Star Formation Newsletter #333 29-36

武藤恭之

No. 29

A triple star system with a misaligned and warped circumstellar disk shaped by disk tearing

arXiv:2004.01204

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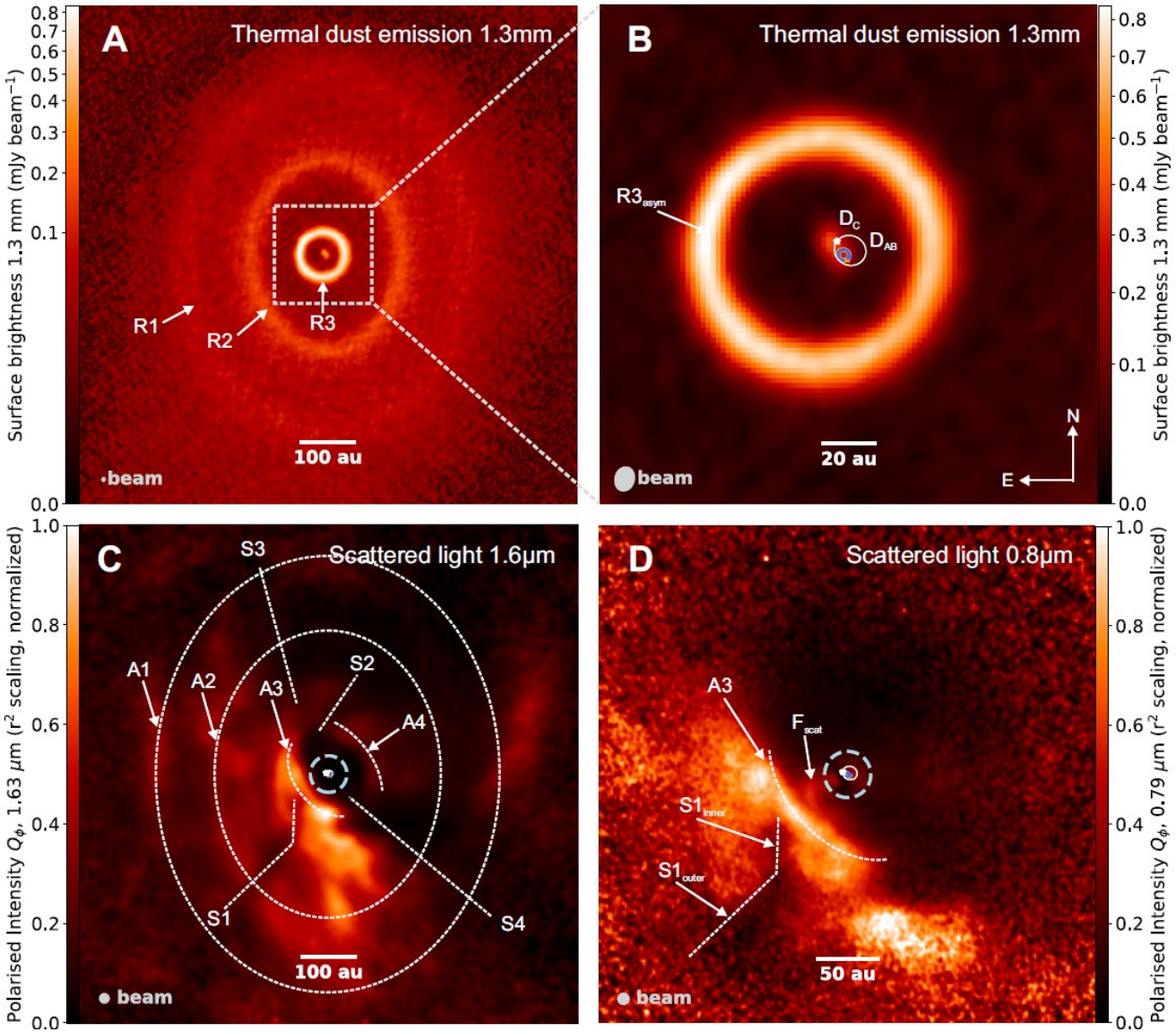
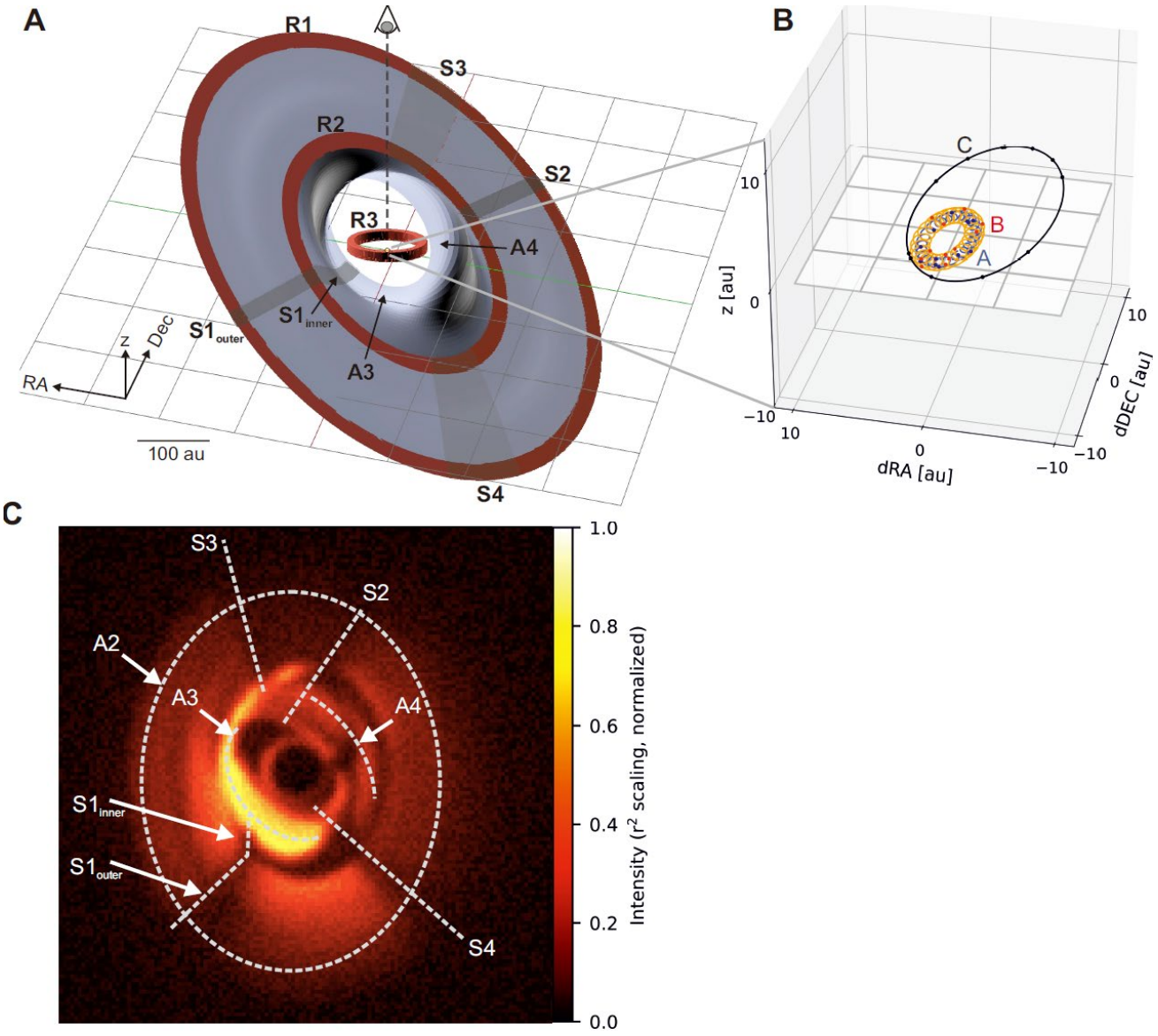
Young stars are surrounded by a circumstellar disk of gas and dust, within which planet formation can occur. Gravitational forces in multiple star systems can disrupt the disk. Theoretical models predict that if the disk is misaligned with the orbital plane of the stars, the disk should warp and break into precessing rings, a phenomenon known as disk tearing. We present observations of the triple-star system GW Orionis, finding evidence for disk tearing. Our images show an eccentric ring that is misaligned with the orbital planes and the outer disk. The ring casts shadows on a strongly warped intermediate region of the disk. If planets can form within the warped disk, disk tearing could provide a mechanism for forming wide-separation planets on oblique orbits.

- 三重星系 GW Ori の軌道と周囲の円盤の観測
- 星たちは、離心率が 0.2 程度の軌道にある
- 近赤外線の観測で、影のような構造が見えており、電波で見えるリングも中心がずれていて、互いに傾いたリング構造を持った星＋円盤の系
- 三重星系と円盤の相互作用で、このような構造ができそう

円盤の熱放射と赤外線散乱光



円盤構造、三重星の軌道、散乱光のモデル



No. 30

Physicochemical models: source-tailored or generic?

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arXiv:2008.04798

ABSTRACT

Physicochemical models can be powerful tools to trace the chemical evolution of a protostellar system and allow to constrain its physical conditions at formation. The aim of this work is to assess whether source-tailored modelling is needed to explain the observed molecular abundances around young, low-mass protostars or if, and to what extent, generic models can improve our understanding of the chemistry in the earliest stages of star formation. The physical conditions and the abundances of simple, most abundant molecules based on three models are compared. After establishing the discrepancies between the calculated chemical output, the calculations are redone with the same chemical model for all three sets of physical input parameters. With the differences arising from the chemical models eliminated, the output is compared based on the influence of the physical model. Results suggest that the impact of the chemical model is small compared to the influence of the physical conditions, with considered timescales having the most drastic effect. Source-tailored models may be simpler by design; however, likely do not sufficiently constrain the physical and chemical parameters within the global picture of star-forming regions. Generic models with more comprehensive physics may not provide the optimal match to observations of a particular protostellar system, but allow a source to be studied in perspective of other star-forming regions.

- 星形成における化学進化計算コードの比較
- 物理モデルの仮定や、化学反応計算の違いが、どのように分子の存在量に影響するか
- 物理的な条件の仮定の方が、化学モデルの仮定に比べて結果への影響が大きい
- 天体固有のモデルでも、不定性は大きい

基本的な考え方：
分子雲コアの collapse 前から collapse 後までを追う
比較的単純化した力学モデルの中で、化学進化を追う

3つのモデルを考える：

- W14-M20: IRAS16293 用の1次元モデル
- S20: IRAS16293 用の1次元モデル

- D16: 2次元の一般的なモデル

1次元モデル: envelope のモデル
化学計算は bulk, surface, gas の3相

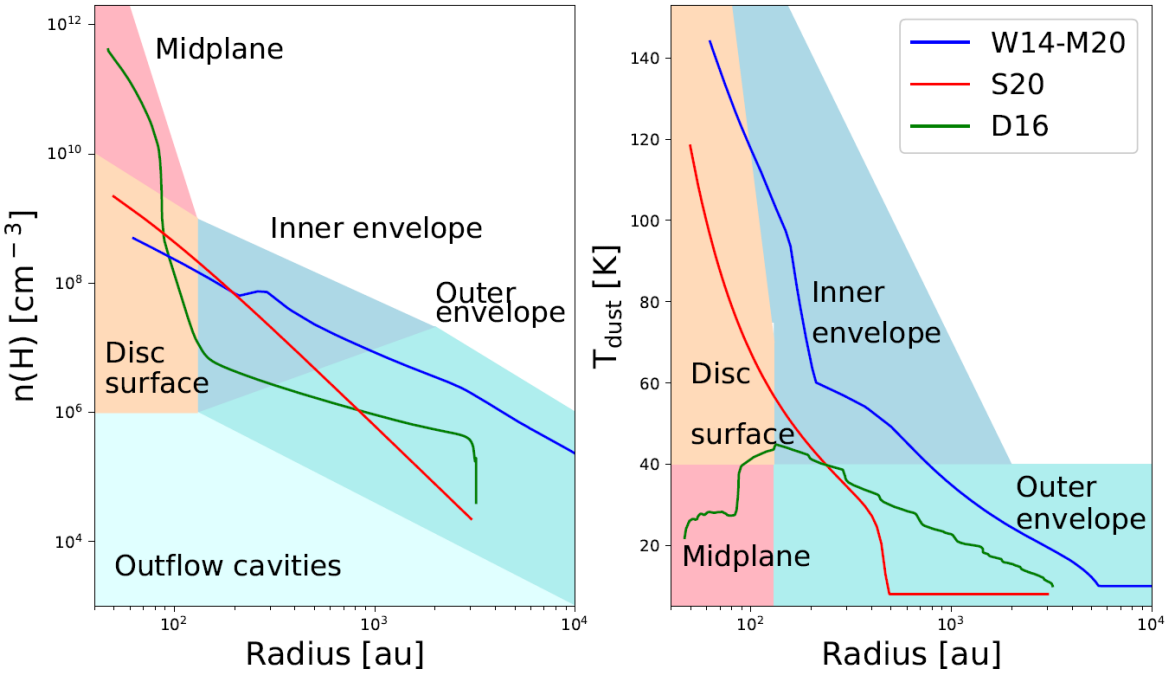
2次元モデル: 円盤も入ってくる
化学計算は bulk+surface, gas の2相

Parameter	W14-M20[a]	S20[b]	D16[c]
$T_{dust,gas}$ [K]	10	8	10
n_H [cm^{-3}]	2.0×10^4	2.3×10^4	4.0×10^4
A_v [mag]	4.5	5.0-7.5	10
ζ_{CR} [s^{-1}]	1.3×10^{-17}	1.3×10^{-17}	5.0×10^{-17}
$t_{precollapse}$ [yr]	1.0×10^6	1.0×10^6	3.0×10^5
$t_{collapse}$ [yr]	3.4×10^5	3.2×10^5	2.5×10^5
t_{*birth} [yr]	2.5×10^5	3.1×10^5	2.0×10^4
t_{*birth} [$t_{collapse}$]	0.73	0.97	0.08

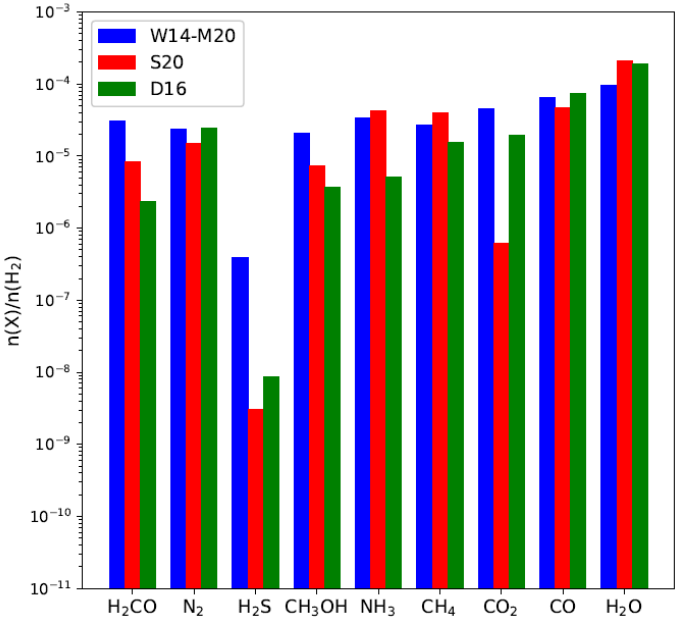
物理モデルのパラメータの違い

重要なパラメータ：
- t_{precollapse}
- 分子雲コアが重力収縮を開始するまでの時間

1次元モデルと2次元モデルの違い
- 1次元モデルのパラメータ領域は、基本的に envelope 領域
- 2次元モデルは、円盤のパラメータ領域も入っている

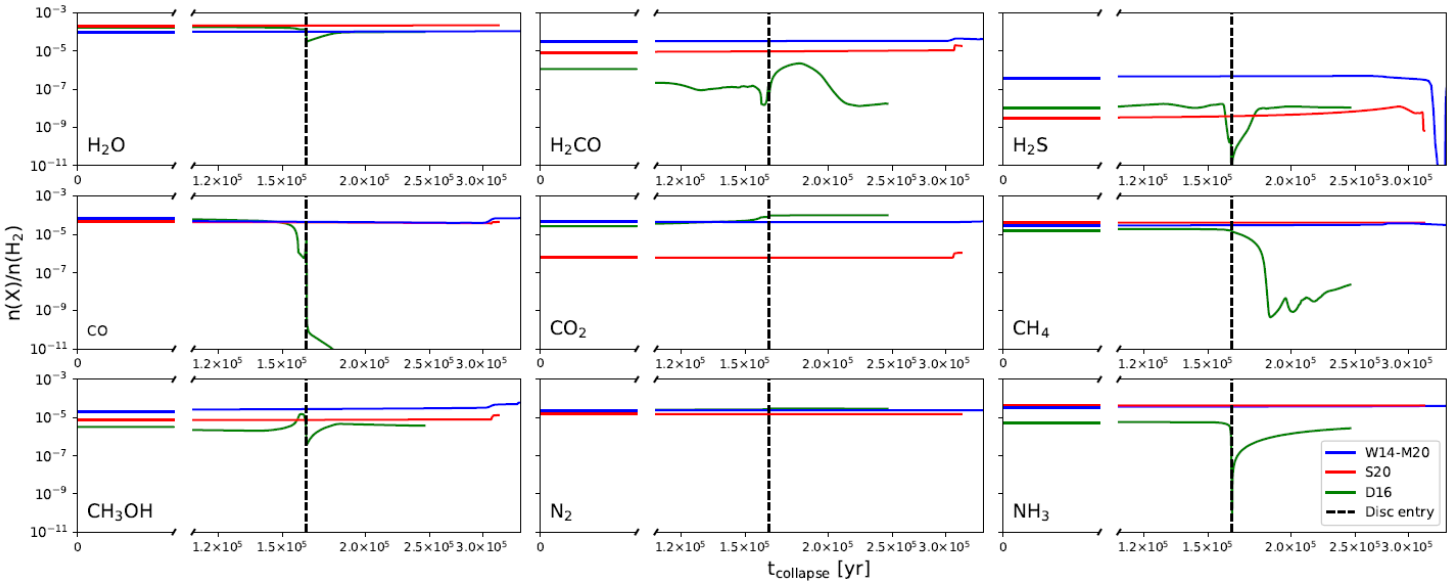


Collapse 直前の分子のアバンダンス
- S20 の CO が少ない
  ➔ 理由はよく分からない
- D16 の NH3, H2CO, CH3OH が少ない
  ➔ precollape の時間が短いため
- H2S の違い
  ➔ 初期に仮定した元素の abundance の違い（S20 と D16 は S が少ない）

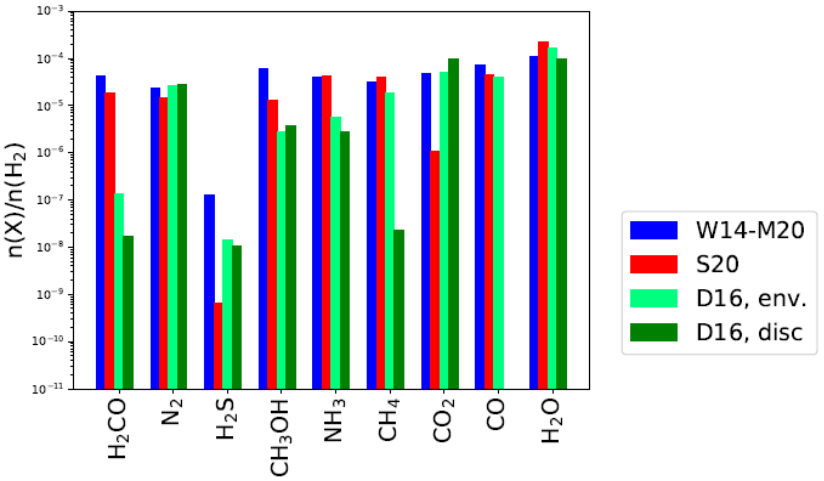


Collapse における分子のアバンダンス
- H2S, CO2 の量の違いは collapse 後もそのまま保たれる
- D16 に入っている円盤（小さく、冷たく、濃いガス）形成は、N2 以外の全ての分子で効果が大きい

黒点線:
円盤形成



Collapse 後の分子のアバンダンス
- H2S, CO2 の量の違いは collapse 後もそのまま保たれている
- 最終的には、envelope のアバンダンスは、そこそこどのモデルでも一致
- D16 が全体的に分子が少ない傾向
  ➔ D16 のモデルは年齢が若い
- disk のアバンダンスは envelope と異なる



化学進化モデルでは、年齢やタイムスケールが重要な要素になる

※化学反応モデル（2相／3相）の違いは、H2CO や CH3OH の量の違いに影響するが、そこまで大きな影響ではなさそう

論文の結論：
- precollapse phase の仮定に気をつける必要がある。t_{precollapse} の違いは 30万年程度だが、その時点での分子のアバンダンスに影響が大きく、それを collapse 後まで引きずる
- 物理的な状況の仮定の違いの影響は、化学反応計算の影響よりも大きい
- 円盤を空間分解するような高解像度観測（ALMA 観測）では、円盤などの構造を入れたモデルが必要になる。

No. 35

The family of amide molecules toward NGC 6334I

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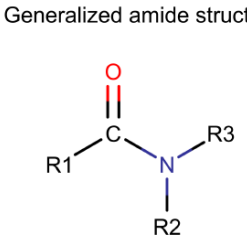
arXiv:2008.09157

Amide molecules produced in space could play a key role in the formation of biomolecules on a young planetary object. However, the formation and chemical network of amide molecules in space is not well understood. In this work, ALMA observations are used to study a number of amide(-like) molecules toward the high-mass star-forming region NGC 6334I. The first detections of cyanamide (NH_2CN), acetamide ($CH_3C(O)NH_2$) and N-methylformamide (CH_3NHCHO) are presented for this source. These are combined with analyses of isocyanic acid (HNCO) and formamide (NH_2CHO) and a tentative detection of urea (carbamide; $NH_2C(O)NH_2$). Abundance correlations show that most amides are likely formed in related reactions occurring in ices on interstellar dust grains in NGC 6334I. However, in an expanded sample of sources, large abundance variations are seen for NH_2CN that seem to depend on the source type, which suggests that the physical conditions within the source heavily influence the production of this species. The rich amide inventory of NGC 6334I strengthens the case that interstellar molecules can contribute to the emergence of biomolecules on planets.

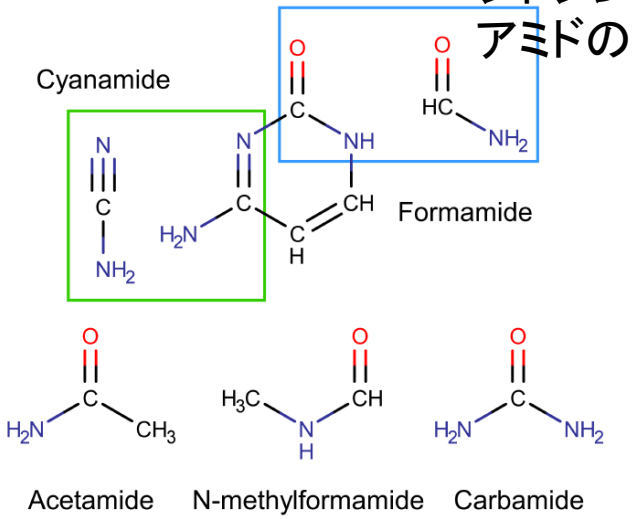
- 大質量星形成領域 NGC6334I における、アミドを持った分子の発見
  - すでに、様々な複雑分子が見つかっている領域
- NH2CN, CH3C(O)NH2, CH3NHCHO を見つけ、アバンダンスを他の天体と比較
- どの天体でも同じようなアバンダンスであり、似たような反応（星間ダスト中の氷の上での反応？）で出来たものと思われる
  - ただし、NH2CN はソースによってアバンダンスが異なり、天体の環境の違いを反映しているかもしれない
- 生命関連物質は星間空間起源？



アミドの一般構造

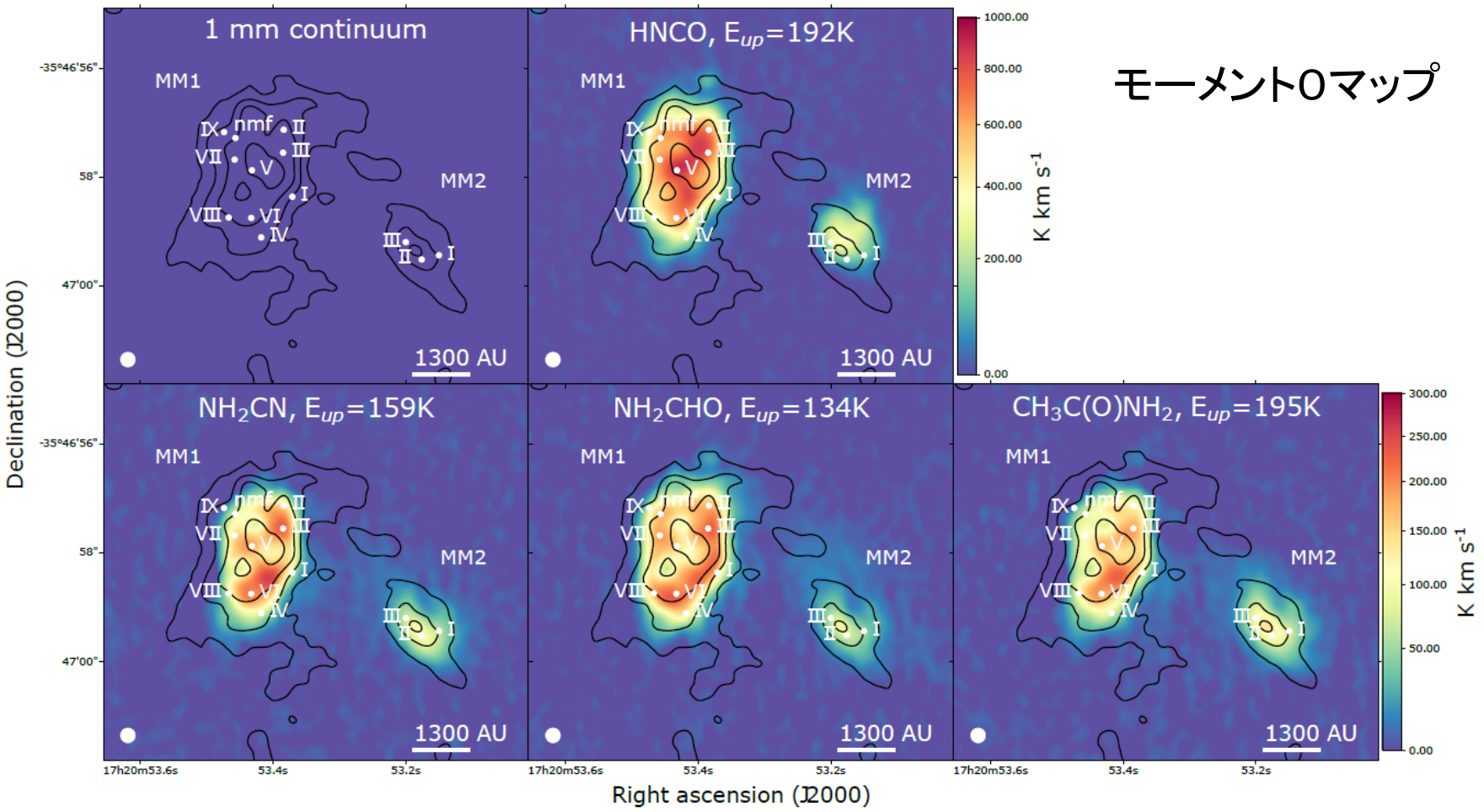
Nucleobase Cytosine

シトシンの中に、アミドの構造



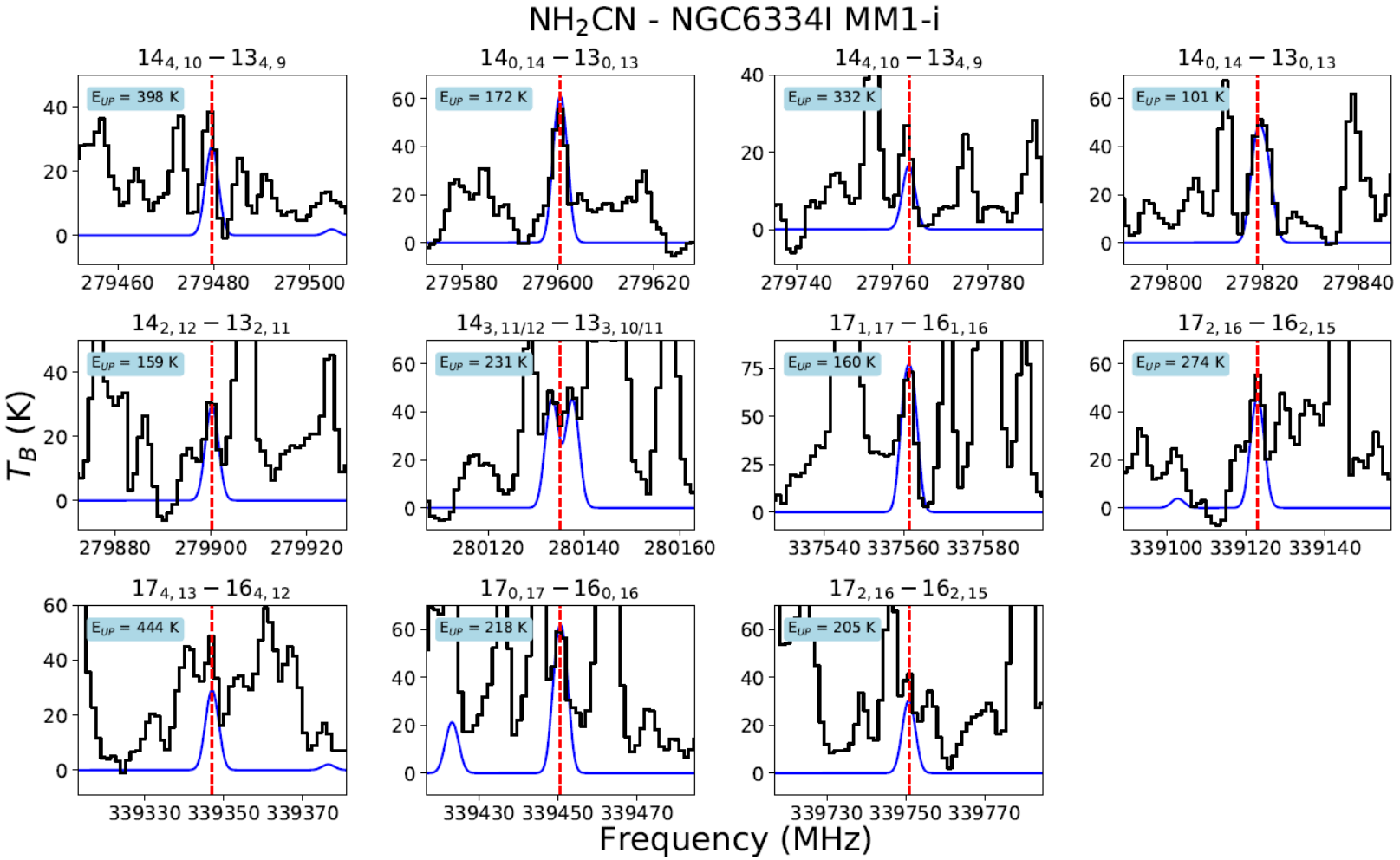
観測：大質量星形成領域 NGC6334I の ALMA 観測。
これまでに、CH3CHO, CH3COOH などの O を持った分子や、NH2CHO などの N を持った分子が観測されている領域

Position	RA	DEC	$V_{\rm LSR}^{\dagger}$	ΔV	$T_{\rm ex}$	$T_{\rm BG}^{\ddagger}$			
						(a)	(b)	(c)	(d)
	hh:mm:ss	dd:mm:ss	(km s^{-1})	(km s^{-1})	(K)	(K)			
MM1-i	17:20:53.373	-35.46.58.341	-7.0	3.25	135	10.1	26.9	31.3	31.3
MM1-ii	17:20:53.386	-35.46.57.112	-4.0 – -4.5	3.25	175	38.9	79.7	94.6	85.1
MM1-iii	17:20:53.387	-35.46.57.533	-5.2	3.00	225	50.8	108.2	129.7	120.3
MM1-iv	17:20:53.420	-35.46.59.088	-8.2	3.50	150	15.7	38.4	44.8	73.6
MM1-v	17:20:53.434	-35.46.57.856	-4.4	3.25	285	69.0	159.3	192.7	176
MM1-vi	17:20:53.435	-35.46.58.731	-7.0 – -7.5	3.25	190	30.2	77.6	88.6	94.4
MM1-vii	17:20:53.459	-35.46.57.661	-4.0	3.00	185	43.4	96.5	112.4	106.7
MM1-viii	17:20:53.469	-35.46.58.724	-6.8	3.00	150	25.8	57.1	64.7	81.9
MM1-ix	17:20:53.475	-35.46.57.156	-5.0	2.50	150	16.9	36.8	45.2	65.7
MM1-nmf	17:20:53.461	-35.46.57.284	-4.5	2.50	150	31.1	66.8	80.9	88.1
MM2-i	17:20:53.152	-35.46.59.416	-9.0	2.80	150	9.2	21.8	27.8	57.5
MM2-ii	17:20:53.178	-35.46.59.494	-9.0	2.80	200	17.4	44.4	58.6	98.4
MM2-iii	17:20:53.202	-35.46.59.175	-7.8	2.80	180	18.9	44.2	57.7	76.1

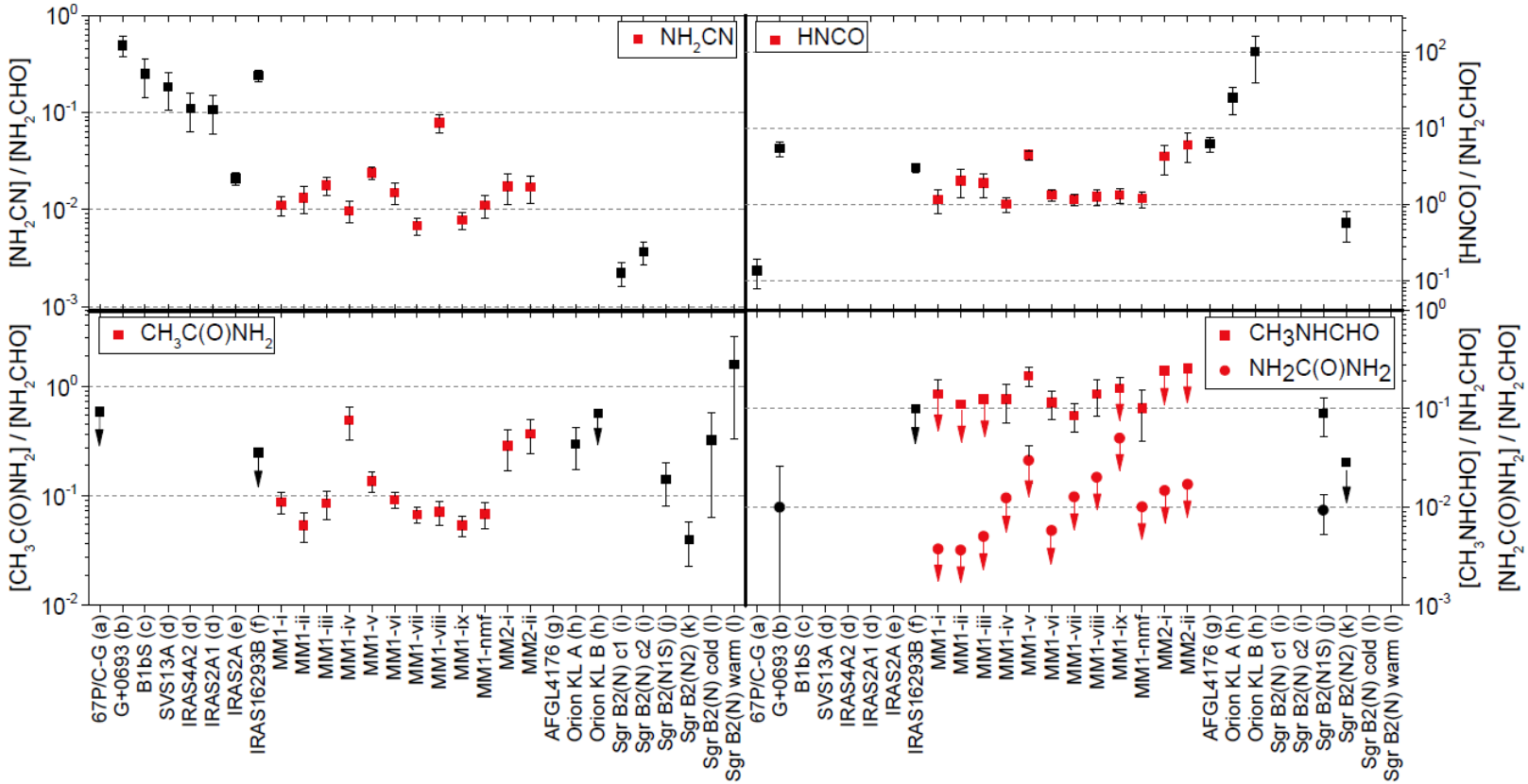


モーメント0マップ

i, ii, iii,... の位置で、スペクトルを取って解析



MM1-I の位置での NH2CN のスペクトル



領域内／他の領域との NH2CHO に対するアバンダンスの比較

- NH2CN: NGC3884I の中では、ほぼ同じ程度のアバンダンスだが、他の領域と比較すると1桁違う
  - 大質量星形成領域では、NH2CN が少ない？ガス密度が高いと生成反応が抑えられる可能性？温度環境が NH2CN と NH2CHO の desorption の量を決めている？
- HNCO: だいたい interstellar の平均的な量程度。NGC3884I の中で、MM2 の方が MM1 より5倍程度大きい
  - イオン化率の違いを表している？

No. 31

SCExAO/CHARIS Near-IR Integral Field Spectroscopy of the HD 15115 Debris Disk

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arXiv:2008.00309

We present new, near-infrared (1.1–2.4 μm) high-contrast imaging of the debris disk around HD 15115 with the Subaru Coronagraphic Extreme Adaptive Optics system (SCExAO) coupled with the Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS). SCExAO/CHARIS resolves the disk down to $\rho \sim 0\farcs2$ ($r_{\rm proj} \sim 10$ au), a factor of $\sim$3–5 smaller than previous recent studies. We derive a disk position angle of PA $\sim 279\fdg4$–$280\fdg5$ and an inclination of $i \sim 85\fdg3$–$86\fdg2$. While recent SPHERE/IRDIS imagery of the system could suggest a significantly misaligned two ring disk geometry, CHARIS imagery does not reveal conclusive evidence for this hypothesis. Moreover, optimizing models of both one and two ring geometries using differential evolution, we find that a single ring having a Hong-like scattering phase function matches the data equally well within the CHARIS field of view ($\rho \lesssim 1''$). The disk's asymmetry, well-evidenced at larger separations, is also recovered; the west side of the disk appears on average around 0.4 magnitudes brighter across the CHARIS bandpass between $0\farcs25$ and $1''$. Comparing STIS/50CCD optical photometry (2000–10500 Å) with CHARIS NIR photometry, we find a red (STIS/50CCD–CHARIS broadband) color for both sides of the disk throughout the $0\farcs4$–$1''$ region of overlap, in contrast to the blue color reported at similar wavelengths for regions exterior to $\sim 2''$. Further, this color may suggest a smaller minimum grain size than previously estimated at larger separations. Finally, we provide constraints on planetary companions, and discuss possible mechanisms for the observed inner disk flux asymmetry and color.

- SCExAO/CHARIS による、デブリ円盤 HD15115 の直接撮像
- SPHERE で報告された、misaligned ring の構造は検出できなかった
- 非軸対称構造を見つけた
- HST 観測と合わせると、grain size が小さそう

No. 32

A 3mm chemical exploration of small organics in Class I YSOs

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arXiv:2006.12526

There is mounting evidence that the composition and structure of planetary systems are intimately linked to their birth environments. During the past decade, several spectral surveys probed the chemistry of the earliest stages of star formation and of late planet-forming disks. However, very little is known about the chemistry of intermediate protostellar stages, i.e. Class I Young Stellar Objects (YSOs), where planet formation may have already begun. We present here the first results of a 3mm spectral survey performed with the IRAM-30m telescope to investigate the chemistry of a sample of seven Class I YSOs located in the Taurus star-forming region. These sources were selected to embrace the wide diversity identified for low-mass protostellar envelope and disk systems. We present detections and upper limits of thirteen small ($N_{\rm atoms} \leq 3$) C, N, O, and S carriers - namely CO, HCO^+, HCN, HNC, CN, N_2H^+, C_2H, CS, SO, HCS^+, C_2S, SO_2, OCS - and some of their D, ^{13}C, ^{15}N, ^{18}O, ^{17}O, and ^{34}S isotopologues. Together, these species provide constraints on gas-phase C/N/O ratios, D- and ^{15}N-fractionation, source temperature and UV exposure, as well as the overall S-chemistry. We find substantial evidence of chemical differentiation among our source sample, some of which can be traced back to Class I physical parameters, such as the disk-to-envelope mass ratio (proxy for Class I evolutionary stage), the source luminosity, and the UV-field strength. Overall, these first results allow us to start investigating the astrochemistry of Class I objects, however, interferometric observations are needed to differentiate envelope versus disk chemistry.

- IRAM 30m 望遠鏡による、Class I 天体の 3mm での分子輝線サーベイ
- C, N, O を含む小さな分子（元素数3以下）の量などを調べた
- Chemical differentiation が Class I 段階で起こっていることを示唆

Wind-MRI interactions in local models of protoplanetary discs: I. Ohmic resistivity

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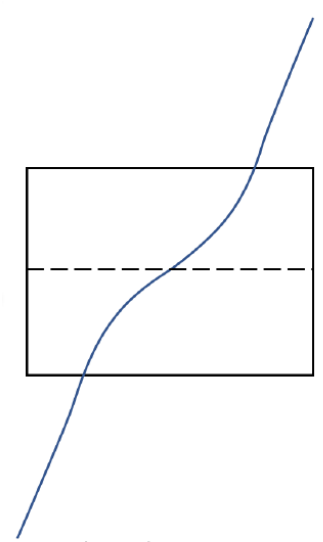
arXiv:2008.00906

A magnetic disc wind is an important mechanism that may be responsible for driving accretion and structure formation in protoplanetary discs. Recent numerical simulations have shown that these winds can take either the traditional 'hourglass' symmetry about the mid-plane, or a 'slanted' symmetry dominated by a mid-plane toroidal field of a single sign. The formation of this slanted symmetry state has not previously been explained. We use radially local 1D vertical shearing box simulations to assess the importance of large-scale MRI channel modes in influencing the formation and morphologies of these wind solutions. We consider only Ohmic resistivity and explore the effect of different magnetisations, with the mid-plane β parameter ranging from 10^5 to 10^2. We find that our magnetic winds go through three stages of development: cyclic, transitive and steady, with the steady wind taking a slanted symmetry profile similar to those observed in local and global simulations. We show that the cycles are driven by periodic excitation of the $n = 2$ or 3 MRI channel mode coupled with advective eviction, and that the transition to the steady wind is caused by a much more slowly growing $n = 1$ mode altering the wind structure. Saturation is achieved through a combination of advective damping from the strong wind, and suppression of the instability due to a strong toroidal field. A higher disc magnetisation leads to a greater tendency towards, and more rapid settling into the slanted symmetry steady wind, which may have important implications for mass and flux transport processes in protoplanetary discs.



Slanted symmetry

- 磁気円盤風と、根元の円盤の磁場構造との関係を調べる
- 磁場構造が “slanted symmetry” という傾いた場合にどうなるかを調べる
  - 円盤で MRI の channel mode が卓越するような場合
- 円盤磁場が強いと、slanted symmetry になりうる

No. 34

Evidence for dense gas heated by the explosion in Orion KL

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arXiv:2008.04564

We mapped the kinetic temperature structure of Orion KL in a ∼20″ (∼8000 AU) sized region with para-H_2CS $7_{07} - 6_{06}$, $7_{26} - 6_{25}$, and $7_{25} - 6_{24}$ making use of ALMA Band 6 Science Verification data. The kinetic temperatures obtained with a resolution of 1.″65×1.″14 (∼550 AU) are deduced by modeling the measured averaged velocity-integrated intensity ratios of para-H_2CS $7_{26} - 6_{25}/7_{07} - 6_{06}$ and $7_{25} - 6_{24}/7_{07} - 6_{06}$ with a RADEX non-LTE model. The kinetic temperatures of the dense gas, derived from the para-H_2CS line ratios at a spatial density of 10^7 cm^{-3}, are high, ranging from 43 to >500 K with an unweighted average of ∼170 K. There is no evidence for internal sources playing an important role in the heating of the various structures identified in previous work, namely the elongated ridge, the northwestern clump, and the eastern region of the compact ridge, while the high temperatures in the western region of the compact ridge may be dominated by internal massive star formation. Significant gradients of kinetic temperature along molecular filaments traced by H_2CS indicate that the dense gas is heated by the shocks induced by the enigmatic explosive event, which occurred several hundred years ago greatly affecting the energetics of the Orion KL region. Thus, with the notable exception of the western region of the compact ridge, the high temperatures of the dense gas in Orion KL are probably caused by shocks from the explosive event, leading to a dominant component of externally heated dense gas.

- Orion KL の 8000AU 程度の領域の運動温度のマッピング
- 様々な構造について、加熱に寄与する internal source がある証拠は見つからなかった
- 数100年前に起こった、爆発的な何らかの現象が、Orion KL の energetics に強い影響を与えている可能性がある

No. 36

Gas-grain model of carbon fractionation in dense molecular clouds

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arXiv:2008.13411

Carbon containing molecules in cold molecular clouds show various levels of isotopic fractionation through multiple observations. To understand such effects, we have developed a new gas-grain chemical model with updated ^{13}C fractionation reactions (also including the corresponding reactions for ^{15}N, ^{18}O and ^{34}S). For chemical ages typical of dense clouds, our nominal model leads to two ^{13}C reservoirs: CO and the species that derive from CO, mainly s-CO and s-CH_3OH, as well as C_3 in the gas phase. The nominal model leads to strong enrichment in C_3, c-C_3H_2 and C_2H in contradiction with observations. When C_3 reacts with oxygen atoms the global agreement between the various observations and the simulations is rather good showing variable ^{13}C fractionation levels which are specific to each species. Alternatively, hydrogen atom reactions lead to notable relative ^{13}C fractionation effects for the two non-equivalent isotopologues of C_2H, c-C_3H_2 and C_2S. As there are several important fractionation reactions, some carbon bearing species are enriched in ^{13}C, particularly CO, depleting atomic ^{13}C in the gas phase. This induces a ^{13}C depletion in CH_4 formed on grain surfaces, an effect that is not observed in the CH_4 in the solar system, in particular on Titan. This seems to indicate a transformation of matter between the collapse of the molecular clouds, leading to the formation of the protostellar disc, and the formation of the planets. Or it means that the atomic carbon sticking to the grains reacts with the species already on the grains giving very little CH_4.

- 炭素の同位体分別に関する、gas-grain chemistry の新しいモデル
- 13C の reservoir が多くなり、気相の CO に 13CO が多くなり、atomic 13C が少なくなる。その結果、ダスト上で出来る CH4 に 13C が少なくなる
  - 太陽系で（特にタイタンで）観測されている現象と合わない
- 星形成段階と惑星形成段階で、物質が変わっているかもしれない