How a Precessional Oscillation Ceases: Observational Evidence for the Dissolution of the Circumstellar Disk of Pleione

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Abstract Observational evidence presented in this article confirms recent theoretical predictions that sustained tidal forcing leads to disk warping, splitting into inner and outer components, and eventual dissipation of the outer disk. The morphology of the line profiles indicates a recurrent, tidally induced tilt of the circumstellar disk by approximately 30°. This scenario is directly confirmed in the present article. In particular, the exponential decay and ultimate disappearance of the orbital modulation in the Hα central absorption demonstrate the physical dissolution of the detached outer disk. These observations document, for the first time, the extinction of a tidally driven precessional oscillation in a Be-star disk.

1. Introduction

Pleione (28 Tau) is a classical Be star well known for recurrent transitions between Be and shell phases on timescales of several decades. Such behavior has long been attributed to changes in the geometry and orientation of its circumstellar disk. The system's binary nature introduces an additional dynamical agent: a companion star in an eccentric orbit with a period of 218 days. Recent theoretical and modeling efforts, such as by Marr *et al.* (2022) and Suffak *et al.* (2023), have significantly improved the interpretation of the variability of the Pleione disk parameters. Marr *et al.* (2022) demonstrated that the observed Be–shell transition between 2005 and 2019 can be reproduced without invoking changes in disk density, solely through variations in disk inclination caused by precession. Building on this, Suffak *et al.* (2023) showed that sustained tidal torques can destabilize a tilted disk, leading to its separation into inner and outer components, with the outer disk precessing independently and ultimately dissipating. The present study provides long-term observational evidence that directly traces this predicted evolutionary sequence.

2. Relevance of the central depression (CD)

The depth of the Hα CA (often also "central depth" or "central absorption") is defined as the difference between the local continuum level (equal to unity) and the minimum value at the line minimum intensity (Figure 1). While the Hα emission line samples the disk as a whole, the region probed by the shell lines, represented by the depth of the central depression CC', is restricted to the line of sight. The diagnostics they provide should not be ignored, as their properties reflect the structure and dynamics of the disk in the observer's direction.

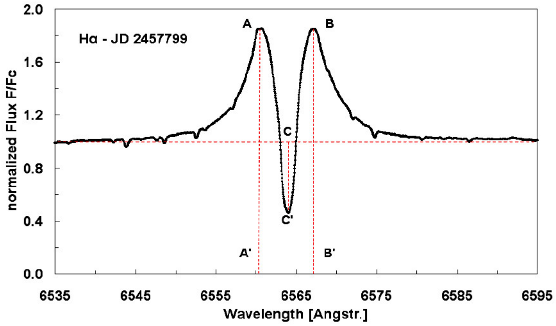

Figure 1. Measured quantities illustrated on an Hα line profile: (AA') and (BB') emission peaks, depth of the central depression (CC'). The horizontal line marks the normalized continuum.

2.1. Diagnostic value

The CD is a direct proxy for the optical depth of the disk along the line of sight and the inclination. A deep CD (near 0 or very small flux values in the core) indicates that dense disk material is obscuring the star's photosphere. This is characteristic of the "shell phase" (edge-on).

2.2. The inverse trend 1/CD

An increase in this value (or a decrease in CD depth) means that absorption is weakening. This has been observed since JD 2456500 (around 2013). This suggests that the absorbing matter is moving away from the line of sight and could have two causes: 1. Geometrically: the disk precesses out of the line of sight (transition from edge-on to pole-on); 2. Physically: the disk dissipates, and its density decreases.

The Marr model predicts that both occur: The detached outer ring precesses and dissipates. The observed data impressively confirm this process. Importantly, comparable orbital modulation was absent during earlier strong shell phases in the 1970s and around 1980, indicating a fundamentally different disk geometry during those epochs.

3. Tidally induced disk tilting

The depth and temporal behavior of the shell absorption require a temporary increase in the effective inclination of the disk relative to the observer. The observed absorption strengths imply a tilt angle of approximately 30° relative to the stellar equatorial plane.

This result is fully consistent with the inclination ranges explored by Marr *et al.* (2022), who showed that changes between roughly 25° and 144° can reproduce the observed transitions between emission-dominated and shell-type Hα profiles at constant disk density. In this framework, the periodic strengthening of the shell absorption during periastron passages reflects transient increases in the projected disk column density due to tidal tilting.

4. Disk precession, splitting, and physical scenario

Marr *et al.* (2022) modeled the disk as a single, coherently precessing structure with a precession period of approximately 80 years. However, hydrodynamic simulations by Suffak *et al.* (2023) demonstrate that sustained tidal forcing of a sufficiently tilted disk leads to a dynamical instability.

In the scenario of the schematic model in Figure 2, the inner disk gradually settles back toward the star's equatorial plane, while mass feeding from the stellar interior continues to sustain the disk. At the same time, the outer disk undergoes slow precession over a period of about 15 years and progressively dissipates. This sequence forms part of a repeating cycle of roughly 34 years, which consistently explains both the short-term and long-term variability observed in Pleione.

The disk tearing, its precession, and its gradual dispersal are most clearly reflected in the time evolution of the central absorption depth (CD) in the Hα line profile. Figure 3 illustrates the long-term behavior of the CD over a 27-year interval, together with its inverse representation (1/CD, shown as red points).

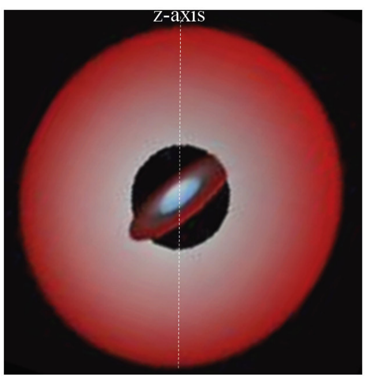

Figure 2. A schematic view of a dissipating circumstellar disk system. The star is located at the center (blue) and is surrounded by two distinct disk components: an inner disk (dark red) and an outer disk (orange), separated by a gap. The z-axis indicates the star's rotation axis (with kind permission of R. Hirata (2008)).

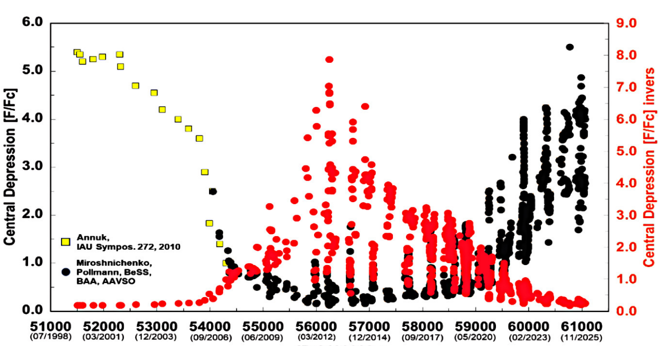

Figure 3. Long-term evolution of the Hα central absorption depth (CD) and its inverse (1/CD, red points). The gradual increase of 1/CD reflects the progressive weakening of the shell absorption. See text for data sources.

5. Observational evidence for disk dissipation

The long-term evolution of the Hα central absorption provides the total amount of material along the line of sight through the outer part of the disk, i.e. the summed amount of gas from the edge of the optically dense inner region to the outer regions of the disk.

Figure 3 shows the time frame of the changes in the CD and its reciprocal 1/CD, with the latter particularly illustrating the circumstances. Spectra/CD data are from Annuk (2011), Miroshnichenko (2025), and the spectroscopy databases of the BeSS, BAA, and AAVSO (Obs. de Meudon. 2025; British Astron. Assoc. 2025; Kloppenborg 2025).

Beginning around JD 2456500, the inverse CD follows an exponential decay (Figure 3), indicative of a systematic reduction in absorbing material. After subtraction of this exponential trend, the residuals in Figure 5 reveal a clear 218-day modulation until approximately JD 2461000.

6. Physical interpretation of the decay timescale τ

The exponential fit to the long-term evolution of the inverse central absorption introduces a characteristic decay timescale τ. Although formally obtained as a fit parameter, τ has a clear physical meaning in the context of the disk-splitting scenario. The central absorption depth in Hα is proportional to the projected column density of circumstellar material along the line of sight. Consequently, the inverse quantity 1/CD provides a sensitive measure of the amount of absorbing material in the detached outer disk and is consistent with the radiative transfer predictions of the hydrodynamic tearing disk model in Suffak *et al.* (2024). An exponential increase of 1/CD therefore implies an exponential decrease of the effective absorbing column density.

In this framework, the decay timescale τ represents the characteristic dissipation timescale of the outer disk component after its dynamical detachment from the inner disk. Specifically, τ corresponds to the time over which the absorbing column density of the outer disk is reduced to approximately 1/e of its initial value.

A dissipation time (τ) of 6.7 years (2446 days, Figure 4) for the outer ring fits well with a cool, detached ring whose viscosity is possibly lower than that of the hot inner disk. The fitted exponential decay strongly suggests that dissipation is dominated by viscous diffusion (as theoretically expected) and not by chaotic instabilities or stellar winds ("blowing off"). Observations of other Be stars, such as 66 Ophiuchi, show dissipation times ranging from years to decades (Marr 2022).

This behavior cannot be explained by geometric effects such as disk precession or inclination changes alone, as explored by Marr *et al.* (2022). Instead, the observed exponential decay requires a genuine physical loss of disk material, consistent with the gradual dispersal of a disk that is no longer replenished by mass injection from the star.

The value of τ therefore provides a direct observational constraint on the dissipation efficiency of a tidally detached Be-star disk. Together with the observed duration over which the orbital modulation persists, τ offers an empirical benchmark

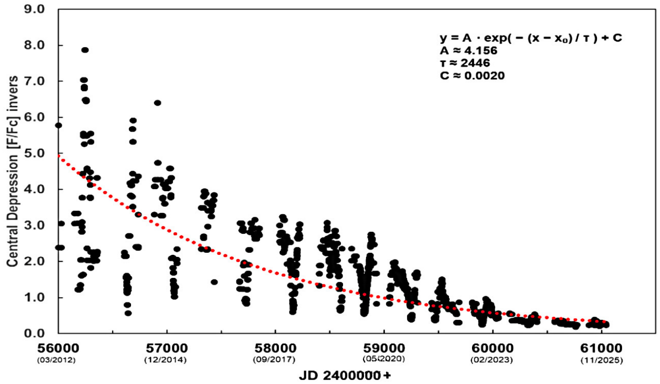

Figure 4. Exponential fit to the inverse CD long-term trend. The parameters A (initial amplitude), τ (decay timescale), and C (constant background) were determined by least-squares minimization. Beyond JD ≈ 2461000, the orbital modulation disappears entirely.

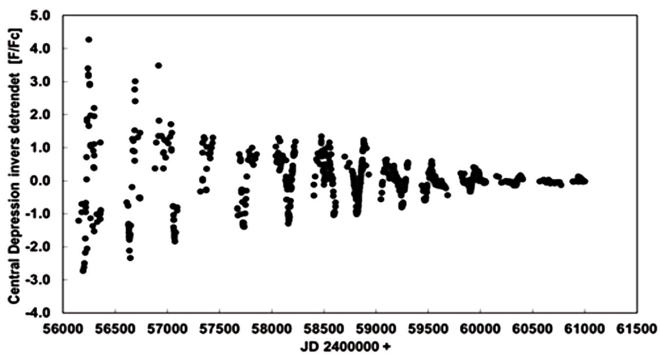

Figure 5. Residuals after subtraction of the exponential trend from 1/CD. The absence of the 218-day signal demonstrates that the outer disk component subject to tidal forcing has fully dissipated.

for future hydrodynamic and viscous disk simulations, such as those presented by Suffak *et al.* (2023).

The Hα-V/R ratio of Pleione also exhibits periodic modulation with a characteristic timescale of 218 days. This value agrees with the variability of the central absorption component (CD) and is consistent with the results reported by Pollmann and Leonardi in *IBVS* No. 6199 (2015). The period estimate is based on spectroscopic time-series observations of the Hα line profile obtained over several observation intervals. The reproducibility of the 218-day period supports the interpretation that the V/R variability and the modulation of the central absorption CD are determined by the same underlying dynamic process in the circumstellar disk.

7. Novel observational contributions beyond Marr *et al.* (2022) and Suffak *et al.* (2023)

While the studies of Marr (2022), Marr *et al.* (2022), and Suffak *et al.* (2023) provide a consistent theoretical framework, they are necessarily limited by model assumptions and temporal coverage. The present work extends these studies in several fundamental ways.

The exponential decay of the inverse central absorption provides the first direct observational tracer of outer-disk dissipation in Pleione. Disk precession alone cannot produce such a decay; it requires a genuine reduction of disk mass.

The data demonstrate the extinction of the tidally driven orbital modulation. The disappearance of the 218-day signal once the exponential decay has progressed confirms a key but previously untested prediction of the disk-splitting scenario: tidal signatures vanish when the outer disk is gone.

The long-term dataset allows an observational separation of geometric variability and physical disk loss. Early variations are consistent with inclination effects at constant density, while the later behavior unequivocally indicates real dissipation.

Finally, the continuous temporal coverage across a critical evolutionary phase uniquely documents the transition from a tidally modulated, precessing disk to a state where the outer disk has completely vanished. This provides quantitative constraints on dissipation timescales that are not accessible from modeling alone.

8. Conclusions

Long-term Hα monitoring of Pleione provides direct observational confirmation of recent theoretical predictions for tidally distorted Be-star disks. The observations show that:

1. A ~34-year cycle, in which the inner disk returns to the equatorial plane and the outer disk precesses and dissipates, explains the Pleione CD variability.

2. The exponential decay of the Hα central absorption traces the physical dissipation of this disk.

3. The disappearance of the orbital modulation marks the extinction of a tidally driven precessional oscillation.

These results establish a clear empirical link between disk precession, disk splitting, and disk dissipation in Pleione. They further demonstrate the exceptional scientific value of sustained spectroscopic monitoring and highlight the important role of coordinated amateur–professional collaboration.

9. Acknowledgement

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