Stellar Rotation

in the Kepler era

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From rotation periods to stellar ages

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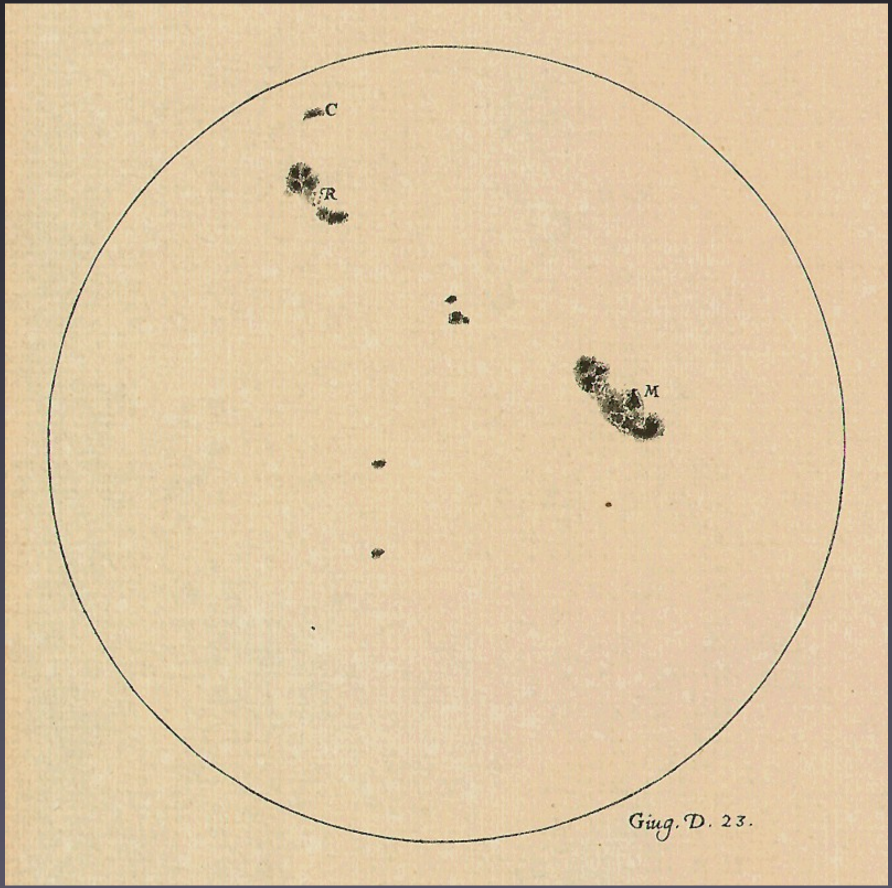
MPS Solar Group Seminar, March18, 2014

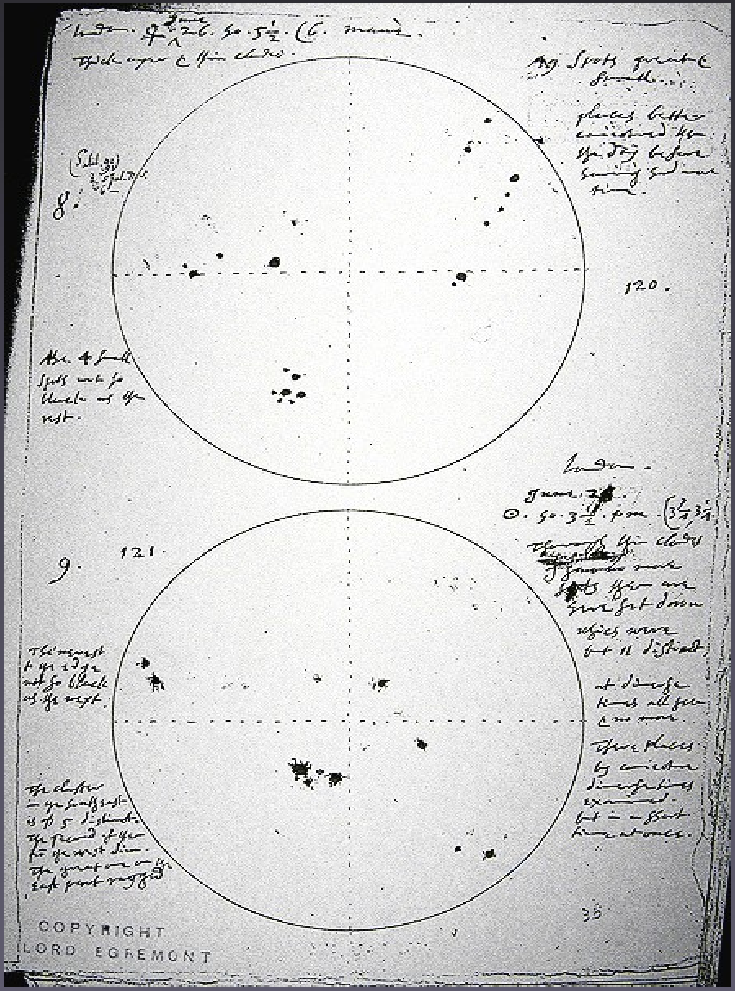
Long time ago…

- Telescope: invented ~ 1608
- Galilei discovered dark spots on the Sun
- Many others followed: T. Harriot, J. & D. Fabricius, C. Scheiner…

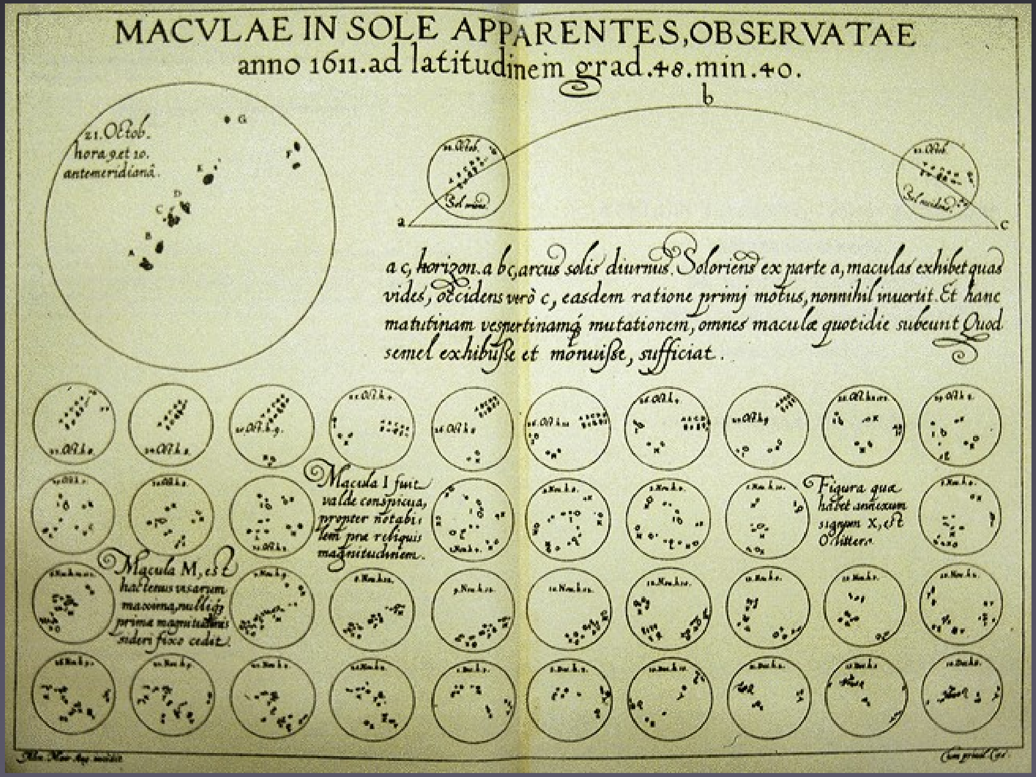


Sun spot observations

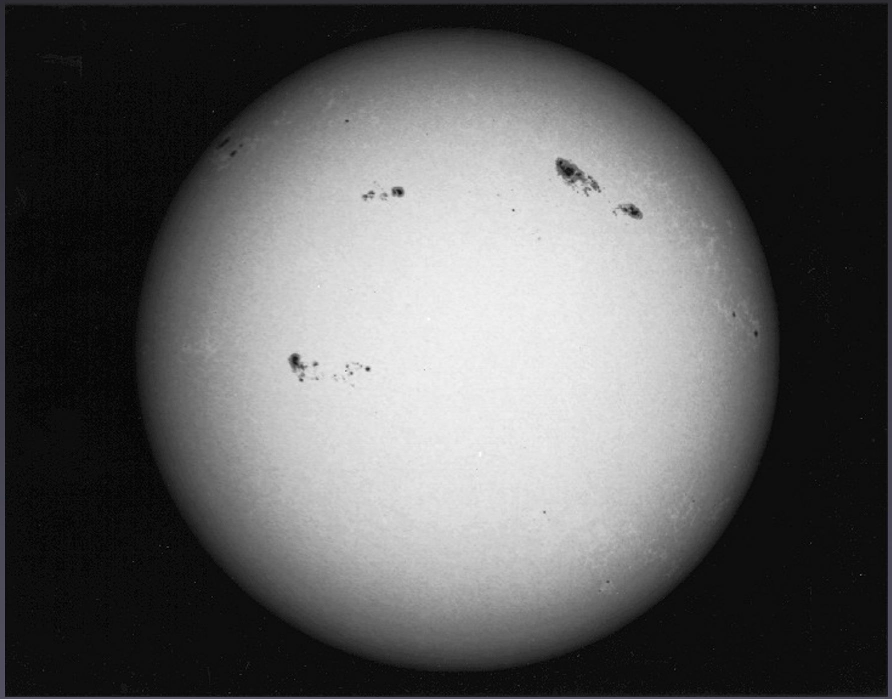
Thomas Harriot

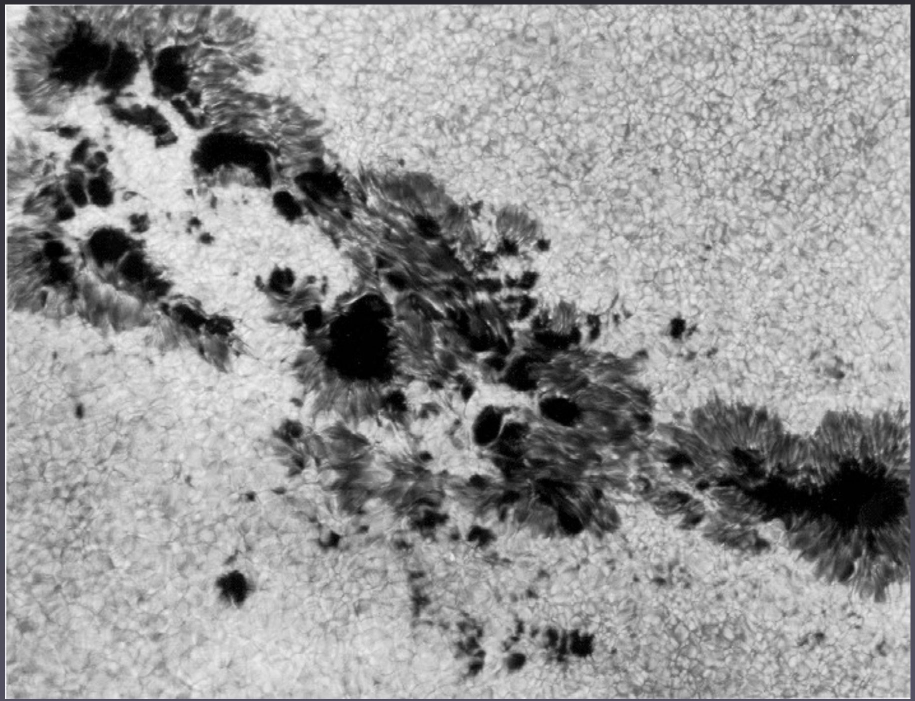


Christoph Scheiner



Sun spots today





From the Sun to the stars

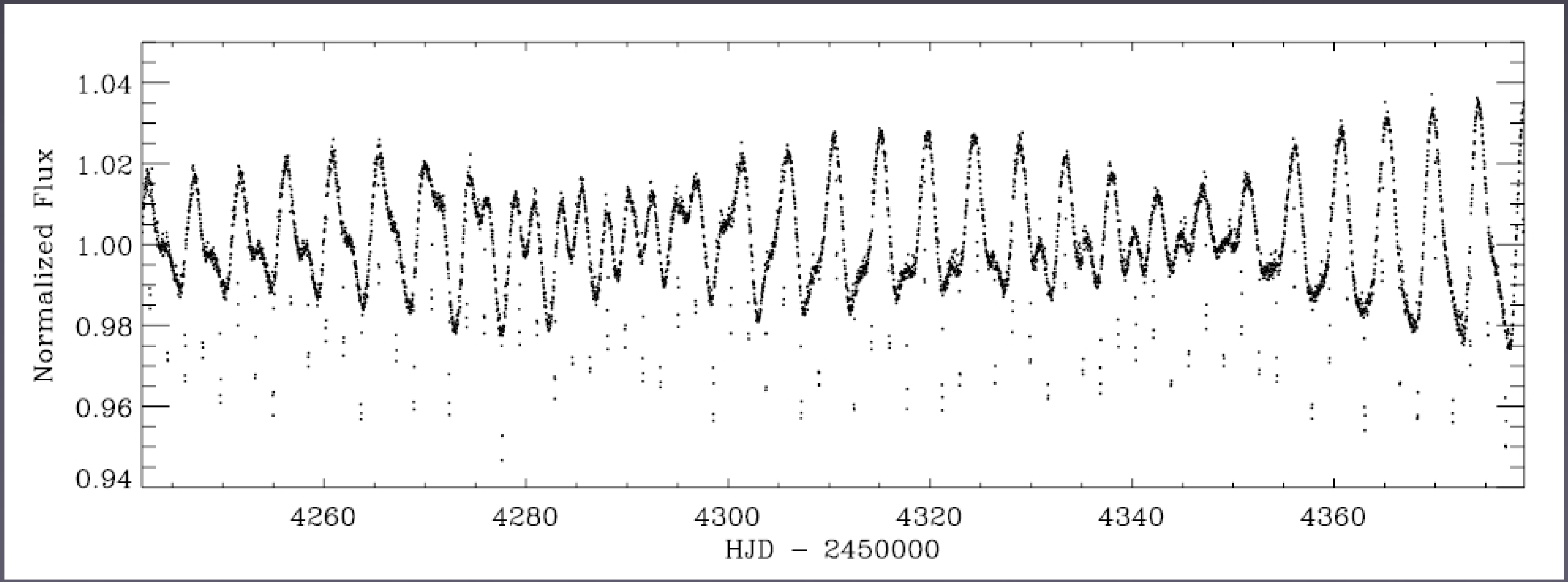
- Problem: Cannot resolve spots on distant stars
- But: Star spots cause (periodic) variability in stellar light curves
- High-precision light curves from space telscopes: MOST, CoRoT, Kepler, (PLATO)

→ achieve stellar rotation periods!

Star spots today

- CoRoT-2 light curve: periodic variability due to star spots
- Beat-shape: More than only one rotation period!

  → Differential rotation (DR)



Stellar rotation
↔
Chromospheric activity

- Spotted star

  → (strong) magnetic fields

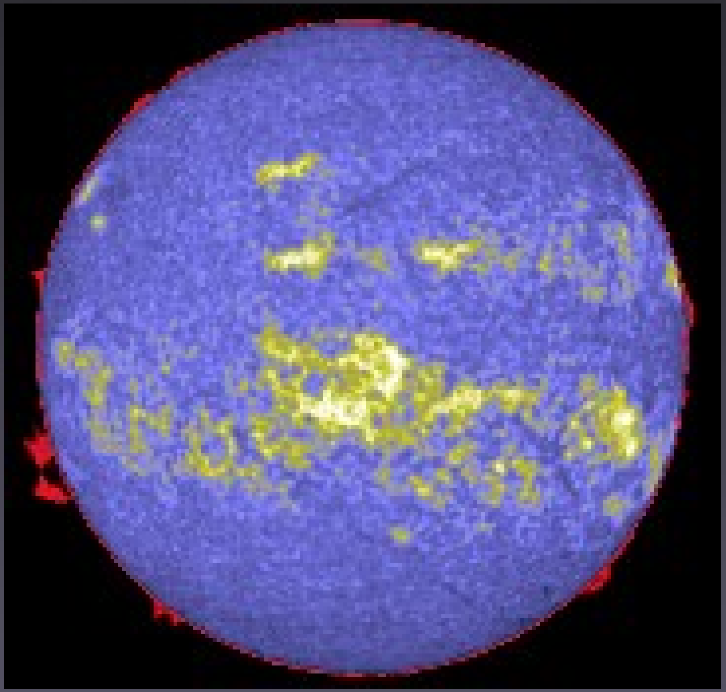
  → Magnetic field heats the chromosphere

  → chromospheric emission

- Mount Wilson H-K project (1980): Rotation period & chrom. Activity

  → Use CaII H & K as rotation indicator

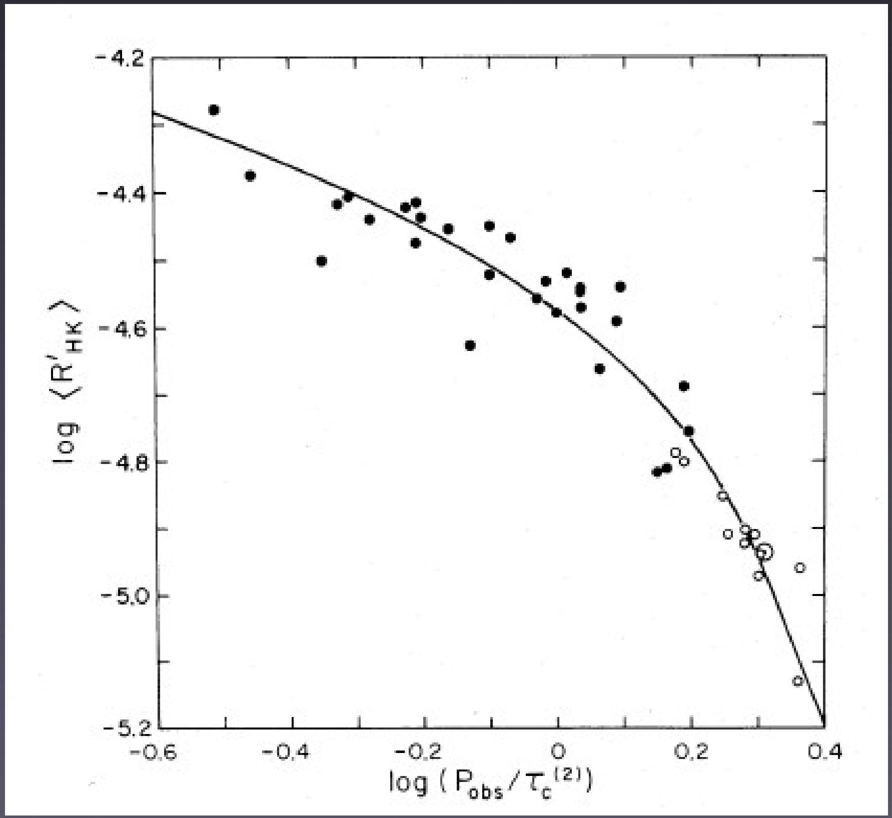
Solar chromosphere



Activity-rotation relation

- log R'_HK vs. Rossby number for Mount Wilson stars: closed (young), open (old) stars
- Activity increases toward fast rotators

Noyes (1984)



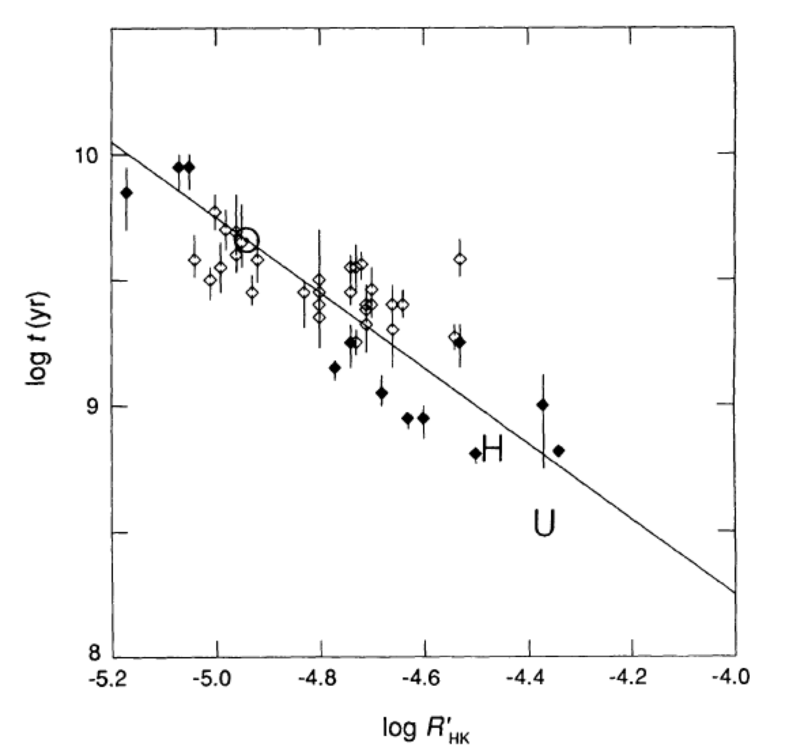
Activity-age relation

- Activity index

  log R'_HK vs.stellar age t for visual binaries, single

  F stars & open clusters
- Activity decreases with age

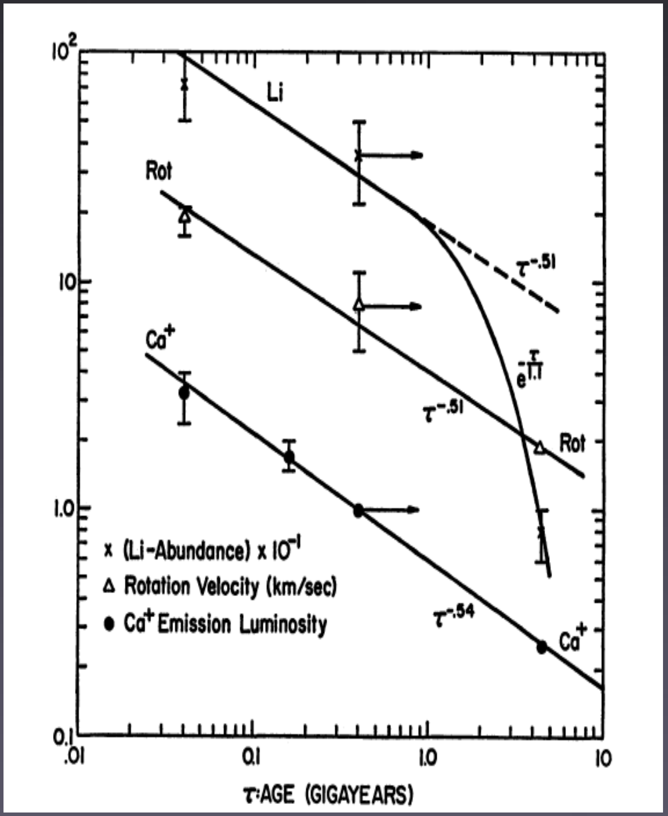
Soderblom, Duncan & Johnson (1991)



Age-rotation-activity relation

- Skumanich showed relation between activity (CaII), age(Li), and rotation rate
- All trends ~ t^-1/2

Skumanich (1972):



Kepler Roadmap

- Measure (mean) rotation period

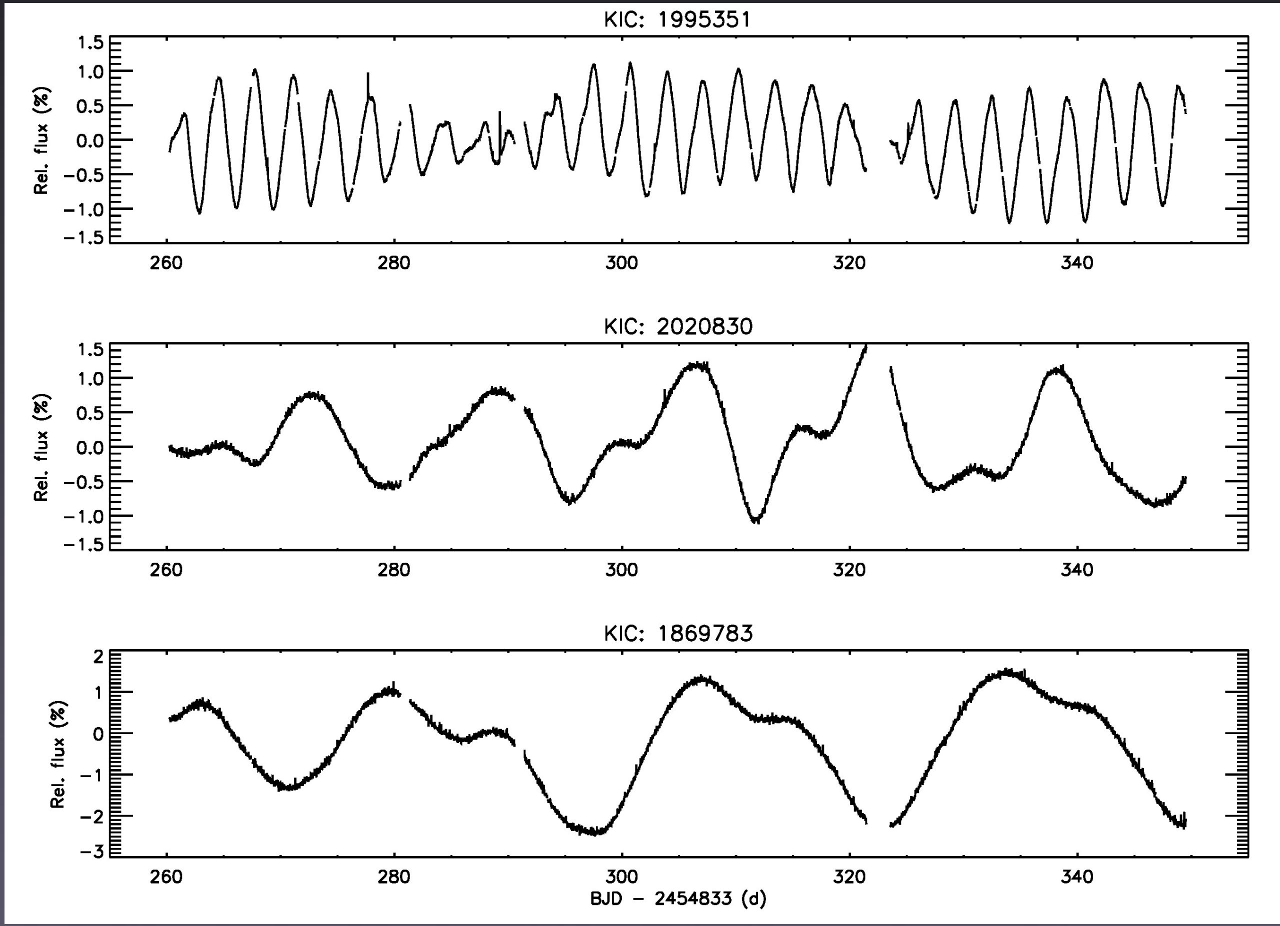
  → esp. account for differential rotation

- Use rotation-mass-age relations (Gyrochronology)

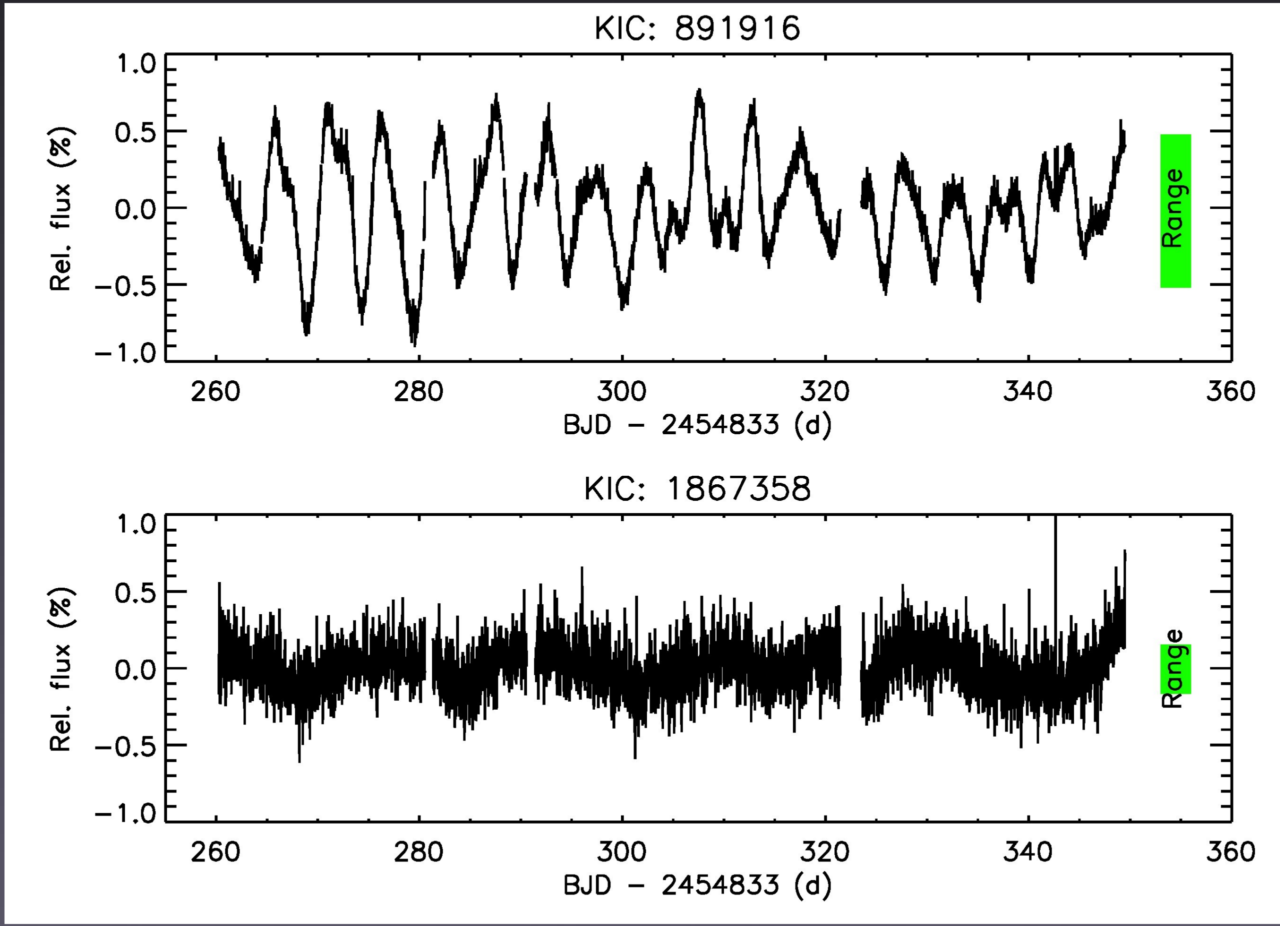
  → yield stellar ages + errors

Data & Methods

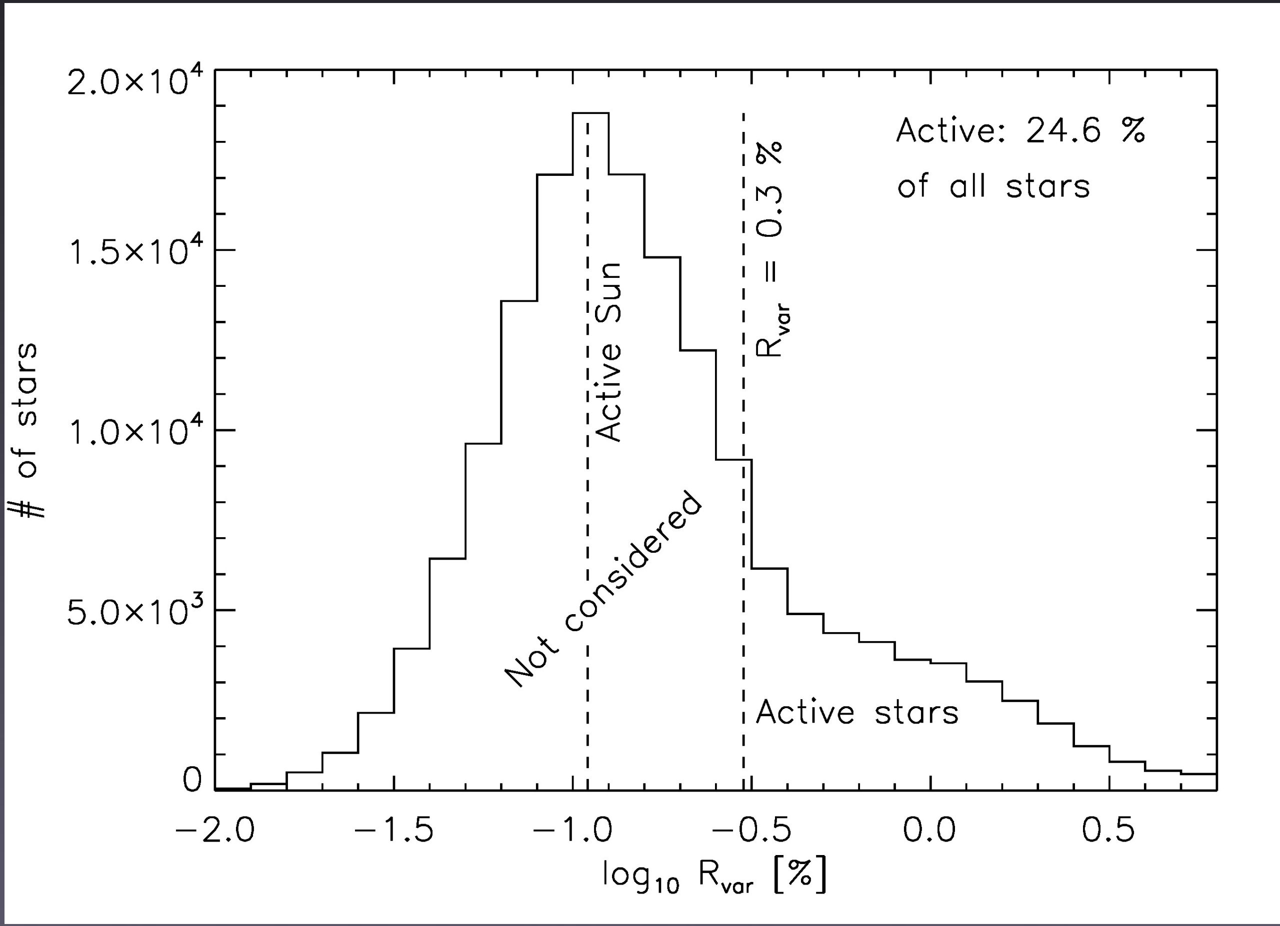
Active Kepler stars



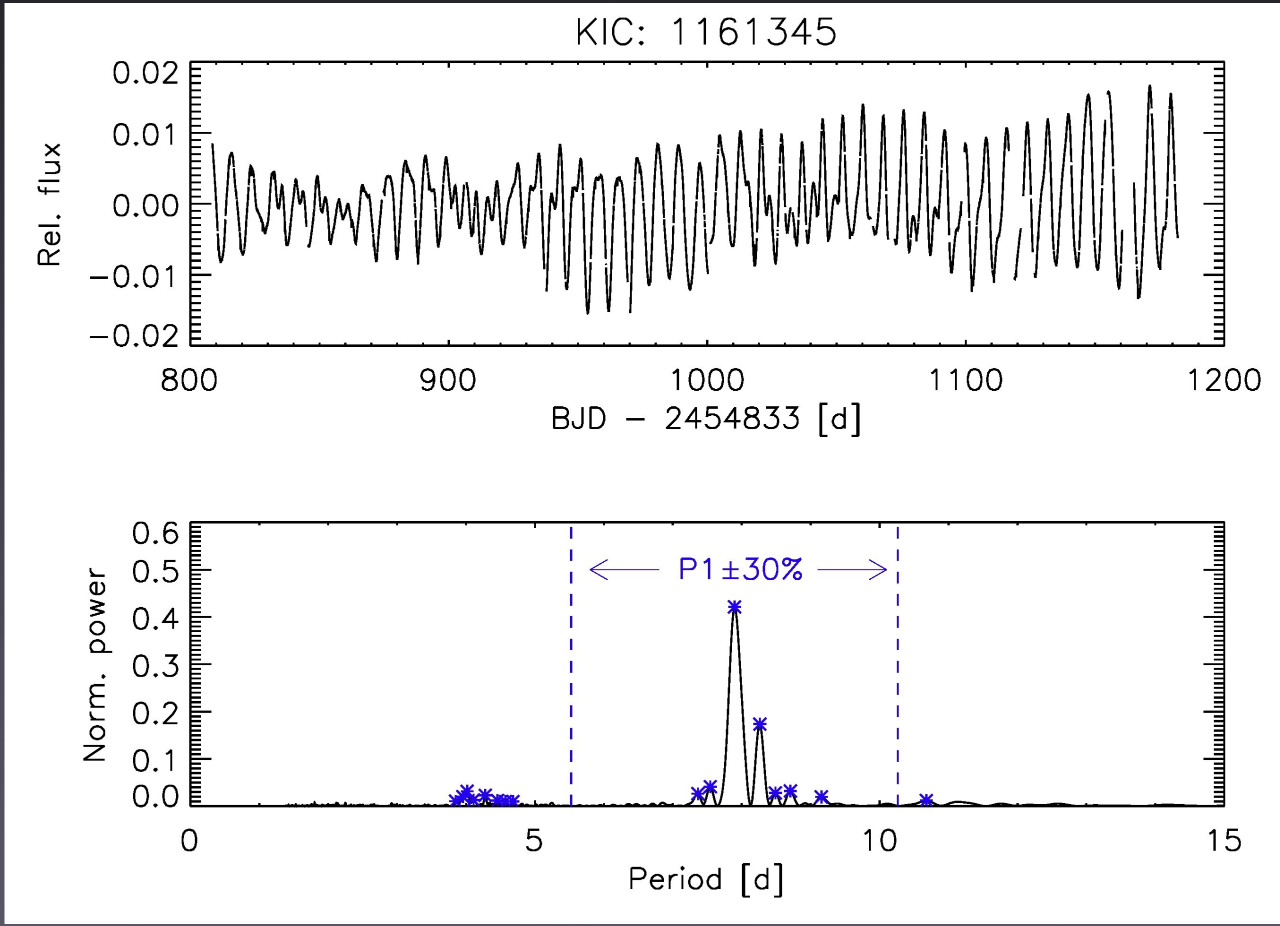
Use variability range



How many active stars?



How to measure periods?
→ Lomb-Scargle periodogram



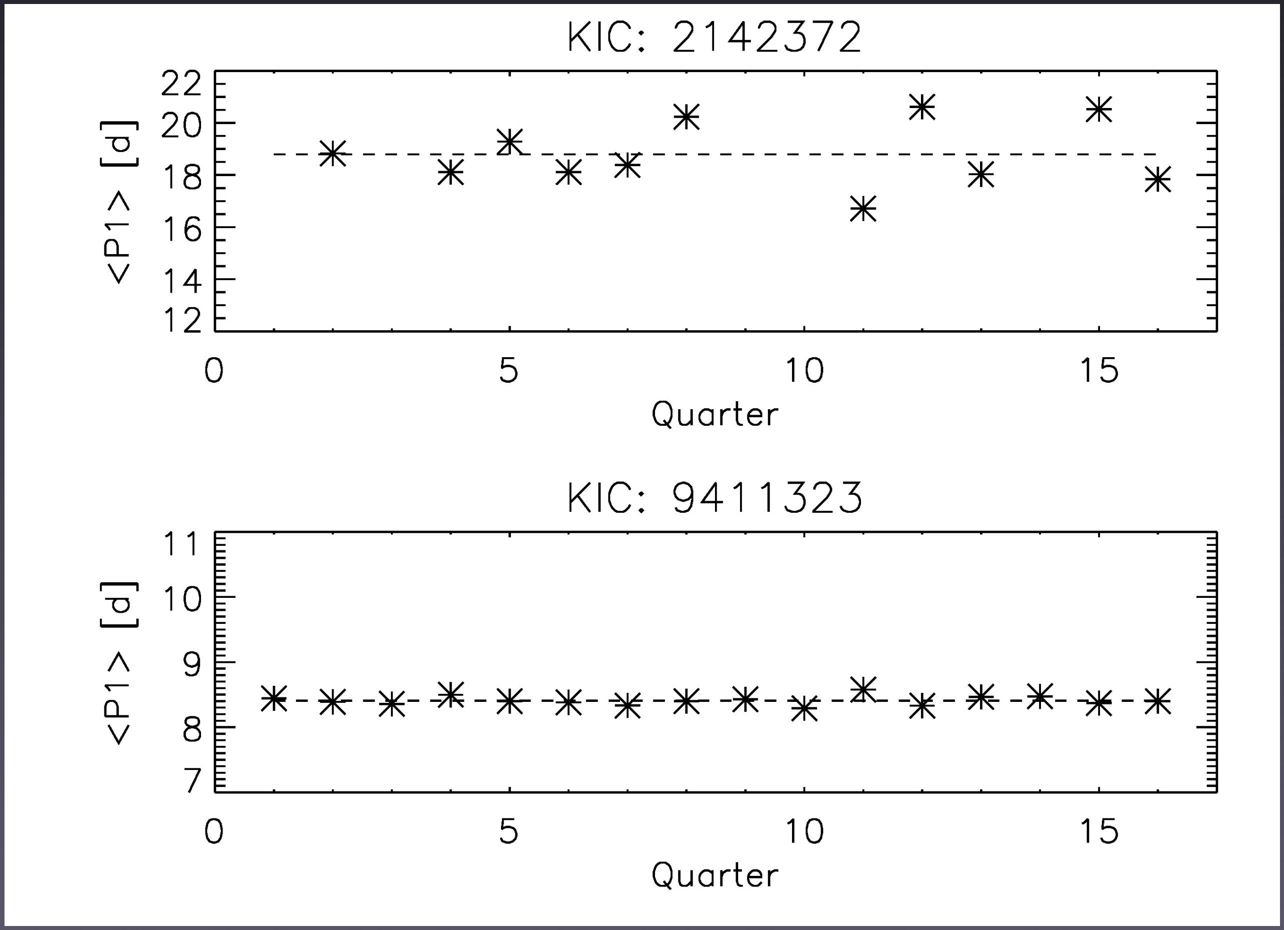
Define Periods

- Period with highest peak: P1
- Search for 2nd period adjacent (±30%) to P1
- If present: P2 (2nd highest peak)
- Problem: Periods change with time!

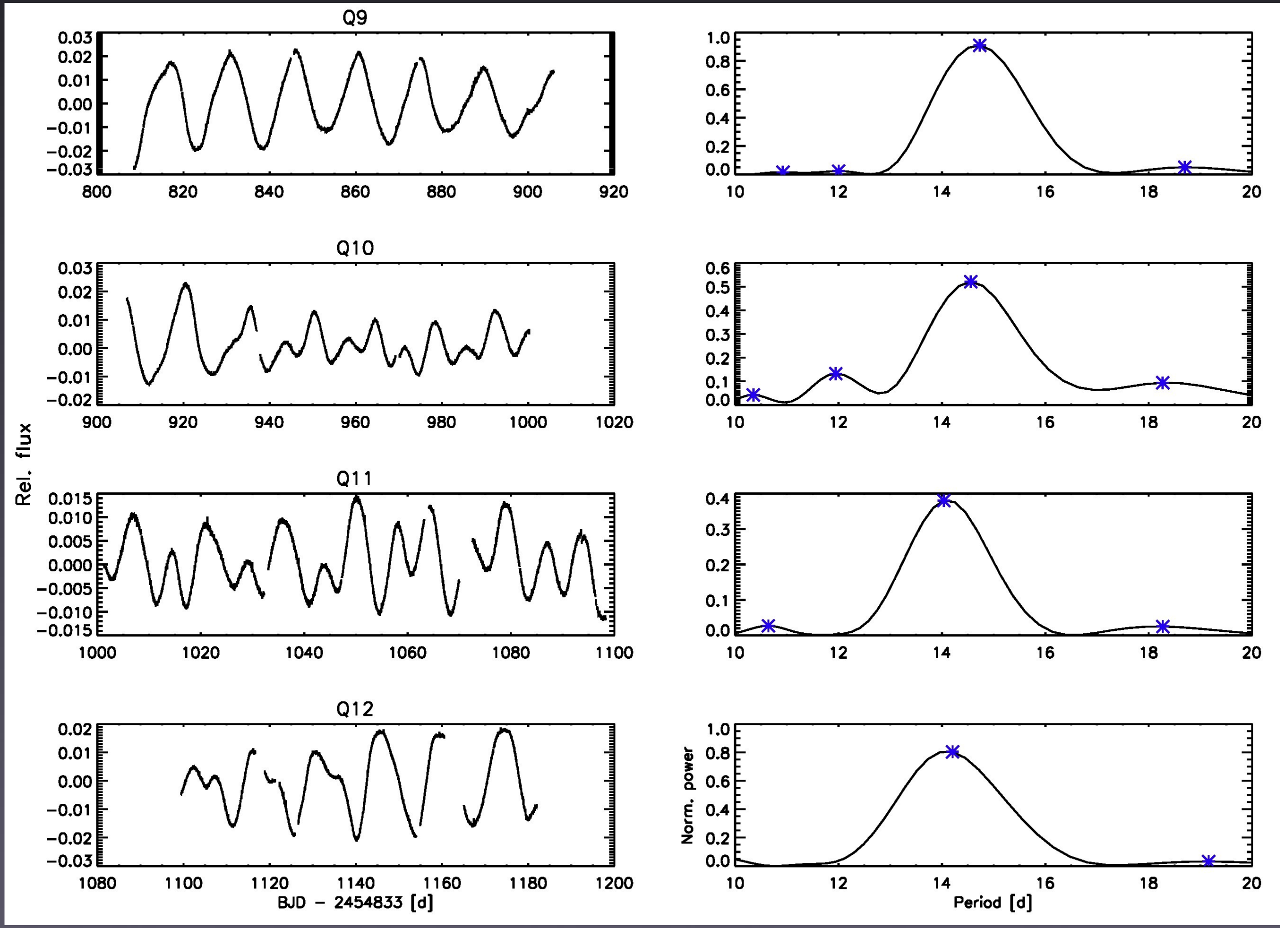
→ Compare different segments of the light curve

→ Use mean periods!

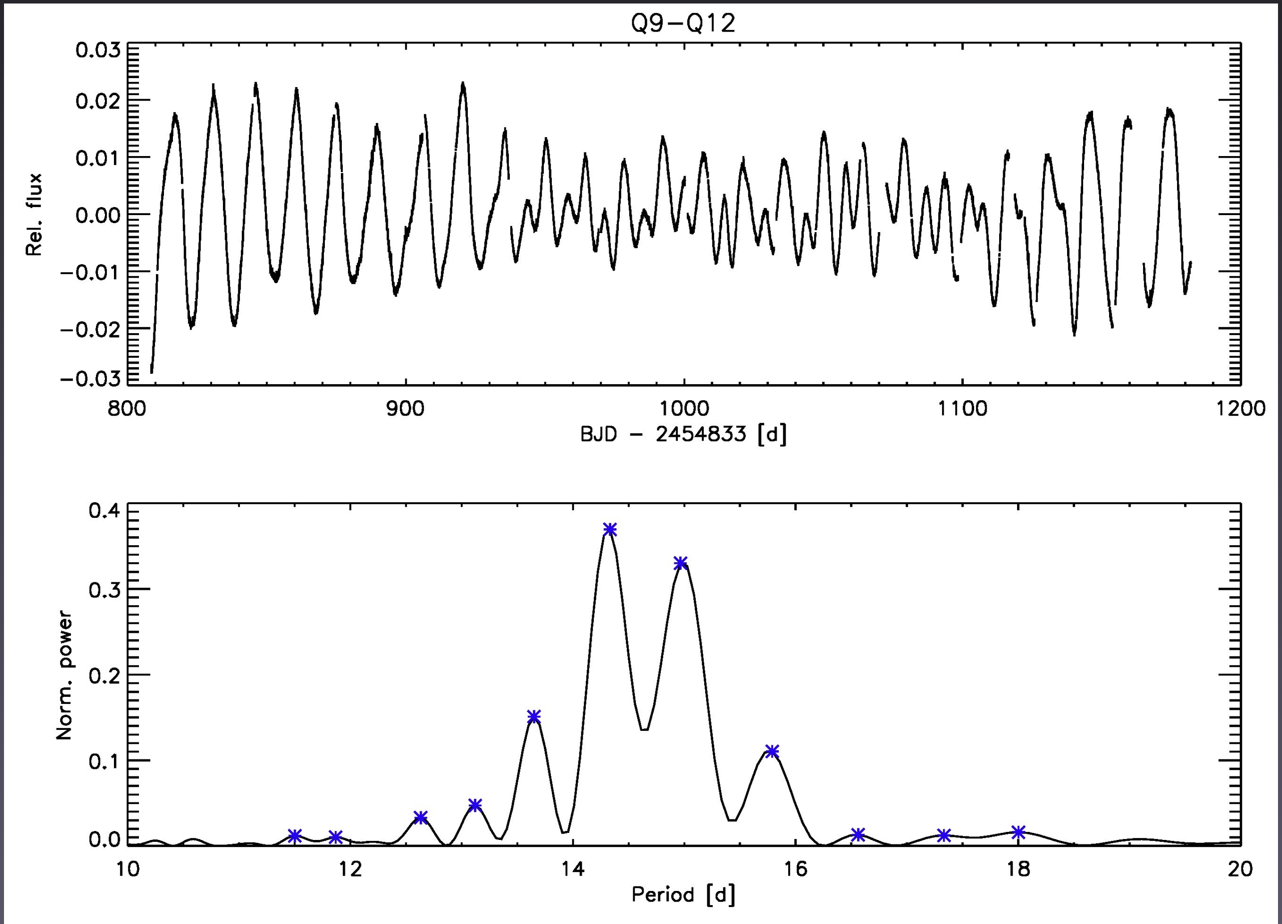
Quarterly P1 change



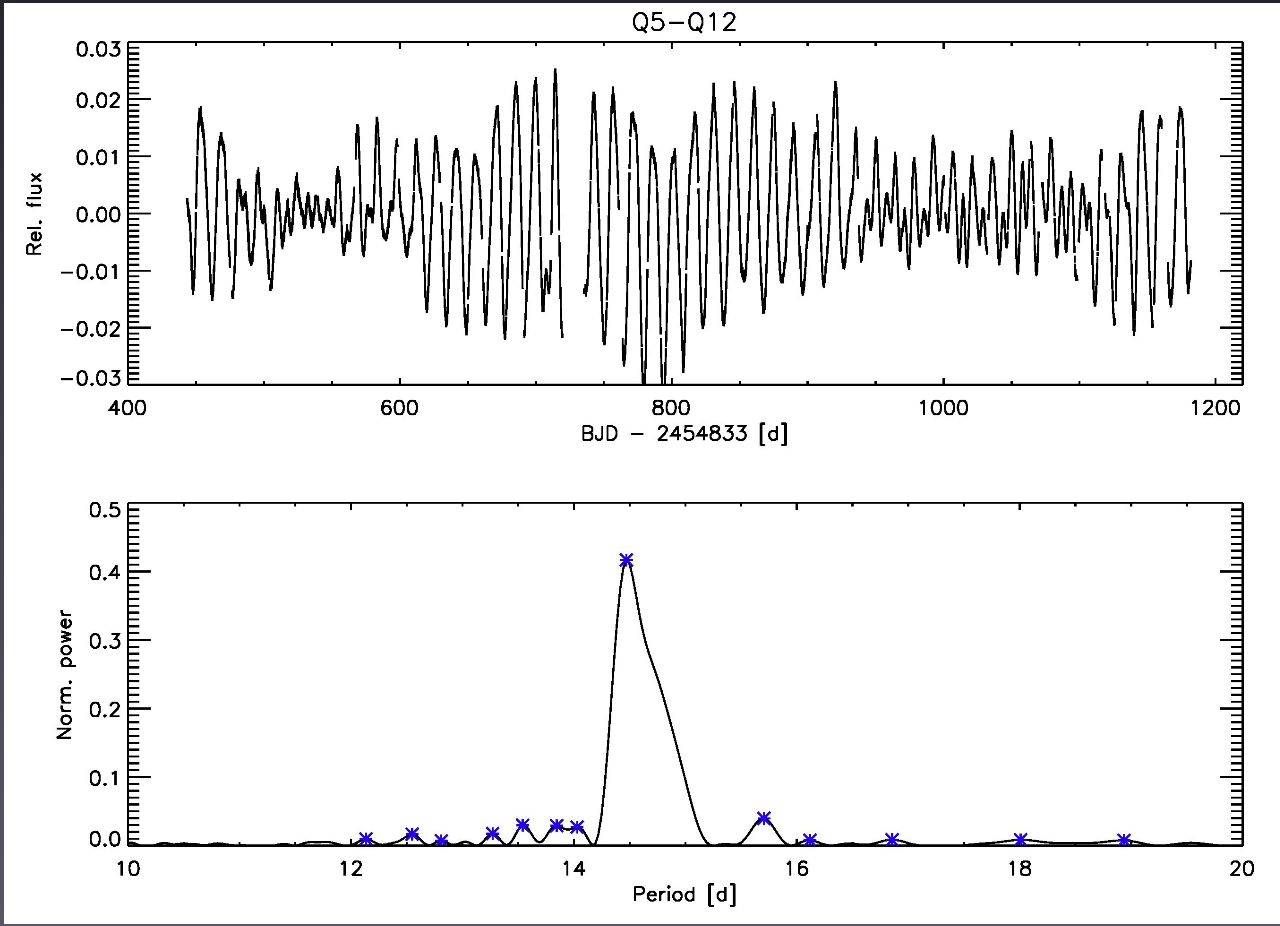
Quarterly light curve & periodogram change



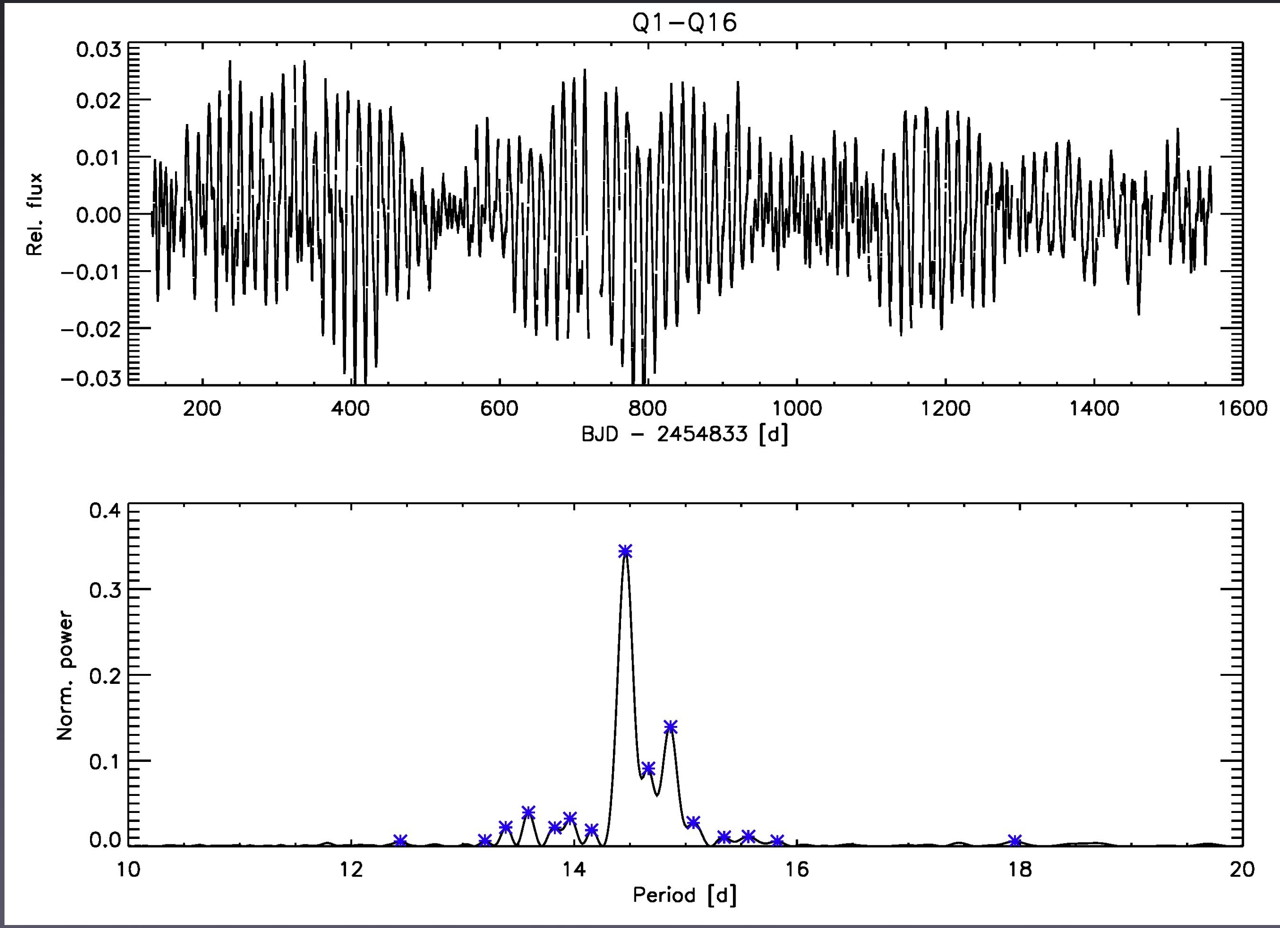
Q9-Q12 Segment



Q5-Q12 Segment

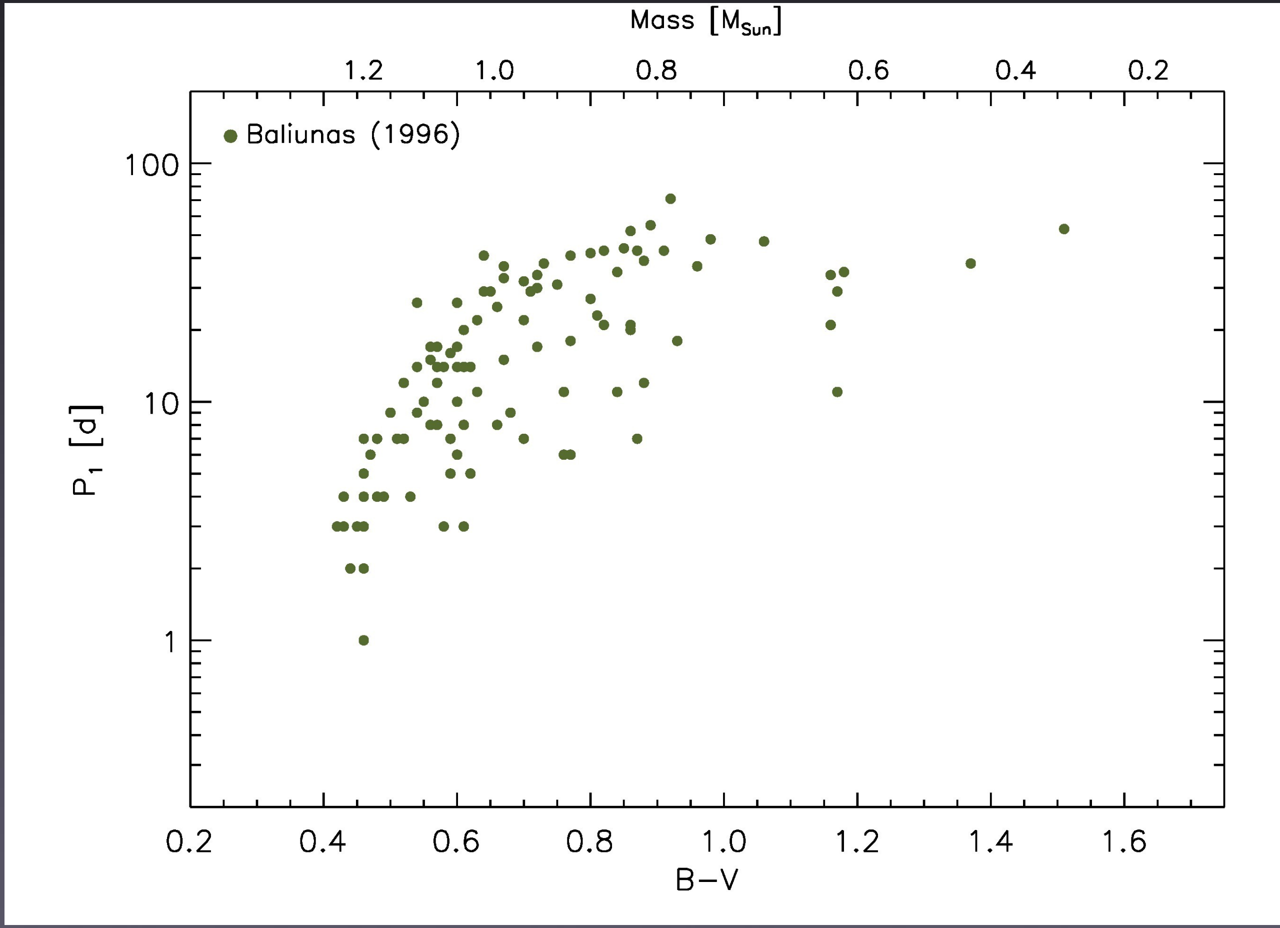


Full light curve

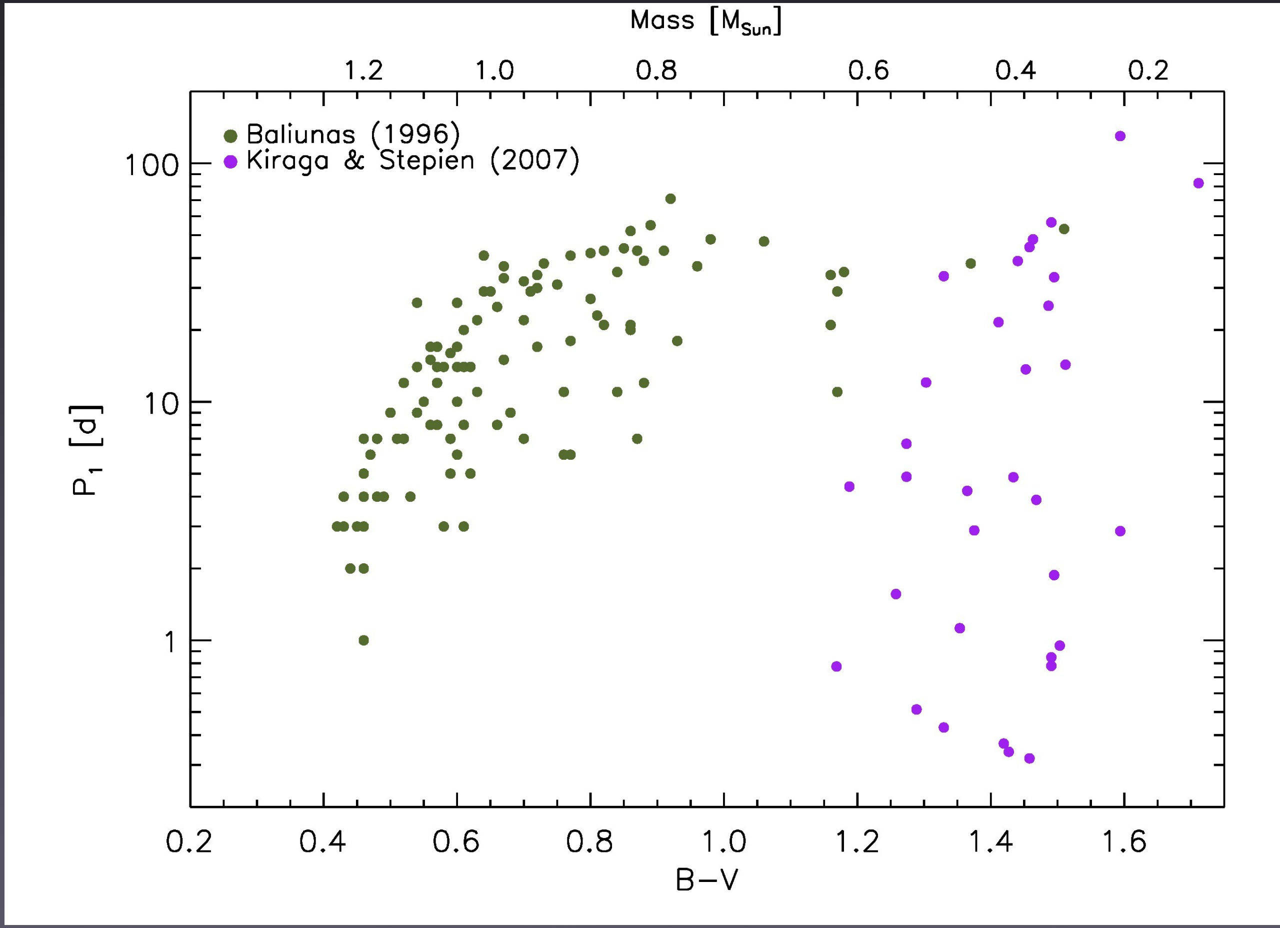


Rotation

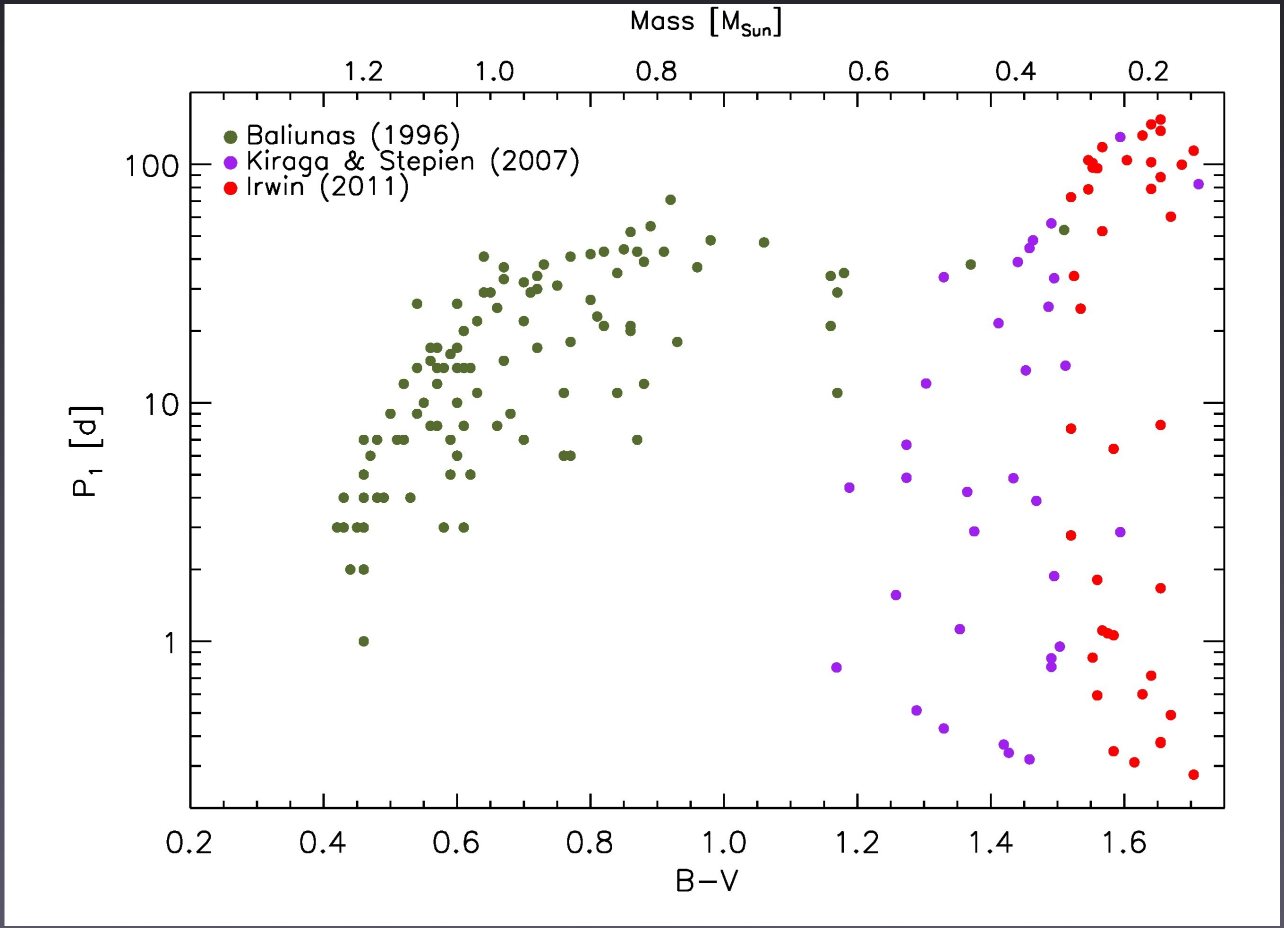
Color vs. rotation period



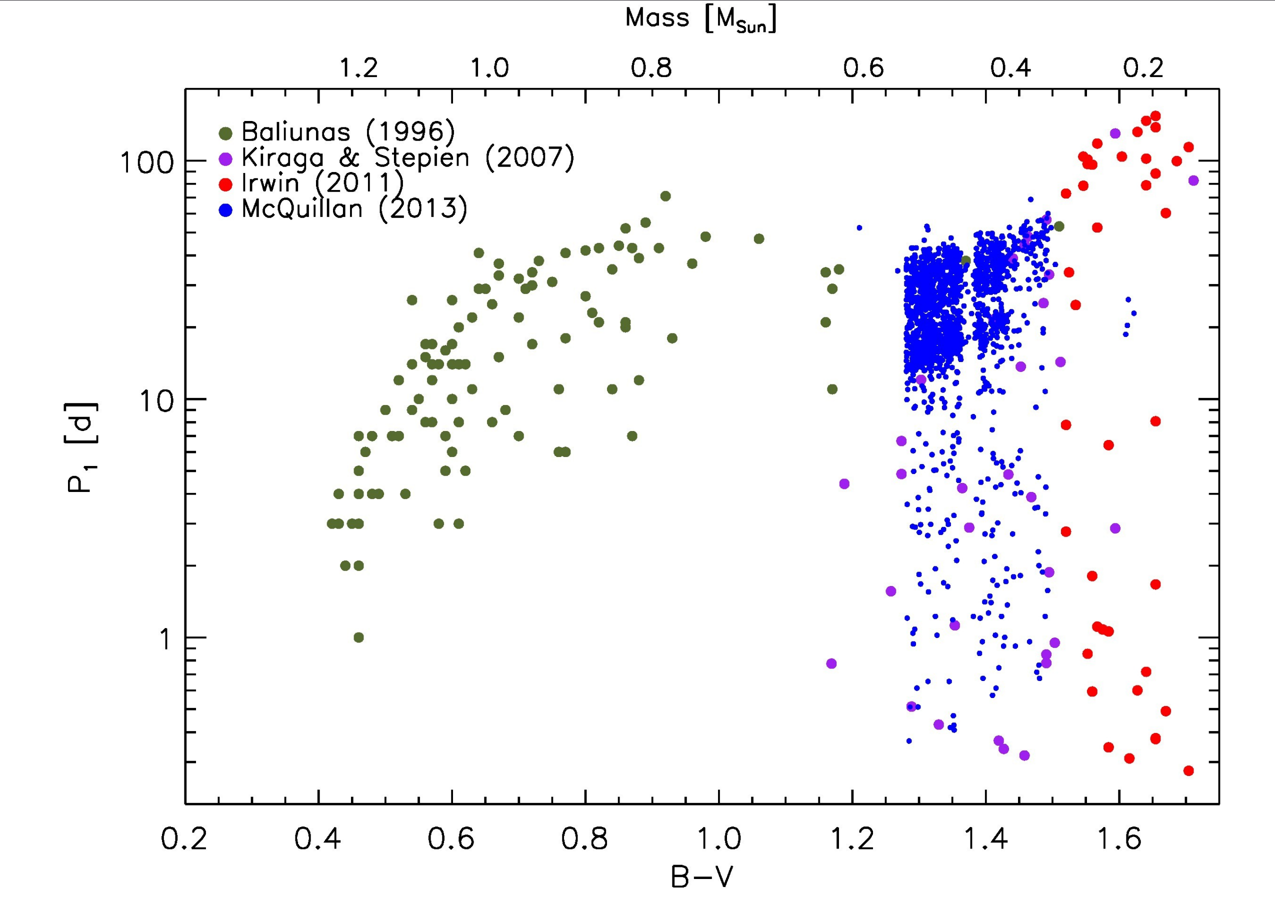
Color vs. rotation period



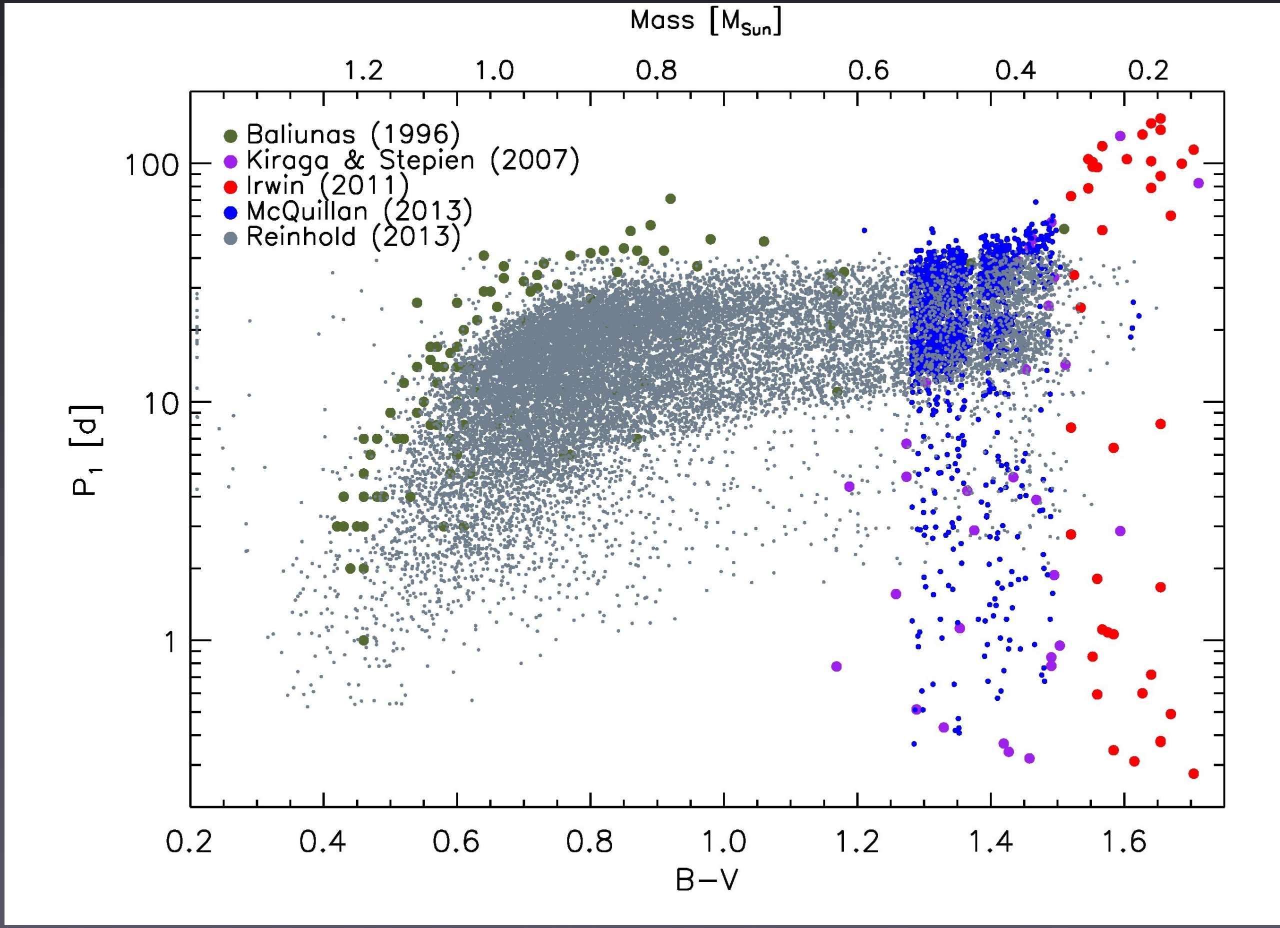
Color vs. rotation period



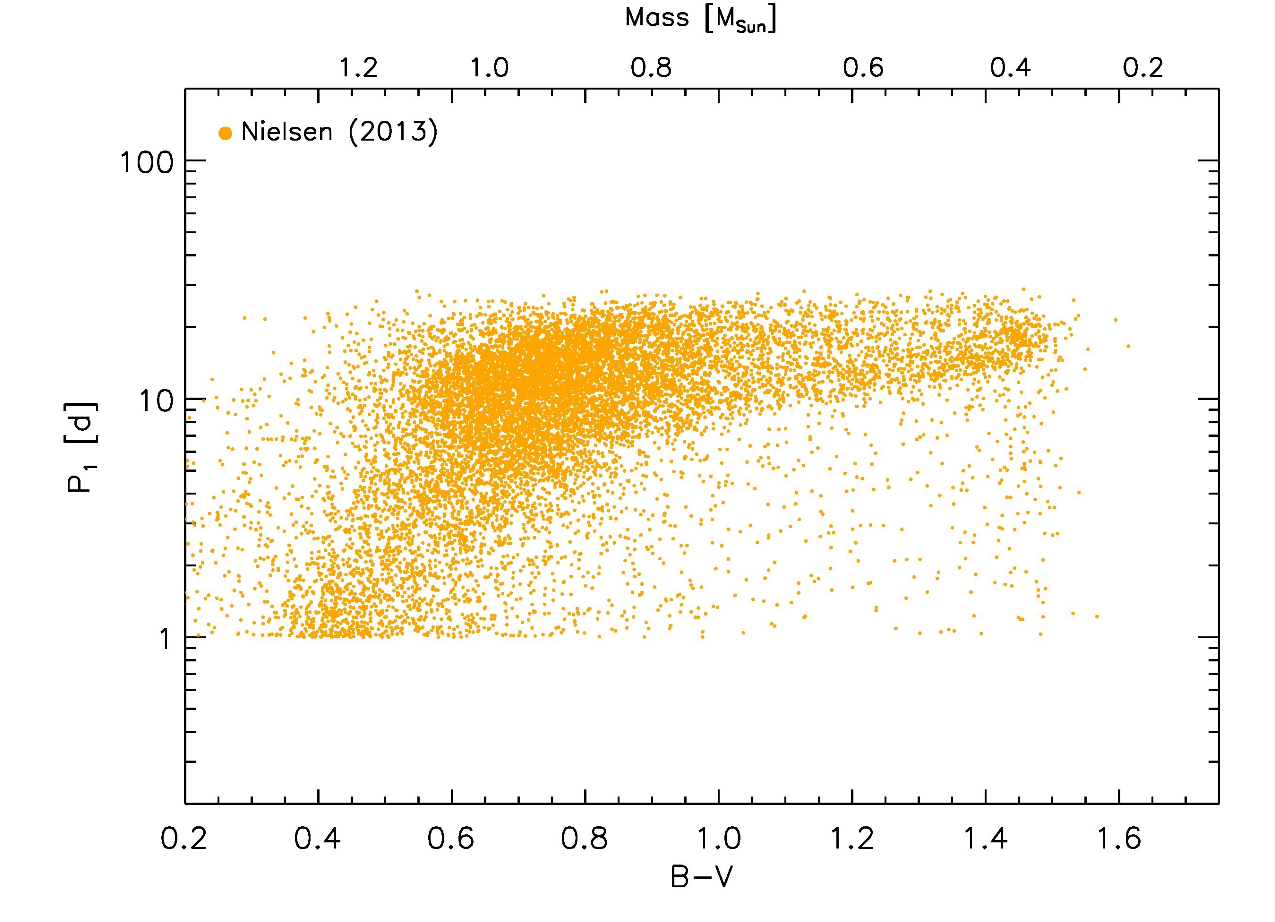
Color vs. rotation period



Color vs. rotation period

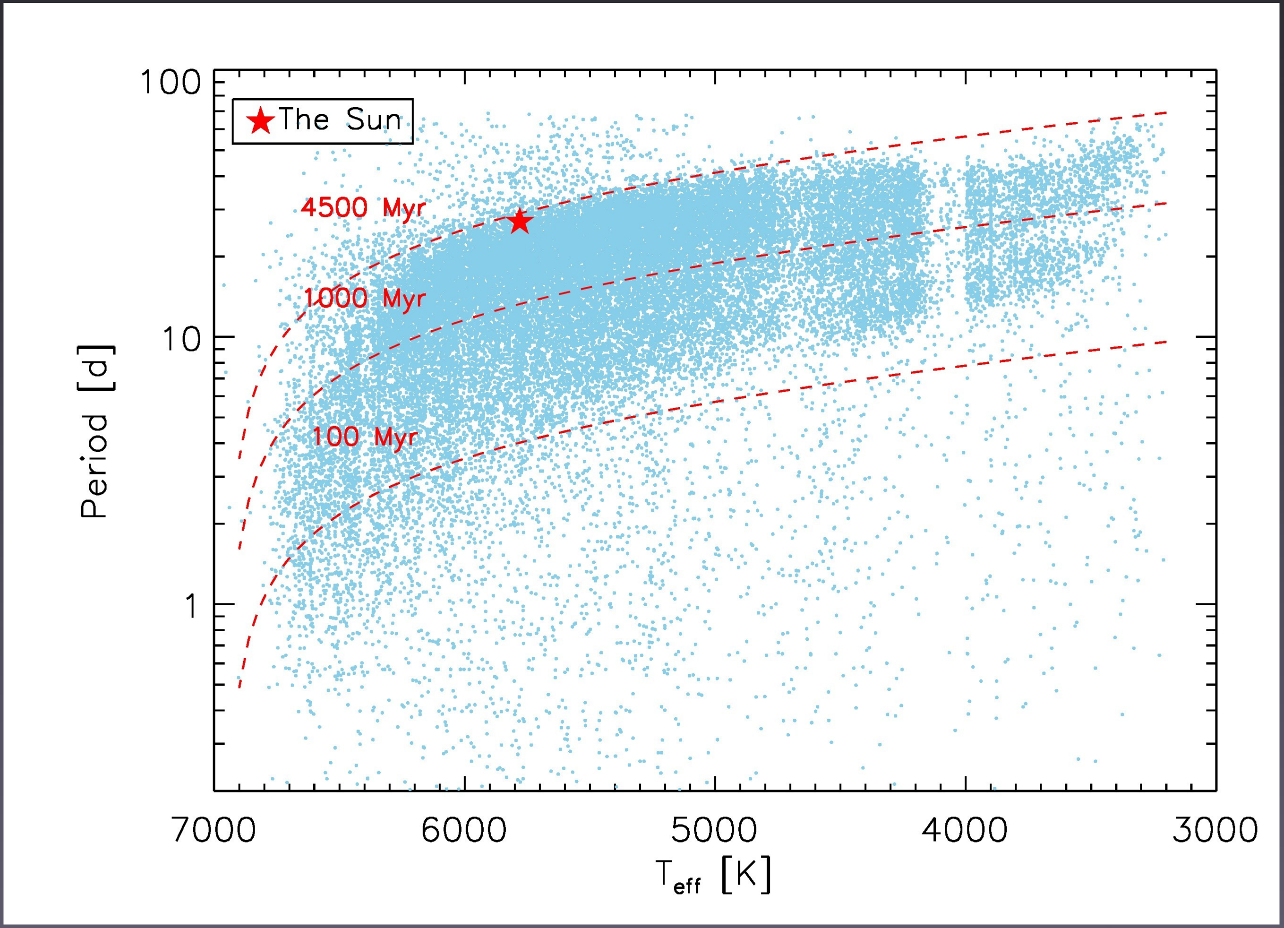


Color vs. rotation period



Teff vs. rotation period

McQuillan et al. (2014)



Kepler results

Measured rotation periods with Kepler:

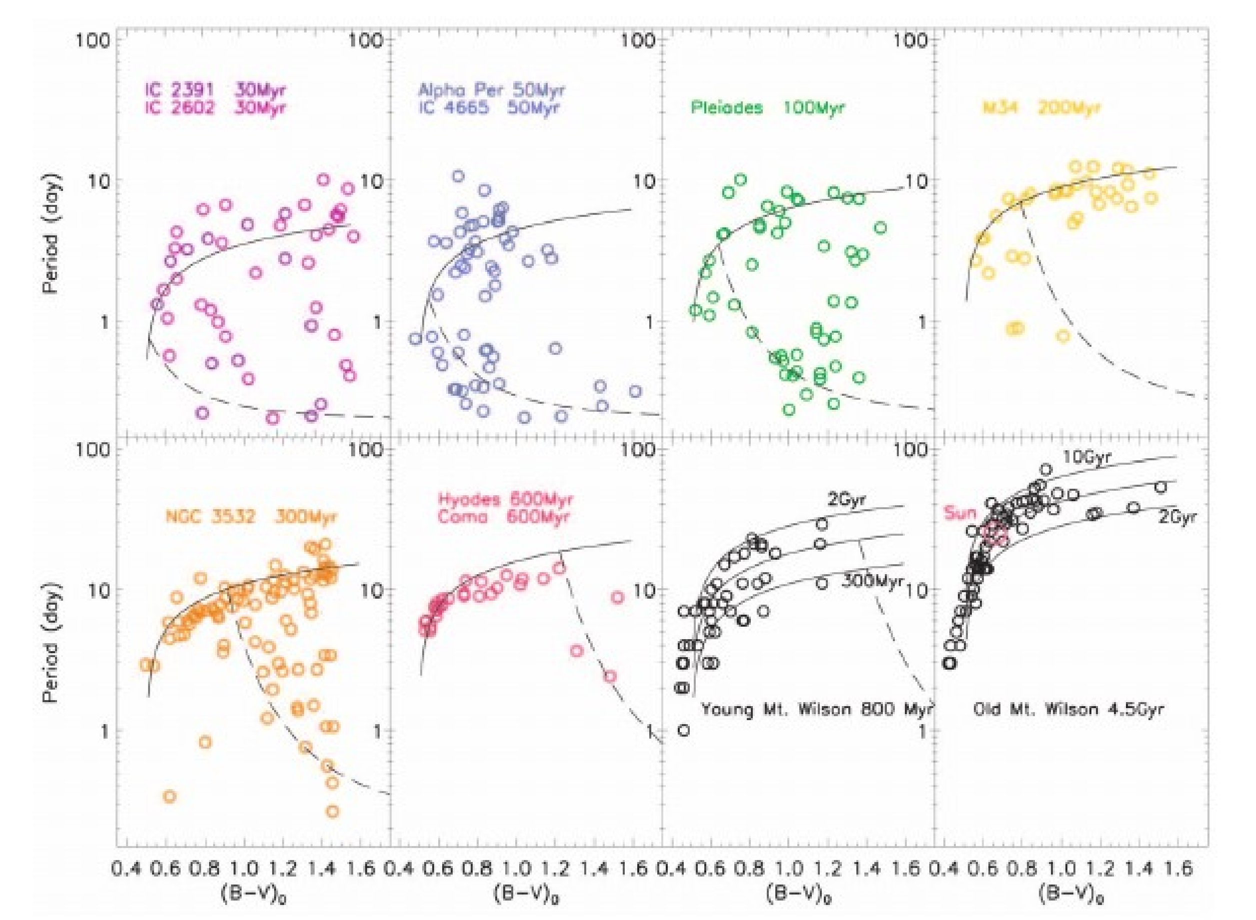
- McQuillan et al. (2013a): 1570 (M dwarfs)
- Nielsen et al. (2013): 12.151 stars
- McQuillan et al. (2013b): 737 (KOI)
- Walkowicz & Basri (2013): 950 (KOI)
- Reinhold et al. (2013): 24.124 stars
- McQuillan et al. (2014): 34.030 stars!!!

Gyrochronology

- First introduced by Sydney Barnes (2003)
- Method based on rotational braking due to stellar winds
- Uses open clusters: ages known
- Measure B-V color & rotation period
- Yield color - period – age relation!

→ Calculate ages of field stars!

Rotational braking



Problems...

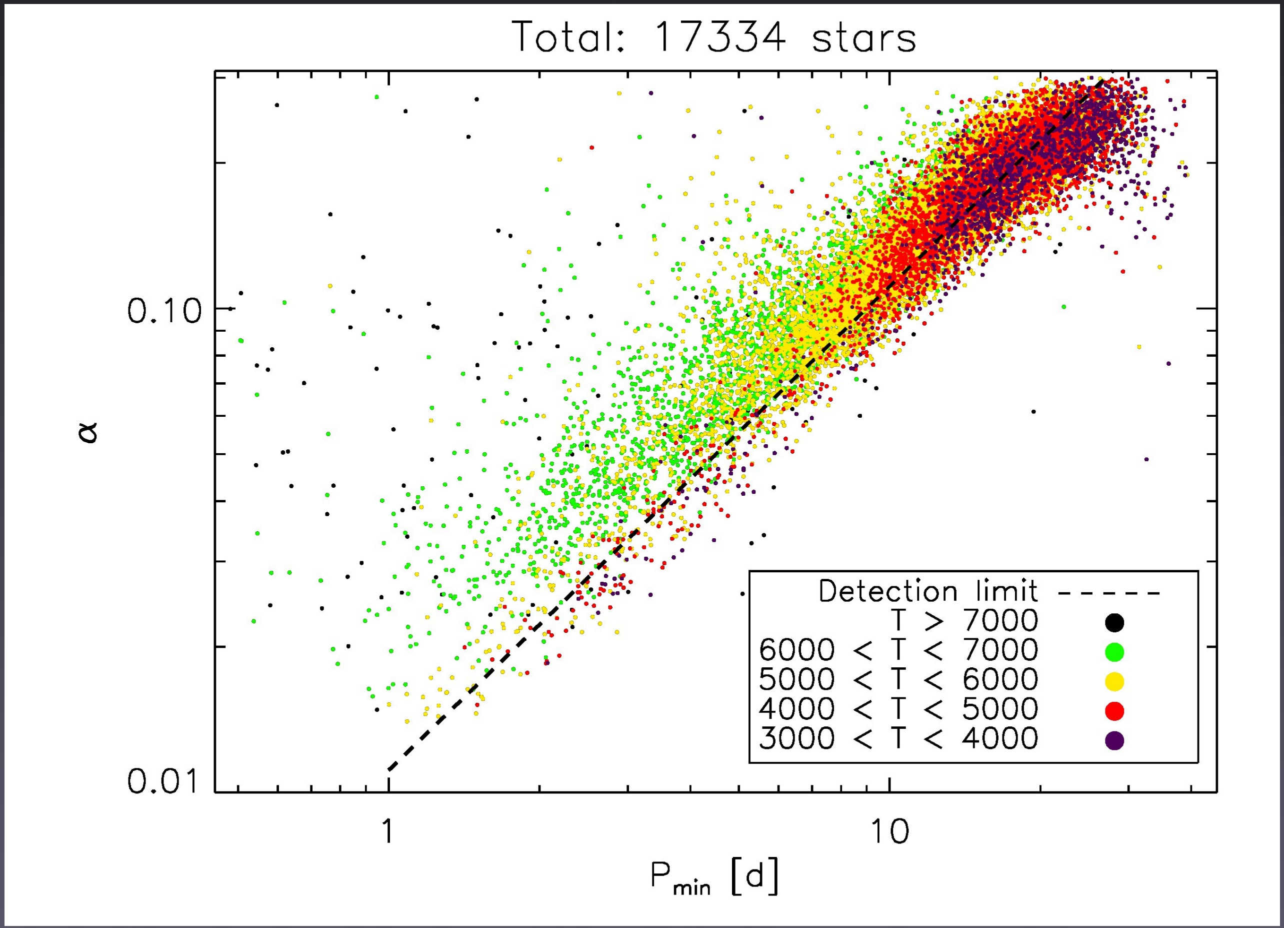
- Calibration for young FGK stars mostly
- Older stars: The Sun (age known); ages for Mount Wilson stars from activity-age relations
- Error sources:
    - Differential rotation
    - Initial range of rotation periods
    - Kepler: No B-V color

Differential Rotation

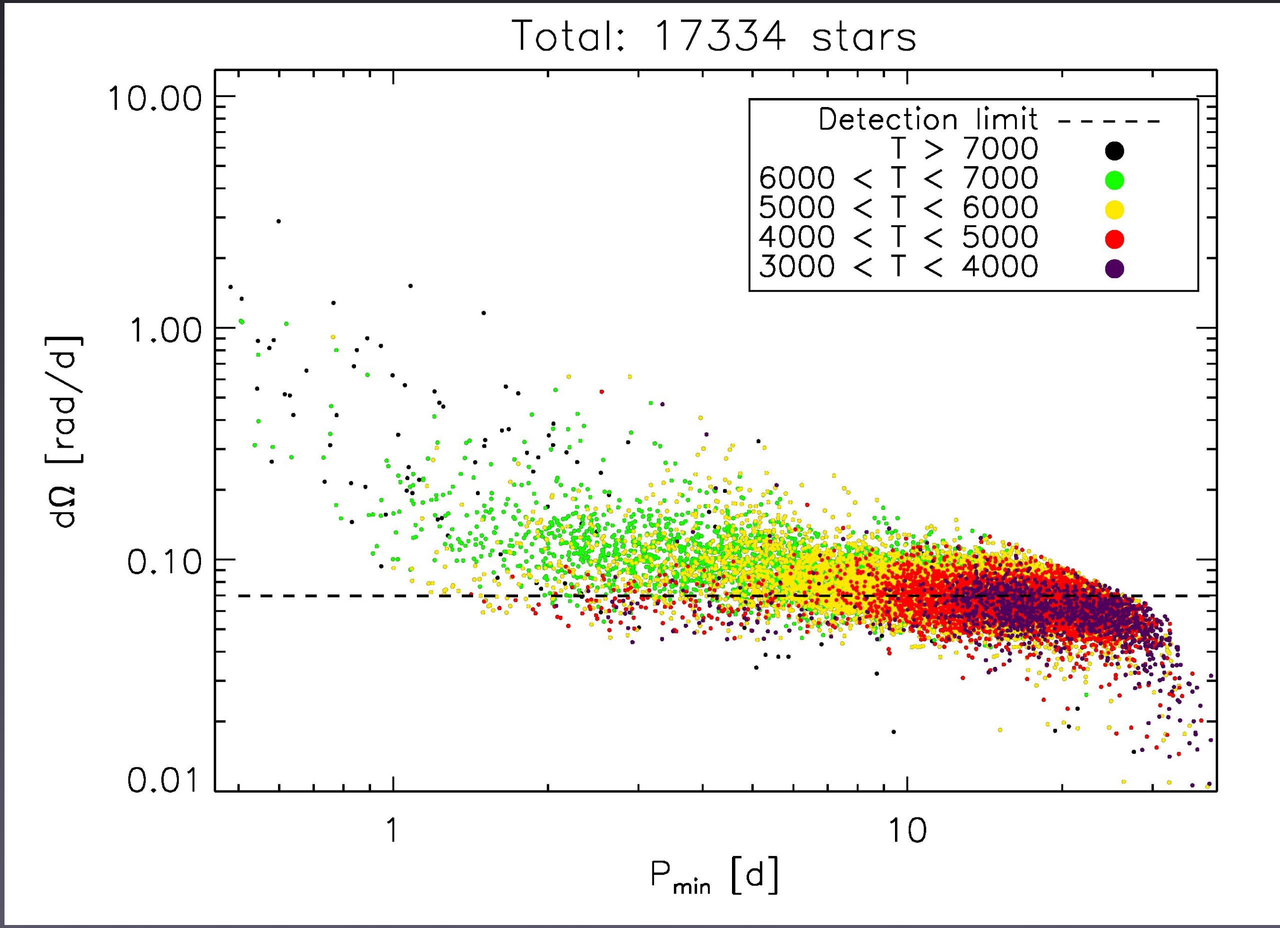
Quantities

- Most light curves: 2 periods found
- Sort periods according P1<P2 and compute DR quantities:
    - Relative DR: alpha=(P2-P1)/P2
    - Absolute DR: dOmega=2pi(1/P1-1/P2)
- How do these quantities correlate with Teff & Pmin?

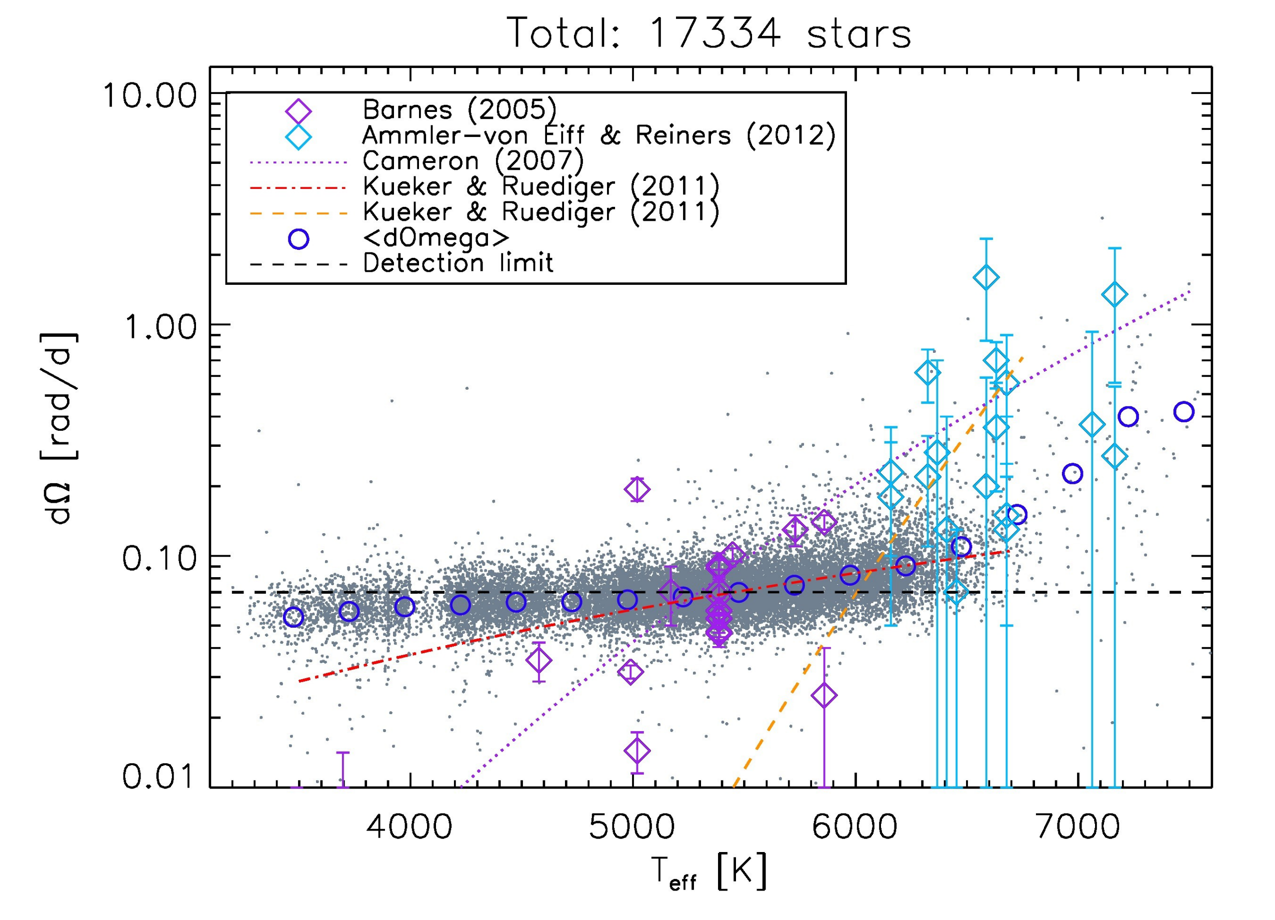
Pmin vs. alpha



Pmin vs. dOmega

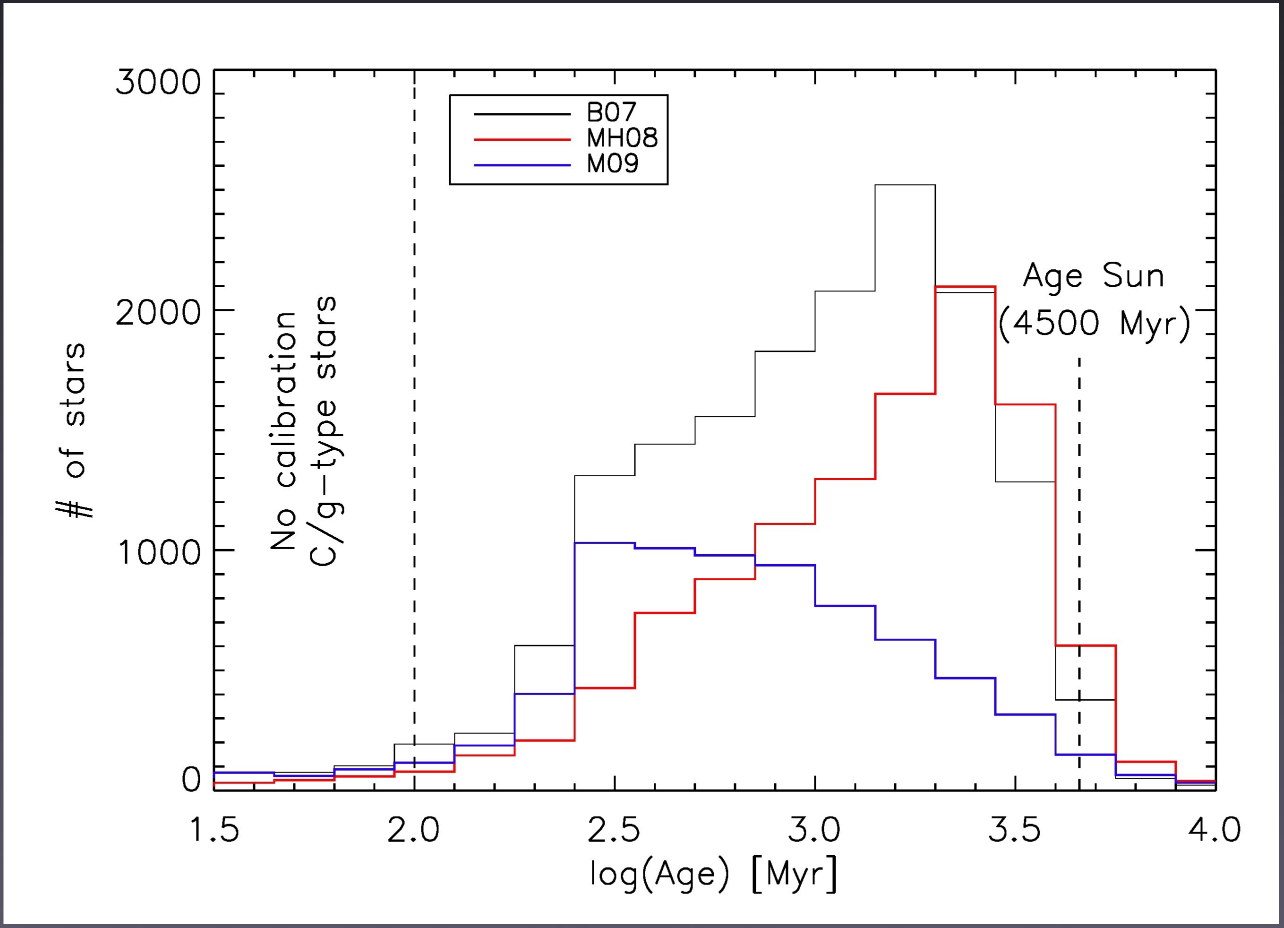


Teff vs. dOmega



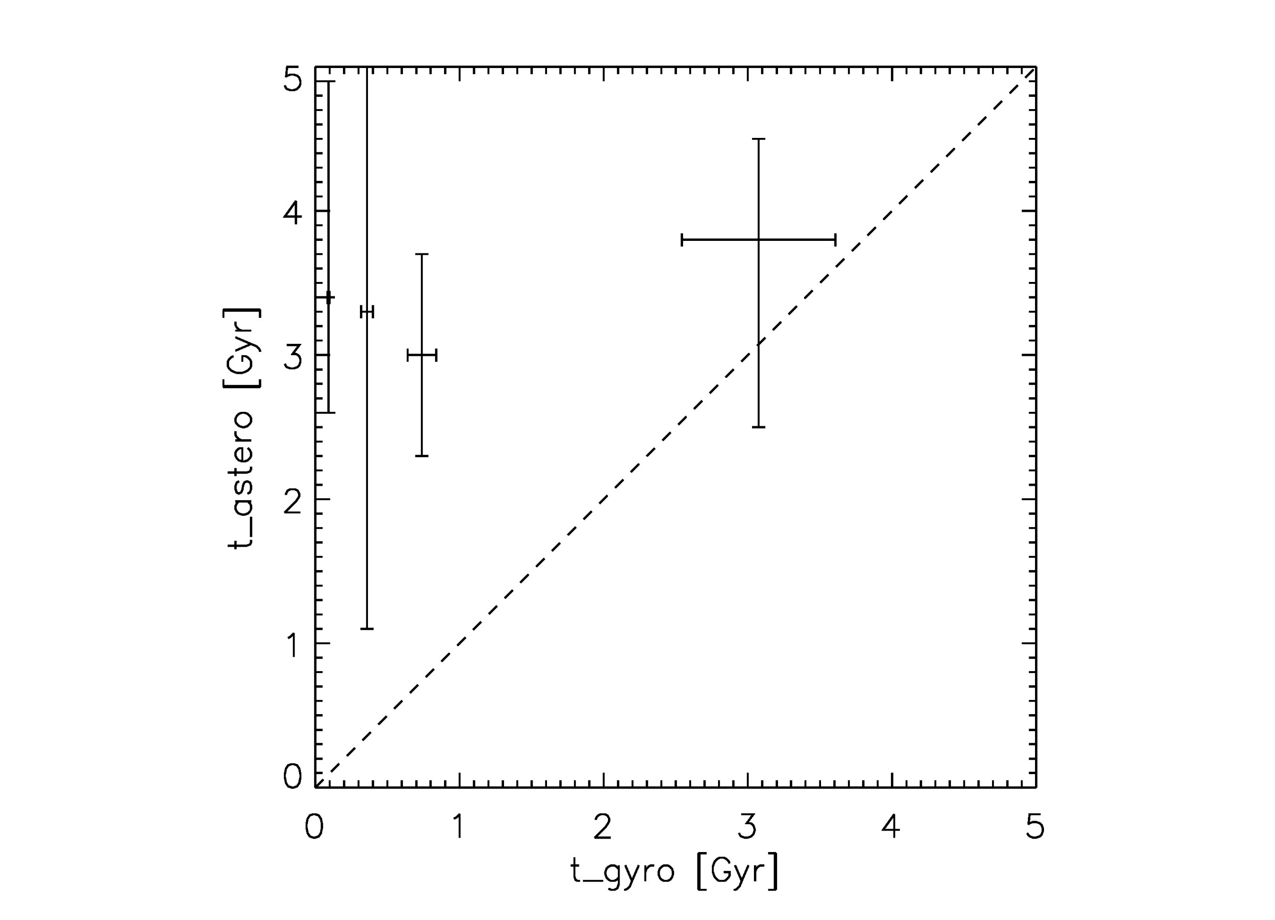
Stellar Ages

Gyro ages



B07
MH08
M09
No calibration
C/g−type stars
Age Sun
(4500 Myr)
# of stars
3000
2000
1000
0
1.5
2.0
2.5
3.0
3.5
4.0
log(Age) [Myr]

Gyro vs. Astero Ages



Conclusions

- Mean rotation period: Well known for many stars!
- DR: Exact values not well known for many stars because
  - peaks change over time (DR, spot evolution, instr. effects)

    → range of rotation periods for the same star
- Ages: Gyrochronology provides most reliable ages for young-mid age field stars
  - DR induces error in age
  - Problem: old stars (age > 2 Gyr)