HST/STIS imaging of Fomalhaut: New main belt structure and confirmation of Fomalhaut b's eccentric orbit

Paul Kalas & James Graham
University of California, Berkeley
Michael Fitzgerald *(UCLA)*
Mark Clampin *(NASA GSFC)*

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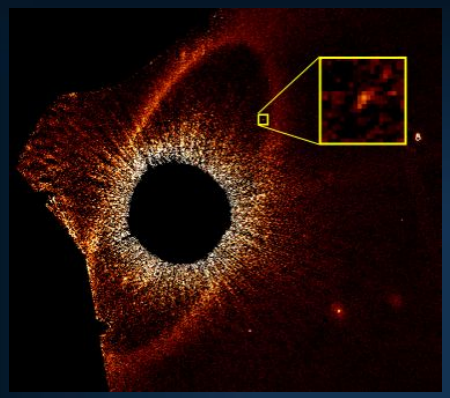
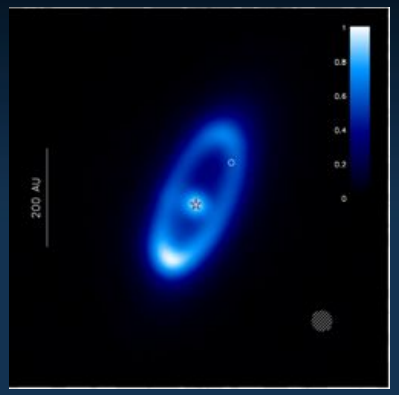
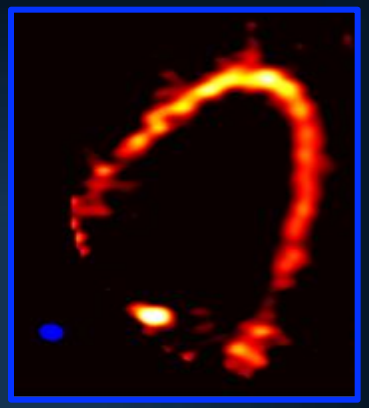
Very Brief Introduction



Kalas et al. 2013



Acke et al. 2012

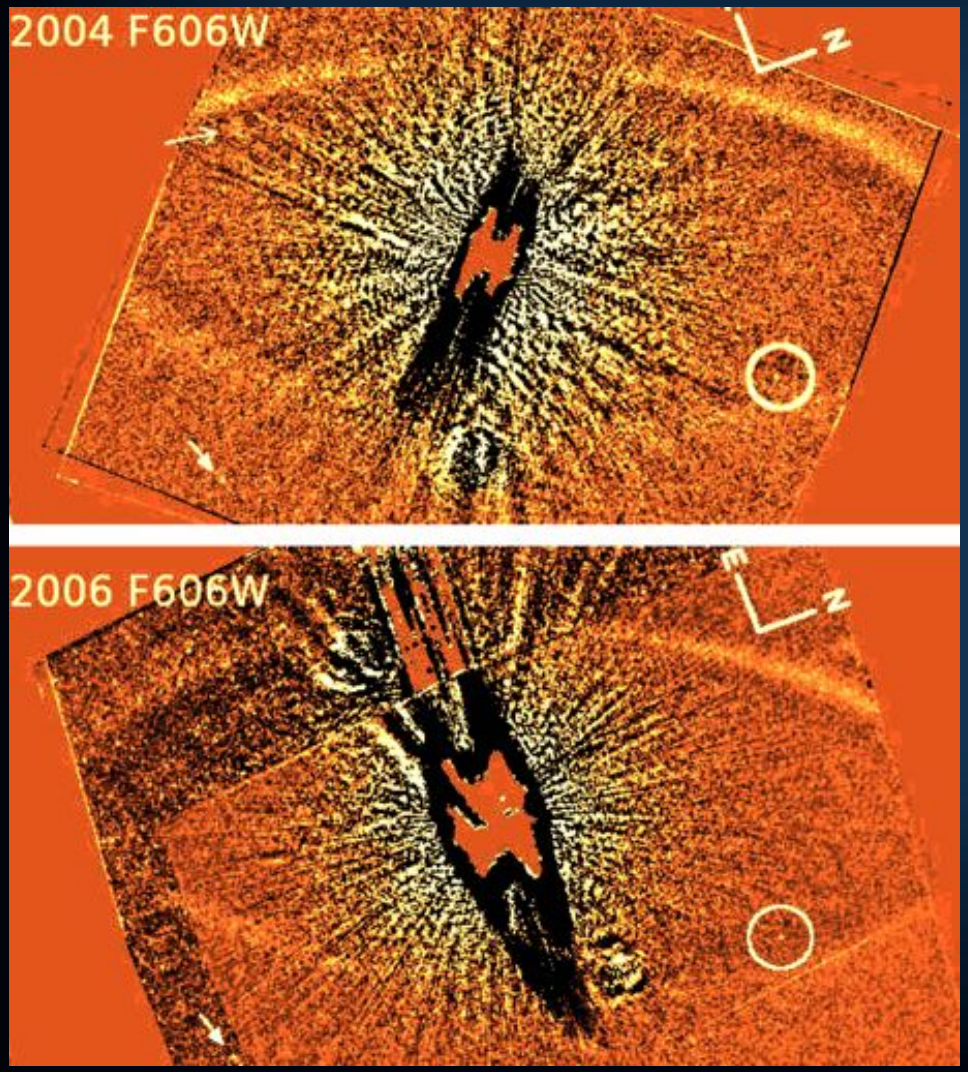


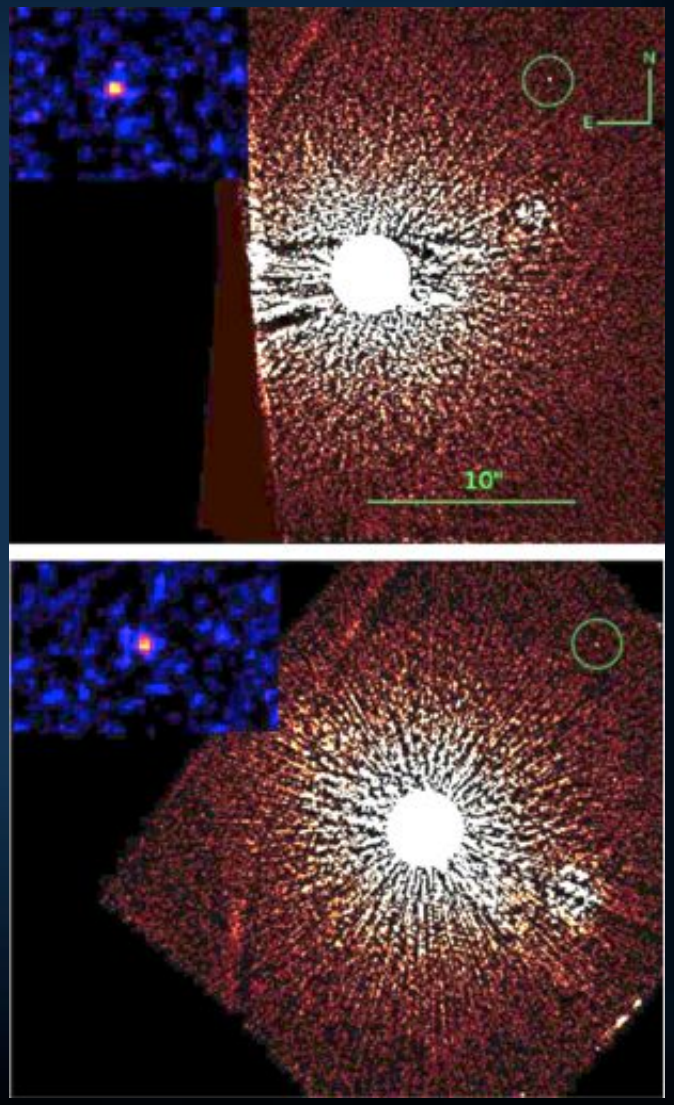
Boley et al. 2012

- Fomalhaut is a 2 solar mass, 440 Myr-old, A star at 7.7 pc
- Dusty debris belt at 140 AU radius mapped from optical to millimeter wavelengths.
- HST optical data with ACS/HRC revealed faint proper motion companion Fomalhaut b interior to the dust belt.
- Fomalhaut b may represent light reflected from a circumplanetary ring or irregular satellite dust swarm
- Not detected in IR -> mass is less than ~1 Jupiter

Fomalhaut b *confirmed* in HST data by *two independent studies*

Galicher et al. 2013 & Currie et al. 2012

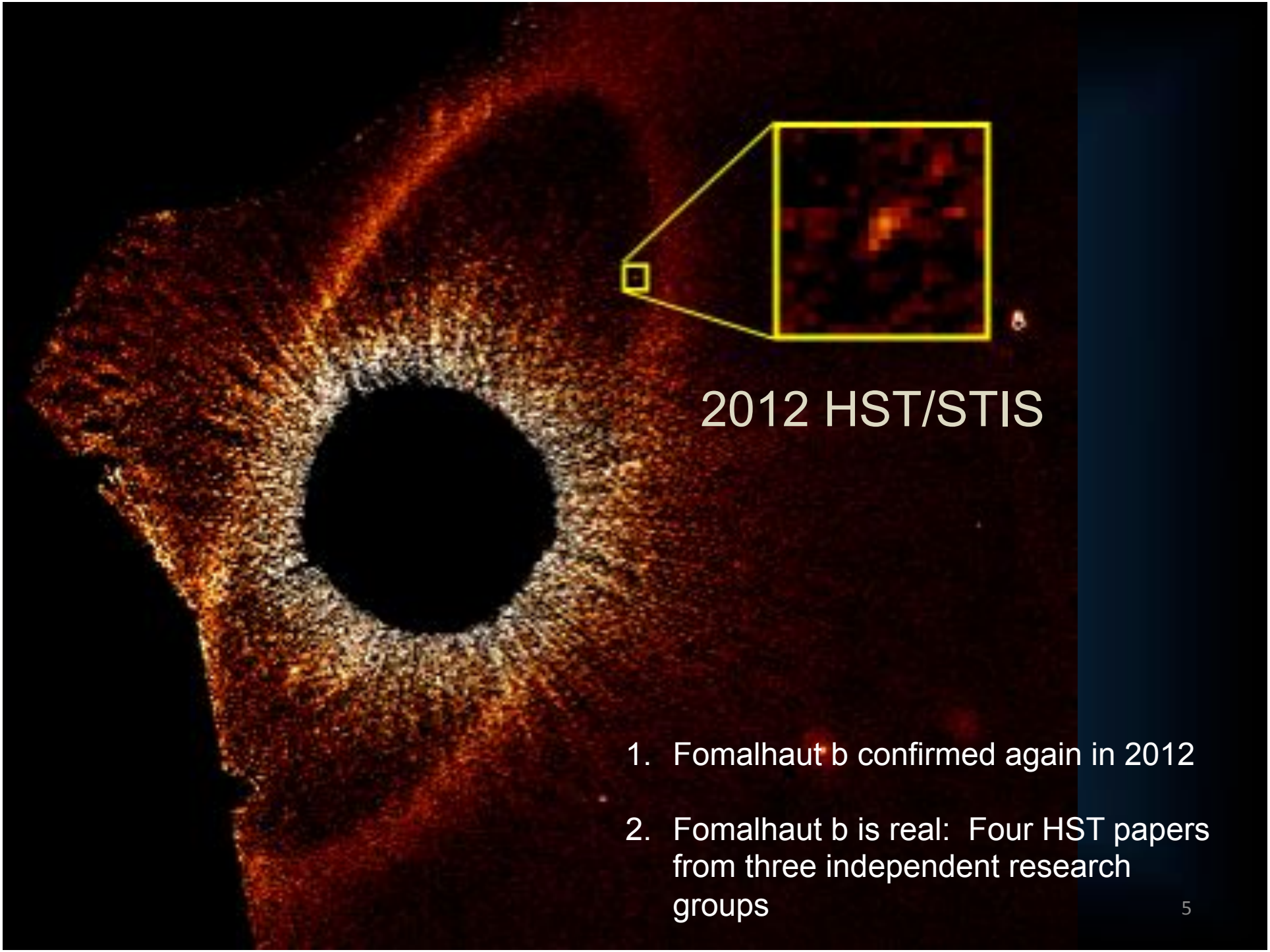




New results

submitted to ApJ; http://lanl.arxiv.org/abs/1305.2222

- Re-analysis of astrometry and error sources for 2004, 2006 ACS data, and 2010 STIS data.
- New Observations with HST/STIS obtained May 2012
  - 12 orbits, 12 roll angles
  - STIS coronagraphic wedge, blocks 2.5 arcsec
  - 0.05077"/pix, no filters, 0.2-1.0 micron
  - Use self-subtraction at multiple rolls, no PSF star

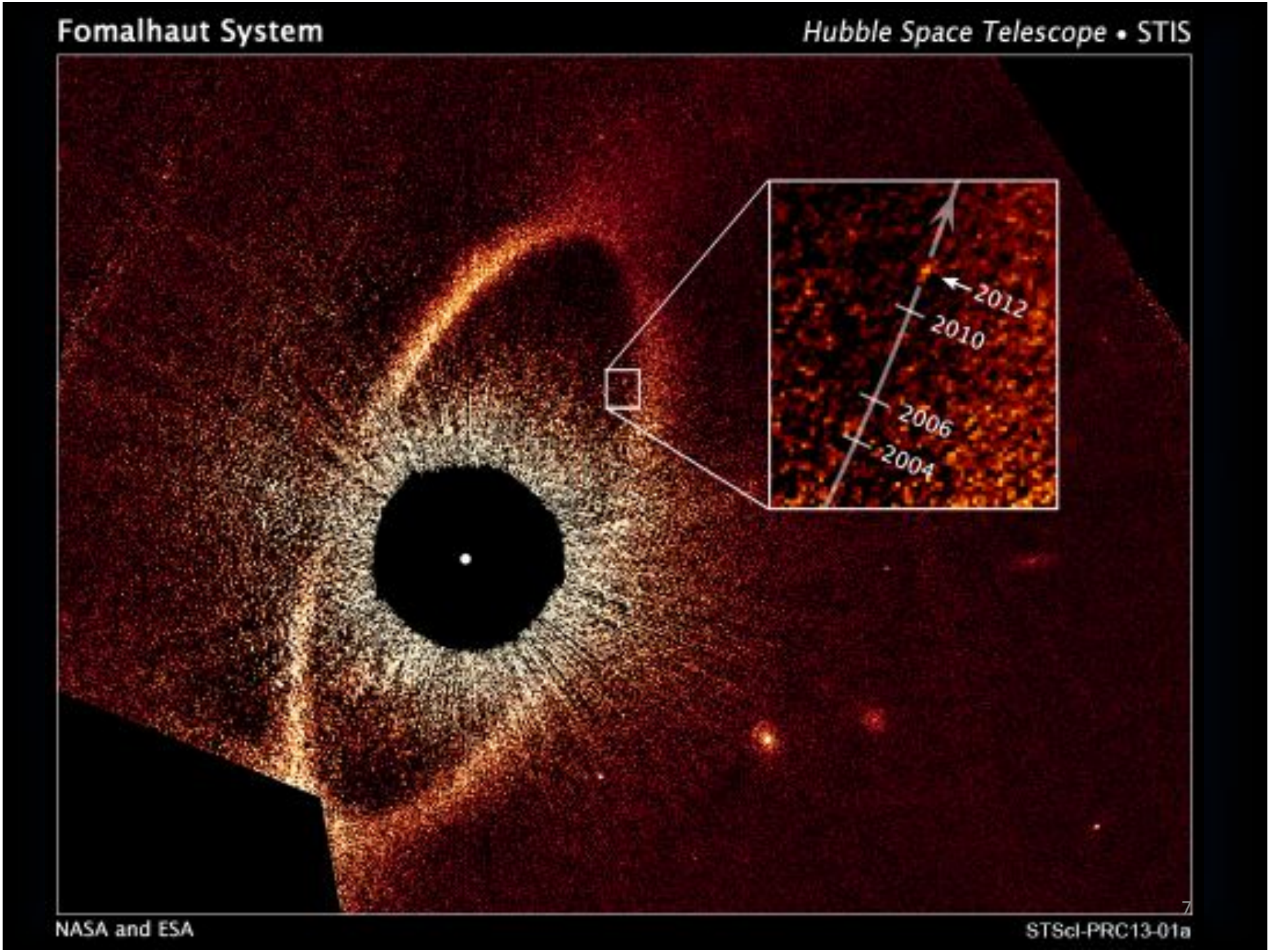


1. Fomalhaut b confirmed again in 2012

2. Fomalhaut b is real: Four HST papers from three independent research groups

Kalas, Graham, Fitzgerald, & Clampin, IAU 299, 06/2013

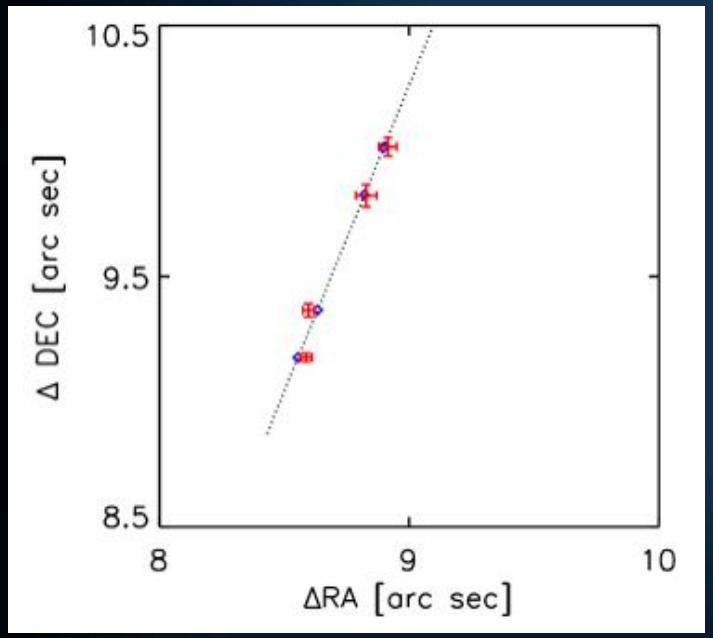
Tracking Fomalhaut b for eight years with Hubble


Fomalhaut System
Hubble Space Telescope • STIS
2012
2010
2006
2004
NASA and ESA
STScI-PRC13-01a

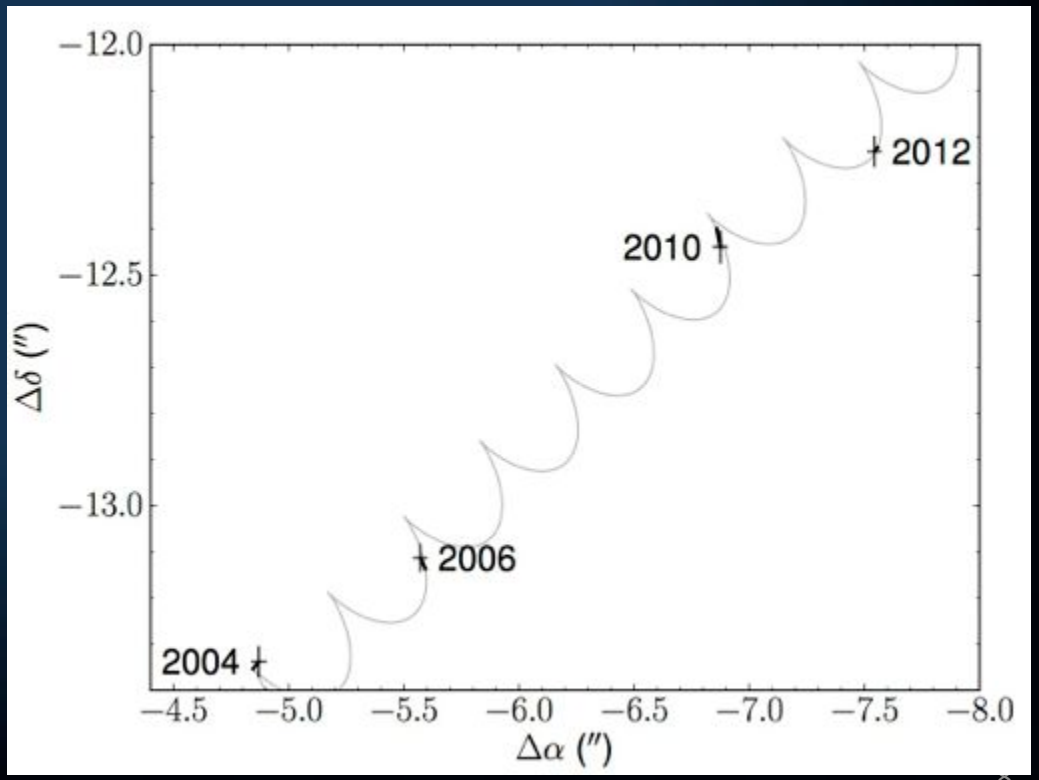
Fomalhaut b's highly eccentric orbit is confirmed

Astrometry on a single background star detected at all four epochs fits the expected parallax and proper motion trajectory relative to Fomalhaut.

Fomalhaut b

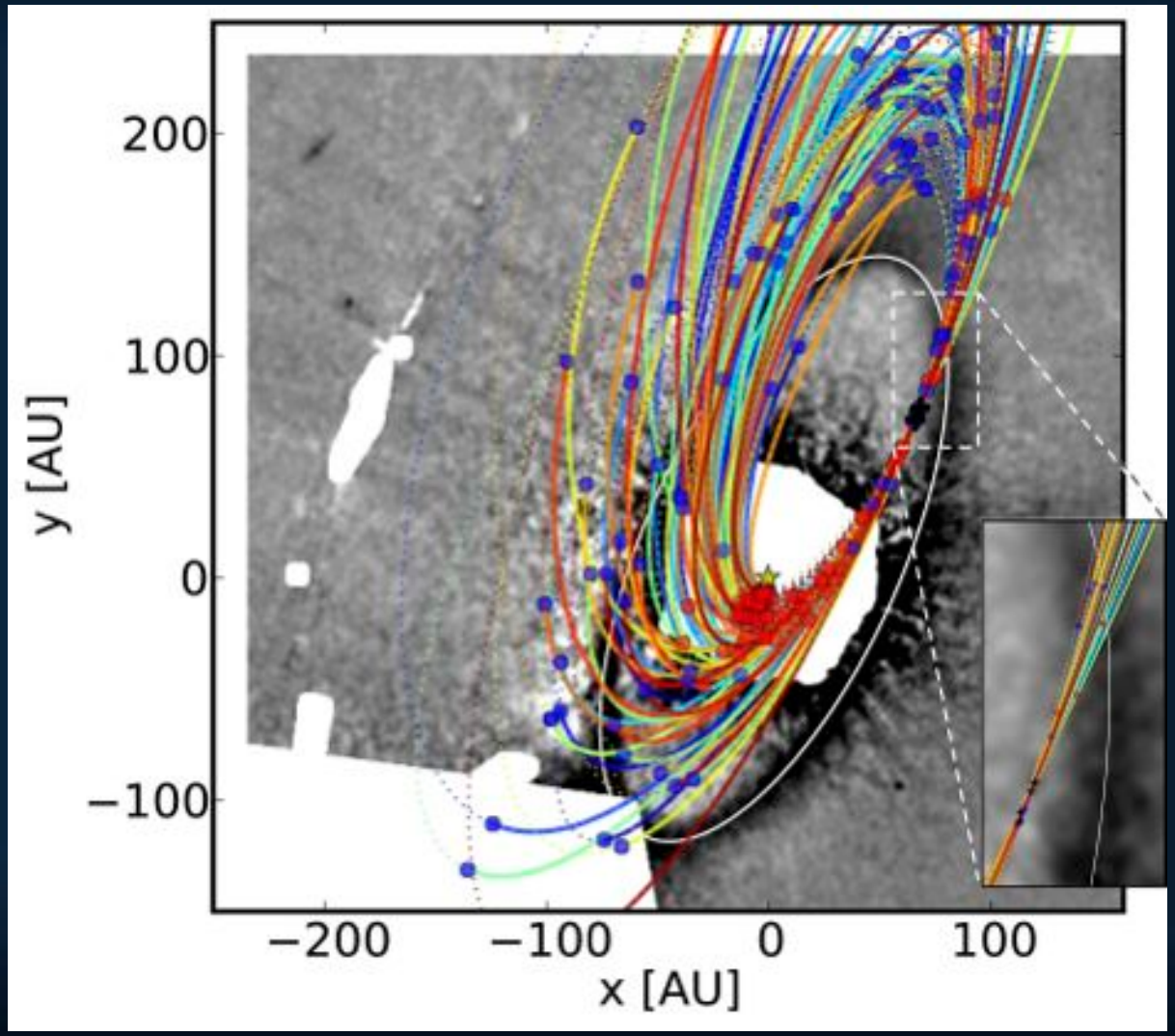


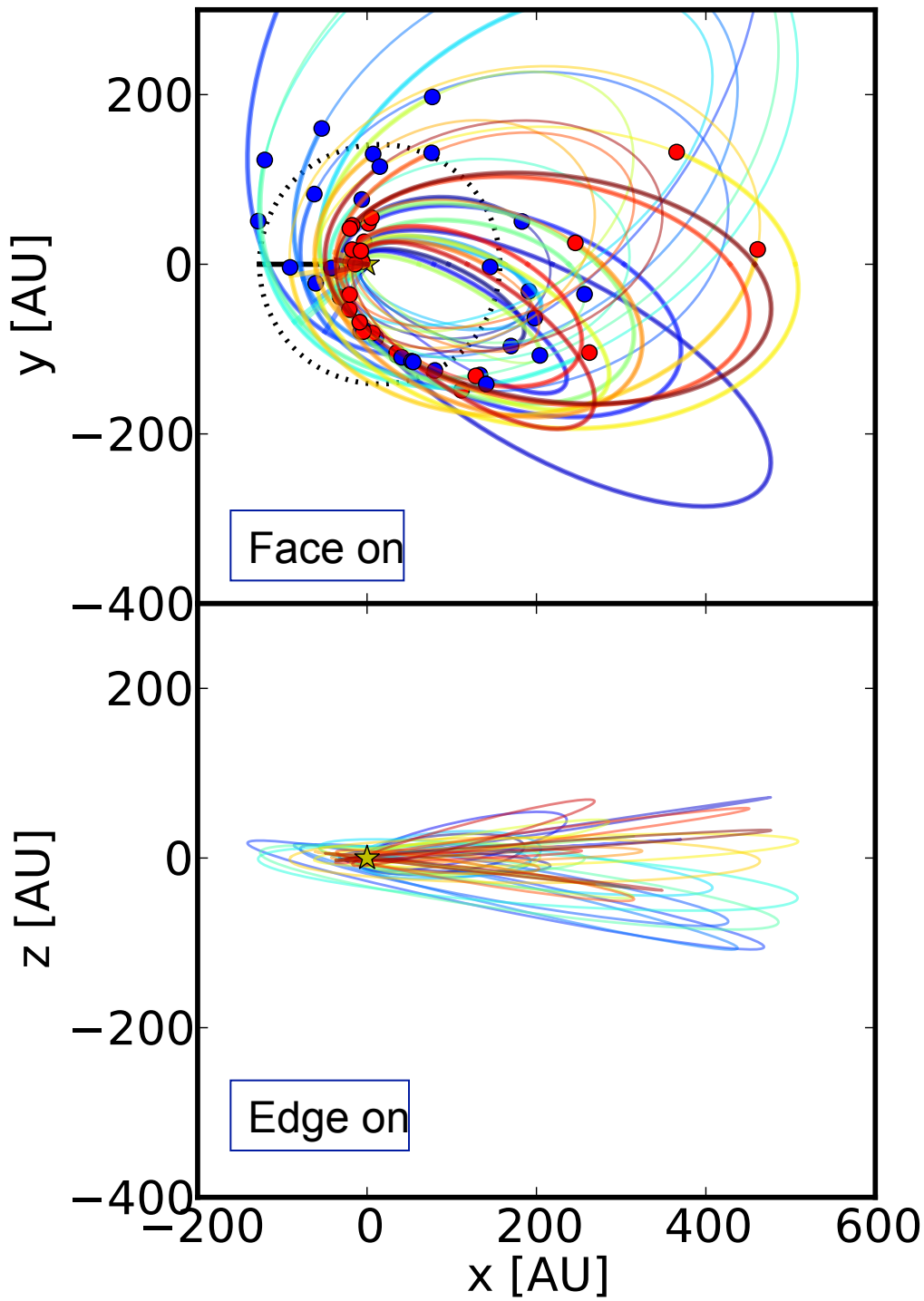
Background star



MCMC method developed by James Graham to sample the posterior probability distribution for the orbital elements based on 4 epochs of astrometry

Sample of 100 orbits drawn from the Markov chains





New estimate for the Fomalhaut b orbital elements.

a = 177± 68 AU [Main Belt ~ 140 AU]

e = 0.8 ± 0.1 [Main Belt ~ 0.1]

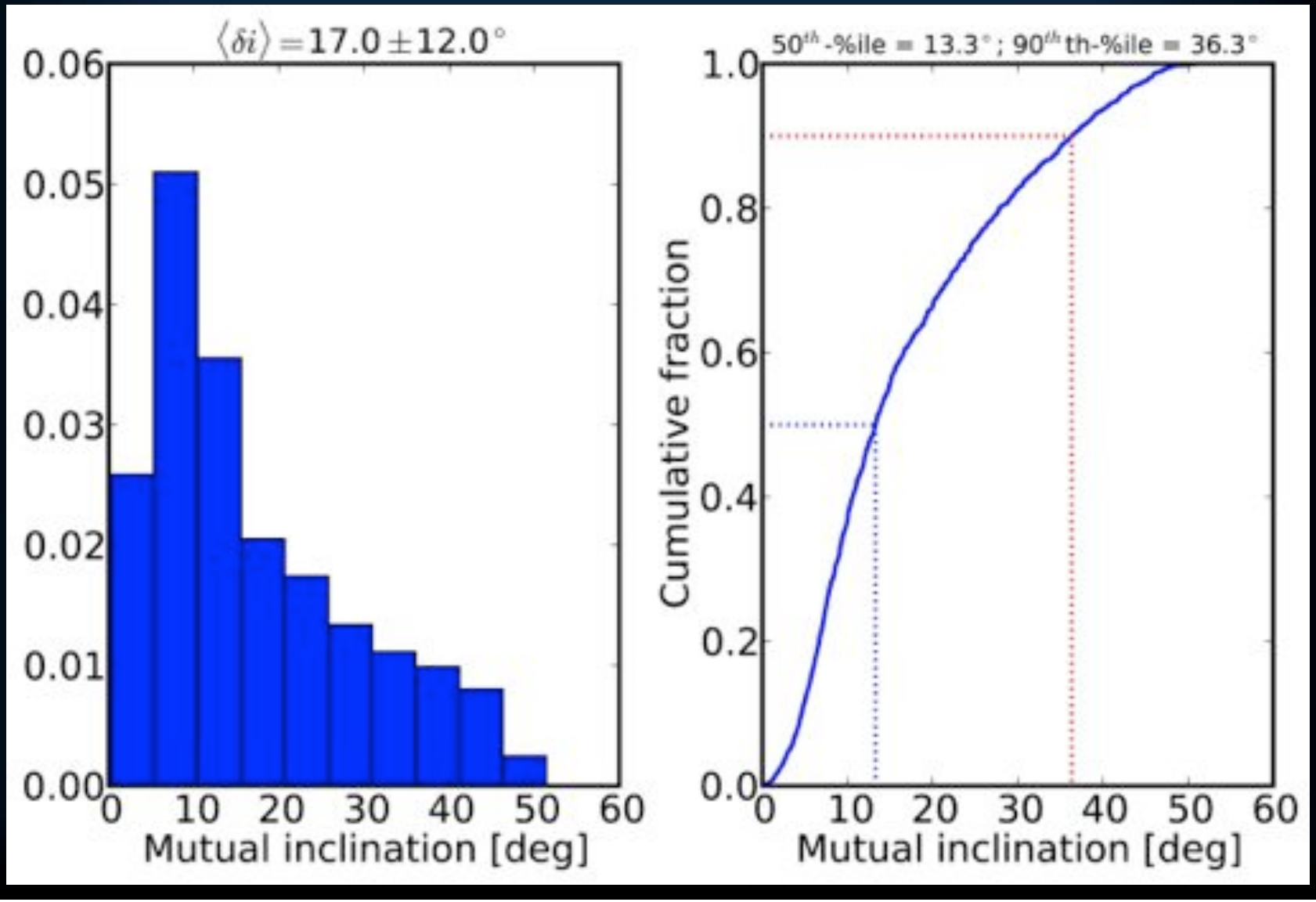
q = 32 ± 24 AU, Q = 322 ± 119 AU

I = 17° ± 12°

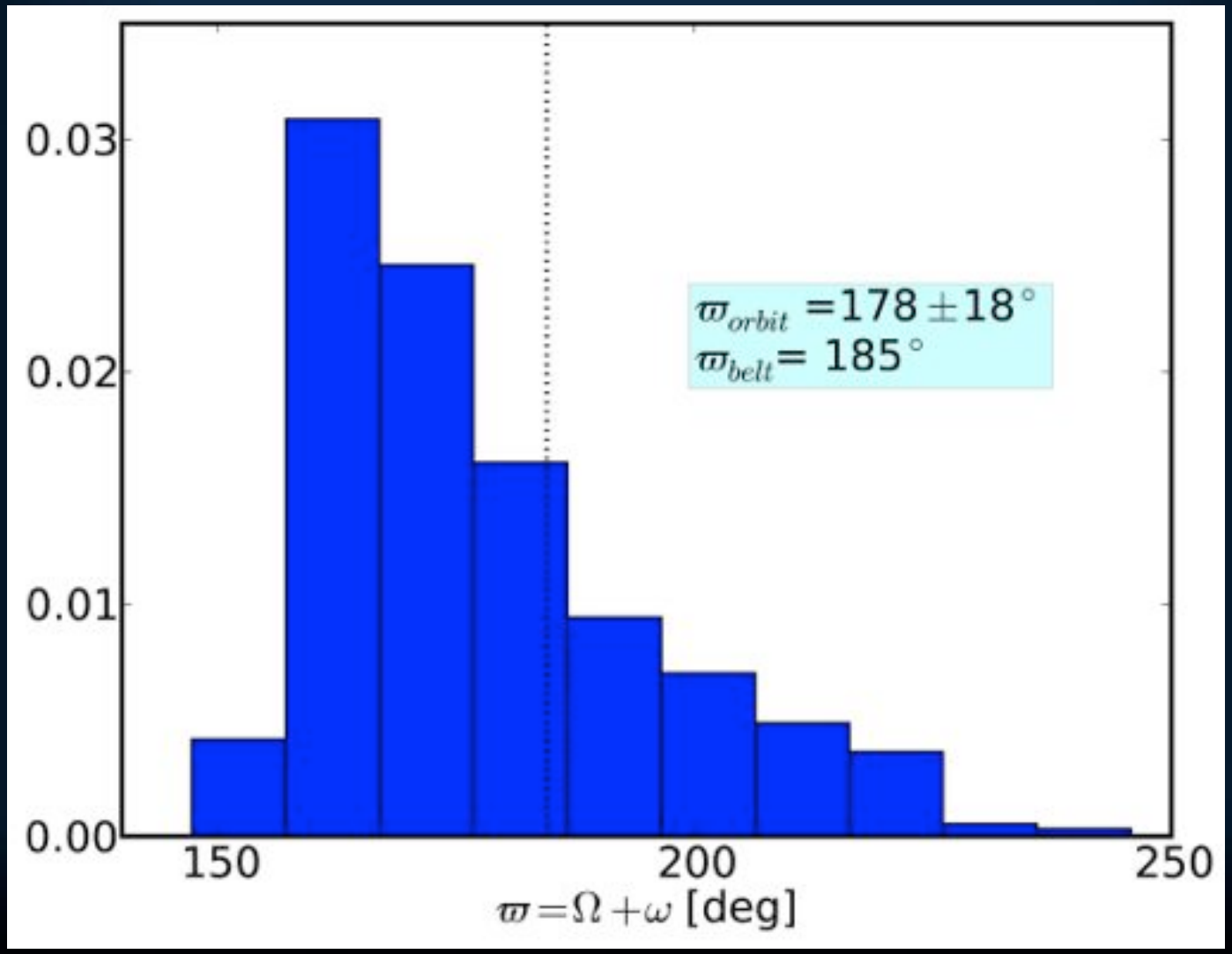
P ~ 1700 yr [Main Belt~1100-1400 yr]

Kalas et al. 2013, submitted to ApJ

Is Fomalhaut b still dynamically related to the belt? Mutual Inclination



Is Fomalhaut b still dynamically related to the belt? Apsidal Alignment



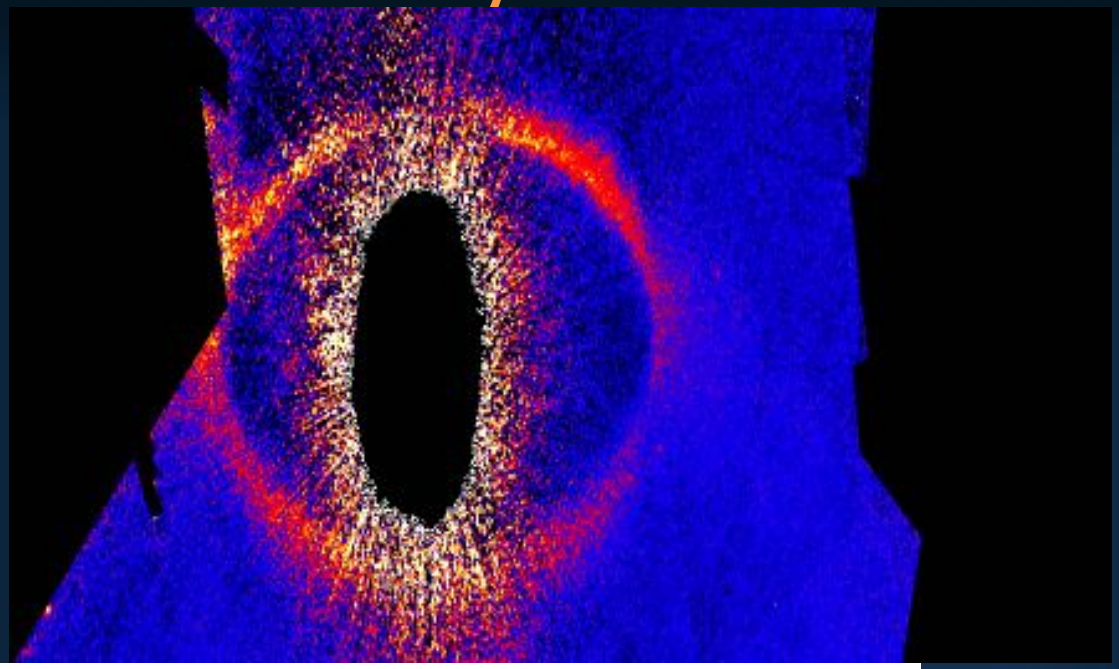
Belt Halo Detected in Northwest
(comparable southeast field not available)

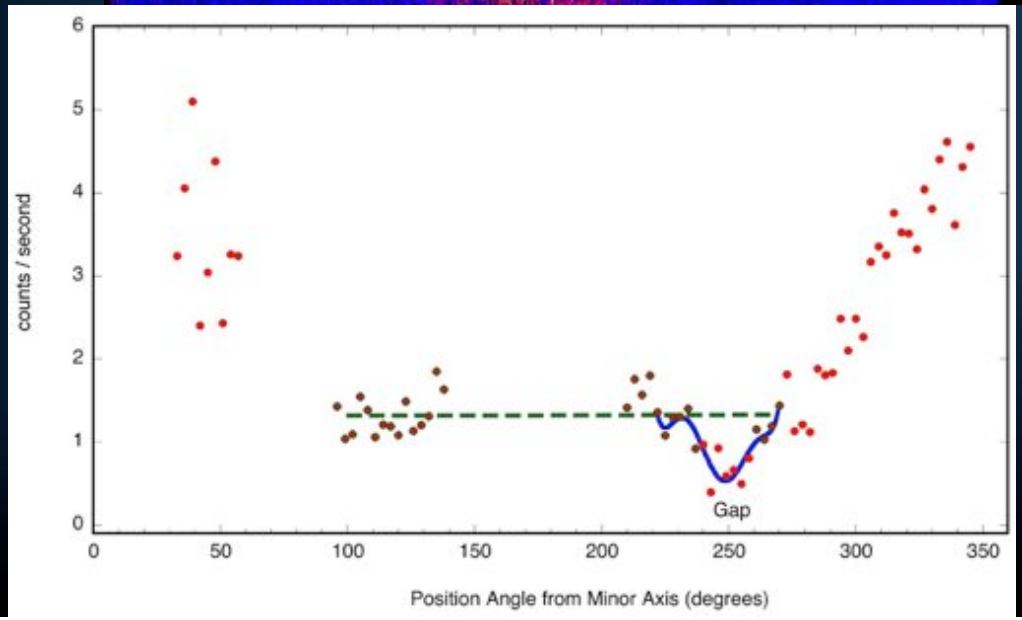
Extended halo of dust out to 209 AU, possibly >276 AU with bending morphology

- Previous images detect a narrow belt 133-165 AU
- New data show the belt extends at least out to 209 AU radius
- Belt halo not linear – bends downward in image above

Take home point: Belt has perturbed structure at large distances from star

Discovery of Main Belt Gap

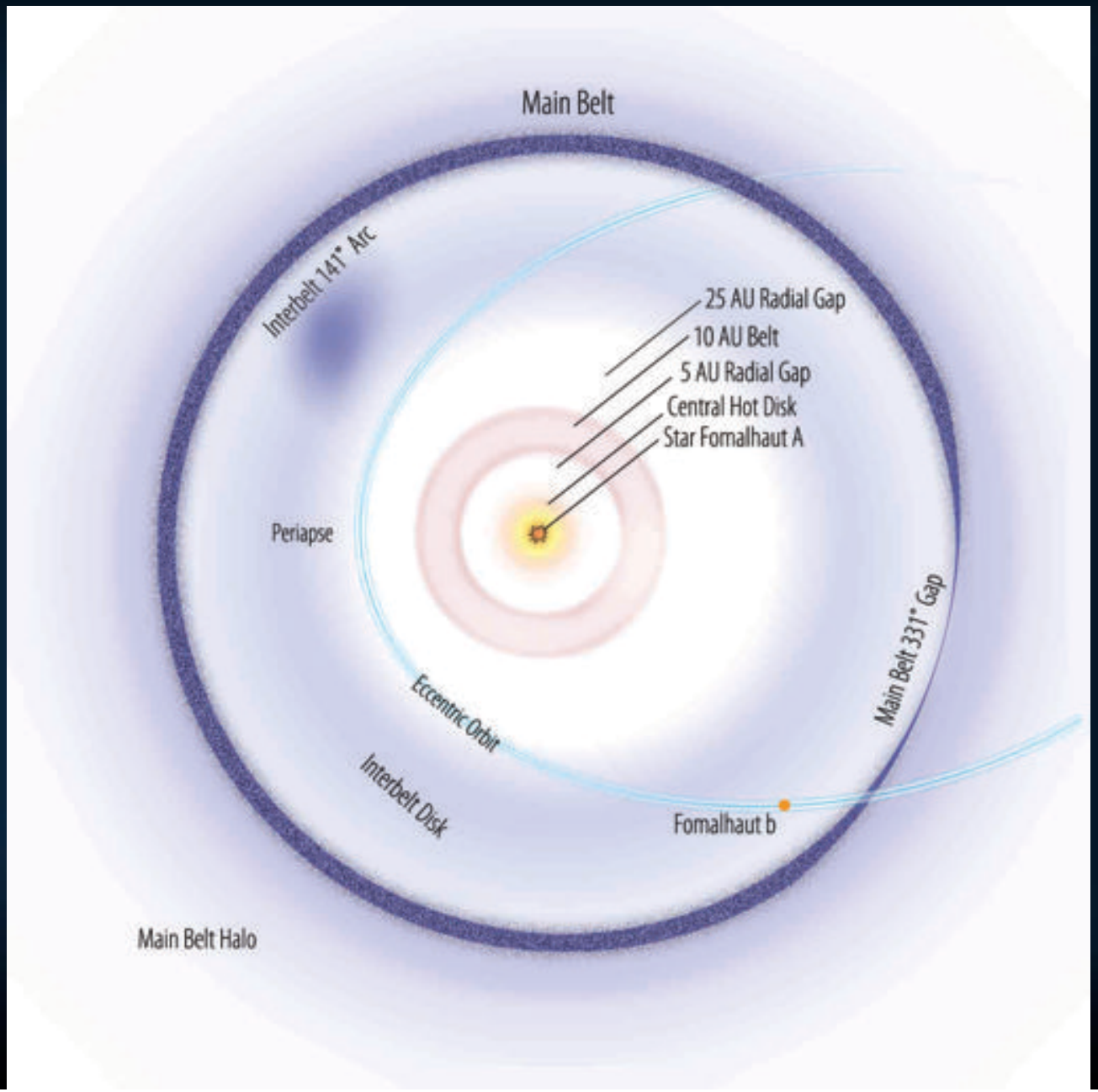




Not totally empty,
FWHM=50 AU

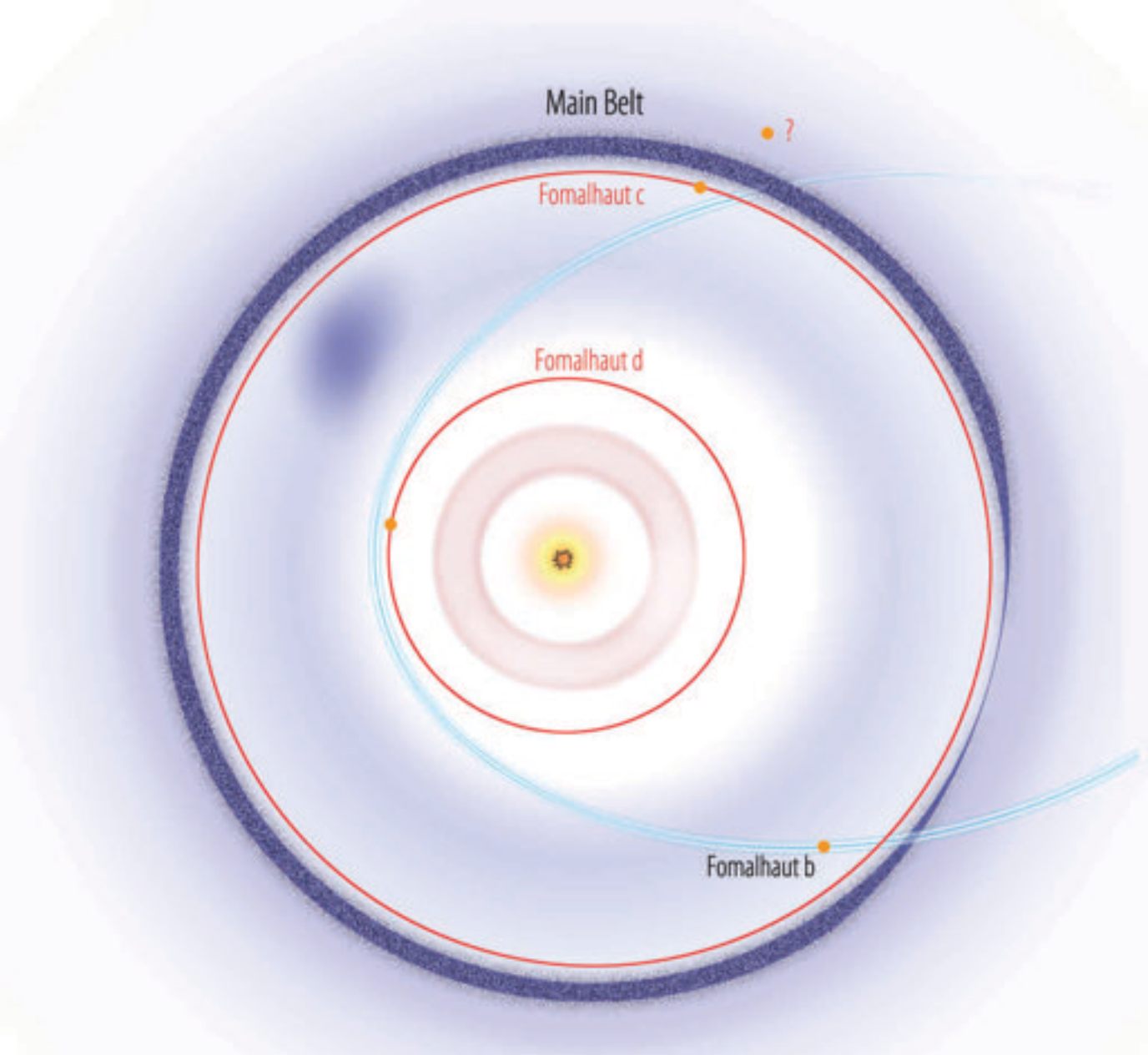
Kalas et al. 2013, submitted to ApJ

Sketch of the Fomalhaut system based on *observations*

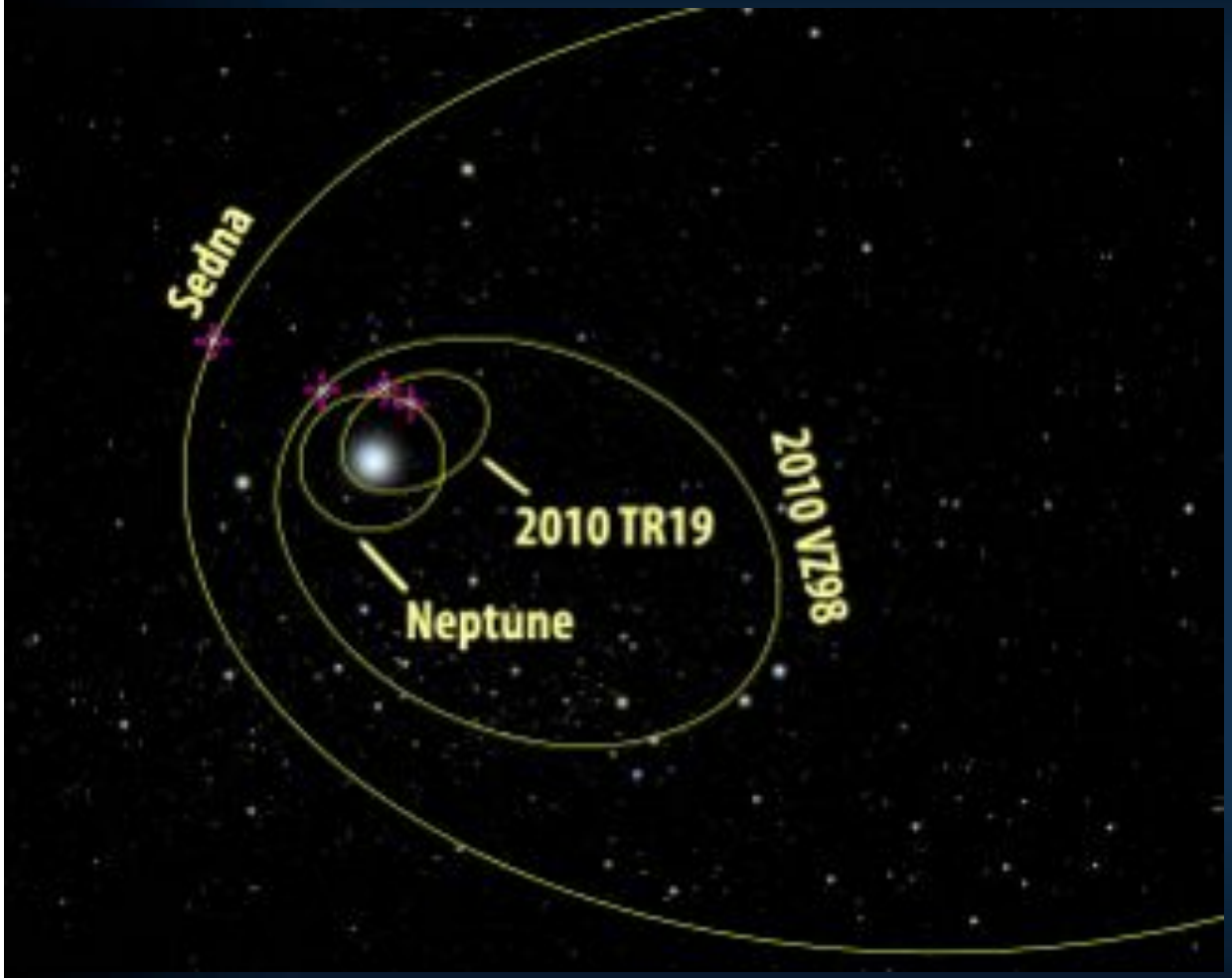


What accounts for Fomalhaut b's high eccentricity?

Multi-planet system: Was Fomalhaut b scattered in, or out?



Fomalhaut b scattered in



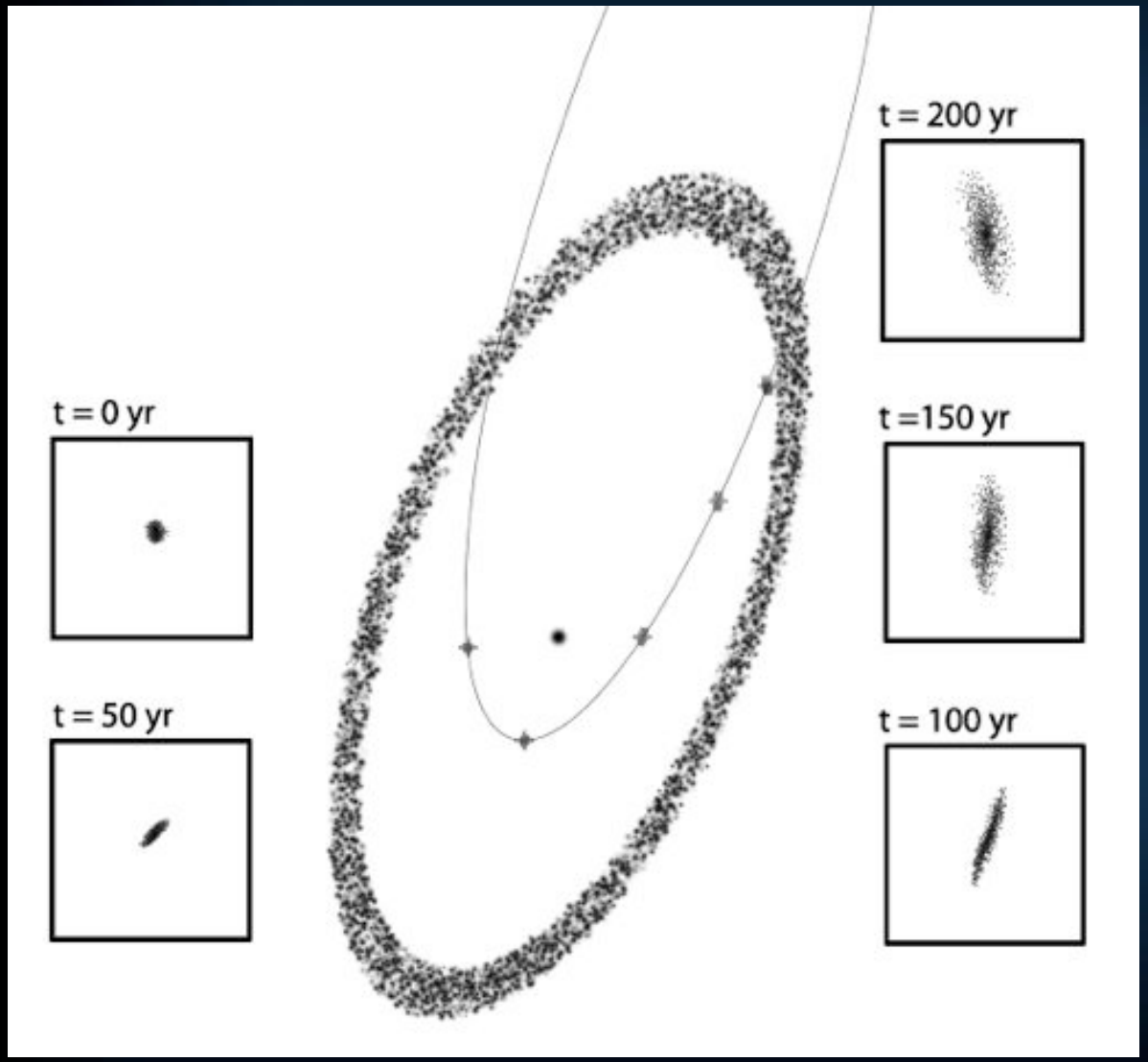
Fomalhaut b's orbit is similar to a minority of *Centaurs*, such as 2010 TR19, which enters into our planetary system (*crosses Neptune's orbit*) on a very elliptical orbit.

Implication:

(1) Fomalhaut b has a *short-lived* orbital configuration.

(2) Fomalhaut b is very low-mass.

Fomalhaut b is a low-mass, Centaur-like object?



Question: How massive does a central object have to be so that an 30 R_J (0.014 AU) radius cloud is not disrupted by tidal shearing at periapse?

Answer: 5 x10^{21} kg >Ceres, <Pluto

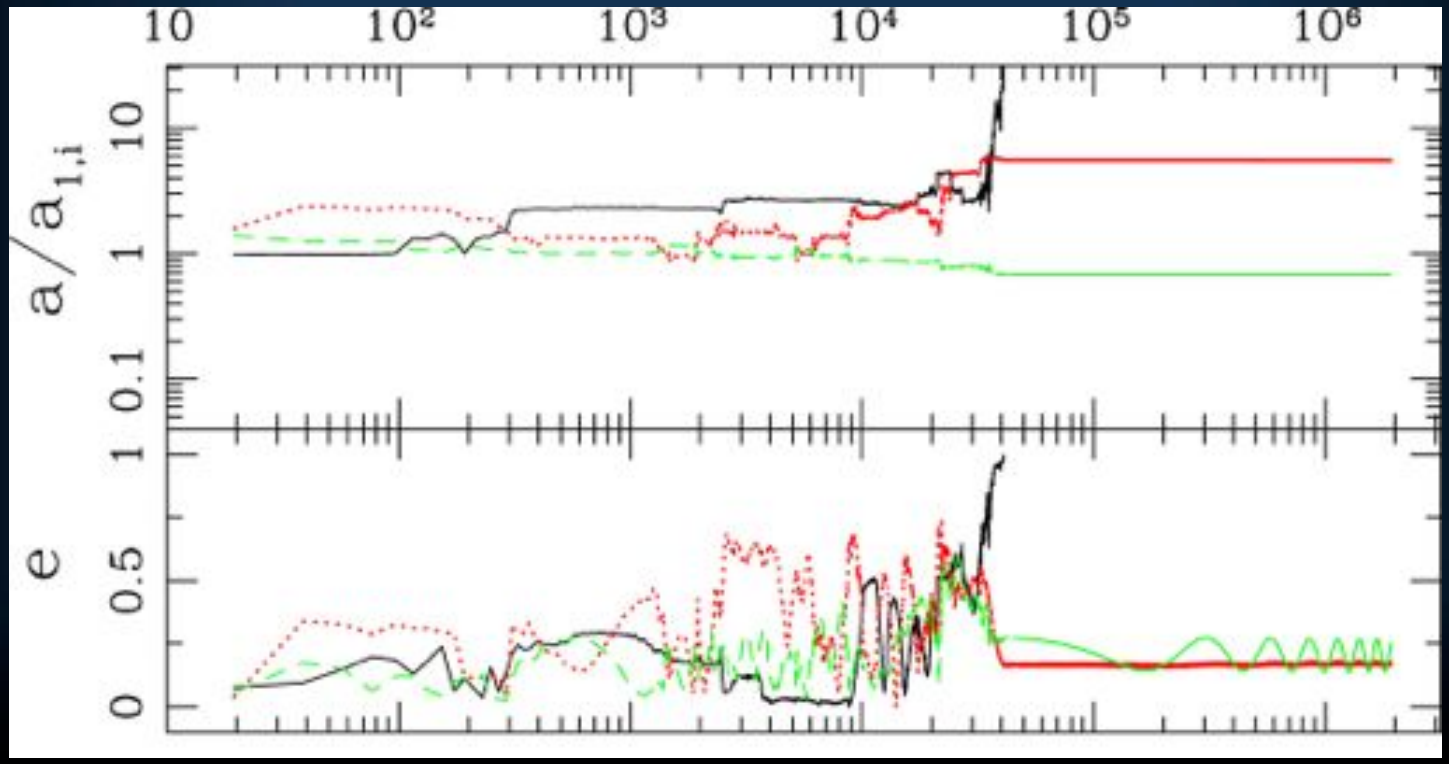
Mass of dust required consistent with a single cratering impact on the dwarf planet.

Numerical model (Kalas et al. 2013)

Fomalhaut b is a planet that was scattered out?

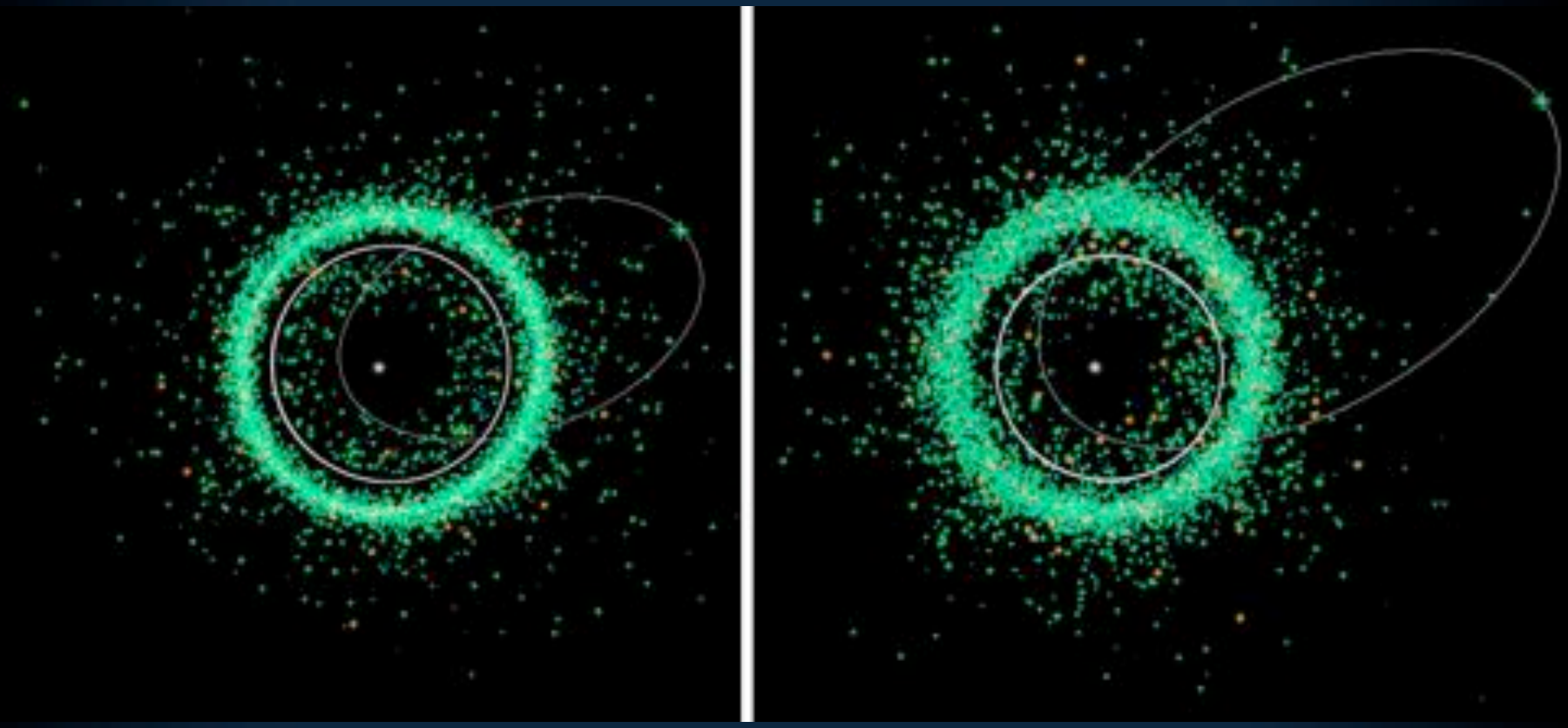
Example from Chatterjee et al. 2008

- Simulate 3-planet systems, variety of mass ratios, inclinations, separations
- Massive planets eject lesser mass planets.
- Mutual inclinations change
- Planet with outer final orbit tends to have higher eccentricity.



Does Fomalhaut b disrupt the belt if coplanar?

Belt edges erode, timescale depends on mass



Neptune mass after 300 kyr

Saturn after 75 kyr

Nested coplanar Jupiter + Eccentric NON-coplanar Neptune

http://www.youtube.com/watch?v=kD9t2vAo3uQ

Take home points

- Fomalhaut b is real

Summary

- The Fomalhaut b orbit after 8 years of HST imaging:
  - Eccentric: e=0.8±0.1
  - "Belt crossing" *in projection*
  - Periastron at 32±24 AU
  - Mutual inclination w.r.t. belt <36˚
- Minimum mass is a dwarf planet, maximum is ~1 M_J
- The belt survives planet crossings, but new features unexplained.
- Open questions: Was it scattered in or scattered out? What is the relationship to the belt? Where are the other planets, if any?

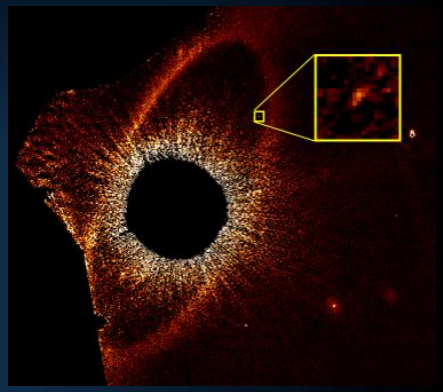
Future Observations

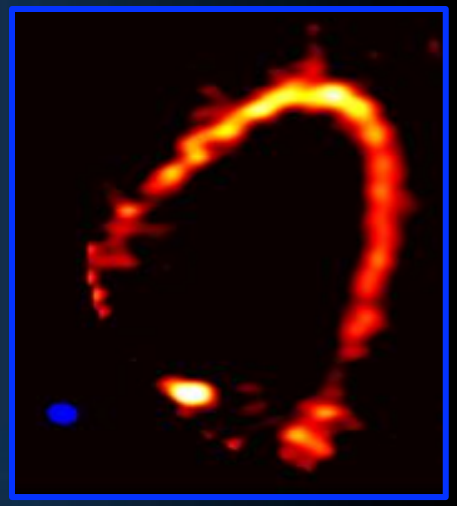
- With HST, refine Fomalhaut b's orbit, as well as photometry and morphology. Build SNR on the belt to map substructure.

- With ground-based telescopes, use ALMA to map the dust in the system, and adaptive optics to search for Fomalhaut c.

- Theory: Understand the dynamical history of the Fomalhaut system, providing an improved understanding of our own solar system's early evolution.

- Around 2032, Fomalhaut b may begin crossing through the main belt, producing new phenomena.





ALMA
Boley et al. 2011