Activity, rotation and stellar ages
using Kepler

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Long time ago...

- Telescope invented
  \( \sim 1608 \)
- 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
(as seen by SOHO)
From the Sun to the stars

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

- CoRoT-2 light curve: periodic variability due to star spots
  → achieve stellar rotation periods!
- 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
  → Use CaII H & K as rotation indicator
Activity-rotation relation

- Activity indicator $R'_{HK}$ vs. Rossby number $P/\tau$ (rotation period over convective turnover time) for Mount Wilson stars
- Symbols:
  - closed = young stars
  - open = old stars
- Activity increases towards fast rotators!

Noyes (1984)
Activity-age relation

- Stellar age $t$ vs. activity index $R'_{\text{HK}}$ for visual binaries, single F stars & open clusters
- Activity decreases with stellar age!

Soderblom, Duncan & Johnson (1991)
Activity-rotation-age relation

- Skumanich (1972) showed relation between activity indicator (CaII), age $\tau$ (Li), and rotation rate $v \sin i$

- All trends $\sim \tau^{-1/2}$
What can *Kepler* do?
Kepler: Rotation periods!

McQuillan et al. (2014)
How to measure periods?

- Auto-correlation function (ACF)
- Lomb-Scargle periodogram
Kepler: activity?

- Difficult: Only lightcurves, no spectra!
  → variability amplitude $R_{\text{per}}$, but no chromospheric activity measure $R'_{\text{HK}}$
Measured rotation periods with Kepler (so far...)

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

How can we use these periods?
Gyrochronology: Infer stellar ages from rotation periods & color (mass)!

- Stars spin down due to stellar winds (rotational braking)
  → color-period & color-age dependence

S. Barnes (2003, 2007)
Problems...

- Calibration mostly for young FGK stars
- Old stars: The Sun (age known); ages for Mount Wilson stars from activity-age relations
- Error sources:
  - Different color & period ranges used for calibration
  - Differential rotation $\rightarrow P \pm \Delta P$
  - Stars are born with initial range of rotation periods $P_0$
  - Kepler: No B-V colors (g-r colors used instead)
Gyro ages

- Sample of ~16,000 stellar rotation periods
- Different relations: Only valid for certain color & period range → stars missing!
Differential rotation
Measure differential rotation with Lomb-Scargle periodogram
Difficult: Same star but full lightcurve...

→ More than one period due to differential rotation, spot evolution, ...
Significant peaks?

→ Differential rotation or spot evolution?
Conclusions

- **Activity**: Relations between chromospheric activity, stellar age, and rotation period well established
  - **Kepler**: no direct relation between amplitude and period (or age)

- **Rotation**: (Mean) rotation periods well known for thousands of stars!

- **Ages**: Gyrochronology provides reliable ages for young-mid age field stars
  - **Problem**: old stars (age > 2 Gyr)

- **Differential Rotation**: Difficult to distinguish from spot evolution; additional periods induce errors in gyro ages!