„Frontiers of extragalactic astrophysics“

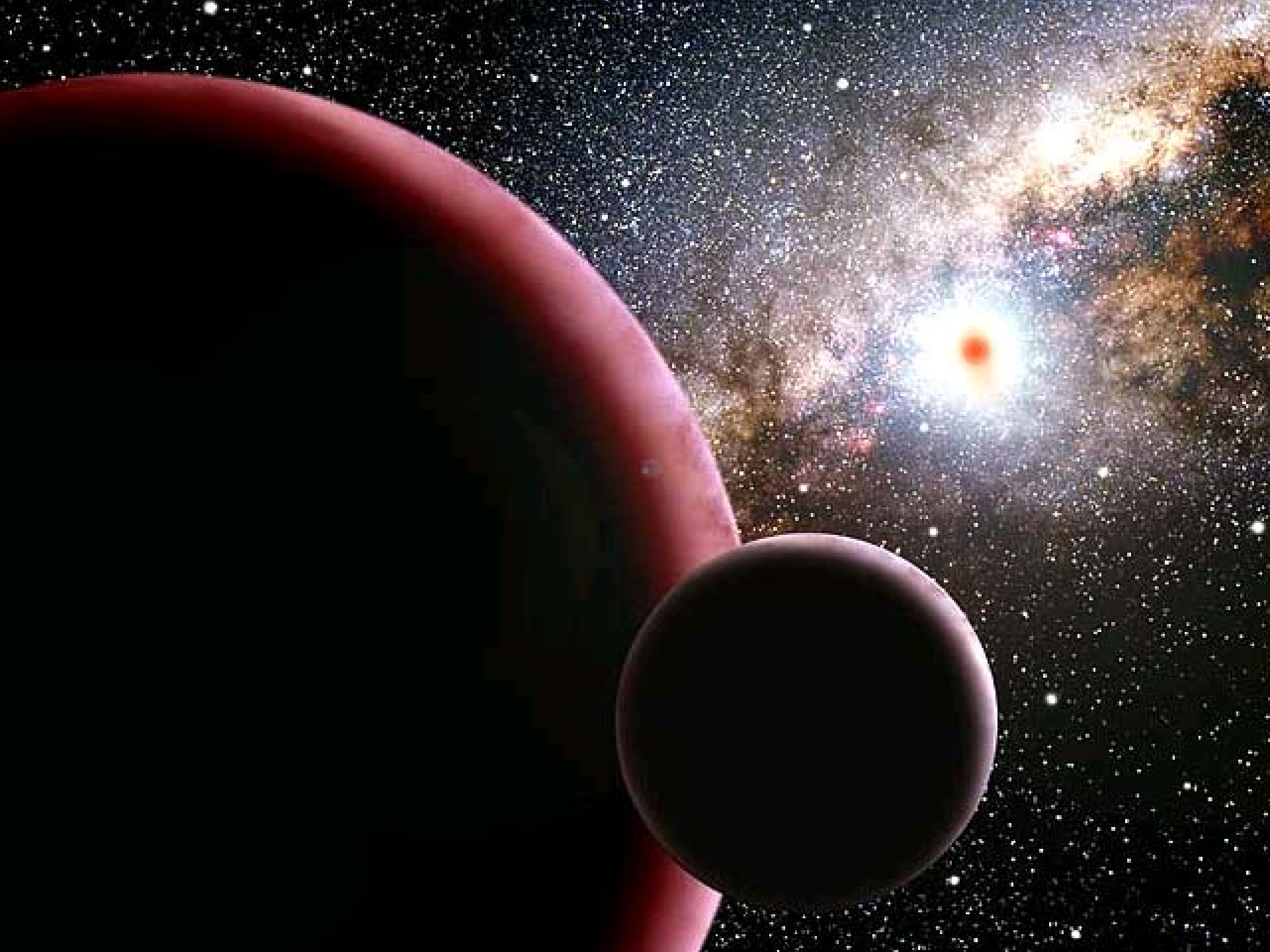
SoSe 2009

Silke Britzen
Max-Planck-Institut für Radioastronomie
Bonn

Tel.: 0228 525 280
E-mail: sbritzen@mpifr-bonn.mpg.de
Internet: http://www.mpifr-bonn.mpg.de/staff/sbritzen/

Programm SoSe 09

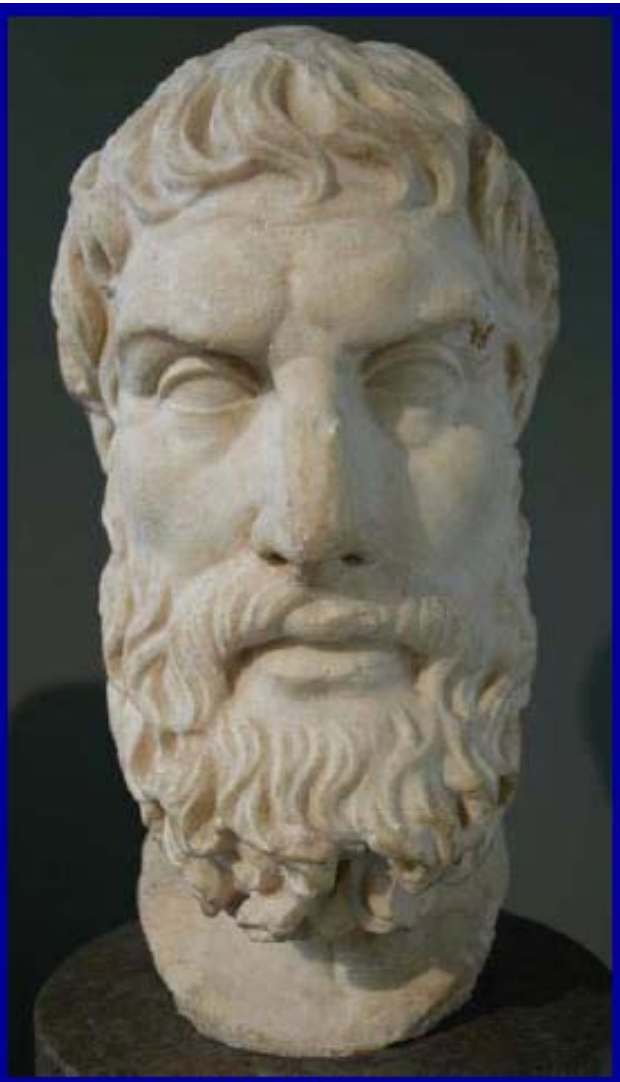
03.04.	Überblick über die Themen des Semesters
17.04.	Die Konstanz der Naturkonstanten
08.05.	Aus aktuellem Anlass: Planck & Herschel
22.05.	Äquivalenzprinzip & Schleifen-Quantengravitation
05.06.	Zeit & Zeitreisen
19.06.	**Gibt es Extraterrestrisches Leben?**



Heute:

- SETI
- Die Suche nach Exo-Planeten
- Die neuen Riesen-Interferometer
- Corot
- Kepler
- Darwin
- Hyperteleskope

Früher ….

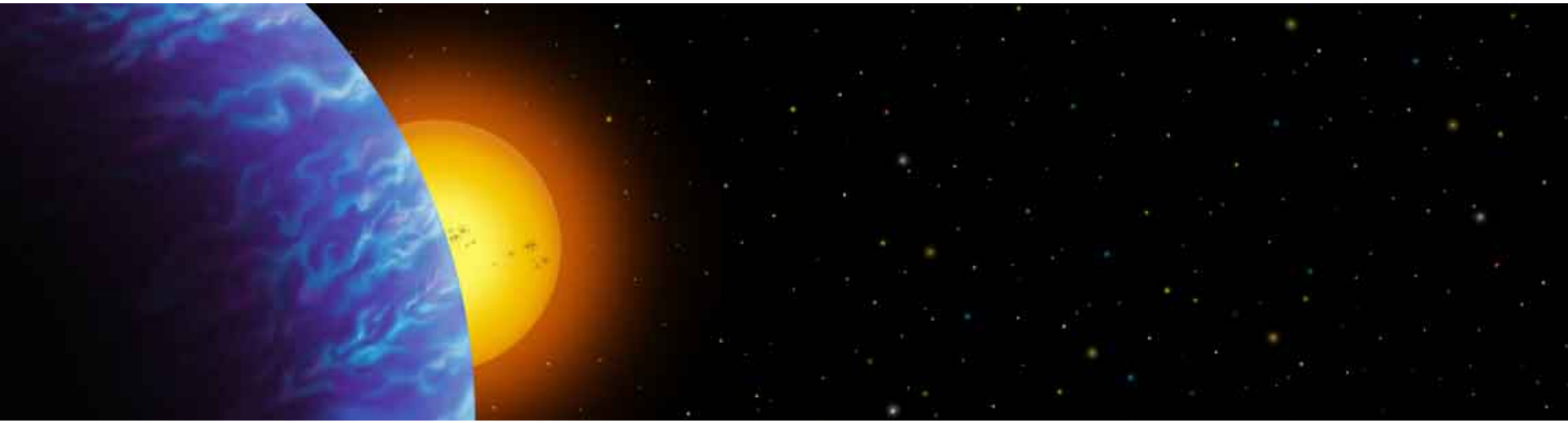


Ἀλλὰ μὴν καὶ κόσμοι ἄπειροί εἰσιν, οἵ θ' ὅμοιοι τούτῳ καὶ ἀνόμοιοι.

Moreover, there is an infinite number of worlds, some like this world, others unlike it.

Epicurus, ca. 300 BC

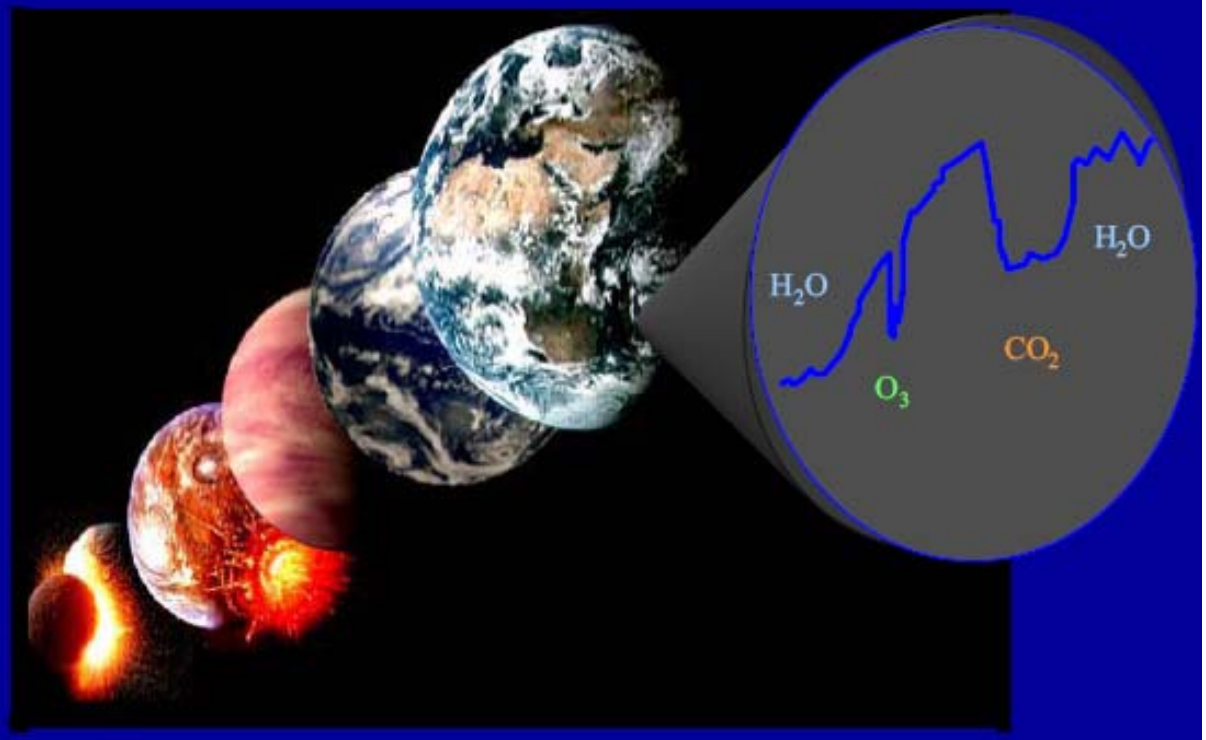
EXOPLANETS



"Innumerable suns exist; innumerable earths revolve around these suns in a manner similar to the way the seven planets revolve around our sun. Living beings inhabit these worlds."

- Giordano Bruno, Italian monk of the sixteenth century

In Zukunft …



European Space Agency, ca. 2020 AD

Was ist Leben?

What Defines a "Living" Organism?

- Encapsulation from environment ("identity")
- Metabolism
  - Use of nutrients
  - Respiration
- Self-replication
  - Capacity to multiply
  - Inheritance (pass on characteristics to offspring)
- Darwinian evolution
  - Ability to adapt to environmental changes

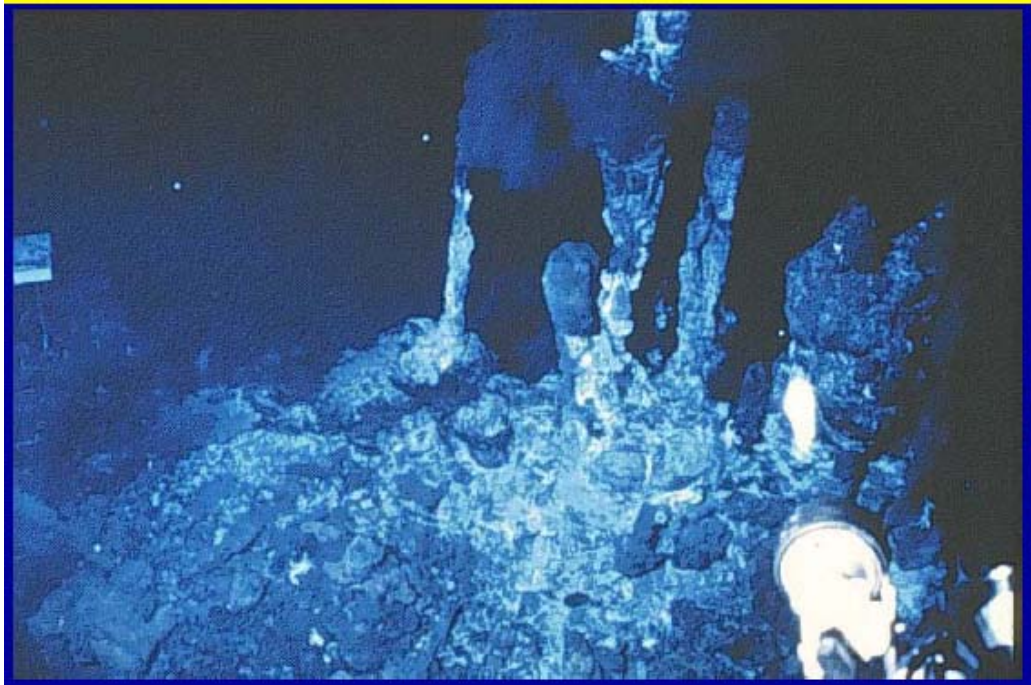
Seit wann gibt es auf der Erde Leben?

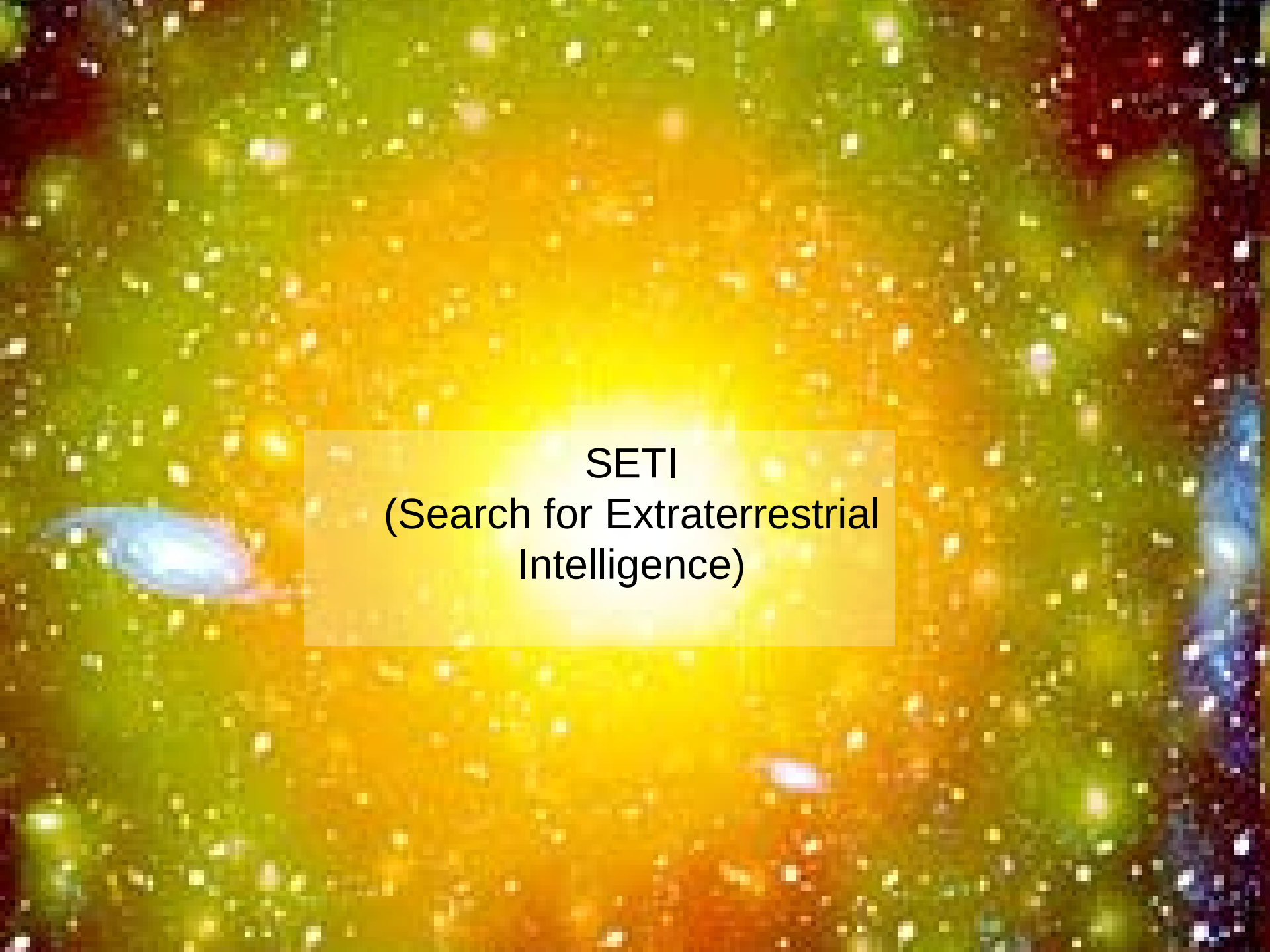
Time Line for Life on Earth (Scaled down to One Day)

- 00:00 The Big Bang
- 16:30 Solar system (including Earth) forms
- 18:15 First micro-fossils
- 20:40 Oxygen in the atmosphere
- 23:00 First multi-cellular organisms
- 23:15 First land animals and land plants
- 23:53 Extinction of the dinosaurs
- 23:59:30 First ancient man
- 23:59:58 Modern man (homo sapiens)
- 23:59:59.98 Pyramids

Auch das ist Leben …

“Black Smoker” on Ocean Floor




SETI
(Search for Extraterrestrial Intelligence)

Wie optimiert man die Suche?

- Wissenschaftler erwarten „Kontakt“ in diesem Millenium (nicht mit Bakterien, sondern intelligentes Leben lokalisieren)
- Wie machen sich „Außerirdische“ bemerkbar?
  - Vermutlich mittels Radiosignale
- Besser zuhören, oder senden?
  - Hören!! Und dann antworten … Sollte man antworten? (Anthropologen fürchten, daß sollten die Außerirdischen reisen können, sie die Menschheit auslöschen wollten, da lebende Kreaturen programmiert sind, ihre Rivalen auszulöschen ….)
  - Wir senden ohnehin seit Jahrzehnten – was werden sie von unserer Intelligenz halten?
- „Absence of evidence wouldn‘t be evidence of absence“
- Wir sind das Ergebnis von Zeit und Zufall: Würde die Evolution nochmal ablaufen, wären da vielleicht keine Menschen … Wir sollten nicht unbedingt „Intelligenz“ auf anderen Planeten erwarten
- Welche Alternativen zu Intelligenz kann es geben?
- ISS: wert das eigene Gewicht in Gold, weder praktisch noch inspirierend … (Sir M. Rees)
- Mondbasis: Versicherungsargument – um flüchten zu können, im Fall eines Asteroideneinschlags
- Hören = SETI
- Suchen = Suche nach Exoplaneten
- Senden = Arecibo Message, ARTE, etc.

Die „Anderen“ verstehen ….

- Gasförmige Lebewesen? Körperlose Intelligenzen?
- Würden wir sie verstehen können?
- Würden sie sich darum bemühen, daß wir sie verstehen können?
- Jahrhundertelanges Forschen um die „Message“ entschlüsseln zu können?
- Vergleich zu „irdischen“ Relikten aus der Vergangenheit, für die wir heute immer noch Zeit brauchen. Wieviel schwieriger wäre es, zukünftiges Wissen zu verstehen?
- „The signal is the message“ (M. McCluhan)

SETI

A picture taken in 1985 when we had a reunion (back row: George Grove, Fred Crews, Omar Bowyer, Frank Drake, Kochu Menon; front row: Bob Viers, Dewey Ross, Bill Meredith, Troy Henderson, Bob Uphoff).

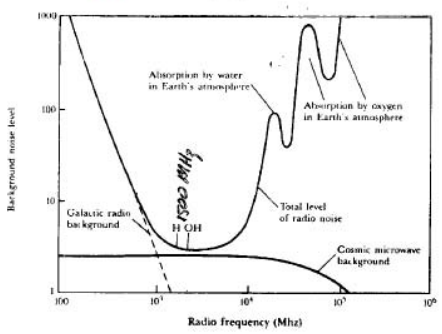
Photos courtesy NRAO archives.

SETI

- Arecibo Radioteleskop, 1000 nahe Sternsysteme (200 Lichtjahre)
- Sollte eine Zivilisation in 100 Lichtjahre Distanz eine Antenne von Arecibo-Größe besitzen und senden, dann wäre ein 10 Kilowatt-Sender genügend um unsere Aufmerksamkeit zu erreichen

SETI : Search for ExtraTerrestrial Intelligence

- **Einzige realistische Möglichkeit ET zu finden ist über Radiofrequenzen**
  - Radio läuft mit Lichtgeschwindigkeit über die ganze Galaxie
  - geringer Energiebedarf
  - wir haben bereits die Fähigkeit, über die ganze Galaxis zu empfangen und zu senden (die Erde ist mittlerweile ein stärkerer Radioemitter als die Sonne)
- **Wie sollten wir hören?**
  - relativ ruhige Frequenzen, geringe interstellare Absorption
  - ⇨ sogenanntes "water hole"
- **Wonach sollten wir hören?**
  - komplexe Signale auf regulärem Trägersignal



SETI

- **Our Mission**
- **The mission of the SETI Institute is to explore, understand and explain the origin, nature and prevalence of life in the universe.**
- *We believe we are conducting the most profound search in human history — to know our beginnings and our place among the stars.*
- The SETI Institute is a private, nonprofit organization dedicated to scientific research, education and public outreach.
- The Institute comprises 3 centers, the Center for SETI Research, the Carl Sagan Center for the Study of Life in the Universe and the Center for Education and Public Outreach.
- Founded in 1984, the Institute today employs over 150 scientists, educators and support staff. Research at the Institute is anchored by two centers. Dr. Jill Tarter leads the Center for SETI (Search for Extraterrestrial Intelligence) Research as Bernard M. Oliver Chair for SETI. Dr. Frank Drake is the Director for the Carl Sagan Center for the Study of Life in the Universe

SETI

Sponsorship

- Institute projects have been sponsored by:
- NASA Ames Research Center
- NASA Headquarters
- National Science Foundation
- Department of Energy
- US Geological Survey
- Jet Propulsion Laboratory (JPL)
- International Astronomical Union
- Argonne National Laboratory
- Alfred P. Sloan Foundation
- David & Lucile Packard Foundation
- Paul G. Allen Foundation
- Gordon and Betty Moore
- Universities Space Research Association (USRA)
- Pacific Science Center
- Foundation for Microbiology
- Sun Microsystems
- Hewlett Packard Company
- William and Rosemary Hewlett
- Bernard M. Oliver
- And many others

SETI

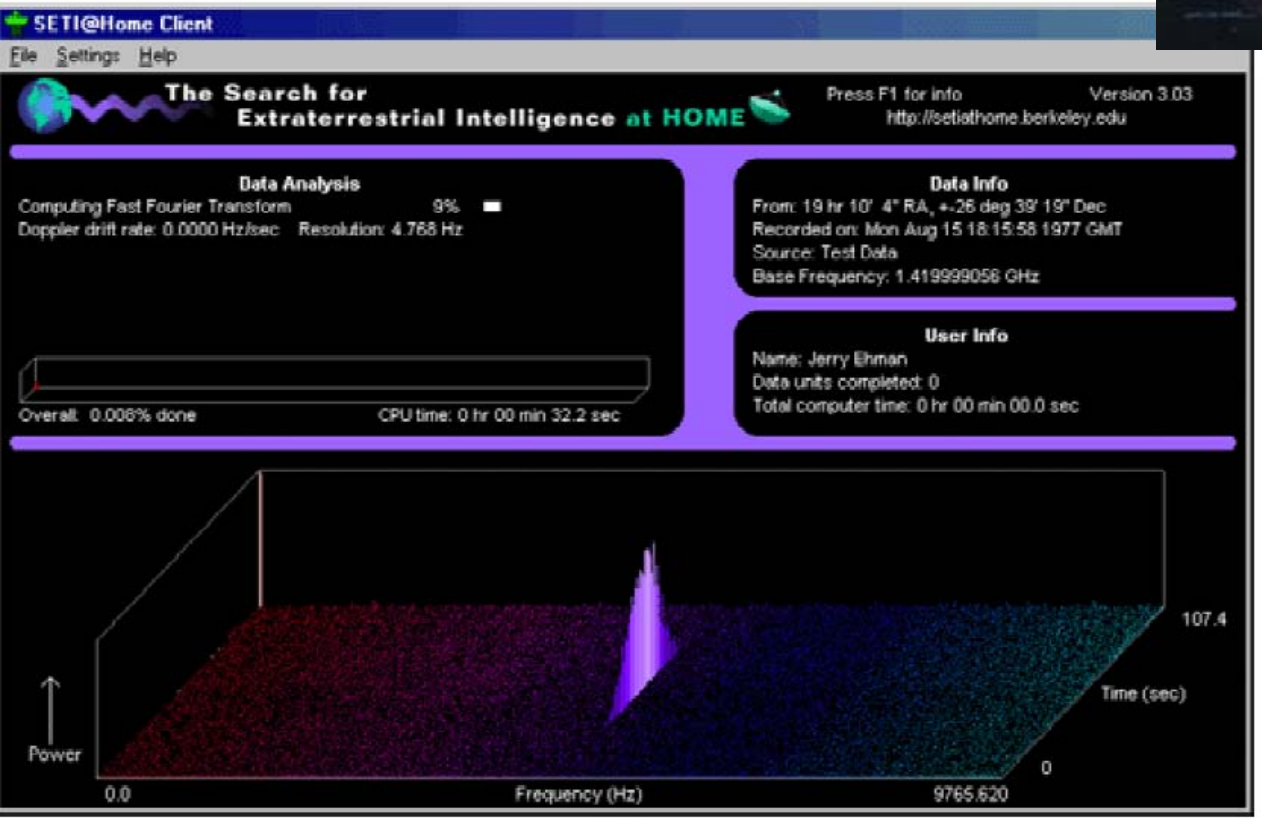
- **Organization Status**
- The SETI Institute is a nonprofit corporation founded in 1984 (California Corporation #1261957). The Institute is a scientific and educational organization governed by the provisions of Section 501(c)(3) of the U.S. Internal Revenue Code, and the Institute's Federal identification number for reporting and tax purposes is 94-2951356.
- All contributions to the Institute will be used to further the goals described above and are deductible to the donor for both State and Federal income tax purposes.

SETI INSTITUTE

ARE WE ALONE? SCIENCE RADIO FOR THINKING SPECIES

Am 22.05.09 10 Jahre; 5 Mio Freiwillige in 226 Ländern haben 3 Mio Jahre an Computerzeit zur Verfügung gestellt

SETI@home



Verschiedene Pulse:

- ET
- Pulsare
- Explodierende Priomordiale Schwarze Löcher
- Extragalaktische Pulse
- Neue Phänomene

Gemessene Pulse

Master Science Database

Table	**#**	**Last 24 hours**
Spikes	1,112,226,799	1,493,111
Gaussians	319,215,441	179,950
Pulses	534,399,769	718,690
Triplets	506,652,242	468,167
Workunits	610,487,185	400,640
Results	599,446,197	654,442
Overflow** rate	2.8% (inserted during last 10 minutes)	

Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence

(Source: *Acta Astronautica* Vol. 21. No. 2. pp. 153-154, 1990 by Pergamon Press)

Agree to observe the following principles for disseminating information about the detection of extraterrestrial intelligence:

1. Any individual, public or private research institution, or governmental agency that believes it has detected a signal from or other evidence of extraterrestrial intelligence (the discoverer) should seek to verify that the most plausible explanation for the evidence is the existence of extraterrestrial intelligence rather than some other natural phenomenon or anthropogenic phenomenon before making any public announcement. If the evidence cannot be confirmed as indicating the existence of extraterrestrial intelligence, the discoverer may disseminate the information as appropriate to the discovery of any unknown phenomenon.

2. Prior to making a public announcement that evidence of extraterrestrial intelligence has been detected, the discoverer should promptly inform all other observers or research organizations that are parties to this declaration, so that those other parties may seek to confirm the discovery by independent observations at other sites and so that a network can be established to enable continuous monitoring of the signal or phenomenon. Parties to this declaration should not make any public announcement of this information until it is determined whether this information is or is not credible evidence of the existence of extraterrestrial intelligence. The discoverer should inform his/her or its relevant national authorities.

SETI

3. After concluding that the discovery appears to be credible evidence of extraterrestrial intelligence, and after informing other parties to this declaration, the discoverer should inform observers throughout the world through the Central Bureau for Astronomical Telegrams of the International Astronomical Union, and should inform the Secretary General of the United Nations in accordance with Article XI of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Bodies. Because of their demonstrated interest in and expertise concerning the question of the existence of extraterrestrial intelligence, the discoverer should simultaneously inform the following international institutions of the discovery and should provide them with all pertinent data and recorded information concerning the evidence: the International Telecommunication Union, the Committee on Space Research, of the International Council of Scientific Unions, the International Astronautical Federation, the International Academy of Astronautics, the International Institute of Space Law, Commission 51 of the International Astronomical Union and Commission J of the International Radio Science Union.

4. A confirmed detection of extraterrestrial intelligence should be disseminated promptly, openly, and widely through scientific channels and public media, observing the procedures in this declaration. The discoverer should have the privilege of making the first public announcement.

5. All data necessary for confirmation of detection should be made available to the international scientific community through publications, meetings, conferences, and other appropriate means.

6. The discovery should be confirmed and monitored and any data bearing on the evidence of extraterrestrial intelligence should be recorded and stored permanently to the greatest extent feasible and practicable, in a form that will make it available for further analysis and interpretation. These recordings should be made available to the international institutions listed above and to members of the scientific community for further objective analysis and interpretation.

SETI

8. No response to a signal or other evidence of extraterrestrial intelligence should be sent until appropriate international consultations have taken place. The procedures for such consultations will be the subject of a separate agreement, declaration or arrangement.

Selber die Wahrscheinlichkeiten berechnen …

- **Die Greenbank-Formel:**

N = R * Fp * Ne * Fl * Fi * Fc * L

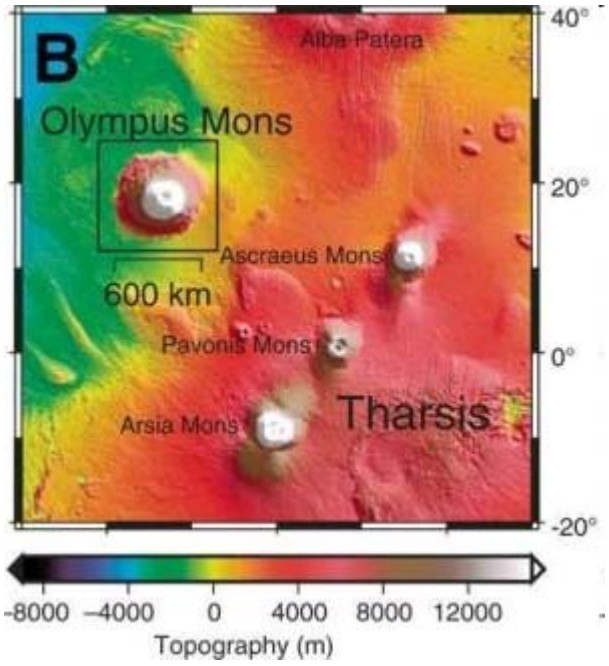
Symbol	Bedeutung	optimistisch	vorsichtig	pessimistisch
R	Entstehungsrate sonnenähnlicher Sterne/Jahr	15	2	0.5
Fp	Wahrscheinlichkeit eines Planetensystems (%)	30	10	1
Ne	Anzahl Planeten in der Ökosphäre	2	1	0.5
Fl	Planeten mit entwickeltem Leben (%)	50	20	1
Fi	Planeten mit intelligentem Leben (%)	10	5	1
Fc	Planeten mit entwickelter Technik (%)	10	5	1
L	Lebensdauer einer technischen Zivilisation (Jahre)	1 Million	10 000	100
N	Zahl der vorhandenen kommunikationsfähigen Zivilisationen in unserer Galaxie	45.000	1	0

Auf http://www.abenteuer-universum.de/leben/leben.html
selber ausrechnen, wieviele Zivilisationen es gibt / geben könnte!


Extraterrestrisches Leben
im Sonnensystem?

Mars

Zählt zu den erdähnlichen Planeten, liegt aber außerhalb der Ökosphäre (habitable Zone). In unserem Sonnen-System befindet sich nur die Erde innerhalb.
Mars erscheint als trockener Wüstenplanet. Bislang vorliegende Ergebnisse lassen jedoch den Schluss zu, daß die Marsatmosphäre vor Milliarden Jahren wesentlich dichter war und Reichlich Wasser auf der Oberfläche vorhanden war.

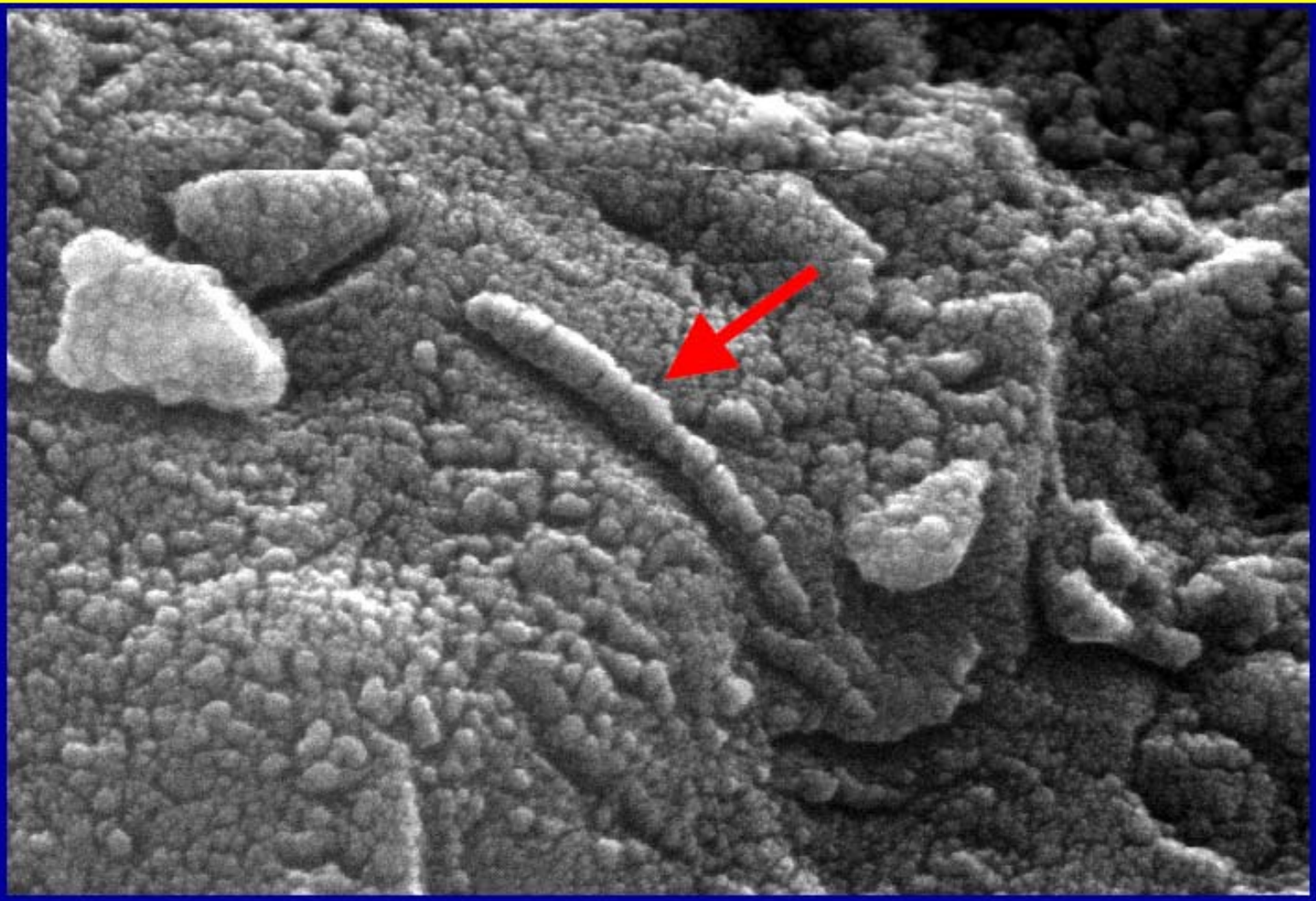


Using a computer modeling system to figure out how Olympus Mons came to be, McGovern and Morgan reached the surprising conclusion that pockets of ancient water may still be t rapped under the mountain. (Credit: Rice University/NASA)

ALH84001 – a Meteorite from Mars

- 4.5 billion years ago: ALH84001 formed on Mars
- 16 million years ago: blasted off Mars by impact
- 13,000 years ago: landed on Earth
- 1984: found on Allan Hills ice field, Antarctica

Fossil Bacteria in ALH84001?

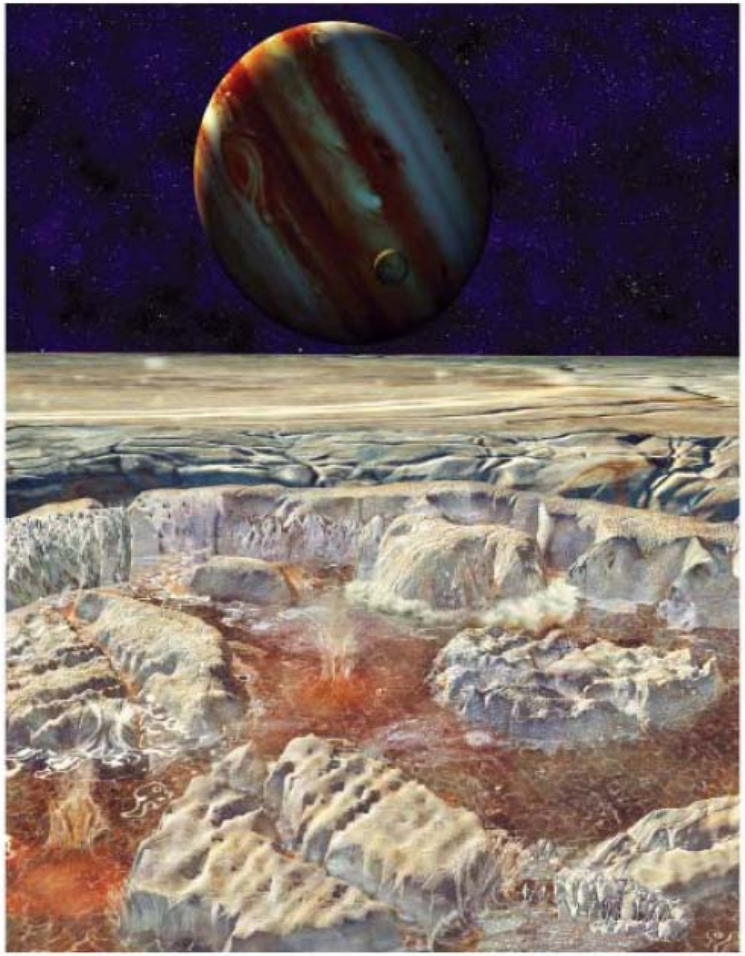


Mars

1900 hat eine französische Stiftung den Guzman Preis von 100 000 Francs ausgesetzt für den ersten Kontakt mit einer extraterrestrischen Spezies – aber Mars wurde ausgeschlossen – Marsianer zu detektieren galt als zu einfach ….

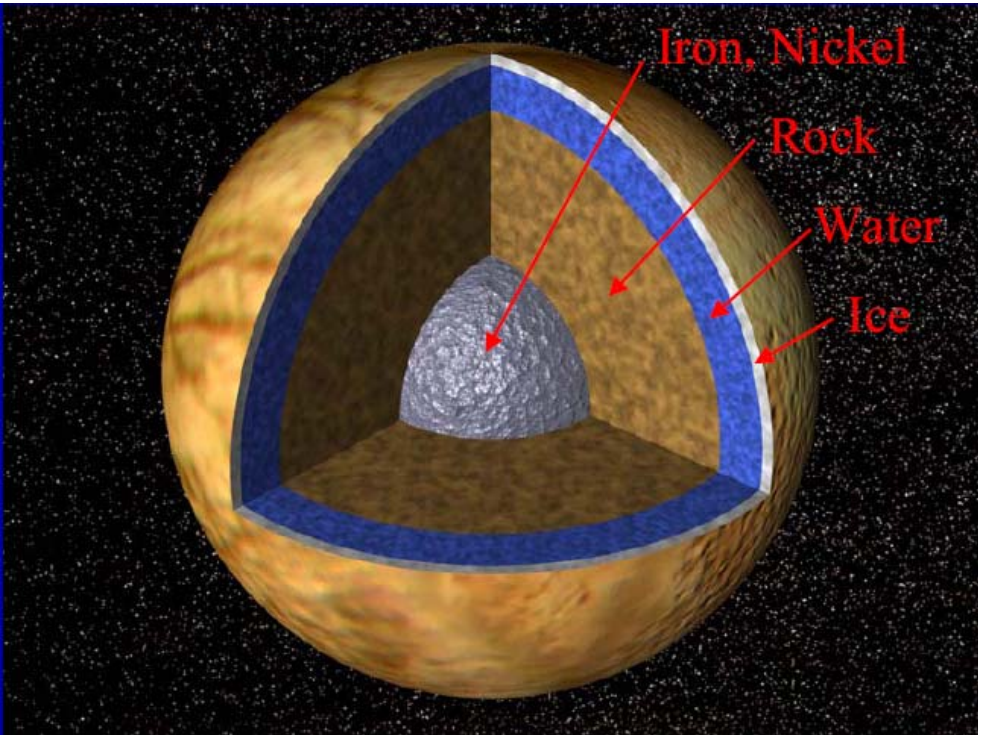
Europa

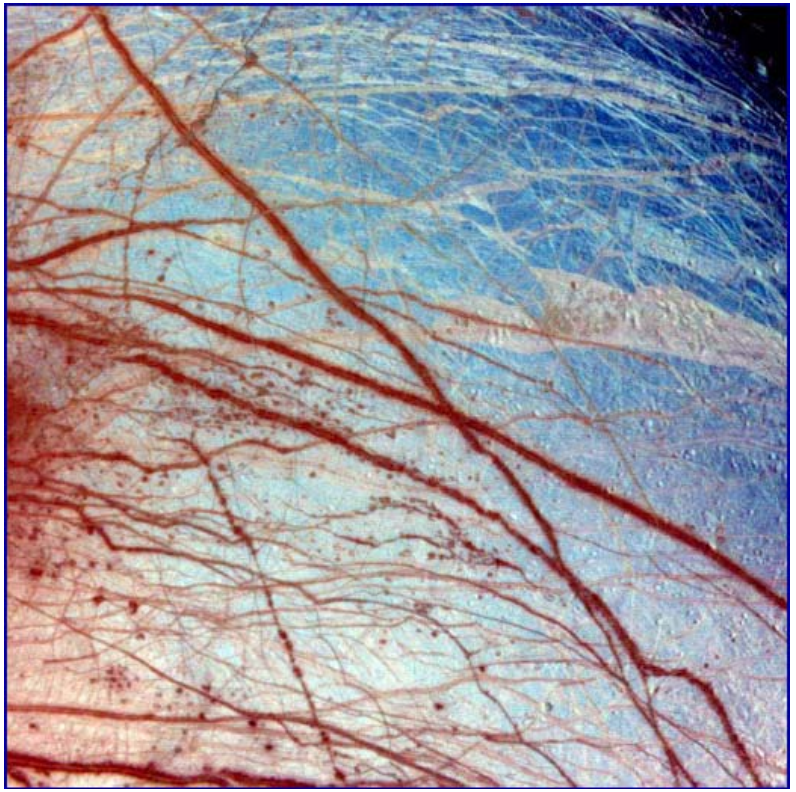
Der zweite und kleinste der Vier großen Monde des Jupiter. Sechstgrößte im Sonnen-system.
Temperatur maximal -150 Grad -dennoch vermutet man, daß sich unter einer Kruste aus Wassereis ein bis zu 90 km tiefer Ozean aus Wasser befinden könnte.



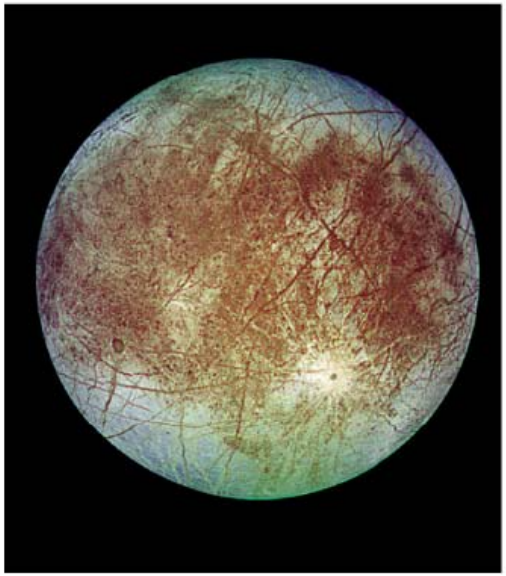
c

Aussichtsreichster Kandidat im Sonnensystem: Europa

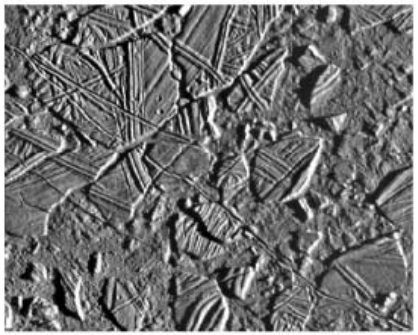




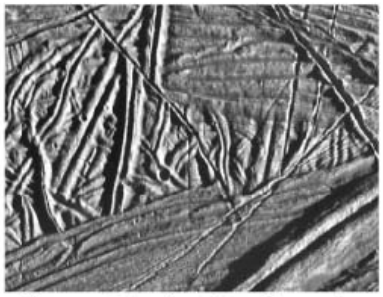
Europa



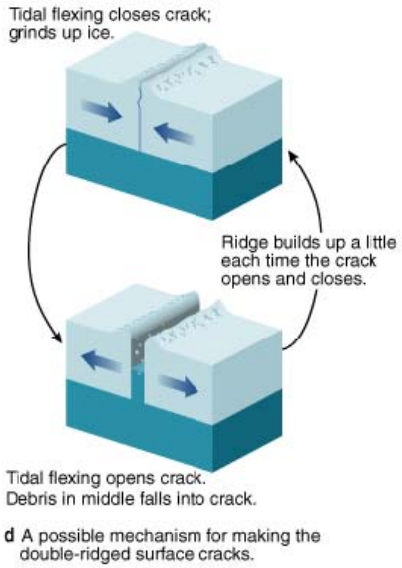
a Europa's icy crust is criss-crossed with cracks.



b Some regions show jumbled crust with icebergs, apparently 'rozen in slush.

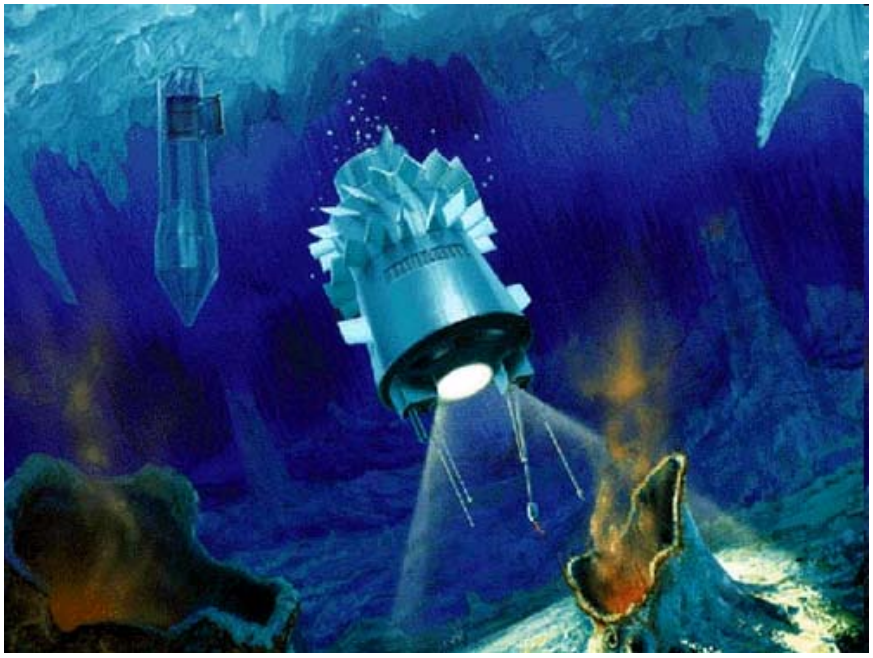


c Close-up photos show that surface cracks have a double-ridged pattern.



d A possible mechanism for making the double-ridged surface cracks.

Netzwerk von kreuz und quer verlaufenden Gräben und Furchen, Ähnlichkeit mit Rissen und Verwerfungen auf irdischen Eisfeldern. Kältevulkanismus oder durch den Ausbruch von Geysiren aus warmem Wasser entstanden, woduch die Eiskruste auseinander gedrückt wurde.



Für 2020 Start des Europa Jupiter Systems Mission/Laplace, 2 Orbiter Jupiter Europa Orbiter, Jupiter Ganymede Orbiter

Die Suche nach Exoplaneten

EXOPLANET HYPERSPACE

exoplanets.org

Main page of the California/Carnegie Planet Hunters

exoplanets.org/linkframe.html

Links to tutorials and to explanations of different future plans

Definition eines Planeten

IAU RESOLUTION 5A

The IAU therefore resolves that "planets" and other bodies in our Solar System, except satellites, be defined into three distinct categories in the following way:

(1) A "planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape , (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

(3) All other objects except satellites orbiting the Sun shall be referred to collectively as "Small Solar-System Bodies“.

…1992 - 2007

- 1992: Erste entdeckte Planeten umkreisen PSR 1257+12 (Masse: 3.9 und 4.3 M_E, Periode: 98.2 und 66.5 Tage)
- 1994: Dritter Planet um PSR 1257+12 entdeckt (Masse: 0.02 M_E, Periode: 25.2 Tage)
- 1995: Extrasolarer Planet um den sonnenähnlichen Stern 51 Pegasi (Masse: 0.46 M_J, Periode: 4.2 Tage)
- 2007: 192 Planetensysteme (davon 23 Mehrfachsysteme) mit 233 Planeten

Planets Outside the Solar System

- Detecting planets orbiting other stars is very hard
  - Like trying to look for a firefly close to a powerful lighthouse from a distance of 1000 km
- We can currently use indirect methods to detect planets
- First planet around other star found in 1995
- About 350 extrasolar planets known to date
  - Most of them are gas giants (like Jupiter or Saturn)
  - First large rocky planets detected recently

…Beobachtungsmethoden

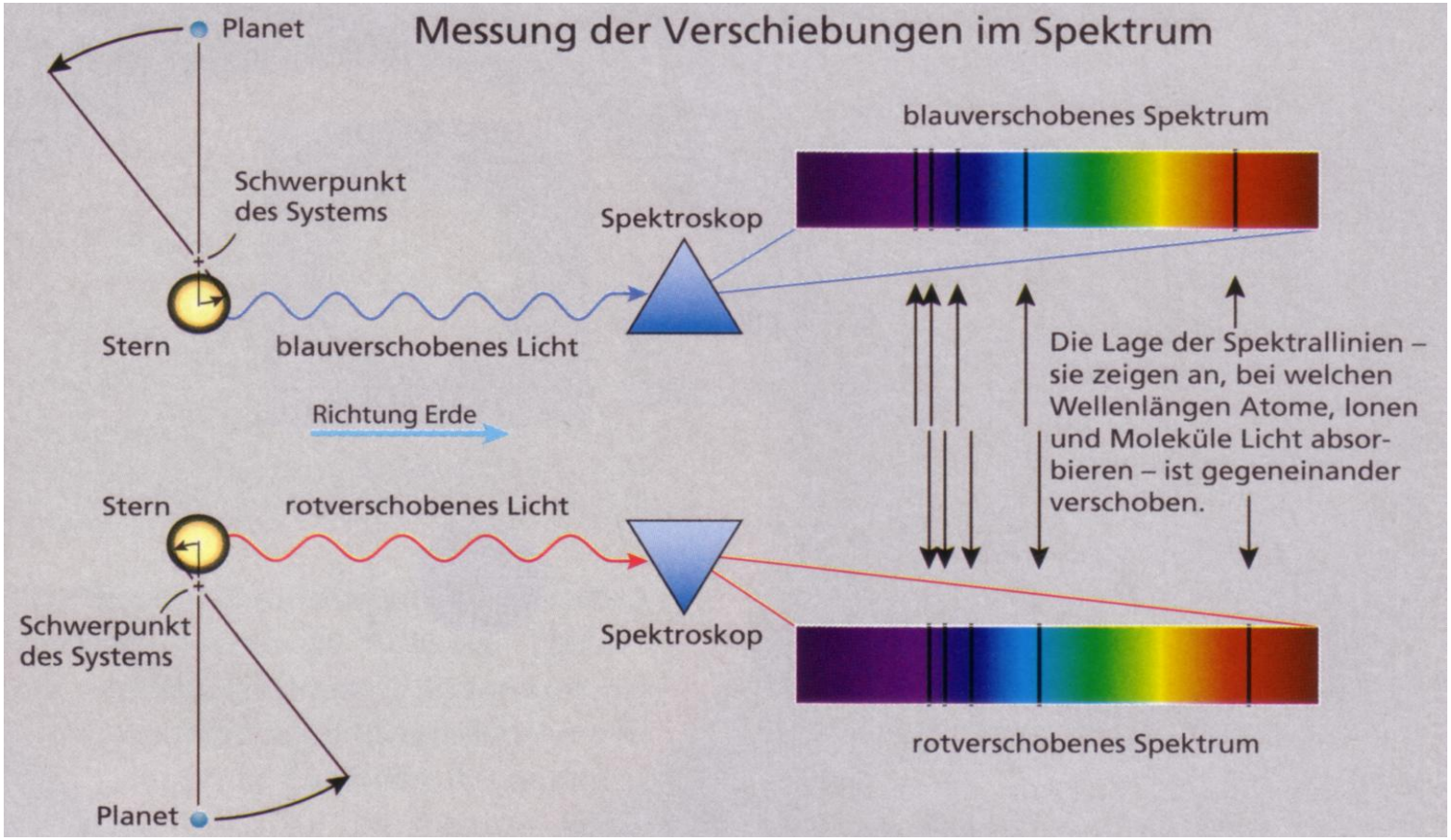
Indirekte Beobachtung

- Doppler-Spektroskopie (Radialgeschwindigkeit)
- Photometrie (Transit)
- Astrometrie
- Pulsar Timing
- Microlensing

Direkte Beobachtung

- Auslöschungsinterferometrie
- Abdunkelung des Zentralsterns

…Radialgeschwindigkeit

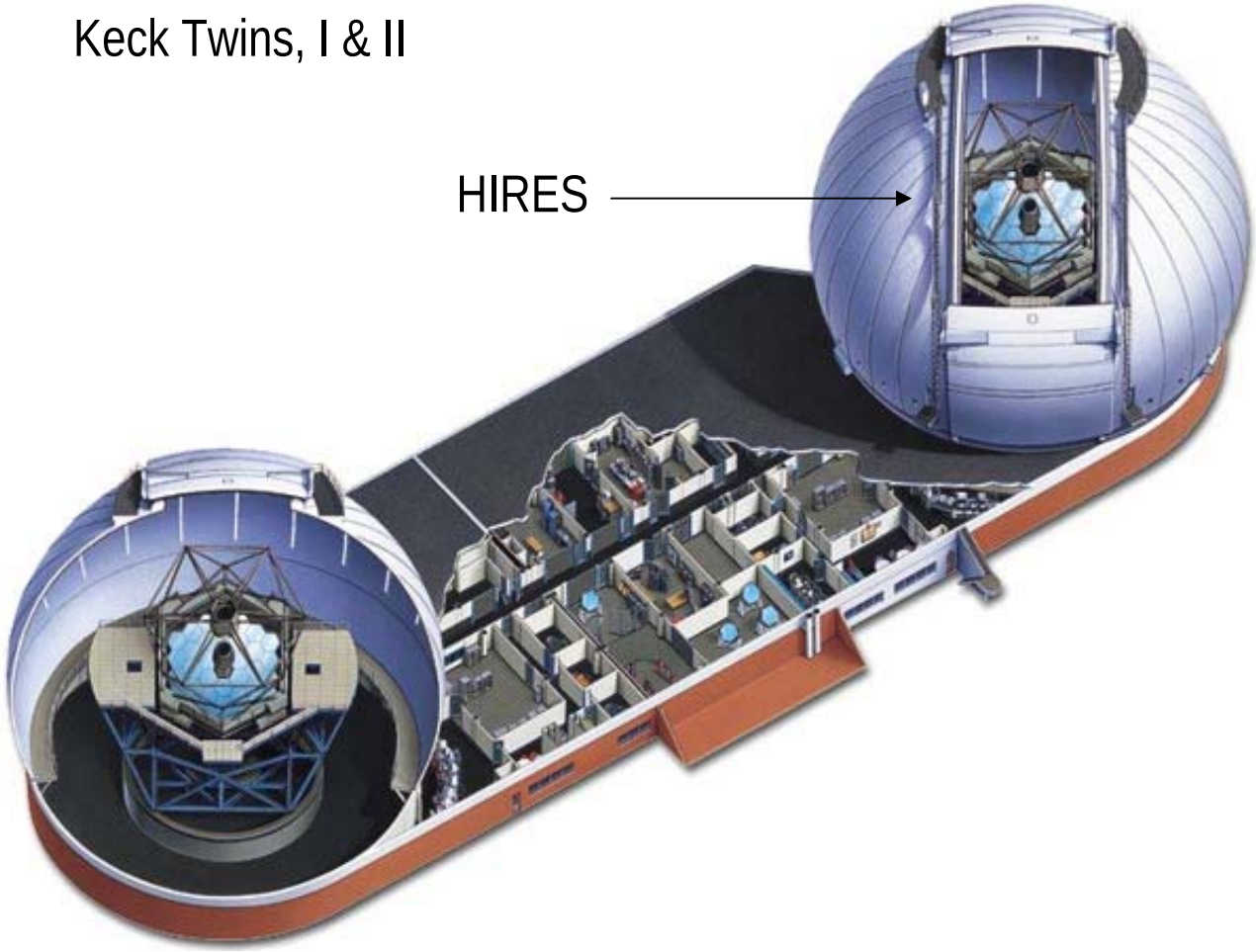


Einfluss auf Bewegung der Sonne: Jupiter 12.5 m/s, Erde 0.04 m/s

Gut geeignet, um Planeten mit ~Jupitermasse zu finden

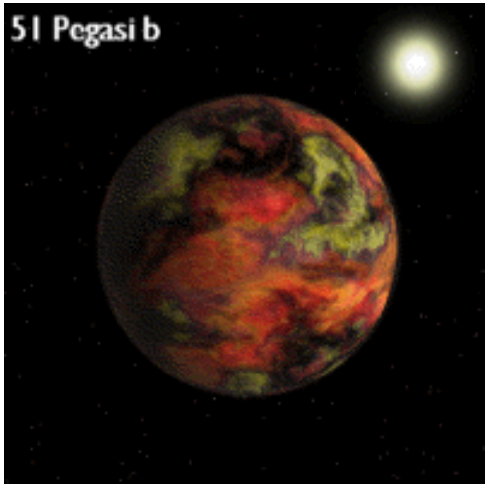
RADIAL VELOCITY METHOD

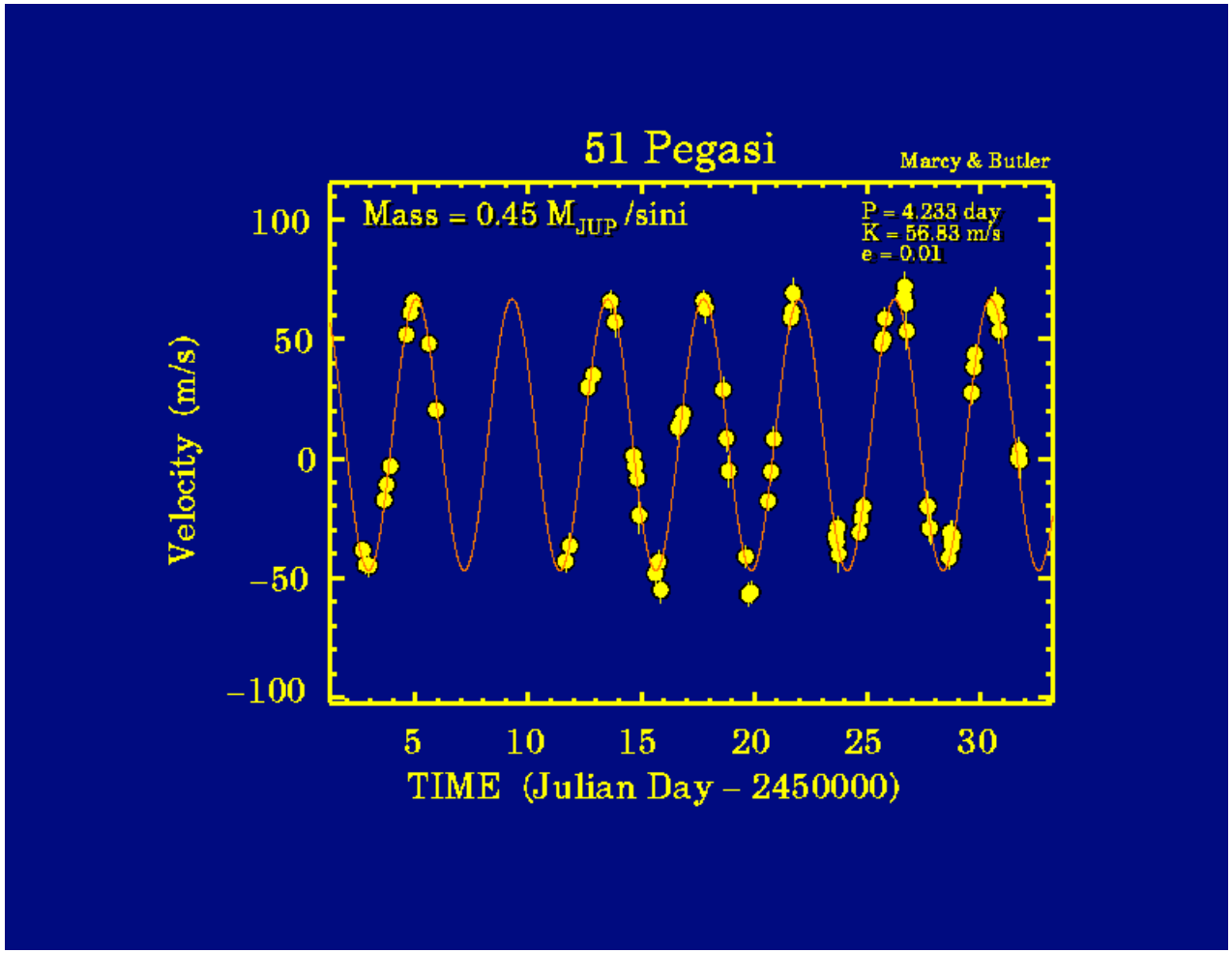
Keck Twins, I & II



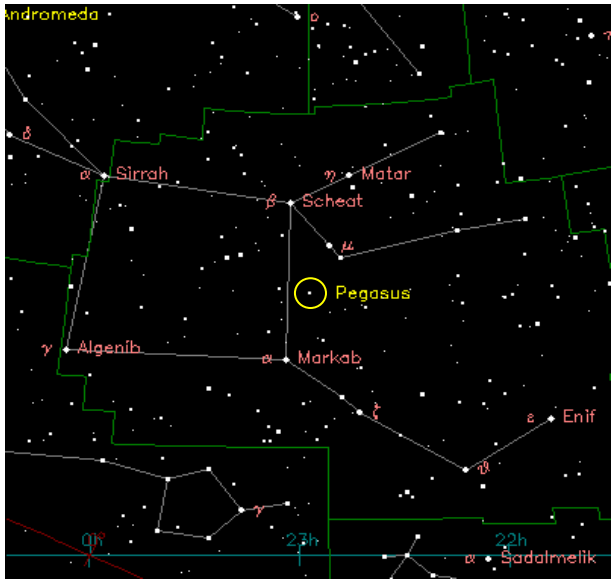
RADIAL VELOCITY METHOD

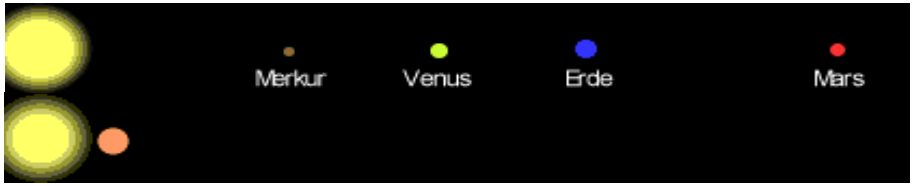
(Doppler Shifts Of Star Light)





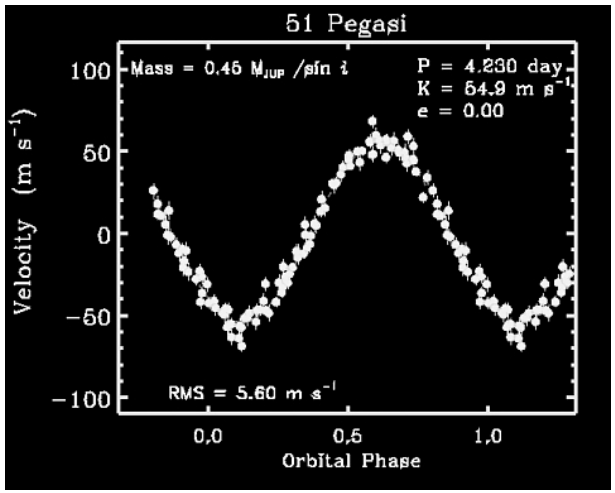
…51 Pegasi b („Hot Jupiter“)





51 Pegasi

- Spektraltyp: G2 IV
- Masse: 0.95 $M_\odot$
- Radius: 1.3 $L_\odot$
- Oberflächentemp.: 5770 K
- Entfernung: 42 Lj



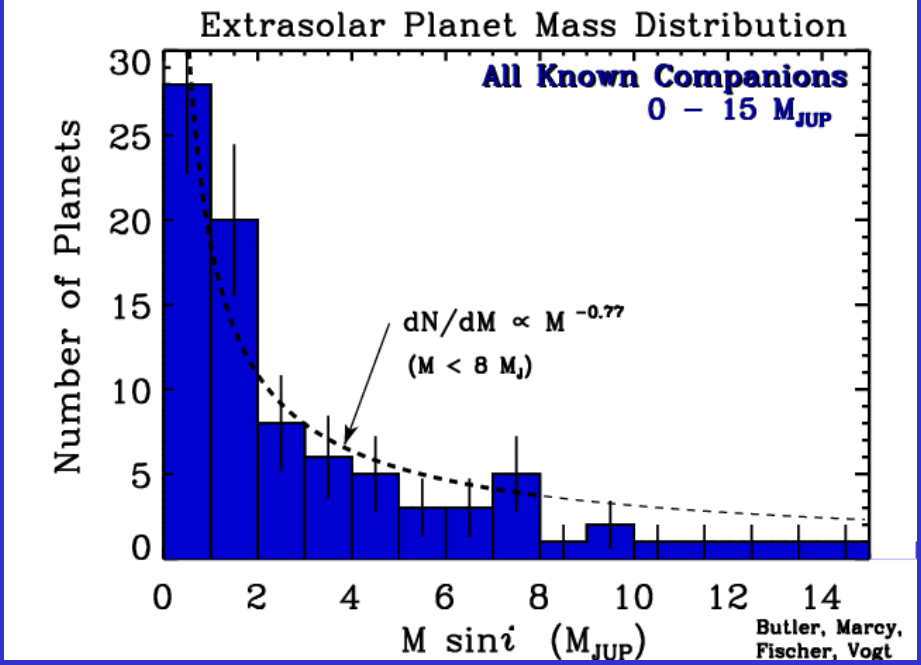
51 Pegasi b

- Masse: 0.47 M_J/sin i
- Umlaufszeit: 4.2 Tage
- Entfernung vom Stern: 0.052 AU
- Mittl. Temperatur: 1300 K
- Gebundene Rotation

RADIAL VELOCITY METHOD

(Doppler Shifts Of Star Light)

The number of planets with a given “mass”.

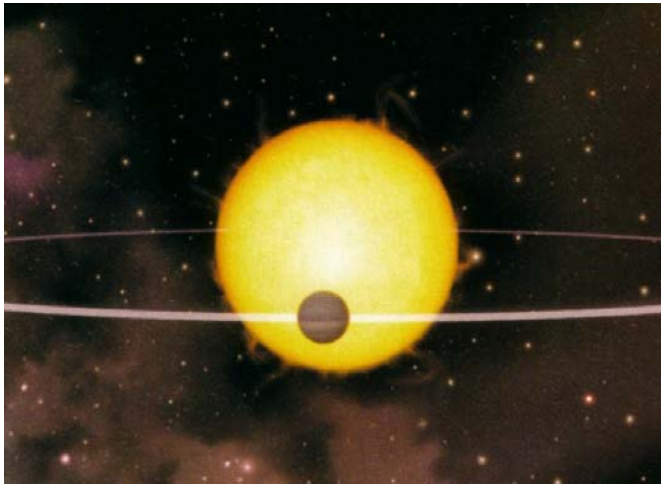


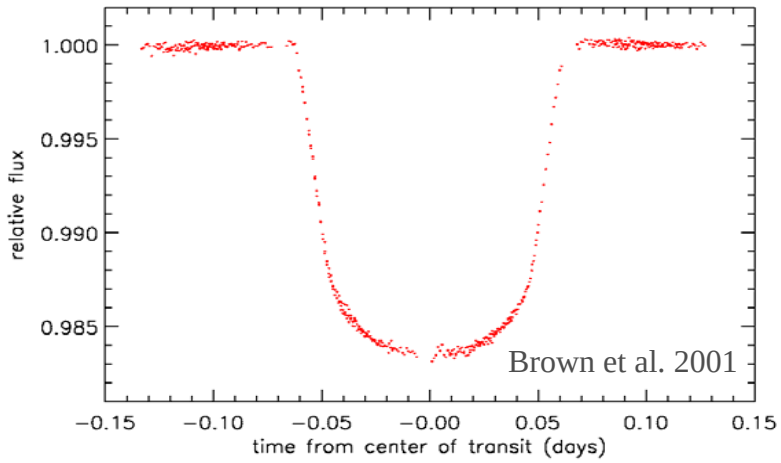
1) One cannot get the mass directly, if the inclination of the system is unknown

2) One determines combined quantity of planet mass and the inclination angle

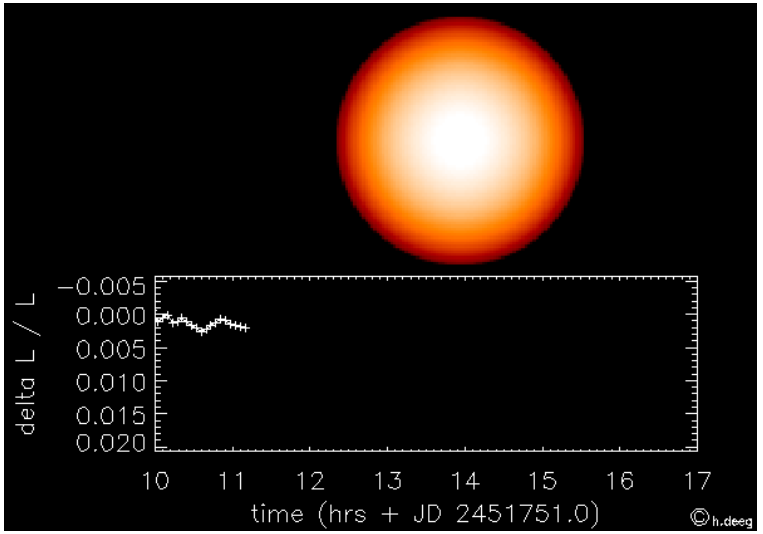
3) Most planets are of smaller “mass” (these are hardest to find) - thus low “mass” planets are very numerous indeed

…Photometrie (Transit)

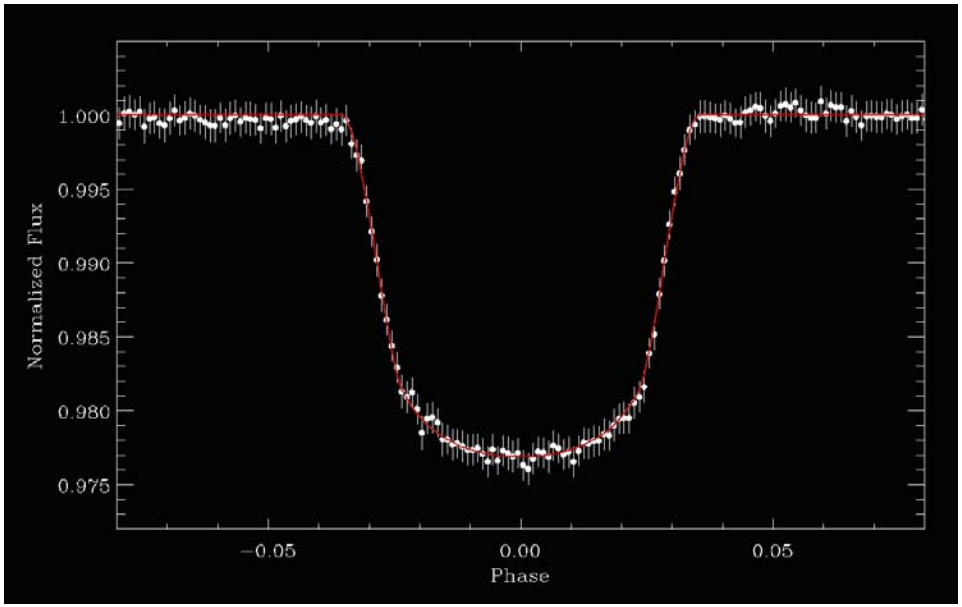




- Gut geeignet, um enge Begleiter zu finden
- Untersuchung der atmo-sphärischen Zusammensetzung



…Corot-Exo-1b



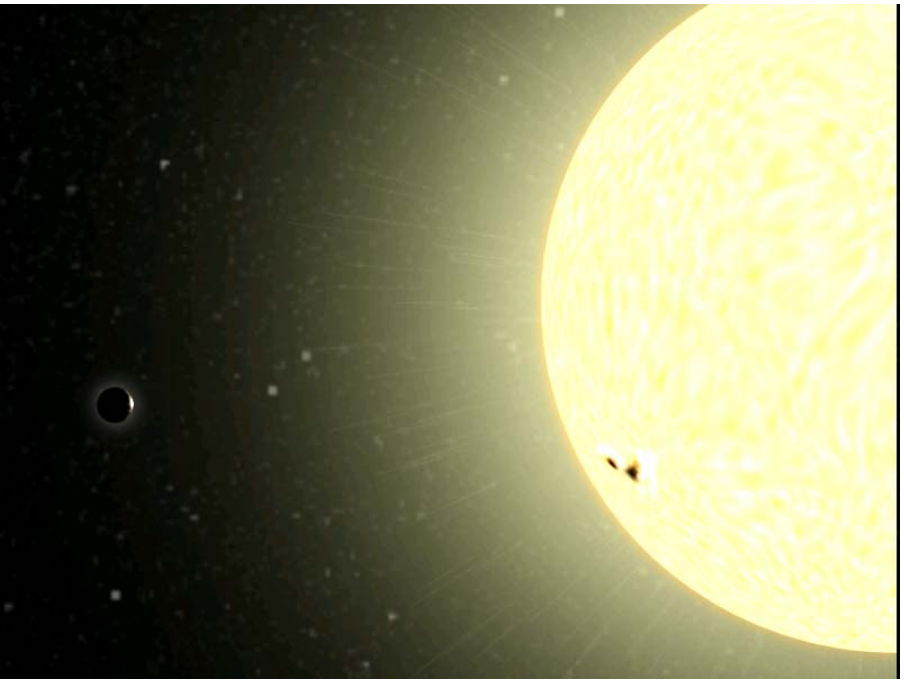
Corot-Exo-1

- Spektraltyp: G2V
- Masse: ?? $M_\odot$
- Radius: 1.2 $R_\odot$
- Entfernung: 1500 Lj

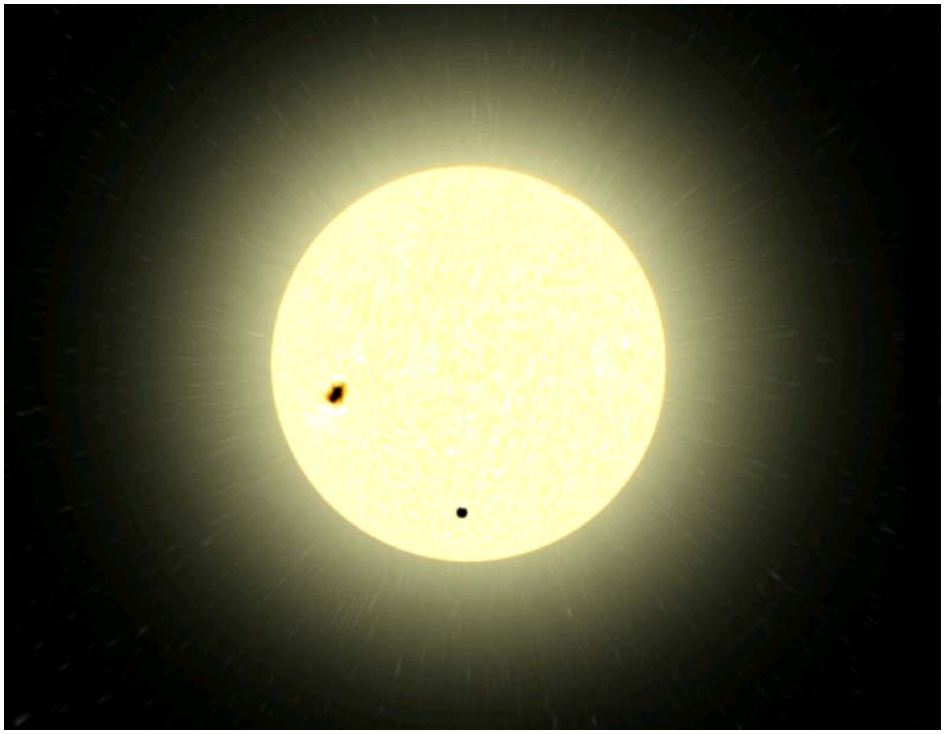
Corot-Exo-1b

- Masse: 1.3 M_J
- Umlaufszeit: 1.5 Tage
- Entfernung vom Stern: ?? AU
- Radius: 1.5-1.8 R_J

COROT-Exo-7b



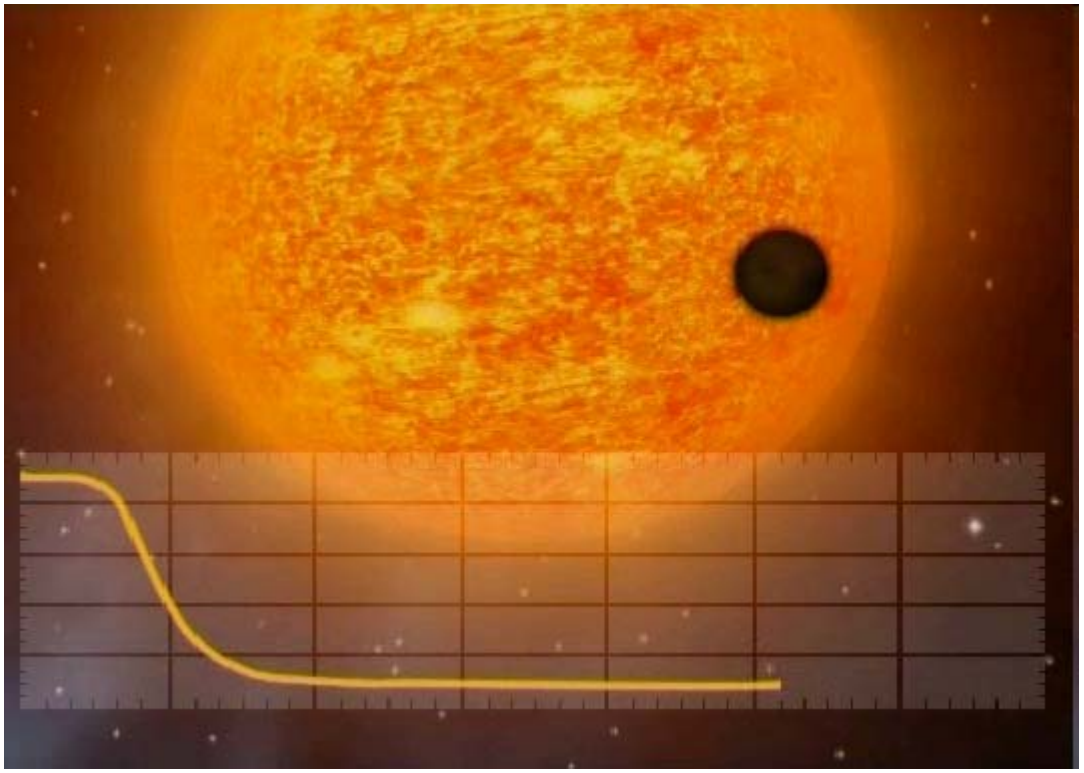
CoRoT-Exo-7b, dargestellt als punktförmiger Schatten unten links vor seinem Zentralstern Bild: Klaudia Einhorn



CoRoT-Exo-7b zieht in der maßstabsgetreuen, künstlerischen Darstellung vor seinem Stern Bild: Klaudia Einhorn

Bislang sind 337 Exoplaneten gefunden worden (Stand: Februar 2009). COROT (Convection, Rotation and Planetary Transits) sucht nach kleinen, massearmen und steinigen Exoplaneten (Helligkeitsschwankungen).

COROT-Exo-7b

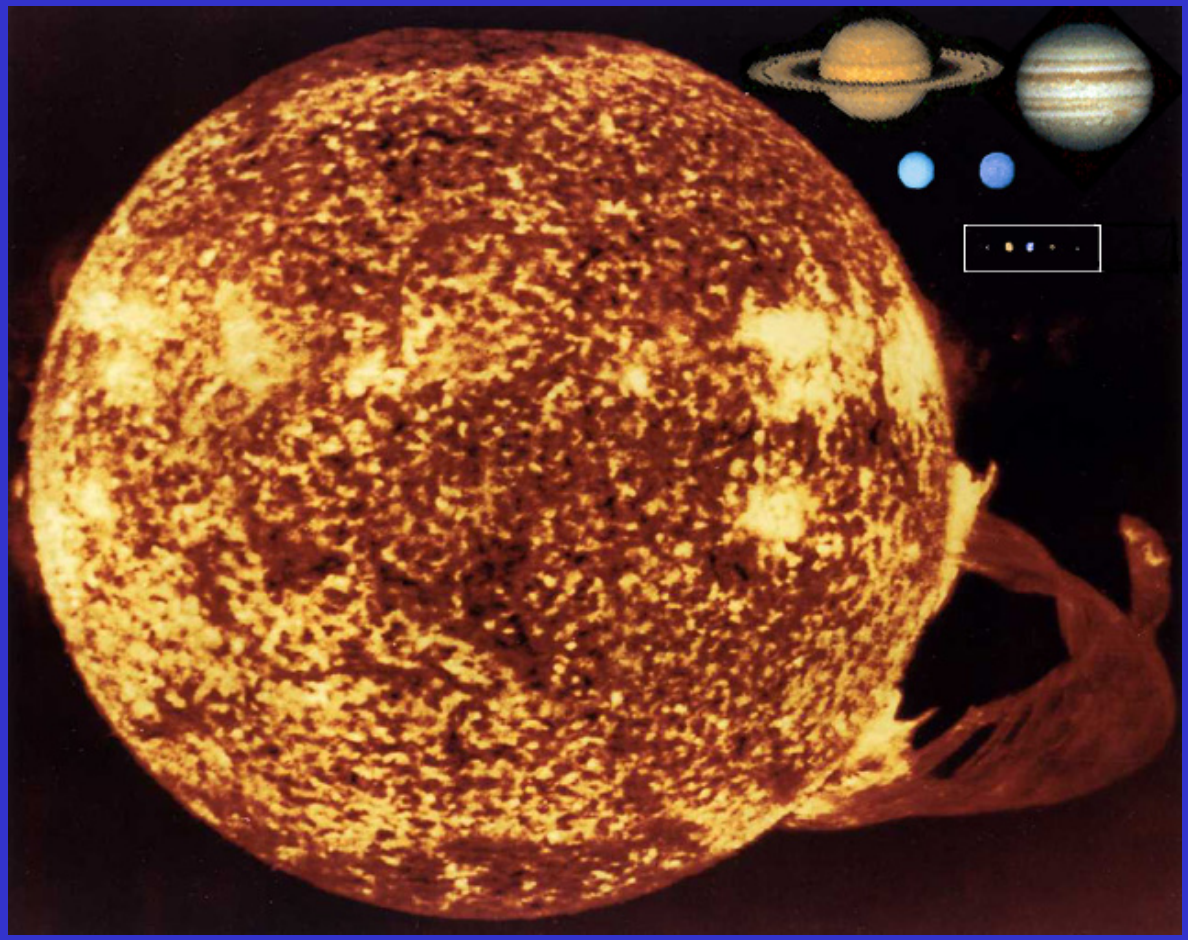


Veranschaulichung der Helligkeitsschwankung durch einen vorbeifliegenden Planeten, der einen kleinen Flecken erzeugt. Bild: CNES

Auch hier: kein Leben!! Temperaturen von 1000-1500 Grad, Oberfläche steinig oder aus Lava bestehend. Könnte auch teils aus Wasser und Stein bestehen und Eine heiße Atmosphäre aus Wasserdampf besitzen.

TRANSIT METHOD

(Brightness Variations Due to Planet Eclipses)



…. Here are the relative sizes of planets in our Solar System.

TRANSIT METHOD

(Brightness Variations Due to Planet Eclipses)

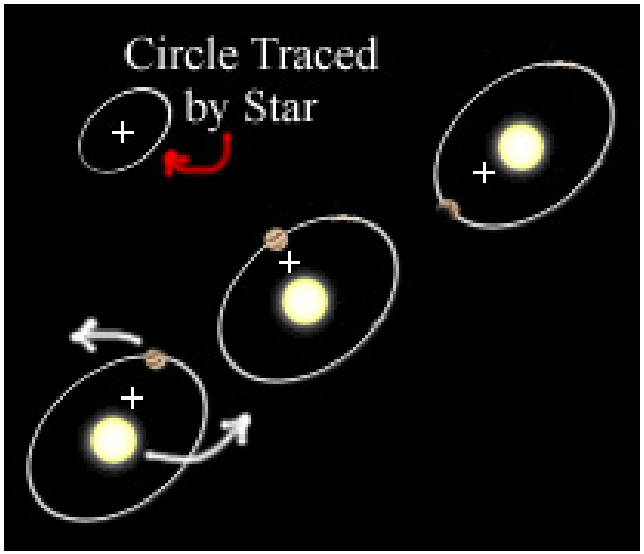
Well…. In principle this can be done.

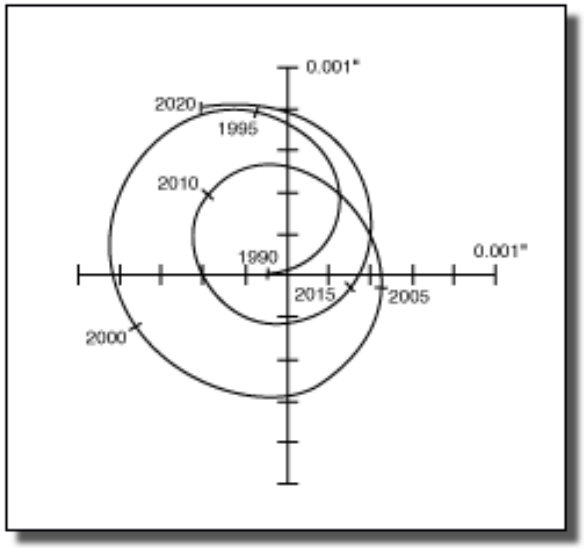
Like other methods… it is a technical challenge.

And, well. If you can find an edge-on (highly inclined planetary system) and it had a Jupiter, you would have to wait about 10 years between events and the event lasts only days.

I would not invest time and resources in the TRANSIT METHOD

…Astrometrie





Astrometric displacement of the Sun due to Jupiter as seen from 10 parsecs.

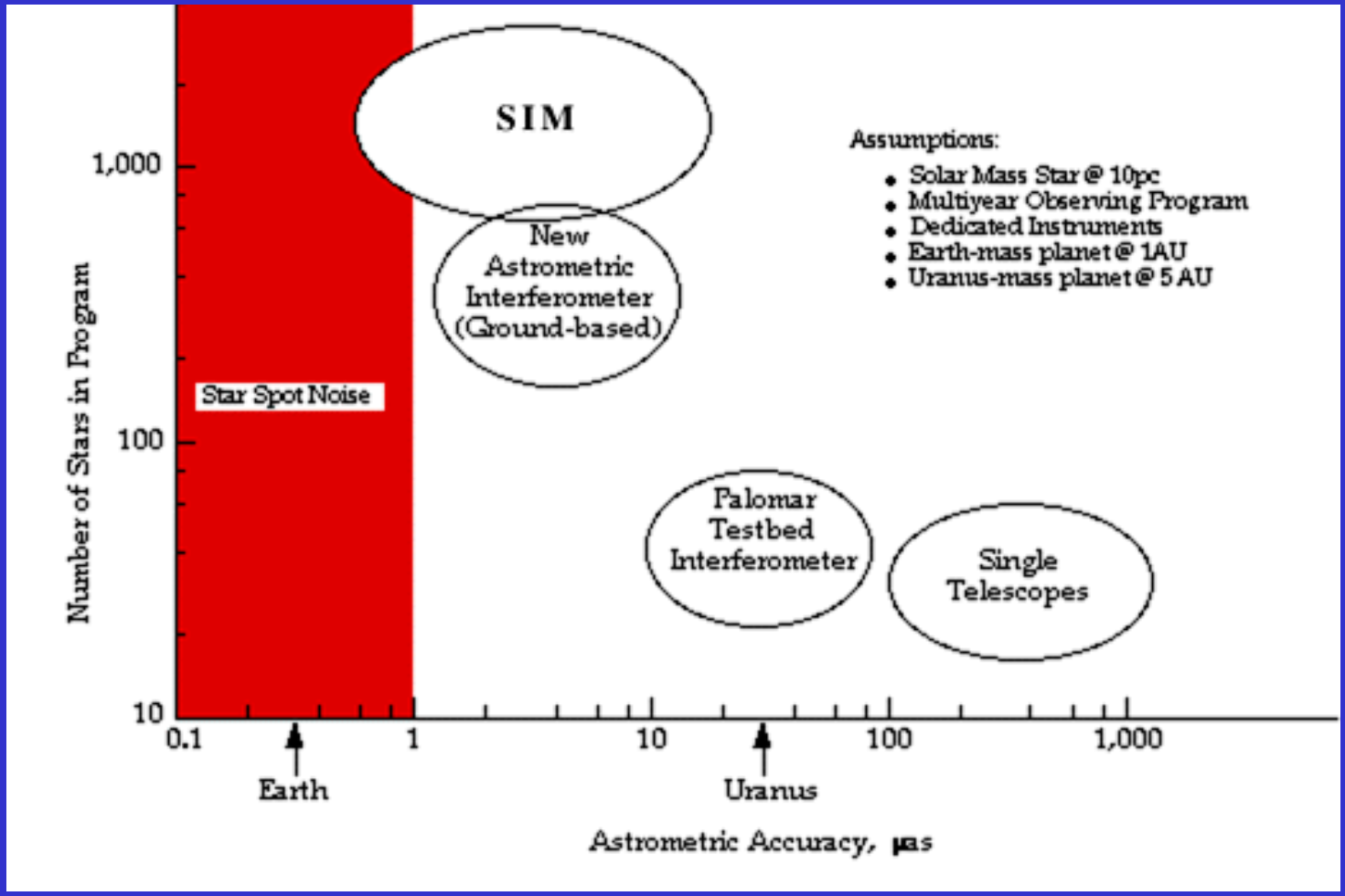
Aus 10 pc Entfernung gesehen, verursacht Jupiter ein „Wackeln“ der Sonne um 500 µarcsec (Erde 0.3 µarcsec)

Masse des Planeten kann direkt bestimmt werden

Benötigte Genauigkeit wird noch nicht erreicht

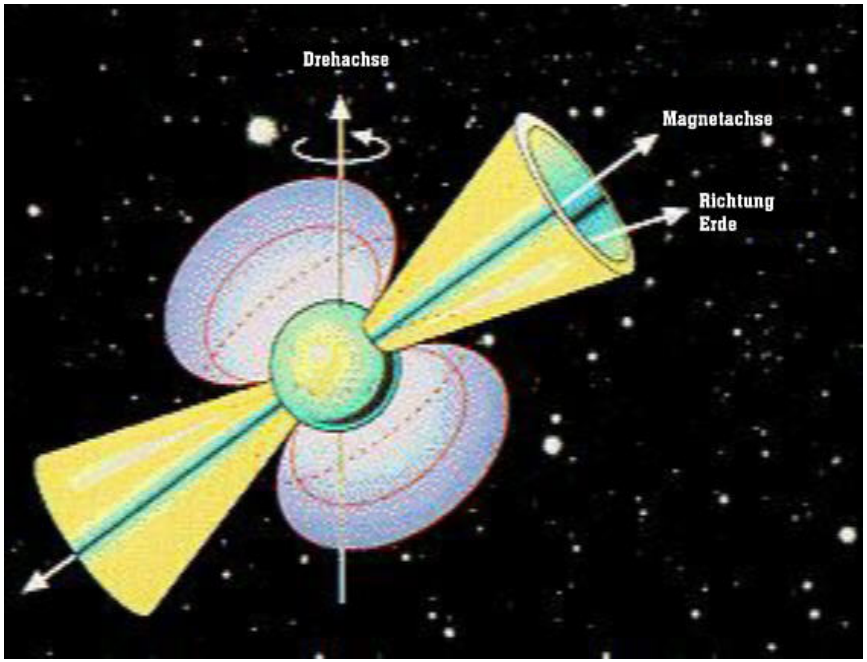
ASTROMETRY METHOD

(Movement With Respect to Background Stars)



Assumes Our Solar System at 10pc (32 lys) distance.

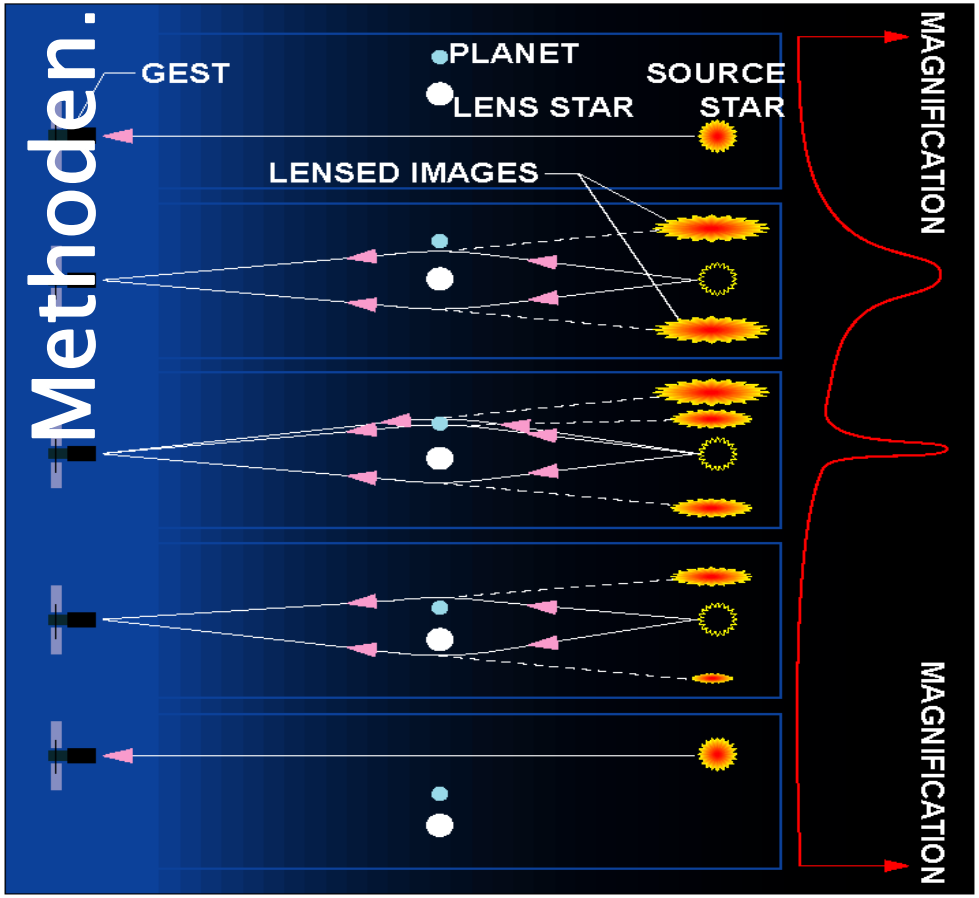
…Pulsar timing



Rotationsachse und Symmetrieachse des Magnetfeldes sind nicht parallel → Aussendung regelmäßiger Signale

Ein den Pulsar umkreisender Planet verursacht eine Bewegung um das Baryzentrum des Sterns, die zu periodischen Variationen der Signale führt

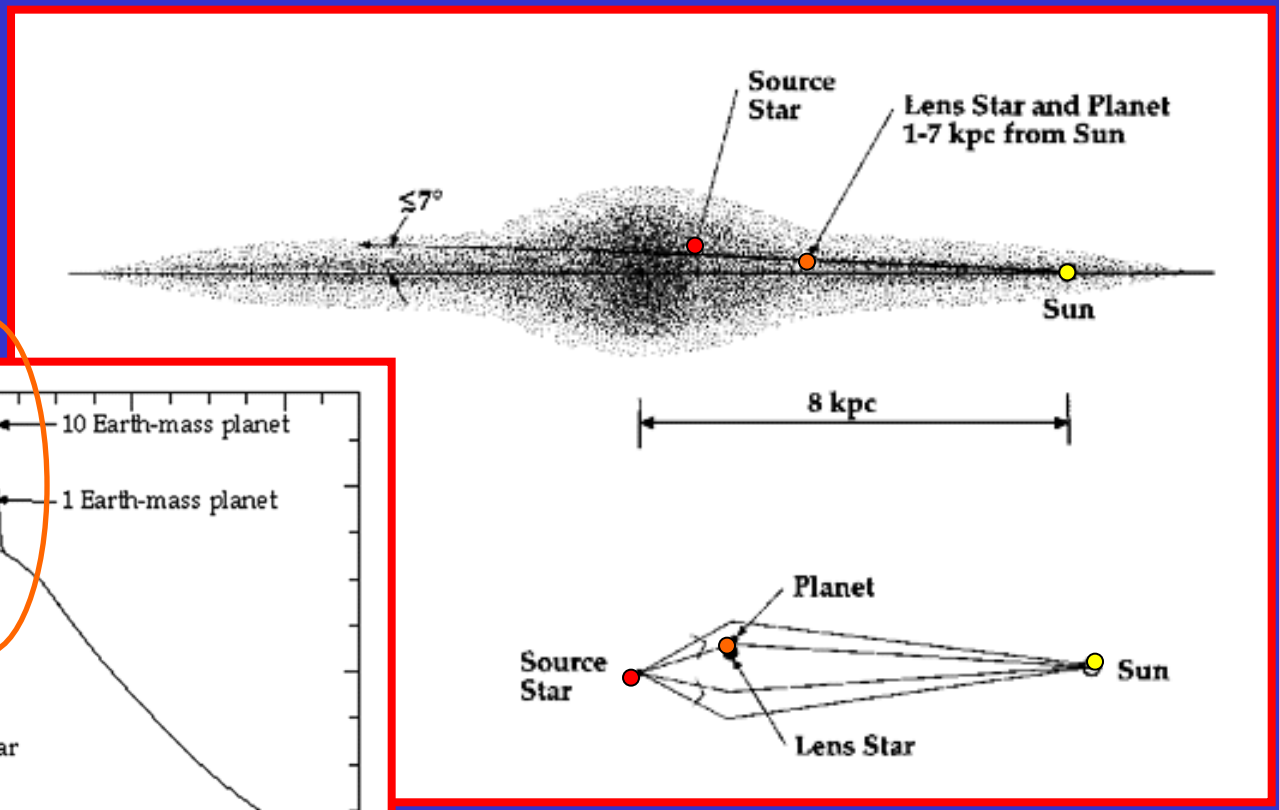
…Microlensing

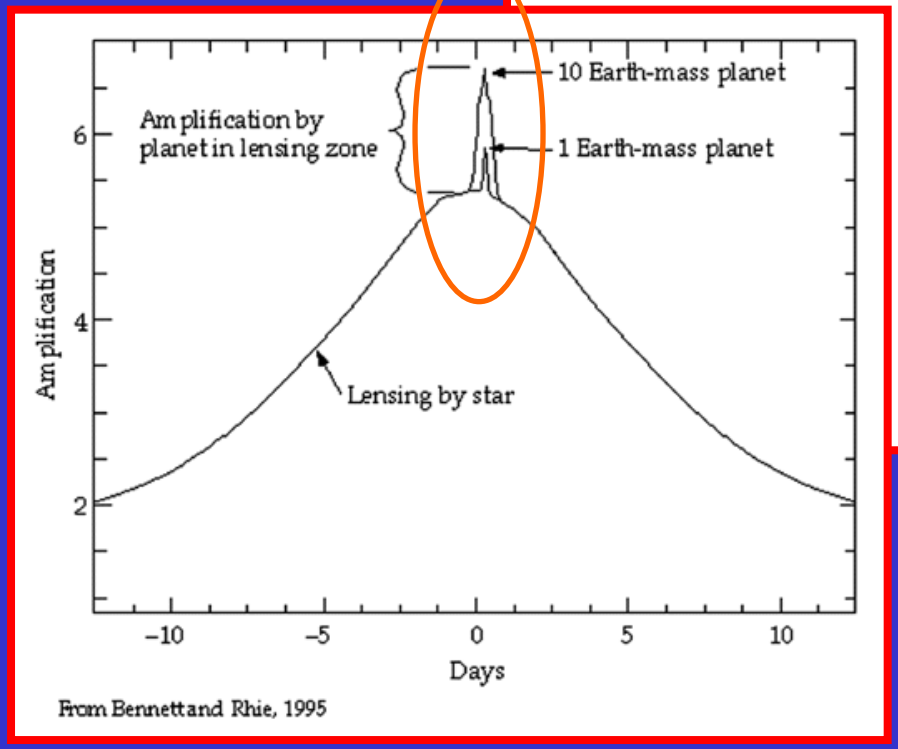


- Objekt im Vordergrund wirkt als Linse und verstärkt Licht des Sterns
- Planet um Linsenobjekt beeinflusst Helligkeits-verstärkung
- Mehrere verzerrte Bilder
- Lichtbeugung von Planetenmasse abhängig
- Größte Empfindlichkeit bei 2-3 AU (Einstein Ring-Radius)
- Günstig vor galaktischem Hintergrund
- Geeignet, um Planeten mit Erdmasse zu entdecken

MICROLENSING METHOD

(Quick Brightness Spikes Due to Gravitational Lensing of Background Stars)

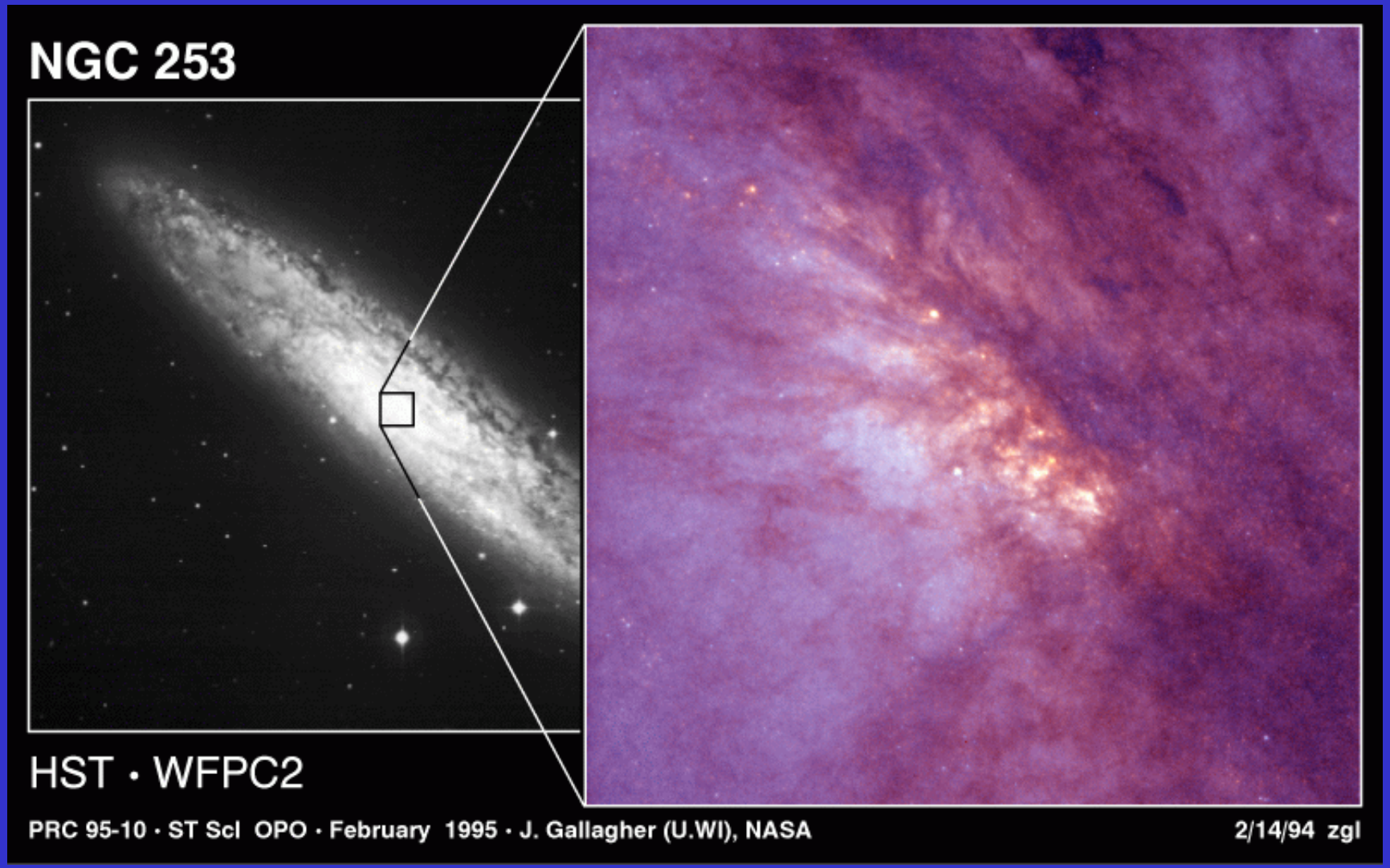




Pros: Very sensitive for all masses and orbits

Cons: Requires dedicated telescope network imaging 10x per night

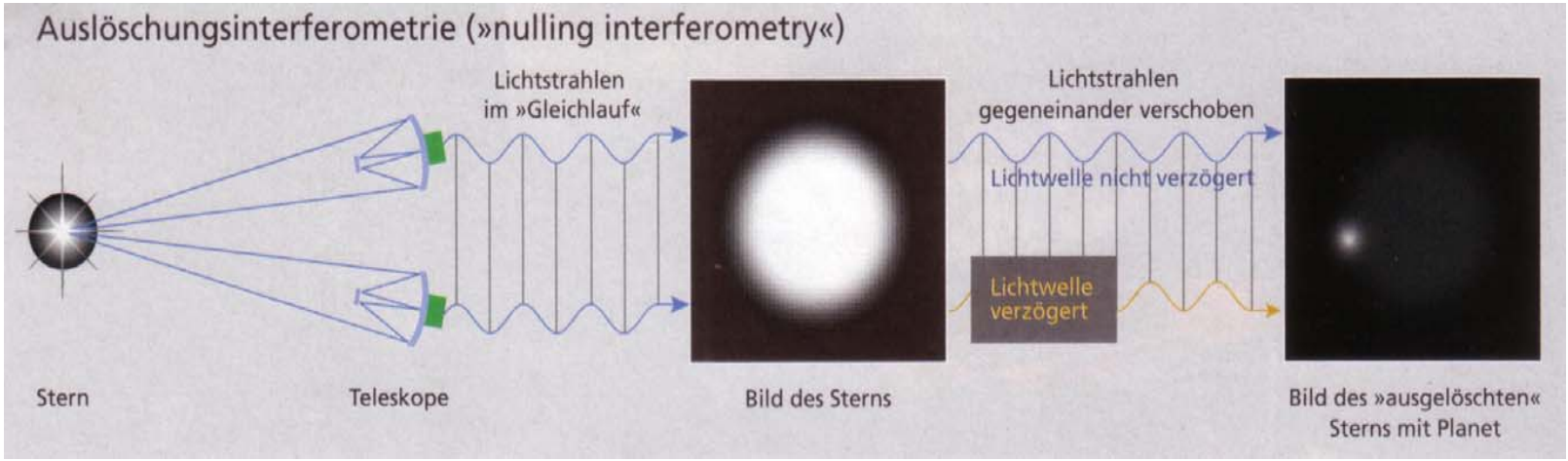
MICROLENSING METHOD



In the future, one can do this in external galaxies!

…Auslöschungsinterferometrie

- Auslöschen des Zentralsternlichtes
- Beobachtung des reflektierten Lichts des Planeten

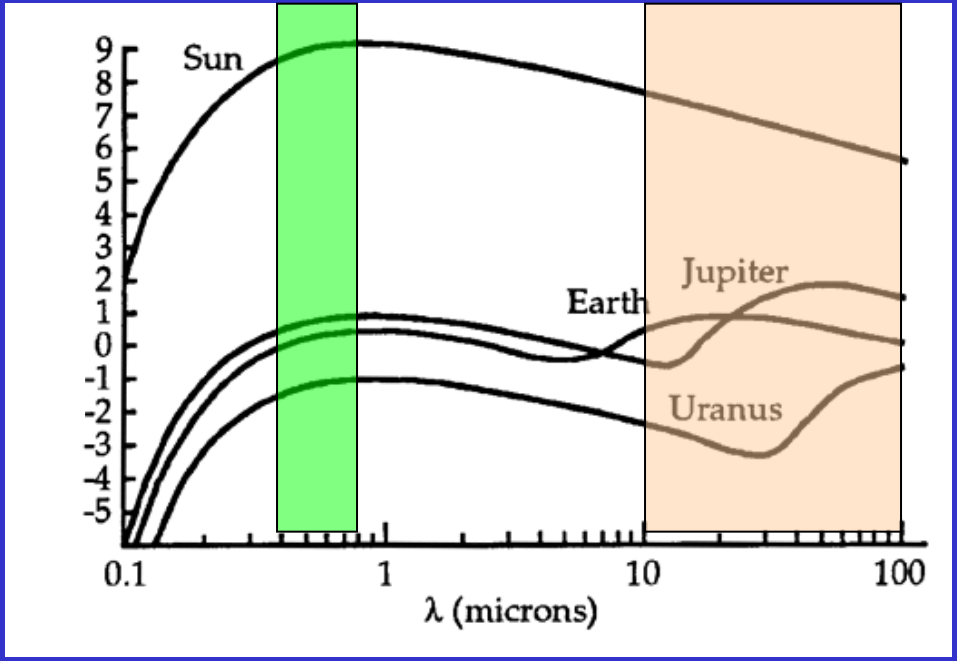


IMAGING METHOD

(Imaging of Reflected/Reprocessed Starlight)

Optical: star/planet = 1 billion = 10^9

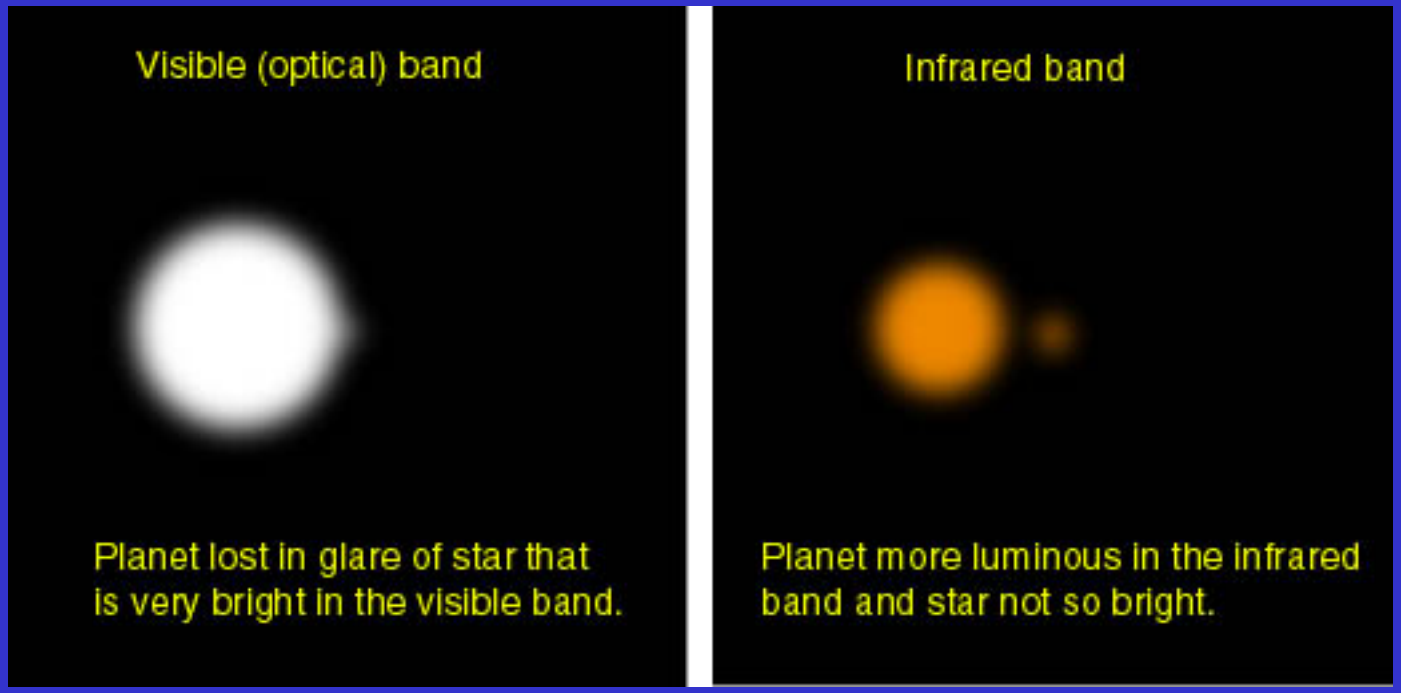
Infrared: star/planet = 1 million = 10^6

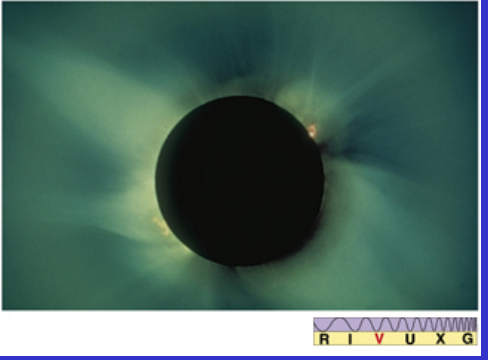


We need to search in the infrared and we need some extra help! Block out the star!

IMAGING METHOD

(Imaging of Reflected/Reprocessed Starlight)

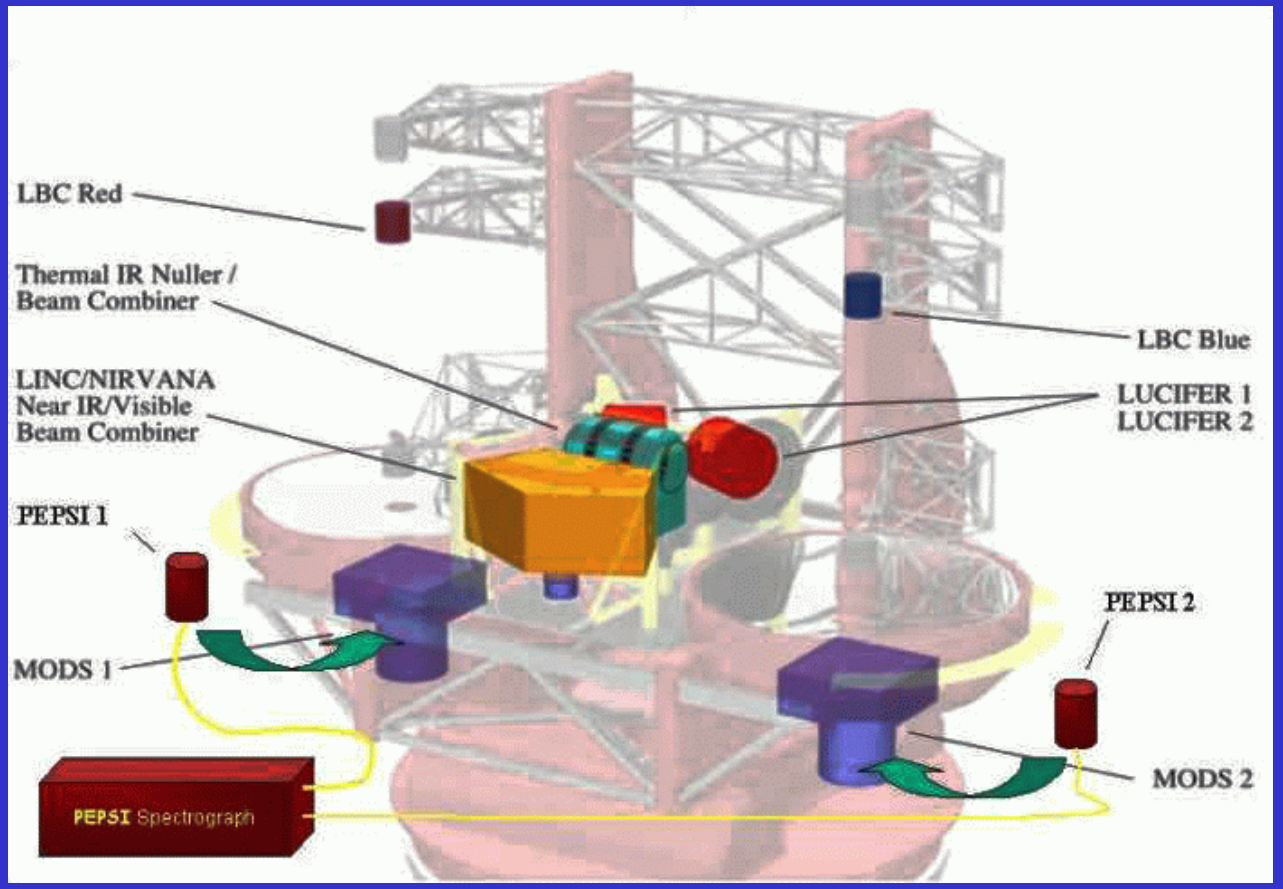




IMAGING METHOD

Interferometery and Adaptive Optics (AO)
nulling the star light

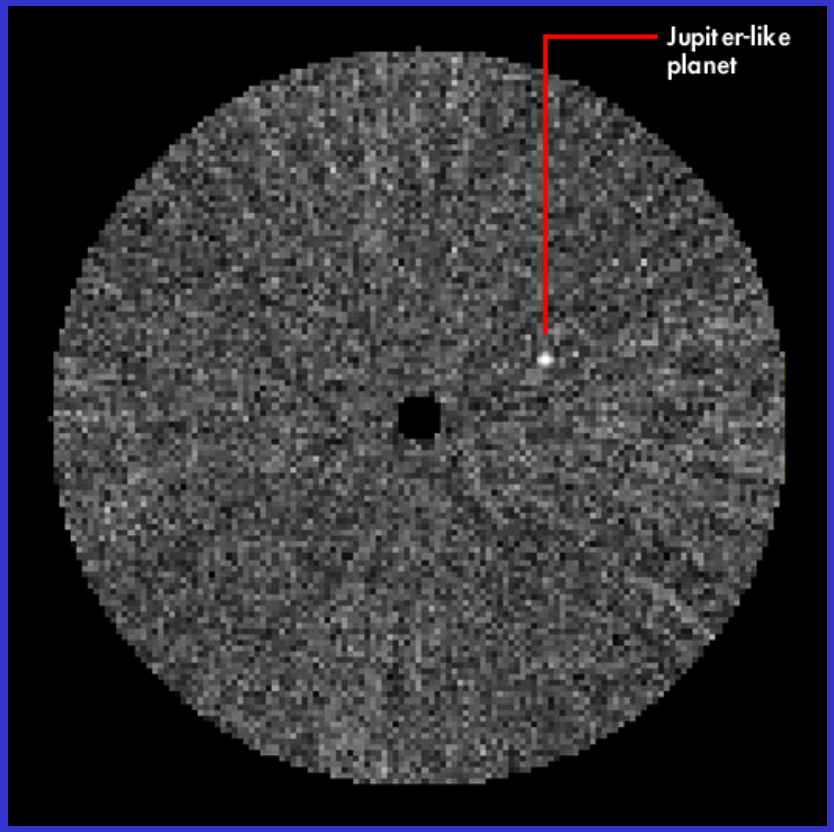
This old fashioned way of blocking out the star is called a coronagraph, which is being replaced by interferometery ….



Requires large telescopes and specialized instrumentations…

IMAGING METHOD

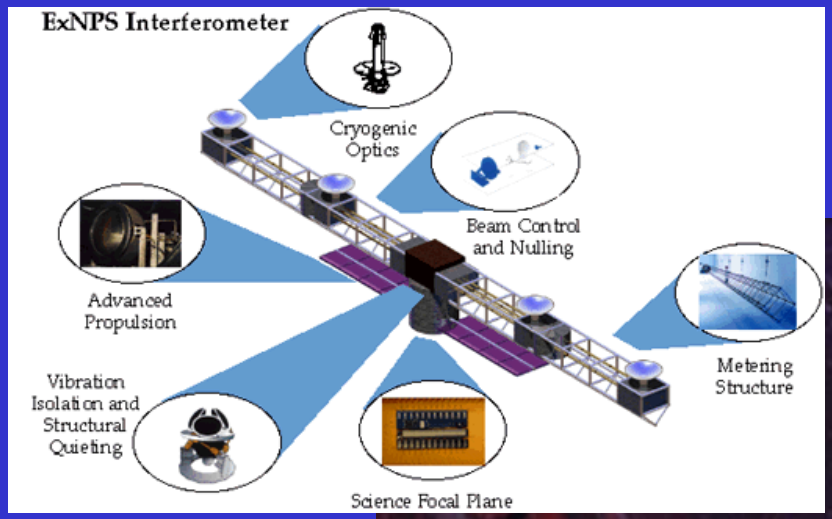
(Simulated Image of Jupiter in “solar system” 10pc distant)



Using interferometery in the infrared from the ground.
Success does not depend upon inclination of system, but brightness of planet.

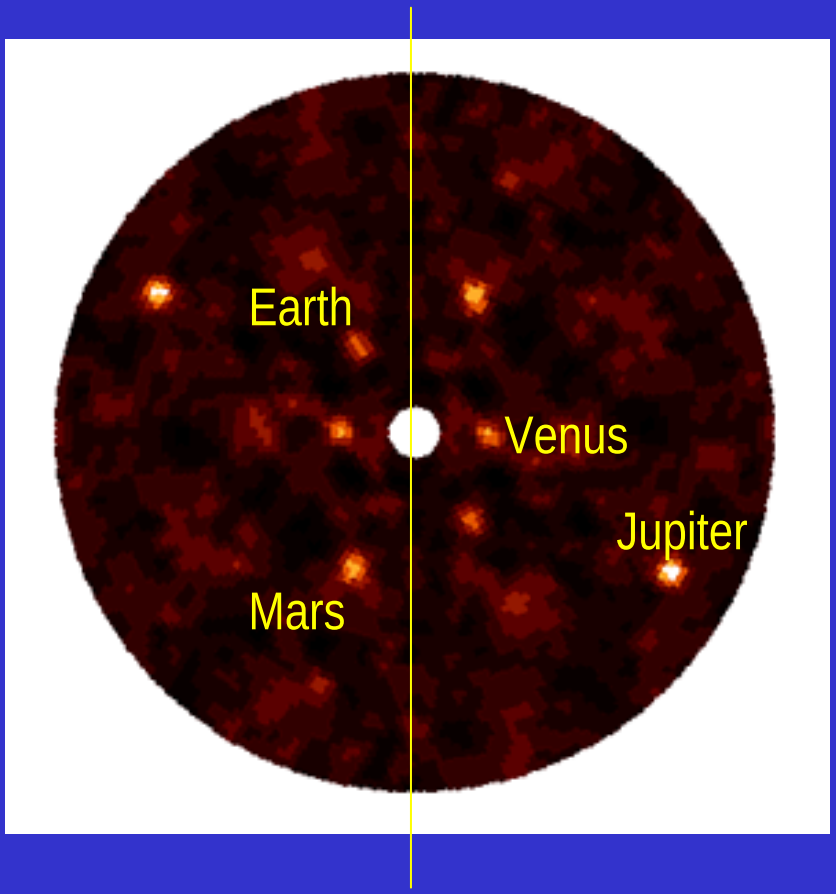
IMAGING METHOD

(taking it to the next level- the future)



IMAGING METHOD

(Family Portrait- Venus, Earth, Mars, and Jupiter)

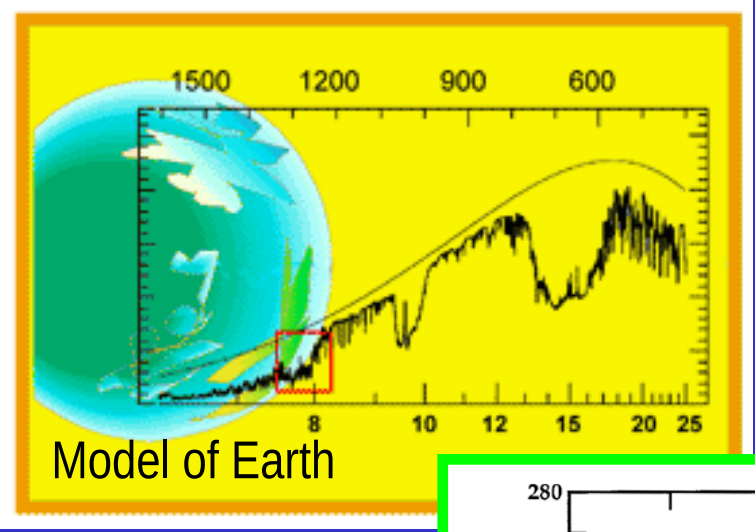


The images are reflected about the origin- artifact of interferometery method

Space based interferometery can probe deeper… mostly because of the bigger collecting area of the telescope.

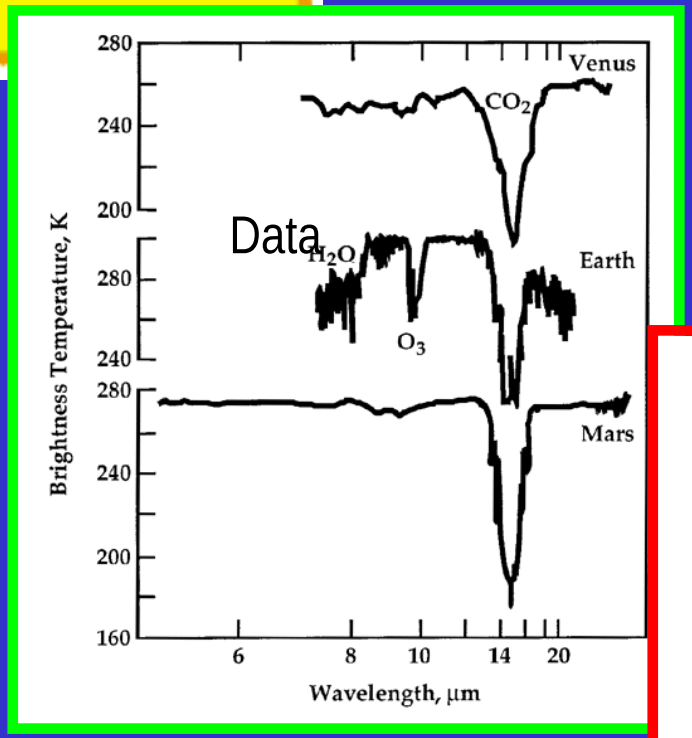
LIFE: THE HOLY GRAIL

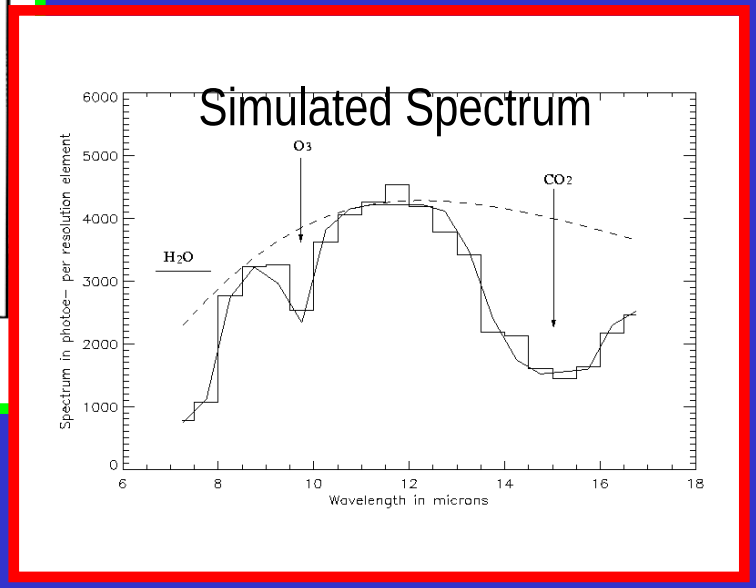
(look for water and ozone)



Venus, Earth, & Mars all have CO_2

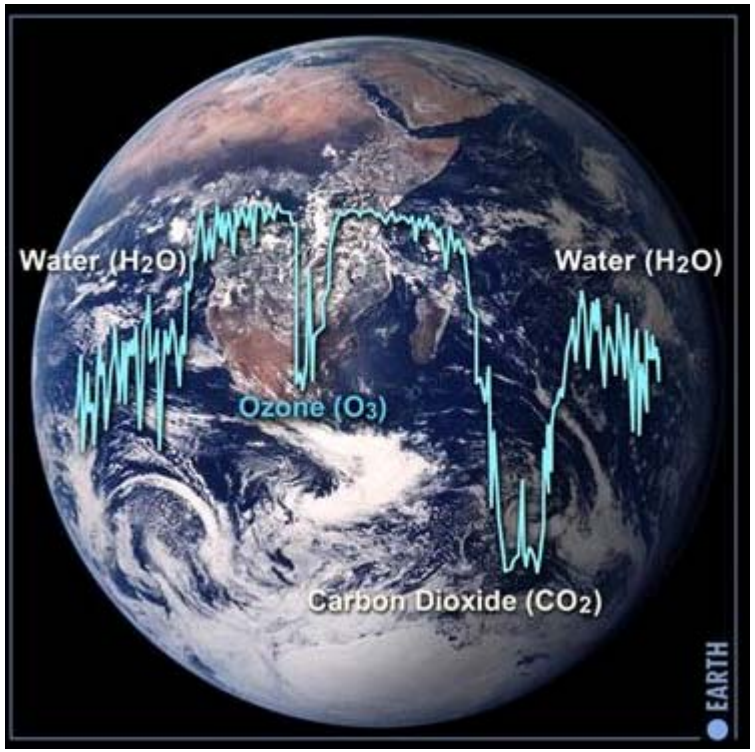
Earth has H_2O and O_3

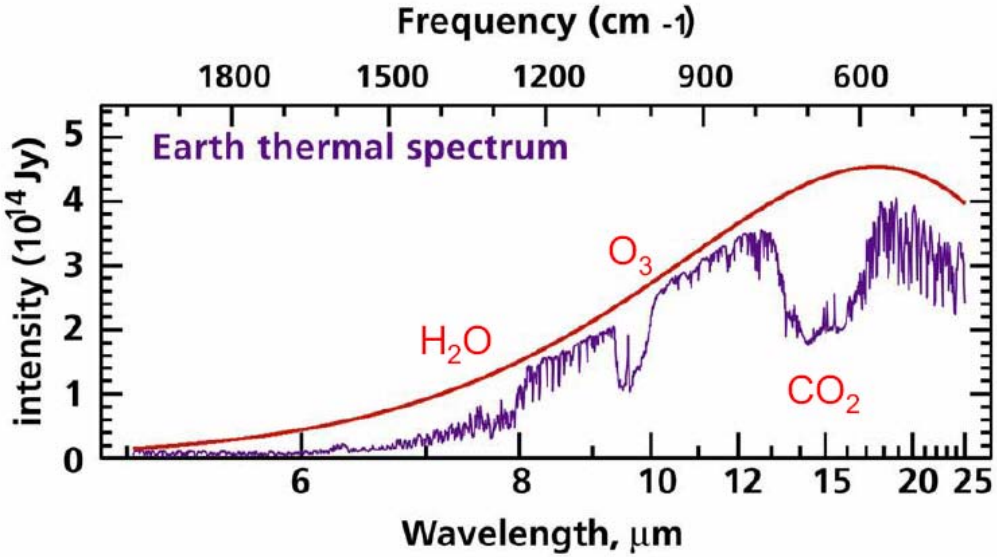




These features are in the infrared (again!)

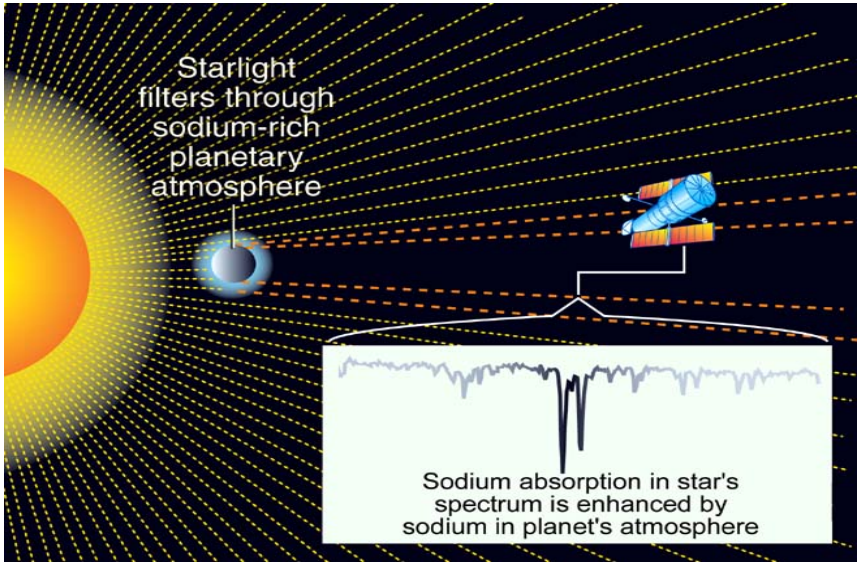
Das Ziel …

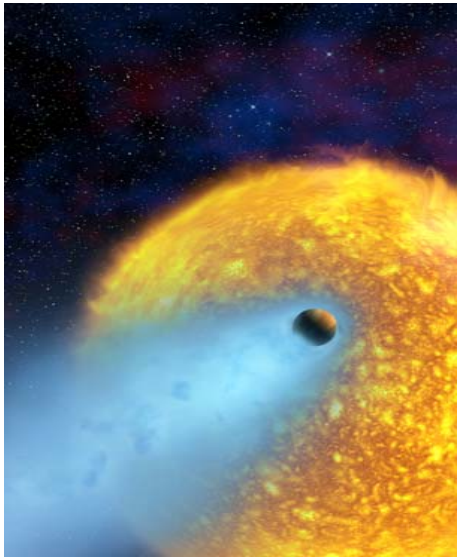




Würden "ALIENS" die Atmosphäre unseren Planeten mit einem Spektrografen untersuchen,
fänden sie reichlich
Sauerstoff, Ozon und Kohlendioxid.
Es wäre ein klarer Hinweis auf biologisches Leben,
sofern sie es als solches einstufen und erkennen.
(Bild: ESA 2001/Illustration von Medialab)

HD 209458b





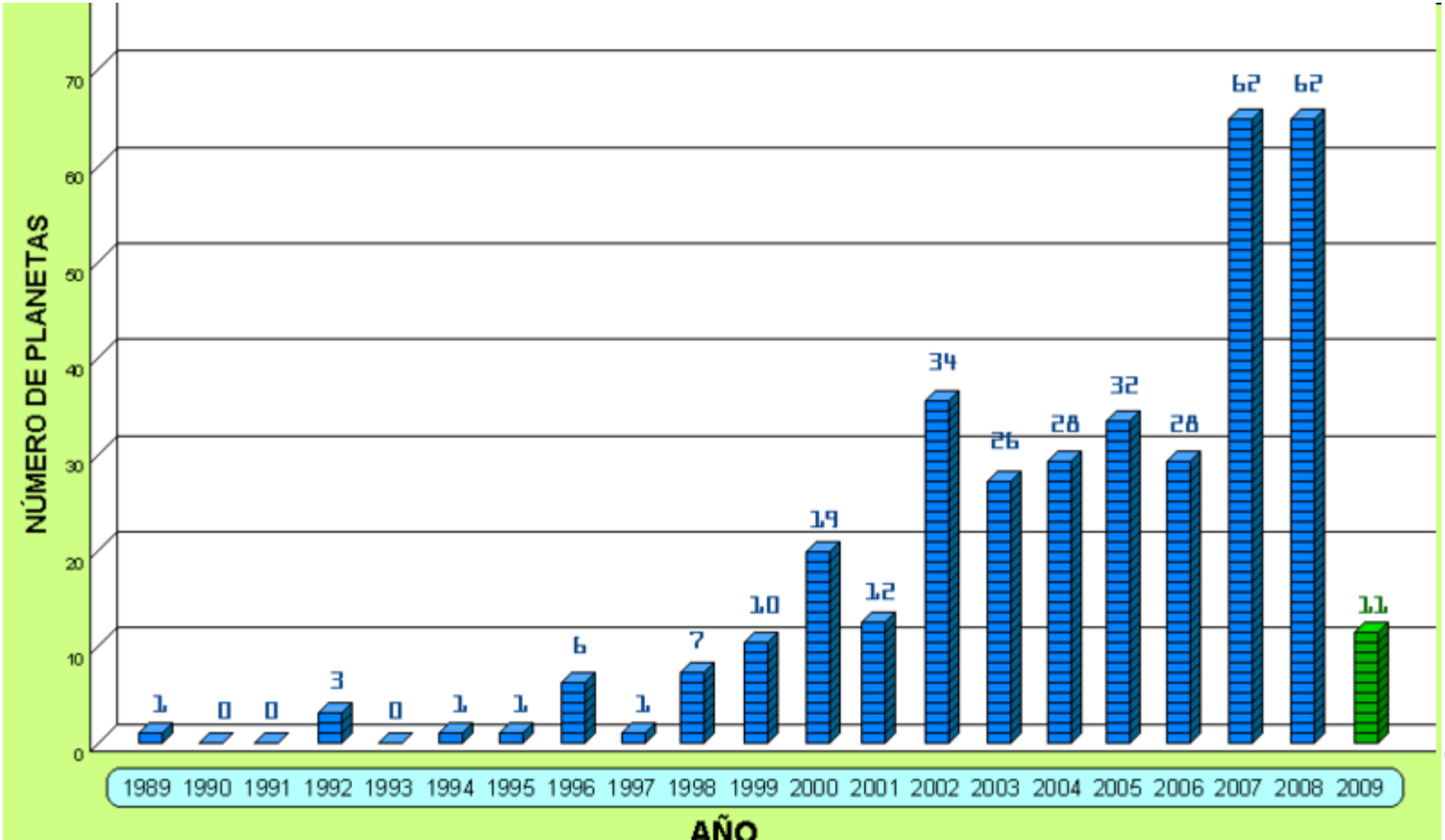
Erste Beobachtung einer extra-solaren Planetenatmosphäre (HST)

Verlustrate: ~10^8 kg/s

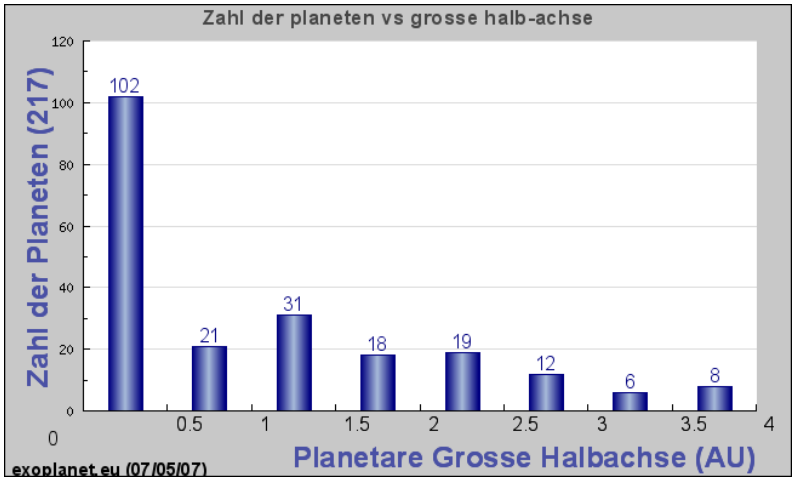
Entfernung vom Stern: ~ 7 Mio. km

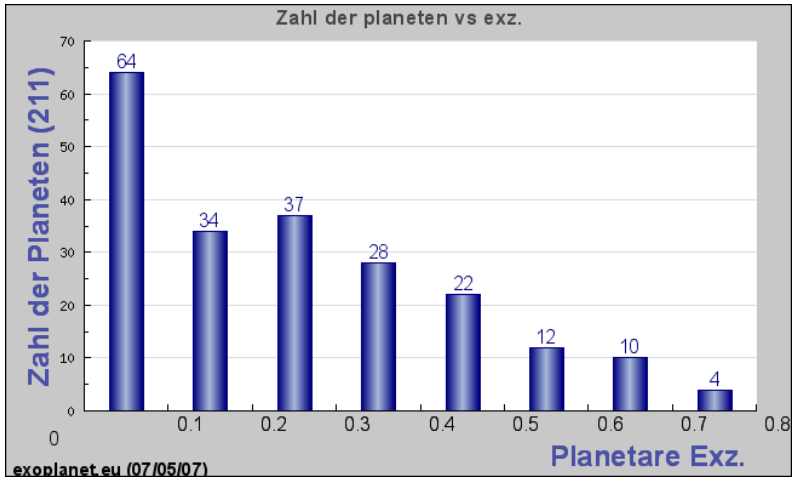
- Wasserstoff
- Kohlenstoff
- Sauerstoff
- Natrium

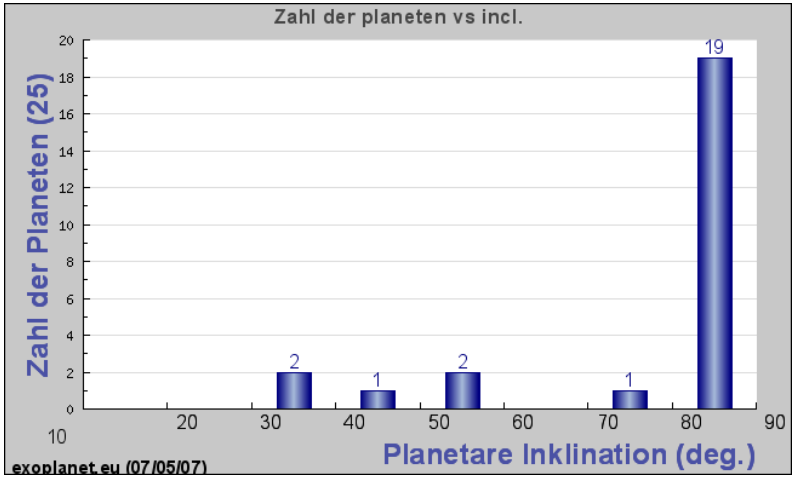
Anzahl entdeckter Exoplaneten pro Jahr									
1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	0	0	3	0	1	1	6	1	7
1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
10	19	12	34	26	28	32	28	62	62
2009									
11									

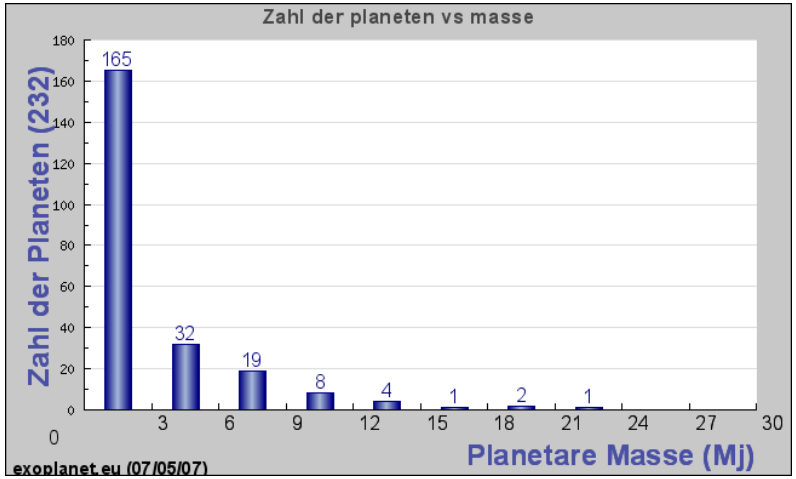


…Bahnparameter

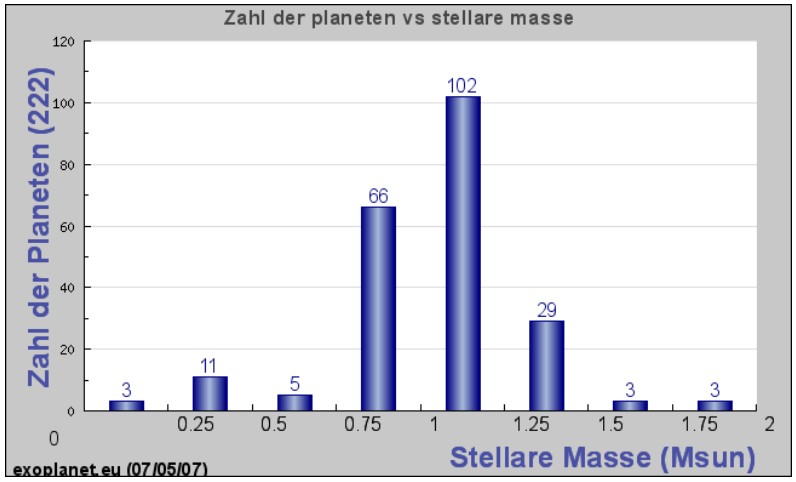


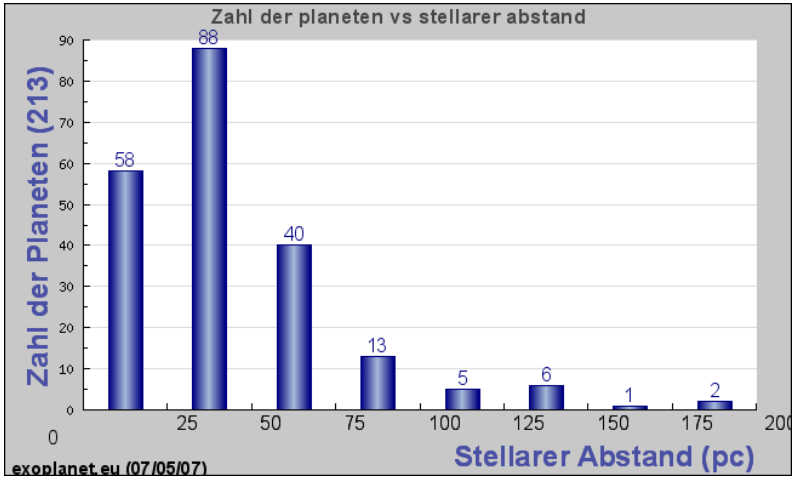






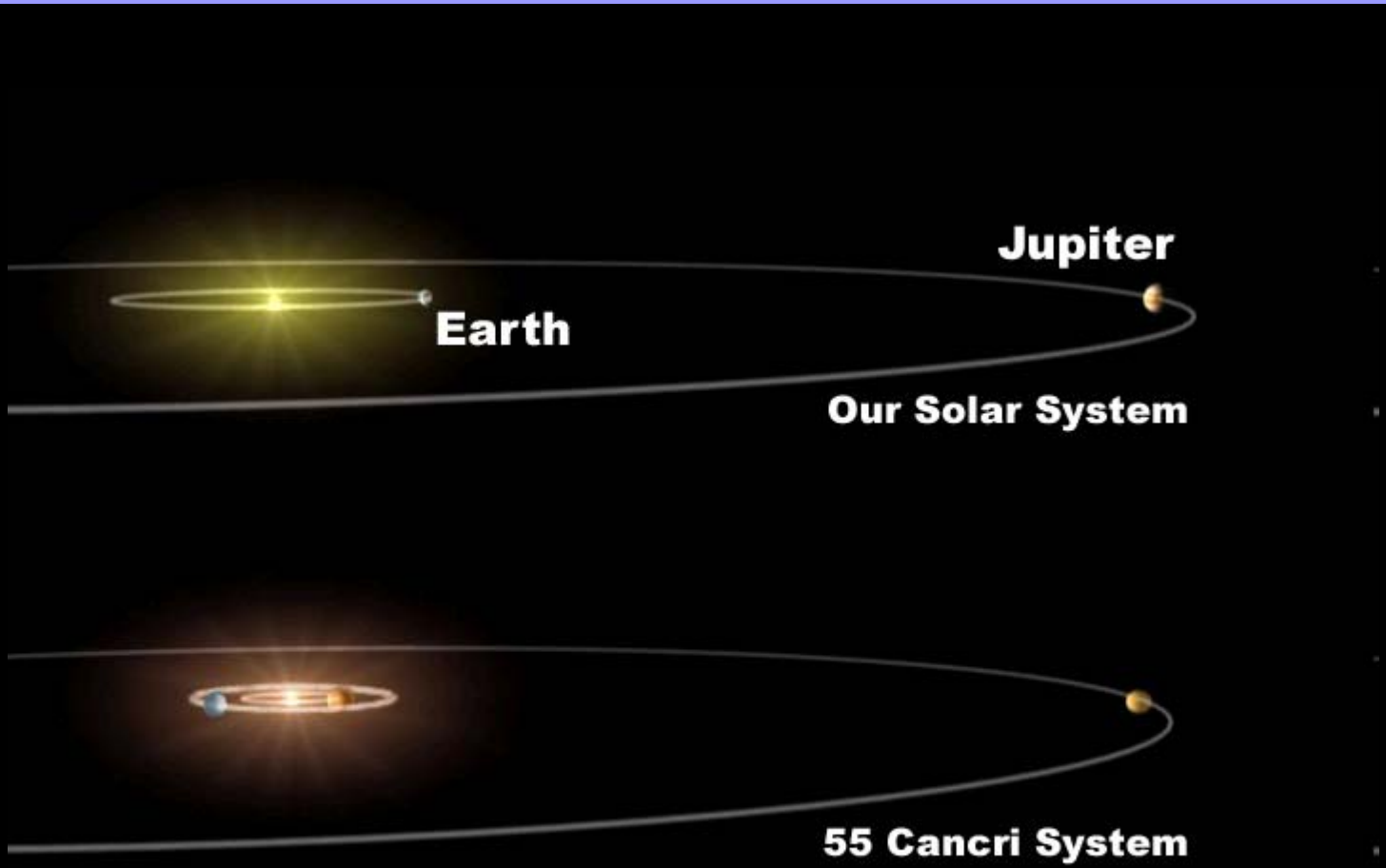
…Sternparameter





…Charakteristische Eigenschaften

- Zahlreiche Planeten mit Jupitermasse (Gasriesen) und geringer Entfernung zum Zentralstern („Hot Jupiters“)
  (durch Radialgeschwindigkeitsmethode bevorzugt entdeckt)
- Mögliche Entstehung: in großem Abstand zum Zentralstern entstanden und anschließend nach innen gewandert
- Einige Gasriesen mit hoher Exzentrizität
- Einige terrestrische Planeten ($M \sim 10\ M_E$) um Hauptreihensterne
- Über 20 Doppel- und Mehrfachsternsysteme mit Planeten


Jupiter
Earth
Our Solar System
55 Cancri System


Die Zukunft:
Interferometer im All

Pixels

finer

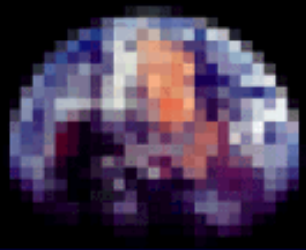
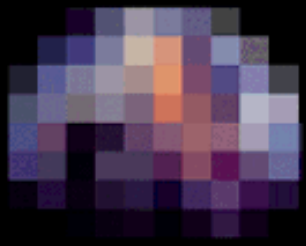
coarser

Telescope

bigger

smaller

Pixel / Diameter	Pixel size @ planet (km)	Image	Interferometer Requirements	Collecting Area	Baseline
400	32		IR Visible	144 km² 1,296 km²	100,000 km 5,000 km
100	128		IR Visible	0.64 km² 5.76 km²	24,000 km 1,200 km

Pixel / Diameter	Pixel size @ planet (km)	Image	Interferometer Requirements	Collecting Area	Baseline
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1276		IR Visible	64 m² 576 m²	2,4km 120 km

In our life times?

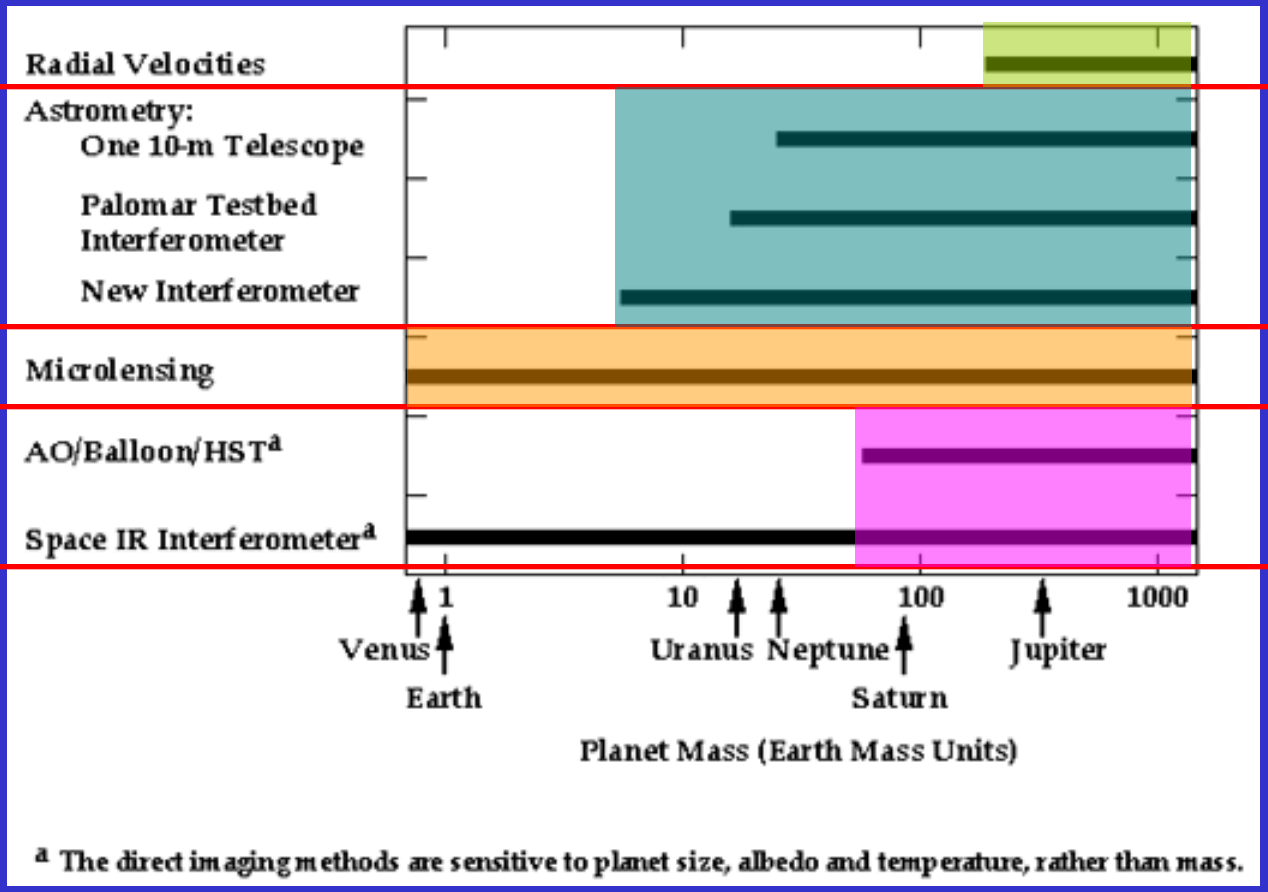
COMPARING METHODS
MASS SELECTION

Doppler Velocity

Astrometry

Lensing

Imaging



[a] The direct imaging methods are sensitive to planet size, albedo and temperature, rather than mass.

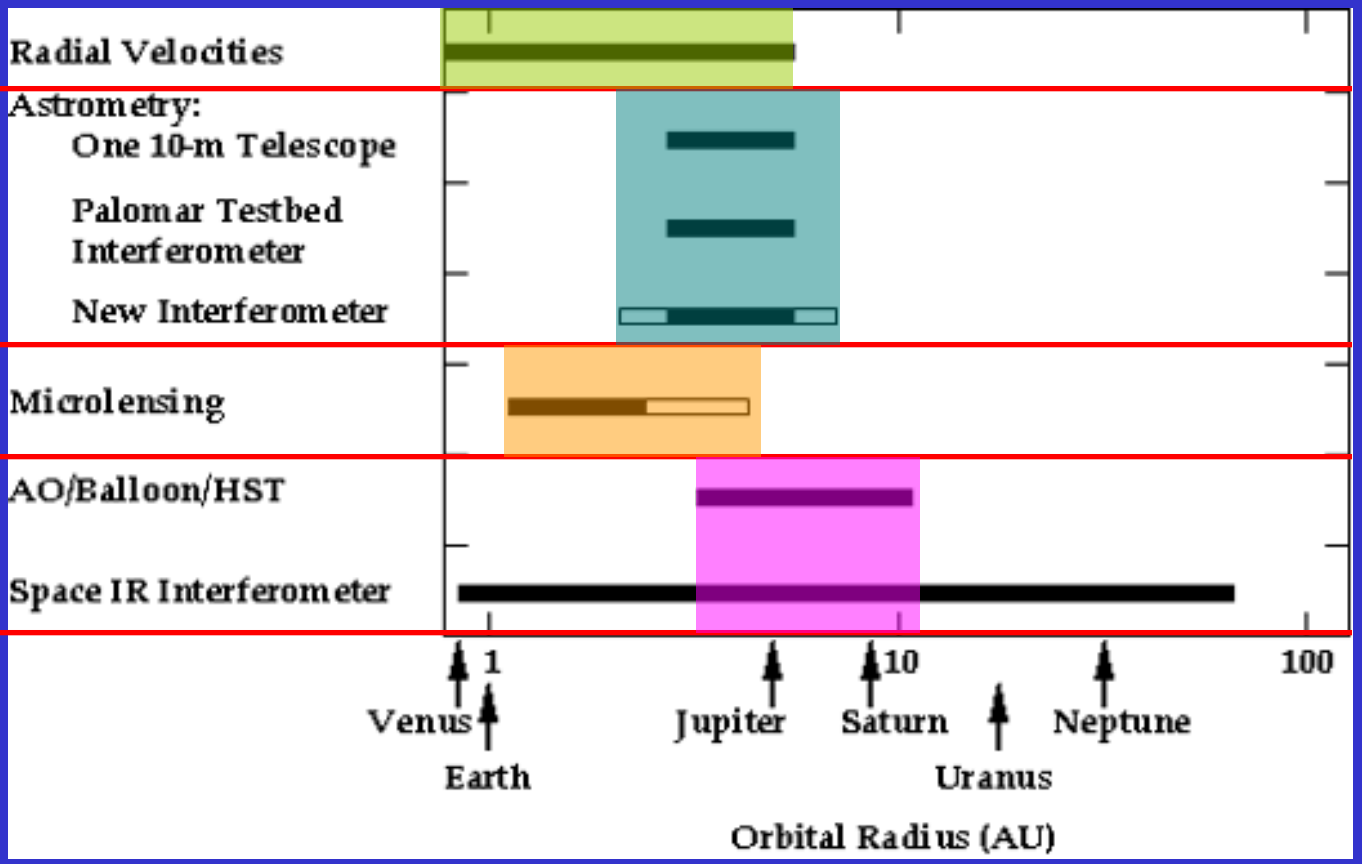
COMPARING METHODS
ORBIT SELECTION

Doppler Velocity

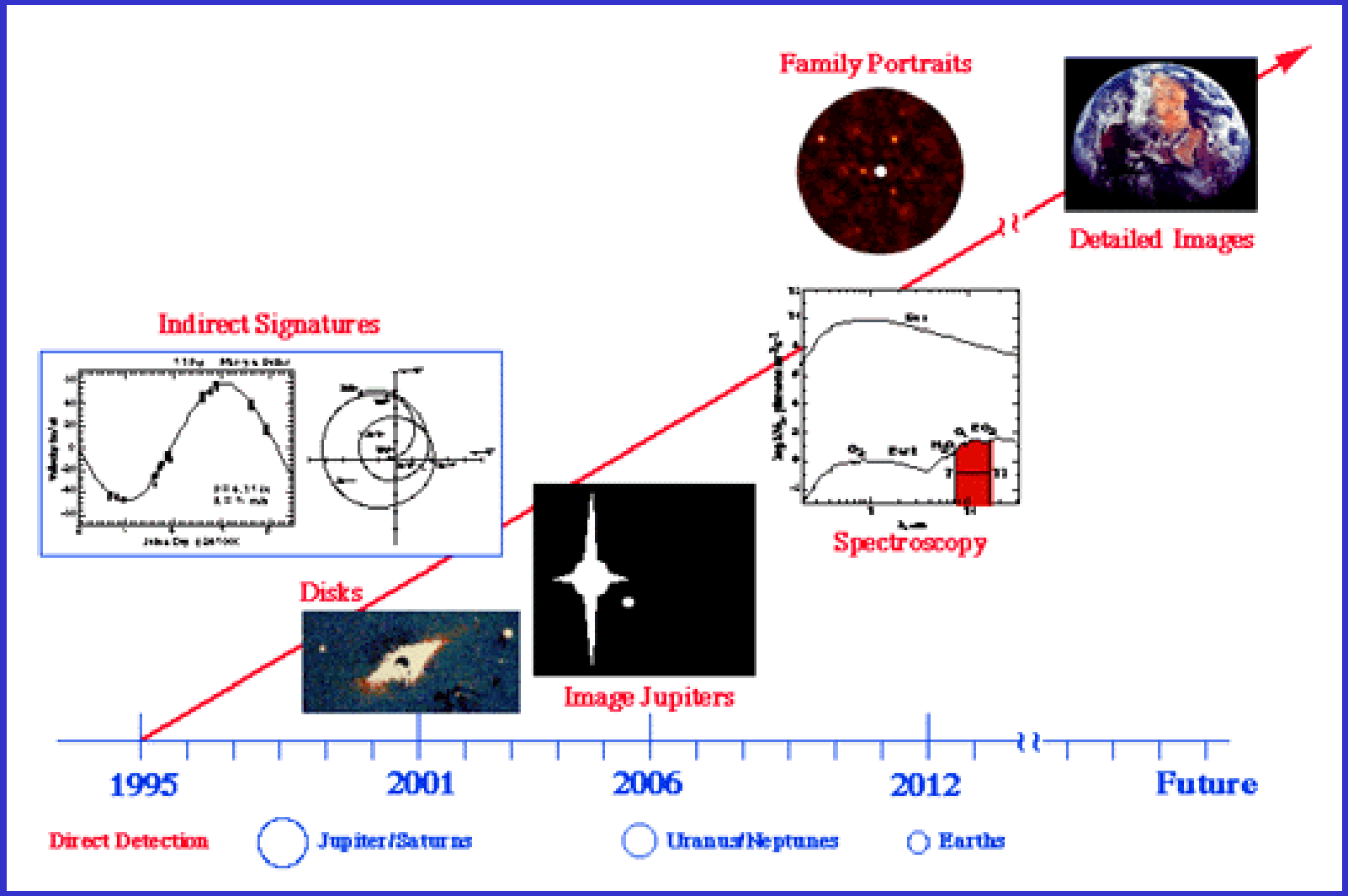
Astrometry

Lensing

Imaging



NASA's PLANET HUNTING ROADMAP

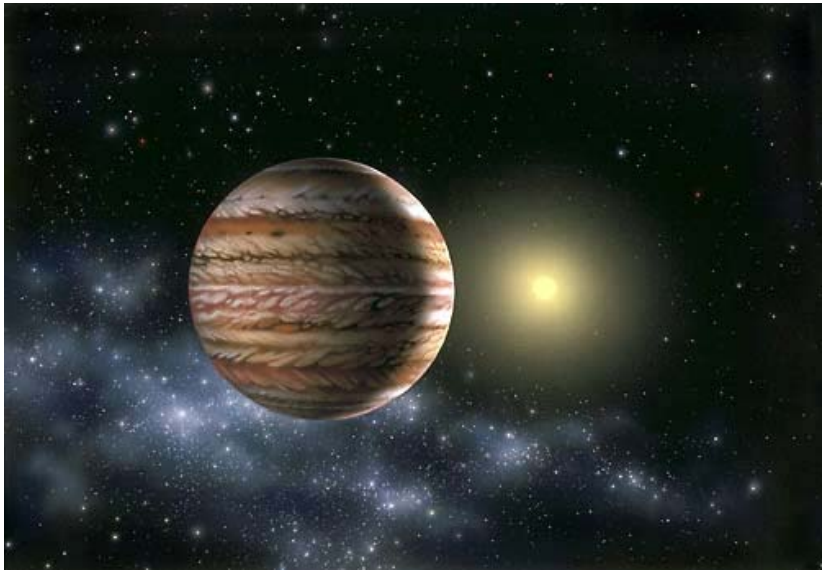


Künftige Projekte

- **Atacama Large Millimeter Array (ALMA): 2010**
  - Mm-Interferometer: direkte Entdeckung junger Gasriesen
- **Kepler: 2007**
  - Planetenbedeckungen
- **James Webb Space Telescope (JWST): 2011**
  - Direkte Abbildung sich bildender Gasriesen ?
- **Space Interferometry Mission (SIM): 2009**
  - Astrometrie
- **Terrestrial Planet Finder (TPF): 2012**
  - Koronagraph
  - IR-Interferometer
- **Terrestrial Planet Imager (TPI): 2015**
  - Entweder ein Koronograph im sichtbaren Licht
  - Oder ein Infrarot-Interferometer mit langer Basislänge

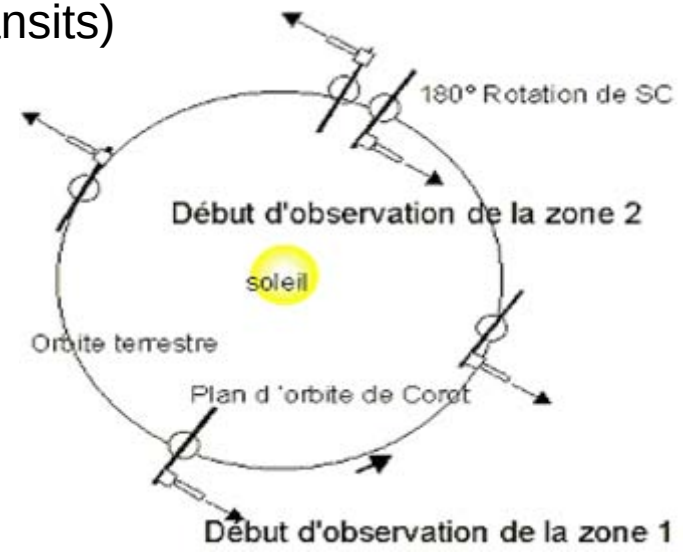
…Geplante Missionen

- BOSS (Big Occulting Steerable Satellite)
- Darwin
- GAIA (Global Astrometric Interferometer for Astrophysics)
- GEST
- Hypertelescope Projects
- JWST
- Kepler
- MOST
- Origins Billion Star Survey
- SPIRIT
- SIM (Space Interferometry Mission)
- TPF (Terrestrial Planet Finder)
- UMBRAS



COROT

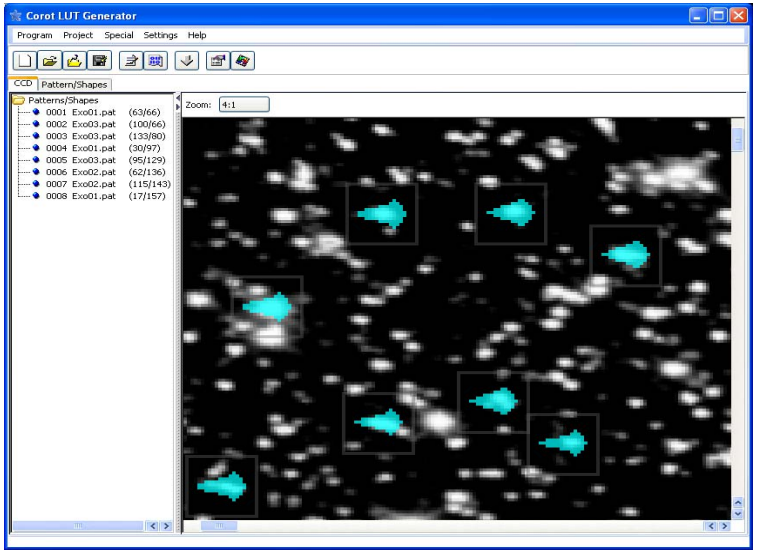
COROT (Convection Rotation and planetary Transits)

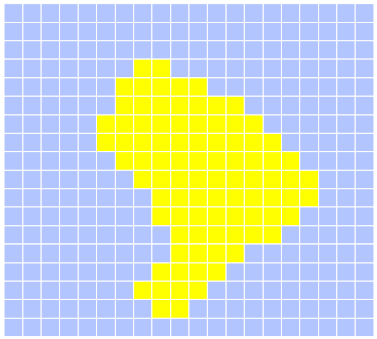


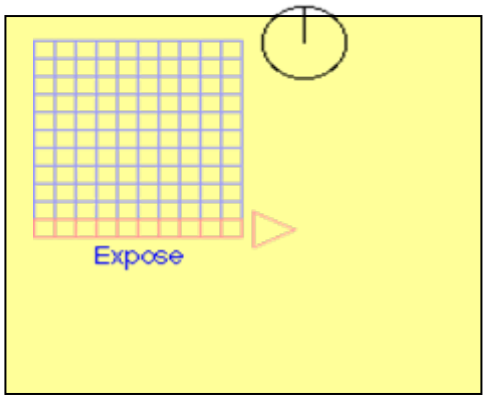
- CNES, ESA Mission - Start Oktober 2006
- Dauer: ca. 2 ½ Jahre
- Polare Erdumlaufbahn in 830 km Höhe
- Messung der Strahlungsintensität von Sternen im sichtbaren Wellenlängenbereich
- Sternpulsationen
- Planetendurchgänge

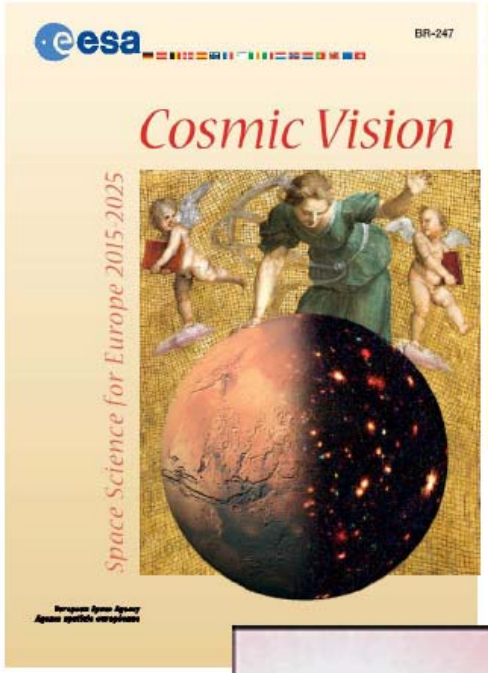
COROT

- Spiegelteleskop (Brennweite: 1080 mm; Öffnung: 27 cm; Gesichtsfeld: 2.8 × 2.8 Bogengrad)
- Mit Hilfe von 4 CCD-Kameras gleichzeitige Beobachtung von ca. 12.000 Sternen über einen Zeitraum von 6 Monaten
- Aufteilung des Lichts in einen grünen, blauen und roten Anteil
- Selektion von bis zu 6000 relevanten Bereichen



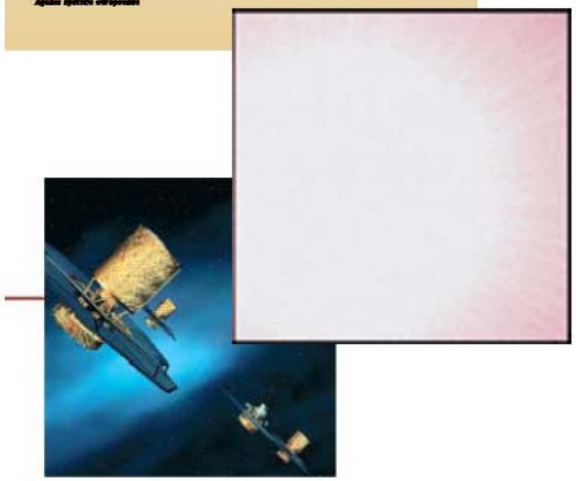






Cosmic Vision is centered around four Grand Themes:

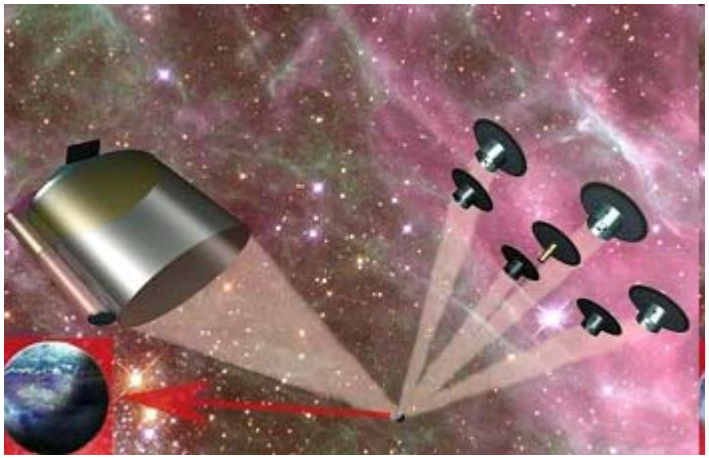
1. **What are the conditions for planet formation and the emergence of life?**
   - **From gas and dust to stars and planets**
   - **From exo-planets to biomarkers**
   - **Life and habitability in the Solar System**
2. **How does the Solar system work?**
3. **What are the Fundamental Physical Laws of the Universe?**
4. **How did the Universe originate and what is it made of?**

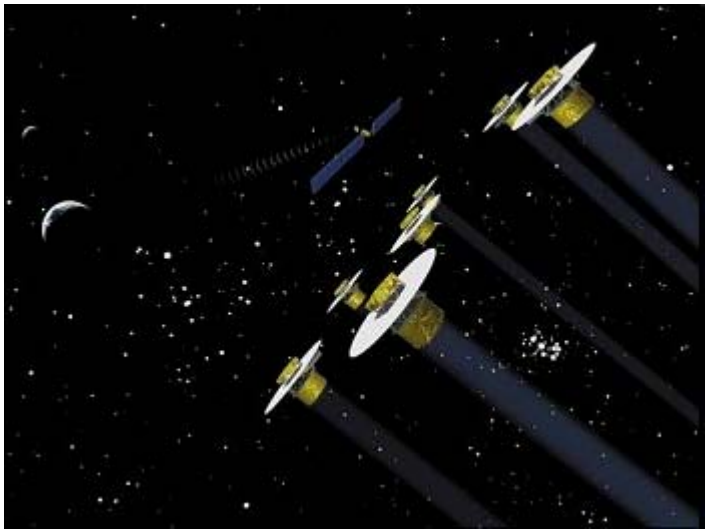


Proposed strategy:

First:	In-depth analysis of terrestrial planets (Darwin / NIRI)
Next:	Understand the conditions for star, planet and life formation (Far IR observatory / Solar Polar Orbiter)
Later:	Census of Earth-sized planets & explore Europa (Terrestrial Planet Astrometric Surveyor / Europa orbiter / lander)
Finally:	Image terrestrial exo-planet (beyond 2025) (Large Optical Interferometer)

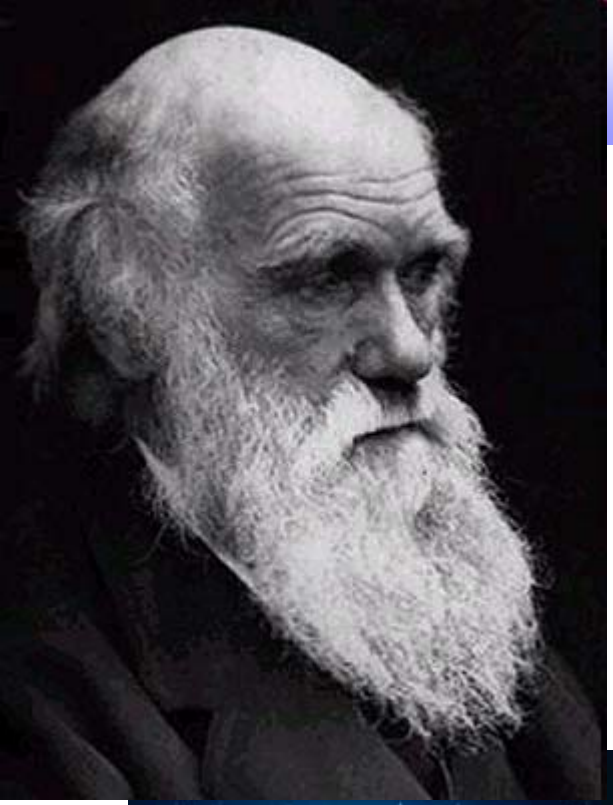
Die Zukunft

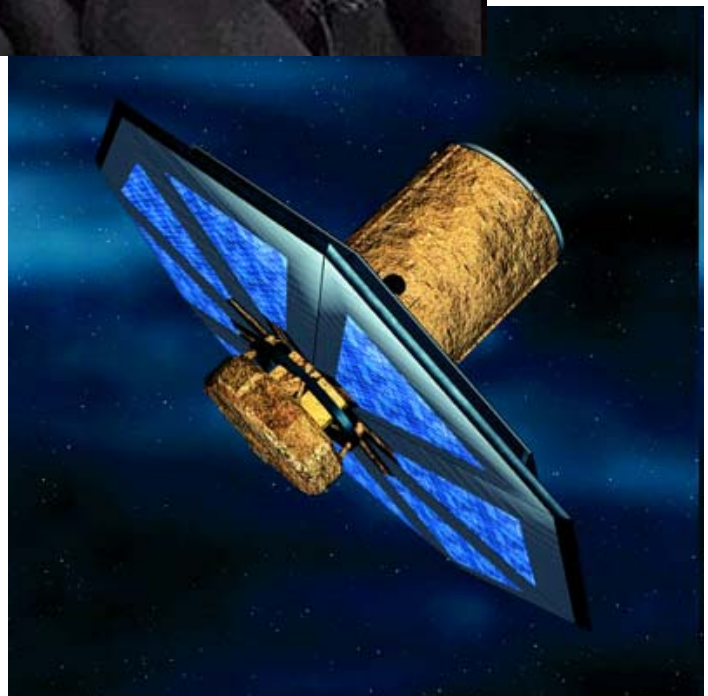




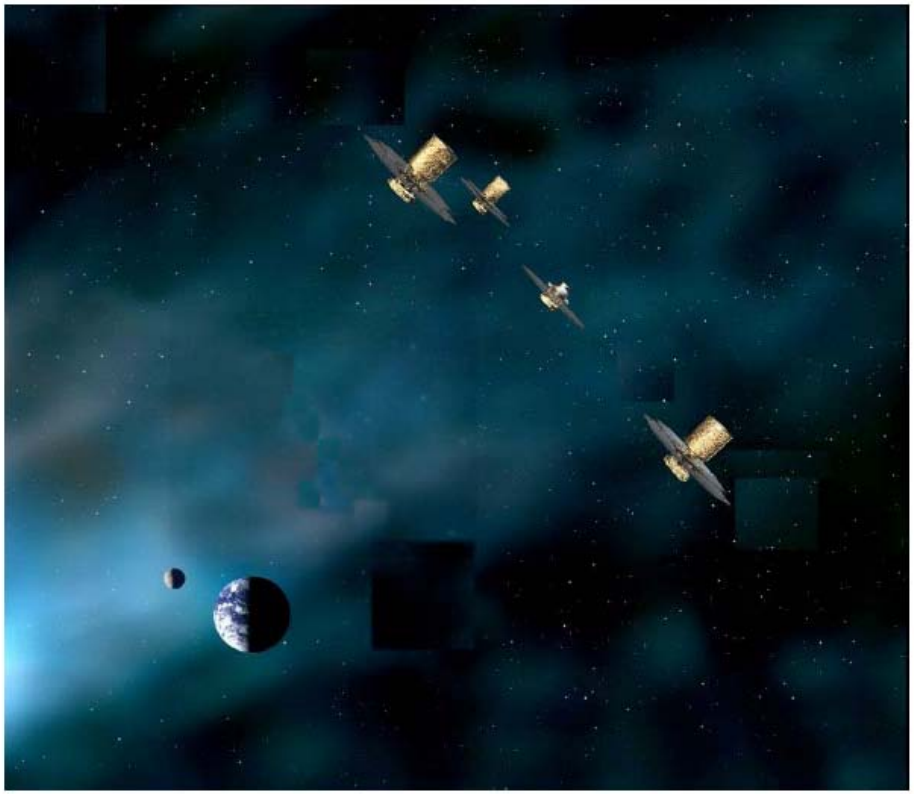
Die Suche nach erdähnlichen Planeten mit Spuren von Leben geht in der nächsten Dekade
in die entscheidende Runde. (Bild: NASA/JPL-Caltech)

Darwin

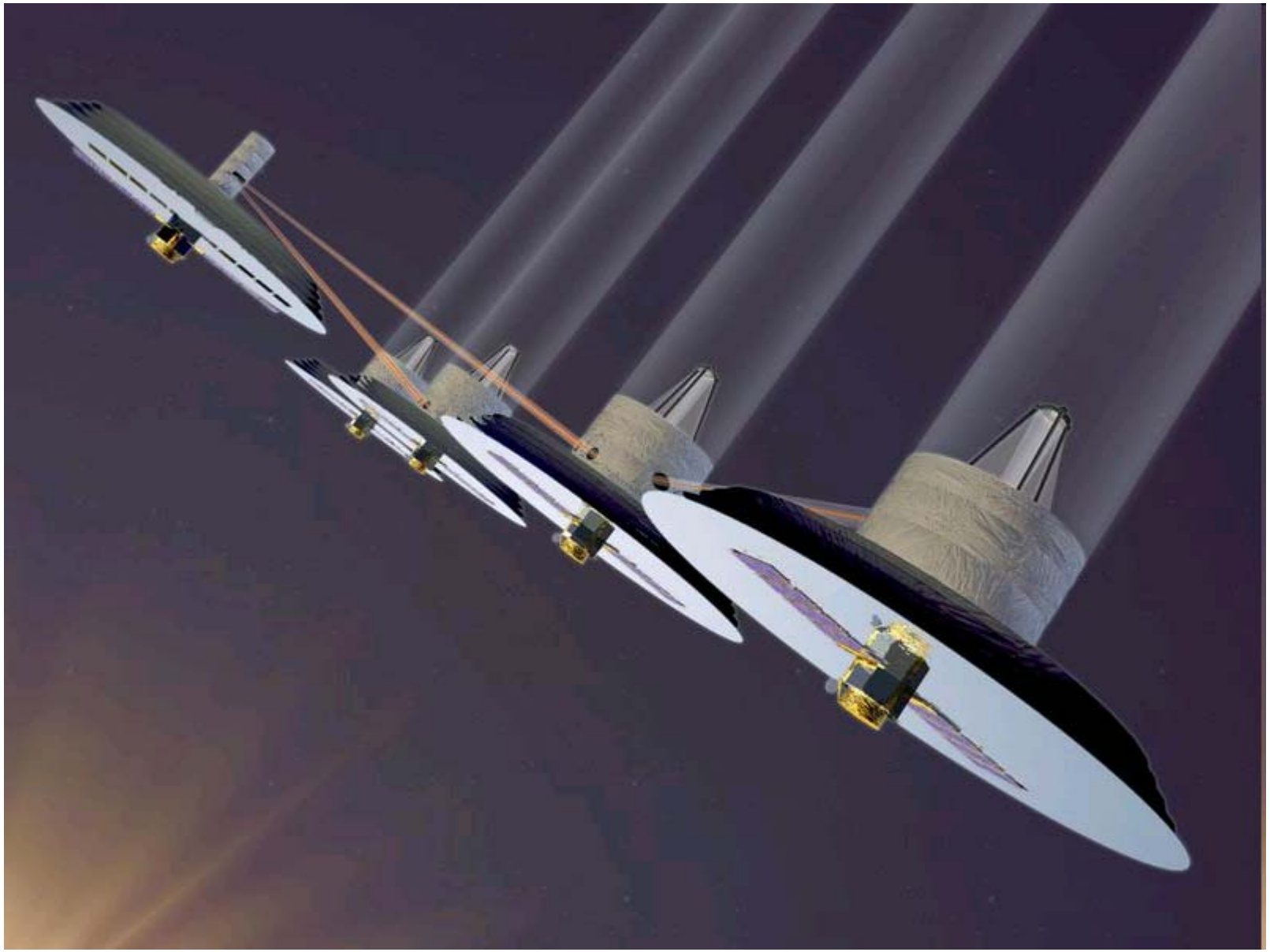




Darwin Mission
direct observation!



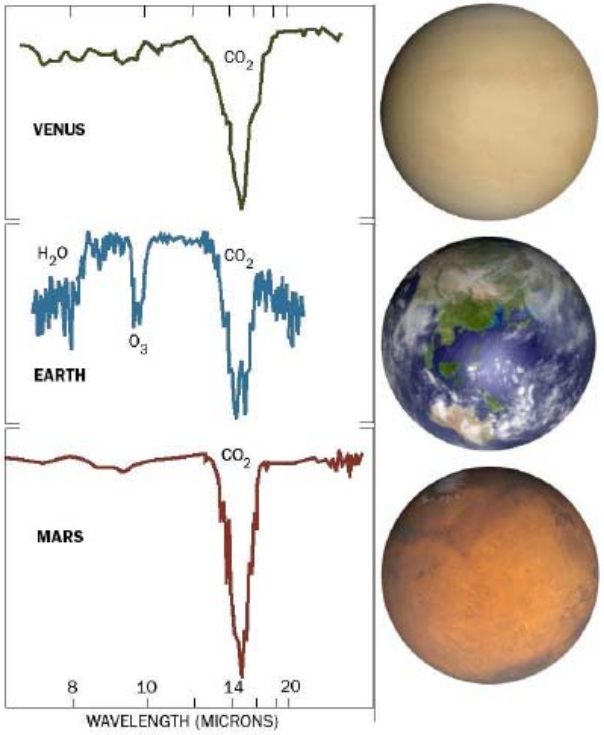
Darwin

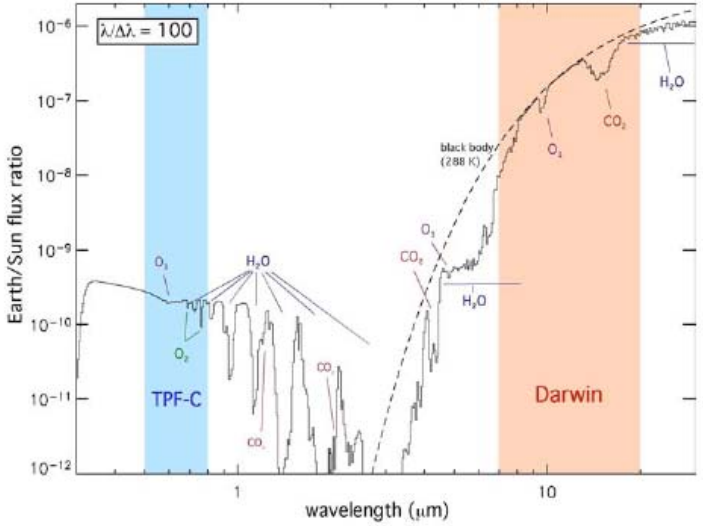


Darwin

- Terrestrial-Planet-Finder (TPF der NASA, 1.7 Milliarden Dollar) und Darwin der ESA sind Interferometrie-Superteleskope – Bildschärf entspricht der eines 100m großen Fernrohrs
- TFP, 2014/15, NASA-Teleskop-Quintett, Suche nach erdähnlichen Planeten in bis zu 50 Lichtjahren Entfernung, 100mal genauer als Hubble
- Darwin: Flotte von 8 Raumfahrzeugen, die am Lagrange-Punkt L2, 1.5 Mio km von der Erde entfernt (Gravitationskräfte halten sich dort die Waage), Raumschiffe stehen im Raum still; sollen erdähnliche Planeten aufspüren und in deren Atmosphäre nach chemischen Spuren von Leben suchen; die teleskopeigenen Spektrographen zerlegen das von den Planeten reflektierte Licht in seine farblichen Bestandteile: Temperatur und chemische Zusammensetzung der Exoatmosphären können ermittelt werden

Bio markers





The goal is to find rocky planets with an atmosphere out of photo-chemical balance.

(cf. Lederberg, 1965 and Lovelock, 1965)

Working definition:

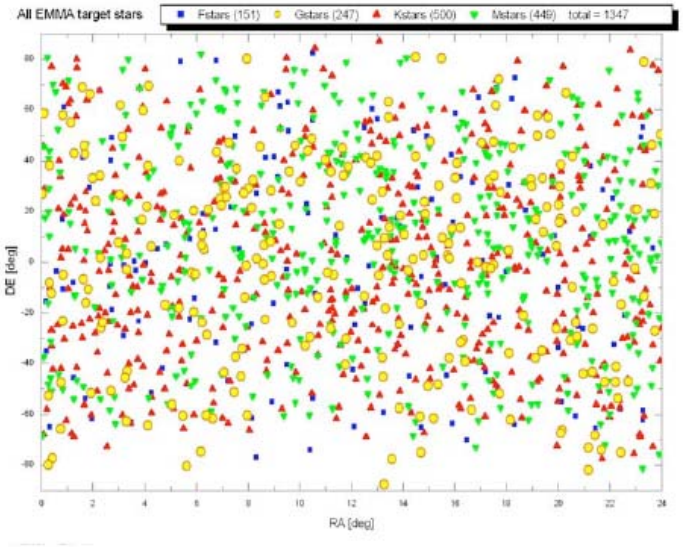
Life ≡ O_3 + H_2O + CO_2

Ideally, detect reduced molecules (CH_4, N_2O) as well

DARWIN Target catalogue

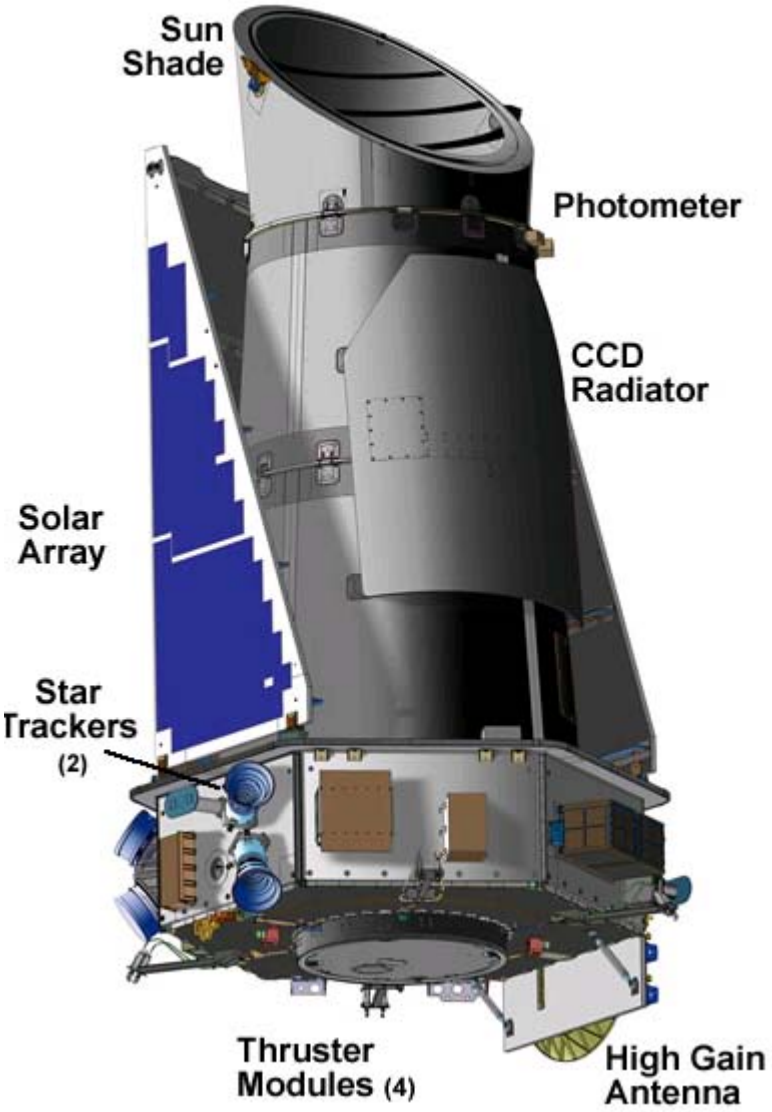
Single stars out to 25 pc:

Spec. Type	Number
F	43
G	100
K	244 (incomplete)
M	241 (incomplete)
Total:	608



All missing late K and M stars within 25 pc will be found by GAIA in ~ 1.5 year of mission time because of large parallax and sensitivity (GAIA can observe down to R = 25 magnitude)

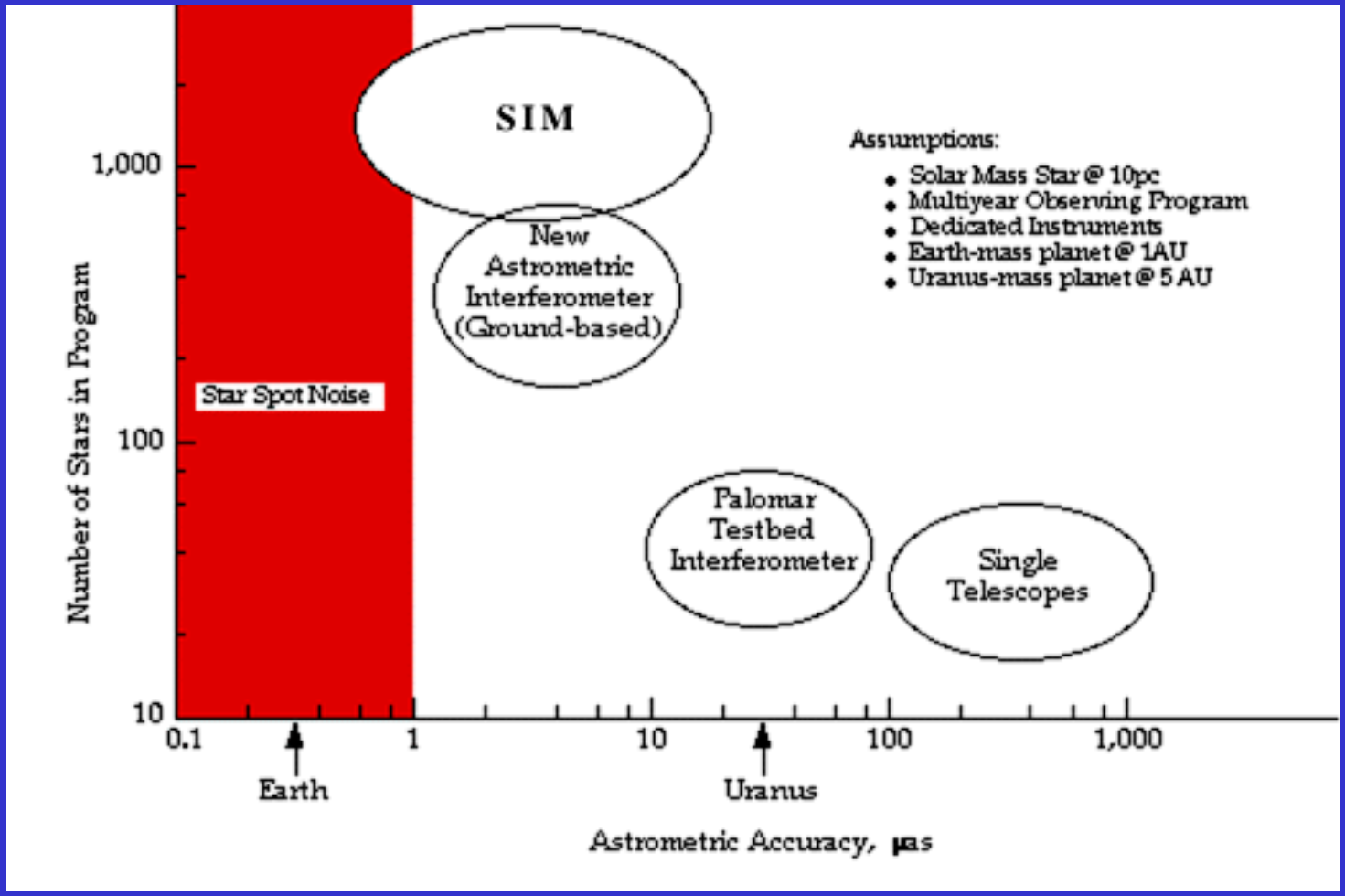
Kepler


Sun Shade
Photometer
CCD Radiator
Solar Array
Star Trackers (2)
Thruster Modules (4)
High Gain Antenna


DELTA

ASTROMETRY METHOD

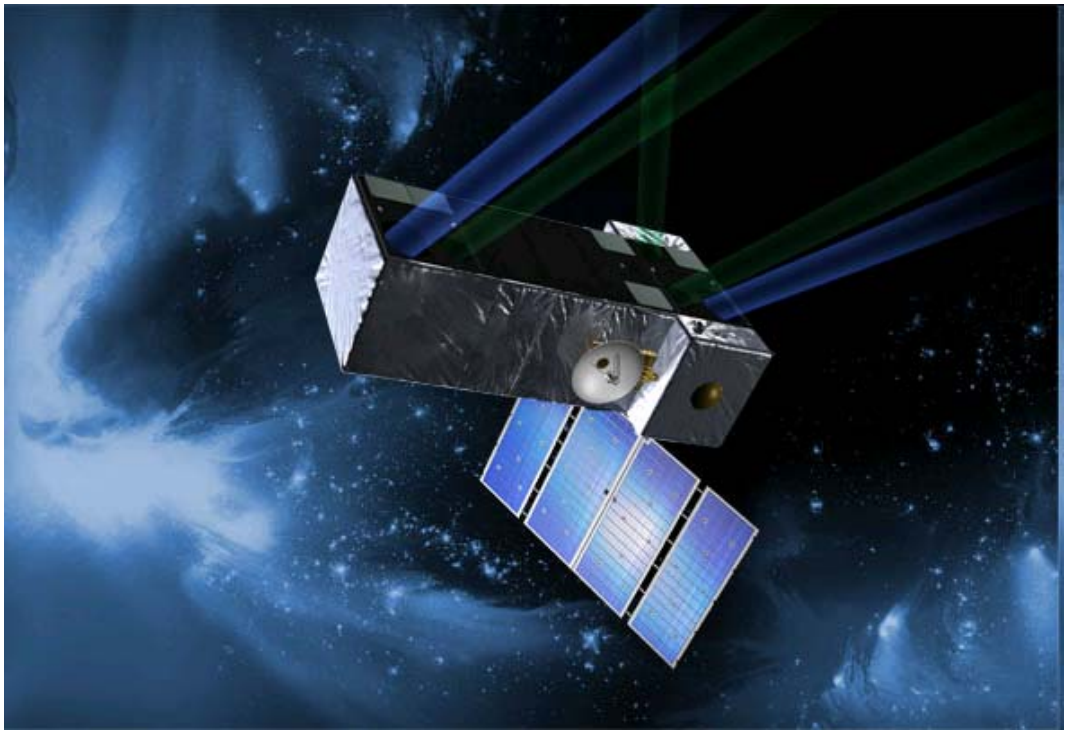
(Movement With Respect to Background Stars)



Assumes Our Solar System at 10pc (32 lys) distance.

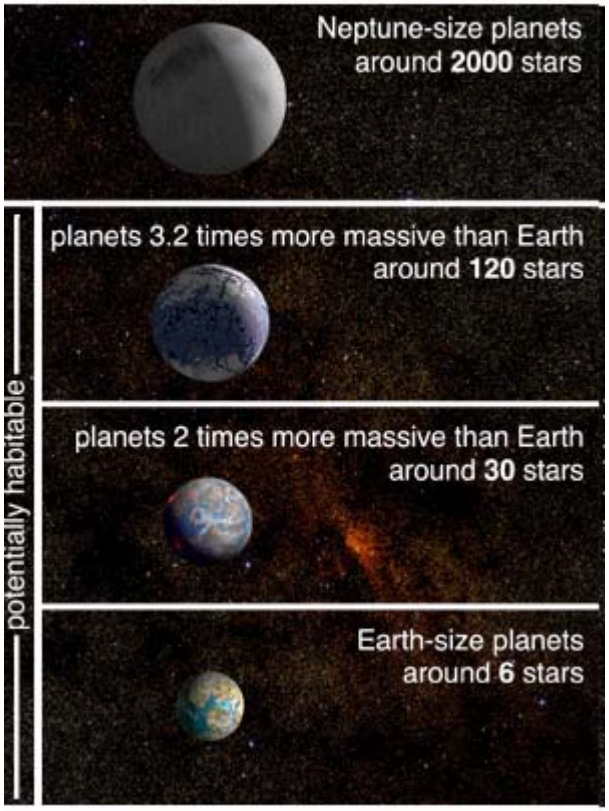
SIM Lite

ASTROMETRIC OBSERVATORY



SIM PlanetQuest

will be able to find:



Hyperteleskope: Exo Earth Imager (EEI)

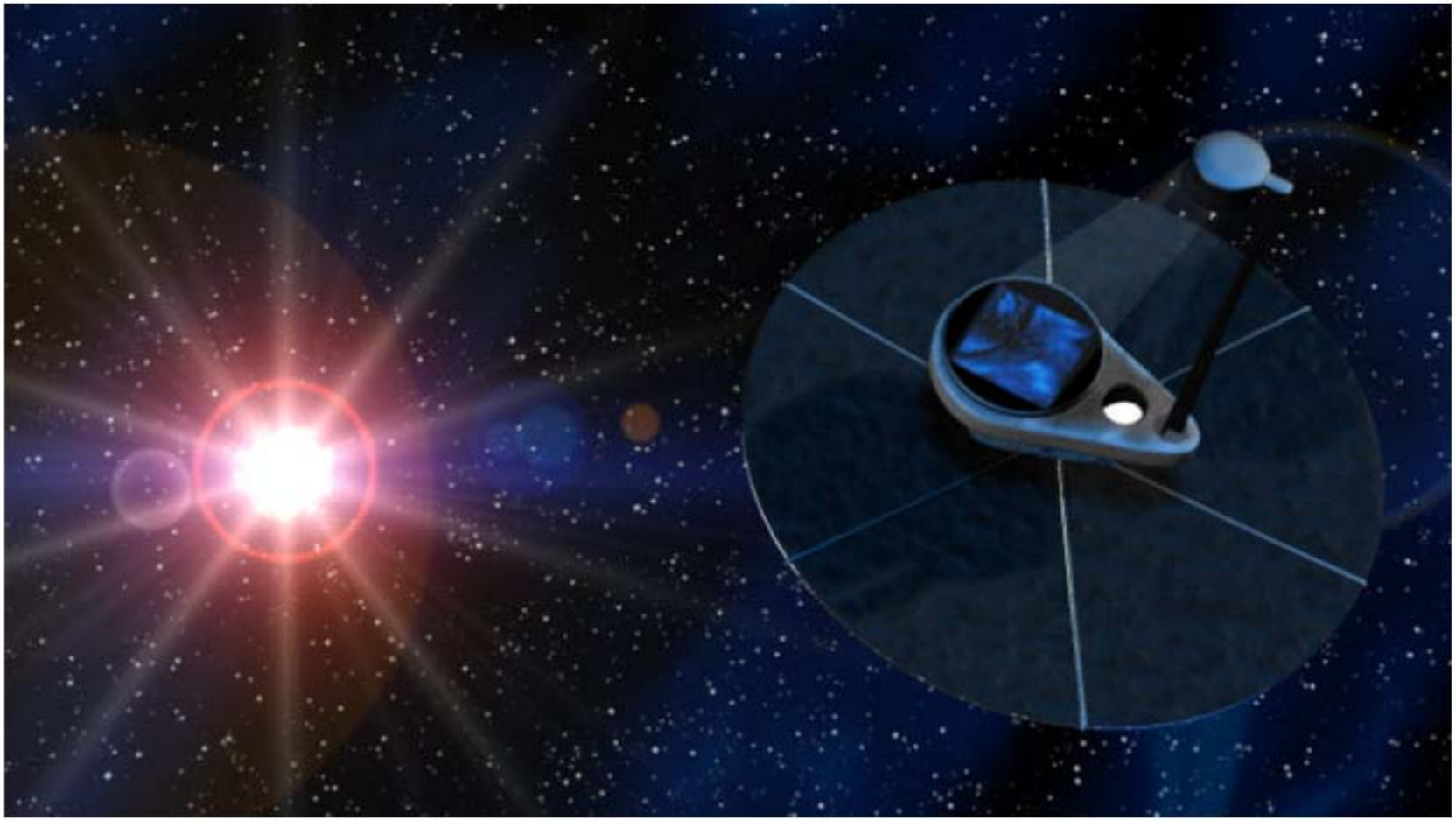
- Labeyrie arbeitet seit einigen Jahrzehnten an der Verwirklichung seines Traums:

Bilder von erdähnlichen Planeten

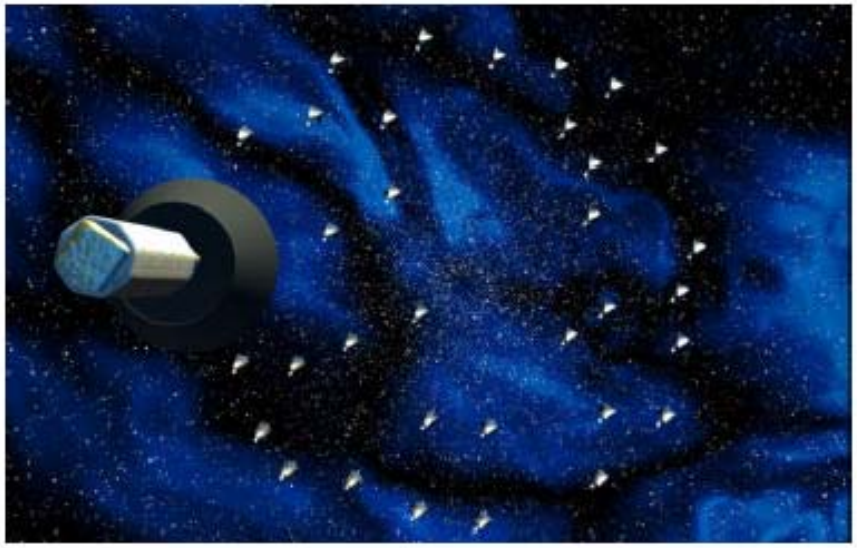
- Testläufe mit kleinen Prototypen
- 1999 erstmals vorgestellt
- Sein geplantes Observatorium mit einem Durchmesser von einigen 100 km soll sogar auf einem 30 Lichtjahre entfernten Exoplaneten noch ein Stück Land von der Größe des irdischen Amazonasgebiets und blaue Ozeane und weiße Polarkappen ablichten
- Riesenfernrohr, daß aus vielen kleinen Spiegelelementen bestehen soll: 150, mit jeweils einem Durchmesser von 3m; In geschlossener Formation soll der Durchmesser der Teleskop-Flotte 100 km betragen und im All ein Gebiet von 8000 Quadratkilometern abdecken

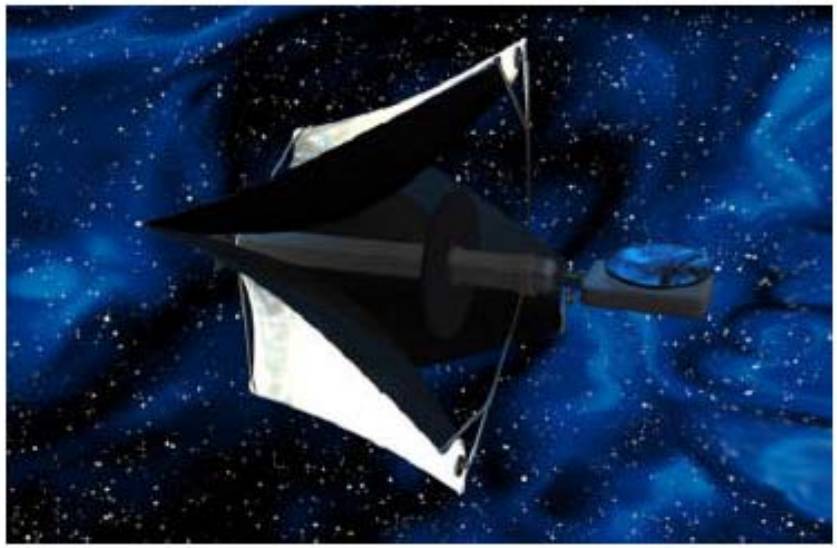
Hyperteleskope

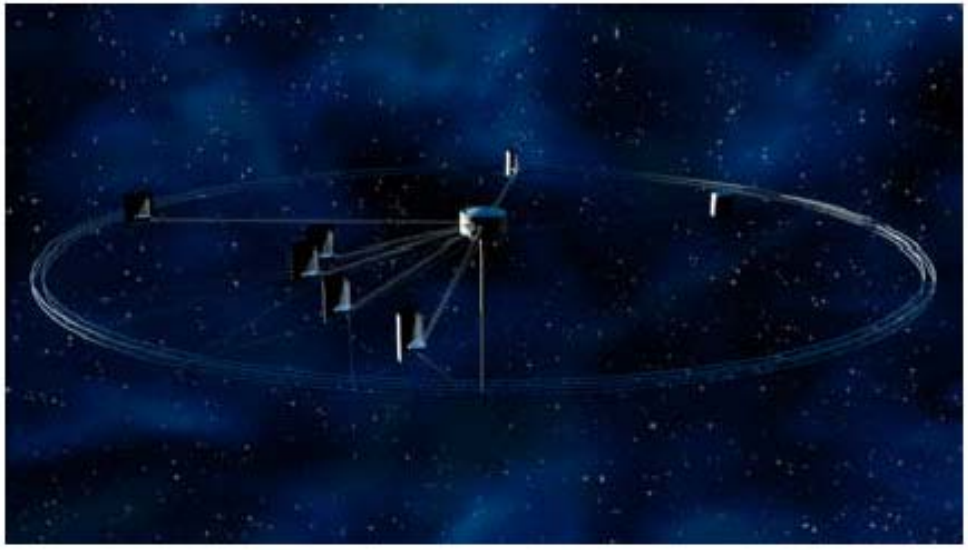
Antoine Labevrie

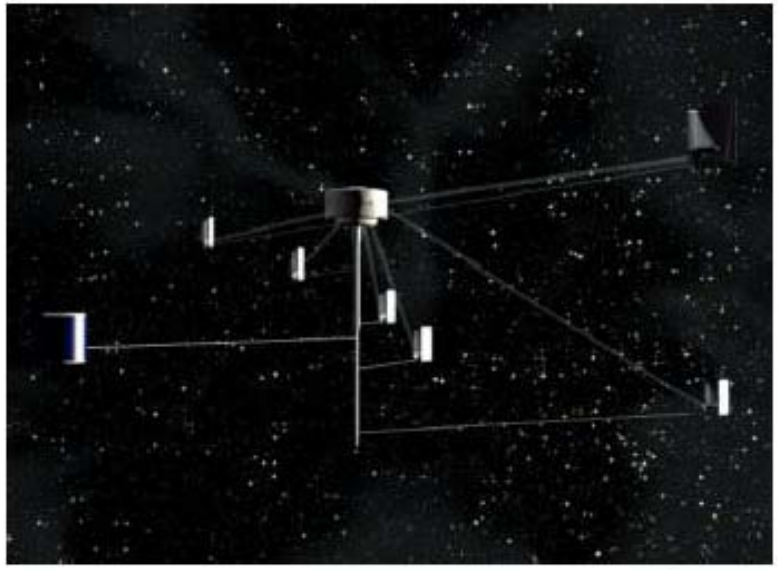


Hypertelescopes










Weiter geht‘s im Wintersemster …
(Neues zur Kosmologie, etc.)