# Realistic limitations of detecting planets around young active stars

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# Impact of Starspots on Planet Detection

- Time variant line asymmetries caused by activity can lead to biased RV measurements
- Major cause of R V jitter are starspots which distort absorption line profiles
- Distribution of starspots is important

  → Low latitude spots are stronger than high latitude spots
- Use realistic spot distributions from Doppler Images of G & K dwarfs (thin convection zone) and M dwarfs (almost fully convective)

# Starspots on M dwarfs

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- TiO band analysis indicates spot coverage: 20 to 40% (O'Neal et al 2004)

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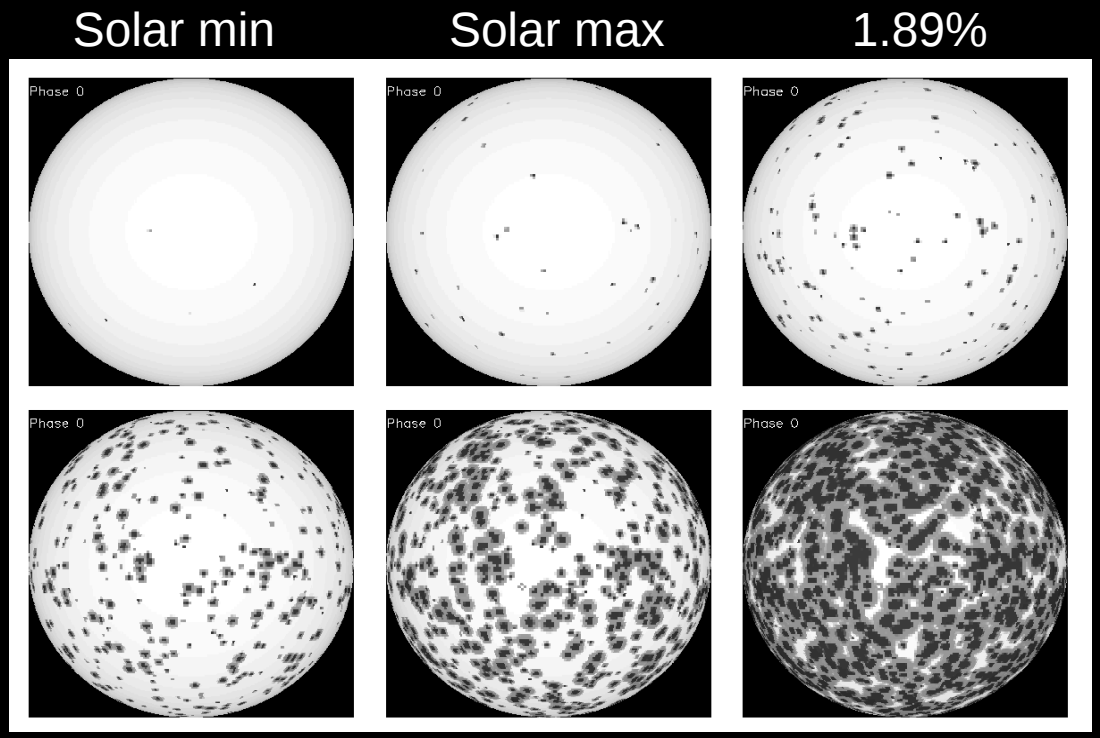
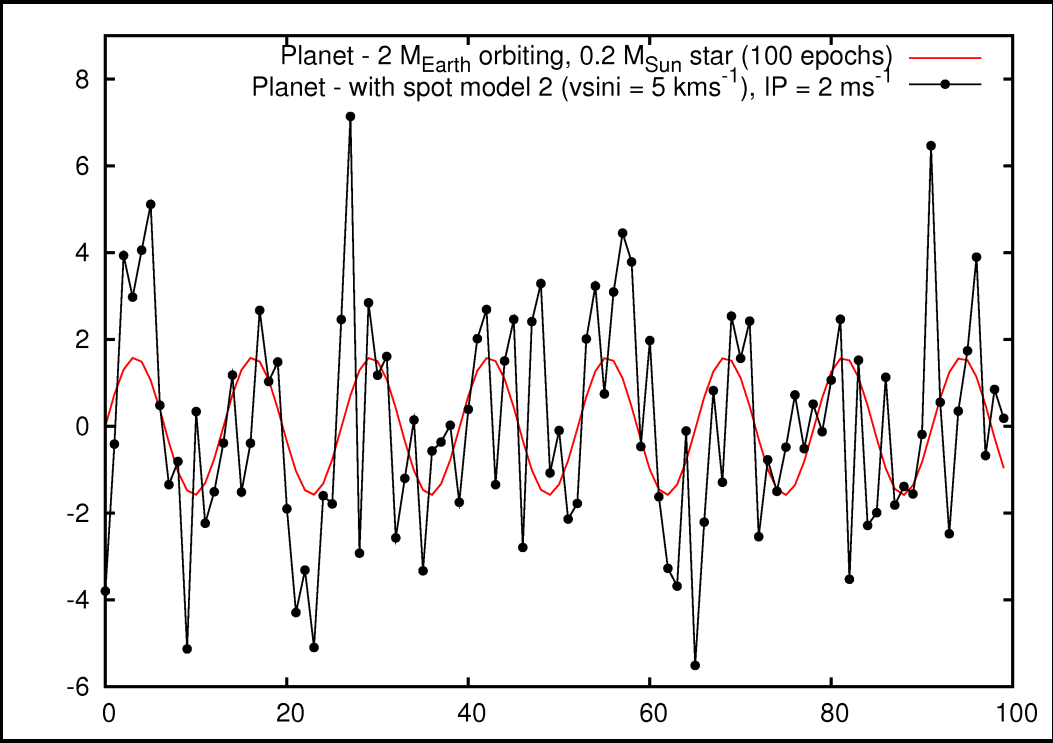
- Solar activity levels are extrapolated to active stars (Solanki 1999)
- Generate line profiles from 3D stellar model using imaging code DoTs



# How do spots impact RV curve?

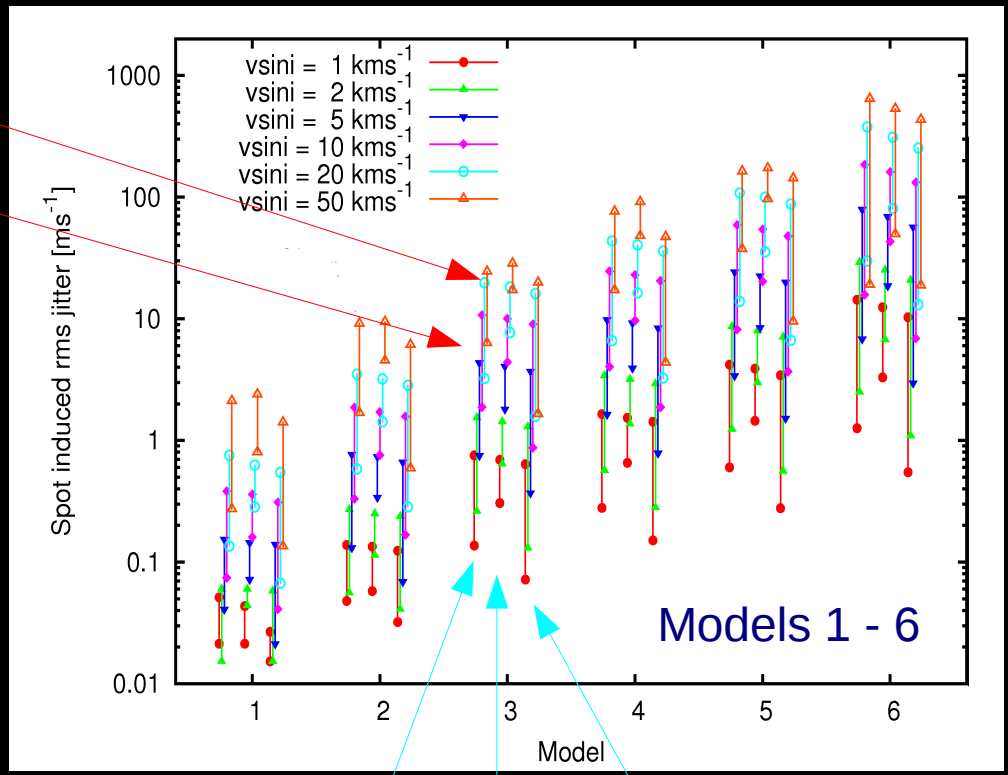
- Investigate $T_{ph}/T_{spot}$ contrast variations
- V band
- Generate Stellar profile




Example of a simulated stellar RV curve: - 2 $M_{earth}$ planet
- 0.2 $M_{sun}$ star + 100 epochs
- *v*sin*i* = 5 km/s + IP = 2m/s

# Radial Velocity – Random Spots

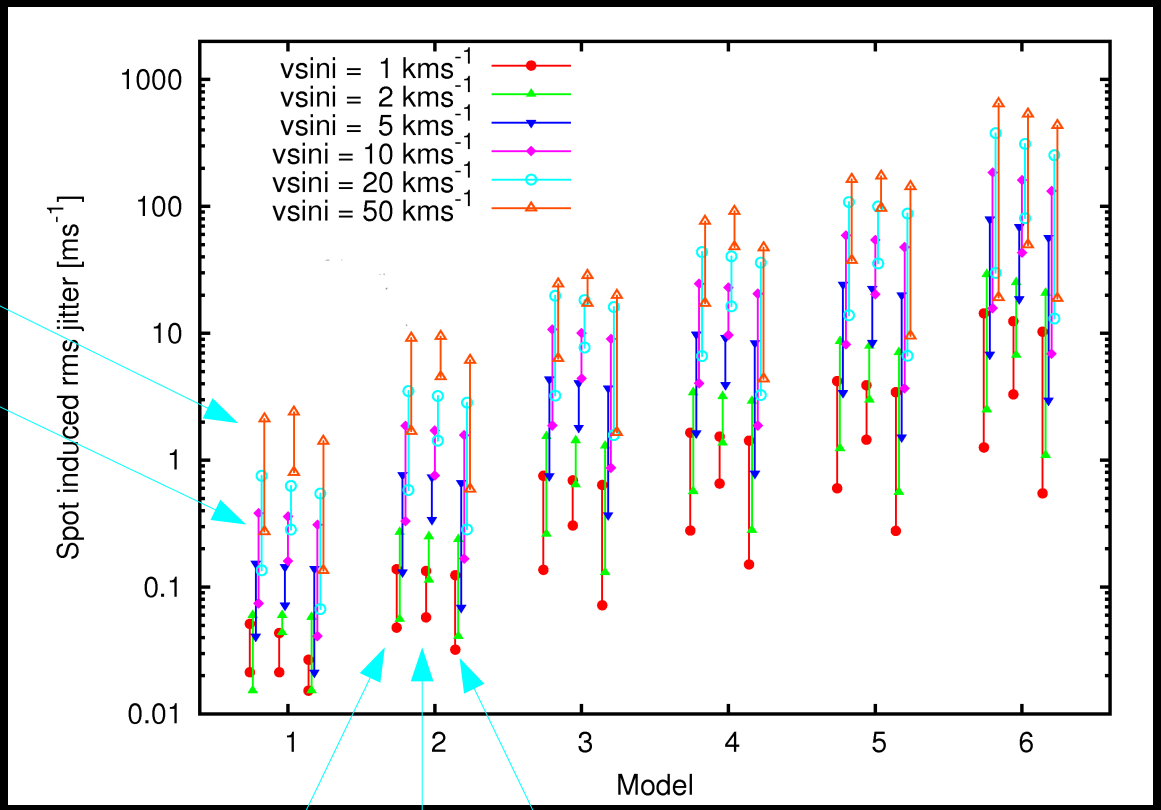
- $T_{s1} = 0.65\ T_p$
- $T_{s2} = T_p - 200K$
- Solar min + max models lowest RV jitter ~ 10 cm/s
- In agreement with Lagrange et al (2010)
- Placing spots randomly decreases jitter!




M7 V : M5 V : M0 V
0.1 : 0.2 : 0.5 $M_{sun}$

# Radial Velocity – *vsini*

- $T_p/T_s$ contrast ratios:
  - $T_{s1} = 0.65\ T_p$
  - $T_{s2} = T_p - 200K$
- Doubling vsini results in doubling jitter
- Spot contrast ratio is important

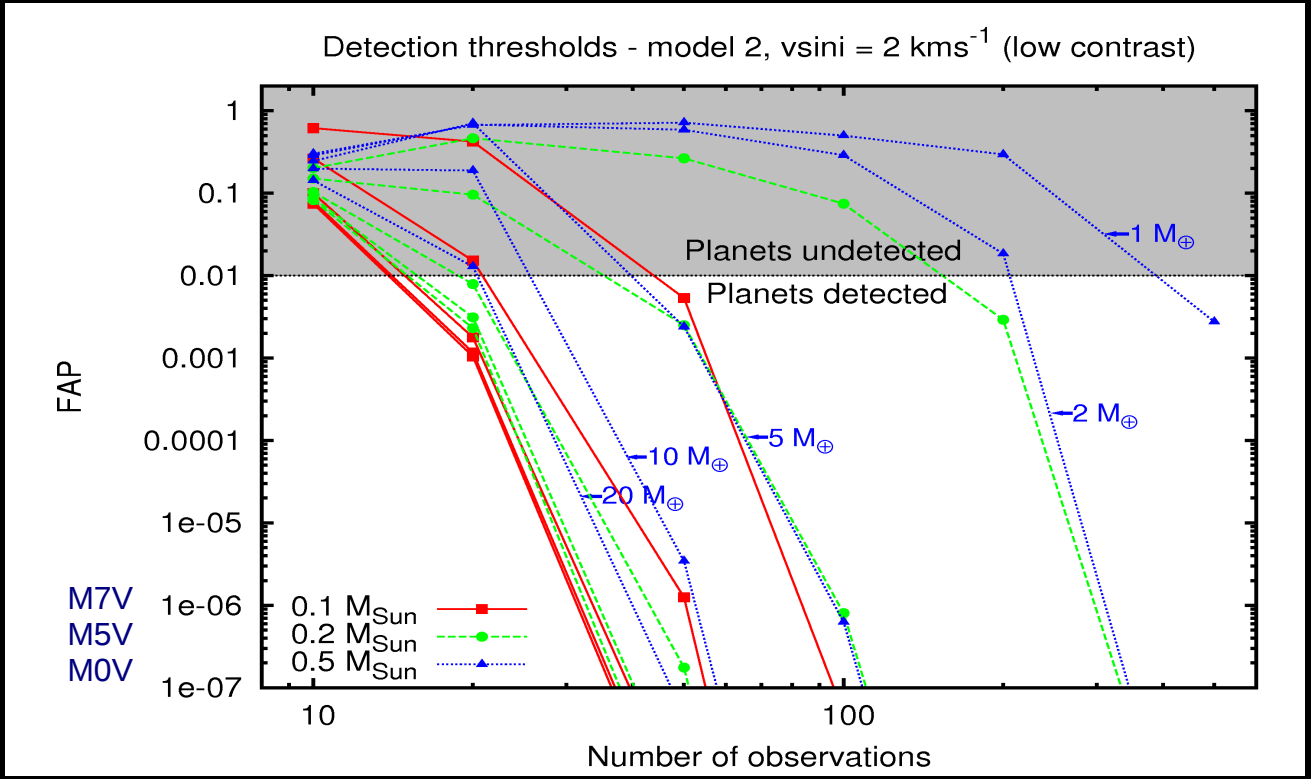



M7 V : M5 V : M0 V
0.1 : 0.2 : 0.5 $M_{sun}$

# Detection Thresholds – M dwarfs

- Low-mass planets orbiting centre of habitable zone
- $M_{planet}$ = 1, 2, 5, 10 and 20 $M_{earth}$
- $M_{star}$ = 0.1, 0.2 and 0.5 $M_{sun}$
- 10, 20, 50, 100, 200 & 500 epochs of observation (on consecutive nights)
- Radial Velocity Jitter: (1) spots + (2) instrumental
- Random observational phase + Lomb Scargle periodogram analysis

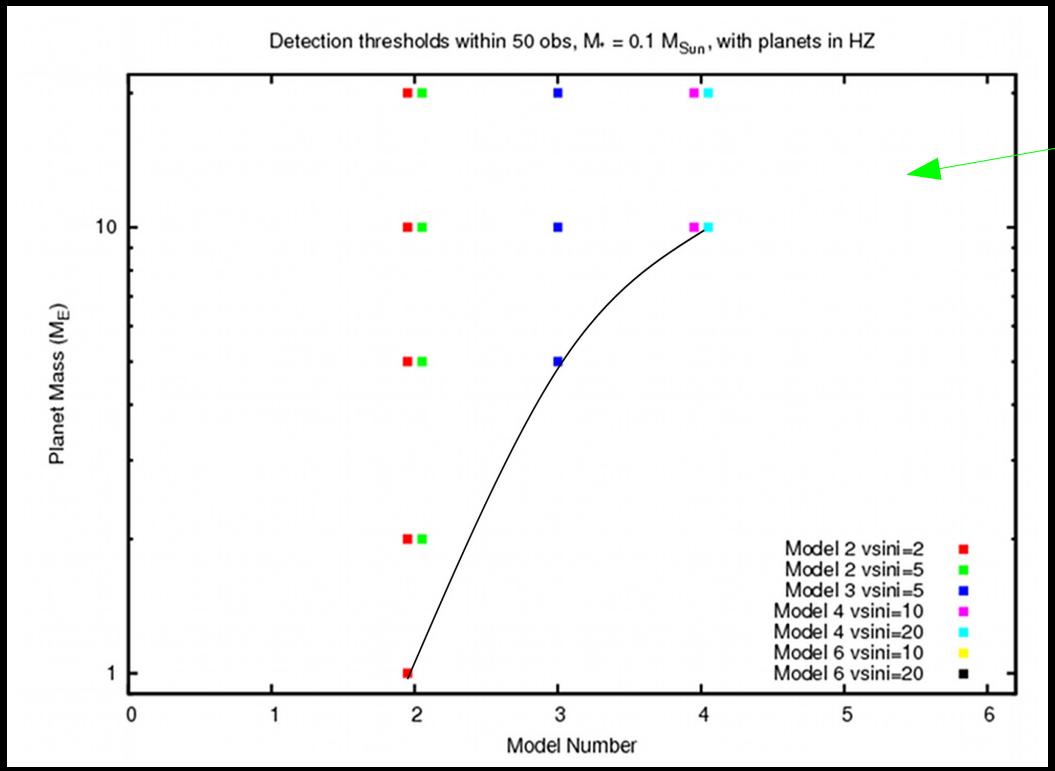
# Planet Detection – M dwarfs




- Full set of models shows that the ability to detect a planetary signal decreases with increasing stellar activity and *v* sin *i*
- Planet Detection: Models of Solar Min/Max (*v*sin*i*=2km/s);
  - 1 $M_{earth}$ around 0.1/0.2 $M_{sun}$ in 50 obs
  - 1 $M_{earth}$ around 0.5 $M_{sun}$ in 500 obs

# Planet Detection M dwarfs

$M_{star}$ = M7 / 0.1 $M_{sun}$

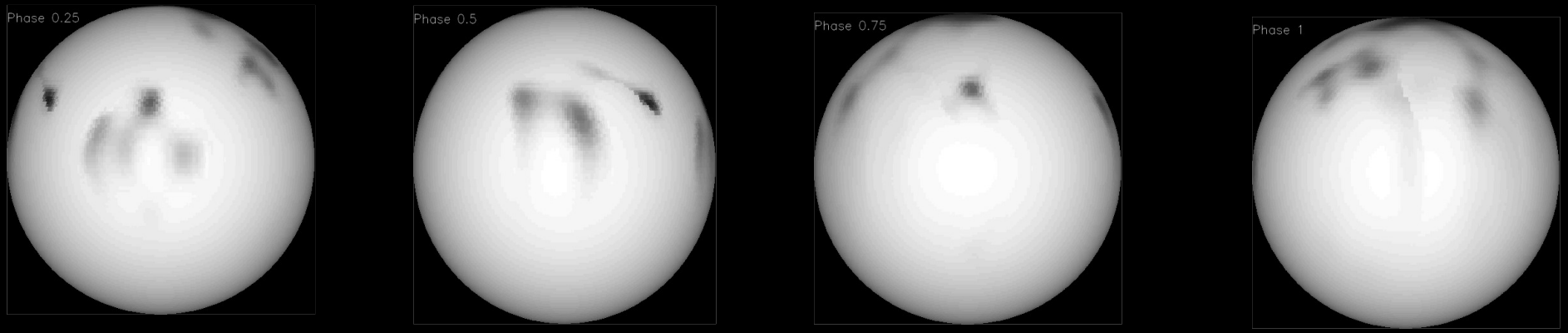



No Planets for Model 5 & 6

- v sin i increases with activity level – detections within 50 obs
- Doubling vsini ⇒ doubles jitter
- 1 $M_{earth}$ planets can be detected around stars with Solar activity

# Model 1. Starspots on G & K dwarfs

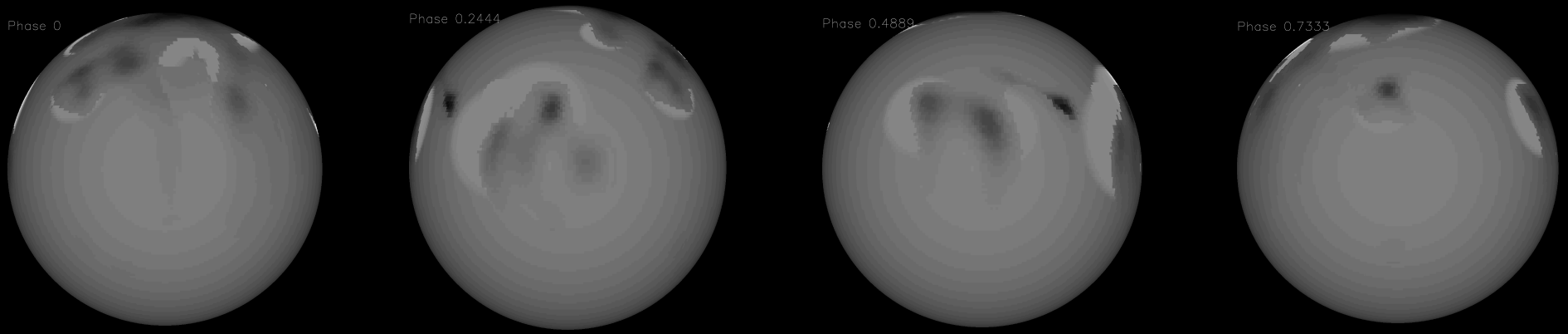
- Doppler Images of  G dwarfs typically show polar spots with some low latitude spot coverage – 10 % coverage (Jeffers et al 2011))
- Use Doppler Images of the G dwarf HD141943 and K dwarf AB Dor  as input spot distributions
- Generate line profiles from 3D stellar model using imaging code DoTs




HD 141943

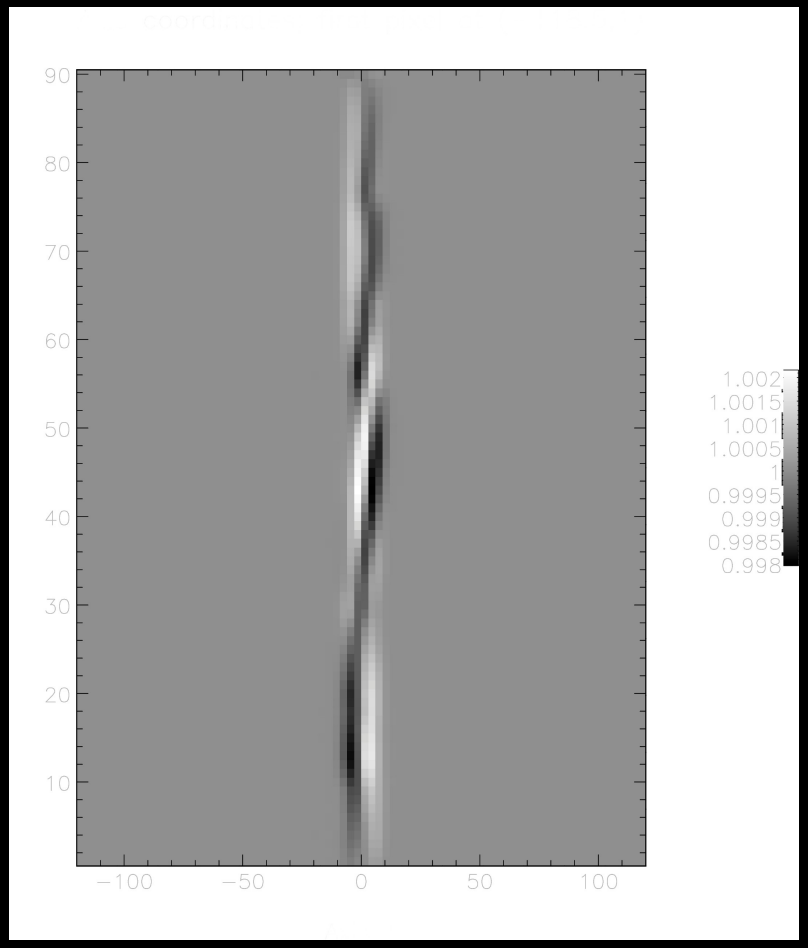
# Model 2. Plage on G & K dwarfs

- Observations show that the Ca H & K emission of young stars is not correlated with photometric brightness → spot dominated at activity maximum
- Limb brightening
- Use Doppler Images of the G dwarf HD141943 and K dwarf AB Dor as basis distribution and model plage to have radius x 2 $R_{spot}$

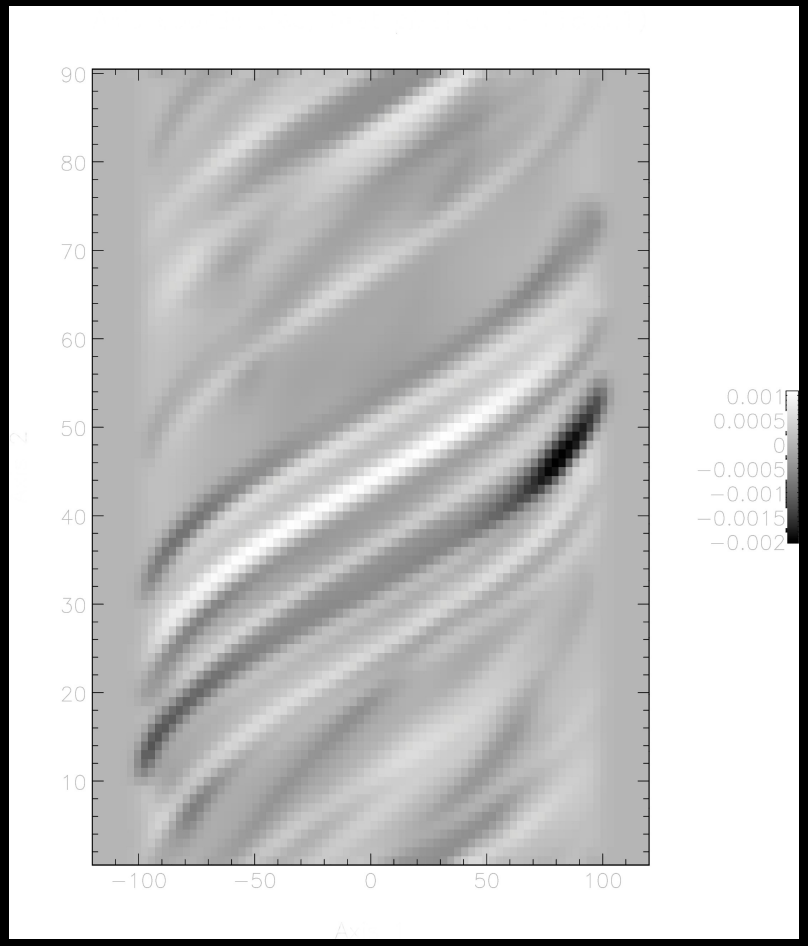



HD 141943

# Spots + Plage on G & K dwarfs




Vsini = 5 km/s

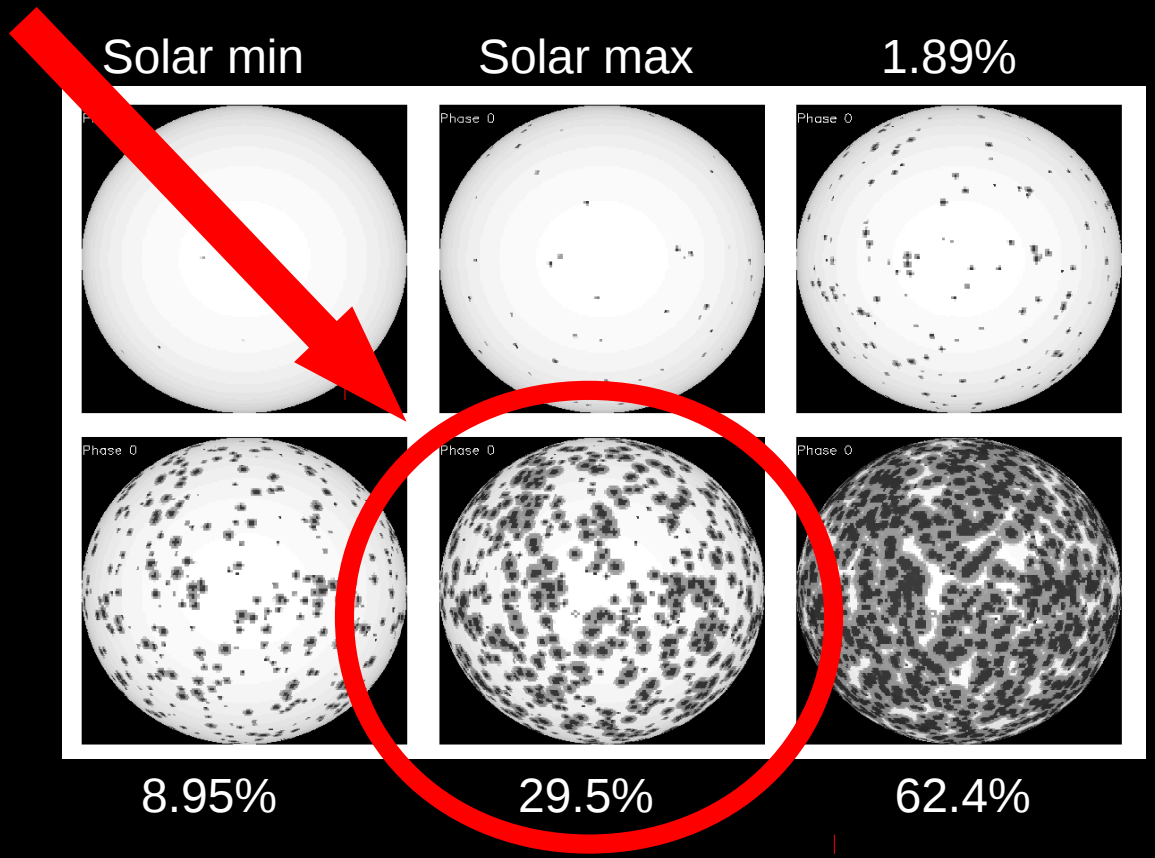



Vsini = 100 km/s

HD 141943 – mean profile subtracted

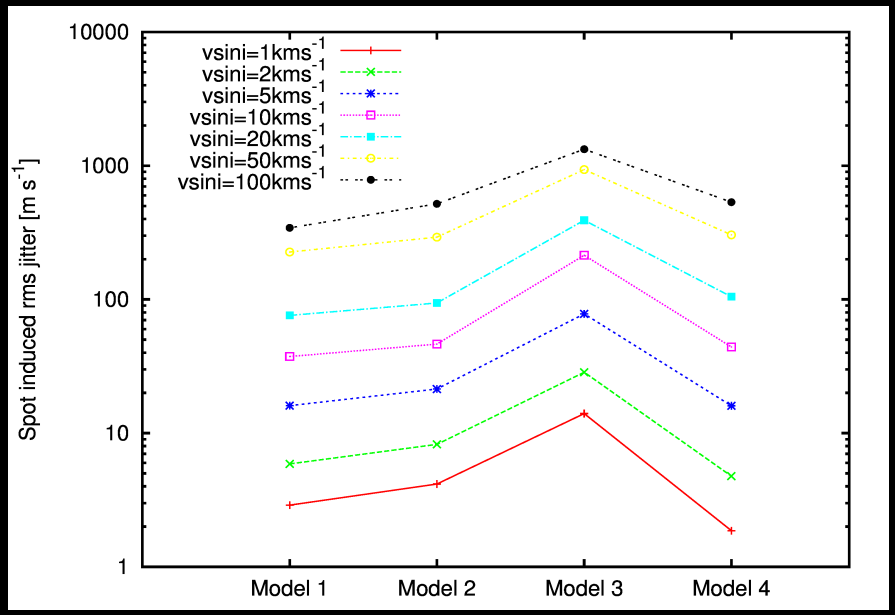
# Model 3. Unresolved Spots

- Doppler Images of (~fully convective) G & K dwarfs show uniform spot coverage – 10 % coverage
- TiO band analysis indicates spot coverage: 20 to 40% (O'Neal et al 2004)
- Apply model with 29.5% spots to Doppler Image + Plage model

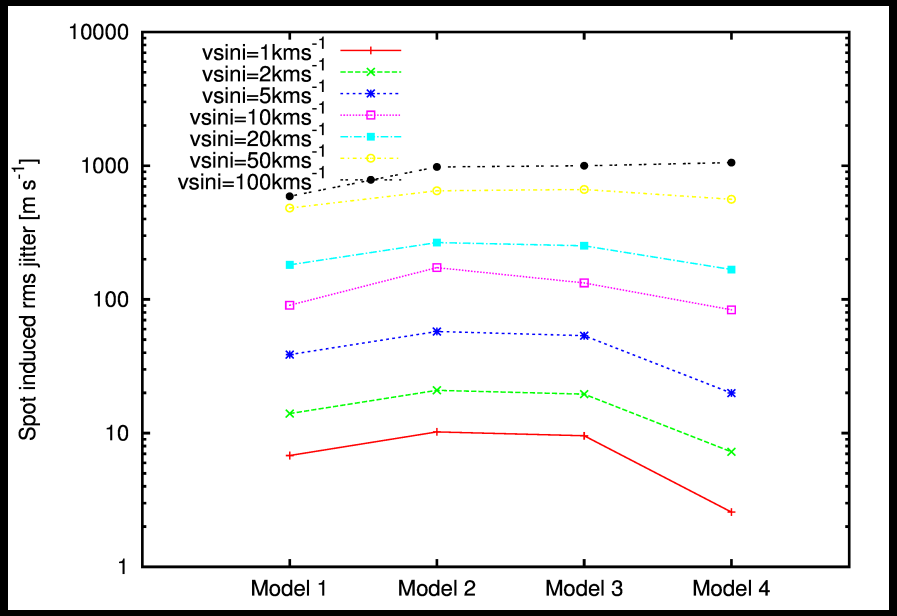


# Activity Induced Jitter

G dwarfs




K dwarfs




DI

DI +PI

DI+PI+Rspots

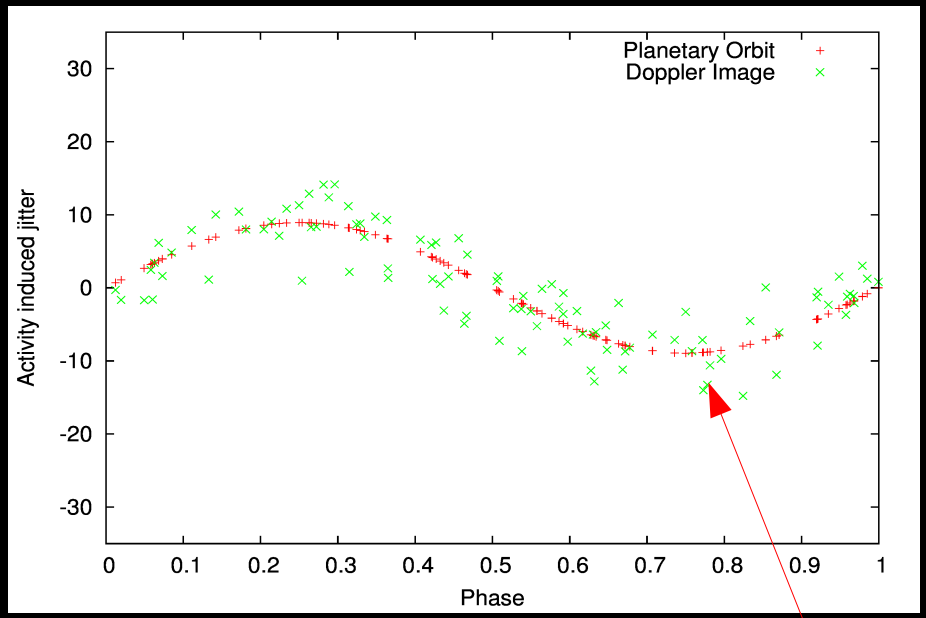
DI+PI+DR

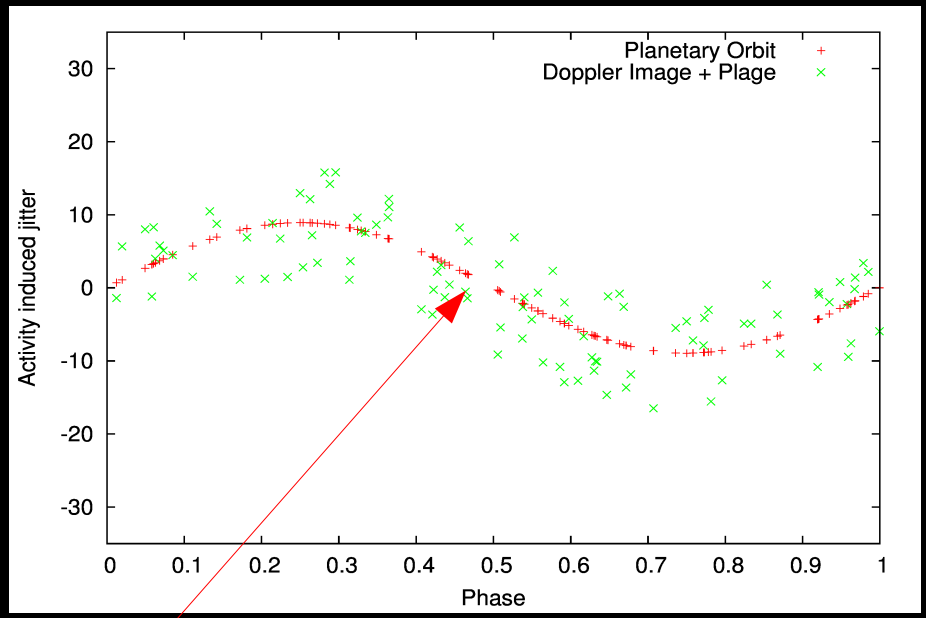
- Line profiles are generated using imaging code DoTs
- $M_{star}$ = 0.8 + 1.0 $M_{sun}$ Vsini=5, 10, 20, 50, 100 km/s

# Simulate Detection Thresholds

- $M_{planet}$ = 1, 2, 5, 10 and 20 $M_{earth}$ + 1, 2 and 5 $M_{jupiter}$
- $a_{planet}$ = 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1 AU
- $M_{star}$ = 1.0 $M_{sun}$ Vsini=5, 10, 20, 50, 100 km/s
- 10, 20, 50, 100 & 200 epochs of observation (on consecutive nights)
- Radial Velocity Jitter:(1) stellar activity + (2) instrumental

# Radial Velocity



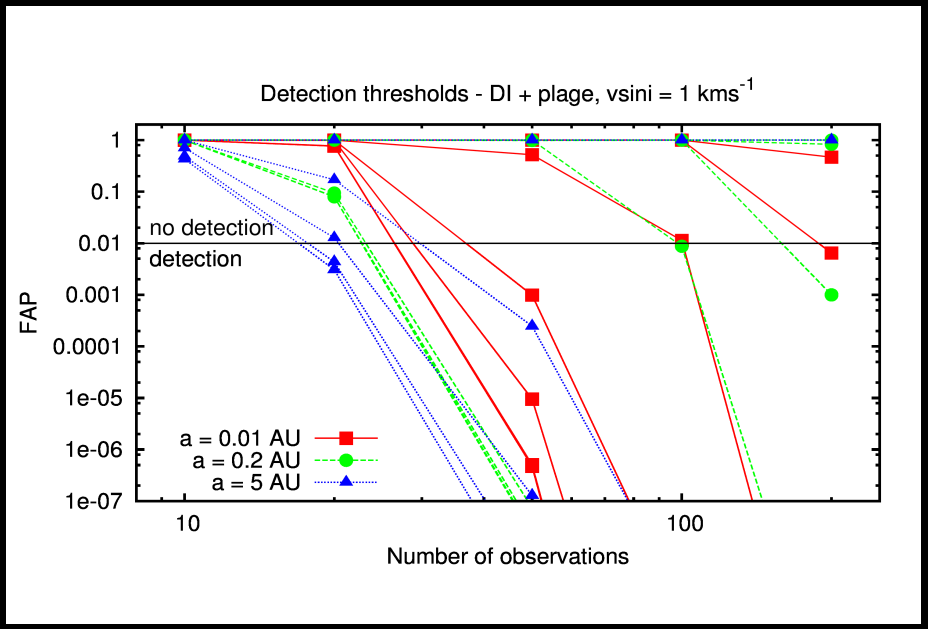

Doppler Image activity jitter

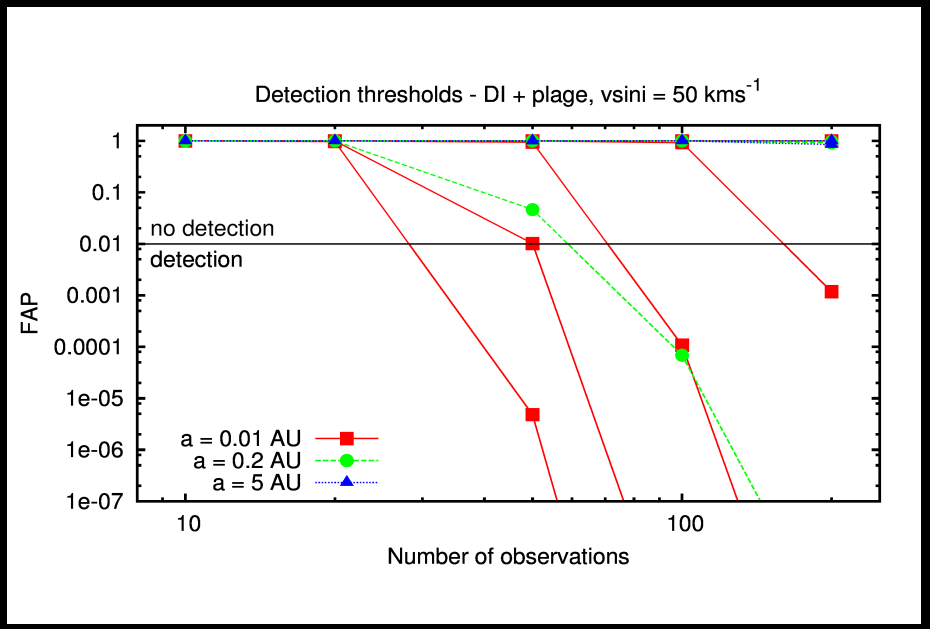
Doppler Image + Plage activity jitter

PLANET

Planet mass = 10 $M_E$ orbiting G dwarf at 0.01 AU

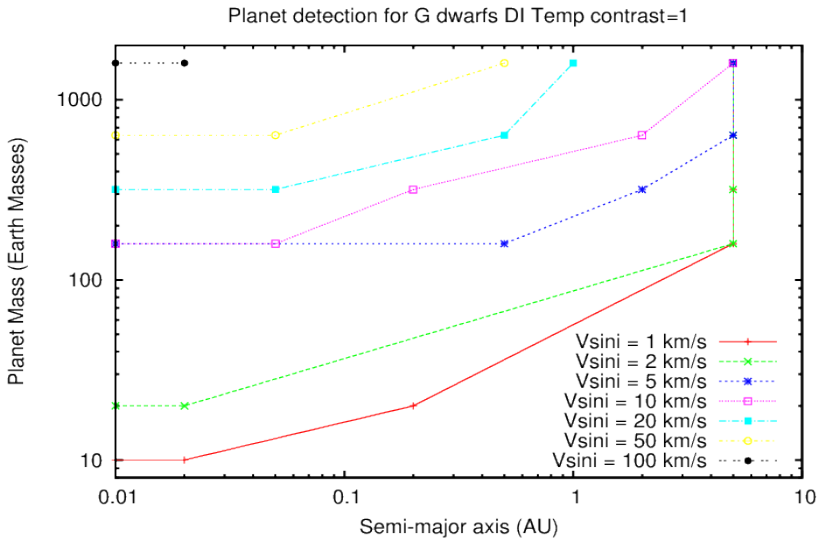
# Planet Detection




- Random observational phase + Lomb Scargle periodogram analysis

# Planet Detection G dwarfs



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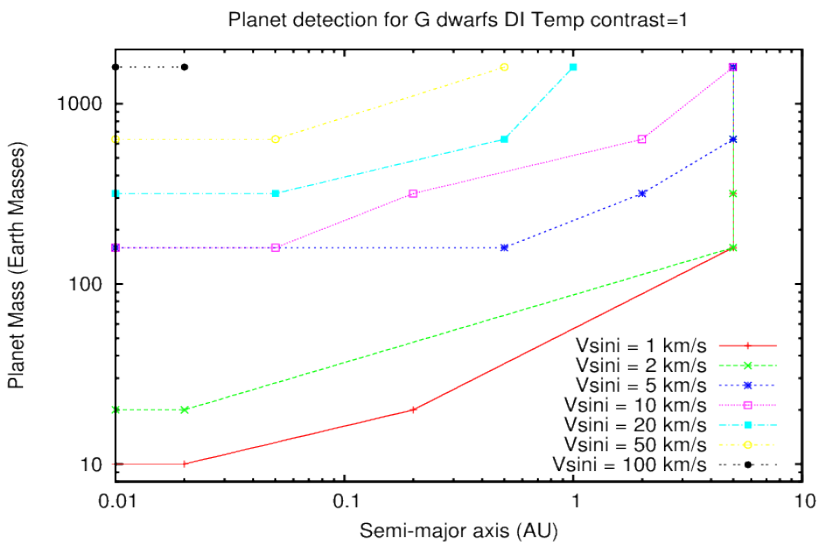


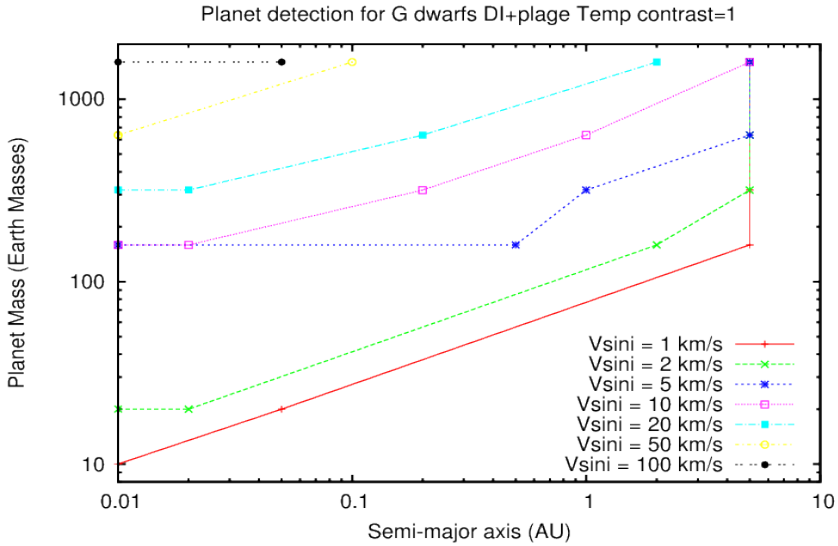

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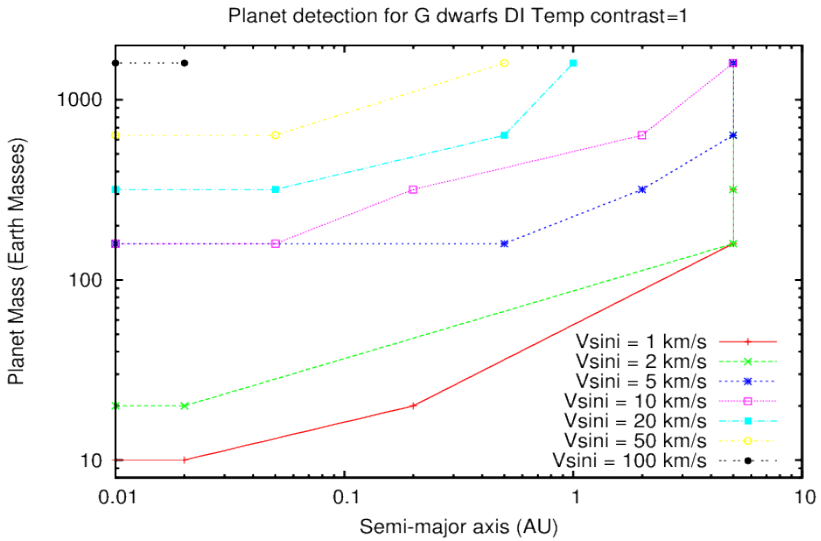


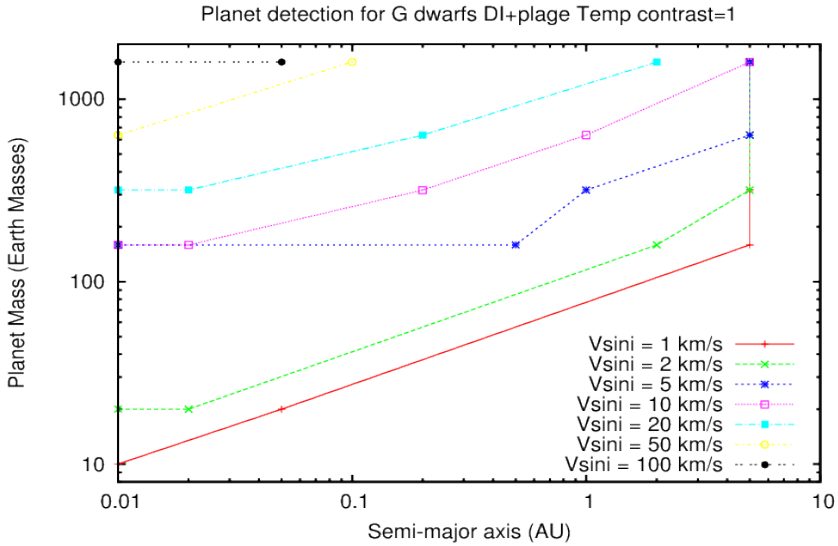


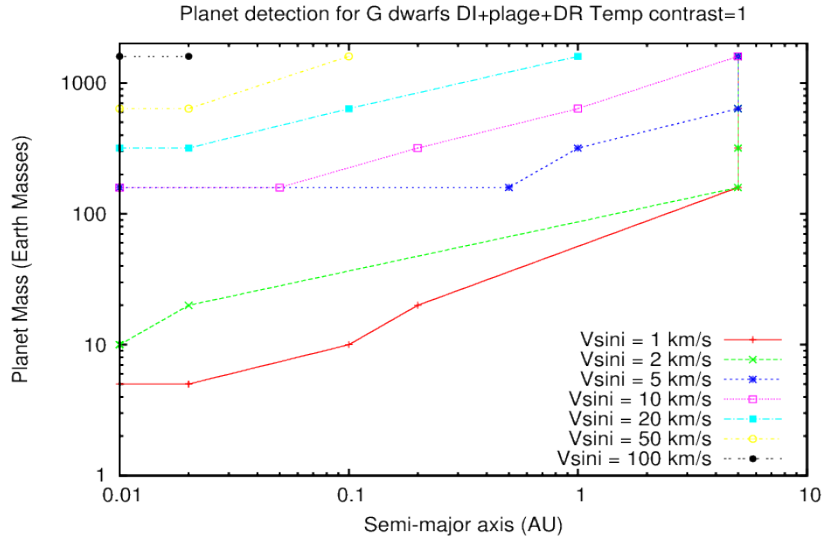

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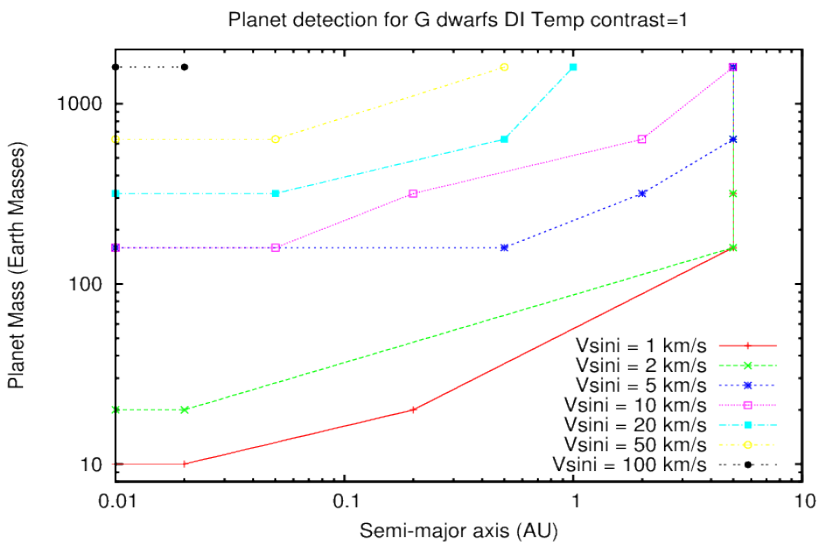
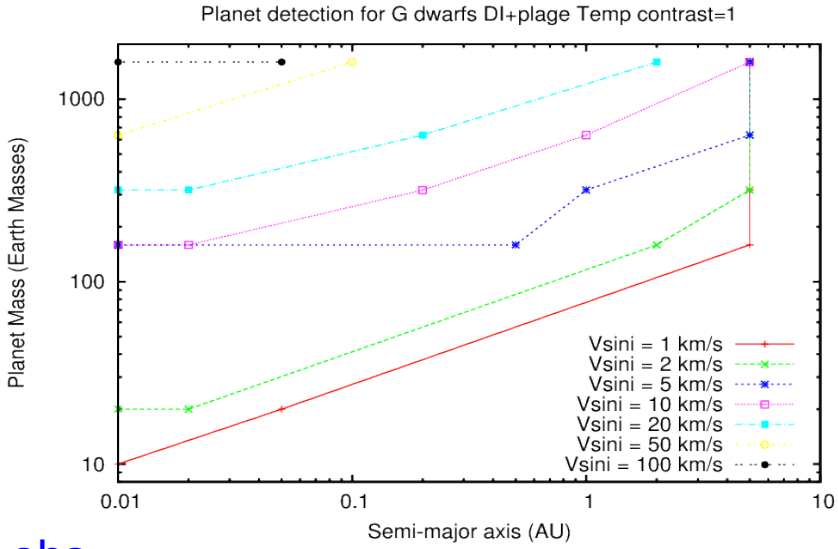
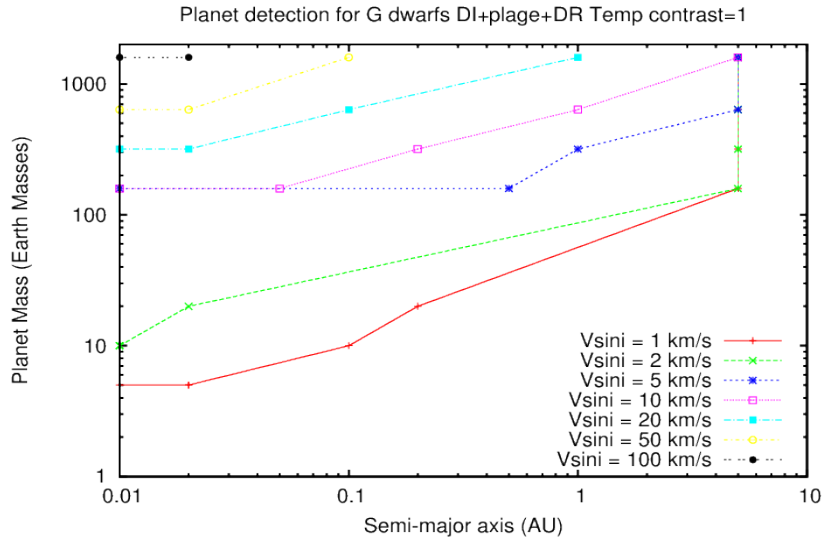
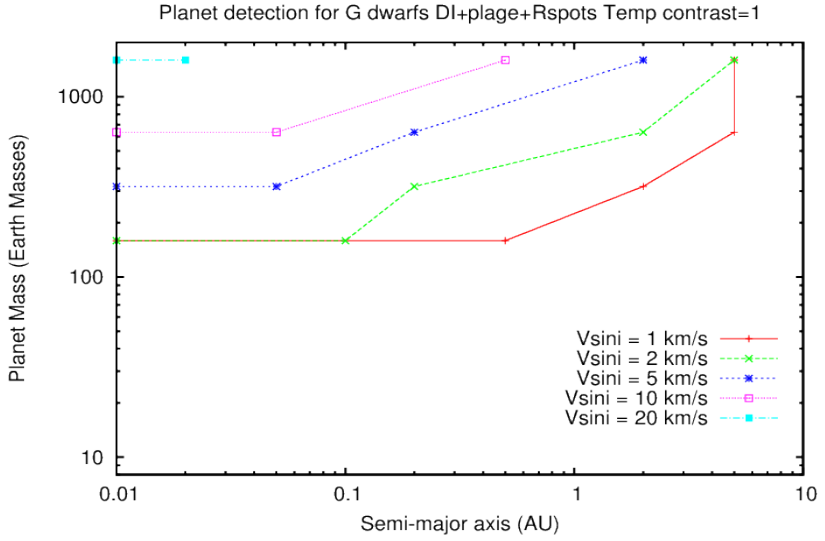


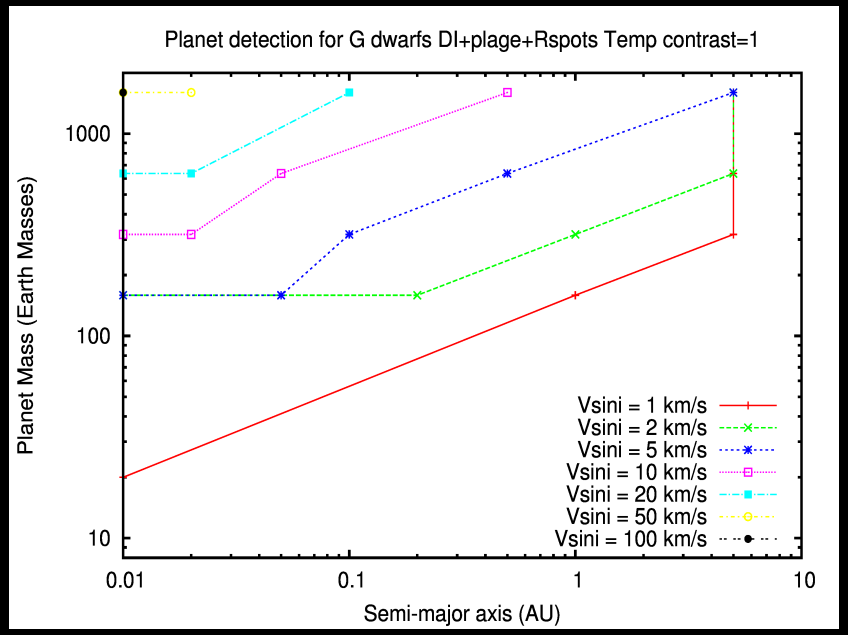




50 obs

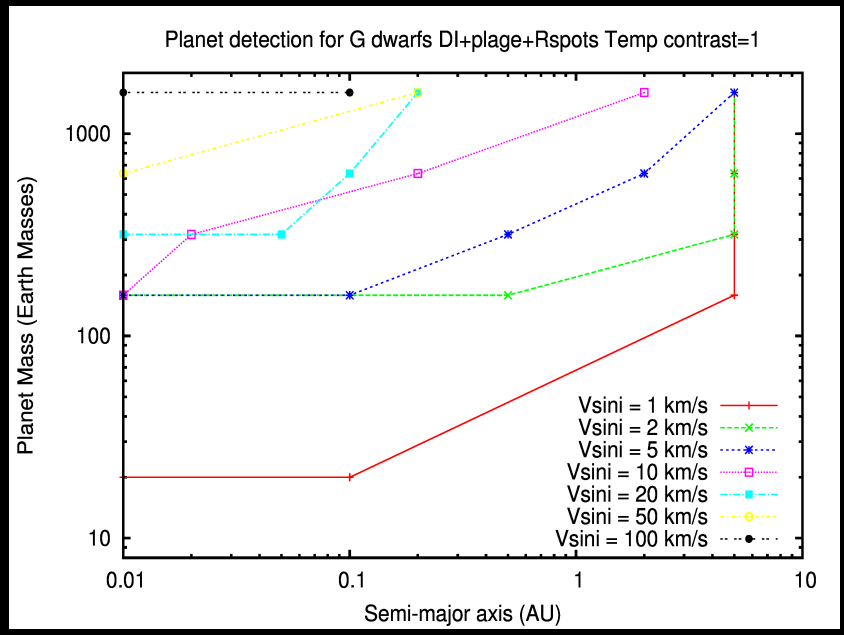


# Planet Detection G dwarfs




100 obs




200 obs

~10 $M_{jupiter}$ @ 0.05 AU in 50 obs

~ 6 $M_{jupiter}$ @ 0.05 AU in 100 obs

~ 2 $M_{jupiter}$ @ 0.05 AU in 200 obs

# Results

- With only several 10s of epochs it is possible to detect habitable zone Earth-like planets orbiting late M dwarfs + 1 $M_{Jupiter}$ planets around active G & K dwarfs
- Variation in vsini + contrast ratio are important factors in determining detection thresholds
- Next steps are to:
  - Use same spot patterns for G and K dwarfs to make a direct comparison
  - Improve planet-hunting techniques
  - Investigate activity removal methods