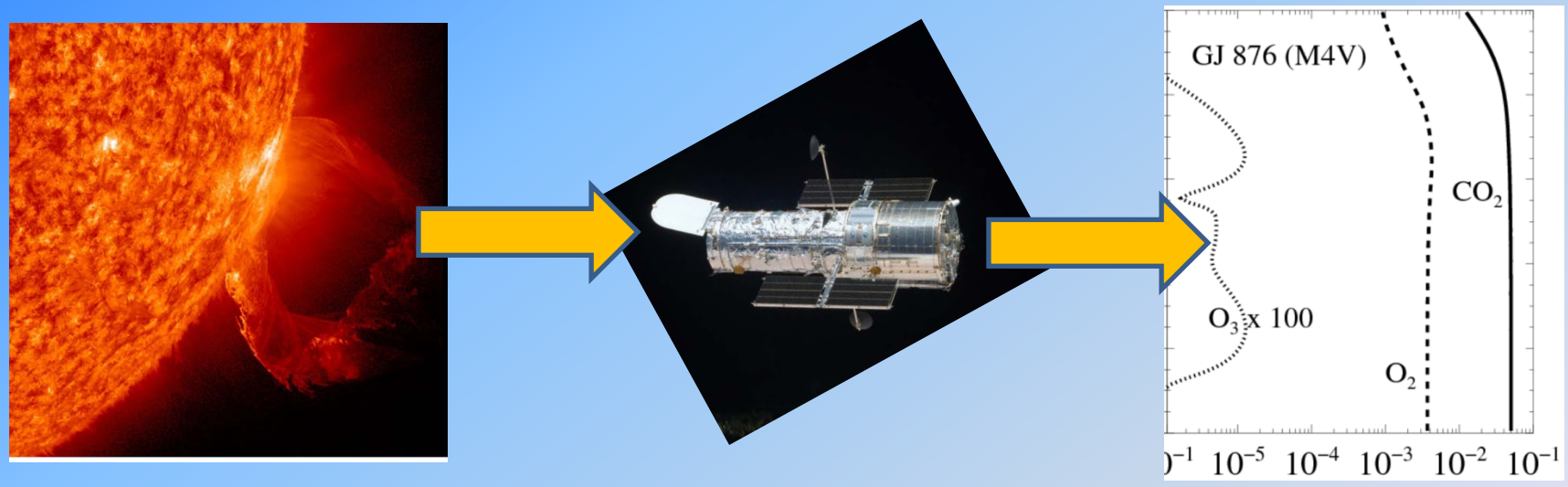
The Ultraviolet Radiation Environment in the Habitable Zones Around Low-Mass Exoplanet Host Stars



Kevin France

University of Colorado at Boulder

NUVA Challenges in UV Astronomy

07 October 2013

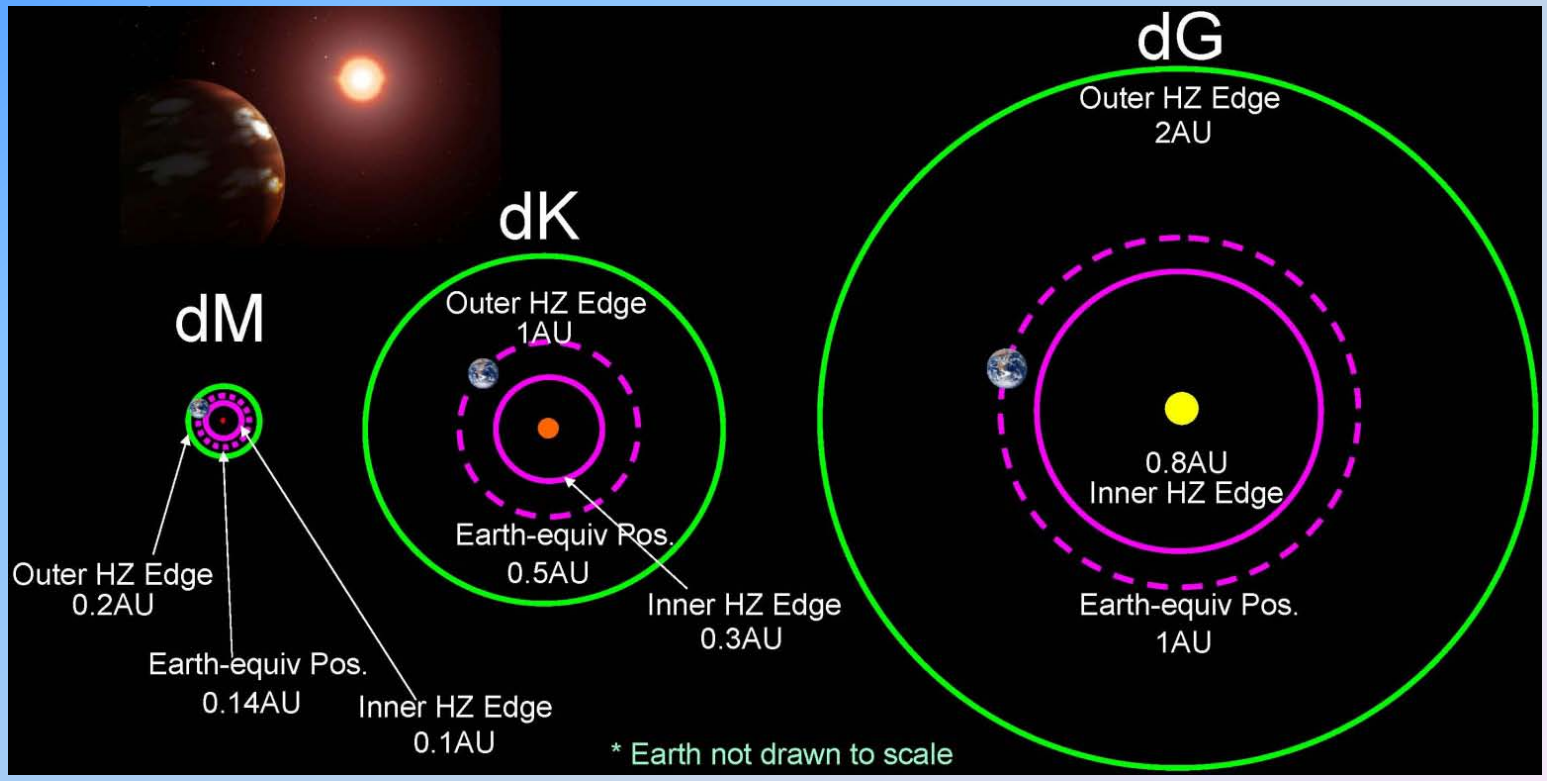
CASA 1985
CENTER FOR ASTROPHYSICS AND SPACE ASTRONOMY

Co-authors

- Jeff Linsky – JILA/Colorado
- Parke Loyd – CASA/Colorado
- Feng Tian – Tsinghua Univ.

Collaborators:
Tom Ayres, Alex Brown, Rachel Bushinsky, Jim Davenport, Shawn Domagal-Goldman, Cynthia Froning, Jim Green, Suzanne Hawley, Sarah LeVine, Pablo Mauas, Aki Roberge, John Stocke, Mariela Vieytes, Lucianne Walkowicz

Heating and Chemistry of Planetary Atmospheres



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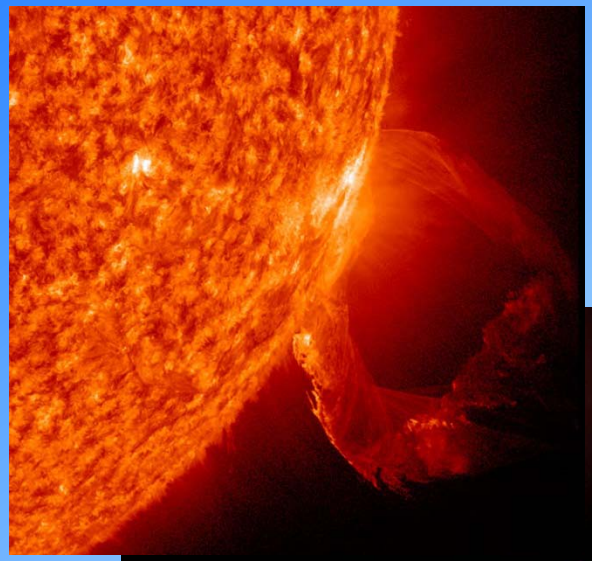
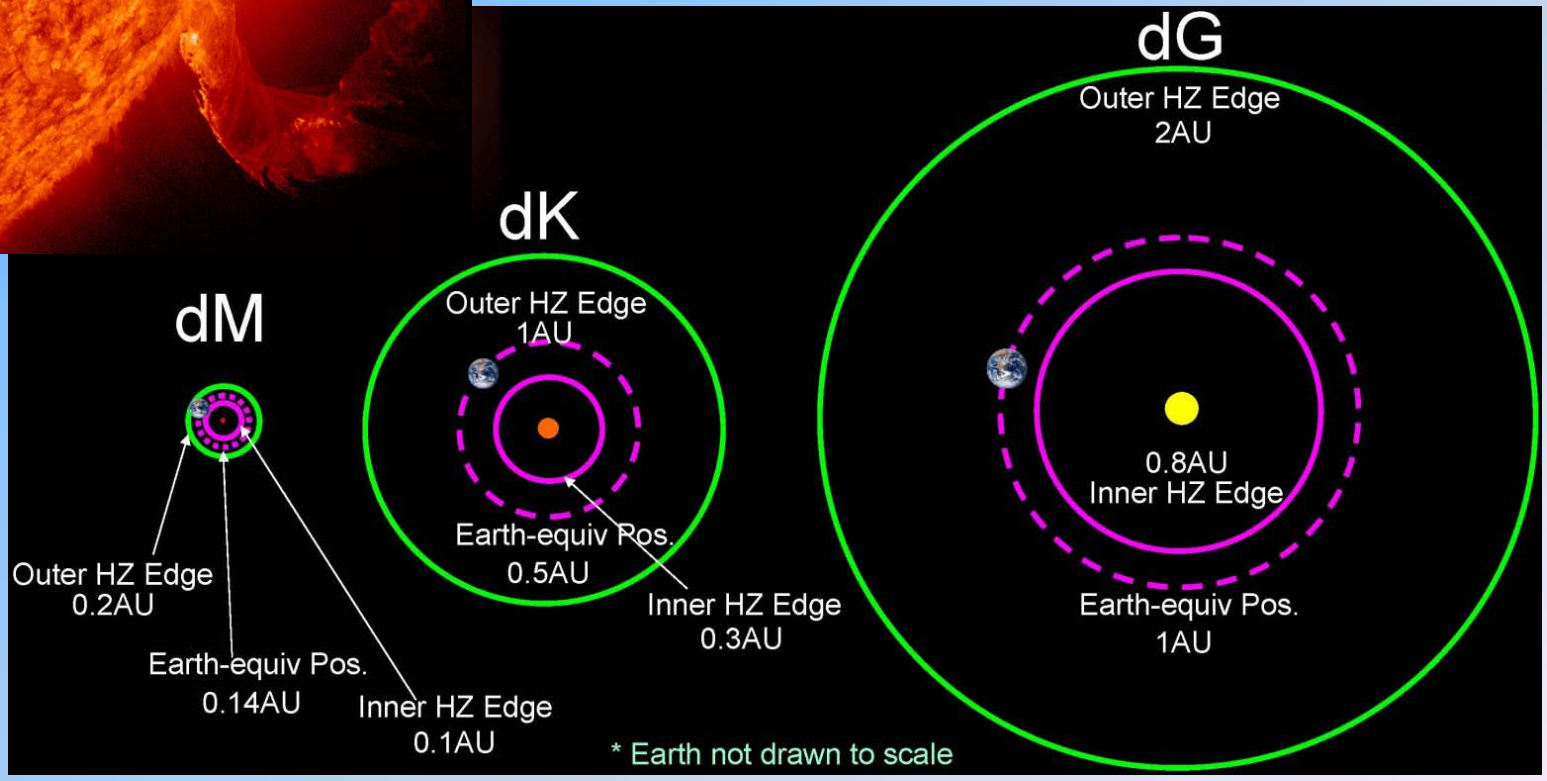
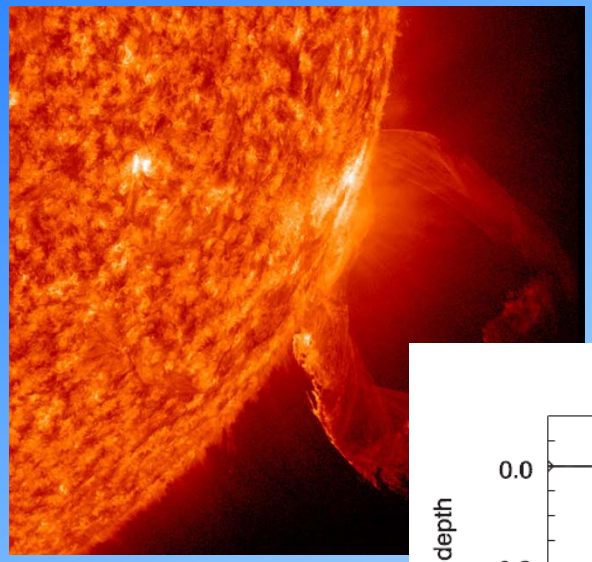
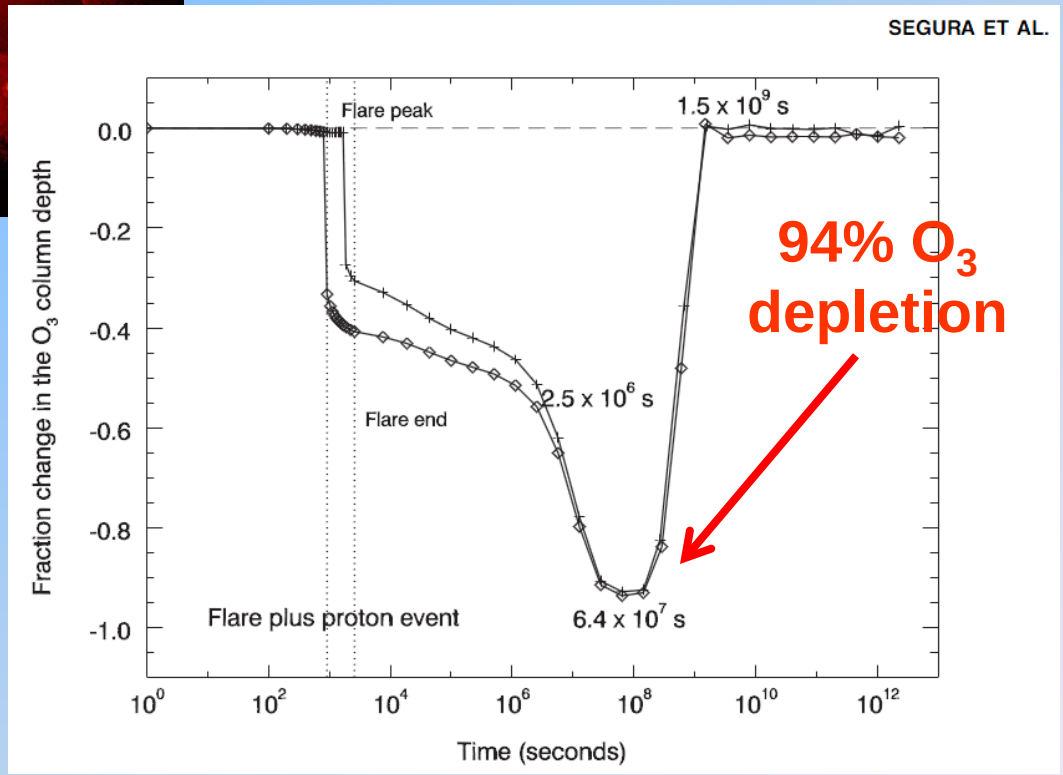




Heating and Chemistry of Planetary Atmospheres

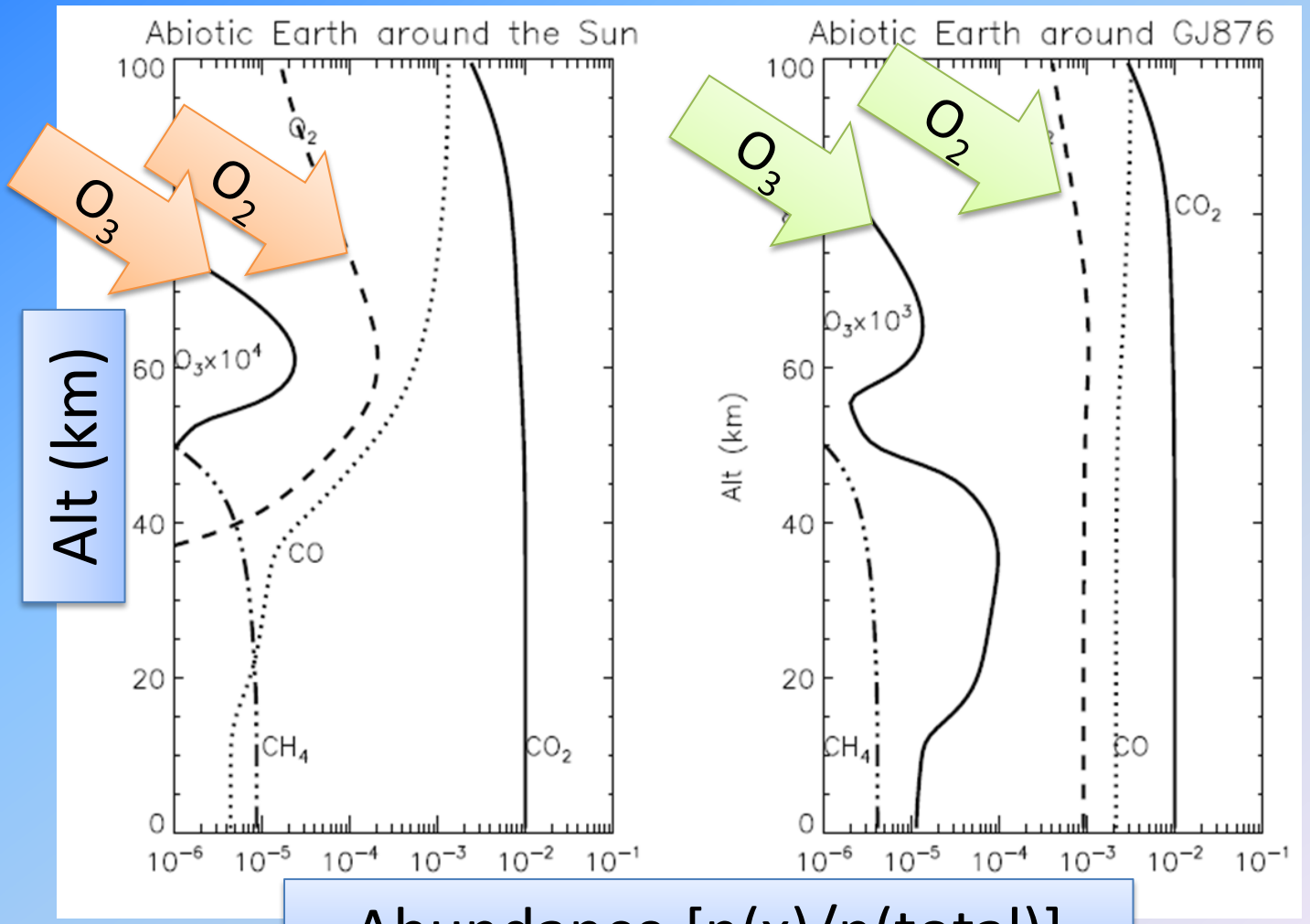




Segura+, AsBio, 2010

Exoplanet Atmospheres: Exo-Earths

Detectable Levels of O_2 and O_3 *without an active biosphere*



Tian, France et al. – submitted.
Domagal-Goldman et al. submitted

(Kasting & Catling 2003;
Segura et al. 2007)

Exoplanet Atmospheres: Exo-Earths

- Habitable planet candidates exist today
  - The FUV+NUV radiation fields of their host stars control the photochemical structure of their atmospheres – including formation of biomarkers (e.g., O_2, O_3, CO_2, CH_4)
  - But we know ***very*** little about chromospheric/coronal structure of average low-mass (M and late K) stars


GJ 667 Cc
(Anglada-Escudé et al. 2012)

Definitions:
EUV = 10 – 90 nm
LUV = 91 – 116 nm
FUV = 117 – 170 nm
NUV = 171 – 310 nm

Exoplanet Atmospheres: Exo-Earths

•Many models assume zero activity/UV flux, influencing the predicted atmospheric chemistry and therefore, habitability

<u>Specific Challenges:</u>

- FUV Sensitivity
- Proper treatment of Lyα is impossible with most existing M-dwarf data sets
- EUV radiation (10 – 91 nm) is important for atmospheric heating, mass-loss, and photochemistry, but is impossible to observe for *most* M dwarfs

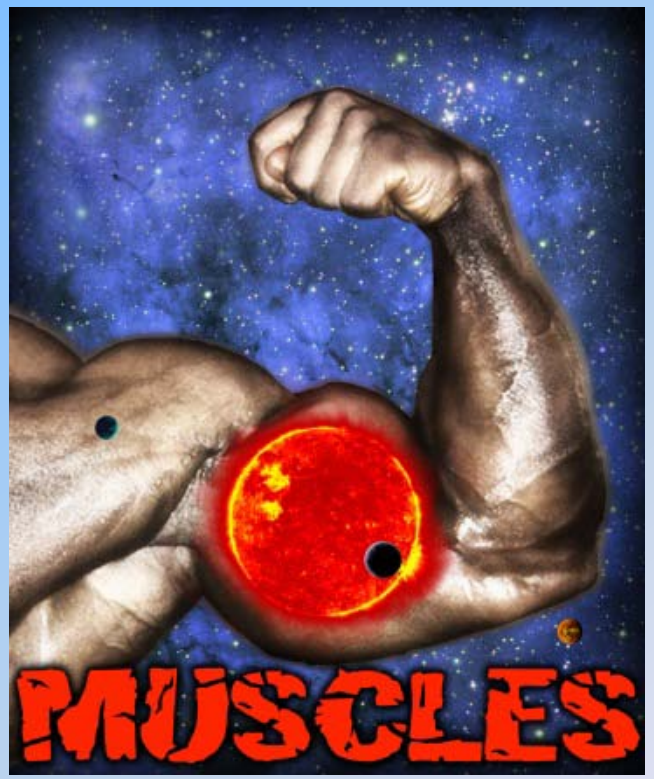
Observational Program

- **Optical/NIR** - North: APO, South: El Leoncito, VLT
- **FUV/NUV**
- **EUV**

PI – France

Observational Program

- **Optical**
- **FUV/NUV** - *Hubble* Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems
- **EUV**



(CU student Sarah LeVine)

PI – France

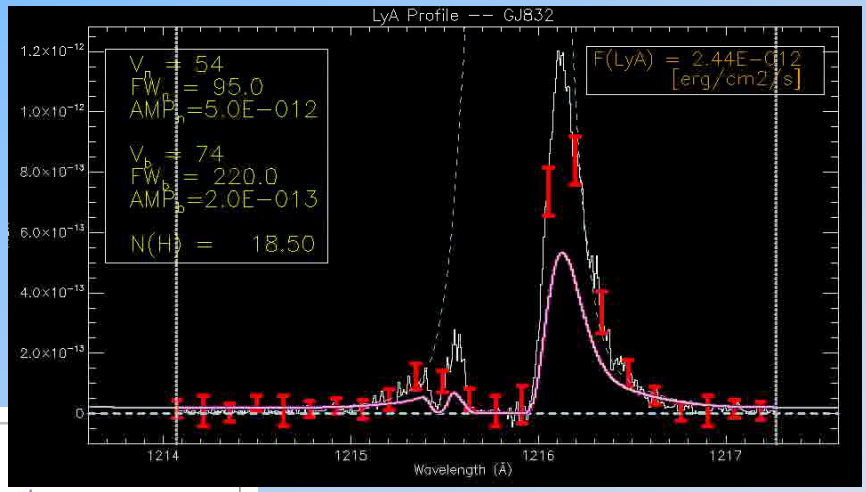
MUSCLES

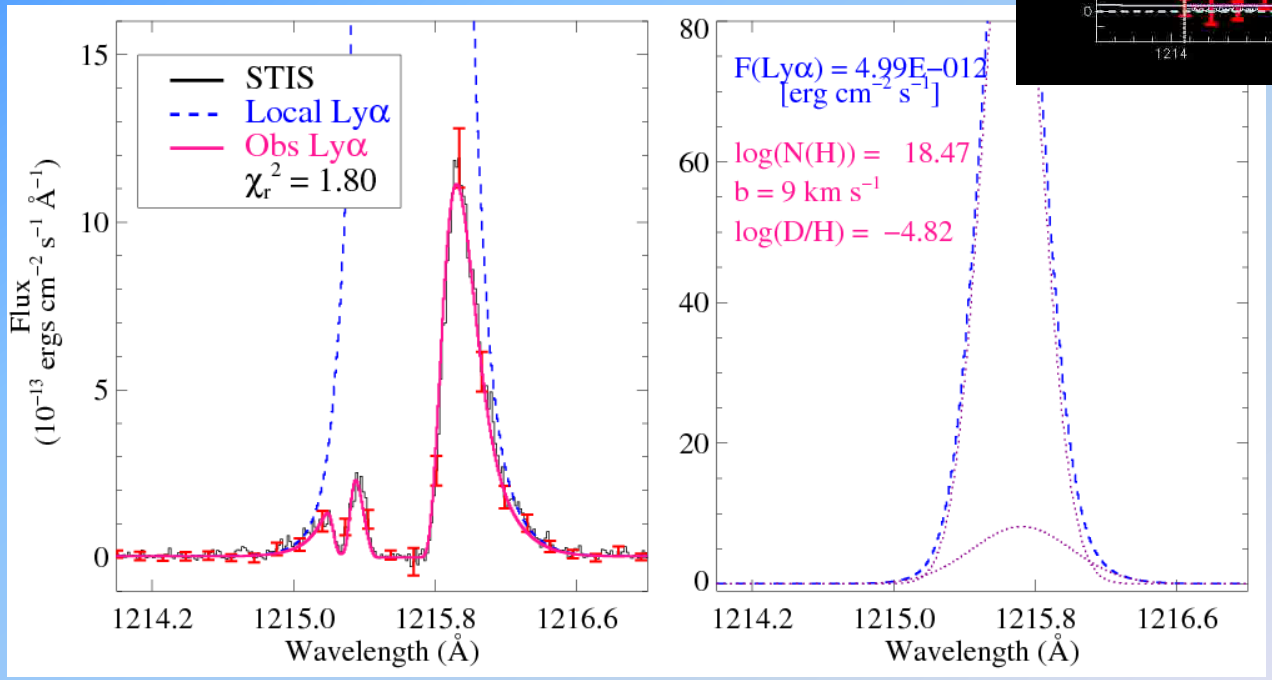
- Project MUSCLES: A pilot survey of 6 M dwarf exoplanet hosts at d < 15 pc
- What is the UV radiation environment in the habitable zones of M dwarf exoplanetary systems?
- UV variability on `inactive' M dwarfs?

http://cos.colorado.edu/~kevinf/muscles.html

M dwarf Lyα

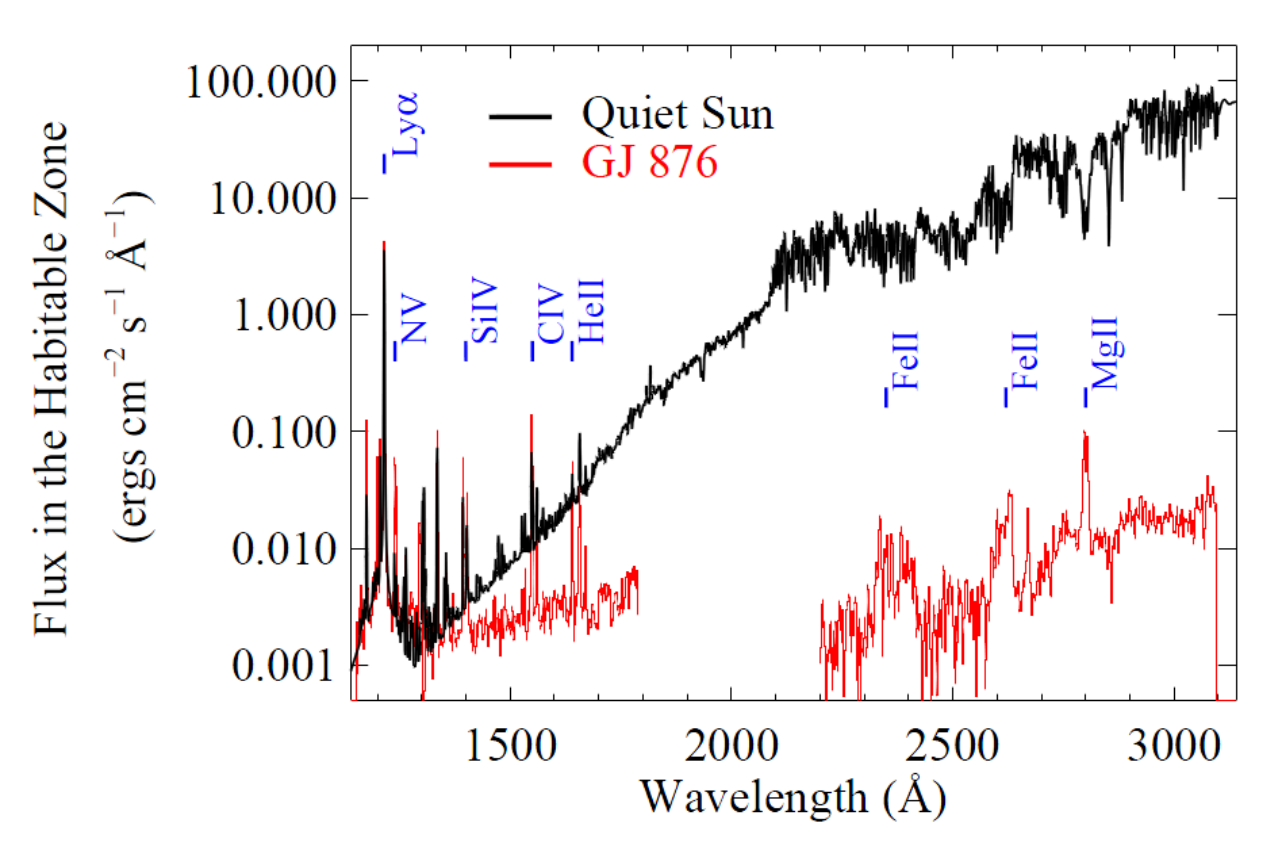
- Project MUSCLES: Lyα Reconstruction





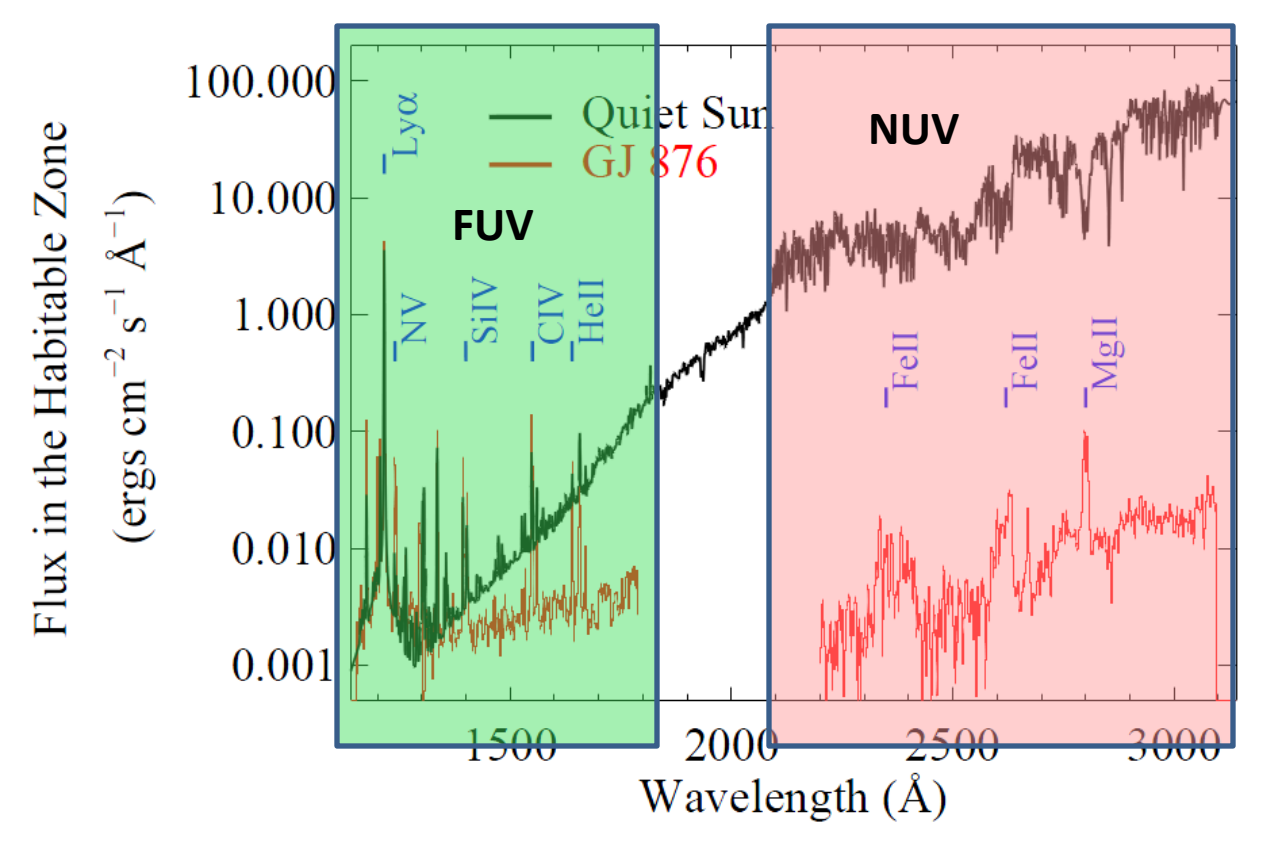
M dwarf FUV and NUV vs. Solar

- Project MUSCLES: GJ 876, UV Spectrum

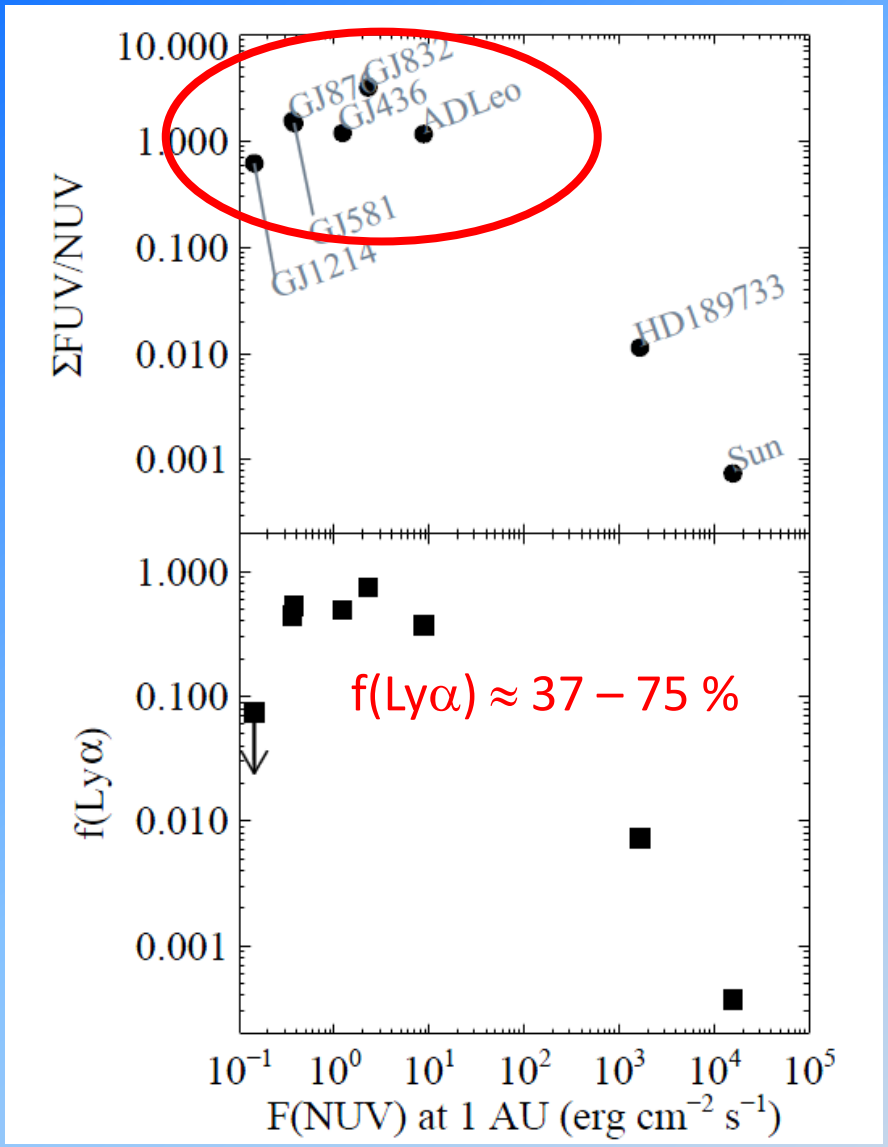


France et al. (ApJL-2012c)

FUV/NUV ratio



FUV/NUV – Atmospheric Oxygen Chemistry
Segura+, AsBio, 2010



M -- FUV/NUV ~ 1- 3

Sun -- FUV/NUV ~ 10^{-3}

France et al. (ApJ-2013)

http://cos.colorado.edu/~kevinf/muscles.html

cos.colorado.edu/~kevinf/muscles.html

Send Kevin France more grant money

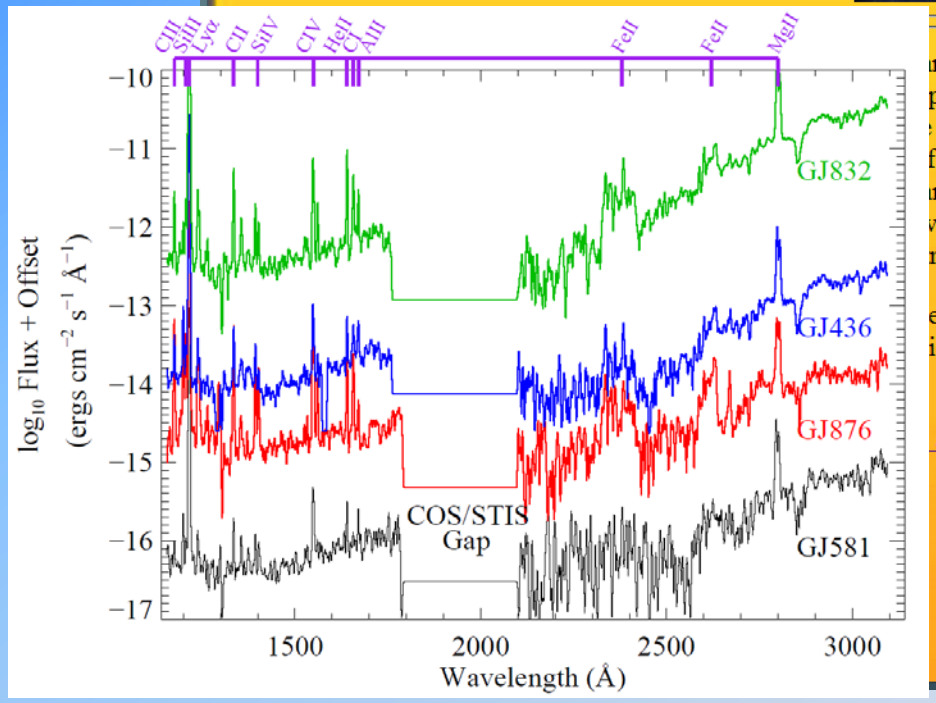
MUSCLES

Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanet host Stars

MUSCLES Team

Publications

- GJ 581
- GJ 876
- GJ 436
- GJ 832
- GJ 667C
- GJ 1214



nce to discover habitable worlds in the coming decade. The planets is critically important for proper modeling of their realistic input for atmospheric models of planets orbiting f 6 M dwarf exoplanet host stars using the COS and STIS rs, the spectra cover the 1150-3140A bandpass, and include ebsite is designed to be a community resource for studies of mospheres.

ectra for scientific analysis, we request that you cite France is work has made use of the MUSCLES M dwarf UV

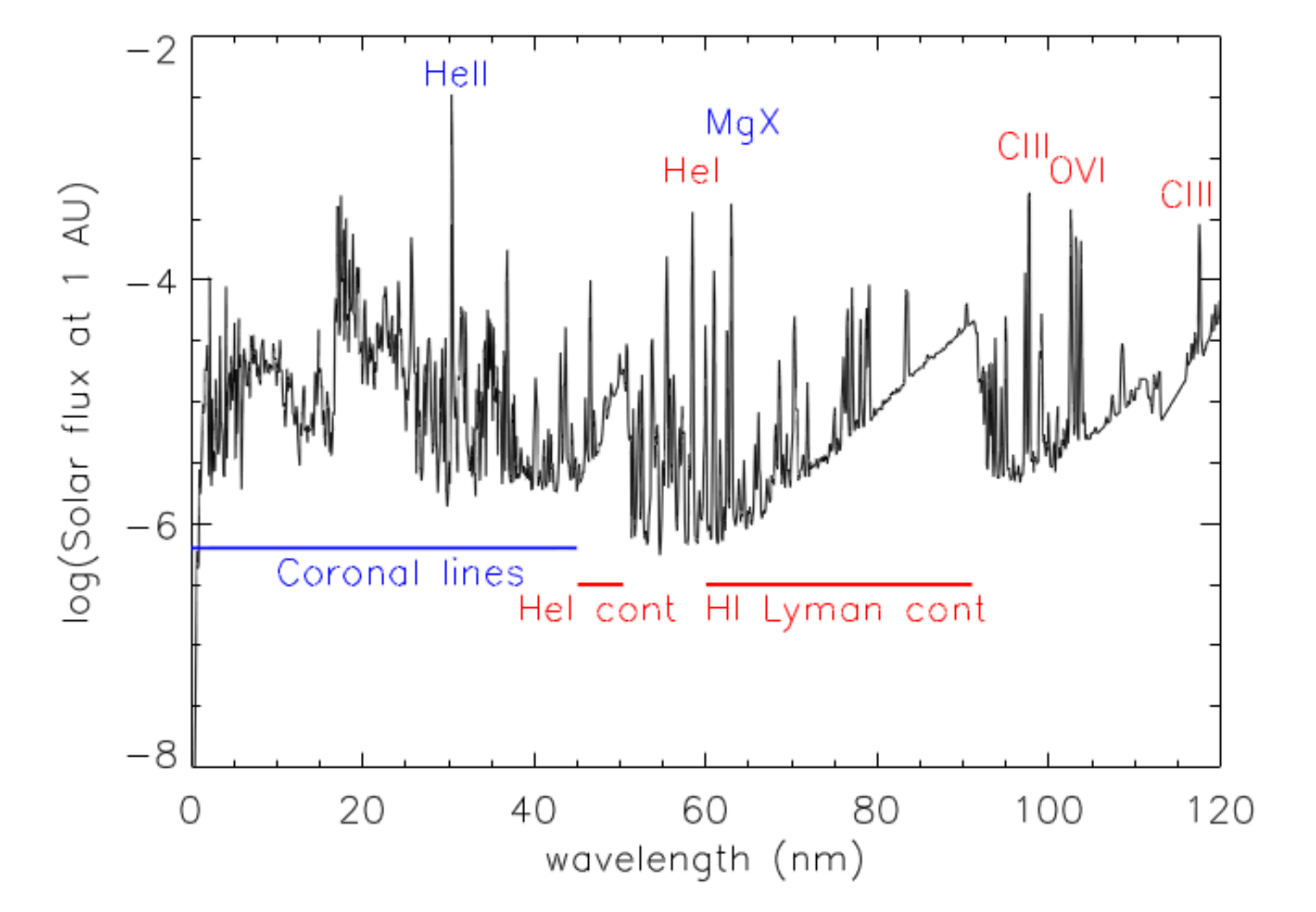
and Space Astronomy, University of Colorado. The

Observational Program

- **Optical** - APO, El Leoncito, VLT
- **FUV/NUV** - *Hubble*
- **EUV** – Solar models + *EUVE* constraints

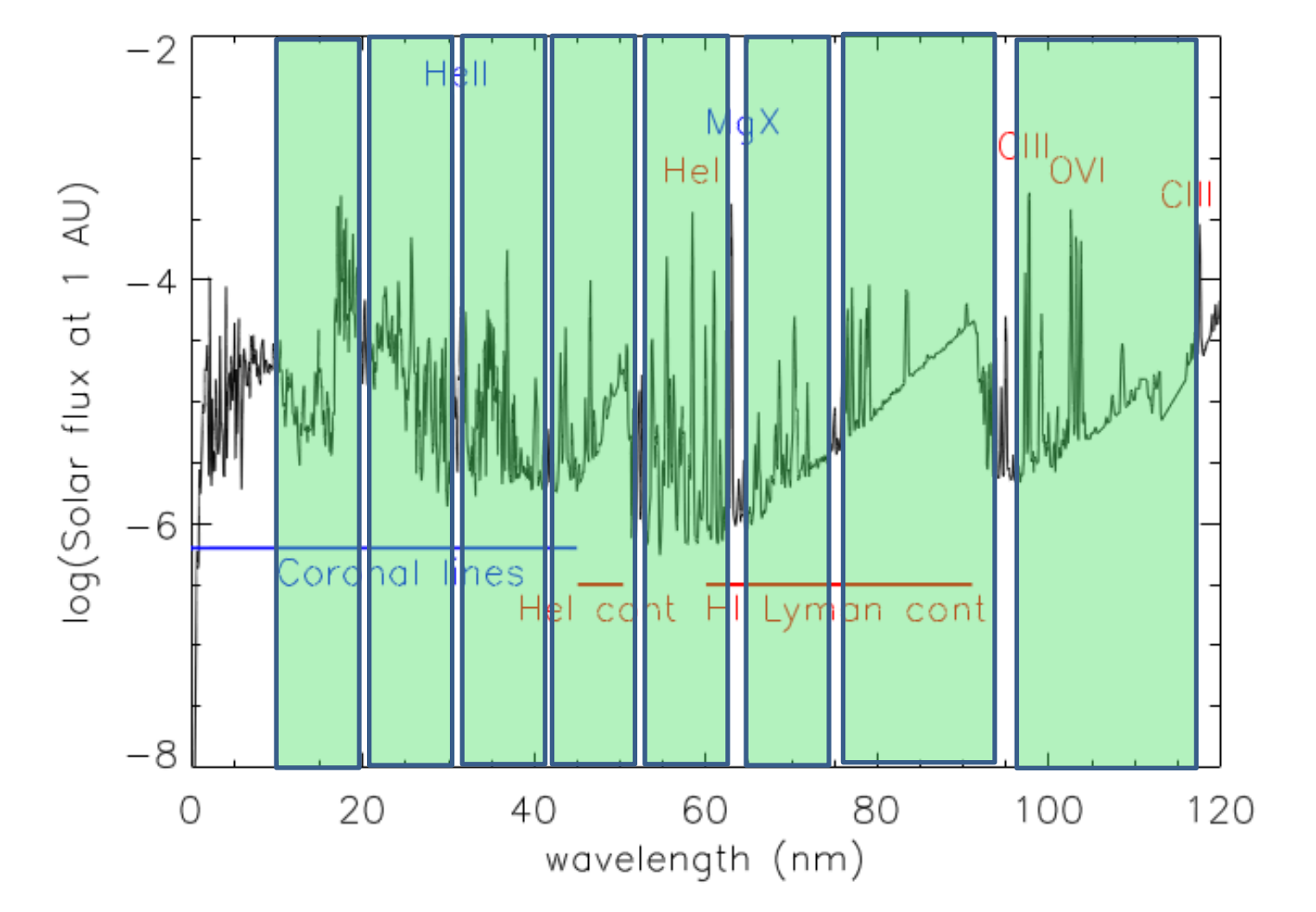
PI – France

EUV Estimates: F(EUV) / F(Lyα)



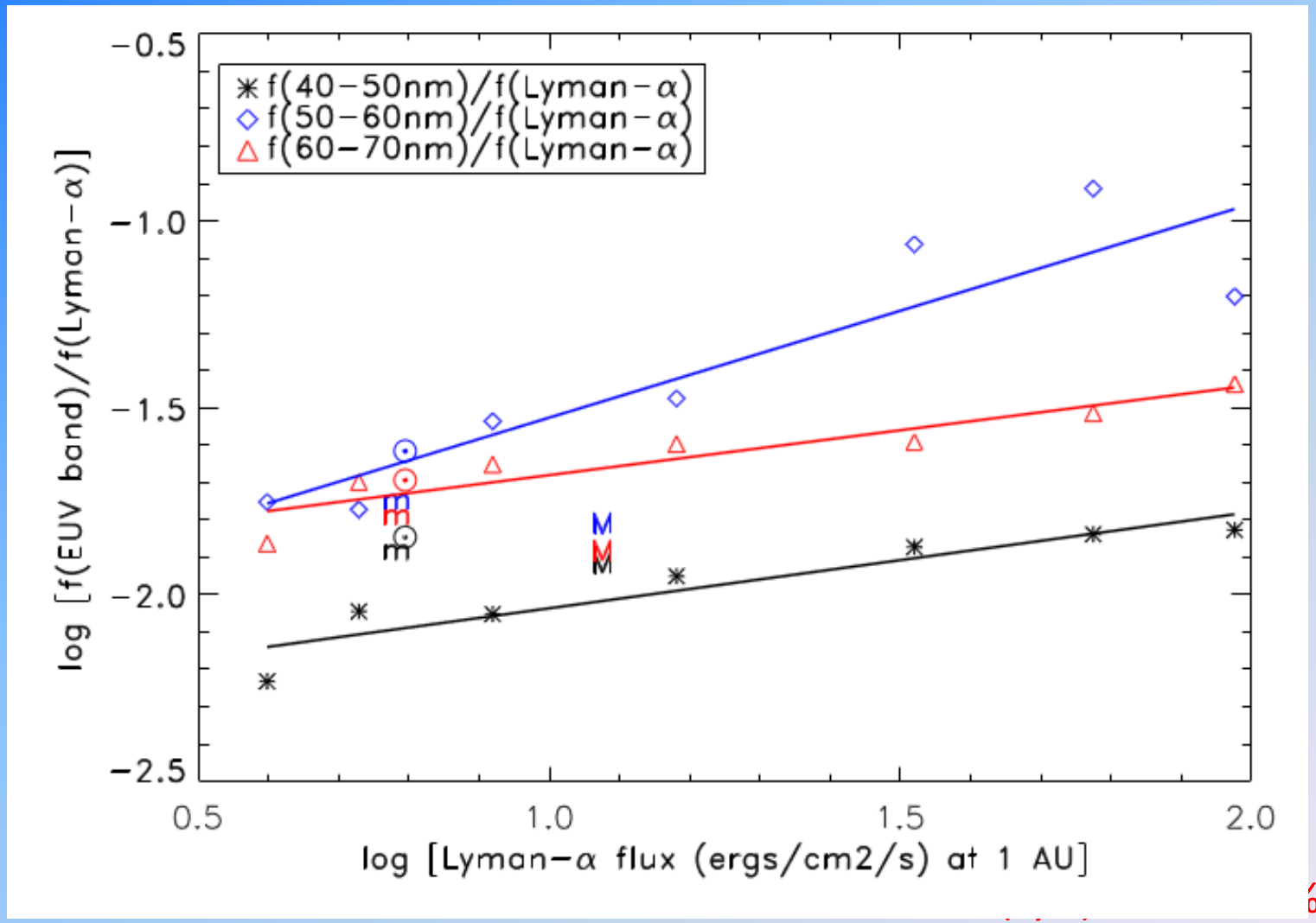
Linsky et al. (ApJ-accepted)

EUV Estimates: F(EUV) / F(Lyα)



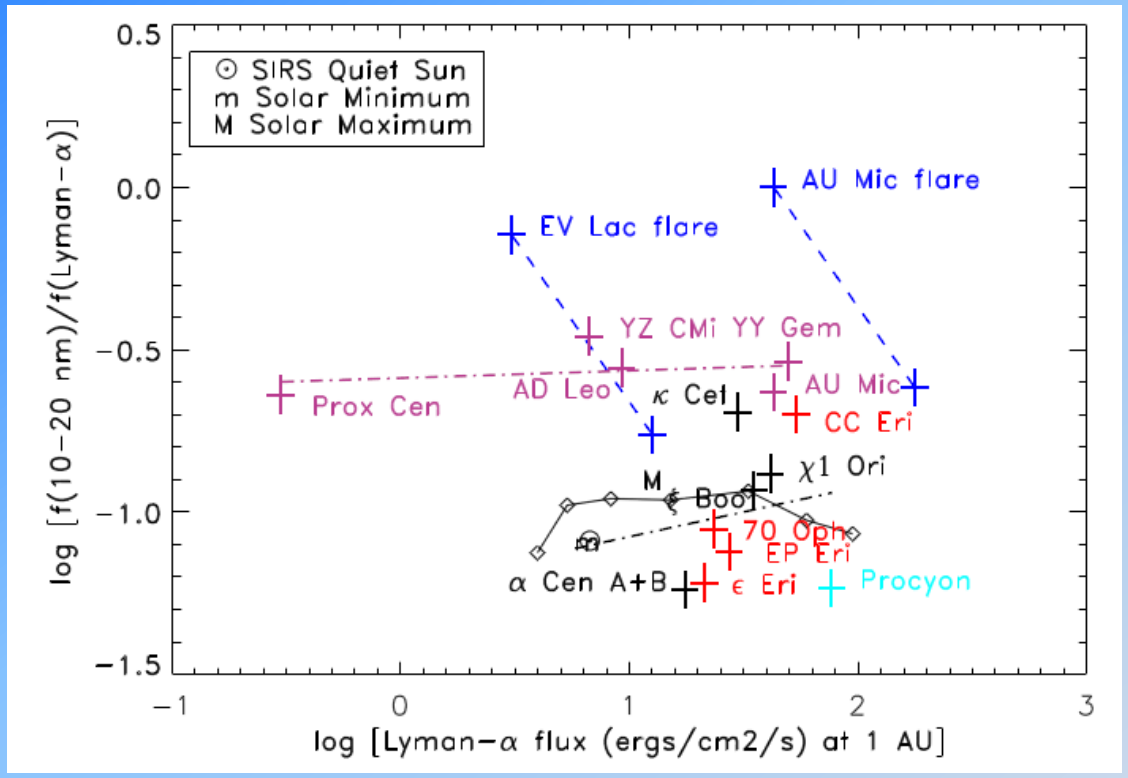
Linsky et al. (ApJ-accepted)

Solar Models: F(EUV) / F(Lyα)



Linsky et al. (ApJ-accepted)

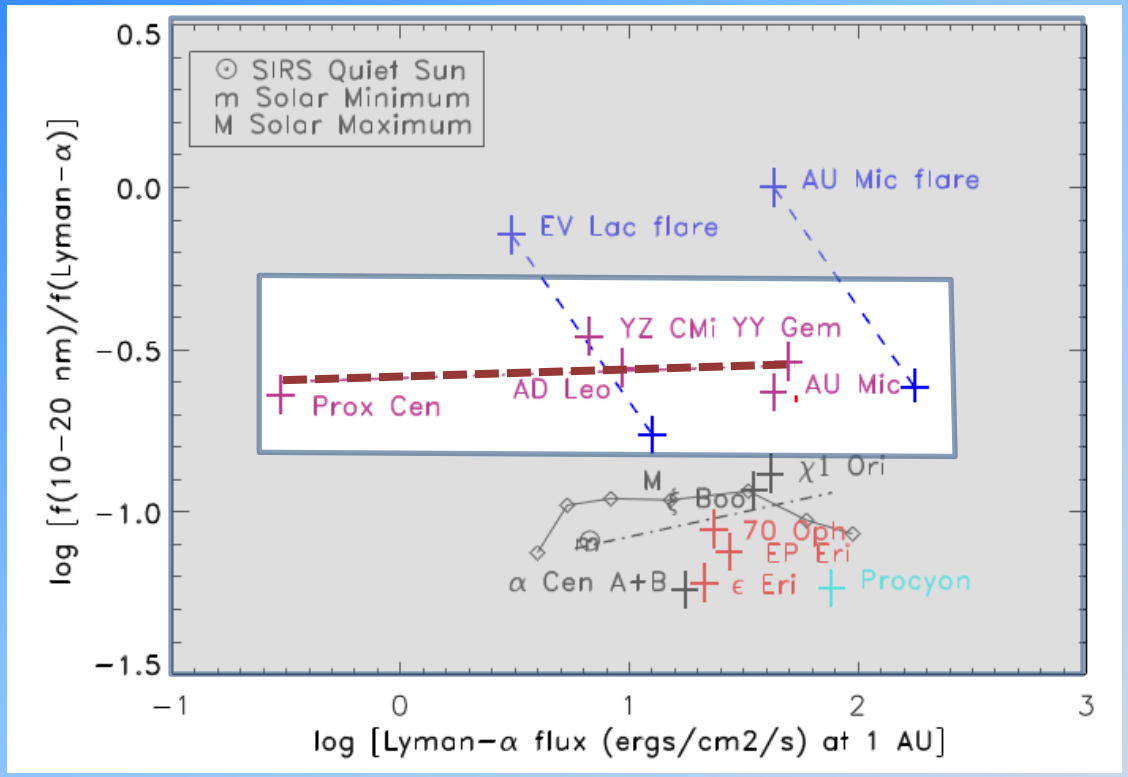
EUVE M dwarfs: F(EUV) / F(Lyα)



Linsky et al. (ApJ-accepted)

EUVE M dwarfs: F(EUV) / F(Lyα)

M-dwarf EUV calculations:



Linsky et al. (ApJ-accepted)

Based on *EUVE* data, M dwarf F(EUV)/F(Lyα) ratios agree with solar model, modulo an empirically constrained offset, e.g.,

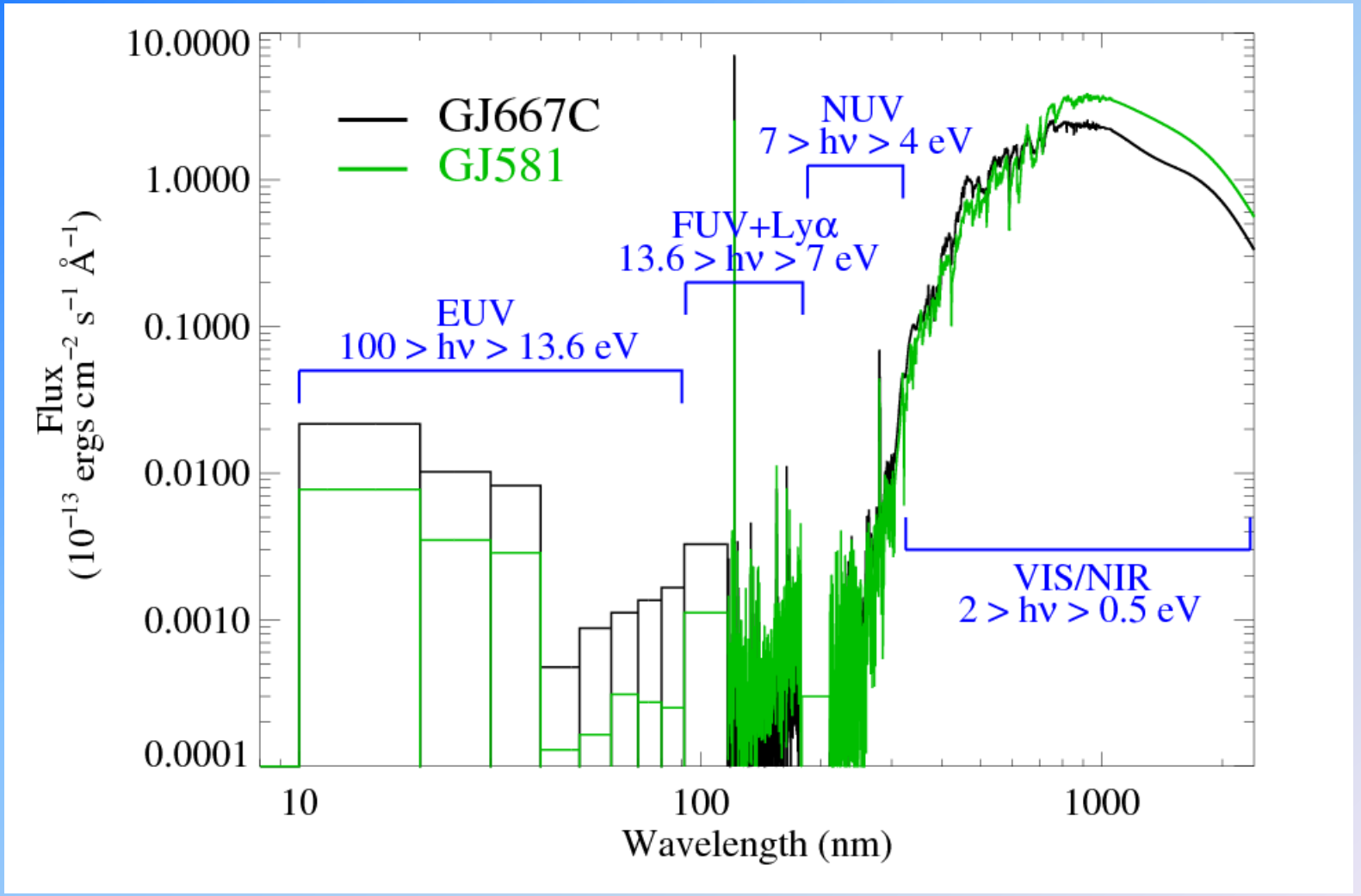
$$\log (F(EUV)/F(Ly\alpha))_M = \log (F(EUV)/F(Ly\alpha))_\odot + \Delta F$$

$\Delta F(10 - 20\ nm) = +0.37$ [16%]

$\Delta F(20 - 30\ nm) = -0.01$ [24%]

$\Delta F(30 - 40\ nm) = -0.03$ [18%]

EUV → NIR Stellar Irradiances

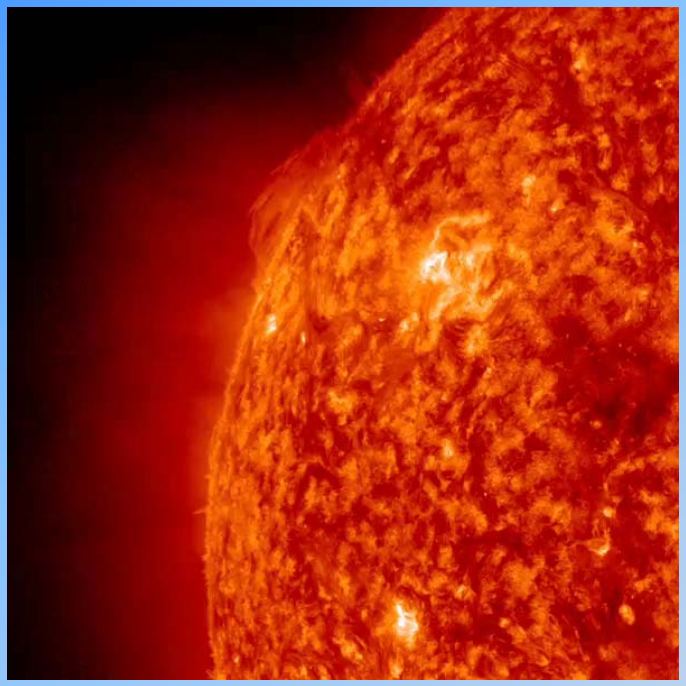


Tian, France, & Linsky (in prep)

UV variability in “weakly active” (> 1 Gyr) M dwarf exoplanet host stars

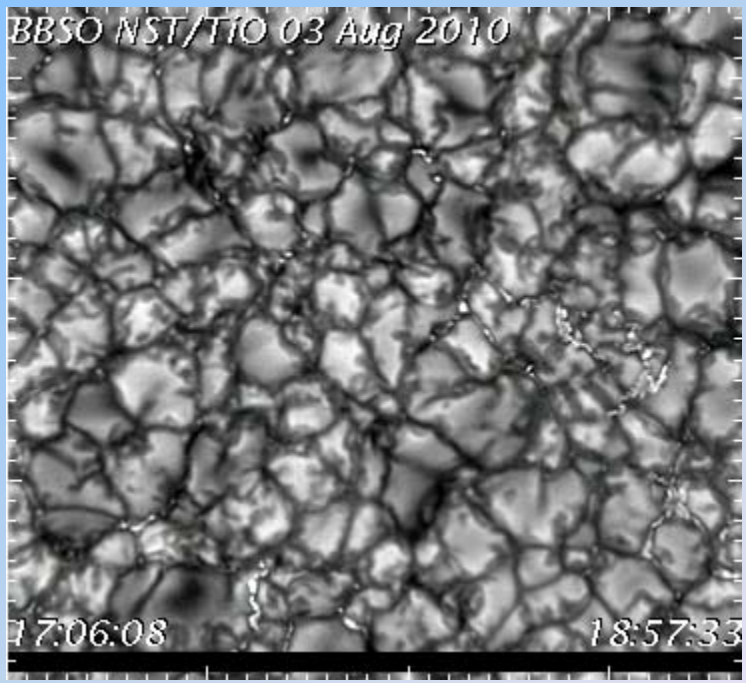
UV variability in “weakly active” (> 1 Gyr) M dwarf exoplanet host stars

Flares



Credit: SDO

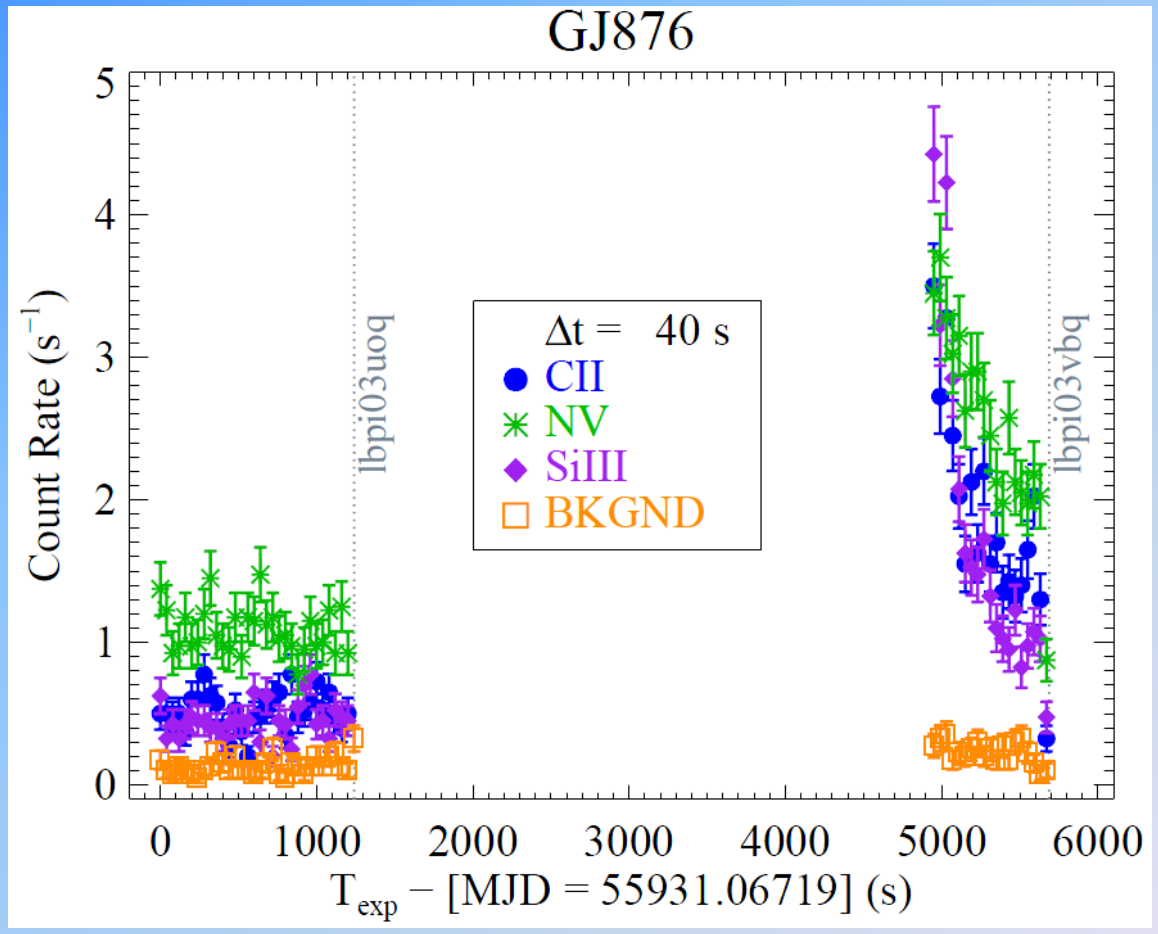
Stochastic Fluctuations



Credit: Big Bear Solar Observatory

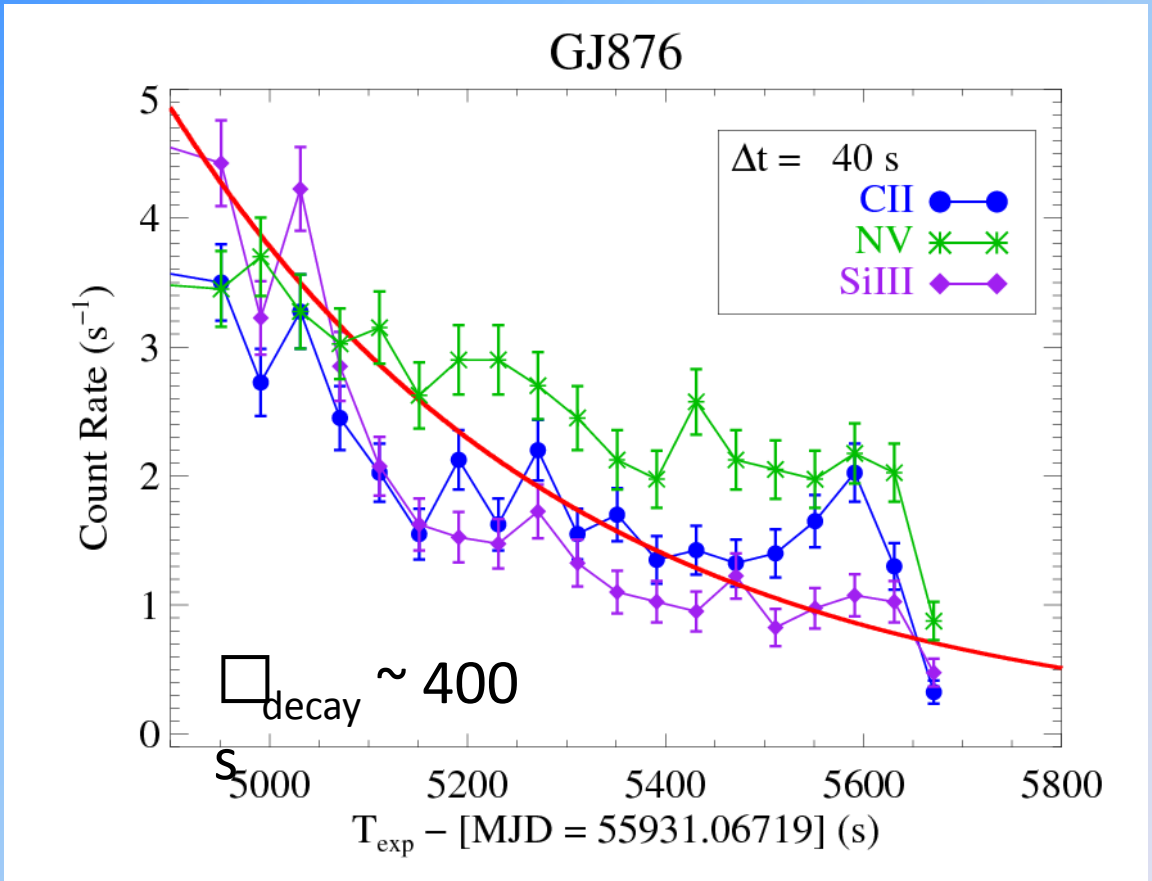
UV variability in “weakly active” (> 1 Gyr) M dwarf exoplanet host stars

- Optically Inactive M-dwarf GJ 876, FUV Flare



France et al. (ApJL-2012c)

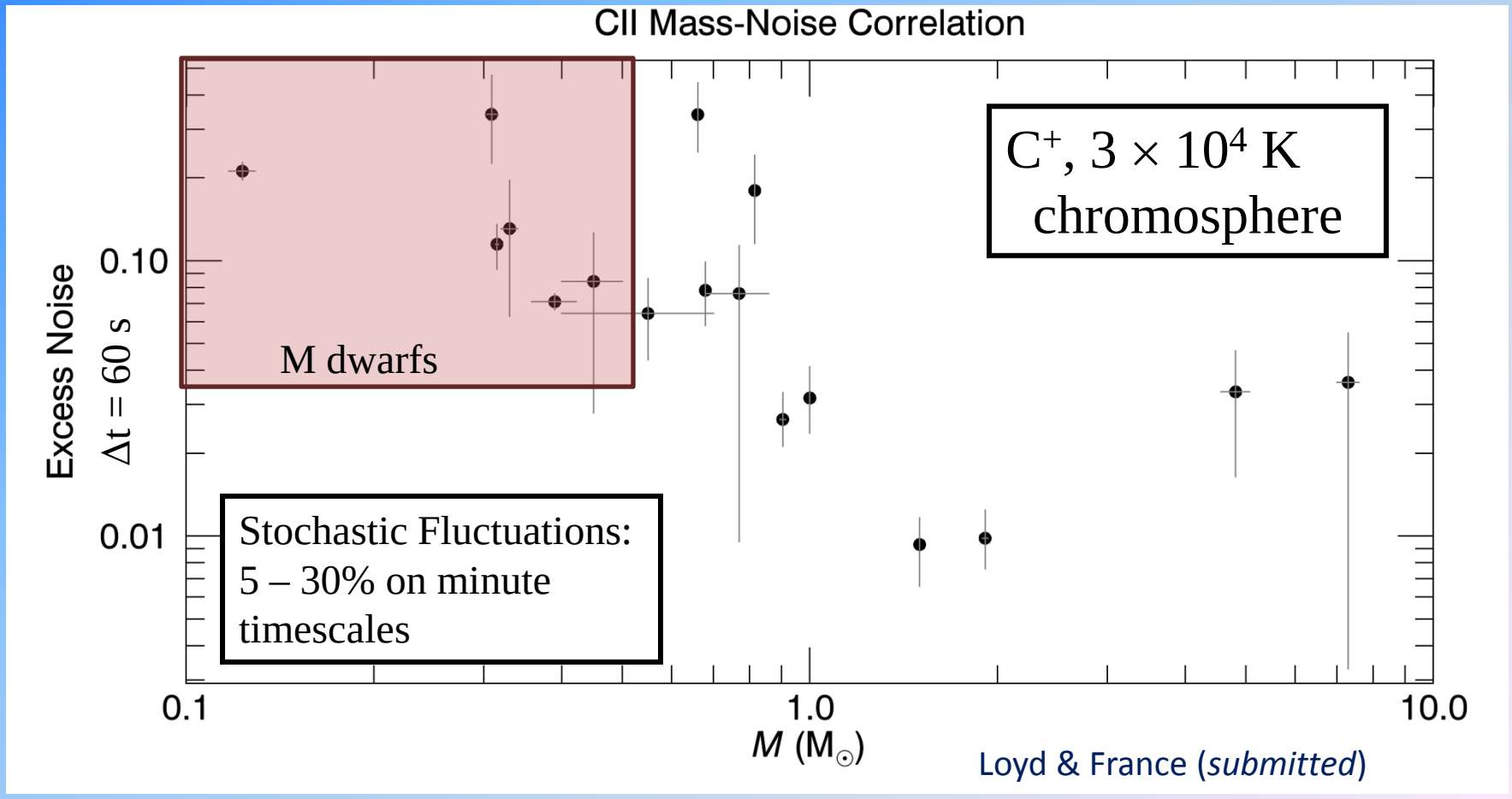
- 50 – 500% increases on 10^2 – 10^3 second timescales



France et al. (ApJL-2012c)

UV variability in M dwarf exoplanet hosts

- Stochastic Fluctuations = "excess" noise beyond photometric uncertainties, after removing flares.



Summary

Summary

1) First study of the energetic radiation environment around M dwarf exoplanet host stars including NUV, FUV, Lyα, and EUV

2) Lyα comprises 30 – 80% of the total FUV+NUV flux

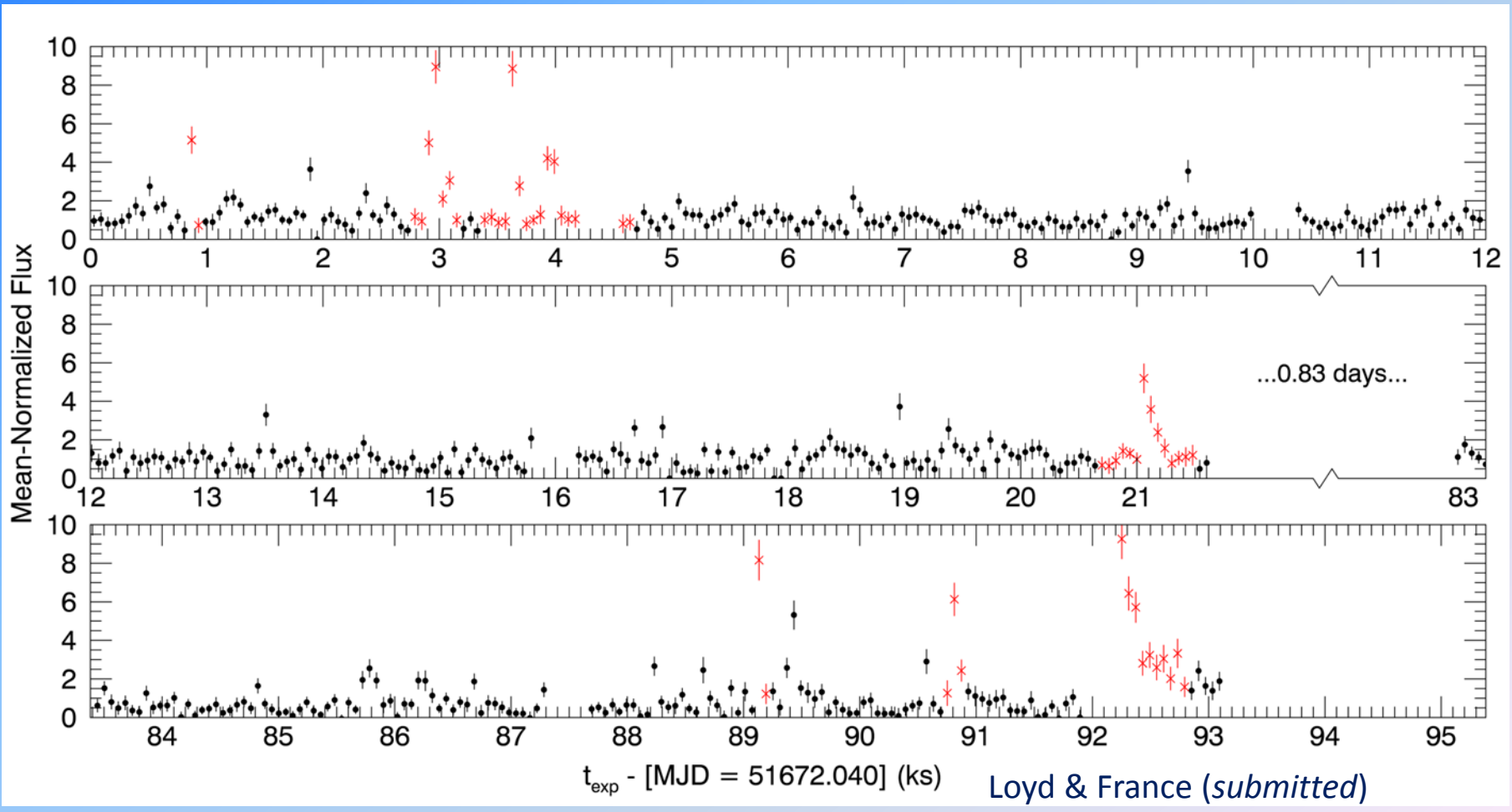
3) FUV/NUV ~ 1, important for atmospheric chemistry and the production of "biomarkers" (e.g., oxygen photochemistry)

4) FUV flares (50 – 500% increases on 10^2 – 10^3 second timescales) are present on *almost* all M dwarf exoplanet host stars observed to date. Stochastic fluctuations at 5 – 30% level typical.

Thank you

Excess Noise:

- Iteratively screen for flares exponential flare kernel
- Compute excess noise as Gaussian width of the lightcurve flux distribution beyond the photometric noise



Loyd & France (*submitted*)

Excess Noise:

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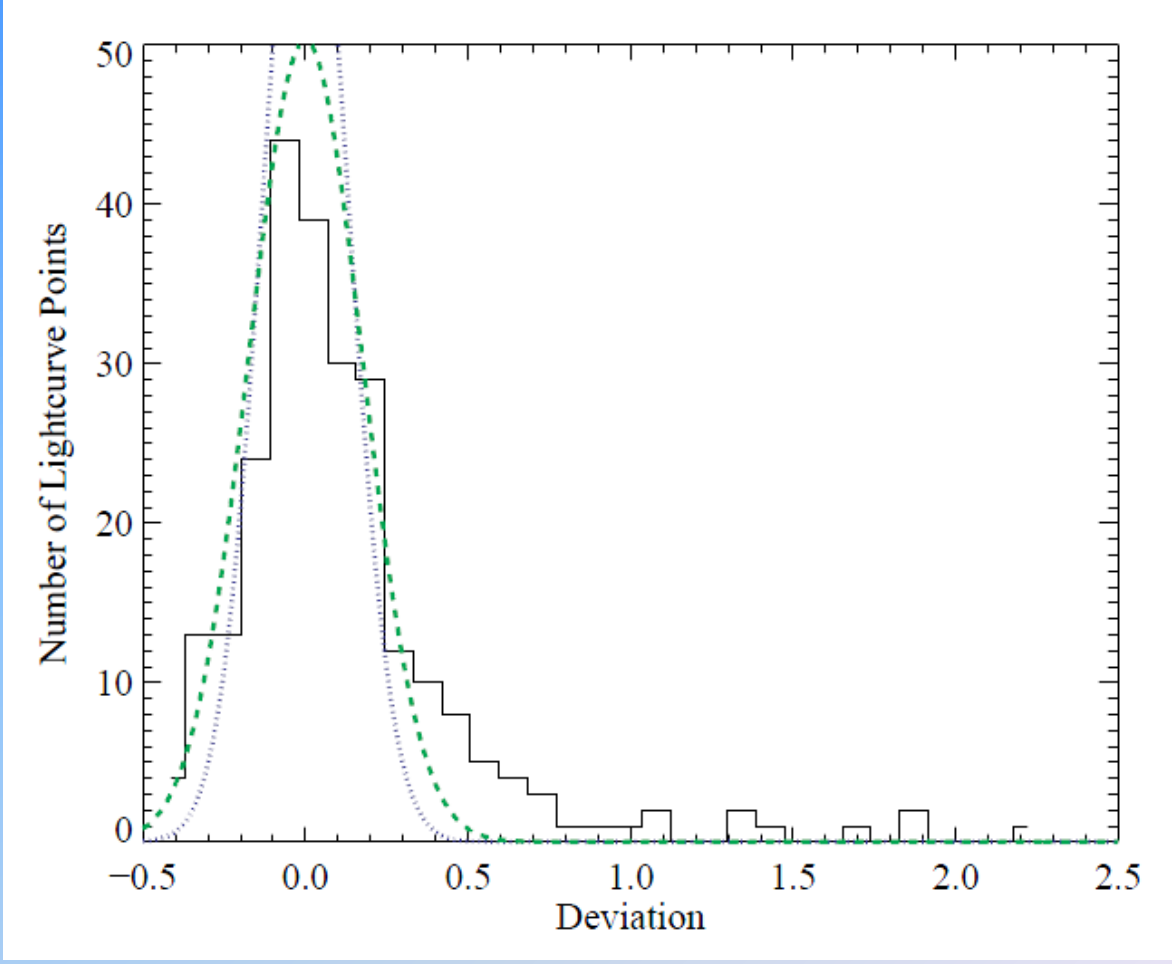

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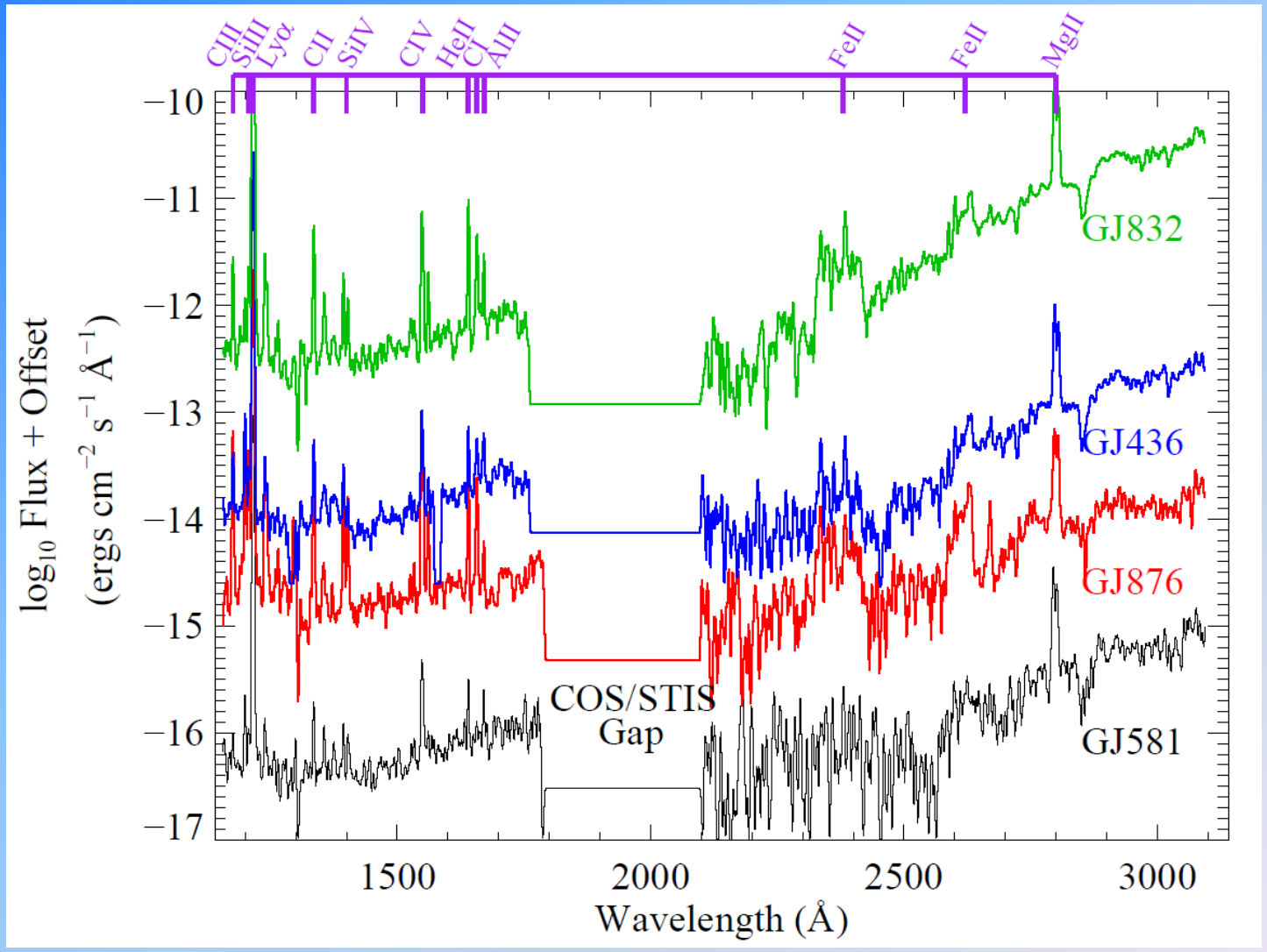
MUSCLES: Spectra

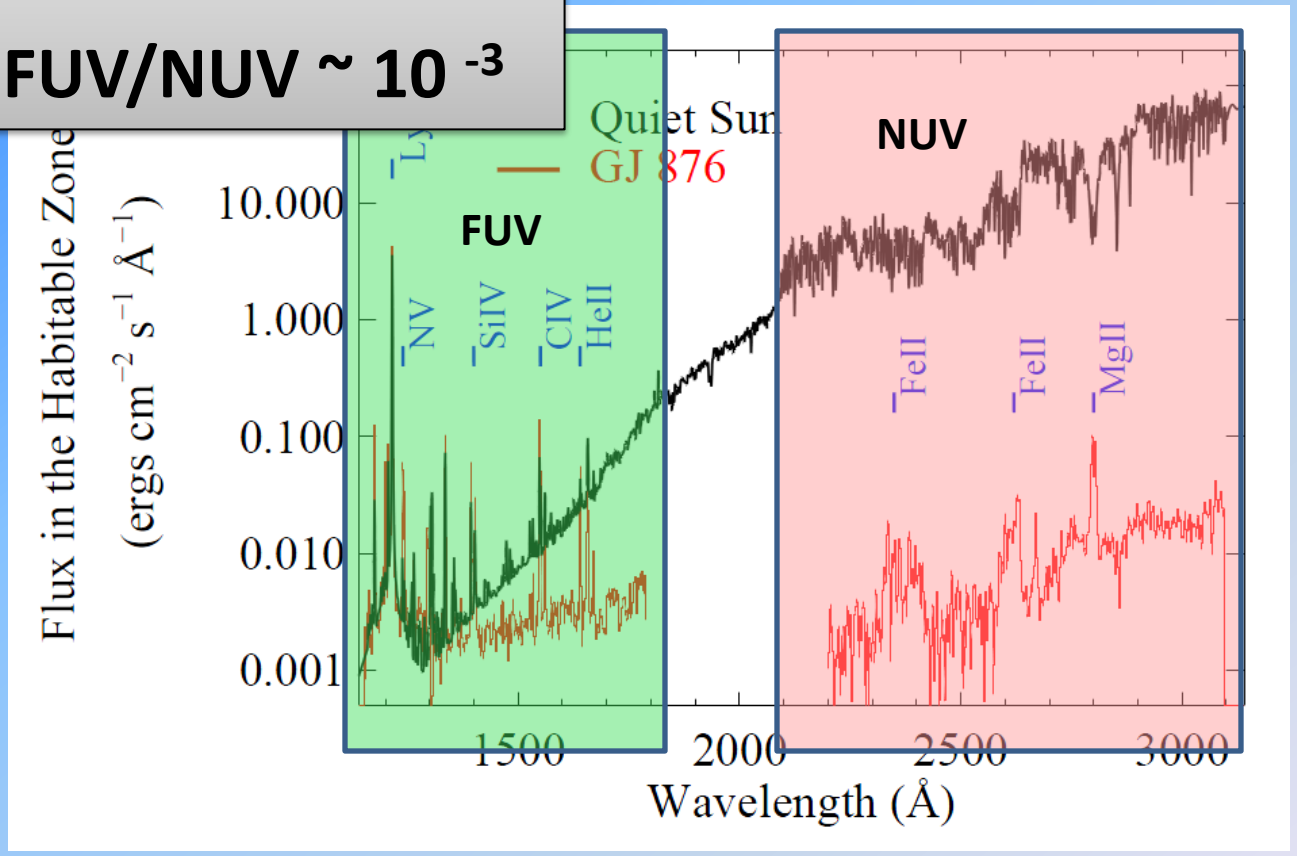


France et al. (ApJ-2013)

FUV/NUV ratio

M -- FUV/NUV ~ 1- 3

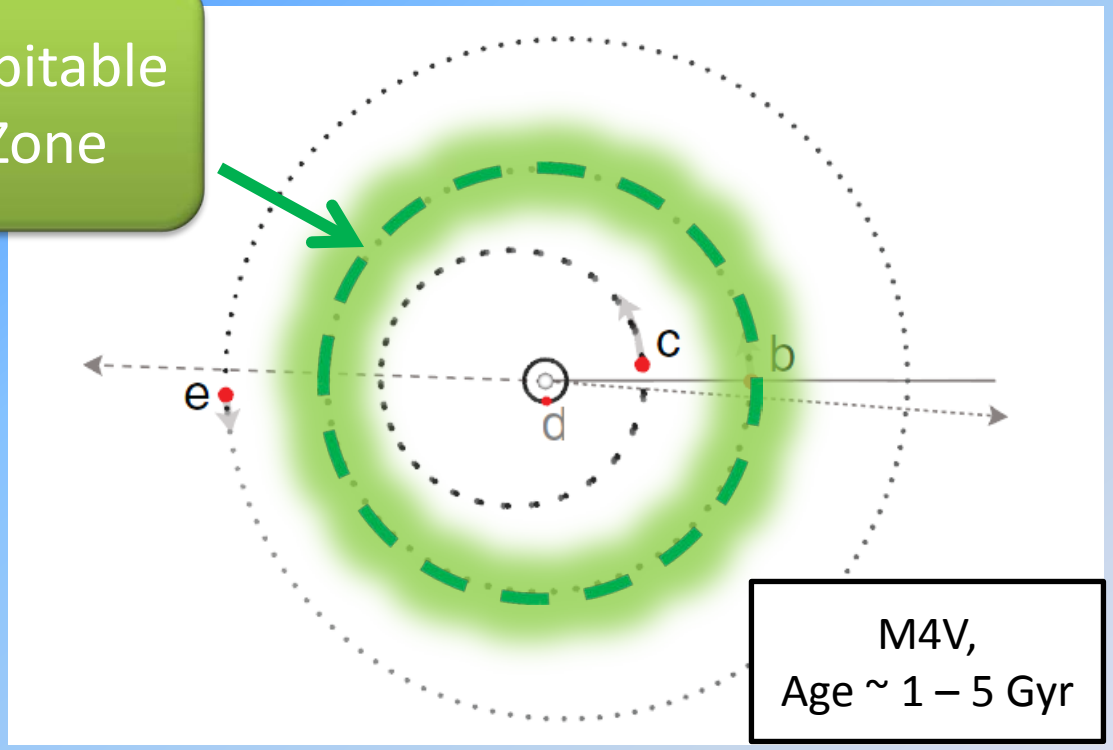
Sun -- FUV/NUV ~ 10^{-3}



FUV/NUV – Atmospheric Oxygen Chemistry
Segura+, AsBio, 2010

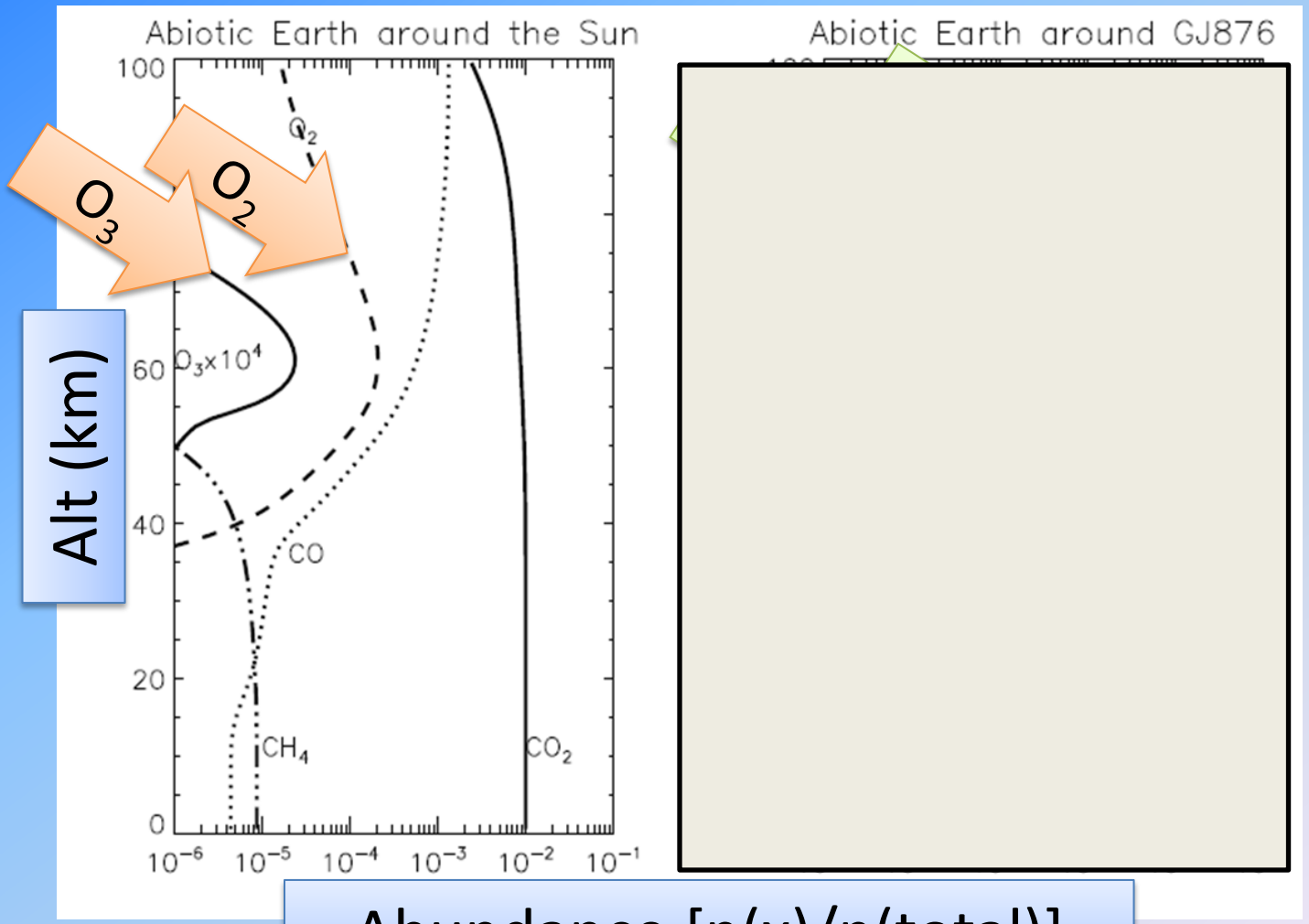
Potential Biomarkers on Exo-Earths

- Project MUSCLES: Initial Modeling Results, "Inactive" M dwarf GJ 876



Rivera et al. 2010

Exoplanet Atmospheres: Exo-Earths



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(Kasting & Catling 2003;
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Exoplanet Atmospheres: Exo-Earths

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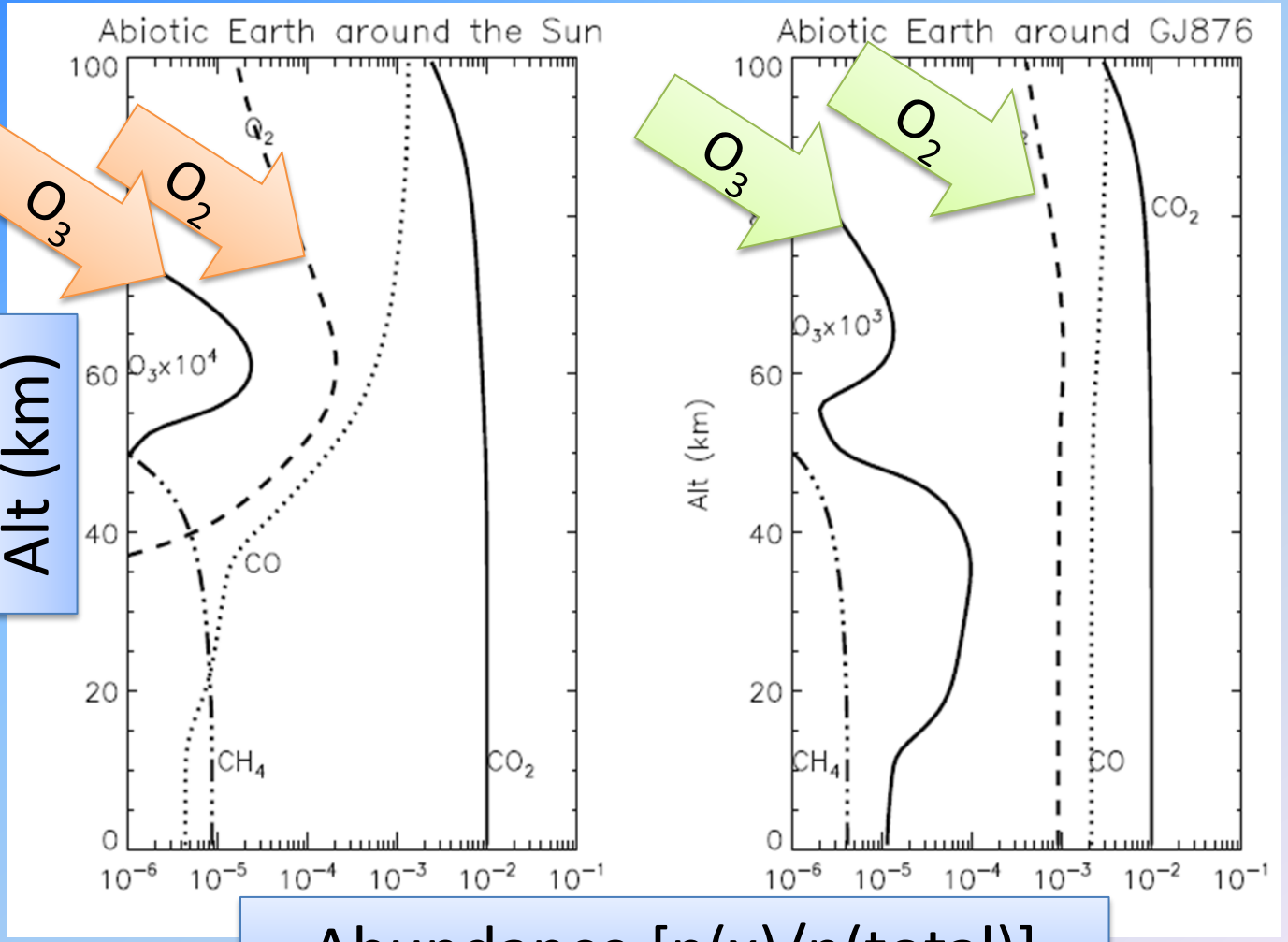

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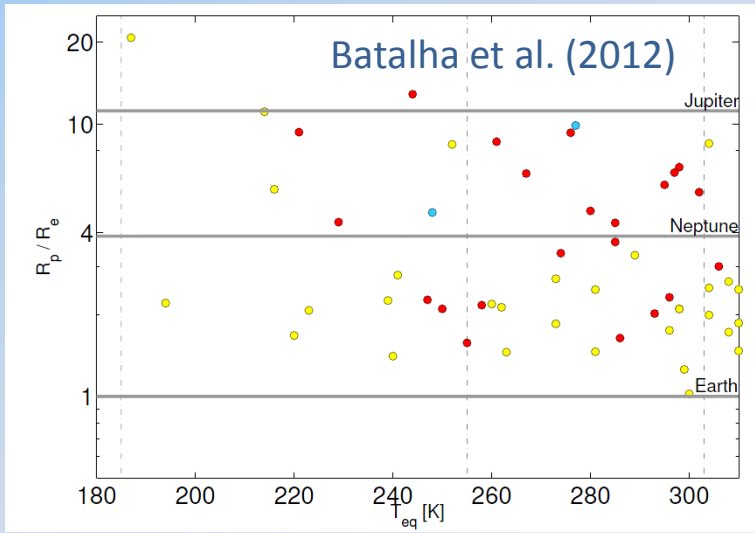
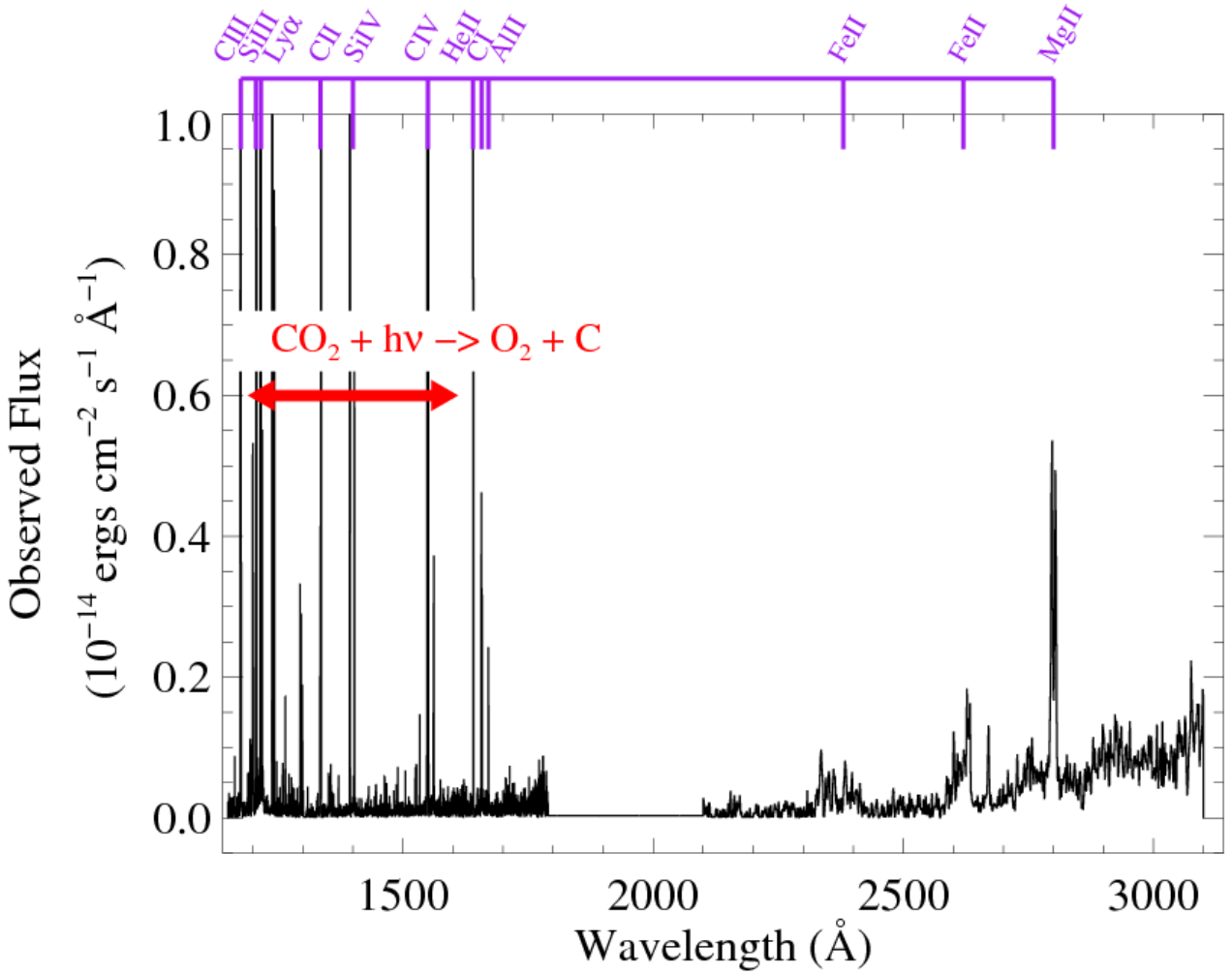
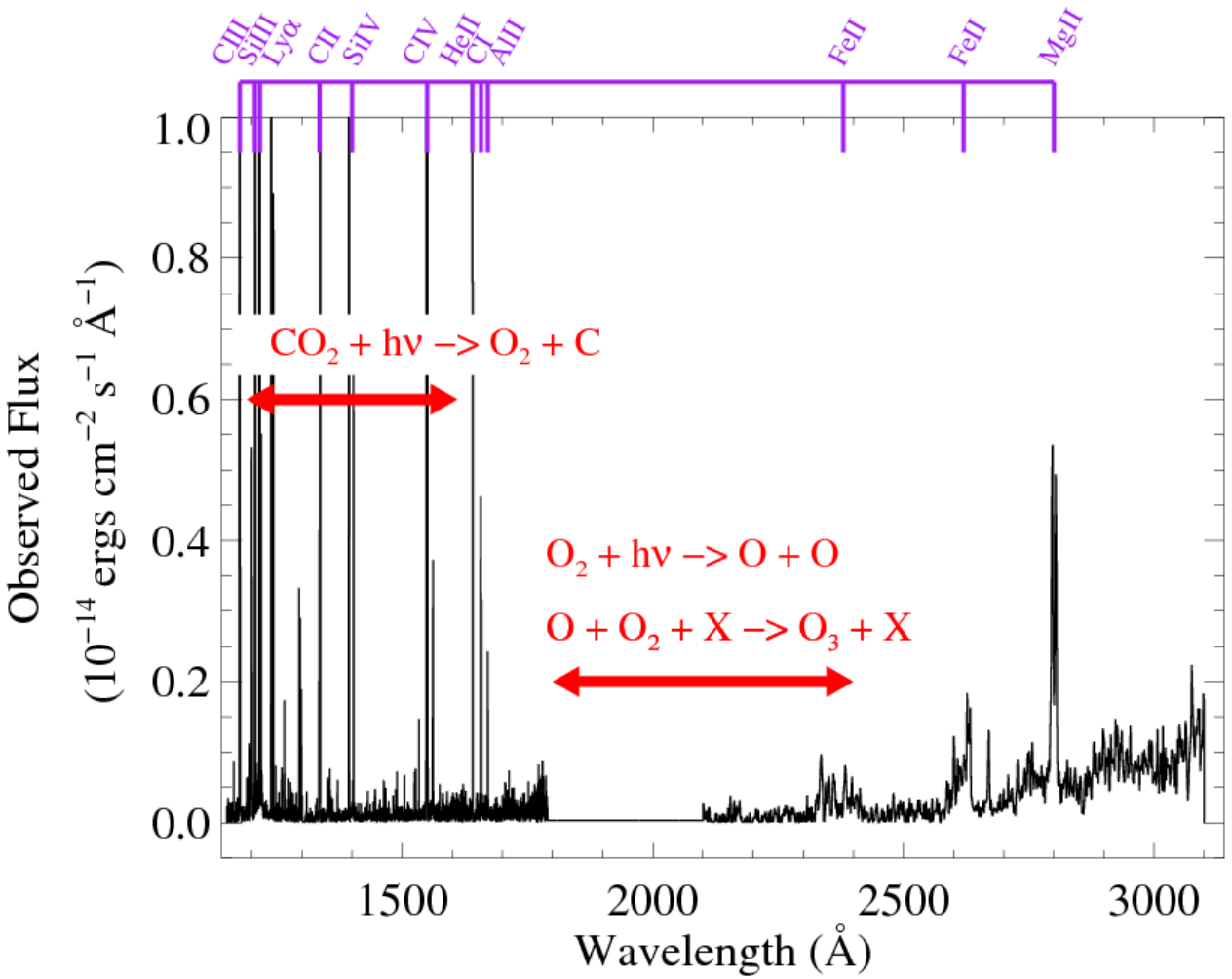


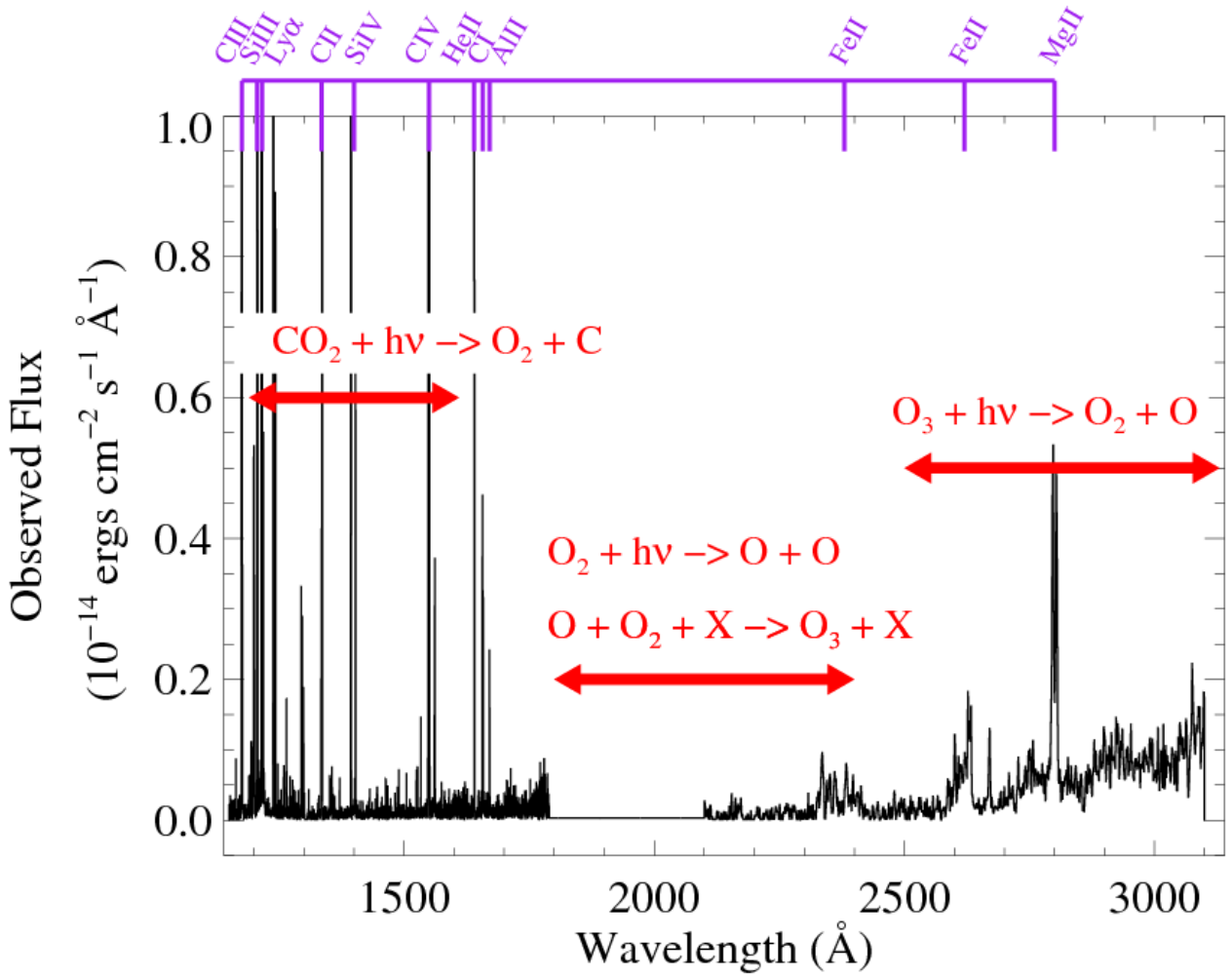
Exoplanet Atmospheres: Exo-Earths



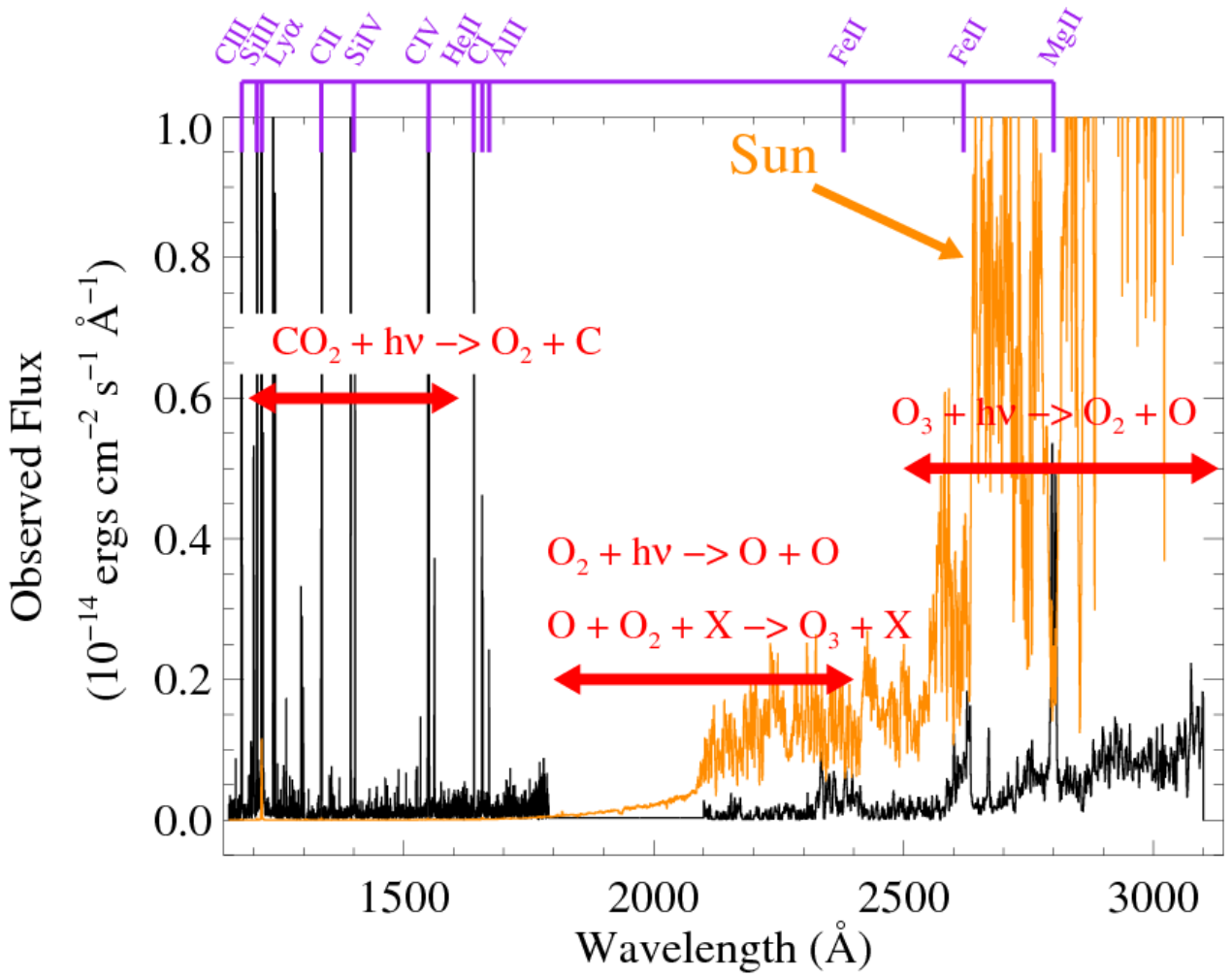
Exoplanet Atmospheres: Exo-Earths



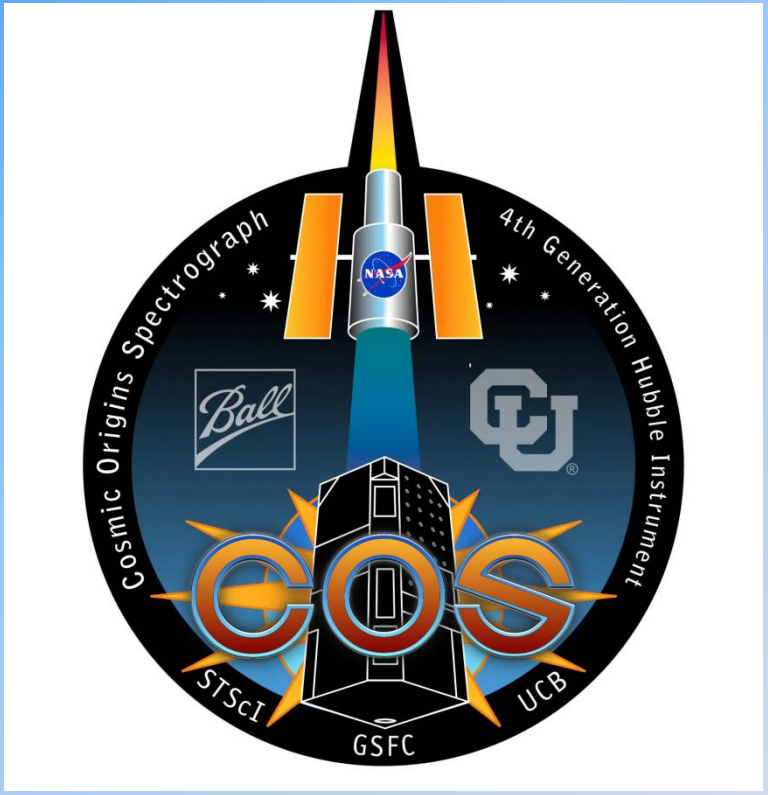
Exoplanet Atmospheres: Exo-Earths



Exoplanet Atmospheres: Exo-Earths

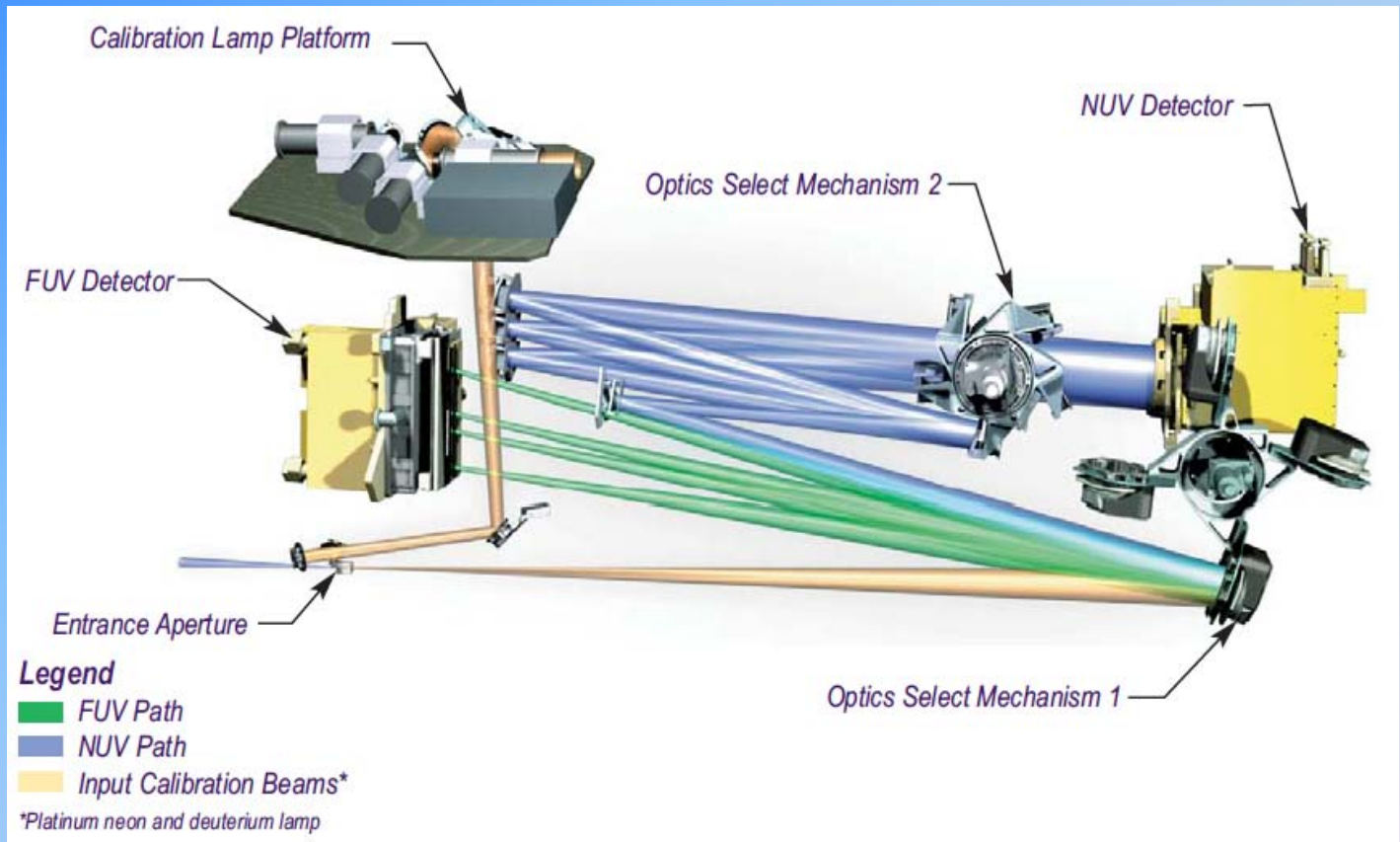


Cosmic Origins Spectrograph



Cosmic Origins Spectrograph

- $900 \leq \lambda \leq 3200$ Å
- Holographically ruled diffraction grating for simultaneous dispersion, focus, and correction of spherical aberration of *HST* primary



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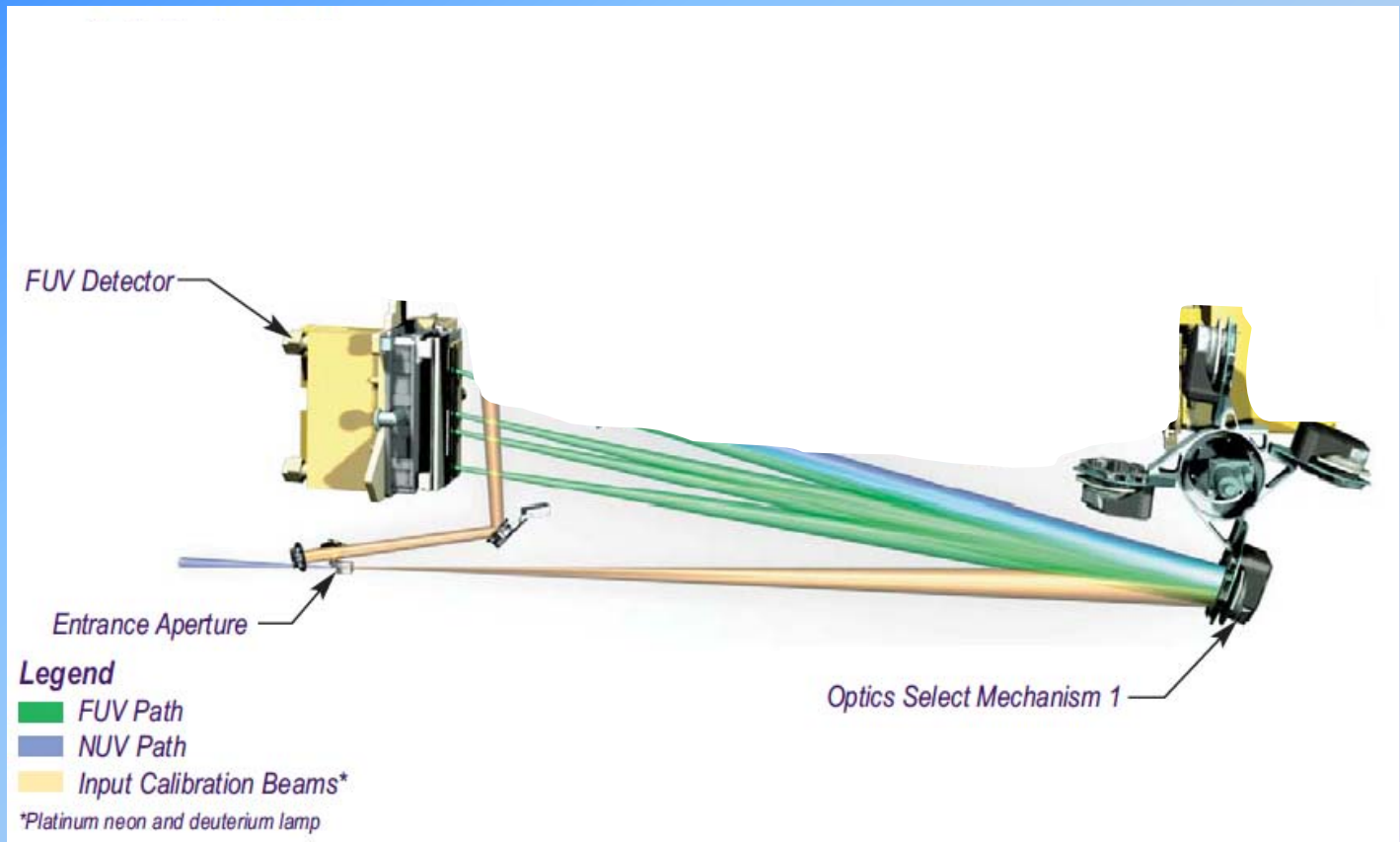
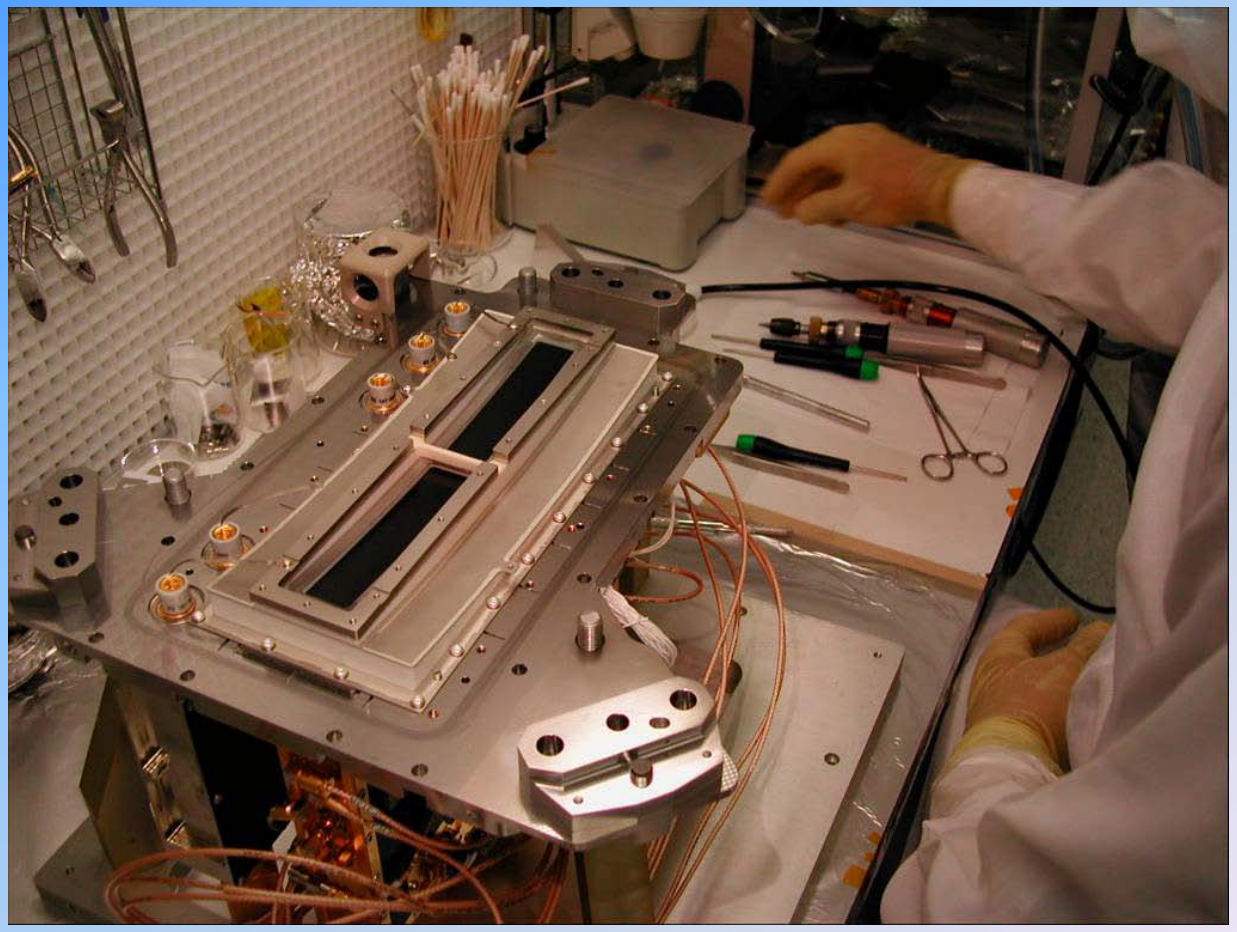


Cosmic Origins Spectrograph

COS FUV micro-channel plate detector:

- UC Berkeley
- CsI Photocathode
- Cross delay line anode



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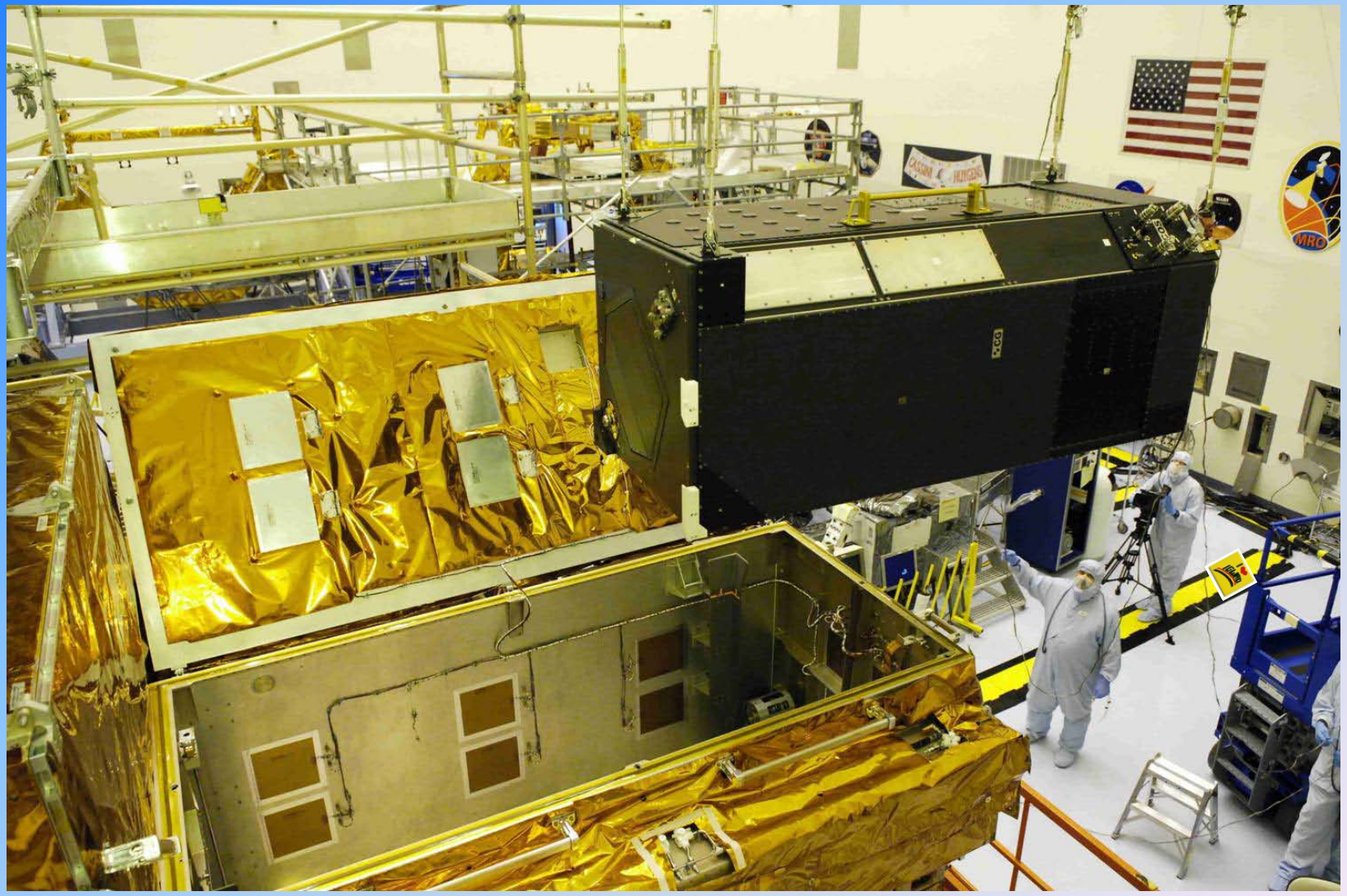

Cosmic Origins Spectrograph

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Cosmic Origins Spectrograph

Cosmic Origins Spectrograph

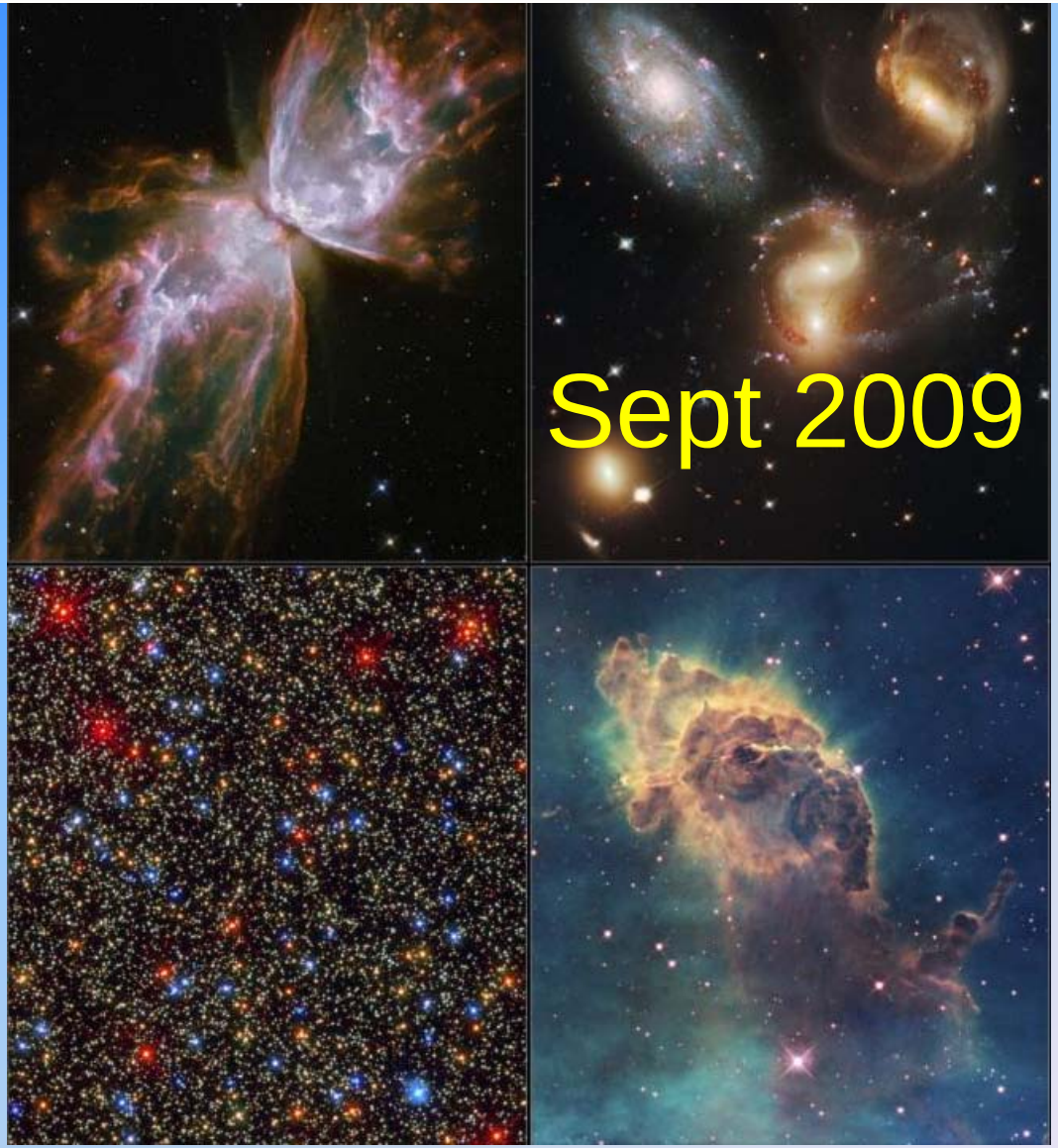
COS Instrument and on-orbit performance: **Green et al. (2012)** & **Osterman et al. (2011)**

"All the News That's Fit to Print"

The New York Times

Late Edition

New York: **Today**, mainly sunny and noticeably less humid, high 79. **Tonight**, clear, low 62. **Tomorrow**, sunny and cool, high 76. **Yesterday**, high 86, low 73. Weather map is on Page D8.



Late Night with Jimmy Fallon

FAME:
AUGUST 3, 2010

Linsky, Yang, France et al. (ApJ – 2010)

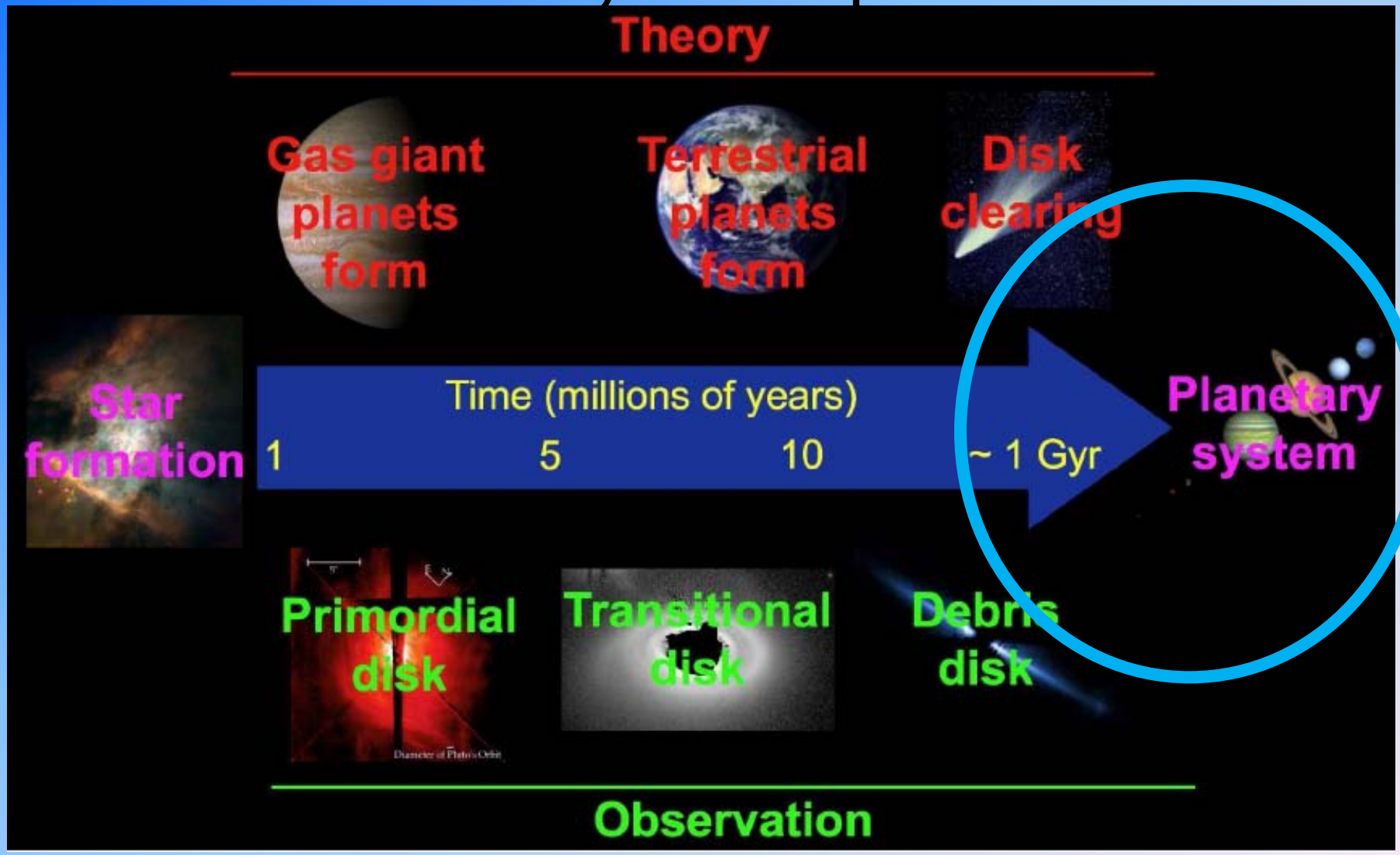
Outline

1. The Radiation Environment in the Habitable Zones of M dwarf Exoplanetary Systems

2. NASA: Implementation of 2010 Decadal Survey, New Instrumentation

3. Sounding Rocket Payloads: Pathfinders for Future Long-duration Astrophysics Missions

Heating and Chemistry of Planetary Atmospheres



A. Roberge et al. 2009 – Astro2010