Probing the physics of exoplanet systems with X-ray observations

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Exoplanets

image credit: NASA/Kepler Team
Exoplanets

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Exoplanets

- **Earth-size**
- **Super-Earth size**
  - 1.25 - 2.0 Earth-size
- **Neptune-size**
  - 2.0 - 6.0 Earth-size
- **Giant-planet size**
  - 6.0 - 22 Earth-size

*Image credit: NASA/Kepler Team*
Exoplanets

Dressing et al. (2013), Batalha(2014), Burke et al. (2015)

They're everywhere:
ca. 1 planet per star
System architectures

image credit: German Air & Space Center (DLR)
System architectures

image credit: German Air & Space Center (DLR)
Habitable zones

image credit: C. Harman
Big questions

- How diverse are exoplanet atmospheres?
- Which exoplanets have the potential to host life?

... Which (exo)planets do host life?
Upcoming exoplanet observatories

TESS, Transiting Exoplanet Survey Satellite
All-Sky search for transiting exoplanets
image credit: MIT

JWST, James Webb Space Telescope
infrared spectroscopy of exoplanet atmospheres
image credit: NASA
Exoplanets: transits

picture credit: NASA
Exoplanet atmospheres: transmission spectroscopy

Exoplanet atmospheres: transmission spectroscopy

picture credit: NASA, modified by K.P.
Exoplanet atmospheres: transmission spectroscopy

[Diagram showing various atmospheric layers and wavebands]

picture credit: NASA, modified by K.P.
Exoplanet atmospheres: transmission spectroscopy

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Exoplanet atmospheres: transmission spectroscopy

HD 209458b (hot Jupiter)

Deming et al. 2013
Exoplanet atmospheres: cloud layers

HAT-P-12b (warm Saturn)

Line et al. 2013
Exoplanet atmospheres: cloud layers

GJ 1214b (super-earth)

Kreidberg et al. Nature 2014
Exoplanet atmospheres: transmission spectroscopy

picture credit: NASA, modified by K.P.
X-ray transits (hot Jupiter HD 189733b)

5 Chandra observations co-added, 20 ks each, 0.2-2 keV

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X-ray transits - X-ray Surveyor

5 observations with X-ray Surveyor, co-added
Different altitudes probed with X-rays
X-ray transmission spectrum of exoplanet atmosphere

Hot Jupiter, $10 \times 30$ ks

Transmission spectrum (transit depth vs. energy), 10 transits

No extended atmosphere, only occulted by optical planetary radius
X-ray transmission spectrum of exoplanet atmosphere

Hot Jupiter, 10 × 30 ks

transmission spectrum (transit depth vs. energy), 10 transits

extended atmosphere, density $2 \times 10^{10} \text{cm}^{-3}$, solar

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Hot Jupiter, $10 \times 30$ ks

extended atmosphere, density $2 \times 10^{10}$ cm$^{-3}$, oxygen $5 \times$ enhanced, rest solar

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X-ray transmission spectrum of exoplanet atmosphere

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Extended atmosphere, density $2 \times 10^{10} \text{ cm}^{-3}$, $5 \times \text{solar}$

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X-ray transmission spectrum of exoplanet atmosphere

Superearth around M dwarf, $100 \times 20$ ks

transmission spectrum (transit depth vs. energy), 100 transits

extended atmosphere, density $2 \times 10^{10}$ cm$^{-3}$, oxygen $5 \times$ enhanced, rest solar
Exoplanets in habitable zones around M dwarfs

TESS all-sky exoplanet search: ca. 60 detections of Earth-sized planets in habitable zones expected, mostly around M dwarfs.

Habitable zones close to host star for M dwarfs; low bolometric luminosity, but fairly high X-ray luminosity!
Stellar X-rays & flares: damage to exoplanet atmospheres

- High X-ray/UV irradiation: evaporation of atmosphere

- Large flares: 90% ozone depletion for several years

Kulow et al. (2014); illustration: Ehrenreich & Bourrier

Segura et al. (2010)
Big X-ray flares: common among low-mass stars

Flares big enough to cause ozone depletion for $\sim 5$ years in habitable zone every $\sim 100$ days!

Feng, Poppenhaeger et al. to be submitted
Exoplanets in habitable zones around M dwarfs

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typical distance: $\lesssim 80$ pc

baseline luminosity: $L_X \gtrsim 3 \times 10^{26}$ erg/s

c. 30% of host stars have stellar companions $\rightarrow$ spatial resolution

Chandra: ca. 200 ks per target, 12 Msec for all
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image credit: MIT

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Detectable in 2 ks with X-ray Surveyor

X-ray detect host star of every Earth-like habitable zone planet in $\sim 120$ ks!
Big questions - X-ray Surveyor

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