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# 大质量恒星形成及其初始条件

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本论文包含对4个课题的研究: 红外暗云、致密冷核的碎裂和氘化、极超致密电离氢区和红外尘泡. 它们不仅属于大质量恒星早期形成的范畴, 而且反映了不同演化阶段的典型特征. 主要内容如下:

(1)关于红外暗云的研究, 我们利用IRAM (Institut de Radioastronomie Millimétrique) 30 m望远镜对一批红外暗云进行了观测, 获得如$HCO^+$、HNC、$N_2^+$和$C^{18}O$的分子谱线. 利用光学厚的$HCO^+$和光学薄的$N_2^+$谱线对这批红外暗云的动力学结构进行测量发现丝状的红外暗云存在着速度梯度; 另外, 我们分析了红外暗云中的分子和尘埃团块的物理形态, 并且研究了其稳定性.

(2)大质量恒星形成早期阶段的团块碎裂是一个非常重要的过程. 根据SCUBA (submillimetre Common-User Bolometer Array) 850 $\mu$m和450 $\mu$m的观测数据，我们建立了一个包含8个大质量恒星形成区的样本, 包括: G18.17、G18.21、G23.97N、G23.98、G23.44、G23.97S、G25.38和G25.71. 课题的研究利用的VLA (Very Large Array)和PbBI干涉仪对样本分别进行了1.3 cm和3.5 mm与1.3 mm的谱线观测. 通过质量-尺度关系的比较, 我们研究了团块、致密核和凝聚核的栖息环境, 及其在不同波段、不同尺度下的团块碎裂特征, 发现潜在的恒星形成可能由附近的致密电离氢区触发.

(3)在大质量恒星形成过程中, 极超致密电离氢区的形成也是一个非常重要的阶段. 在该课题研究中, 我们利用SMA (Submillimeter Array)和VLA对极超致密电离氢区G35.58–0.03进行了高分辨率观测, 共探测到25条不同的跃迁线, 包括8种不同的分子和原子的同位素, 如CO、$CH_3CN$、$SO_2$、$CH_3CCH$、OCS、CS、H30$\alpha$/38$\beta$、$NH_3$的谱线. 极超致密电离氢区中致密核的电子温度$T_e^* \geqslant 5500$ K, 发射量度EM$\approx 1.9 \times 10^9$ pc·cm$^{-6}$, 电子体密度$n_e = 3.3 \times 10^5\,cm^{-3}$, 射电复合线H30$\alpha$和H38$\beta$的线宽是43.2 km·s$^{-1}$, 核本征尺度约为3714 au. 射电复合线H30$\alpha$呈现出电离外向流驱动分子外向流的证据. 分子包层显示出内流和外流的特征, 其质量下落率和质量损失率分别为0.033 $M_\odot$·yr$^{-1}$和0.052 $M_\odot$·yr$^{-1}$. 平均每年气体内流和外流的动量也是一致的, 约为0.05 $M_\odot \cdot km \cdot s^{-1}$. 我们认为, 物质下落占有主导地位, 致密气体的包层质量在迅速增加, 但是内部的吸积可能已经终止.

(4)红外尘泡形成于激发星加热附近的尘埃和电离气体, 并推动周围的物质向外膨胀的过程中, 可能伴随着新一代的恒星形成. 我们发现尘泡N68的壳层结构可能正在向外膨胀. 利用$^{13}CO$和$C^{18}O$辐射, 我们观测到尘泡S51的前端云, 并在壳层结构上发现了新一代的恒星形成的迹象, 其可能是由尘泡的膨胀所触发形成的. 我们认为尘泡N131可能形成于一个丝状的分子云. 该丝状云在内部成群大质量恒星强烈星风的作用下向外膨胀、撕裂, 使其形成两个团块状结构并扫过周围物质形成环形泡.

# High-mass Star Formation and Its Initial Conditions

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In this thesis, we present four works on the infrared dark clouds, fragmentation and deuteration of compact and cold cores, hyper-compact (HC) HII regions, and infrared dust

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bubbles, respectively. They are not only the products of early high-mass star formation, but reflect different evolutionary sequences of high-mass star formation.

(1) Using the IRAM (Institut de Radioastronomie Millimétrique) 30 m telescope, we obtained $HCO^+$, HNC, $N_2{}^+$, and $C^{18}O$ emission in six IRDCs (infrared dark clouds), and study their dynamics, stability, temperature, and density.

(2) Fragmentation at the earliest phases is an important process of massive star formation. Eight massive precluster clumps (G18.17, G18.21, G23.97N, G23.98, G23.44, G23.97S, G25.38, and G25.71) were selected from the SCUBA (submillimetre Common-User Bolometer Array) 850 $\mu$m and 450 $\mu$m data. The VLA (Very Large Array) at 1.3 cm, PbBI at 3.5 mm and 1.3 mm, APEX (Atacama Pathfinder Experiment telescope) at 870 $\mu$m observations were followed up, and archival infrared data at 4.5 $\mu$m, 8.0 $\mu$m, 24 $\mu$m, and 70 $\mu$m were combined to study the fragmentation and evolution of these clumps. We explored the habitats of the massive clumps at large scale, cores/condensations at small scale, and the fragmentation process at different wavelengths. Star formation in these eight clumps may have been triggered by the UC (ultra-compact) HII regions nearby.

(3) The formation of hyper-compact (HC) HII regions is an important stage in massive star formation. We present high angular resolution observations carried out with the SMA (Submillimeter Array) and the VLA (Very Large Array) toward the HC HII region G35.58-0.03. With the 1.3 mm SMA and 1.3 cm VLA, we detected a total of about 25 transitions of 8 different species and their isotopologues (CO, $CH_3CN$, $SO_2$, $CH_3CCH$, OCS, CS, H30$\alpha$/38$\beta$, and $NH_3$). G35.58–0.03 consists of an HC HII core with electron temperature $T_e^* \geqslant 5500$ K, emission measure EM $\approx 1.9\times10^9$ pc·cm$^{-6}$, local volume electron density $n_e = 3.3\times10^5$ cm$^{-3}$, FWHM $\approx$ 43.2 km·s$^{-1}$ for radio recombination lines from both H30$\alpha$ and H38$\beta$ at its intrinsic core size 3714 au. The H30$\alpha$ line shows evidence of an ionized outflow driving a molecular outflow. The molecular envelope shows evidence of infall and outflow with an infall rate of 0.033 $M_\odot$·yr$^{-1}$ and a mass loss rate 0.052 $M_\odot$·yr$^{-1}$. The derived momenta ($\sim$ 0.05 $M_\odot \cdot$ km $\cdot$ s$^{-1}$) are comparable for both the infalling and outflowing gas per year. It is suggested that the infall is predominant and the envelope mass of the dense core is increasing rapidly, but accretion in the inner part might have already been halted.

(4) OB type stars have strong free-free radiation. The ultraviolet radiation from ionizing stars may heat the dust and ionize the gas to sweep up an expanding bubble, probably accompanied by formation of next generation of stars. The position-velocity diagram clearly shows that N68 may be expanding outward. The structure of bubble S51, carried with shell and front side, is exhibited with $^{13}CO$ and $C^{18}O$ emission. Both outflow and inflow may exist in the shell of the bubble S51. They may represent the next generation of stars whose formation was triggered by the bubble expanding into the molecular gas. For the bubble N131, we aim to further explore the molecular clumps and star formation at a higher spatial resolution compared with previous CO observations, and try to speculate its origin. The bubble N131 is likely originated in a filamentary nebula, within which the strong stellar wind from a group of massive stars broke up a pre-existing filamentary nebula into the clumps AD and BC, and sweeped up the surrounded material onto the ringlike shell of the bubble N131.