AGB STARS AS SIGNPOSTS FOR ANCIENT STARBURST ACTIVITY IN THE GALACTIC CENTER

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Abstract

The observed distribution of shell expansion velocities of AGB stars within 50 pc of the Galactic center shows a narrow peak at 19 km/s. We argue from the observables that there is a large population of stars among a more general mixture in the Galactic center that shows similar physical and dynamical properties. We derive M $\lesssim$ 2 $M_\odot$ and thus an age exceeding $\sim$ 1 Gyr. Because of the rapid rotation around the dynamical center and the high age of these stars, we conclude that these stars are tracers of an episode of enhanced star formation, and that our Galaxy has undergone a nuclear starburst in the distant past.

Key words: Masers – Stars: formation – Stars: AGB and post-AGB – Galaxy: center – Galaxy: evolution – Galaxies: starburst

1. Introduction

In order to understand some of the formation and evolution of normal spiral galaxies, it is of crucial importance to trace back the star formation history in our own Galaxy. In particular the Galactic center should give keys to different episodes in the history of galaxy building, although many distinctive clues may have blended, or have gradually been wiped out with time. Complicating the determination of the current (stellar) constituents, an enormous visual extinction hinders the direct view of the stellar population of the Galactic center ($A_V \sim 30$). However, recent surveys in near-infrared and radio wavelengths have yielded some hints on star formation in the recent, and surprisingly also in the more distant past.

Because of the visual extinction and the distance to the Galactic center (8 kpc), the stars that are studied are, in general, the very IR-luminous massive objects; mostly red and blue supergiants. These stars have characteristic life-times in the order of tens of million years. From so-called Helium stars (blue supergiants and Wolf-Rayet stars) one has derived that there must have been a burst of star formation in the Galactic center between 3 and 7 Myr ago. The sample of 'cool' stars (red supergiants and AGB stars) can be used to identify multiple bursts of star formation at earlier epochs: one occurred roughly 30 Myr ago, and other bursts are dated between 100 and 200 Myr, and also more than 400 Myr ago. Conclusions derived from these near-infrared studies thus only reflect the most recent developments ($\leq$ 0.5 Gyr) in the history of the center of our Galaxy.

Stars of low mass, with ages well over 0.5 Gyr (up to $\sim$ 15 Gyr), should contain information on much longer time scales. However, not only are these stars intrinsically weak in the IR, the field in the Galactic center is crowded with such objects. An exception to both constraints is provided by the sample of AGB stars (OH/IR stars and M-type Mira variables). We have performed a sensitive search for such objects within 50 pc of the Galactic center, and detected $\sim$ 50 additional objects. During the analysis of the total sample we were struck by the distribution of expansion velocities ($v_{\rm exp}$) of the 1612 MHz OH maser emission in the circumstellar envelopes. It shows an unexpectedly narrow peak at the high velocity tail at around 19 km/s. From this we conclude that we have found the most massive stellar representatives ($\sim$ 2 $M_\odot$) remaining from an epoch of enhanced star formation, a starburst, more than one Gyr ago (and less than about 4 Gyr ago) in the Galactic center. We estimated that a total of a few 10^7 stars have formed during this event within our field of view of 50 pc of the Galactic center, indicating that our own Galaxy could have been classified as a starburst galaxy in the past. This suggests that most normal spiral galaxies may undergo a phase that has the characteristics of a starburst galaxy.

See Sjouwerman et al. (1999) for an extensive report.

2. Figure 1

In Figure 1 we display the expansion velocity distribution for different samples of OH/IR stars in the Galaxy: the Galactic center (top frame, Sjouwerman et al. 1998), the Galactic bulge (middle, Sevenster et al. 1997) and the combined Galactic disk and anticenter (bottom, Blommaert et al. 1993 and Blommaert et al 1994). In the bottom frame the shaded part shows the contribution of the anticenter data, the histogram is for the combined sets. The shaded histogram in the top panel depicts the fraction of the stars in the bin for which a bolometric magnitude $M_{\rm bol}$ has been measured (Jones et al. 1994, Blommaert et al. 1998, Wood et al. 1998). For example, of the 41 stars in the bin with $v_{\rm exp}$ = 19 km/s, 22 stars have a measured $M_{\rm bol}$. Note that this shaded histogram itself does not show any reference to the value of $M_{\rm bol}$ of the star, just that it

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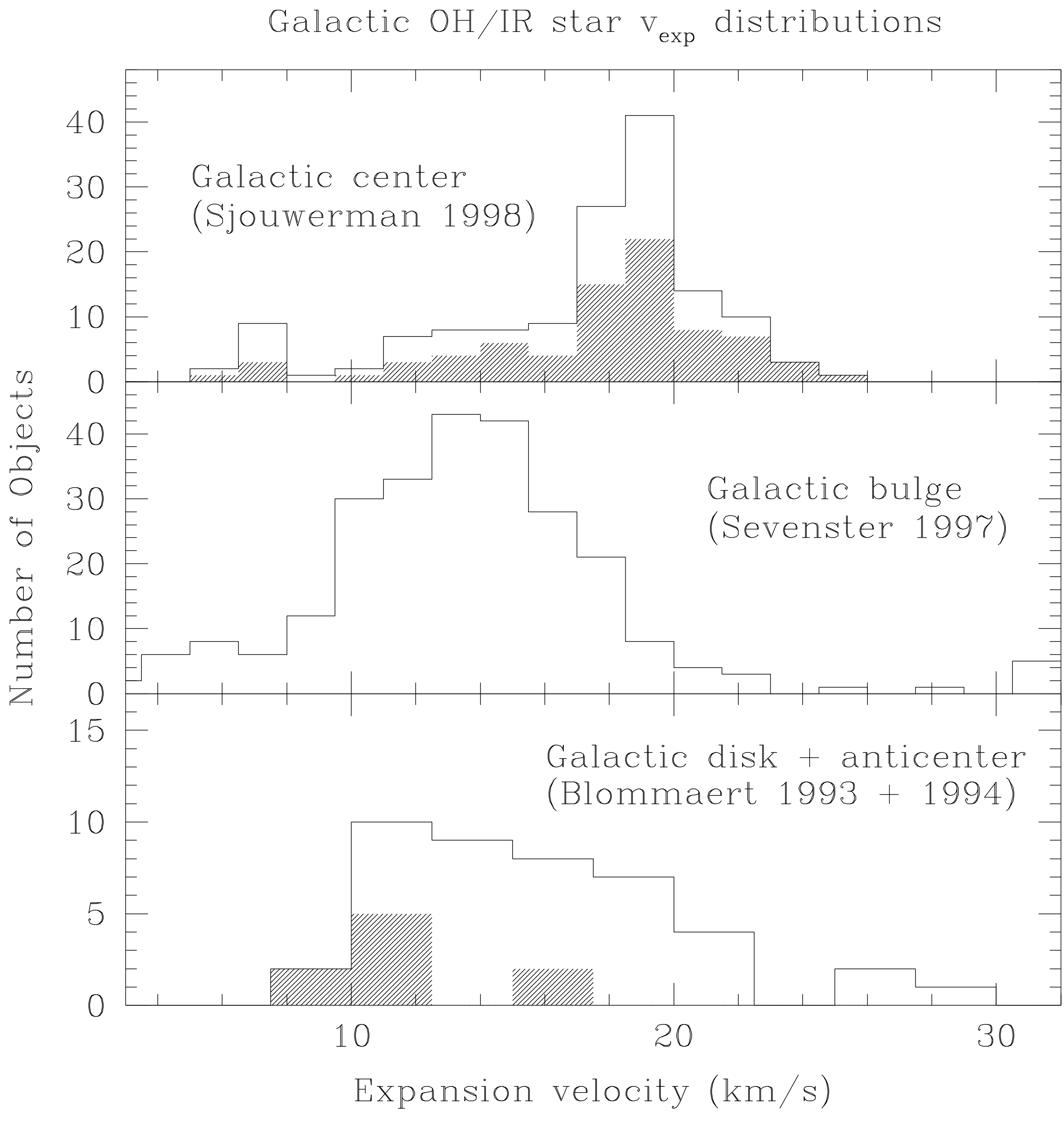

Figure 1. Expansion velocity distribution for OH/IR stars in the Galactic center, the bulge, and the combined disk and anticenter.

is available. Because the shape of the shaded histogram in the top frame follows the histogram itself at about a 50% level, we may assume that the measured values and range in $M_{\rm bol}$ in each bin *roughly* represent the values and range in $M_{\rm bol}$ for all the stars with $v_{\rm exp}$ values of that bin.

Given the observation that the bolometric luminosity from the OH/IR stars in the bulge, on average, is not different from the ones in the center (Blommaert et al. 1998; Wood et al. 1998), the equation

$$v^2_{\rm exp} \propto \delta \cdot \sqrt{L_*} \qquad \text{(Habing et al. 1994)} \qquad (1)$$

shows that the metallicity δ for the OH/IR stars in the center is high. Furthermore, the distribution in the bulge and outer parts of the Galaxy is much broader. We explain this with a mixture of OH/IR stars of different luminosity, metallicity and age, and which is also apparent in the distribution for the central stars. The peak in the distribution for the OH/IR stars in the Galactic center cannot be explained, for example, by the environment (winds, ISM) that would disrupt the maser at low expansion velocities and simultaneously maintain a peaked and high average.

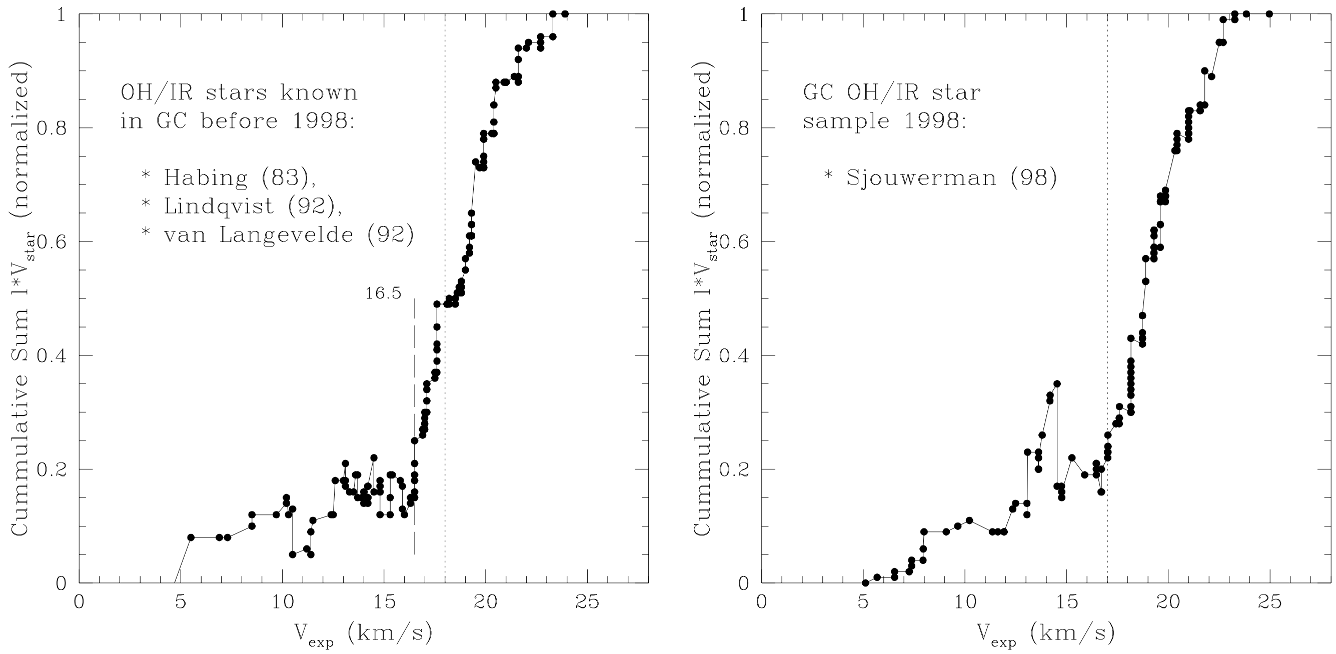

Figure 2. Normalized cumulative sum of $l \times v_{\mathrm{los}}$ as function of v_{exp}. Left the $\approx$ 150 OH/IR stars within 200 pc from the Galactic center known before 1998, right the 1998 sample of $\approx$ 150 stars within 50 pc of the Galactic center. See text for an explanation.

3. Figure 2

By plotting the cumulative sum of $l \times v_{\mathrm{los}}$ as function of v_{exp} in Figure 2, it becomes clear that the OH/IR stars on the high end tail of the expansion velocity distribution rotate rapidly around the center. That is, if a stellar sample follows the rotation curve of the Galaxy ($l \times v_{\mathrm{los}} > 0$), they will add to the cumulative sum. Otherwise, inclusion of counter-rotating stars ($l \times v_{\mathrm{los}} < 0$) will make the cumulative sum to hover around a constant. That is seen clearly in the left hand side diagram for $v_{\mathrm{exp}} < 16.5$ km/s.

Historically, the recognition of a fast rotating, and a non-rotating group of OH/IR stars, has led to a division between the groups, separated by $v_{\mathrm{exp}} = 18$ km/s (in order to get roughly equal samples in Lindqvist et al. 1992). However, the vertical lines in the left hand side diagram of Figure 2 indicate that with this choice, one is "polluting" the non-rotating, low v_{exp}-group with OH/IR stars that clearly belong to the fast rotating group. A division at $v_{\mathrm{exp}} \lesssim 17$ km/s – exactly where the peak in the v_{exp}-distribution arises ! – would have been more proper.

We assume that the steep decline at $v_{\mathrm{exp}} \approx 20$ km/s is caused by the reverse effect that caused the steep rise at $v_{\mathrm{exp}} \approx 17$ km/s. It means that one may identify both OH/IR stars with $v_{\mathrm{exp}} \lesssim 17$ km/s, and OH/IR stars with $v_{\mathrm{exp}} \gtrsim 20$ km/s as part of a general mixture of stars, and that the sample of OH/IR stars with $17 \lesssim v_{\mathrm{exp}} \lesssim 20$ km/s, that of course also contains a fraction of stars from a general mixture, should be investigated separately.

We show our results for observable physical properties of the central star and its expanding shell in Figure 3.

4. Figure 3

Apart from the distribution of stellar pulsation periods (P), one can show that the more peaked distribution of other observables is not likely to be drawn from a linear combination of the distributions from the properties of OH/IR stars with $v_{\mathrm{exp}} \lesssim 17$ km/s, and with $v_{\mathrm{exp}} \gtrsim 20$ km/s. As the total bin for stars with $17 \lesssim v_{\mathrm{exp}} \lesssim 20$ km/s and for stars with $v_{\mathrm{exp}} \gtrsim 20$ km/s is almost the same (3 – 4 km/s), the more peaked distribution in $17 \lesssim v_{\mathrm{exp}} \lesssim 20$ km/s cannot be assigned to narrowing down a bin.

Using equation (1) and a representative M_{bol} distribution, our results indicate that the sample with $17 \lesssim v_{\mathrm{exp}} \lesssim 20$ km/s has an excess of stars that have similar physical properties. That the period of the star does not follow this can be explained by a break-down of the Mira P-L relation for OH/IR stars (Blommaert et al. 1998).

Depending on assumptions of the stellar model, interstellar extinction, etc., we derive that for a star with $M_{\mathrm{bol}} \approx -5$ (or less), the main-sequence mass is 2 $M_{\odot}$ (or less), and the age is $\gtrsim$ 1.1 Gyr (or more). Because the OH/IR stage is a very short lived phase, these "excess" OH/IR stars all have the same mass and age, i.e. just as M_{bol} (L_*) and δ also in a very narrow range. In addition, the $17 \lesssim v_{\mathrm{exp}} \lesssim 20$ km/s group is rotating rapidly and dynamically young (with a high age), indicating that the excess OH/IR stars were formed in a short period of time. We conclude that this is evidence for an epoch of enhanced star formation, probably a nuclear starburst.

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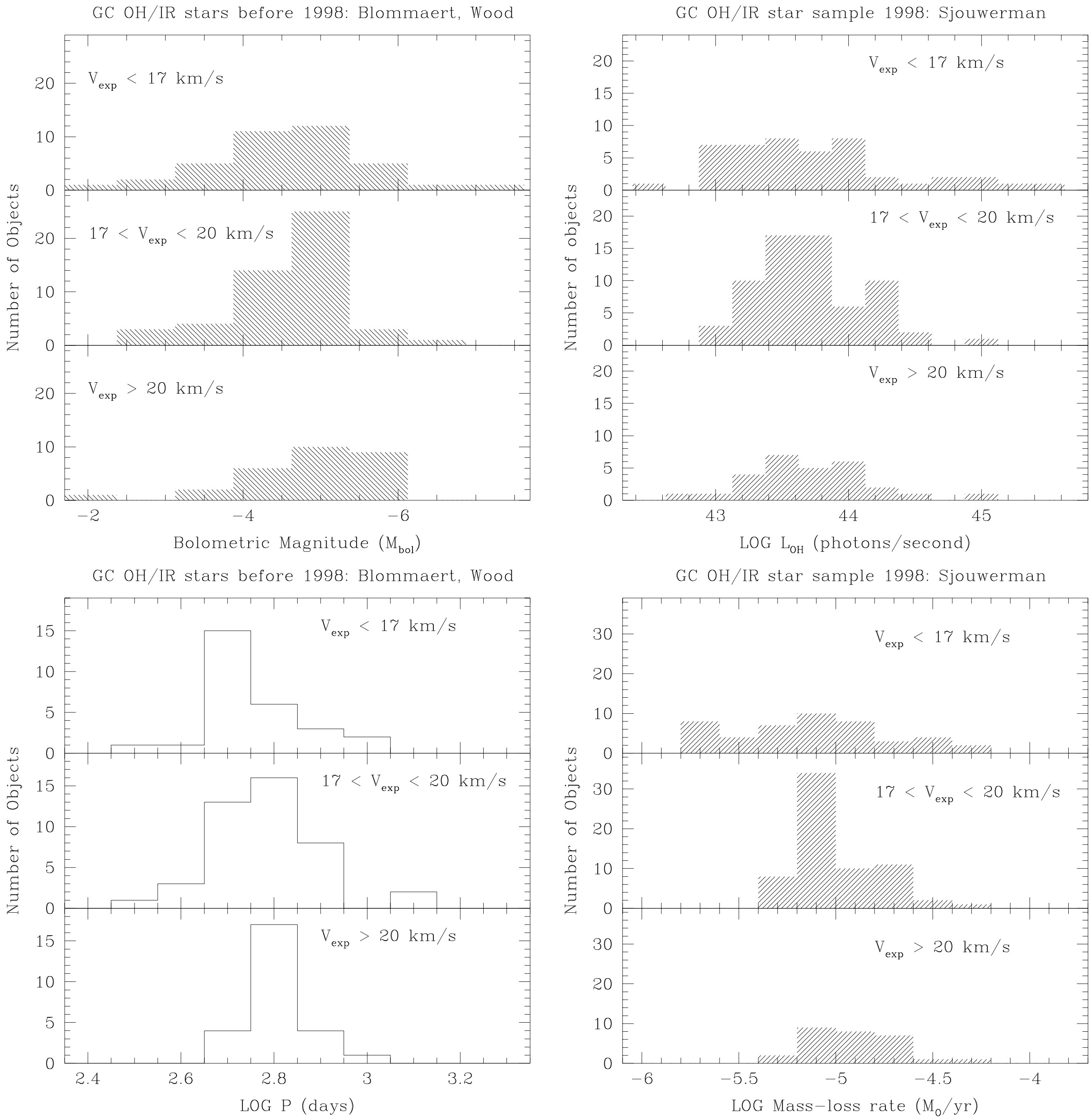

Figure 3. Physical properties of the central star ($M_{\rm bol}, P$) and the expanding OH masing shell ($\dot{\rm M}$, $L_{\rm OH}$) for each $v_{\rm exp}$-group.

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