Stellar Activity

PLATO 2.0 Science Workshop

29 - 31 July 2013

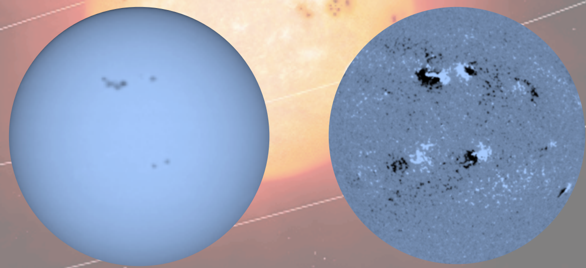
ESTEC, Noordwijk, The Netherlands

Isabella Pagano
INAF - Osservatorio Astrofisico di Catania
isabella.pagano@inaf.it

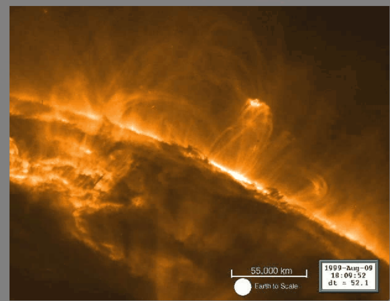
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Stellar Activity

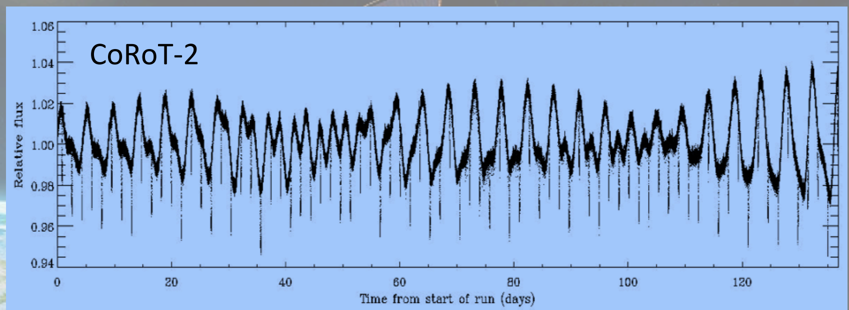
- “Stellar Activity” is a collective name used to group the variability phenomena observed in the outer atmospheres of late type-stars mainly due to the presence of highly structured magnetic fields emerging from the convective envelope.
- Spots, faculae, flares and microflares produce footprints in the optical light curves

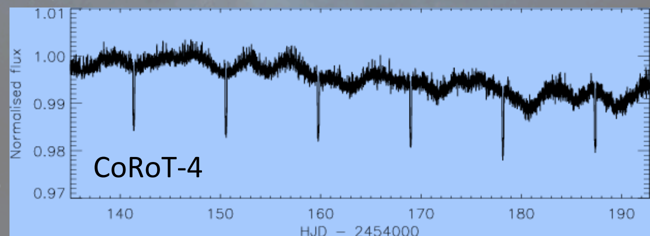


Sun: image of photosphere and magnetogram obtained at Teide (8.3.2012)



Sun: the limb in UV light as seen by TRACE (NASA)





Why Stellar Activity matters?

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

I. Planet Detection & Characterization

A. Stellar Activity is noise for planet detection
It is an additive term to photon noise and instrumental noise.

- **False transit-like dips**, especially for rapidly rotating stars or fast active region evolution;
- Variation of the **out-of-transit light level** that hampers the application of phase-folded search methods, e.g., Box Least Square (BLS, Kovacs et al. 2002);
- **Non-Gaussian noise in the time series** (red coloured noise; Pont et al. 2006; Aigrain et al. 2009; Ofir et al. 2010).

Easily solved by filtering and/or fitting algorithms

Jenkins (2002), Aigrain & Irwin (2004), Moutou et al. (2005), Bonomo et al. (2009), Ofir et al. (2010)

- Filtering algorithms are based on the difference in characteristic timescales and shapes of variations due to activity or transits.

Why Stellar Activity matters?

◆ INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

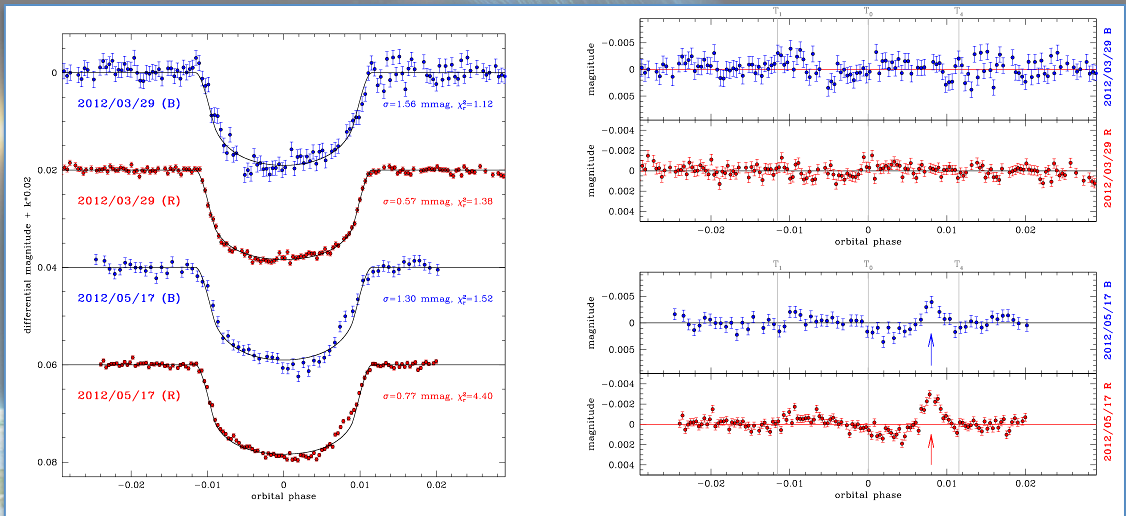
I. Planet Detection & Characterization

B. It is noise for planet characterization:

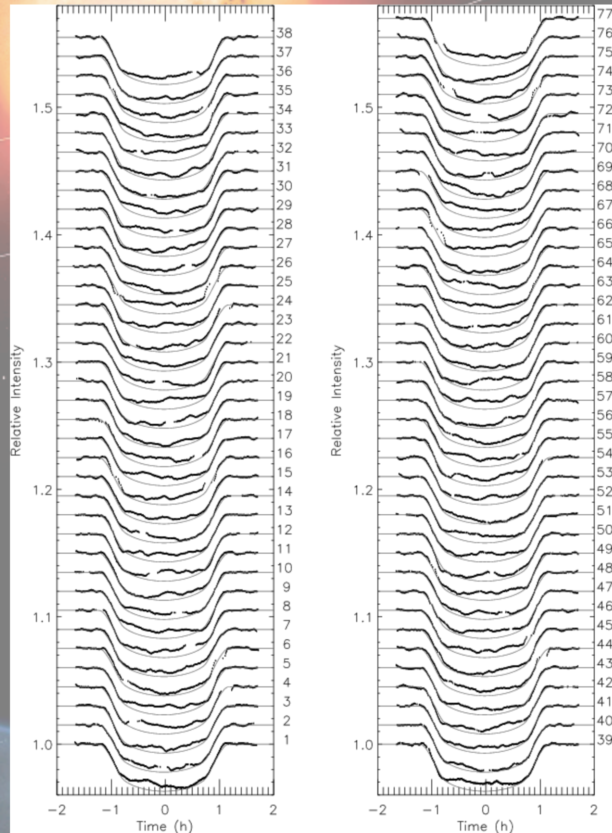
- It alters transit depth, duration and timing,

➔ possible wrong radius estimation;

➔ possible errors on the characterization of the atmosphere.



GJ 1214: 2 transits measured by LBC@LBT simultaneously in B and R ~1.5 months apart (Pagano, Nascimbeni, Piotto et al., in preparation)



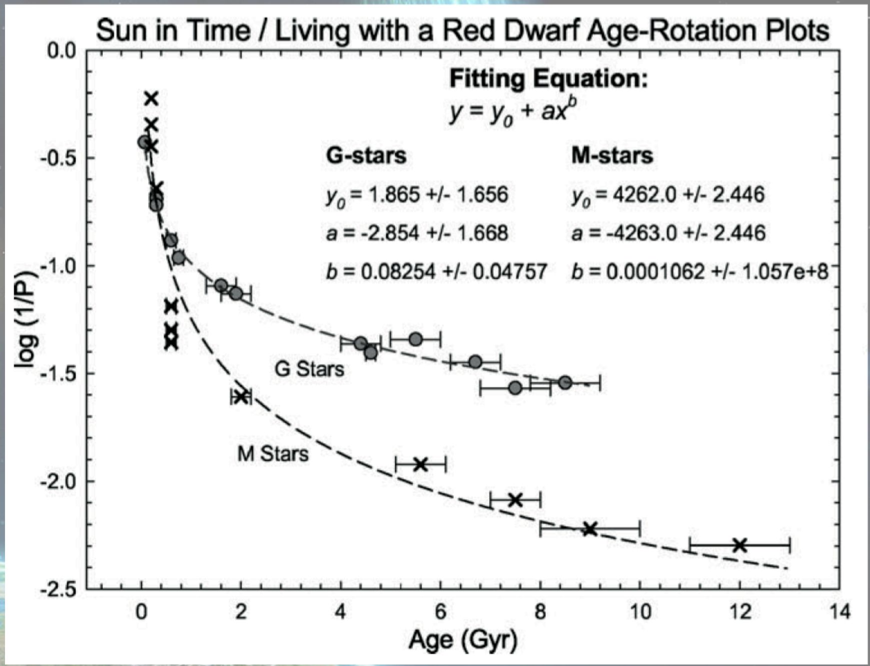
77 transits of **CoRoT-2b** in front of its spotted host star (Silva-Valio et al. 2010, A&A 510, A25)

Why Stellar Activity matters?

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

II. Characterization of the Planetary System evolutionary state

- Spots are tracers for rotation
  - Rotation ➔ Age determination



- Determine the **rotation rate and rotation regime** is key to understand the dynamical star-planets coupling (*see Lanza talk*)

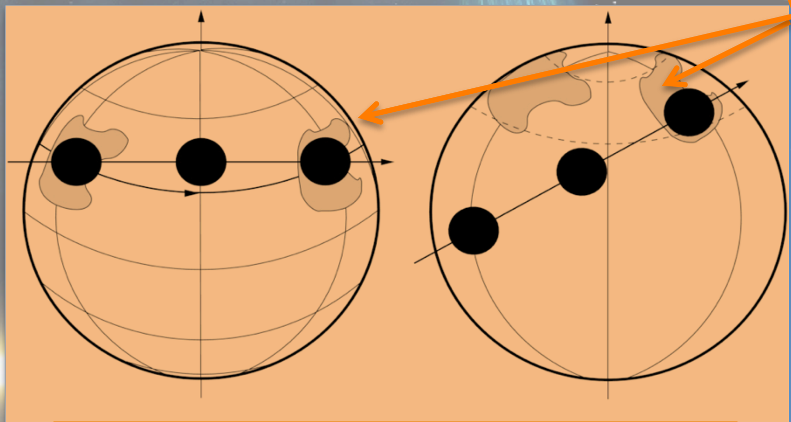
Why Stellar Activity matters?

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

III. Spots can be used to measure the spin-orbit alignment of transiting planets (e.g., Sanchis-Ojeda et al. 2011)

From Nutzman et al. 2011 ApJ 740 L10

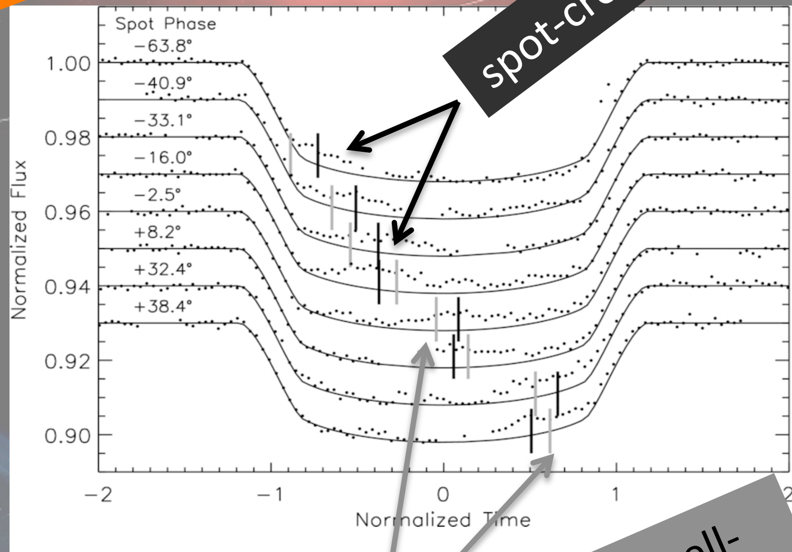
after a 120° rotation of the star



Well aligned   Misaligned
planetary orbit

The **exact timing of a spot crossing during transit constrains λ**, while i_s is largely degenerate with the spot latitude.

spot-crossing timing.



expected spot-crossing time for a well-aligned planet with, λ = 0 and is = 90°.

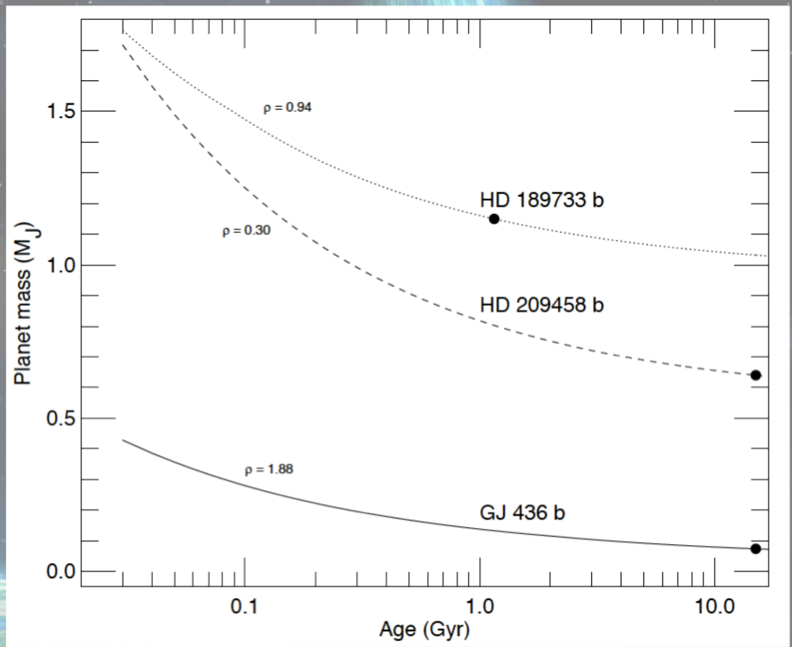
Why Stellar Activity matters?

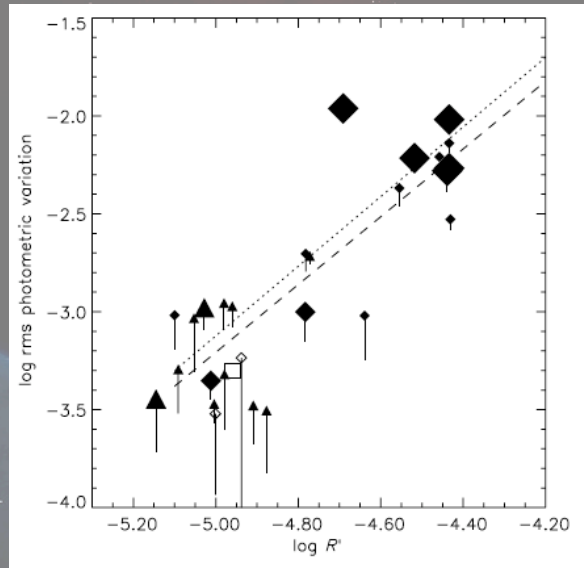
INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

IV. Activity determines the stellar environment

- Special interest to habitability Output from stellar external atmospheres (mainly transition regions and coronae) affects the planetary atmospheric evolution and water inventories.

see Lammer 's talk





Hall et al., 2009, AJ 138, 312

EUV flux from the mother star affects planetary mass evolution (Sanz-Forcada et al. 2011). Mass losses include evaporation by coronal radiation and losses through the Roche Lobe.

Stellar Activity: what kind of targets?

All late-type stars (*Ingredients: sub-photospheric convection and differential rotation*)

- **Sun-like stars:** very broad class...from late F dwarfs to G dwarfs and subgiants.
  - **Solar analogs**: Pop I dwarf with gross properties not very different from those of the Sun.
  - **Solar twins**: have fundamental physical parameters very similar, if not identical to those of the Sun.
- **K and M dwarfs**
- **Rapidly rotatimg stars: PMS & binaries with late –type components** (e.g., BY Dra, RS CVn).

Cayrel de Strobel & Bentolila, 1989, A&A 211, 324

What about stellar activity in the Kepler field?

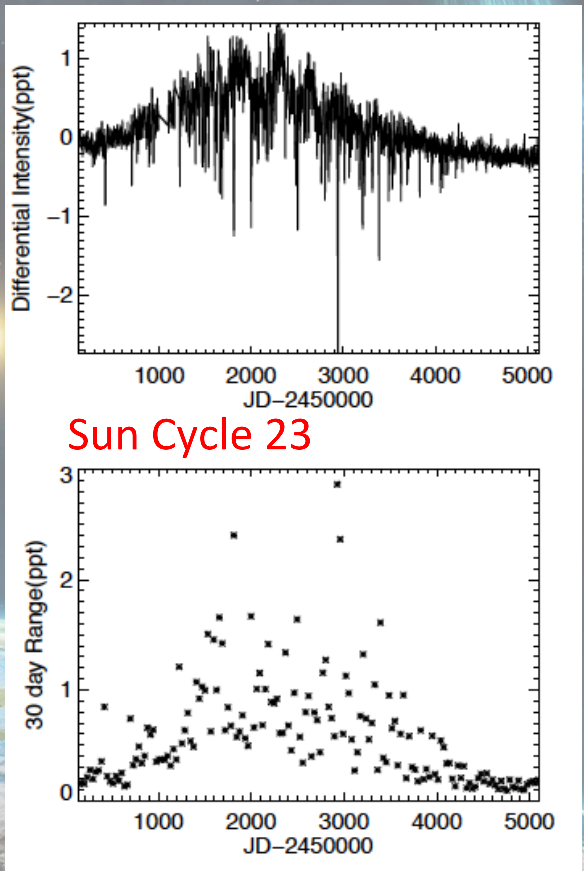
- The Kepler light curves for solar-type stars are somewhat more variable than predicted before launch.
- **Is this due to Stellar Activity?**
  - For **11.5-12.5 magnitude** solar-type stars, Gilliland et al. 2011 show that and on a timescale of ~6 hours:
    - the **intrinsic stellar noise is 50% more then expected**
    - **60% of stars are more active than the Sun**.
  - Similar conclusion reached by McQuillan et al. (2011)

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

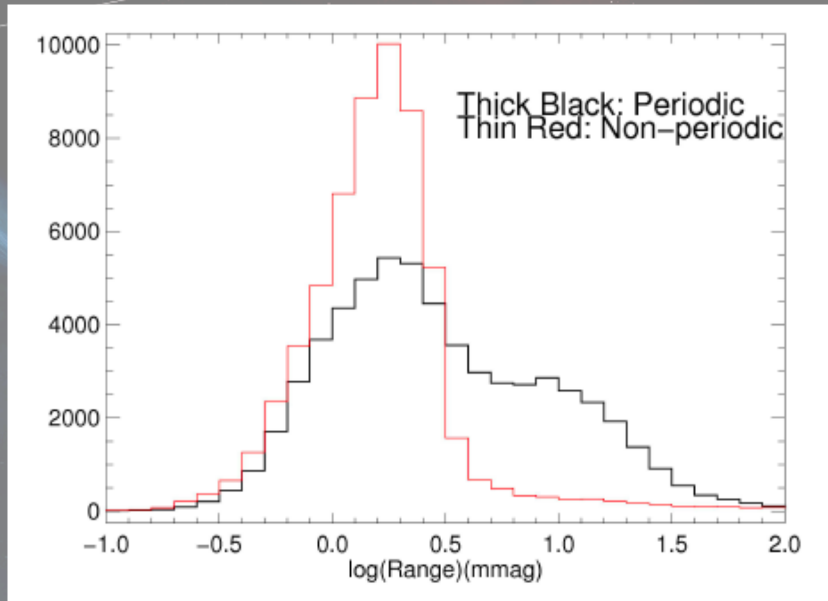
Magnetic activity in the Kepler sample

- Basri et al (2011, 2013) investigated variability of solar like stars at different time scales. They use R_{var} as variability index:

R_{var}=range between the 5th and 95th percentile of differential intensities in a light curve over 30 days.



Most stars with high R_{var} are periodic (Basri et al 2011)



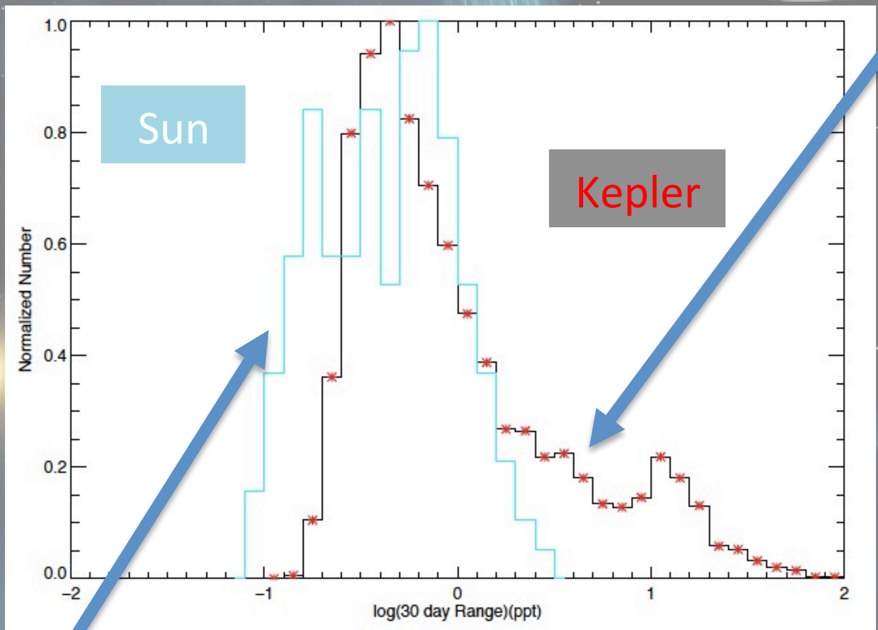
Data from ~1 month observations (Q1)

Magnetic activity in the Kepler sample

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

- **Solar type stars**

Basri et al 2013ApJ...769...37B



About 25% of the bright (>12.5 mag) Kepler sample of are more active – on 1 month time scale - than the Sun at maximum of its cycle.

- Solar data provide snapshots at all solar cycle phases;
- Kepler data sample solar-type stars at all random phases of their cycles.

Solar data show low level variability on 1 month timescale: probably very small rotational modulation present during the extended and very quiet solar minimum of Cycle 23. This is not measured for the stelalr sample given current systematic effects at long timescales in the Kepler pipeline?

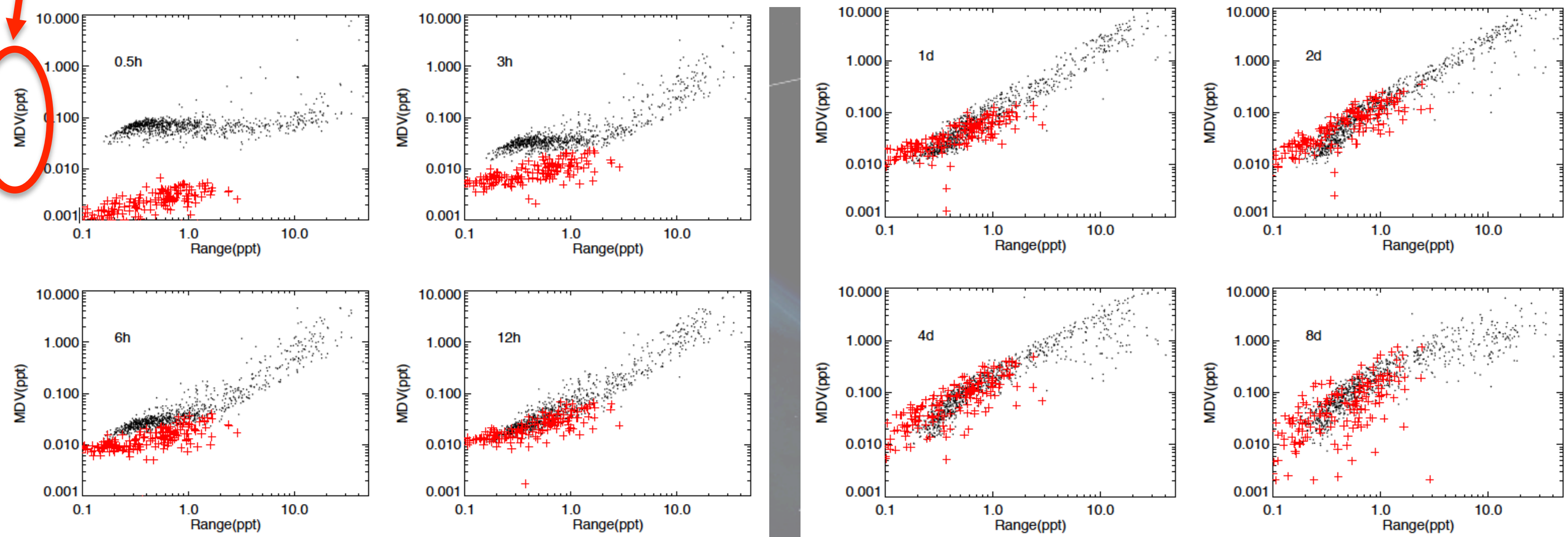
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Magnetic activity in the Kepler sample

MDV (median differential variability) is a metric to measure variability at different time scales.

SUN Kepler

no reasons intrinsic to stars can reproduce the gap between solar and stellar data at time scale < 12hr (Basri et al. 2013)



Basri et al 2013ApJ...769...37B

- ❑ Timescales shorter than 12 hours seem to be clearly affected by noise.
- ❑ For timescales longer than 12 hours, Kepler stars and solar variability show similar spreads, and clear correlations with variability on one-month timescales.

Magnetic activity in the Kepler sample

- Basri et al. (2013) conclusion is in contrast with previously analysis (e.g., Gilliland et al 2011); the difference (30% against 50% of solar type stars more active than the Sun) depends upon the adopted variability metric:
  - MDV is sensible to different timescales
  - CDPP samples the timescale of interest to detection of planets only

→ variability metric constructed to measure the detectability of transits (CDPP) is not particularly suited to assessing the sort of stellar variability

Lesson learned for PLATO: develop from the beginning tools to study also variability.

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Activity vs. spectral type

Table 2. Fraction of Bright Stars More Active than Solar [a]

	late-F (1340) [b]	G (974)	early-K (904)	mid-K (663)	late-K,M (1201)	late-K,M [c]
	6500-6000K	6000-5500K	5500-5000K	5000-4500K	4500-3500K	
R_{var}(30 day)	.17	.28	.41	.64	.91	.63
6hr	.57	.35	.42	.77	.96	.61
12hr	.49	.32	.38	.60	.87	.58
24hr	.41	.32	.38	.58	.86	.59
2day	.25	.30	.39	.58	.87	.61
4day	.16	.30	.42	.63	.91	.66
8day	.12	.26	.41	.63	.90	.60

Basri et al 2013ApJ...769...37B

When one goes to stars cooler than the Sun the fraction of them which are more active than the active Sun increases steadily, becoming almost all of them by early M-dwarfs.

- Their variability at shorter timescales is also greater;
- stellar Rvar is a predictor of stellar MDV(tbin) at most timescales.

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

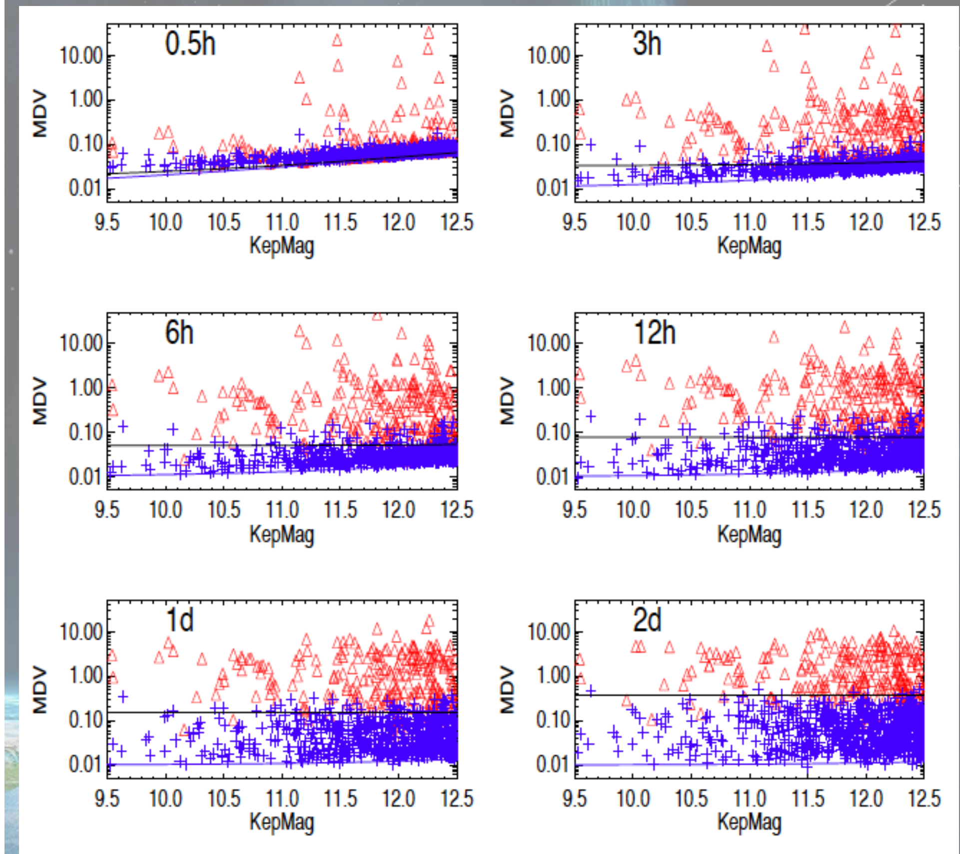
Activity vs spectral type

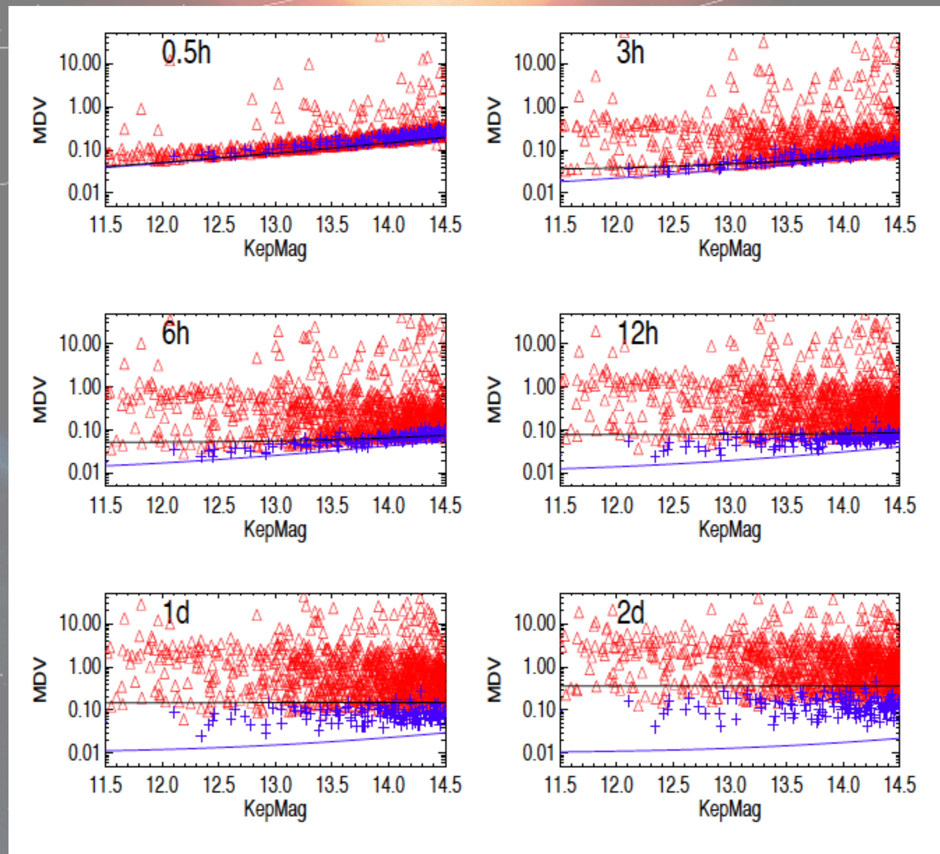
G dwarfs (600 – 5500K)

Late-K (4500-4000K) and early-M dwarfs (<4000K)

~30% more active than the Sun

~90% more active than the Sun

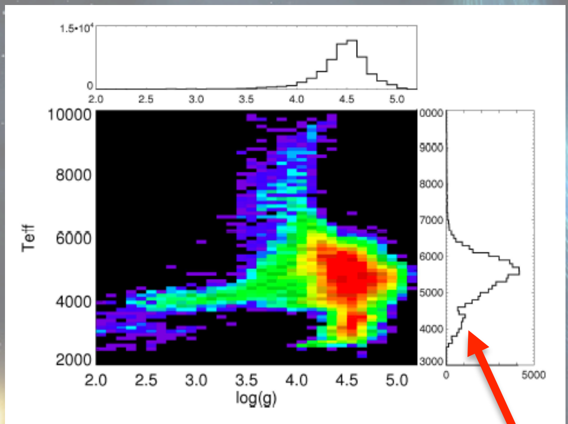




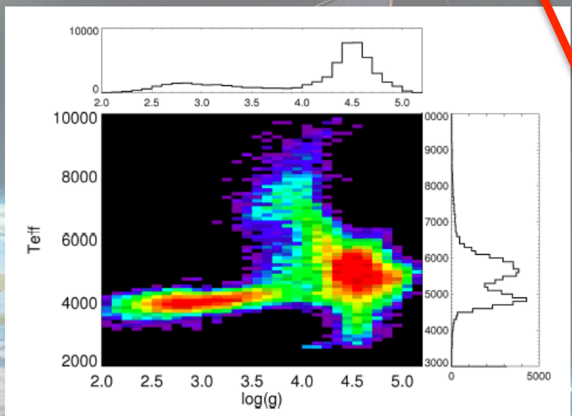
Basri et al 2013ApJ...769...37B

What information from photometric time series

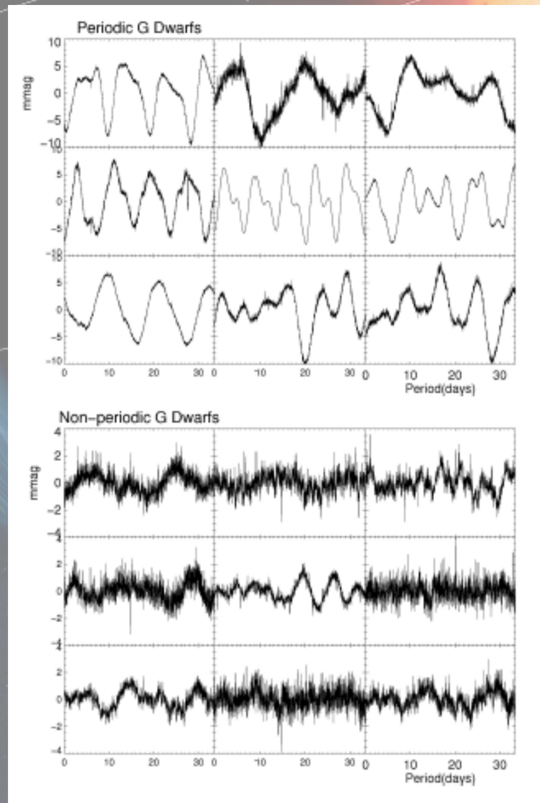
1. Stellar rotation period

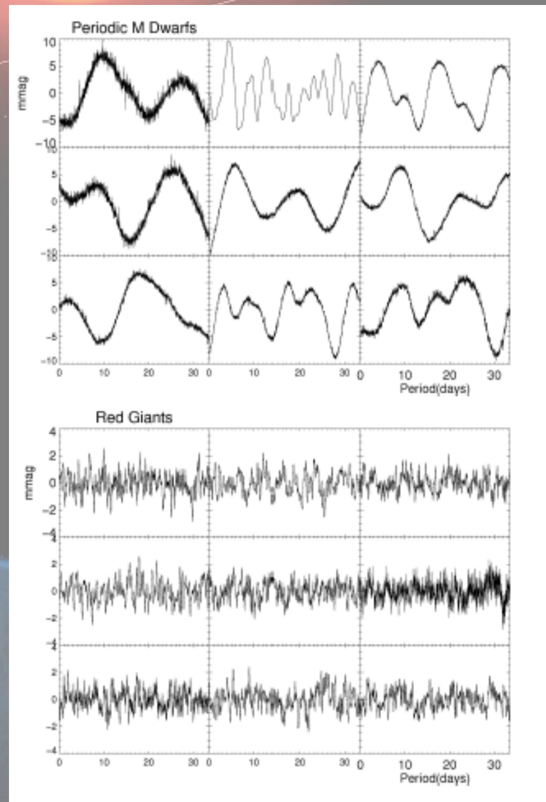


Stars with clear periodicity



Sample non-periodic





A stronger component of cool dwarfs.

Basri et al 2011 AJ 141, 20.

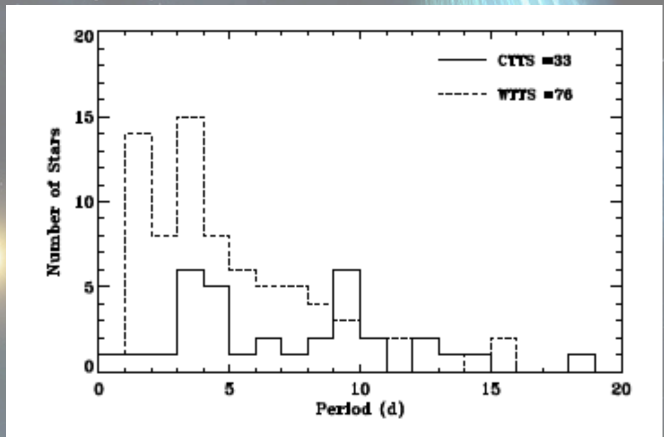
Stellar rotation periods: NGC 2264

CoRoT data

301 monitored cluster members:

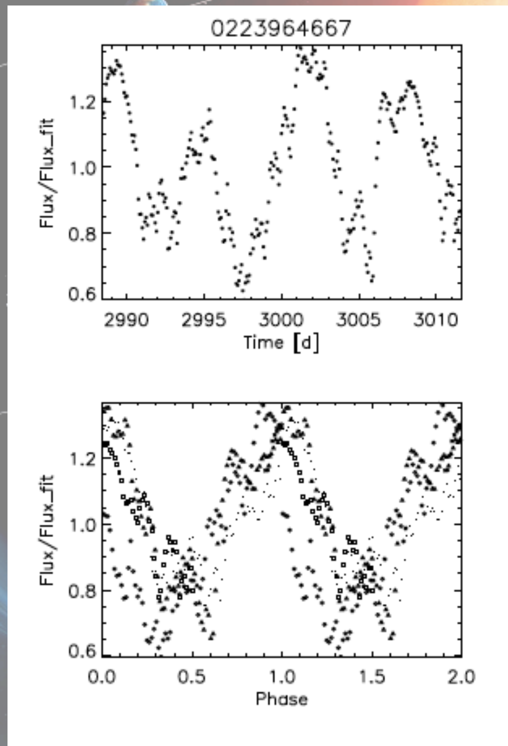
- 63% periodic variable,
- 16% no variability (noise dominated)

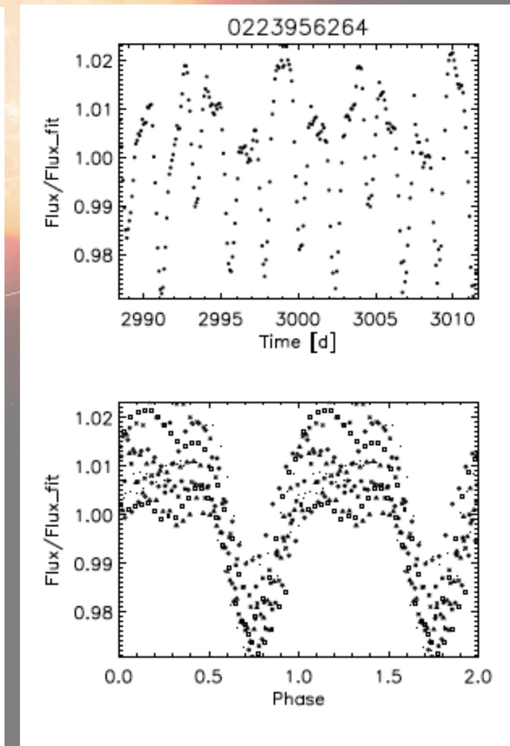
Affer et al. 2913



WTTSs rotating faster than CTTSs:

- WTTS median P_{Rot} = 4.2d ;
- CTTS median P_{Rot} = 7.0 d.





The presence of accretion, or any other properties related to star-disk interaction, affects the rotational period.
The results is consistent with the disk locking scenario (Shu et al. 1994; Hartmann 2002)

Stellar rotation periods in M field dwarfs

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Kepler data

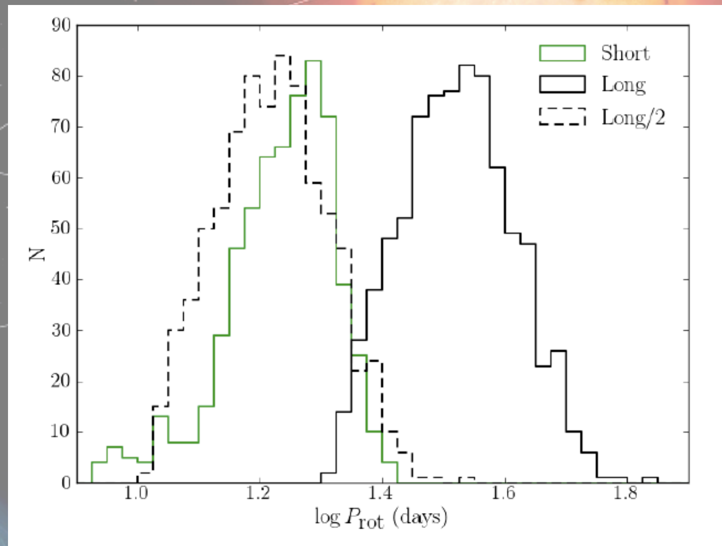
first 10 months of data

Teff ≤ 4000 K and log g > 4.0 dex

$0.3 \leq M/M_{\odot} \leq 0.55$

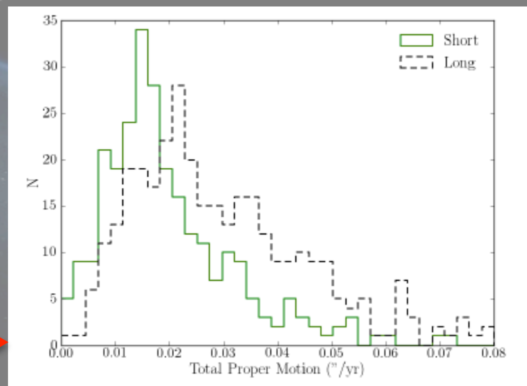
- 2483 stars
- 63% periodic variable,
- Periods: 0.37–69.7 days,
- Amplitudes: 1.0–140.8 mmags.

McQuillan, Aigrain & Mazeh 2013



Period detected fall into two distinct groups:
P=10–25 days (peak at 19 d)
P=25–80 days with (peak at 33 d)

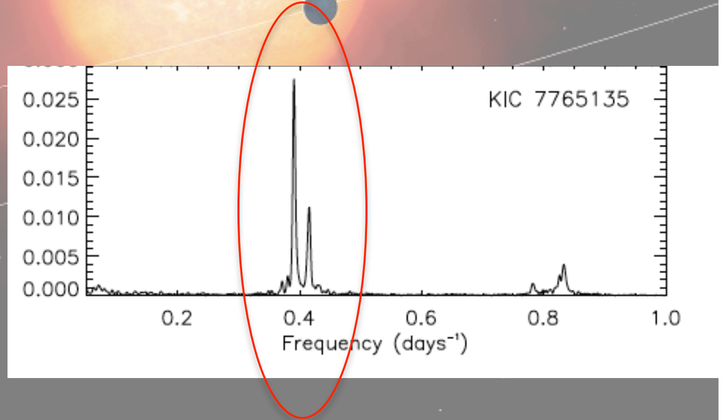
Two stellar populations with different ages, as confirmed also by proper motion distribution. No difference in the galactic latitude distribution of the two components.

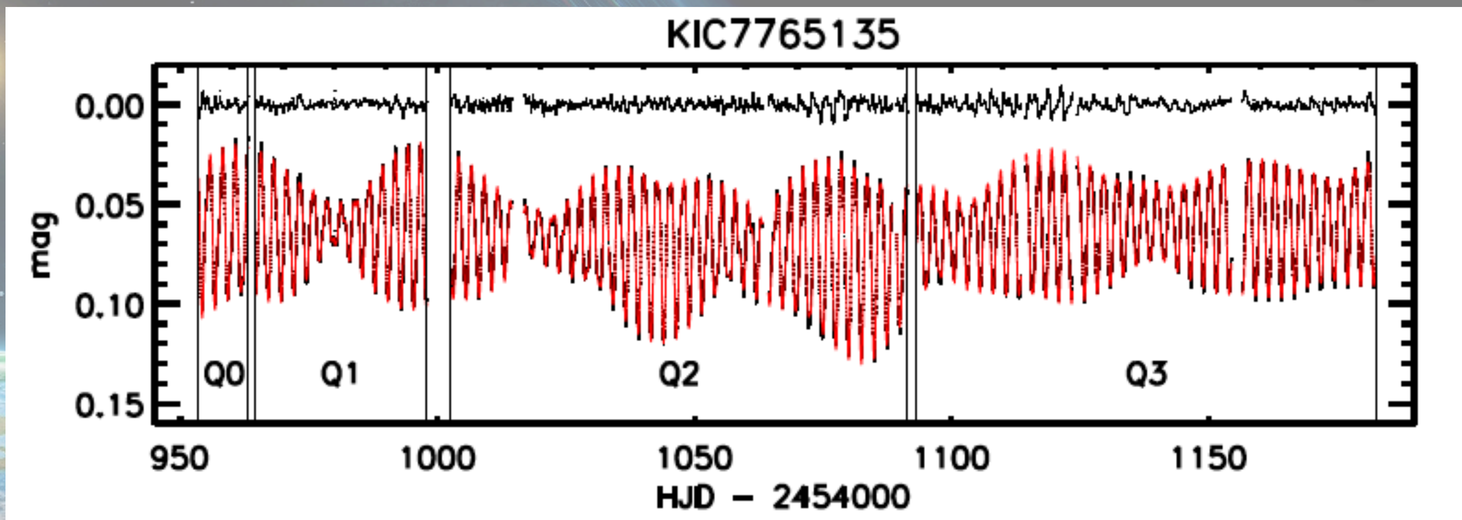


What information from photometric time series

2. Surface differential rotation

- Double peaks in the periodogram
- Rotation period variations
- Phase migration of lightcurve minimum



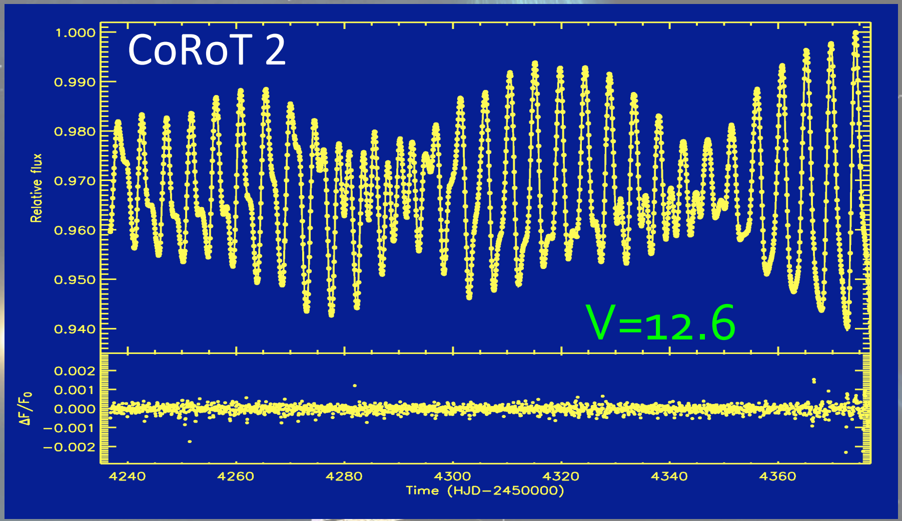


Fröhlich et al. 2012A&A...543A.146F

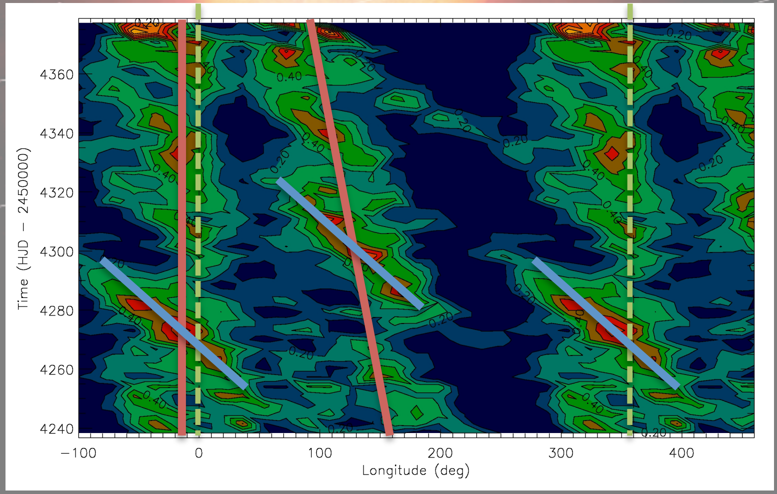
What information from photometric time series

3. **Photospheric Maps**
4. **Time-scale of Active Region evolution**

Lanza, Pagano, Leto et. al., 2009, A&A 493, 193



ΔF≈ 6 %, P_{rot}≈ 4.52 d
20 times more active than the Sun at its maximum



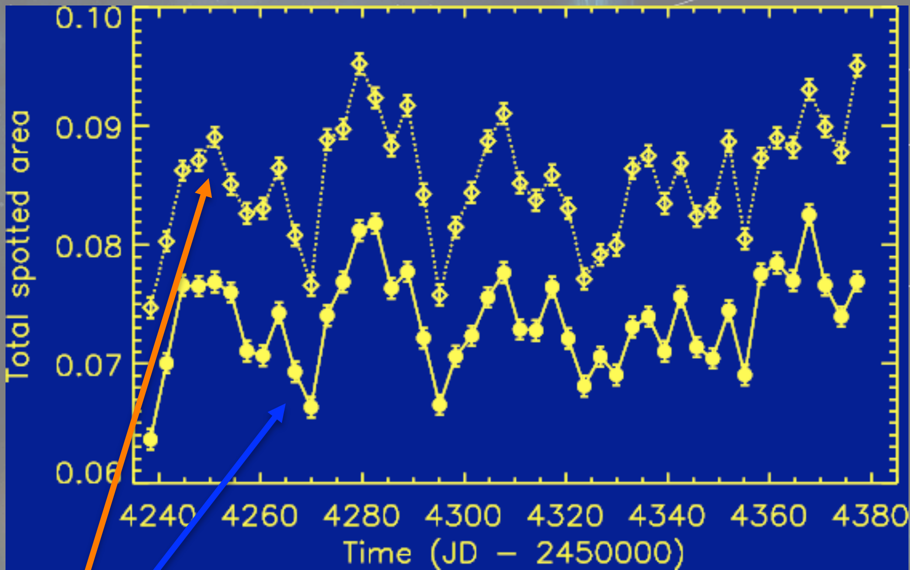
Star: G7 V, 500 Myr,
Planet: M_p=3.31±0.16 M_J P_{orb}=1.743d

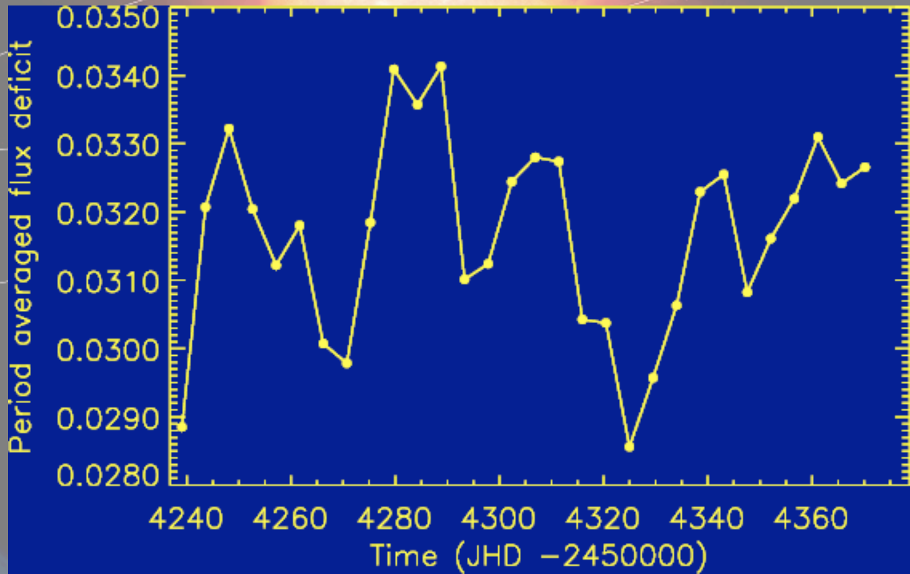
- ✓2 ARs ~ 180 degree apart
- ✓Small differential rotation: **ΔΩ/Ω≈0.007**
- ✓Spots rotate slower tha ARs (1%)
- ✓ARs life ≈ 55 d
- ✓Spot lifetime 20-30 d

CoRoT 2:
Variation of the spot area vs. time

◆ INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Lanza, Pagano, Leto et. al., 2009, A&A 493, 193





Relative flux deficit versus time, averaged along individual rotation periods of 4.52 days.

Spots only: $P_{cyc} = 28.9 \pm 4.8$ d

Spots and faculae with $Q \equiv A_{fac}/A_{spot} = 1.5$: $P_{cyc} = 29.5 \pm 4.8$ d

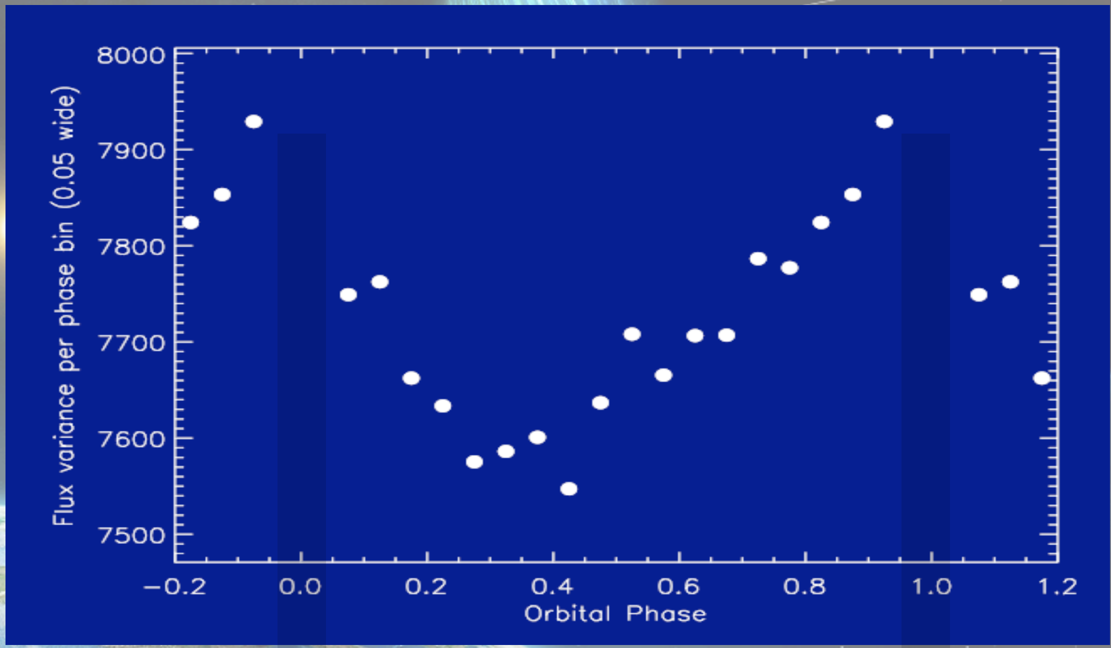
Rieger cycle ?

Is the Rieger-like cycle in CoRoT-2a due to interaction with CoRoT-2b?

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

- The period of starspots variation is 10 times the synodic period of the planet: 2.89 days

Star Planet Interaction



$$\frac{1}{P_{syn}} = \frac{1}{P_{orb}} - \frac{1}{P_{rot}}$$

See Lanza's talk about SPI

Pagano, Leto, Lanza et al. 2009, EM&P, 105, 373

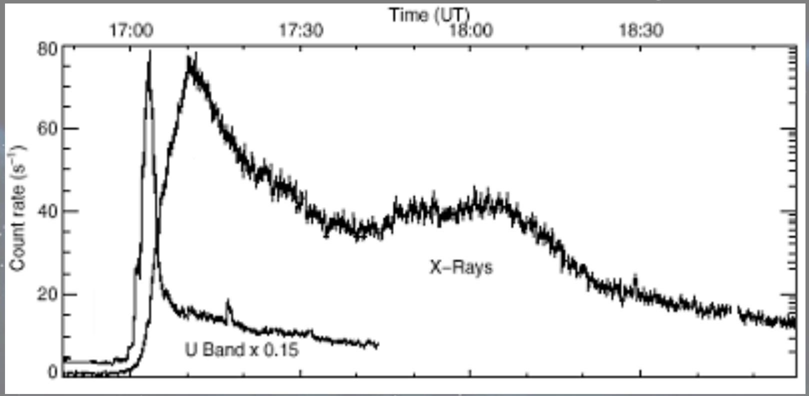
Stellar Flares

Why matter?

- In assessing planetary atmospheric properties:
  - Flares and UV radiation could erode planet atmospheres (Lammer et al. 2007).
- In assessing habitability:
  - Bursts of UV radiation due to stellar flares could be detrimental for life.

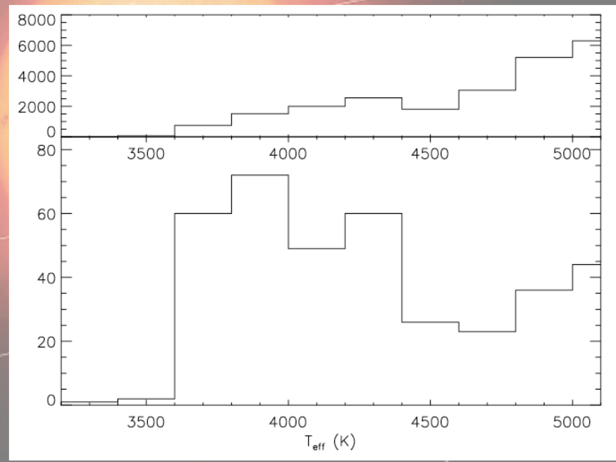
Optical photometric series provide data on **white light flares**, that in stars cooler than the Sun are easily detected and are are tracers of the impulsive phase of the flare, when the soft X-ray emission arises.

- Flare research has focused on detailed studies of a few of the most active known stars.



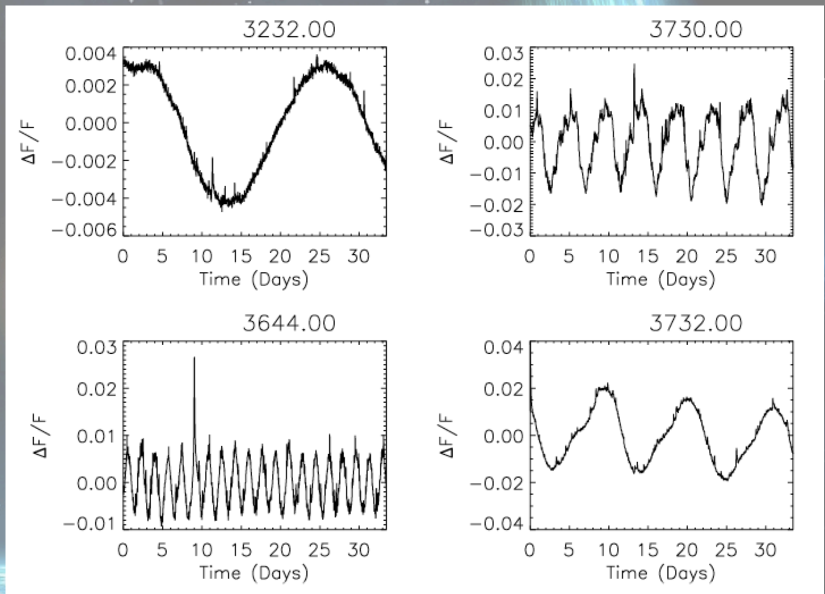
Stellar Flares

Kepler Q1 data – Walkowicz et al. 2011
Cool dwarfs: Teff <5150 K and logg >4.2)



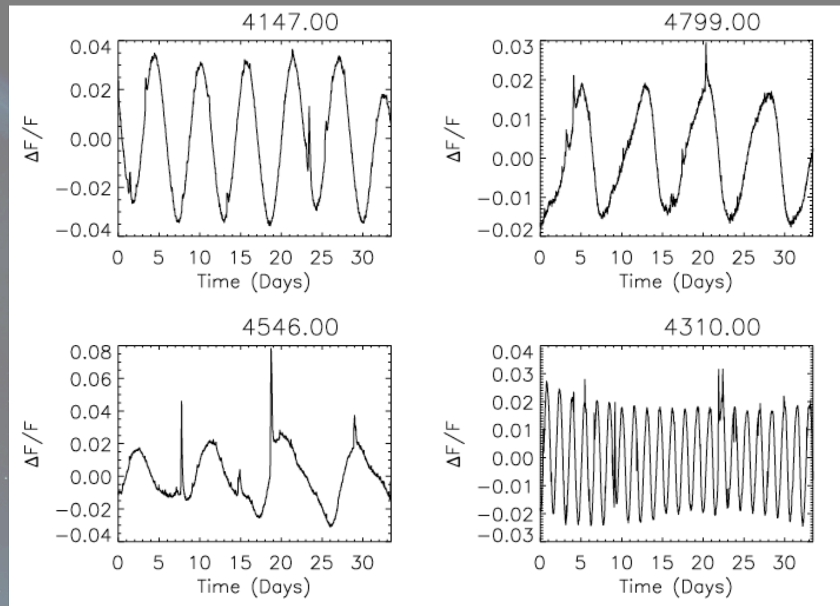
white light stellar flares

Flaring M dwarfs **33.5 days of LC (~30 minutes time res.)**



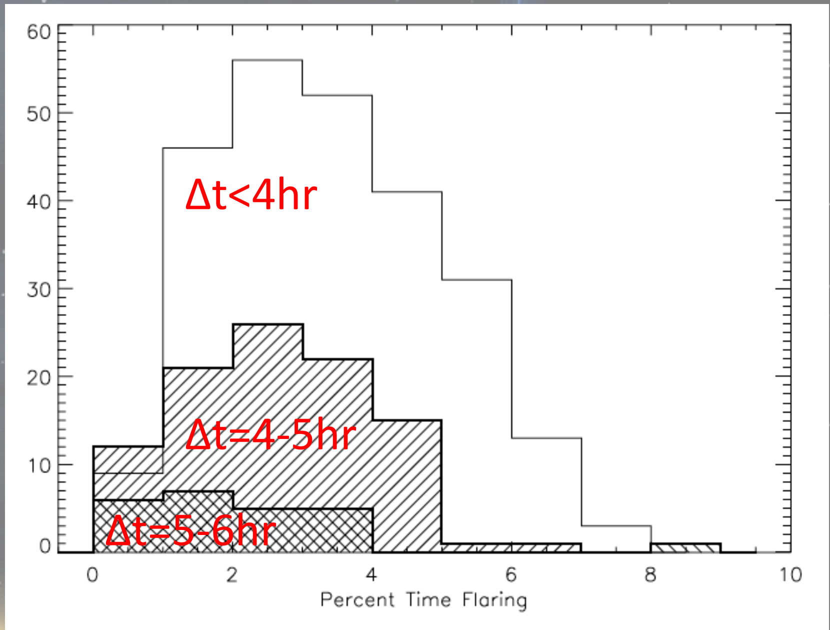
In the local neighbourhood, the flaring fraction is:
~50% M dwarfs
~10% K dwarfs

Flaring K dwarfs



Walkowicz et al 2011AJ....141...50W

Stellar Flares



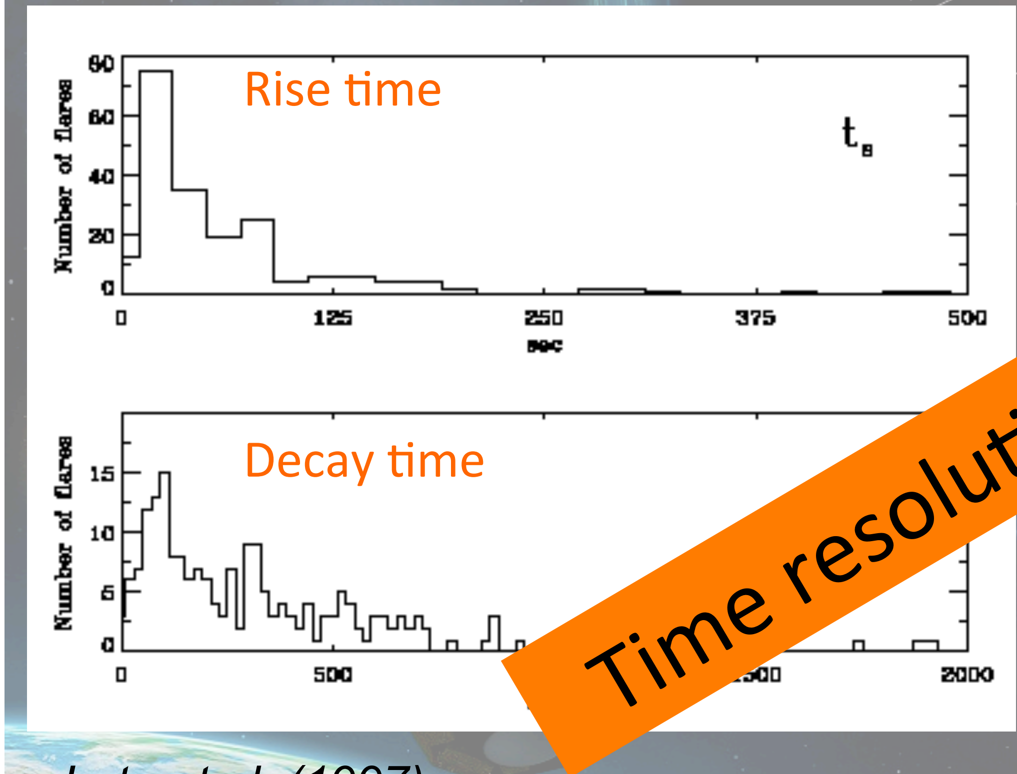
Kepler Q1 data

Walkowicz et al 2011AJ....141...50W

- K dwarfs seems slightly more variable in quiescence than the M dwarfs;
- M dwarfs have a somewhat stronger flares than the K dwarfs
- Stars with longer duration flares tend to flare less frequently.

Flare timescales

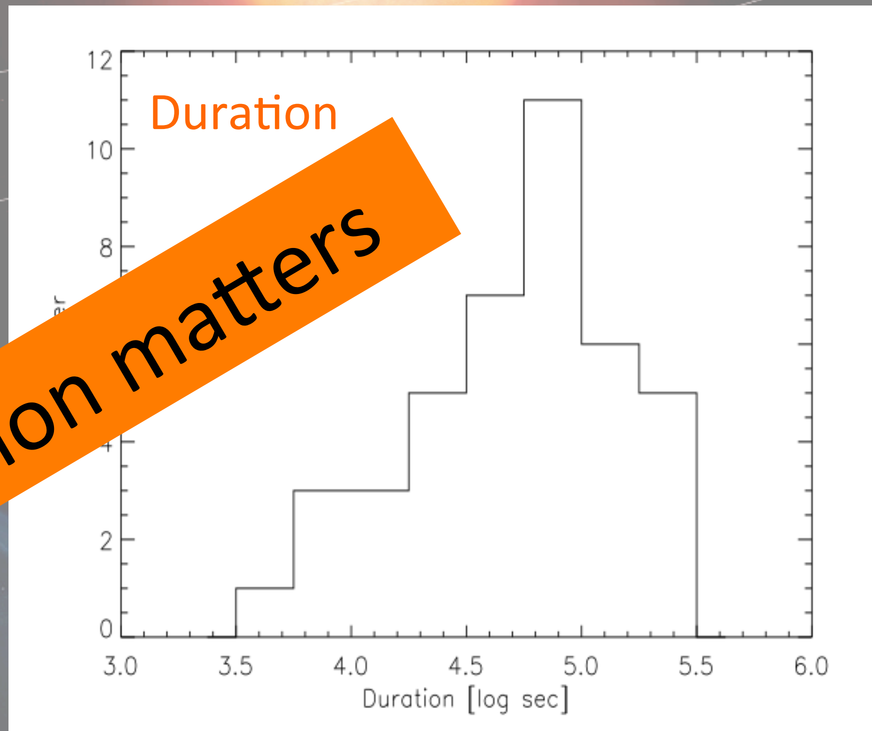
Flare stars – optical data



Leto et al. (1997)

Few minutes to tipically less than 1hr

YSOs – X-ray COUP data



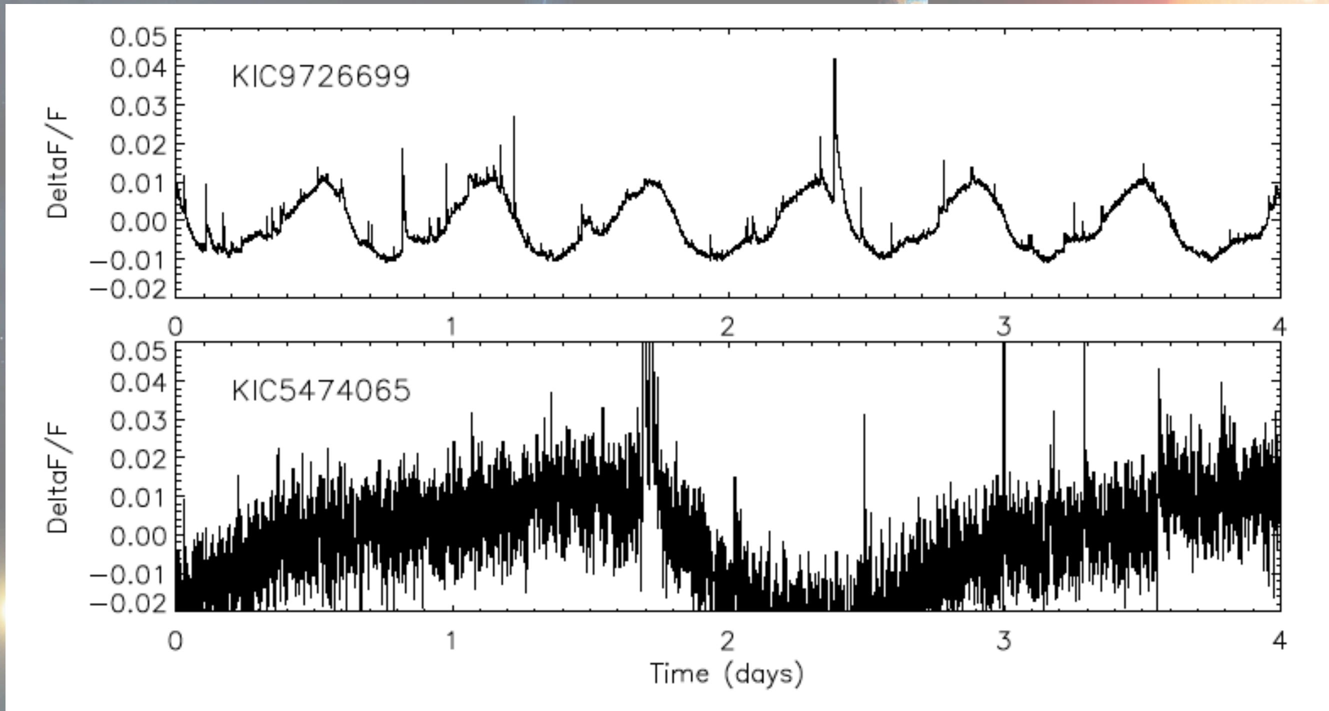
Wolk *et al. (2005)*

1hr to 3 days

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Stellar Flares

Ramsay et al. 2013



Kepler SC data:
~ 60 sec resolution

PLATO 2.0:
With 25 sec (N-CAM) and 2.5 sec (F-CAM) PLATO 2.0 will provide unprecedented results on statistics of stellar flares.

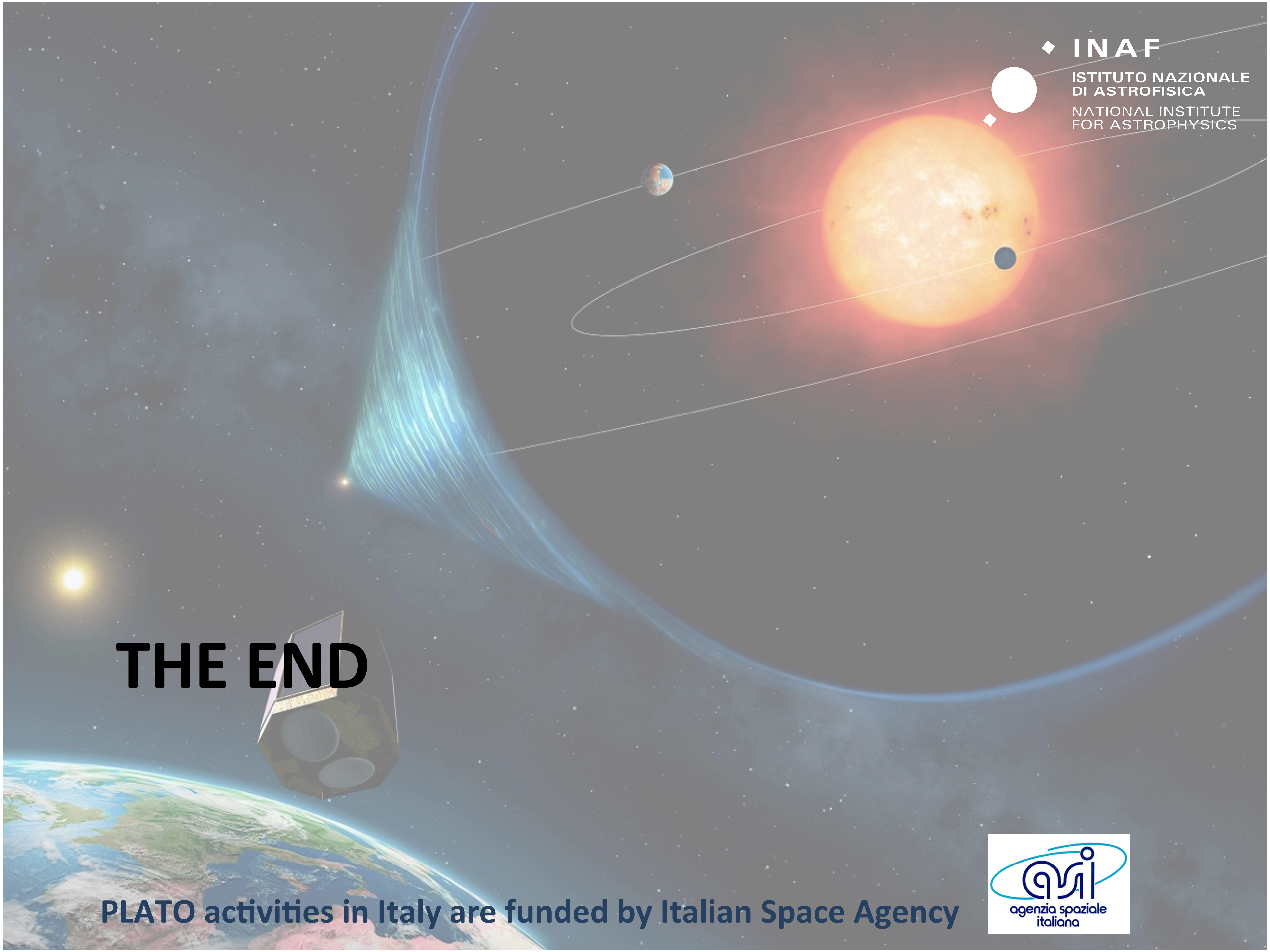
PLATO 2.0 & Stellar Activity

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

- **High photometric accuracy**
  - detection of very low variability levels and extension of our analysis to very slow rotators
- **Uninterrupted time series and high time resolution**
  - no aliasing
  - all variability timescales accessible
- **High number of monitored targets** ***(20,000 sqdeg → 50% of the sky !)***
  - robust statistics.

- Know-how from Kepler, TESS, and Cheops on data reduction → control of systematics…..

PLATO 2.0 will provide accurate relations between **magnetic activity observables** (i.e., rotation, differential rotation, cycles, flare frequency, etc.), and **basic stellar parameters** available with high level of reliability, mainly from asteroseismology and Gaia.



THE END

PLATO activities in Italy are funded by Italian Space Agency

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

agenzia spaziale italiana