Eccentric Planets & Debris Disks interactions

Theory & Observations

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California Institute of Technology

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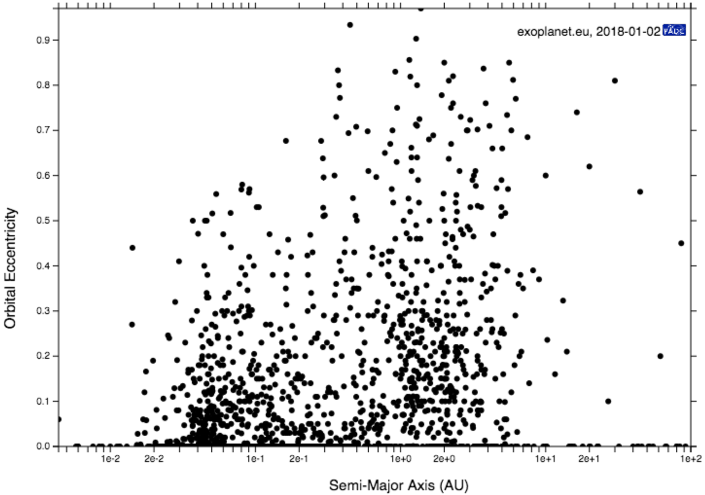
Eccentric planets are common (and fun!)

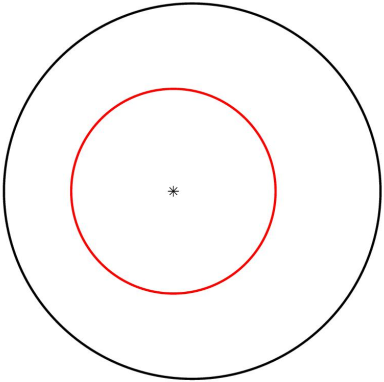


1. Resonant Interactions : setting bodies on cometary orbits

2. Secular Interactions : shaping debris disks into eccentric rings

Possibly large modulations in eccentricity

A planet on an ***eccentric*** orbit & a planetesimal on an ***resonant*** orbit



Close approach to the planet & orbit crossing

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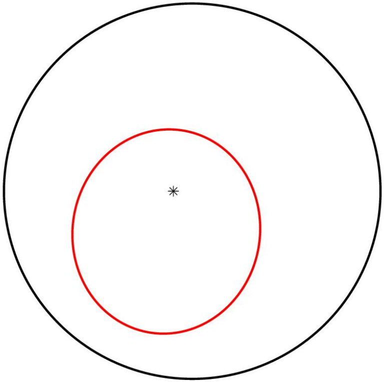

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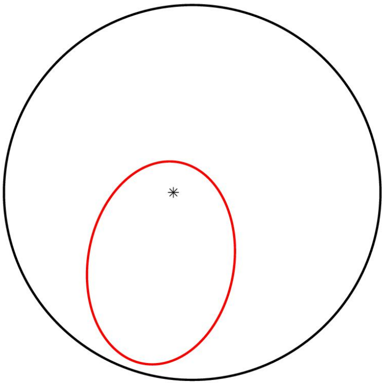

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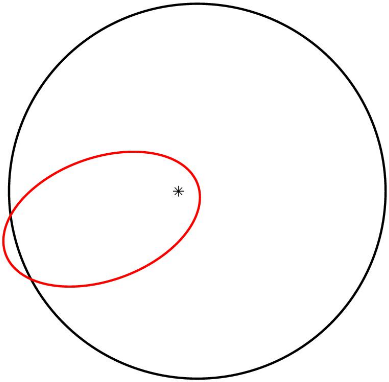

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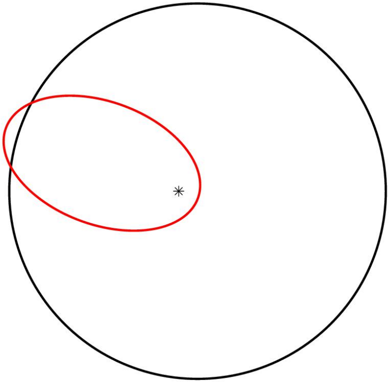

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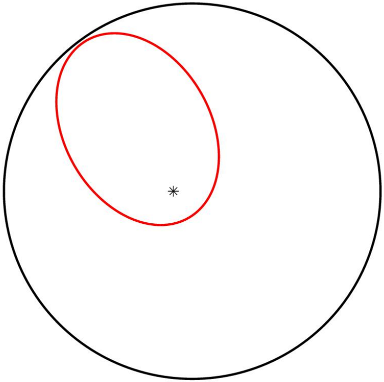

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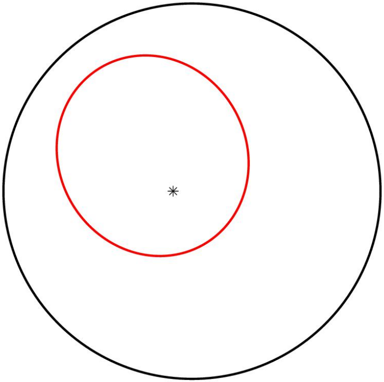

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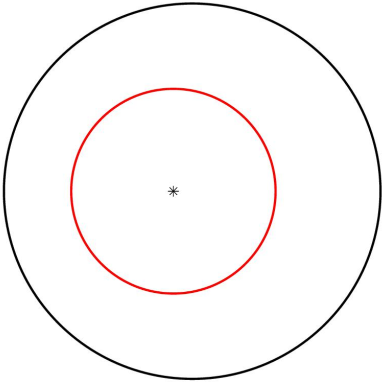

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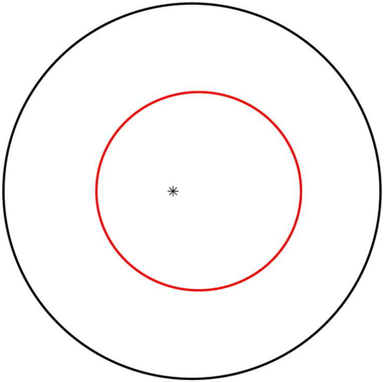


Close approach to the planet & orbit crossing

Exozodis : bright analogues to the Zodiacal cloud

Zodiacal Light seen from Paranal

ESO/Y. Beletsky

Dust within first AUs around a star

Origin : Comet evaporation

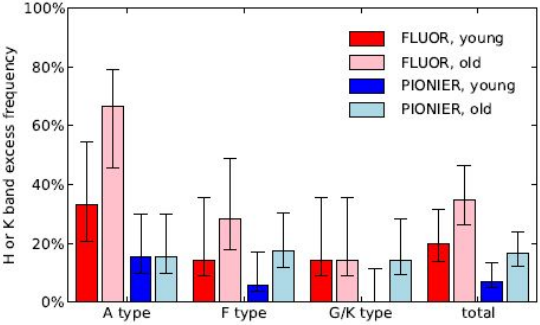
($\sim$ 90% in the Solar System, Nesvorný et al. 2010)

Comets induced via interactions between planet(s) and a reservoir of km-sized bodies

Interferometric Surveys : Results

Combined results of the CHARA/FLUOR & VLTI/PIONIER surveys

(Absil et al. 2013; Ertel et al. 2014a)



Exozodis present in large proportions,
especially in old systems (>100 Myr)
No correlation between an exozodi and a colder reservoir (at that time !)

Possible mechanisms

Option 1 :
delayed cometary activity

LHB-like event

Bonsor et al. (2013)

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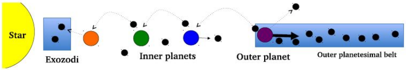
Option 2 :
continuous feeding over long timescales

Scattering by a chain of planets



Bonsor & Wyatt (2012); Bonsor et al. (2012, 2014)

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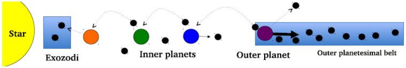

Bonsor & Wyatt (2012); Bonsor et al. (2012, 2014)

Contrived architecture of the planetary system

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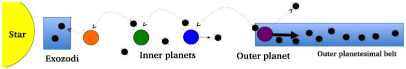


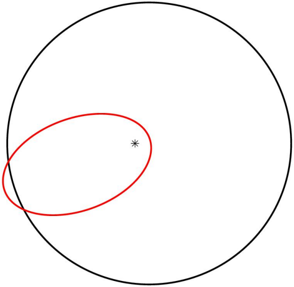
Contrived architecture of the planetary system

Bonsor & Wyatt (2012); Bonsor et al. (2012, 2014)

MMRs with an eccentric planet combines both advantages

MMR with an eccentric planet

Either direct production of cometary orbits $q \leq 1\,\mathrm{AU}$
or
Production through scattering events



Activity delayed :

time for the first cycle to complete

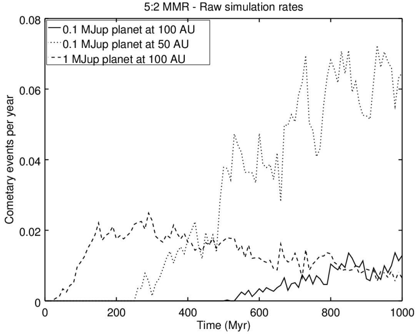
Several 100 Myr possible Faramaz et al. (2015)

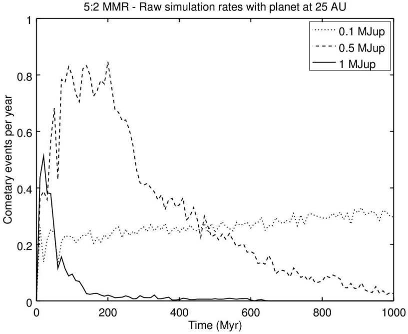
Continuous production :

several cycles before being scattered

Rates ? Timescales ?

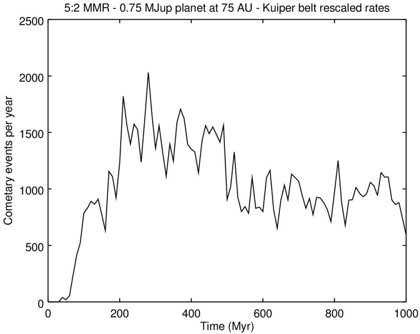
N-Body simulations





It is possible to sustain cometary activity on Gyr timescales direct or indirect !

The Kuiper Belt example
Towards more realistic rates



Detected exozodis are $\sim 10 - 100$ times brighter.

Reservoir 2.5-50 times more massive & brighter than the Kuiper Belt

Currently detection limits : ~ 10 times brighter than the Kuiper belt with *Herschel*, Vitense et al. (2010)

Solar system ~ 120 events per year

Reservoir mass compatible with absence of correlation between cold belt and exozodi.

MMRs between a cold debris belt and eccentric planets
is an efficient mechanism to produce comets and exozodis,
especially in old systems (>100 Myr)

Robust process

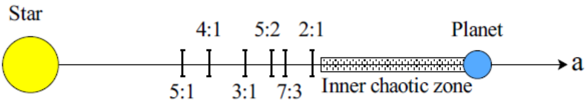
Can work for a large range
of planetary parameters :

$$m_p = 0.1 - 1\, M_{\rm Jup}$$

$$e_p = 0.1 - 0.4$$

Virtually no restriction on the
semi-major axis.

An 0.5 M_{Jup} eccentric planet



Scales with $\mathrm{a_p}$, while $\mathrm{m_p}$ sets relative distances

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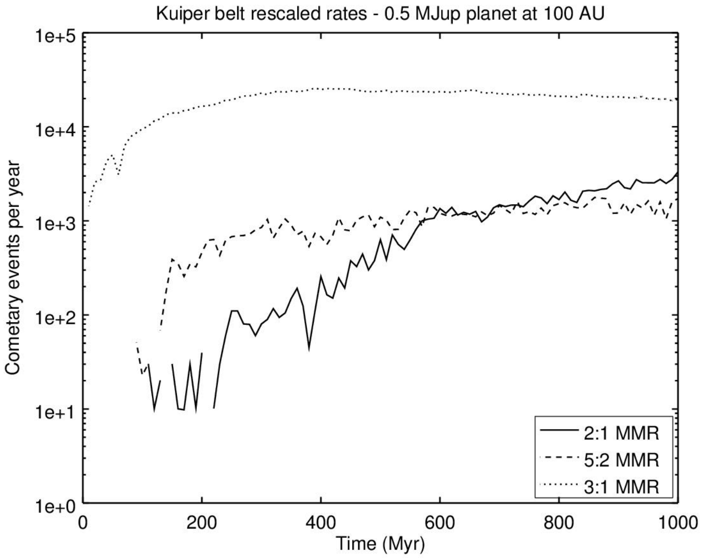
Real belt overlap several MMRs

Process works for several other MMRs.

Works for several MMRs



Big questions :

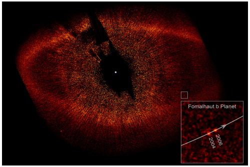
- How frequent are favourable architectures ?
- How does the mechanism accommodate for other planets ?
- Is water and organics delivery easier in systems with eccentric planets ?
- Does life has more opportunities to develop there ? Or to be destroyed ?

1. Resonant Interactions : setting bodies on cometary orbits

2. Secular Interactions : shaping debris disks into eccentric rings

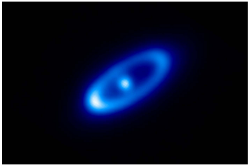
Shaping debris disks into eccentric rings

Fomalhaut, 440 Myr, $e = 0.11$



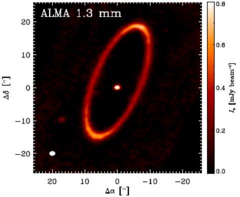
HST (optical)

(Kalas et al. 2005, 2008)



Herschel/PACS 70μm

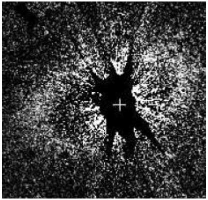
(Acke et al. 2012)



ALMA 1.3mm

(MacGregor et al. 2017)

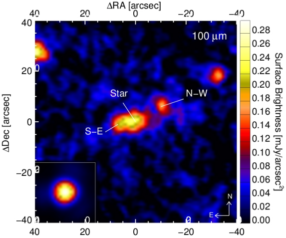
HD 202628, 2 Gyr, $e = 0.12$



HST (optical)

(Krist et al. 2012)

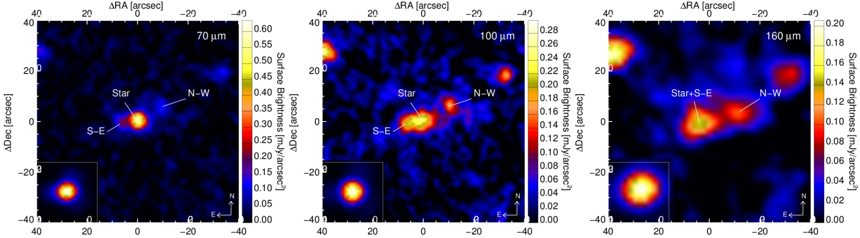
ζ^2 Reticuli , 2 Gyr, $e = 0.3$



Herschel/PACS 100μm

(Eiroa et al. 2010)

Herschel/PACS observations at 70, 100 and 160 microns (Eiroa et al. 2010)



Interpretation : The Disk of ζ^2 Reticuli

- Asymmetric double-lobed feature
- Seen edge-on
- Ring $\sim$ 100 AU & Eccentricity $\geq$ 0.3

- Can such asymmetries survive the Gyr timescales ?
- What perturber creates this pattern ?

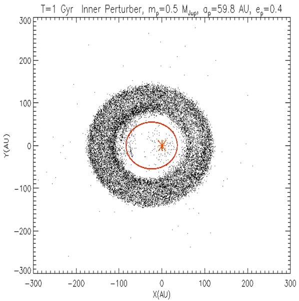
Suspects list

1. The binary companion ζ^1 Ret
2. A yet undetected planet

Good suspects

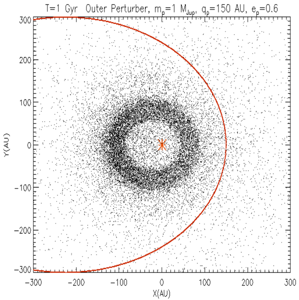
An inner planet

- Shaping the inner edge
- With eccentricity 0.4
- With mass $0.5 M_{\mathrm{Jup}}$



An outer planet

- With eccentricity 0.6
- With mass $1 M_{\mathrm{Jup}}$
- With periastron $150 AU$

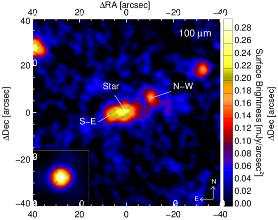


Compare the prints

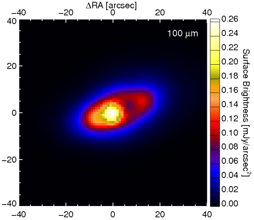
Synthetic images : full comparison with Herschel images

Simulate dust production from the parent planetesimals & Compute its emission

At 100 microns



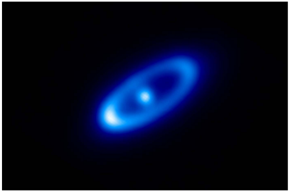
Herschel image



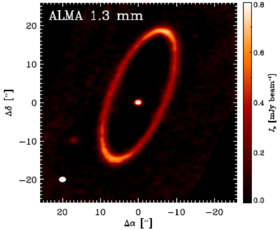
Synthetic image

Main conclusions in 2014 :

1. ζ^2 Reticuli hosts a distant companion with $e \gtrsim 0.3$
2. Eccentric rings can be sustained on Gyr timescales.



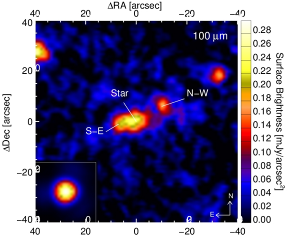
Herschel/PACS 70μm (Acke et al. 2012)

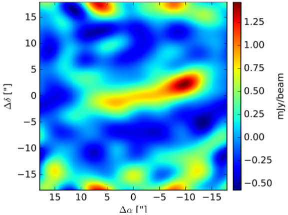


ALMA 1.3mm (MacGregor et al. 2017)

Pericenter-glow (Wyatt et al. 1999)

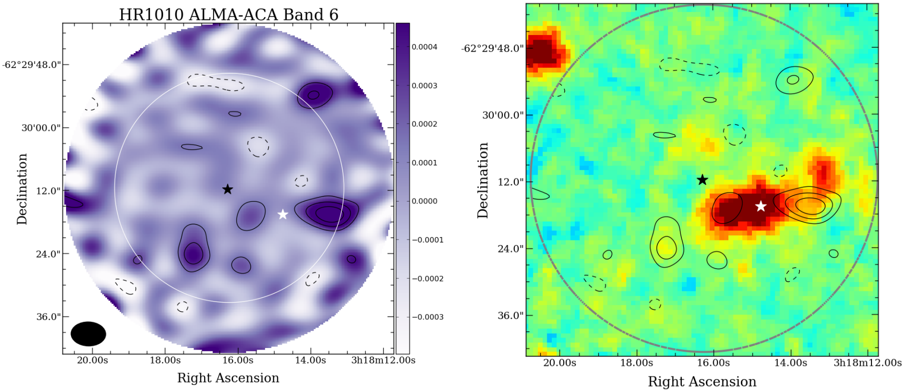
Apocenter-glow (Pan et al. 2016)





Expected ALMA-ACA observations

ALMA-ACA observations
Faramaz et al. 2018



If the debris disk seen with Herschel was real, it should have been detected !

This is not the debris disk you're looking for...

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