Star Formation Newsletter #368 29-42

麻生　有佑　(KASI)

Filament fragmentation: density gradients suppress end-dominated collapse

Elena Hoemann [1,2★] Stefan Heigl [1,3] and Andreas Burkert [1,2,3]

分子雲の分裂は擾乱の成長と端効果。しかし、端のコアが支配的なフィラメントは観測されていない。
フィラメントへの質量流入が端に作る緩やかな密度勾配は端効果を止めるのか？

$$\rho(r) = \rho_c \left[1 + \left(\frac{r}{H}\right)^2\right]^{-2} \quad H^2 = \frac{2c_s^2}{\pi G \rho_c}, \quad \mu = \frac{M}{l}. \quad \mu_{crit} = \frac{2c_s^2}{G} \approx 16.4\ M_\odot\ pc^{-1}, \quad f = \frac{\mu}{\mu_{crit}}. \quad \rho_b = \rho_c(1-f)^2, \quad R = H\left(\frac{f}{1-f}\right)^{1/2}$$

軸方向zでの自己重力による加速度

$$a = -2\pi G\bar{\rho}\left[2z - \sqrt{\left(\frac{l}{2}+z\right)^2 + R^2} + \sqrt{\left(\frac{l}{2}-z\right)^2 + R^2}\right],$$

端ができる(臨界線質量を超える?)時間

$$t_{edge} = \sqrt{\left(\frac{1}{f}-1\right)\frac{2\times 1.66R}{|a(\frac{l}{2} - 1.66\frac{R}{2})|}} \propto \frac{1}{\sqrt{a_{edge}}}$$

端が中心に来る時間

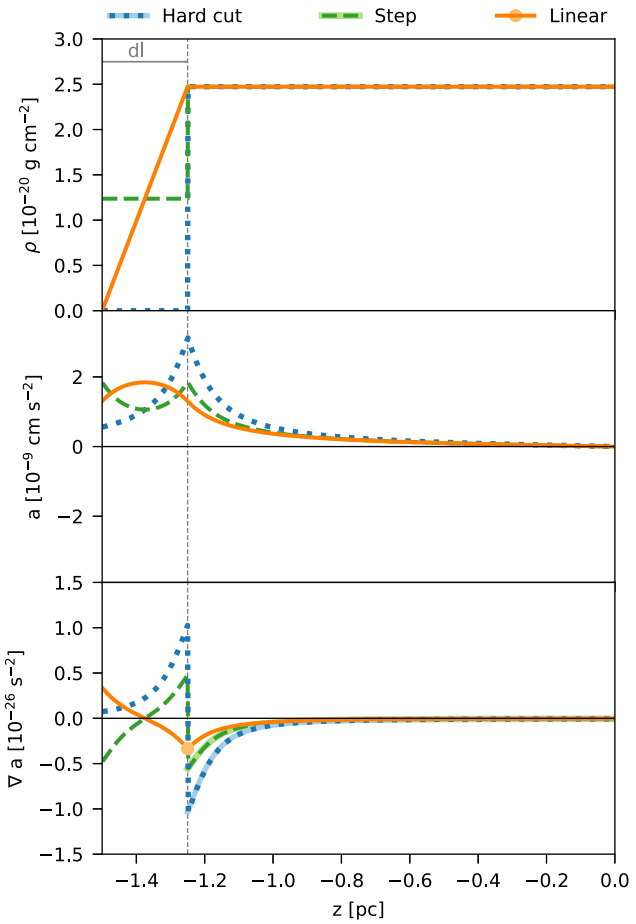
$$t_{col} = \frac{0.42 + 0.28\frac{l/2}{R}}{\sqrt{G\bar{\rho}}} \propto \frac{1}{\sqrt{a_{edge}}}$$

擾乱が収縮コアになる時間

$$t_{pert} = \tau_{dom} \log\left[\left(\frac{1}{f}-1\right)\frac{1}{\epsilon}\right]. \quad \tau_{dom} = \left(4.08 - 2.99f^2 + 1.46f^3 + 0.40f^4\right)/\sqrt{4\pi G\rho_c}.$$

ϵ: 擾乱の強さ~0.09

勾配によって加速を小さくするとt_{edge}は伸びるが、t_{col}も同じように伸びるので、収縮しきる前に端ができる。t_{pert}はa_{edge}に依らないので、$t_{edge} > t_{pert}$にはできる。



Filament fragmentation: density gradients suppress end-dominated collapse

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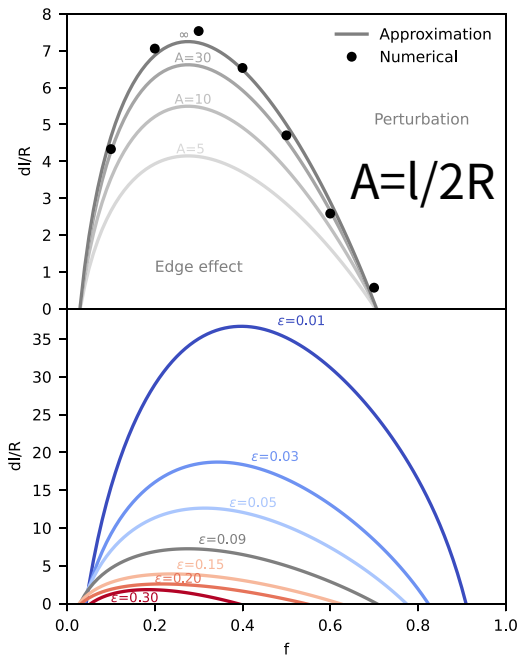
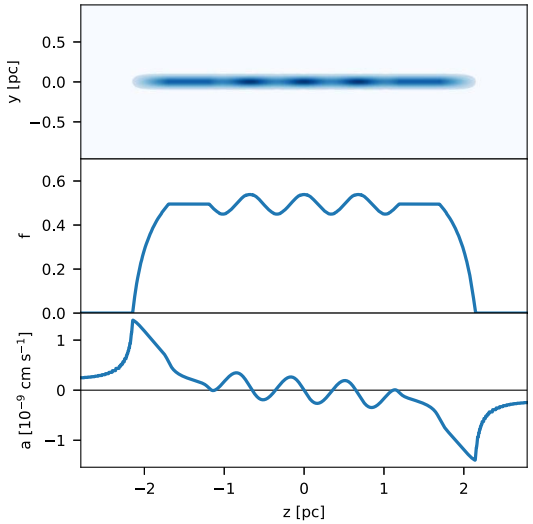
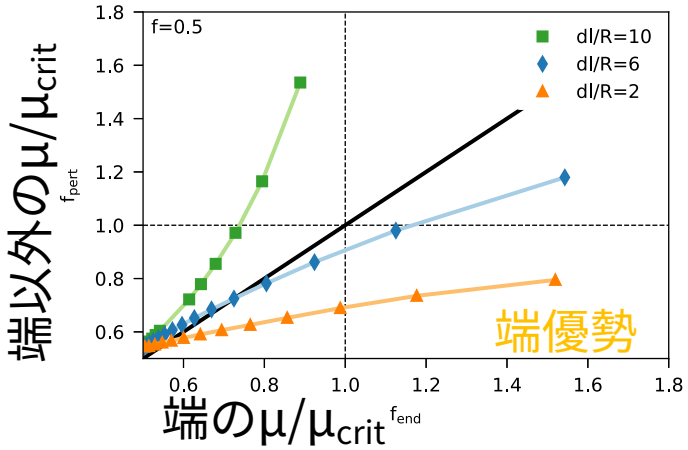
線形勾配の場合$t_{edge}=t_{pert}$となるdl/Rを近似的に求めた。

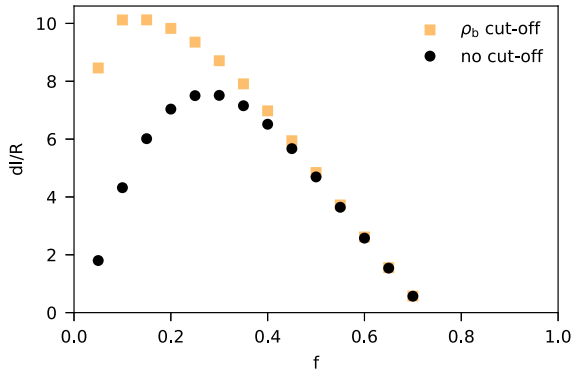


AMRコードRAMSESで等温流体シミュレーションをして確認。
内側のコアと端のコアどちらが早く収縮するか。



R=0.1 pc, l=3 pc,
f=0.5, dl/R=6, ϵ=0.09
→ 収縮はほぼ同時。





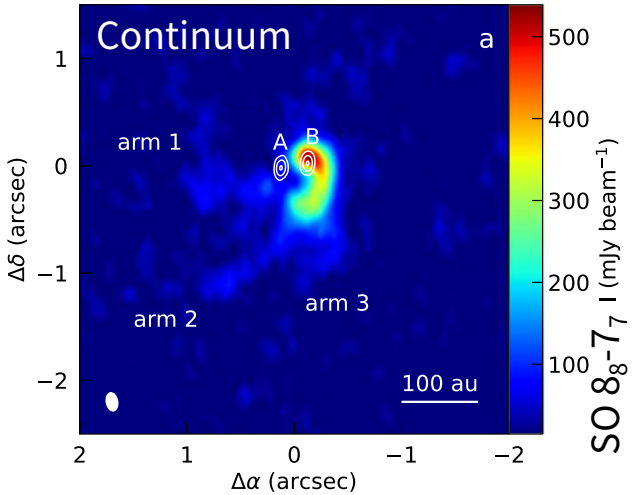
勾配部の外の密度が0ではなくρbだと軽い (f<0.4) フィラメントで端を防ぐのにより大きな勾配が必要。

端の勾配は観測では示されていない。Barnard 5はFWHM~0.03 pcより長い~0.05 pcの勾配領域があるが、フィラメントがf>>1なので本研究とは比べられない。

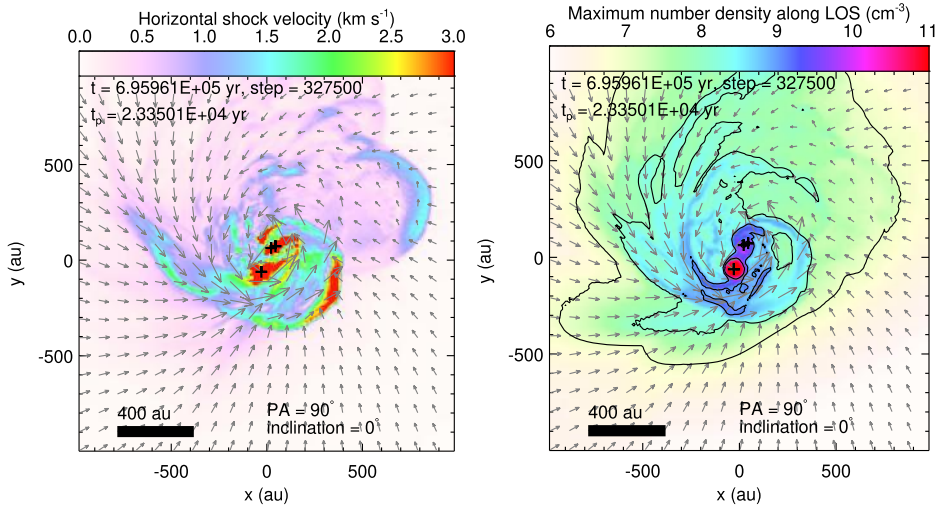
Triple Spiral Arms of a Triple Protostar System Imaged in Molecular Lines

Jeong-Eun Lee[1,2], Tomoaki Matsumoto[3], Hyun-Jeong Kim[4], Seokho Lee[4], Daniel Harsono[5], Jaehan Bae[6], Neal J. Evans II[7], Shu-ichiro Inutsuka[8], Minho Choi[4], Ken'ichi Tatematsu[9], Jae-Joon Lee[4], and Daniel Jaffe[7]

星形成の主モードである連星形成を理解するために力学的相互作用が消える前を見るべき。
エンベロープがあると乱流分裂と円盤分裂が混ざる。磁場も。
IRAS04239+2436, ALMA, 857 μm, 0.1" (14 au), 42-au連星 (主星は未分解連星), 0.14-0.20 Mo.



SOは10^7 cm^{-3}, 3 km/sの衝撃波でも検出できる。
→SO渦状腕は連星トルクをエンベロープが受けた結果。



三重連星、三重渦状腕。Matsumoto+'15の乱流エンベロープ中の三重連星のシミュレーションを再解析。
AMRコードSFUMATO,
磁場無し、初期はフィラメント、(1.56 pc)^3, T=10 K,
$\rho(R) = \frac{2c_s^2}{\pi G R_0^2} \frac{1}{(1+(R/R_0)^2)^2}$, R_0=0.05 pc, $P(k) \propto k^{-4}$, <M>=1,
$P(\rho) = c_s^2 \rho (1 + (\rho/\rho_{cr})^{7/5}$, ρ_{cr}=10^{-13} cm^{-3}, ρ_{sink}=10^{-11} g cm^{-3},
r_{sink}=2.45 au.
乱流分裂でできた最初の星から円盤分裂で次々。
エンベロープ連星相互作用でSOが出る衝撃波速度、密度。

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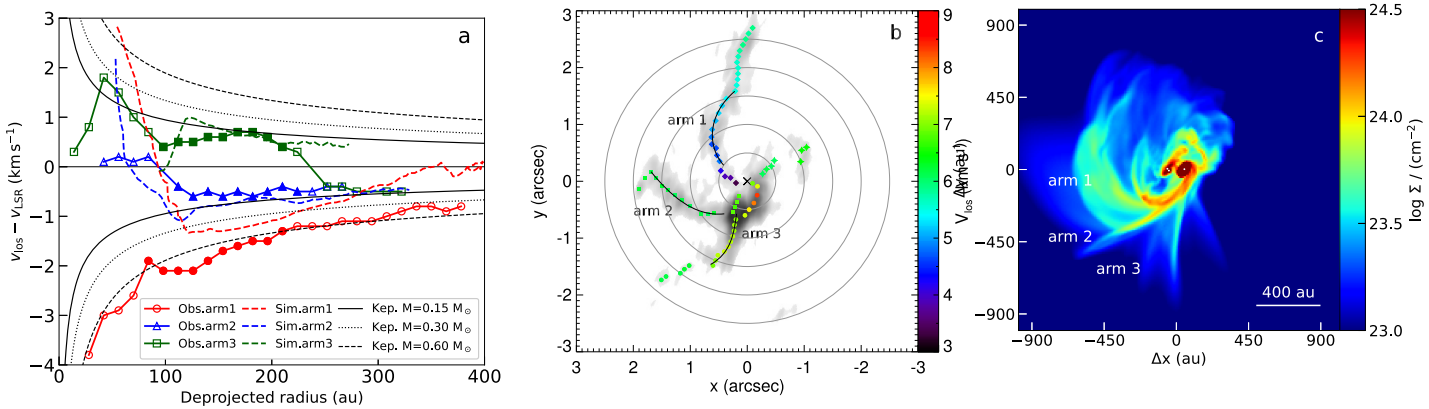
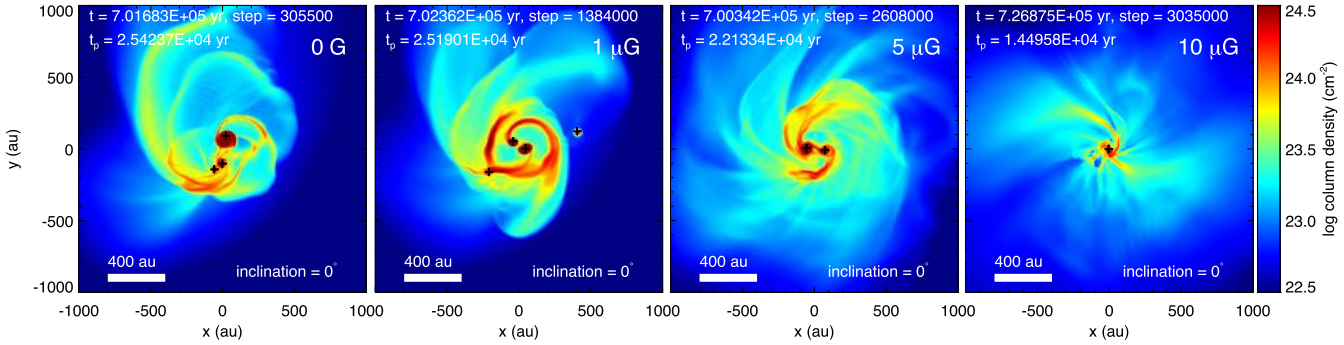
シミュレーションと比べると、太いストリーマーがあってSOもHCNも強い（近赤で暗い）Bが主星。

deprojected, i=55 °, PA=140° (CSDs)



連星間隔はシミュレーションが2倍大きいので、空間スケールを半分にすると観測と近い。特に内側は単一ケプラー曲線ではない。
sim arm 1は<150 auで回転～落下。
sim arm 2, 3は<100 auで落下優勢。

フィラメントに垂直な磁場で始めるオーム散逸入りMHDでは磁場が強いと連星にならない。

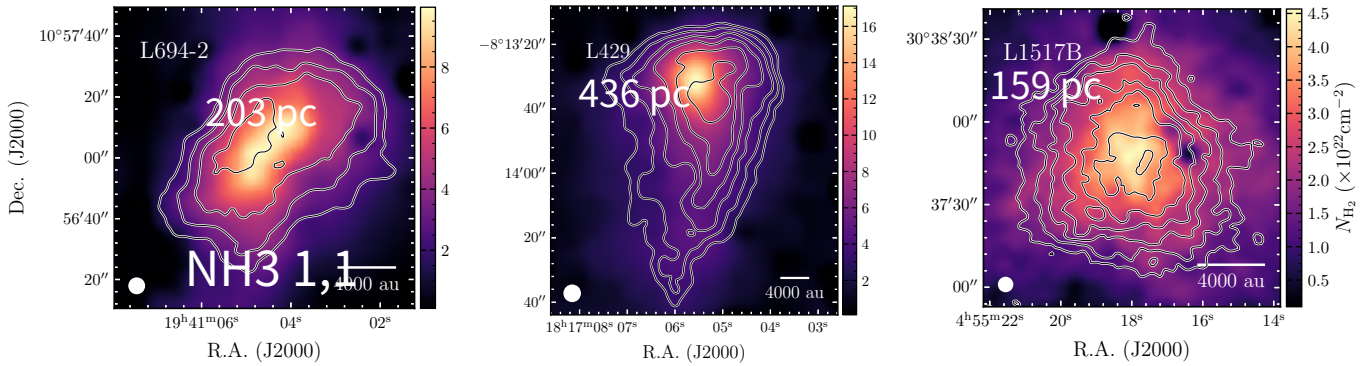


原始連星系ではダストのドリフトが早く、星周円盤も小さいので、惑星形成のための物と時間が少ない。今回のエンベロープとの相互作用する<10 auのダスト円盤も惑星形成の困難さを示す。

Initial conditions of star formation at ≲2000 au: physical structure and NH_3 depletion of three early-stage cores

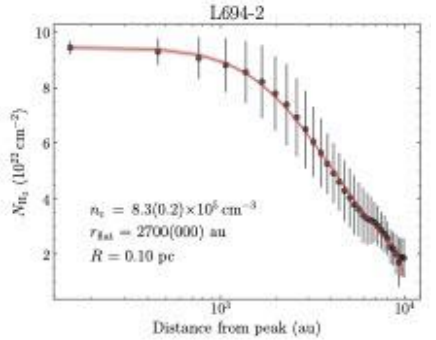
Y. Lin[1], S. Spezzano[1], J. E. Pineda[1], J. Harju[2], A. Schmiedeke[3], S. Jiao[4], H. B. Liu[5], and P. Caselli[1]

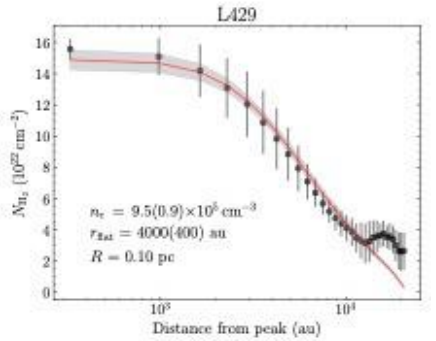
前星コアは星形成直前の状況や臨界に至るISM進化の理解を助ける。
前星コアは分子の凍結によるD化率の上昇という段階。NH_3の減少が最近観測された。
JVLA, K-band, NH_3 1,1 & 2,2, dv=0.05 km/s. GBTもコンバイン。



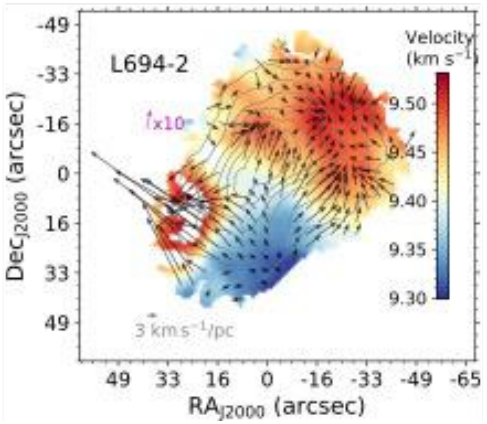
Herschel 250, 350, 500 μm からT_{dust}.
JCMT 850 μmから$\tau_{850\mu m}$及び$\tau_{8\mu m}$.
Spitzer 8 μmから$N(H_2)$.

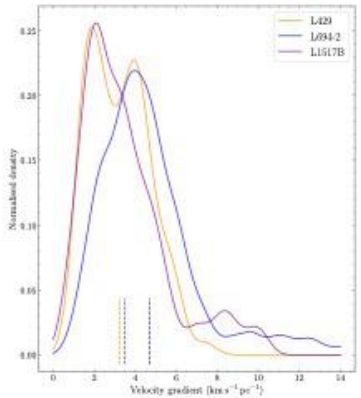
$$n(r) = \frac{n_c}{(r/r_{\rm flat})^2+1}$$



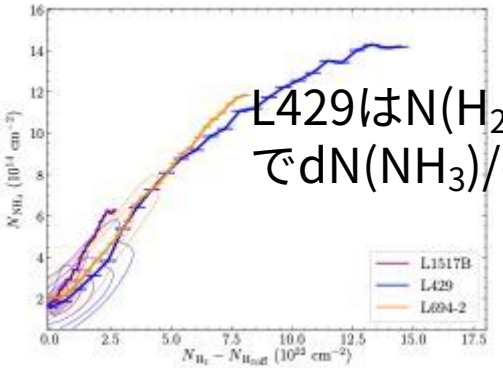


NH_3は1,1と2,2のみにいるという低温モデルからV_{LSR}, σ_V, T_{kin}, T_{ex}, $N(NH_3)$.

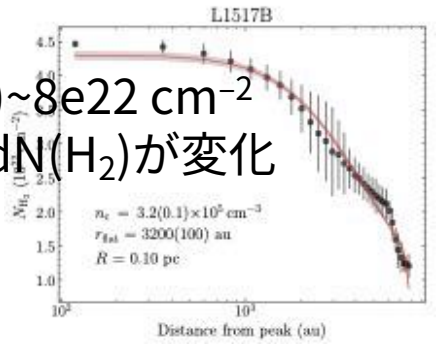




より高密度なコアほど低温で熱化に近く、大きい速度勾配を示す領域がある。



L429は$N(H_2)$~8e22 cm^{-2}でd$N(NH_3)$/d$N(H_2)$が変化



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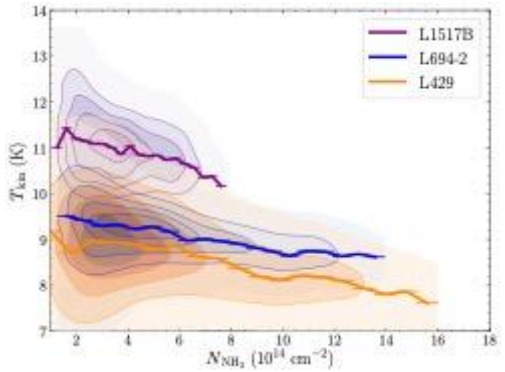
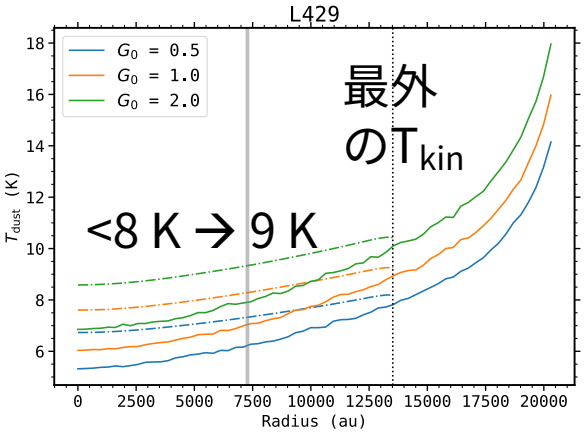


高密度ほど低温。
L694-2は一定←わずかに傾いた長球コアという過去研究(?)
prototypical 前星コアL1544よりは温度勾配が小さく、今回の方が若い可能性。

RADMC3DでコアのT_{kin}プロファイルを再現。
破線は実線を視線方向に質量で平均した温度。
３天体ともG_0=1-2 (普通のISRF)で再現。



L429の高密度部分以外$dN(NH_3)/dN(H_2)$~1なのでNH_3の存在量は変化なし。
L429の$dN(NH_3)/dN(H_2)$が変わる密度は4e4 cm^{-3}で、H-MM1という別のコアでdepletionが起こる2e5 cm^{-3}には届いていないので、今回の緩やかな勾配は低密度 (という若さ) のせい。

T_{kin}からマッハ数を評価すると非熱的乱流は全て亜音速。
コアの平坦部の長さと中心のジーンズ長を比べるとL429, L694-2がL1517Bより不安定。
L429, L694-2はコアの外で大きな速度勾配が見られたので分子雲からの質量降着かもしれない。→コアから円盤への降着と繋げたい。

Brightness and mass accretion rate evolution during the 2022 burst of EX Lupi⋆

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ABSTRACT

Context. EX Lupi is the prototype by which EXor-type outbursts were defined. It has experienced multiple accretion-related bursts and outbursts throughout the last decades, whose study have greatly extended our knowledge about the effects of these types of events. This star experienced a new burst in 2022.

Aims. We aim to investigate whether this recent brightening was caused by temporarily increased accretion or by a brief decrease in the extinction, and to study the evolution of the EX Lupi system throughout this event.

Methods. We used multi-band photometry to create color-color and color-magnitude diagrams to exclude the possibility that the brightening could be explained by a decrease in extinction. We obtained spectra using the X-shooter instrument of the Very Large Telescope (VLT) to determine the $L_{\rm acc}$ and $\dot{M}_{\rm acc}$ during the peak of the burst and after its return to quiescence using two different methods: empirical relationships between line luminosity and $L_{\rm acc}$, and a slab model of the whole spectrum. We examined the 130 year light curve of EX Lupi to provide statistics on the number of outbursts experienced during this period of time.

Results. Our analysis of the data taken during the 2022 burst confirmed that a change in extinction is not responsible for the brightening. Our two approaches in calculating the $\dot{M}_{\rm acc}$ were in agreement, and resulted in values that are two orders of magnitude above what had previously been estimated for EX Lupi using only a couple of individual emission lines, thus suggesting that EX Lupi is a strong accretor even when in quiescence. We determined that in 2022 March the $\dot{M}_{\rm acc}$ increased by a factor of 7 with respect to the quiescent level. We also found hints that even though the $\dot{M}_{\rm acc}$ had returned to almost its pre-outburst levels, certain physical properties of the gas (i.e. temperature and density) had not returned to the quiescent values.

Conclusions. We found that the mass accreted during this three month event was 0.8 lunar masses, which is approximately half of what is accreted during a year of quiescence. We calculated that if EX Lupi remains as active as it has been for the past 130 years, during which it has experienced at least 3 outbursts and 10 bursts, then it will deplete the mass of its circumstellar material in less than 160 000 yr.

この論文は、星EX Lupiの2022年の噴発を調査します。輝度の増加は、静穏な状態と比較して質量降着率が7倍に増加したため、主にこれに起因していました。この3ヶ月のイベント中には、通常の静穏な状態で降着されるものの約半分にあたる、合計0.8月質量の物質が降着しました。この研究は、EX Lupiが静穏な期間であっても強力な降着源であることを示しています。過去の活動を考慮すると、もし活発なままであれば、EX Lupiはその周囲の物質を約160,000年未満で枯渇させると推定されています。

Forming rocky exoplanets around K-dwarf stars

P. Hatalova[1,2], R. Brasser[3,4], E. Mamonova[1,2], and S. C. Werner[1,2]

ABSTRACT

Context. New space telescopes, such as the upcoming PLATO mission, aim to detect and study thousands of exoplanets, especially terrestrial planets around main-sequence stars. This motivates us to study how these planets formed. How multiple close-in super-Earths form around stars with masses lower than that of the Sun is still an open issue. Several recent modeling studies have focused on planet formation around M-dwarf stars, but so far no studies have focused specifically on K dwarfs, which are of particular interest in the search for extraterrestrial life.

Aims. We aim to reproduce the currently known population of close-in super-Earths observed around K-dwarf stars and their system characteristics. Additionally, we investigate whether the planetary systems that we form allow us to decide which initial conditions are the most favorable.

Methods. We performed 48 high-resolution N-body simulations of planet formation via planetesimal accretion using the existing GENGA software running on GPUs. In the simulations we varied the initial protoplanetary disk mass and the solid and gas surface density profiles. Each simulation began with 12 000 bodies with radii of between 200 and 2000 km around two different stars, with masses of 0.6 and 0.8 $M_\odot$. Most simulations ran for 20 Myr, with several simulations extended to 40 or 100 Myr.

Results. The mass distributions for the planets with masses between 2 and 12 $M_\oplus$ show a strong preference for planets with masses $M_\mathrm{p} < 6\ M_\oplus$ and a lesser preference for planets with larger masses, whereas the mass distribution for the observed sample increases almost linearly. However, we managed to reproduce the main characteristics and architectures of the known planetary systems and produce mostly long-term angular-momentum-deficit-stable, nonresonant systems, but we require an initial disk mass of 15 $M_\oplus$ or higher and a gas surface density value at 1 AU of 1500 g cm^{-2} or higher. Our simulations also produce many low-mass planets with $M < 2\ M_\oplus$, which are not yet found in the observed population, probably due to the observational biases. Earth-mass planets form quickly (usually within a few million years), mostly before the gas disk dispersal. The final systems contain only a small number of planets with masses $M_\mathrm{p} > 10\ M_\oplus$, which could possibly accrete substantial amounts of gas, and these formed after the gas had mostly dissipated.

Conclusions. We mostly manage to reproduce observed K-dwarf exoplanetary systems from our GPU simulations.

この論文では、K矮星の周囲に形成されるスーパーアース系太陽系外惑星に迫る。太陽の質量の0.6倍と0.8倍の2つの恒星を用いて48のシミュレーションを行った。6M_E以下の惑星が有利であったが、観測された近接超地球の直線的増加とは対照的であった。既知の系の特徴を再現するためには、15M_E以上の初期円盤質量と1天文単位で1500g cm-2以上のガス表面密度が必要であった。シミュレーションでは、バイアスのためにまだ観測されていない2 M_E以下の惑星も生成された。地球質量の惑星は急速に形成され、多くの場合ガス円盤が散逸する前に形成されたが、10 M_E以上の惑星は後に形成された。

The VLT MUSE NFM view of outflows and externally photoevaporating discs near the orion bar*

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ABSTRACT

We present Very Large Telescope/Multi-Unit Spectroscopic Explorer Narrow Field Mode observations of a pair of disc-bearing young stellar objects towards the Orion Bar: 203–504 and 203–506. Both of these discs are subject to external photoevaporation, where winds are launched from their outer regions due to environmental irradiation. Intriguingly, despite having projected separation from one another of only 1.65 arcsec(660 au at 400 pc), 203–504 has a classic teardrop shaped 'proplyd' morphology pointing towards θ^2 Ori A (indicating irradiation by the EUV of that star, rather than θ^1 Ori C) but 203–506 has no ionization front, indicating it is not irradiated by stellar EUV at all. However, 203–506 does show [C I] 8727 Å and [O I] 6300 Å in emission, indicating irradiation by stellar FUV. This explicitly demonstrates the importance of FUV irradiation in driving mass loss from discs. We conclude that shielding of 203–506 from EUV is most likely due to its position on the observers side of an ionized layer lying in the foreground of the Huygens Region. We demonstrate that the outflow HH 519, previously thought to be emanating from 203–504 is actually an irradiated cloud edge and identify a new compact outflow from that object approximately along our line of sight with a velocity $\sim$130 km s^{-1}.

この論文では、オリオンバー地域にある2つの若い恒星対象（203-504および203-506）の観測について説明しています。これらの対象は非常に近接しており、660 auしか離れていませんが、放射線に対する応答が異なります。203-504は、θ2 Ori AからのEUV放射線にさらされ、ティアドロップ型の「プロプリド」形状を示します。一方、203-506はEUVの照射を受けていないが、恒星のFUV放射線による[C I] 8727 Åおよび[O I] 6300 Åの放射線を示します。これは、これらのディスクからの質量損失を駆動する際のFUV照射の役割を強調しています。203-506のEUVからの遮蔽は、ユイゲンス領域前景にあるイオン化層の観測者側に位置するためと考えられます。この研究は、アウトフロー（HH 519）の誤識別を明らかにし、約130 km/sの速度を持つ203-504からの新しいコンパクトアウトフローを特定し、これらの複雑な環境に関する洞察を提供します。

Twenty-Five Years of Accretion onto the Classical T Tauri Star TW Hya

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Abstract

Accretion plays a central role in the physics that governs the evolution and dispersal of protoplanetary disks. The primary goal of this paper is to analyze the stability over time of the mass accretion rate onto TW Hya, the nearest accreting solar-mass young star. We measure veiling across the optical spectrum in 1169 archival high-resolution spectra of TW Hya, obtained from 1998–2022. The veiling is then converted to accretion rate using 26 flux-calibrated spectra that cover the Balmer jump. The accretion rate measured from the excess continuum has an average of 2.51×10^{-9} $M_\odot$ yr^{-1} and a Gaussian distribution with a FWHM of 0.22 dex. This accretion rate may be underestimated by a factor of up to 1.5 because of uncertainty in the bolometric correction and another factor of 1.7 because of excluding the fraction of accretion energy that escapes in lines, especially Lyα. The accretion luminosities are well correlated with He line luminosities but poorly correlated with Hα and Hβ luminosity. The accretion rate is always flickering over hours but on longer timescales has been stable over 25 years. This level of variability is consistent with previous measurements for most, but not all, accreting young stars.

この研究は、最も近い太陽質量の若い恒星であるTW Hyaにおける質量降着率の安定性を調査しています。測定された質量降着率は、平均で年間2.51 × 10^(-9) M⊙ yr^(-1) で、FWHMは0.22 dex です。これは、補正の不確実性により最大1.5倍、またLyαなどのラインからのエネルギーを除外することにより最大1.7倍低く評価されている可能性があります。質量降着の輝度はHeラインの輝度と強く相関しますが、HαおよびHβの輝度とは弱く相関します。短期の変動は発生しますが、25年間で質量降着率は安定しており、これはほとんどの若い恒星で見られるものです。

N-body simulation of planetary formation through pebble accretion in a radially structured protoplanetary disk

Tenri JINNO,[1,*] Takayuki R. SAITOH,[1] Yota ISHIGAKI,[2] and Junichiro MAKINO[1]

Abstract

In the conventional theory of planet formation, it is assumed that protoplanetary disks are axisymmetric and have a smooth radial profile. However, recent radio observations of protoplanetary disks have revealed that many of them have complex radial structures. In this study, we perform a series of *N*-body simulations to investigate how planets are formed in protoplanetary disks with radial structures. For this purpose, we consider the effect of continuous pebble accretion onto the discontinuity boundary within the terrestrial planet-forming region ($\sim$0.6 au). We find that protoplanets grow efficiently at the discontinuity boundary, reaching the Earth mass within $\sim 10^4$ yr. We confirm that giant collisions of protoplanets occur universally in our model. Moreover, we find that multiple planet-sized bodies form at regular intervals in the vicinity of the discontinuity boundary. These results indicate the possibility of the formation of solar system-like planetary systems in radially structured protoplanetary disks.

この研究は、最近の電波データで観測されたように、複雑な半径構造を持つ原始惑星円盤を探求することによって、従来の惑星形成理論に挑戦しています。N体シミュレーションと地球質量への原始惑星の効率的成長を調べるため、地球型惑星形成領域内 (~0.6 au) の不連続境界での連続的な小石の降着を検討しました。その結果、原始惑星は約10,000年で地球質量に効率的に成長します。原始惑星間の巨大衝突は普遍的であり、不連続境界近くで定期的に複数の惑星サイズの天体が形成されます。これらの結果は、このような半径構造を持つ原始惑星円盤で太陽系に似た惑星系が形成される可能性を示唆しています。

Measuring the numerical viscosity in simulations of protoplanetary disks in Cartesian grids

The viscously spreading ring revisited

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ABSTRACT

Context. Hydrodynamical simulations solve the governing equations on a discrete grid of space and time. This discretization causes numerical diffusion similar to a physical viscous diffusion, whose magnitude is often unknown or poorly constrained. With the current trend of simulating accretion disks with no or very low prescribed physical viscosity, it becomes essential to understand and quantify this inherent numerical diffusion, in the form of a numerical viscosity.

Aims. We study the behavior of the viscous spreading ring and the spiral instability that develops in it. We then use this setup to quantify the numerical viscosity in Cartesian grids and study its properties.

Methods. We simulate the viscous spreading ring and the related instability on a two-dimensional polar grid using `PLUTO` as well as `FARGO`, and ensure the convergence of our results with a resolution study. We then repeat our models on a Cartesian grid and measure the numerical viscosity by comparing results to the known analytical solution, using `PLUTO` and `Athena++`.

Results. We find that the numerical viscosity in a Cartesian grid scales with resolution as approximately $\nu_{\rm num} \propto \Delta x^2$ and is equivalent to an effective $\alpha \sim 10^{-4}$ for a common numerical setup. We also show that the spiral instability manifests as a single leading spiral throughout the whole domain on polar grids. This is contrary to previous results and indicates that sufficient resolution is necessary in order to correctly resolve the instability.

Conclusions. Our results are relevant in the context of models where the origin should be included in the computational domain, or when polar grids cannot be used. Examples of such cases include models of disk accretion onto a central binary and inherently Cartesian codes.

この研究は、降着円盤のシミュレーションにおける数値粘性を調査しています。調査結果によれば、カルテシアングリッド内では、数値粘性は解像度（Δx）に比例してvnum ∝ Δx^2 とスケールし、一般的な設定において有効なα値は約10^(-4)に相当します。さらに、極座標グリッド内では、螺旋不安定性がドメイン全体にわたる単一の主導螺旋として現れることが示され、正確な表現を得るために十分な解像度の重要性が強調されています。

Kinematic signatures of a low-mass planet with a moderately inclined orbit in a protoplanetary disk

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Abstract

A planet embedded in a protoplanetary disk produces a gap by disk–planet interaction. It also generates velocity perturbation of gas, which can also be observed as deviations from the Keplerian rotation in the channel map of molecular line emission, called kinematic planetary features. These observed signatures provide clues to determine the mass of the planet. We investigated the features induced by a planet with an inclined orbit through three-dimensional hydrodynamic simulations. We found that a smaller planet, with an inclination of $\sim 10^{\circ}$–20°, can produce kinematic features as prominent as those induced by a massive coplanar planet. Despite the kinematic features being similar, the gap is shallower and narrower compared with the case in which the kinematic features are formed by a coplanar planet. We also found that the kinematic features induced by an inclined planet were fainter for rarer CO isotopologues because the velocity perturbation is weaker at the position closer to the midplane, which was different in the case with a coplanar massive planet. This dependence on the isotopologues is distinguished if the planet has an inclined orbit. We discussed two observed kinematic features in the disk of HD 163296. We concluded that the kink observed at 220 au can be induced by an inclined planet, while the kink at 67 au is consistent to that induced by a coplanar planet.

この研究は、原始惑星円盤内での傾斜した軌道を持つ惑星の影響を調査しました。調査結果によれば、約10°から20°の傾斜を持つ小さな惑星は、大規模で共面の惑星と同じように顕著な運動学的特徴を生み出します。しかし、これらの特徴が似ているにもかかわらず、傾斜した惑星によるディスク内の隙間は共面の惑星による場合と比べて浅くて狭いことが示されました。また、特徴の可視性は使用するCOアイソトポログに依存し、稀なCOアイソトポログを使用すると特徴がより暗くなります。これらの結果は、惑星の傾斜が原始惑星円盤内の観測特徴に与える影響を理解する上で重要です。

Modelling star cluster formation: Gas accretion

Jeremy Karam ★ and Alison Sills

ABSTRACT

The formation of star clusters involves the growth of smaller, gas-rich subclusters through accretion of gas from the giant molecular cloud (GMC) within which the subclusters are embedded. The two main accretion mechanisms responsible for this are accretion of gas from dense filaments and from the ambient background of the cloud. We perform simulations of both of these accretion processes onto gas-rich star clusters using coupled smoothed particle hydrodynamics to model the gas and N-body dynamics to model the stars. We find that, for both accretion processes, the accreting star cluster loses some of its original mass while gaining mass from either the ambient background or the dense filament. The amount of mass lost from both of these processes is small compared to the total mass of the cluster. However, in the case of accretion from a background medium, the net effect can be a decrease in the total mass of the cluster if it is travelling fast enough through the ambient medium ($>4\,\mathrm{km\,s^{-1}}$). We find that the amount of mass lost from the cluster through filamentary accretion is independent of the density, width, or number of filaments funnelling gas into the cluster and is always such that the mass of the cluster is constantly increasing with time. We compare our results to idealized prescriptions used to model star cluster formation in larger scale GMC simulations and find that such prescriptions act as an upper limit when describing the mass of the star cluster they represent.

この論文は、巨大分子雲（GMC）からのガス供給を通じた星団の形成と成長を調査しています。2つの主要な供給メカニズムが研究され、星団の元の質量がわずかに減少する結果が得られました。特筆すべきは、環境背景からの供給時に、速度が4 km/sを超える場合、星団の総質量が減少する可能性があることです。ただし、フィラメント供給を介して、フィラメントの特性に関係なく、星団の質量は一貫して時間とともに増加します。星団の形成シミュレーションに使用される理想化されたモデルは、通常、星団質量の上限を表しています。

Unveiling the Dynamics of Dense Cores in Cluster-forming Clumps: A 3D Magnetohydrodynamics Simulation Study of Angular Momentum and Magnetic Field Properties

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Abstract

We conducted isothermal magnetohydrodynamics simulations with self-gravity to investigate the properties of dense cores in cluster-forming clumps. Two different setups were explored: a single rotating clump and colliding clumps. We focused on determining the extent to which the rotation and magnetic field of the parental clump are inherited by the formed dense cores. Our statistical analysis revealed that the alignment between the angular momentum of dense cores, $\boldsymbol{L}_{\rm core}$, and the rotational axis of the clump is influenced by the strength of turbulence and the simulation setup. In single rotating clumps, we found that $\boldsymbol{L}_{\rm core}$ tends to align with the clump's rotational axis if the initial turbulence is weak. In colliding clumps, however, this alignment does not occur, regardless of the initial turbulence strength. This misalignment in colliding clumps is due to the induced turbulence from the collision and the isotropic gas inflow into dense cores. Our analysis of colliding clumps also revealed that the magnetic field globally bends along the shock-compressed layer, and the mean magnetic field of dense cores, $\boldsymbol{B}_{\rm core}$, aligns with it. Both in single rotating clumps and colliding clumps, we found that the angle between $\boldsymbol{B}_{\rm core}$ and $\boldsymbol{L}_{\rm core}$ is generally random, regardless of the clump properties. We also analyzed the dynamical states of the formed cores and found a higher proportion of unbound cores in colliding clumps. In addition, the contribution of rotational energy was only approximately 5% of the gravitational energy, regardless of the model parameters for both single and colliding cases.

この研究では、等温磁気流体力学シミュレーションと自己重力を用いて、クラスター形成クランプ内の密なコアの特性を調査しました。研究は2つのシナリオを探究し、単一の回転するクランプと衝突するクランプを対象にしました。密なコアの角運動量とクランプの回転軸との整列は、乱流の強さと設定に影響を受け、初期の乱流が弱い単一の回転するクランプでは整列が見られましたが、衝突から生じる乱流のため、衝突するクランプでは整列が起こりませんでした。研究はまた、密なコアの磁場と角運動量との間の角度は一般的に両シナリオでランダムであり、回転エネルギーが全てのケースで重力エネルギーの約5%しか寄与しないことを発見しました。

Complex Organic Molecules in a Very Young Hot Corino, HOPS 373SW

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Abstract

We present the spectra of complex organic molecules (COMs) detected in HOPS 373SW with the Atacama Large Millimeter/submillimeter Array (ALMA). HOPS 373SW, which is a component of a protostellar binary with a separation of 1500au, has been discovered as a variable protostar by the JCMT transient monitoring survey with a modest (∼30%) brightness increase at submillimeter wavelengths. Our ALMA target-of-opportunity observation at ∼345 GHz for HOPS 373SW revealed extremely young chemical characteristics with strong deuteration of methanol. The dust continuum opacity is very high toward the source center, obscuring line emission from within 0.″03. The other binary component, HOPS 373NE, was detected only in $C^{17}O$ in our observation, implying a cold and quiescent environment. We compare the COM abundances relative to CH_3OH in HOPS 373SW with those of V883 Ori, which is an eruptive disk object, as well as other hot corinos, to demonstrate the chemical evolution from envelope to disk. High abundances of singly, doubly, and triply deuterated methanol (CH_2DOH, CHD_2OH, and CD_3OH) and a low CH_3CN abundance in HOPS 373SW compared to other hot corinos suggest a very early evolutionary stage of HOPS 373SW in the hot corino phase. Since the COMs detected in HOPS 373SW would have been sublimated very recently from grain surfaces, HOPS 373SW is a promising place to study the surface chemistry of COMs in the cold prestellar phase before sublimation.

この論文は、HOPS 373SWという、1500auの感覚を持つ原始恒星バイナリ内の複雑な有機分子（COMs）のスペクトルを提供します。私たちのALMA観測（約345 GHz）により、メタノールの強力な重水素化が明らかになり、若い化学的特性が示唆されました。他のホットコリノとの比較から、HOPS 373SWは非常に初期の進化段階にあり、重水素化メタノールの豊富さが高く、CH_3CNの豊富さが低いことから、COMsの表面化学を調べる理想的な場所であると示唆されています。これは昇華前の冷たい前星段階での研究に適しています。

The dusty Rossby wave instability (DRWI): linear analysis and simulations of turbulent dust-trapping rings in protoplanetary discs

Hanpu Liu [1,2]★ and Xue-Ning Bai [3,4]★

ABSTRACT

Recent numerical simulations have revealed that dust clumping and planetesimal formation likely proceed in ring-like disc substructures, where dust gets trapped in weakly turbulent pressure maxima. The streaming instability has difficulty operating in such rings with external turbulence and no pressure gradient. To explore potential paths to planetesimal formation in this context, we analyse the stability of turbulent dust-trapping ring under the shearing sheet framework. We self-consistently establish the pressure maximum and the dust ring in equilibrium, the former via a balance of external forcing versus viscosity and the latter via dust drift versus turbulent diffusion. We find two types of $\gtrsim H$-scale instabilities (H being the pressure scale height), which we term the dusty Rossby wave instability (DRWI). Type I is generalized from the standard Rossby wave instability (RWI, which is stationary at the pressure maximum and dominates in relatively sharp pressure bumps. Type II is a newly identified travelling mode that requires the presence of dust. It can operate in relatively mild bumps, including many that are stable to the standard RWI, and its growth rate is largely determined by the equilibrium gas and dust density gradients. We further conduct two-fluid simulations that verify the two types of the DRWI. While Type I leads strong to dust concentration into a large gas vortex similar to the standard RWI, the dust ring is preserved in Type II, and meanwhile exhibiting additional clumping within the ring. The DRWI suggests a promising path towards formation of planetesimals/planetary embryos and azimuthally asymmetric dust structure from turbulent dust-trapping rings.

最近のシミュレーションから、微弱な乱流圧力の極大値を持つ環状ディスク副構造で、塵の凝集と微惑星の形成が発生する可能性が示唆されています。ただし、外部の乱流と圧力勾配のない領域では、ストリーミング不安定性に課題があります。この研究は、せん断シートの枠組み内で乱れた塵捕獲リングの安定性を探り、二つのタイプの塵のロスビー波不安定性を特定しています。タイプIは鋭い圧力の山で支配的で、ガス渦中で塵の濃縮を引き起こしますが、タイプIIは新たに特定された移動モードで、比較的穏やかな山でも機能し、塵のリングを保存し、その内部で凝縮をもたらします。これらの発見は、乱れた塵捕獲リング内での微惑星の形成と塵の構造に対する洞察を提供します。