Star Formation in Lynds Dark Nebulae

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Our team observed two Lynds clouds (LDN 425 and LDN 981) using the Spitzer Space Telescope IRAC (3.6, 4.5, 5.8, and 8 microns), and MIPS (24 microns). A preliminary literature search provided IRAS data indicating star formation may be taking place in LDN 425 and LDN 981. The goals of this project were to further explore the known young stellar objects (YSOs) in the two clouds and to search for additional embedded YSOs. In this poster we present our observational methods and the results of our observations including SEDs, color-color diagrams, and color composite images. This research was made possible through the Spitzer Space Telescope Research Program for Teachers and Students and was funded by the Spitzer Science Center (SSC) and the National Optical Astronomy Observatory (NOAO). Please see our companion education posters by McDonald et al. titled "Spitzer - Hot and Colorful Student Activities" and Guastella et al. entitled "Research Based Astronomy in the Classroom: Lessons Developed for Investigating YSOs Using APT, Excel, MaxImDL, and MOPEX".

Background

Dust is found everywhere in the universe. It is in our houses and in large areas of our Galaxy and the Universe, dating all the way back to nearly the beginning of time (e.g., Yan et al. 2005). This dust was formed initially from massive short-lived stars such as Cassiopeia A (e.g., Rho 2008). Dust can also be formed from old, dying stars that used to be like our Sun. Dust found in molecular clouds is crucial to the star formation process because it allows the gas to cool down enough so that clumps of the cloud can condense into pre-stellar cores under the influence of self-gravity. From there, the cores evolve into YSOs, which will consist of the central protostellar object and a circumstellar disk of dust. The circumstellar disk of dust associated with the YSOs can be used to make planets, and possibly provide the foundation for life itself.

Additionally this pervasive dust collects in large areas all over our galaxy. In 1962, Beverly Lynds undertook a general survey of dark nebulae based on Palomar Schmidt photographs (Lynds 1962). Lynds determined the RA and DEC of the center of the cloud and made visual estimates of the opacity of each cloud. A scale of 1 to 6 was used with the higher the number associated with the greater (visual) opacity.

Recent research on star formation in large molecular cloud complexes, such as the Cepheus Flare (Kun 1995), Orion, Perseus (Rebull et al. 2007), and Taurus molecular clouds, have included studies of a number of LDN. Less attention has been given to isolated Lynds clouds, such as LDN 1616 (Cooksey 2001) and LDN 981, located in Cygnus. LDN 981 has a linear structure, with several filaments radiating out from a central core, one of which terminates in V1331 Cyg, a known YSO. Quanz et al. (2008) studied this region near V1331 Cyg; it may be a member of a group of YSOs that has recently emerged from this dark nebula.

What could have prompted star formation in this nebula? Scattered supernova remnants can be found at various locations within Cygnus. These include the Cygnus Loop (Veil nebula) and one discovered in 2000, SNR G069.0+02.7 (Mavromatakis 2002). Cygnus OB associations are members of a group of massive stars, some of which have produced supernovae with resultant shock waves and cavities in the ISM (Plüschke 2002). Could a slightly earlier episode of this have resulted in star formation in LDN 981 that remains as of now undetected?

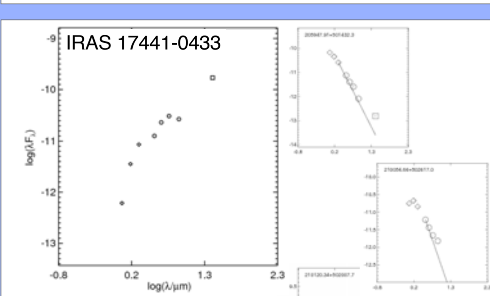
Another isolated dark nebula is LDN 425. While it is not directly associated with any molecular cloud complex, there is mention of an extended distribution of dust between the main clouds in Chamaeleon, Lupus and Ophiuchus (Sartori 2000). Ophiuchus is another region of active star formation, much of which is localized in a region centered on ρ Oph. According to Wilking (1992), the Ophiuchus molecular cloud complex is one of the most prominent areas of star formation for low to intermediate mass stars. Padgett et al. (2008) recently presented Spitzer/MIPS data over a 14.4 square degree map of the entire Ophiuchus molecular cloud, finding more than 300 YSO candidates. Could LDN 425 be part of this "extended dust distribution" and be on the fringes of the Ophiuchus star formation region?

Both LDN 981 and LDN 425 are small, isolated, dark molecular clouds that could contain regions of active star formation within them; both are associated with IRAS sources, and based on prior shallow surveys, they both have a YSO candidate in the neighborhood. Spitzer observations with IRAC and MIPS allowed us to see deep inside the cloud, deeper than any prior observations could, and possibly revealed hidden star formation that is ongoing in these clouds.

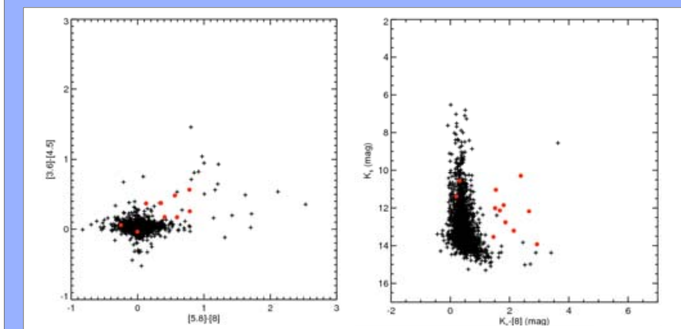
LDN 425

Lynds 1962 reports galactic coordinates L(II)-21.6, B(II)-12.30
RA 17:44.2, DEC -4:40 [1950], Opacity class 5

LDN 425 is an irregularly shaped Class 5 Dark Cloud containing IRAS 17441-0433. The possibility of a YSO near the region was speculated by Carballo in 1992 and later confirmed in papers by Connelley et al. (2007) as well as Lee and Myers (1999). Connelley observed a spatially resolved near-infrared source that suggests an YSO due to its K-band morphology; they think it is a reflection nebula. Our IRAC and MIPS observations revealed the illuminating object. IRAC total time is 657 seconds (36 sec per position) and the MIPS-24 total time is 395 seconds (72 sec per position).



SEDs for IRAS 17441-0433 (in LDN 425) and for three new YSO candidates in LDN 981. In all figures, $\lambda F\lambda$ is in ergs/s/cm2, and λ is in cm; diamonds are 2MASS data, circles are IRAC data, and squares are MIPS-24 data. In the new YSO candidates, there is an additional Rayleigh-Jeans slope provided to guide the eye for expected photospheric fluxes, e.g., points above this line are indicative of IR excesses.



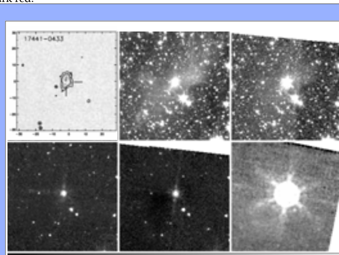
IRAC color-color diagram (left) and IRAC+2MASS color-magnitude diagram (right) for LDN 981. Potential YSOs have colors much redder than the (much more numerous) stars without infrared excesses, which are found in the locus of points with zero color. The red dots are potential YSOs selected from any of 5 different color-magnitude criteria.

LDN 981

Lynds 1962 reports galactic coordinates L(II)-89.92, B(II)-2.87
RA 20:58.0, DEC +50:0 [1950], Opacity class 6

LDN 981 is described as a "roughly elliptical core with five elongated dark filaments" (referred to as F1-F5), where, located at end of one finger, about 8′ long, is V1331 (Quanz et al. 2007). LDN 981 has a distance of 700 pc (Lee and Myers 1999). V1331 Cyg, which seems to be associated with LDN 981, has distances reported from 694 pc (Chavarria 1981) to 550 pc (Shevchenko et al. 1991). With V1331 Cyg having two rings of dust, it is suggested to be a pre-outburst FU Ori candidate (Quanz et al. 2007). The IRAC total time is 2152 sec (36 sec per pt), and the MIPS-24 total time is 1191 sec (72 sec per pt).

Composite image of LDN 981 using Adobe Photoshop and FITS Liberator by Jennifer Butchart, OCHS. IRAC-1 (3.6 um)=dark purple; IRAC-2 (4.5 um)=dark blue; IRAC-3 (5.8 um)=green; IRAC-4 (8 um)=orange; MIPS-1 (24 um)=dark red.



Morphology of IRAS 17441-0433 in LDN 425 at (left to right, top to bottom), deep K (reverse greyscale, from Connelley et al. 2008, 1′ on a side; note different scale compared to the other images, which are all ~5.5′ on a side), IRAC-1 (3.6 um), IRAC-2 (4.5 um), IRAC-3 (5.8 um), IRAC-4 (8 um), and MIPS-1 (24 um). (North is up in all cases.) The source is resolved at K-band (2.2 um) and 3.6 um, and possibly 4.5 um as well. There is additional nebulosity seen at 3.6 and 4.5 microns.

Discussion

LDN 425: The previously-known YSO was clearly detected in LDN 425; our observations provide a first look at this object in the mid-IR bands. Comparing the deep K-band image from Connelley et al. (2008) to ours, an interesting morphology can be seen. This object is resolved at both 2.2 and 3.6 microns; see below left. Its SED also appears on the lower left. Its shape indicates substantial IR excess, and suggests that this source is dusty. The apparent slight discontinuity in the SED between the near-IR and mid-IR suggests some intrinsic source variability. We would like to model this source and obtain more deep imaging in optical/NIR wavelengths. In this cloud, we detected two additional objects with colors suggestive of Class II YSOs.

LDN 981: LDN 981 does not have any previously known YSOs in the region covered by all bands of our observations. However, by looking for the red objects (looking for infrared excesses), we find 13 candidate YSO candidates with small excesses in at least one band. SEDs for three of these objects are included in this poster.

Future work: We would like to pursue follow-up optical spectroscopy to verify that our found candidate objects are indeed YSOs and not just background objects.

Spitzer Research Program for Teachers and Students

The Spitzer Space Center (SSC) and the National Optical Astronomy Observatory (NOAO) are working together to provide teachers and students with authentic science experiences using observing time on the Spitzer Space Telescope. The main goal is to inspire students to pursue STEM careers, as well as to engage the public in sharing the experience of exploration and discovery. These goals are consistent with some of the IYA 2009 goals.

More information can be found on the Cool Cosmos website:
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/teacher_research
or our wiki: https://coolwiki.ipac.caltech.edu/

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