Disks in Nearby Planetary Systems with JWST and ALMA

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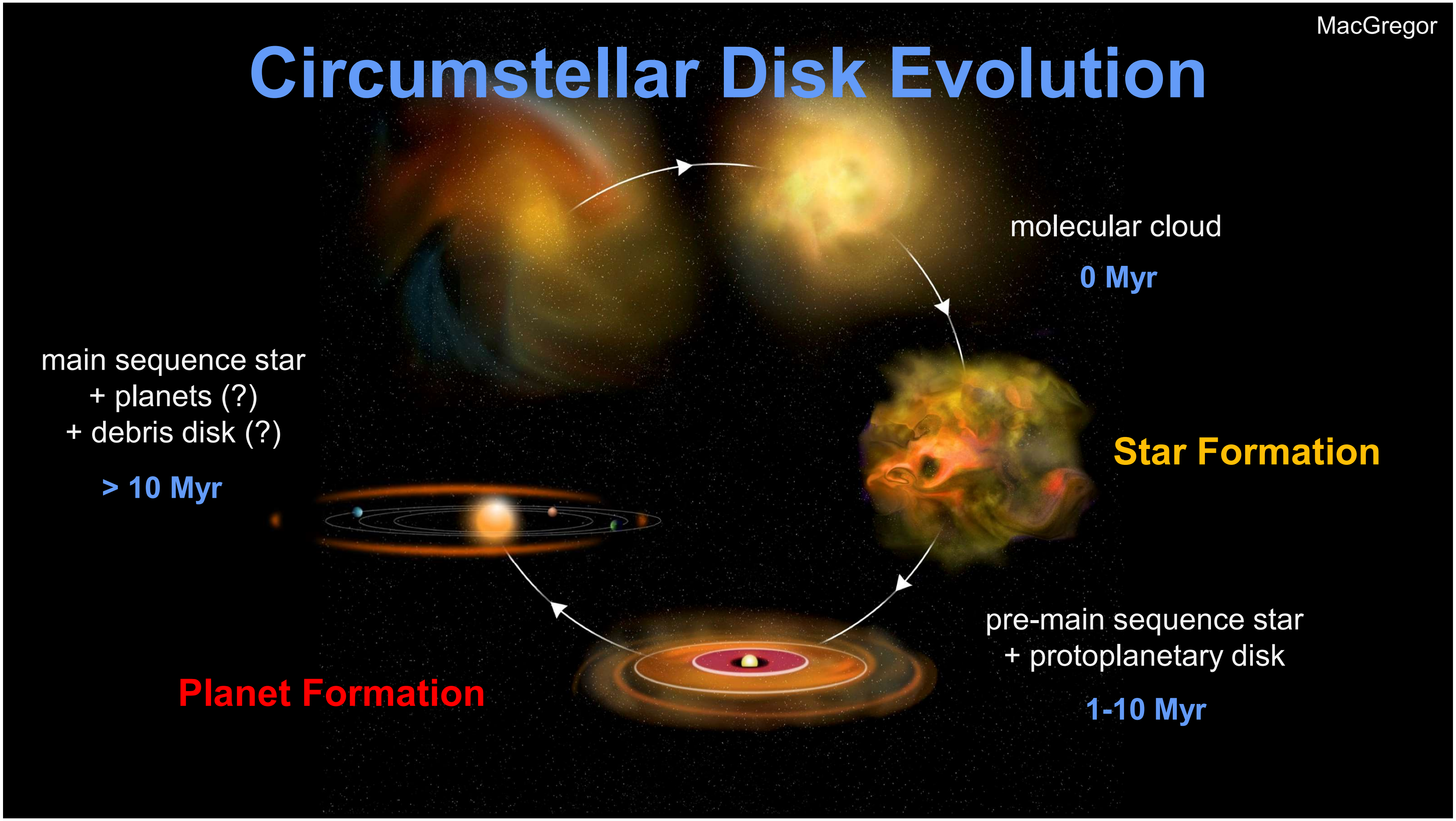
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Circumstellar Disk Evolution
molecular cloud
0 Myr
Star Formation
pre-main sequence star
+ protoplanetary disk
1-10 Myr
Planet Formation
main sequence star
+ planets (?)
+ debris disk (?)
> 10 Myr

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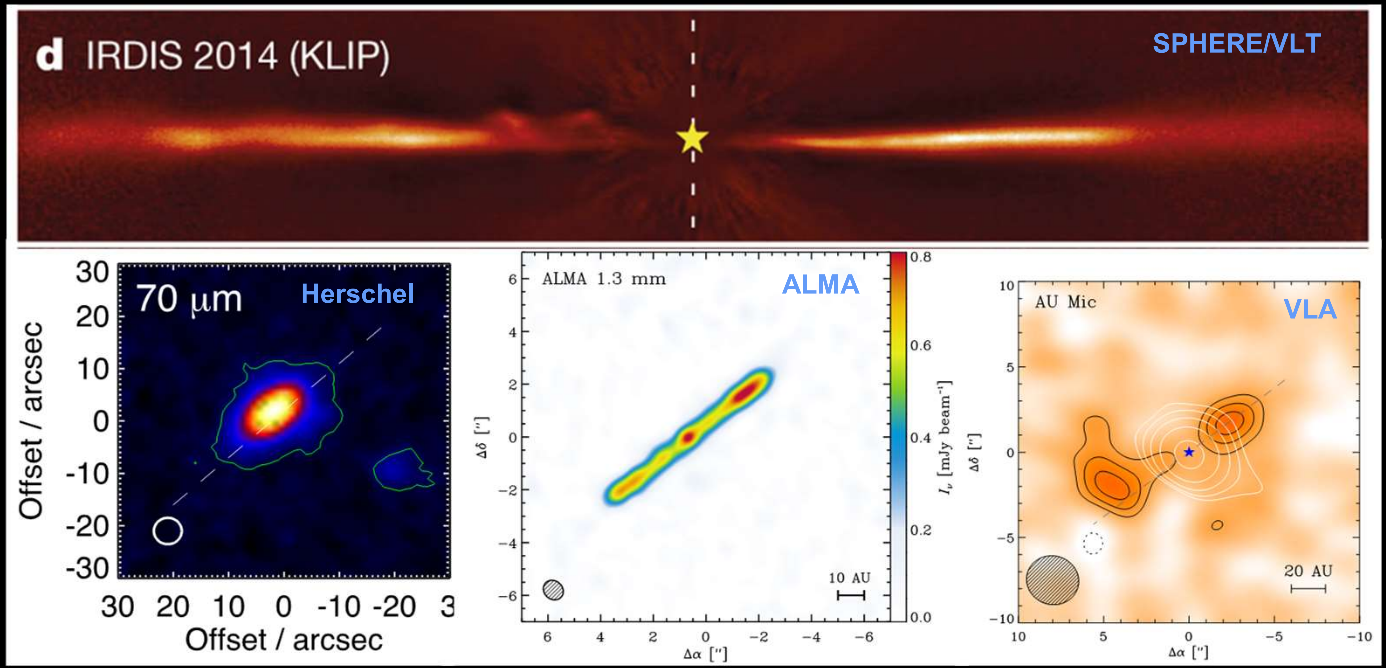
Debris Disks: Observables

First extrasolar debris disk detected as “excess” infrared emission by IRAS (Aumann et al. 1984)



Boccaletti et al (2015), Matthews et al. (2015), MacGregor et al. (2013), MacGregor et al. (2016a)

Now, resolved at wavelengths from optical (scattered light) to millimeter and radio (thermal emission)

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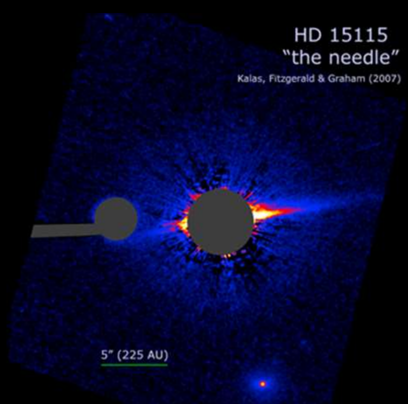
Planet-Disk Interactions

Planets orbiting a star can gravitationally perturb an outer debris disk

Expect to see a variety of structures: warps, clumps, eccentricities, central offsets, sharp edges, etc.

Goal: Probe for wide separation planets using debris disk structure

HD 15115



Asymmetry

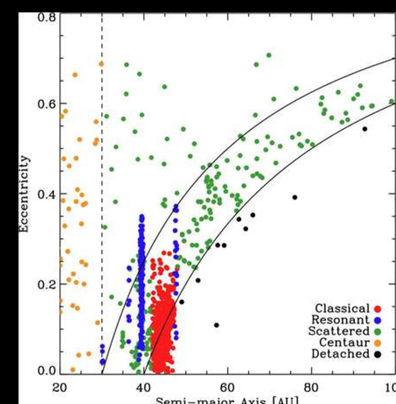
Kalas et al. (2007)

β Pictoris

Warp

Lagrange et al. (2010)

Kuiper Belt



Resonance

Jewitt et al. (2009)

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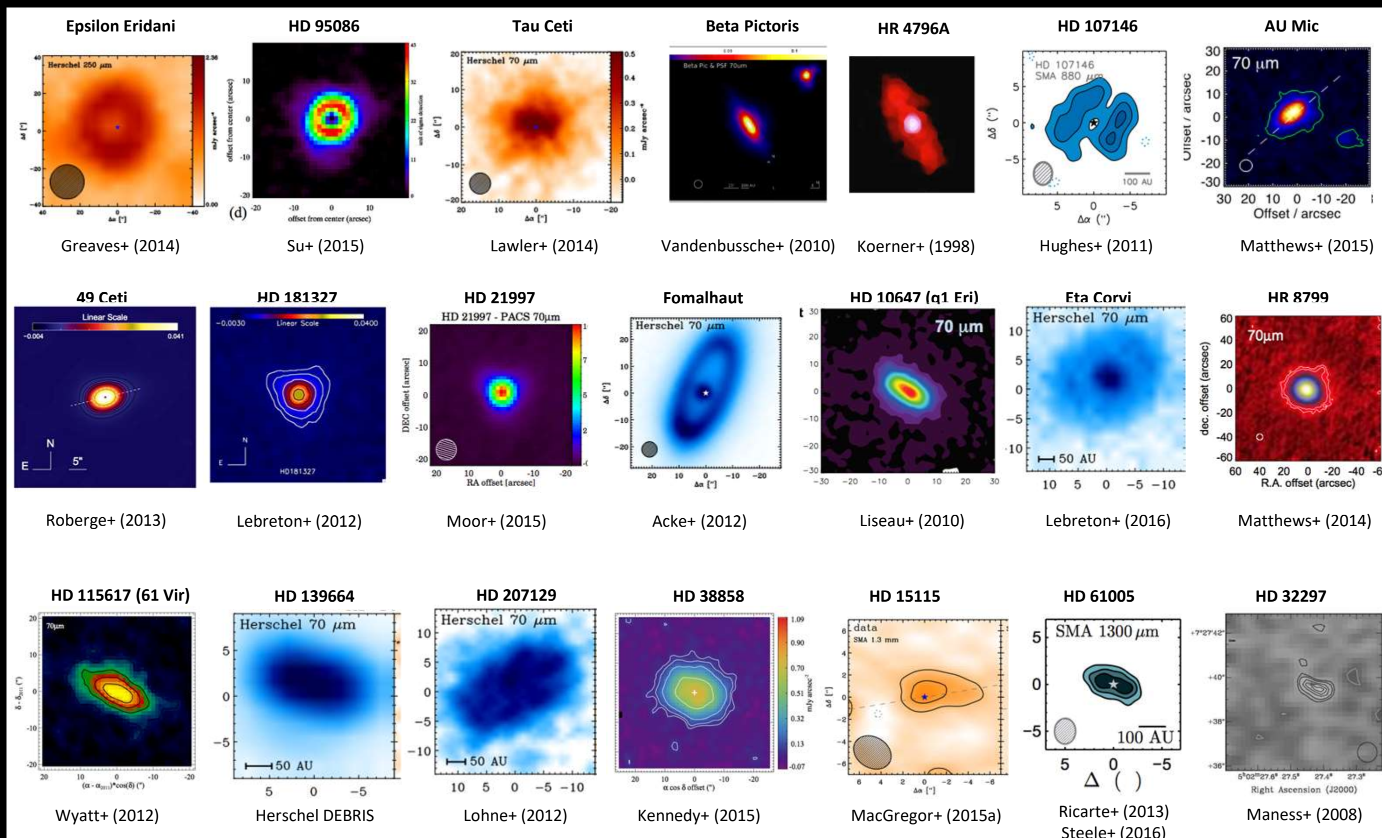
Debris Disks Before ALMA



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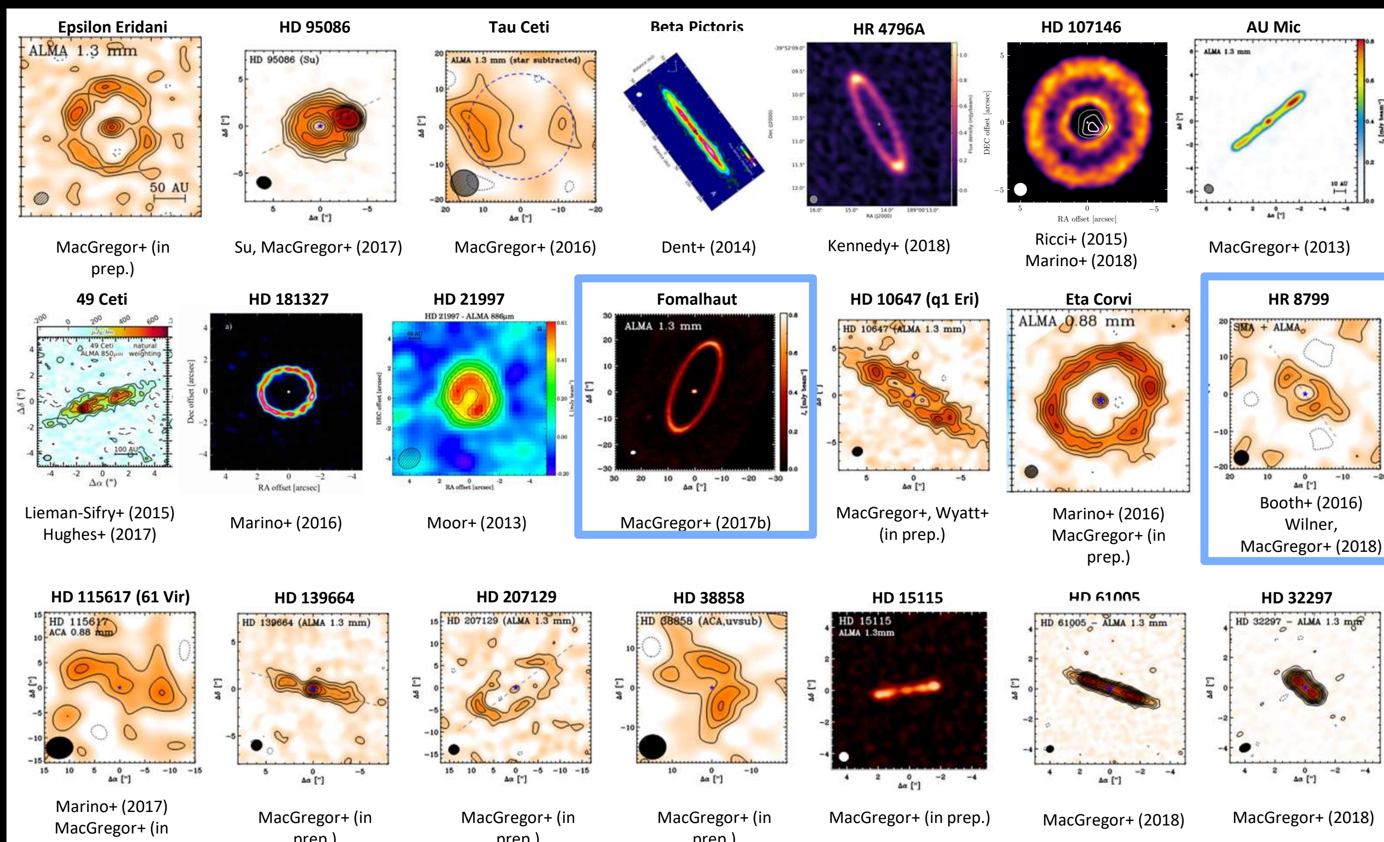
And Now With ALMA…



The Fomalhaut System

First image from *Hubble* showed narrow belt with possible planet (Kalas et al. 2005, 2008, 2013)

Half of the disk imaged by ALMA in Cycle 0 (Boley et al. 2012)

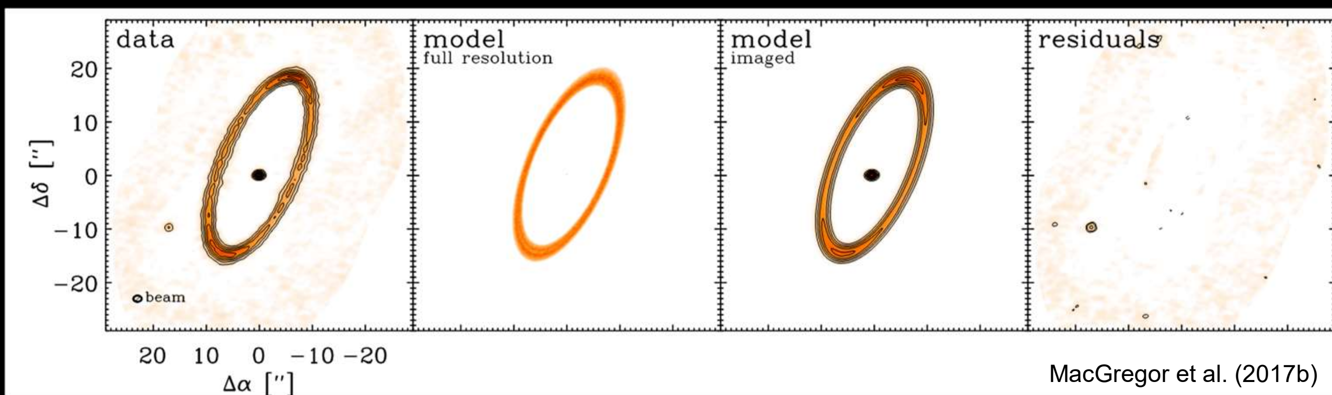
Follow-up ALMA image in Cycle 2 (White et al. 2016)

ALMA Cycle 3 project to complete a 7-pointing mosaic map (PI Paul Kalas, MacGregor et al. 2017, Matrà et al. 2017)

A-type star — 7.7 pc — 440 Myr

MacGregor et al. (2017b)

Modeling Disk Structure



MacGregor et al. (2017b)

F_{belt} [mJy]	=	24.7 ± 0.1
F_{star} [mJy]	=	0.75 ± 0.2
R_{belt} [AU]	=	136.3 ± 0.9
Δa [AU]	=	13.5 ± 1.6
incl [°]	=	65.6 ± 0.3
PA [°]	=	337.9 ± 0.3
e_f	=	0.12 ± 0.01
e_p	=	0.06 ± 0.04
ω_f [°]	=	22.5 ± 4.3

New approach for modeling eccentric rings:

1. Compute true anomaly and orbital positions for ~10^4 particles
2. Create 2D histogram of particle positions binned at pixel resolution
3. Assume $r^{-0.5}$ temperature profile and compute flux in each pixel
4. Account for disk geometry (inclination, position angles), offsets, etc.

Incorporate into MCMC framework previously

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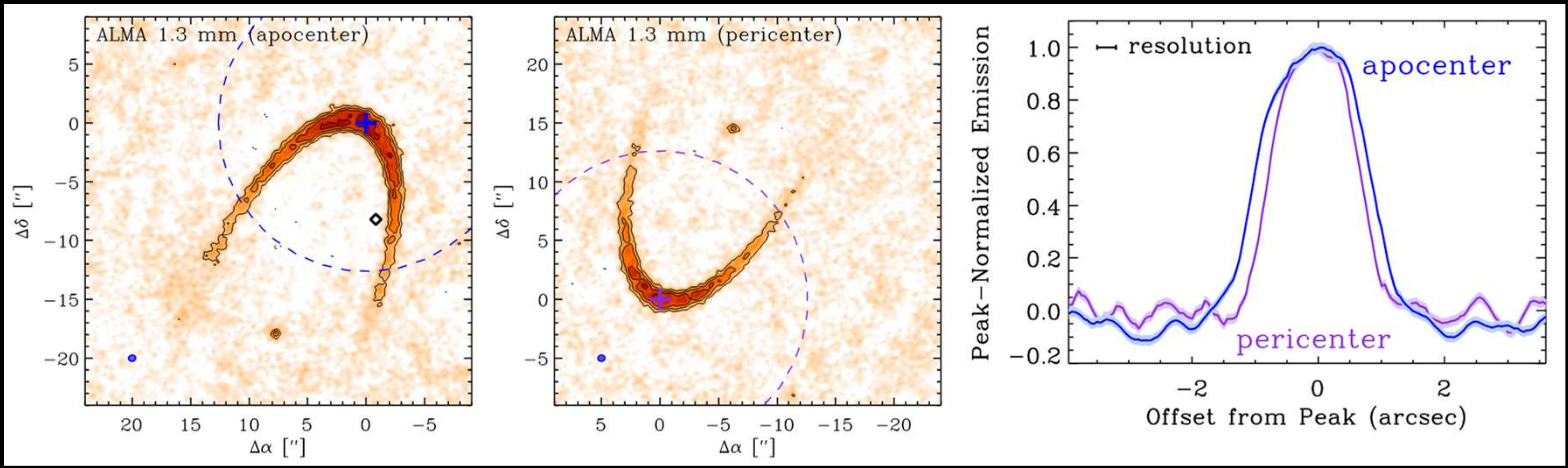
Probing Planet-Disk Interactions

If a disk is shaped by a planet, theory predicts azimuthal variations in the disk width, with the largest difference between apocenter and pericenter

Expected width difference for Fomalhaut is resolvable with ALMA (~4 AU)



New observations will . . .

(1) determine whether the disk is shaped through secular perturbations by a planet

(2) identify any additional small-scale substructure in the disk

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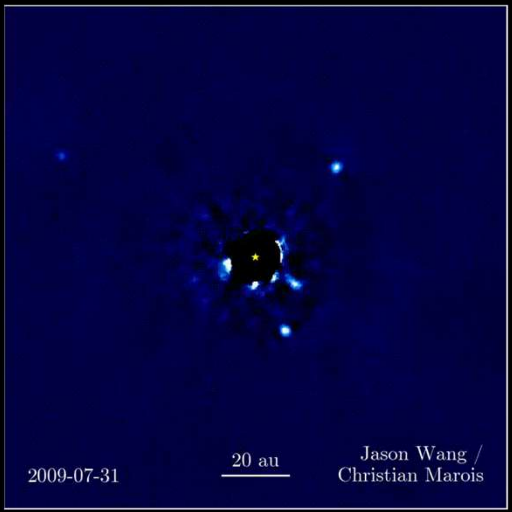
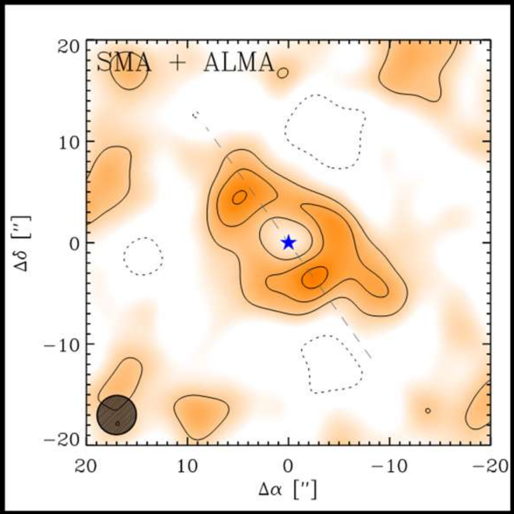
The HR 8799 System

A-type star — 39.4 pc — 30 Myr





Wilner, MacGregor, et al. (2018)

System consists of:

1. Four 5—10 M_{Jup} directly-imaged companions with projected separations of 14, 24, 38, and 68 AU (Marois et al. 2008, 2010; Marley et al. 2012)
2. A warm inner belt (T ~ 150 K)
3. A cold outer belt (T ~ 35 K)
4. Extended halo of small grains out to ~1000 AU

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The Mass of Planet b

Translate constraint on disk inner edge into constraint on mass of planet b (Pearce & Wyatt 2014):

$$R_{\rm in} = a_{\rm pl} + 5a_{\rm pl}\left(\frac{M_{\rm pl}}{3M_*}\right)^{1/3}$$

$$R_{\rm in} = 104^{+8}_{-12}\ \rm AU$$

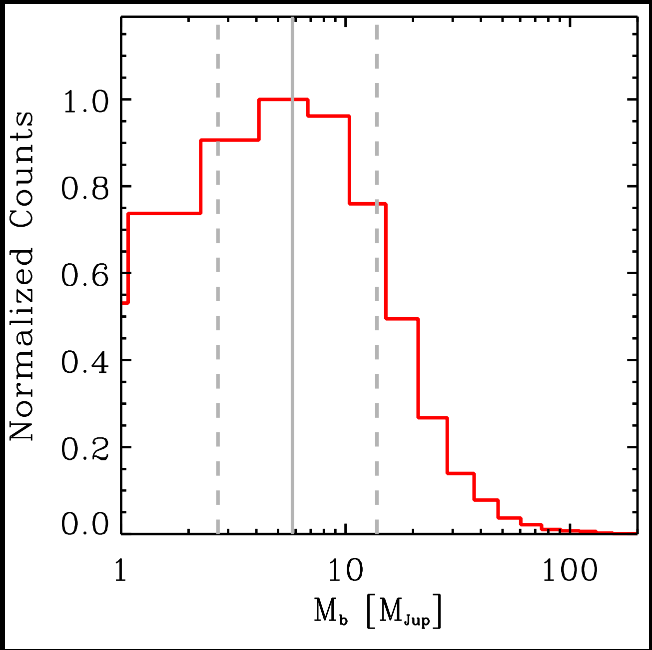
Adopting:

$$a_{\rm pl} = 68\ \rm AU$$

$$M_* = 1.56\ \rm M_\odot$$

Yields:

$$M_{\rm pl} = 5.8^{+7.9}_{-3.1}\ \rm M_{Jup}$$



Wilner, MacGregor, et al. (2018)

Current mass estimates derived from evolutionary models
Need for an independent constraint!

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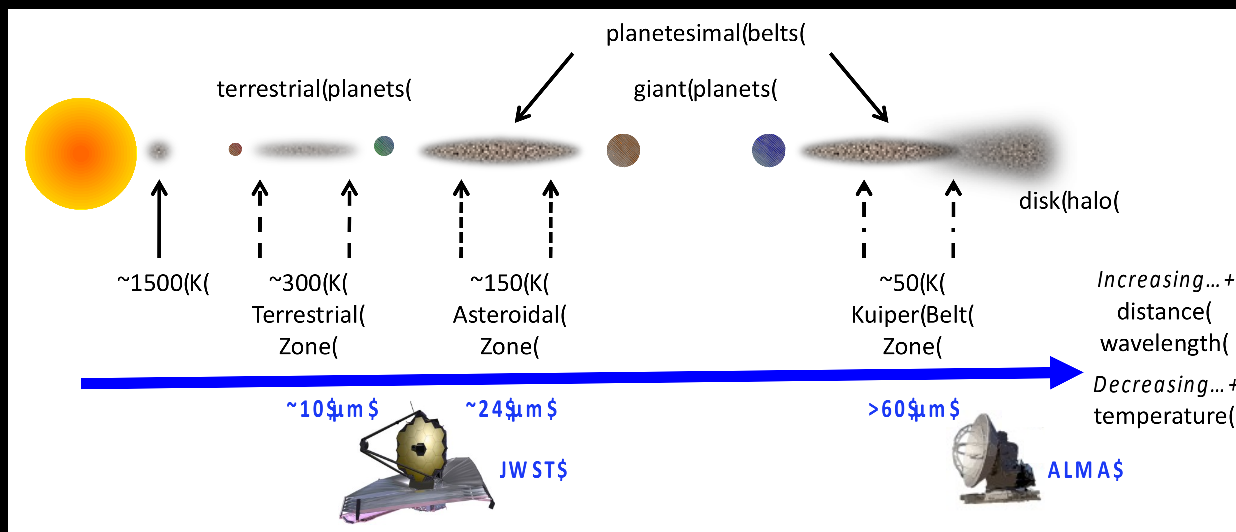
ALMA and JWST

ALMA can…

1. Resolve structure in cold Kuiper Belt analogues
2. Detect molecular gas lines (e.g., CO isotopologues)



JWST can…

1. Resolve structure in debris disks with multiple components
2. Probe grain composition (silicate features) and atomic gas lines (e.g., H_2O)

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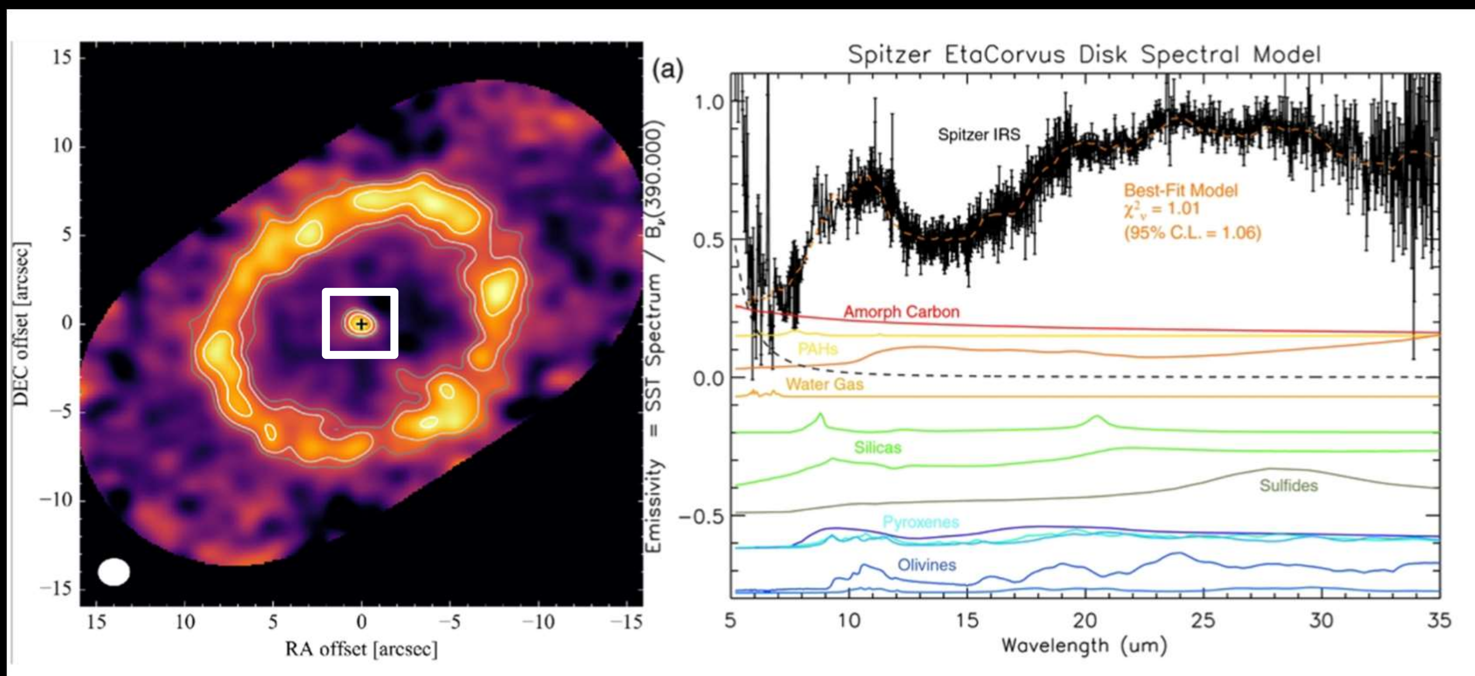
The Eta Corvi System

Hot (300 K) asteroidal dust at a few AU

Spitzer IRS spectrum shows water- and carbon-rich 10 μm silicate emission feature

ALMA



Spitzer

Marino et al. (2016); Lisse et al. (2012)

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Take-Aways

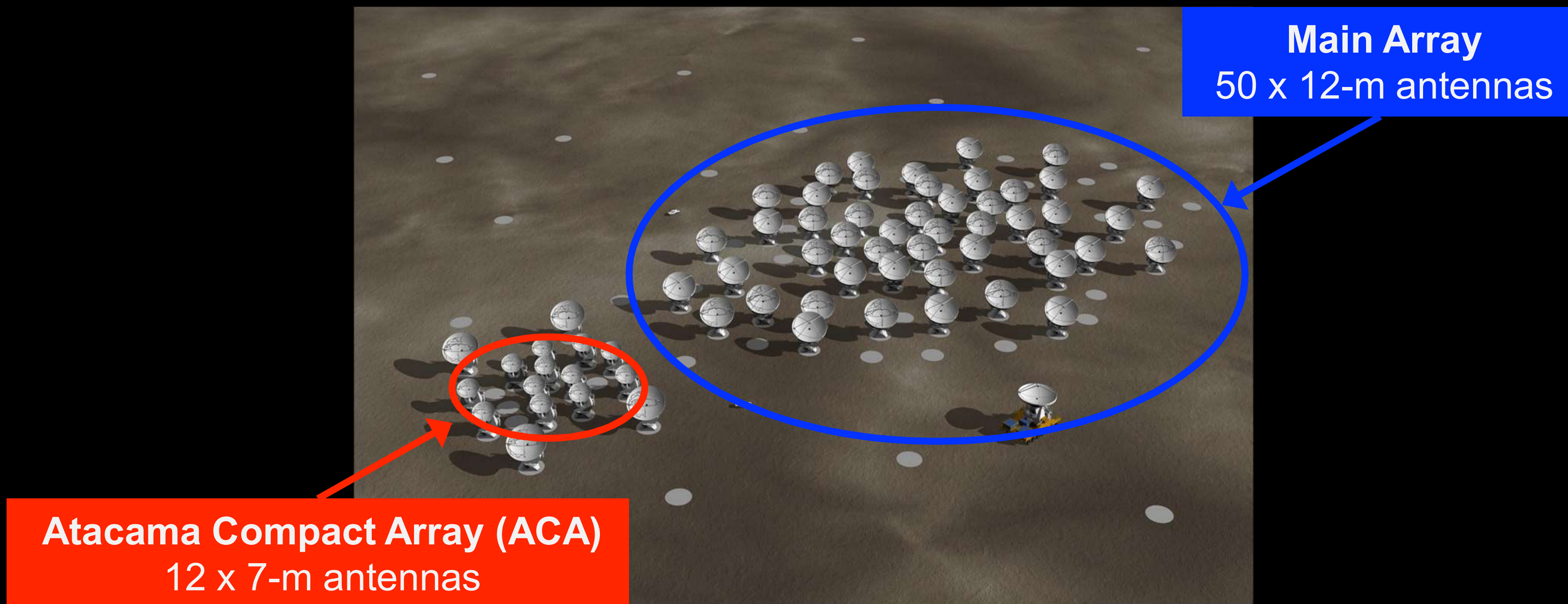
(1) ALMA has revolutionized our understanding of debris disks at millimeter wavelengths by increasing *both* resolution and sensitivity.

(2) JWST will provide complementary information on warm debris disks, as well as grain composition and disk gas content.

(3) We can robustly model and characterize the millimeter emission of nearby debris disks (e.g., Fomalhaut, HR 8799).

(4) In nearby systems, we are beginning to make connections between debris disk structure and underlying planetary systems.

The ALMA Array



All observations shown here taken at 1.3 mm (230 GHz, Band 6) with 8 GHz of bandwidth and two linear polarizations (XX, YY)