# The Mystery Behind Proplyd Scarcity in H II Regions Other Than the Orion Nebula

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## Abstract

This paper investigates the peculiar observations surrounding the transient nature of proplyd stellar objects. The paper will begin with a discussion on the basic formation of a proplyd, and the emission lines we use to observe them and their behavior. We will discuss the most prominent location for their existence as of today, the Orion Nebula, before addressing the two main hypotheses for their scarcity in H II regions elsewhere across the universe: Proplyd lifetime and current limitations in stellar observational equipment. Current investigations using numerical solutions discuss the Proplyd lifetime problem and will be briefly mentioned here. A small discussion on the advancement in observations illuminating the current launch of the James Webb Telescope and its capabilities in the Infra-red emission range, which could possibly shed more light into the mystery of the proplyd, will also be discussed.

## Introduction

We observe the formation of young stellar objects (YSOs) in regions of interstellar medium across the universe. Pre-nuclear burning objects, also known as protostars, are caused by small perturbations in the hydrostatic equilibrium first researched by Sir James Jean in 1902. A special selection of YSOs, known as proplyds, are caused by the external photoevaporation on a protoplanetary disk (PPD) surrounding a central protostar. This is due to their exposure to strong far ultraviolet and extreme ultraviolet photons from a neighboring massive star shedding its molecular cloud (Winter et al., 2019). The term "proplyd", coined by O'Dell, Wen & Hu (1993), refers to the circumstellar disk during this process and its final ionized state

(Caroll, & Ostlie, 2018). These YSOs form quite differently to your isolated collapsing cloud core (Mesa-Delgado et al., 2012).

A relatively large abundance of proplyds are found in the Orion Nebula (M42). In fact, “Never has a bona fide family of proplyds similar to those found in the Orion Nebula been found in another H ll region” (Marco et al., 2006). This mystery has led to several studies and theories on the transient nature of proplyds across the universe and why there is currently an overwhelming majority of proplyds in the Orion Nebula.

## Theory

In order to perform our simplified discussion on the formation of proplyds, we must first ignore the effects due to rotation, magnetic fields and turbulence. The conditions met for a stable system can be described by the following equation:

$$E_k + E_U = 0$$

Where K and U denote the Kinetic and Gravitational Potential energy (GPE) of the system respectively. This equation is known as the Virial Theorem and any deviation from this condition can result in drastic changes to the morphology and final state of the matter in our frame. For a spherical molecular cloud to collapse, the GPE must be greater than the kinetic energy of the system. External forces cause the initial change, and we can now denote the critical condition for collapse as follows:

$$\frac{3(M_{crit})kT}{\mu M_H} < \frac{3}{5}\left(\frac{G(M_{crit})^2}{R_{crit}}\right)$$

K and G denote constants, $M_H$ denots the mass of hydrogen and $\mu$ is the mean molecular weight of the gas (Caroll, & Ostlie, 2018).

From the previous equation we can derive Jean's criterion. For critical radius, the criterion can be denoted as follows:

$$R_{Jeans} = \sqrt{\frac{15kT}{4\pi G\mu M_H \rho_0}}$$

$\rho_0$ Signifies the initial mass density of the cloud (Caroll, & Ostlie, 2018).

This means that for a radius greater than the Jean's radius, we can expect a collapse of material in our system. For a full derivation, please see (Caroll, & Ostlie, 2018).

In order to form a protoplanetary disk, we can no longer ignore rotation. Due to the conservation of angular momentum, as the cloud begins to collapse a preferential direction of material surrounding the newly formed protostar creates a protoplanetary disk. The PPD is thought to be a region of planet formation and for an isolated system, the timescale of PPD dispersion (which limits the time for planet formation) is on the scale of ~ 3 Myr (Winter et al., 2019). However, proplyds are continually under threat due to the bombardment of powerful ionizing radiation from the nearby giant star at a rate of $\geq 10^4$G$_0$ ( 1 G$_0$ ≡ $1.6 * 10^-3 erg cm^{-2} s^{-1}$) (Winter et al., 2019). Therefore, proplyd material is much more likely to dissipate before any planet formation (Kornmesser, 2015).

The unique morphology of the bow shocks surrounding the proplyd resemble the shape of a comet where the head is oriented toward the central giant star and its tail forming further along the same axis (Garcia-Arredondo et al., 2001). The shape itself is a product of the interaction between the photoevaporating material of the proplyd and the surrounding stellar winds (Garcia-Arredondo et al., 2001).

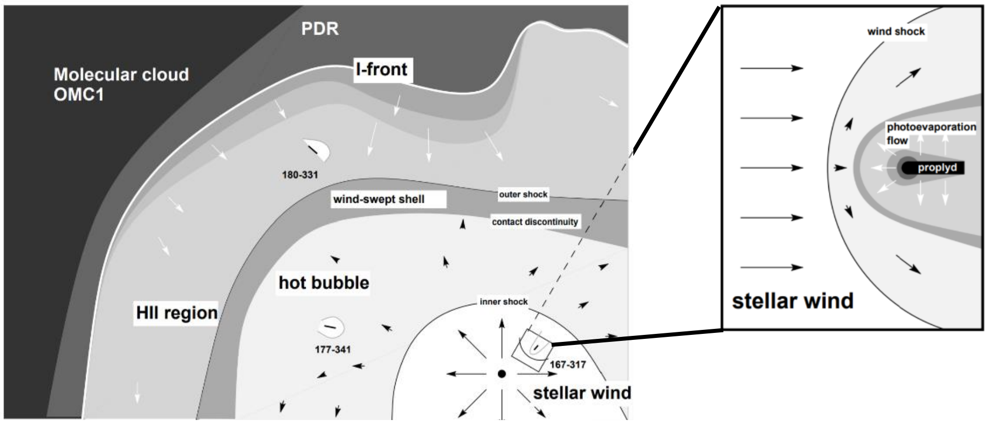


*Figure 1: Visual representation of proplyd interaction with surrounding molecular cloud (Garcia-Arredondo et al., 2001)*

Proplyds were first discovered through direct observation of Hα, [N II], and [O III] emission lines and are also visible in 11.7 $\mu$m silicate dust emission lines (Garcia-Arredondo et al., 2001). However, The Hubble Space Telescope has captured stunning images of these peculiar YSOs at visual wavelengths (Sharky, & Ricci, 2009).

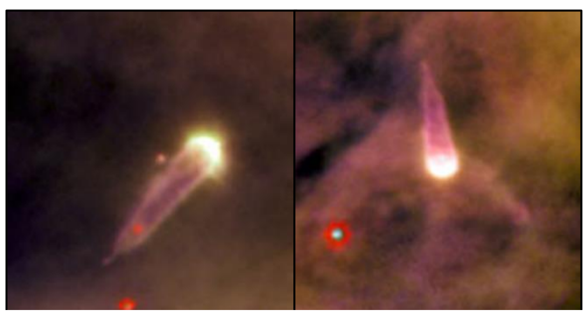

*Figure 2: Proplyd images produced by HST (Sharky, & Ricci, 2021)*

Investigations into the thermal dust emission and shocks in the Orion Nebula performed by Smith et al., noted that their observations showed the majority of proplyds were visible in the thermal Infra-red (IR) and of particular importance in the Mid IR with high-spatial resolution (Smith et al., 2005).

## Discussion

The Orion Nebula holds the greatest quantity of proplyds within our knowledge. More than 80% of all known YSOs (up to one arcminute across) surrounding the trapezium of giant stars are found to obtain proplyd features (Smith et al., 2005). A significant contributor to the formation of proplyds can be explained by the primary star $\theta^1$ Orionis C ($\theta^1$C). Proplyds in the Orion Nebula can be segmented into two distinct groups: proplyds in close proximity to $\theta^1$C that emit a range of photons from the excited proplyd gas, as opposed to proplyds which have formed at a greater distance from the primary star and display a dark silhouette against the background nebula (Smith et al., 2005) (Sharky, & Ricci, 2009).

Studies conducting observational analysis of molecular clouds other than the Orion Nebula come to a halt as their proplyd candidates lack all requirements in order to successfully classify. This considerably confusing dilemma is explained by Smith et al. (2005). Their paper insists that proplyds at great distances are only visible near the bright massive star that creates their irregular shape (Smith et al., 2005). However, all proplyds in this region tend to have very short lifespans of around 500,000 years (Marco et al., 2006). This suggests that we are currently viewing a relatively young region of the Orion Nebula where the formation and existence of proplyds is viable. Physicists tend to steer away from any suggestion that we may be special and so evidently recent studies are attempting to debunk this hypothesis.

Using numerical solutions, Winter et al. (2019) attempt to solve the proplyd lifetime problem with simple dynamic models and movement of proplyds across the Orion Nebula. The migration of older PPD populations, coupled with the target of strong irradiation towards the youngest proplyds with the highest abundance of material can prove that the current state of the Orion Nebula Cluster does not require an incredibly small relative age in order to explain the observed data. (Winter et al., 2019).

While the former attempts to explain the scarcity of proplyds due to the timescale of their lifetime, another proposal suggests that we must reassess our own observational equipment. The Hubble Space Telescope (HST) is one of the most preferable methods to observe and investigate the abundance of proplyds across the universe, and its abundance in the Orion Nebula. Its position in the nights sky orbiting the Earth can produce a higher resolution than most ground-based observations (Summers, 2019). However, even the HST has its limitations. Using a simple equation that relates the angular resolution, R, circular aperture, D, and photon wavelength, L, we can specify the resolution of the HST (NASA 2009).

$$R = \frac{1.22L}{D}$$

This should result in a resolution ~ 50AU ($1\text{AU} = 1.496 * 10^{11}m$) (Marco et al., 2006). While this is sufficient for observing proplyds in the closest star-forming region, it is believed that the limitations of the HST, and any ground-based telescopes, prevent any further investigation with a high degree of return (like that of the Orion Nebula) for proplyd spotting. This is mainly due to the inability to correctly distinguish between a true proplyd and regions with similar attributes such as fragments of molecular cloud material (Marco et al., 2006).

On-going investigations into proplyds in regions such as the Carina Nebula (Smith et al., 2003) and Giant H II Region NGC 3603 (Mucke et al., 2002) show promising results of proplyd candidates indicating that our current equipment may be our underlying limiting factor.

However, the James Webb space telescope, firing into the sky on December 22nd, 2021, aboard an Ariane 5 rocket, will undoubtedly explore and discover new physics to describe the formation of stars, galaxies and molecular clouds that we have never seen before. Its optimized spectrum coverage of 0.6 to 28 micrometers is mostly in the IR with some visible light (mostly in the red and yellow). As the successor to the HST, it's also built with an incredibly large circular aperture and collecting area. In comparison, the James Webb telescope will have ~ $28m^2$ collecting area in contrast to the ~$4.5m^2$ collecting area of the HST (NASA., 2020). A staggering ~$2.7m$ increase in diameter and optimized IR spectrum observation equipment will outperform any current equipment currently used to study proplyds in H II regions.

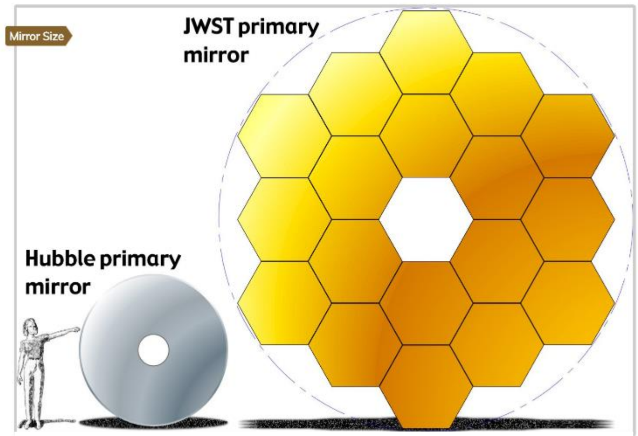


*Figure 3: Relative size difference for Hubble and James Webb telescope collecting area (NASA, 2020).*

## Conclusion

The acceptance of a relatively short lifespan of proplyds, while may seem plausible to some, suggests that our investigation into PPDs outside of the Orion Nebula Cluster will be unsuccessful in most cases. However, we must admit that all human civilizations ponder about the uniqueness of our position and time in our universe, and I believe it would be foolish to assume that we are special in this instance. While the lifetime of proplyds is shortened due to external photoevaporation to a certain degree, with all of our recent advancements in observational technology, our current quantity of known proplyds will undoubtedly increase. In particular, the James Webb telescope and its intricate design will bring "new light" to our knowledge of star formation in and around H II regions. It is therefore more plausible to assume that there are more fitting explanations which we have yet to uncover.

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