

# On the formation of Earth-like planets in the habitable zone of binary star systems

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# Introduction

At least 50% of the stellar systems have 2 or more stars

Confirmed exoplanets: ~ 3,500

Candidates still to be confirmed: ~ 4,500

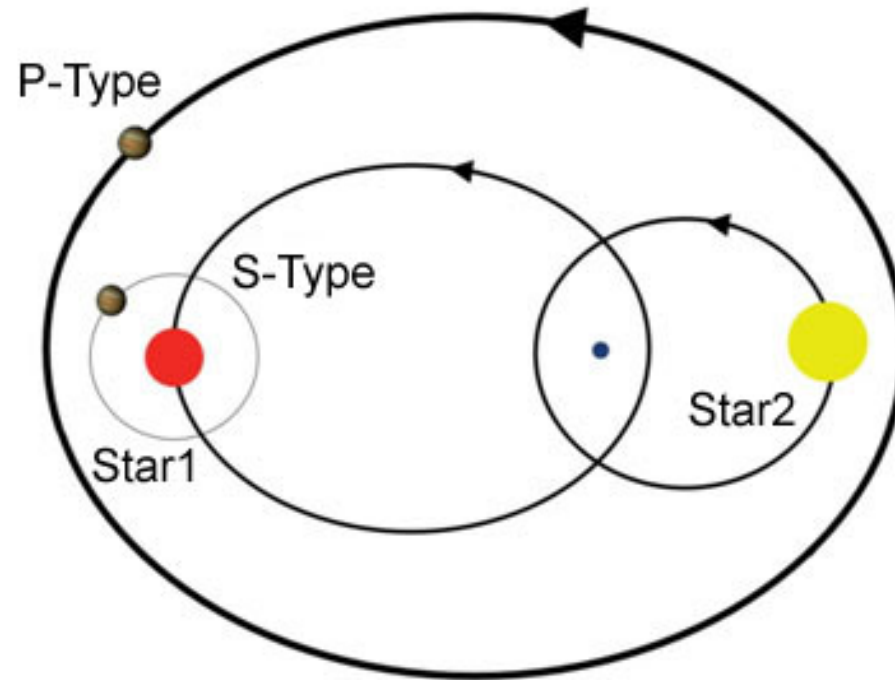
Multiplanetary systems: 582

Single star systems with planets: 2,609

Binary star systems with planets: 156

Planets of binary systems in P-type orbits: 21

# S-type X P-type



# Circumbinary Systems

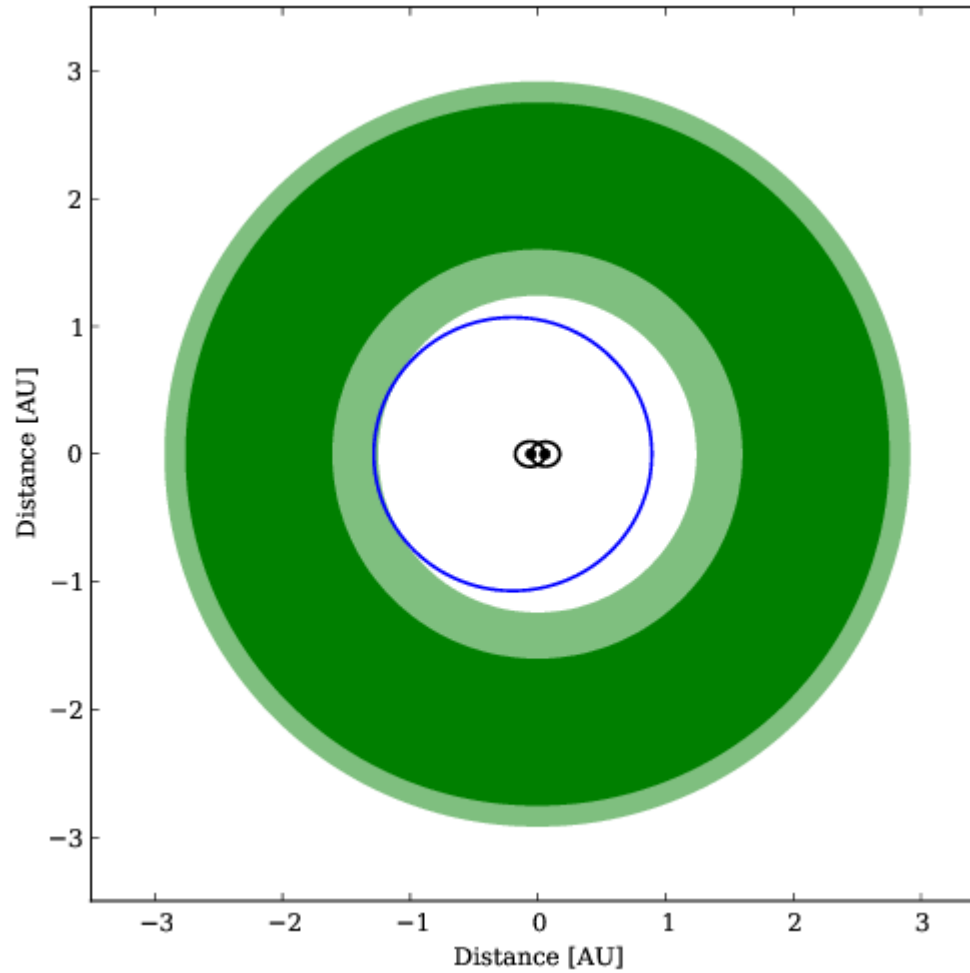
SYSTEM	discovery	a [au]	e	planets	M1 [m_Sun]	M2 [m_Sun]
DP Leo AB b	2009	0,0027	0	1	0,6	0,009
FW Tauri AB b	2013	11		1	0,28	0,28
HD 106906 AB b	2013			1	1,3	1,3
HU Aqr AB b	2011	0,0039	0	1	0,88	0,2
Kepler-16 AB b	2011	0,2243	0,159	1	0,6897	0,2026
Kepler-1647 AB b	2015	0,1276	0,1602	1	1,22	0,97
Kepler-34 AB b	2012	0,2288	0,521	1	1,048	1,021
Kepler-35 AB b	2012	0,1762	0,142	1	0,888	0,809
Kepler-38 AB b	2012	0,147	0,103	1	0,949	0,249
Kepler-413 AB b	2013	0,1015		1	0,82	0,5432
Kepler-451 AB b	2015	0,0041		1	0,48	0,12
Kepler-453 AB b	2014	0,1848		1	0,944	0,194
Kepler-47 AB b	2012	0,0836	0,0234	2	1,043	0,362
NN Ser AB bc	2010	0,0039		2	0,535	0,111
NY Vir AB bc	2011	0,0044		2	0,46	0,14
OGLE-2007- BLG-349 (AB) b	2016	0,08		1	0,41	0,3
PSR B1620-26 / WD J1623-266 B	2003	0,2	0,025	1	1,35	0,6
Ross 458 AB c	2010			1	0,6	0,075
Roxs 42 AB b	2013			1	0,89	0,36
RR Cae AB b	2012	0,0076		1	0,44	0,182
SR 12 AB c	2011			1	0,3	

-  pulsar
-  unstable
-  lack of data

# Selected Systems

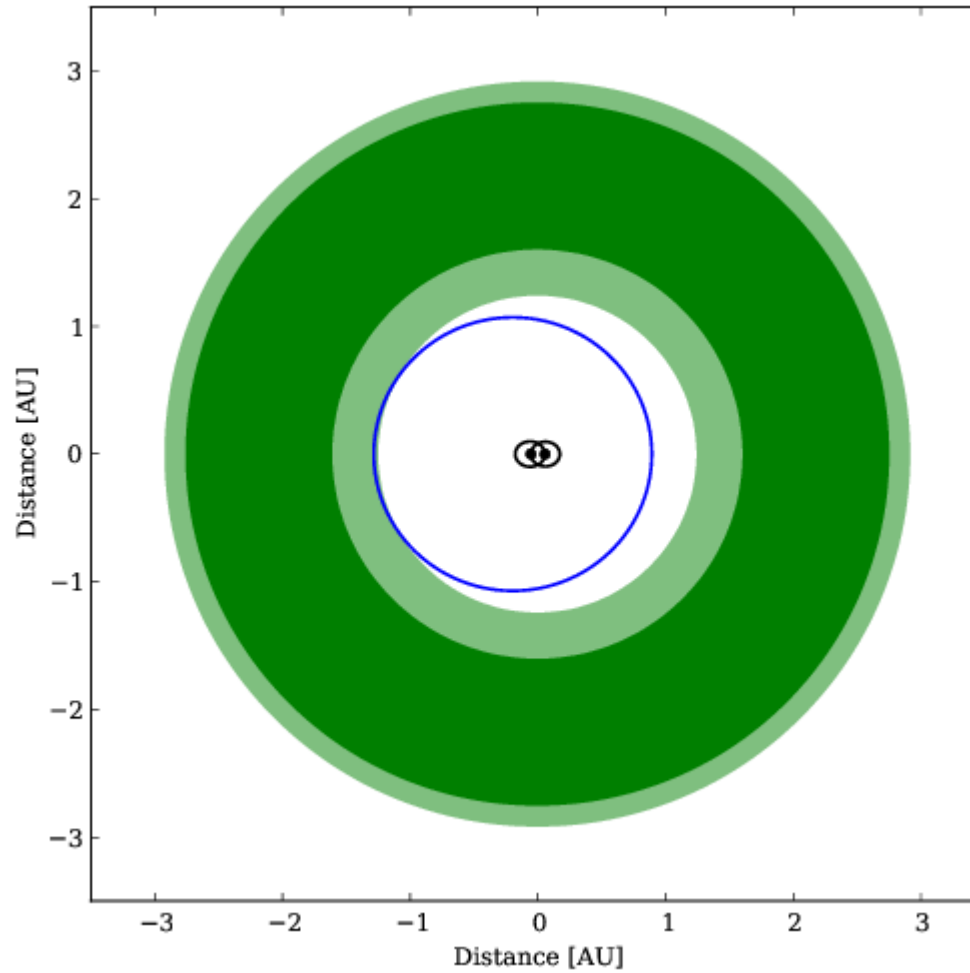
<b>System</b>	<b><math>M_A</math></b> ( $m_{\text{Sun}}$ )	<b><math>M_B</math></b> ( $m_{\text{Sun}}$ )	<b><math>a_{\text{bin}}</math></b> (au)	<b><math>e_{\text{bin}}</math></b>	<b><math>a_{\text{planet}}</math></b> (au)	<b><math>e_{\text{planet}}</math></b>	<b><math>M_{\text{planet}}</math></b> ( $m_{\text{Jup}}$ )	<b>HZ range</b> (au)
Kepler-34	1.048	1.021	0.229	0.521	1.089	0.182	0.220	1.25-2.80
Kepler-35	0.890	0.810	0.176	0.142	0.603	0.042	0.127	0.90-2.10
Kepler-38	0.949	0.249	0.147	0.103	0.464	0.030	0.016	1.25-2.95
Kepler-413	0.820	0.542	0.102	0.037	0.355	0.118	0.210	0.30-0.90
Kepler-453	1.043	0.362	0.084	0.023	0.790	0.036	0.030	0.51-1.30
Kepler-1647	1.221	0.968	0.128	0.160	2.7205	0.058	1.520	1.40-4.00

# Habitable Zone

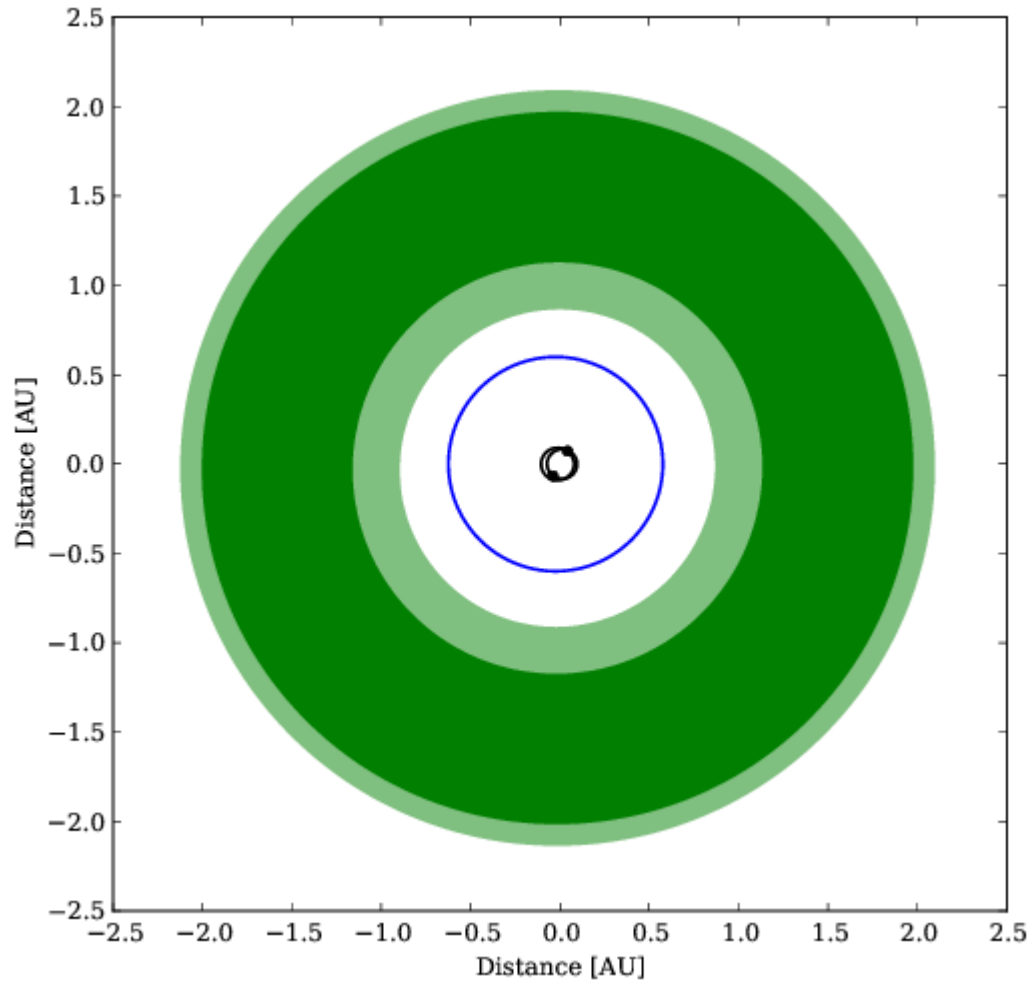


Kaltenegger & Haghighipour (2013)

# Kepler 34

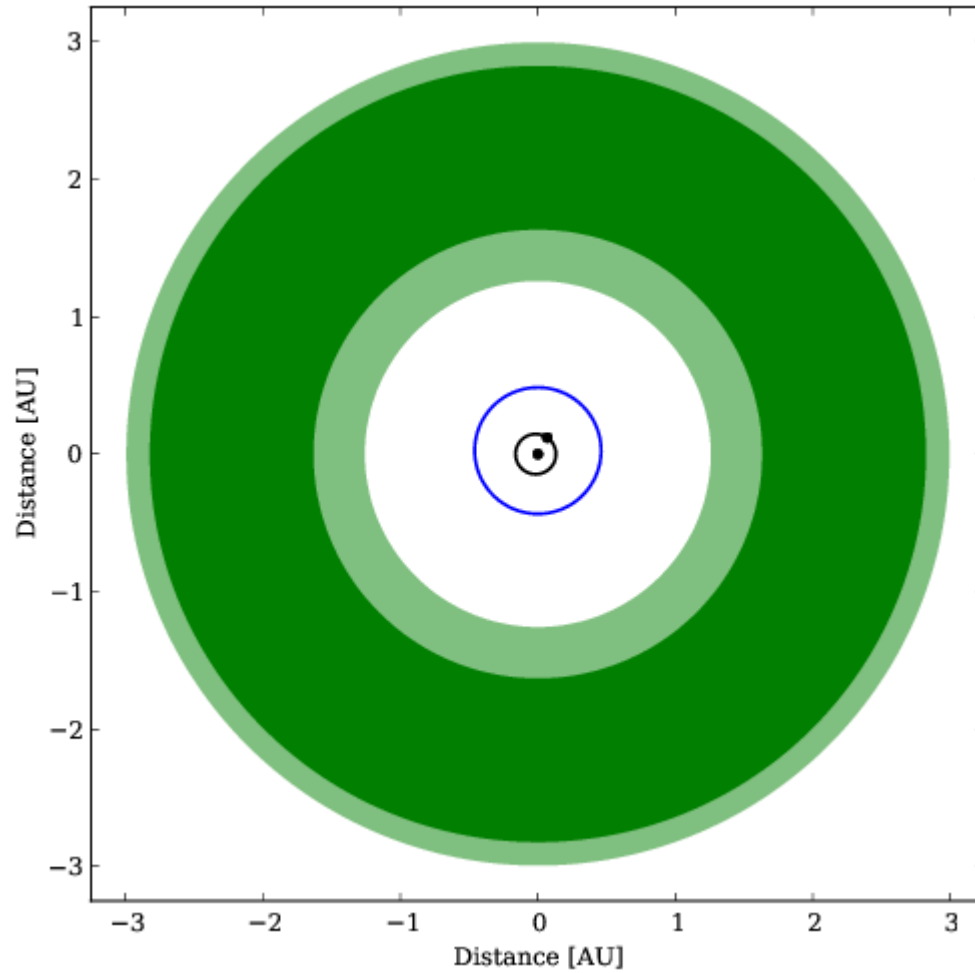


# Kepler 35

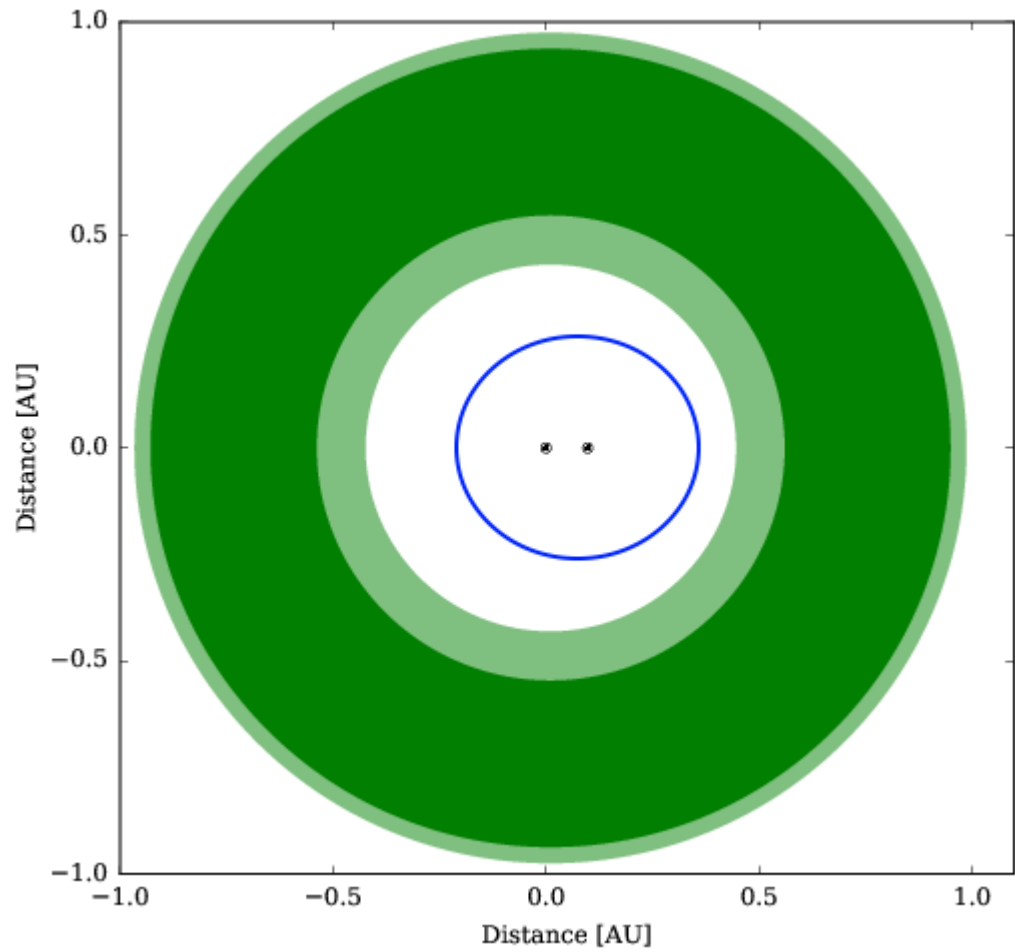




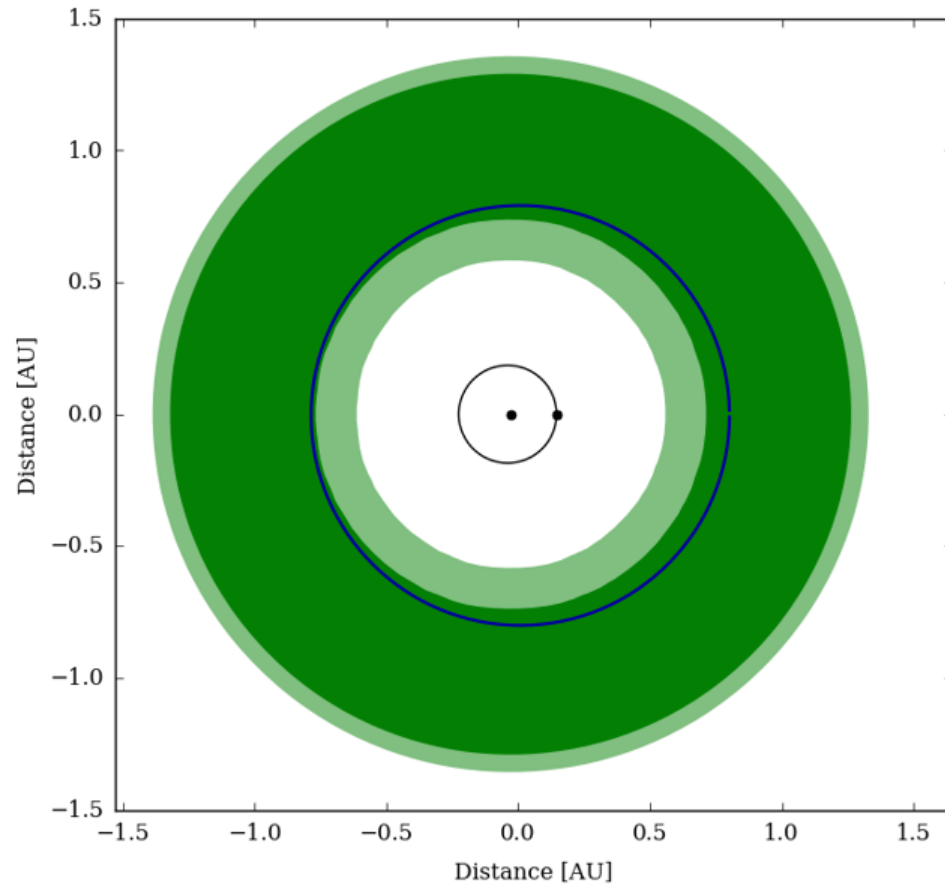
# Kepler 38



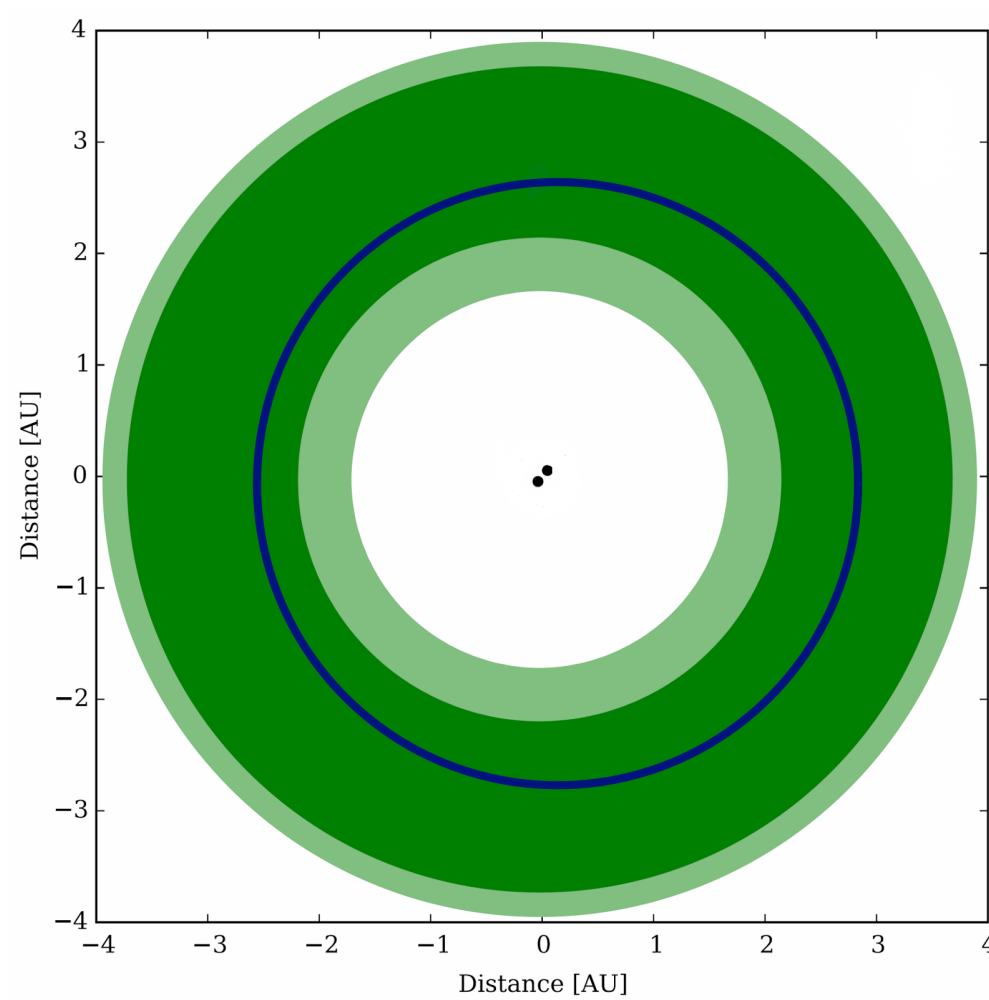
# Kepler 413



# Kepler 453



# Kepler 1647



# Numerical Simulation

## Binary stars + Planet + Disk

Total Disk Mass = 3 M<sub>Earth</sub>

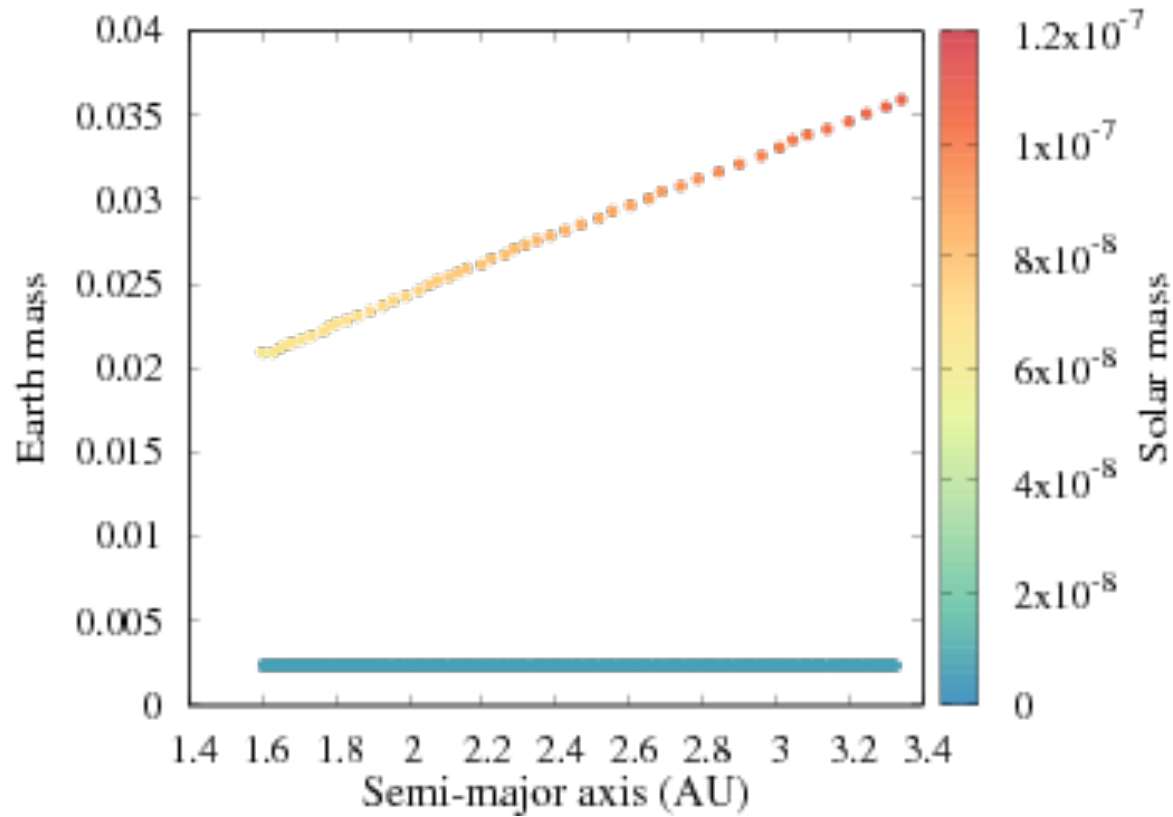
50% Embrios + 50% planetesimals

Embrios:  $\Sigma(r) = \Sigma_0 r^{-\alpha}$       $\Sigma_0 = 8 \text{ g/cm}^3$   
 $\alpha = 1.5$

Planetesimals:  $\sim 0.002 \text{ M}_{\text{Earth}}$

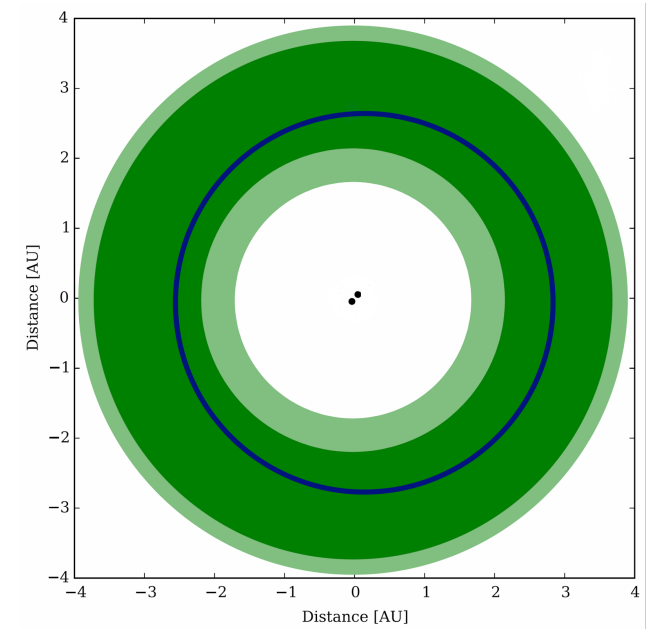
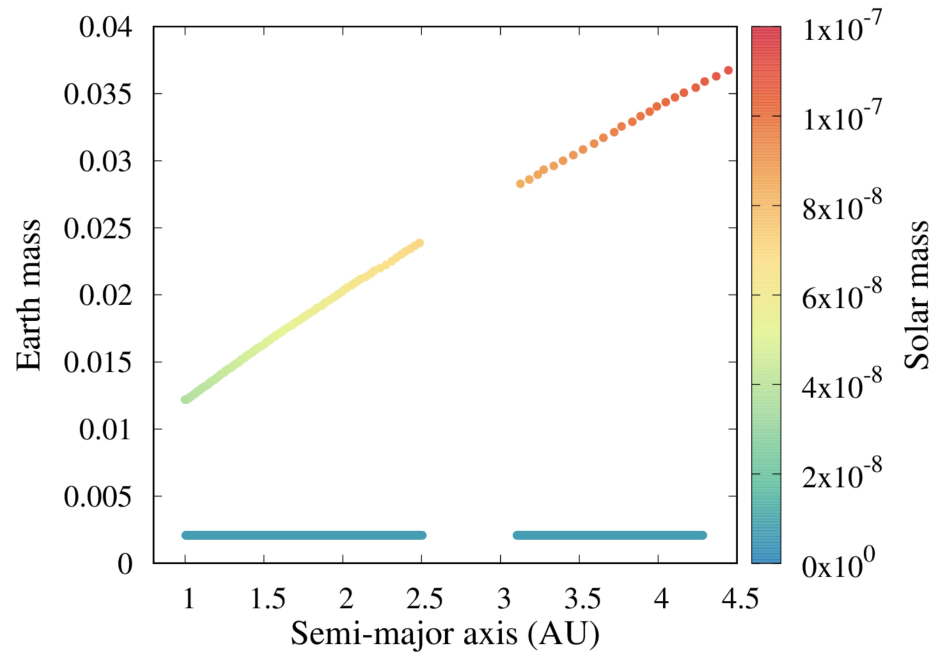
- radial distribution  $\sim \text{HZ}$
- near circular ( $e = 0 - 0.01$ )
- near coplanar ( $i = 0 - 0.5 \text{ deg}$ )

# Initial Conditions



Kepler 34

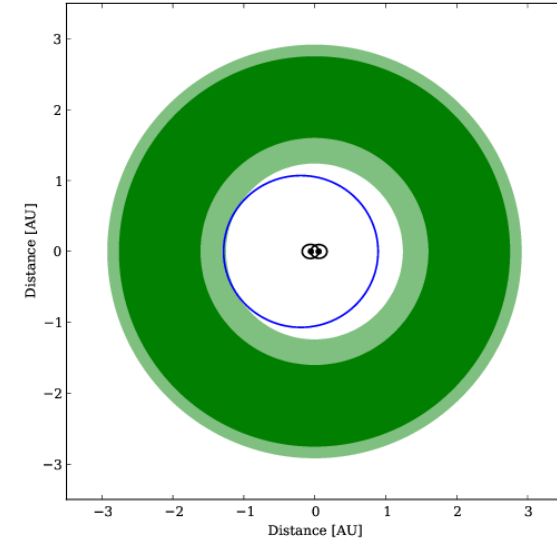
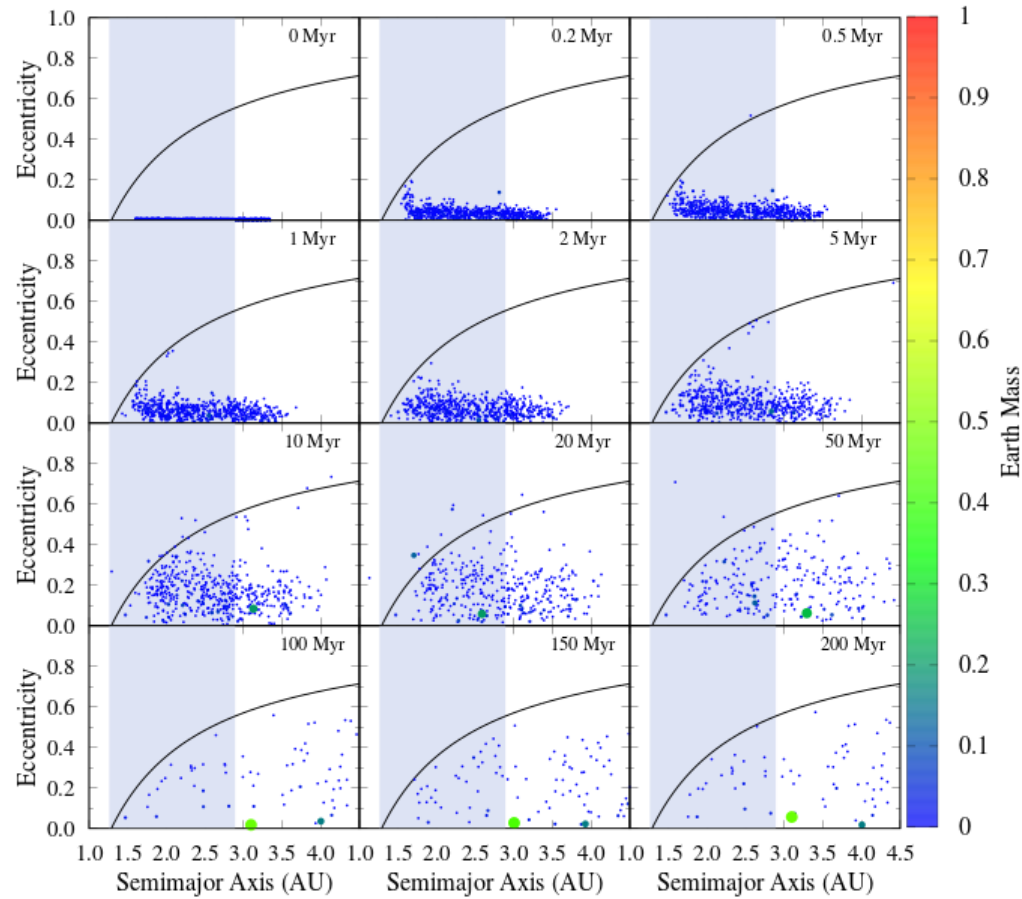
# Kepler 1647



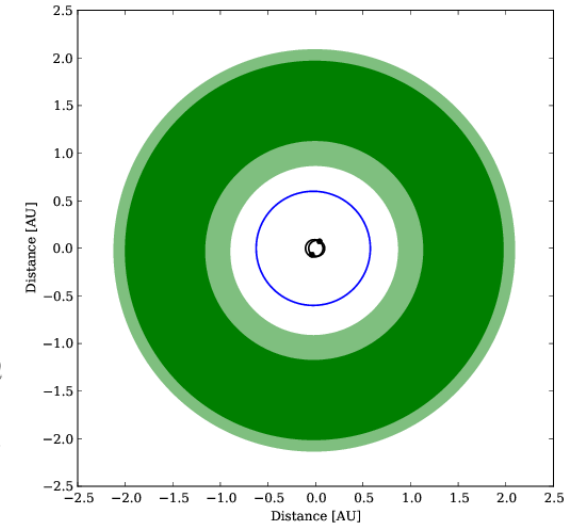
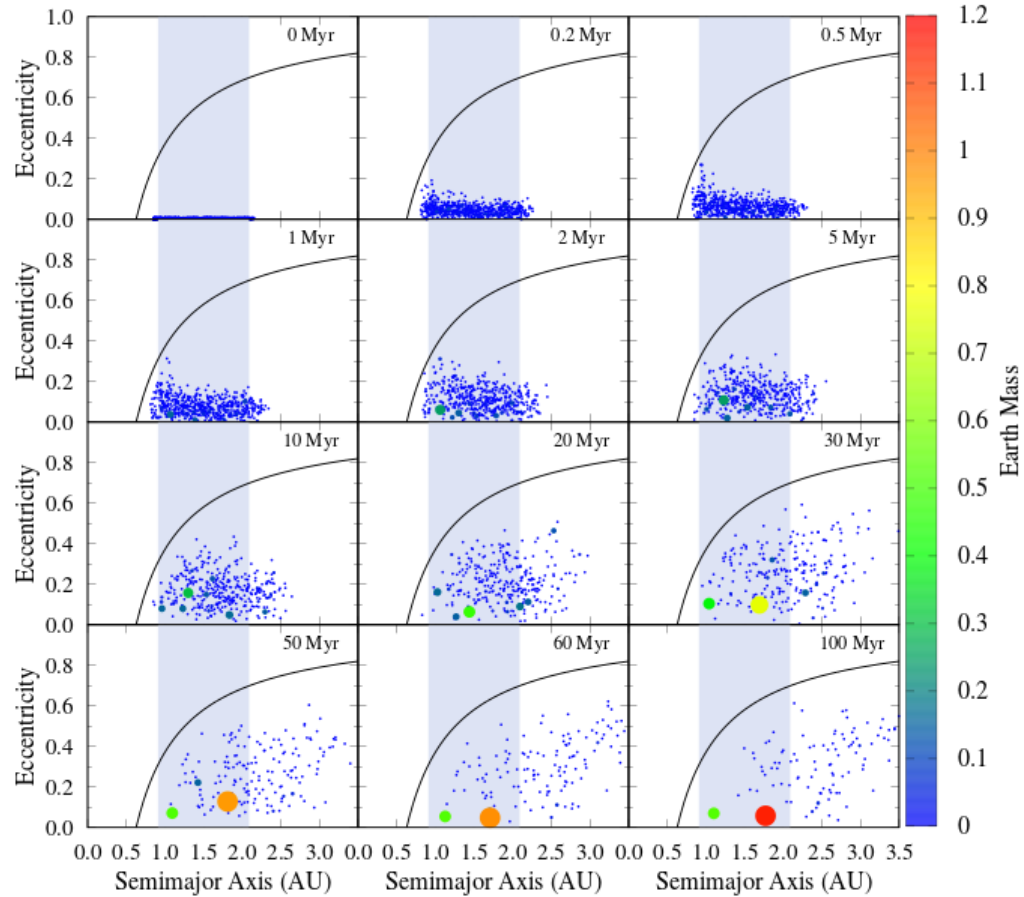
# Preliminary Results



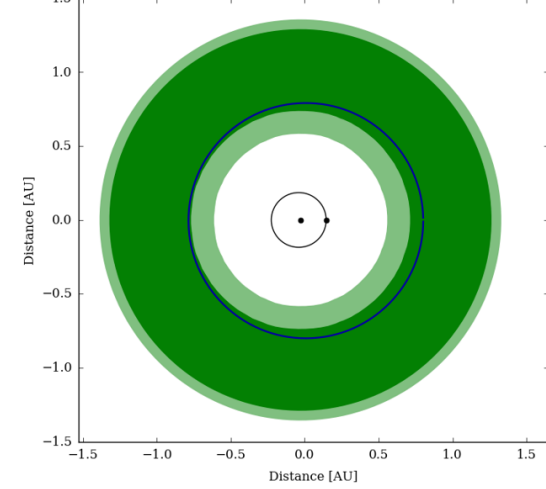
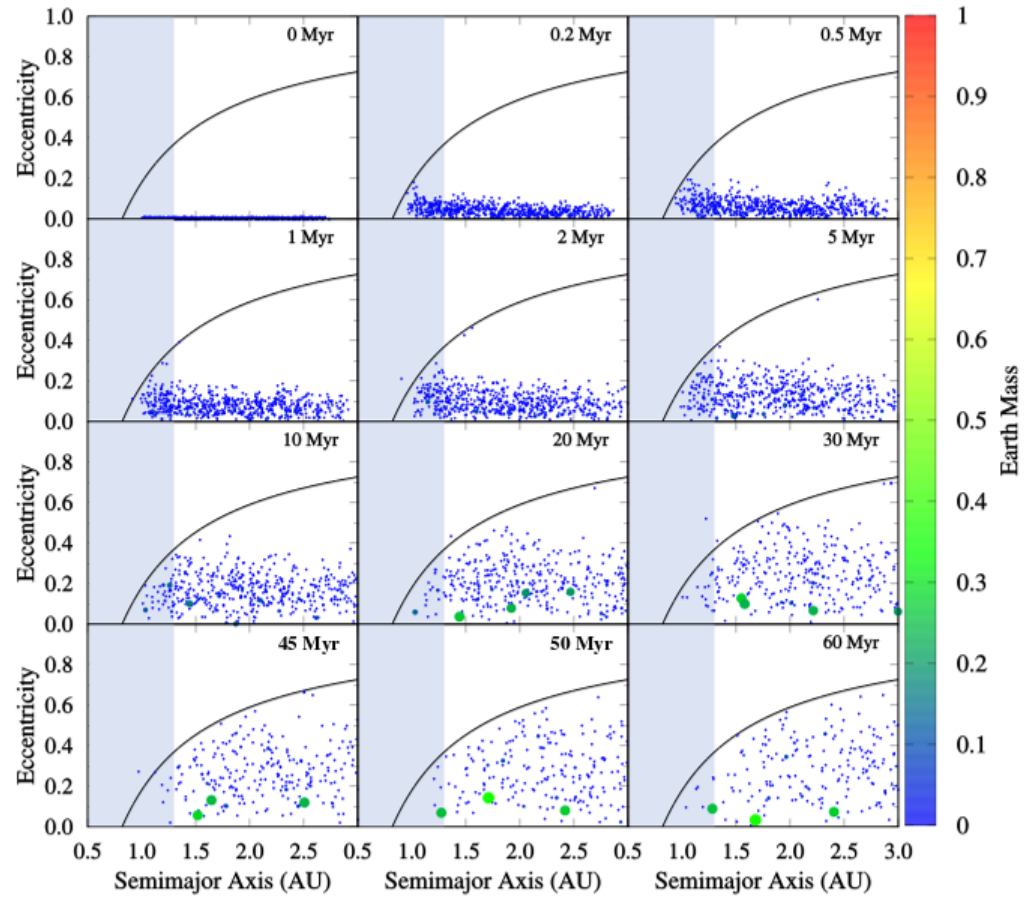
# Kepler 34



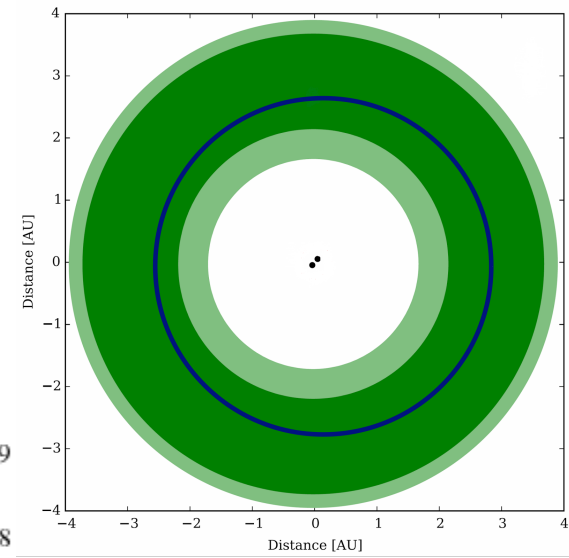
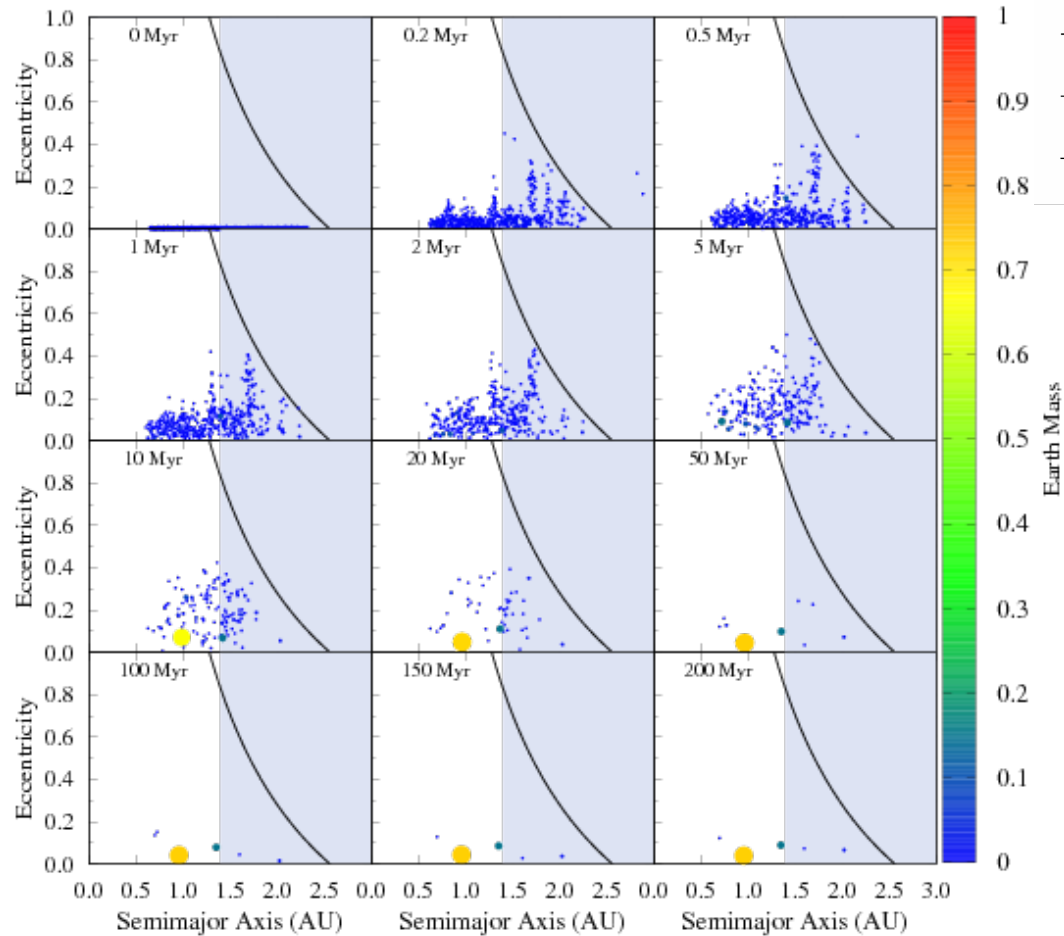
# Kepler 35



# Kepler 453



# Kepler 1647



# Next Steps

## Binary stars + Planet + Disk

Total Disk Mass = 3 M<sub>Earth</sub>

50% Embrios + 50% planetesimals

Embrios:  $\Sigma(r) = \Sigma_0 r^{-\alpha}$

$$\Sigma_0 = 8 \text{ g/cm}^3$$

$$\alpha = 1.5$$

**Thank You!**