Theoretical Limb Darkening for Pulsating Classical Cepheids

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Cepheids: good distance indicators

**P-L relation** (Leavit, 1906)

HST key project (Freedman et al., 2001)

**BUT**

the P-L relation needs to be calibrated using nearby Cepheids of known distance

**Geometric! Baade-Wesselink method**
(see Sasselov & Karovska, 1994)

\[ D = \frac{R_m + \Delta R}{\alpha + \Delta \alpha} \]

interferometric determination of Cepheid angular radius

=> direct distance determination
Interferometers measure **visibilities:** accurate limb darkening models are required to derive angular diameters for geometric B-W method

An accurate limb darkening profile requires a good model of the stellar atmospheric structure

**Project summary:**

Derive "realistic" spectral intensity distributions for pulsating classical Cepheids, using time-dependent hydrodynamics and a full set of opacities -> **realistic limb darkening**

Radiative transfer (full set of opacities) + time-dependent hydrodynamics cannot be solved in a self-consistent way (excessive computing power)

**Our approach:**

- Compute for each pulsational phase the dynamic structure of the Cepheid atmosphere (reduced set of opacities) as in Sasslov & Lester (1994)
- Derive the full set of opacities for the dynamic atmosphere (ATLAS opacities, Kurucz 1970, 1993)
- Compute the emergent intensity and the limb darkened profile

**Limitations:**
Rosseland opacities still computed in LTE conditions. Intensities are however much improved, because the thermodynamical state of the model atmosphere is set by the hydrodynamic simulations
For each pulsational phase, dynamic model is fitted with a grid of static (ATLAS) models

Intensities are computed for an atmosphere having:

- $\log g$ from best fit
- $T_{\text{eff}}$ from observations (Krockenberger et al. 1997)
- $V_{\text{turb}}, L/H, \text{metallicity and Rosseland opacity from best fit model}$
- $T, x_{\text{He}}, P$ from dynamic model (excluding chromosphere and overshooting regions)

**Results: (1)**

Limb darkening in our hydrodynamic models is different from limb darkening of similar hydrostatic models.

A shockwave crossing the atmosphere reduces the amount of limb darkening at all wavelengths.

At minimum radius limb darkening is larger in our dynamic models.
Results: (2)

The shape of the limb profile and the amount of limb darkening depends on the pulsational phase.

A single limb darkening parametrization is inadequate to describe the limb profile at different pulsational phases and wavelengths.
**Results:** (3)

Limb darkening is **larger at shorter wavelength**

A unique limb darkening parametrization is **inadequate to describe the limb profile at different pulsational phases and wavelengths**

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a quasi-static phase

900nm | 500nm | 700nm

a shockwave crossing the atmosphere

blue reference lines are solar limb darkening

<--- center ---- limb --->
Conclusions

• Derived time and wavelength dependent limb darkening profiles for pulsating Cepheids

• Amount of limb darkening is different between dynamic and static models. The shape of the profile is also different and depends on the pulsational phase and wavelength

• Hydrodynamic simulations are crucial to determine limb-to-center profiles for pulsating Cepheids; hydrodynamic effects are already measurable with available interferometers (soon.)