# Classical Novae and the Lithium problem

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# Summary

i) (basic of) physics of outburst
ii) nova populations
iii) the galactic nova rate and the Lithium problem

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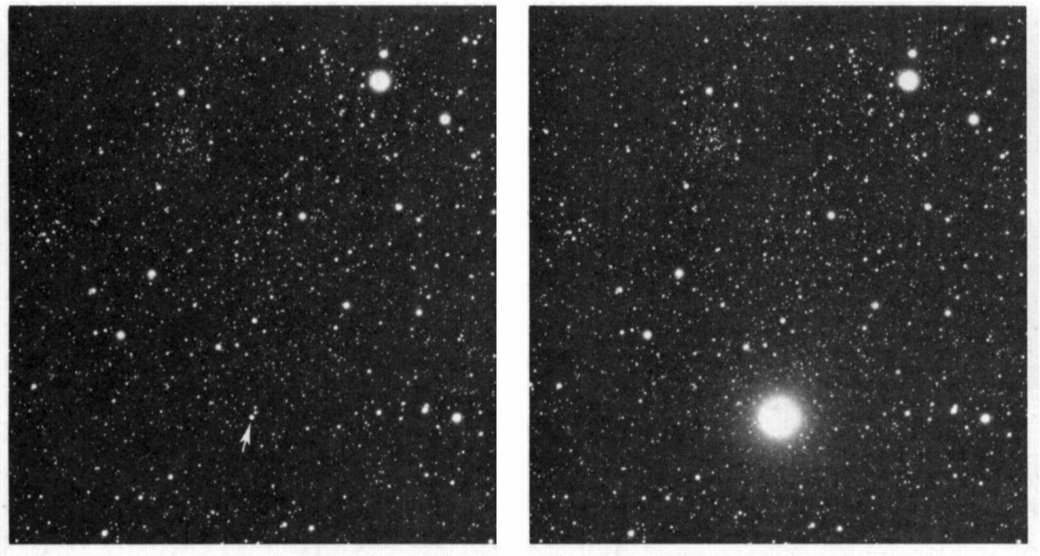
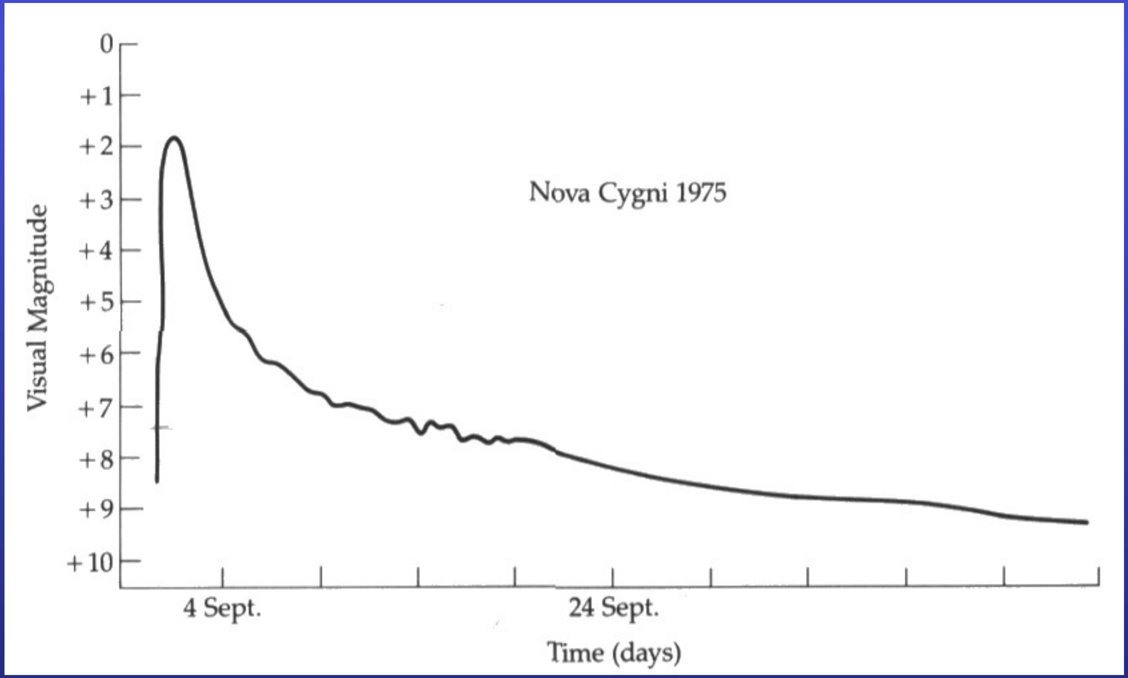
# Nova Phenomenon:

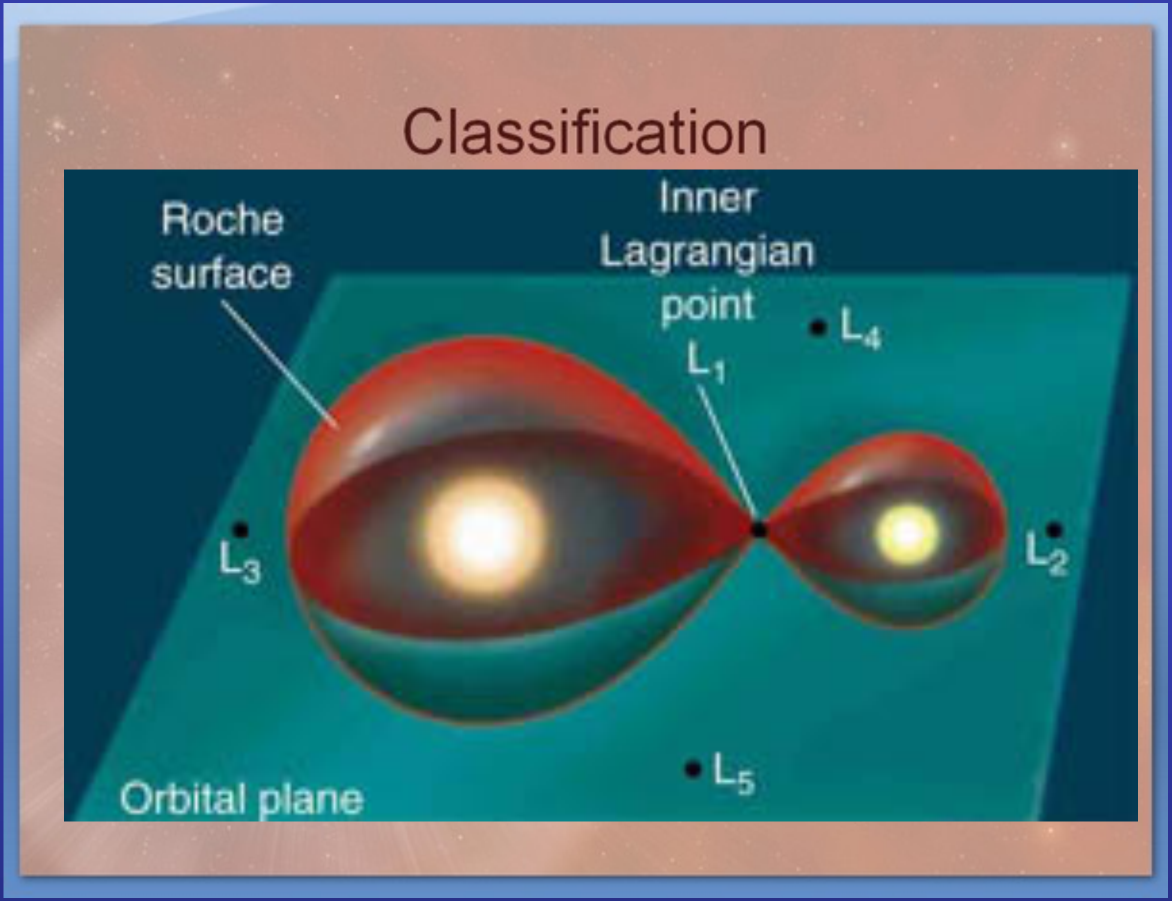
Phenomenology similar to SN:

different energetic scale, $10^{45}$ vs $10^{51/53}$ erg





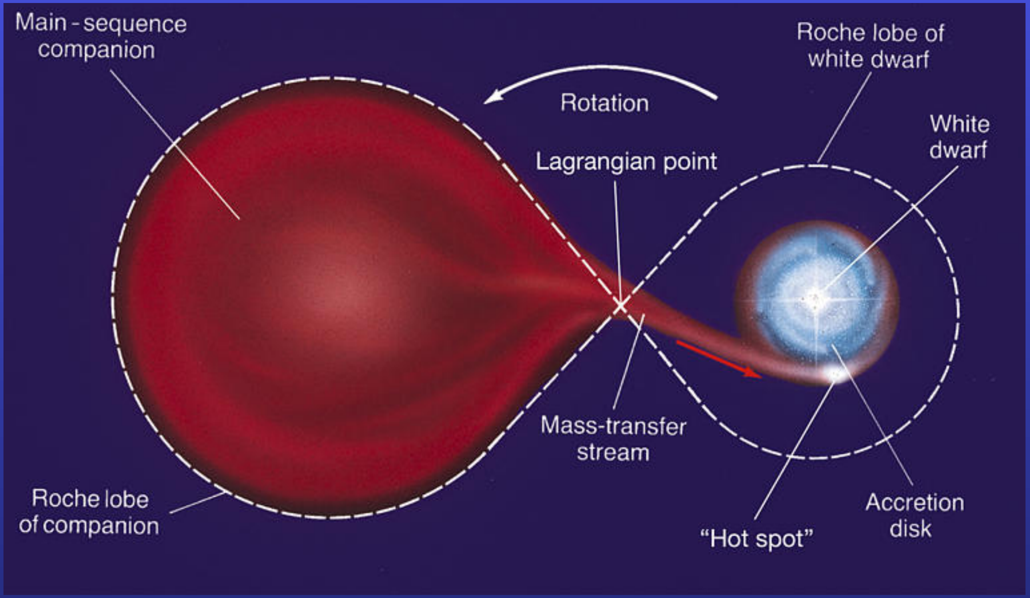
# Roche Lobes



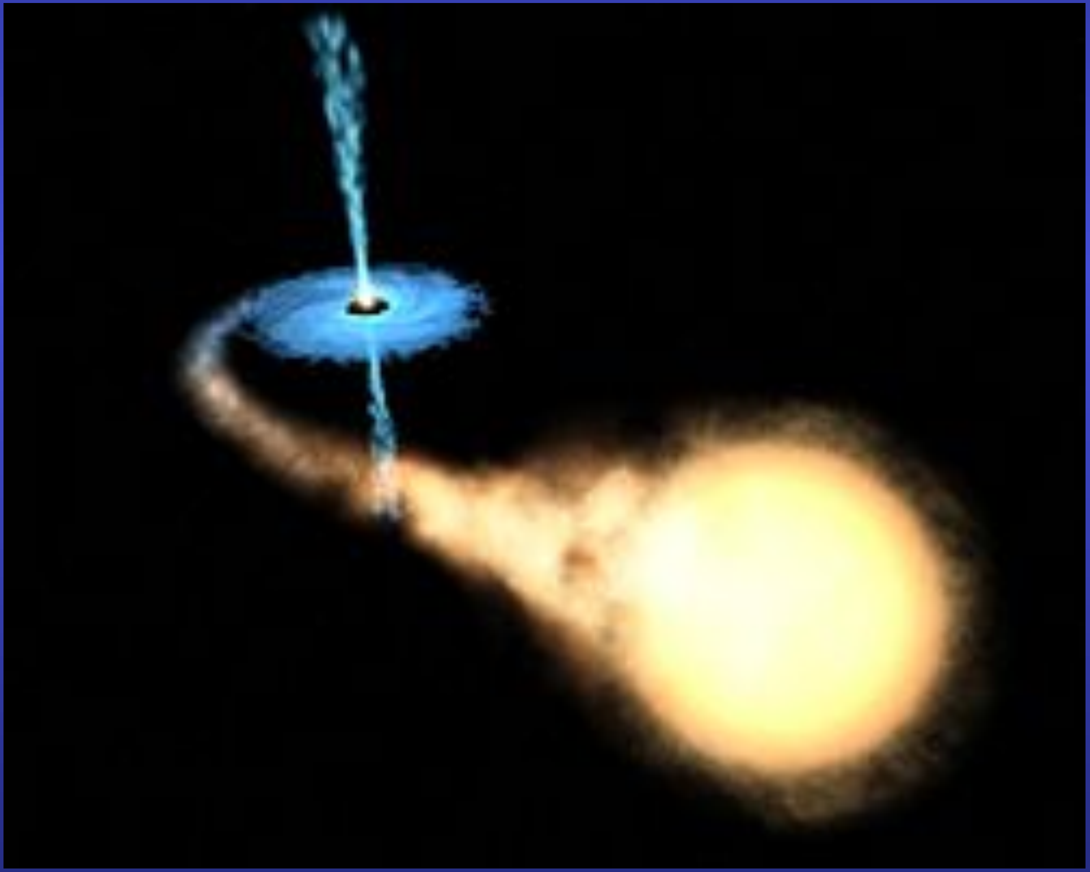
If we draw the surface of constant potential energy, the isopotential surface close to each stars are ~ spherical BUT a larger radii, due to the tidal forces, it becomes oval shaped. There is a particular isopotential surface which has a "digit 8" shape. These two lobes are called Roche Lobes and the point they are connected if the first Lagrange point, **L1**. The gravitational forces due to the stars are balanced.

# Roche Lobes cont'd

The star of the system which evolves (→ red subgiant/giant) will fill in its roche lobe and the stellar material at L1 is not longer bound to the star and can fall onto the companion.

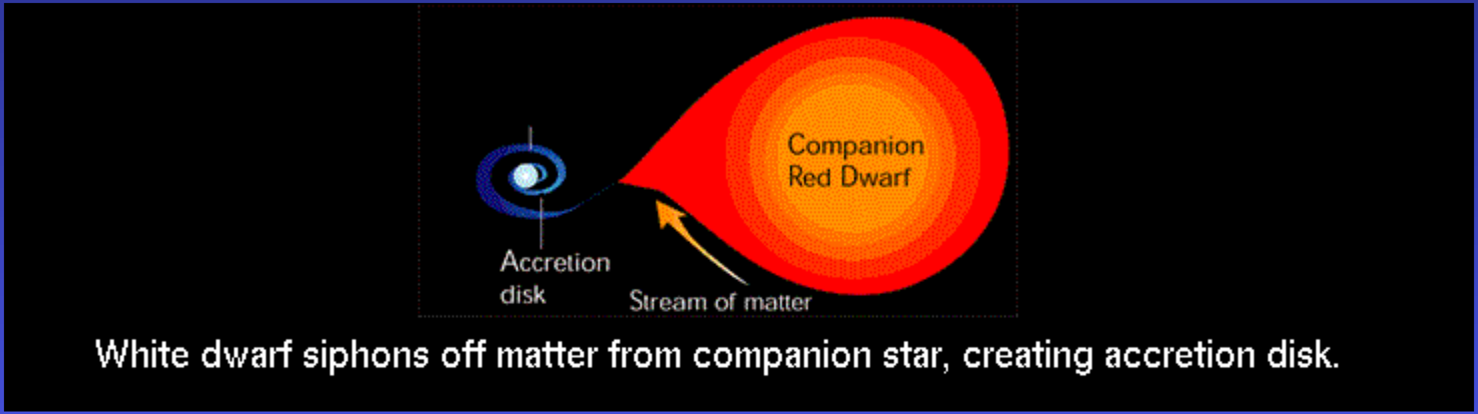


# The Accretion Disk



When the gas is falling towards a compact object it usually has some angular momentum with respect to the accreting star. As a consequence the gas will not fall directly onto the object but will start orbiting it. Gas particles having different orbits will collide with each other and the motion of the gas will be circularized. Through friction, turbolence and viscosity the gas before falling onto the compact object forms an accretion disk.

# The Nova phenomenon



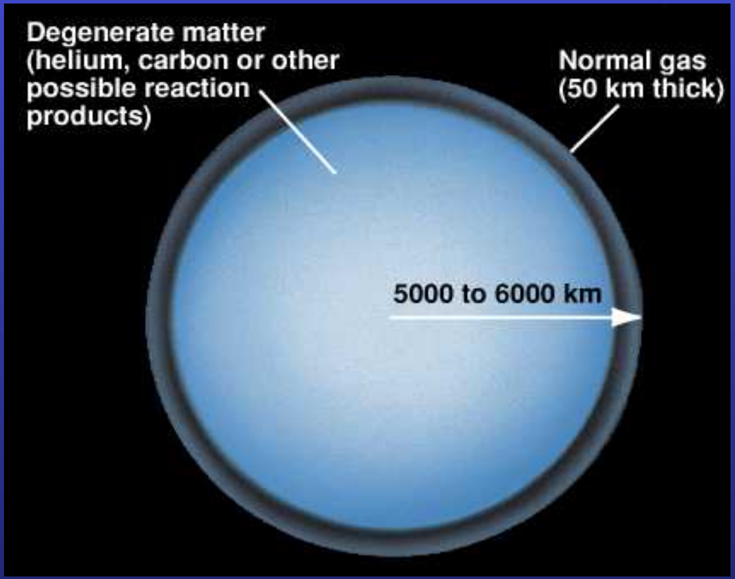
White dwarf siphons off matter from companion star, creating accretion disk.

When pressure at bottom of accreted layer (mostly H) is

$P > 10^{19}$ dyne cm$^{-2}$

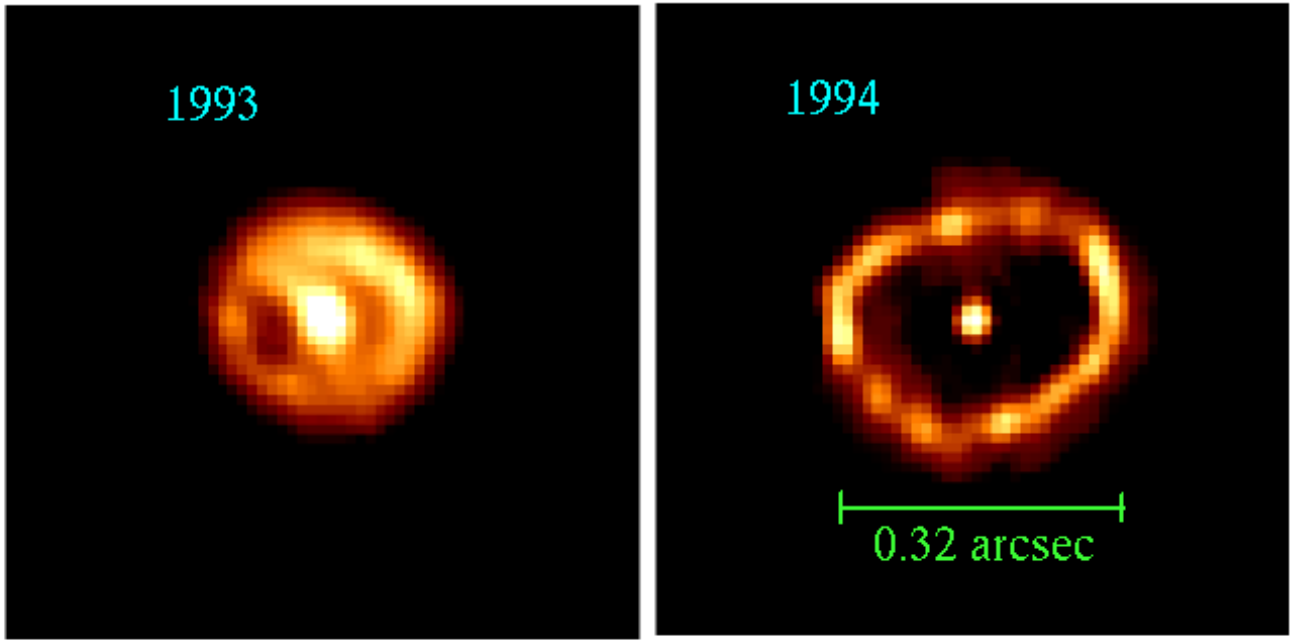
→ Explosive H-burning
→ violent TNR
→ accreted shell ejected (v ~ 1000-5000 km $s^{-1}$)

$\Delta m_{acc} \sim R^4_{WD}/M_{WD}$



# Nova Cygni 1992

Hubble Space Telescope
Faint Object Camera



Pre-COSTAR
Raw Image

With COSTAR
Raw Image

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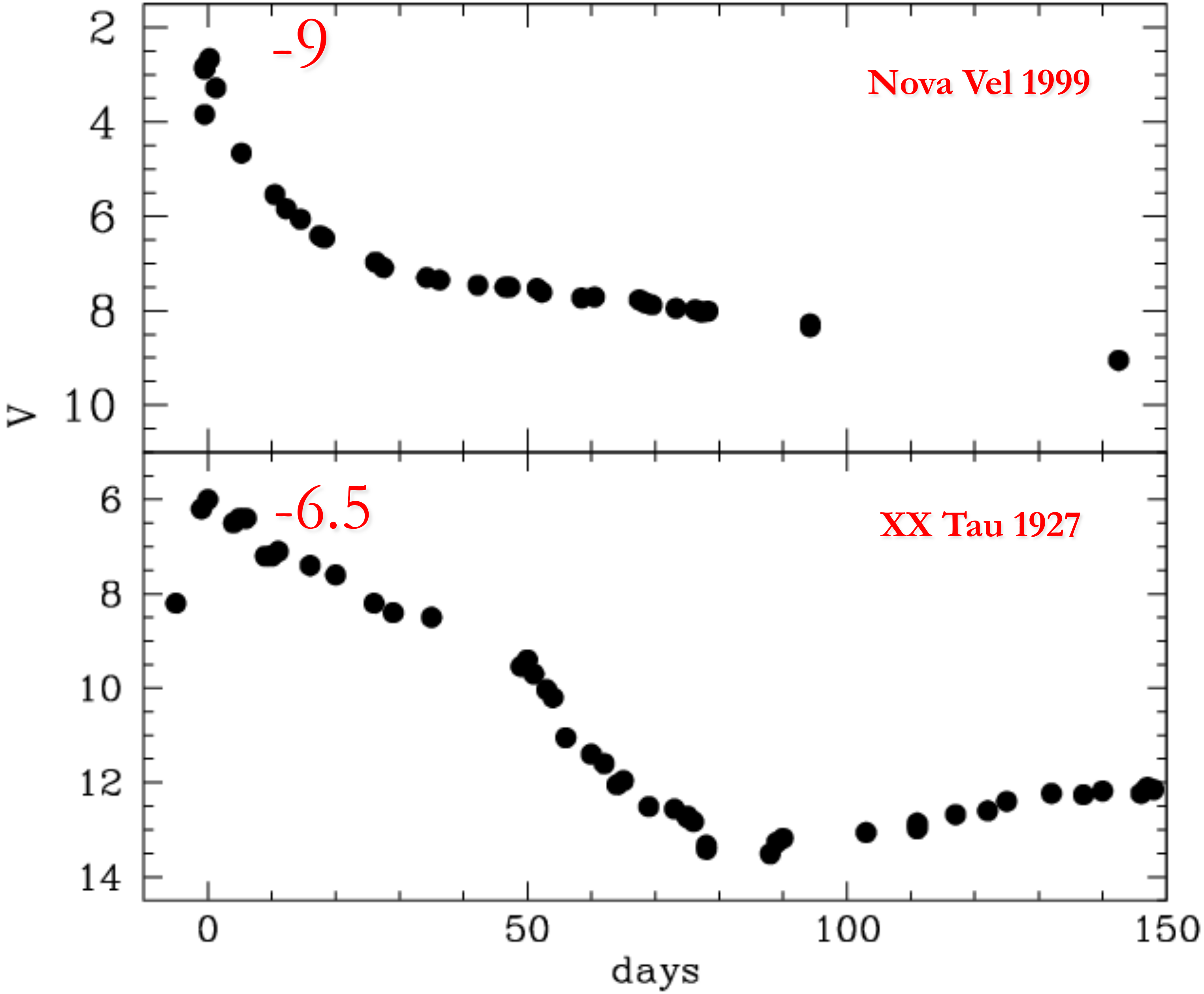
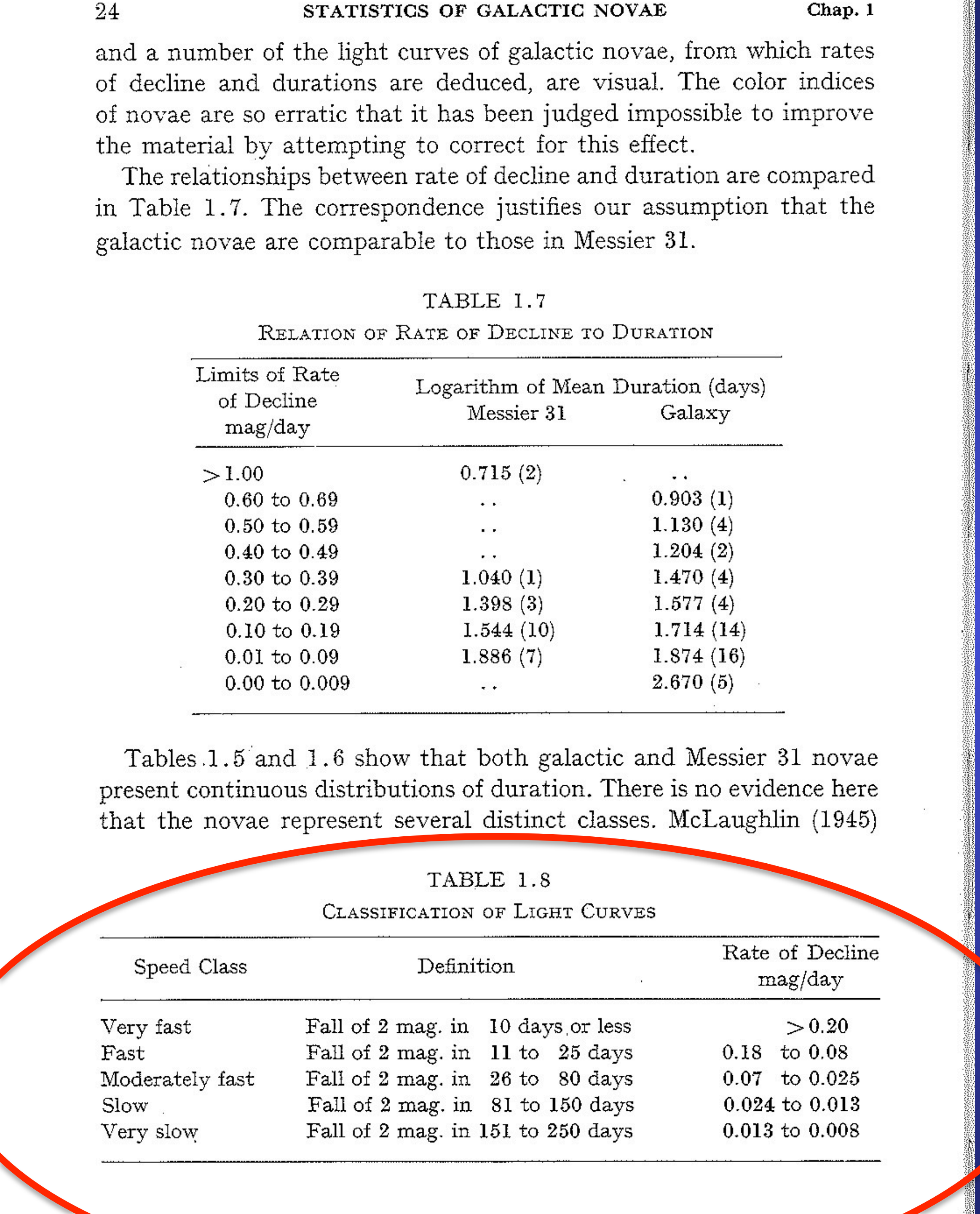


-9
Nova Vel 1999
-6.5
XX Tau 1927
V
2
4
6
8
10
6
8
10
12
14
0
50
100
150
days

# “ The Galactic Novae ”
# Cecilia P-G, 1957



and a number of the light curves of galactic novae, from which rates of decline and durations are deduced, are visual. The color indices of novae are so erratic that it has been judged impossible to improve the material by attempting to correct for this effect.

The relationships between rate of decline and duration are compared in Table 1.7. The correspondence justifies our assumption that the galactic novae are comparable to those in Messier 31.

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| Limits of Rate of Decline mag/day | Logarithm of Mean Duration (days) | |
|---|---|---|
| | Messier 31 | Galaxy |
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| 0.60 to 0.69 | . . | 0.903 (1) |
| 0.50 to 0.59 | . . | 1.130 (4) |
| 0.40 to 0.49 | . . | 1.204 (2) |
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| 0.10 to 0.19 | 1.544 (10) | 1.714 (14) |
| 0.01 to 0.09 | 1.886 (7) | 1.874 (16) |
| 0.00 to 0.009 | . . | 2.670 (5) |

Tables 1.5 and 1.6 show that both galactic and Messier 31 novae present continuous distributions of duration. There is no evidence here that the novae represent several distinct classes. McLaughlin (1945)

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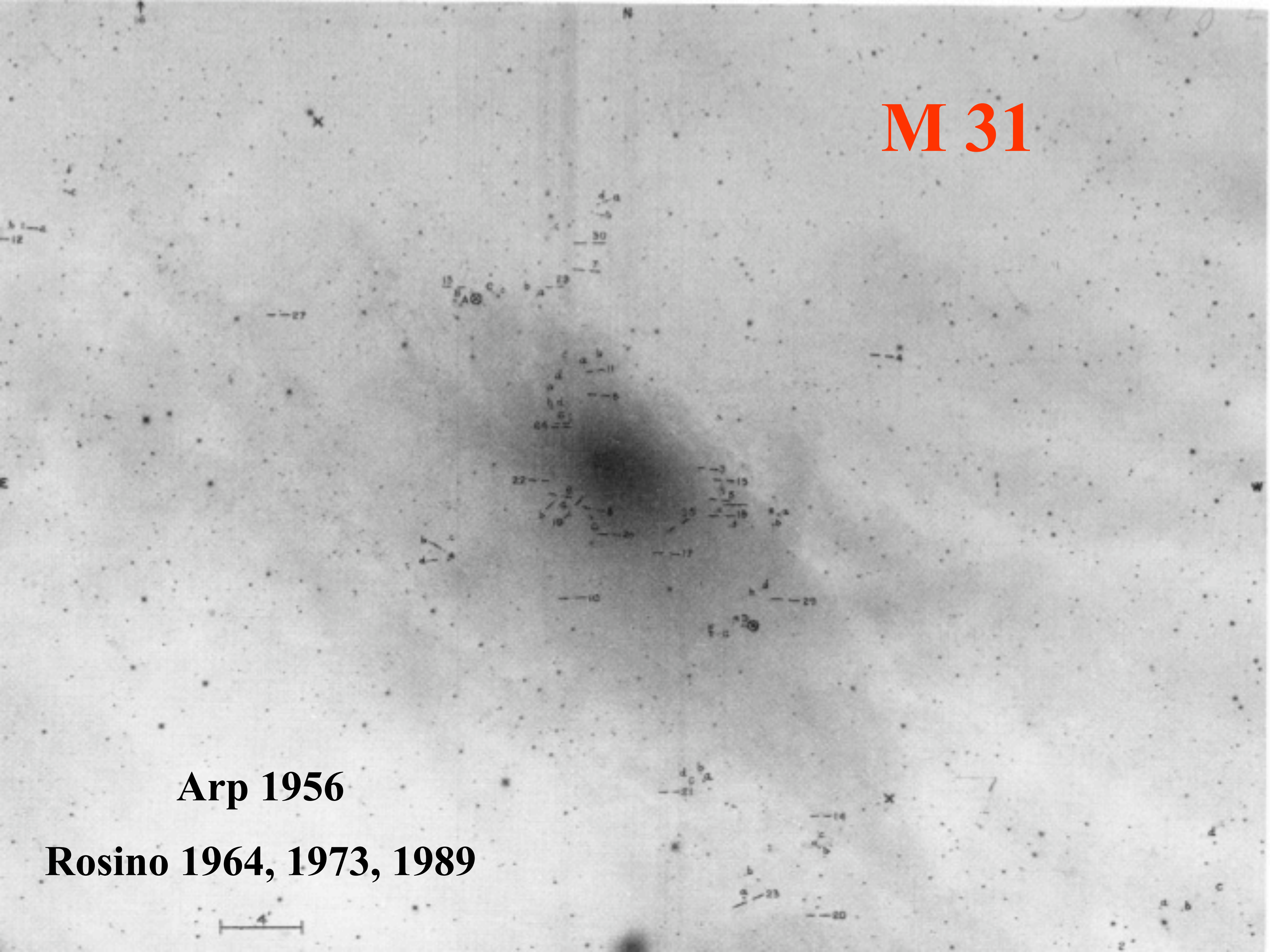
| Very slow | Fall of 2 mag. in 151 to 250 days | 0.013 to 0.008 |

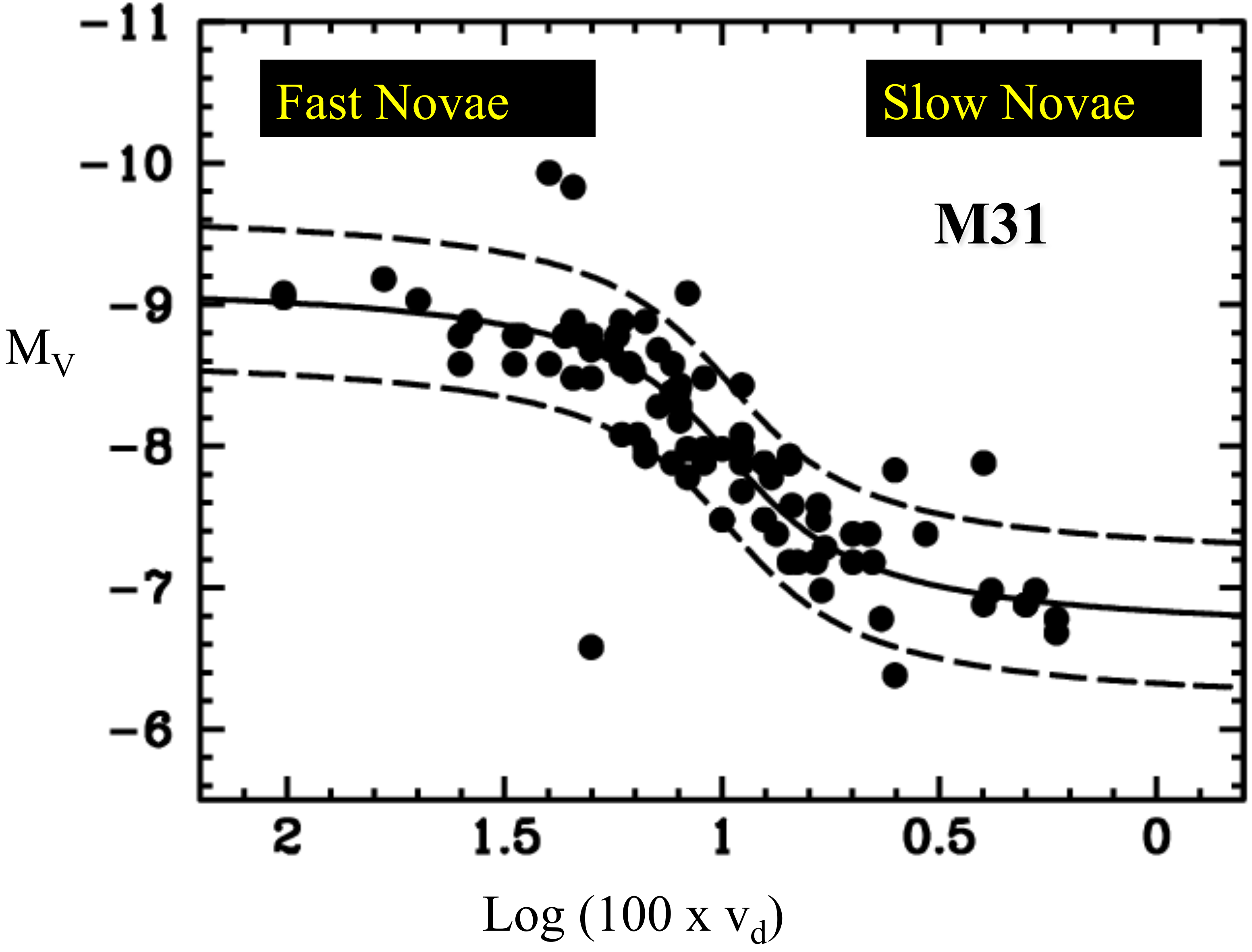
# M 31



Arp 1956

Rosino 1964, 1973, 1989

# The MMRD



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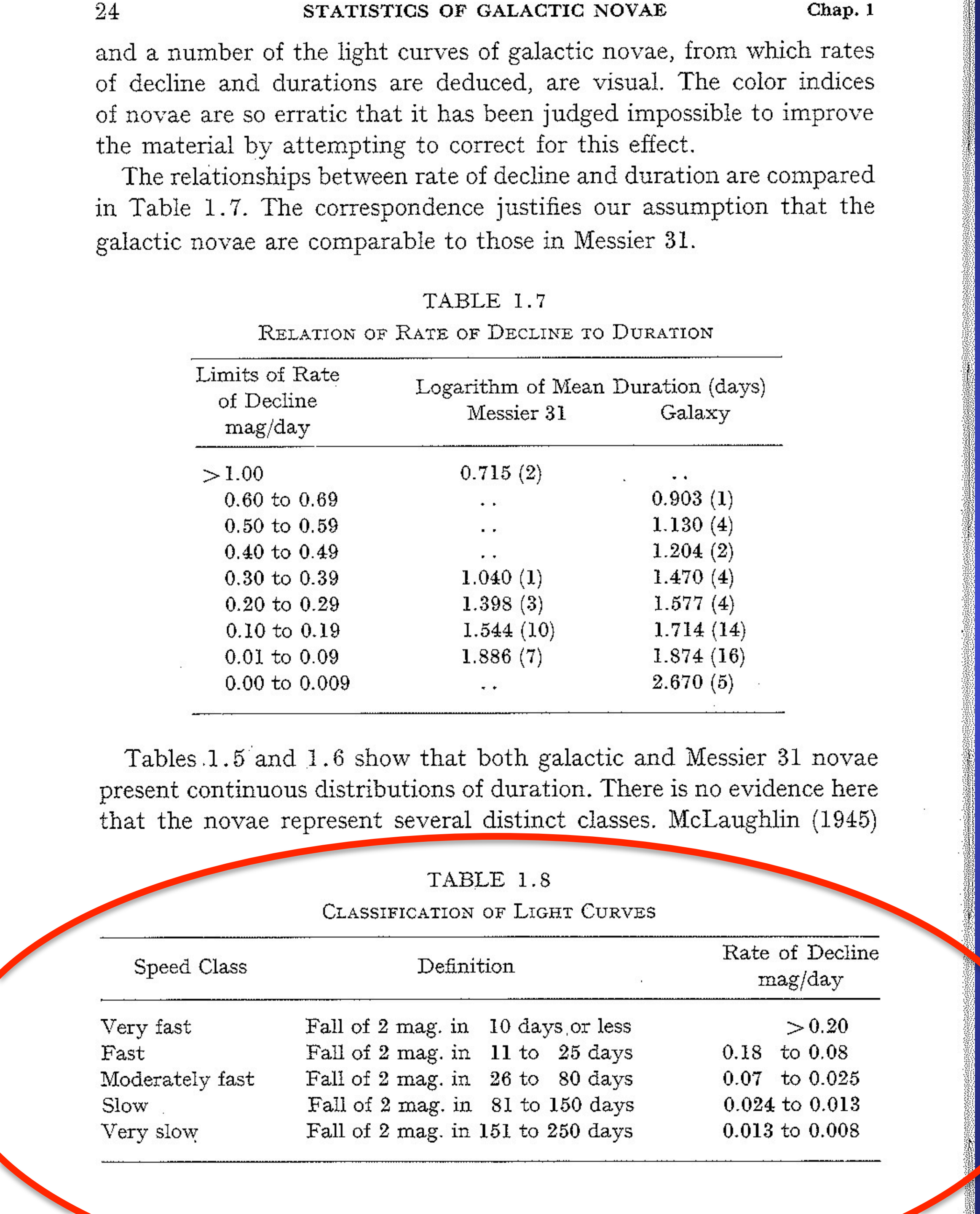

24 STATISTICS OF GALACTIC NOVAE Chap. 1

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Speed classes

vs.

Basic Properties of the Nova progenitors ?

# The physical parameters of the outburst are primarly determined by the:

- Mass of the WD
- Accretion rate
- Temperature of the WD
- Magnetic Field
- Composition of the accreted material
- Mixing processes between accreted envelope and underlying WD

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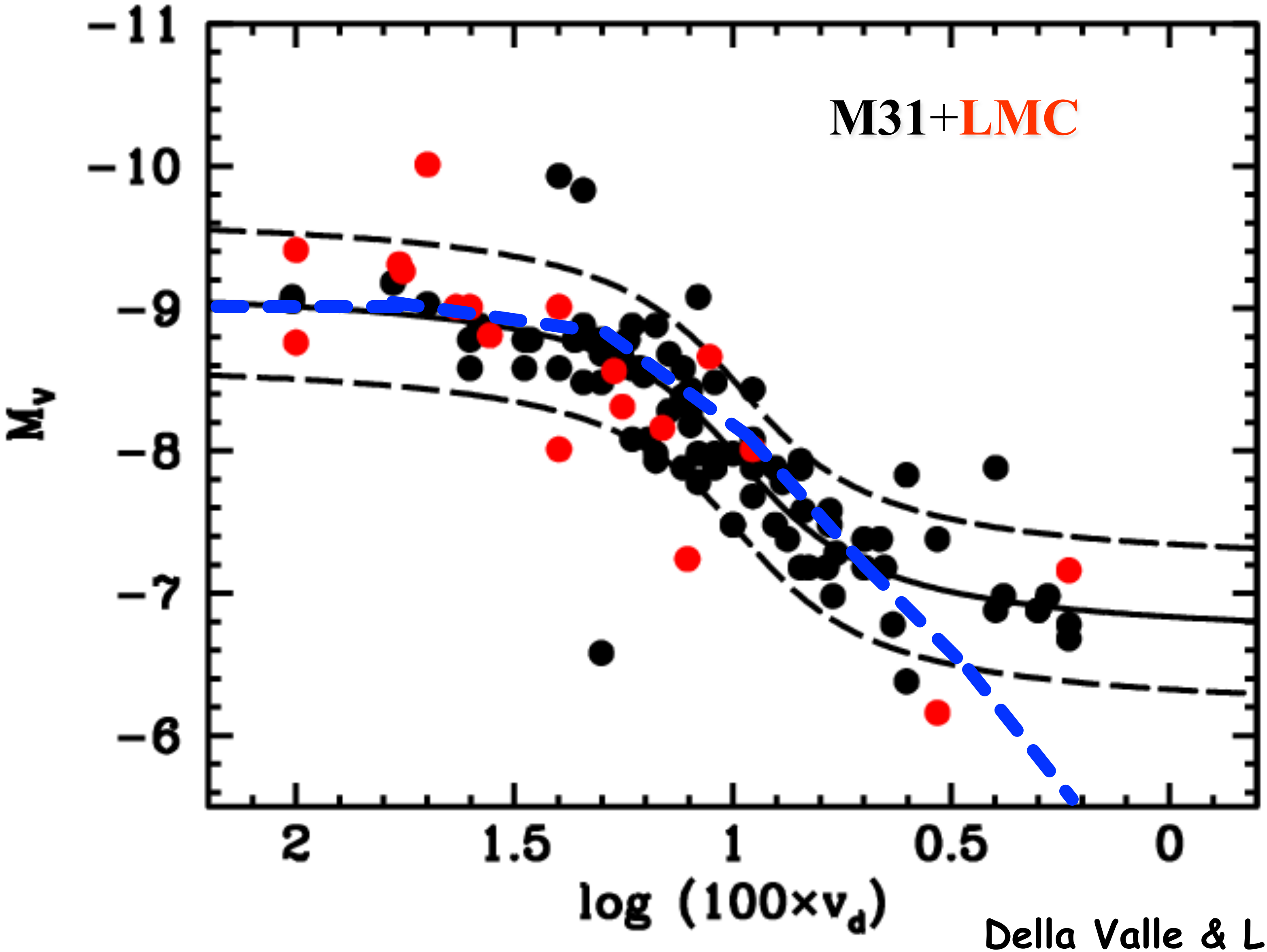
# $M_{B\,(max)} = -8.3 \times 10 \times \log M_{WD}$



Della Valle & Livio 1995

….however as a first order of approximation one can say that '***the more massive is the WD the more powerful is the outburst***'

$$L_{max} \sim \log M_{WD}$$

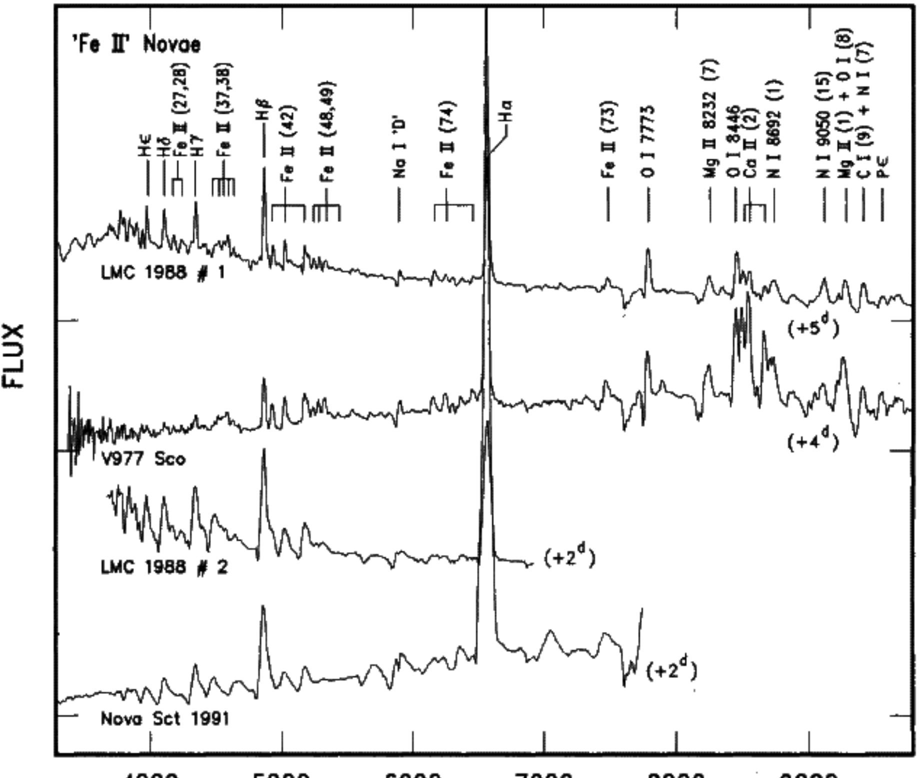
$$M_{B\ (max)} = -8.3 \times 10 \times \log M_{WD}$$

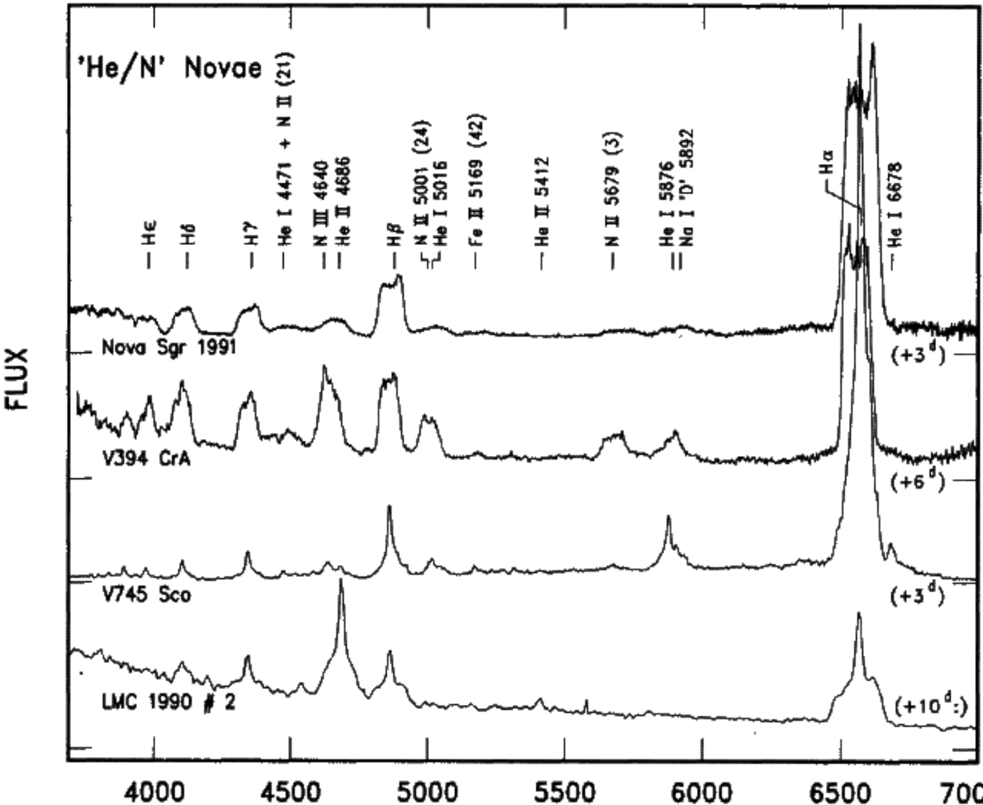
| 'Fe II' Class | 'He/N' Class |
|---|---|

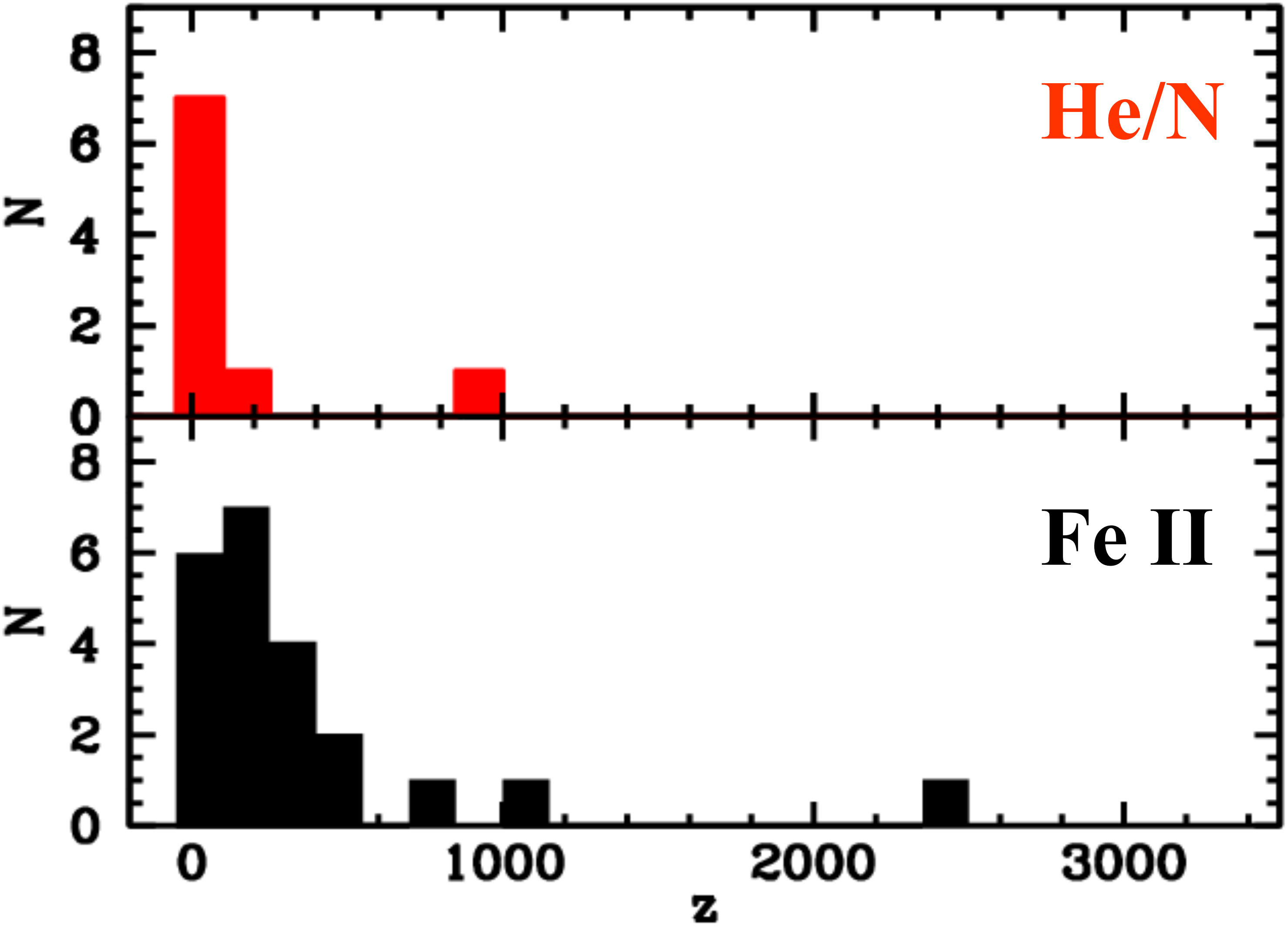
Williams 92

Narrower lines (HWZI < 2,500 km/sec)
Frequent P Cygni absorption profiles
Slower spectral evolution (weeks)
Initial forbidden lines:
 N and O auroral transitions
 [O I] λ6300
Low ionization fluorescence lines in red

Broad lines (HWZI > 2,500 km/sec)
Flat-topped line peaks with little absorption
Faster spectral evolution (days)
Initial forbidden lines:
 [Fe X] λ6375 and [Fe VII] λ6087
 [Ne III] or [Ne V]
 or no forbidden lines at all

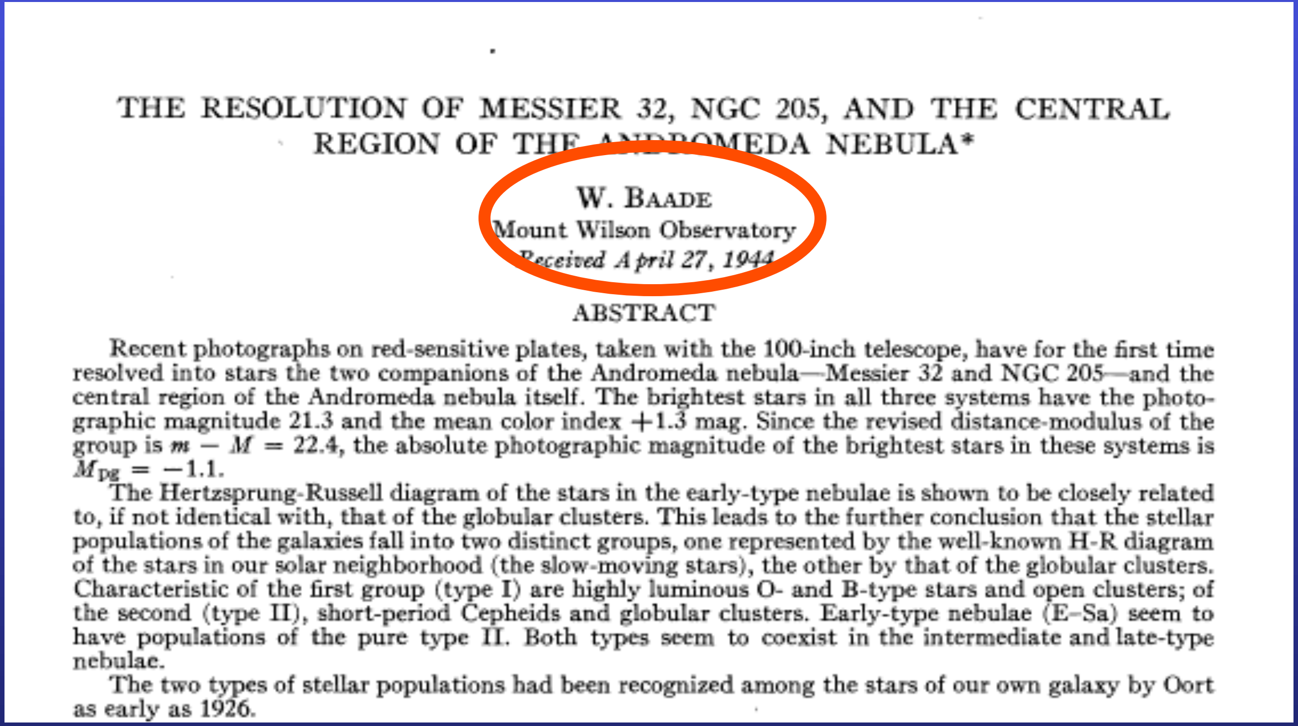






adapted from DV & Livio 1998

Baade (ApJ, 1944) introduced the concept into astronomy that **different kinds of stellar populations have different spatial distribution within the galaxies.** We can take advantage of this notion to find out useful hints about the population assignments of the progenitors of Novae. Due to their luminosities ($M_V \sim -6/-9$) Novae are particularly suited for this purpose because they can be identified in the Milky Way and in external galaxies.



THE RESOLUTION OF MESSIER 32, NGC 205, AND THE CENTRAL REGION OF THE ANDROMEDA NEBULA*

W. Baade
Mount Wilson Observatory
*Received April 27, 1944*

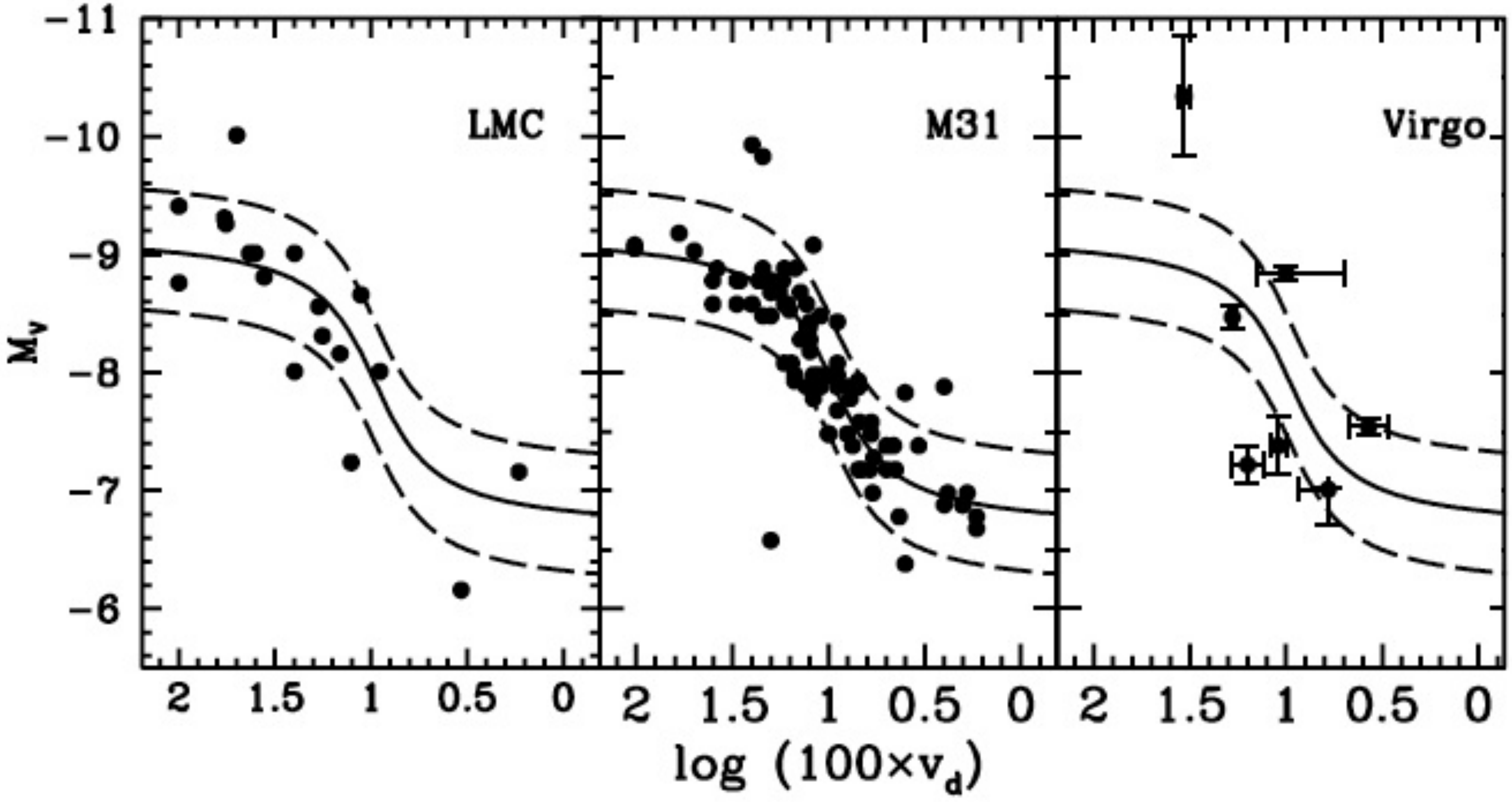
ABSTRACT

Recent photographs on red-sensitive plates, taken with the 100-inch telescope, have for the first time resolved into stars the two companions of the Andromeda nebula—Messier 32 and NGC 205—and the central region of the Andromeda nebula itself. The brightest stars in all three systems have the photographic magnitude 21.3 and the mean color index +1.3 mag. Since the revised distance-modulus of the group is $m - M = 22.4$, the absolute photographic magnitude of the brightest stars in these systems is $M_{pg} = -1.1$.

The Hertzsprung-Russell diagram of the stars in the early-type nebulae is shown to be closely related to, if not identical with, that of the globular clusters. This leads to the further conclusion that the stellar populations of the galaxies fall into two distinct groups, one represented by the well-known H-R diagram of the stars in our solar neighborhood (the slow-moving stars), the other by that of the globular clusters. Characteristic of the first group (type I) are highly luminous O- and B-type stars and open clusters; of the second (type II), short-period Cepheids and globular clusters. Early-type nebulae (E–Sa) seem to have populations of the pure type II. Both types seem to coexist in the intermediate and late-type nebulae.

The two types of stellar populations had been recognized among the stars of our own galaxy by Oort as early as 1926.

WD Mass →



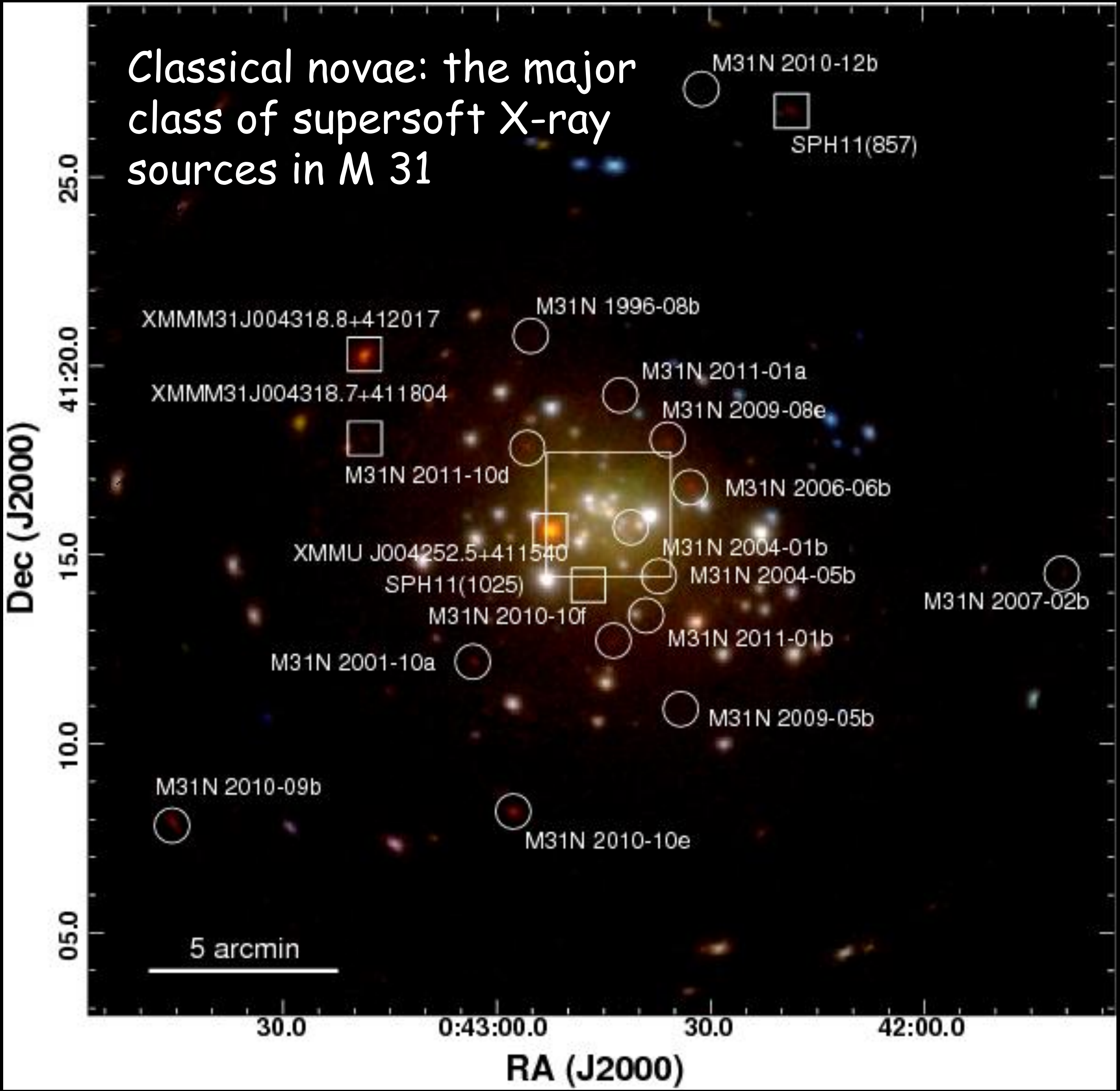
Disk        Disk + Bulge        only Bulge

# Milky Way Nova Populations

1. A typical "disk nova" is a "fast nova" whose lightcurve is characterized by a bright maximum, up to $M_V \sim -9$ and fast decline $t_3<20$d or $t_2<12$d and belongs to the He/N class. The progenitor is preferentially located at small heights above the galactic plane (<100-150pc) and it is related to the oldest fraction of Pop I stellar population, therefore the WD is relatively massive ($M_{WD} \geq 1M_{\odot}$)

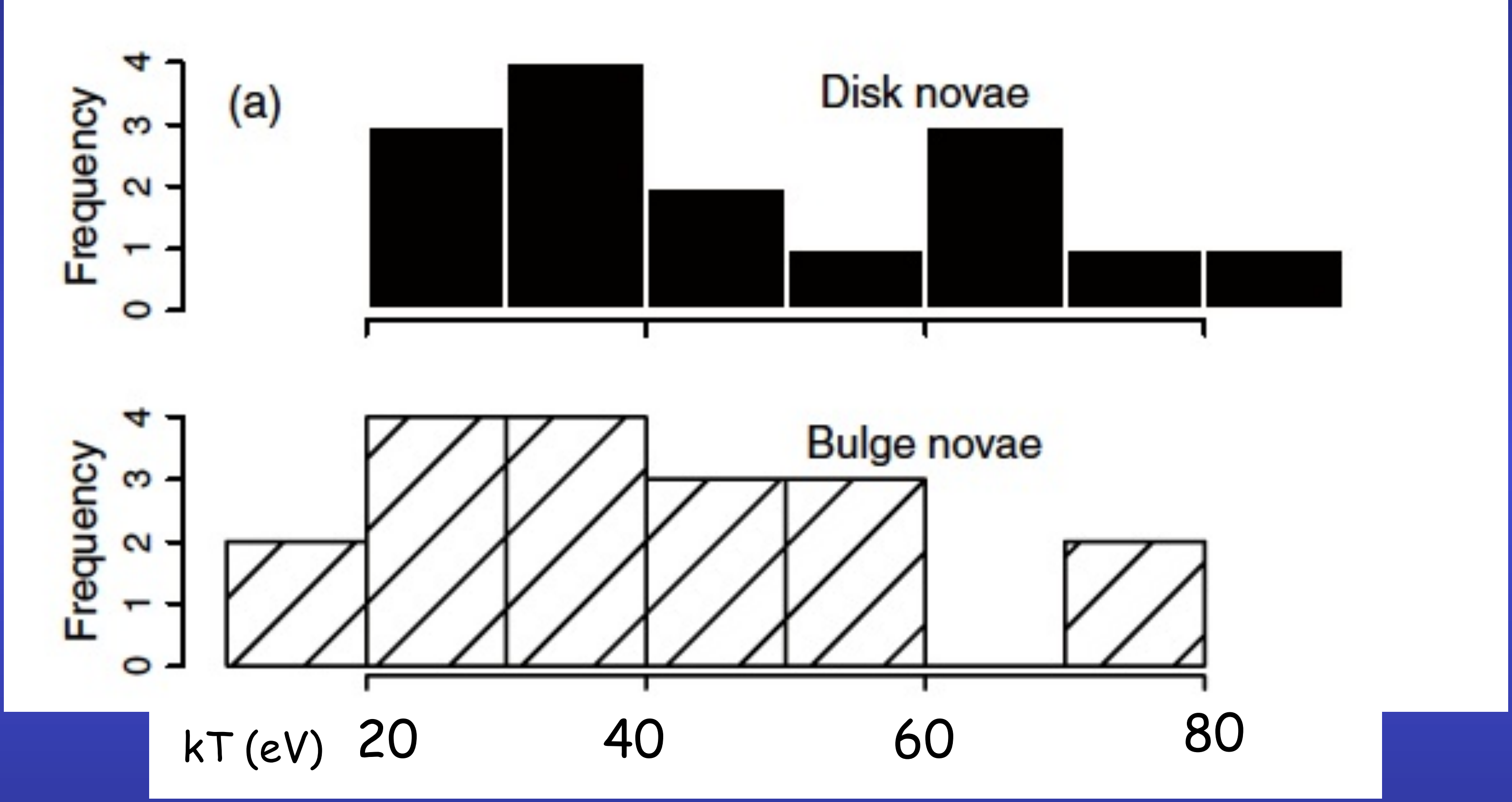
2. A typical "bulge nova" is a "slow nova" whose lightcurve is characterized by a relatively fainter maximum $M_V \sim -7$ and slow decline $t_3>20$-25d and normally belongs to the FeII class. The progenitors extend up to ≥ 1000pc from the Galactic plane and are likely to be related to a Pop II stellar population of the bulge/thick disk and therefore associated with less massive WDs ($M_{WD} \leq 1M_{\odot}$)

# Classical novae: the major class of supersoft X-ray sources in M 31



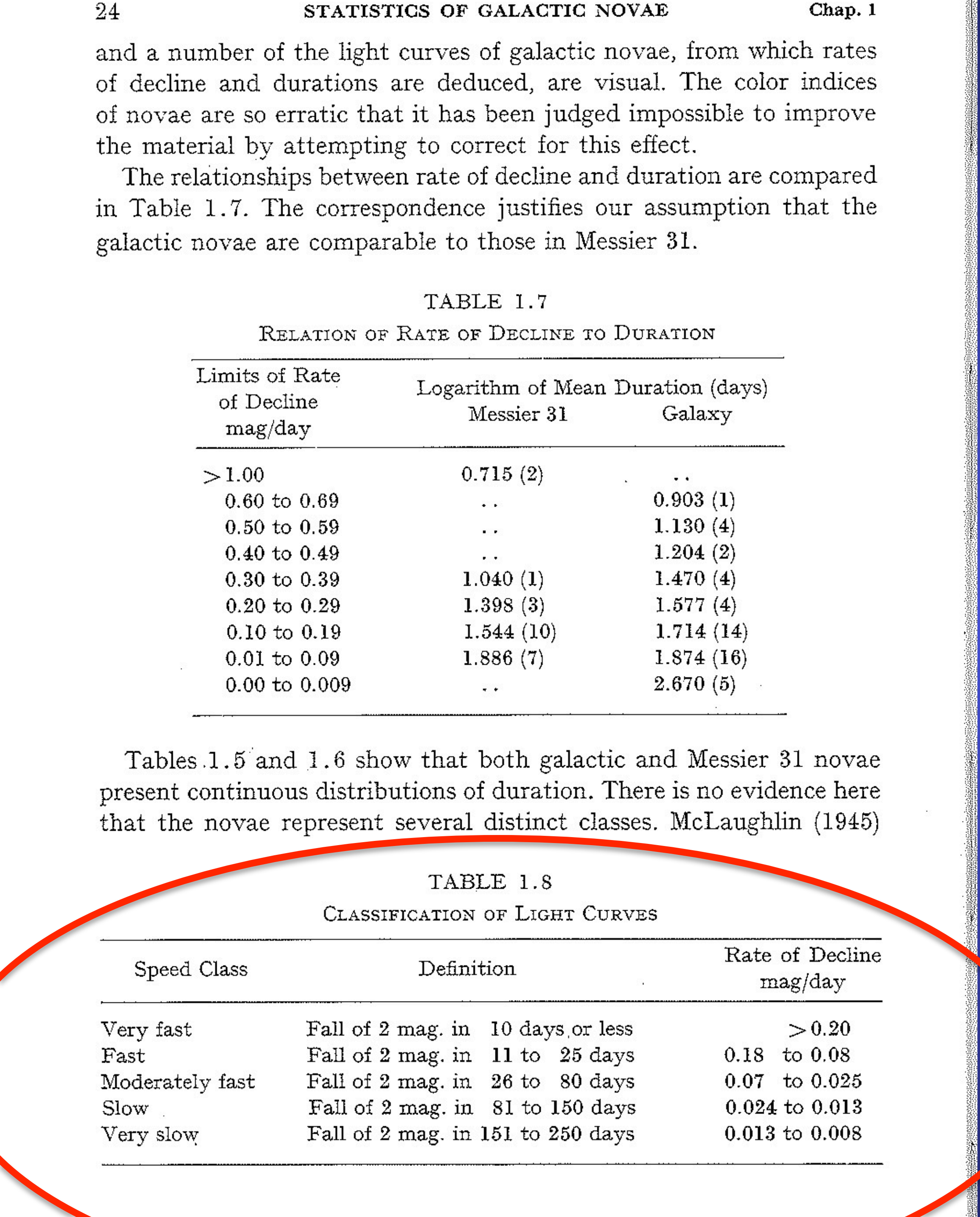
Henze et al. 2014, 2011, 2010

Henze et al. 2013



Distributions of the effective BB temperature kT for disk and bulge Novae (≤ 90%)

# “ The Galactic Novae ” Cecilia P-G, 1957



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From morphological classification to physical classification

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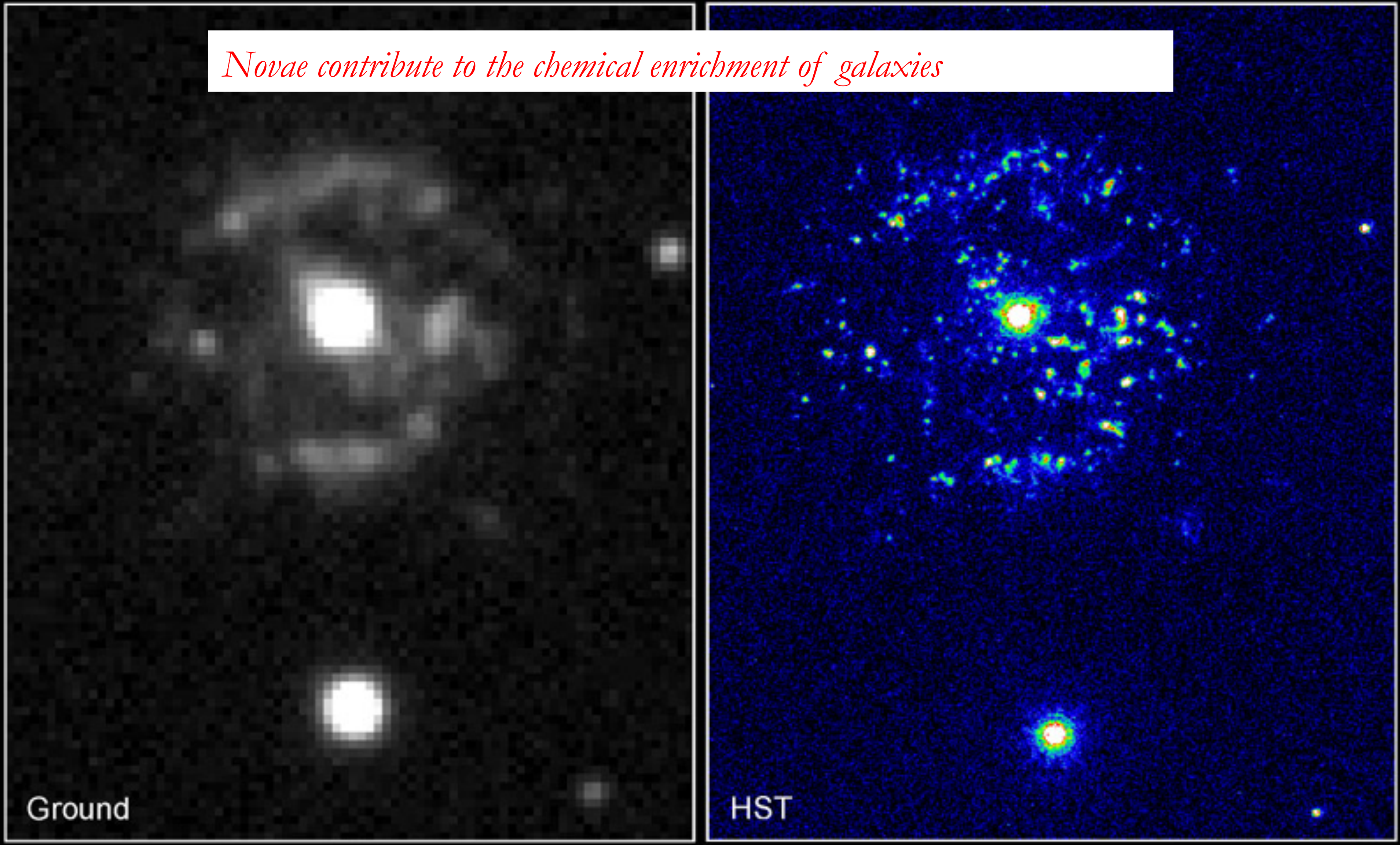
# *Novae contribute to the chemical enrichment of galaxies*



**Recurring Nova T Pyxidis**

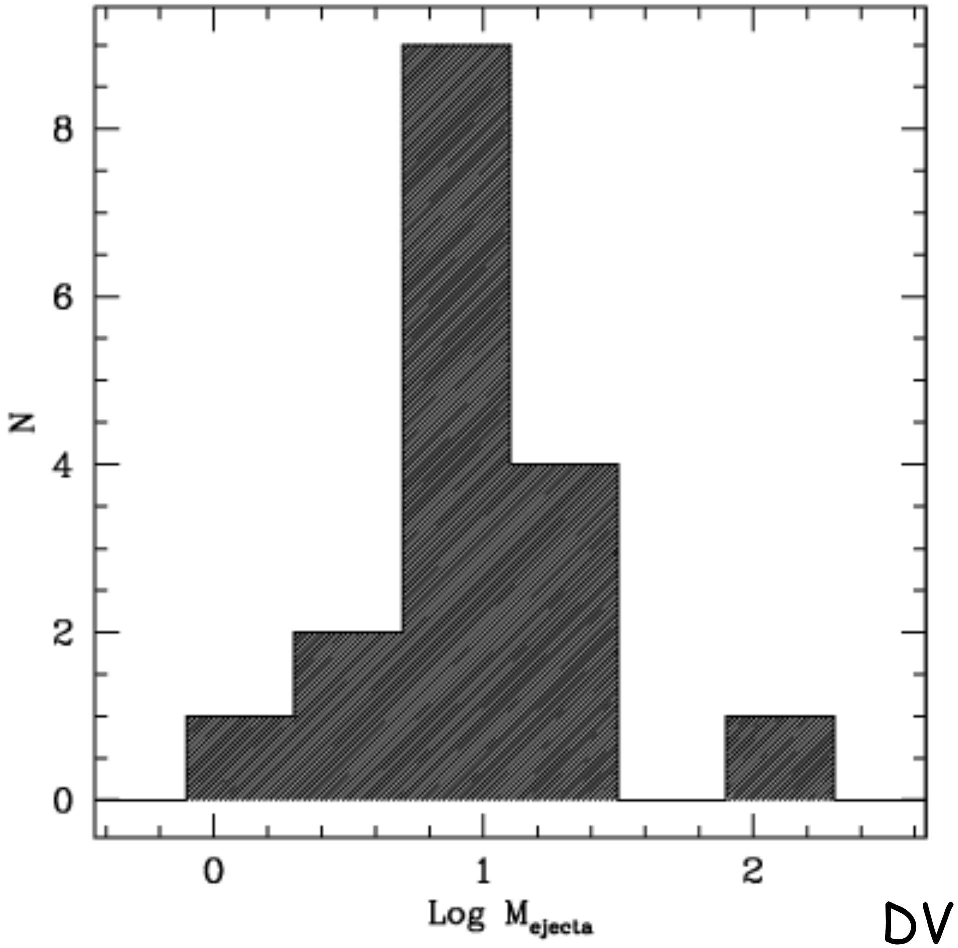
HST • WFPC2

PRC97-29 • ST ScI OPO • September 18, 1997

M. Shara and R. Williams (ST ScI), R. Gilmozzi (ESO) and NASA

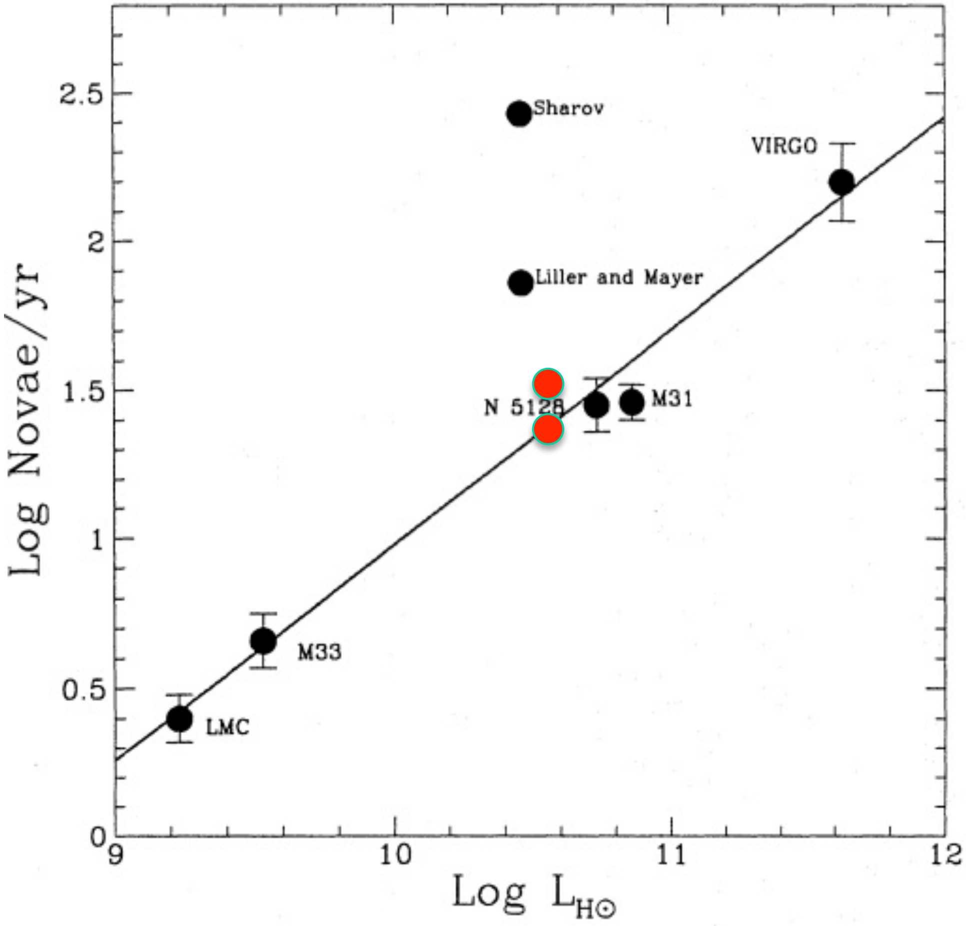
# Mass of ejected shell

$10^{-4/-5}\,M_\odot$



DV et al. 2002

M. Della Valle & M. Livio: On the nova rate in the Galaxy 787



24 novae/yr DV & Livio 1995

35 novae/yr Shafter 1997

**Fig. 1.** The nova rate as a function of H-Luminosity of the parent galaxies

M. Della Valle & M. Livio: On the nova rate in the Galaxy 787

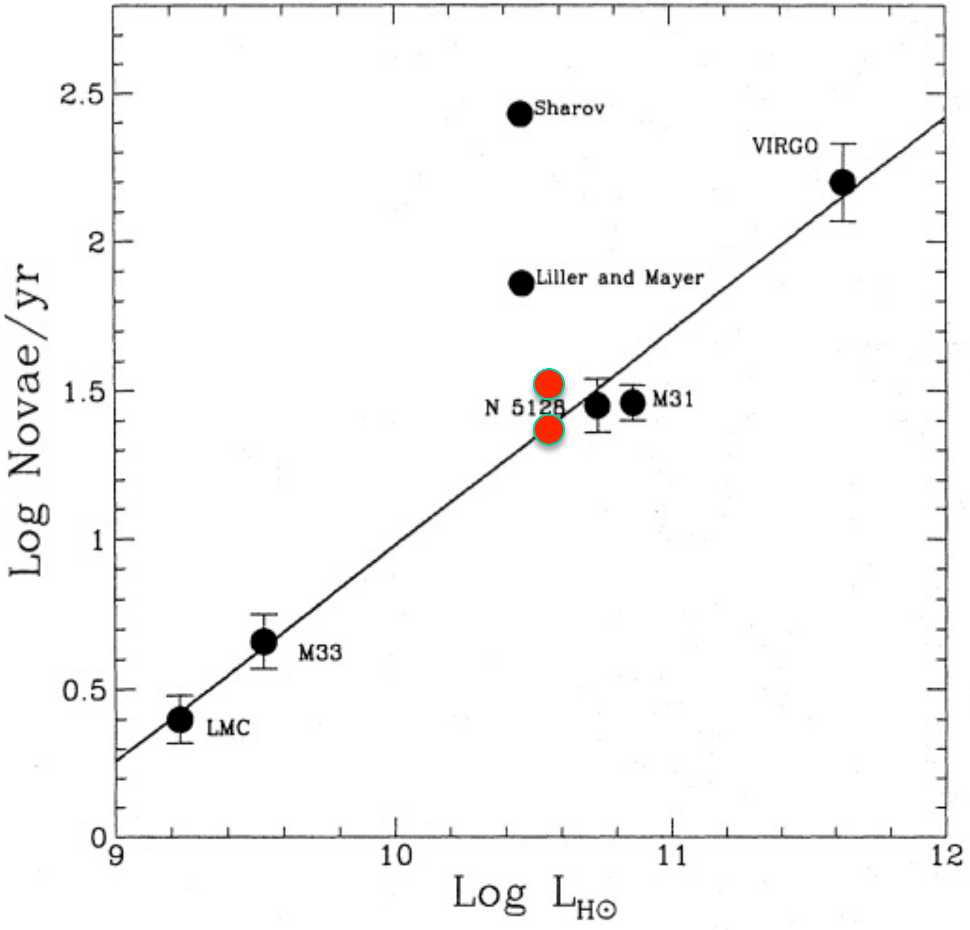


**Fig. 1.** The nova rate as a function of H-Luminosity of the parent galaxies

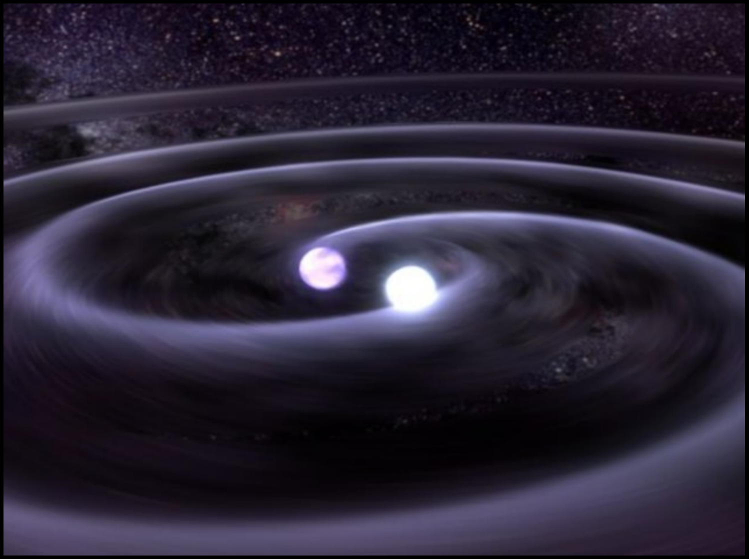
24 – 35 novae/yr
$\times 10^{-4} \times 100$ yr-→ ~ 0.3 $M_\odot$

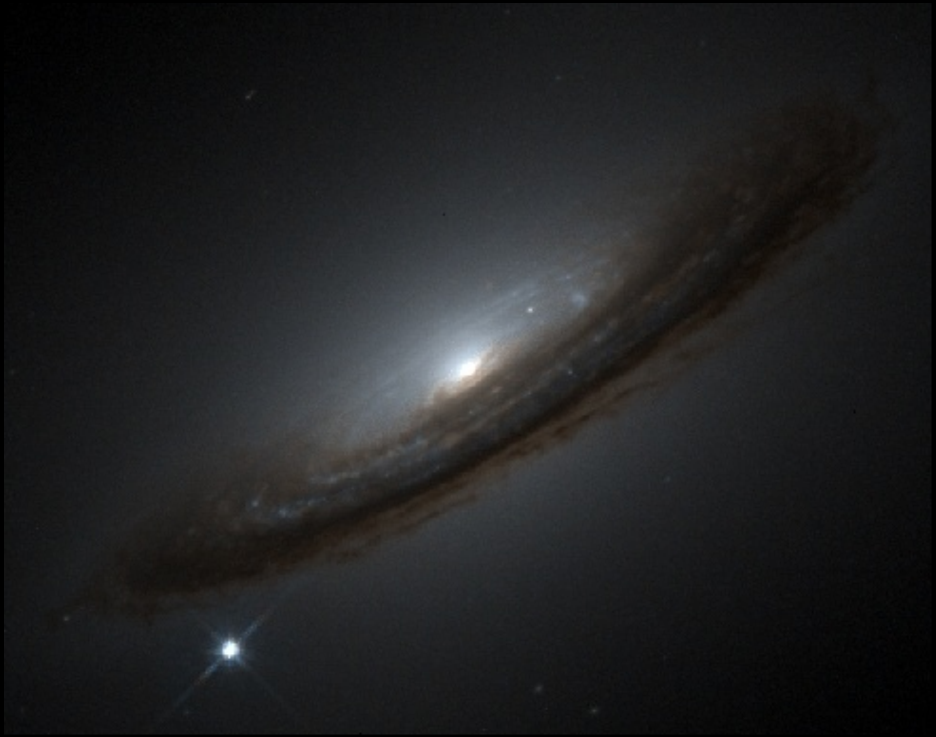
SNe- II + Ia

10-20 $M_\odot$ vs. 1.4 $M_\odot$

Only SNe-Ia

$\sim 1.4\ M_\odot$





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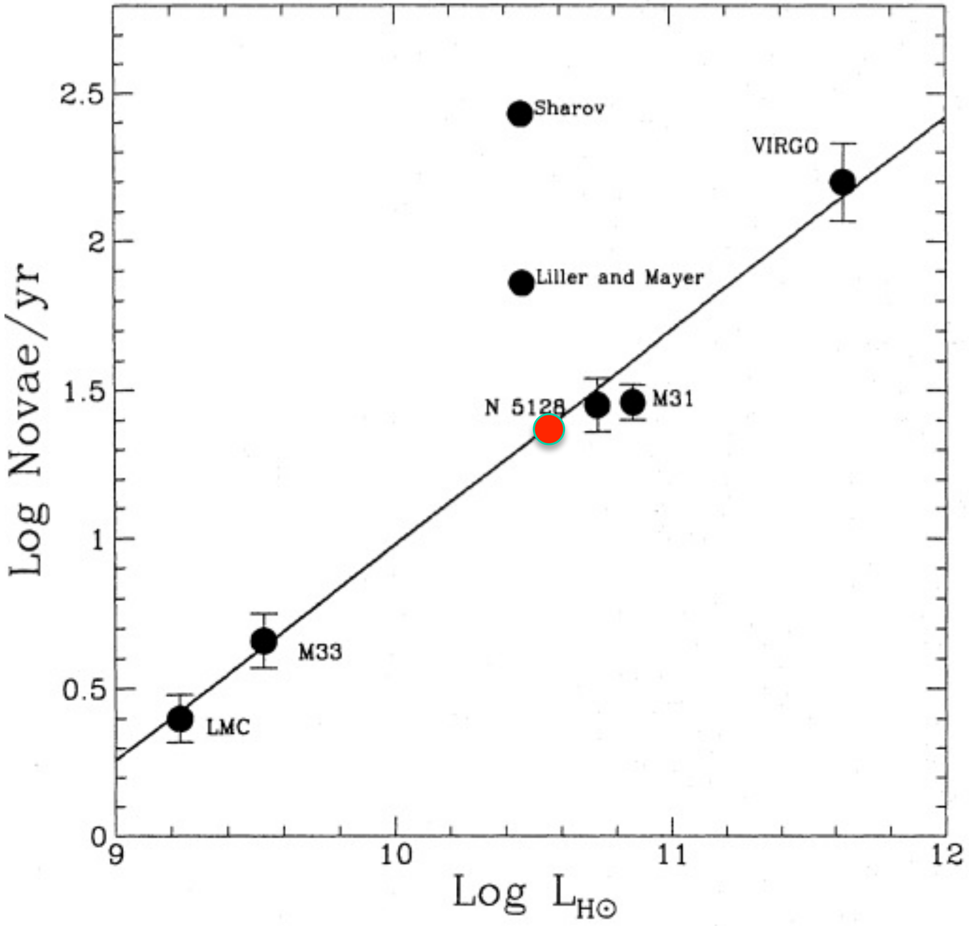


**Fig. 1.** The nova rate as a function of H-Luminosity of the parent galaxies

24-35 novae/yr
x $10^{-4}$ x 100 yr-→ ~ 0.3 $M_\odot$

cf. ~ 1.4 $M_\odot$ from SNe-Ia

# Novae can produce interesting concentrations of rare isotopes

(100-1000 times solar values)

- $^{13}$C; $^{15}$N

Sparks, Starrfield, Truran (1978);
Williams (1985);

- $^{7}$Li

Arnould and Norghard (1975);
Starrfield et al. (1978);
D'Antona and Matteucci (1991)

- $^{22}$Na; $^{26}$Al

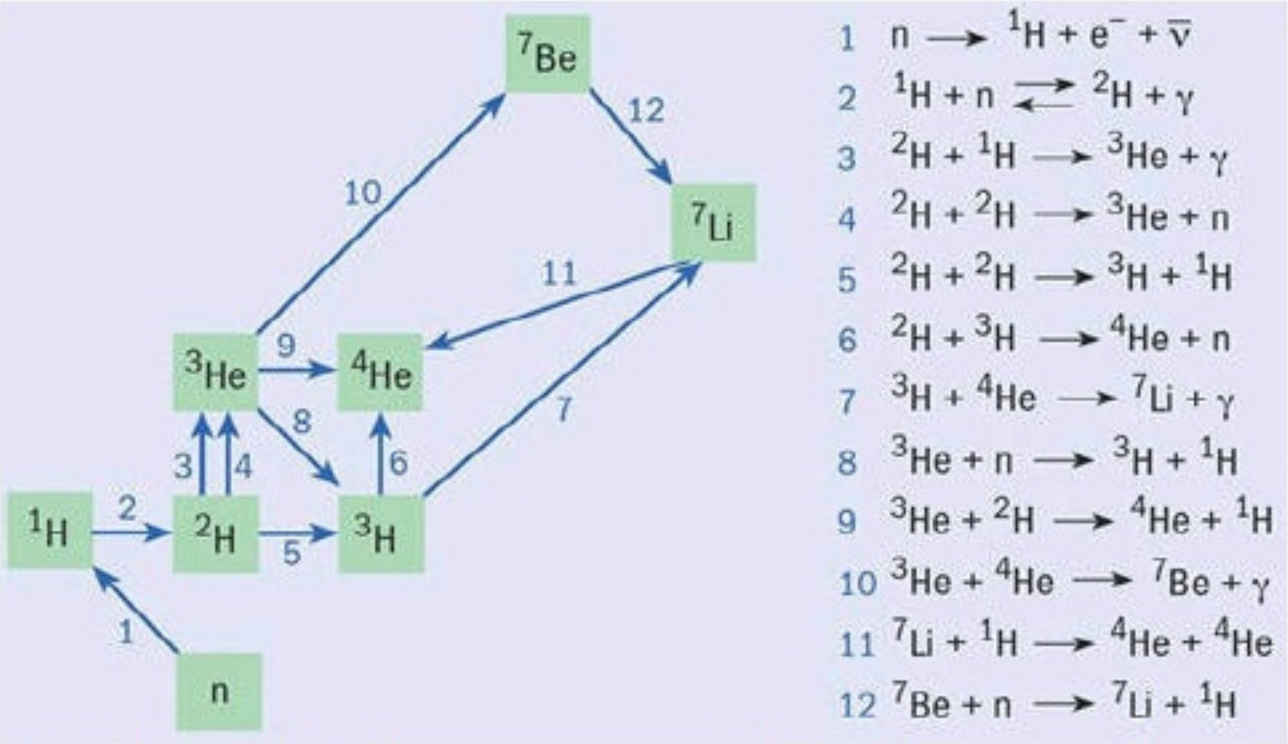
Hillebrandt and Thielemann (1982);
Kolb and Politano (1997)

- Ne

Livio and Truran (1994)

# Primordial lithium abundance

The primordial abundance of elements depends on the baryon/photon density ratio η :



1 $n \longrightarrow {}^1H + e^- + \bar{\nu}$

2 $^1H + n \rightleftarrows {}^2H + \gamma$

3 $^2H + {}^1H \longrightarrow {}^3He + \gamma$

4 $^2H + {}^2H \longrightarrow {}^3He + n$

5 $^2H + {}^2H \longrightarrow {}^3H + {}^1H$

6 $^2H + {}^3H \longrightarrow {}^4He + n$

7 $^3H + {}^4He \longrightarrow {}^7Li + \gamma$

8 $^3He + n \longrightarrow {}^3H + {}^1H$

9 $^3He + {}^2H \longrightarrow {}^4He + {}^1H$

10 $^3He + {}^4He \longrightarrow {}^7Be + \gamma$

11 $^7Li + {}^1H \longrightarrow {}^4He + {}^4He$

12 $^7Be + n \longrightarrow {}^7Li + {}^1H$

Larger is the ratio, the more reactions there will be among baryons to produce deuterium, and consequently 4-helium, 3-helium and lithium via several channels

# Primordial lithium abundance

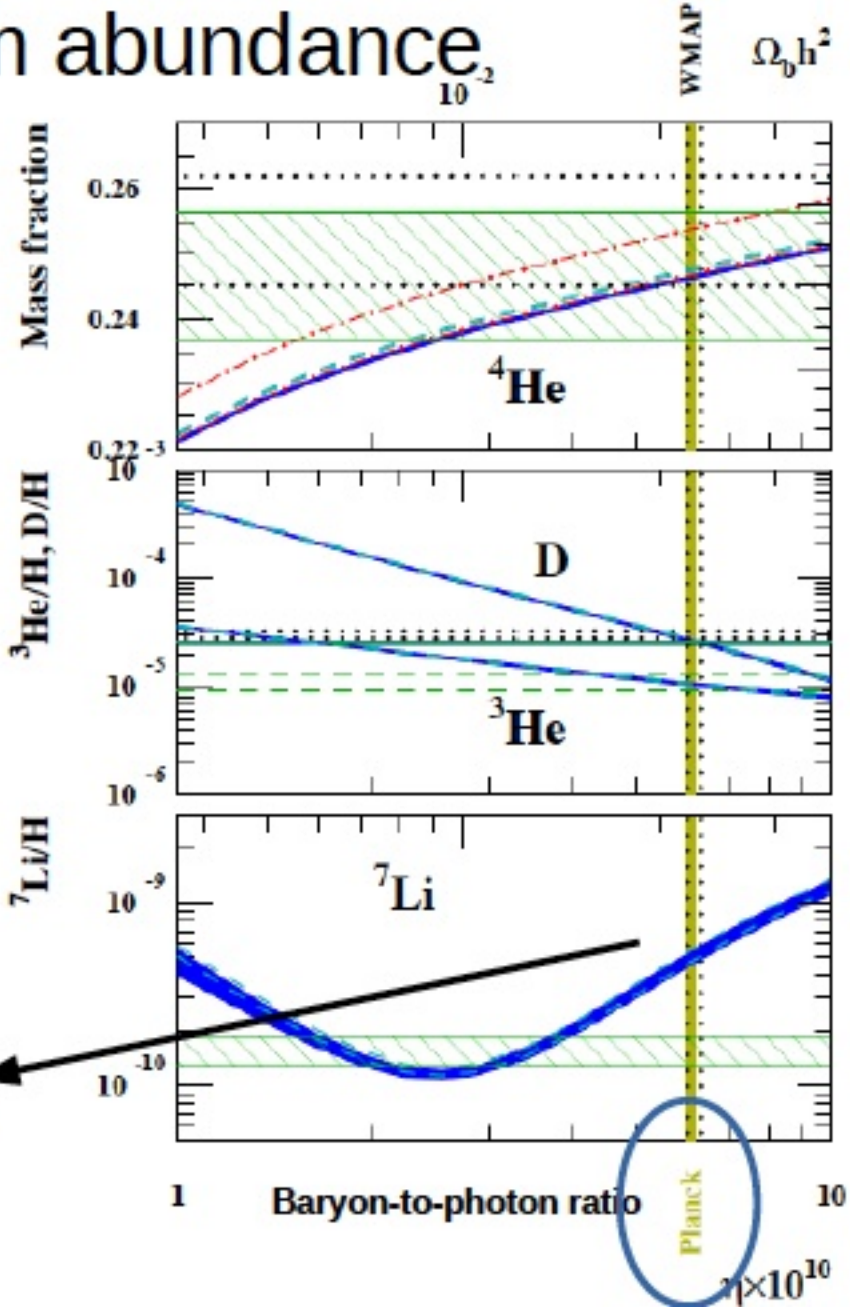
Calculated primordial abundances from Standard Big Bang Nucleosynthesis (and reaction rates) for :

4-Helium

Deuterium

3-Helium

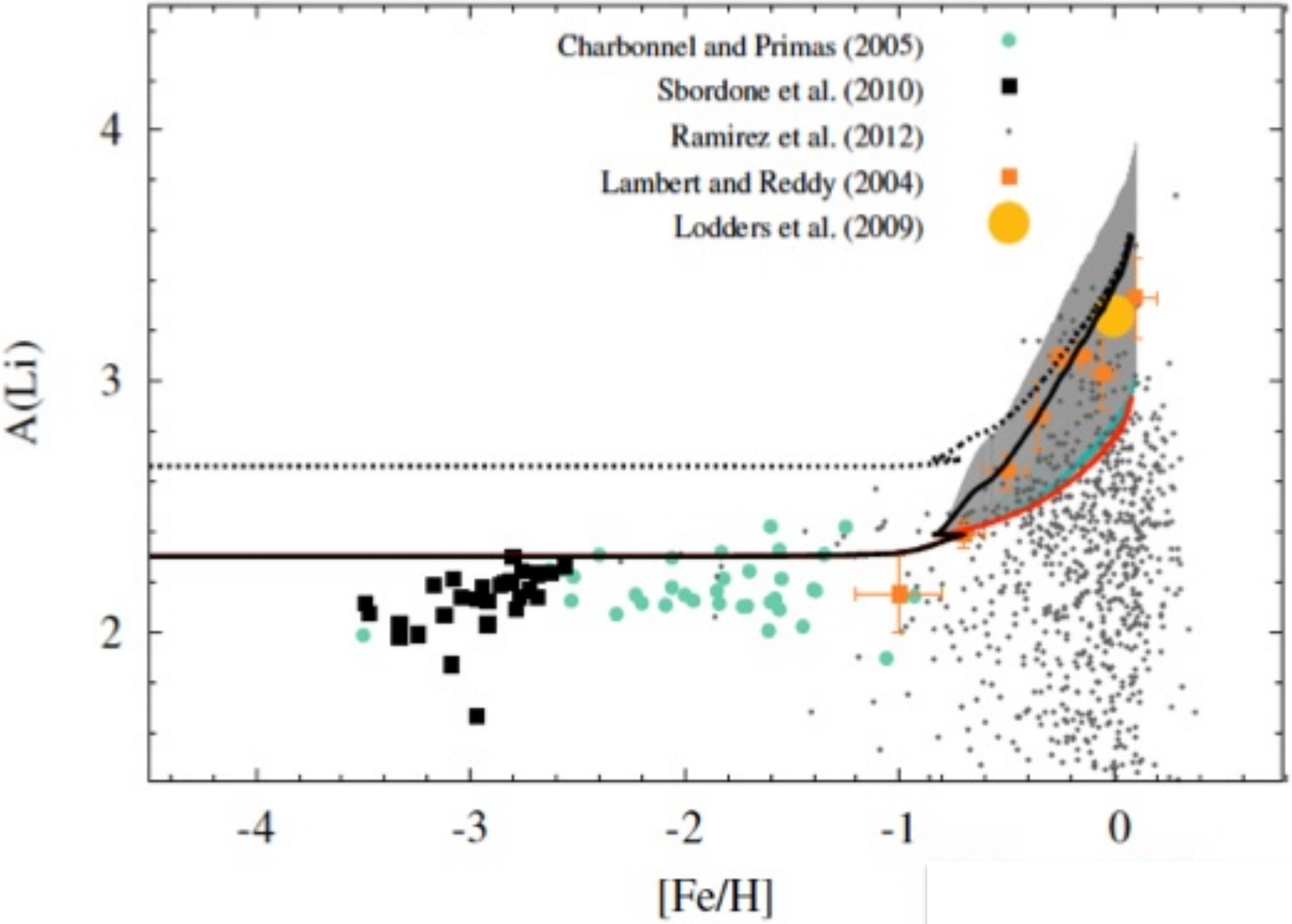
7-Lithium



**From Planck observation of η**

| | This work | Observations |
|---|---|---|
| $Y_p$* | 0.2461–0.2466 | $0.2465 \pm 0.0097$ |
| D/H ($\times10^{-5}$) | 2.57–2.72 | $2.53 \pm 0.04$ |
| $^3$He/H ($\times10^{-5}$) | 1.02–1.08 | $1.1 \pm 0.2$ |
| $^7$Li/H ($\times10^{-10}$) | 4.56–5.34 | $1.58^{+0.35}_{-0.28}$ |

# Galactic Li enrichment by novae



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# ON $^7$Li PRODUCTION IN NOVA EXPLOSIONS*

Department of Physics

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Laboratory for

Institut für K

*Recei*

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*Research Note*

# Upper Limits for the Li/Na Ratio in Novae

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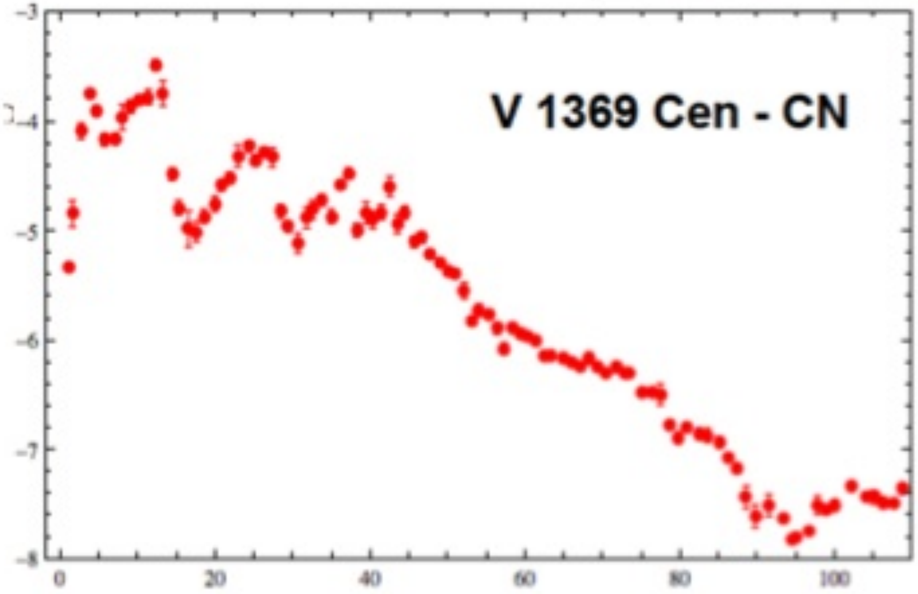
**Summary.** The absence of the lithium resonance doublet combined with the presence of the sodium $D_1$ and $D_2$ lines in absorption for three novae, enabled upper limits to the logarithmic abundance ratio [Li/Na] to be obtained. These values found for the slow nova HR Delphini and the fast novae IV Cephei and NQ Vulpeculae are 3.8, 4.4 and 4.5 respectively, the first value being of the same order as the overabundance predicted in the most favourable theoretical case.

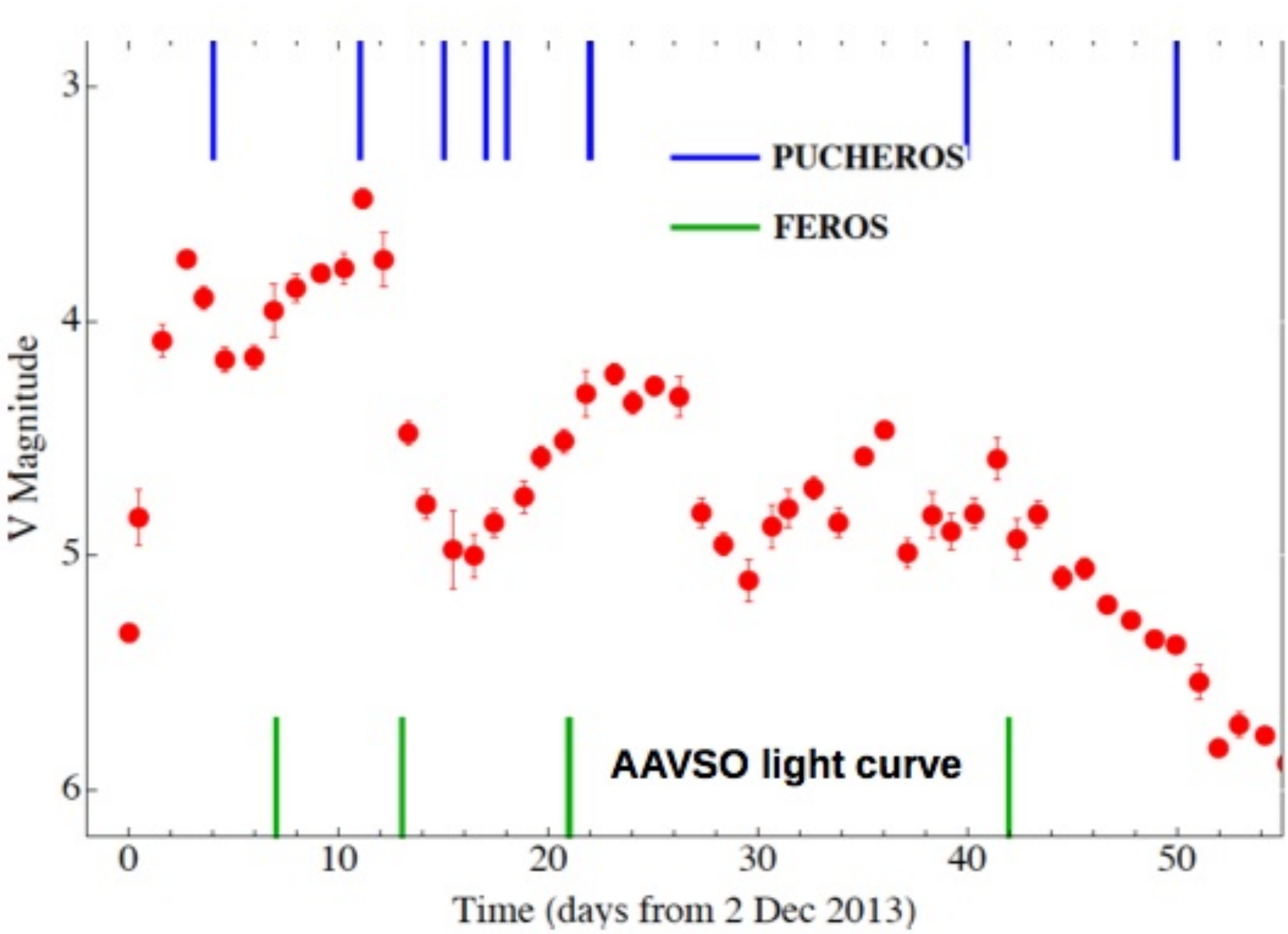
$V_{max} = 3.5$

50 days



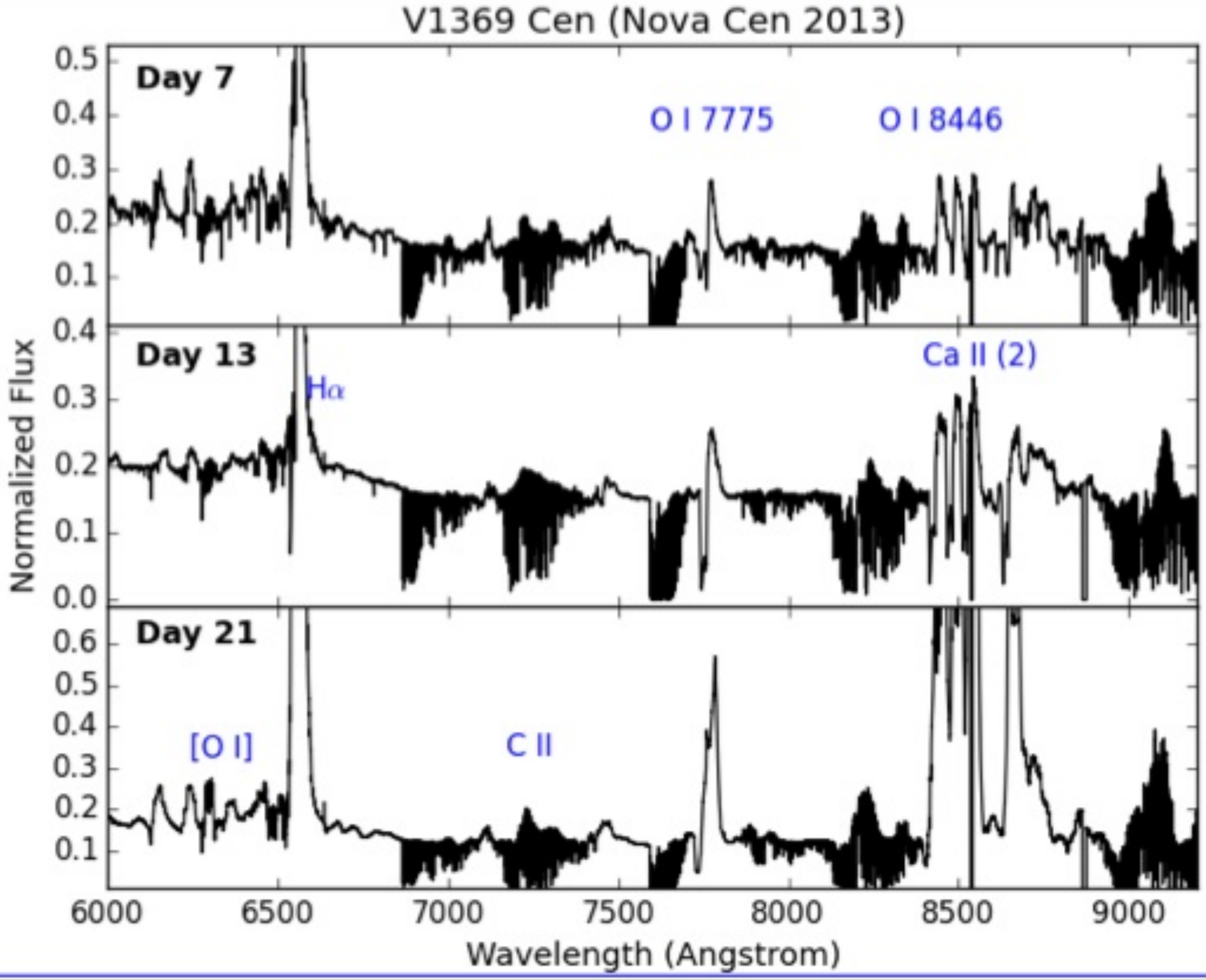
The brightest nova of the XXI century !!! (up to now...)

# Observations



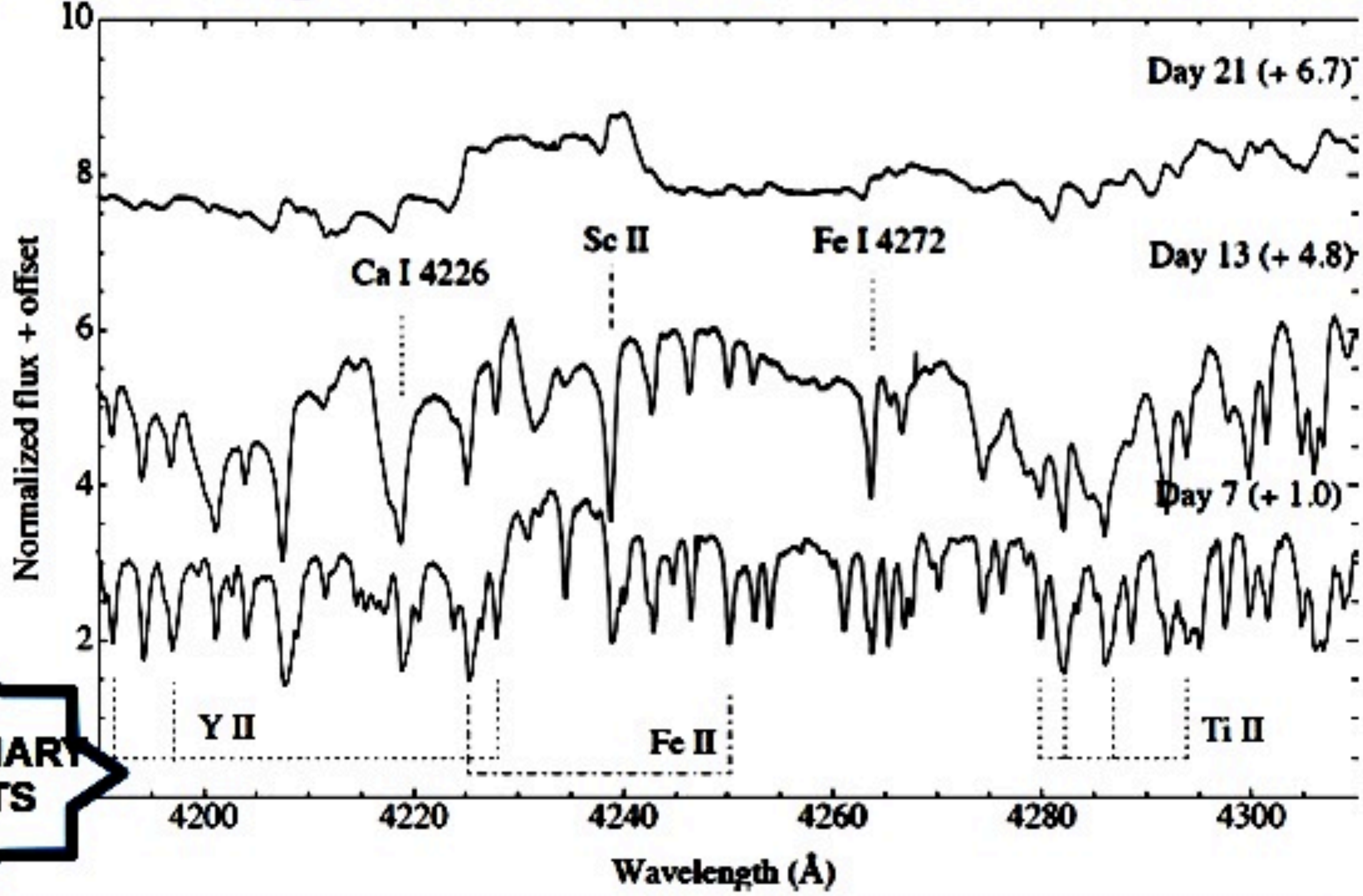
0.50m @PUC

2.2m @La Silla


V1369 Cen (Nova Cen 2013)
Day 7
O I 7775
O I 8446
Day 13
Hα
Ca II (2)
Day 21
[O I]
C II
Normalized Flux
0.5
0.4
0.3
0.2
0.1
0.4
0.3
0.2
0.1
0.0
0.6
0.5
0.4
0.3
0.2
0.1
6000
6500
7000
7500
8000
8500
9000
Wavelength (Angstrom)

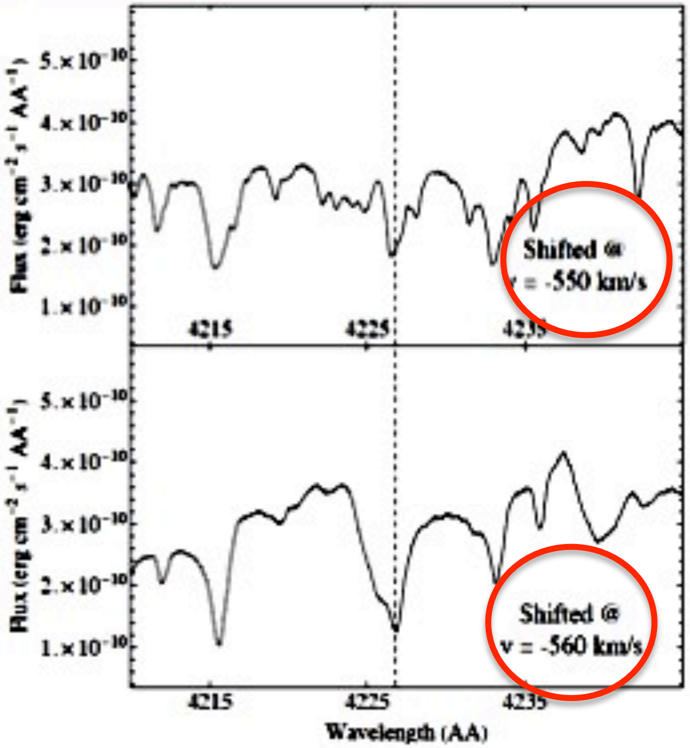
# ID absorption features

## 319 ID of singly-ionized heavy-elems with Ein < 6eV

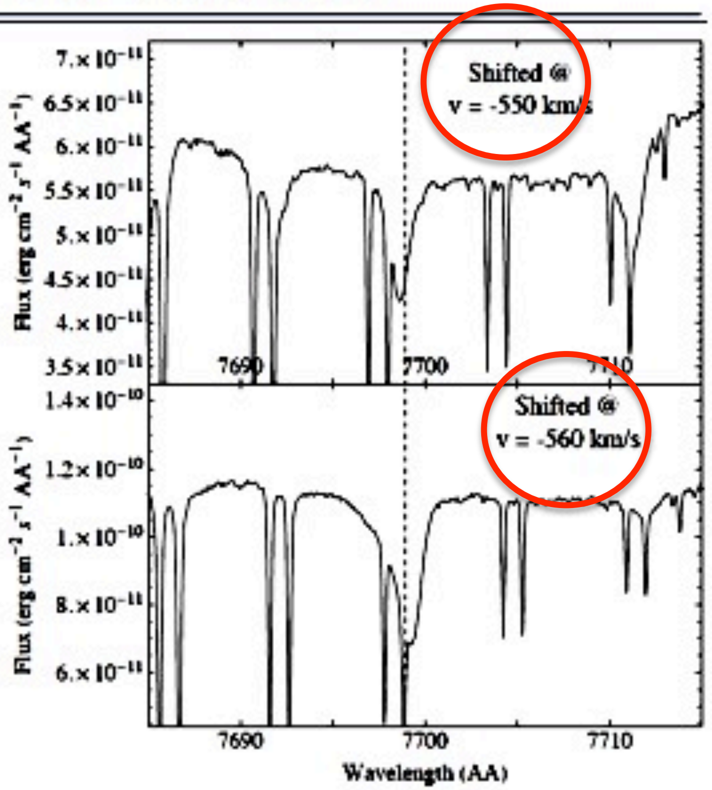


PRELIMINARY RESULTS

# The case of Li I 6708



Ca I 4226



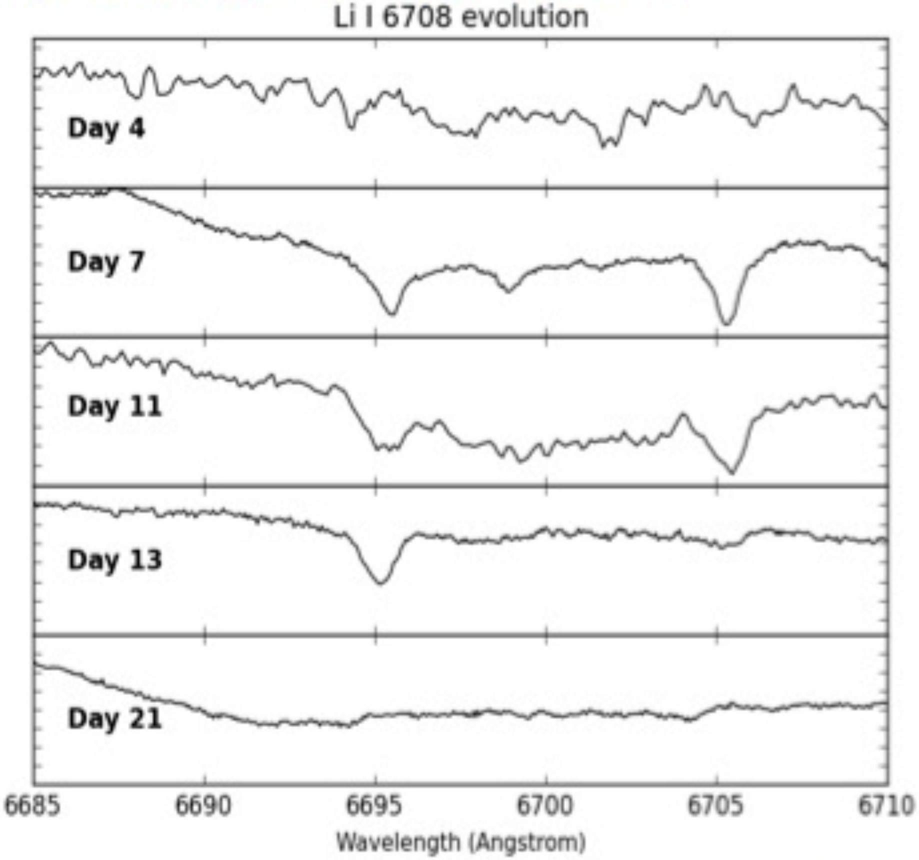
K I 7699

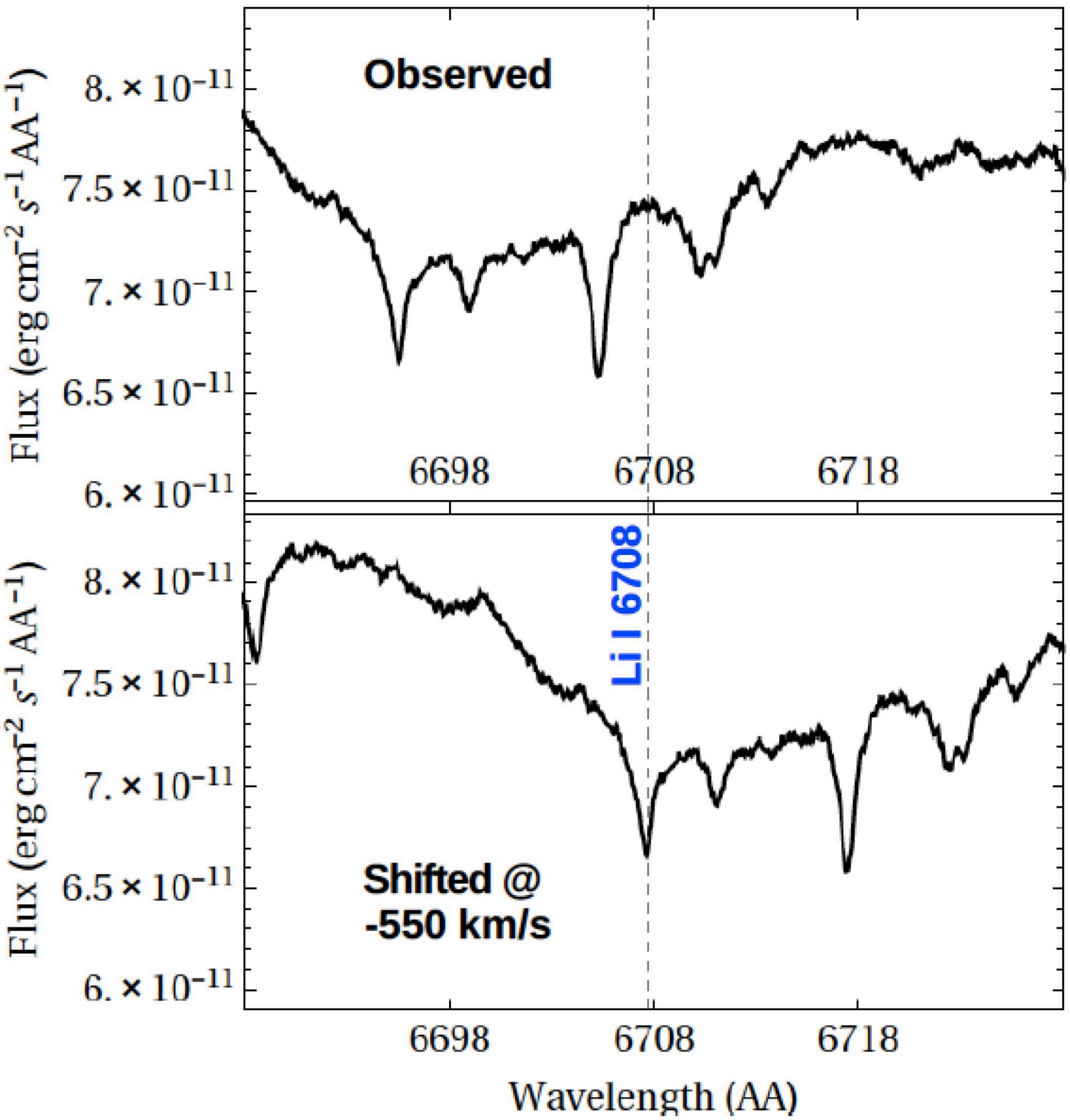
# The case of Li I 6708

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 ...

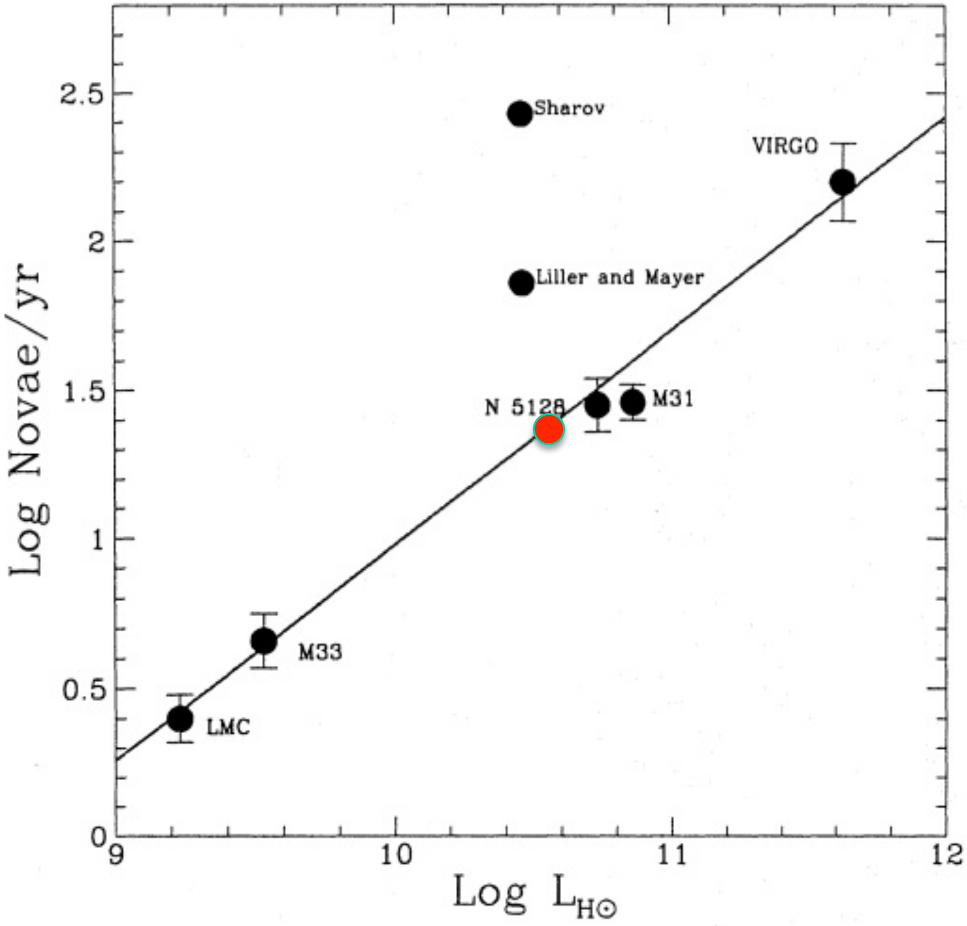



Observed
Shifted @
-550 km/s
Li I 6708
Flux (erg cm$^{-2}$ $s^{-1}$ AA$^{-1}$)
8. × 10$^{-11}$
7.5 × 10$^{-11}$
7. × 10$^{-11}$
6.5 × 10$^{-11}$
6. × 10$^{-11}$
6698
6708
6718
Wavelength (AA)

# Estimate of mass ejected

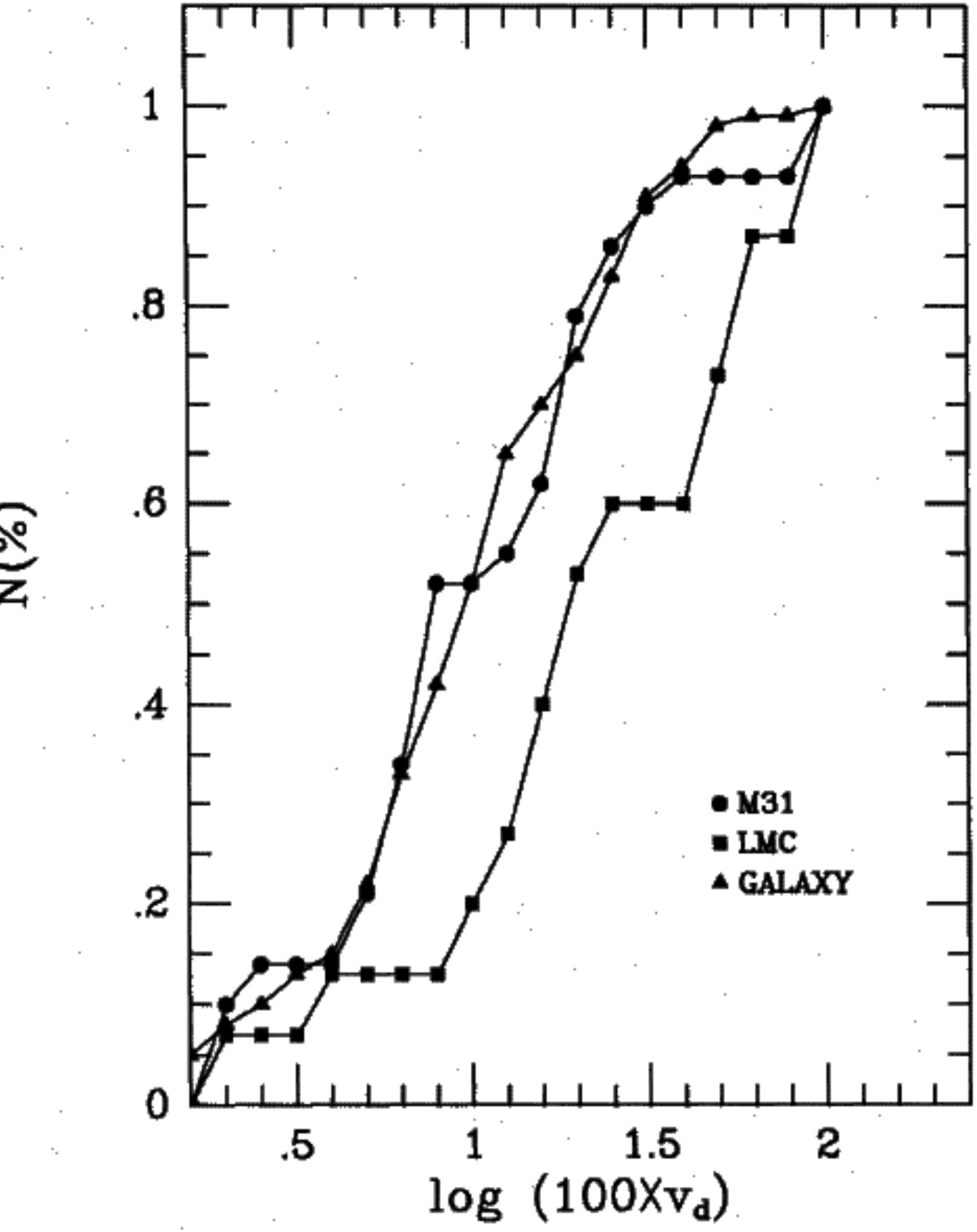
Mass Li = $0.3 - 4.8 \times 10^{-10}$ Msun

M. Della Valle & M. Livio: On the nova rate in the Galaxy 787



24 novae/yr DV & Livio 1995
35 novae/yr Shafter

**Fig. 1.** The nova rate as a function of H-Luminosity of the parent galaxies



The cumulative distribution of the rates of decline for M31 and LMC are different (K-S gives <1%).

Novae in the MW are mostly bulge novae → FeII class

DV & Duerbeck 1993

# Estimate of mass ejected

Mass Li = 0.3 – 4.8 × $10^{-10}$ Msun

\+

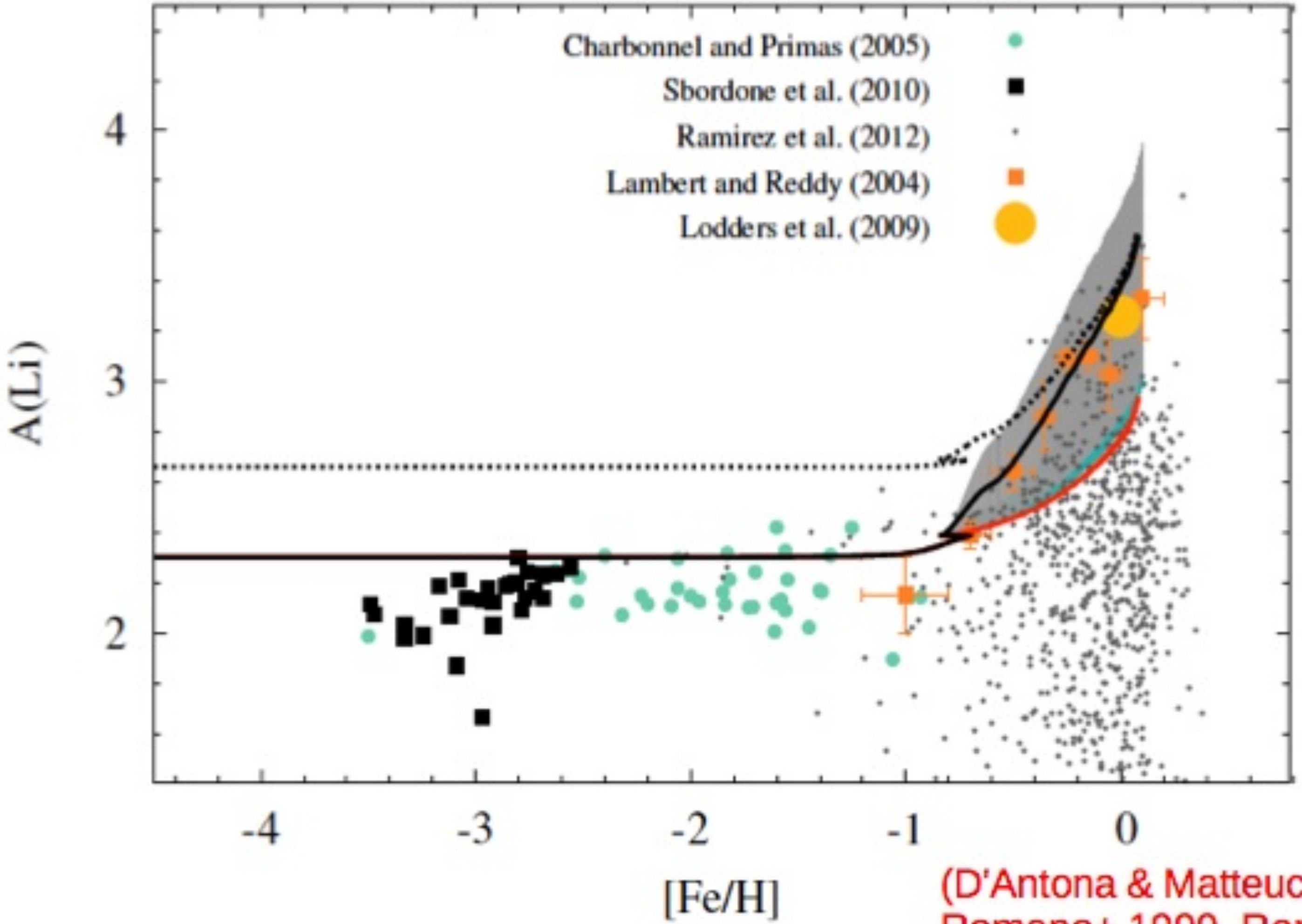
“Slow” nova rate in the MW = 15–24 yr$^{-1}$

→ Mass Li,tot ≤ 17 MSun Gyr$^{-1}$

↙

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

# Galactic Li enrichment by novae



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

# Conclusions and Perspectives

- V1369 Cen still represents a perfect laboratory for many nova studies !!!

- Open questions: possible multiple ejecta, complete analysis of early narrow absorptions, origin of high-energy emission ...

- ...Li presence → physics of explosion: 1) efficiency of convection and 2) timescales of TNR

- The Li yield inferred from V1369 Cen, and extended to all slow novae, is sufficient to explain the overabundance of Li in young star populations

$\sim 10^{24}$ erg