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# Observation of the 2011 explosion of the recurrent nova T Pyxidis

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**Abstract.** T Pyxidis is a cataclysmic variable that falls into the category of Recurrent Novae. Unlike classical Novae, recurrent Novae provide us with the opportunity of witnessing the physical processes of a complete cycle of a Nova. Its last explosion in 2011 was observed with the VLT/X-Shooter spectrograph in three spectral bands (Ultraviolet, Visible, and near-infrared), providing unprecedented details of the process. Based on four different methods and comparing the results with the ones available in the literature, we derived an extinction of 0.25 mag and a distance of 2880±230 parsecs. As of the physical parameters, the hydrogen and oxygen mass of the ejecta are measured from emission lines, leading to approximately $10^{-7}$ and $10^{-8}$ $M_\odot$, respectively. Moreover, the observation of several P Cygni profiles on a same line supports the idea that there are several expanding gas shells.

**Resumo.** T Pyxidis é uma variável cataclísmica que entra na categoria de nova recorrente. Diferente de novas clássicas, novas recorrentes nos fornecem a oportunidade de testemunhar os processos físicos de um ciclo completo de uma nova. Sua última explosão em 2011 foi observada com o espectrógrafo VLT/X-Shooter em três bandas (Ultravioleta, Visível e Infravermelho próximo), fornecendo detalhes sem precedentes do processo. Com base em quatro métodos diferentes e comparando os resultados com disponíveis na literatura, obtivemos uma extinção de 0,25 mag e uma distância de 2880±230 parsecs. A partir dos parâmetros físicos, a massa de hidrogênio e oxigênio expelida é medida a partir das linhas de emissão, totalizando $10^{-7}$ e $10^{-8}$ $M_\odot$, respectivamente. Além disso, a observação de múltiplos perfis P Cygni em uma mesma linha apoia a ideia de que existem diferentes sistemas de gás em expansão.

**Keywords.** novae – cataclysmic variables – spectroscopic

## 1. Introduction

Classical novae are thermonuclear explosions occurring in a binary system where a white dwarf is accreting mass from a Roche-lobe filling main sequence star (for a review, see Bode & Evans (2008)). Although classical novae are interpreted to be periodic phenomena according to Shara et al. (1986), the time between explosions is of tens of thousands of years, given their mass accretion rate. Therefore, it is only possible to study a complete cycle through recurrent novae that occur on a time scale comparable to a human life. T Pyx occupies a special space in its category as a recurrent nova. It is has the shortest orbital period and the slowest decline rate among RNe. It has exploded six times since its discovery in 1890, and is therefore considered one of the best studied novae. It was expected to explode in the late 1980s, but it was only in 2011 that another explosion was detected. Also, it fits into a hybrid spectral class since its spectra show both He/N and Fe II lines appearing in an order never seen before. Therefore, T Pyx provides us with the opportunity of studying in unprecedented detail the physical processes that occur during a nova explosion. The spectral evolution is visible in Figure 1. The goal of this work is to derive the physical properties of T Pyx and understand if the mass of the white dwarf increases or decreases during a cycle. Since recurrent novae usually have more massive white dwarfs than classical novae, if its mass increases after each cycle, it might reach the Chandrashekar limit and eventually explode like a type Ia supernova.

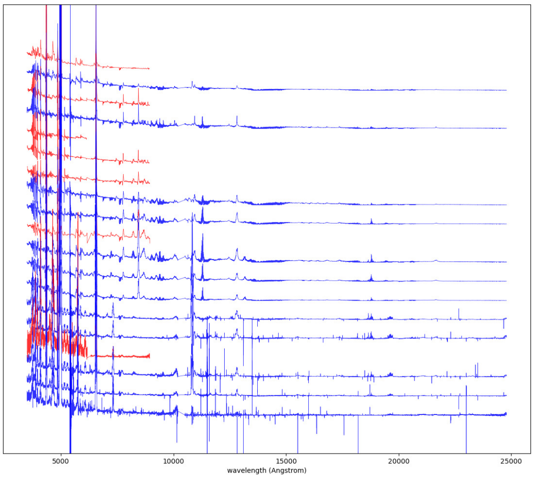

**Figure 1.** Spectral evolution of T Pyx by VLT/X-Shooter (in blue) and SOAR/Goodman (in red).

## 2. Methodology

Given the irregular line shapes and the lack of theoretical models for comparison, we use IRAF *(Image Analysis and Reduction Facility)* to measure the main emission (and some absorption) lines. IRAF allows us to perform Gaussian fits in order to get the wavelength, the flux, the FWHM *(Full Width at Half Maximum)* - and the equivalent line width. Finally, to use the flux-corrected values of the main lines, we subtract the appropriate extinction from the spectra using IRAF's *deredden* function. In total, more than 5400 emission and absorption lines were measured. Every plot and calculation were performed using programs developed in Python exclusively for this work.

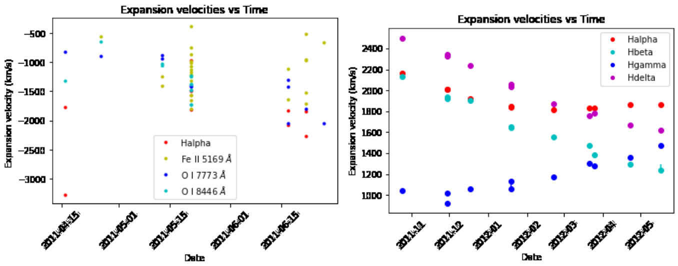

**Figure 2.** Evolution in time of the expansion velocities of the optically thin and thick gases obtained by analysing P Cygni profiles of the main emission lines and the four main Balmer emission lines, respectively.

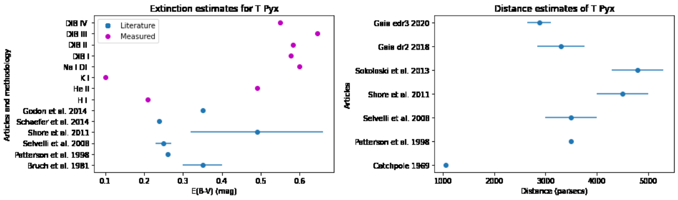

**Figure 3.** T Pyx extinction and distance estimates found in the literature based on papers published in the past 40-60 years.

## 3. Analysis

In order to understand the evolution in time of the expanding material, we analyse both the optically thick and thin gas. We can derive the expansion velocities of the optically thick material by studying the P Cygni profiles of the main emission lines present in the early stages of the explosion. Certain lines show more than one P Cygni profile simultaneously. Therefore, different velocities are observed for the same emission line on the same day implying in the existence of several expanding gas shells. In general, in absolute value, the velocities are increasing with time. On the other hand, we look at the main Balmer recombination lines in the later stages to derive the same parameter for the optically thin gas. The velocities derived using H$\alpha$, H$\beta$ and H$\delta$ decrease with time while those calculated with H$\gamma$ increase. The results are displayed in Figure 2.

There are several methods listed in Ederoclite et al. (2006) to determine the extinction that depend on different emission lines that were generated in the explosion or absoption lines due to the interstellar matter present in the line of sight. More precisely, we reproduce the procedures adopted in Williams (1994), Munari & Zwitter (1997) and Friedman et al. (2011). The extinctions of the interstellar medium calculated according to each method are then compared with the results found in previous estimates available in the literature. The values found using DIBs, sodium, and helium provide extinctions 0.1 to 0.2 mag higher than the others. Given that most of those presented in the literature fluctuate between 0.25 and 0.35 mag, we chose to adopt an extinction of 0.25 mag. Among the distances that were found, the one published by Gaia Collaboration et al. (2020) has the smallest error. For this reason, we determined the physical parameters based on this value: 2880±230 parsecs.

Also based on Ederoclite et al. (2006), we derived an optical depth ($\tau$) of 5.2, of 4750 K and the oxygen and hydrogen abundance of the ejected material (around $10^{-8}$ for oxygen and $6{\times}10^{-7}$ $M_{\odot}$ for hydrogen. These values were obtained based on nebular physics concepts thoroughly explained in Williams (1994) and Osterbrock & Ferland (2006).

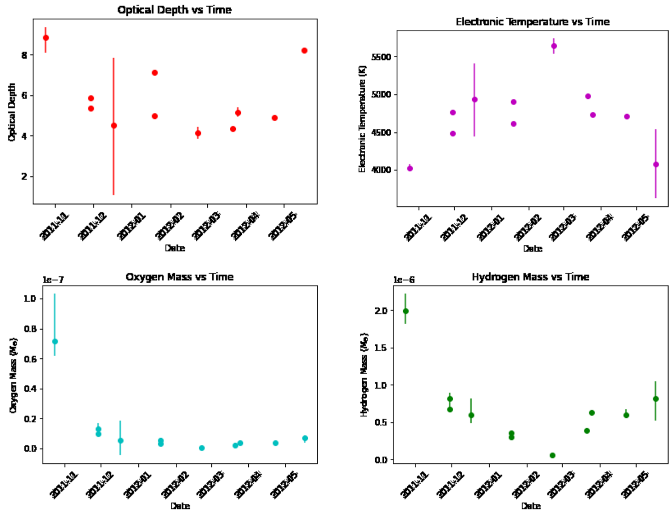

**Figure 4.** From left to right, top to bottom: Evolution in time of the optical depth, electronic temperature, oxygen mass and hydrogen mass. The biggest uncertainty observed for $\tau$ is due to a flux measurement error. This error propagates into the uncertainty estimates of all parameters which are not independent from $\tau$.

## 4. Conclusion

The precision and accuracy of this kind of analysis relies mostly on line identification and measurement. Thus, good spectral resolution and signal to noise are essential to obtain more reliable data. Line contamination is expected and explains most of the overestimated extinction values and the increasing tendency of the H$\gamma$ derived expansion velocity. The extinction outliers obtained with the DIBs are most likely due to calibration issues: this method isn't applicable for this line of sight. On the other hand, we compared the physical parameters with the ones derived in Ederoclite et al. (2006) and found that they were all compatible except for the oxygen and hydrogen masses that were 5 to 10 times smaller. Given that V5114 Sgr is a classical nova, it had thousands of years to accrete matter while T Pyx had only 45 years, which explains the discrepancy. Finally, regarding the white dwarf's mass, we used the mass accretion rate derived by Selvelli et al. (2008) and found that the results of this work lead to a possible mass loss during a cycle. Therefore, as pointed out by Selvelli et al. (2008), T Pyx will not become a SN Ia.

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