Magnetic Activity and Flares in the Near-UV of Exoplanet Host Stars

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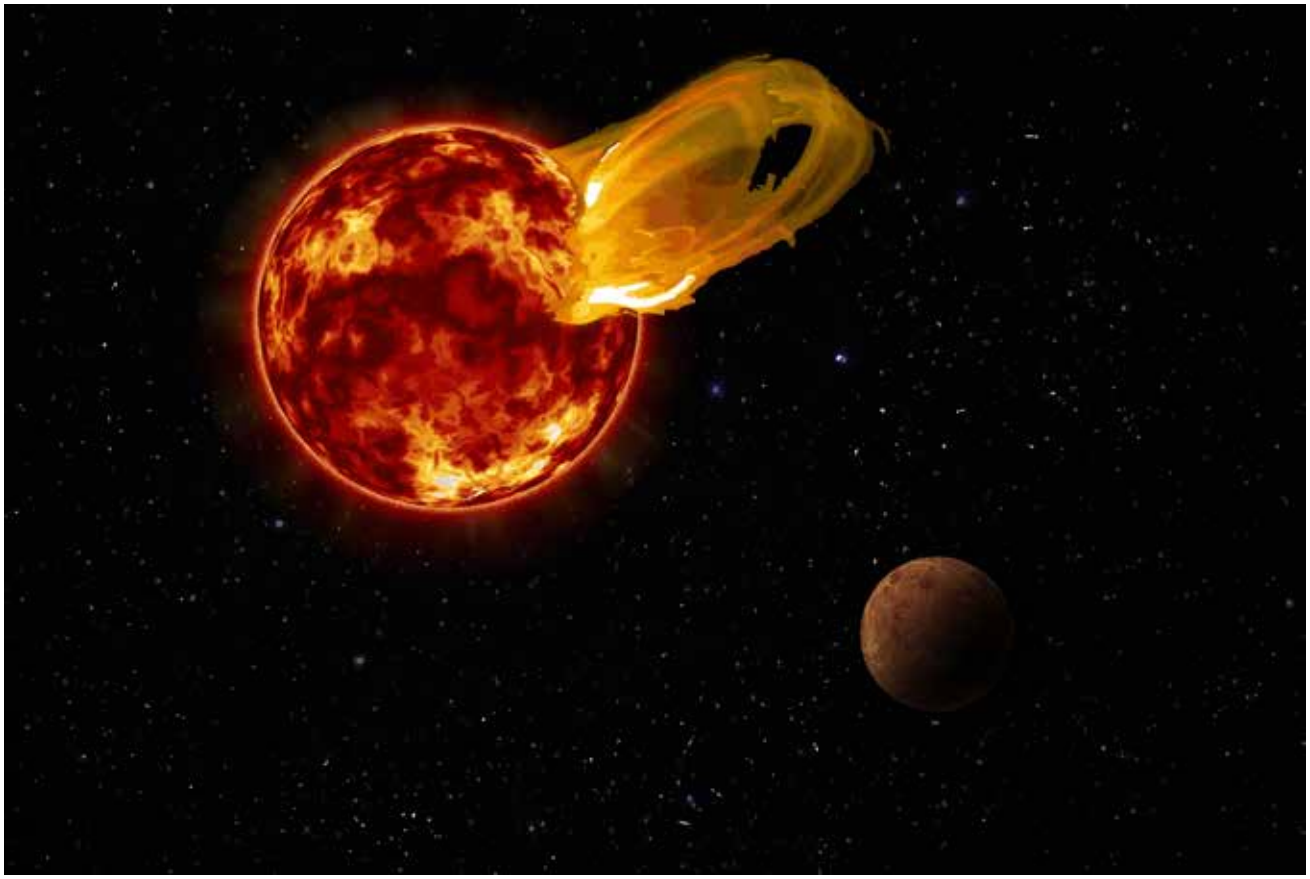


Overview

- Overview of M dwarfs
- Flares from magnetically active M dwarfs (dMe stars)
- NUV flare properties: what's known and not known
- What new simulations with electron beam heating predict

-- 1/3 R_{Su}

-- T_{eff} ~ 2

-- L<1/10

-- Habit

-- fully co

-- 70% of

-- P_{rot} < 3

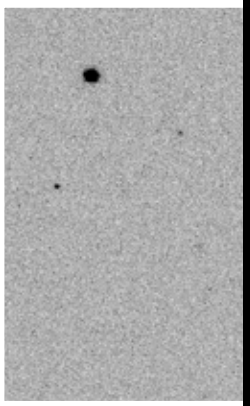
-- dMe =

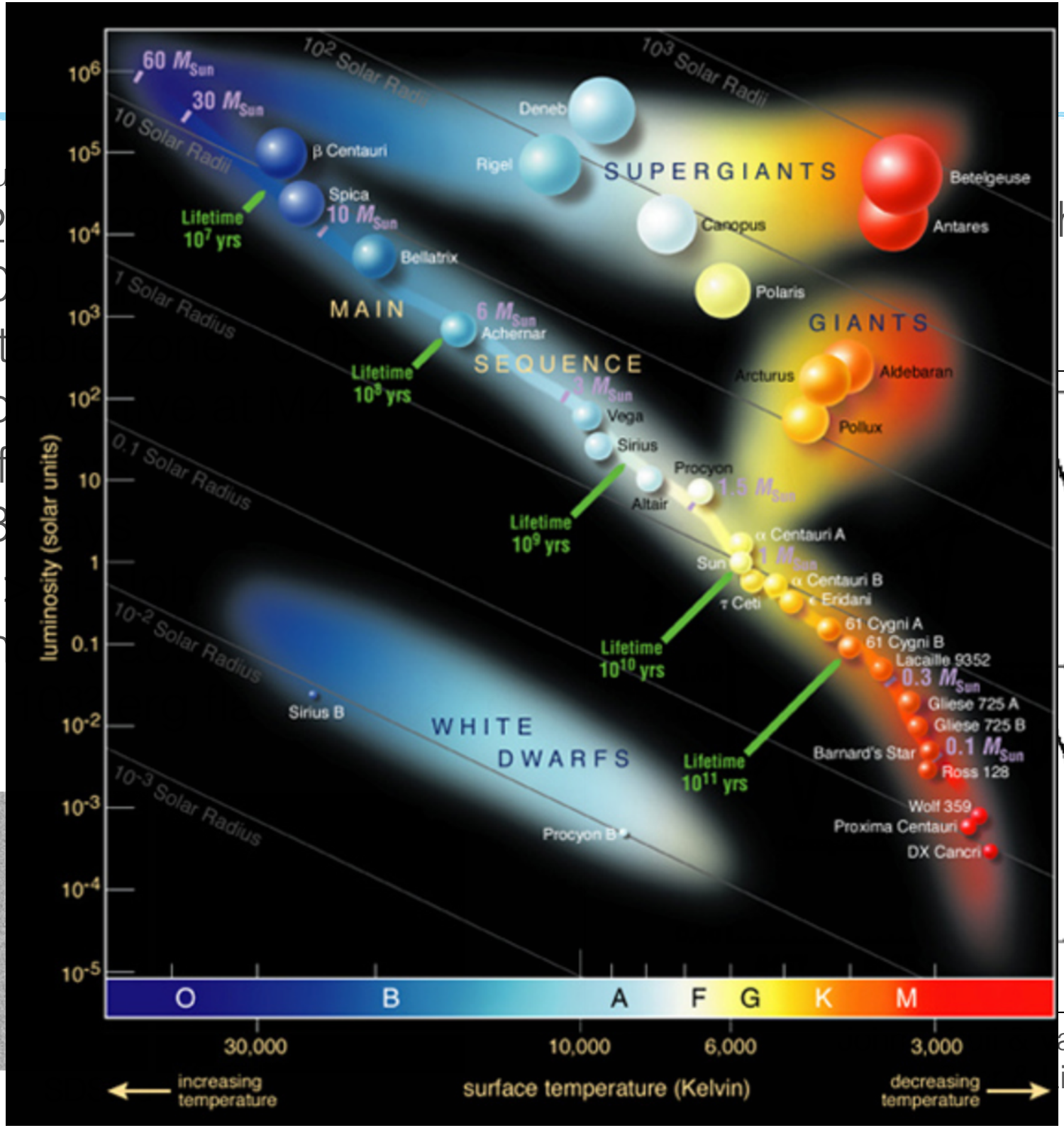
quiescen

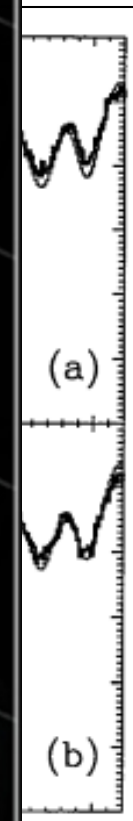
-- rate of

heric

50% of



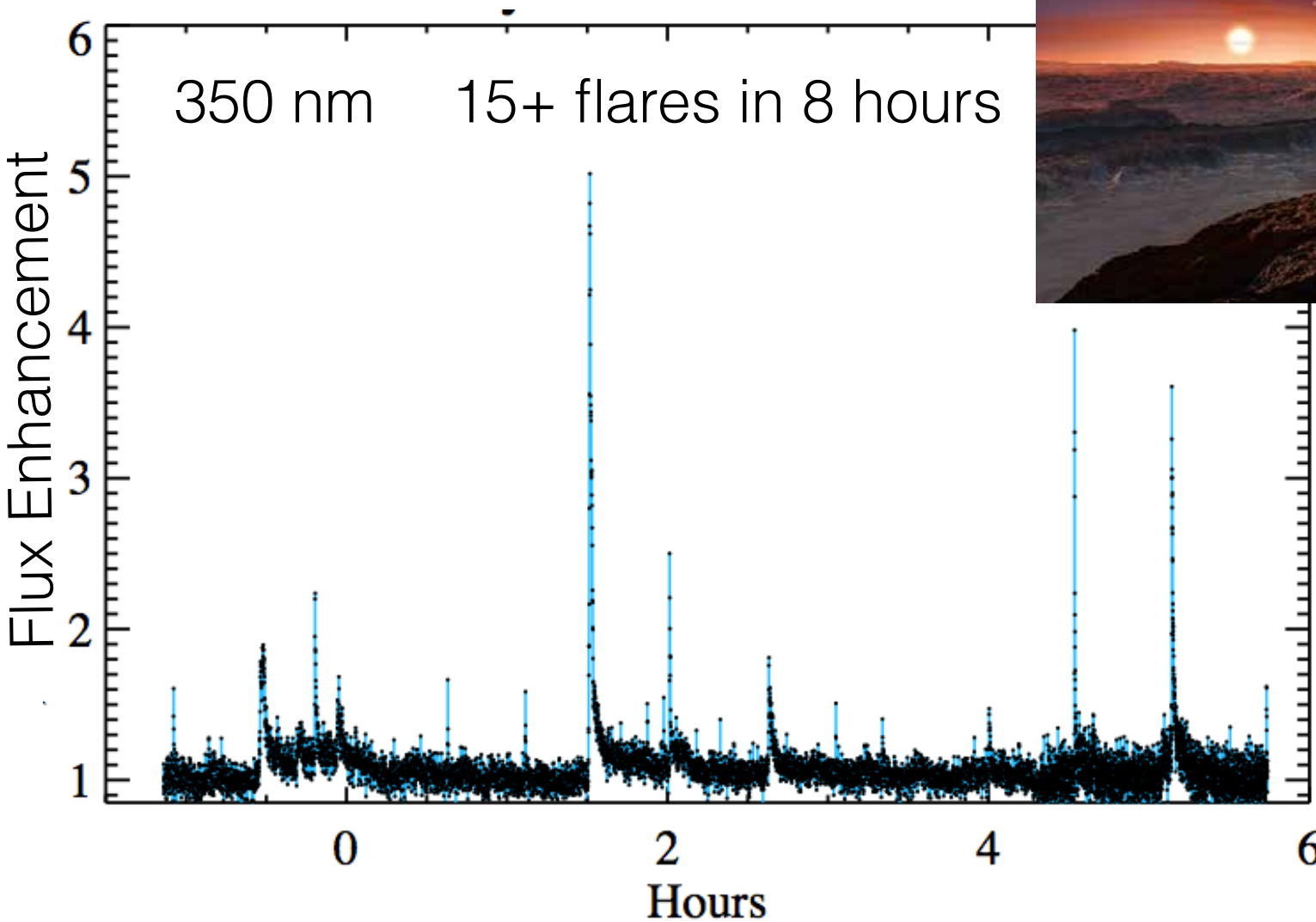




alenti 1996

insky 1985

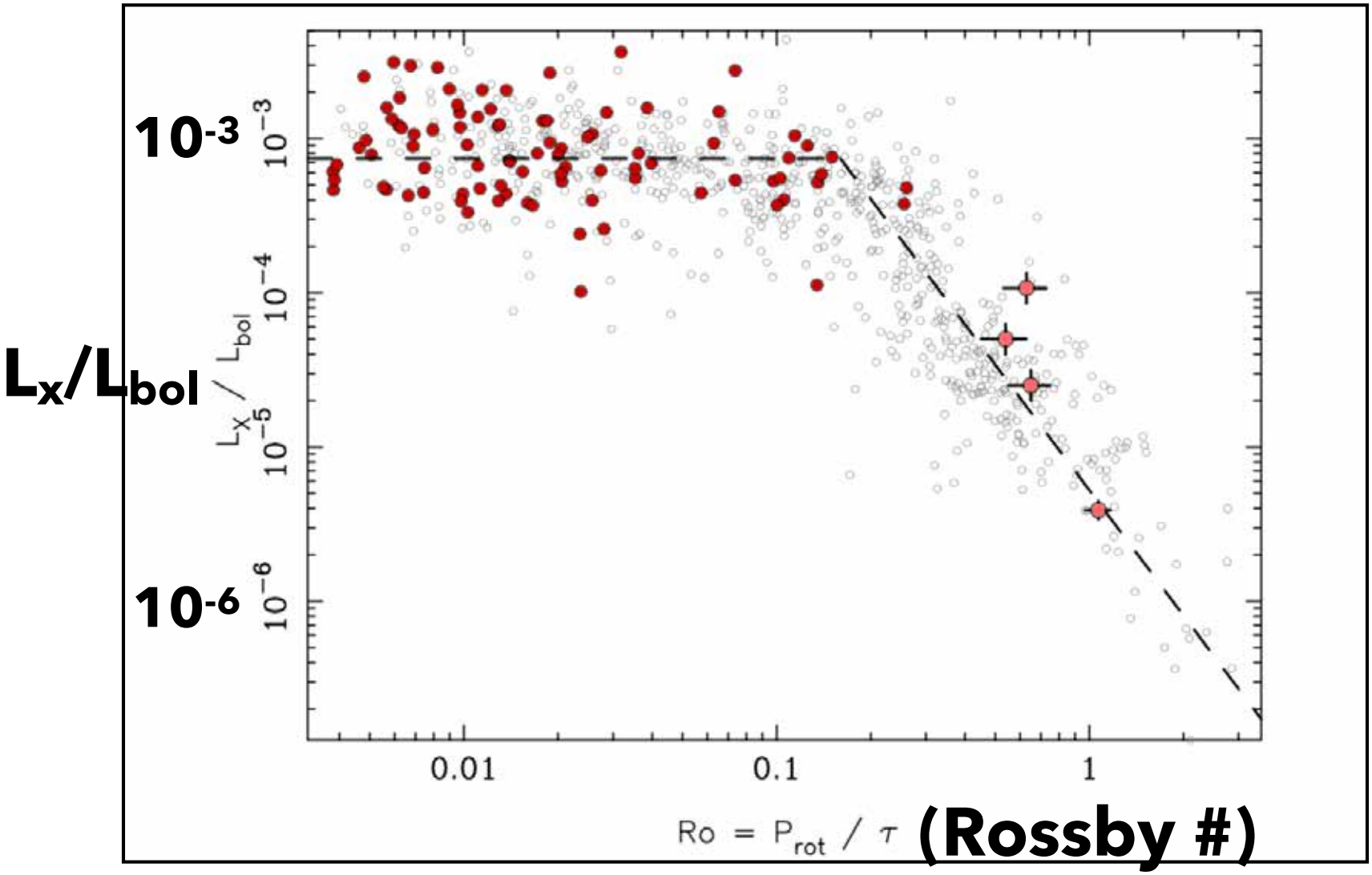
The Flares of Proxima Centauri



We observe red dwarf stars for flares for a similar reason that we observe them for planets

Kowalski, Mathioudakis et al. 2016, ApJ
3.6m NTT at La Silla Observatory

Magnetic activity saturation in M dwarfs

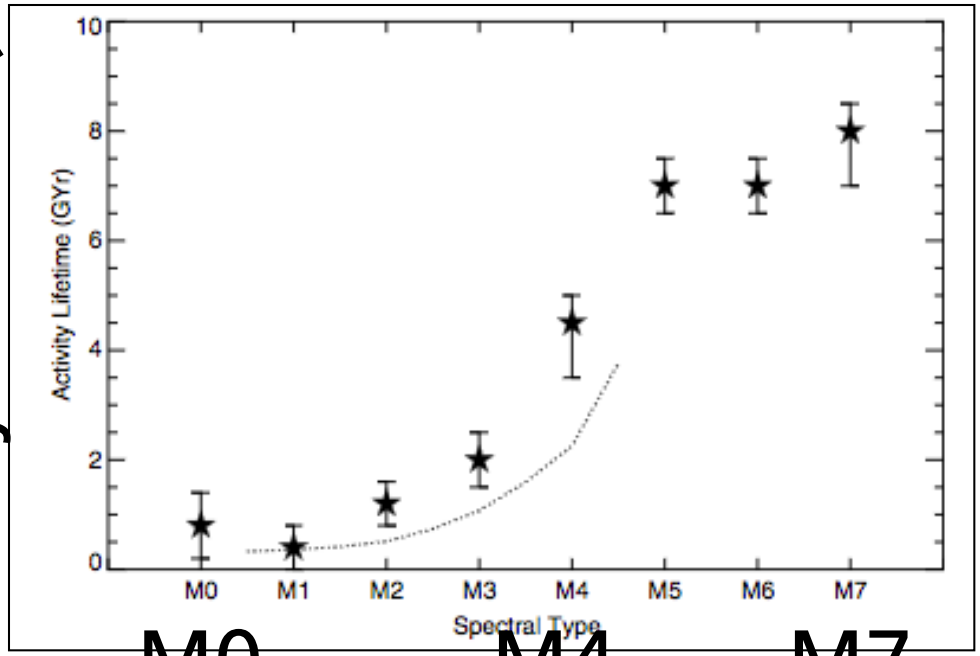


Wright & Drake 2016 Nature

Active M dwarf (dMe) Stars

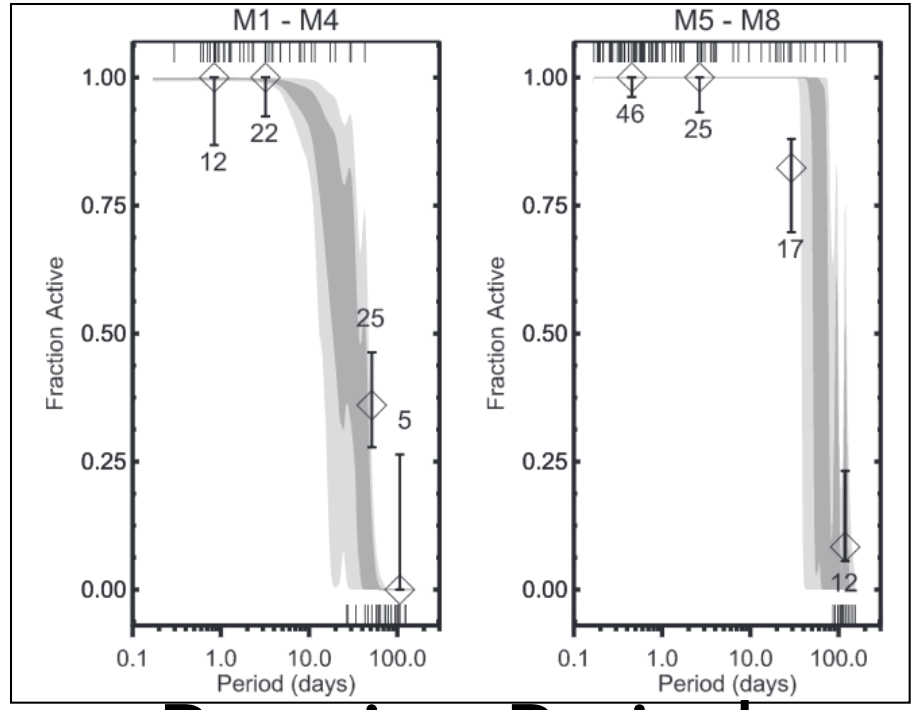
Long activity lifetimes (according to H-alpha)

Activity lifetime (Gyr)



M0 M4 M7

West et al. 2008



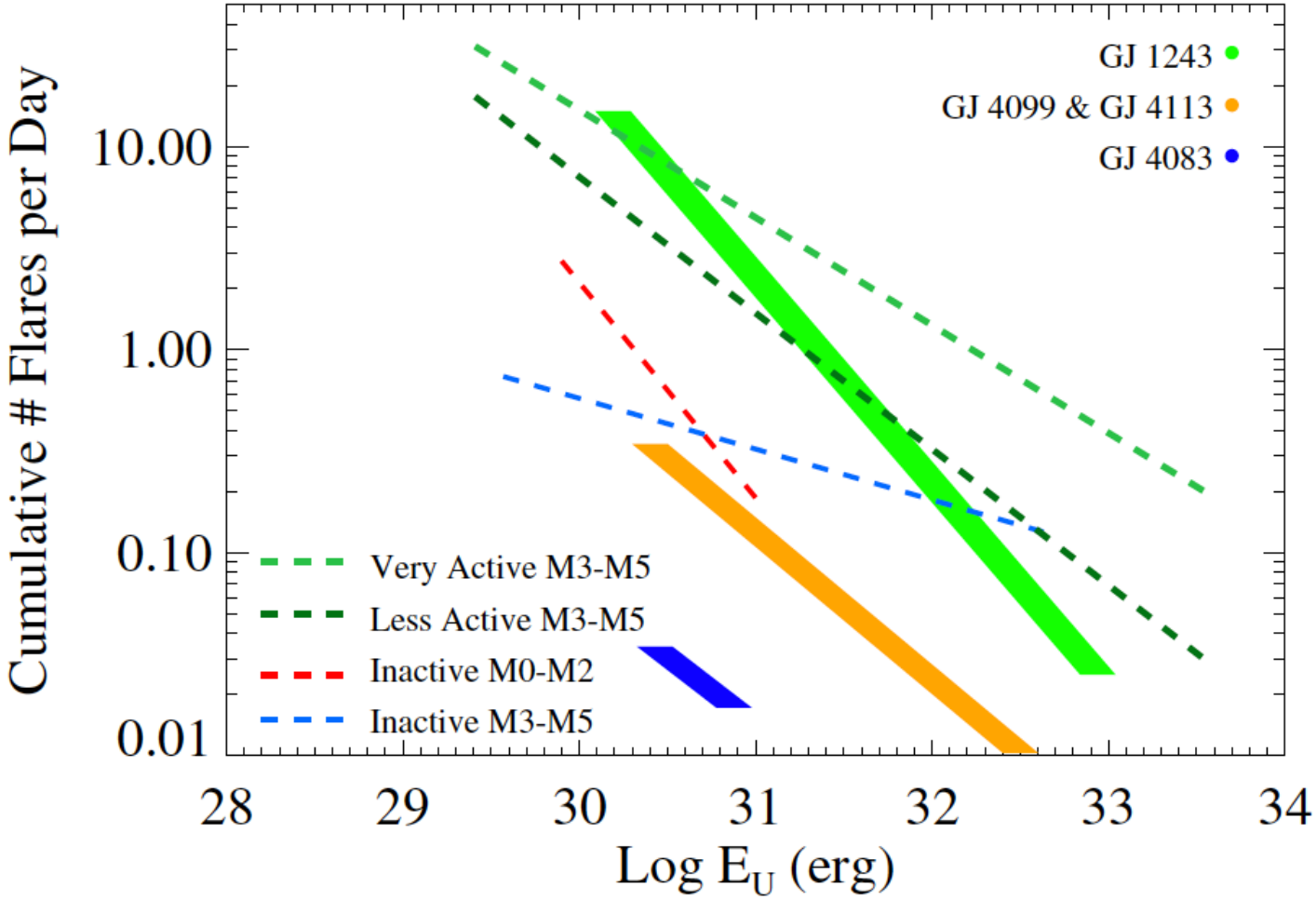
Rotation Period

West et al. 2015

Late type (M5-M8) dwarfs stay active also for long rotation periods

Flares Rates of Active vs. "Inactive" M dwarfs

Flare rate varies among active stars, from active to inactive

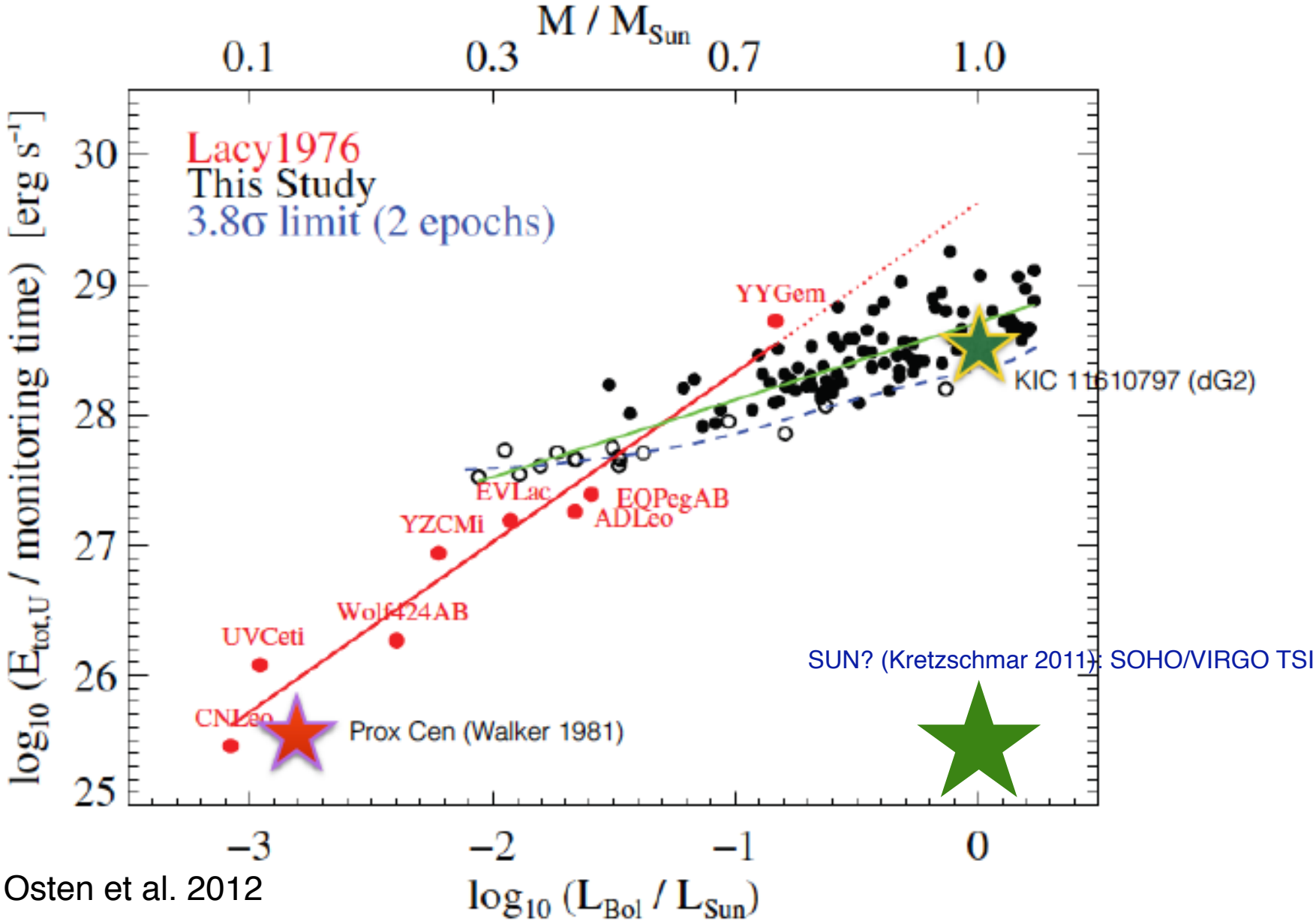


Hawley et al. 2014

Inactive M stars also produce energetic flares (Paulson et al. 2006, Kowalski et al. 2009, Hilton 2011, France et al. 2016)

Average flaring luminosity in U increases with non-flaring stellar luminosity

Total flare energy / total monitoring time

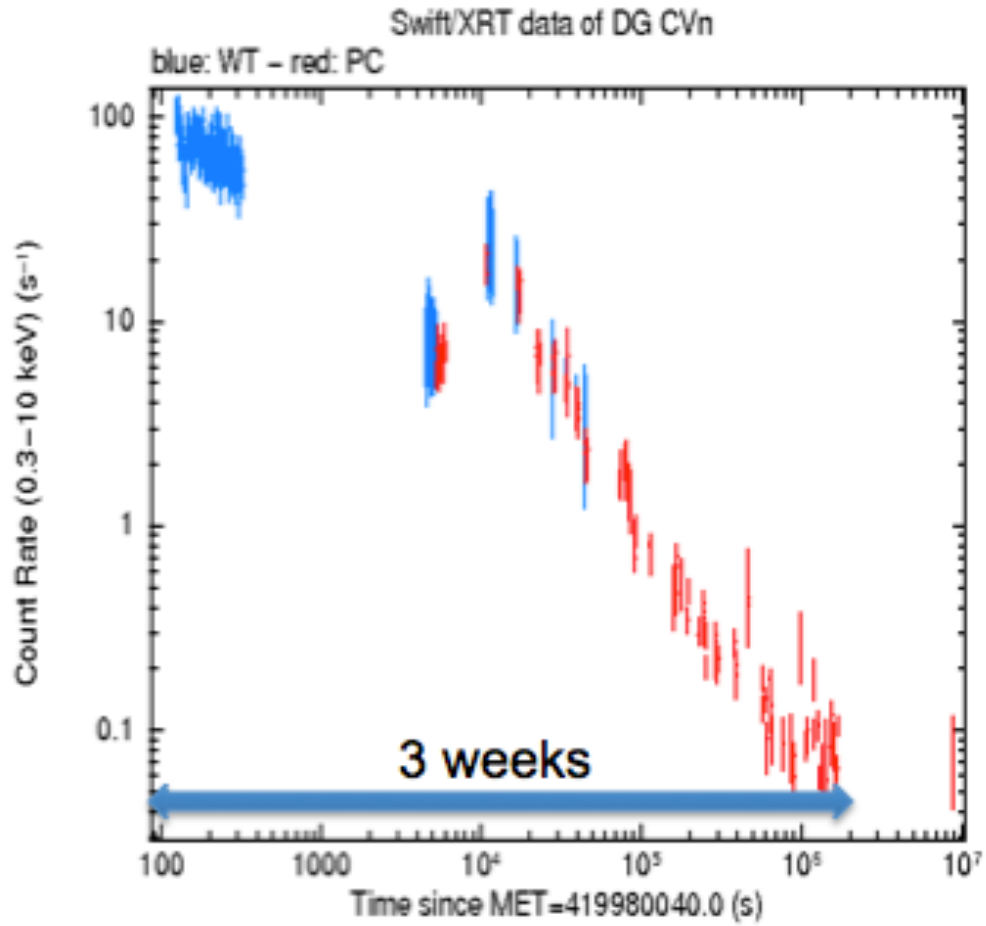


Osten et al. 2012

Swift BAT Triggered on Large Stellar X-Ray Flare

DG CVn is pair of M4 V stars at ~18 pc believed to be very young ~ 30 Myr

DG CVn flared on April 23, 2014



Swift XRT soft X-ray light curve of DG CVn flare (note that both axes are logarithmic!)

Osten et al. 2016 ApJ

- Record "super-flare" for solar neighborhood M dwarf star
- **Peak V-band increase 200x; X-ray super bolometric luminosity**
- Peak X-ray temperature of 300 MK is ~ 10 x solar flare T_{Peak}
- Total flare energy 10^{36} erg is 10^3 x largest solar flare energy
- Flare decay time is 2-3 weeks

Is Prox Cen b habitable?

- 5×10^{29} erg (total) vs. 5×10^{30} erg (total) for Sun
- Can occasionally produce 10^{32} erg flares (Gudel et al. 2002)
- Inverse square law for habitable zone: 400x irradiance

Overview

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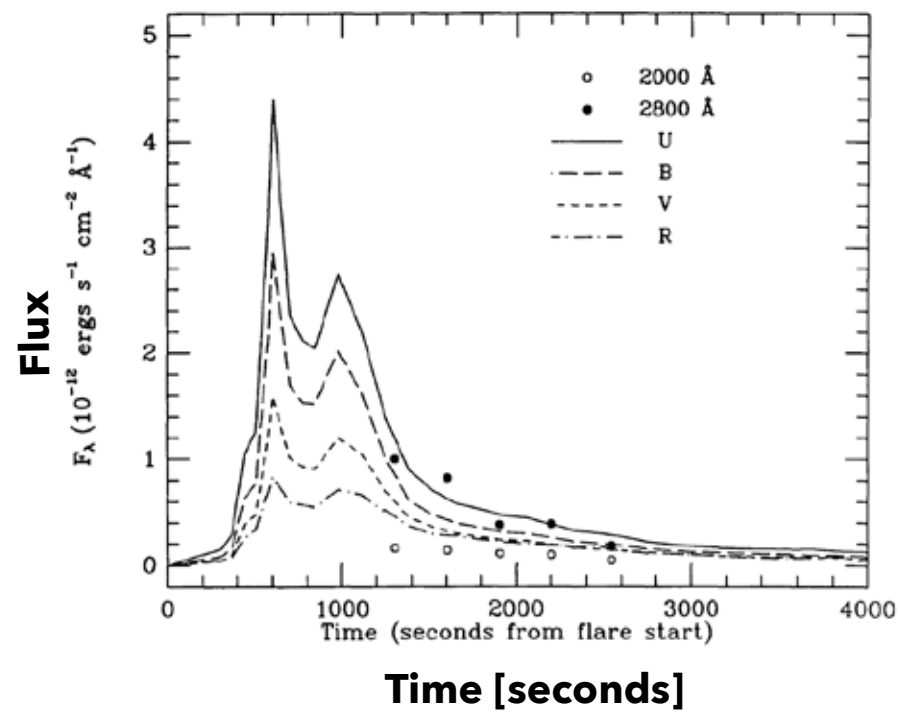
- Flares from active M dwarfs (dMe stars)
- <u>NUV flare properties: what's known and not known</u>
- What new simulations with electron "beam" heating predict

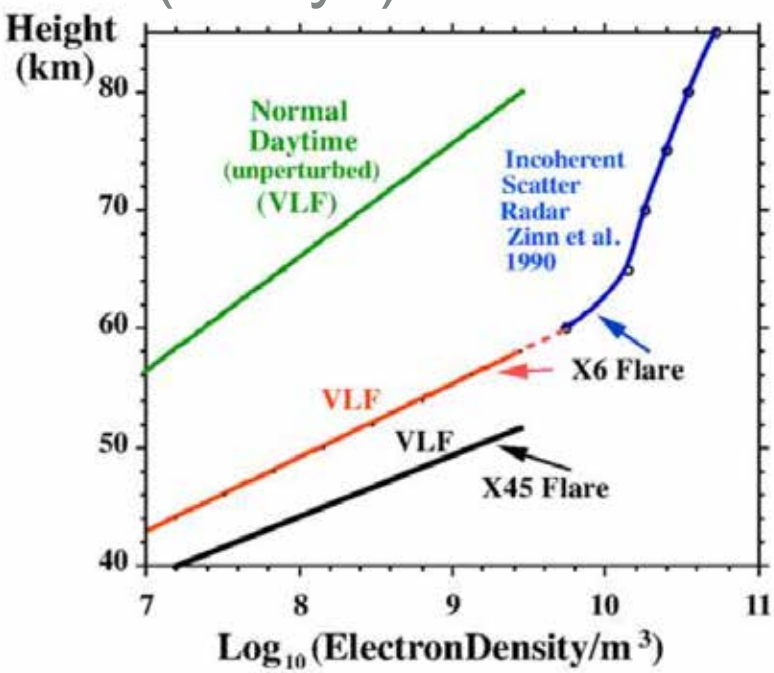
Basic Facts of Giant NUV Flares

- The Great Flare of AD Leo: Hawley & Pettersen 1991, Hawley & Fisher 1992
  - 45% of 120 - 820 nm energy in NUV from 200 - 400 nm
  - like a T ~ 9000 - 10^4 K blackbody
  - 90% energy in flare continuum (Hawley & Pettersen 1991), but can vary (Hawley et al. 2007, Kowalski et al. 2013)



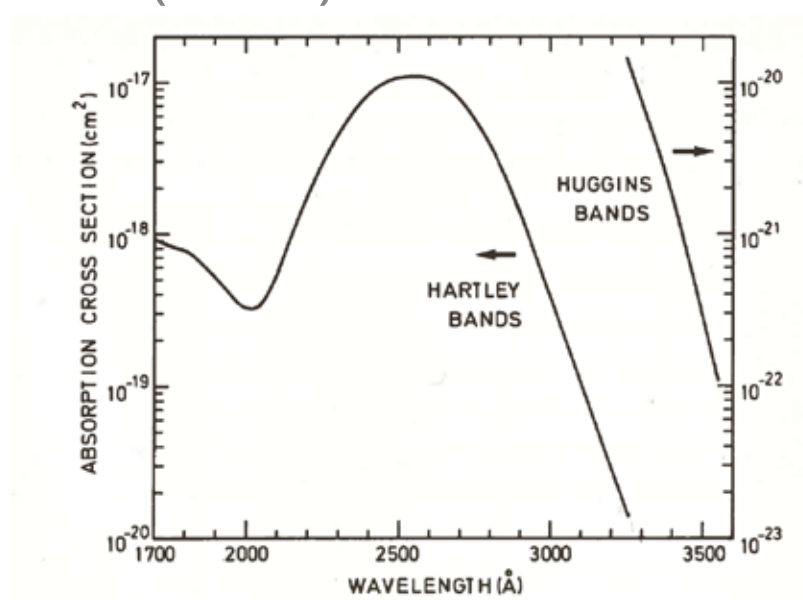
Flare irradiation of planetary atmospheres

- Ionization of D region (X-rays)



Thomson et al. 2005

- Ozone photodissociation (NUV)

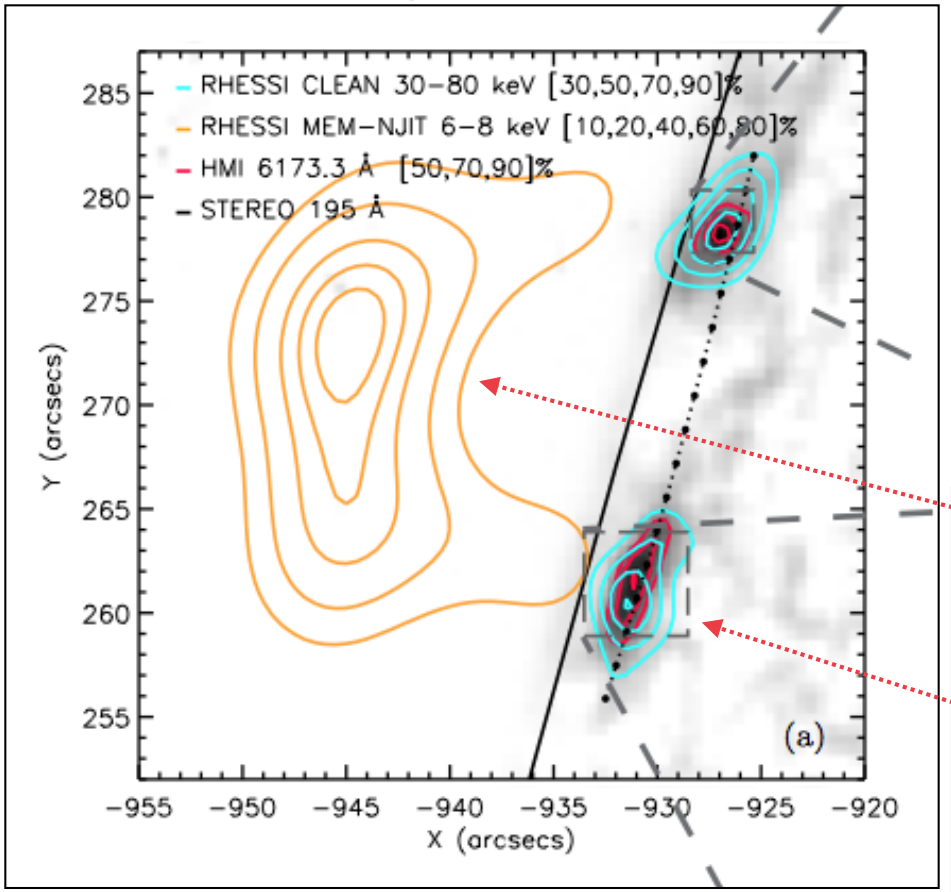


Banks & Kockarts 1973, Aeronomy
Ackerman 1971

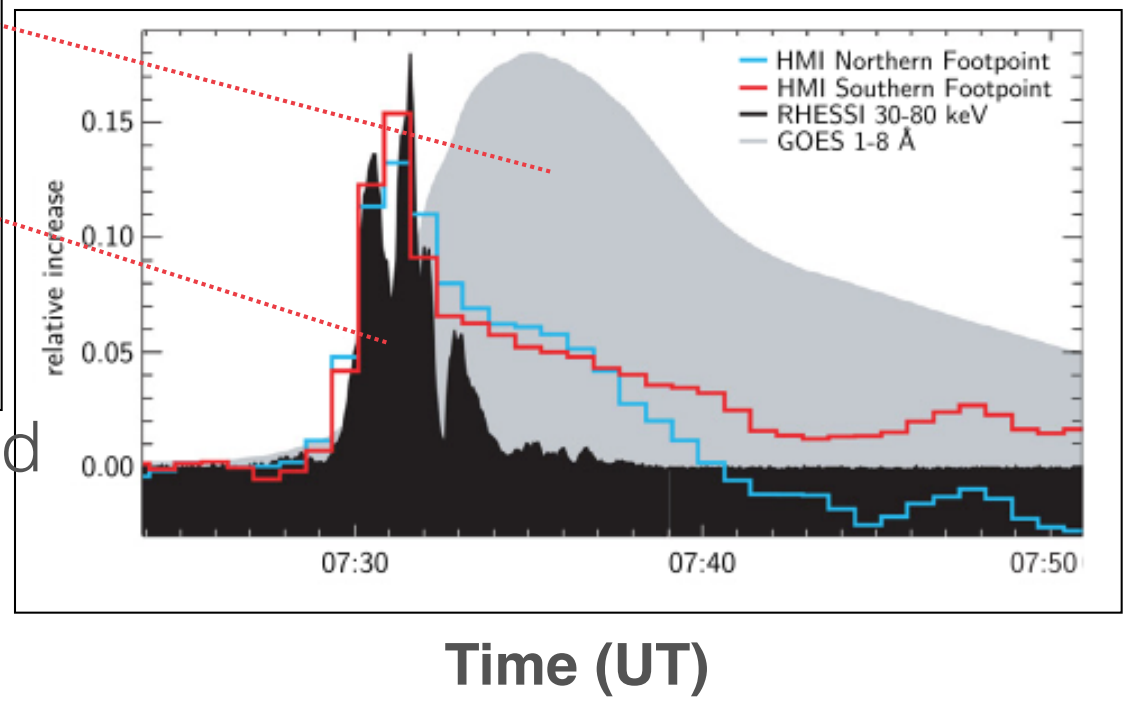
- EUV and Lyman-alpha also v. important (Milligan et al. 2014)

Solar Flares

- white-light: broadband (optical & NUV) impulsive radiation coinciden in time and space with (nonthermal) X-rays (E> 20 keV)

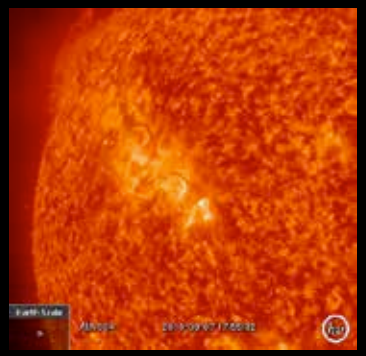


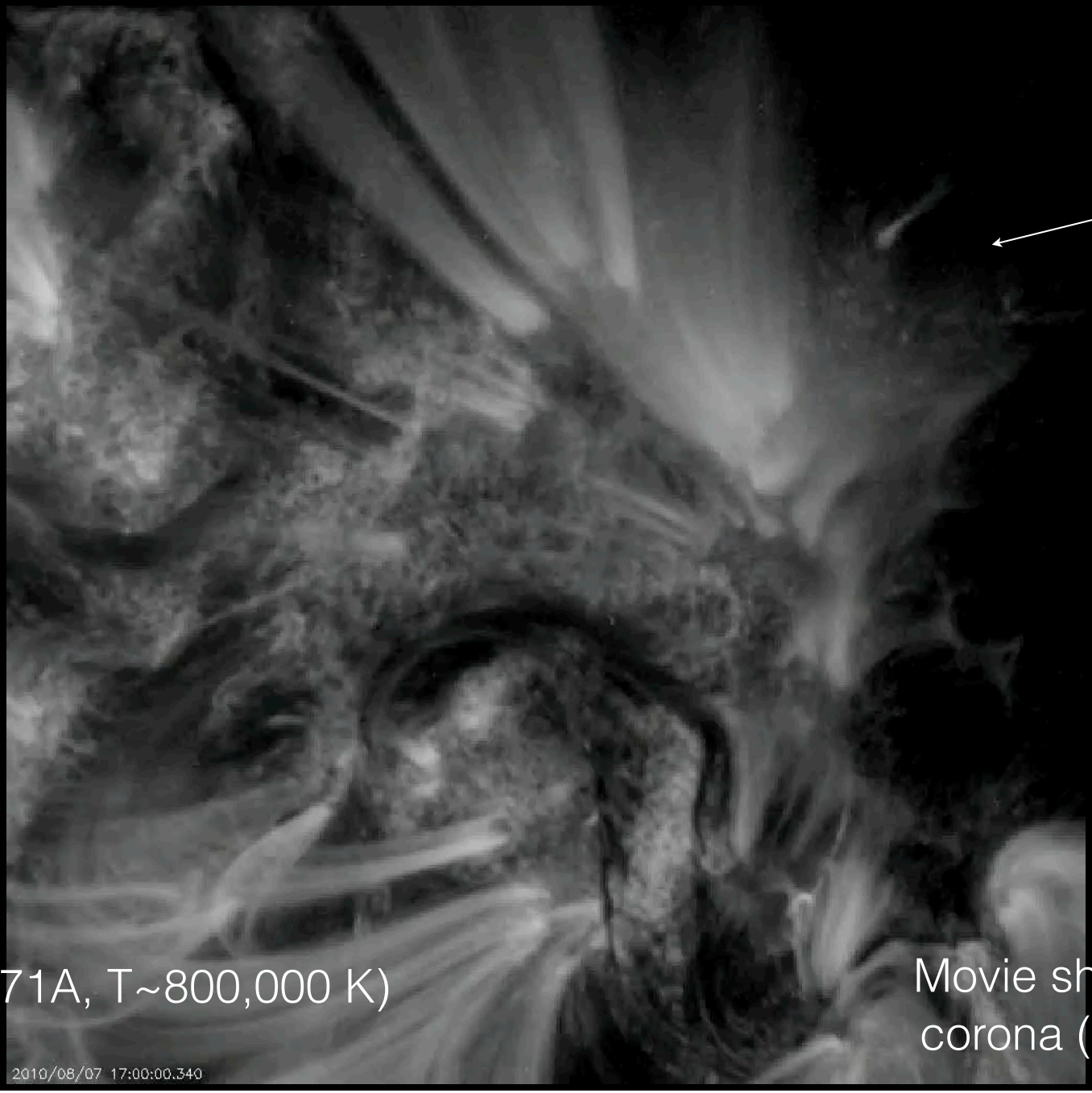
Observations of limb solar flares (Martinez-Oliveros et al. 2012, Krucker et al. 2015)



- white-light: spatially confined to "footpoints"
- soft (thermal) x-rays: hot loops

A Two-Ribbon Solar Flare





X

M

C

B

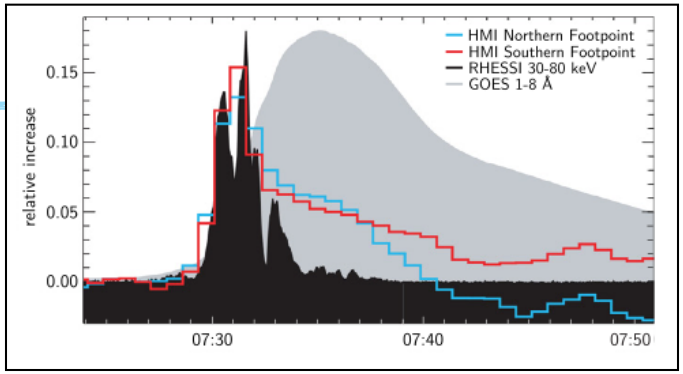
SDO/AIA (171A, T~800,000 K)

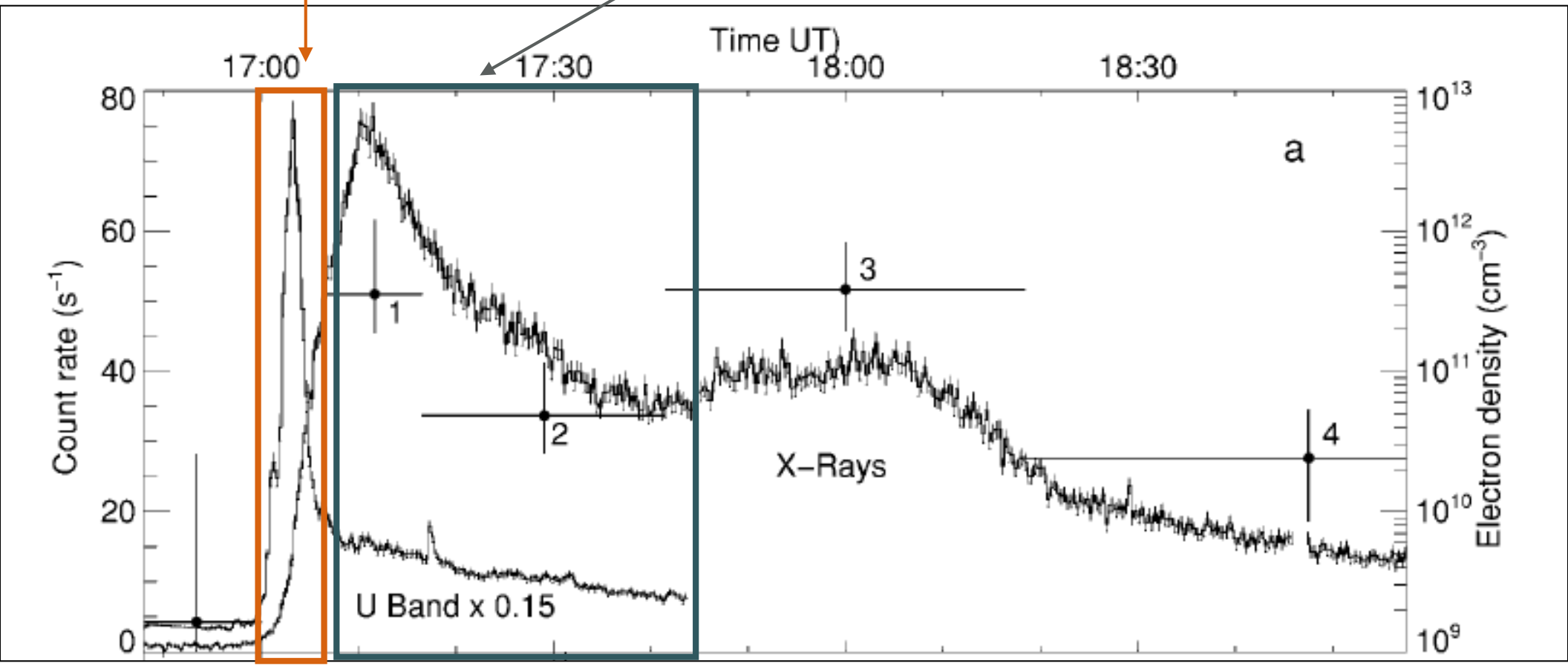
Movie showing lower corona (from above)

The solar-stellar connection

Impulsive phase (U-band is white-light, proxy for hard X-rays), 10,000 K “footpoints”

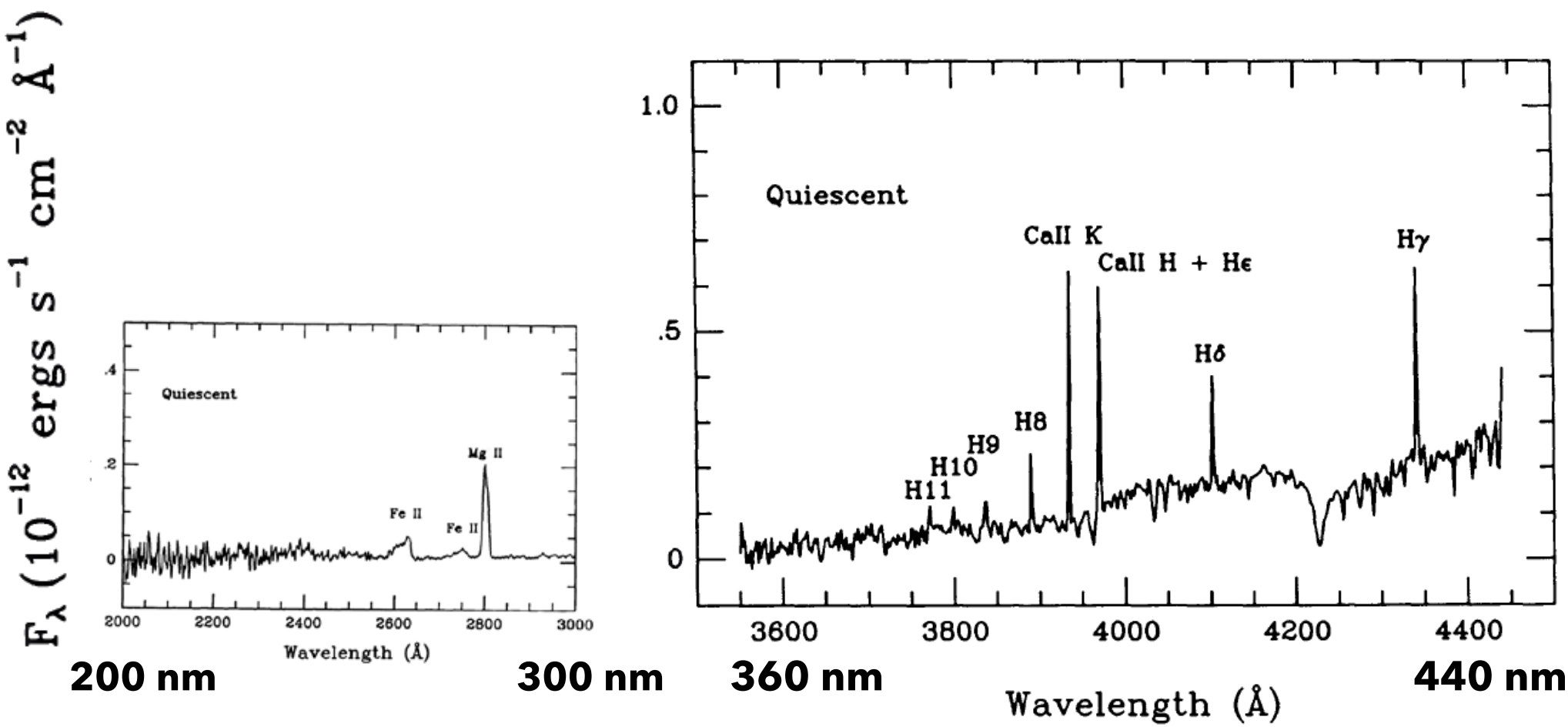
Gradual phase (bright soft X-rays), 10-30 MK “loops”





Gudel et al. 2002 (flare on dM5.5e Proxima Centauri)

The Near-UV in Quiescence

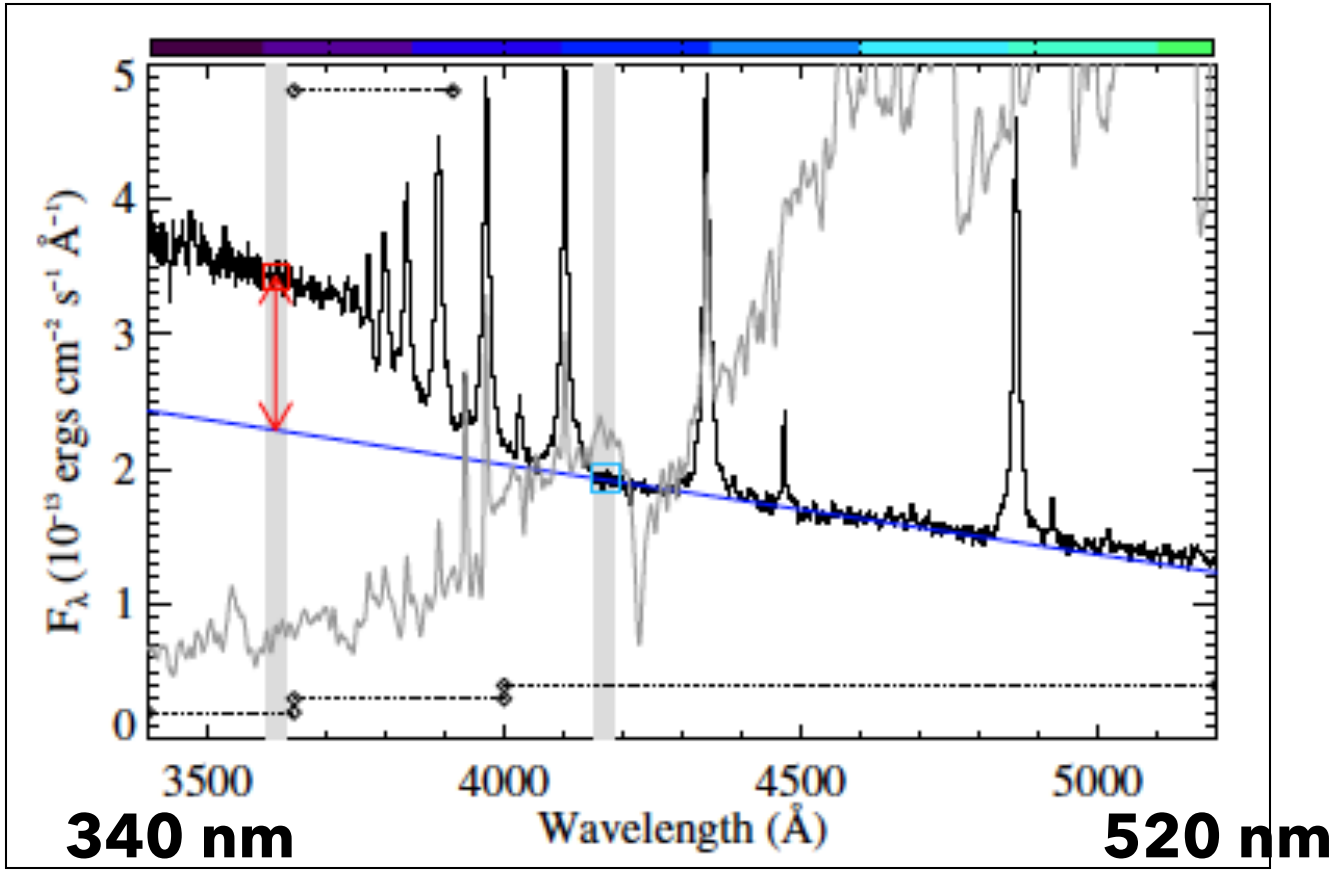


Hawley & Pettersen 1991

NUV/Blue Flare Spectra at Balmer jump

How we compare to models:

- Measure the **Balmer jump ratio** = F_{3600} / F_{4170}
- Measure a blue-to-red continuum ratio = F_{4170} / F_{6000}

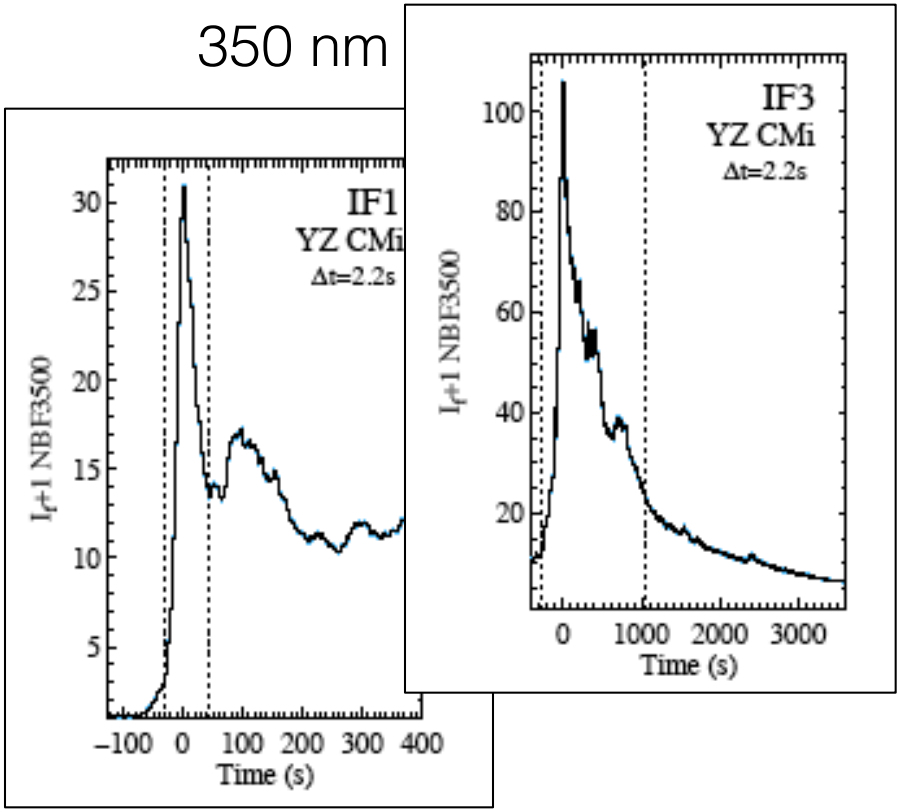


M dwarf flare spectra; Kowalski et al. 2013

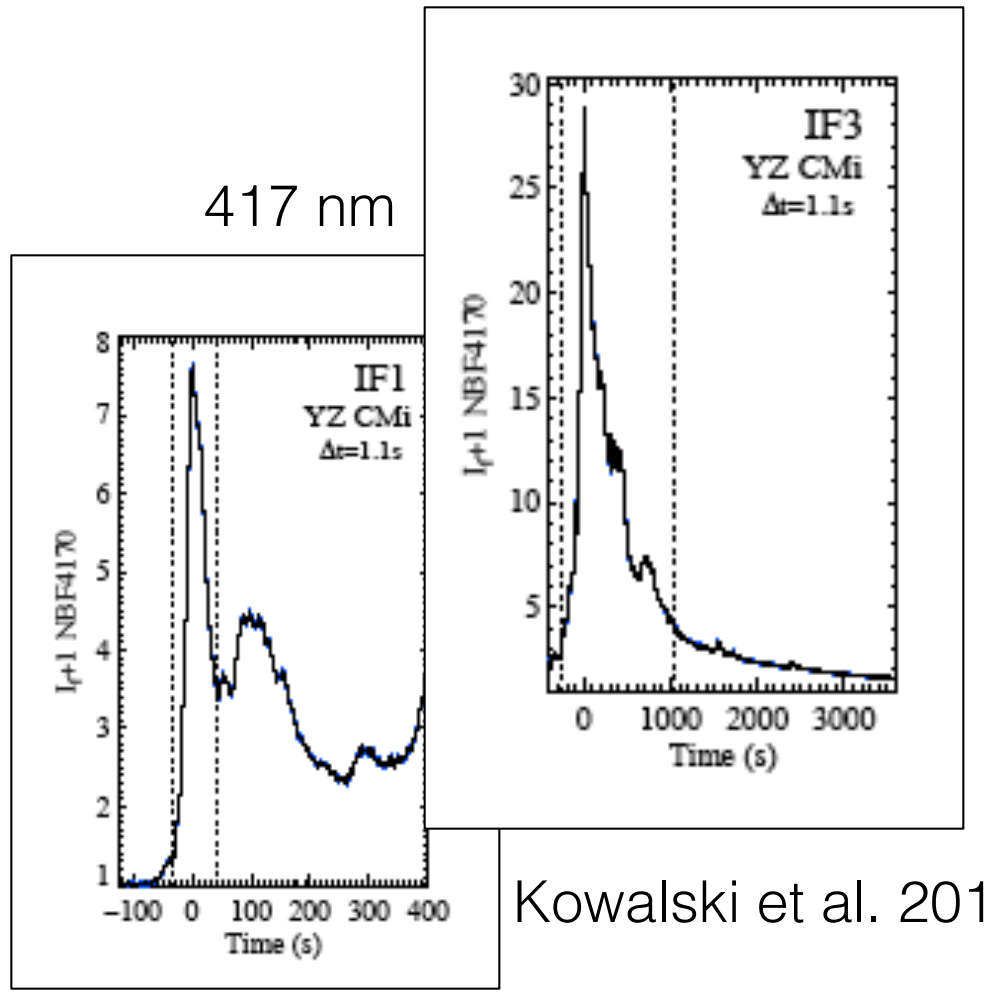
Balmer jump ratio time evolution

ULTRACAM light curves of flares on YZ CMi

350 nm



417 nm

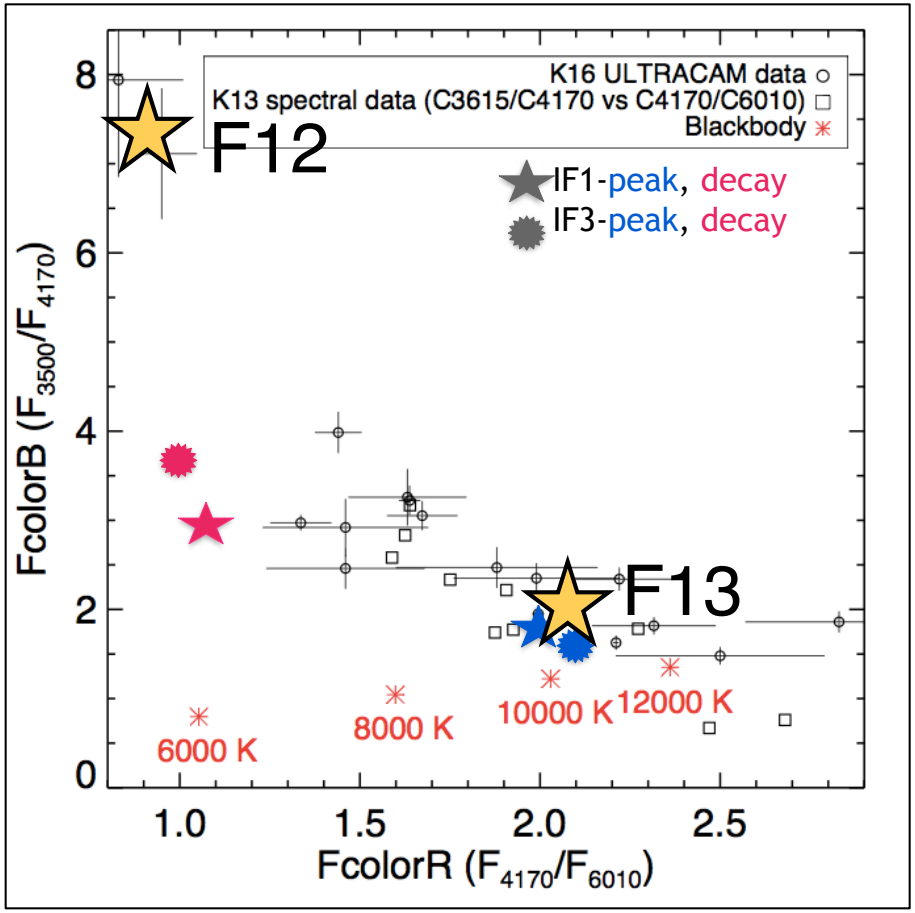


Kowalski et al. 2016

F11

Continuum Flux Ratios Constrain Heating Models

Larger Balmer jump ratio

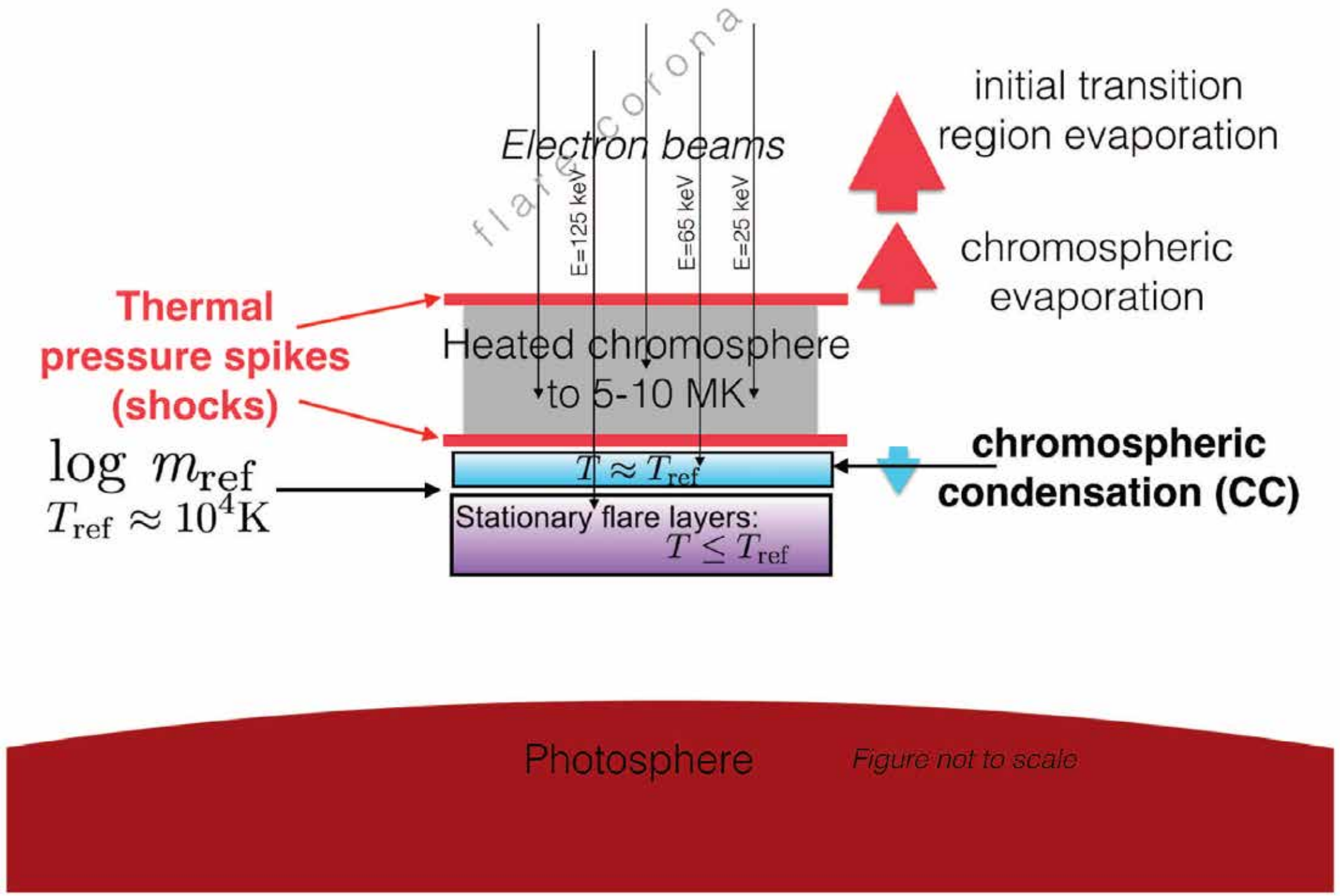


Bluer (hotter) optical continuum

- Models calculated with the 1D RADYN flare code (Carlsson & Stein 1997, Allred et al. 2015)

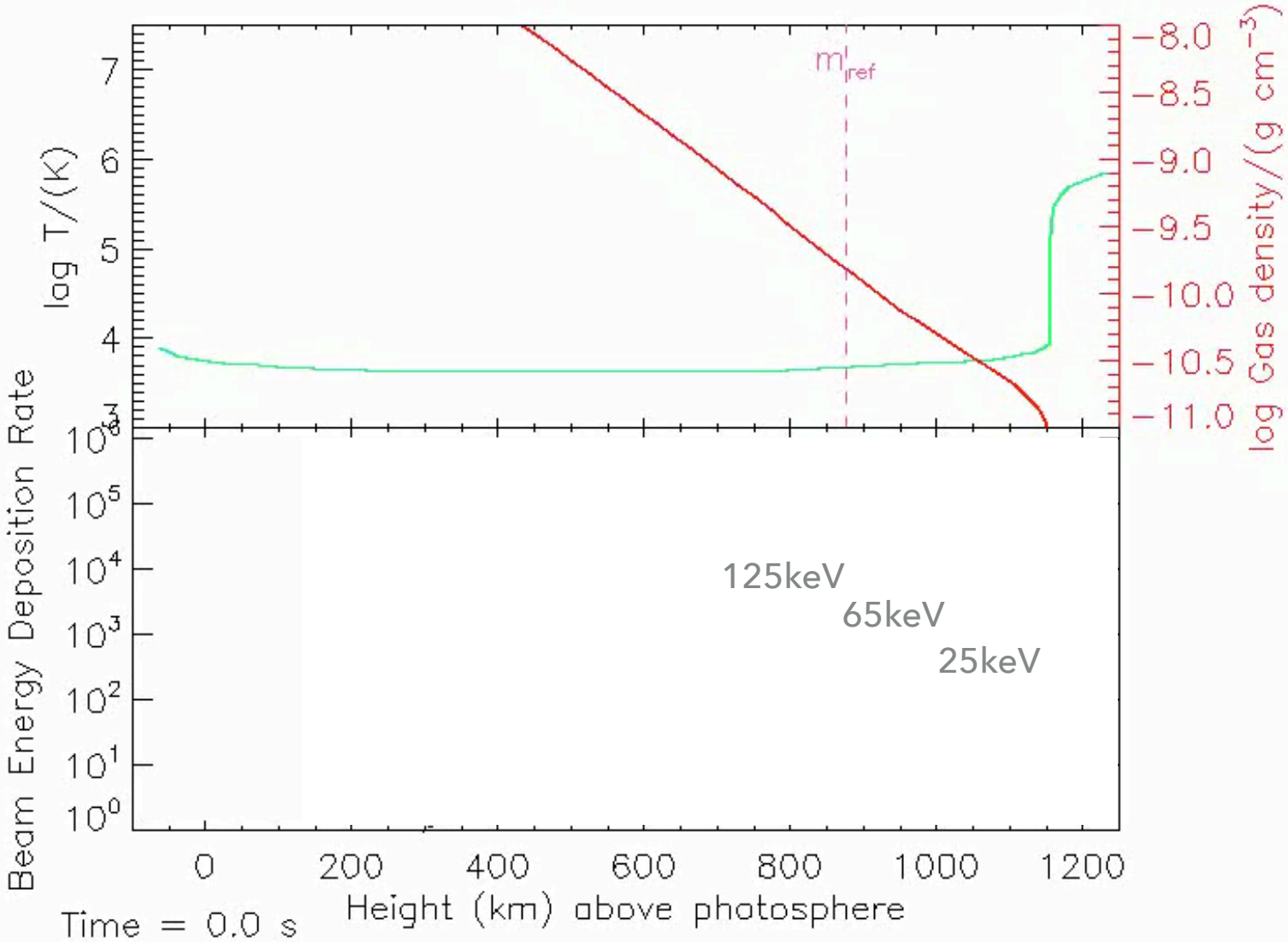
F# = energy flux density

Kowalski et al. 2016



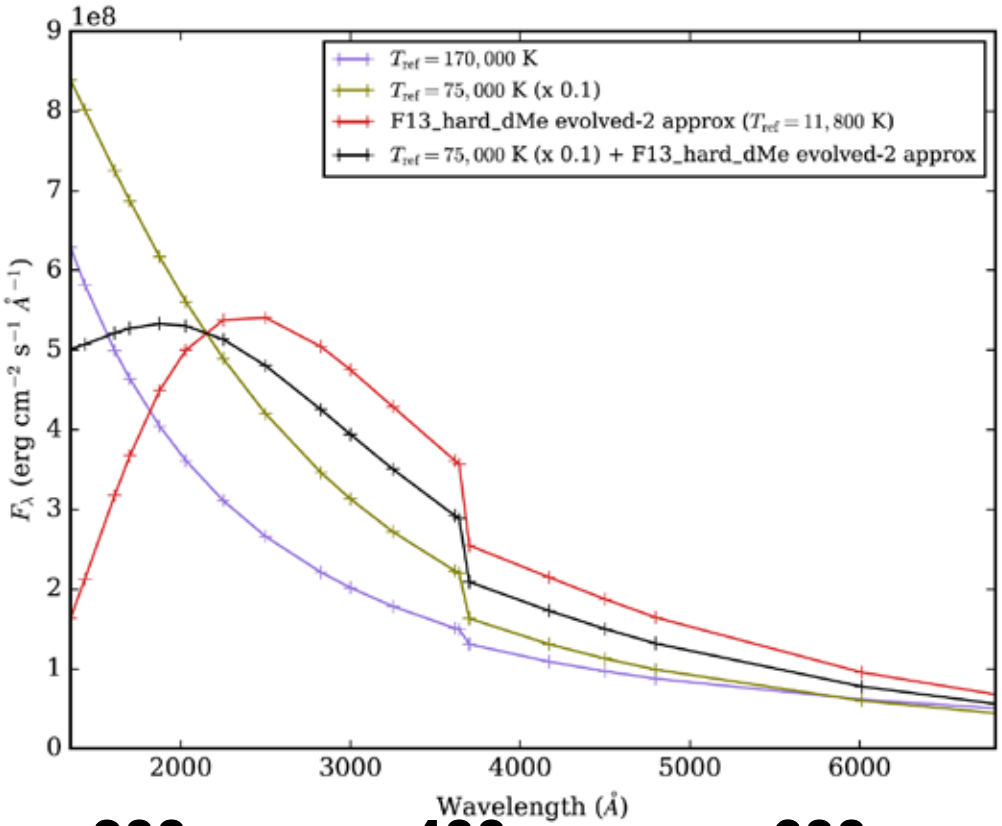
Kowalski & Allred 2018

High electron beam energy flux densities create compressions in the chromosphere, can reproduce continuum and line radiation



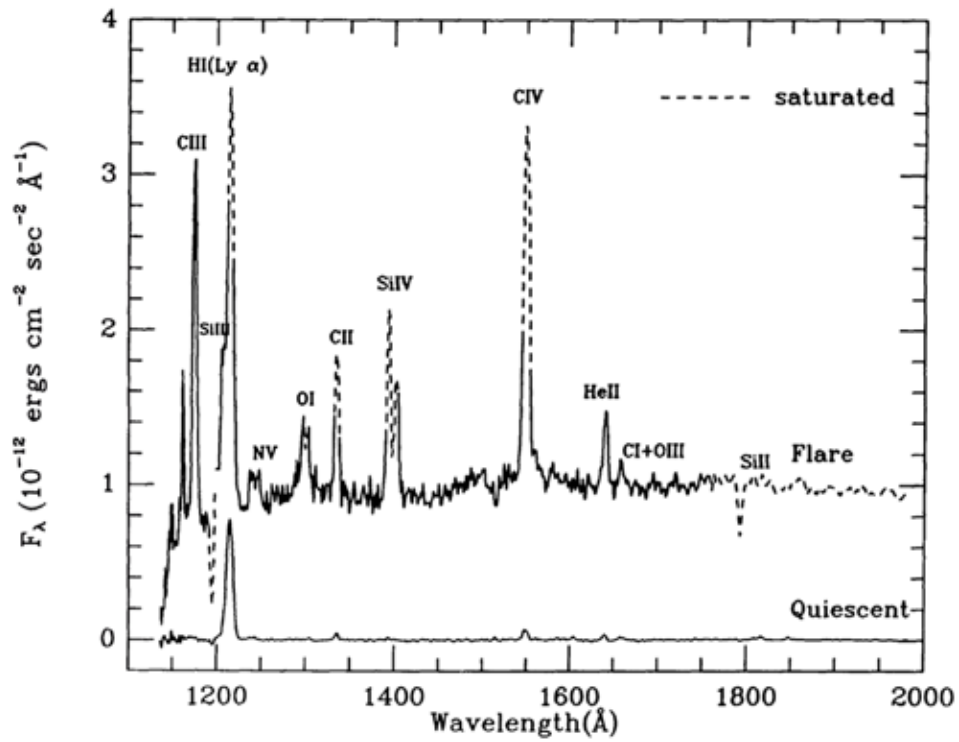
Kowalski et al. 2017, Kowalski & Allred 2018

Where do the flare continuum spectra peak in the NUV?



200 nm **400 nm** **600 nm**

Kowalski & Allred 2018



120 nm **200 nm**

Hawley & Pettersen 1991

Conclusions

- Exoplanet hosts (dM and dMe stars) produce energetic continuum and line radiation during flares in the NUV
- The properties can be reproduced by high-energy flux density electron beams
- Need NUV data of impulsive phase from 200 - 350 nm to understand the origin of this radiation in dM and dMe flares and for comprehensive input to ozone photochemistry models