在 Taurus 分子雲中尋找 VeLLO

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摘要

觀測原始恆星剛誕生時的物理狀況,對於研究恆星形成的過程是非常重要的。根據Spitzer太空望遠鏡所觀測到的資料，在分子雲之中，有些灰塵聚集所形成的分子雲核裡,發現非常黯淡的星體 (亮度小於0.1倍 $L_{\odot}$),我們稱之爲VeLLOs (Very Low Luminosity Objects)。因此，對於研究早期恆星的形成，這些VeLLOs是絕佳的觀測目標。除此之外，這些VeLLOs被認爲有可能是質量很輕的原始恆星甚至是原始棕矮星。而因爲Taurus分子雲是最靠近我們的分子雲之一，從Taurus裡尋找這些VeLLOs，對於研究它們有著高解析度的優點。我們採用Dunham在2008年的論文裡所使用尋找VeLLOs的方法，他所使用的條件是根據第零以及第一階段原始恆星的光能分佈圖(Spectral Energy Distribution)所建立。但是，雖然Taurus有著距離近的優點，卻也有著低消光的缺點，這個缺點迫使我們會觀測到非常多的背景銀河系。這些背景銀河系的距離非常地遠，若只有使用光能分佈圖的方法，背景銀河系會參雜在我們想要觀測的VeLLOs裡。我們利用在別的分子雲中，所發現的VeLLOs來做了比對,發現 [5.8] - [24.0] > 4這個星色可以用來區分VeLLO以及背景銀河系。最後，我們從Taurus的資料裡選出了九顆通過這些條件的VeLLO候選者，而且這九顆VeLLOs的光能分佈圖都與第零或第一階段的原始恆星非常相似。未來在毫米、次毫米波段的觀測數據，都將會對這些VeLLO候選者的性質有著更進一步的了解。

Searching for Very Low Luminosity Objects (VeLLOs) in the Taurus Molecular Cloud

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Abstract

Observing protostars right after they formed from their parent cores is crucial for understanding the earliest phase of star formation. Discovered by Spitzer Space Telescope, Very Low Luminosity Objects (VeLLOs) are the faintest embedded sources currently known (internal luminosity, L_{int} < 0.1 solar luminosity), hence the best targets for studying the star formation in the earliest stage. On the other hand, VeLLOs could also be very low mass protostars or even proto brown dwarfs. Since Taurus is one of the closest clouds, it provides the best possible spatial resolution for investigating the nature of VeLLOs. We search for VeLLOs in Taurus adopting the color and luminosity criteria from Dunham et al. (2008), which are derived from known young Class 0 and early Class I objects. However, because the extinction in Taurus is very low, the contamination from background galaxies is especially high. Studying the previously identified VeLLO candidates, we found that [5.8] – [24.0] > 4 mag is a good criterion for eliminating galaxies. As a result, we select 9 VeLLO candidates in Taurus and all candidates have colors consistent with Class 0 or Class I sources. Further observations at submillimeter wavelengths are needed for confirming the YSO nature of these candidates.

關鍵字 (Key words): 恆星形成 (stars: formation)、低質量恆星 (stars: low-mass)

1. Introduction

Observing protostars right after they formed from their parent cores is crucial for understanding the initial conditions of star formation. Very Low Luminosity Objects (VeLLOs) are discovered by Spitzer Space Telescope (Young et al. 2004; Dunham et al. 2008), and they are thought to be the faintest embedded Young Stellar Objects (YSOs) with intrinsic luminosity $L_{int} < 0.1L_{\odot}$. Therefore, studying VeLLOs provides the best chance to explore the early phase of star formation. The low luminosity of VeLLOs is well below the lower limit predicted by accretion theory for ordinary mass stars, and this phenomenon suggests that they are either extremely young protostars or extremely low mass protostars. Observations toward VeLLOs can provide valuable information to advance our understanding of star formation.

Current observations of VeLLOs show a large variety on their physical properties. The mass of their cores can be varying larger than 10 times. Infall signature has been detected in L1521F and IRAM 04191, but not in L1014. Moreover, their outflows could be very compact (L1014 and L1521F) or extended to parsec scale (IRAM 04191). Detail studies of kinematics and chemical properties of individual VeLLO are necessary to identify the nature of each VeLLO. Because Taurus is the closest molecular cloud in the northern sky, it is easier to obtain a complete sample on faint sources like VeLLOs with high resolution than from other clouds.

2. Sample Selection and Result

We select our VeLLO candidates from the Spitzer Space Telescope's Taurus Legacy Project data combined with the criteria Dunham et al. (2008) used to search VeLLOs. Dunham used the average SED for Class 0 and early Class I sources as templates (Fig.1) to derive select criteria for VeLLOs. However, going through the criteria and examining their images are not enough, because many of them could be background galaxies due to the low extinction of Taurus. Lee et al. (2009) have mentioned that the color [5.8]-[24] is red for their VeLLO candidate and also other three known VeLLOs. After checking this criterion to 30 identified VeLLOs in Dunham et al. (2008), we found that all of them are located in the range of [5.8]-[24] > 4 mag, (Fig.2). In addition, because we believe that VeLLOs are still embedded in cores, we then added an extra criterion that the extinction value must be larger than 4 mag for VeLLO candidates; the average extinction value of whole Taurus cloud is about 3 mag. Finally, we obtain 9 VeLLO candidates. In order to examine that if these candidates have SEDs consistent with those of YSOs at Class 0/I stage, we use the Online SED Fitter for YSOs provided by Robitaille et al. (2006) which contains 20,000 models with different physical parameters. The results are shown in (Fig.3) where we plot the best 100 models for each candidate. We have selected 9 VeLLO candidates in the Taurus Molecular Cloud. In order to better determine their destiny and nature, we will propose submillimeter observation to help us constrain the properties of disk and envelope. We also list the IRAC and MIPS images of them, (Fig.4).

Reference:

Dunham et al., 2008, *ApJS*, 179, 249

Barrado et al., 2009, *A&A*, 508, 859

Robitaille et al., 2007, *ApJS*, 169, 328

Lee et al., 2009, *ApJ*, 693, 1290

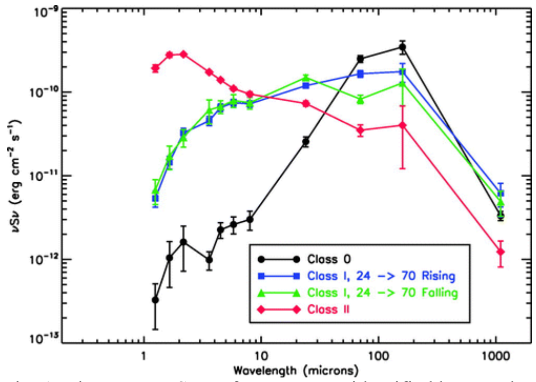

Fig. 1: The average SEDs for protostars identified by Enoch et al. (2007, 2008) in Perseus, Serpens, and Ophiuchus.

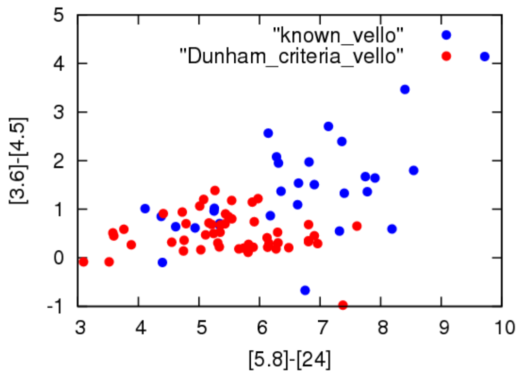

Fig. 2: The diagram we use the data from identified VeLLOs, we can find that all objects have the color [5.8]-[24] > 4

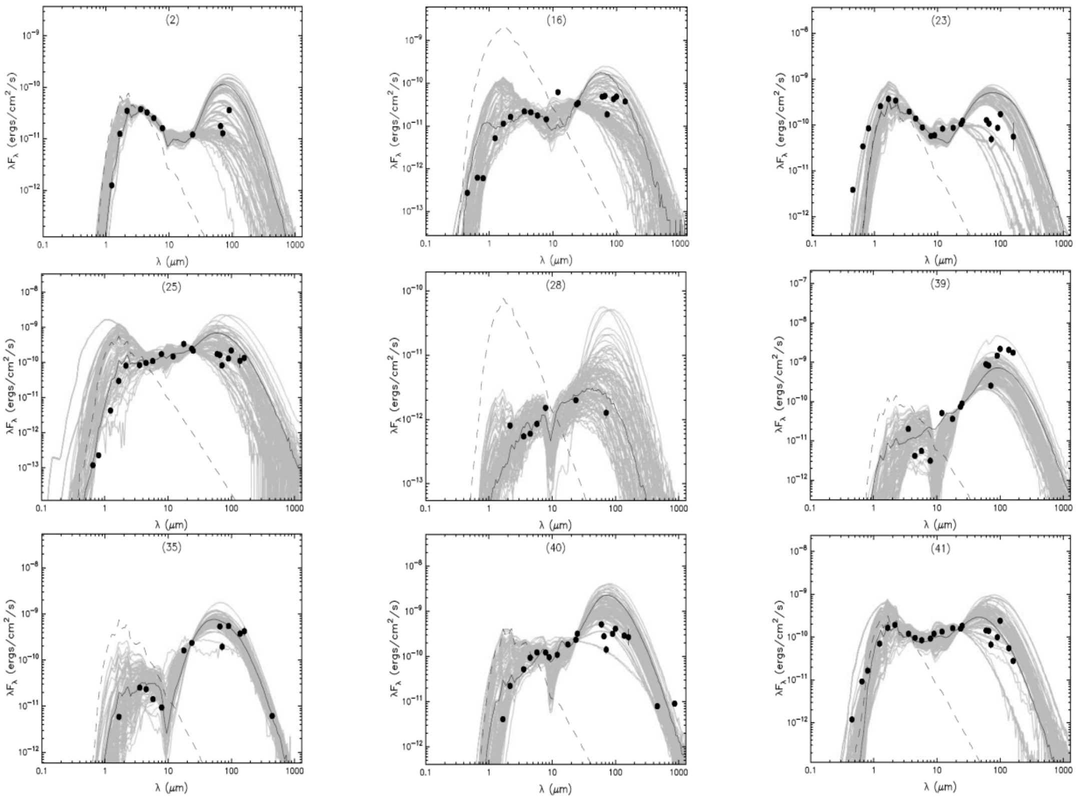

Fig. 3: Fitting SEDs of each object, each panel with 100 best models.

Source number	IRAC1	IRAC2	IRAC3	IRAC4	MIPS1	MIPS2	MIPS3
2							
16							
23							
25							
28							
35							
39							
40							
41							

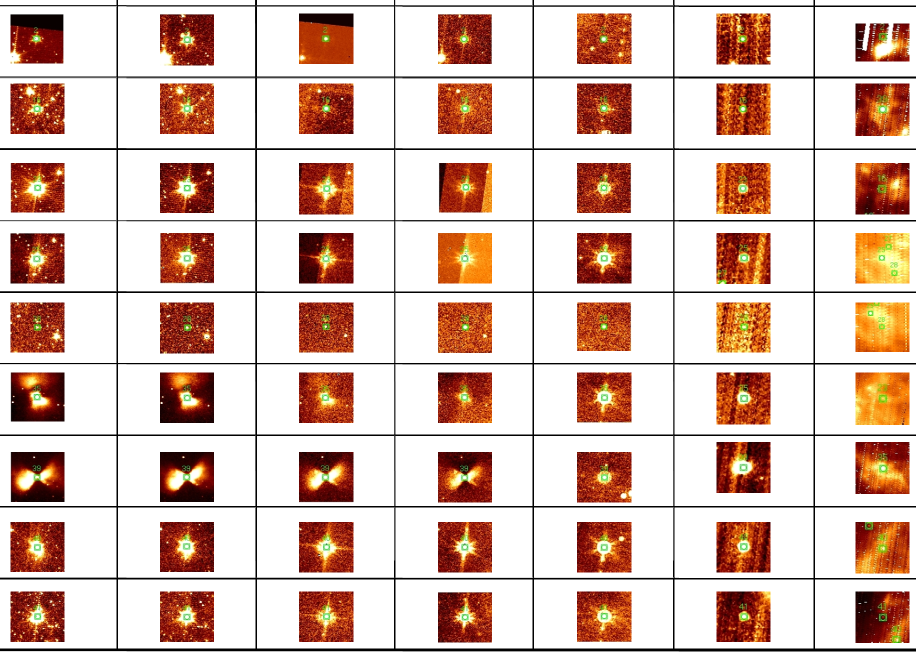

Fig. 4: The IRAC and MIPS images of each VeLLO candidates.