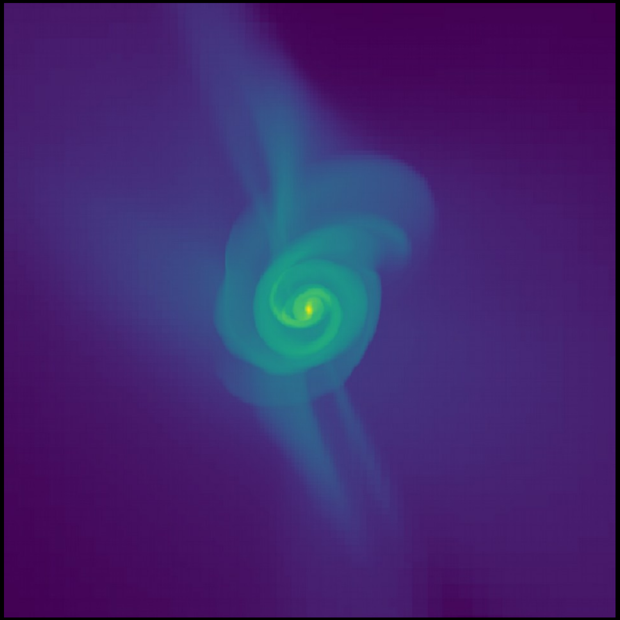
Elbereth 2020

A rotating disk from a nonrotating cloud: Is the angular momentum conserved?

Antoine Verliat, Patrick Hennebelle, Anaëlle J. Maury, Mathilde Gaudel



Antoine Verliat

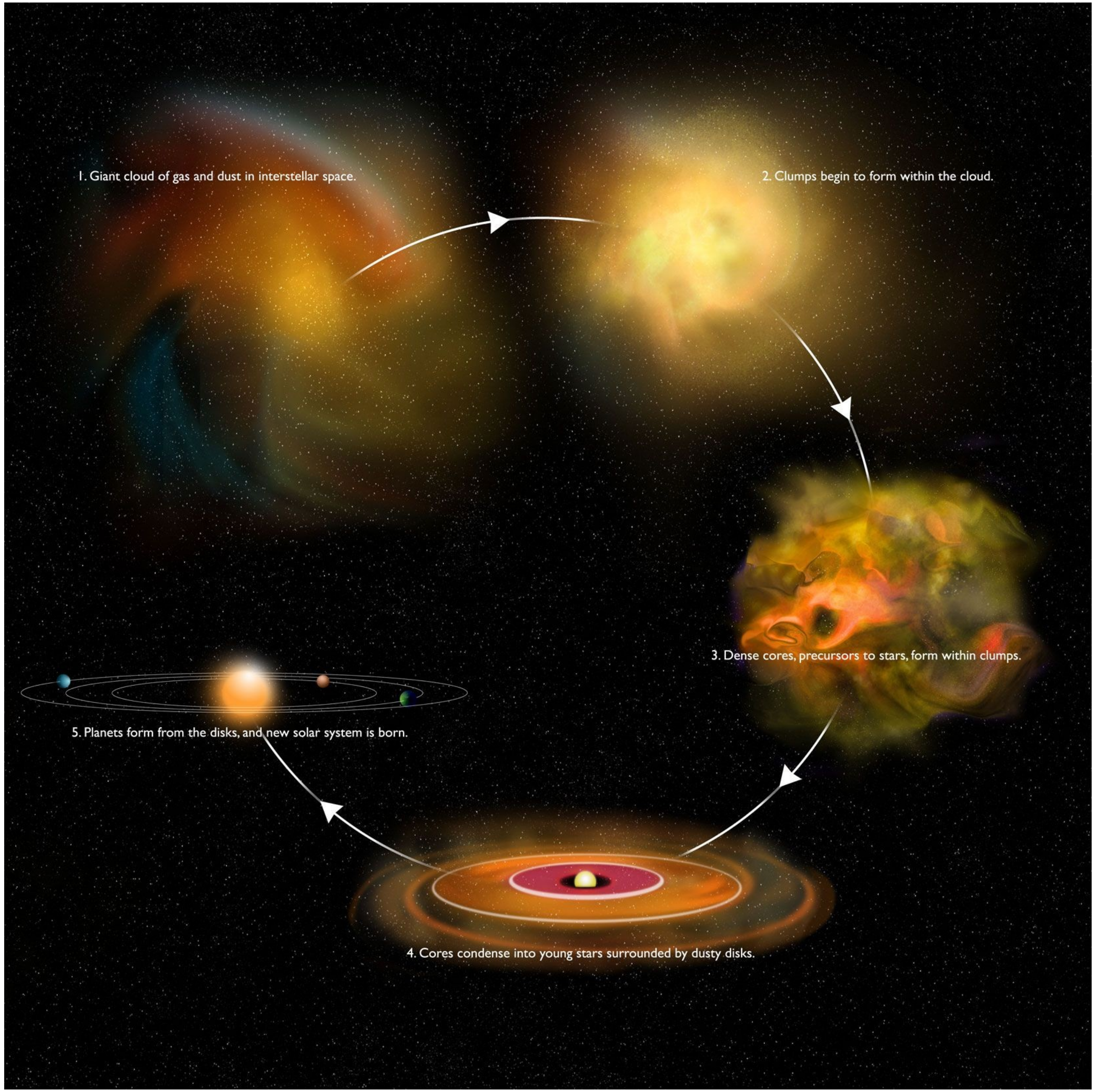
28th of February, 2020

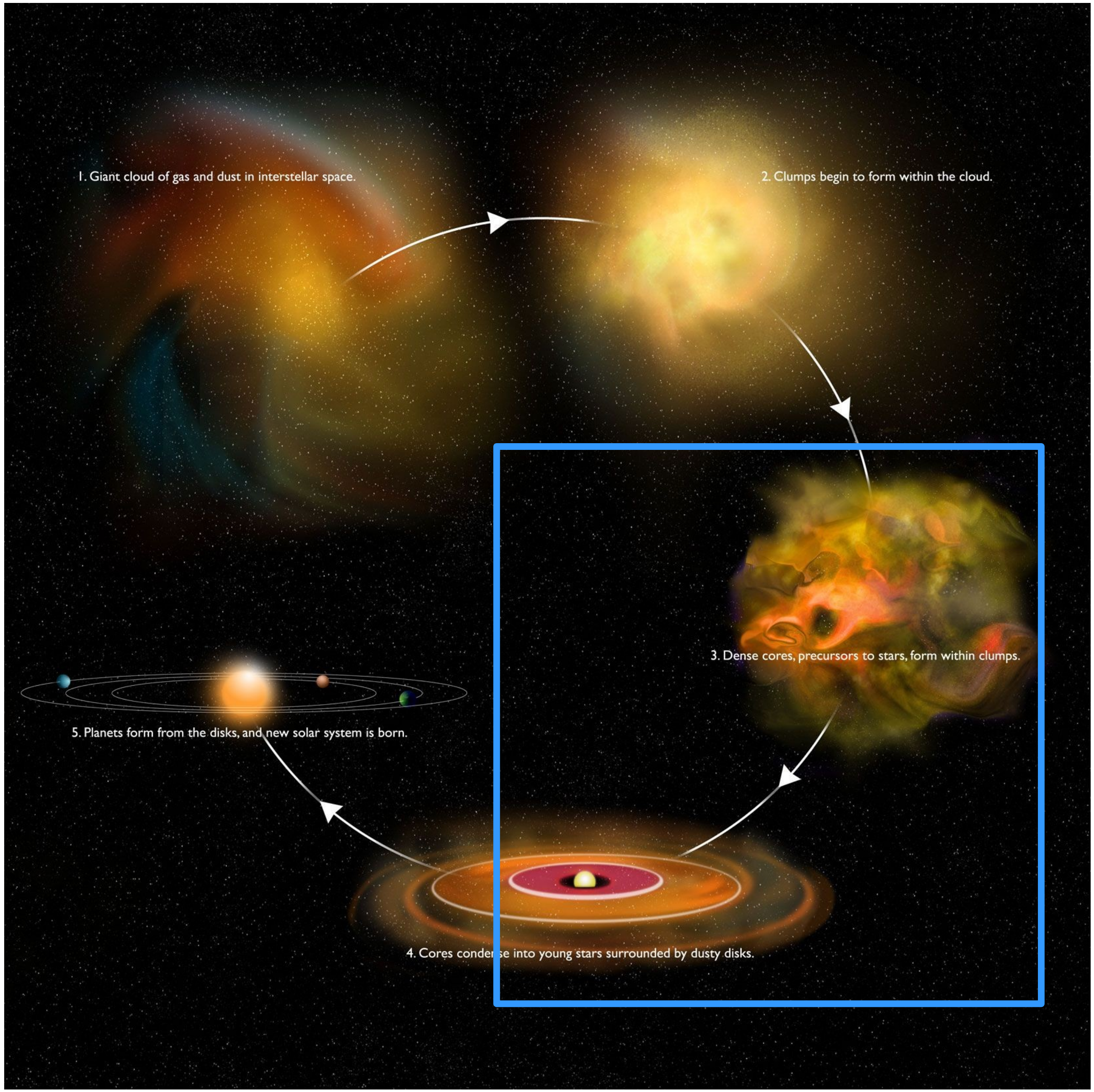
Introduction

I/ Axisymmetrical model

II/ Nonaxisymmetrical collapse

III/ Comparison with observations


1. Giant cloud of gas and dust in interstellar space.
2. Clumps begin to form within the cloud.
3. Dense cores, precursors to stars, form within clumps.
4. Cores condense into young stars surrounded by dusty disks.
5. Planets form from the disks, and new solar system is born.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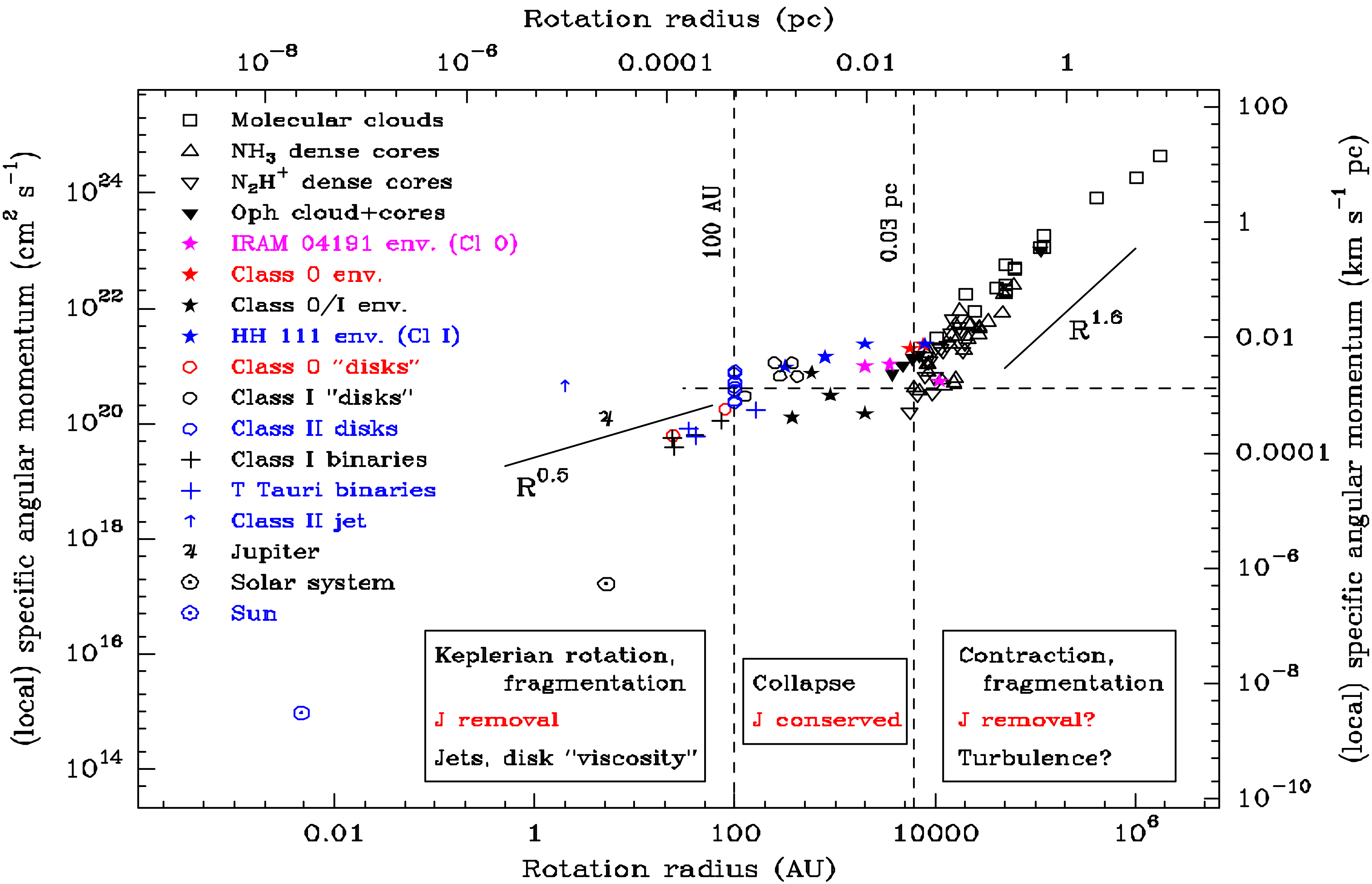
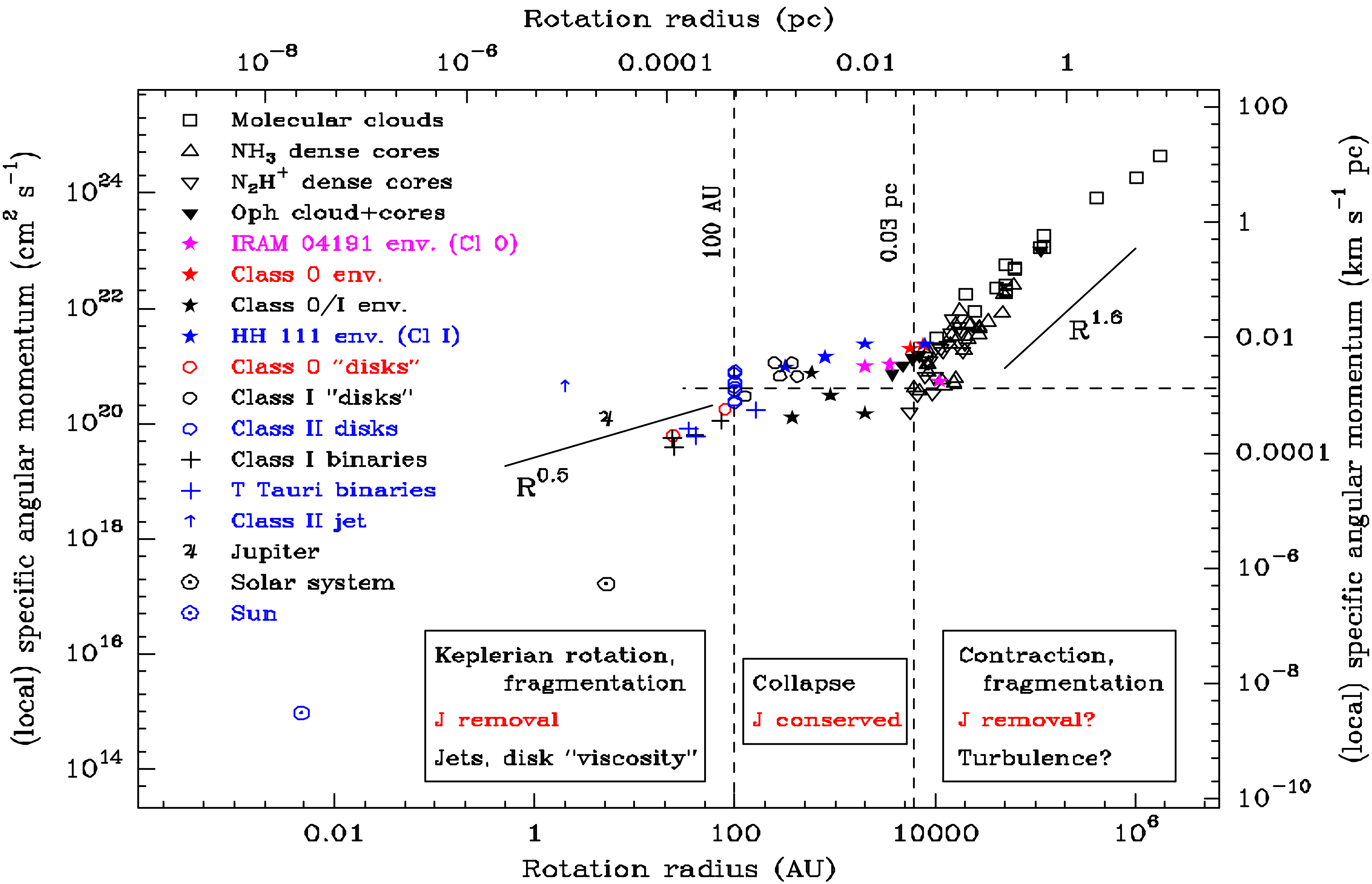


from Belloche (2013)



Rotation is inherited from large scales

from Belloche (2013)

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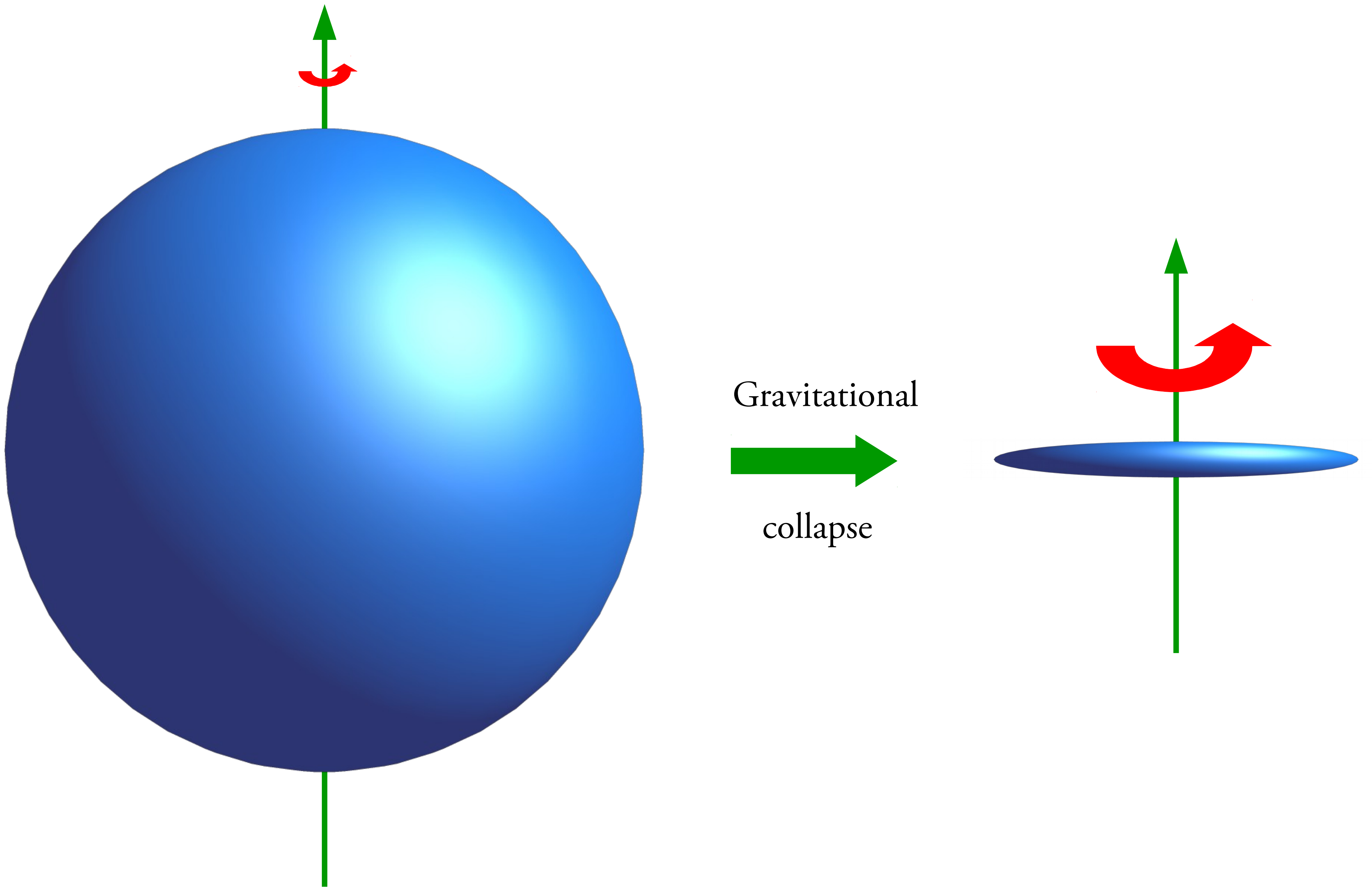
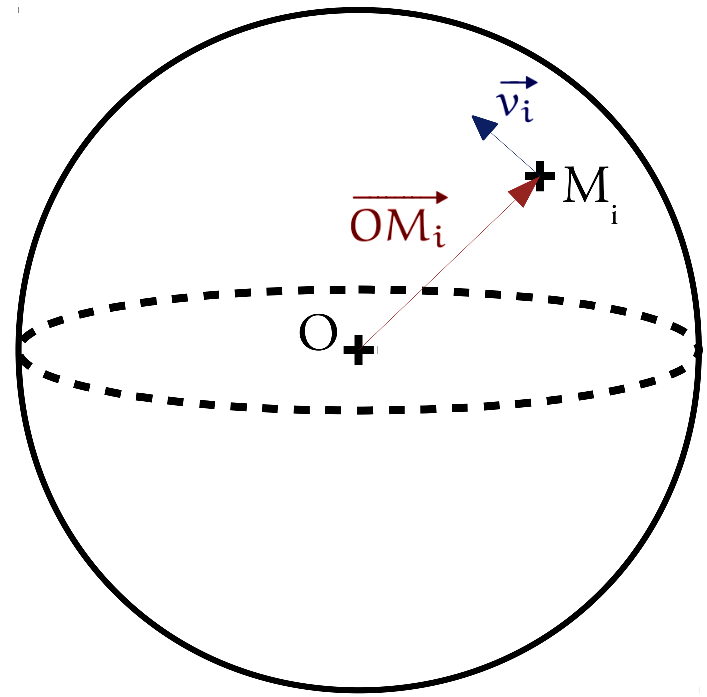
I/ Axisymmetrical model

« Conservation of angular momentum »



2 important hypothesis:

- Axisymmetrical collapse
- Isolated system



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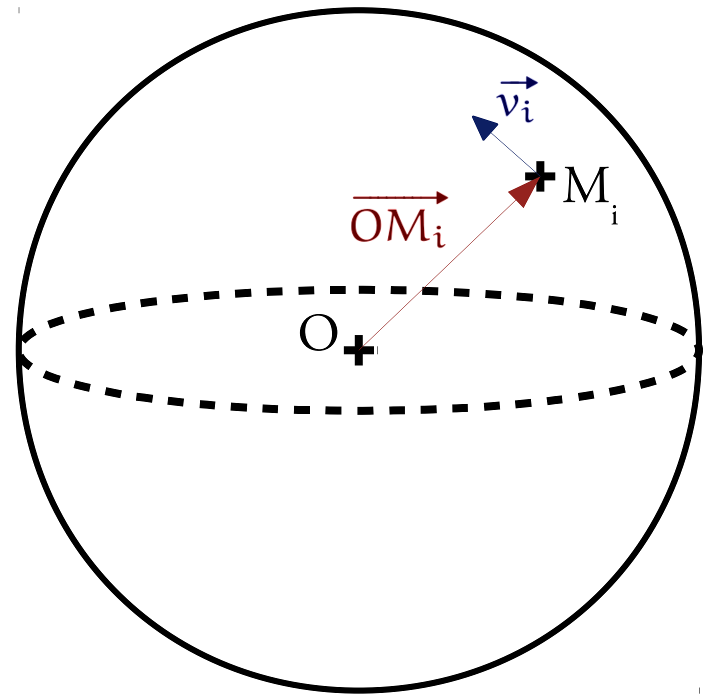

$$\Longrightarrow \quad \sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} = \overrightarrow{cte}$$

2 important hypothesis:

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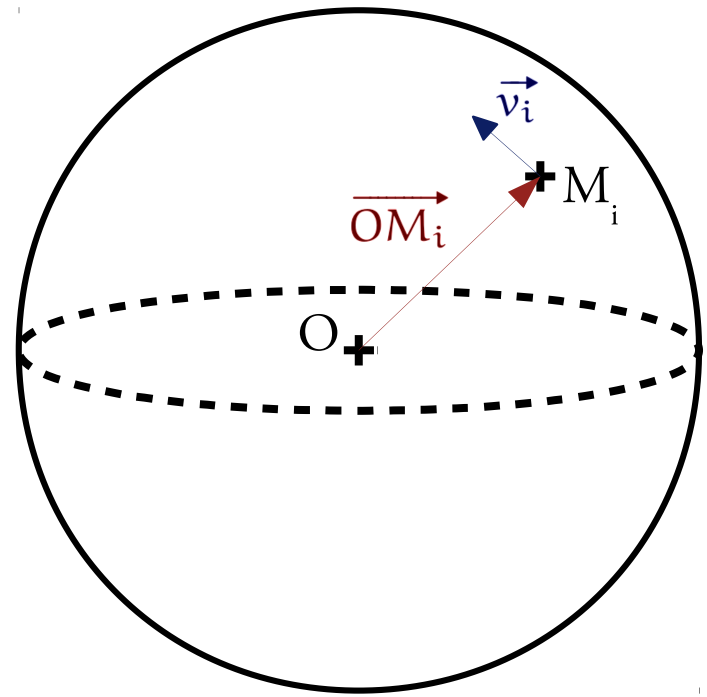
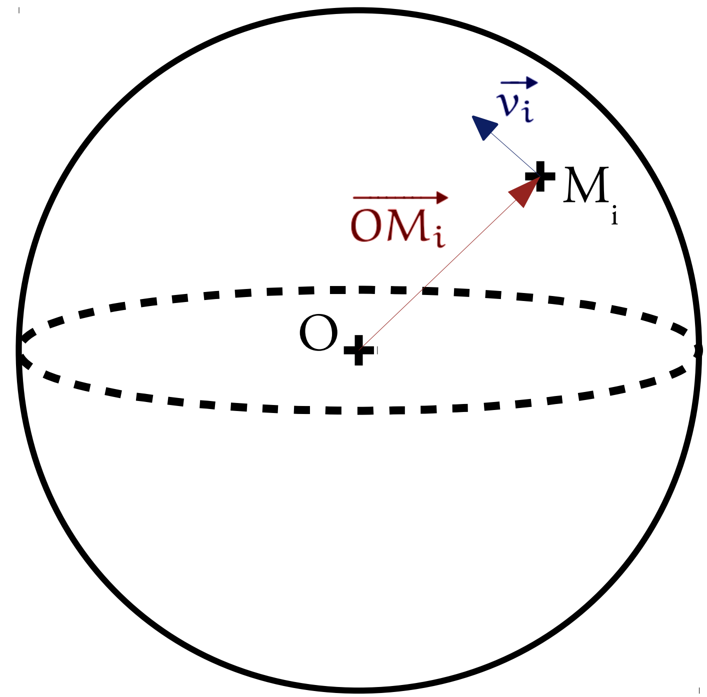


No initial velocities $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} = \vec{0}$

$\Longrightarrow$ no rotating Larson core

2 important hypothesis:

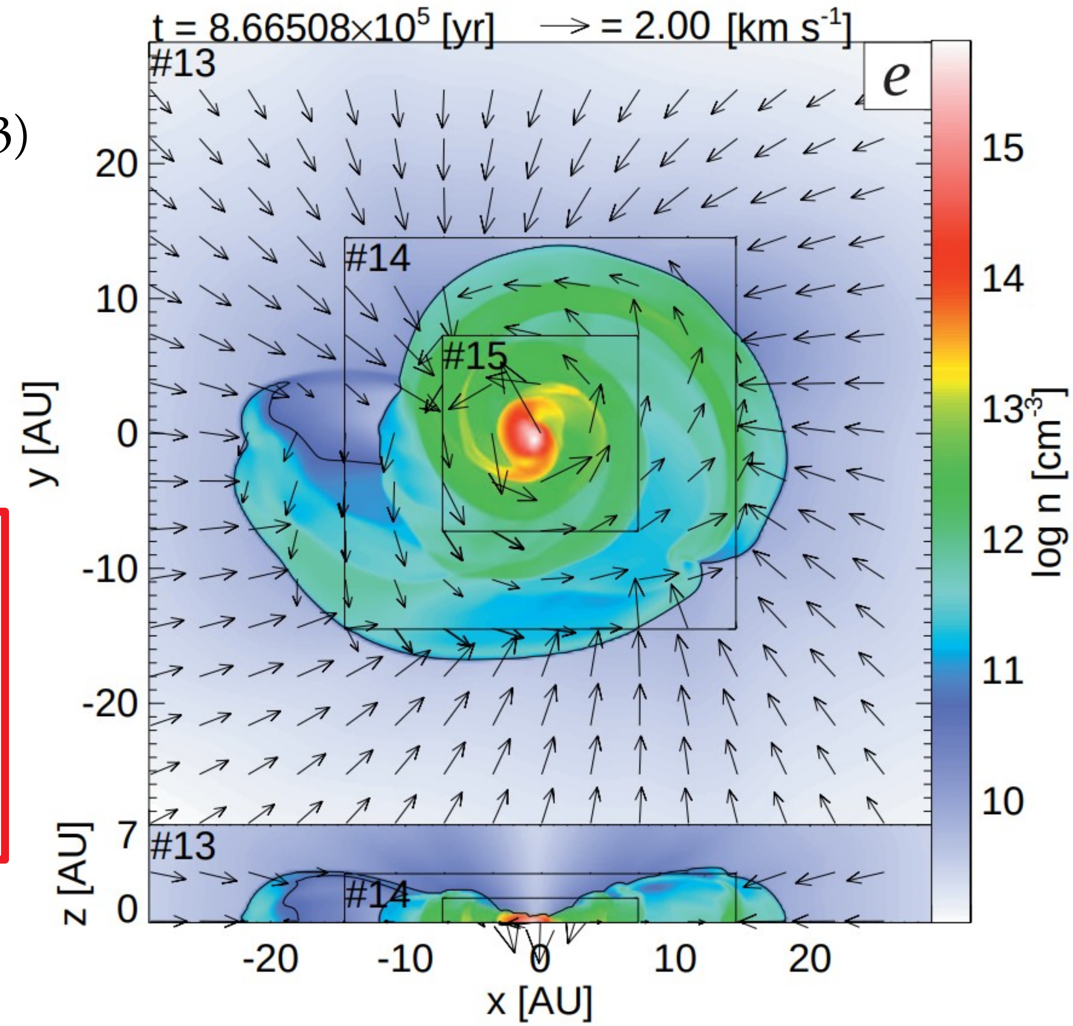
- Axisymmetrical collapse
- Isolated system



Initial rotation $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} \neq \vec{0}$

$\Longrightarrow$ formation of a disk

from Matsumoto & Hanawa (2003)



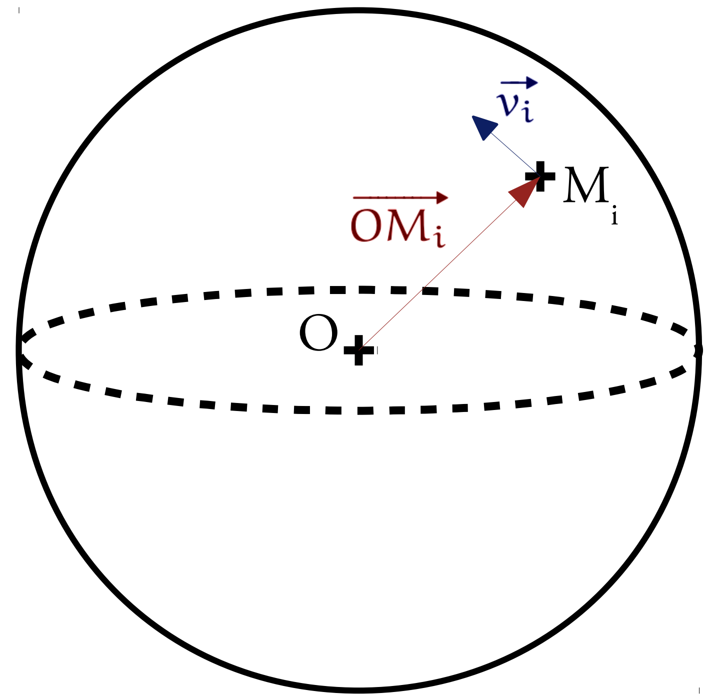
Bate (1998)
Matsumoto & Hanawa(2003)
Machida et al. (2005)
Hennebelle & Fromang (2008)

Initial rotation $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} \neq \vec{0}$

$\Longrightarrow$ formation of a disk

2 important hypothesis:

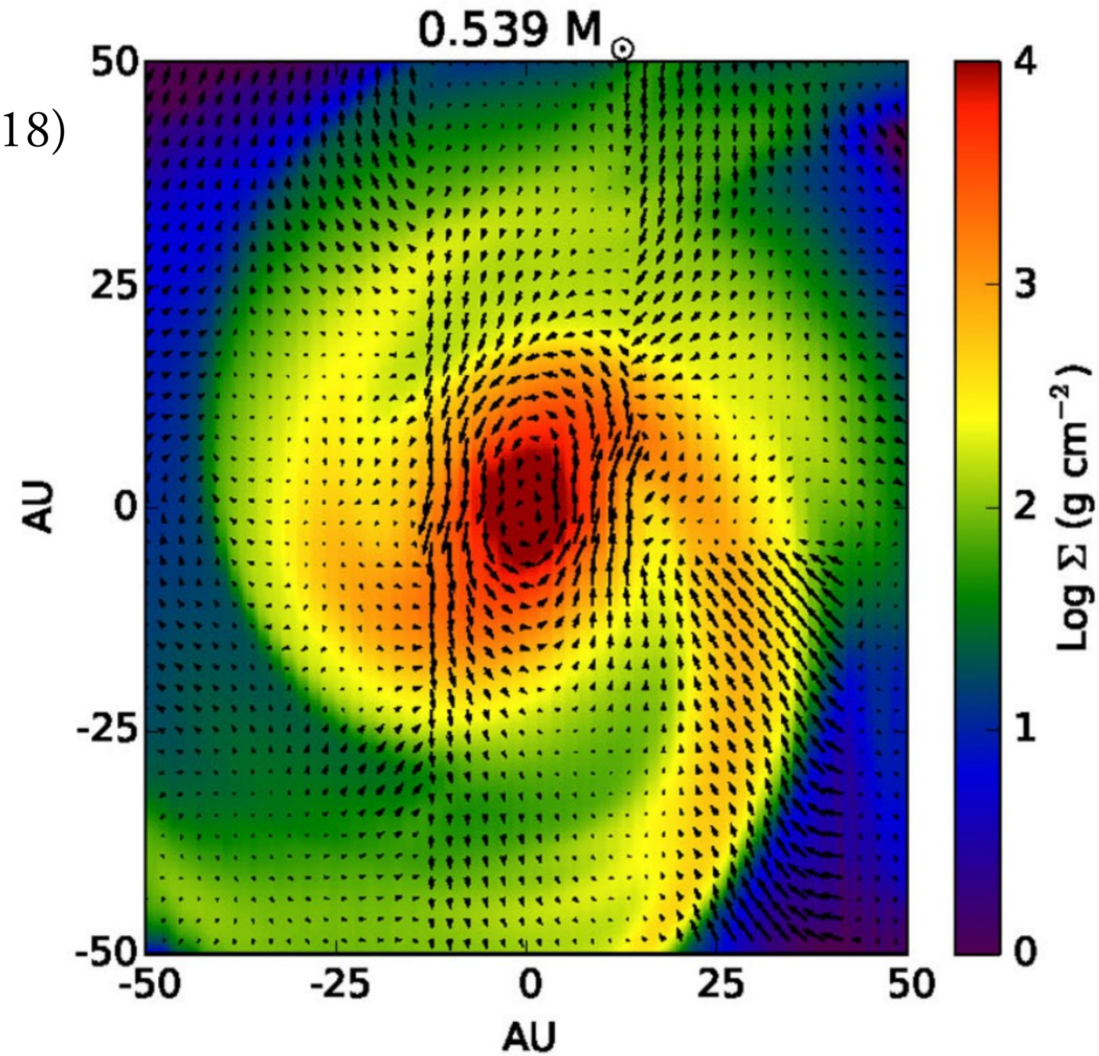
- Axisymmetrical collapse
- Isolated system



Initial turbulent velocity field $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} \neq \vec{0}$

$\Longrightarrow$ formation of a disk

from Gray et al. (2018)



Bate et al. (2003)
Goodwin et al. (2004)
Dib et al. (2010)
Hennebelle et al. (2016)
Gray et al. (2018)
Kuznetsova et al. (2019)

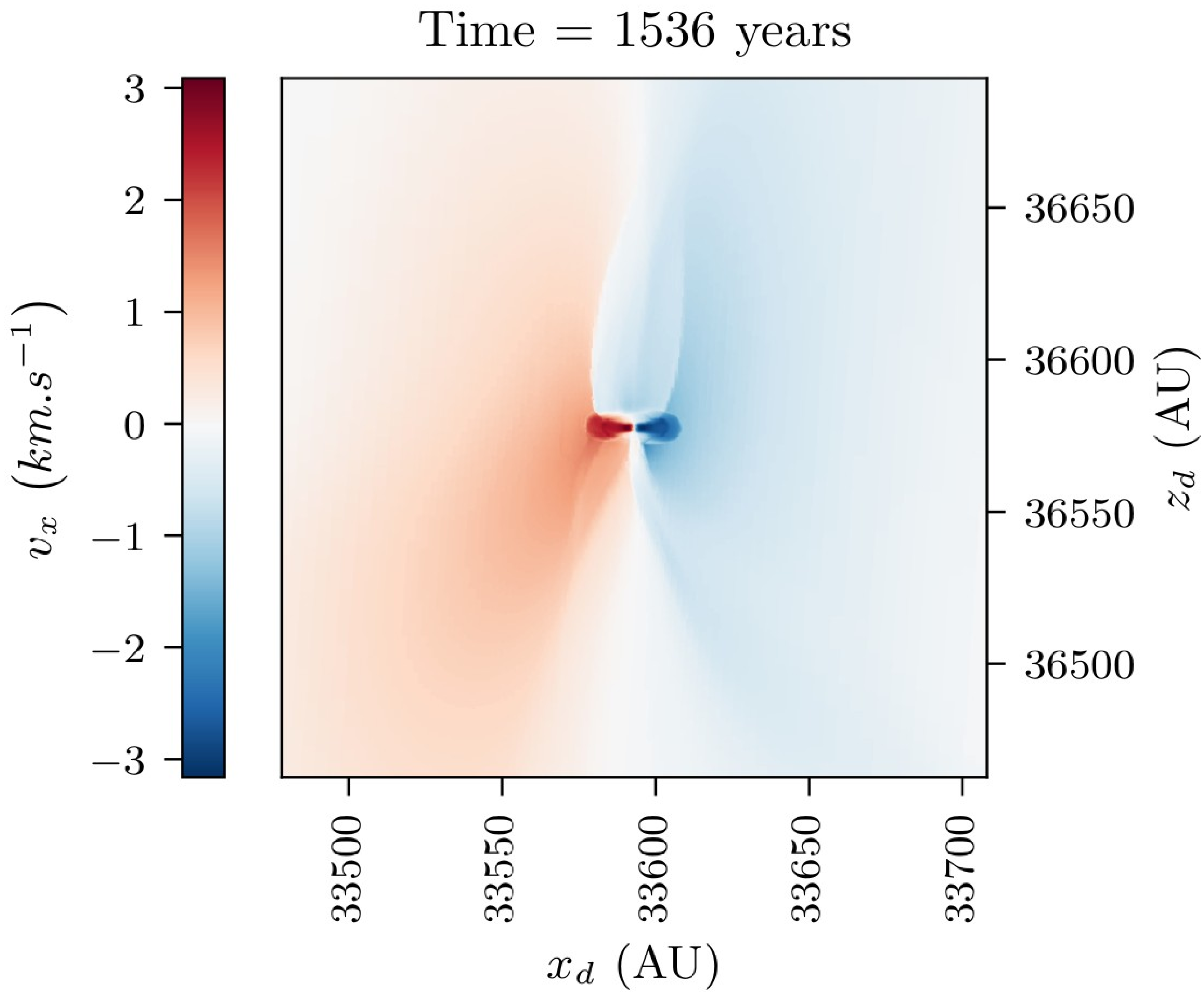
Initial turbulent velocity field $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} \neq \vec{0}$

$\Longrightarrow$ formation of a disk

- From which scale the angular momentum is inherited?

- Large disk = important large scale rotation?
  Small disk = low large scale rotation?

- Observationally: interpretation of velocity gradients as rotation is questionnable when observing misaligned or even reversed velocity gradients.


Time = 1536 years
3
2
1
0
−1
−2
−3
v_x $(km.s^{-1})$
36650
36600
36550
36500
z_d (AU)
33500
33550
33600
33650
33700
x_d (AU)

- From which scale the angular momentum is inherited?

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- Observationally: interpretation of velocity gradients as rotation is questionnable when observing misaligned or even reversed velocity gradients.

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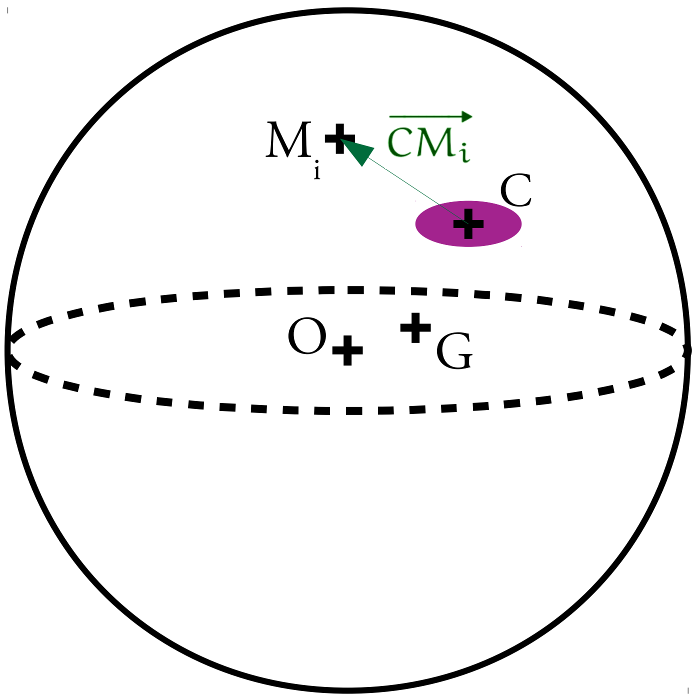
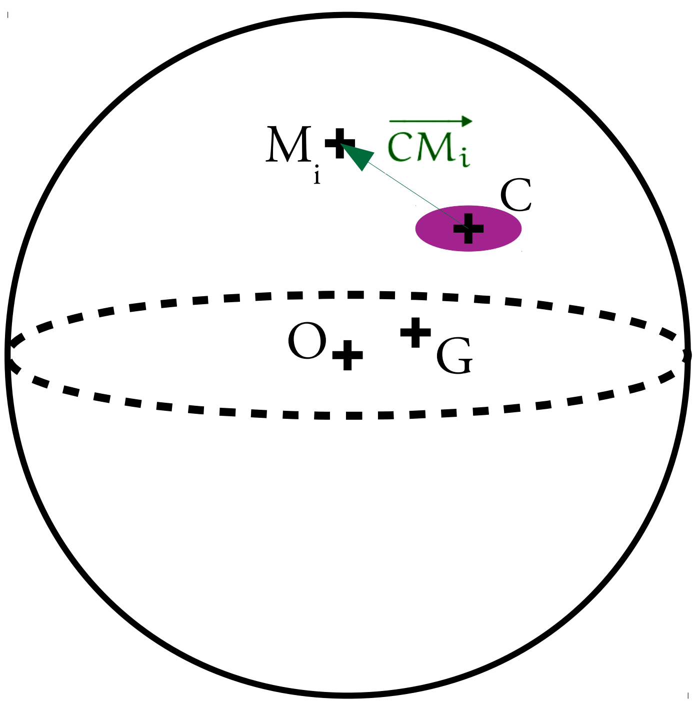
$$\vec{v_i} = \vec{0}$$



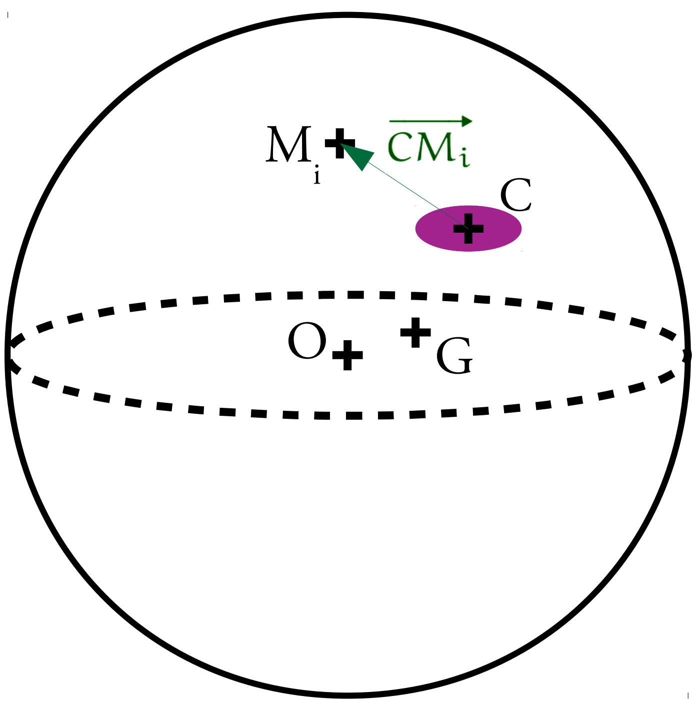
$$\overrightarrow{v_i} = \vec{0}$$

$$\sum_i m_i \overrightarrow{OM_i} \wedge \overrightarrow{v_i} = \vec{0}$$



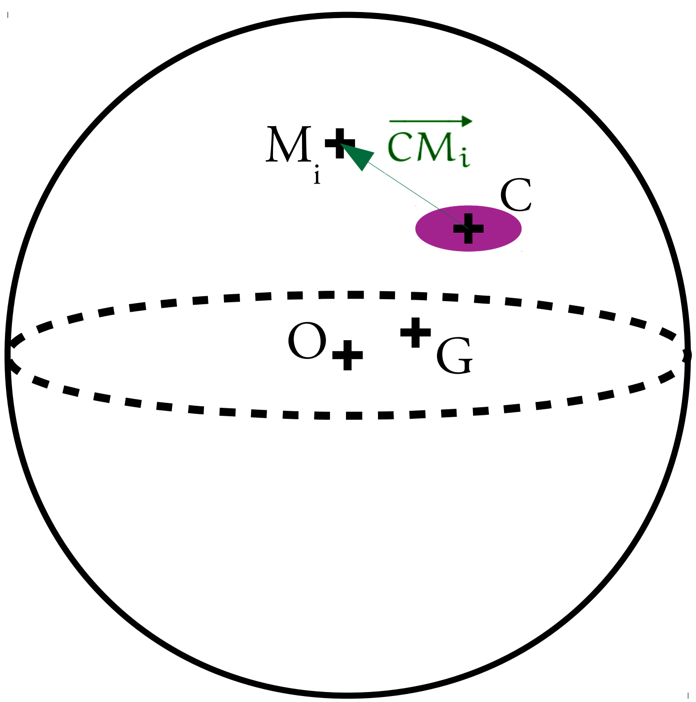
$$\vec{v_i} = \vec{0}$$

$$\sum_i m_i O \cdots \wedge \vec{v_i} = \vec{0}$$



$$\vec{v_i} = \vec{0}$$

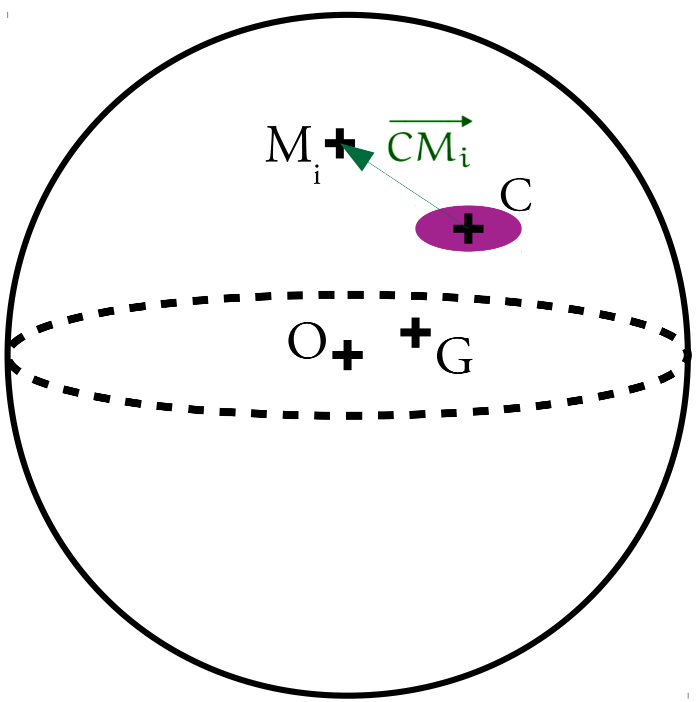
$$\sum_i m_i \mathrm{O}\cdots \wedge \vec{v_i} = \vec{0} \Longrightarrow \vec{\sigma_C}\big|_{\mathcal{R}'} = \sum_i m_i \overrightarrow{CM_i} \wedge \frac{d\overrightarrow{CM_i}}{dt}$$



$$\vec{v_i} = \vec{0}$$

$$\sum_i m_i O \ldots \wedge \vec{v_i} = \vec{0} \implies \vec{\sigma_C}\Big|_{\mathcal{R}'} = \sum_i m_i \overrightarrow{CM_i} \wedge \frac{d\overrightarrow{CM_i}}{dt}$$

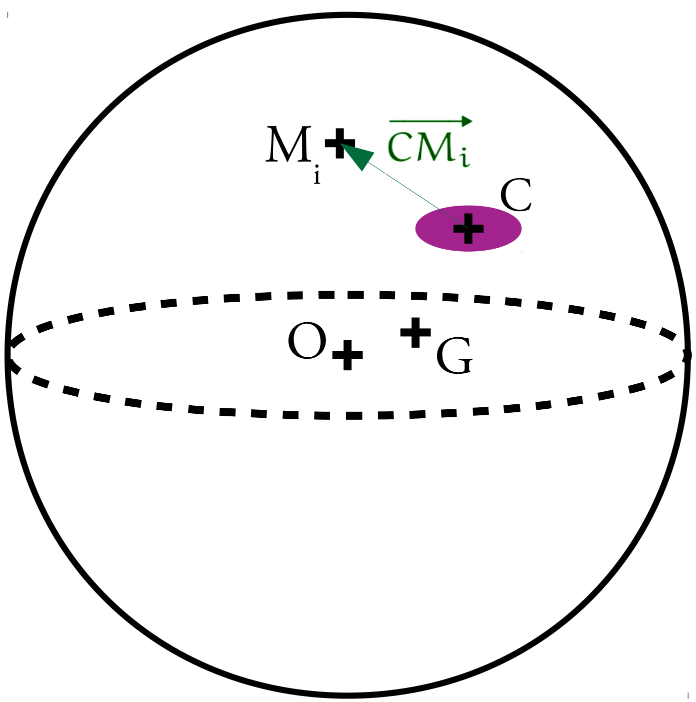
$$\implies \vec{\sigma_C}\Big|_{\mathcal{R}'} = M\overrightarrow{GC} \wedge \frac{d\overrightarrow{OC}}{dt}$$



$$\vec{v_i} = \vec{0}$$

$$\sum_i m_i O \ldots \wedge \vec{v_i} = \vec{0} \Longrightarrow \vec{\sigma_C}\big|_{\mathcal{R}'} = \sum_i m_i \overrightarrow{CM_i} \wedge \frac{d\overrightarrow{CM_i}}{dt}$$

$$\Longrightarrow \vec{\sigma_C}\big|_{\mathcal{R}'} = M\overrightarrow{GC} \wedge \frac{d\overrightarrow{OC}}{dt}$$



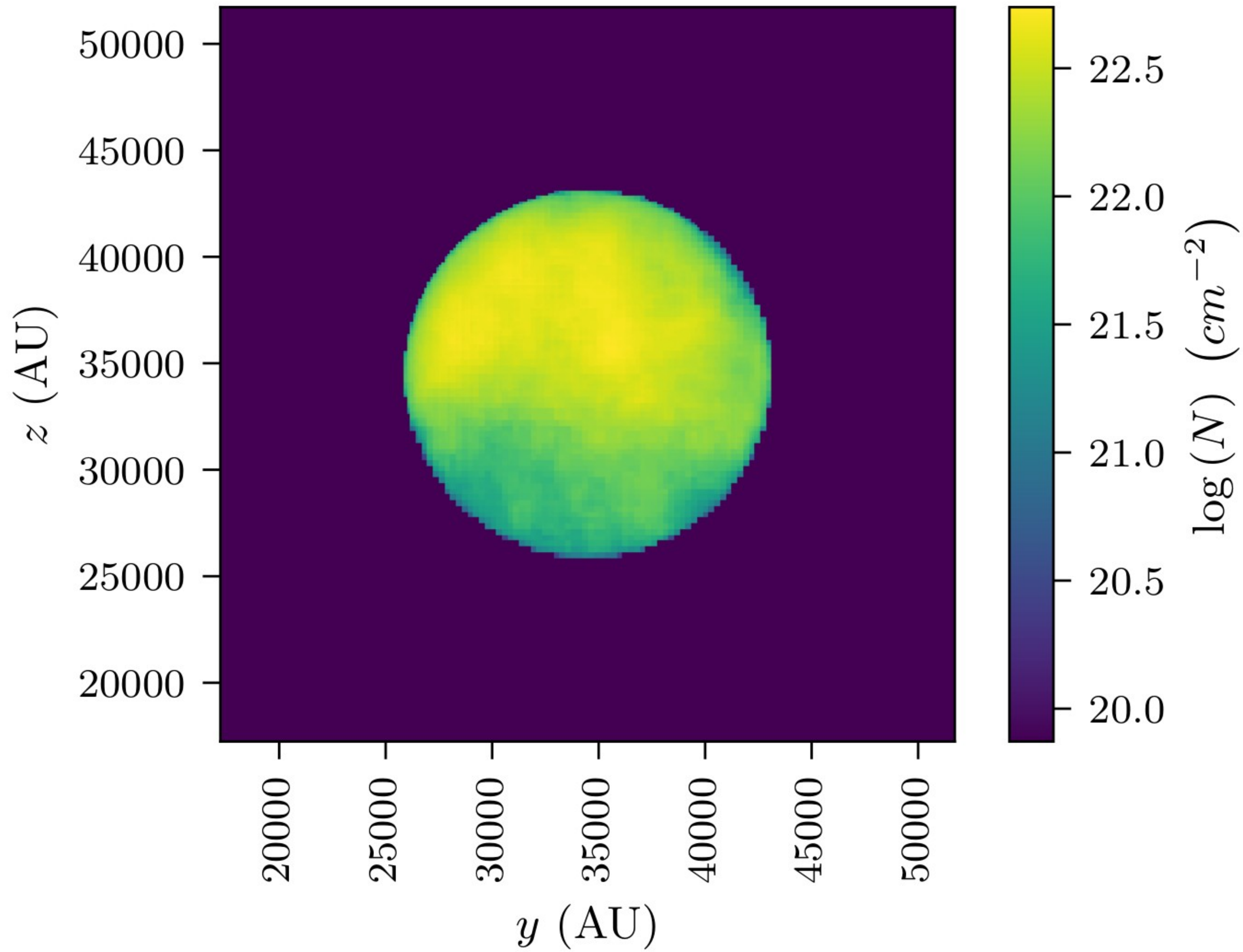
$$\frac{d\vec{\sigma_C}\big|_{\mathcal{R}'}}{dt} = M\overrightarrow{GC} \wedge \frac{d^2\overrightarrow{OC}}{dt^2}$$

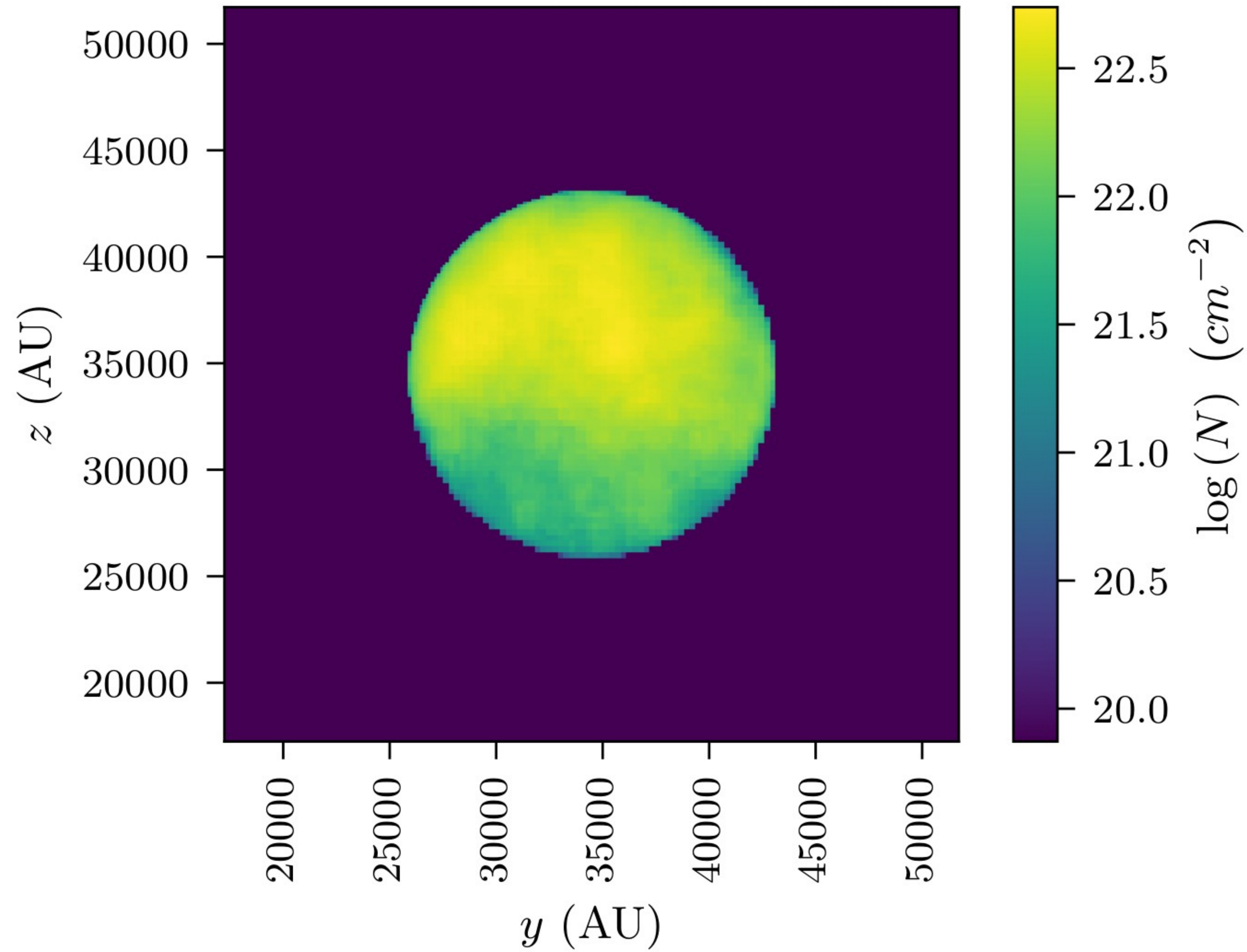
Effect of inertial force on each cells

RAMSES code →

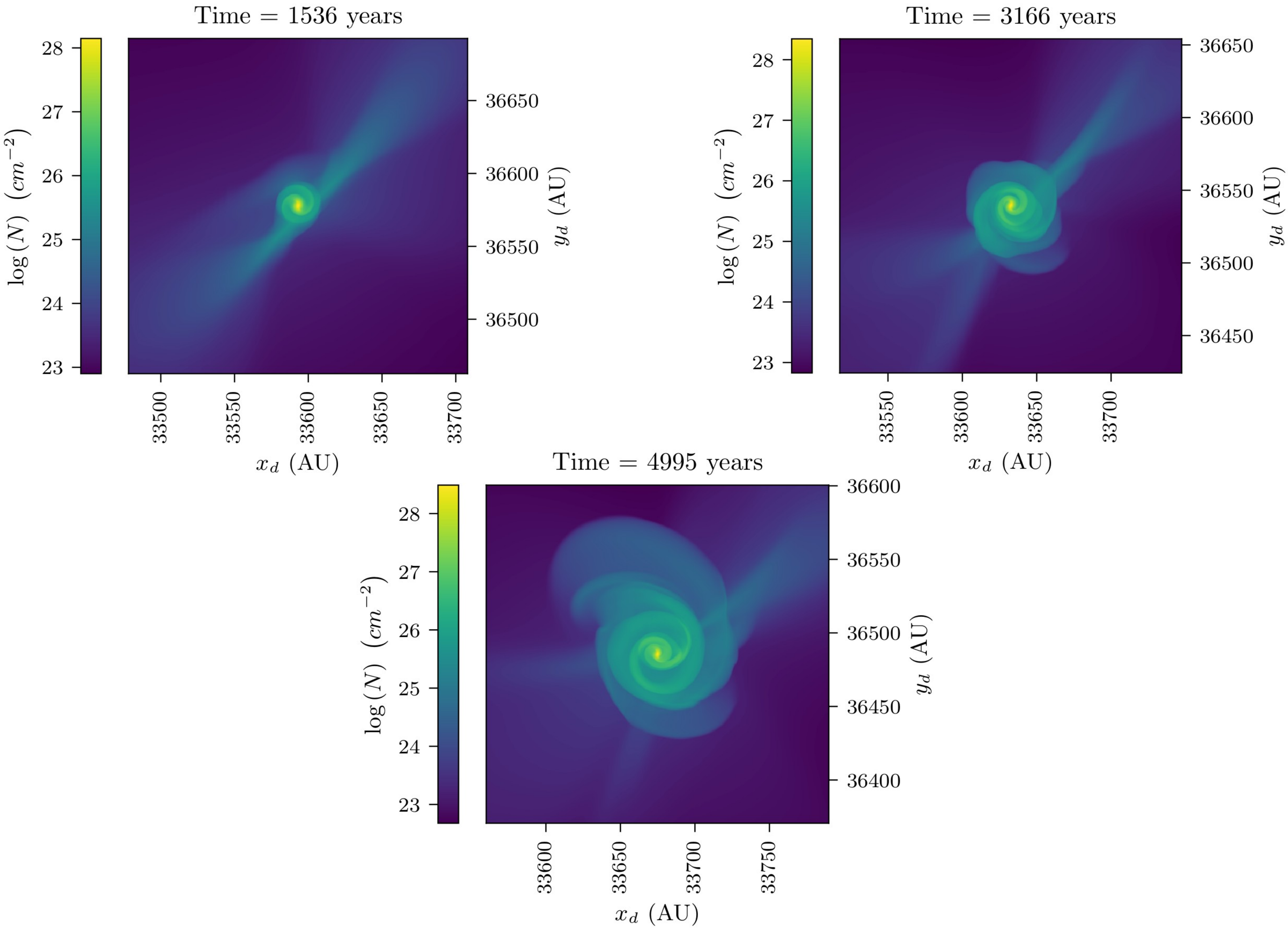
Hydrodynamics

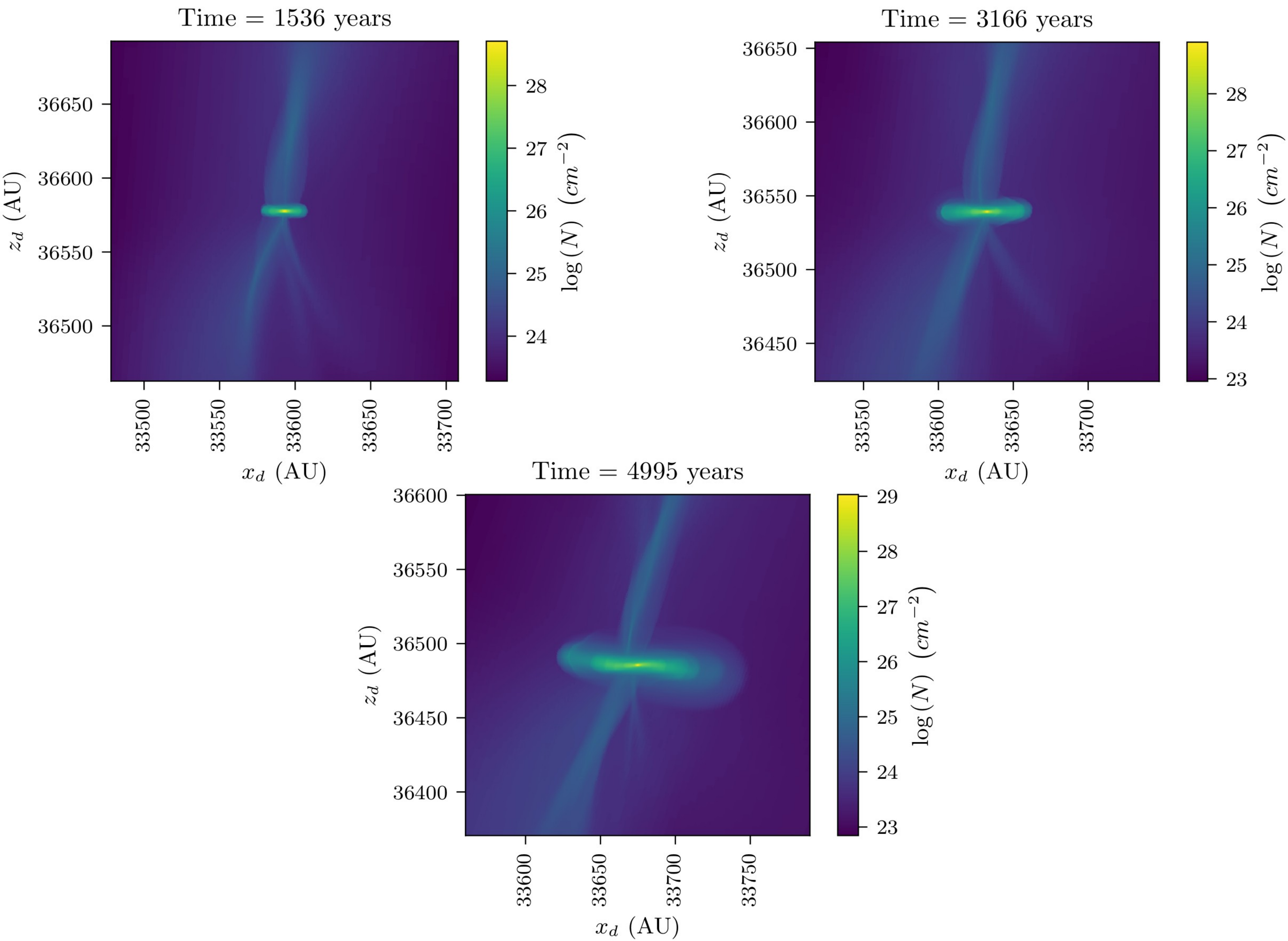
Gravitation


50000
45000
40000
35000
30000
25000
20000
z (AU)
20000
25000
30000
35000
40000
45000
50000
y (AU)
22.5
22.0
21.5
21.0
20.5
20.0
log (N) (cm^-2)



NO initial velocities $\Longrightarrow$ $\sum_i m_i \overrightarrow{OM_i} \wedge \vec{v_i} = \vec{0}$


Time = 1536 years
Time = 3166 years
Time = 4995 years
log(N) (cm^-2)
28
27
26
25
24
23
x_d (AU)
y_d (AU)
33500
33550
33600
33650
33700
33750
36400
36450
36500
36550
36600
36650


Time = 1536 years
z_d (AU)
36650
36600
36550
36500
33500
33550
33600
33650
33700
x_d (AU)
$\log(N)\ (cm^{-2})$
24
25
26
27
28
Time = 3166 years
z_d (AU)
36650
36600
36550
36500
36450
33550
33600
33650
33700
x_d (AU)
$\log(N)\ (cm^{-2})$
23
24
25
26
27
28
Time = 4995 years
z_d (AU)
36600
36550
36500
36450
36400
33600
33650
33700
33750
x_d (AU)
$\log(N)\ (cm^{-2})$
23
24
25
26
27
28
29

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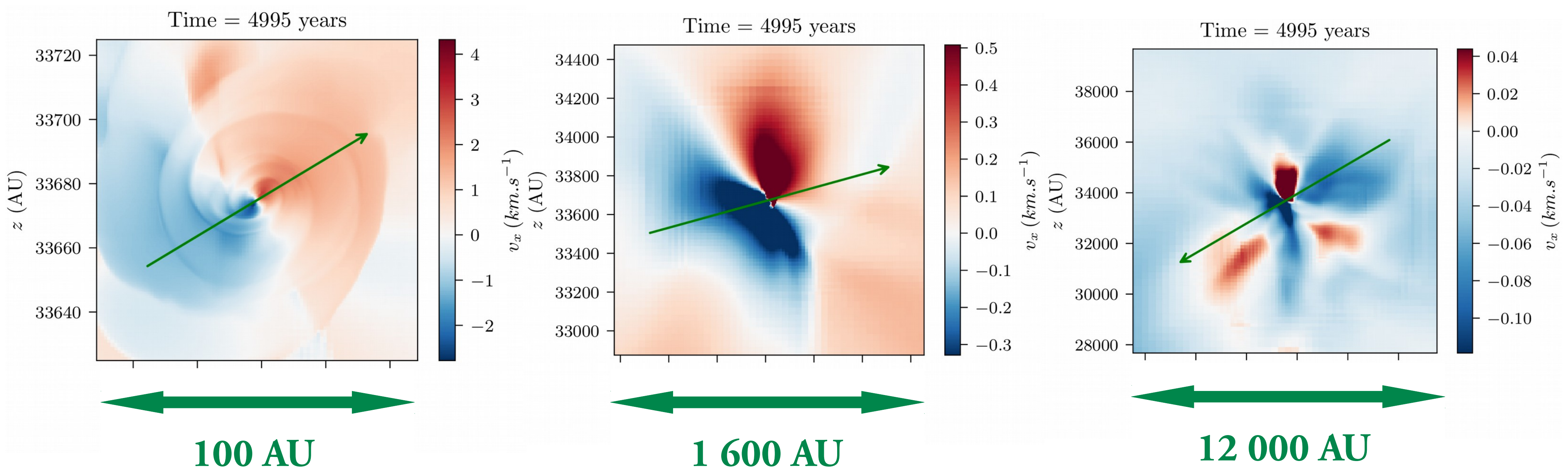
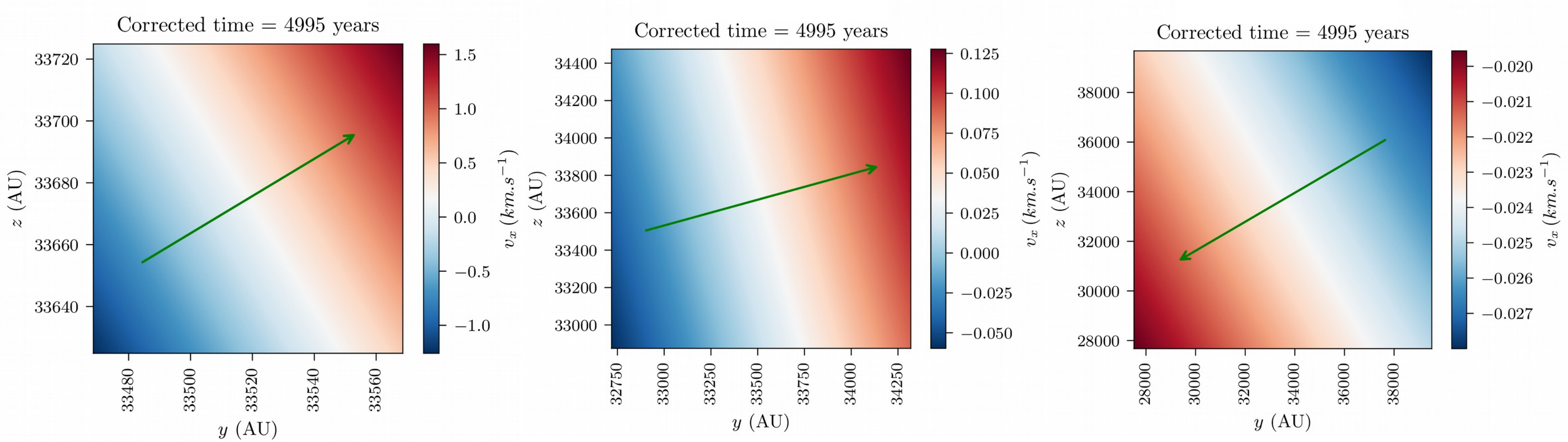
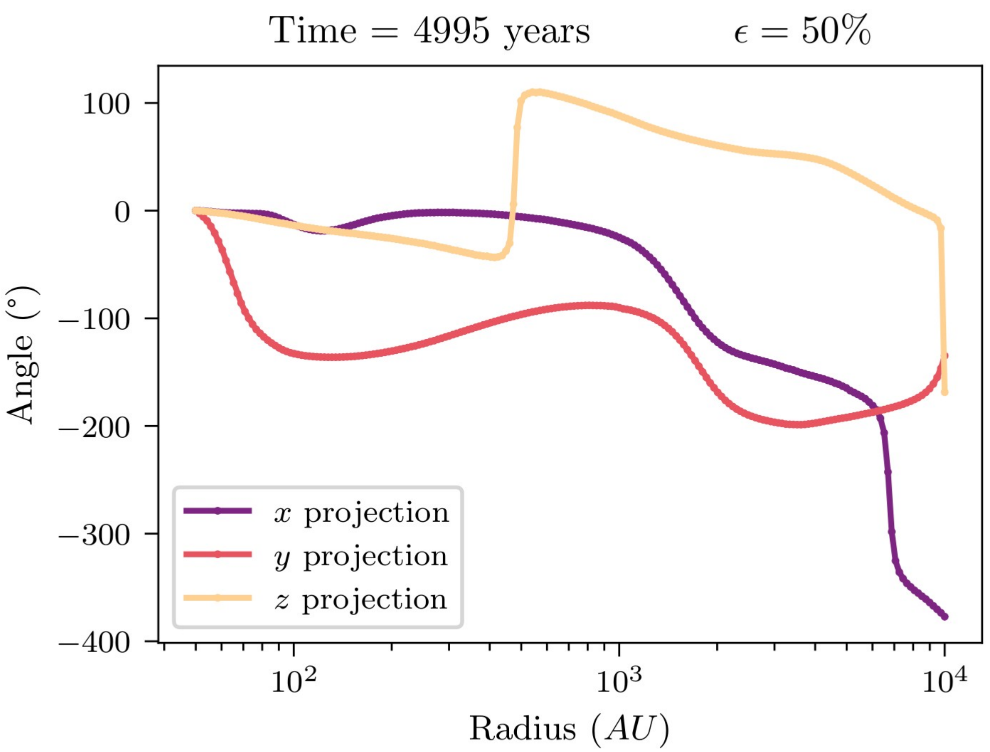
Velocity gradients analysis – method

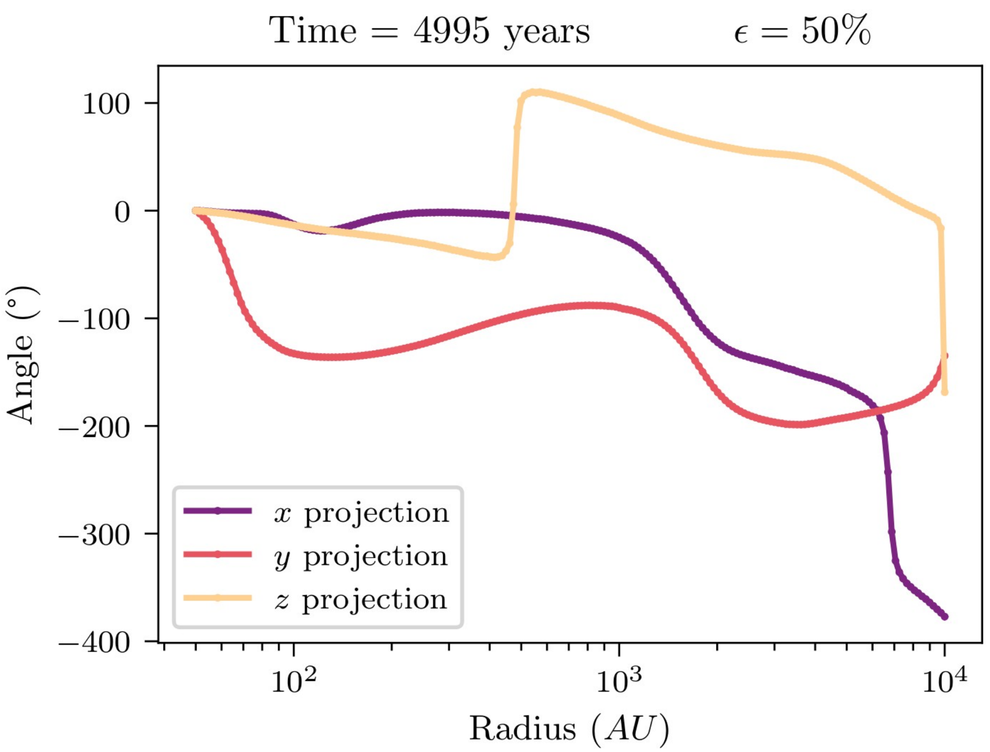


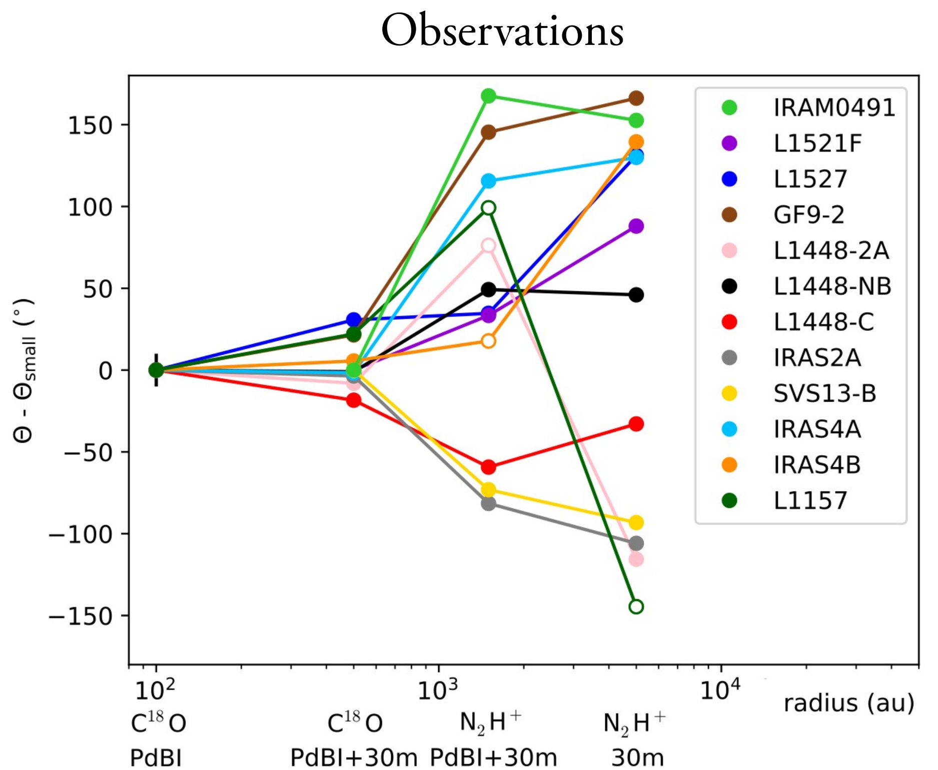
Fitted by a solid-body rotation profile



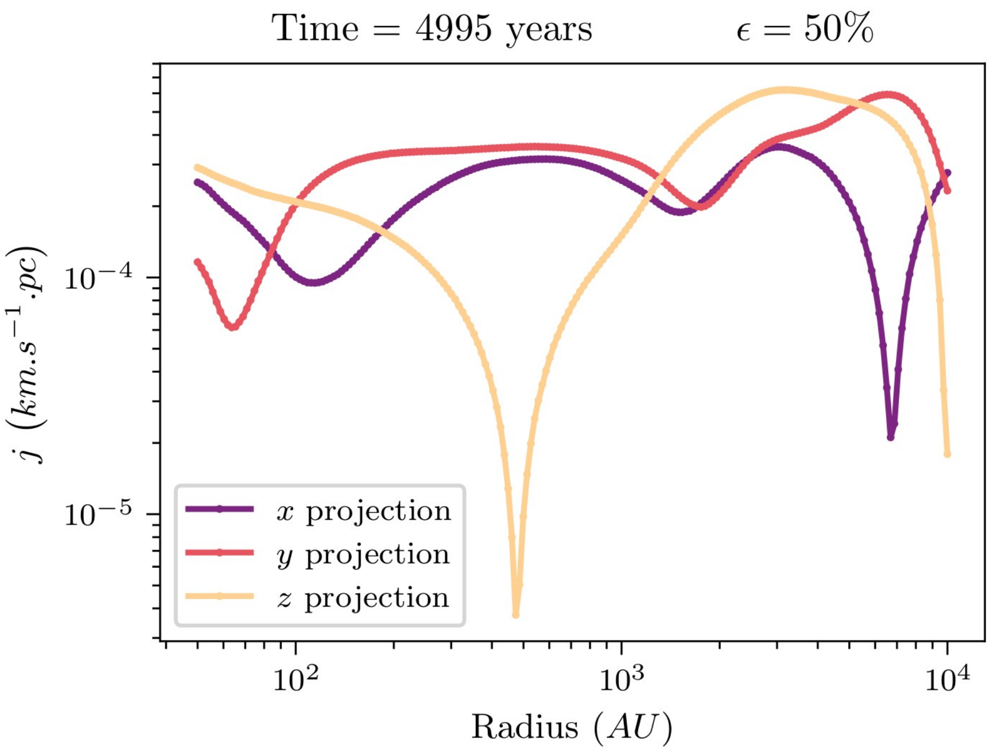

Time = 4995 years
$\epsilon = 50\%$
100
0
−100
−200
−300
−400
Angle (°)
10^2
10^3
10^4
Radius (AU)
x projection
y projection
z projection

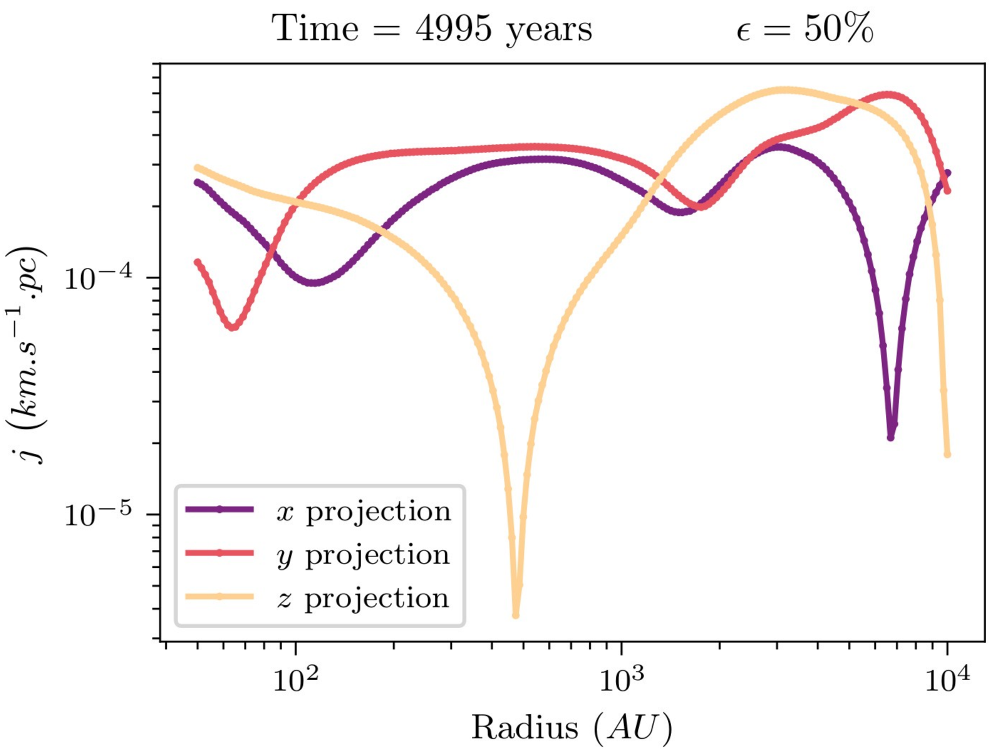
Velocity gradients analysis – results



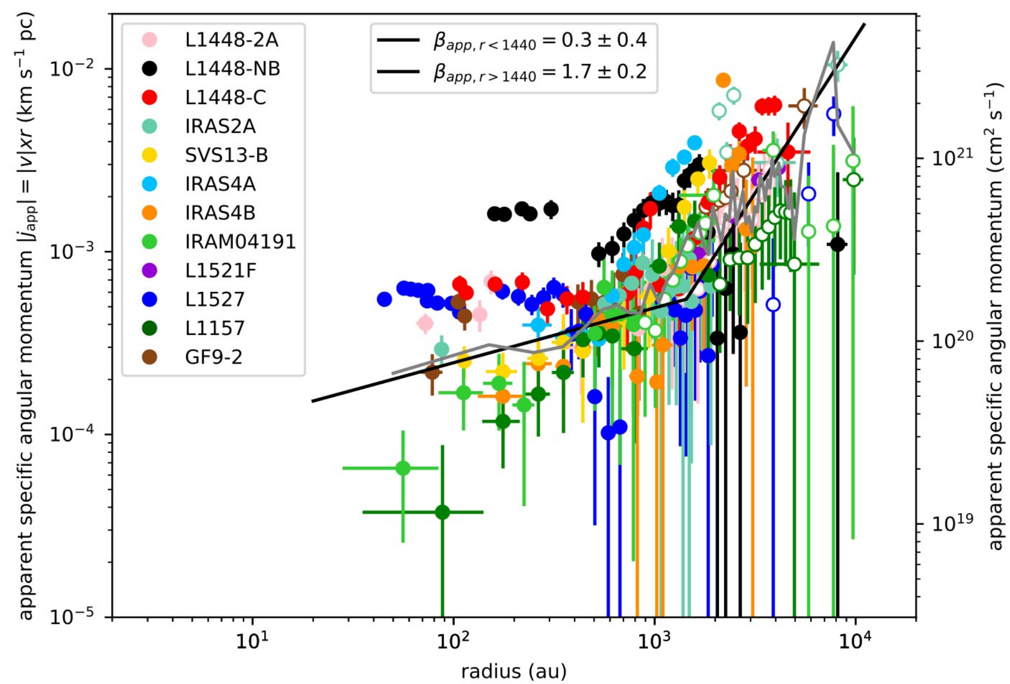


from Gaudel+CALYPSO (accepted)

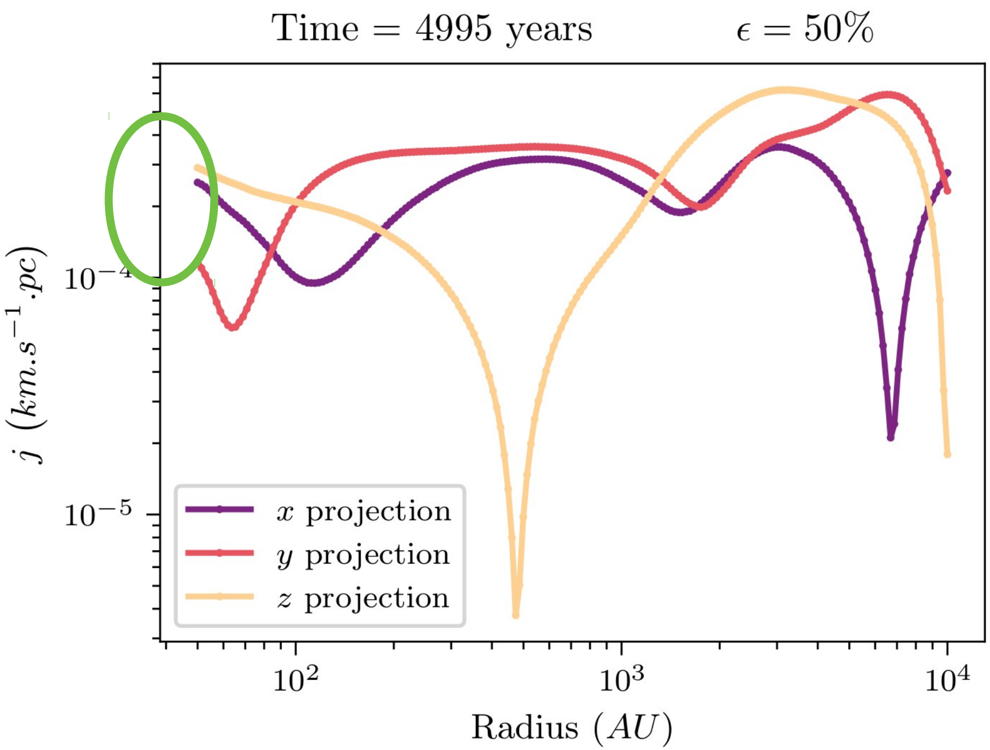

Time = 4995 years
ε = 50%
$j\ (km.s^{-1}.pc)$
10^{-4}
10^{-5}
10^{2}
10^{3}
10^{4}
Radius (AU)
x projection
y projection
z projection



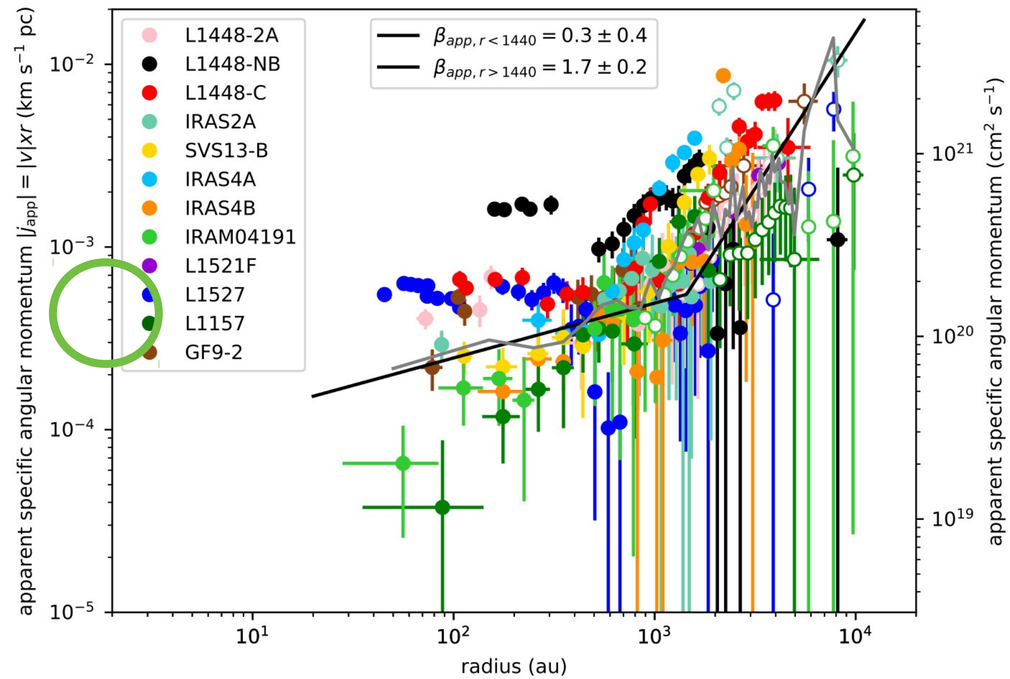
Observations



from Gaudel+CALYPSO (in prep.)



Observations



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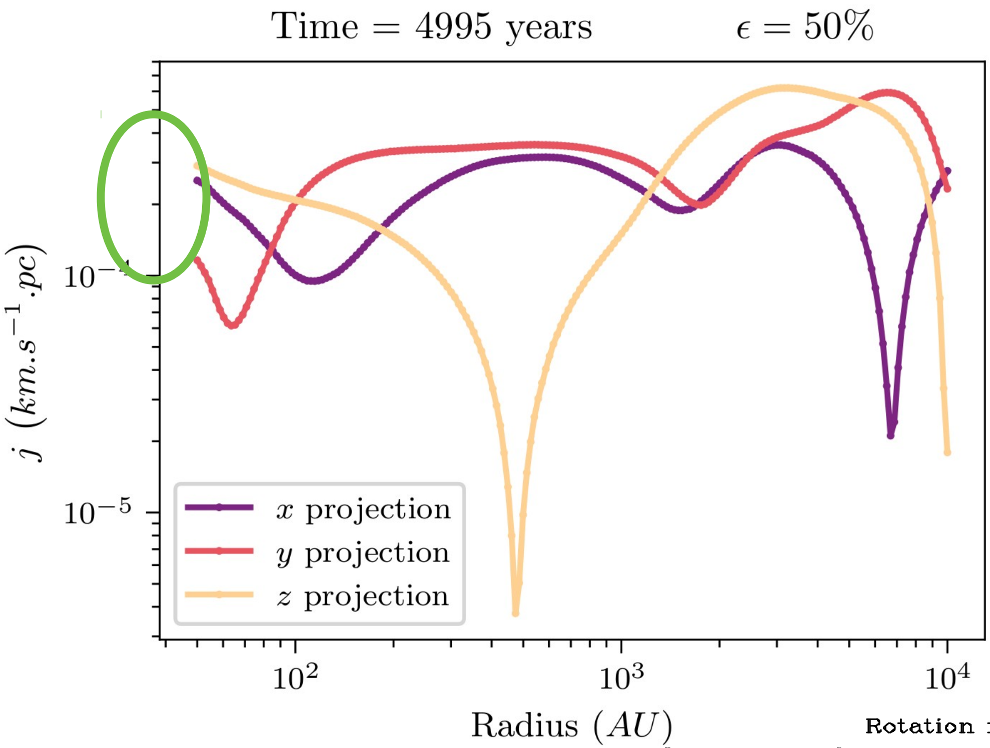
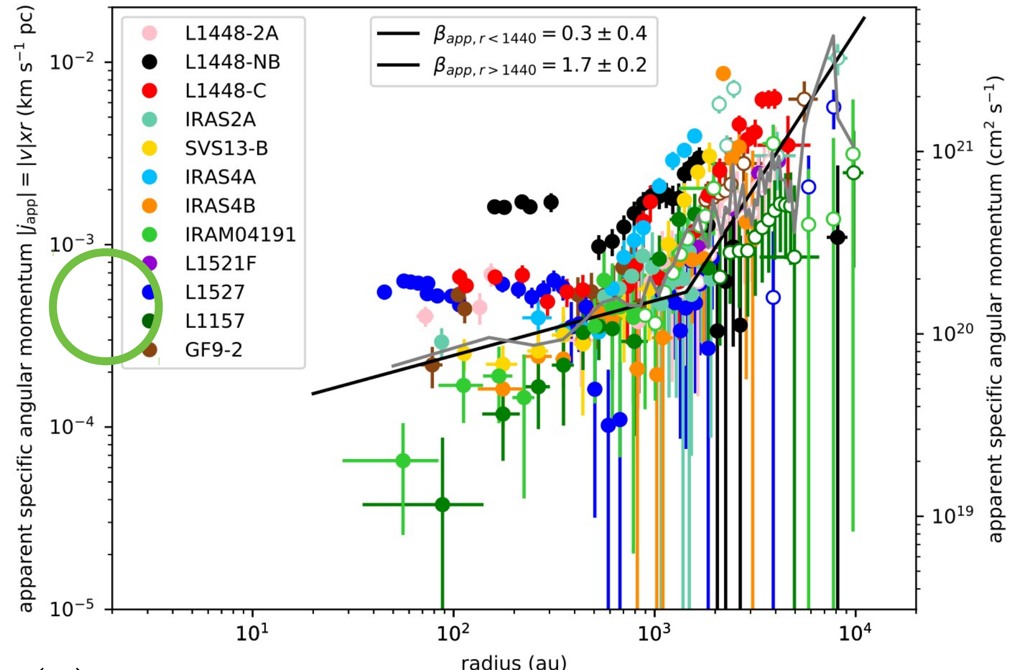
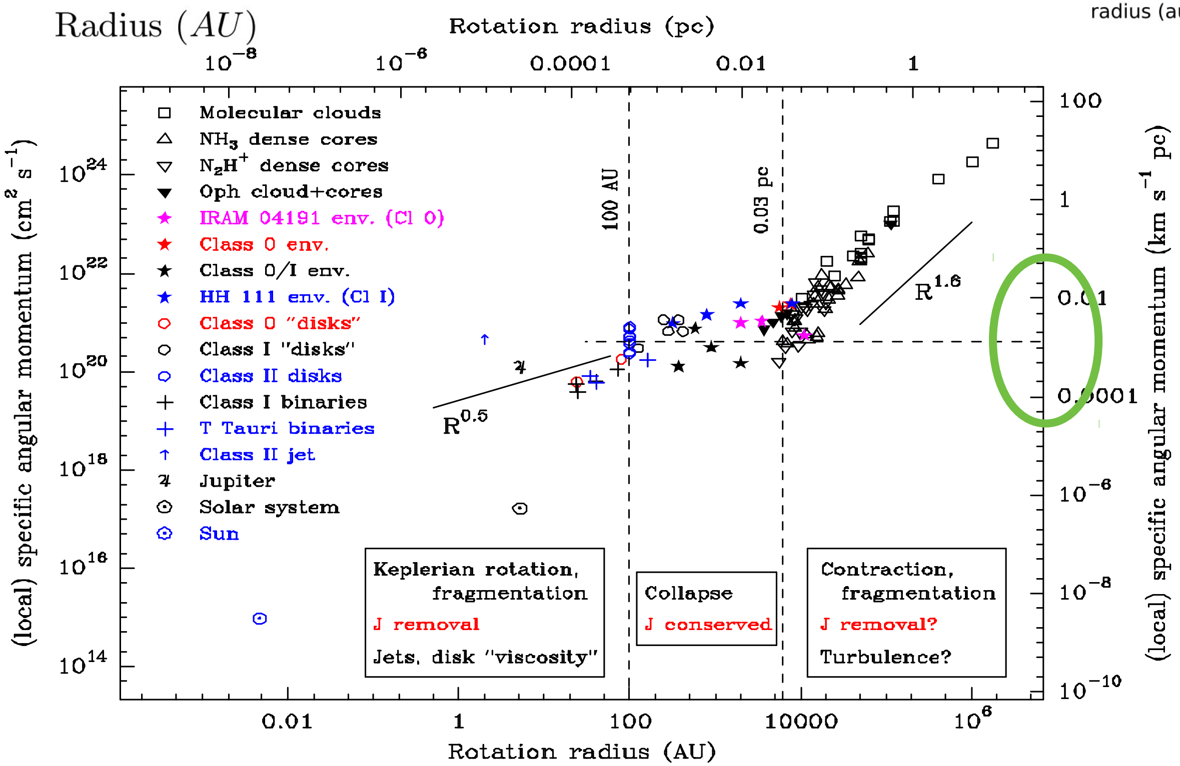
Velocity gradients analysis – results







from Belloche (2013)

Gaudel+CALYPSO (accepted) →

- $j \propto R^{0.2}$ for R < 1000 AU
- around $3\,.10^{-4}\,\mathrm{km.s^{-1}.pc}$
- strong misalignement of velocity gradients between disk and envelope

Conclusion

- The angular momentum *computed in the frame of the disk, in relation to the center of the disk* is not conserved

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→ Rotation can be generated « locally » by the asymmetry of the collapse

→ A new paradigm?
At least for some sources?

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  → Rotation can be generated « locally » by the asymmetry of the collapse

  → A new paradigm?
  At least for some sources?

- Disks seems to be natural outcomes of a collapse, as soon as it is « a bit » asymmetric

Thank you for your attention !

Antoine Verliat

Supervisor: Patrick Hennebelle

28th of February, 2020

- RAMSES code → Hydrodynamics, Gravitation

- 3D cubic box: sides of 70 000 AU (0.33 pc)

- 10 levels of AMR → 0.26 AU equivalent maximal resolution

- Prestellar dense core: 17 500 AU in diameter, 2.5 $M_\odot$

- The angular momentum *computed in the frame of the disk, in relation to the center of the disk* is not conserved

  → Rotation can be generated « locally » by the asymmetry of the collapse

  → A new paradigm?
  At least for some sources?

- Disks seems to be natural outcomes of a collapse, as soon as it is « a bit » asymmetric

- Large disks → necessity for angular momentum extraction mechanisms

- MHD → smaller disks

- Density fluctations + initial rotation → higher specific angular momentum
  → angular dispersion of velocity gradient lower

Conclusion

- The angular momentum *computed in the frame of the disk, in relation to the center of the disk* is not conserved

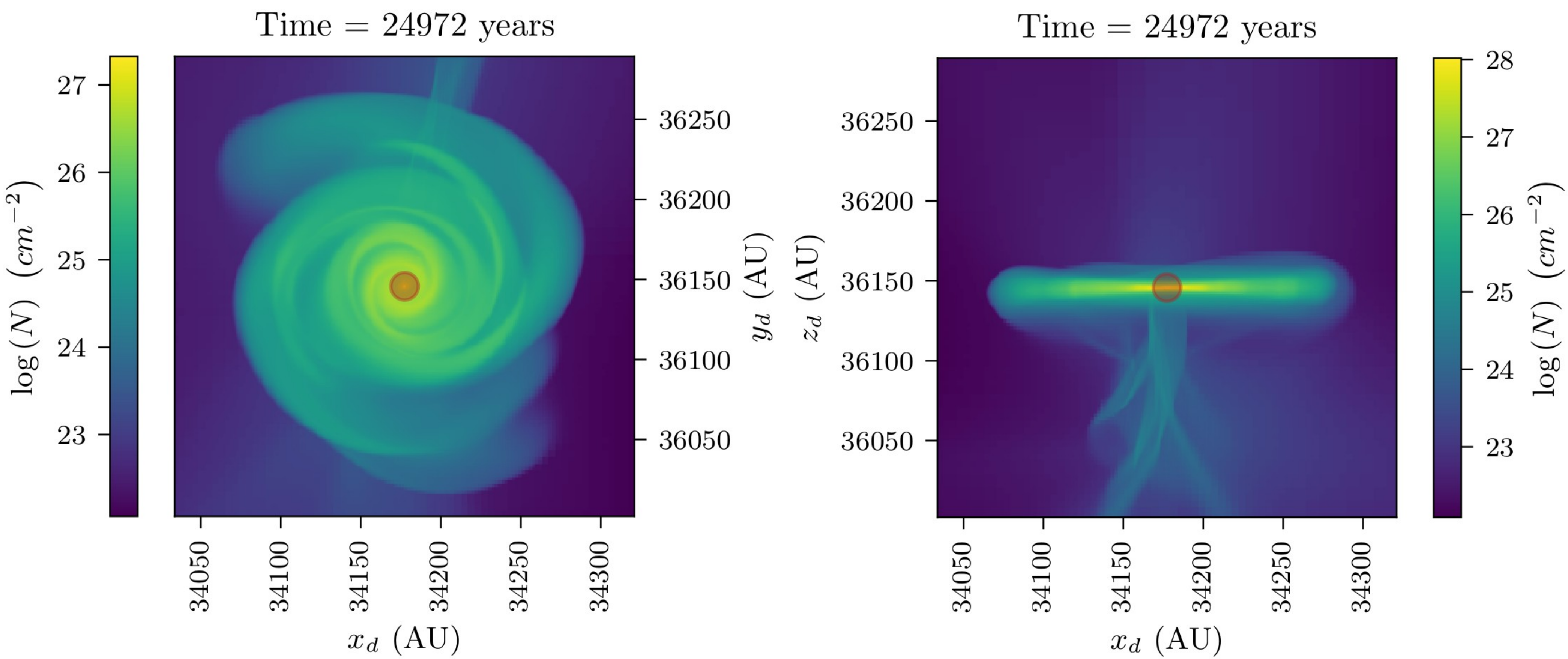
  → Rotation can be generated « locally » by the asymmetry of the collapse

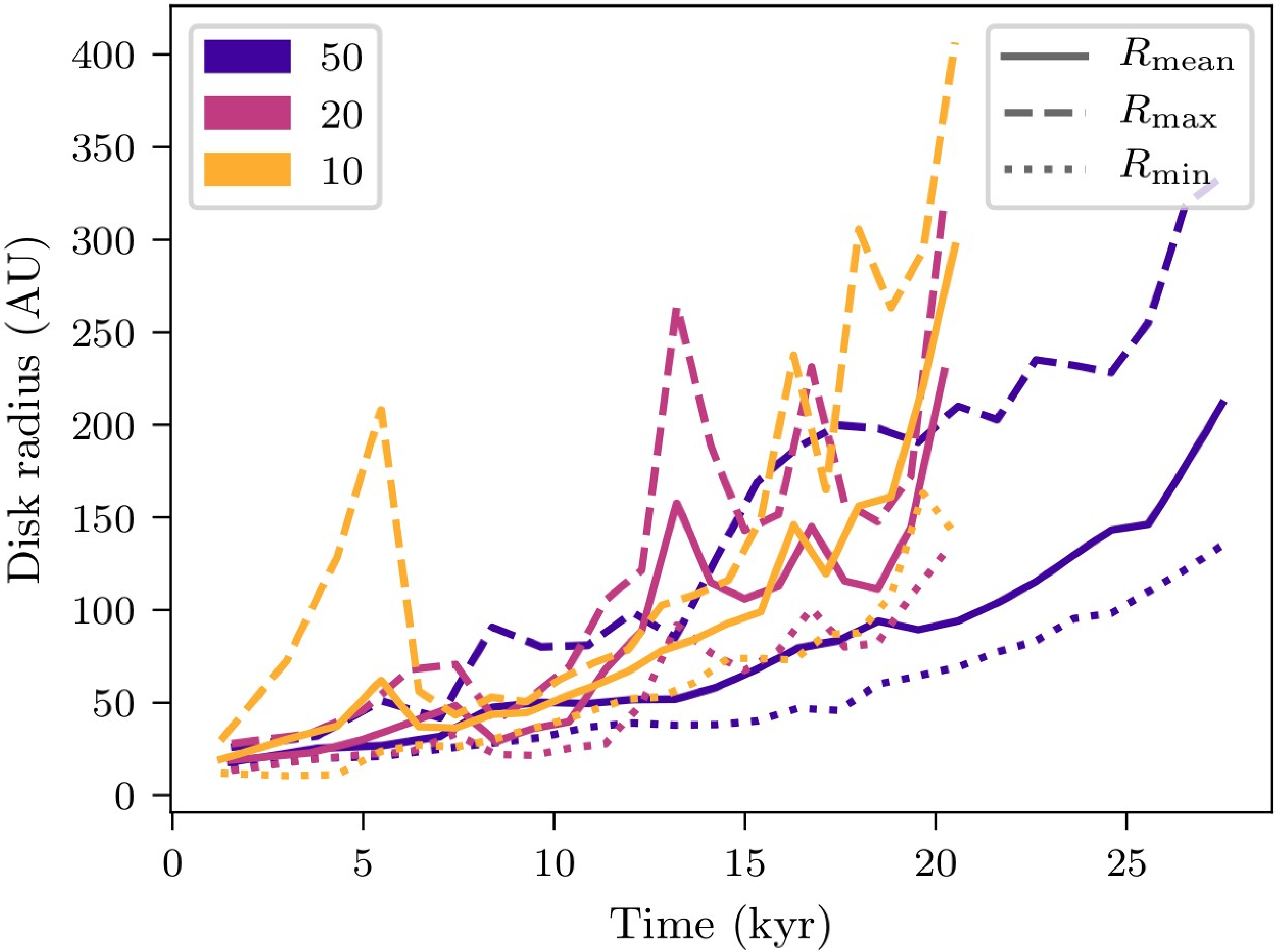
  → A new paradigm?
  At least for some sources?

- Disks seems to be natural outcomes of a collapse, as soon as it is « a bit » asymmetric

- Large disks → necessity for angular momentum extraction mechanisms

- MHD → smaller disks


Time = 24972 years
Time = 24972 years
$\log(N)$ (cm^{-2})
x_d (AU)
y_d (AU)
z_d (AU)
27
26
25
24
23
28
34050
34100
34150
34200
34250
34300
36250
36200
36150
36100
36050


50
20
10
R_{mean}
R_{max}
R_{min}
Disk radius (AU)
Time (kyr)
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25