鄰近分子雲內的原恆星數量統計

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摘要

我們發明一種新的方法利用Spitzer太空望遠鏡的光度資料來找出在分子雲內的原恆星。由於原恆星與背景星系的光譜在紅外線波段相當類似，而Spitzer能夠觀測到很暗的背景星系，因此，原恆星的統計工作成爲一個困難的問題。以往的方式是比較原恆星跟星系的樣本在雙色指數圖或星等星色圖上的分布位置。然而，使用何種雙色指數圖以及星等星色圖來統計卻因人而異，而原恆星或星系的分布區域常是人爲定義出來的。這裡，我們發展一個新的分類方式，以統計三到五度星等空間的星系樣本密度來做爲星系機率。這個方法可以減低人爲的誤差，並且使用多度星等空間等同於考慮了所有星等星色圖的組合。因此，我們可以公平的找出分子雲內的原恆星。

Population of Young Stellar Objects in Nearby Molecular Clouds

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Abstract

We develop a new method to identify YSOs from star-forming regions using the photometry data of the Spitzer space telescope. Because SEDs of YSOs are similar to SEDs of background galaxies and Spitzer is sensitive enough to detect those galaxies, it has been difficult to separate YSOs and galaxies using only those photometry data. To solve this problem, previous works have developed several criteria according to the difference of the areas occupied by YSOs and galaxy sample in color-magnitude and color-color diagrams (hereafter CMD and CCD). However, different works used different CMDs and CCDs and defined criteria for separating YSOs and galaxies are often set by eyes. Here we develop a new method to measure the probability for a source to be a background galaxy; we calculate the density of pure galaxy sample in the multi-dimensional magnitude space and use the density as the probability of background galaxy. Our method is equivalent to use all CMDs and without artificial criteria. Thus, we can fairly identify the YSOs in the star-forming regions.

關鍵字（Keywords）：原恆星（protostar）、雙色指數圖（color-color diagram）、星等星色圖（color-magnitude digram）

1. Introduction

A full census of Young Stellar Object (YSO) population in star-forming region is necessary and important to understand the evolutions of YSOs. Spitzer Space Telescope is sensitive enough to detect faint and embedded YSOs, thus providing an excellent opportunity to make a complete survey of YSOs in molecular clouds. Since the SEDs of background galaxies and YSOs are similar in the infrared wavelengths, separating galaxies and YSOs has become a difficult problem. Recently, Harvey et al. (2007) defined a galaxy probability to identify the YSOs in molecular clouds, which is calculated from several criteria according to the occupied area of the presumed pure galaxies sample, Spitzer Wide-Area Infrared Extragalactic Survey (SWIRE) data, in several CCDs and CMDs. However, the selection CCDs or CMDs is subjective and the criteria are rather artificial. In addition, Harvey's method requires the sources to be detected in five Spitzer bands, IRAC1-4 and MIPS1. The faint YSOs are probably left out by this stringent requirement. In this work, we develop a new method to naturally calculate galaxy probability with minimum bias and it can be applied to sources which were detected no less than three bands.

2. YSO selection method

2.1 Selection principle

Here we demonstrate that using multi-magnitude space as our selection tool is equivalent to using all possible CMDs. 1) all configurations of CMDs which consisted of two bands are equivalent to each other (Figure 1). 2) A CMD is just a projection in multi-dimensional magnitude space. In Figure 2, the projection in multi-space from the projection directions, a and b, are equal to the two CMDs. Therefore, our multi-dimensional method is equivalent to using all CMDs and we can find the projection direction where the YSOs and galaxies can be separated more obviously (Figure 3) compare to all CMDs.

2.2 Selection procedure

We develop a procedure to measure our galaxy probability. Our steps are as follows:

1) The stars are removed by SED fitting.
2) In order to fairly compare the YSOs and background galaxies, we do extinction correction for the entire source catalog using the extinction values calculated from background stars.

   We made a five-dimensional magnitude grid with five axes of IRAC1-4 and MIPS1 and cell size of 0.2 magnitude. We count the galaxy number from SWIRE data in each cell and smooth the grid using a Gaussian beam with standard deviation σ=3 (0.6 magnitude). The densities of the galaxies in the grid are defined as our new galaxy probability. Since we set our Gaussian beam with peak of 1, we selected our YSOs with galaxy probability

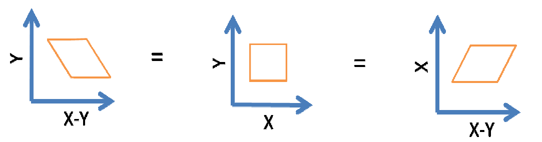

Fig. 1: The space covered by a magnitude-magnitude diagram of X and Y bands is equivalent to the CMD of (X-Y, Y) or (X-Y, X).

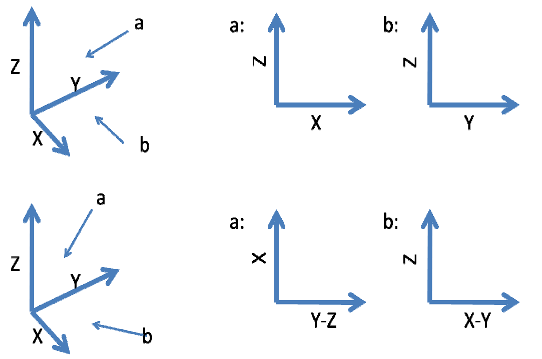

Fig. 2: A CMD is a projection in the multi-dimensional magnitude space.

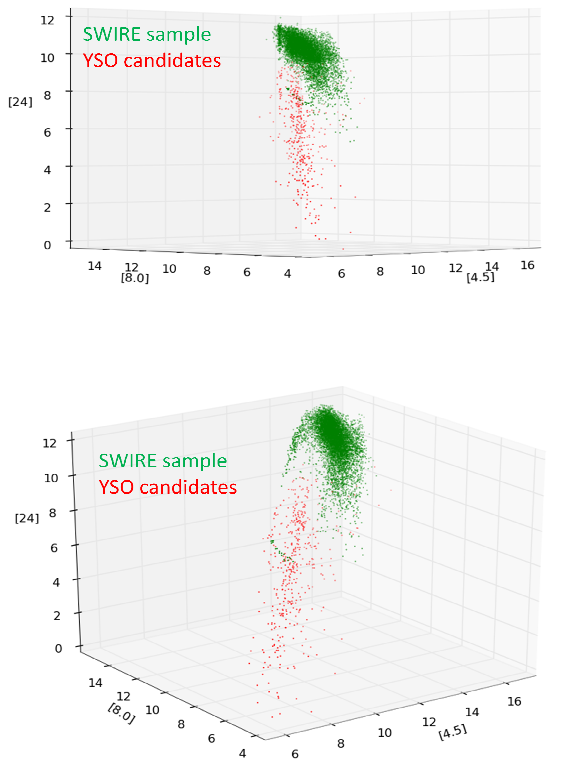

Fig. 3: Compare the separation of YSOs in Perseus and galaxies in different projection directions. Top figure is equivalent to CMD of ([4.5]-[8.0],[24])

smaller than 1. The same process is applied to the sources with detections in only three or four bands (e.g. 3-D or 4-D magnitude grid).

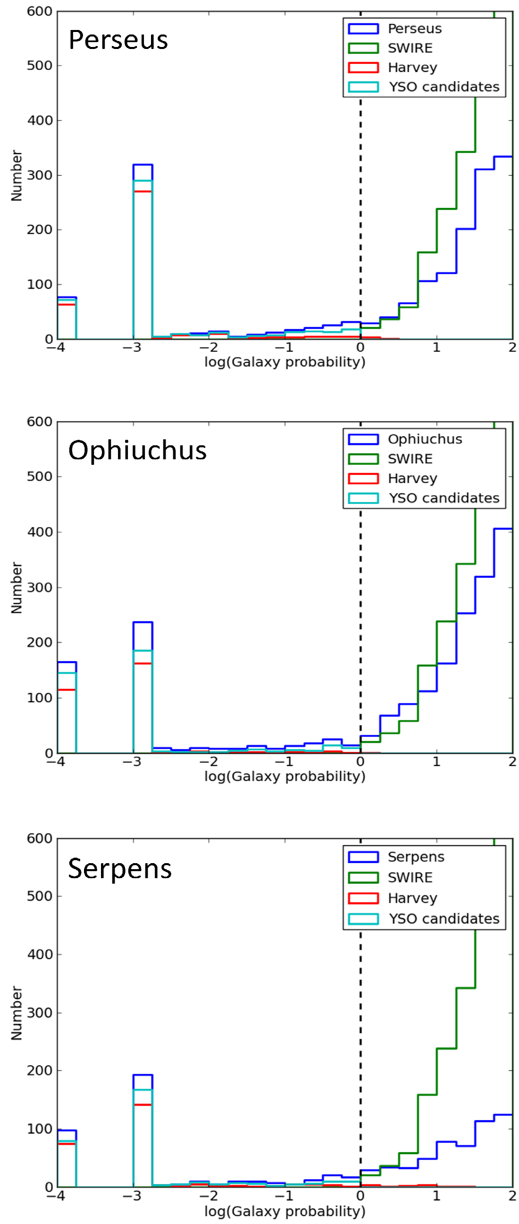

Fig. 4: The histogram of our galaxy probability for catalog from clouds, SWIRE and Harvey's candidates.

3) Some flux measurements of sources have problems because the automatic source extraction and PSF-fitting process is imperfect. We check their images and delete the sources with problems.

3. Result

We compare our selection method to Harvey's method for three molecular clouds, Perseus, Ophiuchus and Serpens (Figure 4). Since we smooth out the multi-dimensional magnitude array using a Gaussian beam with peak of 1, our galaxy probability of all SWIRE sources should be larger than 1. Therefore, we define our YSOs candidates with galaxy probability smaller than 1. It is noteworthy that in figure 4 some sources with galaxy probability smaller than 1 are removed after our fluxes measurement check of image. Furthermore, in order to present our galaxy probability on a logarithmic scale, we set the minimum galaxy probability in our grid to 0.001 (-3 in logarithmic scale) and for the bright sources outside our grid we set its galaxy probability to 0.0001.

4. Discussion

We develop a new method to identify YSOs in molecular clouds. Although our method contains no artificial bias, it still may contain false identifications in certain situations: 1) If our galaxy sample, SWIRE data, is incomplete, some nearby galaxies can be classified as YSOs. 2) We cannot identify the YSOs if their SED is extremely similar to galaxies. However, in this work, we find many new YSO candidates and we can select YSOs using the boundary of galaxy probability to obtain YSOs candidates based on different degree of confidence that is fairly defined.

Reference

Harvey et al., 2007, *ApJ*, 663:1149-1173