

Diversity of Habitable planets: anthropic principle, panspermia, and Fermi Paradox

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19 slides



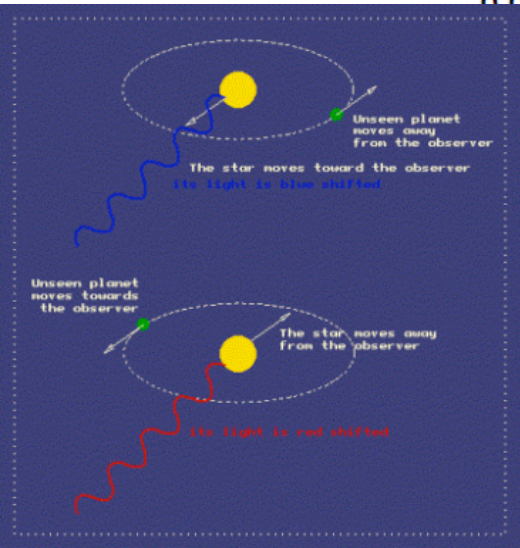
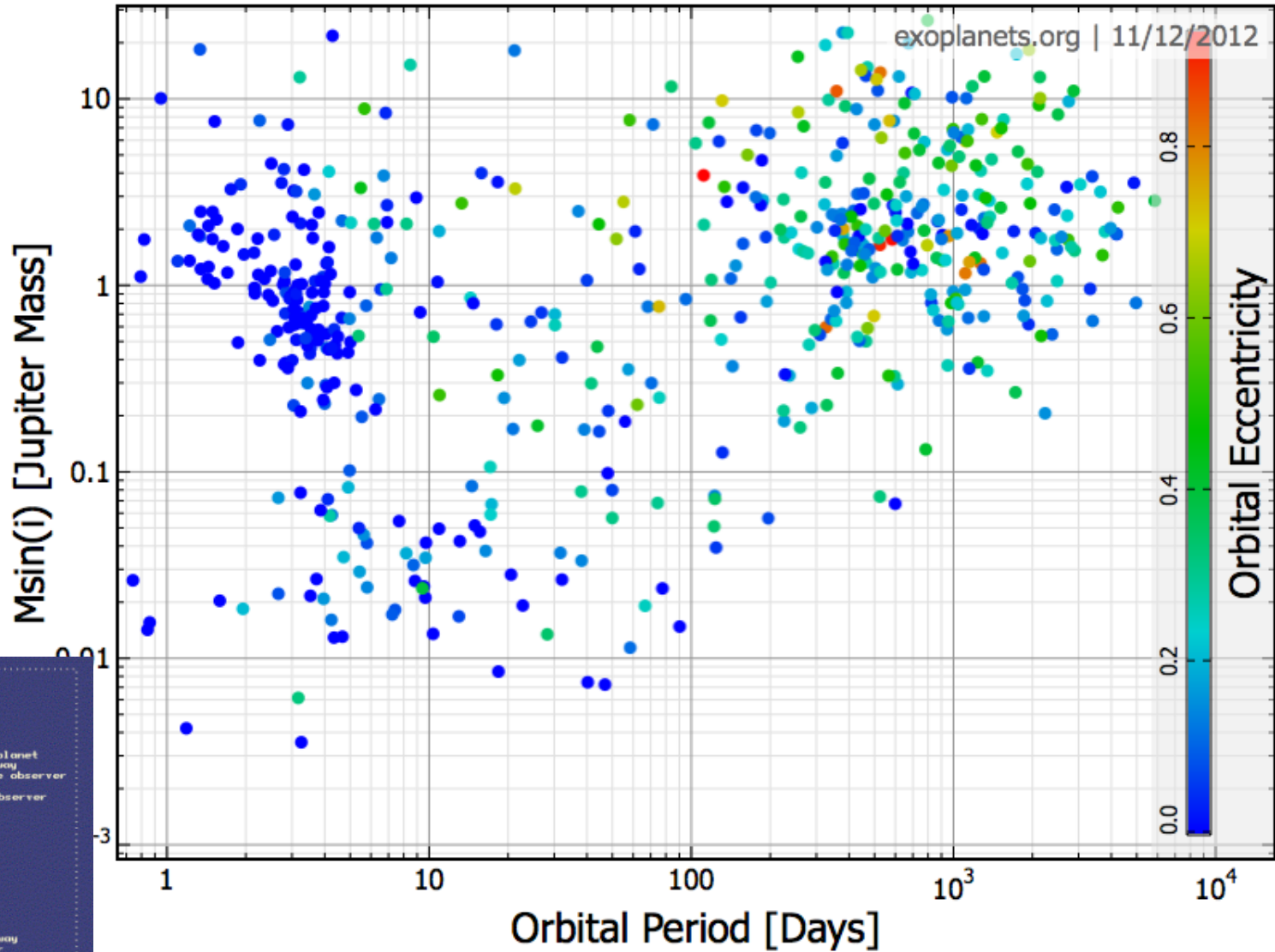
Anthropic Principle

Brandon Carter 1983

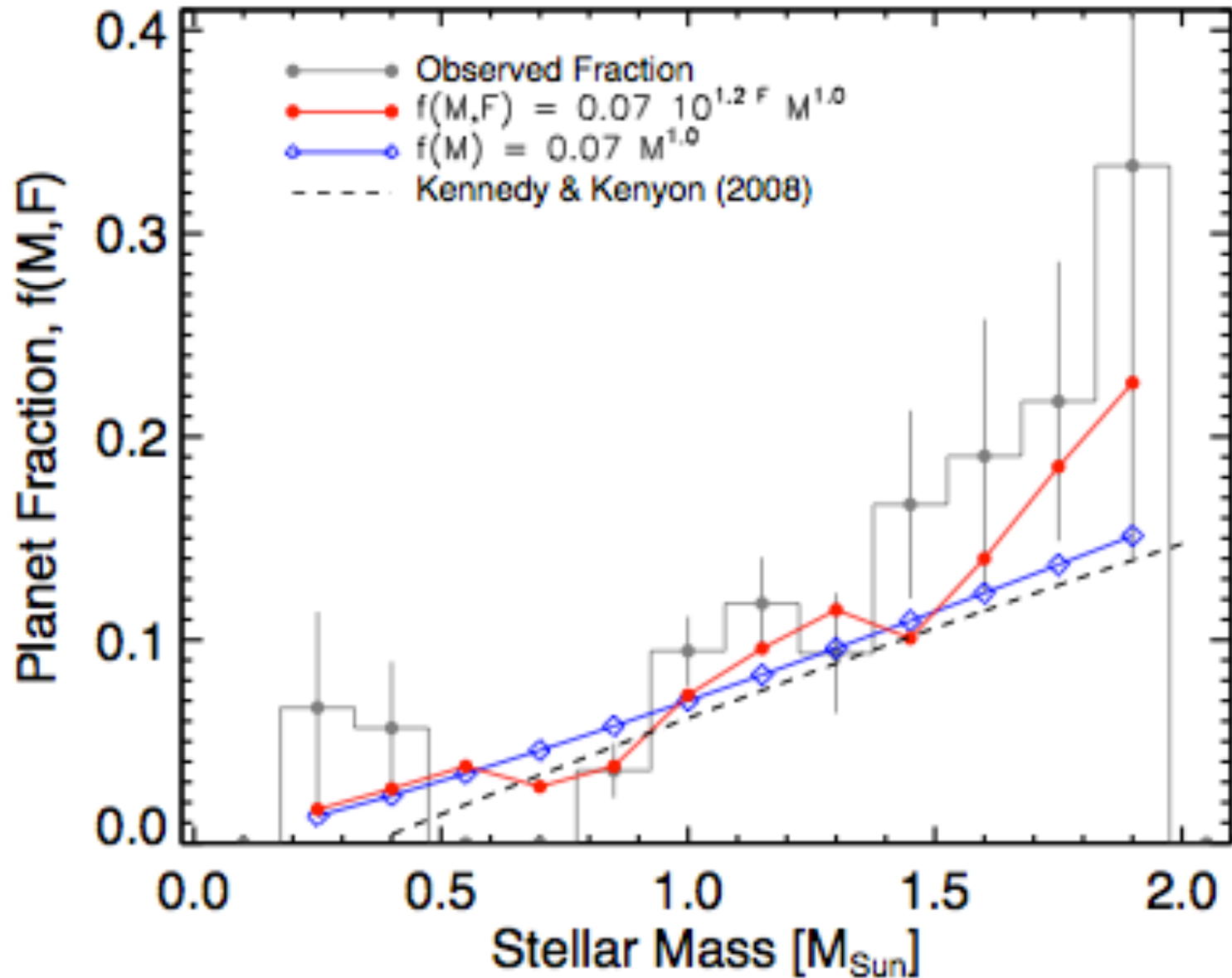


- Astrophysical and cosmological theorists run the risk of error in the interpretation of astronomical and cosmological information unless due account is taken of the **biological restraints under which the information was acquired.**
(Strong Anthropic Principle)
- Biological theorists also run the risk of error in the interpretation of the evolutionary records unless they take due heed of **the astrophysical restraints under which evolution took place.**
(Weak Anthropic Principle).

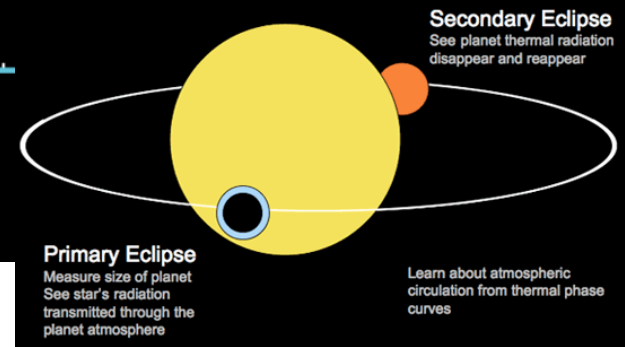
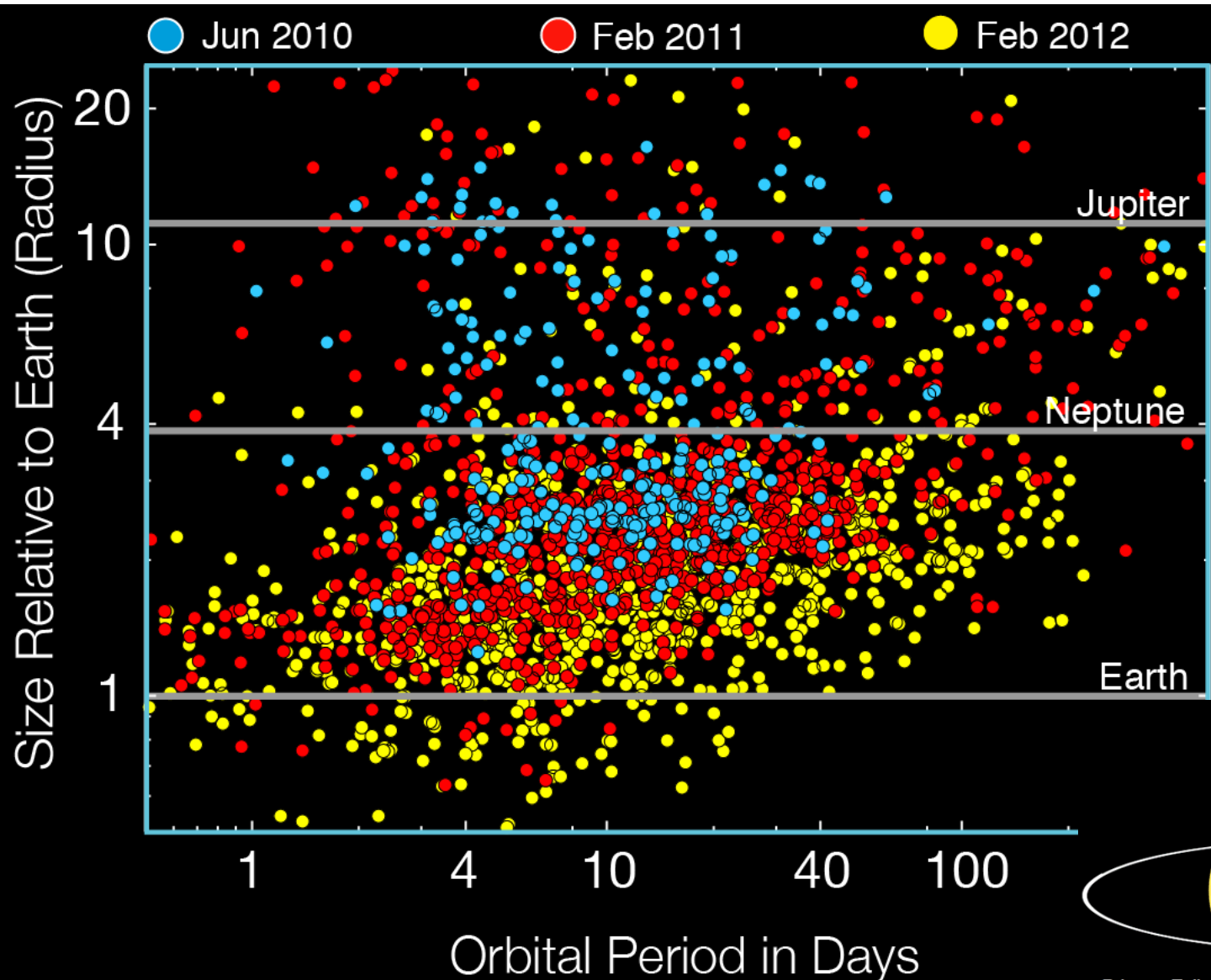
RV surveys: kinematic diversity



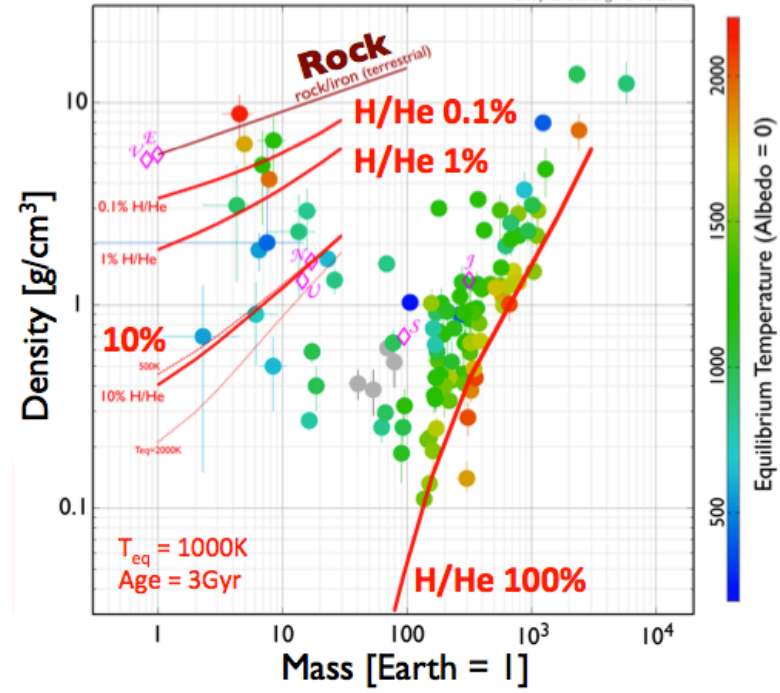
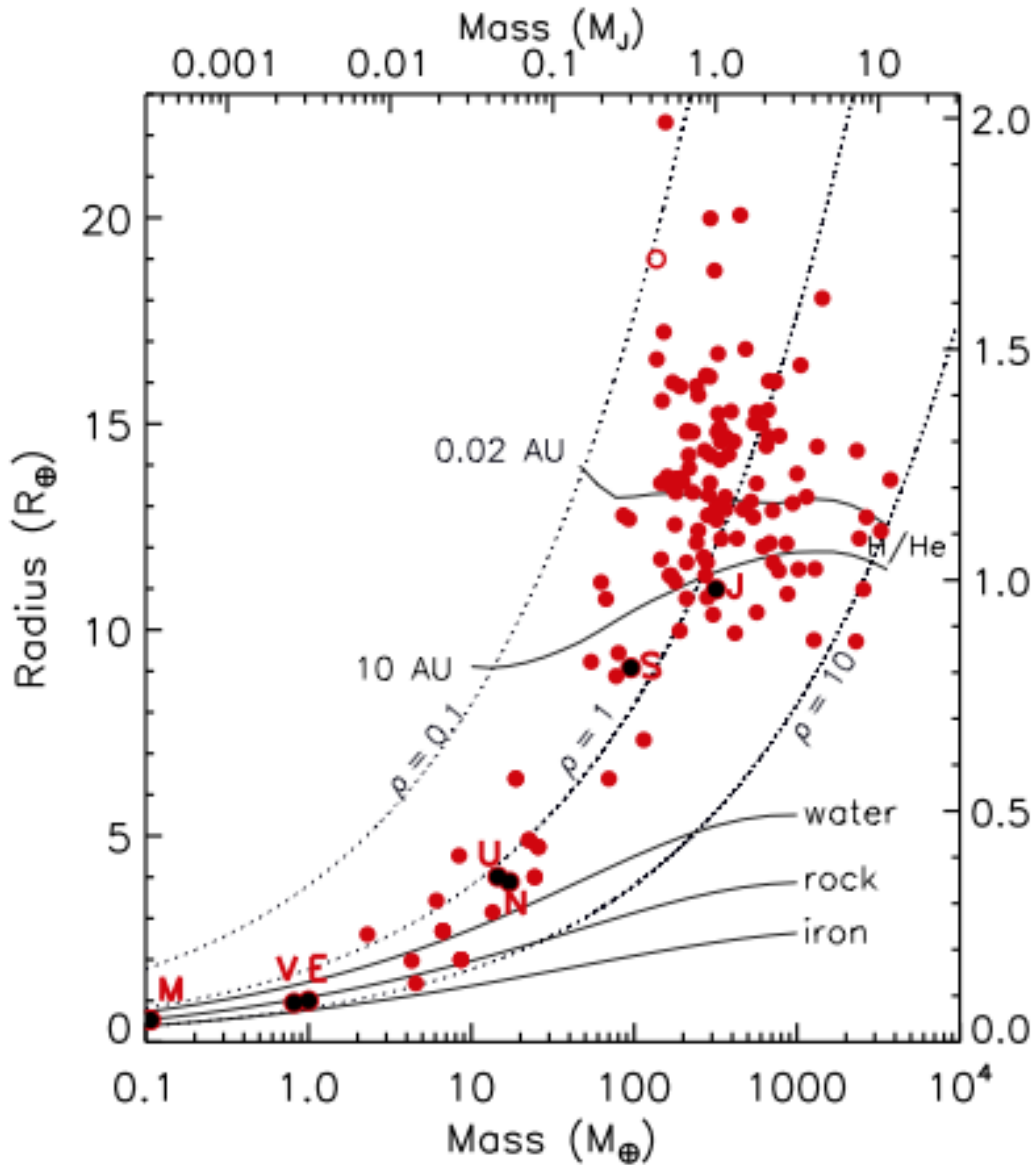
Gas giants: ubiquity



Transit surveys: size distribution

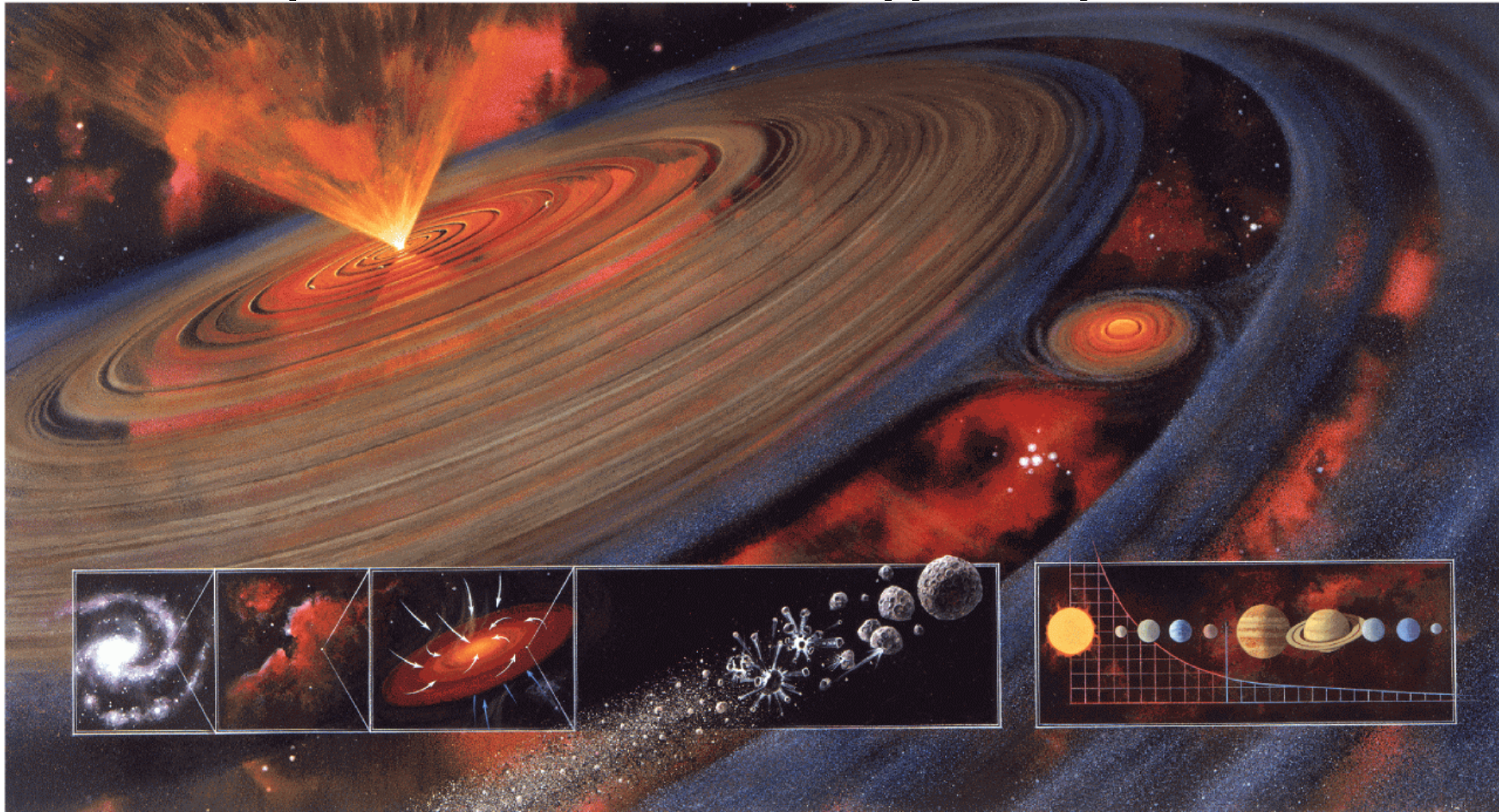


Structural diversity



Ikoma

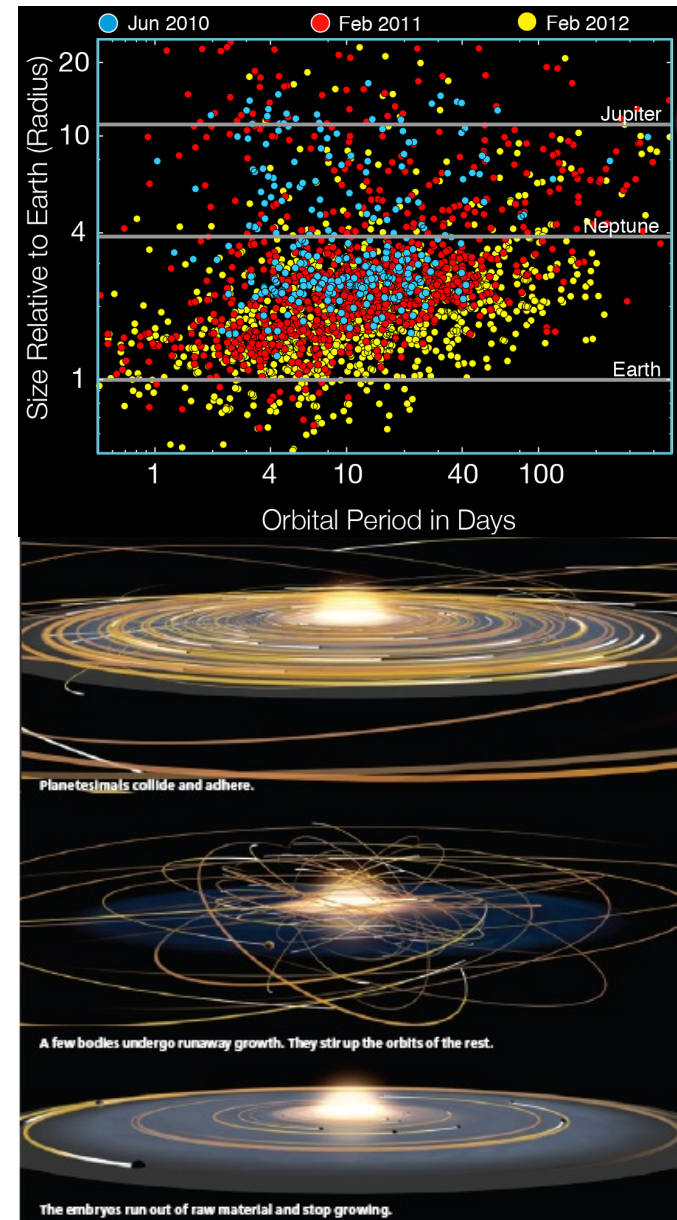
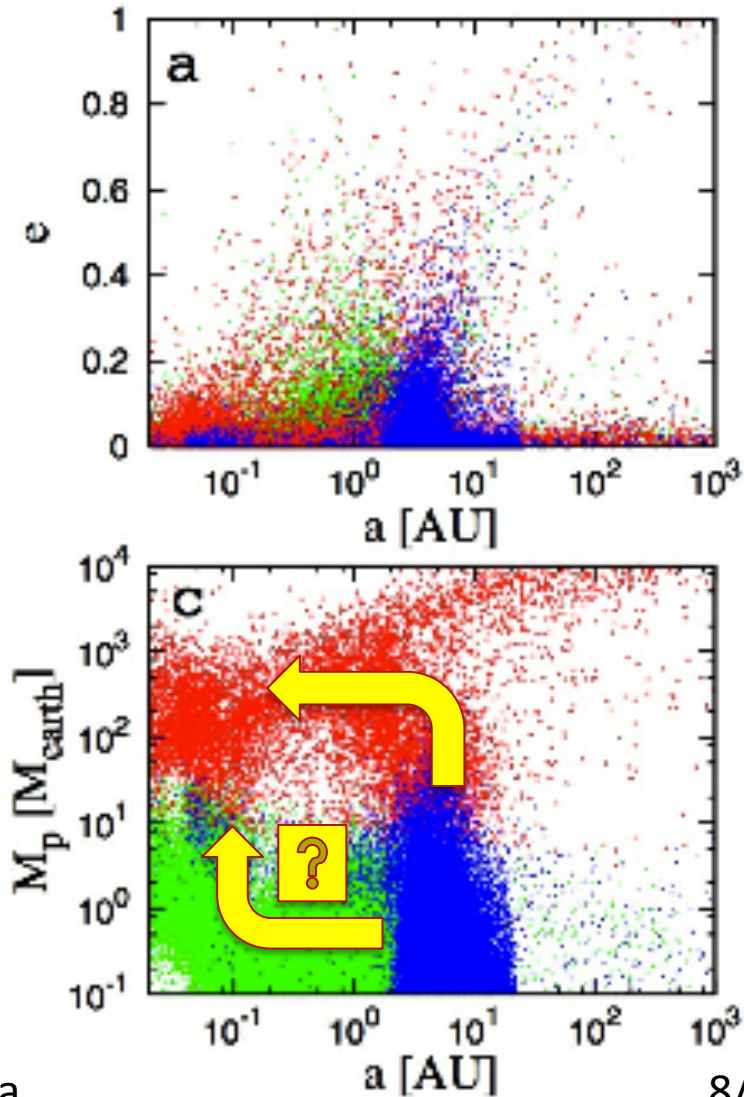
Sequential assemblage of planets

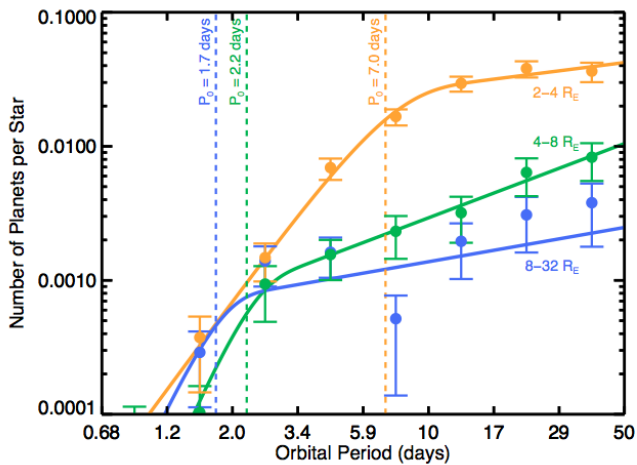
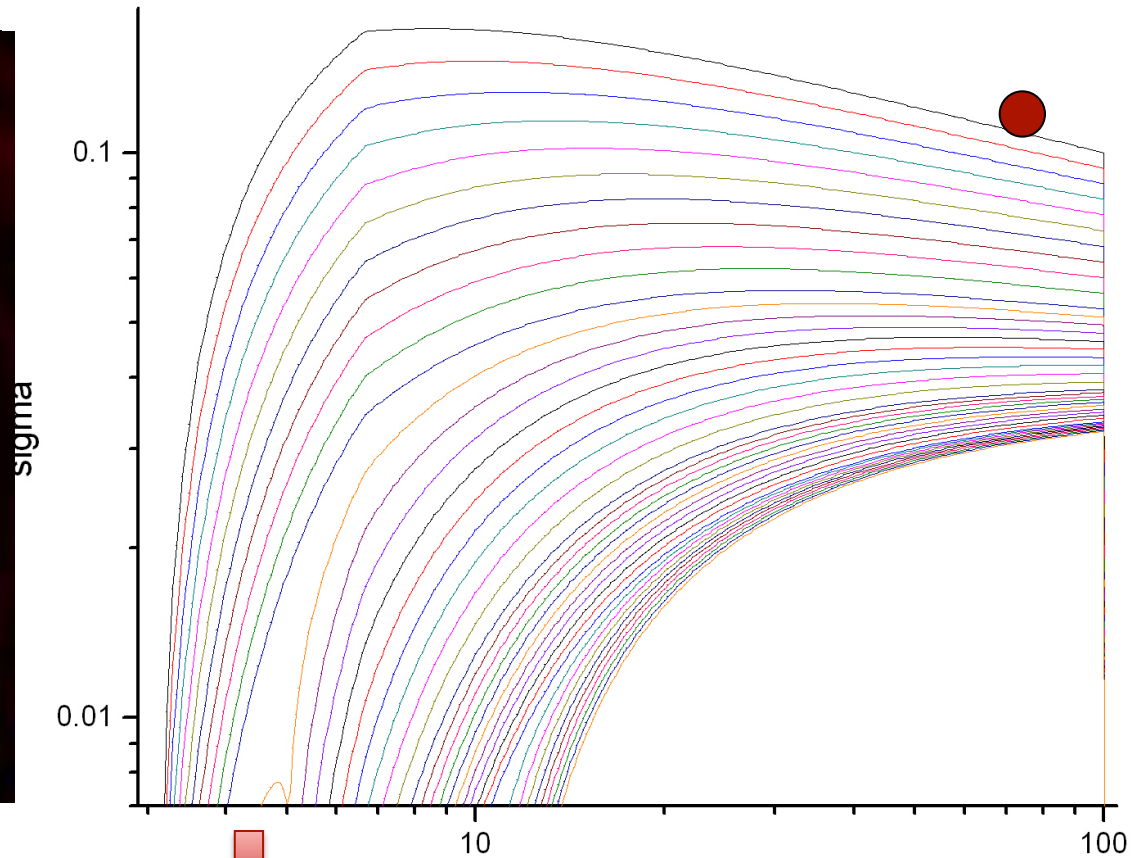


- Paradigm shifts:
- a) natural and robust outcome => planets are common
 - b) competing processes => planetary diversity
 - c) mobility => planetary systems' probabilistic destinies
 - d) changing boundary conditions => evolving habitable zones

Super Earths: some key issues

- Did super Earths assemble in situ or form at large a and migrate?





radius / Rstar

Migration of a Super Earth in protostellar disk around a magnetized T Tauri star. The Super Earth: (a) grows & migrate inward to inner-edge; (b) migrates slightly outwards with the expanding disk inner edge; (c) halts migrating after gas is mostly depleted. (Ju et al 2013 in preparation)

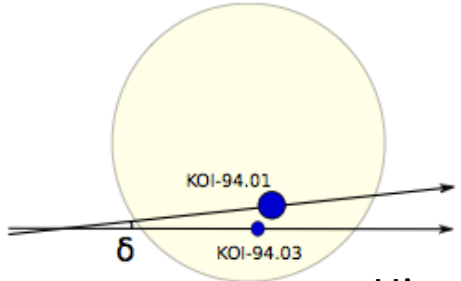
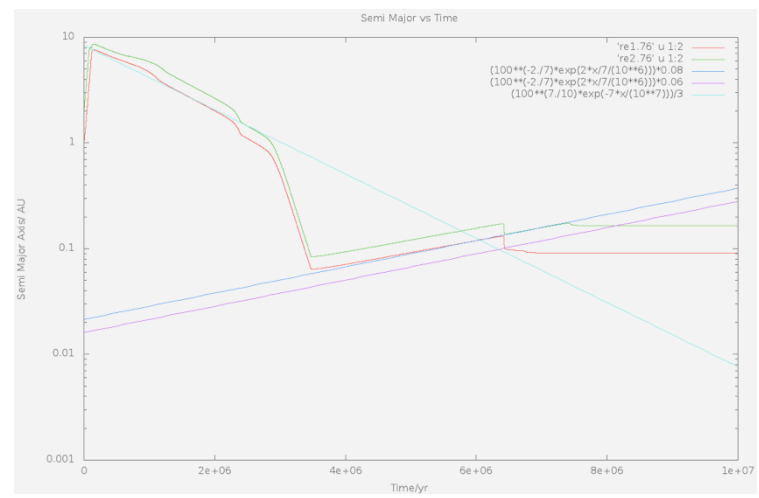
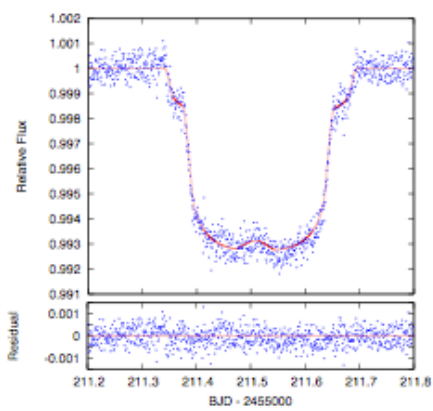
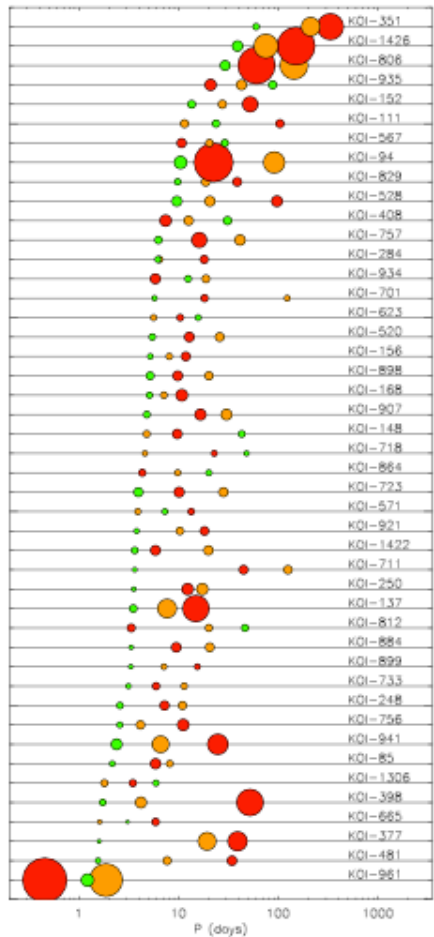
→ To model P distribution of Kepler's new-found planetary candidates.

9/19

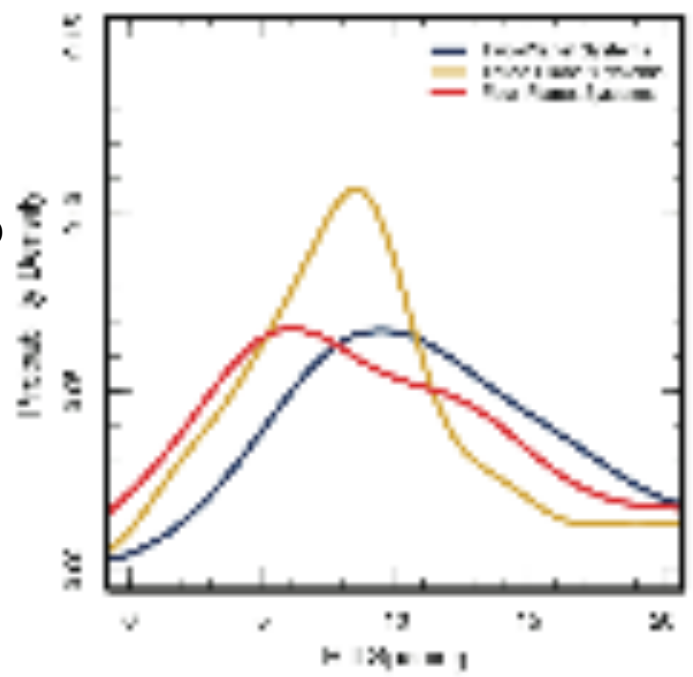
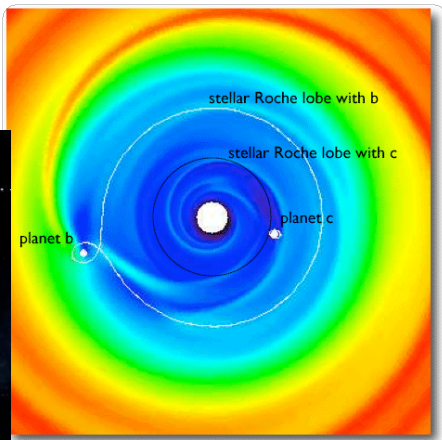
KIAA undergraduate student Ju Wenhua now at Princeton U

New Candidate Catalog

Close packing and stability of multiple systems



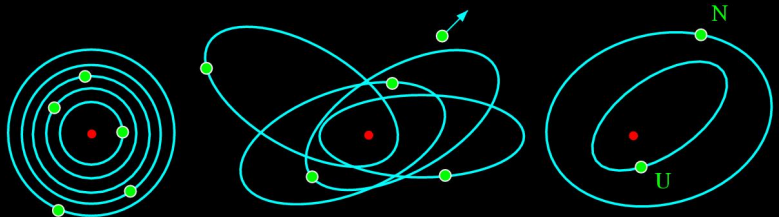
Hirano



Dai

Zheng

Dynamical perturbation by Jupiter-like planets



A gas giant planet disrupted by a sun-like star as a result of planet-planet scattering or the Kozai effect.

Nagasawa

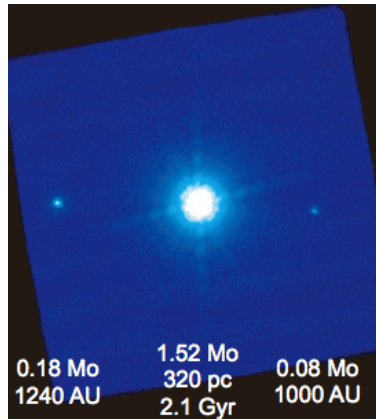
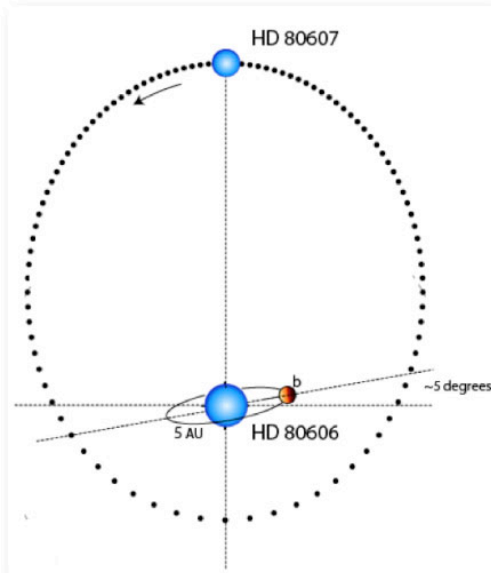
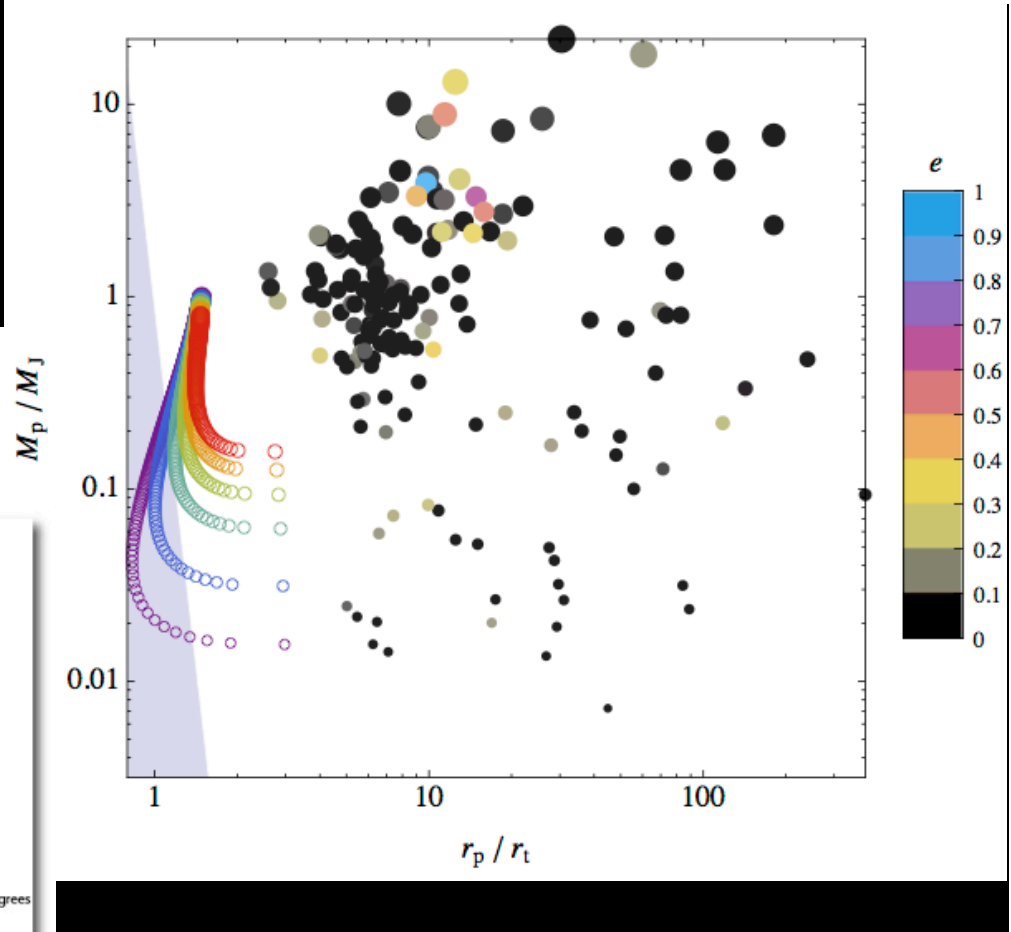
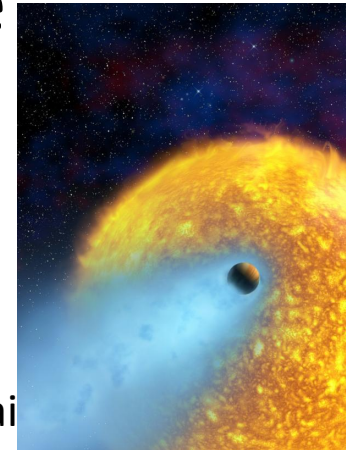


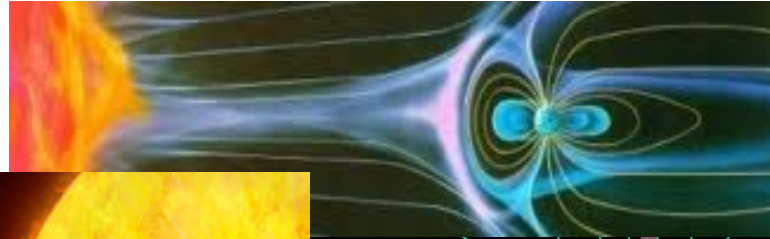
Image of HAT-P-7 (12"x12"). Upper right: AADI image of HAT-P-7. Lower right: AstraLux z' band image of HAT-P-7 and

Many competing physical processes

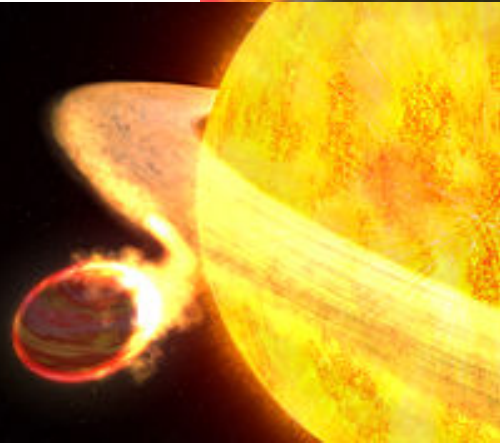
Origin of diverse planetary structure



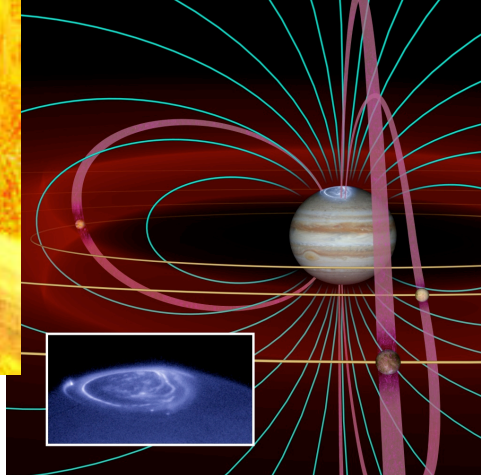
Dai



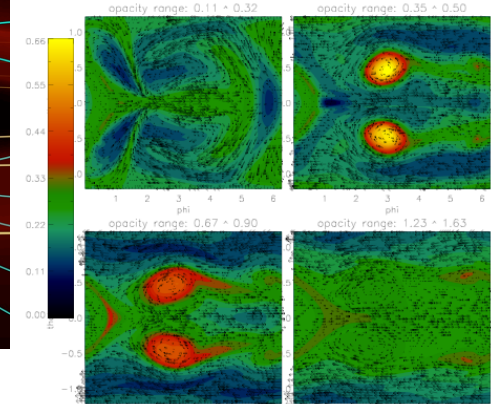
Li



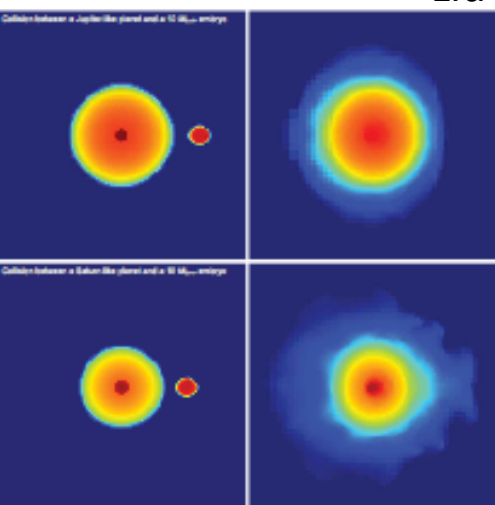
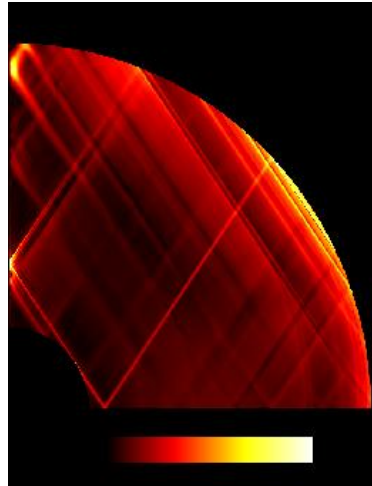
Liu



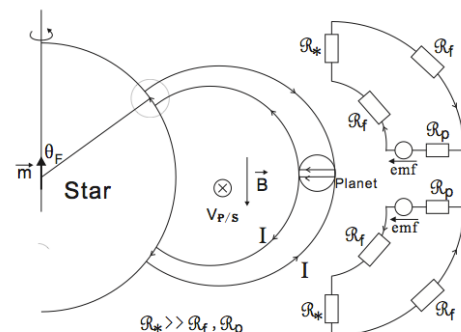
Zhu



Ogilvie

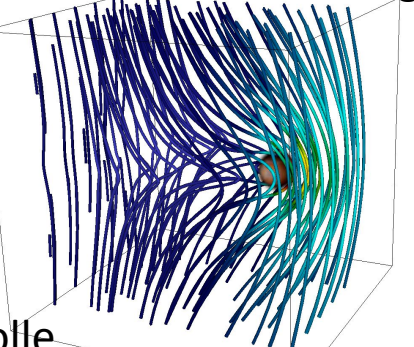


Laine



12/19

Dobbs-Dixon, Wang

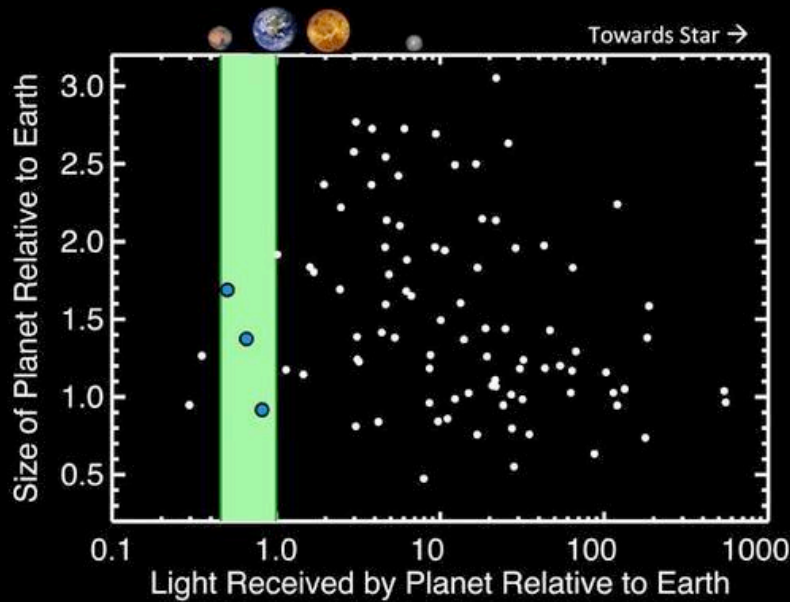


de Colle

Potential life-supporting platforms:

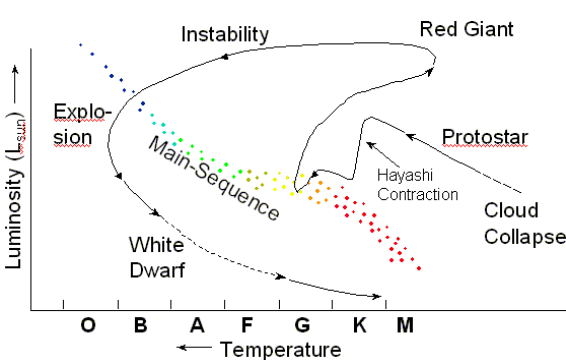
- a) **evolving** habitable zones
- b) **common** habitable planets

95 Planet Candidates Orbiting Red Dwarfs

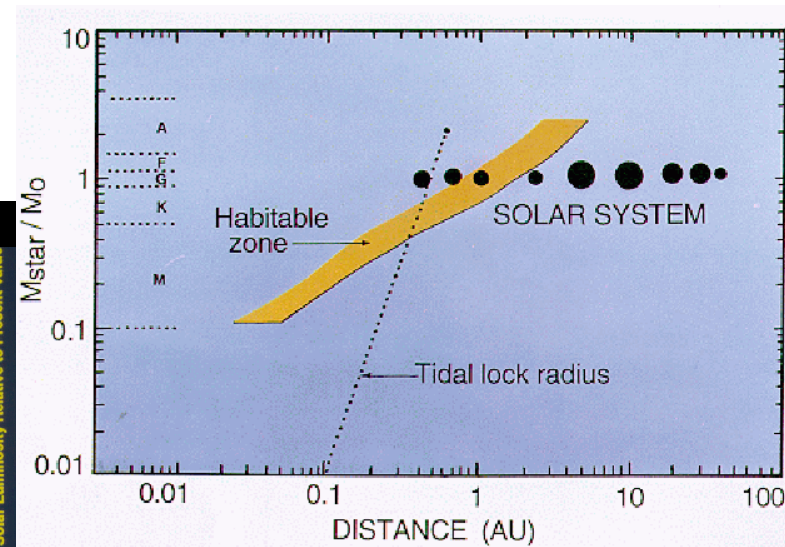
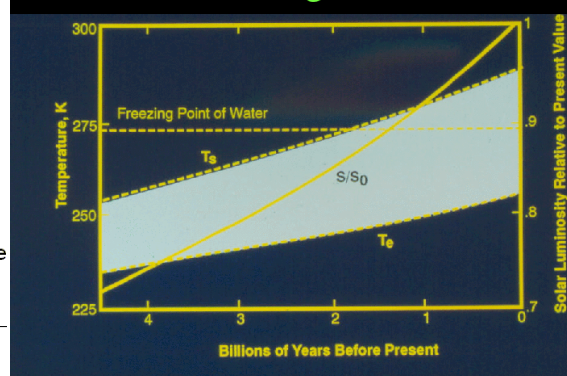


- 1) Many cradles to start native lives
- 2) Changing boundary condition as driving force for Darwinian evolution
- 3) Many targets for directed panspermia
- 4) Prospects of statistical survey & analysis quantitative proofs for genesis models

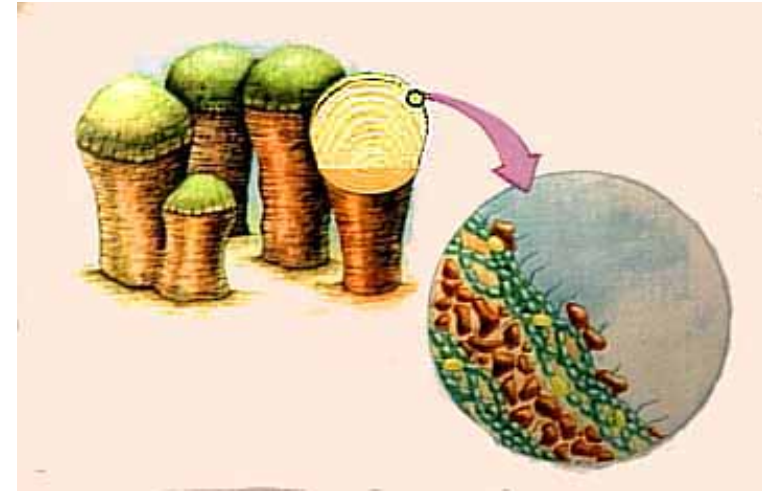
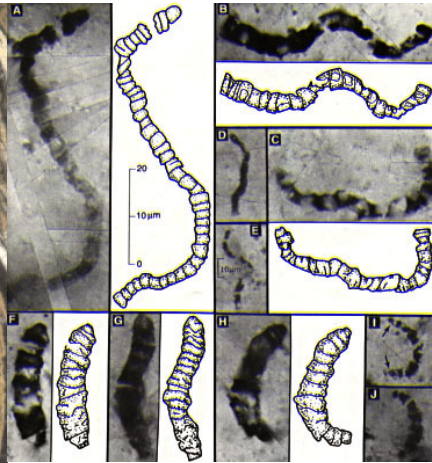
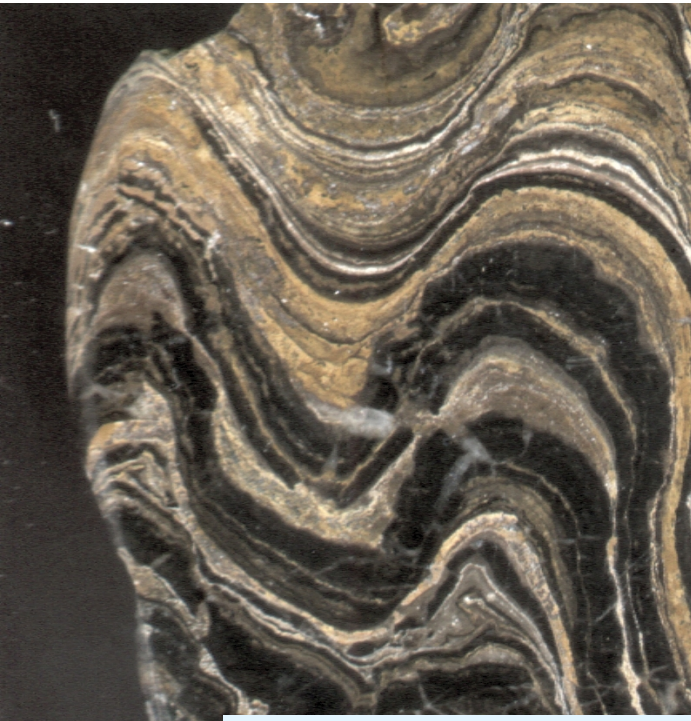
Evolution of the Sun



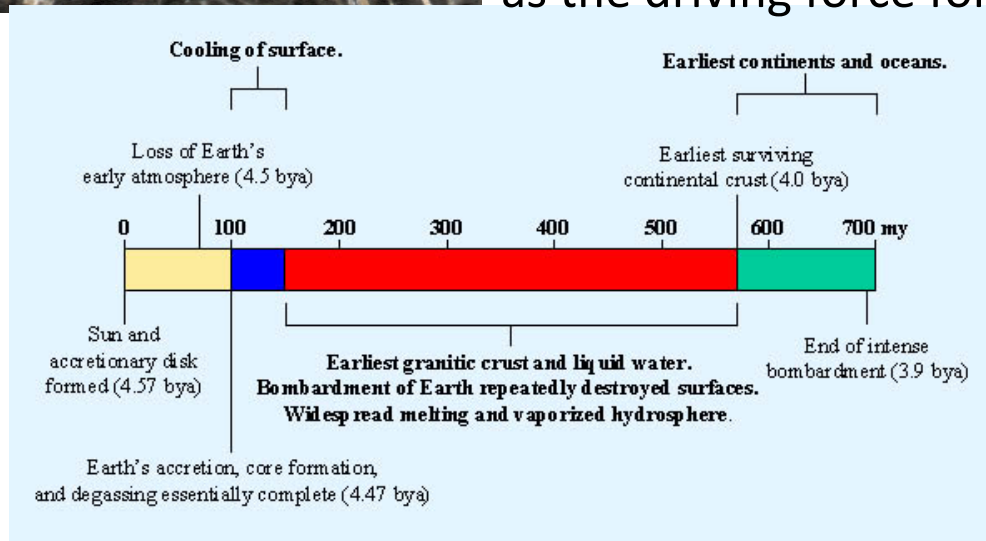
The Faint Young Sun Problem



Option 1: *In situ* origin of life on Earth

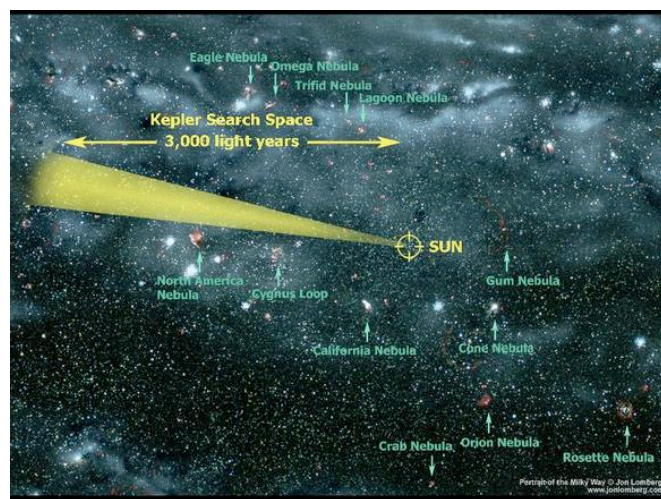


- 1) What makes Earth **unique** in SS?
- 2) What **time scale** is needed ?
- 3) **Changing boundary conditions** as the driving force for evolution

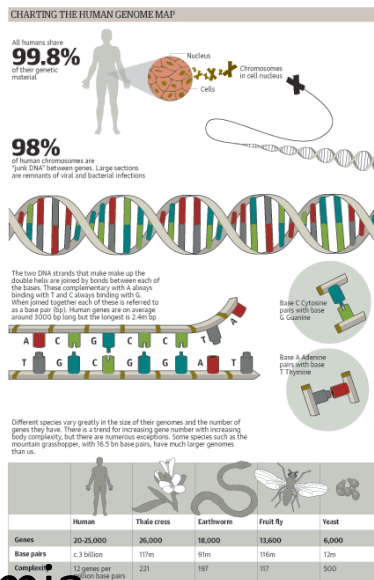
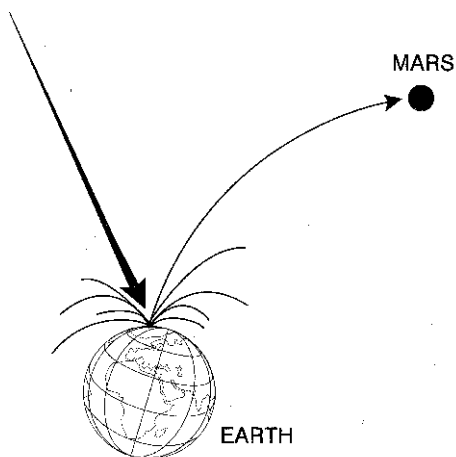


Option 2: Panspermia

difficult to verify



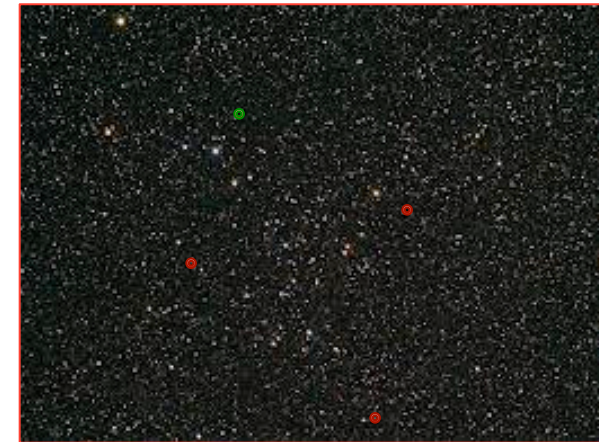
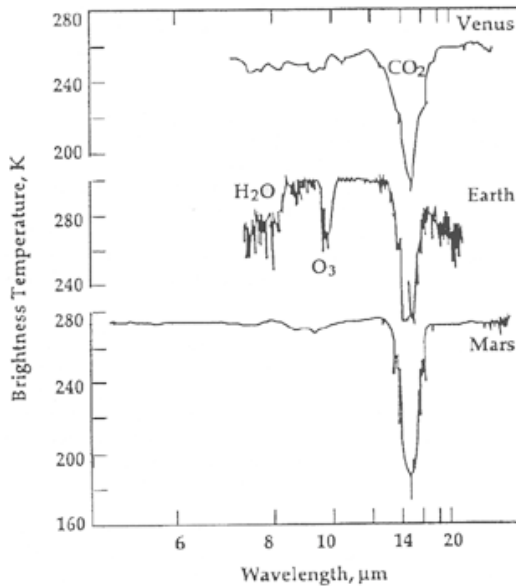
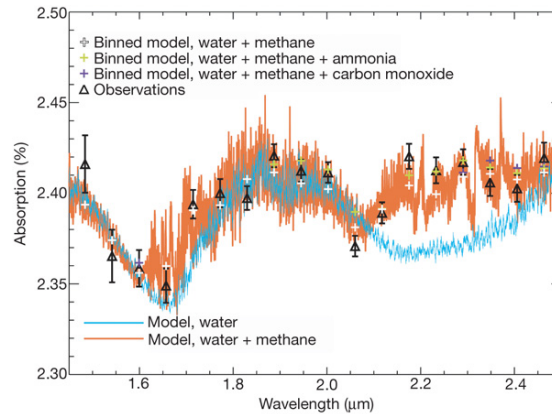
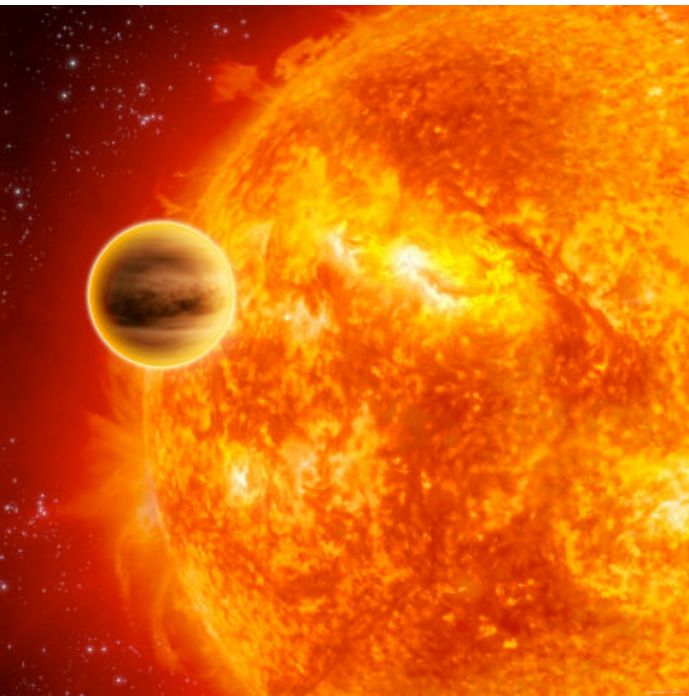
Ballistic (interplanetary) panspermia
Litho (interstellar) panspermia



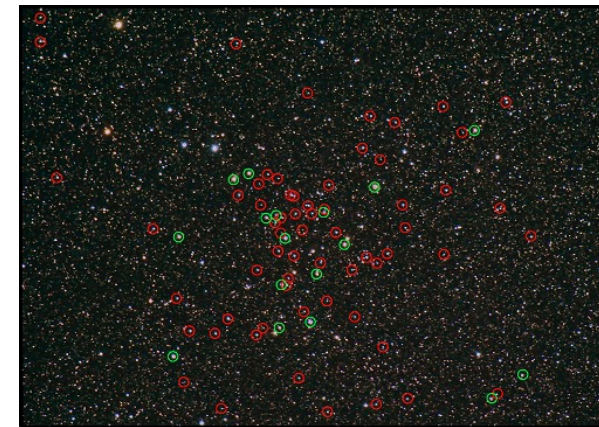
15/19

Directed (informational) panspermia
Few show-stoppers. **Possible => probable** Liang

Search for clustered distribution and age of habited planets



versus



A systematic survey for bio-signatures on habitable planets.

- 1) Spatial and temporal distribution
- 2) Dependence on stellar and planetary-system properties

Fermi's paradox: WHERE IS ET?

Ingredient for Darwinian Evolution:

Meta-stable information bases

Survival against obstacles and disasters:

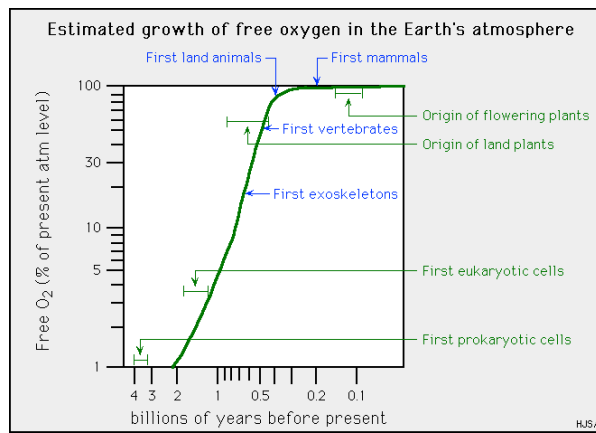
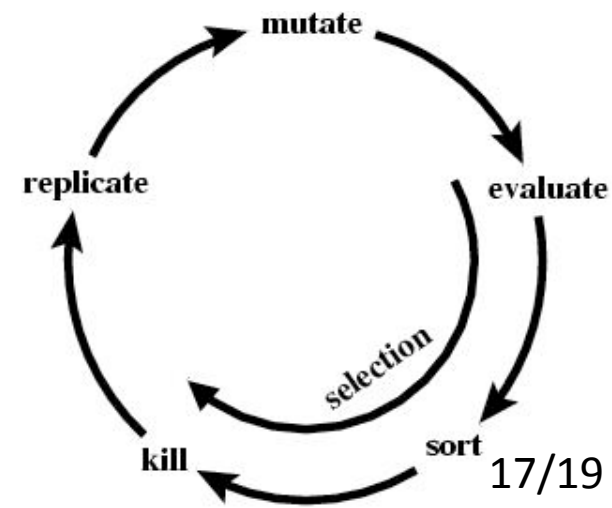
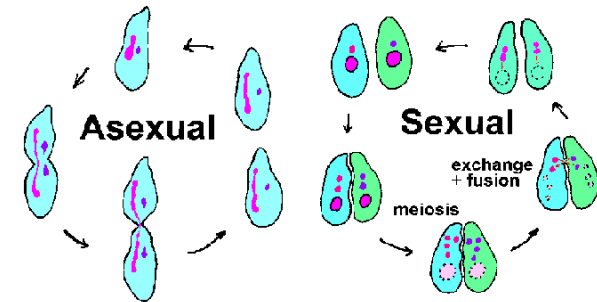
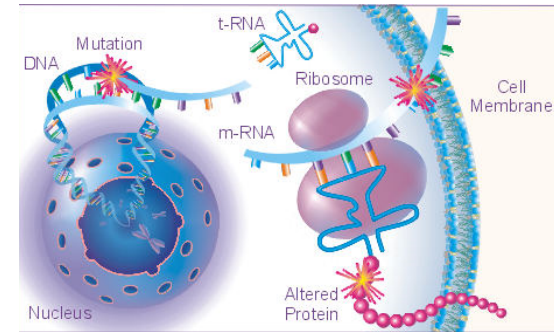
Exponential growth & dissemination of mutation
sexual genetic reproduction

Adaptation and competition for resources:

Natural selection, expansionism, "space filling".

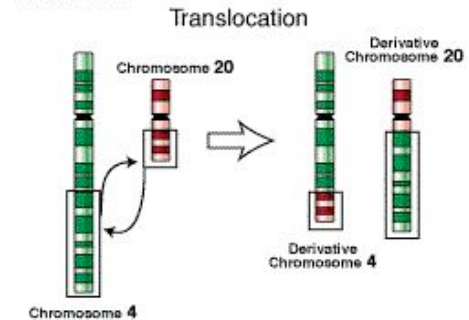
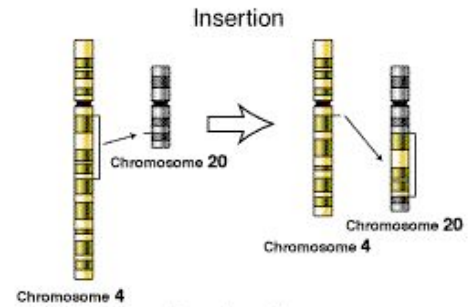
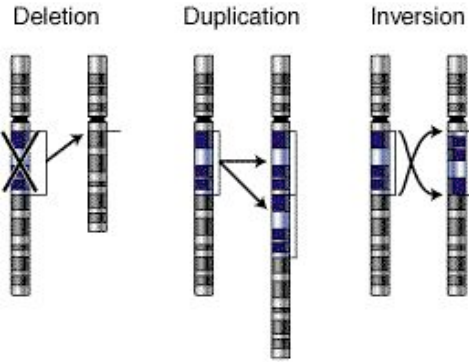
Intelligence and self awareness:

strategy for survival and proliferation.

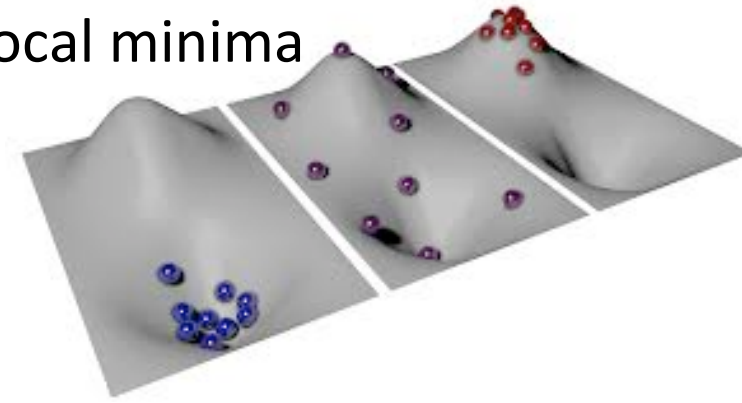
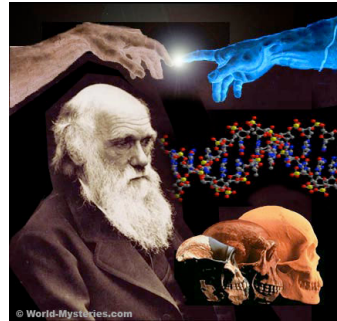


Fitness peaks & "potential" valleys

Types of mutation



Passive versus active local minima



Local, regional, and global minima

18/19



Advanced civilization may be
 1 trapped into evolutionary
 holes
 2 reached nonlinear saturation,

Summary

- Planet formation is a series of robust, complex, competitive process.
- Multiple paths of migration during formation and evolution have produced the statistical properties of planetary systems.
- Individual planets' structure and planetary systems' dynamical architecture are DIVERSE.
- Comparative planetology is needed to understand the mean and dispersion in the boundary conditions of habitable environments.
- Weak anthropic principle provides a scientific and philosophical basis for an interdisciplinary approach in the search for our roots & destiny.
- Characterization of exoplanets will greatly expand our horizon with sites of ongoing biological and geological genesis and evolution.
- The discovery and systematic census of bio-signatures on habitable planets will provide historic paradigm-changing evidences to back up extraordinary speculations.
- **May ELSI play a prominent and leading role in this exciting scientific endeavor and global, profound intellectual pursuit.**