The circumstellar environment of B[e] Supergiants

G. Maravelias[1], M. Kraus[1,2], L. Cidale[3,4], M. L. Arias[3,4], A. Aret[2], M. Borges Fernandes[5]

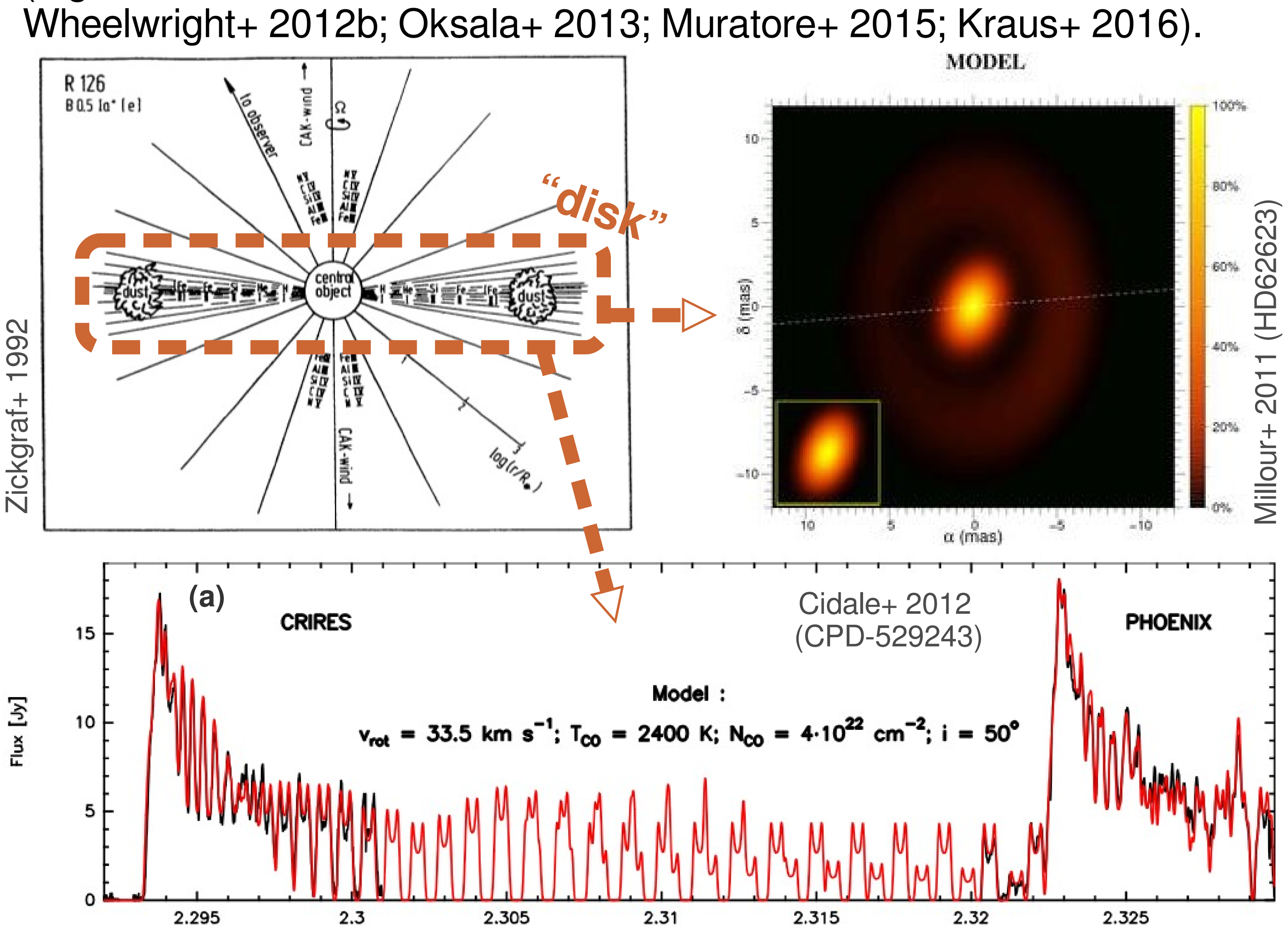
[1]Astronomický ústav, Akademie věd České republiky, Czech Republic, [2]Tartu Observatory, Estonia, [3]Departamento de Espectroscopía Estelar, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina, [4]Instituto de Astrofísica de La Plata, Argentina, [5]Observatório Nacional, Brazil

Abstract

Massive stars affect strongly the insterstellar medium through their intense stellar winds and their rich chemically processed material as they evolve. This interaction becomes substantial in short-lived transition phases of massive stars (e.g. B[e] Supergiants, Luminous Blue Variables, Yellow Hypergiants) in which mass-loss is more enhanced and usually eruptive. A complex environment, combining atomic, molecular and dust regions, is formed around these stars. In particular, the circumstellar environment of B[e] Supergiants is not well understood. To address that, we have initiated a campaign to investigate these environments for a sample of Galactic and Magellanic Cloud sources. Using high-resolution optical and near-infrared spectra (MPG-ESO/FEROS, GEMINI/Phoenix and VLT/CRIRES, respectively), we examine a set of emission features ([OI], [CaII], CO bandheads) to trace the physical conditions and kinematics in their formation regions. We find that the B[e] Supergiants are surrounded by a series of single and/or multiple equatorial rings, of different temperatures and densities, a probable result of previous mass-loss events. In many cases the CO forms very close to the star, while we notice also an alternate mixing of densities and temperatures (which give rise to the different emission features) along the equatorial plane.

Introduction

Zickgraf et al. (1985) proposed a two-component model with a line-driven polar wind and a cooler, equatorial, outflowing disk (of lower velocity but of higher density). However, this outflow scenario seems outdated and recent high-resolution NIR spectroscopy and interferometry has revealed detached dusty disks with Keplerian rotation (e.g. Liermann+ 2010, Millour+ 2011; Aret+ 2012; Cidale+ 2012; Wheelwright+ 2012b; Oksala+ 2013; Muratore+ 2015; Kraus+ 2016).



In NIR spectra we can detect CO bands in emission originating from the hot inner edge of the molecular disk which can be modeled as a narrow rotating ring of gas (Kraus+ 2000, Kraus 2009; Liermann+ 2010; Oksala+ 2013). Further support to this kinematical model comes from optical spectra where a set of lines display broadened and (usually) double-peaked emission lines. The optically thin lines of [OI] λ5577, λλ6300,6363 and [CaII] λλ7291,7323 form under different temperatures and densities. In particular, [CaII] forms rather close to the star. [OI] λ5577 forms approximately at the same region with [CaII] lines or a little further, while the doublet [OI] λλ6300,6363 originates from further out (Kraus+ 2010; Aret+ 2012, 2016). In lower temperatures (<5000 K) molecules of CO, TiO, and SiO can form, as well as dust further away.
Combining the kinematical information from all these tracers allows us to probe the structure of the disk.

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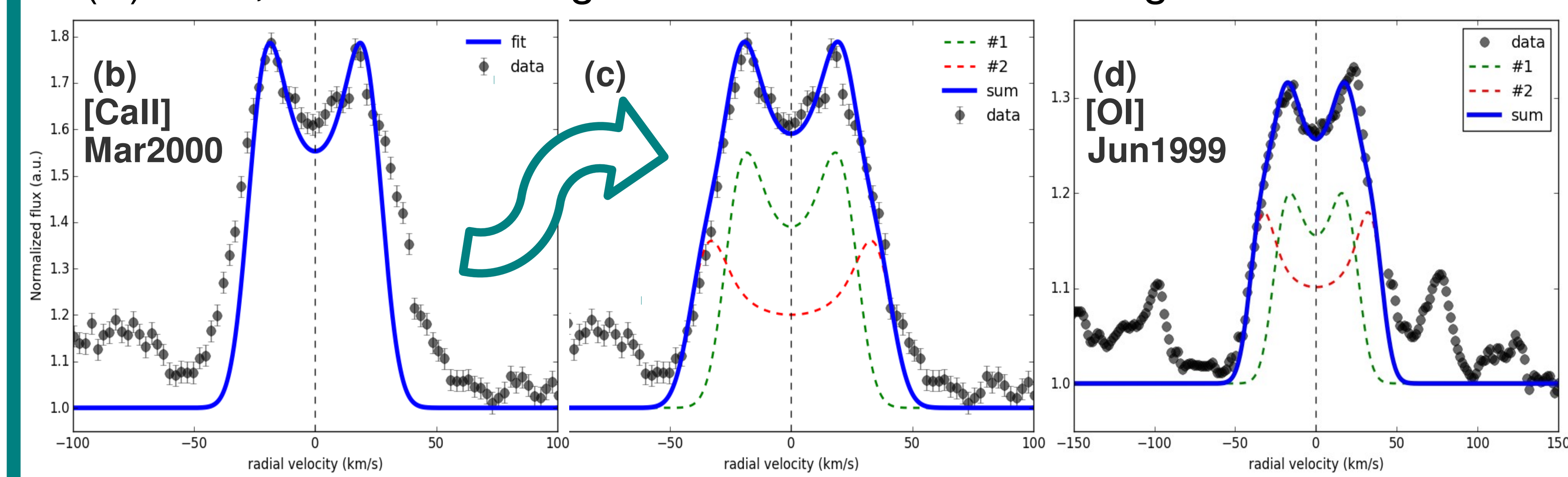
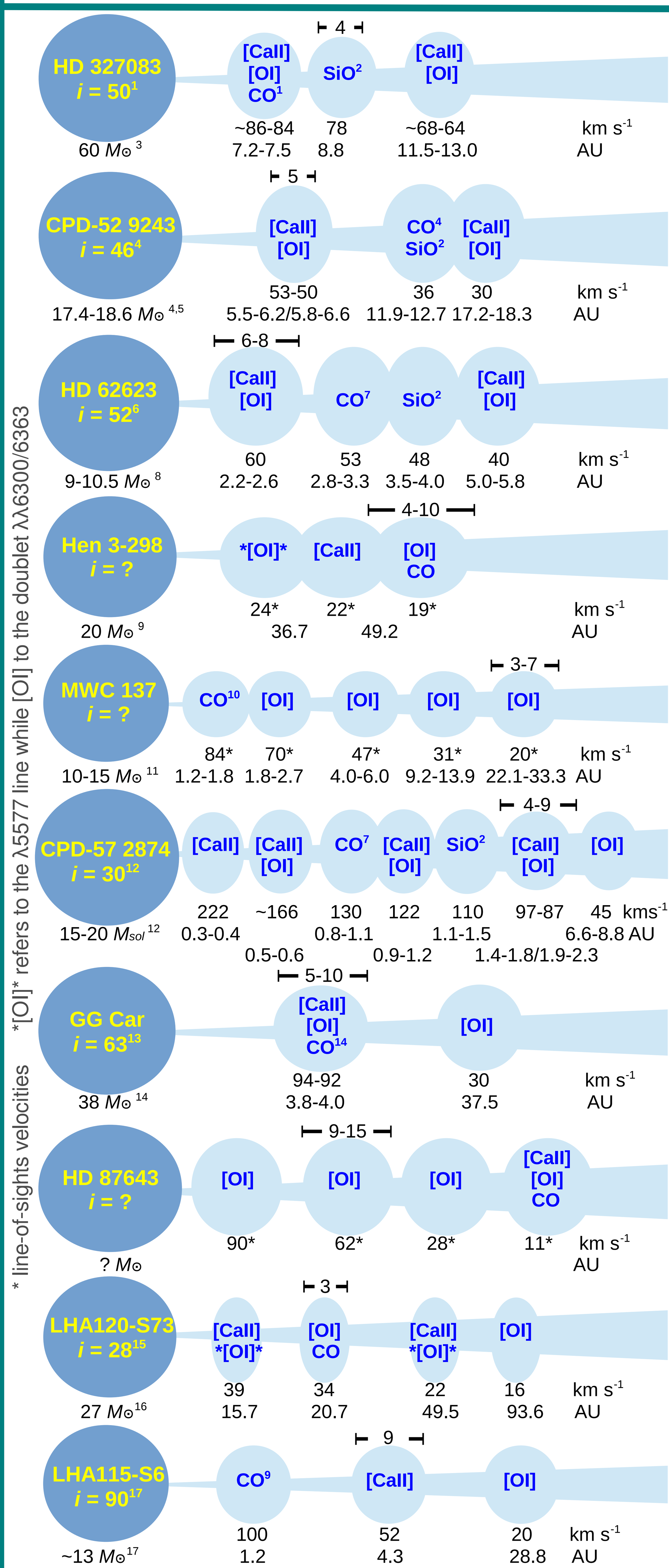
Analysis

For the kinematical model a rotational velocity (Vrot, de-projected, whenever the inclination angle is known) is convolved with a Gaussian component (Vg), a combination of the instrument's spectral resolution (~5.5-6.5 kms^{-1} for FEROS), a typical thermal velocity (~1-2 kms^{-1}) and some random internal motion of the gas (a few kms^{-1}), which we interpret as typical ring-width. Our approach is the following:
(i) determine first the rotational velocity of CO rings (its emission features are a direct evidence of gas presence)
(ii) assuming the same formation region of optical emission and CO (in a homogeneous disk) we test if the CO velocity is sufficient to fit the profiles
(iii) if not, we either change that value or add more rings in our model.



Fitting example for CPD-52 9243: (a) Determine Vrot for the CO ring at 33.5 kms^{-1} (Cidale+ 2012; see spectrum at lower left), (b) This velocity is not sufficient to fit the [CaII] λ7292 line, (c) But if we use two rings (Vrot_1=30±1 kms^{-1} and Vg_1=9±1 kms^{-1}, Vrot_2=52±1 kms^{-1} and Vg_2=9±1 kms^{-1}) then their total sum matches the observed one. (d) The same approach leads us to two rings also for the [OI] λ6300 line (at Vrot_1=31±1 kms^{-1} and Vg_1=10±1 kms^{-1}, Vrot_2=50±1 kms^{-1} and Vg_2=9±1 kms^{-1}). Thus, both lines are forming in two separate regions with a typical ring-width of ~5 kms^{-1} each (see Maravelias+ 2016).

Results



3 or 2 rings: CO+SiO form a common region, circumbinary structure (binary within CO ring)

3 or 2 rings: CO+SiO atomic gas in common ring, and atomic gas closer to star than CO

4-2 rings: CO+SiO and atomic gas may form a common ring, atomic gas ring closer than CO

3(?) rings or possible only one with coexisting gas – note the presence of [OI]5577 line

4 rings of [OI] further out than the CO ring, but no [CaII] present complex environment with a jet (see 11)

7 rings – possible disk, complex structure with alternate regions of atomic/molecular gas

2 rings with only [OI] further out, a circum-binary structure (binary within CO ring)

4 rings of [OI], [CaII] only at the outermost ring + CO (binary ?)

4 rings, with [OI]5577+ [CaII] rings and CO(+ [OI]6300) in between, only [OI]6300 further out (see more in 16)

3 rings, CO closer to star, [OI] is probably circumbinary (B[e] to A separation ~13AU)

Conclusion

Common picture? Each system displays a unique environment, but all show a sequence of rings. *Common formation mechanism?* Either mass loss triggered by non-radial pulsations and/or other instabilities, or even due to the presence of objects that can clear their paths and stabilize these rings.