Massive Star Formation at Various Metallicities: Feedback, Chemistry, and Dust

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the latest dinner in Colorado (Dec 2022)

the reunion in Visegrád (June 2025)

Massive stars are fundamental drivers of galactic evolution, exerting powerful feedback on their surroundings and shaping the ecology of their host galaxies. Over the past decade, high-resolution observations and state-of-the-art theoretical modeling have significantly advanced our understanding of their formation processes. Here, we present our theoretical and observational studies of massive star formation in Galactic and lower-metallicity environments.

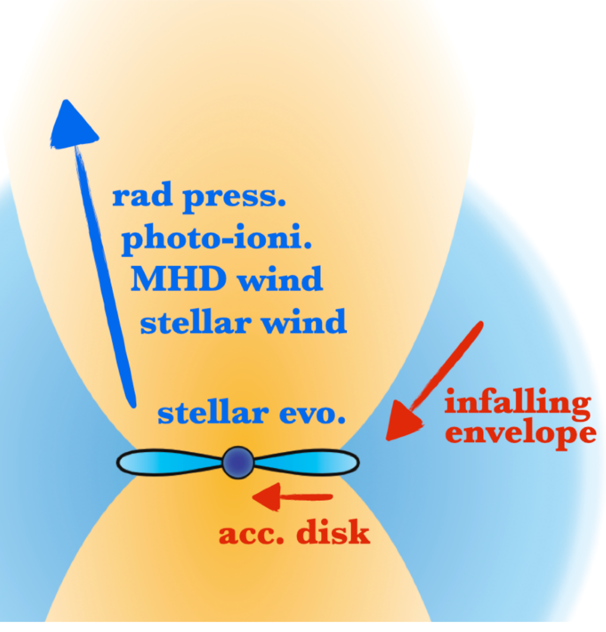
Come talk to me if you're interested in feedback physics, astrochemistry, or low-Z star formation!

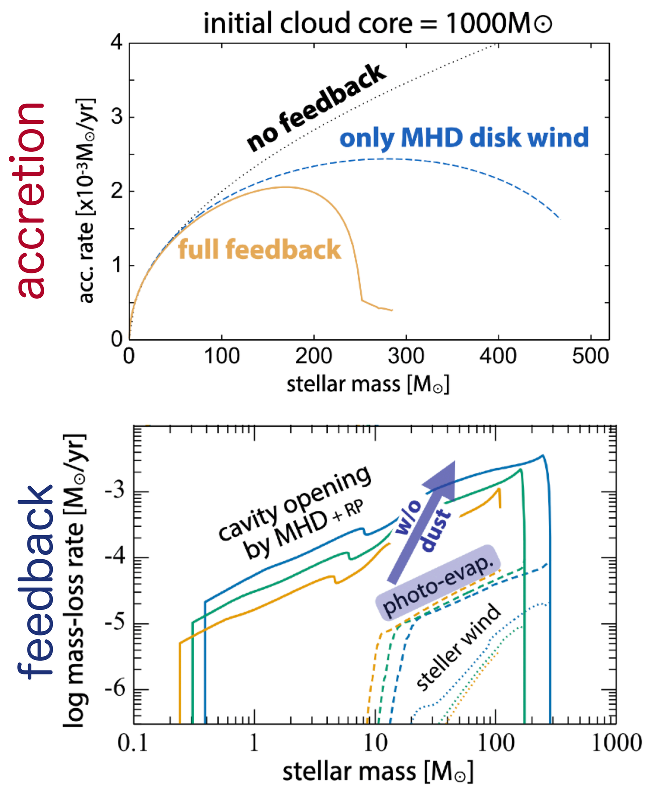
1. Feedback Problem in the Formation of Very Massive Stars

Massive protostars emit intense radiation (>10⁴ L⊙) at high temperatures (>10⁴K), which was long believed to halt their growth through radiative feedback, including radiation pressure and photoionization. Conventional wisdom suggests that once feedback becomes strong, accretion should stop at ~20–40M⊙ → **But is that really the case?**

Theory said "No Problem"

KT, Tan+17





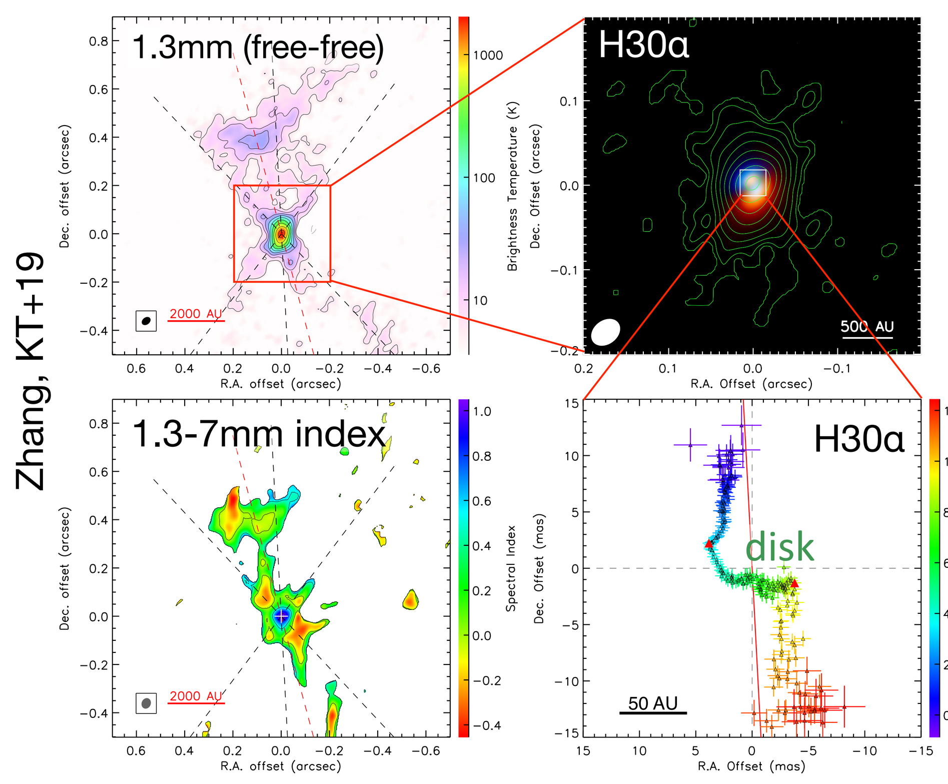
Our simulations demonstrate that **stars exceeding 100 M⊙ can form via disk accretion**, even in the presence of strong radiative feedback.

EUV absorption by dust grains plays a crucial role in regulating the photoevaporation rate.

see also rad/MHD simulations by Kuiper+18, Rosen+22, Commerçon+23

ALMA results supported theory

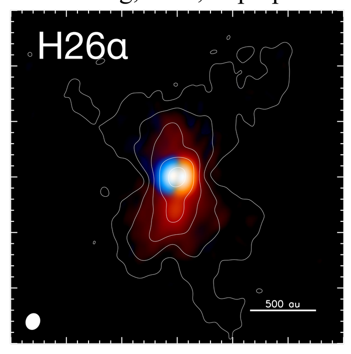
G45.47+0.05: ~(2-5)x1e5L⊙ at 8.4kpc

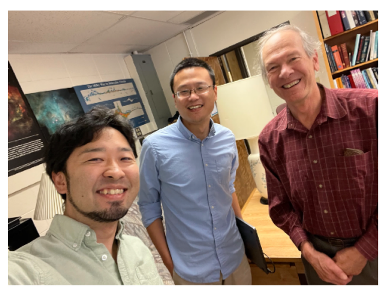


Our high-resolution ALMA and VLA observations revealed **a rotating ionized-disk around a ~50 M⊙ protostar, demonstrating that disk accretion can persist even under strong UV feedback**.

We are conducting a survey, **HiPPOS**, to provide robust statistical constraints on massive star formation

Zhang, KT+, in prep.





Yichen visiting Colorado (Oct 2022)

2. Dust and Gas in Hot Disks around Massive Protostars

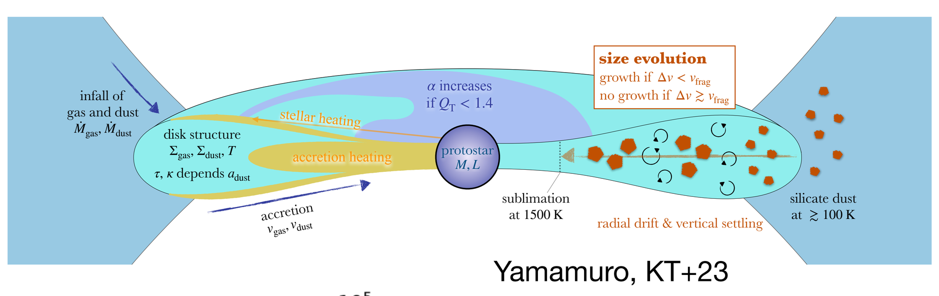
Accretion disks around massive protostars are hot, often exceeding several hundred kelvin (cf. <100 K for protoplanetary disks of low-mass stars observed by ALMA). These extreme conditions provide a unique opportunity to study **ice-free silicate dust** and **gaseous refractory molecules**.

The Evolution of Silicate Grains

Interested? Head over to R. Yamamuro's poster →

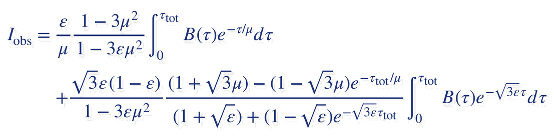
Constraining silicate grain growth processes is key to understanding rocky planet formation

hot disk model with silicate grain evolution

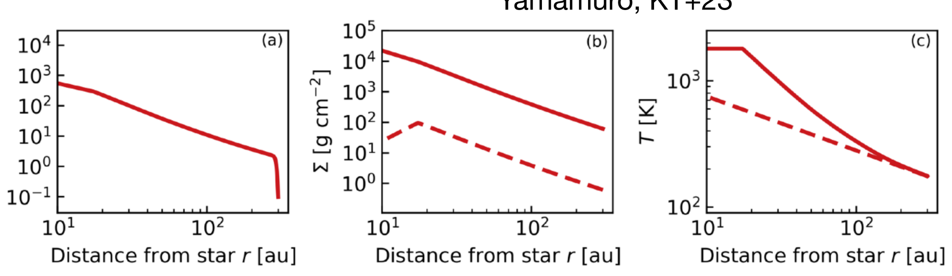


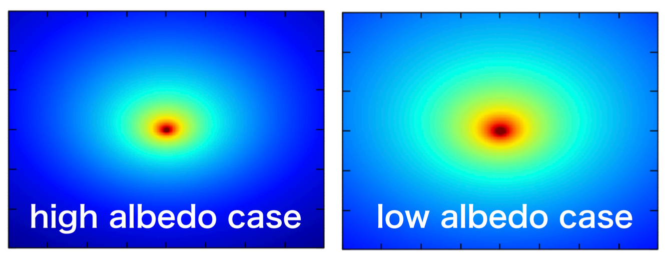
Yamamuro, KT+23

new analytic solution of disk continuum emission



Yamamuro+25 (under rev); KT+, in prep.

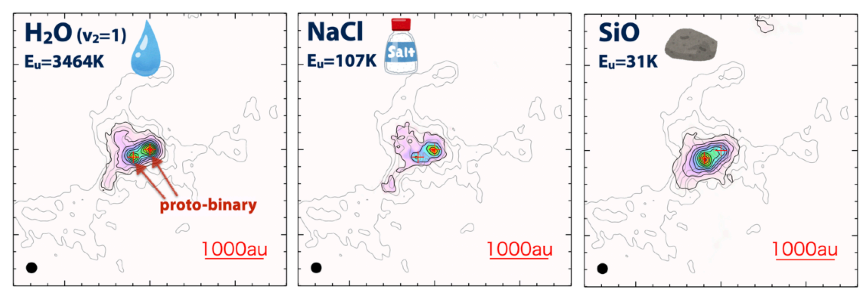




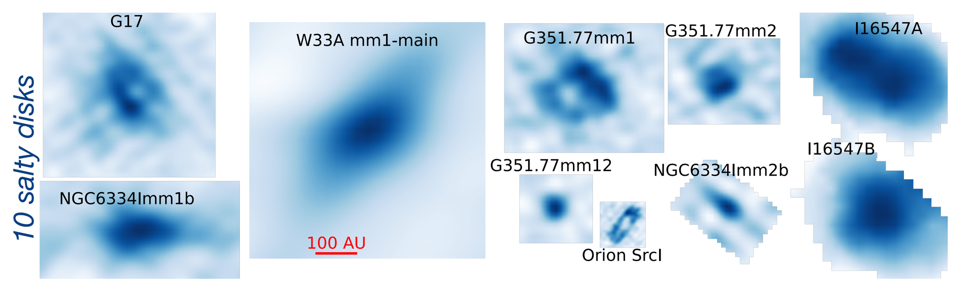
Grain size growth significantly alters opacities, affecting disk thermal structure and disk appearance in observations

Gaseous Refractories in Salty Disks

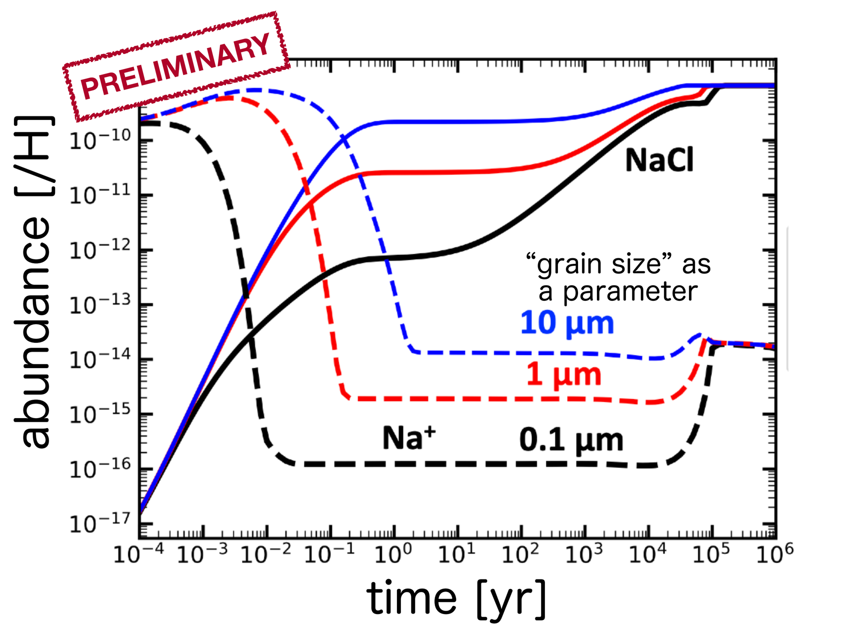
A new avenue of astrochemistry — bridging the gap from hot cores to meteoritics



KT+20; Ginsburg+23 (see also Ginsburg+18, 19; Tachibana+19)



Unique molecular lines trace hot disks at ~100 au, i.e., highly excited transitions and refractory species



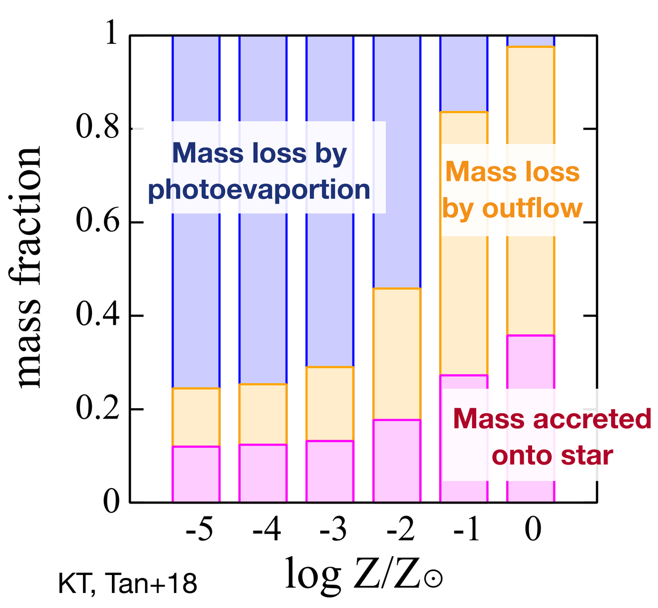
We started the first hot-disk chemical modeling based on the updated UMIST database

3. Low Metallicity to Explore Universality and Diversity

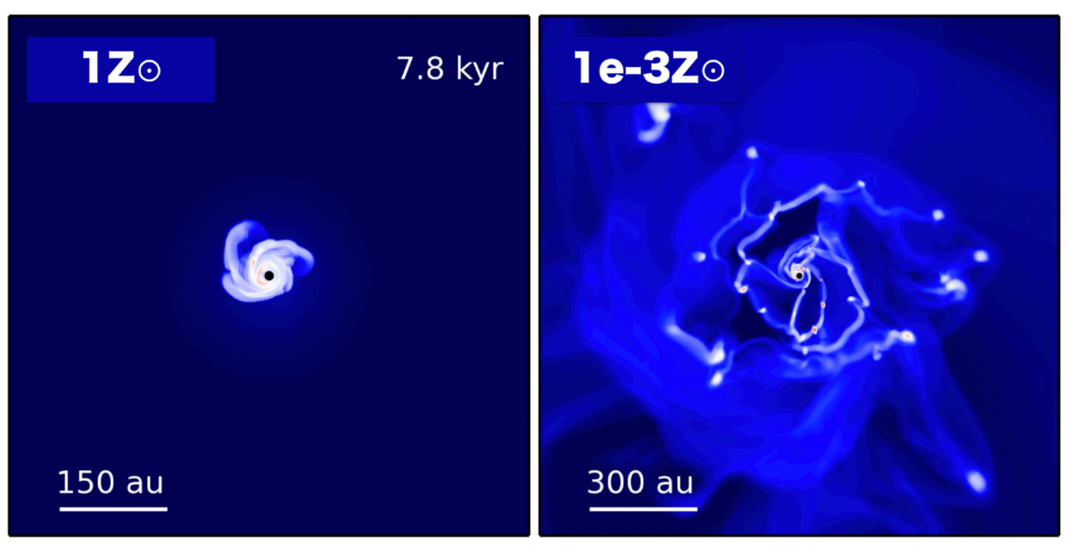
Massive stars are key players in the evolution of ISM in galaxies across cosmic time. Studying their formation in low-metallicity environments helps us determine **whether the dynamical and chemical processes involved are universal or shaped by environment**

Models for Extremely Low-Z Cases

Theoretical studies suggest that the dynamics of massive star formation may significantly change as metallicity decreases by orders of magnitude



KT, Tan+18

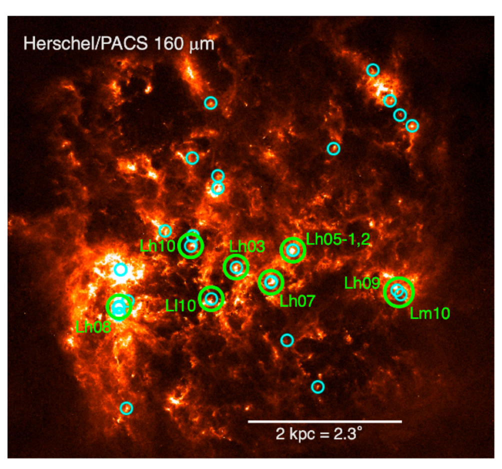


Matsukoba, KT+18; KT & Omukai+14

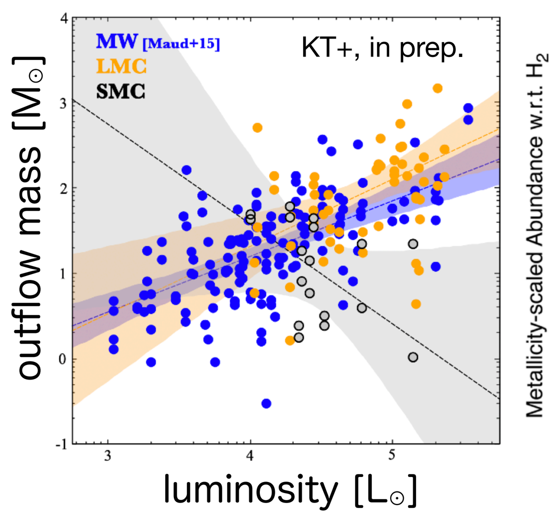
Photoionization becomes stronger, and disks more fragile, **at ≪0.01Z⊙**

Protostars in the Magellanic Clouds

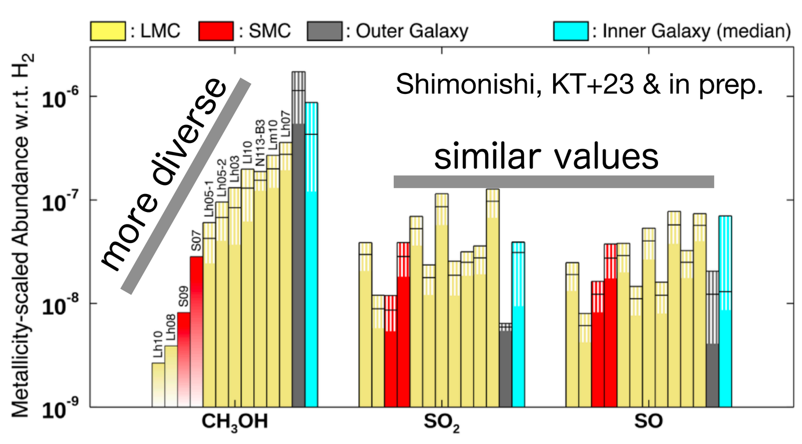
Our ALMA survey, MAGOS, is unveiling the sub-pc scale structures of massive protostars in the nearby low-metallicity galaxies, LMC & SMC



30 in LMC, 10 in SMC (limited to >10⁴ L⊙)



Outflows in the SMC might be weaker



The diversity in methanol abundance may reflect variations in the cold prestellar phase