The Exozodi Problem: A Modeler's Perspective

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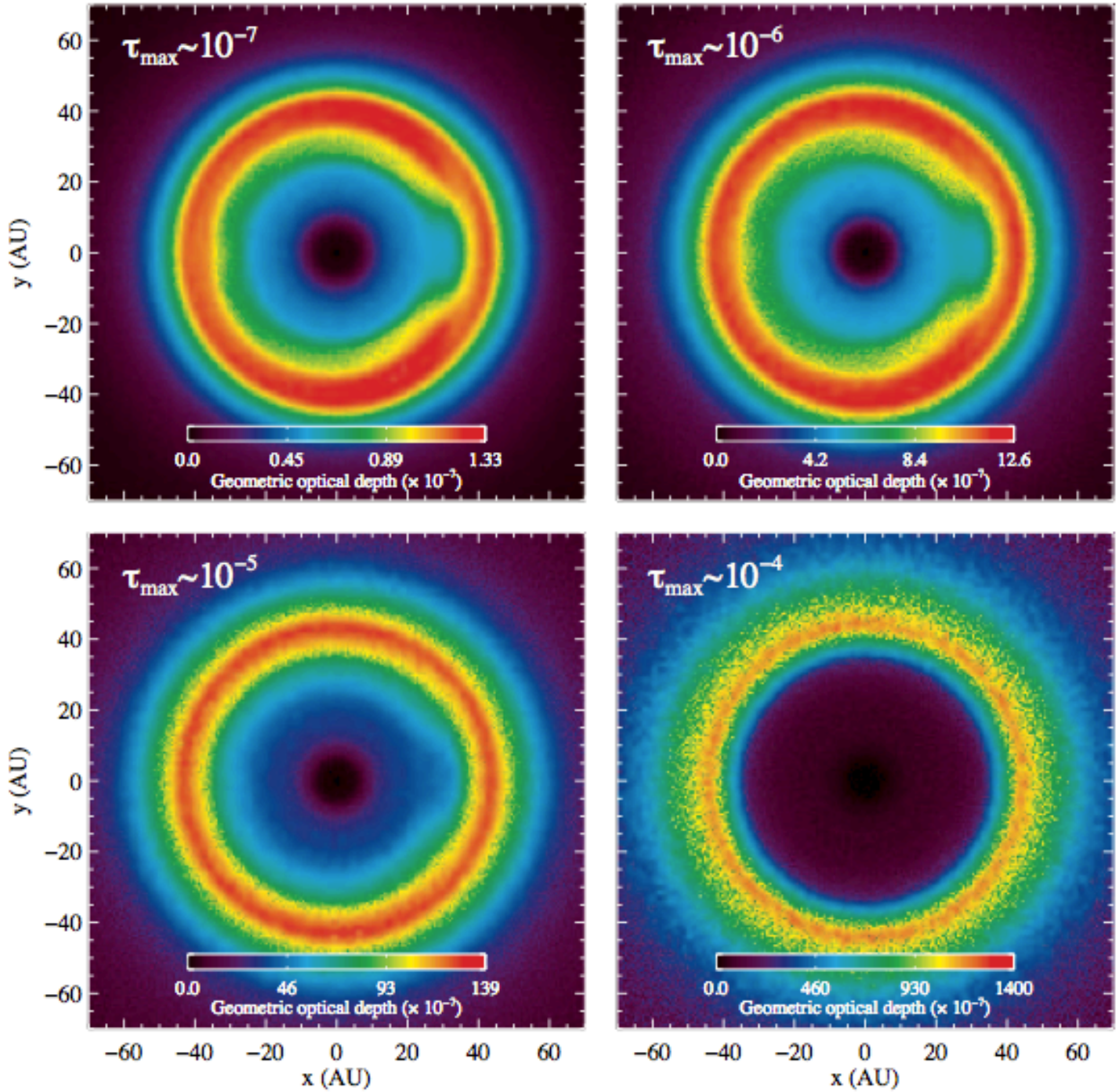
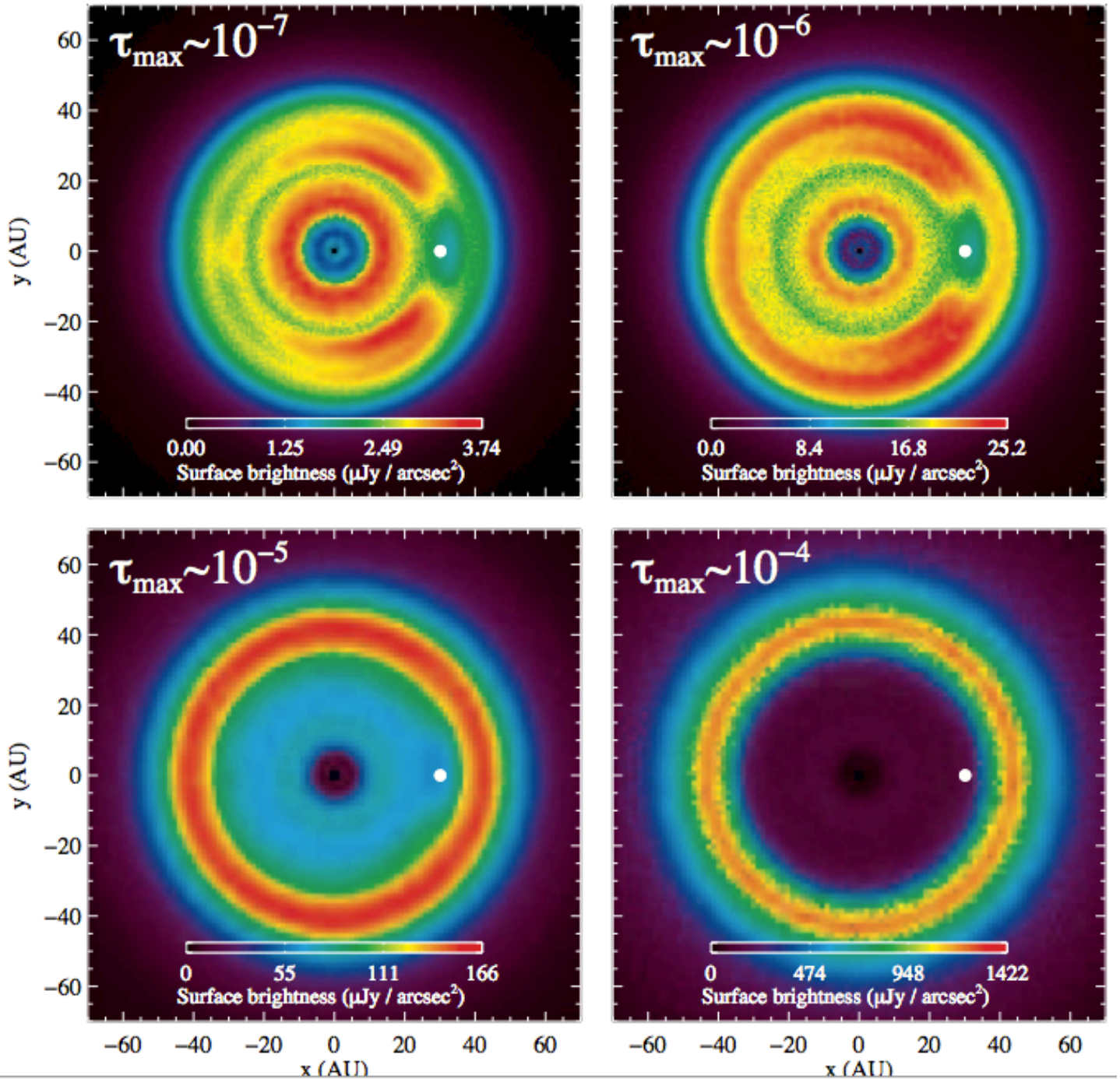
MIT

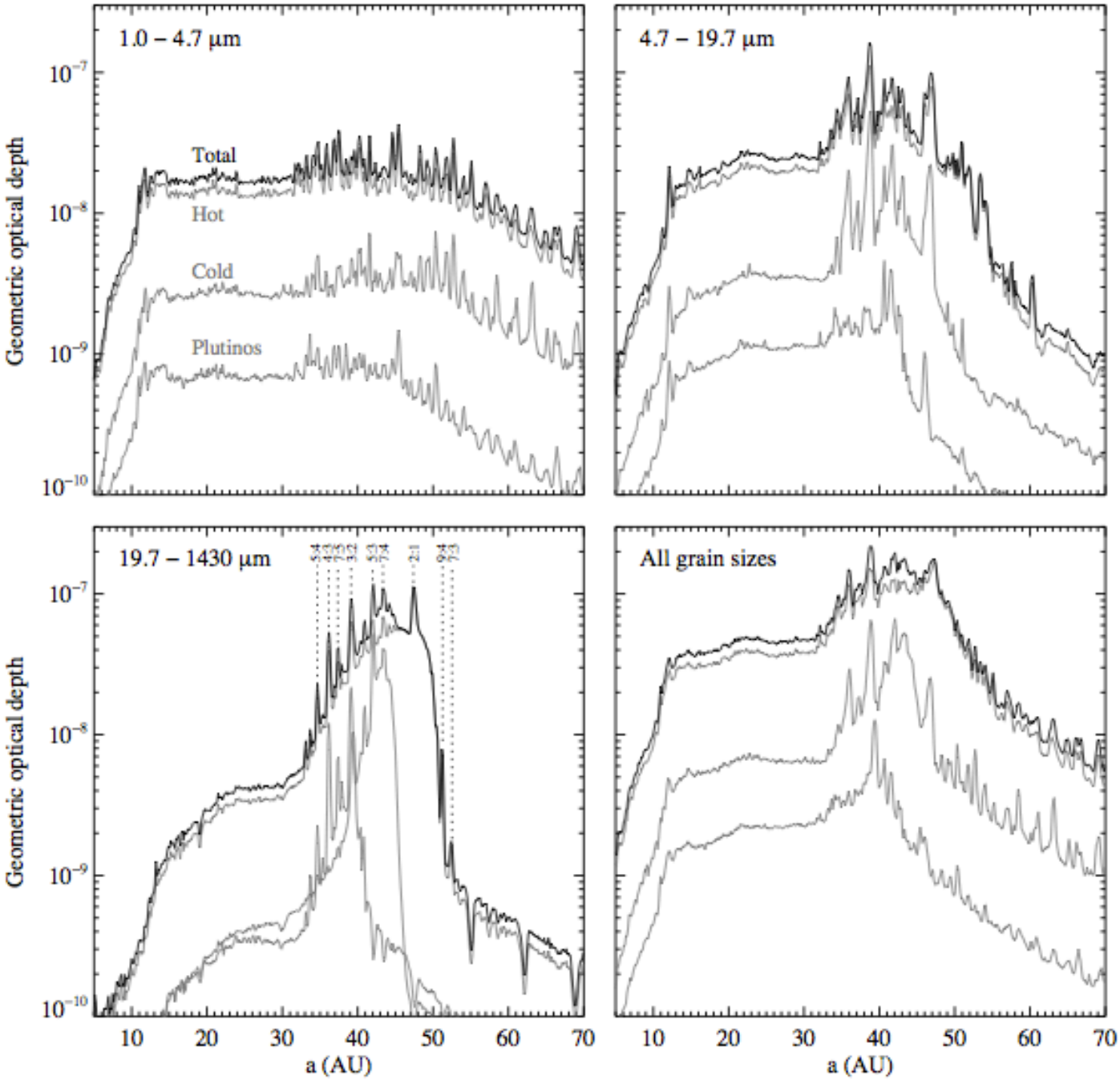
"Emission from exozodiacal dust is likely to be the largest source of astrophysical noise in direct imaging and characterization of exoplanets."

- Exoplanet Community Report (2009)

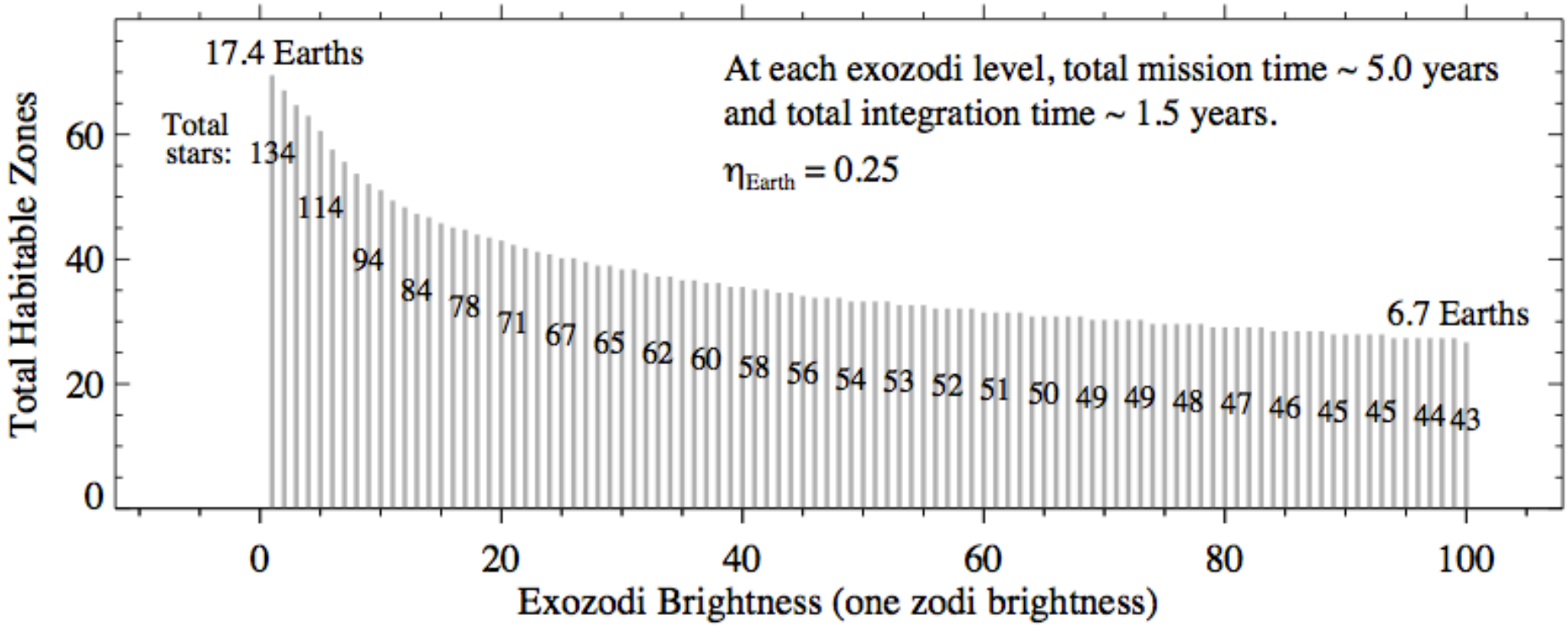
ISAS/JAXA

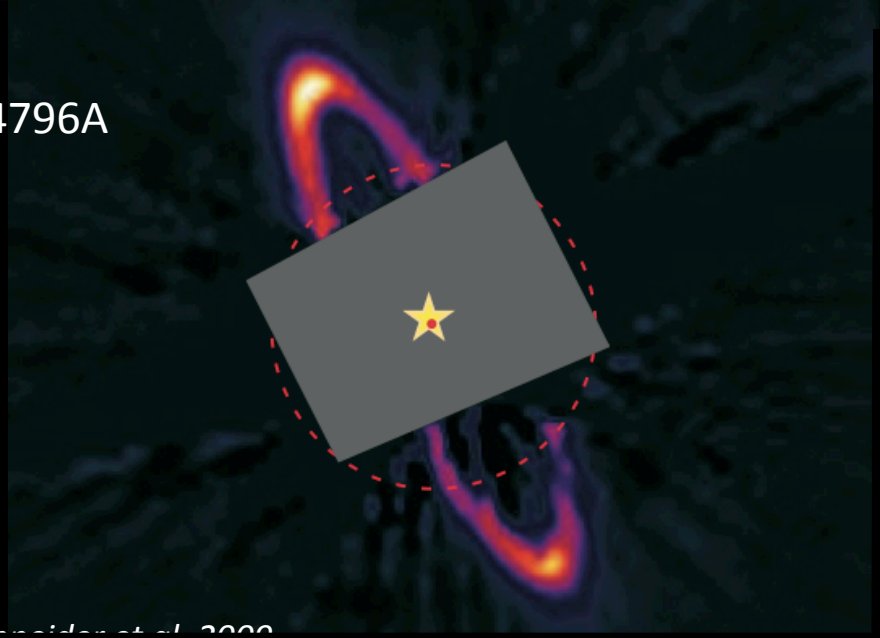

τmax~10−7
τmax~10−6
τmax~10−5
τmax~10−4
0.0
0.45
0.89
1.33
4.2
8.4
12.6
46
93
139
460
930
1400
Geometric optical depth (× 10−7)
y (AU)
x (AU)
60
40
20
0
−20
−40
−60


τmax~10−7
τmax~10−6
τmax~10−5
τmax~10−4
0.00 1.25 2.49 3.74
0.0 8.4 16.8 25.2
0 55 111 166
0 474 948 1422
Surface brightness (μJy / arcsec²)
y (AU)
x (AU)
60 40 20 0 −20 −40 −60

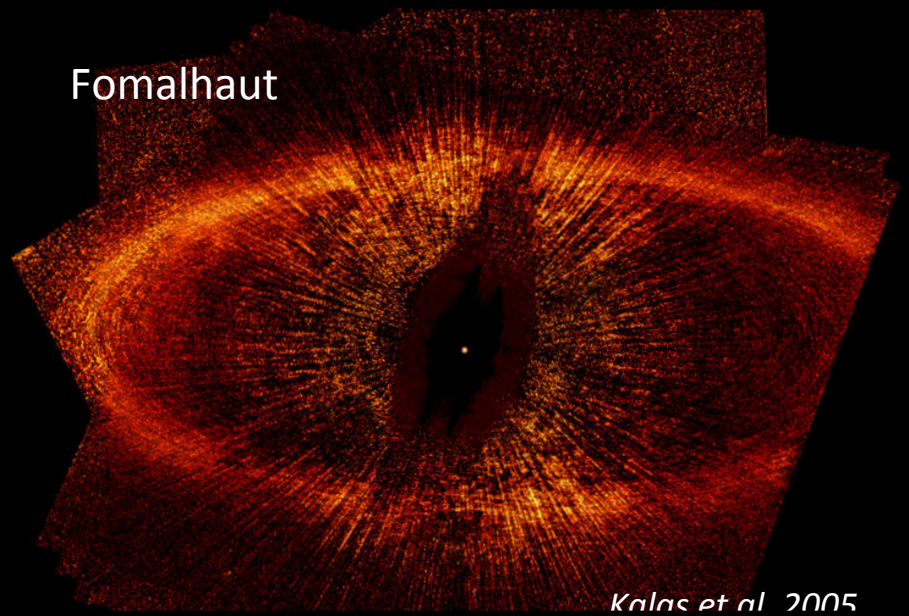

1.0 – 4.7 μm
4.7 – 19.7 μm
19.7 – 1430 μm
All grain sizes
Total
Hot
Cold
Plutinos
Geometric optical depth
a (AU)
10
20
30
40
50
60
70
10^{-7}
10^{-8}
10^{-9}
10^{-10}

Exozodis increase integration time





Schneider et al. 2000



Kalas et al. 2005

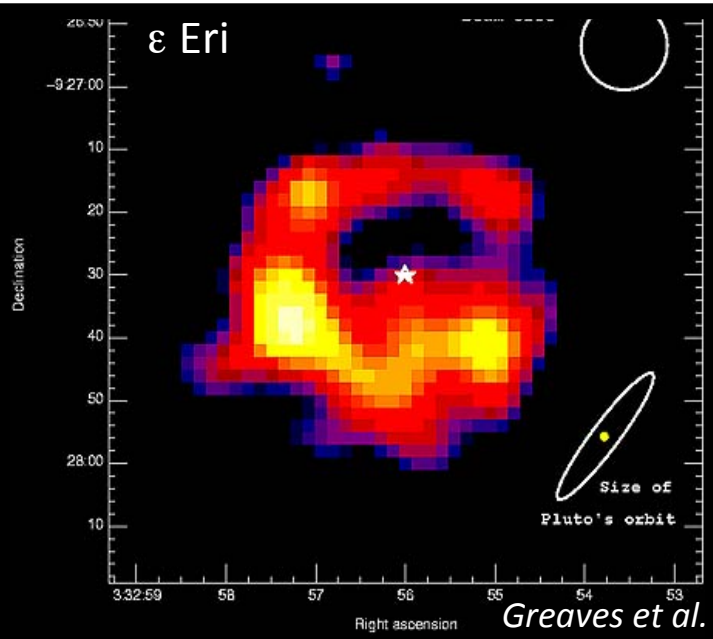
Will exozodi structure be problematic?

Ring structures

Offsets

Clumps

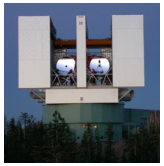
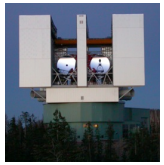
Gaps



Greaves et al. 1998

The Exozodi Problem

Brightness?

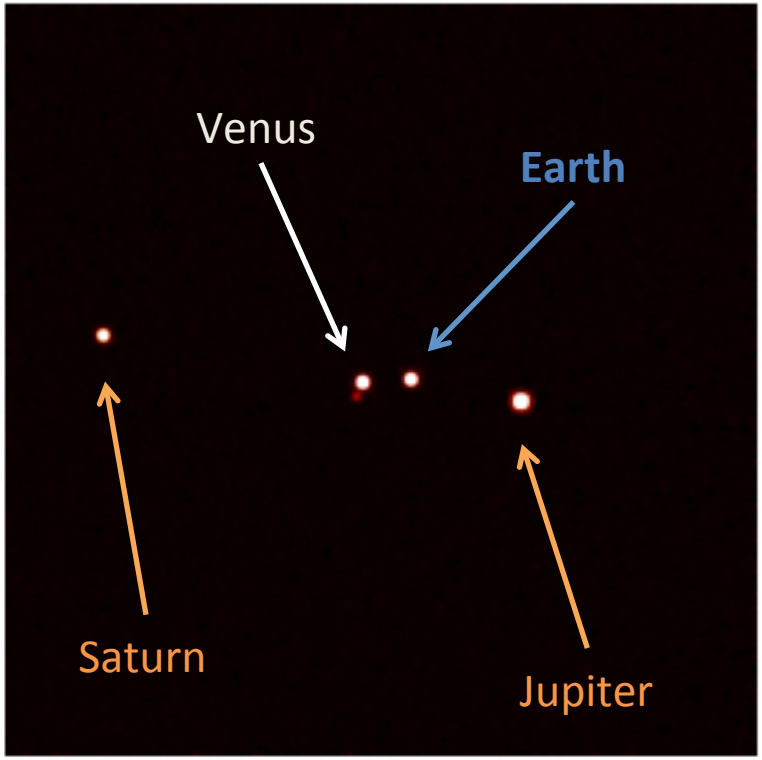
- Typical number of zodis 
- Distribution of dust 

Structures?

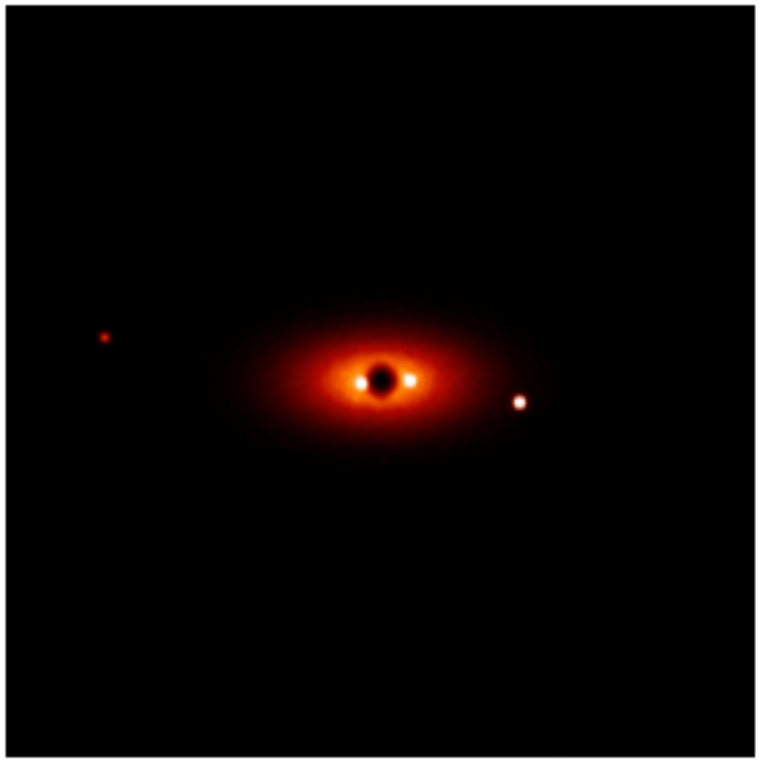
- Recent massive collisions
- Offsets
- Resonant rings of trapped dust
- Resonant rings of trapped planetesimals

Our solar system @ 10 pc, viewed with NWO

Without dust



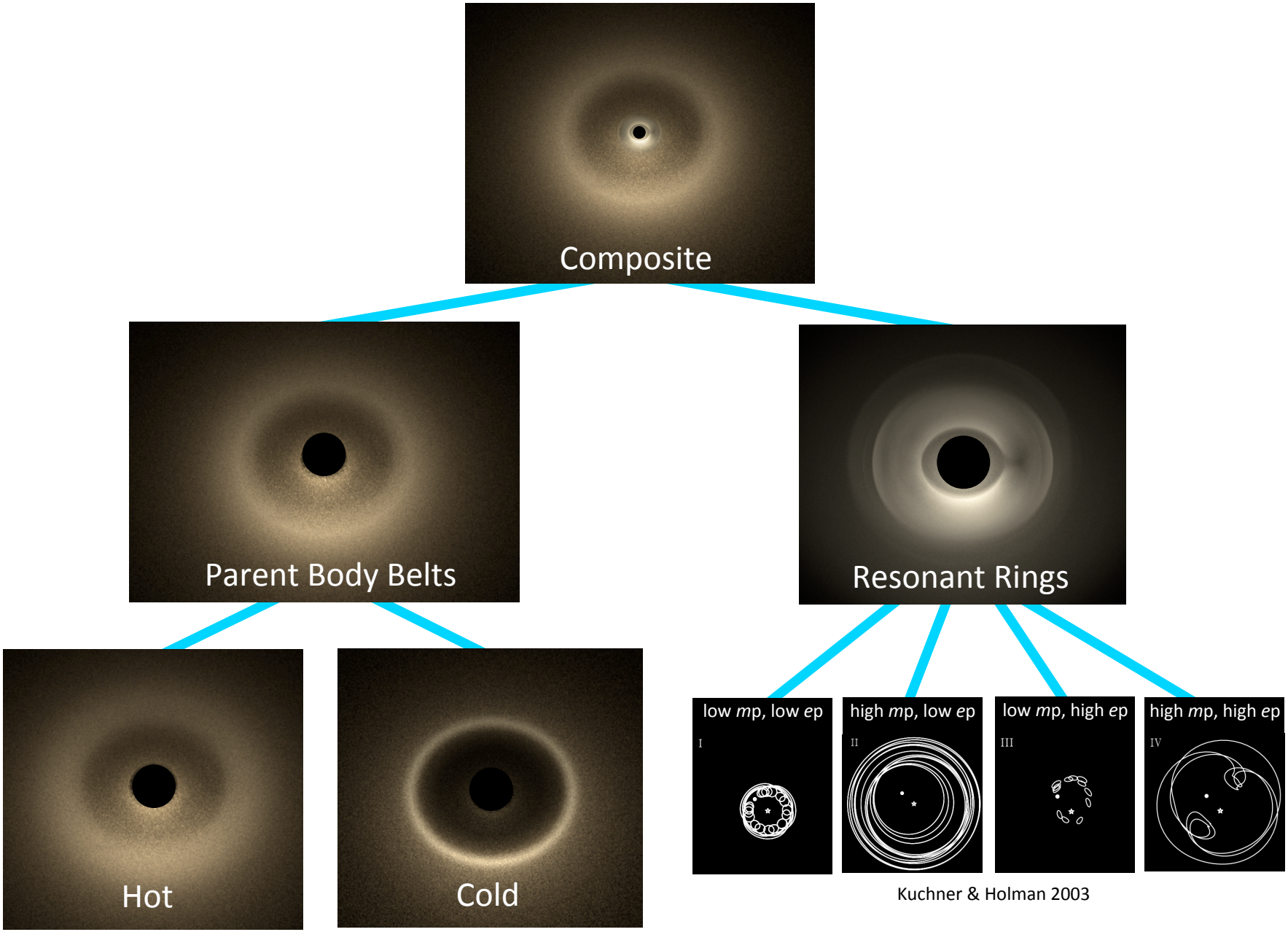
With our zodiacal cloud



0.4 μm, 4 m NWO external occulter

Cash et al. (2010)

Structures in Debris Disks



Kuchner & Holman 2003

The Exozodi Problem

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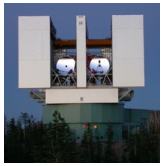
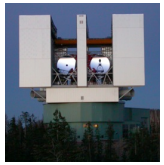
- Typical number of zodis 
- Distribution of dust 

Structures?

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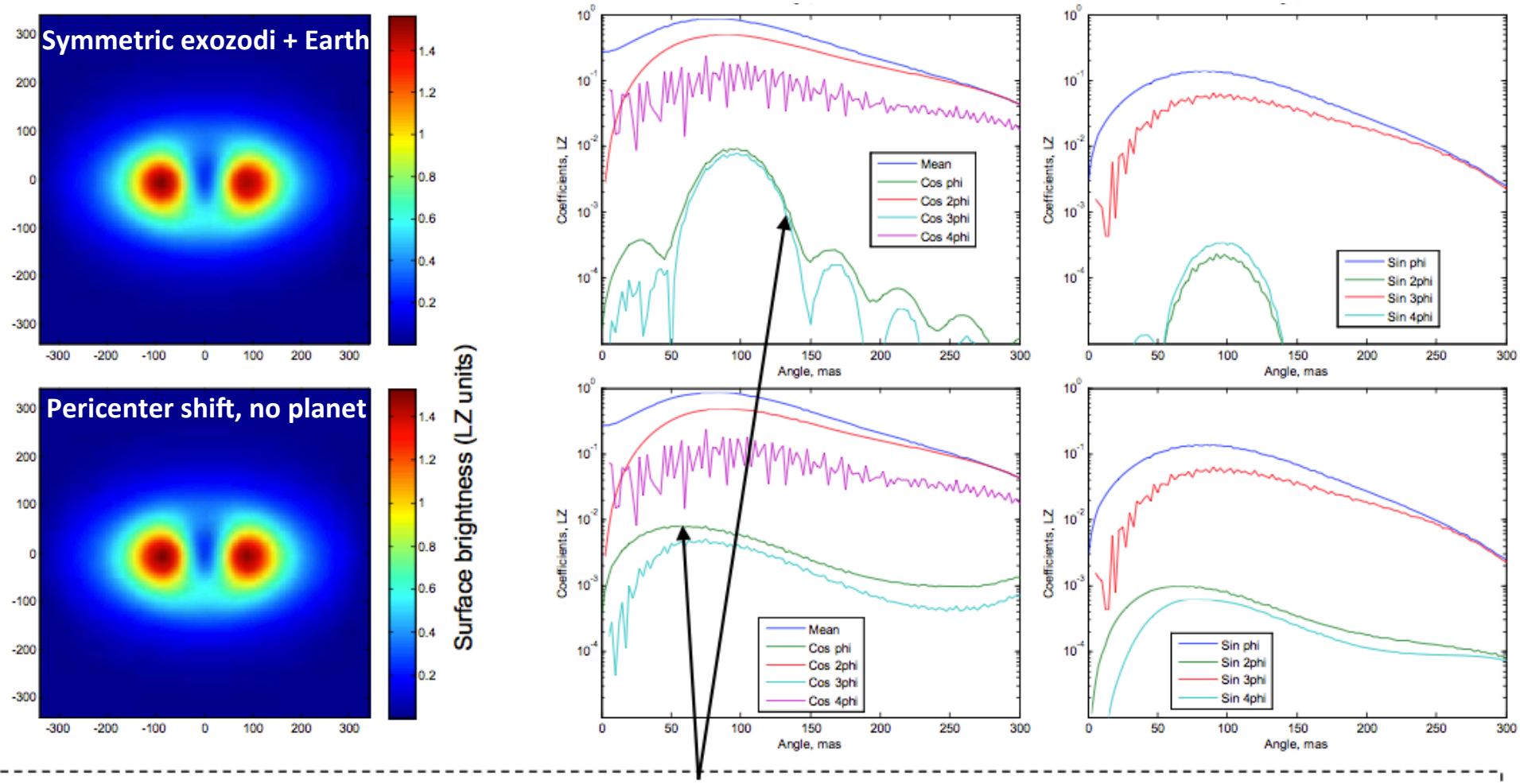
Exozodi Offsets

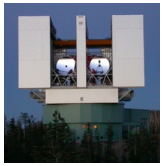
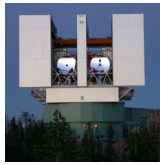


The differences between these 2 curves are < 1% of the average EZ flux

Noecker & Kuchner (2010)

The Exozodi Problem

Brightness?

- Typical number of zodis 
- Distribution of dust 

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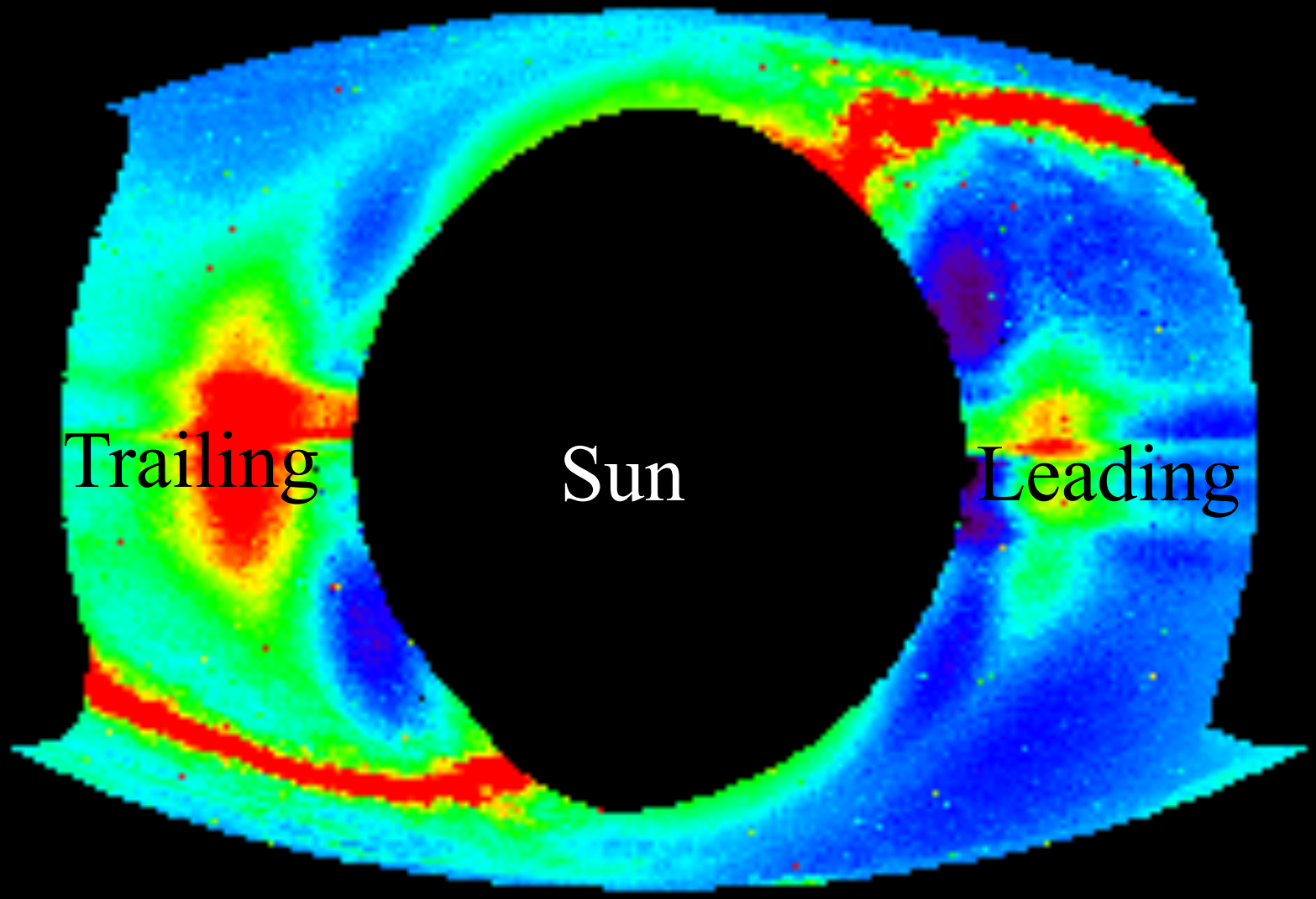
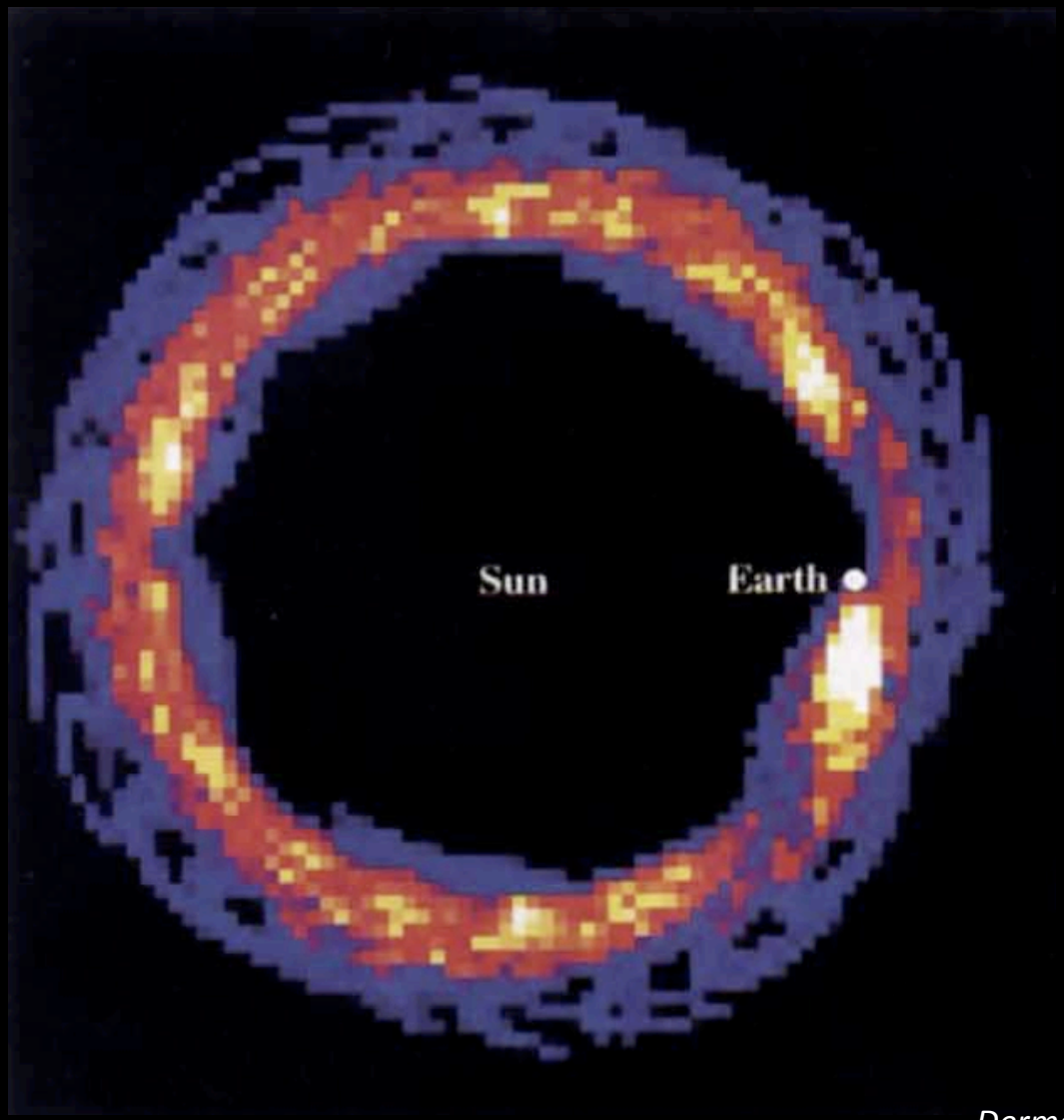
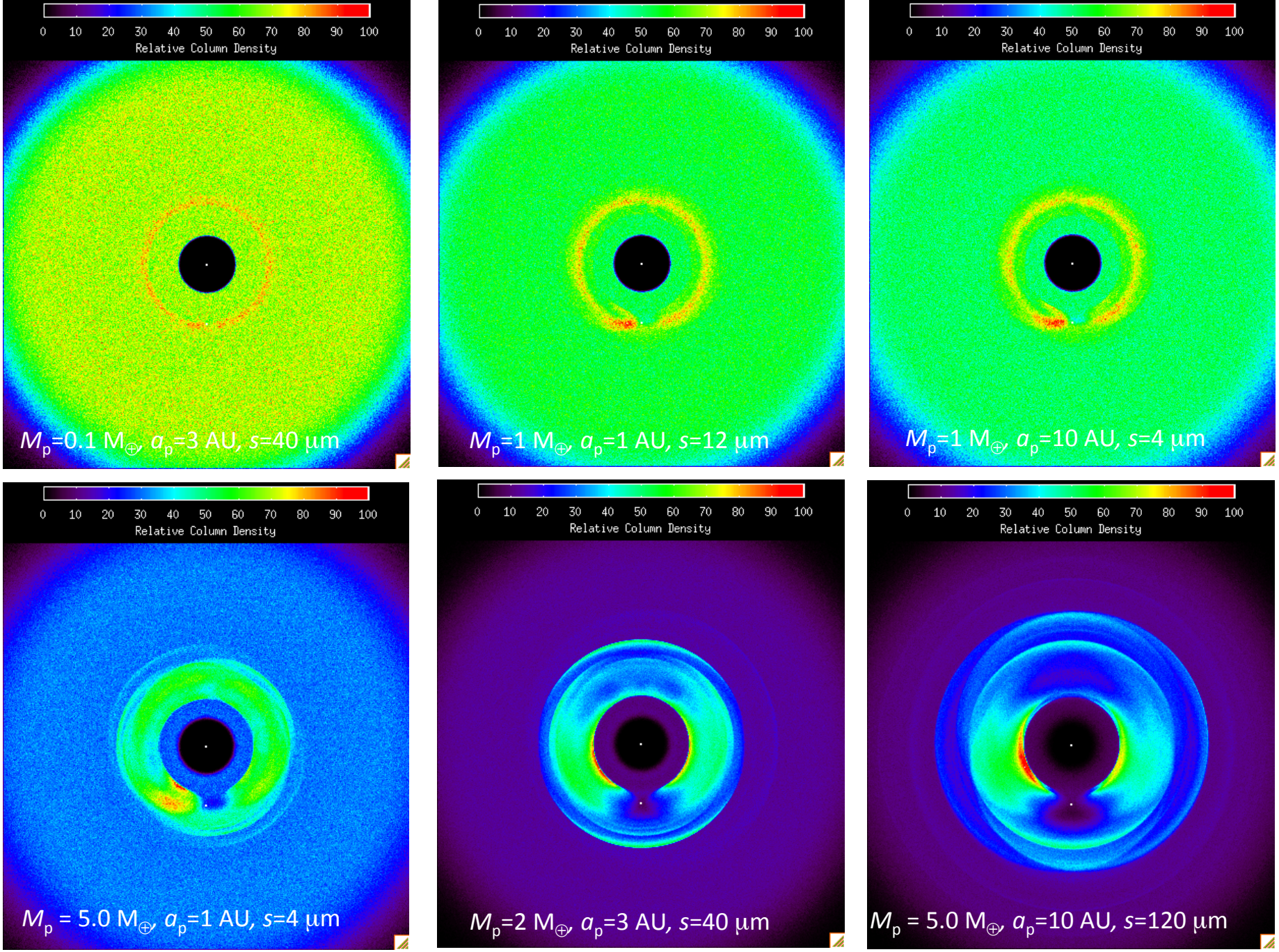


Reach et al. 1995

Resonant Rings in Exozodis



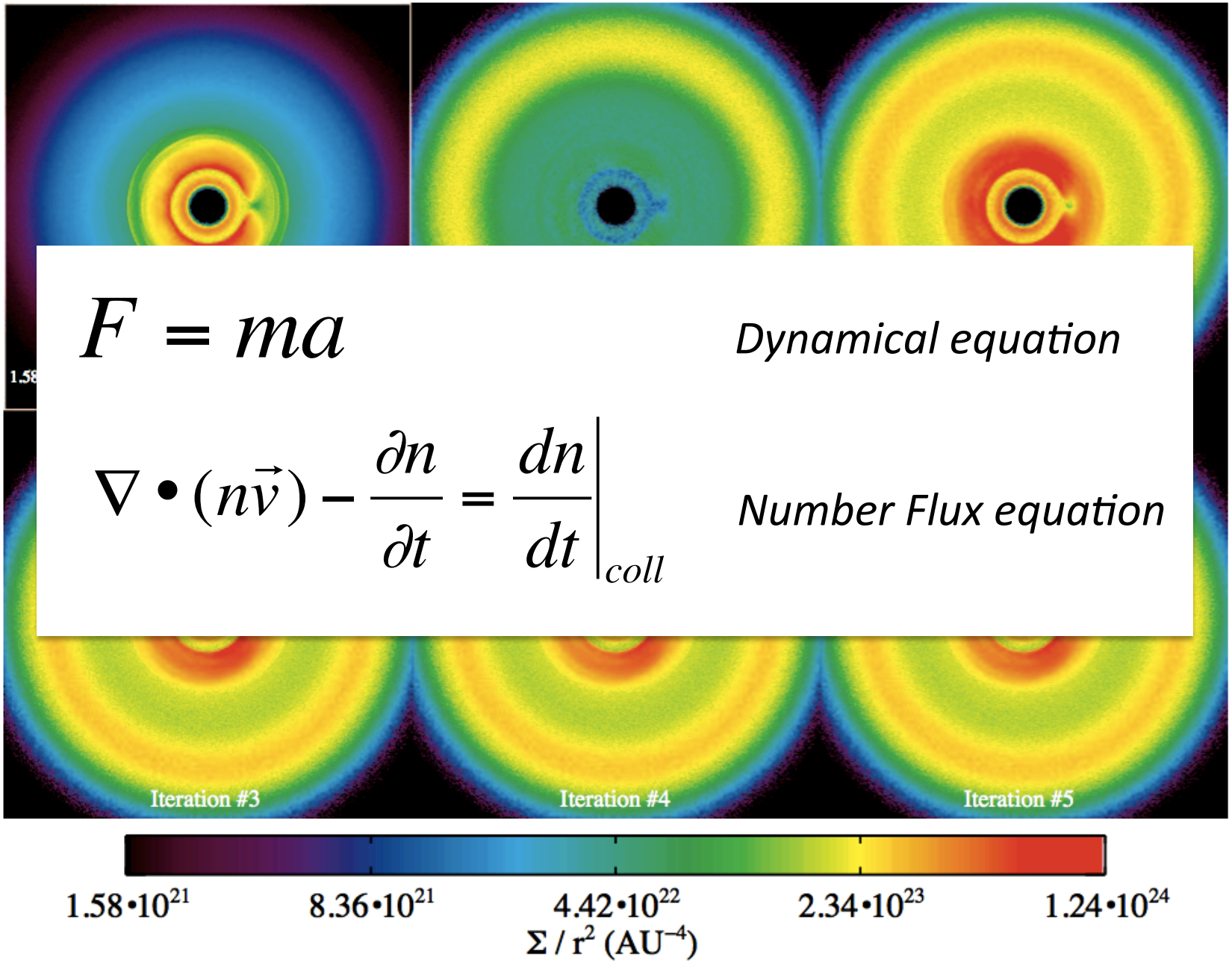
Dermott et al. 1994



Catalog online @ http://asd.gsfc.nasa.gov/Christopher.Stark/catalog.php

Stark & Kuchner (2008)

Collisional Grooming Algorithm



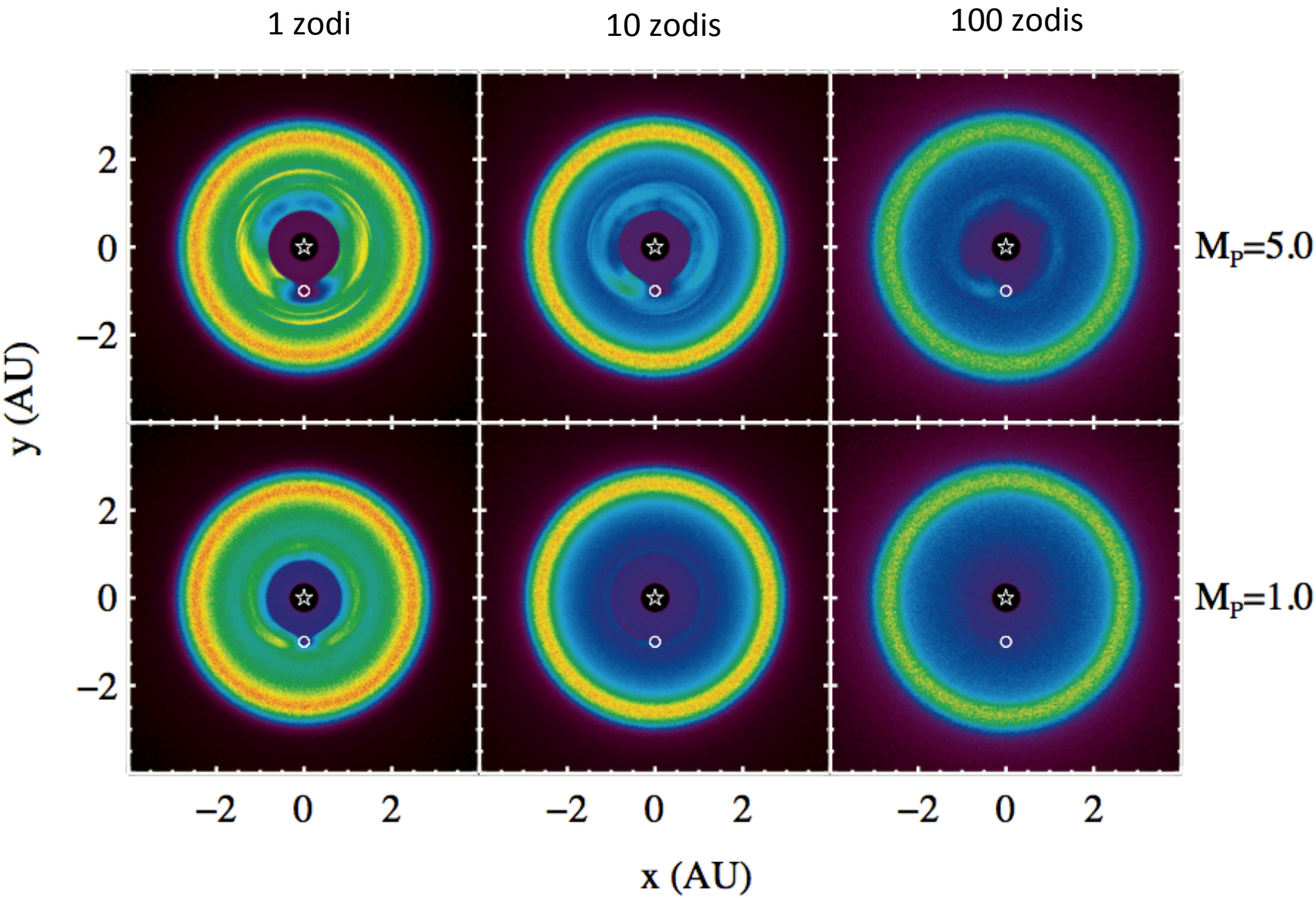
$$F = ma$$

Dynamical equation

$$\nabla \bullet (n\vec{v}) - \frac{\partial n}{\partial t} = \left.\frac{dn}{dt}\right|_{coll}$$

Number Flux equation

The Worst Case Scenario for Exozodi Structure



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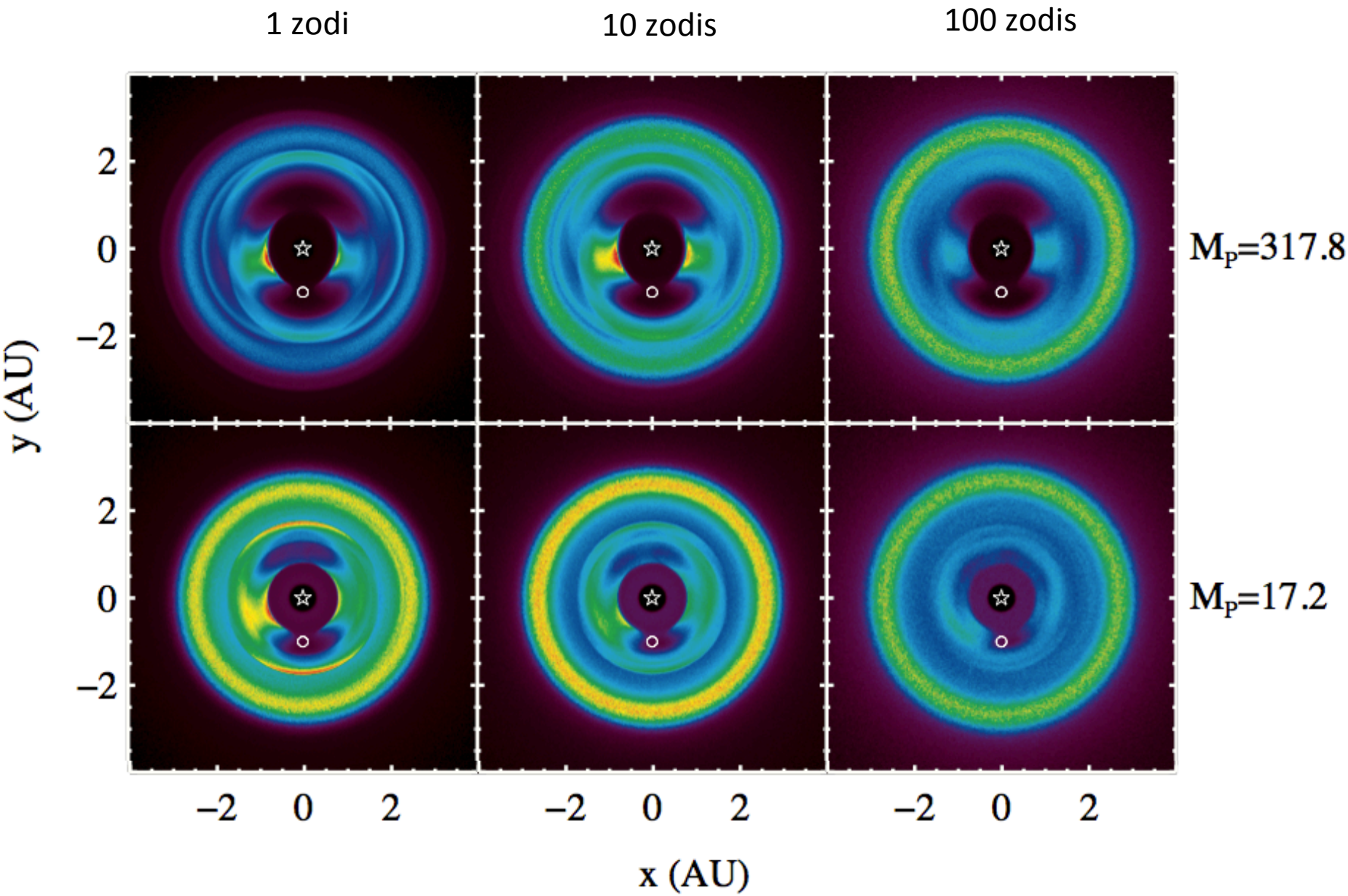
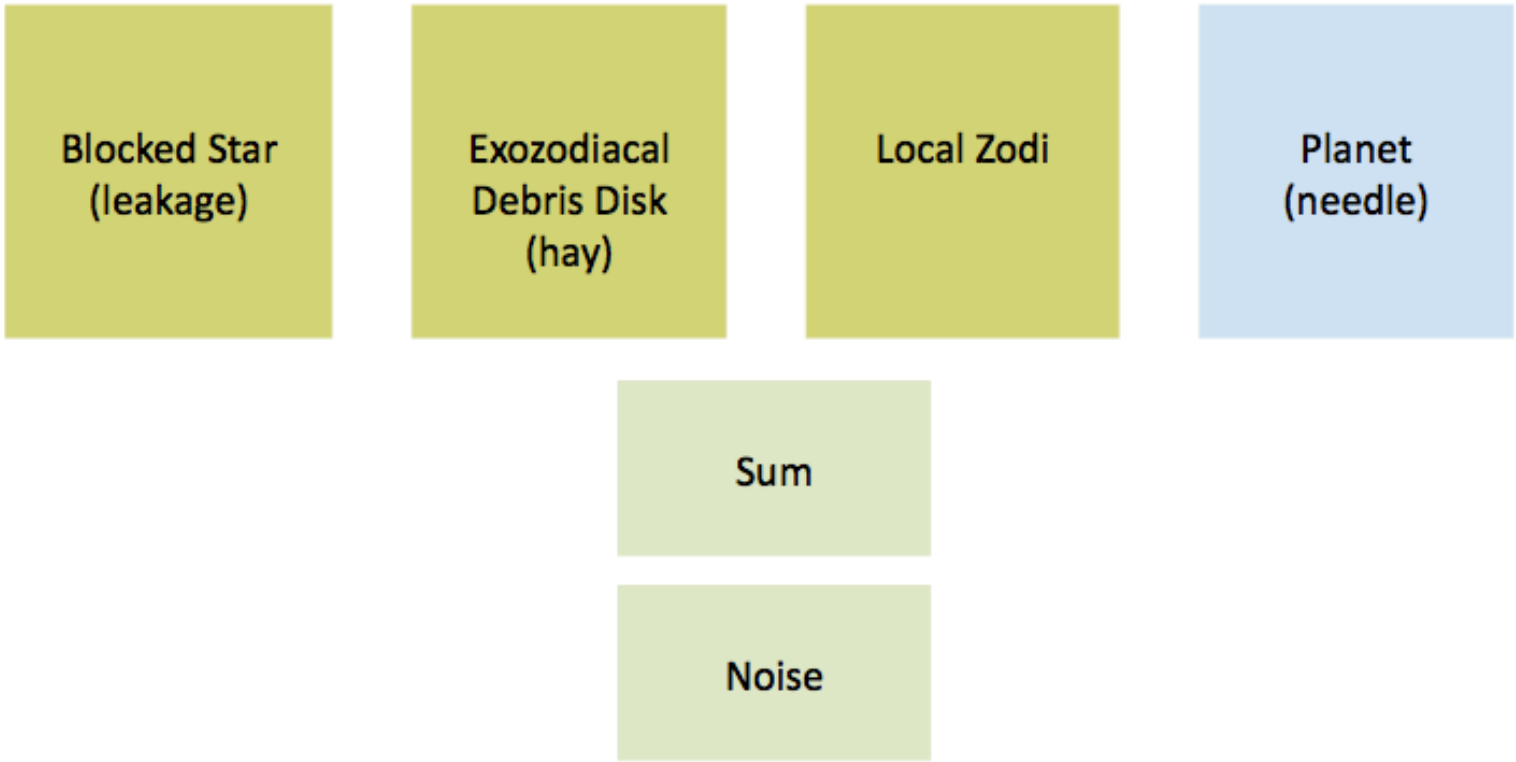


Model: Haystack + Needle

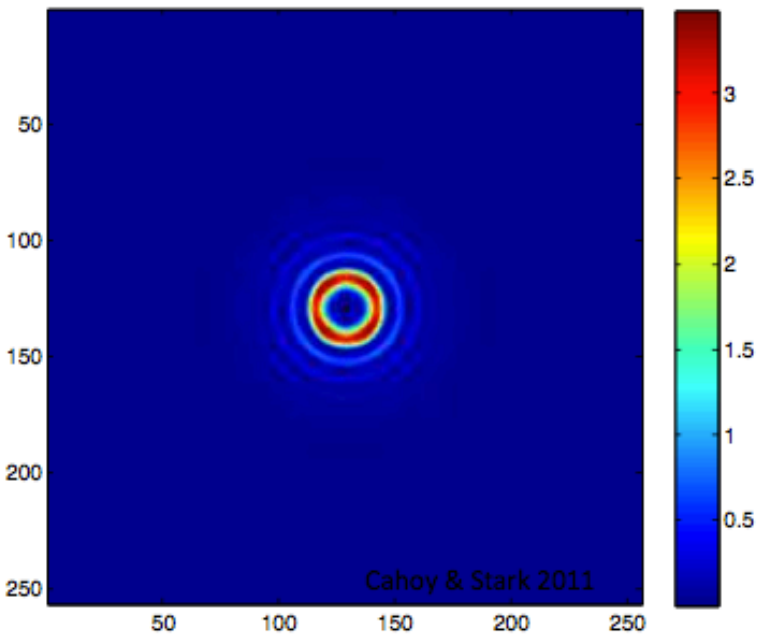


- Initial CFITS coronagraph simulation developed by O. Guyon
- K. Cahoy developed ability to incorporate unique Exozodiacal Debris Disk input

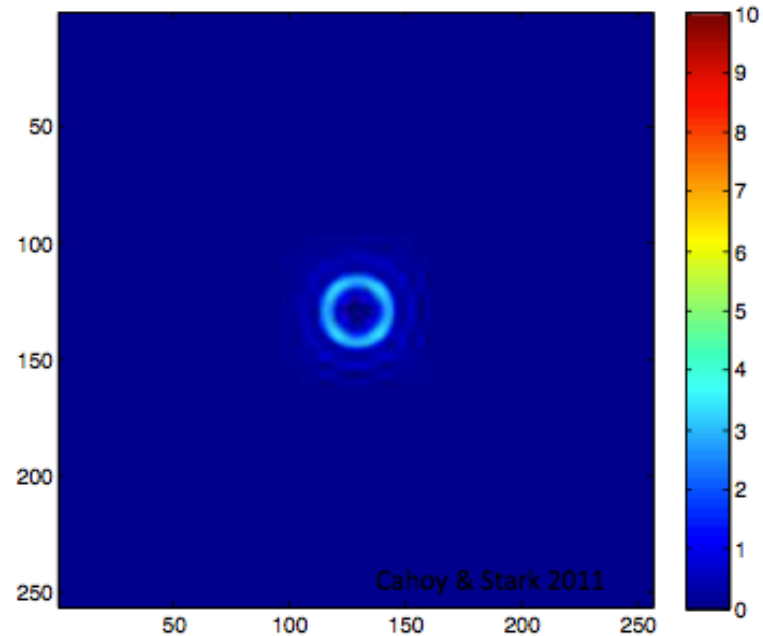
Slide courtesy of K. Cahoy

Blocked Star: Sun at 10 pc

Auto color scale to highlight detail



Fixed color scale (10) for comparison

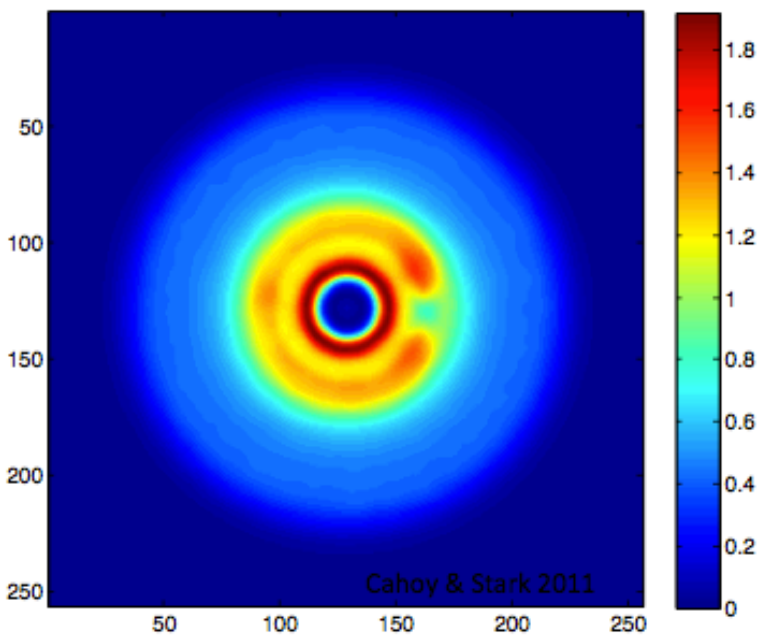


- 4-meter diameter telescope, PIAA coronagraph

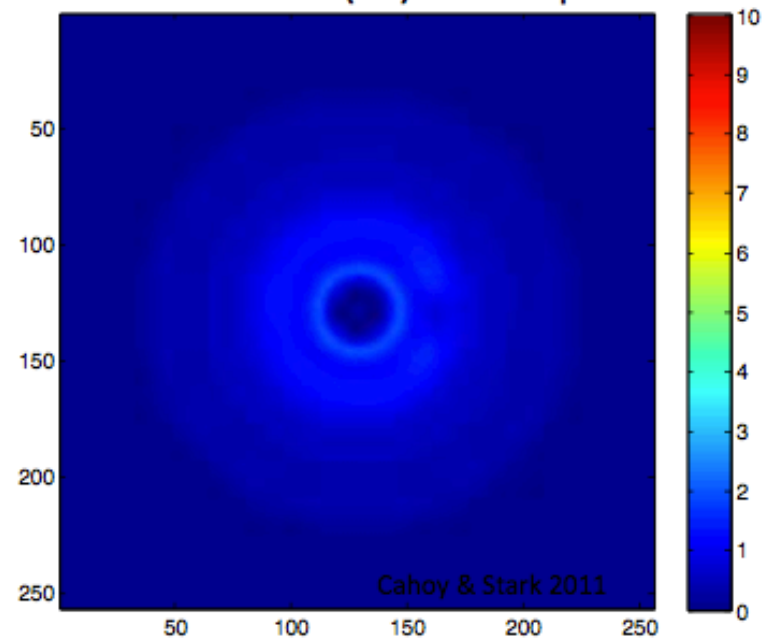
Slide courtesy of K. Cahoy

Exozodiacal Debris Disk

Auto color scale to highlight detail



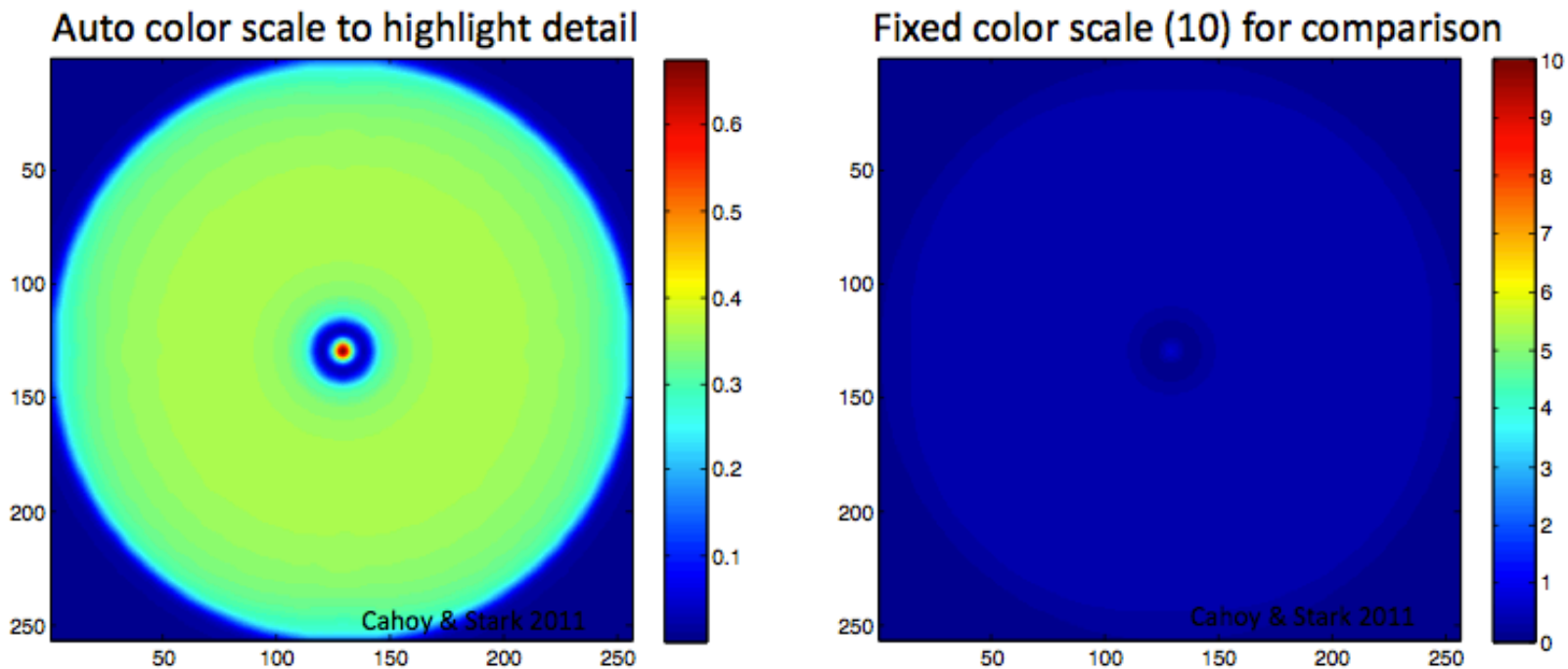
Fixed color scale (10) for comparison



- 1 Zodi EZ model, 1 M_E planet at 1 AU
- albedo = 0.5, g = 0.2, 0 inclination = 0°

Slide courtesy of K. Cahoy

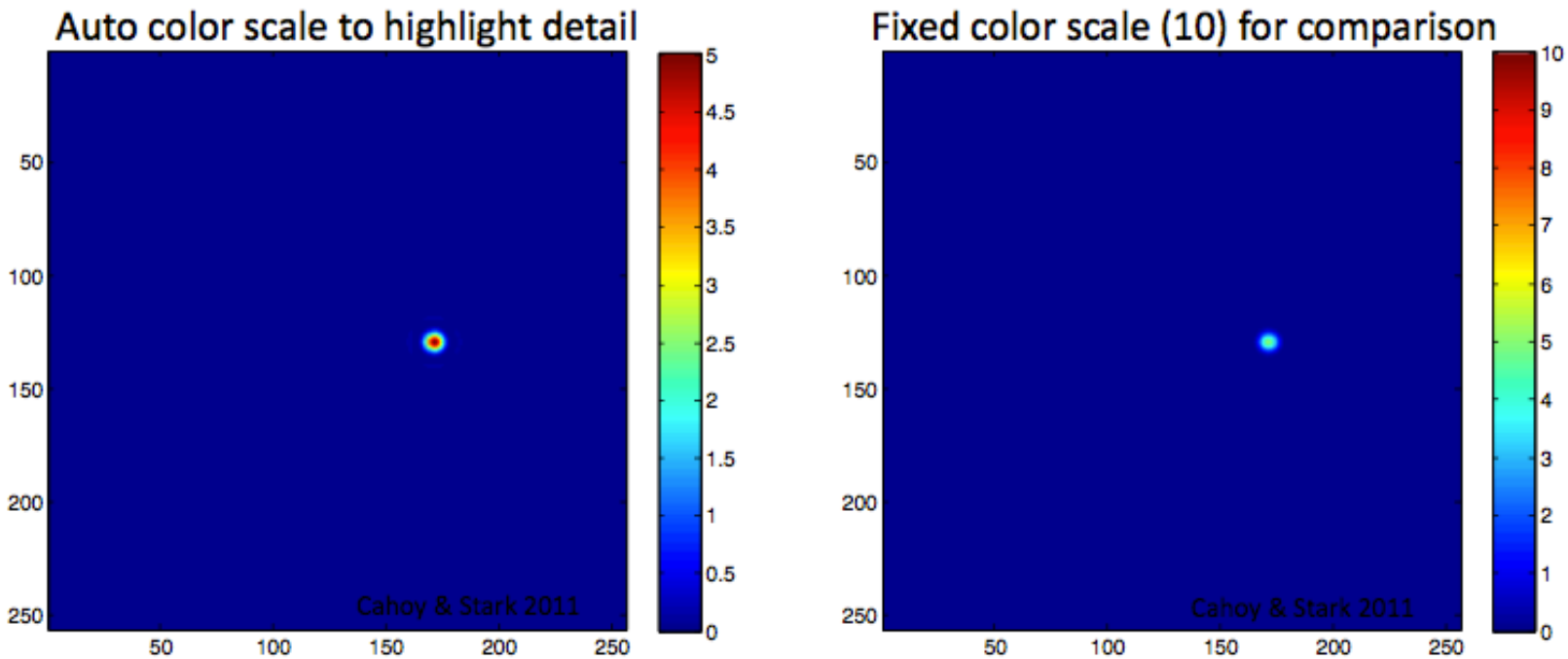
Local Zodi



- Local zodi is 1, function of model system location on sky

Slide courtesy of K. Cahoy

Planet

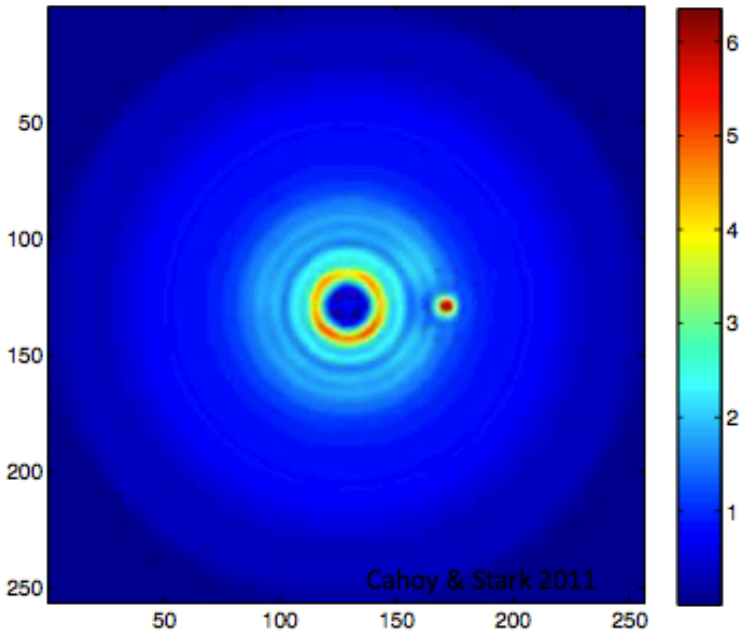


- 1 ME planet at 1 AU as seen by 4 m D telescope with PIAA coronagraph
- 365 nm with planet albedo = 0.3
- Reflected light in the optical

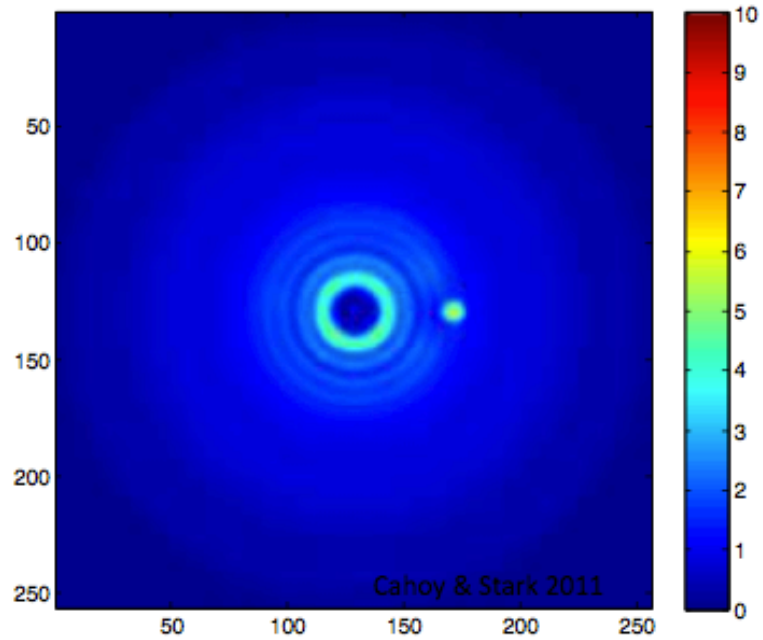
Slide courtesy of K. Cahoy

Sum

Auto color scale to highlight detail



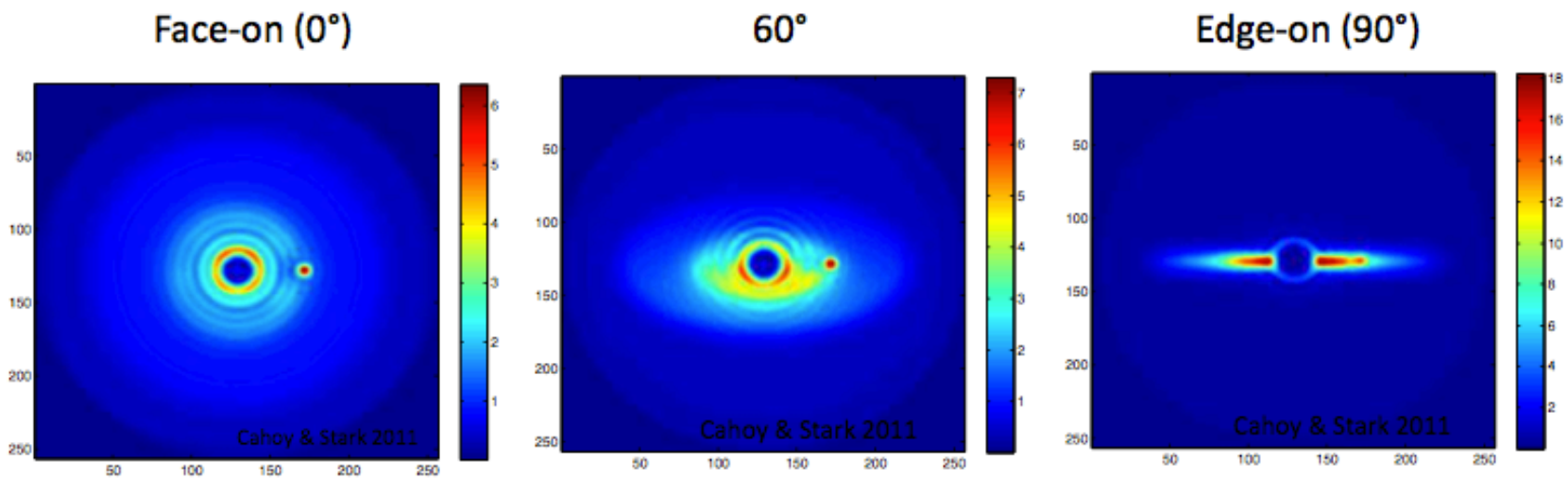
Fixed color scale (10) for comparison



- Stellar leakage + EZ model + Z model + P model
- As seen by coronagraph, with 0.45 throughput, but without detector noise

Slide courtesy of K. Cahoy

Different inclinations

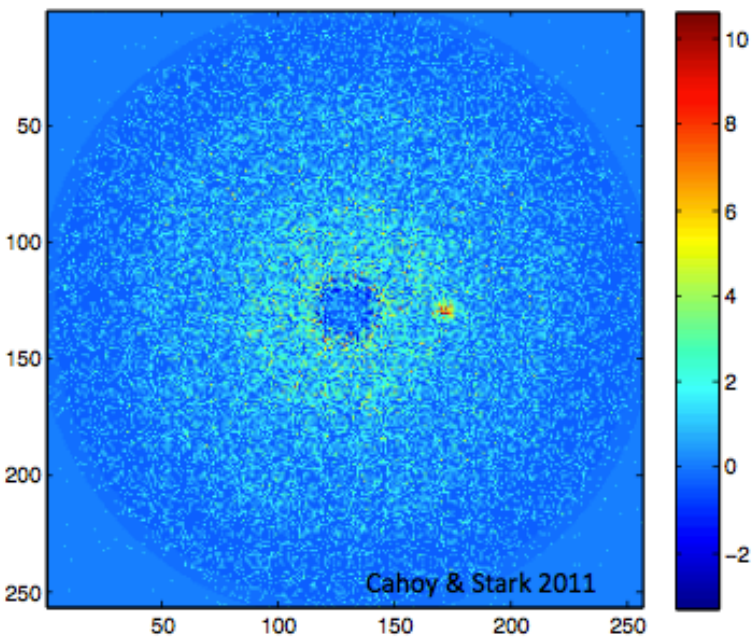


- Geometry makes a difference in SNR, line-of-sight

Slide courtesy of K. Cahoy

Noise

Auto color scale to highlight detail



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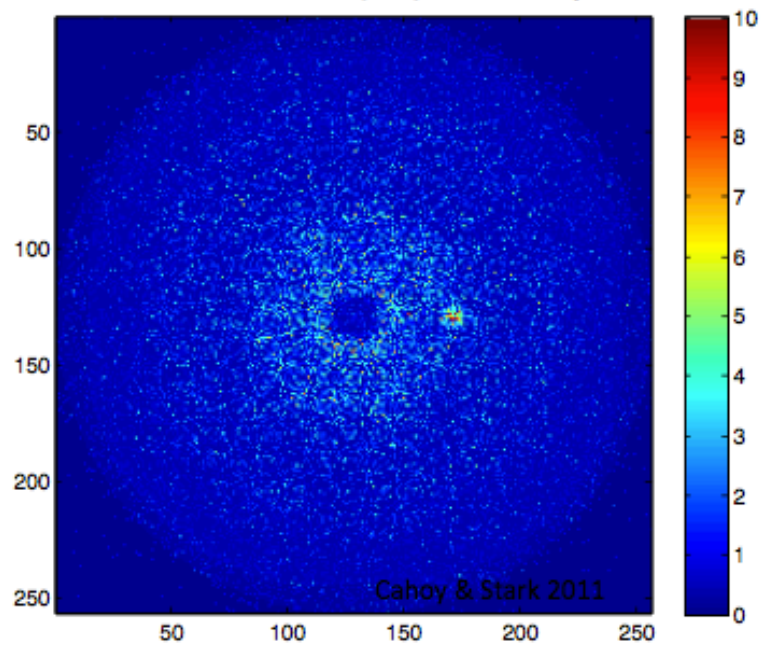
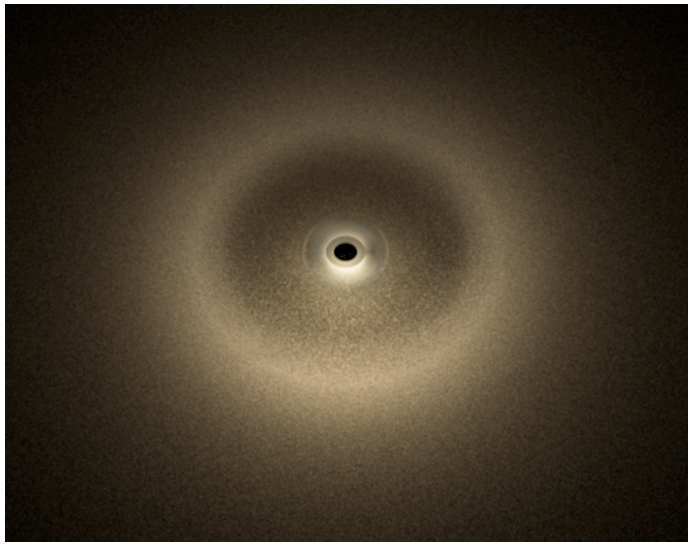


- Example with Poisson noise

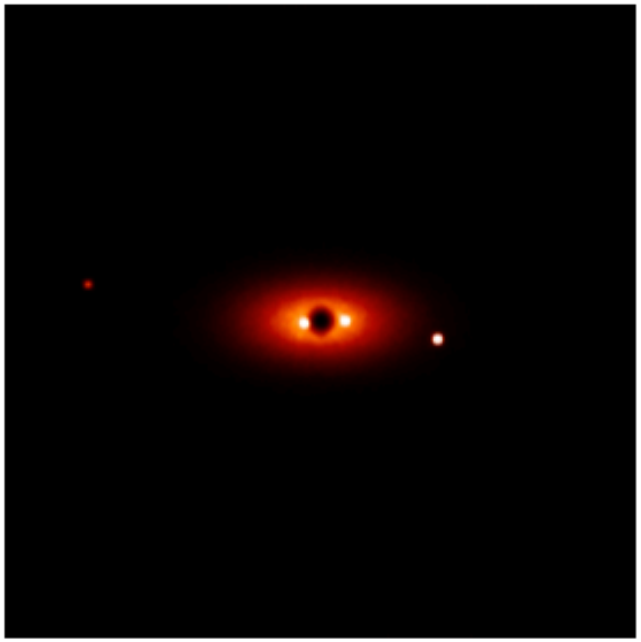
Slide courtesy of K. Cahoy

Exozodi models for the IPS

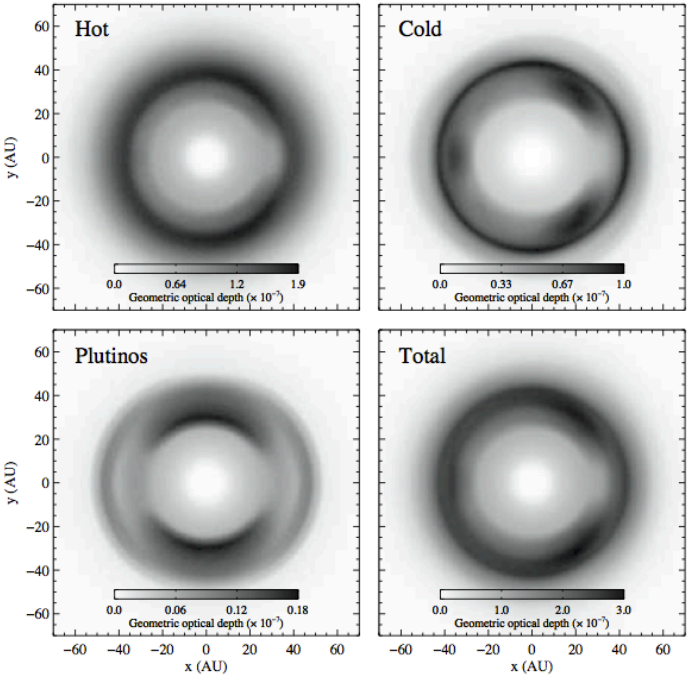


Piecewise models

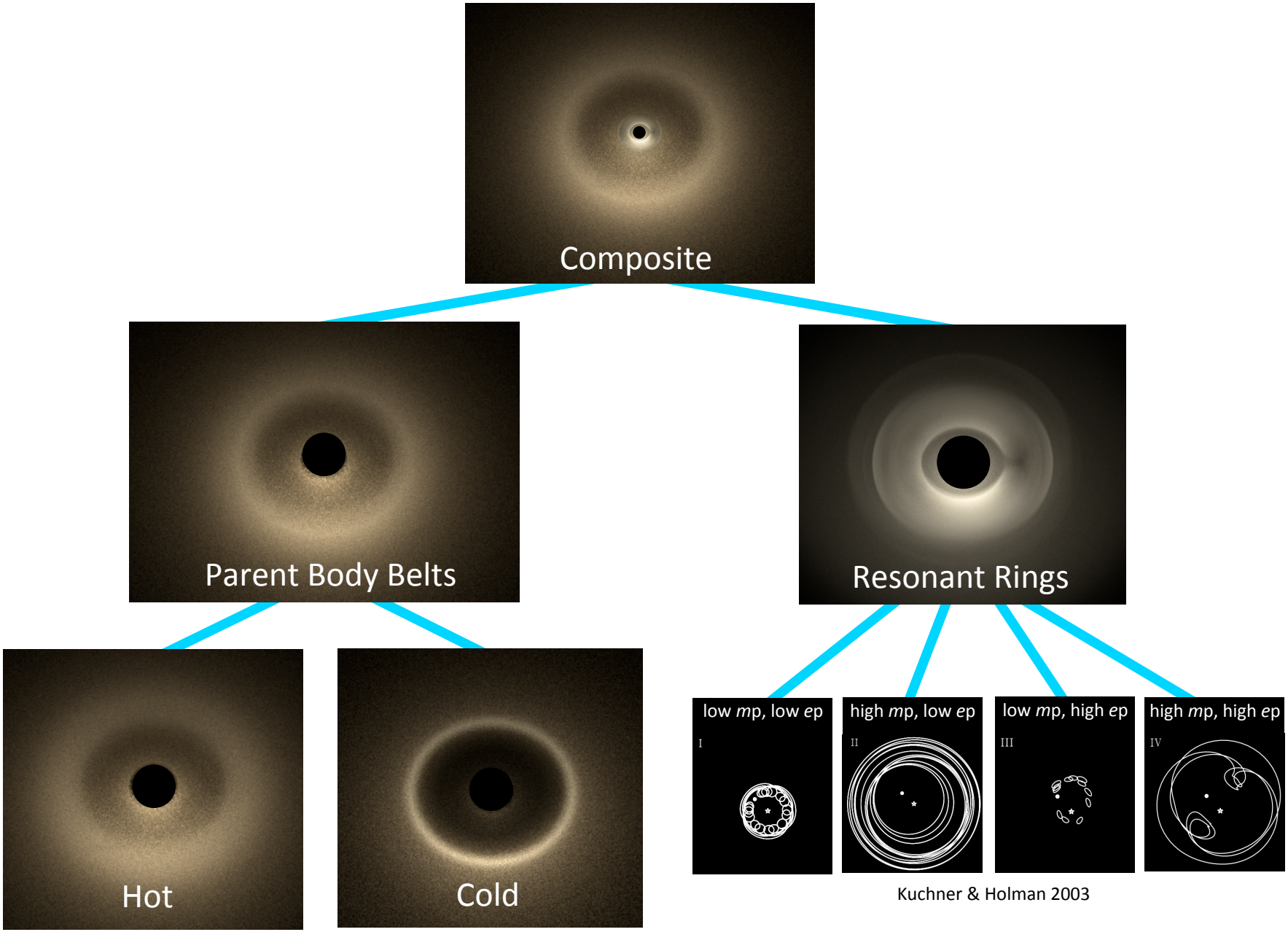
Zodi analog only



Self-consistent
multi-source simulations



Structures in Debris Disks



Kuchner & Holman 2003

Summary

- Exozodis may exhibit a variety of complex dust distributions
- Exozodi offsets can produce brightness asymmetries that mimic a planetary signal
- We have modeled the worst-case scenario for clumpy dust rings produced by resonant dust trapping & will address this source of confusion this year
- Piecewise models of structured exozodis may be possible for IPS

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