Stars and exoplanets: interaction, rotation, activity

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Exoplanets: exciting & newsworthy

- Temperature map of brown dwarf (Crossfield et al. 2014)
- Transits of multi-ring system (Kenworthy et al. 2015)
- Detection of exoplanet spin (Snellen et al. 2014)
- X-ray detection of extended atmosphere (Poppenhaegger et al. 2013)
Exoplanets

image credit: NASA/Kepler Team
Exoplanets

image credit:
NASA/Kepler Team
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:

Exoplanets: they're everywhere (1 per star) e.g. Dressing et al. (2013)
System architectures

image credit:
German Air & Space Center (DLR)
Possible interaction types
Possible interaction types

e.g. Cuntz et al. (2000)
Possible interaction types

e.g. Cuntz et al. (2000)
Possible interaction types

- magnetic fields
- tides
- planetary atmospheres
Exoplanet host stars
Magnetic activity

- flares
- X-ray emission
- UV emission

image credit: SDO
How stars age on the main sequence

loss of angular momentum through stellar wind ("magnetic braking")
How stars age on the main sequence

loss of angular momentum through stellar wind ("magnetic braking")
Magnetic interaction

tides

magnetic fields

planetary atmospheres
Template: stellar binaries

image credit:
V. Holzwarth, S.G. Gregory

image credit:
Uchida & Sakurai (1985)
Template: stellar binaries

Binary YY Gem
Guedel et al. (2002)

Binary AR Lac
Siarkowski et al. (1996)
Magnetic interaction:
Hot Jupiters and stellar coronae
Magnetic interaction: Hot Jupiters and stellar coronae

solar eclipse in white light
image credit: K. van Gorp
Planet-induced activity?

courtesy of O. Cohen
Planet-induced activity?

Shkolnik et al. (2005, 2008)

HD 179949
$P_{\text{orb}} = 3.1 \text{ d}$
$P_{\text{rot}} = 11 \text{ d}$

upsilon And
$P_{\text{orb}} = 4.6 \text{ d}$
$P_{\text{rot}} = 9.5 \text{ d}$

Shkolnik et al. (2005, 2008)
Magnetic flare triggering?

other works:
Lanza (2013)
Scandariato et al. (2013)
Strugarek et al. (2014)

Pillitteri et al. (2015 submitted)
Absence of magnetic effects

WASP-18 (1.2 $M_{\text{Sun}}$): completely X-ray dark!

Miller et al. (2012), Pillitteri et al. (2014)

$\upsilon$ And (1.3 $M_{\text{Sun}}$): varies with stellar rotation, not with Hot Jupiter orbit

Poppenhaeger et al. (2010)
Tidal interaction

Mathis & Remus
(2013)
Tidal interaction and orbital obliquities

Albrecht et al. (2012)
Test for planet-induced activity

more Hot Jupiter-like

more active
Test for planet-induced activity

Kashyap et al. (2008)
Test for planet-induced activity

Miller et al. (2014)
Test for planet-induced activity

- Poppenhaeger et al. (2011)
- Alves et al. (2010)
- Canto Martins et al. (2011)
- Shkolnik (2013)

Graph showing a relationship between $\log L_x$ and $\log M_{pl} [M_{jup}]$.
What do we see?
What do we see?
What do we see?
What do we see?

more active

more Hot Jupiter-like

Poppenhaeger et al. (2011)
Bias-controlled sample: planet-hosting wide binaries

image credit: Mugrauer et al. (2007); see also Raghavan (2006)
Planet-hosting wide binaries

HD 189733 Ab B

CoRoT-2 Ab B

55 Cnc Abcde B

upsilon And Ab B

tau Boo Ab B

HAT-P-20 Ab B

HD 46375 Ab B

HD 178911 A Bb

HD 109749 Ab B

Poppenhaeger et al. (2014), Poppenhaeger et al. in prep.
Planet-hosting wide binaries

strong tidal interaction

- CoRoT-2
- HD 189733

weak tidal interaction

- ups And
- 55 Cnc
Planet-hosting wide binaries

![Graph showing the relationship between log age and more active, with different markers for F/G stars, K stars, and M stars.](image-url)
Planet-hosting wide binaries
Planet-hosting wide binaries

The diagram shows a scatter plot with the x-axis labeled as 'log age' and the y-axis labeled as 'log $L_X$'. The plot includes data points labeled 'ups And A' and 'ups And B', indicating active stars. The y-axis also has a label 'more active'.
Planet-hosting wide binaries

![Graph showing the relationship between log age and log Lx, with data points for CoRoT-2 B and HD 189733 B indicated.]

CoRoT-2 B
HD 189733 B
Planet-hosting wide binaries
Several over-active systems

Poppenhaeger et al. (2014), Poppenhaeger et al. in prep.

- More active
- \( \log L_x \)
- Strong tidal interaction
- Weak tidal interaction
- Planet-free companions
- Planet-hosting stars
- Planet-hosting stars (expected)
Tidal effect in very close systems

planet-induced enhanced activity (and rotation):

- massive exoplanet (at least 1 $M_{\text{Jup}}$)

- very close orbit (3 days or less)

- low-mass host star, i.e. thick convection zone (less than 1 $M_{\text{Sun}}$)

→ activity enhancement of 1-2 orders of magnitude possible
Improving stars as clocks

oscillation frequency
spectrum:

$\Delta \nu \rightarrow$ mean density
$\delta \nu \rightarrow$ density in core
+ evolution models
= stellar age
Improving stars as clocks

WD spectrum:

\( T_{\text{eff}}, \log(g) \rightarrow \) mass, cooling time + progenitor lifetime = stellar age
Exoplanetary atmospheres

- Tides
- Magnetic fields
- Planetary atmospheres
Atmospheres and high-energy photons

image credit: NASA
Atmospheres and high-energy photons

image credit: NASA
Spectra of atmospheres

Hot Jupiter
HD 209458 b

Deming et al. (2013)
Spectra of atmospheres

Super-earth
GJ 1214 b

Kreidberg et al. (2014)
X-ray transits: extended atmospheres

Poppenhaeger et al. (2013)
X-ray transits: extended atmospheres

Poppenhaeger et al. (2013)
X-ray transits: extended atmospheres

Poppenhaeger et al. (2013)
Extended atmospheres

- X-ray absorption at 1.7 $R_{opt}$
- Density at X-ray absorbing altitude: ca. $10^{11}$ cm$^{-3}$
- Temperature ca. 20000 K
Extended atmospheres in UV/X-ray

Hot Neptune GJ 436 b: comet-like tail

Kulow et al. (2014)
Extended atmospheres in UV/X-ray

HD 209458 b: Vidal-Madjar et al. (2003), Linsky et al. (2010)

HD 189733 b: Lecavelier des Etangs et al. (2010), Bourrier et al. (2013), Ben-Jaffel & Ballester (2013)

55 Cnc b: Ehrenreich et al. (2012)

WASP-12 b: Haswell et al. (2012), Fossati et al. (2013)

CoRoT-2 b: Czesla et al. (in prep.)
Atmospheric evaporation

driven by X-ray and extreme UV photons

e.g. Murray-Clay et al. (2009), Lecavelier des Etangs (2004)

total estimated mass loss: small for Jupiters (few %), substantial for small (Neptune-like) exoplanets

see also

Sanz-Forcada et al. (2011)

Lopez et al. (2013)
Interaction between stars and exoplanets

Interaction possible through tides or magnetic fields

Magnetic interaction
  - difficult to observe due to intrinsic variability of stellar magnetic structure

Tidal interaction
  - orbital obliquities; activity enhancements for very close systems

Effect on exoplanet atmospheres and habitability
  - X-ray/UV driven evaporation, flares
Moving forward

Exoplanet atmospheres

▪ high-energy transit observations of exoplanets (ASTRO-H, eROSITA)

Tidal interaction

▪ constrain theoretical tidal quality factors of stars from exoplanet lifetimes from systems with known interaction

Fundamental properties of exoplanet host stars

▪ independent ages (seismology, white dwarf companions) and activity in the presence of planets
Interactions of exoplanets and their host stars

Scott Wolk
K. P.
Cecilia Garraffo
Jürgen Schmitt
Hans-Moritz Günther
Ofer Cohen
Ignazio Pillitteri