The role of X-ray variability in shaping the period–radius valley

Characterising the variability of FGK stars with Gaia and XMM-Newton

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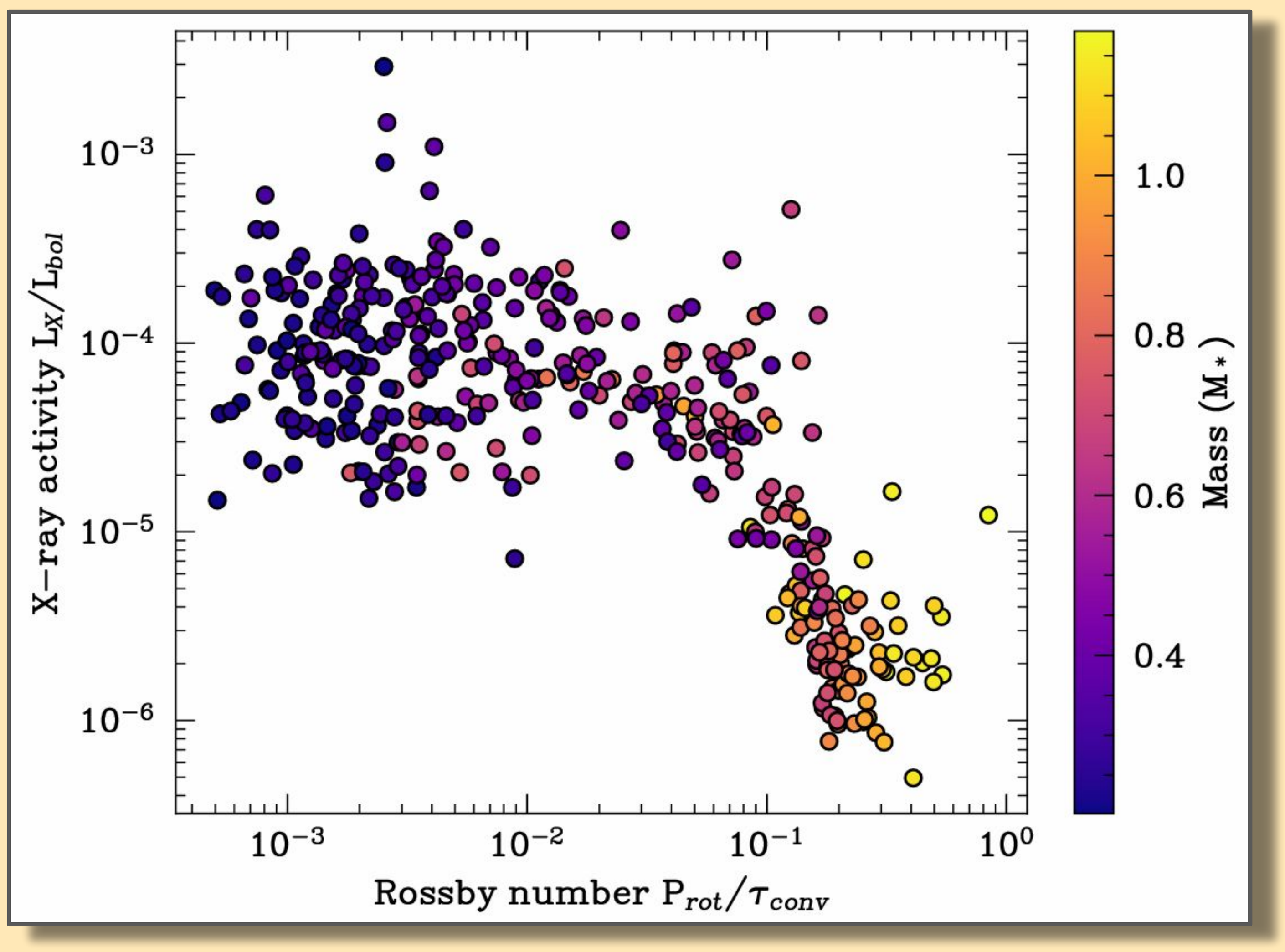

Figure 1. Rotation-activity relation of cluster stars from Godoy-Rivera+21, showing a large scatter in X-ray activities. Colour represents the stellar mass.

The Rotation-Activity Relation

- X-rays emitted by stars affect the evolution of the atmospheres of close-in exoplanets, sculpting the **radius valley** (Owen+17) and the **Neptunian desert** (Owen+18**).**
- Simulating the evaporation history of exoplanets requires knowledge of the **X-ray emission history** of their stars.
- It can be estimated from rotational evolution models, as spin period and X-ray activity are related via the **rotation-activity relation** (Wright+11).
- However, this relation has a **large scatter** in the X-rays of one order of magnitude each way (Johnstone+21, see **Figure 1**).
- What could cause this scatter?
  - Random X-ray variability (e.g. flares, activity cycles)
  - Intrinsic activity levels

The Gaia-XMM Crossmatch

- I aimed to characterised the **X-ray variability of individual stars** by crossmatching **Gaia DR3** with archival data from the X-ray telescope **XMM-Newton**.
- **Gaia** tells us:
  - Which targets are stars, their spectral type, and their distance.
- **XMM-Newton** tells us:
  - **X-ray fluxes from the last 25 years**.
  - How X-rays vary (if a star is observed multiple times).
- I obtained X-ray detections for ~6000 stars within 200 pc, with **2000 stars observed multiple times**.
- These are separated by **timescales spanning days to decades.**
- Some stars have been observed many times (10+ observations) spanning spectral types from early F to late M dwarfs (**Figure 2**).
  - A few are the target of variability studies.
  - Others happen to be in the right place (e.g. next to the Triangulum Galaxy).

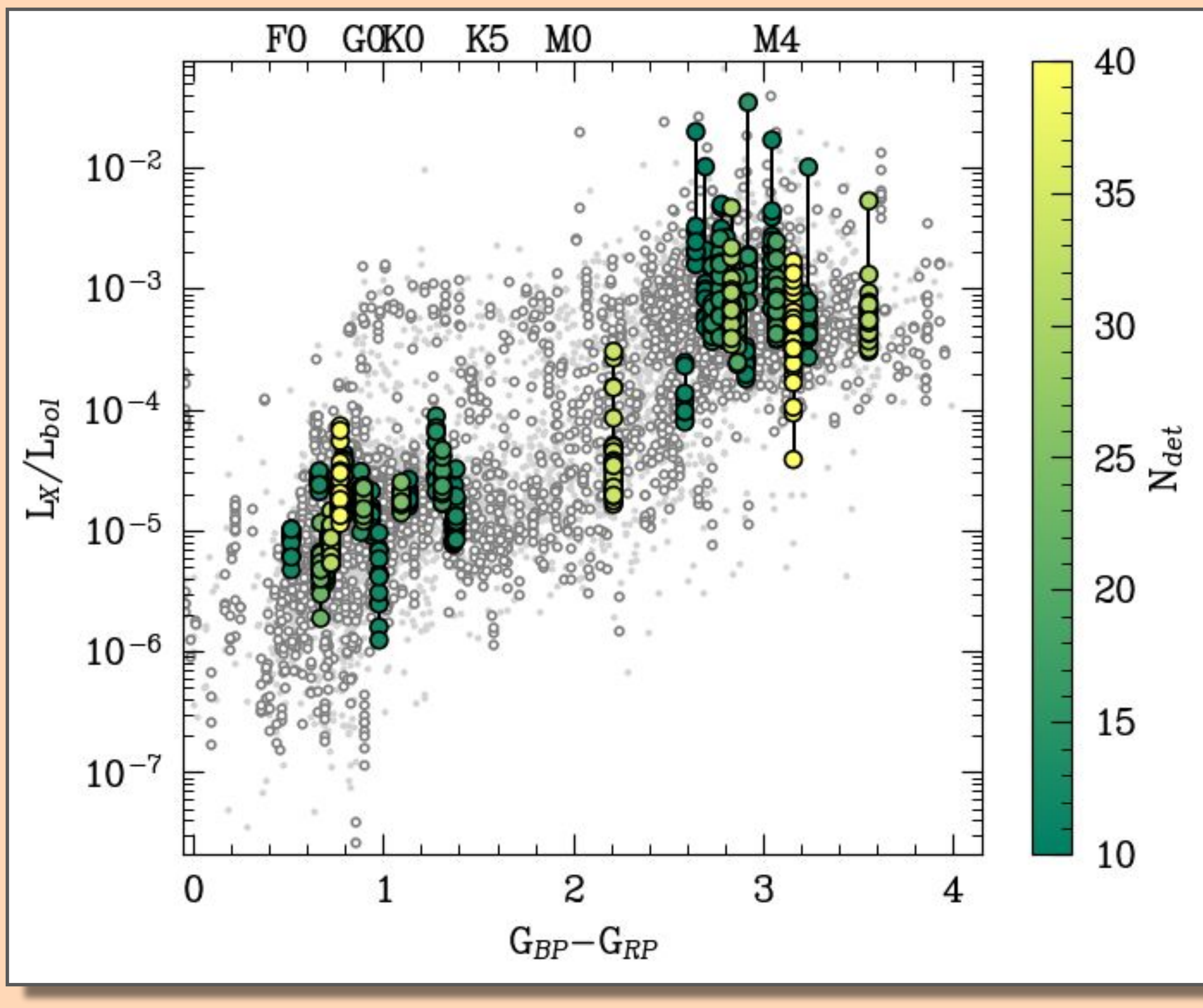

Figure 2. X-ray activity vs Gaia colour index for stars in our sample with multiple X-ray observations. Stars with 10+ observations are highlighted.

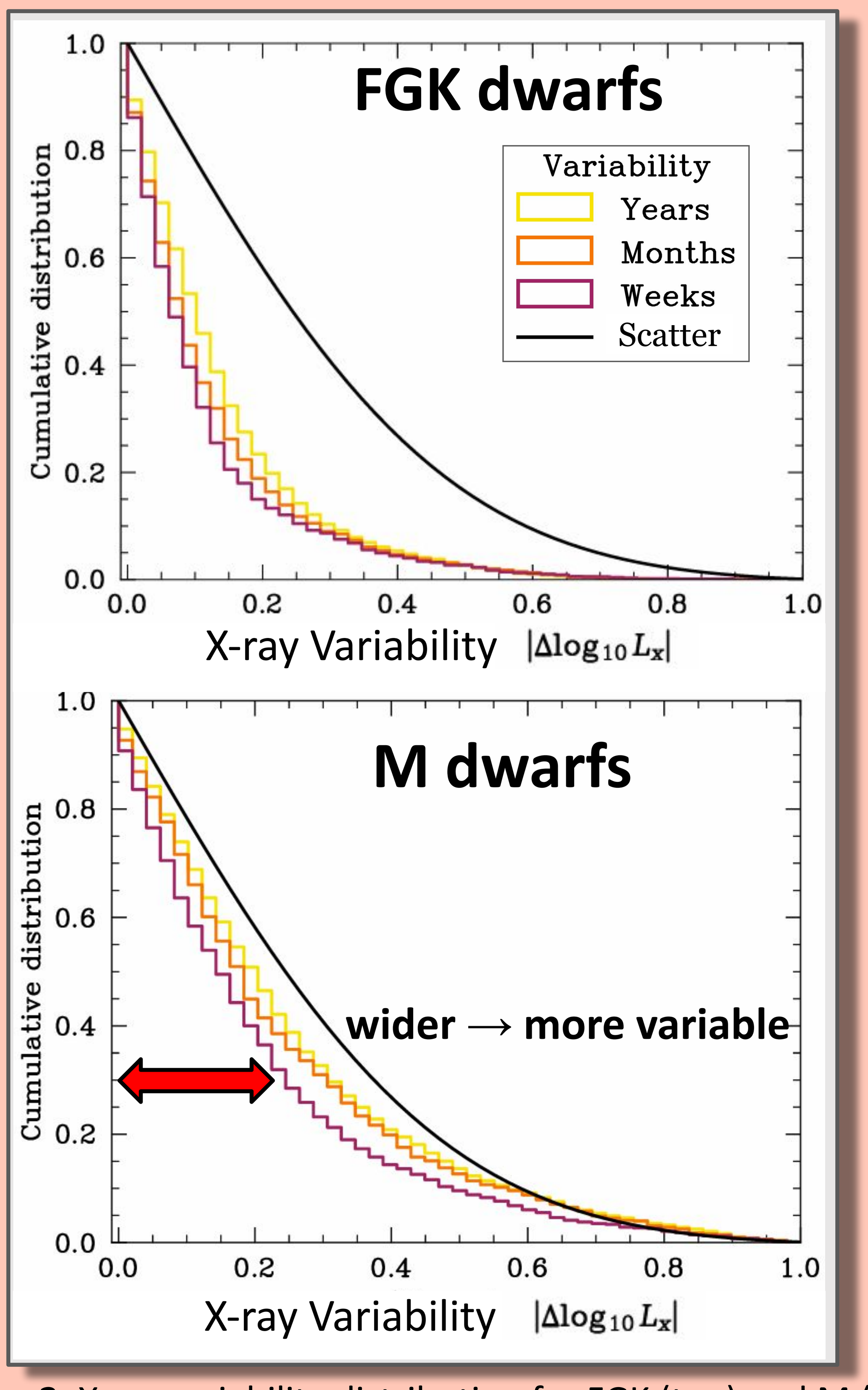

Figure 3. X-ray variability distribution for FGK (top) and M (bottom) stars on timescales from weeks to decades, compared to the scatter.

The Variability of FGK & M Stars

- How to determine **X-ray variability**:
  1. Take **pairs of observations** from the same star.
  2. Their ratios are the **variability level** and the time between them is the **timescale.**
- In **Figure 3**, I compare the distribution of ratios with the observed X-ray scatter.
- I found:
  - **FGK stars** vary **half as much** as the scatter, only by a factor of 2-3.
  - **M dwarfs match the scatter** in their variability.
  - **All stars reach** most of **their variability level in weeks**, and only increase marginally in decades.
- A one-order-of-magnitude **scatter is not consistent with** the variability of **FGK stars**!
- This suggests FGK stars may have **intrinsic activity levels**, where their X-ray activity is consistently above/below the mean of the rotation-activity relation (see **Fig. 1**).
- Moreover, recent studies of **open clusters** with **Gaia membership lists** find **a lower X-ray scatter for FGK stars compared to M dwarfs** (Núñez+22).

References

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