The Rise of Nova V1674 Herculis

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HTTPS://ARXIV.ORG/ABS/2410.16460

Presentation by
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Background

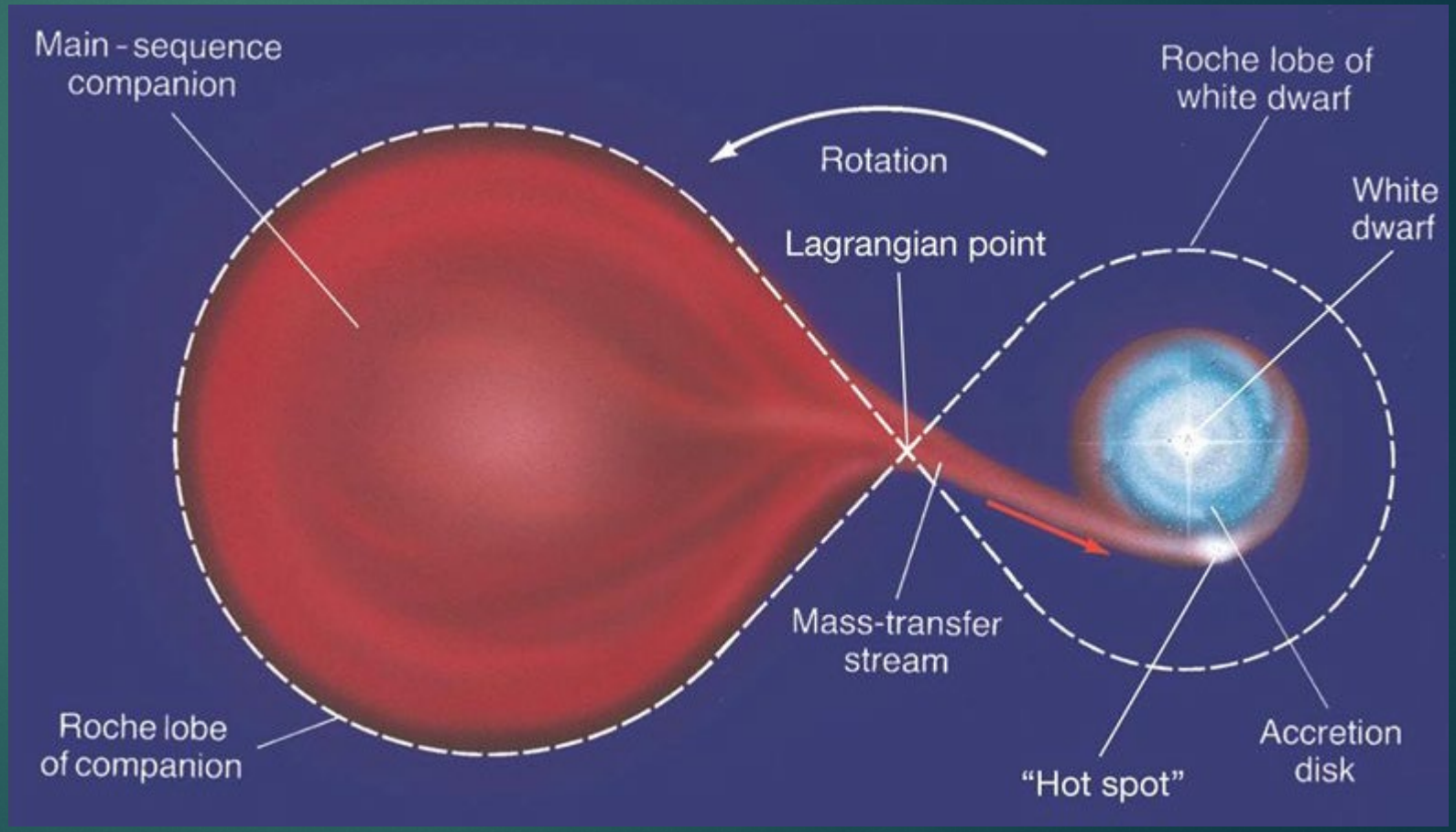
Nova Explosions

- Starts with a binary white dwarf and main sequence or aging giant star
- The white dwarf begins to capture the outer atmosphere of the donor star
- Hydrogen accumulates in the dwarf's atmosphere until it reaches ~20 million K
- Runaway fusion occurs, blowing away the remaining gas
- In some cases, this process repeats cyclically

- Because of their transient nature, most novae are not discovered until around their peak brightness

Anatomy of a Nova

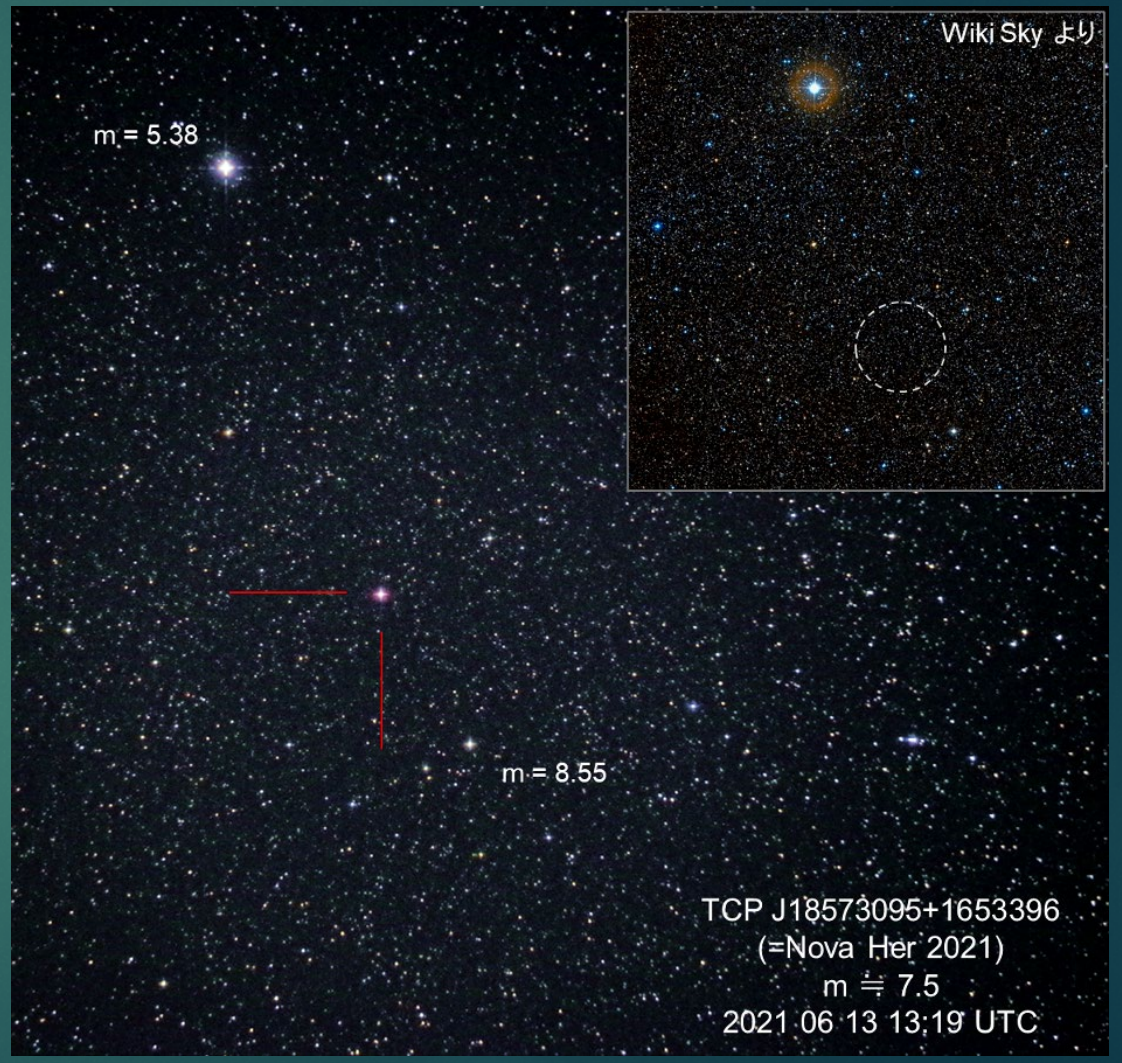
- Roche Lobe
  - Region within which material is gravitationally bound to the star
  - Both stars have a lobe
- Accretion disk
  - A disk of ~~stolen~~ donated stellar material
- Mass-transfer stream
  - The stream of material across the lobes



V1674 Her

Nova V1674 Herculis

- Often shortened to V1674 Her
- A nova in Hercules on June 12, 2021
- Among the top 5% of novae by brightness
  - Peak magnitude of ~ 6.2 in the V band
- Rapid rise in brightness
- Rapid declined in brightness
  - Dropped 2 magnitudes from peak in only 1 day
  - The fastest decline on record



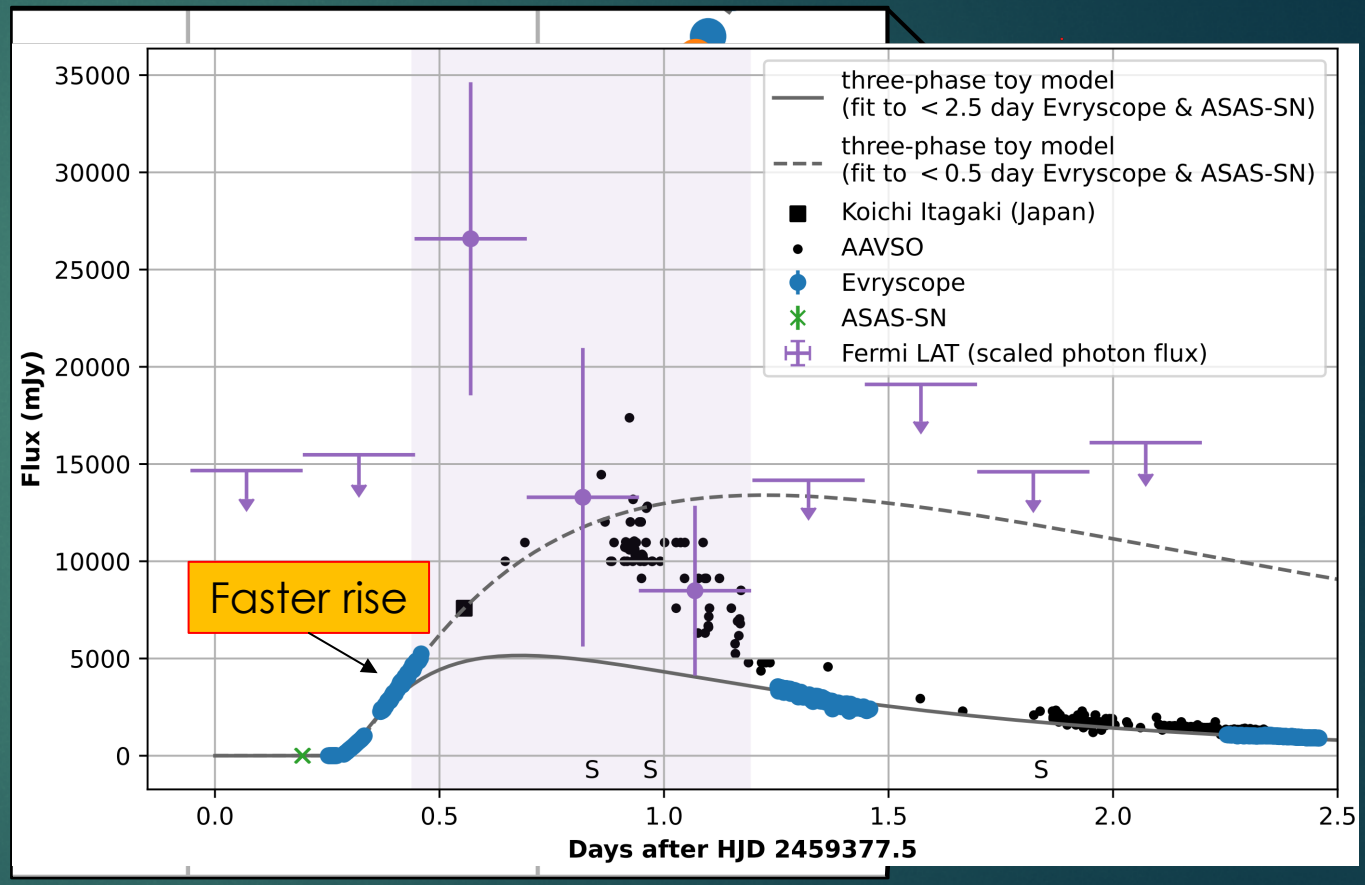
Nova V1674 Herculis

- Observed by 3 wide field, transient event oriented observatories
  - ZTF: Zwicky Transient Facility
    - Takes a full survey of the northern sky every three nights
  - ASAS-SN: All Sky Automated Survey for SuperNovae
    - Takes a full sky survey daily
  - Evryscope
    - Evryscope 20 wide-angle cameras with continuous coverage of 8,000 square degrees at a time
- These observatories provide brightness data prior to, during, and after the nova
- This event is a unique opportunity to observe rapid nova development and gain insights into white dwarf accretion in binary systems

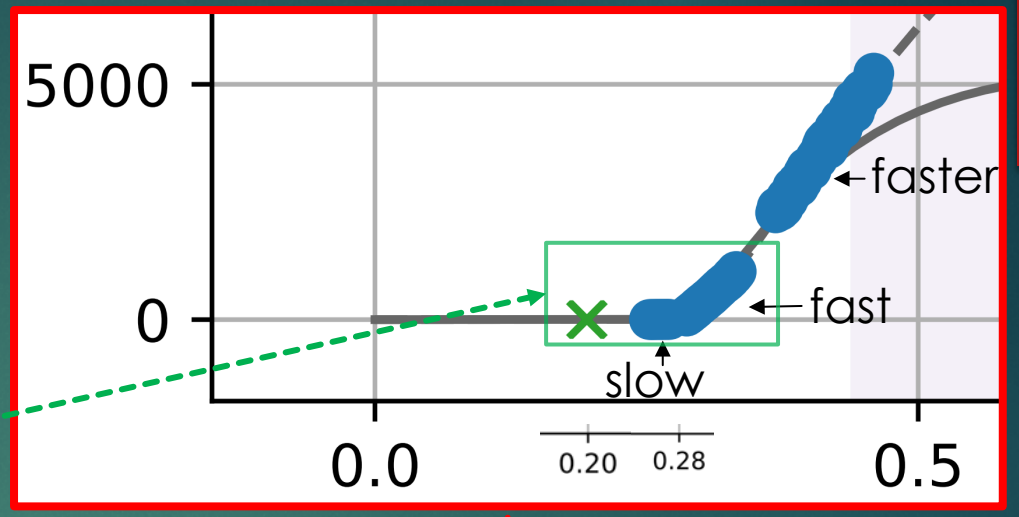
The Data

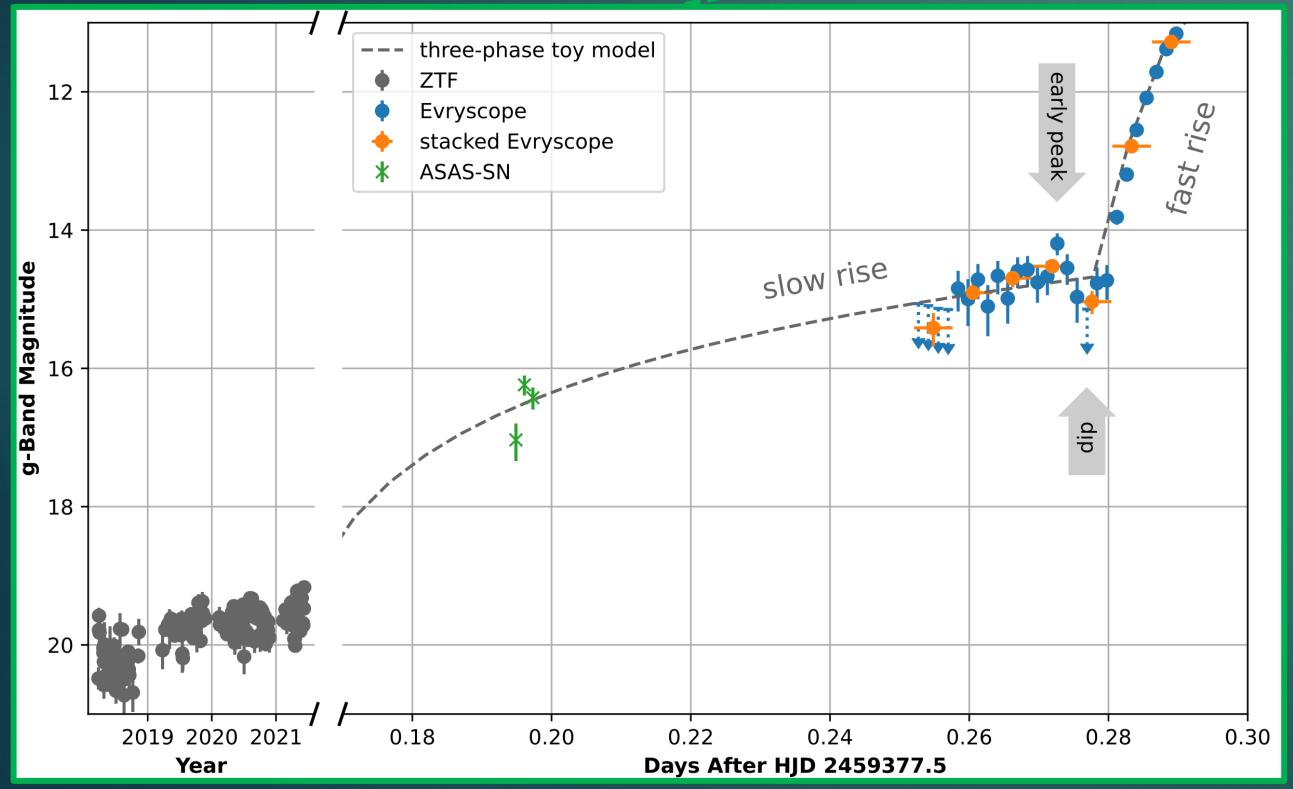
Light Curve Findings

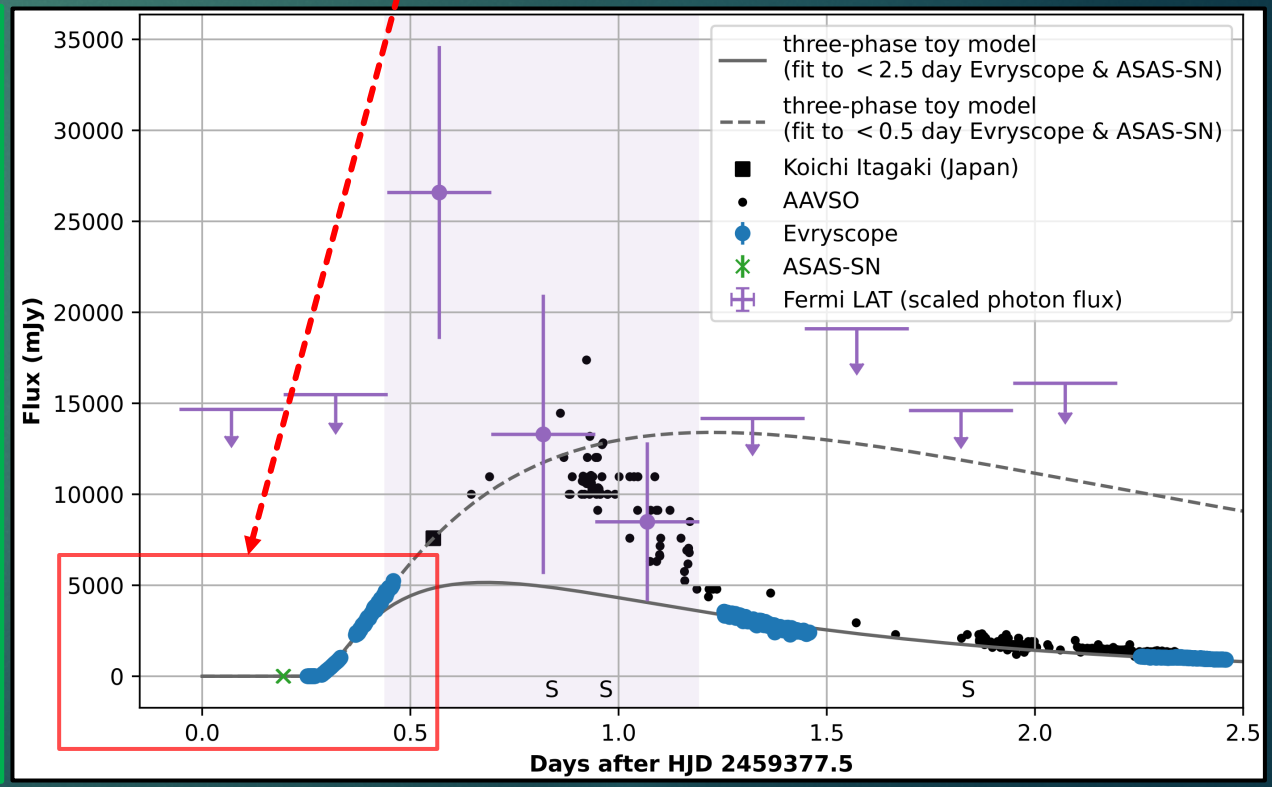
- The evolution of the brightness can be broken into 3 phases
  - Slow rise:
    - An initial brightening of ~5 mag over the measurements in the quiescent period
    - Note that early ASAS-SN data varies on a timescale of minutes
    - Dip
  - Fast rise:
    - A 1 hour period of roughly linear increase by ~11.5 mag
  - Faster rise:
    - A 3.5 hour linear increase, now at a higher rate than the fast rise



Plots Compared







Modeling

Models for Nova Brightness

- Classical
  - Thermonuclear heating
- Proposed:
  - Expansion at constant luminosity
  - Reprocessing by accretion disk and donor star
  - 3-phase model

Thermonuclear heating

- The classic model of a nova
- Material is accreted and heated in the white dwarf's photosphere
  - Luminosity increases
- The dwarf has roughly constant radius until the outward radiative force, F_r, is greater than the inward gravitational force, F_g
  - Maximum luminosity occurs (Eddington Limit)
- The authors calculated the expected luminosity at hydrostatic equilibrium based on mass, radius, and distance estimates for the star
- The result of mag $\gtrsim$ 20.6 is too faint to explain early observations from ASAS-SN and Evryscope
- **Other factors must be at play**

Expansion at constant luminosity

- Proposed toy model to explain the brightness
- Thermonuclear fusion progresses until the hydrostatic equilibrium is reached and then broken
- The white dwarf expands and the surface cools
- Overall luminosity decreases but the peak wavelength falls into the optical region

Expansion at constant luminosity

- Issues:
  - This model does not explain the distinct phases in V1674's development
  - The model predicts a fast rise but a slow decline
  - Still under-predicts brightness
- Utility in finding limits:
  - This model places an upper limit on the white dwarf and accretion disk radii at key moments in the development
  - The white dwarf was unlikely to fill its Roche lobe prior to the early peak and dip due to a predicted luminosity higher than the actual observed luminosity
  - It may have reached the outer radius of its accretion disk, ~1.9×10^{10}cm
    - The model predicts that reaching this radius may correspond to the initial explosion and start of the fast rise phase

Reprocessing by accretion disk and secondary

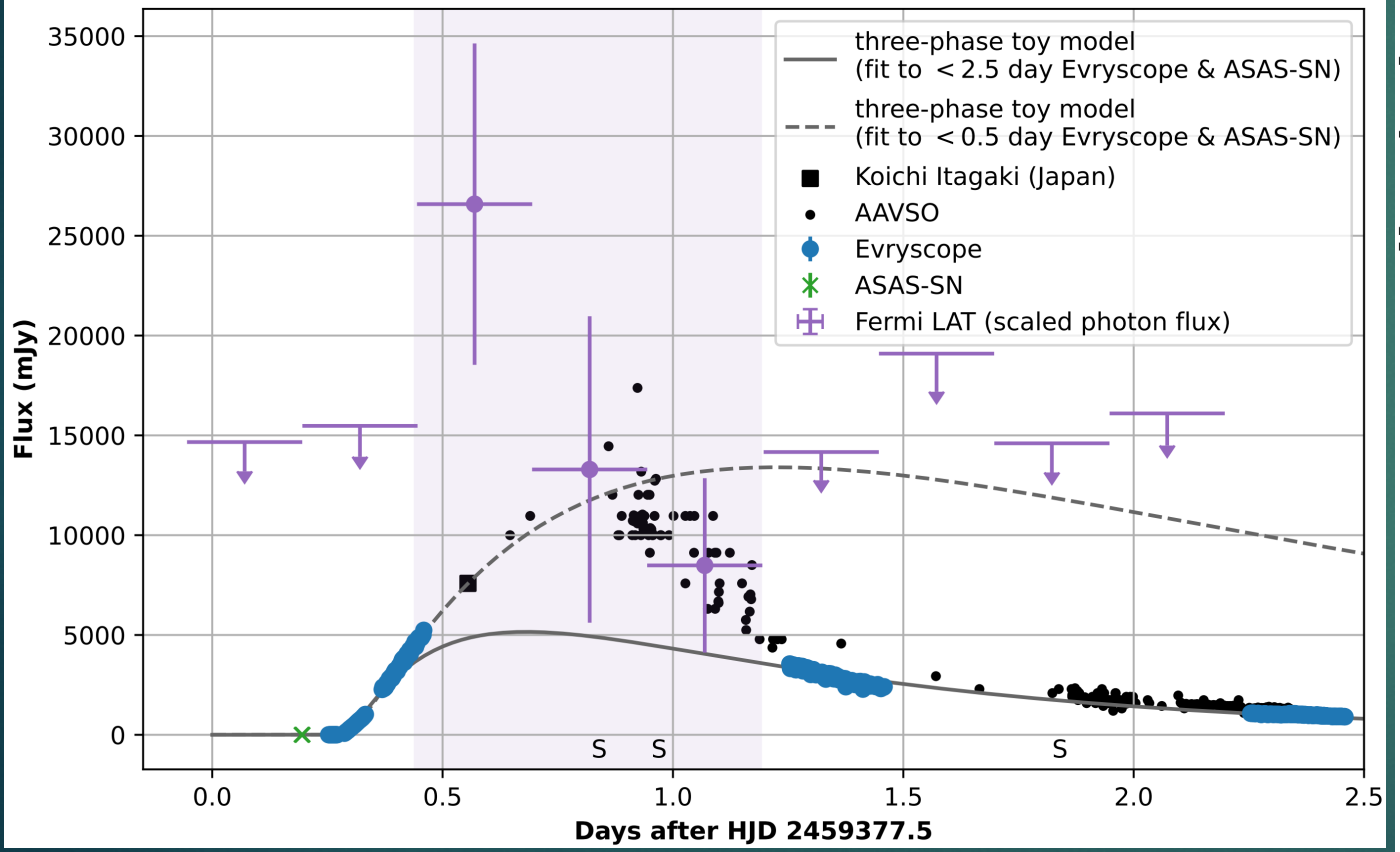
- Proposed toy model
- X-rays are emitted in the dwarf
- They are then absorbed and re-emitted at longer wavelengths in the accretion disk and irradiated side of the donor star
- The model predicts that this "reprocessed" luminosity will dominate the optical spectrum until the dwarf exceeds 1/5th of the way to the outer edge of the accretion disk
- If the dwarf engulfed the disk prior to overcoming reprocessed luminosity, it may explain the brief dip in brightness

3- phase model

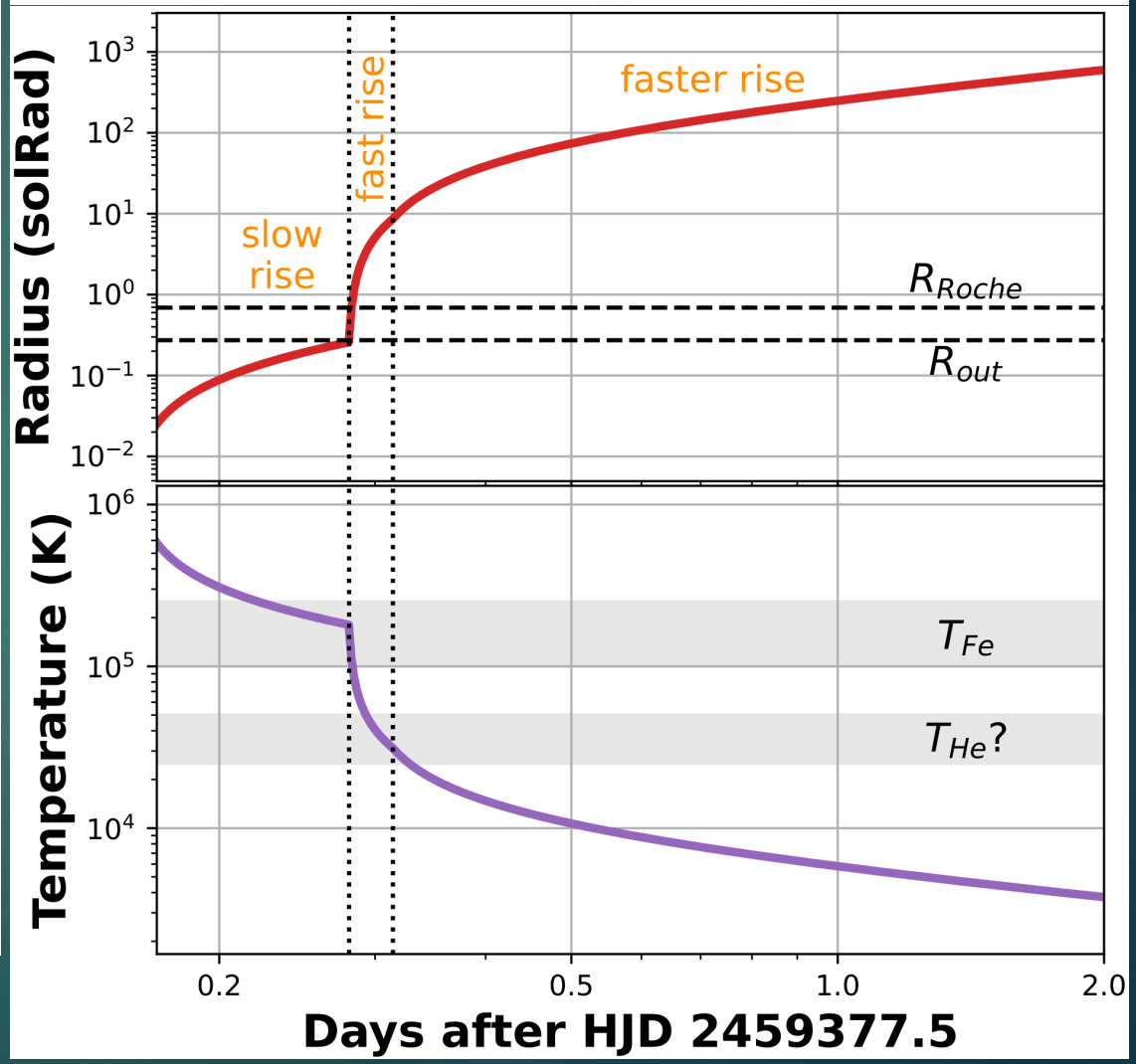
- The final toy model
- Assumes 3 distinct expansion rates of the white dwarf
- Fitted to the observed start time for each phase
- Predicts a temperature drop near the time of fast rise
- Predicts photospheric velocity of ~2,800km/s in the faster rise phase
  - The Swift observatory found ~3,000km/s blue shift in P-Cygni absorption troughs, indicators of gaseous envelope
- Over or underestimates post-peak brightness depending on the data used to fit
- Does not predict the dip

3- phase model

Three-phase toy model fits (grey curves) to the ASAS-SN and Evryscope measurements



Radius and temperature evolution of the best-fit three-phase toy model



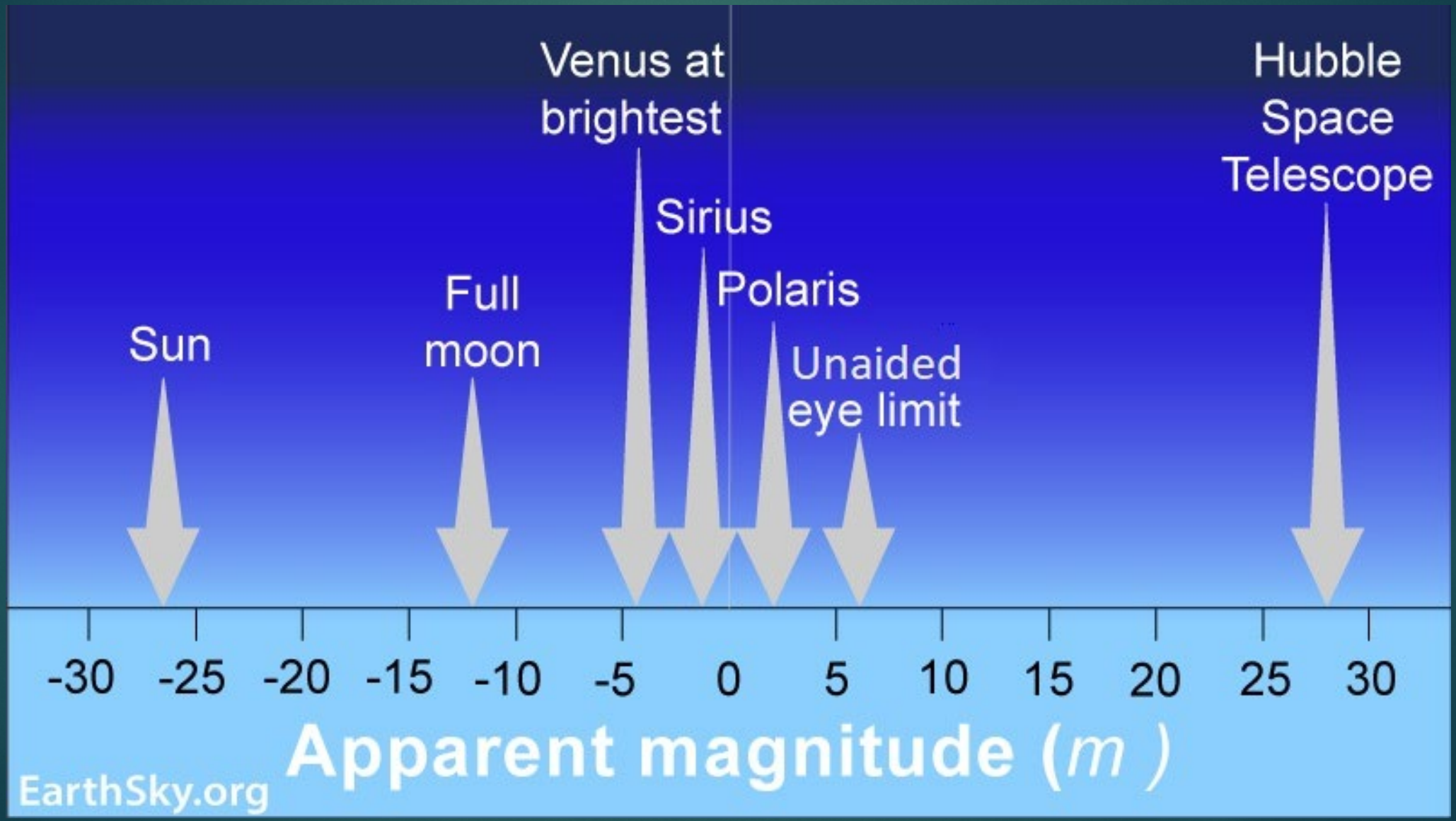
Conclusions

- A 3-phase toy model of V1674 matches or predicts some prominent features in the observed data
  - Temperature drop at the slow-fast transition point
  - Photosphere velocity
- Future modeling involving hydrodynamic simulations may help to understand the complex transitions between phases
- V1674 Herculis demonstrates the value of high-cadence, wide-field optical surveys to studies of novae in their earliest phases

Backup Slides

Transient event observatories

- ZTF: Zwicky Transient Facility, a wide-field sky astronomical survey. Full northern sky survey every three nights
- ASAS-SN: All Sky Automated Survey for SuperNovae, has 20 robotic telescopes in the northern and southern hemispheres with a full sky survey completed ~daily
- Evryscope: a pair of high cadence telescope in Hawaii and Chile
  - Evryscope North is a system of 20 wide-angle cameras delivering a total field covering 7409 square degrees with 13.1 arcsec pixels down to around 16th magnitude in the g-band every two minutes
  - The G-band is a molecular bandhead in the solar spectrum at around 430 nm, mainly consisting of electronic transitions between rotational and vibrational sublevels of the CH molecule.


Venus at brightest
Hubble Space Telescope
Sirius
Full moon
Polaris
Sun
Unaided eye limit
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
Apparent magnitude (m)
EarthSky.org

V598 Puppis

- Much longer time scale
  - V1674 peaked within a day of notable increase in brightness
  - V1674 dropped 2 magnitudes within a day of the peak