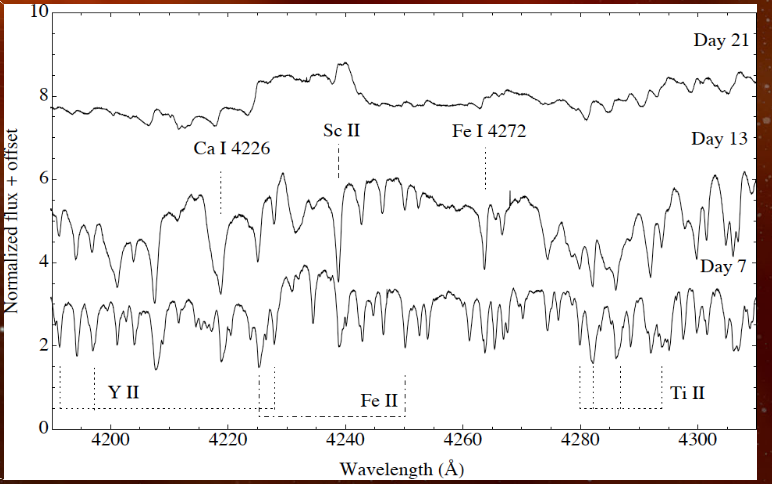
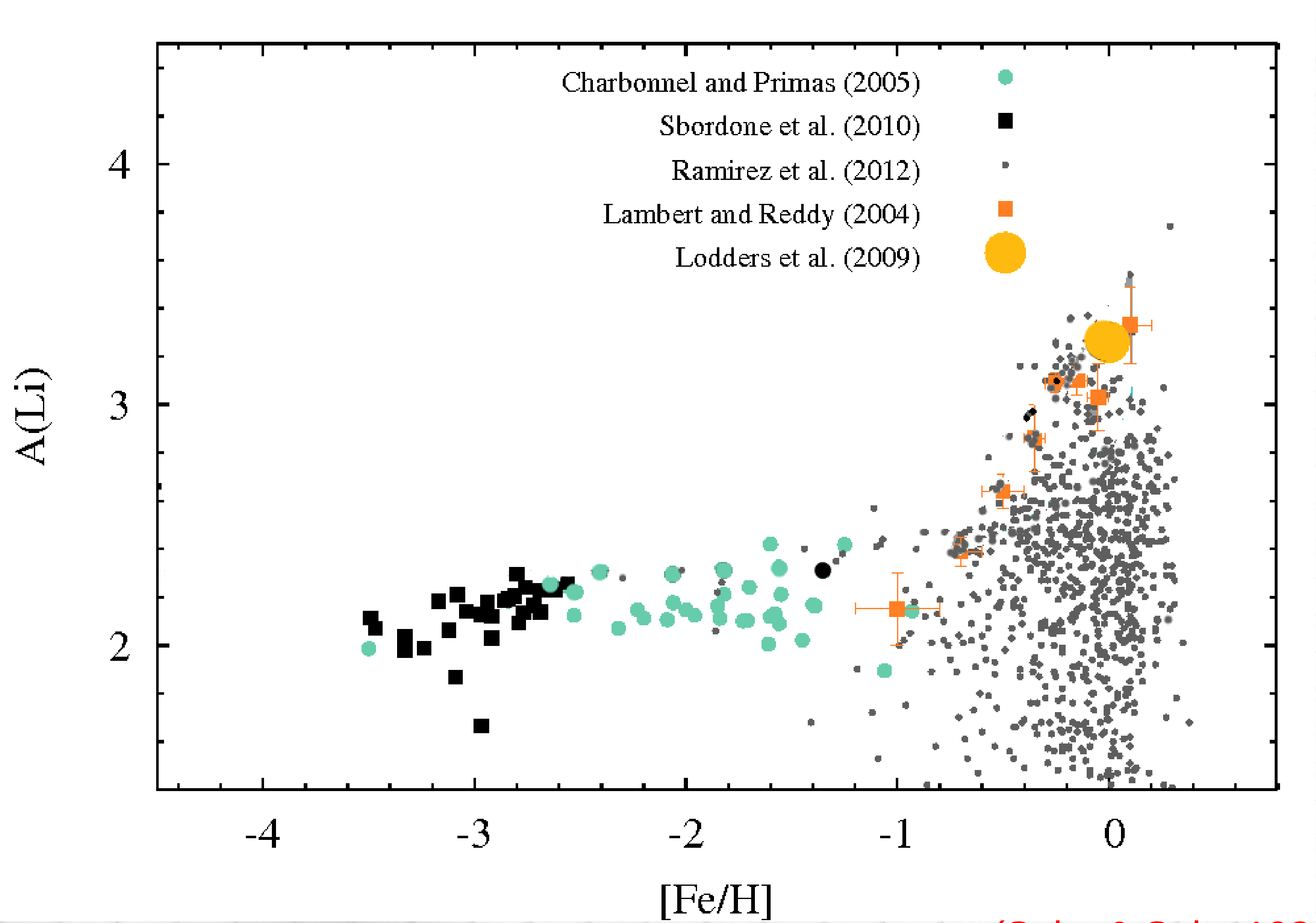
Novae as lithium factories in the Galaxy

First evidences

L. Izzo, M. Della Valle
E. Mason, F. Matteucci, D. Romano
L. Pasquini, L. Vanzi, R. Williams, A. Jordan
J.M. Fernandez, P. Bluhm, R. Brahm, N. Espinoza

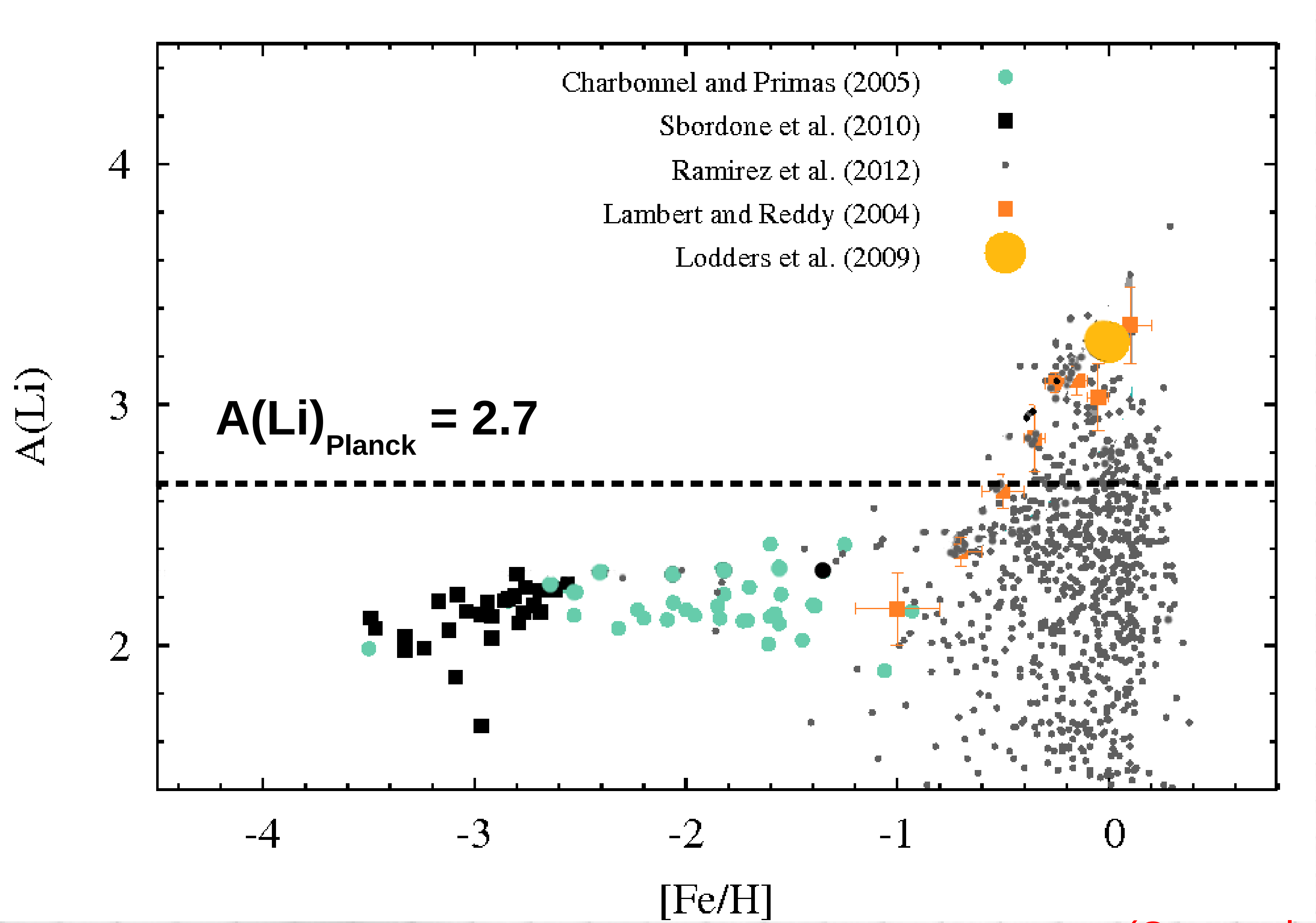


Prologue



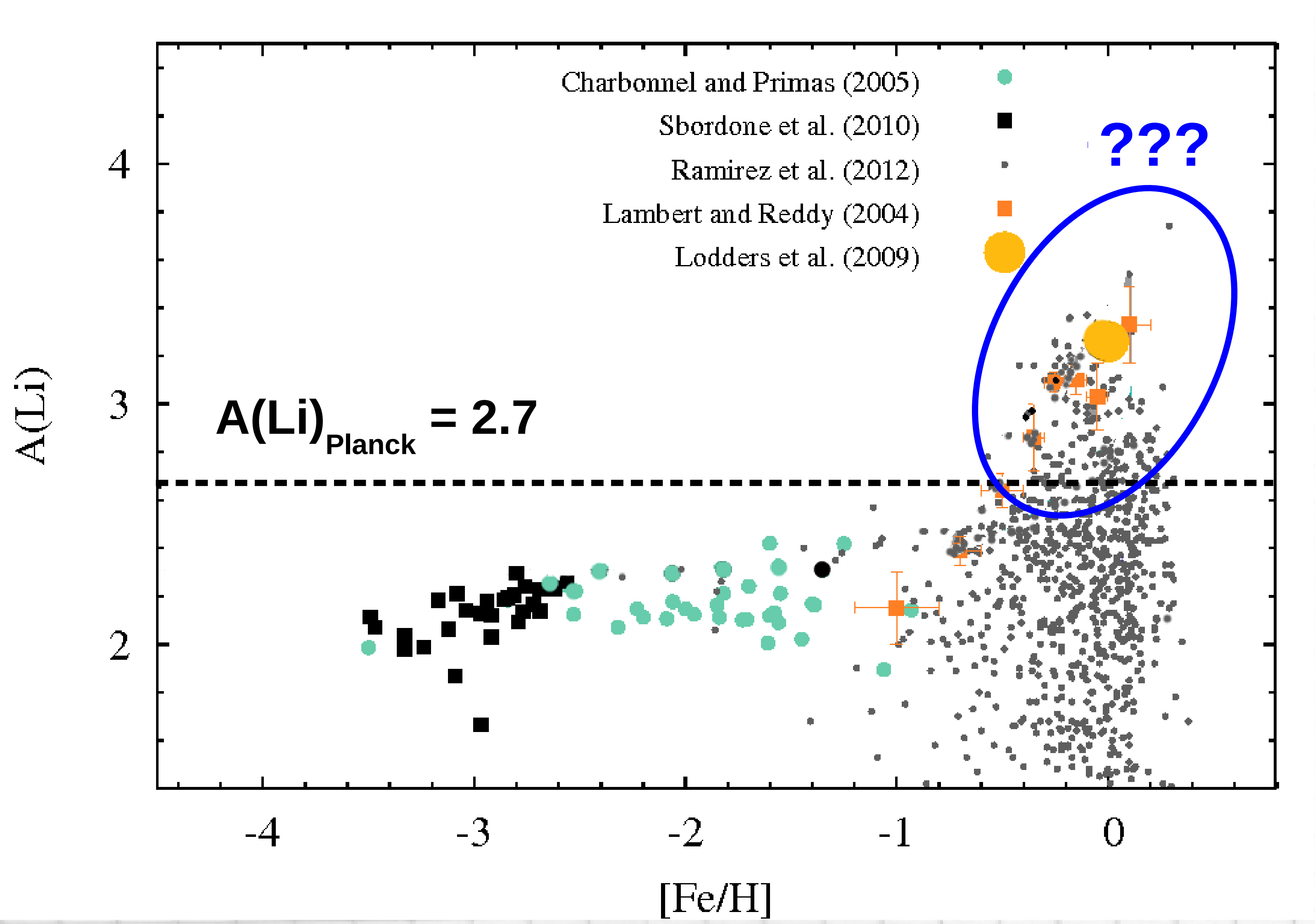
(Spite & Spite 1982, 1990)

Prologue



(Coc et al. 2014)

Prologue



Charbonnel and Primas (2005)
Sbordone et al. (2010)
Ramirez et al. (2012)
Lambert and Reddy (2004)
Lodders et al. (2009)
???
A(Li)Planck = 2.7
A(Li)
4
3
2
-4
-3
-2
-1
0
[Fe/H]

Prologue

Possible lithium farms in the Galaxy

a) cosmic-ray spallation of i.s. gas (p + CNO)

(Reeves+ 1990)

b) Cameron-Fowler mechanism

(Cameron & Fowler 1971)

1) $^{3}He + ^{4}He \rightarrow ^{7}Be + \gamma$
2) convection
3) $^{7}Be + e^{-} \rightarrow ^{7}Li + \nu$

Prologue

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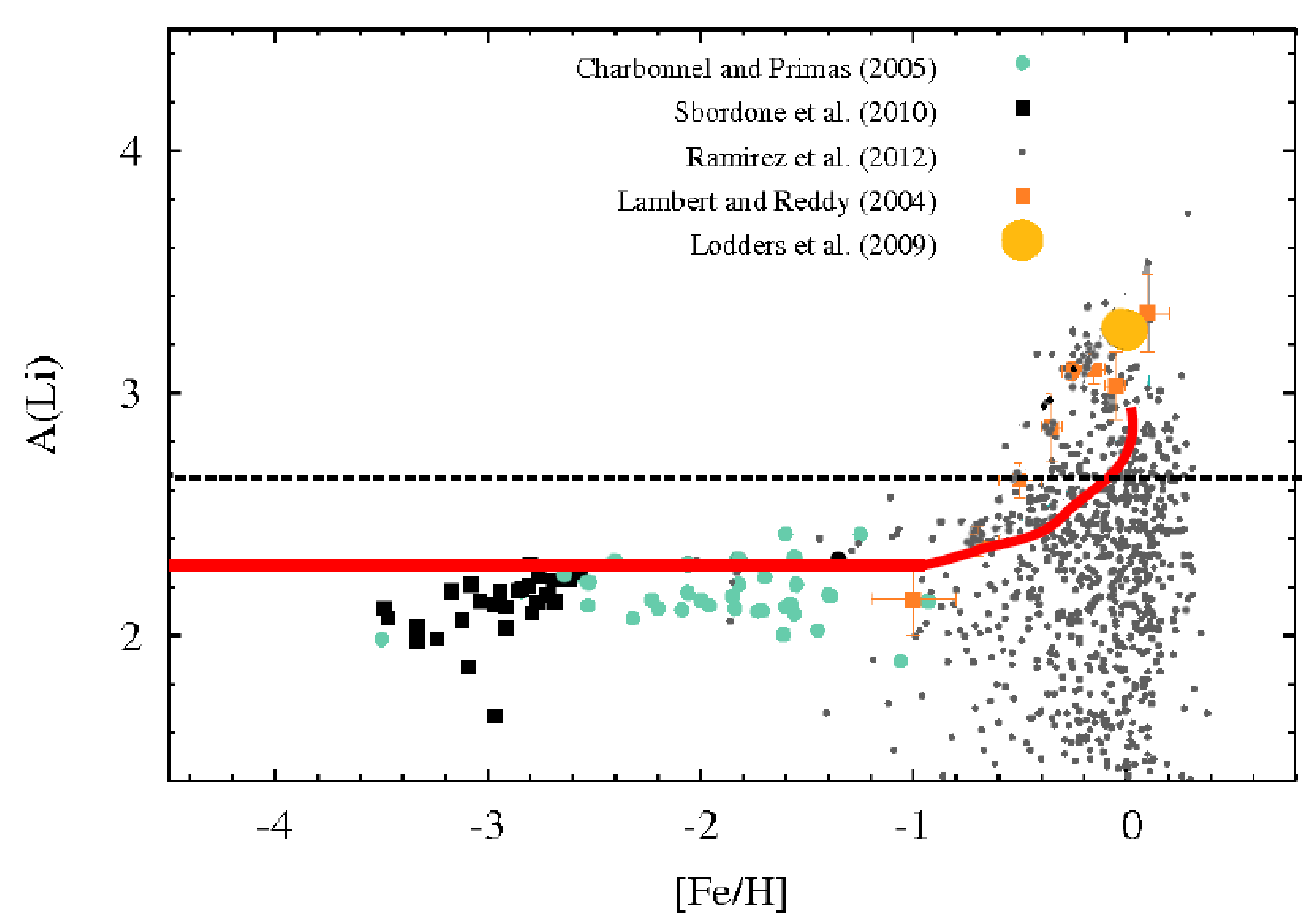
AGB stars
Novae

Cosmic-ray + AGN



Novae

Classical Novae are the most "dramatic" event in the lifecycle of a Cataclismic Variable

CV $\rightarrow$ binary system composed by a degenerate primary star (white dwarf) and a late type MS secondary star

Novae

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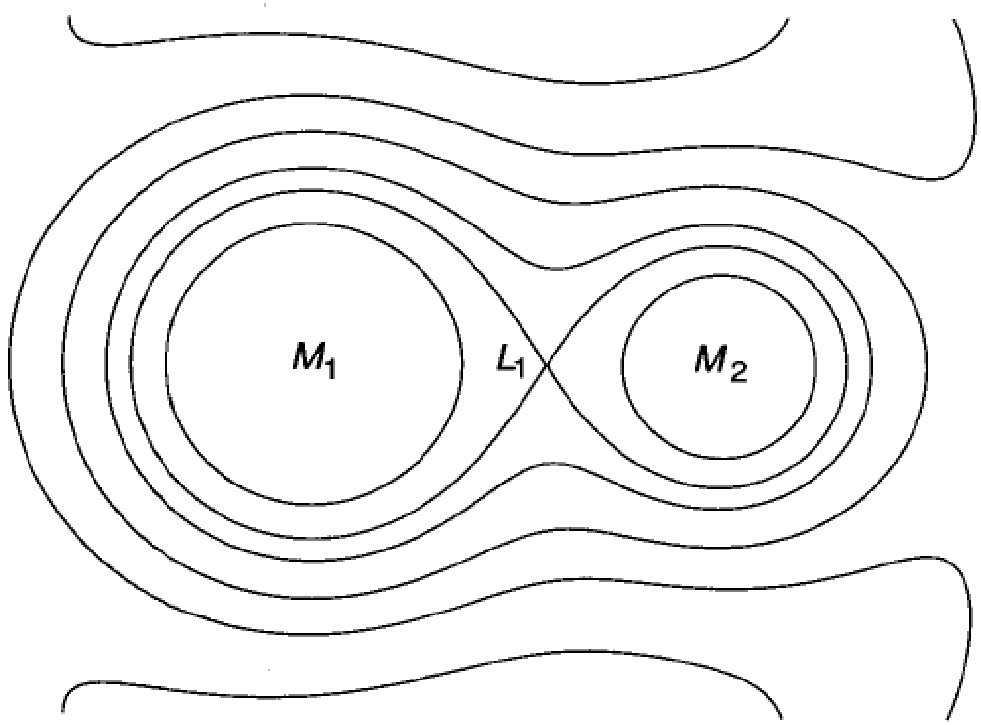
CV → binary system composed by a degenerate primary star (white dwarf) and a late type MS secondary star

The WD accretes matter from the secondary, which piles-up on the WD surface

When the pressure at the bottom of the H-accreted layer > degeneracy pressure
→ expansion of the external layers

The Roche geometry and accretion mechanism in CVs



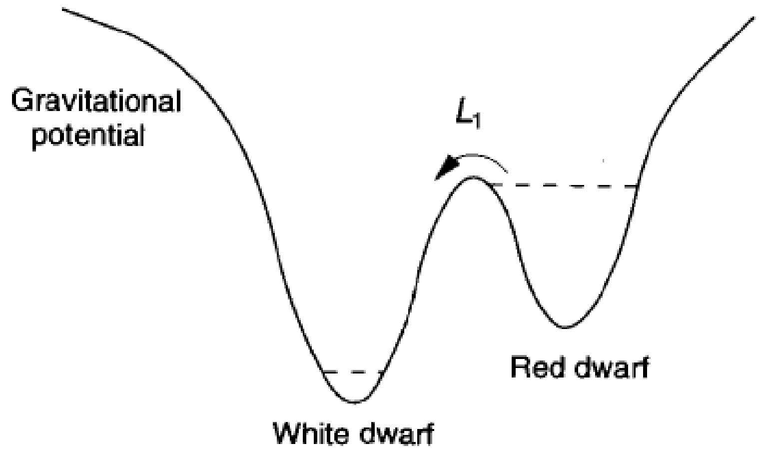


Fig. 2.4: The Roche lobes can be visualised as gravitational wells in which matter flows downhill. When the red dwarf overfills its Roche lobe, matter flows over the L_1 point into the Roche lobe of the white dwarf.

Nucleosynthesis in Novae

A WD is a burnt-out core of a star

→ mainly He, heavy elements as C, N, O, Ne, Mg

As H is accreted from secondary

→ p+p chain produces ^{3}He, via Deuteron

formation of main ingredients for ^{7}Be production

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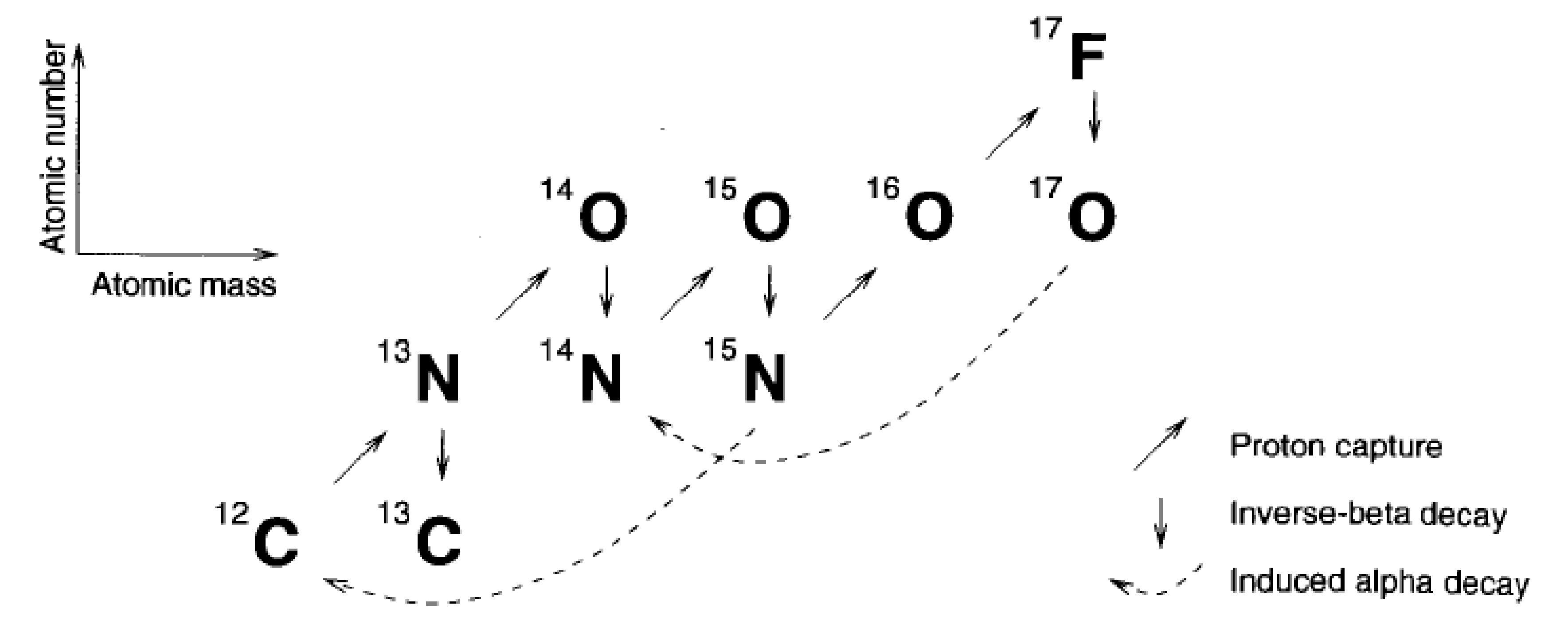
At larger temperatures (10^{7} K) and deeper layers
CNO cycle
→ H burns into He by using nuclei of C, N and O as catalysts
→ Isotopes of CNO inverse-beta decay (half-life 100s)
→ The runaway speeds up, implying strong convective motions and providing "fresh" H for burning

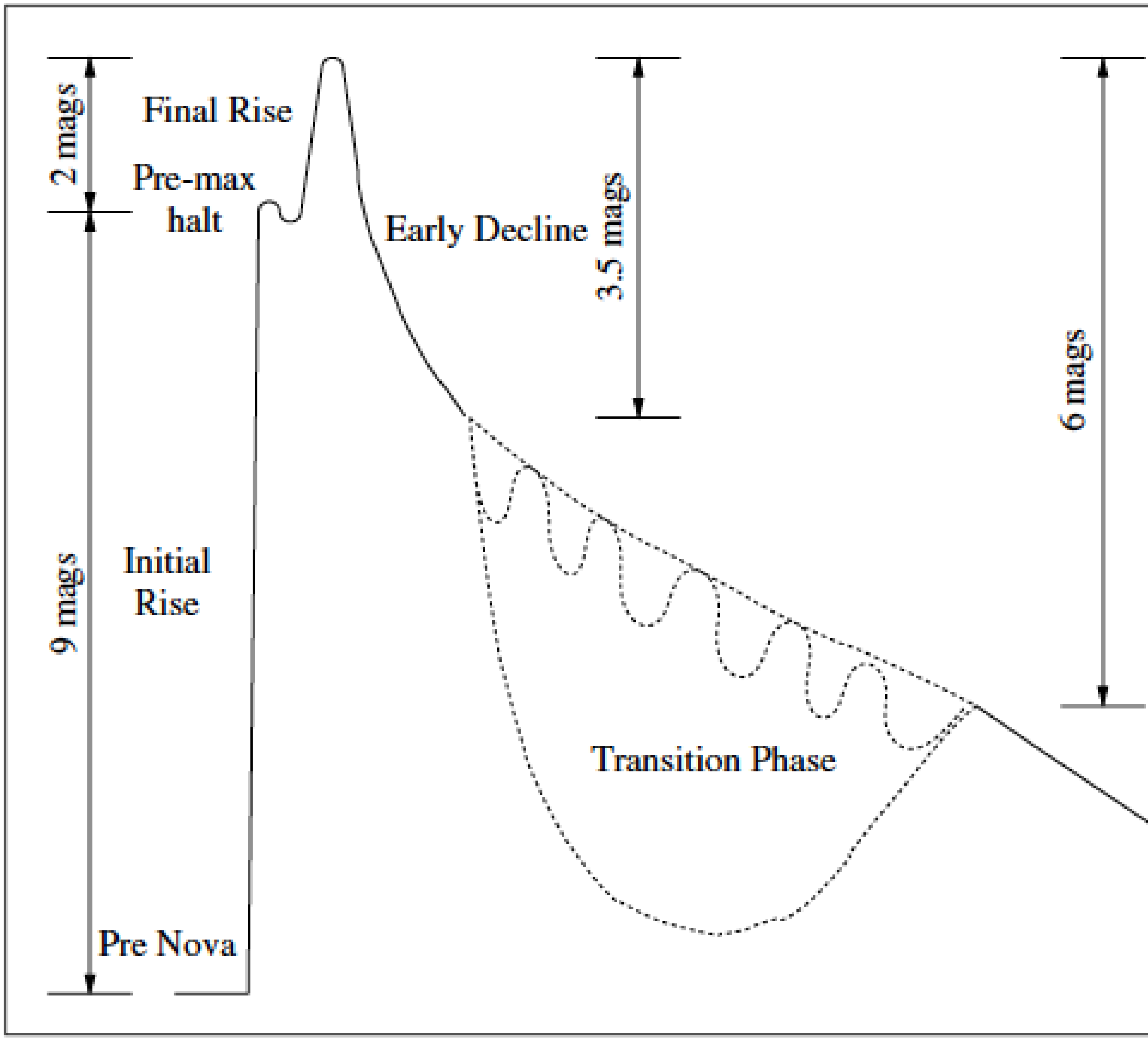
Nucleosynthesis in Novae

CNO cycle



- Radioactive nuclei energy is deposited into the expanding nova shell, driving expansion
- Novae as possible farms of ^{13}C and ^{15}N

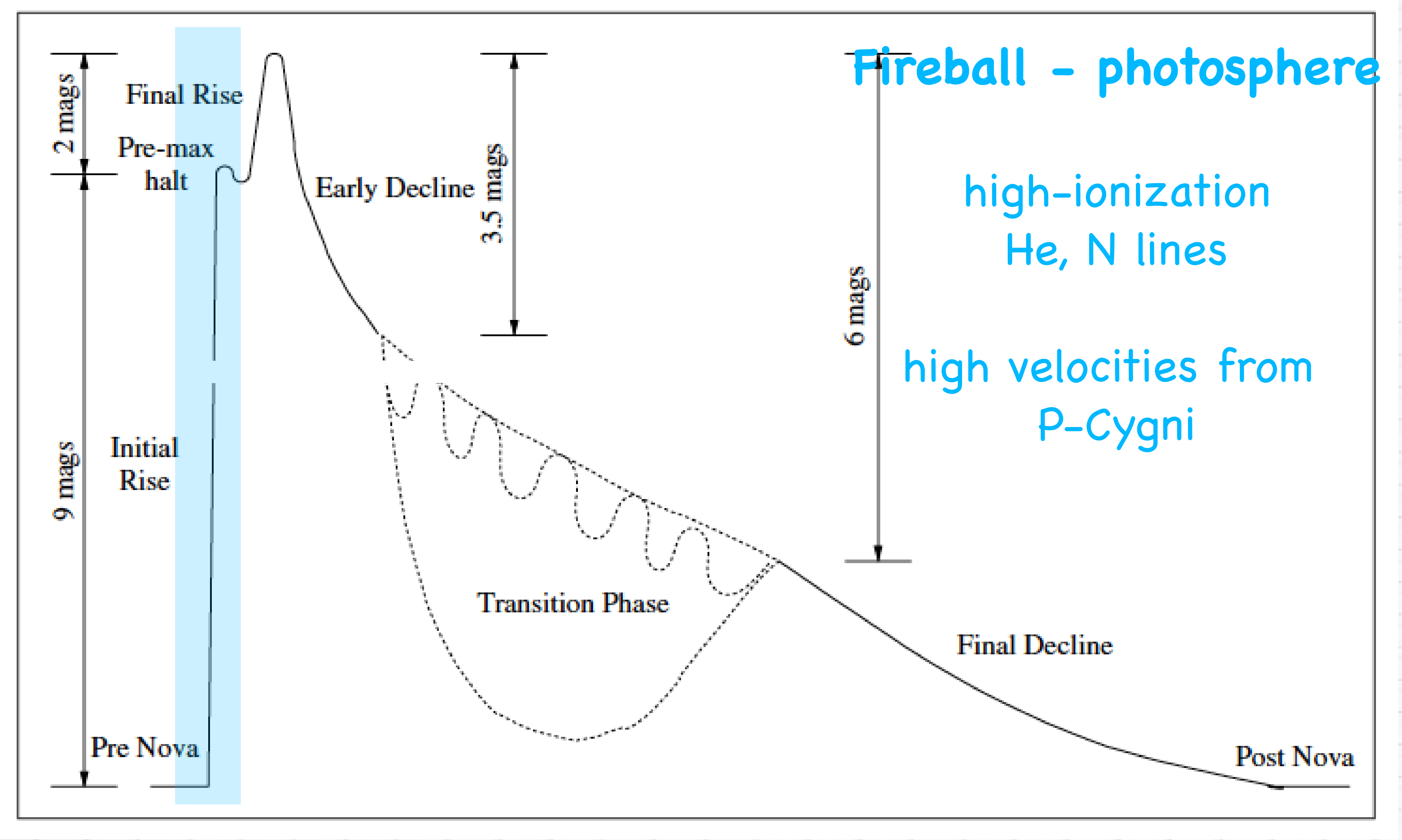
Phenomenology of Novae



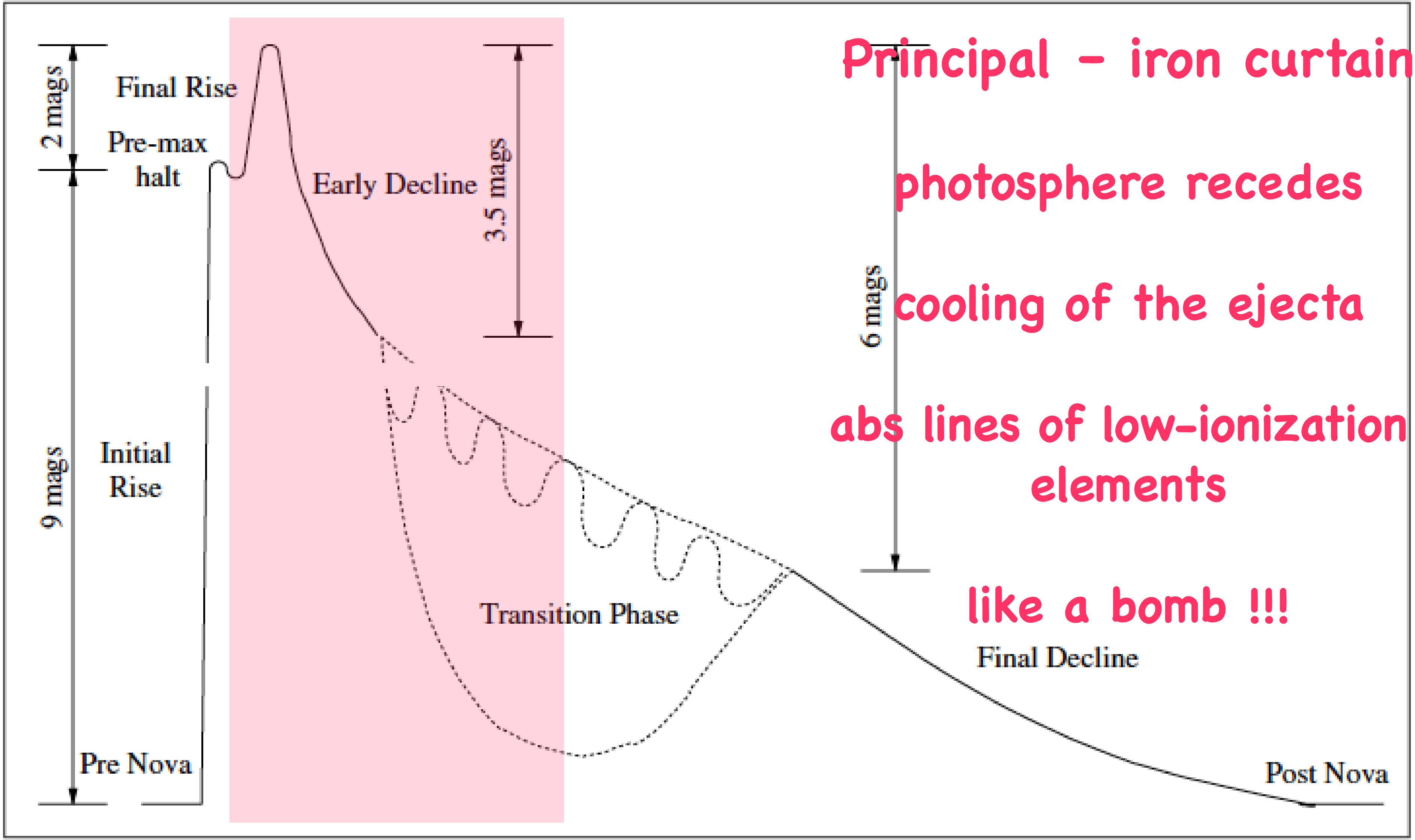
Optical (V)

→ **4 main phases**

Phenomenology of Novae



Phenomenology of Novae



Principal – iron curtain

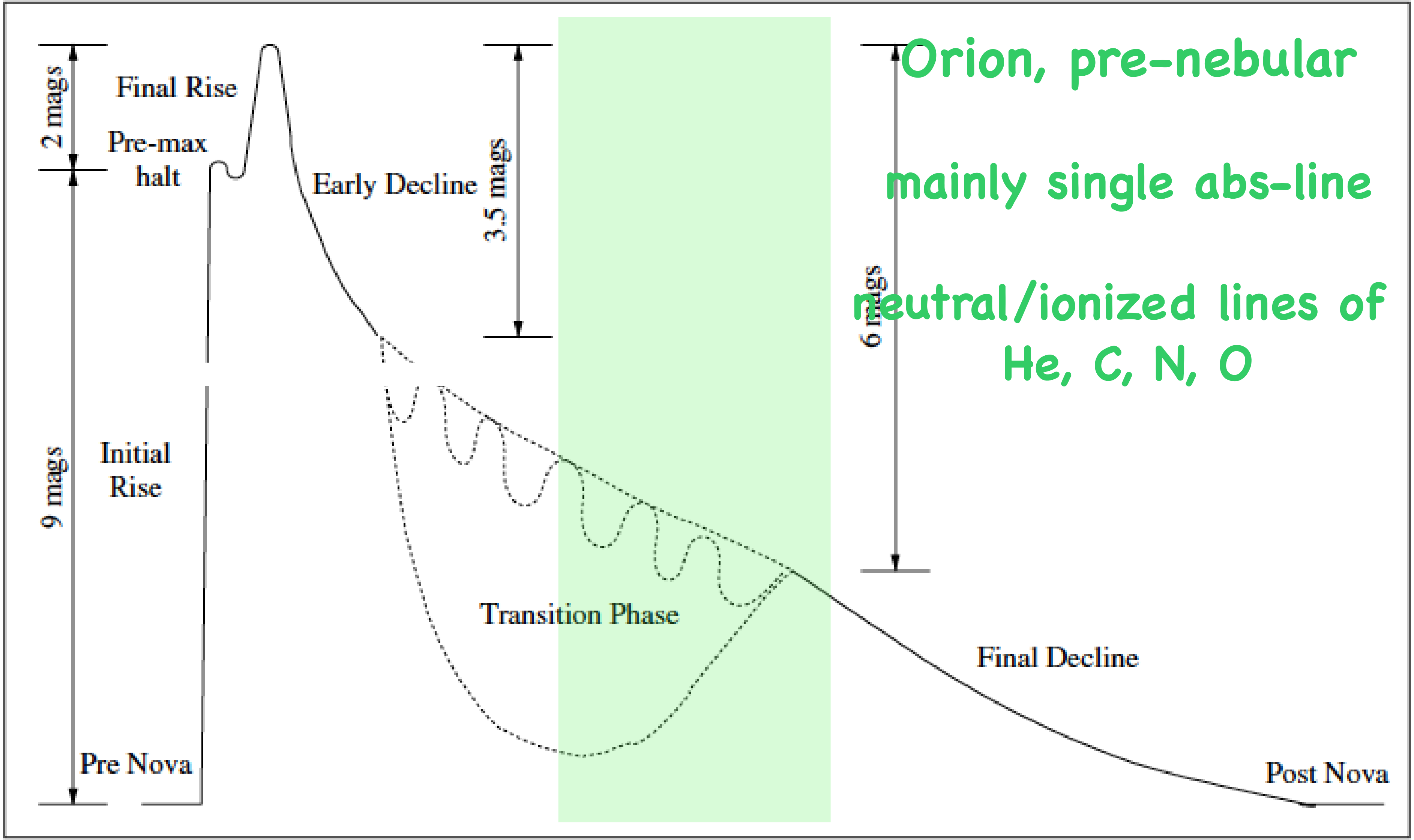
photosphere recedes

cooling of the ejecta

abs lines of low-ionization elements

like a bomb !!!

Phenomenology of Novae

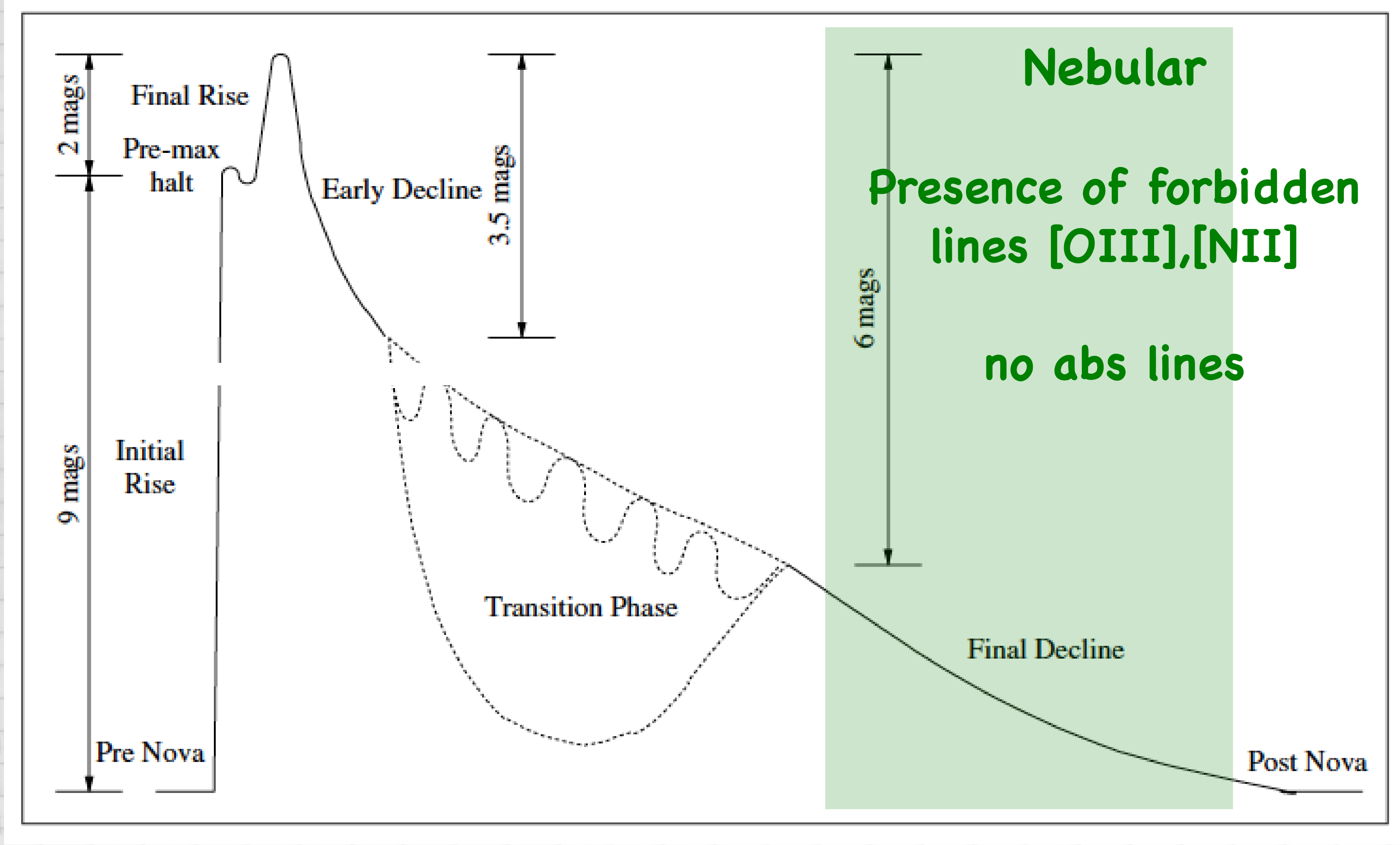


Orion, pre-nebular

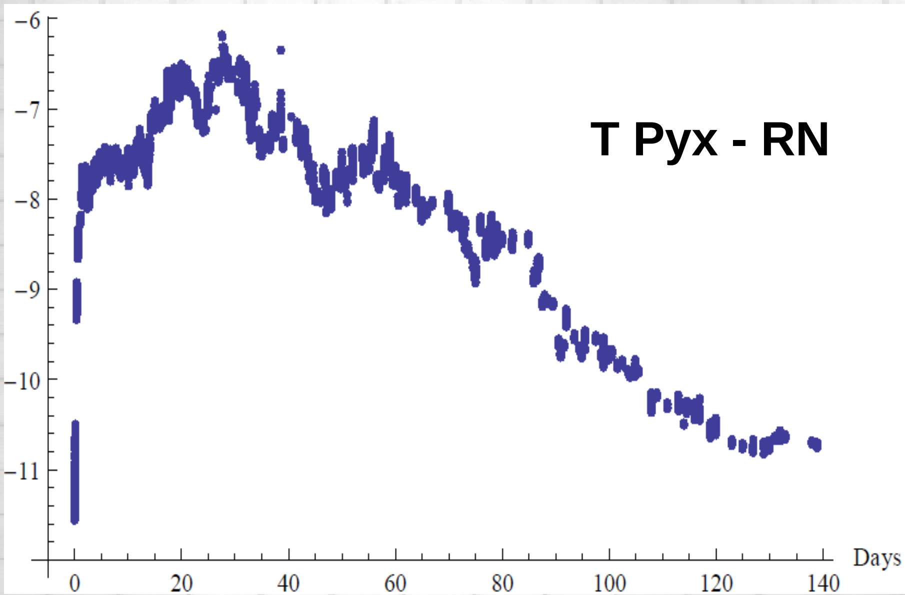
mainly single abs-line

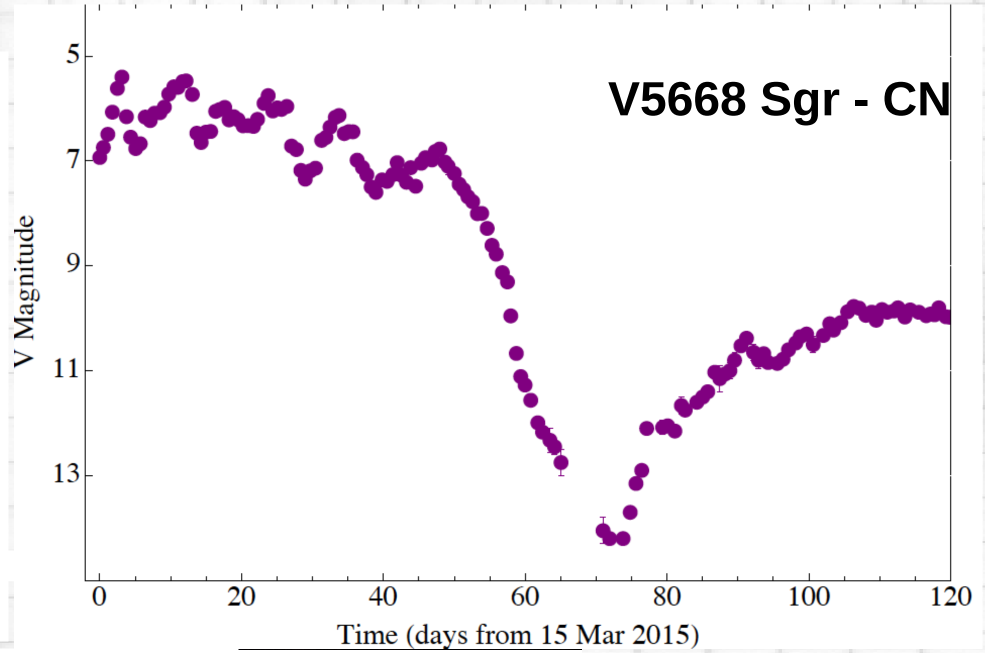
neutral/ionized lines of
He, C, N, O

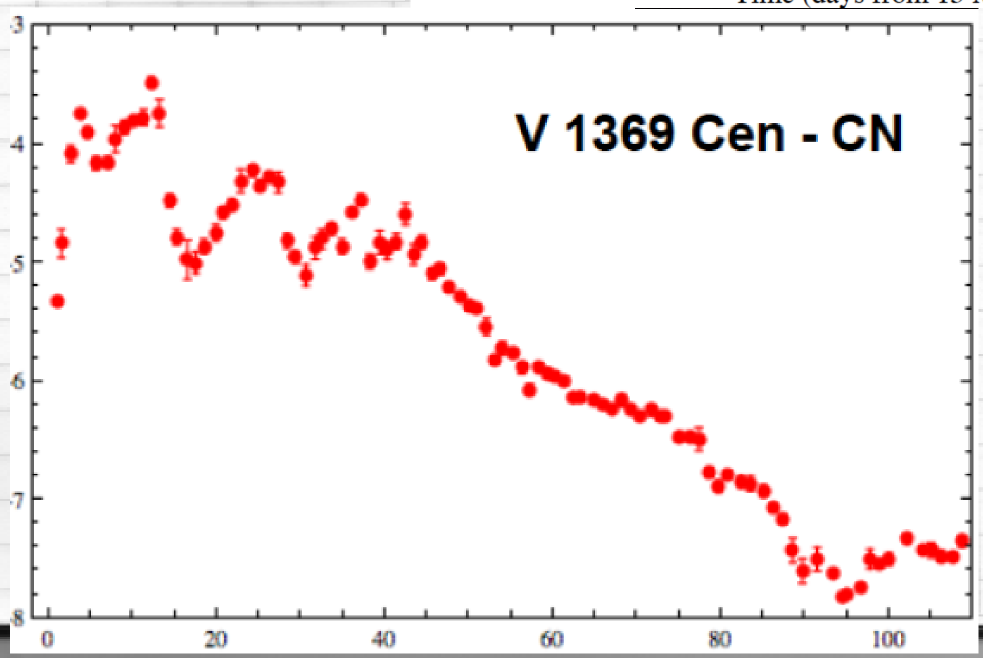
Phenomenology of Novae



Phenomenology of Novae







Phenomenology of Novae

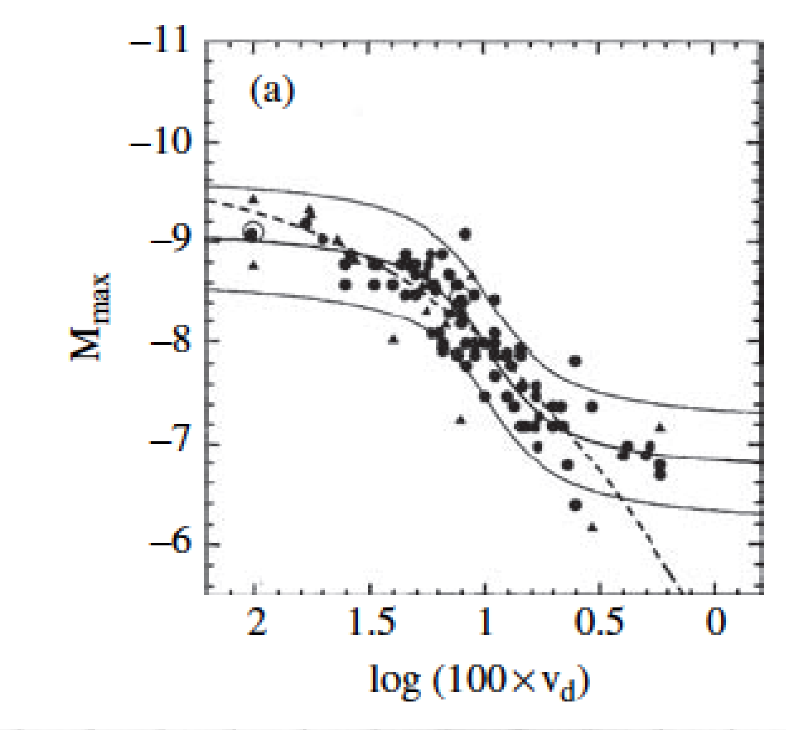
Brighter – faster; Dimmer – slower

MMRD relation : amplitude of outburst ***A*** vs decay time t_n

S-relation

$$M_V = -7.92 - 0.81 \arctan \frac{1.32 - \log t_2}{0.23},$$

used also as distance indicator



(Della Valle & Livio 1995)

Recurrent Novae

All CNe are **recurrent**

Timescales of recurring outbursts vary from few years (T Pyx, RS Oph, U Sco,... 10 RNe) to $10^4 - 10^5$ years

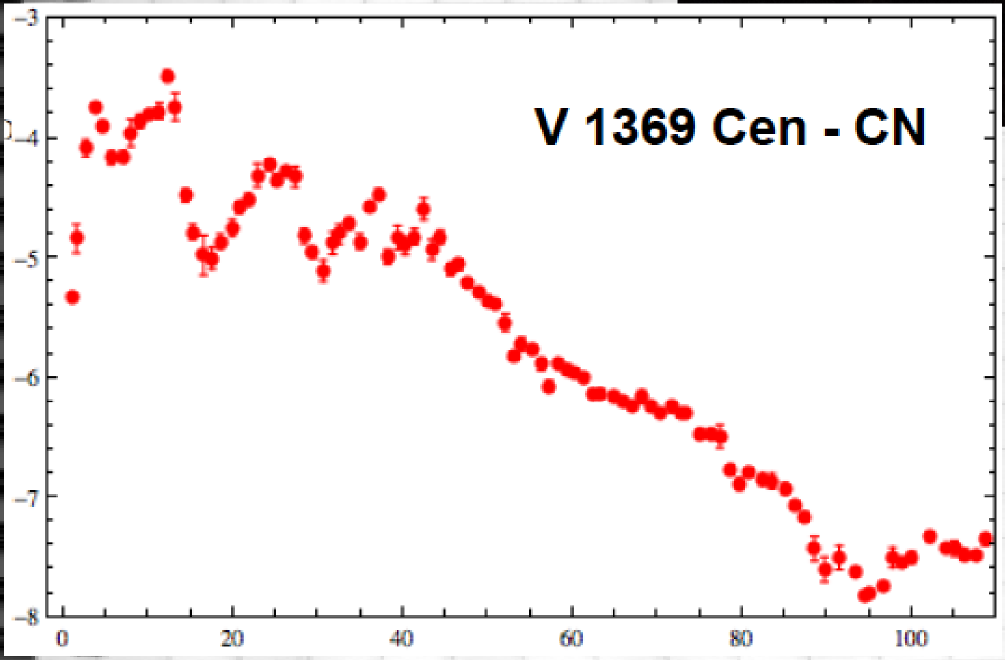
→ We see only 1 outburst from a CN !!!

Short recurrence times have been interpreted to indicate:
- WD mass close to Chandrasekhar limit
- high accretion rate onto the primary WD

Nova Cen 2013

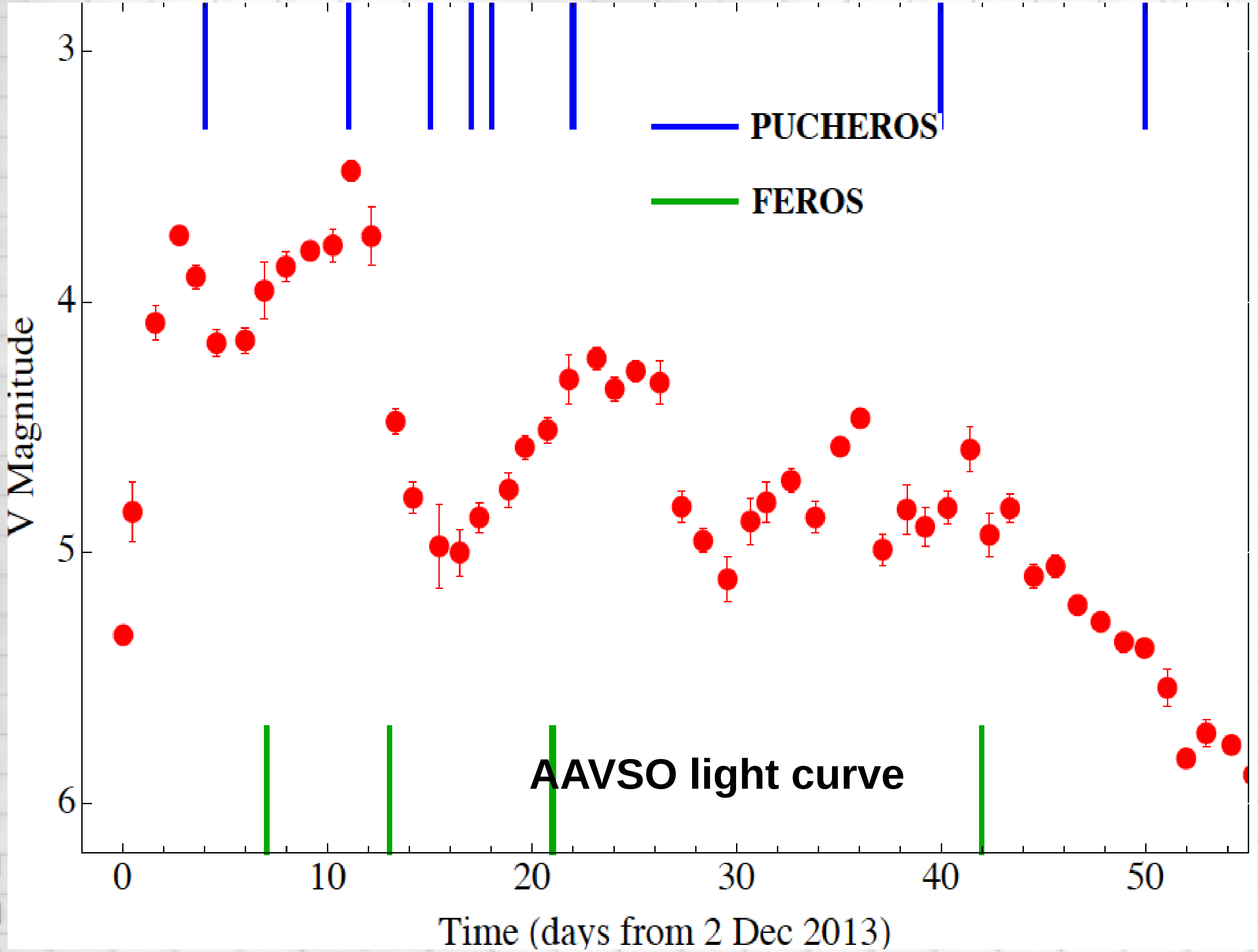
$V_{max} = 3.5$

$T_2 = 50$ days



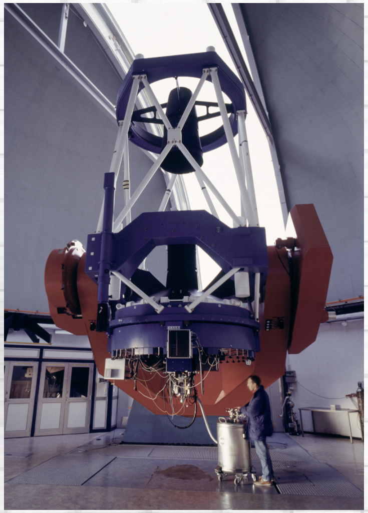
The brightest nova of the XXI century !!! (up to now...)

Observations

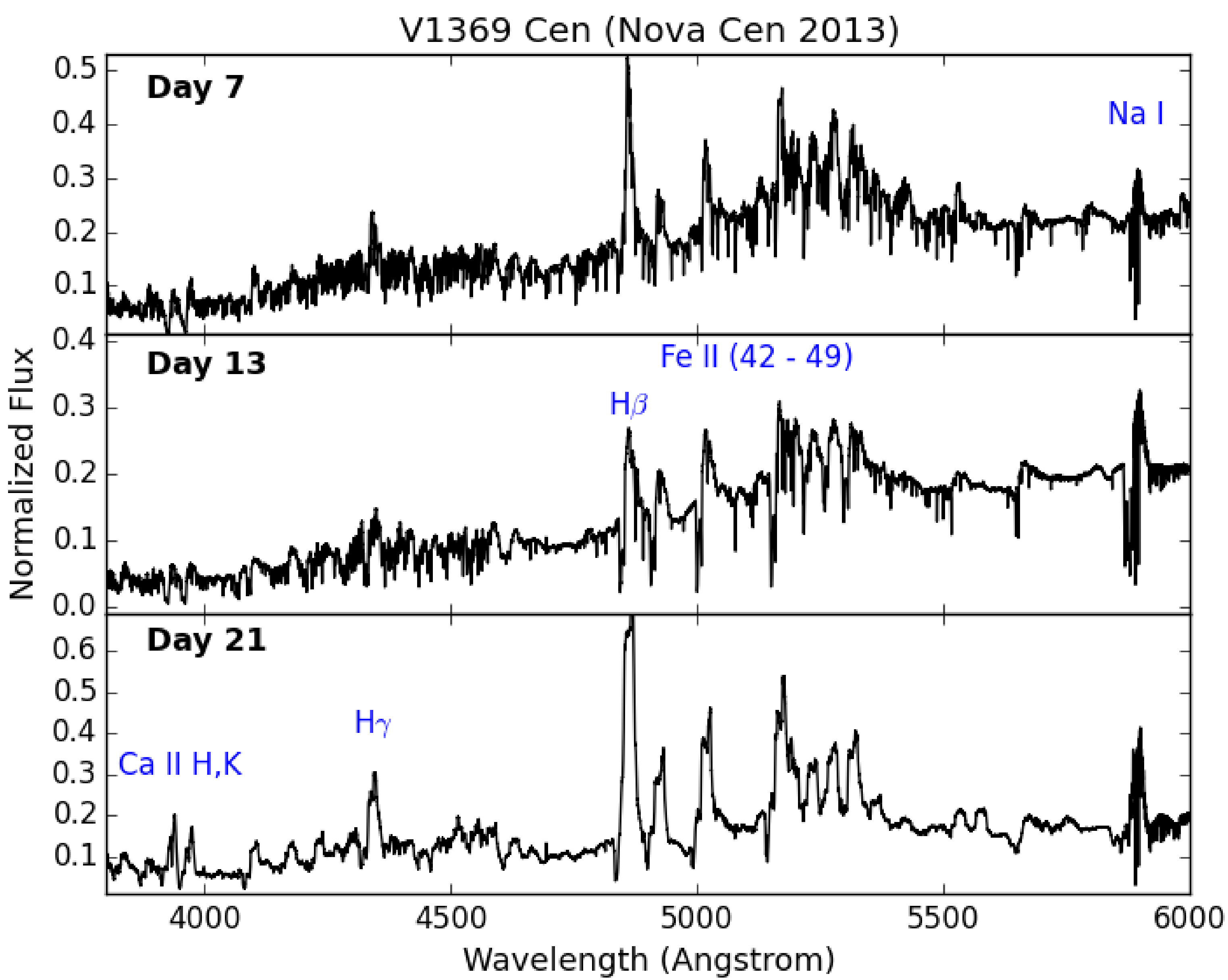


0.50m @PUC

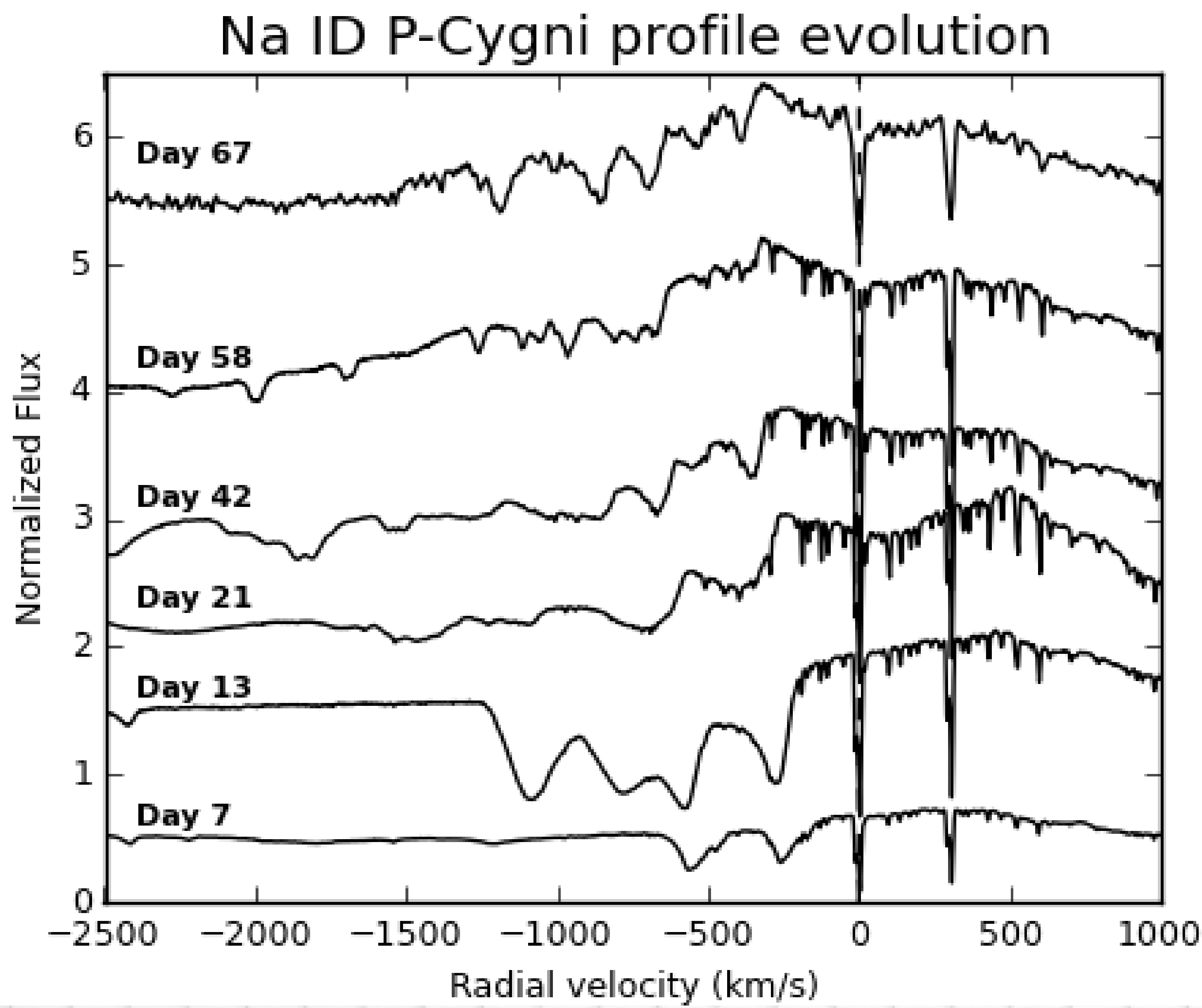
2.2m @La Silla



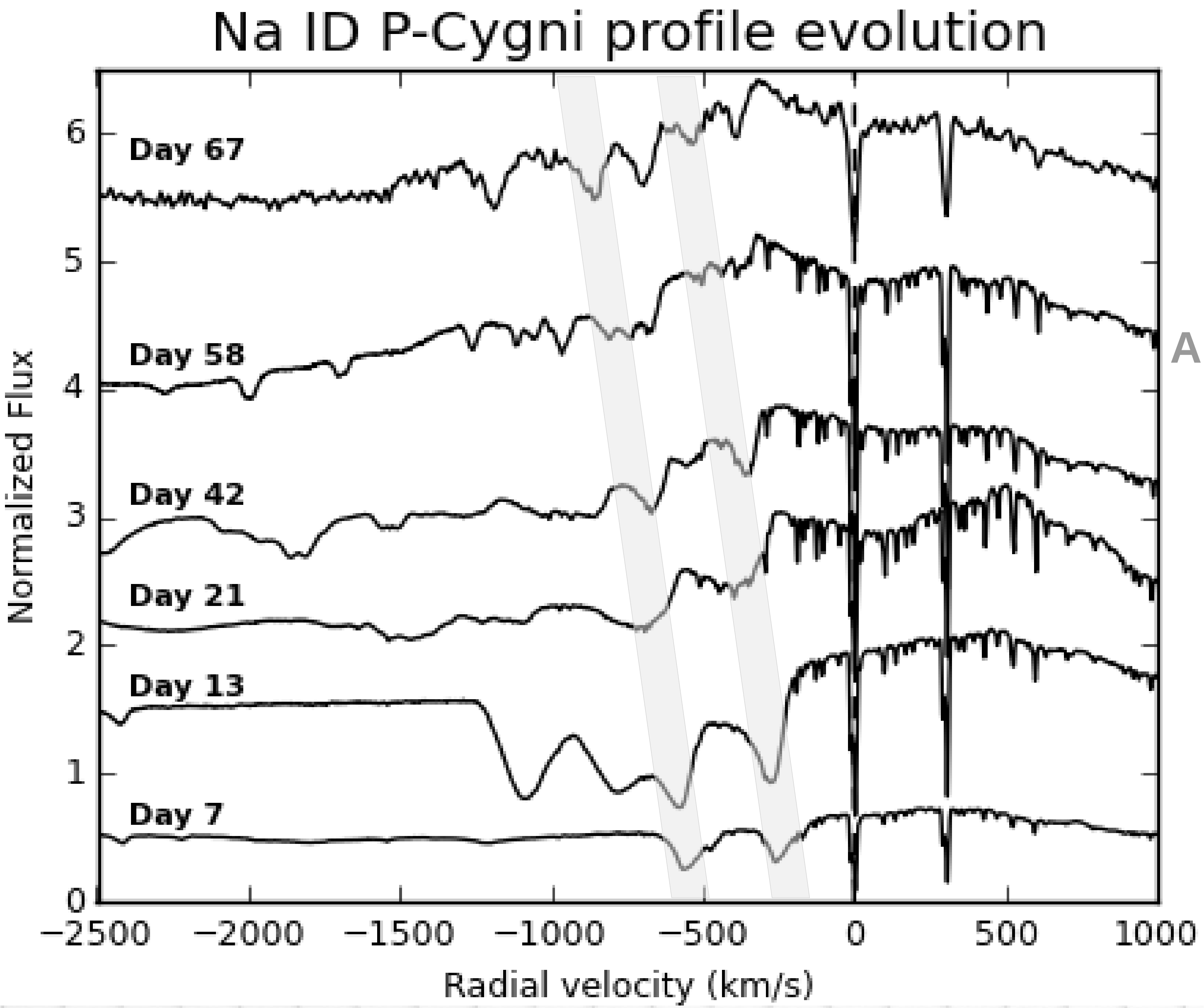
The "iron curtain" phase



P-Cygni evolution

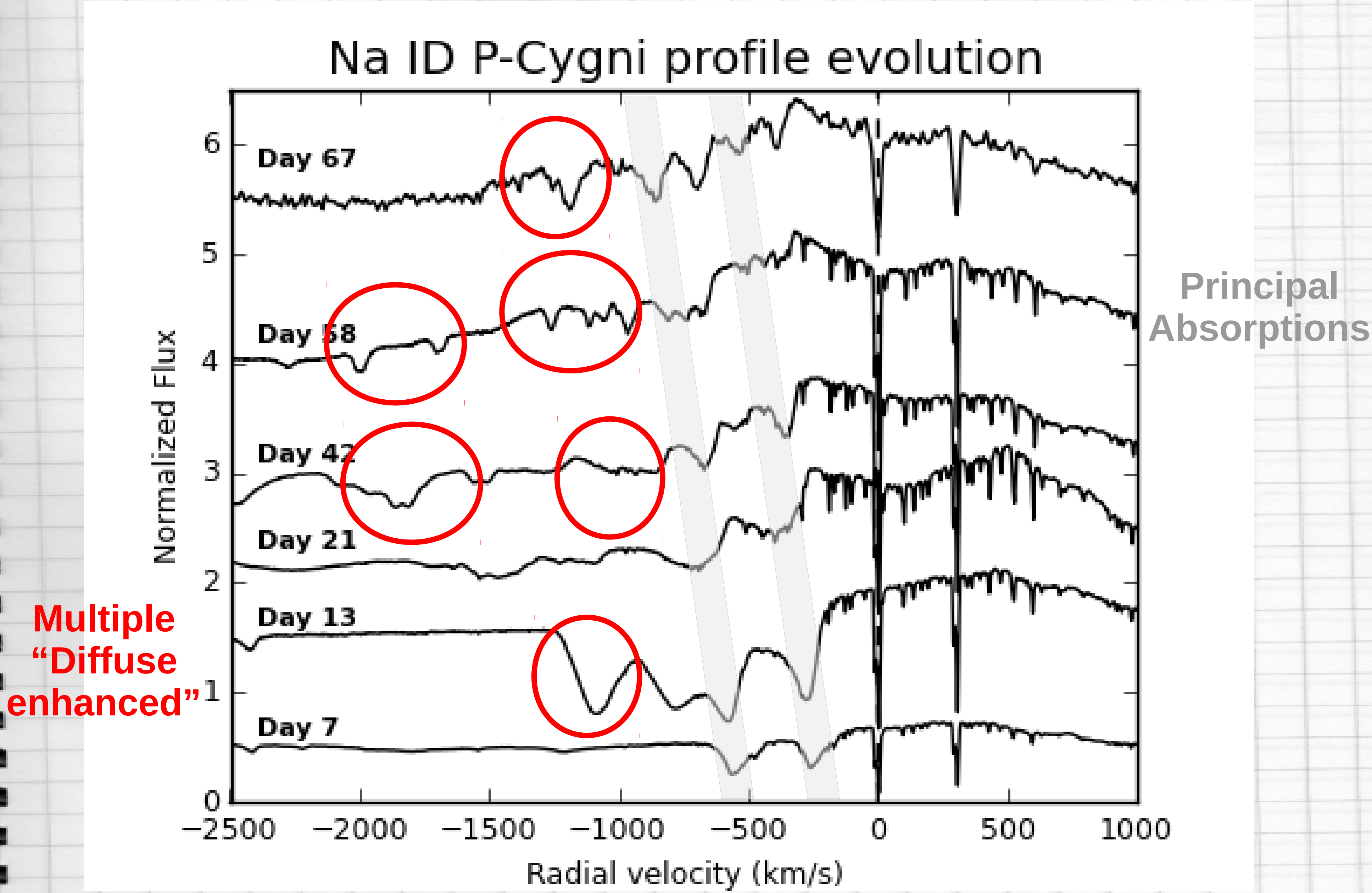


P-Cygni evolution



Principal Absorptions

P-Cygni evolution



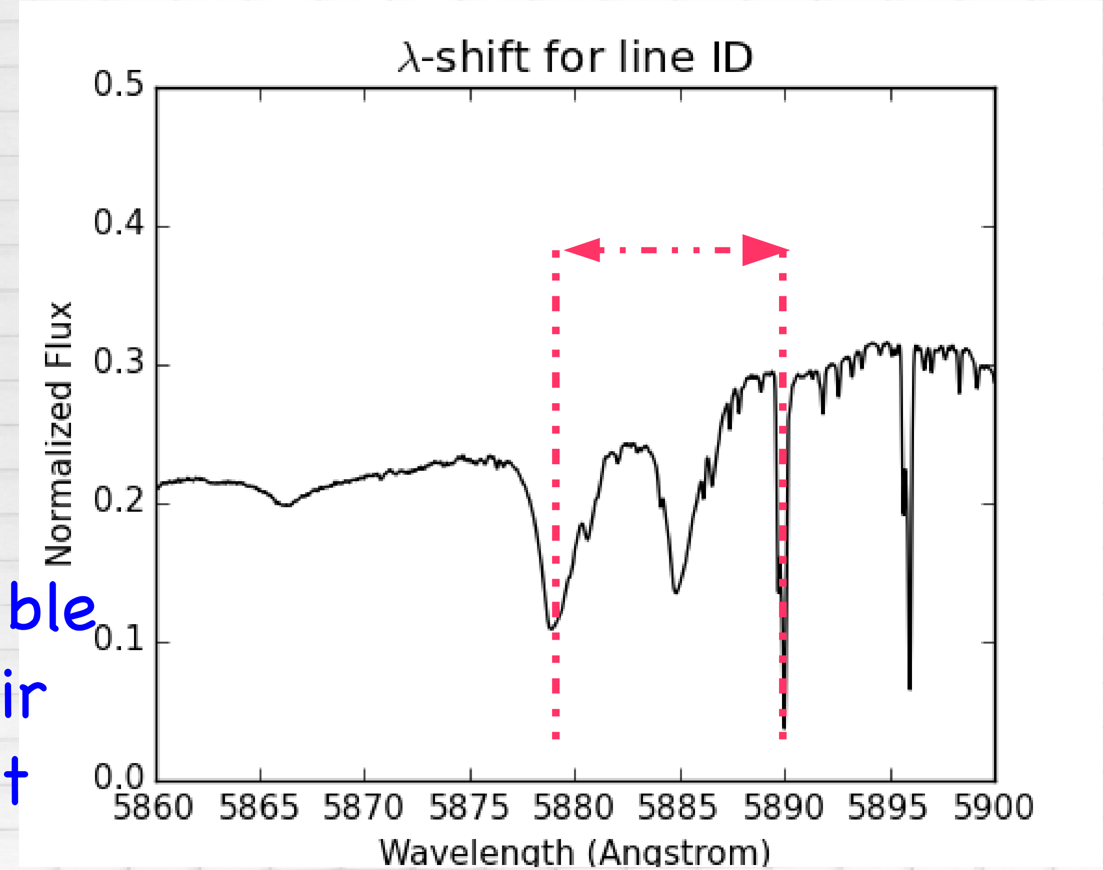
ID absorption features

- GOAL : using principal velocity absorption to identify absorption lines (...mainly the narrow ones...)

(Williams+ 2008)

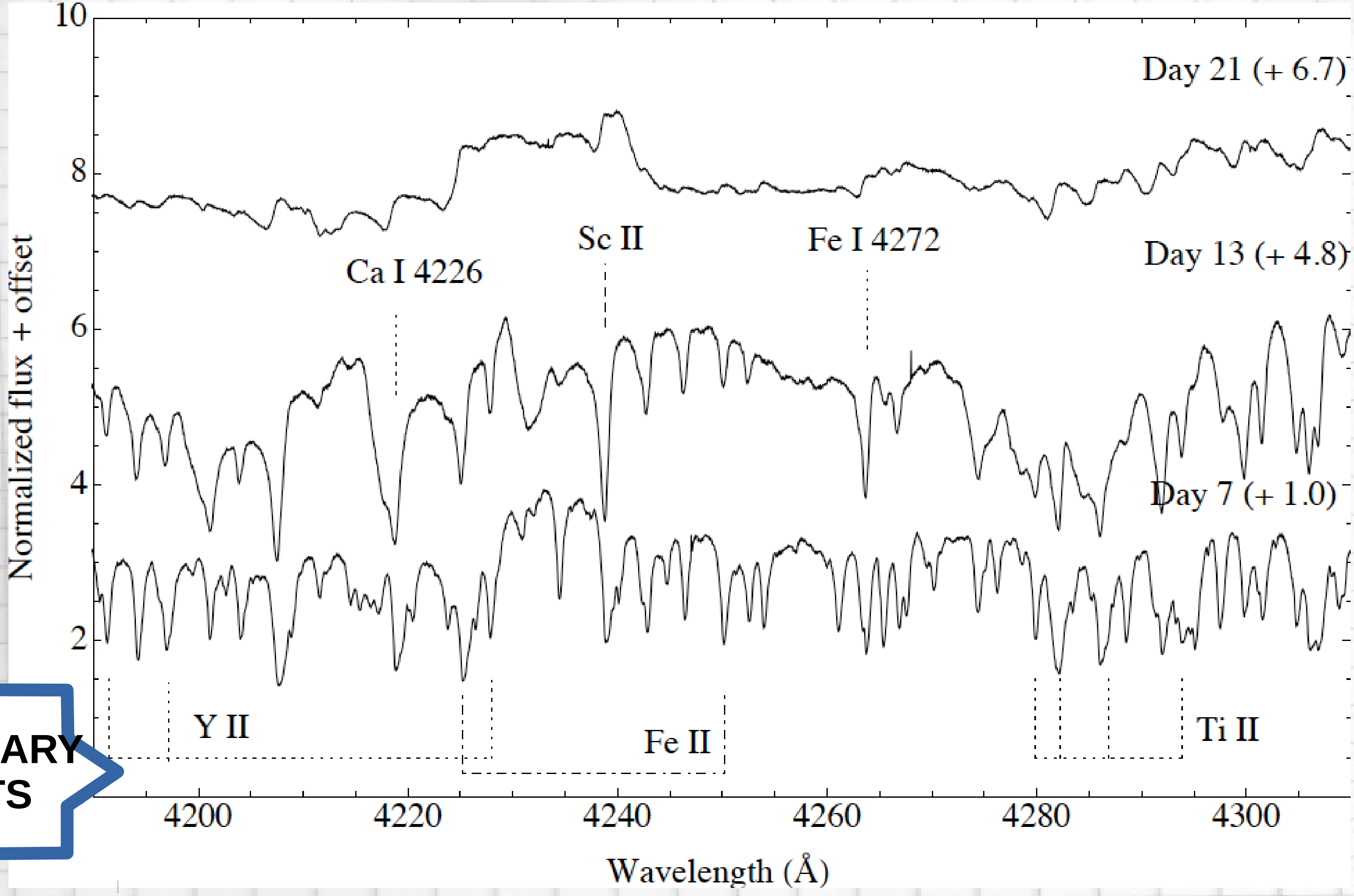
X = λshift / λrest

From a database of possible transitions we check their presence in our dataset



ID absorption features

~320 ID of singly-ionized heavy-elems



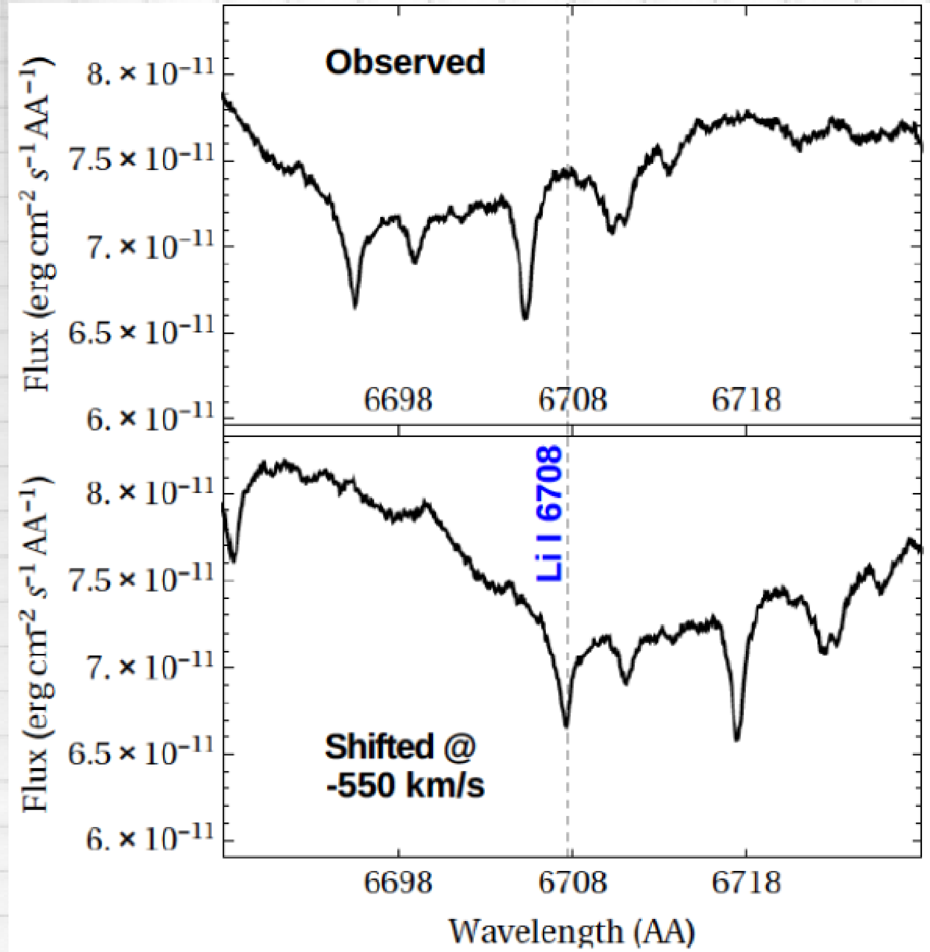
PRELIMINARY RESULTS

The case of Li I 6708

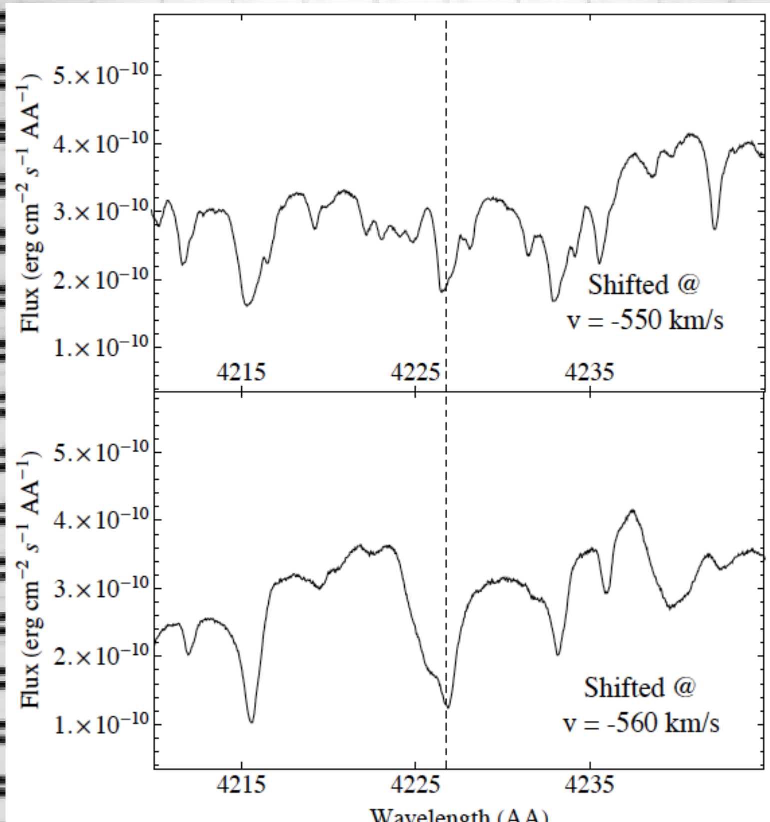
Detection of a feature @ 6695.6 on Day 7
→ Li I 6708 expanding @ -550 km/s

Observed for about two weeks

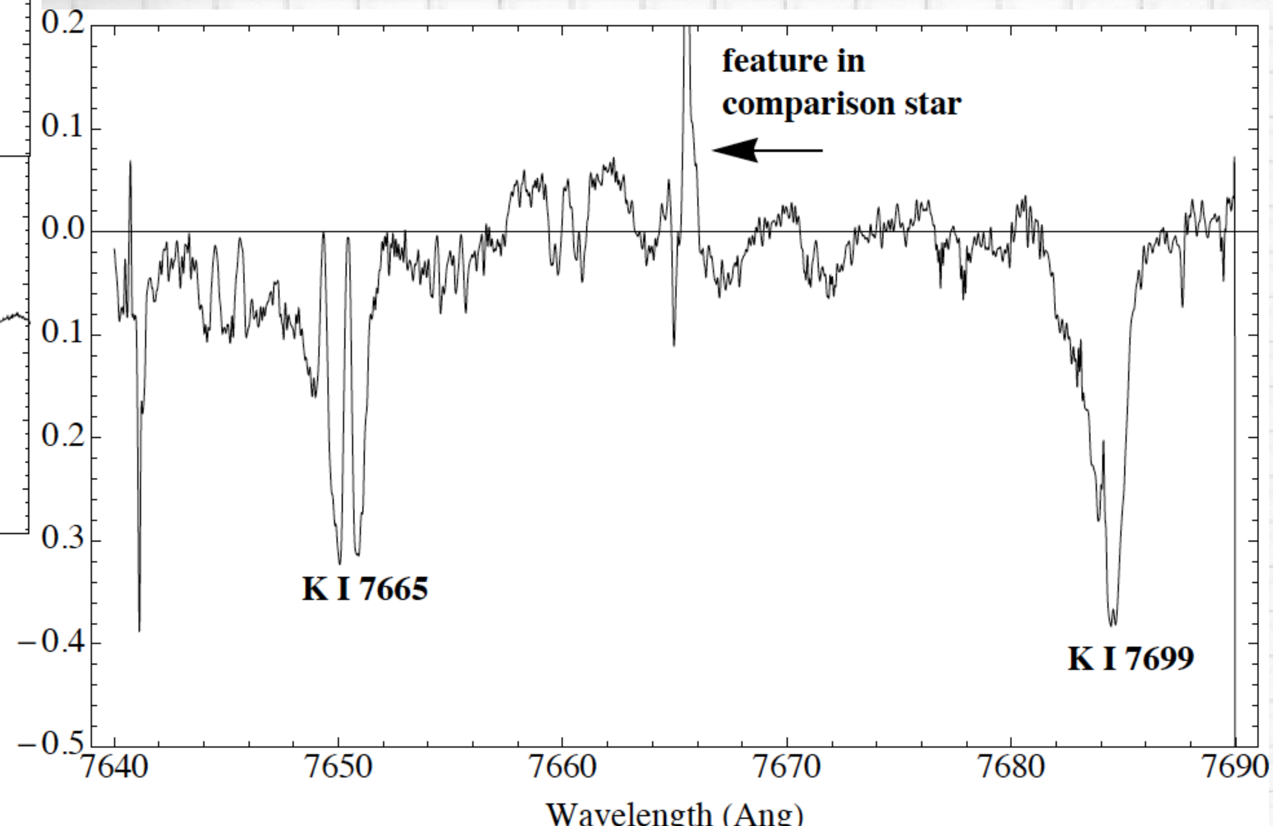
ID of other neutral resonance lines as
Ca I 4226
K I 7665-7699
… and Na I …



The case of Li I 6708



Ca I 4226



K I doublet deblended from telluric lines

→ *Obs EW ratio = 0.54 – loggf ratio = 0.50*

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

c) these wavelength of these absorptions vary with time (as the principal absorption moves on)

The case of Li I 6708

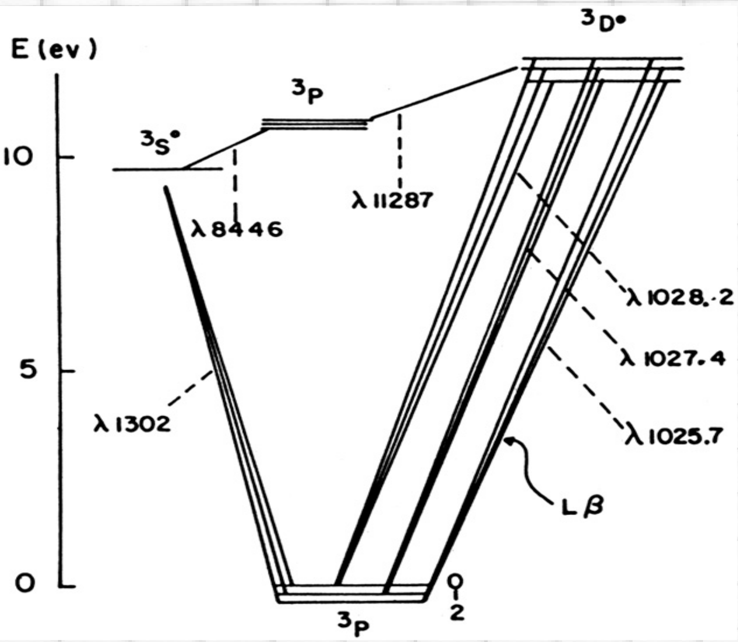
➔ Fluorescence – UV pumping :

1) excitation by photon absorption (continuum or line coincidence) from a level l to a level x > l

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/

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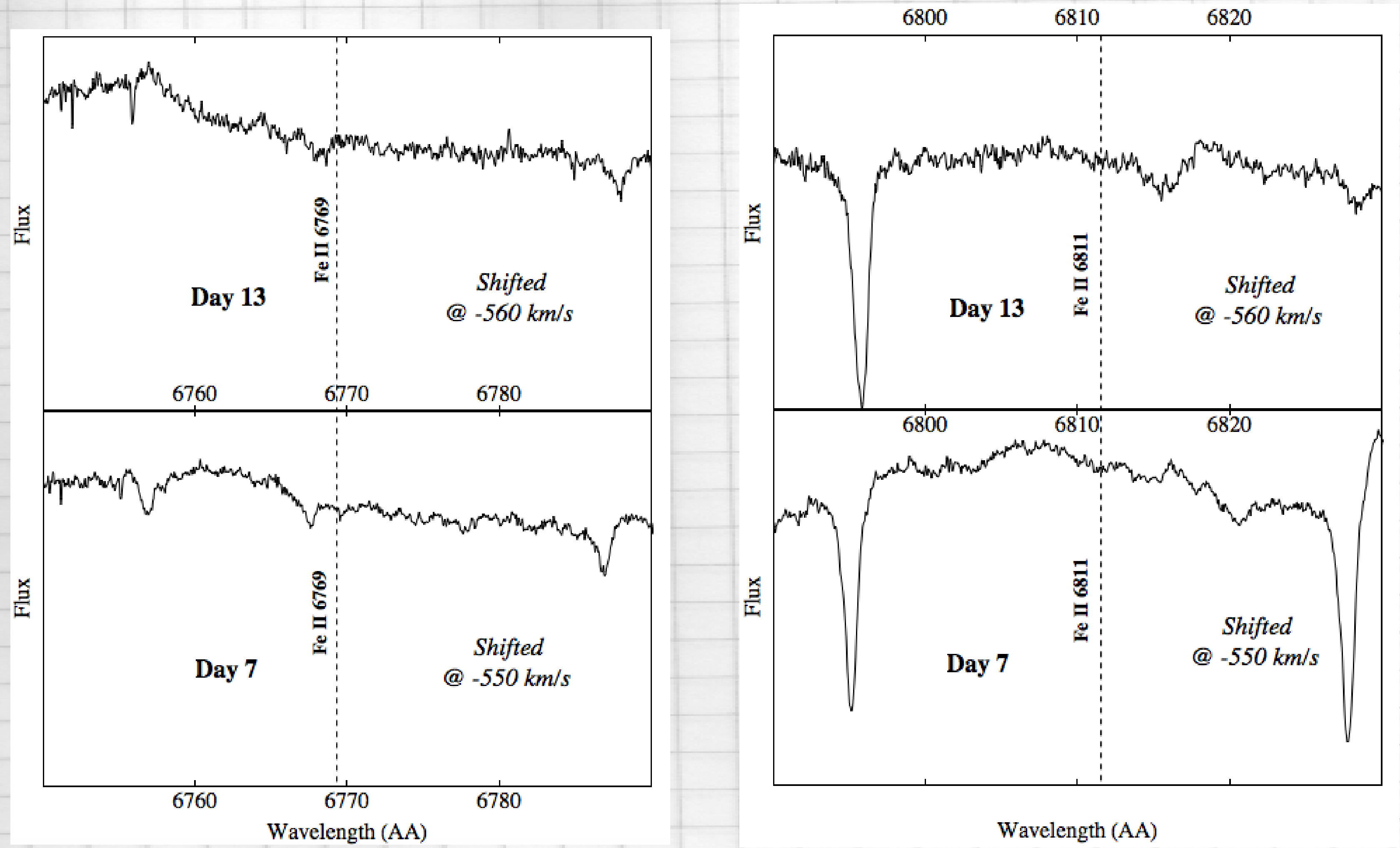
6708.	Cl VII	E1	2D-2Fo	5/2 - 5/2	70.569600 - 72.417400	ASD

Electric 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

- Li, K and Na are alkali metals with similar Grotrian diagrams and resonant transition

(Friedjung 1979)

- The ratio of their $\tau \propto$ abundance ratio :

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

(Spitzer 1998)

- We use the abundance ratio Li/Na and Li/K to determine the ejected mass through numerical results of nova models of Josè & Hernanz (1998)

Estimate of mass ejected

Yields from CO Nova Models (Mass Fractions)

Nucleus	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

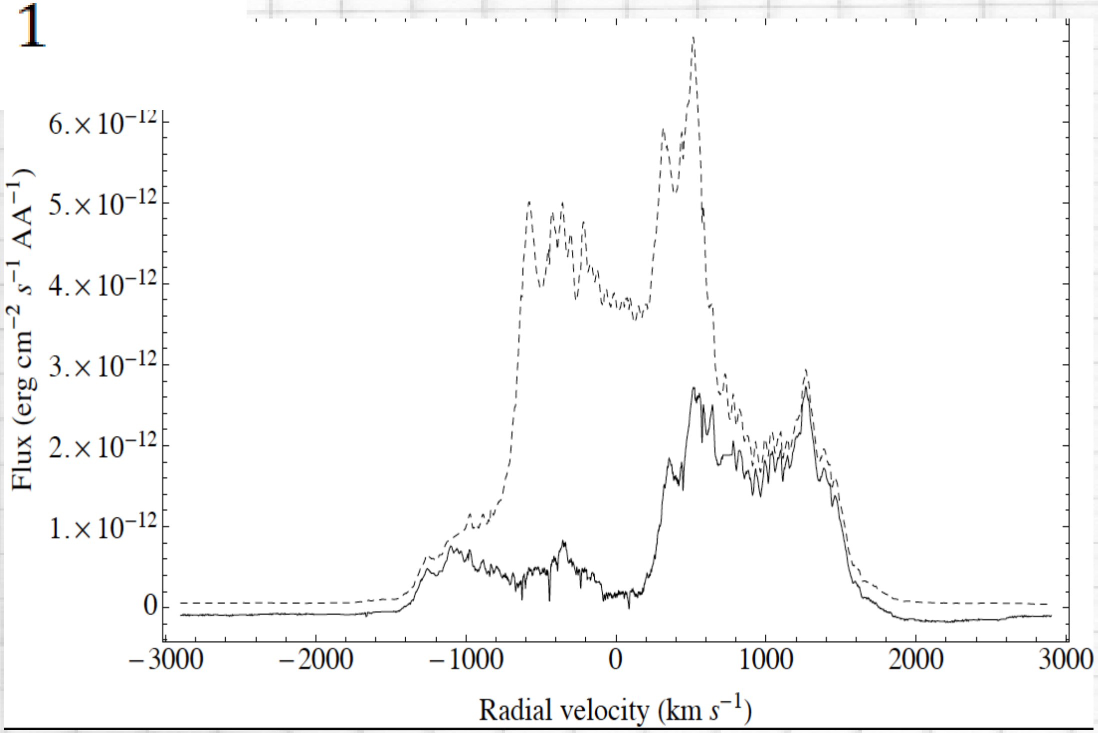
$$N_e = \sqrt{T_e} \cdot \frac{1.94 \cdot 10^5 - \dfrac{1.97 \cdot 10^4 \cdot R_2}{(e^{25000/T_e})}}{\dfrac{61.5 \cdot R_2}{(e^{25000/T_e})} - 1}$$

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

(Osterbrock 1989)

[N 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)

Ne = Np

Distance (= 2.5 kpc)

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

Estimate of mass ejected

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

+

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

(DellaValle&Livio 1994, Shafter 1997)

"slow" novae :

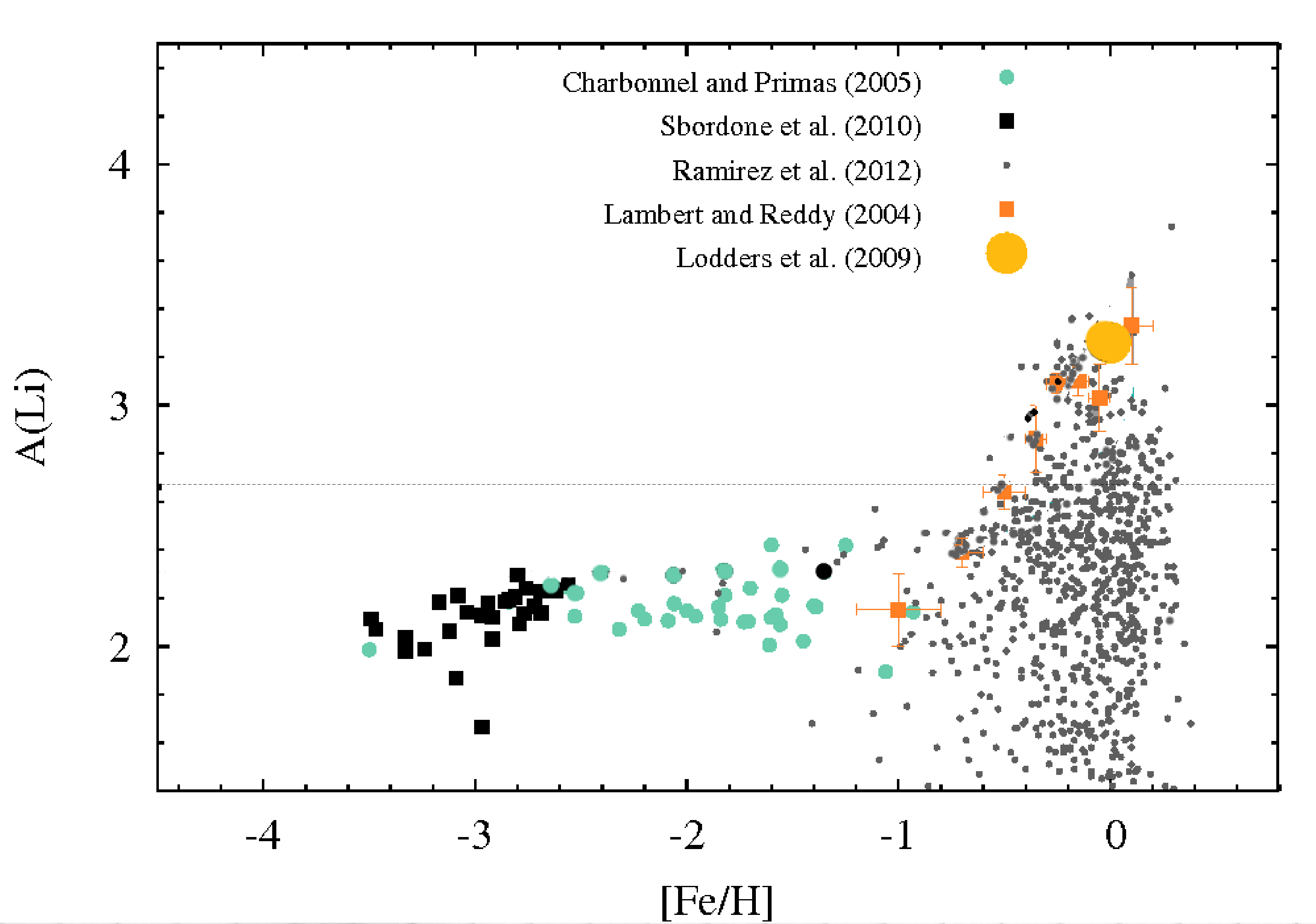
→ more massive nova ejecta

→ 70% of the nova pop of the MW → $\underline{15\text{-}24\ yr^{-1}}$

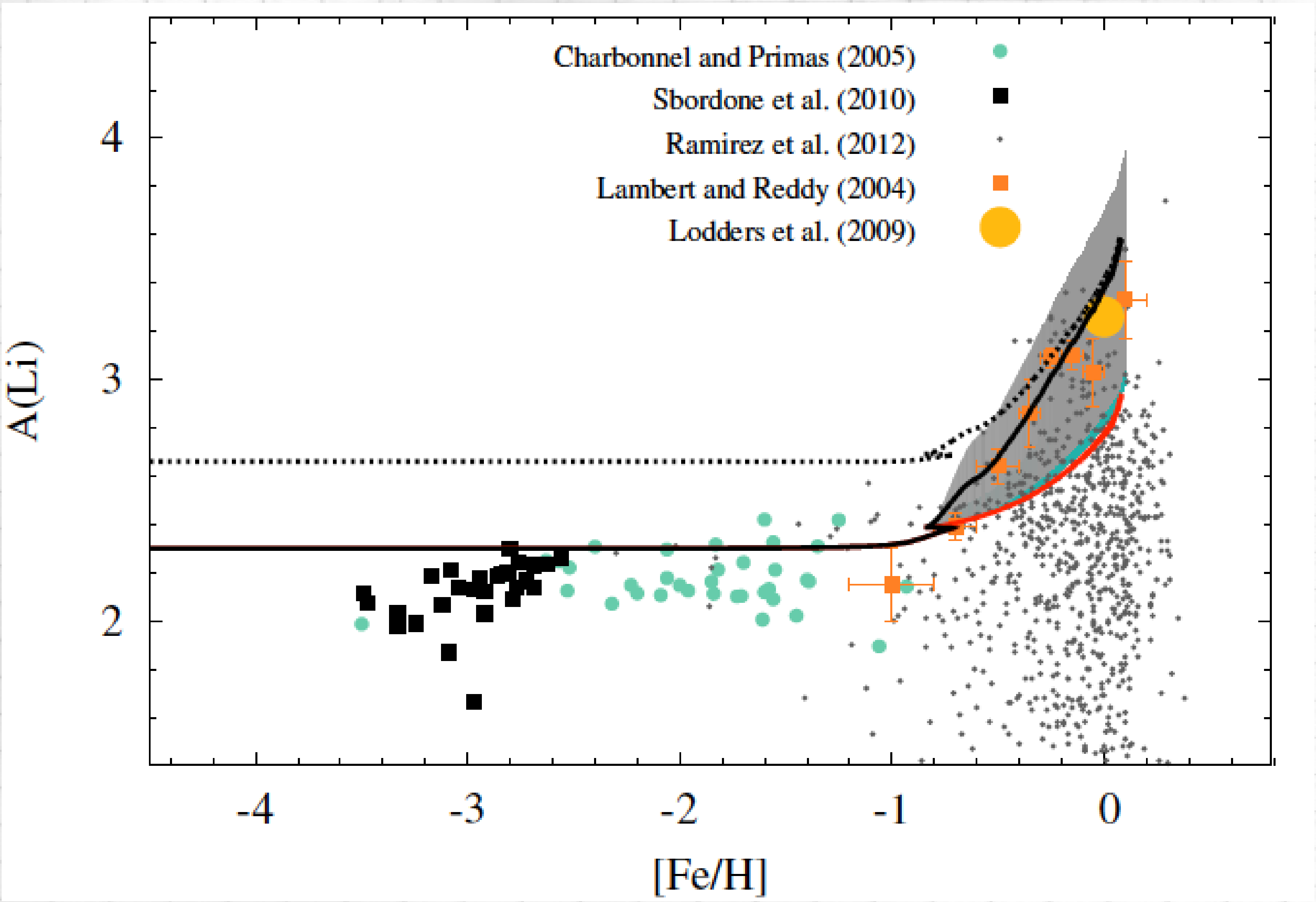
(DellaValle&Duerbeck 1993)

Testing the Galactic chemical evolution of Li by considering this contribution from all nova systems

Galactic Li enrichment



Galactic Li enrichment by novae



(D'Antona & Matteucci 1991, Romano+ 1999, Romano+ 2001, Izzo+ 2015)

The New York Times

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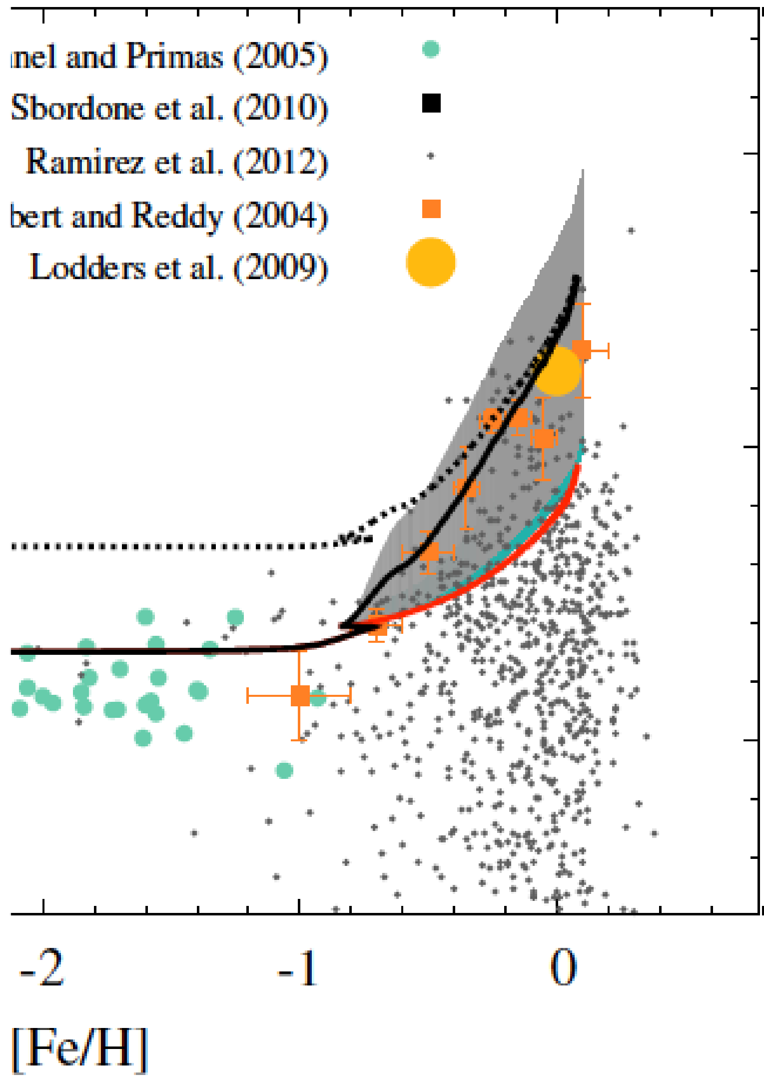
Observatory

EUROPEAN SOUTHERN OBSERVATORY

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 New York Times

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NEW YORK, TUESDAY, AUGUST 4, 2015

Observatory

EUROPEA

ASTRONOMY

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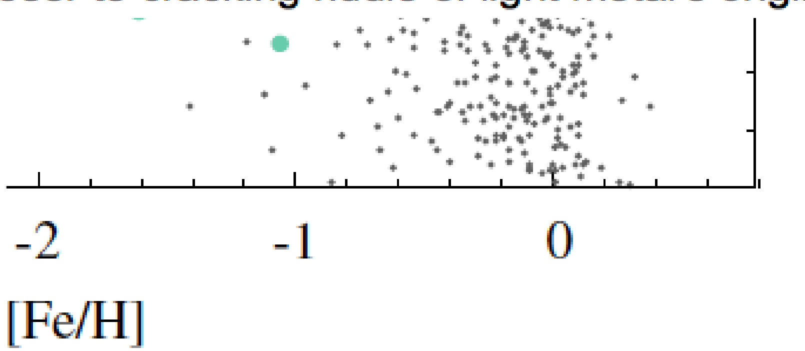
Science

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

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



Details on Galactic chemical model

Based on the two-infall model

(Chiappini+1997)

It includes:

- AGB & super-AGB stars
- Galactic cosmic-rays
- Novae

(Karakas+2010, Doherty2014, Lemoine1998)

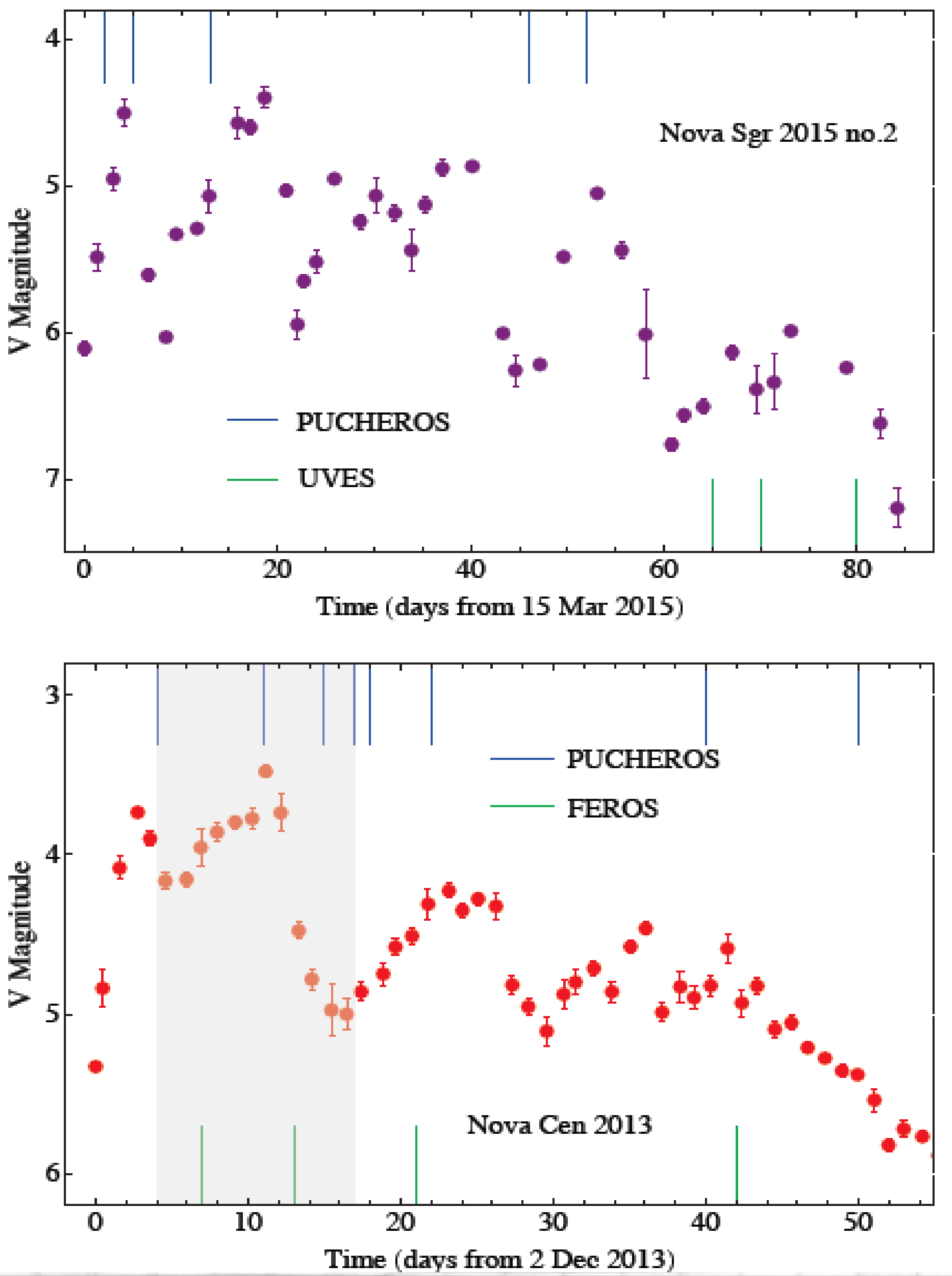
- The Galactic thick disk and inner halo form by accretion of "primordial" gas on short timescale (1Gyr), that turned into stars as long as its density below a threshold

- The thin disk forms out of infall of gas on longer timescales (7-8 Gyr)

(Romano+ 1999,2001)

Perspectives

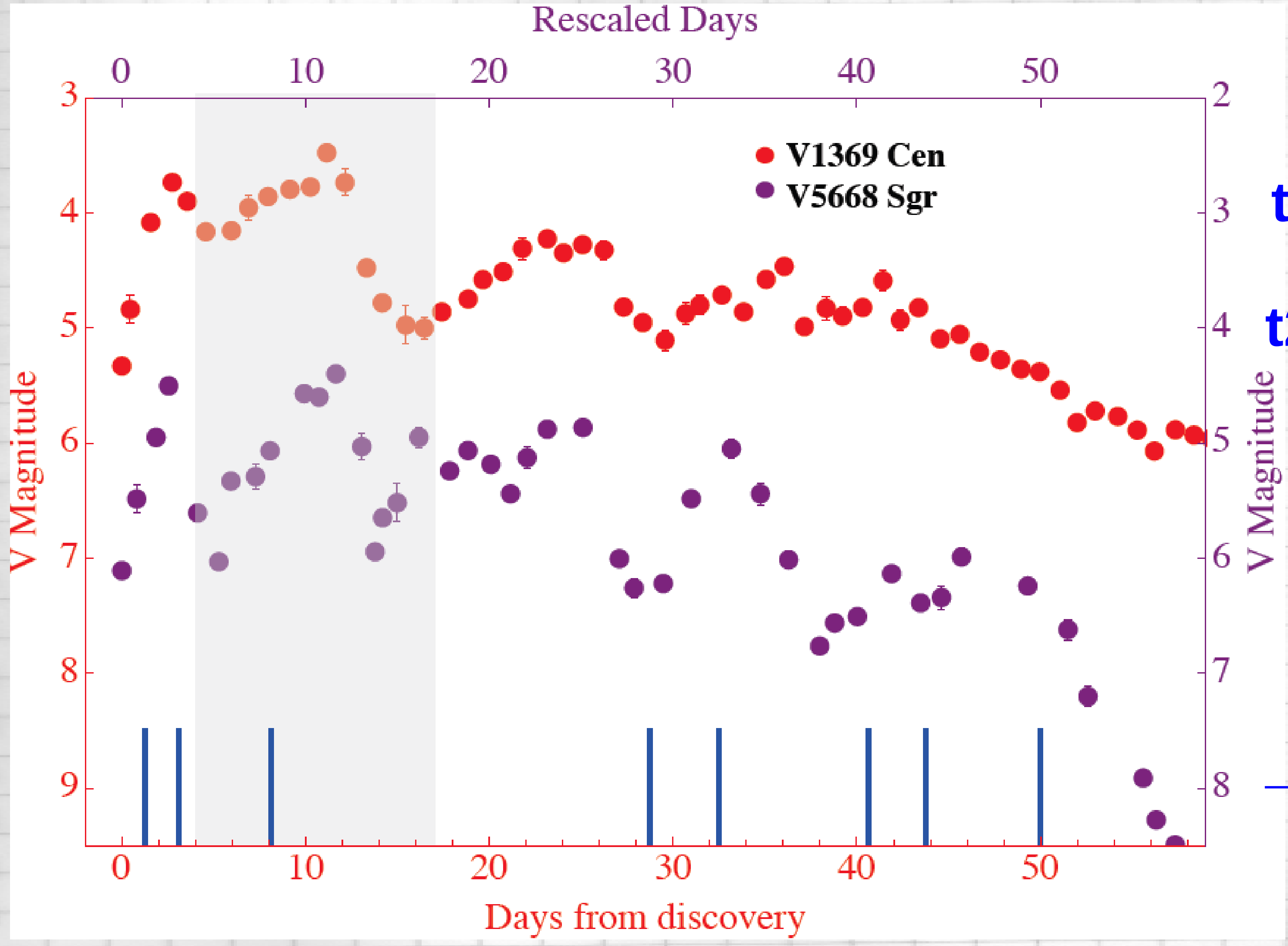
- Confirming the results obtained with V1369 Cen through Li detection in other novae (V5668 Sgr ?)



t2 Sgr = 80 dd

t2 Cen = 50 dd

AAVSO data - rebinned



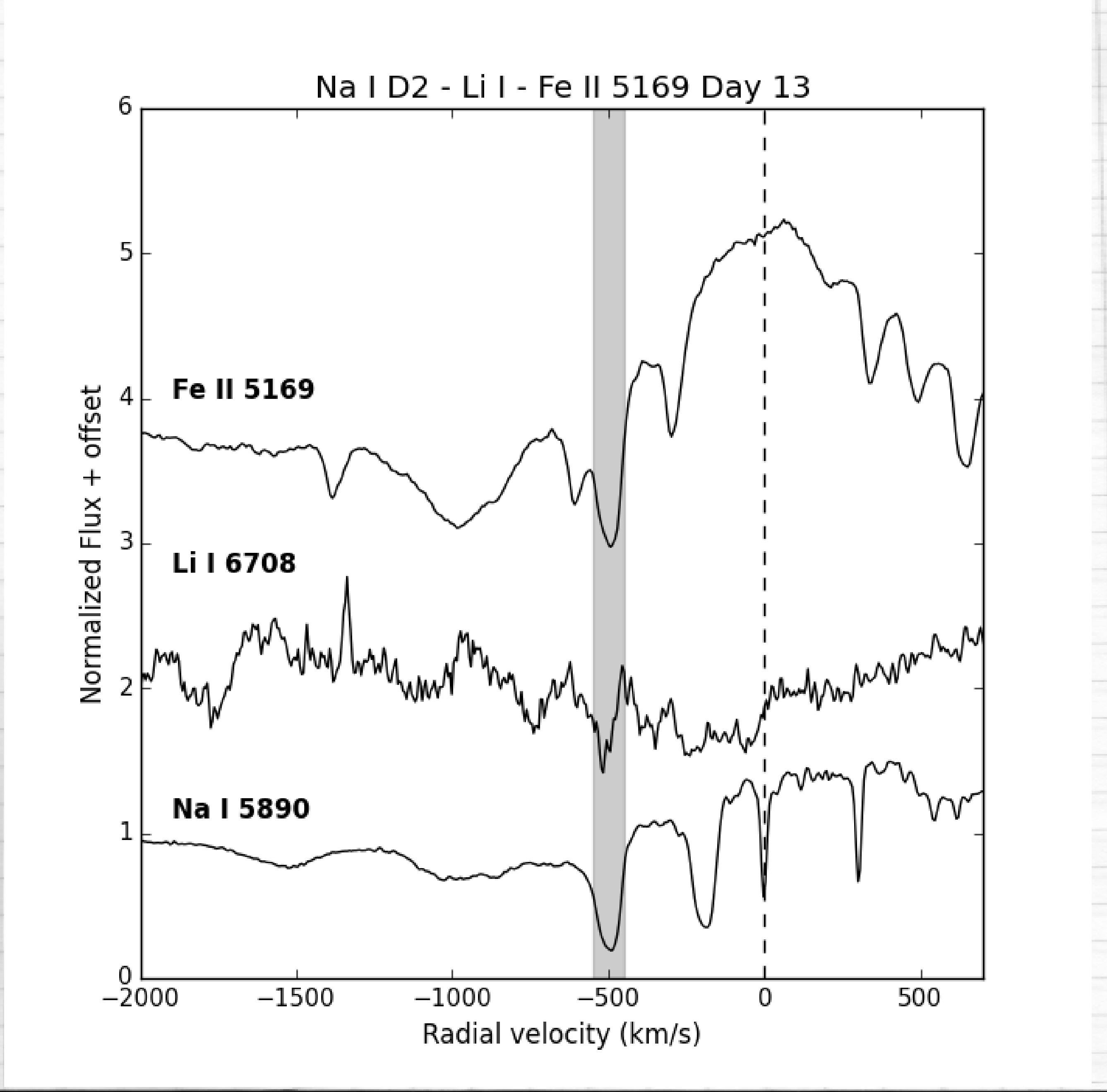
t2 Sgr = 80 dd

t2 Cen = 50 dd

Scale factor
→ t* = 0.625 t_{obs}

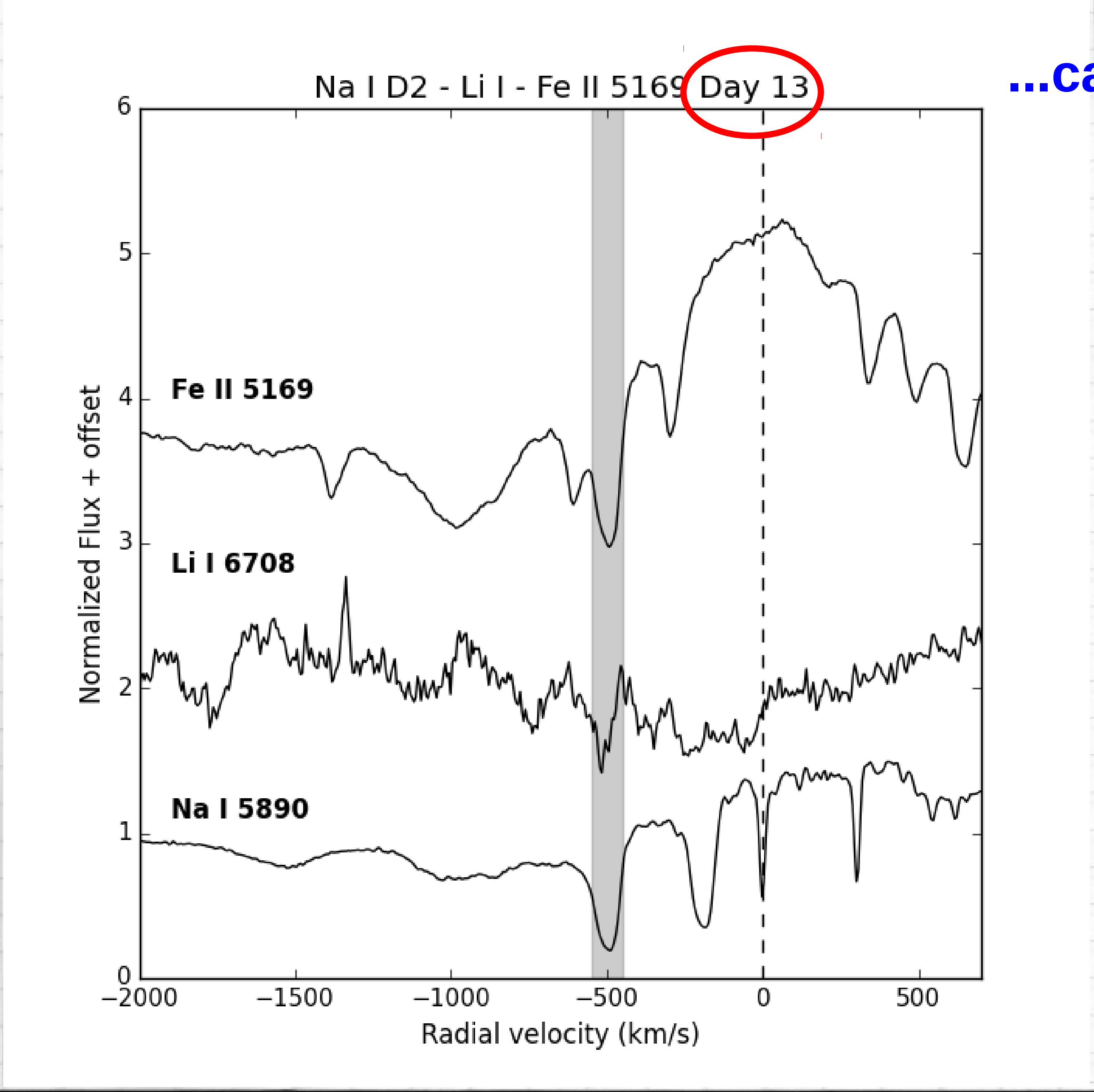
AAVSO data - rebinned

I'm so happy...



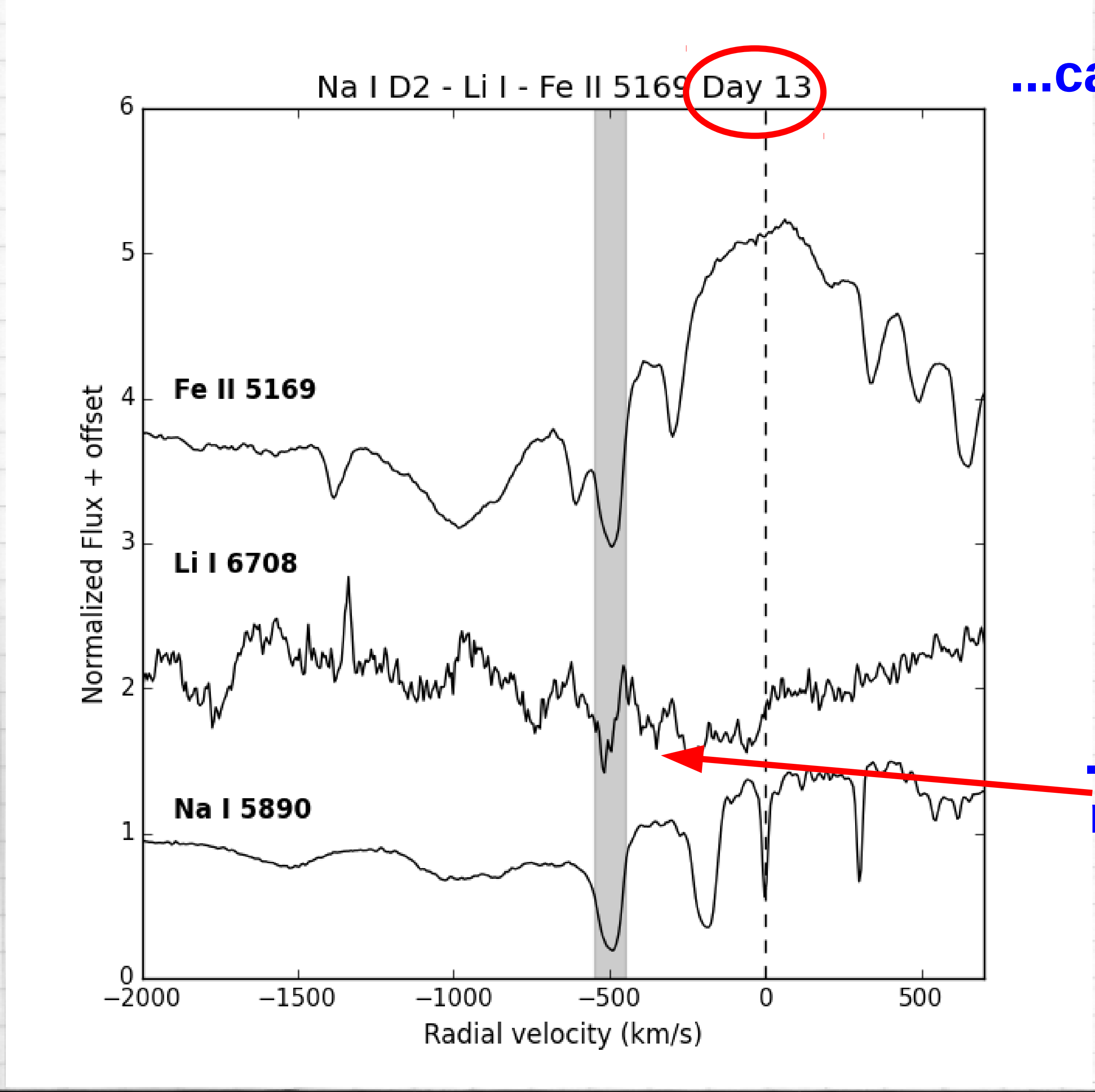
Na I D2 - Li I - Fe II 5169 Day 13
Fe II 5169
Li I 6708
Na I 5890
Normalized Flux + offset
Radial velocity (km/s)
0
1
2
3
4
5
6
−2000
−1500
−1000
−500
0
500

I'm so happy...



...cause today...

I'm so happy...



...cause today...

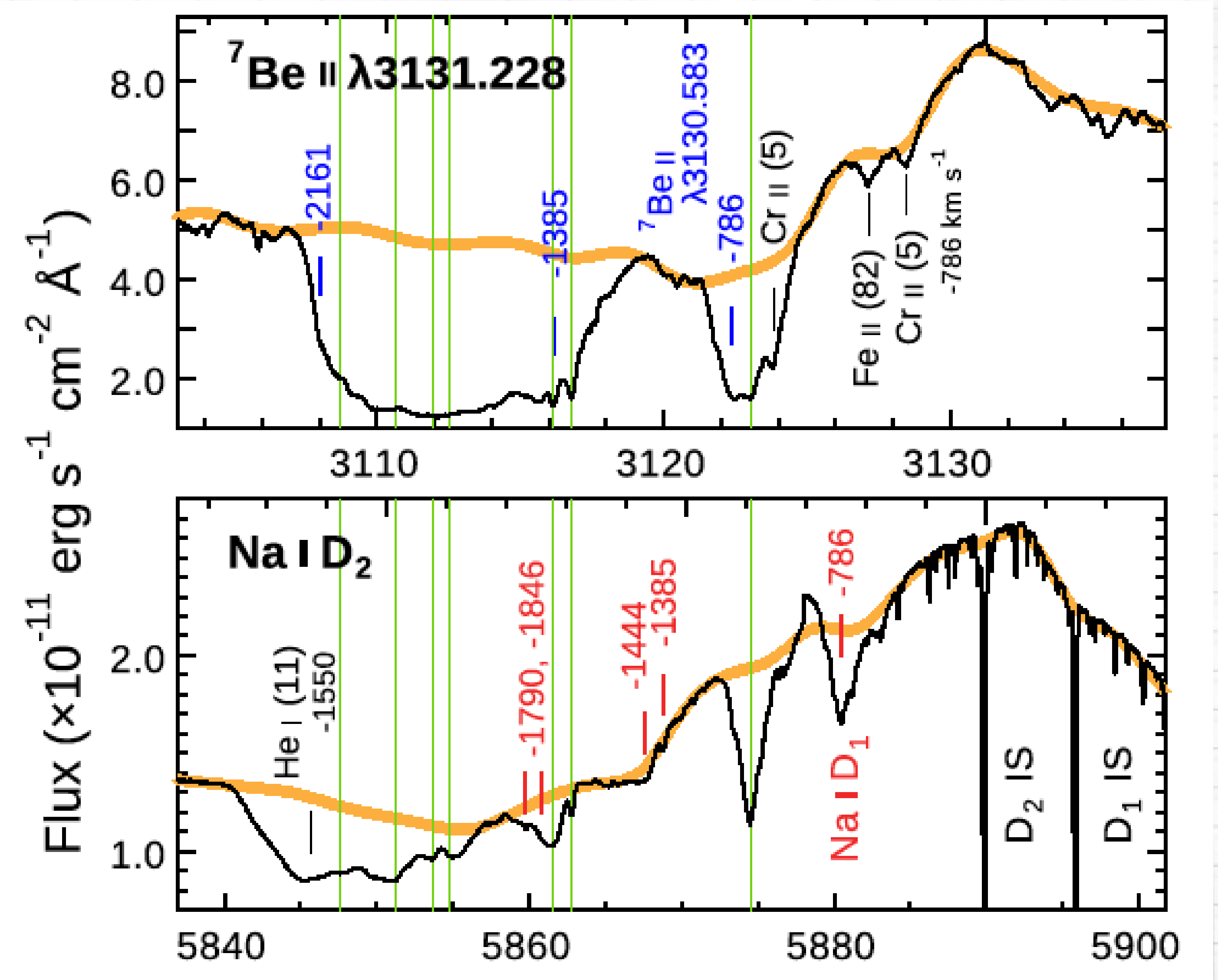
...I've found my friend...

Perspectives

- Confirming the results obtained with V1369 Cen through Li detection in other novae
(V5668 Sgr ?)

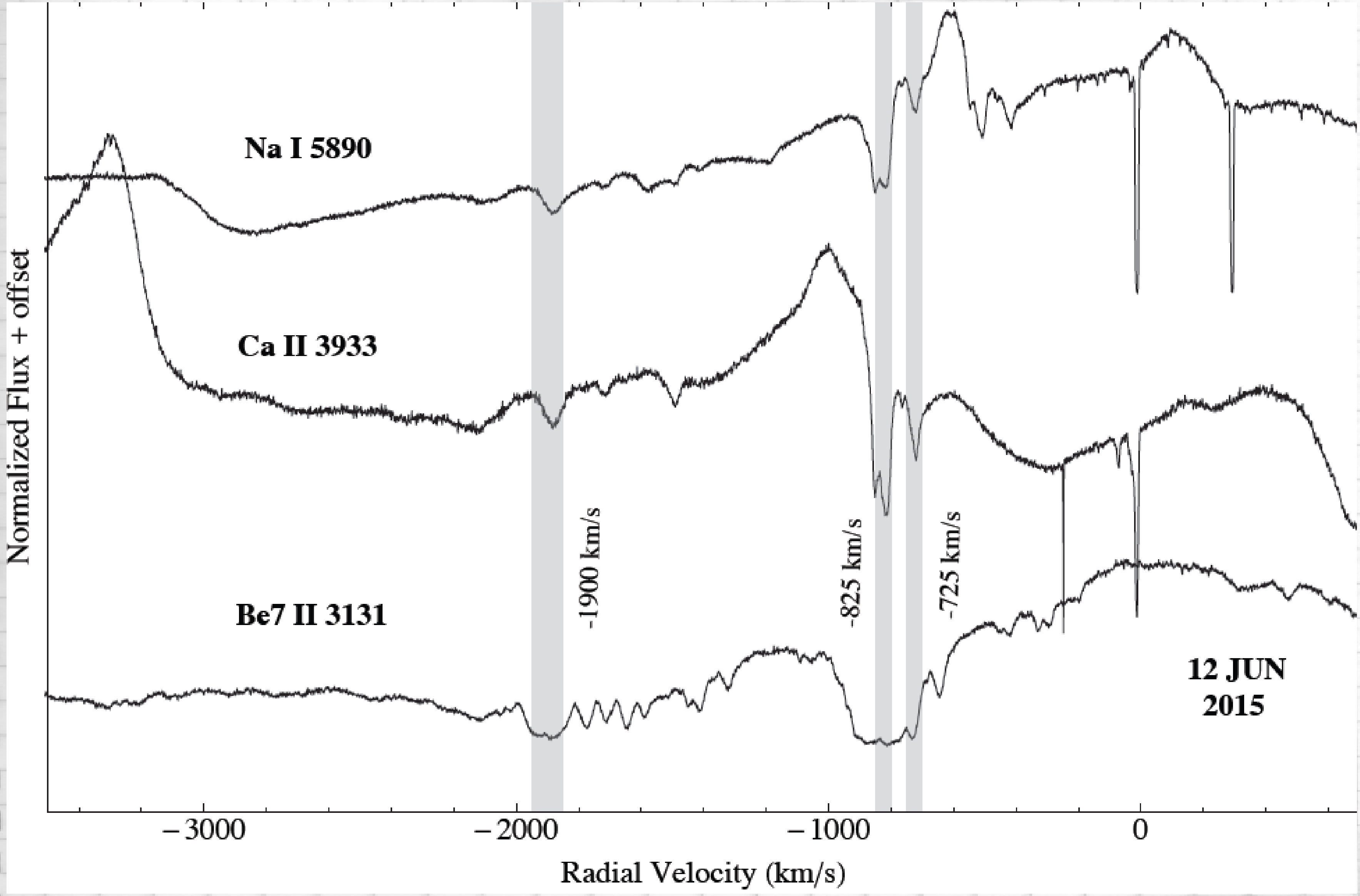
- Recent Be II detection → V5668 Sgr as laboratory
(see Tajitsu et al. 2016)

Ionized Beryllium



(Tajitsu+ 2016)

Ionized Beryllium



Work in preparation

Ionized Beryllium – abundances

The abundance of Li obtained by Izzo et al. (2015) from the Li I λ6708 is lower than the ^{7}Be (= Li) abundances obtained in the present study. There had been no report in literature of detection of the Li I λ6708 line among post-outburst novae before Izzo et al. (2015). Be-

Tajitsu+ 2016

...but...

hours as it was in the Schwarzschild-Härm calculations. The lifetime of the ^{3}He$(\alpha,\gamma)^7$Be reaction is a few hours near 8×10^7 ° K. It is thus evident that the ^{3}He content of the stellar envelope would be converted to ^{7}Be. Even if the *average* ^{3}He mass fraction in the outer envelope is only 10^{-7}, the amount of ^{7}Be produced would be a factor of 10 higher

than the lithium abundances in WZ Cas, WX Cyg, T Ara, and T Sgr. Most of the ^{7}Be would be mixed to a much cooler region before the formation of ^{7}Li by electron capture takes place. It would seem possible that much of the ^{7}Li could be preserved at the surface once the outer envelope has relaxed back toward its former state.

Cameron-Fowler 1971

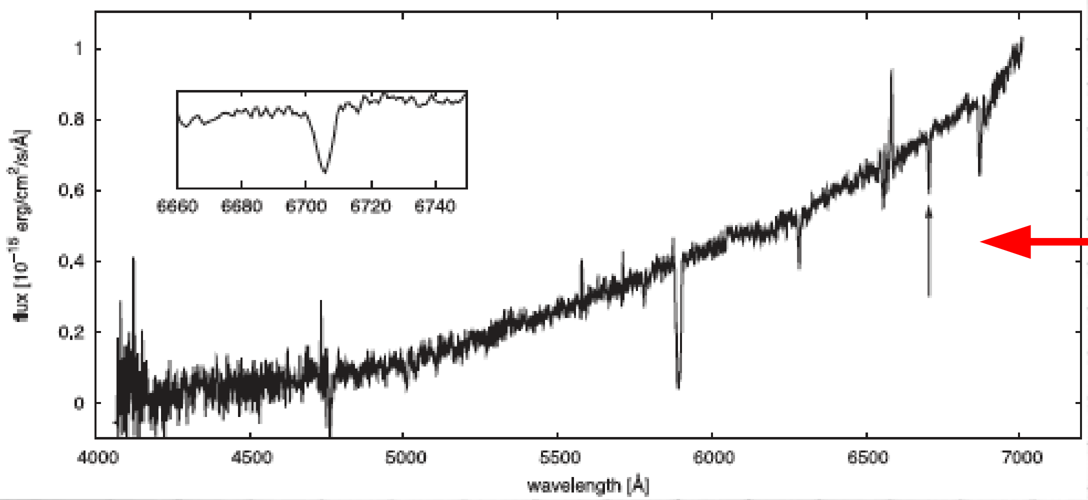
Perspectives

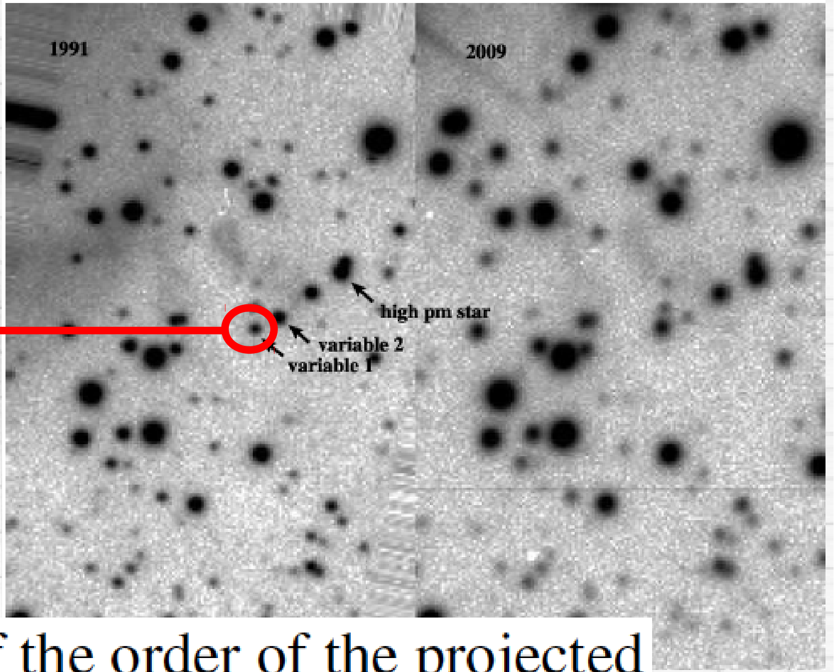
- Confirming the results obtained with V1369 Cen through Li detection in other novae (V5668 Sgr ?)
- Recent Be II detection → V5668 Sgr as laboratory (see Tajitsu et al. 2016)
- Spectroscopical analysis of nova remnant

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 2×10^{-11} $M_\odot$. The derived velocity of the cloud is about 100 km s^{-1}, if it expands in a plane of the sky.

Perspectives

- Confirming the results obtained with V1369 Cen through Li detection in other novae (V5668 Sgr ?)
- Recent Be II detection → V5668 Sgr as laboratory (see Tajitsu et al. 2016)
- Spectroscopical analysis of nova remnant
- CNe as possible Galactic farms of ^{13}C and ^{15}N ???

The end

Gracias !!!