Spectra of Miras and Semi-Regulars over the pulsational cycle

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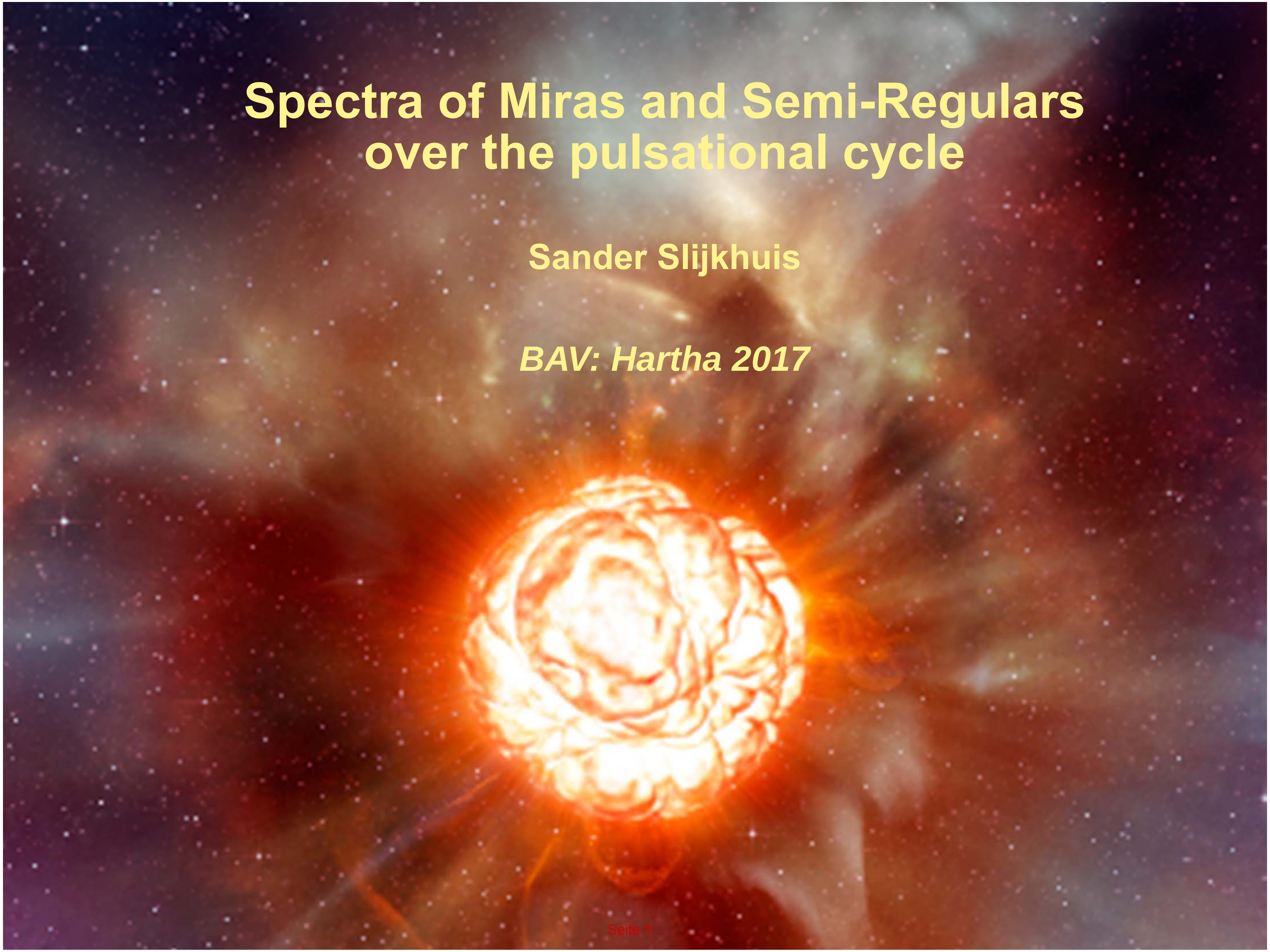
BAV: Hartha 2017

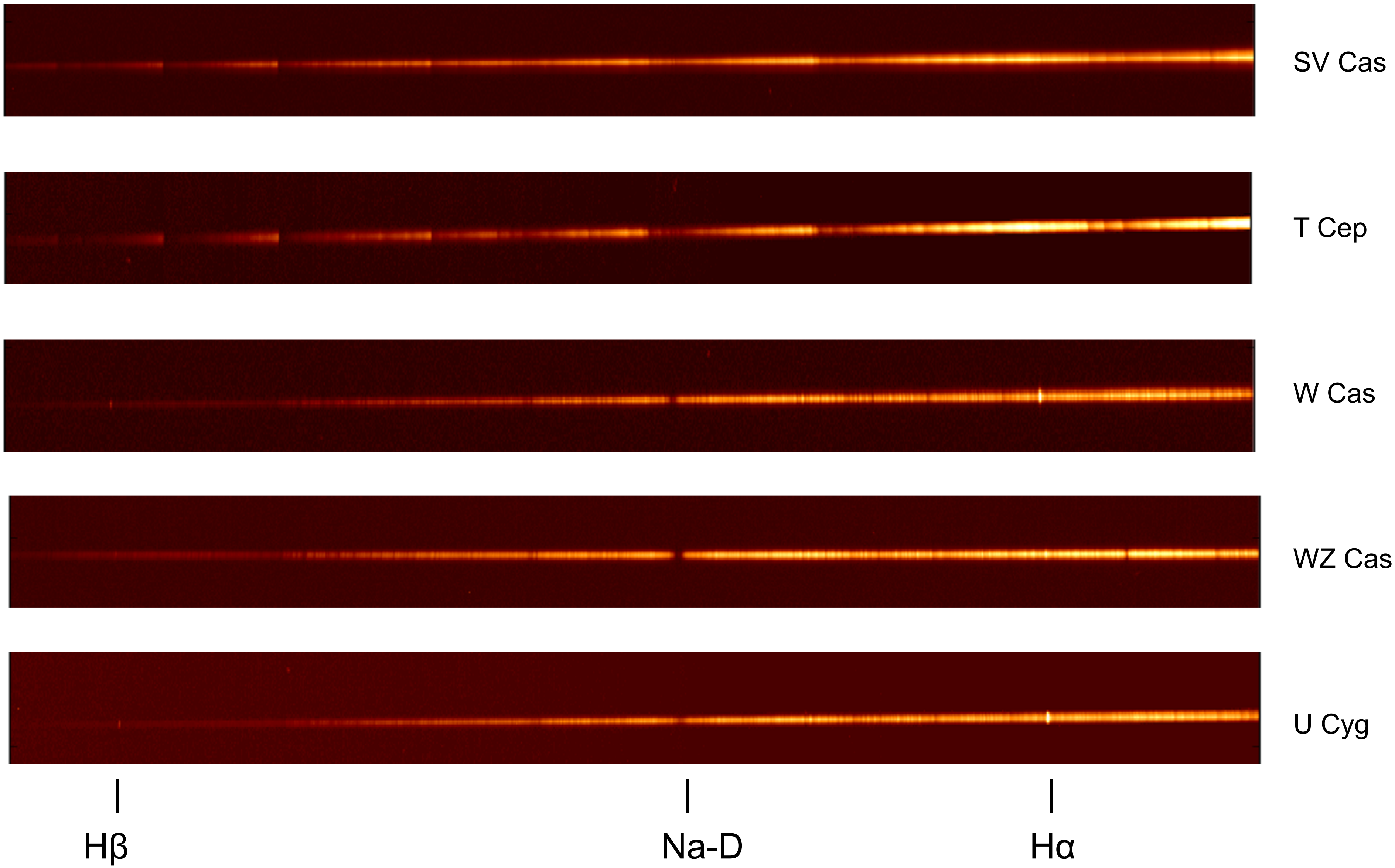


Overview

- This talk is about Long Period Variables (LPV) of variability type M, SRa, SRb
  - Spectral class M (for O-rich) or C [old designation N,R] (for C-rich)
  - Not variability class SRc (red supergiants) or SRd / RV Tau (yellow supergiants)
    although there are many similarities in the atmospheric physics

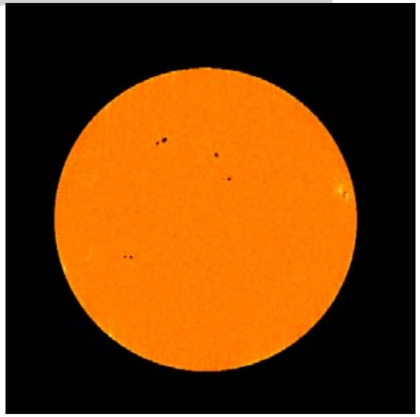
- Topics:
  - Some examples of my spectra
  - Model of the stellar atmosphere (for pulsating red giants)
  - Literature: observations of spectral changes during pulsation phase
  - Which observations are in reach of amateurs
  - Example: “Light Curve” of H*α* emission strength in C**.

Examples of spectra (near maximum)



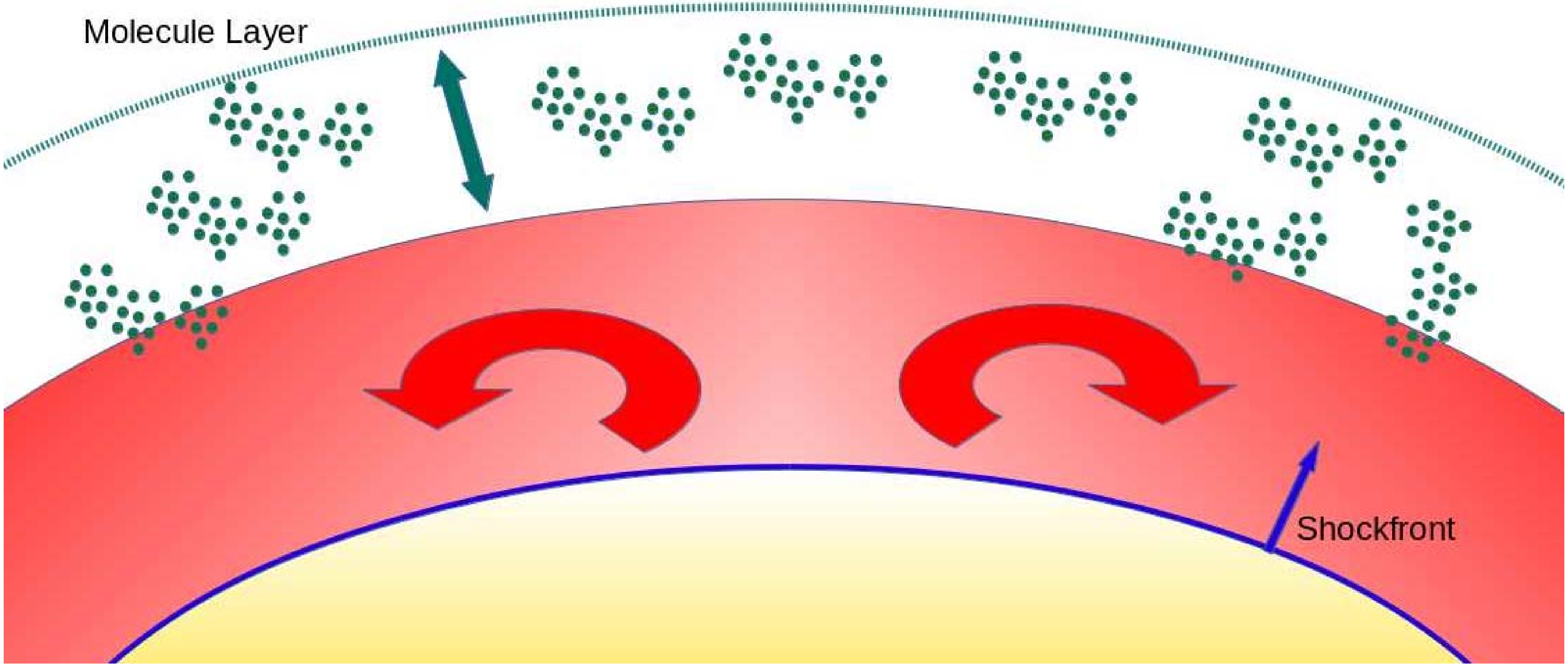
How do red giants look like ?

- Main-Sequence star (e.g. Sun):
  - high surface gravity
  - sharply defined photosphere



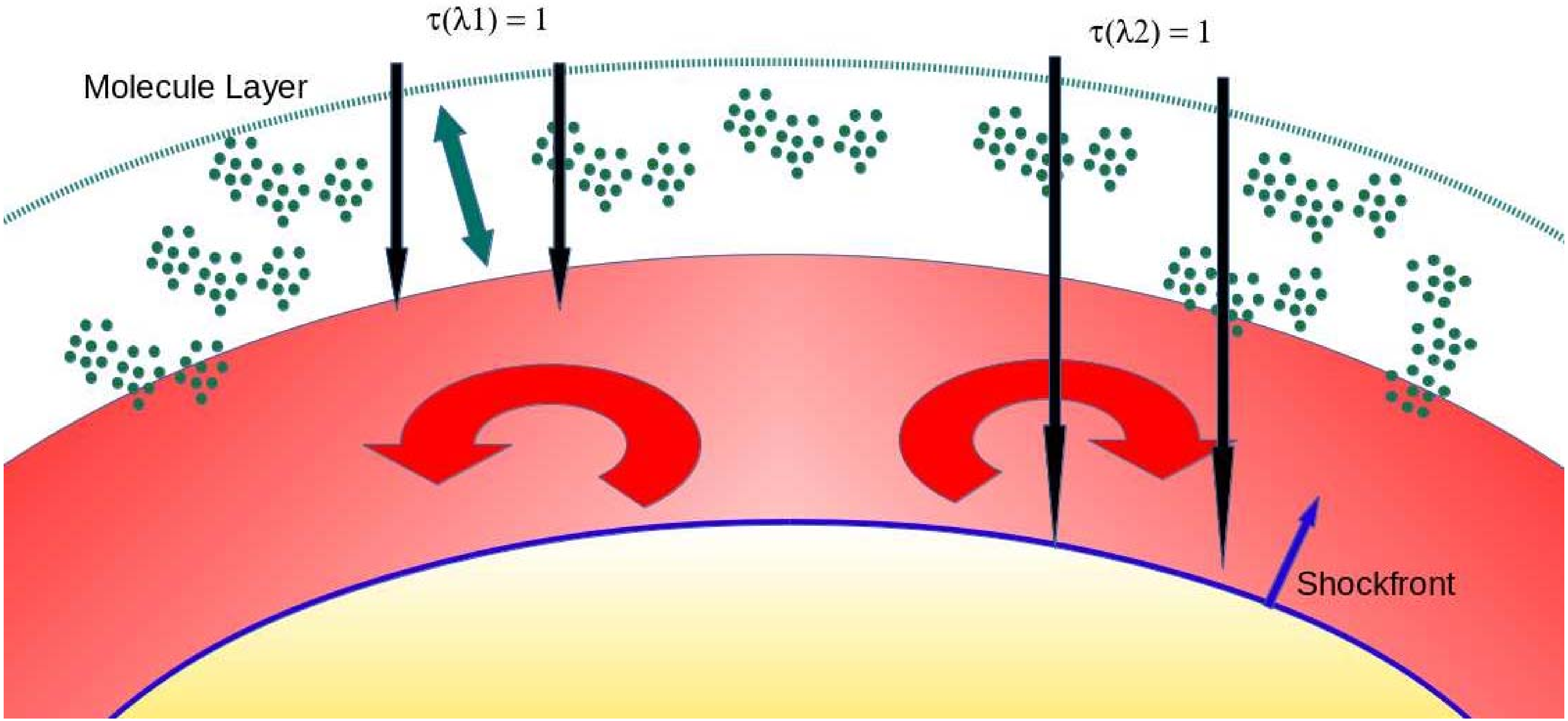
- Red Giant
  - very low surface gravity
  - extremely tenuous, loosely bound photosphere (like vacuum on earth)
  - dynamically unstable atmosphere
    - giant convection cells
    - pulsation-driven shock waves -> mass loss

Mira Atmosphere Model



- Outer convective layer (supercells); in upper atmosphere molecules may form (if temperature low enough); at part of the pulsation phase shock waves may be present; dynamics not well known

Mira Atmosphere Model



- How deep we can see into the atmosphere may depend strongly on wavelength (opacity). Very thin atmosphere => small change in opacity may imply large change in distance

Literature: spectral features in various phases (1)

- Disclaimer: significant variations from star to star
  for each star differences from cycle to cycle
  - Observational bias: large part of literature before ~1985 using photographic plates -> mostly for blue region / little Hα obs. / C-stars too faint in blue

- Spectral types become later from MAX to MIN
  - No strong correlation between V magnitude and Sp.type
  - Sp.type mainly determined by Temperature and opacity, not necessarily by pulsational contraction/expansion
    - note that 99% of radiation of LPVs is in Infrared
      -> visual LC not necessarily representative of pulsation process
    - for Miras, visual LC may precede Infrared LC by up to phase 0.2

- Emission lines emerge in ascend towards MAX and remain until some time before MIN
  - O-rich stars: Hγ and Hδ strongest, Hβ weak Hα weak or absent
  - C-rich stars: Hα and Hβ strong
  - Emission lines tend to be stronger in cycles with brighter maxima
  - Some atomic or even molecular em.lines (AlO) (shock or outflow??)

Literature: spectral features in various phases (2)

- Line velocities:
  - Significant velocity changes over the phase
  - Molecular and atomic lines may behave differently
  - Atomic lines from different elements / excitation potential may behave differently
    - tendency for lines with higher e.p. (formation temperature) to have more red-ward velocities
      (interpretation: warm post-shock material falls back while cooler pre-shock material is pushed outward)
    - note: location of line forming region depends on opacity
  - In the NIR many absorption lines are double (both infalling and outflowing material)
  - Near MAX Balmer emission lines may be double or triple
  - In the visible, velocities are systematically higher (more infalling or less outflowing) than in NIR
    - NIR has lower opacity and we can see deeper through molec.layers
  - In the NIR, maximum light corresponds to minimum velocity (outflow)
  - In Miras velocities may vary +/- 15 km/s, in SR much less

What can amateurs do ? (1)

- Main amateur problem: not enough photons!
  - UBV photometry: integrate spectrum over bandwidth of ~1000 Å
  - Spectroscopy: preferred resolution smaller than 1 Å
    - factor 1000 or 7.5 mag
    - can (and must) have longer exposure times, but also great light loss through grating and slit; moreover we want good S/N per pixel (~3 pixels per resolution element)
      => 7-8 mag brighter limiting magnitude is realistic

- Solution:
  - Observe brightest stars only
  - Reduce the spectral resolution
    - my spectrograph has ~4 Å resolution (R=1600 @Hα)
    - Limiting magnitude ~9
      for red stars (B-V > 1) near Hα around V = 10.5
      (and in blue mag 7-8)

What can amateurs do ? (2)

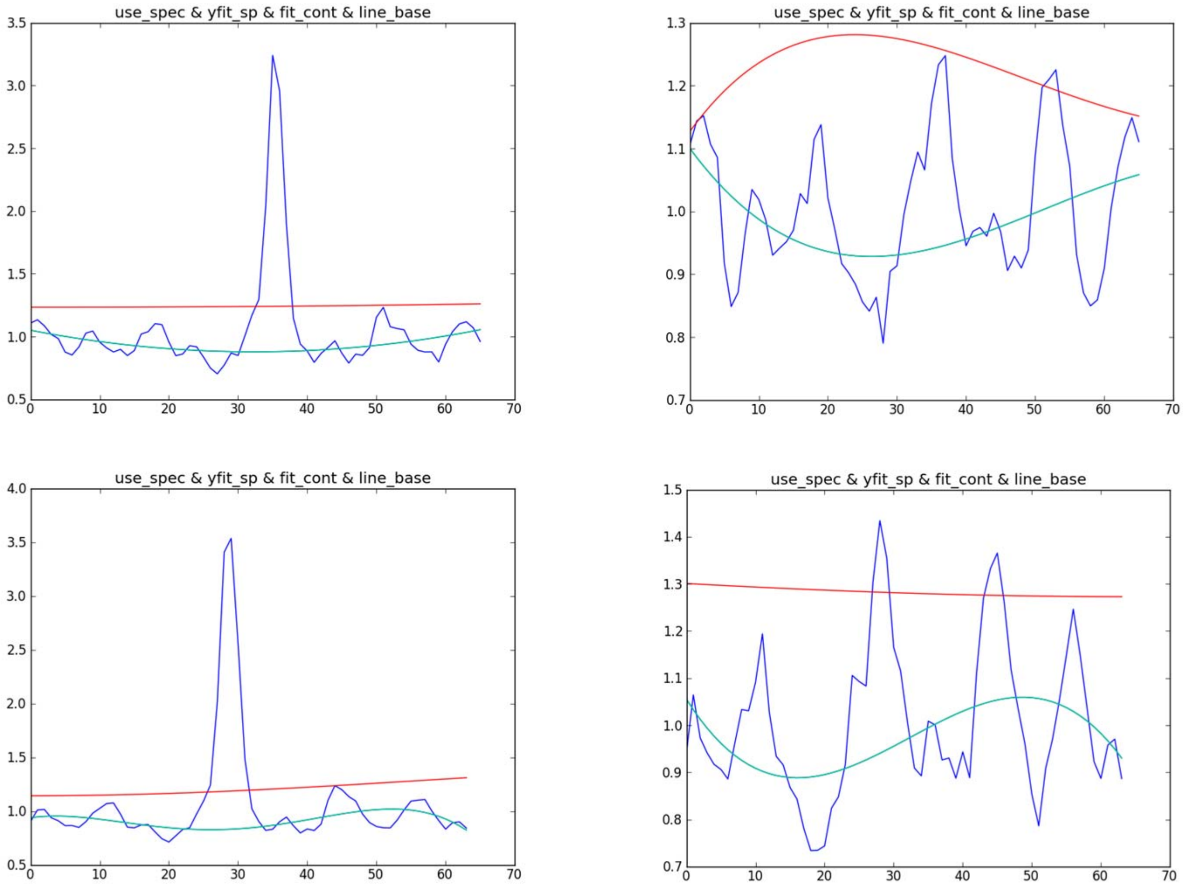
- Spectral class for various phases of the light curve
  - Measure of temperature and/or molecular absorption
  - Information partly independent from Light Curve (LC)
    - on the other hand accurate determination of spectral type not trivial -> scientific value?
    - for O-rich stars: Wing photometry (TiO strength) probably more accurate

- Velocity measurements:
  - Very interesting since details of dynamics in photosphere still poorly known
  - Only useful with high resolution (0.3 Å or better)
    - Can observe brightest stars only, and only near maximum light

What can amateurs do ? (3)

- Line strengths of emission (and absorption) lines over the LC
  - In the literature several qualitative descriptions of the strength of emission lines, but little quantitative information published
  - However, scientific interpretation may be difficult, as absorption by overlaying molecular layers may be significant [dominant?] in the optical region
  - Some processes, such as Aluminium-Oxide formation, have little known behaviour over several pulsation periods
- …

Hα line in LPVs near Max / Min



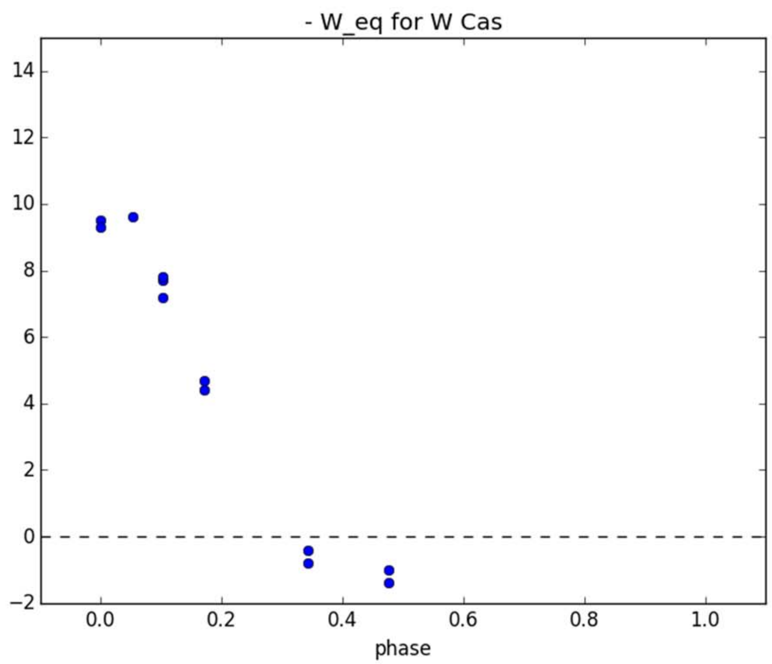
W Cas

U Cyg

Red: fitted pseudo-continuum level
Blue: fitted mean absorption in continuum

Hα line strength over phase

- Equivalent width: $W_{eq} = \int \frac{F_{cont} - F\_Line}{F\_cont} d\lambda$ (but where is the continuum…)
- W_eq is independent of instrument resolution
  (but the location of the pseudo-continuum is…)



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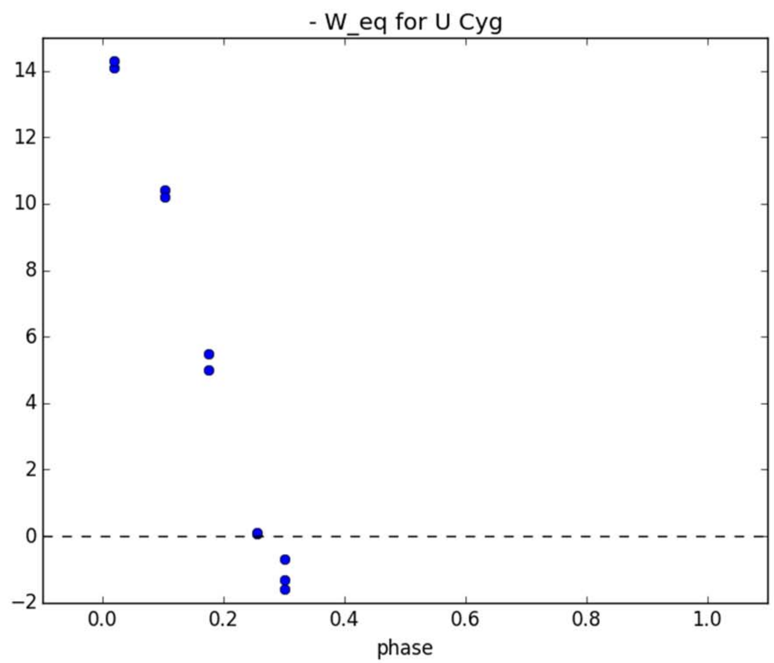

U Cyg

Conclusions

- LPVs show a manifold of spectral variations over phase and over cycle
- Coarse picture understood, but many details not well known
- Long-term spectroscopic data are still sparse (except for brightest stars like o Ceti, χ Cyg)
- Amateurs may be able to contribute:
  - Phase dependent line intensities for visually bright stars
  - Cycle-to-cycle variations near MAX for moderately bright stars
    - possibly velocities near MAX for brightest stars