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# VLTI + MIDI STUDY OF THE HIGH MASS PROTOSTELLAR CANDIDATE NGC 3603 IRS 9A

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RESUMEN

La formación y evolución temprana de estrellas gran masa está entre los temas más "calientes" en astrofísica. Los estudios interferométricos de estas estrellas jovenes y de sus ambientes circunestelares (envolturas, discos y jets) en las longitudes de onda del infrarrojo cercano y medio aún son escasos y en términos de su análisis de datos/interpretación muy desafiantes. Aquí reportamos sobre observaciones del candidato protoestelar de alta masa NGC 3603 IRS 9A que emprendimos con VLTI + MIDI en el 2005, complementado por imágenes en el infrarrojo cercano y medio y datos espectroscópicos. Discutimos nuestros resultados obtenidos mediante dedicados esfuerzos de modelado, empleando ambos códigos DUSTY y MC3D de transferencia radiativa para un número seleccionado de geometrías de la fuente y distribuciones superficiales del brillo.

ABSTRACT

The formation and early evolution of high mass stars is among the hottest topics in astrophysics. Interferometric studies of these young stars and their circumstellar environments (envelopes, disks and jets) at near and mid infrared wavelengths are still rare and in terms of data analysis/interpretation very challenging. We here report on observations of the high mass protostellar candidate NGC 3603 IRS 9A which we undertook with VLTI + MIDI in 2005, complemented by near and mid infrared imaging and spectroscopic data. We discuss our results obtained from dedicated modeling efforts, employing both DUSTY and MC3D radiative transfer codes for a selected number of source geometries and surface brightness distributions.

*Key Words:* stars: early-type — stars: formation — stars: pre-main sequence — techniques: high angular resolution — techniques: interferometric

## 1. INTRODUCTION

There is growing evidence that high-mass stars are forming in a way similar to their lower mass counterparts, through accretion from a surrounding disk of gas and dust (e.g., Chini et al. 2004; Patel et al. 2005; Jiang et al. 2005; Cesaroni et al. 2005; Beltran et al. 2006). However, all these high mass protostellar candidates have at best a spectral type of early B (e.g., Shepherd et al. 2007; Nielbock et al. 2008). In addition, as the central stellar object is usually not visible directly due to heavy extinction by dust, the ultimate convincing case of a high mass star - disk system, where the stellar mass has been determined directly (e.g., by spectroscopy), is still missing.

In a comprehensive multi-wavelength study of the Galactic starburst region NGC 3603 we have successfully searched for high mass protostellar candidates (Nürnberger & Petr-Gotzens 2002; Nürnberger et al. 2002; Nürnberger & Stanke 2003; Nürnberger 2003, 2008). For one of these sources, NGC 3603 IRS 9A, our data indicate that it might be the first and desperately sought-after protostar of spectral type O. Although its pristine molecular cloud core has been dispersed / displaced already (due to strong stellar winds and energetic radiation from the nearby high mass main sequence stars of the NGC 3603 OB cluster), IRS 9A is still surrounded by gravitationally bound material within a rather massive disk - envelope system ($A_K \sim 2$ mag). Fortunately, today's state-of-the-art near and mid IR instrumentation allows to overcome such extinction values, and to probe the central protostar and to characterize its circumstellar material through sensitive imaging and spectroscopy at high angular resolution. In this context, interferometry at near and mid infrared wavelengths (e.g., with MIDI and AMBER at the VLTI) has developed into a very useful and mature tool during the last few years.

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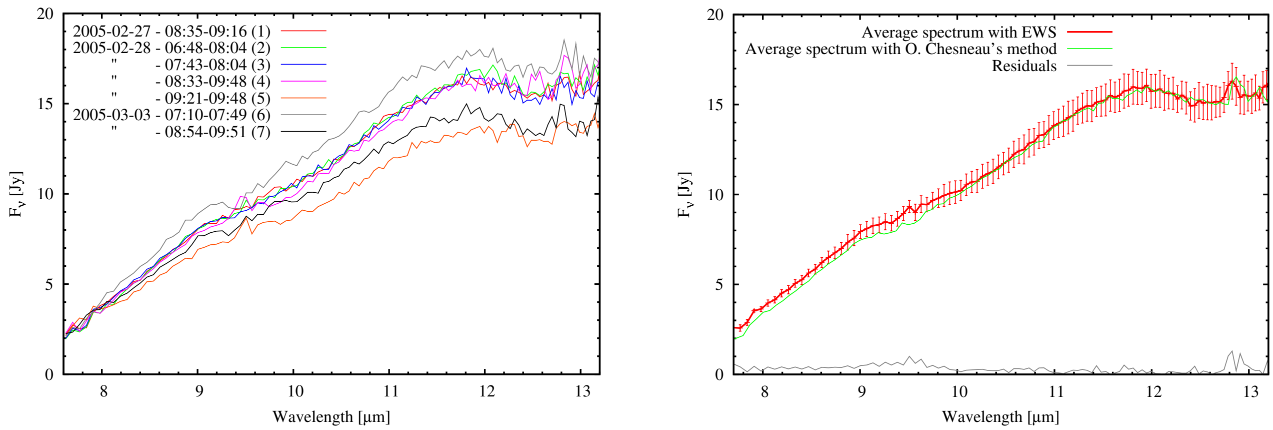


Fig. 1. *Left:* Spectra of the seven individual MIDI measurements of IRS 9A, as obtained with EWS. The legend indicates the date of the observation, together with the time of the photometric measurement of both IRS 9A and the associated standard star HD 107446. *Right:* Comparison of the mean spectrum of IRS 9A obtained with EWS to the one obtained with Chesneau's flux calibration method. The error bars are the standard deviations resulting from the seven individual measurements.

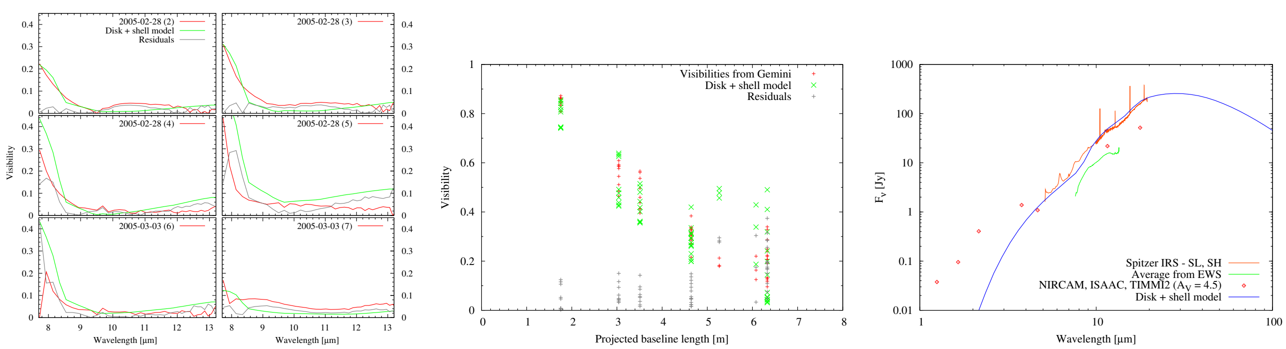


Fig. 2. Best model results obtained for IRS 9A using a disk + shell model from MC3D. *Left and center:* Comparison of the model results to the visibilities measured with MIDI and GEMINI, respectively. *Right:* The same disk + shell model gives a rather good representation of the overall SED of IRS 9A.

## 2. OBSERVATIONS AND DATA REDUCTION

During three nights in February and March 2005 we made use of the unique capabilities (high angular resolution and high sensitivity) offered by VLTI and observed IRS 9A (together with an appropriate standard star, namely HD 107446) with MIDI on the UT2 – UT3 and UT3 – UT4 baselines. In total, 7 sets of calibrated visibilities were obtained. For subsequent data reduction and analysis, the dedicated IDL code OYSTER was used in combination with the two software packages MIA (MIDI Interactive Analysis) and EWS (Expert Work Station). More details on observation and reduction of these MIDI data can be found elsewhere (Vehoff 2009; Hummel et al., in preparation).

## 3. MODELING EFFORTS AND RESULTS

Figure 1 shows the individual flux calibrated spectra (left panel) and the mean spectrum (right panel) of IRS 9A extracted from our MIDI data using EWS. Within the covered wavelength range of 8–13 $\mu$m, the MIDI spectrum of IRS 9A rises steeply with increasing wavelength and appears mostly featureless (no silicate feature), except for a clear detection of the [Ne II] 12.81 $\mu$m line. The calibrated visibilities of IRS 9A, as obtained with EWS from our individual MIDI measurements (see Figure 2, left panel), are always smaller than 0.1 above a wavelength of 9 $\mu$m, indicating that at these wavelengths IRS 9A is fully resolved by our MIDI observations on spatial scales of 30–95 mas.

In contrast, a more compact structure emerges at wavelengths below 9 $\mu$m, for which the visibilities reach values up to 0.4 for some of our measurements.

The sparse coverage of the u-v plane obtained with optical/infrared interferometry does usually not allow image reconstruction, but calls for (radiative transfer) models to obtain more detailed information about source structure and / or kinematics. In the case of IRS 9A, suitable models should be able to reproduce simultaneously: (1) the MIDI visibilities, (2) complementary visibilities obtained from GEMINI aperture masking, (3) the overall SED of IRS 9A and, (4) the overall source morphology deduced from complementary imaging and spectroscopy.

To achieve these goals, rather complex models need to be applied, covering a large parameter space (e.g., source geometry, size and composition of dust grains). Rather simple solutions (e.g., spherical symmetric disk models from DUSTY) do not fulfill the above requirements. Instead, we obtained our best results with a fully three-dimensional disk + shell model from MC3D (see Figure 2). More details on our modeling efforts and the obtained results can be found elsewhere (Vehoff 2009; Hummel et al., in prep.).

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