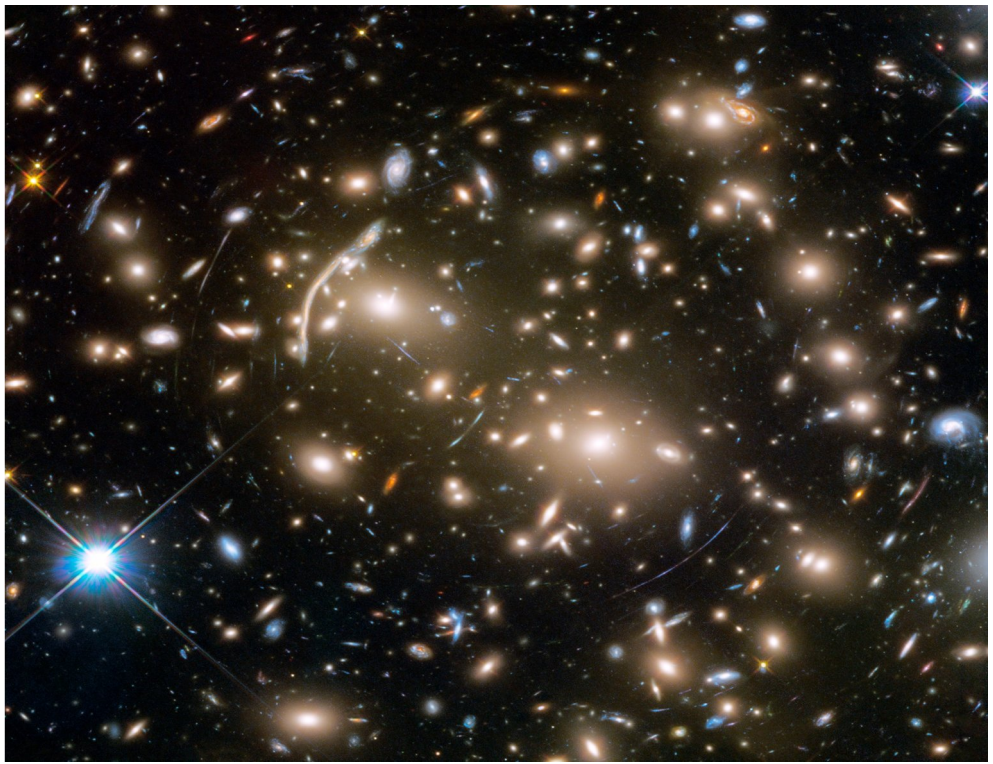
Quick, Informal Survey of Astronomy's Open Questions

Syzygy Asymptote / Dr. W. F. Wall



Galaxy Cluster Abell 370 showing lensing of background galaxies. Hubble Space Telescope, APOD, NASA

The Entire Universe in 20 Minutes!!

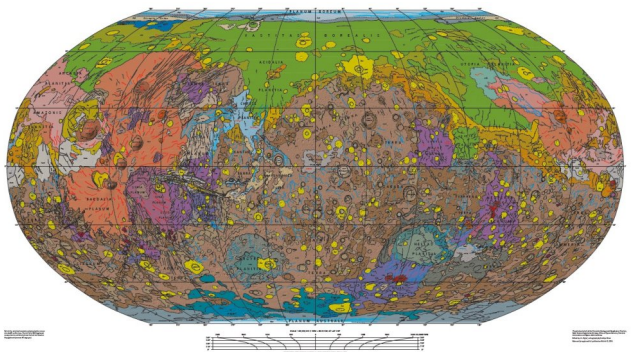
- Overly ambitious (i.e., insane)? Probably.

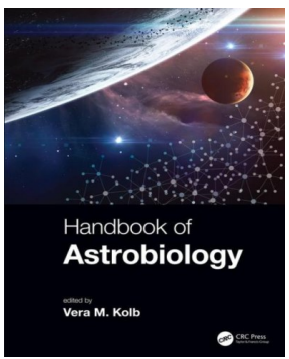
- Useful in some way. Probably.
- You tell me.

Open Questions in Astronomy

Introduction:

- Fields of scientific inquiry are vast enough that compiling and prioritizing a list of the research questions of such a field is daunting.
  - Prioritizing to determine the *key* questions is difficult because it often requires hindsight to determine what truly *were* the important issues.
- While any scientific field is truly vast, it's arguably more so for astronomy because it literally encompasses the rest of the universe.





  - Physics, chemistry, geology, and biology are vast fields in themselves, but astronomy overlaps and even pushes back the frontiers in those fields: (almost?) every subfield of physics*, and also the very real subfields of astrochemistry, astrogeology, astrobiology.

*Classical, relativity, atomic, nuclear, thermodynamics, electromagnetism, condensed matter, fluid dynamics, plasma, geophysics, acoustics, computational,...

Open Questions in Astronomy

Introduction (cont'd):

- It is nonetheless worthwhile to attempt to ascertain those key questions to better understand a field, like astronomy, and its "boundaries" (separating *what is astronomy?* from *what is **not** astronomy?*) and to set priorities for future research (and perhaps inspire future research).
- **Promotes thinking outside the box!**
- **It's a great learning experience! Especially in the preparation of this presentation.**

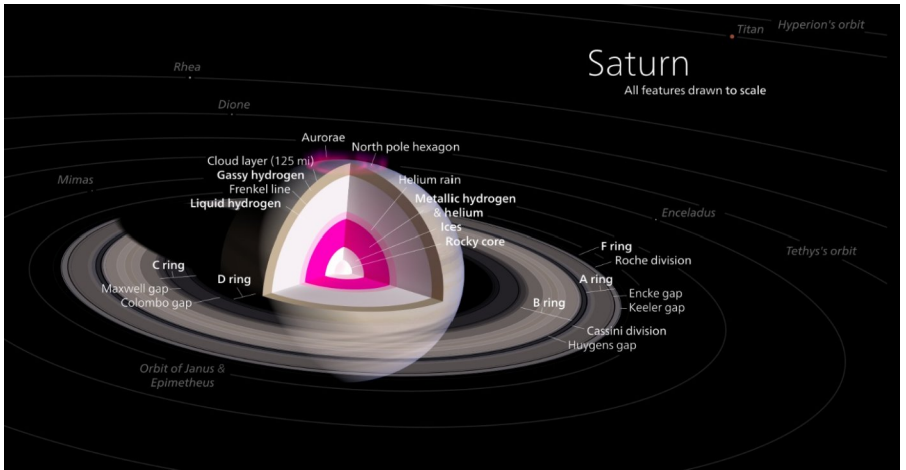
Open Questions in Astronomy

(Incomplete List)

https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_astronomy

Planetary astronomy:

- How does accretion form planetary systems?
- Where did Earth's water come from?
- Are there any planets beyond Neptune?
- What is the explanation for the elongated orbits of a group of Kuiper belt objects?
- Why does the magnetosphere of Saturn exhibit a (slowly changing) periodicity close to that at which the planet's clouds rotate?
- What is the true rotation rate of Saturn's deep interior?



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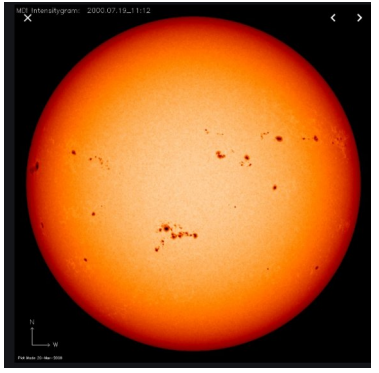
Stellar astronomy:

- How does the Sun generate its periodically reversing large-scale magnetic field?
- How do other solar-like stars generate their magnetic fields, and what are the similarities and differences between stellar activity cycles and that of the Sun?
- What caused the Maunder Minimum and other grand minima, and how does the solar cycle recover from a minimum state?
- Why is the Sun's corona (outer atmospheric layer) so much hotter than the Sun's surface?
- Why is the magnetic reconnection effect many orders of magnitude faster than predicted by standard models?



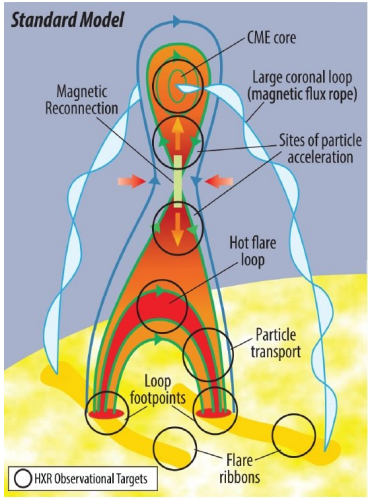


Figure 1. HXR observations emission from all key points in the standard model of solar eruptive events.

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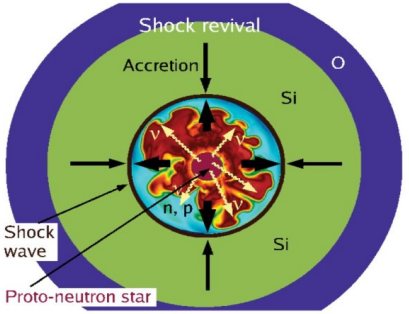
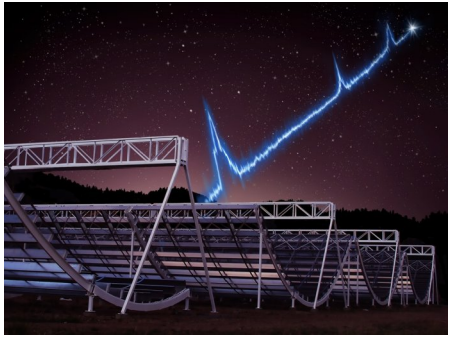
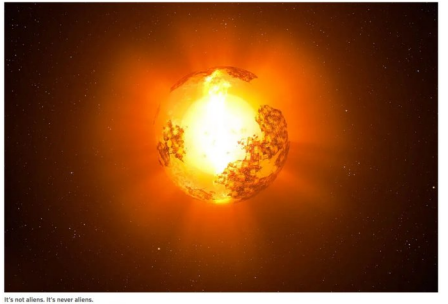


Stellar astronomy (cont'd):

- What is the origin of the stellar initial mass spectrum? *(Star formation! See more later.)*
- What is the exact mechanism by which an implosion of a dying star becomes an explosion?
- What explains Fast Radio Bursts (FRBs)? Transient radio pulses lasting only a few milliseconds, from emission regions thought to be no larger than a few hundred kilometres, and estimated to occur several hundred times a day. While several theories have been proposed, there is no generally accepted explanation for them. The only known repeating FRB emanates from a galaxy roughly 3 billion light years from Earth.



- How do very high energy cosmic rays manage to travel cosmological distances despite being "absorbed" by the cosmic background radiation? The ***Oh-My-God particle*** and other ultra-high-energy cosmic rays: What physical processes create cosmic rays whose energy exceeds the GZK cuttoff?[8]
- Nature of KIC 8462852, commonly known as Tabby's Star: What is the origin of unusual luminosity changes of this star?



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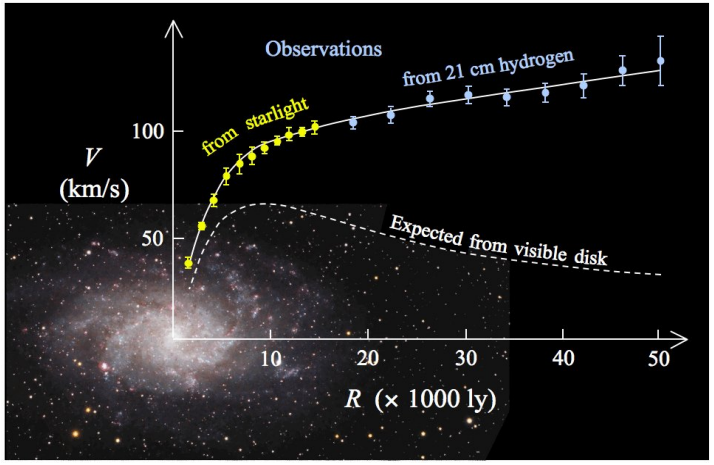

Galactic Astronomy

- Can the discrepancy between the observed and predicted spiral galaxy rotation curves be attributed to dark matter or modified Newtonian gravity (MOND)?
- Is there a universal age–metallicity relation (AMR) in the Galactic disk (both "thin" and "thick" parts of the disk)?
  - Although in the local (primarily thin) disk of the Milky Way there is no evidence of a strong AMR, a sample of 229 nearby "thick" disk stars has been used to investigate the existence of an age–metallicity relation in the Galactic thick disk, and indicate that there is an age–metallicity relation present in the thick disk. Stellar ages from asteroseismology confirm the lack of any strong age-metallicity relation in the Galactic disc.
- Spiral density waves?

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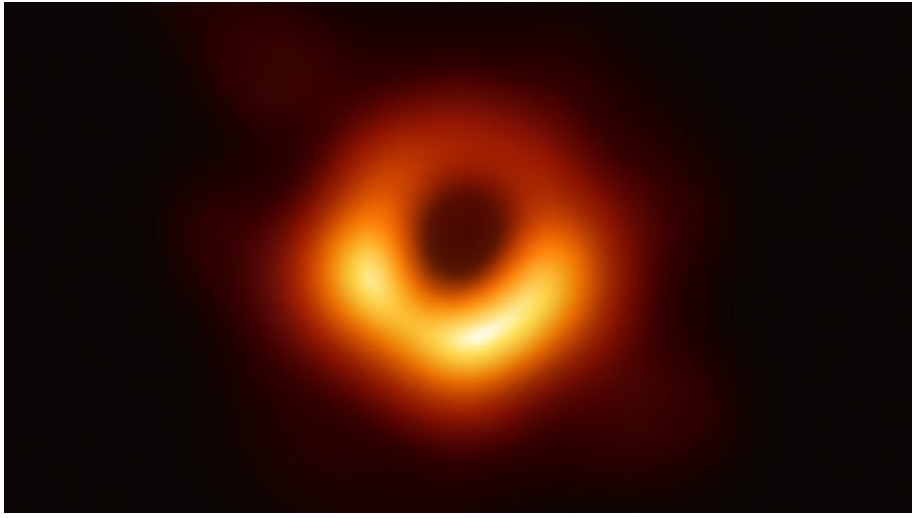

EHT
The first ever picture of a black hole: It's surrounded by a halo of bright gas

Black Holes

- Does general relativity break down in the interior of a black hole due to quantum effects, torsion, or other phenomena?
- Do black holes have an internal structure? If so, how might the internal structure be probed?
- Do black holes produce thermal radiation as expected on theoretical grounds?
  - If so, and black holes can evaporate away, what happens to the information stored in them (since quantum mechanics does not provide for the destruction of information)? Or does the radiation stop at some point leaving black hole remnants?
- Final parsec problem: Supermassive black holes appear to have merged, and what appears to be a pair in this intermediate range has been observed, in PKS 1302-102. However, theory predicts that when supermassive black holes reach a separation of about one parsec, it would take billions of years to orbit closely enough to merge - more than the age of the universe.

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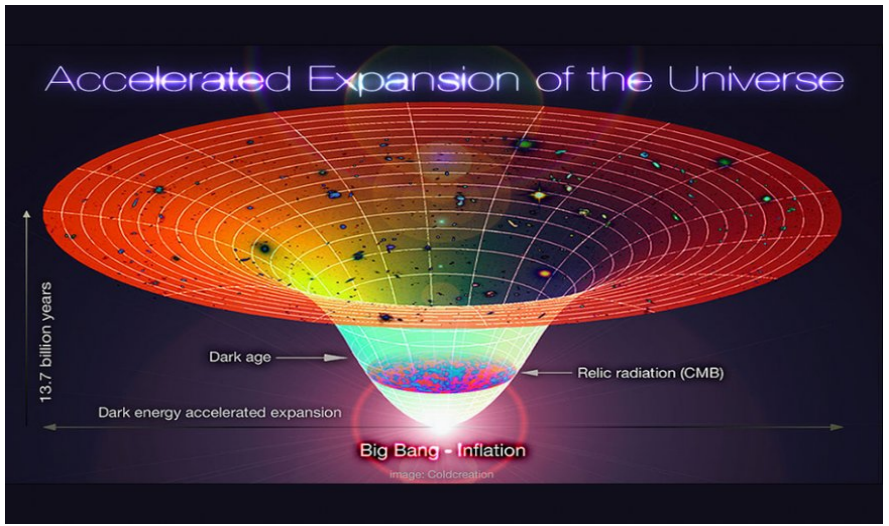
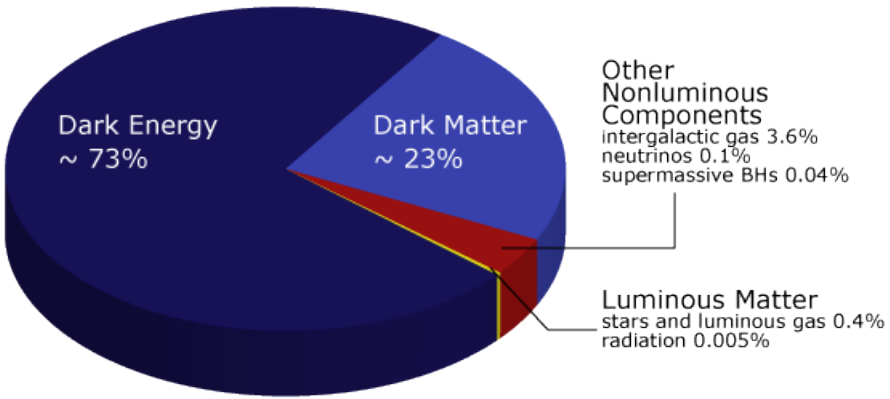
Cosmology

- What are the distributions of dark matter and dark energy in the universe?
- Dark matter: What is the identity of dark matter? Is it a particle? Is it the lightest superpartner (LSP)?
- Do the phenomena attributed to dark matter point not to some form of matter but actually to an extension of gravity? (i.e., MOND – modified Newtonian gravity)
- *Why do Cosmic Microwave Background fluctuations give a different Hubble constant from that determined from Cepheid stars and SN?*
- What is the cause of the observed accelerated expansion (de Sitter phase) of the universe?
- Why is the energy density of the dark energy component of the same magnitude as the density of matter at present when the two evolve quite differently over time? Could it be simply that we are observing at exactly the right time?





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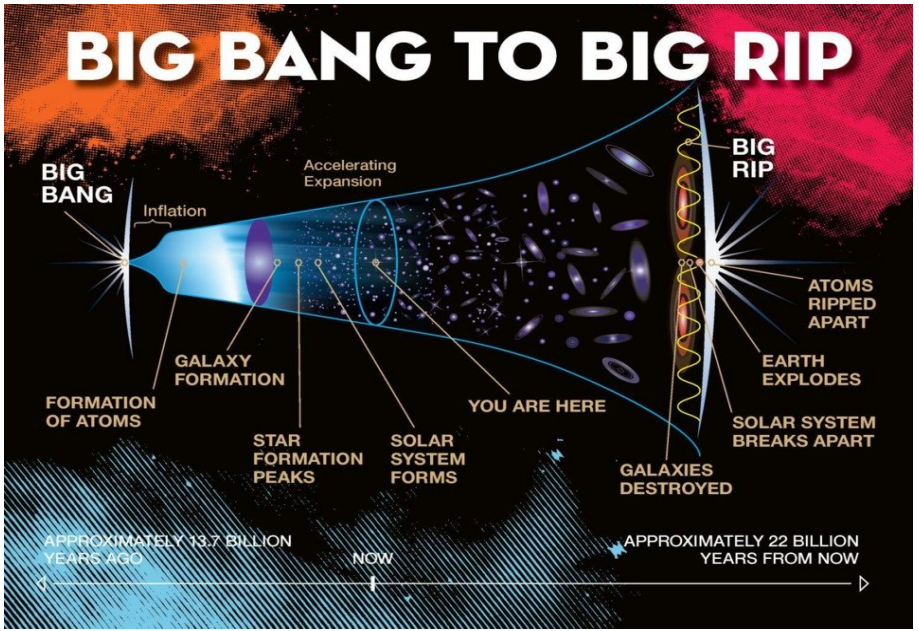
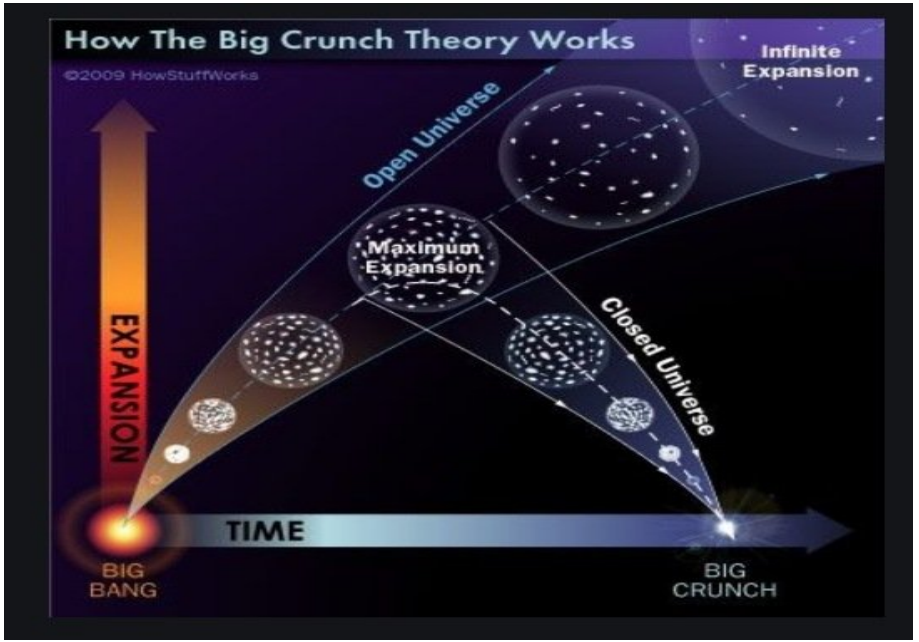
Cosmology (cont'd):

- Axis of evil: Some large features of the microwave sky at distances of over 13 billion light years appear to be aligned with both the motion and orientation of the solar system. Is this due to systematic errors in processing, contamination of results by local effects, or an unexplained violation of the Copernican principle?
- Origin and future of the universe: How did the conditions for anything to exist arise? Is the universe heading towards a Big Freeze, a Big Rip, a Big Crunch, or a Big Bounce? Or is it part of an infinitely recurring cyclic model?





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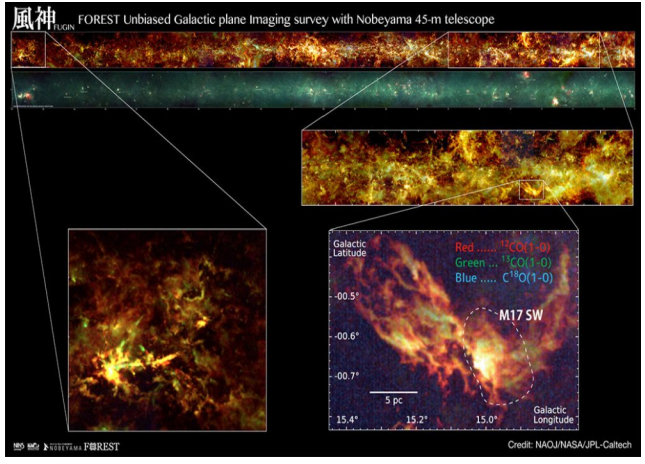
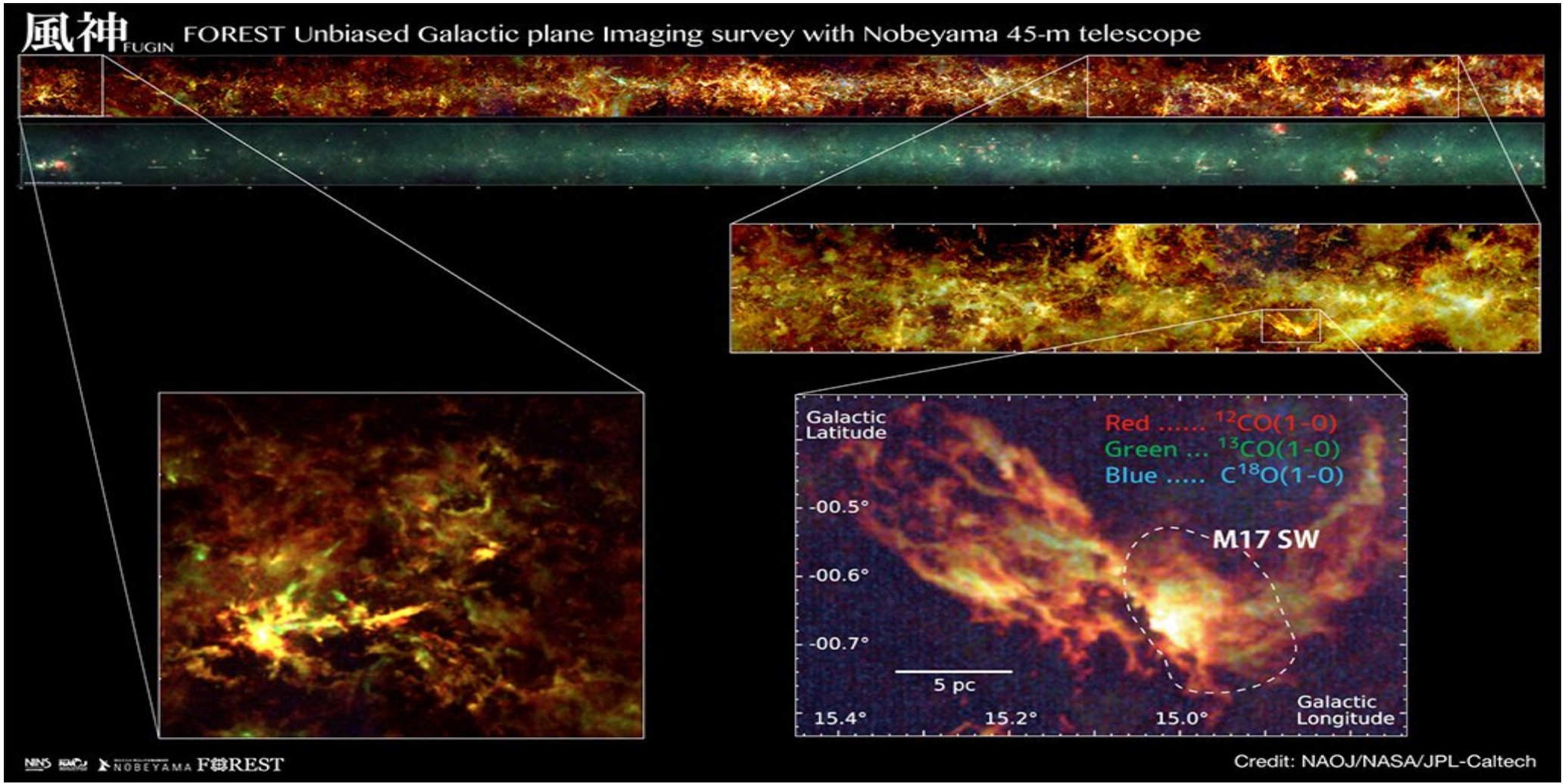


Star Formation (!) and Molecular H_2 Clouds

- How do initial conditions in protostellar cloud cores determine final stellar properties?
- What conditions in parent molecular clouds determine whether an isolated star forms or a stellar cluster forms? If the latter, how do those conditions determine the properties of resultant stellar clusters, such as the initial mass function (IMF)?
- How does environment influence star formation?
- What is the role of feedback in determining how young stars regulate or terminate star formation?

- Are the Giant Molecular Clouds (GMC) that form the majority of stars turbulently supported or are they undergoing large-scale collapse in the form of global hierarchical collapse? (Enrique Vazquez et al. 2019)



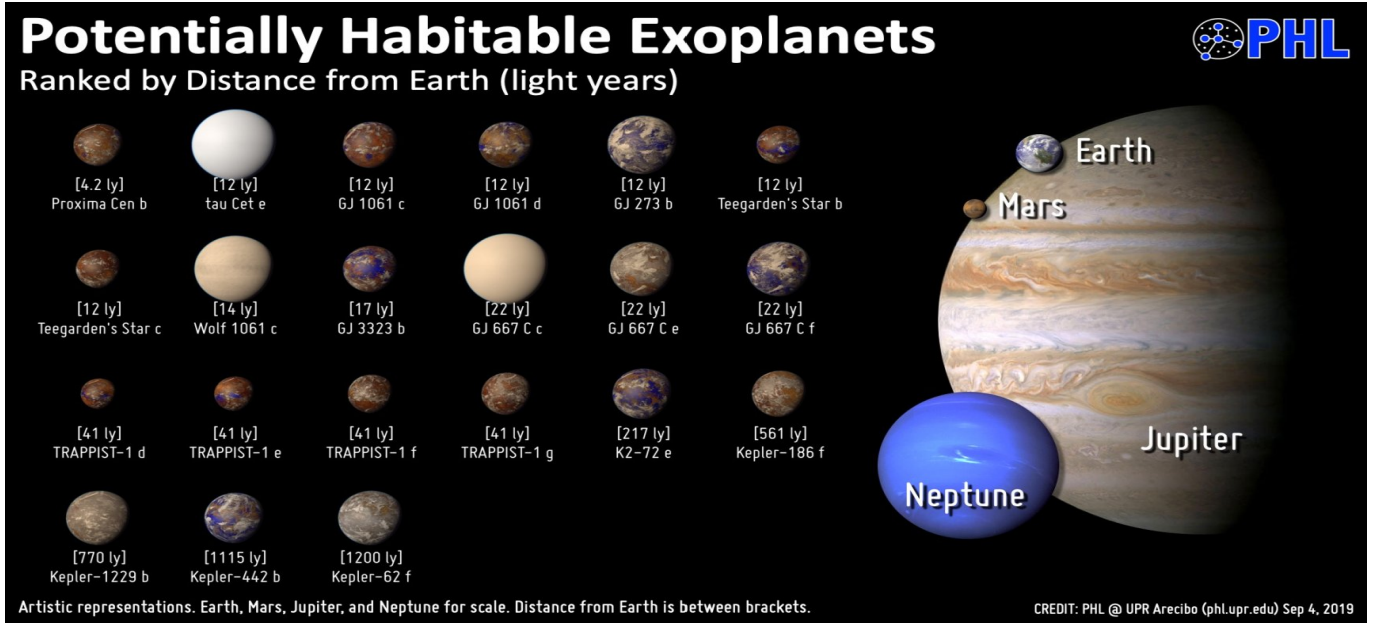
Radio map of the Milky Way obtained by FUGIN project. Top: Three color (false color) radio map of the Milky Way (l=10-50 deg) obtained by the FUGIN Project. Red, green, and blue represent the radio intensities of 12CO, 13CO, and C18O, respectively. Second Line: Infrared image of the same region obtained by the Spitzer Space Telescope. Red, green, and blue represent the intensities of 24μm, 8μm, and 5.8μm radio waves respectively. Lower-right Zoom-In: Three color radio map of the Milky Way (l=12-22 deg) obtained by the FUGIN Project. The colors are the same as the top image. Lower-Left Zoom-In: Enlarged view of the W51 region. The colors are the same as the top image.Lower-Right Zoom-In: Enlarged view of the M17 region. The colors are the same as the top image. *See Umemoto, T. et al. 2017 PASJ, 69, 78.*

Open Questions in Astronomy

(Incomplete List)

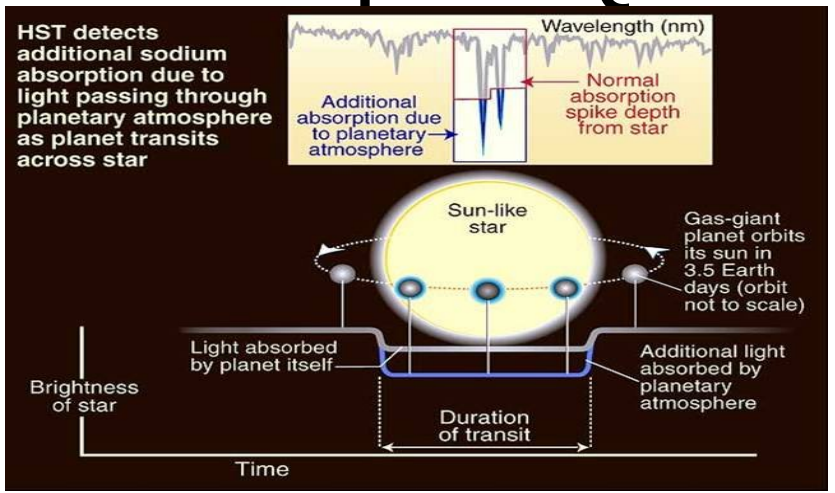
Exoplanets and Extraterrestrial Life

- How do gas-giant exoplanets and rocky exoplanets form? The same mechanism or not?
- Why is there a gap in exoplanets with radii between 1.5 and 2 Earth radii?
- How do the rotations of exoplanets interact with their orbits?
- How common are exomoons?



(Important caveat: The exoplanet images are merely artistic depictions.)

Open Questions in Astronomy



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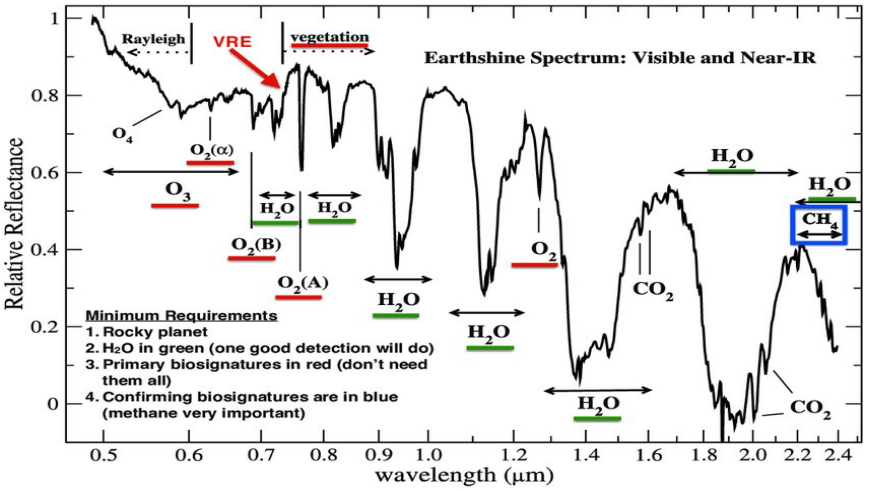

This figure overlays a number of important biosignatures on Turnbull et al.'s 5 spectrum of earth seen as an exoplanet. In addition to the features shown here, there is a strong O3 bandhead at about 260 nm that is considered a primary biosignature. The vegetation red edge (VRE) is caused by chlorophyl from plants. The individual spectral features are discussed in the text. See *Rauscher et al. 2015, Proc. SPIE 9602.*

Exoplanets and Extraterrestrial Life (cont'd):

- Is there other life in the Universe?
- Is it possible to find *unambiguous* biosignatures in the spectra of exoplanet atmospheres?
  [Biology, Geology, Physics (atmospheric physics, spectroscopy)]
- Which stellar spectral types are more likely to favour life-bearing exoplanets?
- Is there other intelligent life?
- If so, what is the Fermi paradox solution?
- Nature of ***Wow! signal***: Was this singular event a real signal and, if so, what was its origin?

CONCLUSIONS!

- Feeling confused and overwhelmed?
  - Then you are normal!
  - It was the “whole” universe in about 20 minutes
- This was an incomplete, somewhat disorganized survey, *but* conveys sense of the breadth of astronomy and the many active subfields of research that promise to surpass the frontiers of not only astronomy, but of physics, chemistry, geology, and ***even biology!***

References

- https://www.sciencemag.org/news/2019/07/newly-discovered-exoplanet-trio-could-unravel-mysteries-super-earth-formation
- Schneider, J. 2017, arXiv:1712.07479v2
- https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_astronomy
- https://www.scientificamerican.com/article/tilted-exoplanets-may-explain-decade-old-astronomical-mystery/
- Meadows, V. et al. 2018 Astrobiology, 18, 6, https://www.liebertpub.com/doi/full/10.1089/ast.2017.1727
- https://www.space.com/hubble-constant-discrepancy-explained.html
- https://www.researchgate.net/publication41117232_Star_Formation_Answering_Fundamental_Questions_During_the_Spitzer_Warm_Mission_Phase
- Vazquez-Semadeni, E. et al. 2019 arXiv:1903.11247v1
- https://en.wikipedia.org/wiki/Universe#/media/File:NASA-HS201427a-HubbleUltraDeepField2014-20140603.jpg
- https://pubs.usgs.gov/sim/3292/
- New Yorker Magazine.
- https://en.wikipedia.org/wiki/Saturn#/media/File:Saturn_diagram.svg
- https://earthobservatory.nasa.gov/images/37575/sunspots-at-solar-maximum-and-minimum
- Christe, S., 2017 arXiv:1701.00792
- http://inspirehep.net/record/1198936/plots
- http://www.astronomy.com/news/2019/01/repeating-fast-radio-burst-detected-for-second-time-in-history
- https://www.newscientist.com/article/2157641-weird-dim-star-isnt-due-to-alien-megastructure-its-just-dust/
- https://en.wikipedia.org/wiki/Modified_Newtonian_dynamics#/media/File:M33_rotation_curve_HI.gif
- https://www.nasa.gov/feature/goddard/2017/messier-51-the-whirlpool-galaxy
- https://www.bbc.com/news/science-environment-47873592
- https://www.extremetech.com/extreme/212679-what-is-dark-energy
- http://thescienceexplorer.com/universe/first-time-scientists-may-detect-dark-matter-nearby-galaxy
- https://www.learner.org/courses/physics/unit/text.html?unit=10&secNum=1
- https://www.pinterest.com/pin/305681893427570488/
- https://comicvine.gamespot.com/images/1300-6332157
- https://apod.nasa.gov/apod/ap170506.html
- http://www.the13thfloor.tv/2016/03/10/the-story-behind-the-legendary-lost-ending-of-the-shining/
- https://phys.org/news/2018-01-radio-milky.html
- http://wise.ssl.berkeley.edu/gallery_rho_ophiuchi.html
- https://www.researchgate.net/figure/This-figure-overlays-a-number-of-important-biosignatures-on-Turnbull-et-als-5-spectrum_fig1_281312445
- http://www.astro.wisc.edu/~townsend/static.php?ref=diploma-9
- https://www.amazon.ca/NECA-Extra-Terrestrial-Stunt-Puppet-Figure/dp/B00C7YOLYS