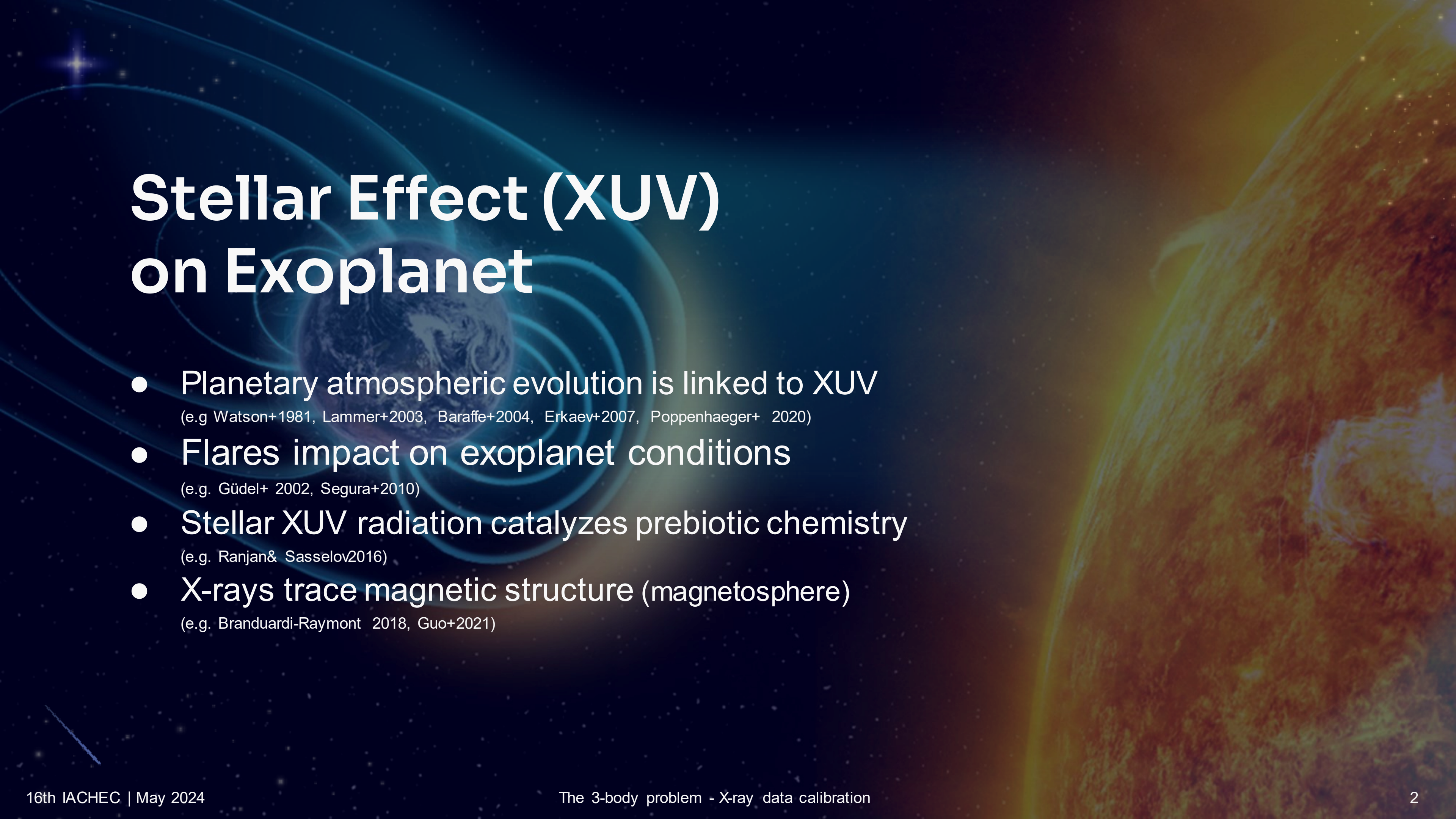
The 3-body problem:

calibrating X-ray observations of a triple-star system

Suri Rukdee, MPE

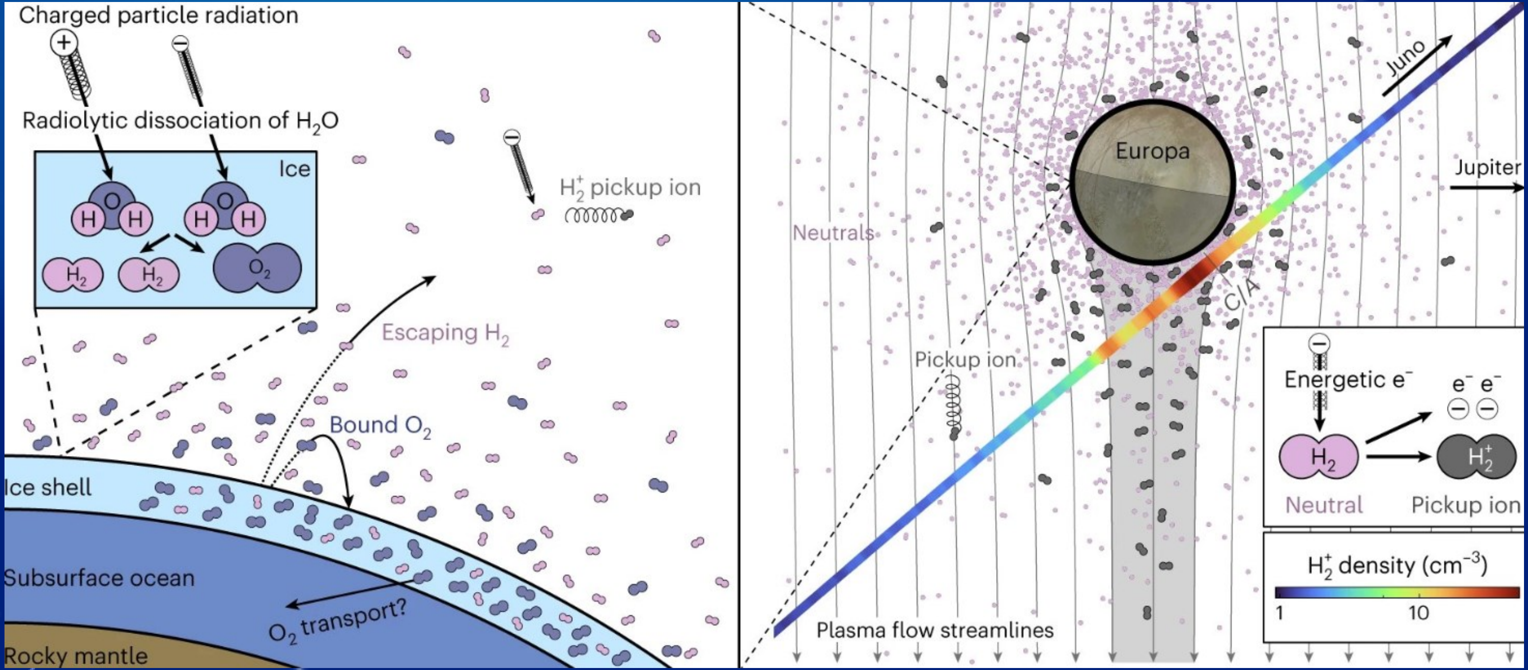
X-ray variability of the triplet star system LTT1445 and evaporation history of the exoplanets around its A component arXiv:2401.17303v2
S. Rukdee, J. Buchner, V. Burwitz, K. Poppenhäger, B. Stelzer, P. Predehl



Stellar Effect (XUV) on Exoplanet

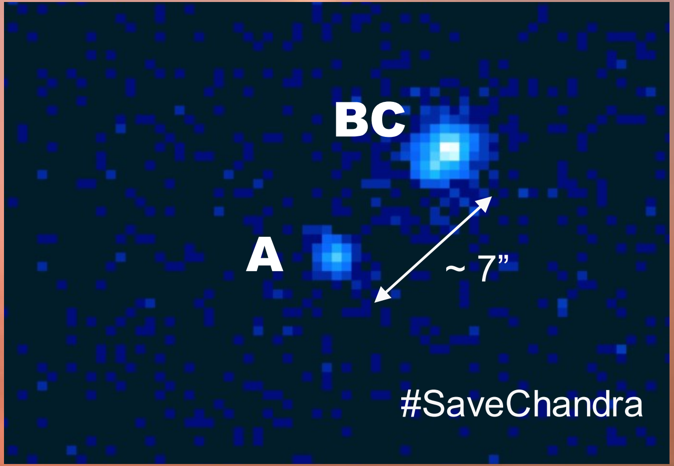
- Planetary atmospheric evolution is linked to XUV
  (e.g Watson+1981, Lammer+2003, Baraffe+2004, Erkaev+2007, Poppenhaeger+ 2020)
- Flares impact on exoplanet conditions
  (e.g. Güdel+ 2002, Segura+2010)
- Stellar XUV radiation catalyzes prebiotic chemistry
  (e.g. Ranjan & Sasselov 2016)
- X-rays trace magnetic structure (magnetosphere)
  (e.g. Branduardi-Raymont 2018, Guo+2021)

Oxygen Build-up



Szalay+ 2024

LTT 1445



3
M-Dwarfs

6.8 pc
from the sun

250 years
A-BC orbital period

36 years
BC orbital period

3 terrestrial
exoplanets

Outline

01

Low counts data

Very Faint X-ray source

02

Plasma Model

The comparison between APEC and VAPEC model

03

Temperature

Apply temperature distribution for analysis

04

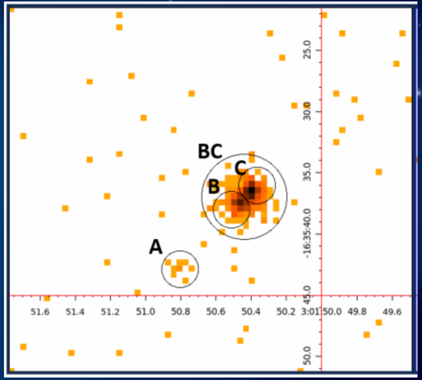
Age

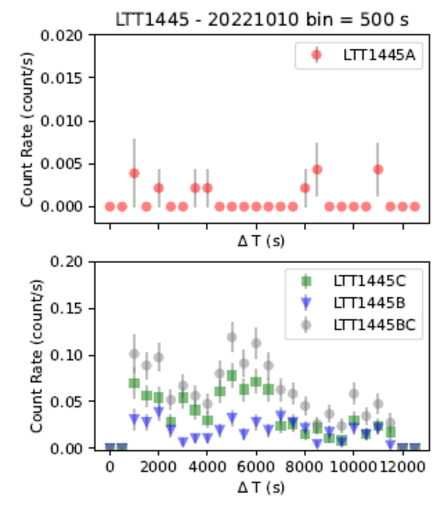
Contraint the age of the system from model

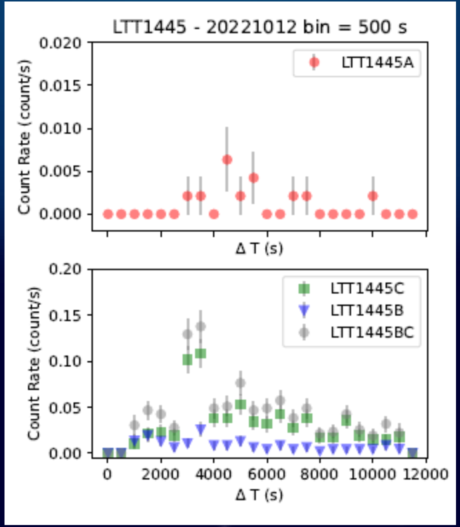
01

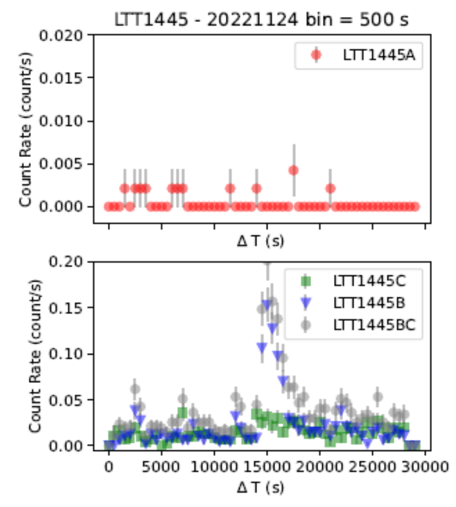
Low counts

Low counts





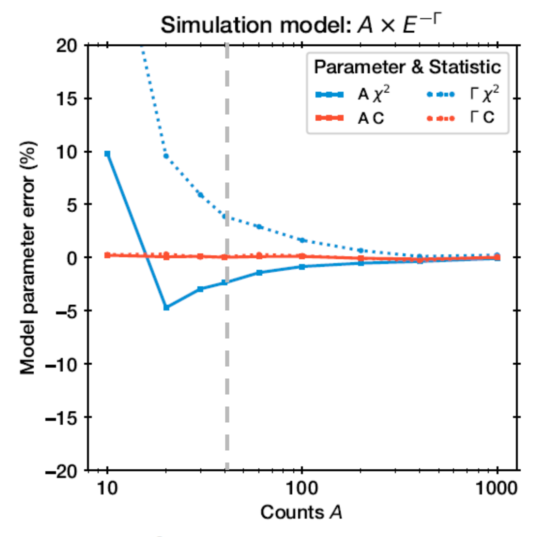




Rukdee+ 2024

X^2 vs C-stat

- χ2 rooted in Gaussian statistics
  - normally distributed data uncertainties
  - compares observed and expected values
  - can lead to biased estimates, especially with fewer than 40 counts (Humphrey+2009).
- C-stat ideal for Poisson statistics
  - low counts or background-dominated scenarios
  - unbiased estimates of model parameters and uncertainties.



Buchner & Boorman+ 2022

Fun fact: Bayesian framework nested sampling, is also commonly used in exoplanet searches (Nelson+ 2020) and atmosphere radiative transfer modeling (Mollière+ 2019)

BXA-plasma

BXA connects the X-ray spectral analysis environments Xspec/Sherpa to the nested sampling algorithm ‘UltraNest’

- **Bayesian Parameter Estimation**
- **Model comparison**

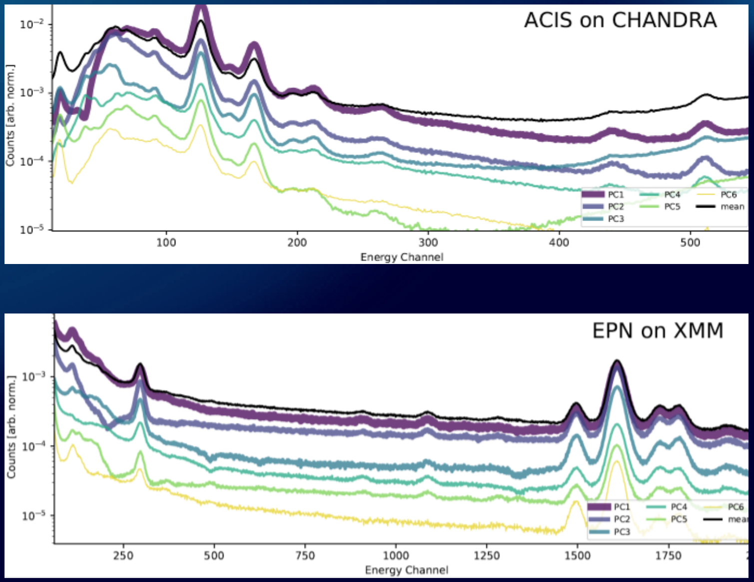
BXA-plasma connects BXA with plasma models e.g. APEC, VAPEC

https://github.com/SurangkhanaRukdee/BXA-Plasma

Buchner+ 2014
Rukdee+ 2024

PCA-based background models

- Simmonds et al., 2018 introduced a machine-learning approach for deriving empirical background models, using PCA
- Background spectral models leverage known correlations between bins and instrument behaviors to extract more information from low-count data.
- PCA models, trained in log10(counts + 1) space, operate on detector channels without passing through the response.
- Fitters enhance PCA models by adding Gaussian lines at points of significant fit mismatch, with complexity increasing based on improvements in the Akaike information criterion (AIC)



Simmonds+ 2018

02

Plasma Model

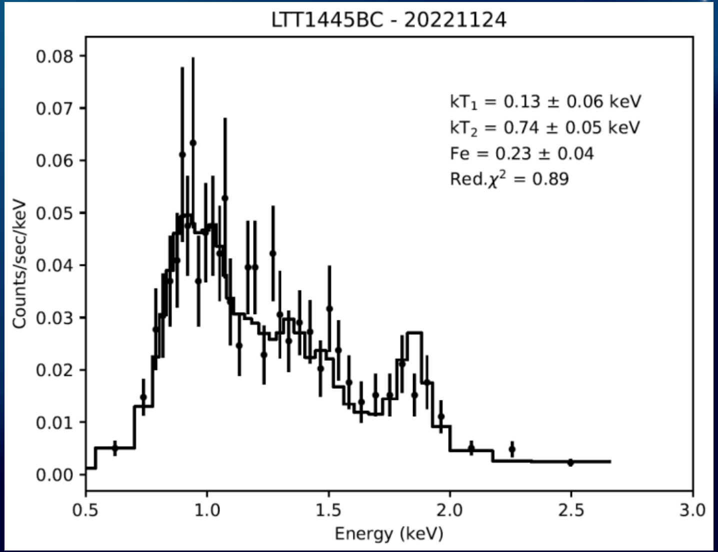
Plasma Model

APEC: Astrophysical Plasma Emission Code

- Metal abundances (He fixed). The elements included are C, N, O, Ne, Mg, Al, Si, S, Ar, Ca, Fe, Ni

VAPEC: Variant APEC model

- Allows variant of abundances for He, C, N, O, Ne, Mg, Al, Si, S, Ar, Ca, Fe, Ni wrt Solar

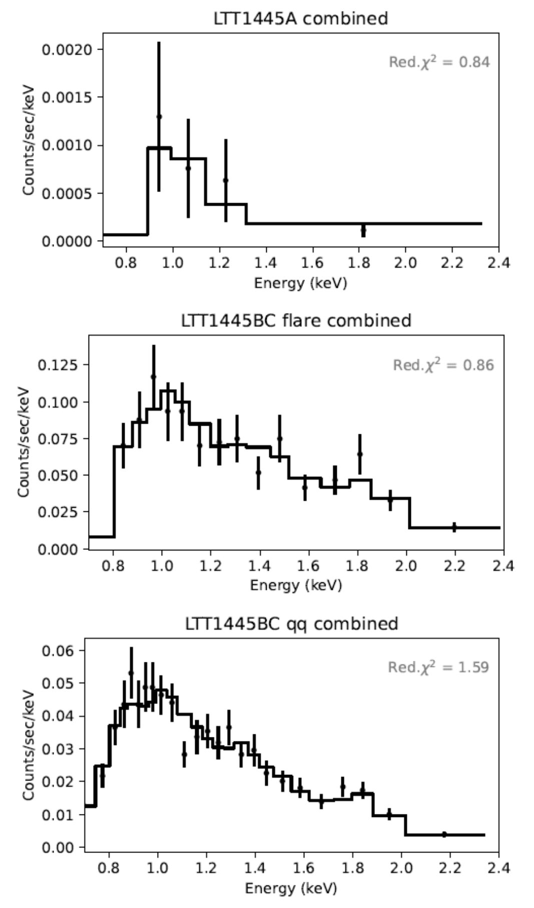


Rukdee+ 2024

BXA model comparison

- Compare APEC and VAPEC on the flare dataset
- Fit abundances, temperature, normalization, sigma
- Disclaimer: low counts data

Model	In(Z)	C-stat
APEC	-114.8±0.47	214.14
VAPEC	-115.3±0.46	212.87



Rukdee+ 2024

03

Temperature

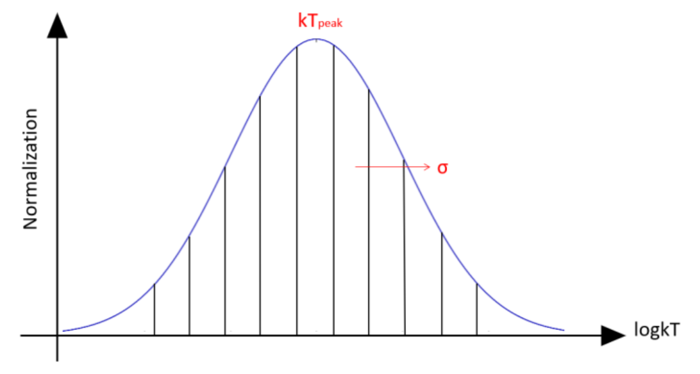
Plasma Temperature

Robrade & Schmitt 2005

- ☐ Study 4 active M-stars: M3.5 – M4.5
- ☐ Temperature Grid: the 3 –T and the 6 -T model lead to fully consistent results on abundance

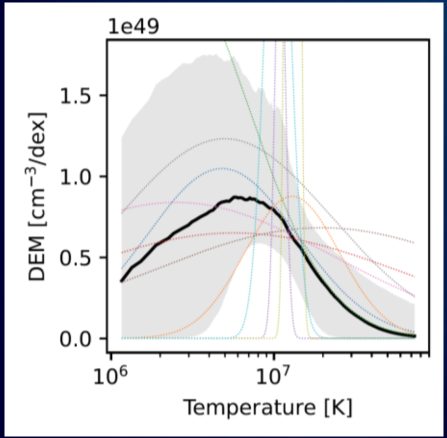
Rukdee+ 2024

- ☐ Temperature Distribution
- ☐ Capture the behavior of the plasma temp. better than a single point (kT1 or kT2)
- ☐ Approximated by summing many single temperature component > increase sampling

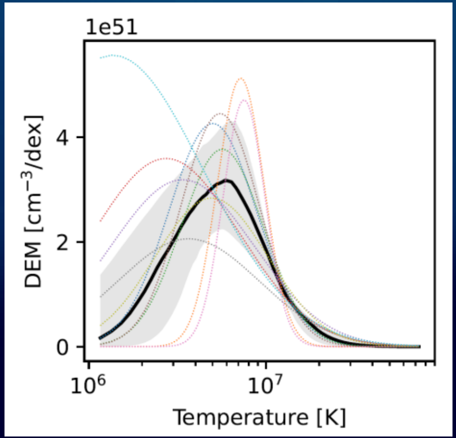


Temperature ~~grid~~ distributions

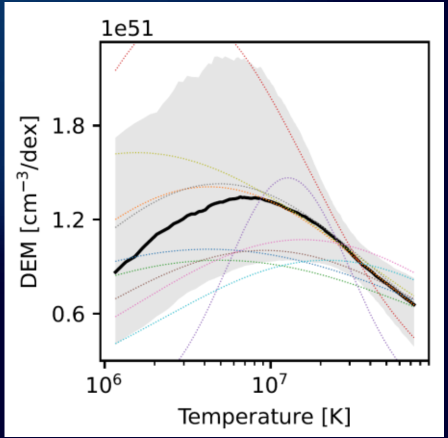
Quiescence



Quasi-Quiescence



Flare



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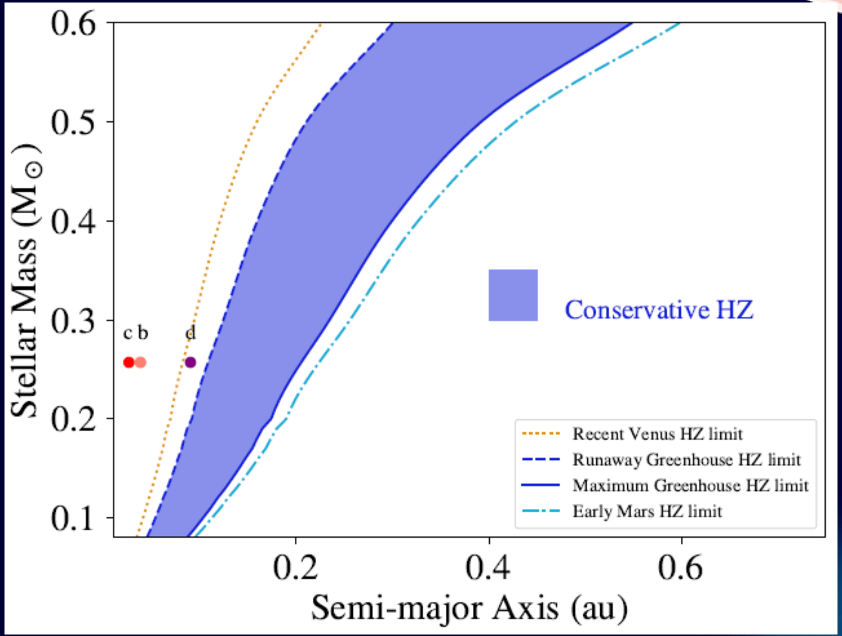
X-ray luminosity on the planets

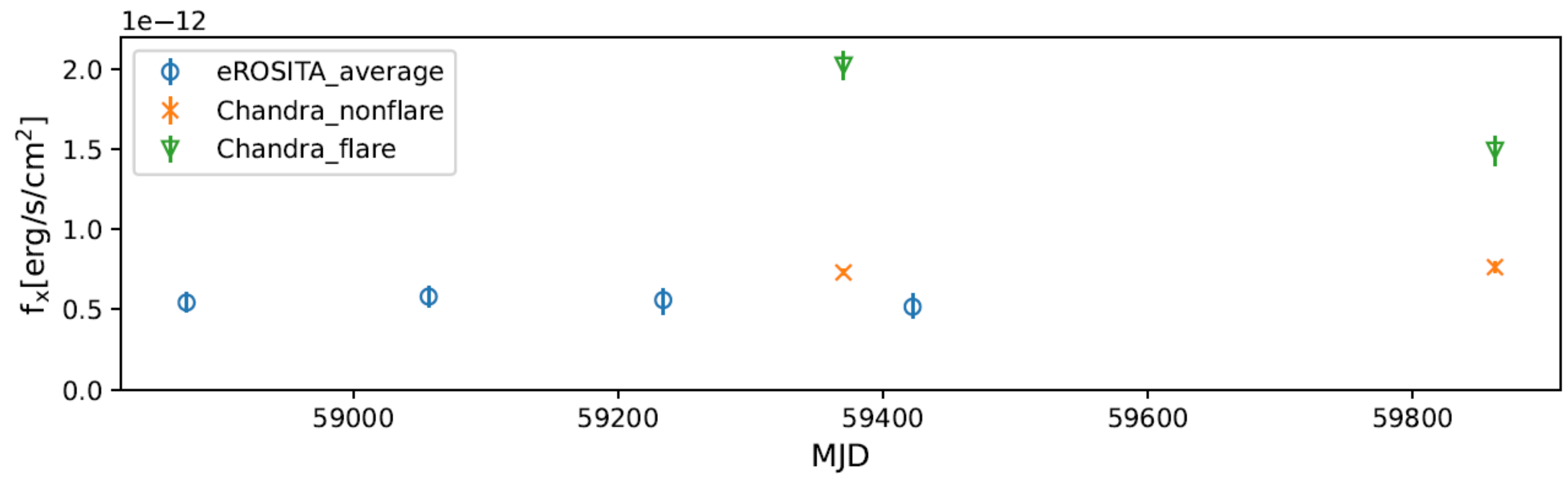
A’s X-ray radiation is ~400^2 x more powerful than BC according to the distance/location from the planets

Star	LogLx (Flare)	LogLx (NonFlare)
A	27.31±0.10	26.16±0.24
BC	27.93±0.03	27.64±0.02

Brown+ 2022
Rukdee+ 2024



Long-term Monitoring on BC

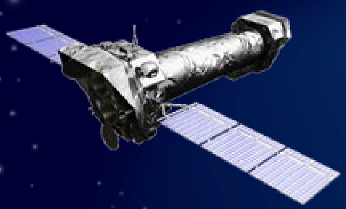


Caveat: as of 2020, Chandra is most sensitive from 0.9-7 keV, while eROSITA has most sensitive energy range from 0.3-2.3 keV

04

Age

Age of the Star



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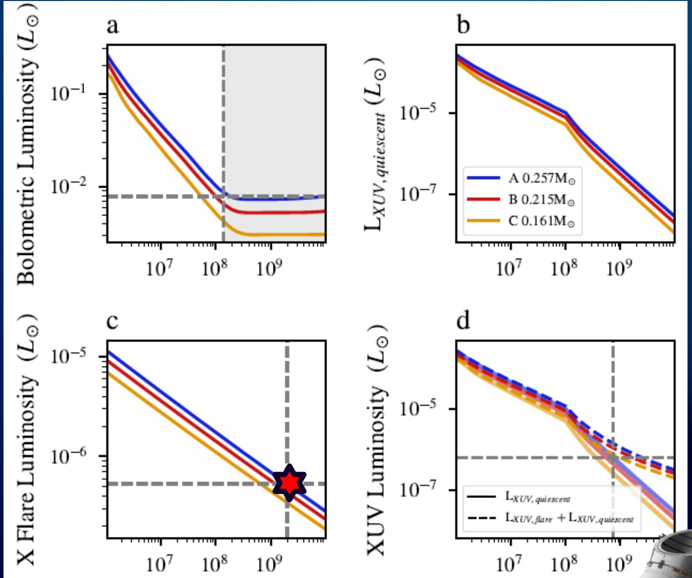
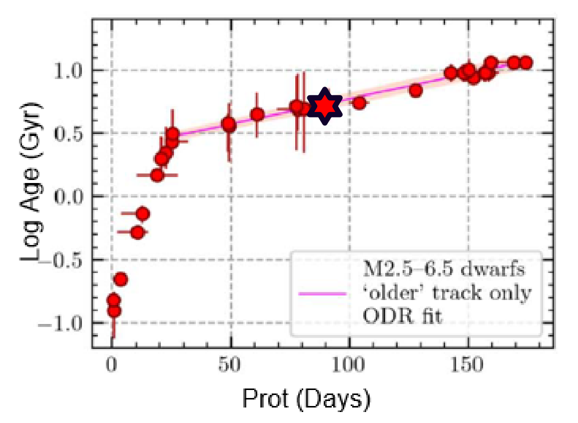
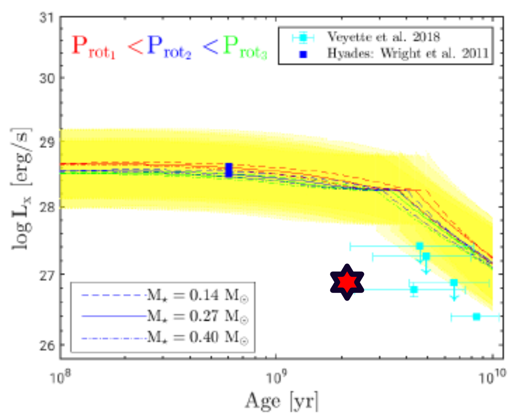


Engle+ 2023

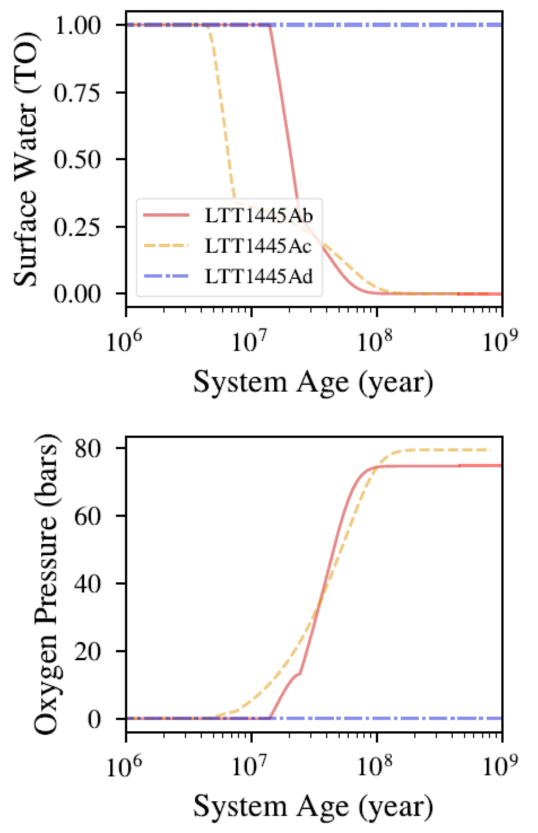




Magaudda+ 2020

Water loss & Oxygen Build-up

- ☐ A's age estimated ~2 Gyr
- ☐ Surface water of 1.0 Terrestrial Ocean



Rukdee+ 2024

Summary

We encourage using C-stat for the low-count data.

We use BXA to connect the X-ray spectral analysis environments Xspec/Sherpa to the nested sampling algorithm UltraNest’ and the plasma model with temperature distribution (BXA-plasma) for

- systematically analyzing a large data set
- comparing multiple models
- analyzing low counts data with realistic models

X-ray irradiation causes abiotic O_2 build-up in the atmosphere

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