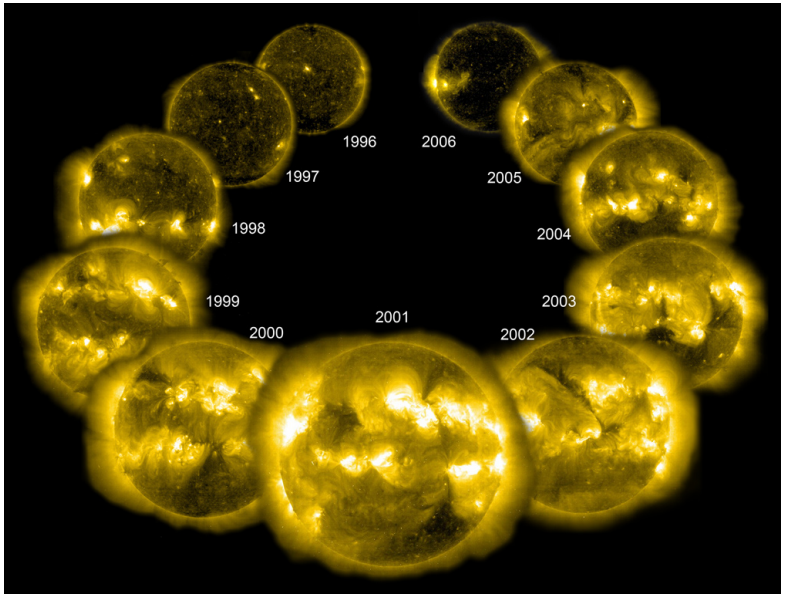



# The Sun is less active than other solar-like stars

Timo Reinhold, Max Planck Institute for Solar System Research, Göttingen, Germany

**Virtual Nordic Dynamo Seminar, 9 June 2020, Göttingen**

# Outline

1. Introduction: Solar activity
2. Solar vs. stellar activity: Is the Sun an (un)usual solar-like star?
3. Possible explanations
4. Conclusions

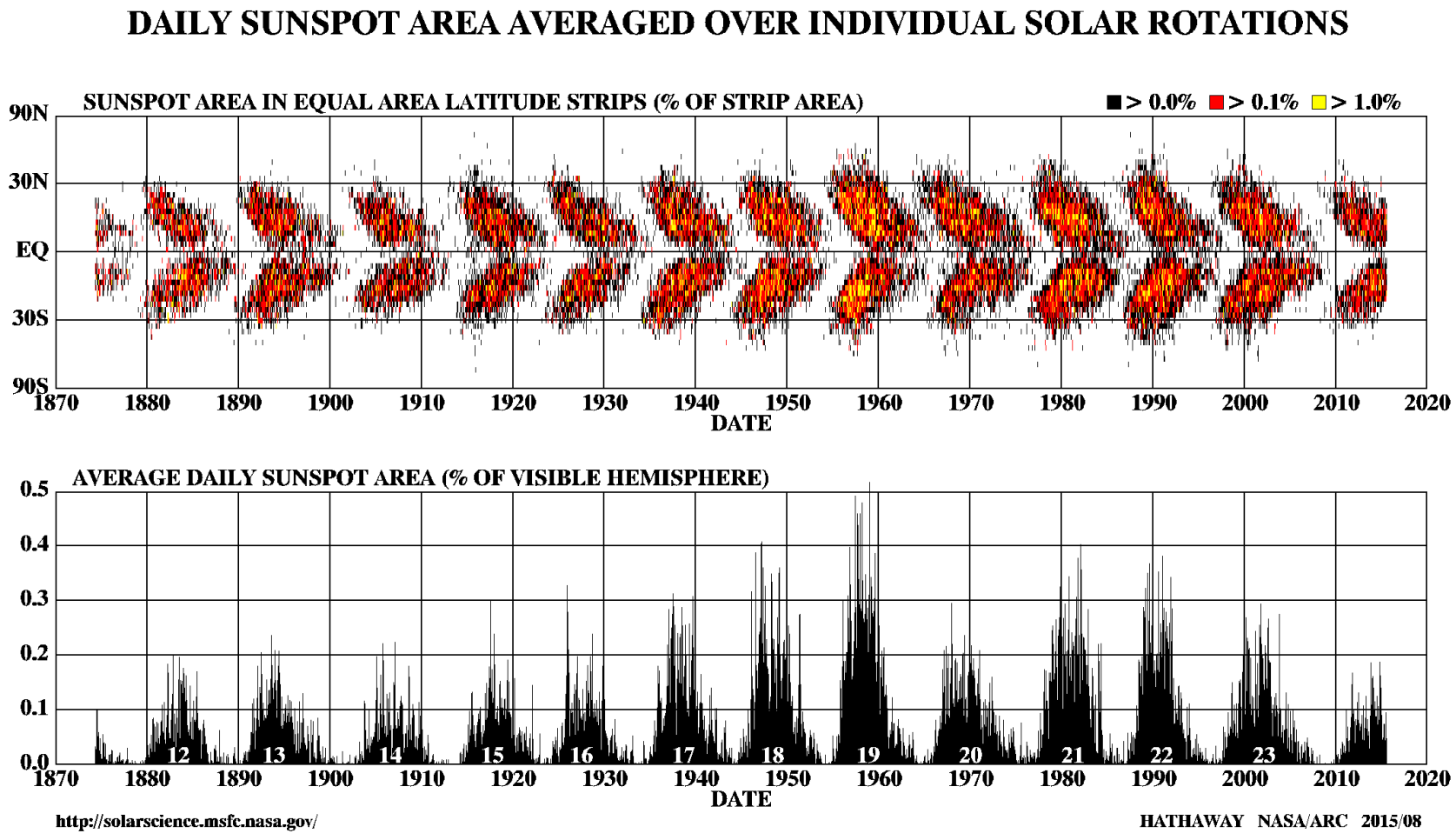
# Motivation

- Compare solar and stellar activity/variability to put the Sun into context of other solar-like stars
- "Solar-like" means stars that have similar fundamental parameters (effective temperature, rotation period, metallicity, etc.) as the Sun
- Understand the causes of the different activity levels. In other words: How (un)usual is solar compared to stellar variability?

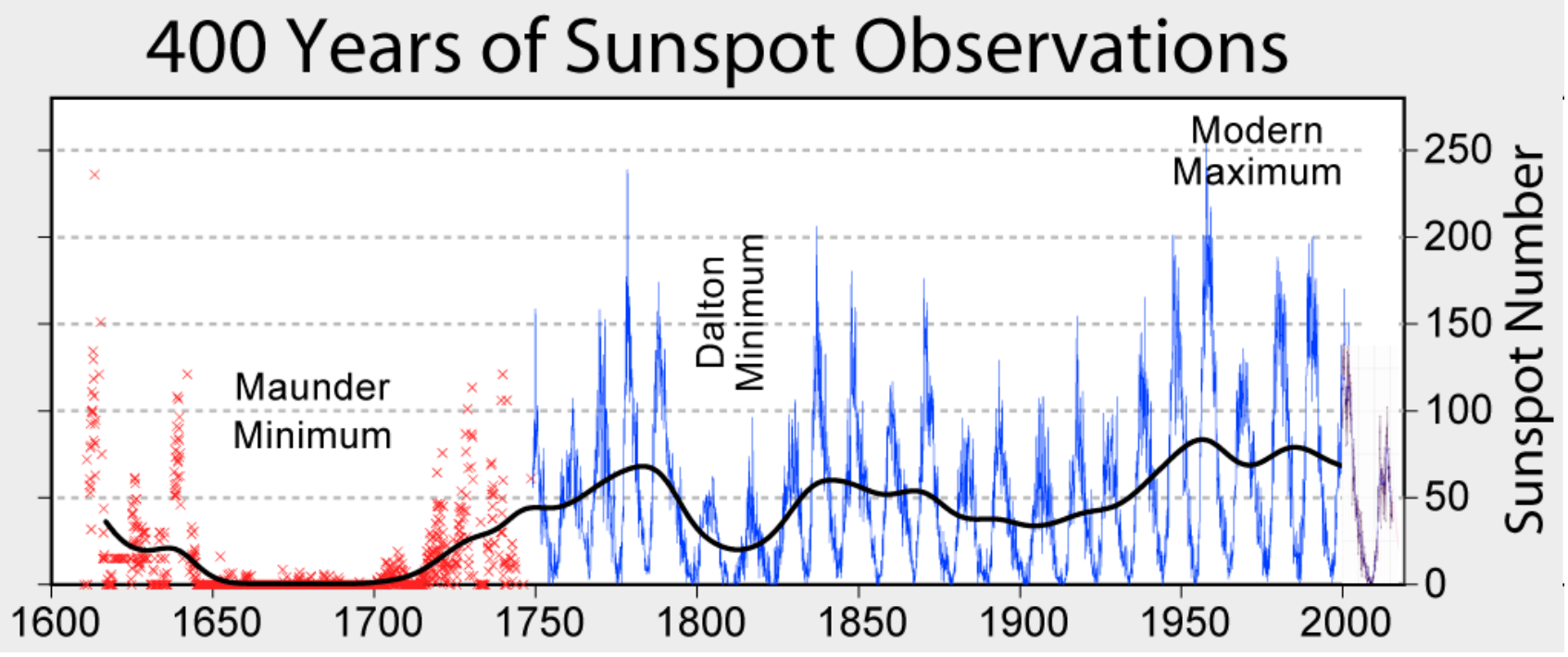
# Solar rotational variability

Start movie

# The Solar Cycle: 140 years of solar activity

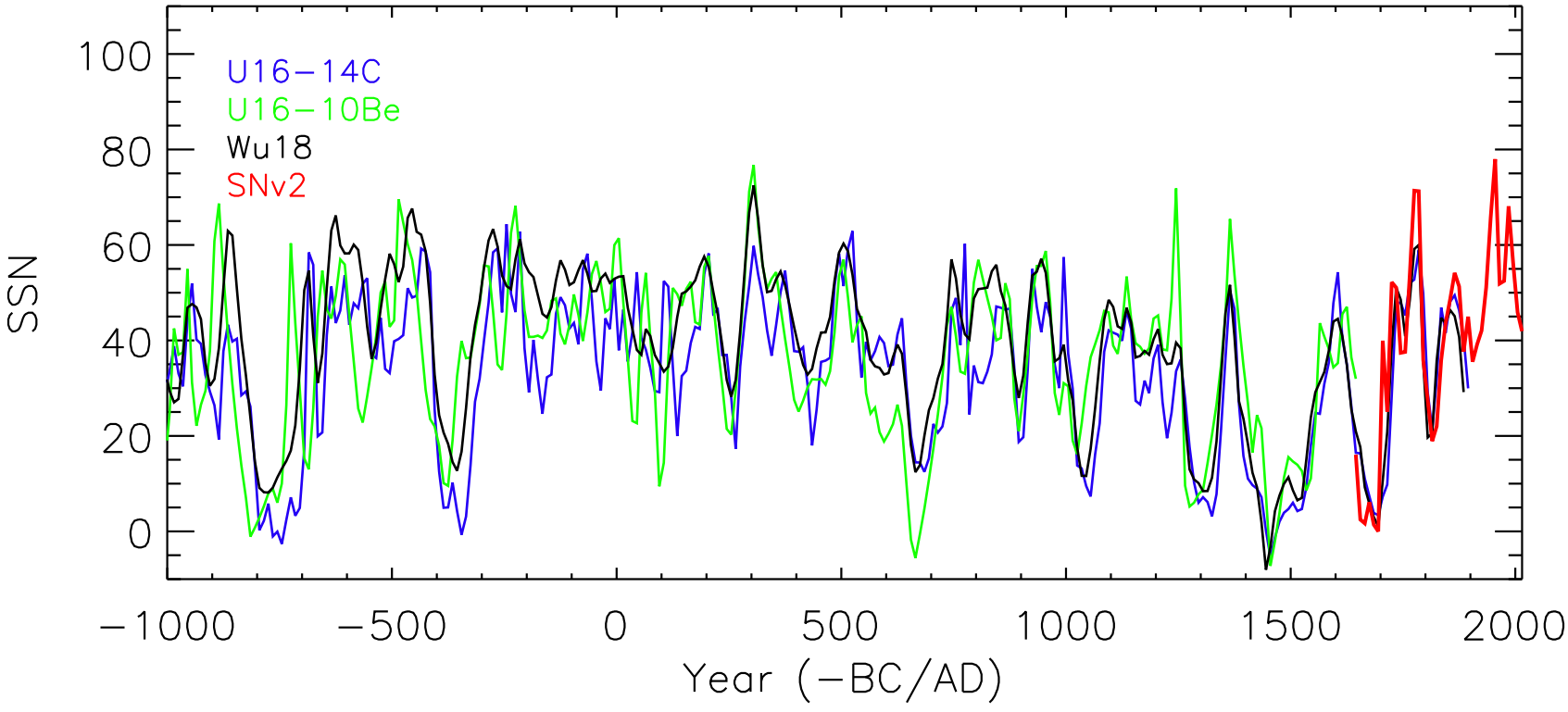


# The Solar Cycle: 400 years of Sunspots




credits: Robert A. Rohde
(https://commons.wikimedia.org/wiki/File:Sunspot_Numbers.png)

# The Solar Cycle: 9000 years of solar activity




Wu et al. (2018)

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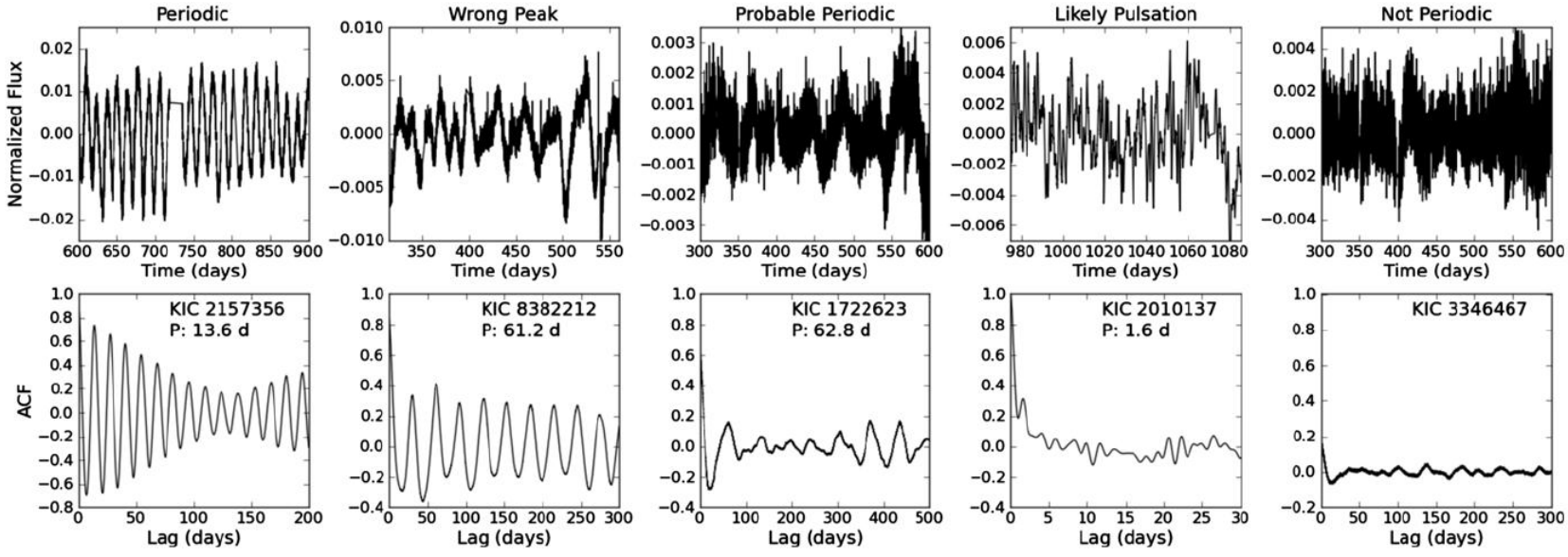
# The Kepler telescope

- The Kepler telescope observed $\sim 200,000$ stars for 4 years with high precision
- Rotation periods could be measured from the light curves for thousands of stars (Reinhold et al. 2013; Walkowicz & Basri 2013; McQuillan et al. 2014), etc.

# Kepler light curves

## Rotation periods

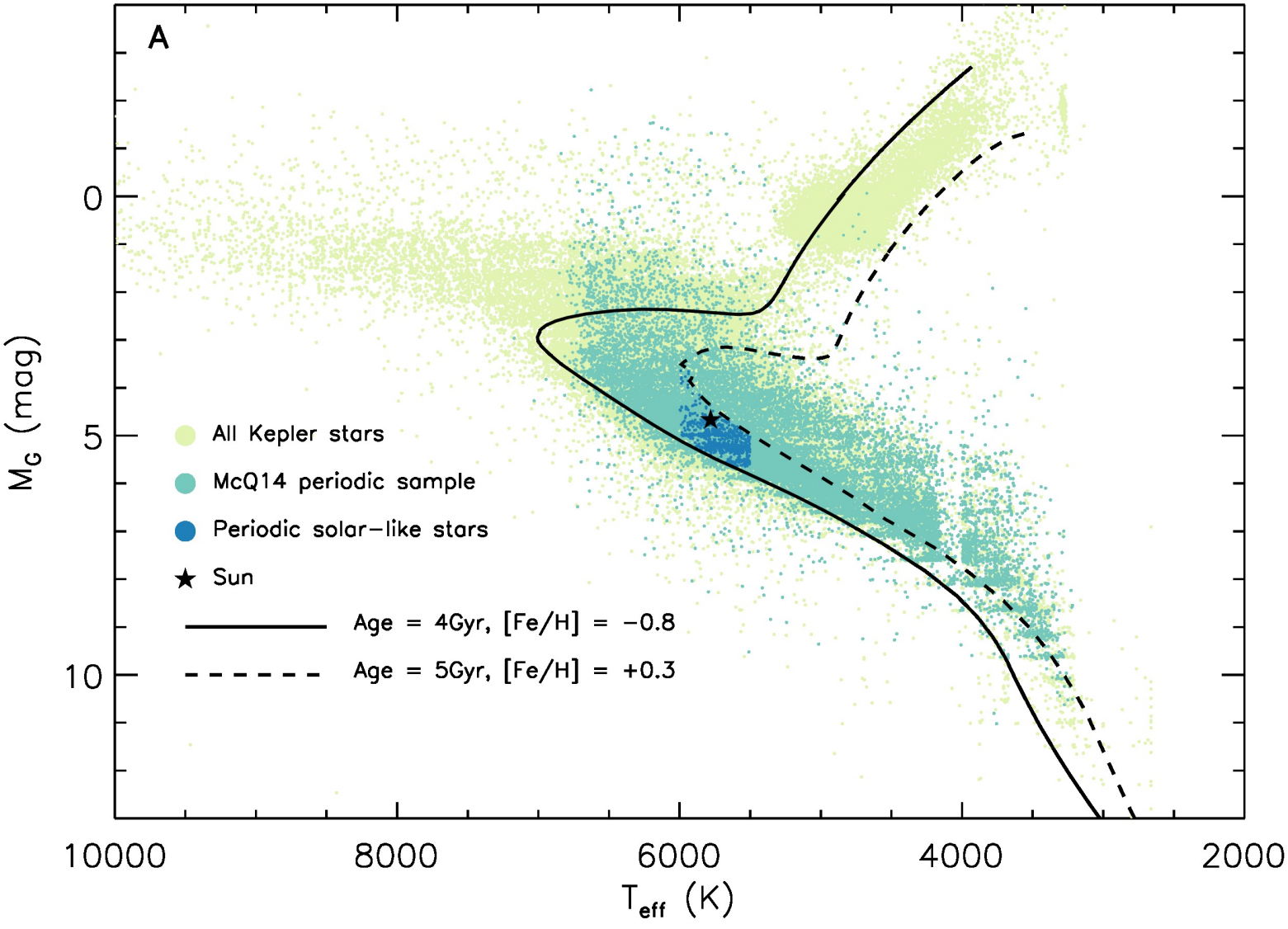


# The solar-like sample

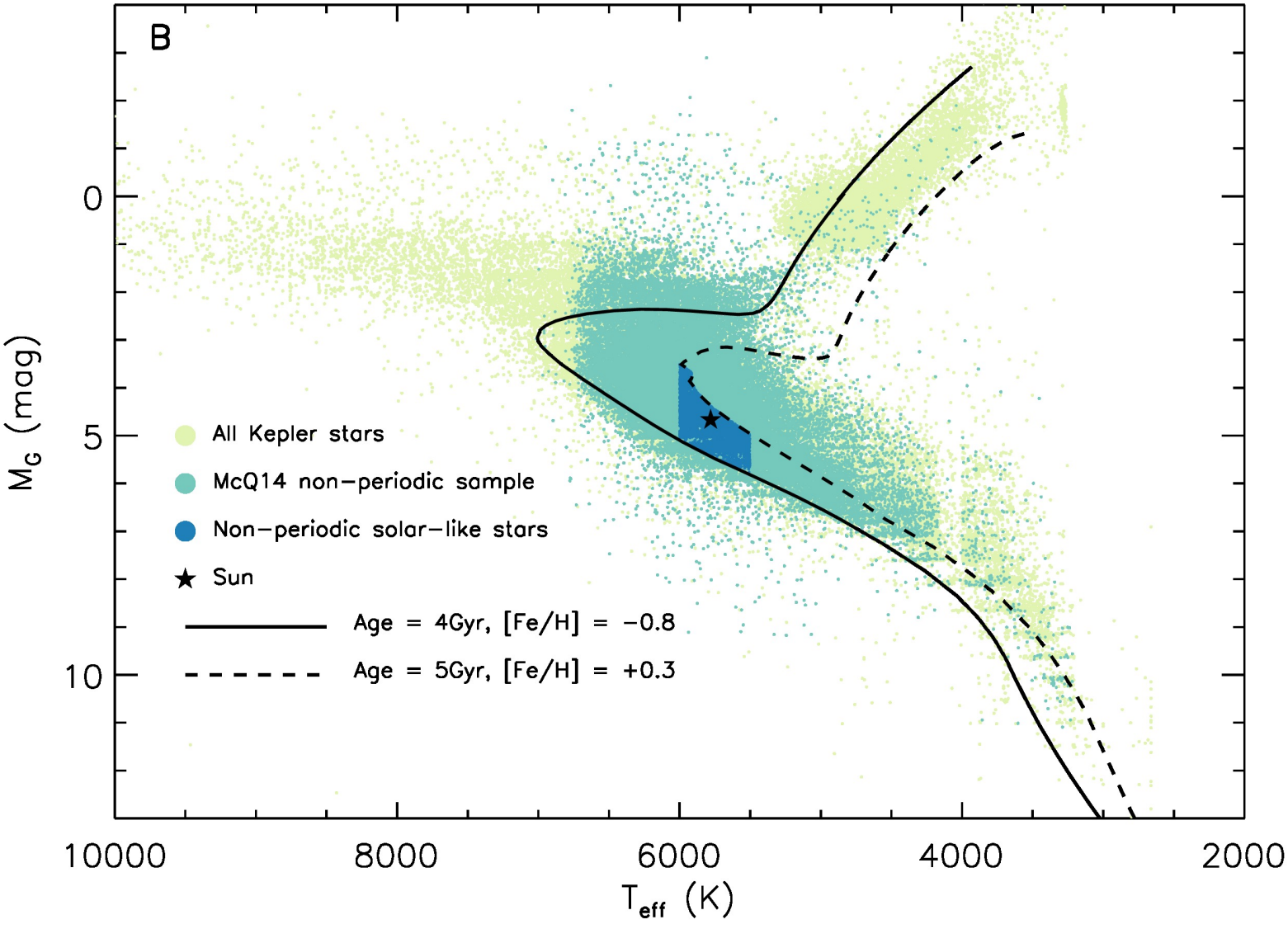
- McQuillan et al. (2014): 34,030 stars with detected rotation periods, and 99,000 stars without detected rotation periods; call them "periodic" and "non-periodic" sample in the following

- Select solar-like stars from both samples:
  - $5500\,\mathrm{K} < \mathrm{T_{eff}} < 6000\,\mathrm{K}$ and log $g > 4.2$ (Mathur et al. 2017)
  - $20\,\mathrm{d} < \mathrm{P_{rot}} < 30\,\mathrm{d}$ (for periodic sample)
  - Use Gaia DR2 data to select only main sequence stars: construct Hertzsprung-Russell diagram (HRD) and select stars between isochrones of [4 Gyr, M/H=-0.8] and [5 Gyr, M/H=0.3]
  - Discard stars fainter than 15th magnitude

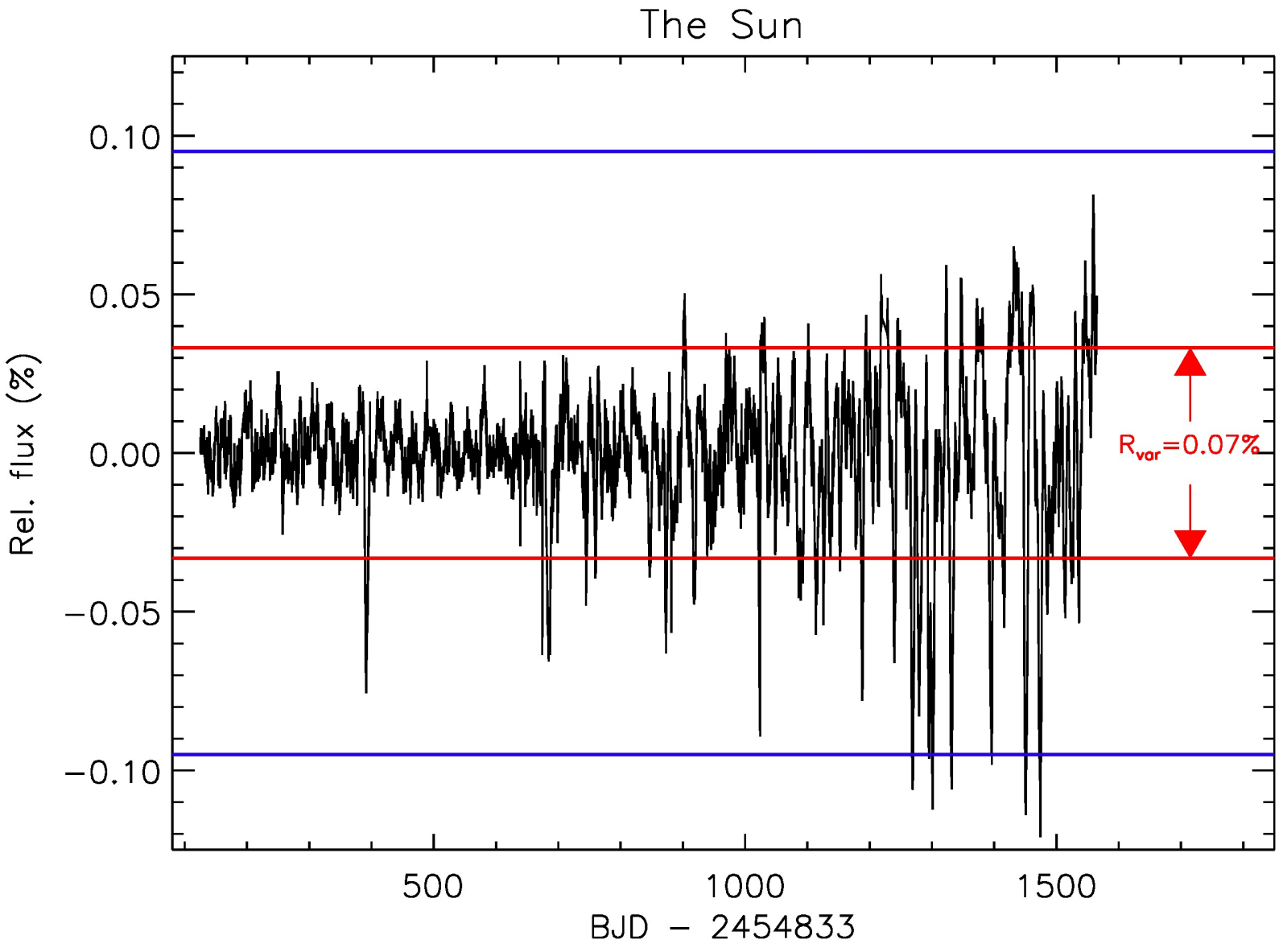
# The periodic sample



# The non-periodic sample



# Measure the light curve variability using $\mathrm{R_{var}}$



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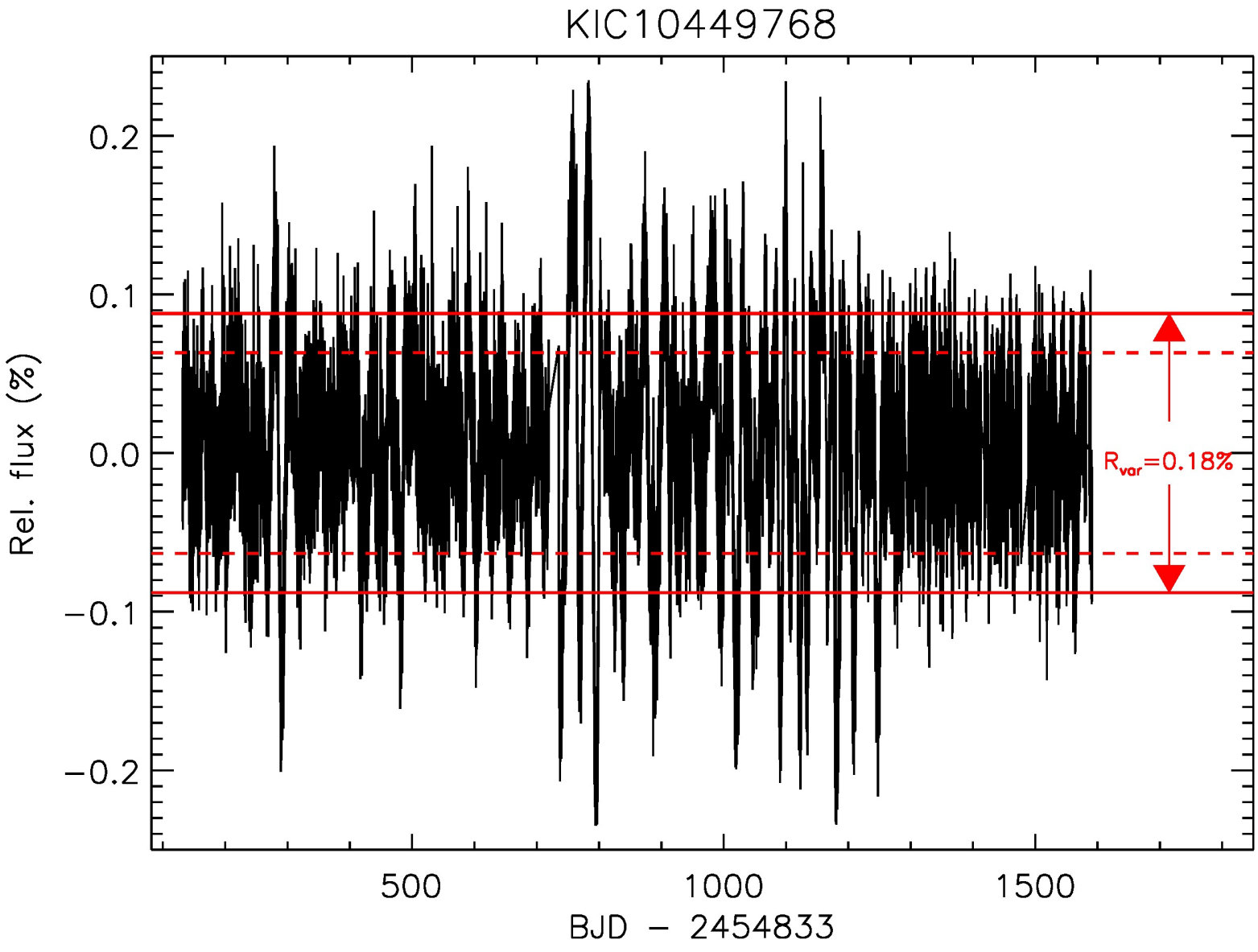

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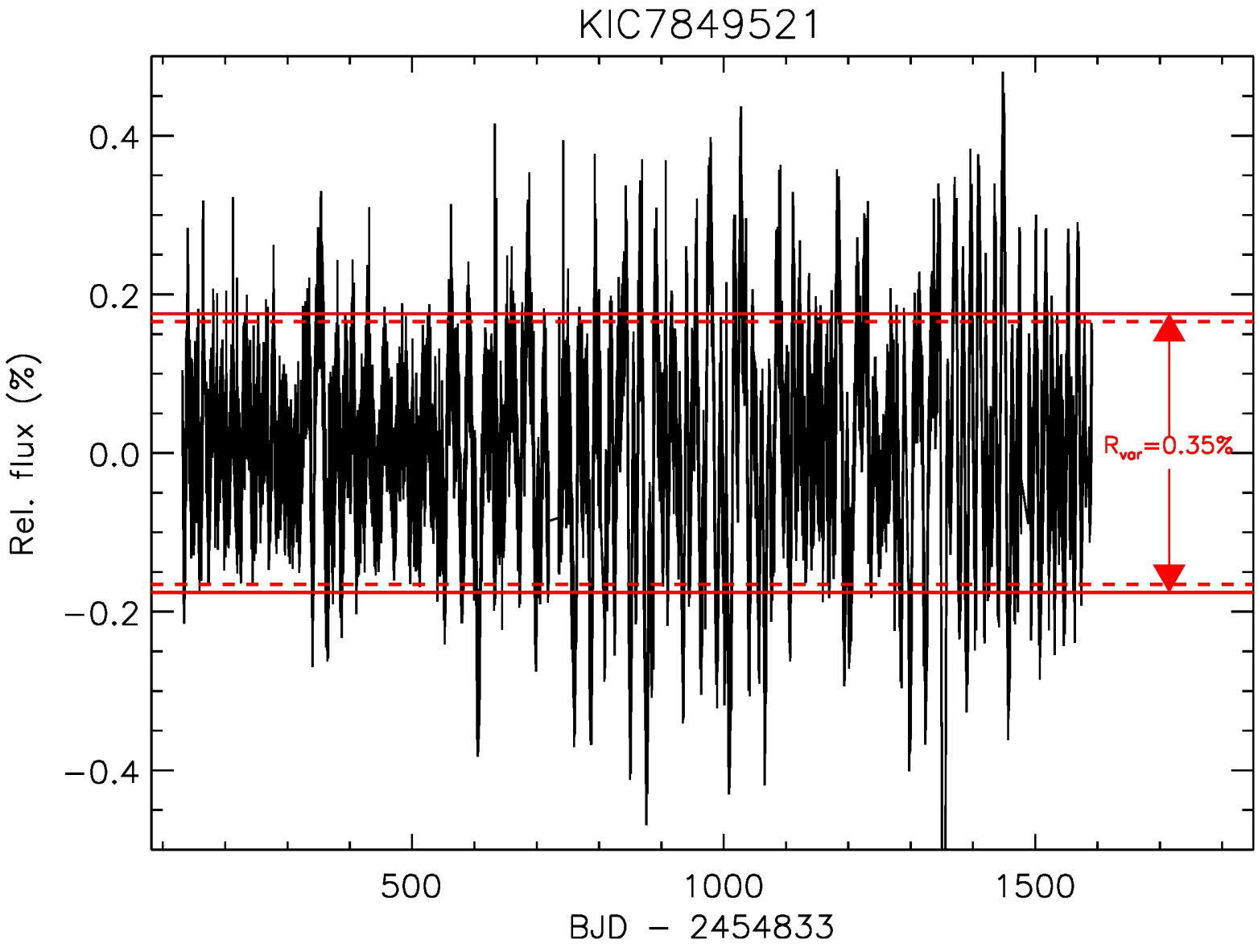

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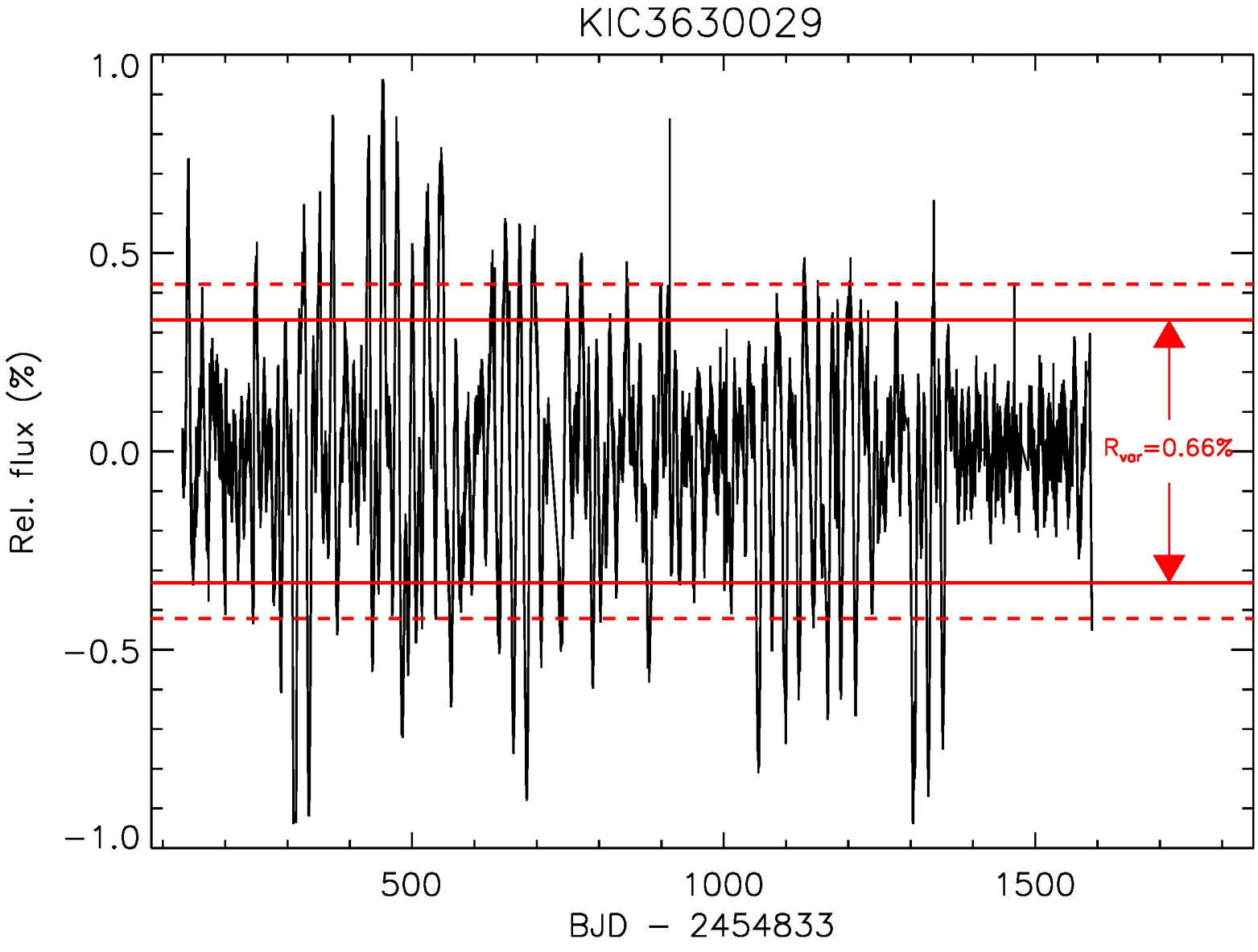
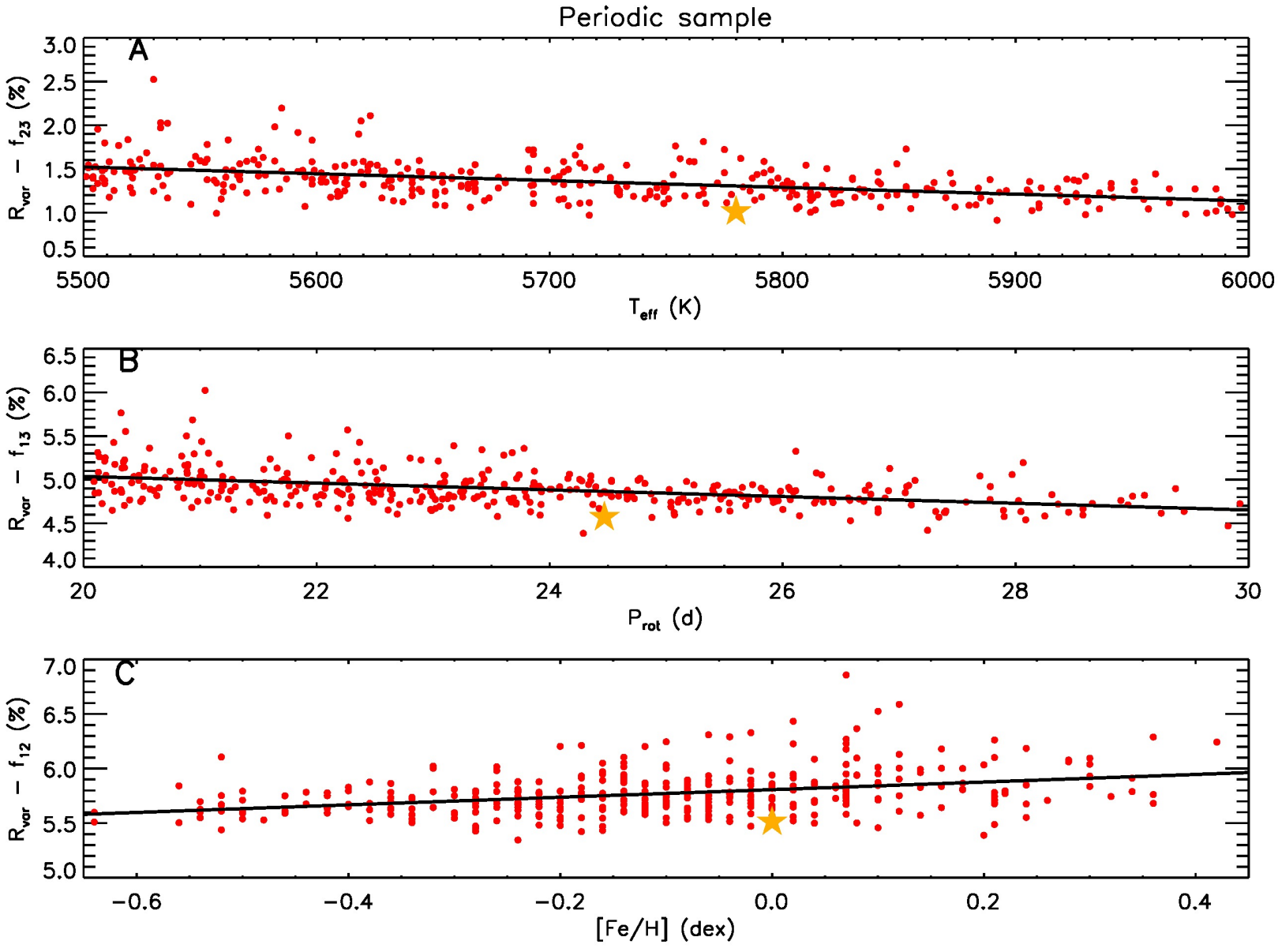
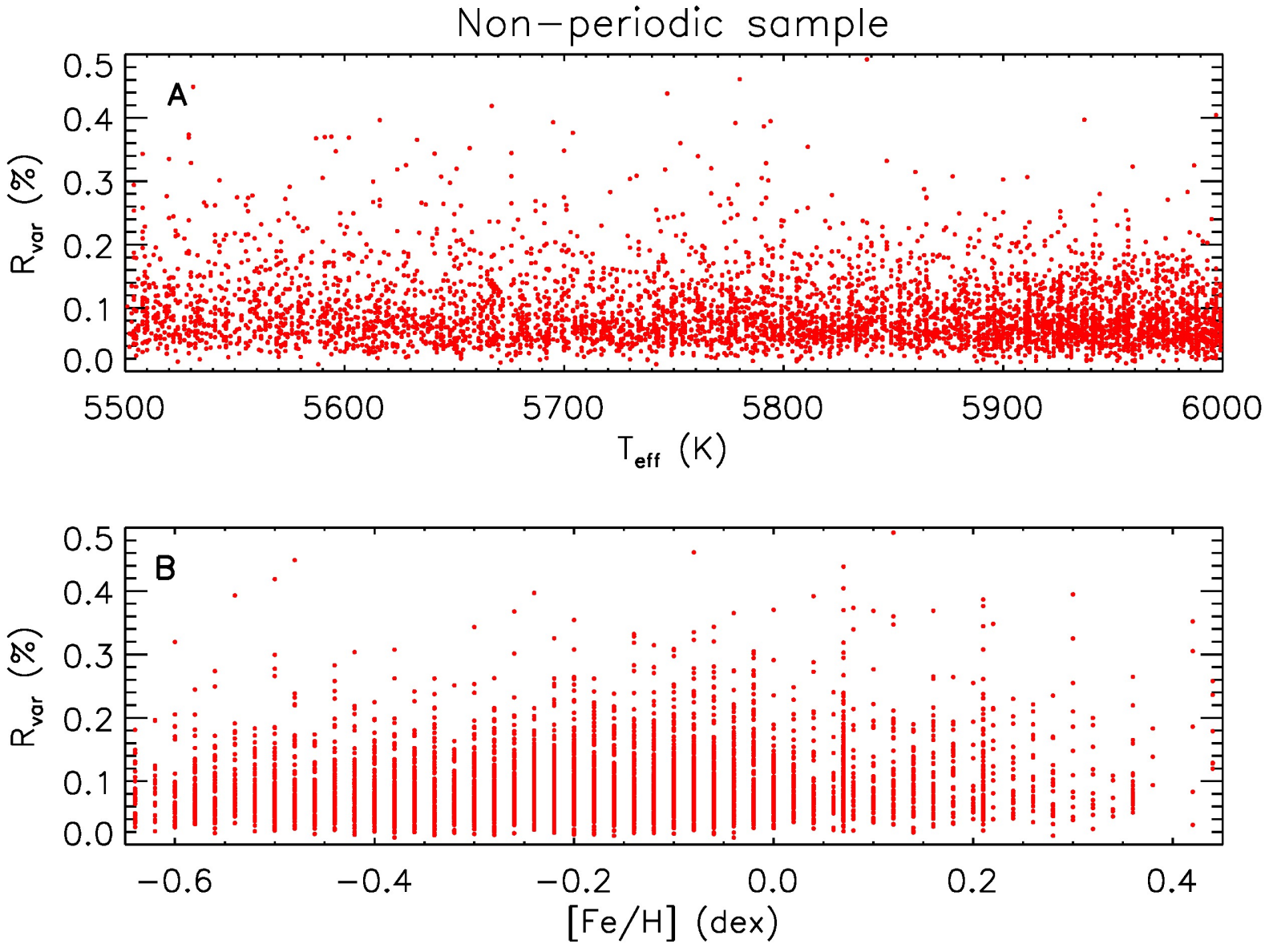


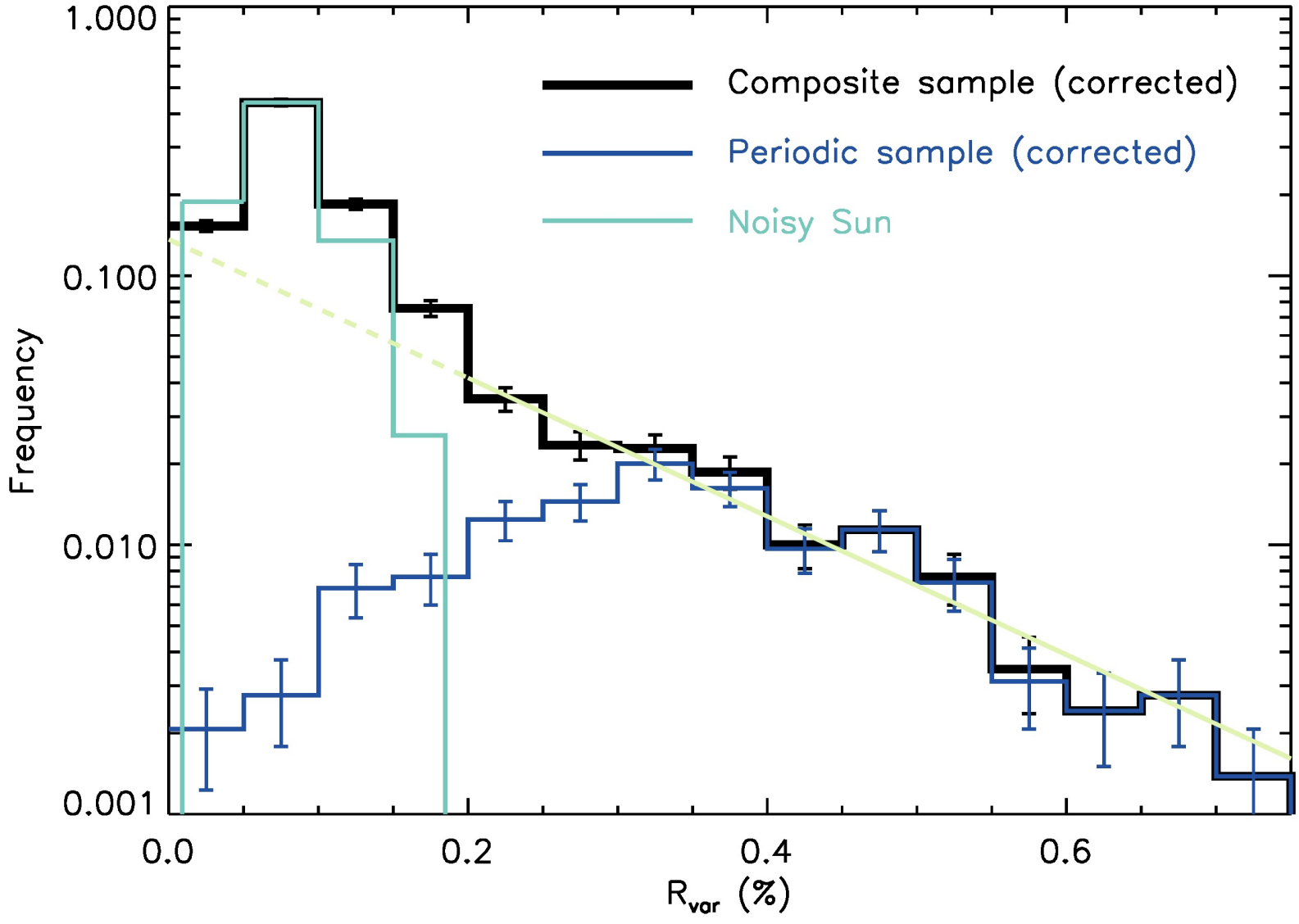
# $R_{var}$ dependence on fundamental parameters



# $R_{var}$ dependence on fundamental parameters



# The variability distribution



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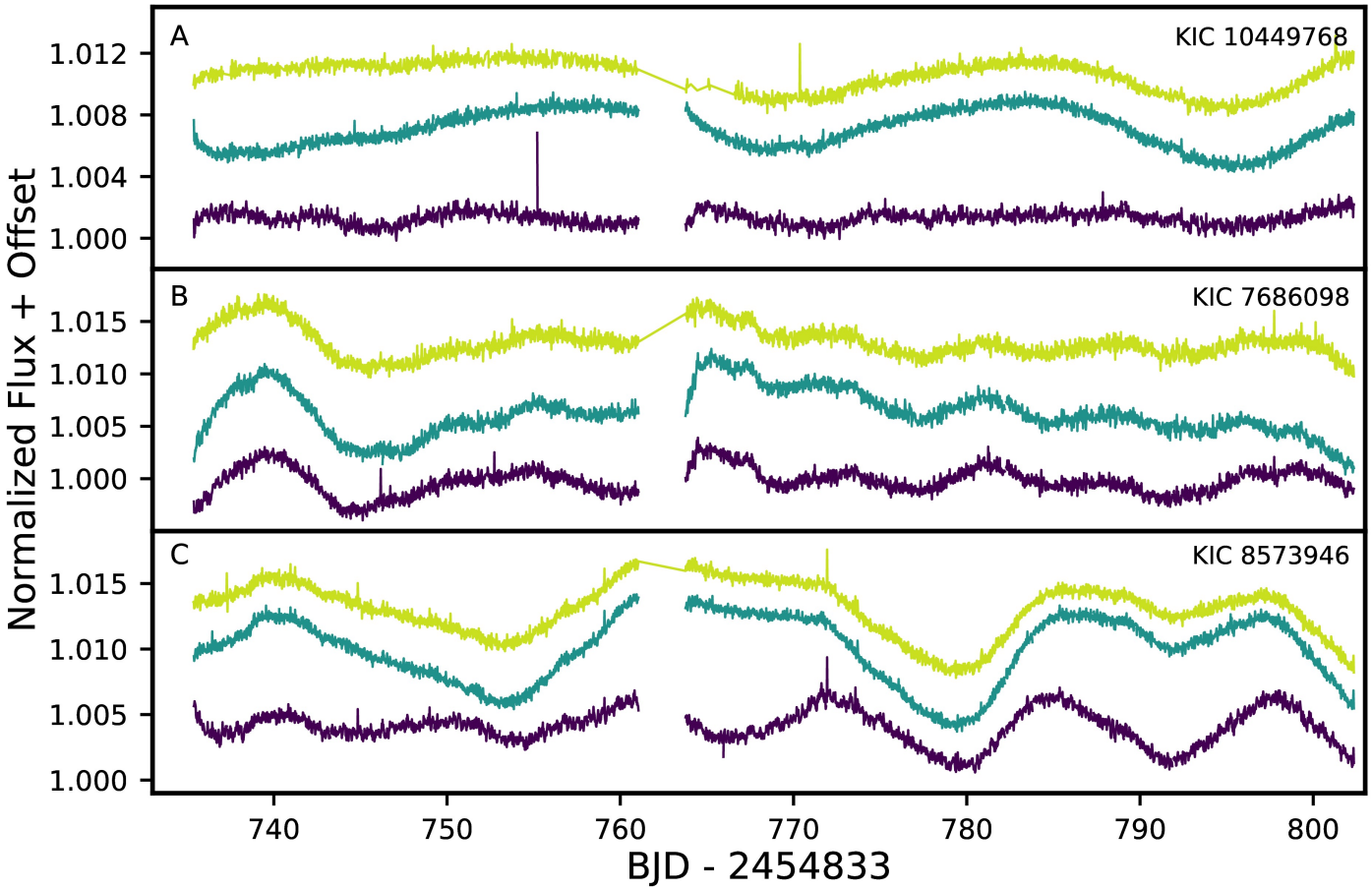
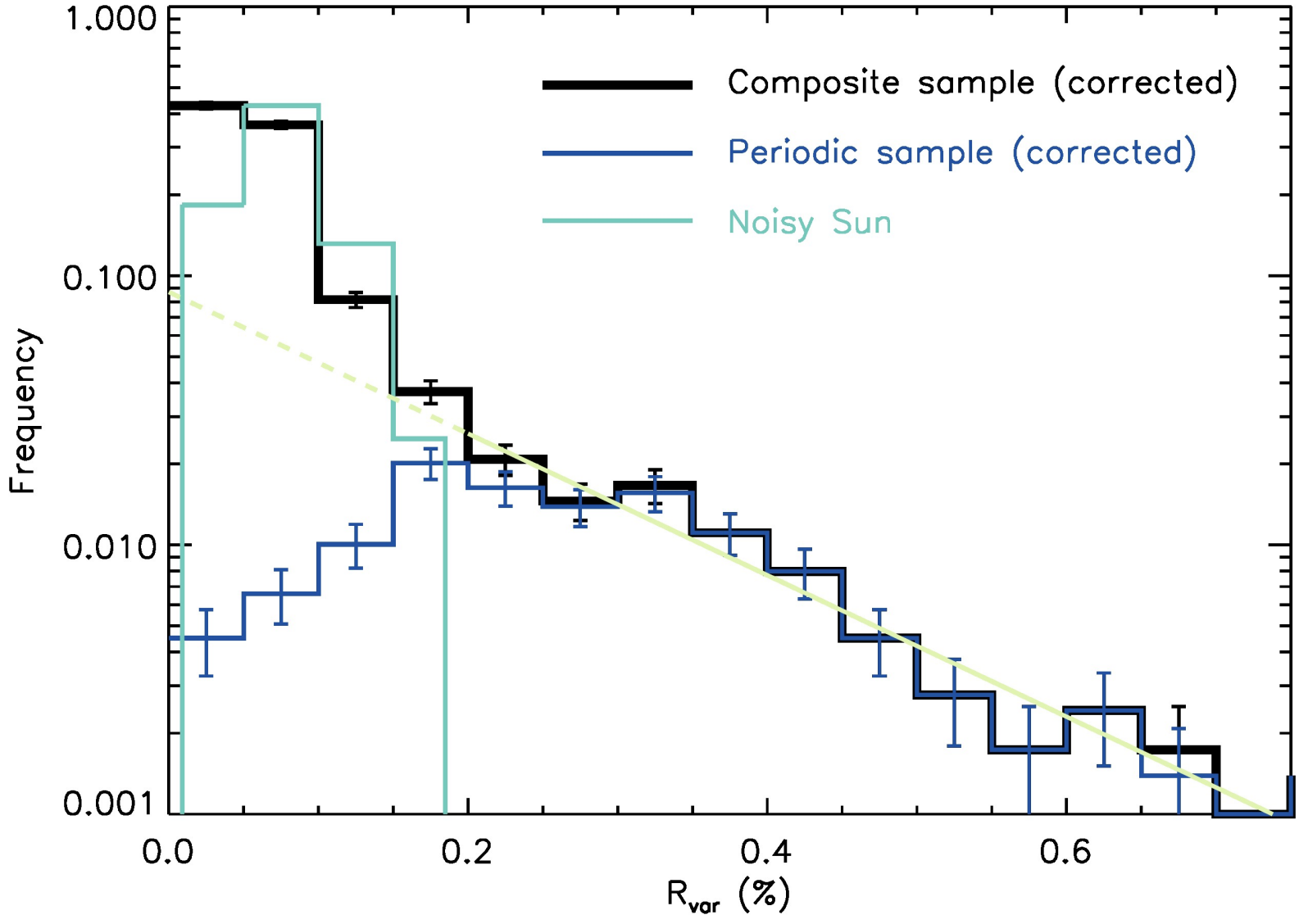
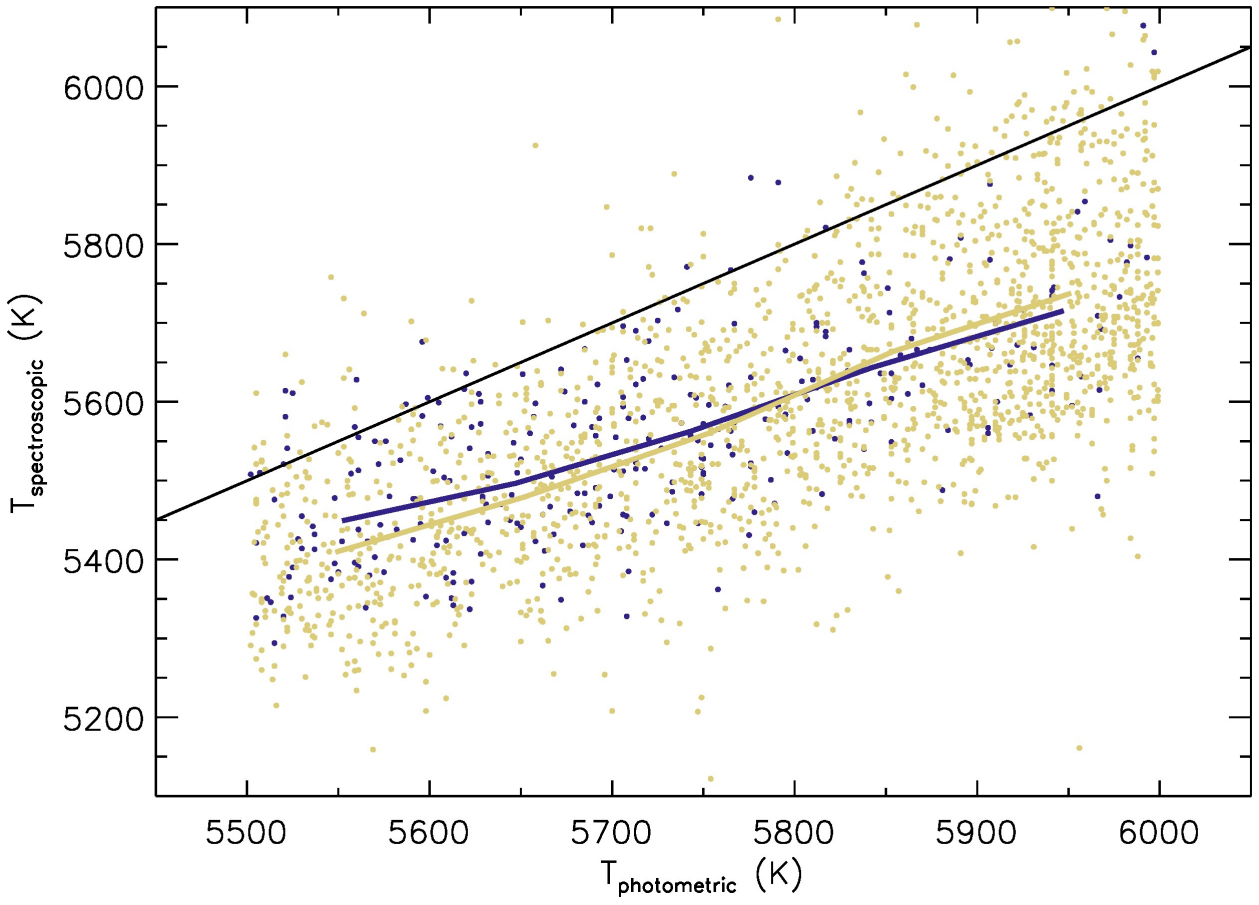
# Kepler data reduction?



# –> Similar variability distribution



# Accuracy of fundamental parameters?



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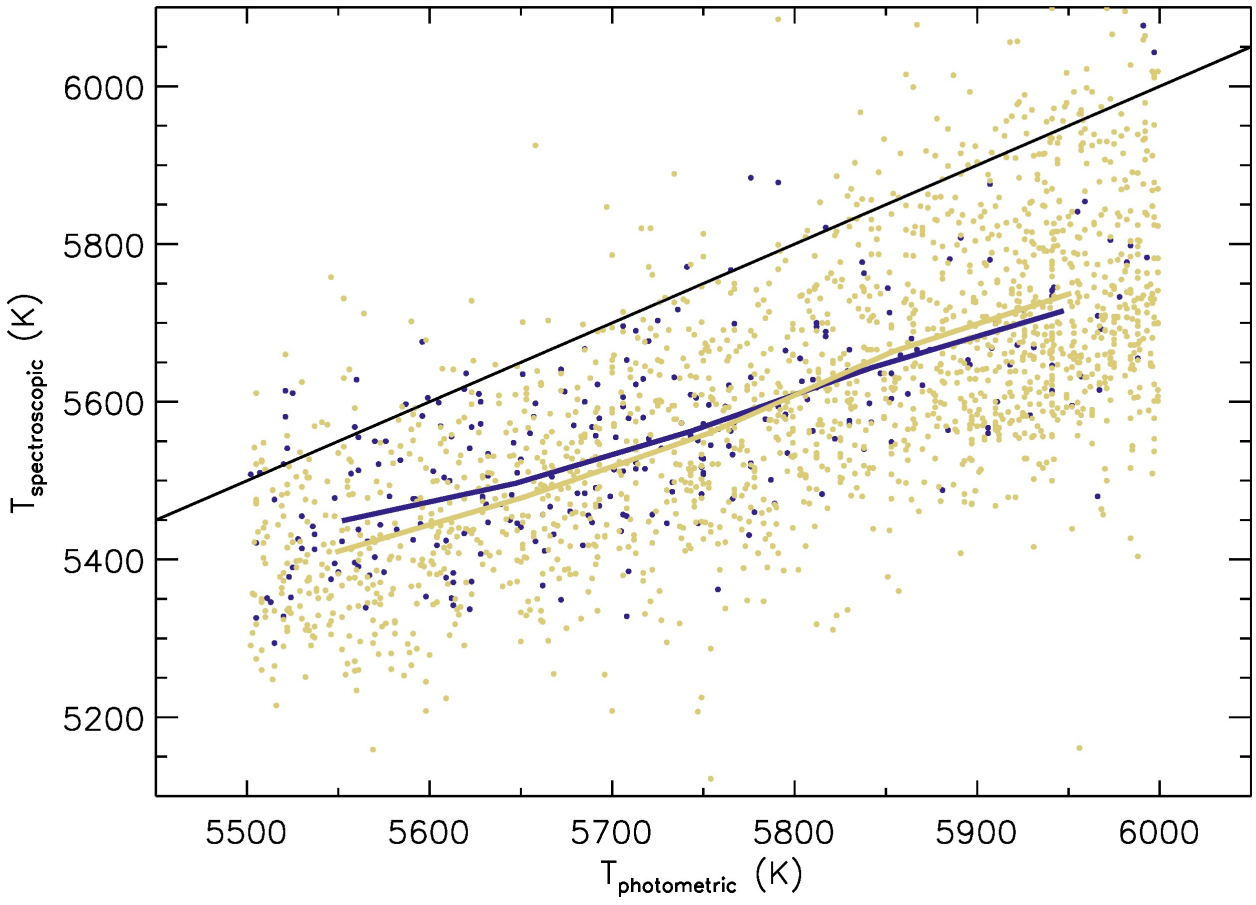
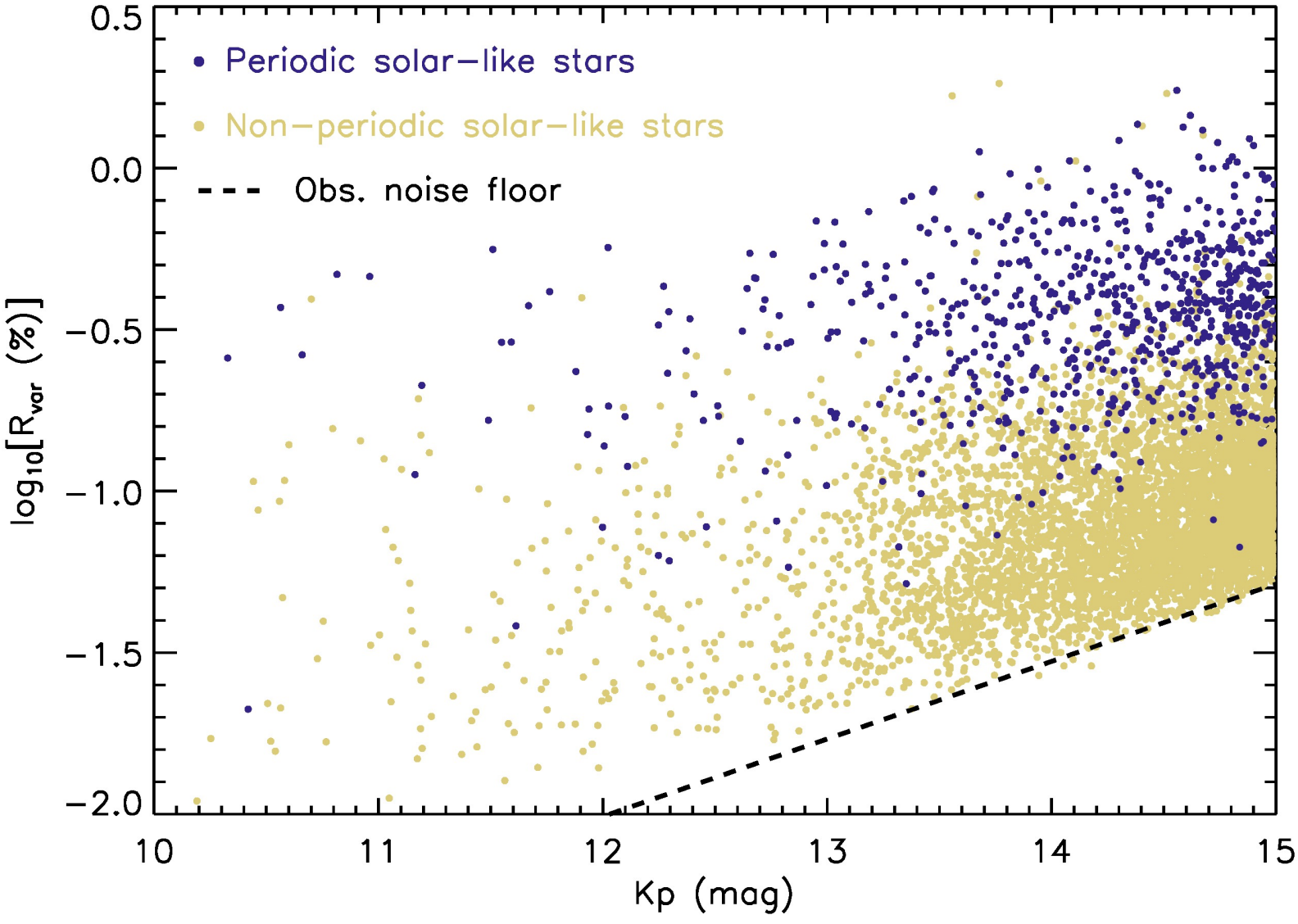



–> Different temperature offsets but no difference between periodic and non-periodic sample!

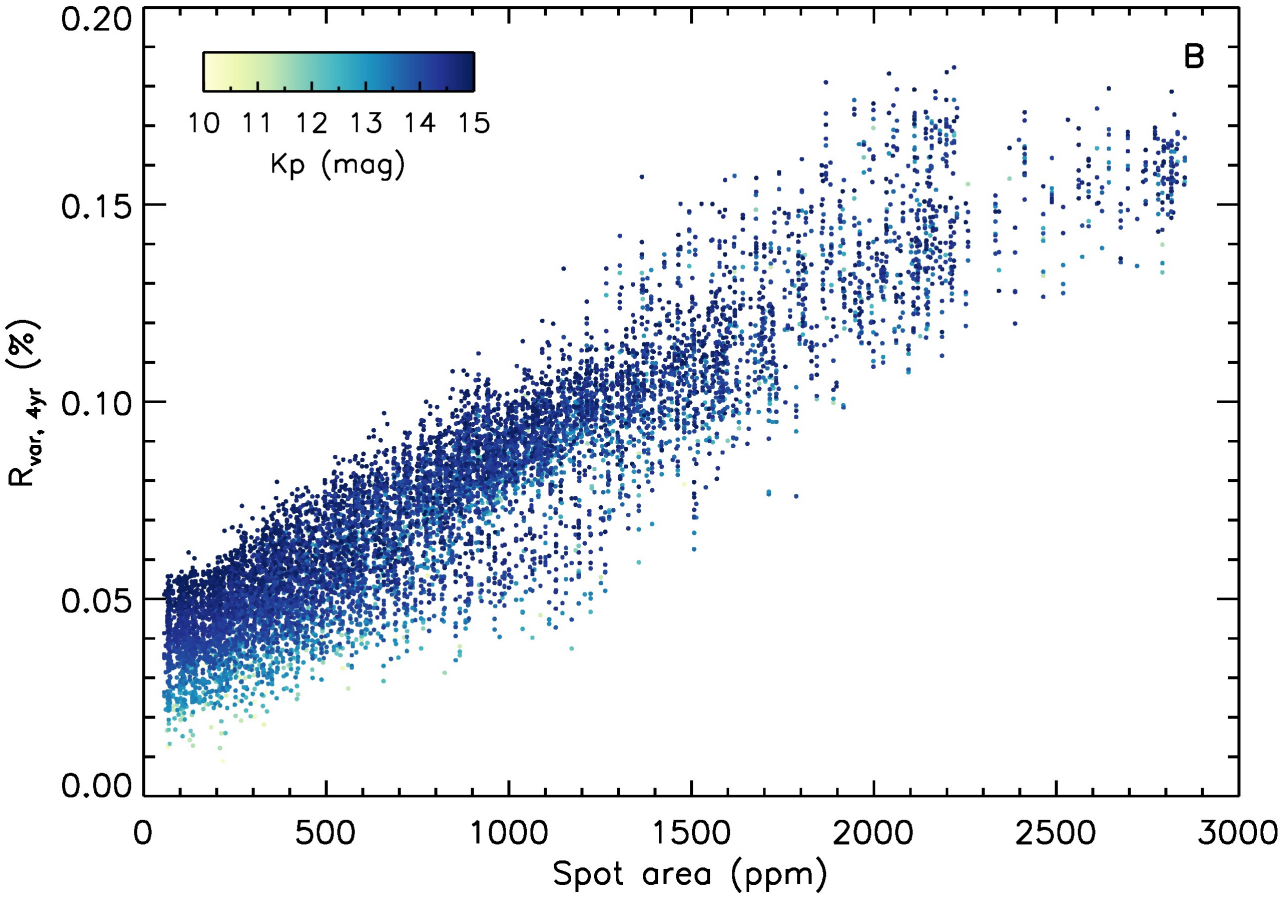
# Other explanations

- $\mathrm{R_{var}}$ correction on fundamental parameters? Small effect
- Active background star? –> Excluded by Gaia
- Inclination effect? –> Smaller variability for $i < 90^{\circ}$
- Kepler passband? Effect small (Nèmec et al. 2020)

# How would the Sun look as a Kepler star?



# The "Keplerized" Sun



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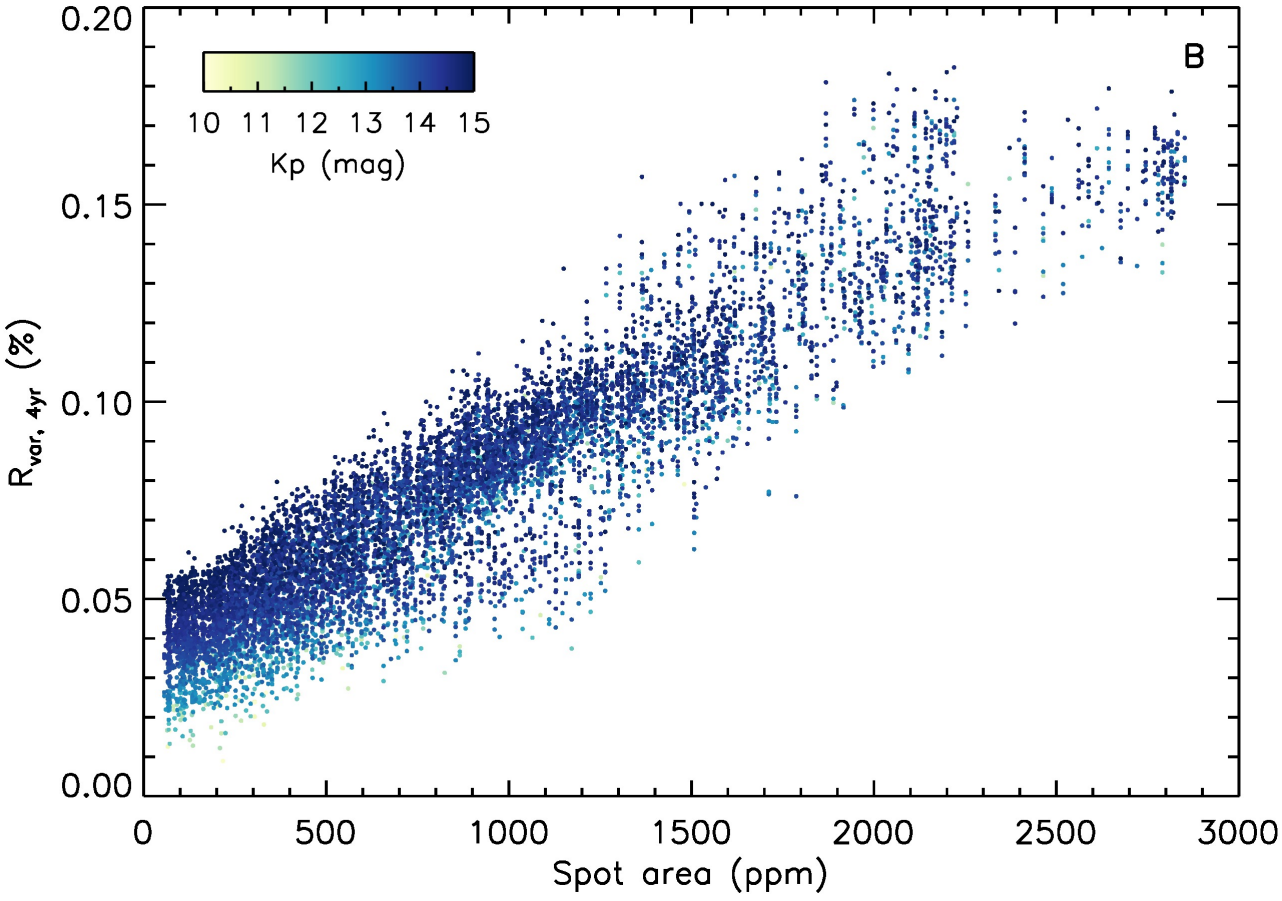
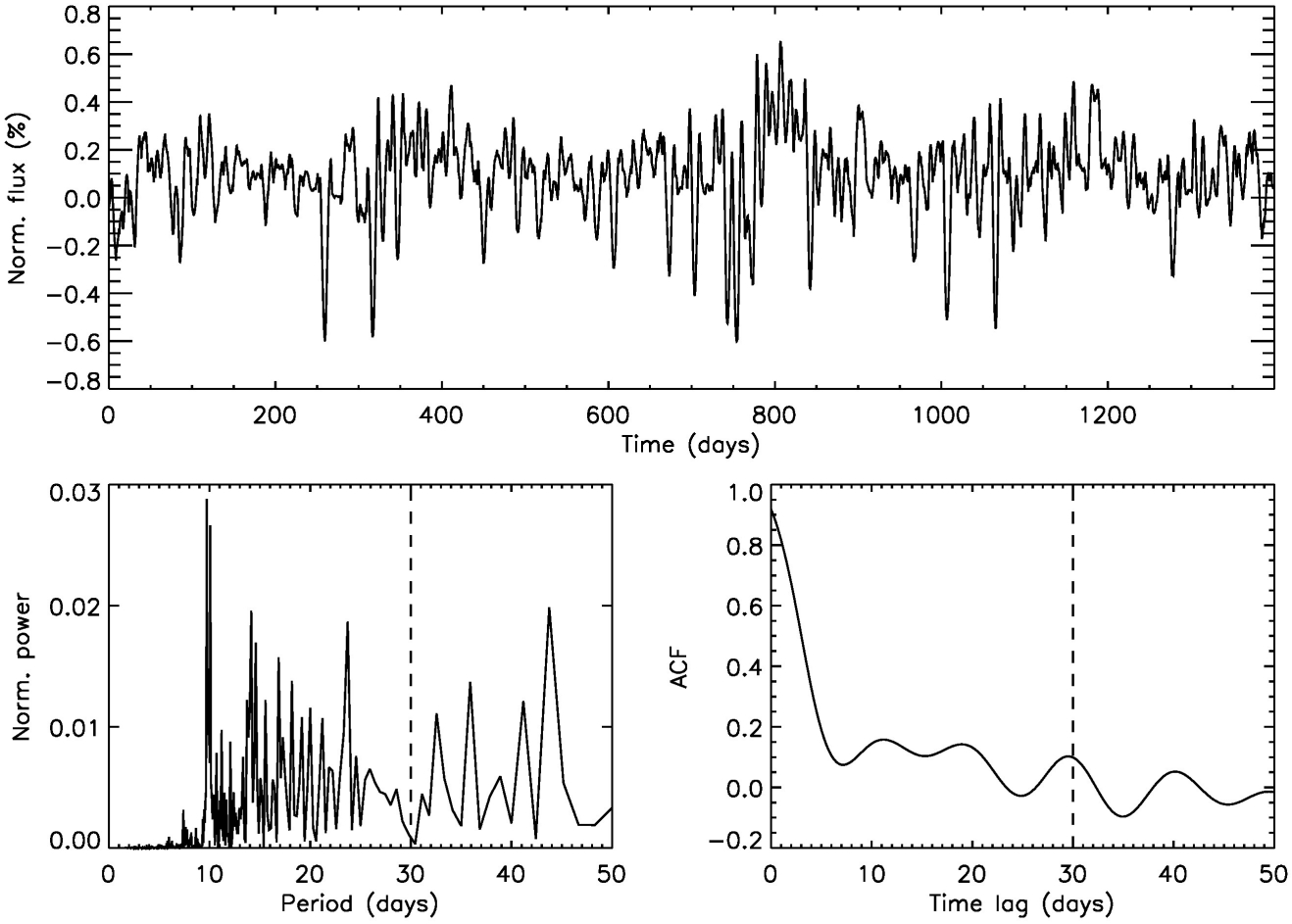
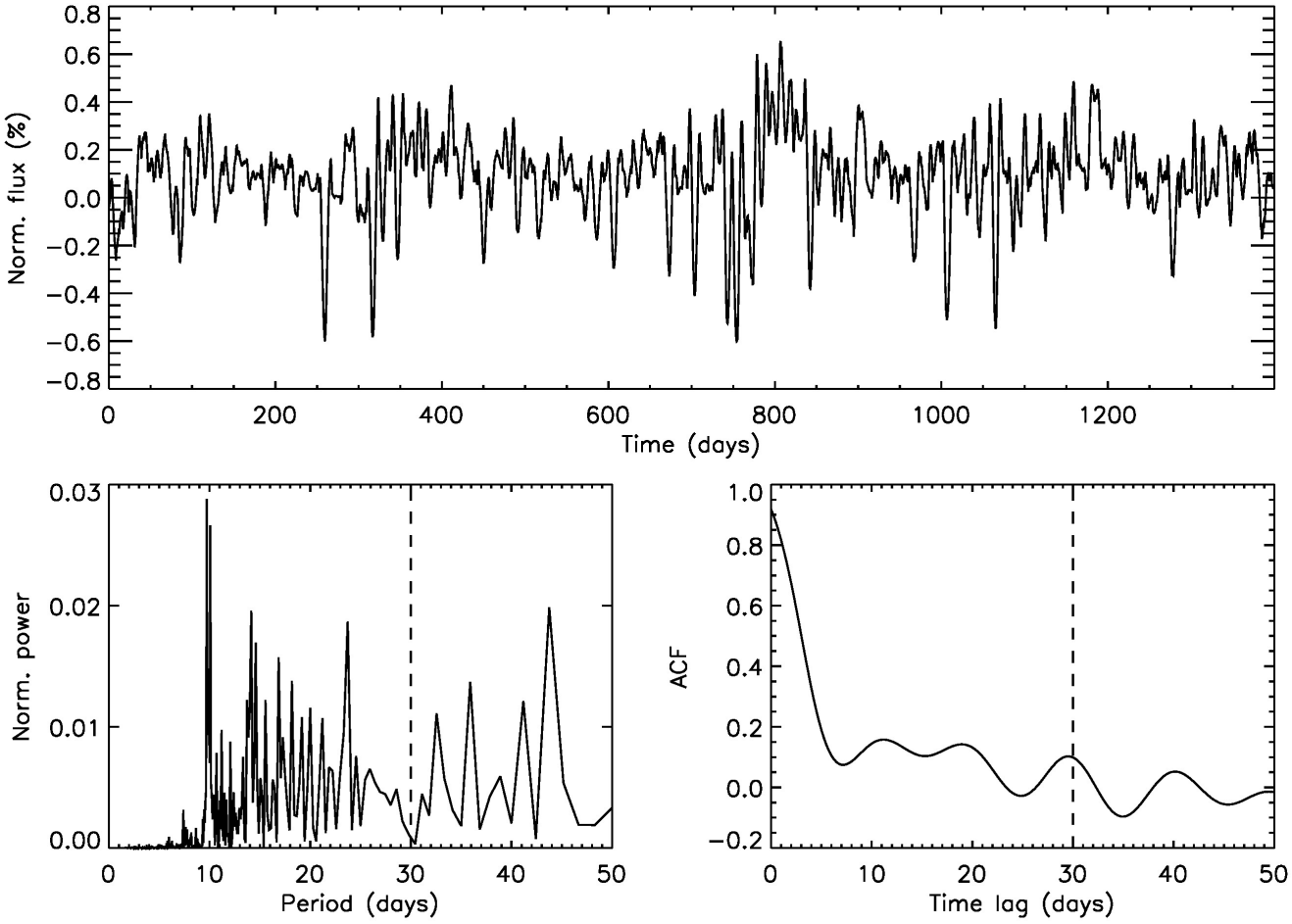



–> Correlation between photometric variability and magnetic activity!

# Is the Sun a (non-)periodic star?



# Is the Sun a (non-)periodic star?




–> The Sun would most probably belong to the non-periodic sample!

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# Conclusions

Summary:

- Magnetic activity of a star is determined by rotation period and effective temperature –> However, the majority of (true) solar-like stars are more active than the Sun!

- Solar variability common among non-periodic stars

Conclusions:

1. Solar-like stars are different from the Sun in some (unknown) quantity

   or

2. The variability distribution shows the full range of variabilities of solar-like stars –> also the Sun could potentially become that active at some point in time

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