Astrobiological simulation: Make your own galaxy!

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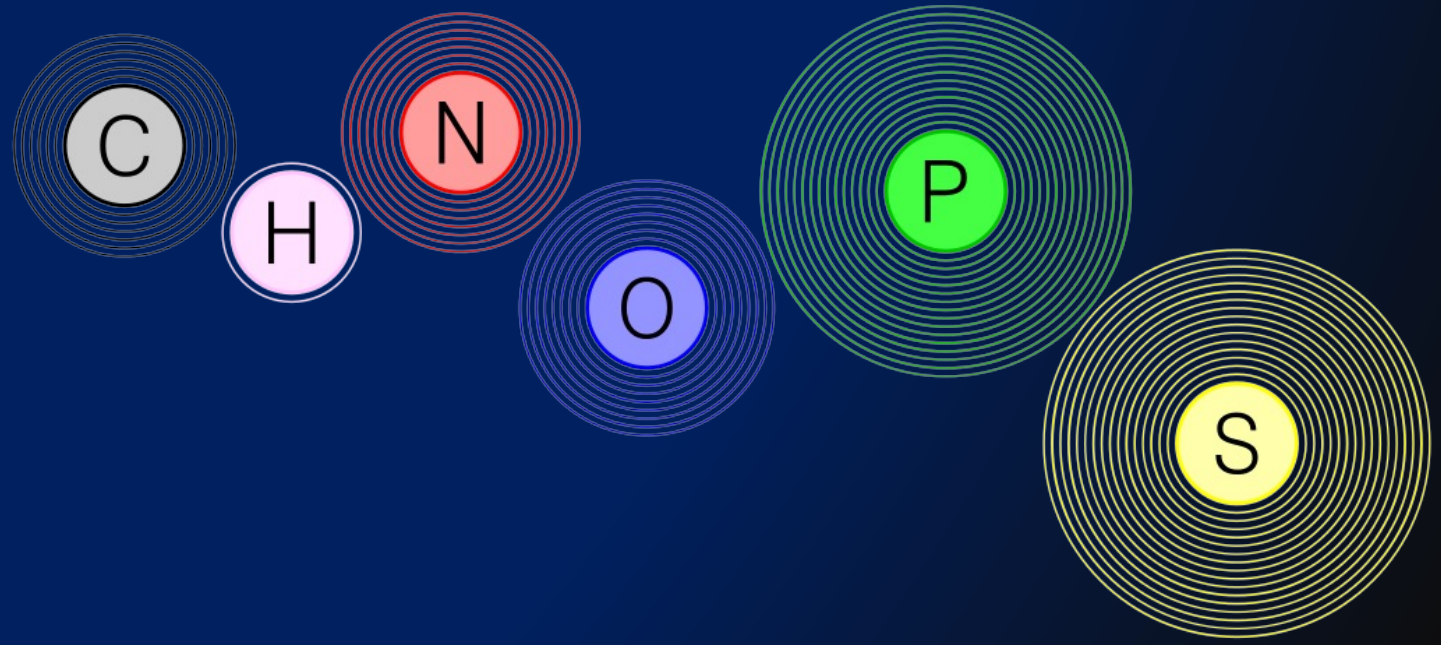
Stefan Andjelkovic

sandjelk@andrew.cmu.edu

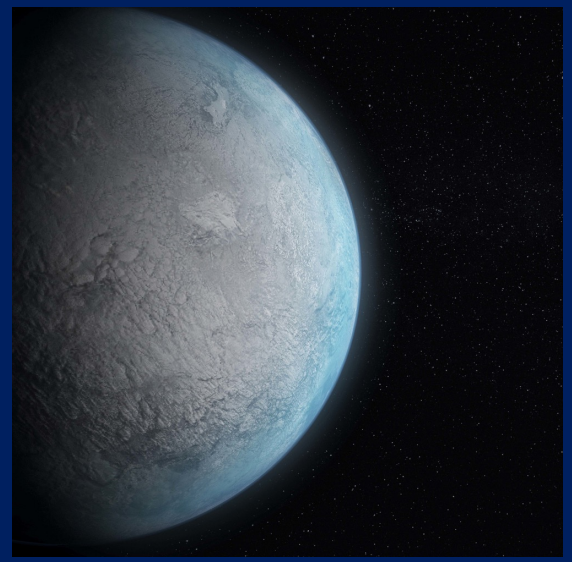
List of ingredients to make life

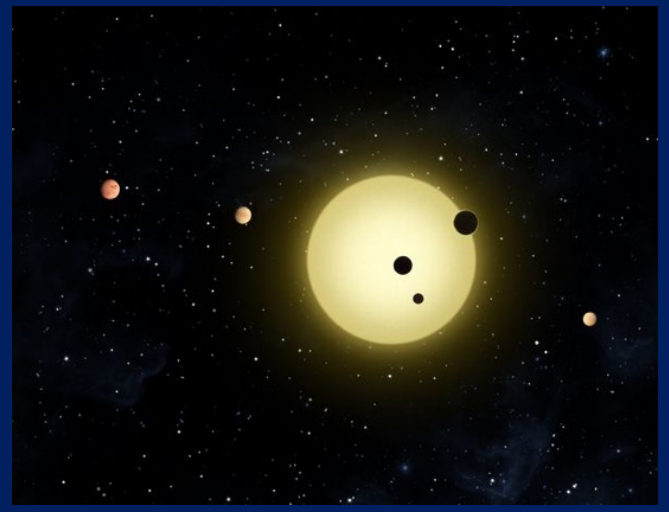
- **Water** – for chemical reactions (proteins can't work without it)
- 6 important elements: C, H, N, O, P, S
- Minerals (iron, calcium and magnesium)
- Heat – (thanks, Sun!)



Where to make this life form?

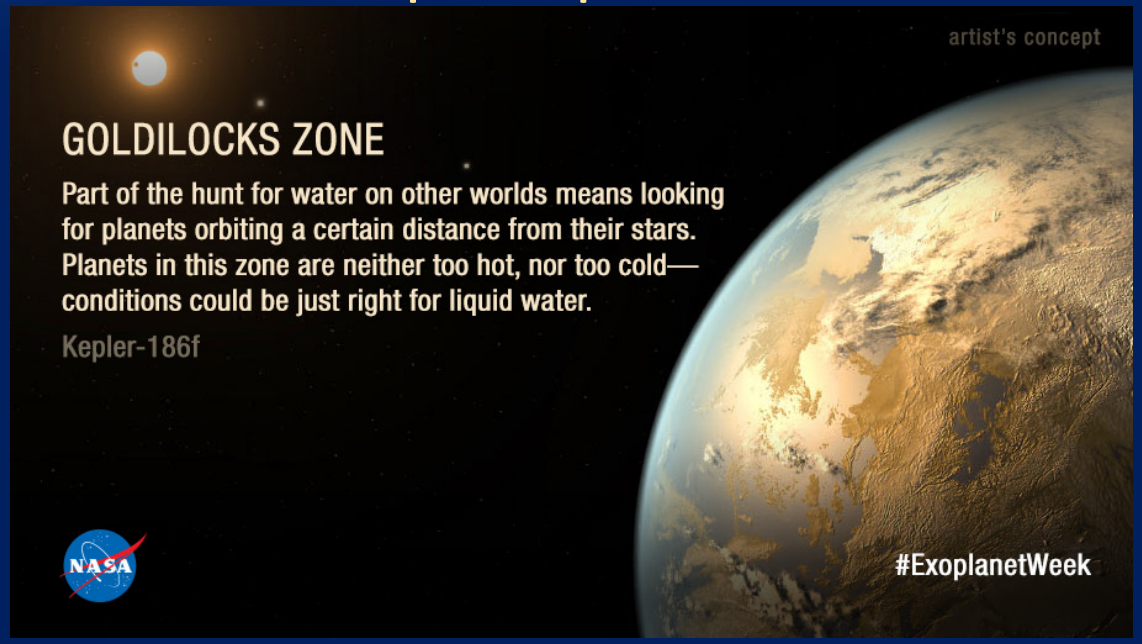
- On a planet…
- …orbiting a star…
- …in a galaxy!

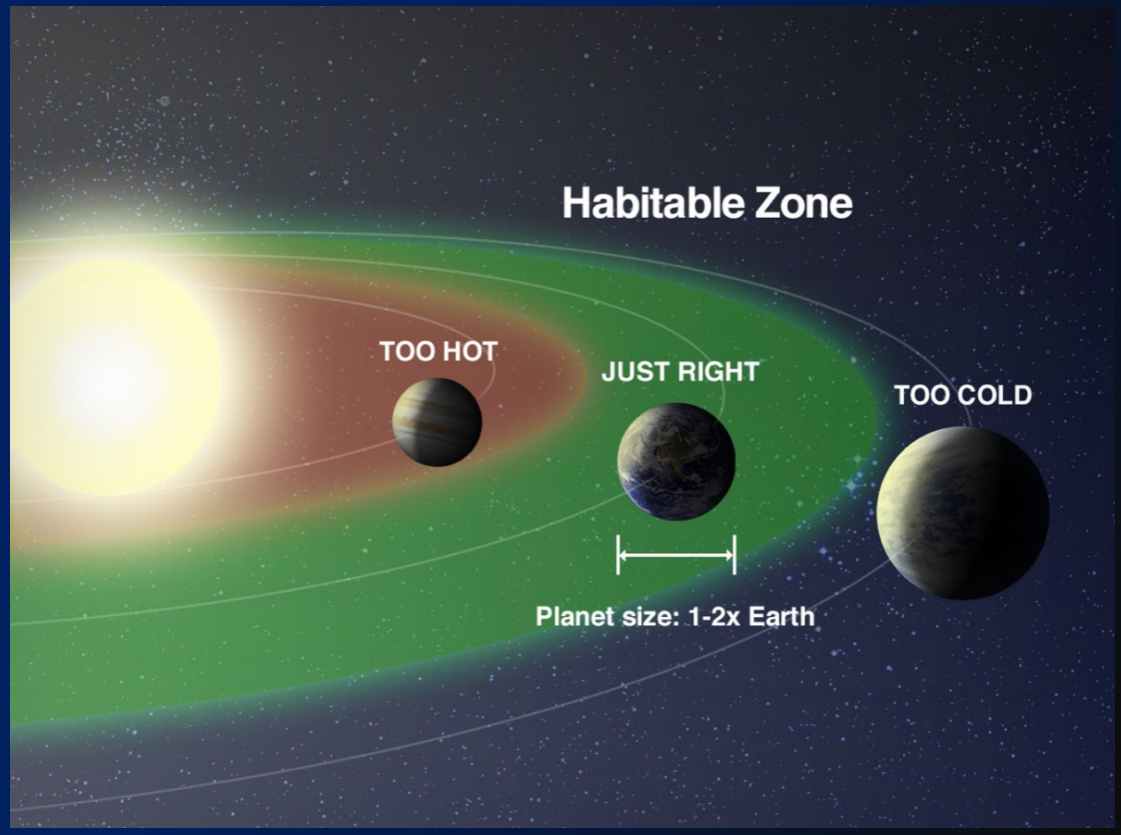




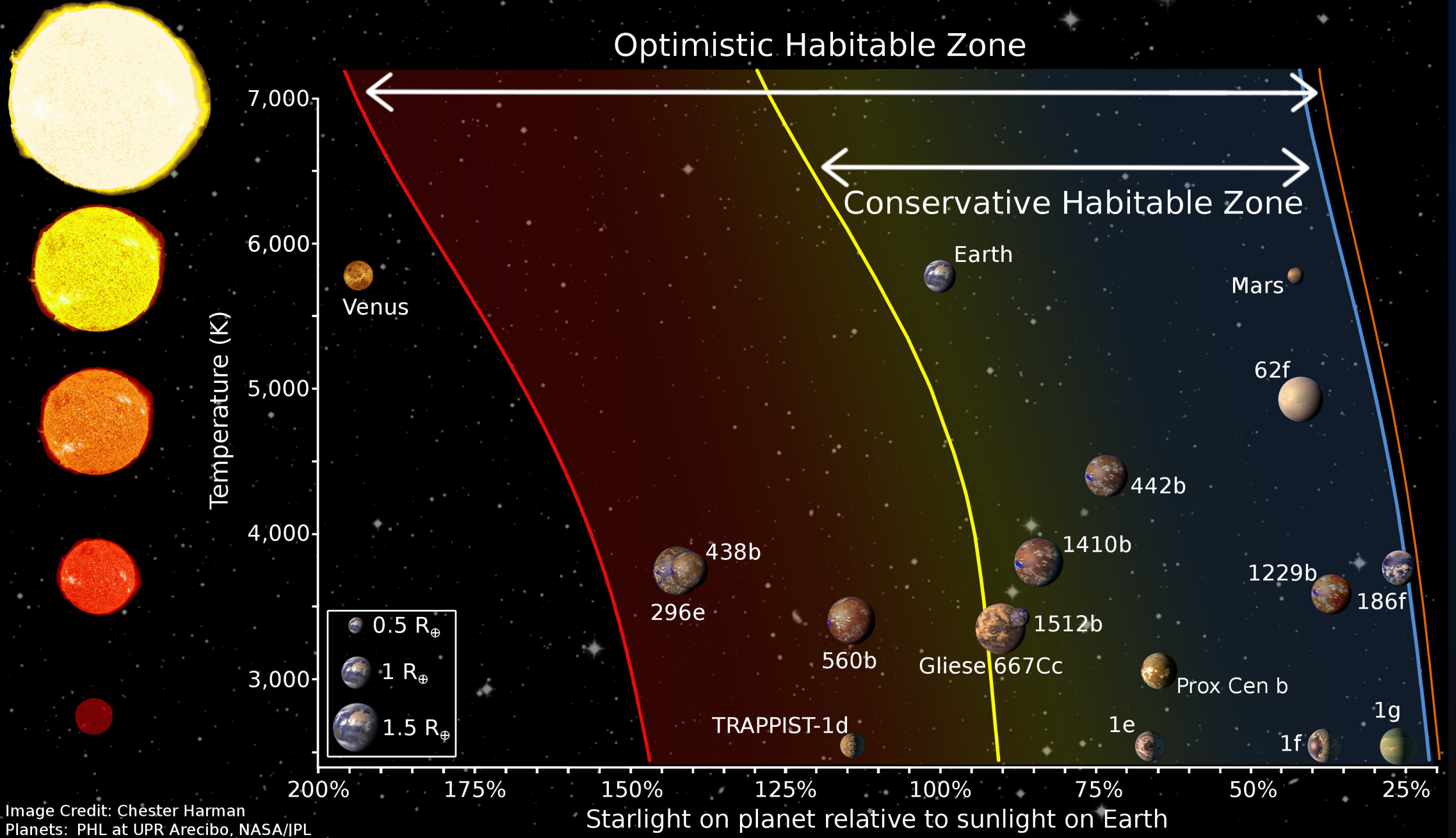
Habitable zone (circumstellar)

- Key ingredient for life: water
- Goldilocks principle



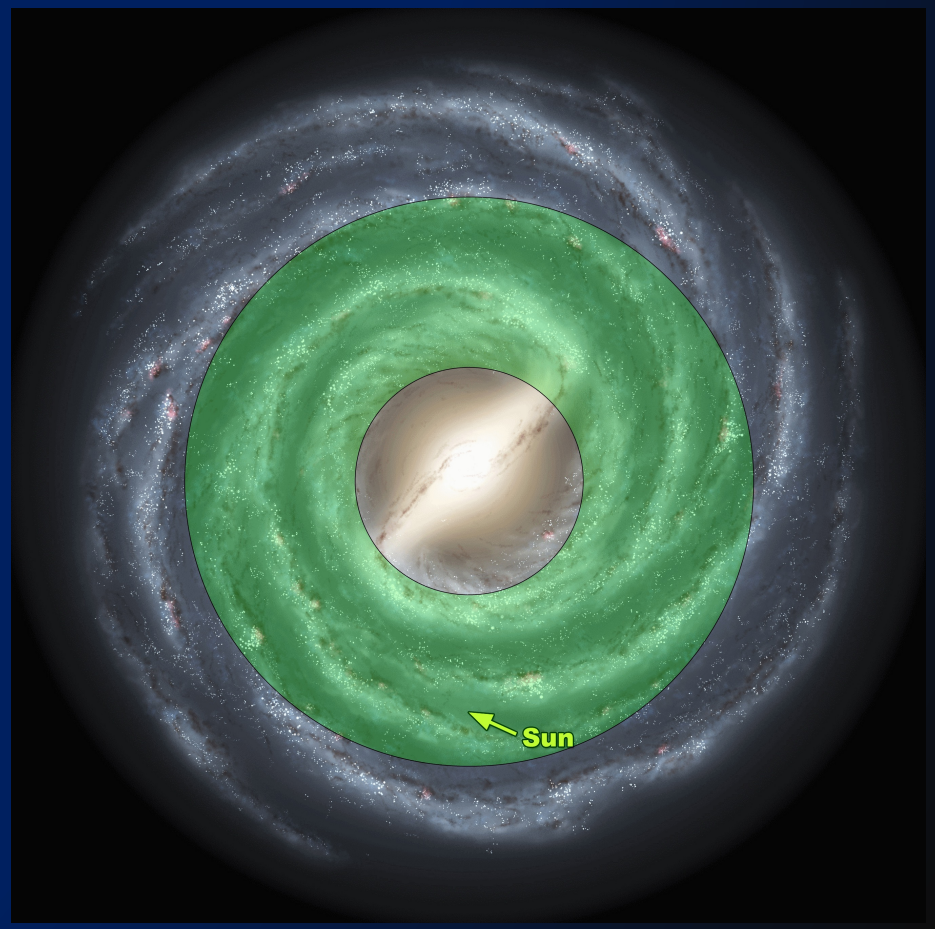


- Size and position depends on the star temperature


Optimistic Habitable Zone
Conservative Habitable Zone
Temperature (K)
7,000
6,000
5,000
4,000
3,000
Venus
Earth
Mars
62f
442b
1410b
438b
296e
1229b
186f
1512b
560b
Gliese 667Cc
Prox Cen b
TRAPPIST-1d
1e
1g
1f
0.5 R⊕
1 R⊕
1.5 R⊕
200%
175%
150%
125%
100%
75%
50%
25%
Starlight on planet relative to sunlight on Earth
Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL

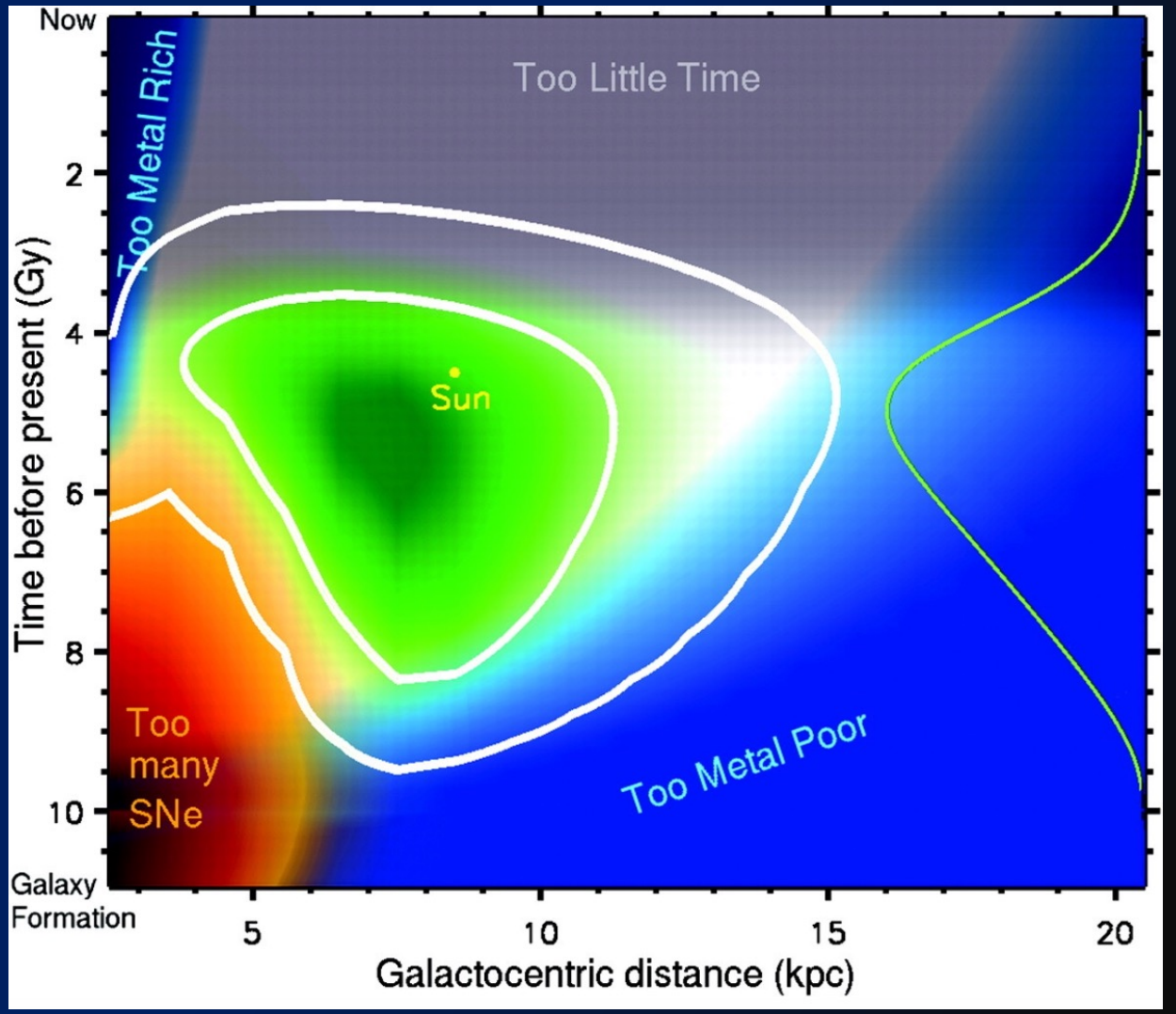
Galactic habitable zone

- Where are we most likely to find life in a galaxy?
- Not too close
  - Too many giant Jupiter-like planets
- Not too far
  - Not enough elements heavier than He



So when can life start?

- Not too late
- Not too close to the center of the galaxy
- Not too far out
- Life on our planet started later than expected!

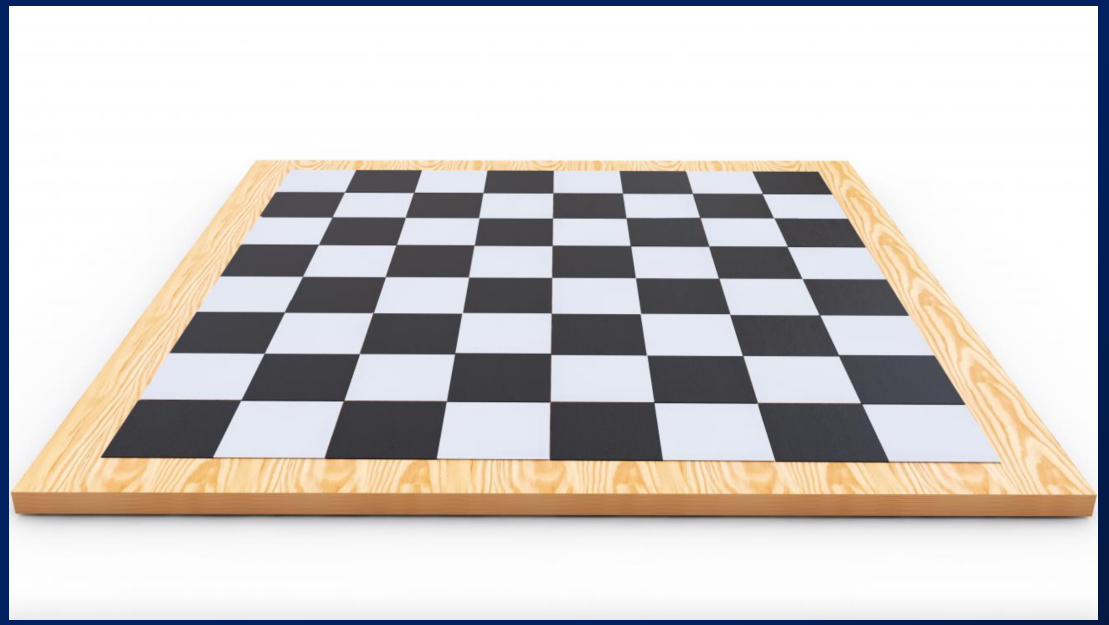


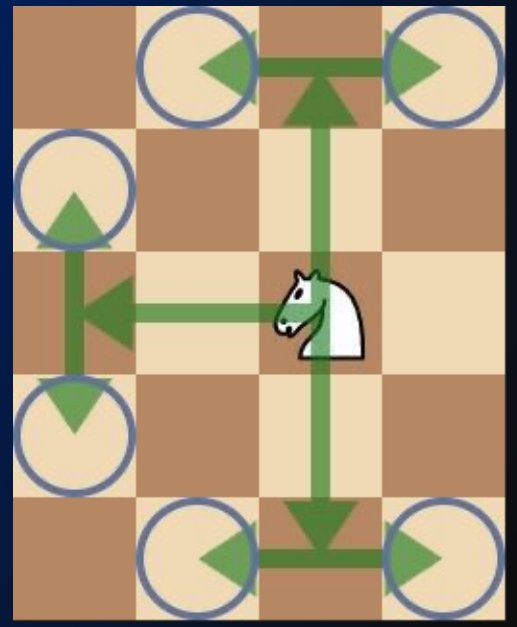
So where are the aliens?

- Drake equation (1961) – a guess how many civilizations are there in a galaxy?
  - $N = R_* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$
- The results are 0 < N < 100 millions civilizations
- Search for Extraterrestrial Intelligence (SETI)
- What can we do?
  - Run ***simulations***

Probabilistic cellular automata

- It’s like chess:
  - Probabilistic – different moves you can make
  - Cellular – we split the galaxy into cells/fields (like chessboard)
  - Automata – we define the rules (each figure has legal moves)





Probabilistic cellular automata

0 = NO LIFE

1 = SIMPLE LIFE (bacteria)

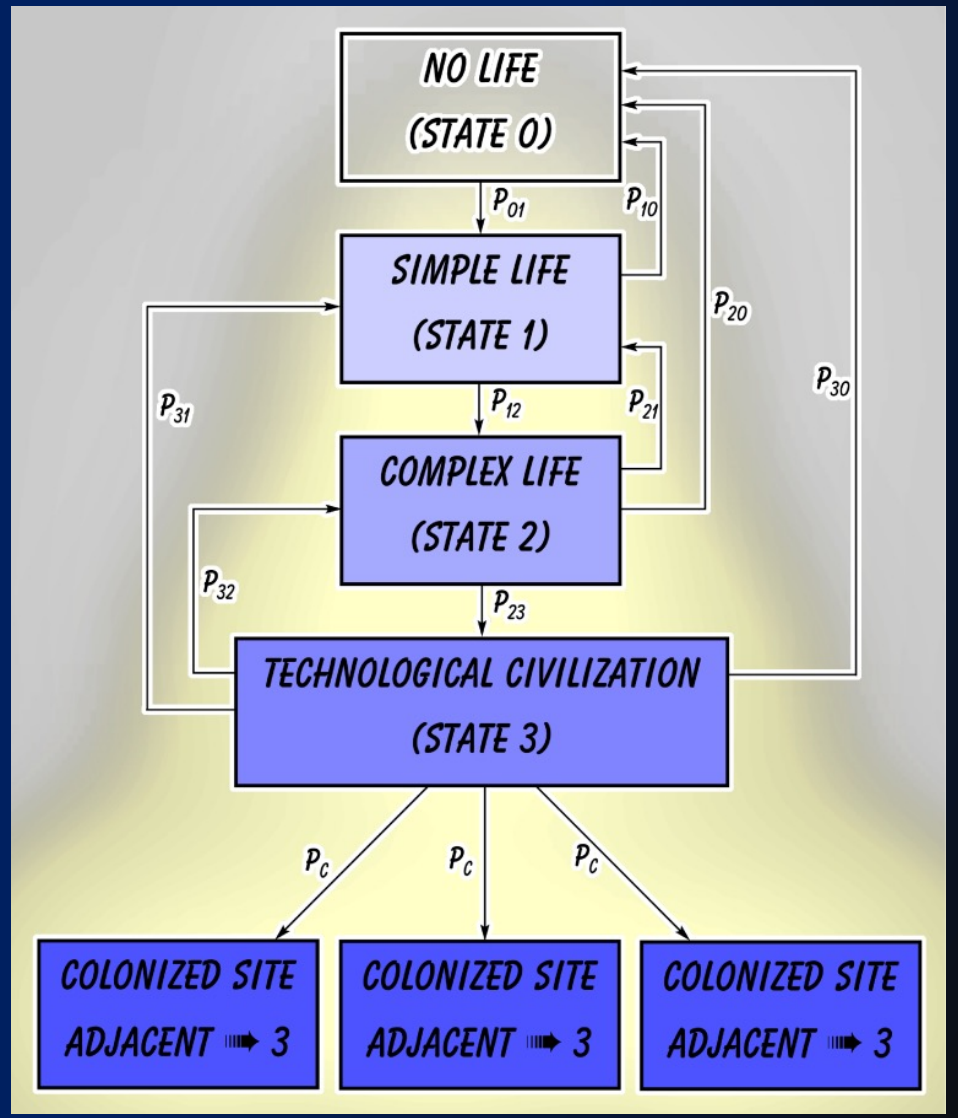
Probabilistic cellular automata

2 = COMPLEX LIFE (plants/animals)

3 = TECHNOLOGICAL CIVILIZATION

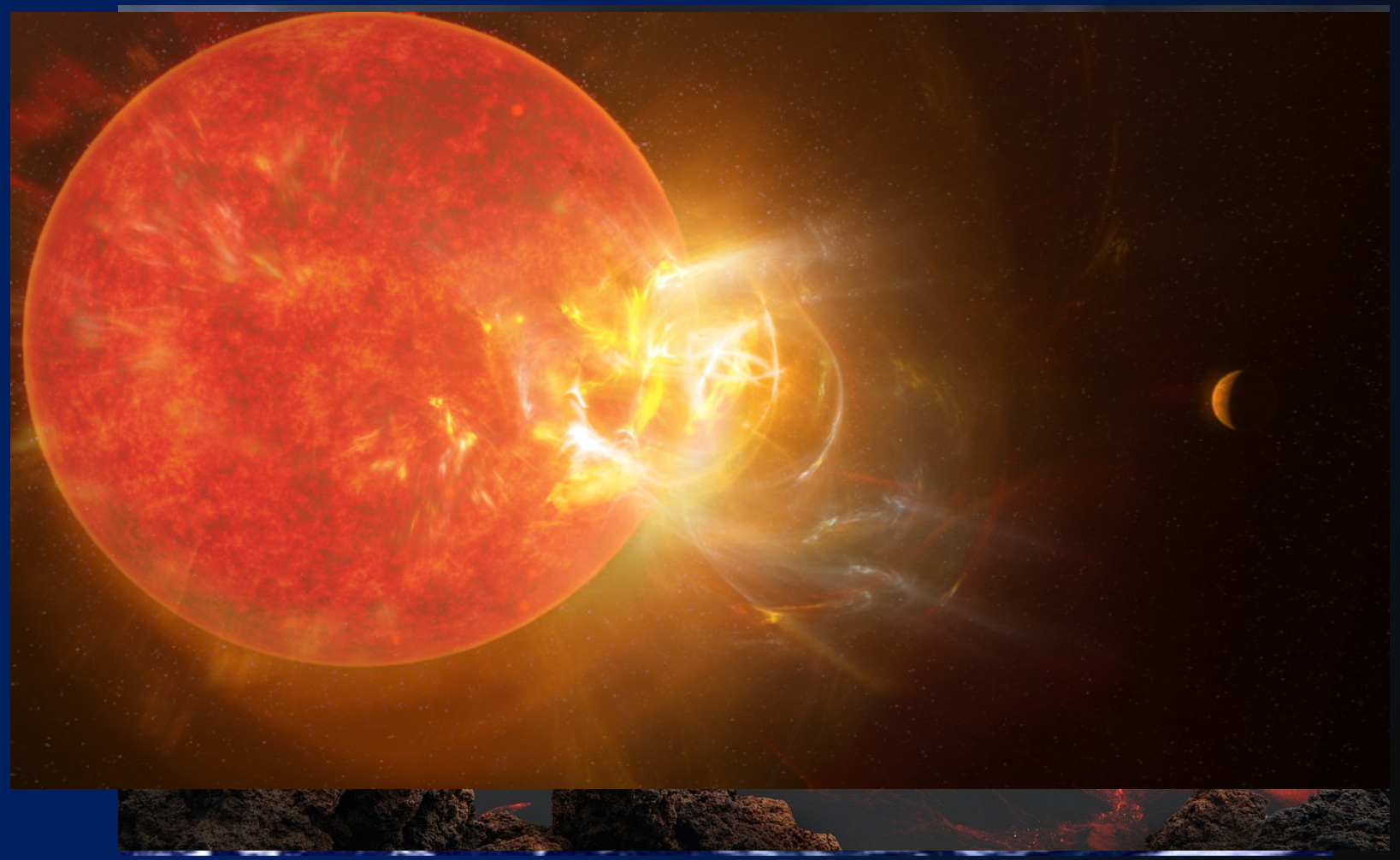
Transition rules

- Evolution
  - X->X+1
- Catastrophic event
  - Wipeout
    - X->0
  - Setback
    - 2->1, 3->1, 3->2
- Colonization
  - X->3



Catastrophic event - wipeout

- 1->0 or 2->0:
  - Asteroid impact
  - Super-volcanism
  - Climate change
  - Bio-sphere collapse
  - Parent star flares



Catastrophic event - wipeout

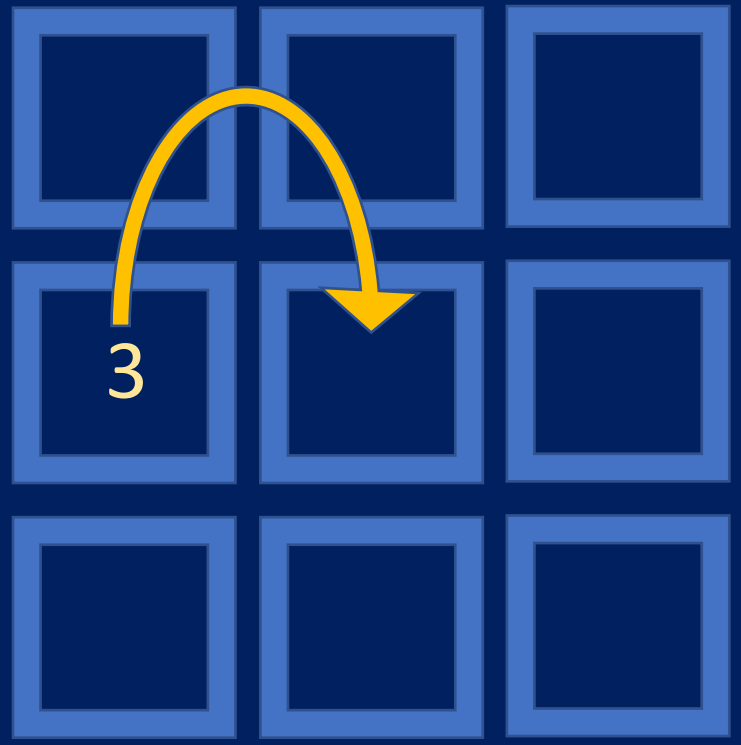
- 3->0:
  - Any of the 1->0 and 2->0
  - Technological catastrophe (evil robots, nuclear explosion…)

Catastrophic event - setback

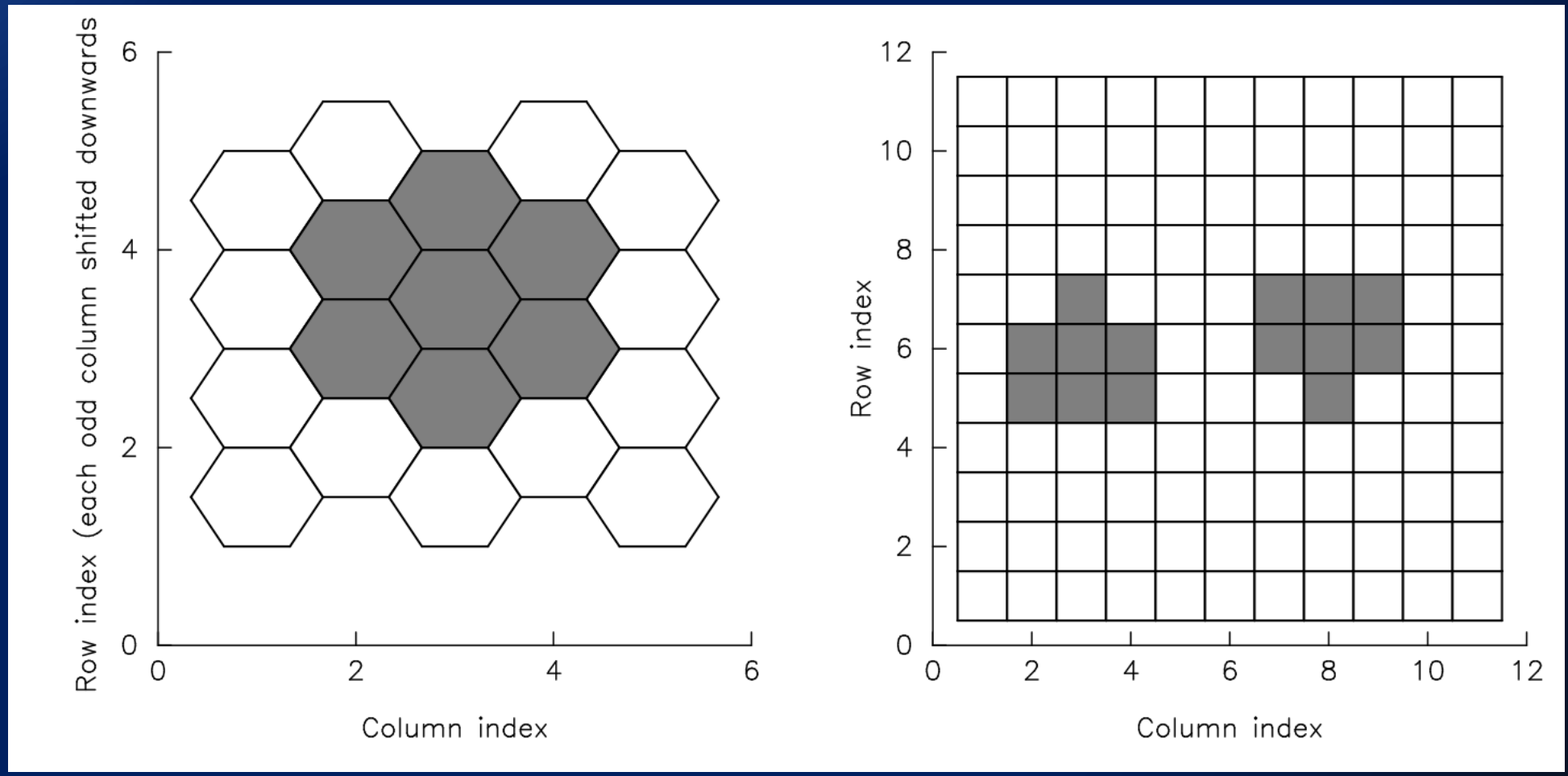
- Doesn’t kill all life, but takes it down a level
- 3->1,
  3->2,
  2->1

Colonization

- 0->3, 1->3, 2->3:
  - Needs settlers from “the neighborhood”

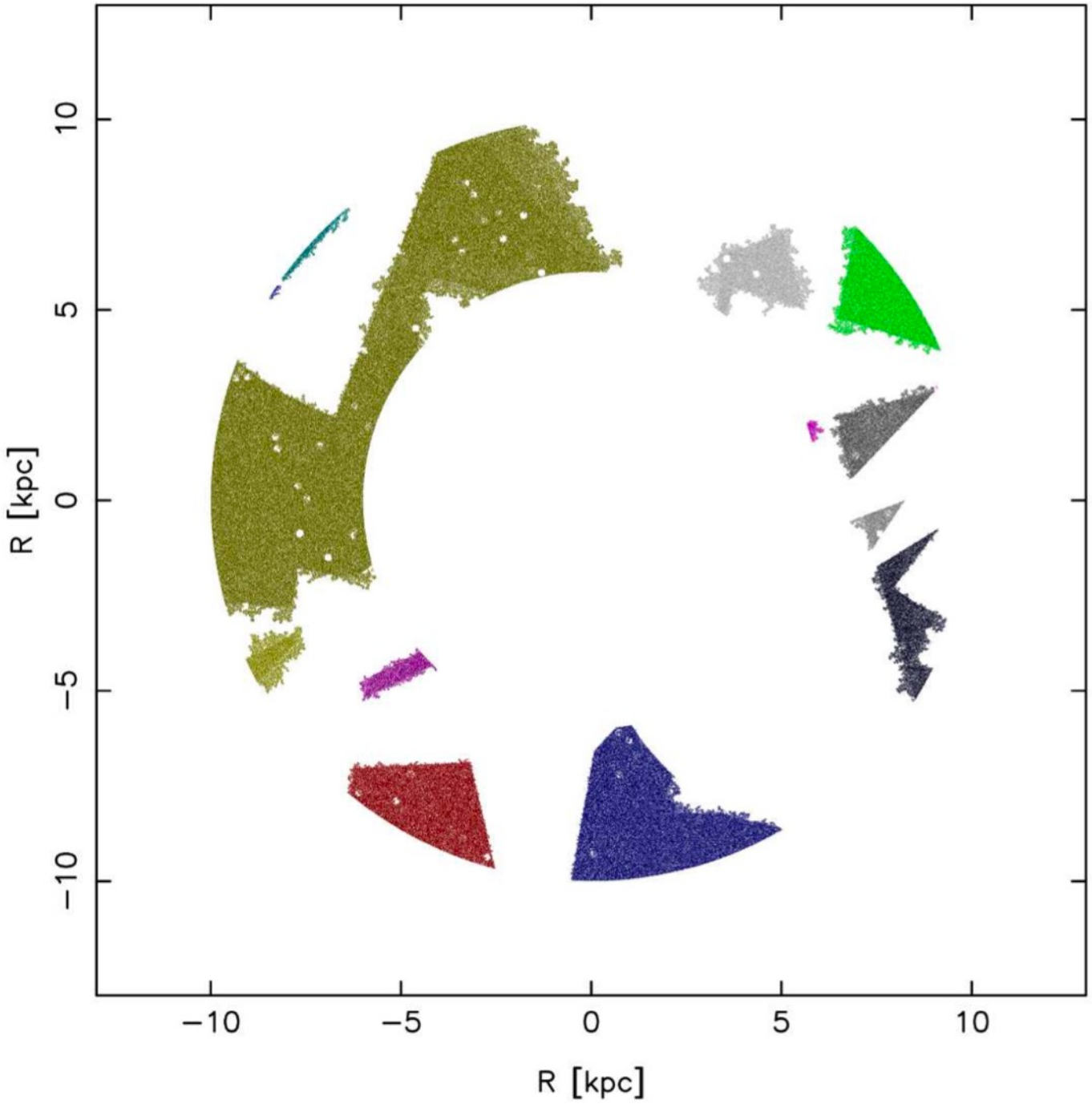


PCA lattice


Row index (each odd column shifted downwards
0
2
4
6
Column index
Row index
0
2
4
6
8
10
12
Column index

Simulation

- How long will a single time step be?
  - 5 million years
- How long will the whole simulation be?
  - 10 billion years
- What the galaxy map would look like in the end?



And now…

… it’s demo time!