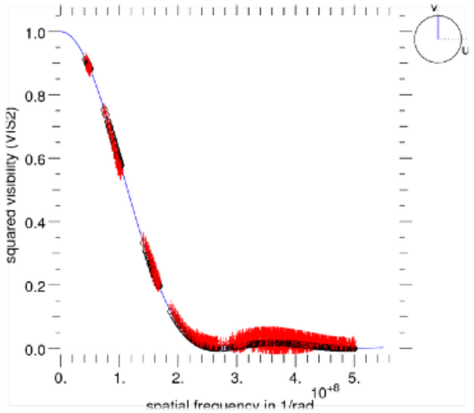
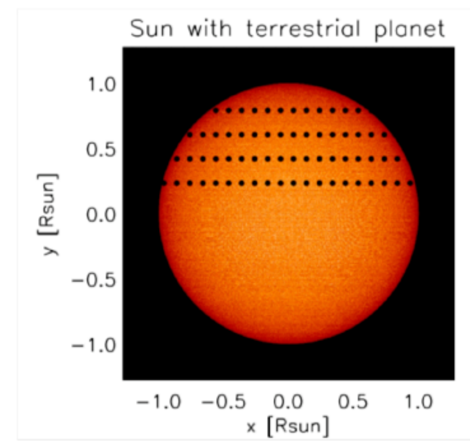
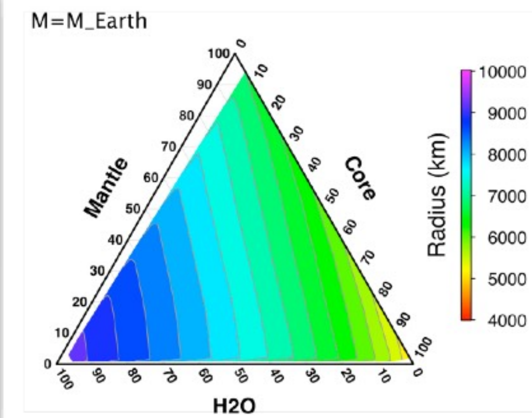






A HIGH ANGULAR RESOLUTION VIEW ON EXOPLANETS AND SPOTS

Roxanne Ligi

INAF - Osservatorio Astronomico du Brera

Marie Skłodowska-Curie/AstrofIT2 Fellow

PLATO Limb-Darkening Workshop

26-27 February 2019

INTRODUCTION

- Different effects can perturb the determination of stellar parameters.

- The stellar diameter takes part of the determination of many stellar and planetary parameters.

- Many phenomenon perturb the determination of the stellar radius:

    - the limb-darkening ➙ to get a reliable radius

    - magnetic spots

    - granulation

- High angular resolution can be of great help on this story.

IMPACT OF A SPOT ON THE STELLAR RADIUS

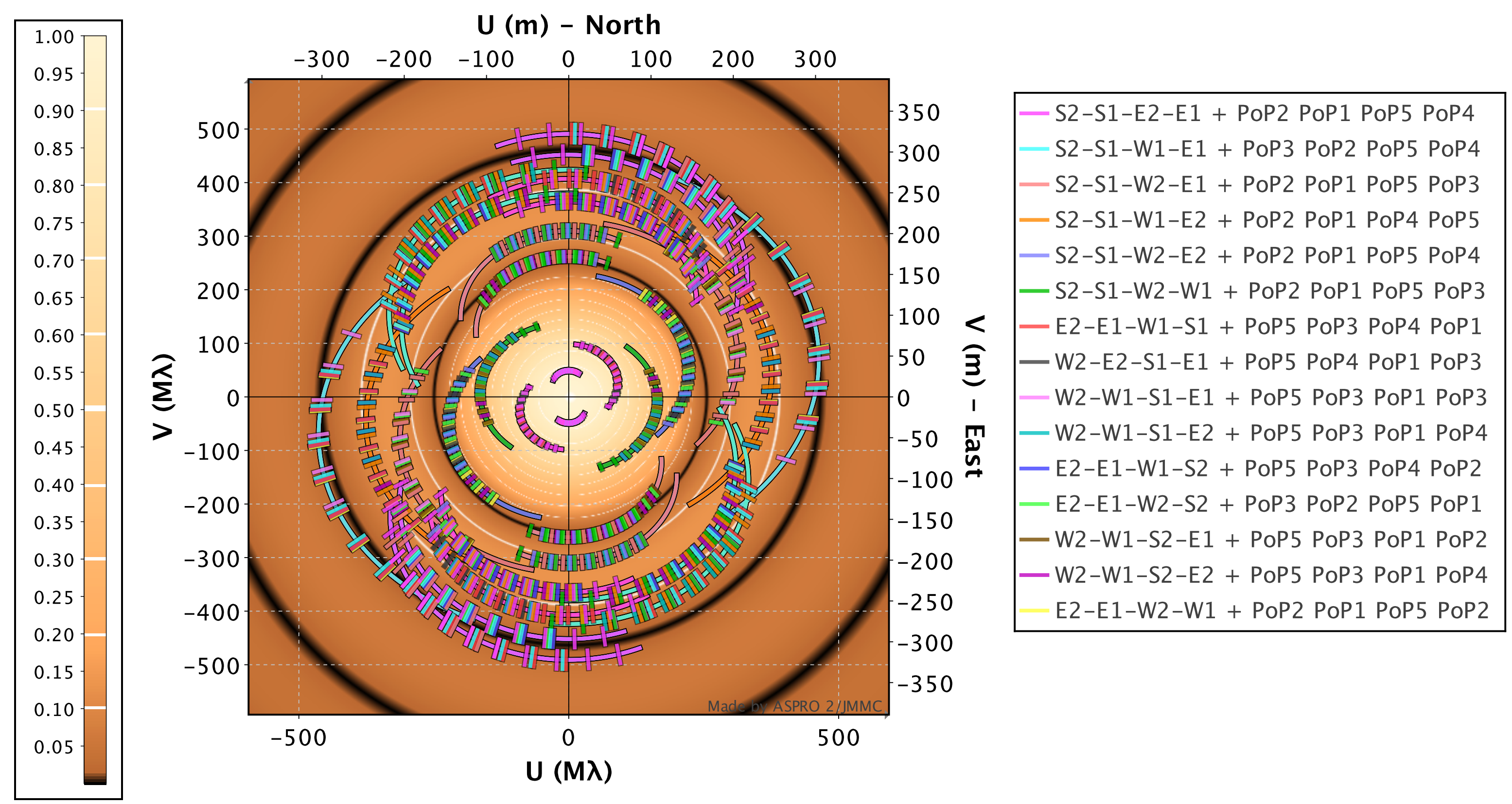
Solar-like star with no spot

T_{eff} = 5800 K

1. Create oifits with Aspro2

4T VEGA/CHARA at **656 nm**, all baselines

Disk model: **θ = 1 mas** (makes ~ 1.5 $R_{\odot}$ at 14 pc, or ~ 1 $R_{\odot}$ at 9.3 pc)



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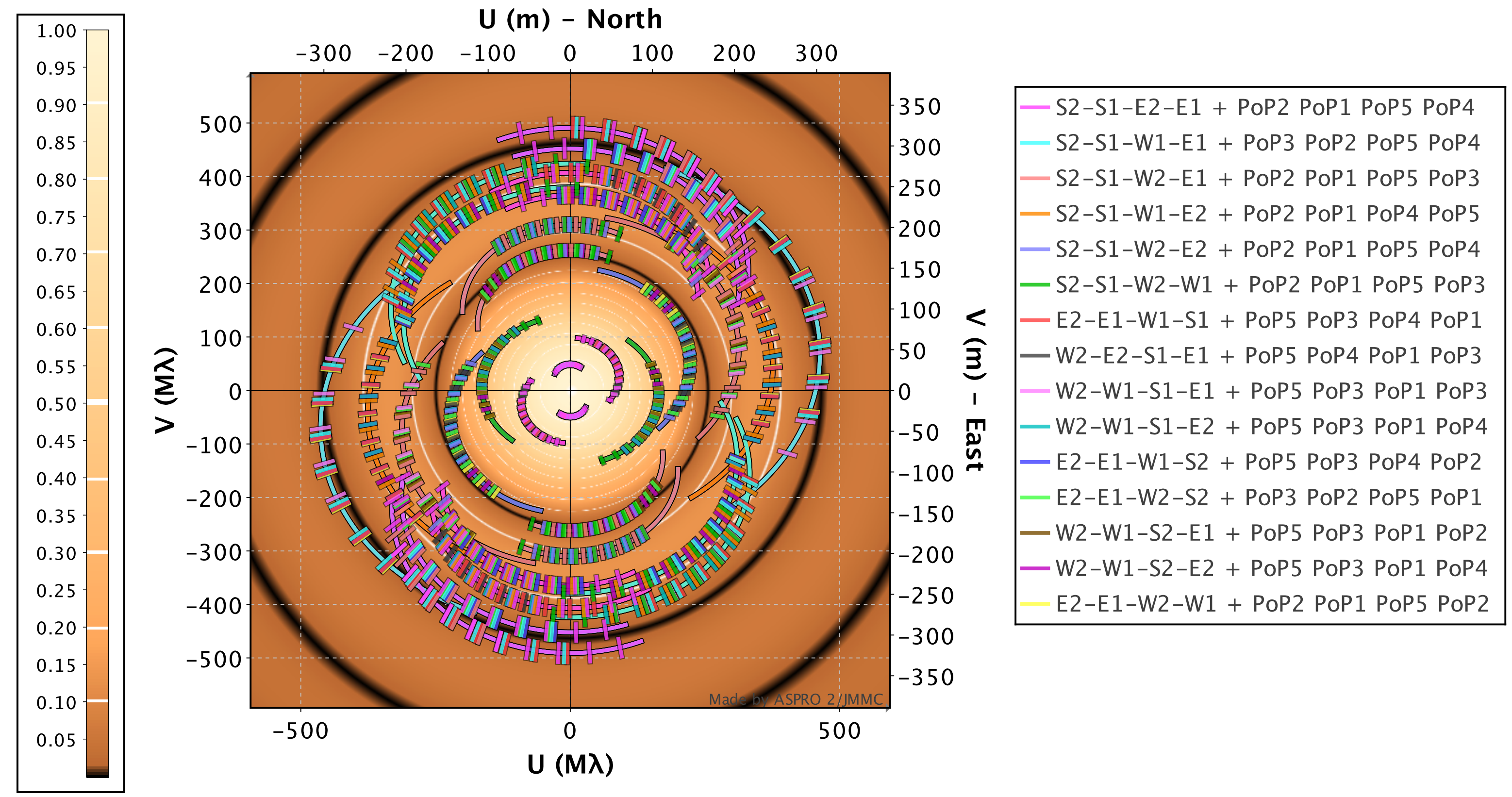
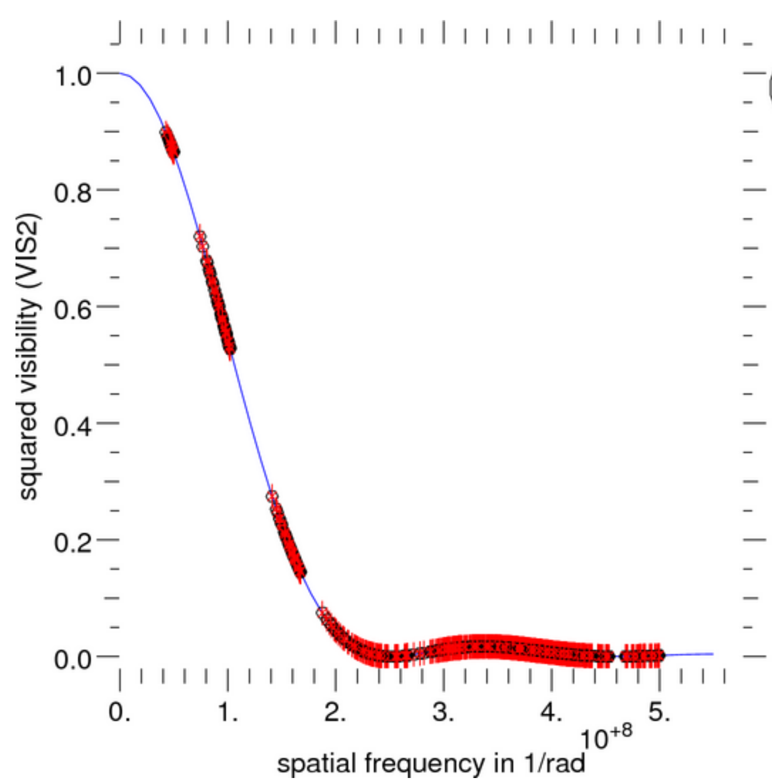
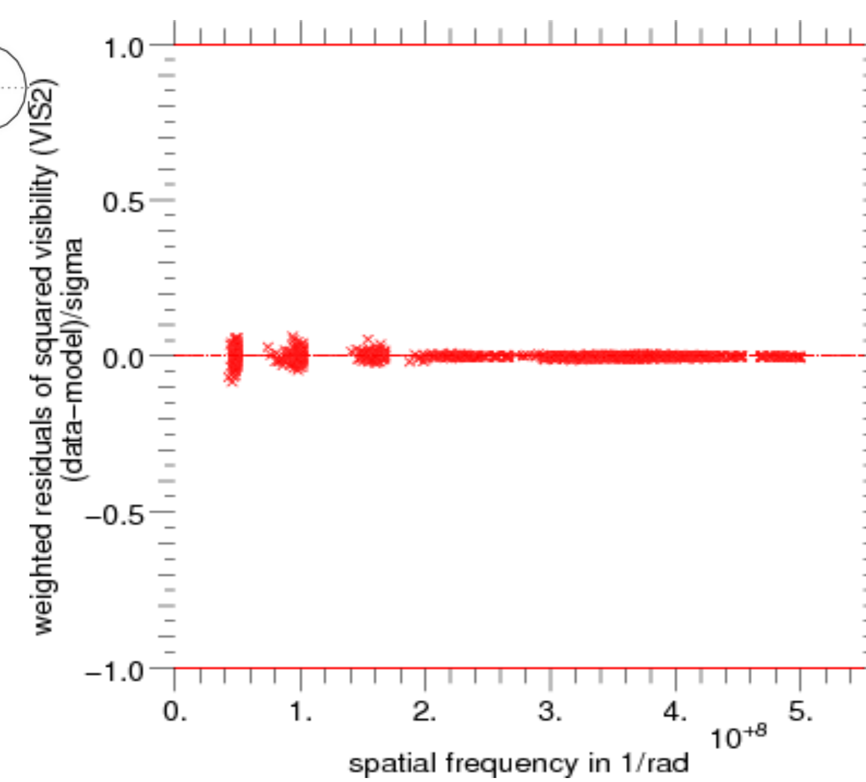


2. Then inject in LITpro

Disk model ➙ 1.0± 2.2e-05 mas

reduced χ^2 = 0.0001237





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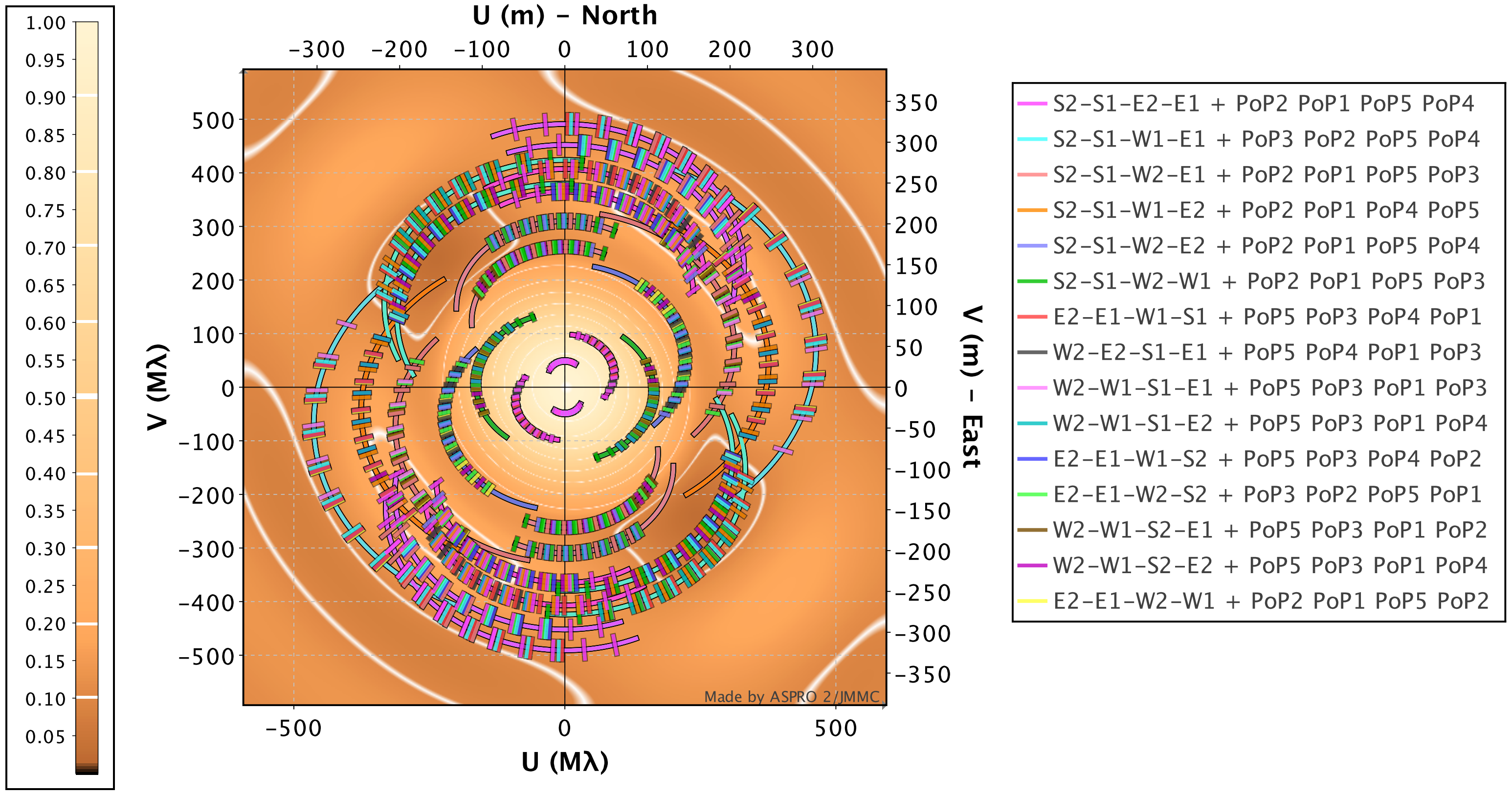
Spot model: **0.1 mas, $T_{eff,s}$ = 4000 K**



IMPACT OF A SPOT ON THE STELLAR RADIUS

Solar-like star with a spot

T_{eff} = 5800 K

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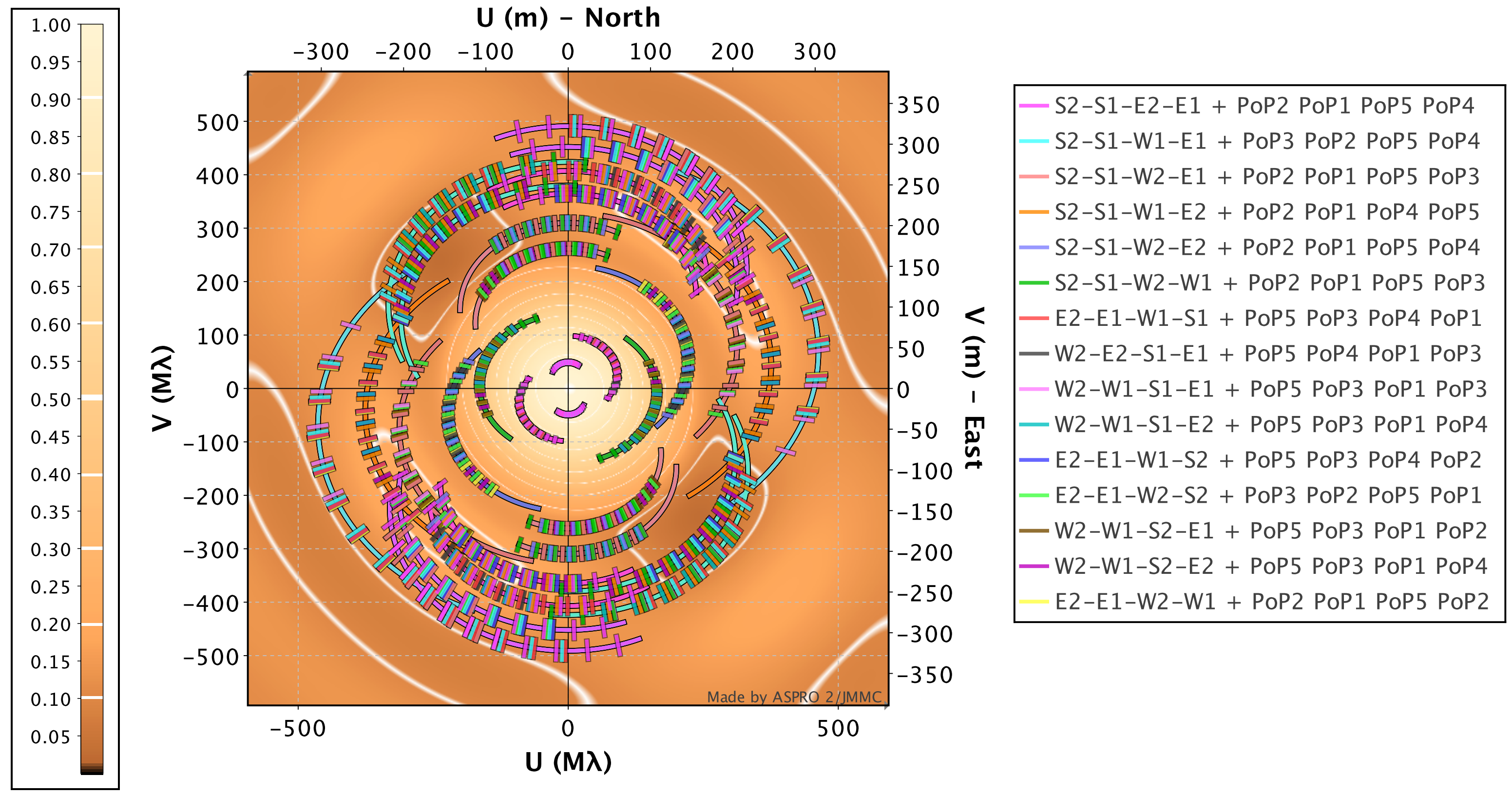
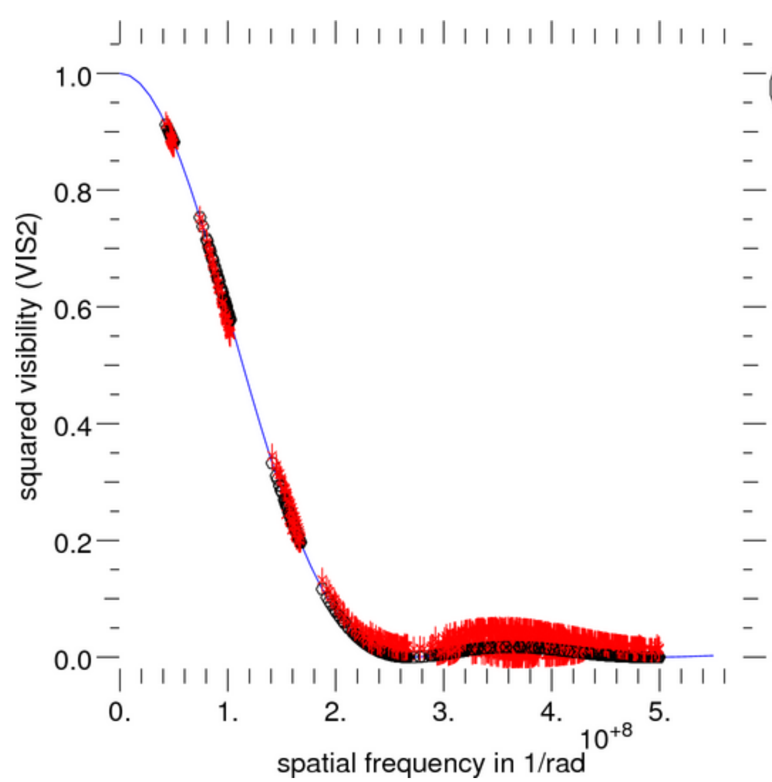
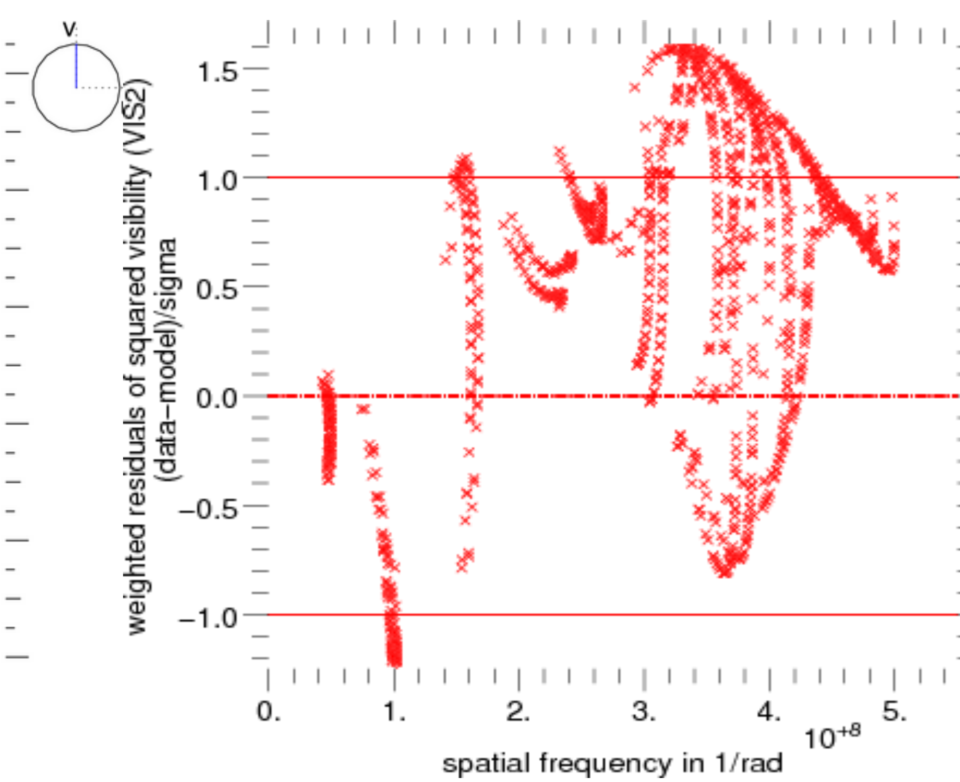


2. **Then inject in LITpro**

   Disk model ➙ 0.93 ± 0.00158 mas
   makes 0.93 $R_\odot$ @ 9.3 pc
   or 1.4 $R_\odot$ @ 14pc

   reduced χ^2 = 0.7711





IMPACT OF A SPOT ON THE STELLAR RADIUS

Solar-like star with a spot

T_{eff} = 5800 K

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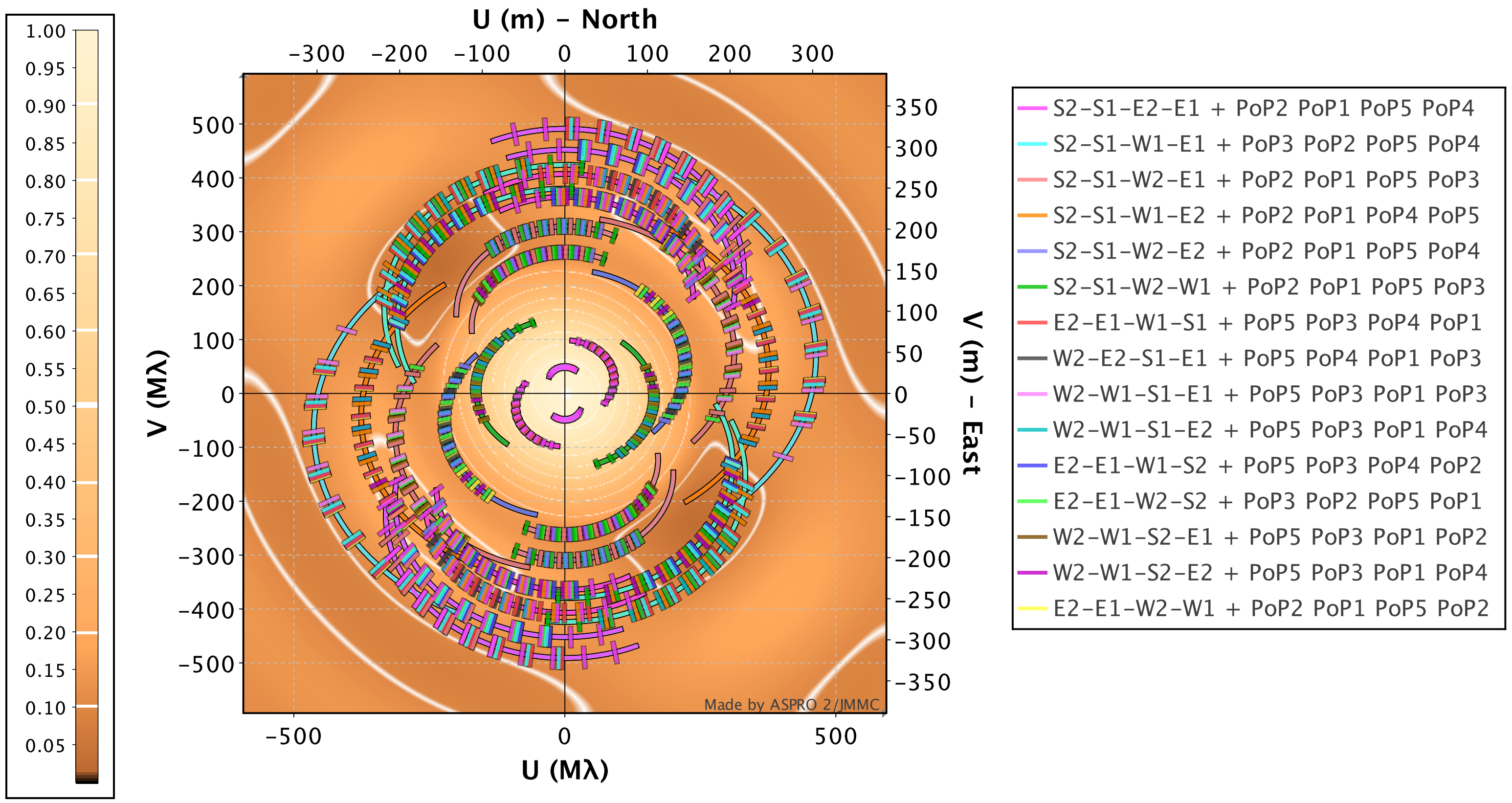

IMPACT OF A SPOT ON THE STELLAR RADIUS

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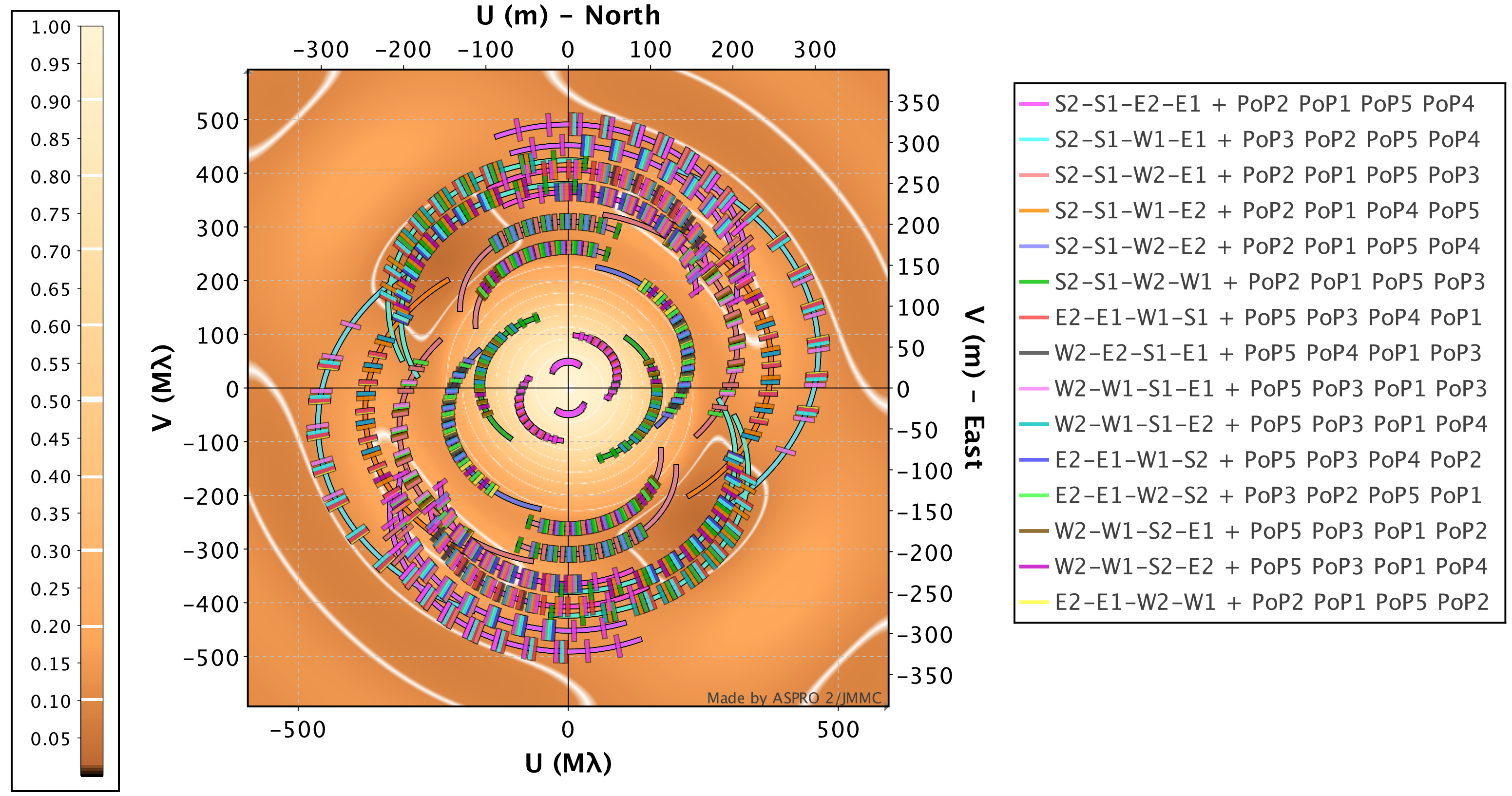
   all baselines

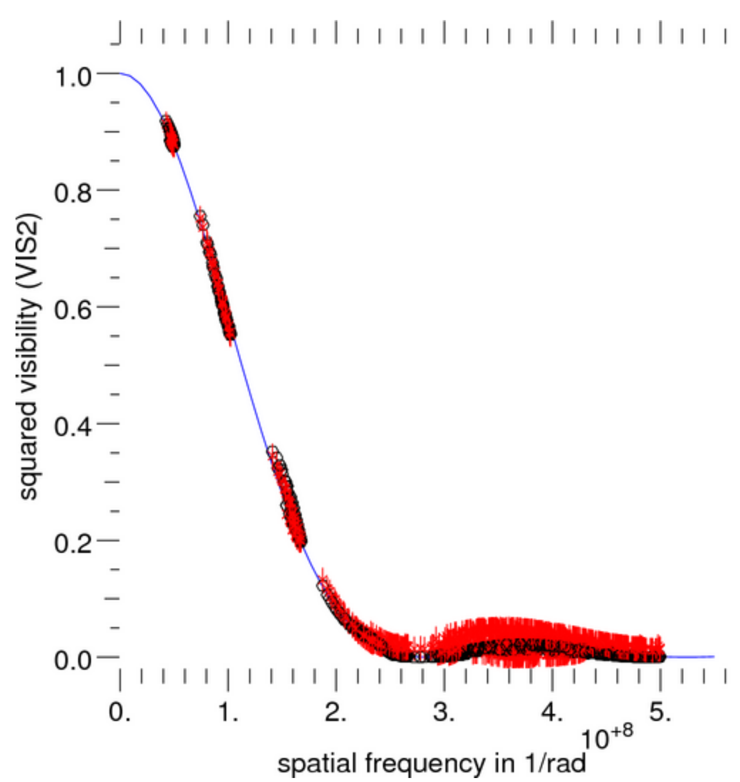
   Disk model: **θ = 1 mas**
   (makes ~ 1.5 $R_\odot$ at 14 pc,
   or ~ 1 $R_\odot$ at 9.3 pc)

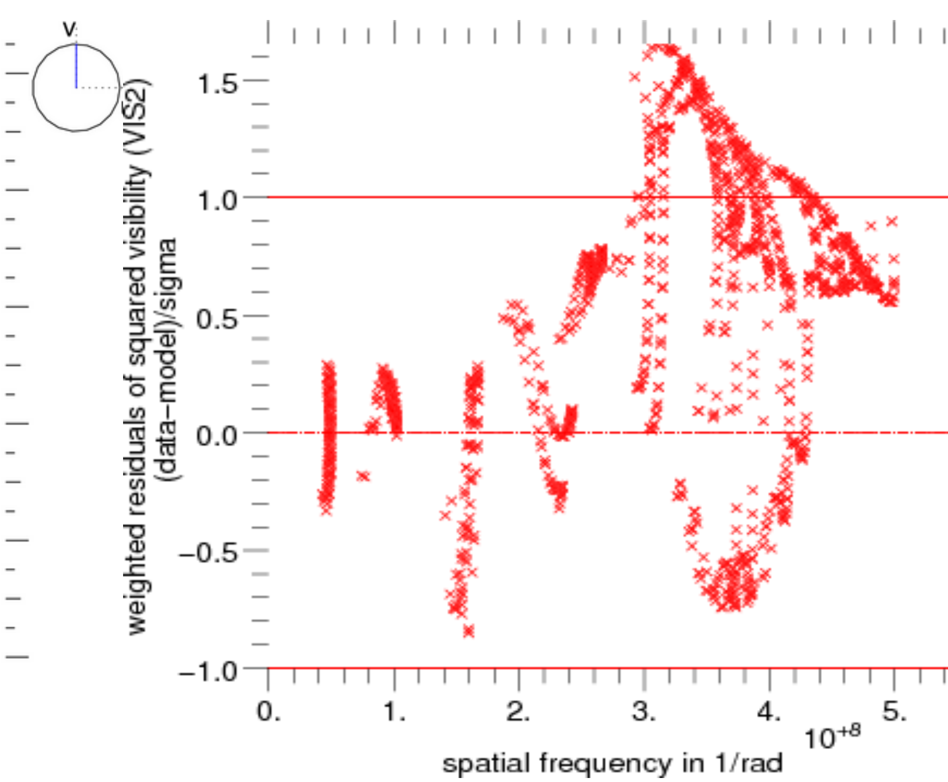
   Spot model: **0.1 mas, $T_{eff,s}$ = 4000 K**

2. **Then inject in LITpro**

   2 disks model
   Disk1 ➙ 0.90167 ± 0.002 mas
   reduced χ^2 = 0.5951



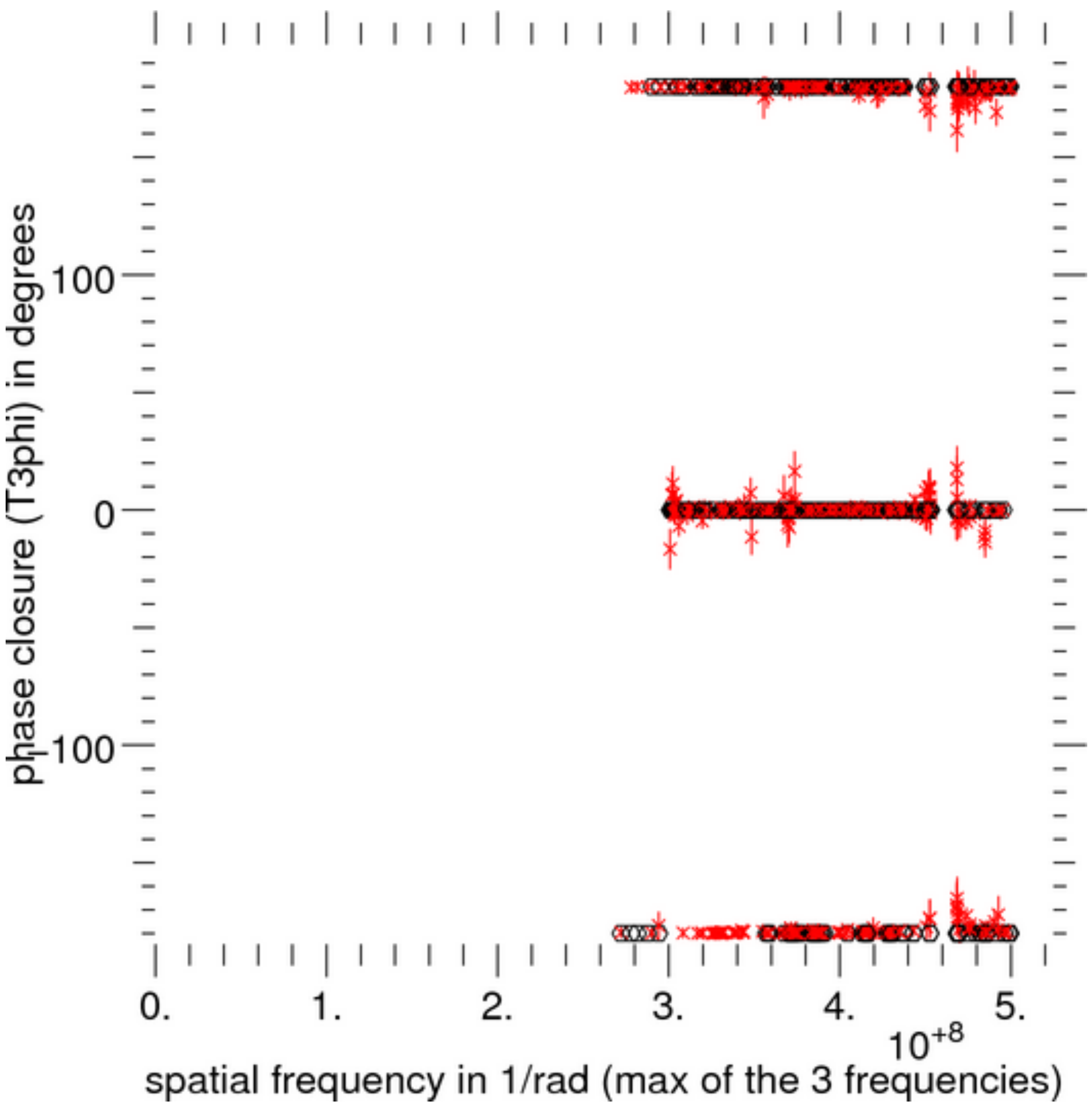




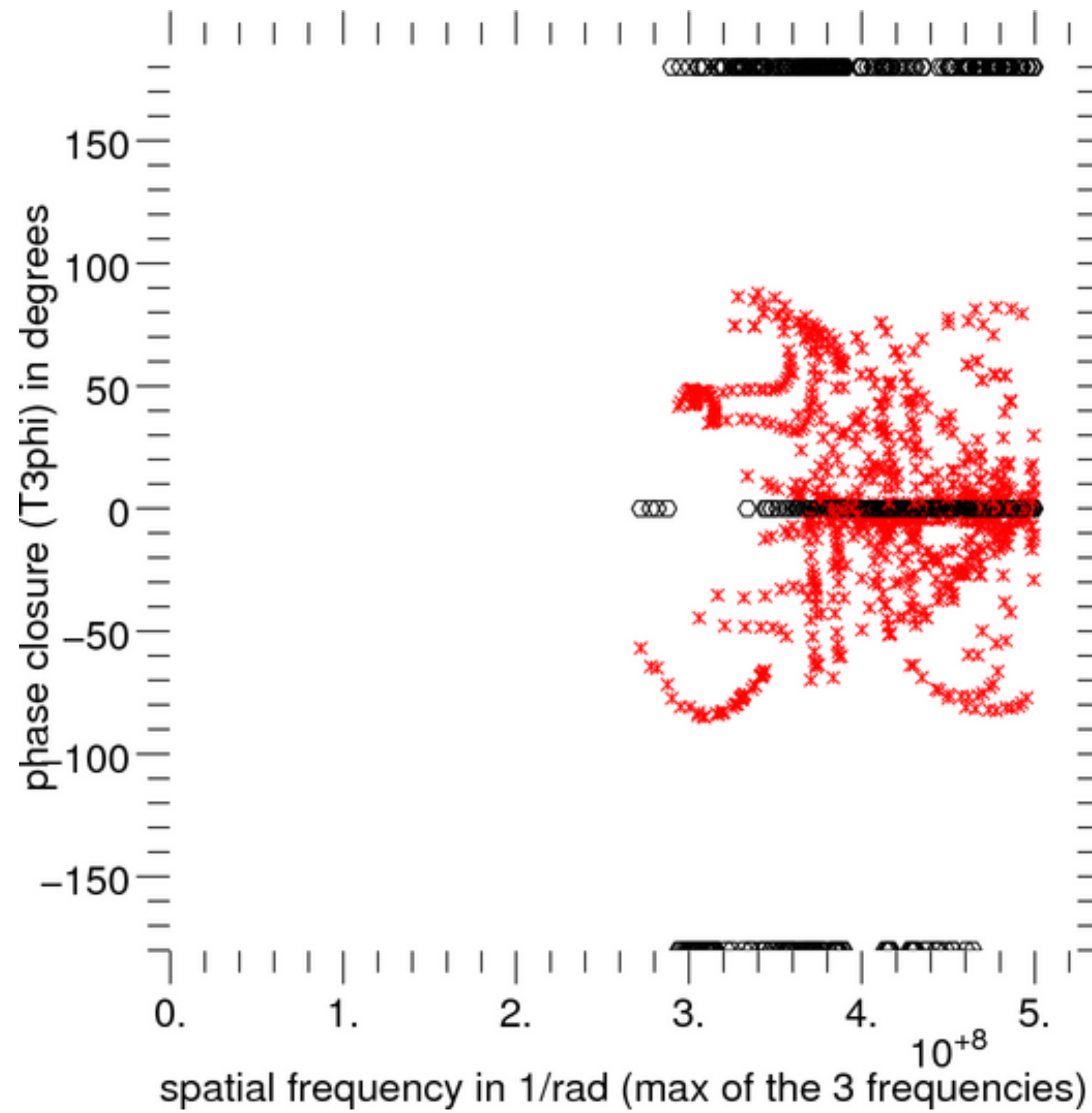
IMPACT OF A SPOT ON THE STELLAR RADIUS

Closure Phases

No spot



Spot (1 disk model)



GENERAL STATEMENTS

What does it mean?

- A simple fit does not seem precise enough to derive the angular diameter, if measurements at low V^2
- It is very hard to distinguish between spotted and non spotted stars with the V^2 only
- There are other effects to be taken into account…

So, how to know if we measure a « realistic » diameter, or if it is over/under-estimated? (open question)

- Would need the closure phases, but often not possible
- Trust the residuals? But could be due to other effects.
- Rely on other activity markers? There are other indicators of stellar activity, but can we relate them to the measurement of the angular diameter?
- Still need to quantify the effect of the spot(s).

IMPACTS ON EXOPLANETARY PROPERTIES

- Direct impacts on **stellar parameters**:

  Effective temperature : $T_{\mathrm{eff},\star} = \left(\frac{4 \times F_{\mathrm{bol}}}{\sigma_{\mathrm{SB}} \theta_{\mathrm{LD}}^2} \right)^{0.25}$ ➞ $L_\star = 4\pi d^2 F_{\mathrm{bol}}$

  Other parameters through stellar evolution models: $M_\bigstar$, $\mathrm{age}_\bigstar$…

- Linked to **exoplanetary properties**:

  Habitable Zone (HZ) (Jones et al. 2006) $\propto L_\bigstar / T_{\mathrm{eff},\bigstar}{}^2$

  Stellar mass: $M_\bigstar = (4\pi/3) R_\bigstar{}^3 \rho_\bigstar$ so planetary mass $m_{\mathrm{p}} \sin(i) = \frac{M_\star^{2/3} P^{1/3} K (1-e^2)^{1/2}}{(2\pi G)^{1/3}}$

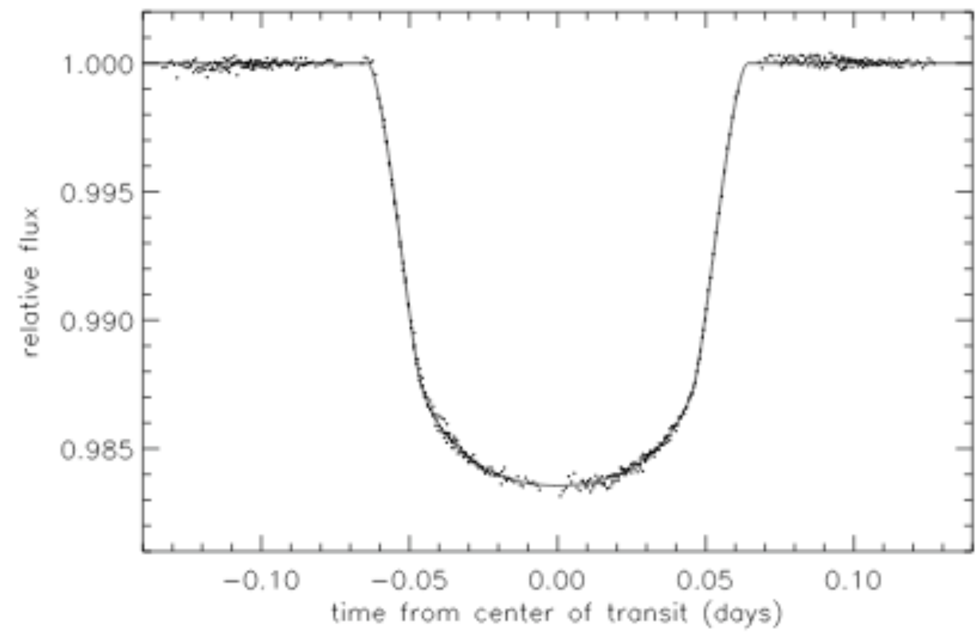
  And planetary density (transit) $\rho_p = \frac{3^{1/3}}{2\pi^{2/3} G^{1/3}} \rho_\star^{2/3} R_\star^{-1} T D^{-3/2} P^{1/3} K (1-e^2)^{1/2}$

IMPACTS ON EXOPLANETARY RADIUS

Imagine a solar-like star:

With a transiting exoplanet: $\Delta F/F$=0.0165 (~TD of HD209458 b)

And with:



Brown et al. 2001

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1 $R_\odot$**

  → We get **1.25 R_{Jup}**

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1 $R_\odot$ → 0.93 $R_\odot$**

  → We get **1.16 R_{Jup}** (-7%)

IMPACTS ON EXOPLANETARY RADIUS

Imagine a solar-like star:

With a transiting exoplanet: $\Delta F/F=0.0165$ (~TD of HD209458 b)

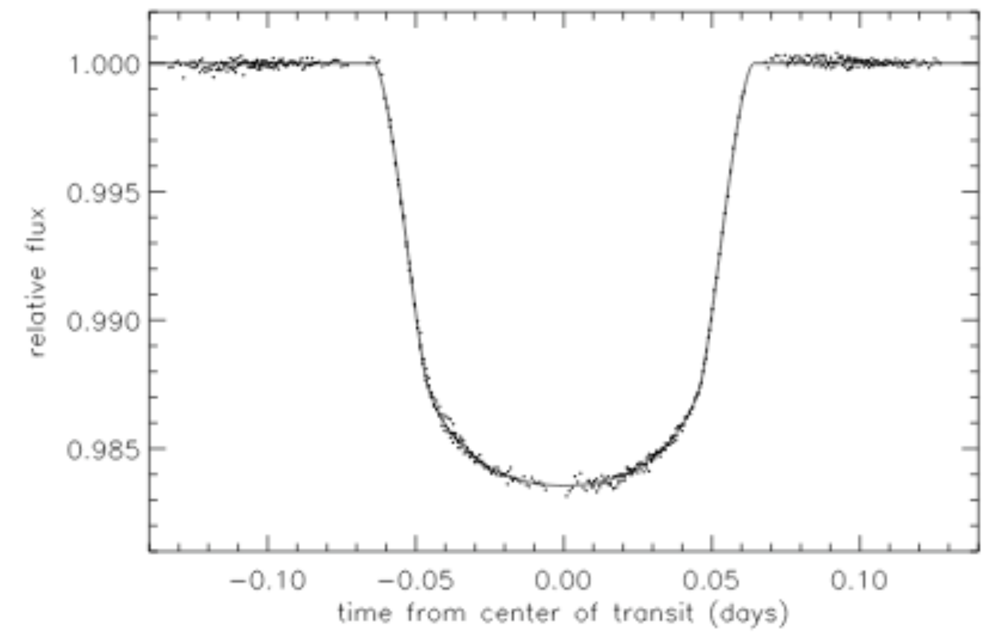
And with:

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1.5 $R_\odot$**

  → We get **1.88 R_{Jup}**

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1.5 $R_\odot$ → 1.4 $R_\odot$**

  → We get **1.75 R_{Jup}** (-7%)

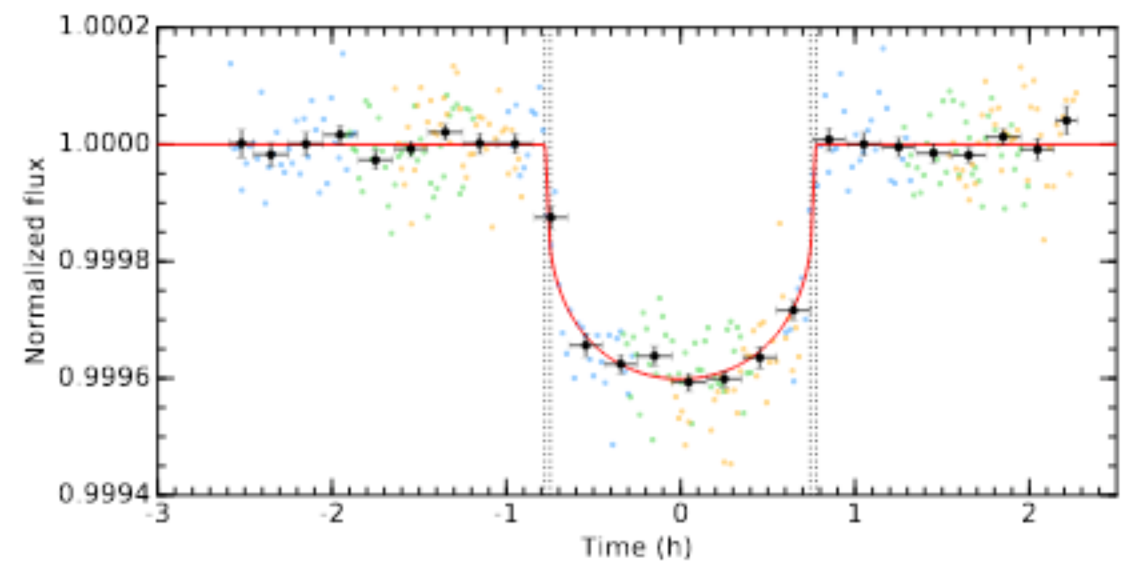


Brown et al. 2001

IMPACTS ON EXOPLANETARY RADIUS

Imagine a solar-like star:

With a transiting exoplanet: $\Delta F/F = 0.0003312$
(TD of 55 Cnc e)



Bourrier et al. 2018

And with:

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1 $R_\odot$**

  → We get **1.98 $R_\oplus$**

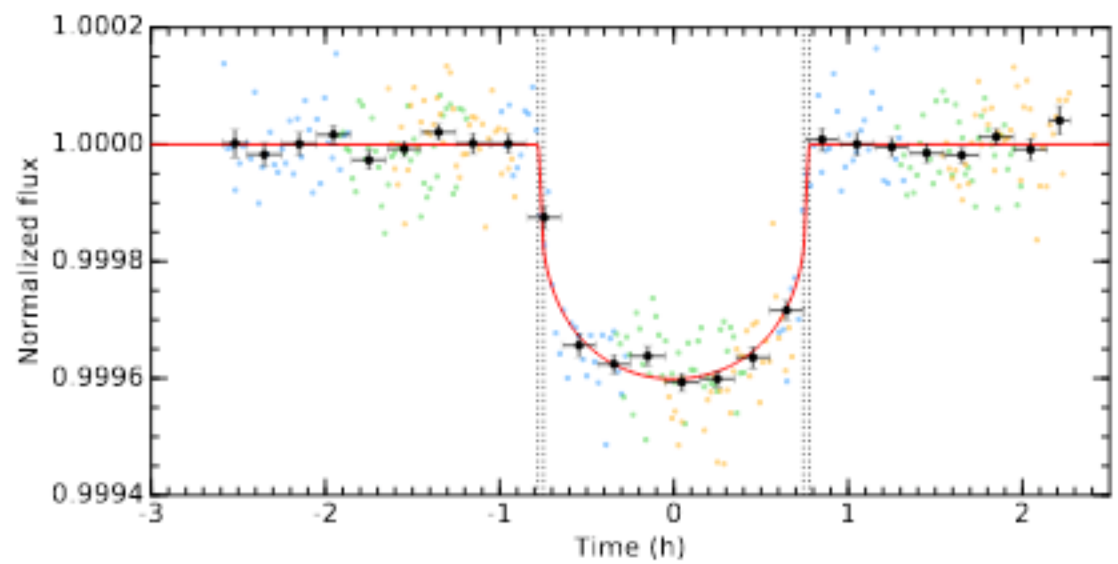
- **θ =**1 mas, T_{eff} = 5800K, 1 $M_\odot$, **1 $R_\odot$ → 0.93 $R_\odot$**

  → We get **1.85 $R_\oplus$** (-7%)

IMPACTS ON EXOPLANETARY RADIUS

Imagine a solar-like star:

With a transiting exoplanet: ΔF/F=0.0003312 (TD of Cnc e)



Bourrier et al. 2018

And with:

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_{\odot}$, **1.5 $R_{\odot}$**

  → We get **2.98 $R_{\oplus}$**

- **θ =**1 mas, T_{eff} = 5800K, 1 $M_{\odot}$, **1.5 $R_{\odot}$ → 1.4 $R_{\odot}$**

  → We get **2.78 $R_{\oplus}$** (-7%)

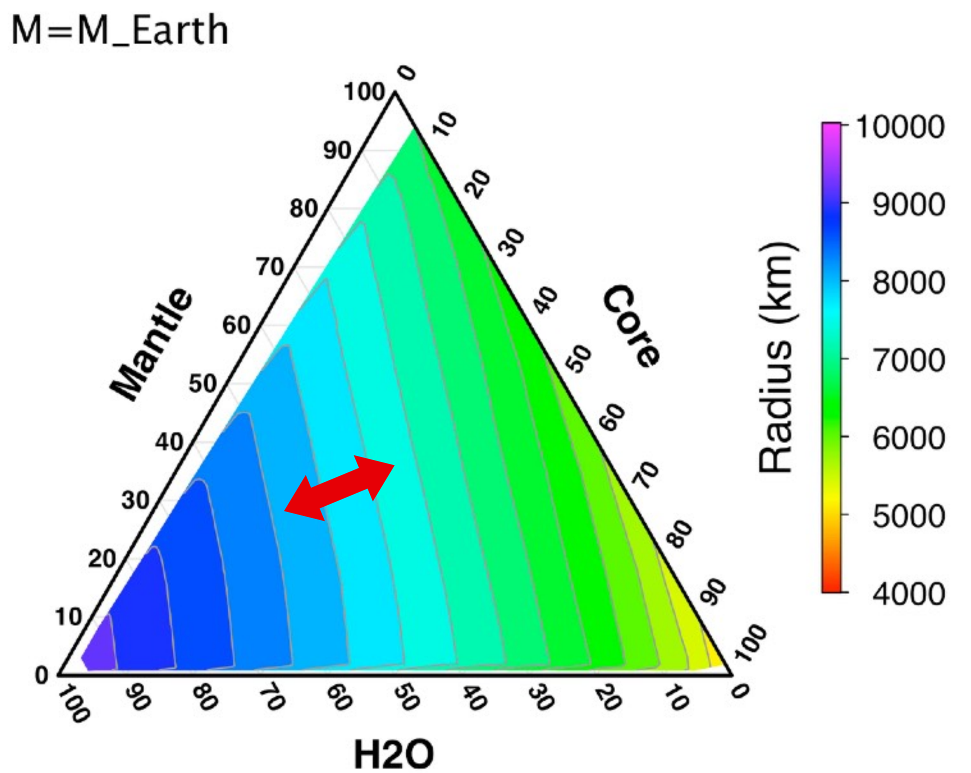
IMPACTS ON EXOPLANETARY RADIUS

Summary

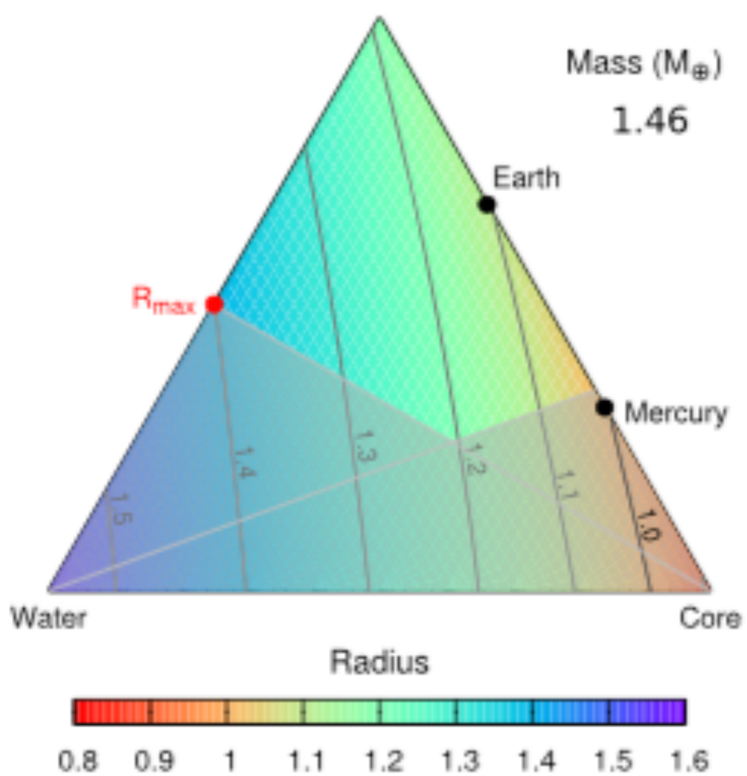
$\Delta F/F$	**1 $R_\odot$**	**0.93 $R_\odot$**	**1.5 $R_\odot$**	**1.4 $R_\odot$**
0.0165	**1.25 R_{Jup}**	**1.16 R_{Jup}**	**1.88 R_{Jup}**	**1.75 R_{Jup}**
0.0003312	**1.98 $R_\oplus$**	**1.85 $R_\oplus$**	**2.98 $R_\oplus$**	**2.78 $R_\oplus$**

823 km *1274 km*

IMPACTS ON EXOPLANETARY COMPOSITION

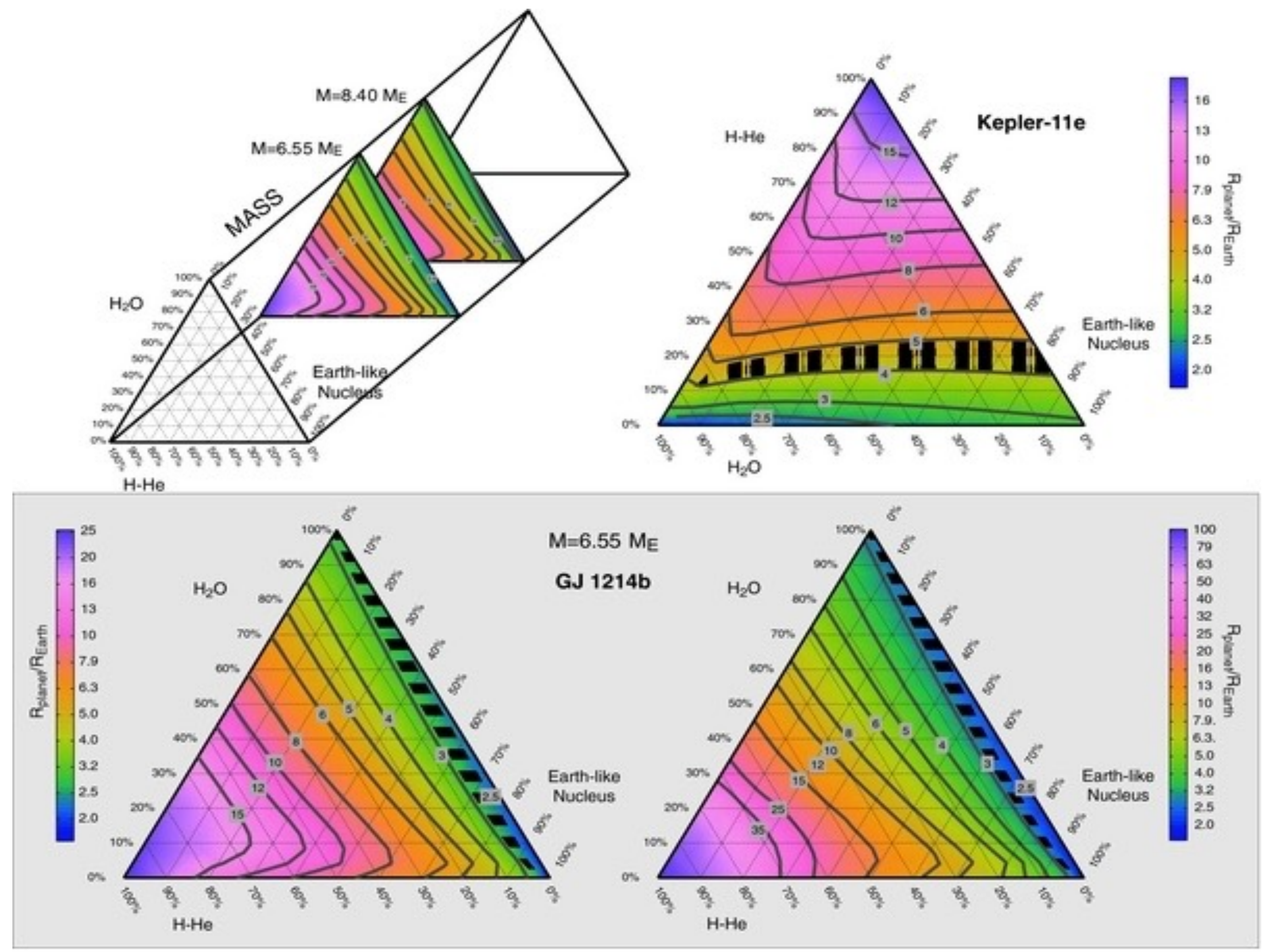


Valencia et al. 2006



Brugger et al. 2016

Valencia et al. 2013
(Bulk Composition of GJ 1214b and Other Sub-Neptune Exoplanets)



EXAMPLE: GJ504

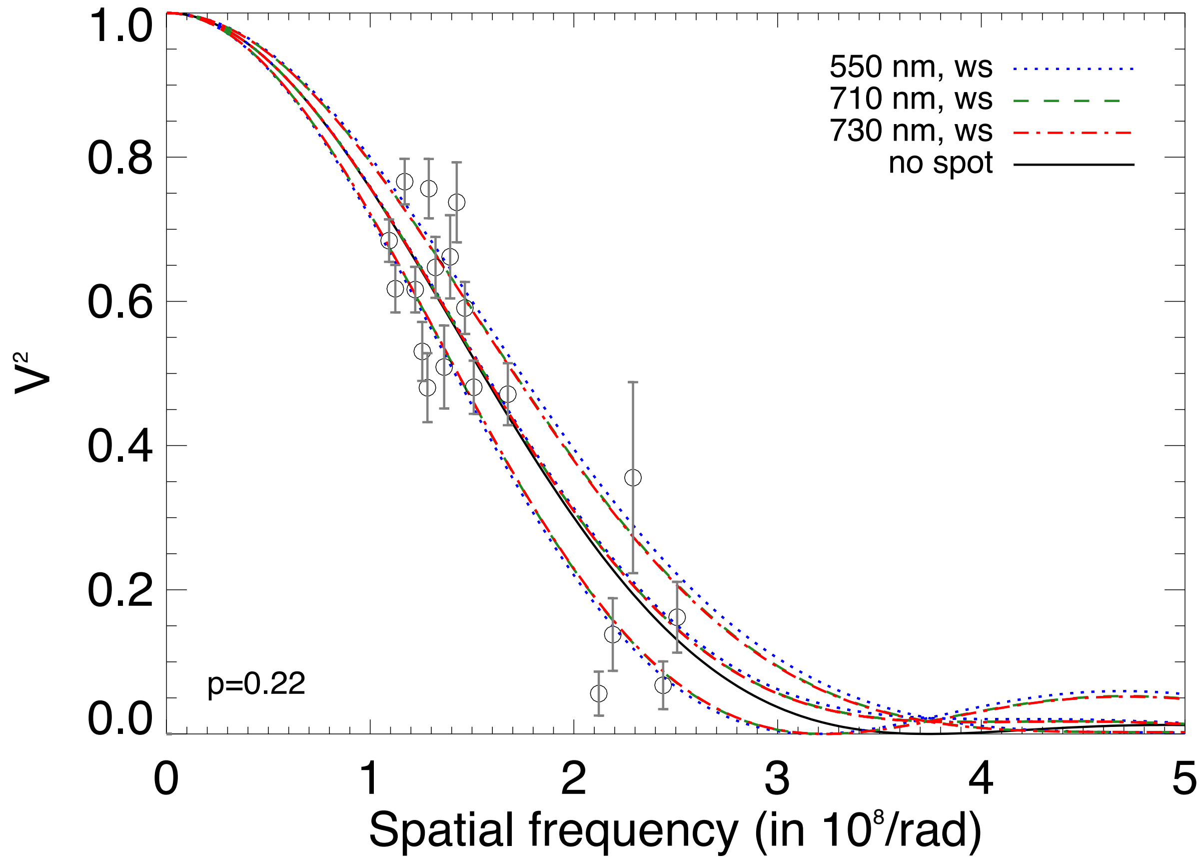
θ = 0.71 mas

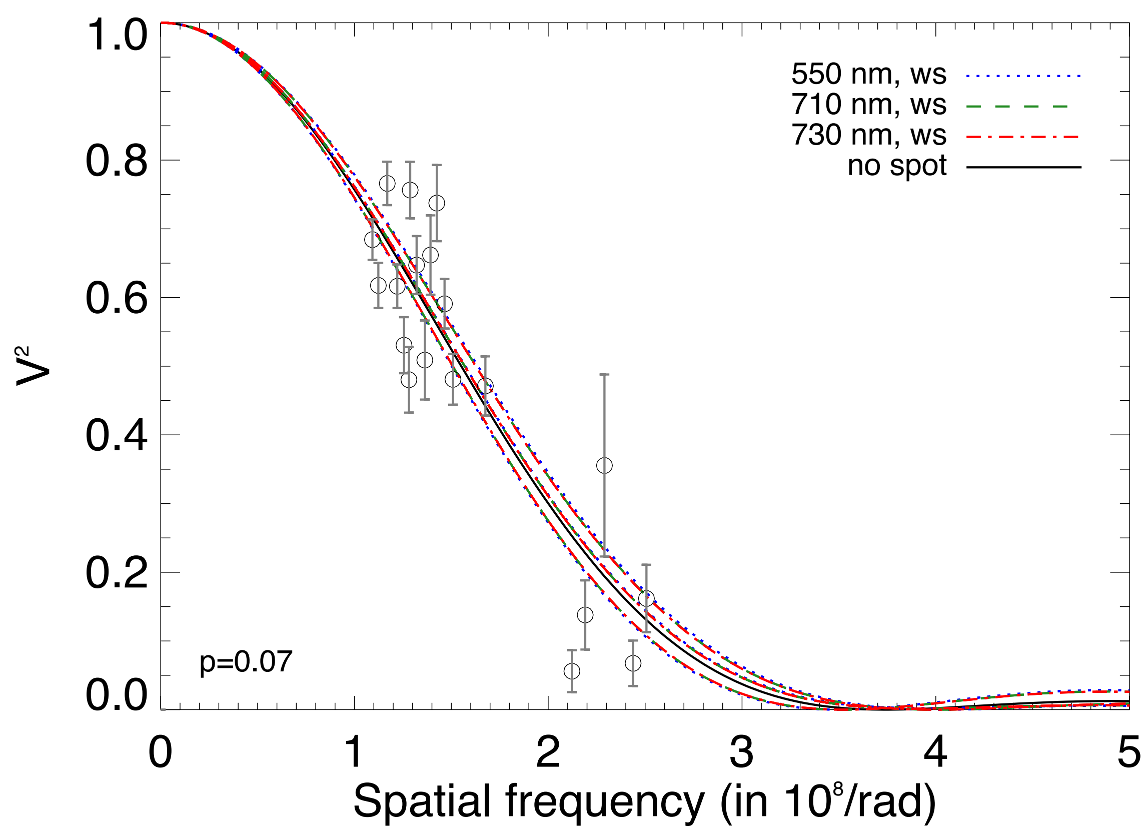
T_{eff} = 6200 K

Observations with VEGA/CHARA

Spot of 4200 K, two filling factors (7 and 22%)

➞ Could the dispersion in the V^2 measurement be due to stellar spots?





Bonnefoy et al. 2018

using COMETS (Ligi et al. 2015)

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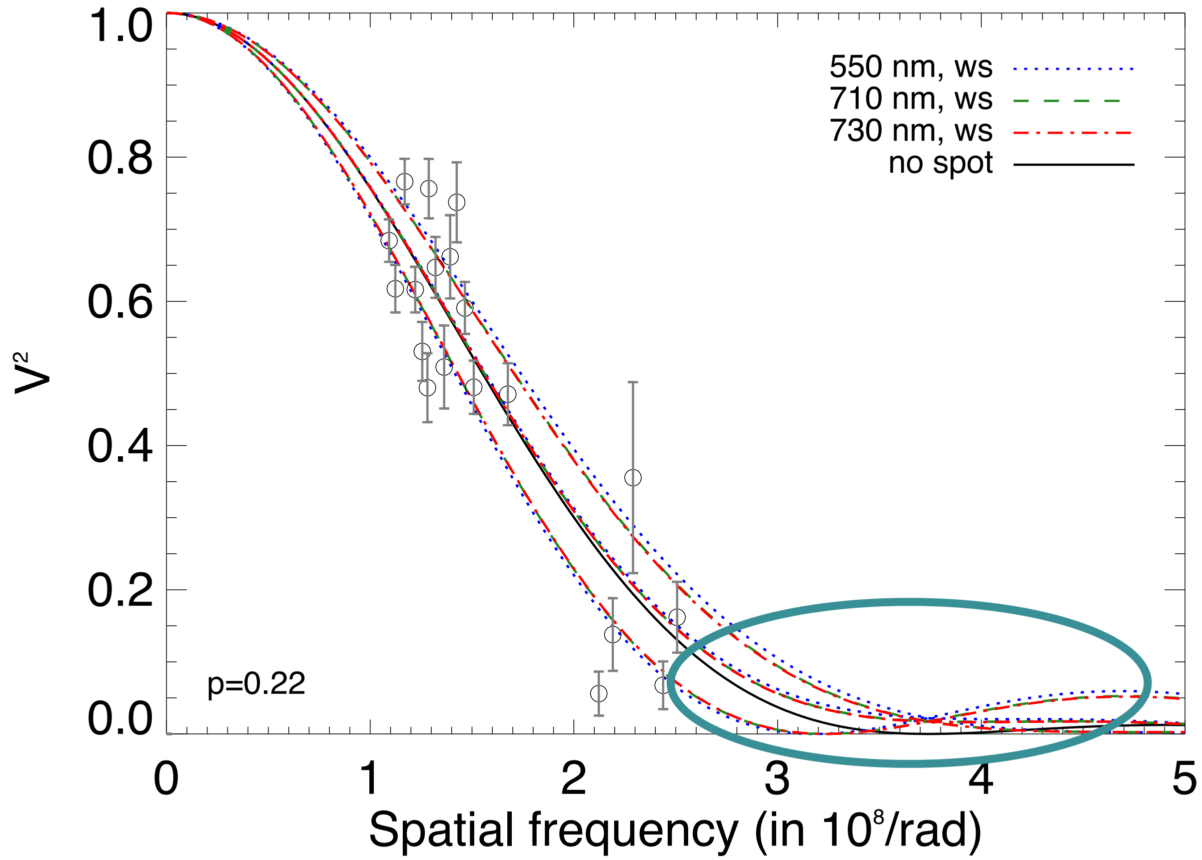
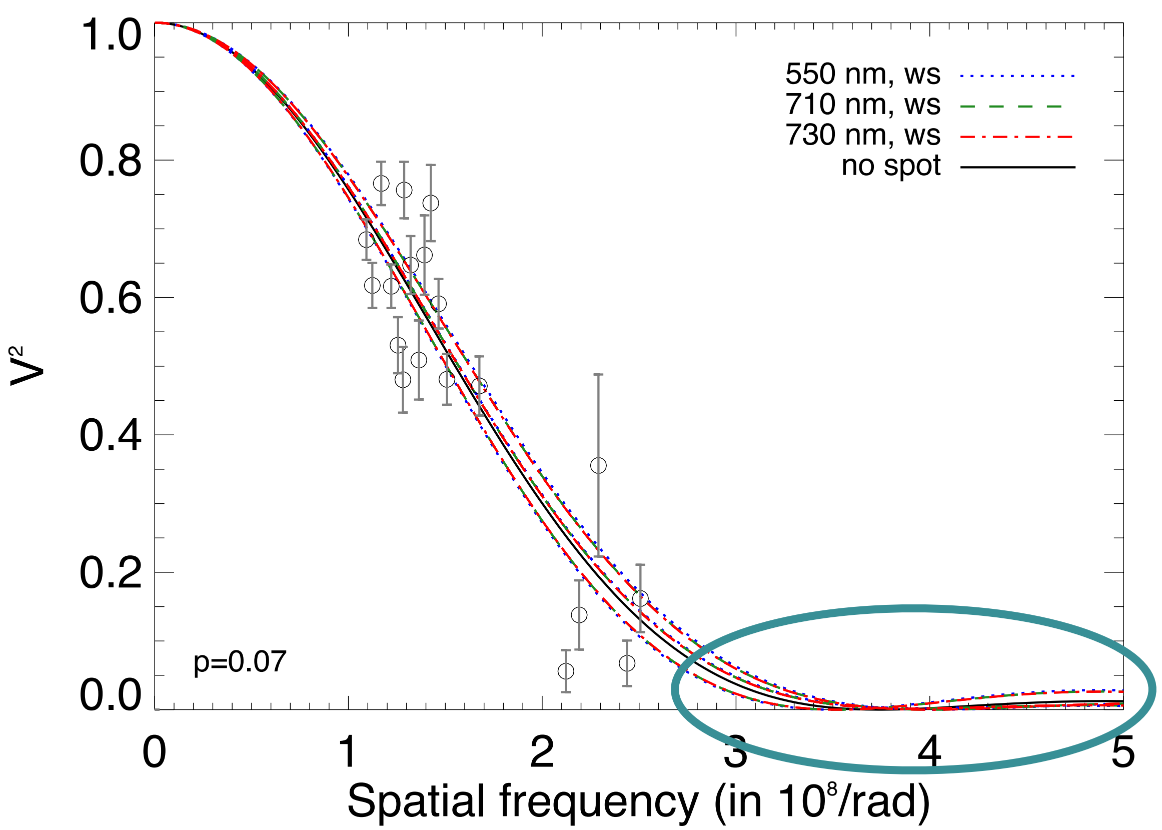




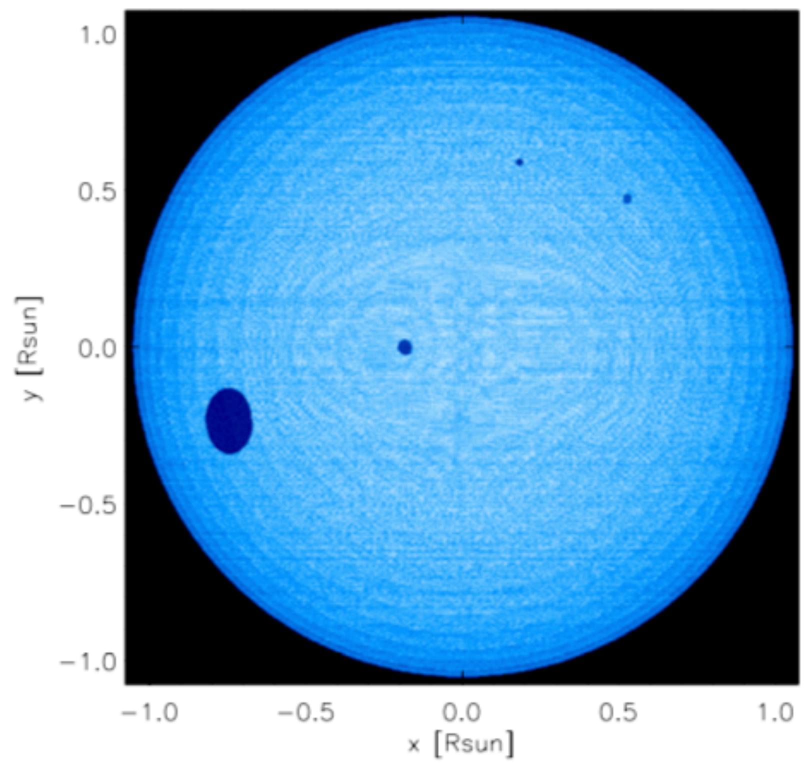
- The V^2 curves with and without a spot can be mixed ➞ need a follow-up in time
- Effects at low V^2

Bonnefoy et al. 2018

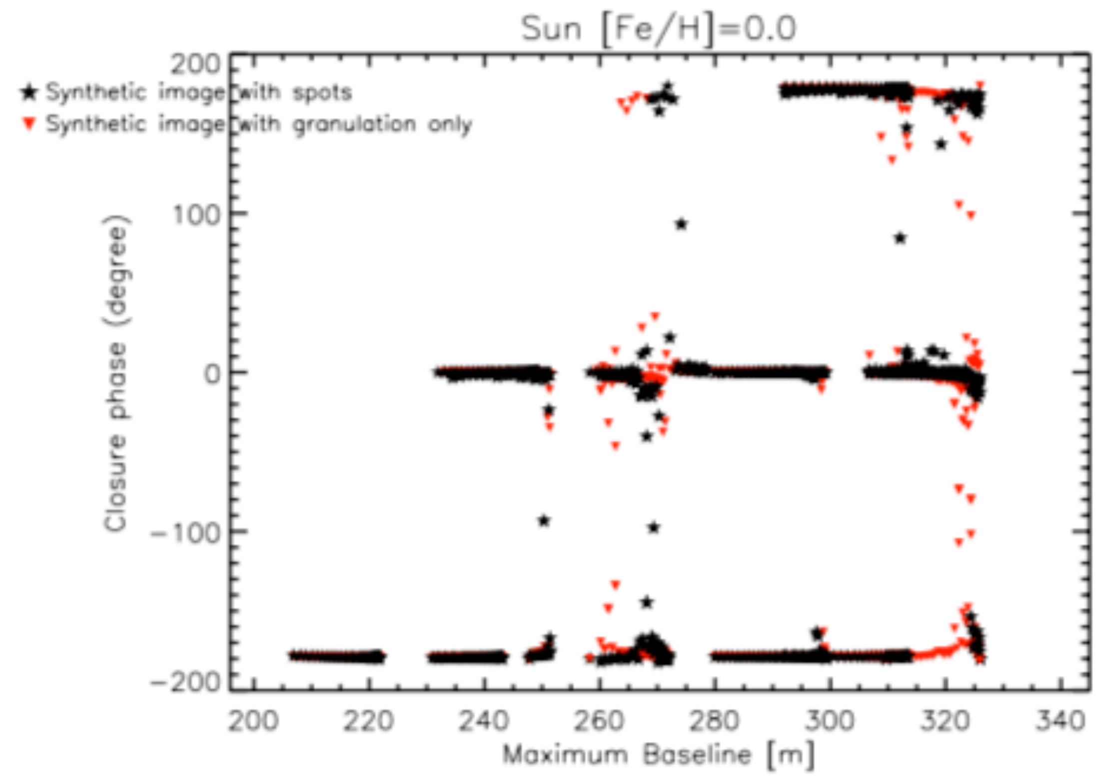
using COMETS (Ligi et al. 2015)

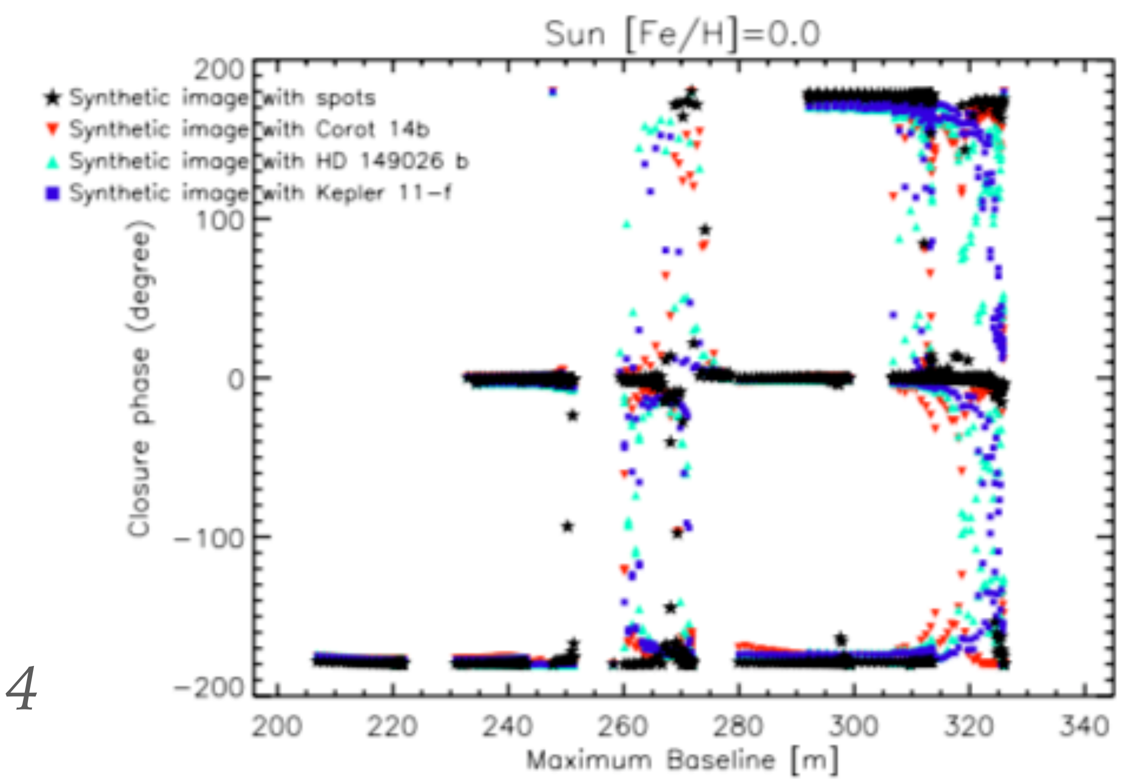
OTHER EFFECT: GRANULATION

Model



Spots, convection and transiting planets signatures can be mixed up in the CP.



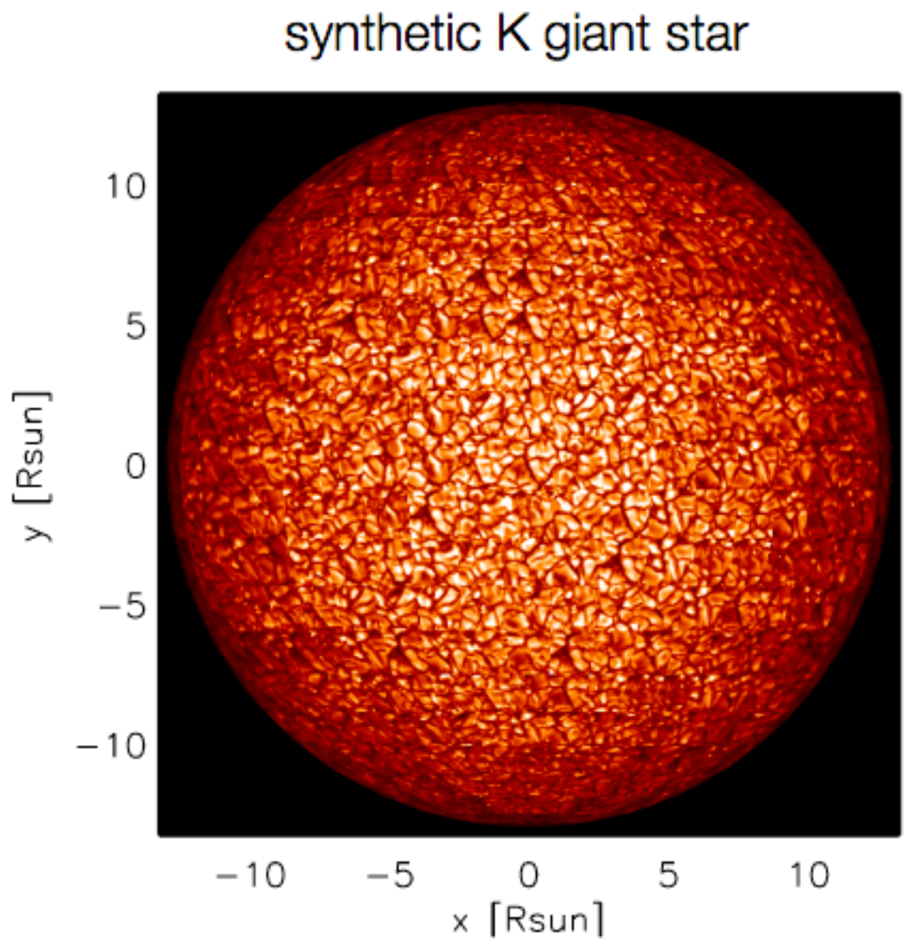


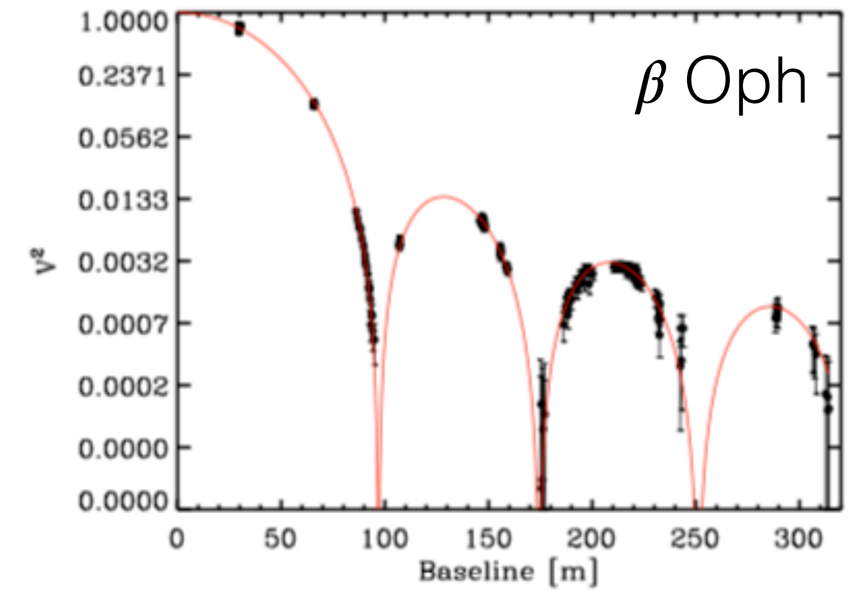
Chiavassa et al. 2014

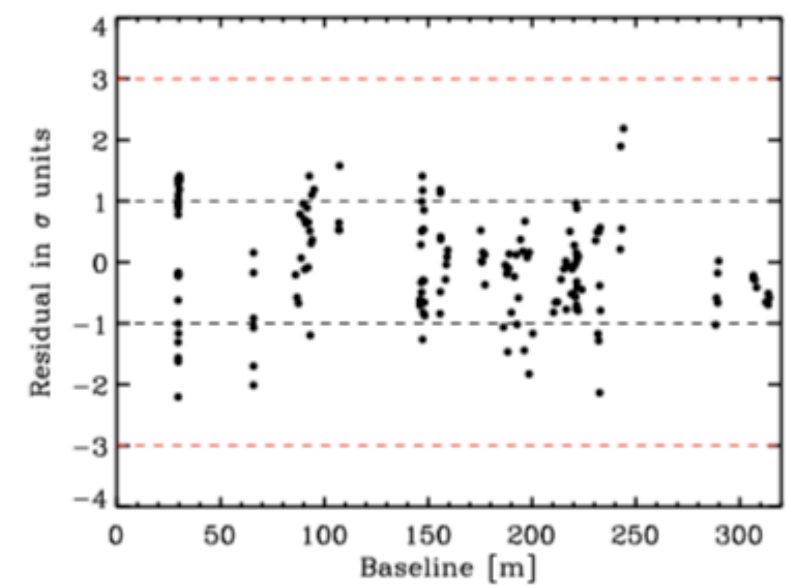
Using OPTIM3D

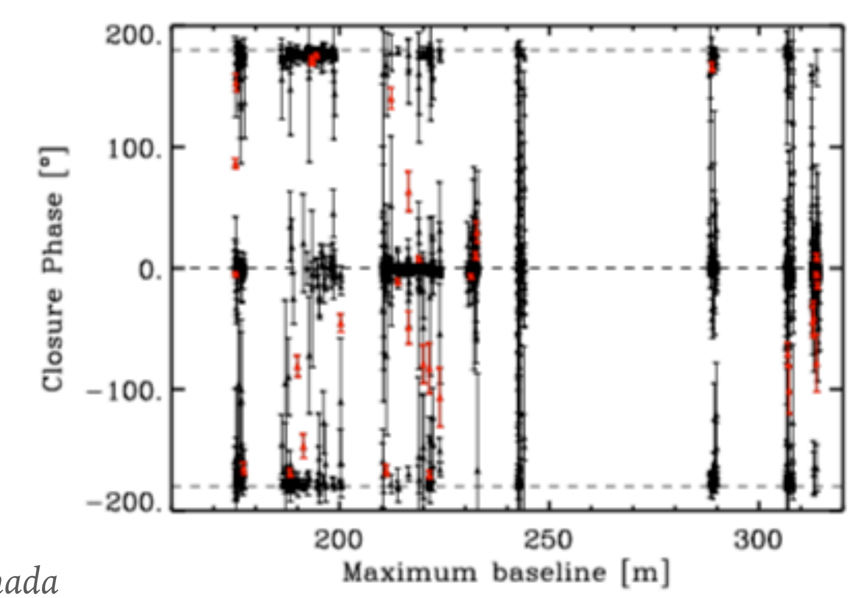
OTHER EFFECT: GRANULATION

Observations









Observations with MIRC/CHARA of K Giant stars

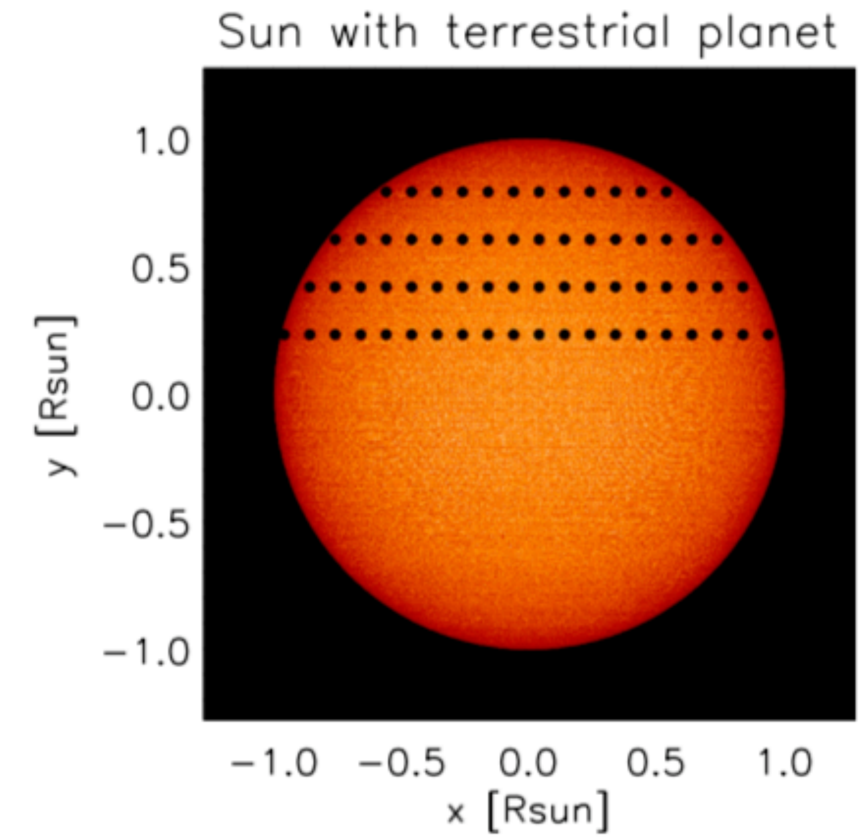
Departure from 0±π ➞ signature of convection
Correlated with gravity?

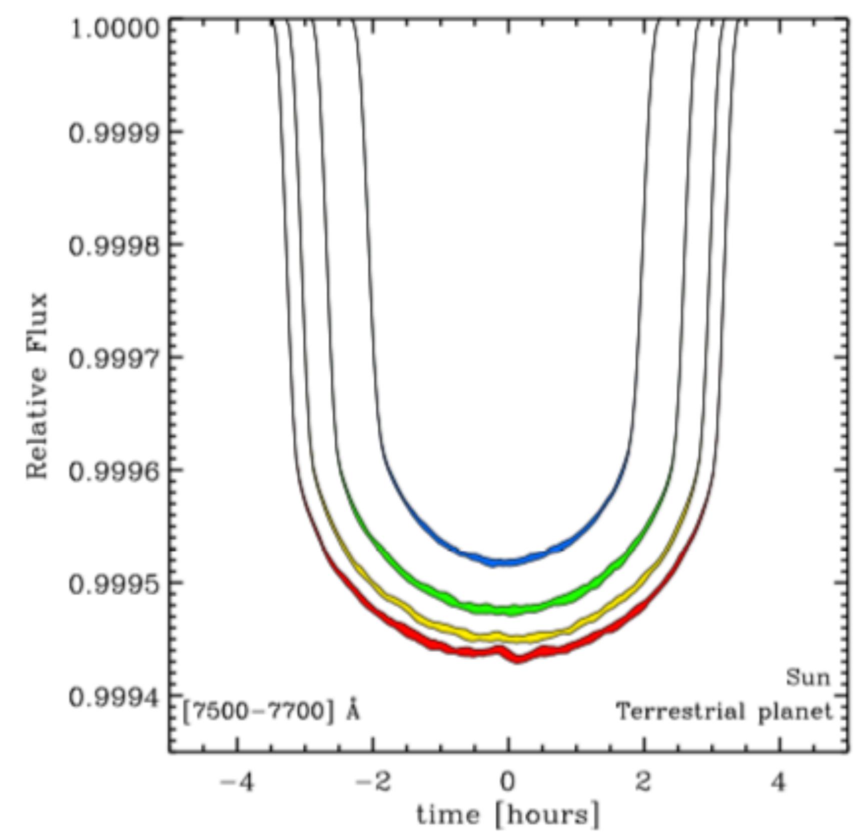
Chiavassa et al. 2017a

OTHER EFFECT: GRANULATION

The granulation patterns affect the photometric measurements (transits):

- timescale of granulation (~10 min) < timescale of transit (up to hours)
- Occultation of local regions of the photosphere with diverse surface brightness





Chiavassa et al. 2017b

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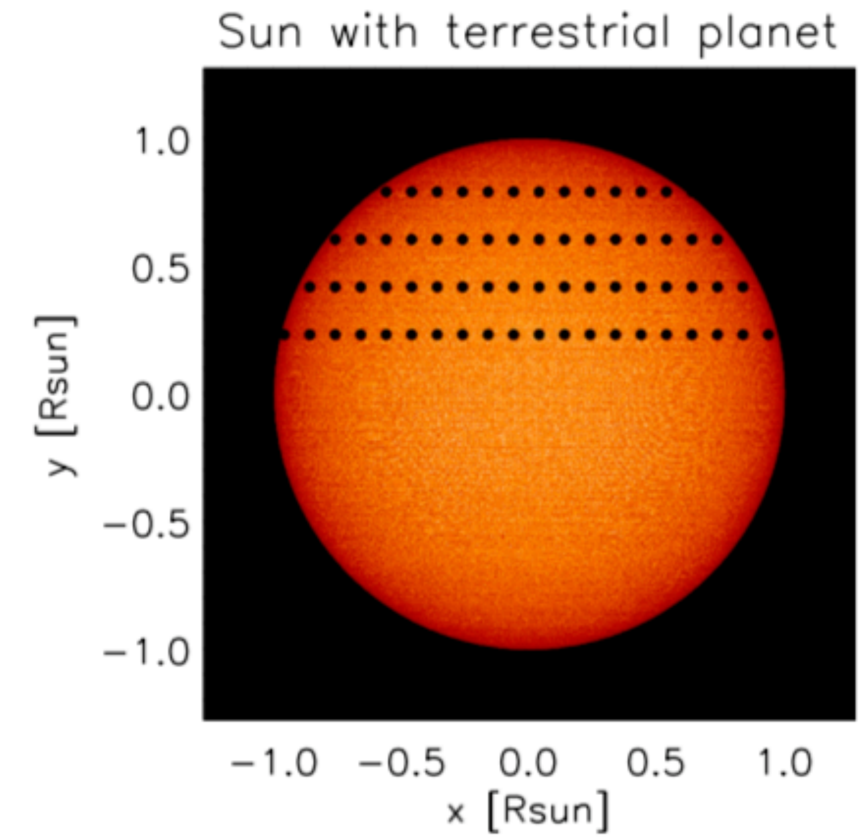
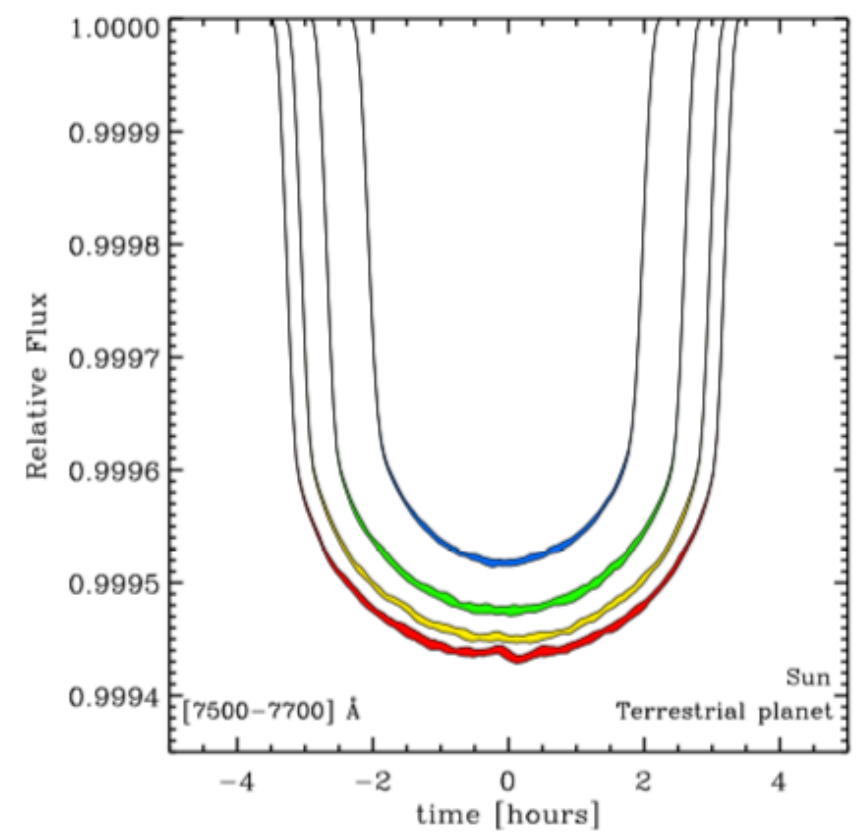


1. Granulation affects the photon noise (up to 3% noise)
2. Stronger fluctuations for larger planets and optical wavelengths
3. Radius fitting: variation of 0.47% to 0.90% in the planetary radius (Sun and terrestrial planet)



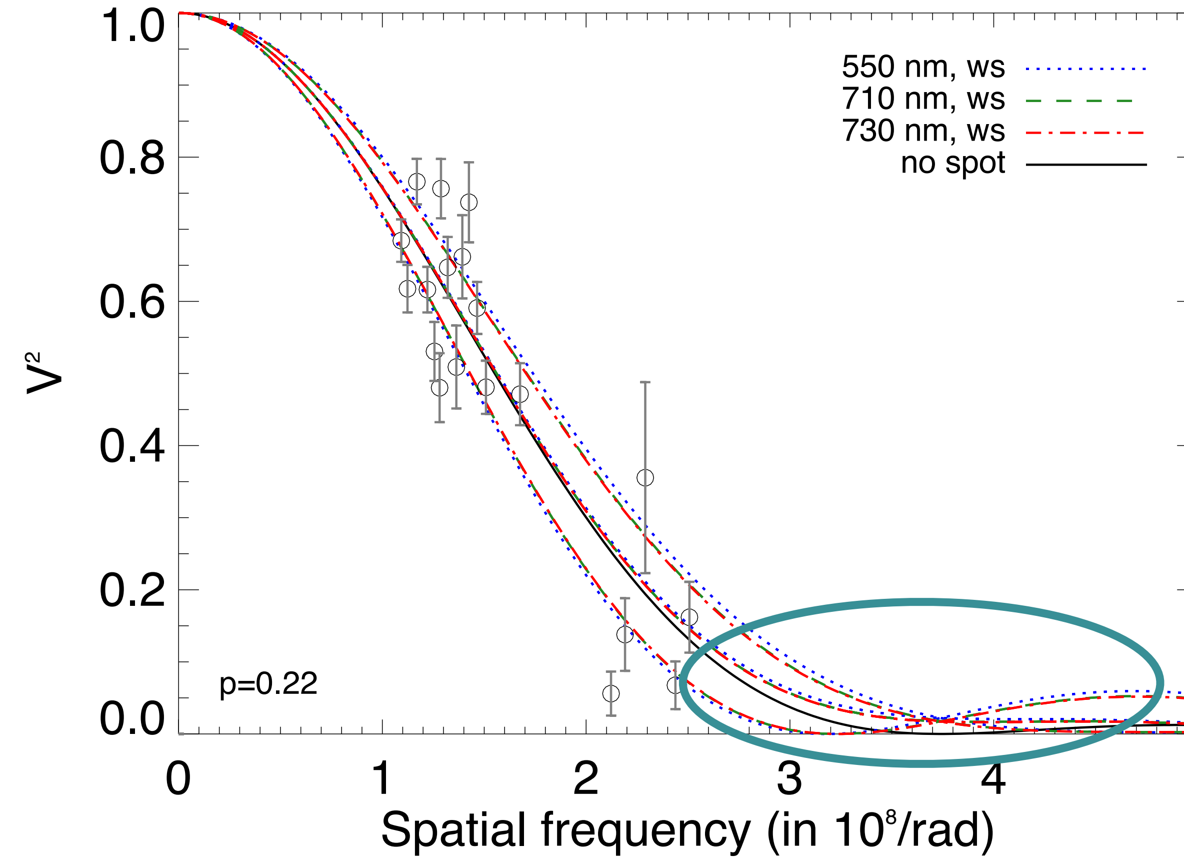
Chiavassa et al. 2017b

CONCLUSION

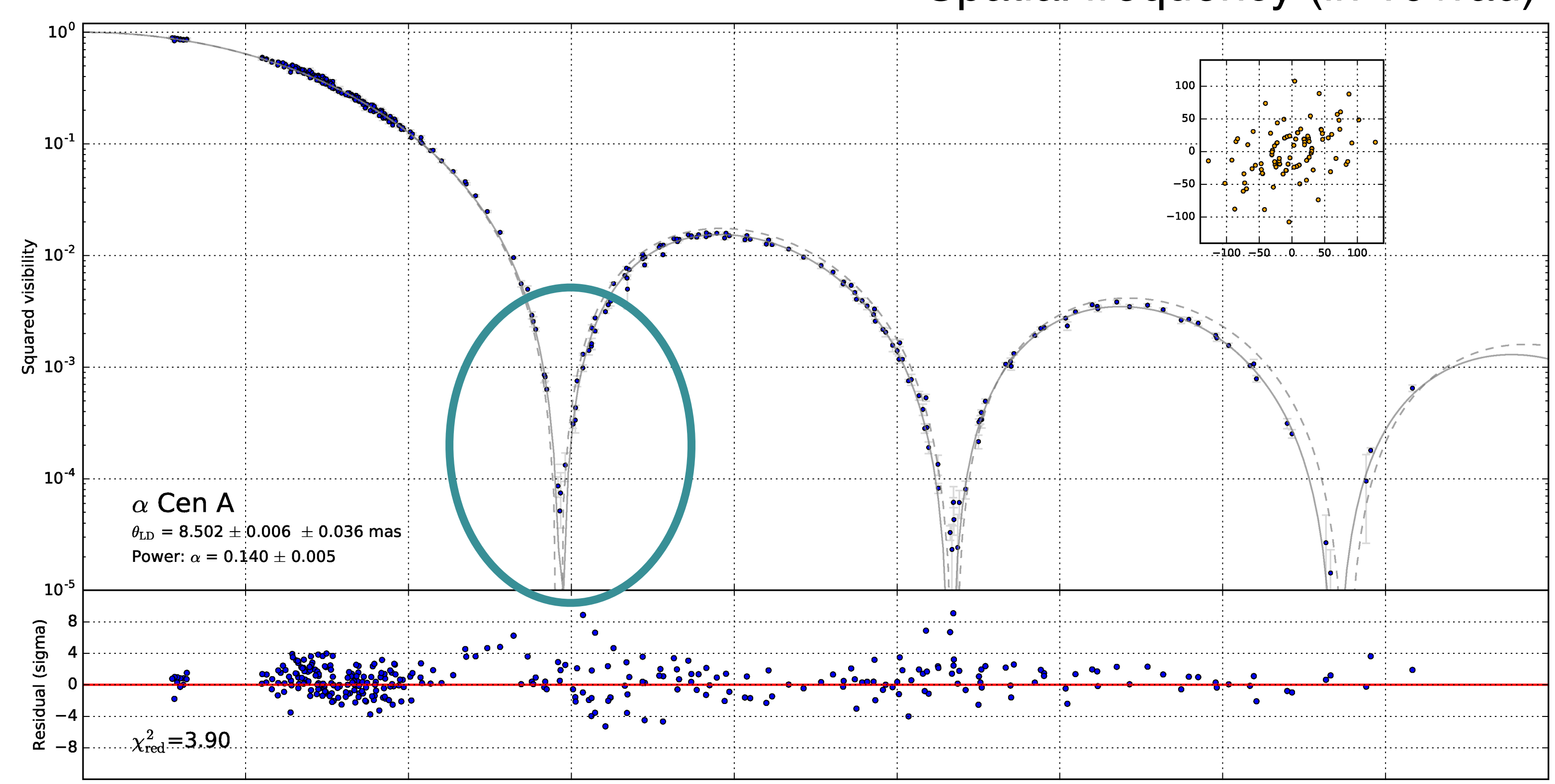
Bonnefoy et al. 2018

Taking into account all the effects simultaneously is necessary.

But is it possible?



Different signatures between the limb-darkening and stellar spots



Kervella et al. 2017

CONCLUSION

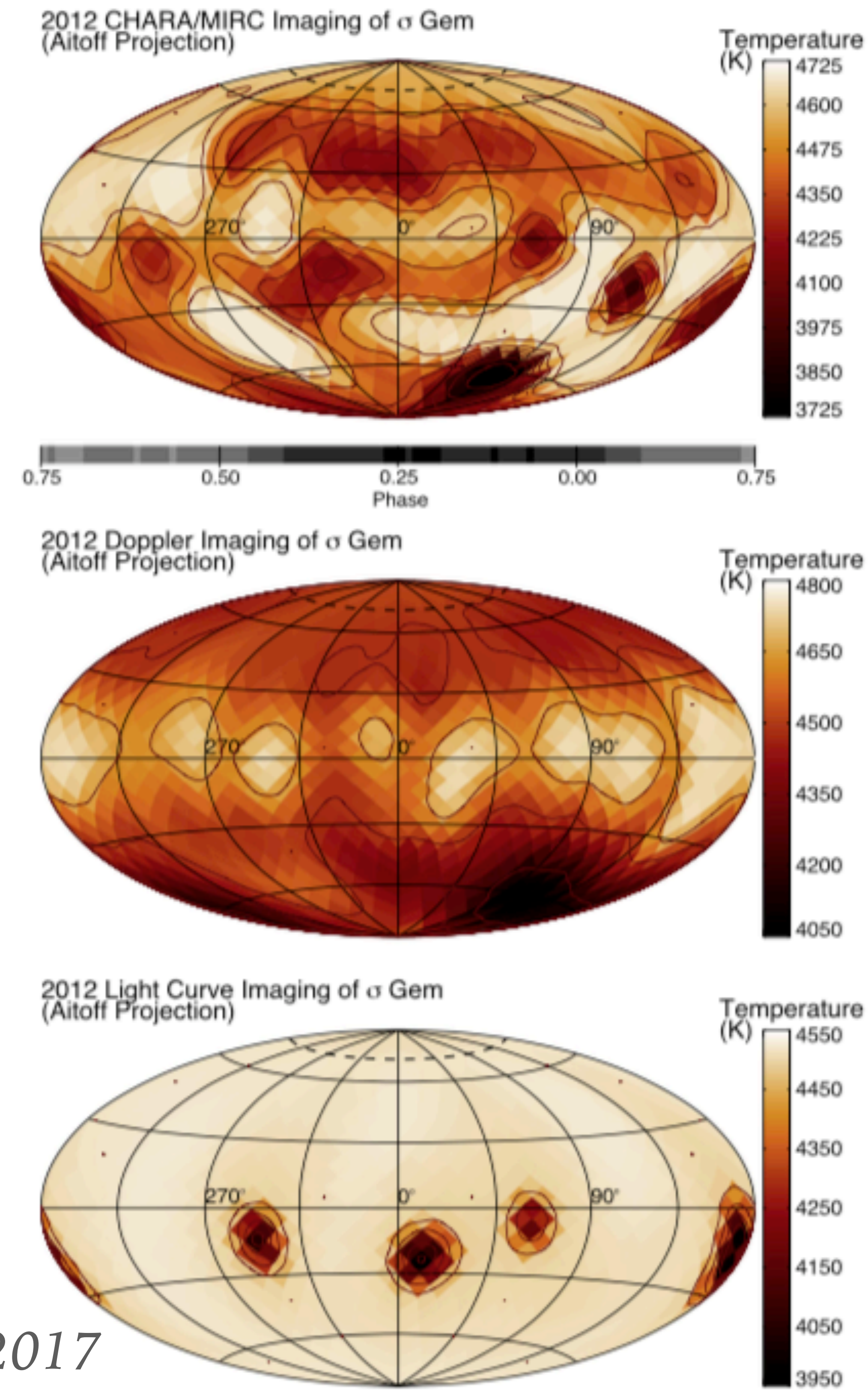
Solution 1: current imaging?

- not possible on all type of stars
  → use benchmarks stars?
- some discrepancies between techniques.

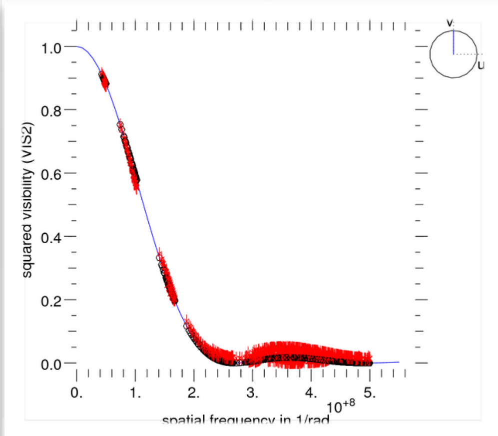
Solution 2: new instruments

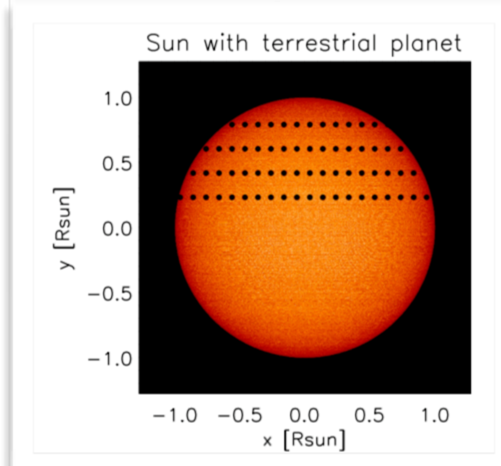
- SPICA/CHARA
  (c.f. Denis's talk)
- MIRCX/CHARA

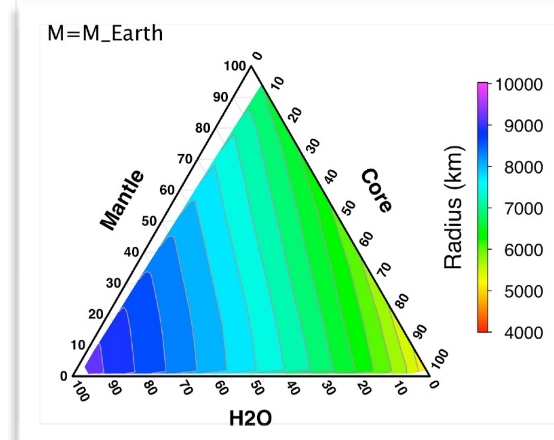
Solution 3: Follow-up in time, multi-techniques?



Roettenbacker et al. 2017







THANK YOU FOR YOUR ATTENTION