Vortex formation in self-gravitating protoplanetary disks

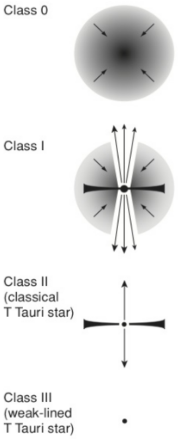
Kristóf Rozgonyi[1], Zsolt Regály[2]

[1]Eötvös Loránd University, Budapest

[2]Konkoly Observatory, Budapest

PAPAP, Gran Sasso,
5 October, 2016

Context I: protoplanetary disks



P. Armitage, (2010)

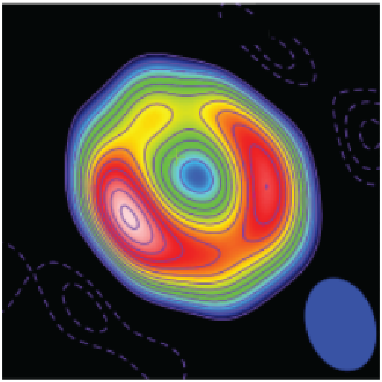
- Young stars form from diffuse gas clouds
- The cloud has too big angular momentum to collapse directly to a protostar
- For a few million years the disc exists in a quasi-static equilibrium
- To accrete, angular momentum must be lost or redistributed within the disk

Context II: vortices in disks

- Some protoplanetary discs show asymmetric brightness morphology
- Large-scale vortices are considered to be the origin of these structures
- These anticyclonic vortices can trap dust particles, providing proper conditions for planet formation
- Main question: what are the conditions for the formation of long-live vortices?

Context II: vortices in disks

- Some protoplanetary discs show asymmetric brightness morphology
- Large-scale vortices are considered to be the origin of these structures
- These anticyclonic vortices can trap dust particles, providing proper conditions for planet formation
- Main question: what are the conditions for the formation of long-live vortices?

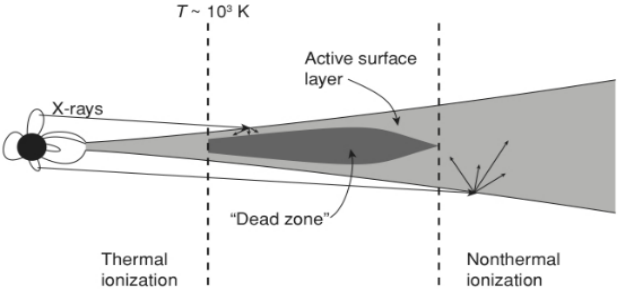


Brown et al., (2009)

The angular momentum problem

- Angular momentum can be transported trough friction
  $\Rightarrow$ viscosity of the gas is required
- Turbulence in the gas can be the origin of viscosity
- Problem: Keplerian rotation stabilizes the disc
  $\Rightarrow$ no turbulence in the gas
- If the disc is partially ionized Magneto-rotational instability (MRI) can cause an effective viscosity (α prescription)

Dead zone in protoplanetary disks

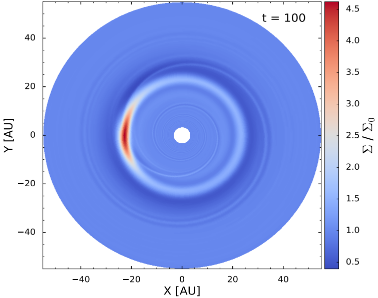


P. Armitage, (2010)

- In the poorly ionized region called "Dead zone" (DZ) the disc is not accreting
- Due to the reduced accretion the gas piles up
  $\Rightarrow$ density and pressure maximum develop

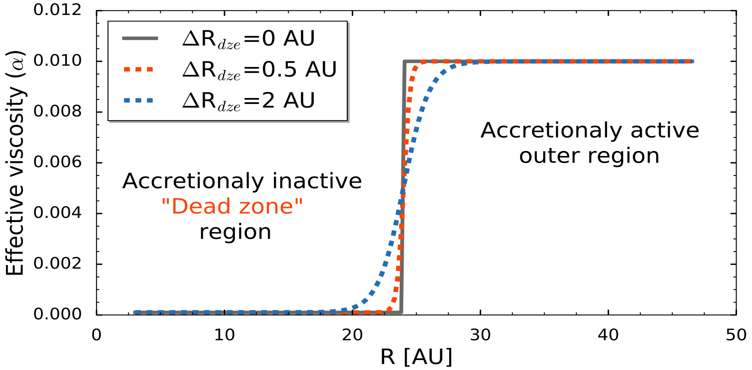
Rossby wave instability

- Density bump could trigger Rossby wave instability (RWI)
- RWI is an exponentially growing non-axisymmetric anticyclonic perturbation
- There is a pressure maximum in the eye of the vortex which can collect dust particles



Conditions for vortex formation in disks

- Vortex formation requires sharp viscosity transition



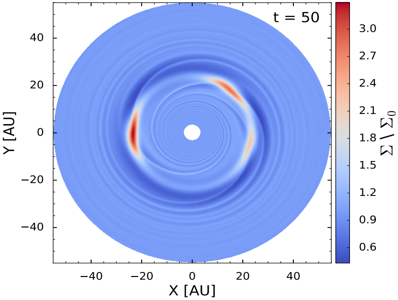
- Self-gravity of the disk could also play an important role in the formation and evolution of RWI

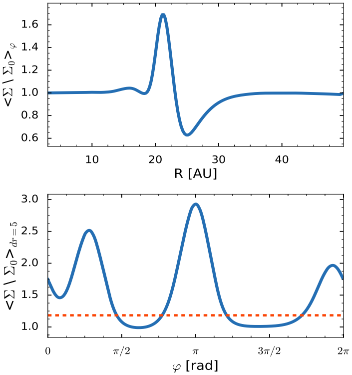
Set of disc simulations

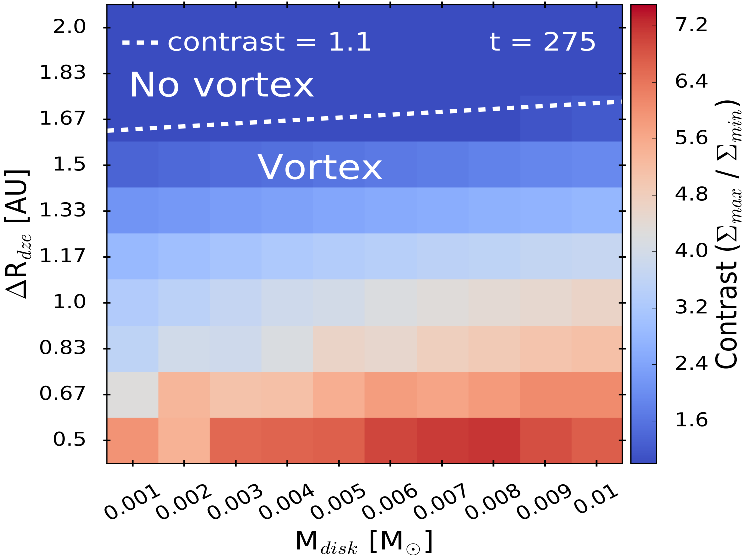
- We modeled vertically-integrated 2D disks with the GPU based GFARGO code
- We solved the Navier-Stokes and continuity equations with/without self-gravity in a local isothermal approximation
- We investigated the effect of the sharpness of the DZ edge and the mass of the disc on the formation of the vortex
- We modeled 100 disks in the parameter space:
  - $\Delta R_{dze} = 0.5$ - 2 AU
  - $M_{disc} = 0.001$ - 0.01 $M_\odot$
- Example simulation

Identification of vortices

- We cut a radial window around maxima of the disk profile normalized with the initial density profile
- We investigated the Fourier-spectra and the contrast ($\Sigma_{max}/\Sigma_{min}$) of the radially averaged azimutal profile
- Condition for vortex formation: azimutal contrast > 1.1

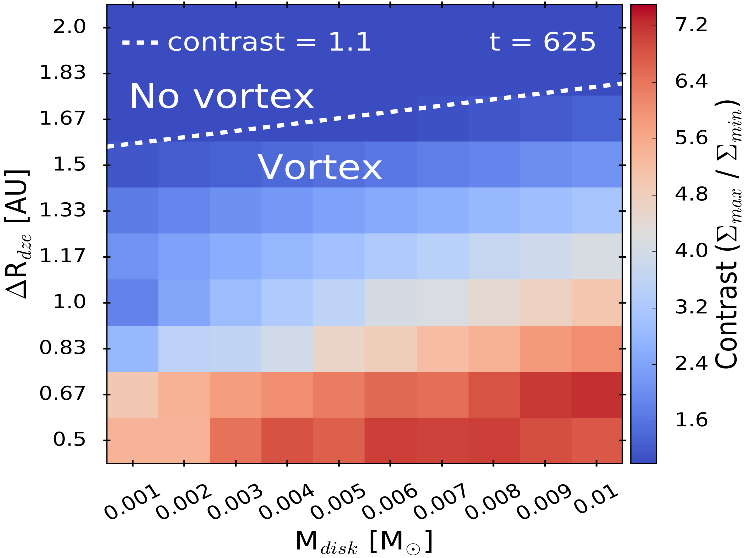




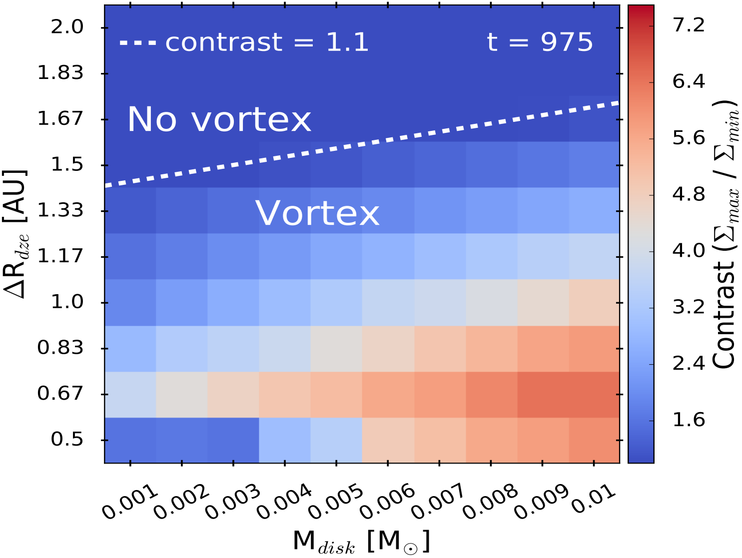


contrast = 1.1
t = 275
No vortex
Vortex
2.0
1.83
1.67
1.5
1.33
1.17
1.0
0.83
0.67
0.5
ΔR$_{dze}$ [AU]
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
M$_{disk}$ [M$_\odot$]
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
Contrast (Σ_{max} / Σ_{min})

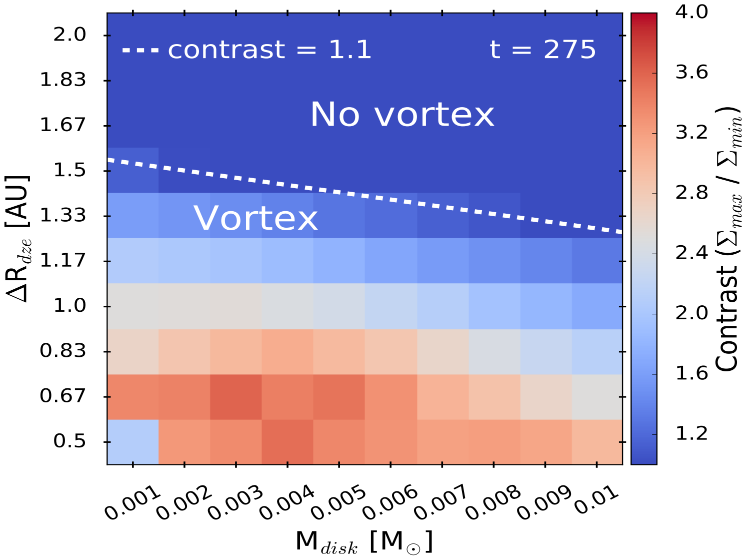
Parameter study: non self-gravitating models



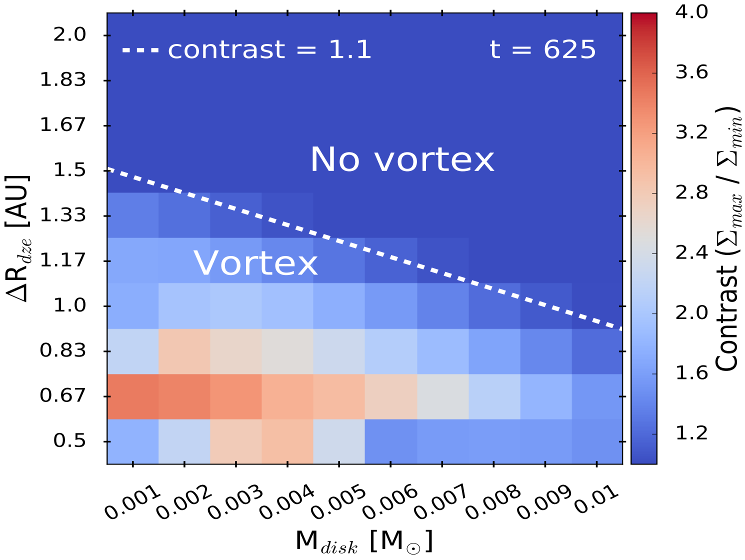
Parameter study: non self-gravitating models

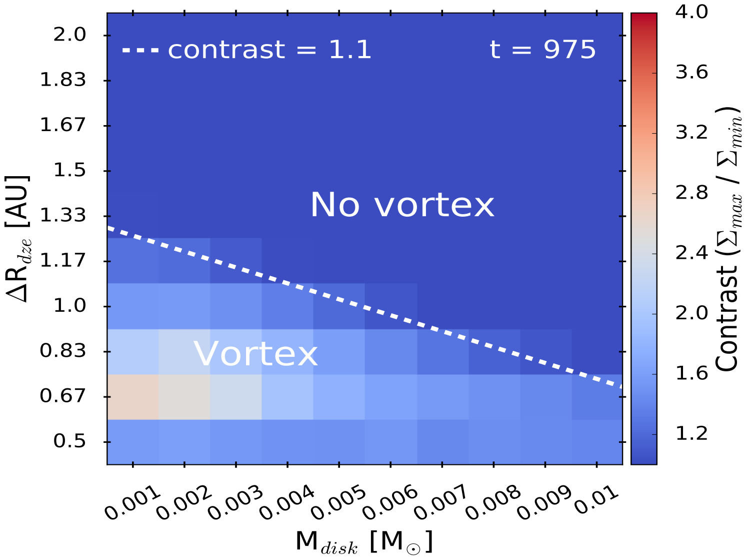


Parameter study: self-gravitating models



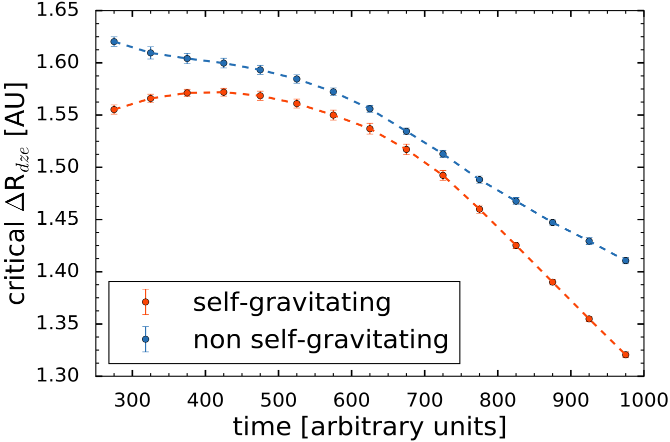
Parameter study: self-gravitating models




contrast = 1.1
t = 975
No vortex
Vortex
2.0
1.83
1.67
1.5
1.33
1.17
1.0
0.83
0.67
0.5
ΔR_{dze} [AU]
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
M_{disk} [$M_\odot$]
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
Contrast (Σ_{max} / Σ_{min})

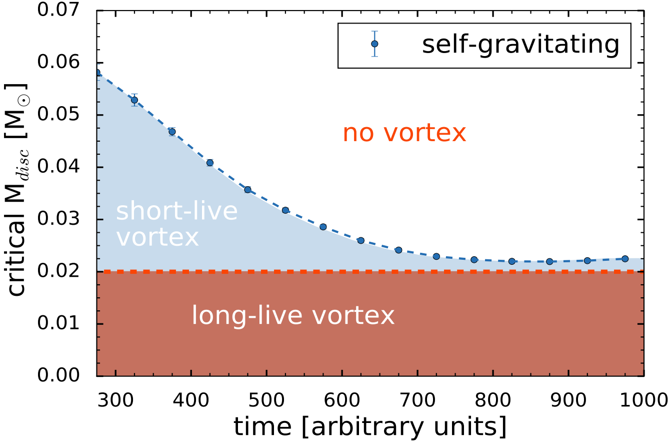
Results: critical ΔR_{dze}

- Interception of the y axis of the fitted slope determines the required sharpness of the DZ edge for vortex formation



Results: critical M_{disc}

- Interception of the x axis of the fitted slope determines the required disk mass for vortex formation in case of infinitely sharp viscosity transition



Conclusion

- We investigated the effect of the sharpness of DZ edge and the disk mass on the excitation of RWI
- Large-scale vortex excitation requires sharper DZ if self-gravity is taken into account
- Self-gravity weakens vortices for high-mass disks
- Main conclusion: Hypothetical vortex-aided planet formation favors low-mass disks