ASTR/GEOL-2040: Search for life in the Universe: Lecture 40

- Artificial life (wrap up)
- Review of all topics!
- & what after the Final

Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590
and Wednesdays 11-12 in D230)

FCQ: currently at 43%

ASTR 2040 (001), GEOL 2040 (001)
CROSS LISTED

Roster: **105** View Course Roster

Course Evaluations

Active
3 Days Remaining
Ends 12/15/2017 at 11:59 PM MST

Results
Available 1/12/2018 at 8:00 AM MST

43%
Response Rate

105
Enrolled Students

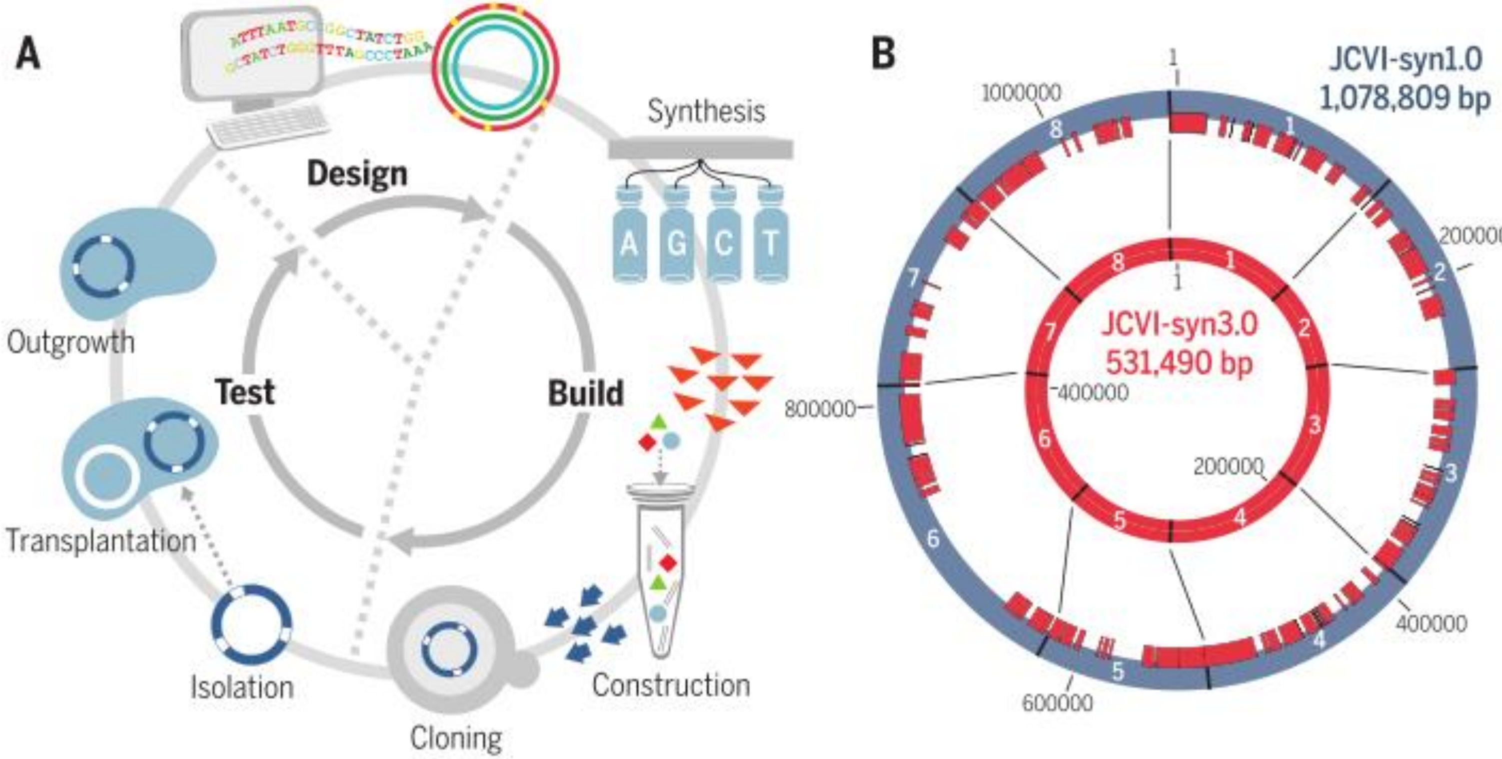
ok, still 3 days to go…

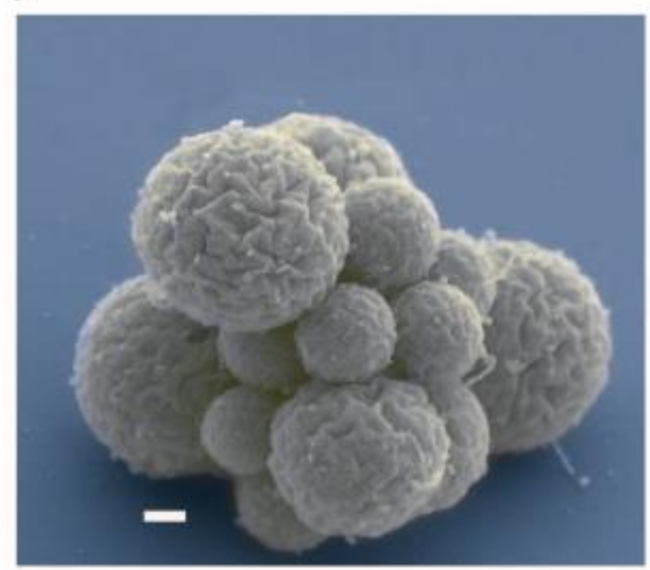
Design and synthesis of a minimal bacterial genome

Clyde A. Hutchison III,[1*†] Ray-Yuan Chuang,[1†‡] Vladimir N. Noskov,[1]
Nacyra Assad-Garcia,[1] Thomas J. Deerinck,[2] Mark H. Ellisman,[2] John Gill,[3]
Krishna Kannan,[3] Bogumil J. Karas,[1] Li Ma,[1] James F. Pelletier,[4§] Zhi-Qing Qi,[3]
R. Alexander Richter,[1] Elizabeth A. Strychalski,[4] Lijie Sun,[1||] Yo Suzuki,[1]
Billyana Tsvetanova,[3] Kim S. Wise,[1] Hamilton O. Smith,[1,3] John I. Glass,[1]
Chuck Merryman,[1] Daniel G. Gibson,[1,3] J. Craig Venter[1,3*]

We used whole-genome design and complete chemical synthesis to minimize the 1079–kilobase pair synthetic genome of *Mycoplasma mycoides* JCVI-syn1.0. An initial design, based on collective knowledge of molecular biology combined with limited transposon mutagenesis data, failed to produce a viable cell. Improved transposon mutagenesis methods revealed a class of quasi-essential genes that are needed for robust growth, explaining the failure of our initial design. Three cycles of design, synthesis, and testing, with retention of quasi-essential genes, produced JCVI-syn3.0 (531 kilobase pairs, 473 genes), which has a genome smaller than that of any autonomously replicating cell found in nature. JCVI-syn3.0 retains almost all genes involved in the synthesis and processing of macromolecules. Unexpectedly, it also contains 149 genes with unknown biological functions. JCVI-syn3.0 is a versatile platform for investigating the core functions of life and for exploring whole-genome design.

Science 351, 1414-U73 (***2016***)





Four design-build-test cycles produced JCVI-syn3.0. (**A**) The cycle for genome design, building by means of synthesis and cloning in yeast, and testing for viability by means of genome transplantation. After each cycle, gene essentiality is reevaluated by global transposon mutagenesis. (**B**) Comparison of JCVI-syn1.0 (outer blue circle) with JCVI-syn3.0 (inner red circle), showing the division of each into eight segments. The red bars inside the outer circle indicate regions that are retained in JCVI-syn3.0. (**C**) A cluster of JCVI-syn3.0 cells, showing spherical structures of varying sizes (scale bar, 200 nm).

Avoid dangers of A-life

- Engineer bacterium that lives of unnatural ingredients (amino acids not occurring in the wild)
- Engineer life based on slighly altered bio-chemistry
- Do biology on the keyboard (software life)
  - Quickly evaluate new drug designs
  - Ethical dilemmas remain

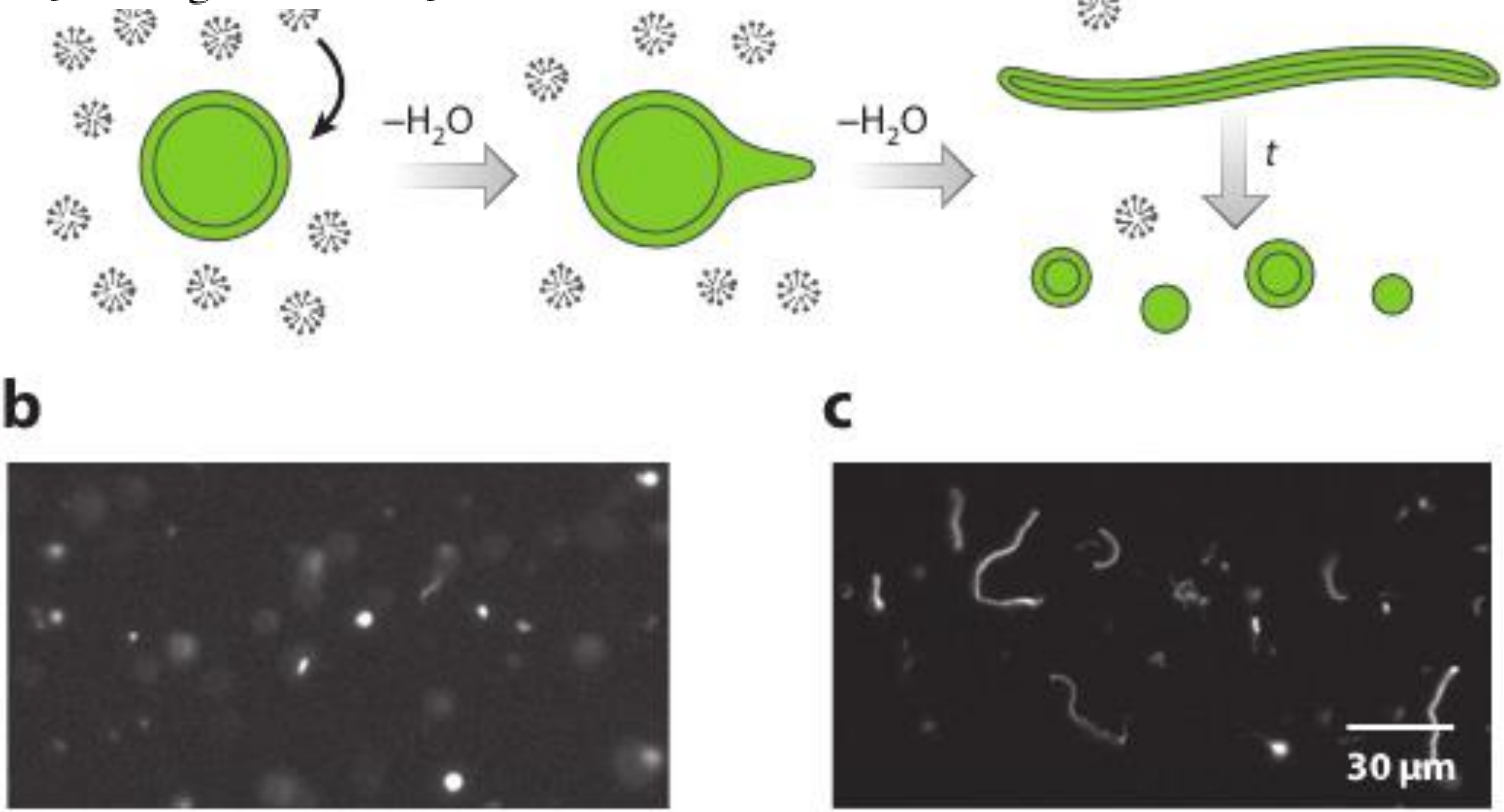
Life from raw ingredients

- Also called: A-Life or ALife
  - Szostak & Cech (Nobel Prize 2009)
  - Org soup + clay surface → RNA strands
- One of those might, by chance, reproduce
  - Fastest, most accurate → survive
- RNA-based cells
  - Mix RNA strands with fatty acids → cells
  - Fast-forward chem evol 10^{12} copies, etc

Progress Toward Synthetic Cells

Annu. Rev. Biochem. 2014. 83:615–40

J. Craig Blain and Jack W. Szostak



Should we create A-life?

- Advantages: fuel, cancer, rem waste, etc...
- Dangers: deadly organisms w/o nat enemies
  - Biowarfare, hard-to-foresee risks
- Engineer → cannot survive in the wild
  - Rebuild code → nonnatural amino acids
  - i.e., amino acids outside the usual 20
- Hope: learn more about origin of life

Websites for papers

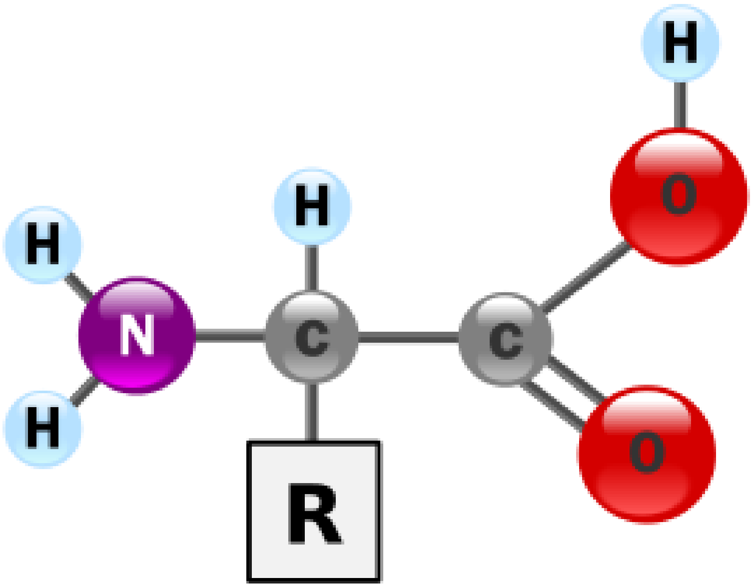
- Web of Science
- See the links under my home page
  - http://lcd-www.colorado.edu/~axbr9098/teach/ASTR_2040/
- Web of Science, Google Scholar, ADS
- See also link to D2L

Preparation for the Final

- Sample final & solutions on D2L
- Review all lectures & clicker questions
  - Understand the answers, or ask & email
- Special accommodations: I’ve sent emails
  - Please respond!

What kind of molecule?

A. Carbohydrate
B. Lipid
C. Amino acid
D. Nucleotide

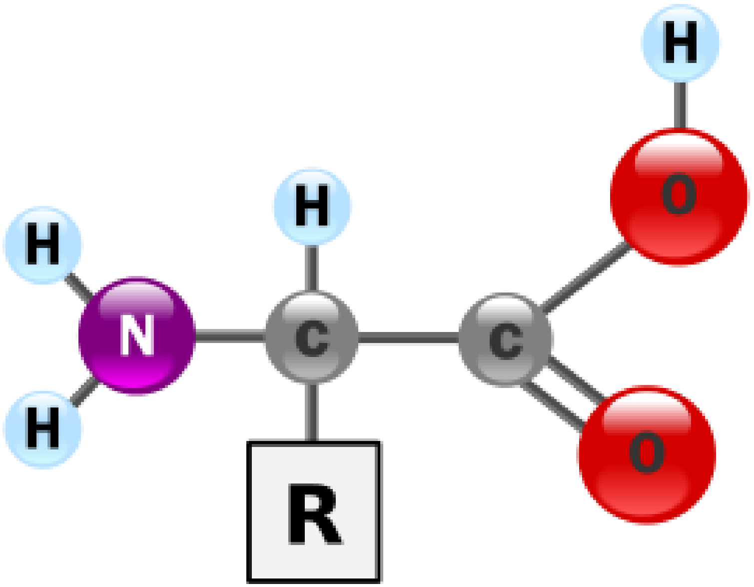


Recognize 3 of the 4 endings?

- – COOH carboxyl group
- – OH hydroxyl group
- – CH_3 methyl group
- – NH_2 amino group

What kind of molecule?

A. Carbohydrate
B. Lipid
C. Amino acid
D. Nucleotide



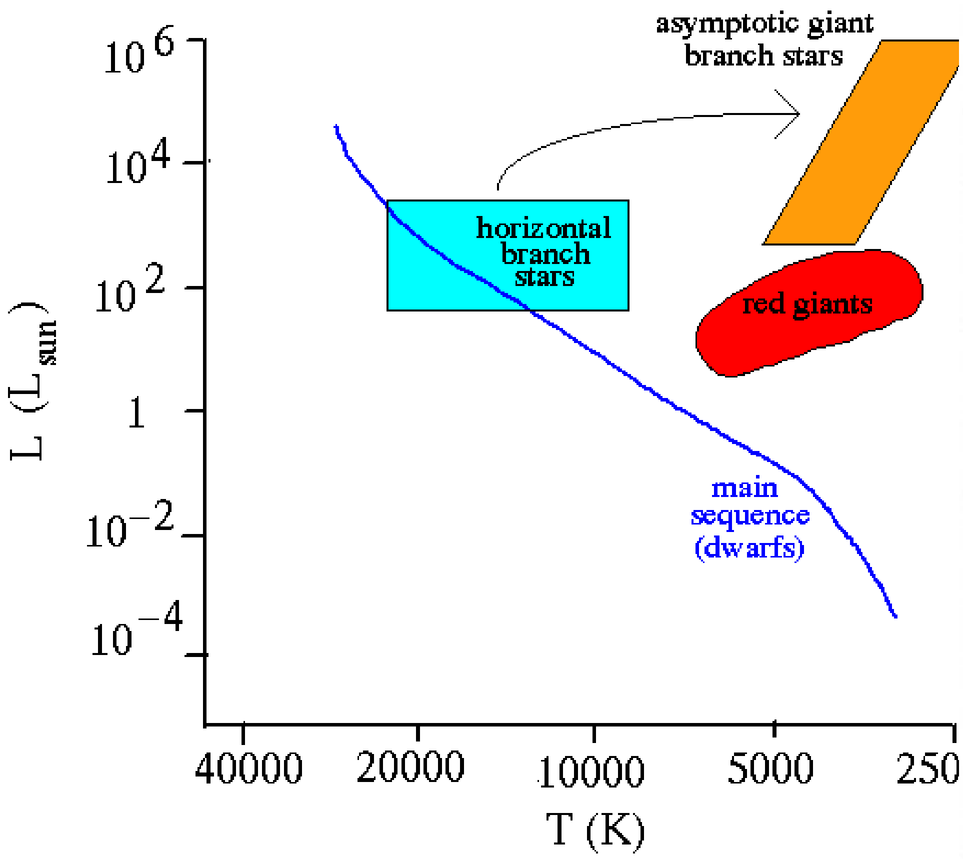
Amino, because of $-NH_2$
Acid, because of $-COOH$

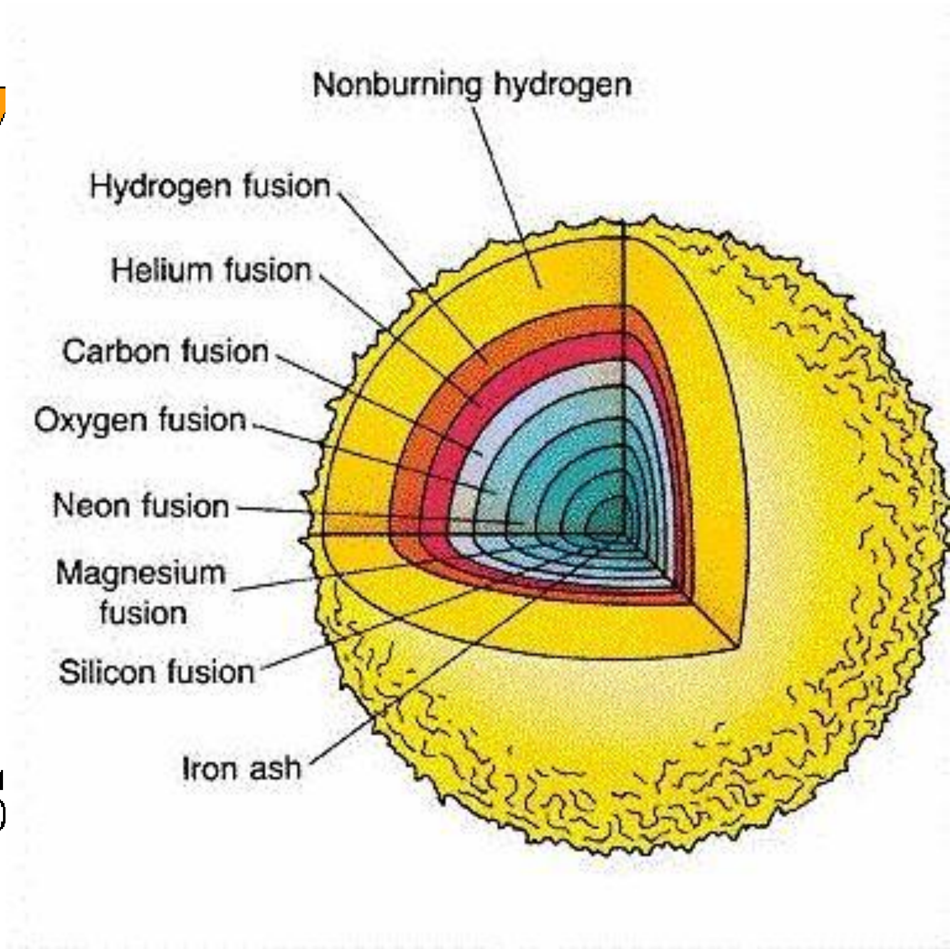
Where does the carbon of all life come from?

A. From the ash of supernova explosions?
B. From gamma ray bursts?
C. From neutron star mergers?
D. From late stages if stellar evolution?
E. From the Big Bang?

Where does carbon come from?

- Carbon comes from nuclear fusion in stars



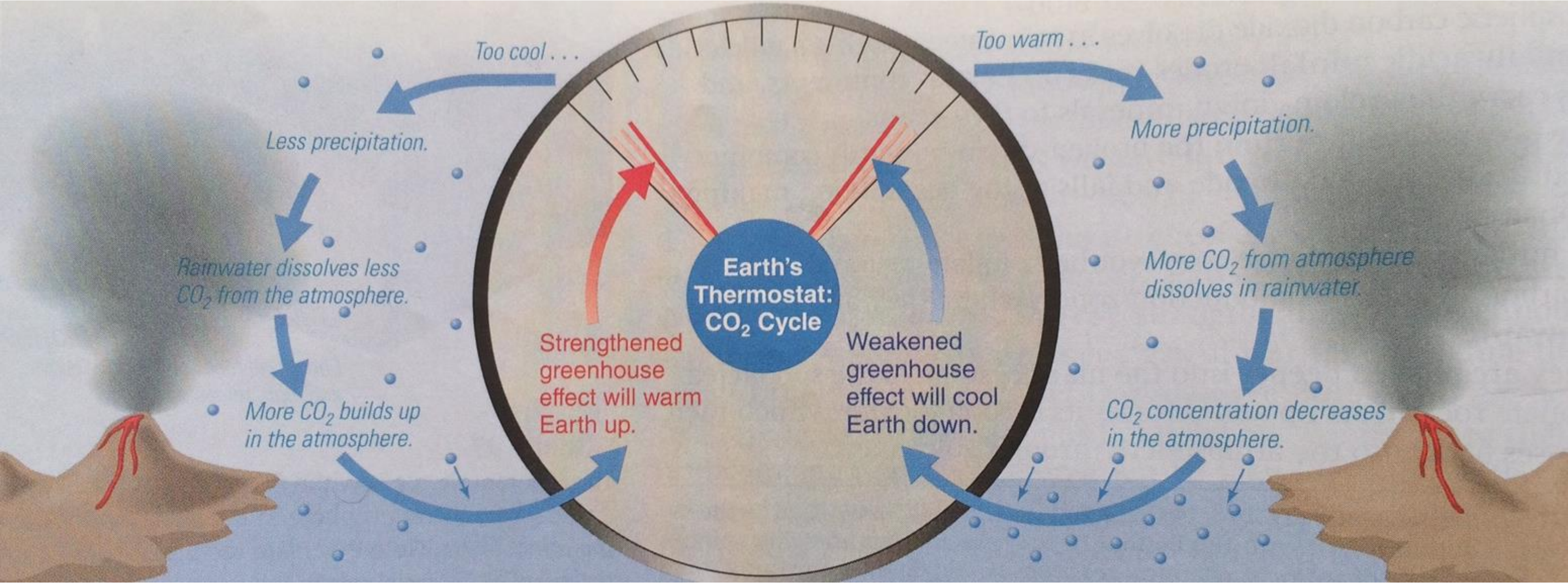


Where does the carbon of all life come from?

A. From the ash of supernova explosions?
B. From gamma ray bursts?
C. From neutron star mergers? → gold!
D. From late stages if stellar evolution? →up to iron
E. From the Big Bang? → only up to lithium

The CO_2 thermostat

CO_2 high, warm, more rain



atmospheric CO_2 reduced

What is a relevant reaction here?

A. $2FeO + 2H_2O \rightarrow Fe_2O_3 + 2H_2$

B. $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$

C. $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Lect 12: relevant reaction?

- $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$
  - Calcium carbonate
  - solid deposit (sea bed)
  - carbonate rock (limestone)
- from acid rain: $H_2O + CO_2 = H_2CO_3$
  - Contact with rock: weathering

The CO_2 thermostat

- Recycling rate sensitive to temperature
- CO_2 → warmer (greenhouse)
  - More evaporation, more rainfall
- Pulling more CO_2 out of atmosphere
  - Weaker greenhouse effect
- Negative feedback

CO_2 thermostat: other way around

- Less CO_2 → cooler
  - less evaporation, less rainfall
- Less removal of CO_2 out of atmosphere
  - greenhouse effect becomes stronger
  - and it gets warmer again
- Again: negative feedback

What is a relevant reaction here?

A. $2FeO + 2H_2O \rightarrow Fe_2O_3 + 2H_2$
B. $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$
C. $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Where are the other two relevant?

A. $2FeO + 2H_2O \rightarrow Fe_2O_3 + 2H_2$

B. $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$

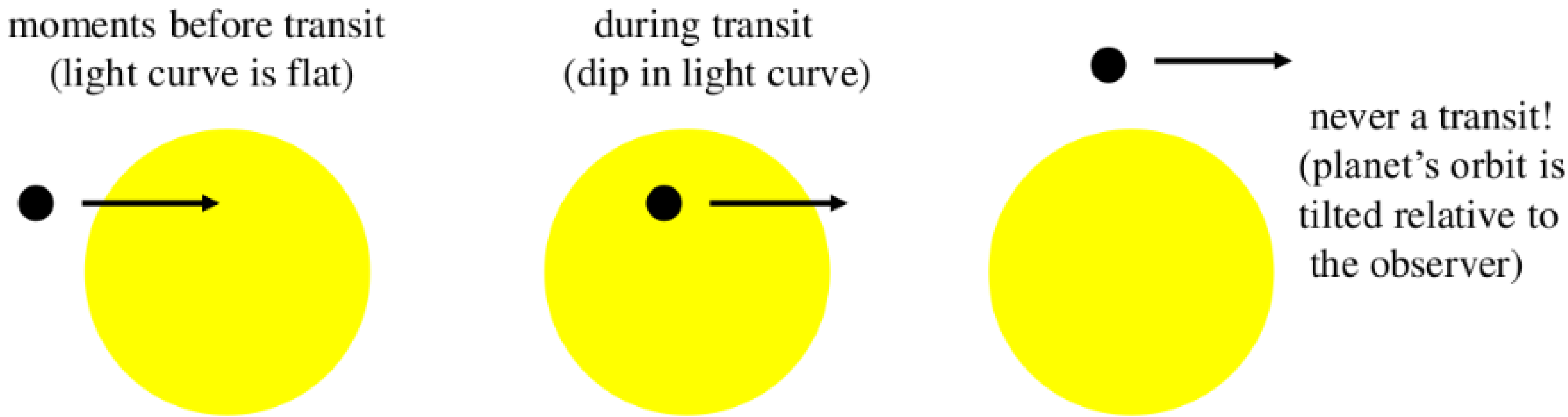
C. $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

A. Hydrothermal (alkaline) vents

B. Water loss in upper atmosphere

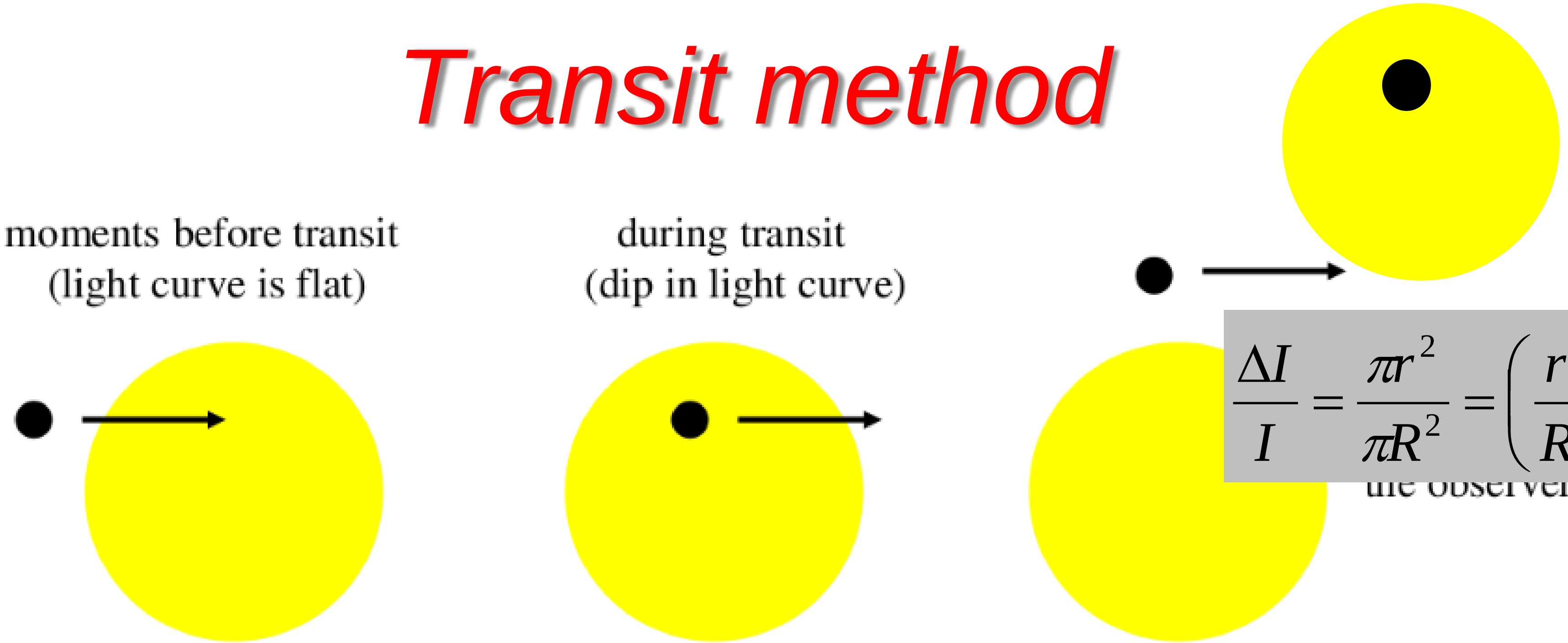
C. Carbonsequestration

Transit method



A. Can only determine upper limit on its mass
B. Can only determine lower limit on its mass
C. Can only determine upper limit on its radius
D. Can only determine lower limit on its radius
E. Neither of the above

Transit method



$$\frac{\Delta I}{I} = \frac{\pi r^2}{\pi R^2} = \left(\frac{r}{R}\right)^2$$

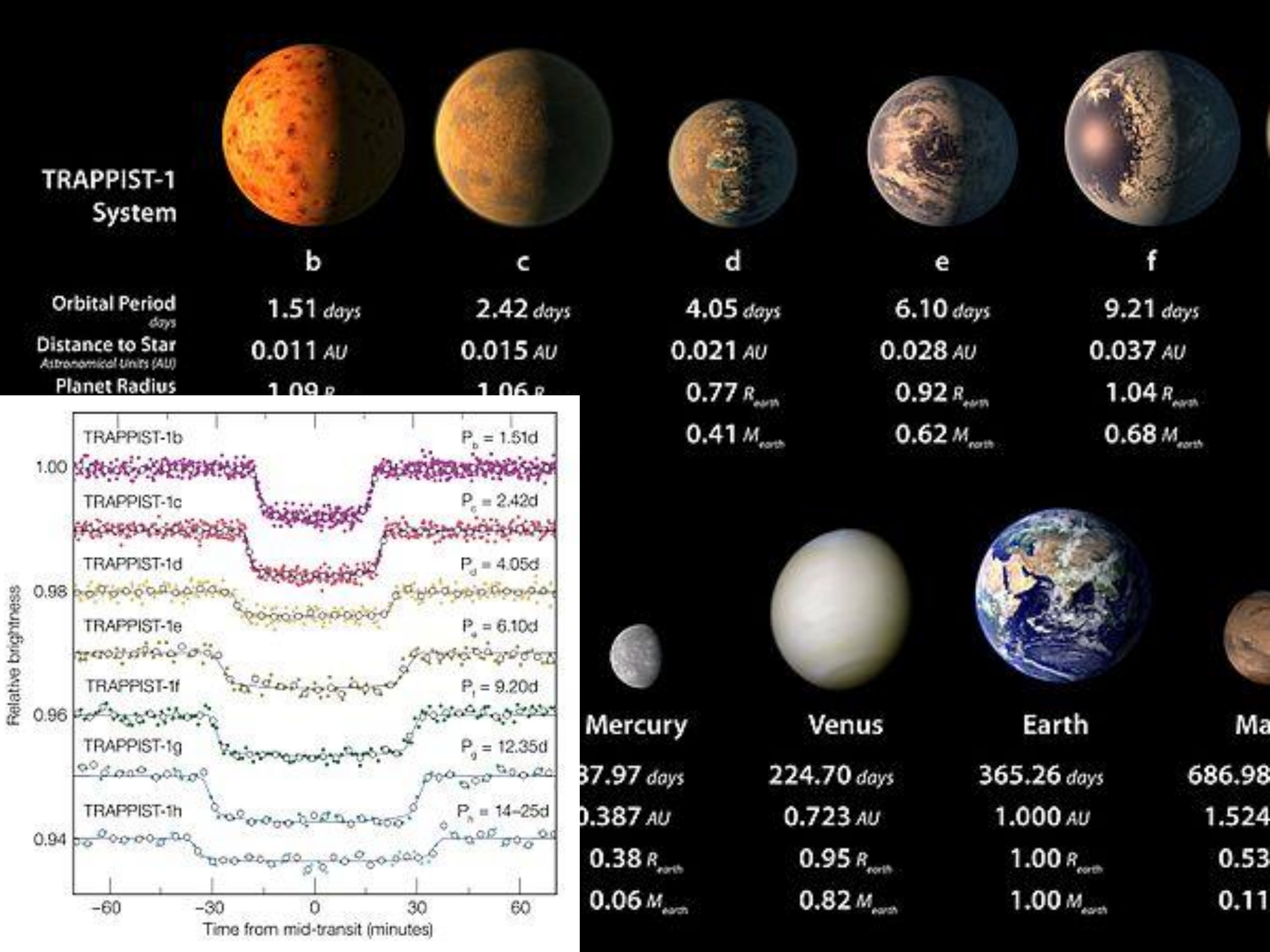
A. Can only determine upper limit on its mass

B. Can only determine lower limit on its mass

C. Can only determine upper limit on its radius

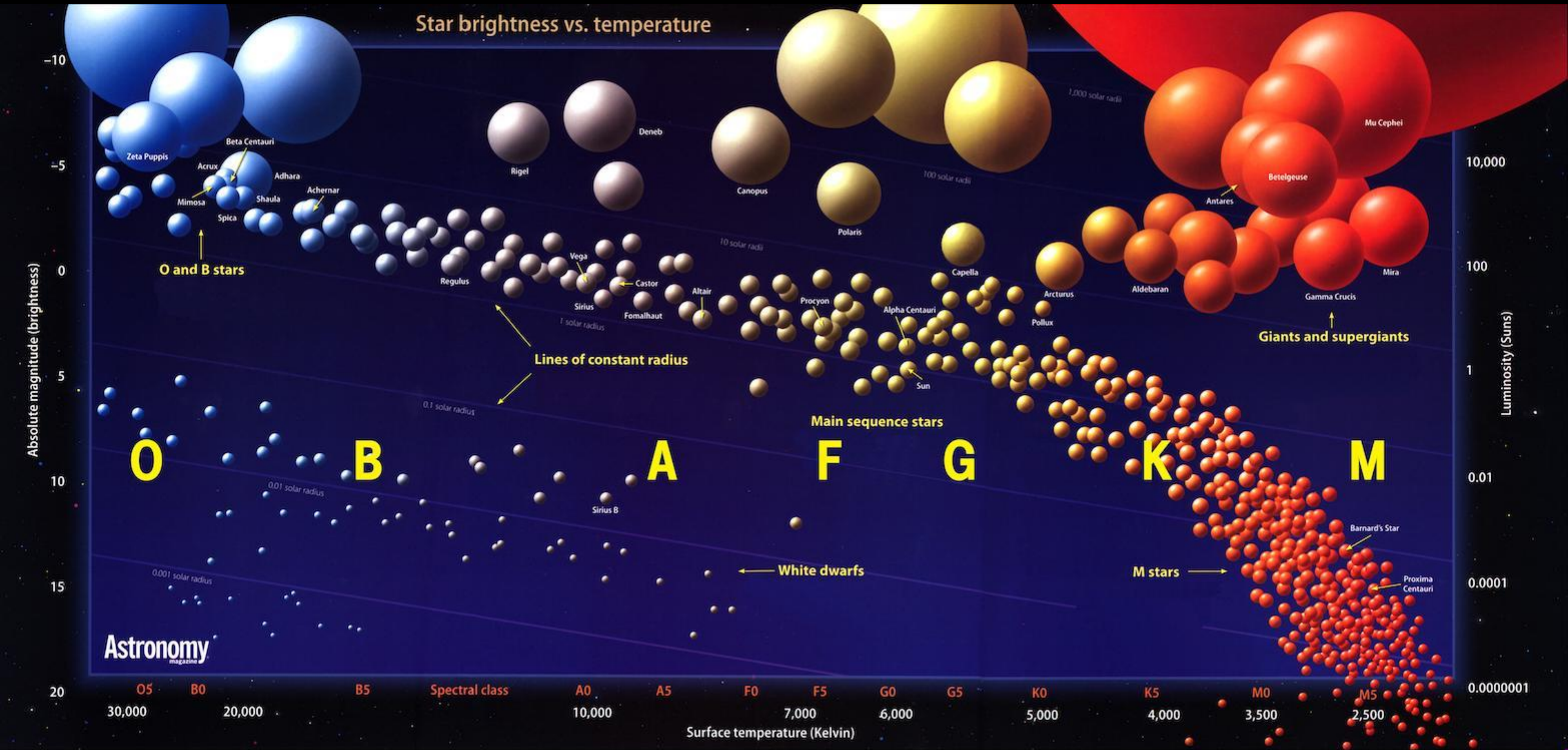
D. Can only determine lower limit on its radius

E. Neither of the above


TRAPPIST-1 System
b
c
d
e
f
Orbital Period
days
Distance to Star
Astronomical Units (AU)
Planet Radius
1.51 days
2.42 days
4.05 days
6.10 days
9.21 days
0.011 AU
0.015 AU
0.021 AU
0.028 AU
0.037 AU
0.77 R earth
0.92 R earth
1.04 R earth
0.41 M earth
0.62 M earth
0.68 M earth
Mercury
Venus
Earth
224.70 days
365.26 days
0.723 AU
1.000 AU
0.38 R earth
0.95 R earth
1.00 R earth
0.06 M earth
0.82 M earth
1.00 M earth
TRAPPIST-1b
P b = 1.51d
TRAPPIST-1c
P c = 2.42d
TRAPPIST-1d
P d = 4.05d
TRAPPIST-1e
P e = 6.10d
TRAPPIST-1f
P f = 9.20d
TRAPPIST-1g
P g = 12.35d
TRAPPIST-1h
P h = 14–25d
1.00
0.98
0.96
0.94
Relative brightness
−60
−30
0
30
60
Time from mid-transit (minutes)

Ultracool dwarfs

- Must be closer to host star
- But “inhabitants’ suffer severe radiation



Intelligenty life in the Universe?

- Drake's equation: $N = R_b\, t$

Rate (number per unit time) at which broadcasting civilizations appear in our galaxy

Time over which they broadcast

Most conservative estimate?

A. $N = 1$

B. $N = 8$

C. $N = 10^{11}$

Lect 33: Life in the Universe?

- Drake's equation: $N = R_b\ t$

Rate (number per unit time)
at which broadcasting civilizations
appear in our galaxy

Time over
which they
broadcast

- N = ? (at least 1)   = us on Earth
- t = ?   > 50 yr … 100 yr
- $R_b > 0.02\ \text{yr}^{-1}$

*Finally, & **after** the final*

- Let me know how it's going
  - Sometime surprises?
- Science is something you can work with
  - Is more important than knowing details
  - Find original literature etc
- Thanks to Erika for help & advice
- Thanks to Batya for making her way through your homework