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Prestellar grain-surface origins of deuterated methanol in comet 67P/ Churyumov- Gerasimenko

Maria N. Drozdovskaya et al.

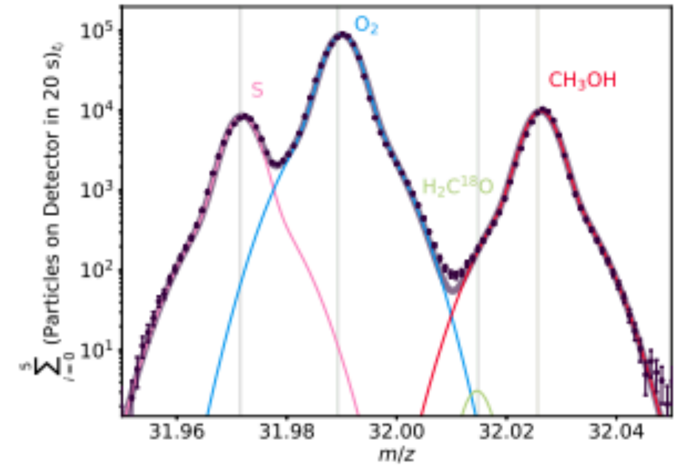
ABSTRACT

Deuterated methanol is one of the most robust windows astrochemists have on the individual chemical reactions forming deuterium-bearing molecules and the physicochemical history of the regions where they reside. The first-time detection of mono- and di-deuterated methanol in a cometary coma is presented for comet 67P/Churyumov–Gerasimenko using *Rosetta*–ROSINA data. D-methanol (CH_3OD and CH_2DOH combined) and D_2-methanol (CH_2DOD and CHD_2OH combined) have an abundance of 5.5 ± 0.46 and 0.00069 ± 0.00014 per cent relative to normal methanol. The data span a methanol deuteration fraction (D/H ratio) in the $0.71 - 6.6$ per cent range, accounting for statistical corrections for the location of D in the molecule and including statistical error propagation in the ROSINA measurements. It is argued that cometary CH_2DOH forms from CO hydrogenation to CH_3OH and subsequent H-D substitution reactions in CH_3-R. CHD_2OH is likely produced from deuterated formaldehyde. Meanwhile, CH_3OD and CH_2DOD, could form via H-D exchange reactions in OH-R in the presence of deuterated water ice. Methanol formation and deuteration is argued to occur at the same epoch as D_2O formation from HDO, with formation of mono-deuterated water, hydrogen sulfide, and ammonia occurring prior to that. The cometary D-methanol/methanol ratio is demonstrated to agree most closely with that in prestellar cores and low-mass protostellar regions. The results suggest that cometary methanol stems from the innate cold ($10 - 20$ K) prestellar core that birthed our Solar System. Cometary volatiles individually reflect the evolutionary phases of star formation from cloud to core to protostar.

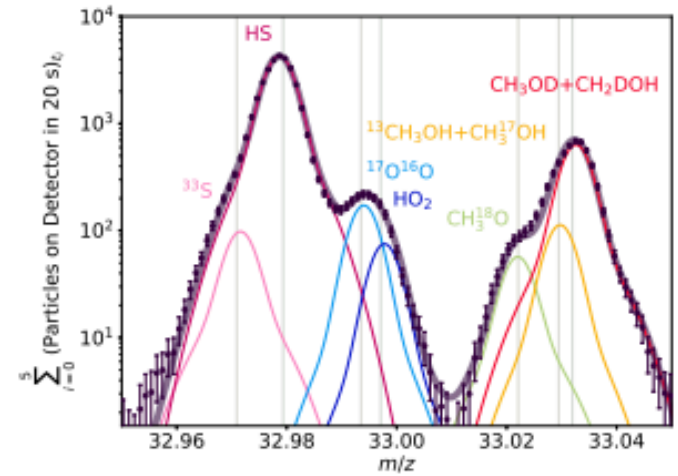
- 67P彗星(ロゼッタミッション)で重水素化メタノールを検出
- prestellar/protostellar coreと同程度のD/H ratio

  →太陽系がcold core段階だった際に形成された

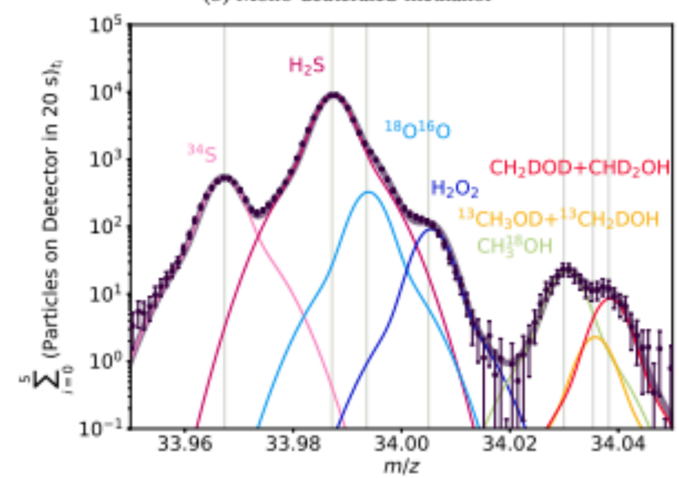
- D/Hは星形成段階/環境で異なっている
  →形成史を調べる上で重要
- メタノールは重要なvolatileだがD/H比は分かっていない
- ROSINA Double Focusing Mass Spectrometer (DFMS) / Rosetta



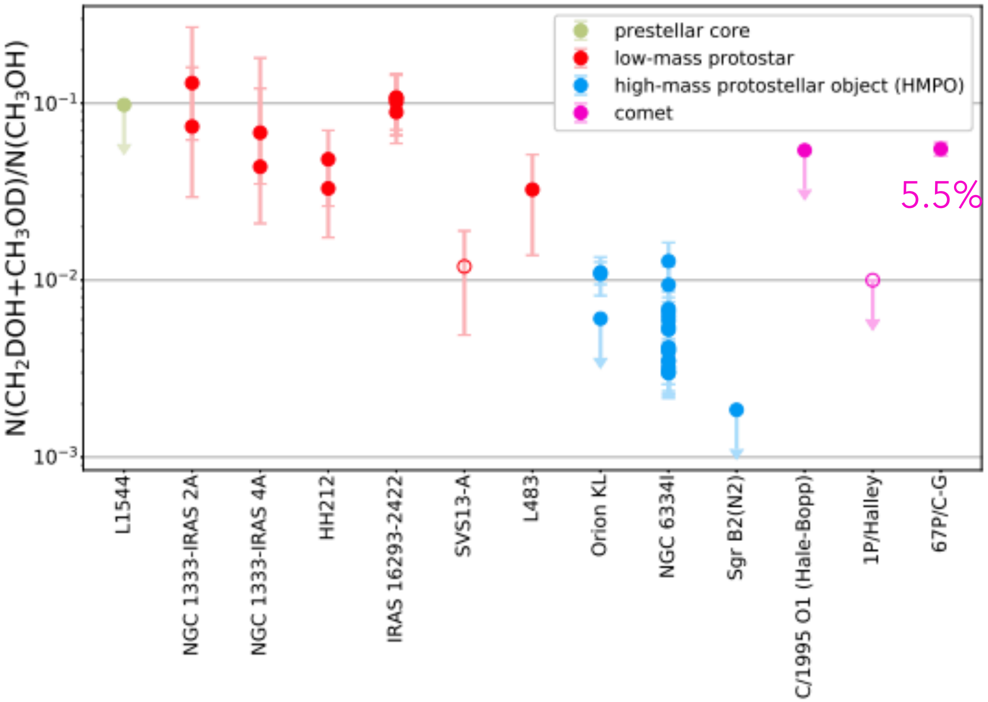
(a) Normal methanol



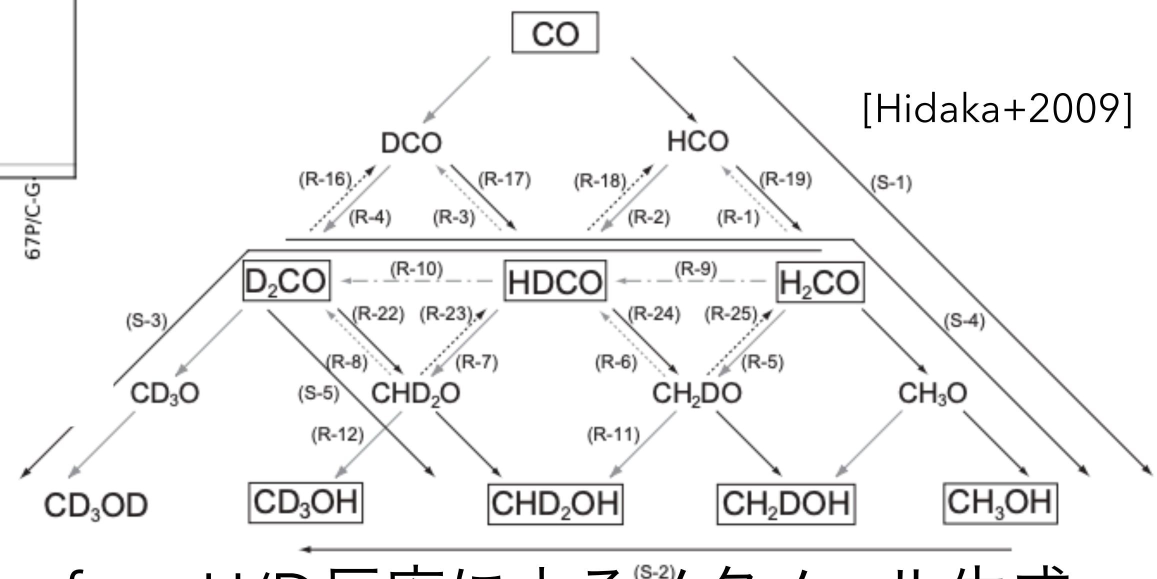
(b) Mono-deuterated methanol



(c) Di-deuterated methanol



- low-mass protostarと同程度



[Hidaka+2009]

- CO/H2O ice上でのgrain surface H/D反応によるメタノール生成
  →67Pの低温期を示唆, かつH/Dと反応する十分な時間も必要
- (D2-met./D-met.) / (D-met./met.)比はstatistically expected程度
  ≠水では大きい値を取る [Altwegg+17]
  - コアでHDO, D2Oを作る前にH2Oを分子雲で多量に作っておく [Furuya+16,17]
    - D-methanol/methanol > D2O/HDO >> HDO/H2O の関係と(partially)整合

- C/O同位体比
  - 16O/18Oおよび12C/13CはH2O, CO2, CH3OHで同程度
    - C,Oの起源は共通(grain surface chemistry)
  - H2COのC, O同位体比はH2O, CH3OH, CO2, COの半分 [Altwegg+2020]

    →H2COはgas-phase chemistryでも作られるかも

- 結果から見る67P volatilesの形成史
  - 分子雲->コア->原始星の進化トラックとconsistent
    - 分子雲にてH2O, CO, CO2のgas生成
    - コアでHDO, HDS, NH2D, CH3OHがgrain surface chemistryで生成
      - D2Oや重水素化メタノールも
  - 低温期で形成されたはず
    - CO/H2O iceにおけるH/D反応を起こす
    - local ISMより2~3桁大きいメタノールのD/H比

      →モデル計算により<25Kを示唆

An observational correlation between magnetic field, angular momentum and fragmentation in the envelopes of Class 0 protostars?
Maud Galametz et al.

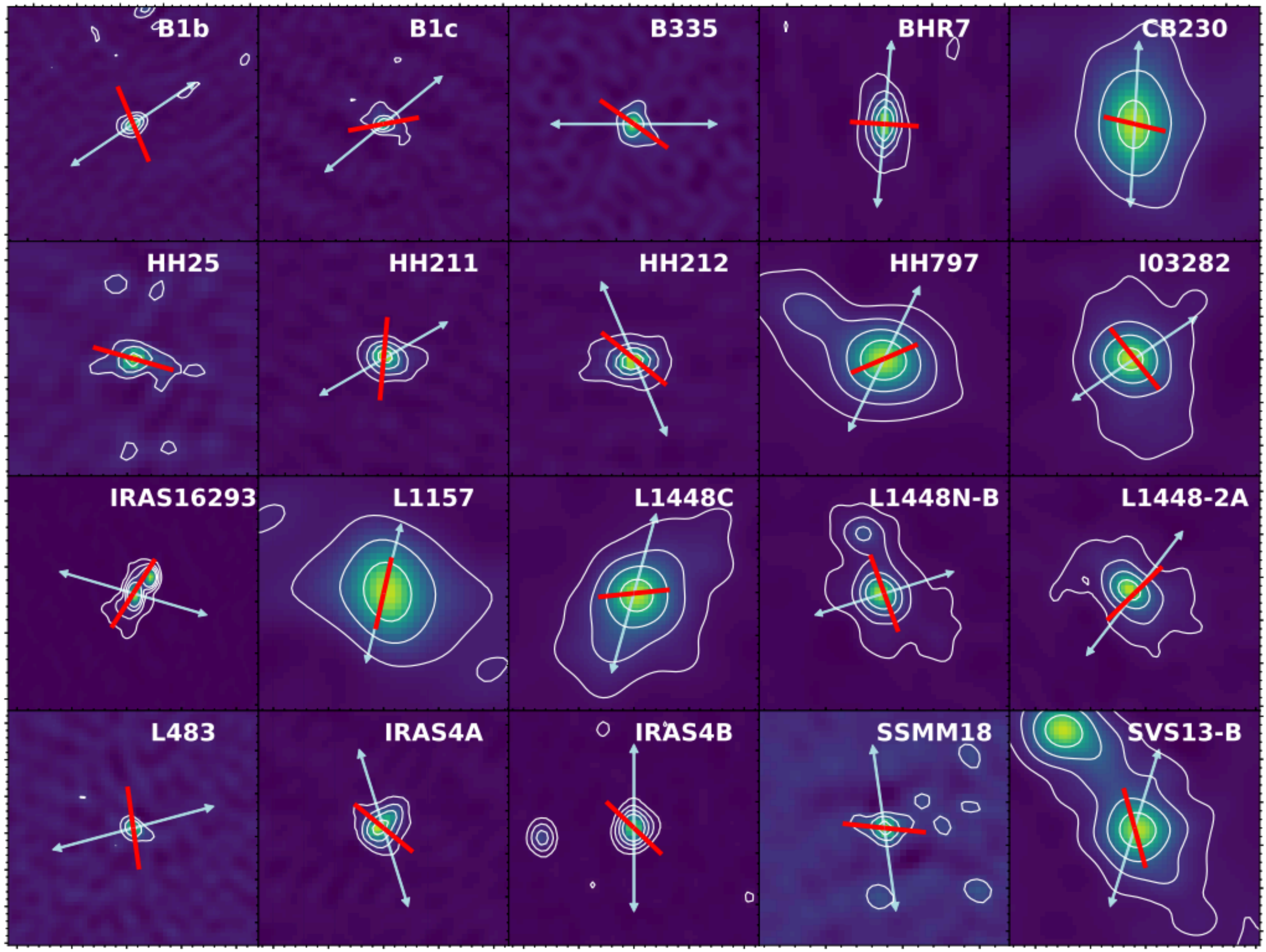
ABSTRACT

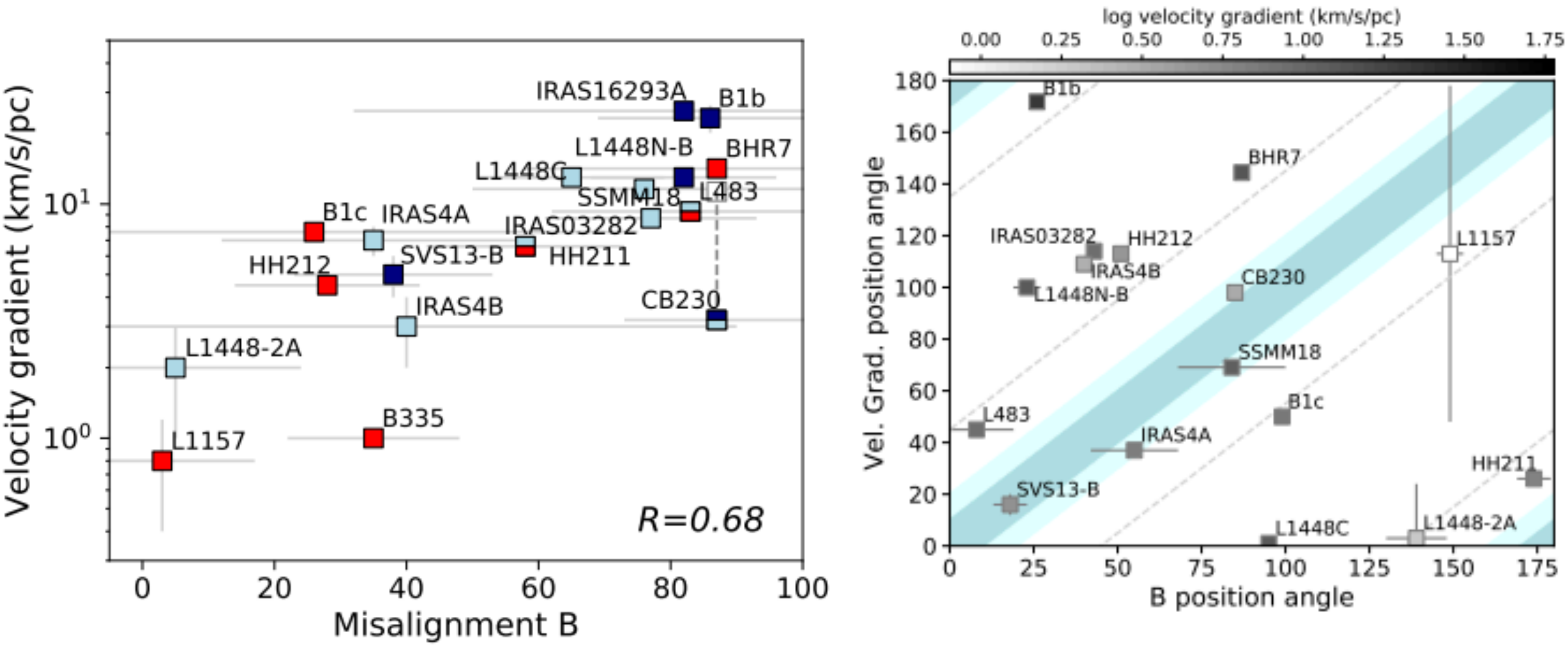
Aims. Our main goal in this analysis is to assess the potential role of magnetic fields in regulating the envelope rotation, the formation of disks, and the fragmentation of Class 0 protostars in multiple systems.
Methods. We used the Submillimeter Array to carry out observations of the dust polarized emission at 0.87 mm in the envelopes of a large sample of 20 Class 0 protostars. We estimated the mean magnetic field orientation over the central 1000 au envelope scales to characterize the orientation of the main component of the organized magnetic field at the envelope scales in these embedded protostars. This direction was compared to that of the protostellar outflow in order to study the relation of their misalignment and the kinematics of the circumstellar gas. The latter is traced through the velocity gradient that is observed in the molecular line emission (mainly N_2H^+) of the gas at intermediate envelope scales.
Results. We discover that the misalignment of the magnetic field orientation is strongly related to the outflow and the amount of angular momentum observed at similar scales in the protostellar envelope. This reveals a potential link between the kinetic and the magnetic energy at envelope scales. The relation could be driven by favored B-misalignments in more dynamical envelopes or by a dependence of the envelope dynamics on the initial large-scale B configuration. By comparing the trend with the presence of fragmentation, we observe that single sources are mostly associated with conditions of low angular momentum in the inner envelope and good alignment of the magnetic field with protostellar outflows at intermediate scales. Our results suggest that the properties of the magnetic field in protostellar envelopes are tightly related to the rotating infalling gas that is directly involved in the formation of stars and disks: we find that it may not only affect the fragmentation of protostellar cores into multiple stellar systems, but also sets the conditions that establish the pristine properties of planet-forming disks.

- SMAの偏波観測でClass0天体における磁場の役割を調べる
- B-fieldのmisalignmentはoutflowとエンベロープの角運動量に関係

- B-field misalignmentの重要性
  - 角運動量輸送, 円盤サイズ決定, 磁気制動カタストロフィ問題 etc.
- SMA 860μm連続波偏光観測
  - 20 Class 0に対し~1000au envelopeスケールの偏波を捉える

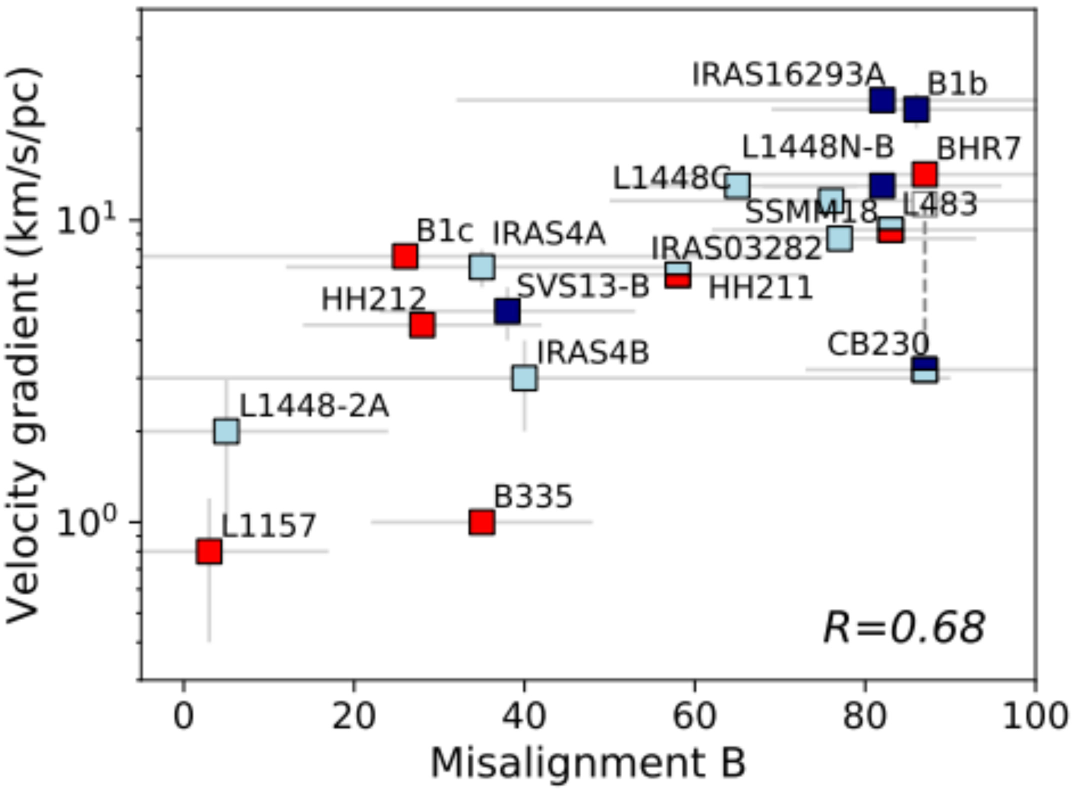
- 偏光ベクトルを平均化(高SN化)
- Outflow軸(文献)とのmisalignmentを算出
- N2H+エンベロープの回転構造(文献)と比較





- エンベロープ速度勾配の大きさとBズレの間に強い相関
    - 強いinfall/rotationによりBズレが起こる？
- 一方、速度勾配のPAとBのPAに相関はない

→エンベロープのgas motionではなく、Bがalignした系で磁気制動が効き角運動量を抜いている？



- ダストコアのsub peakの個数でmultiplicityを導出
  - single
  - double
  - >triple

- single starは左下に、multiple starは右上に固まる

  → B-fieldのalignmentは星形成コアの分裂に寄与している

  MHD simulationの結果と整合的

- エンベロープのトレーサー選択、Outflowのcontamination、projection効果などの問題は残っている
  - そもそも偏光でBが見えているかどうかも議論がある(self scatteringなど)

Herschel Gould Belt Survey Observations of Dense Cores in the Cepheus Flare Clouds
James Di Francesco et al.

ABSTRACT

We present *Herschel* SPIRE and PACS maps of the Cepheus Flare clouds L1157, L1172, L1228, L1241, and L1251, observed by the *Herschel* Gould Belt Survey (HGBS) of nearby star-forming molecular clouds. Through modified blackbody fits to the SPIRE and PACS data, we determine typical cloud column densities of 0.5-1.0 $\times$ 10^{21} cm^{-2} and typical cloud temperatures of 14-15 K. Using the *getsources* identification algorithm, we extract 832 dense cores from the SPIRE and PACS data at 160-500 μm. From placement in a mass vs. size diagram, we consider 303 to be candidate prestellar cores, and 178 of these to be "robust" prestellar cores. From an independent extraction of sources at 70 μm, we consider 25 of the 832 dense cores to be protostellar. The distribution of background column densities coincident with candidate prestellar cores peaks at 2-4 $\times$ 10^{21} cm^{-2}. About half of the candidate prestellar cores in Cepheus may have formed due to the widespread fragmentation expected to occur within filaments of "transcritical" line mass. The lognormal robust prestellar core mass function (CMF) drawn from all five Cepheus clouds peaks at 0.56 $M_\odot$ and has a width of $\sim$0.5 dex, similar to that of Aquila's CMF. Indeed, the width of Cepheus' aggregate CMF is similar to the stellar system Initial Mass Function (IMF). The similarity of CMF widths in different clouds and the system IMF suggests a common, possibly turbulent origin for seeding the fluctuations that evolve into prestellar cores and stars.

The Herschel Orion Protostar Survey: Far-Infrared Photometry and Colors of Protostars and Their Variations across Orion A and B

William J. Fischer et al.

ABSTRACT

The degree to which the properties of protostars are affected by environment remains an open question. To investigate this, we look at the Orion A and B molecular clouds, home to most of the protostars within 500 pc. At $\sim$ 400 pc, Orion is close enough to distinguish individual protostars across a range of environments in terms of both the stellar and gas projected densities. As part of the *Herschel* Orion Protostar Survey (HOPS), we used the Photodetector Array Camera and Spectrometer (PACS) to map 108 partially overlapping square fields with edge lengths of $5'$ or $8'$ and measure the 70 μm and 160 μm flux densities of 338 protostars within them. In this paper we examine how these flux densities and their ratio depend on evolutionary state and environment within the Orion complex. We show that Class 0 protostars occupy a region of the 70 μm flux density versus 160 μm to 70 μm flux density ratio diagram that is distinct from their more evolved counterparts. We then present evidence that the Integral-Shaped Filament (ISF) and Orion B contain protostars with more massive envelopes than those in the more sparsely populated LDN 1641 region. This can be interpreted as evidence for increasing star formation rates in the ISF and Orion B or as a tendency for more massive envelopes to be inherited from denser birth environments. We also provide technical details about the map-making and photometric procedures used in the HOPS program.

Multi-directional mass-accretion and collimated outflows in W51
Ciriaco Goddi et al.

ABSTRACT

We observed the W51 high-mass star-forming complex with ALMA's longest-baseline configurations, achieving an angular resolution of ~20 milliarcseconds, corresponding to a linear resolution of ~100 au at $D_{\rm W51}$ = 5.4 kpc. The observed region contains three high-mass protostars in which the dust continuum emission at 1.3 mm is optically-thick up to a radius $\lesssim$1000 au and has brightness temperatures $\gtrsim$200 K. The high luminosity ($\gtrsim 10^4$ $L_\odot$) in the absence of free-free emission suggests the presence of massive stars ($M \gtrsim 20$ $M_\odot$) at the earliest stages of their formation. Our continuum images reveal remarkably complex and filamentary structures arising from compact cores. Molecular emission shows no clear signs of rotation nor infall on scales from 150 to 2000 au: we do not detect disks. The central sources drive young ($t_{\rm dyn}$ ~100 years), fast (v ~100 km s^{-1}), powerful ($\dot{M} > 10^{-4}$ $M_\odot$ yr^{-1}), collimated outflows. These outflows provide indirect evidence of accretion disks on scales $r \lesssim$100–500 au (depending on the object). The active outflows are connected to fossil flows that have different orientations on larger spatial scales, implying that the orientations of these small disks change over time. These results together support a variant of an accretion model for high-mass star formation in which massive protostars do not form a large, stable Keplerian disk during their early stages, but instead they accrete material from multiple massive flows with different angular momentum vectors. This scenario therefore contrasts with the simplified classic paradigm of a stable disk+jet system, which is the standard model for low-mass star formation, and provides an experimental confirmation of a multi-directional and unsteady accretion model for massive star formation.

STARFORGE: The effects of protostellar outflows on the IMF
David Guszejnov et al.

ABSTRACT
The initial mass function (IMF) of stars is a key quantity affecting almost every field of astrophysics, yet it remains unclear what physical mechanisms determine it. We present the first runs of the STARFORGE project, using a new numerical framework to follow the formation of individual stars in giant molecular clouds (GMCs) using the GIZMO code. Our suite include runs with increasingly complex physics, starting with isothermal ideal magnetohydrodynamic (MHD) and then adding non-isothermal thermodynamics and protostellar outflows. We show that without protostellar outflows the resulting stellar masses are an order of magnitude too high, similar to the result in the base isothermal MHD run. Outflows disrupt the accretion flow around the protostar, allowing gas to fragment and additional stars to form, thereby lowering the mean stellar mass to a value similar to that observed. The effect of jets upon global cloud evolution is most pronounced for lower-mass GMCs and dense clumps, so while jets can disrupt low-mass clouds, they are unable to regulate star formation in massive GMCs, as they would turn an order unity fraction of the mass into stars before unbinding the cloud. Jets are also unable to stop the runaway accretion of massive stars, which could ultimately lead to the formation of stars with masses $> 500\,M_\odot$. Although we find that the mass scale set by jets is insensitive to most cloud parameters (i.e., surface density, virial parameter), it is strongly dependent on the momentum loading of the jets (which is poorly constrained by observations) as well the the temperature of the parent cloud, which predicts slightly larger IMF variations than observed. We conclude that protostellar jets play a vital role in setting the mass scale of stars, but additional physics are necessary to reproduce the observed IMF.

Physical conditions of gas components in debris disks of 49 Ceti and HD 21997

Aya E. Higuchi et al.

ABSTRACT

Characterization of gas component in debris disks is of fundamental importance for understanding its origin. Toward this goal, we have conducted non-LTE (local thermodynamic equilibrium) analyses of the rotational spectral lines of CO including those of rare isotopologues (^{13}CO and C^{18}O) observed toward the gaseous debris disks of 49 Ceti and HD 21997 with the Atacama Large Millimeter/submillimeter Array (ALMA) and Atacama Compact Array (ACA). The analyses have been carried out for a wide range of the H_2 density, and the observed line intensities are found to be reproduced, as far as the H_2 density is higher than 10^3 cm^{-3}. The CO column density and the gas temperature are evaluated to be $(1.8–5.9)\times10^{17}$ cm^{-2} and 8–11 K for 49 Ceti and $(2.6–15)\times10^{17}$ cm^{-2} and 8–12 K for HD 21997, respectively, where the H_2 collision is assumed for the rotational excitation of CO. The results do not change significantly even if electron collision is considered. Thus, CO molecules can be excited under environments of no H_2 or a small number of H_2 molecules, even where the collision with CO, C, O, and C^+ would make an important contribution for the CO excitation in addition to H_2. Meanwhile, our result does not rule out the case of abundant H_2 molecules. The low gas temperature observed in the debris disks is discussed in terms of inefficient heating by interstellar and stellar UV radiation.