Lyman α emission from the Fomalhaut debris disk

Gianni Cataldi[1,2], Alexis Brandeker[1,2], Göran Olofsson[1,2]

[1]Department of Astronomy, Stockholm University

[2]Stockholm University Astrobiology Centre

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The eccentric dust ring of Fomalhaut: planetary perturbations or gas-dust interactions?

Gianni Cataldi[1,2], Alexis Brandeker[1,2], Göran Olofsson[1,2]

[1]Department of Astronomy, Stockholm University

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Outline

1. Debris disks
2. The Fomalhaut system and its eccentric dust ring
3. Planetary perturbations: Fomalhaut b
4. The eccentric dust ring revisited: gas-dust interactions

What are debris disks?

- circumstellar, gas-poor disks consisting of dust, comets and leftover planetesimals
- Kuiper belt / asteroid belt analogues
- follow protoplanetary phase after $\sim$10 Myr
- size: from a few AU to $>$1000 AU
- dust continuously replenished by collisions
- several hundred examples known today

Image credit: NASA

What are debris disks?

What debris disks can tell us. . .

- constrain planet formation theory (e.g. efficiency of planetesimal formation)
- disk structures may indicate planets
- composition of dust → composition of planets

Image credit: NASA

The Fomalhaut system

- spectral type: A-star
- distance: 8 pc
- age: 400 Myr
- eccentric dust ring with semi-major axis of ~140 AU

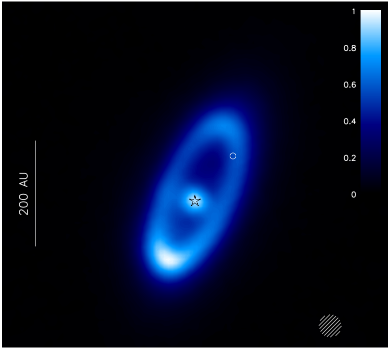
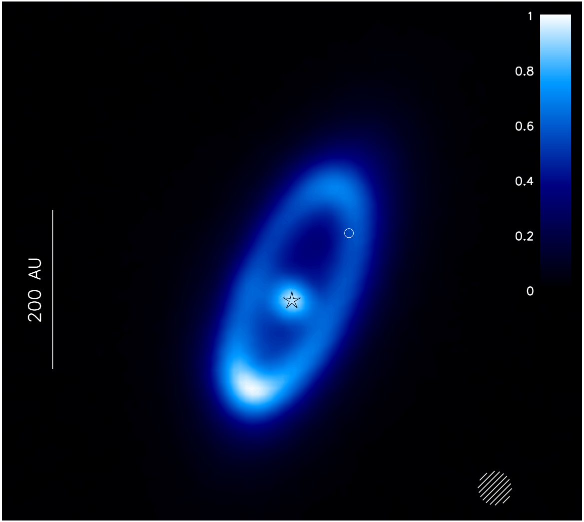


Image credit: Acke et al. 2013

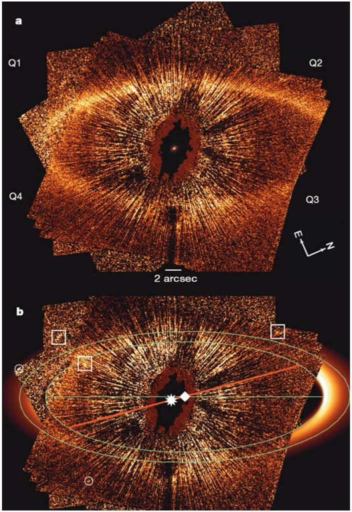
The Fomalhaut dust ring



Herschel PACS 70 μm Image credit: Acke et al. 2013

Is a planet shaping the dust ring?

- Indications for a planet shaping the dust ring (Kalas et al. 2005):
  - centre of dust ring offset by ∼15 AU from star
  - sharp inner edge
- ⇒ search for planetary candidates



Optical HST image. Image credit: Kalas et al. 2005

Detection of Fomalhaut b

- detection of Fomalhaut b with HST (Kalas et al. 2008, 2011, 2013)

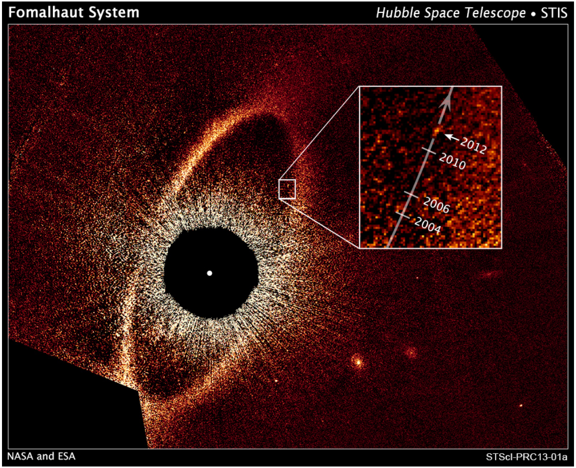


Image credit: NASA and ESA

The nature of Fomalhaut b

- puzzling spectral properties:
  - detected in optical (e.g. Kalas et al. 2013)
  - . . . but non-detection in mid-IR (e.g. Janson et al. 2012)
- ⇒ inconsistent with models of planetary spectra
- ⇒ detection in *reflected* starlight
- ⇒ need additional reflecting surface

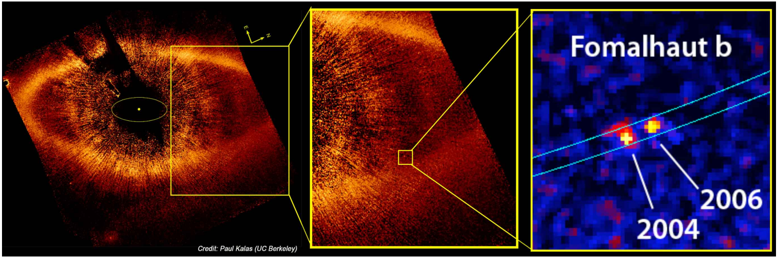


Image credit: Paul Kalas (UC Berkeley)

The nature of Fomalhaut b

- proposed models:
  - circumplanetary dust disk (Kalas et al. 2008)
  - transient dust cloud (Kalas et al. 2008)
  - swarm of irregular moons around 2–100 $M_\oplus$ planet (Kennedy & Wyatt 2011)

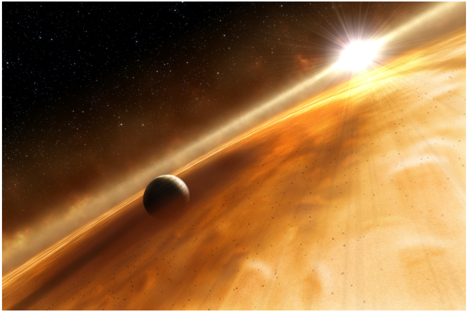


Image credit: ESA, NASA, and L. Calcada (ESO for STScI)

Swarm of irregular satellites

- irregular moon = "satellite on distant, inclined, often eccentric and retrograde orbit" (Wikipedia)
- most are believed to have been captured
- e.g. Saturn: 38 irregular satellites known

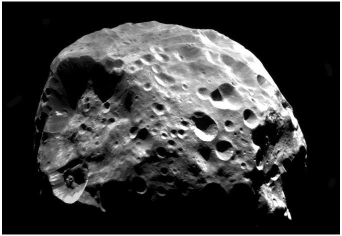
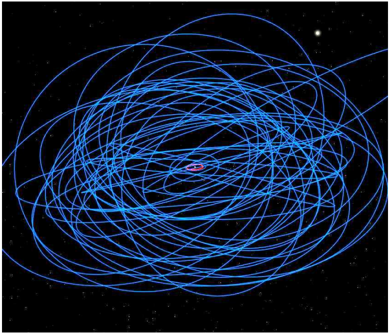


Image credit: NASA/JPL/Space Science Institute

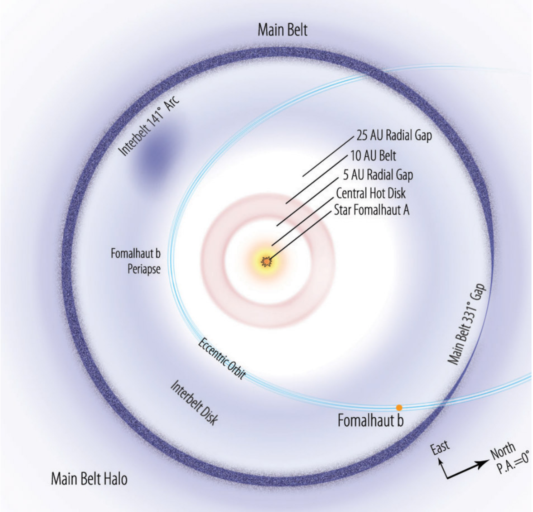
Swarm of irregular satellites

- satellites erode by collisions and produce dust
- presumably more dust for planets around young stars
- Fomalhaut b: irregular satellites of a few lunar masses around 2–100 $M_\oplus$ planet can explain the detected emission



Fomalhaut b and the eccentric dust ring revisited

- orbit of Fomalhaut b highly eccentric ⇒ unlikely to be responsible for eccentricity / morphology of the disk!



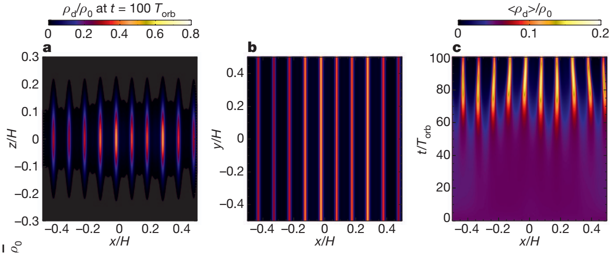
Kalas et al. 2013

Fomalhaut b is not responsible for the morphology of the disk. What now?

- Fomalhaut c ?
- close stellar encounter ?
- . . . gas-dust interactions ?

Sharp (eccentric) rings through gas-dust interactions

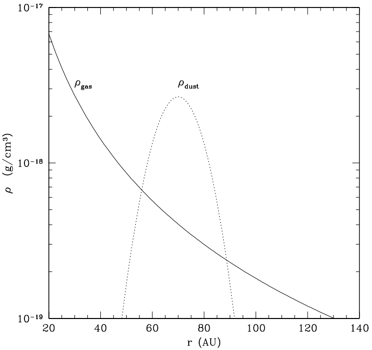
- alternative without invoking planets: gas-dust interactions
- dust affects gas temperature - gas affects dust dynamics
- operates for stars with spectral type as late as K
- works for a wide range of dust and gas masses



Lyra & Kuchner 2013

The photoelectric instability

- start with generic dust enhancement (e.g. from collision)
- gas is primarily heated by photoelectrons from the dust
- photoelectric instability:
    - dust heats gas by photoelectric effect
    - ⇒ gas temperature rises
    - ⇒ gas pressure rises
    - dust concentrates where gas pressure is maximum
    - ...



Besla & Wu 2007

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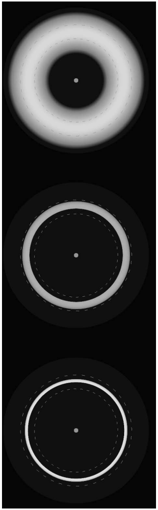
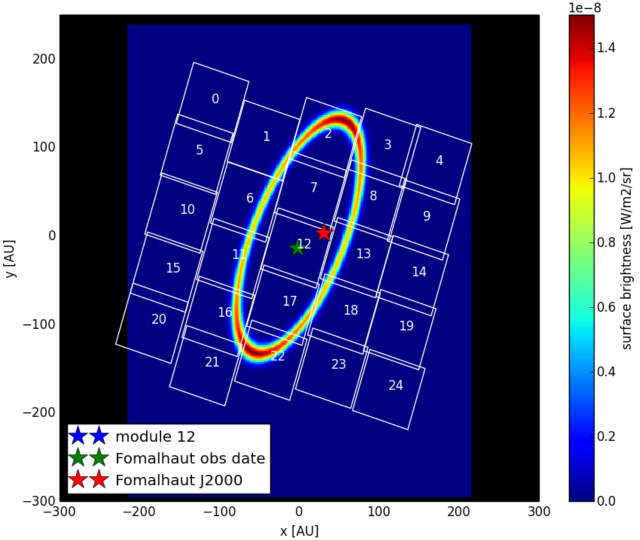


Besla & Wu 2007

Search for gas in the Fomalhaut dust ring

- search for gas emission within the Fomalhaut dust ring:
  - C II 158 μm and O I 63 μm: *Herschel* PACS (non-detections)
  - CO 867 μm: ALMA (non-detection)
- known dust ring structure allows "forward modelling" approach
- general strategy:
  1. derive upper limits on O I / C II / CO gas *luminosity*
  2. convert into total gas mass using the gas ionisation / thermal balance code ONTARIO

PACS observations



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Debris disks

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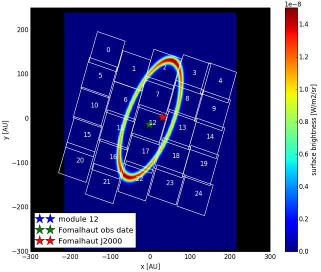
Planetary perturbations: Fomalhaut b

The eccentric dust ring revisited: gas-dust interactions

preliminary result for C II

- analysis indicates that PACS data can give stringent upper limits
- upper limits (95% confidence level):
  - solar abundances: $\lesssim 1.9 \cdot 10^{-3}\ M_{\oplus}$ of gas ($\Rightarrow \epsilon \gtrsim 10$)
  - C overabundant 300×: $\lesssim 6.0 \cdot 10^{-5}\ M_{\oplus}$ of gas ($\Rightarrow \epsilon \gtrsim 300$)



Summary

1. The Fomalhaut system appears as an increasingly complex planetary system
2. The exact nature of Fomalhaut b is unclear
3. Current constraints on the orbital elements of Fomalhaut b suggest a different origin of the ring morphology:
    - Fomalhaut c
    - gas-dust interactions
    - (interactions with other stars)
4. We use *Herschel* PACS and ALMA to search for gas in the Fomalhaut dust ring to test whether gas-dust interactions could be at work