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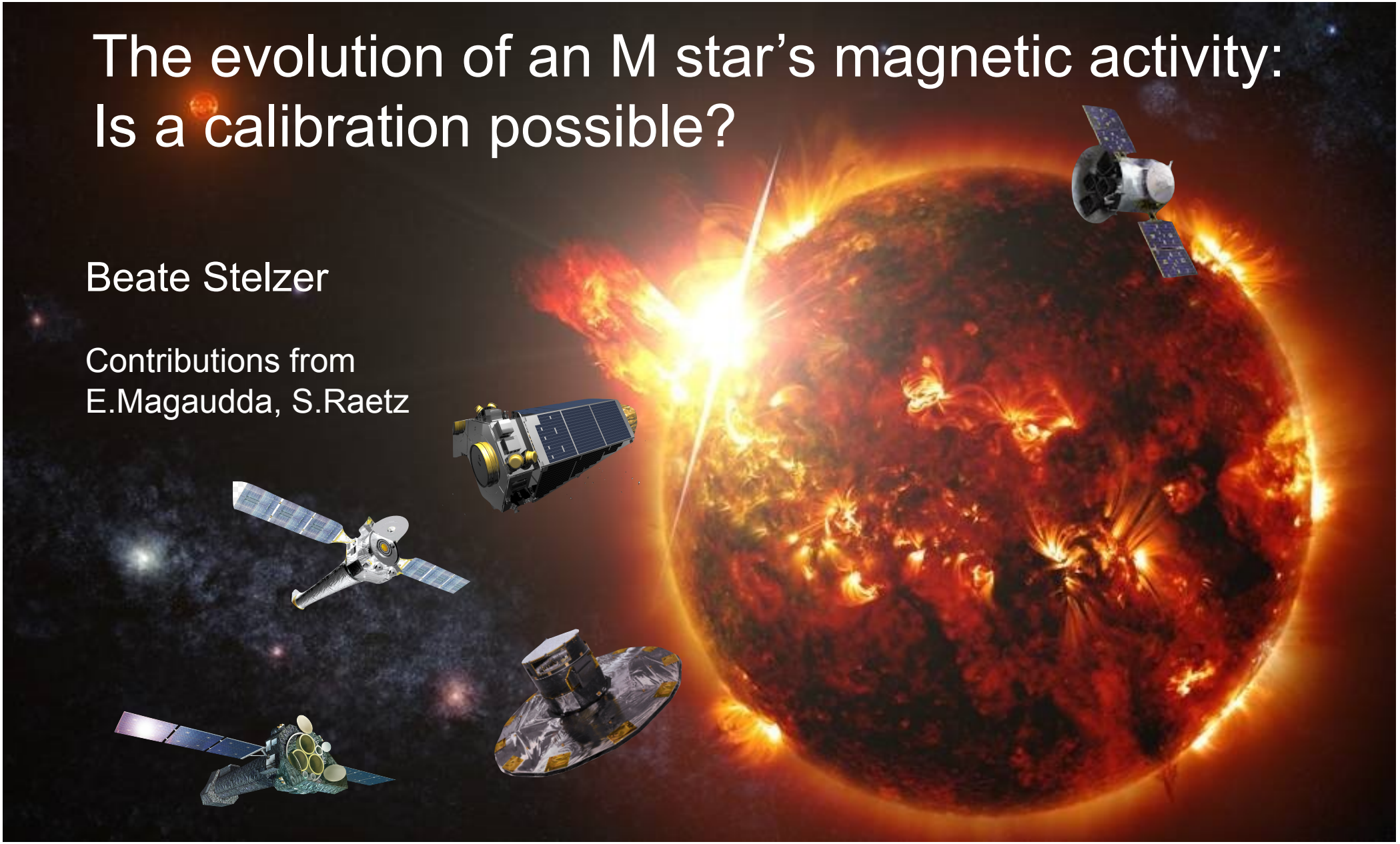
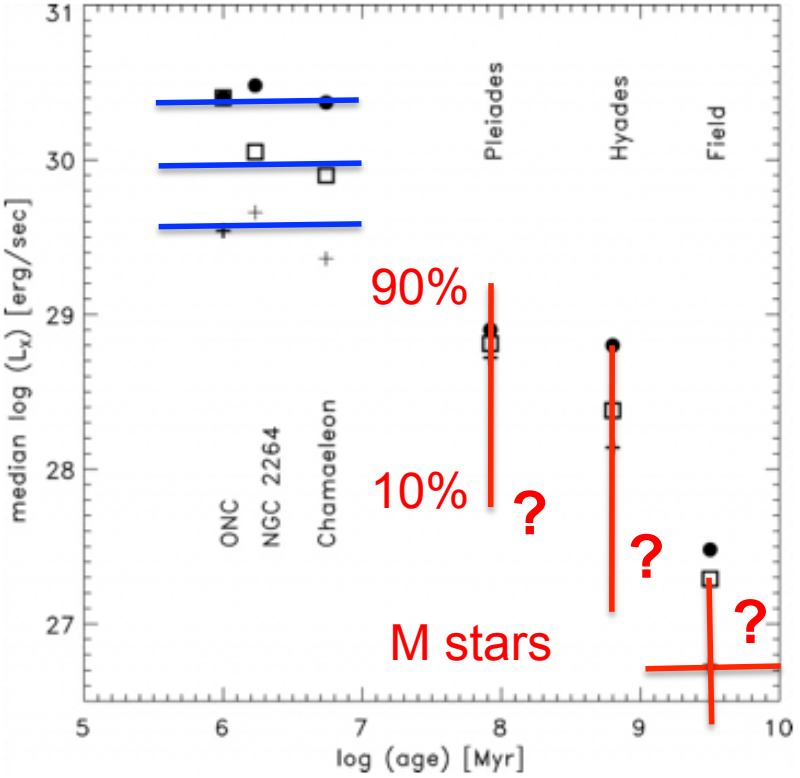
The evolution of an M star's magnetic activity: Is a calibration possible?

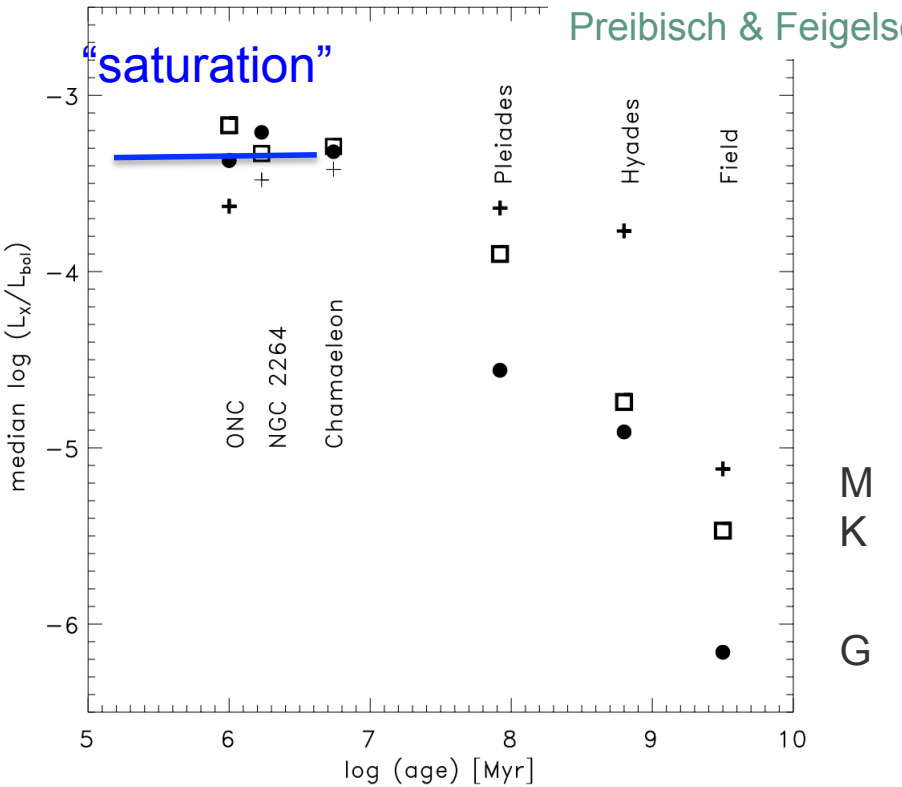
Beate Stelzer

Contributions from
E.Magaudda, S.Raetz



State-of-the-art age – activity relation:





Preibisch & Feigelson (2005)

Mass dependent "saturation" at young ages; X-rays drop by 3 dex from 10Myr to Gyrs

But: X-ray luminosities from ROSAT:
* **incomplete** at the faint end, i.e. **for old age and SpT M**
* only available for **field stars without known age**

Why worry about magnetic activity of M dwarfs ?

(A) a proxy for magnetic fields (i.e. the stellar dynamo)

(B) influence on the chemistry in exoplanet atmospheres

(C) evaporation of exoplanet atmospheres

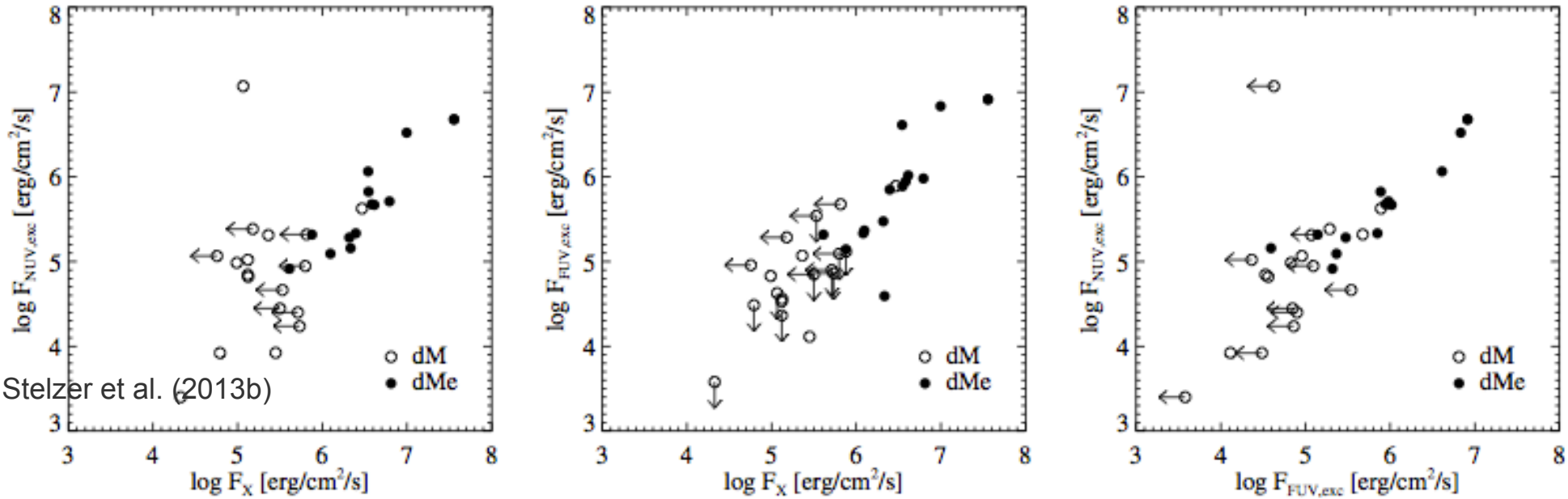
Activity is a key parameter
in the assessment of habitability of close-in planets

Why X-rays as a proxy for magnetic activity ?

Study of UV and X-ray emission of M dwarfs within 10pc (**"10pc sample"**)

Stelzer et al. (2013)

NUV (GALEX): ~ 180 – 280 nm *FUV (GALEX): ~ 135 – 180 nm* *X-rays (ROSAT): ~ 0.1-2.4 keV*

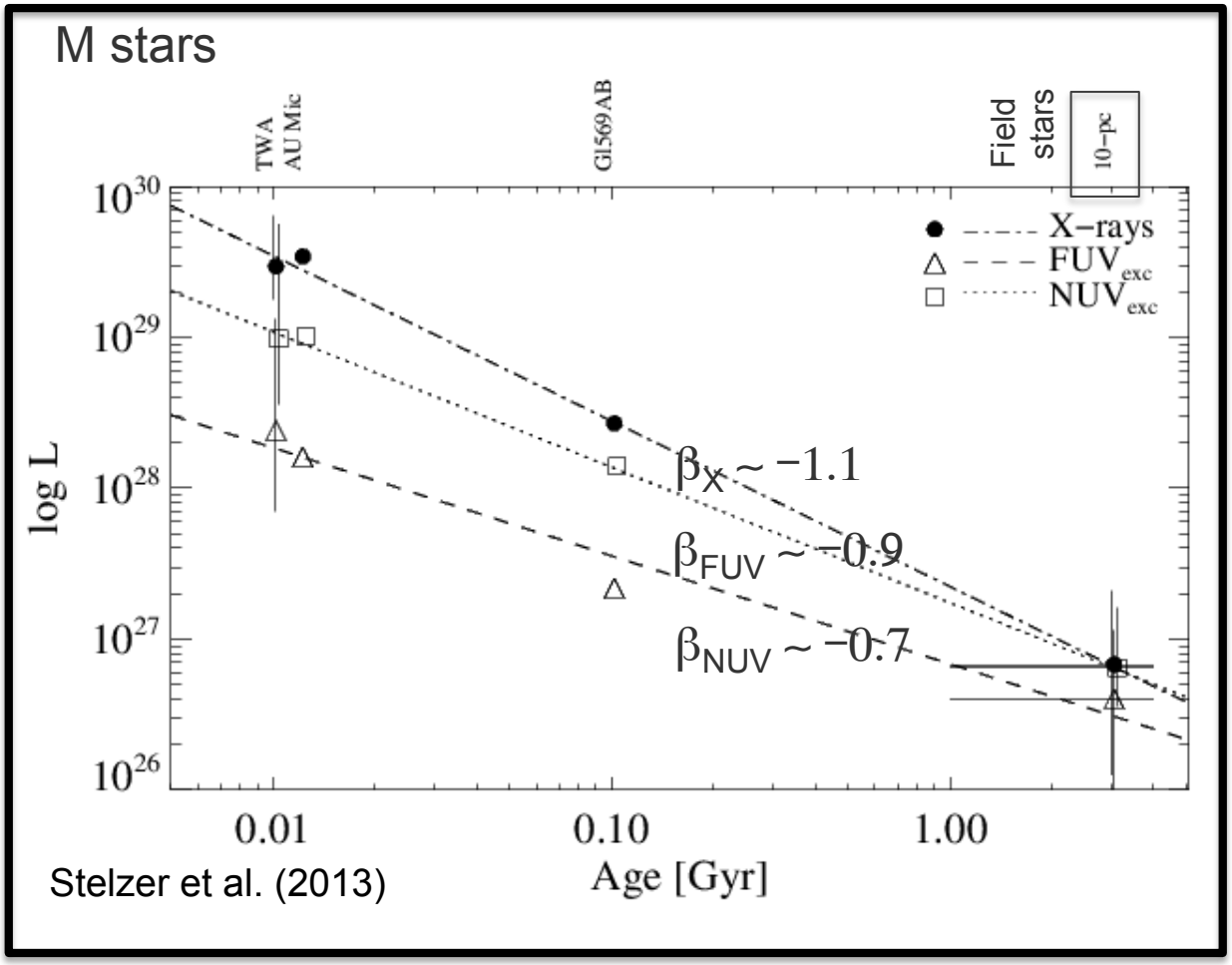


Stelzer et al. (2013b)

Many stars with no Hα emission are detected in X-rays
→X-ray and UV are more sensitive tracers of activity than Hα

X-rays easier to measure than UV

Recent studies of the **age evolution of X-ray activity:**



Stelzer et al. (2013)

GALEX UV + ROSAT X-ray study for:

* "10pc sample" (field star ages)
* M dwarfs in TWA (10Myr)

→

** high-energy emission drops by 3 dex from 10Myr to Gyrs*

** age decay faster at shorter λ*

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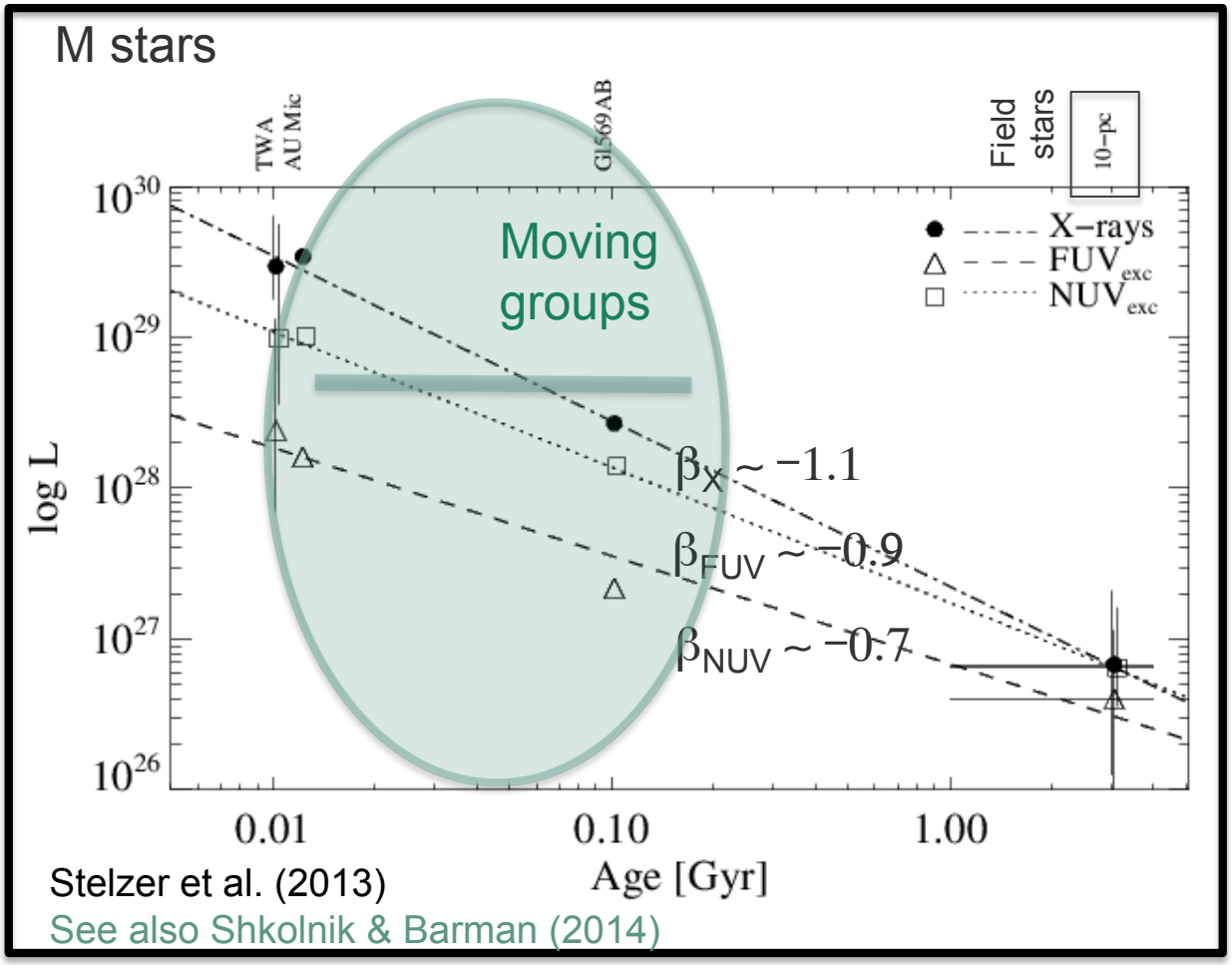

Stelzer et al. (2013)
See also Shkolnik & Barman (2014)

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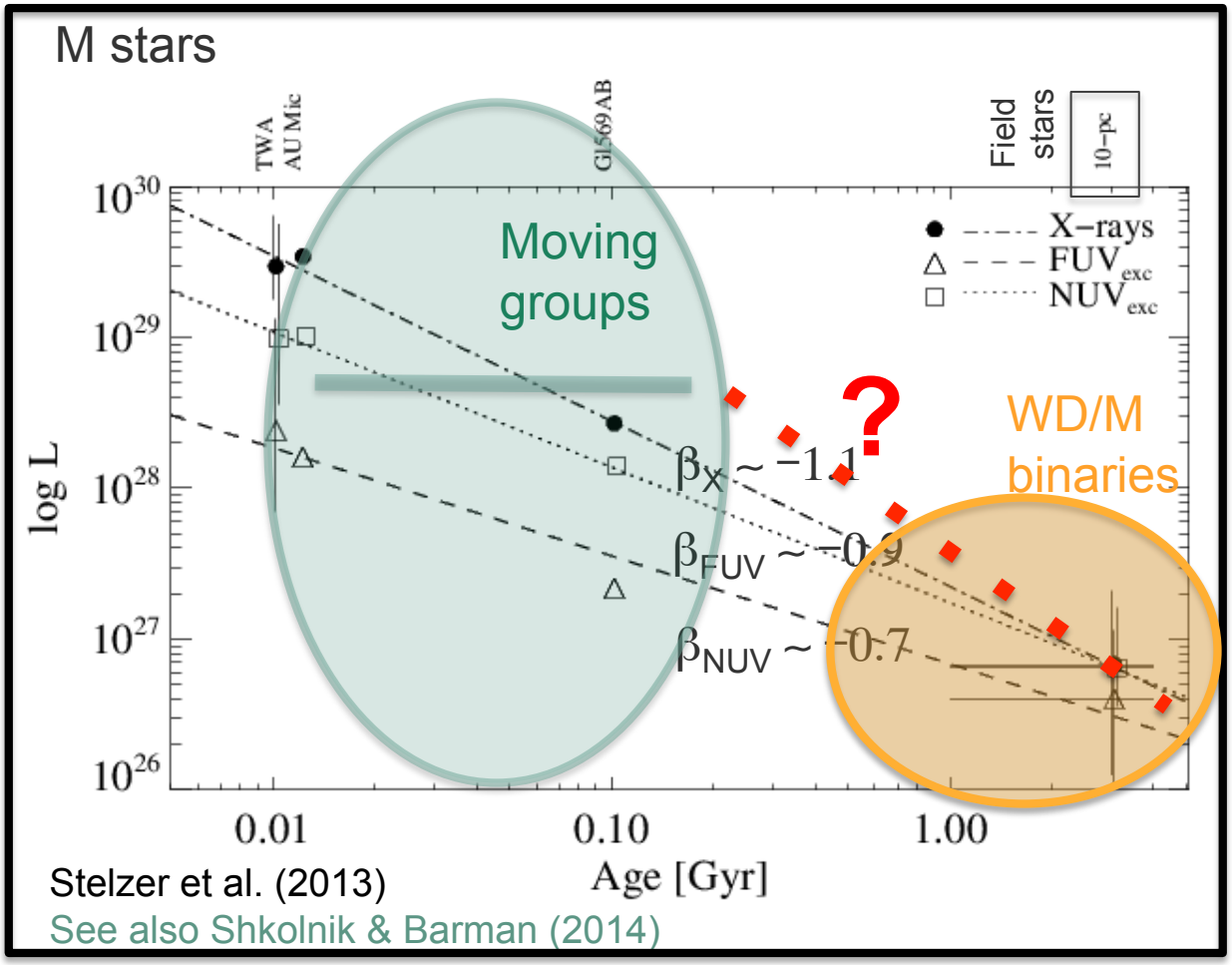


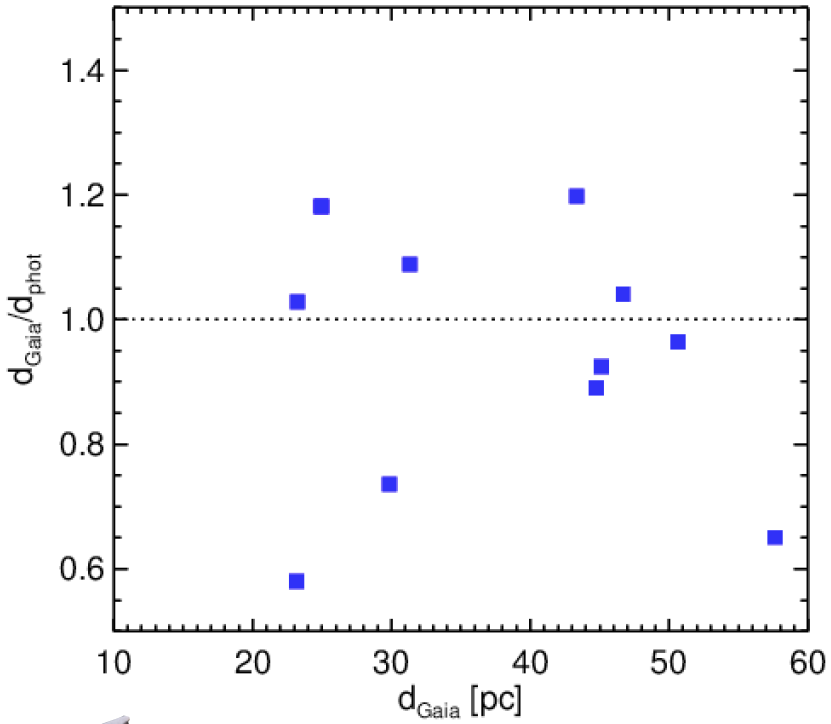
Stelzer et al. (2013)
See also Shkolnik & Barman (2014)

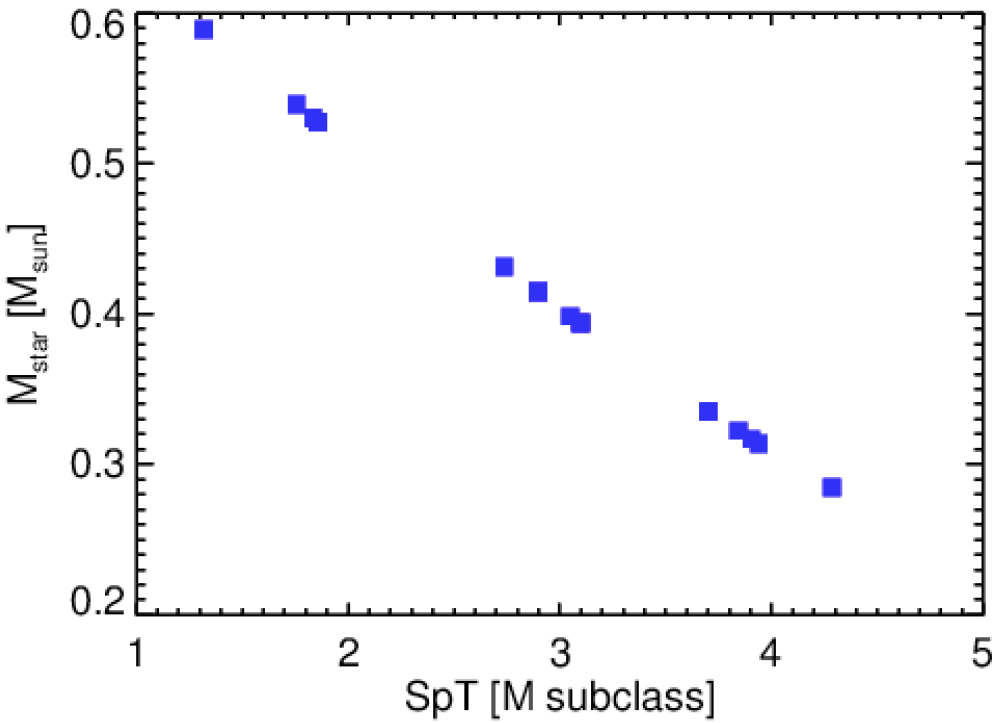
How to constrain the evolution of X-ray and UV luminosity at ages > few 100 Myrs ?

Approach:
Use White Dwarfs in resolved binaries with M dwarfs as a chronometer

WD ages: progenitor + cooling M dwarf …. assumed coeval

M dwarf (companions to WDs): Sample properties

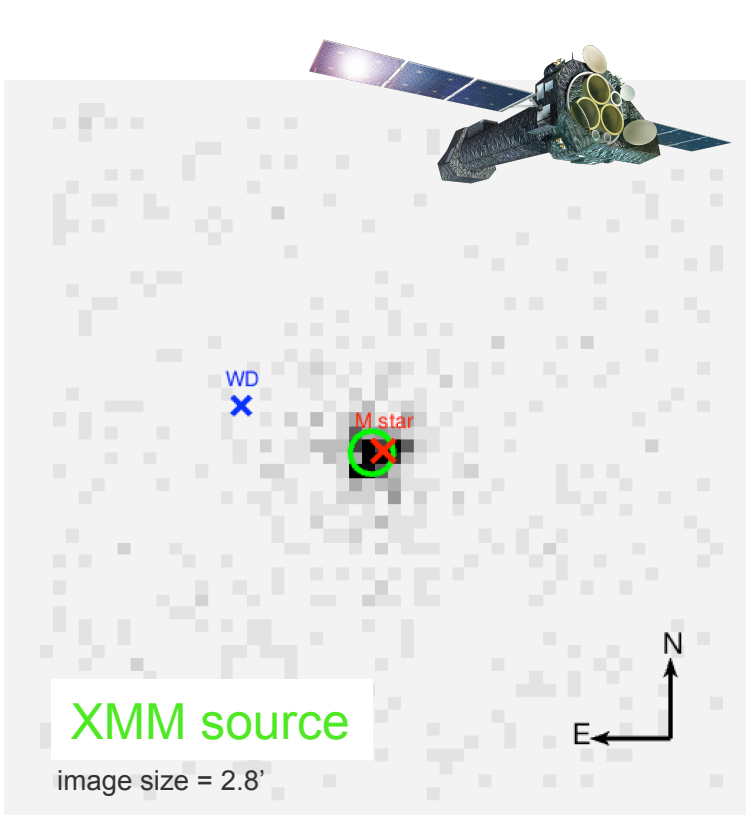


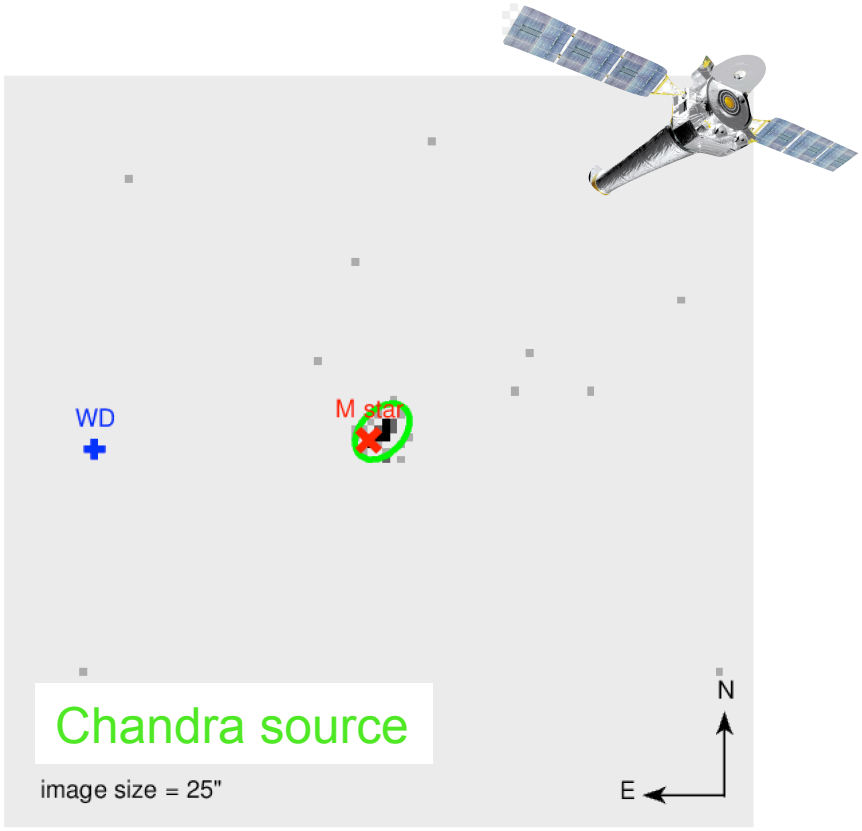


Validated Gaia distances for all but 2 M dwarfs

Early- to mid-M SpT

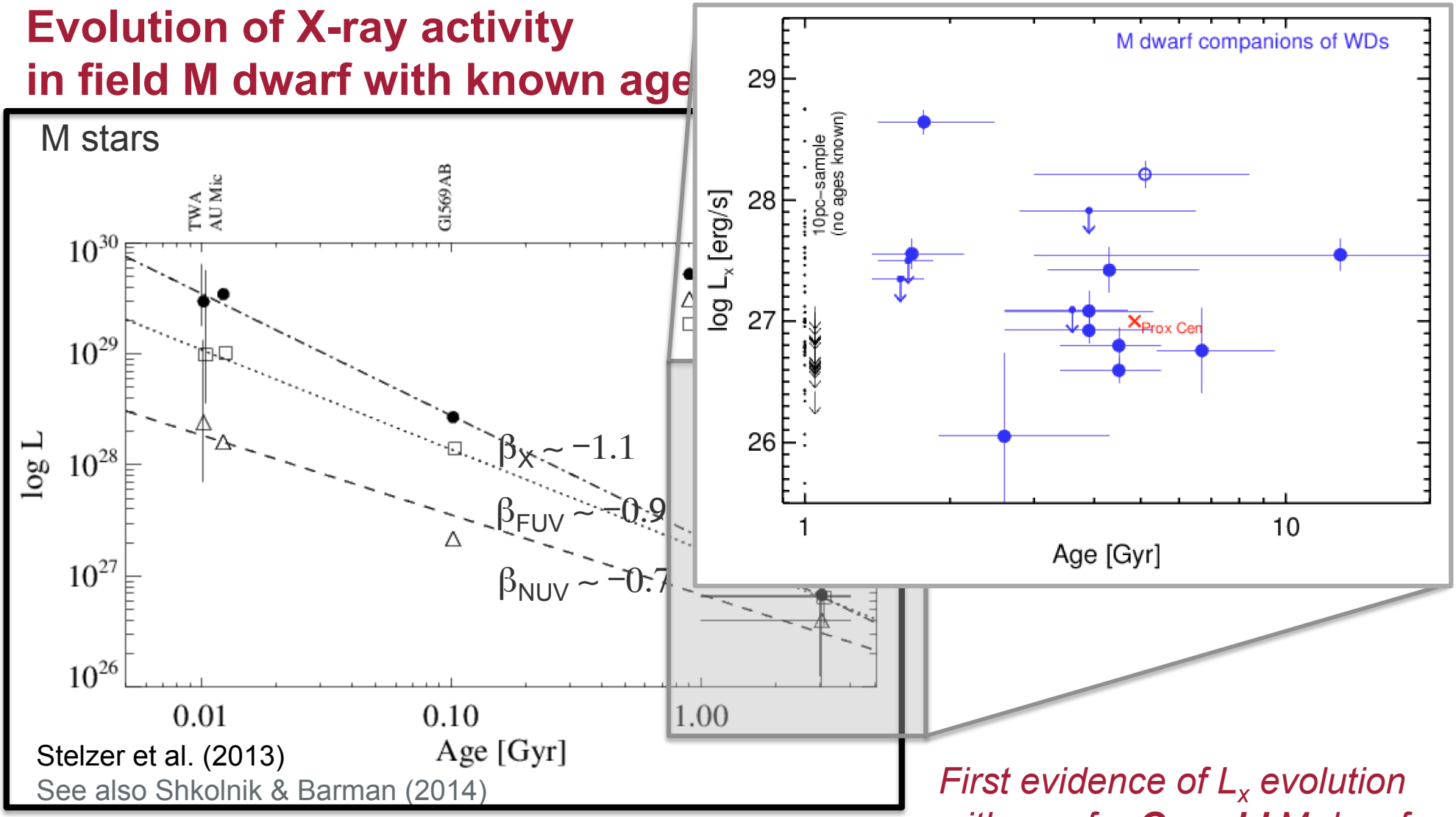
Deep X-ray observations of (coeval) White Dwarf / M dwarf pairs





DA White Dwarfs (Gyrs-old, T_{eff} ~ 10000K) → no X-ray emission
bound (co-moving) M dwarf companion → X-ray activity

Evolution of X-ray activity in field M dwarf with known age

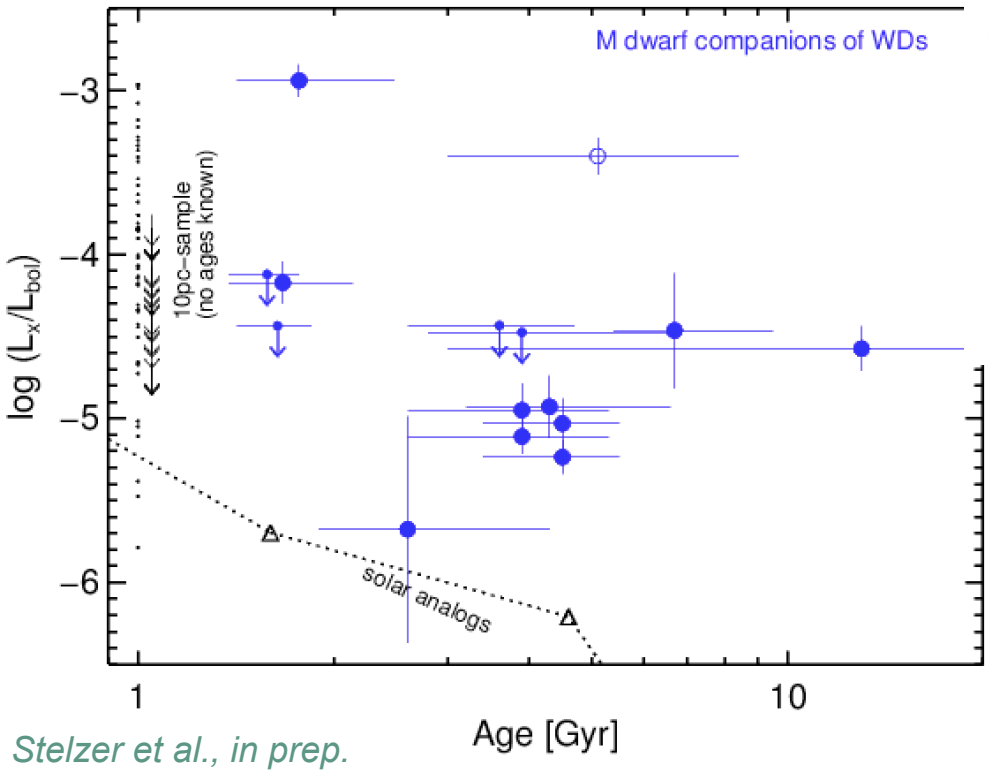


Stelzer et al. (2013)
See also Shkolnik & Barman (2014)

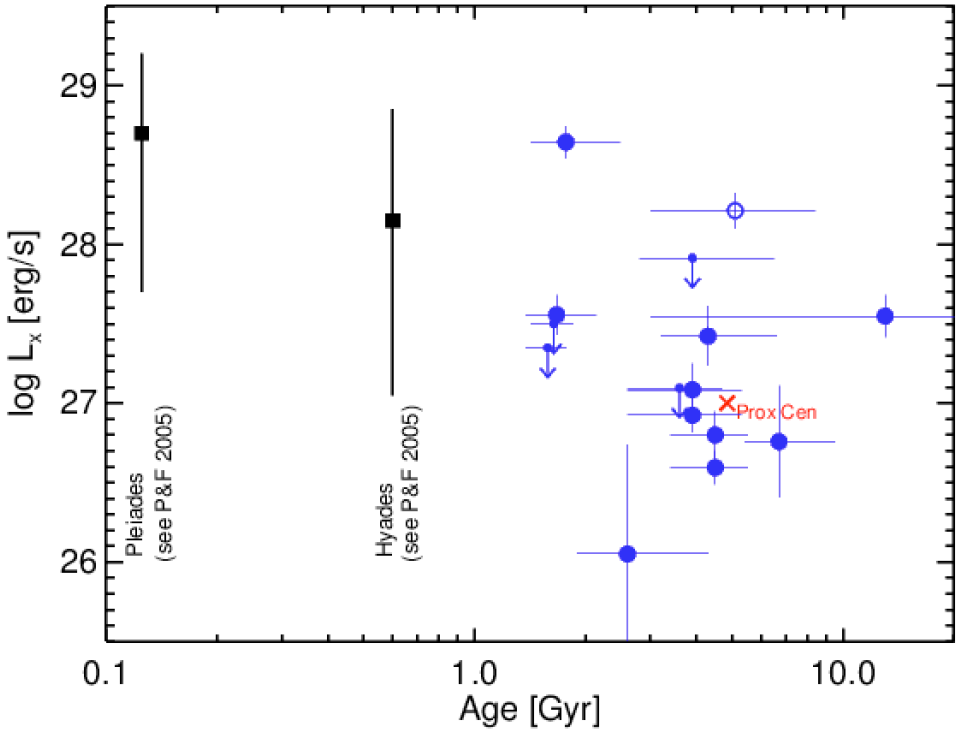
*First evidence of L_x evolution with age for **Gyr-old** M dwarfs.*

But: large spread of X-ray emission level at given age

L_x/L_{bol} of M dwarfs much higher than for solar-type stars of the same age
→ M dwarfs drop slower out of "saturation"



Stelzer et al., in prep.



Next:

attempting a calibration …….

PRELIMINARY FIT:

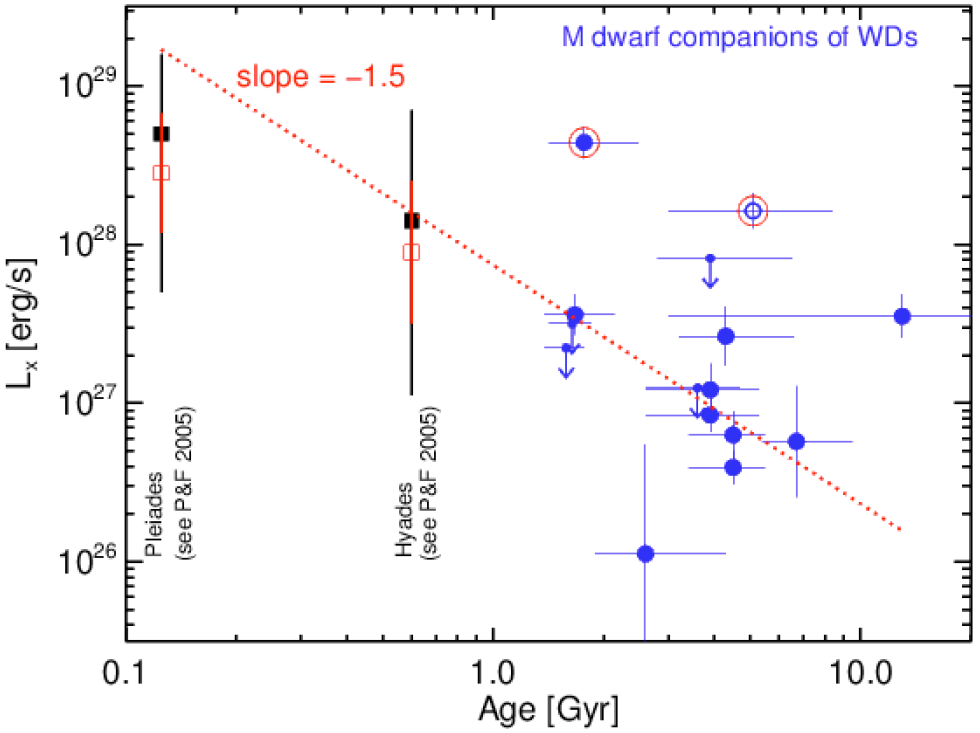
$$\log L_x = A + B * \log Age$$

Result depends on "interpretation" of the available data !

* *high-activity outliers*

* *mean L_x + range of L_x for clusters*

* *upper limits*

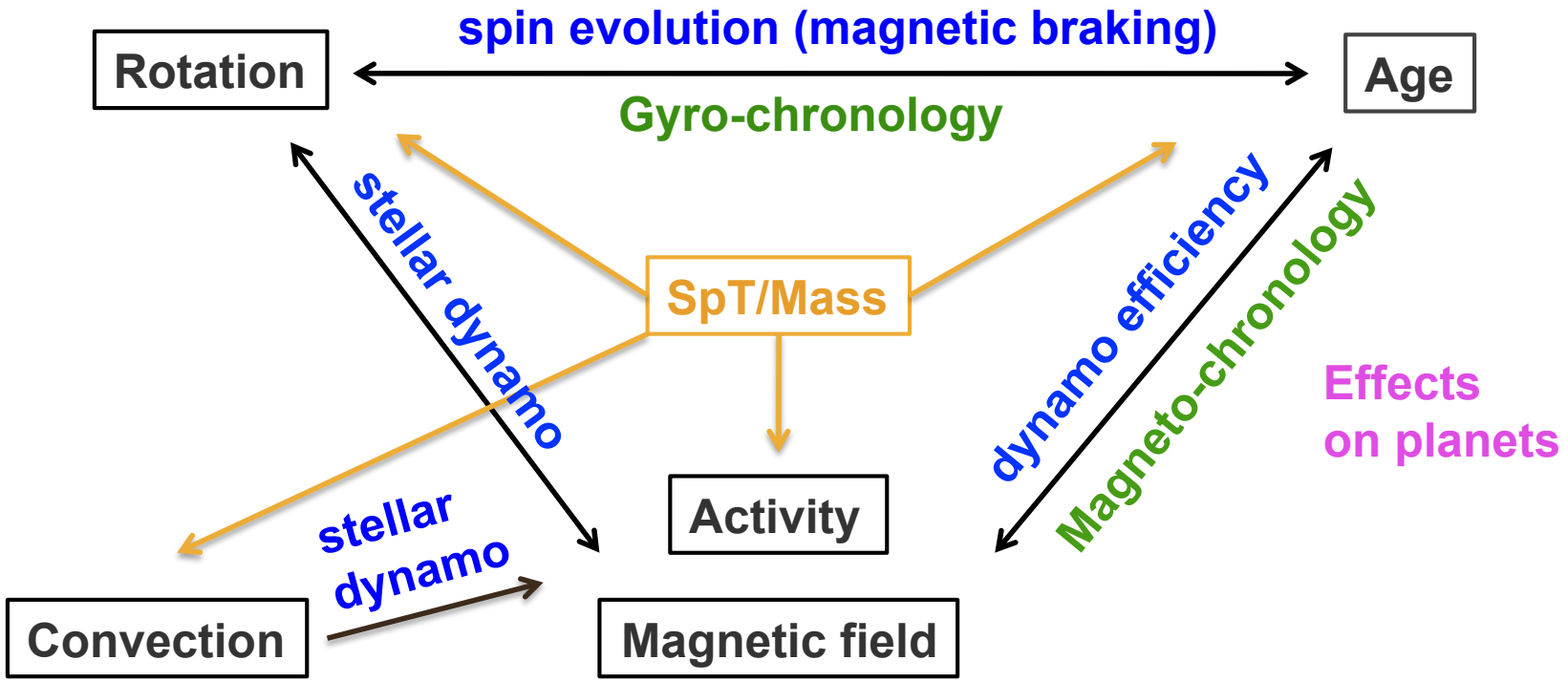


What causes the spread at given age?

→ Rotation ?
→ Magnetic field structure ?

Stelzer et al., in prep.

The activity-age relation in context:

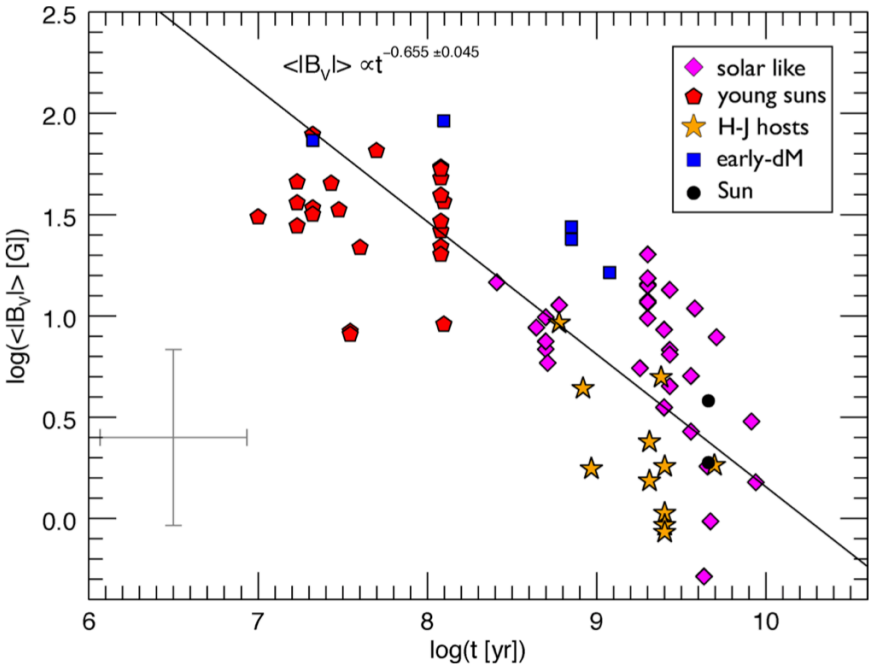


Problem: No sample exists for which all parameters can be measured.

Magnetic fields of the M dwarfs in WD binaries:

UNKNOWN !

Direct magnetic field detections through Zeeman Doppler Imaging exist for very few M dwarfs, and not in for Gyr ages.



Vidotto et al. (2014)

A Skumanich-like correlation between surface-averaged field and age, but lots of scatter

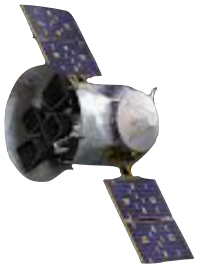
Current limitations of ZDI:

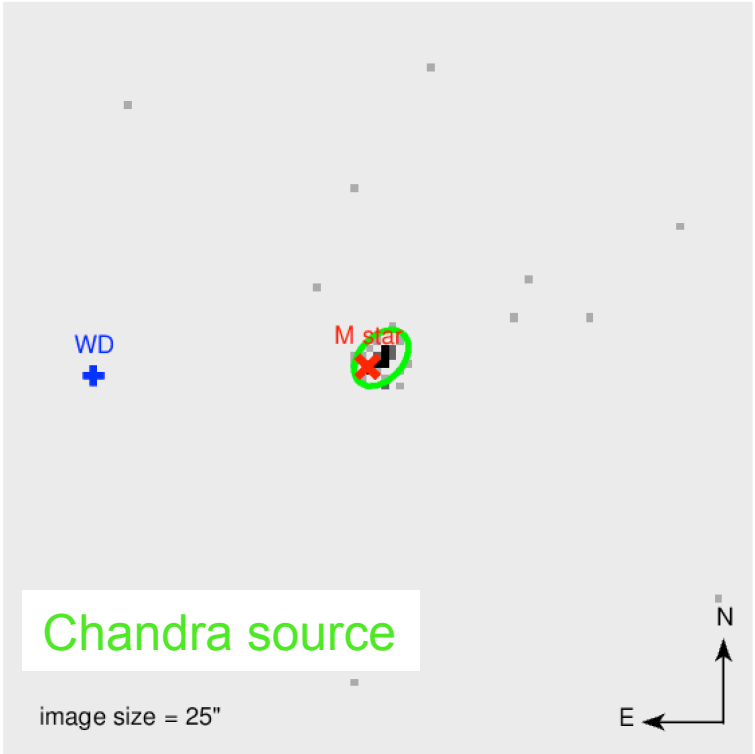
* large observational effort
* sensitive only to large-scale fields (related to winds but not activity)
* limited to bright mostly solar-type stars

Rotation periods of the M dwarfs in WD binaries

Not included in the MEarth sample (Newton+17)

But: **TESS (All-Sky Survey)**



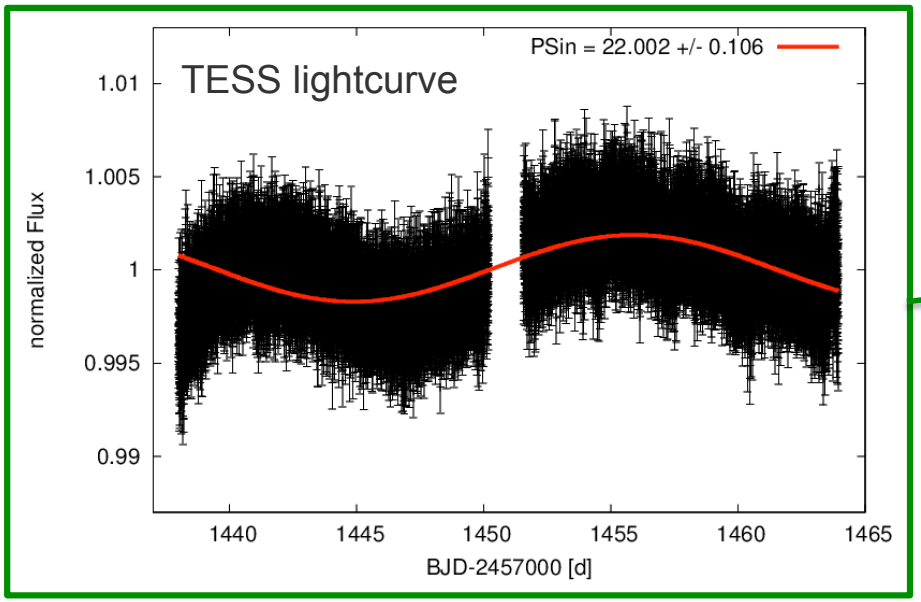


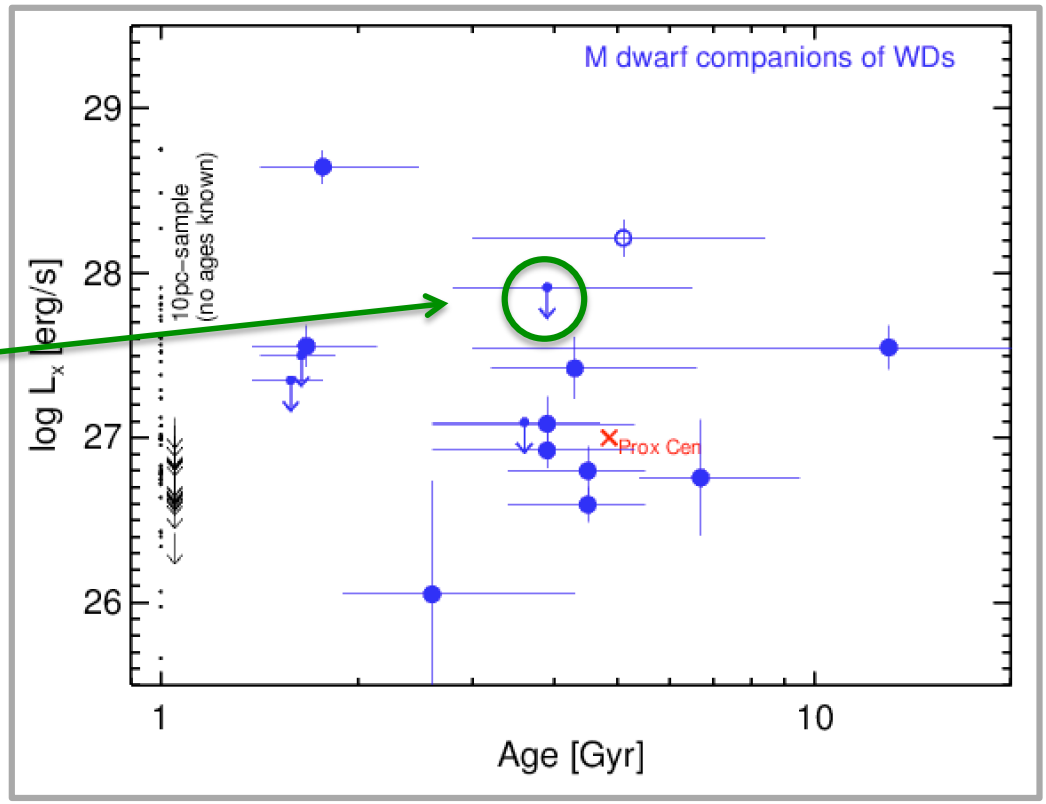
* all but two WD / M binaries are in the TCL

* potential source confusion

TESS pixel size = 21”
→ some images comprise both the WD and the M star

Rotation periods of the M dwarfs in WD binaries



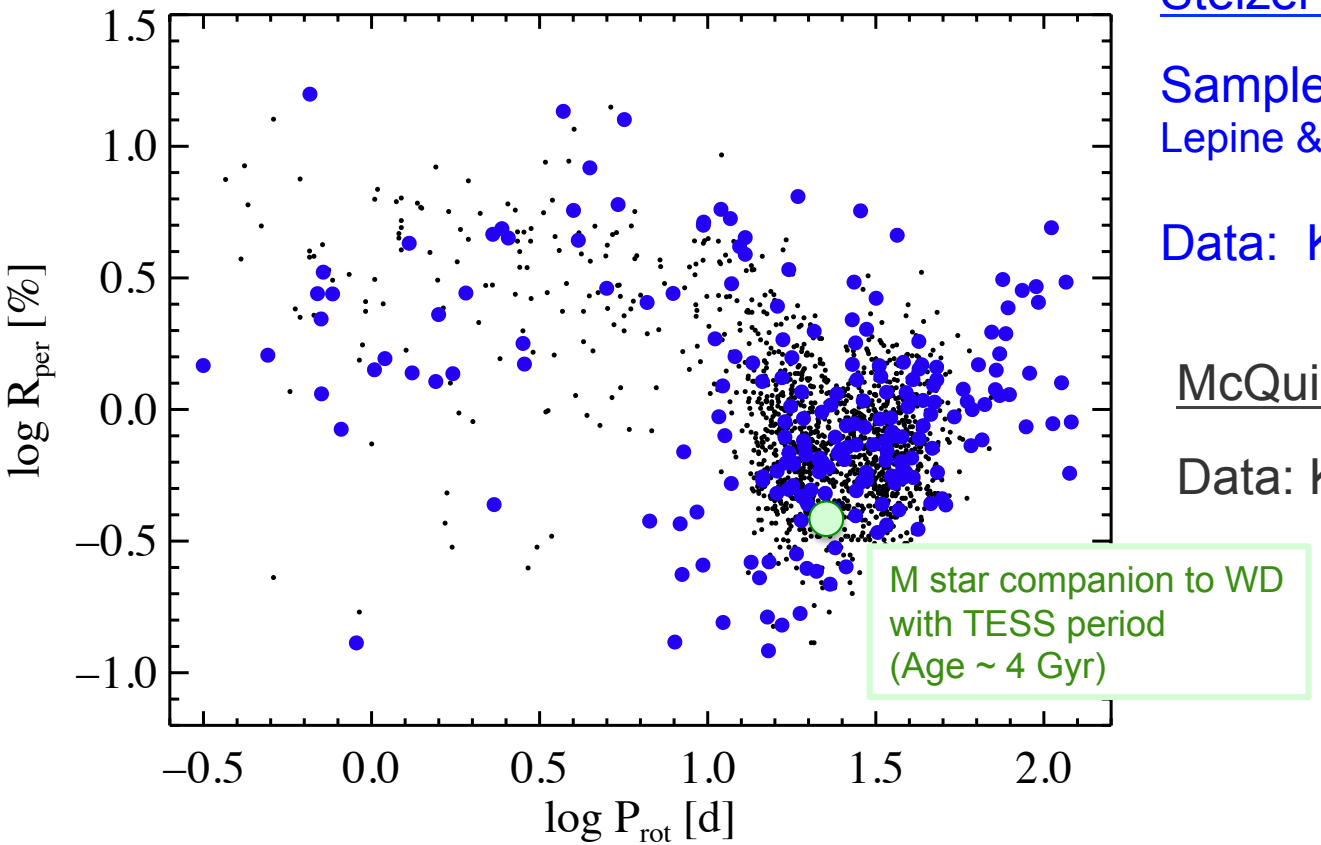


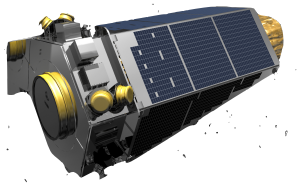
TESS lightcurves will be available, but not all might provide periods.

(limited precision, source confusion)

Next: **M dwarf with known age in activity-rotation relations**

Rotation amplitude - rotation relation for M dwarfs





Stelzer+16

Sample: near, bright M dwarfs
Lepine & Gaidos (2011)

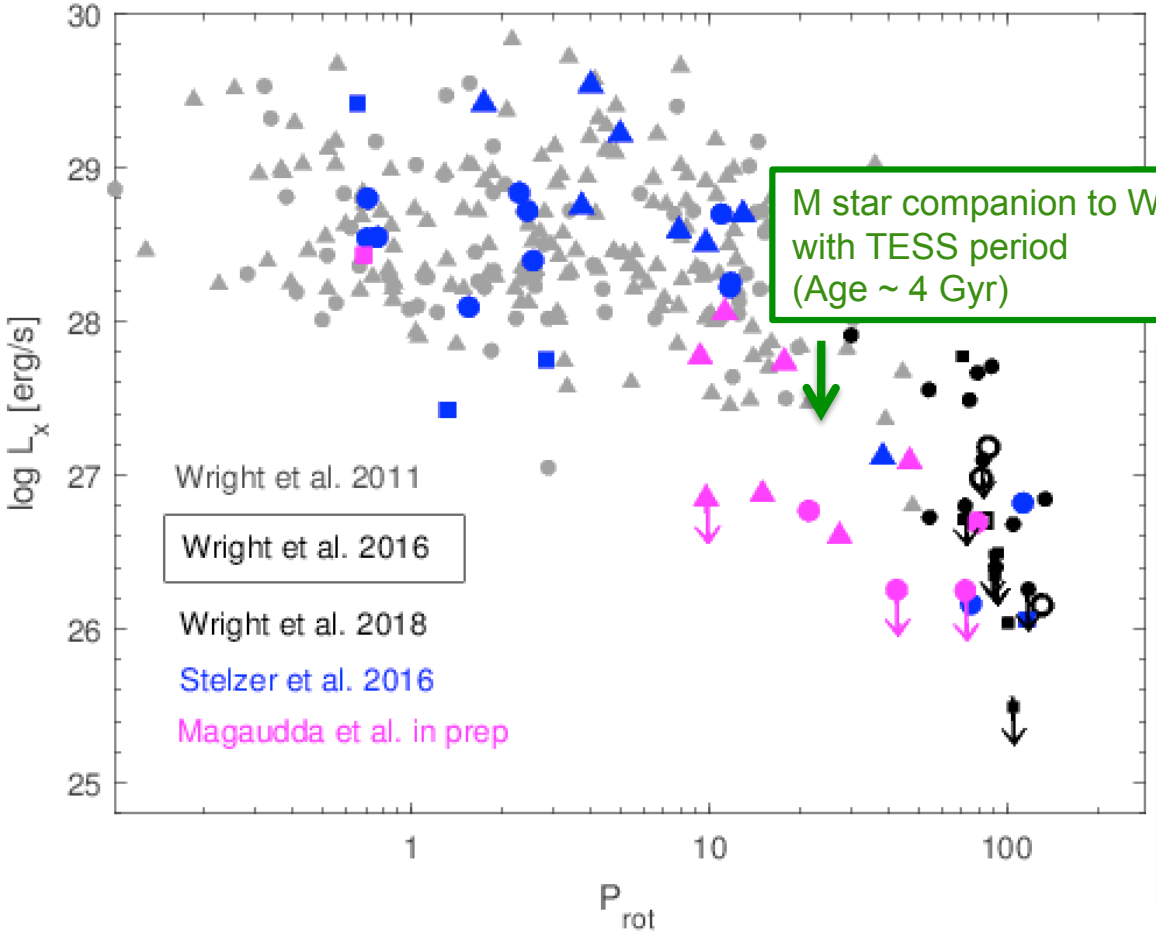
Data: K2 mission

McQuillan+14

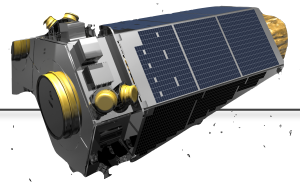
Data: Kepler mission

A bimodal behavior of fast and slow rotators; boundary is P_{rot} ~ 10 d.

X-ray activity - rotation relation for M dwarfs



P_{rot} from MEarth + X-ray activity from archives and Chandra (Wright+11,+18; **see Nick's talk**)



P_{rot} from K2
+ X-ray activity from:

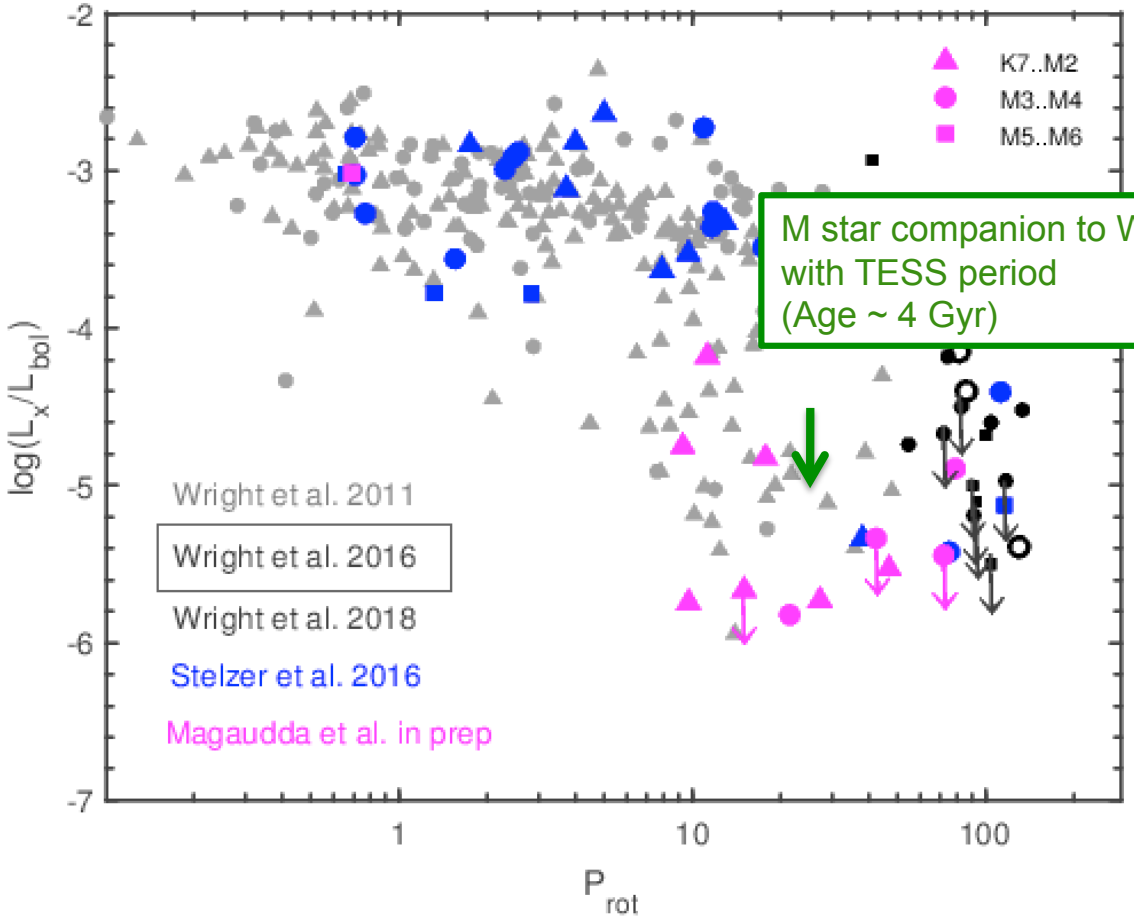
ROSAT, XMM archives

Chandra + XMM-Newton follow-up

Sample: near, bright M dwarfs
Lepine & Gaidos (2011)

Some very low X-ray upper limits for P_{rot} > 10 d.

X-ray activity - rotation relation for M dwarfs



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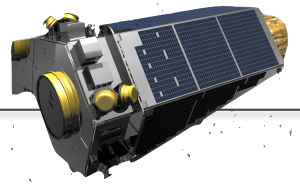

P_{rot} from K2
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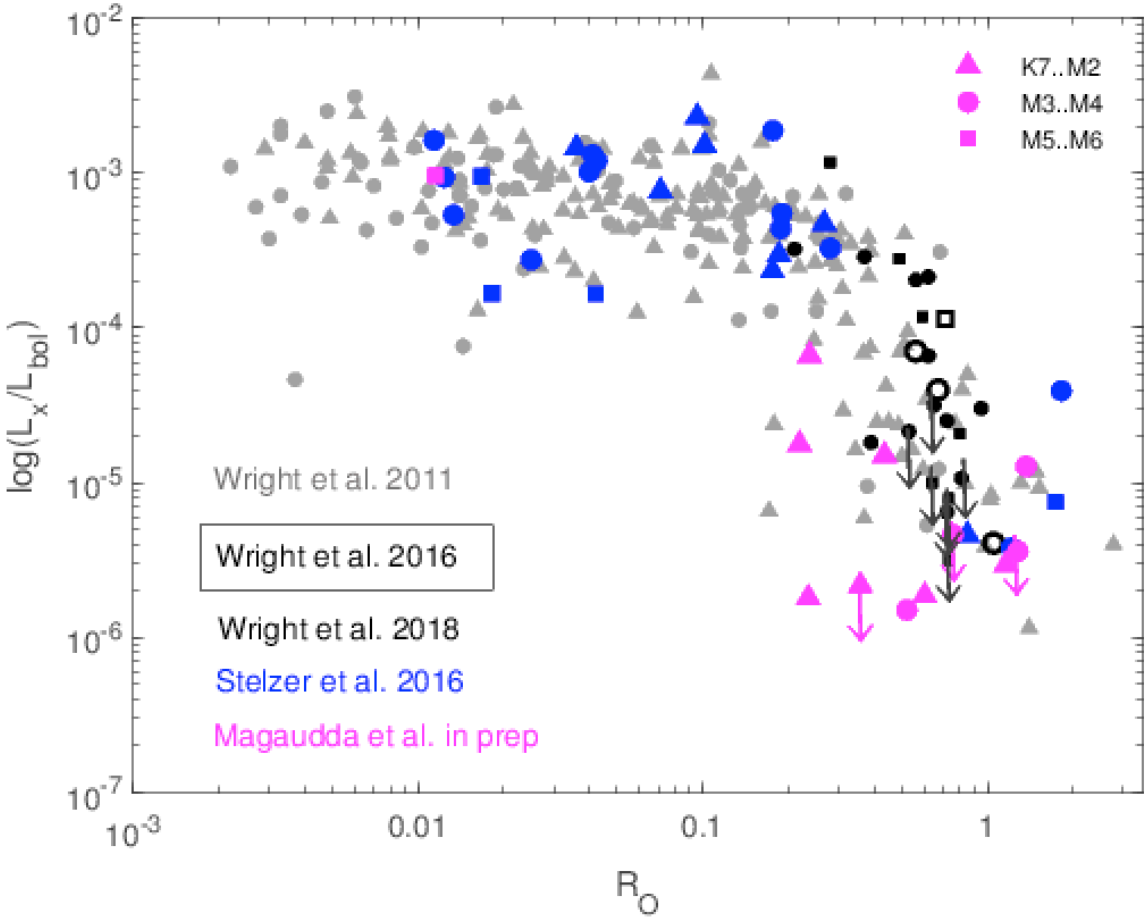
Sample: near, bright M dwarfs
Lepine & Gaidos (2011)

** L_x/L_{bol} instead of L_x: scatter in saturated level decreases.*
** Different P_{rot} distribution for partially and fully convective stars in non-saturated regime (P_{rot}> 10d)*

X-ray activity - rotation relation for M dwarfs



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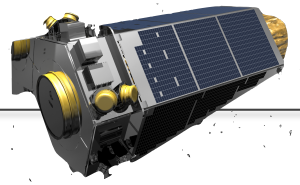


P_{rot} from K2
+ X-ray activity from:

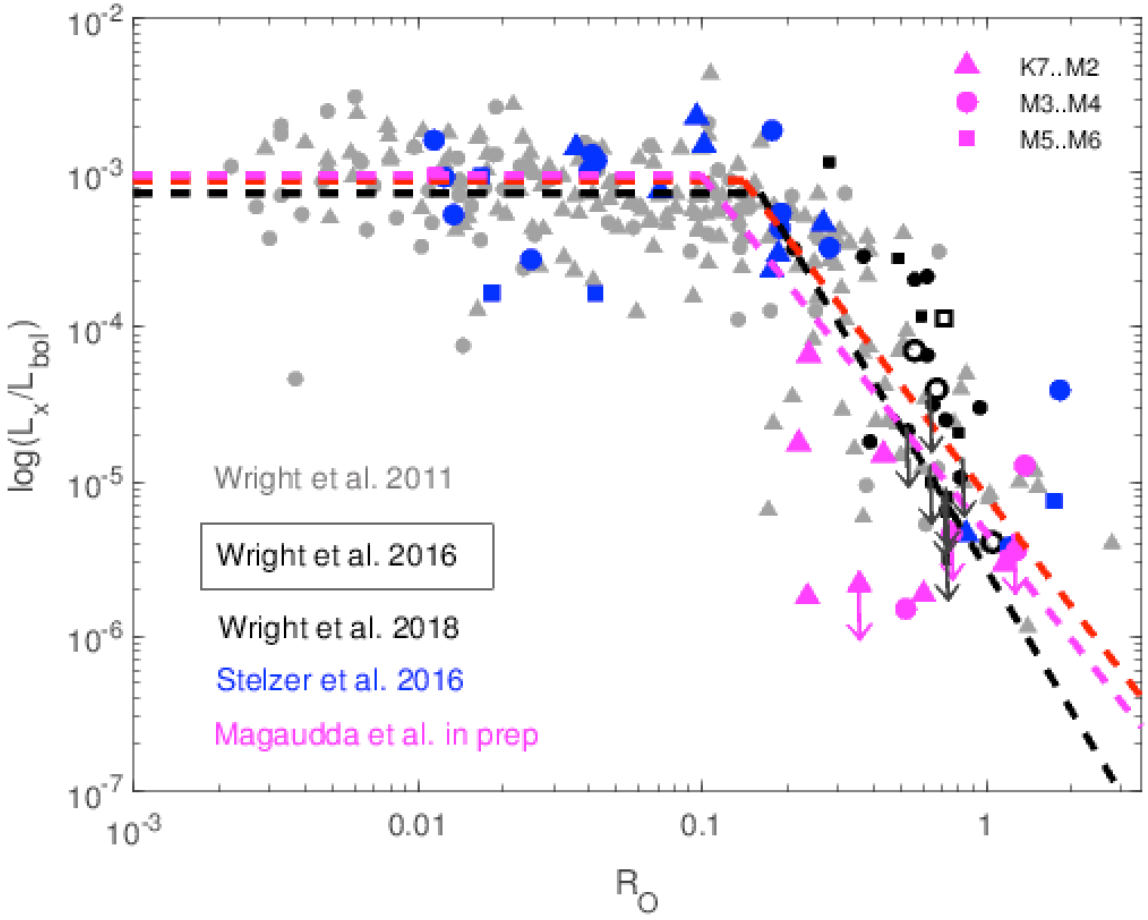
ROSAT, XMM archives

Chandra + XMM-Newton follow-up

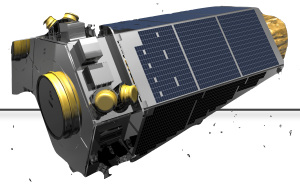
Sample: near, bright M dwarfs
Lepine & Gaidos (2011)

** $R_0 = P_{Rot} / \tau_{conv}$ instead of P_{Rot}: distribution in non-saturated regime gets narrower*

X-ray activity - rotation relation for M dwarfs



P_{rot} from MEarth + X-ray activity from archives and Chandra (Wright+11,+18; **see Nick's talk**)



P_{rot} from K2
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ROSAT, XMM archives

Chandra + XMM-Newton follow-up

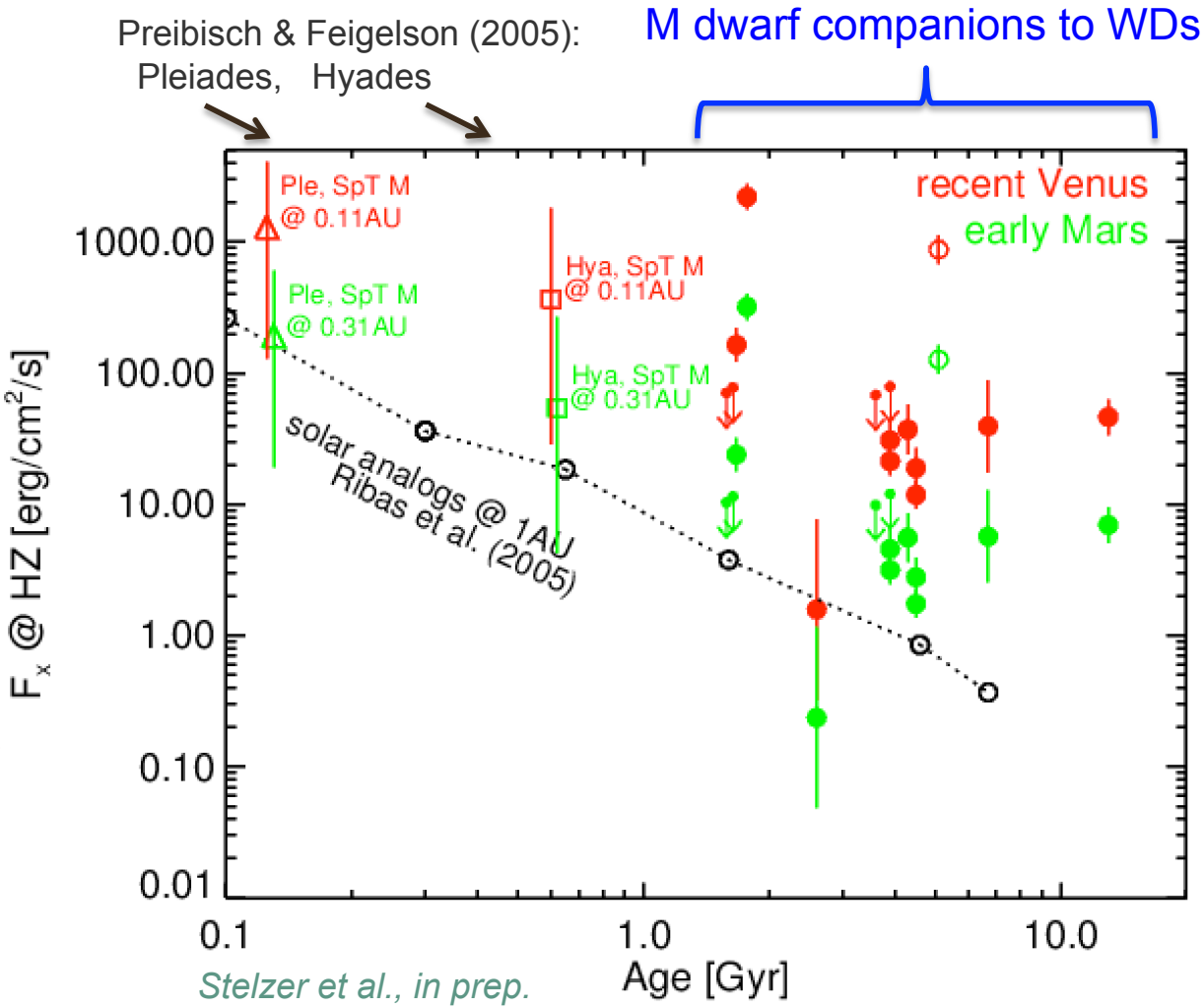
Sample: near, bright M dwarfs
Lepine & Gaidos (2011)

** Power-law fits in the non-saturated regime give similar slope*

Time-evolution of M dwarf X-ray flux in the Habitable Zone

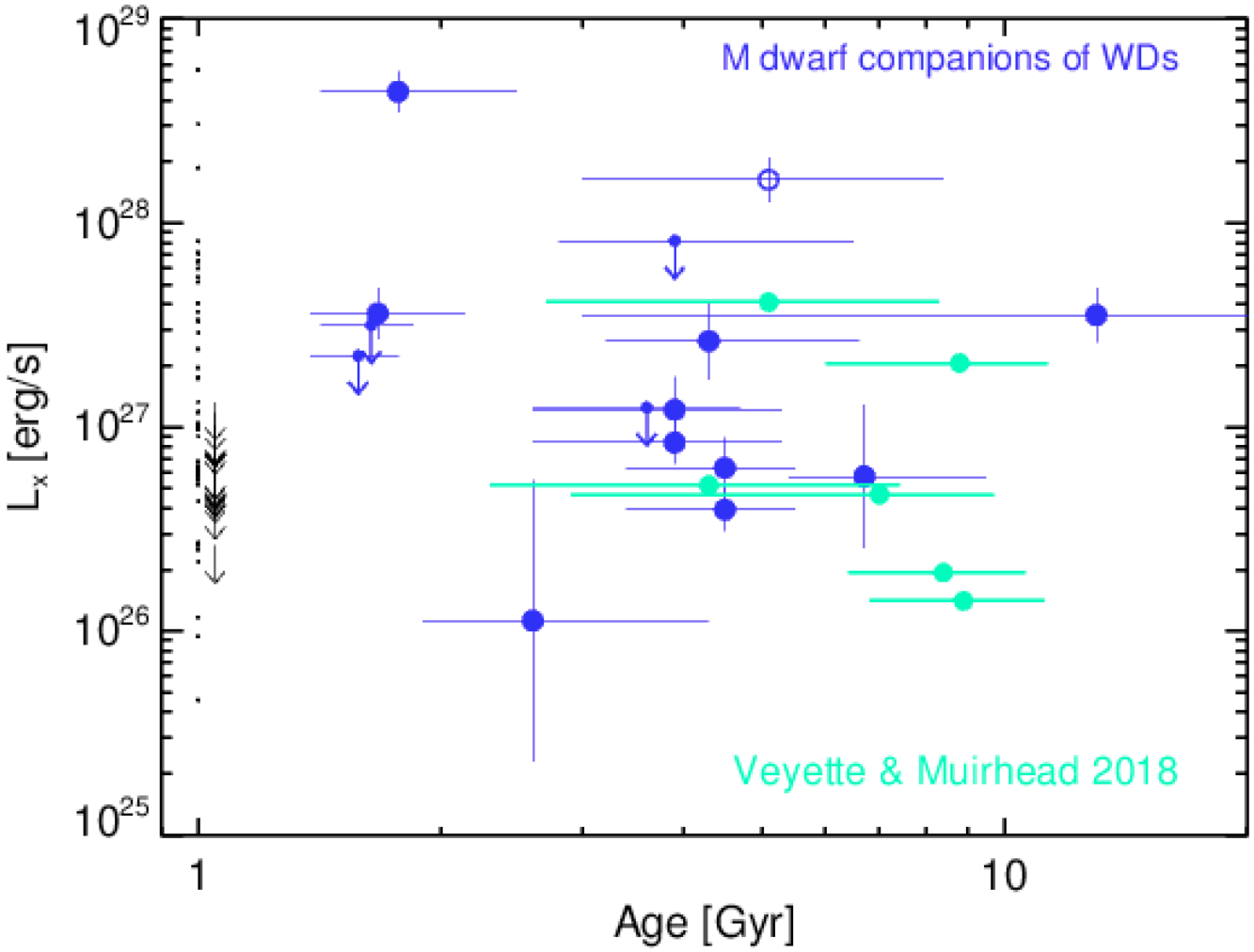
X-ray flux
in the habitable zone
of M dwarfs (0.1…0.3AU)
is higher than
in the HZ of G dwarfs (1AU)
by 0.5 … 1 dex at least

But:
Origin of high-activity outliers
must be understood
for reliable calibration.



Stelzer et al., in prep.

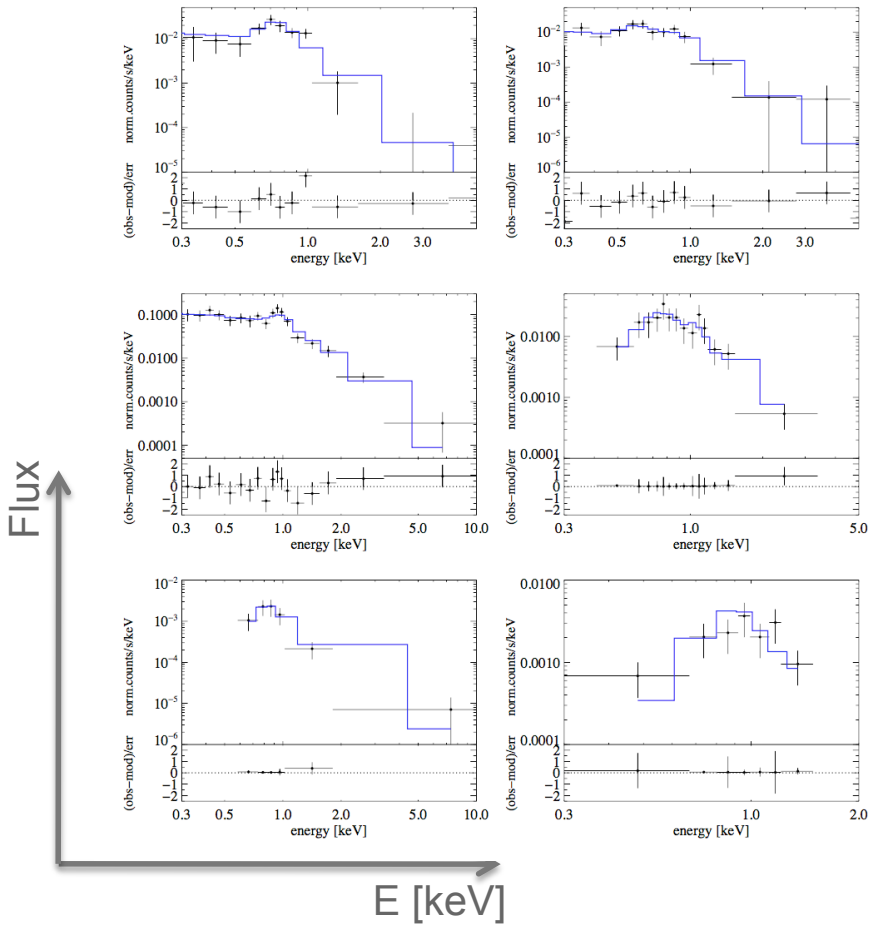
A quick doubling of sample size……

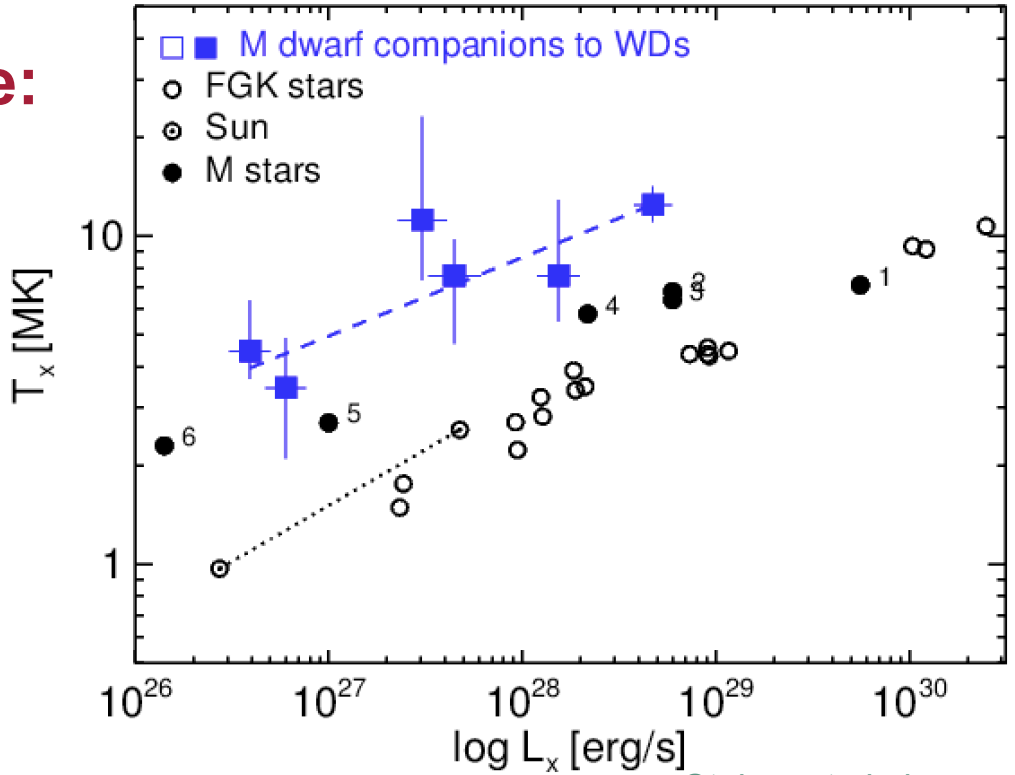


Planet hosts with ages from chemical dating (see talk by P.Muirhead)

…. a dirty X-ray analysis

X-ray spectra – temperature for M dwarfs with known age:





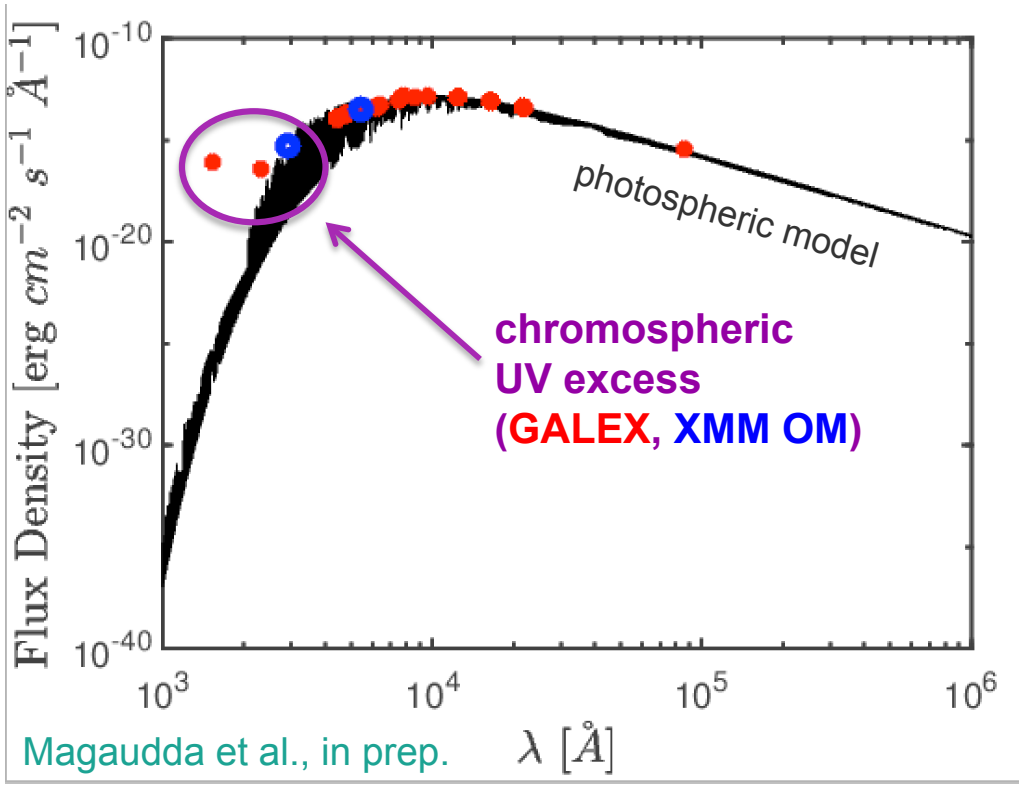
Stelzer et al., in prep.

* *First T_x – F_x relation for M stars with individual ages.*
* *Joint decrease of both parameters.*

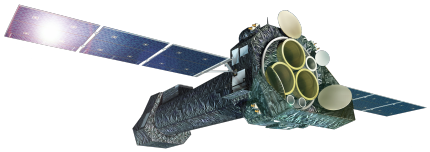
→ ***input to models of planet atmosphere evolution***

Other proxies of magnetic activity ? → UV emission

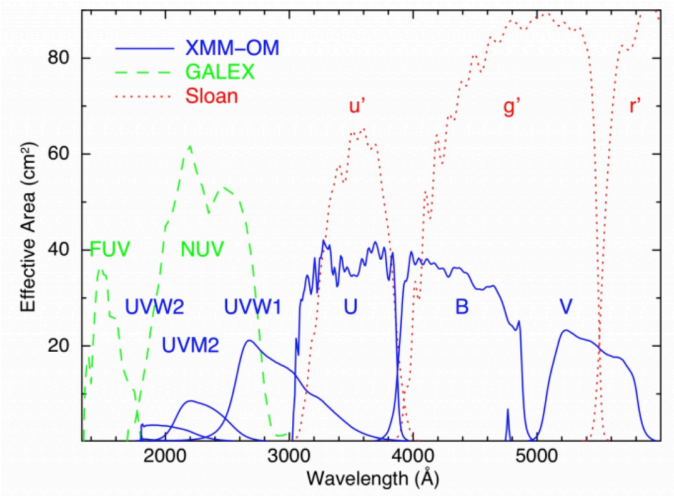
* SED of an M4 dwarf
(from SUPERBLINK sample; Lepine & Gaidos 2011)



Magaudda et al., in prep.



The Optical Monitor onboard XMM-Newton provides UV fluxes in 3 filters.

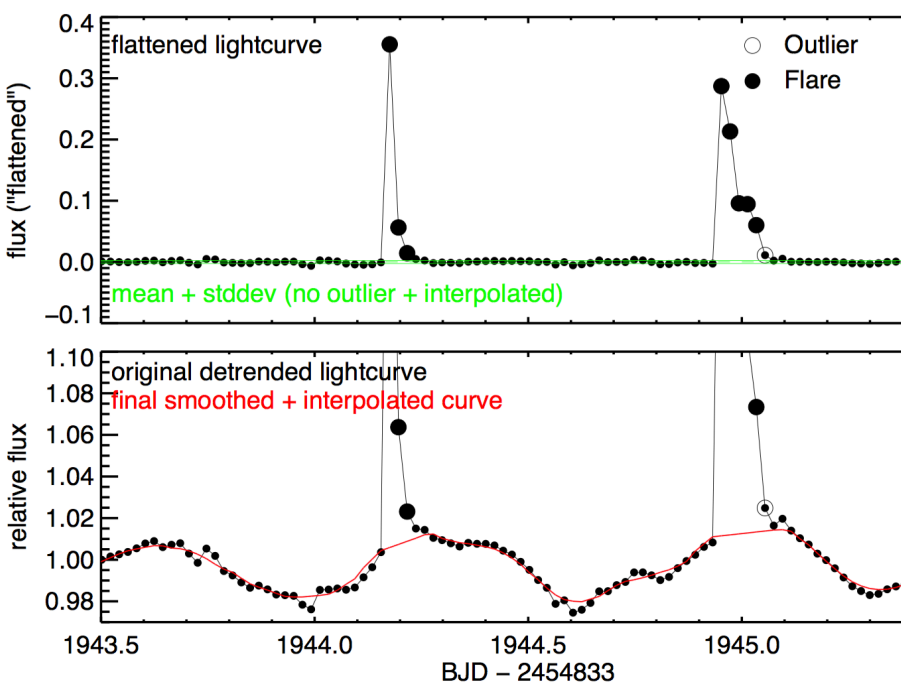


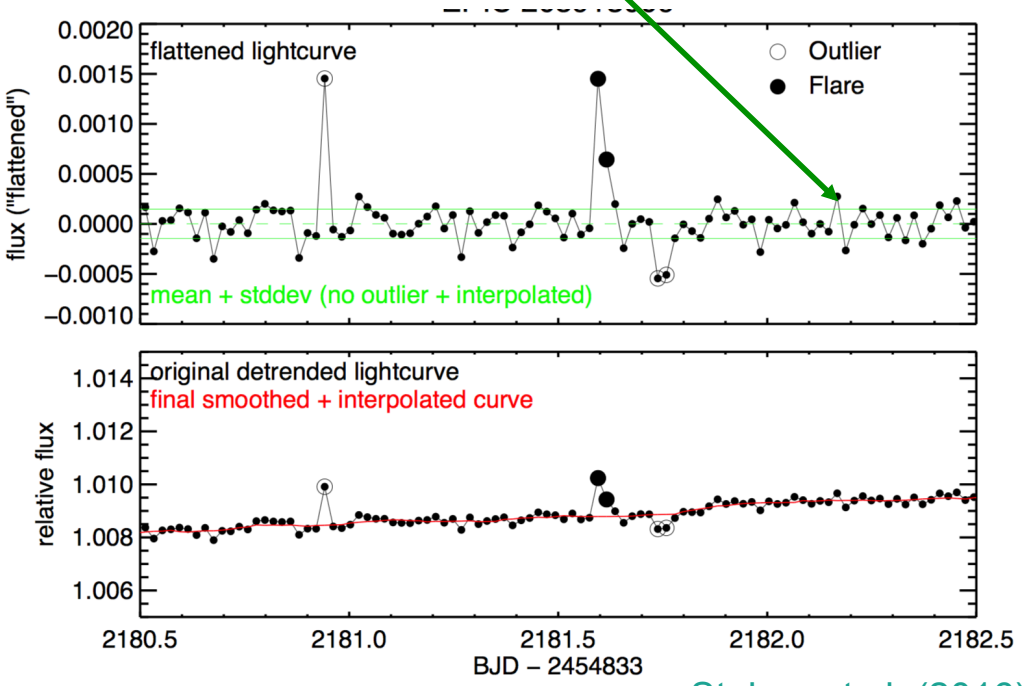
Other proxies of magnetic activity ? → photometric variability

Diagnostics of magnetic activity in photometric timeseries:

* amplitude of rotation cycle
* flares
* residual variability (S_flat)

S_{flat} …. Standard deviation of `flattened' lightcurve

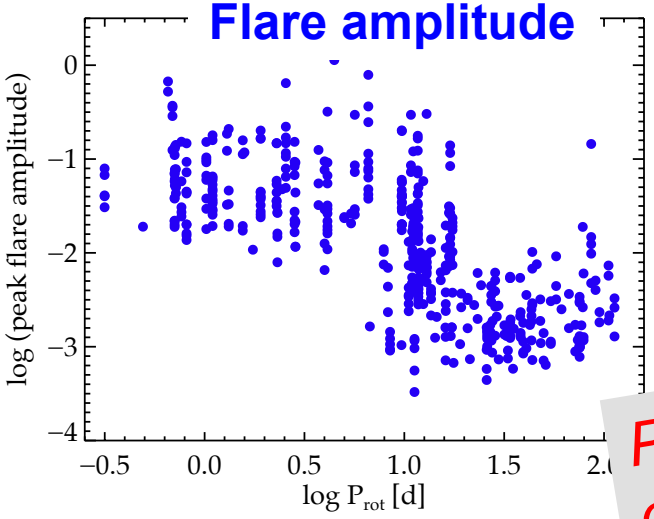




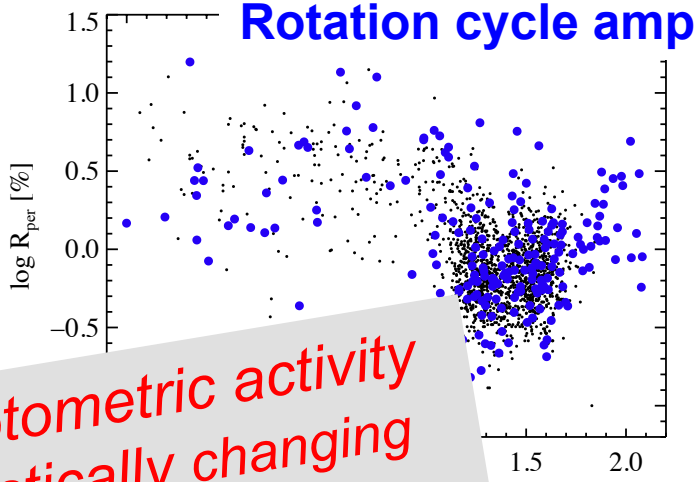
Stelzer et al. (2016)

K2 lightcurves of Superblink M dwarfs (from Lepine & Gaidos 2011):

Flare amplitude



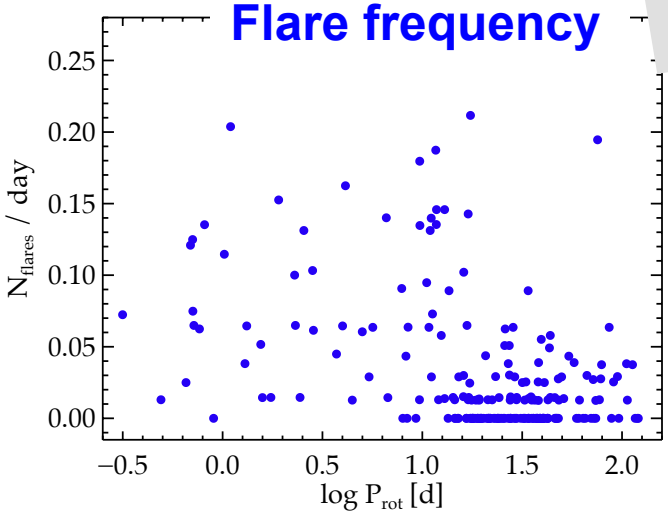
Rotation cycle amplitude



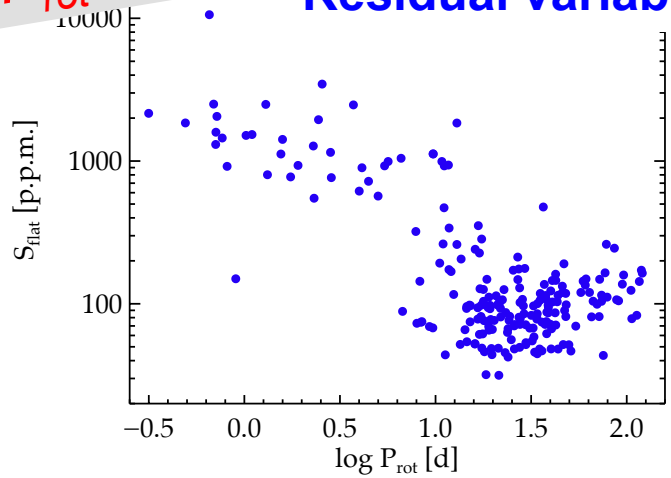
Stelzer+16. Updated Figs. S.Rätz

Photometric activity drastically changing at P_{rot} ~ 10 d

Flare frequency



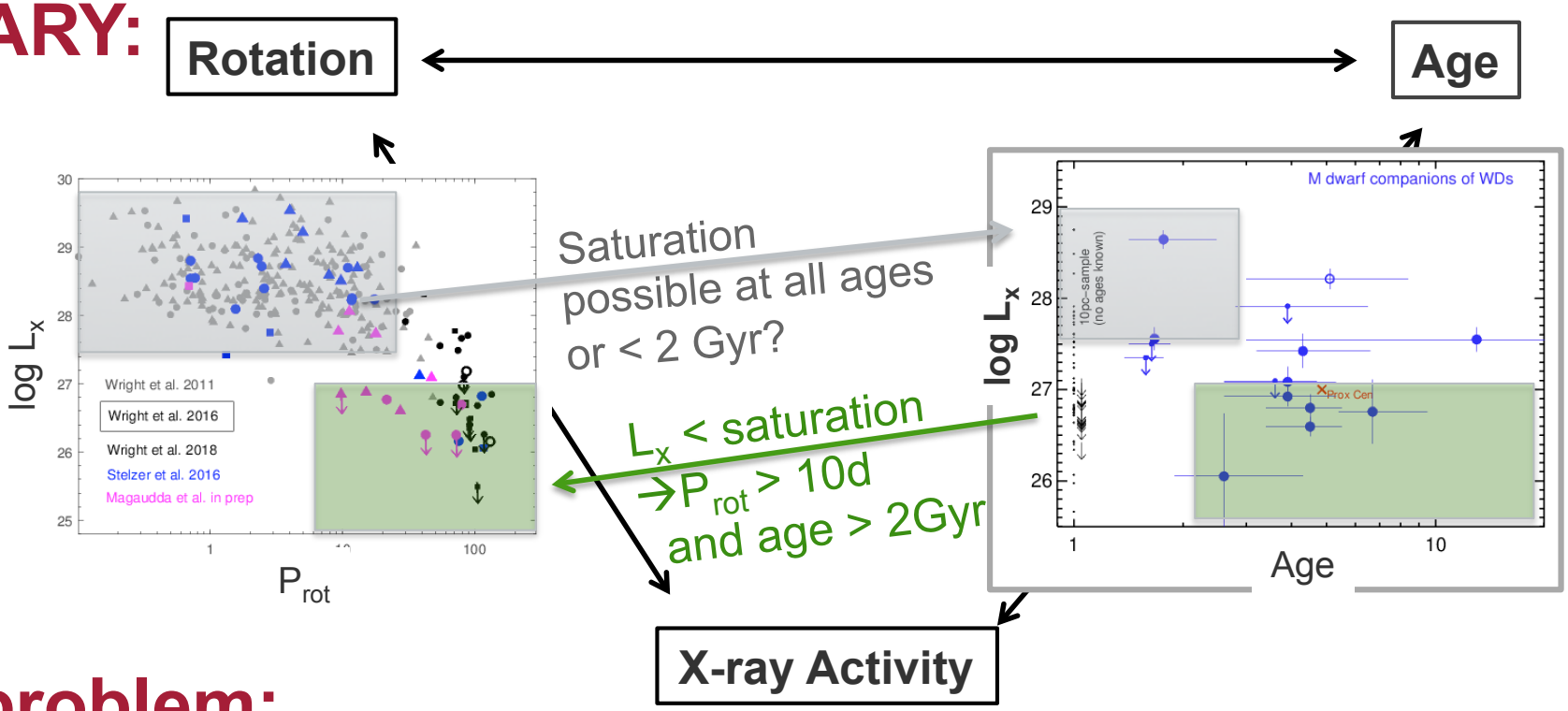
Residual variability



Application of analysis to younger samples underway
→Study age evolution of WL flares

(see also Talk by E.Elin)

SUMMARY:



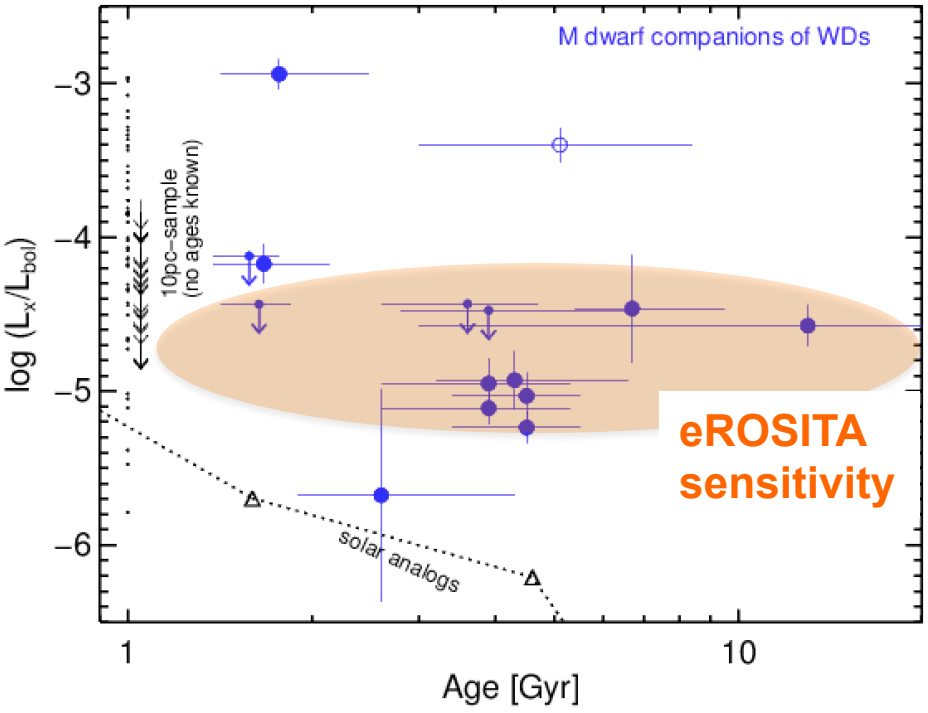
Major problem:

Samples accessible to multi-wavelength observations

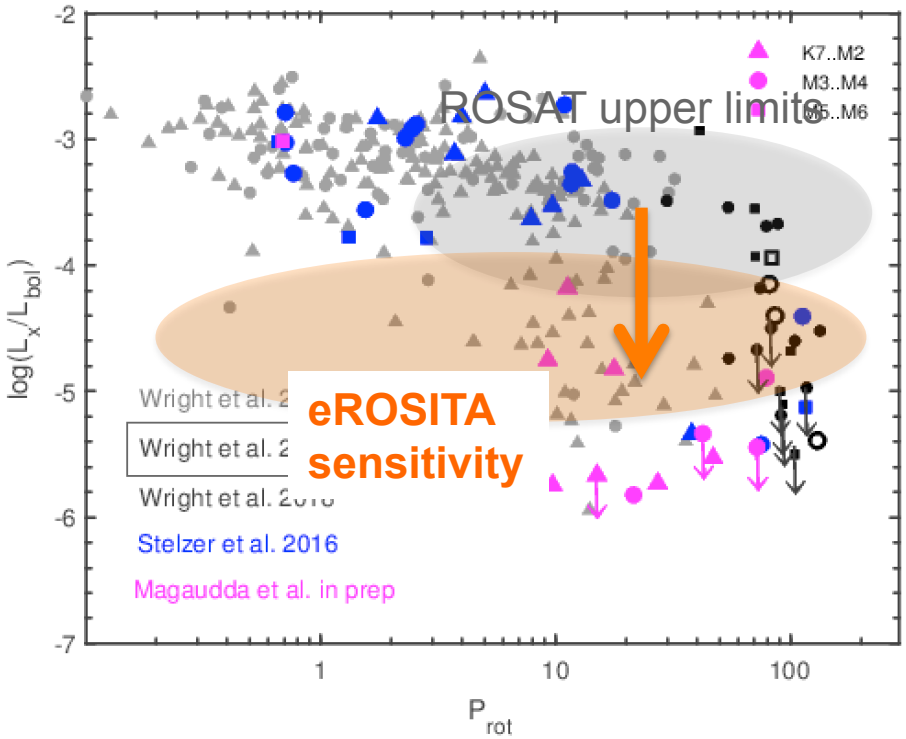
But:

More data is coming ! → **eROSITA, TESS, Gaia, …**

Upcoming improvements (1):
More X-ray measurements of M dwarfs



Russian-German X-ray satellite
Launch: Summer 2019



***All-Sky X-ray survey**, eRASS:*
factor 20 deeper than ROSAT RASS