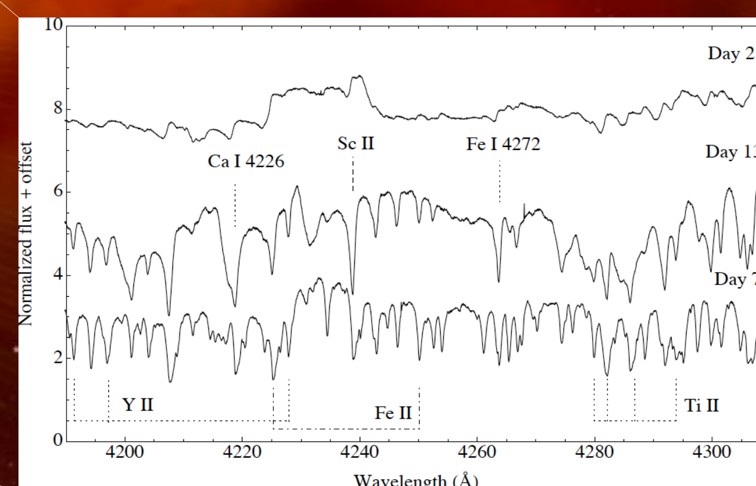
Le fabbriche di Litio nella Galassia :

le novae

L. Izzo

V AstroUAN meeting - Napoli

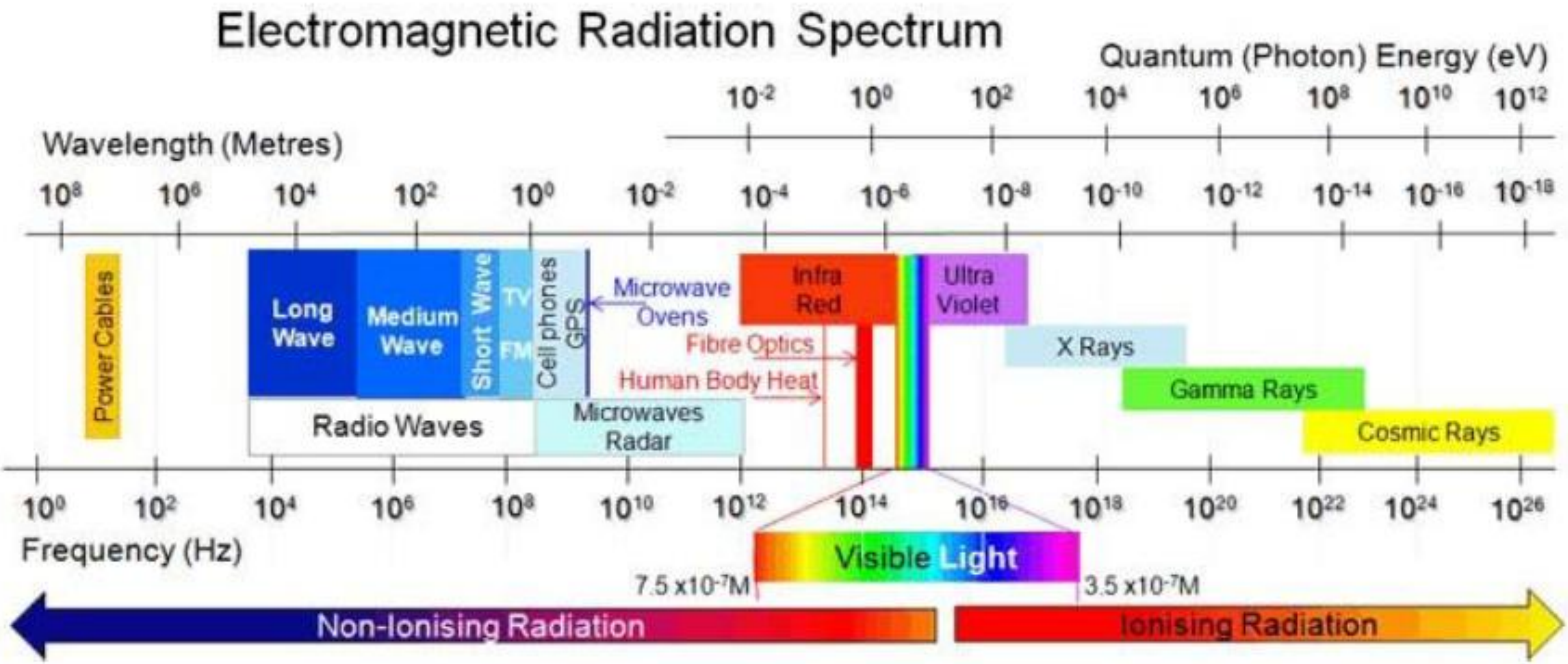


Outline

- Spettroscopia
- Cosa è una nova
- La nova V1369 Cen (Nova Cen 2013)
- Identificazione del Litio I 6708
- Conseguenze e conclusioni
- Astronomia amatoriale e novae

Spettroscopia

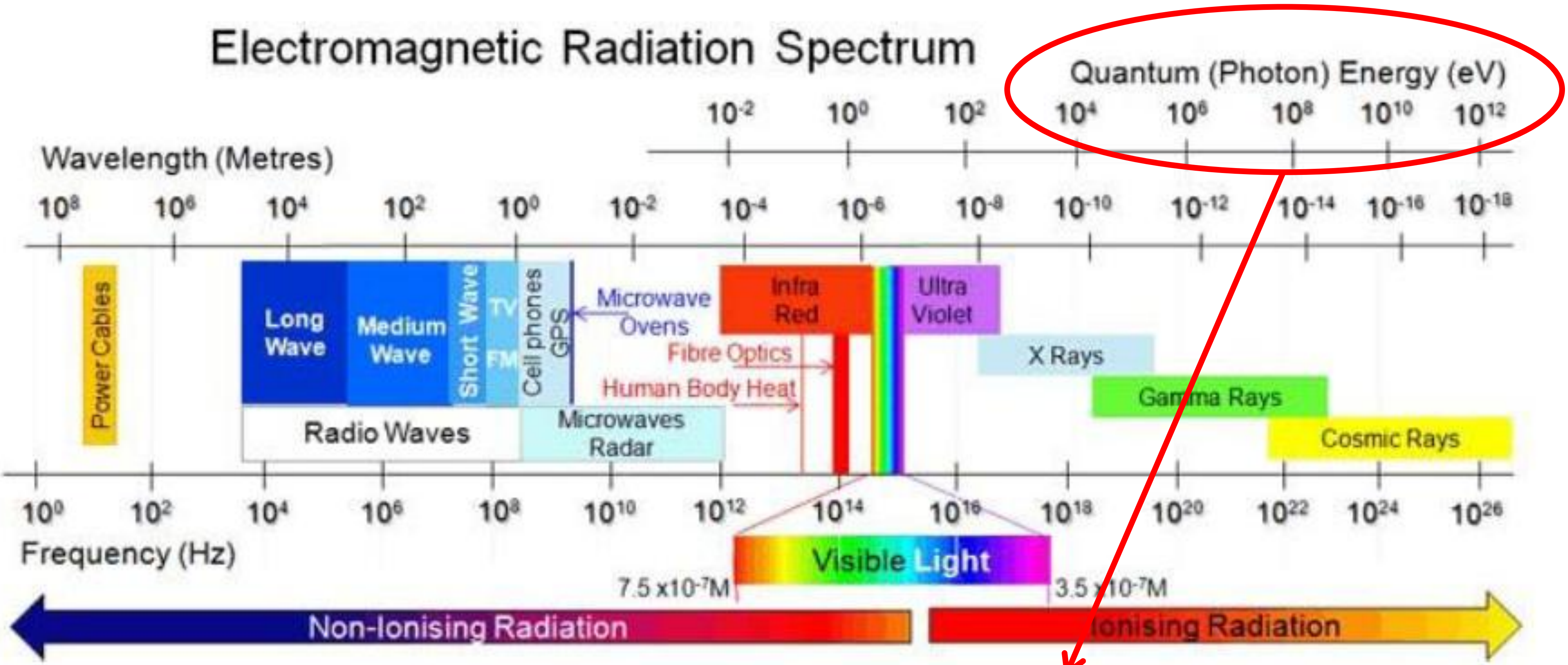
Luce → radiazione elettromagnetica



Velocità della luce **c = νλ**

Spettroscopia

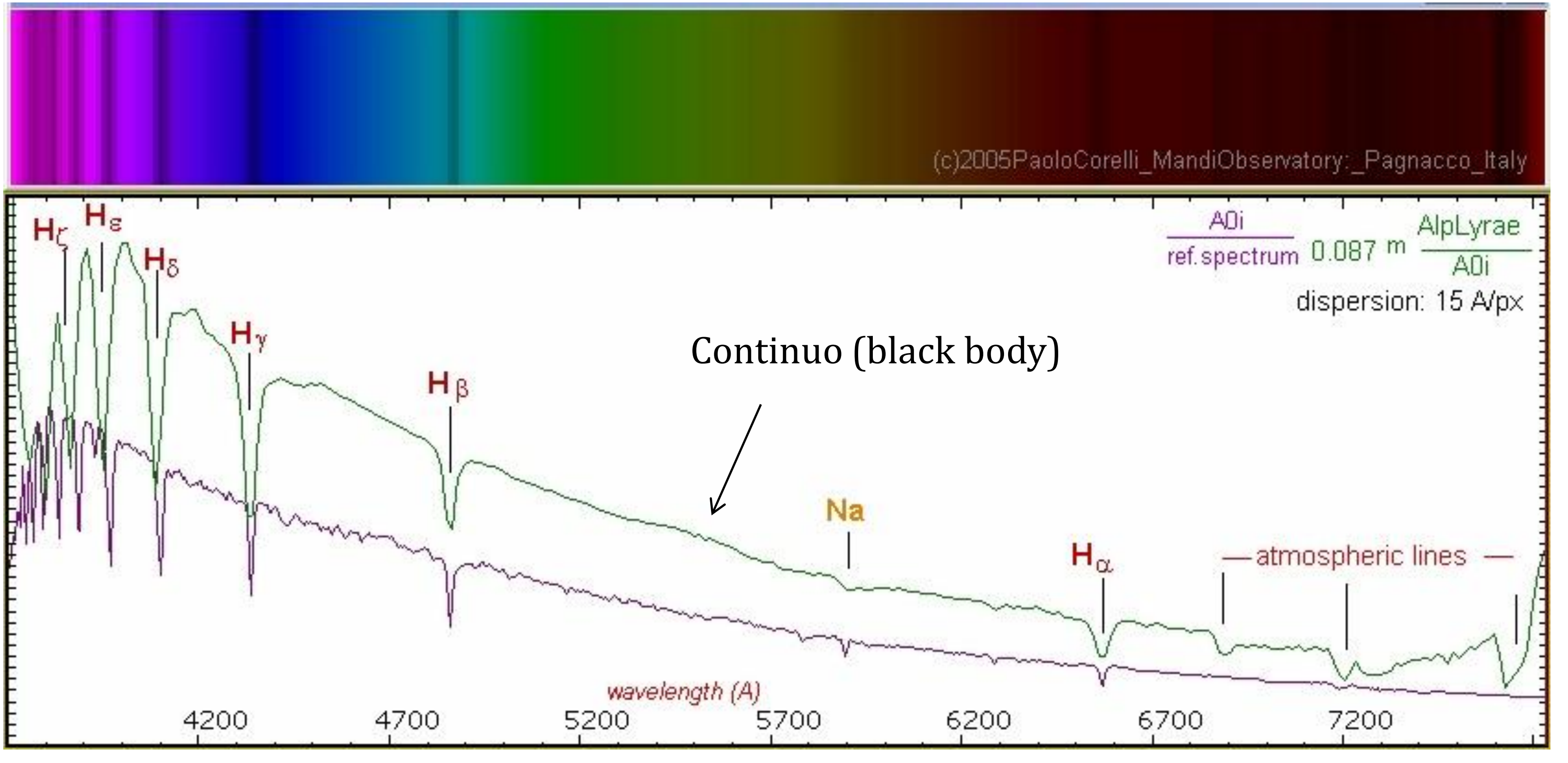
Luce → radiazione elettromagnetica

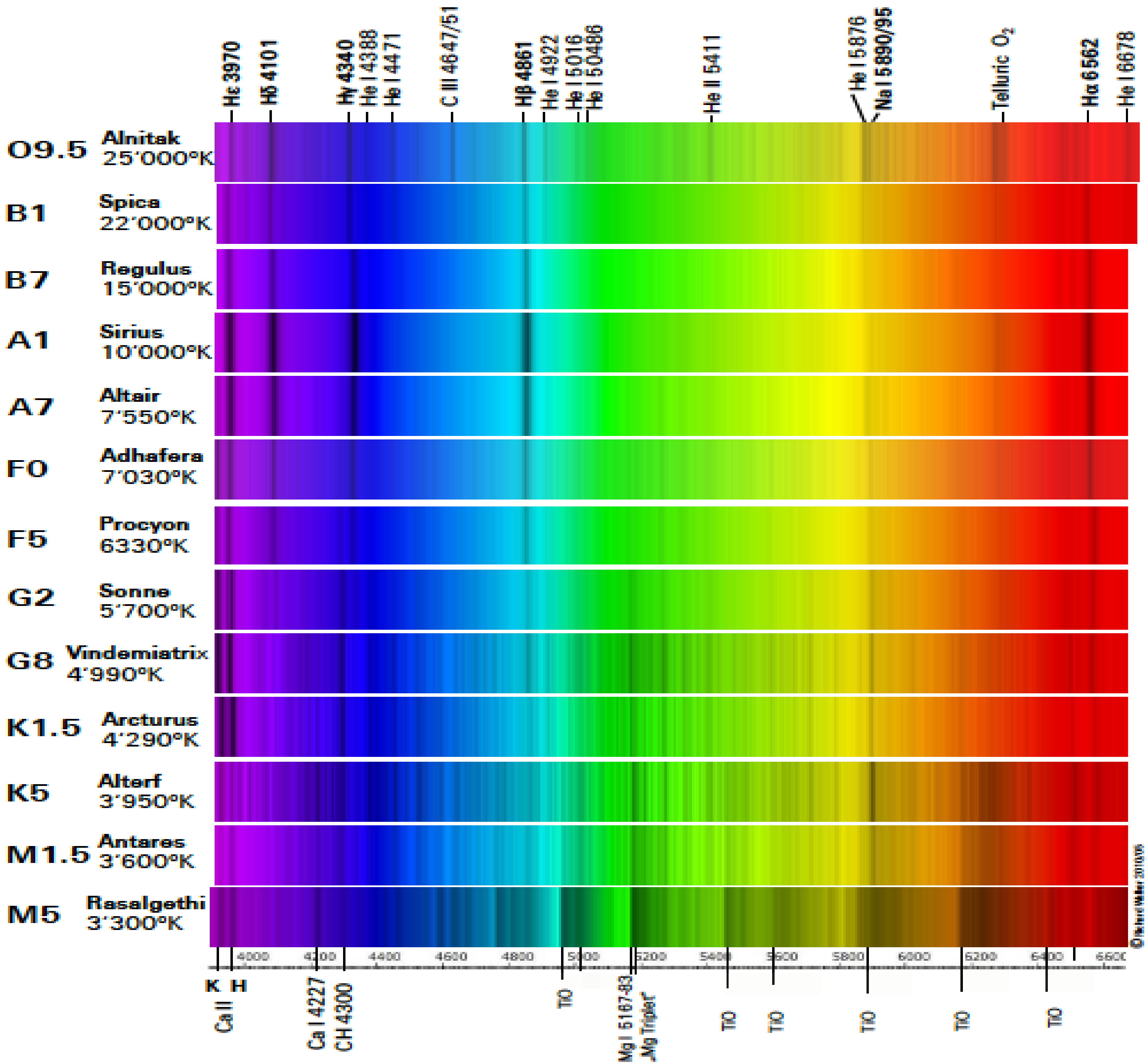


Energia dei fotoni **E = h ν**

Spettroscopia

Spettro stellare → distribuzione in λ (ν) del flusso
di radiazione e.m. emesso da una stella





Hε 3970
Hδ 4101
Hγ 4340
He I 4388
He I 4471
C III 4647/51
Hβ 4861
He I 4922
He I 5016
He I 50486
He II 5411
He I 5876
Na I 5890/95
Telluric O2
Hα 6562
He I 6678
O9.5 Alnitak 25'000°K
B1 Spica 22'000°K
B7 Regulus 15'000°K
A1 Sirius 10'000°K
A7 Altair 7'550°K
F0 Adhafera 7'030°K
F5 Procyon 6330°K
G2 Sonne 5'700°K
G8 Vindemiatrix 4'990°K
K1.5 Arcturus 4'290°K
K5 Alterf 3'950°K
M1.5 Antares 3'600°K
M5 Rasalgethi 3'300°K
4000
4200
4400
4600
4800
5000
5200
5400
5600
5800
6000
6200
6400
6600
K
H
Ca II
Ca I 4227
CH 4300
TiO
Mg I 5167-83
„Mg Triplet"
TiO
TiO
TiO
TiO
TiO

Spettroscopia

Spettrografo – come ottenere uno spettro

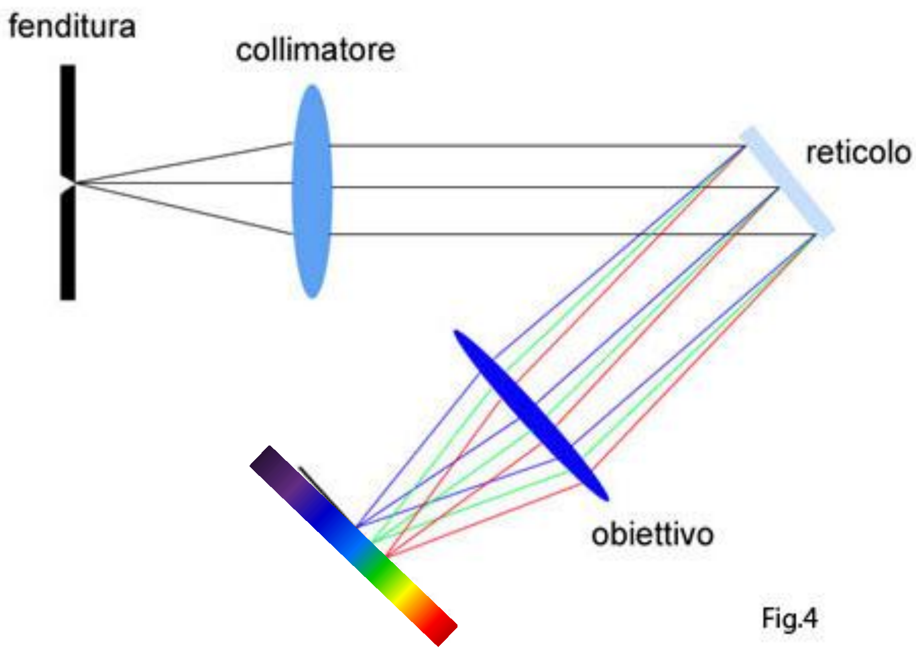
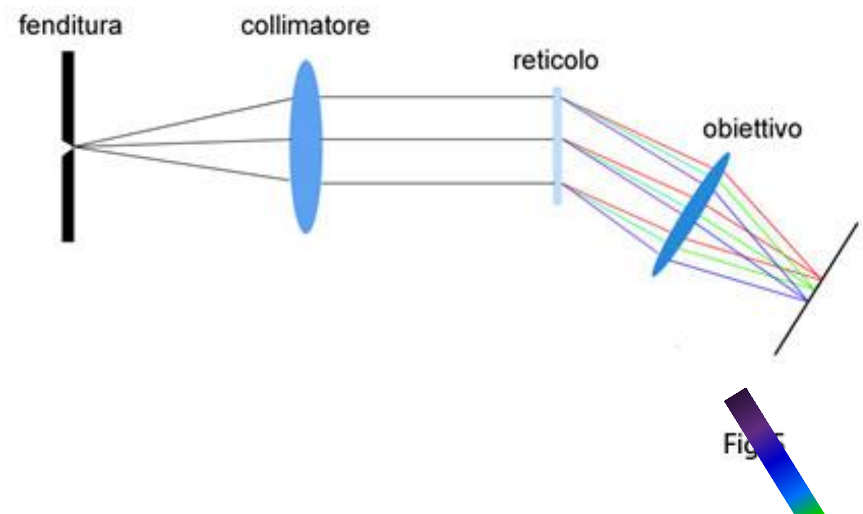


Fig.4

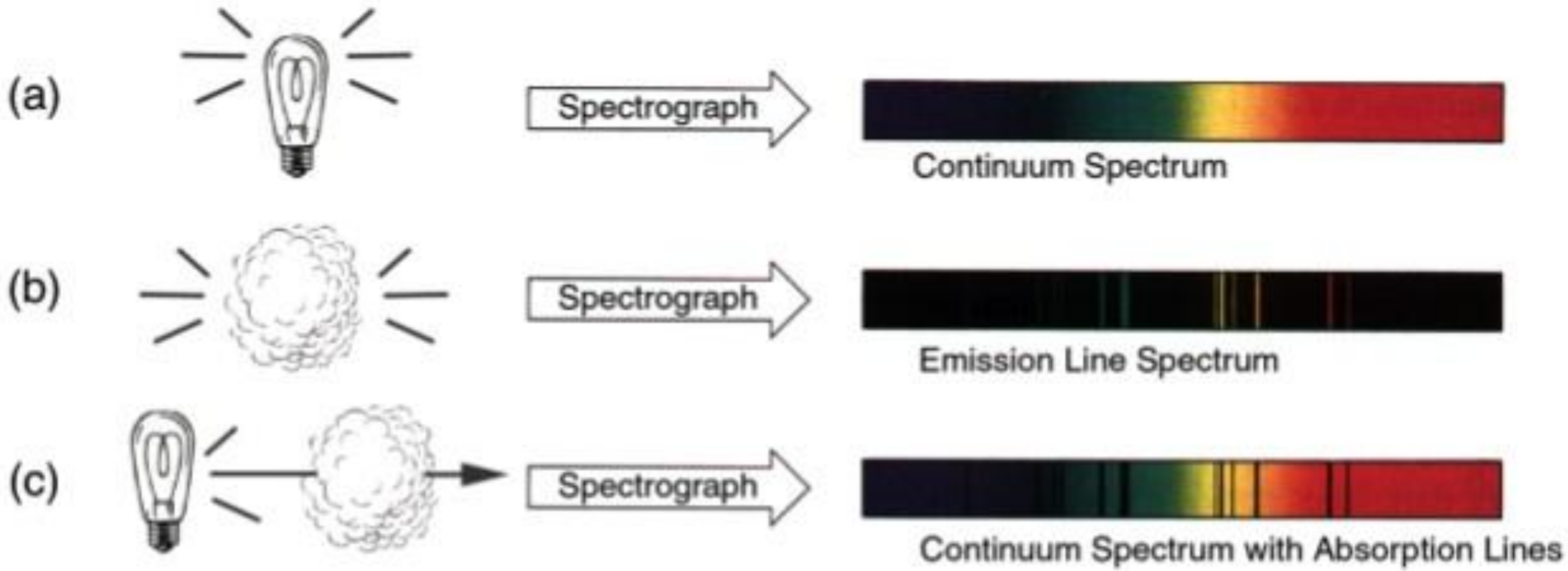
riflessione



trasmissione

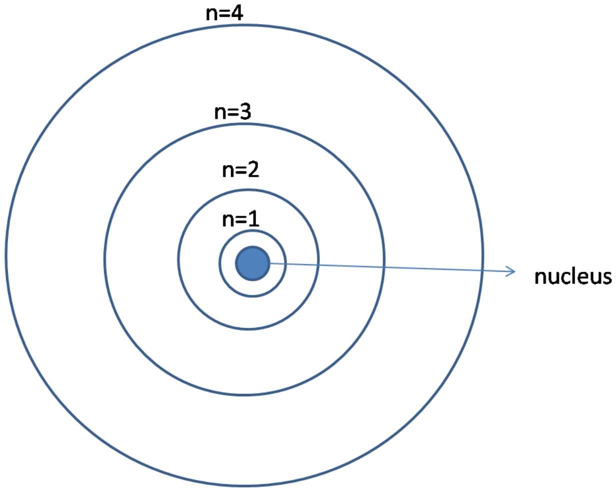
Spettroscopia

Righe spettrali



Spettroscopia

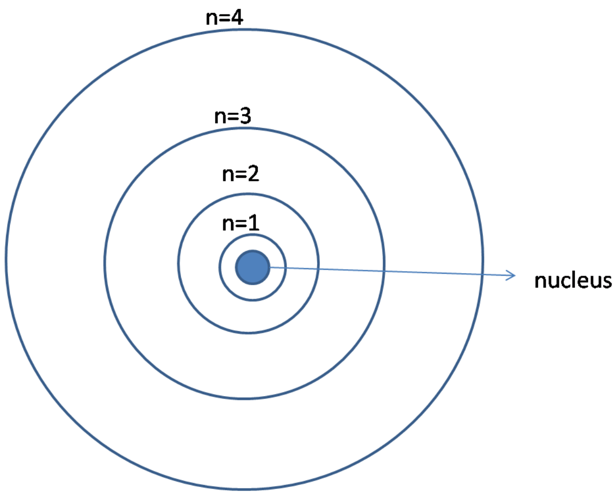
Righe spettrali – Caso atomo H



Atomo di Bohr

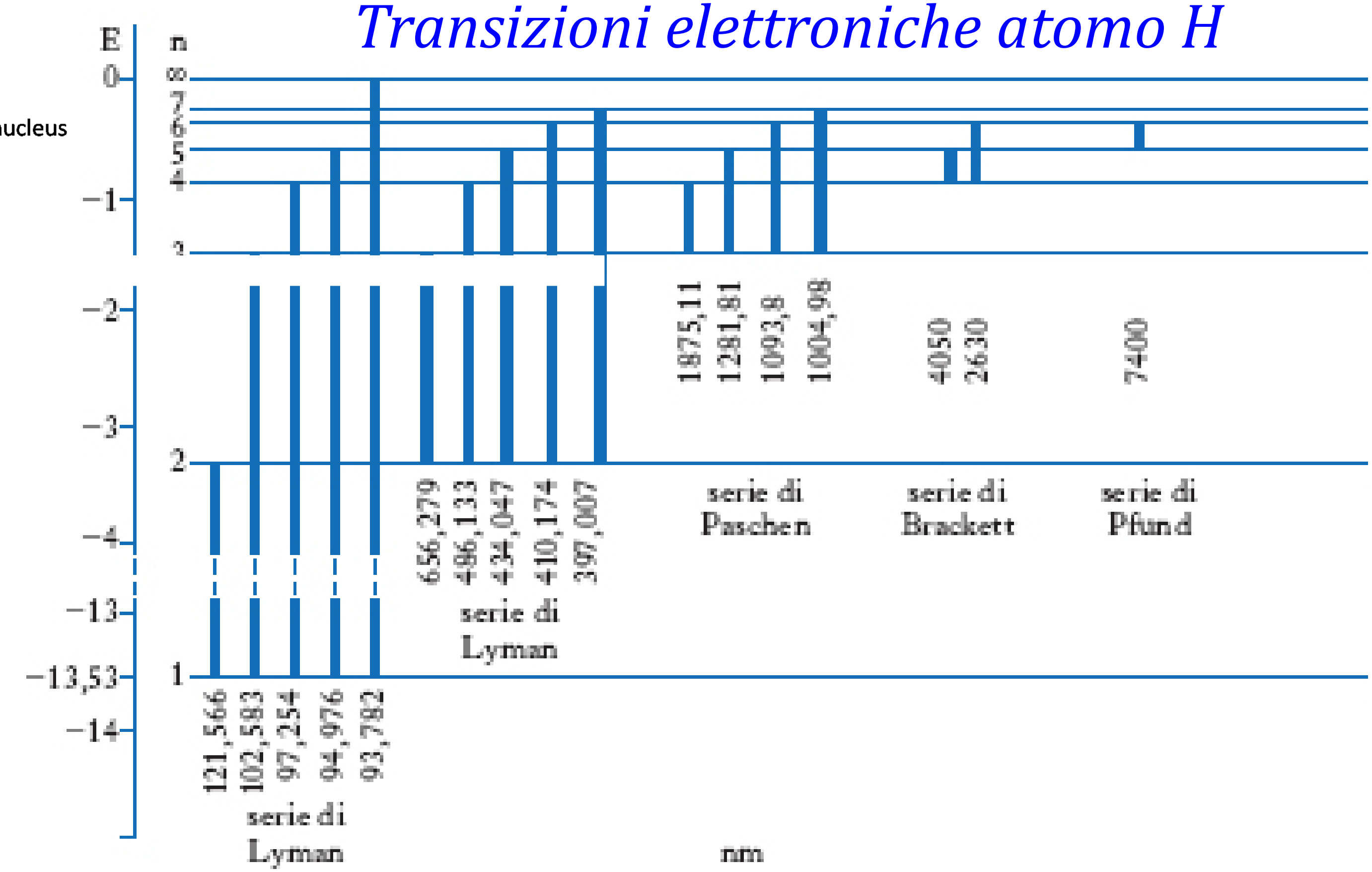
Spettroscopia

Righe spettrali – Caso atomo H



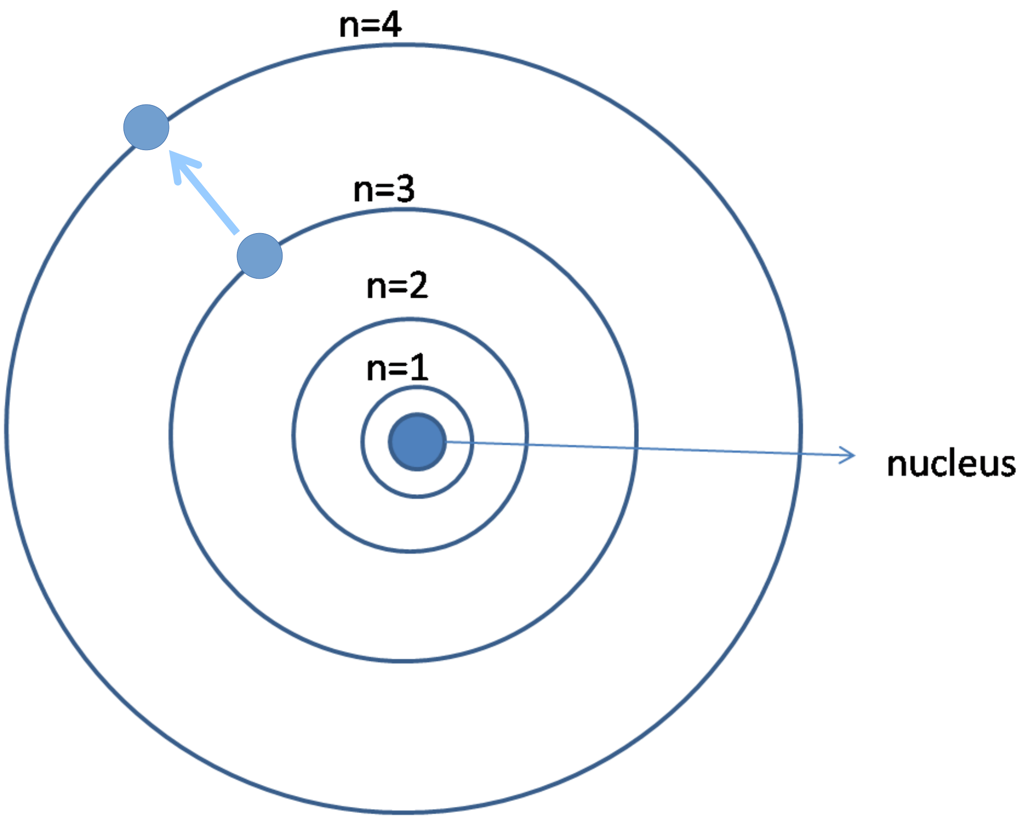
Atomo di Bohr

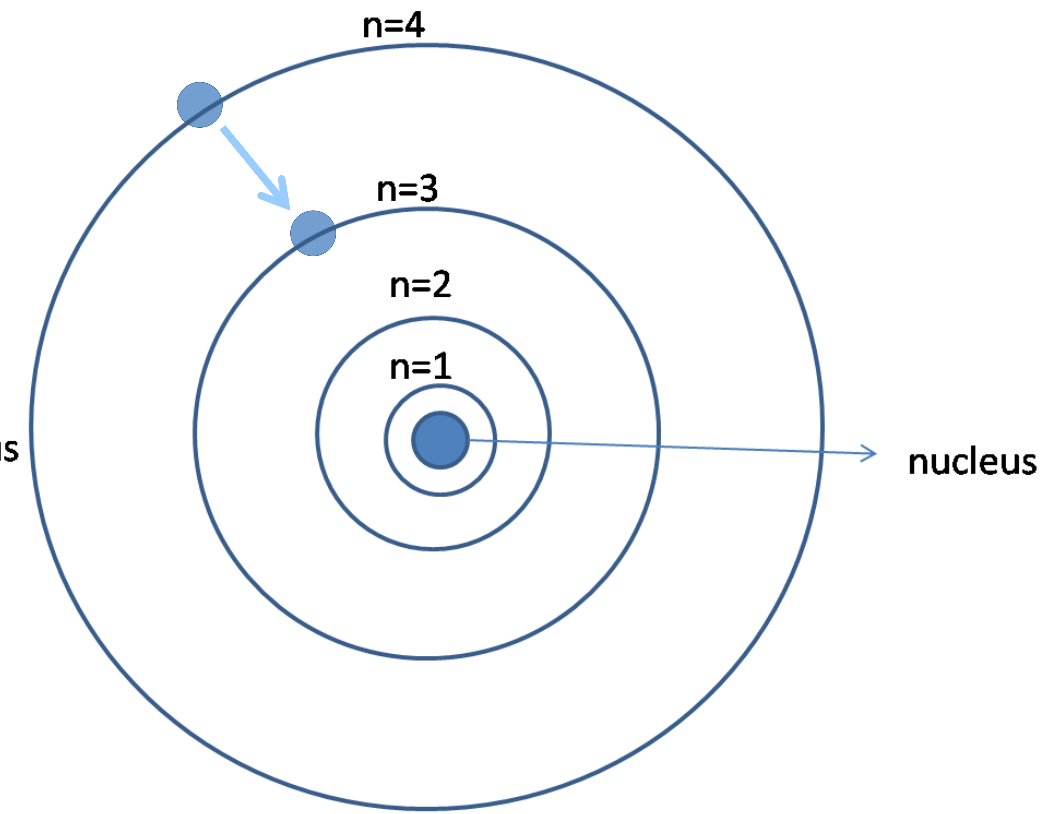
Transizioni elettroniche atomo H



Spettroscopia

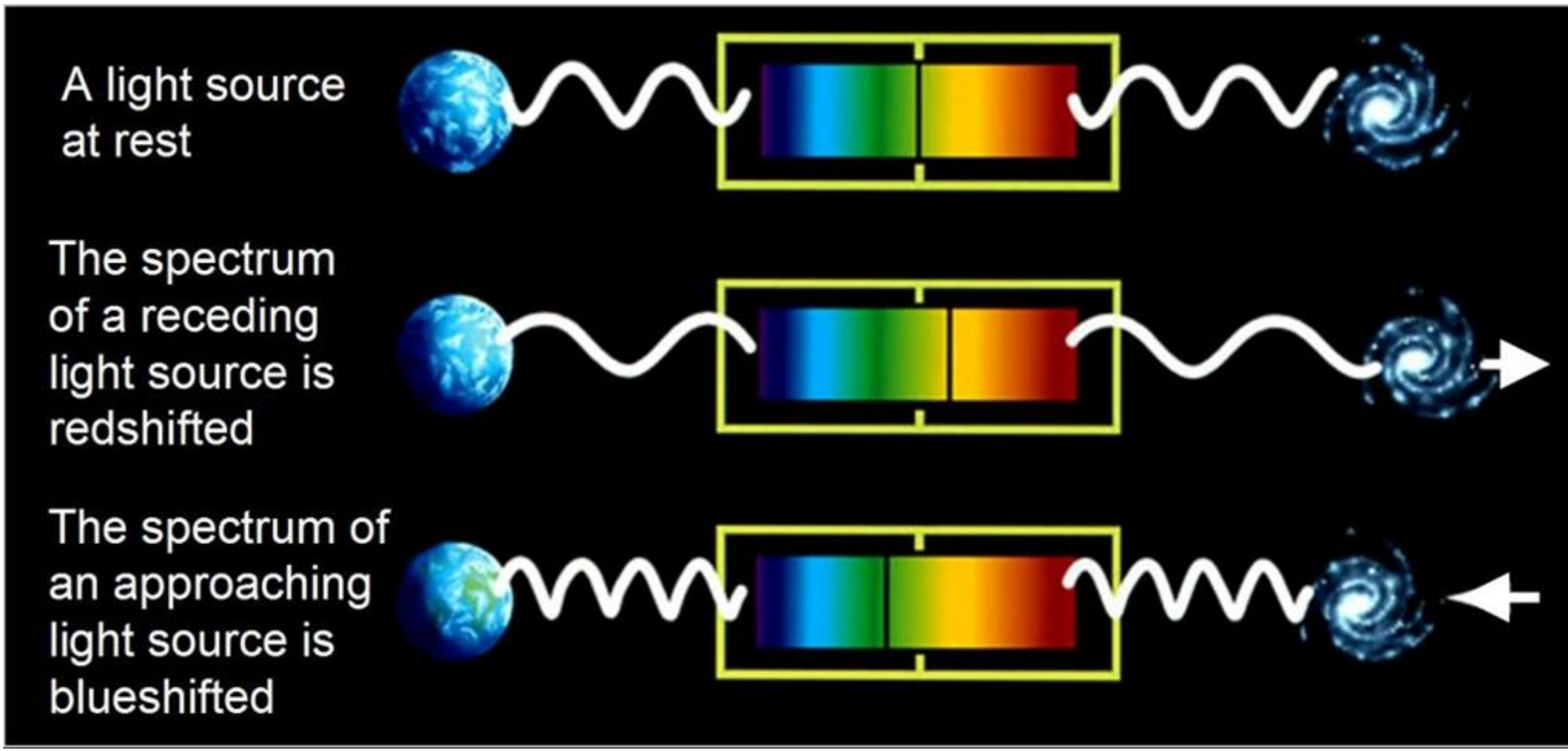
assorbimento *emissione*





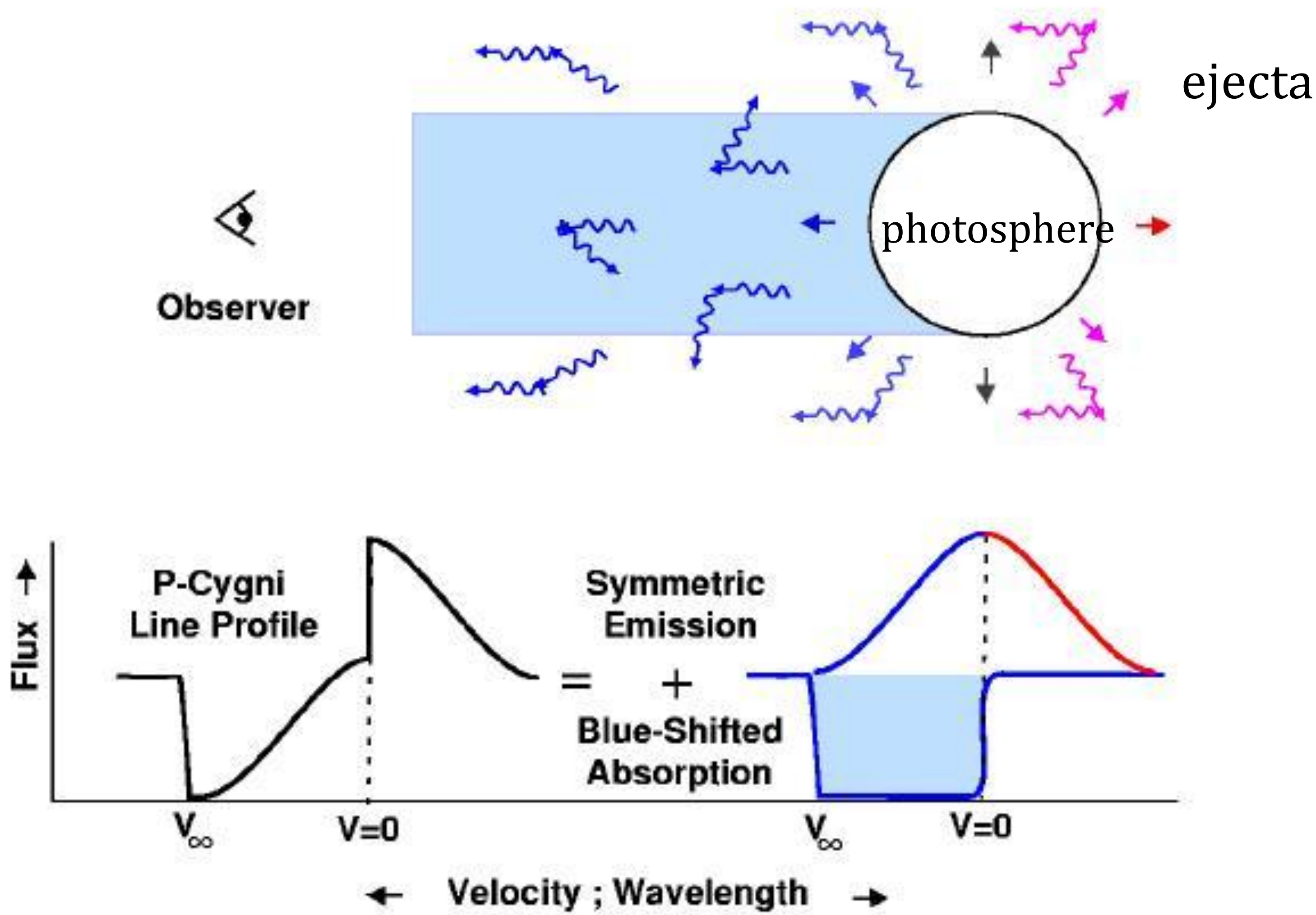
Spettroscopia

Velocità radiali e Profili P-Cygni

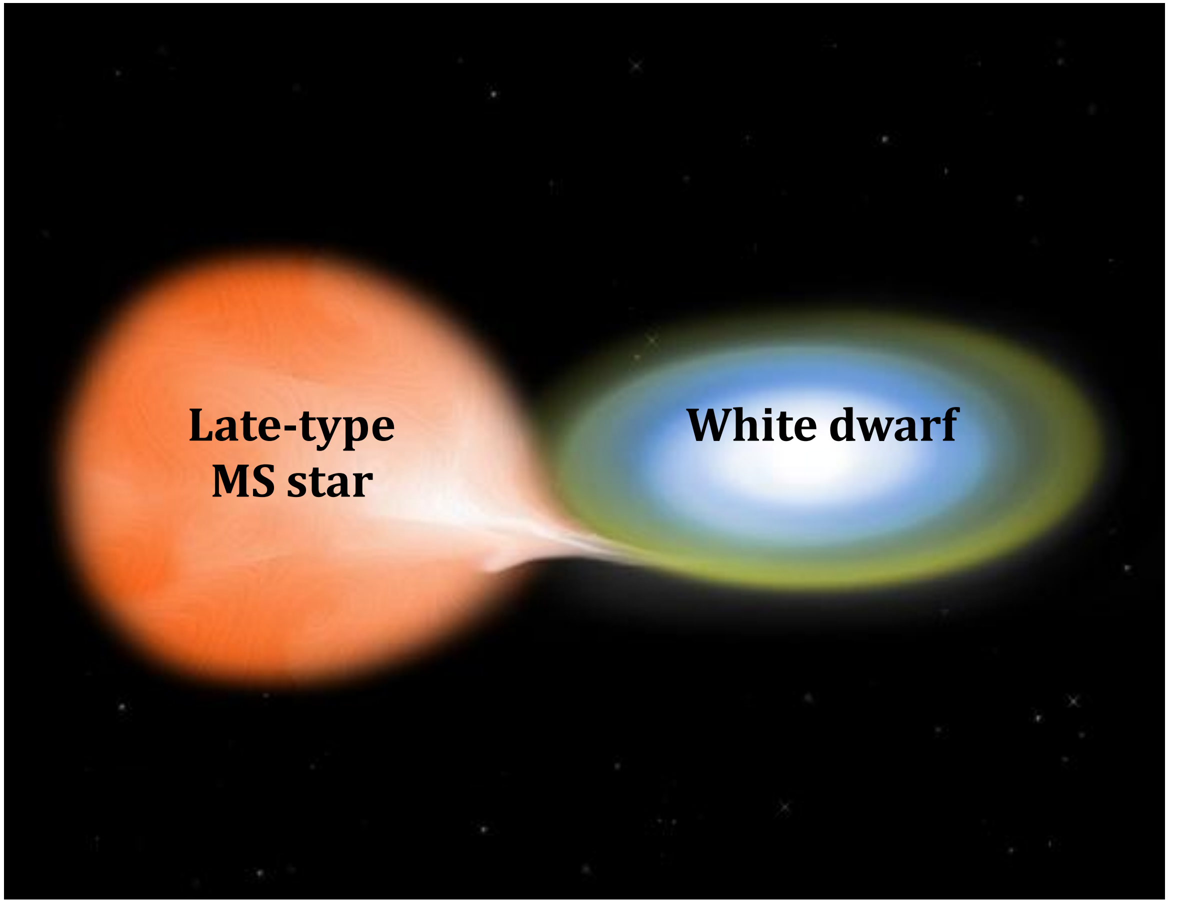


Spettroscopia

Velocità radiali e Profili P-Cygni



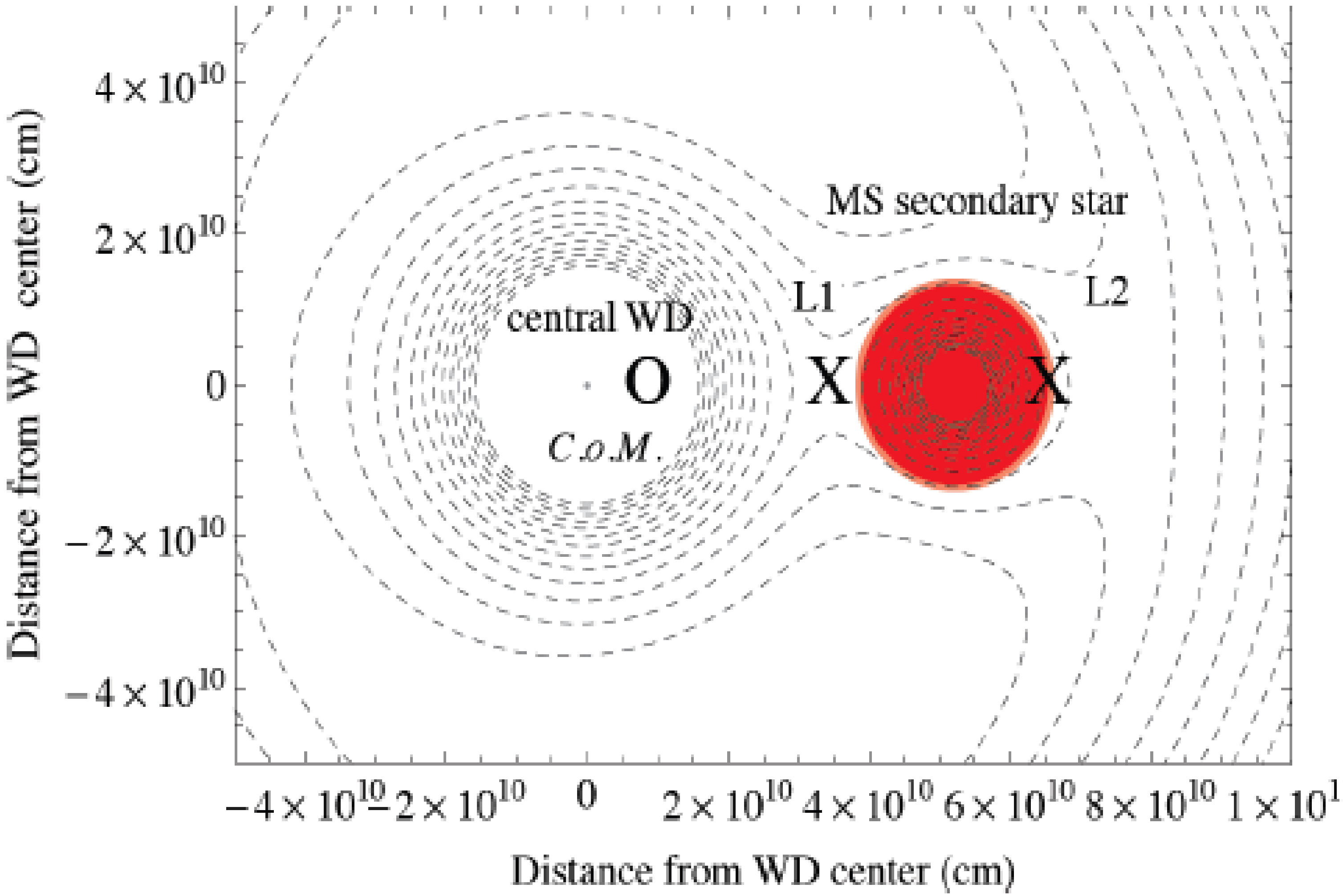
Novae



La nana bianca cattura gas dalla compagna...

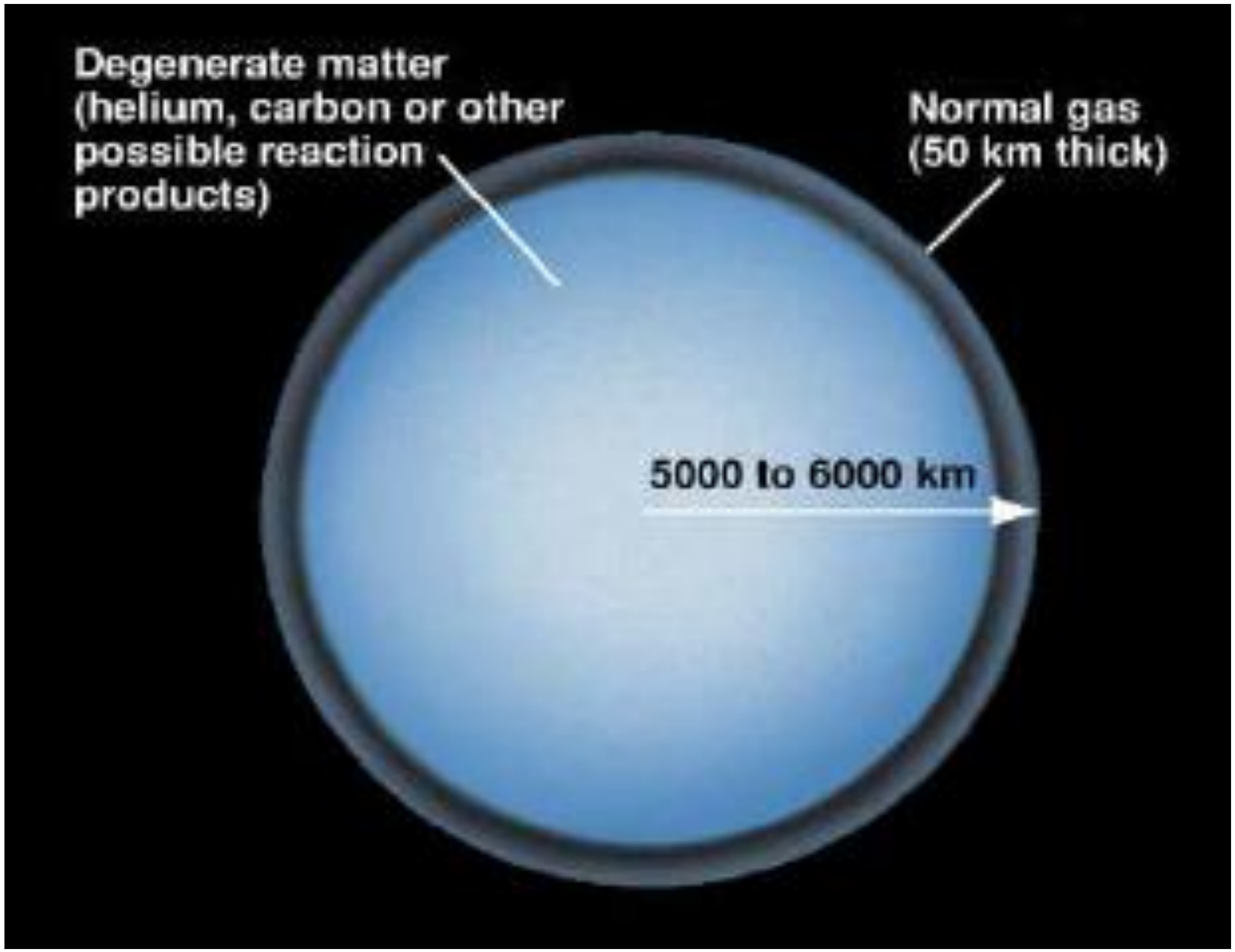
Novae

...tramite il meccanismo di “Roche”



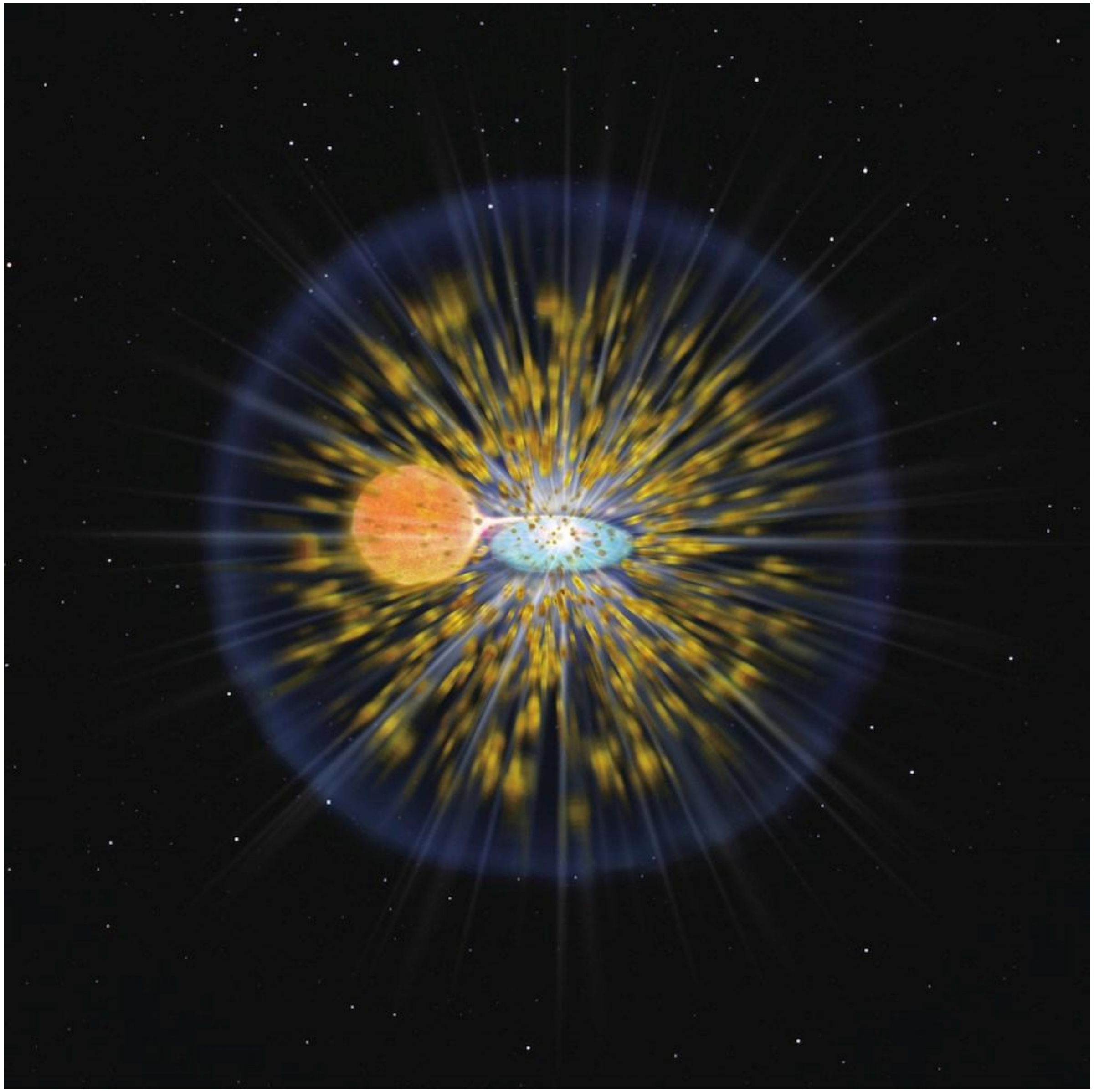
Novae

Il ThermoNuclear Runaway



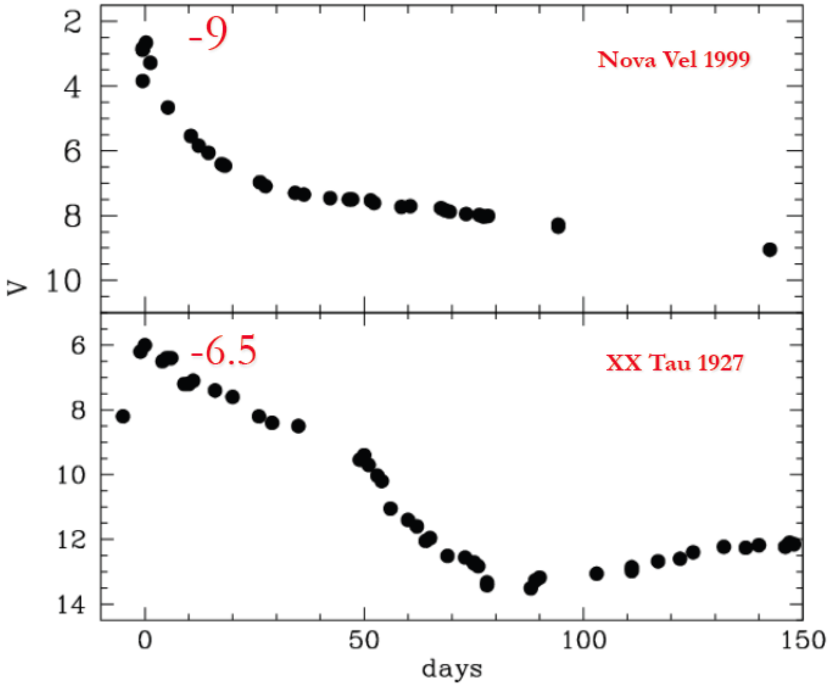
Quando la pressione alla base del gas "accreted" > 10^{14} N cm^{-2}

Novae

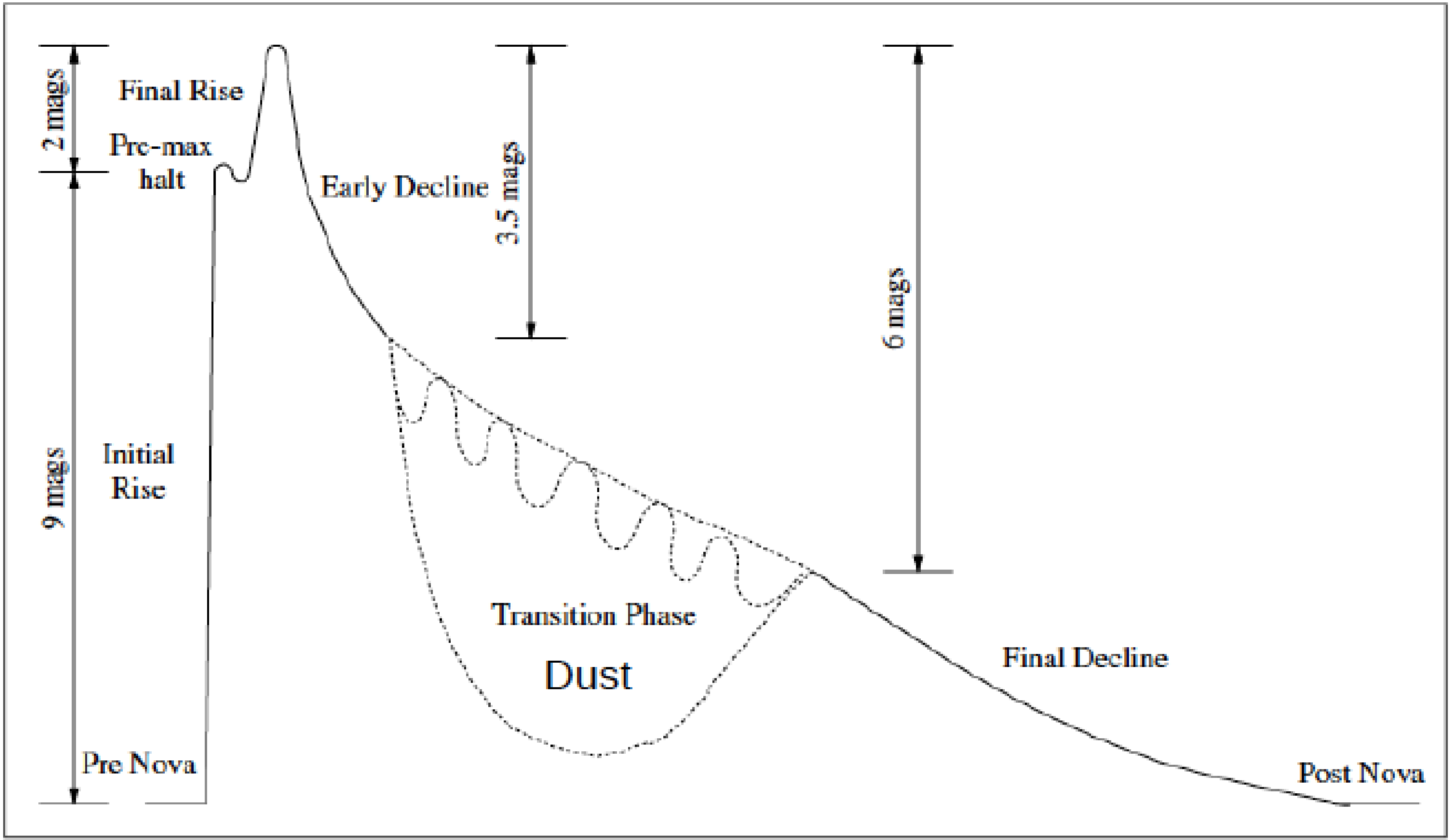


Nova outburst

aumento di 6-9 magnitudini



Novae



2 mags
Final Rise
Pre-max
halt
Early Decline
3.5 mags
6 mags
9 mags
Initial
Rise
Transition Phase
Dust
Final Decline
Pre Nova
Post Nova

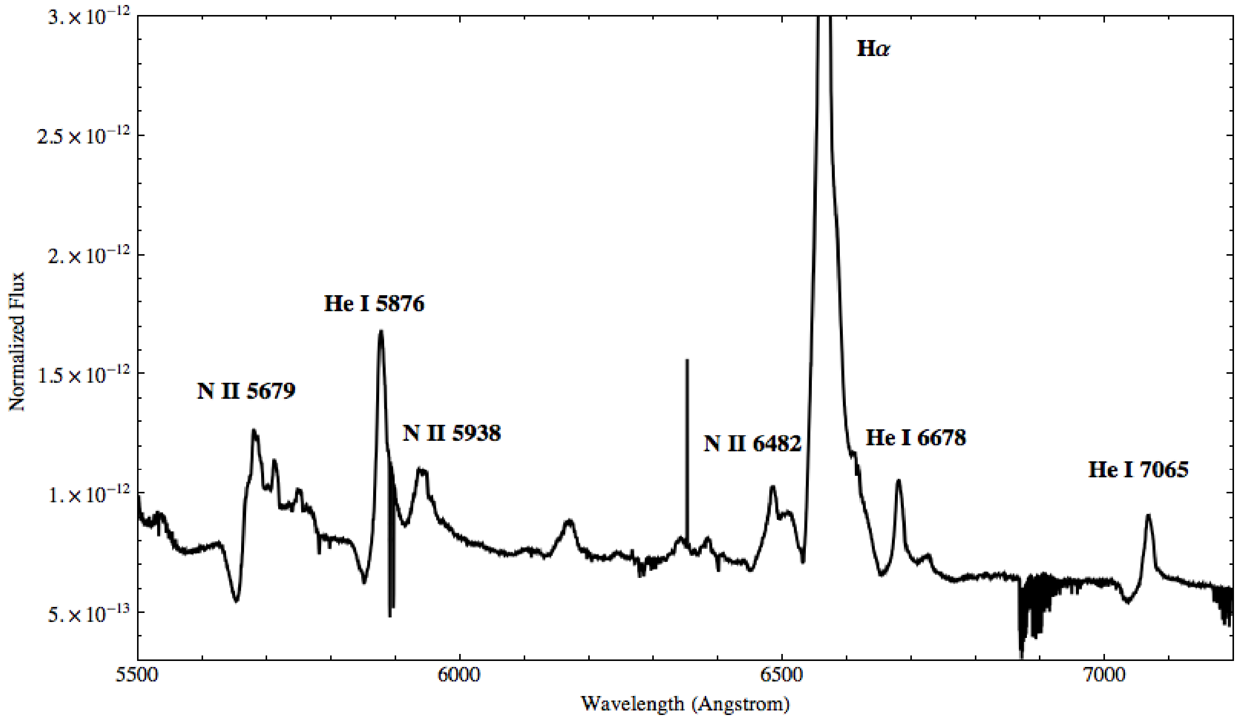
Fenomenologia

Spectroscopic evolution – "fireball"

Subito dopo il TNR : fotosfera che espande rapidamente

→ $t_{exp} << t_{cool}$

→high-ionization He, N righe spettrali con "high-vel absorptions"



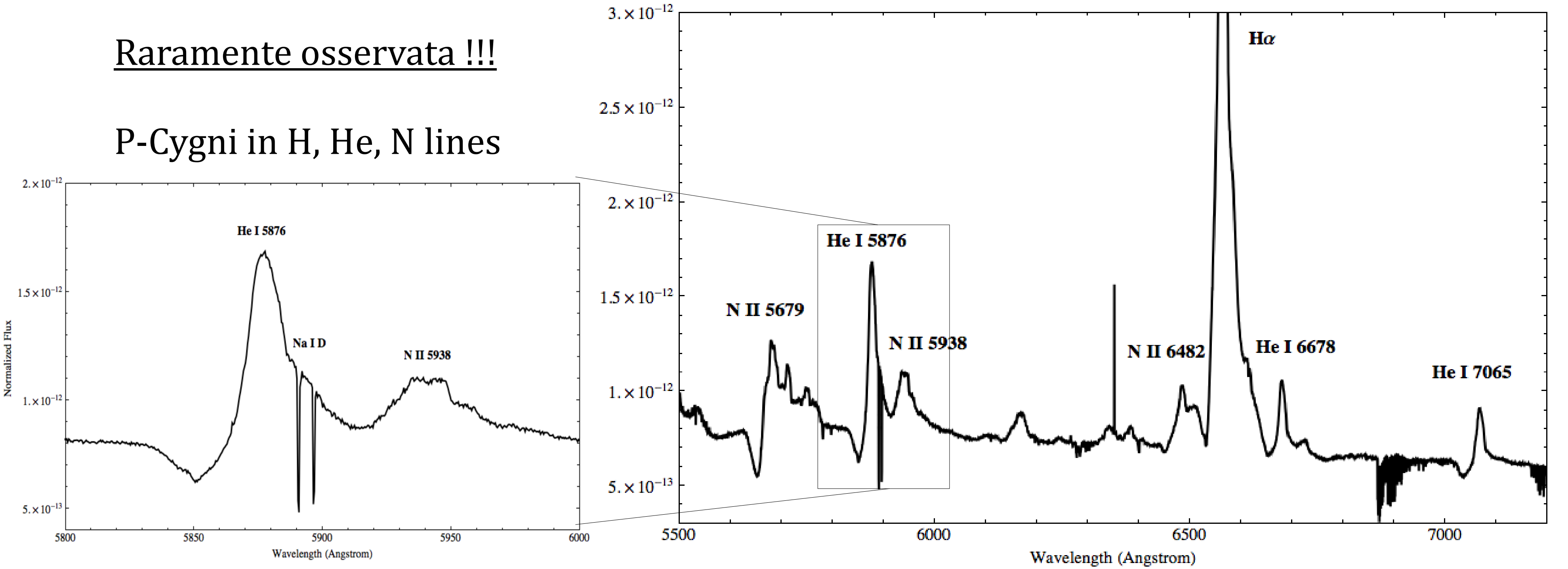
Fenomenologia

Spectroscopic evolution – "fireball"

Subito dopo il TNR : fotosfera che espande rapidamente
→ $t_{exp} \ll t_{cool}$
→high-ionization He, N righe spettrali con "high-vel absorptions"

<u>Raramente osservata !!!</u>

P-Cygni in H, He, N lines



Fenomenologia

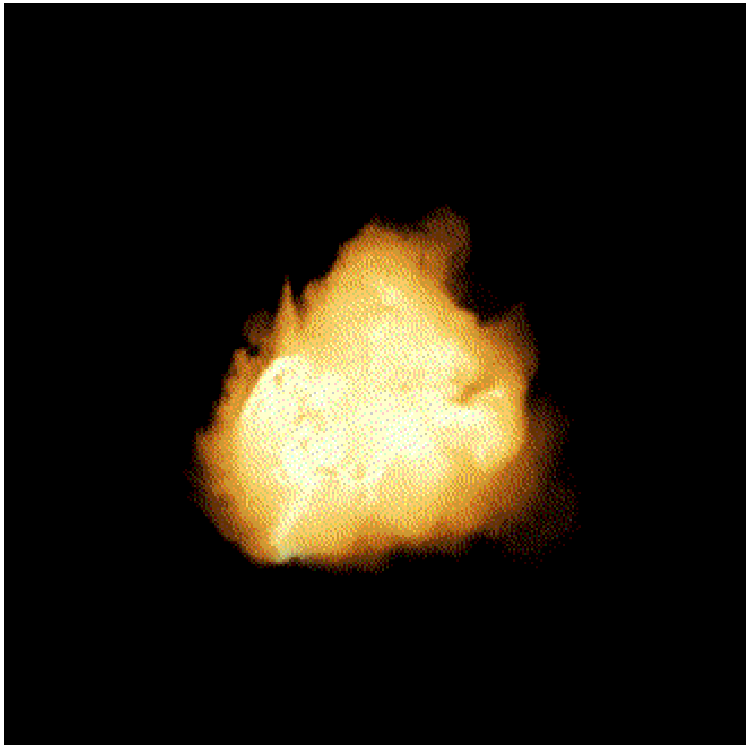
Spectroscopic evolution – "iron-curtain" *

maximum, l'ejecta si raffredda, e la fotosfera recede verso l'interno ... co

Fenomenologia

Spectroscopic evolution – "iron-curtain" *

maximum, l'ejecta si raffredda, e la fotosfera recede verso l'interno ... co



Fenomenologia

Spectroscopic evolution – "iron-curtain" *

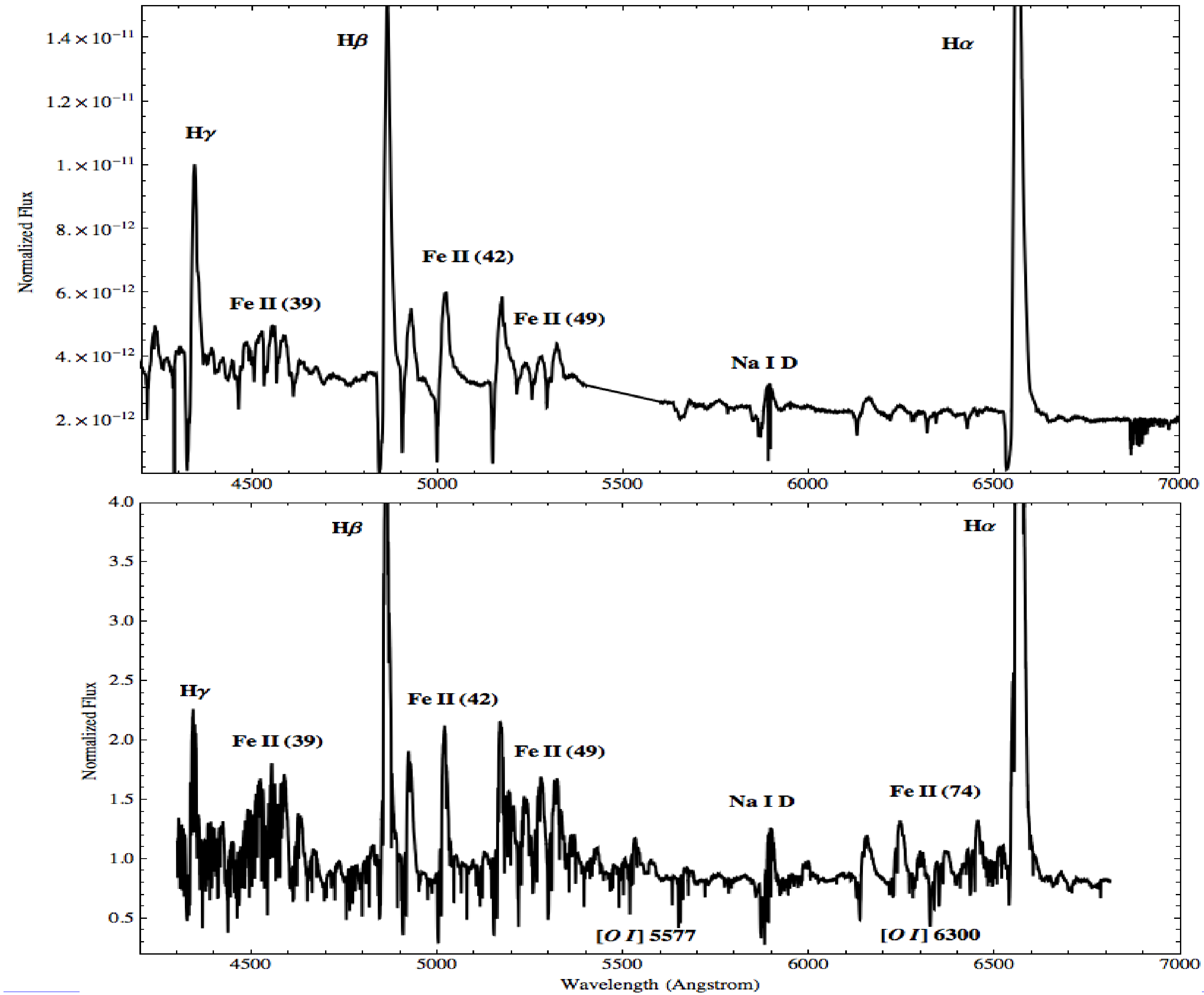
maximum, l'ejecta si raffredda, e la fotosfera recede verso l'interno ... co

→ P Cygni profiles

→ High-ionization lines spariscono

→ presenza di Fe-peak elementi

Fenomenologia



T Pyx
28 days
VLT-XSH

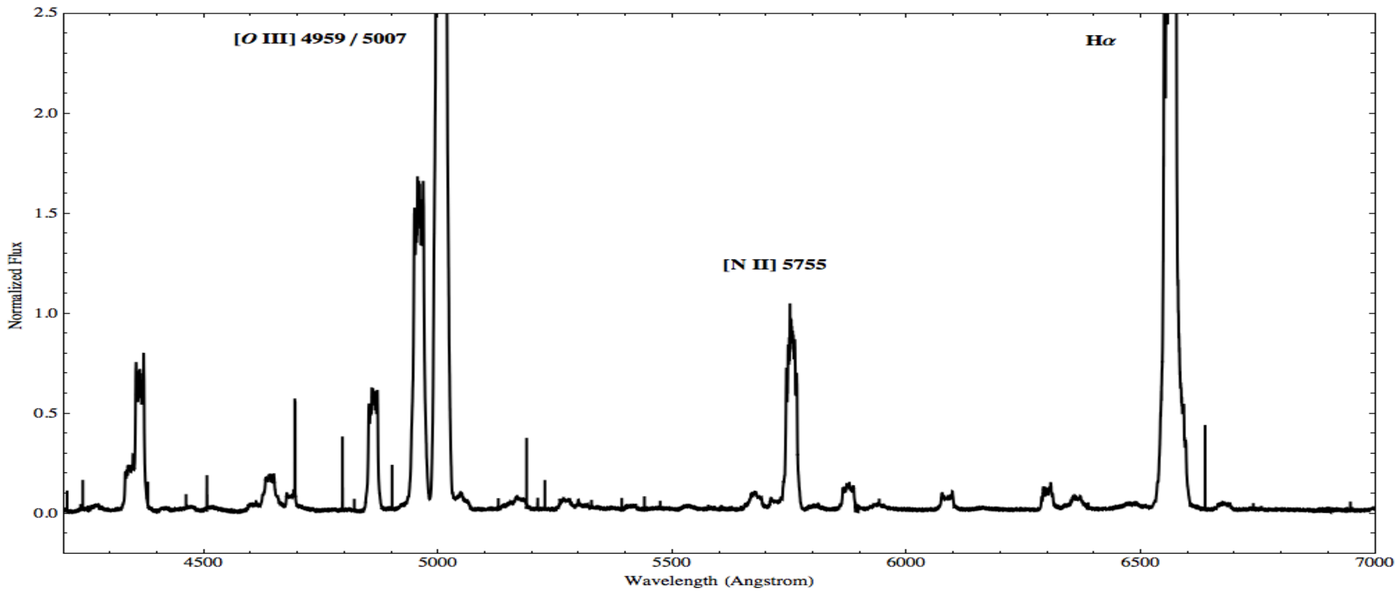
V1369 Cen
11 days
PUCHEROS

Fenomenologia

Fase nebulare

Ejecta completamente "congelato"

Righe di H, He e proibite di N, C, O e Ne
→ i principali prodotti del TNR

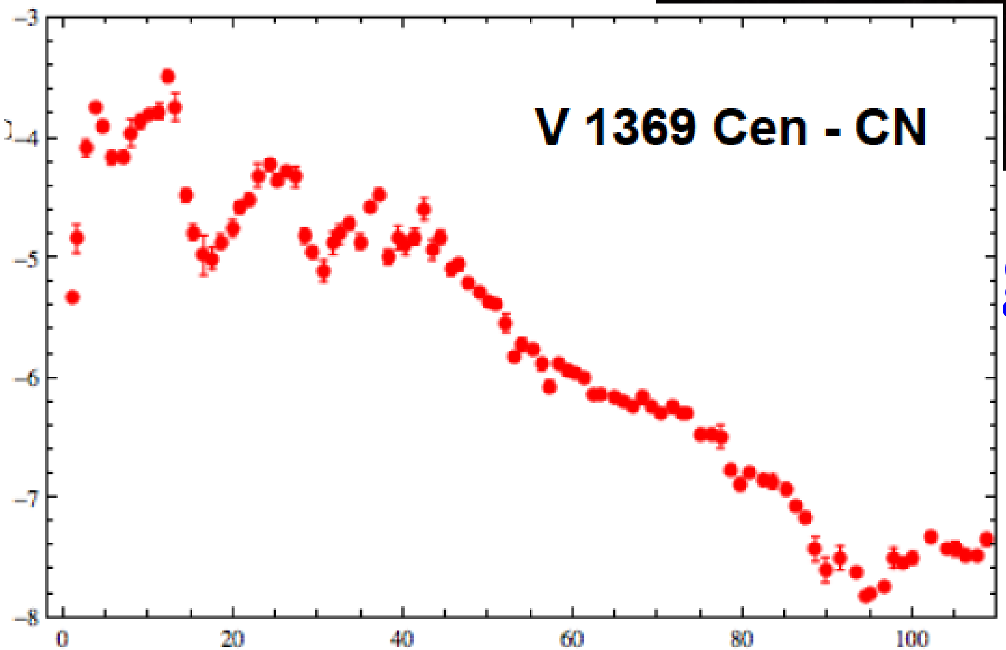


V1369 Cen
243 days
FEROS

"Nebular"

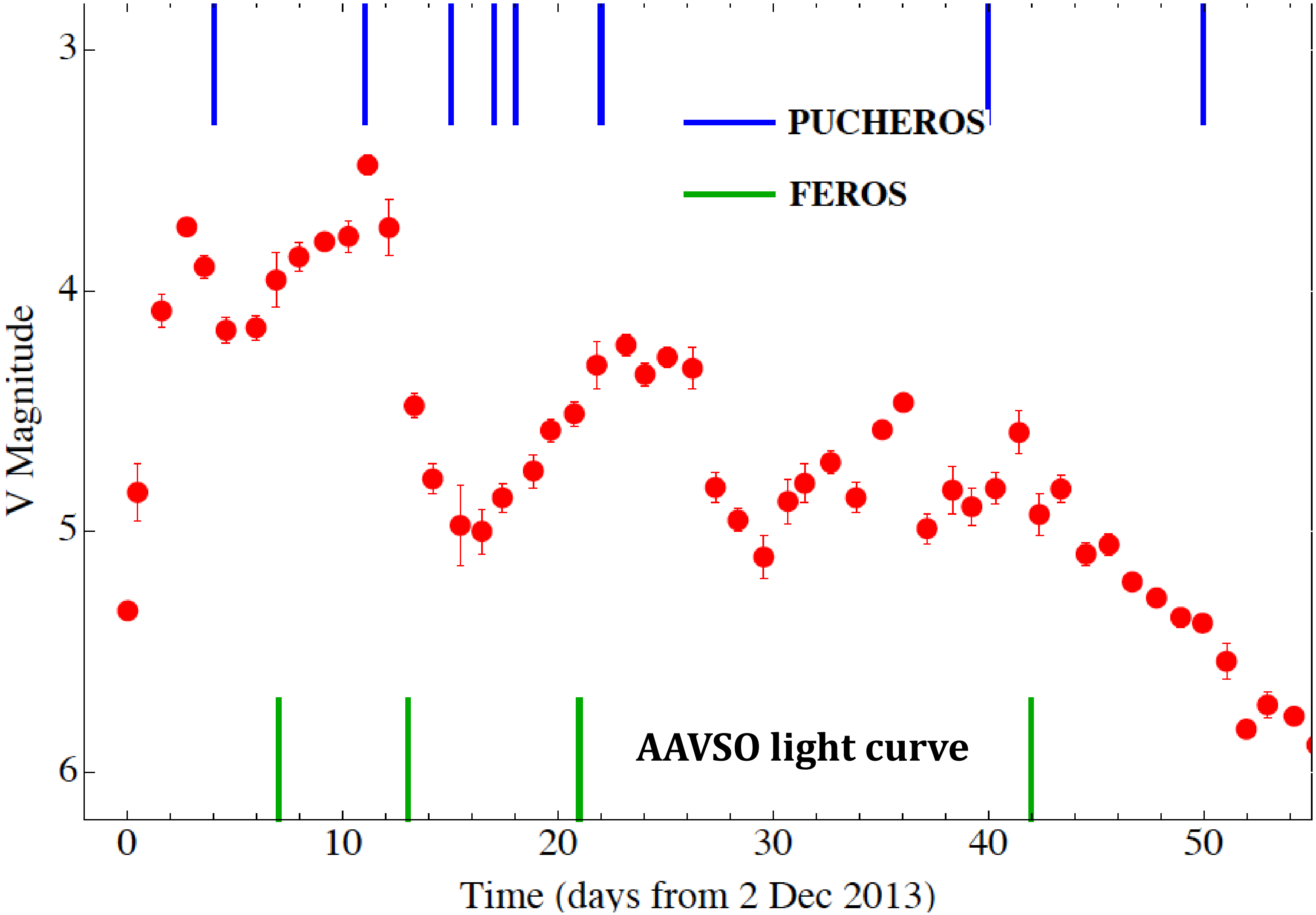
$V_{max} = 3.5$

50 days



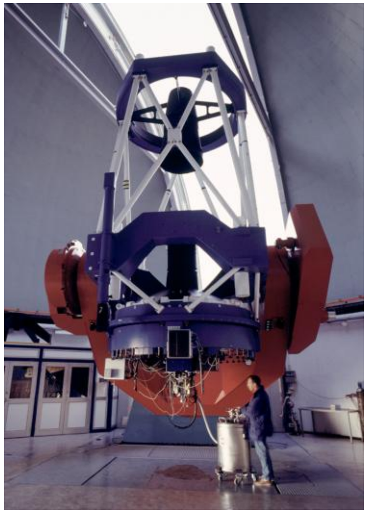
ghtest nova of the XXI cent
(up to now...)

Nova Cen 2013

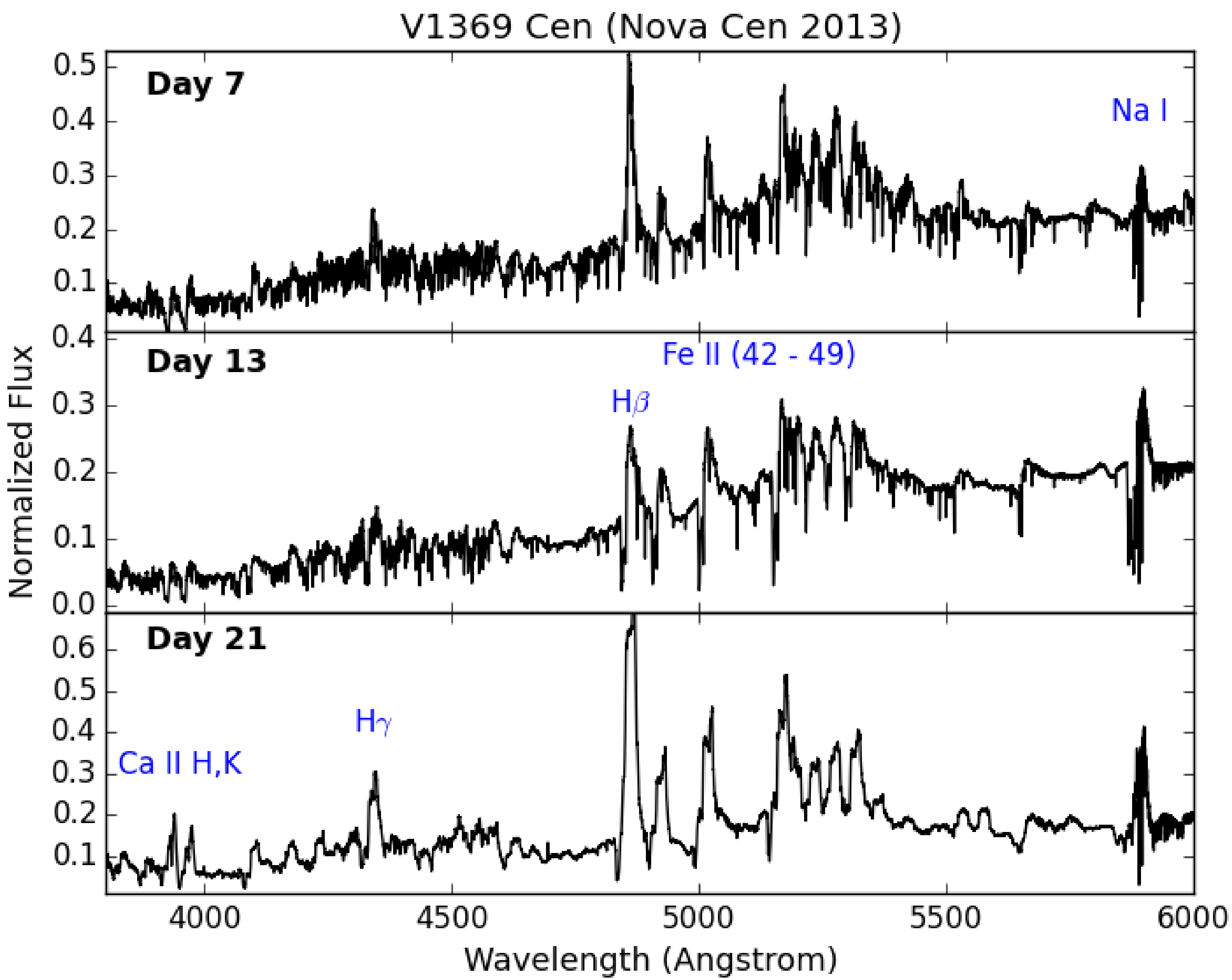


0.50m @PUC

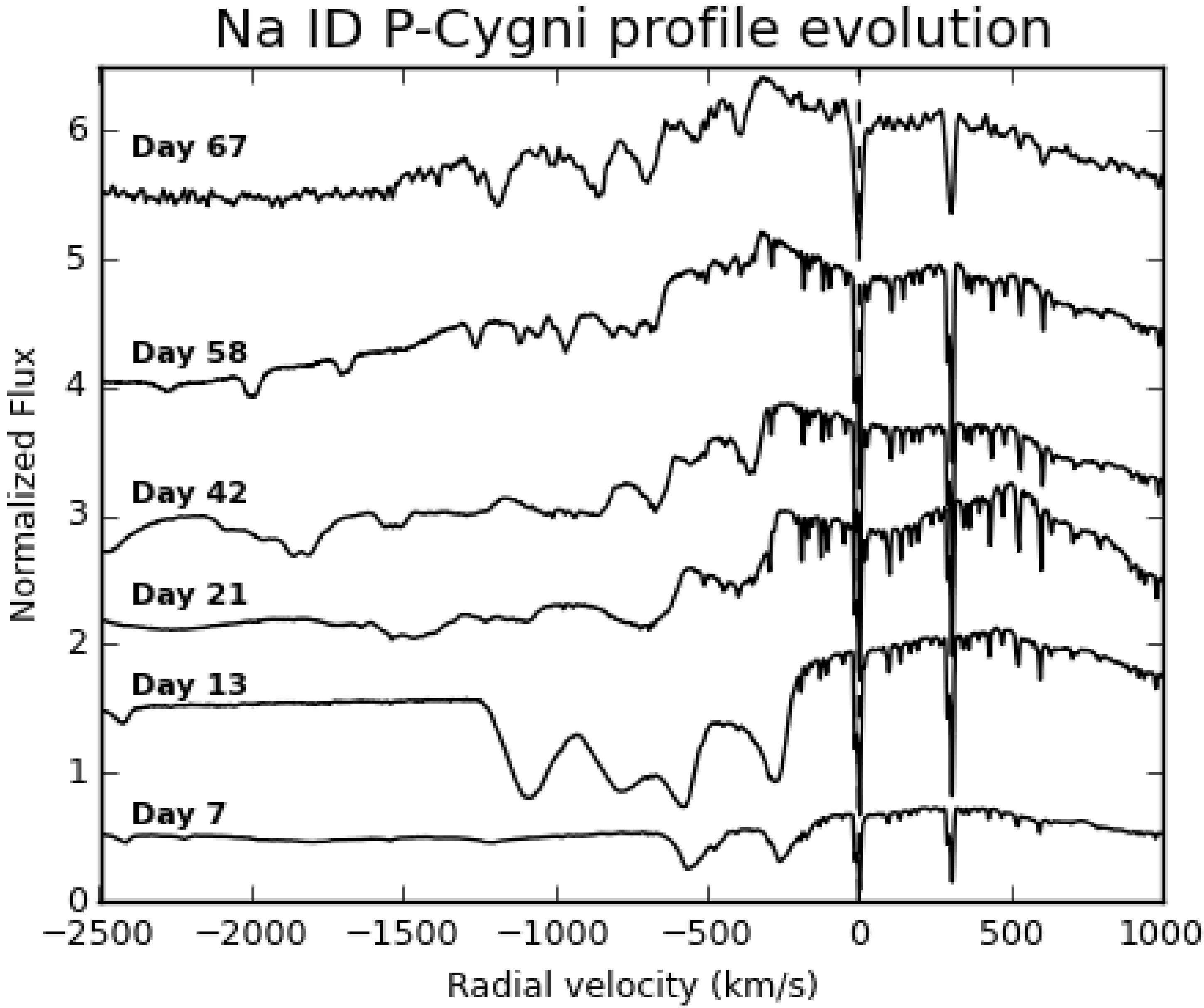
.2m @La Silla



Nova Cen 2013



Nova Cen 2013

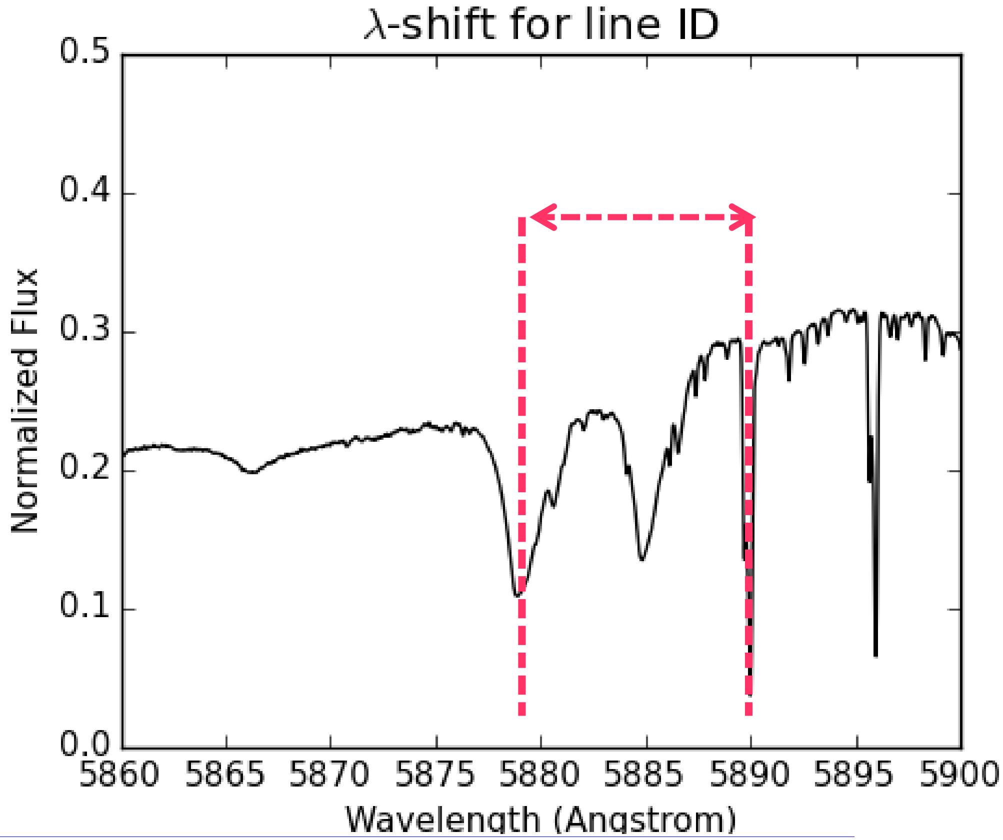


ID righe in assorbimento

→GOAL : usare la velocità principale misurata nelle righe de

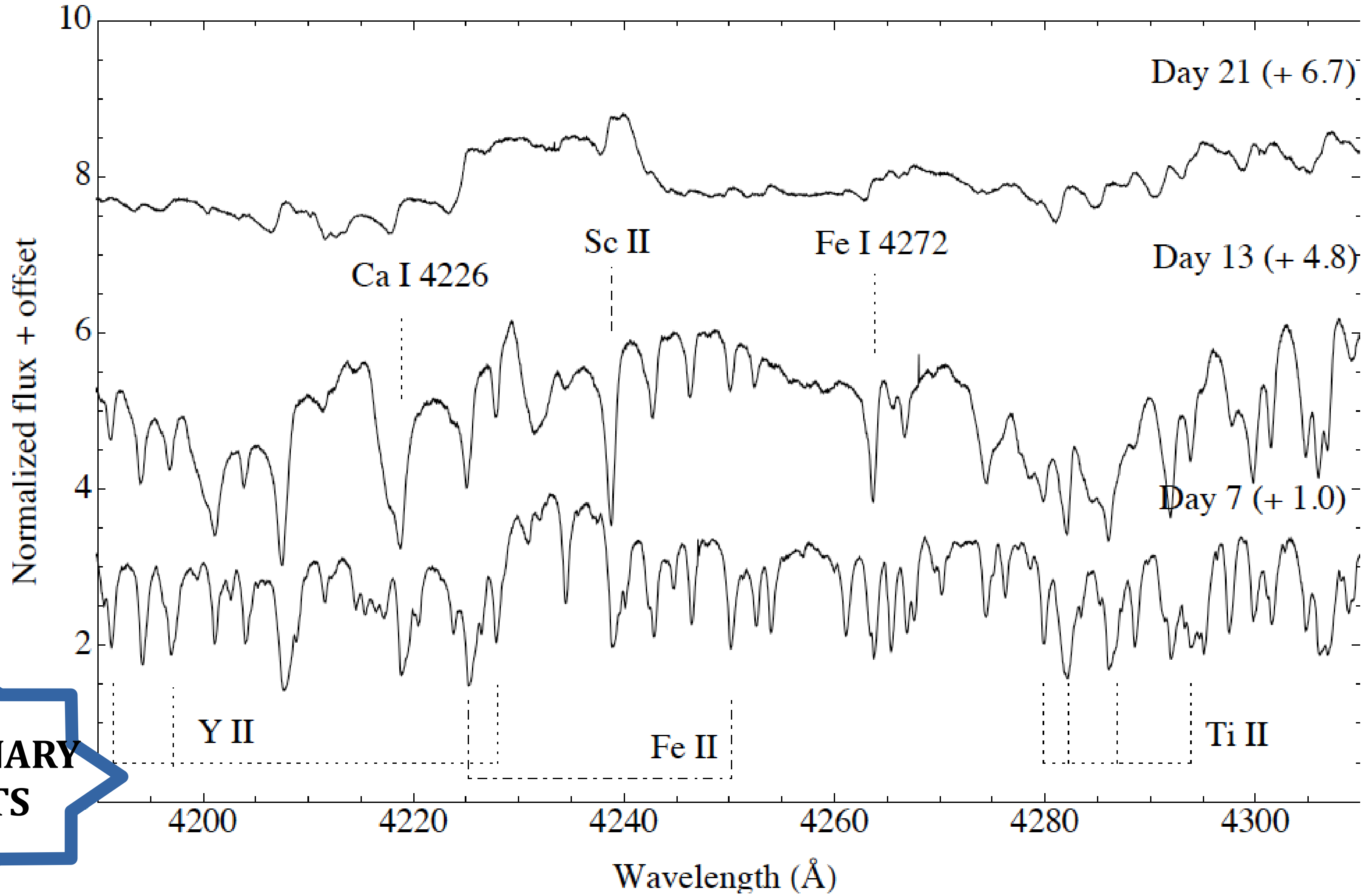
(Williams+ 2008)

X = λshift / λrest



ID righe in assorbimento

319 righe "narrow" identificate



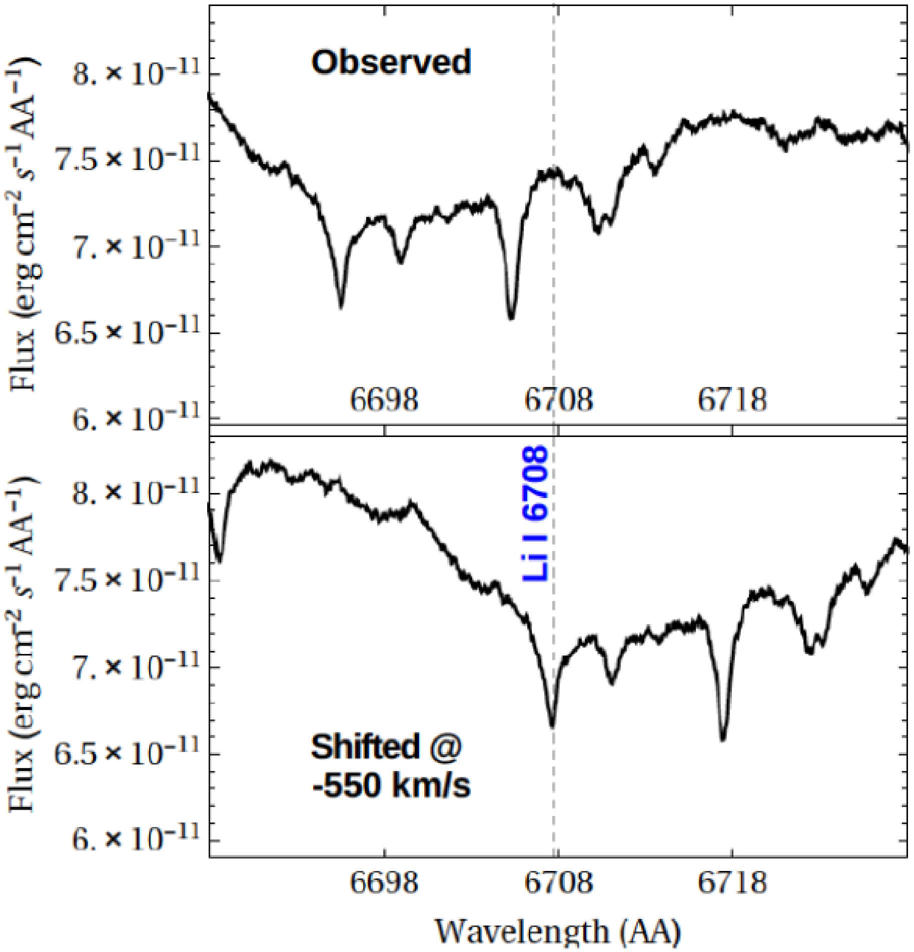
PRELIMINARY RESULTS

La riga di Li I 6708

ID di una riga @ 6695.6 on Day 7
→ Li I 6708 in espansione @ -550 km/s

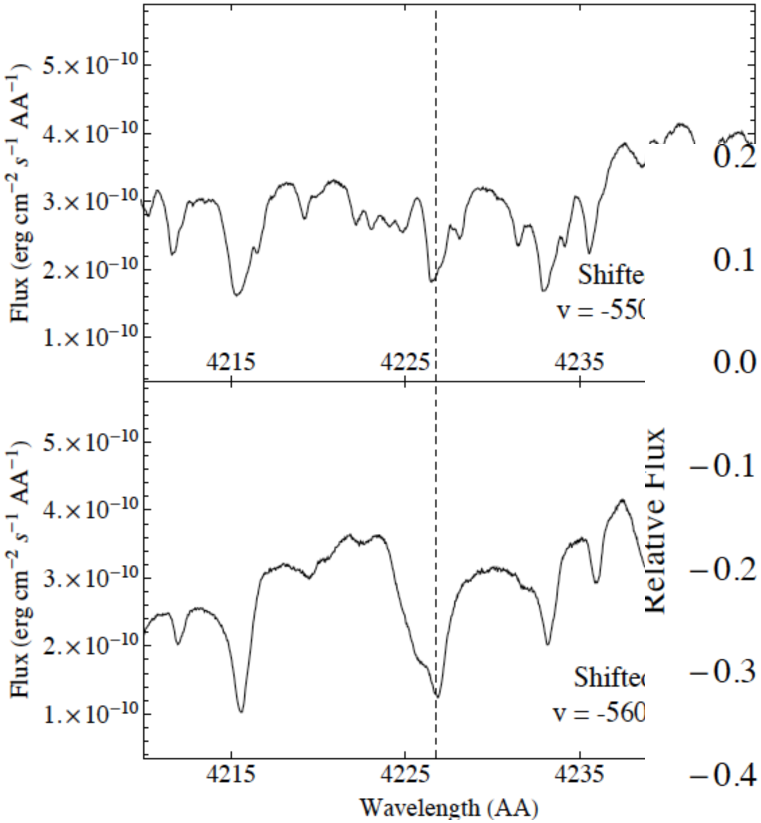
rvato per due settimane dall'out

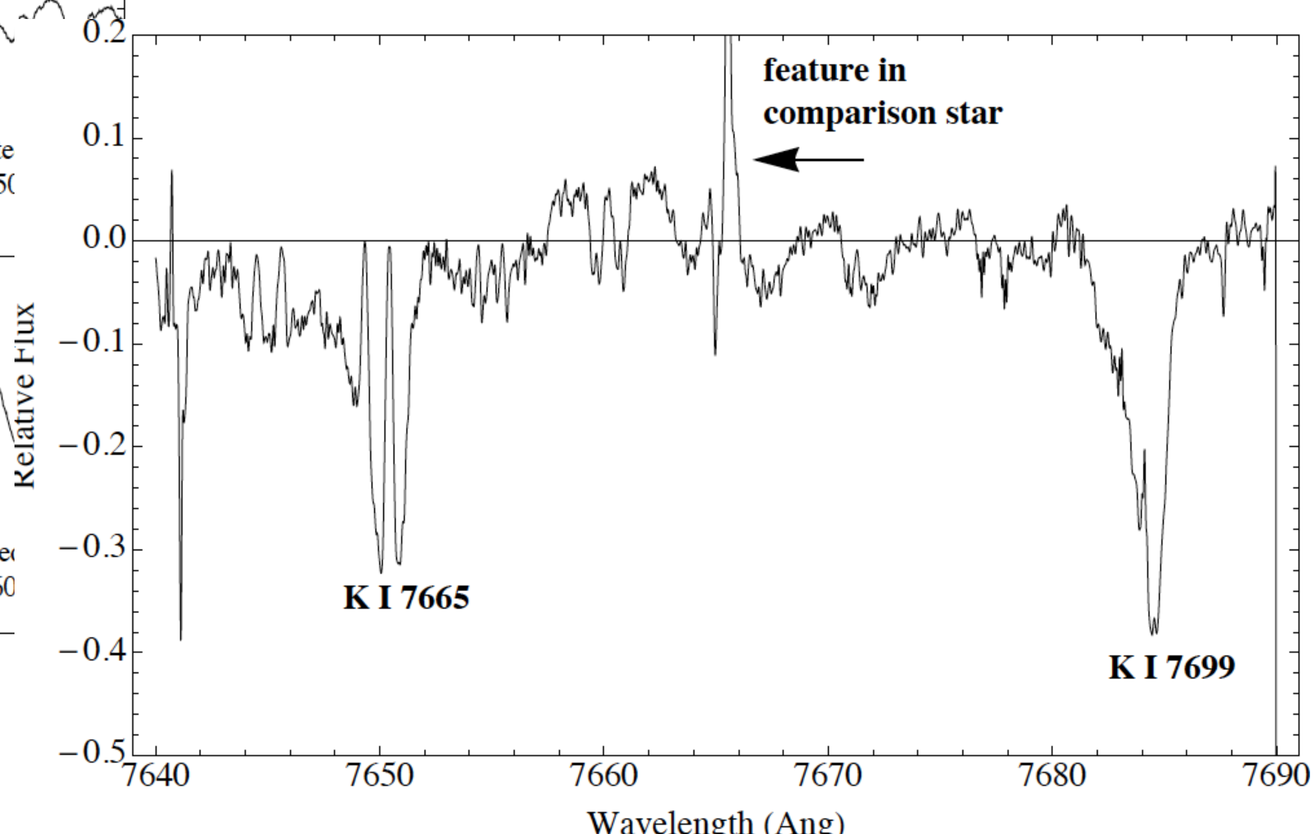
ghe con simile "configuraz elett
Ca I 4226
K I 7665-7699
… and Na I …



La riga di Li I 6708

Ca I 4226





K I doublet deblended from telluric lines

The case of Li I 6708

Possible alternative to Li I 6708 ID

→DIB ? NO !

→a) no known DIB @ 6695.6

→b) DIB should persist with time

ength of these absorptions vary with time (as the principal absorpt

The case of Li I 6708

→UV pumping :

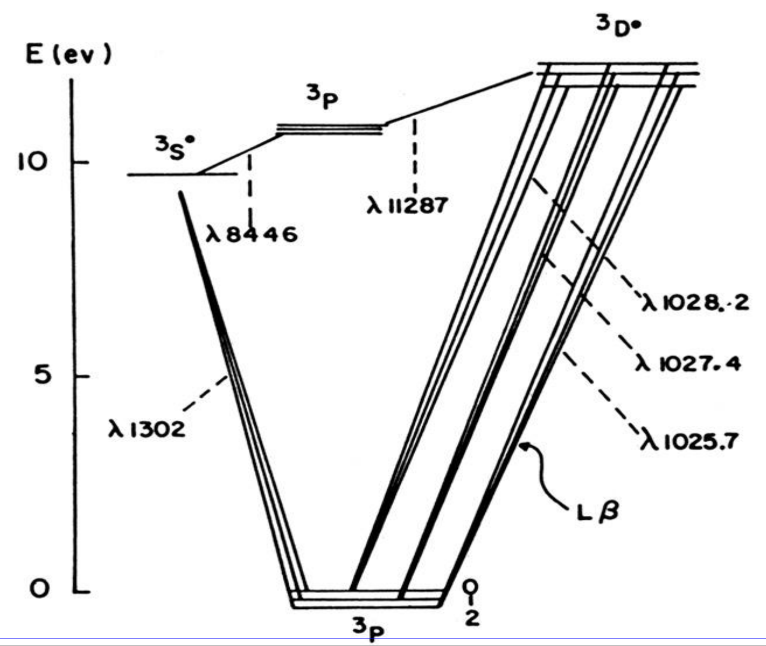
n by photon absorption (continuum or line coincidence) from a level l to

→2) spontaneous emission from x to a lower level u > l

→

<u>We would have a set of over-populated levels</u>

Example of line-pumping:
O I 8446 pumped
by H I Ly-beta 1025.72
(coincident with
O I 1025.76)



The case of Li I 6708

→Possible electric dipole transitions around
→ Li I 6707.8

-LAB-WAVL-ANG-AIR-	--SPC--	TT	-------TERM--------	-J_i-J_k-	--LEVEL-ENERGY--EV---	-REF---
6707.52	V I	E1	z4Go-e4F	9/2 - 7/2	2.742663 - 4.590589	ASD
6707.539	Fe II	E1	4Fo-4G	9/2 - 7/2	11.206500 - 13.054420	ASD
6707.64	Cr I	E1	c3D-x3Do	2 - 1	4.207484 - 6.055375	ASD
6707.75	Sc I	E1	4Do-4D	3/2 - 5/2	4.049237 - 5.897098	ASD
6707.76	Ti III	E1	3F-3Fo	3 - 3	16.515574 - 18.363434	ASD
6707.761	Li I	E1	2S-2Po	1/2 - 3/2	0.000000 - 1.847859	009
6707.84	Ne II	E1	1[2]o-2F	5/2 - 7/2	37.630381 - 39.478217	025,059
6707.9	V III	E1	g2D-v2Do	3/2 - 3/2	19.475450 - 21.323270	ASD
6707.912	Li I	E1	2S-2Po	1/2 - 1/2	0.000000 - 1.847817	009
6707.914	Kr I	E1	1/2[3/2]-3/2[3/2]o	2 - 2	12.143651 - 13.991468	ASD
6708.	Cl VII	E1	2D-2Fo	5/2 - 5/2	70.569600 - 72.417400	ASD

→database : LineList v2.05

http://www.pa.uky.edu/~peter/newpage/

The case of Li I 6708

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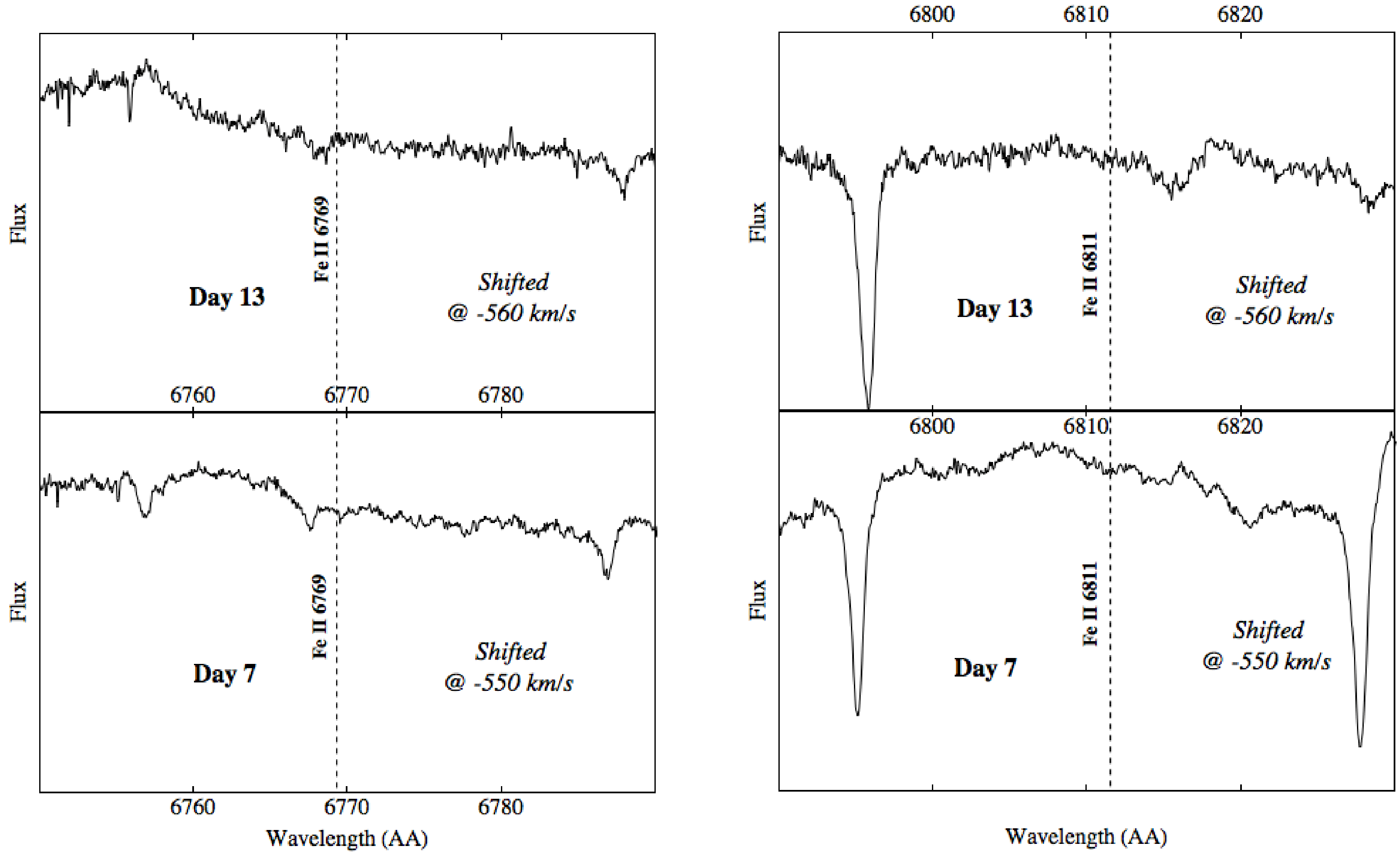
6707.914	Kr I	E1	1/2[3/2]-3/2[3/2]o	2 - 2	12.143651 - 13.991468	ASD
6708.	Cl VII	E1	2D-2Fo	5/2 - 5/2	70.569600 - 72.417400	ASD

c dipole transitions with same initial level
(J = 9/2)

Fe II 6769-272 4Fo-4G 9/2 - 9/2 11.206500 - 13.037568
Fe II 6811.491 4Fo-4G 9/2 - 11/2 11.206500 - 13.026219

The case of Li I 6708

→ NO Fe II



Massa totale di Li - novae

Mass Li = $\underline{0.3 – 4.8 \times 10^{-10}}$ Msun

+

nova rate in the MW = 20-34 yr^{-1}

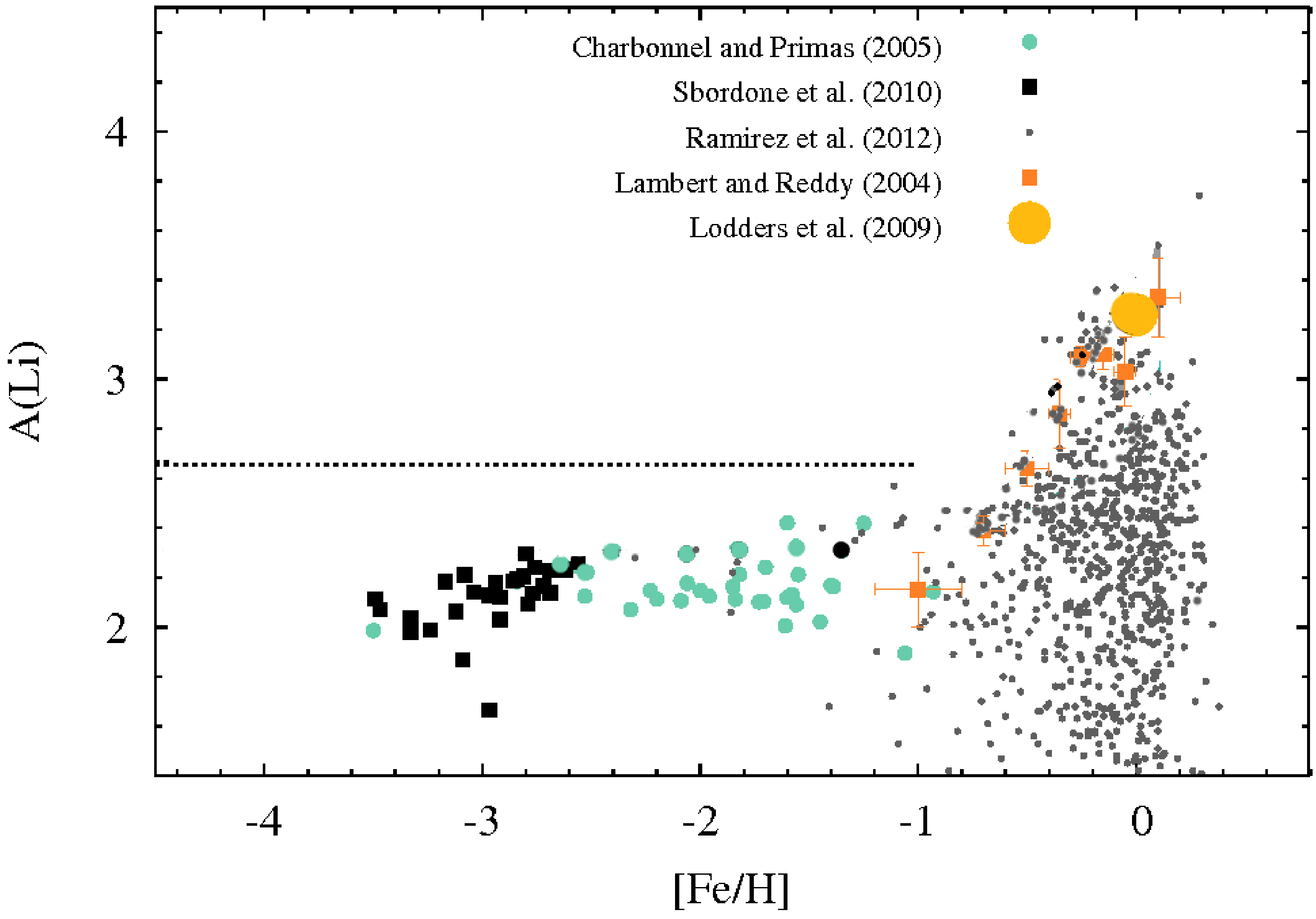
"slow" novae :

→ Ejecta più massivo

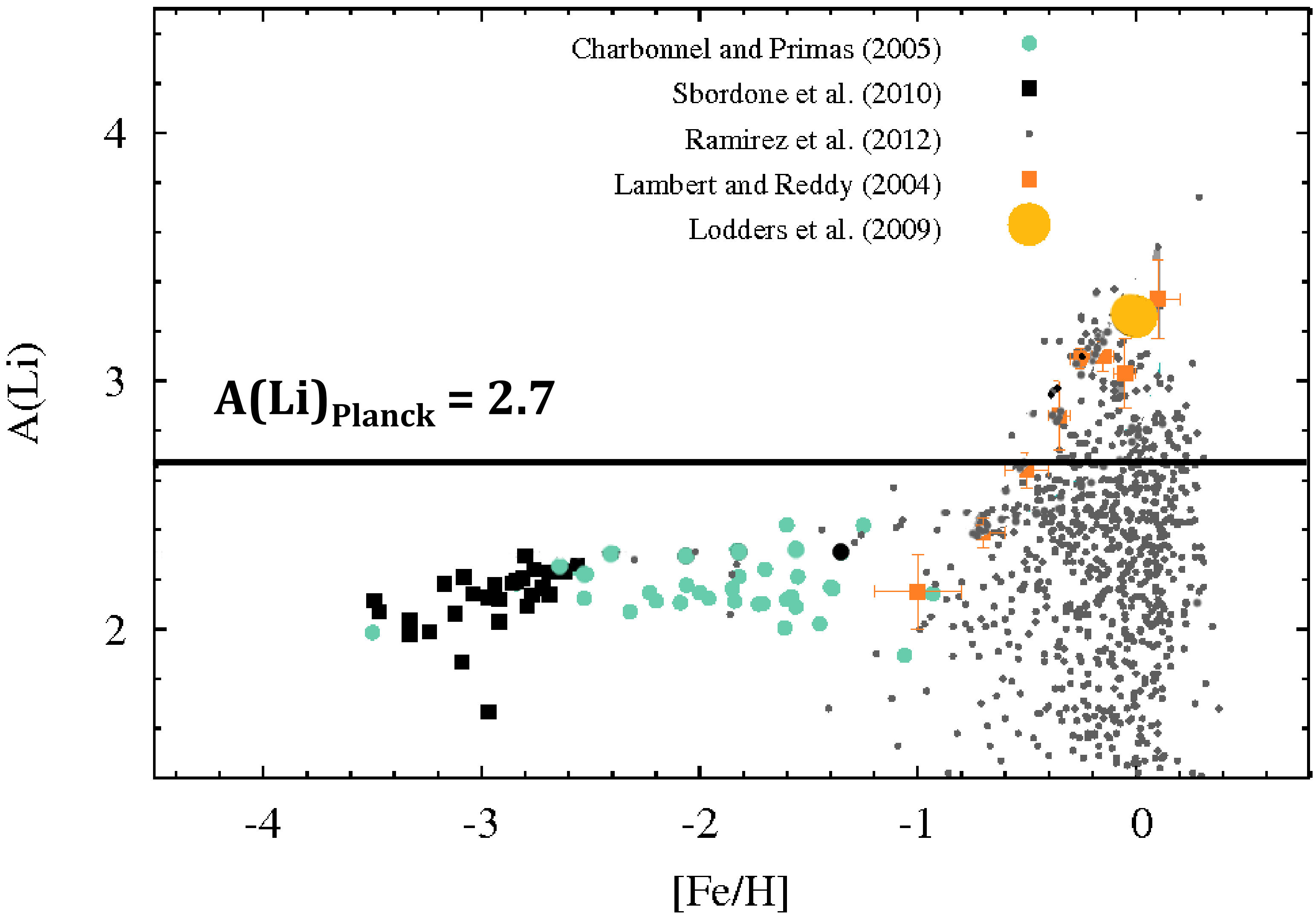
→ 70% della MW pop di novae → 15-24 yr^{-1}

⇨ Mass Li ~ 5 – 200 Msun

Conseguenze

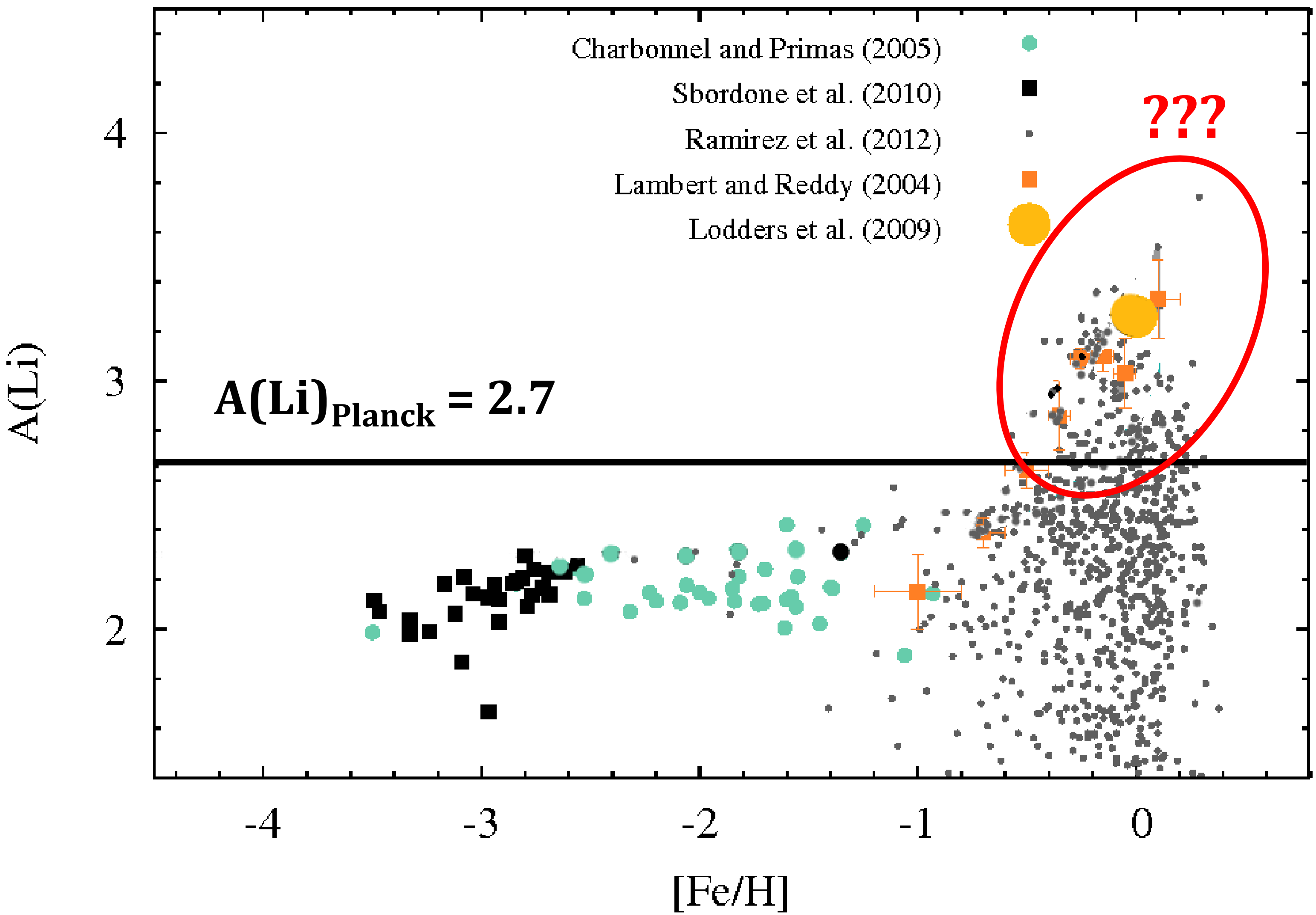


Conseguenze



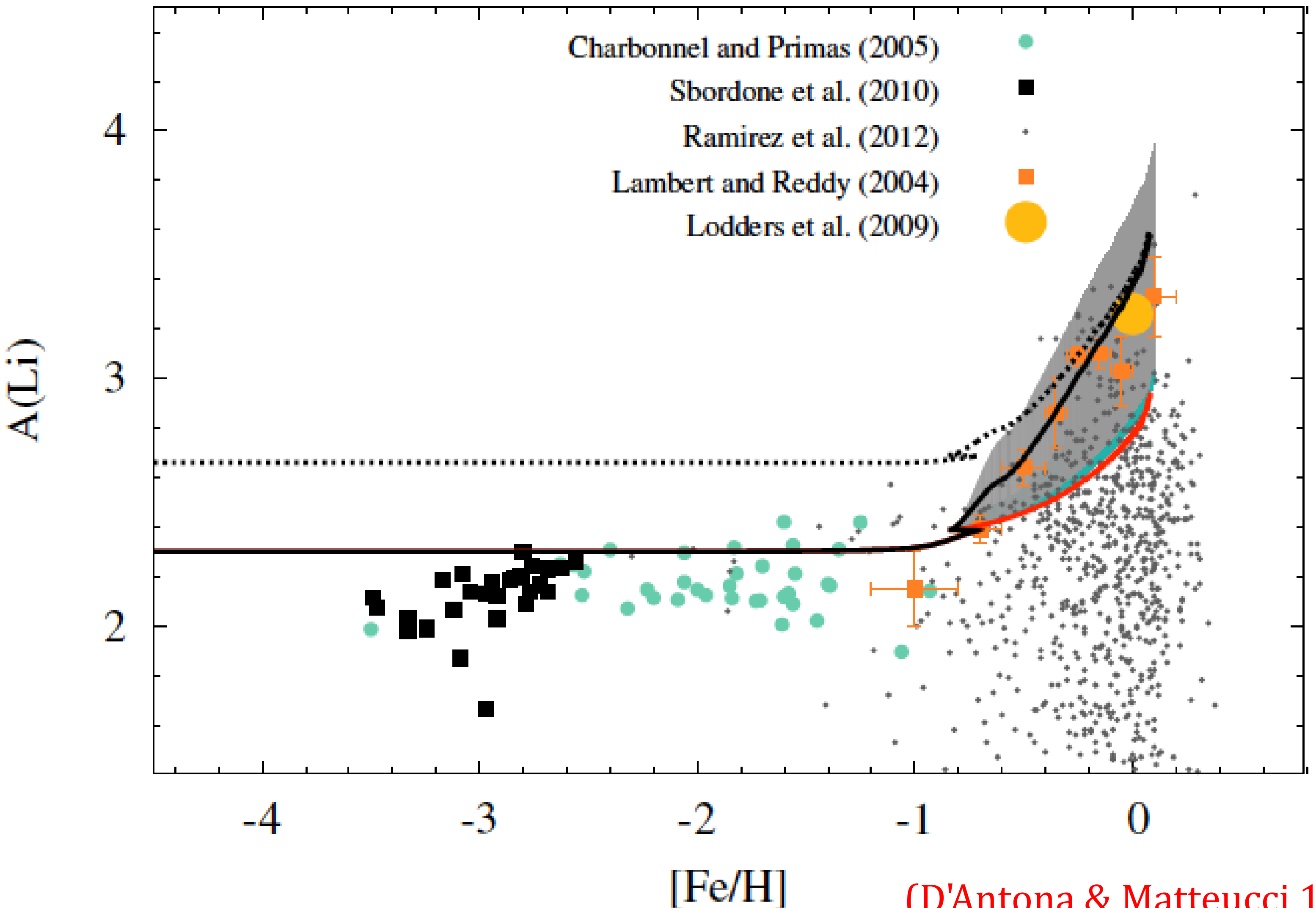
(Coc et al. 2014)

Conseguenze



(Coc et al. 2014)

Conseguenze



(D'Antona & Matteucci 1991, Romano+ 1

Novae & amateurs

vae (le CV in generale) rappresentano un target speciale per gli astr

→Scoperta tramite strumenti a largo campo

→Monitoring multi-filtri (BVRI, no LRGB !!!)

nediata ripresa per determinare se nova o DN o altro (sia fotom che

→Ricerca in galassie vicine (tramite H-alpha filter)

HR & amateurs

mi anni, la strumentazione a disposizione dell'amatore è molto "im

pi con diametro up to 30-40cm + CCD con ampio campo + spettrogr

→ Monitoring novae in HR

→ Non solo novae: ricerca di esopianeti !!!

→ Studio dei fenomeni di accrescimento su CV magnetiche e non

Altre conseguenze...

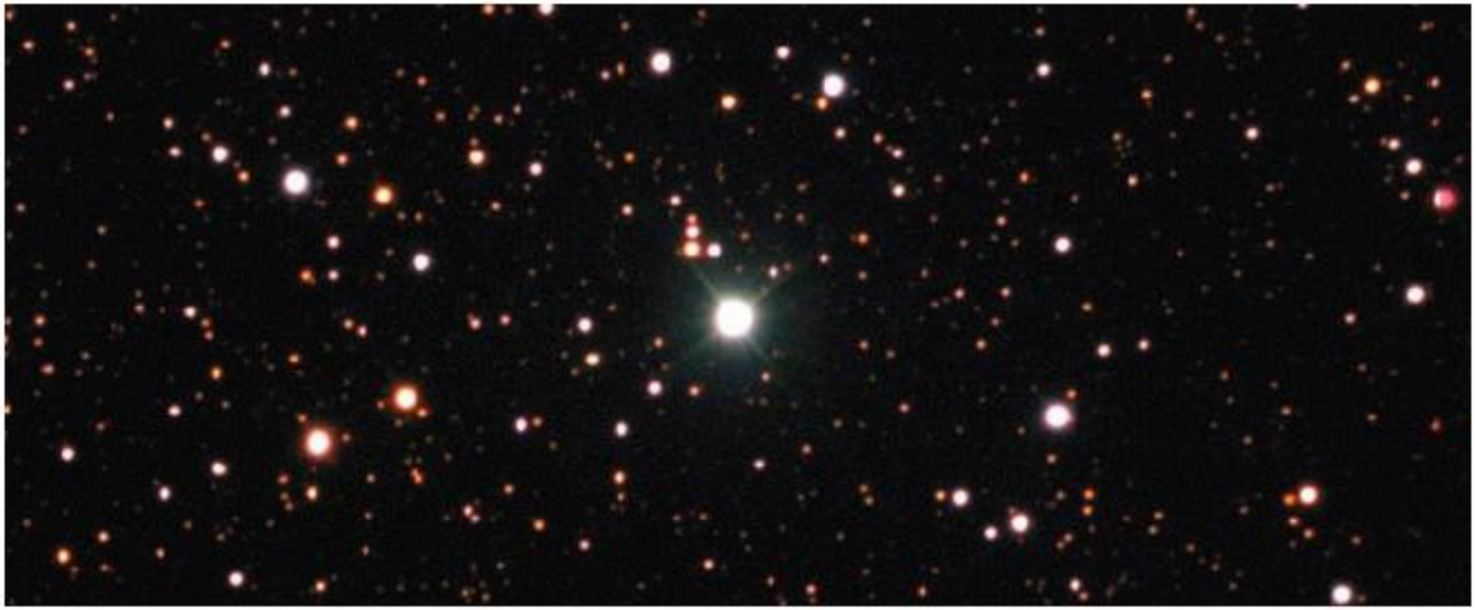
European
Southern
Observatory

eso1531 — Science Release

SPACE SCOOP

First Detection of Lithium from an Exploding Star

29 July 2015



The chemical element lithium has been found for the first time in material ejected by a nova. Observations of Nova Centauri 2013 made using telescopes at ESO's La Silla Observatory, and near Santiago in Chile, help to explain the mystery of why many young stars seem to have more of this chemical element than expected. This new finding fills in a long-missing piece in the puzzle representing our galaxy's chemical evolution, and is a big step forward for astronomers trying to understand the amounts of different chemical elements in stars in the Milky Way.

Altre conseguenze...

Altre conseguenze...

Observatory

EUROPEAN SOUTHERN OBSERVATORY

The New York Times

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NEW YORK, TUESDAY, AUGUST 4, 2015

ASTRONOMY

Theory on Lithium in Stars May Be Confirmed

Astronomers believe that the metal lithium was created during the Big Bang 13.8 billion years ago. Yet old stars often have less lithium than might be expected, while young stars seem to have much more. Some scientists have speculated the source of extra lithium in young stars may be stellar explosions, or novae, expelling matter into space. Now lithium has been found in material ejected by the younger star Nova Centauri 2013, which may confirm the theory. The observation was made by telescopes at La Silla Observatory, the European Southern Observatory's site in Chile, above.

The Register®

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Science

Exploding 'laptop batt' IN SPAAACE! Speeding lithium spaffed by nova

One step closer to cracking riddle of light metal's origins

The case of Li I 6708

Possible alternative to Li I 6708 ID

→DIB ? NO !

→a) no known DIB @ 6695.6

→b) DIB should persist with time

ength of these absorptions vary with time (as the principal absorpt

The case of Li I 6708

→UV pumping :

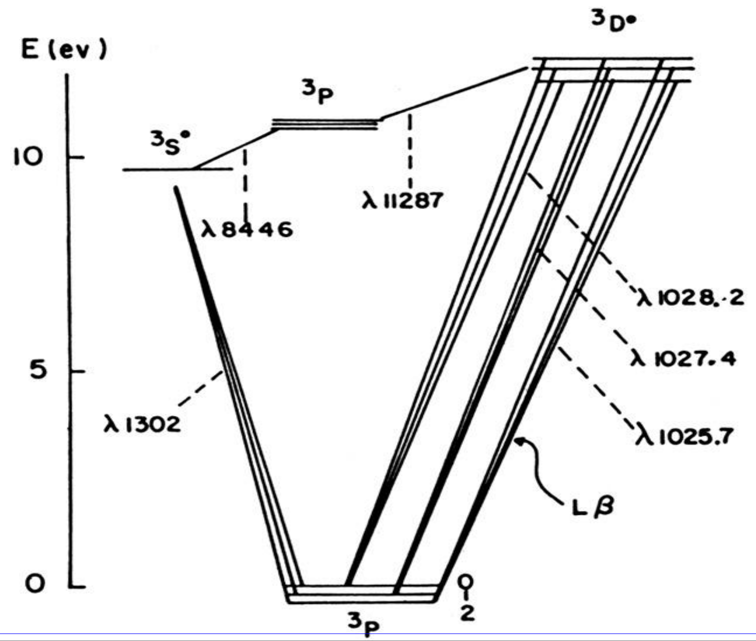
n by photon absorption (continuum or line coincidence) from a level l to

→2) spontaneous emission from x to a lower level u > l

→

We would have a set of over-populated levels

Example of line-pumping:
O I 8446 pumped
by H I Ly-beta 1025.72
(coincident with
O I 1025.76)



The case of Li I 6708

→Possible electric dipole transitions around
→ Li I 6707.8

-LAB-WAVL-ANG-AIR-	--SPC--	TT	--------TERM--------	-J_i-J_k-	--LEVEL-ENERGY--EV---	-REF---
6707.52	V I	E1	z4Go-e4F	9/2 - 7/2	2.742663 - 4.590589	ASD
6707.539	Fe II	E1	4Fo-4G	9/2 - 7/2	11.206500 - 13.054420	ASD
6707.64	Cr I	E1	c3D-x3Do	2 - 1	4.207484 - 6.055375	ASD
6707.75	Sc I	E1	4Do-4D	3/2 - 5/2	4.049237 - 5.897098	ASD
6707.76	Ti III	E1	3F-3Fo	3 - 3	16.515574 - 18.363434	ASD
6707.761	Li I	E1	2S-2Po	1/2 - 3/2	0.000000 - 1.847859	009
6707.84	Ne II	E1	1[2]o-2F	5/2 - 7/2	37.630381 - 39.478217	025,059
6707.9	V III	E1	g2D-v2Do	3/2 - 3/2	19.475450 - 21.323270	ASD
6707.912	Li I	E1	2S-2Po	1/2 - 1/2	0.000000 - 1.847817	009
6707.914	Kr I	E1	1/2[3/2]-3/2[3/2]o	2 - 2	12.143651 - 13.991468	ASD
6708.	Cl VII	E1	2D-2Fo	5/2 - 5/2	70.569600 - 72.417400	ASD

→database : LineList v2.05

http://www.pa.uky.edu/~peter/newpage/

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c dipole transitions with same initial level

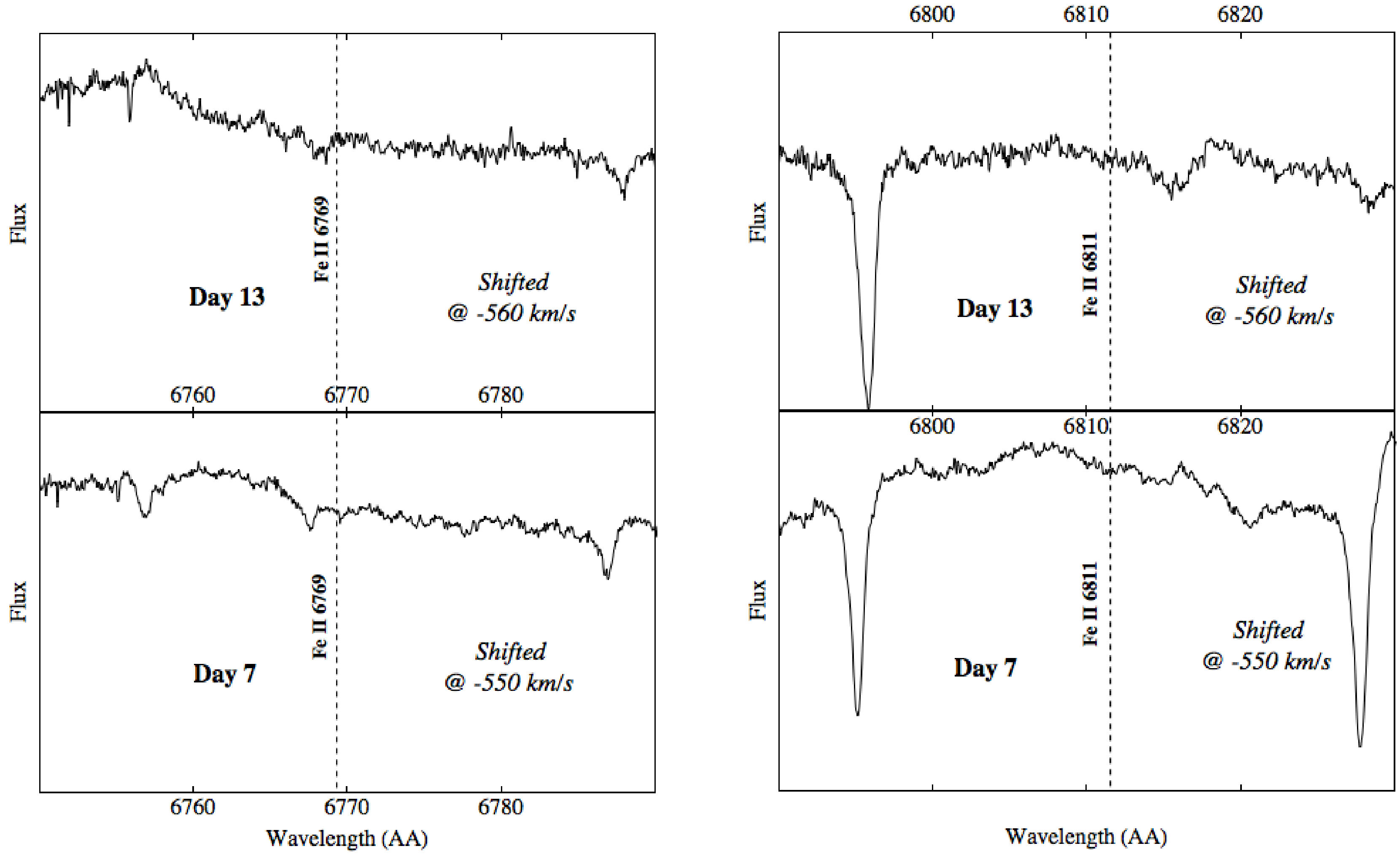
(J = 9/2)

Fe II 6769-272 4Fo-4G 9/2 - 9/2 11.206500 - 13.037568

Fe II 6811.491 4Fo-4G 9/2 - 11/2 11.206500 - 13.026219

The case of Li I 6708

→ NO Fe II



Estimate of mass ejected

Procedure

Na are alkali metals with similar Grotrian diagrams and resonant t

→The ratio of their τ ∞ abundance ratio :

(Friedjung 1979)

d Li/K to det

$$\frac{A_m(Li)}{A_m(Na)} = \left(\frac{W_{Li6708}}{6708^2} \Big/ \frac{W_{NaD2}}{5890^2} \right) \times \frac{gf_{NaD2}}{gf_{Li6708}} \times \frac{u_{Li}}{u_{Na}}$$

al results of n

(Spitzer 1998)

Estimate of mass ejected

Yields from CO Nova Models (Mass Fractions)

Nucleus	Model CO1	CO2	CO3	CO4	CO5	CO6	CO7[a]
^{1}H	5.1E − 1	3.3E − 1	3.2E − 1	4.7E − 1	3.0E − 1	1.2E − 1	3.0E − 1
^{3}He	7.0E − 6	9.2E − 6	6.1E − 6	1.5E − 6	4.1E − 6	2.8E − 6	3.7E − 6
^{4}He	2.1E − 1	1.4E − 1	1.5E − 1	2.5E − 1	1.6E − 1	9.0E − 2	1.6E − 1
^{7}Be	4.4E − 7	9.6E − 7	3.1E − 6	6.0E − 6	8.1E − 6	4.0E − 6	3.1E − 6
^{22}Ne	2.6E − 3	5.0E − 3	5.0E − 3	2.2E − 3	4.8E − 3	7.3E − 3	5.0E − 3
^{22}Na	3.4E − 7	3.0E − 7	1.6E − 7	3.8E − 7	2.9E − 7	1.1E − 7	8.5E − 8
^{23}Na	3.6E − 5	3.6E − 5	3.4E − 5	1.6E − 5	2.0E − 5	2.4E − 5	3.4E − 5
^{24}Mg......	5.7E − 5	6.3E − 5	1.6E − 5	4.4E − 6	1.8E − 5	1.0E − 5	2.8E − 6
^{38}Ar.......	1.2E − 5	7.7E − 6	7.7E − 6	1.2E − 5	7.7E − 6	3.8E − 6	7.7E − 6
^{39}K	2.6E − 6	1.7E − 6	1.7E − 6	2.6E − 6	1.7E − 6	8.7E − 7	1.7E − 6

(Josè & Hernanz 1998)

Estimate of ejected H mass

Estimate of mass ejected

Mass H II from Hbeta:

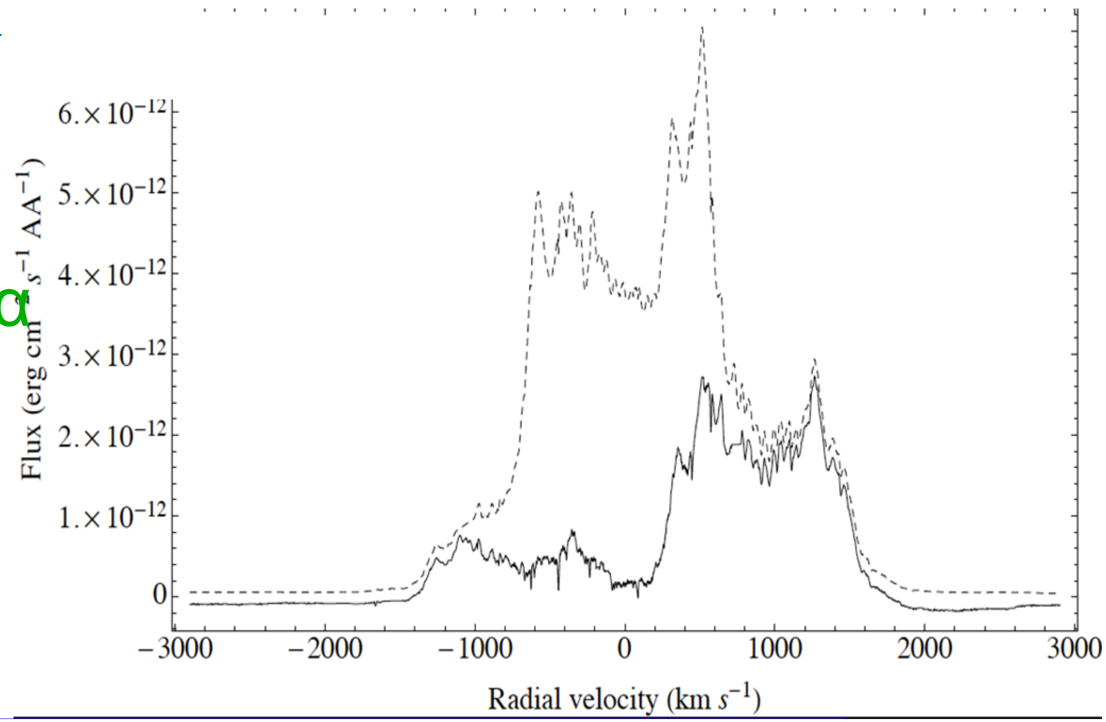
1) Estimate of e- density from [N II] in nebular phase

$$N_e = \sqrt{T_e} \cdot \frac{1.94 \cdot 10^5 - \dfrac{1.97 \cdot 10^4 \cdot R_2}{(e^{25000/T_e})}}{\dfrac{61.5 \cdot R_2}{(e^{25000/T_e})} - 1}$$

$$R_2 = \frac{I(6548) + I(6584)}{I(5755)}$$

(Osterbrock 1989)

II] 6548, 6584 deblended from Hα using Hβ as template



(Mason + 2005, Ederoclite + 2005)

Estimate of mass ejected

Mass H II from Hbeta:

2) Assuming ejecta as spherical shell of radius $r = v_{\rm exp} \Delta t$

→Volume $V = 4\pi (v_{\rm exp} \Delta t)^3 f$

(Mustel & Boyarchuk 1970)

→3) The observed Hβ flux is given by

$$I_\lambda = \left[\left(\frac{4\pi j_\lambda}{N_{\rm e} N_{\rm p}} \right) N_{\rm e} N_{\rm p} V \right] \frac{1}{4\pi d^2}$$

Emissivity (Osterbrock)

Distance (= 2.5 kpc)

Ne = Np

Estimate of mass ejected

Mass H = 10^{-4} Msun

→ With f* = 0.5

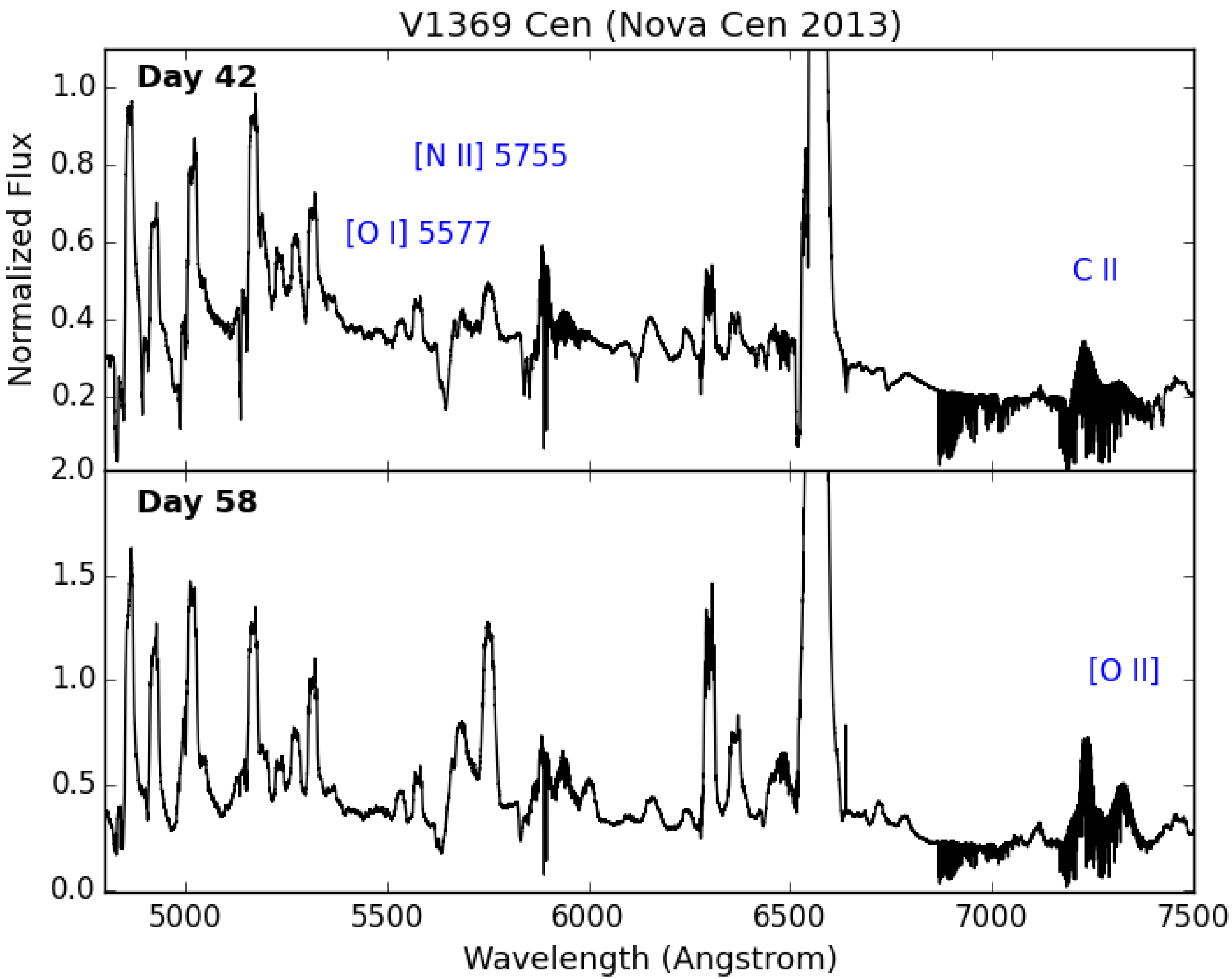
→

From Jose&Hernanz 1998 table
+ abundance ratio
Li/Na & Li/K

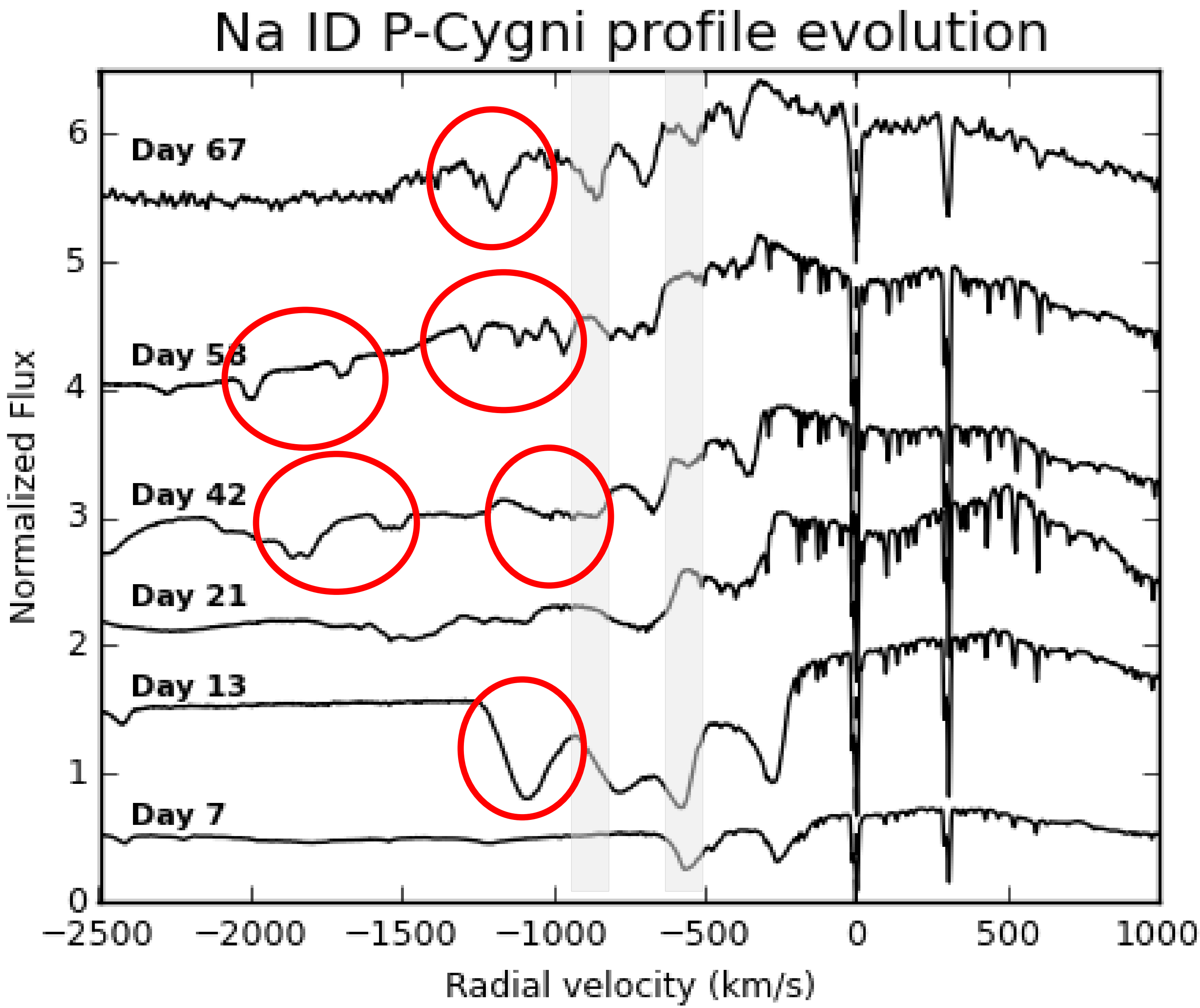
→Mass Li = 0.3 – 4.8 x 10^{-10} MSun

*f is the filling factor

Pre-nebular phase



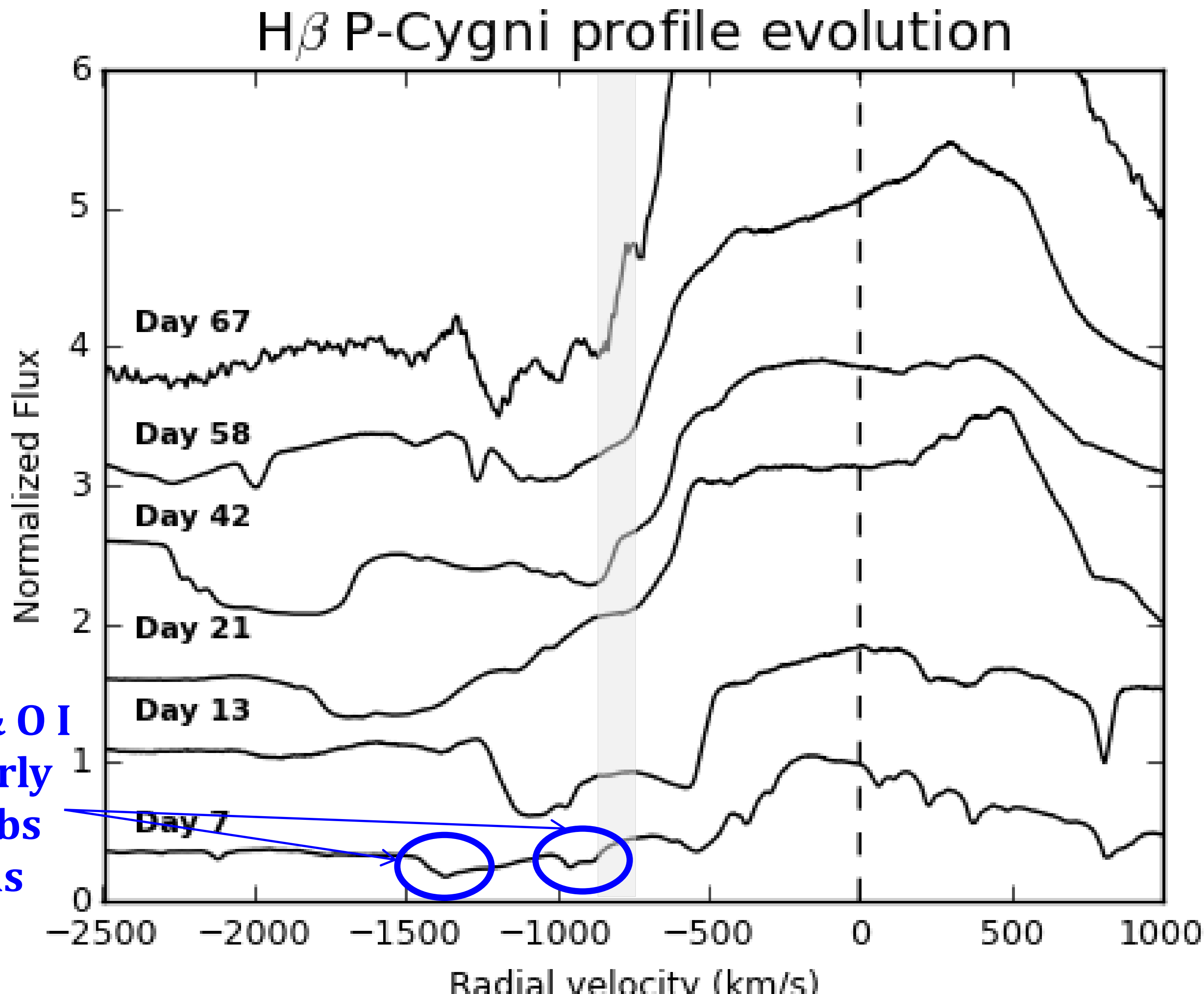
P-Cygni evolution



Principal Absorptions

Multiple "Diffuse enhanced"

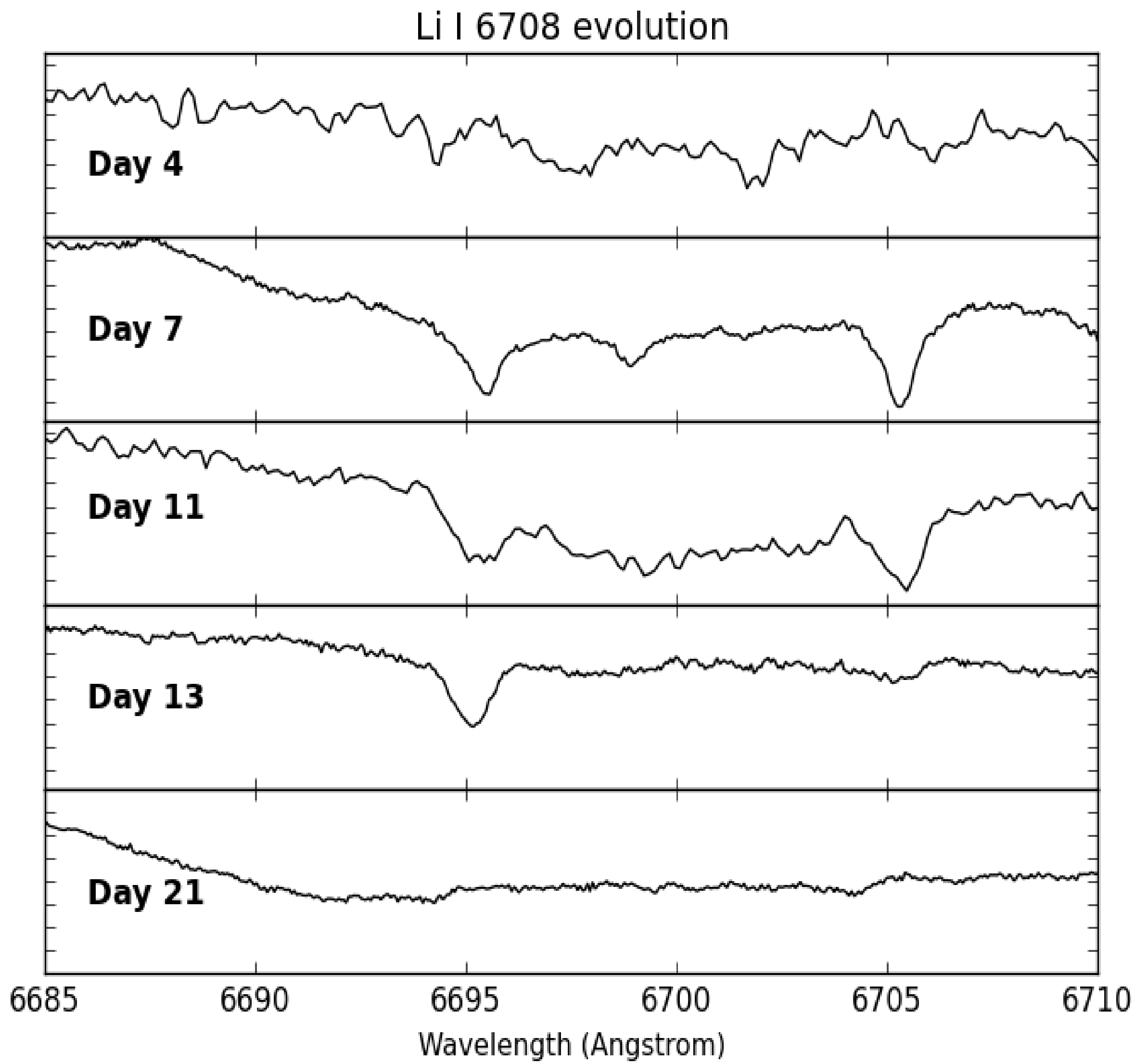
P-Cygni evolution



Balmer & O I show early faster abs systems

Principal Absorptions

Lithium evolution



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ntaneous emission from possible UV-excited element (maybe Ne II,

→Line coincidence difficult...

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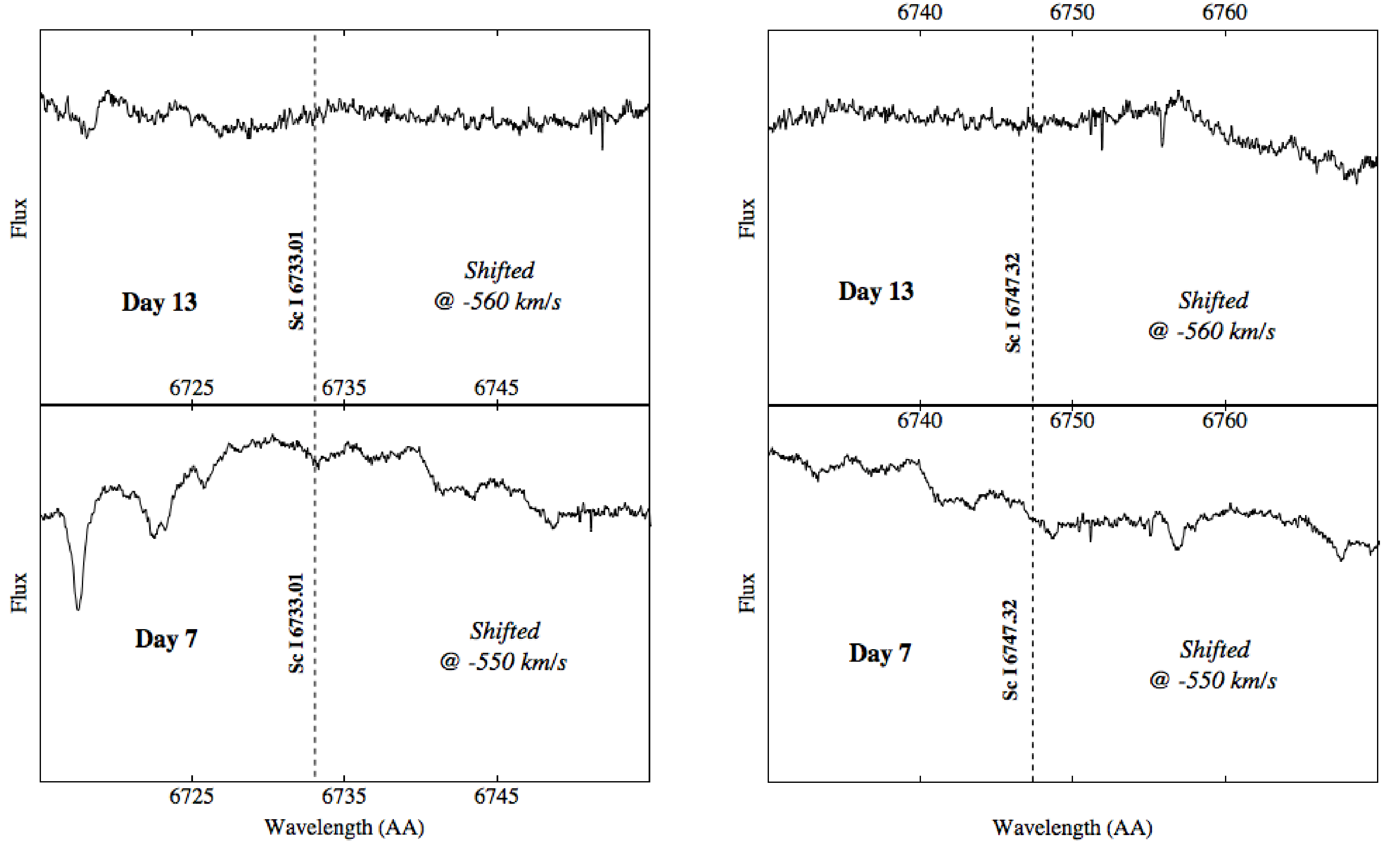
pole transitions with same initial level (J = 9/2)

Sc I 6733.01 4Do-4D 3/2 - 3/2 4.049237 – 5.89016
Sc I 6747.32 4Do-4D 3/2 - 1/2 4.049237 – 5.88626

Fe II 6769-272 4Fo-4G 9/2 - 9/2 11.206500 - 13.037568
Fe II 6811.491 4Fo-4G 9/2 - 11/2 11.206500 - 13.026219

The case of Li I 6708

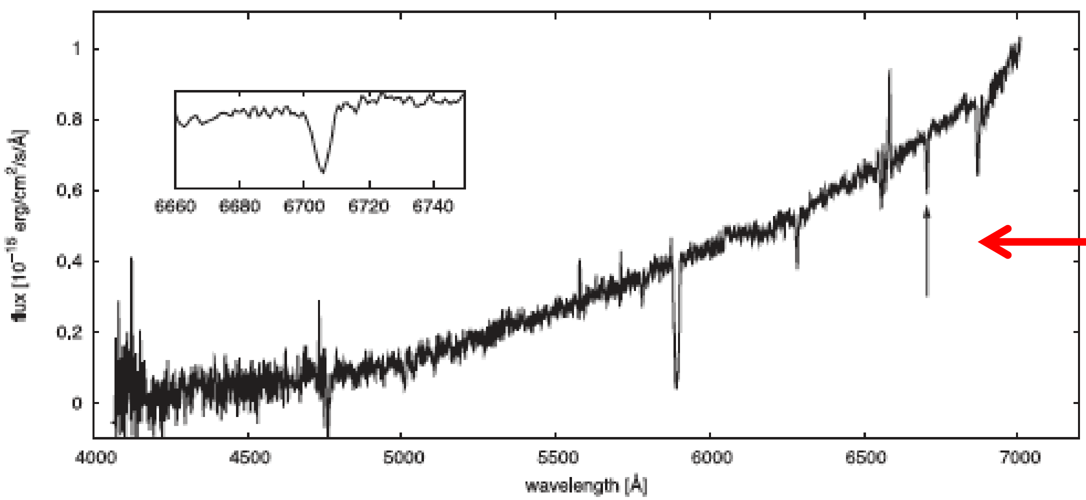
→ NO Sc I

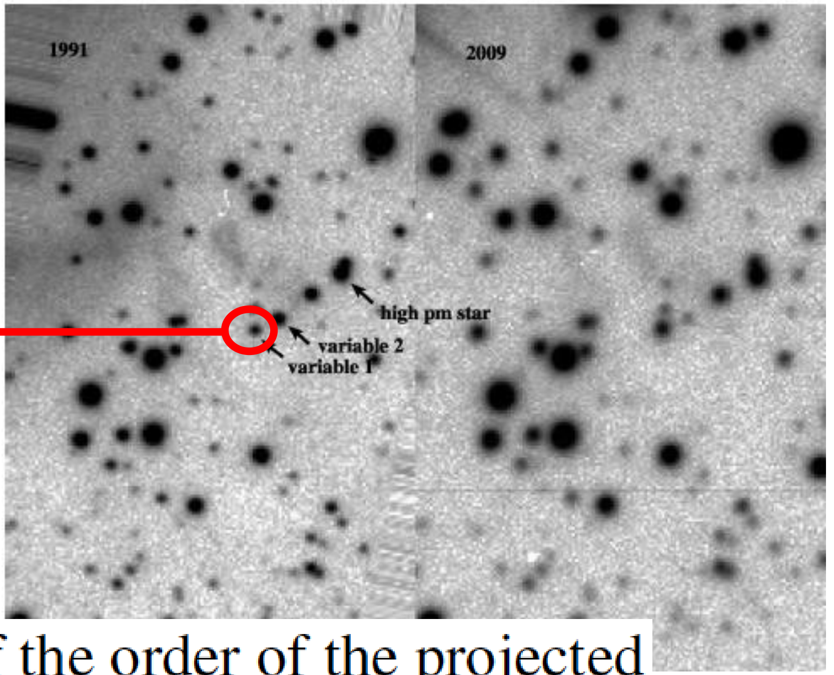


The case of CK Vul

CK Vul: evolving nebula and three curious background stars

M. Hajduk,[1★] P. A. M. van Hoof[2] and A. A. Zijlstra[3]





Assuming the extent of the cloud is of the order of the projected distance of the two stars, the total lithium mass is of the order of $2 \times 10^{-11}\,\mathrm{M}_\odot$. The derived velocity of the cloud is about $100\,\mathrm{km\,s^{-1}}$, if it expands in a plane of the sky.

High-resolution – V1369 Cen

DIBs and estimate of distance

→Na I D and DIB @ 5780.5, 6196.0, 6613.6 → E(B-V)

→From CH DIB @ 4300 → LSR velocity = -12.8 km/s

Friedman + (2011); Shore+ (2011)

→From Sun velocity (ϴ=220 km/s) and rotation curve of Galaxy

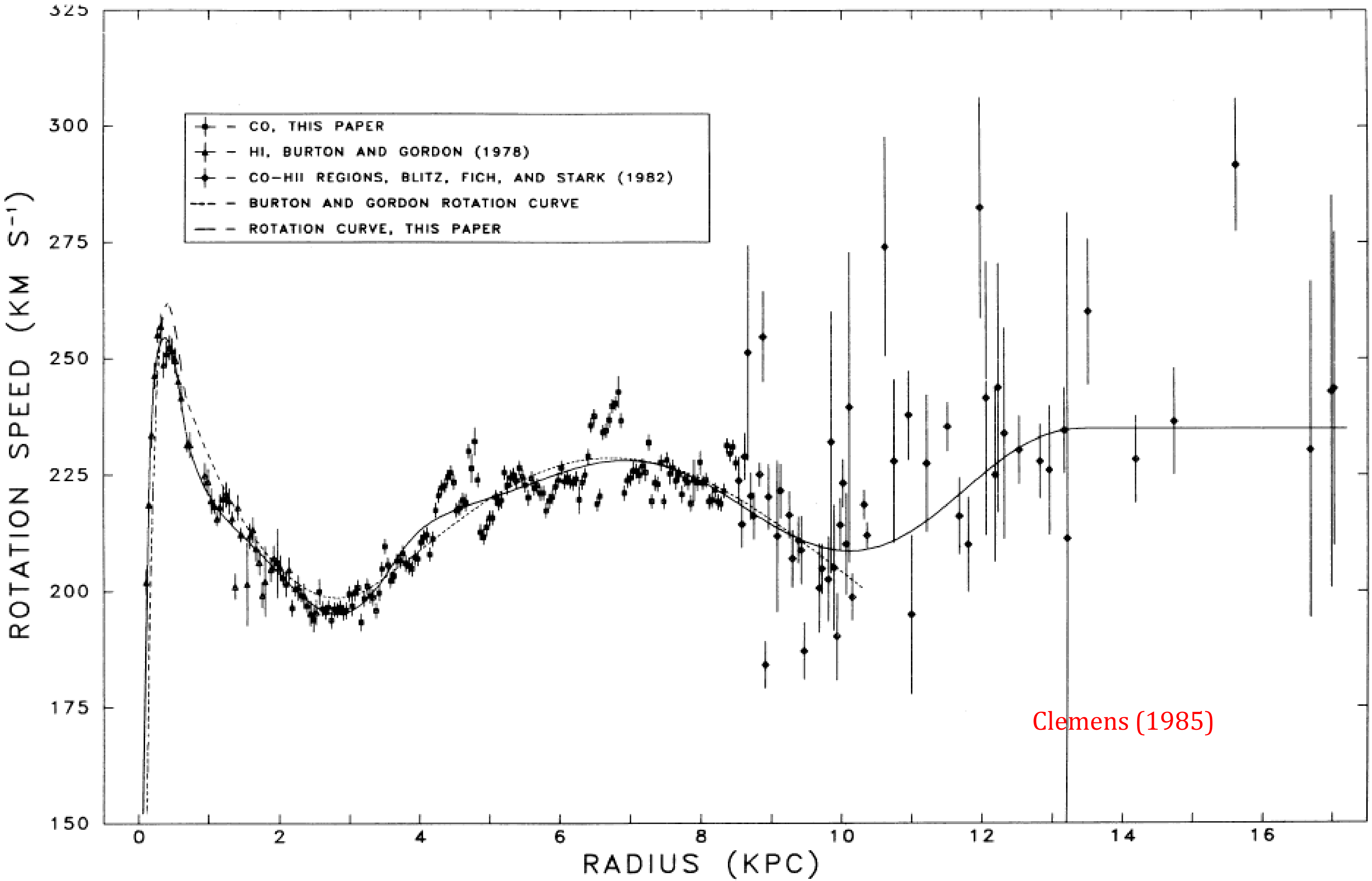
Clemens (1985)

⇓

→ limit to distance = 2.4-2.5 kpc

→in agreement with estimation from UV IS lines with HST/STIS

High-resolution – V1369 Cen



High-resolution – V1369 Cen

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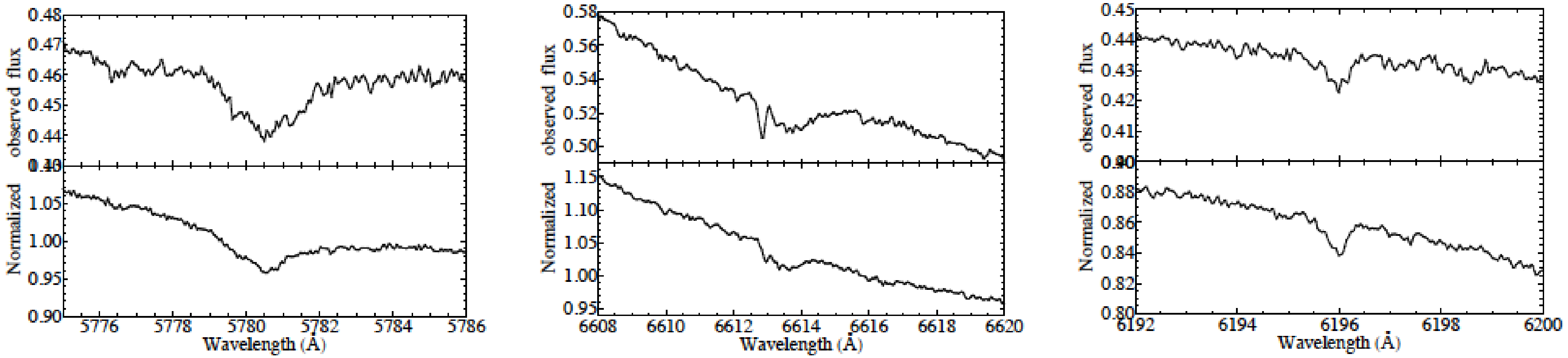
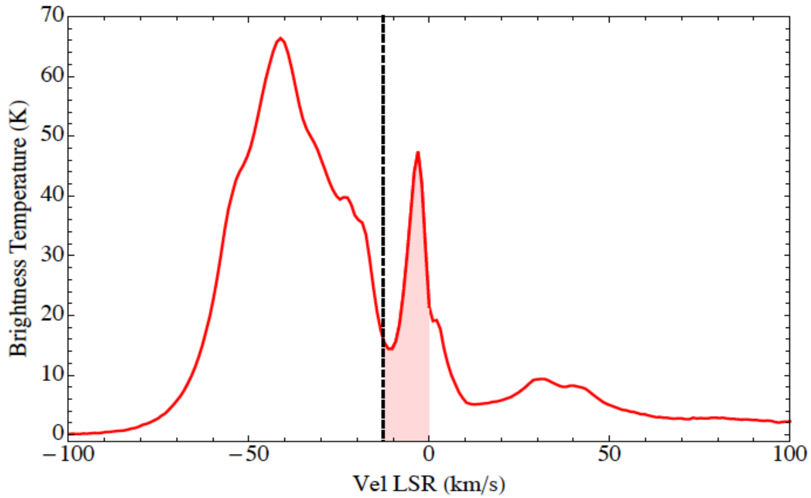




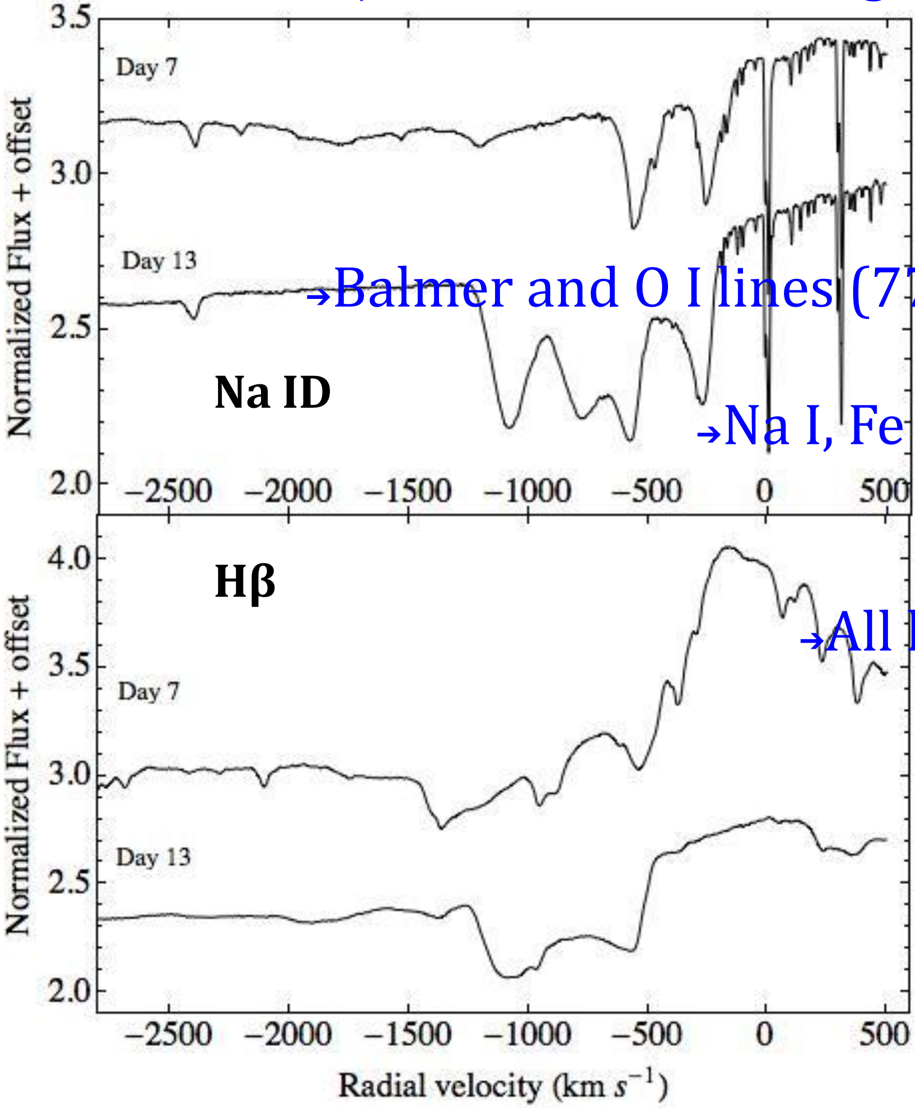
$$NH = 1.823 \times 10^{18} \int_v T_B \, dv,$$

$$NH = 6.60 \times 10^{20} \text{ cm}^{-}2,$$

From E(B-V) → $NH = 6.88(+2.26, -1.68) \times 10^{20}$

High-resolution – V1369 Cen

Ejecta kinematic along the entire evolution



1st epoch

→Common regime (v_1 = -550 km/s)

→Balmer and O I lines (7775, 8446 AA) show an additional exp velo

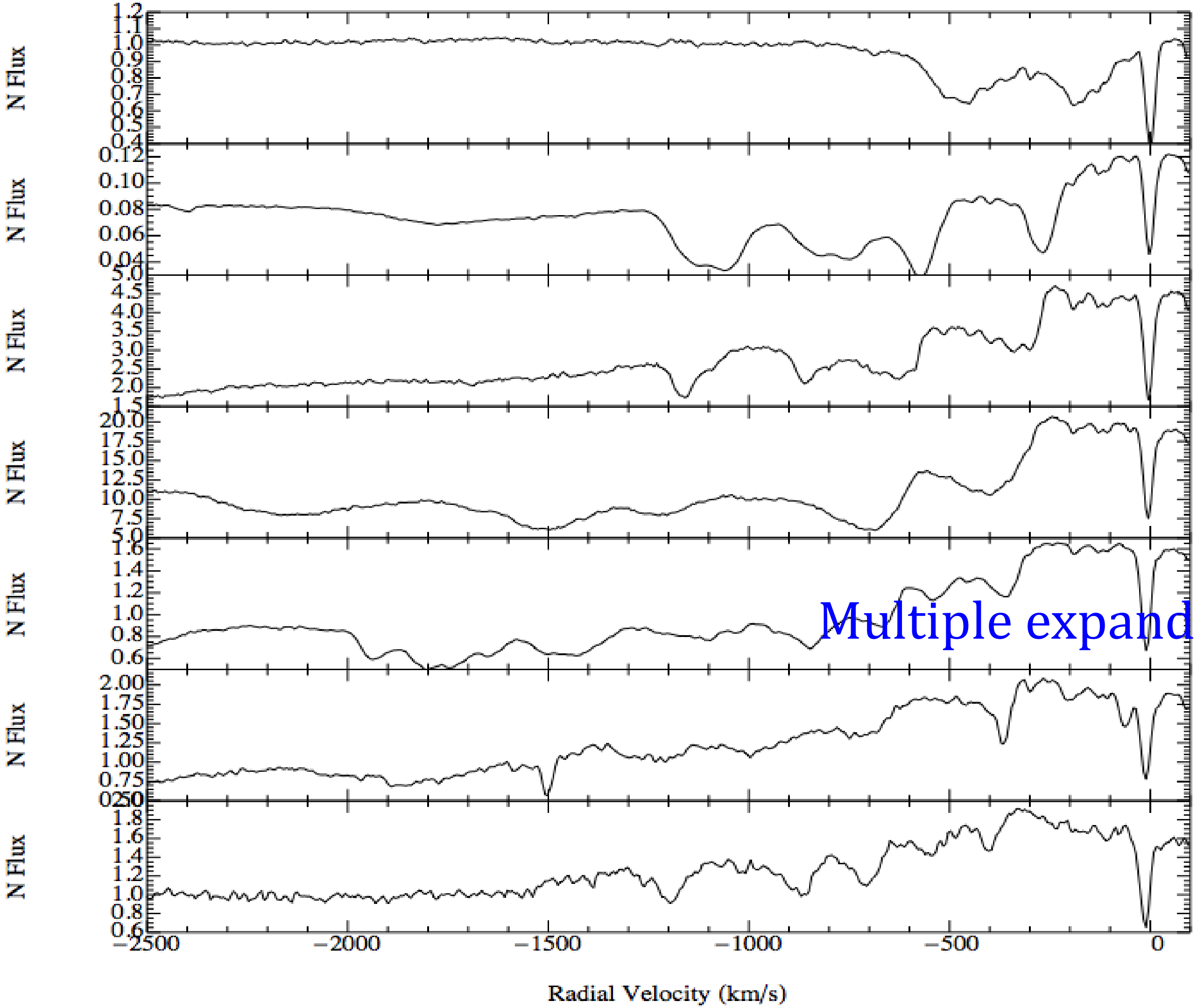
→Na I, Fe II and narrow abs show only the "slower"

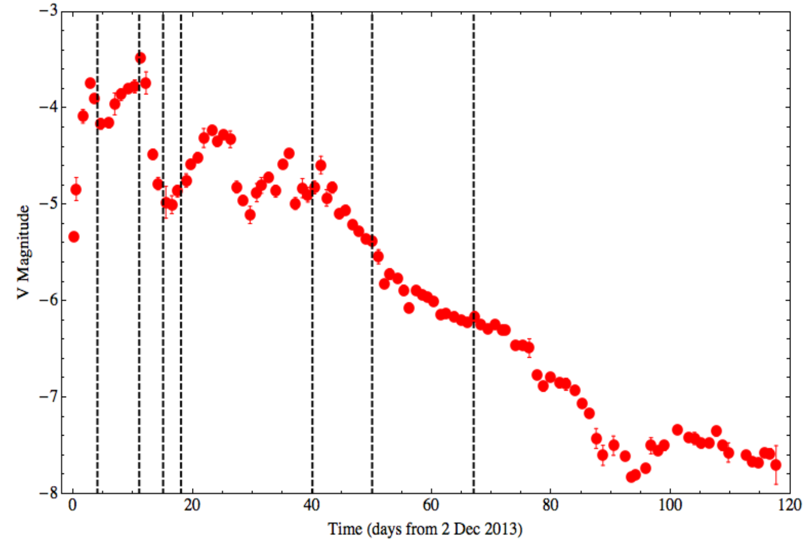
→**2nd epoch**

→All lines show a further velocity v_3 = -1350 kr

High-resolution – V1369 Cen

Ejecta kinematic along the entire evolution

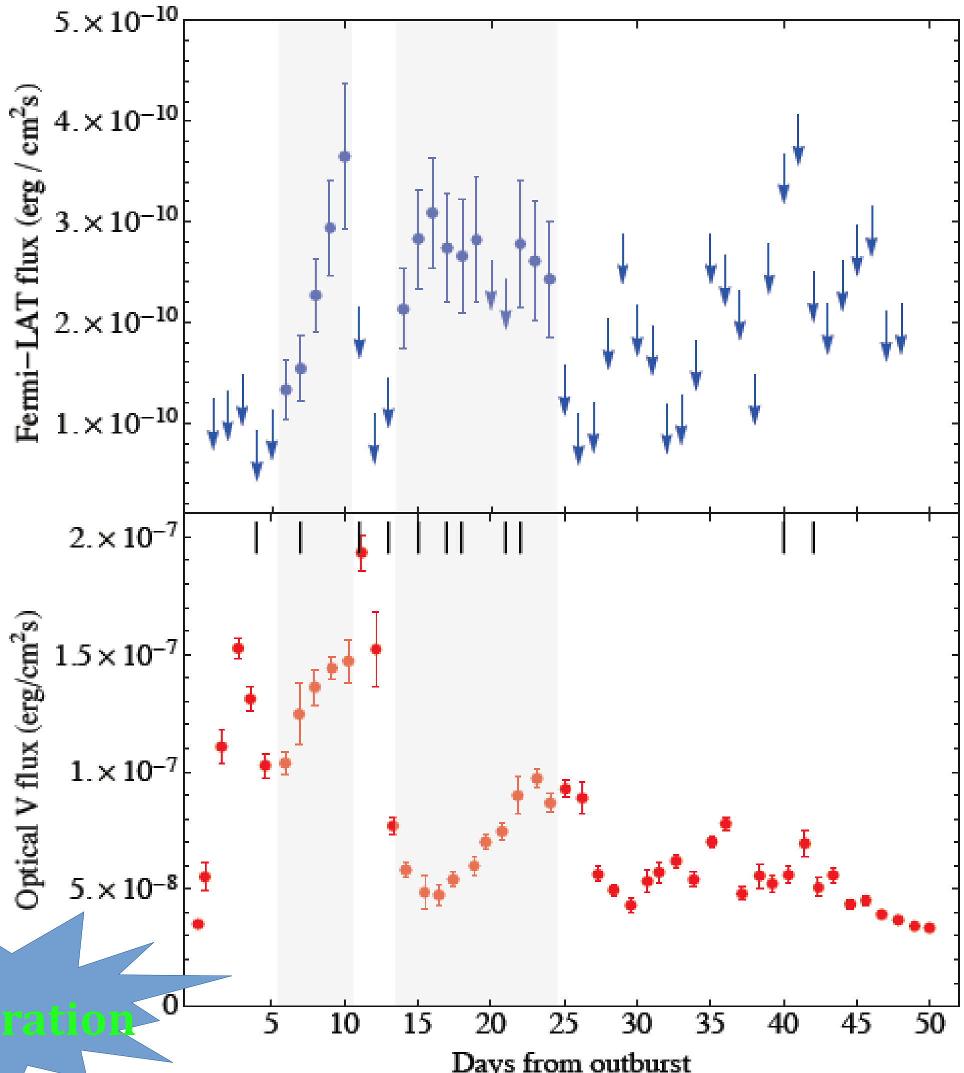




Multiple expanding systems coincident with optic

High-resolution – V1369 Cen

Ejecta kinematic along the entire evolution



In preparation

Multiple velocities

between multiple shells with differe

MeV-GeV detected in four novae (V407 Cyg, V339 Del, V1324 Sco, V959 Mon)

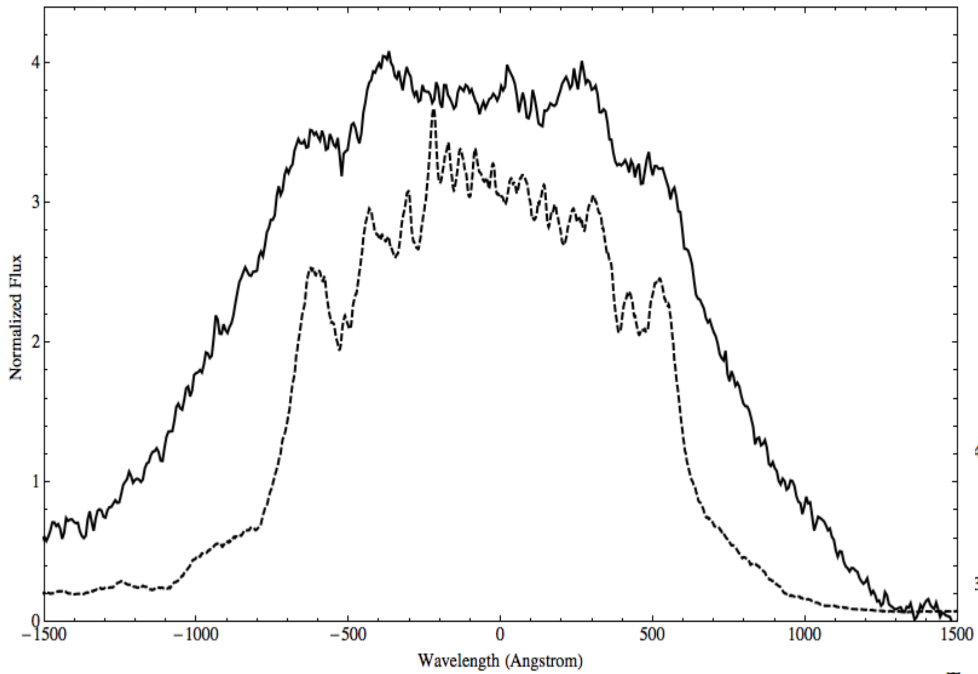
Fermi-LAT collaboration (2014)

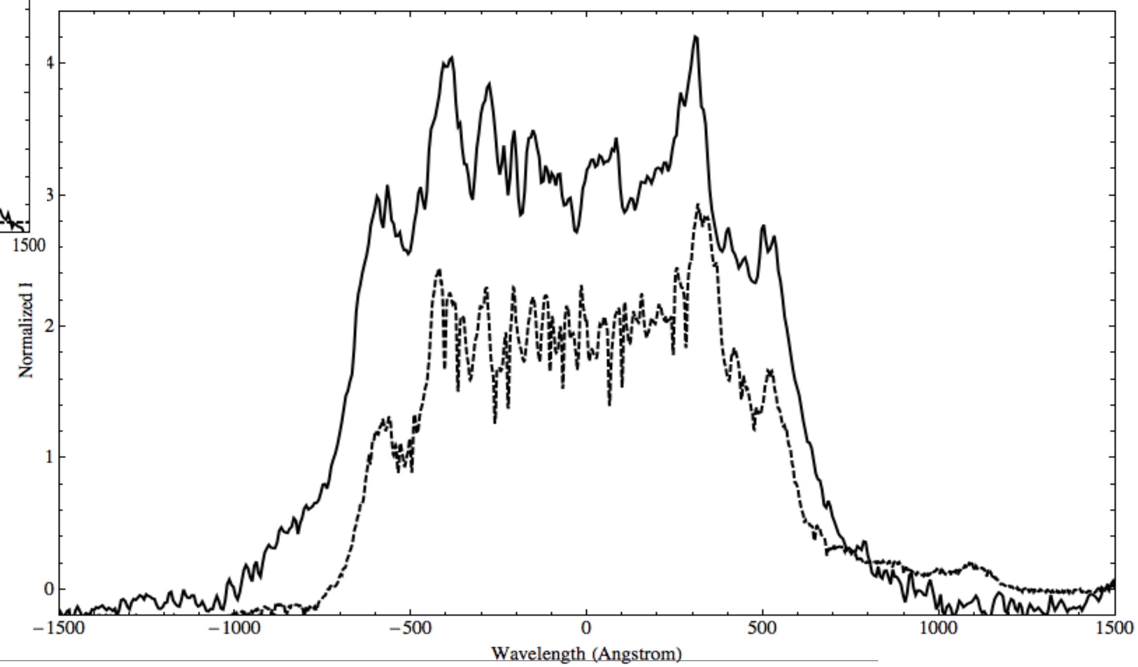
High-resolution – V1369 Cen

→fine structures - Density, temperature and abundances in single knots

The cases of [N II] 5755 and
[O I] 6300

still slight acc in knots after 170 dd

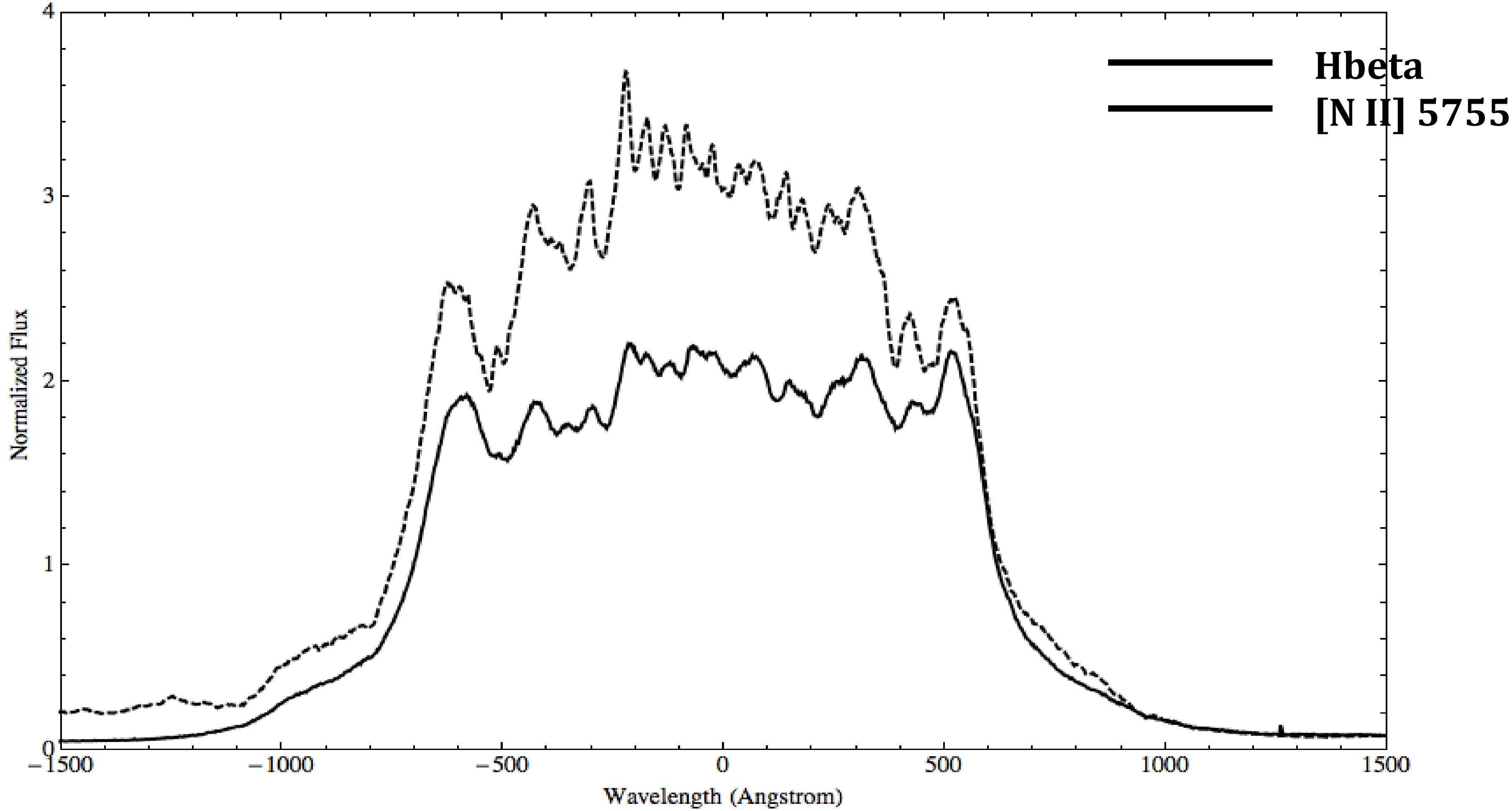




PUCHEROS 72 days
FEROS 243 days

High-resolution – V1369 Cen

Check between [N II] 5755 and Hβ



Display the distribution of elements in knots

High-resolution – V1369 Cen

Physical properties from lines ratio

→Optical depth and Temperature from [O I]

$$\frac{F_{\lambda 6300}}{F_{\lambda 6364}} = \frac{(1 - e^{-\tau})}{(1 - e^{-\tau/3})} \quad \Longrightarrow \quad \frac{F_{\lambda 6300}}{F_{\lambda 5577}} = 0.023 \frac{(1 - e^{-\tau})}{\tau} \exp\left(\frac{25{,}800}{T_e}\right)$$

Williams (1994)

→Electron density from [O III], [N II]* lines

$$\frac{j_{4959} + j_{5007}}{j_{4363}} = 7.73 \frac{\mathrm{e}^{3.29\times 10^{-4}/T_\mathrm{e}}}{1 + 4.5 \times 10^{-4} \frac{N_\mathrm{e}}{T_\mathrm{e}^{1/2}}}$$

Osterbrock & Ferland

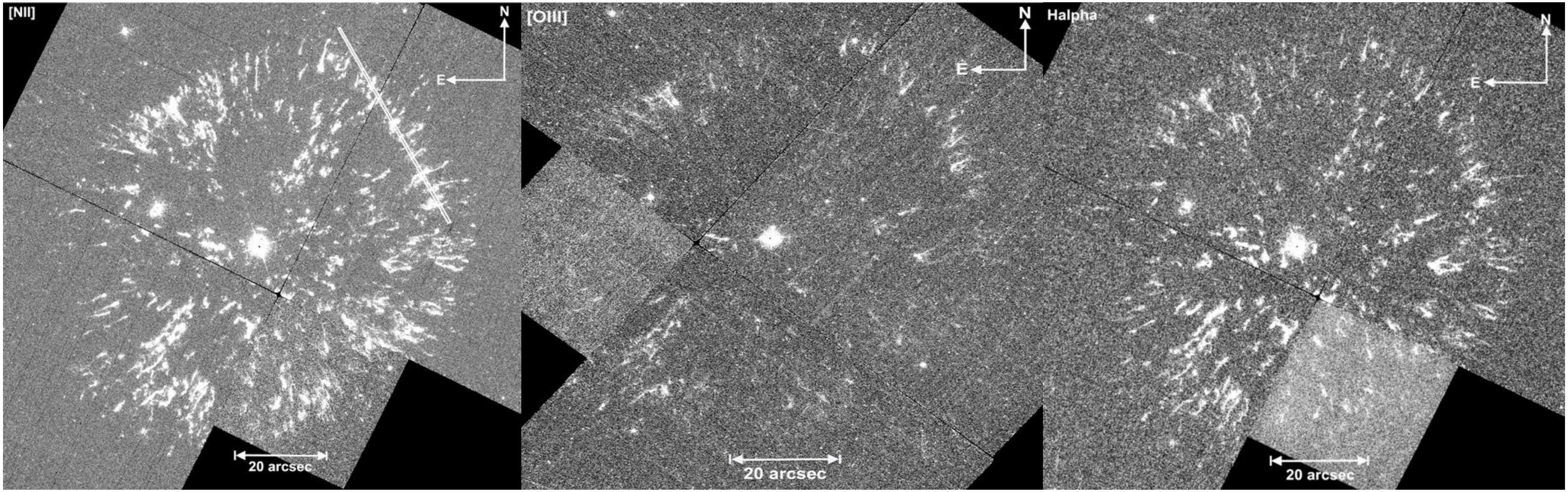
→Filling factor from Balmer (Hbeta) and max v_{exp}

$$\epsilon = \frac{j_{\mathrm{H}_\alpha} d^2}{g_\alpha n_\mathrm{e}^2 V}$$

Ederoclite (2006)

Gracias !!!

[N II] **[O III]** **Halpha**



GK Per
HST/WFPC2
Shara+ (2012)