A *Herschel* and BIMA Study of the Sequential Star Formation Near the W48A Hii Region

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We report a linear age gradient found in the W48A star formation region from age dating based on luminosity-mass diagram together with submm-radio molecular line and continuum data. Also the surroundings of W48A show evidence of an evolutionary gradient suggesting that a large-scale external force, probably the Aquila Supershel, influenced the entire W48 region.

Keywords: mm-interferometry, infrared observations, star formation, W48.

1 Introduction

Sequential star formation is observed in OB associations, on the borders of Hii regions, and is thus expected to be also present in earliest stages of star formation. Observations have shown that early star-forming clouds indeed contain several evolutionary phases of star formation [8, 12]. Determining the age gradients across a star-forming region can give insight into the star formation history and whether or not the gradient is a consequence of triggering.

The W48A star forming region is know to host several different stages of star-formation: a Hii region, a masing young stellar object (YSO), and prestellar cores. To derive age estimations and evolutionary stages of all the star-forming objects in and around W48A we have used new *Herschel* 70–500 μm maps from the HOBYS Key-Programme [7], together with molecular line and continuum BIMA and IRAM 30 m observations, and archival ammonia VLA and continuum JCMT data.

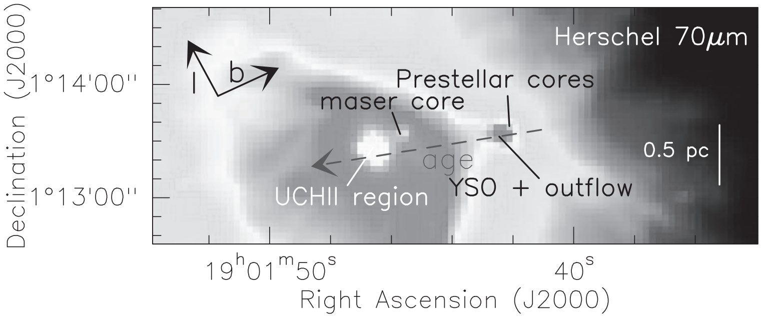

Fig. 1. Age gradient in the W48A star forming region

2 Sequential star formation in W48A

From the *Herschel* and BIMA maps we identified three objects: the UC Hii region, the maser emitting YSO, and a YSO with a CO outflow (Fig. 1). The prestellar cores were not detected, however the cold and dense 'streamers' in which they are situated were.

The first ages of the three detected objects were estimated from a bolometric luminosity-envelope mass diagram [5], in which a position corresponds to a certain age and evolutionary stellar track. The envelope mass was determined by fitting the spectral energy distribution (SED) of the thermal dust continuum including not only *Herschel*, but also the JCMT and IRAM 30 m data, taking into account the free-free contamination by the UCHii region. The bolometric luminosity was determined from this same SED but including also the *WISE* data. The ages determined with this method are $\sim$0.8 Myr for the UC Hii region and the maser source, and 0.15 Myr for the YSO with outflow. All the three objects lie on high-mass star evolutionary tracks.

The UC Hii region age is similar to age estimates from the literature for these kinds of objects ($\sim$0.6 Myr, [6]). Based on the bolometric luminosity we estimate the spectral type of the ionizing star to be O8, in agreement with its radio properties [11]. Age estimates of the maser core, based on class II methanol emission which is thought to be excited before the onset of the Hii region and quenched by the ionizing radiation of the star [14], yield ages less or equal to Hii regions $\lesssim 10^{-1}$ Myr. In addition, the detection of the CH_3CN molecule, commonly found in hot cores, and the absence of any radio emission due to free-free emission of the ionizing star, confirm that this is a massive YSO in a younger evolutionary stage than the UC Hii region. For the high-mass YSO without maser emission we detected a massive collimated outflow. Also this source contained CH_3CN emission, and based on the $[CH_3CN]/[NH_3]$ abundance ratio, which can be used as a chemical clock [3], we estimated an age of $\sim$0.06 Myr, which agrees with typical ages for high-mass YSOs. Finally, the ages of the massive, deuterated prestellar cores found by [9] in the "cold

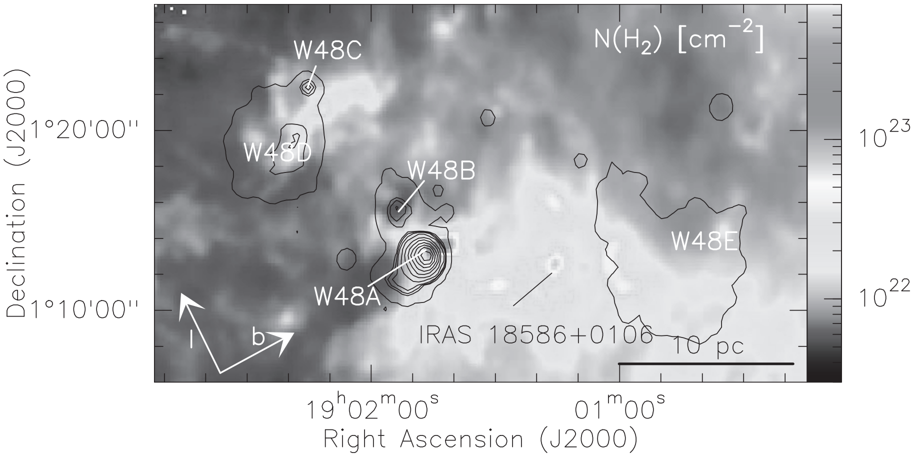

Fig. 2. Age gradient in the surroundings of the W48A star forming region. NVSS 21-cm emission is shown in contours

streamers", should have ages <0.05 Myr [2].

Thus the luminosity-mass diagram ages are a bit higher for the maser core and the YSO with outflow than those derived from the molecular line emission, but agree within one order of magnitude. We thus confirm a linear age gradient in the direction of Galactic latitude (Fig. 1).

3 Sequential star formation around W48A

The age gradient seen in W48A cannot be triggered by the UC Hii region, as the shock wave propagation across W48 is too slow due to the high density. Thus, the star-forming 'seeds' in W48A were assembled before the onset of the Hii region. The observed age gradient in a relatively isolated region, located almost 100 pc ($b = -1.4°$) below the Galactic Plane, suggests the presence of a large-scale external force.

There are several other Hii regions present (W48B–D, see Fig. 2) in the surroundings of W48A. One can estimate the evolutionary state of a Hii region based on the extension of the Strömgren shell, visible by its free-free emission in the radio continuum. Using the NVSS [10] we estimated the ratio of the integrated to peak 21 cm flux of the Hii regions, from which one can estimate the extension of the shell, to find also here an age gradient along Galactic latitude, where W48D is the most evolved Hii region and W48A the youngest. At latitudes higher than W48A, there is another high-mass star-forming region IRAS 18586 ([1], Fig. 2), at the same LSR velocity as W48A, that should be much younger than W48A, since it has no radio continuum emission, nor methanol maser emission. Finally, also the *Herschel* column density (Fig. 2) and temperature maps of the whole W48 region reveal that there is a large reservoir of cold dense gas with a high potential to form gas at $b > b_{\rm W48A}$. The surroundings of W48A thus show the same evolutionary gradient as we found in W48A, confirming a large-scale external force.

The best candidate for this large scale external force is the Aquila Supershell located 6° below the Galactic plane [4]. This supershell is expanding from below into the Galactic plane, forming a cone-like shape which points towards the W48 star-forming regions. The expansion direction matches the direction of the age and evolutionary gradients found in W48A and its surroundings. Also the LSR velocities of this cone observed in HI are overlapping with those of the W48 Hii regions. We therefore consider the Aquila Supershell a very plausible candidate to have swept up the material from which the W48 star-forming regions then formed.

This work has been published as [13].

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