DISENTANGLING STELLAR ACTIVITY FROM EXOPLANETARY SIGNALS WITH INTERFEROMETRY

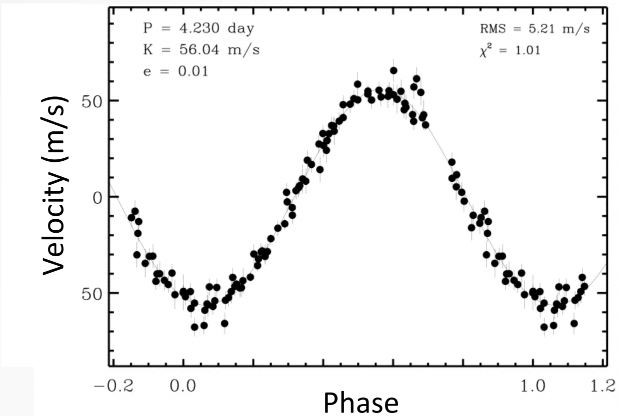
Roxanne Ligi

Denis Mourard, Anne-Marie Lagrange, Karine Perraut & Andrea Chiavassa

CoRot Symposium 3 – Kepler KASC-7 joint meeting

INTRODUCTION

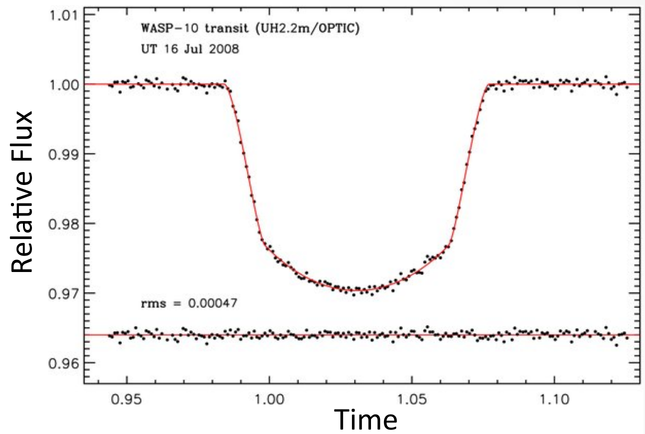
Radial Velocity:



$$\frac{(m_p \sin i)^3}{(M_\star + m_p)^2} = \frac{P}{2\pi G} K^3 (1-e)^{3/2}$$

accuracy on $m_p / M_\star$ << 1%

Transits:



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1. Obtain stellar parameters with 2% accuracy

Stellar activity (magnetic spots, granulation) ➔ noise + false detection

2. How can we deal with stellar activity?

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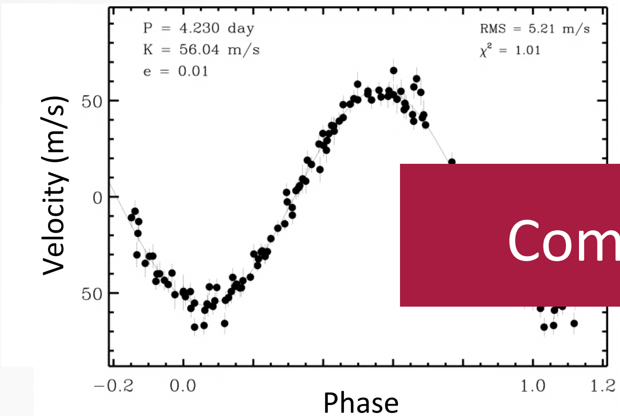

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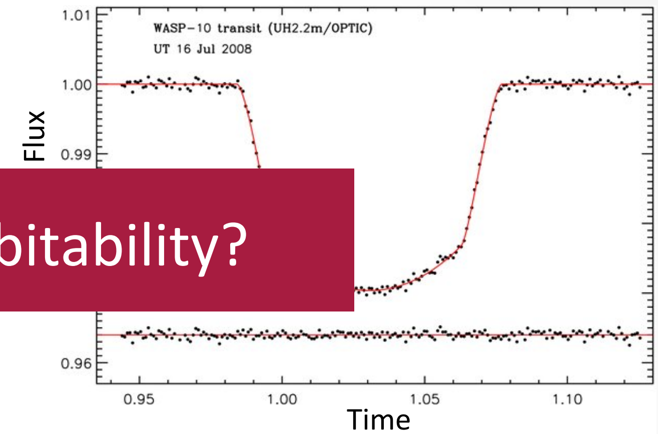

Composition? Habitability?

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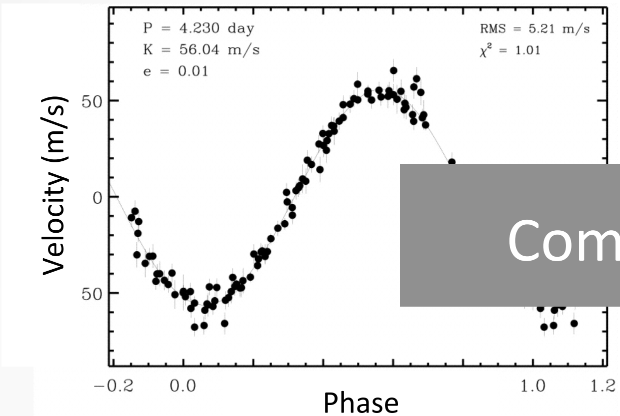

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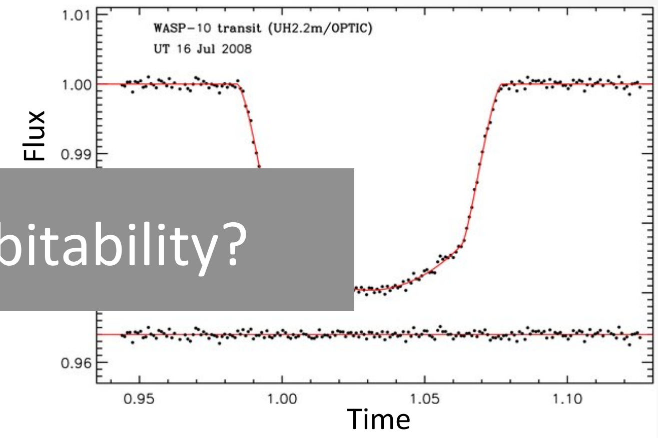

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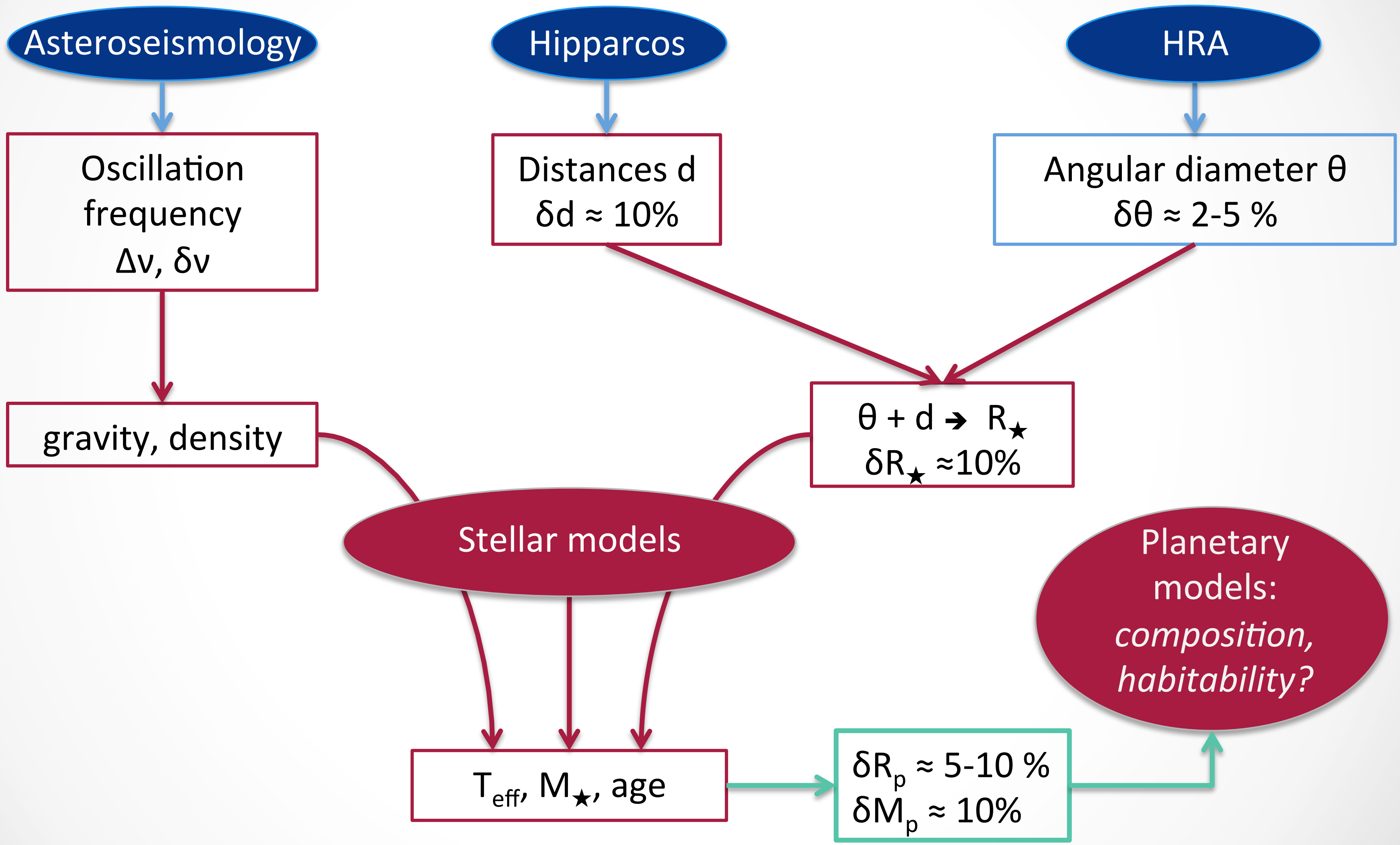
STELLAR PARAMETERS



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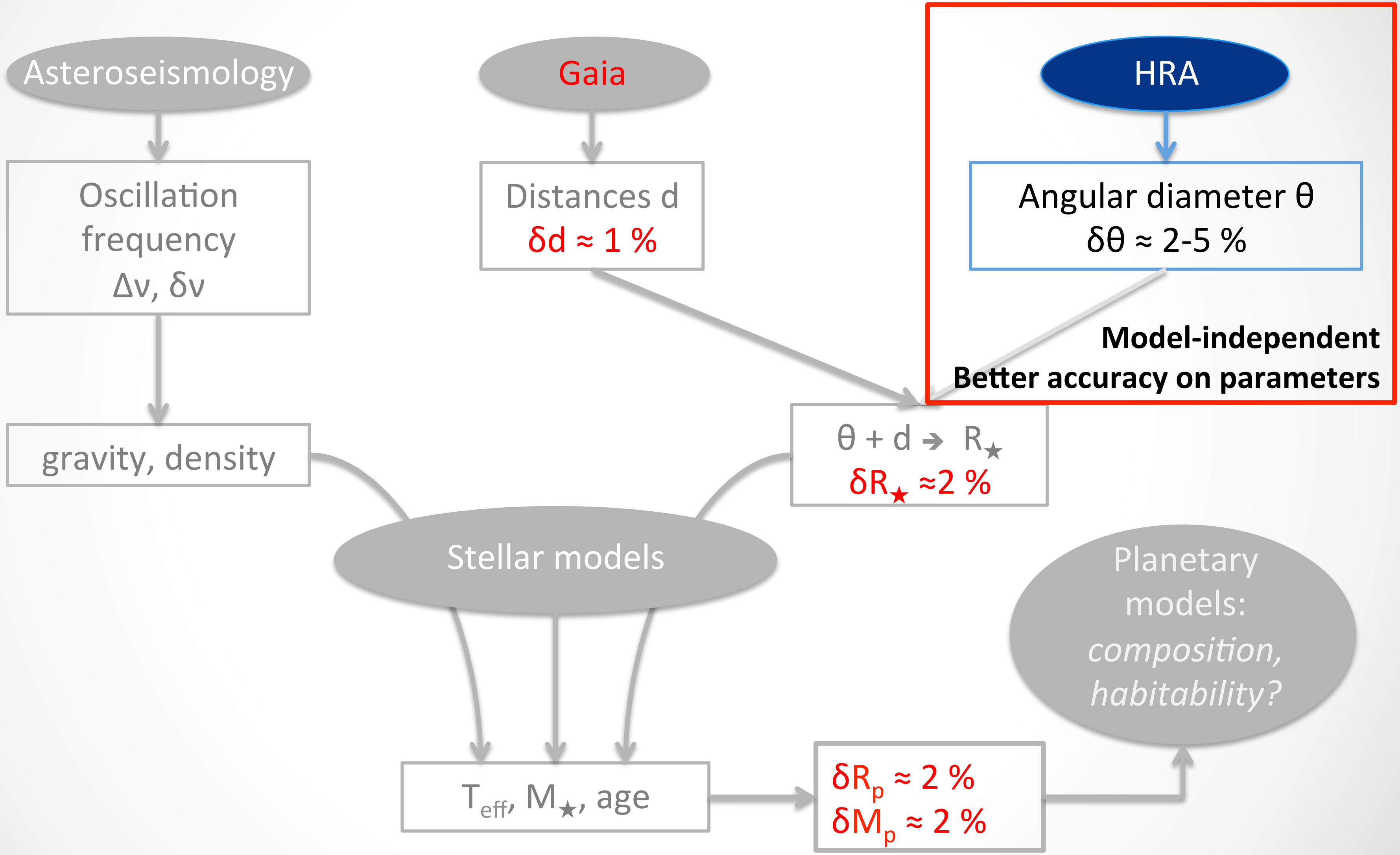
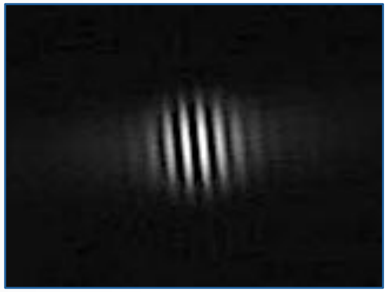


INTERFEROMETRY PRINCIPLE

Two beams ψ_1 et ψ_2 coming from the same source and mixed in a coherent way.



van Cittert & Zernicke theorem:

« complex degree of mutual coherence Υ_{12} equals the Fourier transform of the spatial intensity distribution of the source. »

$$\frac{\langle \psi_1 . \psi_2^* \rangle}{\sqrt{\langle |\psi_1{}^2| \rangle . \langle |\psi_2{}^2| \rangle}} = \gamma_{12} = \frac{\hat{\mathrm{I}}\left(\frac{B}{\lambda}\right)}{\hat{\mathrm{I}}(0)}$$

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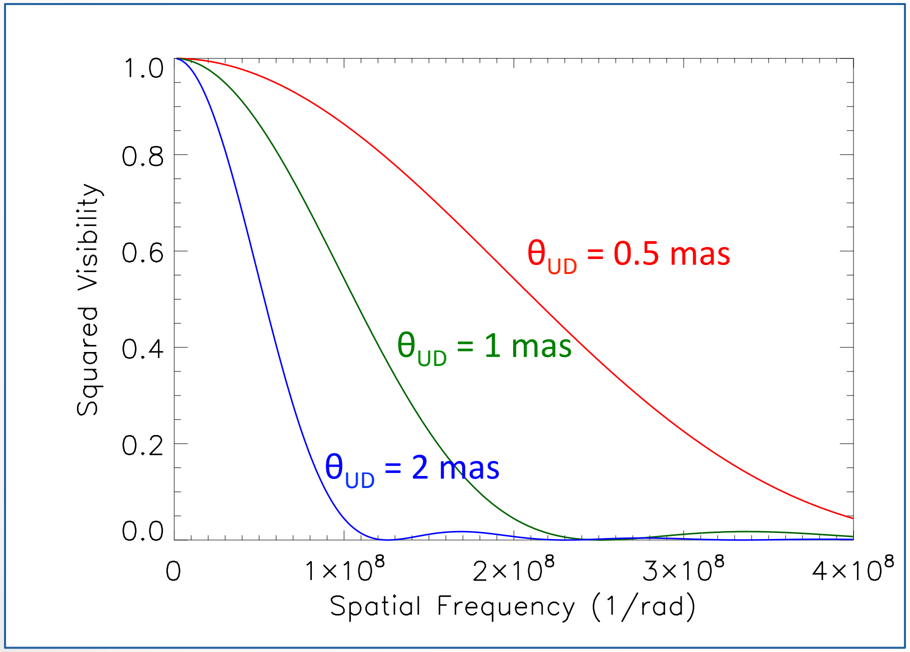

$$|\gamma_{12}| = V_\lambda \left(\frac{B}{\lambda}\right)$$ Measured by the interferometer

Uniform disk : $$V_\lambda{}^2 \left(\frac{B}{\lambda}\right) = 4 \left|\frac{J_1(z)}{z}\right|^2$$

with $$z = \pi \theta_{UD} \, {}^{B}/_{\lambda}$$

INTERFEROMETRY PRINCIPLE

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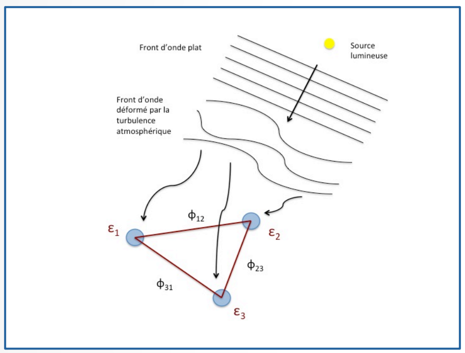

$$\arg(\gamma_{12}) = \Phi\left(\frac{B}{\lambda}\right)$$

$$|\gamma_{12}| = V_\lambda \left(\frac{B}{\lambda}\right)$$

Measured by the interferometer

Measurement of differential phases
and

if 3 telescopes :
3 arguments,
3 phases:
measurement of the
phase closure

$$\Sigma \left\{ \begin{array}{l} \phi_{12}^{mes} = \phi_{12}^{abs} + \epsilon_1 - \epsilon_2 \\ \phi_{23}^{mes} = \phi_{23}^{abs} + \epsilon_2 - \epsilon_3 \\ \phi_{31}^{mes} = \phi_{31}^{abs} + \epsilon_3 - \epsilon_1 \end{array} \right.$$

$$\Downarrow$$

$$\phi_{12}^{mes} + \phi_{23}^{mes} + \phi_{31}^{mes} = \phi_{12}^{abs} + \phi_{23}^{abs} + \phi_{31}^{abs}$$

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STELLAR PARAMETERS

Interferometric results

Summary for 17 stars:

<$\delta\theta_\star$> = 2.4 % with <δd> = 3.8 %

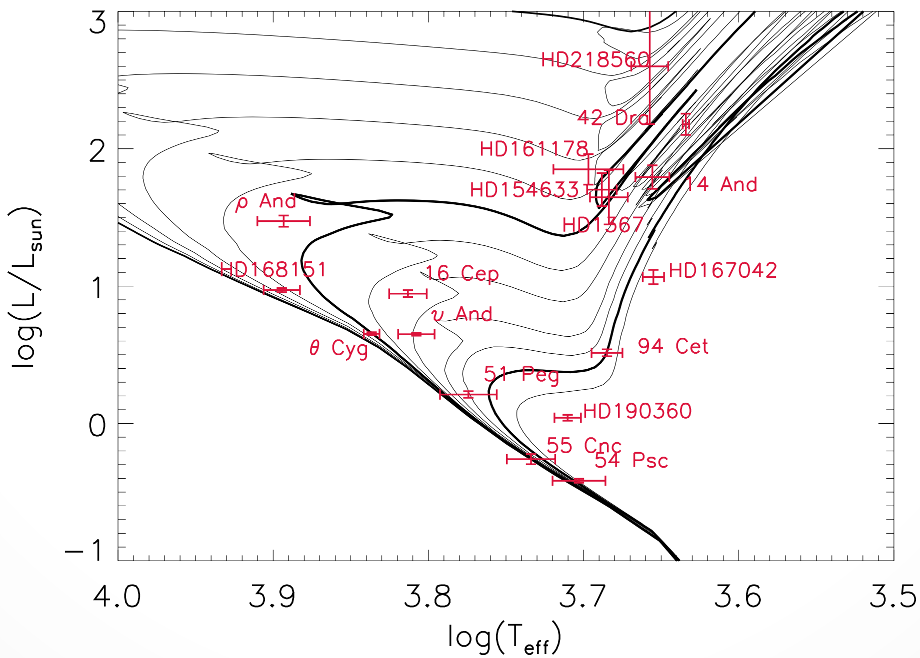
<δR> = 5.0 %

<δT_{eff}> = 100 K

HR diagram

➔ stellar masses and ages

➔ minimum masses of exoplanets



Ligi et al. 2012

Ligi et al., in prep.

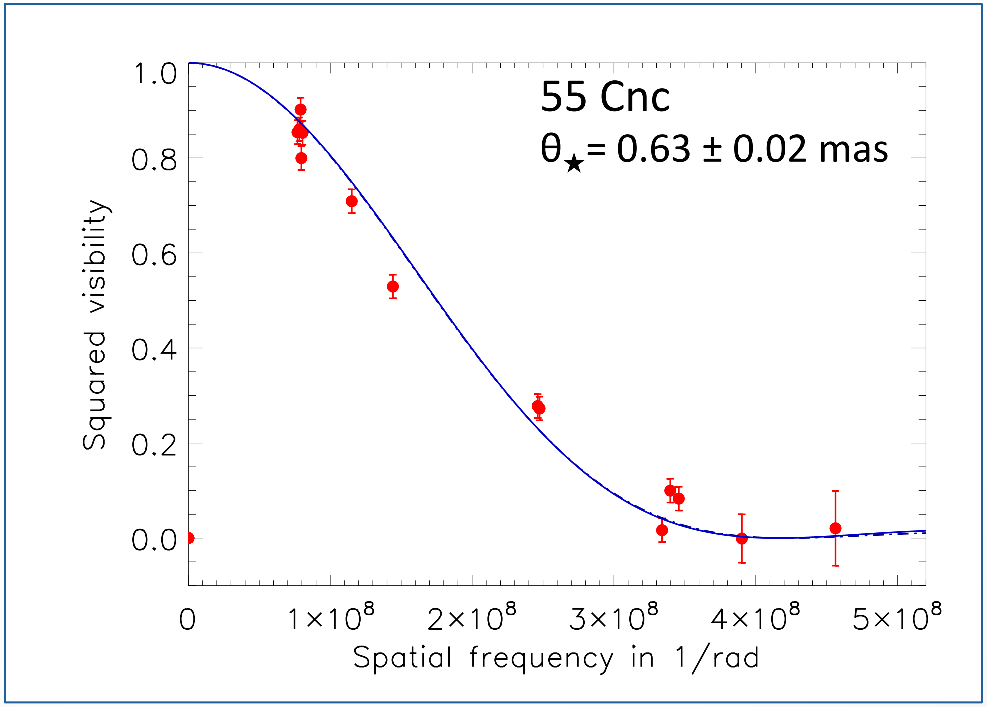
PARSEC tables (*Bressan et al. 2012)*

INTERFEROMETRY PRINCIPLE

Limitations

Current limitations:

- the measured signals contain the signal of the stellar intrinsic noise
- not possible to directly measure the LD, nor stellar activity effects… : not possible to measure very low visibilties



INTERFEROMETRY PRINCIPLE

Limitations

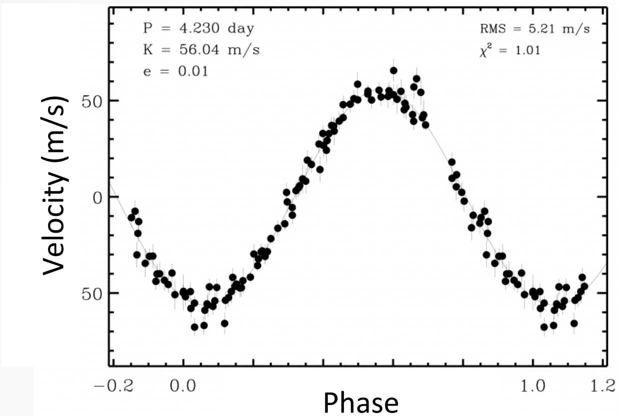
In the future : more sensitive instruments

- the noise signal will be measurable ➔ AO
- transiting exoplanets can be characterized

- Improve instrumentation
- Impact of stellar activity on interferometric observables?
  - future needs in instrumentation?
  - prepare adequate observing strategies
  - prepare the interpretation of future data ➔ evolved models, disentangle exoplanets and activity signals

STELLAR ACTIVITY

Radial Velocity:



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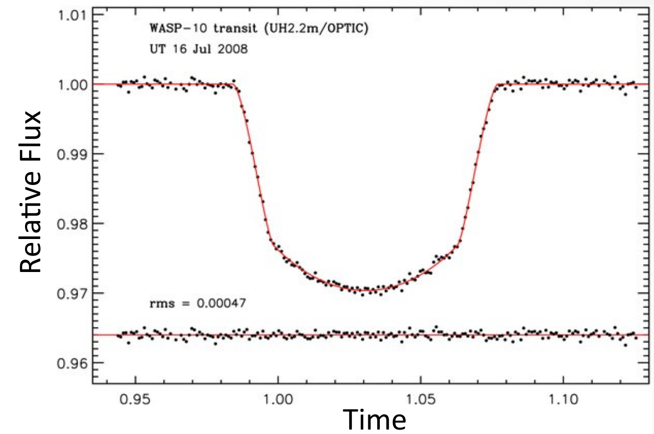

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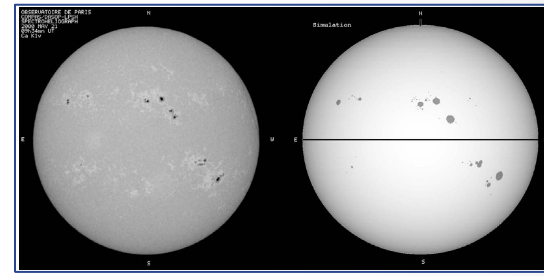
STELLAR ACTIVITY

Stellar activity linked to the detection and characterization of exoplanets:

- Radial velocity measurements :
  - Spots can mimic planetary signals (ex. : HD166435, *Queloz et al. 2001, Gliese d and g*)
  - Noise on RV and BVS (e.g. *Lagrange et al. 2010, Meunier et al. 2010, Dumusque et al. 2011, Boisse et al. 2011, Desort et al. 2007…)* bigger than the exopanet's signal



Lagrange et al. (2010)

- Transits:
  - Disturb photometric measurements, anomalies (e.g.: Sanchis-Ojeda & Winn 2011)
  - *Kepler* and CoRoT

➔ **Need to detect and characterize stellar activity**

INTERFEROMETRY AND PLANETARY TRANSITS

Could interferometry be of any help?

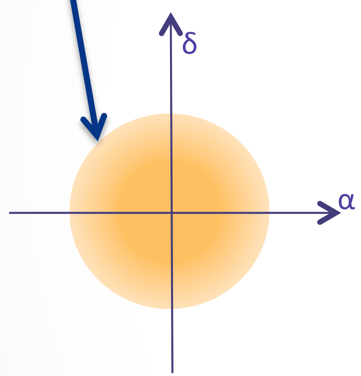
- Bridge the gap between direct imaging (wide companions) and RV (close companions) *(Le Bouquin & Absil 2012)*
- Only method to provide the transit velocity, stellar and planetary radius, impact parameter and transit ingress time without the need of other observations (*van Belle et al. 2008*) through closure phase measurements ➔ inclinaison and orientation of the planetary orbit
- Attemps to detect exoplanets or spots with interferometry: *Matter et al. (2010); Zhao et al. (2008, 2011); Baron et al. (2012)*

BUT no study in the visible; however

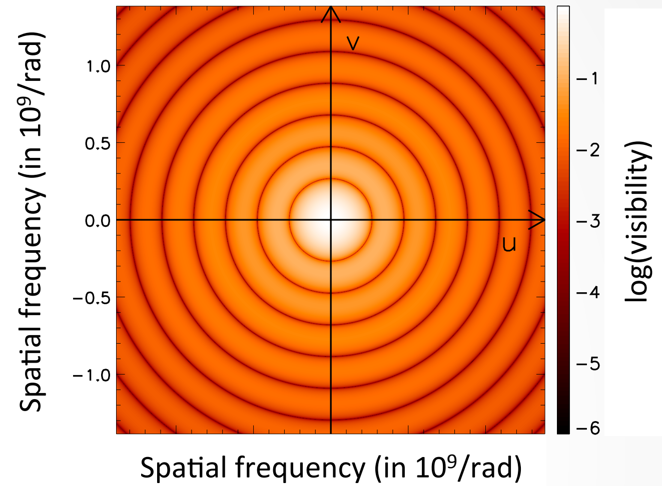
- Better angular resolution
- Complementary spectral domain to RV and photometry

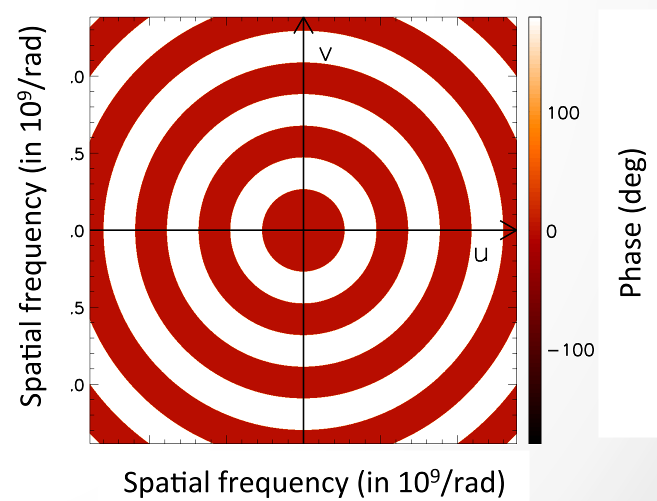
COMETS: *COde for Modeling ExoplaneTs and Spots*

Reference star:
limb-darkened disk



Analytical
TF





Ligi et al., A&A, 2014, subm.

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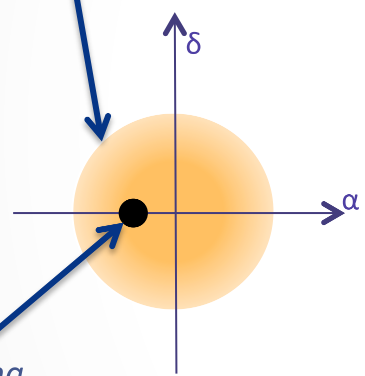
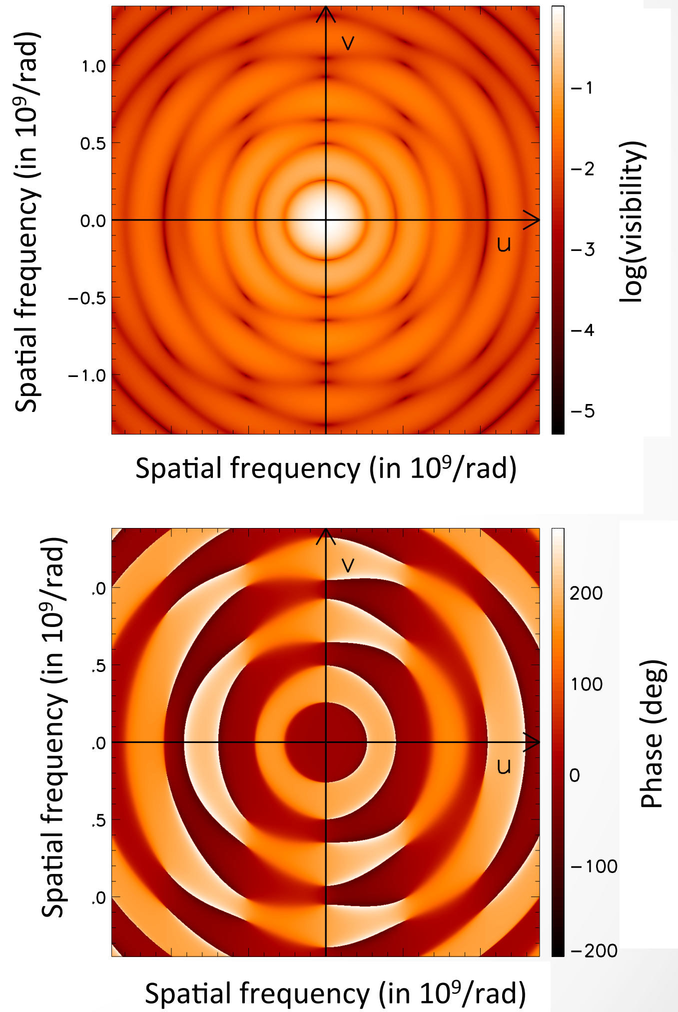


transiting exoplanet

Additional components

Analytical TF



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COMETS: *COde for Modeling ExoplaneTs and Spots*

Detectability: MBL

Minimum Baseline Length

Two ways:

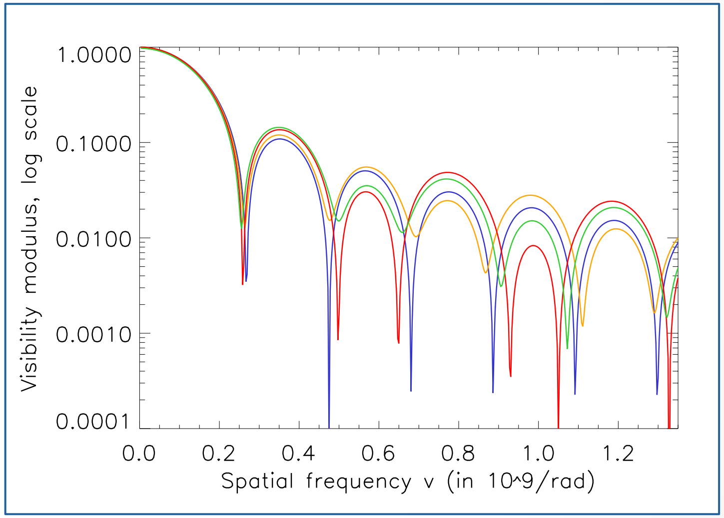
Absolute difference:

$$V_p^2 - V_*^2 > S$$

Relative difference:

$$\frac{V_p^2 - V_*^2}{V_*^2} > \frac{1}{SNR} = \frac{\sigma V^2}{V_*^2}$$

Squared visibility



- star
- star + exoplanet

COMETS: *COde for Modeling ExoplaneTs and Spots*

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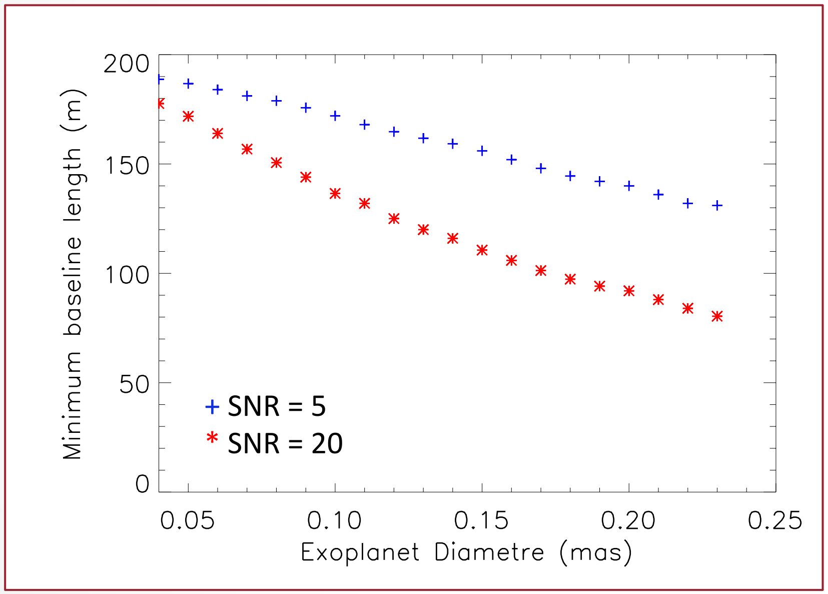
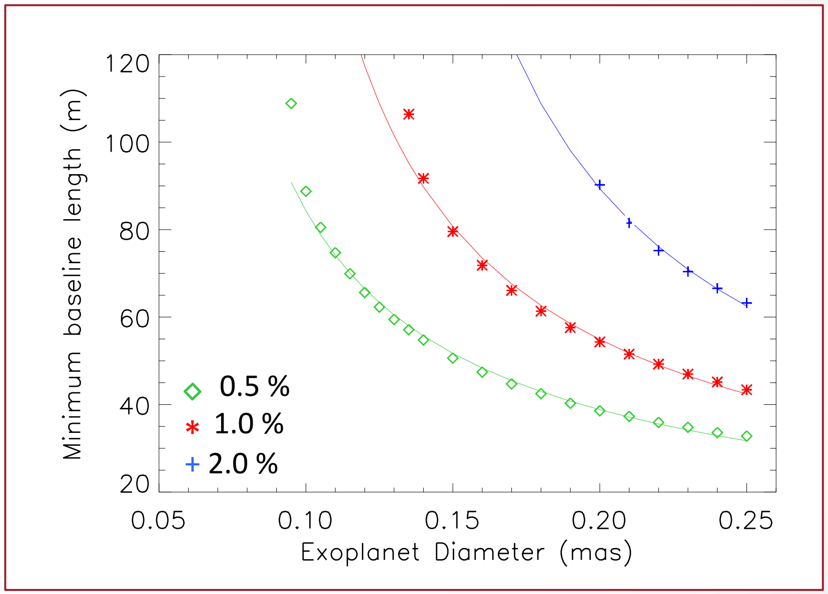
Minimum Baseline Length



Relative error on squared visibilities



Absolute error on squared visibilities

- Test of other parameters: exoplanet position, intensity spot…

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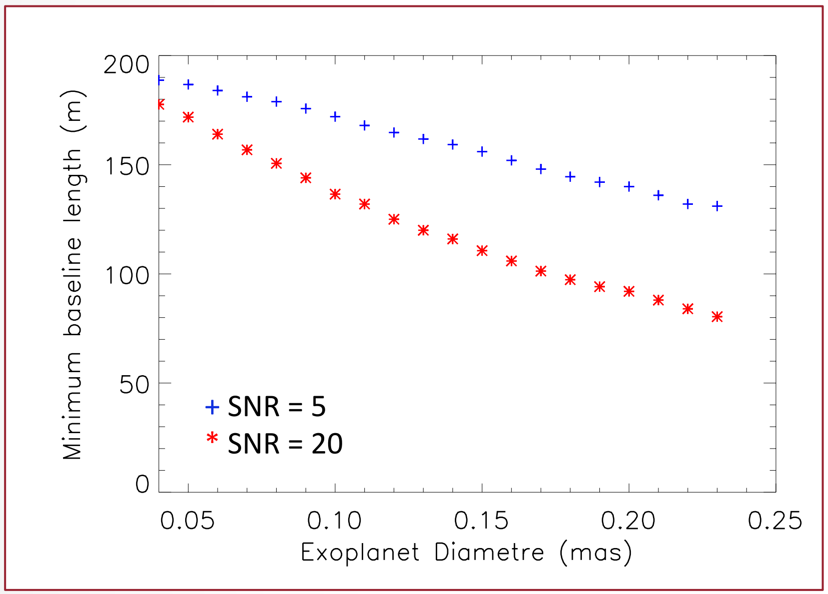

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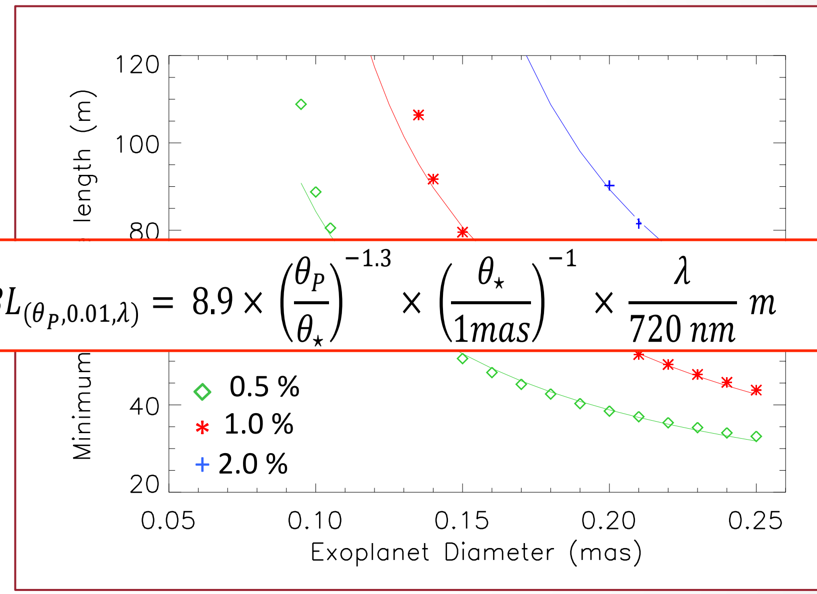

$$MBL_{(\theta_P,0.01,\lambda)} = 8.9 \times \left(\frac{\theta_P}{\theta_\star}\right)^{-1.3} \times \left(\frac{\theta_\star}{1mas}\right)^{-1} \times \frac{\lambda}{720\,nm}\, m$$

Absolute error on squared visibilities

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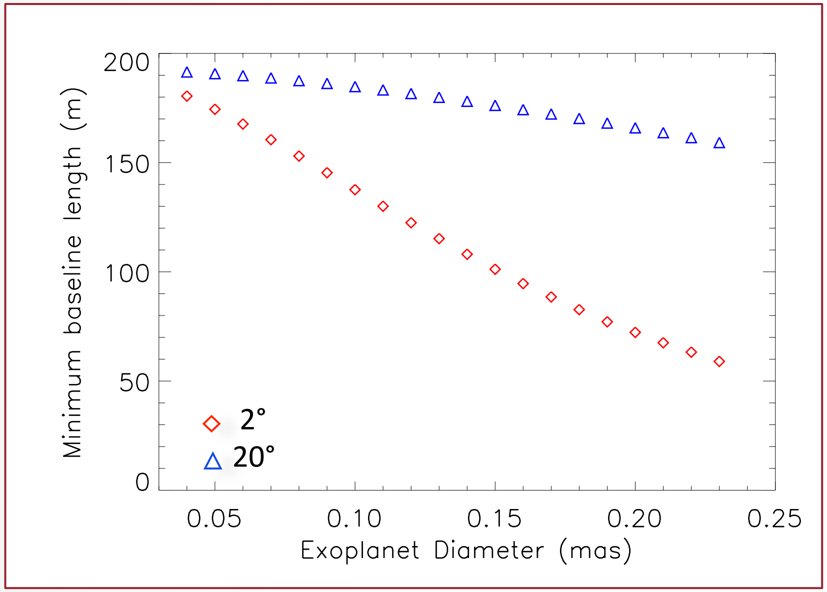


Phase

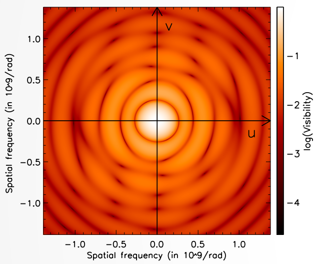
Smallest detectable exoplanet in front of a 1 mas star

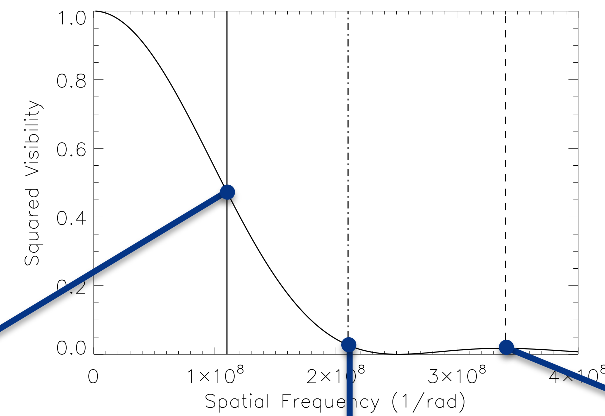
	0.5 %	**SNR = 20**
V^2	0.09 mas 110m	0.04 mas 180m
Phase	0.04 mas 180m	

Baselines already exist (e.g., VEGA/CHARA)
Need more sensitivity (< 1%): is it reachable ?

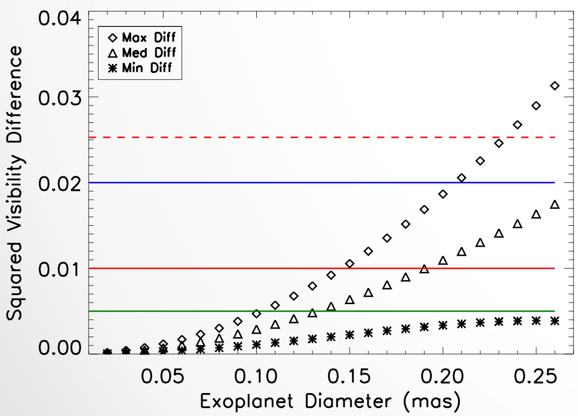
COMETS: *COde for Modeling ExoplaneTs and Spots*

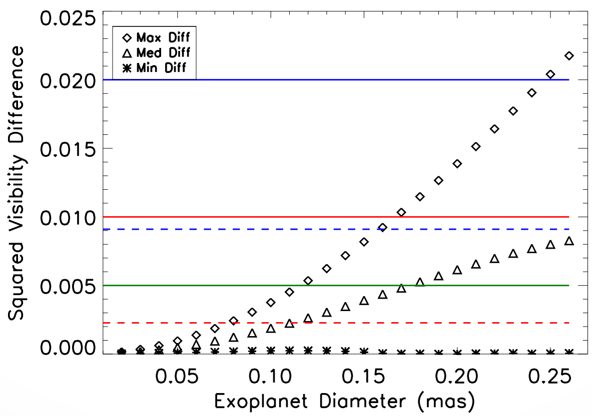
3 spatial frequencies to probe 3 values of the *squared visibilities*

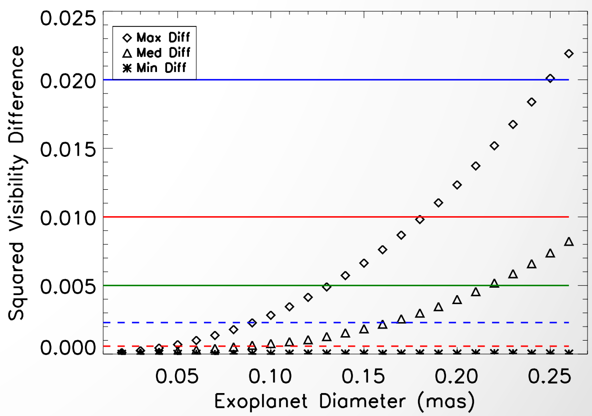




- 0.5 %
- 1.0 %
- 2.0 %
- SNR = 5
- SNR = 20

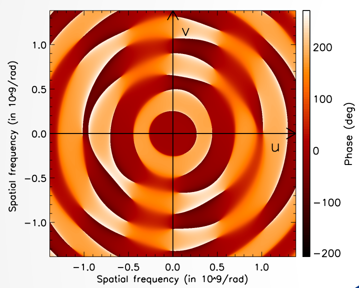


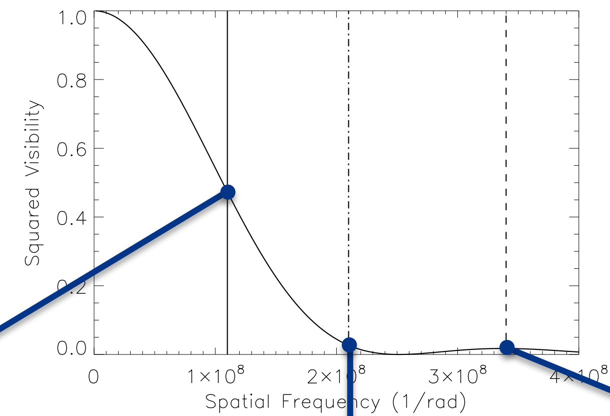


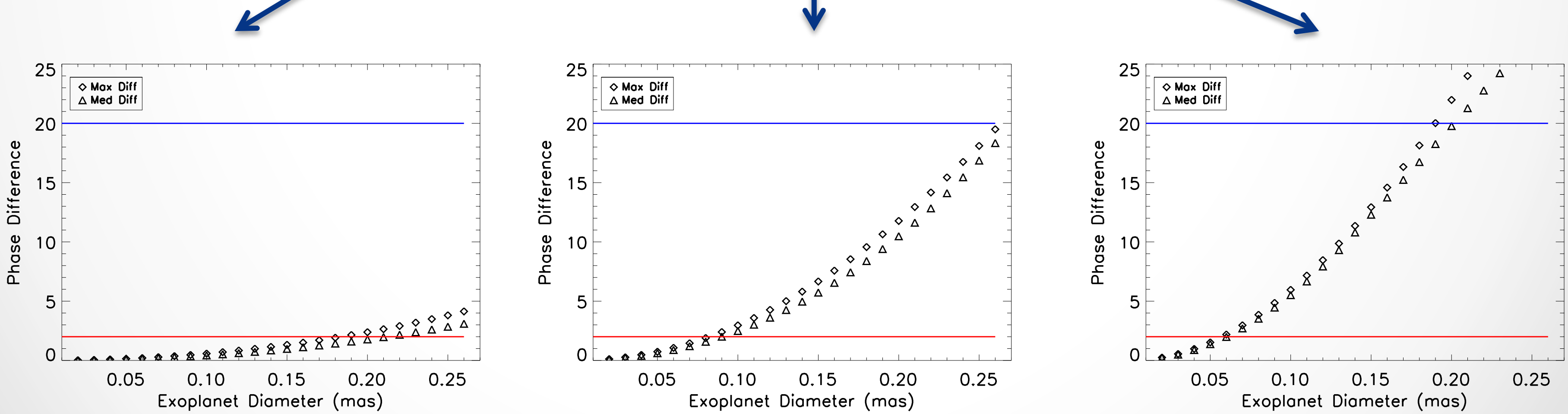


COMETS: *COde for Modeling ExoplaneTs and Spots*

3 spatial frequencies to probe 3 values of the *phases*







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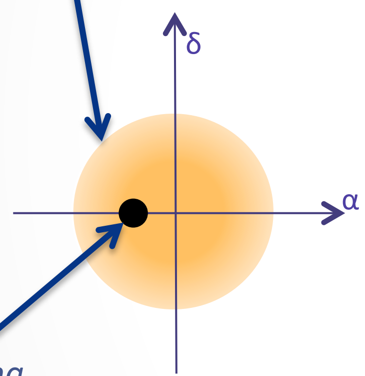
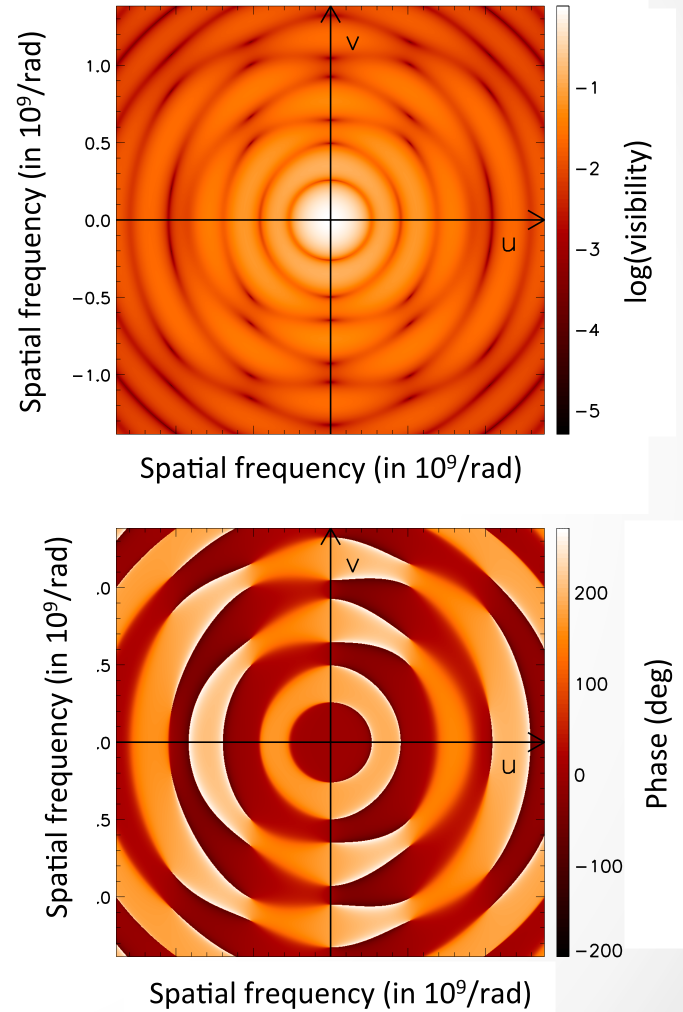


transiting exoplanet

Additional components

Analytical TF



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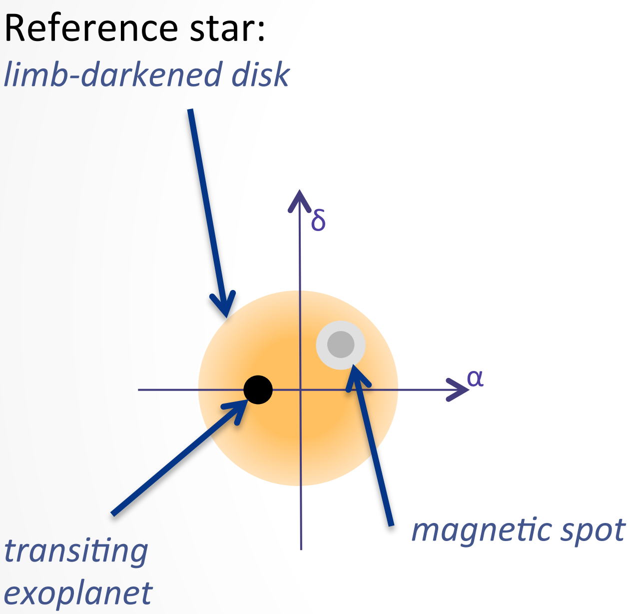

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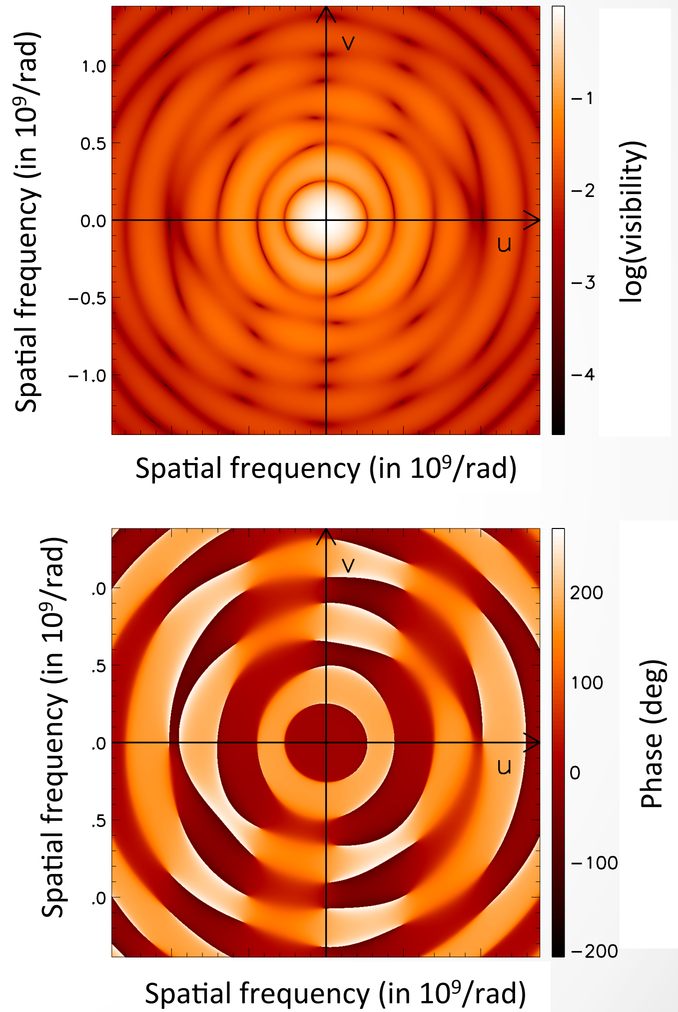

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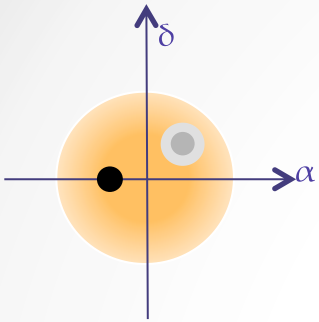
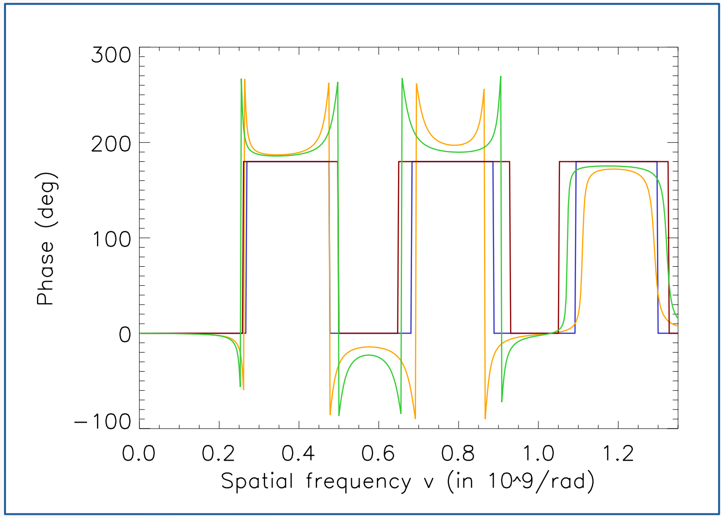
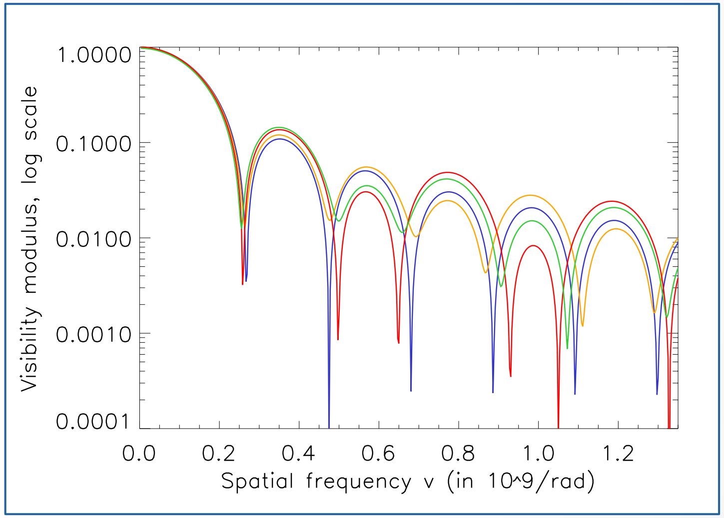


Cut in the v direction

Phase



Squared visibility



- star
- star + exoplanet
- star + spot
- star + exoplanet + spot

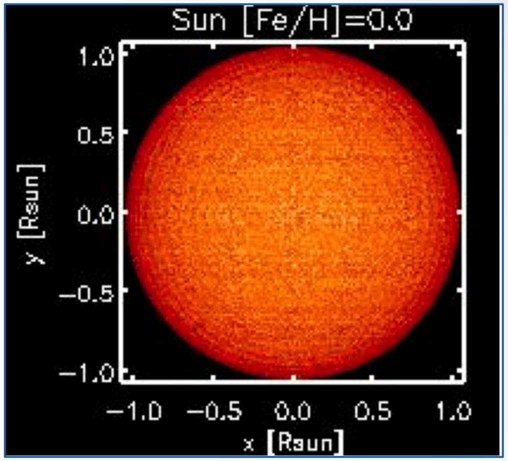
Results

- Determination of the effect of exoplanet diameter and position, spot intensity on the complex visibility signal
- A transiting exoplanet affects the interferometric observables even on a spotted star
- First lobe very slightly affected → do not affect the measured radius
- Importance of measuring visibilities in the 2^{nd} lobe and beyond
- Improvment of instruments' sensitivity and kilometric baselines: need more than 1% precision on squared visibilties and 2° on phase for Earth-like planets characterization

GRANULATION

Chiavassa, Ligi et al. 2014, A&A, in press

3D radiative-hydrodynamical simulations
(Stagger grid, *Magic et al. 2013*)
Synthetic stellar images
(Optim3D, *Chiavassa et al. 2009*).



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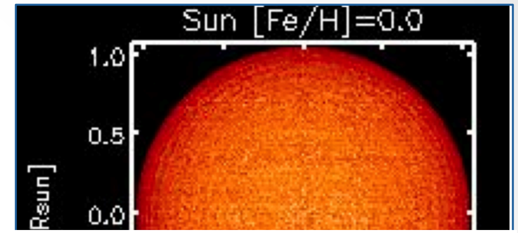
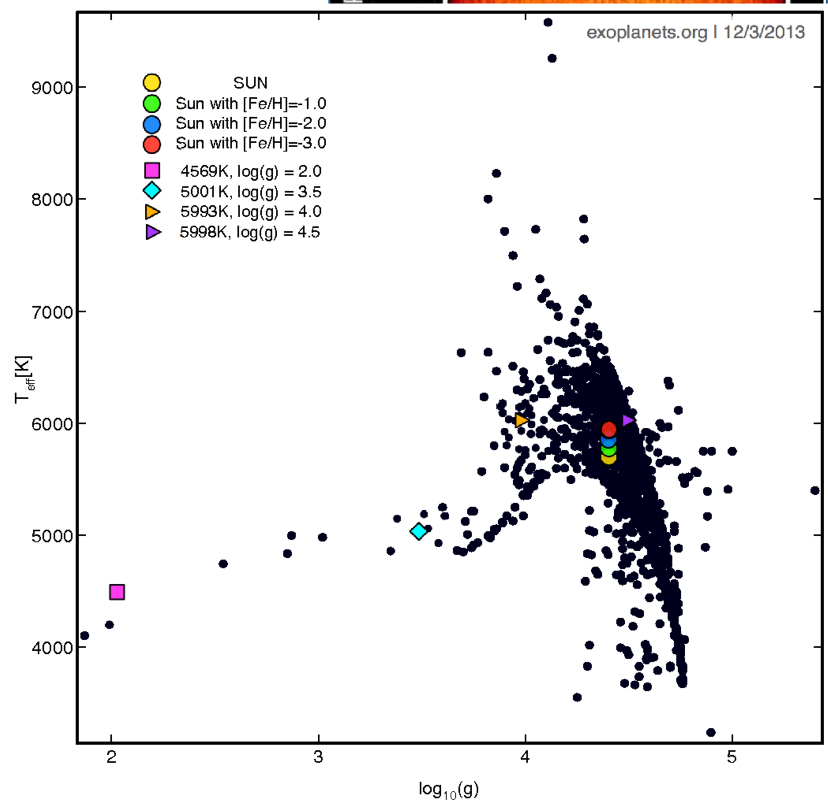
Partially covering the *Kepler* planets
Aimed to be extended to other stars in the HR diagram



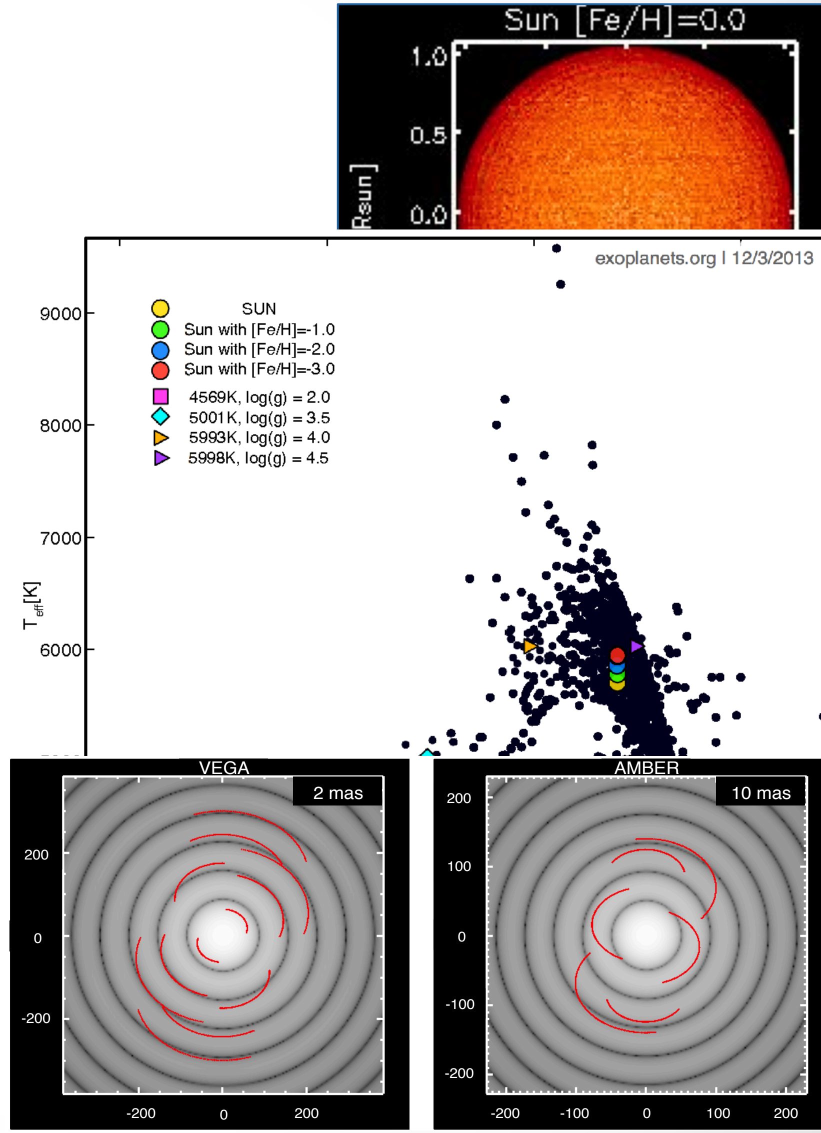


GRANULATION

Chiavassa, Ligi et al. 2014, A&A, in press

3D radiative-hydrodynamical simulations
(Stagger grid, *Magic et al. 2013*)
Synthetic stellar images
(Optim3D, *Chiavassa et al. 2009*).

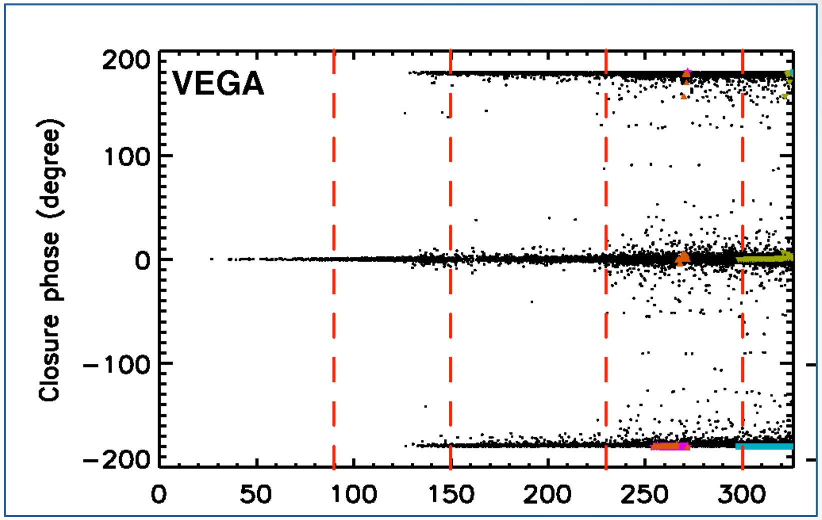
Partially covering the *Kepler* planets
Aimed to be extended to other stars in the HR diagram



Closure phase measurements
Test with different instruments:
VEGA, CLIMB, MIRC… (CHARA)
NPOI
PIONIER, MATISSE, GRAVITY…(VLTI)

GRANULATION

Detection of granulation with closure phase
➔ needs data points up to the 3rd and 4th lobes, and in some cases, the 5th or 6th lobes.



Ex.: Procyon and β Com

- Signals from a few degrees to 16°
- PAVO and VEGA: <0.5°, signal from 2nd lobe
- Best appropriate instrument: MIRC (6T), with closure phases of ~10°

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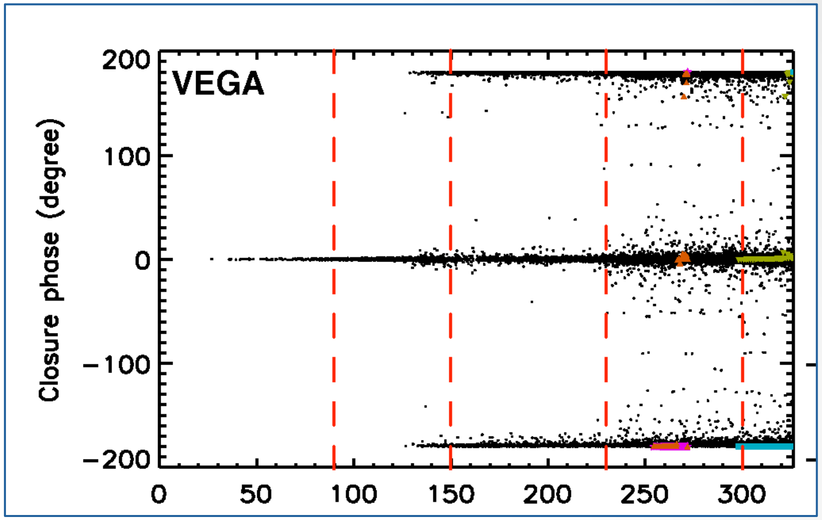

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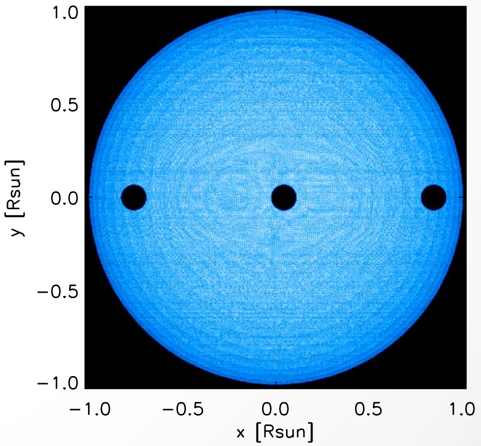
Addition of an exoplanet:

- Signal scales with exoplanet's size
- Larger signal in the optical
- The exoplanet's position affects the signal
- Signal mixed with the granulation signal



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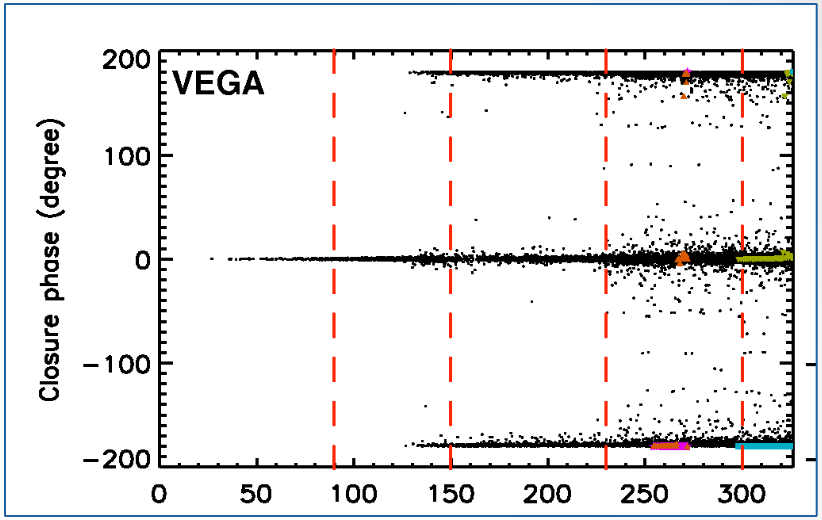

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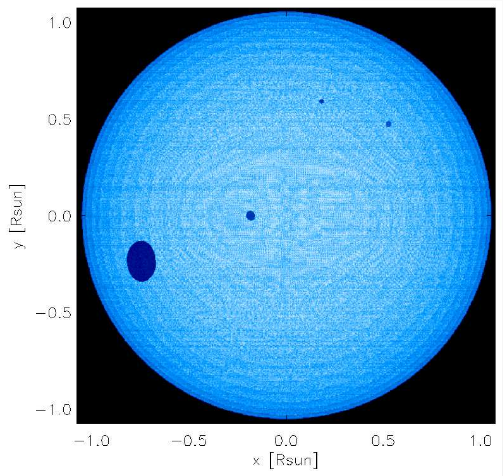


Addition of an exoplanet
Addition of spot:
- Interferometric signal due to spots or exoplanets can be of the same order
- exoplanetary signal contamined by spots' signal

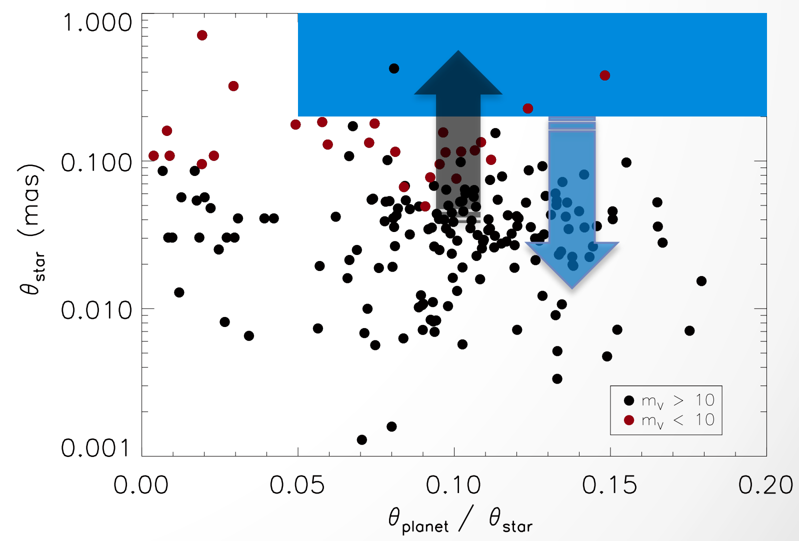
CONCLUSION

- Transiting exoplanets add a signal on interferometric observables
- Their characterization is possible even on a spotted star, but their signal can be mixed up with the activity's signal
  - Timescale variations
  - Scales with the exoplanet's size

- Currently, transiting exoplanets host stars not accessible:
  - Instrumental bias
  - Very low magnitudes

➔ **FRIEND (Bério et al., in prep.)**

➔ **CHEOPS, PLATO, TESS**



THE NEXT DECADE…

Gaia (2014)
Astrometry:
distances, radial velocity
$m_V < 20$

SPHERE/VLT (2014)
Detection and characterization of Giant planets
Direct imaging

VEGA → FRIEND (2015–2017)
Interferometry
$m_V < 8 \rightarrow m_V < 10$

TESS (2017)
Detection of transiting exoplanets
Giants of Earth-like planets
$4 < m_V < 12$
Photometry

CHEOPS (2017)
Characterization of transiting exoplanets
Earth-like → Neptunes
$m_V < 9$
Photometry

PLATO (2024)
Detection and characterization
Earth-like planets
Habitable zone
$4 < m_V < 14$
Photometry

2014 2015 2016 2017 2024

Detection and/or characteriaation of exoplanets
Other instrument

THE NEXT DECADE…

Interferometry:

- A good method to characterize exoplanets host stars
- Complementary data to photometry
- Soon, will get the required sensitivity to characterize exoplanets (ex. with adaptative optics on the CHARA array).
    - closure phase measurements
    - baselines already exist

Coupling PLATO/TESS/… and interferometric data: common targets

- More information on exoplanets and their host stars
- Characterization of exoplanets ➔ habitability, composition…
- Extrapolate to other fainter stars

THANK YOU FOR YOUR ATTENTION