# THE EFFECT OF SPOTS ON THE LUMINOSITY SPREAD OF THE PLEIADES


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***In collaboration with:***

***Michael Gully-Santiago and Gregory Herczeg***

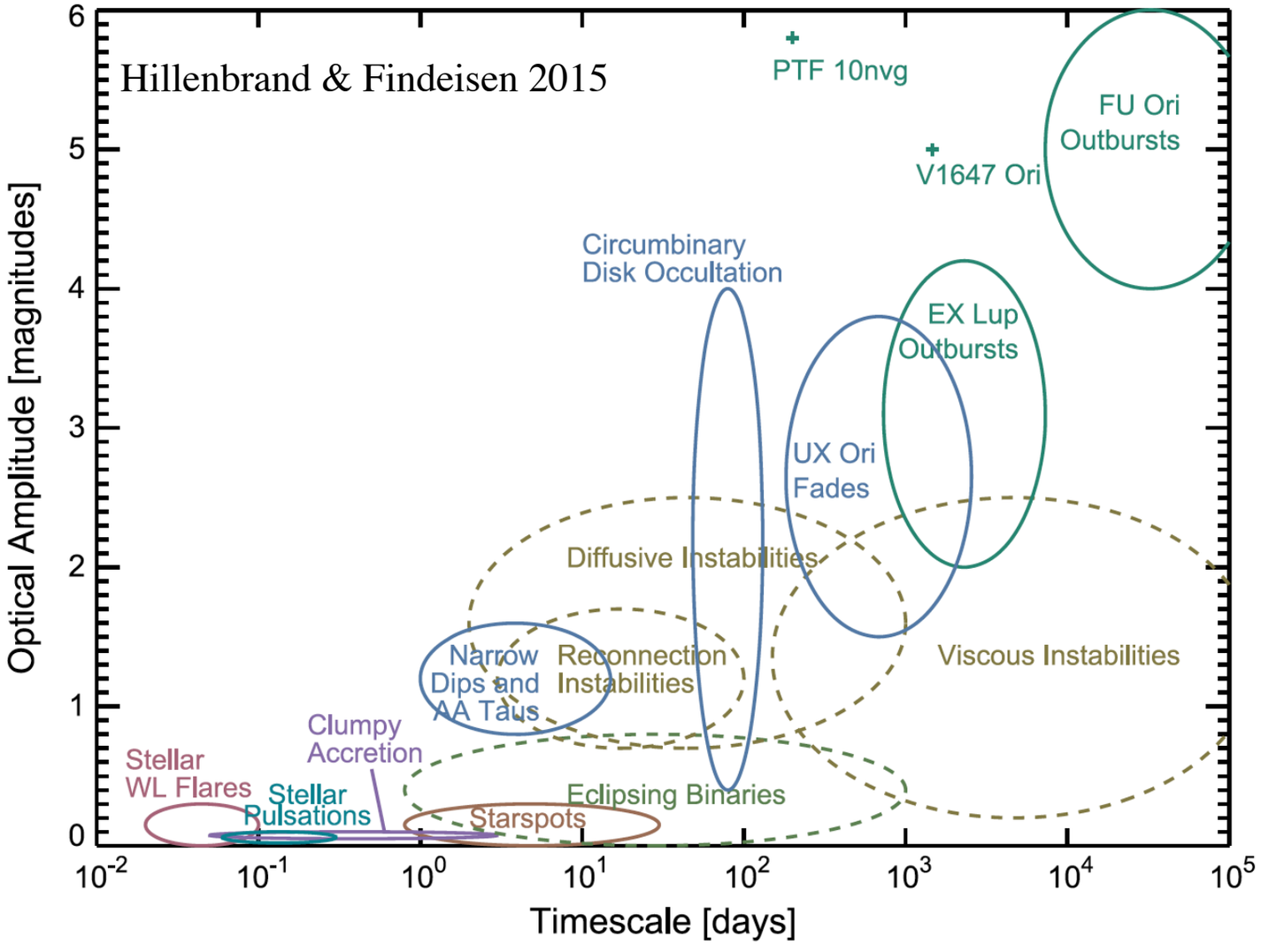
***Last 6 months of my PhD***

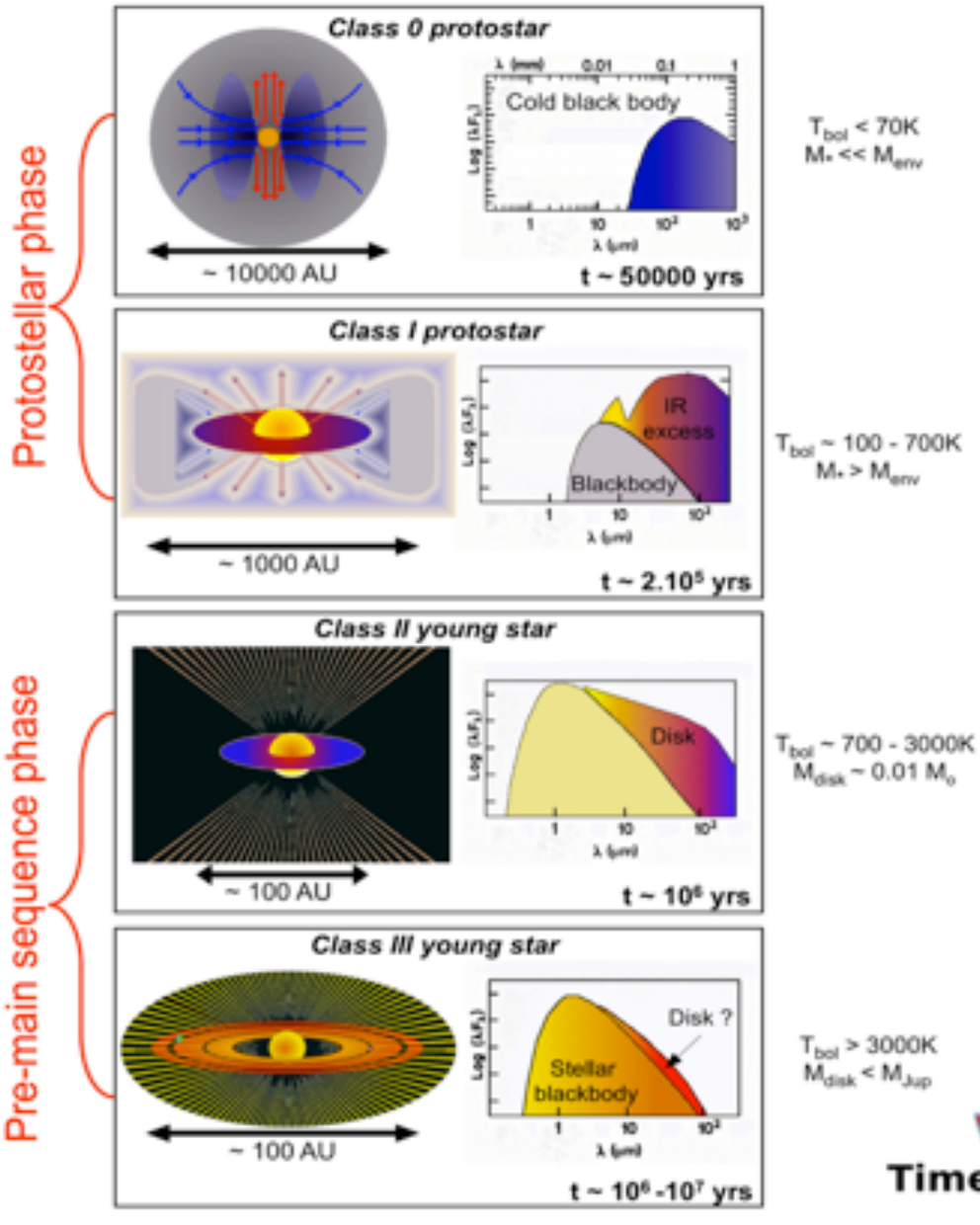


# Introduction

## Why study spots on young stars?

### Young stars are magnetic active



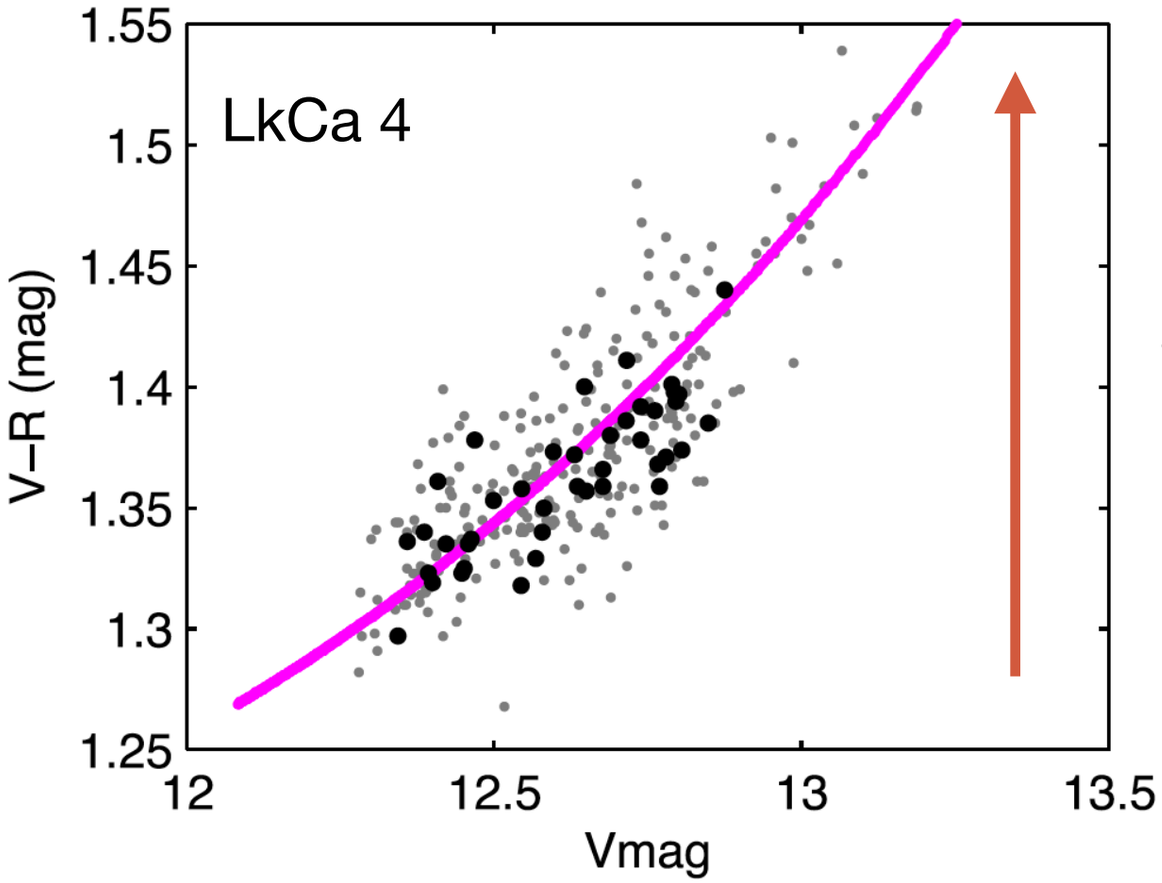




Spots are the most common variability on Class III objects

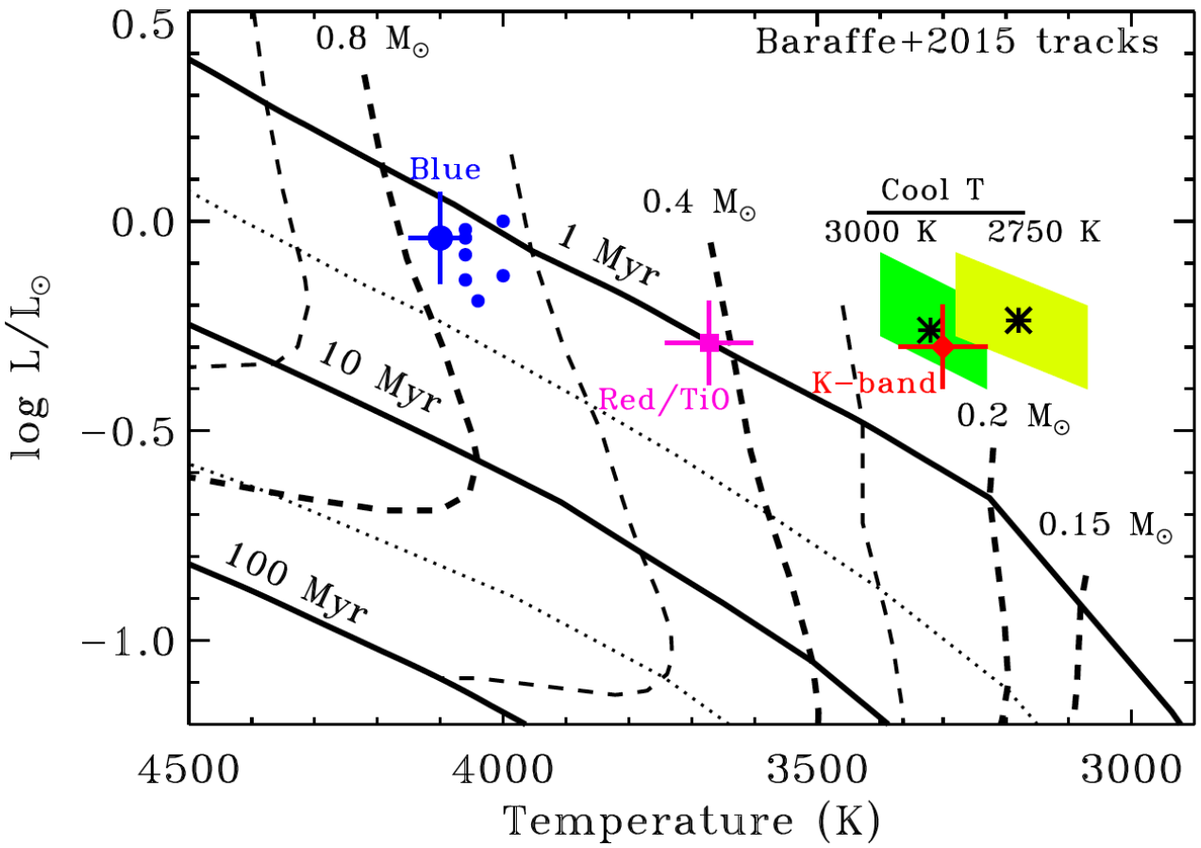
# Introduction

## Spots bias the measurements of stellar parameters

*Redder*




*Fainter*




*Redder*

$T_{hot}$ = 4100 K, $T_{cool}$=2700-3000 K, $f$ = 80%

***"Spots make the star Cooler and Fainter than photosphere."***

*Gully-Santiago et al., 2017*

How will spots affect a young cluster?

# Introduction

| Method | fidelity | scalability | reference |
|---|---|---|---|
| Near-IR Interferometry | High | Low | Rottenbacher et al., 2017 |
| Zeeman Doppler Imaging | High | Low | Donati et al., 2014 |
| SED Modeling | Medium | Medium | Wolk and Walter 1996 |
| Planet Transit | Medium | Low | Morris et al., 2017 |
| Single band high cadence lightcurve | Low | High | Rebull et al., 2016ab |
| Multi-band lightcurve | Medium | Med-High | Grankin et al., 2007 |
| Spectral modeling | Medium | Medium | Fang et al., 2016 |
| Time Series Spectra | High | Low | Gully-Santiago et al., 2017 |

# Some facts about the Pleiades

## Pleiades

Open cluster: 2109 members

Stauffer et al. 2007; Lodieu et al. 2012; Bouy et al. 2015

Distance: centring at 137 pc

Pinsonneault et al. 1998; Soderblom et al. 2005; Melis et al. 2014; Gaia 2016

Age: 125 Myr (disk less)

Li Depletion, Stauffer et al. 1998

Low foreground extinction

Mermilliod 1981

Lots of available data…

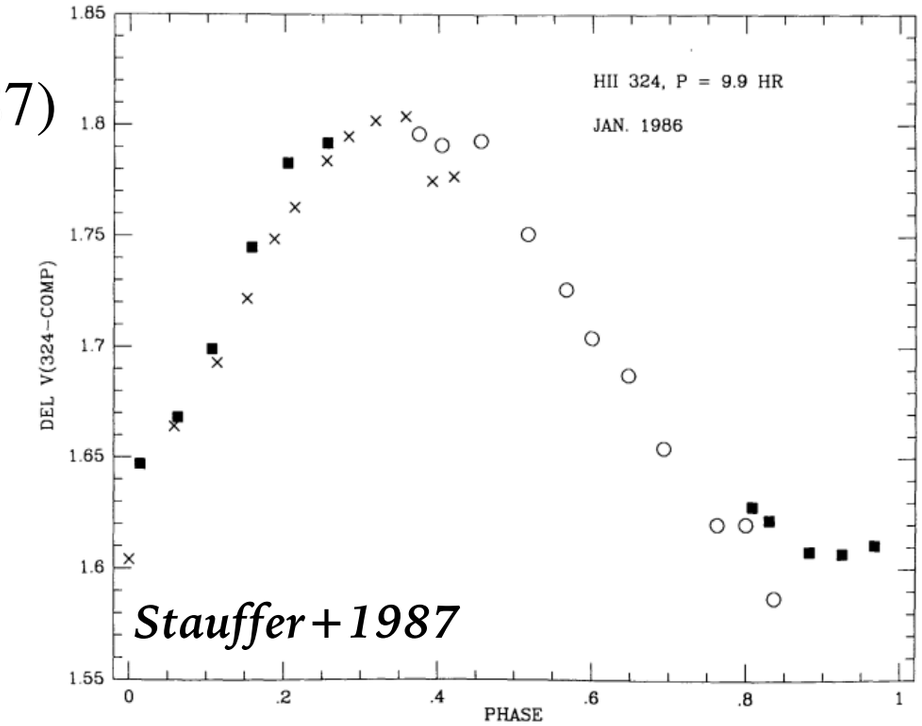
*Lascaux 16500 yrs ago*

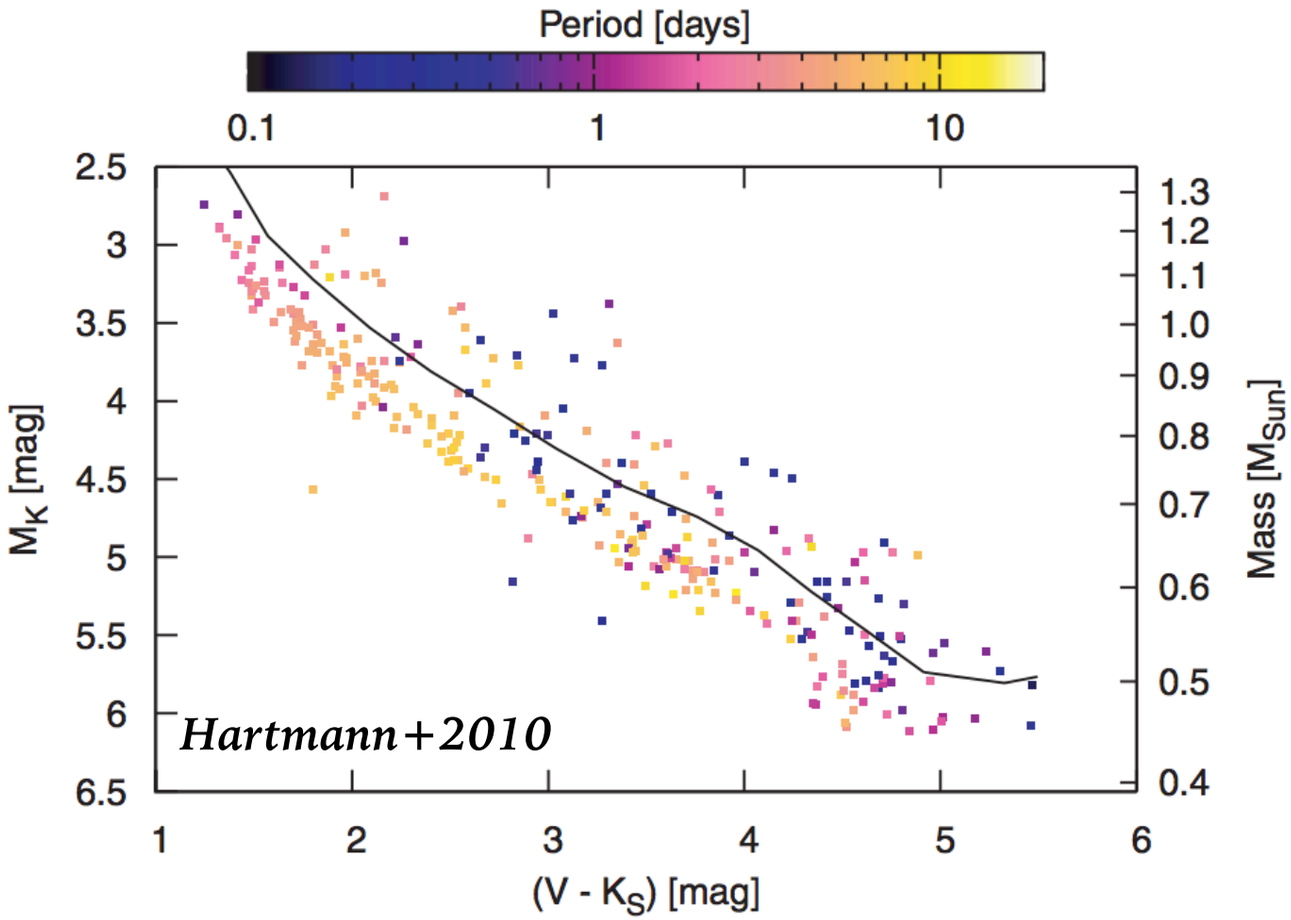
# Previous works on Pleiades

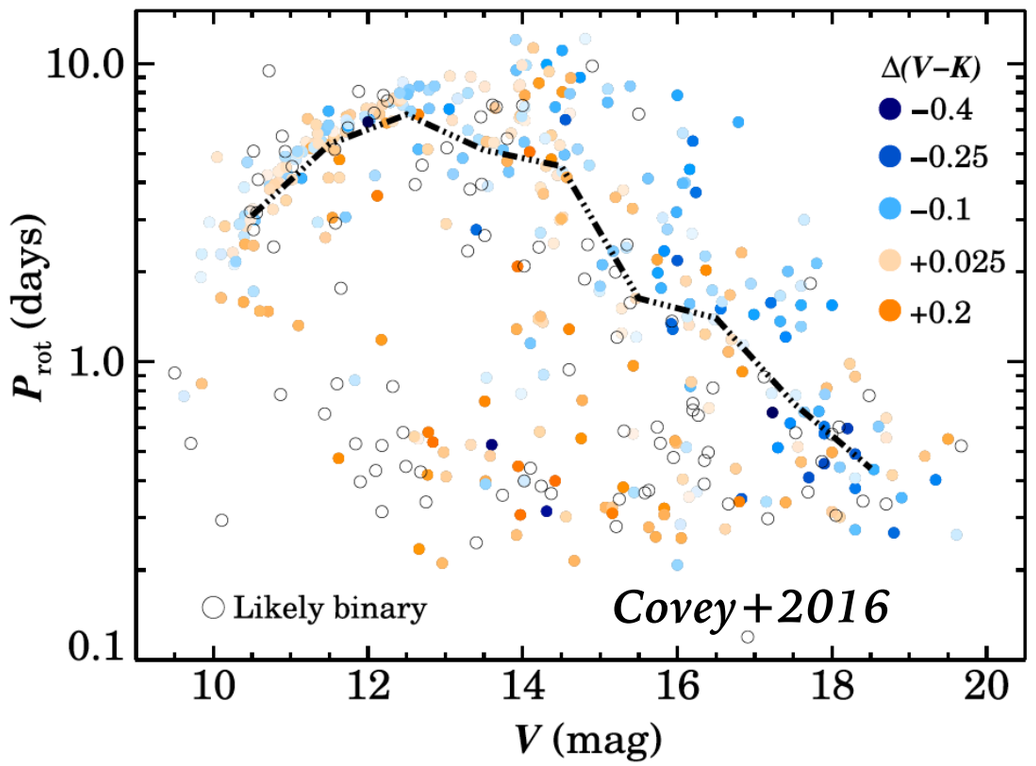
Spots behaviour on low mass members (Stauffer+1987)

Rotation period of Pleiades
(Hartmann+2010; Covey+2016)

Fast rotators are redder in V - Ks (spot!)

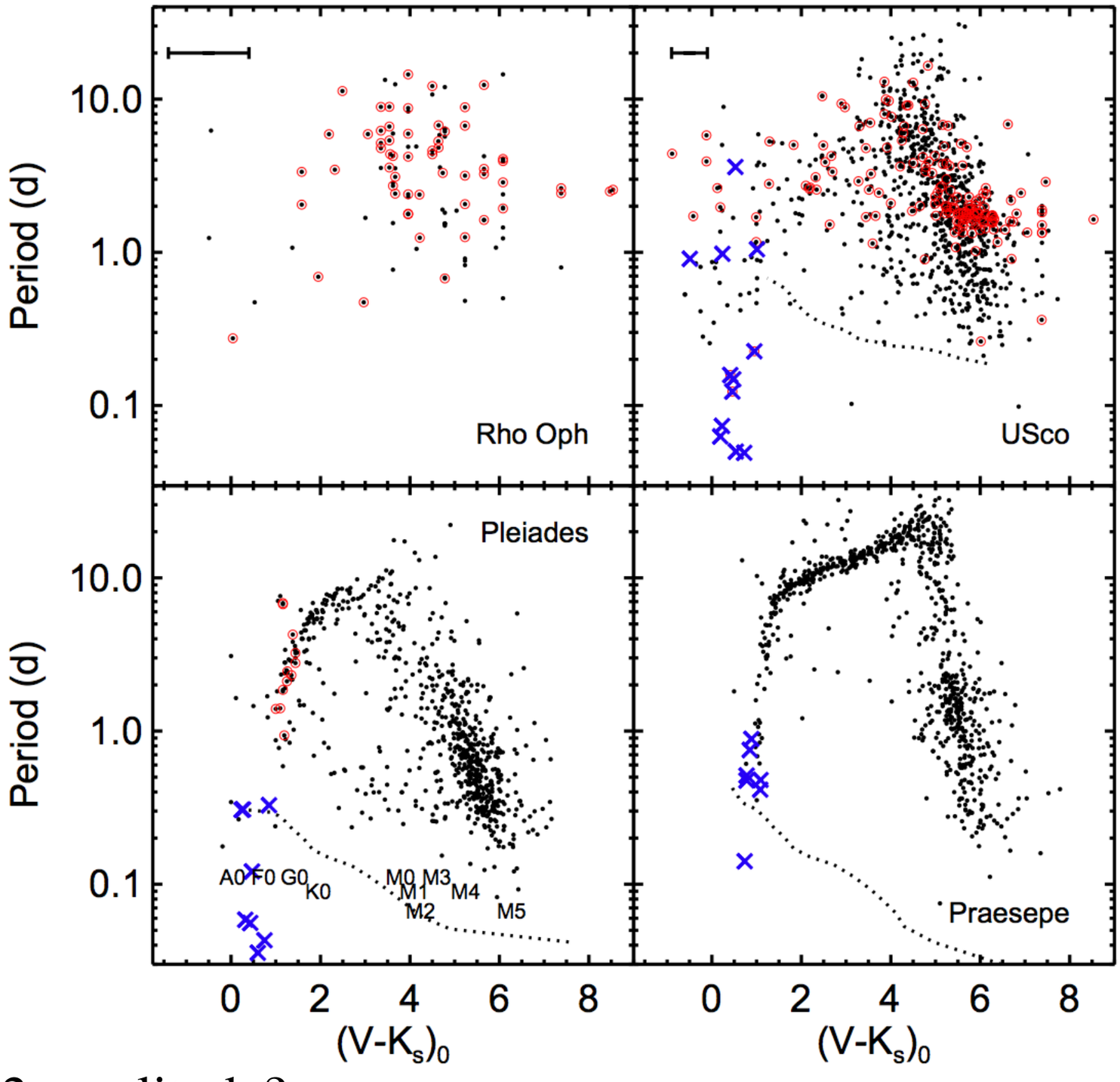


# Introduction

K2 photometry on stellar rotation -> Evolution of angular momentum



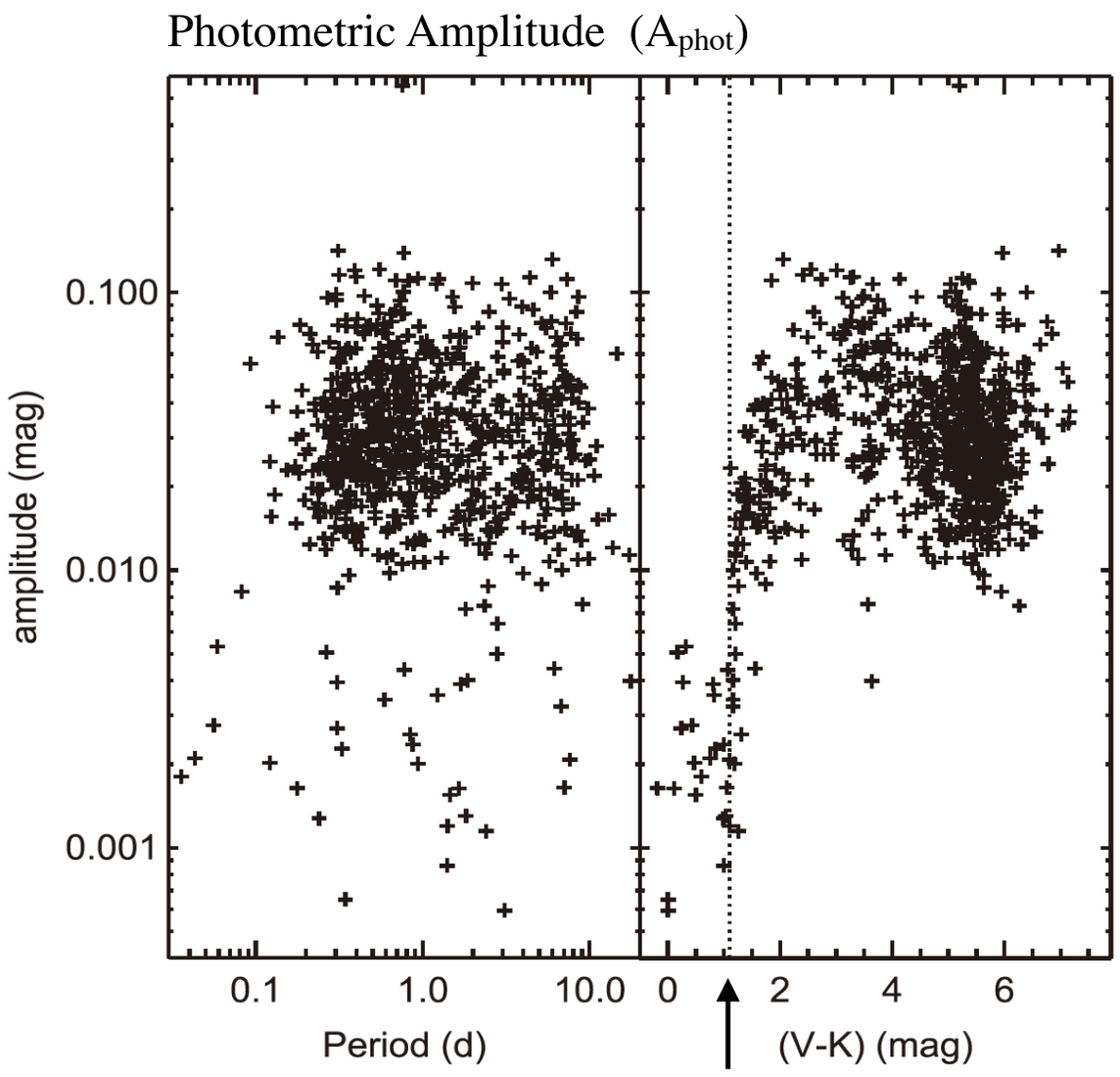

What about K2 amplitude?

Rebull et al., 2018

# Spots on the Pleiades members

## Photometric

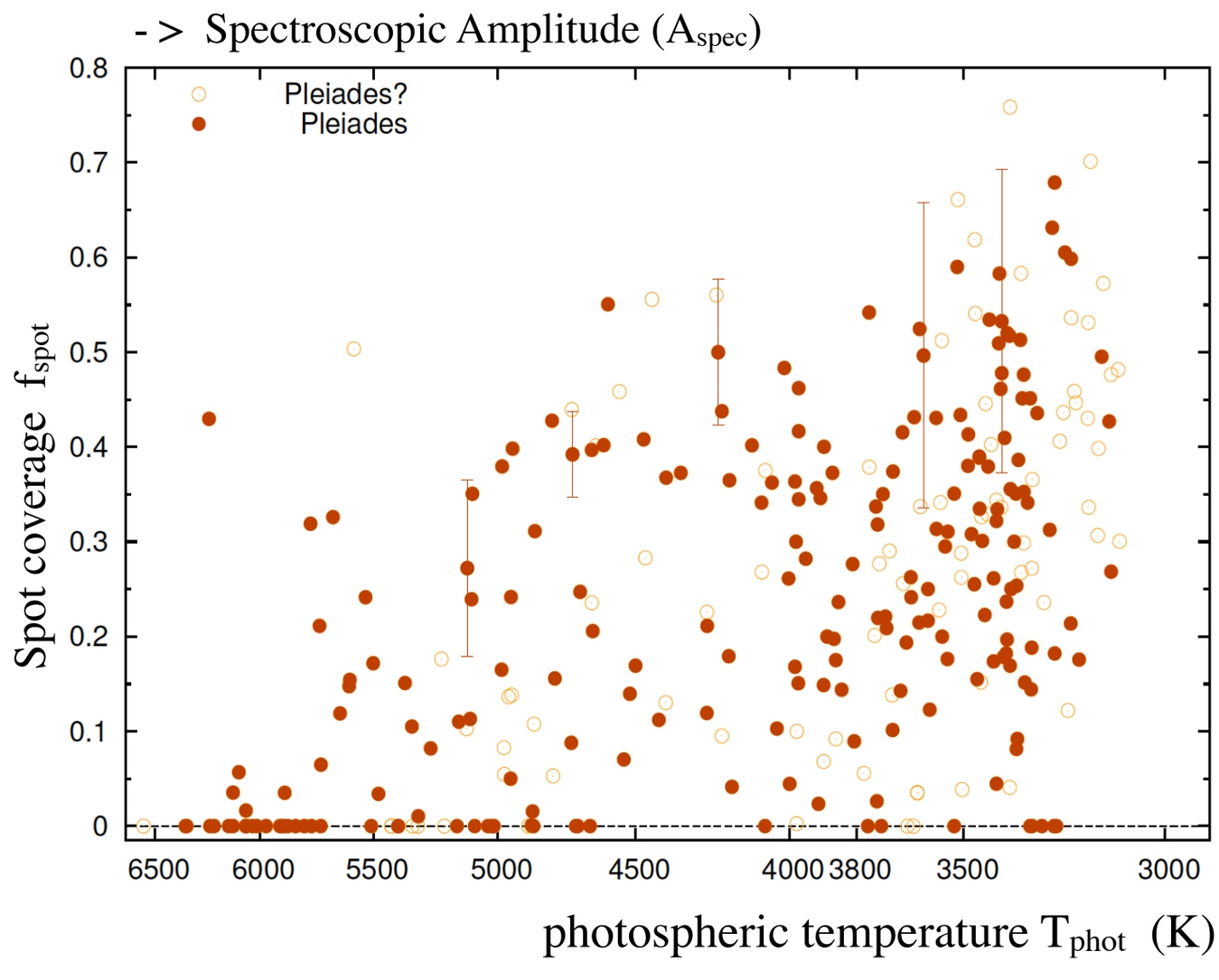
By K2 lightcurves; Rebull et al. 2016a




Stellar pulsation
(Balona et al. 2015)

## Spectroscopic

By LAMOST spectra*; Fang et al. 2016
estimated by $T_{phot}$ and $T_{obs}$ (by TiO band ratio)

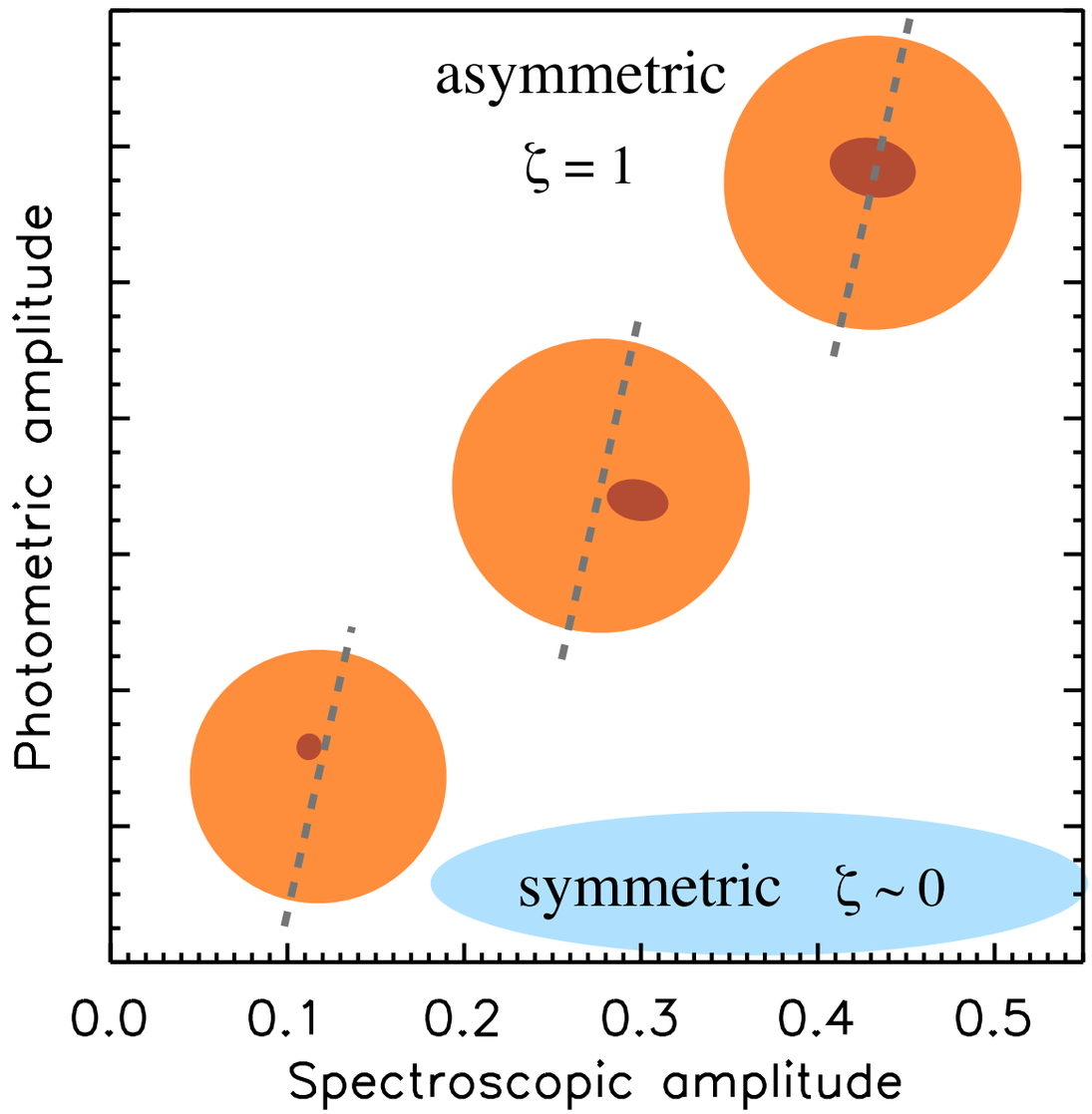


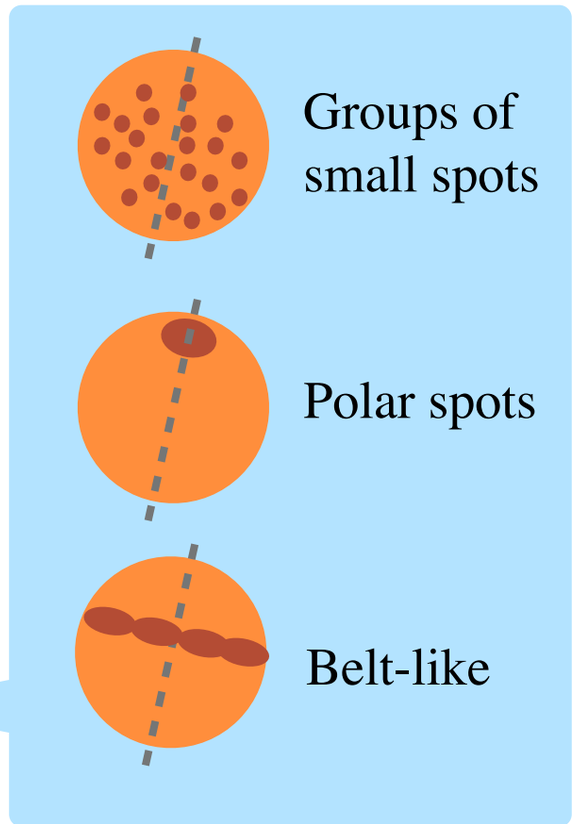

* with least spot coverage assumption

# Spots on the Pleiades members

Photometric amplitude vs. Spectroscopic amplitude

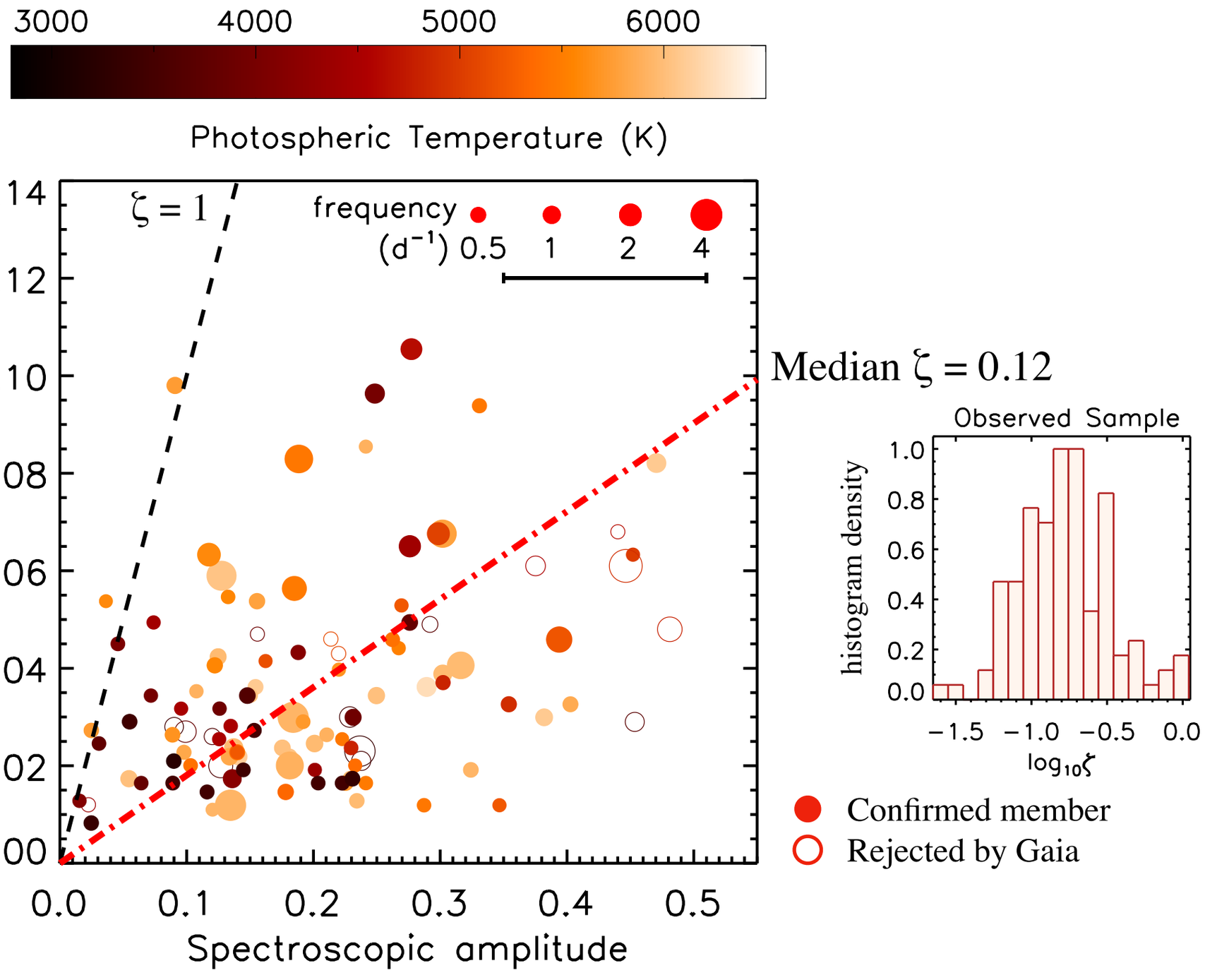
$\zeta = \Delta F_{phot}/\Delta F_{spec}$



# Spots on the Pleiades members

$\zeta = \Delta F_{phot}/\Delta F_{spec}$



# Setting ups for Monte-Carlo simulations

## “Pleiades” cluster (2000 members)

Cluster Age: fixed to 125 Myr

Stellar mass: between 0.08 and 1.32 Solar Mass

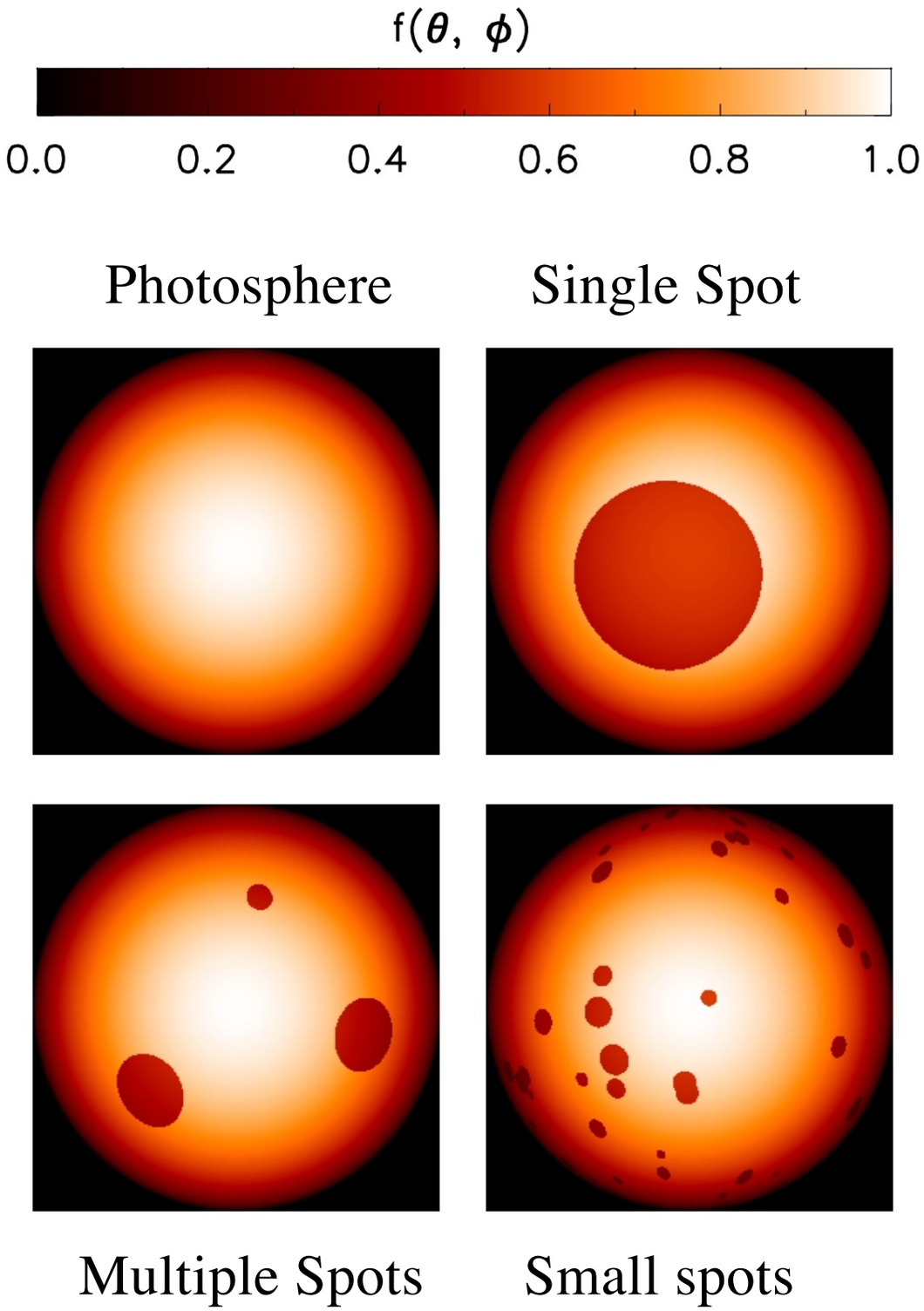
Photospheric temperature: Baraffe et al., 2015
Color: Pecaut et al., 2013 (empirical)

Spot coverage: 1% - 40% $T_{phot} > 3800K$
30% - 50% $T_{phot} < 3800K$
* radiative / convective * Fang+2016 results

Spot temperature: $T_{phot}$ - 2500K to $T_{phot}$ - 50K

Spot morphology: —>

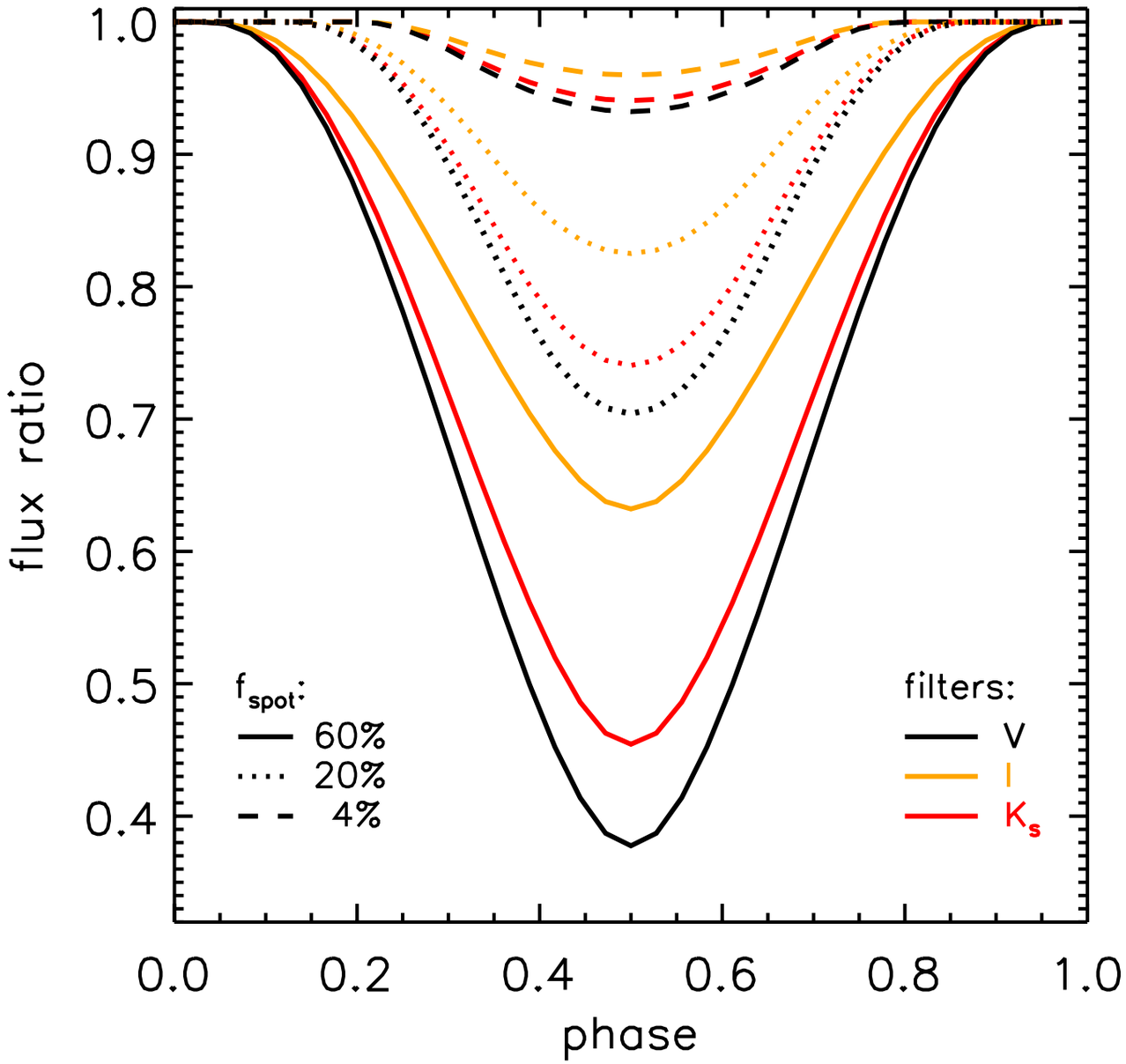
**Synthetic Lightcurves**



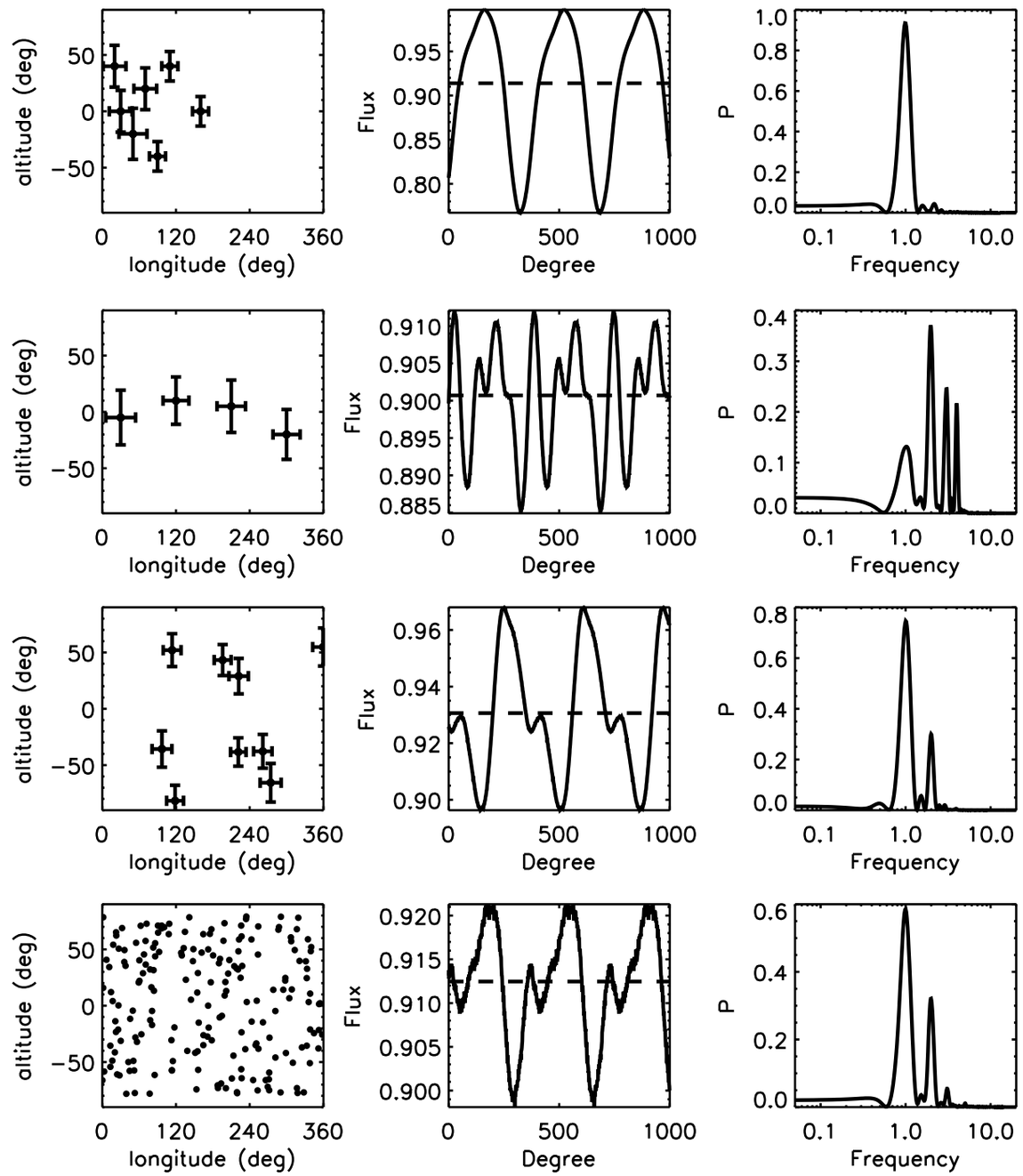
# Spots on the Pleiades members

## Synthetic Lightcurves

### single spot

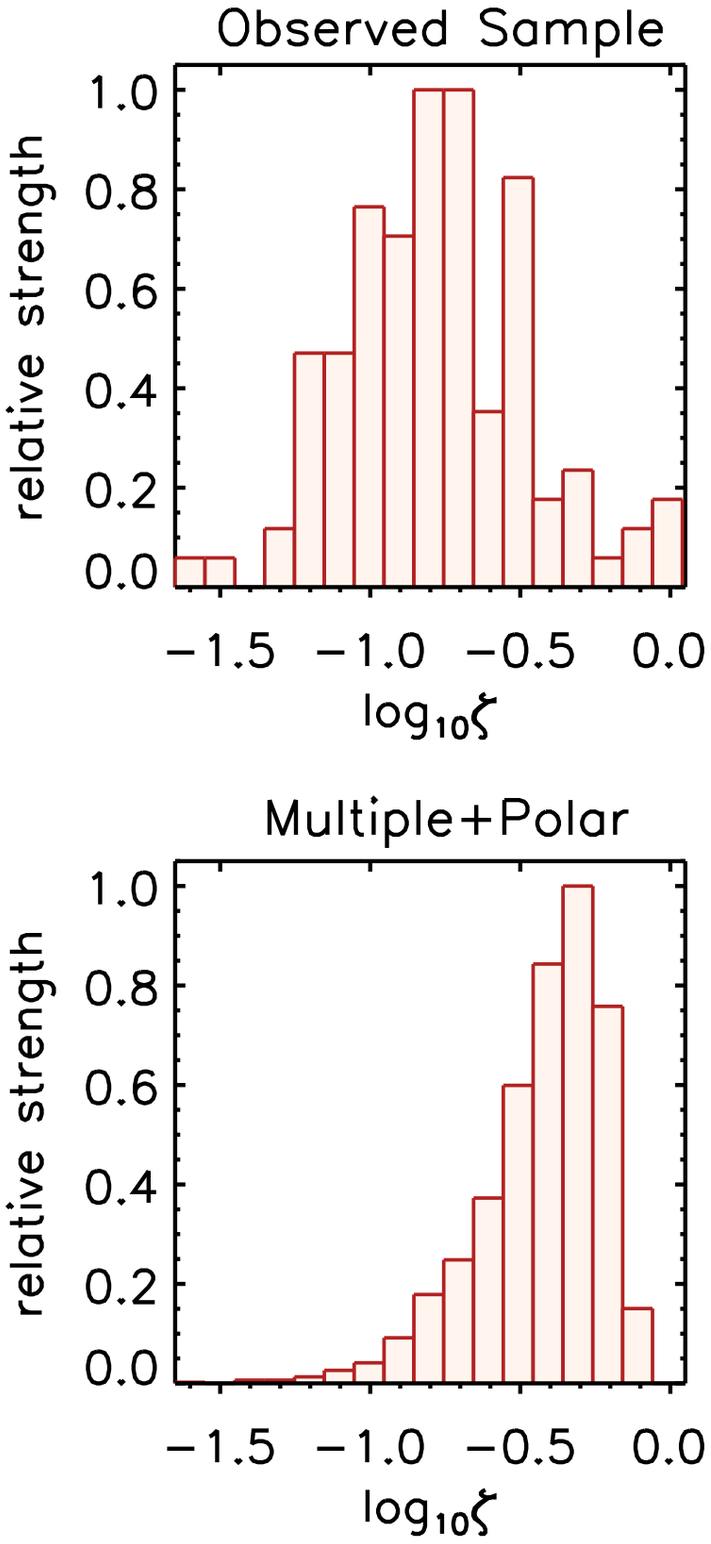


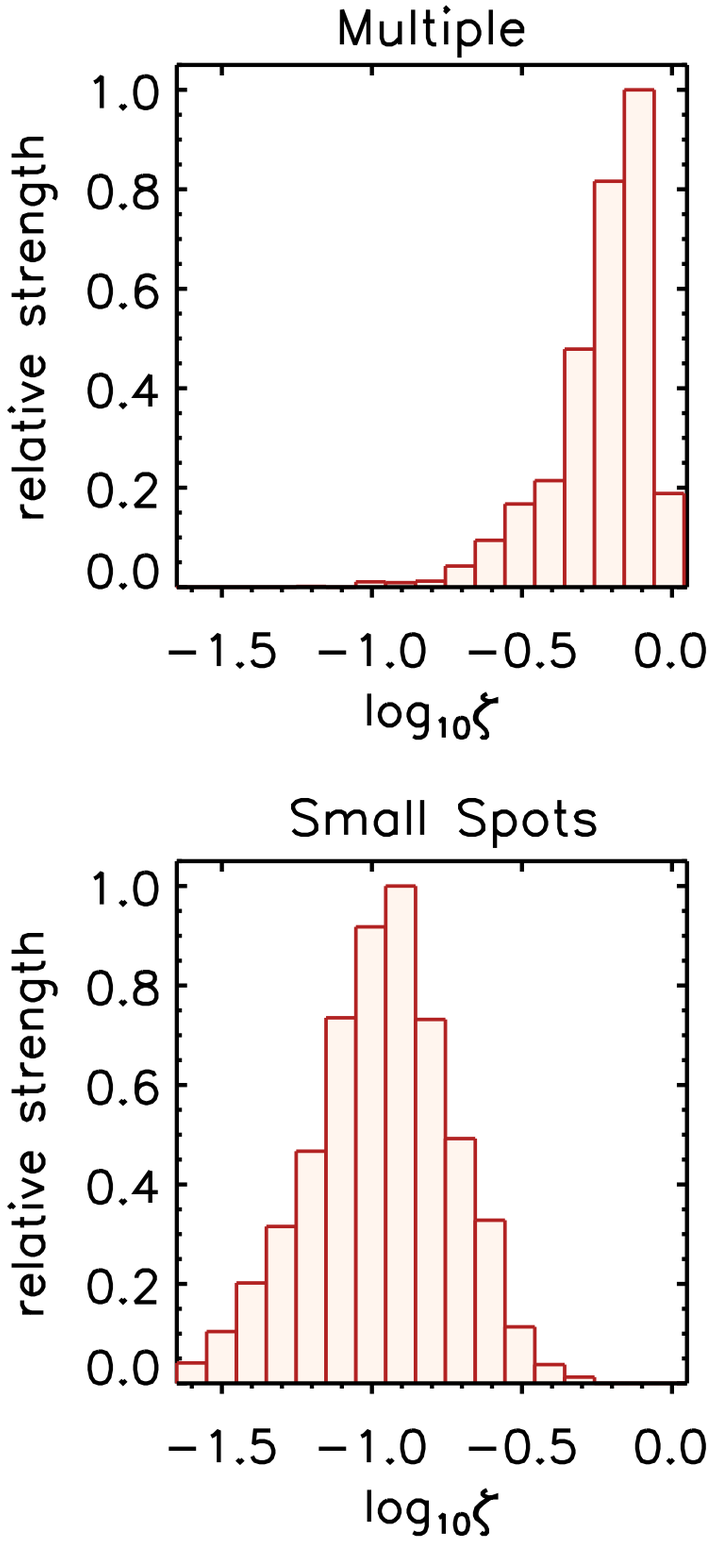

### multiple spot




similar with Lubomir's talk on Tuesday

# Reconstruct the observation



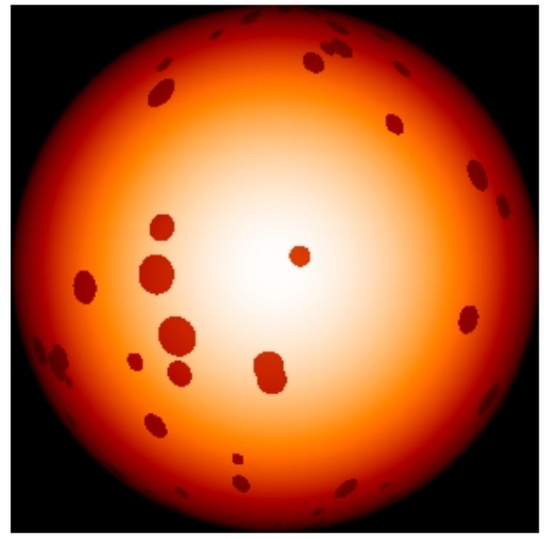






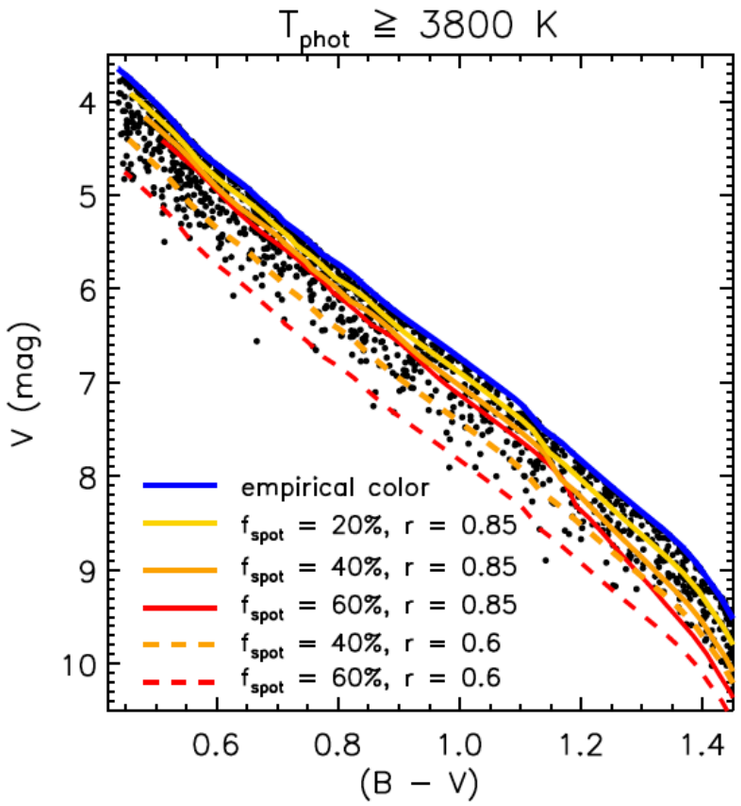

$N_{spot}$: 100 - 200

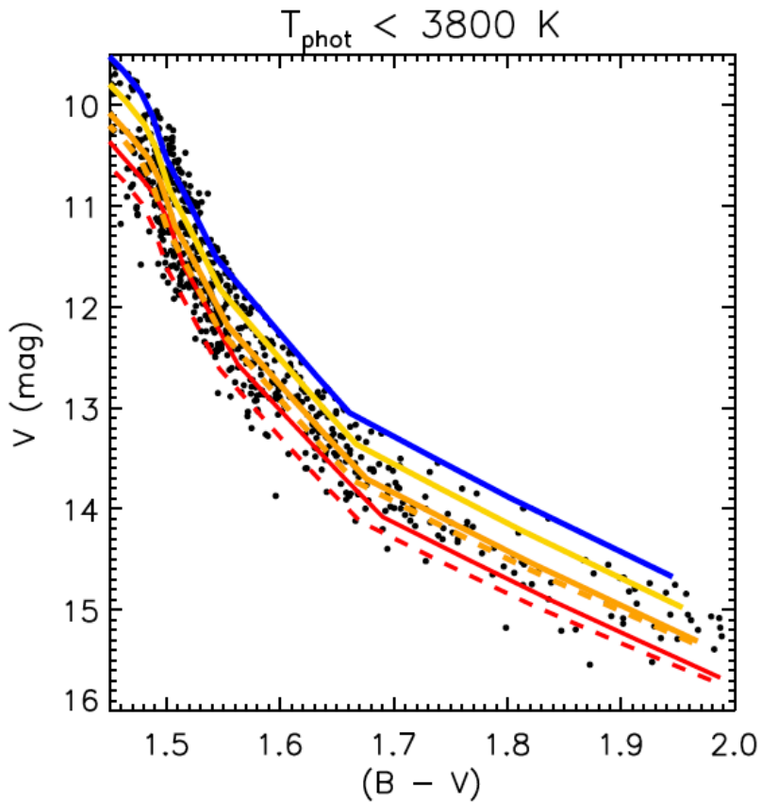
Size: log-normal distribution

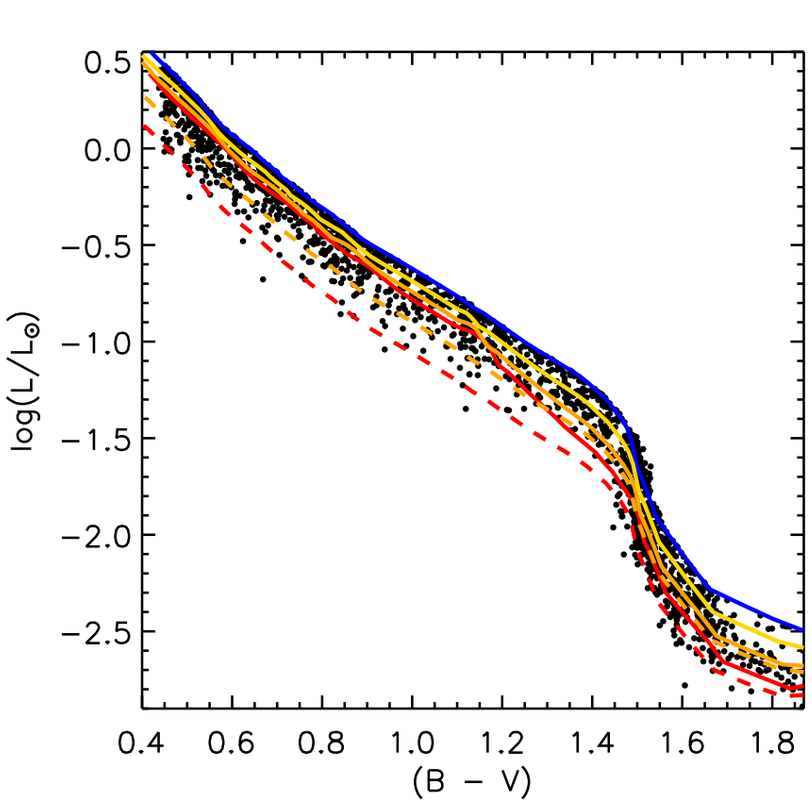


# Consequences of stellar spots in a cluster

## Spreads on colour-magnitude & luminosity diagrams



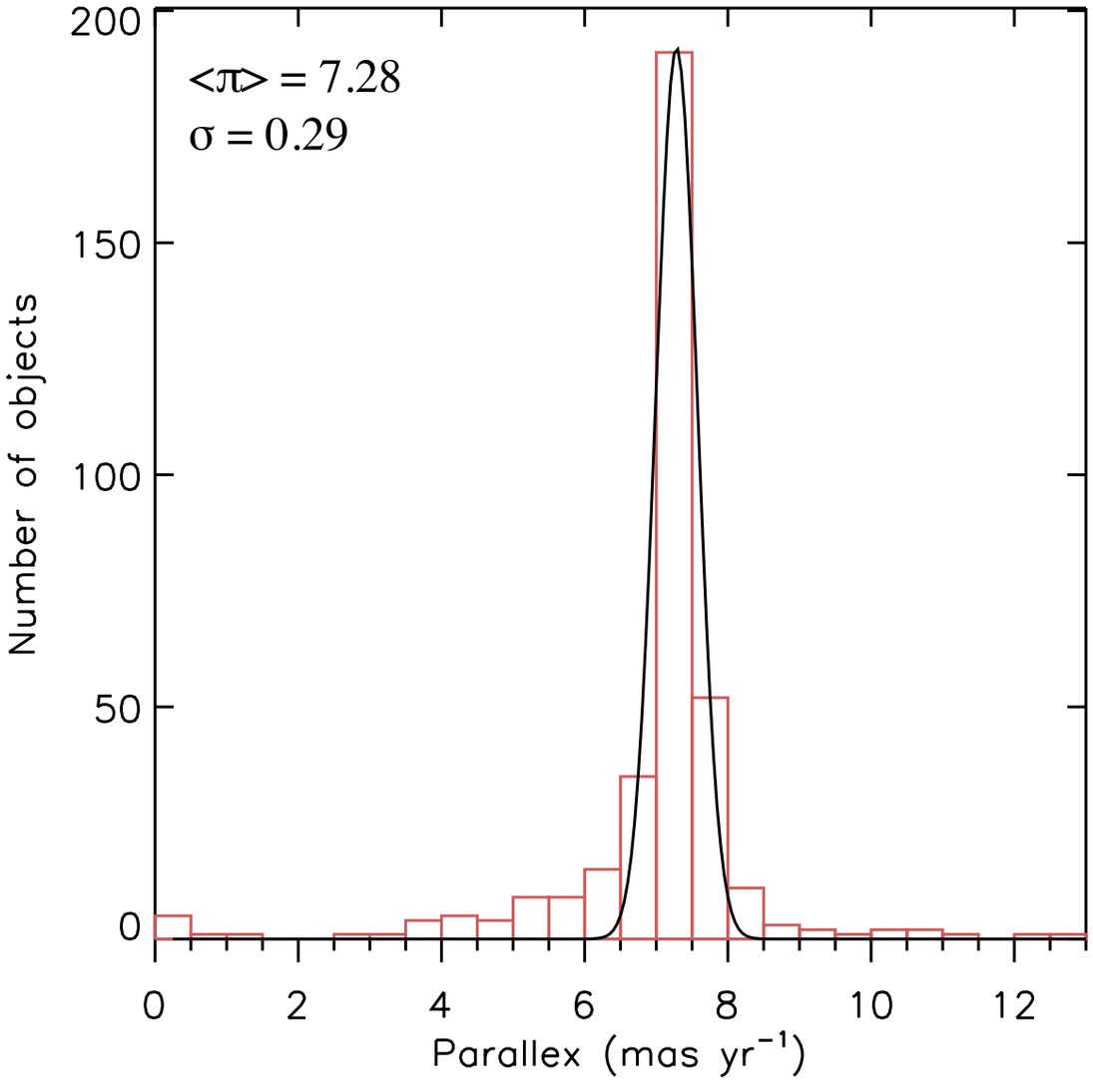

dots: our simulation samples

-> cluster looks redder and fainter

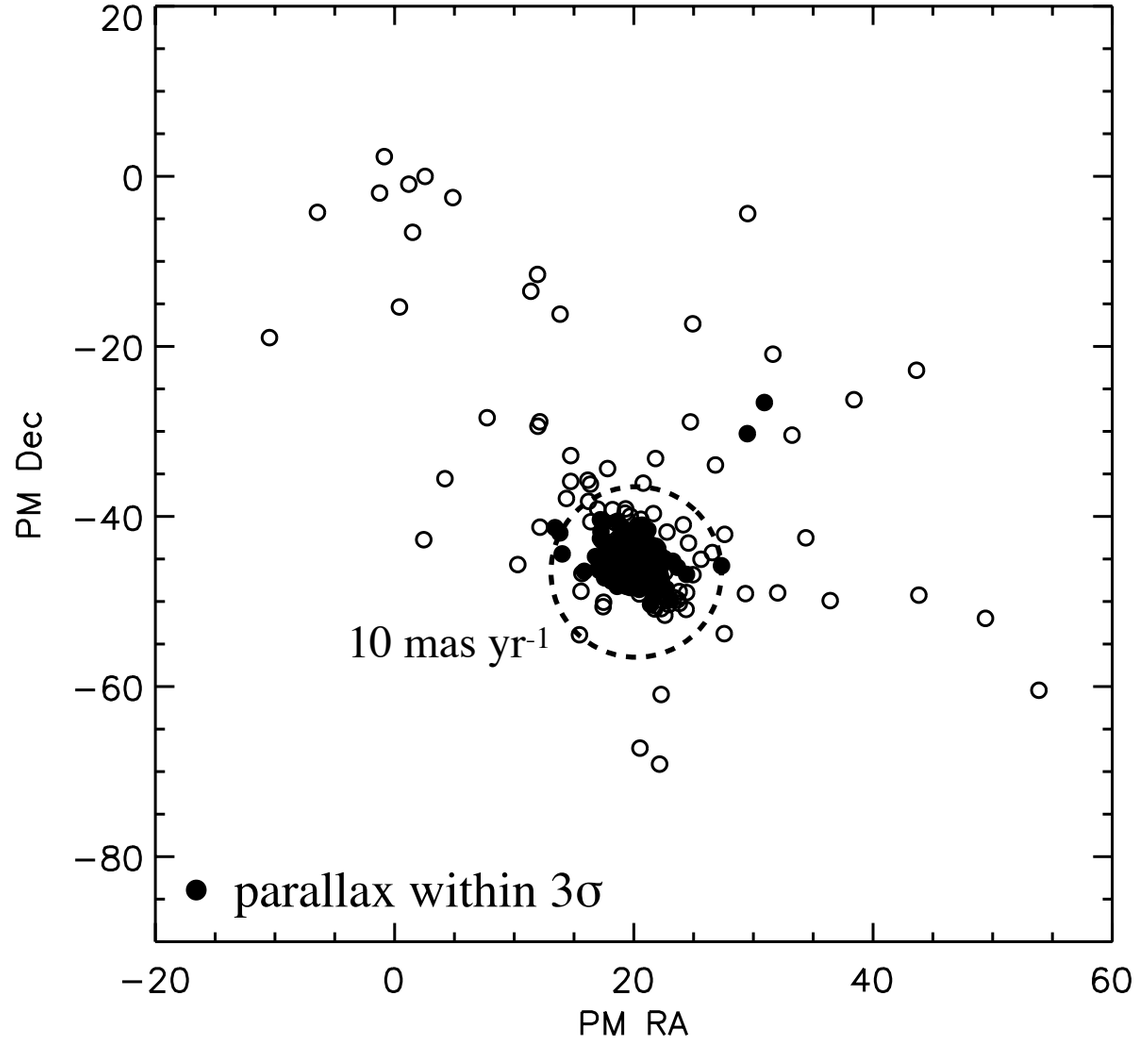
-> comparing with realistic observation

# Membership reclassification of Pleiades by Gaia

Sample: Kamai et al., 2014 with B V I colour (322 single stars with Gaia measurements)




Contamination rate: 25%

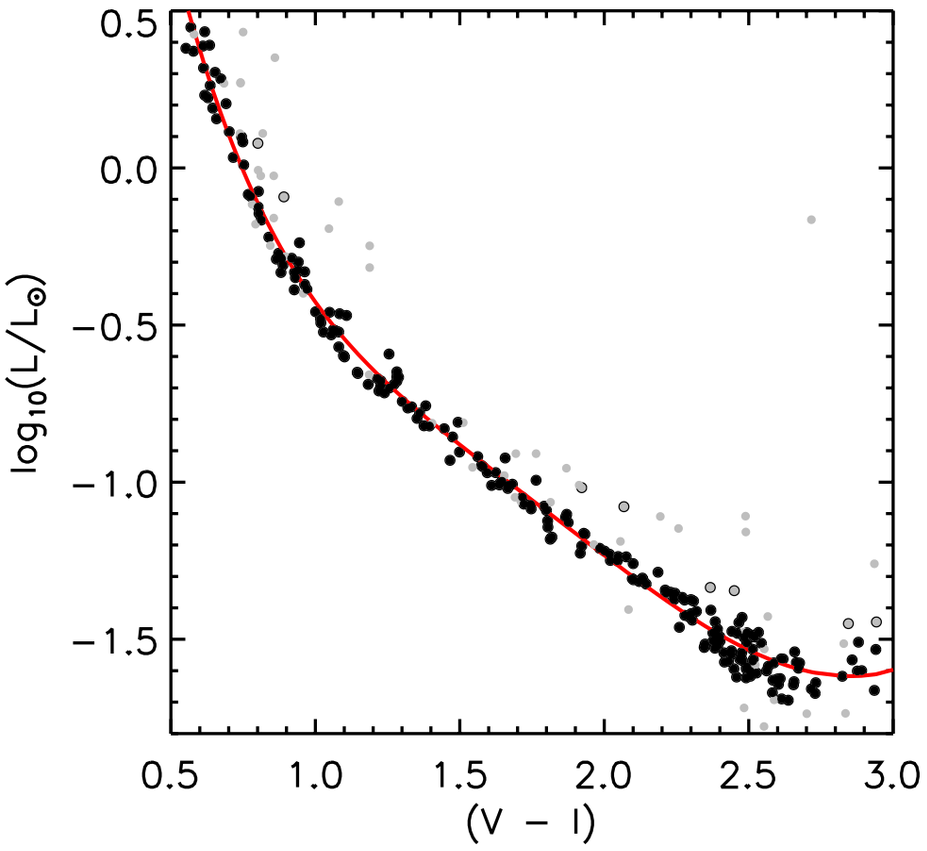


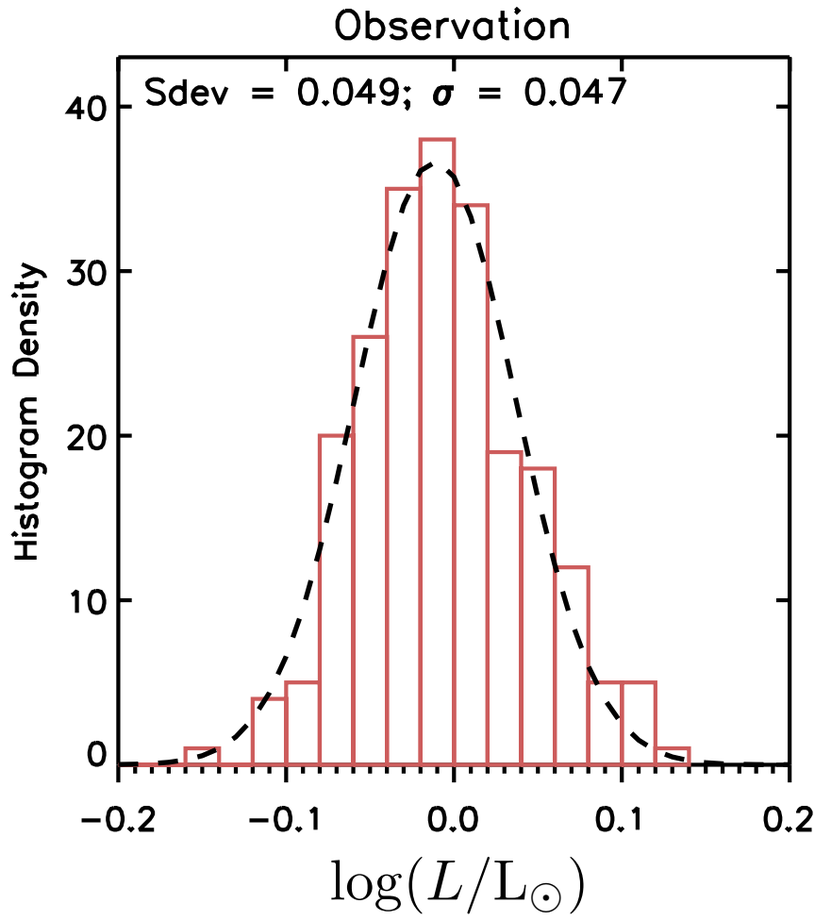
# Luminosity spreads on the Pleiades members

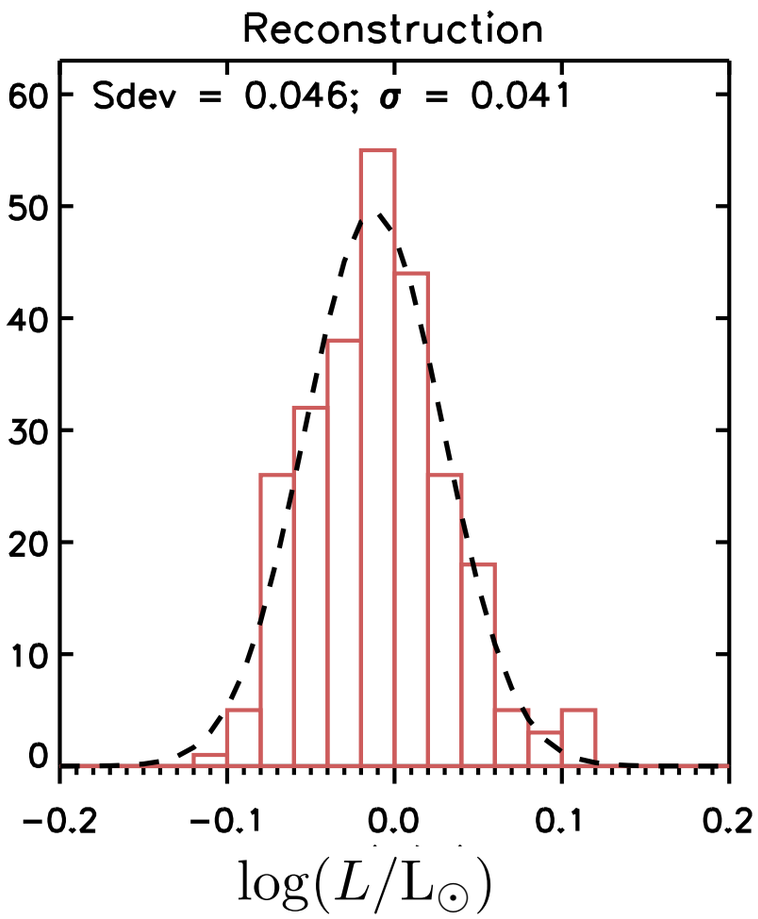
Observation: B V I band from Kamai+2014

Applying Gaia distance, bolometric correction from Pecaut+2013

Simulation: $f_{\rm spot} = 40\% \pm 10\%$



# Take home messages

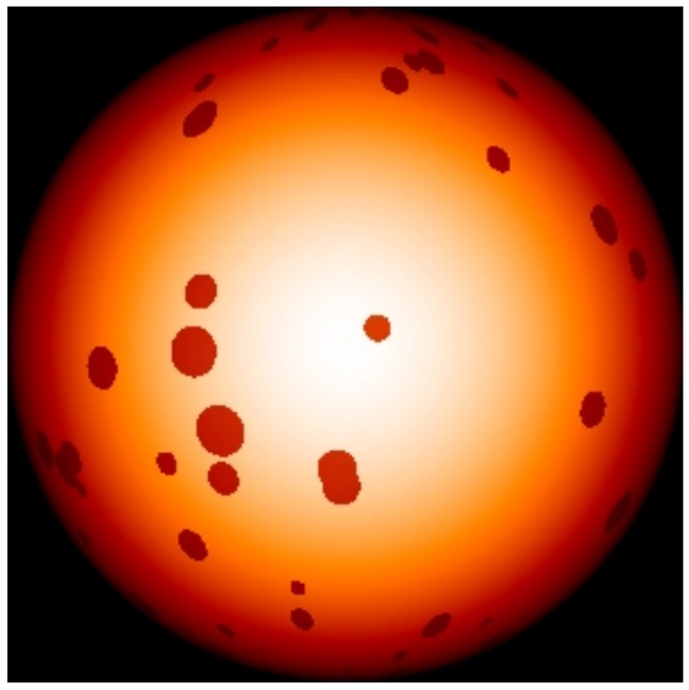
"Don't be fooled by *K2* amplitude"

- The spots on Pleiades members are symmetrically distributed on stellar surfaces
- Young star with spots is redder and fainter than photosphere
- The luminosity spread of Pleiades cluster is 0.05 dex

  Fitted by our simulation with $f_{\rm spot} = 40\% \pm 10\%$

Not including other mechanisms:

- Faculae associated with dark spots
- Inflation of stellar radii due to energy conservation
- Latitudinal  uneven distribution of spots
- Lifetime and evolution of spots

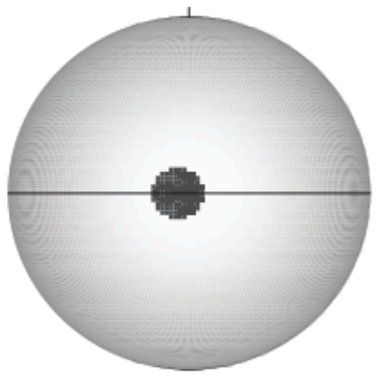


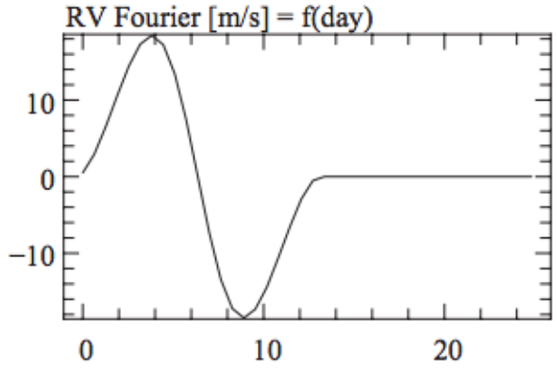
# Star spots - simulations

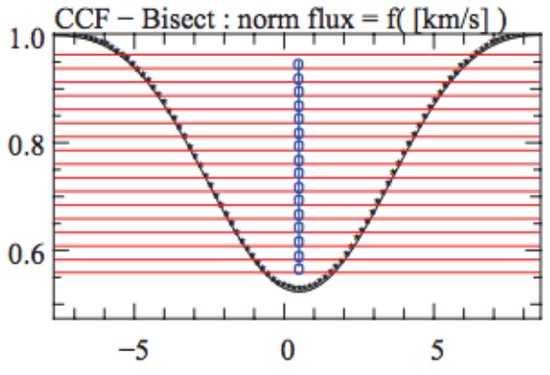
*Desort+2007: Star spots vs. RV*

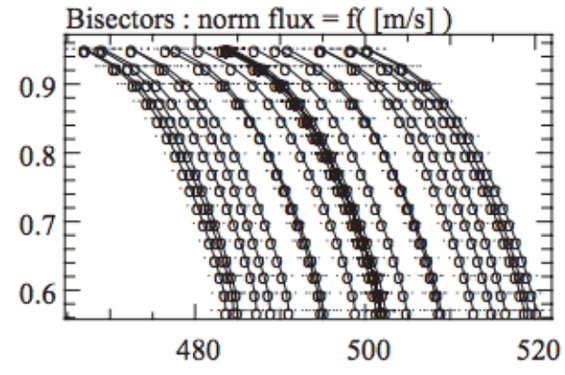
*Barnes+2011: Star spots vs. RV Jitters*

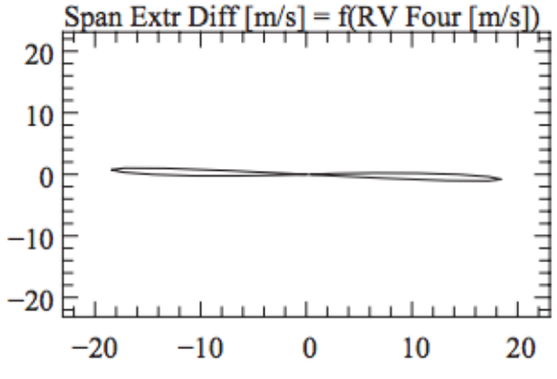
*Rackham+2018: Star spots vs. Transiting planets*

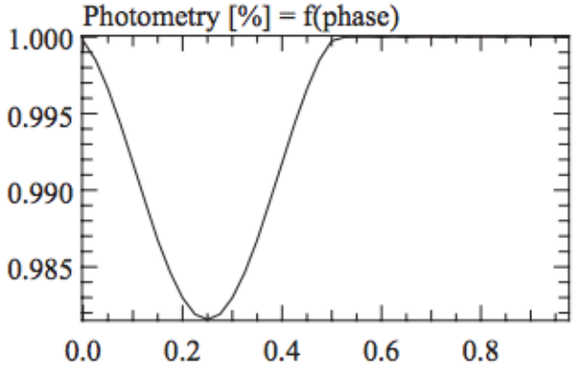


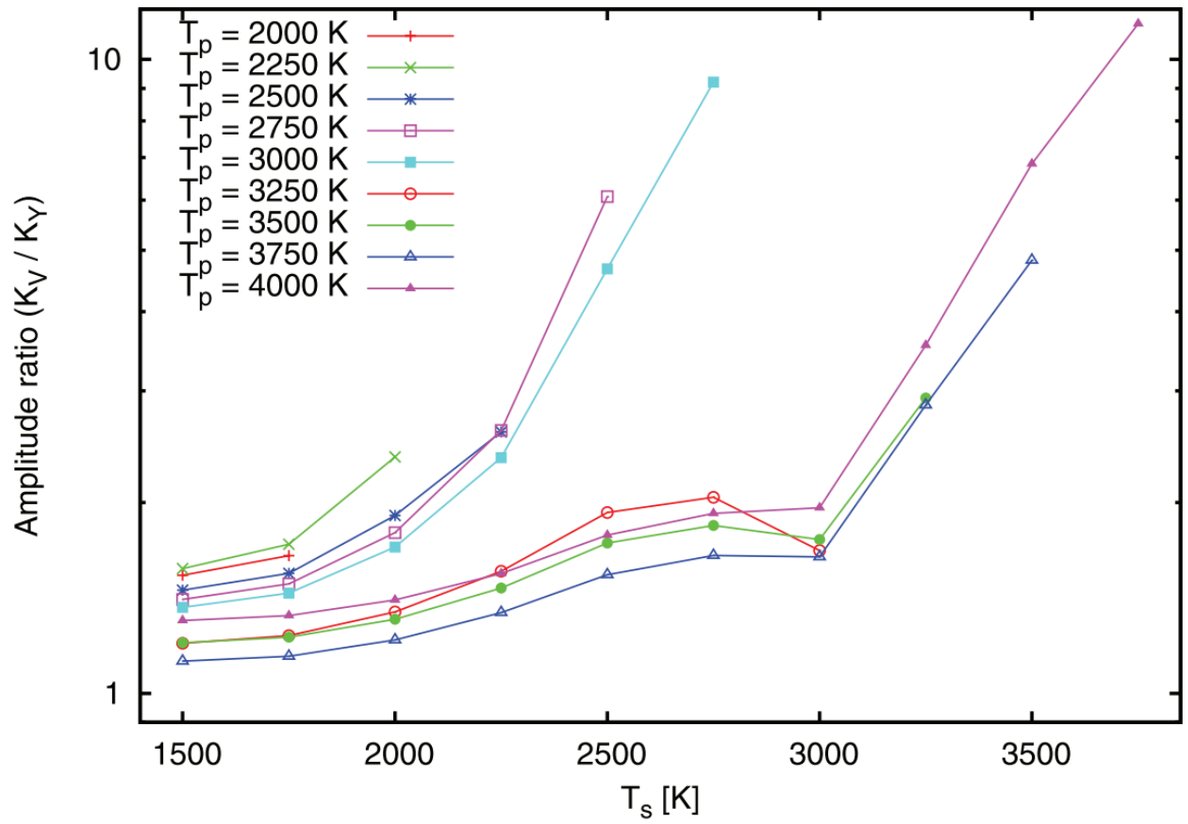


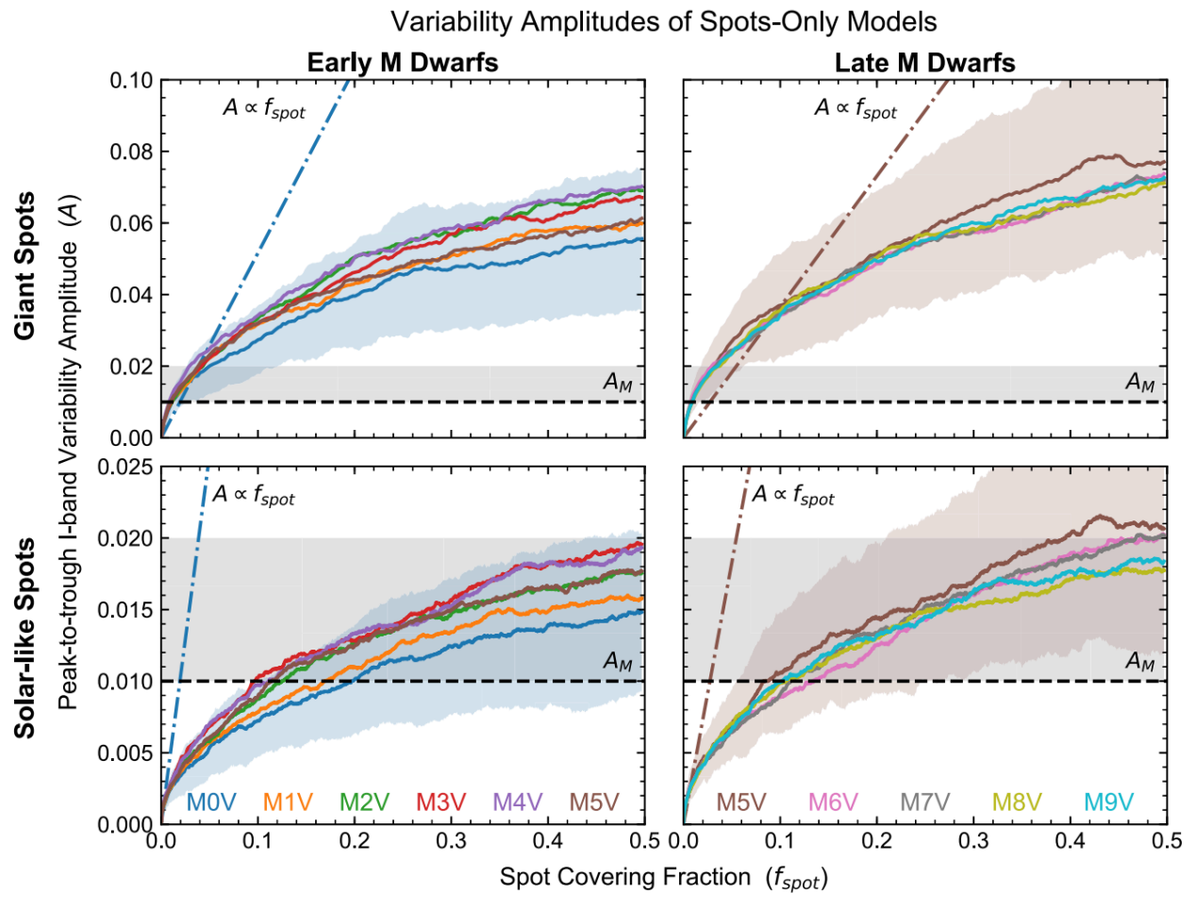



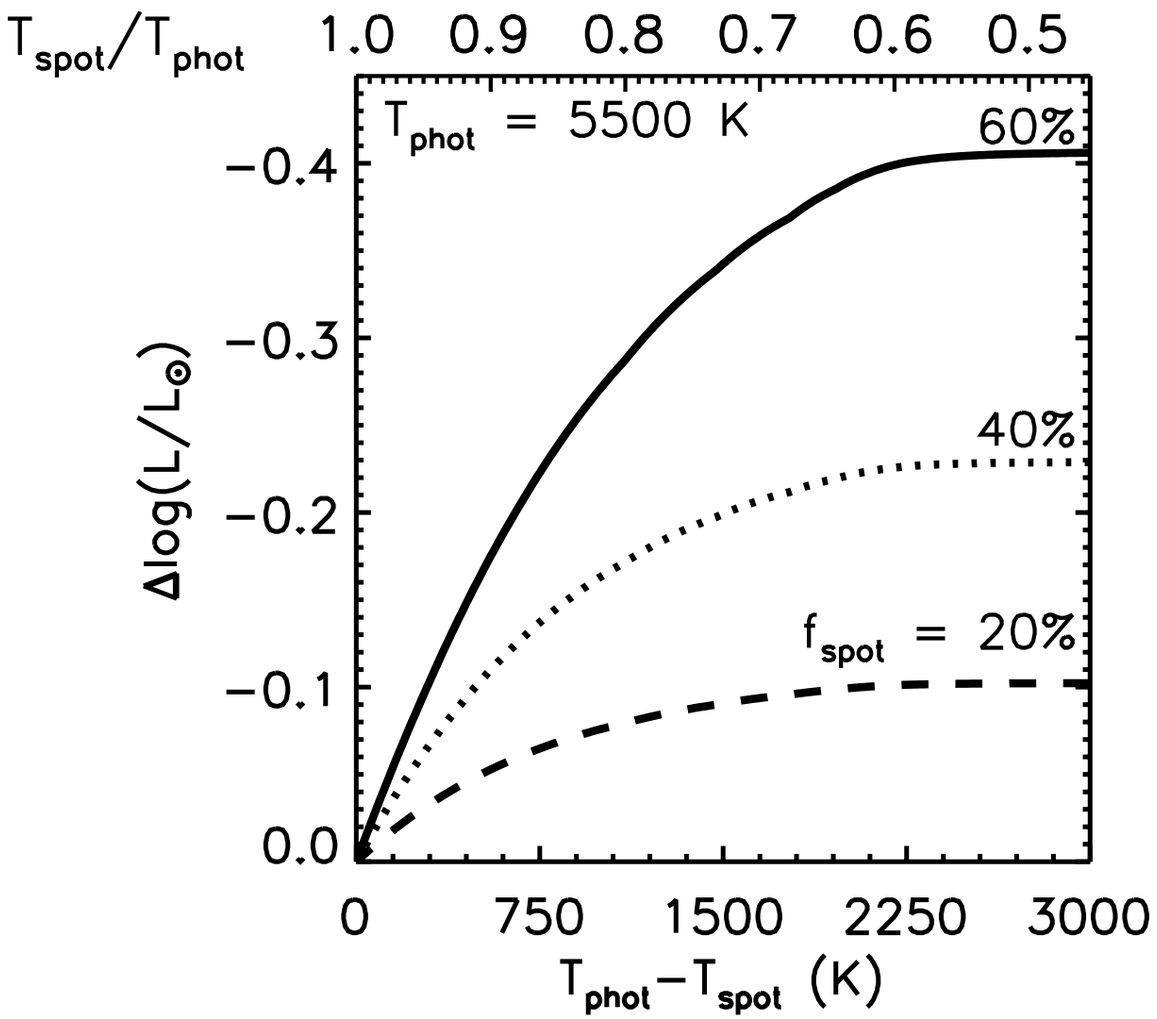



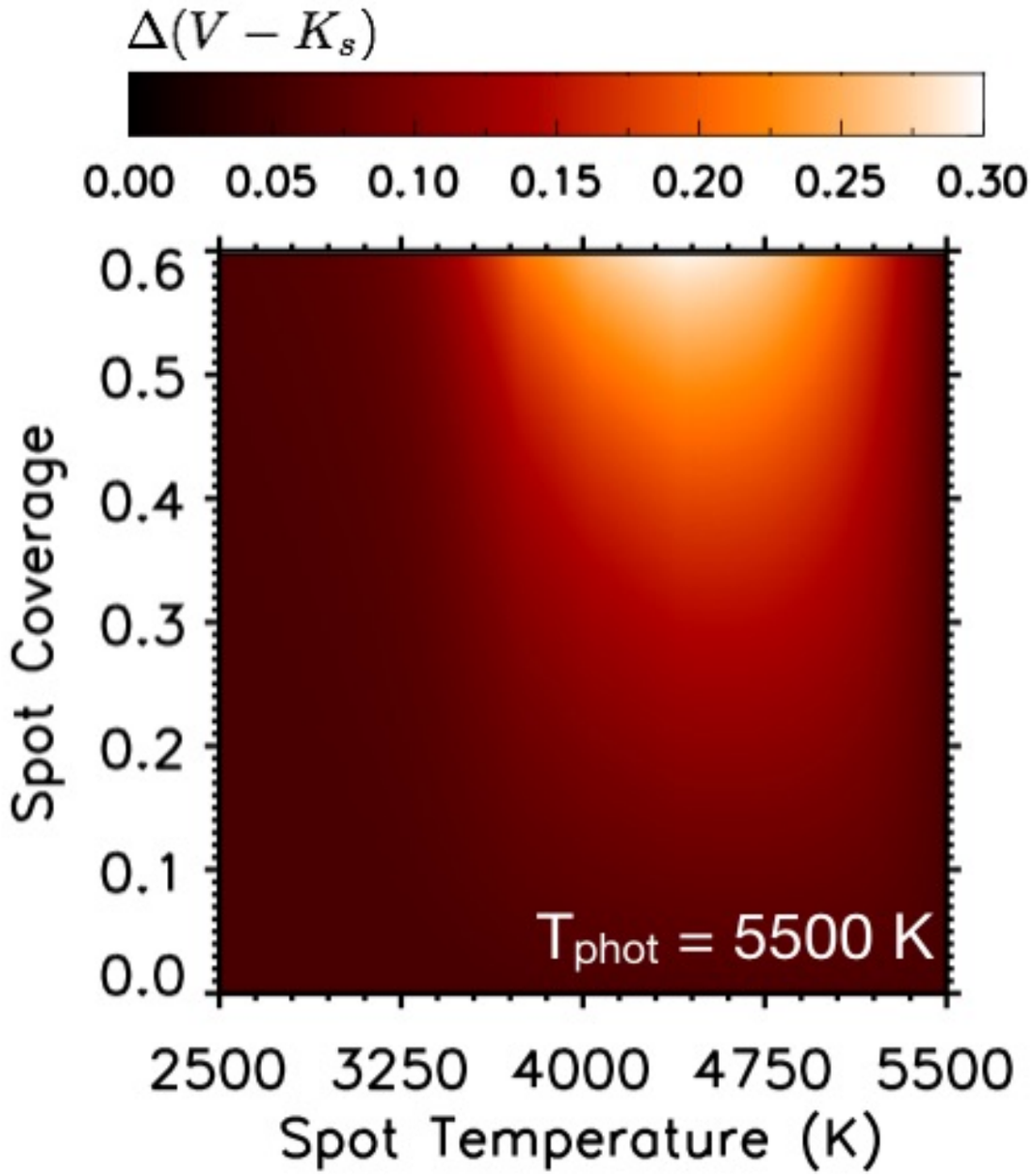



# The observed stellar luminosity and colour

An example when $T_{phot}$ = 5500 K




Maximum $\Delta(V - K_s)$ when $T_{spot} \sim 80\%\ T_{phot}$

# Consequences of stellar spots in a cluster