Star Formation Newsletter #348 24-29

武藤恭之

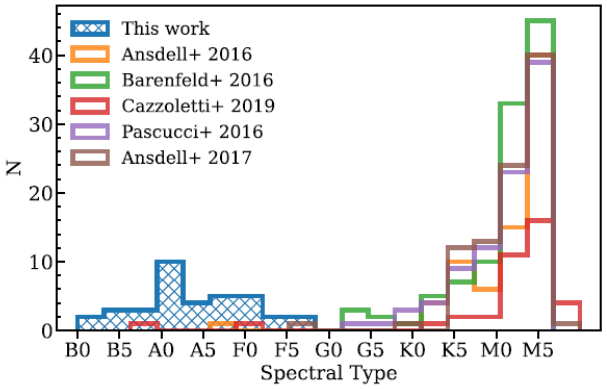
No. 26

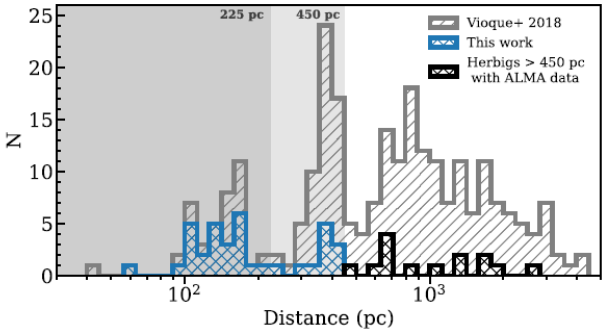
The mass and size of Herbig disks as seen by ALMA

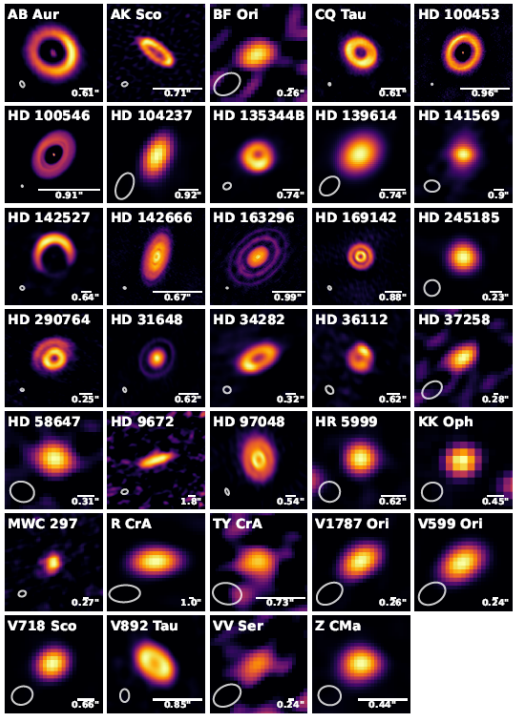
L. Stapper, M. R. Hogerheijde, E. F. van Dishoeck, R. Mentel ★ Many population studies have been performed with the Atacama Large Millimeter/submillimeter Array (ALMA) to understand the bulk properties of protoplanetary disks around young stars. The studied populations mostly consisted of G, K & M stars, with relatively few more massive Herbig stars. With GAIA updated distances, now is a good time to use ALMA archival data for a Herbig disk population study and take an important step forward in our understanding of planet formation. This work determines the masses and sizes of all Herbig dust disks observed with ALMA to date out to 450 pc. These masses and sizes are put into context of the Lupus and Upper Sco T Tauri disk populations. ALMA Band 6 and Band 7 archival data of 36 Herbig stars are used, making this work 64% complete excluding Orion. Using stellar parameters and distances the dust masses and sizes of the disks are determined and survival analysis is used to make cumulative distributions of the dust masses and radii. Herbig disks have a higher dust mass than the T Tauri disk populations of Lupus and Upper Sco by factors of ~ 3 and ~ 7 respectively. In addition, Herbig disks are often larger than the typical T Tauri disk. Although the masses and sizes of Herbig disks extend over a similar range as those of T Tauri disks, the distributions of masses and sizes of Herbig disks are significantly skewed toward higher values. Lastly, group I disks are more massive than group II disks. Based on these findings we speculate that these differences between Herbig and T Tauri disks find their origin in an initial disk mass that scales with the stellar mass, and that subsequent disk evolution enlarges the observable differences, especially if (sub)mm continuum optical depth plays a role. Moreover, the larger disk masses and sizes of Herbig stars could be linked to the increasing prevalence of giant planets with host star mass.

- ALMA で観測された Herbig stars 周囲の円盤の統計
- 36天体のデータを使用、225 pc 以内での completeness は 64%, Orion を除いた 450 pc 以内では 38%
- Herbig 型星の円盤は、T Tauri 型星に比較して、ダスト量が多く、サイズが大きい傾向にある
  - ただし、最もサイズの大きな T Tauri 円盤は、最も大きな Herbig 円盤と同程度の大きさ
- Group I 天体の方が、Group II 天体に比較して重い円盤を持つ傾向にある
  - Group I/II: 中間赤外の SED に Blackbody component がある／ない
  - Group II は、外側に惑星を作れず、内側までダストが落下してきているのではないか
- Herbig 型星の方が重い円盤を持っているのは、中心星質量が重い方が重い円盤を持つという傾向と整合的。また、重い星の方が重い系外惑星を持っているという傾向ともつながりがある

サーベイのサンプル





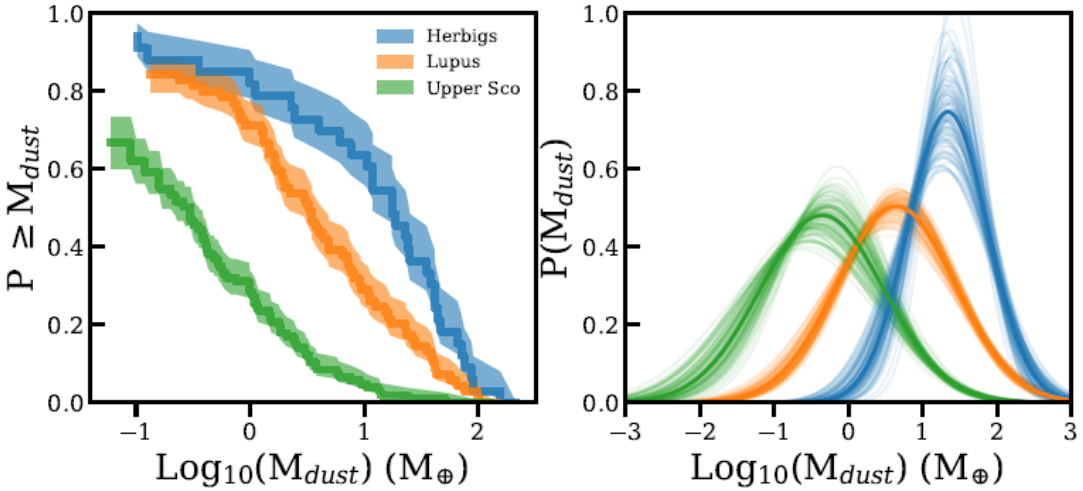


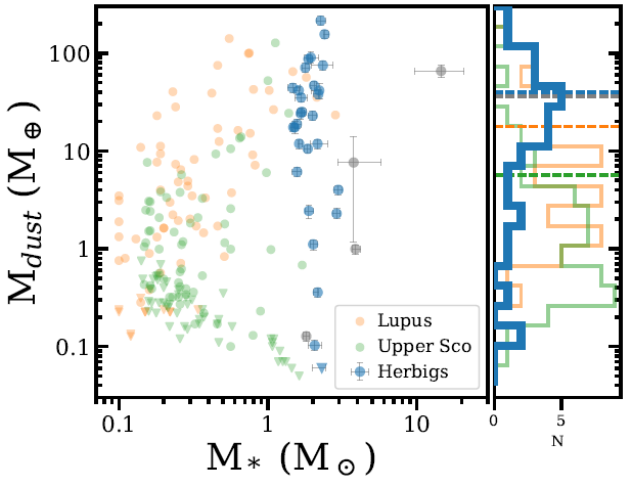
円盤質量の導出

$$M_{\rm dust} = \frac{F_\nu d^2}{\kappa_\nu B_\nu\left(T_{\rm dust}\right)}$$

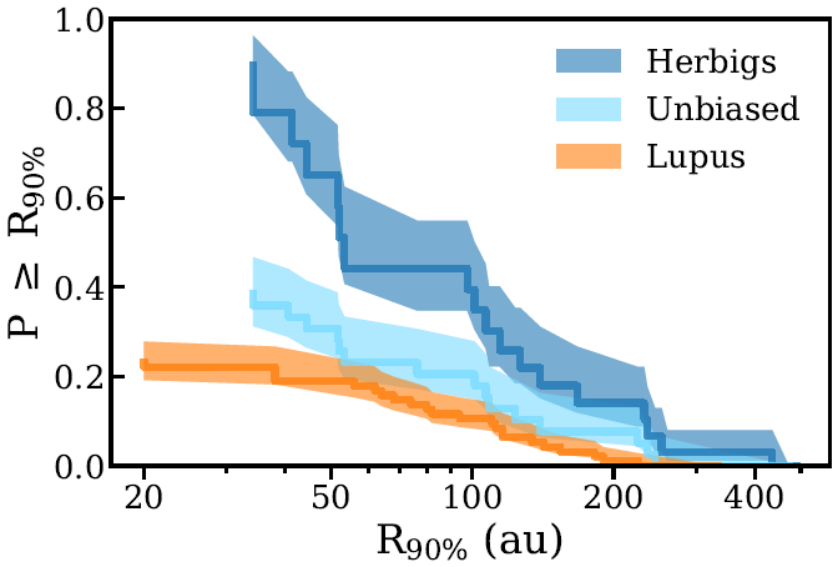
Herbig star 周囲の円盤が重い

	$M_\star\ (M_\odot)$		$M_{\rm dust}$	
	μ	σ	μ	σ
Herbigs	2.44	2.24	$1.34^{+0.05}_{-0.05}$	$0.53^{+0.07}_{-0.07}$
Lupus	0.42	0.48	$0.64^{+0.04}_{-0.05}$	$0.79^{+0.05}_{-0.04}$
Upper Sco	0.43	0.37	$-0.36^{+0.11}_{-0.14}$	$0.83^{+0.09}_{-0.07}$





円盤サイズ分布

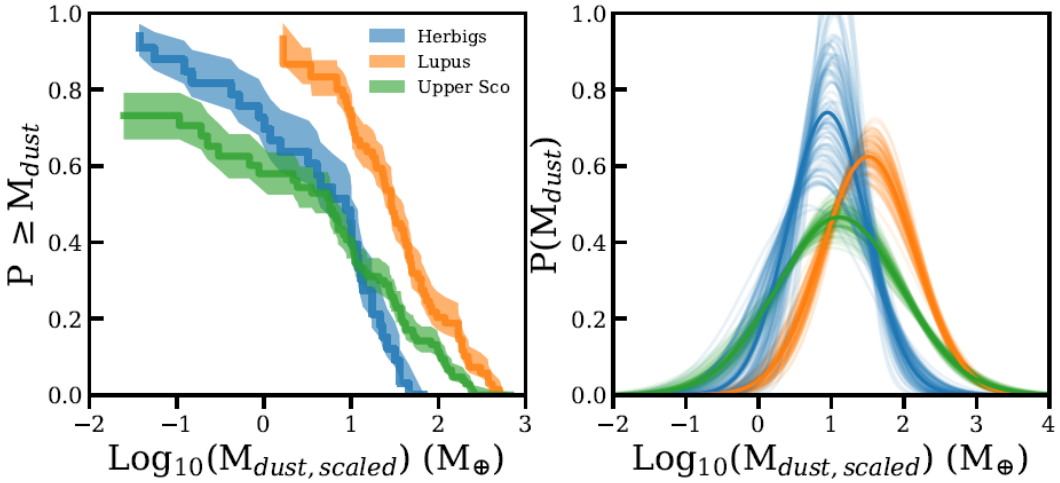


Unbiased: 観測の空間分解能を考慮
空間分解できていない天体は、観測されている最小サイズと同程度の円盤を持つと仮定

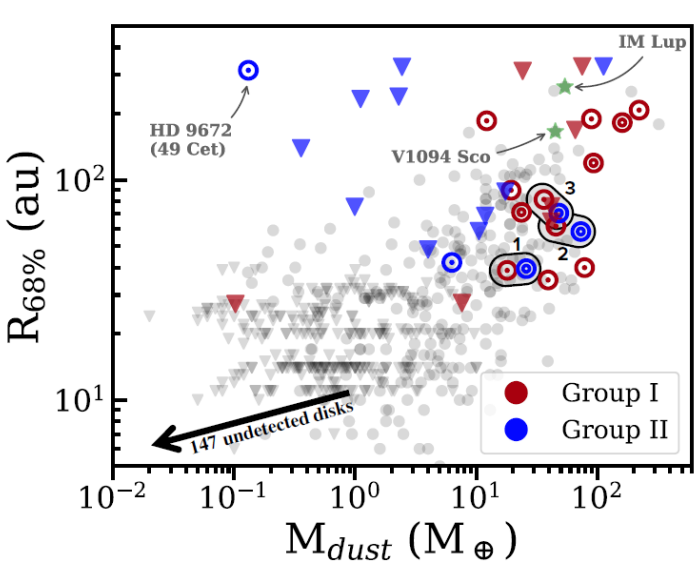
円盤質量分布について、星質量の違いを補正すると、ほぼ同じ分布になる

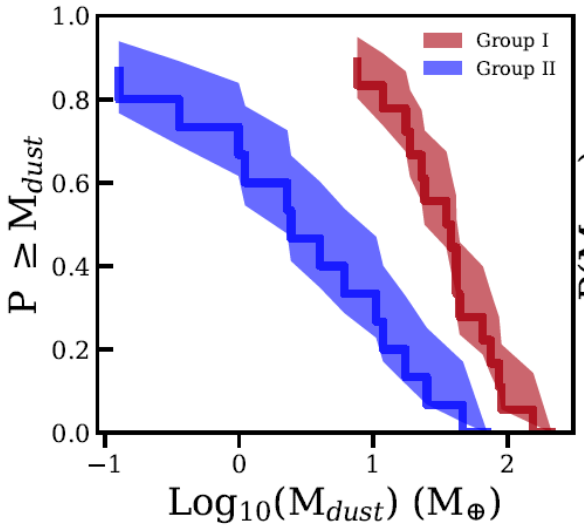
$$M_{\mathrm{dust,\ scaled}} = \left(\frac{M_\star}{1M_\odot}\right)^{-\alpha} \times M_{\mathrm{dust}}$$

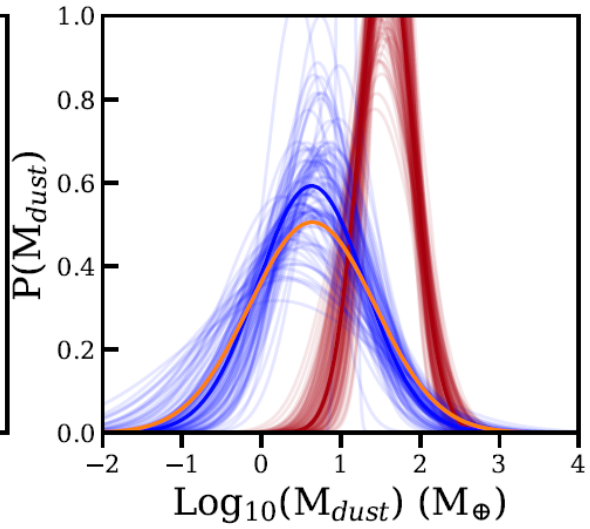
α = 1.8 for Lupus
α = 2.4 for USco
α = 1.4 for Herbig

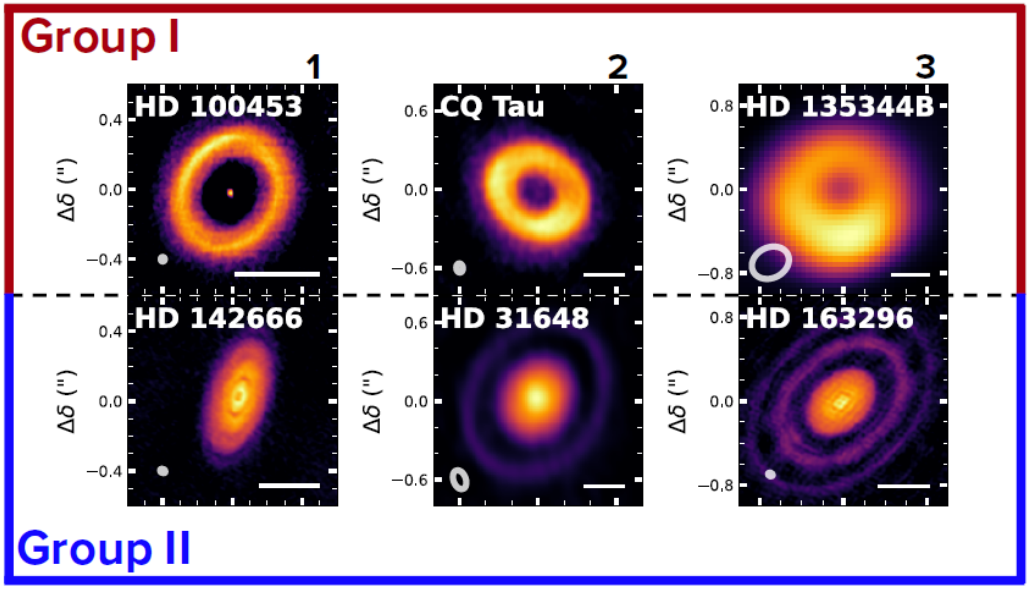


Group I vs Group II









Group I の方が重くて大きい傾向

同程度のサイズ・質量の円盤で比較すると、Group I ははっきりした穴があるが、Group II は中心付近が詰まっている

Group I が、惑星を外側で作れた天体の可能性

No. 28

Secular evolution of MHD wind-driven discs: analytical solutions in the expanded α-framework

Benoît Tabone, Giovanni P. Rosotti, Alexander J. Cridland, Philip J. Armitage, Giuseppe Lodato ★
The evolution of protoplanetary discs and the related process of planet formation is regulated by angular momentum transport and mass-loss processes. Over the past decade, the paradigm of viscosity has been challenged and MHD disc winds appear as a compelling scenario to account for disc accretion. In this work, we aim to construct the equivalent of the widely used analytical description of viscous evolution for the MHD wind case. The transport of angular momentum and mass induced by the wind is parameterized by an α-like parameter and by the magnetic lever arm parameter λ. Extensions of the paradigmatic Lynden-Bell and Pringle similarity solutions to the wind case are presented. We show that wind-driven accretion leads to a steeper decrease in the disc mass and accretion rate than in viscous models due to the absence of disc spreading. If the decline of the magnetic field strength is slower than that of the gas surface density, the disc is dispersed after a finite time. The evolution of the disc in the $\dot{M}_* - M_D$ plane is sensitive to the wind and turbulence parameters. A disc population evolving under the action of winds can exhibit a correlation between $\dot{M}_*$ and M_D depending on the initial conditions. The simplified framework proposed in this work opens to a new avenue to test the effectiveness of wind-driven accretion from the observed disc demographics and constitutes an important step to include wind-driven accretion in planet population synthesis models.

- MHD wind の効果を取り入れた、一次元円盤進化モデルの定式化と解析解
- 円盤風の効果：
  - 角運動量の引き抜きによる質量降着の増加
  - 円盤質量そのものの引き抜き
- 従来の粘性トルクを表す α パラメータに加え、円盤風の効果を表すパラメータを2つ入れ、1次元モデルの定式化を行う
- 1次元進化モデルの解析解を議論
  - 円盤風の効果で、円盤質量が急激に無くなる
  - 円盤は、Mdot – Mdisk のプロットで様々な位置に来ることになり、その correlation は初期条件に依存する

定式化

$$\frac{\partial \Sigma}{\partial t} = \frac{2}{r}\frac{\partial}{\partial r}\left\{\frac{1}{r\Omega}\frac{\partial}{\partial r}\left(r^2 \int_{-H_W}^{+H_W} T_{r\phi} dz\right)\right\} + \frac{2}{r}\frac{\partial}{\partial r}\left\{\frac{r|T_{z\phi}|_{-H_W}^{+H_W}}{\Omega}\right\} - \dot{\Sigma}_W,$$

乱流トルク　　円盤風トルク　　円盤風による質量損失

$$T_{r\phi} \equiv \langle \rho v_r \delta v_\phi - B_r B_\phi / 4\pi \rangle \qquad T_{z\phi} \equiv \langle \rho v_z \delta v_\phi - B_z B_\phi / 4\pi \rangle$$

パラメータの導入

乱流トルク

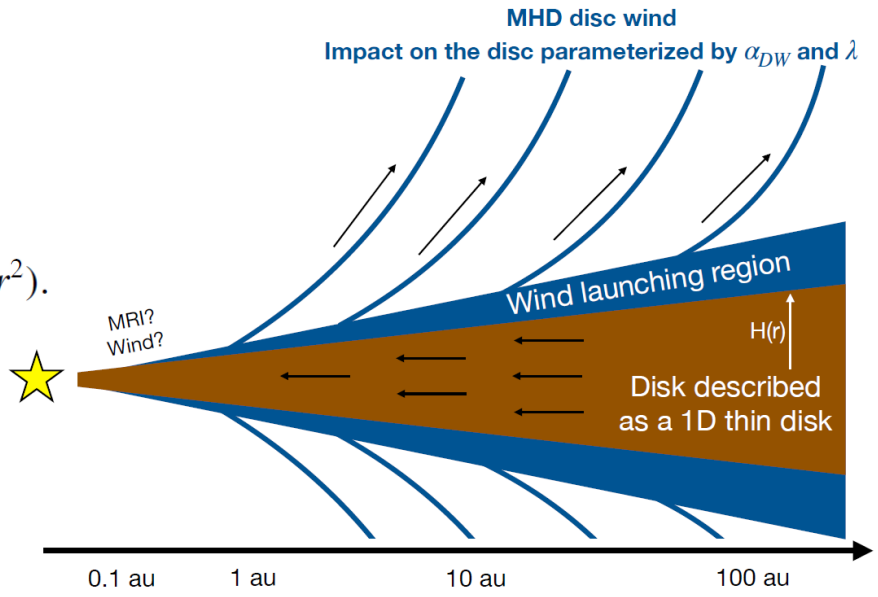
$$\alpha_{\rm SS} \equiv \frac{2}{3}\frac{\int T_{r\phi} dz}{\Sigma c_s^2} = \frac{2}{3\sqrt{2\pi}}\frac{\int T_{r\phi} dz}{HP_0},$$

乱流トルクによる質量降着 $\dot{M}_{\rm acc}^{visc}(r) = \frac{6\pi}{r\Omega}\frac{\partial}{\partial r}(\Sigma c_s^2 \alpha_{\rm SS} r^2).$

円盤風トルク

$$\alpha_{\rm DW} \equiv \frac{4}{3}\frac{r|T_{z\phi}|_{-H_W}^{+H_W}}{\Sigma c_s^2} = \frac{4}{3\sqrt{2\pi}}\frac{|T_{z\phi}|_{-H_W}^{+H_W}}{\epsilon P_0}$$

円盤風トルクによる質量降着 $\dot{M}_{\rm acc}^{DW}(r) = \frac{3\pi\Sigma c_s^2 \alpha_{\rm DW}}{\Omega}$



円盤風による角運動量持ち去り

$$\lambda \equiv \frac{L}{r\Omega(r)},$$

円盤風による質量損失 $\dot{\Sigma}_W = \frac{3\alpha_{\rm DW} c_s^2}{4(\lambda-1)\Omega r^2}\Sigma = \frac{1}{2(\lambda-1)}\frac{\dot{M}_{\rm acc}^{DW}}{2\pi r^2},$

仮定

α_{SS}, α_{DW}, λ は定数。温度は r^{-1/2} で一定

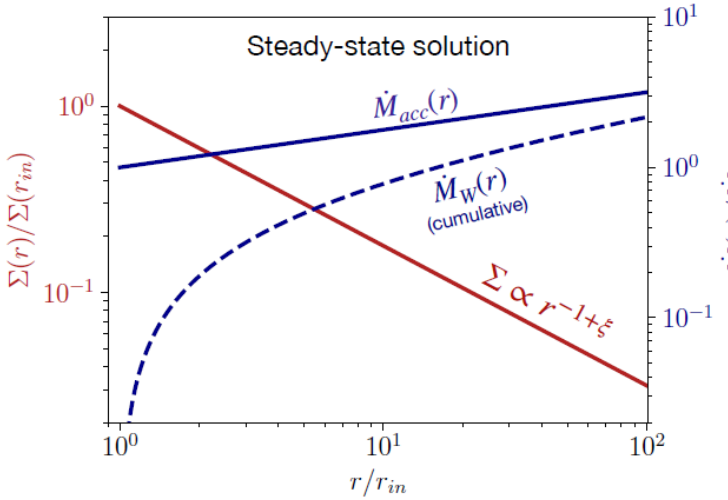
記号　$\tilde{\alpha} \equiv \alpha_{\rm DW} + \alpha_{\rm SS}$　$\psi \equiv \dfrac{\alpha_{\rm DW}}{\alpha_{\rm SS}}$

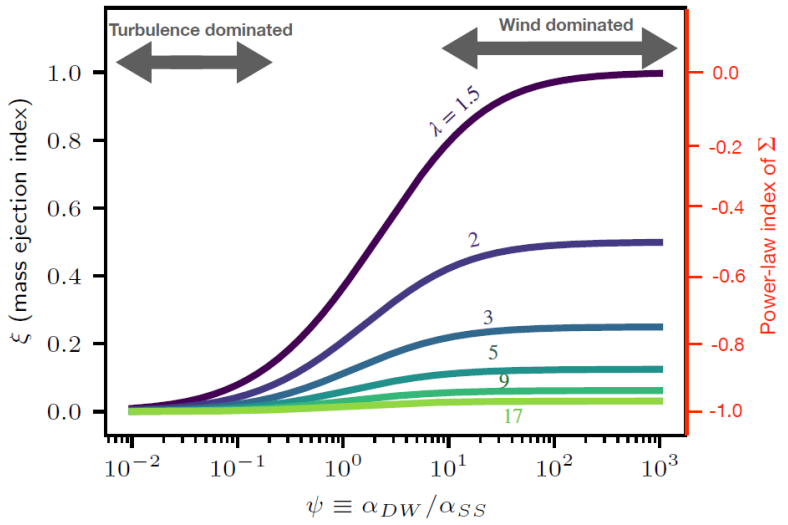
ξ は、local な wind による mass loss rate に対応

$$\xi \equiv \frac{d \ln \dot{M}_{\rm acc}}{d \ln r}$$

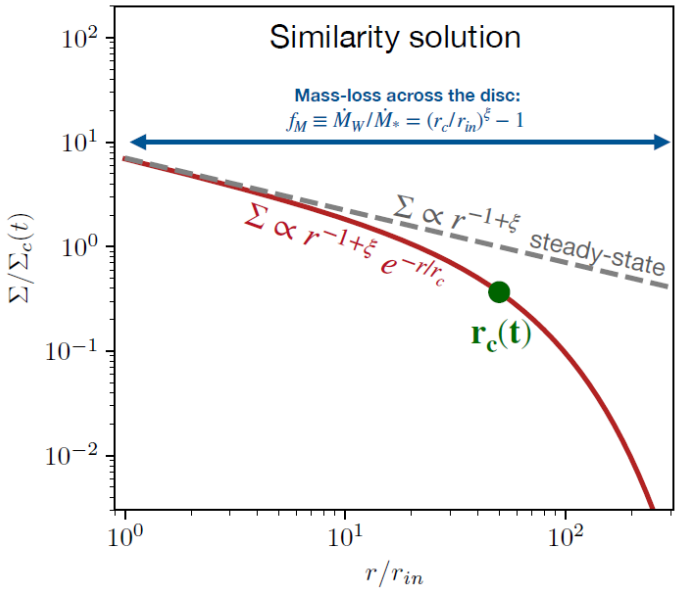
定常解　$\Sigma(r) \propto r^{-1+\xi}$　$\xi = \dfrac{1}{4}(\psi+1)\left[\sqrt{1+\dfrac{4\psi}{(\lambda-1)(\psi+1)^2}}-1\right]$

粘性トルクのみによる質量降着 (ψ=0): ξ=0　　Wind のみによる質量降着 (ψ=∞): ξ=1/(2λ-1)





自己相似解



α_{ss} と λ が時間的に一定である場合、以下のような形の厳密解が存在

$$\Sigma(r,t) = \Sigma_c(t)\left(\frac{r}{r_c(t)}\right)^{-1+\xi} e^{-r/r_c(t)},$$

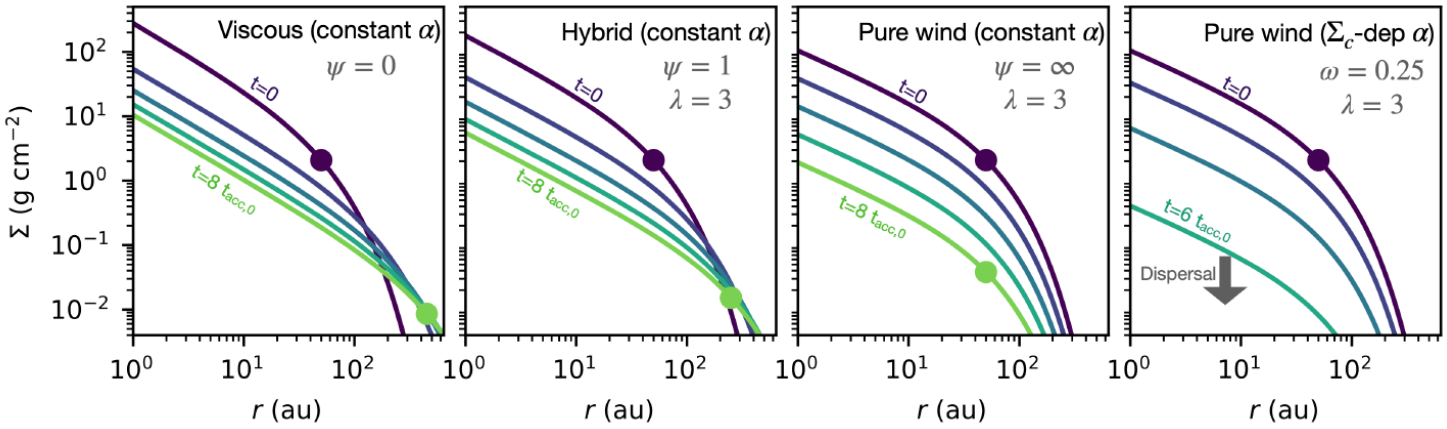
Σc と円盤質量の関係　$\Sigma_c(t) = \dfrac{M_D(t)}{2\pi r_c(t)^2},$

解のパラメータ: 初期の accretion rate　$t_{\rm acc,0} \equiv \dfrac{r_c(t=0)}{3\epsilon_c c_{s,c}\tilde{\alpha}(t=0)},$

α_{DW} の仮定によって、いくつかの解の可能性がある

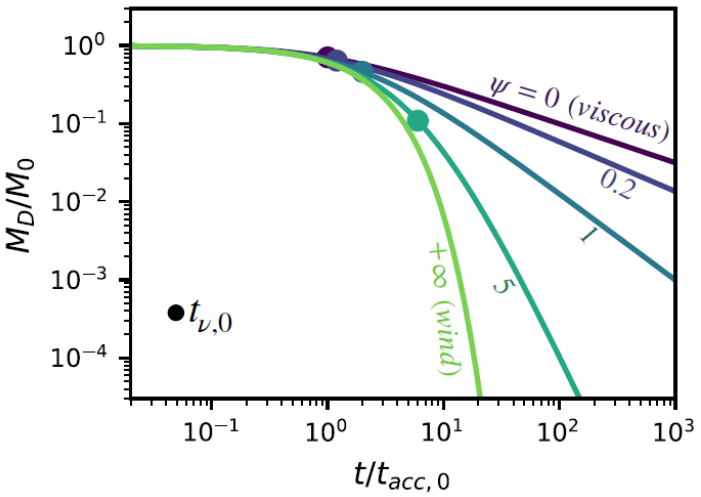
Hybrid: α_{DW} が定数

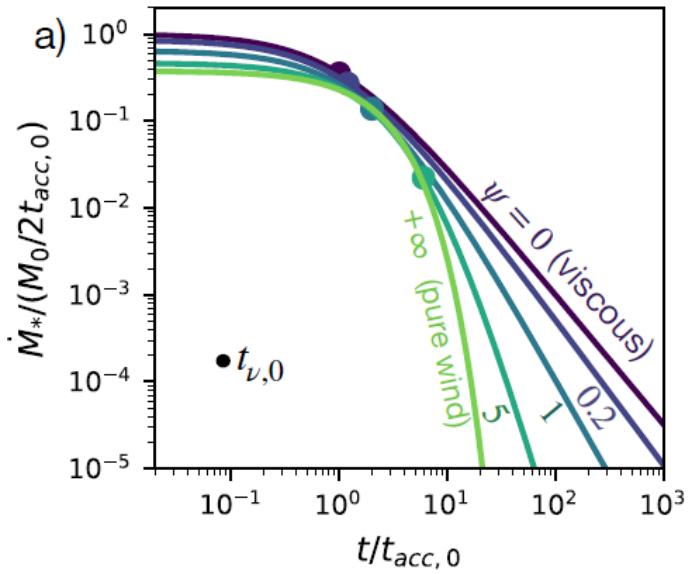
Σ_c-dependent wind torque: α_{DW} が Σ_c の $-\omega$ 乗に比例



円盤進化

Hybrid solution



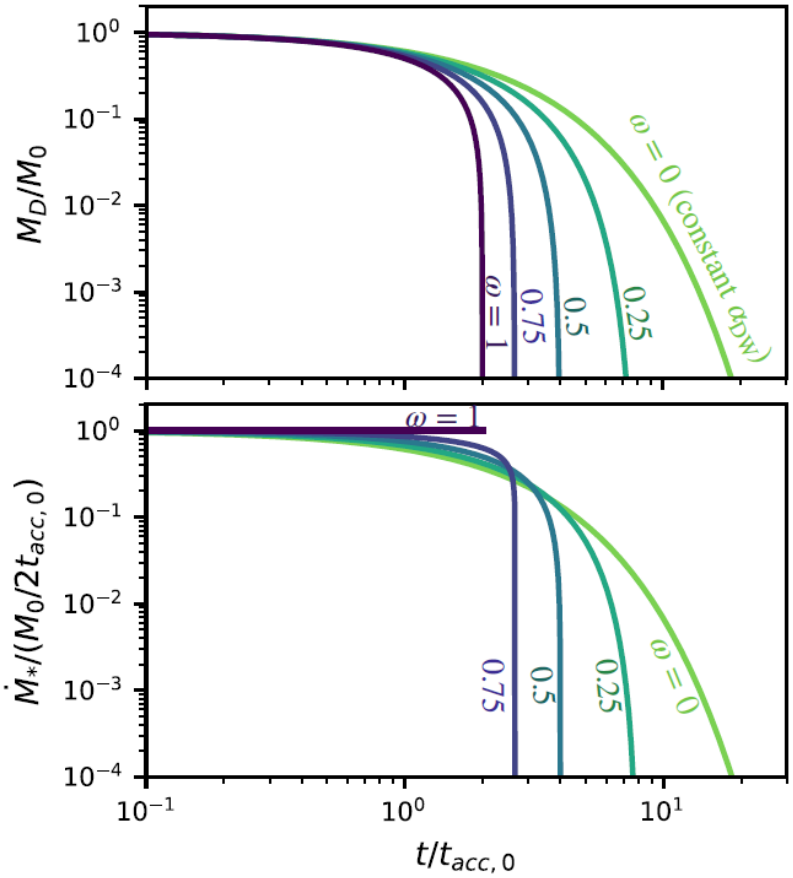


円盤質量

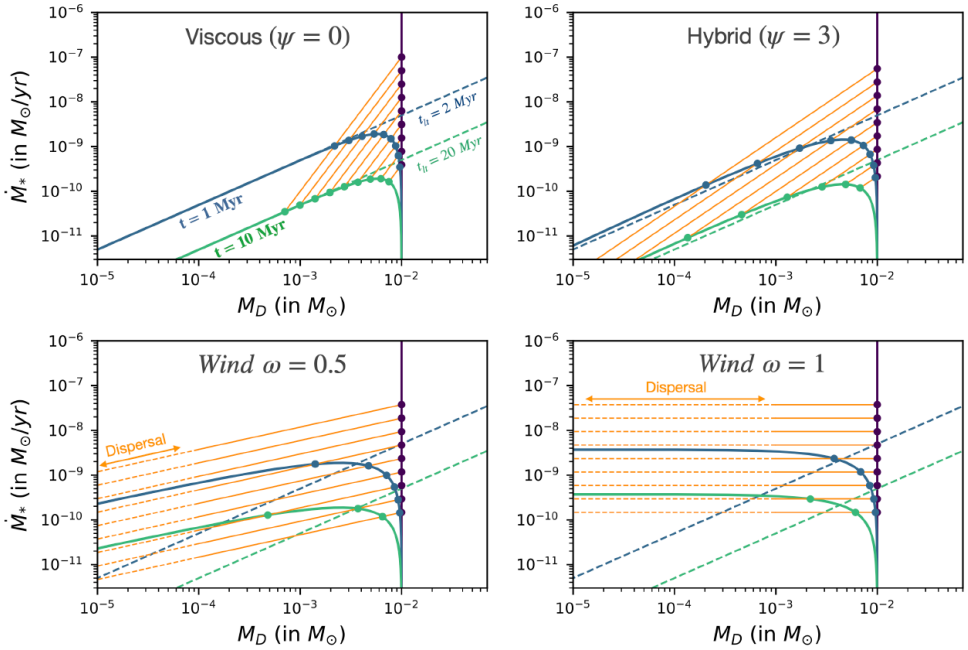
星への降着率

Σ_c-dependent wind torque

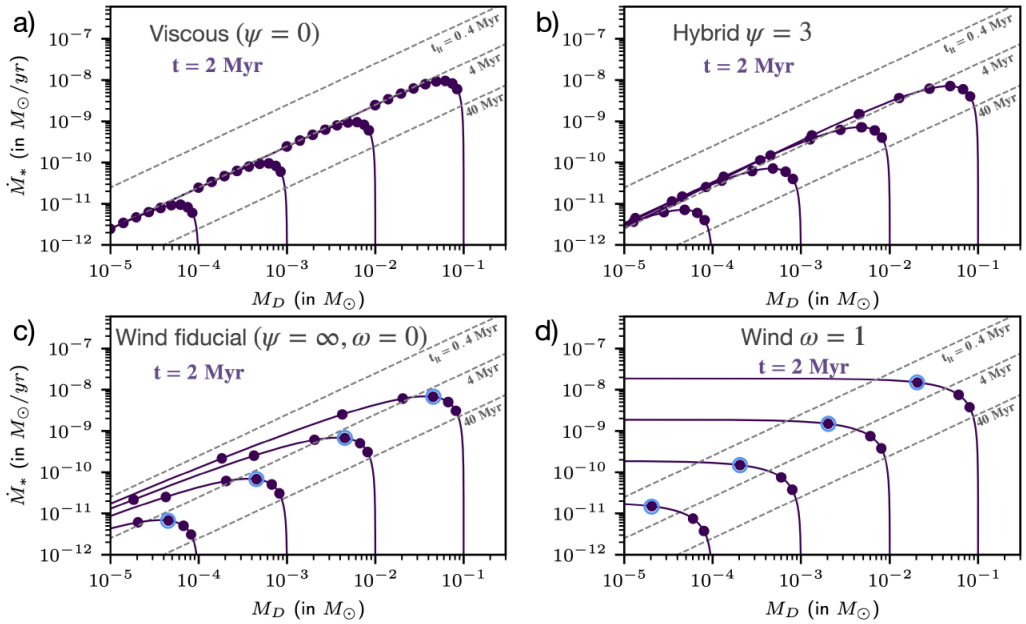
$$\alpha_{\mathrm{DW}}(t) \propto \Sigma_c(t)^{-\omega}$$



星への降着率 vs 円盤質量の面上での進化



初期円盤質量を固定した場合の isochrone



様々な初期円盤質量の場合

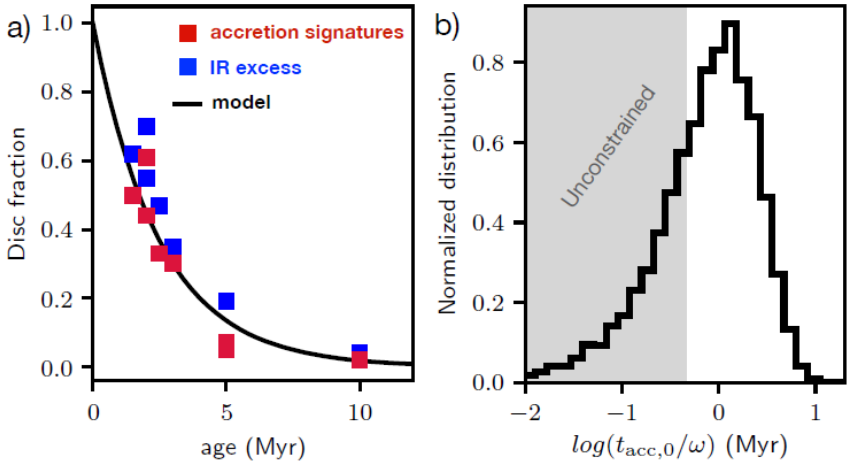
Wind の効果を考えると、Mdot-Mdisk 面上で、同時刻の円盤は様々な位置に来る

No. 29

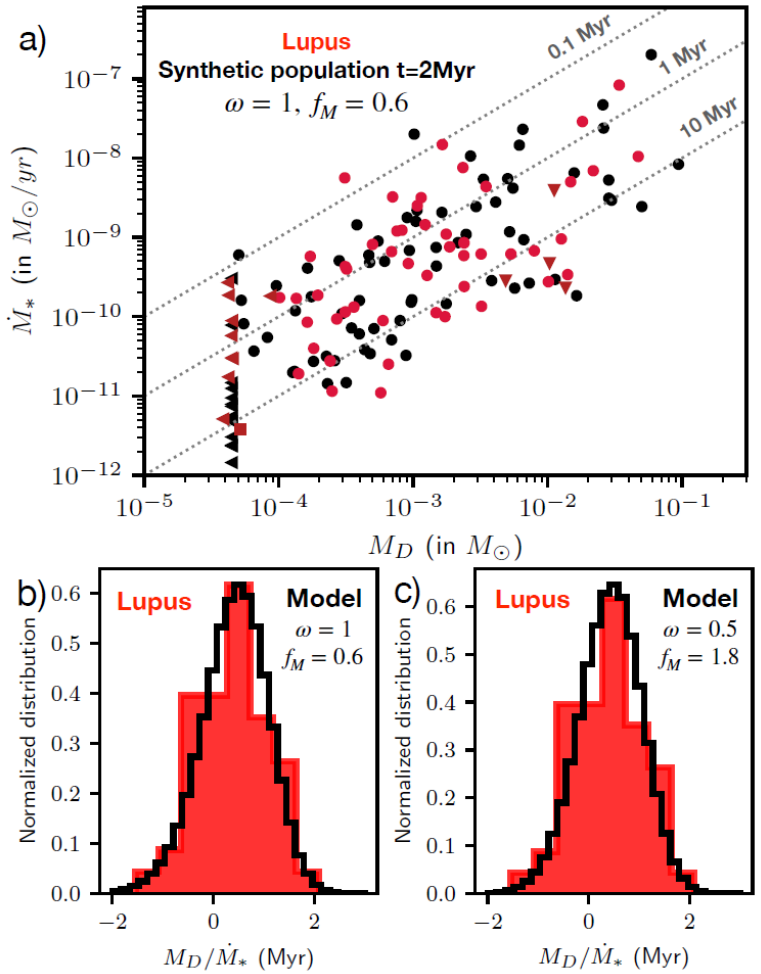
MHD disc winds can reproduce fast disc dispersal and the correlation between accretion rate and disc mass in Lupus

Benoît Tabone, Giovanni P. Rosotti, Giuseppe Lodato, Philip J. Armitage, Alexander J. Cridland, Ewine F. van Dishoeck ★ The final architecture of planetary systems depends on the extraction of angular momentum and mass-loss processes of the discs in which they form. Theoretical studies proposed that magnetized winds launched from the discs (MHD disc winds) could govern accretion and disc dispersal. In this work, we revisit the observed disc demographics in the framework of MHD disc winds, combining analytical solutions of disc evolution and a disc population synthesis approach. We show that MHD disc winds alone can account for both disc dispersal and accretion properties. The decline of disc fraction over time is reproduced by assuming that the initial accretion timescale (a generalization of the viscous timescale) varies from disc to disc and that the decline of the magnetic field strength is slower than that of the gas. The correlation between accretion rate and disc mass, and the dispersion of the data around the mean trend as observed in Lupus is then naturally reproduced. The model also accounts for the rapidity of the disc dispersal. This paves the way for planet formation models in the paradigm of wind-driven accretion.

- Tabone et al. (2021) の円盤進化モデル（論文28）を用いて、観測されている円盤の demographics を議論
  - 様々な星形成領域における disk fraction の観測（Fedele et al. 2010）
  - Lupus の円盤質量分布（Ansdell et al. 2016）と質量降着率（Manara et al. 2019）
  - Lupus は、external photoevaporation の効果が小さい
- 円盤風の影響のみ（粘性トルクを無視）を考慮して、観測されている円盤の分布を説明できる
  - 様々な初期の accretion timescale を持った円盤を考えれば良い
  - ただし、全ての星形成領域で、初期の accretion timescale の分布は同じとして説明可能
- 観測されている円盤の Mdot や Mdisk から、初期の accretion timescale の分布が示唆される



・Disk fraction の観測とモデルの比較
・示唆される初期の質量降着率分布



Lupus の円盤質量分布

No. 24

The impact of the presence of water ice on the analysis of debris disk observations

Thomas A. Stuber, Sebastian Wolf ★
The analysis of debris disk observations is often based on the assumption of a dust phase composed of compact spherical grains consisting of astronomical silicate. Instead, observations indicate the existence of water ice in debris disks. We quantify the impact of water ice as a potential grain constituent in debris disks on the disk parameter values estimated from photometric and spatially resolved observations in the mid- and far-infrared. We simulated photometric measurements and radial profiles of debris disks containing water ice and analyzed them by applying a disk model purely consisting of astronomical silicate. Subsequently, we quantified the deviations between the derived and the true parameter values. As stars in central positions we discuss a β Pic sibling and main-sequence stars with spectral types ranging from A0 to K5. To simulate observable quantities we employed selected observational scenarios regarding the choice of wavelengths and instrument characteristics. For the β Pic stellar model and ice fractions ≥ 50 % the derived inner disk radius is biased by ice sublimation toward higher values. However, the derived slope of the radial density profile is mostly unaffected. Along with an increasing ice fraction, the slope of the grain size distribution is overestimated by up to a median factor of ~ 1.2 for an ice fraction of 90 % while the total disk mass is underestimated by a factor of ~ 0.4. The reliability of the derived minimum grain size strongly depends on the spectral type of the central star. For an A0-type star the minimum grain size can be underestimated by a factor of ~ 0.2, while for solar-like stars it is overestimated by up to a factor of $\sim 4-5$. Neglecting radial profile measurements and using solely photometric measurements, the factor of overestimation increases for solar-like stars up to $\sim 7-14$.

- デブリ円盤の観測の解析では、astronomical silicate から成るダストのモデルが使われることが多い
- 実際の円盤に、水氷のダストがあったら、円盤のパラメータをどのように間違えるかを議論
  - Photometry の観測と、空間分解された円盤の明るさの slope の観測を、モデルを用いて調べる
  - 水氷を入れた円盤モデルの疑似観測を、astronomical silicate のモデルで解析する
- Ice fraction が 50% 以上の場合、inner disk のサイズを overestimate する
  - 実際には氷が昇華している円盤を、大きなサイズの円盤と間違える
- Ice fraction が 90% 程度の場合
  - ダストサイズ分布のベキを、factor 1.2 程度間違える
  - 円盤質量を factor 0.4 程度低く見積もる
  - 中心星がA0型星の場合、最小 grain size を factor 0.2 程度低く見積もるが、中心星が太陽型の場合、最小 grain size を factor 4-5 程度大きく見積もる。円盤の明るさの radial profile が無く、photometry の観測のみを使うと、間違いは factor 7-14 程度にまでなる

No. 25

The physics of the MHD disk-jet transition in binary systems: jetted spiral walls launched from disk spiral arms

Somayeh Sheikhnezami, Christian Fendt ★ We present a detailed physical analysis of the jet launching mechanism of a circum-stellar disk that is located in a binary system. Applying 3D resistive MHD simulations, we investigate the local and global properties of the system, such as the angular momentum transport and the accretion and ejection mass fluxes. In comparison to previous works, for the first time, we have considered the full magnetic torque, the presence of an outflow, thus the angular momentum transport by vertical motion, and the binary torque. We discuss its specific 3D structure, and how it is affected by tidal effects. We find that the spiral structure evolving in the disk is *launched into the outflow*. We propose to call this newly discovered structure a *jet spiral wall*. These spiral features follow the same time evolution, with the jet spiral somewhat lagging the disk spiral. We find that the vertical transport of angular momentum has a significant role in the total angular momentum budget also in a binary system. The same holds for the magnetic torque, however, the contribution from the ϕ-derivative of magnetic pressure and the $B_\phi B_r$ stresses are small. The gravity torque arising from the time-dependent 3D Roche potential becomes essential, as it constitutes the fundamental cause for all 3D effects appearing in our disk-jet system. Quantitatively, we find that the disk accretion rate in a binary system increases by 20% compared to a disk around a single star. The disk wind mass flux increases by even 50%.

- 連星周囲の円盤からの jet 放射についての、物理過程の詳細を、3次元非理想MHDシミュレーションを用いて調べる
  - 円盤に垂直な方向の角運動量輸送や、連星によるトルクも考慮
- 円盤の spiral 構造が、outflow 内に打ち出されることが分かった
  - この構造を、jet spiral wall と名付ける
  - Jet の spiral 構造が、円盤の spiral に少し遅れて現れている
- 円盤に垂直な方向の角運動量輸送は、連星系の全角運動量を決めるのに重要な役割を果たしている。また、連星の重力トルクが、様々な現象の原因になっている。
- 単独星の場合に比較して、連星の場合は、円盤の降着率が 20% 程度増加し、円盤風のフラックスが 50% 程度増加する

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NIR jets from a clustered region of massive star formation: Morphology and composition in the IRAS 18264-1152 region

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★ Massive stars form deeply embedded in their parental clouds, making it challenging to directly observe these stars and their immediate environments. It is known that accretion and ejection processes are intrinsically related, thus observing massive protostellar outflows can provide crucial information about the processes governing massive star formation close to the central engine. We aim to probe the IRAS 18264-1152 (G19.88-0.53) high-mass star-forming complex in the near infrared (NIR) through its molecular hydrogen (H2) jets to analyse the morphology and composition of the line emitting regions and to compare with other outflow tracers. We observed the H2 NIR jets via K-band (1.9-2.5um) observations obtained with the integral field units VLT/SINFONI and VLT/KMOS. SINFONI provides the highest NIR angular resolution achieved so far for the central region (0.2"). We compared the geometry of the NIR outflows with that of the associated molecular outflow probed by CO (2-1) emission mapped with SMA. We identify nine point sources. Four of these display a rising continuum in the K-band and are BrG emitters, revealing that they are young, potentially jet-driving sources. The spectro-imaging analysis focusses on the H2 jets, for which we derived visual extinction, temperature, column density, area, and mass. The intensity, velocity, and excitation maps based on H2 emission strongly support the existence of a protostellar cluster, with at least two (and up to four) different large-scale outflows. The literature is in agreement with the outflow morphology found here. We derived a stellar density of 4000 stars pc^{-3}. Our study reveals the presence of several outflows driven by young sources from a forming cluster of young, massive stars. The derived stellar number density together with the geometry of the outflows suggest that stars can form in a relatively ordered manner in this cluster.

- 大質量星形成領域 IRAS 18264-1152 における molecular hydrogen の、VLT を用いた近赤外線観測。これを、CO(2-1) の molecular jet と比較
  - 角度分解能 0.2 秒角程度。これまでで最も良い。
- 領域に 9個の点源を検出。4個は Brγ や連続波の状況から、若い jet 天体と推定
- H2 jet の観測から、extinction, 温度、柱密度、質量などを導出。この領域に、stellar cluster があることが強く示唆される。星の数密度で 4000個 / pc^3 程度。