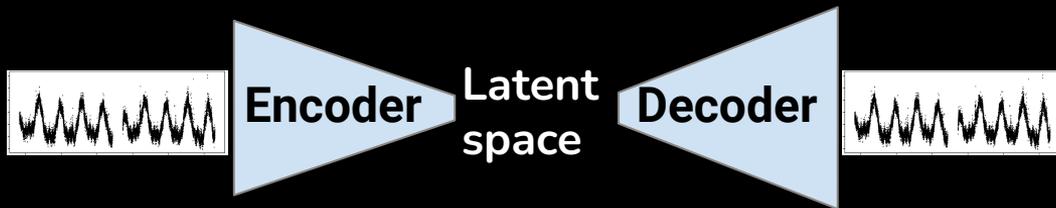


Public misconceptions in exoplanet science

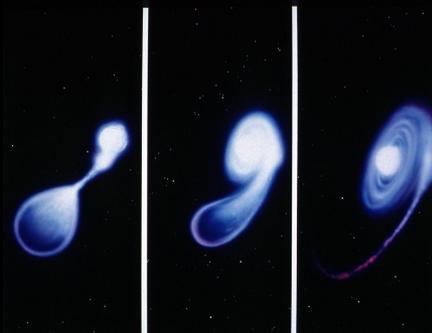
Presenter: Emma Chickles (MIT)
AAS240 Workshop - June 11th, 2022

About me

- Rising second-year physics graduate student at MIT
- TESS census of complex phase modulation of stellar light curves
 - Presentation @ Tue June 14 2PM (Session 225: Fundamental Properties II)



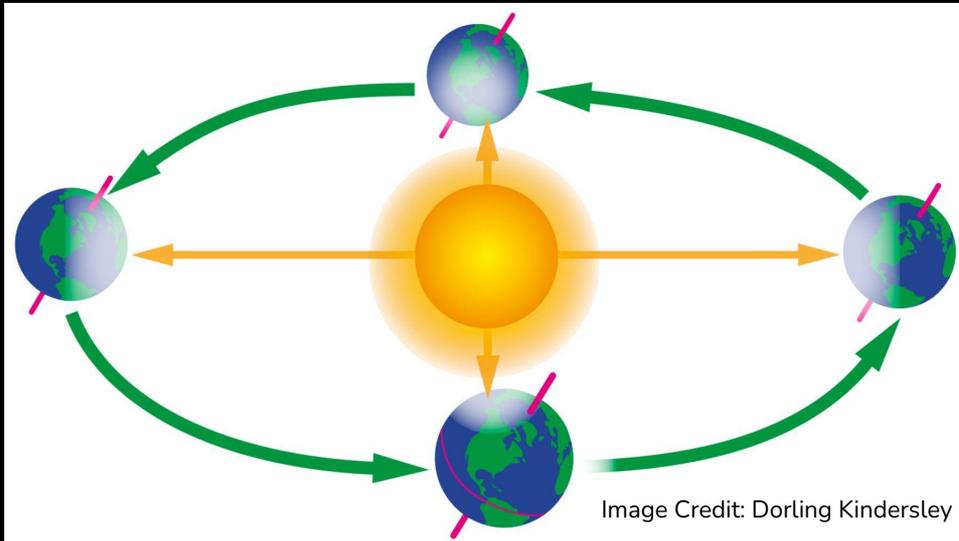
- Searching for eclipsing double white dwarfs in TESS 200s observations
 - Gravitational-wave sources detectable by upcoming LISA
 - Possible Type 1a supernovae progenitors



Credit: Illustration: Dana Berry (STScI)

Definitions of “misconception”

- Involve a “belief system comprised of logically linked sets of propositions” (Fisher 1985, JRST)
- “Any deeply held belief that is inconsistent with currently accepted scientific concepts. Deeply held beliefs are distinctly different from superficial ones, such as details we might memorize for an exam and then promptly forget” (Comins 2001)



Possible logical but inaccurate inferences from diagram:

- Winter occurs when the Earth is farther away from the Sun. Barrier 2010, Phys. Teach. found this was a common misconception among elementary and middle school teachers in North Carolina.
- Earth's orbit is extremely eccentric.

Why we should care misconceptions

- “Are we alone?”: one of the most exciting open questions of science (e.g. [Birch 2013](#), [Kennedy 2005](#))
 - Search of exoplanets fascinates a broad population (e.g. high participation in NameExoWorlds project)
 - We benefit from citizen science (e.g. Planet Hunters, Exoplanet Explorers, SETI@home screensaver)

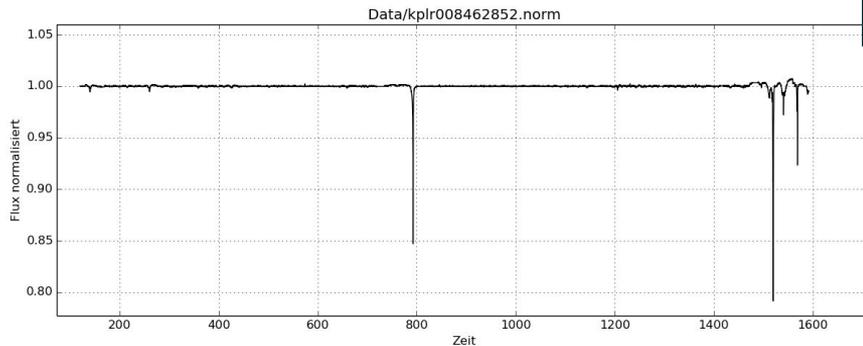


Fig. 5a from Deeg & Belmonte, 2018

Boyajian’s star discovered by Exoplanet Explorers. Figure by [JohnPassos](#).

Why we should care misconceptions

- “Are we alone?”: one of the most exciting open questions of science (e.g. [Birch 2013](#), [Kennedy 2005](#))
 - Search of exoplanets fascinates a broad population

Exoplanets: Crash Course Astronomy #27

1,264,072 views Aug 6, 2015 Today Phil explains that YES, there are other planets out there and astronomers have a lot of methods for detecting them. Nearly 2000 have been found so far ...more

I always get the chills when I watch these because I mean.....space is awesome!

👍 582 🗨️ REPLY

When you said you had a photo of an exoplanet, I GASPED with excitement. My favorite crash course series.

👍 47 🗨️ REPLY

Exoplanets That Might Be Better Than Earth

2,227,236 views Jun 13, 2021 Exoplanets That Might Be Better Than Earth

Imagine if there's alien life out there that has discovered Earth as a possible habitable planet for their society, but they don't know that life is already here

👍 274 🗨️ REPLY

I'm pumped for the James Webb telescope. Seeing hubbles deepfield changed my perspective on everything. I can't wait to see what they see in 2022 alone

👍 313 🗨️ REPLY

What Makes the Exoplanets of Trappist-1 So Special?

1,096,975 views Premiered Dec 21, 2018 Everything you could want to know

Imagine aliens on Trappist 1e watching videos about our solar system and them theorizing about alien life on Earth

👍 1.7K 🗨️ REPLY

Why we should care misconceptions

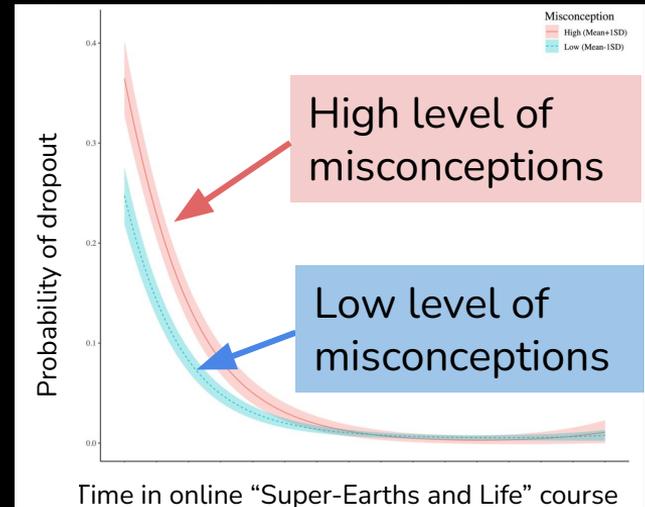
Adapted from Table 1 of
[Bergstrom+2016, JAESE](#)

	Female				Male			
Interest in career	Middle school	Beginning of HS	End of HS	College	Middle school	Beginning of HS	End of HS	College
Astronomy	3.9%	1.8%	1.0%	0.5%	6.0%	3.1%	1.9%	1.4%
Other STEM	2.8%	2.8%	2.6%	2.0%	4.6%	5.5%	5.5%	4.7%

- BUT astronomy is also one of the science subjects people most rapidly lose interest
 - More likely to stay at a superficial and misconceptual understanding
 - Interest in astronomy experiences the most extreme and exponential decrease in interest of all the fields examined ([Bergstrom+2016, JAESE](#))

Adapted
Fig. 1 from
[Chen+2020, JRST](#)

Students holding more misconceptions had a higher dropout rate at the start of the course.



Demonstration of forming misconceptions outside our field of expertise



Kurzgesagt - In a Nutshell
1:30-3:00

How do we study the microbiome?

- Not imaging! Not a microscope!
- Most commonly studied by stool samples or mucosal biopsies → correlative microbiome relationships
- Establishing causality and mechanism:
 - requires, for example, transferring human microbiome samples into mice
 - administer change-inducing treatments, such as antibiotics
 - population studies comparing microbiome differences by location, ethnicity, culture, ...

Misconceptions in exoplanet science

I don't understand how any planet could look like ours these days. I mean when the last time a planet was found with lights on them that never turn off ?

👍 17 🗨️ REPLY

← Confusion about methodology

I was born in 2003, and i hope and pray to live long enough to see our species find life on another planet, and if we work fast enough, inhabit an actual habitable planet outside of earth

👍 118 🗨️ REPLY

← Oversimplified notion of astronomical distance

The fact that Titan and Earth have liquids on their surface proves that liquids on the surface of planets/moons water or something else is extremely common because if it managed to happen twice in our solar system so it might as well happen a lot in other star systems.

👍 264 🗨️ REPLY

← Over-extrapolating based on Earth's properties

I guess people don't realize how bad it would be to live on a planet that much bigger than Earth. The gravity would be so intense you would barely be able to lift your own body.

👍 3 🗨️ REPLY

← Confusion about gravity

Studies on misconceptions of basic astronomy concepts

Understanding of basic concepts are needed to learn about current research findings! ([Chen+2020, JRST](#))

- 1958 **grades 9-12** students, misconceptions persisting at the end of a high school Earth science or astronomy course ([Sadler+2010, AER](#))
- ~900 **undergrad** nonmajor students **pre-instruction**, misconceptions before starting 100 or 200-level astronomy courses ([Simon 2019](#))

-
- | | |
|----|--|
| 1: | unlearned the incorrect belief as a child or adolescent, indicating the lowest degree of misconception retainment |
| 2: | unlearned the incorrect belief as a result of taking AST 109, indicating a medium degree of misconception retainment |
| 3: | retained the incorrect belief even after instruction in AST 109, indicating the highest degree of misconception retainment |
-

Table 2.4. Codes for three relative degrees of misconception retainment

- Studied 215 misconceptions held by 639 **undergrad** students at the University of Maine **pre-instruction** ([Favia 2014](#))

Misconceptions of basic astronomy concepts: Astronomical Distances

- Stars in the Milky Way are as close to each other as planets are to the Sun. Misconception retainment score of 1.89/3.00 ([Favia 2014](#))
 - Space is infinite: 2.58 ([Favia 2014](#))
- Major misconceptions of grades 9–12 after astronomy course ([Sadler+2010, AER](#)):
 - Probes have brought samples back to Earth from many planets.
 - Astronauts have traveled beyond the moon.
 - Telescopes are put in space to get closer to astronomical objects.

- Definition of a “light year” among pre-instructional undergrads:

Units of distance
(54.9%)

Units of speed
(8.8%)

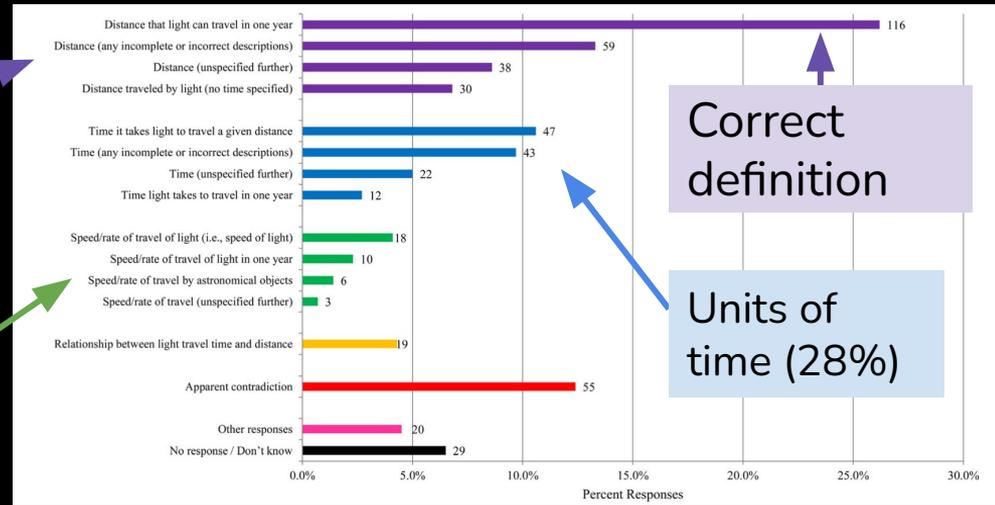


Figure 3 from [Bailey+2012, AER](#)

Misconceptions of basic astronomy concepts: gravity

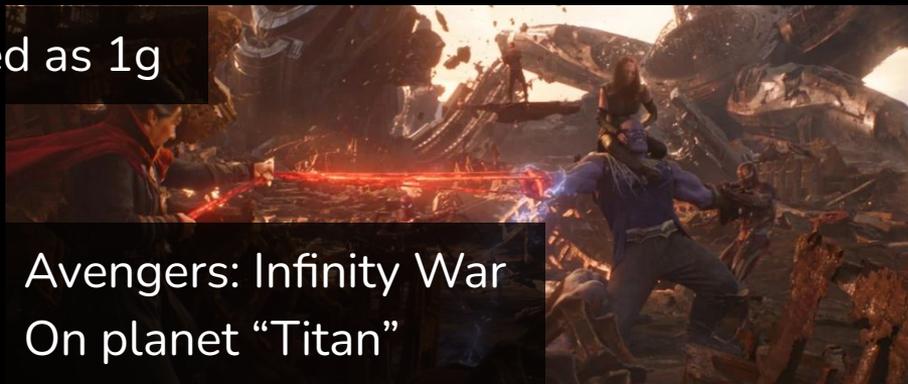
I guess people don't realize how bad it would be to live on a planet that much bigger than Earth. The gravity would be so intense you would barely be able to lift your own body.

👍 3 🗨️ REPLY

$g \sim M/R^2$
E.g. HD 40307g
 $M=8.2M_e$, $R=2.4R_e$
→ 1.42g



Star Wars: Revenge of the Sith
On planet "Mustafar"



Avengers: Infinity War
On planet "Titan"

- Gravity is the strongest force in the universe: Misconception score 2.33 ([Favia 2014](#))
- 7% of students believed Sun's gravity pulled denser, rockier planets close in ([Simon 2019](#))

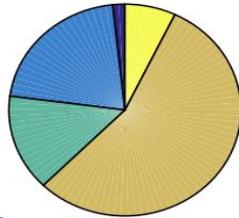
Misconceptions of basic astronomy concepts: Definitions of celestial objects, and relative scale

Only 5% of students clearly stated that a planet must be smaller than a star (Simon, 2014)

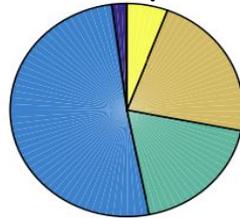
6% of students said there is no difference between a star and a planet (Bailey+2012, AER)

Only 60% of students attempted to define an exoplanet

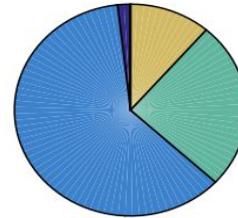
Planet formation



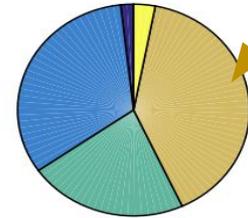
Planet composition



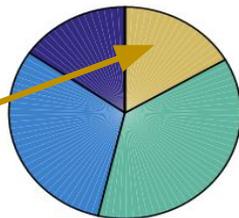
Planet orbits



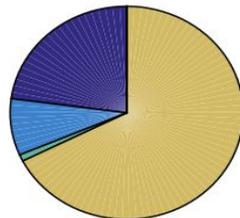
Planet definition



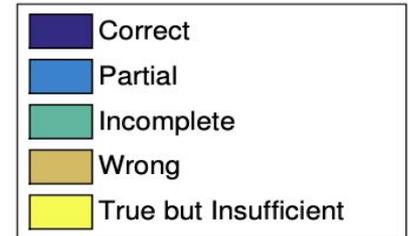
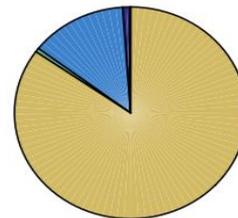
Solar system definition



Exoplanet definition



Solar System formation



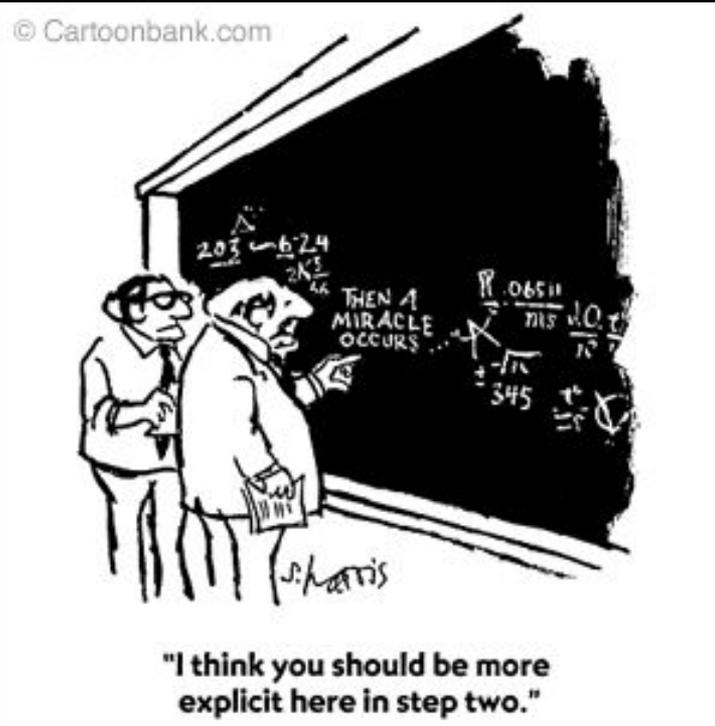
Scoring Distribution Per Question

Students often confused solar system and galaxy (Bailey+2012, AER)

13/172 students expected to find galaxies or nebulae within our solar system

Adapted Fig 2.1 from [Simon 2019](#)

Misconceptions about methodology (Favia 2014)



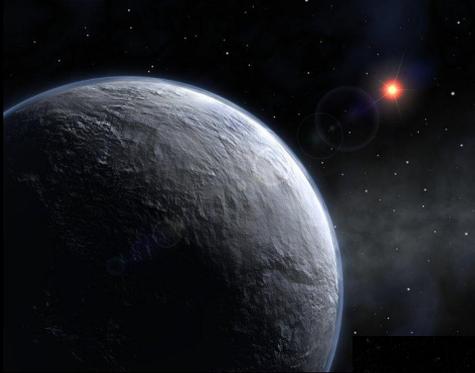
I don't understand how any planet could look like ours these days. I mean when the last time a planet was found with lights on them that never turn off ?

👍 17 🗨️ REPLY

Misconception	Average misconception retainment score
We do not have telescopes in space	1.59
Stars emit only one color of light.	1.79
Smaller telescopes enable astronomers to see smaller details	1.86
The most important function of a telescope is magnification	2.14
Astronomers mostly work with telescopes	2.14

Misconceptions about methodology

- Confusion between artist rendering and direct images

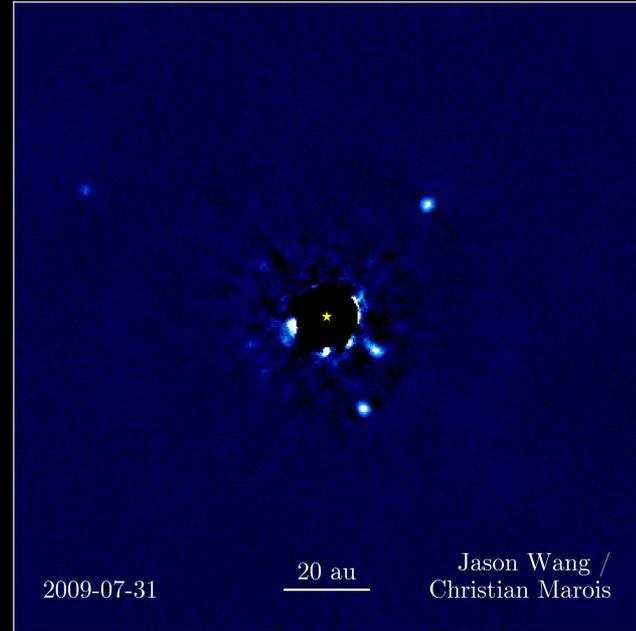


Credit: ESO
Icy exoplanet

Credit: ESA/Hubble, M.
Kornmesser
K2-18b



- In reality, rarely can directly image exoplanets



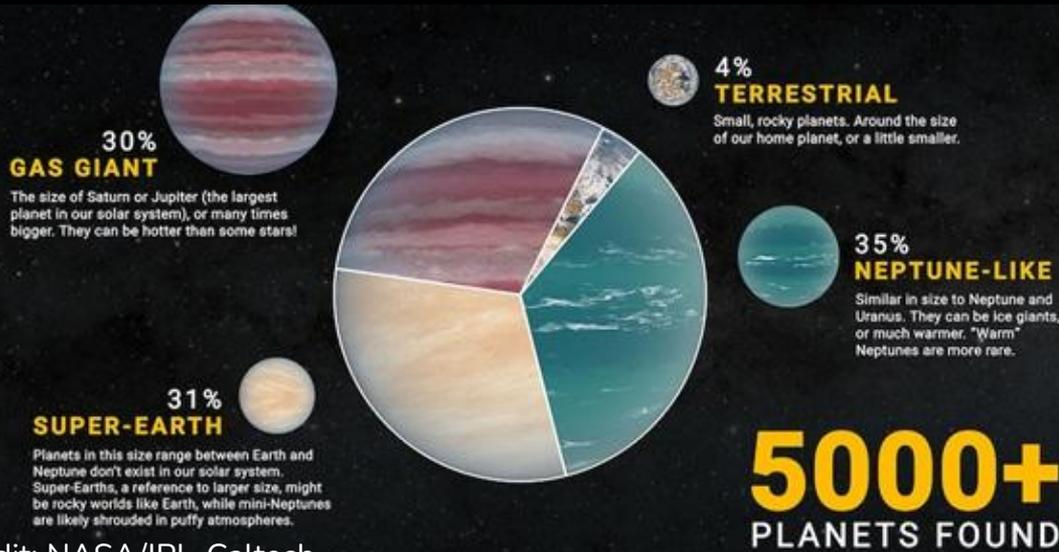
Credit: Jason Wang (Caltech)/Christian Marois (NRC Herzberg)

Misconceptions of planet formation

- New planets and stars don't form: Misconception score of 1.81/3.00 ([Favia 2014](#))
 - The Milky Way is just stars - no gas and dust: 1.73/3.00 (Favia, 2014)
- ~10% of college students claimed the Sun's gravity acts as a catalyst of planetary accretion ([Simon 2019](#))
- 45% of nonmajor pre-instruction undergrad students asserted that our Solar System either formed directly from the Big Bang, or as a direct result of the Big Bang ([Simon 2019](#))
 - ~25% of nonmajor pre-instruction undergrad students said the Big Bang Theory relates to the creation of planetary systems, pre-instruction ([Pranther+2002, AER](#))

Assumptions based on our Solar System

- All stars have planets: Misconception score of 1.80/3.00 ([Favia 2014](#))
- All stars are isolated from all other stars (none are binary): 1.92/3.00 ([Favia 2014](#))



Credit: NASA/JPL-Caltech

SpaceX
@ineed_spacee

Some places on #Earth look like they came from an Exoplanet 🤖

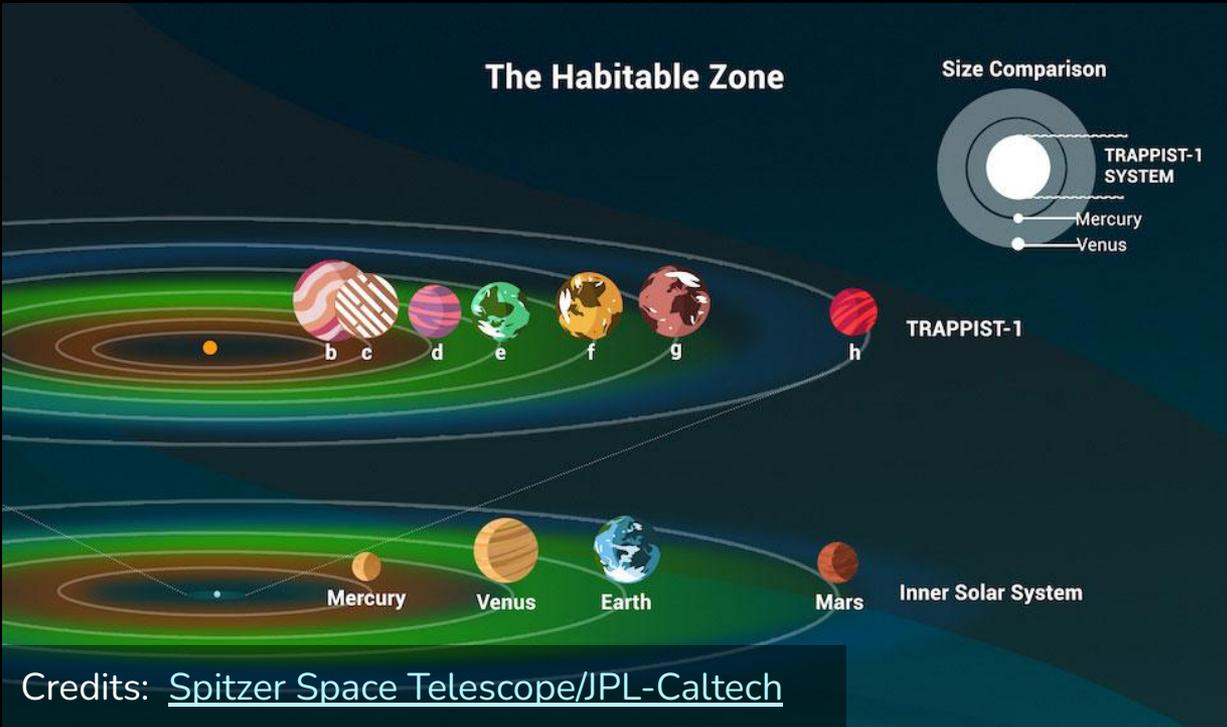


9:08 am · 28 Apr 2022 · Twitter Web App

1,255 Retweets 51 Quote Tweets 13.1K Likes

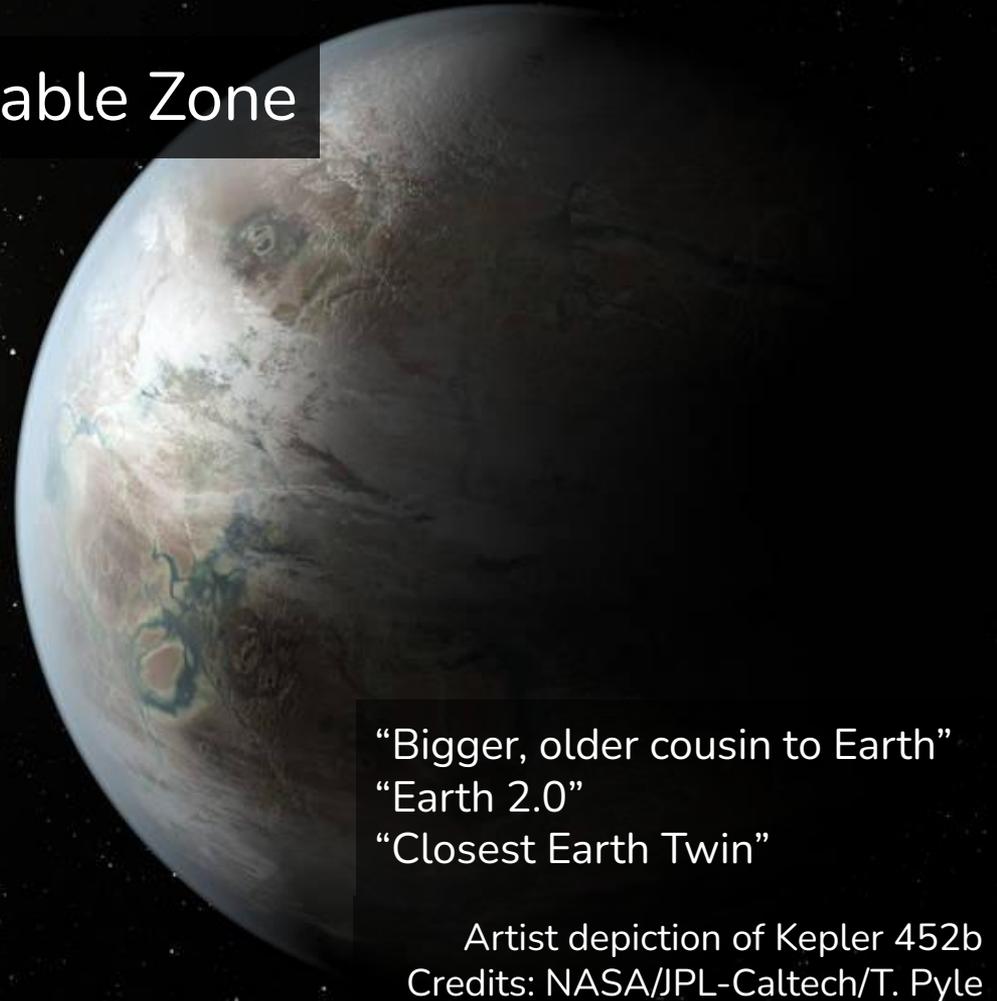
Misconceptions of the Habitable Zone (Kane+2015)

- Habitable Zone: Region around the star where water could exist in a liquid state on the surface of a planet if it has sufficient atmospheric pressure
- Misconception: Habitable Zone planets implies habitable planets.



Misconceptions of the Habitable Zone

- Overuse of term “Earth-like”: similarity to Earth based on a few selected geophysical parameters
- “Earth-like”: implies multiple environmental habitats, presence of a biosphere, complex ecosystems
([Schulze-Makuch & Guinan 2016, *Astrobiology*](#))

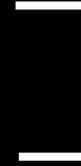


“Bigger, older cousin to Earth”
“Earth 2.0”
“Closest Earth Twin”

Artist depiction of Kepler 452b
Credits: NASA/JPL-Caltech/T. Pyle

From misconceptions to scientific understanding

- Dissatisfaction with currently held concepts
- Encountering new and plausible concepts
- Accommodating new concepts



Theory of cognitive conflict

See discussion in [Schoon 1988](#), [Favia 2014](#), and [this blog](#).

Some examples directly targeting misconceptions:

MYTH VS **REALITY**

The Hubble Space Telescope can take pictures of the surfaces of exoplanets.

It is not possible for Hubble to photograph the surface or atmosphere of an exoplanet.

Planets orbiting other stars are so far away, and so small and faint compared to their stars that at best they appear only as small, faint dots of light.

However, Hubble can collect other data from exoplanets that can help us infer what the surface and atmosphere may be like.

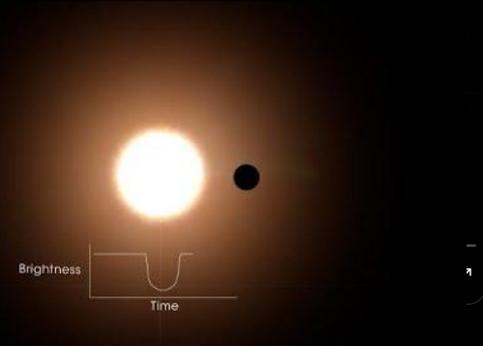
Credit: Space Telescope Science Institute's Office of Public Outreach



World and Science
@WorldAndScience

This is how astronomers detect exoplanet using the transit method

(Credit: NASA's Goddard Space Flight Center/Chris Smith)



From misconceptions to scientific understanding

- Avoid assuming intuition about astronomical distances, relative sizes, timescales (e.g. [Sadler+2010](#), [Favia 2014](#), [Simon 2019](#))
- Exaggeration in media will always be present! ([Schulze-Makuch & Guinan 2017](#))
 - Avoid misnomers and adhere to the definition of terms as they were originally conceived (e.g. habitable zone, Earth Similarity Index, ...)
 - Indicate larger context and limitations

LETTER

doi:10.1038/nature19106

A terrestrial planet candidate in a **temperate** orbit around Proxima Centauri

Guillem Anglada-Escudé¹, Pedro J. Amado², John Barnes³, Zaira M. Berdiñas², R. Paul Butler⁴, Gavin A. L. Coleman¹, Ignacio de la Cueva⁵, Stefan Dreizler⁶, Michael Endl⁷, Benjamin Giesers⁶, Sandra V. Jeffers⁶, James S. Jenkins⁸, Hugh R. A. Jones⁹, Marcín Kiraga¹⁰, Martin Kürster¹¹, María J. López-González², Christopher J. Marvin⁶, Nicolás Morales², Julien Morin¹², Richard P. Nelson¹, José L. Ortiz², Aviv Ofir¹³, Sijme-Jan Paardekooper¹, Ansgar Reiners⁶, Eloy Rodríguez², Cristina Rodríguez-López², Luis F. Sarmiento⁶, John P. Strachan¹, Yiannis Tsapras¹⁴, Mikko Tuomi⁹ & Mathias Zechmeister⁶

References, [Link to Zotero RDF](#)

Item Type	Publication Year	Author	Title
journalArticle	1985	Fisher, Kathleen M.	A misconception in biology: Amino acids and translation
book	2001	Comins, Neil F.	Heavenly Errors: Misconceptions About the Real Nature of the Universe
journalArticle	2010	Barrier, Regina M.	Astronomical Misconceptions
journalArticle	2016	Bergstrom, Zoey; Sadler, Philip; Sonnert, Gerhard	Evolution And Persistence Of Students' Astronomy Career Interests: A Gender Study
journalArticle	2020	Chen, Chen; Sonnert, Gerhard; Sadler, Philip M.; Sasselov, Dimitar; Fredericks, Colin	The impact of student misconceptions on student persistence in a MOOC
journalArticle	2010	Sadler, Philip M.; Coyle, Harold; Miller, Jaimie L., Cook-Smith, Nancy; Dussault, Mary; Gould, Roy R.	The Astronomy and Space Science Concept Inventory: Development and Validation of Assessment Instruments Aligned with the K-12 National Science Standards
thesis	2019	Simon, Molly Nora	Part I: How Did We Get Here? College Students' Preinstructional Ideas on the Topic of Planet Formation, and the Development of the Planet Formation Concept Inventory. Part II: Evidence for Magnetically Driven Protoplanetary Disk Winds

References, [Link to Zotero RDF](#)

Item Type	Publication Year	Author	Title
thesis	2014	Favia, Andrej	An inventory of student recollections of their past misconceptions as a tool for improved classroom astronomy instruction
journalArticle	2012	Bailey, Janelle; Coble, Kim; Cochran, Geraldine; Larrieu, Donna; Sanchez, Roxanne; Cominsky, Lynn	A Multi-Institutional Investigation of Students' Preinstructional Ideas About Cosmology
journalArticle	2002	Pranther, Edward E.; Slater, Timothy F.; Offerdahl, Erika G.	Hints of a Fundamental Misconception in Cosmology
book	2015	Kane, Stephen	Definitions and Caveats of the Habitable Zone
journalArticle	2016	Schulze-Makuch, Dirk; Guinan, Edward	Another Earth 2.0? Not So Fast
thesis	1988	Schoon, Kenneth J	Misconceptions in the Earth and Space Sciences: A Cross-Age Study
thesis	2019	Simon, Molly Nora	Part I: How Did We Get Here? College Students' Preinstructional Ideas on the Topic of Planet Formation, and the Development of the Planet Formation Concept Inventory. Part II: Evidence for Magnetically Driven Protoplanetary Disk Winds

Coffee break!

Planet Hunters Talk @ 1:45 PM

Misconceptions group activity @ 2:15 PM

Slides and Zotero RDF are available on AAS240 Slack:
[#workshop_engaging_the_public_in_exoplanet_science_through_the_legacy_of_tess](#)

Group activity overview

1. Form pairs.
2. ~20 minutes to read/watch materials (news articles, Twitter posts, YouTube videos). For each material, discuss
 - Who was the target audience for this video?
 - What were some effective strategies the video used to engage the audience?
 - Identify which parts of the video could be potentially misleading to a non-expert.
 - How could the video be changed to avoid these misconceptions while still being accessible to the public?
3. In the last ~5 minutes, we will reconvene for a brief group discussion.

Exoplanets 101 | National Geographic



(0:00-2:20)

Who was the target audience for this video?

What were some effective strategies the video used to engage the audience?

Identify which parts of the video could be potentially misleading to a non-expert.

How could the video be changed to avoid these misconceptions while still being accessible to the public?

Exoplanets 101 | National Geographic



YouTube Comments:

- “Judging by the size and composition of all matters in this universe... I highly doubt that we are the only civilization available..”
- “I think alien life could adapt and grow on the "non habitable worlds", we are not the center of the universe so technically there could be life on venus and we just arent looking for it”

Group activity materials	Type
<u>Water discovered on 'habitable zone' exoplanet could actually be methane, new study finds</u>	News article
<u>China Wants to Search for Habitable Planets to 'Expand Our Living Space'</u>	News article
<u>Think Twice About Escaping Earth to an Exoplanet</u>	News article
<u>Astronomy & Astrophysics 101: Exoplanet</u>	News article
<u>Wasp-76b</u>	Twitter post
<u>Kepler-1649c</u>	Twitter post
<u>NASAExoplanets</u>	Twitter account
<u>NASA's New Planet Hunter: TESS</u> 2:59-4:06	Youtube Video
<u>What Is an Exoplanet?</u> 0:52-1:49	Youtube Video
<u>The Most Horrifying Planets Ever Discovered</u> 8:50-9:46	Youtube Video
<u>Scientists Discovered 24 Planets Even Better for Life Than Earth</u> 6:48-7:46	Youtube Video

Questions which arose during workshop

- Misconceptions are not the fault of the students themselves, and are normal outcomes of learning. What K-12 education standards exist for astronomy?
 - The [National Science Education Standards \(1995\)](#) are guidelines for K-12 science education in US schools. Content standards for Earth and Space Science includes:

K-4	5-8	9-12
<ol style="list-style-type: none">1. Properties of earth materials2. Objects in the sky (the sun, moon, stars, clouds, birds, airplanes)3. Changes in earth and sky (natural disasters, weather, patterns of movement of the sun and moon)	<ol style="list-style-type: none">4. Structure of the earth system5. Earth's history6. Earth in the solar system (the sun, eight planets and moons, asteroids and comets, gravity keeping planets in orbit around sun, sun as energy source for Earth)	<ol style="list-style-type: none">7. Energy in the earth system8. Geochemical cycles9. Origin and evolution of the earth system (incl. solar system formed from a nebular cloud)10. Origin and evolution of the universe ("Big bang" theory, hydrogen and helium clumped together to form stars & galaxies)

- But retaining interest in astronomy may require participation in out-of-school activities: students that spend extracurricular time observing stars, or read/watch science-related materials are more likely to be interested in astronomy careers at the end of high school ([Bergstrom+2016, JAESE](#)).
- Please see [AAS's K-12 Resources](#) for more information!

Questions which arose during workshop

- How are teachers trained in astronomy?
 - There is no legally enforced national curricula or examinations. Some states have laws requiring accreditation for schools. See the [U.S. Department of Education](#) website.
 - Teachers have misconceptions about astronomy, too! [Barrier 2010, Phys. Teach.](#) tested elementary and middle school teachers in western NC before astronomy workshops. 32% of participants incorrectly or failed to response to “Why is winter colder than summer?”. Only 4% completely answered and another 28% partially answered “Describe the phases of the Moon and how they are produced.”
- Other great questions we didn’t answer:
 - Children hear about astronomy terms from “exoplanet” to “multiverse” from games, movies, etc. that they aren’t exposed to in the classroom. How can current research findings be integrated into K-12 curricula?
 - How do astronomy education standards in the US differ from other countries?