Star Formation Newsletter No. 334, 43-50

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48. Constraining the Chemical Signatures and the Outburst Mechanism of the Class 0 Protostar HOPS 383

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We present observations toward HOPS 383, the first known outbursting Class 0 protostar located within the Orion molecular cloud using ALMA, VLA, and SMA. The SMA observations reveal envelope scale continuum and molecular line emission surrounding HOPS 383 at 0.85 mm, 1.1 mm, and 1.3 mm.The images show that HCO^+ and $H^{13}CO^+$ peaks on or near the continuum, while N_2H^+ is reduced at the same position. This reflects the underlying chemistry where CO evaporating close to the protostar destroys N_2H^+ while forming HCO^+. We also observe the molecular outflow traced by ^{12}CO $(J = 2 \rightarrow 1)$ and $(J = 3 \rightarrow 2)$. A disk is resolved in the ALMA 0.87 mm dust continuum, orthogonal to the outflow direction, with an apparent radius of ∼62 AU. Radiative transfer modeling of the continuum gives disk masses of 0.02 $M_\odot$ when fit to the ALMA visibilities. The models including VLA 8 mm data indicate that the disk mass could be up to a factor of 10 larger due to lower dust opacity at longer wavelengths. The disk temperature and surface density profiles from the modeling, and an assumed protostar mass of 0.5 $M_\odot$ suggest that the Toomre Q parameter < 1 before the outburst, making gravitational instability a viable mechanism to explain outbursts at an early age if the disk is sufficiently massive.

Accepted by ApJ

https://arxiv.org/pdf/2010.05939.pdf

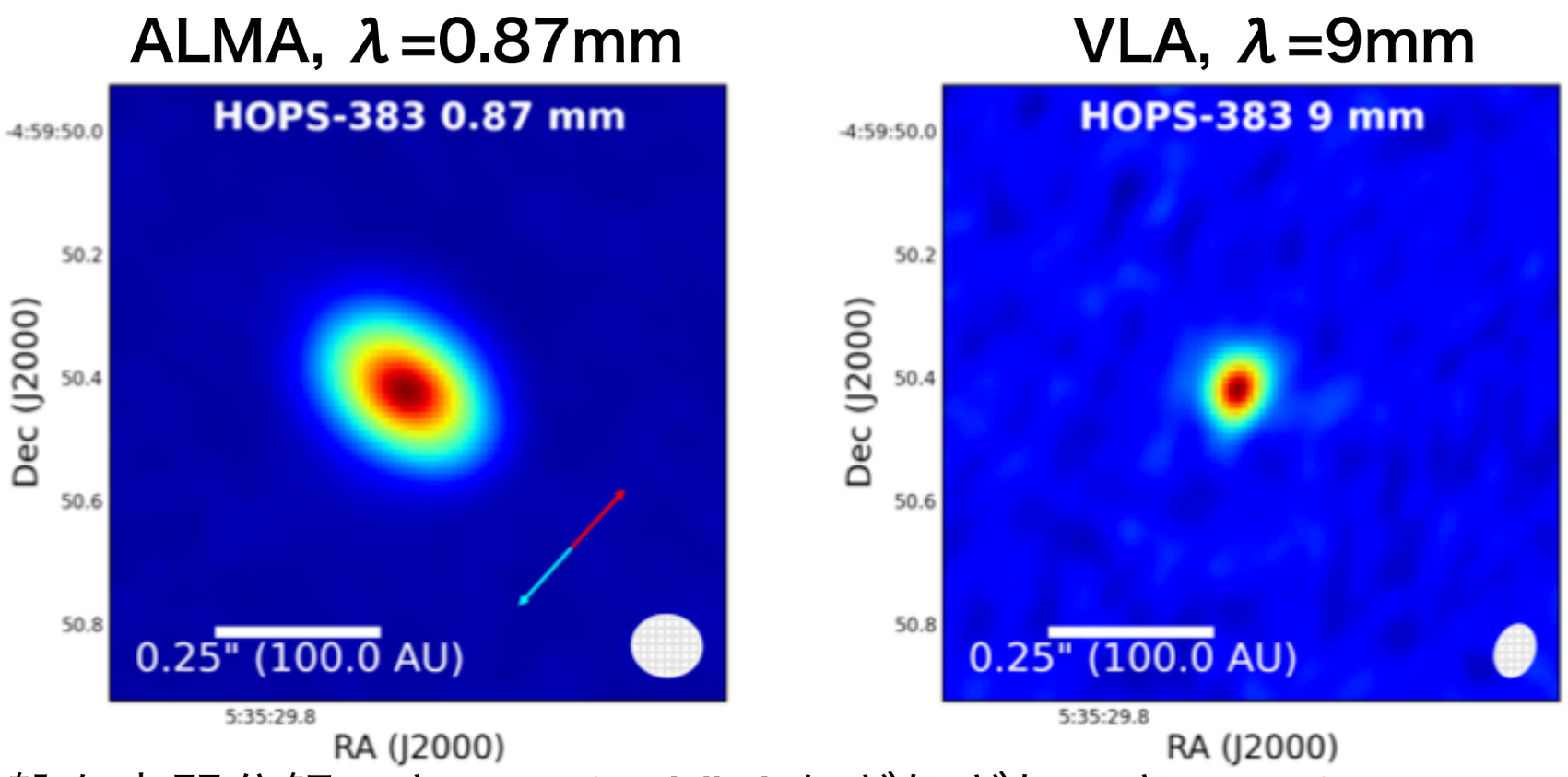
概要：

アウトバーストを起こしているClass 0天体のHOPS 383のALMA, VLA, SMA観測結果。連続波源付近にHCO+とH13CO+が集中する一方、N2H+が減少しており、原始星付近で昇華したCOがN2H+と反応してHCO+になっていることが予想される。ALMA Band 7から円盤質量は0.02Msunと推定されるが、VLAから推定するとその10倍重い可能性もある。いずれでもQ値は1を下回る可能性があり、アウトバーストの起源はGIの可能性が考えられる。

イントロ

- アクリーションバーストは原始星エンベロープや周星円盤の化学組成に大きな影響を与えるが、その性質はよくわかっていない
- これまで観測されてきたアウトバーストの多くはClass I/II
- HOPS 383は(少なくとも2006年に)アウトバーストを起こしている最も若いClass 0 天体
- 本研究ではSMAによる分子輝線観測結果と、ALMA Band 7とVLAによる連続波観測結果を報告する

連続波観測

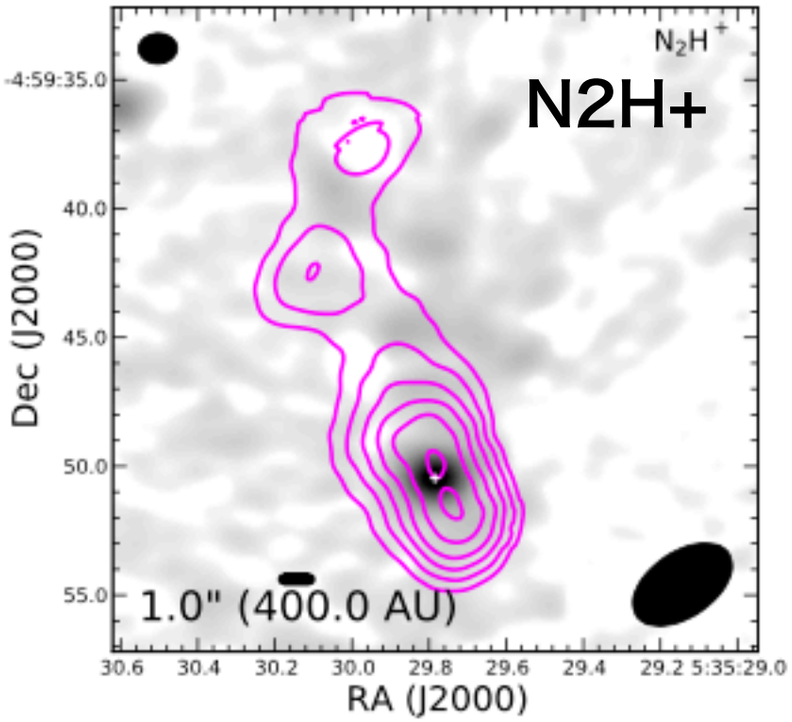


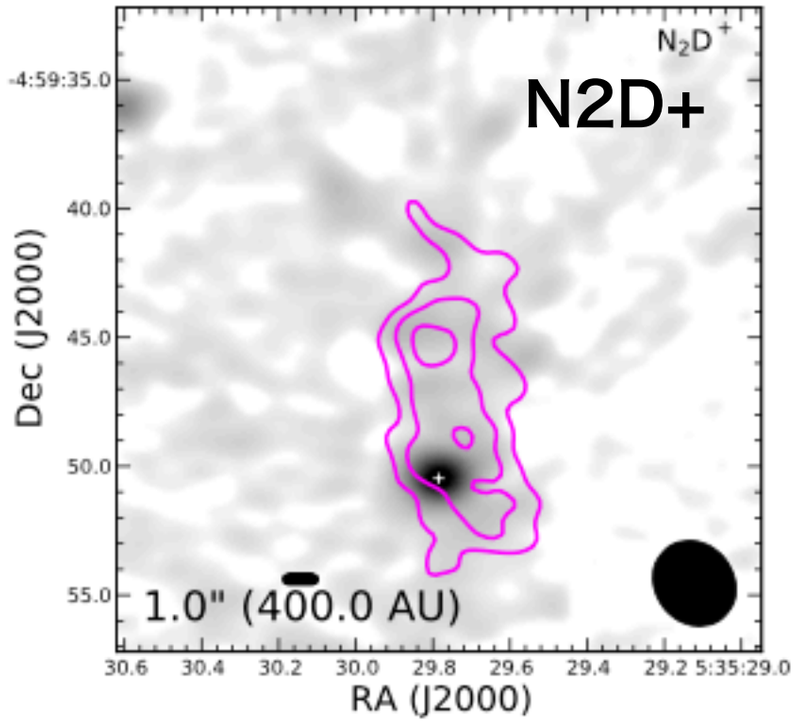
- ALMAは円盤を空間分解できている、VLAもぎりぎりできている
- ALMAの観測から得られた連続波分布の長軸は、後述するアウトフローに綺麗に垂直
- ALMAから推定されるダスト円盤半径は~62au
- フラックスから推定される円盤質量: ALMA=0.04-0.08Msun, VLA=0.06-0.11Msun

SMAによる分子輝線観測

理論的には、

- N2H+, N2D+は、COがダストに凝縮している低温域(<20K)に存在
- HCO+, H13CO+は、気相でCOとH3+やN2H+が反応することで生成(高温域に存在)

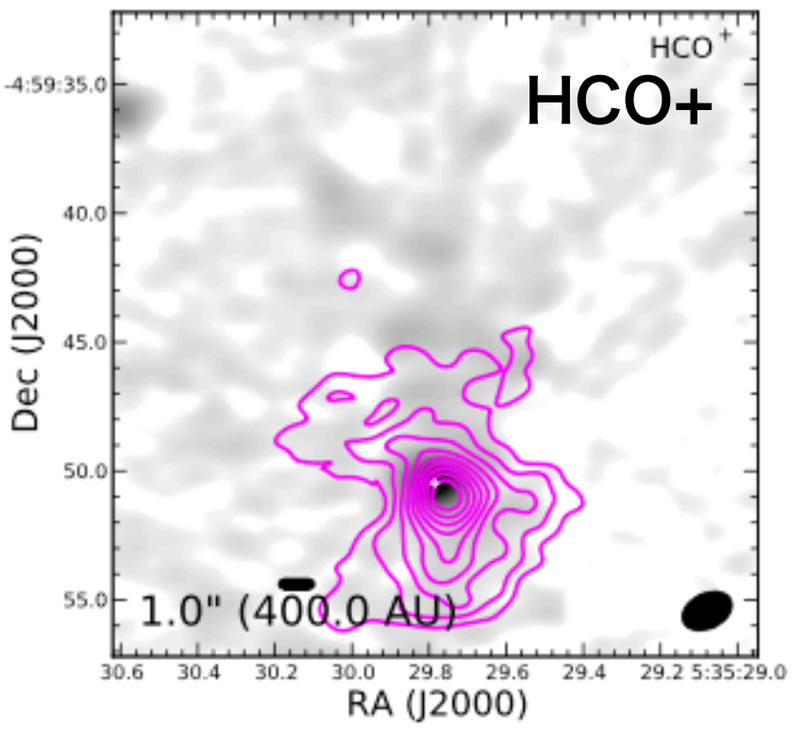


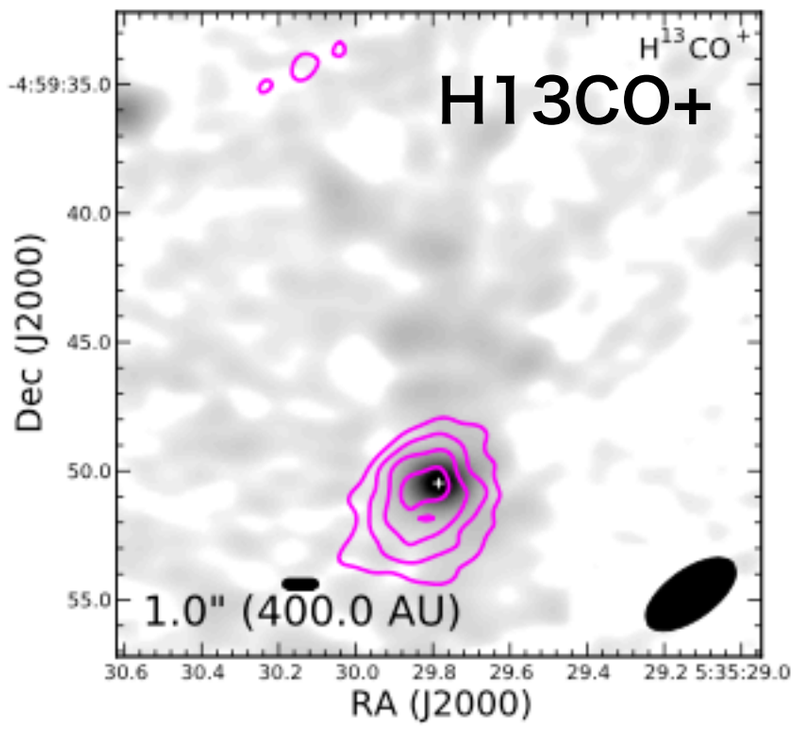


観測結果は

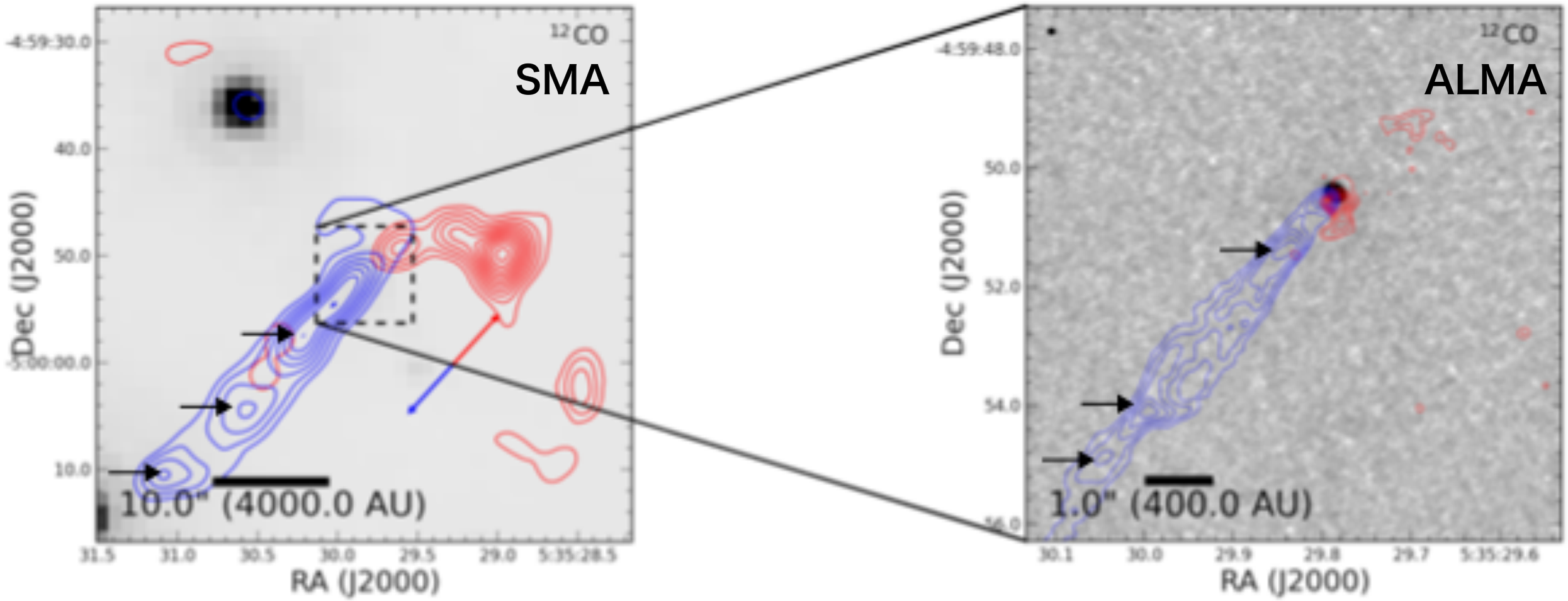
- N2H+は原始星周りでダブルピークの分布(原始星近傍で欠乏している)
- HCO+, H13CO+原始星と同じ位置にピーク

  -> 理論予測とconsistent





12CO(J=3-2)によるアウトフロー構造の同定：

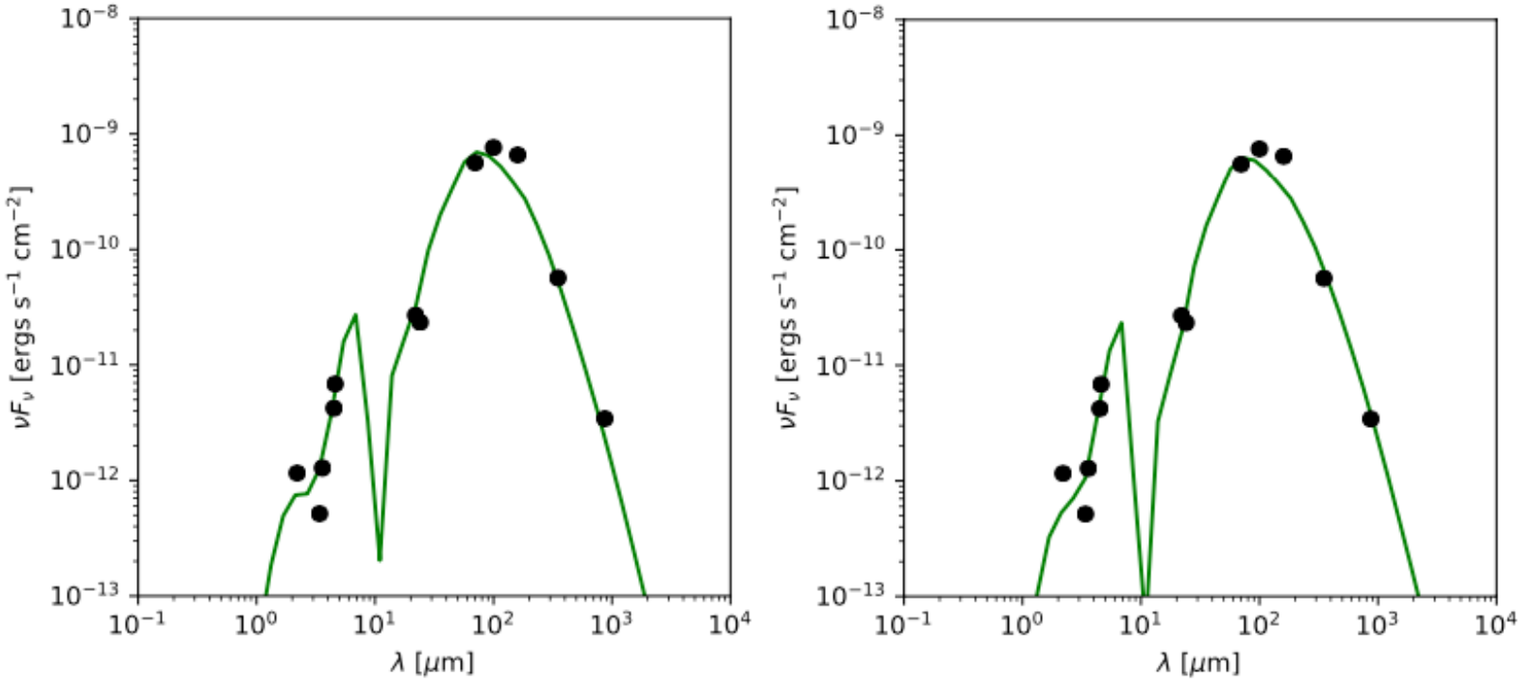


- 綺麗なアウトフロー構造の検出に成功 -> Position angle =137.5度
- アウトフロー中にクランプ状の構造(黒矢印) -> 間欠的なアウトバーストの印？
- アウトフローの速度と原始星からの距離からアウトフローの生成時期を計算すると、最も原始星に近いクランプ(1.35arcsec)は215年前程度
- SMAで検出されてる方のクランプは1400年ごとに生成

SEDフィッティング

円盤+エンベロープのモデルで輻射輸送計算を行い、SEDをよく再現できるパラメータを求めた

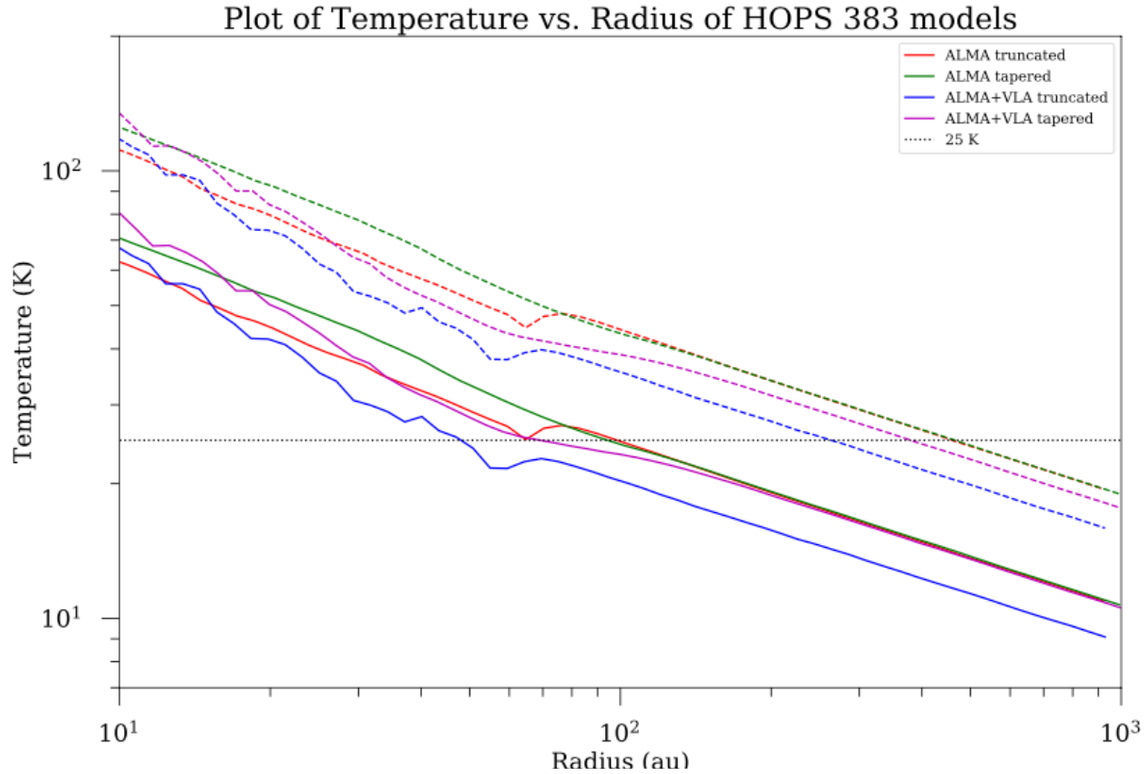
(詳細は割愛)



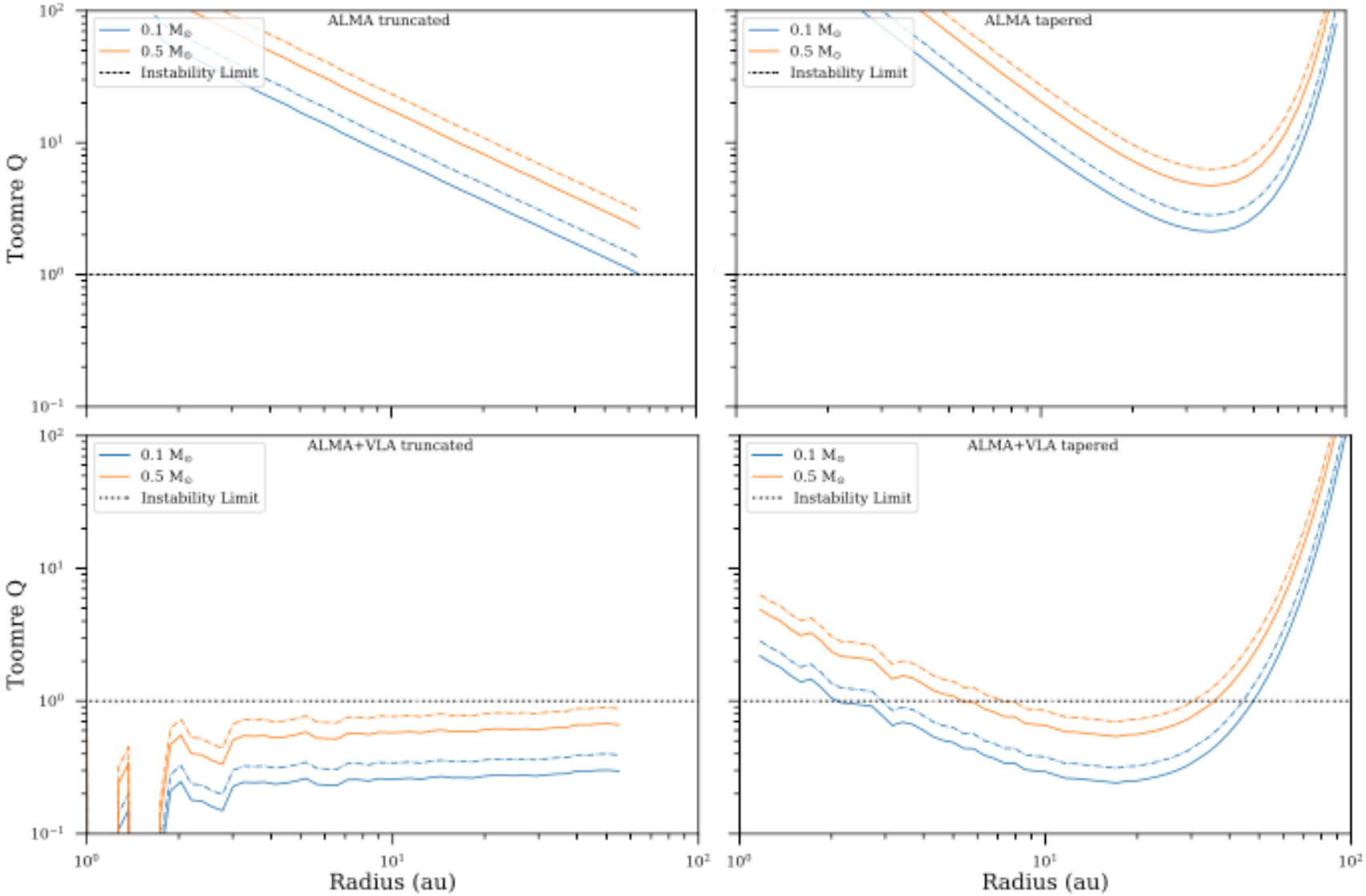
Parameter (unit)	Description	ALMA		ALMA+VLA	
		Truncated	Tapered	Truncated	Tapered
β	Disk scale height exponent	$0.90^{+0.07}_{-0.11}$	$0.61^{+0.12}_{-0.08}$	$0.77^{+0.03}_{-0.02}$	$0.80^{+0.04}_{-0.04}$
f_{cav}	Outflow cavity scaling factor	$0.13^{+0.05}_{-0.07}$	$0.09^{+0.03}_{-0.04}$	$0.15^{+0.03}_{-0.04}$	$0.16^{+0.06}_{-0.06}$
γ	Surface density exponent	$0.65^{+0.11}_{-0.10}$	$-0.09^{+0.14}_{-0.09}$	$1.96^{+0.03}_{-0.05}$	$0.61^{+0.04}_{-0.05}$
h_0(au)	Scale height at 1 au	$0.04^{+0.03}_{-0.02}$	$0.05^{+0.02}_{-0.02}$	$0.09^{+0.01}_{-0.01}$	$0.05^{+0.02}_{-0.01}$
$i(^\circ)$	Inclination	$51.1^{+0.3}_{-0.3}$	$51.5^{+0.4}_{-0.3}$	$50.9^{+1.0}_{-0.7}$	$51.1^{+0.5}_{-0.6}$
ξ	Cavity shape power law exponent	$1.21^{+0.05}_{-0.03}$	$1.22^{+0.05}_{-0.03}$	$0.83^{+0.13}_{-0.05}$	$1.10^{+0.03}_{-0.08}$
$L_*(L_\odot)$	Stellar luminosity	$5.0^{+0.3}_{-0.4}$	$4.9^{+0.3}_{-0.3}$	$4.7^{+0.7}_{-0.4}$	$3.9^{+0.2}_{-0.1}$
$M_{disk}(M_\odot)$	Disk mass	$0.026^{+0.004}_{-0.003}$	$0.020^{+0.005}_{-0.004}$	$0.330^{+0.025}_{-0.028}$	$0.214^{+0.011}_{-0.019}$
$M_{env}(M_\odot)$	Envelope mass	$0.380^{+0.228}_{-0.138}$	$1.111^{+0.602}_{-0.340}$	$0.320^{+0.086}_{-0.055}$	$0.091^{+0.017}_{-0.010}$
R_{disk}(au)	Disk radius	$64.96^{+1.28}_{-1.20}$	$38.33^{+1.35}_{-2.43}$	$57.67^{+0.99}_{-1.05}$	$19.03^{+0.50}_{-0.64}$
R_{env}(au)	Envelope radius	$5857.16^{+2343.90}_{-1556.36}$	$12543.30^{+4066.72}_{-2613.88}$	$2687.71^{+530.65}_{-363.18}$	$2423.51^{+278.53}_{-275.29}$
R_{in}(au)	Disk inner radius	$1.61^{+0.28}_{-0.24}$	$1.04^{+0.23}_{-0.33}$	$0.95^{+0.14}_{-0.11}$	$1.05^{+0.08}_{-0.10}$
$a_{max}(\mu$m)	Maximum grain size in disk	$1116.57^{+650.31}_{-490.06}$	$1907.35^{+845.68}_{-544.45}$	$313.65^{+60.48}_{-87.77}$	$495.65^{+53.21}_{-71.69}$
p	Grain size distribution exponent	$4.34^{+0.08}_{-0.10}$	$3.81^{+0.12}_{-0.06}$	$3.59^{+0.11}_{-0.12}$	$3.81^{+0.09}_{-0.22}$
$P.A(^\circ)$	Position angle	$49.55^{+0.44}_{-0.40}$	$49.43^{+0.32}_{-0.42}$	$49.91^{+0.55}_{-0.88}$	$49.35^{+0.77}_{-0.70}$

円盤の安定性

- フィッティングから予想される温度と面密度からToomre のQを計算
- 温度は、バースト後(右図破線)とバースト前(実線)のそれぞれを考慮
- (バースト前の低温時に不安定->バーストし安定化した可能性があるので)



- ALMAのみから推定される円盤モデル(上段)では、ギリギリ重力的に安定だが、円盤外側では不安定な可能性がある
- ALMA+VLAから推定される円盤モデル(下段)だと幅広い範囲で重力的に不安定
->**アウトバーストの起源がGIである可能性**



50. Planet migration, resonant locking and accretion streams in PDS70: Comparing models and data

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The disc surrounding PDS 70, with two directly imaged embedded giant planets, is an ideal laboratory to study planet-disc interaction. We present three-dimensional smoothed particle hydrodynamics simulations of the system. In our simulations, planets, which are free to migrate and accrete mass, end up in a locked resonant configuration that is dynamically stable. We show that features observed at infrared (scattered light) and millimetre (thermal continuum) wavelengths are naturally explained by the accretion stream onto the outer planet, without requiring a circumplanetary disc around planet c. We post-processed our near-infrared synthetic images in order to account for observational biases known to affect high-contrast images. Our successful reproduction of the observations indicates that planet-disc dynamical interactions alone are sufficient to explain the observations of PDS 70.

Accepted by MNRAS

概要：

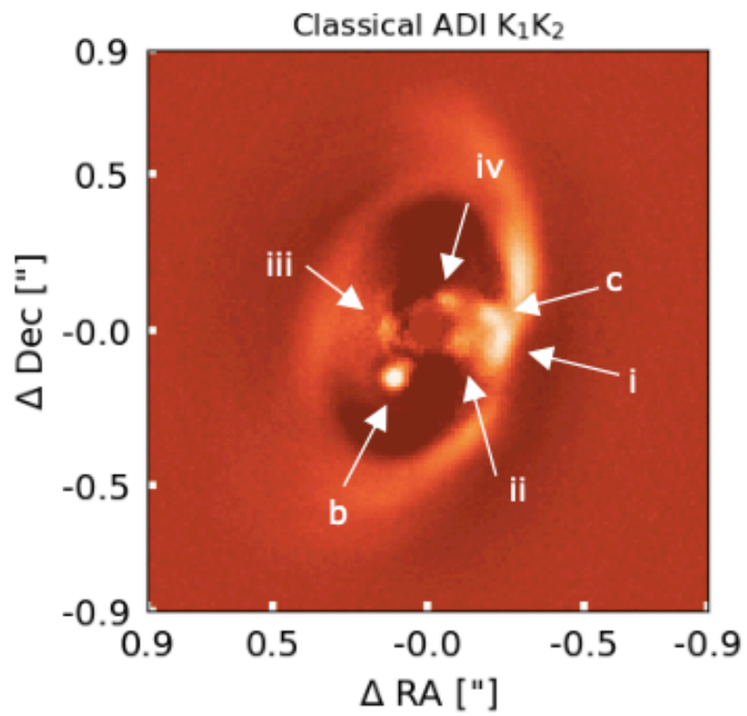
PDS70周りの原始惑星系円盤には2つの巨大ガス惑星候補が検出されている。本研究では、3次元のSPH計算を用いて、初期に低質量で形成された２つの惑星が、自然に、軌道・質量進化し共鳴にはまり、現在の軌道・質量分布になることを示した。加えて、観測で見つかっている円盤の特徴もよく再現できる。

https://arxiv.org/pdf/2009.11893

イントロ

- PDS70には近赤外線観測およびHαで惑星PDS70b,c (r=20, 35au)が検出されている
- 惑星に加え、sub-mmでのリングや近赤外での特徴的な構造が検出されている(右図)
- 本研究では、惑星の軌道と質量がともに進化する過程を流体計算し、これらの観測結果を自然に再現できるか検証
- 先行研究として、2:1の軌道共鳴にはまった2つの惑星を円盤中において、sub-mmの観測を再現したものがある(Bae+19)

Muller et al. 2018



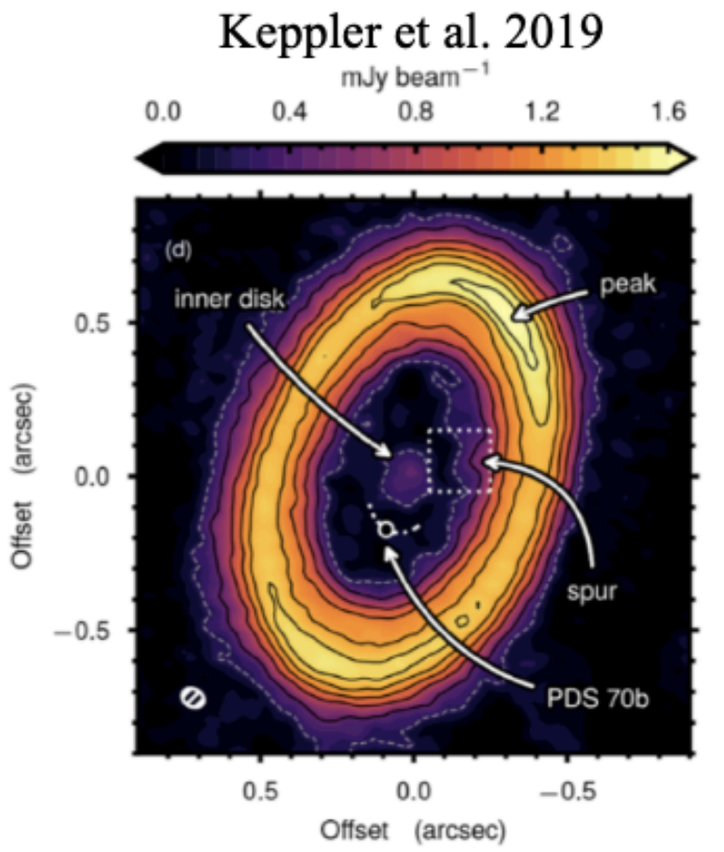
λ=2.11-2.25um

計算手法概要

- PHANTOM (Price+18)によるガス+1mmダストの２流体計算
- 小さいダストはガスとよくカップルしてると仮定し、総量をmmダストの量からMRN分布で外挿して計算
- 初期の惑星分布は右のテーブルに示す3通り

	Simulations		
	Sim 1	Sim 2	Sim 3
M_b (M_J)	2.5	3	3
R_b (au)	20	15	20
$f_b = R_{acc,b}/R_H$	1/8	1/4	1/4
M_c (M_J)	0.5	0.5	0.5
R_c (au)	55	45	45
$f_c = R_{acc,c}/R_H$	1/3	1/4	1/4
R_c/R_b	2.75	3	2.25

Keppler et al. 2019

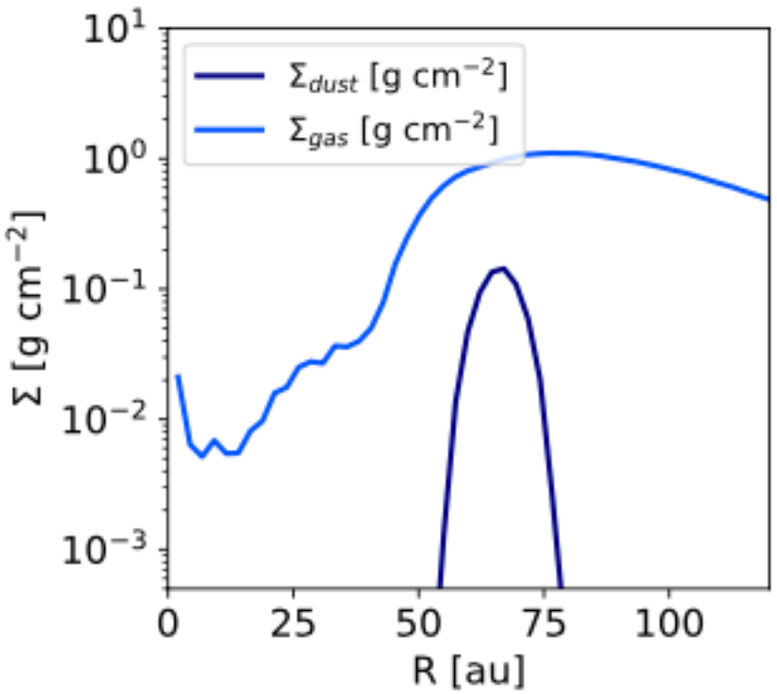


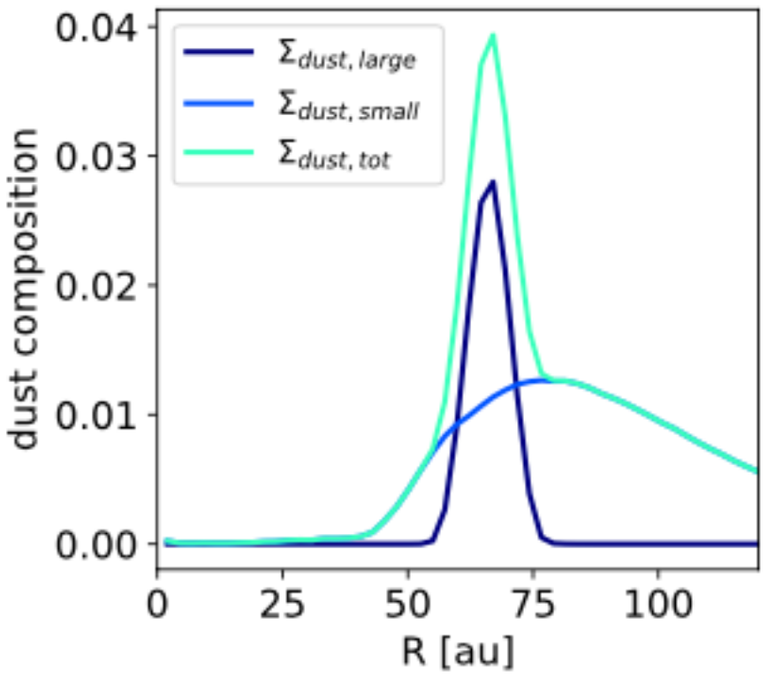
λ=855um

計算結果： 600T_{orb} (0.18Myr)後の結果をみていく

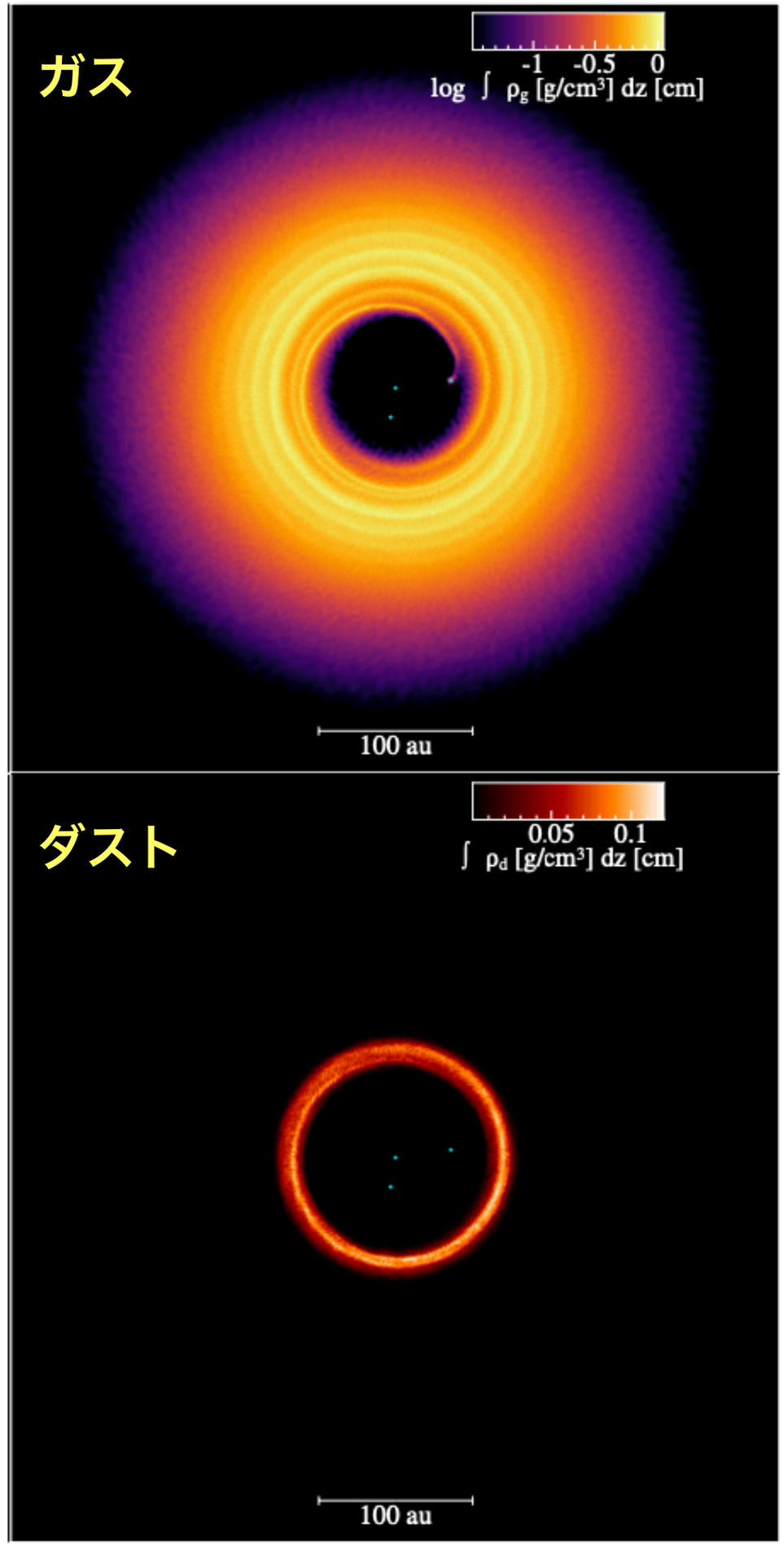
シミュレーション生データ（sim 3, 右図）

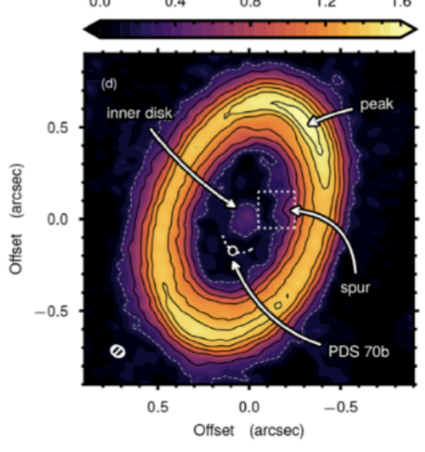
- ２つの惑星によって、ガス円盤にcavityがあく
- 外側の惑星はガス円盤と強く相互作用し、円盤から惑星への流れが見える
- 1mmダストはcavityの外端に堆積してリング状になる

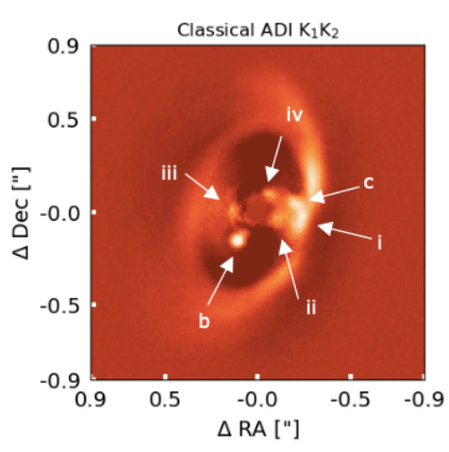




	Simulations		
	Sim 1	Sim 2	Sim 3
M_b (M_J)	4.4	5.	5.3
R_b (au)	19.4	14.2	19.1
M_c (M_J)	4.1	4.3	3.9
R_c (au)	42.6	34.9	36.1
M_{gas} ($M_\odot$)	2.5×10^{-3}	3.5×10^{-3}	3.3×10^{-3}
M_{dust} ($M_\odot$)	5.4×10^{-5}	6.9×10^{-5}	7.0×10^{-5}

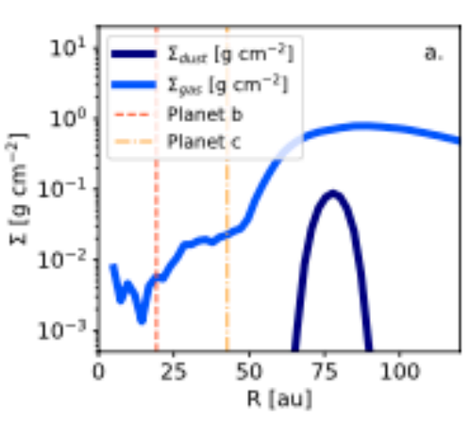


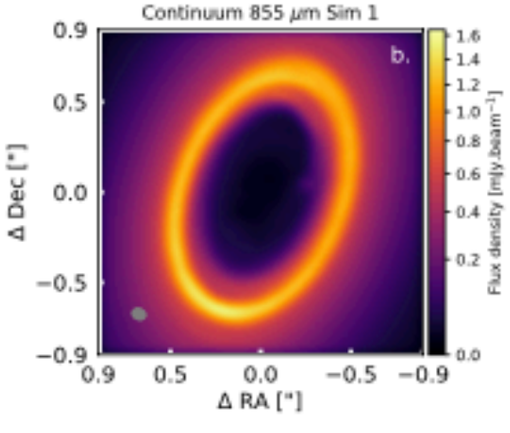


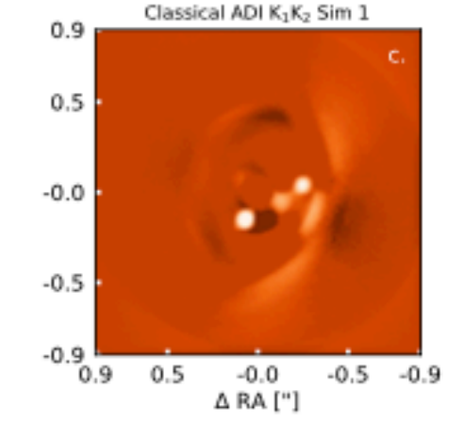


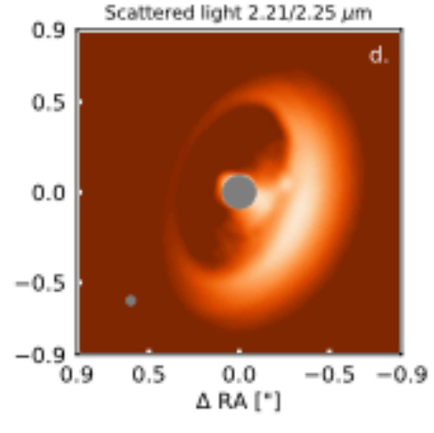
どのモデルでも、自然に、観測されている特徴を”定性的に"再現できるが、sim 3 が一番観測に近い

Sim1

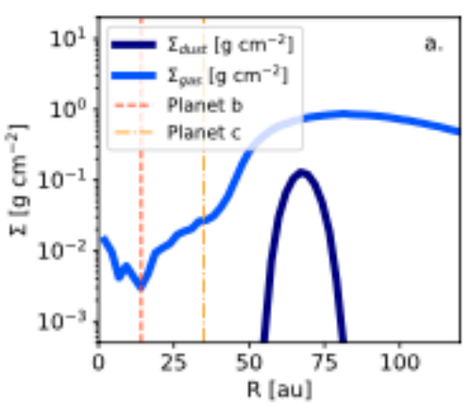


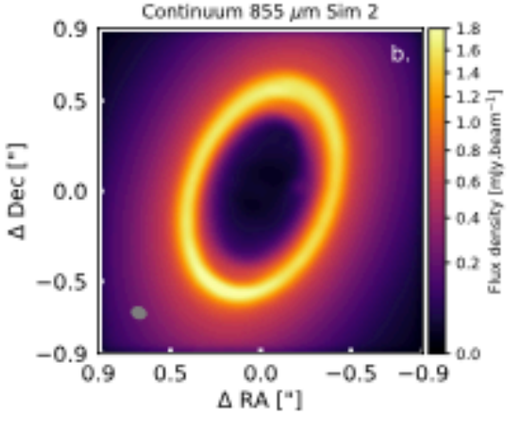


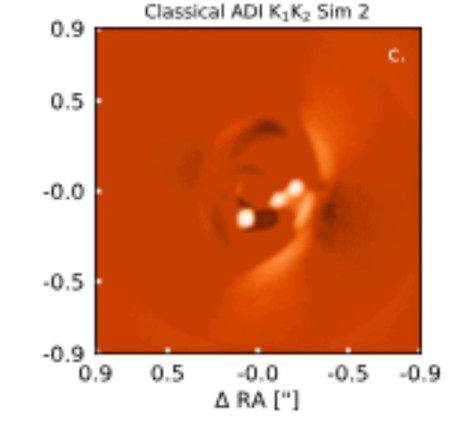


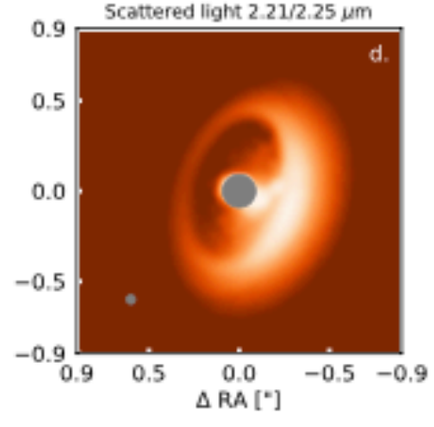


Sim 2

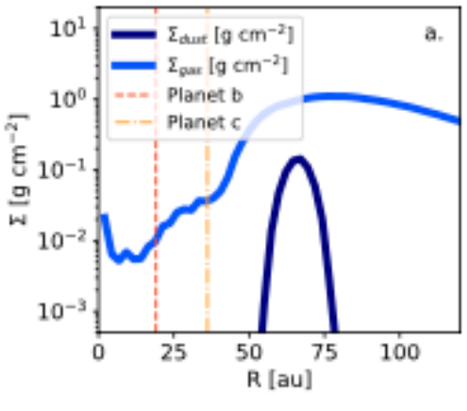


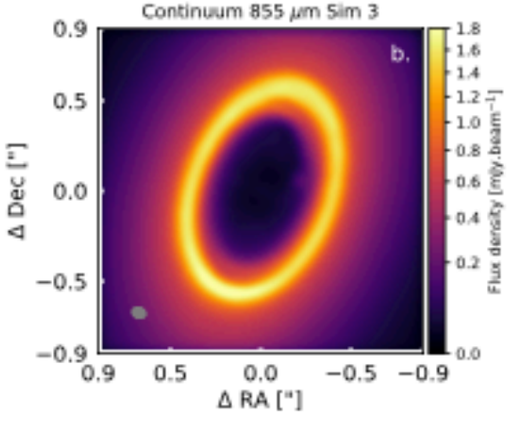


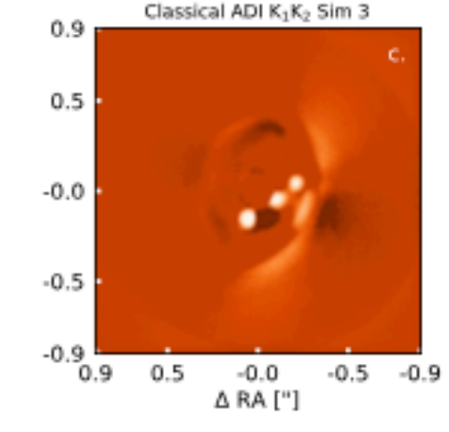


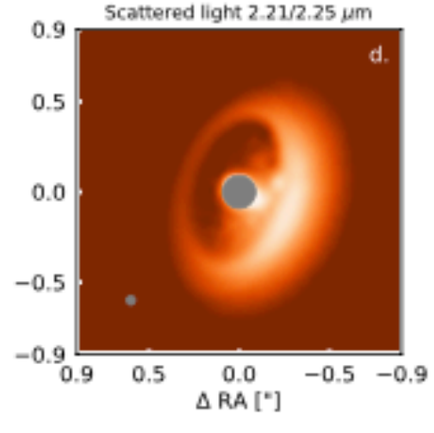


Sim 3

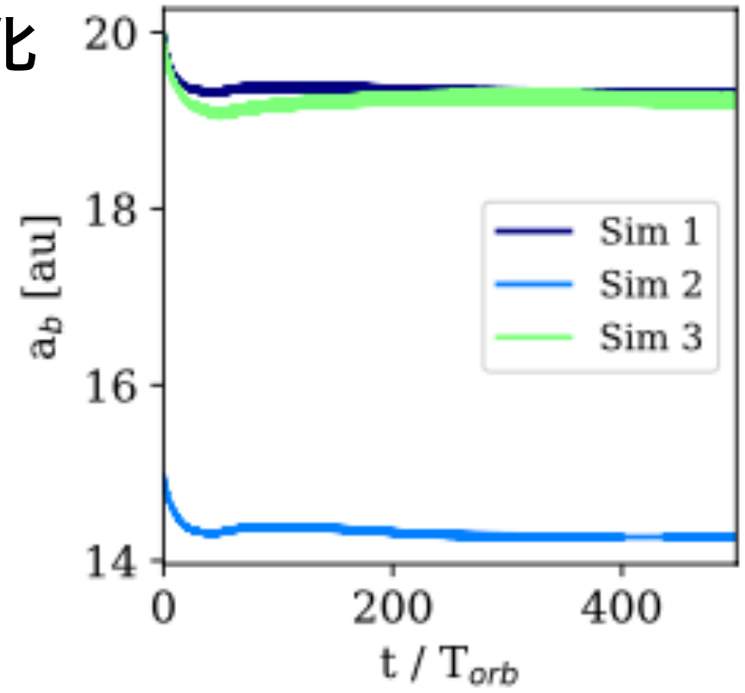


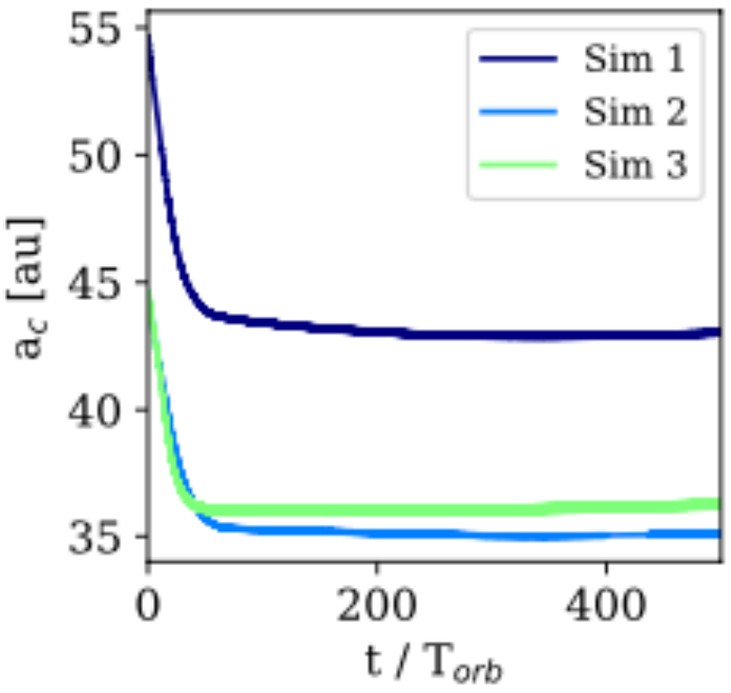


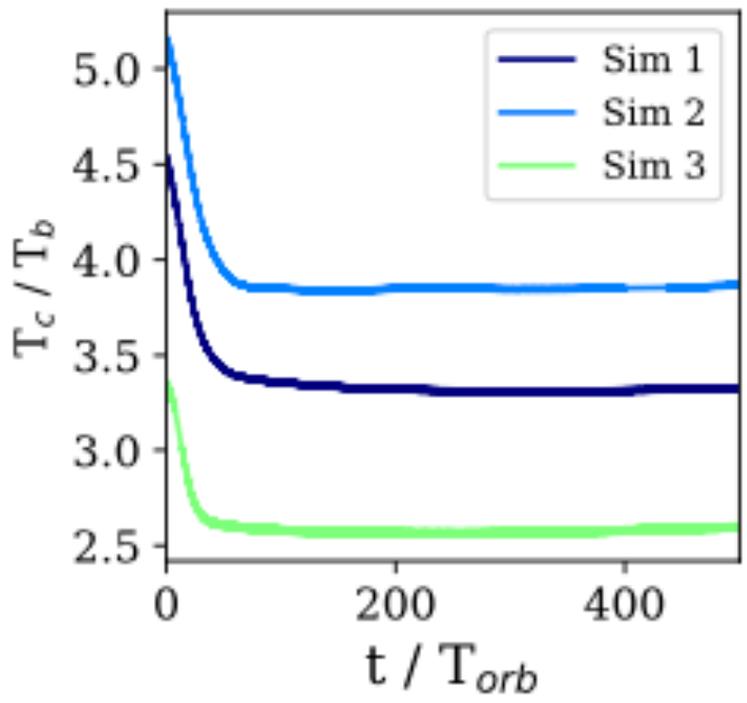




軌道進化

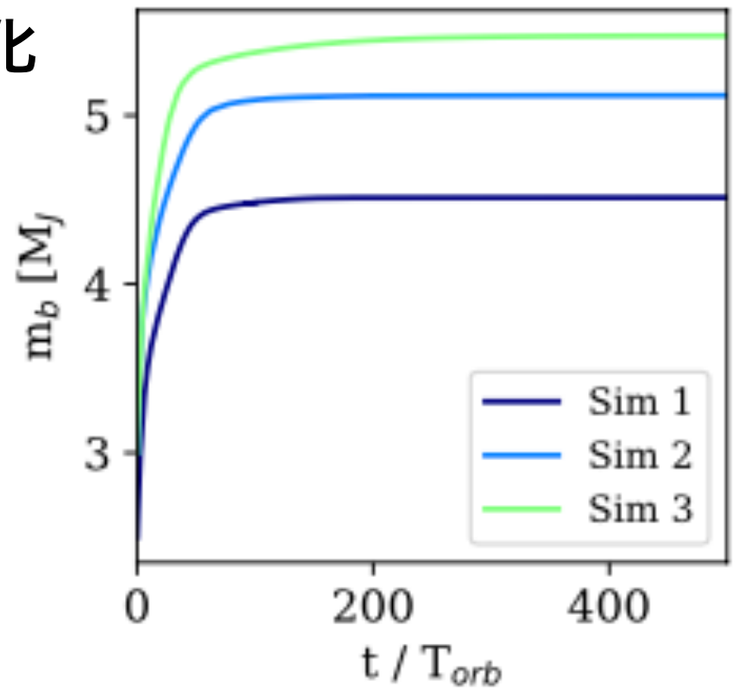


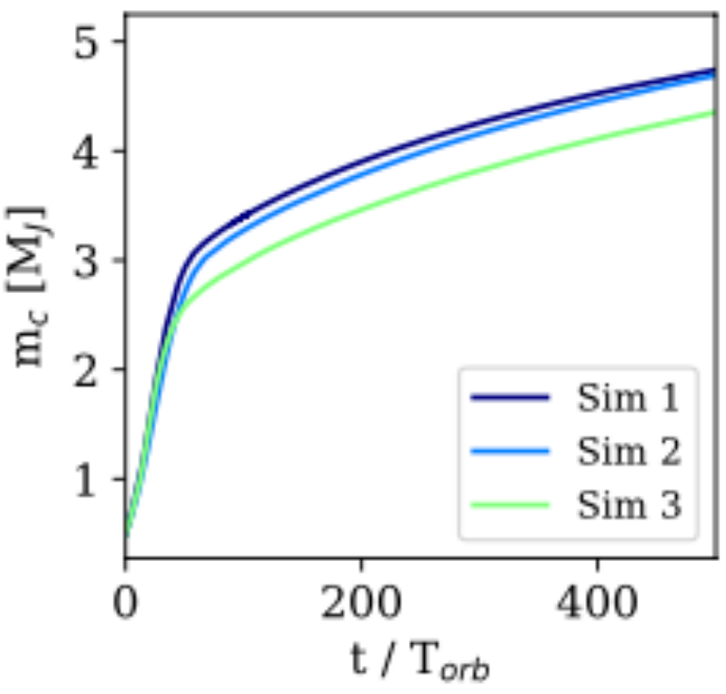


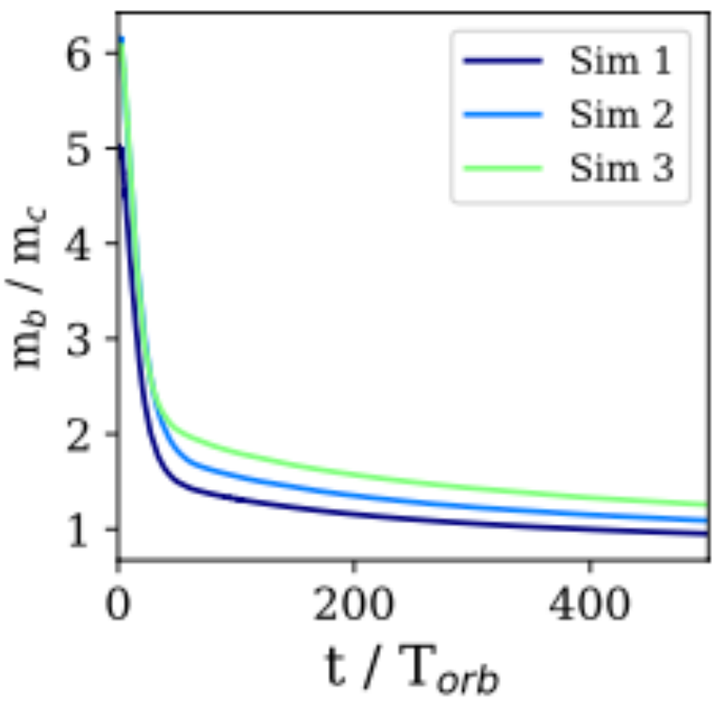


- Planet bは初期質量が重いのですぐにギャップが開いてほとんど移動しない
- Planet cは内側に移動してきて bとの軌道共鳴にはまる
- cの初期位置が遠いほど、外で共鳴にはまる

質量進化







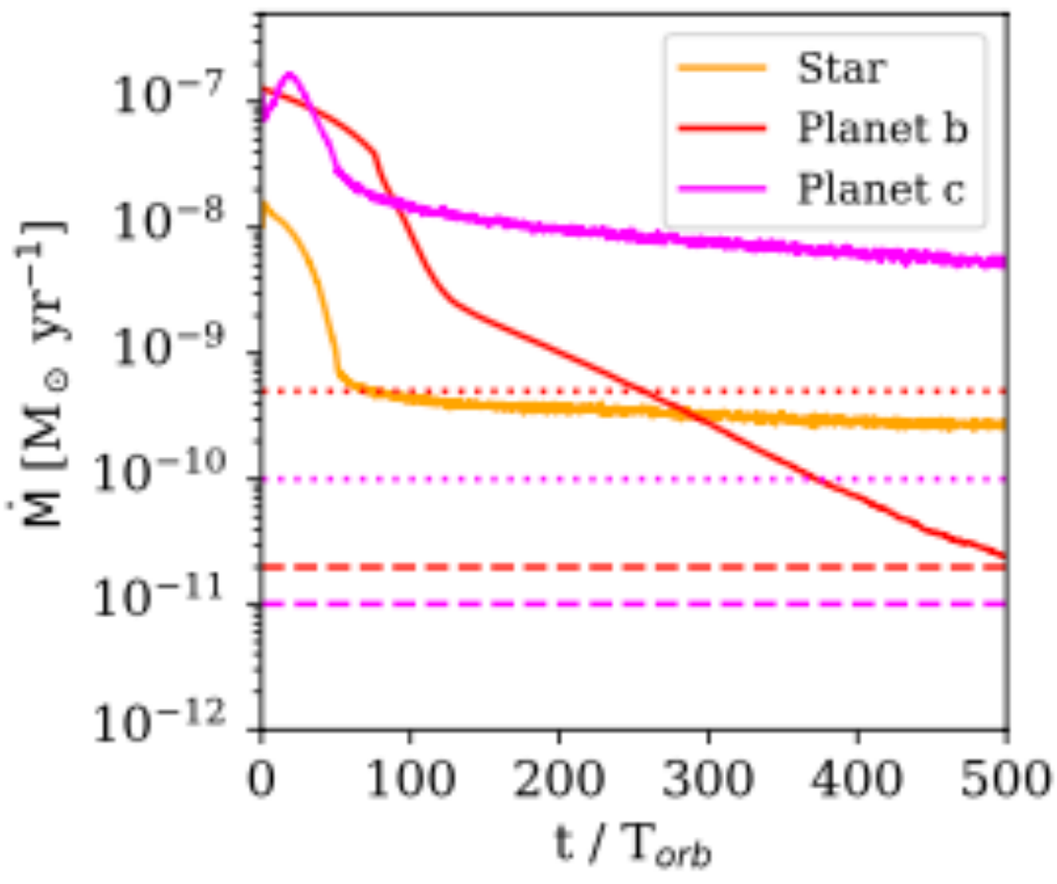
- Cがガスをせきとめるため、Planet bの質量進化は、4-5Mjupでとまる
- Bは外側のガスを獲得できるため、質量進化を続ける -> 将来的にはcの方が重くなる

降着率

- 中心星への降着率は5×10^-10 M*/yr
  - 観測より1桁大きい
  - 中心星のsink半径を2auとしており、実際より大きいからかもしれない

r<2auでMdotが一定なら変わらないような？

- Planet cへの降着率(~10^-8 M*/yr)が、Planet bへの降着率より高い(<10^-10 M*/yr)
  - 観測と逆センス
  - 特に Planet cへの降着率は観測より2桁以上高い
  - 周惑星円盤があれば、降着率は低くなる可能性（本研究では周惑星円盤は解像できていない）
  - ただし、bとcの相対的な降着率の違いは周惑星円盤の影響を受けにくい



実線：シミュレーション
点線：Hashimoto+20
破線：Haffert+19

43. Magnetized filamentary gas flows feeding the young embedded cluster in Serpens South

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Observations indicate that molecular clouds are strongly magnetized, and that magnetic fields influence the formation of stars. A key observation supporting the conclusion that molecular clouds are significantly magnetized is that the orientation of their internal structure is closely related to that of the magnetic field. At low column densities the structure aligns parallel with the field, whereas at higher column densities, the gas structure is typically oriented perpendicular to magnetic fields, with a transition at visual extinctions $A_V \geq 3$ mag. Here we use far-infrared polarimetric observations from the HAWC+ polarimeter on SOFIA to report the discovery of a further transition in relative orientation, i.e., a return to parallel alignment at $A_V \geq 21$ mag in parts of the Serpens South cloud. This transition appears to be caused by gas flow and indicates that magnetic supercriticality sets in near $A_V \geq 21$ mag, allowing gravitational collapse and star cluster formation to occur even in the presence of relatively strong magnetic fields.

Accepted by Nature Astronomy

https://doi.org/10.1038/s41550-020-1172-6
https://arxiv.org/pdf/2009.14100.pdf

44. A “head/tail” plasmon model with a Hubble law velocity profile

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We present a model of a hypersonic, collimated, “single pulse” outflow, produced by an event with an ejection velocity that first grows, reaches a peak, and then decreases again to zero velocity in a finite time (simultaneously, the ejection density can have an arbitrary time-variability). We obtain a flow with a leading “head” and a trailing “tail’ that for times greater than the width of the pulse develops a linear, “Hubble law” velocity vs. position. We present an analytic model for a simple pulse with a parabolic ejection velocity vs. time and time-independent mass-loss rate, and compare it to an axisymmetric gasdynamic simulation with parameters appropriate for fast knots in planetary nebulae. This “head/tail plasmon” flow might be applicable to other high-velocity clumps with “Hubble law” tails.

Accepted by MNRAS, letters

45. First sample of N_2H^+ nitrogen isotopic ratio measurements in low-mass protostars

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Context. The nitrogen isotopic ratio is considered an important diagnostic tool of the star formation process, and N_2H^+ is particularly important because it is directly linked to molecular nitrogen N_2. However, theoretical models still lack to provide an exhaustive explanation for the observed $^{14}N/^{15}N$ values.
Aims. Recent theoretical works suggest that the $^{14}N/^{15}N$ behaviour is dominated by two competing reactions that destroy N_2H^+: dissociative recombination and reaction with CO. When CO is depleted from the gas phase, if N_2H^+ recombination rate is lower with respect to the $N^{15}NH^+$ one, the rarer isotopologue is destroyed faster. In prestellar cores, due to a combination of low temperatures and high densities, most CO is frozen in ices onto the dust grains, leading to high levels of depletion. On the contrary, in protostellar cores, where temperature are higher, CO ices evaporate back to the gas phase. This implies that the N_2H^+ isotopic ratio in protostellar cores should be lower than the one in prestellar cores, and consistent with the elemental value of ≈ 440. We aim to test this hypothesis, producing the first sample of $N_2H^+/N^{15}NH^+$ measurements in low mass protostars.
Methods. We observe the N_2H^+ and $N^{15}NH^+$ lowest rotational transition towards six young stellar objects in Perseus and Taurus molecular clouds. We model the spectra with a custom `python` code using a constant T_{ex} approach to fit the observations. We discuss in appendix the validity of this hypothesis. The derived column densities are used to compute the nitrogen isotopic ratios.
Results. Our analysis yields an average of $^{14}N/^{15}N|_{pro} = 420 \pm 15$ in the protostellar sample. This is consistent with the protosolar value of 440, and significantly lower than the average value previously obtained in a sample of prestellar objects.
Conclusions. Our results are in agreement with the hypothesis that, when CO is depleted from the gas-phase, dissociative recombinations with free electrons destroy $N^{15}NH^+$ faster than N_2H^+, leading to high isotopic ratios in prestellar cores, where carbon monoxide is frozen onto dust grains.

Accepted by A&A

46. NGC 7538 IRS1 - An O Star Driving an Ionized Jet and Giant N-S Outflow

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NGC 7538 IRS 1 is a very young embedded O star driving an ionized jet and accreting mass with an accretion rate $>10^{-4}$ $M_\odot$/year, which is quenching the hypercompact HII region. We use SOFIA GREAT data, Herschel PACS and SPIRE archive data, SOFIA FORCAST archive data, Onsala 20m and CARMA data, and JCMT archive data to determine the properties of the O star and its outflow. IRS 1 appears to be a single O-star with a bolometric luminosity $> 1 \times 10^5$ $l_\odot$, i.e. spectral type O7 or earlier. We find that IRS 1 drives a large molecular outflow with the blue-shifted northern outflow lobe extending to $\sim$ 280 arcsec or 3.6 pc from IRS 1. Near IRS 1 the outflow is well aligned with the ionized jet. The dynamical time scale of the outflow is $\sim 1.3 \times 10^5$ yr. The total outflow mass is $\sim$ 130 $M_\odot$. We determine a mass outflow rate of 1.0 $\times 10^{-3}$ $M_\odot yr^{-1}$, roughly consistent with the observed mass accretion rate. We observe strong high velocity [C II] emission in the outflow, confirming that strong UV radiation from IRS 1 escapes into the outflow lobes and is ionizing the gas. Many O stars may form like low mass stars, but with a higher accretion rate and in a denser environment. As long as the accretion stays high enough to quench the HII region, the star will continue to grow. When the accretion rate drops, the HII region will rapidly start to expand.

Accepted by The Astrophysical Journal

47. FEEDBACK: a SOFIA Legacy Program to Study Stellar Feedback in Regions of Massive Star Formation

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FEEDBACK is a SOFIA (Stratospheric Observatory for Infrared Astronomy) legacy program dedicated to study the interaction of massive stars with their environment. It performs a survey of 11 galactic high mass star forming regions in the 158 μm (1.9 THz) line of [C II] and the 63 μm (4.7 THz) line of [O I]. We employ the 14 pixel Low frequency Array (LFA) and 7 pixel High Frequency Array (HFA) upGREAT heterodyne instrument to spectrally resolve (0.24 MHz) these far-infrared fine structure lines. With a total observing time of 96h, we will cover ~6700 arcmin^2 at 14.1″ angular resolution for the [C II] line and 6.3″ for the [O I] line. The observations started in spring 2019 (Cycle 7). Our aim is to understand the dynamics in regions dominated by different feedback processes from massive stars such as stellar winds, thermal expansion, and radiation pressure, and to quantify the mechanical energy injection and radiative heating efficiency. This is an important science topic because feedback of massive stars on their environment regulates the physical conditions and sets the emission characteristics in the interstellar medium (ISM), influences the star formation activity through molecular cloud dissolution and compression processes, and drives the evolution of the ISM in galaxies. The [C II] line provides the kinematics of the gas and is one of the dominant cooling lines of gas for low to moderate densities and UV fields. The [O I] line traces warm and high-density gas, excited in photodissociations regions with a strong UV field or by shocks. The source sample spans a broad range in stellar characteristics from single OB stars, to small groups of O stars, to rich young stellar clusters, to ministarburst complexes. It contains well-known targets such as Aquila, the Cygnus X region, M16, M17, NGC7538, NGC6334, Vela, and W43 as well as a selection of H II region bubbles, namely RCW49, RCW79, and RCW120. These [C II] maps, together with the less explored [O I] 63 μm line, provide an outstanding database for the community. They will be made publically available and will trigger further studies and follow-up observations.

Accepted by PASP (Vol. 132, No. 1016)

https://iopscience.iop.org/journal/1538-3873

https://arxiv.org/pdf/2009.08730

49. Investigating episodic accretion in a very low-mass young stellar object

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Very low-mass Class I protostars have been investigated very little thus far. Variability of these young stellar objects (YSOs) and whether or not they are capable of strong episodic accretion is also left relatively unstudied. We investigate accretion variability in IRS 54 (YLW52), a Class I very low-mass protostar with a mass of $M_\star \sim 0.1 - 0.2\,\mathrm{M}_\odot$. We obtained spectroscopic and photometric data with VLT/ISAAC and VLT/SINFONI in the near-infrared (J, H, and K bands) across four epochs (2005, 2010, 2013, and 2014). We used accretion-tracing lines (Paβ and Brγ) and outflow-tracing lines (H_2 and [FeII]) to examine physical properties and kinematics of the object. A large increase in luminosity was found between the 2005 and 2013 epochs of more than 1 magnitude in the K band, followed in 2014 by a steep decrease. Consistently, the mass accretion rate ($\dot{M}_{acc}$) rose by an order of magnitude from $\sim 10^{-8}$ $\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ to $\sim 10^{-7}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ between the two early epochs. The visual extinction (A_V) has also increased from ~ 15 mag in 2005 to ~ 24 mag in 2013. This rise in A_V in tandem with the increase in $\dot{M}_{acc}$ is explained by the lifting up of a large amount of dust from the disc of IRS 54, following the augmented accretion and ejection activity in the YSO, which intersects our line of sight due to the almost edge-on geometry of the disc. Because of the strength and timescales involved in this dramatic increase, this event is believed to have been an accretion burst possibly similar to bursts of EXor-type objects. IRS 54 is the lowest mass Class I source observed to have an accretion burst of this type, and therefore potentially one of the lowest mass EXor-type objects known so far.

Accepted by A&A