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ORIGINAL CONTRIBUTION

Evolution of total mass of X-ray transients over different time intervals

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ABSTRACT

This study investigates the temporal evolution of X-ray transients, focusing on the relationship between the total mass of these systems and the increasing number of stars formed after a starburst event. The total binary mass considered is $1.5 \times 10^6\ M_\odot$ and the analysis spans the first 20 million years after the burst. The simulations includes transient sources accreting neutron stars paired with Be-type stars. By analyzing data across different time intervals, we observe a consistent trend where the total mass of X-ray transients decreases over time, while the number of stars increases. This inverse relationship highlights the dynamic interplay between accretion processes, mass loss mechanisms, and environmental factors, such as star formation history and local stellar density. Early stages of evolution show relatively stable mass retention, suggesting efficient accretion mechanisms, whereas later stages exhibit significant mass depletion, likely driven by material exhaustion or outflow processes. These findings provide valuable insights into the lifecycle of X-ray transient systems and their connection to broader astrophysical phenomena, including accretion disk dynamics and high-energy emissions. The results emphasize the importance of continued observations and high-resolution simulations to unravel the complex processes governing the evolution of these transient systems.

KEYWORDS: X-ray Sources, Star burst, Initial mass function

1. INTRODUCTION

Stars form through the fragmentation of molecular clouds under gravitational instability. To understand star formation and evolution, it is crucial to examine the distribution of stellar masses resulting from this fragmentation, known as the **Initial Mass Function (IMF)**. The IMF, often modeled as a power law, provides insights into the frequency of stars at different masses.

The Salpeter IMF, introduced in 1955, describes the mass distribution of stars heavier than the Sun, with an exponent $\alpha = 2.35$. This is mathematically expressed as:

$$\xi(m)\Delta m = \xi_0 \left(\frac{m}{M_\odot}\right)^{-2.35} \Delta m,$$

where $\xi(m)$ is the number of stars per unit mass, m is the stellar mass, $M_\odot$ is the solar mass, and ξ_0 is a constant related to the stellar density. This equation indicates that lower-mass stars are more abundant. However, for less massive stars, the IMF deviates from a power law and tends toward a log-normal distribution.

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Over time, researchers like Kroupa (2001, 2002) and Chabrier (2003) introduced refinements, suggesting a segmented IMF: one slope for high-mass stars ($\alpha \approx 2.35$) and another for low-mass stars ($\alpha \approx 1.0$ to 1.25). These models better align with observational data.

The IMF also sheds light on galactic properties and evolution. For instance, galaxies like Mrk 712 can be modeled using a flatter IMF ($\alpha \approx 1.0$). Additionally, massive X-ray binary systems often provide key insights into starburst activity and galaxy evolution.

This study explores how the total mass evolves over time and across different environments, offering a deeper understanding of stellar populations and galactic dynamics.

2. Mathematical Model

From the perspective of stellar evolution, objects that experience bursts of star formation hold significant importance. Wolf-Rayet galaxies serve as a notable example of such systems ([1], [5]). Focusing solely on the evolution of single stars, Contini et al. [2] proposed that some observed characteristics of the galaxy Mrk 712 could be explained if the initial mass function deviated substantially from the standard value. Specifically, they suggested a "flat" mass distribution with an index of $\beta = 1$, instead of the Salpeter mass spectrum with an index of $\beta = 2.35$, and an upper mass limit of 120M☉. Subsequently, Schaerer [3], also examining the evolution of single stars, demonstrated that these observations could also be interpreted using a Salpeter initial mass function. The equation of the power-law initial mass functions is $\frac{dN}{dM} \propto M^{-\beta}$. In the presesent work we consider β=2.35 and β=1.01.

In 1999, Popov et al [4] provided approximation formulas to simplify the calculation of the number of different types of sources generated in starbursts with arbitrary masses. In these formulas, the time t is expressed in millions of years. Assuming a Salpeter initial mass function (β=2.35) with an upper mass limit of Mup=$120M_{\odot}$, the number of X-ray transients between 5 and 20 million years after the starburst is

$$n(t) = -0.14 \times t^2 + 5.47 \times t - 14.64. \qquad [1]$$

Integral of $n(t)$ gives $\int_5^{20} n(t)\, dt = 438.525 = c_1$(say), and the Probability Density Function (PDF), $f(t)$ is given by $f(t) = \frac{n(t)}{c_1}$. The corresponding cumulative distribution function (CDF) is

$$F(t) = \int_5^t f(t)\, dt = \frac{1}{c_1}\int_5^t n(t)\, dt$$

Substituting the expression for $n(t)$ into the integral:

$$F(t) = \frac{1}{c_1}\left[-0.14\frac{t^3}{3} + 5.47\frac{t^2}{2} - 14.64t\right]_5^t$$

, which implies,

$$F(t) = \frac{1}{c_1}\left[-0.14\frac{t^3}{3} + 5.47\frac{t^2}{2} - 14.64t + \frac{1279}{120}\right]$$

The cumulative distribution function F(t) lies within 0 and 1 for all values of t. Let $F(t) = r_1$, where r_1 is a real number between 0 and 1. We have considered 10^6 random number in [0, 1] and searched for t from the equation 2.

$$-0.14\frac{t^3}{3} + 5.47\frac{t^2}{2} - 14.64t + \frac{1279}{120} = c_1 \times r_1. \qquad [2]$$

We take only real t in every case and calculate the corresponding total number of X-ray transients from the equation 1 in deferent ranges of time, whereas, the number of stars within specific mass ranges can be determined using the mass function, $\Phi(m)$. We have prepared the final data set containing the data induced from case 1 and case 2. The total mass can also be determined from this $\Phi(m)$. The total number of stars with masses between m_1 and m_2 is given by:

$$n(m_1, m_2) = \int_{m_1}^{m_2} \Phi\,(m)\,dm$$

where $\Phi(m)$ is the mass function.

By definition, the mass function satisfies:

$$\frac{dn}{dm} = \Phi(m)$$

The total mass of stars within the same range is:

$$\mathrm{m}(m_1, m_2) = \int_{m_1}^{m_2} m\,\Phi(m)\,dm$$
$$= \int_{m_1}^{m_2} \xi\,(m)\,dm$$

where

$$\xi(m) = m\Phi(m) = m\frac{dn}{dm} = \frac{dn}{d\ln(m)}$$

Assuming a power-law form for the mass function:

$$\Phi(m) = \Phi_0 m^{-\beta}, \quad \xi(m) = \xi_0 m^{-\beta+1}$$

The normalization conditions for $\Phi(m)$ and $\xi(m)$ are:

$$1 = \int_{m_{\min}}^{m_{\max}} \Phi\,(m)\,dm = \frac{\Phi_0}{1-\beta}\left[m_{\max}^{1-\beta} - m_{\min}^{1-\beta}\right]$$

$$1 = \int_{m_{\min}}^{m_{\max}} \xi\,(m)\,dm = \frac{\xi_0}{2-\beta}\left[m_{\max}^{2-\beta} - m_{\min}^{2-\beta}\right]$$

Case 1: $\beta = \mathbf{2.35}$

$$\Phi(m) = \Phi_0 m^{-2.35}, \quad \xi(m) = \xi_0 m^{-1.35}$$

with $m_{\min} = 0.1M_{\odot}$ and $m_{\max} = 120M_{\odot}$. Normalization gives:

$$1 = \frac{\Phi_0}{1.35}\left[m_{\min}^{-1.35} - m_{\max}^{-1.35}\right]$$

$$\Phi_0 = 0.0603 \approx 0.06$$

$$1 = \frac{\xi_0}{0.35}\left[m_{\min}^{-0.35} - m_{\max}^{-0.35}\right]$$

$$\xi_0 = 0.1706 \approx 0.17$$

$$\therefore \quad \Phi(m) = 0.06m^{-2.35}, \quad \xi(m) = 0.17m^{-1.35}$$

Using the above values, the total number of stars is in mass range m_1 to m_2 is

$$n = \int_{m_1}^{m_2} \Phi\,(m)\,dm = \frac{0.06}{1.35}\left[m_1^{-1.35} - m_2^{-1.35}\right]$$

For $m_2 = m_{\max} = 120M_{\odot}$:

$$n = \frac{2}{45}\left[m_1^{-1.35} - (120)^{-1.35}\right]$$

Rearranging for m_1:

$$m_1 = \left[(120)^{-1.35} + \frac{45}{2}n\right]^{-\frac{1}{1.35}}$$

The total mass is:

$$m = \int_{m_1}^{m_2} \xi\,(m)\,dm = \frac{0.17}{0.35}\left[m_1^{-0.35} - m_2^{-0.35}\right]$$

For $m_2 = 120M_{\odot}$:

$$\mathrm{m} = \frac{17}{35}\left[m_1^{-0.35} - (120)^{-0.35}\right]$$

Case 2: $\beta = \mathbf{1.01}$

$$\Phi(m) = \Phi_0 m^{-1.01}, \quad \xi(m) = \xi_0 m^{-0.01}$$

Normalization gives:

$$\Phi_0 = 0.143, \quad \xi_0 = 0.009$$

$$\Phi(m) = 0.143m^{-1.01}, \quad \xi(m) = 0.009m^{-0.01}$$

The total number of stars:

$$n = \int_{m_1}^{m_2} \Phi\,(m)\,dm = \frac{0.143}{0.01}\left[m_1^{-0.01} - m_2^{-0.01}\right]$$

Rearranging for m_1:

$$m_1 = \left[(120)^{-0.01} + \frac{10}{143}n\right]^{-\frac{1}{0.01}}$$

The total mass:

$$m = \int_{m_1}^{m_2} \xi\,(m)\,dm = \frac{0.009}{0.99}\left[m_2^{0.99} - m_1^{0.99}\right]$$

For $m_2 = 120M_{\odot}$:

$$\mathrm{m} = \frac{1}{110}\left[(120)^{0.99} - m_1^{0.99}\right]$$

From these derived equations we have calculated the total number and mass of X-ray transients within specific mass ranges using the mass function and it's normalization. These relations are crucial for stellar population studies and galaxy modeling.

3. Results and Discussion

This study examines how the total mass of X-ray transients changes over various time intervals. By analyzing these variations, we aim to elucidate the underlying mechanisms that govern mass transfer and accumulation in such systems. The temporal perspective adopted here allows for a more comprehensive characterization of the evolutionary behavior of these transients, providing crucial insights into their role within the larger context of high-energy astrophysics. The findings are presented below alongside their relevance to existing astrophysical theories and observations.

Figure 1 shows the total mass of X-ray transients demonstrated a non-linear decrease over the analyzed time periods and number of stars. Significant variability was observed in the total mass down rates after t> 8 milion years after the starbursts. The total mass of X-ray transients demonstrated a decreasing trend over the analyzed time periods. The figure illustrates how the total mass of X-ray transient correlates with the number of stars after a starburst event, for specified time intervals. As time progresses, the total mass decreases, while the number of stars increases. During earlier intervals, such as 5 < t ≤ 7, the mass remained relatively stable with minor fluctuations. However, at intermediate and later intervals (e.g., 14 < t ≤ 16), the mass shows a pronounced decline despite the growing number of stars. This suggests that while new stars are forming, the accretion processes or material available for X-ray transients are diminishing, possibly due to depletion or redistribution([6], [7], [8]).

The figure 1 also reveals variability in mass reduction for different time ranges. At shorter intervals, the mass decrease is gradual, indicating steady loss mechanisms such as radiative winds or donor mass depletion. At longer intervals, the scatter in the data suggests more complex dynamics, possibly influenced by the cessation of accretion or episodic outflows. This highlights the multifaceted nature of mass evolution, where external and internal factors interplay to shape the observed trends.

The data show an inverse relationship between the total mass of X-ray transients and the number of stars over time. Early intervals with higher values are associated with slower mass loss, potentially due to more active accretion ([9],[10],[11]). In contrast, later intervals exhibit steeper declines in mass as increases, suggesting a reduction in available material or the onset of disk instabilities that eject mass from the system. These findings align with theoretical predictions that stellar interactions in dense environments initially sustain accretion before eventual depletion.

The observed decline in total mass over time, accompanied by an increase in the number of stars, reflects the complex lifecycle of X-ray transients. Early stages with relatively stable mass indicate efficient accretion mechanisms, while the subsequent decline suggests the exhaustion of available material or the dominance of outflow processes. These results reinforce the importance of environmental factors, such as star formation history and the local stellar density [12], in shaping the evolution of X-ray transient systems.

Variability in the trends further underscores the dynamic nature of mass evolution. Systems with higher initial values experience prolonged periods of slower mass decline, likely due to sustained interactions with donor stars or dense stellar surroundings. However, as increases, the reduced accretion environment accelerates mass loss, highlighting the transition from active accretion to quiescence.

Comparing these findings with previous studies indicates general consistency while emphasizing the need for high-cadence observations to capture transitional phases. The inverse relationship between and observed in this figure provides a valuable framework for understanding the interplay between accretion efficiency([12],[13],[14]). mass loss mechanisms, and the temporal evolution of transient systems.

In summary, the figure underscores the decreasing total mass of X-ray transients as a natural consequence of accretion lifecycle dynamics, even as the number of stars increases over time. Continued observational campaigns and high-resolution simulations will be crucial in further unraveling the physical processes that govern these complex systems.

4. Conclusions

The analysis highlights a critical aspect of X-ray transient evolution: the inverse relationship between the total mass of X-ray transients and the increasing number of stars following a starburst event. This trend suggests that as the star formation activity intensifies, the accretion processes governing X-ray transients enter a phase of material depletion or redistribution, leading to a decline in their total mass. The findings emphasize the dynamic interplay between accretion mechanisms, disk instabilities, and environmental influences in shaping the lifecycle of these systems. By providing a detailed temporal perspective, this study enriches our understanding of the evolutionary behavior of X-ray transients and their connection to starburst activity. Future investigations incorporating advanced observational techniques and simulations will be pivotal in unraveling the nuances of these processes, ultimately bridging theoretical models with observational realities.

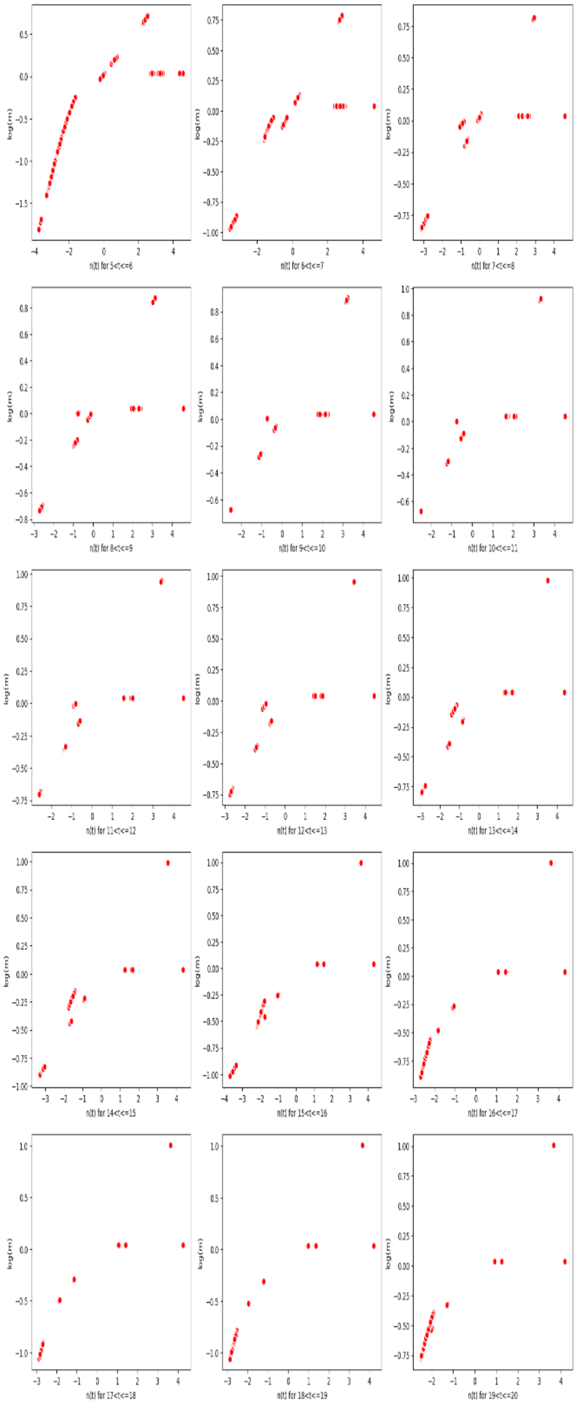

Figure 1: Total mass of X-ray transients versus total number of X-ray transients over different time intervals between 5 and 20 million years after the starburst.

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