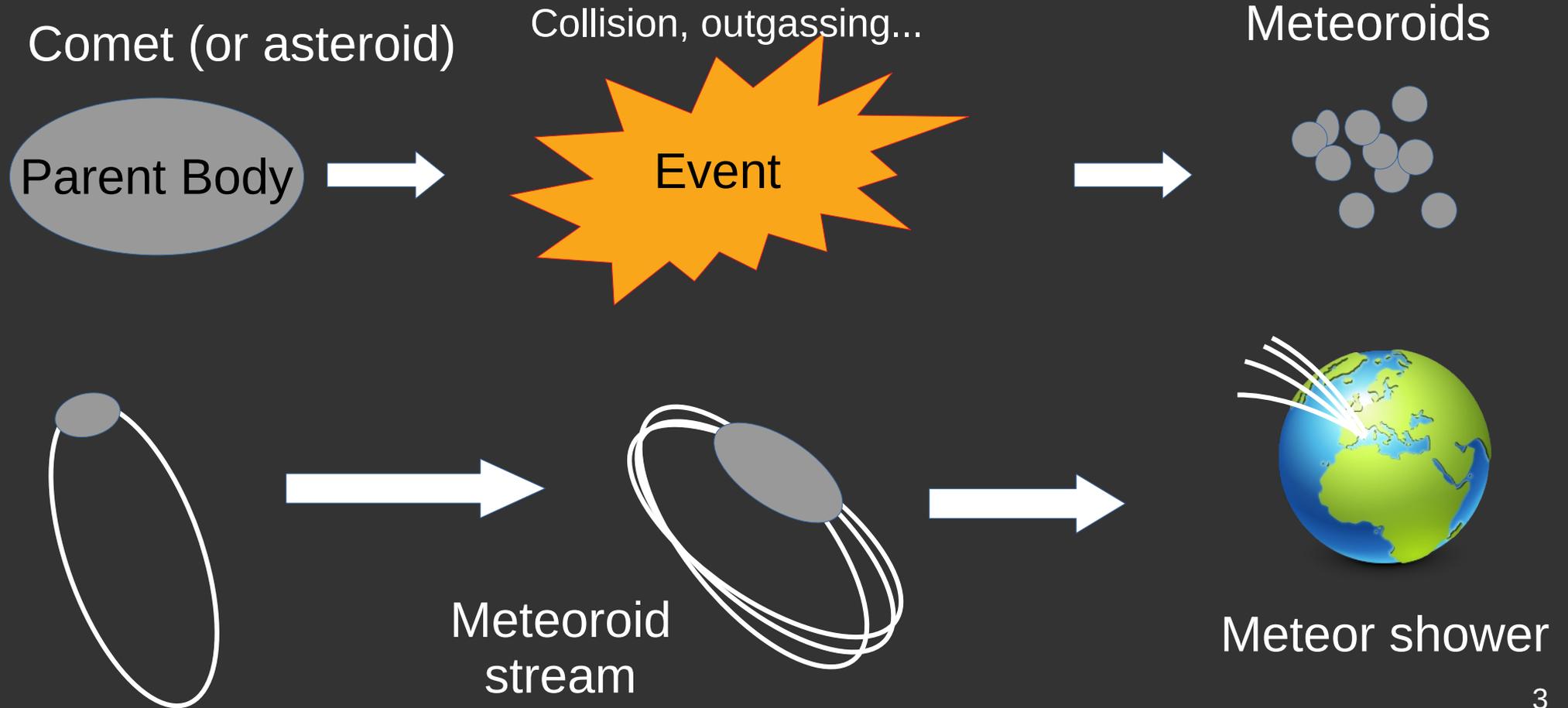


# Dynamics of meteoroid streams as revealed by chaos maps: an overview

# A little about me...

- PhD in Paris Observatory with Jérémie Vaubaillon and Marc Fouchard : “Meteor showers revisited: characterising chaos in meteoroid streams”  
=> study of Geminids, Draconids and Leonids with chaos maps
- Post-doc in ESA/ESTEC on impact risks of meteoroids on spacecrafts  
=> end in October! 
- But also: study of the Taurids with chaos maps

# What are meteoroid streams?



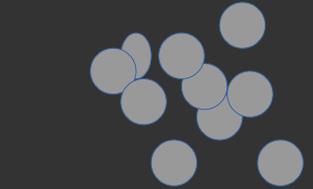
# What are meteoroid streams?

Comet (or asteroid)

Collision, outgassing...

Meteoroids

Parent Body



Meteoroid stream

Meteor shower

# A little bit about meteor showers...

Official definition of a meteor shower: ONE parent body

=> so information about meteor shower = information about the parent body

BUT difficult to prove the origin of meteoroids : non-gravitational forces (NGF) + close encounters + ...

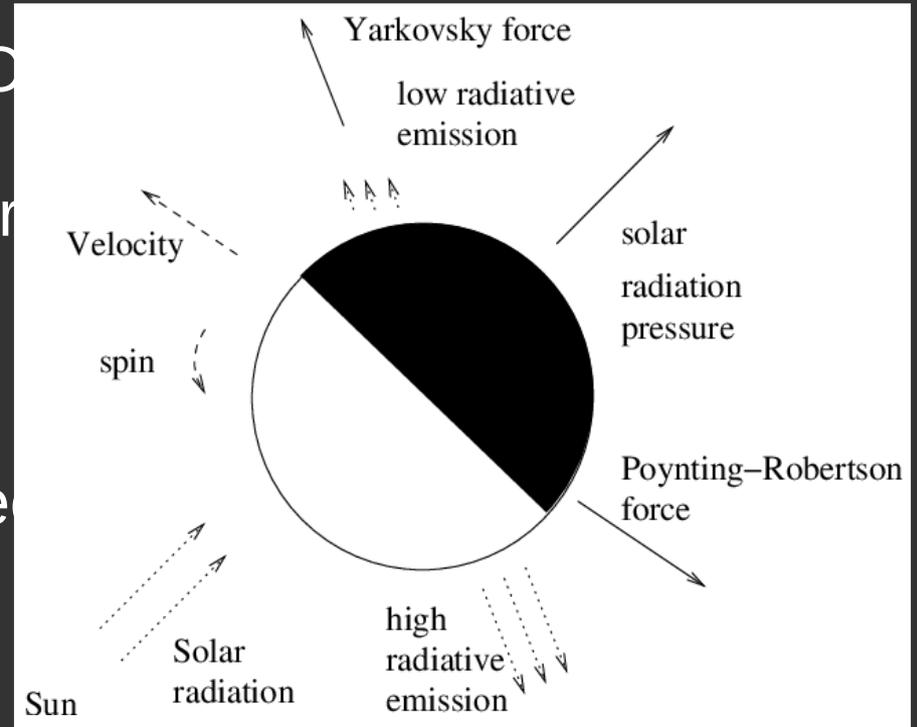
General context for this work: we need to learn more about dynamics of meteoroids between ejection and Earth!

# A little bit about meteor showers...

Official definition of a meteor shower: O

=> so information about meteor shower  
body

BUT difficult to prove the origin of mete  
(NGF) + close encounters + ...



General context for this work: we need to learn more about dynamics  
of meteoroids between ejection and Earth!

# Dynamical chaos and chaos maps

Two orbits initially infinitely close  $\Rightarrow$  divergence

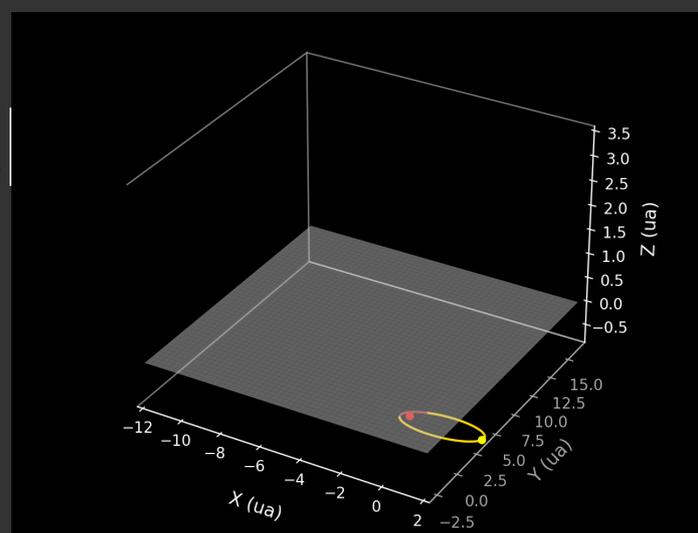
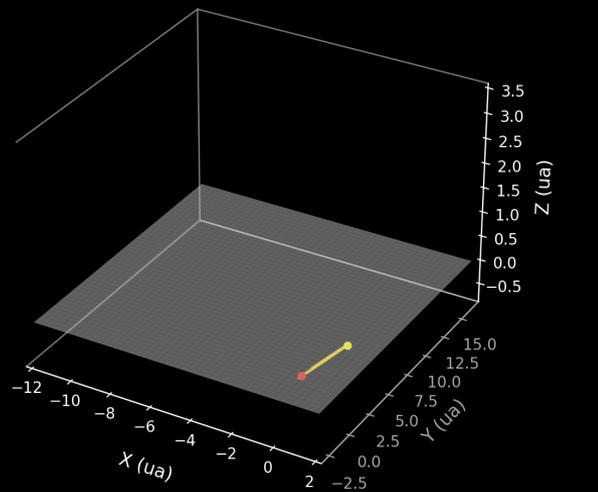
- Exponential divergence: chaotic dynamics
- Linear divergence: regular dynamics (stability)

Chaos maps : drawn thanks to chaos indicator (OFLI). Well-known on other objects.

**Can it reveal major dynamical mechanisms in meteoroid streams ?**

Asteroid streams c

Taurids:  
2P/Encke

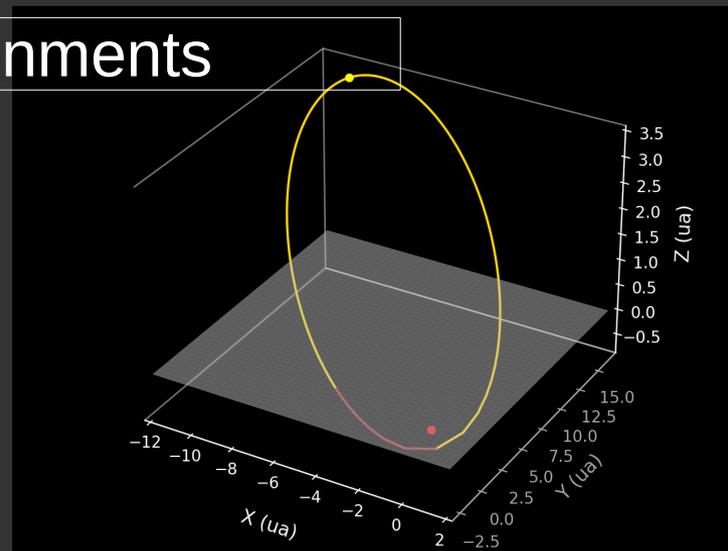
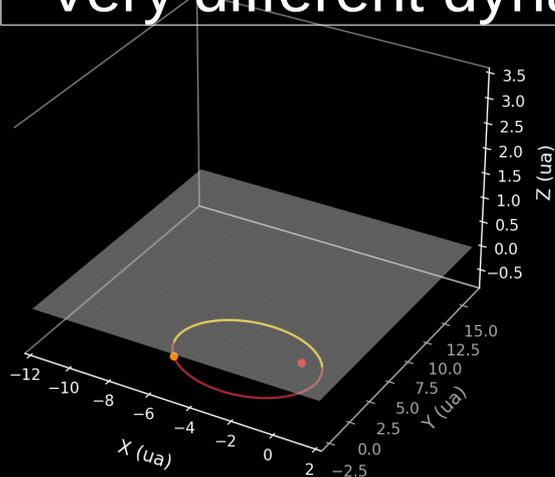


Geminids: asteroid

Very different dynamical environments

Draconids:  
JFC

Leonids:  
HTC



# How to create a chaos map ?

Integration of about 100 000 particles

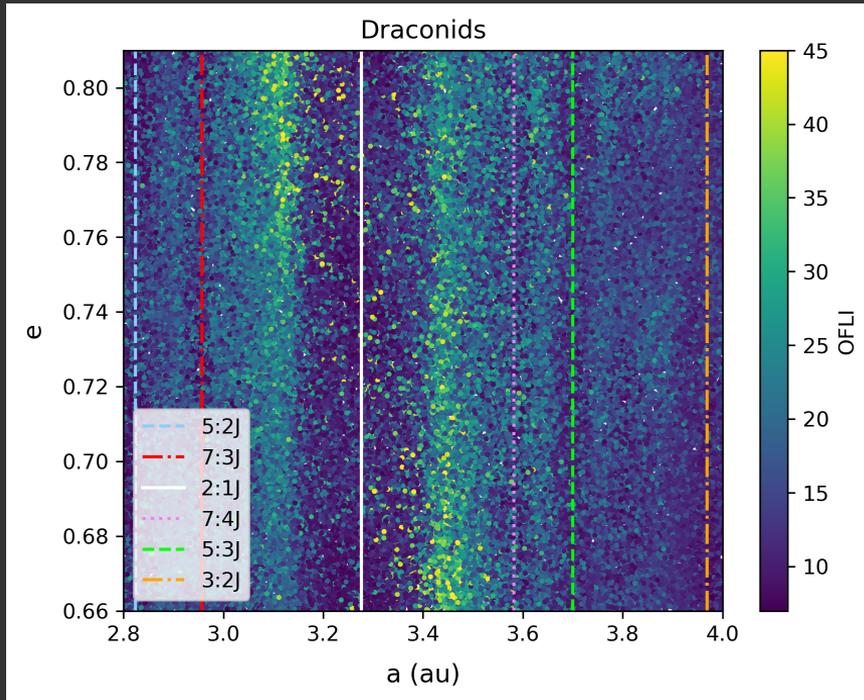
Integration during 1000 years for all meteoroid streams, except the Leonids (2000 years)

Choice of a chaos indicator that is computed during the integration for each particle

Effect of non-gravitational forces (NGF), all planets, Sun and Moon

Different size bins because smaller sizes “feel” the NGFs more.

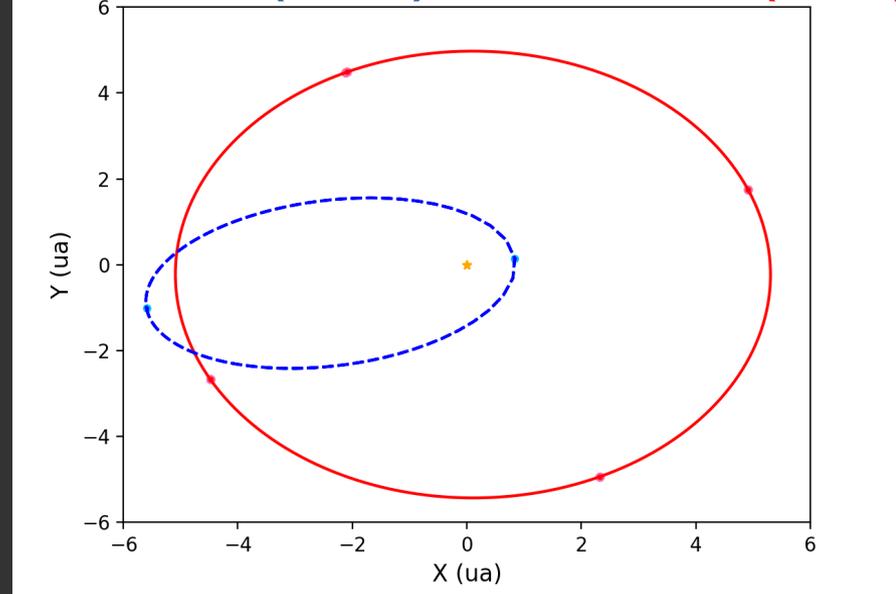
# The effect of Mean-Motion Resonances



The exemple of Draconids:  
MMR with Jupiter

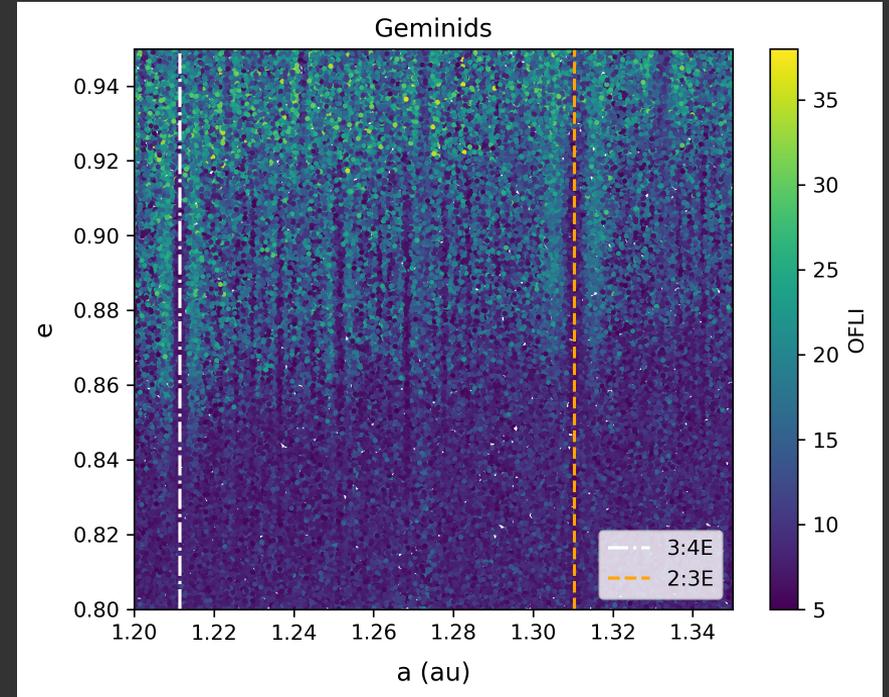
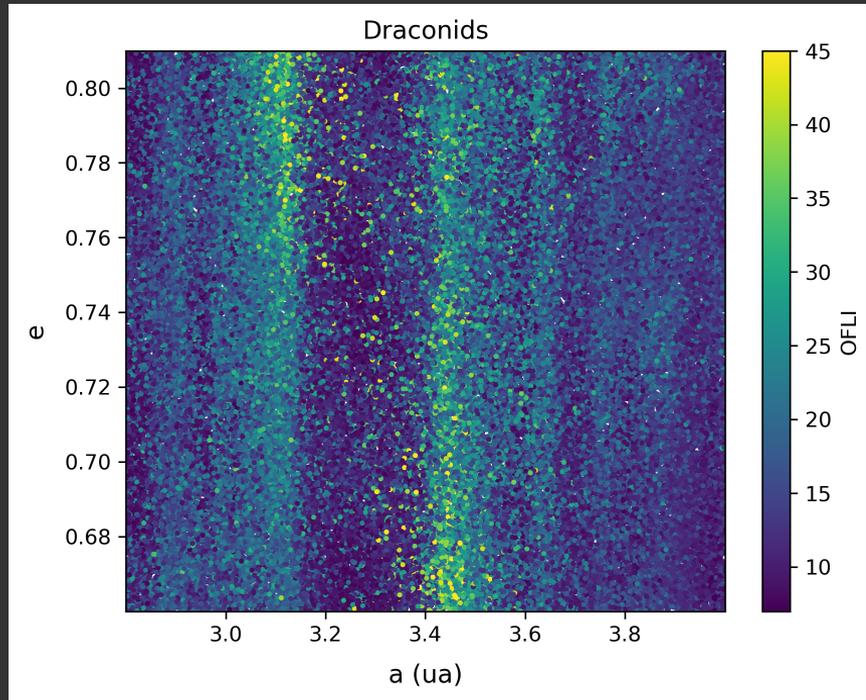
Definition of MMR:

$$2 * \text{Period}(\text{Blue}) = 1 * \text{Period}(\text{Red})$$

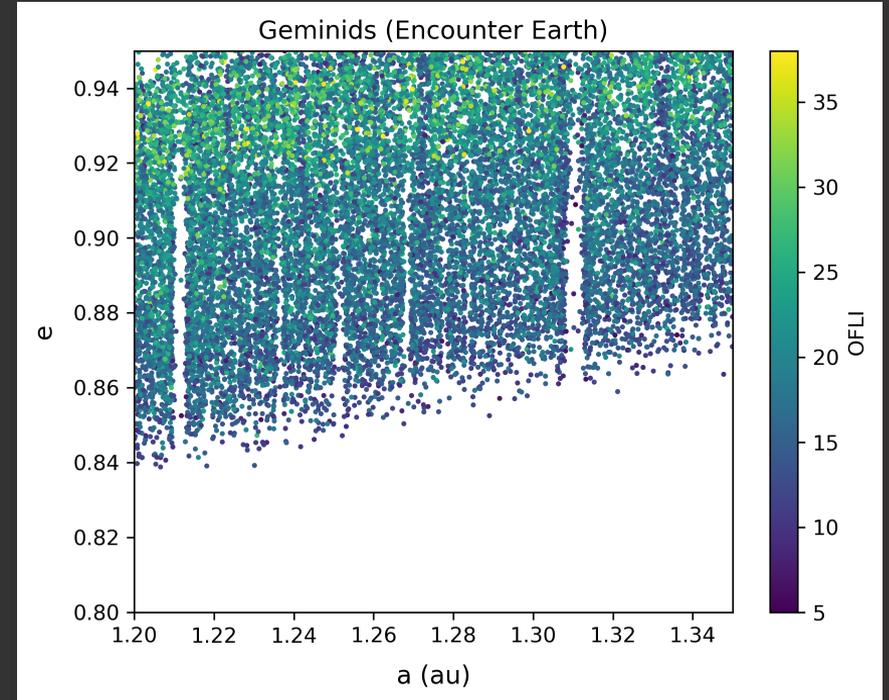
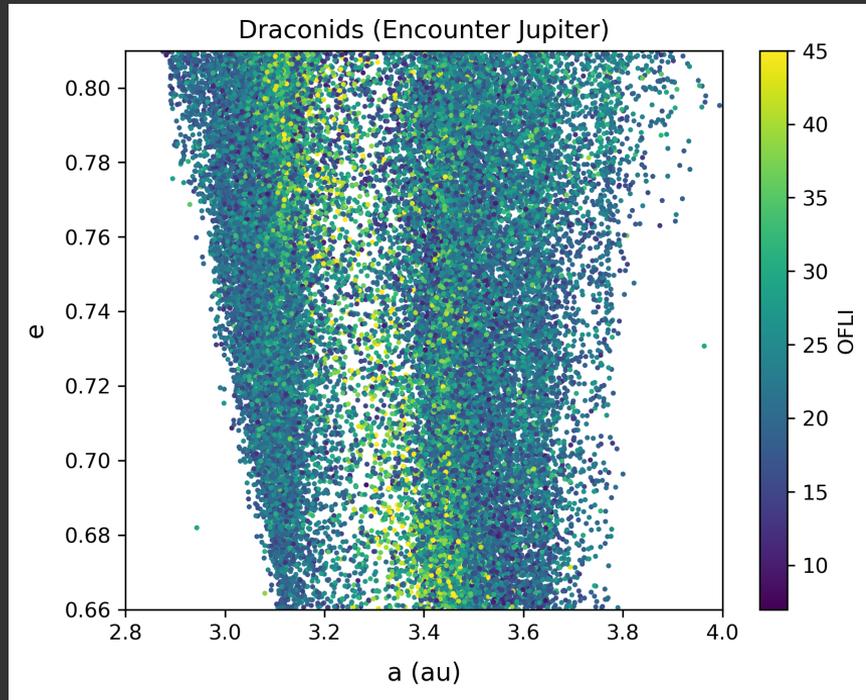


Blue and red in 2:1 MMR

# MMR and close encounters

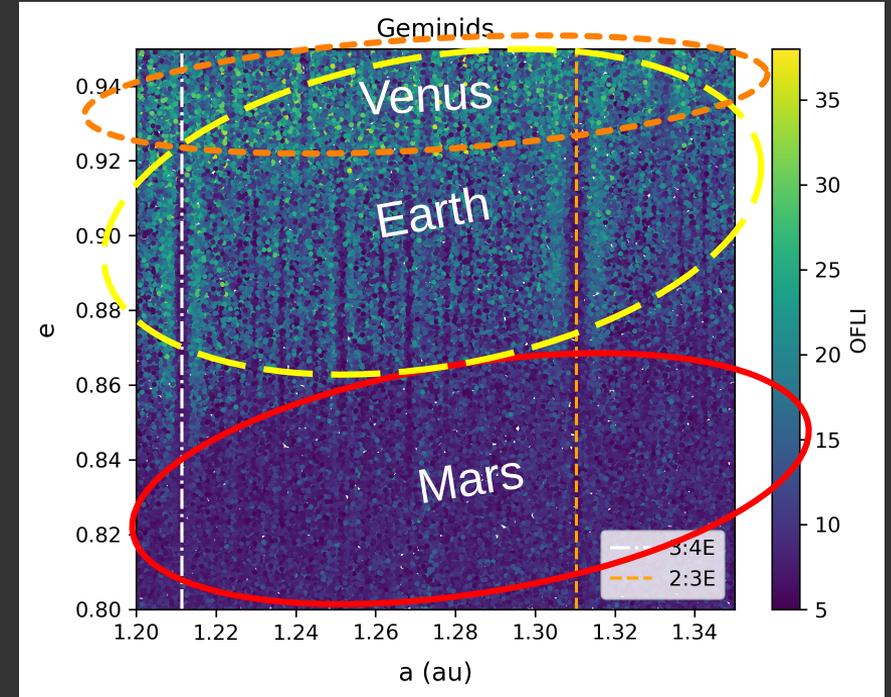
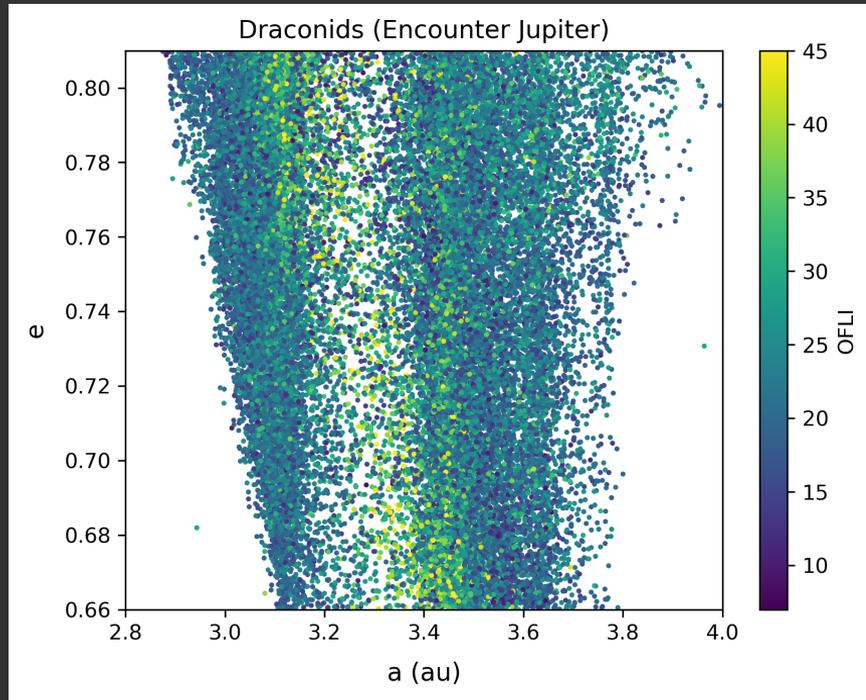


# MMR and close encounters



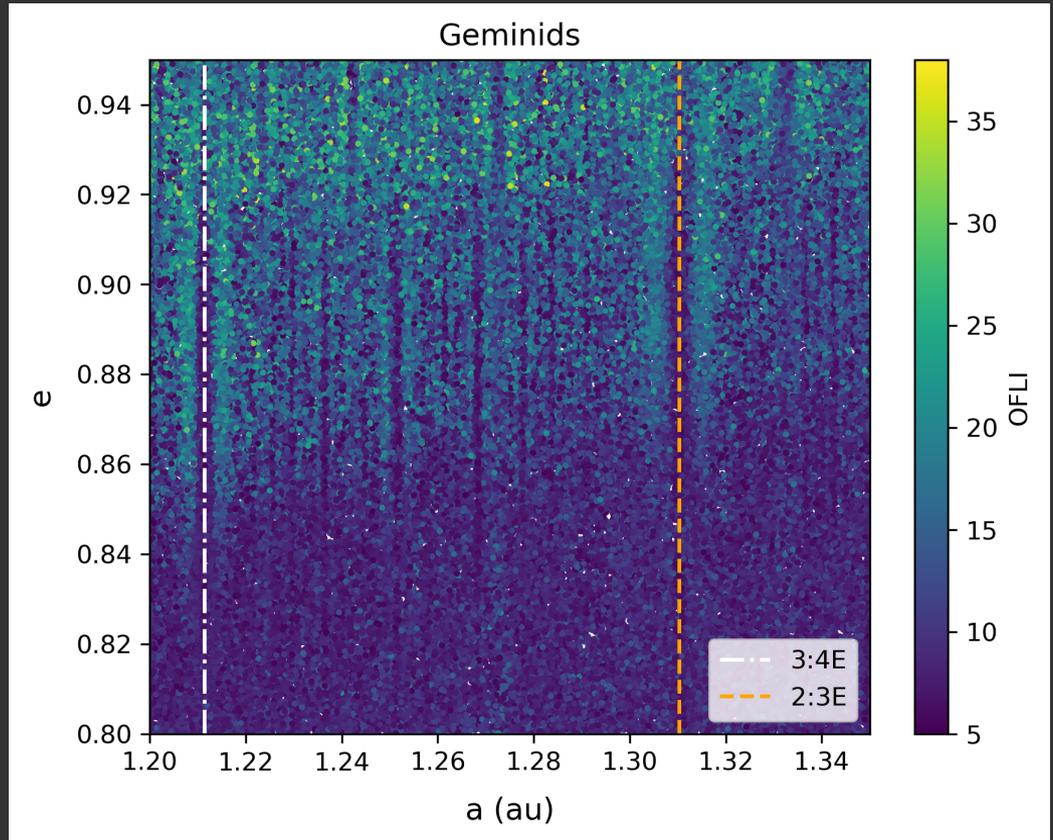
MMR prevent close encounters and thus preserve regularity

# MMR and close encounters



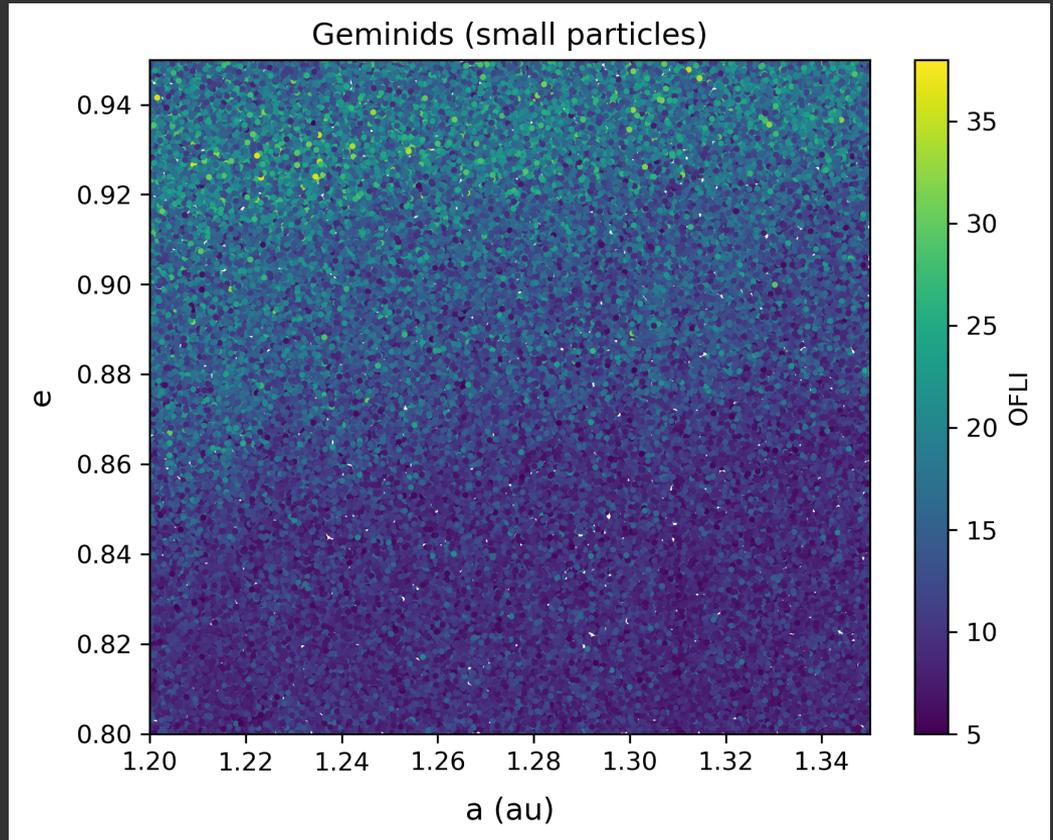
MMR prevent close encounters and thus preserve regularity

# Escaping a Mean-Motion Resonance



# Escaping a Mean-Motion Resonance

The exemple of Geminids :  
MMR disappear from maps  
with smaller particles  
=> NGF

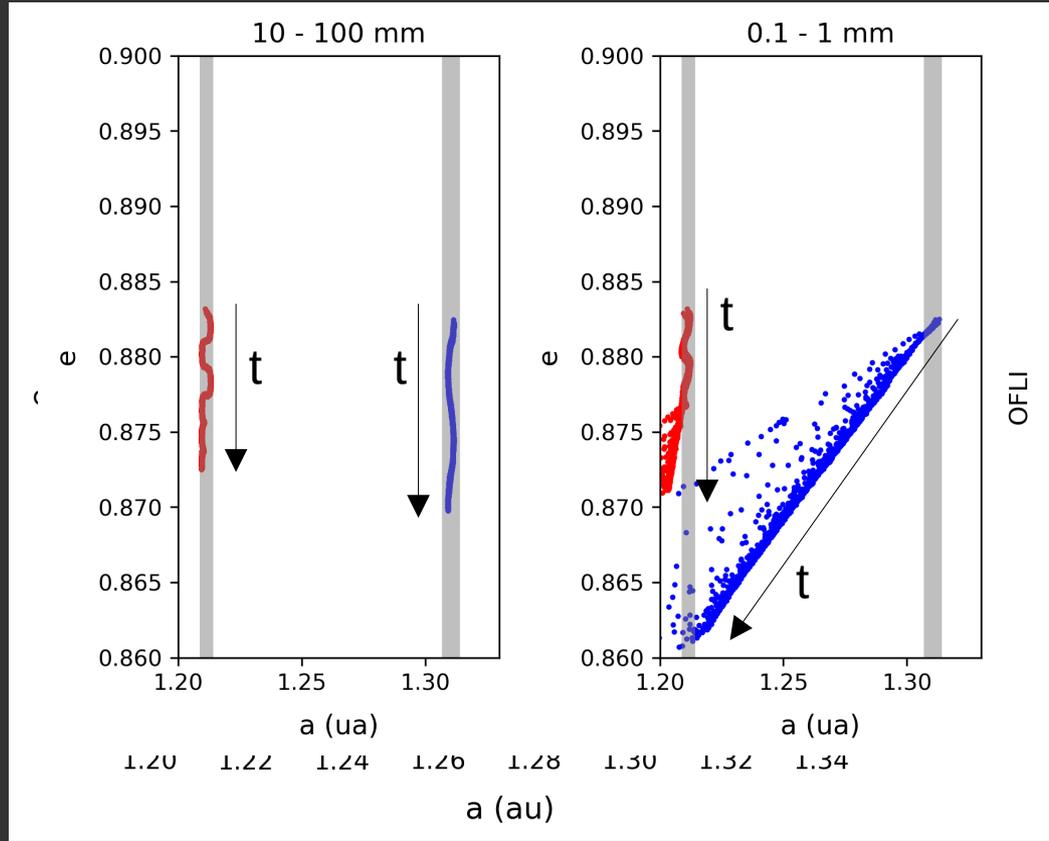


# Escaping a Mean-Motion Resonance

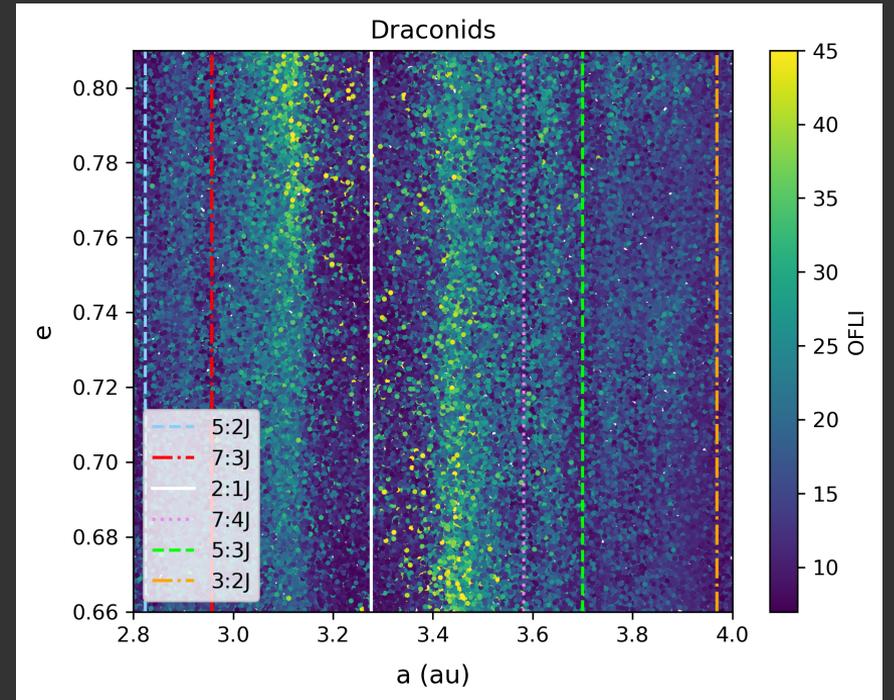
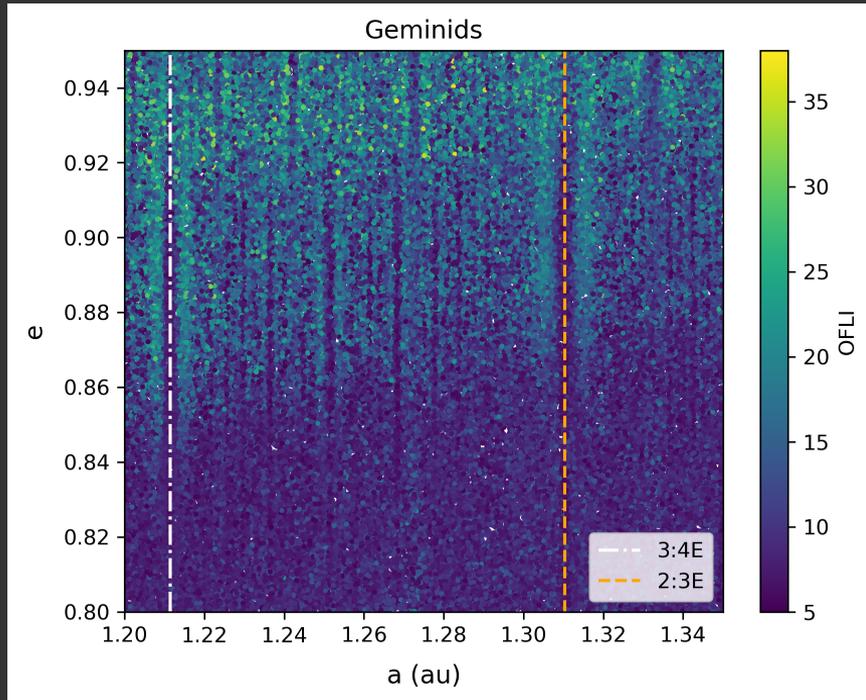
The exemple of Geminids :  
MMR disappear from maps  
with smaller particles  
=> NGF

NGF => diffusion => a  
diminishes => escape from  
MMR

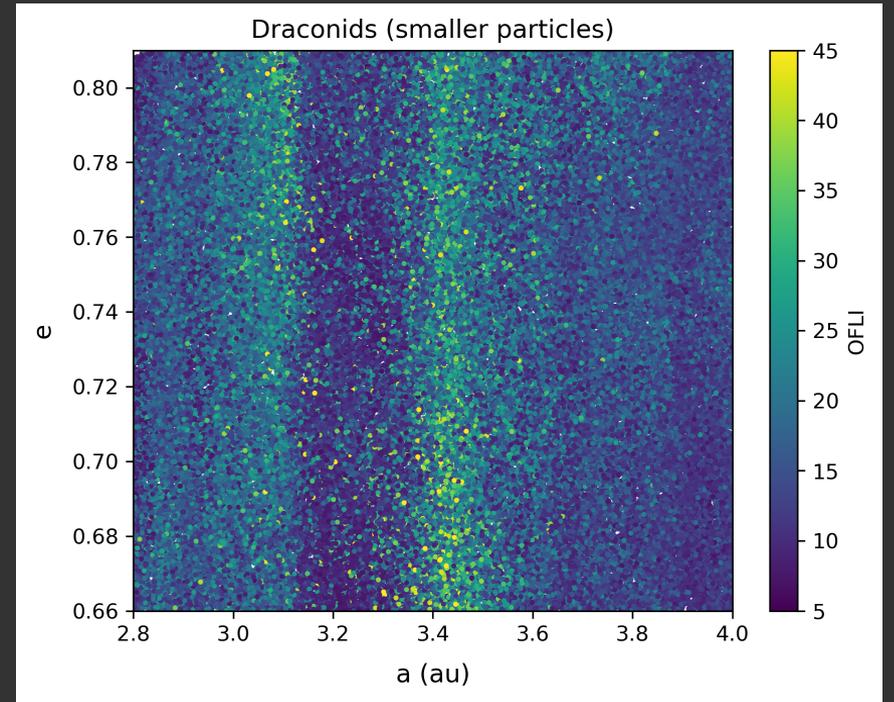
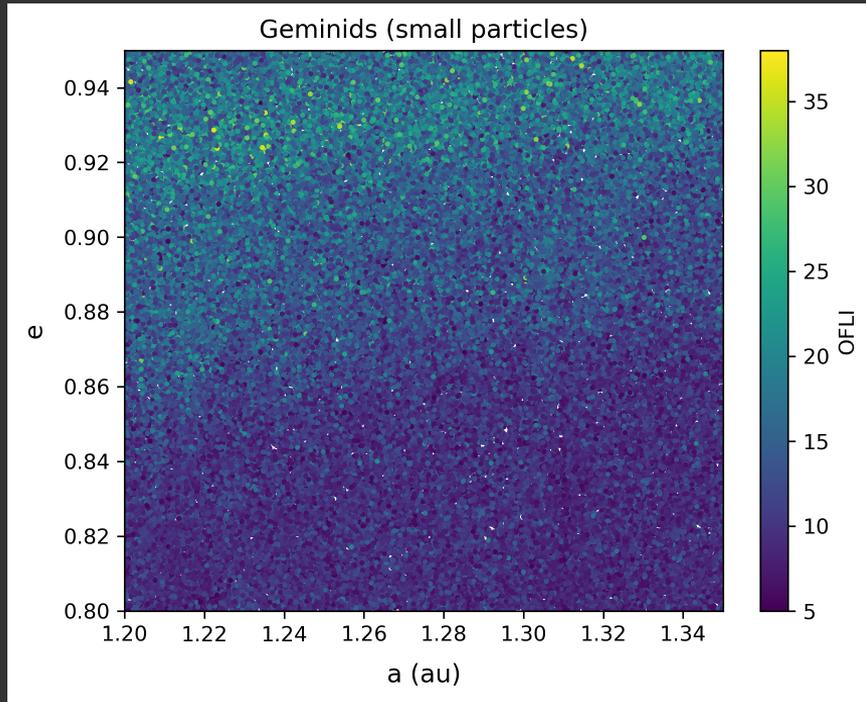
Under some conditions...



# Escaping a Mean-Motion Resonance

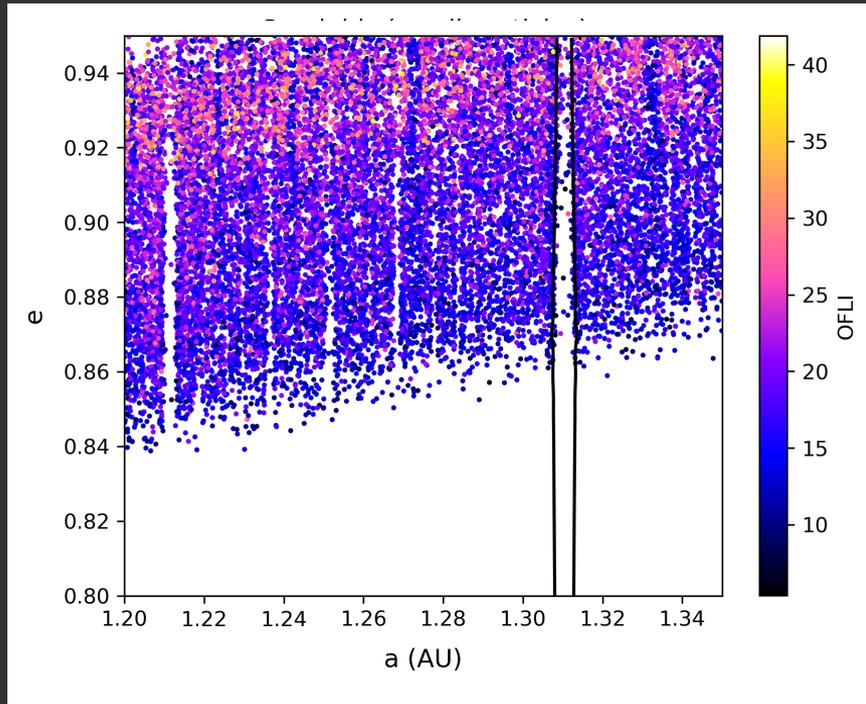


# Escaping a Mean-Motion Resonance

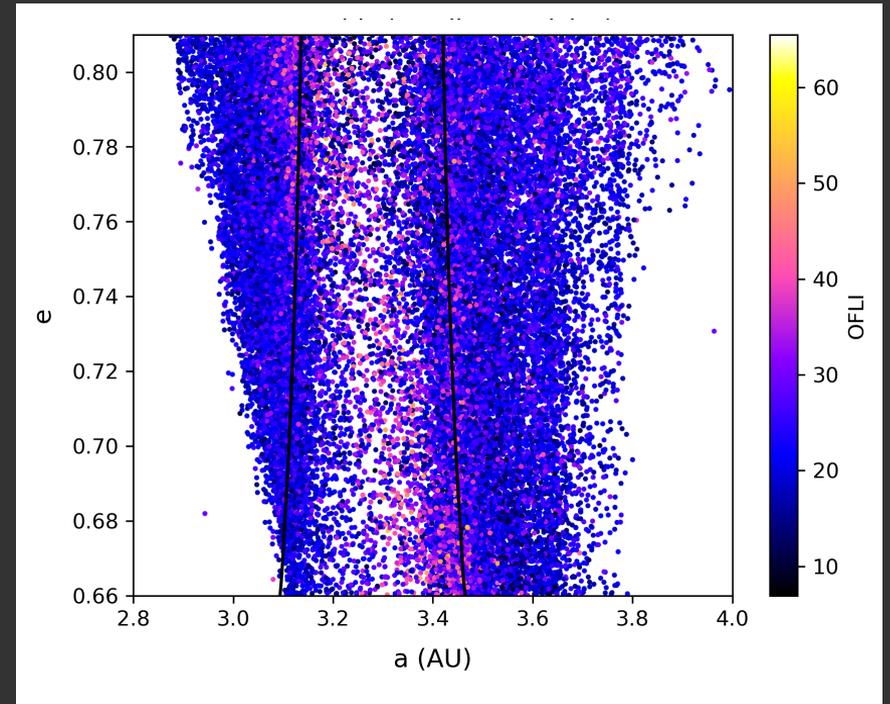


Particles in Geminids can escape, but not Draconids or Leonids... Why ?

# Escaping a Mean-Motion Resonance

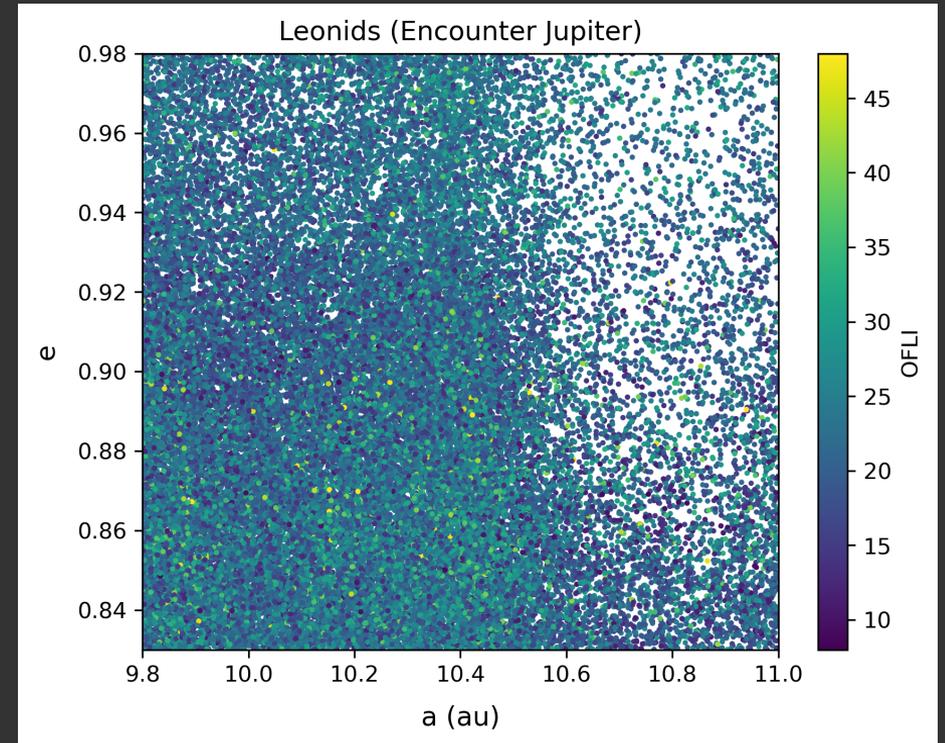
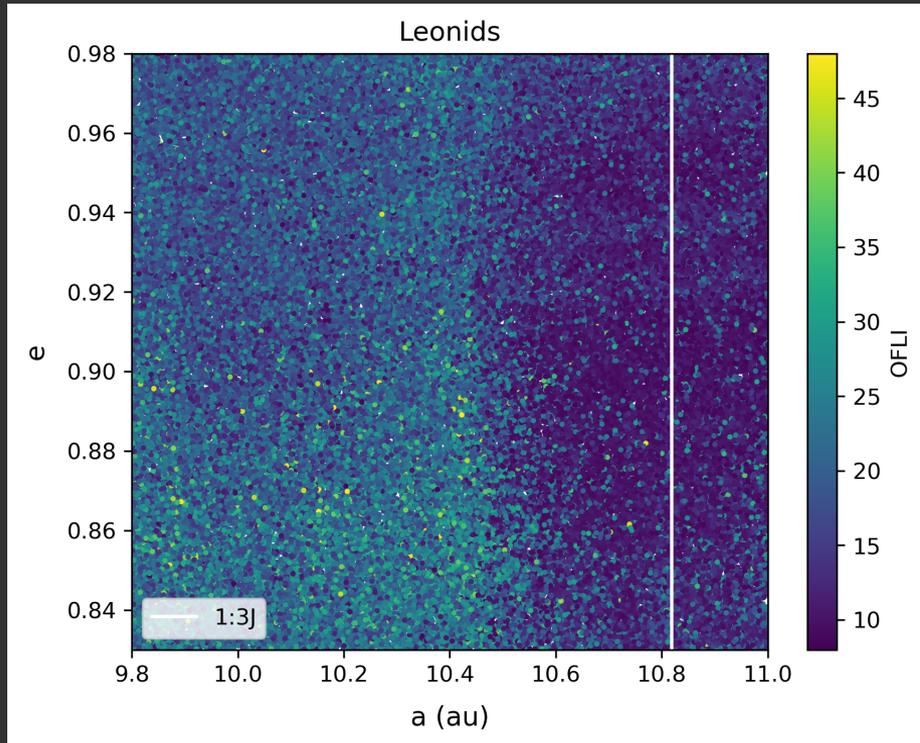


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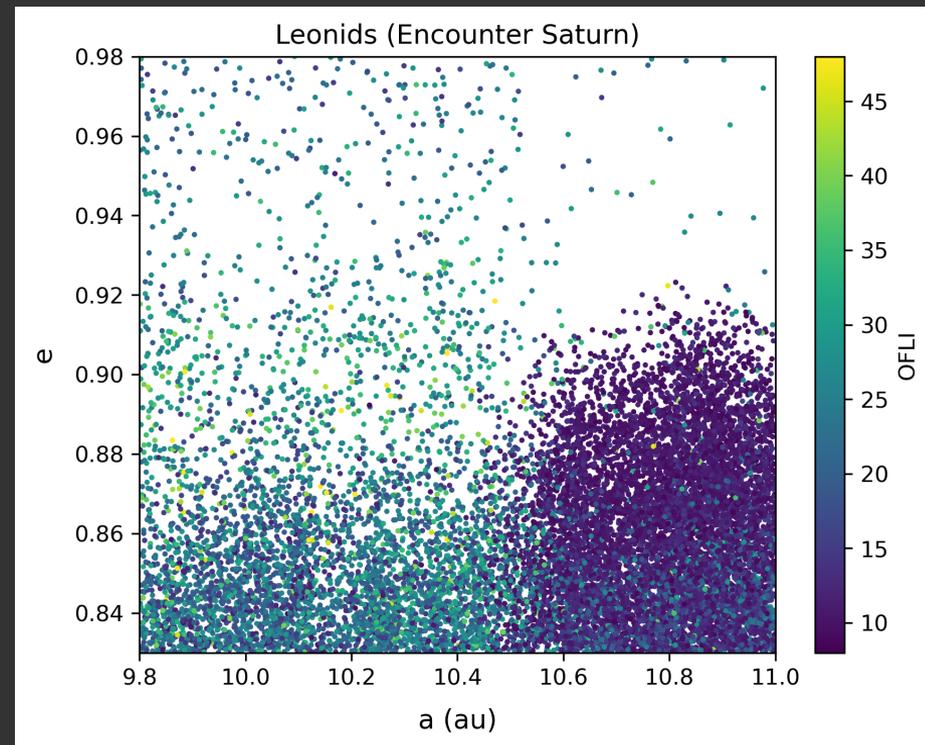
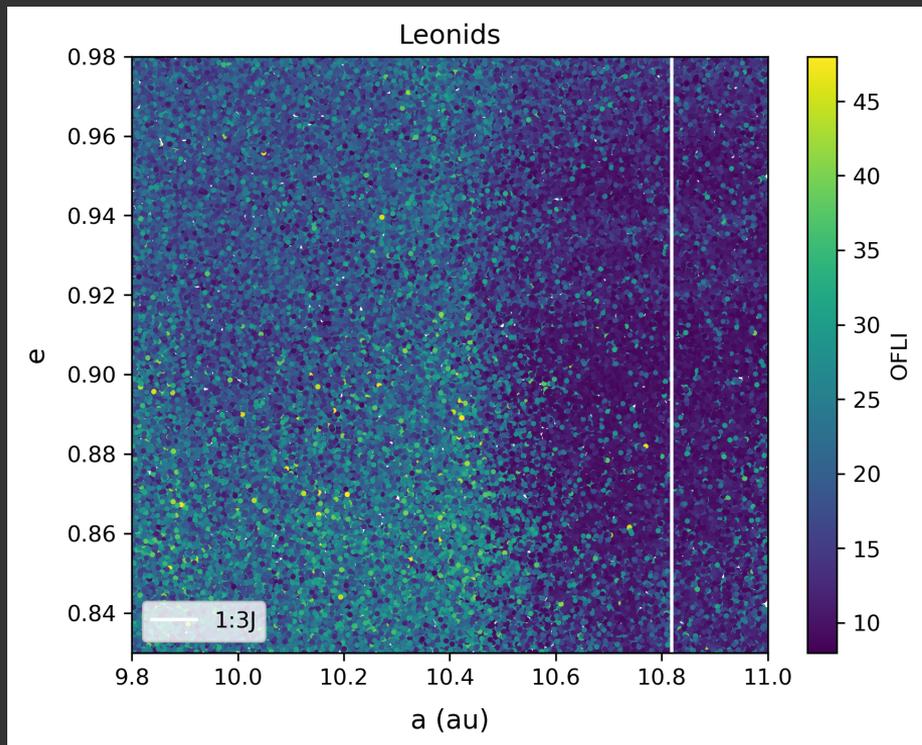


Large MMR : capacity for capture higher + distance to Sun

# Another way to escape MMR



# Another way to escape MMR



LEO : encounters with Saturn can push particles out of the MMR

# A major mechanism

Mini-conclusion : effect of MMR on three meteoroid streams.

MMR prevent particles from encountering the planet they are in resonance with => regularity

Outside of MMR : encounters => chaos

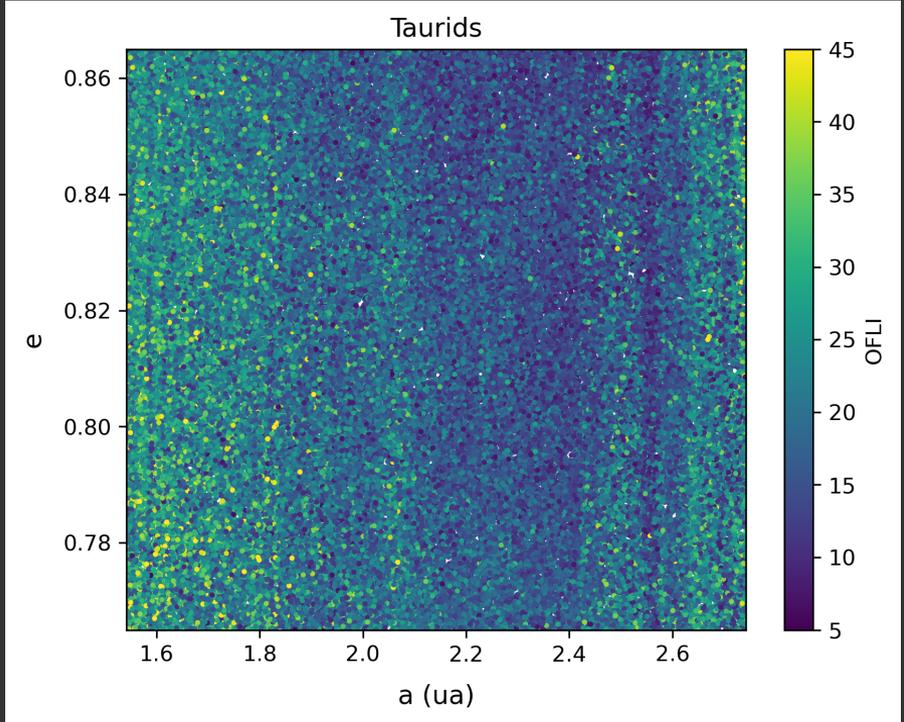
Escape of MMR can happen if :

- 1) close encounters with another planet
- 2) MMR is thin enough

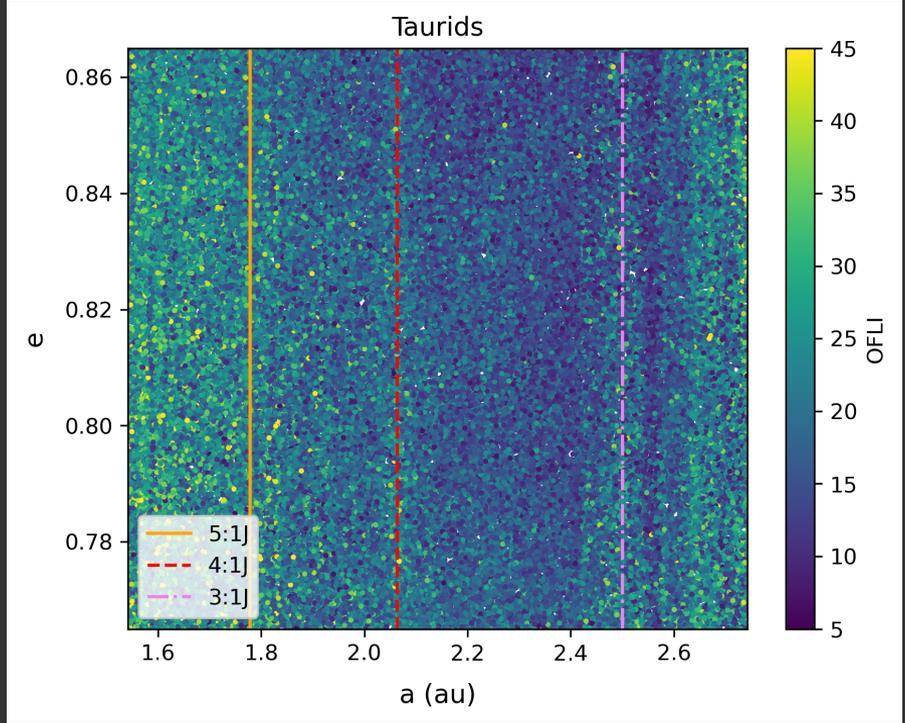
+ particles are close enough to the Sun + small enough

# Another effect of Mean-Motion Resonances

Special case : the Taurids



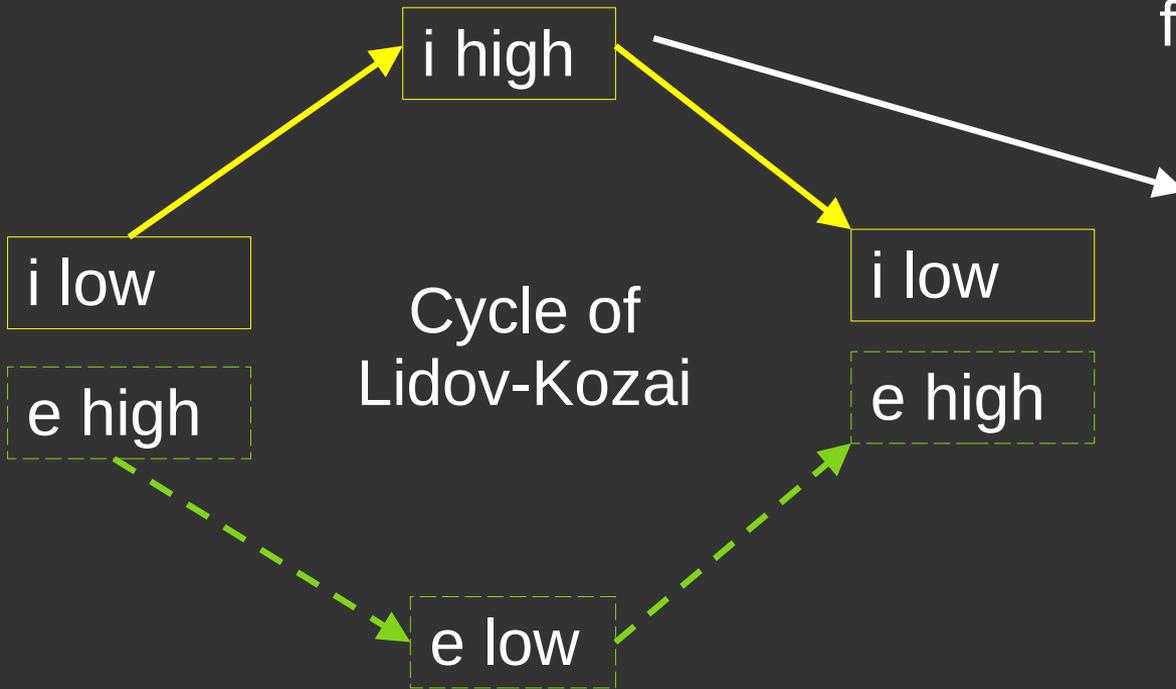
No MMR fits with stable areas



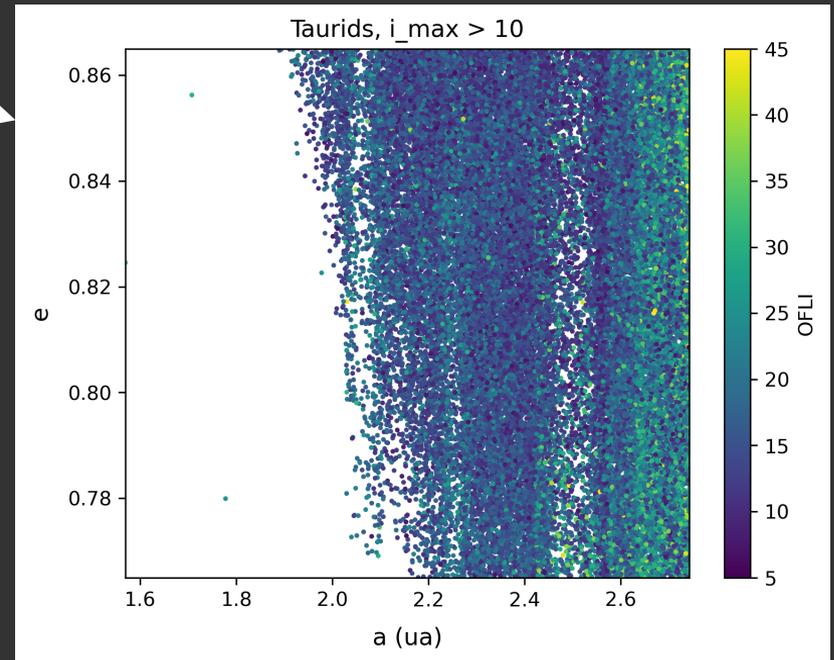
MMR do fit with chaotic areas !!!

# Lidov-Kozai cycle

Effect of Jupiter on the Taurids:

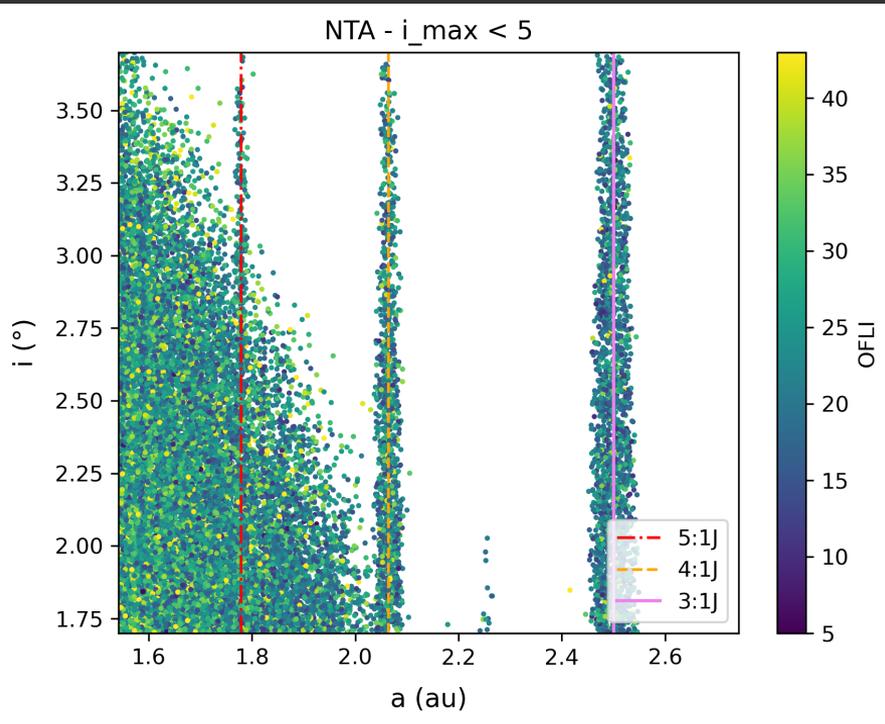


Lidov-Kozai stabilize Taurids by forcing them away from ecliptic

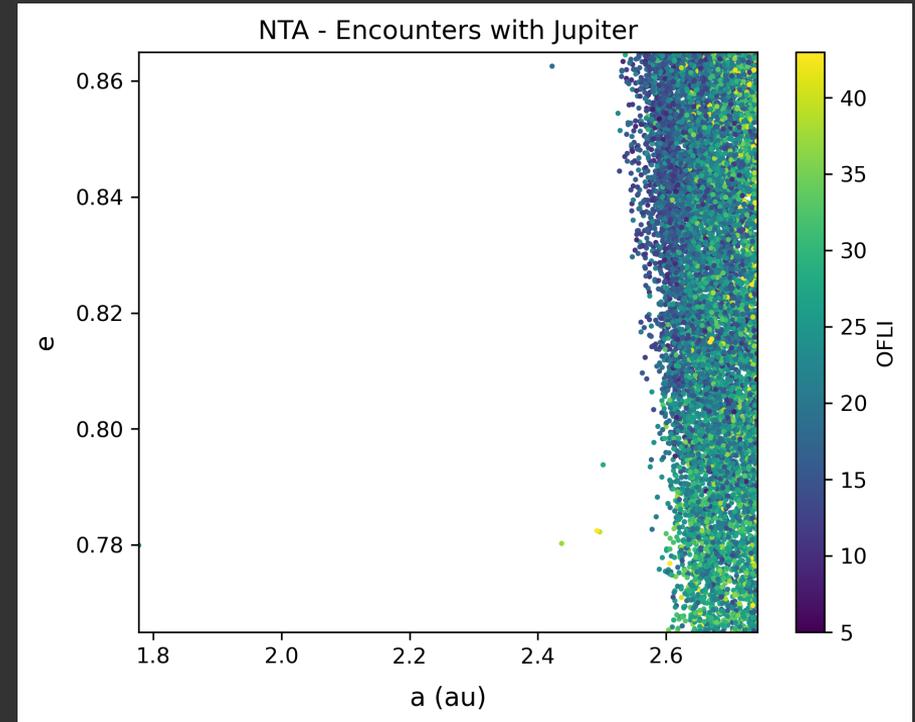


Chaos due to... ?

# Lidov-Kozai cycle vs MMR

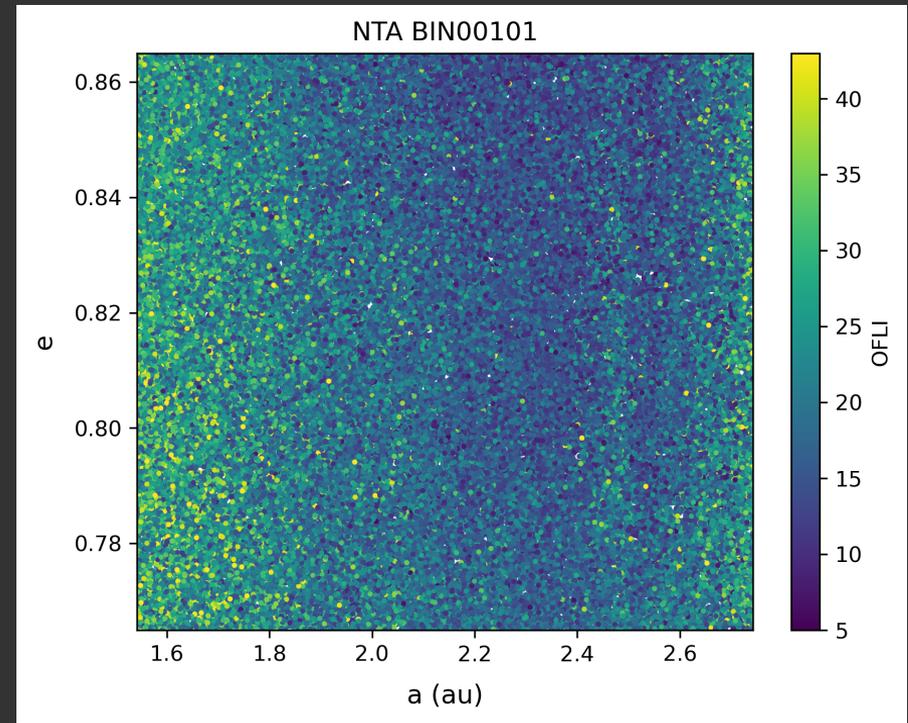
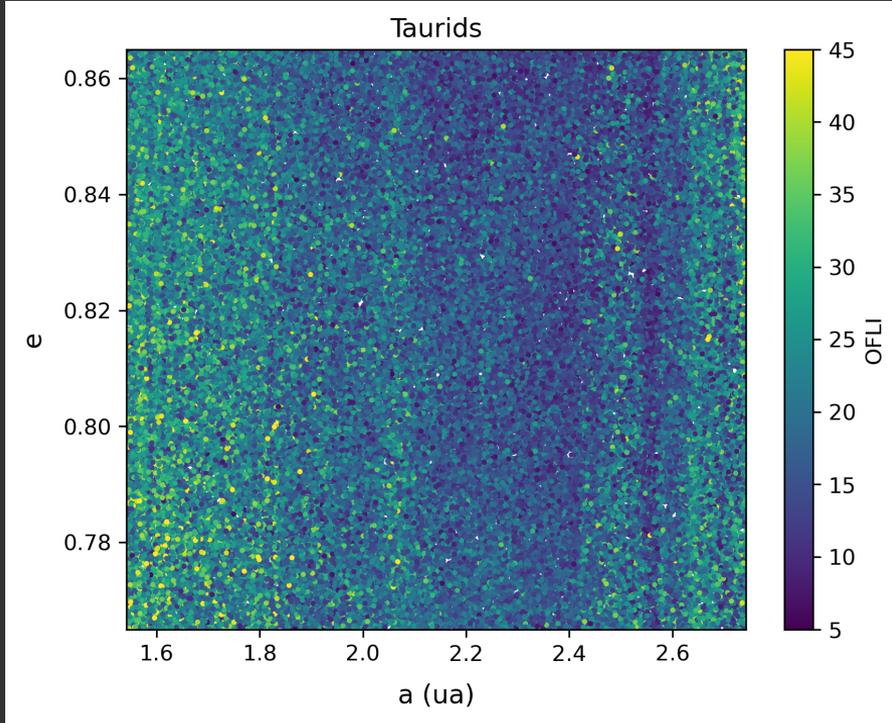


MMR : keep Taurids at low  $i$



Close encounters with Jupiter  
bring chaos

# Taurids and Non-gravitational forces



Smaller particles : higher NGF => less MMR but still Lidov-Kozai ?

# Conclusion

- Chaos maps reveal dynamical mechanisms in meteoroid streams
- MMR preserve regularity by avoiding close encounters
- Possible to escape MMR
- Taurids : Lidov-Kozai brings regularity but MMR preserve from it (chaos)



For more information about the method and previous results : Courtot et al, 2023, 2024.  
Stay tuned for Taurids paper !

Thank you for listening !

Questions ? Remarks ?

