The Search for Habitable Worlds

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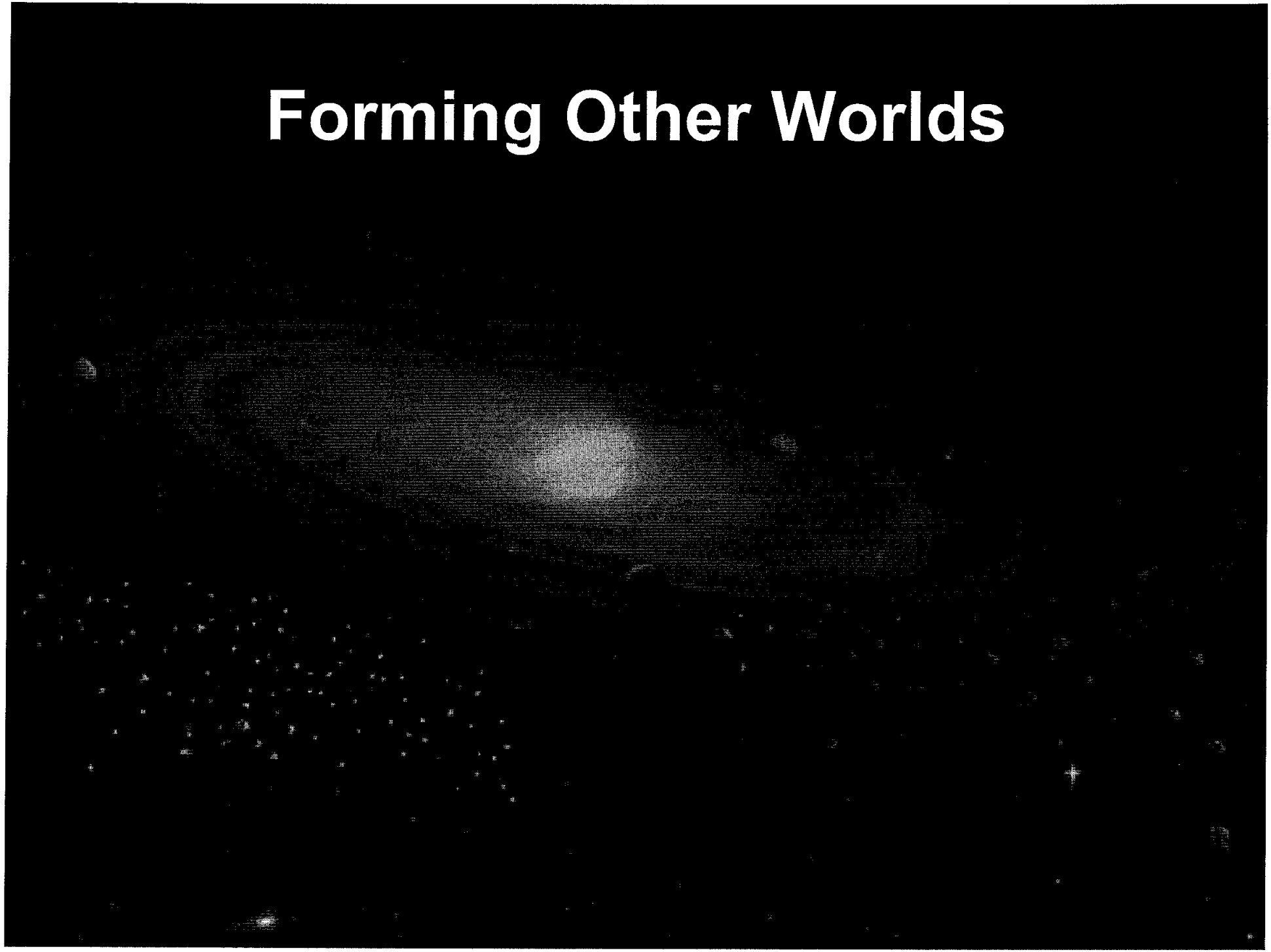
The Search For Habitable Worlds

"There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system. We see only the suns because they are the largest bodies and are luminous, but their planets remain invisible to us because they are smaller and non-luminous. The countless worlds in the universe are no worse and no less inhabited than our Earth."

- GIORDANO BRUNO (1584)

Forming Other Worlds

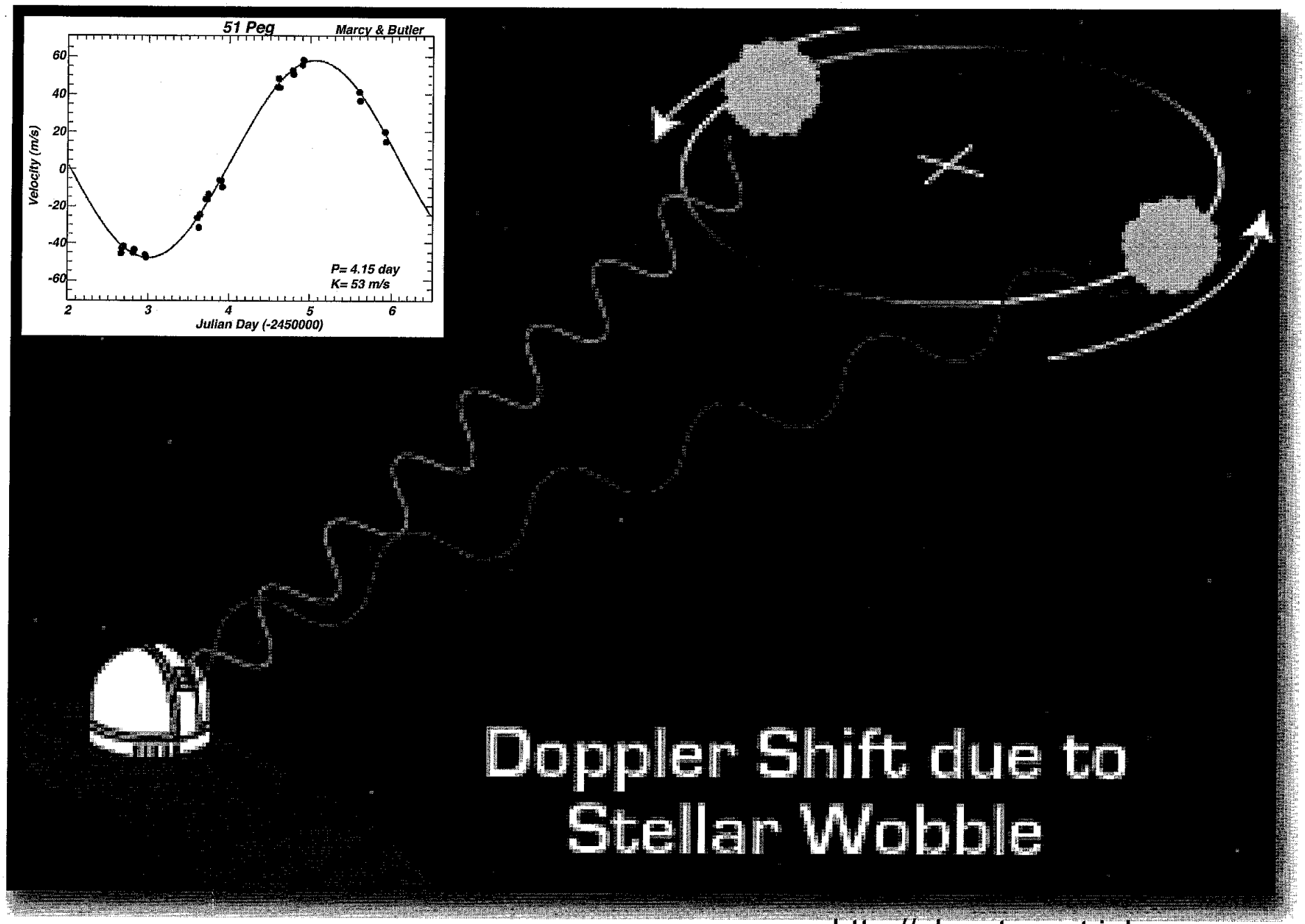


The Search for Planets Around Other Stars

- There are three basic challenges to observing extrasolar planets
  - for the most part, planets don't produce any light of their own
  - they are VERY far away
  - they are lost in the glare of their parent star

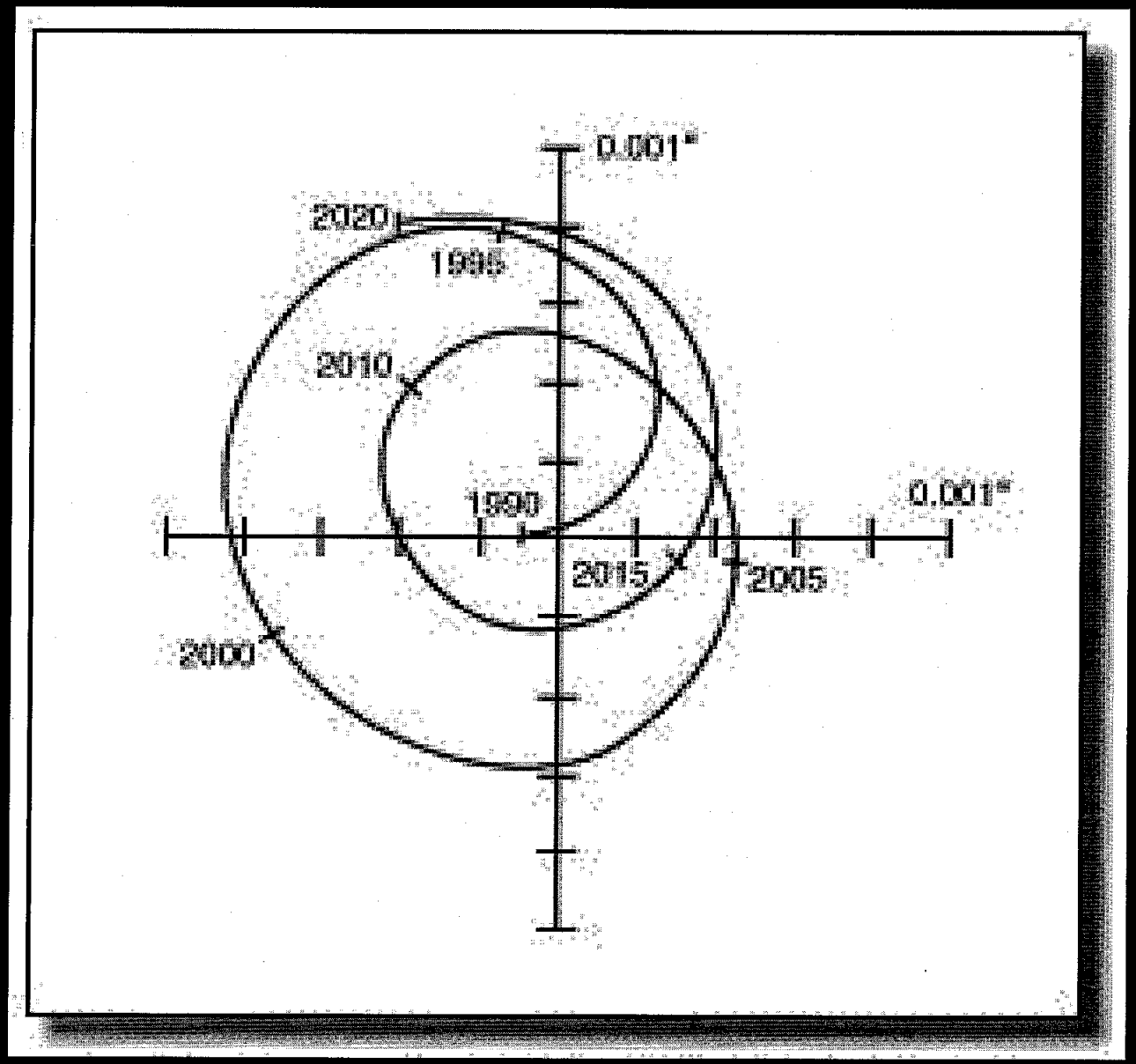
"Trying to observe a planet around Proxima Centauri is like standing in Boston and trying to see a moth around a search light in San Diego"

- The first planets to be found around nearby stars have *never been seen!*
  - They have been inferred via "indirect detection techniques"

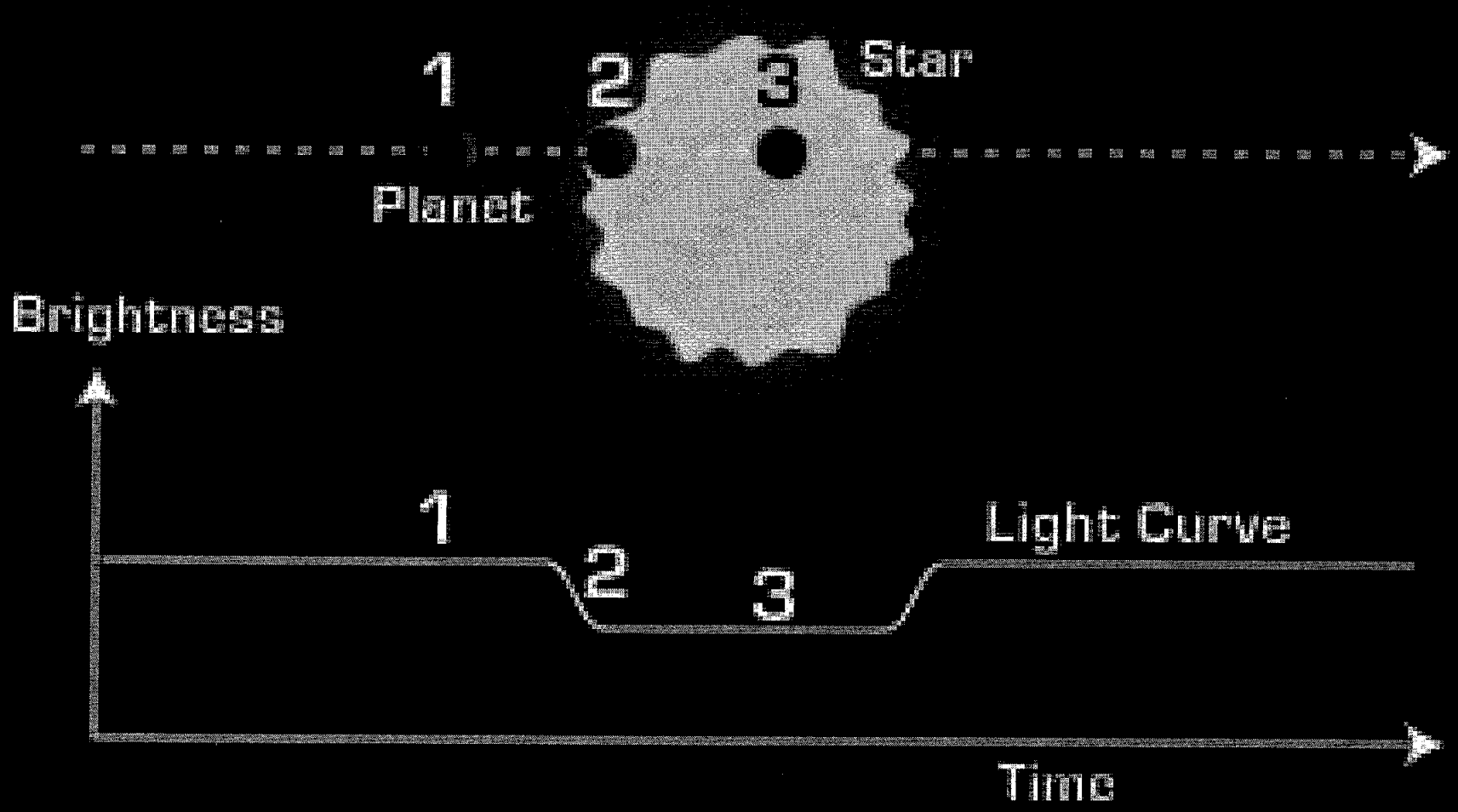


http://planetquest.jpl.nasa.gov

Astrometry

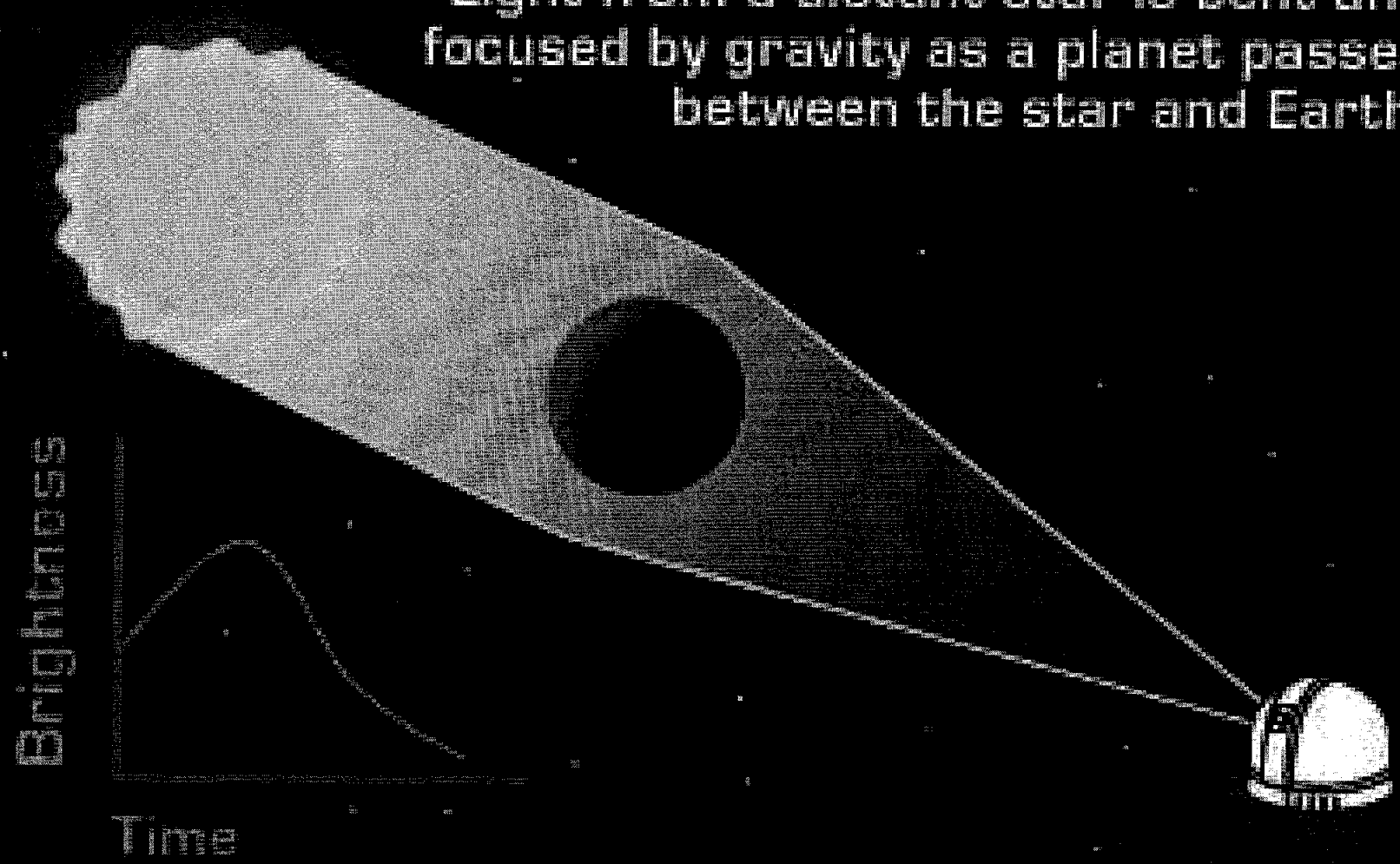


Transit Method



Gravitational Microlensing

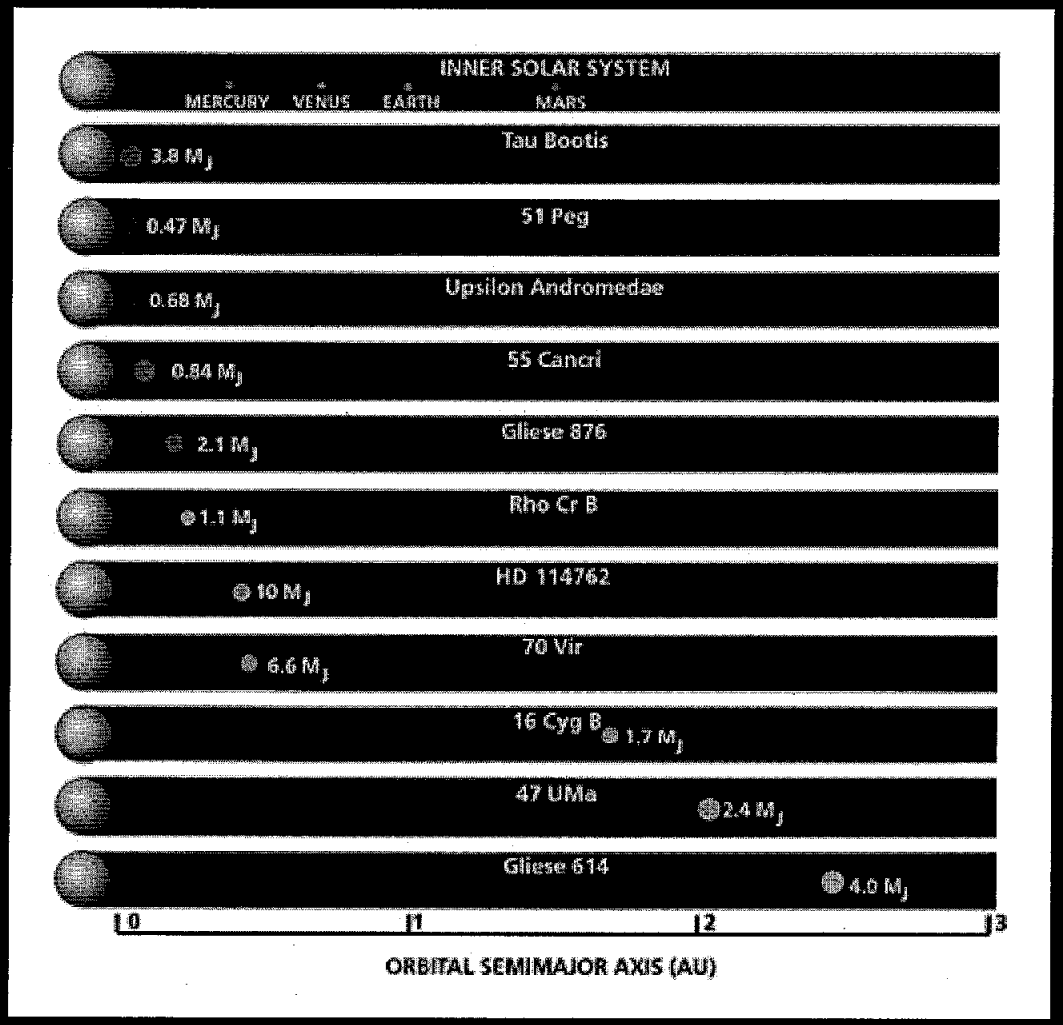
Light from a distant star is bent and focused by gravity as a planet passes between the star and Earth.



Suitable Parent Stars

- To be a suitable "parent" a star must
  - live long enough for planets to form and life to evolve
    - stars 1.5$M_\odot$ (O,B,A) age too quickly
  - Be sufficiently luminous and stable that they don't tidally lock a "warm" planet
    - stars 0.5$M_\odot$ (M) will tidally lock
- Therefore we search for planets around F, G and K stars (yellow to orange)

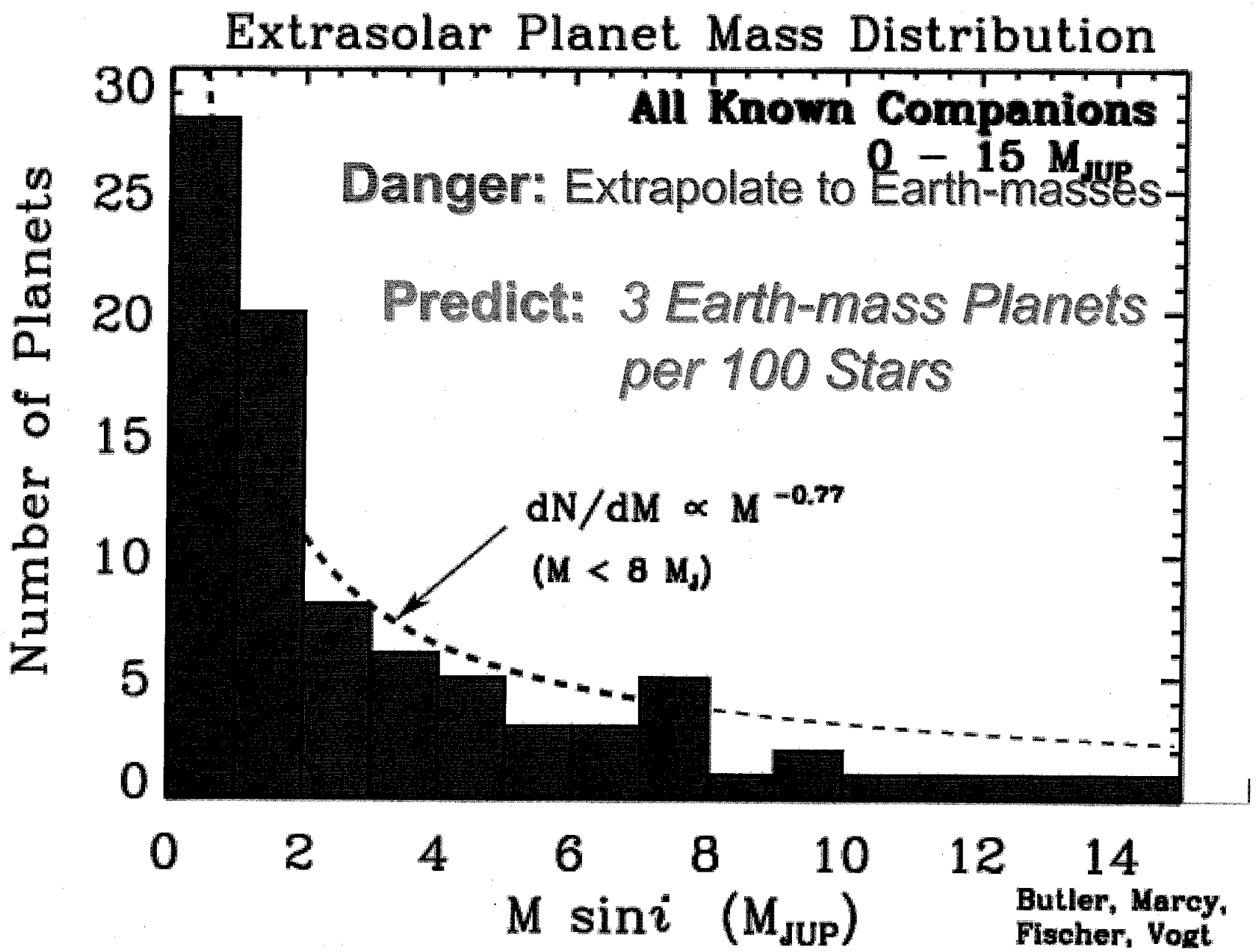
A Multitude of Worlds



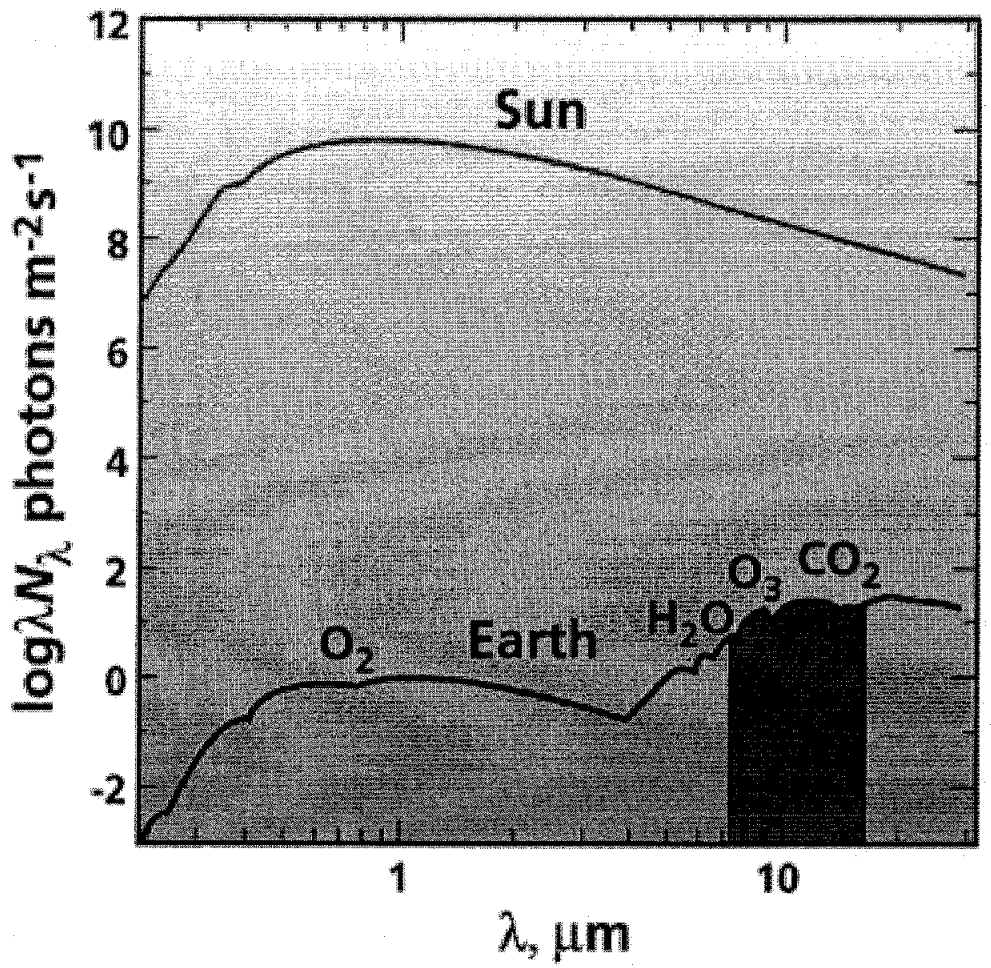
- 101 Planets
- 87 Planetary Systems
- 11 Multiple Star Systems

Bigger Isn't *Always* Better

- These planets are "giant planets"
  - smallest found so far is about the size of Neptune (0.12 M_J)
  - 12% of stars surveyed have giant planets
- Small, rocky, Earth-like terrestrial planets around "friendly" stars still elude us


Extrasolar Planet Mass Distribution
All Known Companions
0 – 15 M_JUP
Danger: Extrapolate to Earth-masses
Predict: 3 Earth-mass Planets per 100 Stars
dN/dM ∝ M^-0.77
(M < 8 M_J)
Number of Planets
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14
M sin i (M_JUP)
Butler, Marcy, Fischer, Vogt

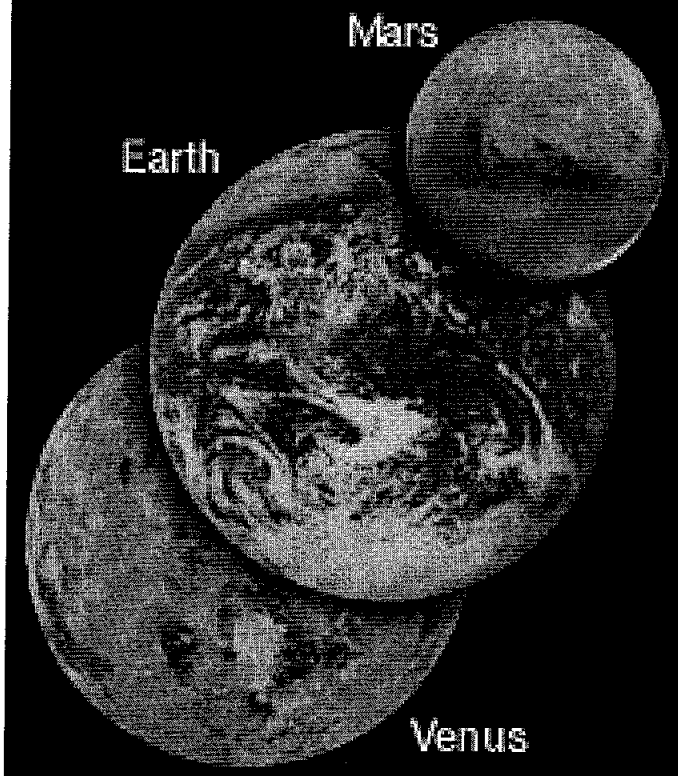
The Search For Earth-Sized Worlds



Direct detection of an Earth-sized planet is *extremely* difficult

- the glare of the parent star is between a million and a billion times brighter than the planet we are looking for!
- We also need very high spatial resolution to separate the planet from its parent star.

Habitable Worlds



- **Location:** the right distance from the central star to maintain liquid water at the surface
- **Planet Mass:** sufficient surface gravity to maintain sufficient atmospheric pressure (but not too much)
- **Atmospheric Composition:** this will affect the reflectivity of the planet, and the climate balance (e.g. the greenhouse effect could warm a planet "on the edge").
- **Circular(ish) Orbits** (e=0.3-0.7)

The Instantaneous Habitable Zone

"The region around a star in which an Earth-like planet could maintain liquid water at some instant in time" (0.93-1.37AU for our Solar System)

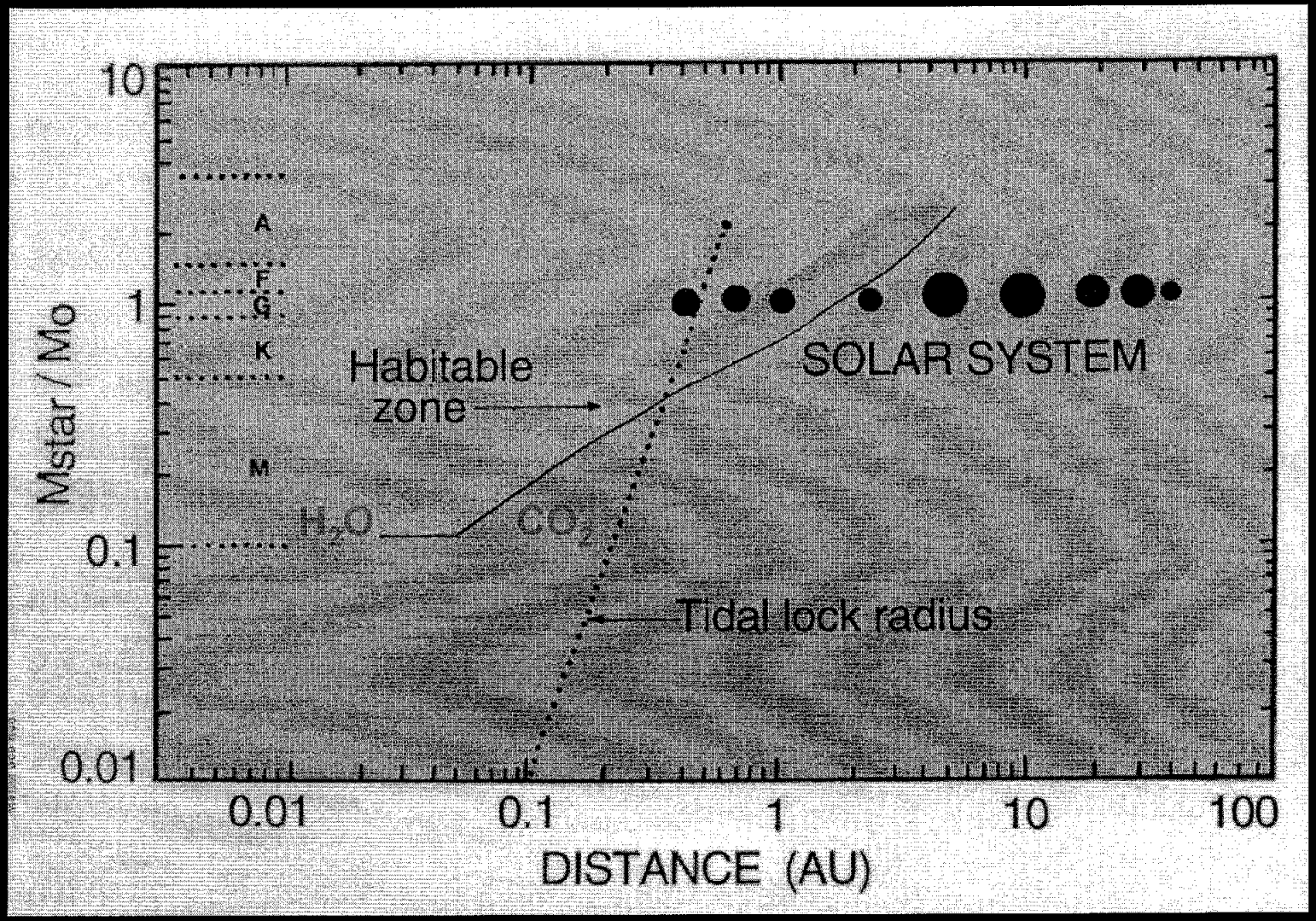


Image courtesy of J.F.Kasting.

After Kasting, Whitmire and Reynolds, 1993

The Continuously Habitable Zone

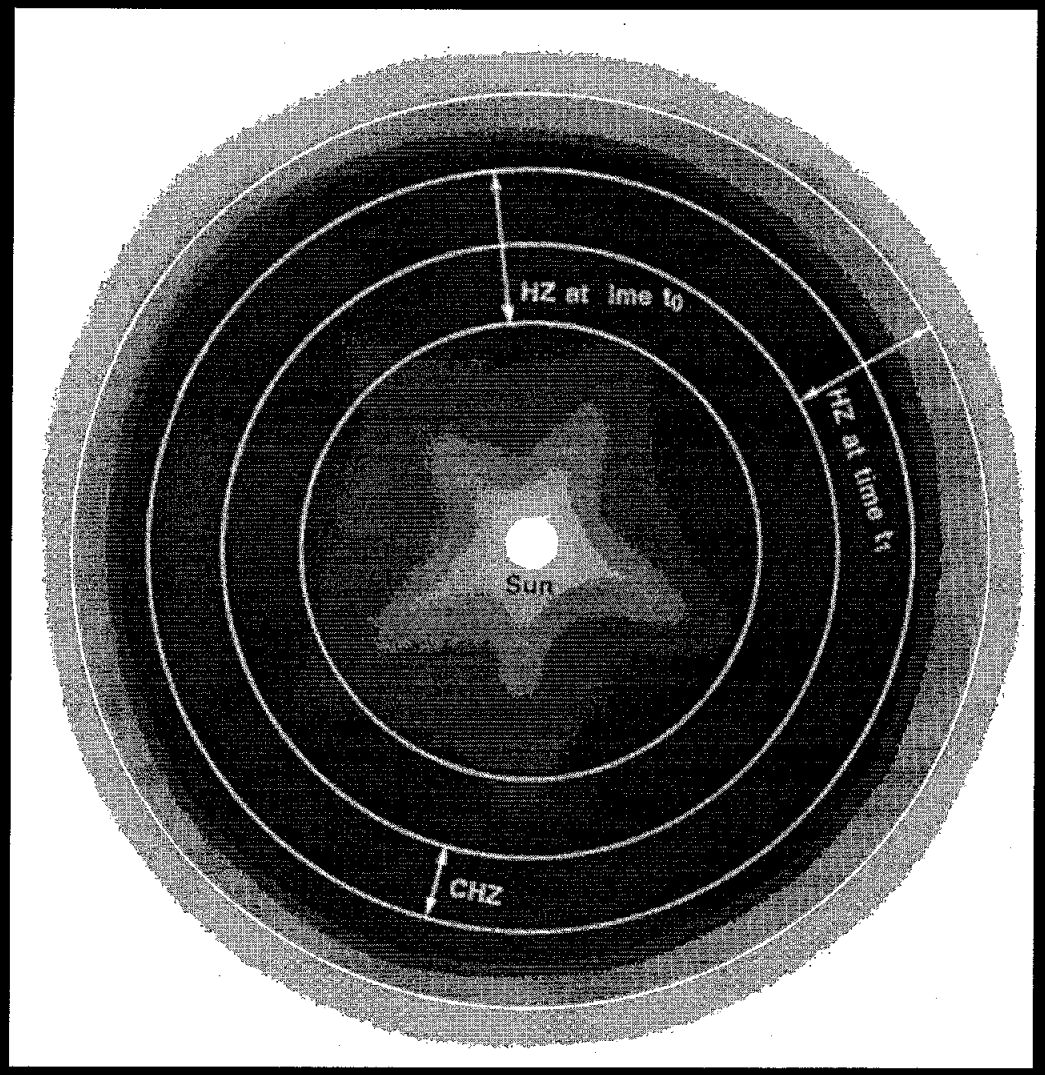
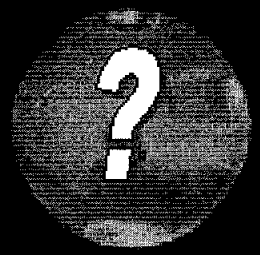


Image courtesy of J.F.Kasting.

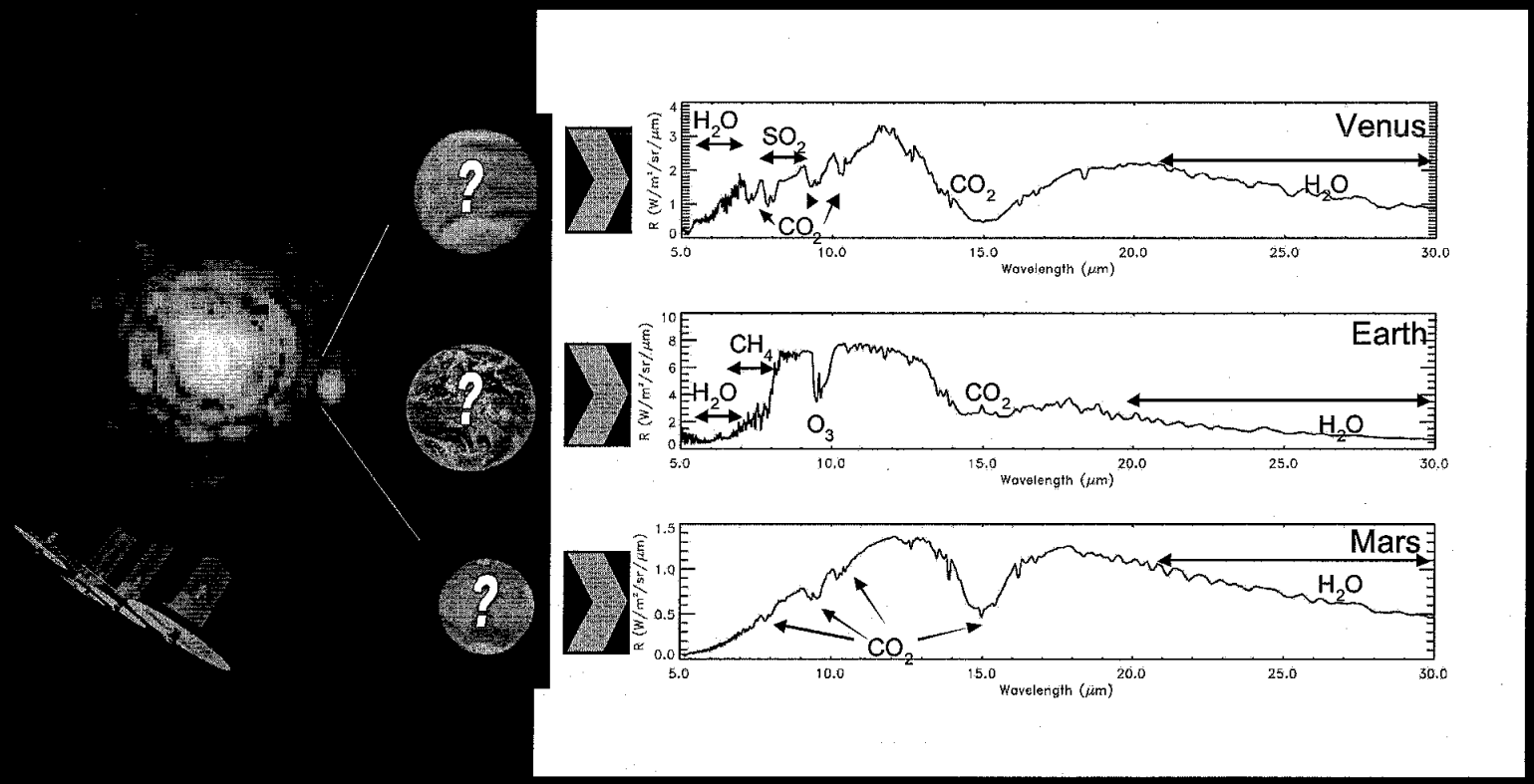
- The region in which a planet could remain habitable for some specified period of time
- Our Solar System has had a CHZ spanning 0.95-1.15AU in the past 4.6 Gy.
- The Sun may become 10% brighter in the next 1.1 Gy, so earth may be too hot in another 500-900My!

How Can We Tell If A Planet Is Habitable?



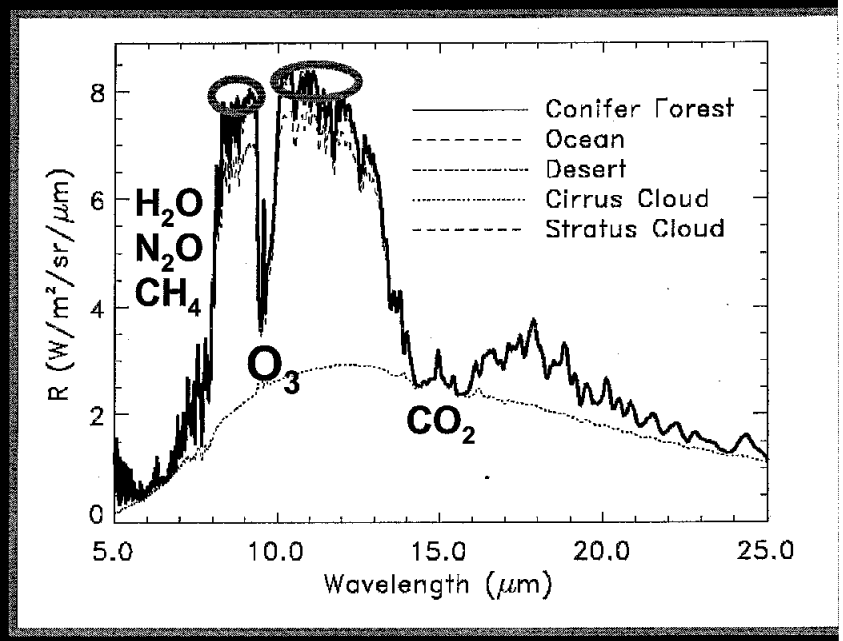
- **Environmental Characteristics**
  - parent star, placement in solar system, other planets
- **Photometric properties and variability**

Recognizing Habitable Worlds

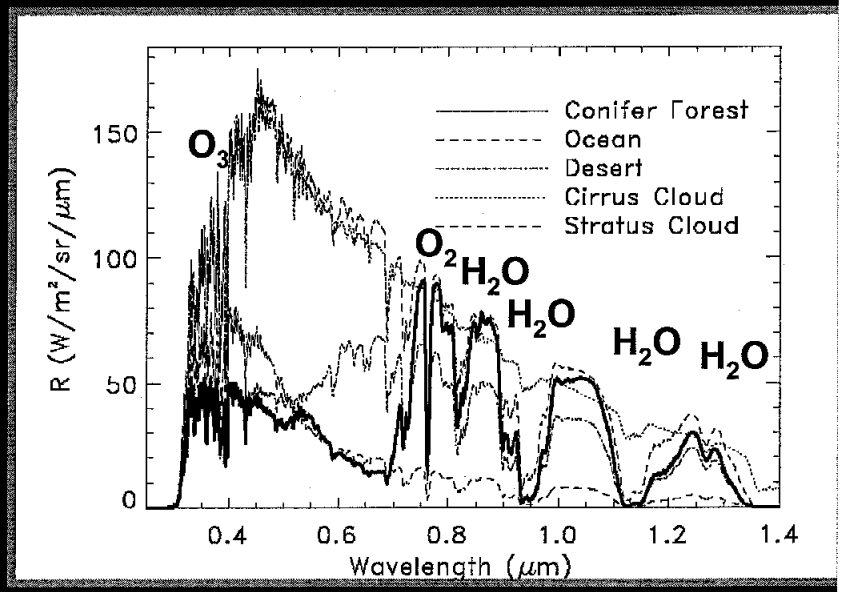


Studying An Earth-Sized Planet

- **Remote-sensing spectroscopy**
  - the presence, composition and physical structure of an atmosphere
  - changes over time, phase and seasonal variations

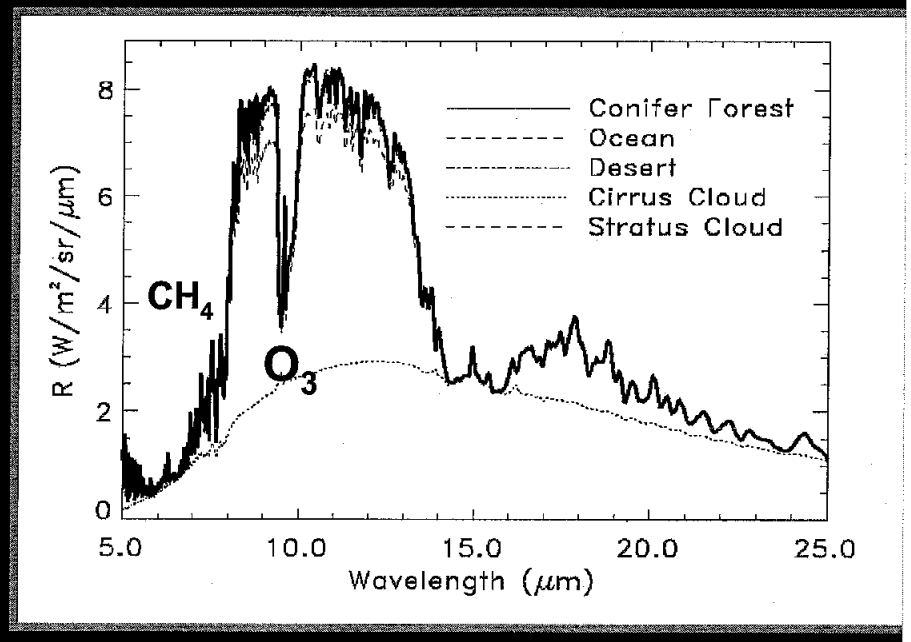


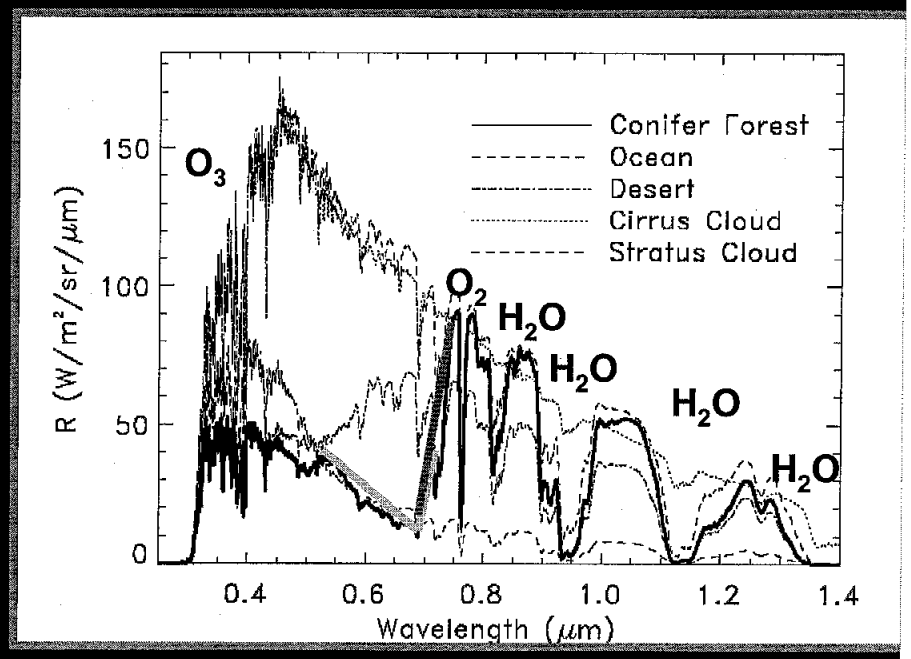
- **Wavelength Choices Affect**
  - which gas signatures are available
  - how far you see into the atmosphere
  - whether clouds get in the way
  - the technology required to make the observation



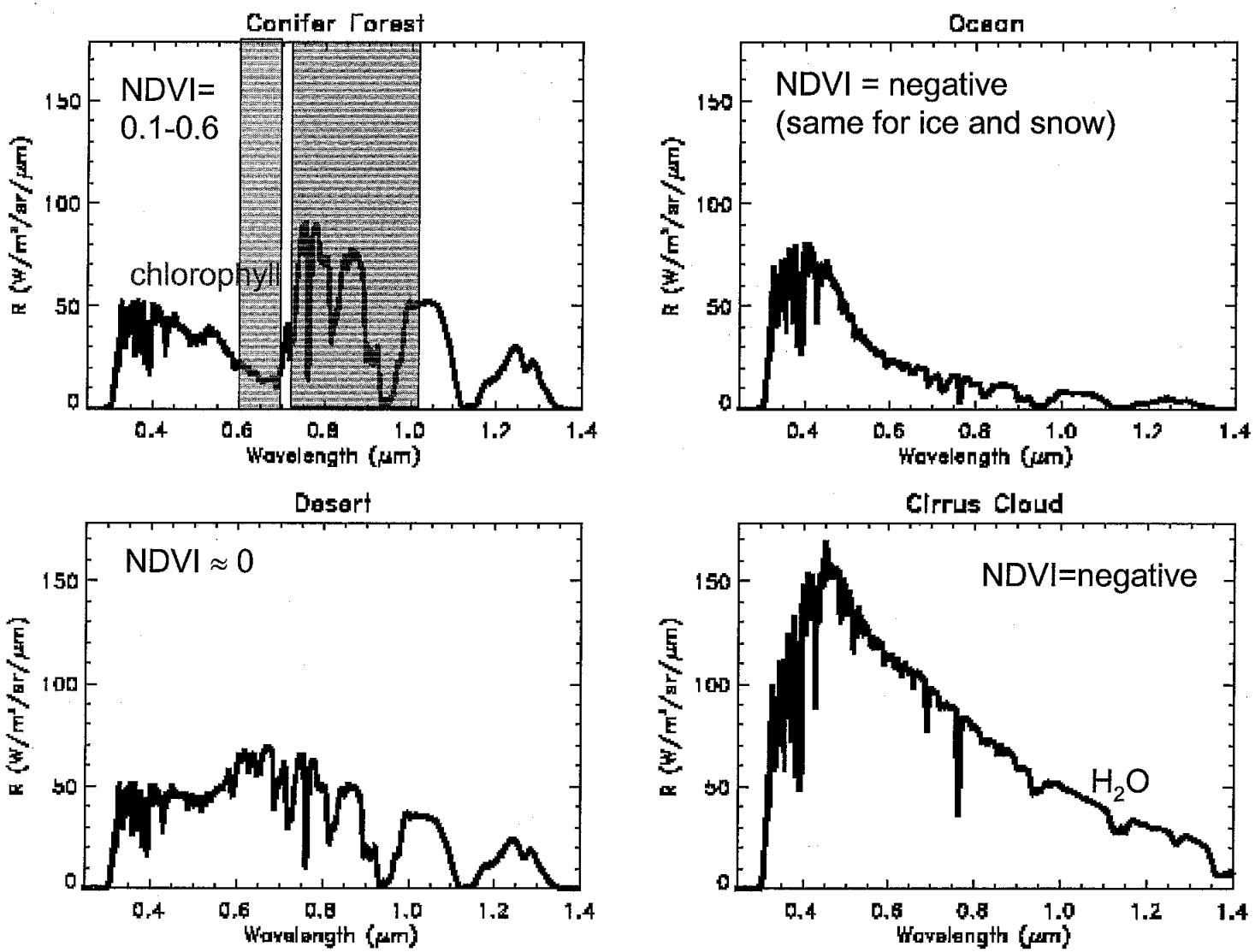
The Signs Of Life

- **Astronomical Biosignatures are** photometric, spectral or temporal features indicative of life
- Widespread life will modify the atmosphere and surface of its planet.
- We may see specific gases, or signs of chemical disequilibrium in the atmosphere that were produced by life:
  - **The Mid-IR** O_3 (sensitive indicator of O_2), CH_4 and N_2O (H_2O - habitability)
  - **The visible (and NIR):** O_2 (direct detection), O_3(UV), CH_4, H_2O
- Sometimes life itself may have a specific surface signature
  - chlorophyll and the red edge

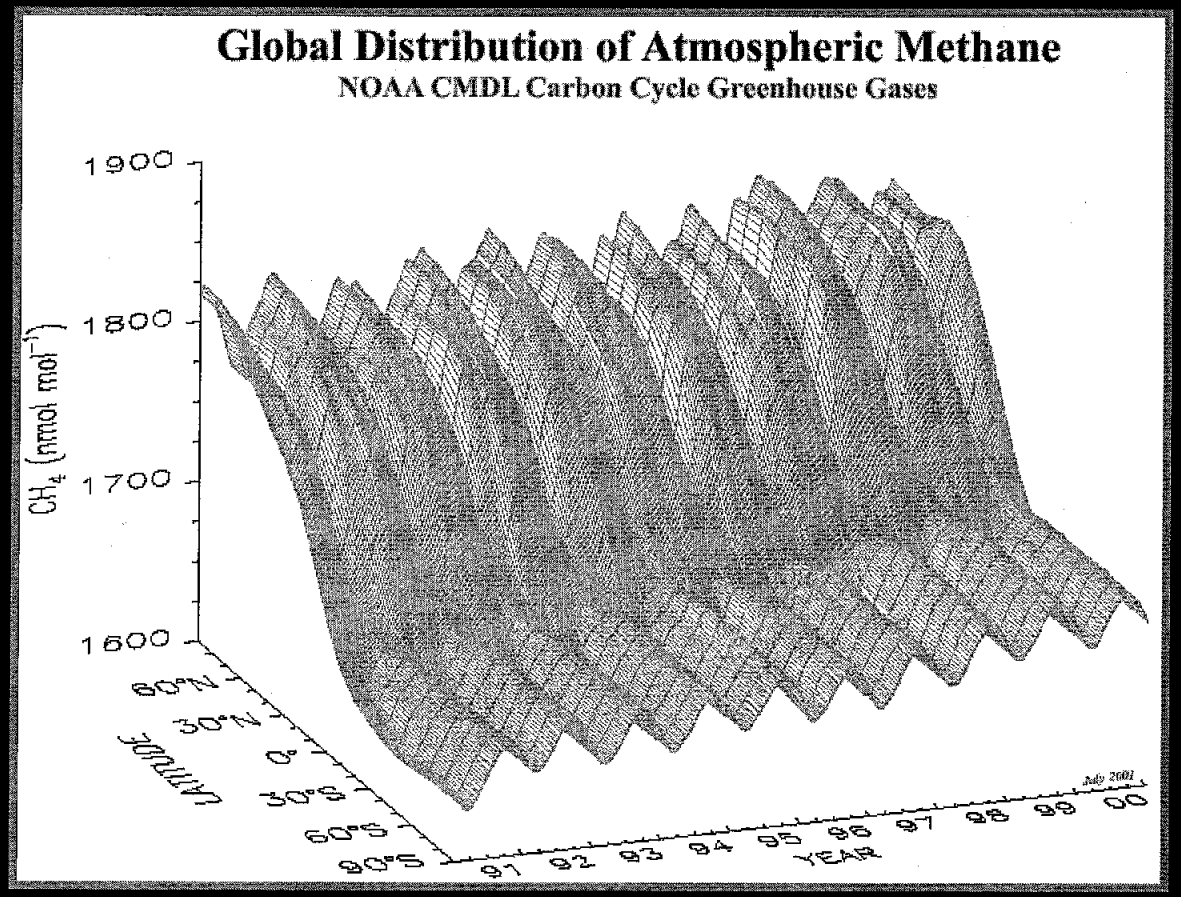




Surface Sensitivity



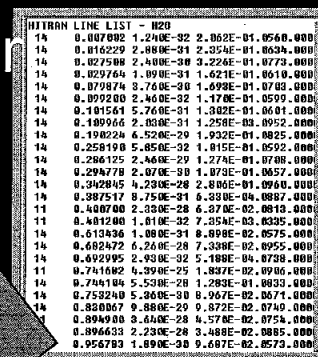
Temporal Signs of Life

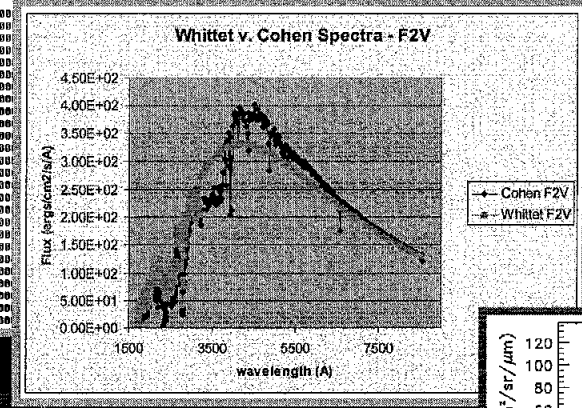


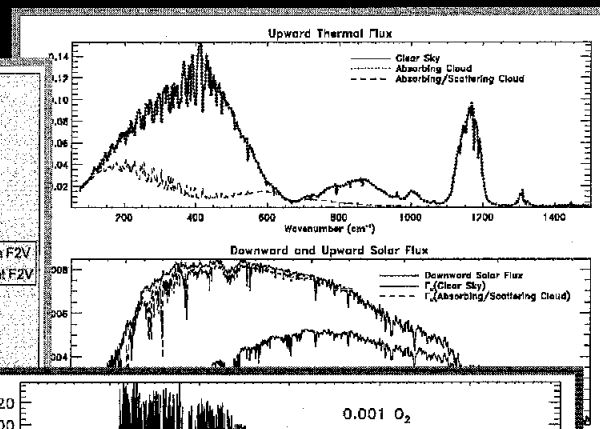
- This could be time-varying gas or surface signatures

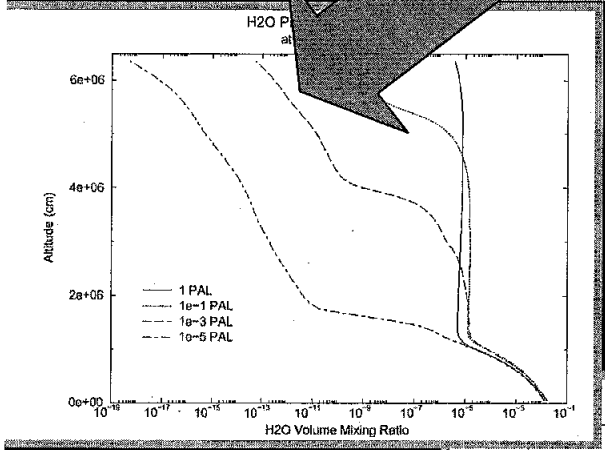
How To Build An Alien World

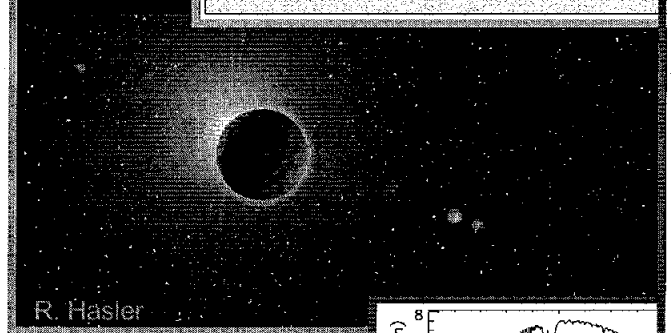
1. Inputs: Stellar spectra and constituent line lists

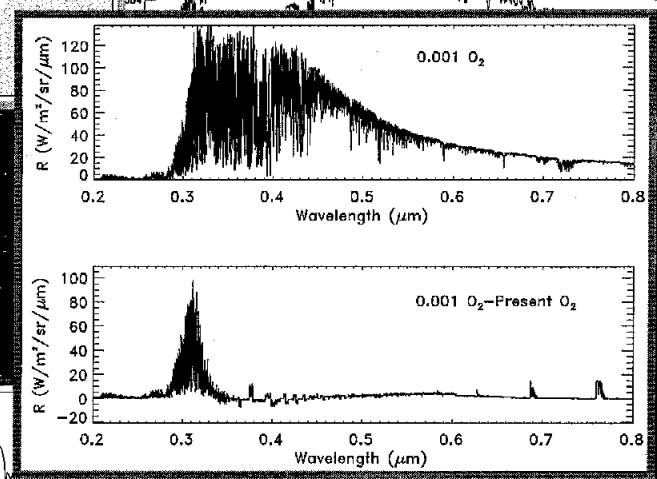




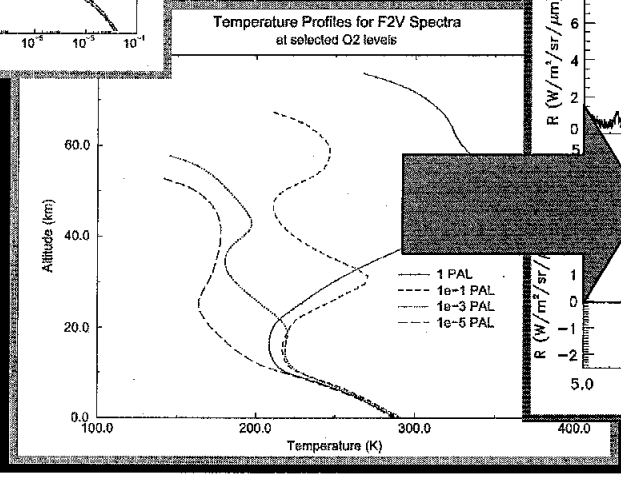


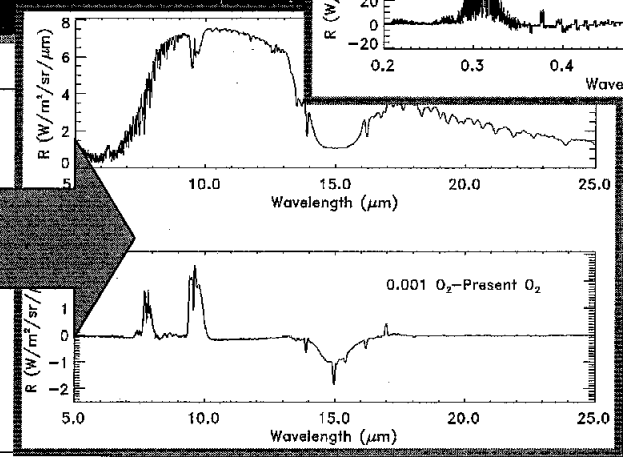




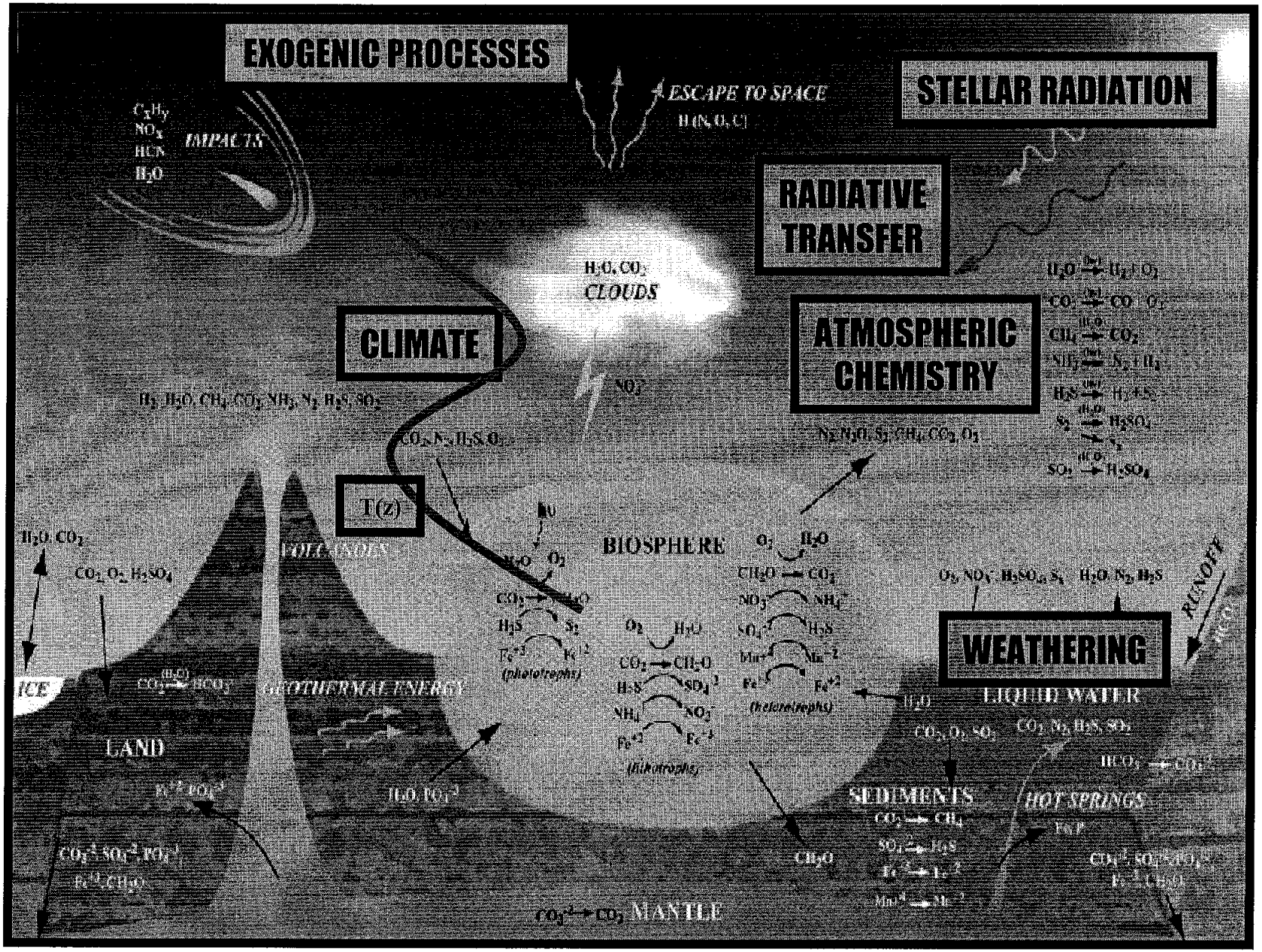


2. Climate-Chemical Model. T, Constituent distribution.





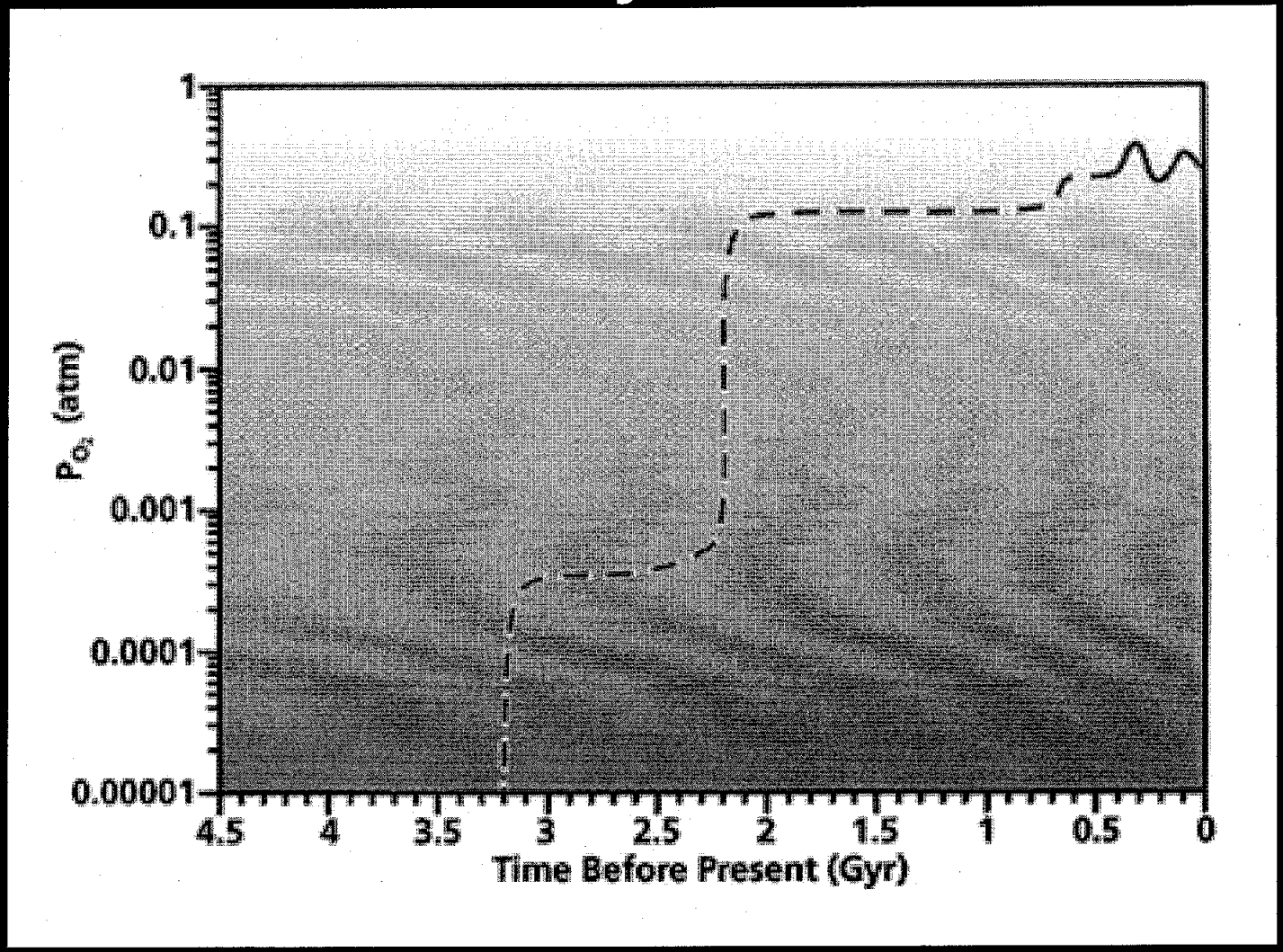
3. Radiative Transfer Model: Planetary Spectra



M. Allen, K. Nealson, V. Meadows

A planet's spectrum is the product of a complex interplay of environmental components and processes.

The Family of Earths

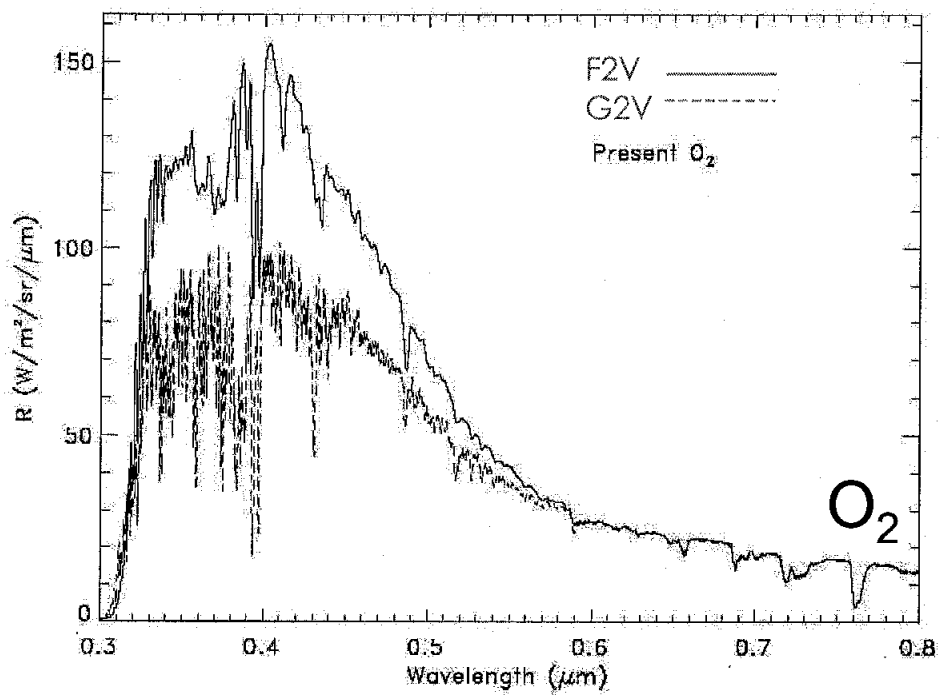


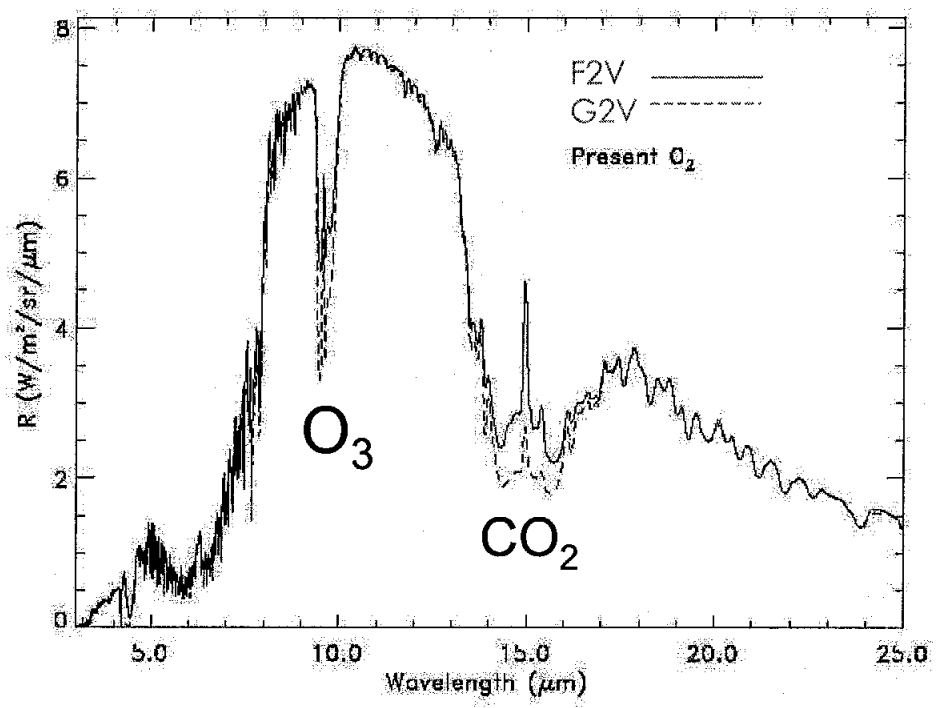
- **The oxygen content of the Earth's atmosphere has significantly changed over 4.6 billion years.**

The Family of Earths

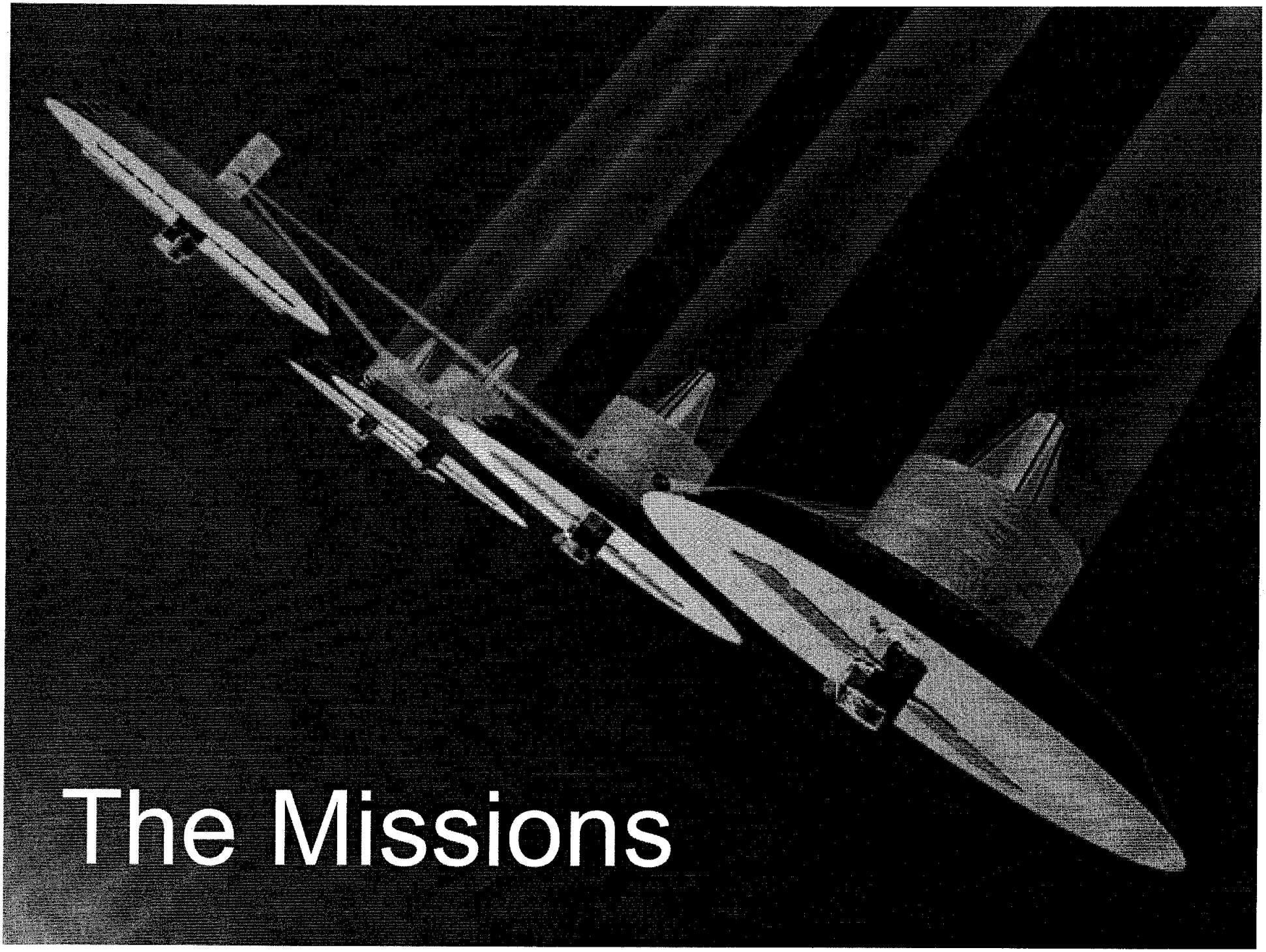
- **The Earth has undergone many changes and would have many very different characteristics at different times!**
- 4.6-4.5Gya - Moon forming impact
- 4.5-3.8Gya - Cooling earth, development of rocky crust, lots of impacts!
- 3.8-2.5Gya - widespread anaerobic life, CO_2, CH_4, development of oxygen producing life, rise of oxygen
- **2.5-2.0Gya** - further oxygenation, haematite, O_3, photosynthesis prospered, anaerobes died, snowball Earth, buildup of CO_2, "Acidic Hothouse"
- **2.0-1.0 Gya** - multicellular life forms (fungi, plants, microbes).
- **1.0-0.5 Gya** - high climate variability, continent breakup
- **0.5Gya - present** - life moves on land, new surface signatures.

Earths Around Other Stars





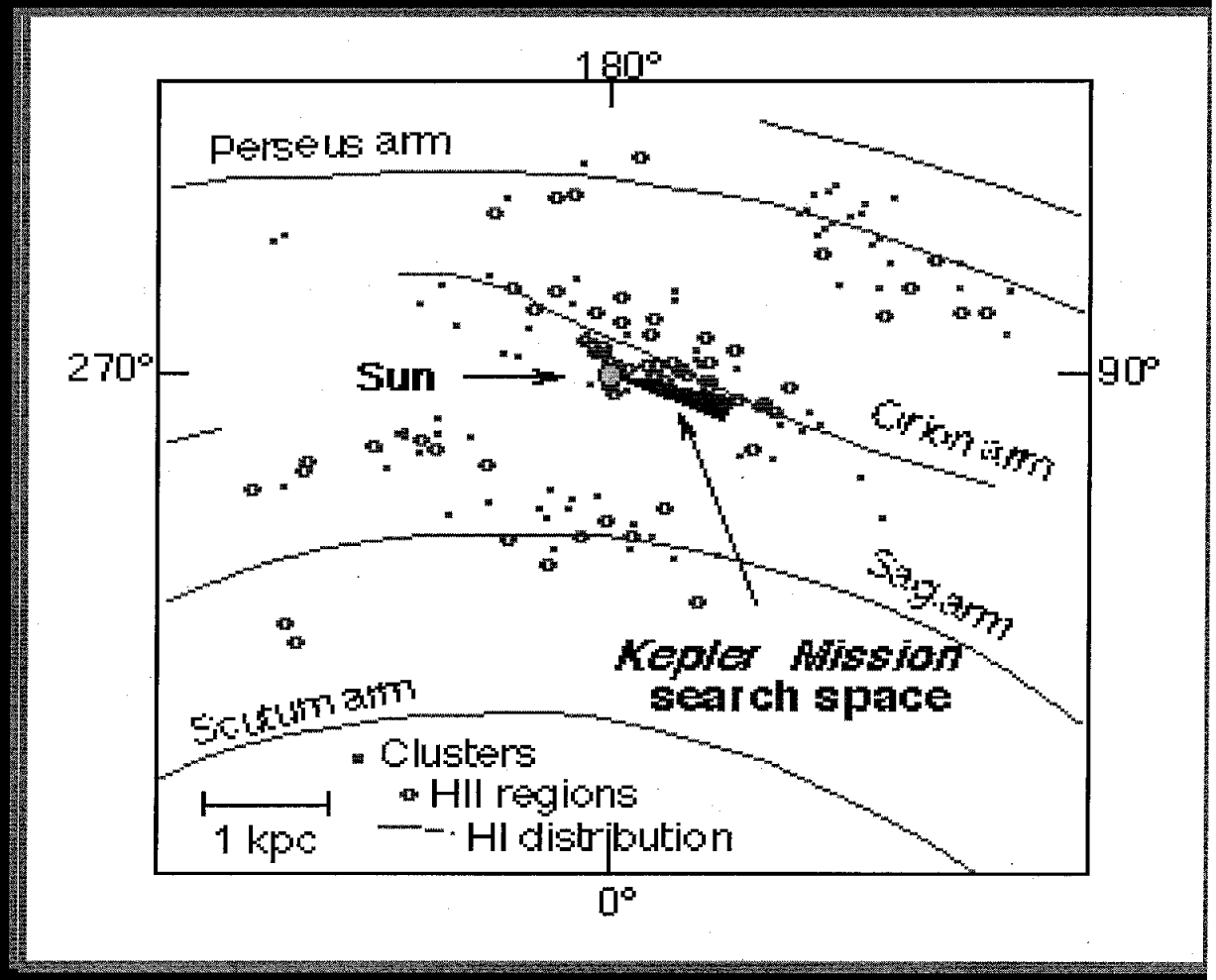
Krelove,Kasting,Cohen,Crisp,Meadows(NAI - VPL)



The Missions

The Kepler Mission

- To detect and characterize hundreds of terrestrial and larger planets in or near the habitable zone (large statistical sample)
- Determine the properties of those stars that harbor planetary systems.
- Estimate the frequency and orbital distribution of planets in multiple-stellar systems

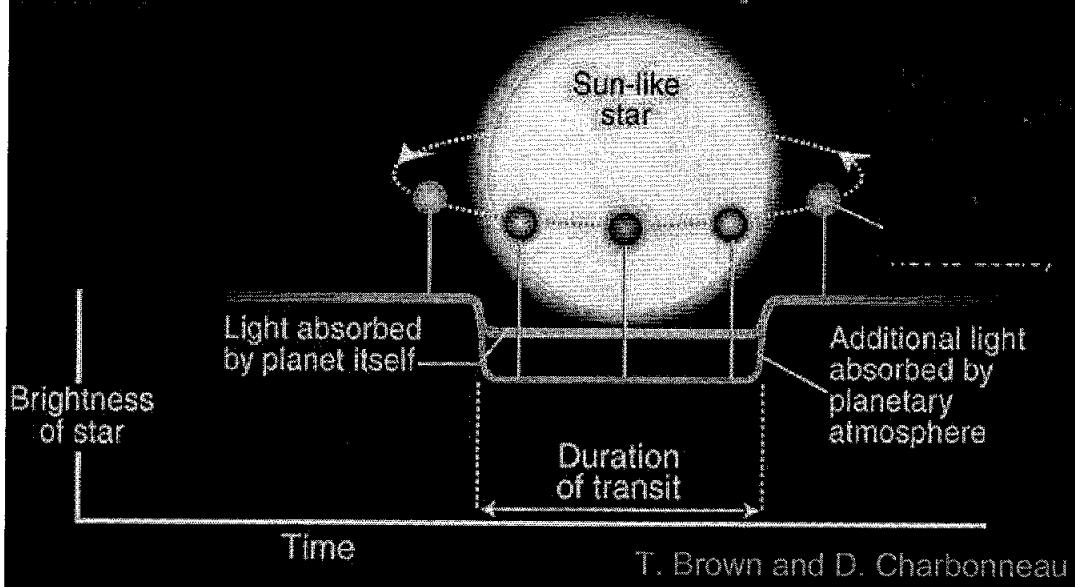


The Kepler Mission

Kepler measures repetitive stellar brightness changes of ~100 parts per million, lasting for 2-16 hours caused by transiting terrestrial planets.
Monitoring 100,000 stars for 4 years!

Launch 2007

Transit Telescope



T. Brown and D. Charbonneau

- Transit gives planet size and orbital period

The Terrestrial Planet Finder Mission

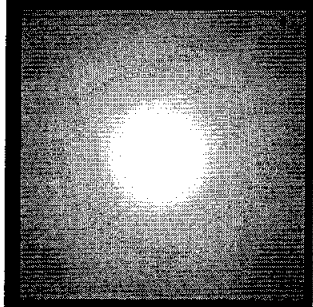
- **Goal: Direct detection and characterization of Earth-sized planets in their habitable zones.**
  - Are there nearby Earth-like planets?
    - Search 150 stars up to 45 light years away
  - Do they have atmospheres?
  - Is there any sign of life?
  - How to planets form?

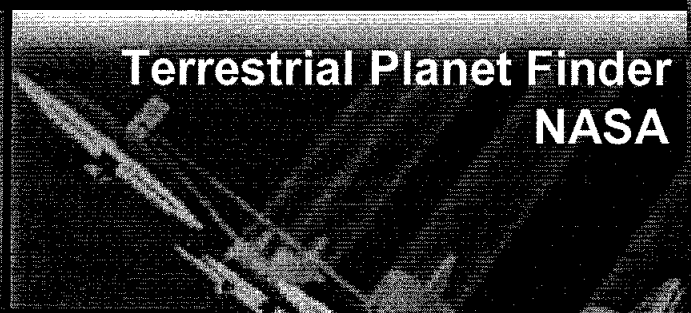
Table 6.1. Time Requirements For Various Configurations of TPF to Observe Terrestrial Planets

Science Goal	12 μm observation of an Earth at 10 pc	4×2 m (5 AU)	4×0.85 m (1 AU)	4×2 m (1 AU)	4×2.7 m (1 AU)	4×3.5 m (1 AU)
Detect Planet	Spectral Resolution R=3 Signal to Noise SNR=5	1.4 hr	470 hr	15.3 hr	5.1 hr	2.0 hr
Detect Atmosphere CO_2, H_2O	R=20/SNR=10	2.4 day	–	18.1 day	5.9 day	2.3 day
Habitable? Life? O_3,CH_4	R=20/SNR=25	15.0 day	–	–	–	14.7 day

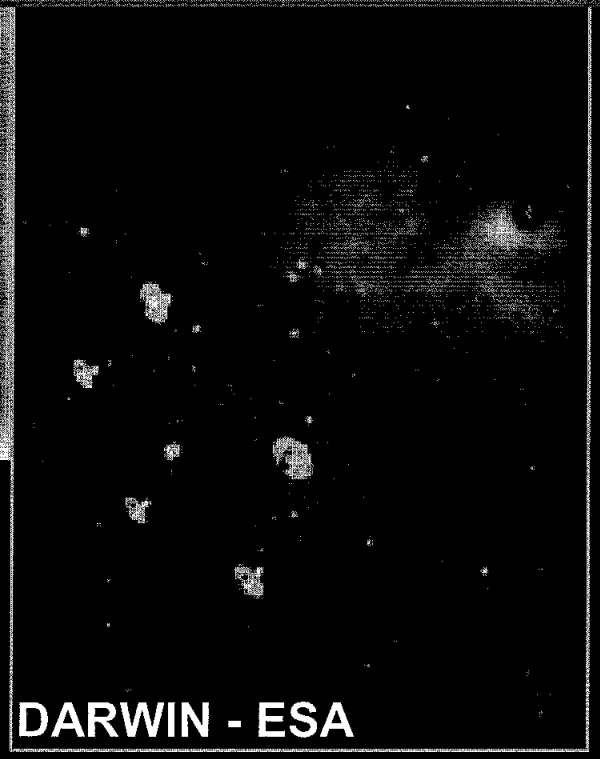
Terrestrial Planet Finders

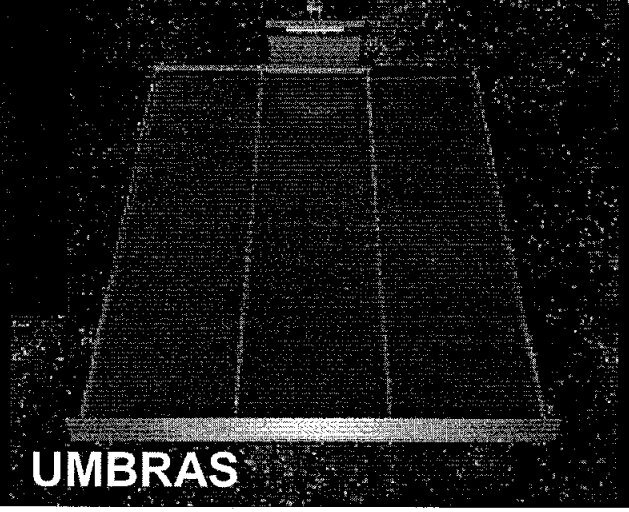
Nulling Interferometers





Direct detection of planets
Launch 2011-2015

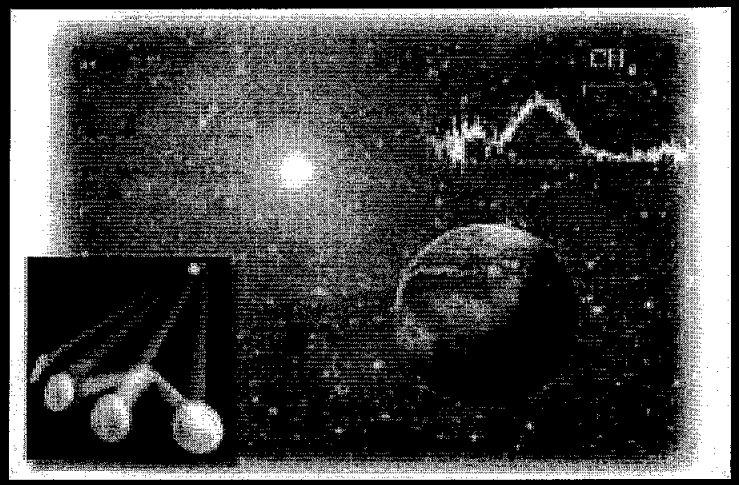


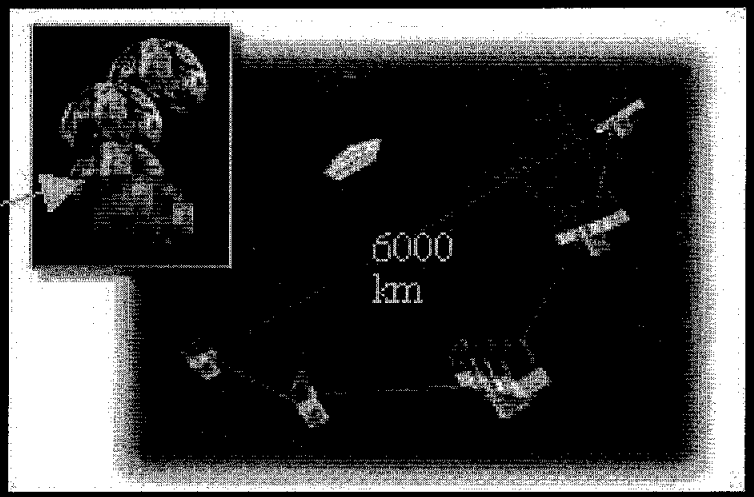


Coronagraphs

Life Finder and Planet Imager

- Life Finder (NASA)
  - chemical signatures of life
- Planet Imager (NASA)
  - spatial resolution on the disk of a planet a few light years away

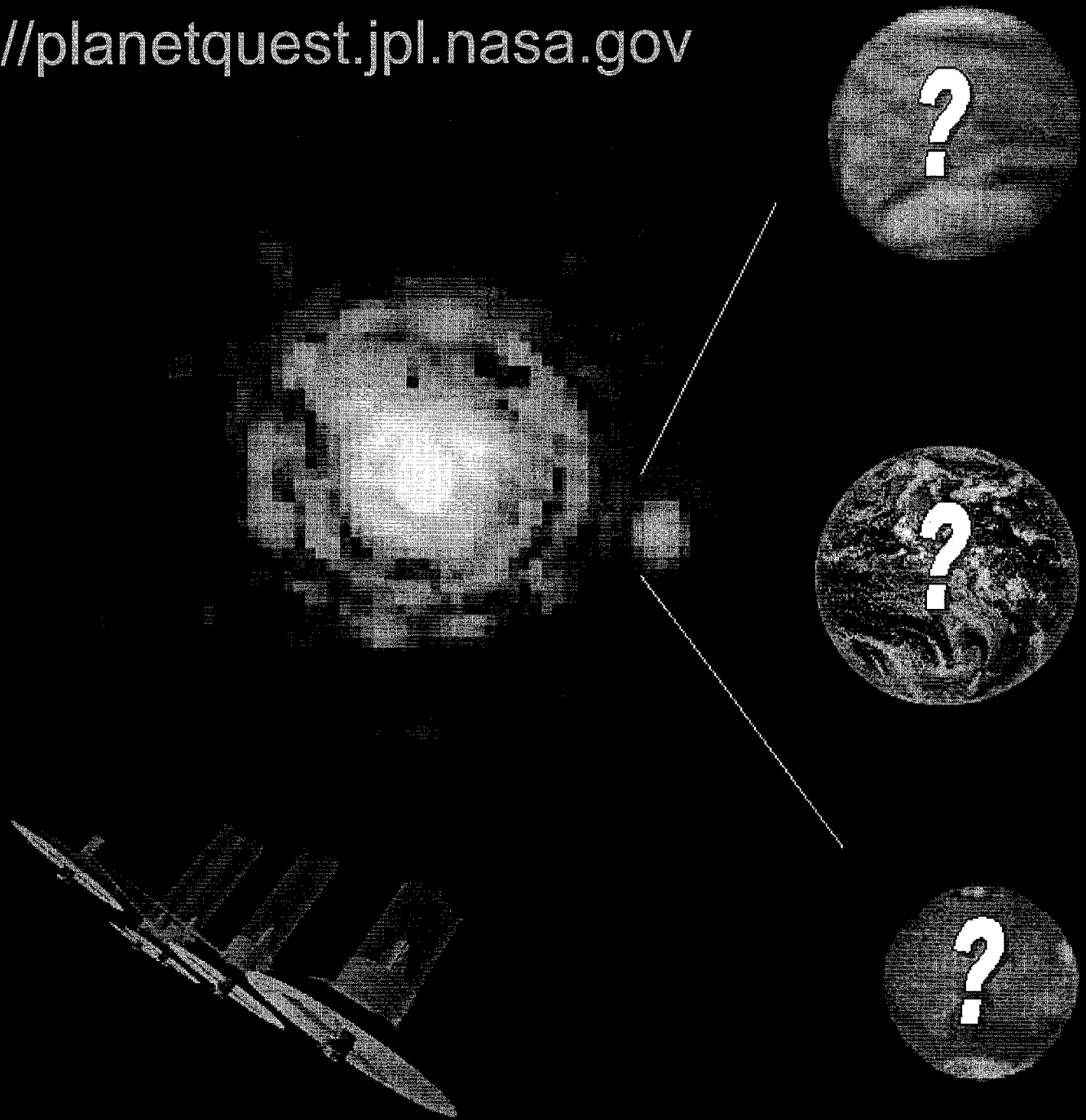


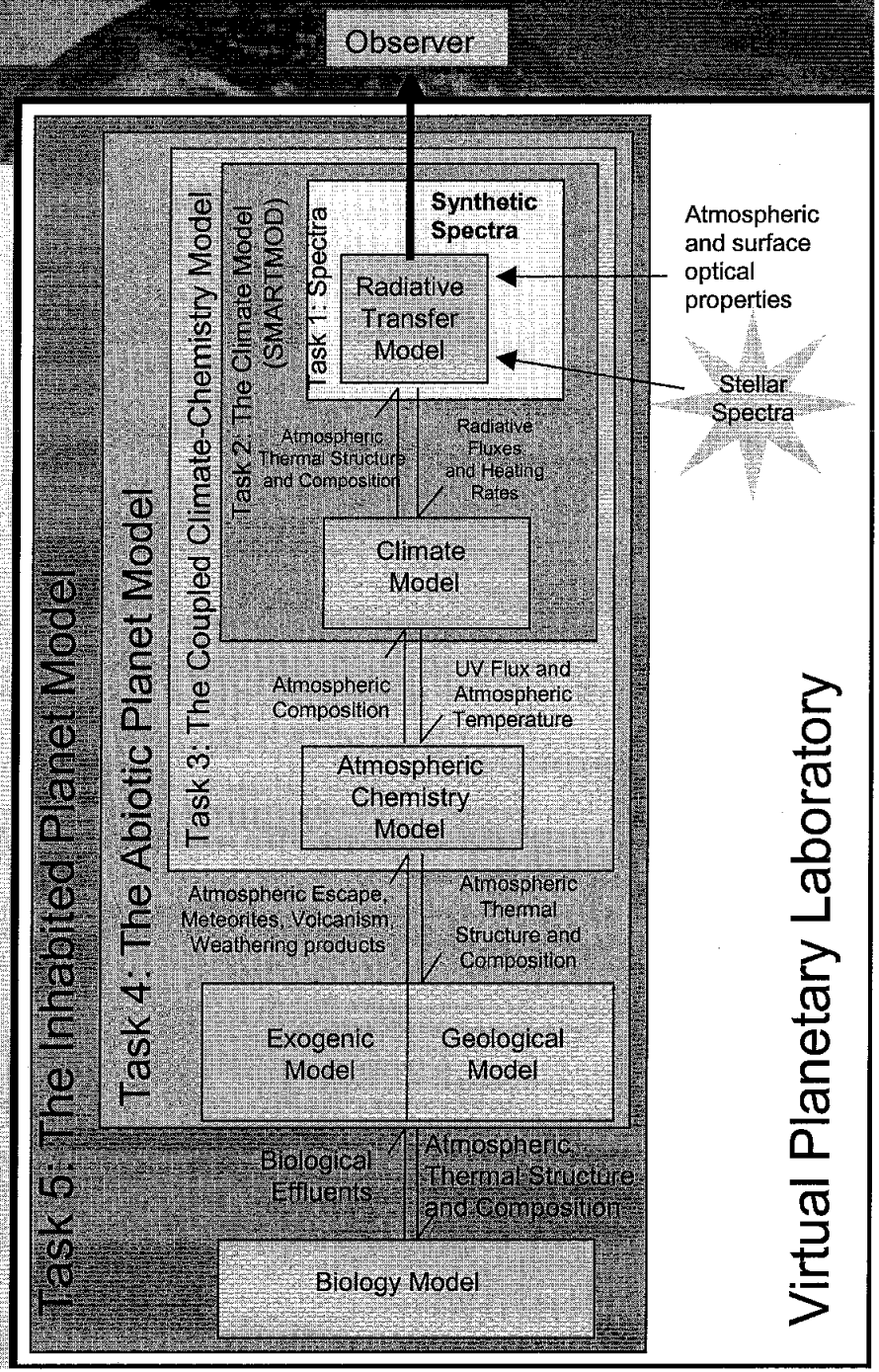


Are there any more habitable or inhabited worlds out there?

G. Chin (GSFC)

http://planetquest.jpl.nasa.gov



THE VIRTUAL PLANETARY LABORATORY

- Couples existing state-of-the-art atmospheric models to produce a model that generates self-consistent planetary atmospheres.
- The VPL will:
  - improve modeling methods, inputs and computational efficiency.
  - cover a broad range of wavelengths
  - consider planets other than Earth, around stars other than our Sun.
  - include non-oxygen producing life
  - ultimately provide a comprehensive, ***flexible*** tool which can be used by a broader community.