THE INITIAL CONDITIONS TO STAR FORMATION:
LOW MASS STARS AT LOW METALLICITY

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Abstract We have measured the present accretion rate of roughly 800 low-mass
\((\sim 1 - 1.4 \, M_\odot)\) pre-Main Sequence stars in the field of SN 1987A in
the Large Magellanic Cloud. The stars with statistically significant
Balmer continuum and Halpha excesses are measured to have accretion
rates larger than \(\sim 1.5 \times 10^{-8} \, M_\odot \, yr^{-1}\) at an age of 12-16 Myrs. For
comparison, the time scale for disk dissipation observed in the Galaxy
is of the order of 6 Myrs.

1. Introduction

From an observational standpoint, most of the effort to characterize
and understand the process of star formation has traditionally been de-
vote to nearby Galactic star-forming regions, such as the Taurus-Auriga
complex, Orion, etc. If this, on the one hand, permits one to observe
very faint stars at the best possible angular resolution, on the other
it is achieved at the expense of probing only a very limited set of ini-
tial conditions for star formation (all these clouds have essentially solar
metallicity, e.g., Padget 1996). Studying the effects of a lower metal-
llicity on star formation is also essential to understand the evolution of
both our own Galaxy, in which a large fraction of stars were formed at
metallicities below solar, and what is observed at high redshifts. With
a mean metallicity of about a third solar, the Large Magellanic Cloud
(LMC) provides an ideal environment for these kinds of studies:
with a distance modulus of 18.57 ± 0.05 (see the discussion in Romaniello et al 2000), the LMC is our closest galactic companion after the Sagittarius dwarf galaxy. At this distance one arcminute corresponds to about 15 pc and, thus, one pointing with a typical imaging instrument comfortably covers almost any star forming region in the LMC (10 pc see, e.g., Hodge 1988);

the depth of the LMC along the line of sight is negligible, at least in the central parts we consider (van der Marel & Cioni 2001). All of the stars can, then, effectively be considered at the same distance, thus eliminating a possible spurious scatter in the Color-Magnitude Diagrams;

the extinction in its direction due to dust in our Galaxy is low, about E(B − V) ≃ 0.05 (Bessell 1991) and, hence, our view is not severely obstructed.

There is currently a widespread agreement that low mass stars form by accretion of material until their final masses are reached (e.g., Bonnell et al 2001 and references therein). As a consequence, the accretion rate is arguably the single most important parameter governing the process of low-mass star formation and its final results, including the stellar Initial Mass Function. Ground and HST-based studies show that there may be significant differences between star formation processes in the LMC and in the Galaxy. For example, Lamers et al (1999) and de Wit et al (2002) have identified by means of ground-based observations high-mass pre-Main Sequence stars (Herbig AeBe stars) with luminosities systematically higher than observed in our Galaxy, and located well above the “birthline” of Palla & Staler (1990). They attribute this finding either to a shorter accretion timescale in the LMC or to its smaller dust-to-gas ratio. Whether such differences in the physical conditions under which stars form will generally lead to differences at the low mass end is an open question, but Panagia et al (2000) offer tantalizing evidence of a higher accretion also for LMC low mass stars.

In this contribution we present the first measurement of the accretion rate onto low-mass pre-Main Sequence stars outside of our Galaxy. The full details of our analysis are reported in Romaniello et al (2004).

2. Measuring the accretion rate

The field of SN 1987A in the LMC was repeatedly imaged over the years with the WFPC2 on-board the HST to monitor the evolution of its Supernova remnant. We have taken advantage of this wealth of data and selected from the HST archive a uniform dataset providing broad-band
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coverage from the ultraviolet to the near infrared, as well as imaging in the Hα line.

The idea that the strong excess emission observed in some Galactic low-mass, pre-Main Sequence stars (T Tauri stars) is produced by accretion of material from a circumstellar disk dates back to the pioneering work of Lynden-Bell & Pringle (1974). The excess luminosity is, then, related to the mass accretion rate. In particular, the Balmer continuum radiation produced by the material from the disk as it hits the stellar surface has been used as an estimator of the mass infall activity (see, for example, Gullbring et al 1998 and references therein).

First, we have identified candidate pre-Main Sequence stars in the field of SN 1987A in the LMC through their Balmer continuum and Hα excesses. We have, then, derived the accretion rate onto the central star with the following equations:

\[
\begin{align*}
L_{\text{acc}} & \simeq \frac{G M_* \dot{M}}{R_*} \left(1 - \frac{R_*}{R_{\text{in}}}\right) \\
\log \left(\frac{L_{\text{acc}}}{L_\odot}\right) & = 1.16 \log \left(\frac{L_{\text{F336W,exc}}}{L_\odot}\right) + 1.24
\end{align*}
\]

The second equation is the Gullbring et al (1998) empirical relation between the accretion luminosity \( L_{\text{acc}} \) and the Balmer excess luminosity, as transformed by Robberto et al (2004) to the WFPC2 F336W filter. The reader is referred to Romaniello et al (2004) for a thorough description of the derivation of \( \dot{M} \).

When interpreted as pre-Main Sequence stars, the comparison of the objects’ location in the HR diagram with theoretical evolutionary tracks allows one to derive their masses (\( \sim 1 - 1.4 \, M_\odot \)) and ages (\( \sim 12 - 16 \) Myrs). At such an age and with an accretion rate in excess of \( \sim 1.5 \times 10^{-8} \, M_\odot \, \text{yr}^{-1} \), these candidate pre-Main Sequence stars in the field of SN 1987A are both older and more active than their Galactic counterparts known to date. In fact, the overwhelming majority of T Tauri stars in Galactic associations seem to dissipate their accretion disks before reaching an age of about 6 Myrs (Haisch et al 2001; Armitage et al 2003). Moreover, the oldest Classical T Tauri star known in the Galaxy, TW Hydrae, at an age of 10 Myrs, \textit{i.e.} comparable to that of our sample stars, has a measured accretion rate some 30 times lower than the stars in the neighborhood of SN 1987A Muzerolle et al (2000).

The situation is summarized in Figure 1, where we compare the position in the age-\( \dot{M} \) plane of the stars described here with that of members of Galactic star-forming regions. An obvious selection bias that affects our census is that we only detect those stars with the largest Balmer continuum excesses, \textit{i.e.} highest accretion rates. There might be stars in the field with smaller accretion rates, either intrinsically or because
they were observed when the accretion activity was at a minimum, which fall below our detection threshold. This selection effect is rather hard to quantify, but it is clear that the locus of the accreting stars that we do detect in the neighborhood of SN 1987A is significantly displaced from the one defined by local pre-Main Sequence stars.

Figure 1. Mass accretion rate as a function of age for Classical T Tauri stars in different star-forming regions (adapted from Muzerolle et al 2000). Our result for the field of SN 1987A is marked with a black square.

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