京都大学
KYOTO UNIVERSITY

京都大学大学院理学研究科附属天文台
岡山天文台

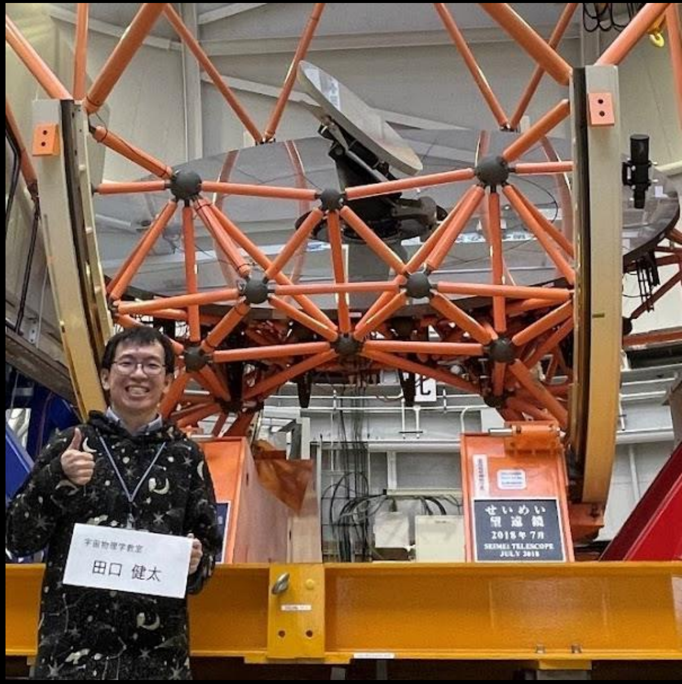
Spectra of Nova V1405 Cas at the Very Beginning Indicate a Low-mass ONeMg White Dwarf Progenitor

2024-06-06

Symbiotic stars, weird novae, and related embarrassing binaries

Kenta Taguchi (Kyoto University) et al.

Supported by the Kyoto University Foundation

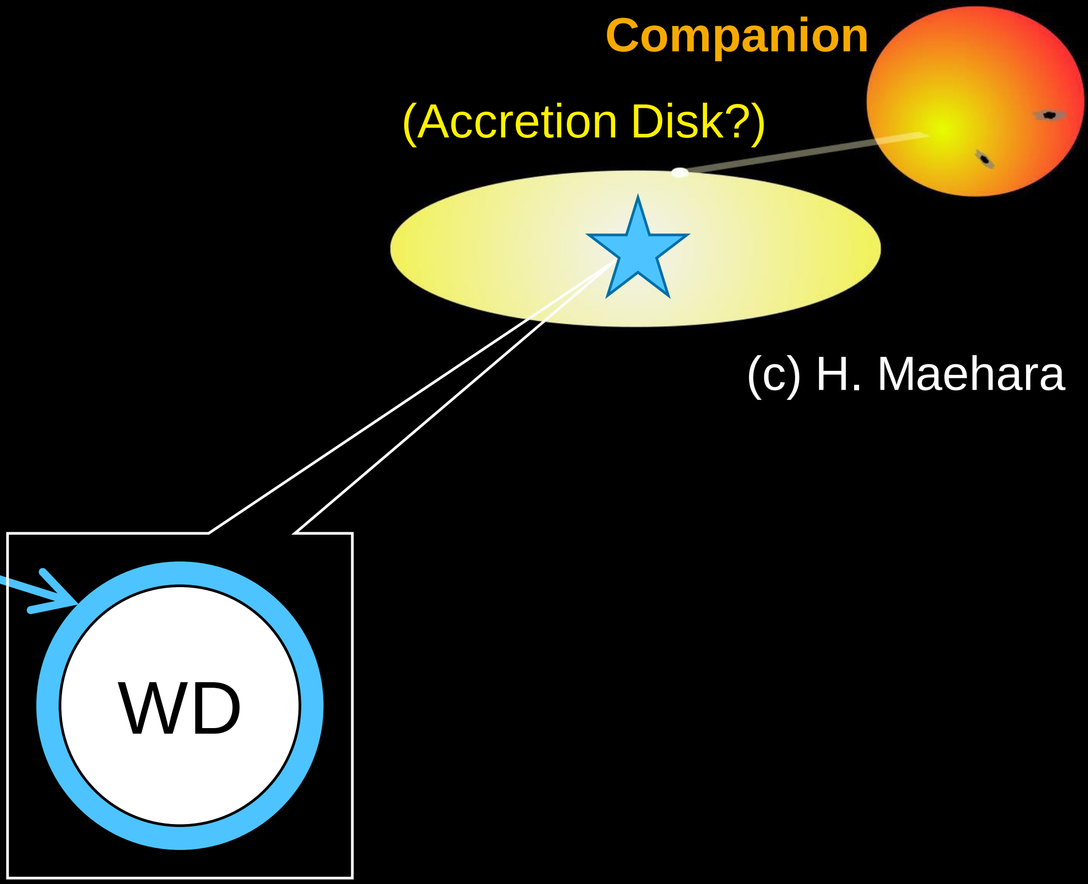


Mechanism of (Classical) Novae: Thermonuclear Runaway

- Binary system of:
  - **White dwarf (WD, primary star)**
    - Run out H → no nuclear reactions
  - A late (companion) star
- H gas from companion accretes on WD
  - Forms an H-rich envelope on WD surface.
- More and more gas accretes

  → ρ of H-envelope ↗

  → Thermonuclear Runaway (TNR)!



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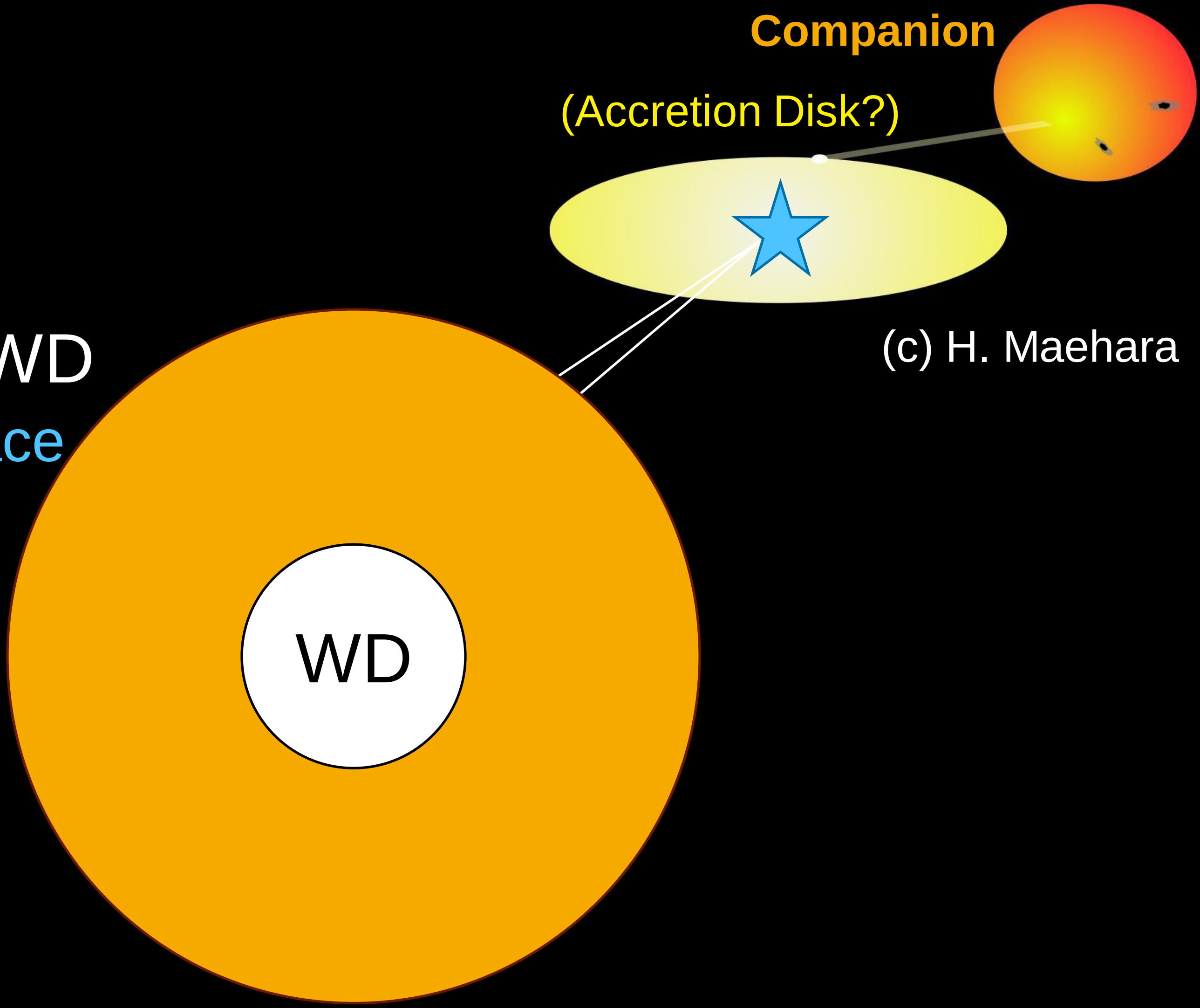
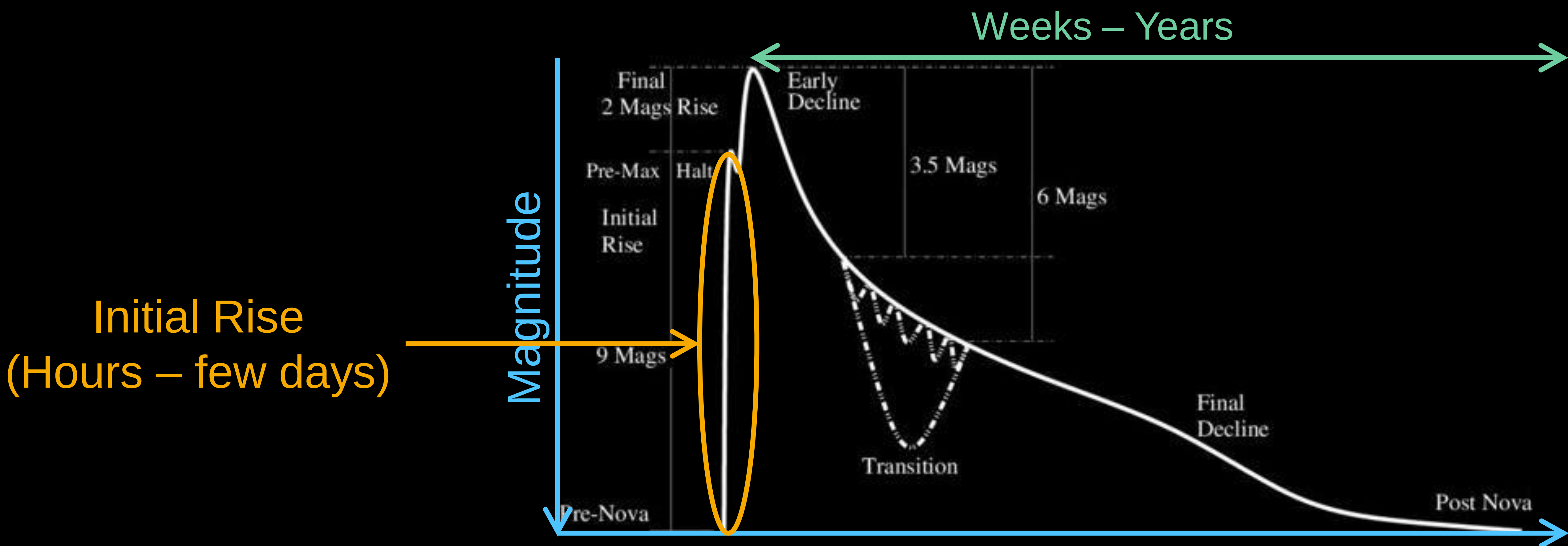


"Typical" Optical Light Curve of Nova (Bode & Evans 2008)

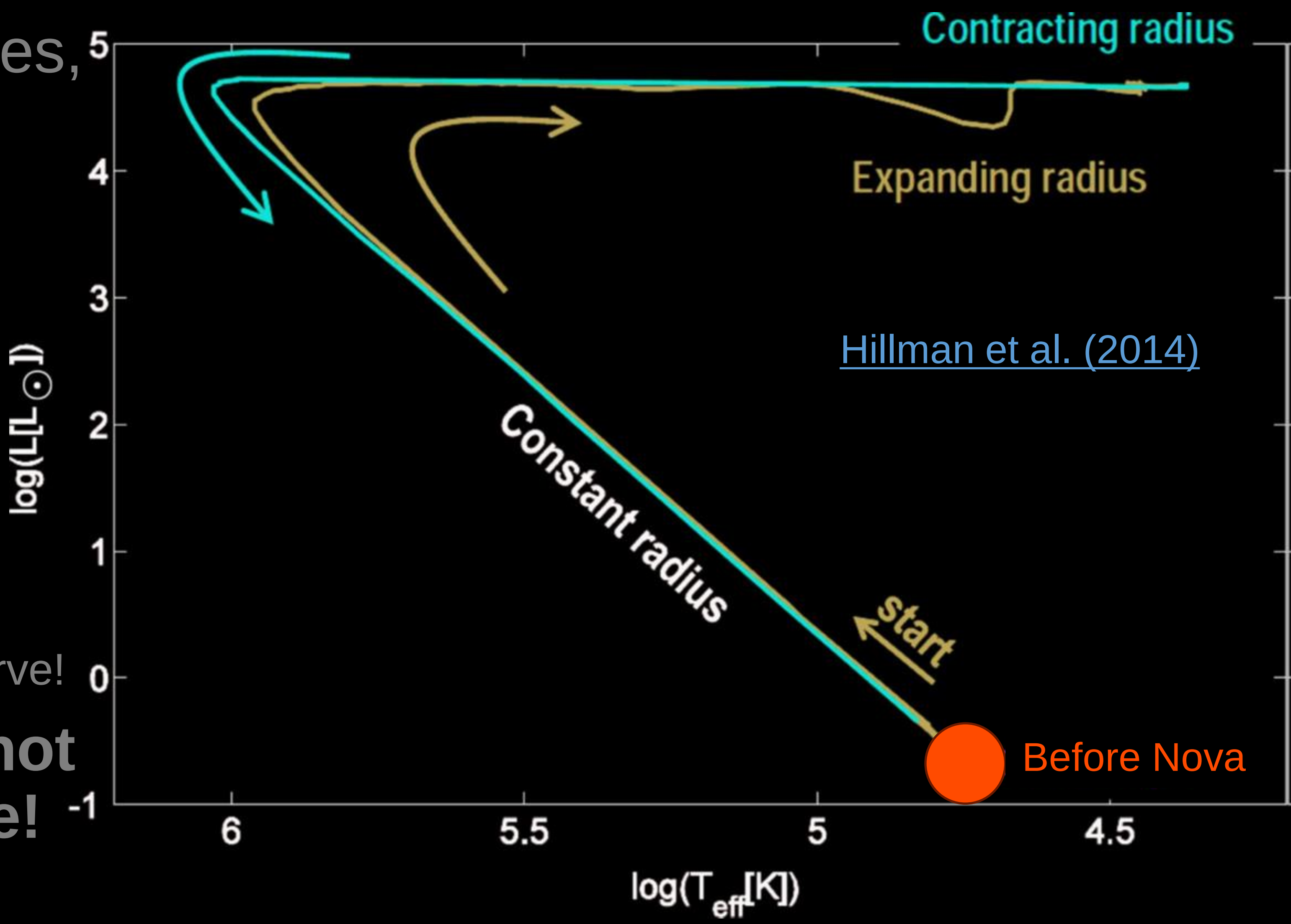


- Fast (slow) novae evolve fast (slow) and have high (low) mass WDs.
  - Some "extremely" slow novae ($\lesssim$ 3%) like RR Tel take $\gtrsim$ years in initial rise.

Nova in the HR Diagram

1. Once nuclear reaction ignites,
   → L and T runs away so rapidly.
   - Typical timescale: ~10 mins
     (Unrealistic to observe)
2. After L reaches Eddington,
   → Radiation pressure works
   → H envelope expands.
   → R_{phot} ↗ → T_{eff} ↘
   → brightens in the optical.
   → Initial Brightening in the light curve!

- **Photosphere is small and hot before the end of initial rise!**



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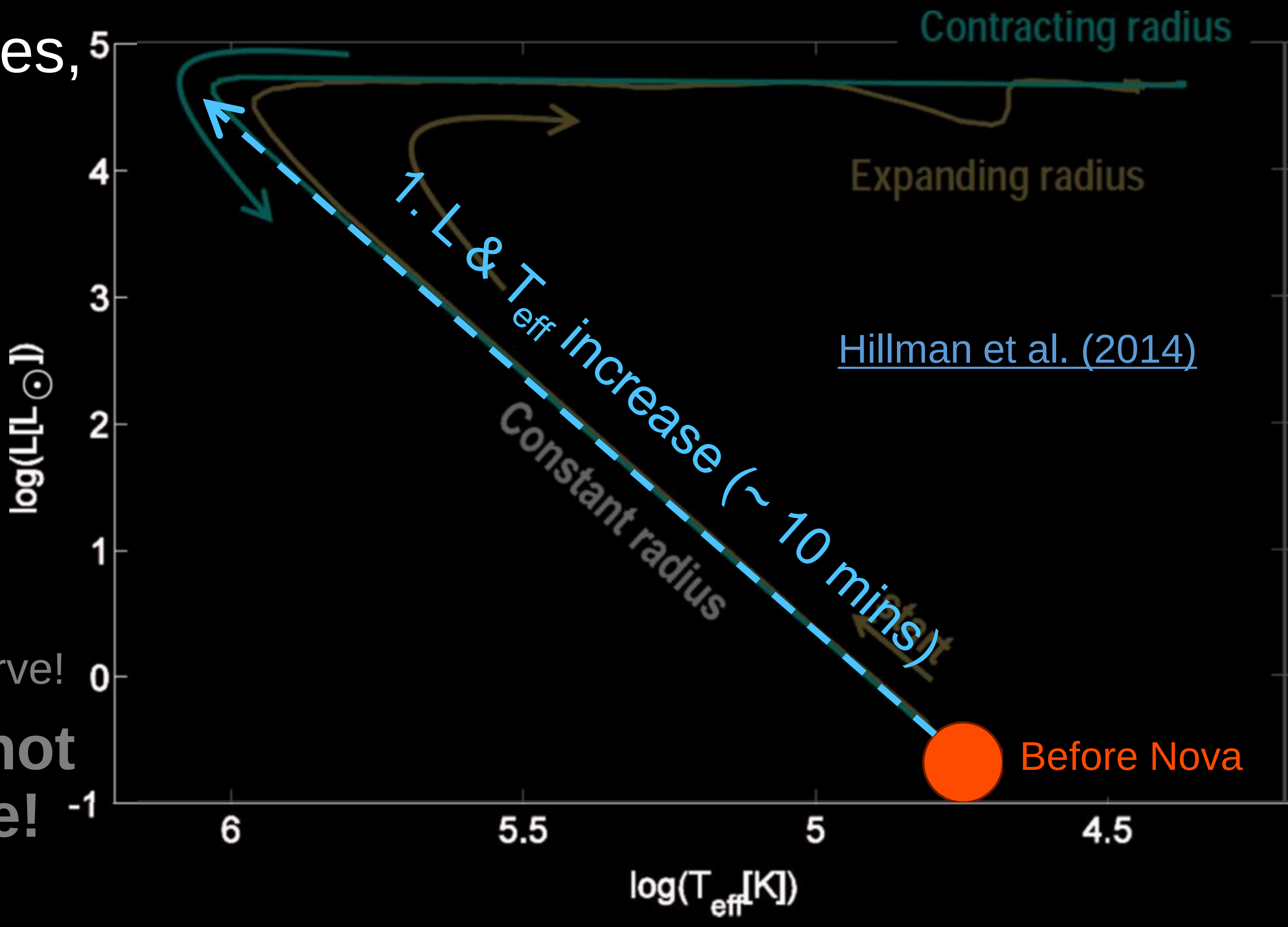

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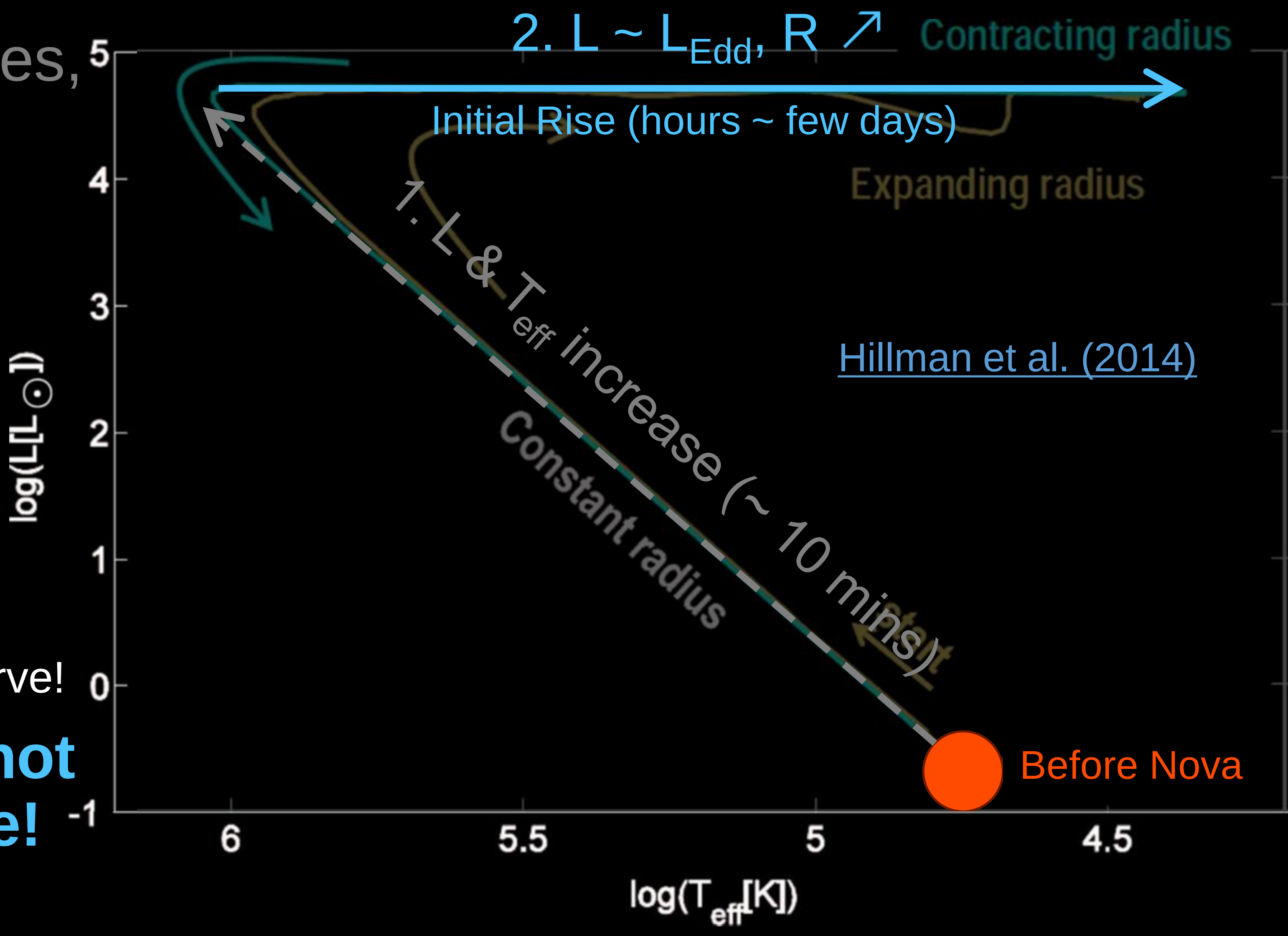
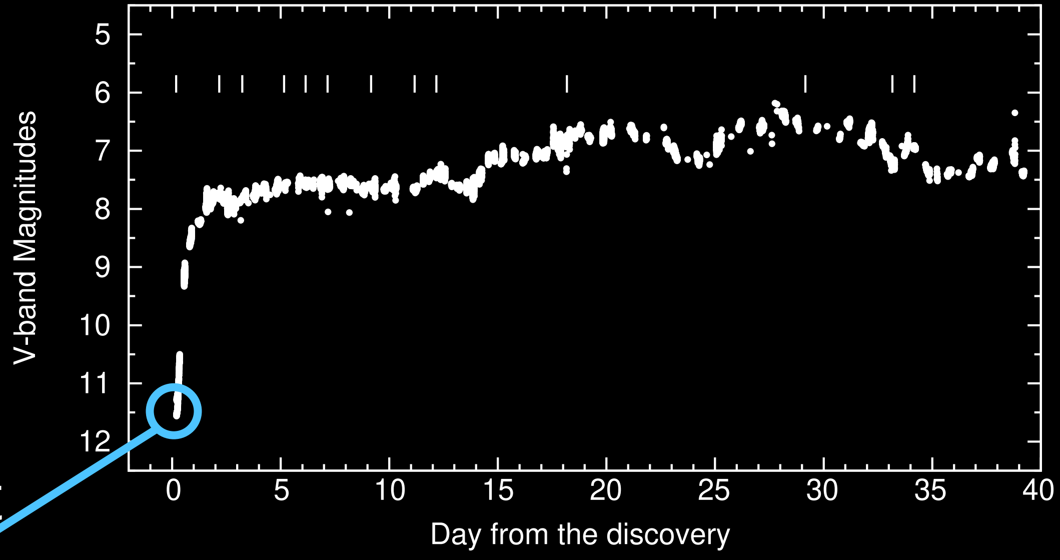
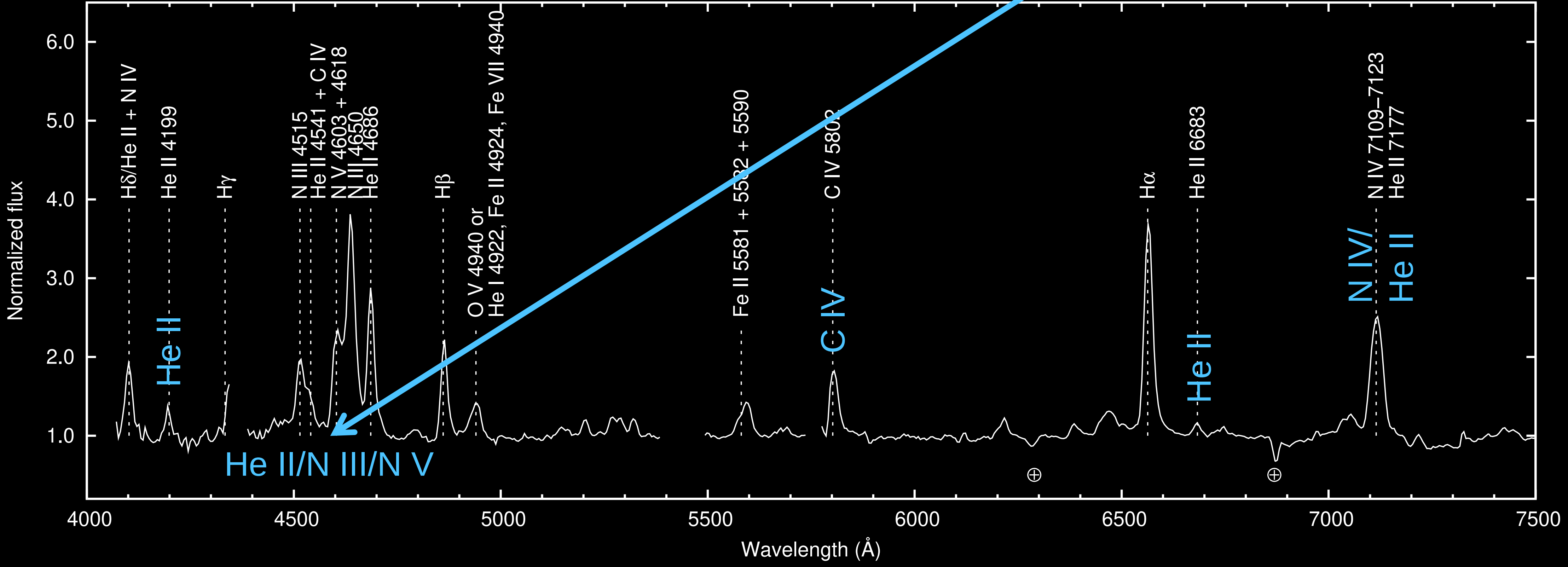


Pioneering Observation: T Pyx (Arai et al. 2015)

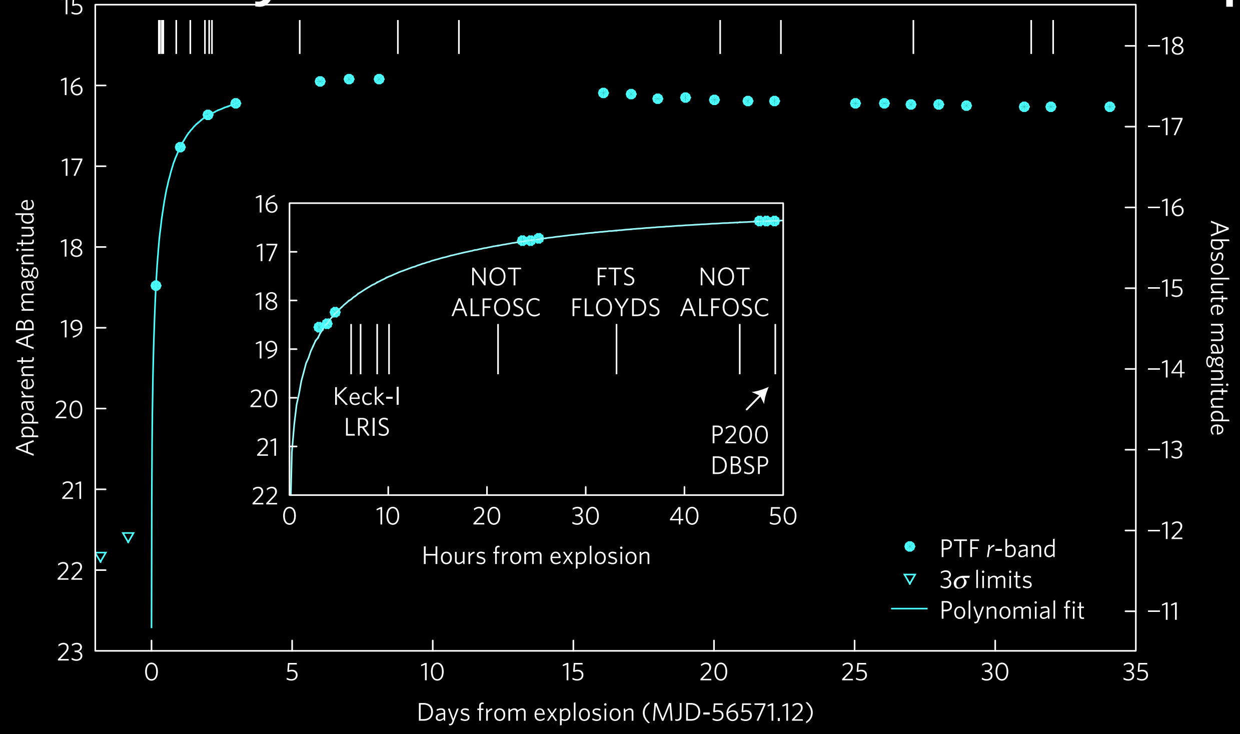
- **Highly-ionized Emission lines**
  - Without absorption components
  - Only seen in the first spectrum of 2011 outburst

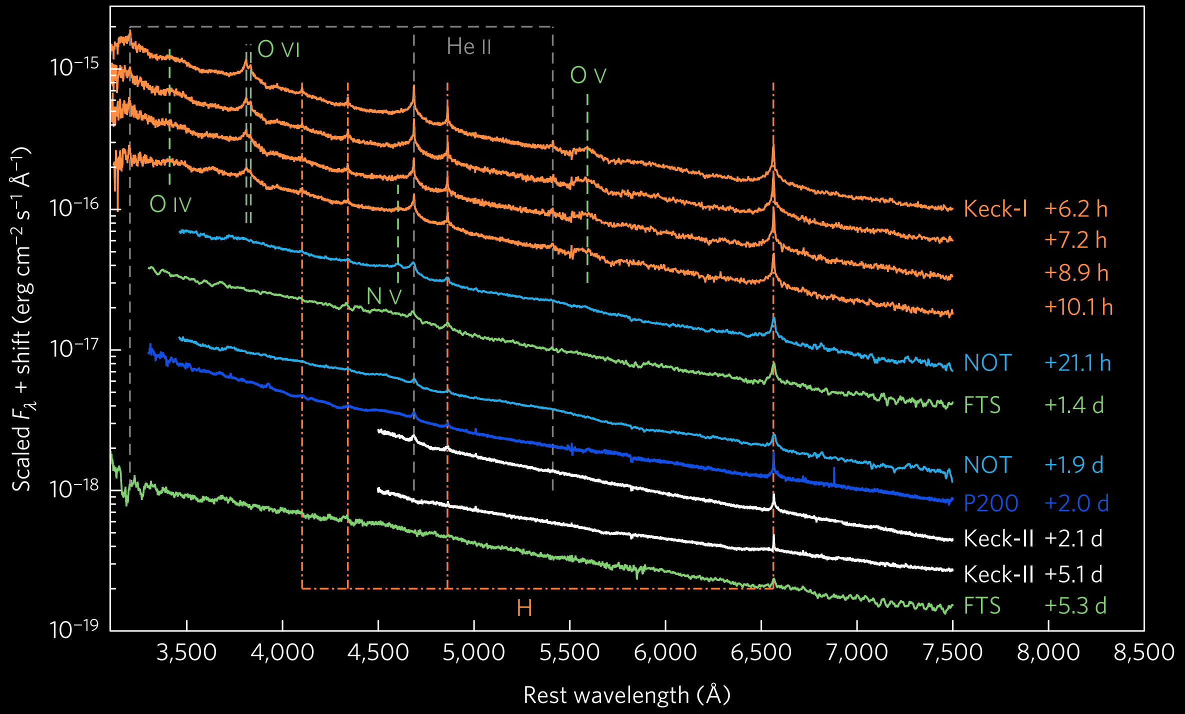




cf. ‘Flash spectra’ of Supernovae (e.g., Yaron et al. 2017)

- Narrow highly-ionized emission lines.
  - Attributed to pre-SN surrounding, circum-stellar material (CSM).
  - Only seen in early stages ($v_{SN}t < R_{CSM}$).
- We may see CSMs of novae from rapid follow-up?

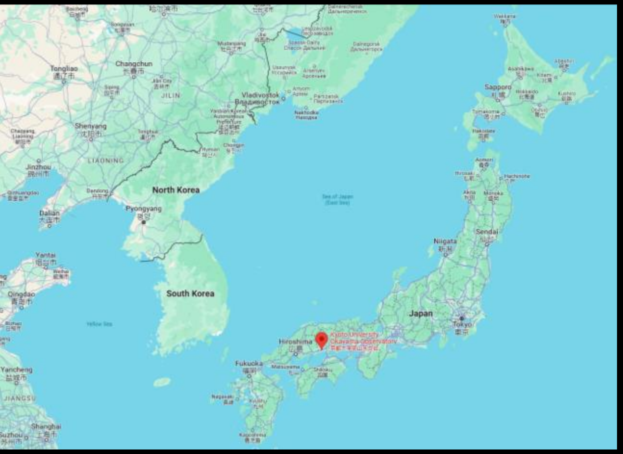




Our 'Hunting' Project Using 3.8-m Seimei (Okayama Observatory, Kyoto University)

- Nova spectra during 'initial brightening' is rare:
    1. 2011: T Pyx (Arai et al. 2015)
    2. 2021: **V1405 Cas (this work)**: very slow nova.
    3. 2022: Gaia22alz (Aydi et al. 2022): symbiotic nova (t_{rise} > 1 year).
    4. 2024: V4370 Oph (Uemura & Nakaoka, ATel #16521): very fast nova.

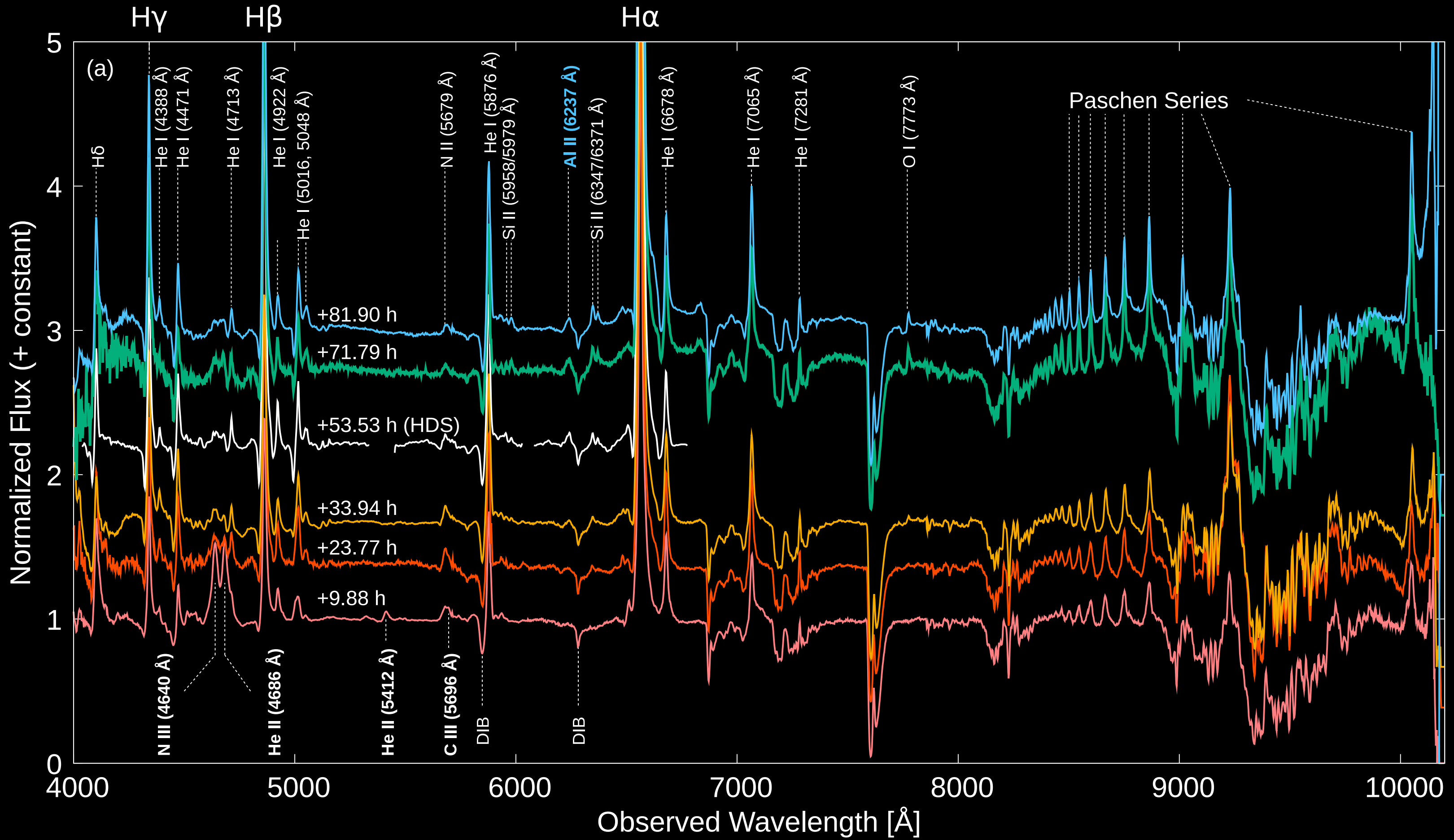
    (Do you know else?)
- Our project (2019 ~): **nova 'candidate' found → spectroscopy ASAP!**

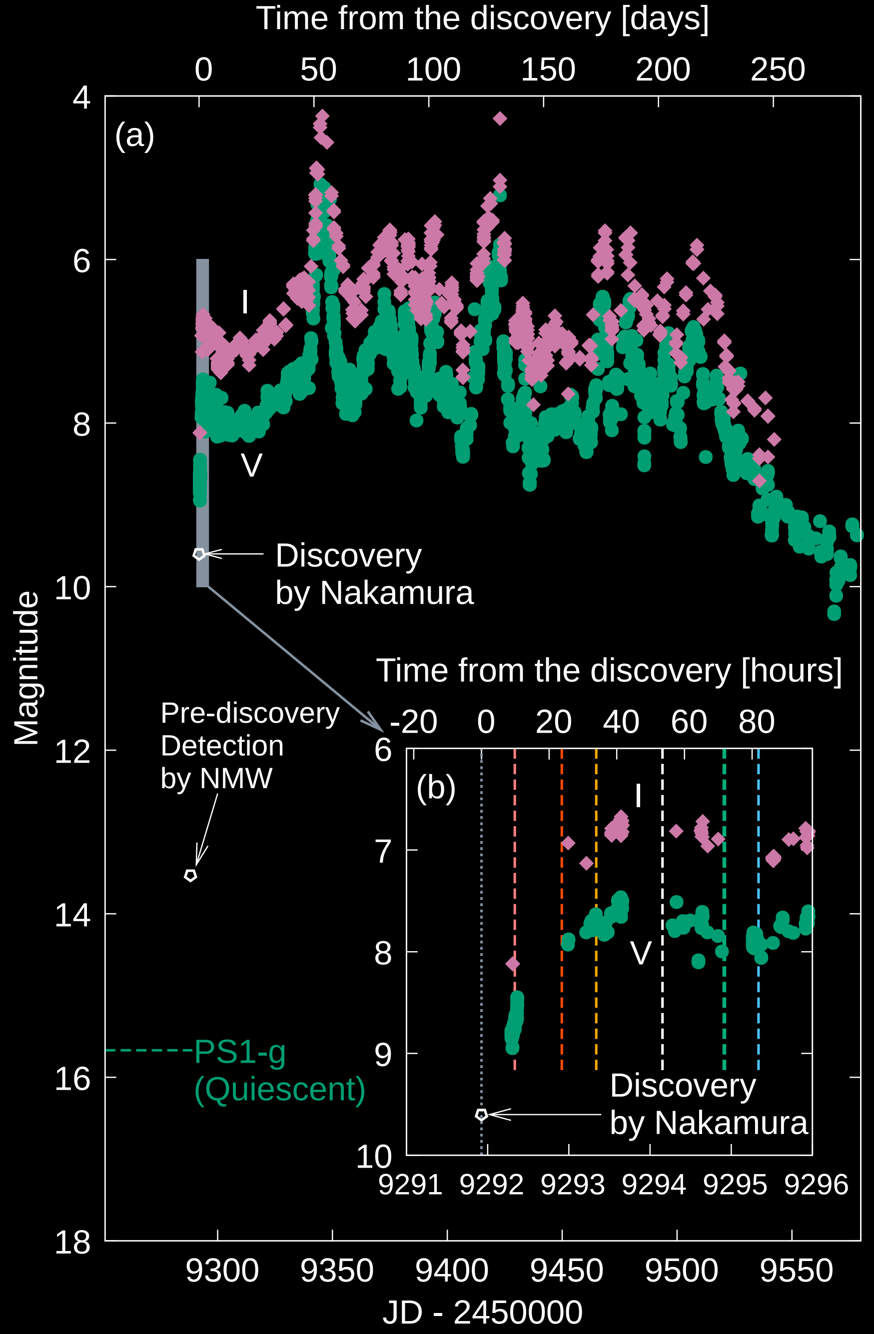


I'm Seimei, largest telescope in Japan.
Now I am 5 years old. I have
1. Integrated-field spectrograph,
2. Tri-color CMOS Camera (max 98fps),
3. Echelle spectrograph.

Early V1405 Cas Spectra

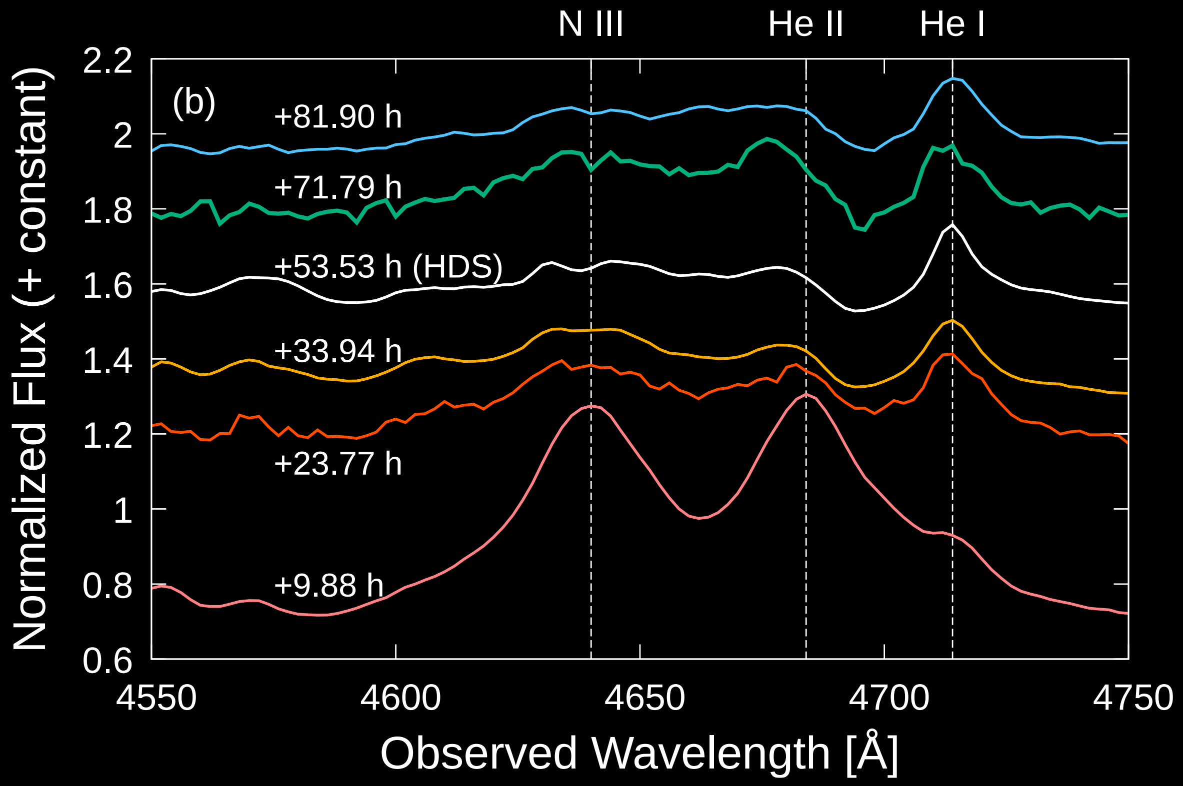
- 4000 – 10000 Å
- 9.88, 23.77, 33.94, 53.53, 71.79, 81.90 hours

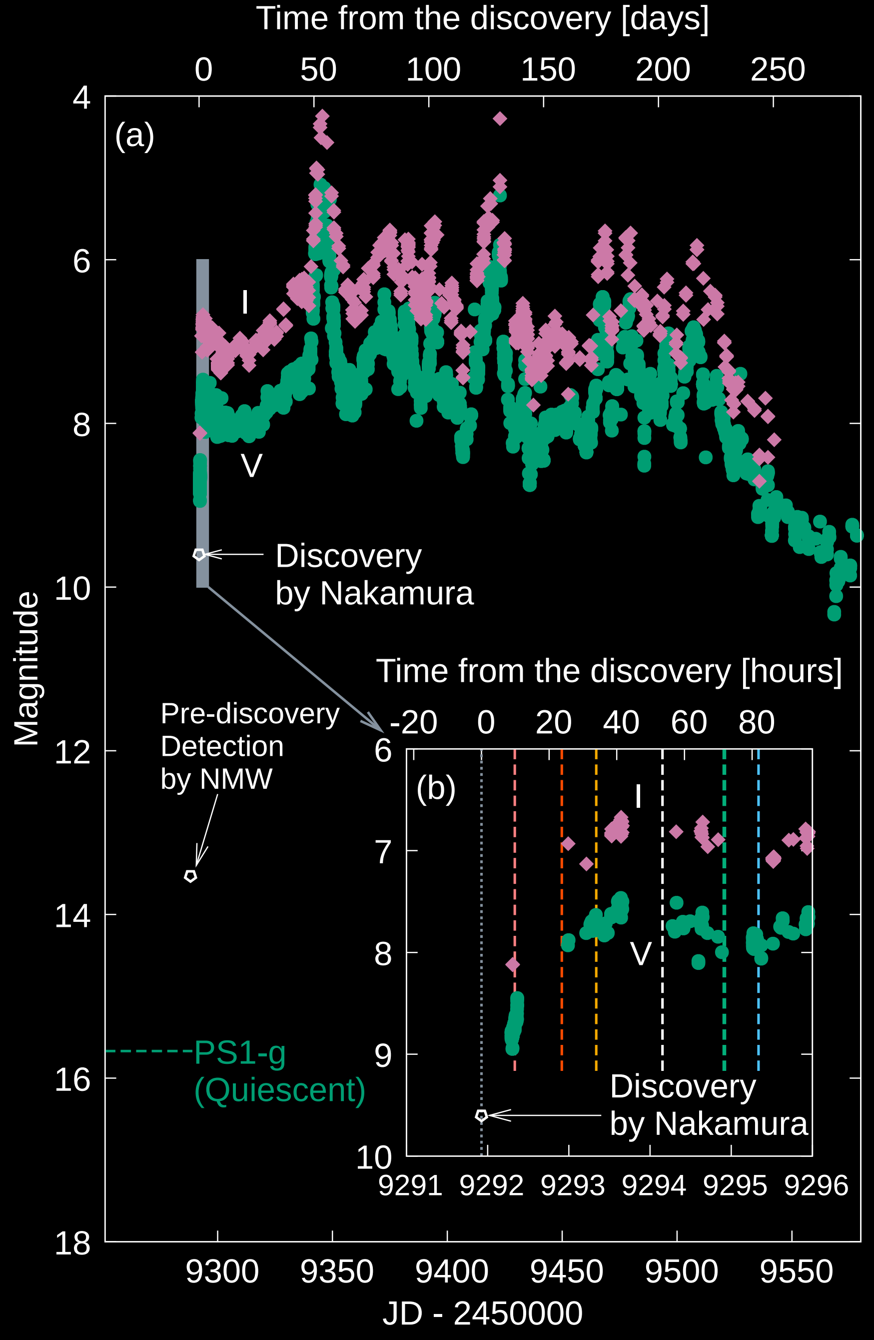




Early V1405 Cas Spectra: (1) During the Initial Rise

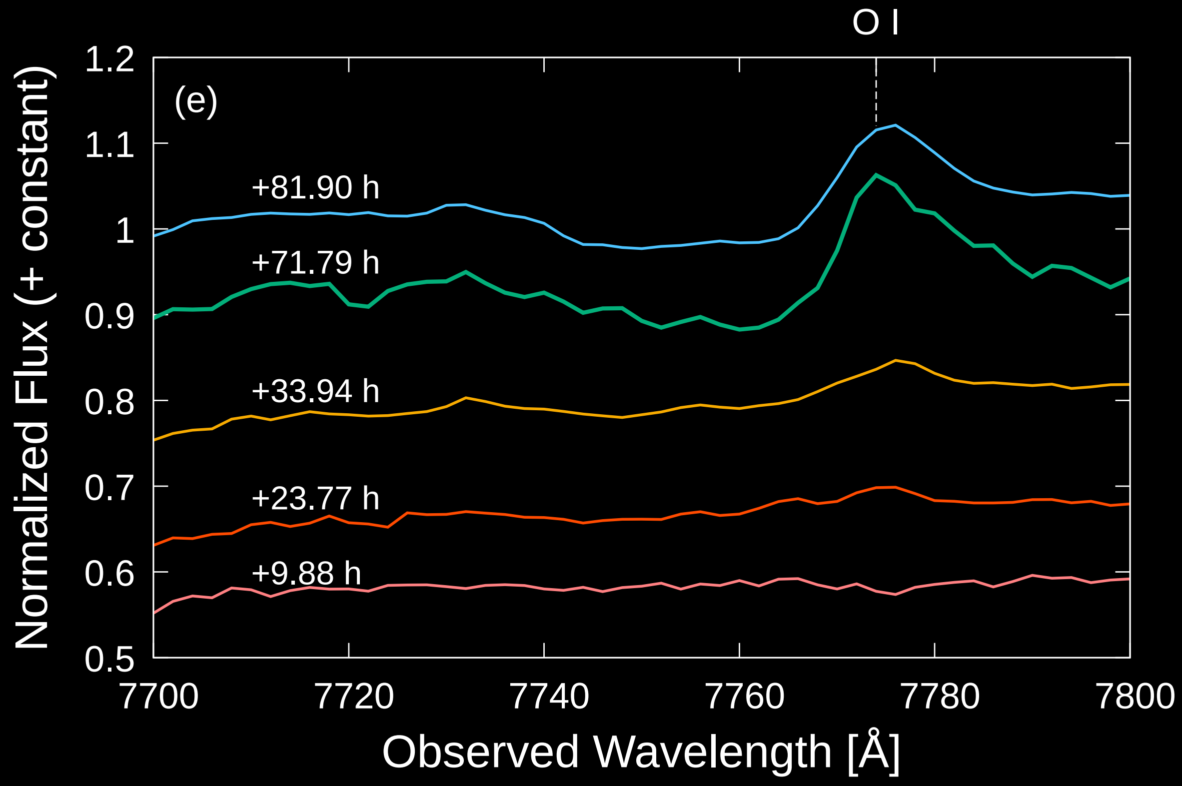
- **Highly-ionized lines only in initial spectrum!**
  - N III and He II (while no C IV, N IV, etc.)
  - **→ It must be hot in early phases!**
    - T ~ 22500 K from our first spectrum (Taguchi et al. 2023)!

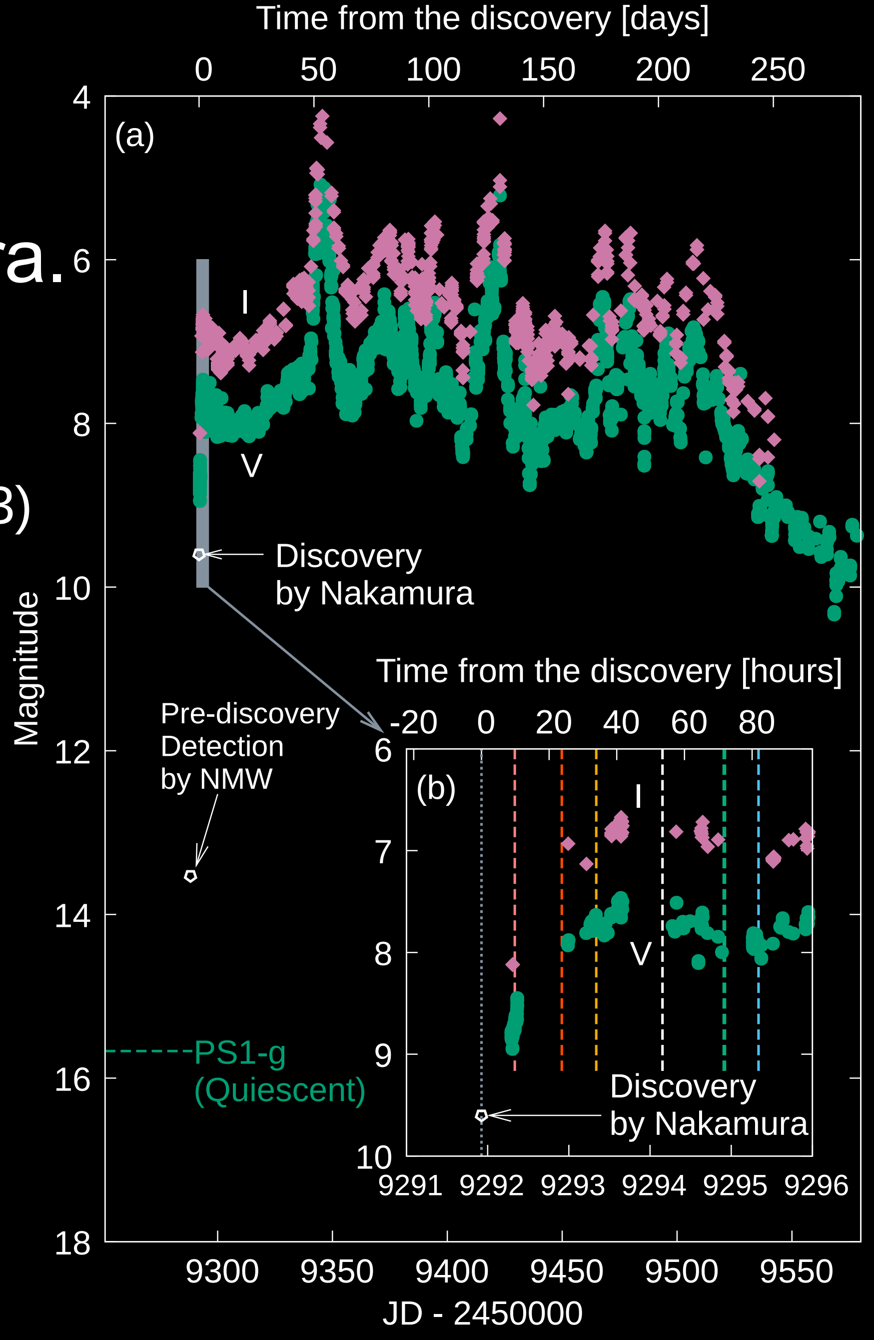




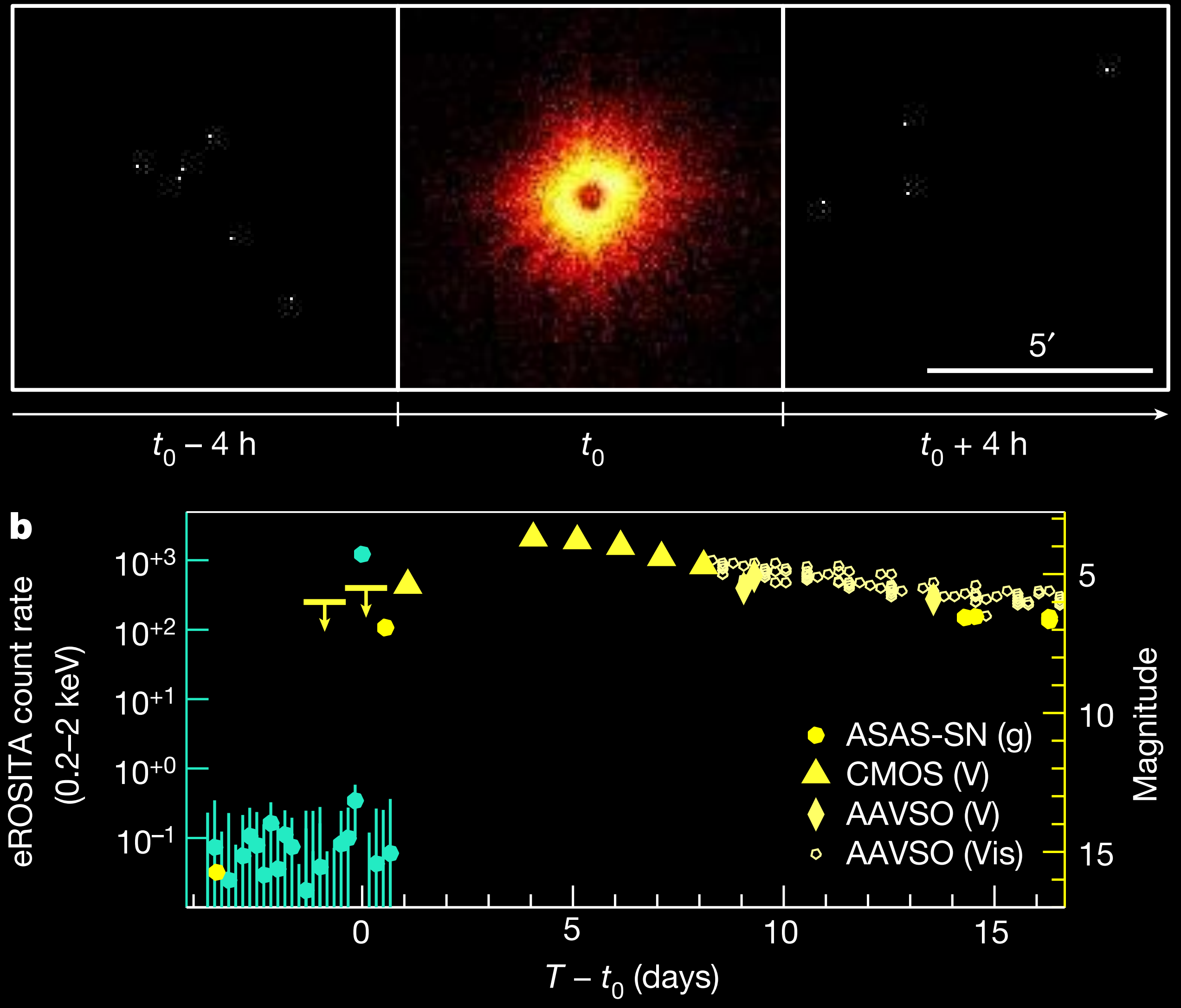
Early V1405 Cas Spectra: (2) After the Initial Rise Phase

- Lower-ionized lines evolved in 'late-initial' spectra.
  - O I, Si II, Al II
  - → **Cooled down!**
    - Decreased to T ~ 10000 K within 1 day! (Taguchi et al. 2023)

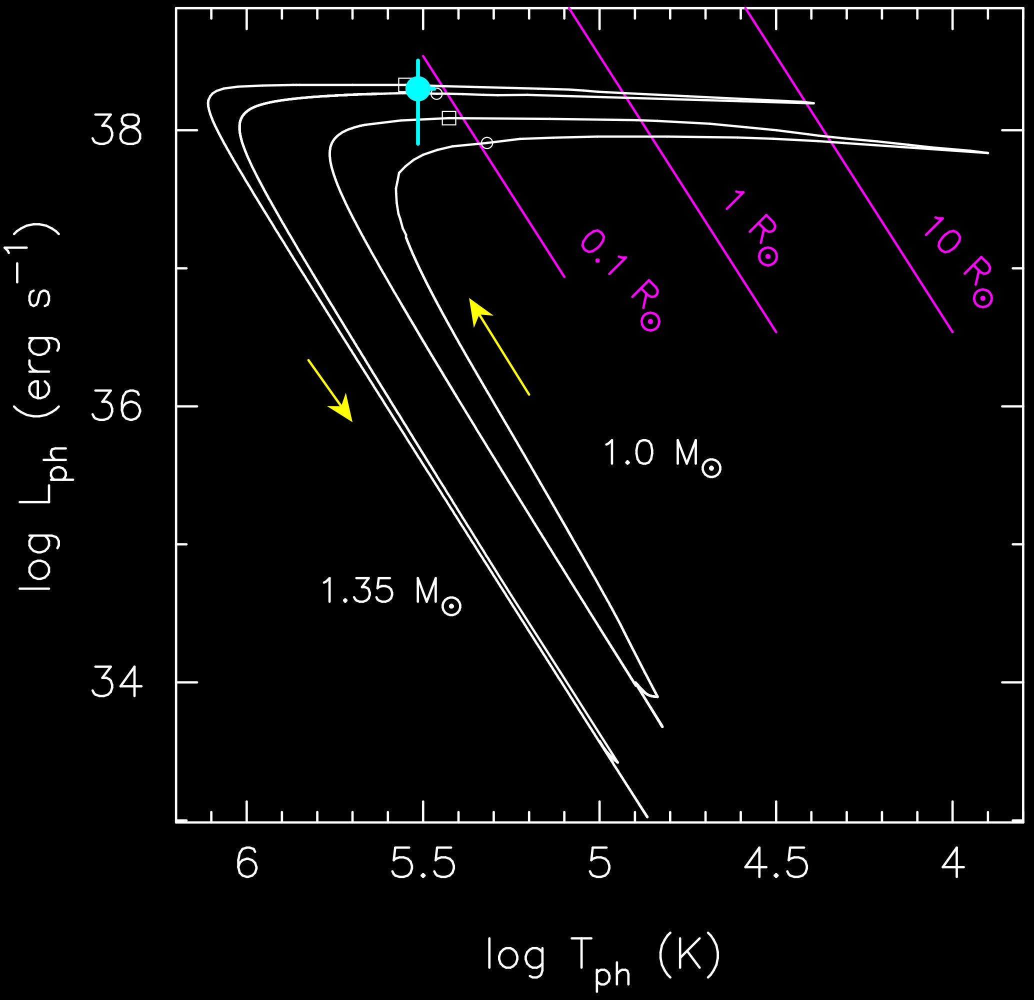




Recent Surprise: Soft X-ray ‘Flash’ from YZ Ret! (4 h cadence scan by eROSITA, König et al. 2022)

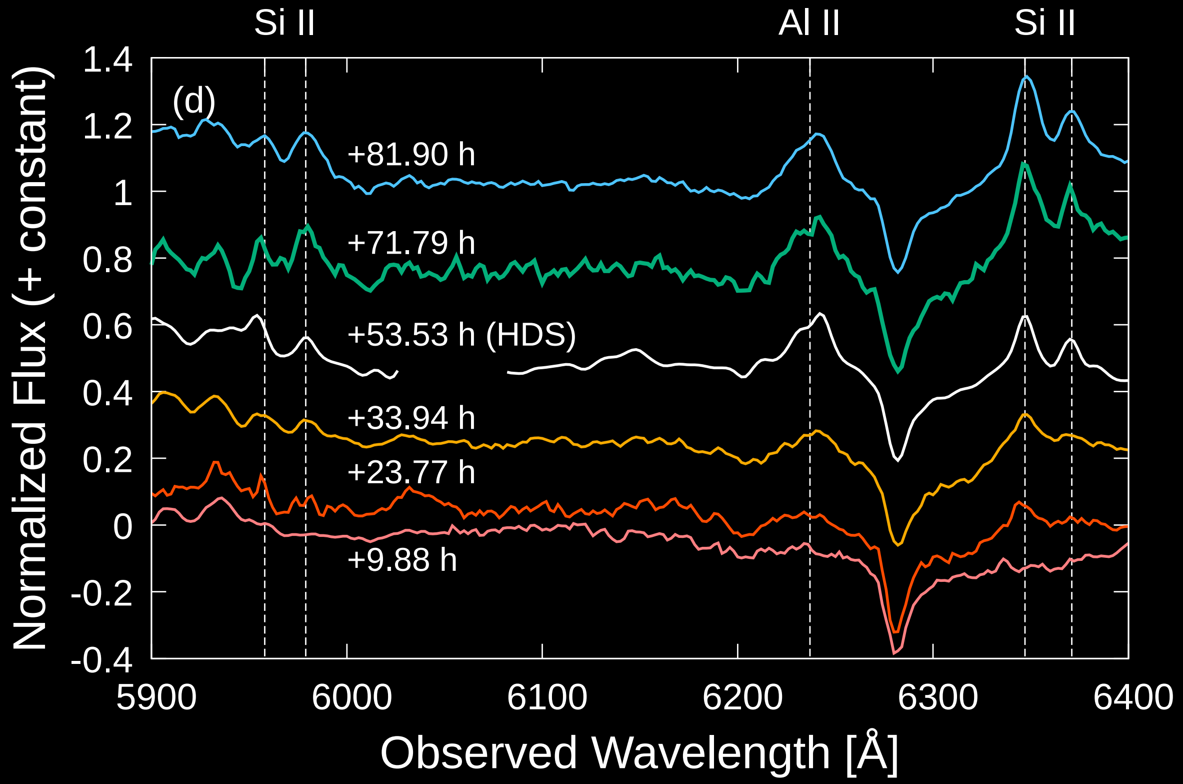


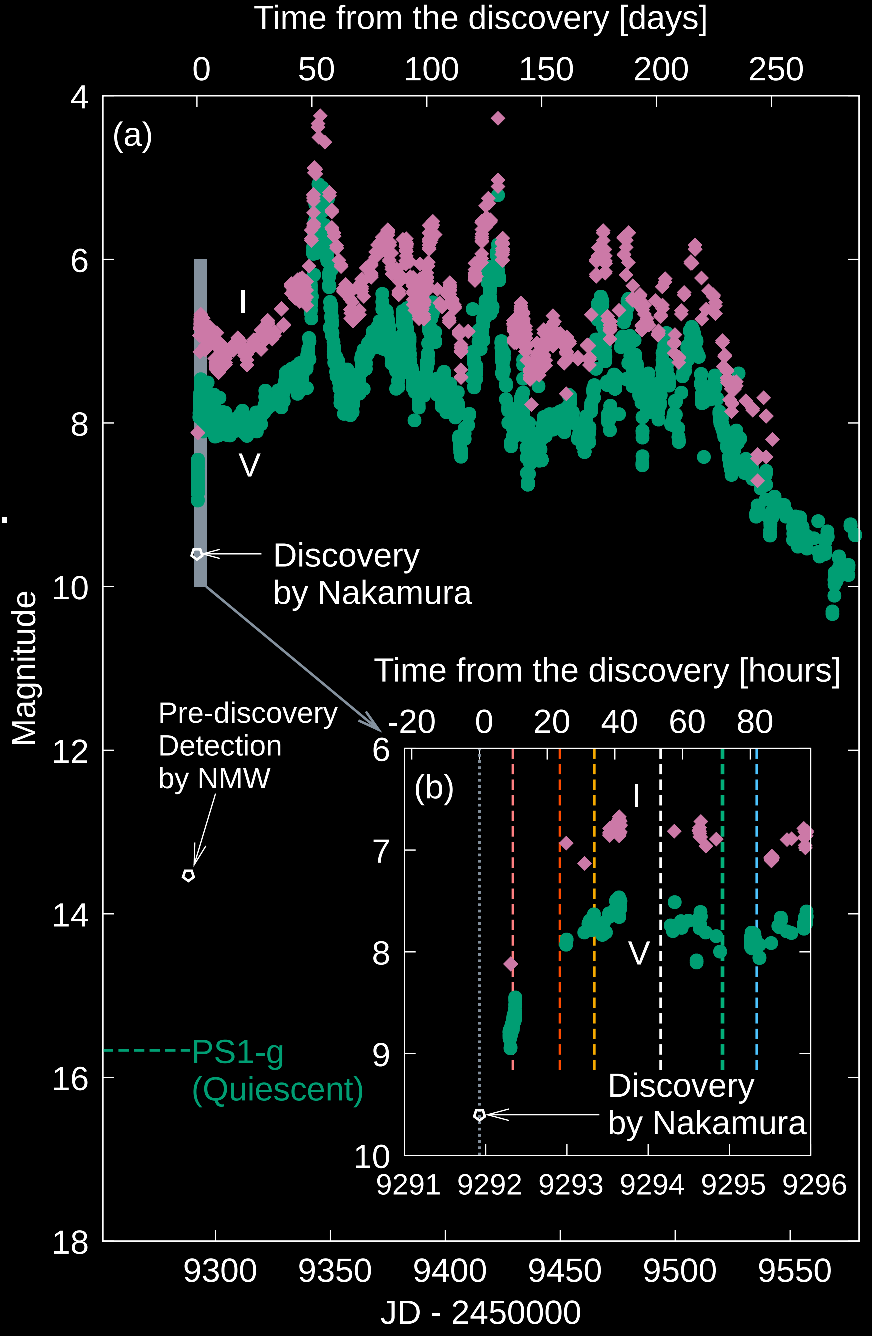
- Model by Kato et al. (2022)



Early V1405 Cas Spectra: (3) Aluminum Excess!

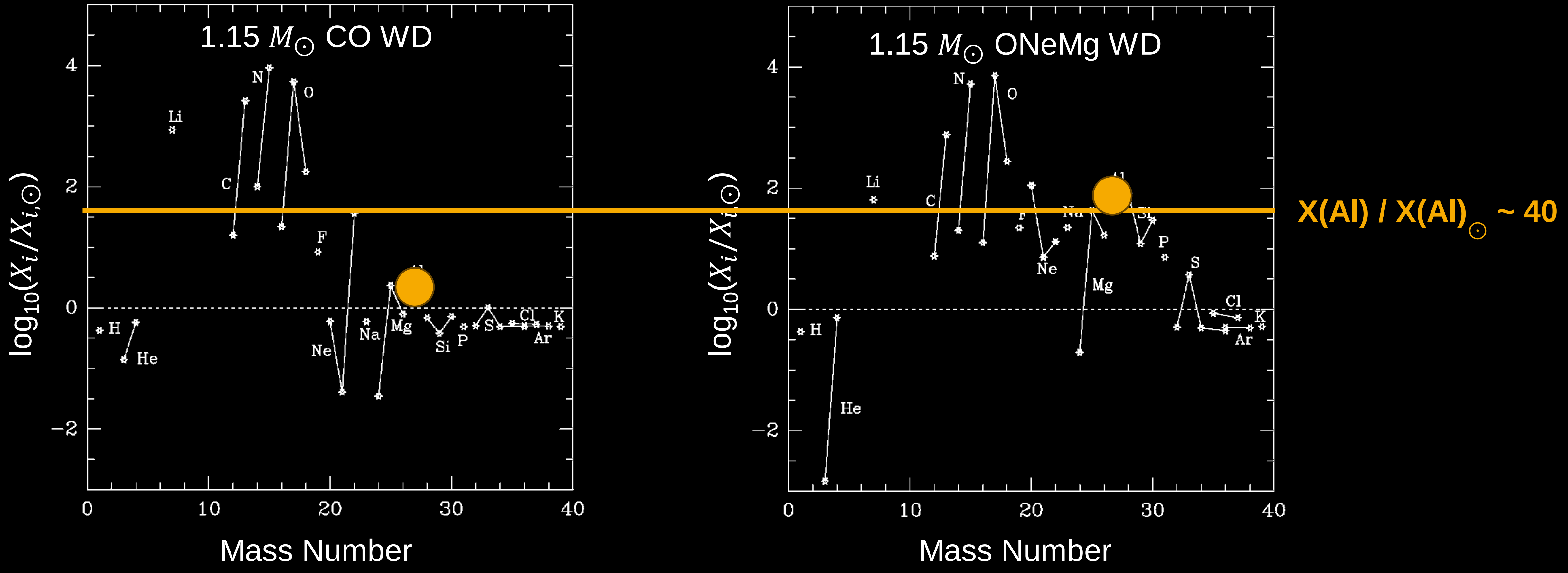
- We identified **Al II (6237 Å) emission lines**!
  - → **X(Al) / X(Al)$_\odot$ ~ 40!**
  - → The WD is an ONeMg WD (next slide)
    - Consistent with neon nova classification by nebular spectra.





Comparison to Nucleosynthesis Models (e.g., José+2006)

- ONeMg WD (neon nova) prefered to CO WD (CO nova) for V1405 Cas.
  → Indeed, neon-nova identification given in the nebular phase (Munari+21).

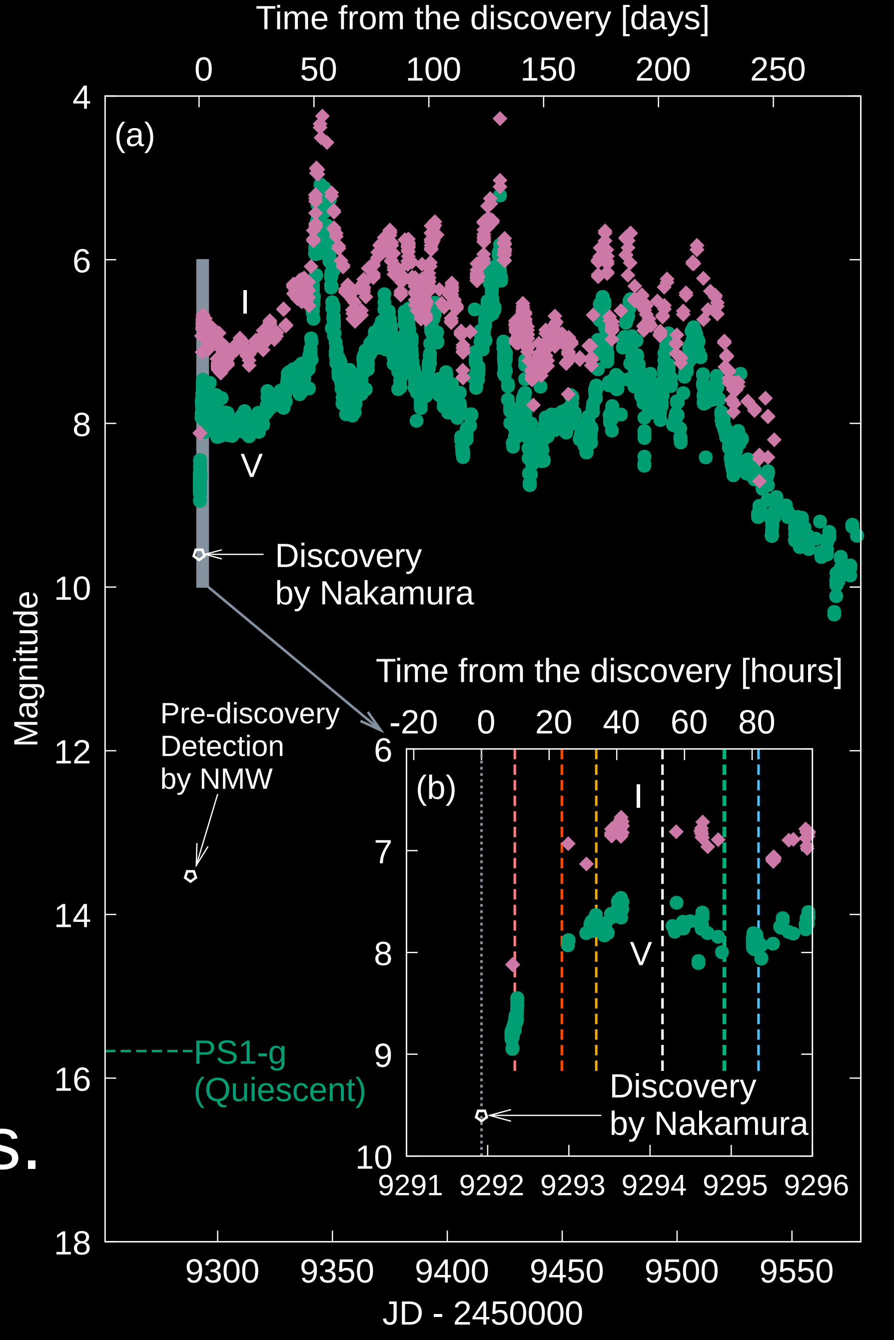


Small WD mass preferred by the light curve

- Very slow evolution.
  - Stayed V ≲ 8 mag for ~ 0.6 years.
- Bumpy light curves around peak.
- Similar light curves to
  - V723 Cas
  - HR Del
  - V1819 Cyg
  - V5558 Sgr

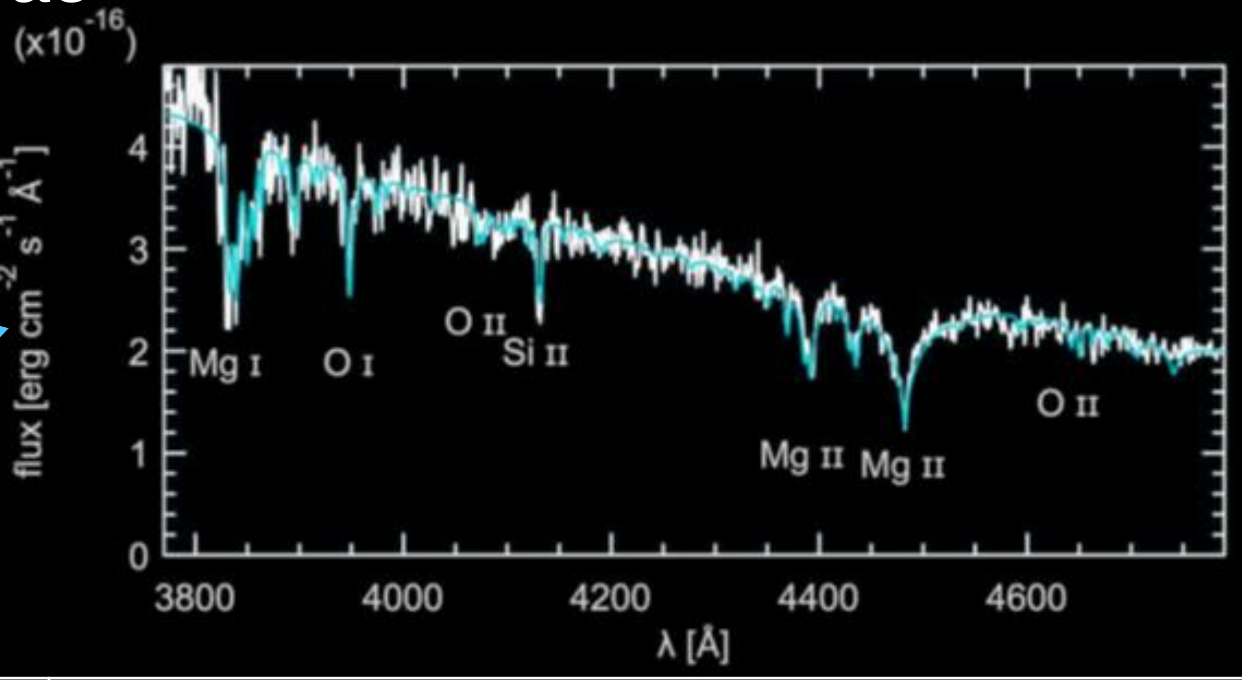
  etc.
- **Small-mass WDs can explain** such light curves.

  (e.g., ≲ 0.7 $M_{\odot}$ by Hachisu & Kato 2015)



Conclusion: V1405 Cas is 3rd Candidate of 'Low-mass ONe(Mg) WD'?!

- Very-slow (~ low-mass WD) neon novae
    1. V1405 Cas (this work)
    2. V723 Cas (Takeda et al. 2018)
3. SDSS J124043.01+671034.68 (Kepler et al. 2016)
    - Naked ONeMg WD?
    - $0.56 \pm 0.09\ M_{\odot}$ from line width?!



- How are they formed?

	CO WD	ONe(Mg) WD
$< 1.1\ M_{\odot}$	Single-star Evolution	**Embarrassing!**
$> 1.1\ M_{\odot}$	RS Oph, V3890 Sgr, ...	Single-star Evolution

Summary

- We confirmed temperature decrease
  - $\gtrsim$ 20000 K (+9.88 hours from discovery) → ~ 10000 K (1 day after discovery)
- We detected aluminum lines

  → $X(Al) / X(Al)_{\odot} \sim 40$

  → ONe(Mg) WD preferred (proven in nebular phase)
- Very-slow light curve

  → Very low-mass WD preferred.
- We summarized V1405 Cas has **low-mass ONe(Mg) WD**!

- To catch very-slow neon nova in early phase, Al overabundance is useful!
  - Neon forbidden lines in nebular phase require delay.