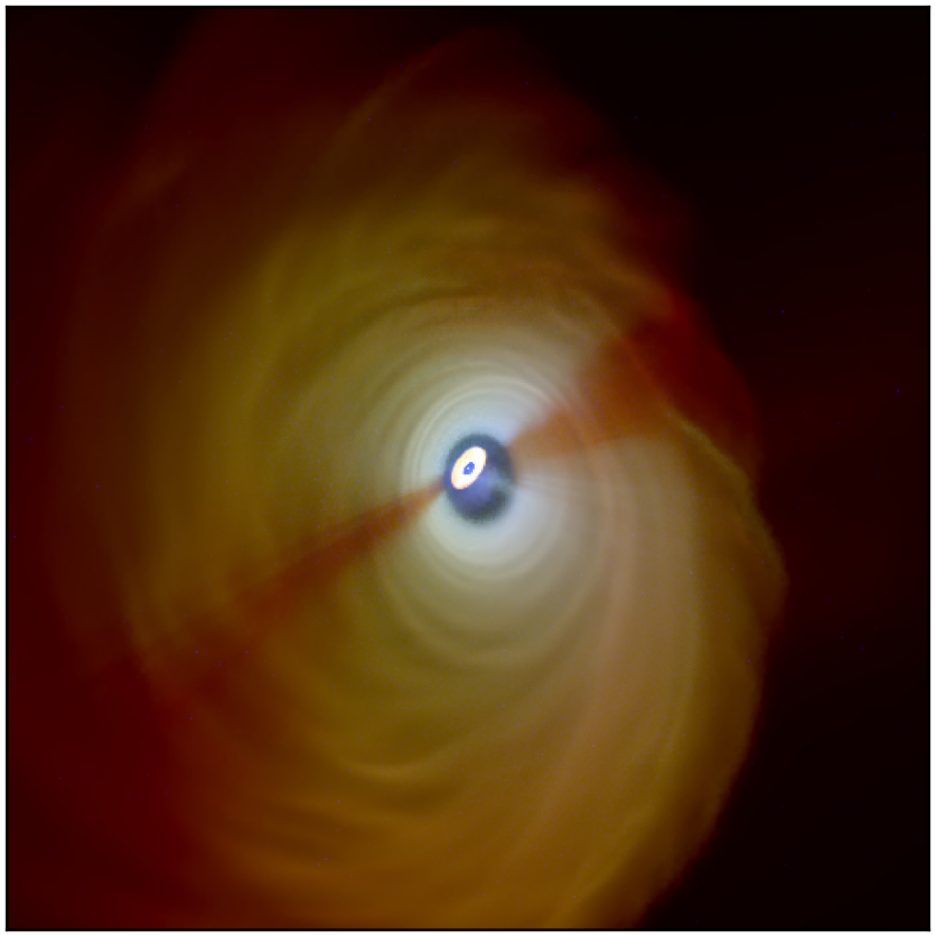
Shadows in disks caused by infall



Michael Küffmeier

Kees Dullemond, Felipe Goicovic,

Stefan Reißl

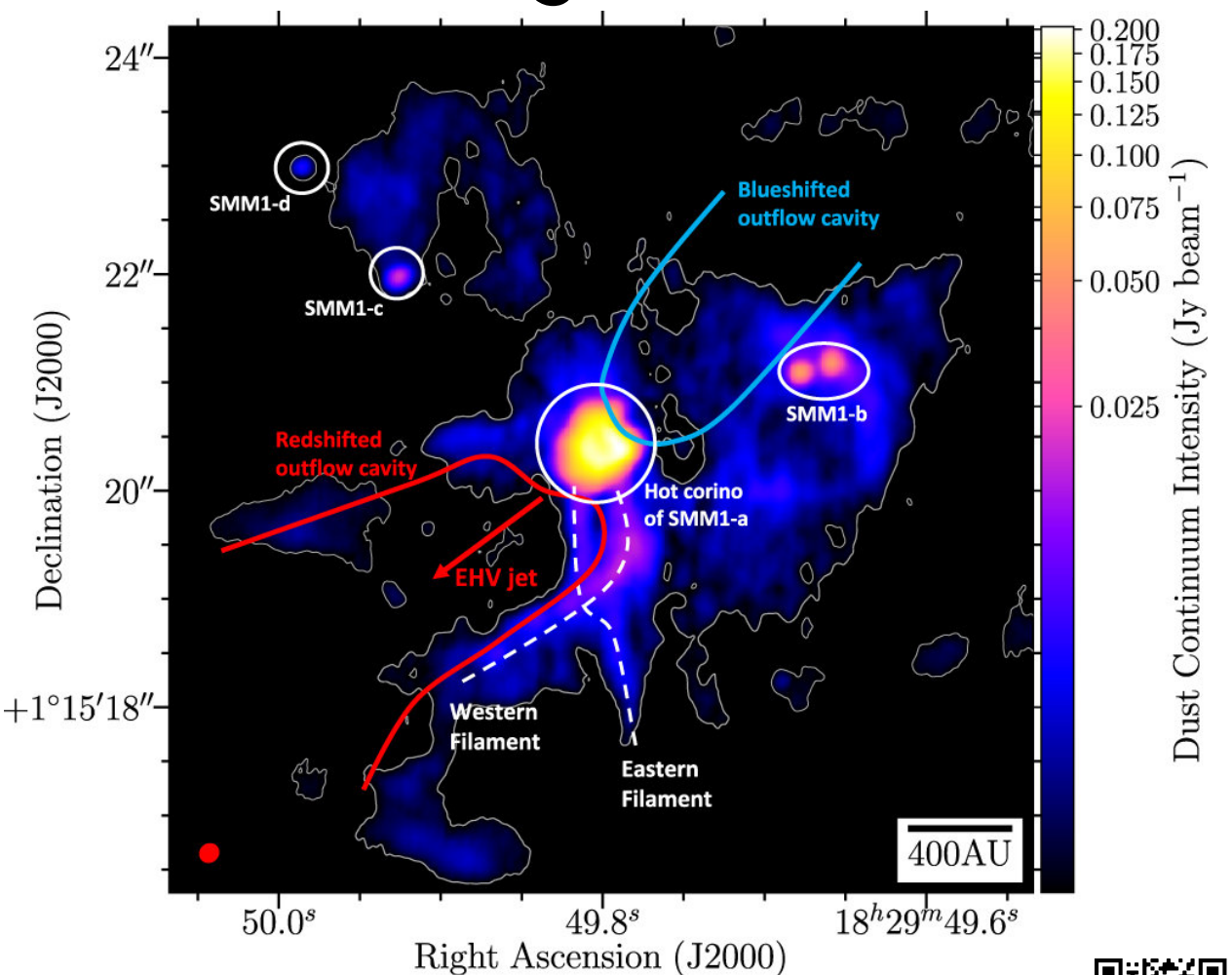
MSCA INDIVIDUAL FELLOWSHIPS 2020

DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

Stars are born and embedded in large assemblies of gas

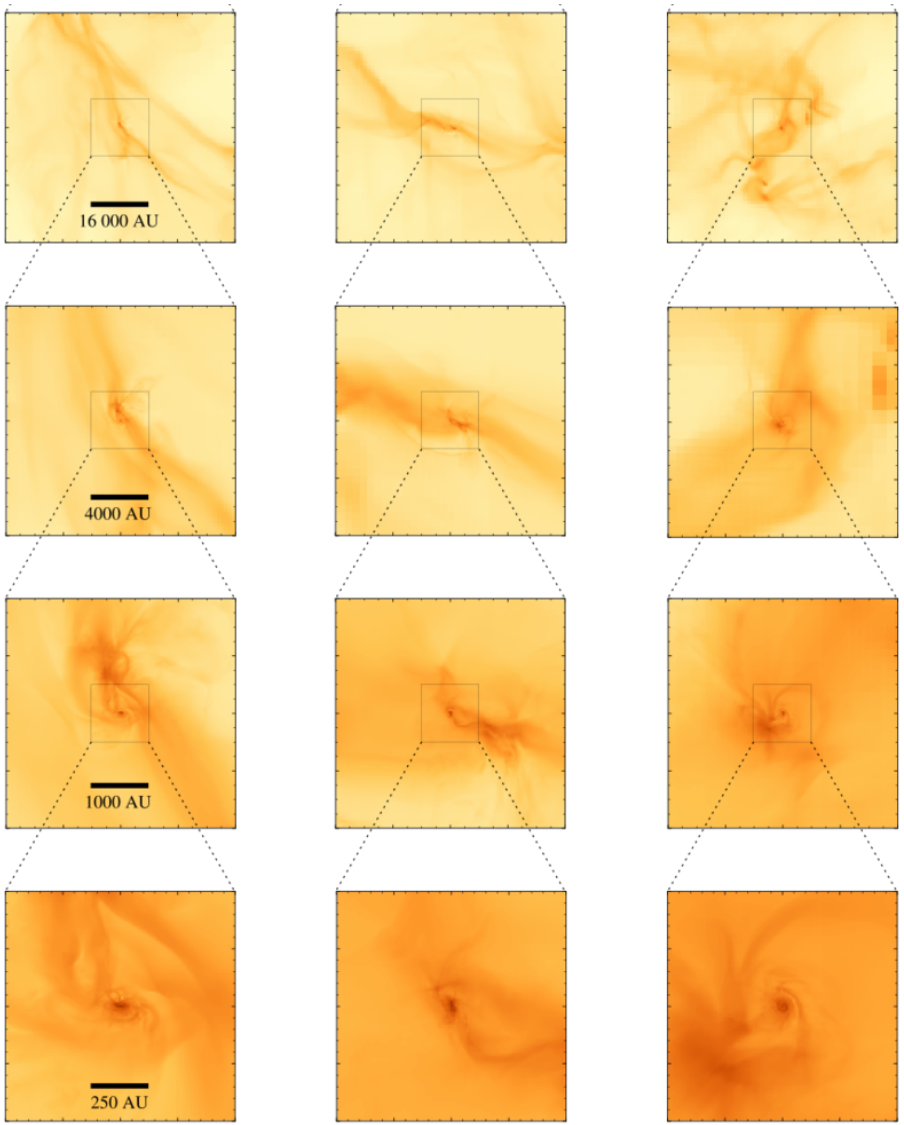
Star-disk systems form and are located in different environments provided by Giant Molecular Clouds (Size: 10 - 100 pc)

recall M. Reiter's review on Tuesday

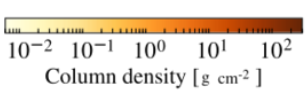


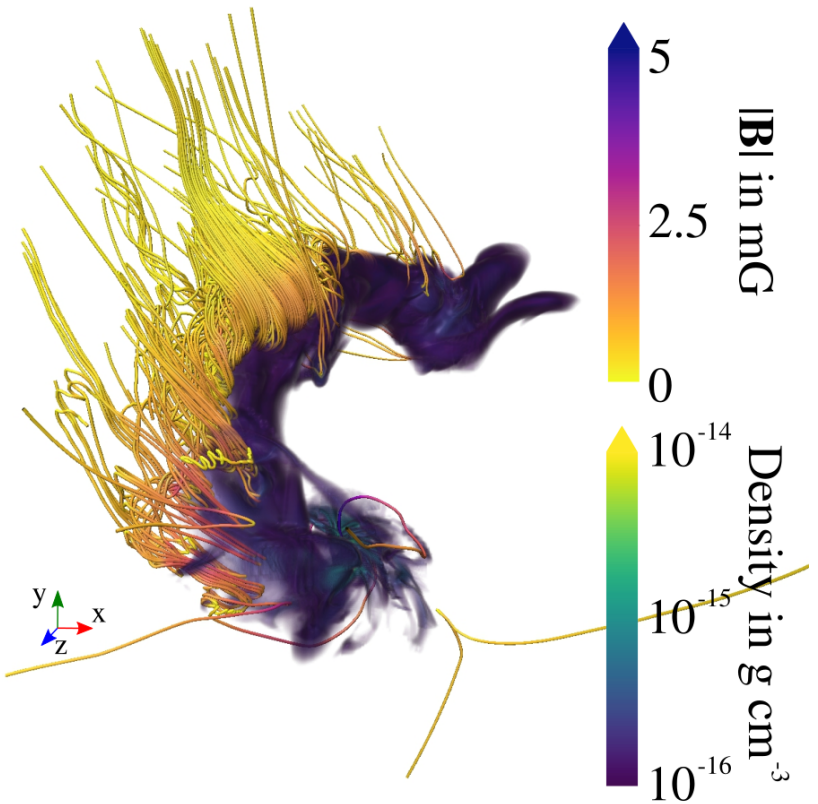
Serpens SMM1 *(Le Gouellec et al. 2019)*

Zoom-in on embedded protostellar multiple



Küffmeier et al. 2018/2019

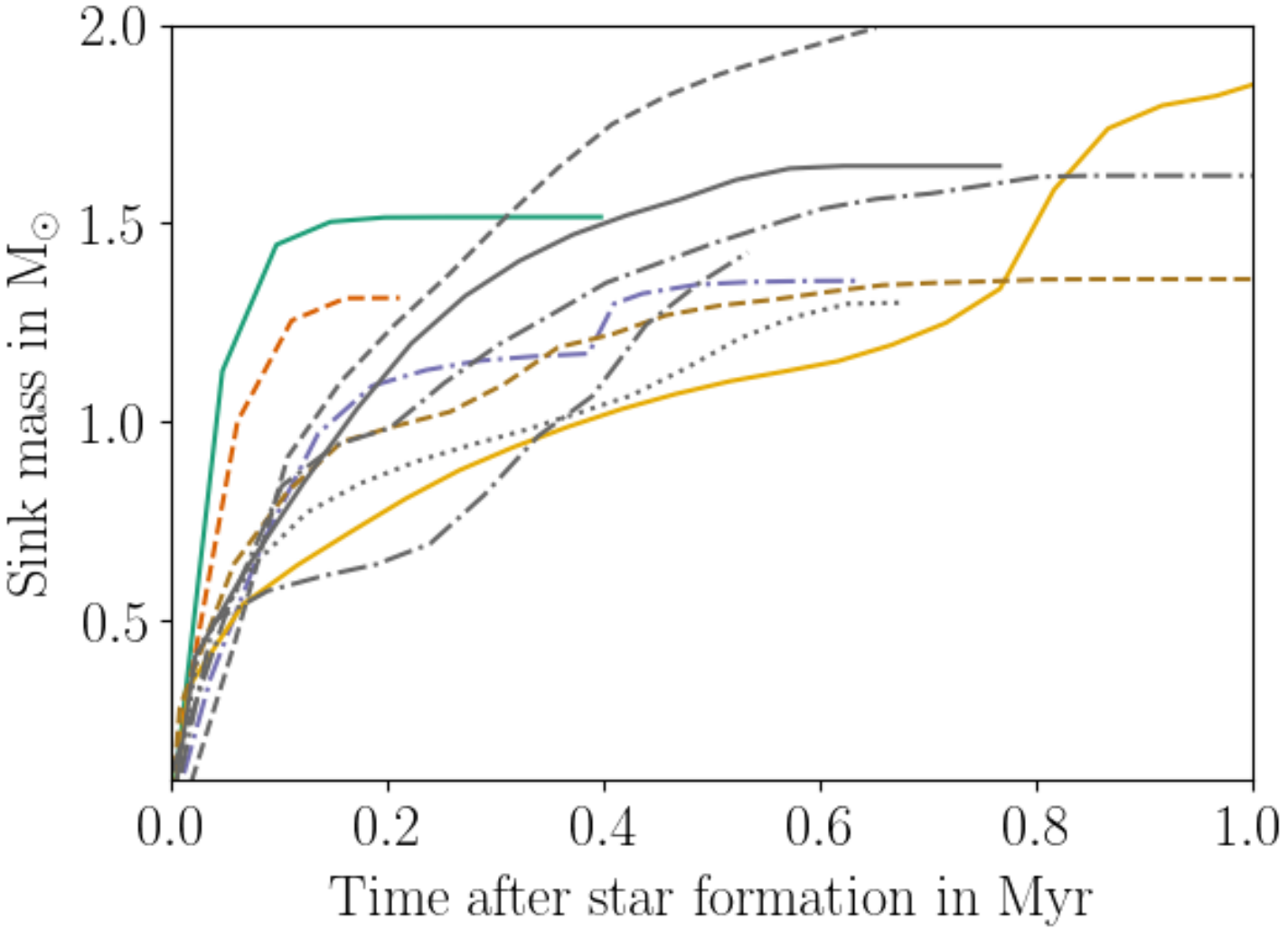




Küffmeier, Reißl, Wolf et al. 2020

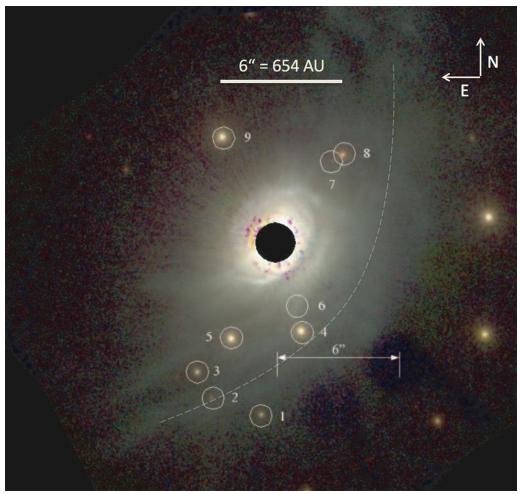
bridge structure similar to IRAS 16293--2422 *(e.g. Sadavoy+ 2018, van der Wiel+ 2019, Maureira+ 2020)*

Similar final mass, but diverse accretion histories



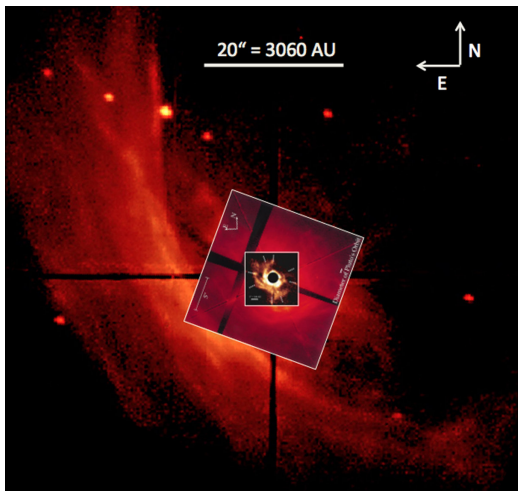
Küffmeier et al. 2017

Late infall



HD 100546

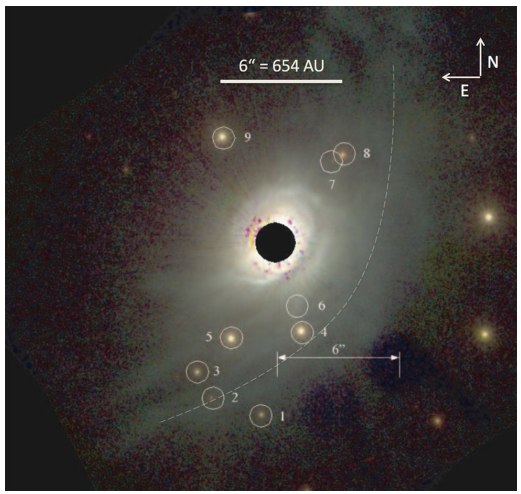
Credit: Ardila+ 2007



AB Aurigae

Credit: Grady+ 1999, Fukagawa+ 2004

Late infall



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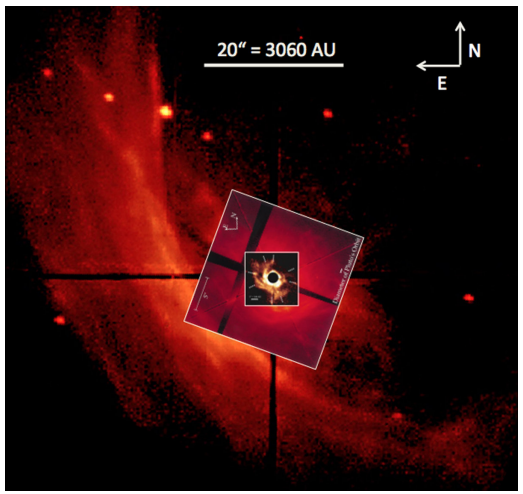

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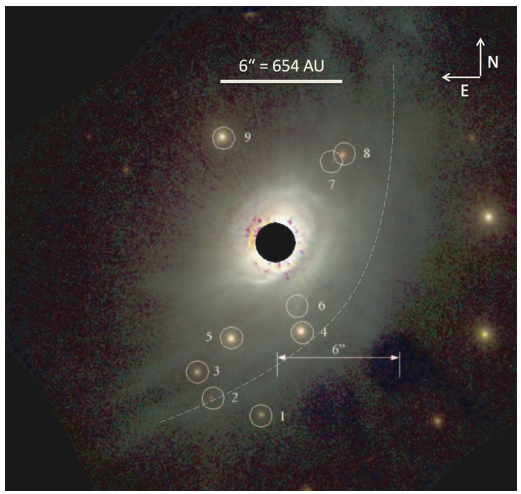
Extended arc-like structures can be induced by late infall

Possibility of "second-generation" disk

(Dullemond, Küffmeier, Goicovic+ 2019, Küffmeier, Goicovic & Dullemond 2020)

Late infall



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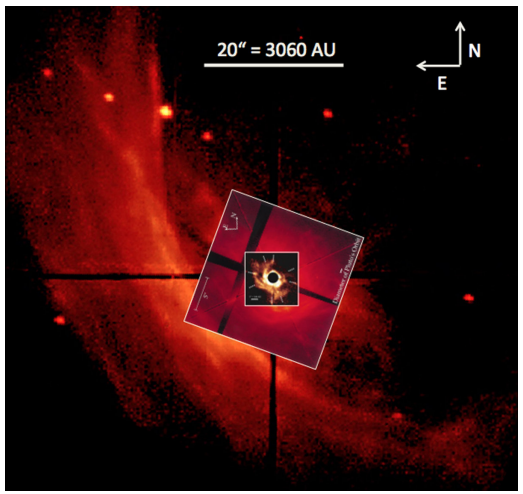

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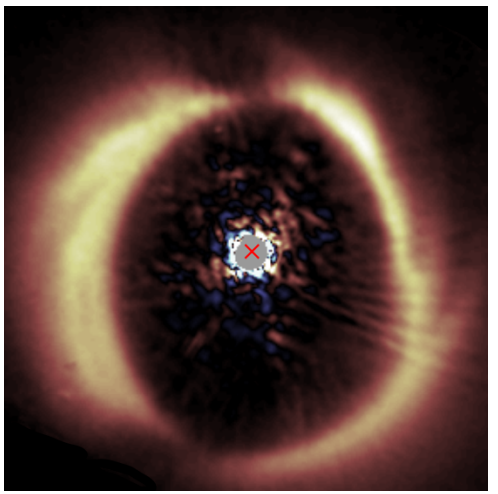

200 au

HD 142527

Credit: Avenhaus+ 2014

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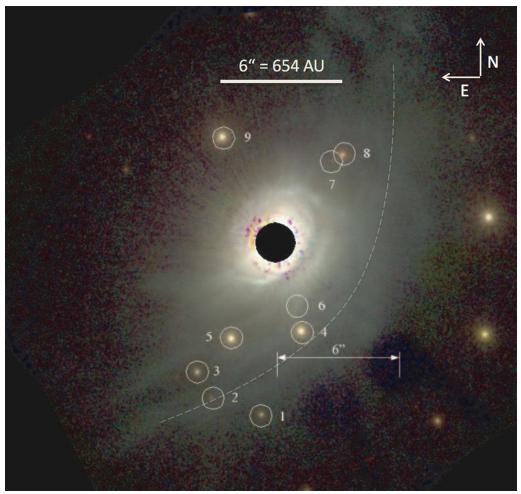

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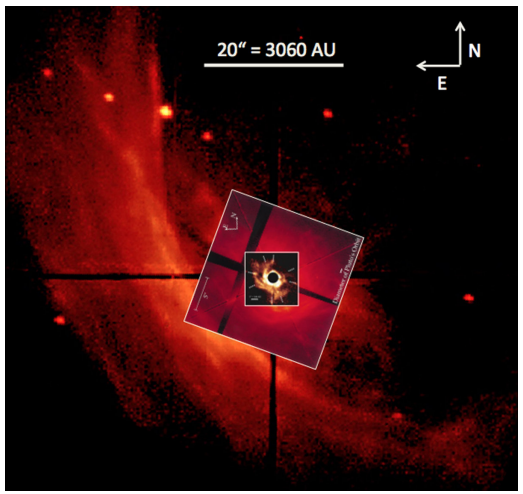

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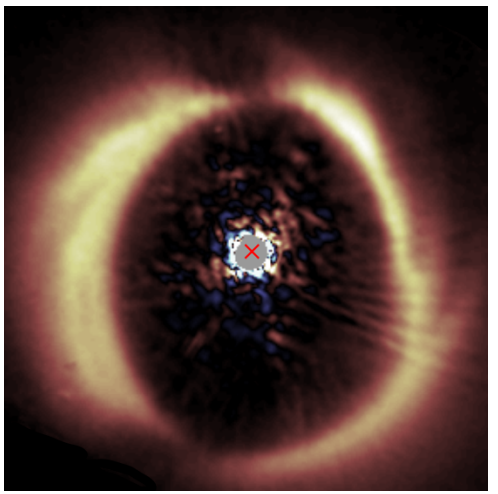


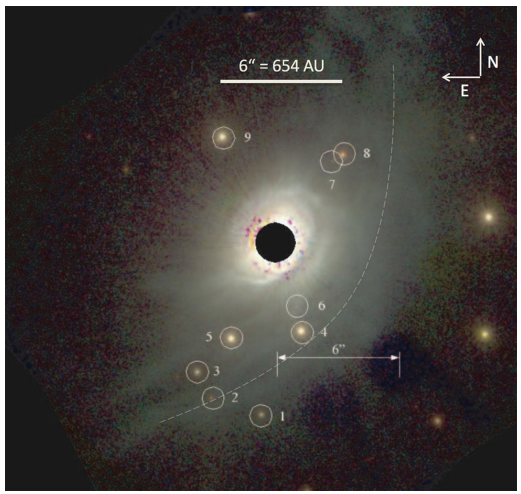
HD 142527

Credit: Avenhaus+ 2014

Shadows due to misaligned inner and outer disk

Credit: Marino+ 2015

Late infall



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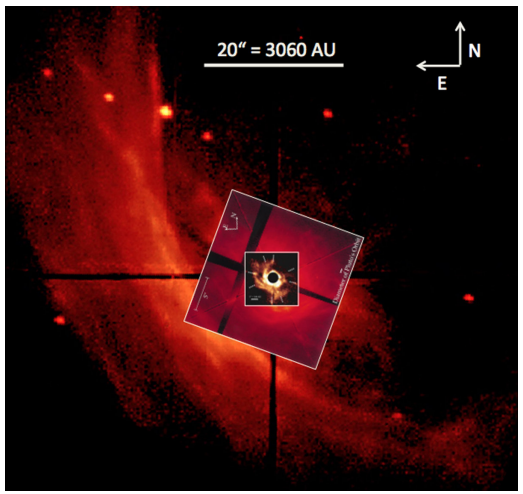

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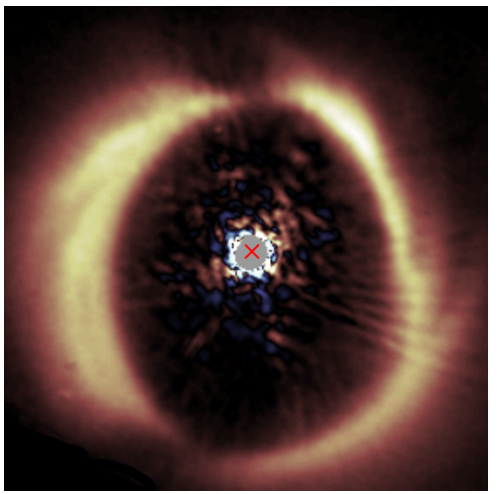

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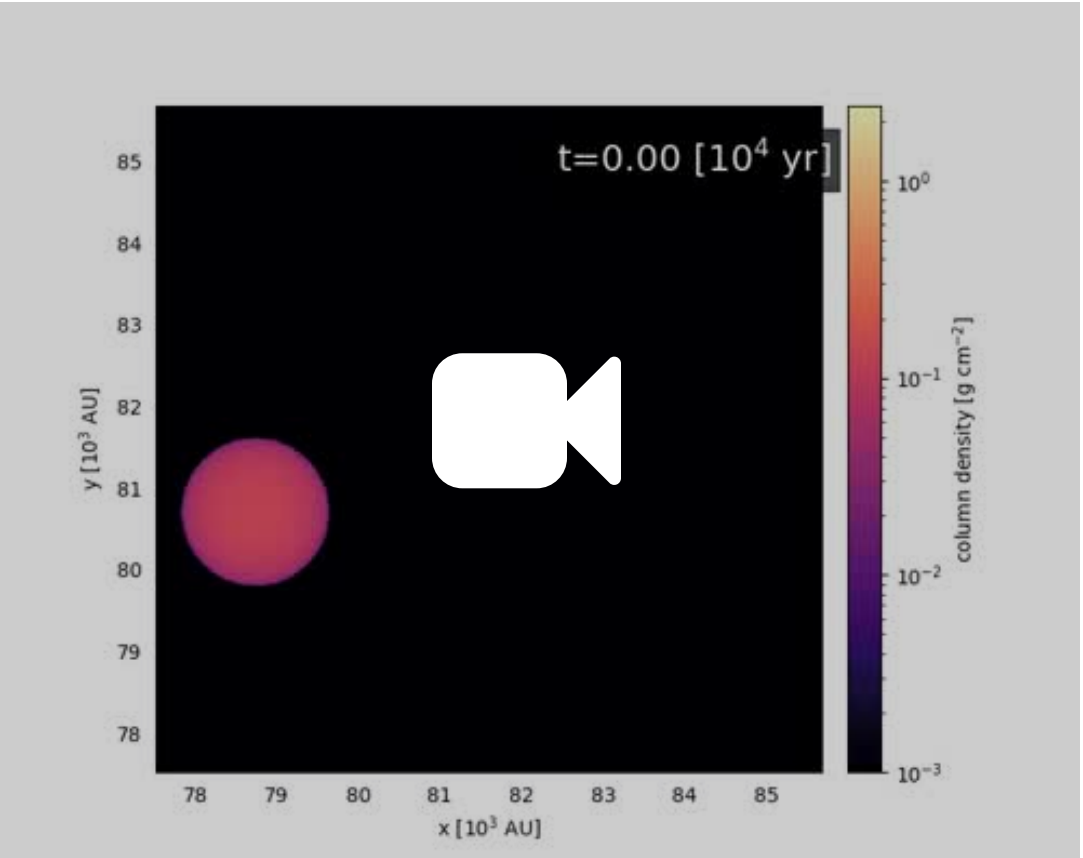
Shadows due to misaligned inner and outer disk

Credit: Marino+ 2015

Can (late) infall cause misalignment of inner and outer disk?

Simulate cloudlet infall onto disk



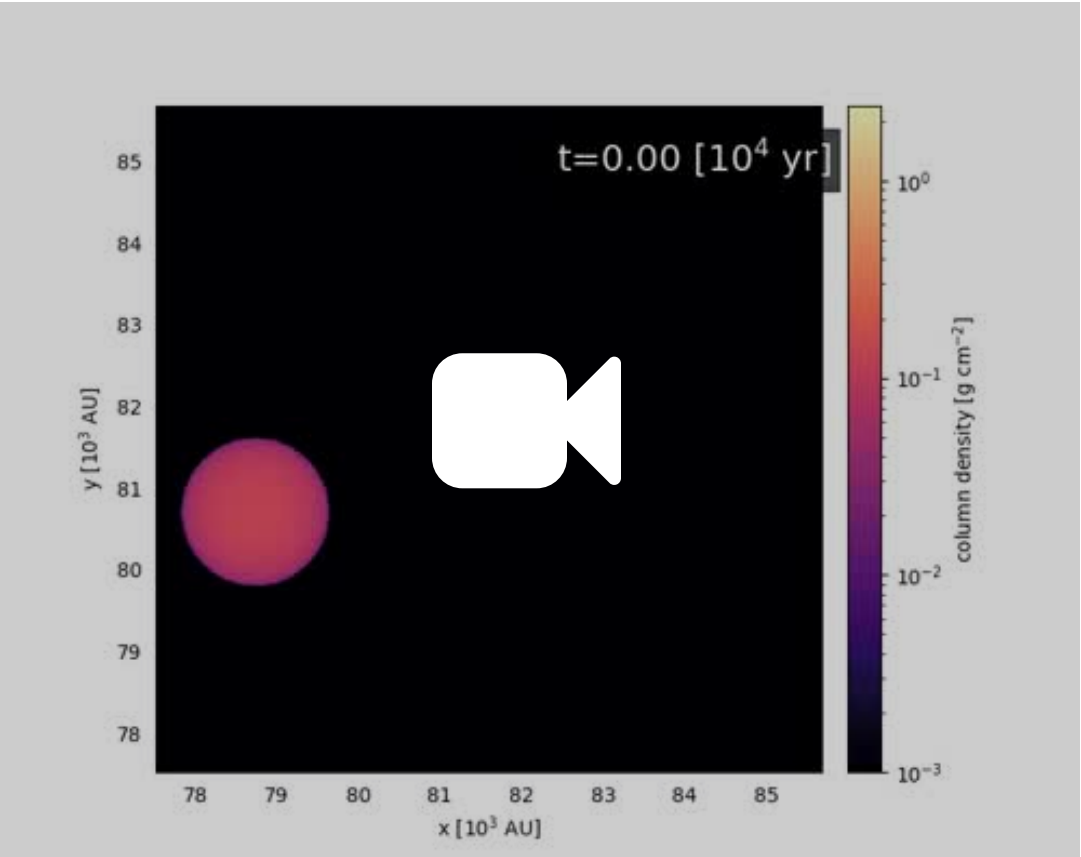
Küffmeier, Dullemond, Reißl, Goicovic + subm

in the spirit of talks by Schoettler and Cuello:

"fly-by of slow walk-away star"

Simulate cloudlet infall onto disk

AREPO, pure hydrodynamical



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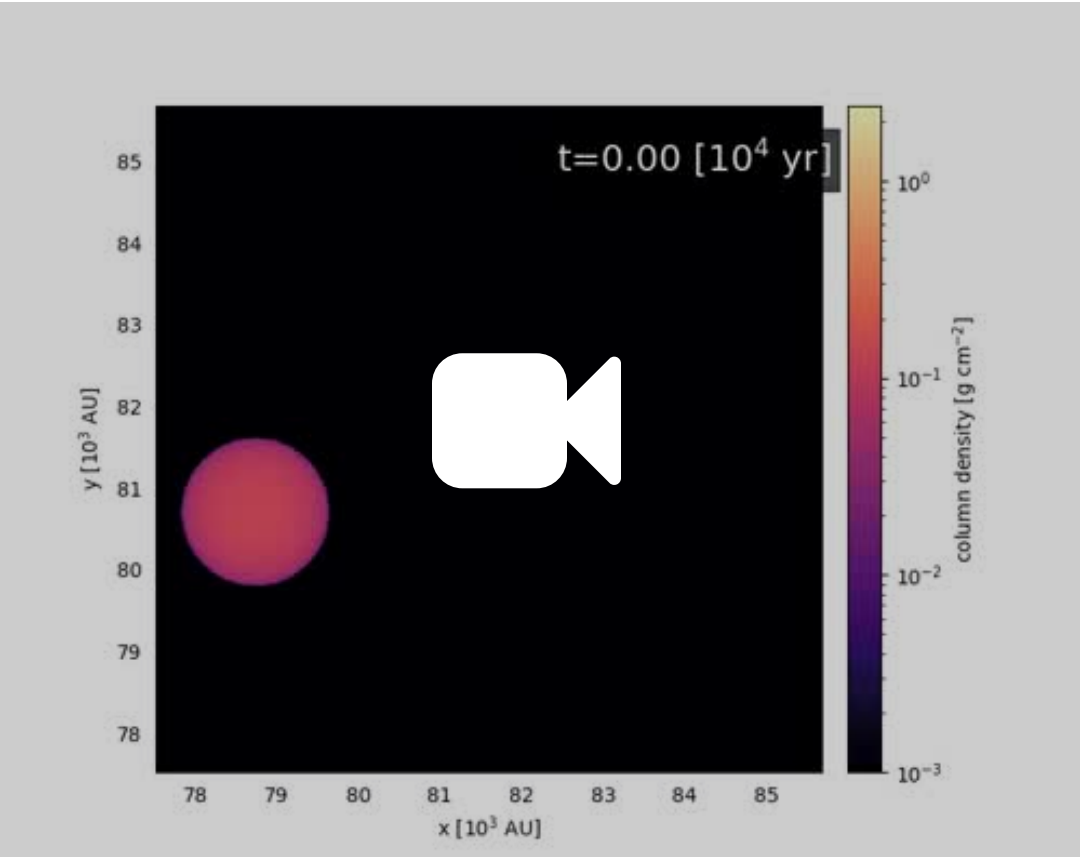
isothermal gas



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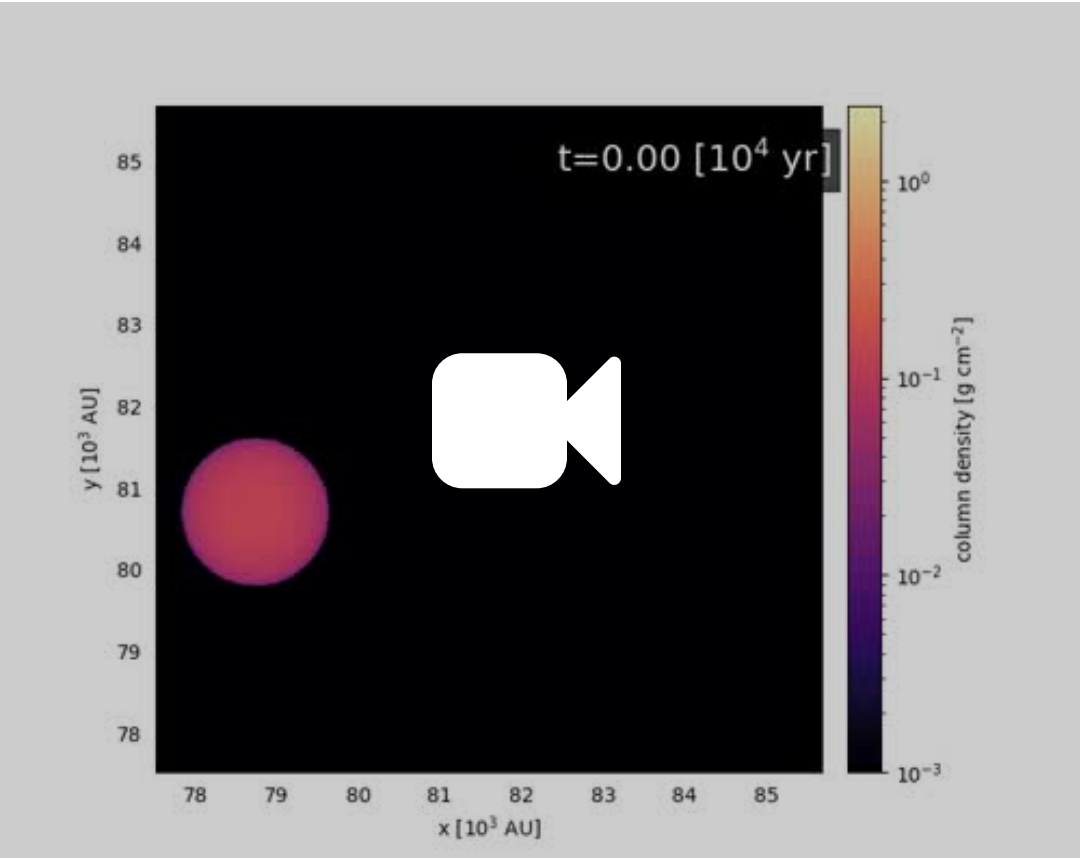
vary infalling angle

$\alpha = 0°(35°, 60°, 90°)$



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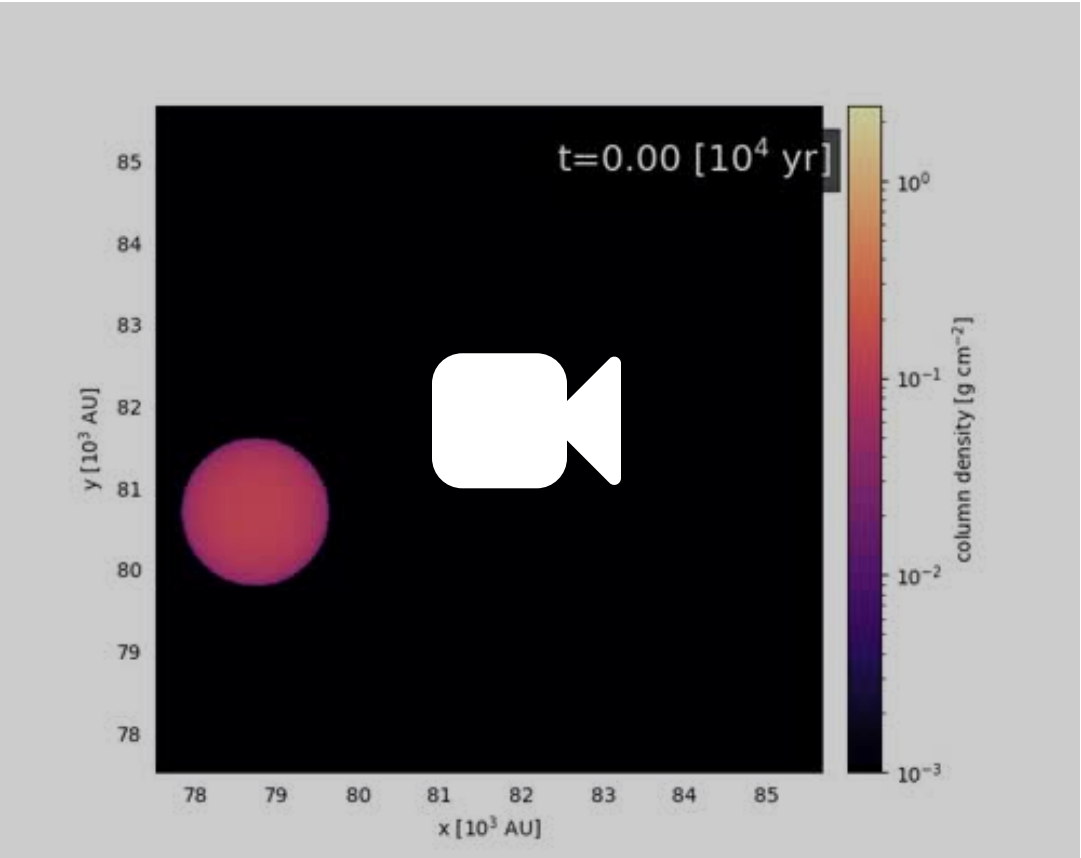

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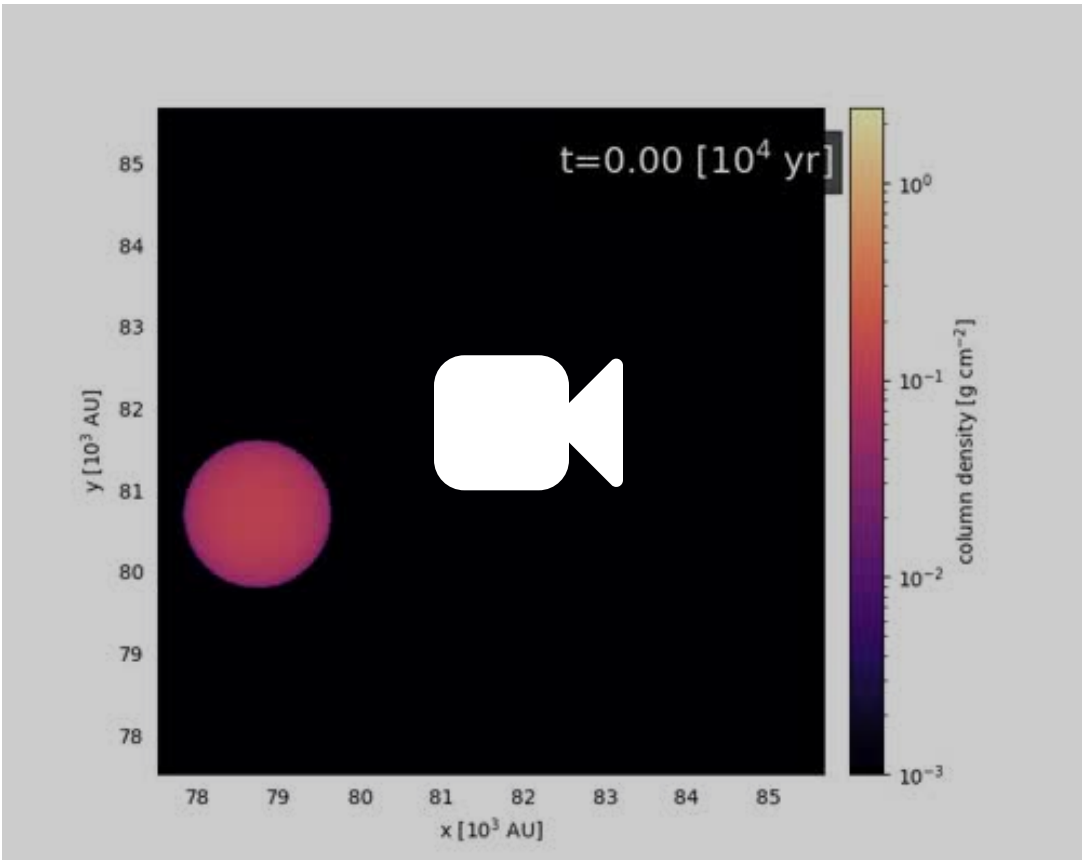


Küffmeier, Dullemond, Reißl, Goicovic + subm

$R_{\rm i,d} = 50\,{\rm au} \quad M_* = 2.5\,{\rm M}_\odot$

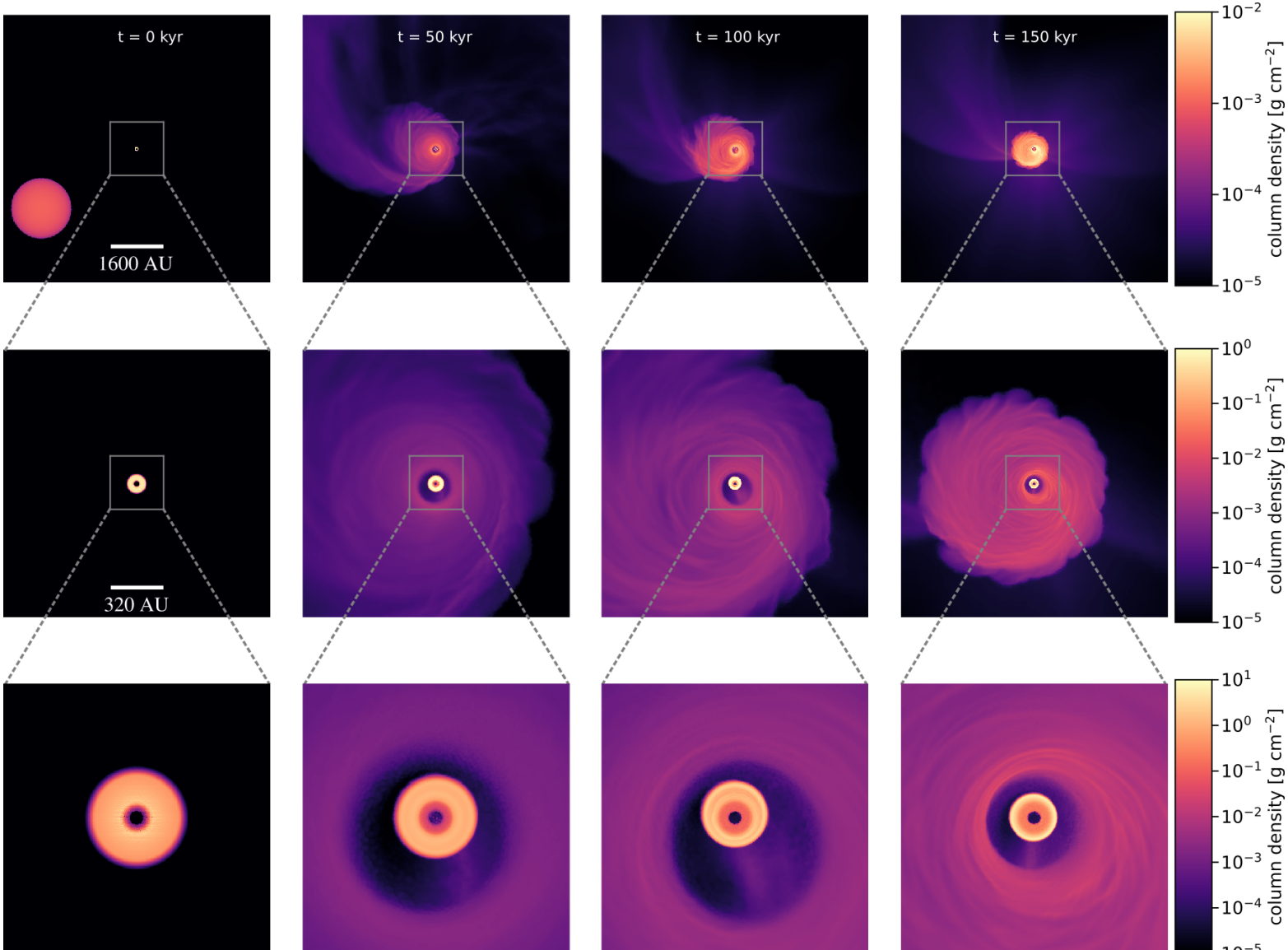
$\Sigma(r) = 170 \left(\frac{\rm g}{\rm cm}\right)^2 \left(\frac{r}{1{\rm au}}\right)^{-3/2}$

$b = 1774\,{\rm au}$

in the spirit of talks by Schoettler and Cuello:
"fly-by of slow walk-away star"

$R_{\rm cloudlet} = 887\,{\rm au} \quad M_{\rm cloudlet}(R_{\rm cloudlet}) = 0.01{\rm M}_\odot \left(\frac{R_{\rm cloudlet}}{5000{\rm au}}\right)^{2.3}$

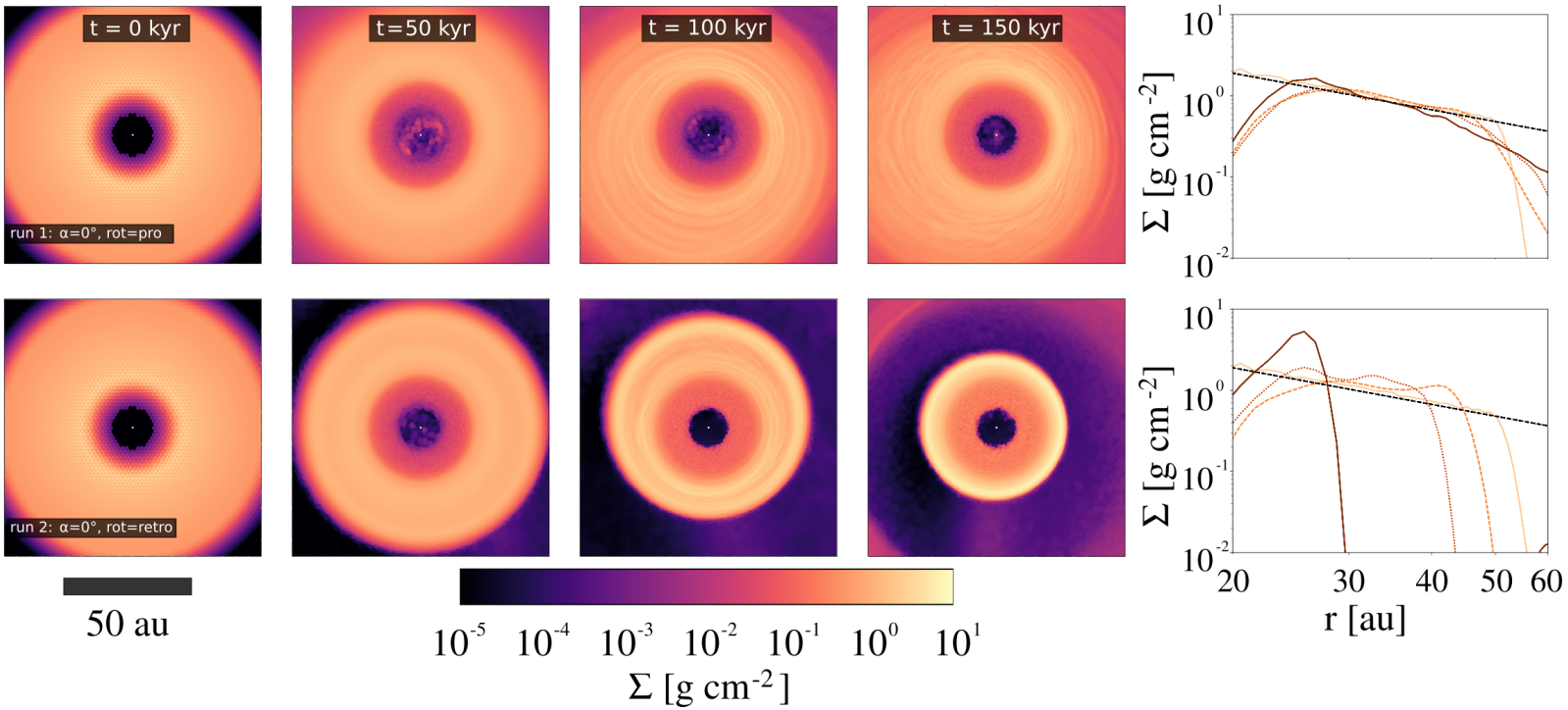
Outer disk forms around inner disk



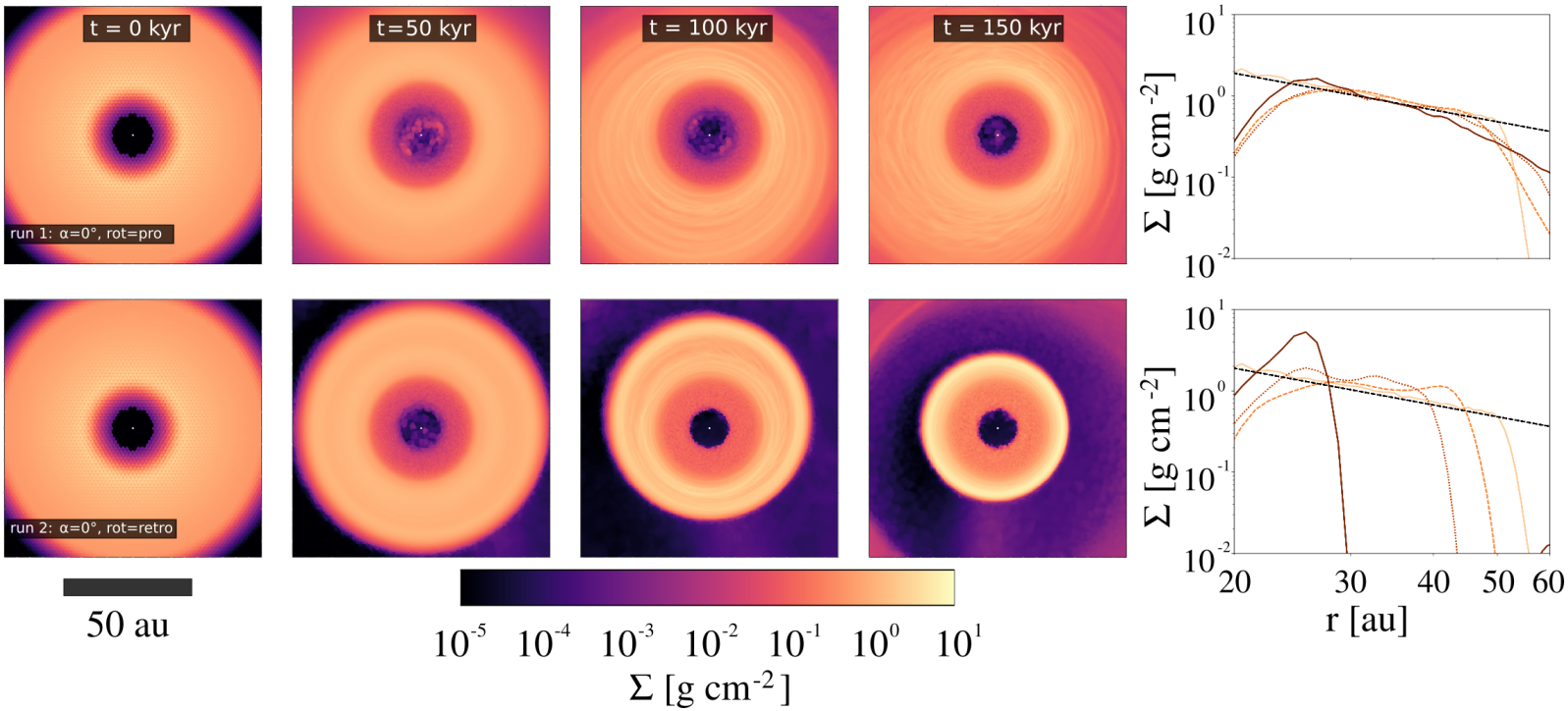
consistent with star formation simulations by Bate '18

Küffmeier+ subm

Prograde vs. retrograde infall

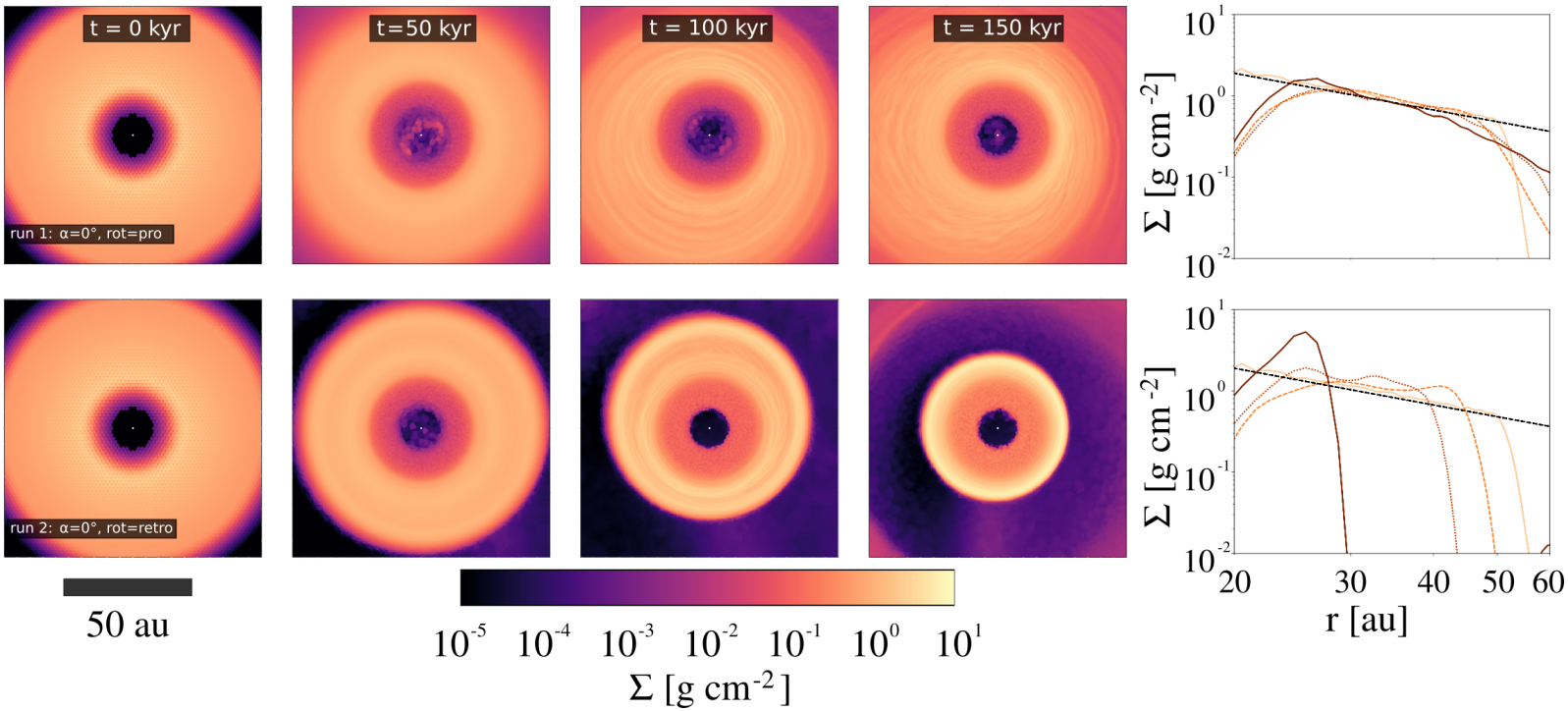


Prograde vs. retrograde infall



Retrograde infall causes:

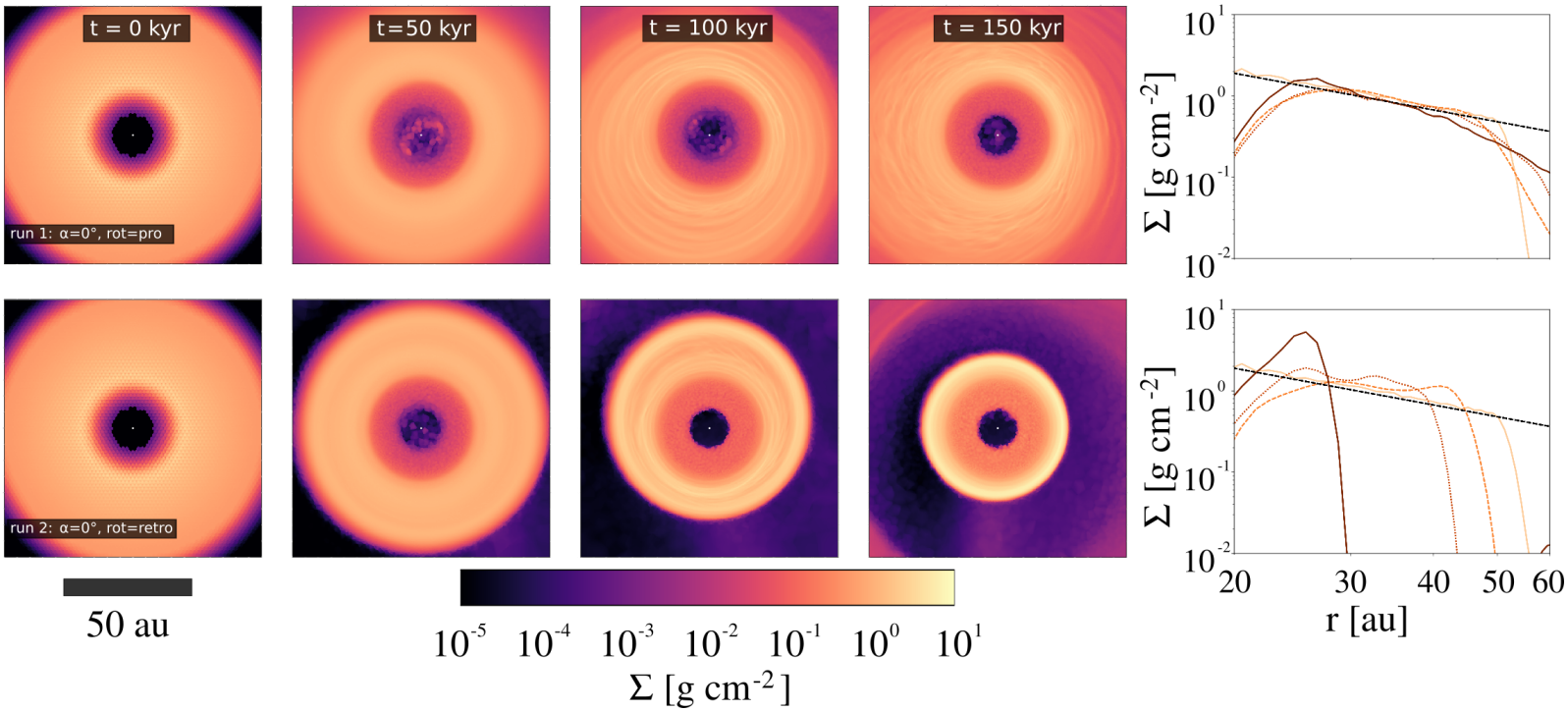
Prograde vs. retrograde infall



Retrograde infall causes:

- counter-rotating inner and outer disk

Prograde vs. retrograde infall

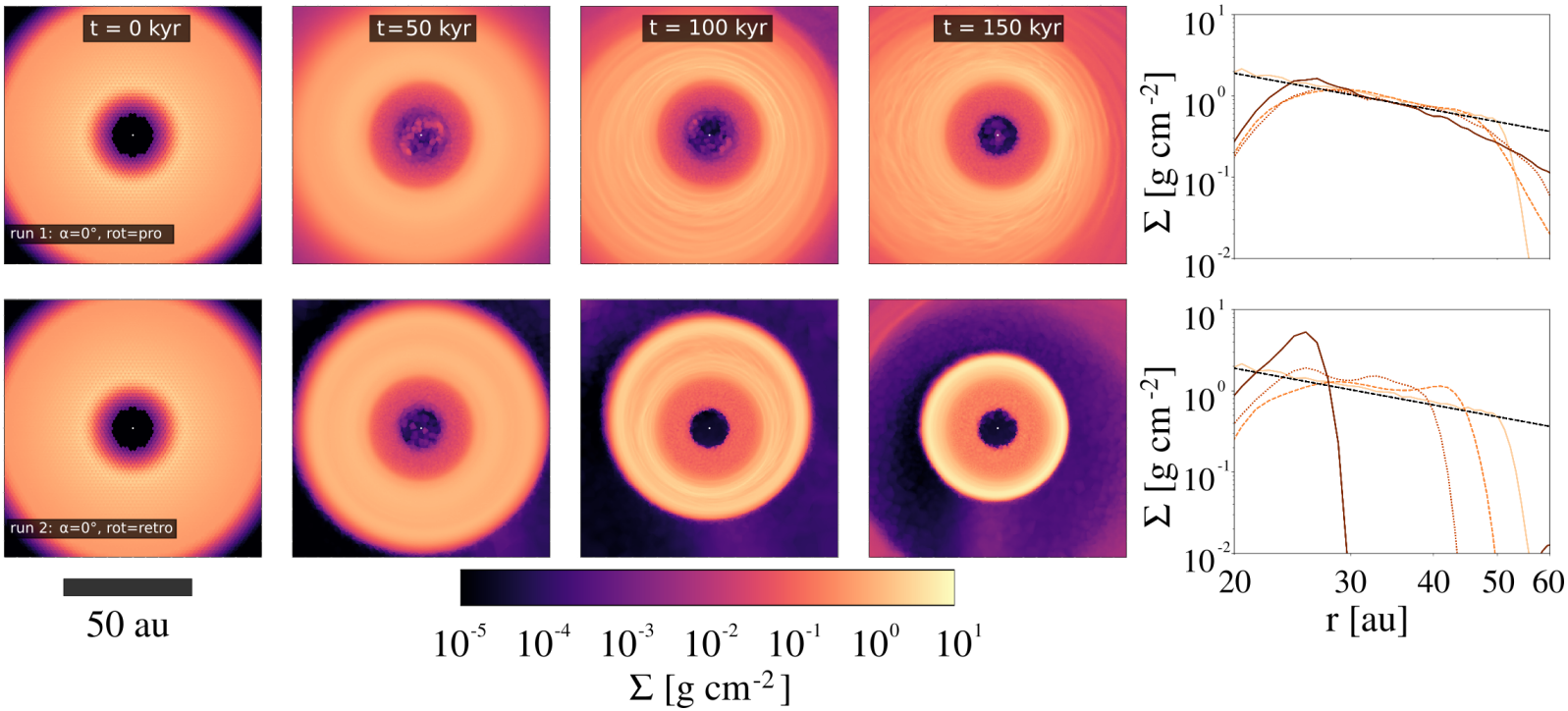


Retrograde infall causes:

- counter-rotating inner and outer disk
- larger and deeper gap between disks

see also Vorobyov+ 2016

Prograde vs. retrograde infall



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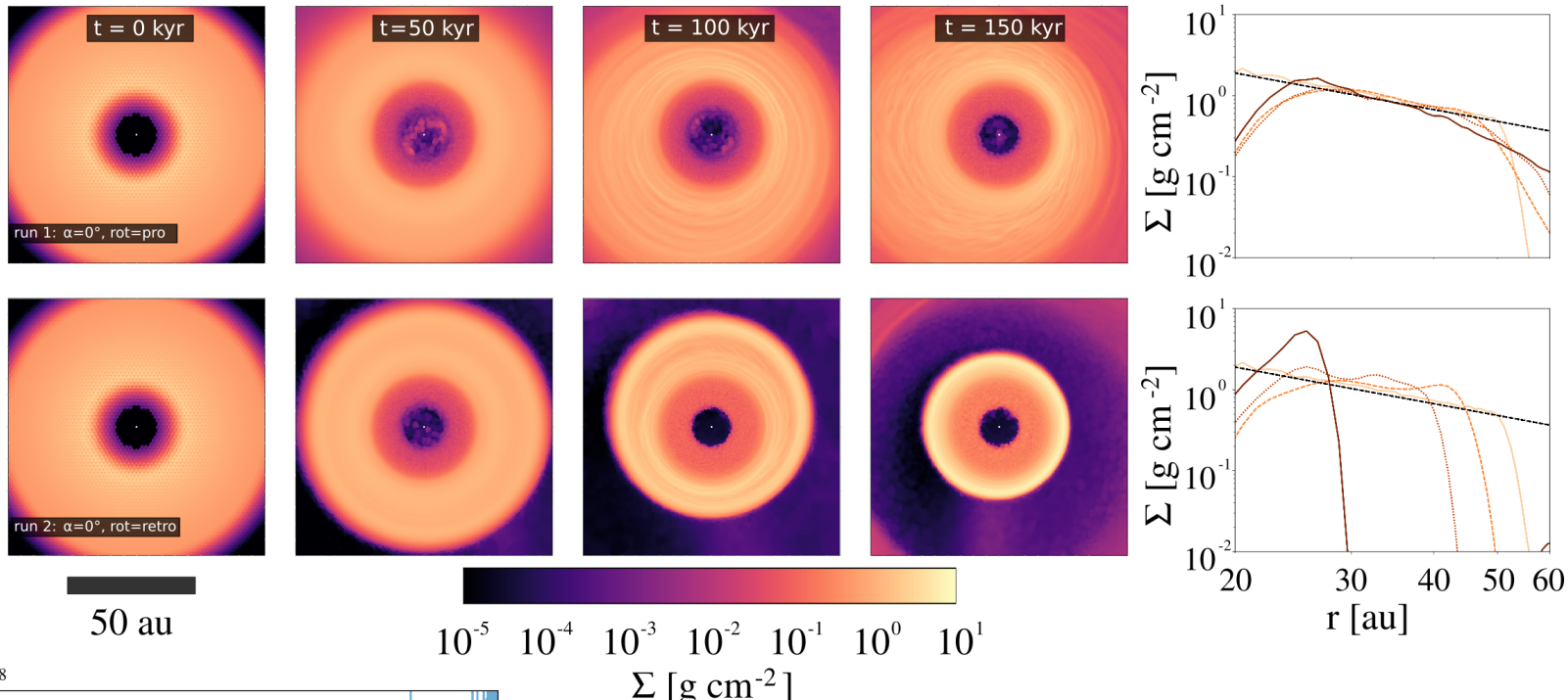

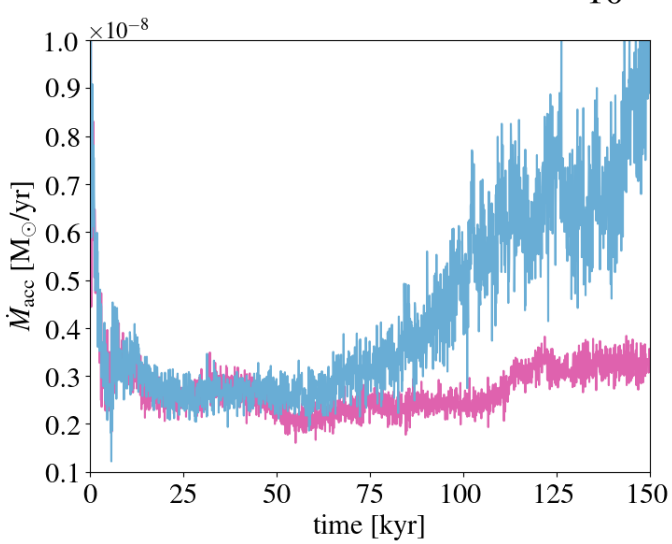

Retrograde infall causes:

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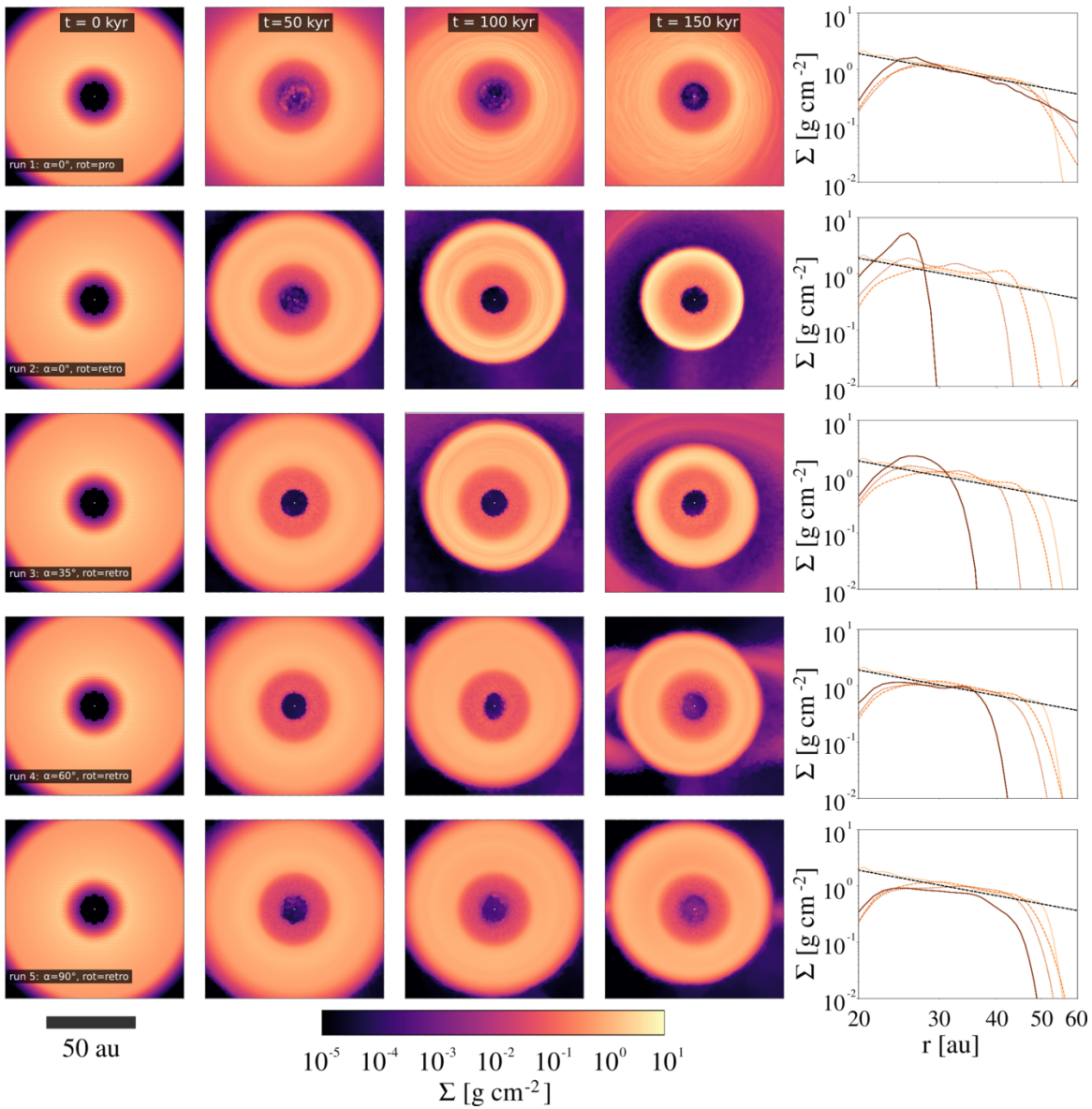
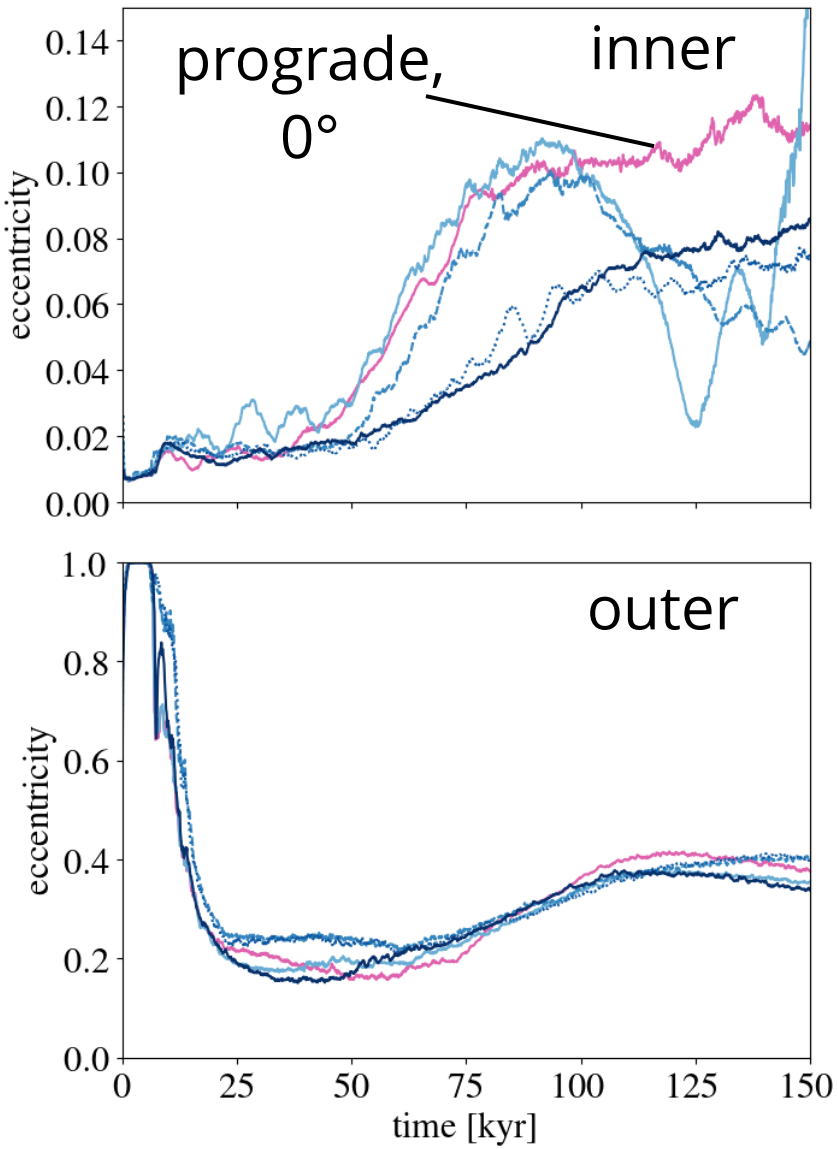
Effect of infall angle on disk



Increasing inclination reduces shrinking of disk due to conservation of angular momentum

Disk evolution: eccentricity



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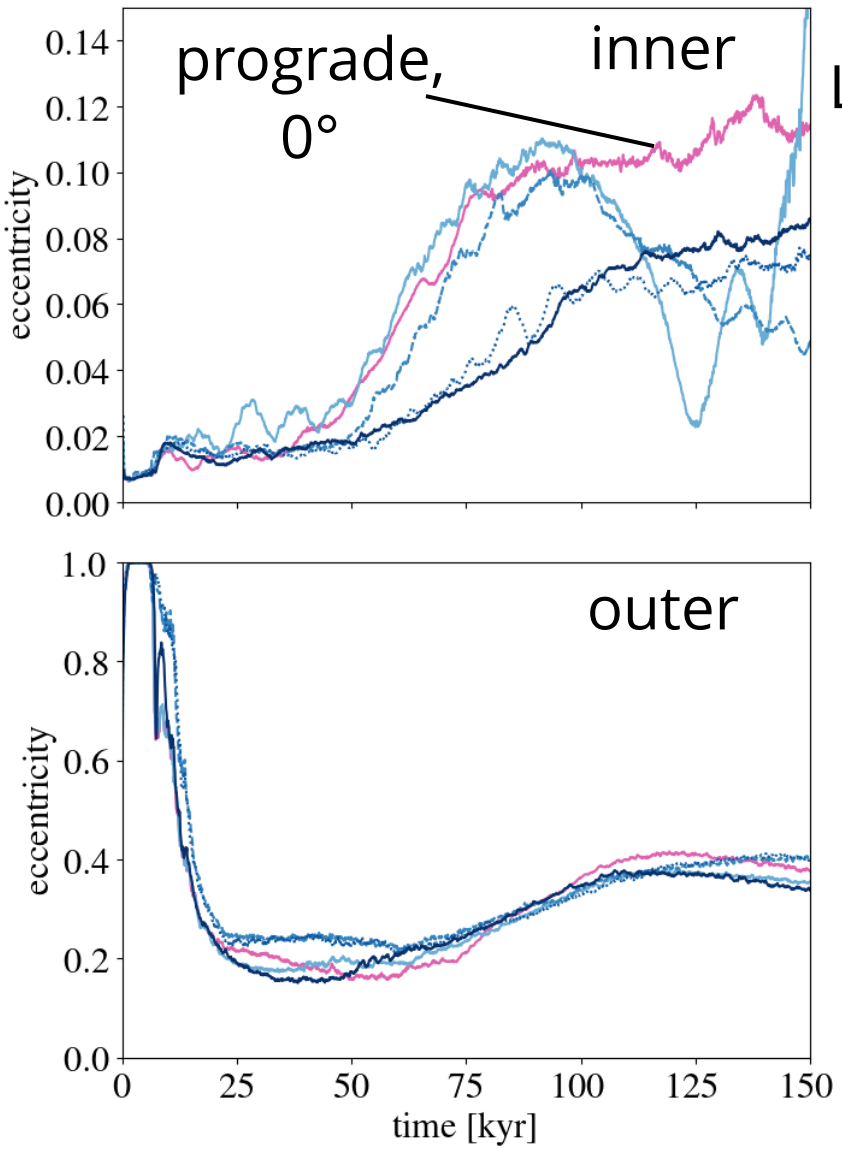
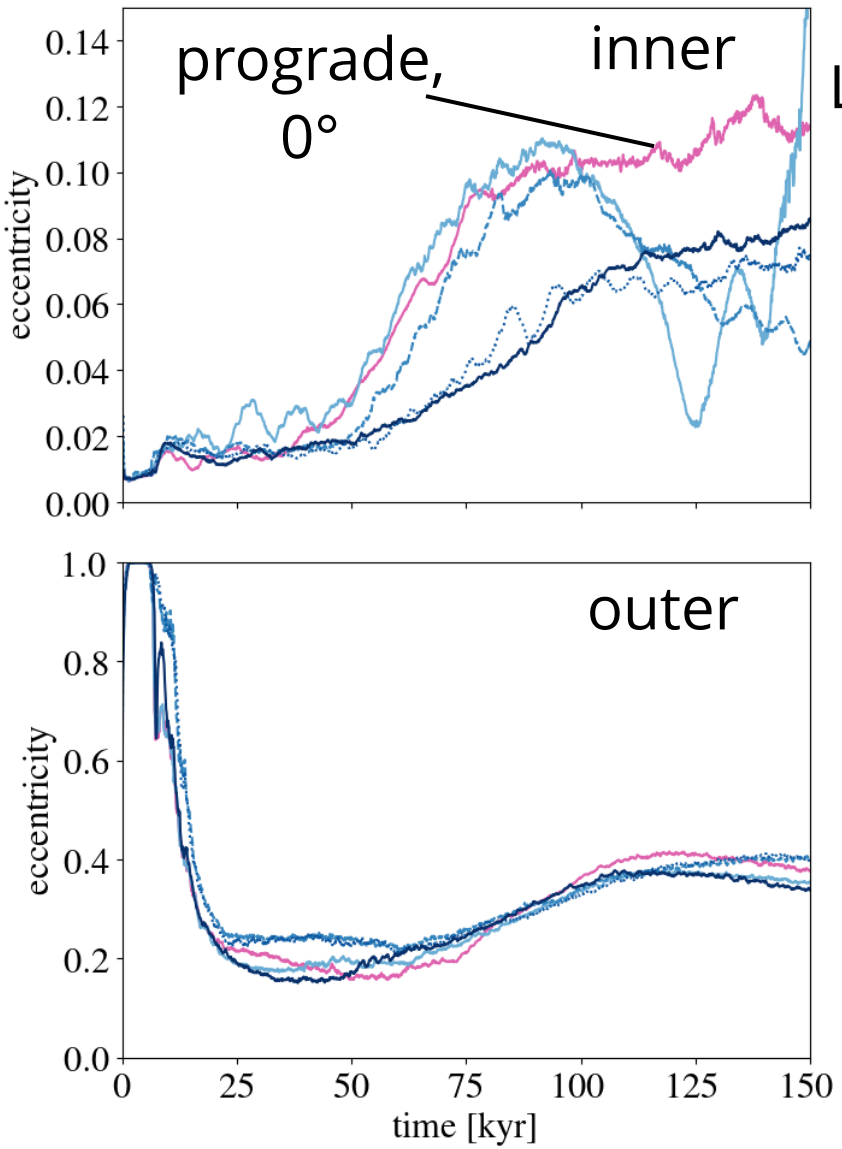


Light to dark: retrograde infall with increasing inclination

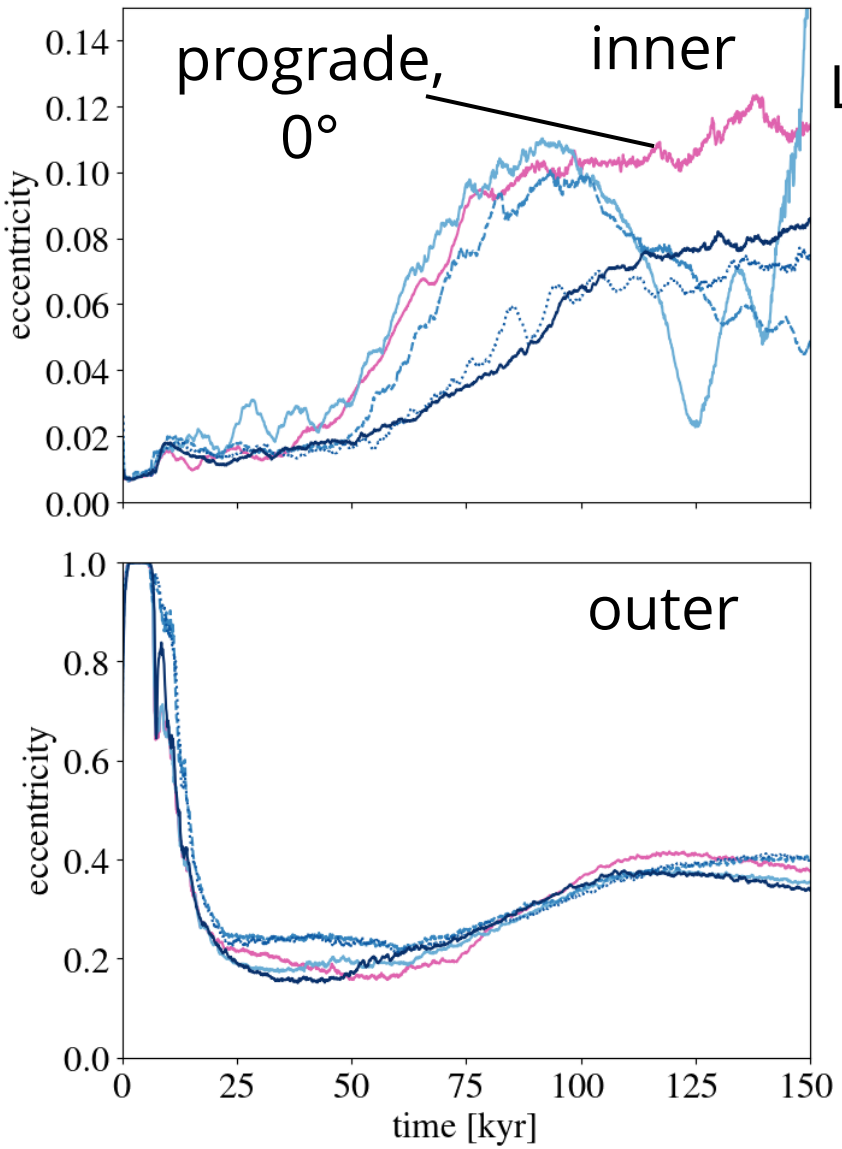
Disk evolution: eccentricity



Light to dark: retrograde infall with increasing inclination

Infall triggers:

Disk evolution: eccentricity



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Infall triggers:

- mild eccentricity in inner disk (up to ~0.1)

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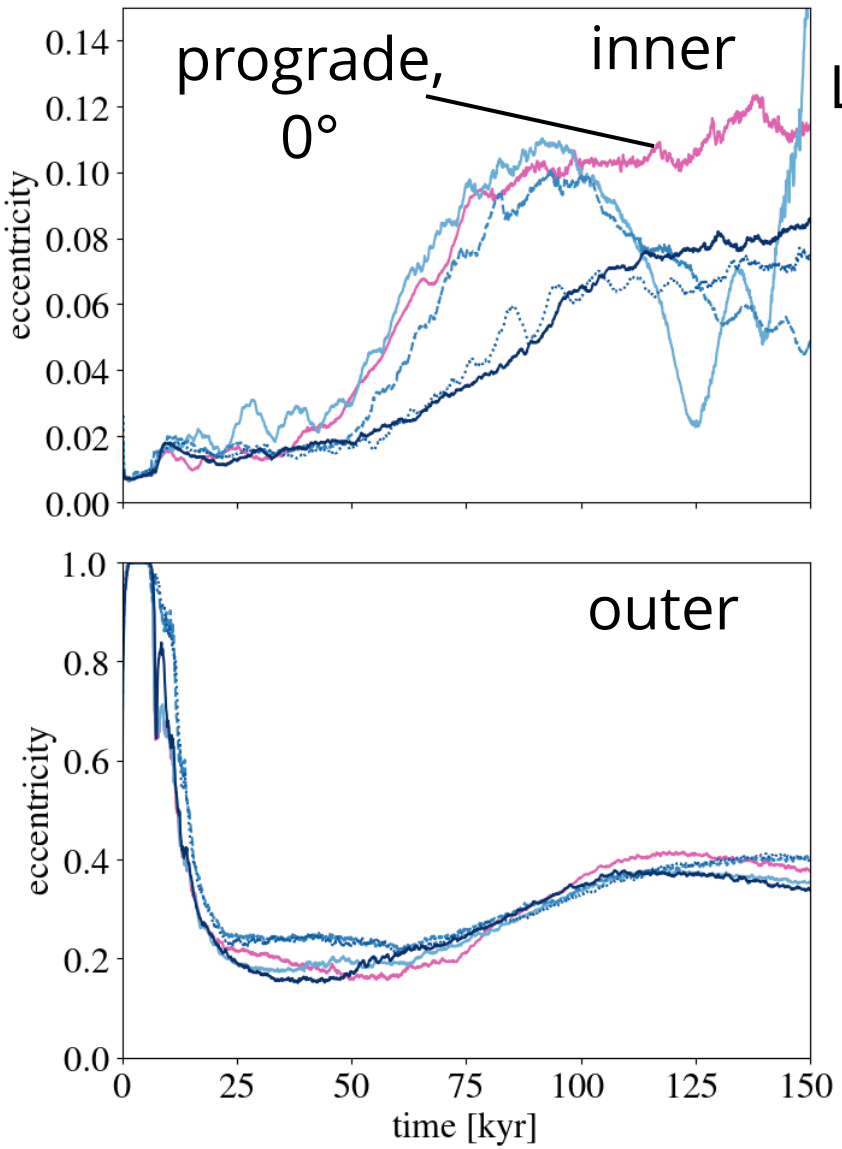

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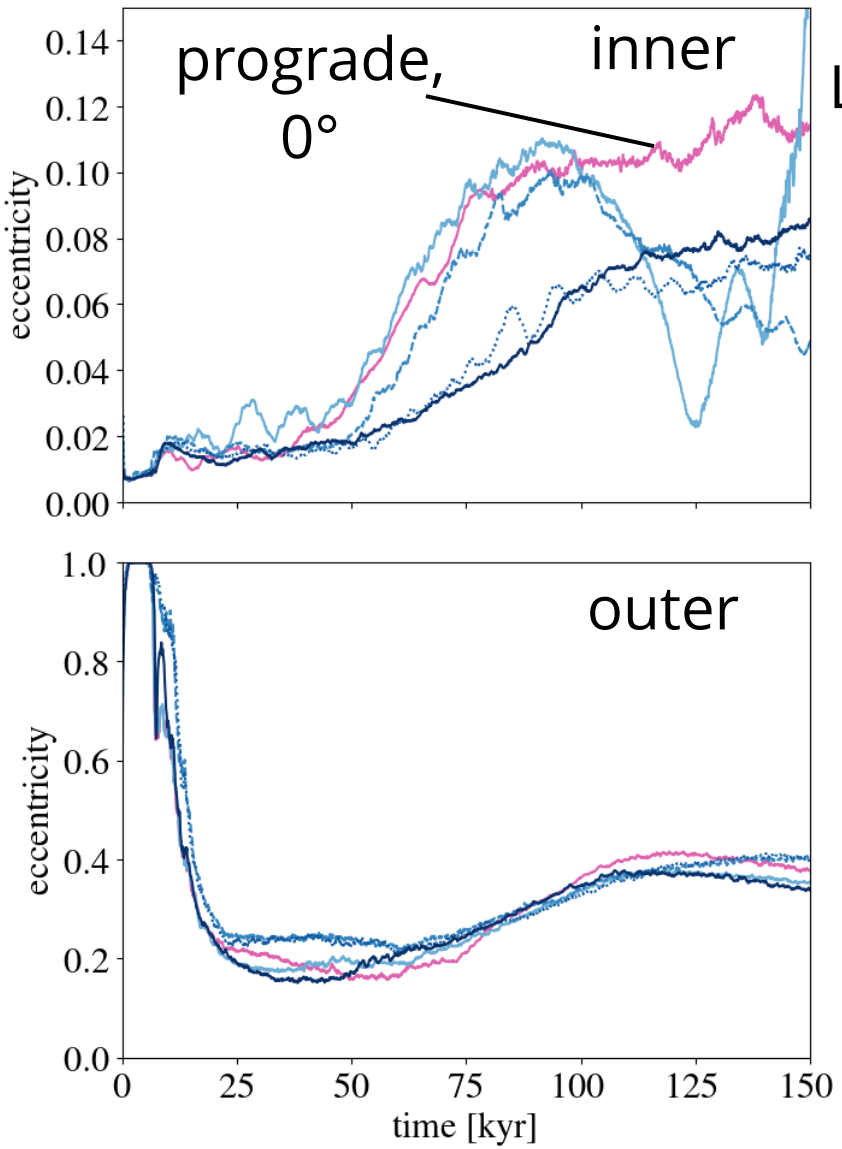

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=> probably measurable with CO channel maps:

a test of infall scenario

Infall mechanism in perspective

Infall mechanism in perspective

Disclaimer:

We are not saying that all shadows are due to misaligned infall!

Infall mechanism in perspective

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In some cases shadows have already been well explained by external companions and/or inner planets (e.g.: HD 100453 *Gonzalez+ '20/Nealon+ '20* or work by *Zhu '19* on planet-induced misalignment)

Infall mechanism in perspective

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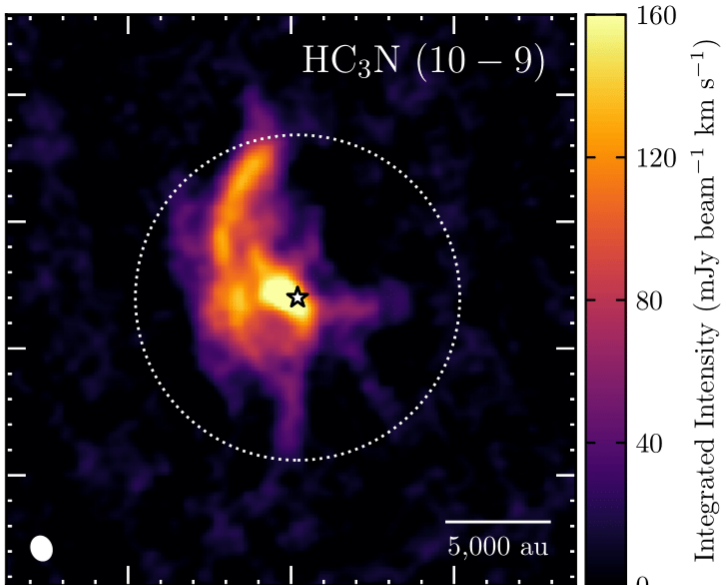


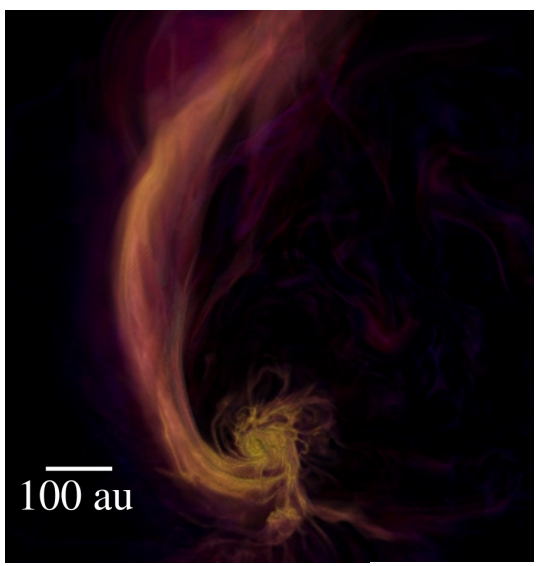
Pineda et al. 2020; see also

[BHB2007] 1 (Alves et al. 2020)

But we need to think out of the disk:

significant fraction of final mass might accrete later through inflow

(Pelkonen et al. 2020)



Küffmeier et al. 2019

Take-away points

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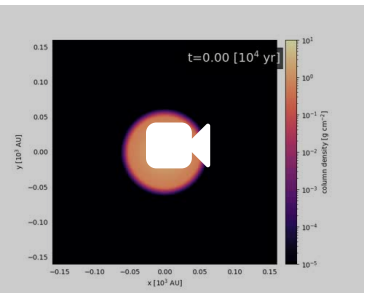
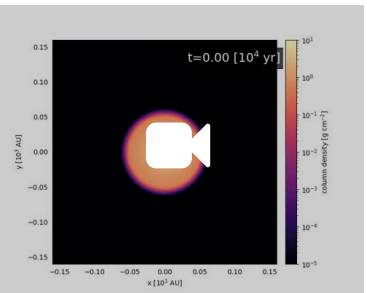


Retrograde infall can cause counter-rotating disks, shrinking of inner disk, formation of gaps (>10 AU) and enhanced accretion.

Take-away points



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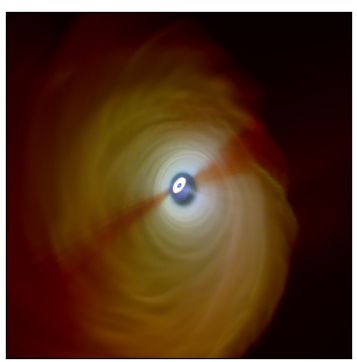
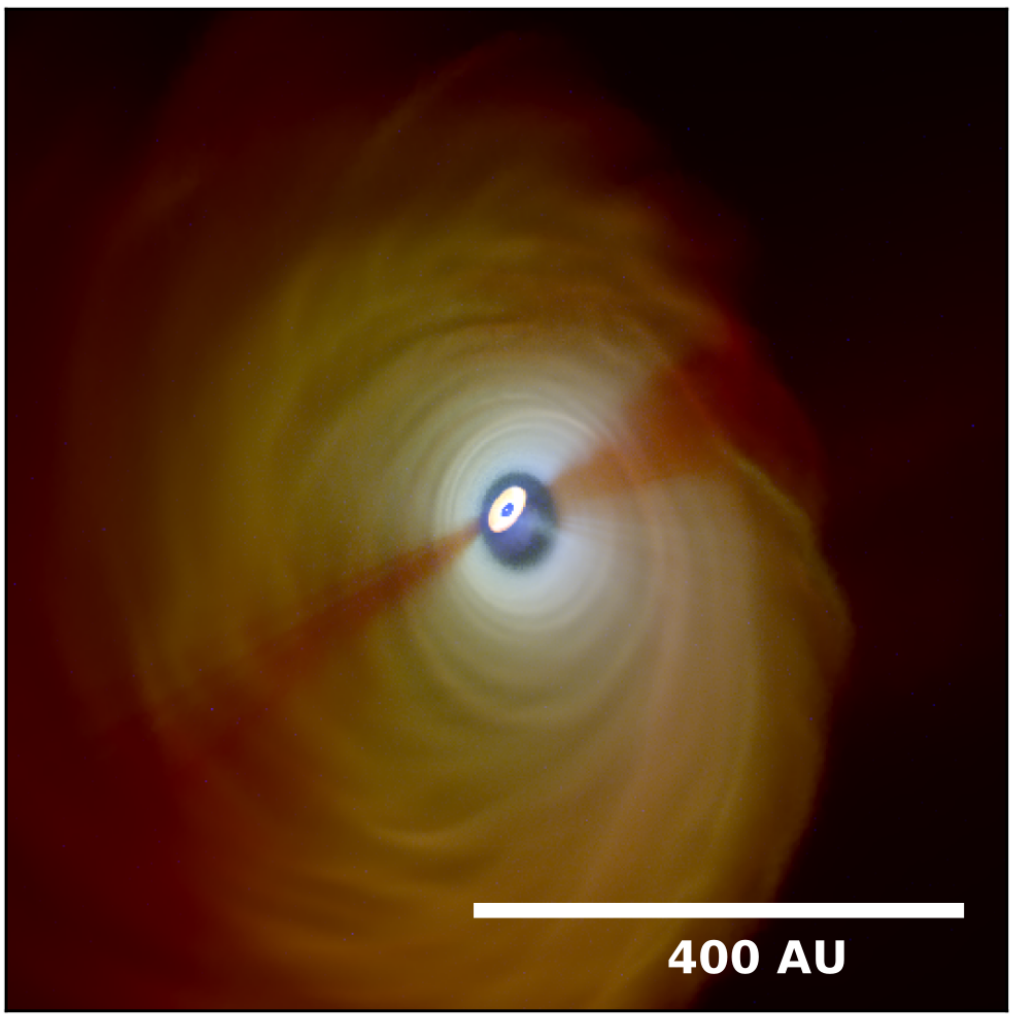


In infall-induced misaligned systems, the outer disk is expected to have higher eccentricity than the inner disk.

WIP: study synthetic observations of infall-induced shadows



RGB image of misaligned system forming from infall with 60°

blue (1.66 micron), green (53 micron), red (870 micron); *Credit: S. Reißl*