



Go with the Flow: Probing the Dynamics During Protostellar Disk Formation

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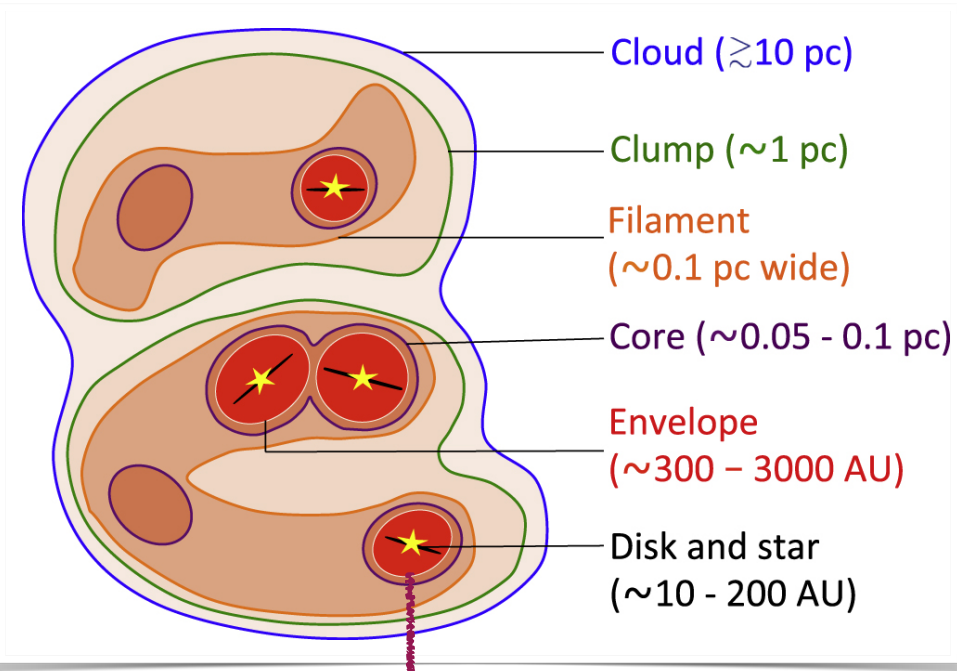
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asmitabhandare.github.io ✨

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Perspectives of Planet and Star Formation, 22/06/2026

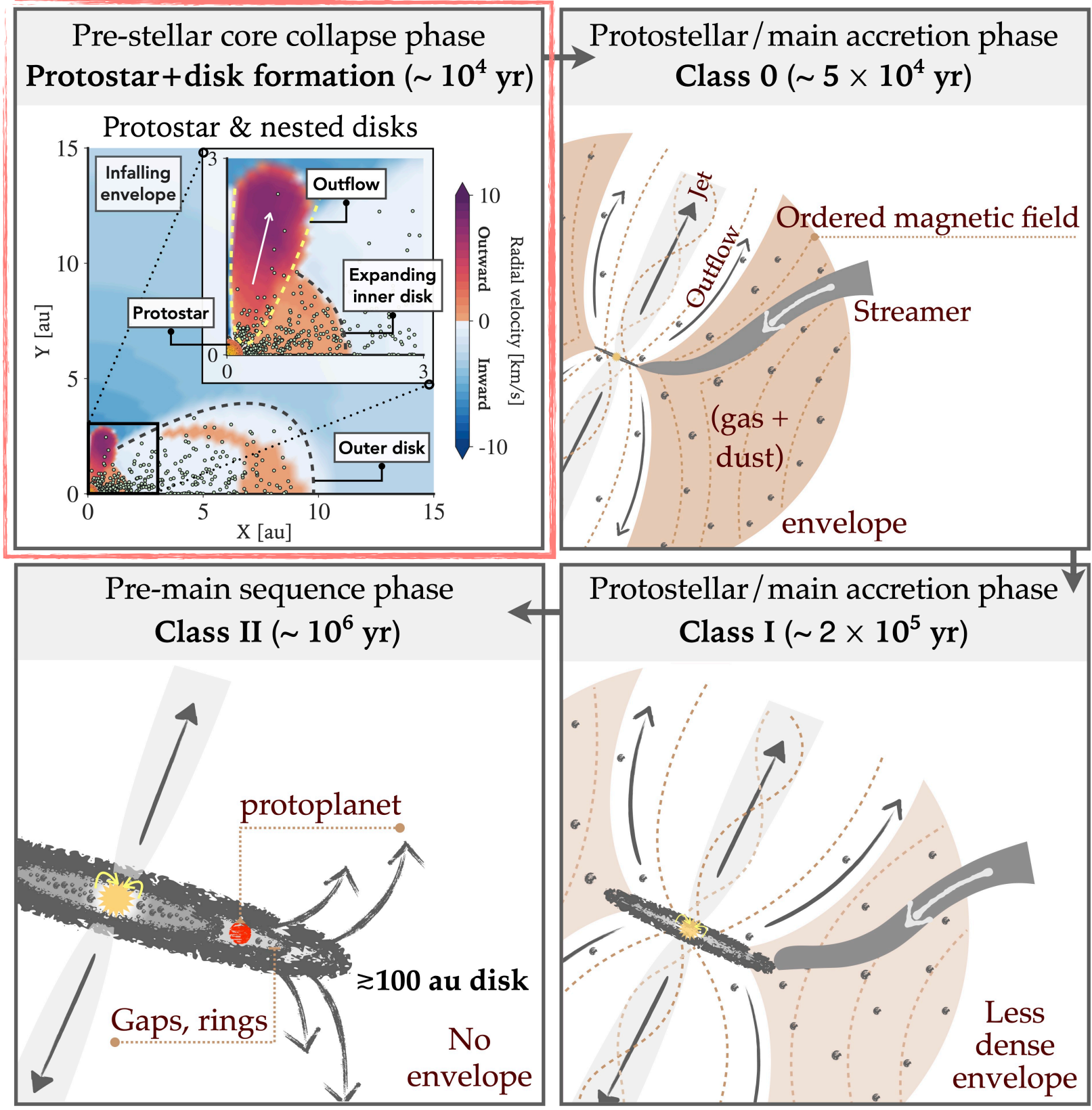
EARLY STAGES OF STAR & DISK FORMATION



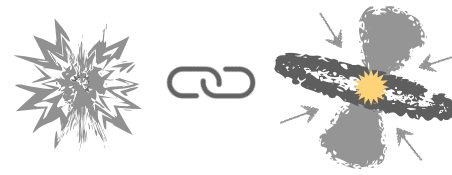
Pokhrel+ 2018



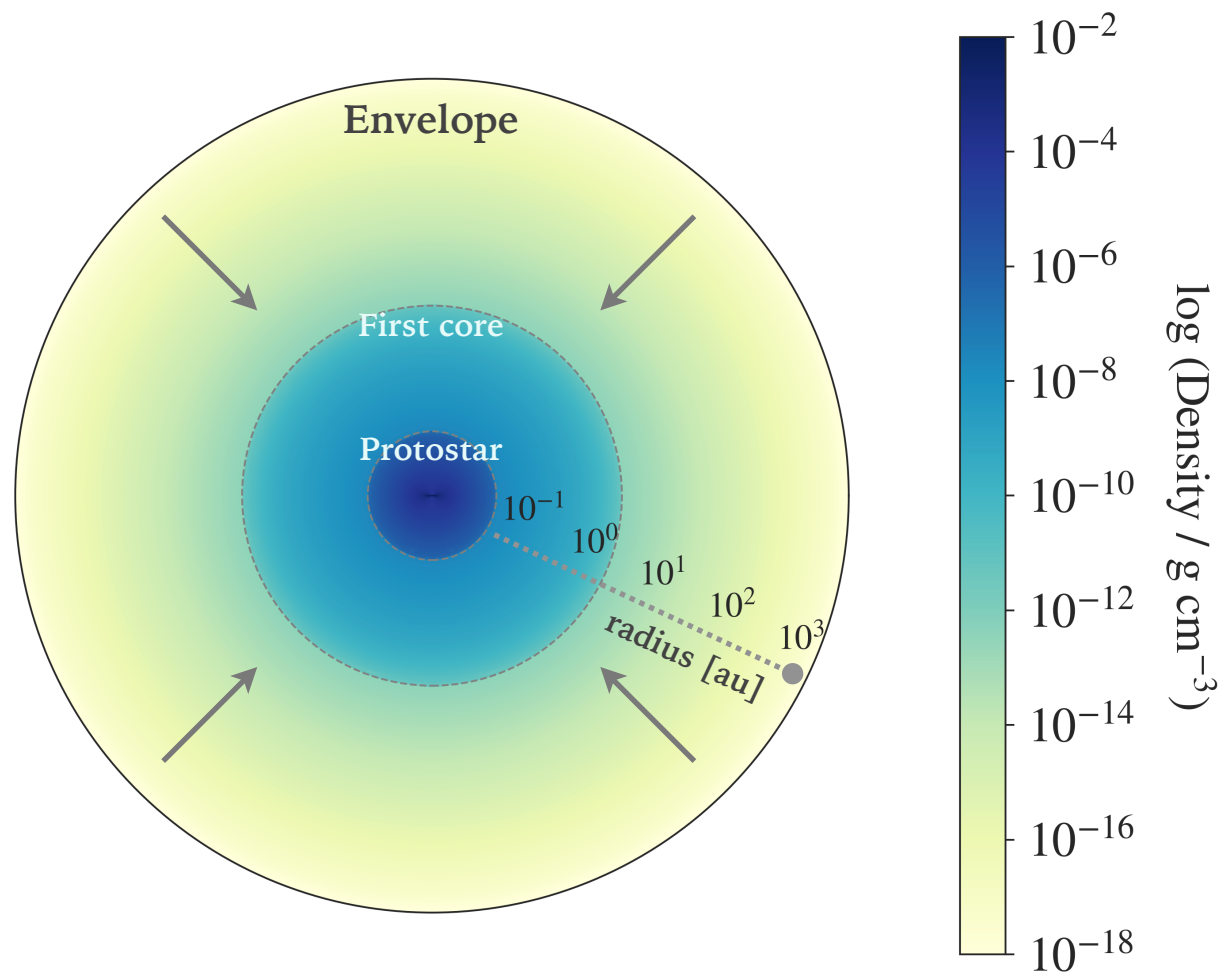
NASA, ESA, CSA, STScI (2022)



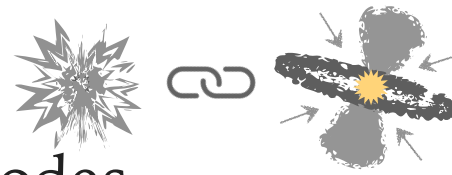
PROTOSTAR & DISK FORMATION



e.g. 1 M_⊙ core collapse

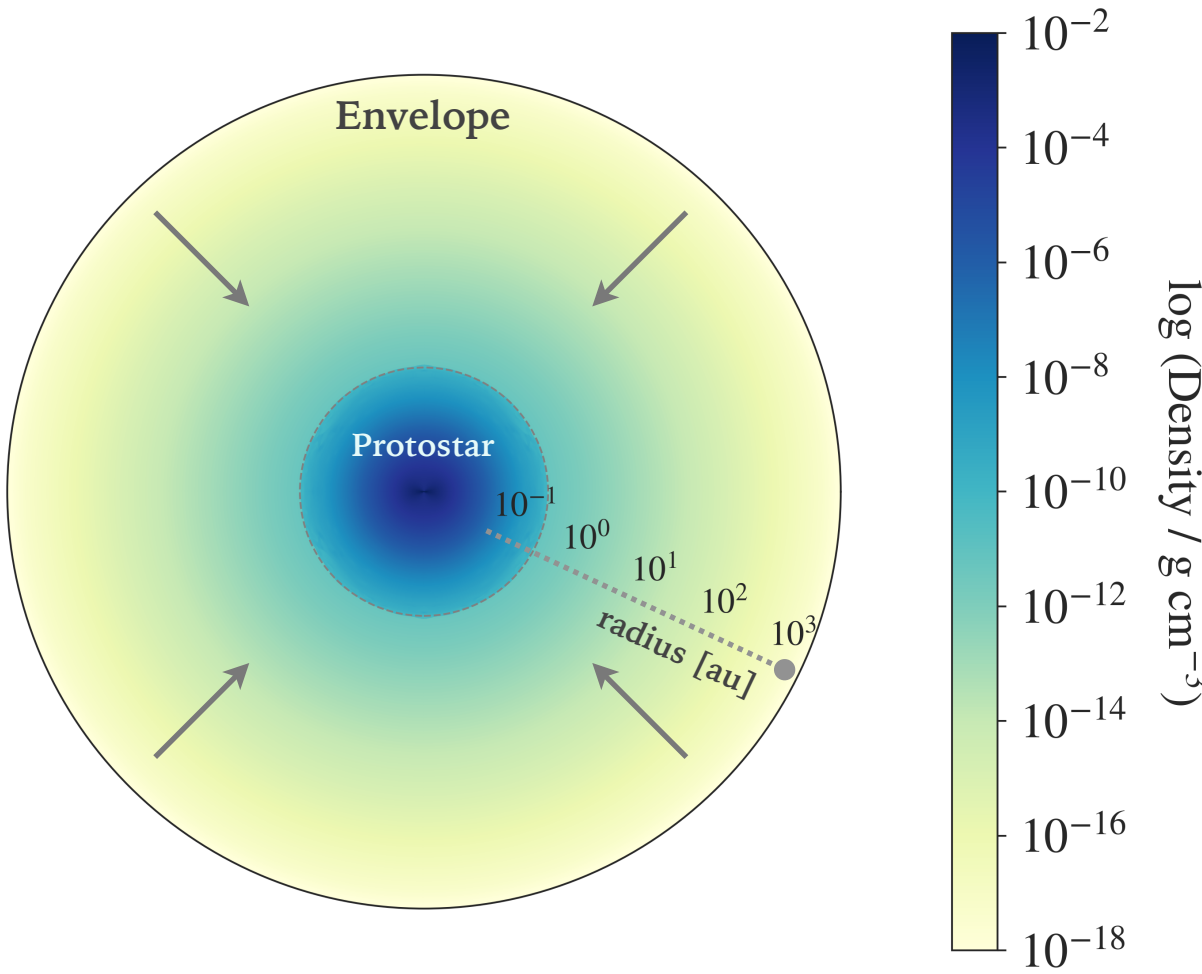


PROTOSTAR & DISK FORMATION

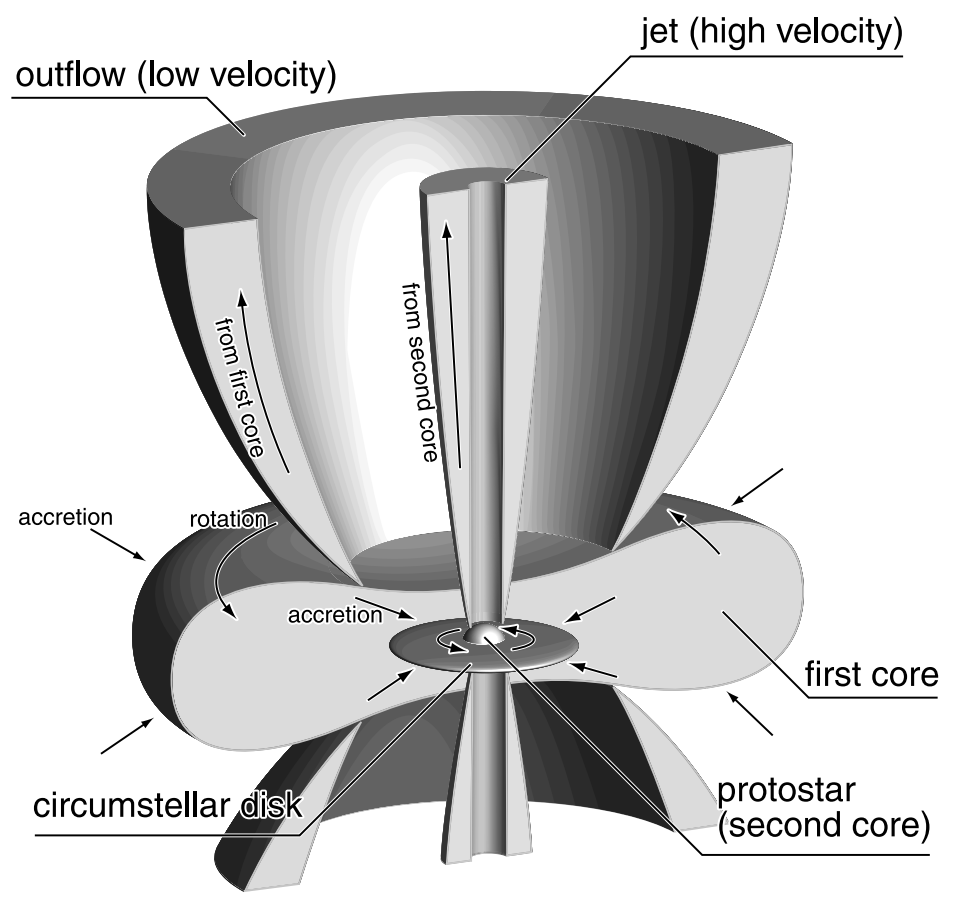


with grid-based (fixed, nested, & AMR), SPH, and Lagrangian moving-mesh codes

e.g. 1 M_⊙ core collapse → 0.04 M_⊙ protostar



Onset of disk formation?



Machida+ 2008



IMPORTANCE OF DUST DYNAMICS



Dust grains provide the building blocks for planet formation!

Gas and dust are strongly coupled: Interstellar medium dust-to-gas mass ratio of 1% with a power-law dust size distribution (MRN) up to $0.25\ \mu\text{m}$ (Mathis+ 1977)

 $\sim 1\ \mu\text{m}$ in pre-stellar cores via mid-infrared light scattered from dense core regions (Steinacker+ 2010; Yang+ 2022; McClure+ 2023) + envelope of young stellar objects (Kwon+ 2009; Miotello+ 2014; Galametz+ 2019)*

$\sim 100\ \mu\text{m}$ in young disks via dust polarization and continuum (Kataoka+ 2015; Valdivia+ 2019; Cacciapuoti+ 2023a, b)*

Dust dynamics is affected by the gas via the drag force



$$F_{\text{drag}} = - \frac{m_{\text{grain}}}{t_s} \Delta v$$

Effects on the thermal budget, evolution of magnetic fields during collapse, and kinematic structure of the disk

*Caution: Observations are uncertain and could change with dust properties

TREATING GAS & DUST DYNAMICS



Interactions between gas & neutral dust
in the Epstein regime
(mean free path of gas $\gg s_{\text{grain}}$)



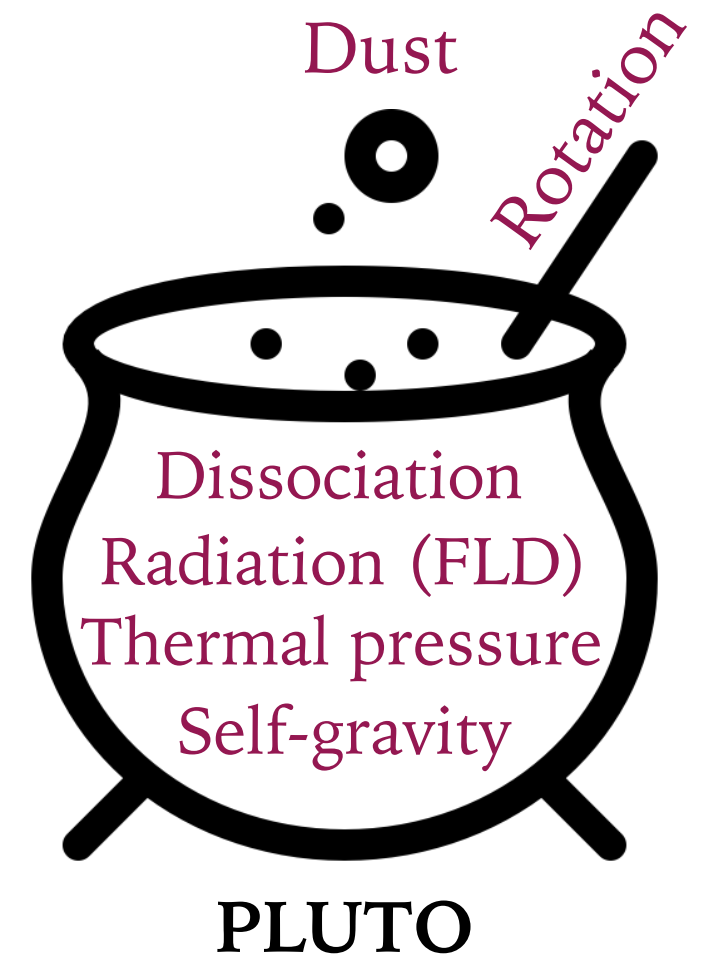
Pressureless fluid (Lebreuilly+ 2020)
or
Lagrangian particles (Koga+ 2022)

see Wurster+ 2016; Zhao+ 2016, 2018, 2020; Dzyurkevich+ 2017; Bate & Lorén-Aguilar 2017; Vorobyov+ 2019, 2021, 2023, 2024, 2025; Lebreuilly+ 2019, 2023; Guillet+ 2020; Silsbee+ 2020; Cridland+ 2022; Tsukamoto+ 2021a,b, 2022; Bate+ 2020; Koga & Machida 2023; Marchand+ 2016, 2019, 2022, 2023; Kawasaki+ 2022, 2023; Vallucci-Goy+ 2024; Verrier+ 2025; Lombart+ 2026....

Hybrid scheme: Fluid gas + Lagrangian dust
(Mignone+ 2007, 2019; Kuiper+ 2010, 2020)

Fixed dust size: 1 μm , 10 μm , and 100 μm

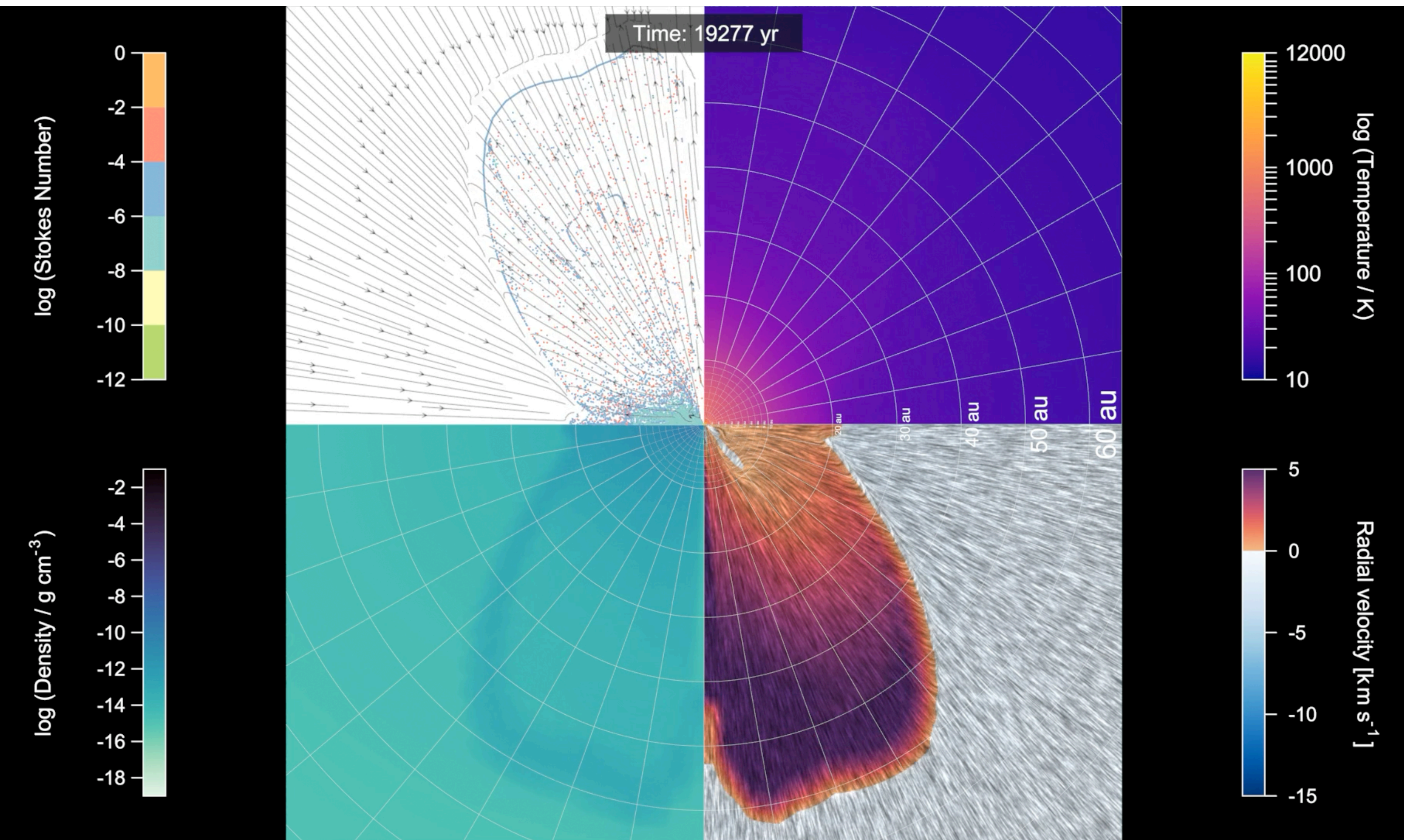
2D RHD collapse simulations with different
initial molecular cloud core properties
(focus on $< 1 \text{ au}$ — protostellar vicinity)



DUSTY COLLAPSE: A 2D VIEW

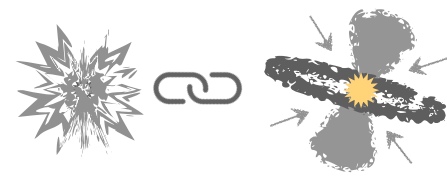
Database: asmitabhndare.github.io/#tara

1 $M_{\odot}$ case: First disk - Second pseudo disk - Outflow - Disks merge

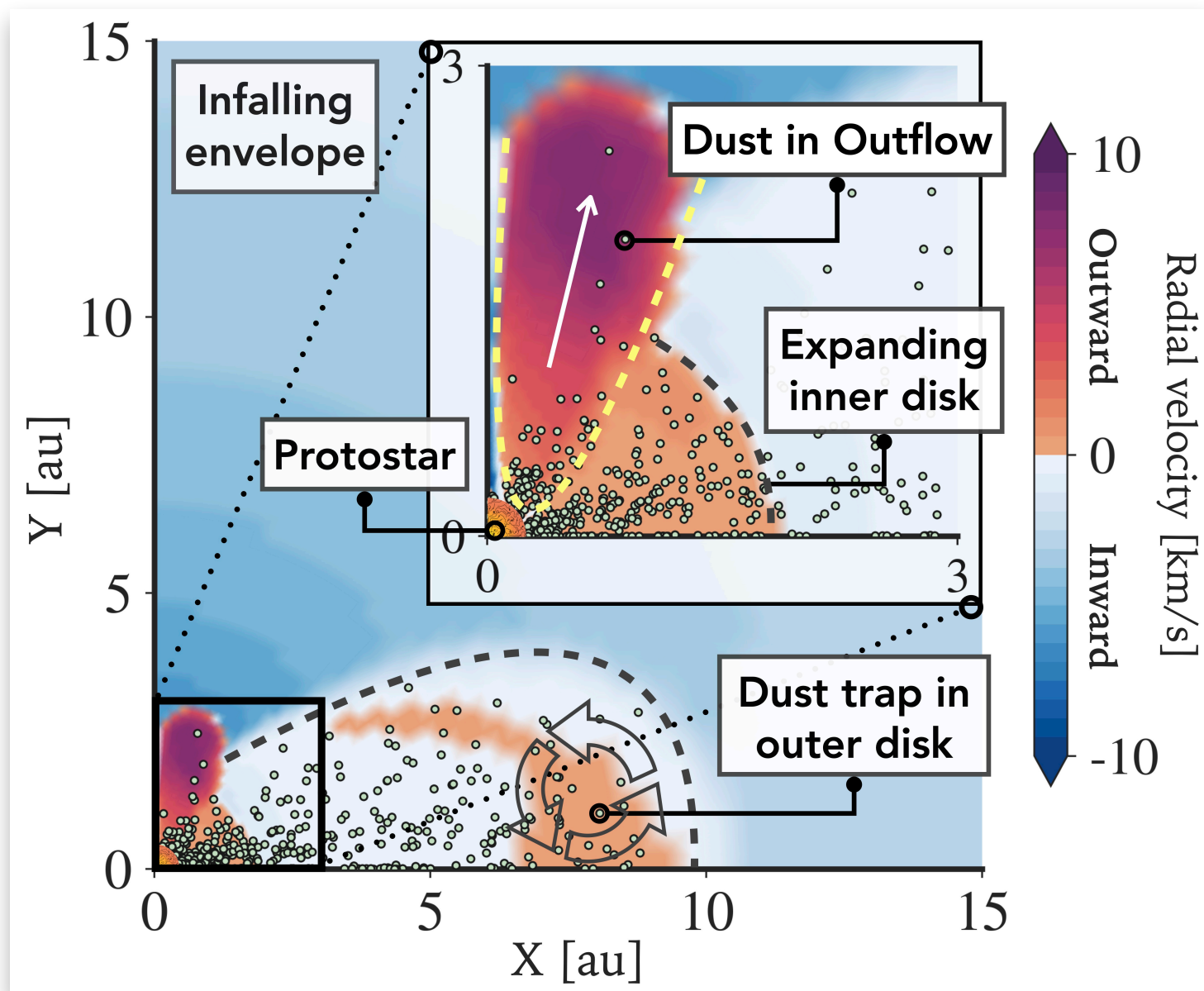


Movie credit: Thomas Müller (HdA, MPIA), Bhandare+ 2024

GAS & DUST DYNAMICS AT BIRTH



Transient dust traps at formation stages:
Mixing & transport occurs in meridional flows & outflow



Bhandare+ 2024

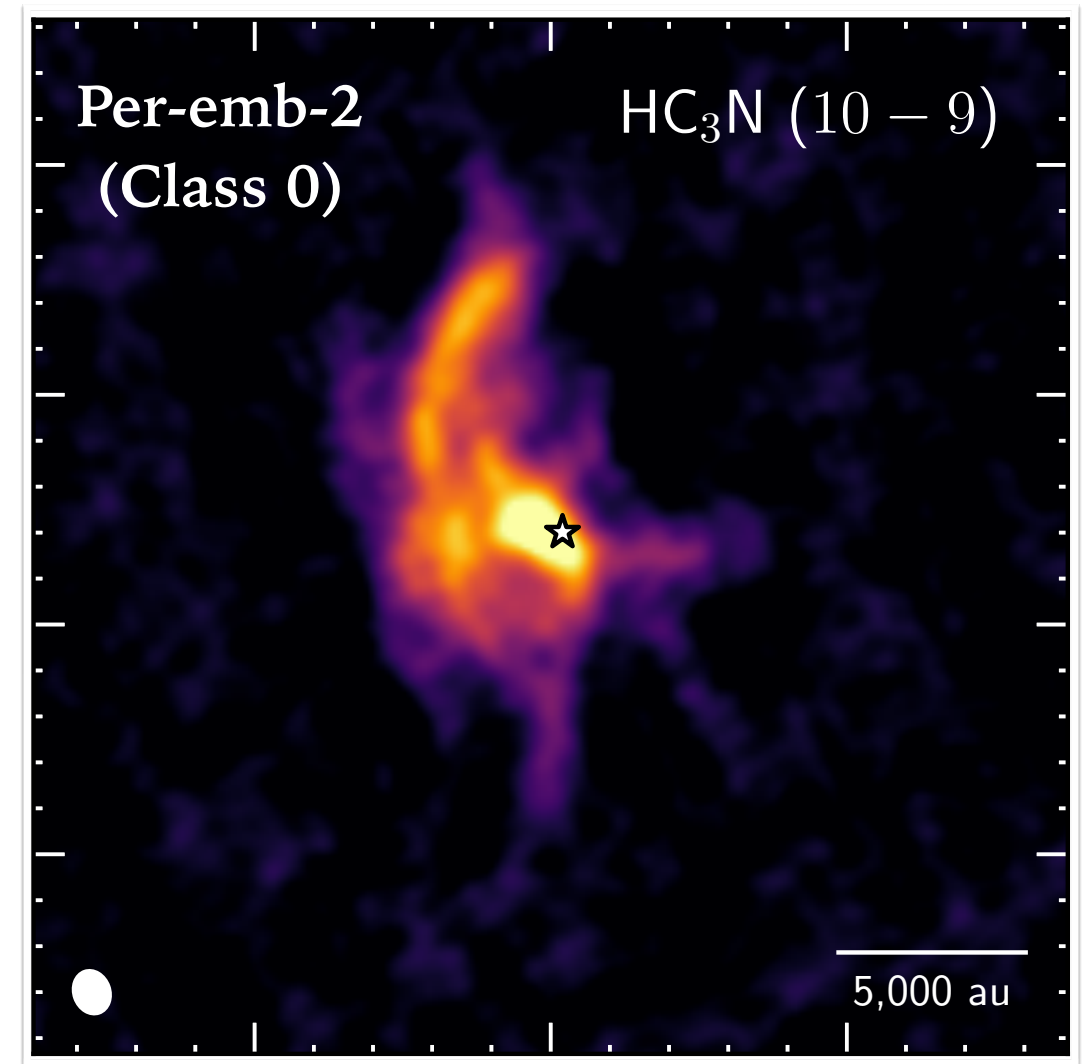
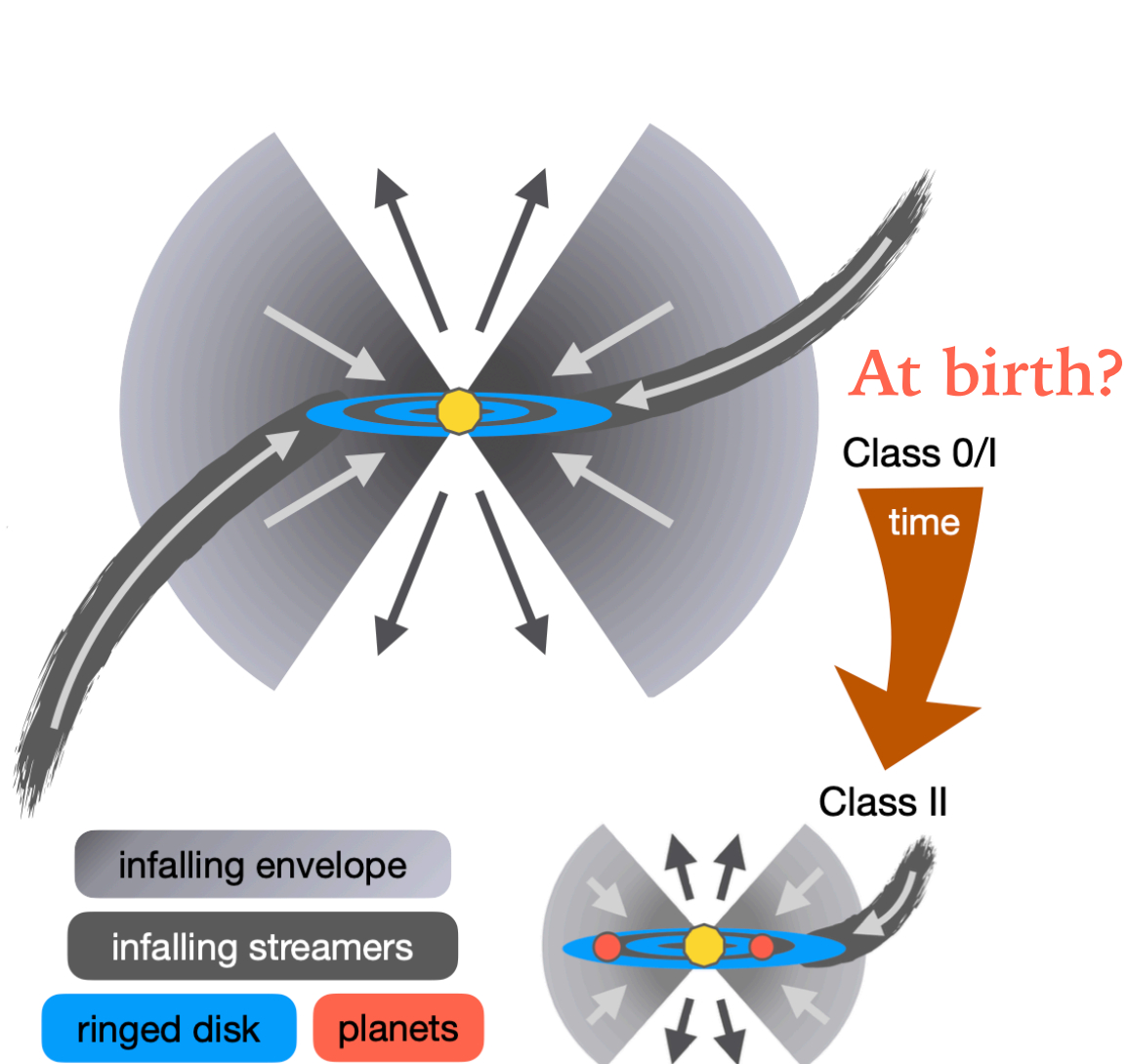
EFFECTS OF ANISOTROPIC INFALL



Anisotropic infall ('streamers') can induce spiral arms, rings, Rossby wave instabilities, disk fragmentation aided by gravitational instabilities, episodic accretion bursts, rejuvenation of disks, misalignment of the star-disk system....

Simulations: Seifried+ 2015; Lesur+ 2015; Bae+ 2015; Hennebelle+ 2017;
Kuznetsova+ 2022; Kuffmeier+ 2018, 2021, 2024; Calcino+ 2025

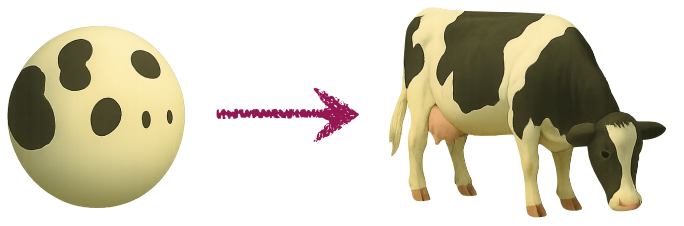
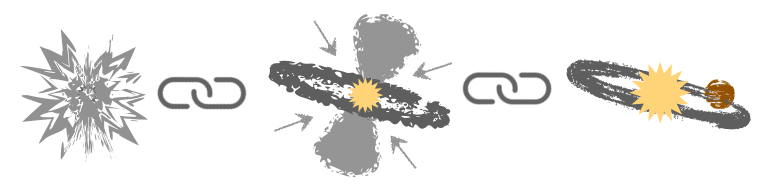
Observational Surveys: PRODIGE, ProPStar, eDisk, JOYS, ANTIHEROES



Segura-Cox et al. in prep, also featured in Pineda et al. (2023)

Pineda+ 2020

PROTOSTAR - DISK - PROTOPLANET FORMATION

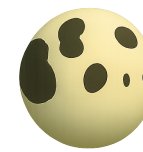


1D/2D/3D

*non-exhaustive list

ONGOING/NEXT STEPS

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Is star-disk-planet formation (and evolution) really sequential?

Realistic initial conditions and values (angular momentum, magnetic field strength, ionization...) from observations

Influence of the environment during different stages to transport and redistribute mass and angular momentum

(Focus: connecting spatial scales, streamers, stellar encounters)

Longer time evolution with accurate sink properties/sub-grid physics
(Focus: broader mass range, outflows/jets/winds, binaries/multiples)

Dust dynamics and evolution during collapse
(Focus: dust coagulation/fragmentation)

Self-consistent simulations including chemical networks

Synthetic observations to compare with real data