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(Form 3)

Summary of Doctoral Thesis

Jungha KIM

Title Understanding the Circumstellar Structure of High-Mass Young Stellar Objects Based on Interferometric Observations

Summary of snapshot imaging survey of H2O maser is presented to examine typical trend in spectral and spatial distributions of maser features and select appropriate target to investigate in detail. Detected 15 H_2O maser sources are classified into three groups: three for "blue", two for "red", and ten for "both". The H2O masers in "both" group are highly expected to trace bipolar outflows and isotropically expanding shells/winds even though targets in "blue" and "red" would be tracing a apart of those structures. These 10 targets in "both" group are largely divided into two groups: five sources are classified as "compact" while others are in "elongated".

G25.82-0.17, having the largest morphology factor of 0.4, is selected for the first case study as a first step to KaVA LP ultimate goals since it shows about 60 features with 60 velocity range, suggesting it is a good laboratory to investigate the connection between the dynamical structures in the vicinity of the powering source and H2O maser 2D and 3D distributions. "Elongated" structure may trace bipolar outflows with high possibility while "compact" structure is hard to imagine what kinds of dynamical structures can be traced. To examine the environmental difference between these two groups, the 3D velocity structures of H2O masers are going to be obtained with monitoring observations. Therefore, G25.82-0.17 having the largest morphology factor of 0.4 was selected for the first case study as a first step to KaVA LP ultimate goals. Based on the results from the imaging survey, monitoring observations were done including G25.82-0.17.

By taking full advantage of VERA and KaVA observations, parallax and proper motions of H_2O masers in G25.82 are measured to estimate accurate distance and 3D velocity structure of H_2O masers for further analysis. In addition, the galactic position and the peculiar motion of G25.82 is presented to compare with other high-mass star forming regions. The 8 maser features have been successfully employed detected in more than five epochs. Obtained parallax is 0.23 $\pm$ 0.02 mas, corresponding to the distance of $4.44^{+0.43}_{-0.36}$ kpc which is a factor of 0.89 (4.44 kpc/5.0 kpc) smaller than the kinematic distances. In case of uncertainty, it is deduced to 10% of 89%.

In addition to annual parallax, internal proper motions of H_2O maser features in G25.82 were measured. In total, 21 H_2O maser features were identified which were detected at least in three epochs. Most of identified H_2O maser features have blueshifted or similar velocities to the systemic velocity of G25.82 (93.7 kms^{-1}). In addition to the bluest feature, slightly redshifted velocity component (97.1 7 kms^{-1} feature) moving toward the NE.

Features having velocities close to the systemic velocity distributed at Dec offset=0 are moving away each other. The central cluster shows motions divided into two groups which are moving toward N and SW

Moreover, the galactic position of G25.82 is measured and it is on the "Scutum-Centaurus Arm" at the edge of "Long Bar" at the galactic center with the location in the middle of other neighboring high-mass star-forming regions. Therefore, G25.82 is also located at the inner Galaxy region where the star formation is actively occurring.

Results of continuum and spectral line observations with ALMA and 22 GHz water (H2O) maser observations using KaVA and VERA toward a high-mass star-forming region, G25.82–0.17 are presented. Multiple 1.3 mm continuum sources are revealed, indicating the presence of young stellar objects (YSOs) at different evolutionary stages, namely an ultra-compact HII region, G25.82–E, a high-mass young stellar object (HM-YSO), G25.82–W1, and starless cores, G25.82–W2 and G25.82–W3. Three sets of CO outflow lobes are detected. Two of them have N–S direction while the other has SE–NW. In addition, two SiO outflows, at N–S and SE–NW orientations, are identified. The CH_3OH 8_{-1}–7_0 E line, known to be a class I CH_3OH maser at 229 GHz is also detected showing a mixture of thermal and maser emission. Moreover, the H_2O masers are distributed in a region »000.25 shifted from G25.82–W1. The CH_3OH 22_4–21_5 E line shows a compact ring-like structure at the position of G25.82–W1 with a velocity gradient, indicating a rotating disk or envelope. Assuming Keplerian rotation, the dynamical mass of G25.82–W1 is estimated to be ~25 $M_\odot$ and the total mass of 20 $M_\odot$-84 $M_\odot$ is derived from the 1.3 mm continuum emission. The driving source of the N1–S1 CO outflow (N–S SiO outflow) is G25.82–W1 while that of the SE–NW CO (SiO) outflow is uncertain. Outflow parameters obtained from the CO 2-1 line, reveal that the N1–S1 CO outflow is tracing the smaller scale and higher velocity outflow from the driving source than the $C^{18}O$ outflow detected by the single-dish observations. Furthermore, the relationships between time-dependent outflow parameters (mass lose rate, force, and luminosity) and with the source luminosity have the similar relationships shown in low-mass to high-mass regime, suggesting the star-forming mode in G25.82 is likely a scaled-up version of low-mass star formation. Detection of multiple high-mass starless/protostellar cores and candidates without low-mass cores implies that HM-YSOs could form in individual high-mass cores as predicted by the turbulent core accretion model. If this is the case, the high-mass star formation process in G25.82 would be consistent with a scaled-up version of low-mass star formation.

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Results of the doctoral thesis screening

博士論文審査結果

Name in Full
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Title
論文題目　Understanding the Circumstellar Structure of High-Mass Young Stellar Objects Based on Interferometric Observations

出願者は、日韓の超長基線干渉計型の電波望遠鏡 KaVA による 15 個の水メーザー天体のスナップショット観測サーベイをもとに研究を行った。出願者自身によるデータ解析により、ドップラー効果で青方偏移成分のみ（2 個）、赤方偏移成分のみ（2 個）、両方の成分が観測されるもの（10 個）の 3 種に分類し、両方観測されるものに関してはさらに、形態的にコンパクトなものと細長い形状をしたものに分類した。このうち最もコンパクトな天体の一つ、G25.82-0.17 に関して特に詳細な観測を行った。まず VERA と KaVA を用いて複数の水メーザーに対し位置の時間変化を精密に測定した。抽出された年周視差量から G25.82-0.17 までの距離を高い精度で決定するとともに、これらメーザー源の 3 次元的な運動を初めて明らかにした。また、この領域の銀河系の大局的運動に対する特異運動の速度ベクトルを得た。一方、アルマ電波望遠鏡を用いた 230GHz 帯の観測から、複数の分子輝線、連続波を検出し、本領域が進化段階の異なる 4 領域に区別されること、うち一つの大質量原始星周囲に回転運動をしていると解釈できるガス雲があること、複数の分子流駆動天体が存在すると考えられることを明らかにした。また、KaVA や VERA で捉えられた水メーザーが、南北に伸びる分子流の根元付近に分布していることも明らかにした。この領域で観測された分子流の運動量や光度などの物理量が、小質量星形成領域で観測されている分子流の物理量の経験則を大中質量星まで延長させたもので説明でき、この分子流が小質量星からの分子流のスケールアップ版であることを示唆した。さらに今回の観測でこの領域には大質量星形成モデルの代表的なモデルである質量降着モデルで予想される小質量分子雲コアの存在が確認できなかったことに関連して、大質量形成モデルの代表的な 2 説である乱流的分子雲コアモデルを支持する議論を含んでいる。本研究は、VLBI による高分解能観測と ALMA 観測を密に連携させることで、単一鏡だけではわからない、遠方にある大質量星形成領域の 3 次元構造や進化段階を明らかにできる可能性を示したものである。以上のように本研究は、大質量星形成領域の知見を深める、新たな観測結果を示すものとして評価されることから、審査委員会は、本論文が学位の授与に値すると判断した。