# Search of HH objects and outflows in Auriga-California Giant Molecular Cloud

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## Introduction

**The Auriga-California molecular cloud (AMC)** is located at a distance of about 450 pc (Lada, Lombardi, & Alves 2009). In contrast to the Orion A molecular cloud, this giant molecular cloud is notable for its relatively quiescent star formation.

The brightest nebulous object in the AMC is probably the Herbig emission-line star LkHα 101. In the infrared, the heavily reddened LkHα 101 is one of the brightest young stars in the sky.

The AMC has been actively studied in dozens of papers (see the review by Andrews & Wolk 2008). It is associated with a group of Hα emission-line stars and at least five B-type stars (Herbig et al. 2004). It is now widely accepted that young stellar objects undergo phases of mass outflows, which play an essential role in the process of star formation. In the visual range, these mass outflows manifest as Herbig-Haro (HH) objects. Despite multi-year investigations, no HH objects had been found in the AMC until recently.

As part of the Byurakan Narrow Band Imaging Survey **(BNBIS),** a search for Herbig-Haro (HH) objects in the Auriga-California Molecular Cloud (AMC) was conductedIn using 1m Schmidt telescope of Byurakan observatory.

Additionally, we use SEIP IRAC and unWISE data to identify molecular hydrogen objects (MHO) and outflows.

## Observations

Observations were performed from 2022 to 2024 using the 1-meter Schmidt elescope of Byurakan Observatory. As a detector, we used the 4K Œ 4K Apogee (USA) liquid-cooled CCD camera, which has a pixel size of 0.868" and a field of view of approximately 1°. Narrowband filters centered on 6560˚A and 6760˚A, both with a FWHM of 100˚A, were used to obtain Hα and [SII] images, respectively. A medium-width filter, centered on 7500˚A with a FWHM of 250˚A, was used for the continuum imaging.

The search for HH objects was done with the classic technique, suggested in 1975 by van den Bergh(1975), by comparison of Hα, [SII] and I-continuum images. Over the years, this has been shown to reliably identify HH objects in the overwhelming majority of cases. The observations covered three regions in the central part of the Auriga-California molecular cloud, as shown in Fig.2.

Fig. 1. 1m Schmidt telescope (left) and detector with filter wheels (right)

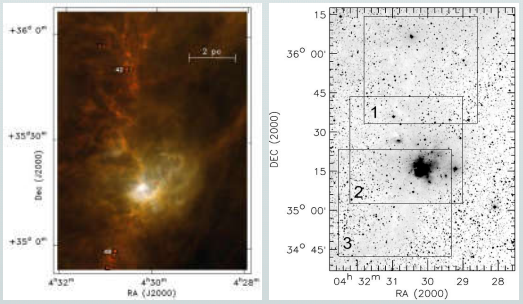


Fig. 2. HERSCHEL false color image with 70μm (blue), 160μm (green), and 250μm (red) of the LkHα101 area and star-forming filament to its north (left panel). DSS2R image of the area with three obseved fields marked by rectangles (right panel)

The Auriga-California Molecular Cloud (AMC) contains an extended region of more than 2° characterized by relatively modest star formation activity. Our observations covered three fields that trace a star-forming filament stretching in the north–south direction, composed of young stellar objects (YSOs; Harvey et al. 2013).

The first field was centered on the young stellar object LkHα 101 (hereafter referred to as the **center** field).

The second field, located about 1° north of LkHα 101, includes far-infrared sources as well as nebulous stellar objects (**north**).

The third field is centered on the young stellar object V347 Per and a group of **Herschel** sources located approximately 30′ south of LkHα 101 (see Fig. 8 in Harvey et al. 2013, **south** field).

In Fig. 1, a DSS2R image of the AMC is shown, with superimposed rectangles indicating the three observed fields using the 1m Schmidt telescope. Below, we discuss each of these fields in detail.

### Central field

We have already published the newly discovered outflow system with a chain of HH objects (HH 1228) to the east of Gaia DR3 1733698638927013 12 (Movsessian et al. 2024). This system clearly visible in SEIP IRAC2 images and, apparently, its source is WISE J043041.16+352940.7 associated with well-defined cone shape infrared reflection nebula, the axis of which is directed toward the HH 1228 flow and its molecular analogue (see Fig. 4, upper side).

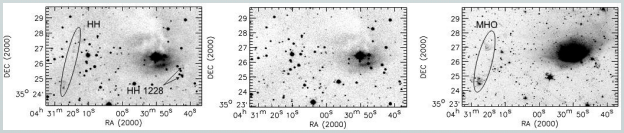


Figure 6.Hα+ [SII] image of the HH flow, located to the north of LkHα101 marked by ellipse. The probable source WISEA J043041.15+352941.4 is outside of the upper border of this

### Northern field

North of LkHα101 stretches a star-forming filament, in which there are several young stellar objects (Harvey et al. 2013; Broekhoven-Fiene, Matthews, & Harvey 2013) as well as nebulous stars surrounded by wisps of dark matter (see the review of Andrews & Wolk(2008)) which have never been studied in detail. In particular, no HH objects were found in this region. Our observations have identified several HH knots, which are mainly associated with deeply embedded YSOs. On the Fig2 the images of northern field in Hα plus [SII], continuum obtained with Schmidt telescope as well as Stitzer SIEP IRAC2 images are shown. Newly discovered HH objects and suspected molecular hydrogen sources (MHO) are marked by arrows.

### Southern field

During narrow-band observations of this region only one week emission knot was discovered about 4' west from nebulous young stellar object V347 Per and the group of HERSCHEL FIR sources. V347 Per is the brightest member of this group of FIR sources in the optical range. We examined this compact group of FIR sources using Spitzer IRAC2 images and revealed jet-like structures. A similar pattern is visible in the unWISE W2 image. To better highlight the extended emission structures, a difference unWISE W2-W1 image, is shown in Fig.8.

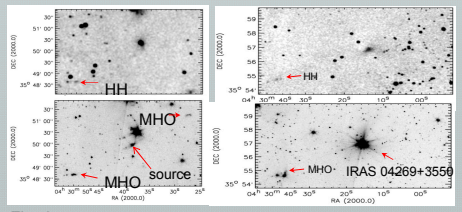


Fig. 2. Hα + [SII] images of two fields **- 2MASS J04303831+3549591** (left top panel) and **IRAS 04269+3550** (right top panel). Spitzer SEIP NIR inages of the same fields (bottom panels).

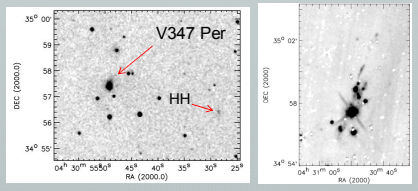


Fig. 2. Hα + [SII] images around V347 Per (left panel) and Spitzer SEIP NIR continuum subtracted image indicating jet – like structures. This group represents a nest of HERSHEL sources.

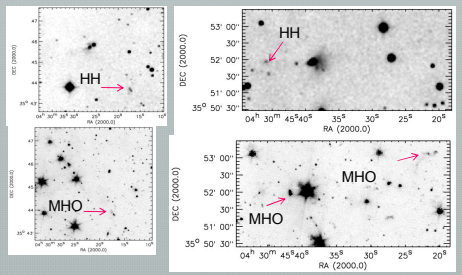


Fig. 2. Hα + [SII] images of two fields **- 2MASS J04302467+3545204** (left top panel) and 2MASS J04303916+3552038 (right top panel). Spitzer SEIP NIR inages of the same fields (bottom panels).

### Conclusion

- First of all this work demonstrates that the 1-m Schmidt telescope of Byurakan Observatory, which was used several decades ago for well-known surveys of active galaxies such as the First Byurakan Survey and Second Byurakan Survey, can still lead to important discoveries.
- During our survey in the AMC were discovered about 5 new HH objects and outflow systems.
- Additionally new molecular hydrogen objects and jets were found using Spitzer SEIP IRAC2 images in the regions were found new HH objects.
- Some of MHOs represents counterparts of newly discovered HH objects.

### References

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