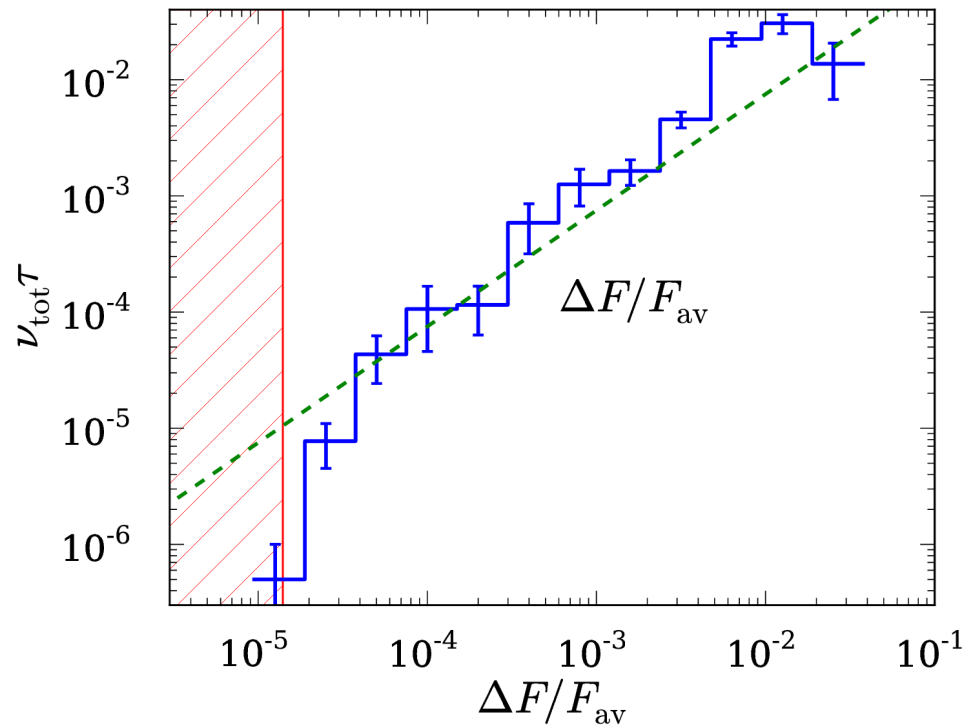# Superflares in G, K and M Type Dwarfs from Kepler Observations

S. Candelaresi, A. Hillier, H. Maehara,
A. Brandenburg, K. Shibata
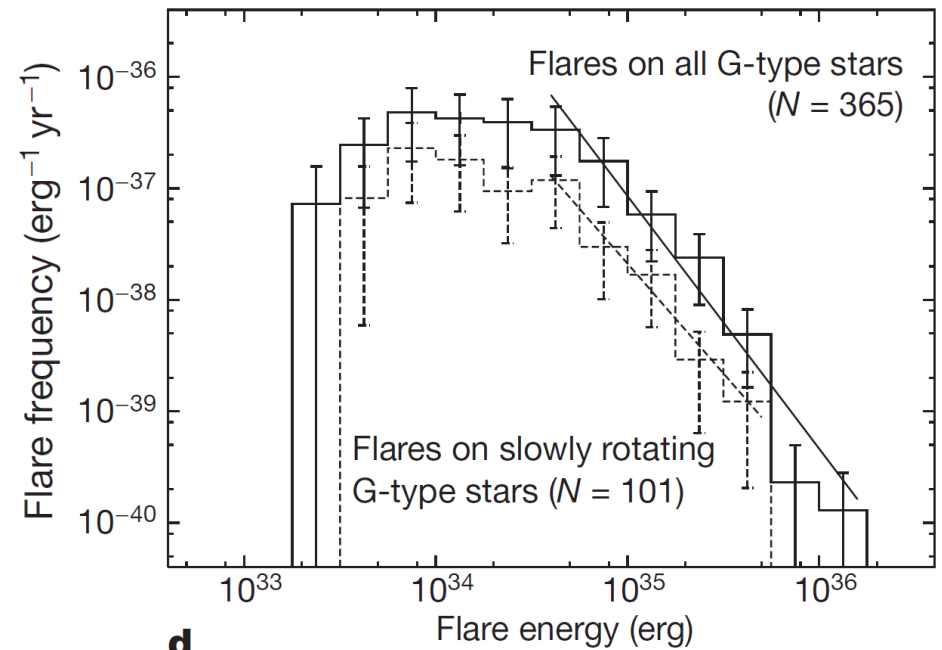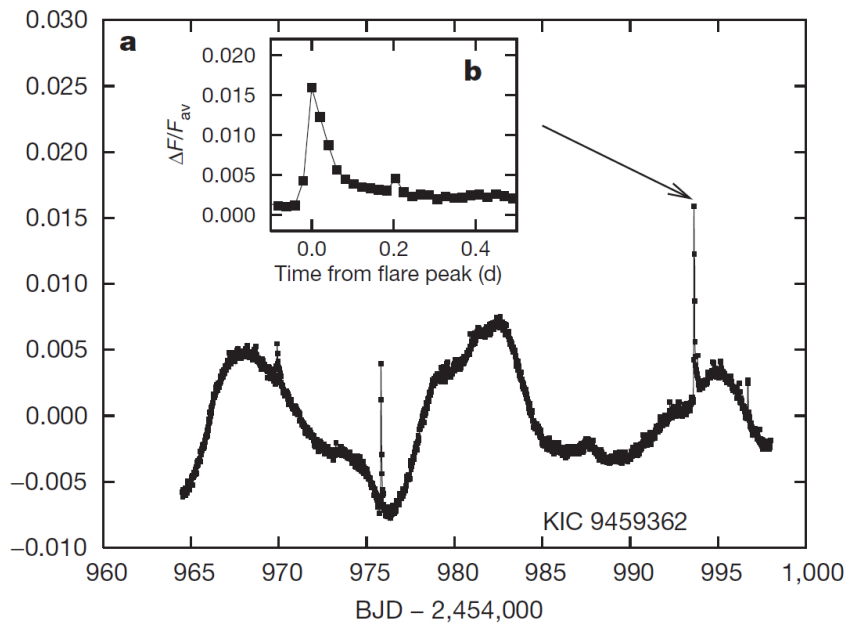
Introduction

superflare = flare with $E > 5 \times 10^{34} \text{erg}$

Use Kepler white light curves.

$$\mathrm{d}N/\mathrm{d}E \propto E^{-\alpha}$$

long cadence: 30 min

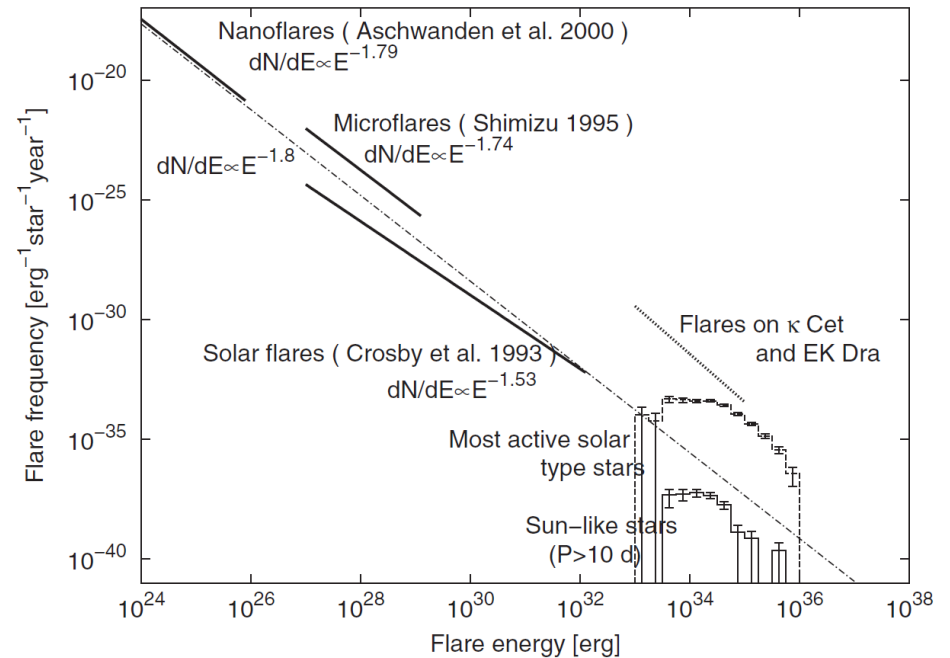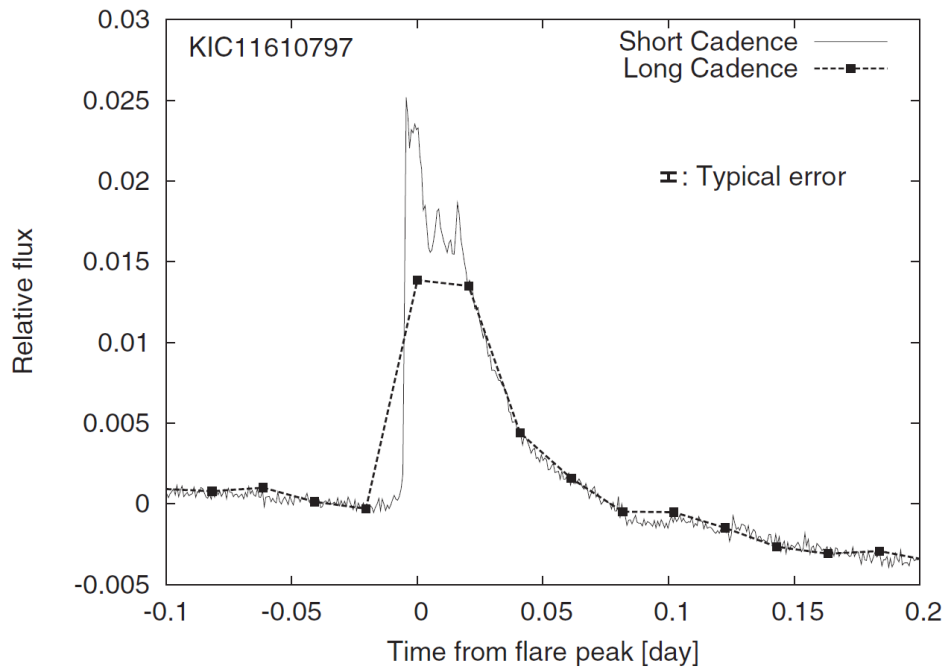148 stars with 365 superflares

(Maehara et al. 2012)

G-type stars
$\alpha = 2.3$

Introduction

short cadence: 1 min
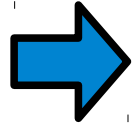
➡ Detect flares below $5 \times 10^{34} \mathrm{erg}$.

(Shibayama et al. 2013)
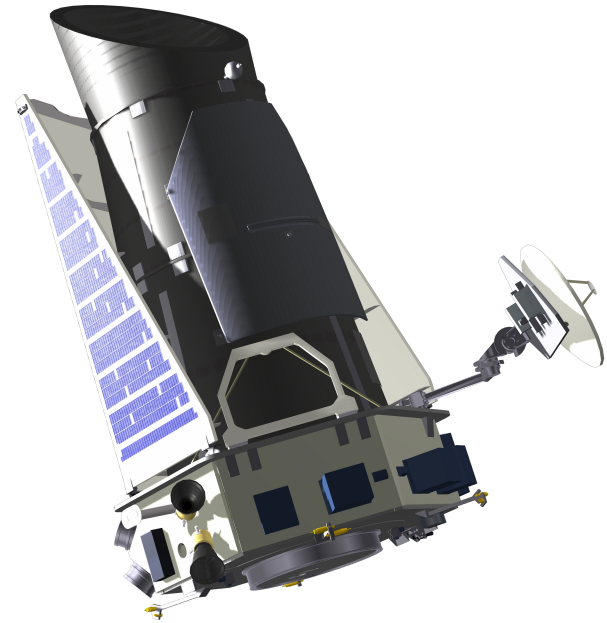
279 stars with 1547 superflares

G-type stars
$\alpha = 2.2$

Improved detection: Bayesian method (Pitkin et al. 2014)

Kepler Sample

- total observed stars: 117,661

- G, K and M-type stars

- Quarters 0 to 6

- 380 flaring stars

- 1690 superflare events

(Koch et al. 2010)

- What environments favor flares?

- Can we reproduce the observations with dynamo calculations?

Correlation Analysis

ν = superflare frequency (number of flares per day)

$\nu\tau$ = normalised superflare frequency

τ = convective turnover time

ν_{tot} = superflare frequency including all stars (for binned averages)

$\Delta F/F_{\mathrm{av}}$ = relative flux variation (proxy for spot coverage)
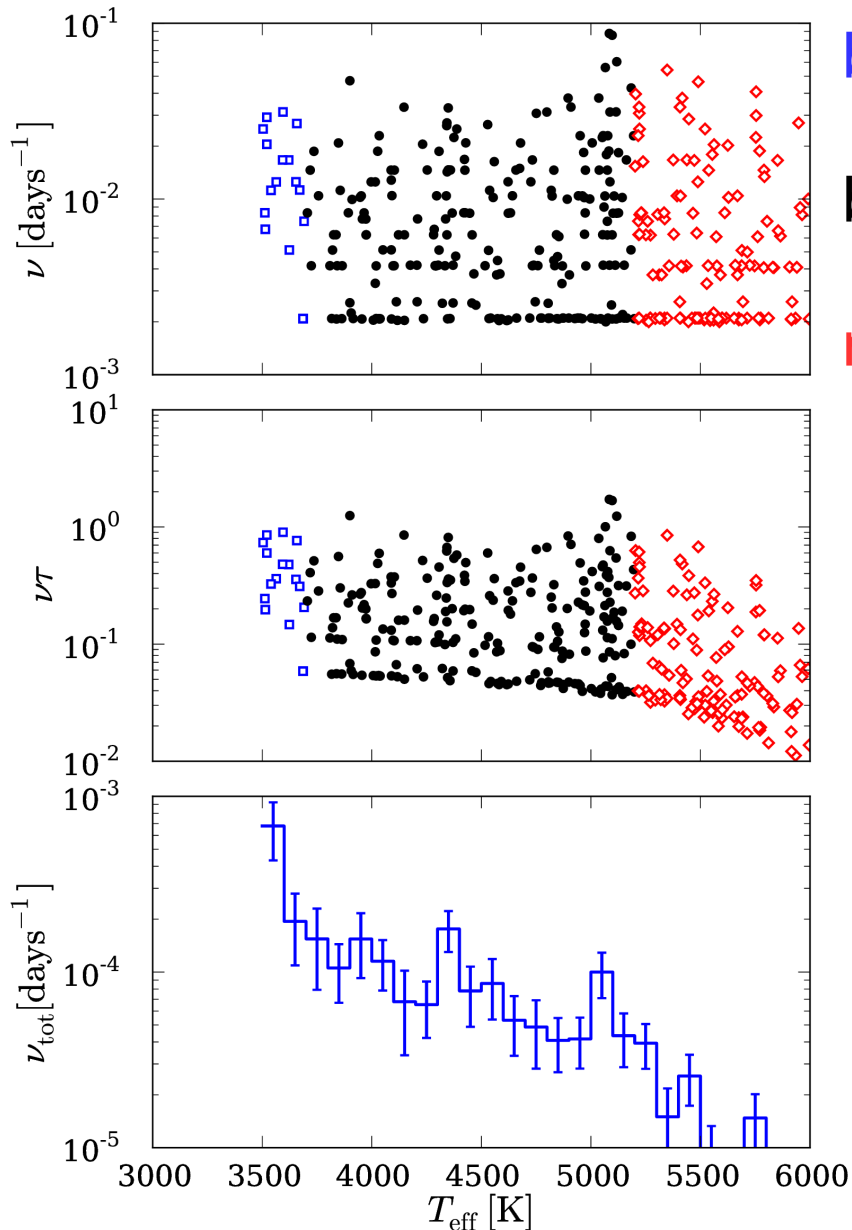
T_{eff} = effective surface temperature

P_{rot} = rotation period [days]

$\mathrm{Ro}^{-1} = \tau/P_{\mathrm{rot}}$ = inverse Rossby number

$\Delta F/F_{\mathrm{av}}$

Temperature Dependence

blue squares:
  M-type stars, $2,400\text{K} < T < 3,700\text{K}$
black dots:
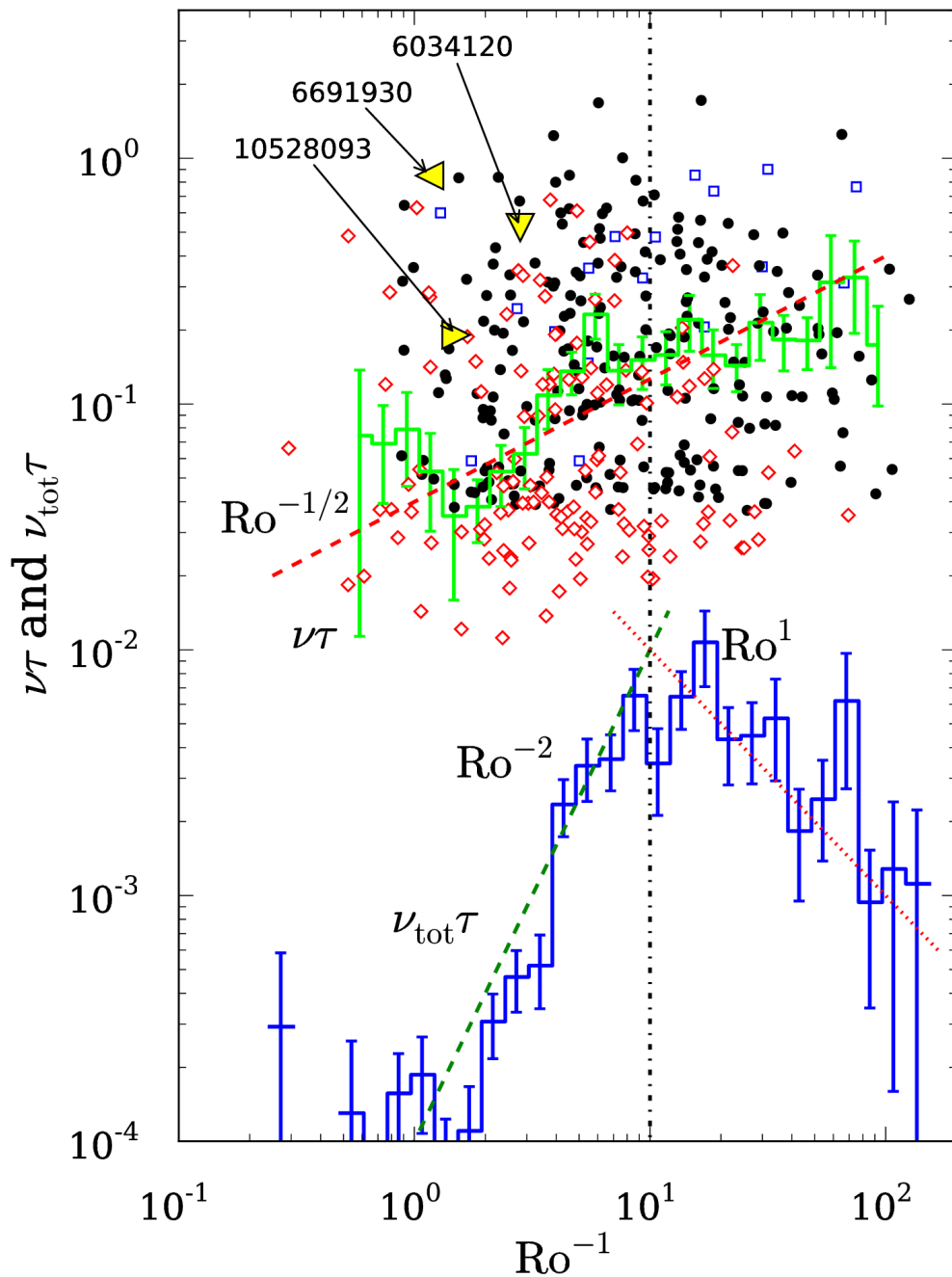 K-type stars, $3,700\text{K} < T < 5,200\text{K}$
red diamonds:
  G-type stars, $5,200\text{K} < T < 6,000\text{K}$

No correlation visible by observing only flaring stars.

Decreasing flaring rate with increasing temperature.

Model calculations by Kitchatinov and Olemskoy (2011) show an increase of eddy diffusion with T.
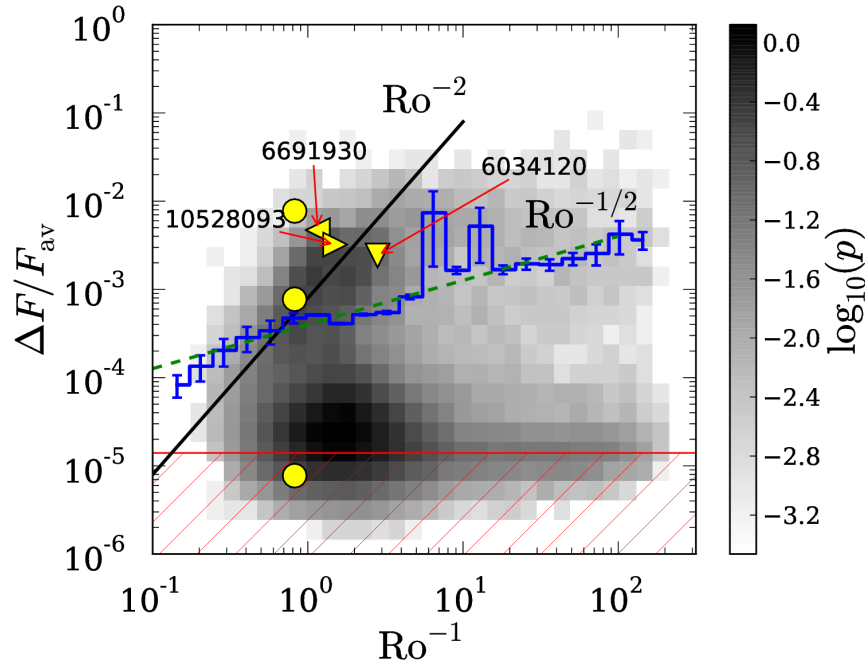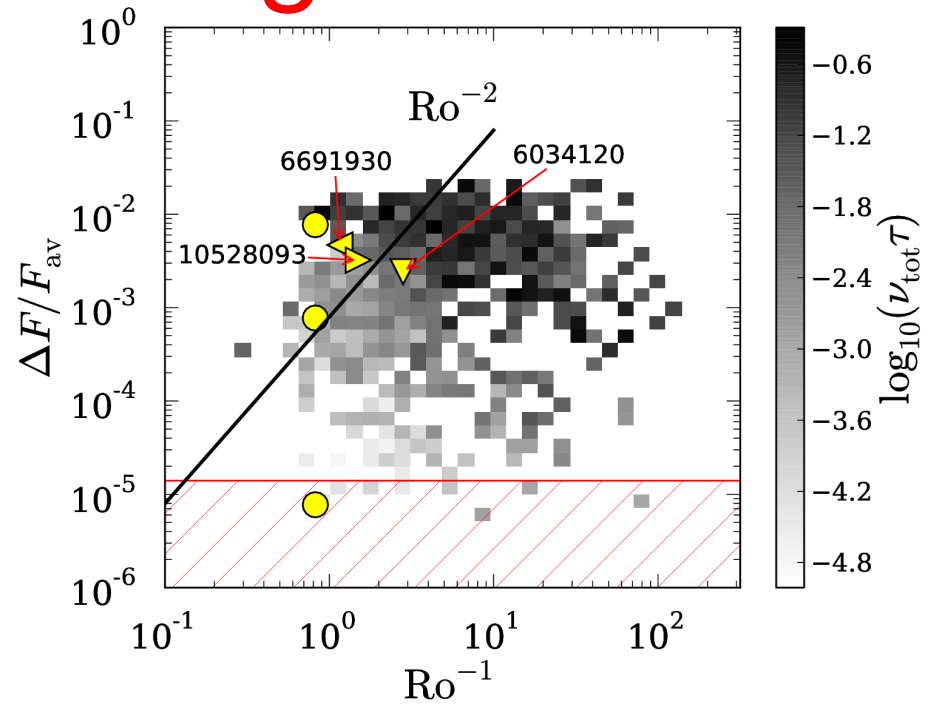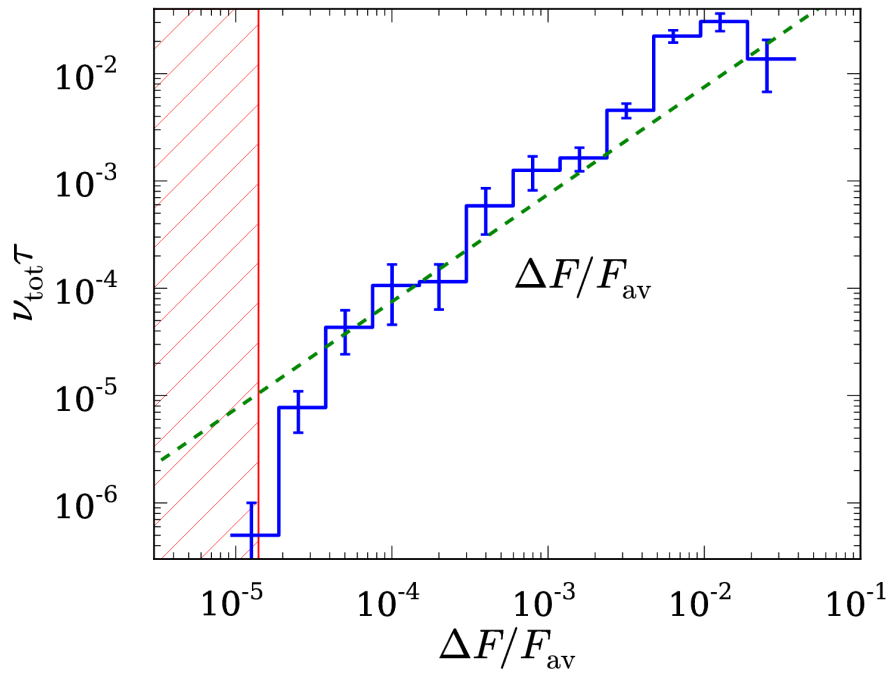
Rotation Rate

Increasing flaring rate with increasing rotation rate.

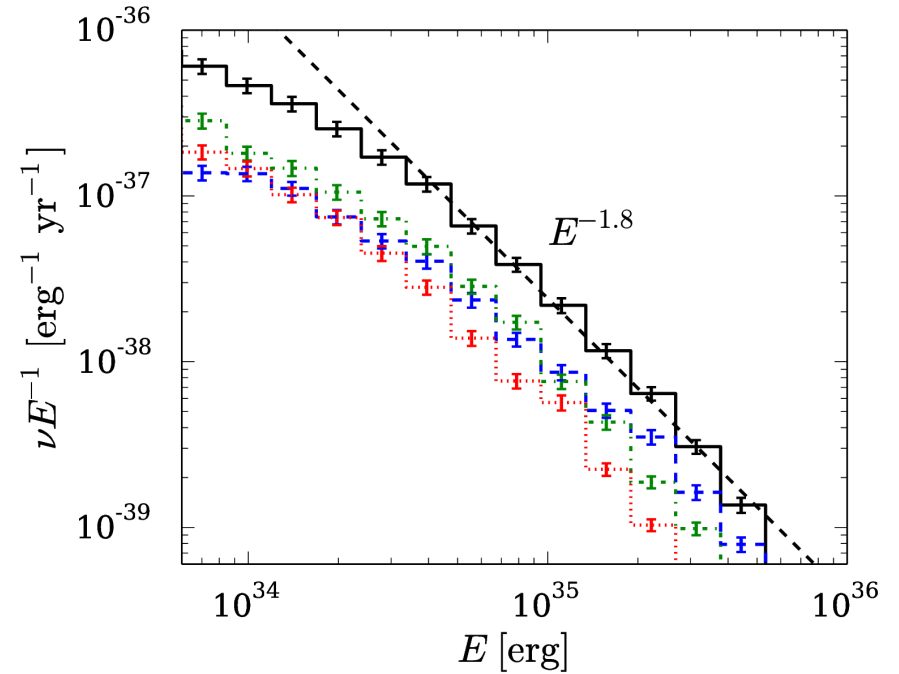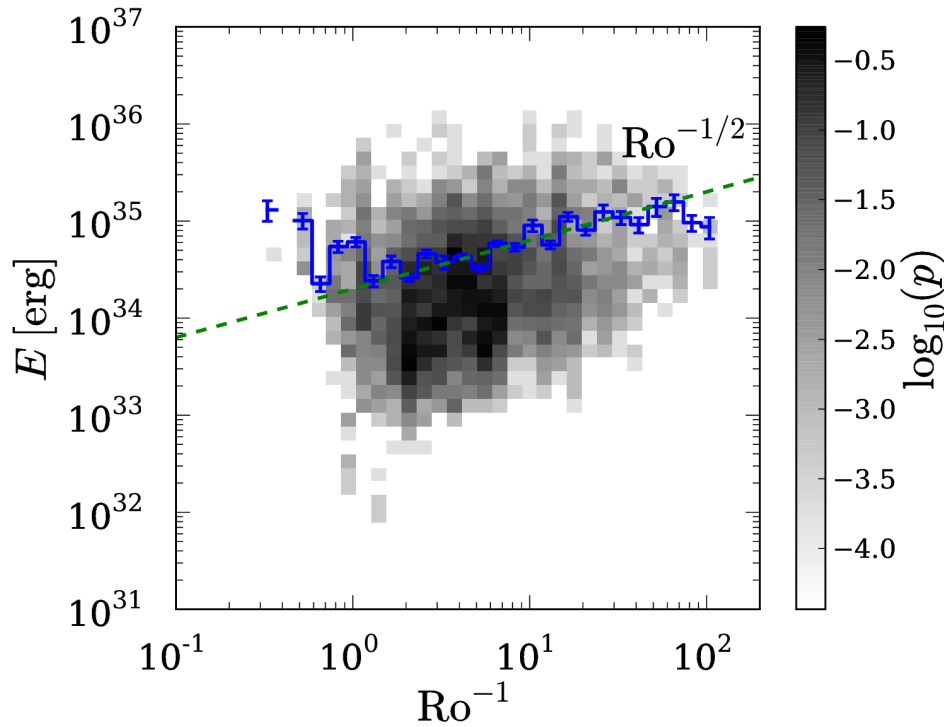Increasing total flaring rate with increasing rotation rate.

Increase of Ro^{-2} is compatible with an increase of X-ray luminosity (Pizzolato et al. 2003; Wright et al. 2011). They find a flattening at $\mathrm{Ro}^{-1} \approx 10$.

Spot Coverage

Magnetic fields induce flares. Higher spot coverage leads then to more frequent flares.

Flare Energy

Average flare energy increases with rotation rate.
Shear increases the dynamo number and the amplification of the magnetic field.

We reproduce previous distributions of the flare energies independently of the Rosssby number (red: $\mathrm{Ro}^{-1} < 2.5$, green: $7 > \mathrm{Ro}^{-1} > 2.5$, blue: $\mathrm{Ro}^{-1} > 7$).

Dynamo Model

Turbulent driven alpha-shear dynamo.
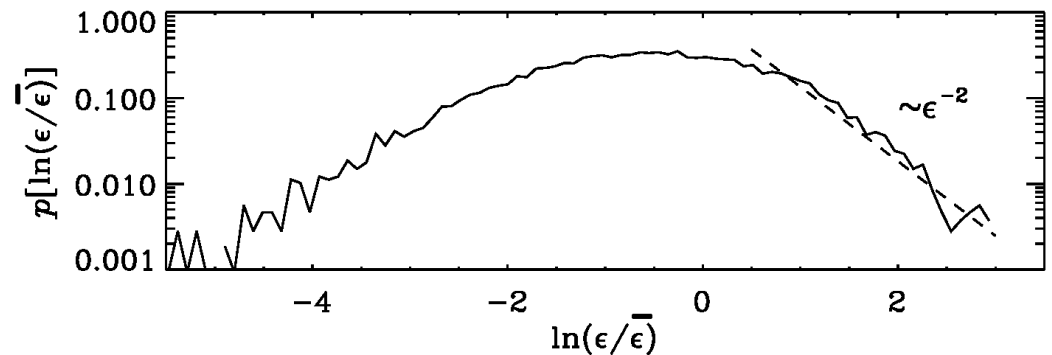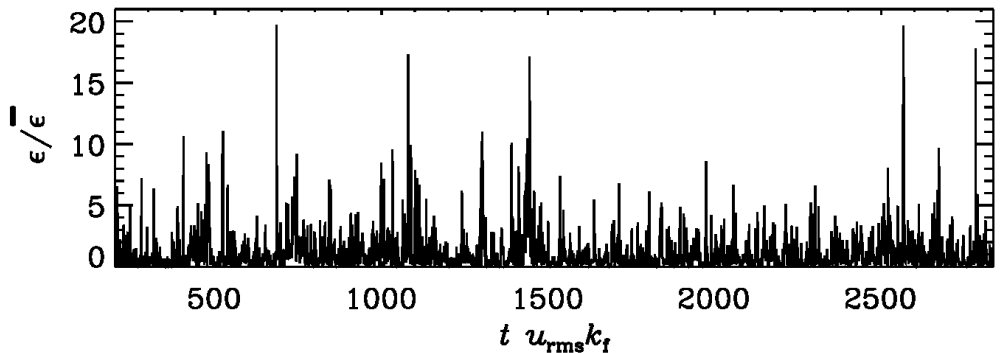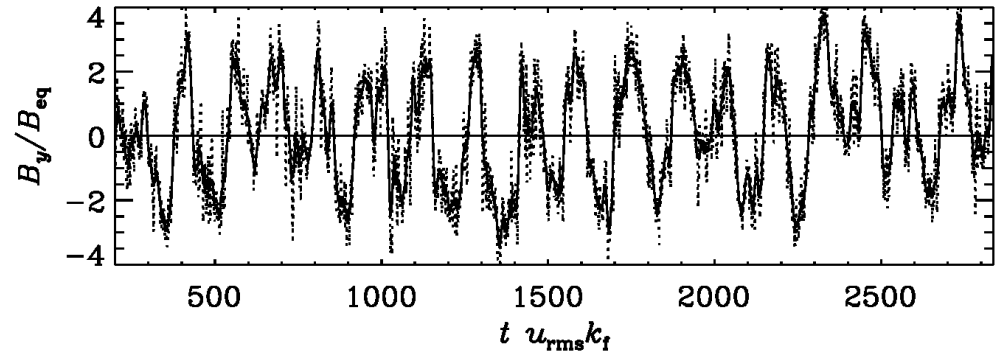
Dynamo number:
$$D = C_\alpha C_S$$
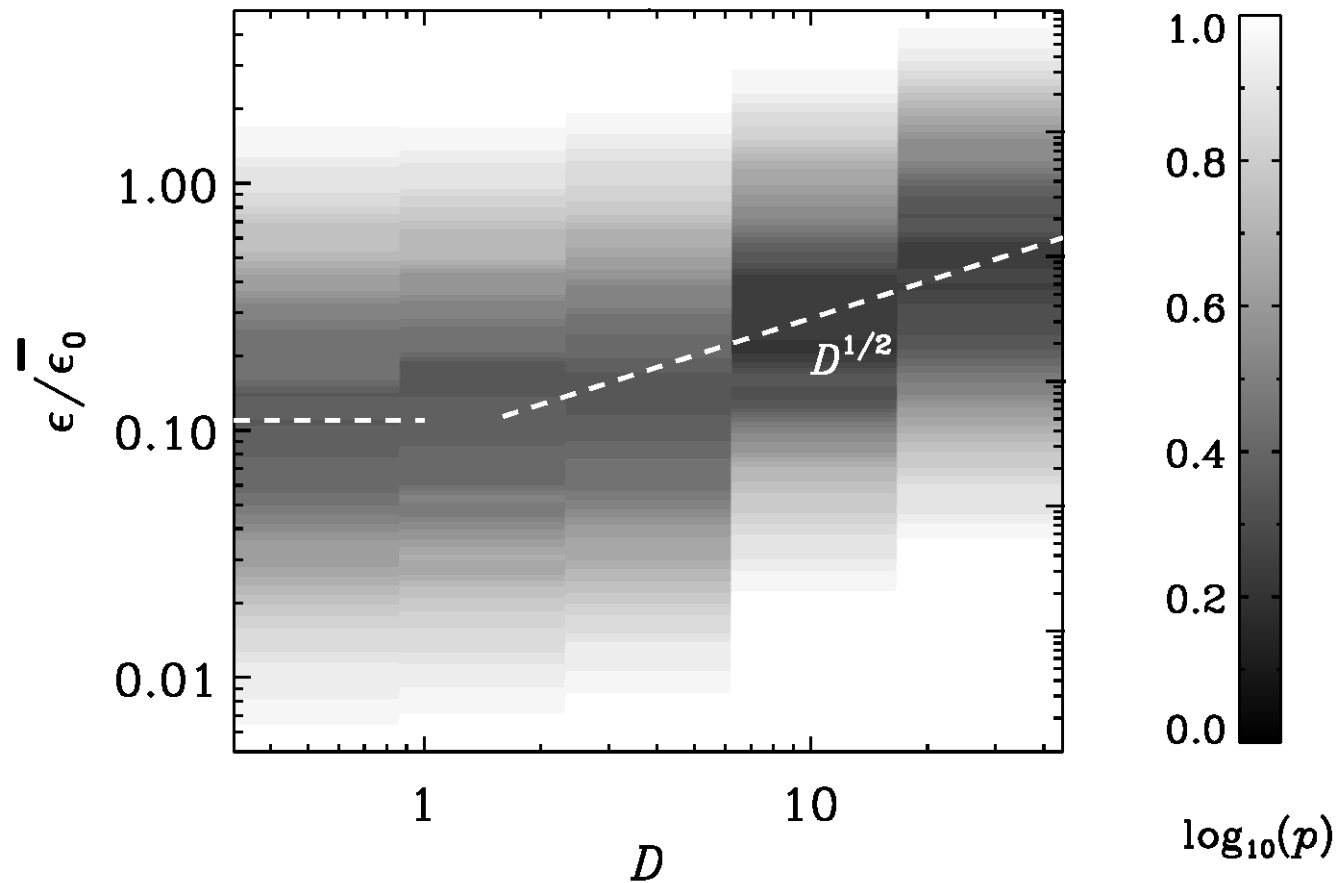
Relative kinetic helicity:
$$C_\alpha = \alpha / \eta_t k_1$$

Shearing rate:
$$C_S = S / \eta_t k_1^2$$

Measure flares through magnetic energy (Ohmic) dissipation $\epsilon / \bar{\epsilon}_0$.

Dynamo Model

$E \propto \mathrm{Ro}^{-1/2}$ is reproduced in dynamo calculations with $\epsilon/\bar{\epsilon}_0 \propto D^{1/2}$.
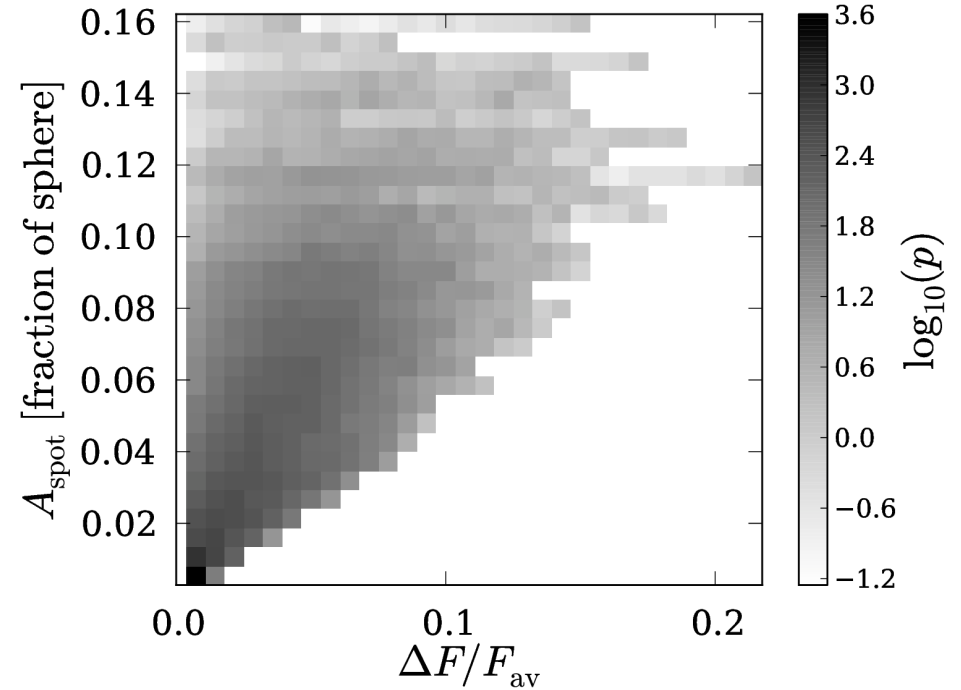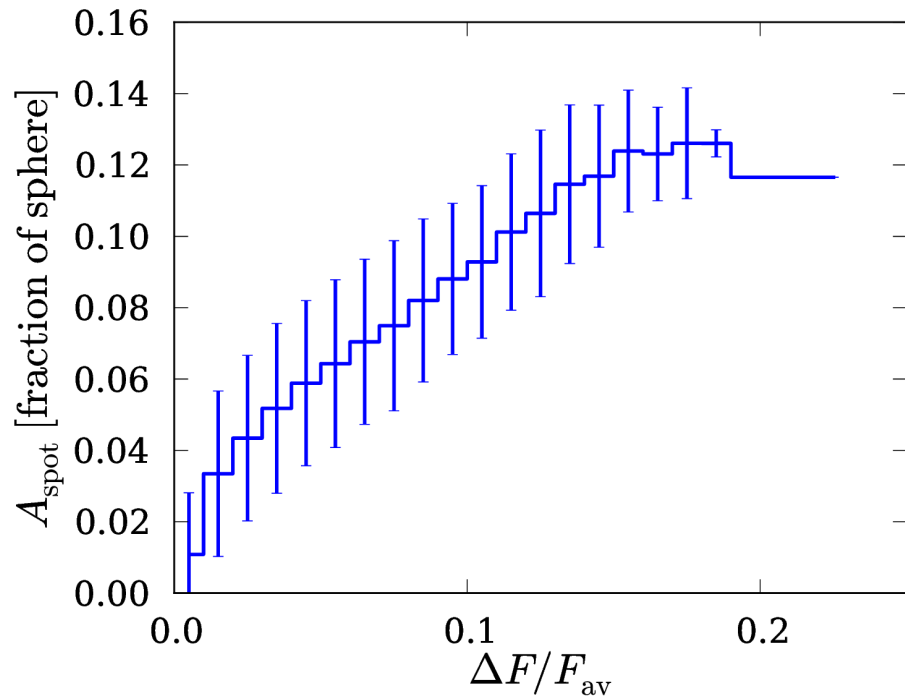
Conclusions

- Superflare rates decrease with effective temperature.

- Rates increase with rotation rate up to a saturation point.

- Average flare energy increases with rotation rate.

- Rotation rate enhances magnetic activity.

- Fast rotators show higher spot coverage.

- Magnetic fields are essential for flares.

- Flare energy characteristics reproduced in dynamo calculations.

(Candelaresi et al. 2014)   simon.candelaresi@gmail.com

Spot Coverage of the Sun
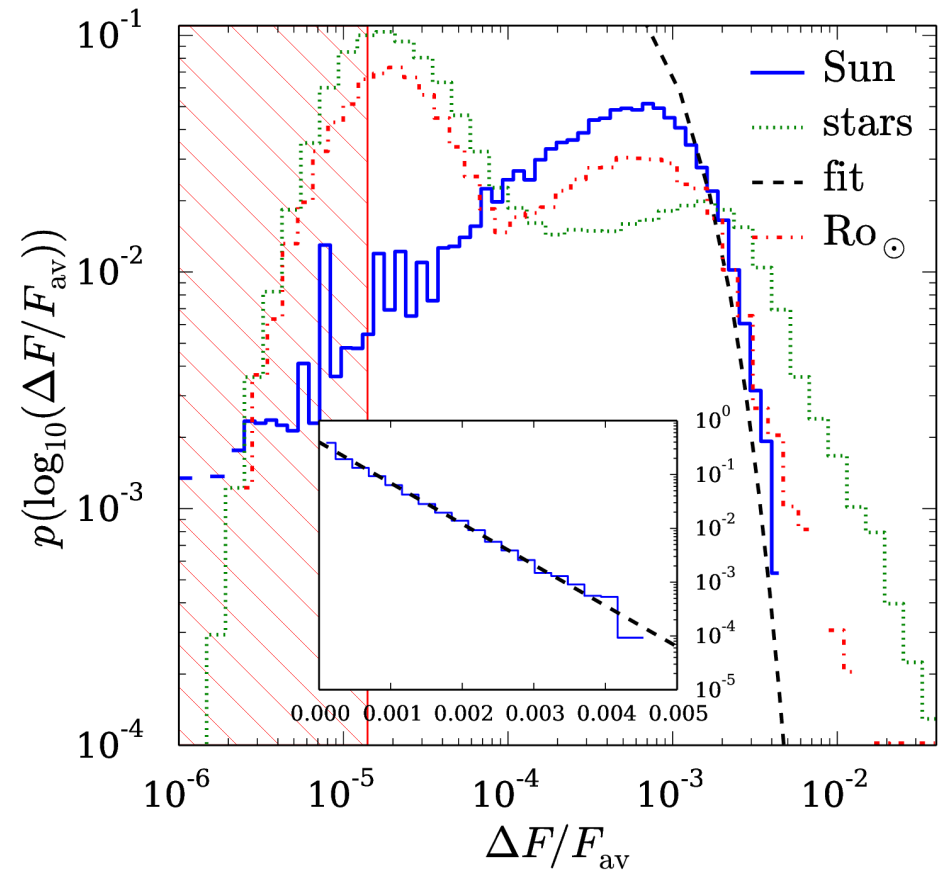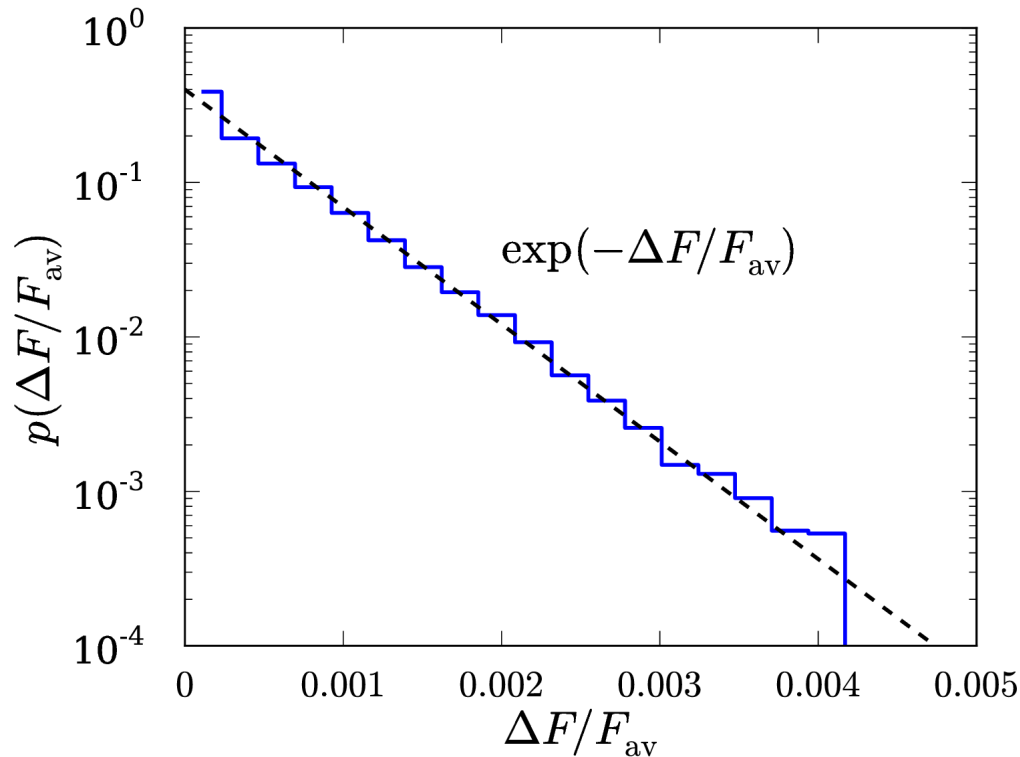
Sun data between 1874 May and 2013 July from Hathaway (http://solarscience.msfc.nasa.gov/greenwch.shtml).

Spot Modelling

Brightness variation can be used as adequate proxy for the
total spot coverage, although there is some significant spread.