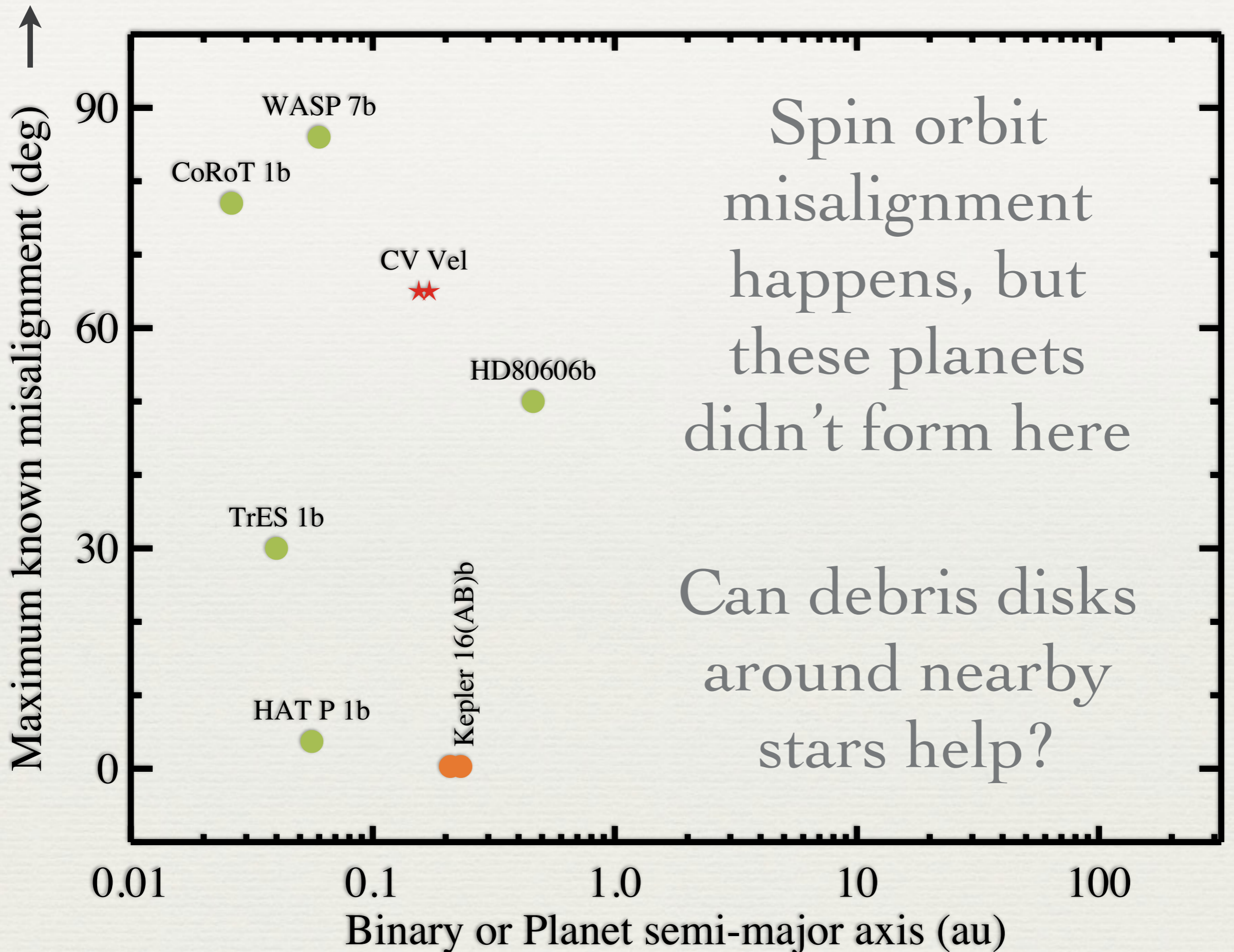





# A wider view of planetary system alignment

Grant Kennedy, IoA, Cambridge  
+ Wyatt & Greaves in UK  
+ Herschel DEBRIS team

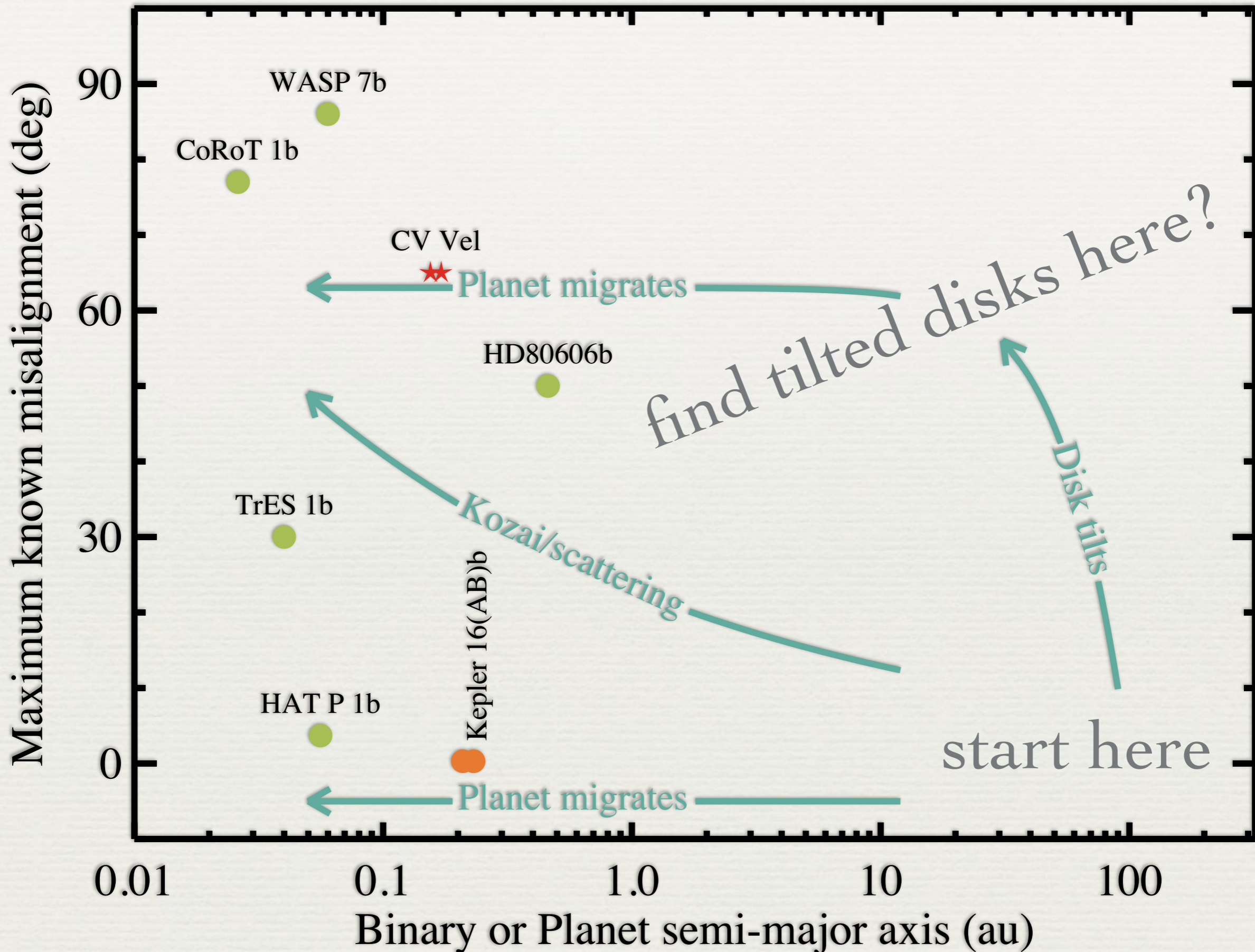


*data from [www.physics.mcmaster.ca/~rbeller](http://www.physics.mcmaster.ca/~rbeller)*

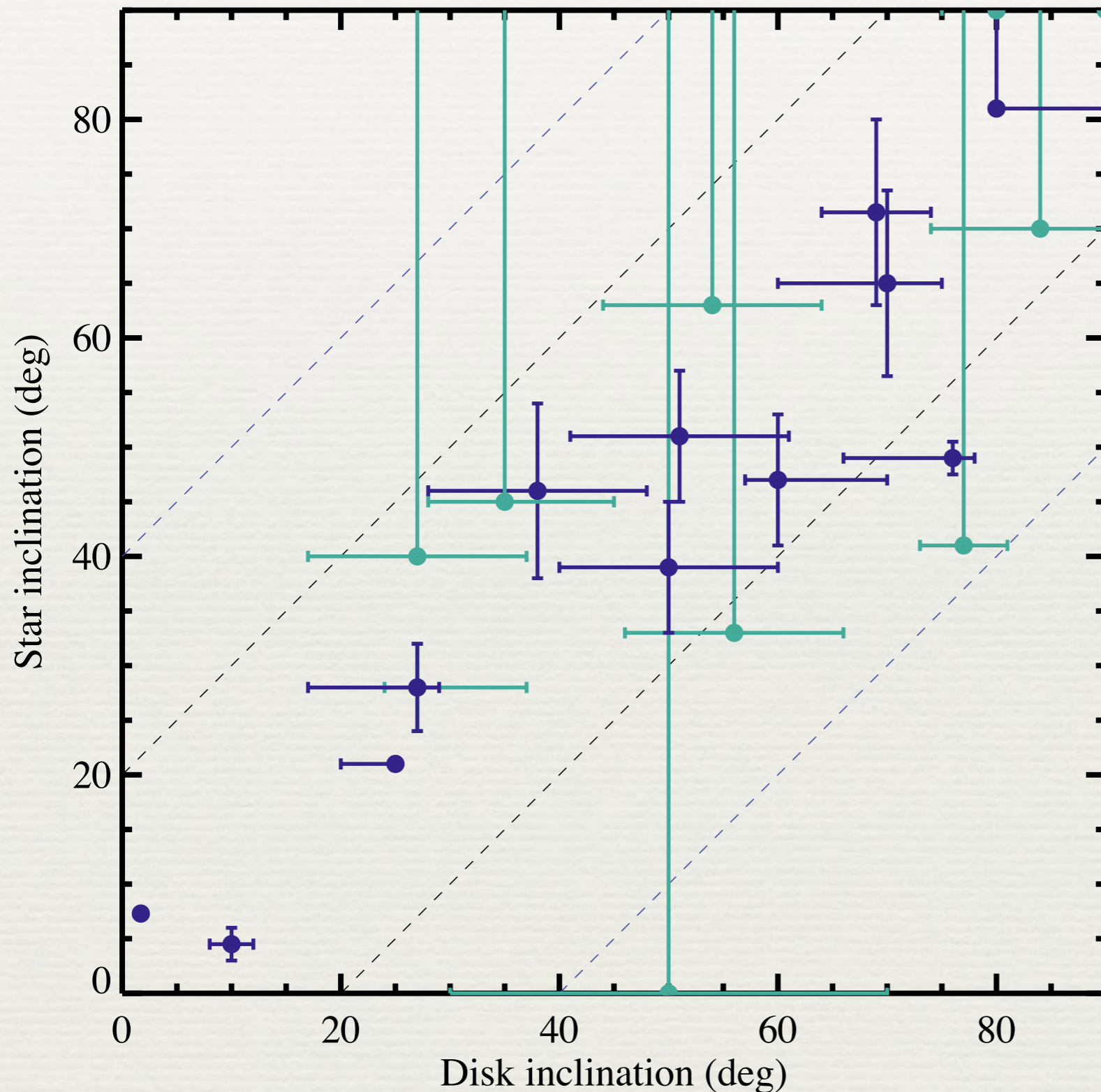
# “normal” planet formation



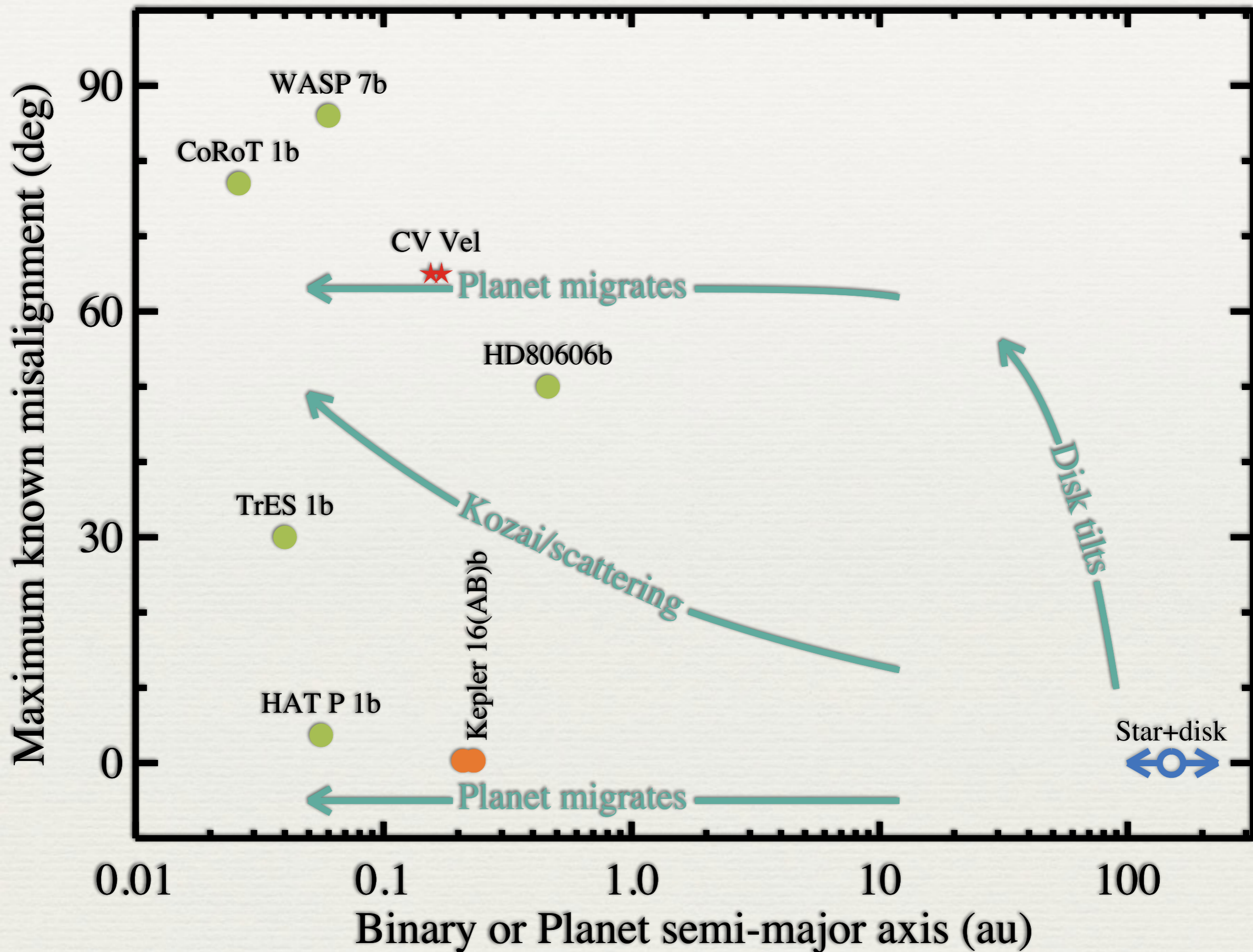
debris disk  
(Kuiper belt analogue)  
has  $i$  of PPD at dispersal



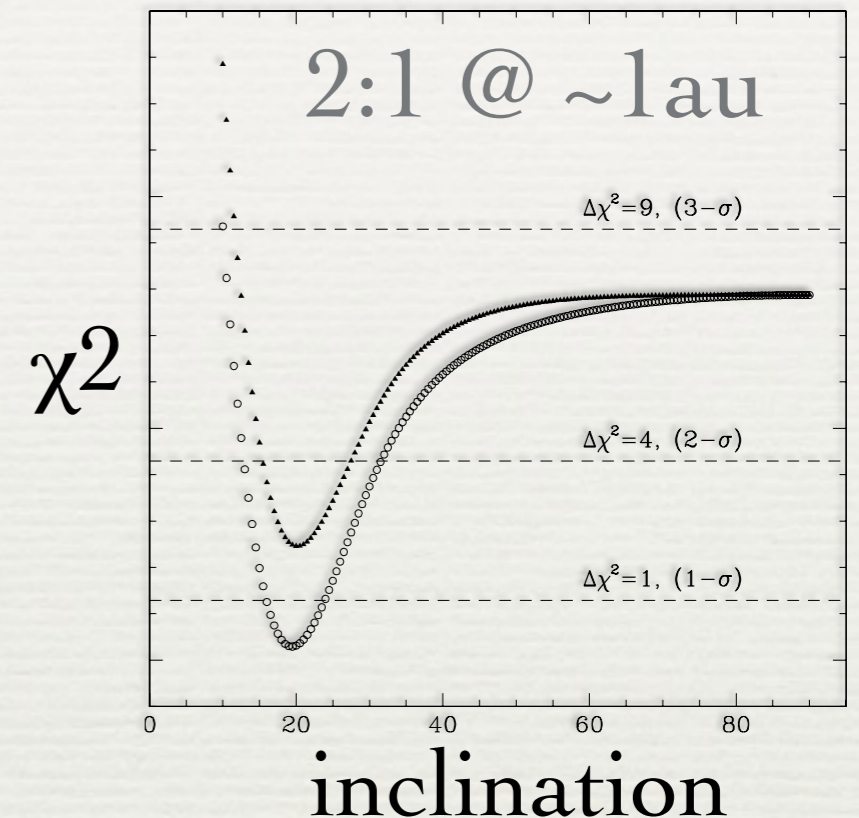
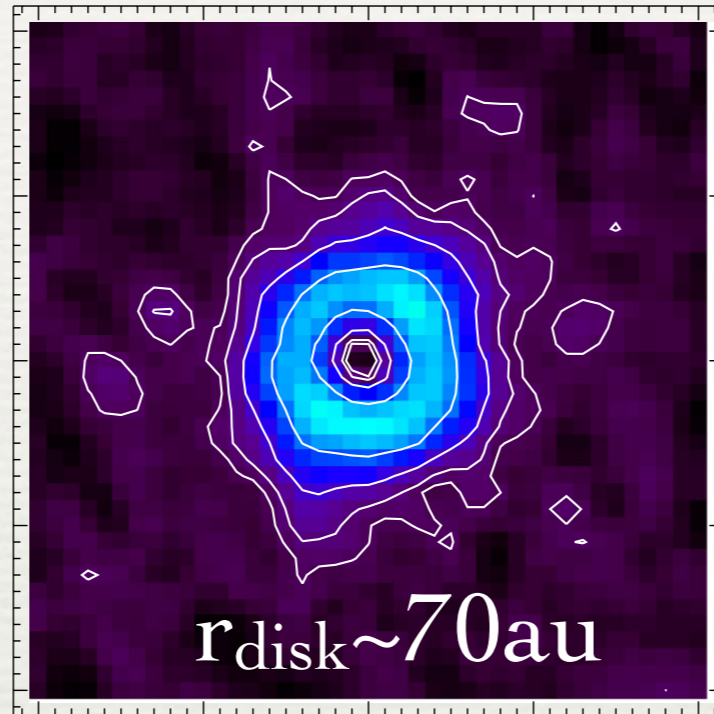
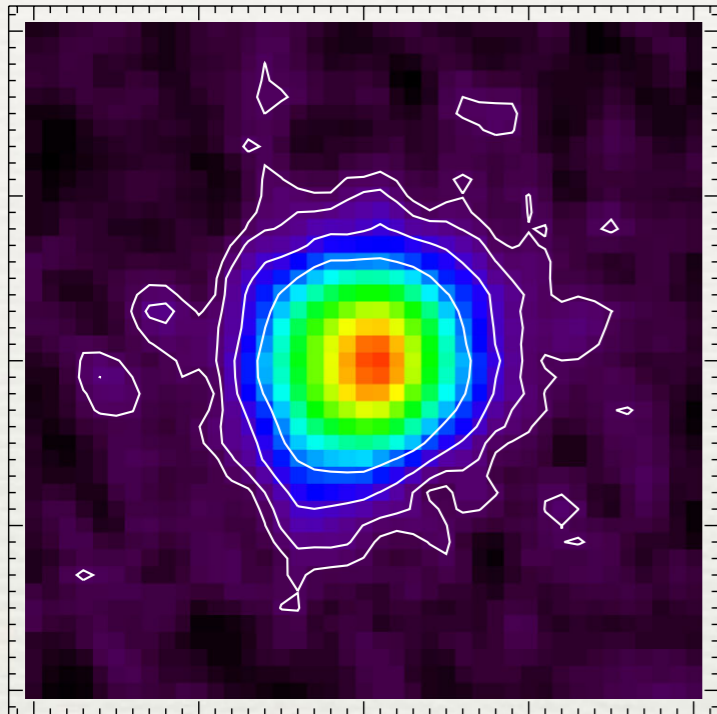
# Stellar spin - disk alignment



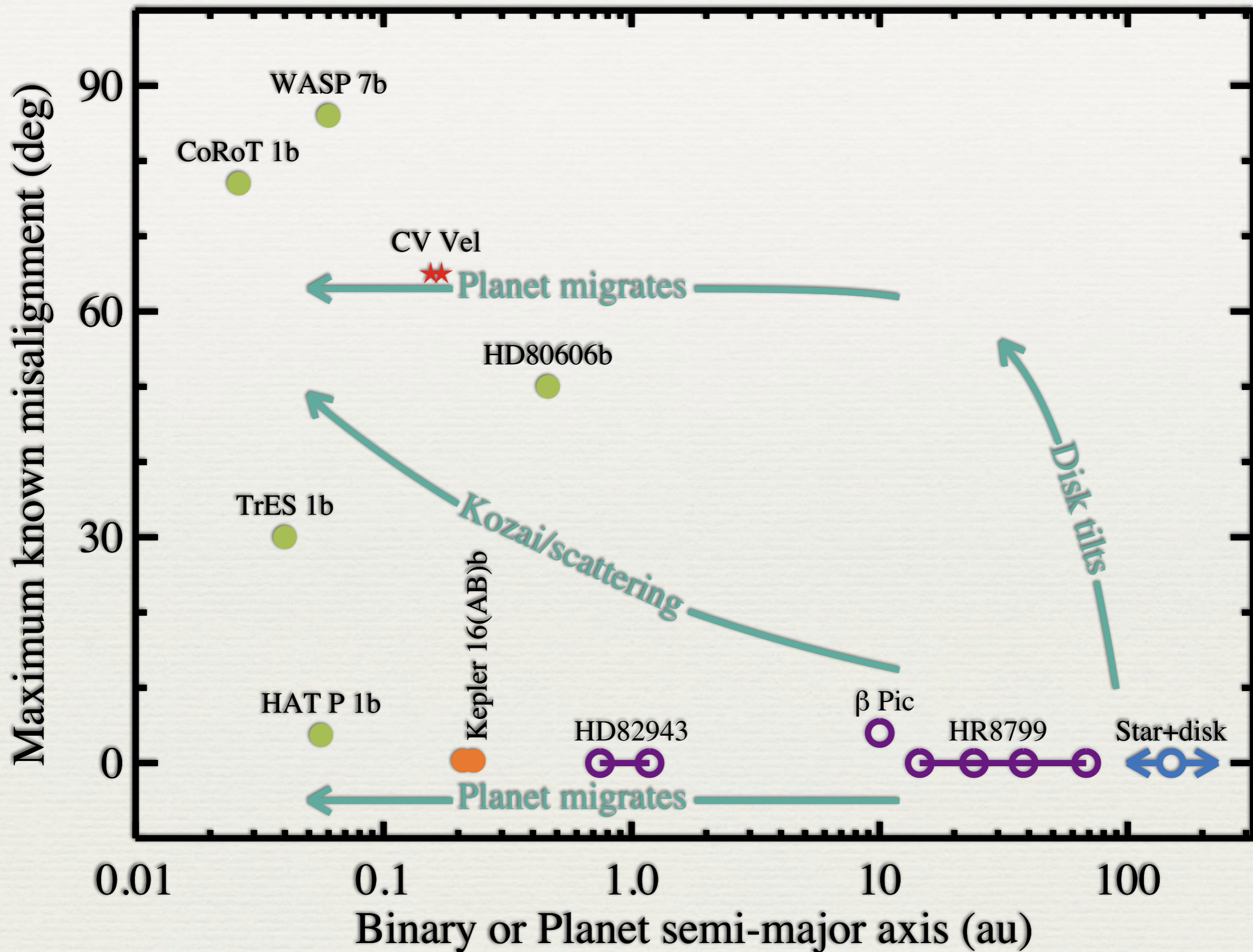
- ◆ No disk “tilting” by companions
- ◆ BUT a tilted debris disk may be easily destroyed by the companion
- ◆ Need to study implications of tilting after gas disk dispersal



# Star-planets-disk alignment

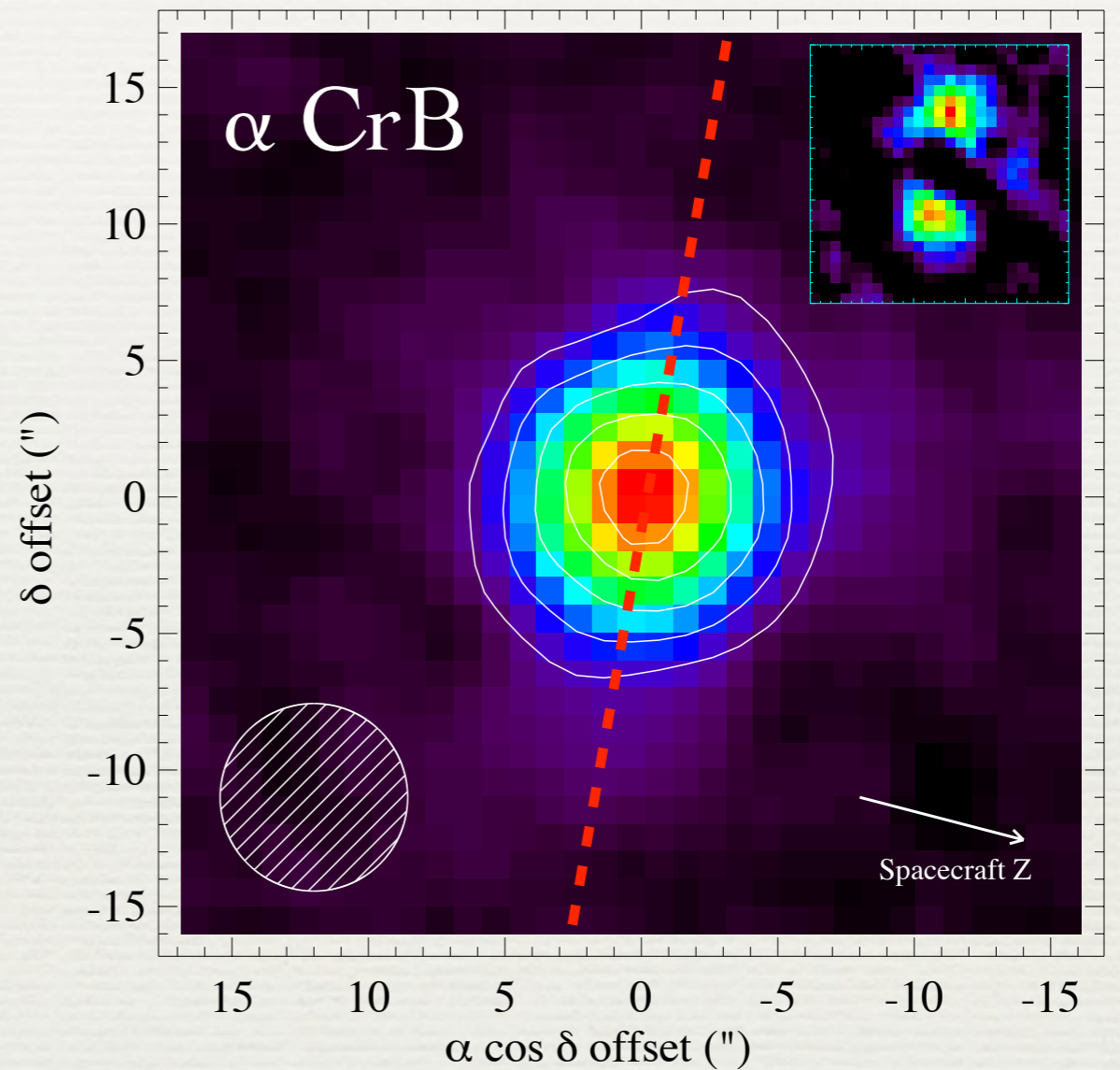
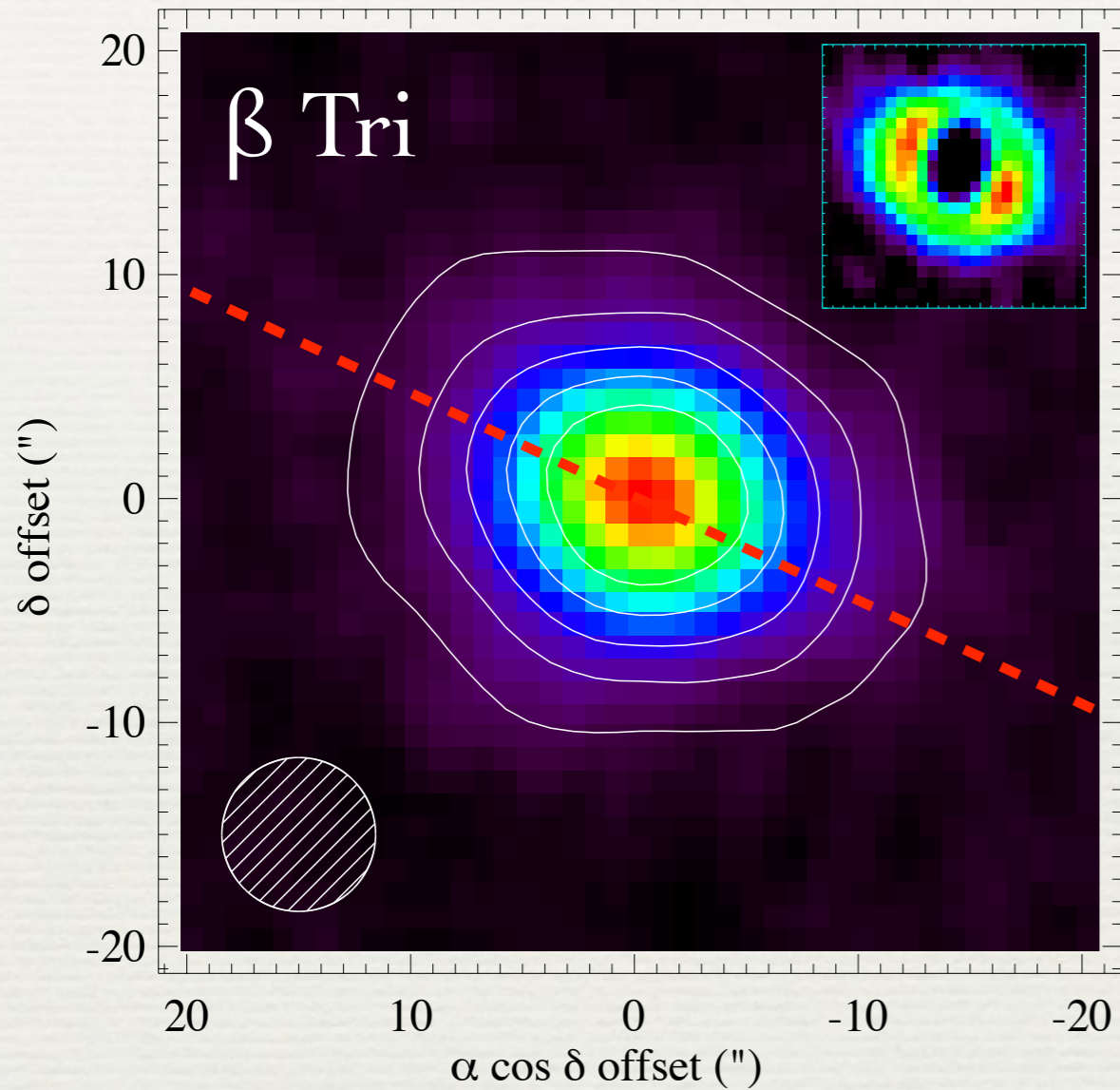


- ♦  $>10$  years of RV to see planet interactions ( $\sim 5M_{\text{Jup}}$ )
- ♦ HD 82943 near to pole-on - system-wide alignment

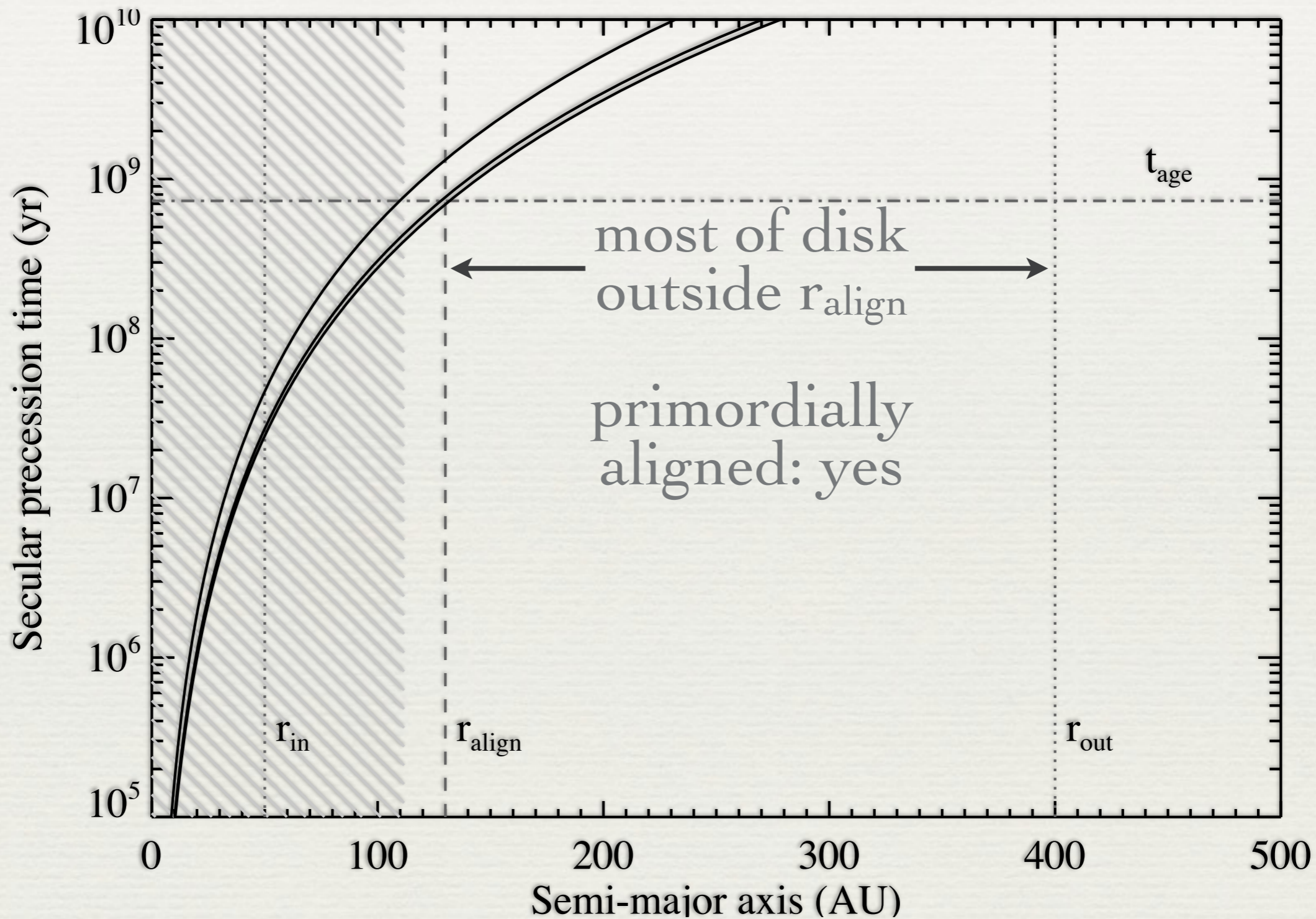
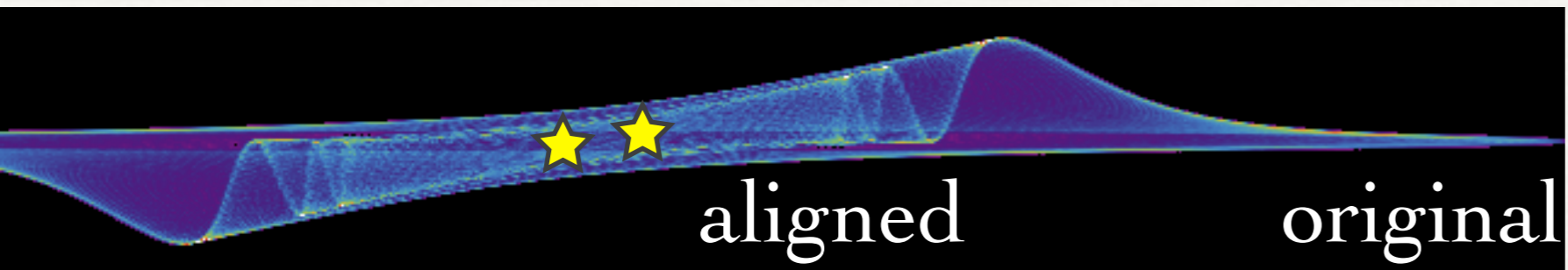


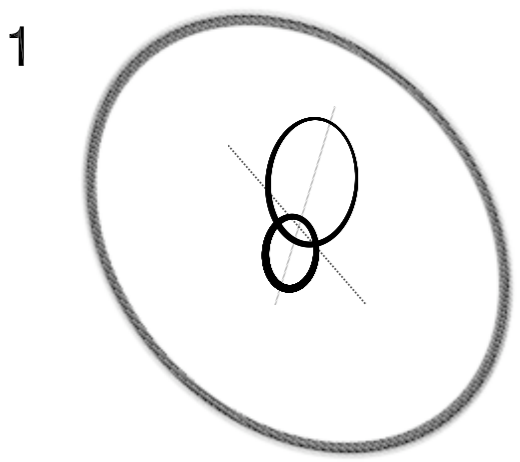


# Binary-disk alignment



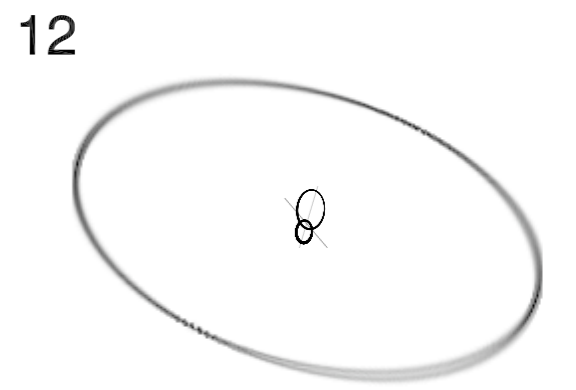
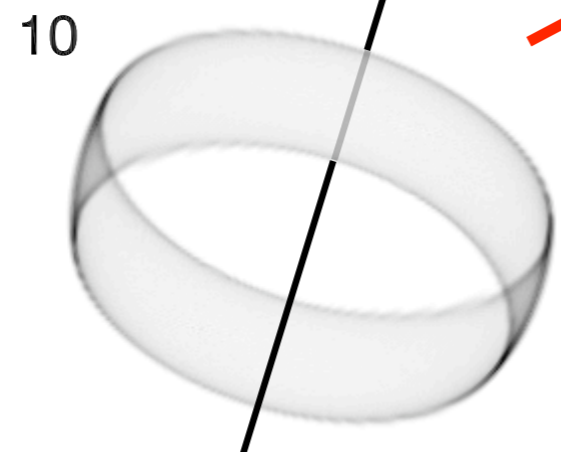
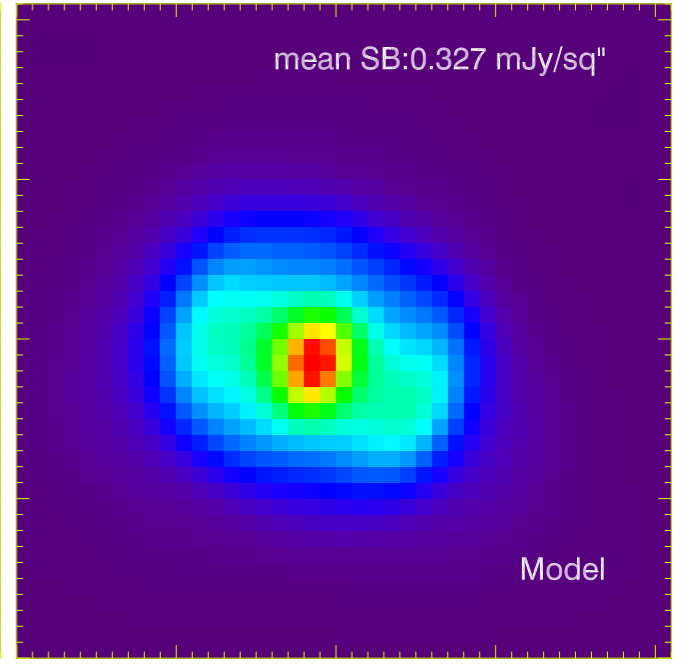
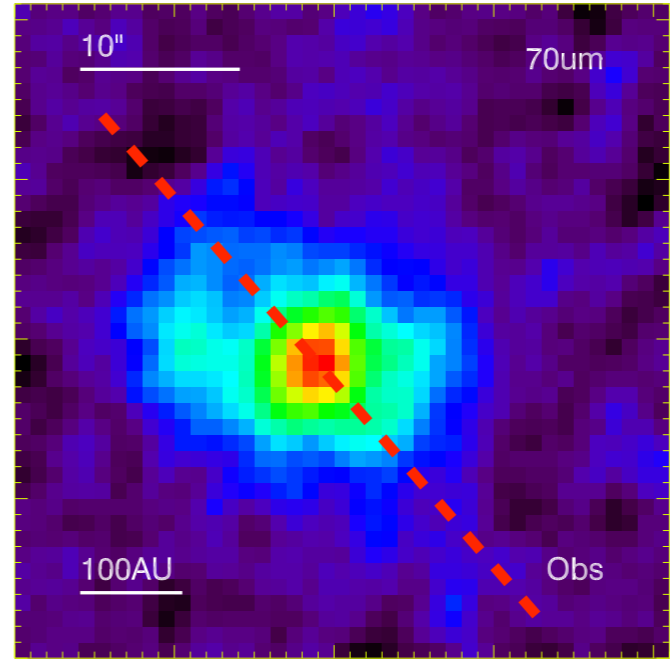
close binaries:  $P$  = weeks/months  
circumbinary planets - alignment expected?

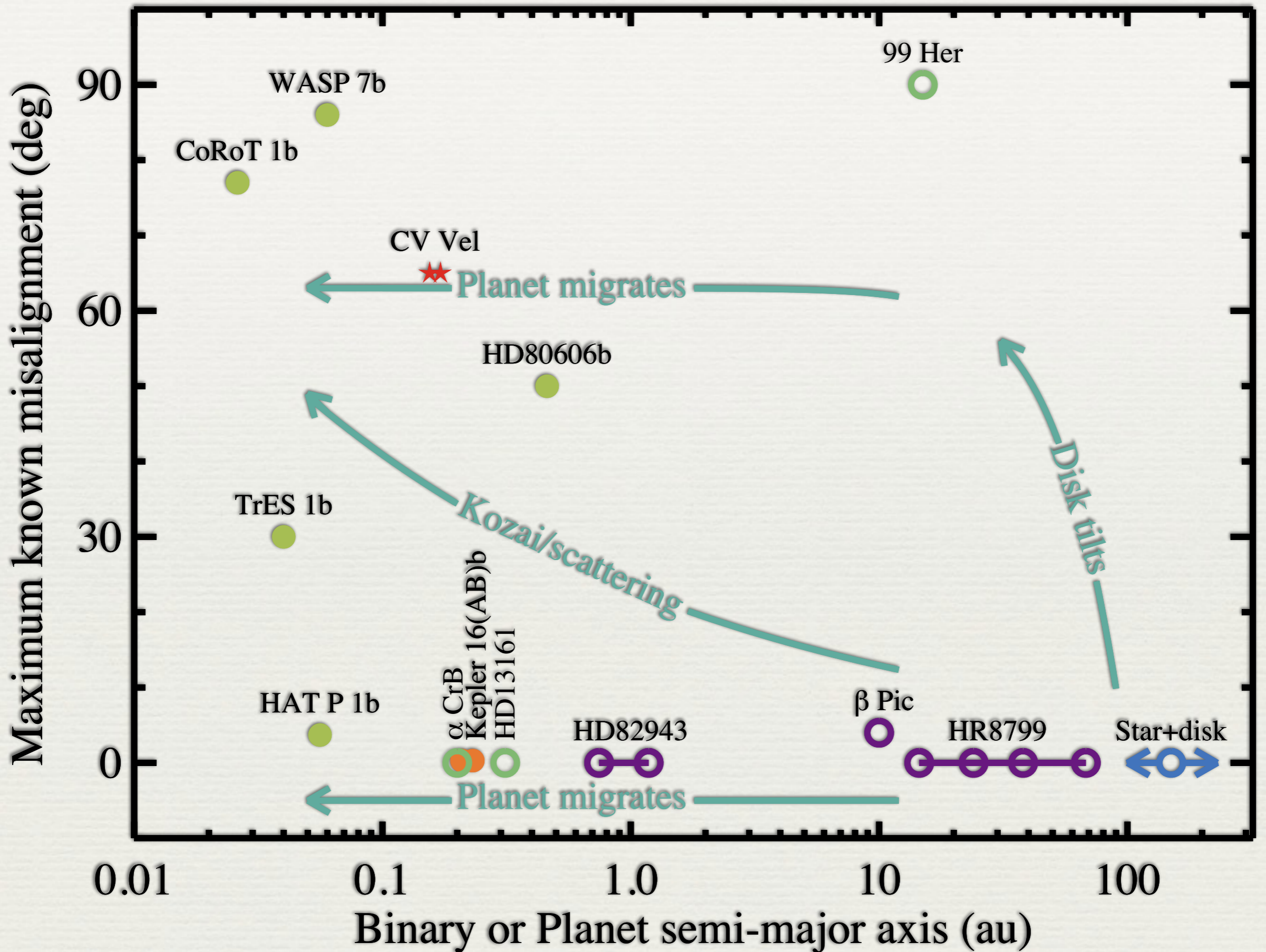




99 Her, 15au:  
2 parameter  
model

how? stellar  
interaction?





90

60

30

0

0.01

0.1

1.0

10

100

CoRoT 1b

WASP 7b

CV Vel

HD80606b

TrES 1b

HAT P 1b

$\alpha$  CrB  
Kepler 16(AB)b  
HD13161

HD82943

$\beta$  Pic

HR8799

Star+disk

99 Her

Planet migrates

Kozai/scattering

Disk tilts

Planet migrates



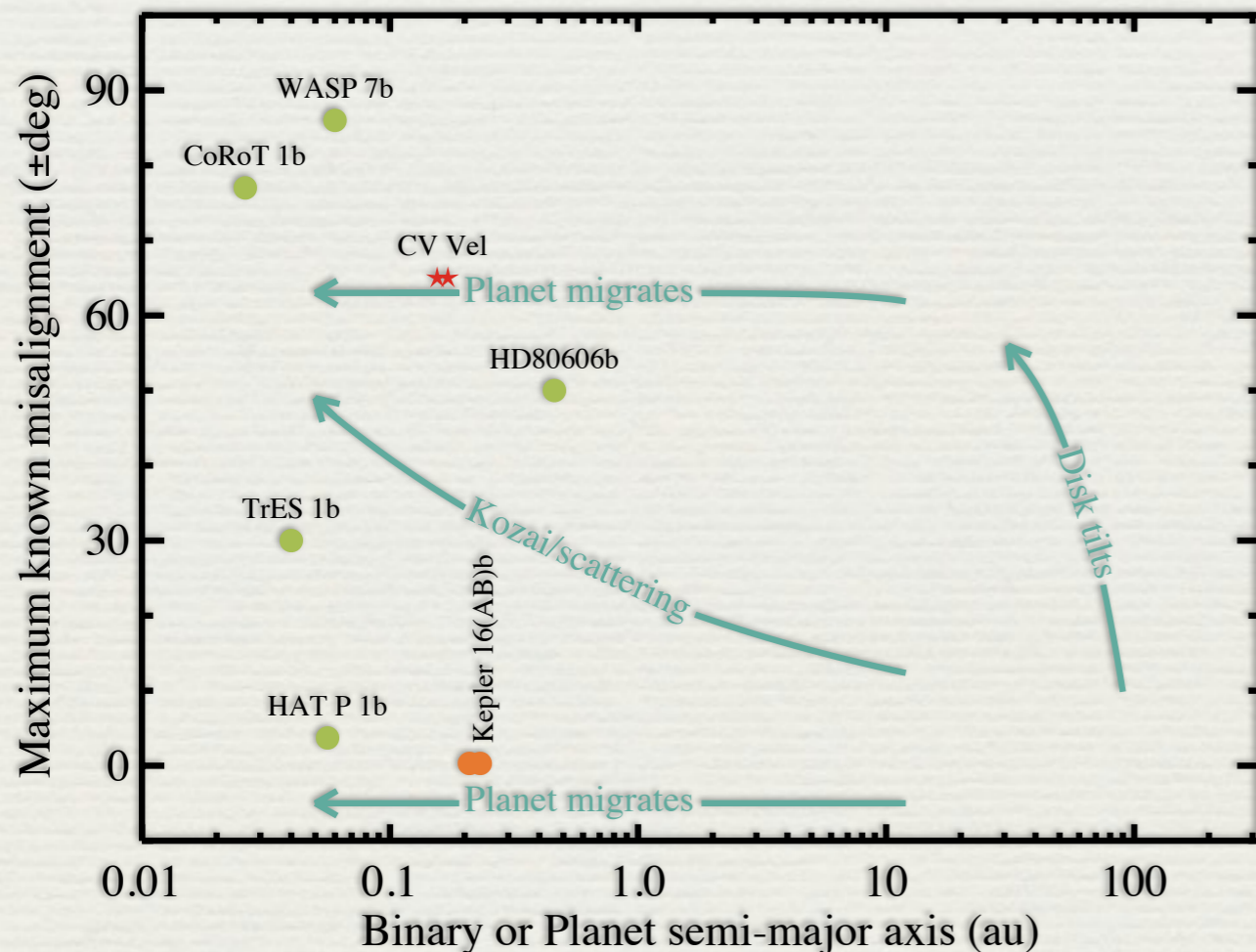
# Outlook



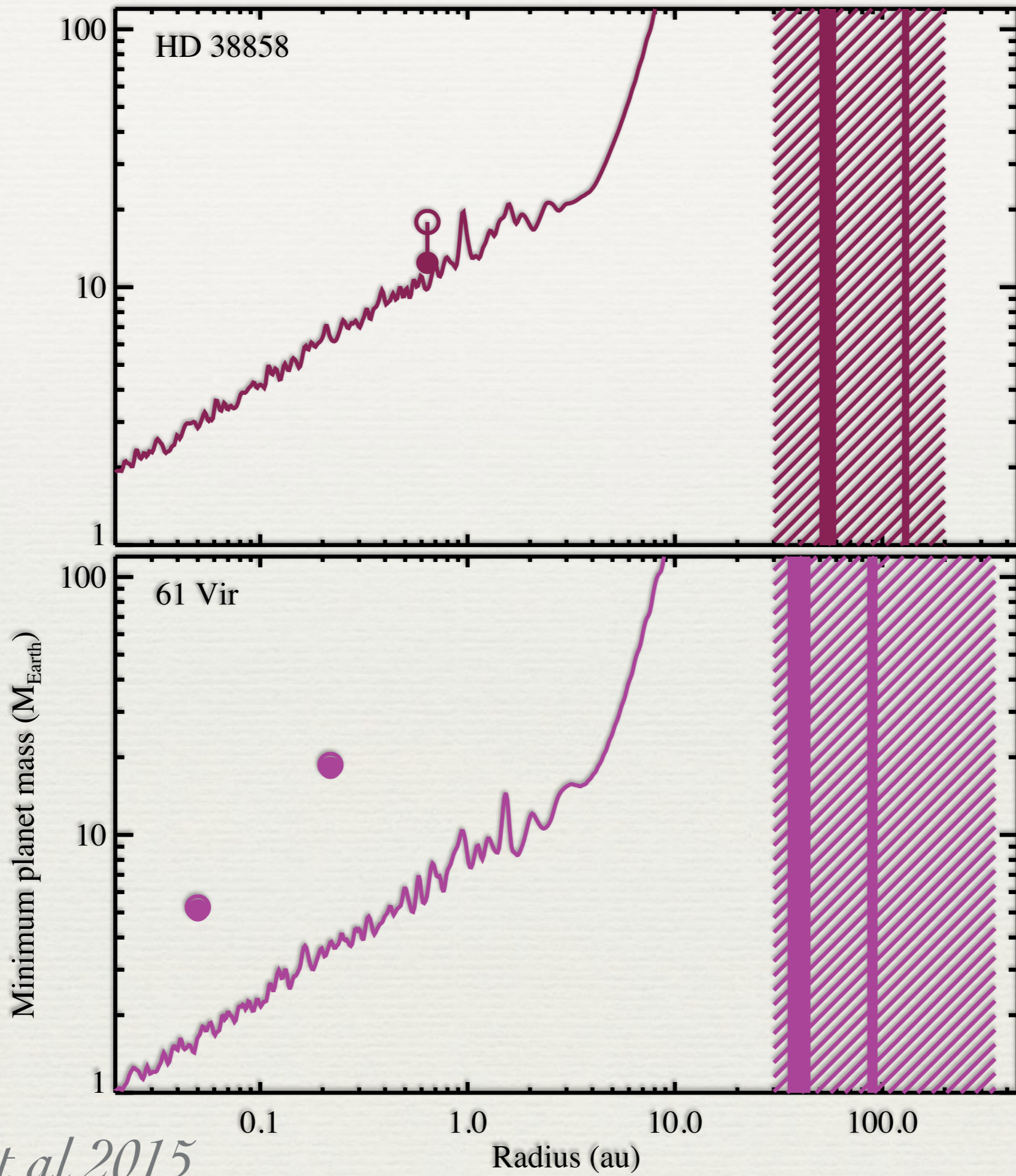
- ◆ Generally infer peaceful history, 99 Her the exception
- ◆ Alignment the norm so far - but so was early RM work
  - ◆ Need more star inclinations - beyond  $v \sin i$ ,  $P$ ,  $R_{\text{star}}$
  - ◆ Disk tilting inferences have caveats - models
- ◆ Circumbinary planets - form in aligned disks?
- ◆ Planet+disk systems rare - no transit+disk systems yet
  - ◆ Need disk/planet characterisation, planet discovery
    - ◆ Best prospect: GAIA astrometry

# Debris disks trace the plane of primordial disk

How do their geometries and structures help?

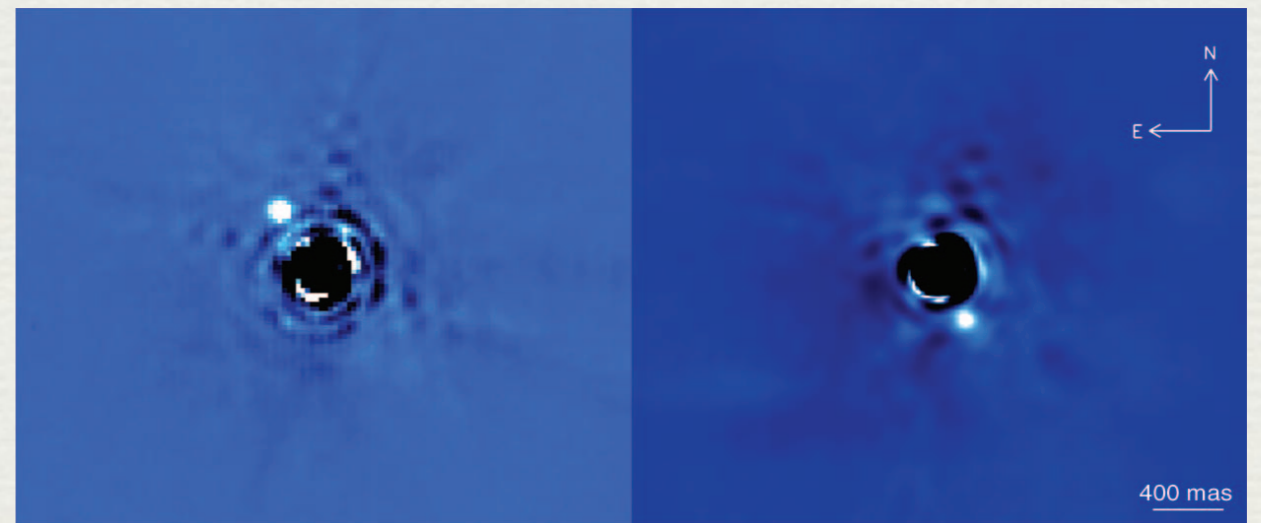
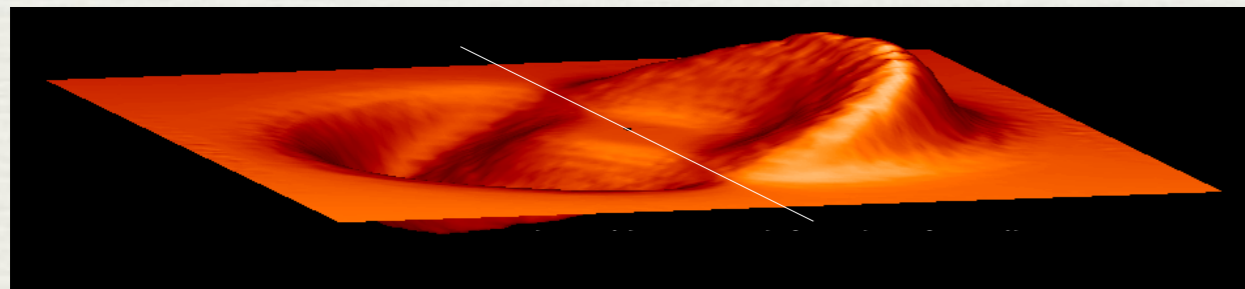
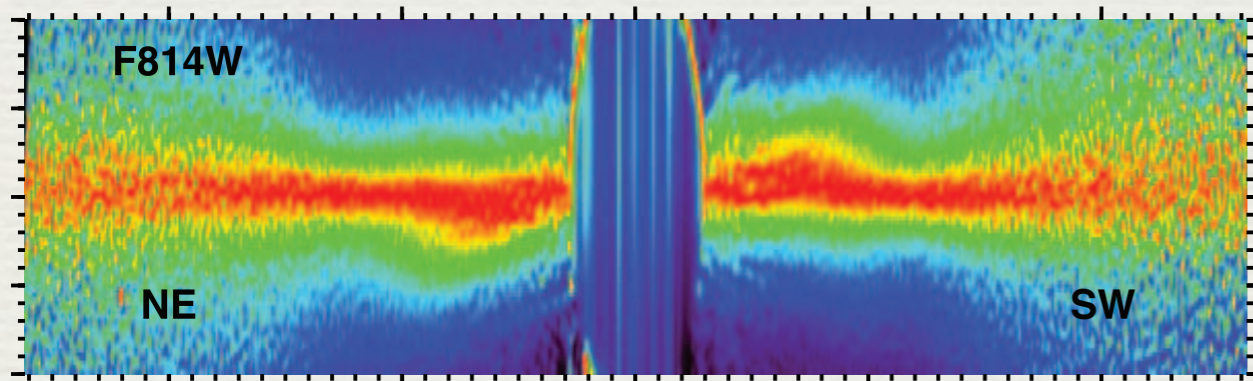
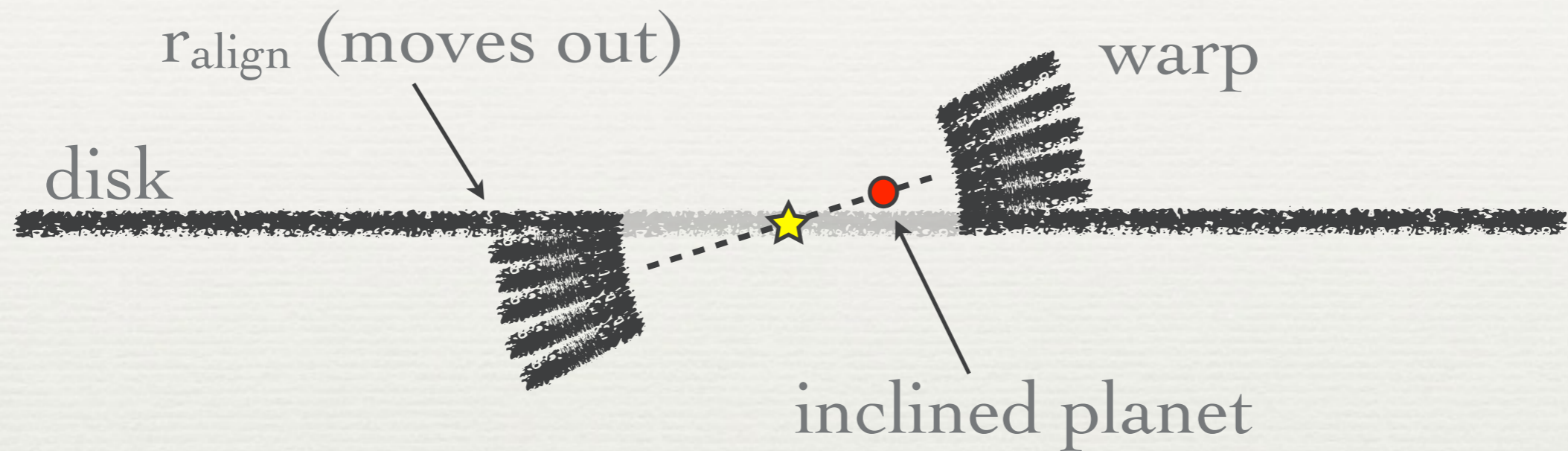


- ◆ Really start there?
- ◆ Circumbinary case?
- ◆ What can we test?
- ◆ What will we test?



# Debris disks feel planets

particles inclined w.r.t. planet



*Lagrange et al 2010*

*Augereau et al 2001*



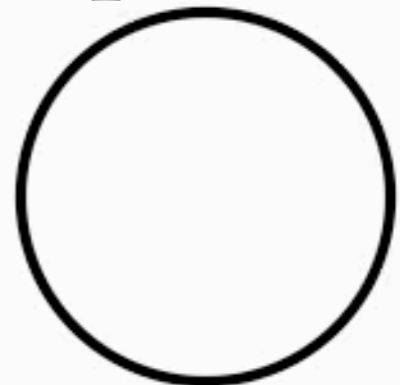
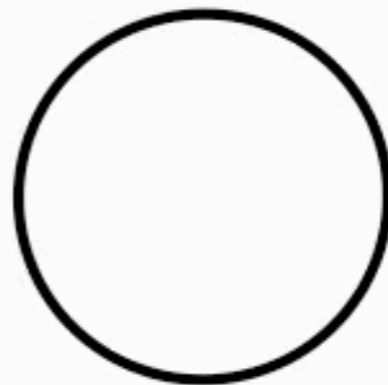
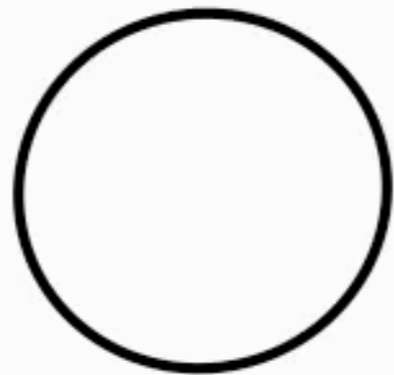
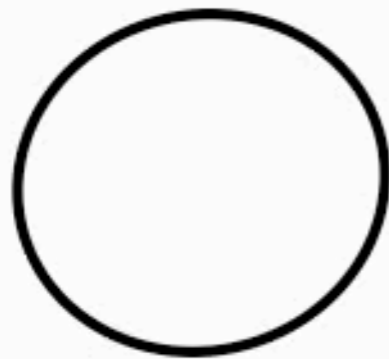
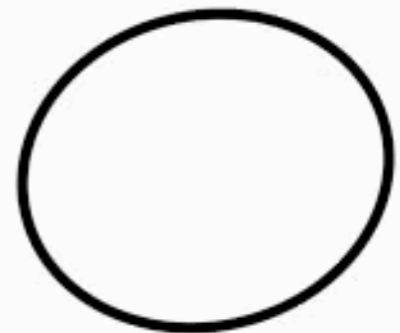
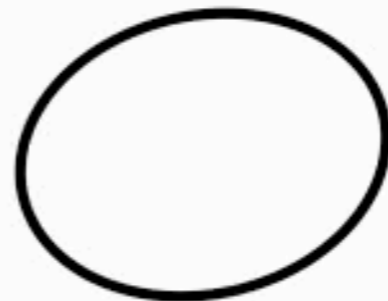
# Circumbinary dynamics

coplanar



×  
pericenter

$e=0.77$



polar

