X-shooter Science Verification Proposal

Title: Accreting high-mass protostars

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Abstract:

We have discovered a sample of high-mass protostellar candidates in M17 whose SEDs from $0.3 - 20\,\mu$m yield luminosities between 100 and several 1000 $L_\odot$. Their colors suggest temperatures of 3000 to 7000 K. These properties are in accord with theoretical models of extremely young ($\sim 10^4$ yr), heavily accreting ($10^{-5} - 10^{-3}\,M_\odot$/yr) protostars currently developing into high-mass stars. In addition, the SEDs clearly display IR excess emission probably due to circumstellar disks. We propose to observe some selected objects from our sample to achieve the following goals:

1. We wish to confirm spectroscopically (UBV) our estimates of the effective temperature in order to reveal the nature of the sources by placing them unambiguously onto recent evolutionary tracks.

2. We are searching for ongoing accretion activity by VIS spectroscopy (e.g. Hα, Ca II triplett).

3. The properties of circumstellar disks and outflows can be studied by NIR spectra ([Fe], H_2, CO).

We expect that these objects are in a rare evolutionary stage supporting the high $\dot{M}$ accretion scenario for high-mass stars. Likewise, it would be for the first time that the existence of such young protostellar objects can be confirmed. Their properties make them ideally suited for X-Shooter because they can be investigated **simultaneously** at visual and IR wavelengths.

Scientific Case:

The main difficulty in the formation of high-mass stars is the very strong radiation pressure acting on a dusty envelope. Theoretical work has shown that a typical accretion rate of $\dot{M} \sim 10^{-5}\,M_\odot$/yr, as expected for low-mass protostars, is insufficient to overcome this barrier. Nakano et al. (2000) have suggested a protostar growing at the very high accretion rate of $\sim 10^{-2}\,M_\odot$/yr while Krumholz, Klein & McKee (2007) have simulated the collapse of turbulent cores and derived accretion rates of more than $10^{-4}\,M_\odot$/yr. If a high accretion rate of $\sim 10^{-4}\,M_\odot$/yr is indeed achieved in massive star formation, stars as massive as $10\,M_\odot$ have not yet arrived at the ZAMS at the end of the accretion phase. These PMS stars are very luminous with $L > 10^4\,L_\odot$ and their effective temperature is much lower than that of the ZAMS stars. **Until now, no such object has yet been firmly detected!** One explanation for the lack of detection is the very short Kelvin-Helmholtz timescale $t_{\rm KH}$ of such PMS stars. For example, in the case with $\dot{M} \sim 10^{-3}\,M_\odot$/yr, $t_{\rm KH}$ falls below 10^4 yr for $M > 10\,M_\odot$ (Hosokawa & Omukai 2008).

We have discovered a number of deeply embedded candidates ($10 < A_V < 20$) in M17 which seem to comply with major predictions from the high $\dot{M}$ scenario. Most of the sources have luminosities between several 100 and 1000 $L_\odot$ as derived from multi-color photometry ($0.5 - 20\,\mu$m) and crude effective temperatures between 3000 and 7000 K as obtained from SED fits. These properties place our objects tentatively onto evolutionary tracks with $\dot{M} \sim 10^{-5} - 10^{-3}\,M_\odot$/yr. The evolutionary stage of our protostellar candidates fall in between luminous high-mass cores and ultra-compact HII regions, as witnessed by signatures of infall motion, detected through various line observations (e.g. Keto & Wood 2006).

We wish to X-Shooter obtain spectra for 10 selected high-mass protostellar candidates. For the UBV spectral range we propose a slit width of 1.6 with a resolution of $R = 3300$, which comprises a fair number of lines – sensitive to a temperature range of 3000 to 10.000 K (e.g. Jacobi & Hunter, 1984 or Allen & Strom, 1995). For the VIS spectral range we will use a slit width of 0.9 with a resolution of $R = 8800$, which will trace in particular the shape of accretion sensitive lines like Hα and the Ca II triplet; further temperature and pressure sensitive lines will help to constrain the properties of the stellar photosphere. Eventually, in the NIR range at a resolution of 5600 we will be able to check for H_2, forbidden Fe lines and for signatures of circumstellar disks as e.g. hydrogen lines or the $2.3\,\mu$m CO band heads. From the data we will infer the following new results:

• The optical spectra will considerably improve our so far crude estimates of the effective temperatures of the protostars and thus confine their location on recent evolutionary tracks.

• With proper temperatures at hand, the correction for interstellar extinction is much more reliable providing an even better estimate of the protostellar luminosity.

• The Hα and Ca II line profiles will give unambiguous evidence for the expected heavy accretion and will maybe even constrain the mass accretion rate.

• The CO band head feature (emission or absorption) will reveal some properties of the circumstellar material. Depending on the inclination of the disks we expect to see double-peaked hydrogen lines. H_2 and forbidden Fe emission will be a unique probe for shocked gas in jets or outflows.

In summary, X-Shooter data would ideally complement our existing photometric results for some of the most remarkable high-mass protostars and would allow a unique determination of their evolutionary stage.

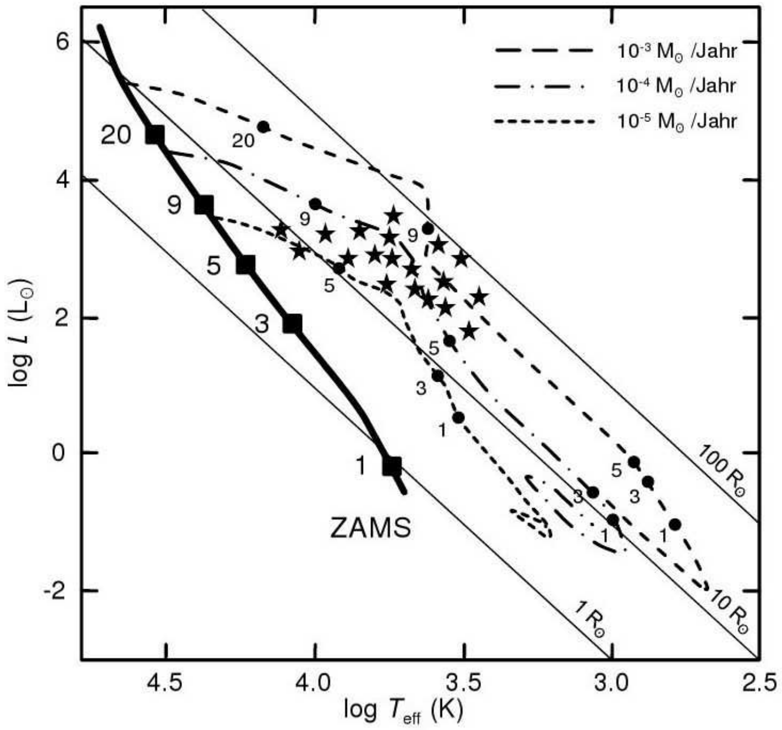

Figure 1: Fig. 1: The stellar birthlines for different accretion rates (adapted from Hosokawa & Omukai 2008). The asterisks denote the most probable locations for our accreting high-mass protostellar candidates. The cases for accretion rates $10^{-3}\,M_\odot$/yr (dashed), 10^{-4} (dot-dashed), 10^{-5} (dotted) are presented. Each track shows the evolution from the initial model, and filled circles on the tracks represent points of the stellar mass $M = 1, 3, 5, 9$, and $20\,M_\odot$.

Target	**RA**	**DEC**	**V** mag	**Mode** (slit/IFU)	**Remarks**
M17	18 17 30	-16 10 00	16 - 19	slit	10 high-mass protostars

Time Justification:

Using the X-shooter ETC Version 3.2.8. and a range of blackbody temperatures between 3000 and 7000 K as suggested by our multi-wavelengths photometry, we have checked the integration times for a brightness range of $16 < V < 19$ (adopting standard conditions, i.e. Airmass 1.2, Seeing 0.8"). We will observe in a nod on slit sequence ABBA. Including the overheads acquisition and setup as well as for the telescope offsets, we end up with about **1 hour** per object. Due to the fact that we cannot really favor one of our candidates over the other, we suggest to observe 5 sources from the sample in order to increase the chance to hit the jackpot. Therefore we apply for **5 hours of telescope time**.