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- 4.4 billion years early oceans form
- 3.5 billion years cyanobacteria start releasing oxygen.
- 2.0 billion years oxygen begins building up in atmosphere
- 540-500 million years Cambrian Explosion
- 225-65 million years dinosaurs and small mammals (dinosaurs ruled)
- · Few million years earliest hominids





7

9



- Direct imaging
- Stellar wobbles and Doppler shifts
- Planetary transits

8





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Planet Kepler-186f is the first known Earth-*size* planet to lie within the habitable zone of a star beyond the Sun.

19



20



21



- ≈ 1 billion rocky planets that are approximately the size of the Earth and are orbiting familiar-looking yellow-sunshine stars in the orbital "habitable zone" where water could be liquid at the surface.
- Many places to explore for life elsewhere!



22

22



24

## Conditions for Life-bearing Planets • Resides in habitable zone: · Jupiter-like planet to clear liquid water the inner zone of small objects • Old enough for evolution to occur (rules out short-lived . Massive moon to stabilize massive stars) the axial tilt (like Earth's Moon) • Stable orbit (binaries poor?) · Host star with enough metals · Plate tectonics 23



Drake "Equation" for the number of "technical civilizations" currently in Milky Way:

 $N = (SFR) x n_{habit planets} x f_{life} x f_{intel} x f_{tech} x L$ 

Simple accounting of our ignorance, which increases from left term to right

25

25

SFR = Star Formation Rate in our galaxy is 5 to 10 per year on average (higher in past) - the only number in Drake Equation which is well determined  $n_{habit planets} = 1$  or more (Kepler results)  $f_{life} = 0.001$  (although life started early here)  $f_{intel} = 0.1$  (took 3 billion years)  $f_{tech} = 1$  (emergence of language)

26











## Fermi's Paradox

If alien life really is common, then why haven't we detected aliens?

- Life is rare
- Interstellar travel is too difficult
- We are quarantined for now
- Maybe contact will be made

31

## Conclusions

- We have covered huge scales of size
- We have explored time over 14 billion years of the history of the Universe
- We can appreciate the limits of our understanding from observations, yet these have revealed an amazing vista and given us an appreciation of our precious Earth
- Keep looking up! Hope to see you at GSU or HLCO in the future!

32

32