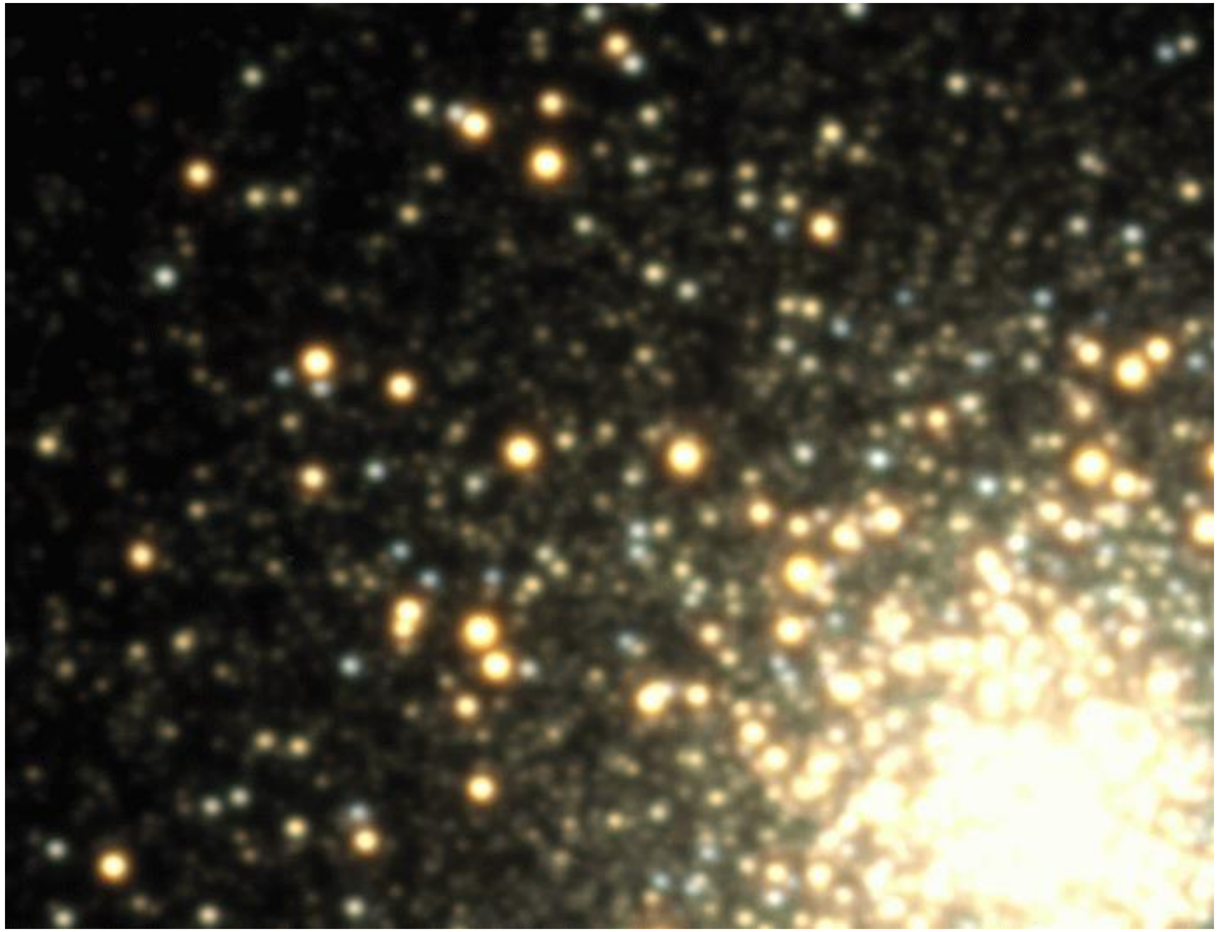
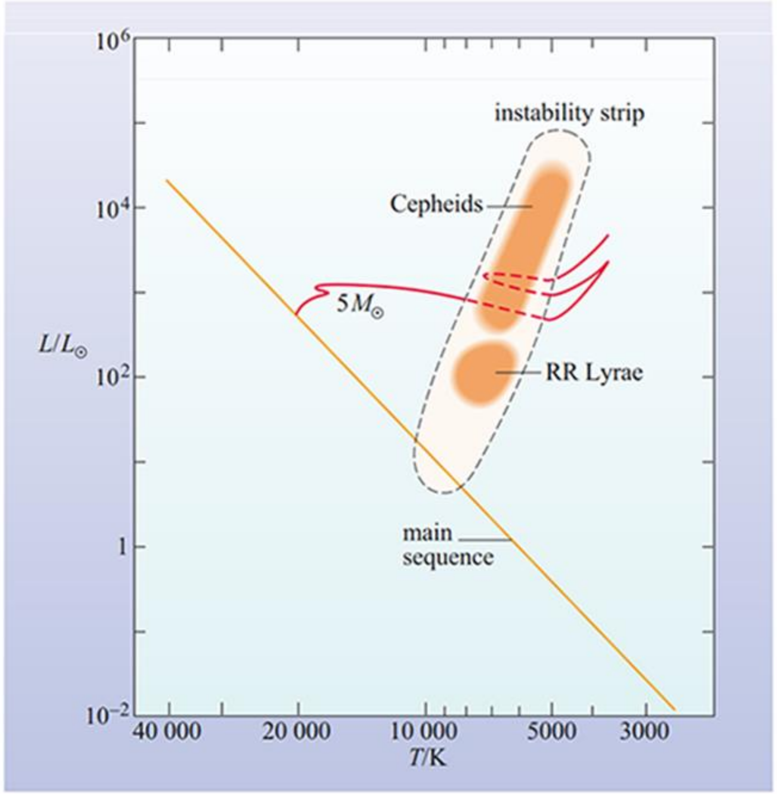
Distance Ladder:
Cepheids and RR Lyrae



By: Peter Wysocki

What are Cepheids and RR Lyrae?

- Post-MS, variable stars in the instability strip
- Periodic changes in brightness that are related to intrinsic brightness



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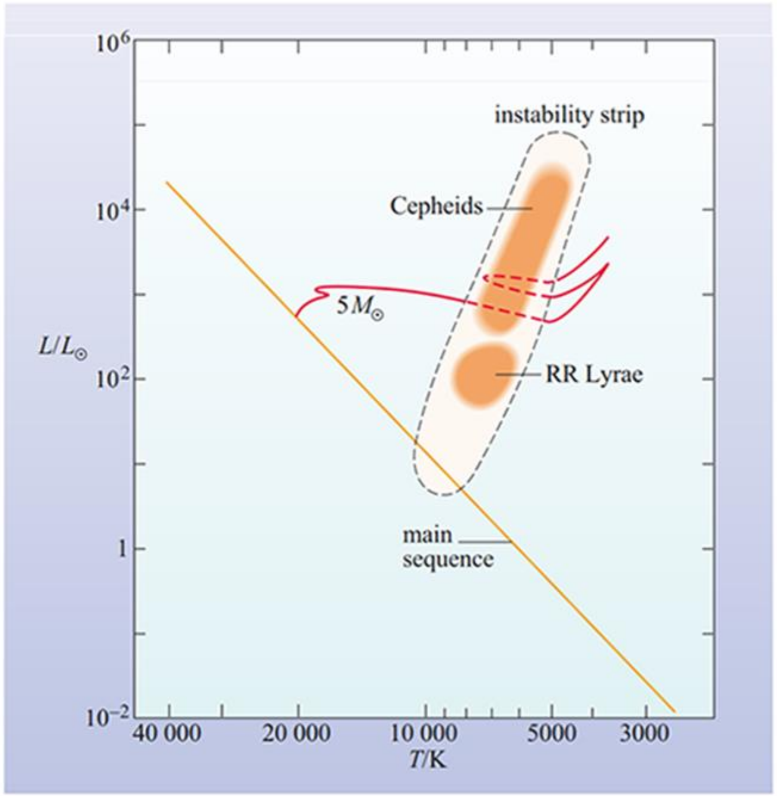
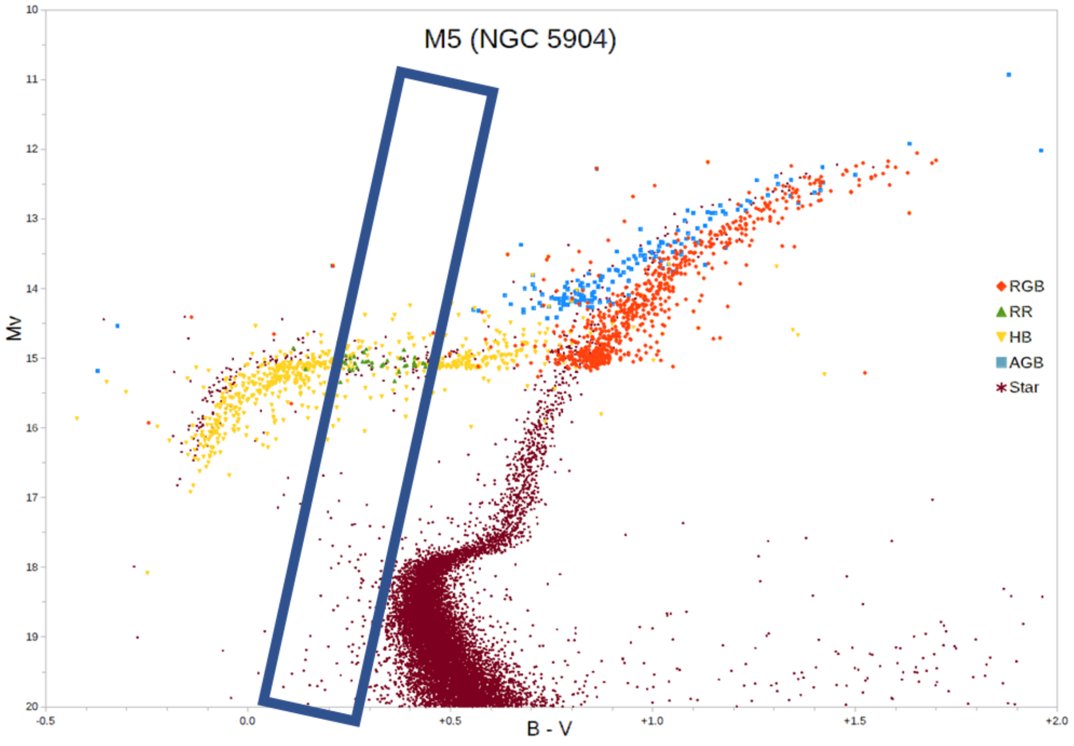
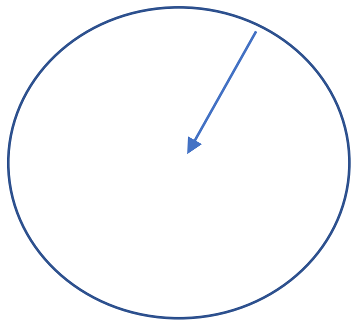




Instability Strip

- Variation caused by pulsation from the ionization of helium

- Photons go through gas
- Gravity condenses star



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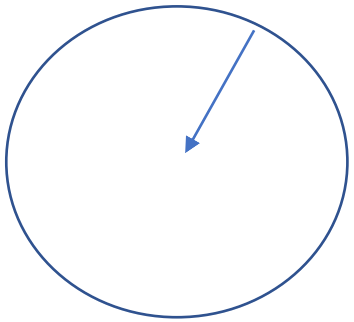
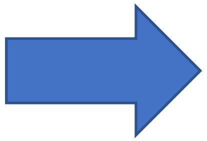
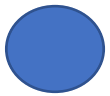


- Temperature increases
- He is ionized
- Gas becomes opaque





- Opacity blocks photon flow
- Pressure increases

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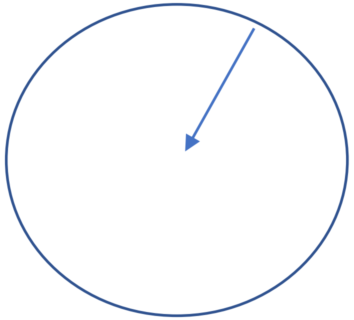

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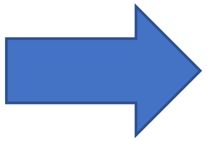

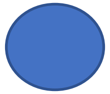

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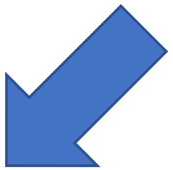

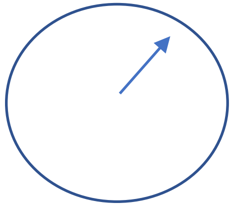

- Pressure expands star
- He cools and becomes less ionized

Instability Strip

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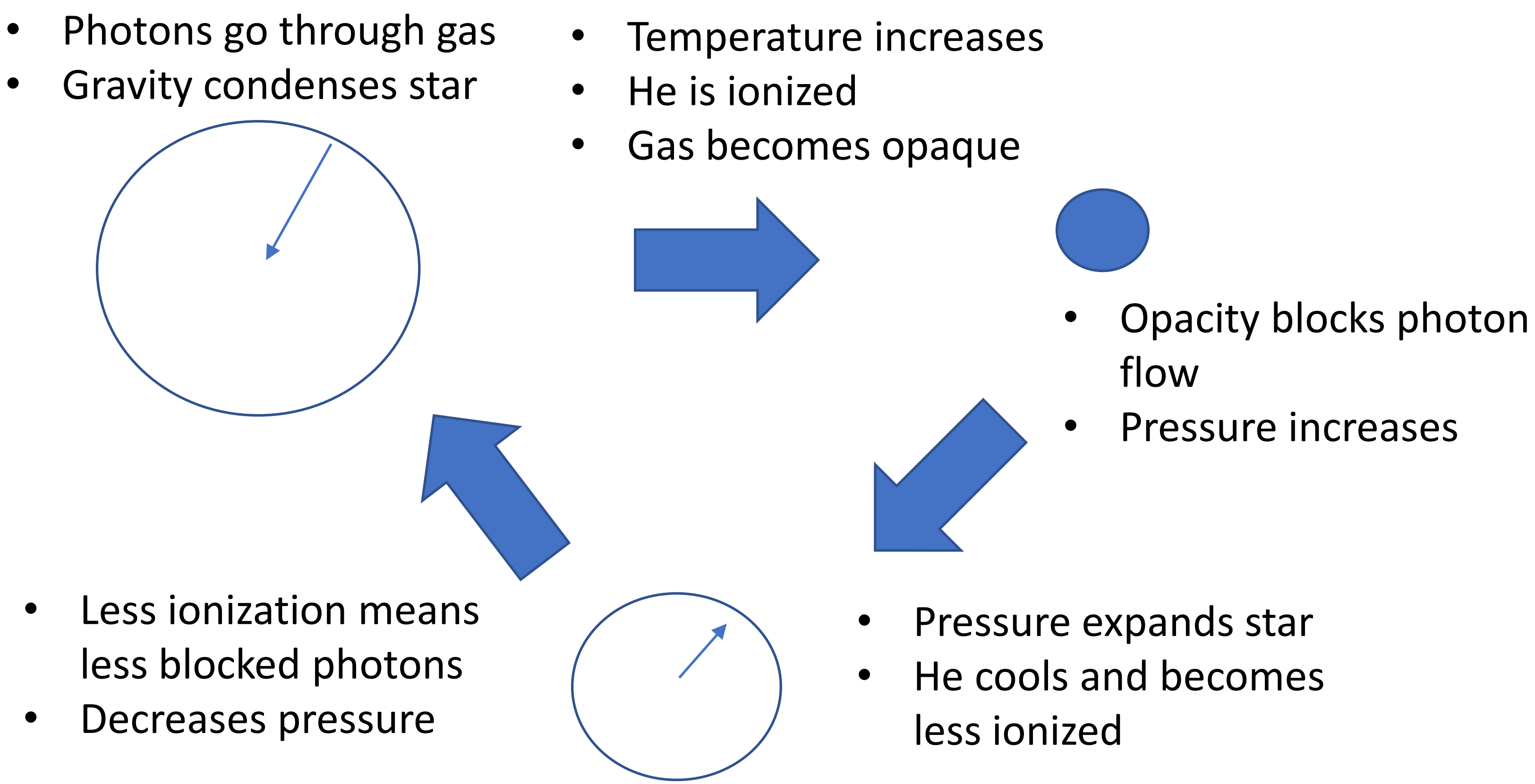

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- Photons go through gas
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- Pressure expands star
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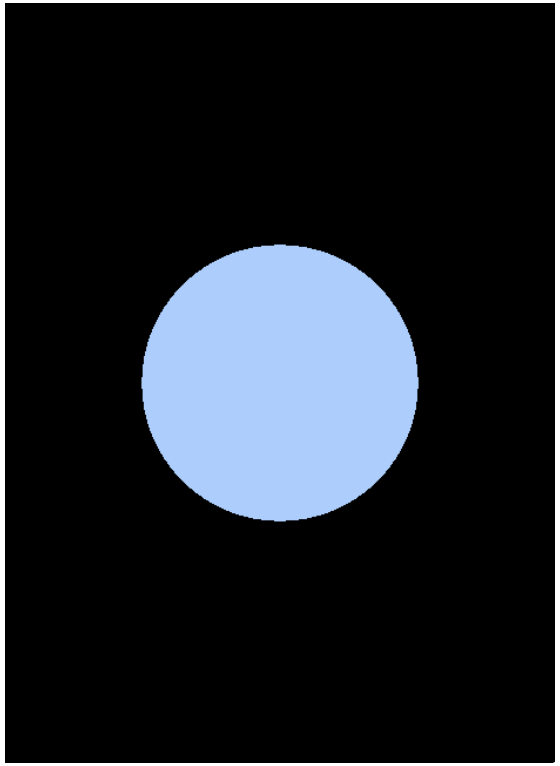
- Less ionization means less blocked photons
- Decreases pressure



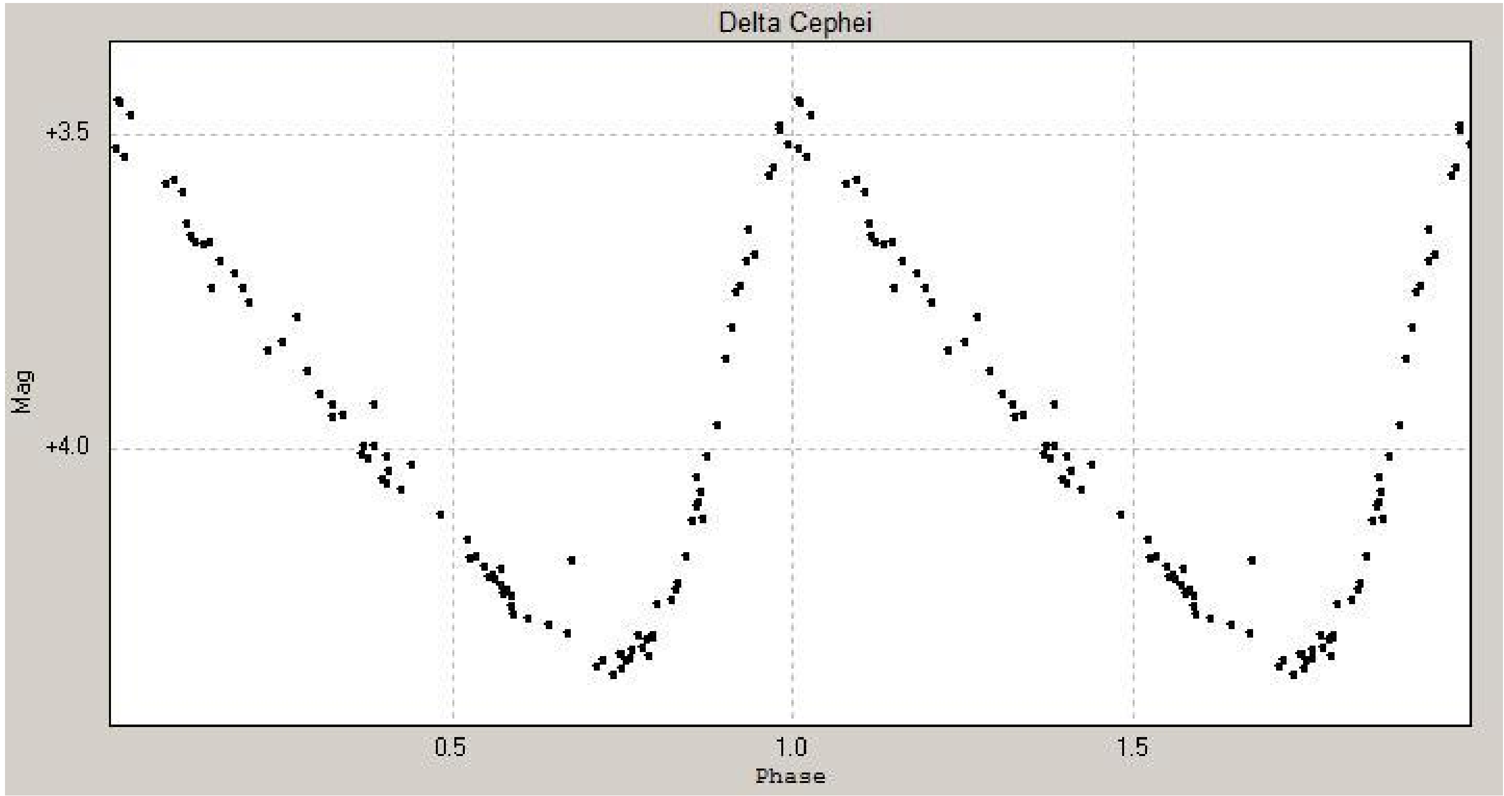
Cepheids

- Evolved Population I stars, lie in galactic plane
- Two Main Types of Cepheids:
  - Classical Cepheids (Can be subdivided into fundamental and first overtone modes)
  - Type II Cepheids (Can be subdivided based on period)

- There is also a third type: Anomalous Cepheids
  - These are thought to be blue stragglers created through mass transfer

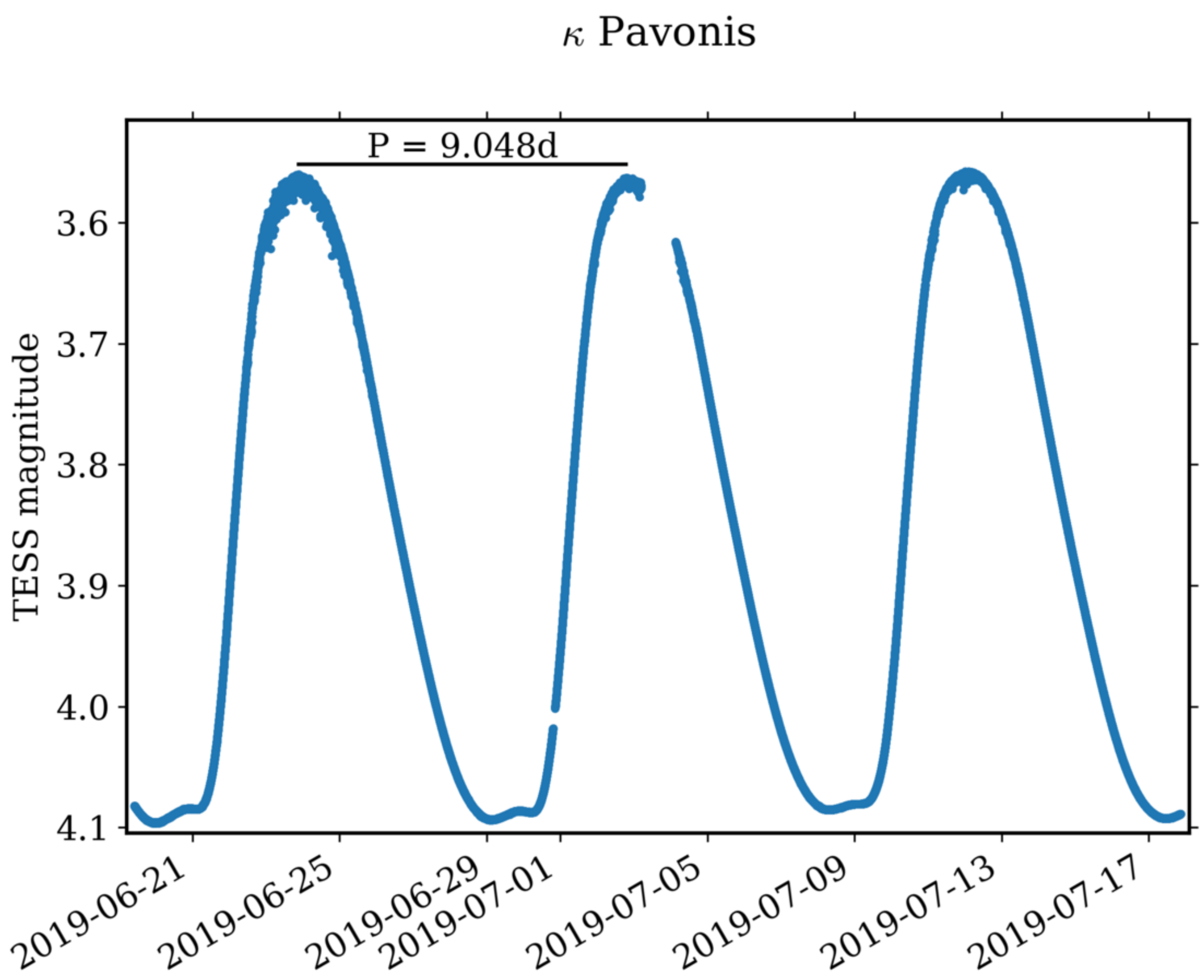
Classical Cepheids

- Initial mass: ~3-15 M⊙
- Luminosity: ~1000 to ~40,000 L⊙
- Period: ~1-few hundred days
- Have a sharp, sawtooth light profile



Type II Cepheids

- Older, lower mass, lower metallicity cepheids
- Three Types:
  - BL Her (Period: 1-4 days)
  - W Virginis (4-20 days)
  - RV Tauri (>20 days)
- ~1.5 mag dimmer than Classical Cepheids
- Rounded light curves

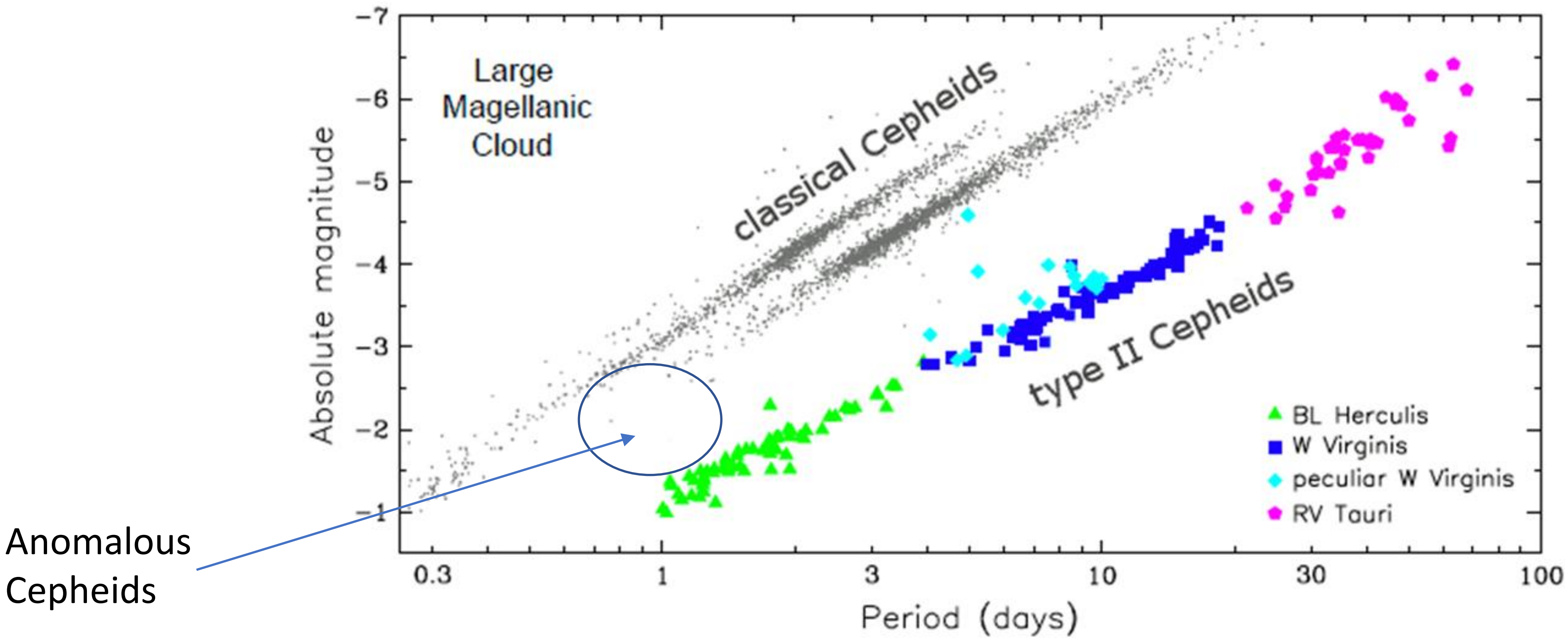


Period-Luminosity Relation (Leavitt’s Law)

- Discovered by Henrietta Leavitt
- Different for Type II and Classical Cepheids
- Has the form:
  $M = \alpha\log(P) + \beta$
- Example:
  Mean Galactic Cepheid Calibration by
  Saha et al. (2015) -> $M_v = -2.81\log(P) - 1.35$
- $m - M = 5\log(d) - 5$

Period-Luminosity Relation (Leavitt's Law)

- Lower mass = less luminous = smaller radius = shorter period
- Brighter cepheids have longer periods



Other Relations

- Intrinsic scatter due to width of instability strip and extrinsic scatter due to reddening
- Period-Luminosity-Color Relation
  - $M_V = a \log P + b(B - V)_0 + c$
  - $(B - V)_0 = (B - V) - E_{B-V}$

Other Relations

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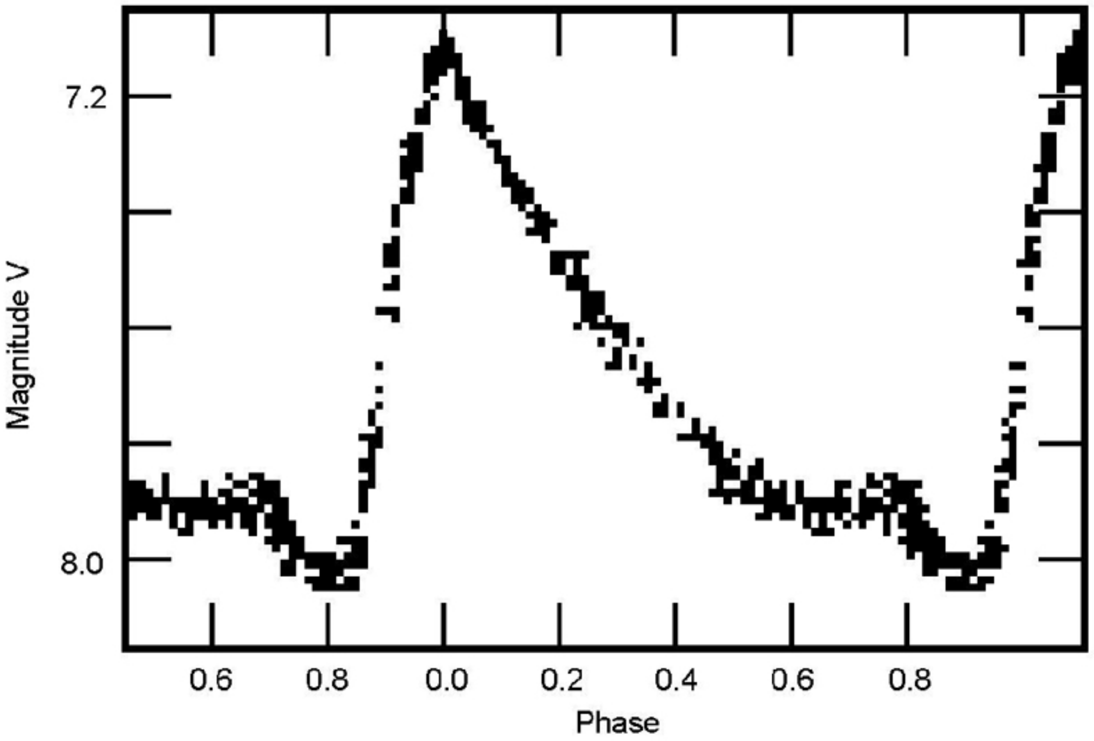
- Wesenheit Function
  - Extinction-free by definition
  - $W = I - 1.55(V - I)$ -> Less affected by strip width and metallicity
  - $W = -3.313\log(P) + 15.892$
    - From Ngeow et al. (2009), calibrated from Galactic Cepheids

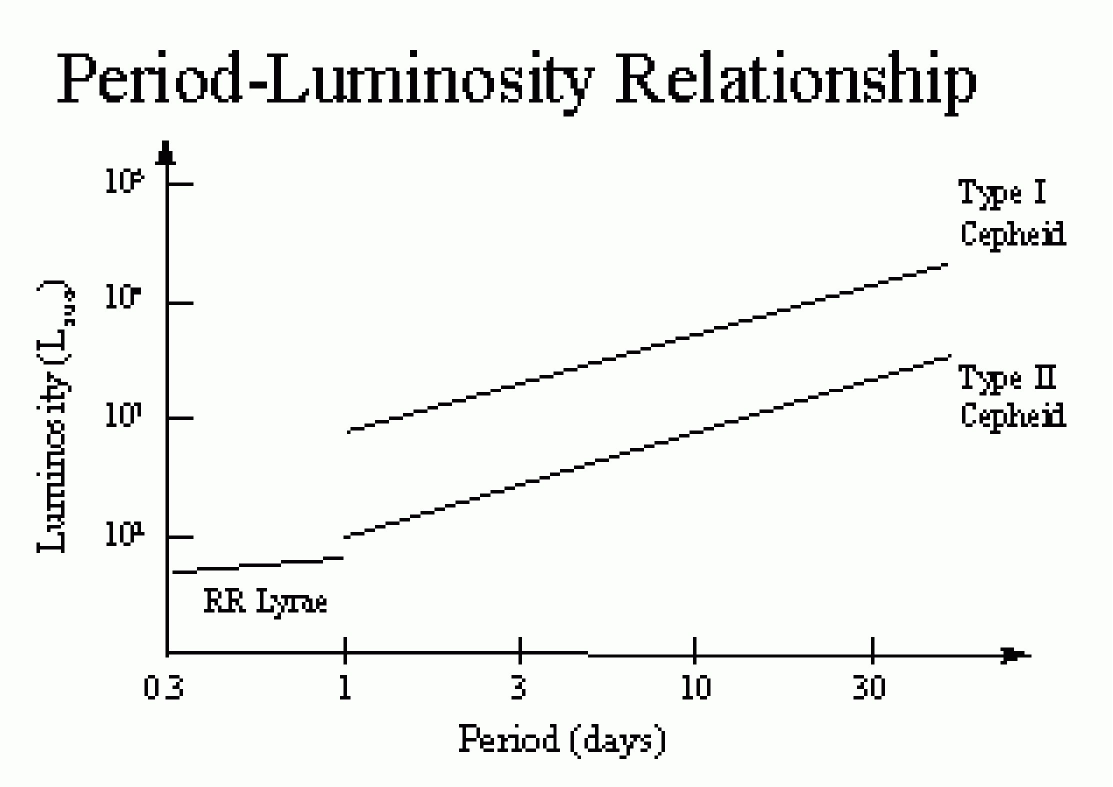
RR Lyrae

- Population II stars, prefer globular clusters
- Old (>10Gyr), metal poor, red giants on the Horizontal Branch
- Initial mass (MS): ~0.8-0.9 M⊙
- Luminosity: ~50 L⊙
- Like cepheids, but smaller and have periods less than a day
- 2 main types based on light curve:
  - RRab (91%) – steep rise in brightness
  - RRc (9%) – short period, rounded
  - RRd (<1%) – double mode oscillators



Period-Luminosity Relationship?

- Relation between period and magnitude in visible bands seems relatively flat
- Can use approximate average absolute mag of Mv = ~0.5
- Better to use infrared bands (K-band)



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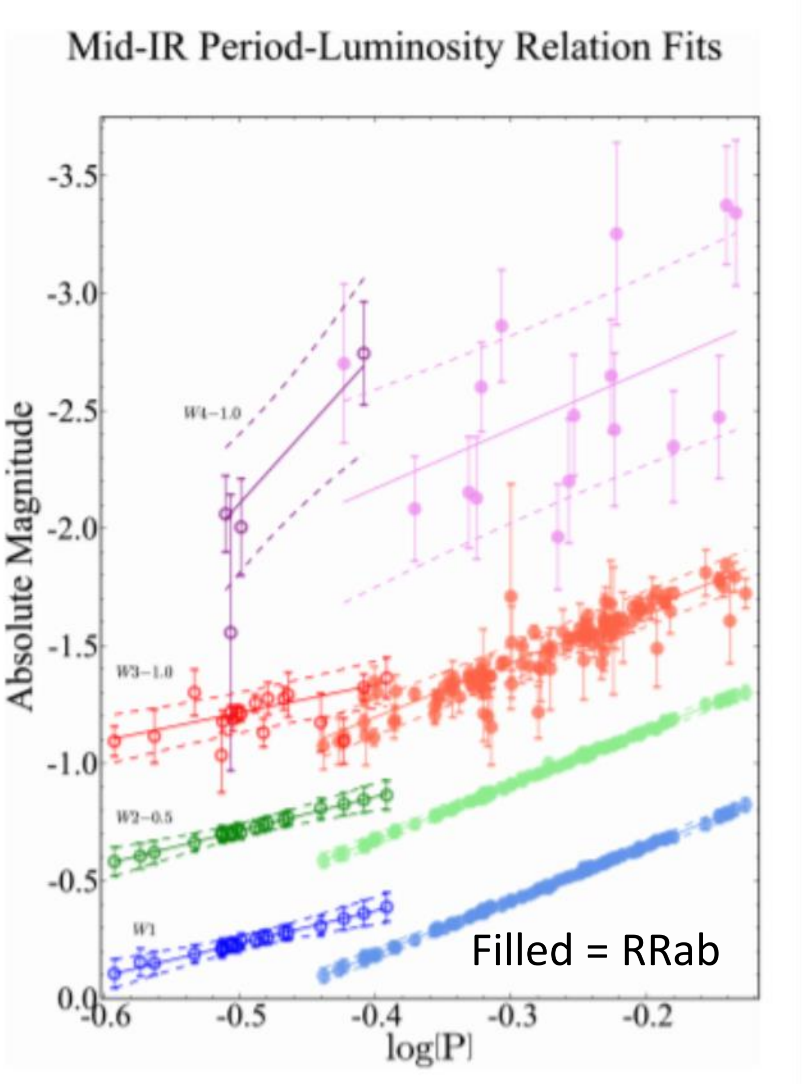

Magnitude-Metallicity Relationship

- Magnitude in V-band is related to metallicity
- M-M relation follows this form:
  $M_V = \alpha[Fe/H] + \beta$

- Example:
  Approximation of literature calibrations by Sandage (2006)
  $M_V = 0.2[Fe/H] + 0.82$

- But evidence for nonlinearity:
- $M_V = \alpha[Fe/H] + \beta + \gamma([Fe/H])^2$

ΔS Method

- How do we find metallicity for faint stars?
- ΔS method created to use low-resolution spectroscopy
- $\Delta S = 10[Sp(H) - Sp(K)]$
  - Sp(H) = a spectral type based just upon the appearance of the Balmer lines
  - Sp(K) = a spectral type based just upon the appearance of the Ca II K line
  - Spectral types are in tenths of a spectral class
  - Spectrogram is obtained at minimum light
- Ex: If Sp(H) = F5, Sp(K) = A4, ΔS = 11
- The lower a star's ΔS value, the higher its metallicity
- RR Lyrae: ΔS = 0-11
- Get metallicity through calibration from RR Lyrae we can get high resolution spectroscopy for
- Example: $[Fe/H] = (-0.16)\Delta S - 0.23$
  (Butler, 1975)

Problems/ Sources of Error

- Need starforming regions
- Need to know type!
  - Historically, it was thought there was only one type of cepheid until the 1950s
- Each bandpass requires own calibration
- Need to avoid blending of sources
- Calibration of cepheids has often been done using LMC cepheids
  - However, it was recently found that LMC cepheids seem to have a different slope than Galactic cepheids
  - Issues include:
    - Metallicity Effects
    - Differential extinction values across LMC

Range of Relevant Distances

- Classical Cepheids have been used to get distances to about 33 Mpc (NGC 4603 – Newman et al., 1999)
- RR Lyrae have been used to get distances to about 859 kpc (Triangulum Galaxy, NGC 598 - Sarajedini et al., 2006)

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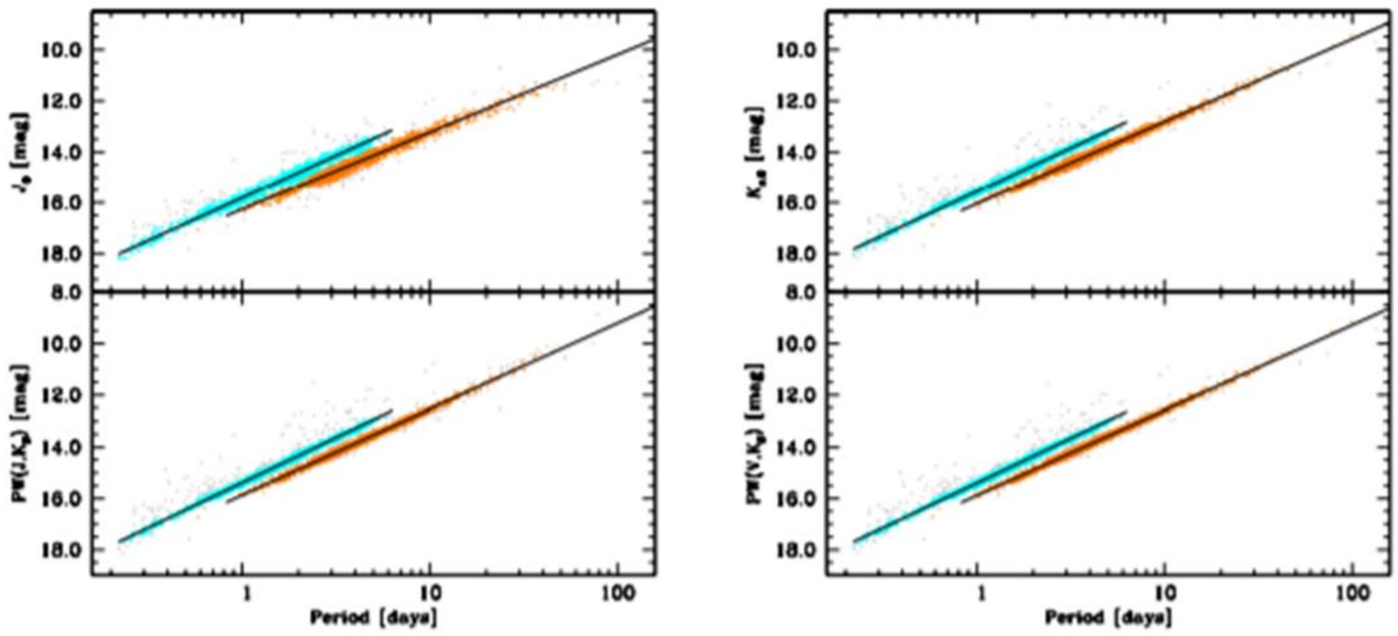
Recent Paper

- Cepheid Distances based on Gaia and VMC@VISTA Observations (Ripepi, et al., 2020)
- NIR observations by VISTA of LMC Classical Cepheids give apparent Period-Luminosity and Period-Wesenheit Relations



Recent Paper

- Calibrated by about 2600 Classical Cepheids found through Gaia and other sources
- Compared slope and zero-point of LMC and Galactic Cepheid PL/PW relations, found differences from metallicity
- Using LMC slopes for Galactic Cepheids and adjusting the zero-point accordingly gives a distance modulus of about 18.69 for LMC, which is about 0.2 mag off.
  - Fundamental Mode: $W(J,K) = -3.332(\log(P)-1) + -6.155$
- Came to conclusion that the zero-point of Gaia is offset by about 0.02 mas – agrees with results from others

Blazhko Effect

- RR Lyrae can host the Blazhko Effect, which is a periodic change in light curve amplitude and shape in a predictable way.
- Competing theories for why included magnetic effects or resonances
- Evidence strongly points to fundamental and high order radial overtone 9:2 resonance now (Szabó et al., 2010)
- Amplitude modulation reduced in IR