

**XI Taller de Ciencias Planetarias – Fev 14 – 18, 2022**

# **Resonant dynamics of newly discovered inner Saturn moons**

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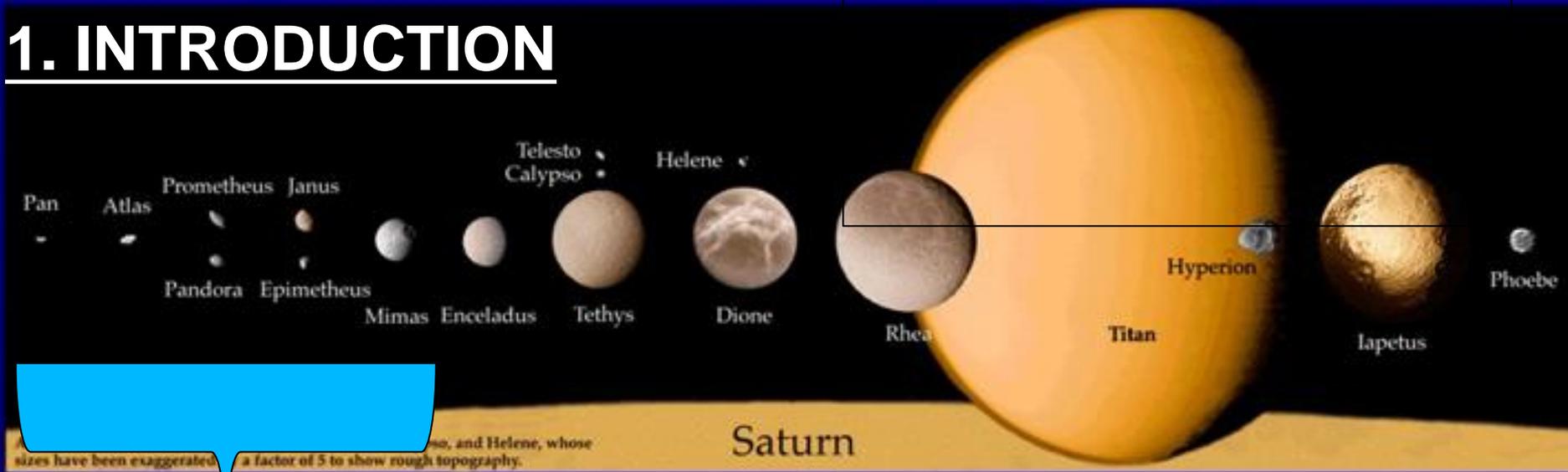
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Institute of Geosciences and Exact Sciences***

***In collaboration with Prof. Adrián Rodríguez (OV-UFRJ), D. T. Ceccatto (Physics Program IGCE).***

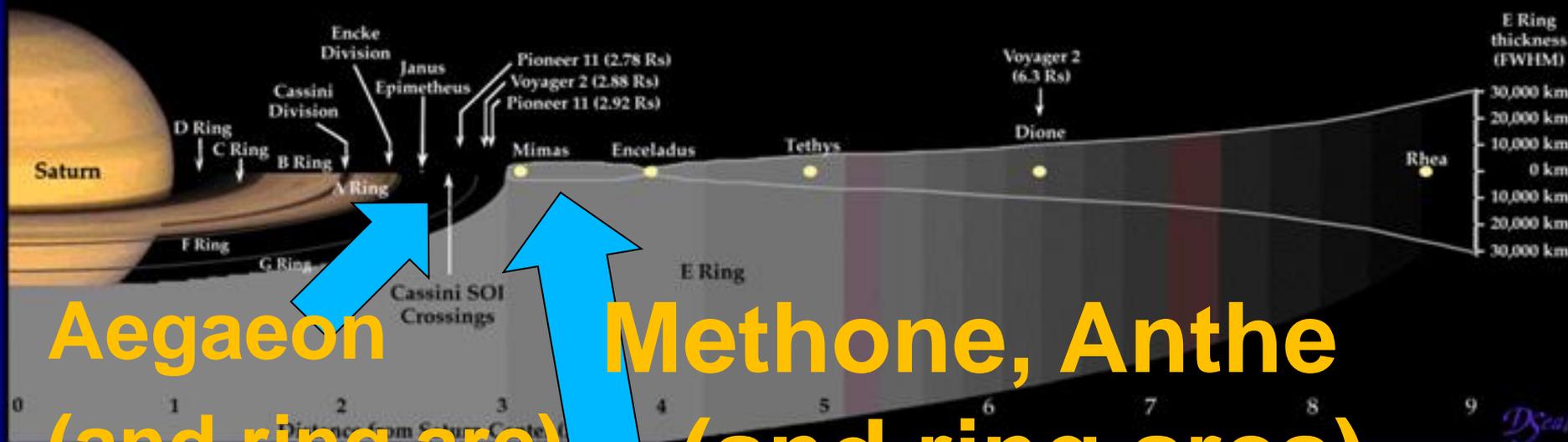
***NCJ is grateful to Fapesp (Sao Paulo State Research Funding Agency), through the processes 2019/15162-2, 2020/06807-7)***

# Saturn's Satellites and Ring Structure

## 1. INTRODUCTION



Not shown:			
Pan	2.22 Rs	Titan	20.3 Rs
Atlas	2.28 Rs	Hyperion	24.6 Rs
Prometheus	2.31 Rs	Iapetus	59.1 Rs
Pandora	2.35 Rs	Phoebe	214.9 Rs



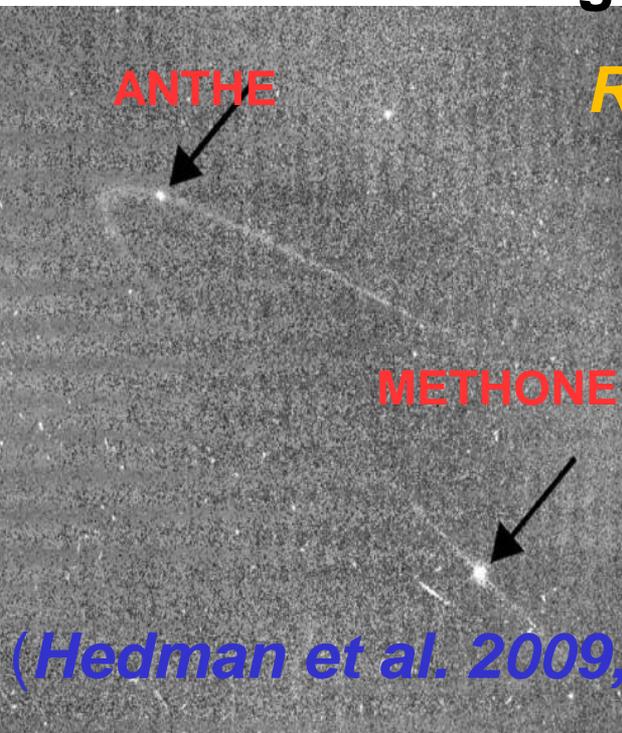
**Aegaeon  
(and ring arc)**

**Methone, Anthe  
(and ring arcs)**

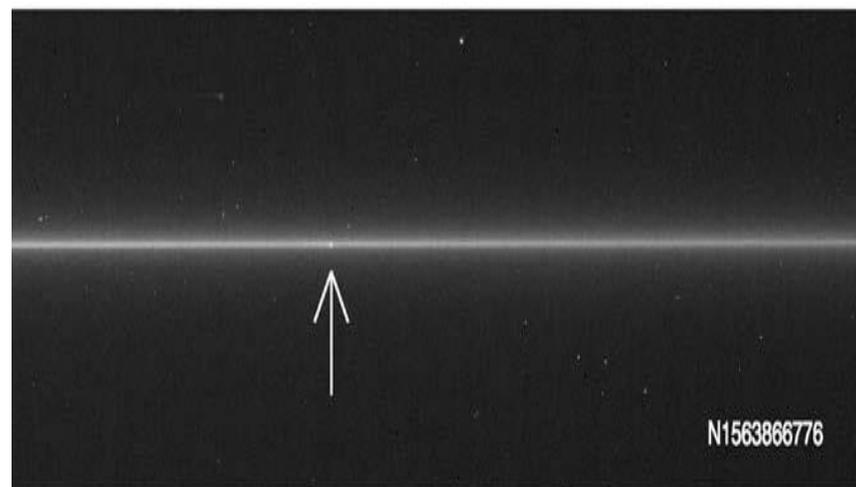
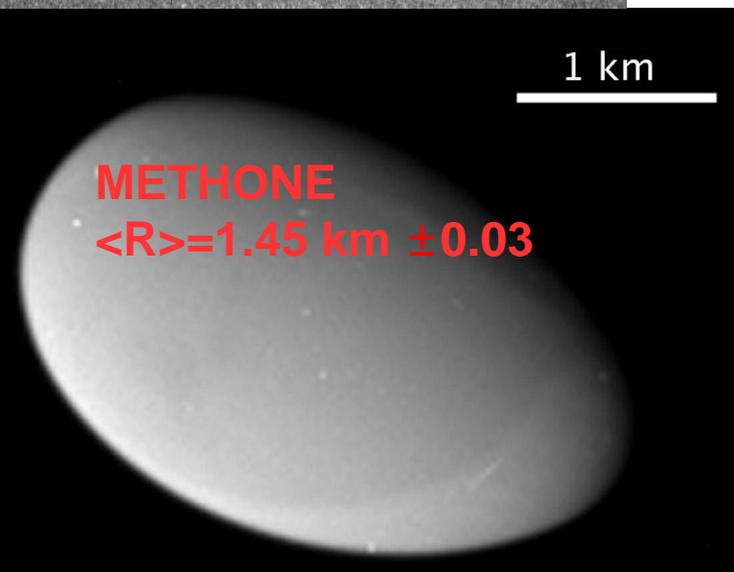
This graphic is available in color if required.

# Gallery of Pictures(Cassini spacecraft) and some key references

Remark: On ring arc dynamics, see the recent publication:



Rodríguez and Callegari 2021, MNRAS 506.



“The only two clear images of Aegaeon obtained prior to mid-2008 found to Date...” (fig. 3 in Hedman et al. 2010, Icarus 207)

# The 15:14 Mimas-Methone MMR

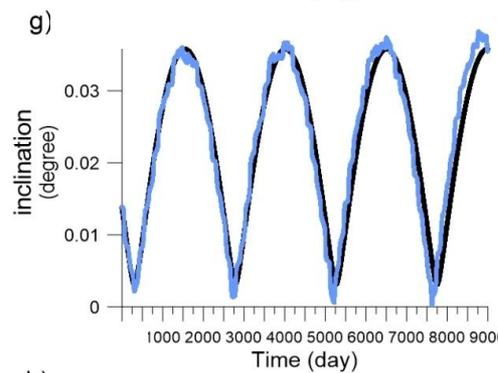
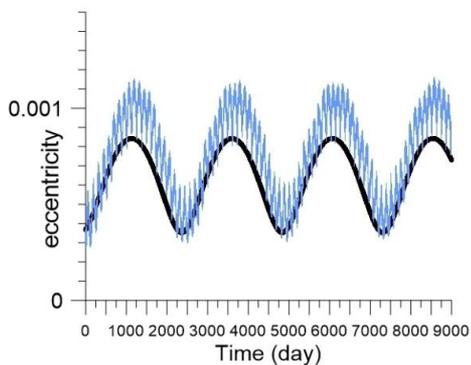
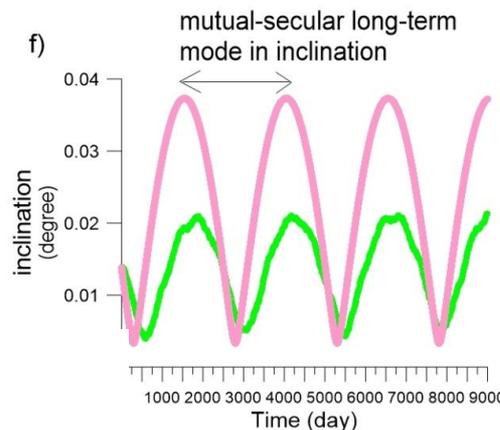
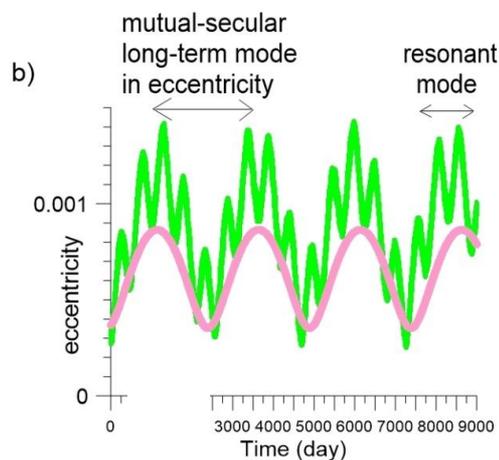
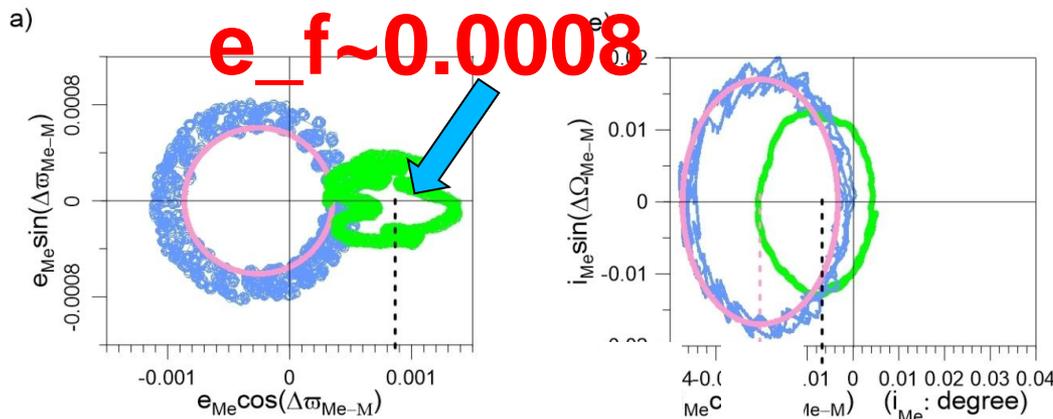
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- Methone: (probably) one of the first discoveries of the Cassini Mission (Porco 2004, IAU Circ. 8401).
- Spitale et al. 2006 (AJ 132) for the first time suggested the angular combination  $\psi_2 = 15\lambda_{Me} - 14\lambda_M - \varpi_{Me}$ , as being the critical angle associated to the 15:14 resonance, where  $\lambda_{Me}$ ,  $\lambda_M$  refer to the mean longitudes of Methone and Mimas, and  $\varpi_{Me}$  to the longitude of pericenter of Methone.
- Hedman et al. (2009) presented a puzzle characteristic of the orbit of Methone: they were the first to report that besides  $\psi_2$ , another angle, namely,  $\psi_1 = 15\lambda_{Me} - 14\lambda_M - \varpi_M$ , *also oscillates around zero*, where  $\varpi_M$  is the longitude of pericenter of Mimas.

# Explanation: FORCED ECCENTRICITY of Methone

Results given in Callegari, Rodríguez and Ceccatto 2021, CMDA 133

fig. 5 in  
Callegari  
et al.  
2021



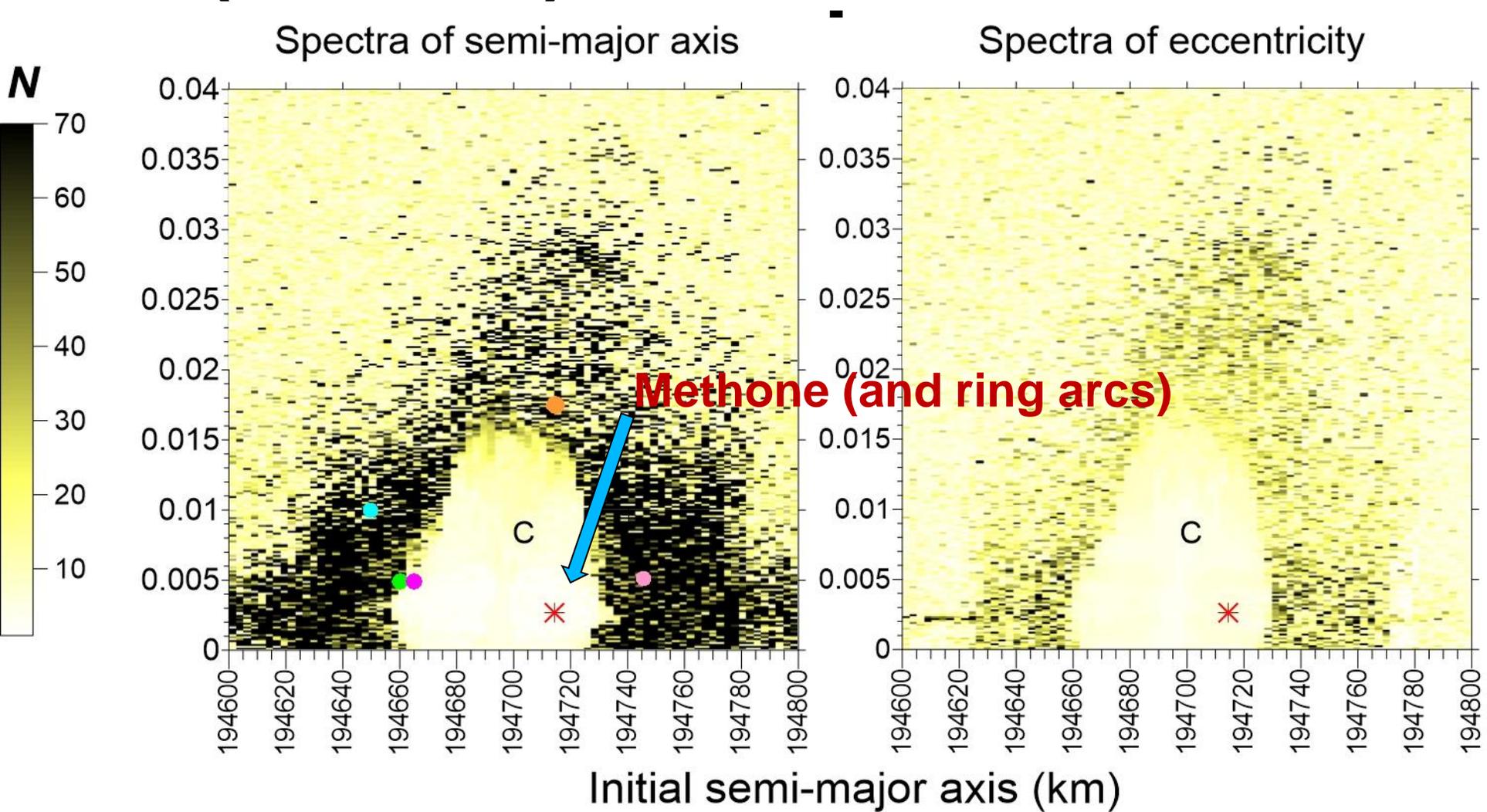
Color  
caption:  
Current  
resonant  
Orbit

Non-  
resonant  
orbit

Pink and  
Black: Linear  
Generalized  
Secular  
Laplace-  
Lagrange  
theory

# *Dynamical Maps: The Phase Space (e x a) of the 15:14 Mimas-Anthe MMR*

## The (isolated) Corotation resonance

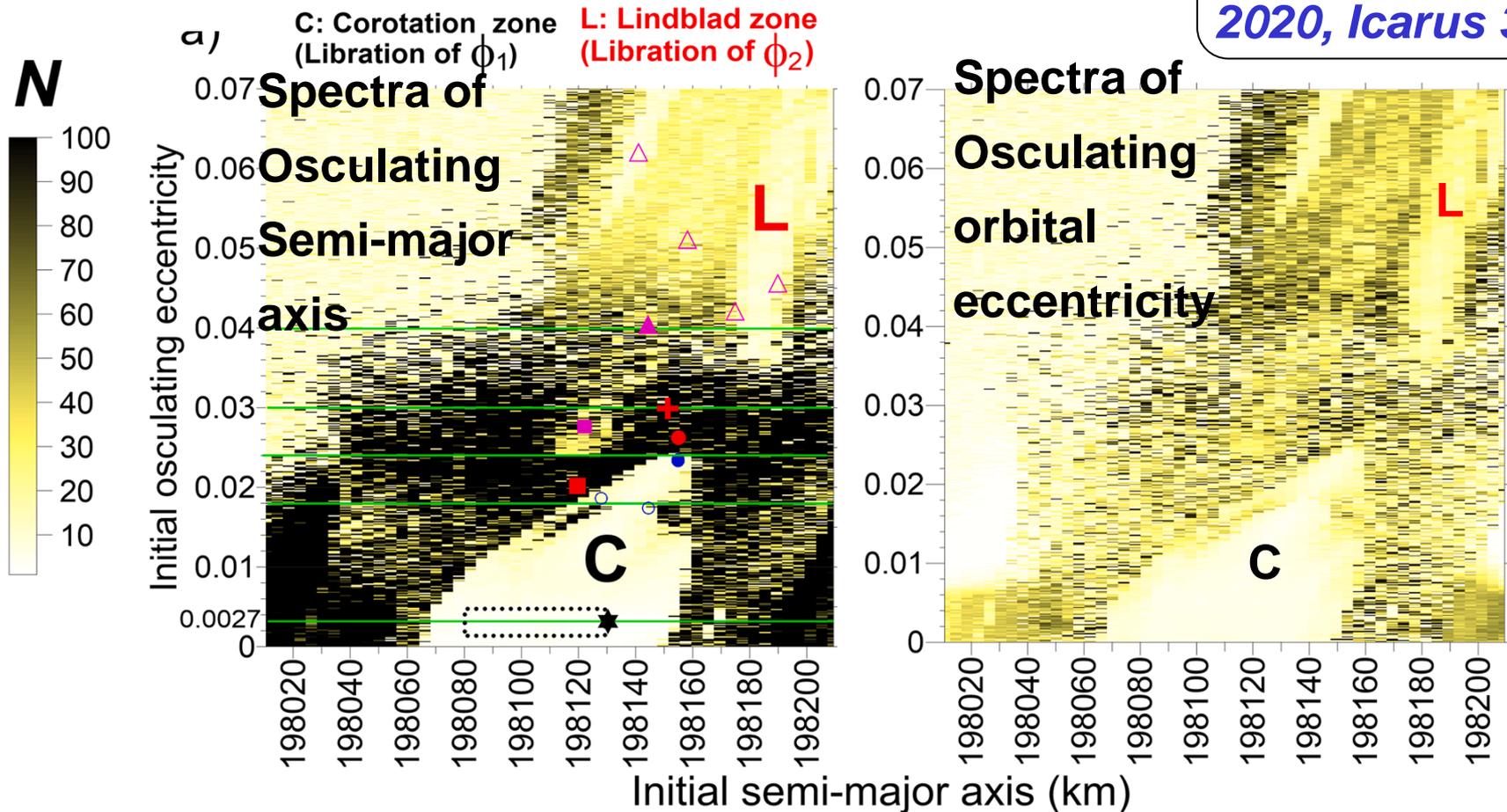


# The Phase Space of the 11:10 Mimas-Anthe MMR

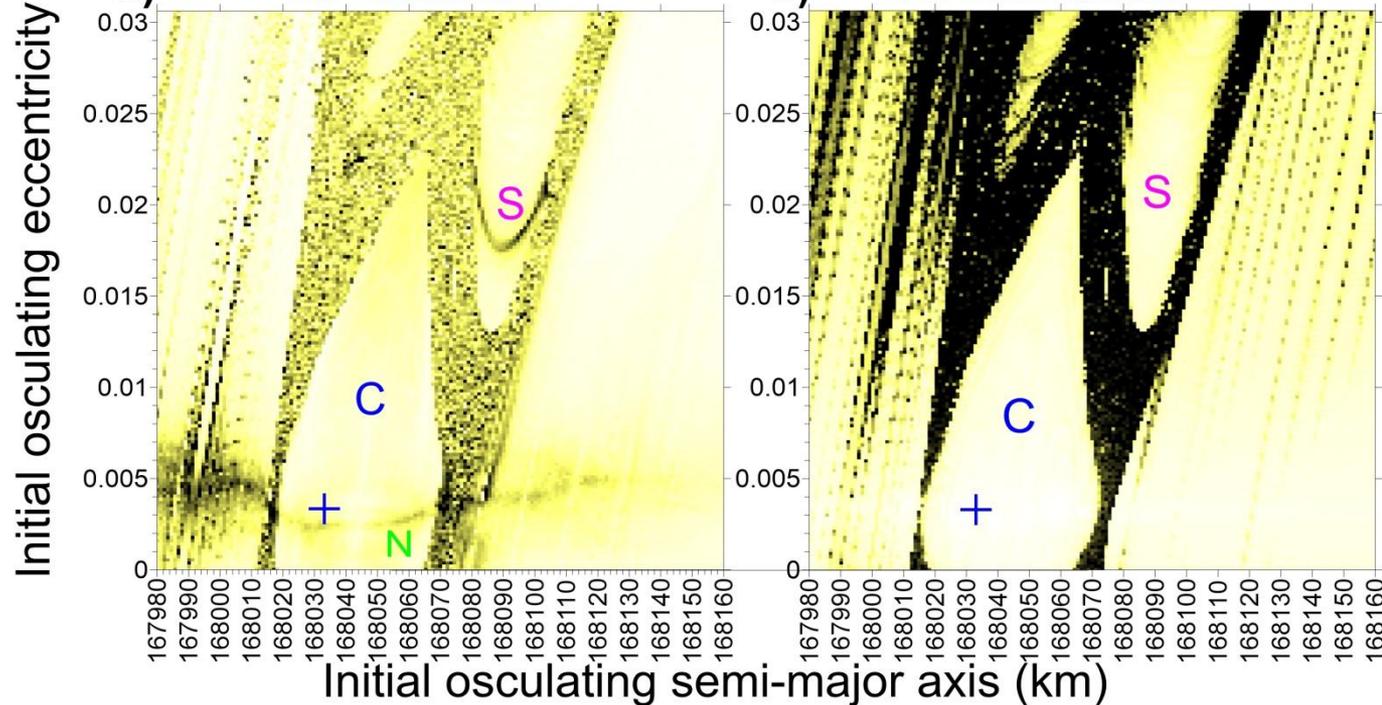
**C:**  $\Phi_1 = 11\lambda_A - 10\lambda_M - \varpi_M$  librates around zero with amplitude  $\sim 80$  deg, where  $\lambda_A$ ,  $\lambda_M$  refer to the mean longitudes of Anthe and Mimas, and  $\varpi_M$  to the longitude of pericenter of Mimas.

**L:**  $\Phi_2 = 11\lambda_A - 10\lambda_M - \varpi_S$ , where  $\varpi_S$  is the longitude of pericenter of a test small satellite.

*Fig. 7 in Callegari and Yokoyama 2020, Icarus 348*



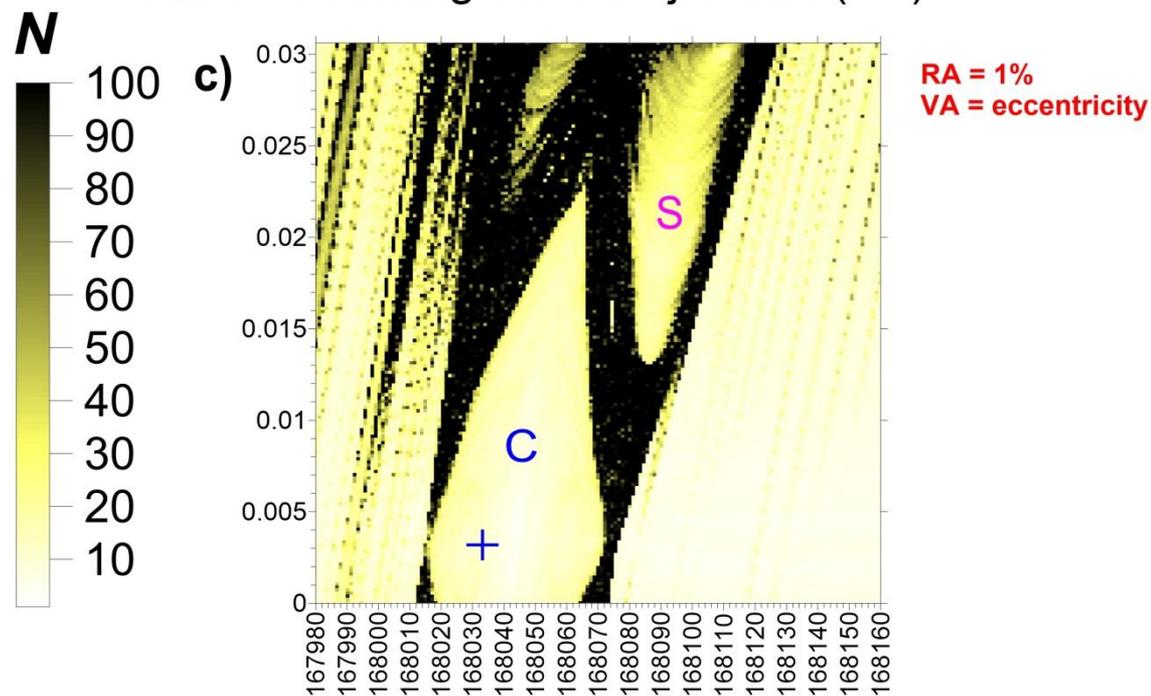
# The Phase Space of the 6:7 Aegaeon-Mimas MMR



S: secular mode

N: forced mode in inclination

+ : current position of Aegaeon (Jan 1, 2016)



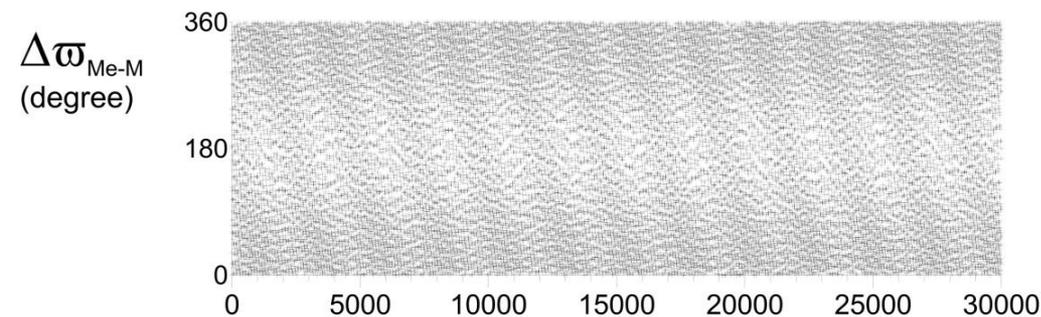
## Conclusions: Fundamental new results and interpretations on resonances

- **A key point on the quantitative interpretation of resonant dynamics of these systems** is that the equilibrium states of the 11:10, 15:14 and 6:7 MMRs with Mimas occurs around  $\varpi_M$ , the longitude of pericenter of Mimas (the corotation angles);
- **The three Corotation resonances are well-defined, all of them stable**, and the critical angles librate around zero.
- **Their chaotic separatrices delimitate their phase space volume. (Recall perturbed pendulum.)**

- We explain also the Mutual-Secular long-term Modes  
(*Brouwer and Clemence 1966*)

### Osculating

$$\Delta\varpi = \varpi_S - \varpi_M$$



### Geometric

