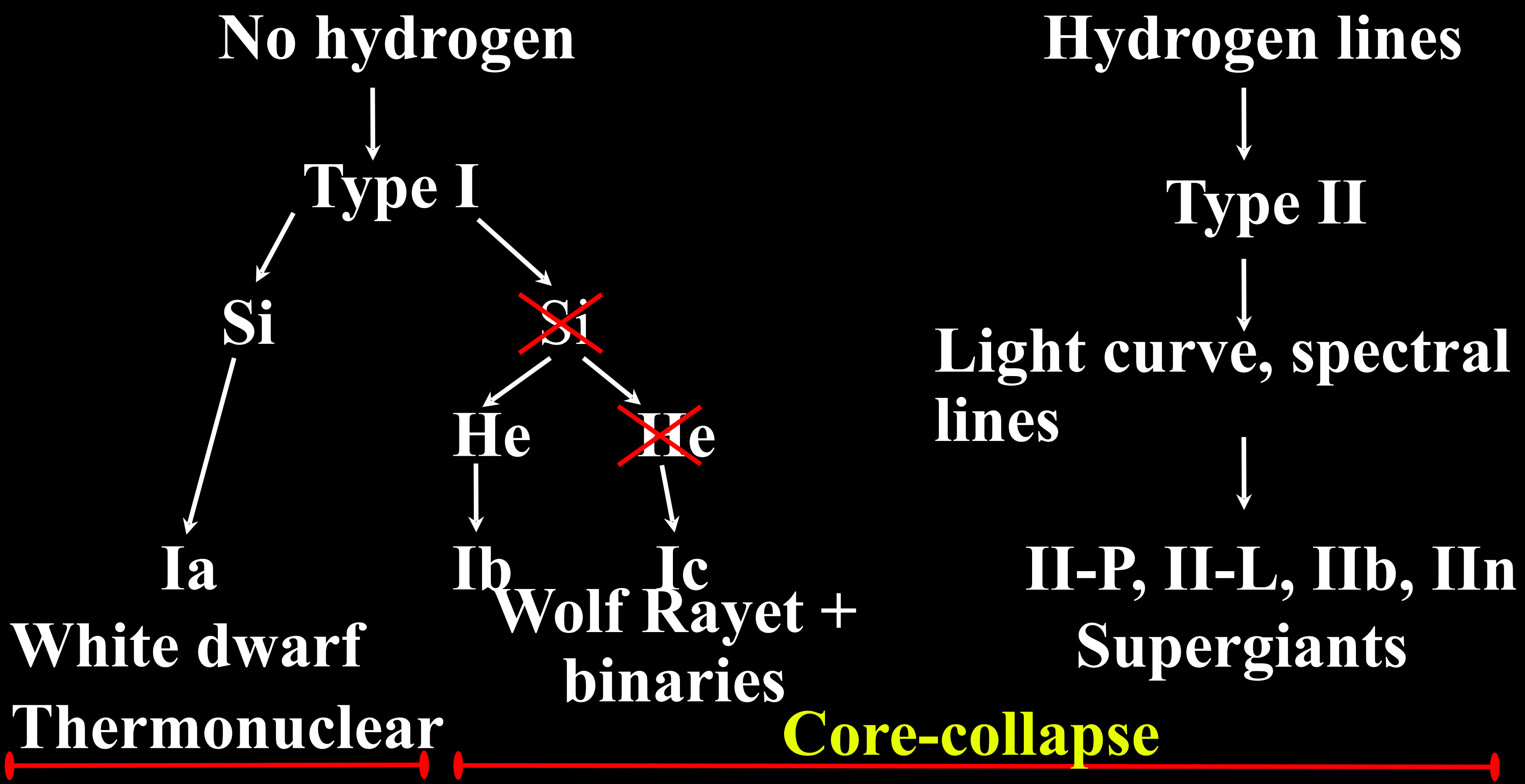
"The average frequency of occurrence of supernovae is about one supernova per extra-galactic nebula per six hundred years", Zwicky (1938)
Number of SNe discovered per year
1000
100
10
1
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year of discovery
First extragalactic SN
Name 'super-nova' coined
Zwicky SN patrol
First robotic SN searches
First major CCD searches
Accelerating universe discovered
Sullivan+2013

Rudolph Minkowski (1895-197

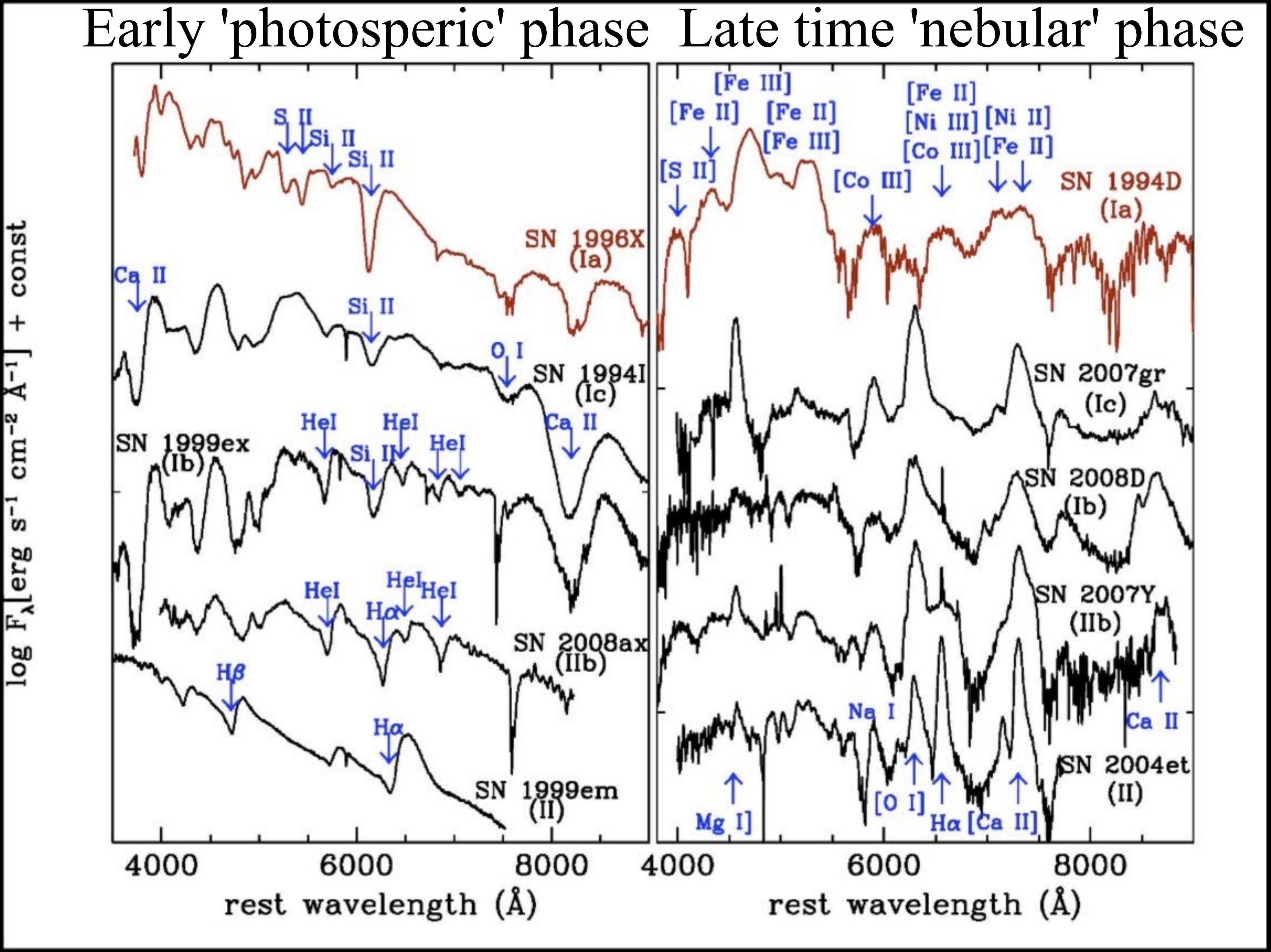
"Spectroscopic observations indicate at least two types of supernovae. Nine objects form an extremely homogeneous group provisionally called type I"

Rudolph Minkowski (1941)

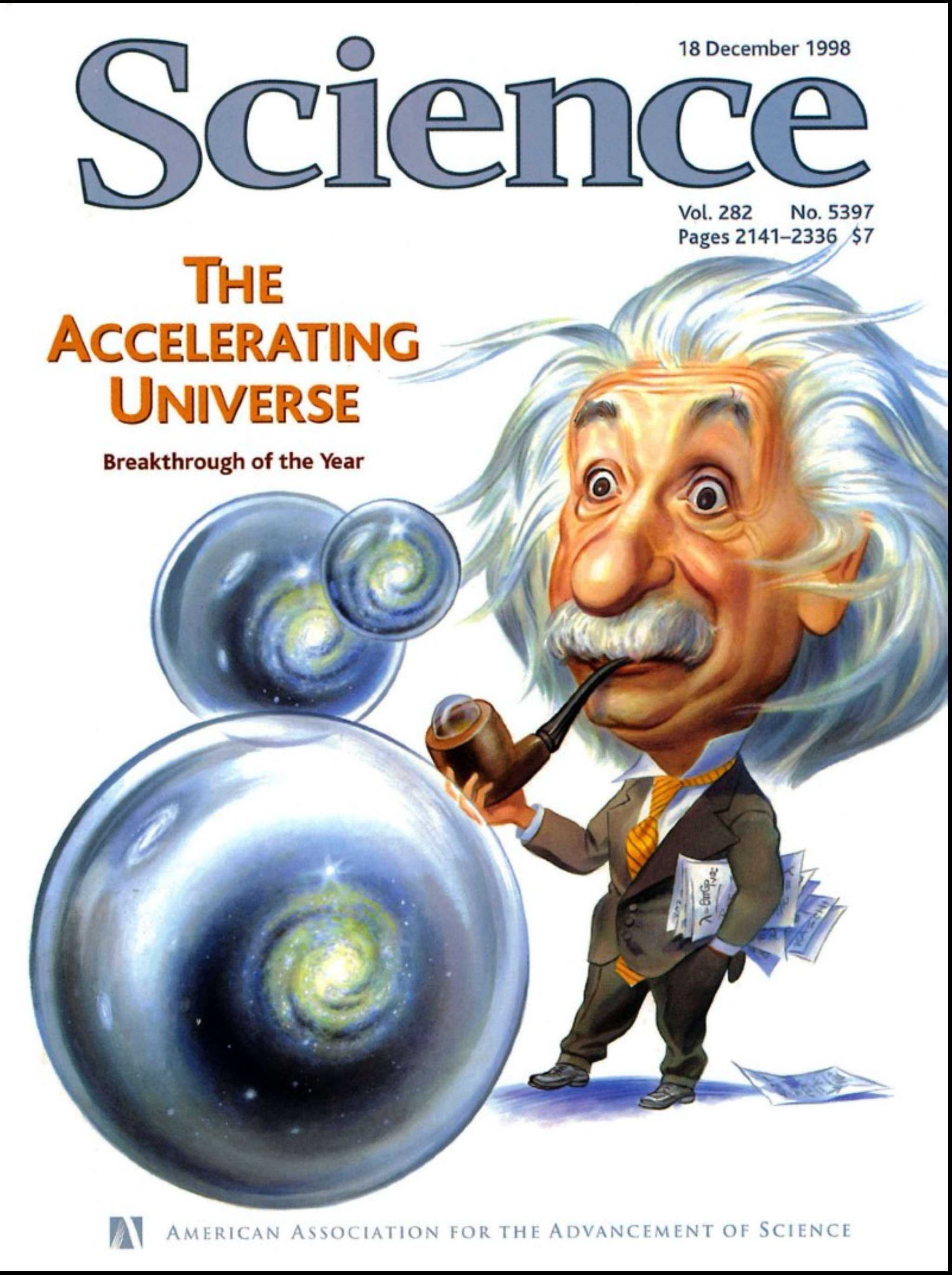
Supernova types

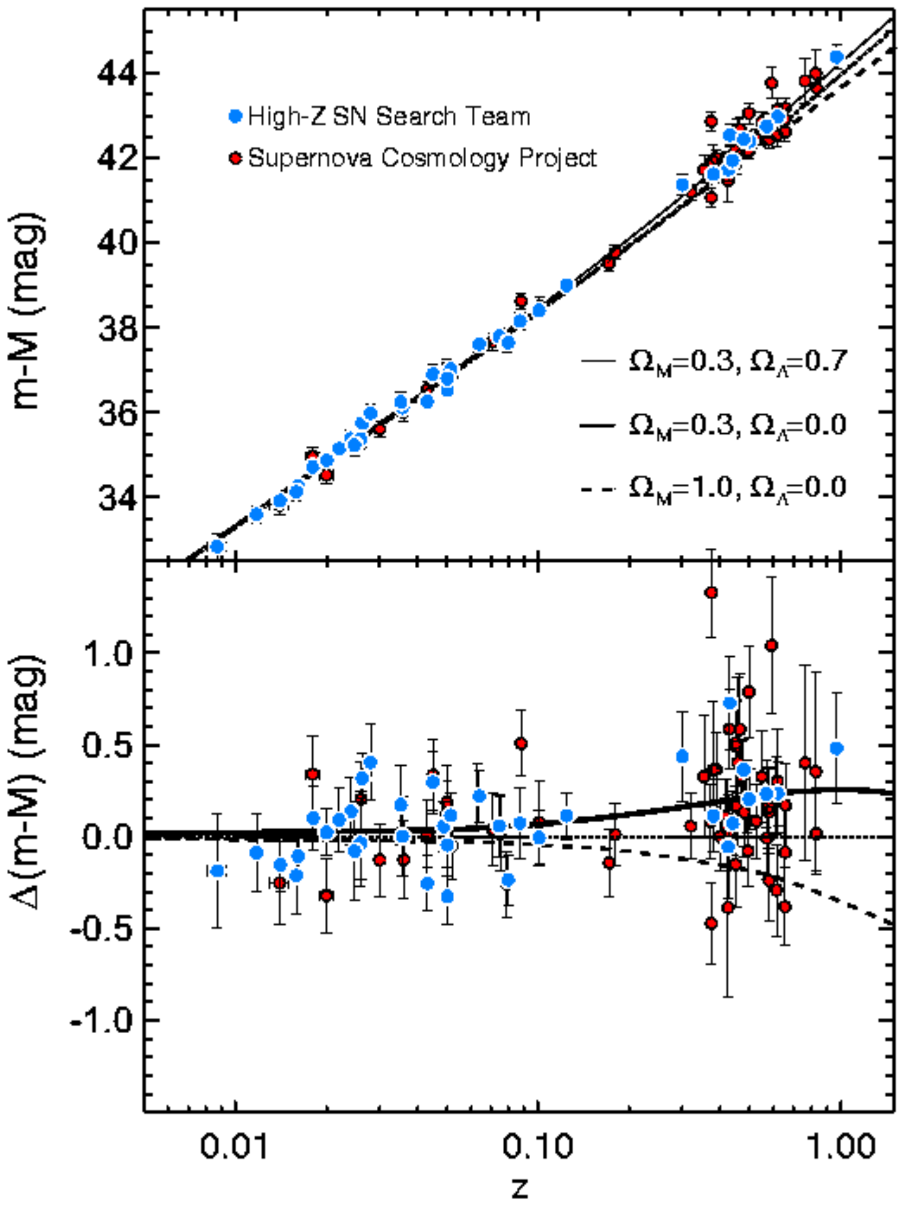


Supernova types



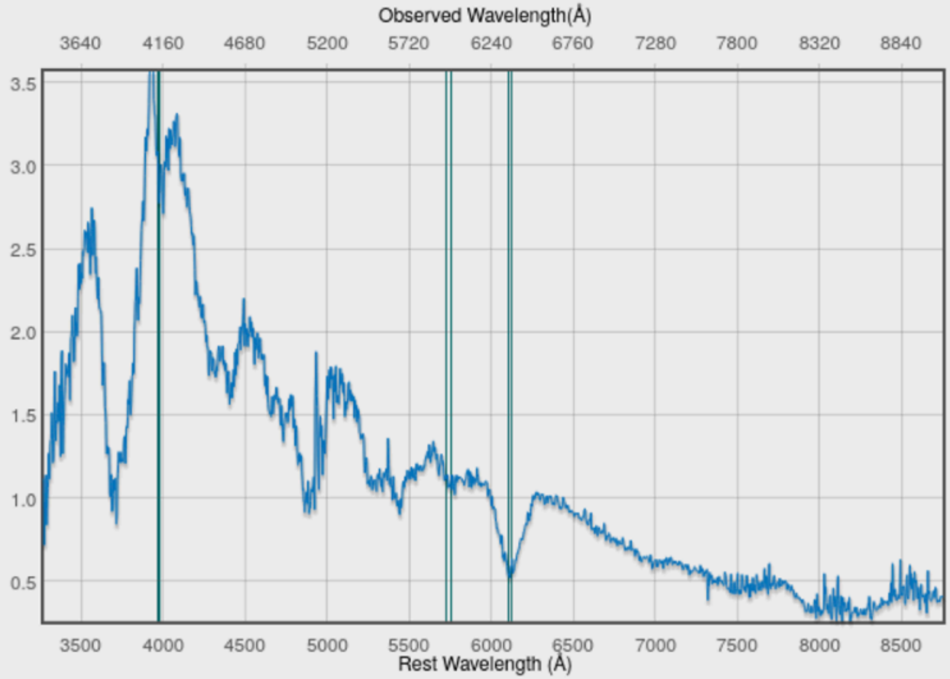
Pastorello+ 2007


18 December 1998
Science
Vol. 282 No. 5397
Pages 2141–2336 $7
THE ACCELERATING UNIVERSE
Breakthrough of the Year
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE


High-Z SN Search Team
Supernova Cosmology Project
Ω_M=0.3, Ω_Λ=0.7
Ω_M=0.3, Ω_Λ=0.0
Ω_M=1.0, Ω_Λ=0.0
m-M (mag)
34
36
38
40
42
44
Δ(m-M) (mag)
1.0
0.5
0.0
-0.5
-1.0
0.01
0.10
1.00
z

SN 2022knm - 2022-05-27 06:50:35.00 UH88 / SNIFS (TNS) z=0.04

Select all spectra | Clear spectra selection | Download selected ASCII | Reload



Show H at	z=0.04	v_{exp}=0 km/s	Show [O II] at	z=0.04	v_{exp}=0 km/s
Show He at	z=0.04	v_{exp}=0 km/s	Show [O III] at	z=0.04	v_{exp}=0 km/s
Show He II at	z=0.04	v_{exp}=0 km/s	Show O V at	z=0.04	v_{exp}=0 km/s
Show C II at	z=0.04	v_{exp}=0 km/s	Show O VI at	z=0.04	v_{exp}=0 km/s
Show C III at	z=0.04	v_{exp}=0 km/s	Show Na at	z=0.04	v_{exp}=0 km/s
Show C IV at	z=0.04	v_{exp}=0 km/s	Show Mg at	z=0.04	v_{exp}=0 km/s
Show N II at	z=0.04	v_{exp}=0 km/s	Show Mg II at	z=0.04	v_{exp}=0 km/s
Show N III at	z=0.04	v_{exp}=0 km/s	Show Si II at	z=0.04	v_{exp}=12000 km/s
Show N IV at	z=0.04	v_{exp}=0 km/s	Show S II at	z=0.04	v_{exp}=0 km/s
Show N V at	z=0.04	v_{exp}=0 km/s	Show Ca II at	z=0.04	v_{exp}=0 km/s
Show O at	z=0.04	v_{exp}=0 km/s	Show [Ca II] at	z=0.04	v_{exp}=0 km/s
Show [O I] at	z=0.04	v_{exp}=0 km/s	Show Fe II at	z=0.04	v_{exp}=0 km/s
Show O II at	z=0.04	v_{exp}=0 km/s	Show Fe III at	z=0.04	v_{exp}=0 km/s
Show Å at	z=0.04	v_{exp}=0 km/s	Show Tellurics		
Show Å at	z=0.04	v_{exp}=0 km/s	Show Galaxy lines at	z=0.04	
Show Å at	z=0.04	v_{exp}=0 km/s	Show WR-WN at	z=0.04	v_{exp}=0 km/s
Show Å at	z=0.04	v_{exp}=0 km/s	Show WR-WC/O at	z=0.04	v_{exp}=0 km/s

Zoom Full | Auto Zoom | Binning factor: 1 (rounded to nearest integer >1)

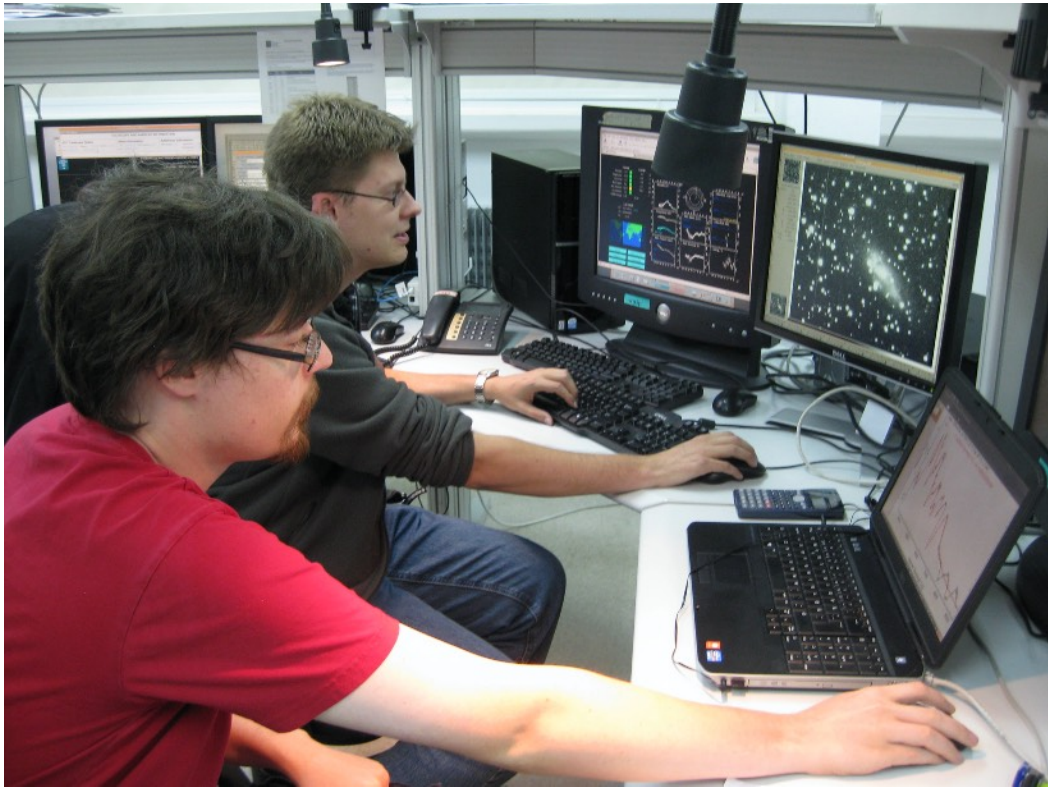
Mouse hovers at WL: 7011.32 (rest),7291.77 (observed)

PESSTO spectroscopic classification of optical transients

ATel #5335; **T. Kangas, E. Kankare, S. Mattila (University of Turku), C. Inserra (QUB), M. Fraser (QUB), R. Scalzo (ANU), M. Nicholl (QUB), A. Gal-Yam, O. Yaron (Weizmann), S. Benetti, A. Pastorello, (INAF - Padova), S. Valenti (LCOGT/UCSB), S. Taubenberger (MPA Garching), S. J. Smartt, K. Smith, D. Young (QUB), M. Sullivan (Uni. of Southampton), C. Knapic, M. Molinaro, R. Smareglia (Trieste), C. Baltay, N. Ellman, E. Hadjiyska, R. McKinnon, D. Rabinowitz, E. S. Walker (Yale University), U. Feindt, M. Kowalski (Universitat Bonn), P. Nugent (LBL Berkeley)**
on ***28 Aug 2013; 18:50 UT***
Distributed as an Instant Email Notice Supernovae
Credential Certification: Seppo Mattila (seppo.mattila@utu.fi)

Subjects: Optical, Supernovae

PESSTO, the Public ESO Spectroscopic Survey for Transient Objects (see Valenti et al., ATel #4037; http://www.pessto.org), reports the following supernova classifications. Targets were supplied by the La Silla-Quest survey (see Hadjiyska et al., ATel #3812) and the OGLE-IV Transient Search (see Wyrzykowski et al., ATEL #4495). All observations were performed on the ESO New Technology Telescope at La Silla on 2013 August 27 (UT), using EFOSC2 and Grism 13 (3985-9315A, 18A resolution). Classifications were done with SNID (Blondin & Tonry, 2007, ApJ, 666, 1024) and GELATO (Harutyunyan et al., 2008, A&A, 488, 383). Classification spectra can be obtained from http://www.pessto.org via WISeREP (Yaron & Gal-Yam, 2012, PASP, 124, 668).



Name	RA (J2000)	Dec (J2000)	Disc. Date	Disc. Source	Disc Mag	z	Type	Phase	Notes
LSQ13bor	03:25:49.08	-19:18:10.5	2013-08-11	LSQ	19.9	~0.11	SN Ia	~9d past max	
LSQ13btf	01:39:20.89	-19:49:29.4	2013-08-15	LSQ	20.5	~0.19	SN Ia	~2d pre max	(1)
LSQ13bth	03:44:10.80	-19:51:12.8	2013-08-15	LSQ	20.1	~0.09	SN Ia	~7d past max	
LSQ13bwl	23:33:55.42	+04:31:00.3	2013-08-20	LSQ	18.4	~0.07	SN Ia	~11d past max	
LSQ13bxv	00:39:22.04	-24:05:01.3	2013-08-21	LSQ	19.1	~0.14	IIn	----	(2)
LSQ13byc	04:08:43.69	-21:38:08.9	2013-08-25	LSQ	19.5	~0.04	SN Ibc	----	(3)
LSQ13byn	01:36:41.14	-17:53:59.1	2013-08-25	LSQ	19.4	~0.11	SN Ia	~7d pre max	
OGLE-2013-SN-051	00:32:19.54	-66:25:44.2	2013-08-16	OGLE	18.8	~0.07	SN Ia	~7d past max	

(1) Best match found with SN 2005hk a couple of days before maximum light.

PESSTO spectroscopic classification of optical transients

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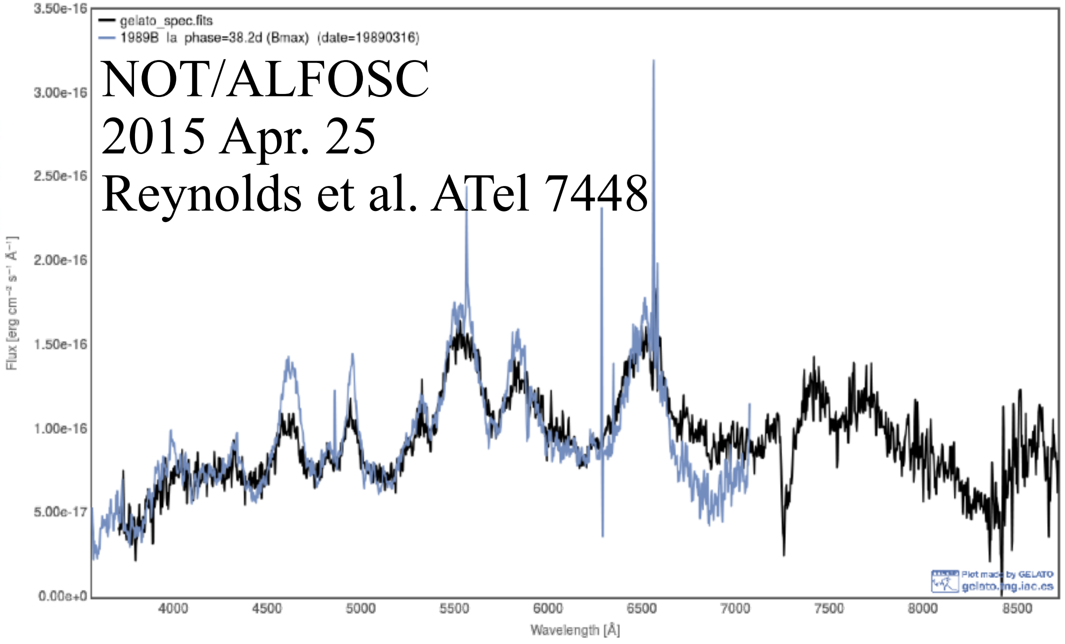

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LSQ13btf	01:39:20.89	-19:49:29.4	2013-08-15	LSQ	20.5	~0.19	SN Ia	~2d pre max	(1)
LSQ13bth	03:44:10.80	-19:51:12.8	2013-08-15	LSQ	20.1	~0.09	SN Ia	~7d past max	
LSQ13bwl	23:33:55.42	+04:31:00.3	2013-08-20	LSQ	18.4	~0.07	SN Ia	~11d past max	
LSQ13bxv	00:39:22.04	-24:05:01.3	2013-08-21	LSQ	19.1	~0.14	IIn	----	(2)
LSQ13byc	04:08:43.69	-21:38:08.9	2013-08-25	LSQ	19.5	~0.04	SN Ibc	----	(3)
LSQ13byn	01:36:41.14	-17:53:59.1	2013-08-25	LSQ	19.4	~0.11	SN Ia	~7d pre max	
OGLE-2013-SN-051	00:32:19.54	-66:25:44.2	2013-08-16	OGLE	18.8	~0.07	SN Ia	~7d past max	

(1) Best match found with SN 2005hk a couple of days before maximum light.