

EXOPLANETAS

Tabaré Gallardo, 29 de setiembre de 2015

Hace unos 2300 años...

- *"Hay infinitos mundos tanto similares como distintos del nuestro"*. Epicuro.
- *"No puede haber mas mundos que uno"*. Aristóteles.

Hoy

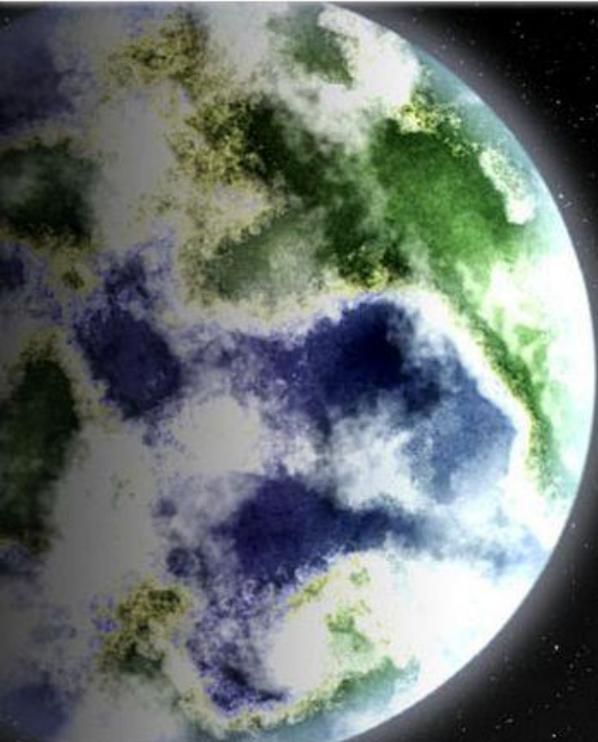
exoplanets.org

Exoplanets
Data Explorer

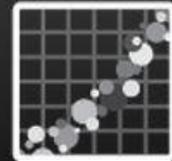
Methodology
and FAQ

Exoplanets
Links

California
Planet Survey



Table



Plots

1618

EOD Planets

Planets with good orbits listed in the Exoplanet Orbit Database

24

Other Planets

Including microlensing and imaged planets

1642

Total Confirmed Planets

3787

Unconfirmed Kepler Candidates

5429

Total Planets

Confirmed planets + Kepler Candidates

The Exoplanet Data Explorer is an interactive table and plotter for exploring and displaying data from the Exoplanet Orbit Database. The Exoplanet Orbit Database is a carefully constructed compilation of quality, spectroscopic orbital parameters of exoplanets orbiting normal stars from the peer-reviewed literature, and updates the Catalog of nearby

Nuestra galaxia

300.000 millones de estrellas



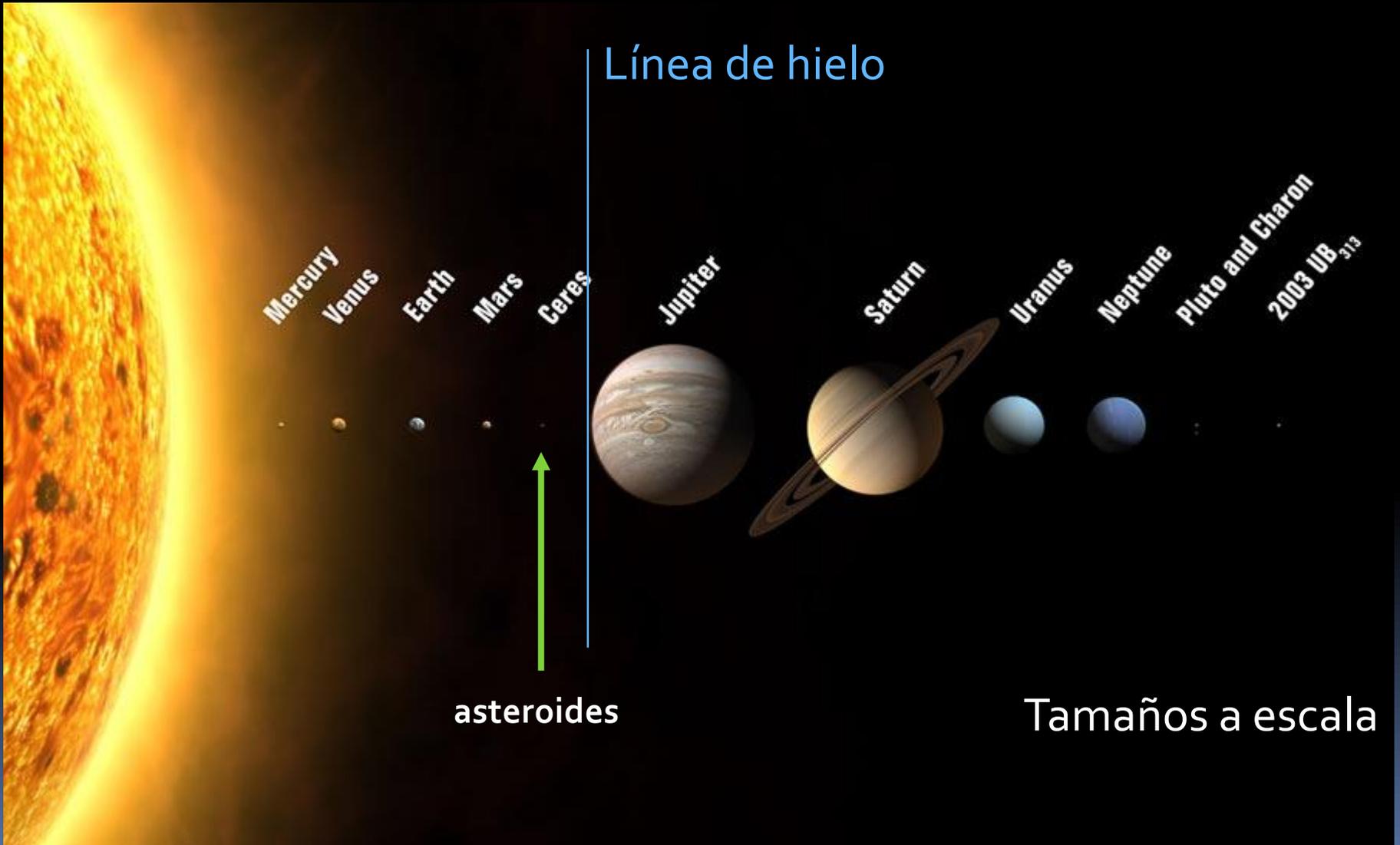
Our Planet Hunting Neighborhood

Sun →

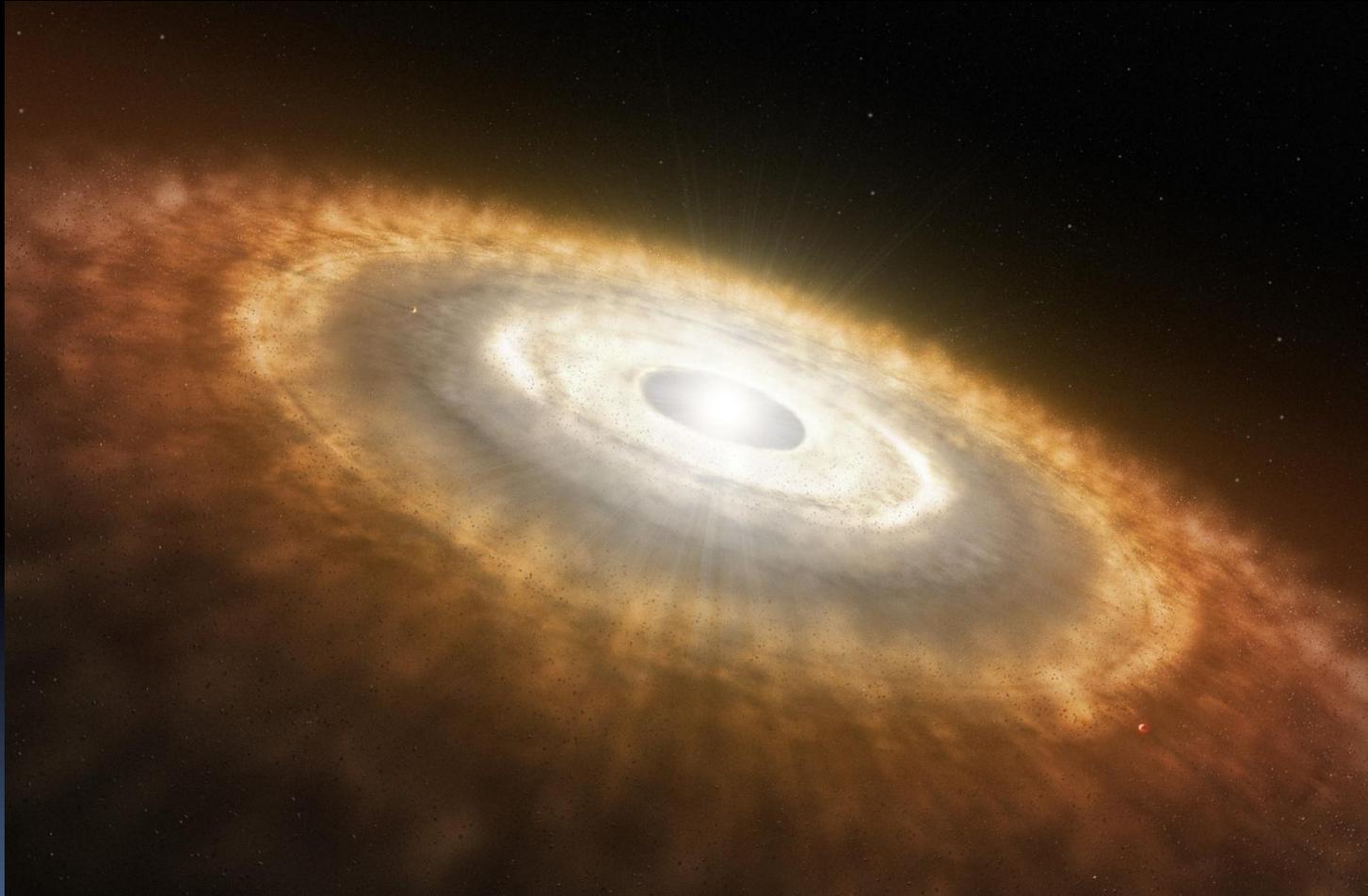
Most of the planets
found to date lie
within about 300
light-years from
our Sun.

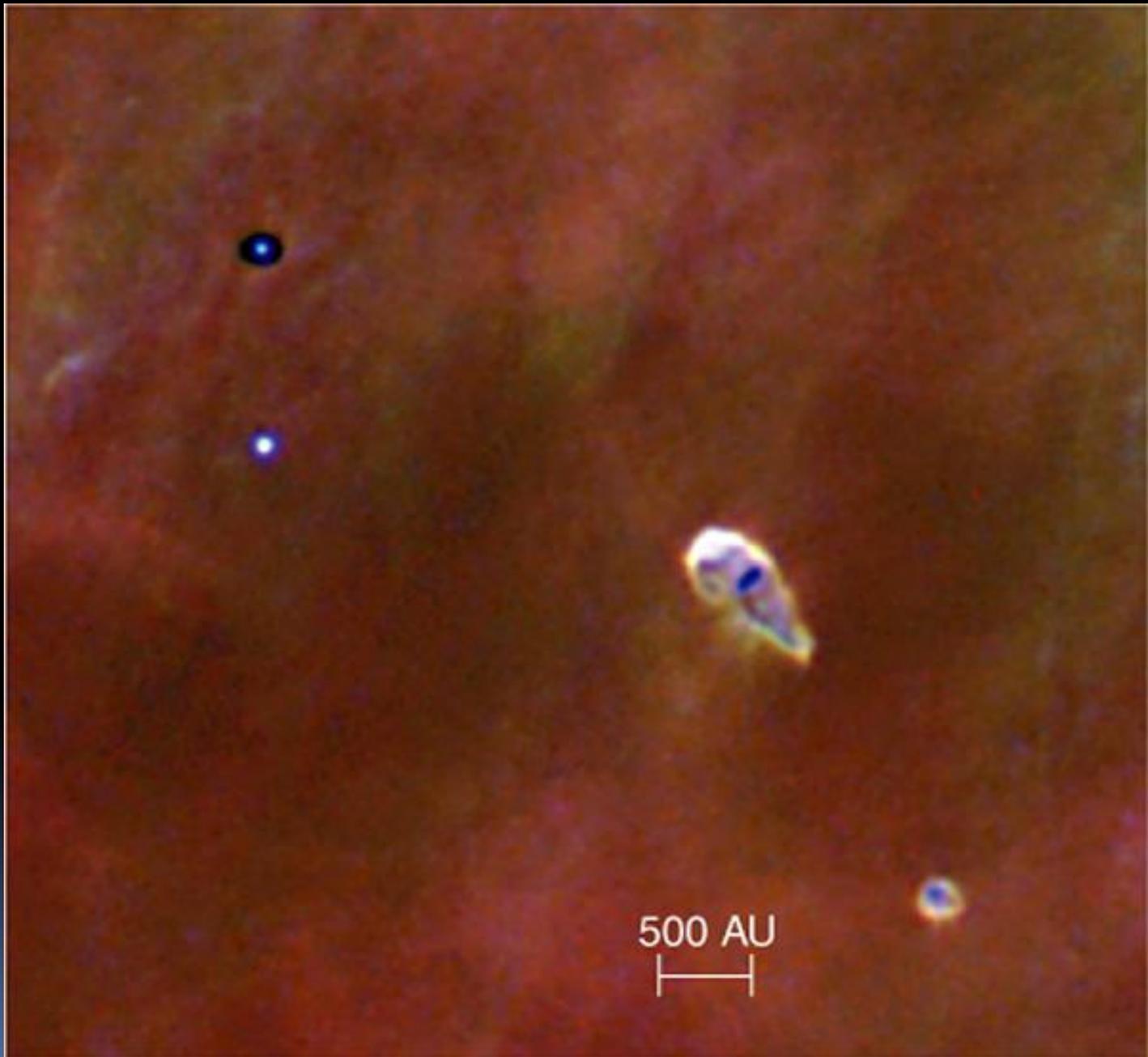
Sistema Solar

Mundos rocosos, gaseosos y helados



Nebulosa protoplanetaria







Protoplanetary Disks in the Orion Nebula HST • WFPC2

NASA, J. Bally (University of Colorado), H. Throop (SWRI),
and C.R. O'Dell (Vanderbilt University) • STScI-PRC01-13

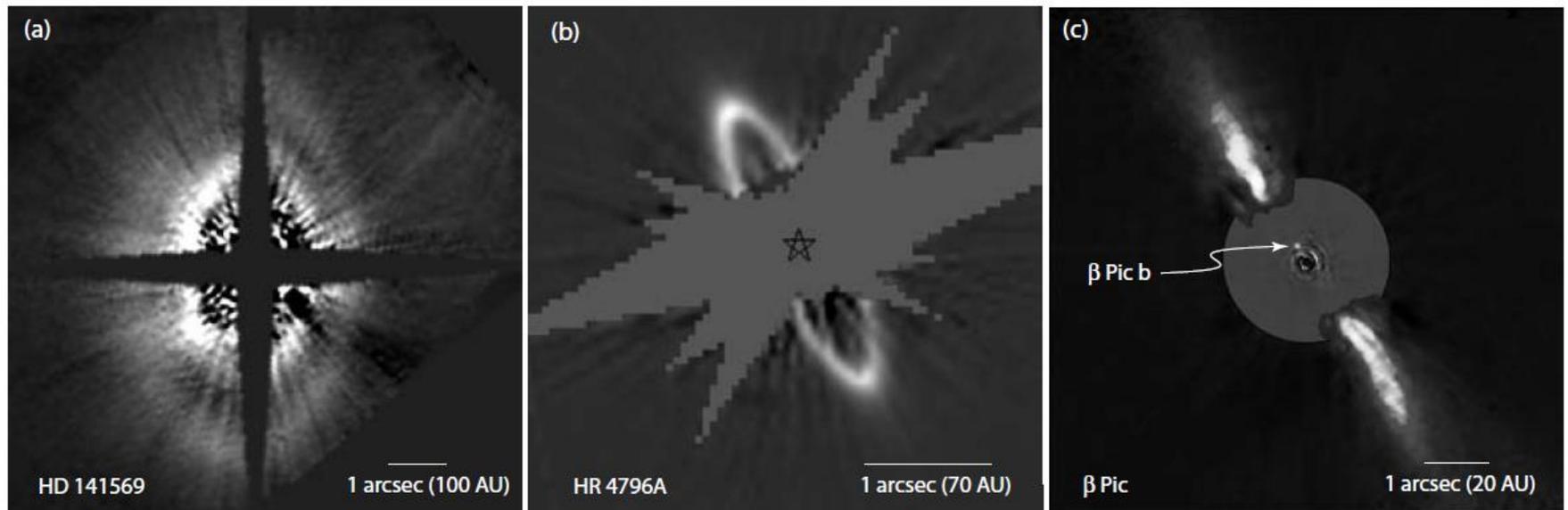
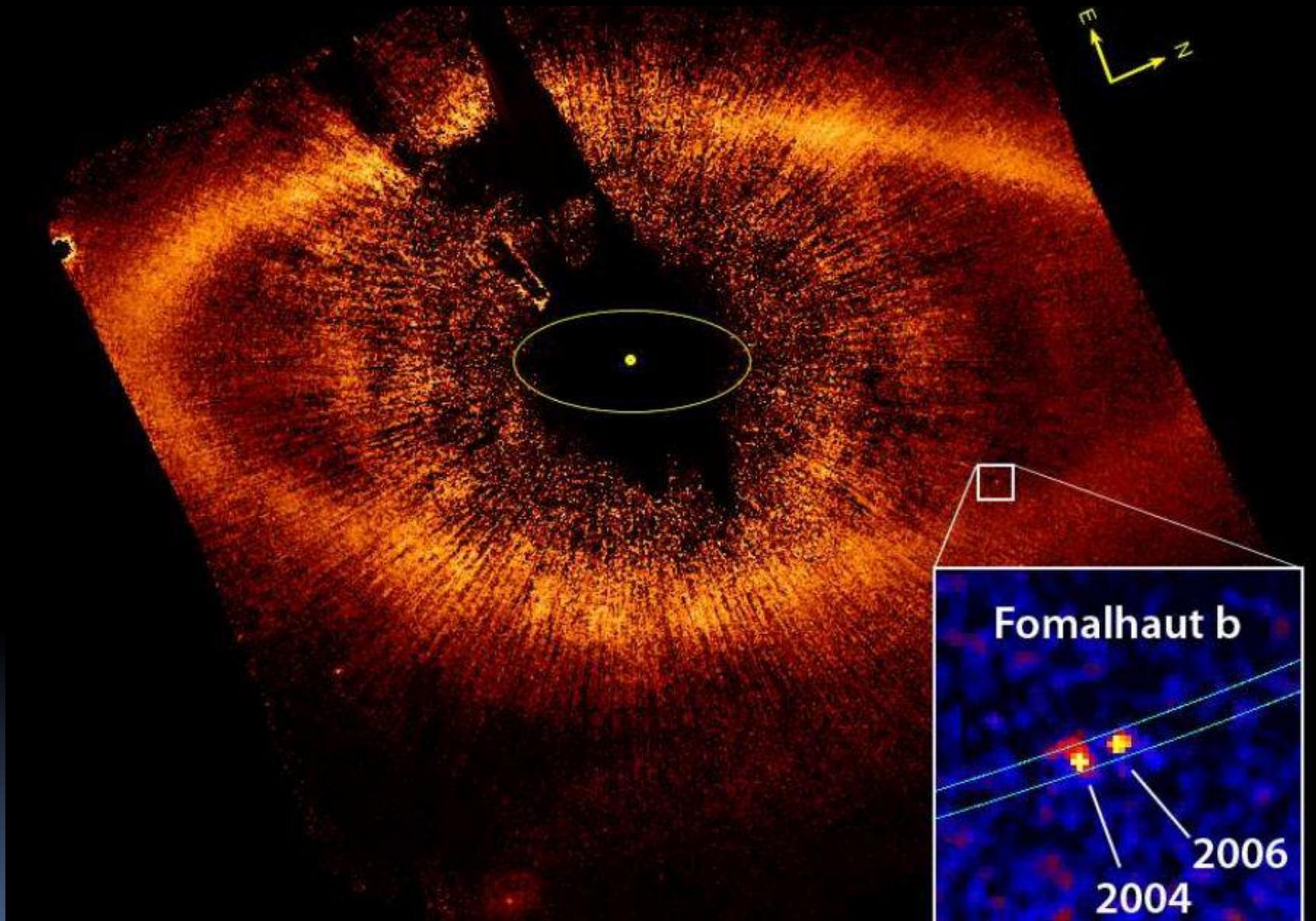
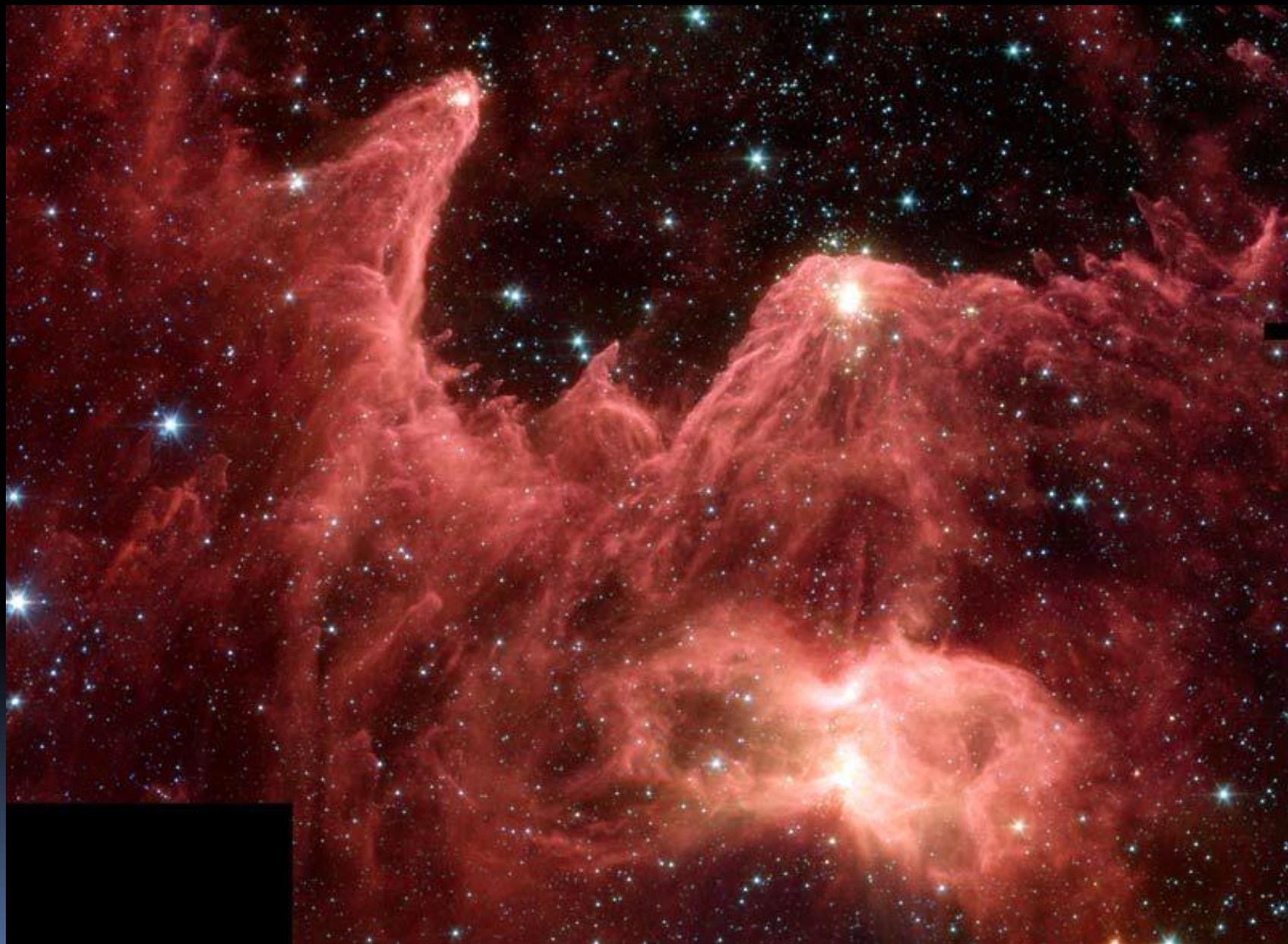


Figure 10.4: Examples of imaged debris disks: (a) HD 141569 observed at $1.1\ \mu\text{m}$ with HST-NICMOS (Weinberger et al., 1999, Figure 1). (b) HR 4796A, observed in the optical with HST-STIS (Schneider et al., 2009a, Figure 2; this version courtesy G. Schneider). (c) β Pic, from combined ESO 3.6-m ADONIS imaging in 1996 (outer region), and $3.6\ \mu\text{m}$ observations with VLT-NACO (inner region) revealing the probably planet, β Pic b (Lagrange et al., 2009b, this version courtesy A.M. Lagrange, D. Ehrenreich, and ESO). In all cases, the geometric central structures are artefacts of the coronagraphic imaging.









Principales elementos en el polvo: CHON



Nebulosa Protoplanetaria

- H y He: 98.5 %
- Minerales + "hielos": 1.5 %
- Minerales: primeros en condensar, generan núcleos de condensación

Mercurio

Día = 2 años mercurianos !

-170 C < Temperatura < 400 C



Venus

Día = - 117 días terrestres

Temperatura media = 500 C

Presión = 90 atm.

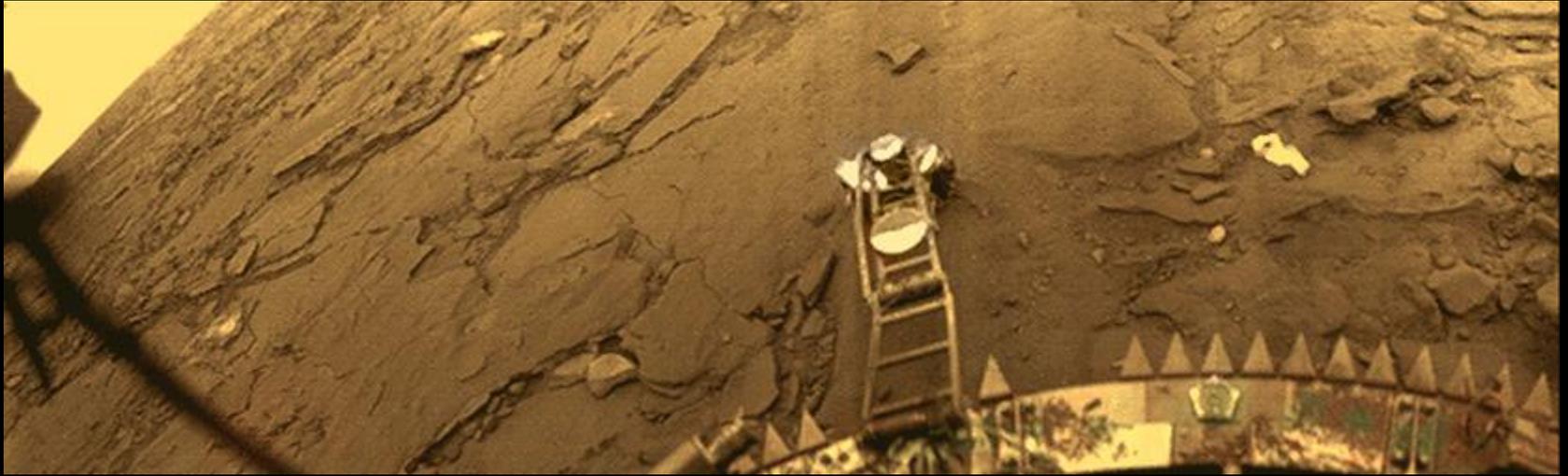
CO₂

No hay agua



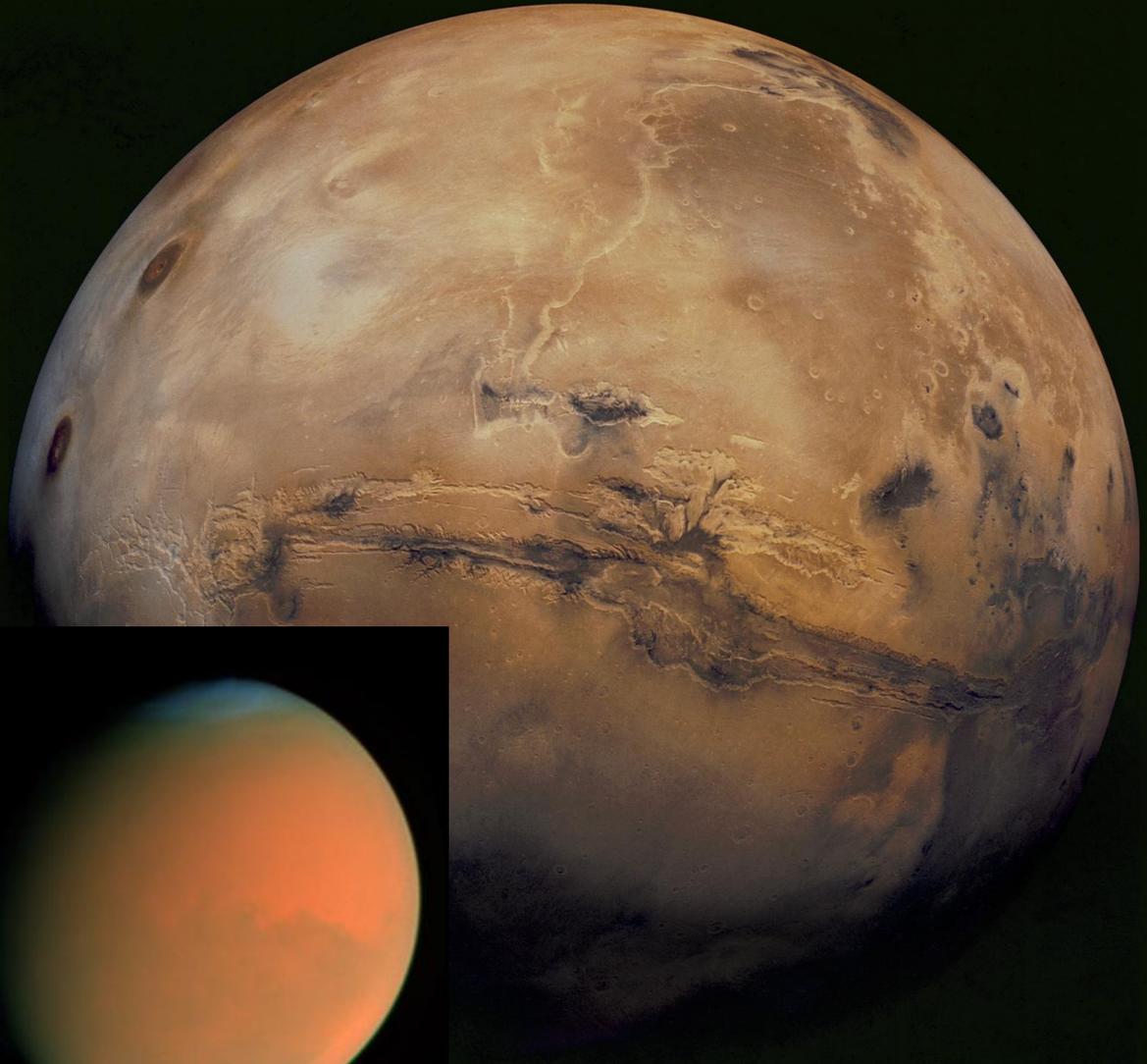
Venus

Roca sólida y seca (basaltos)



Marte

Volcanes fosilizados
Erosión por fluidos
Agua en el pasado



June 26, 2001



September 4, 2001

Marte

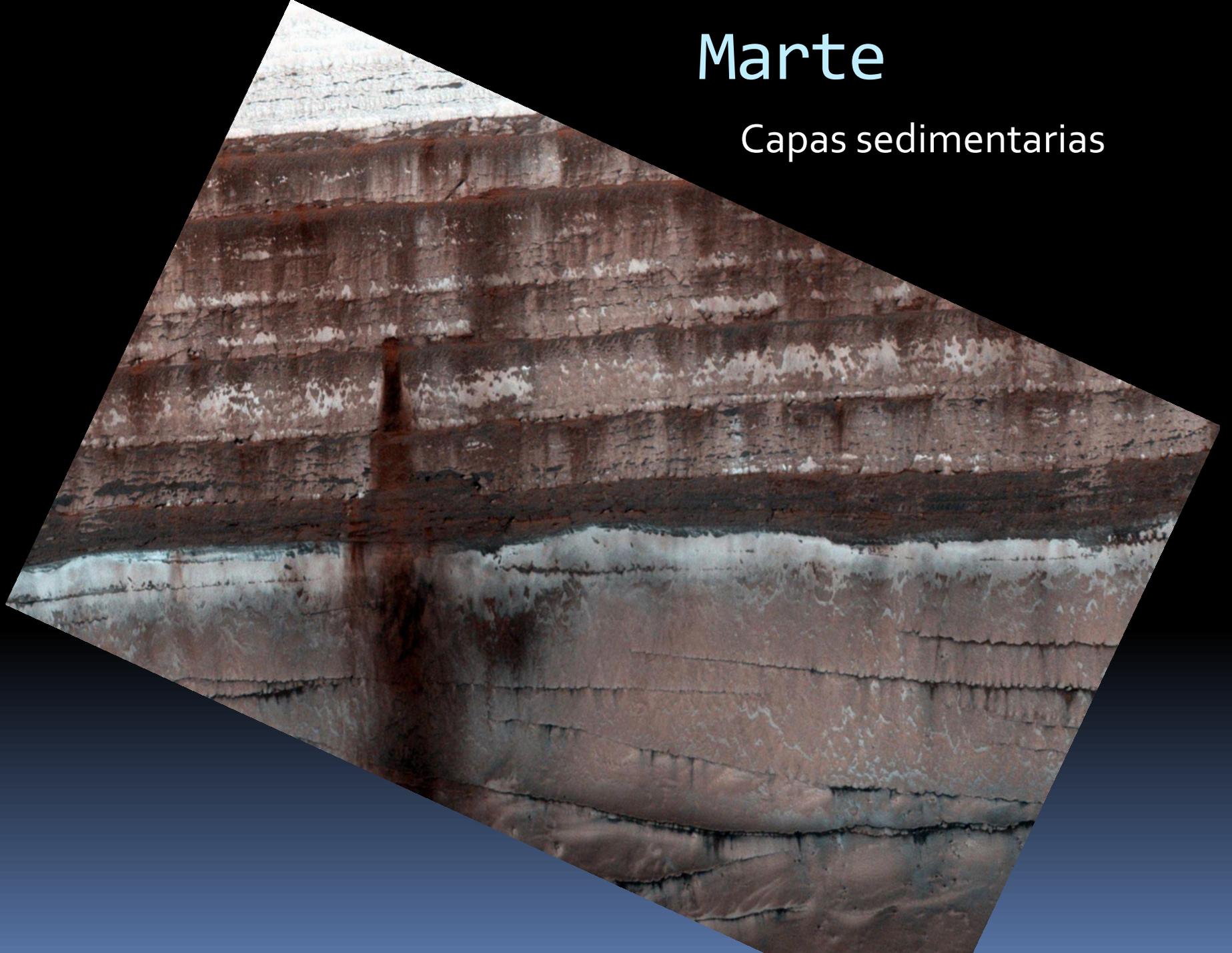
Sin agua superficial.

Hielo subsuperficial (permafrost)



Marte

Capas sedimentarias



Ceres (planeta enano)



Júpiter

H + He

Temp.: -170 C

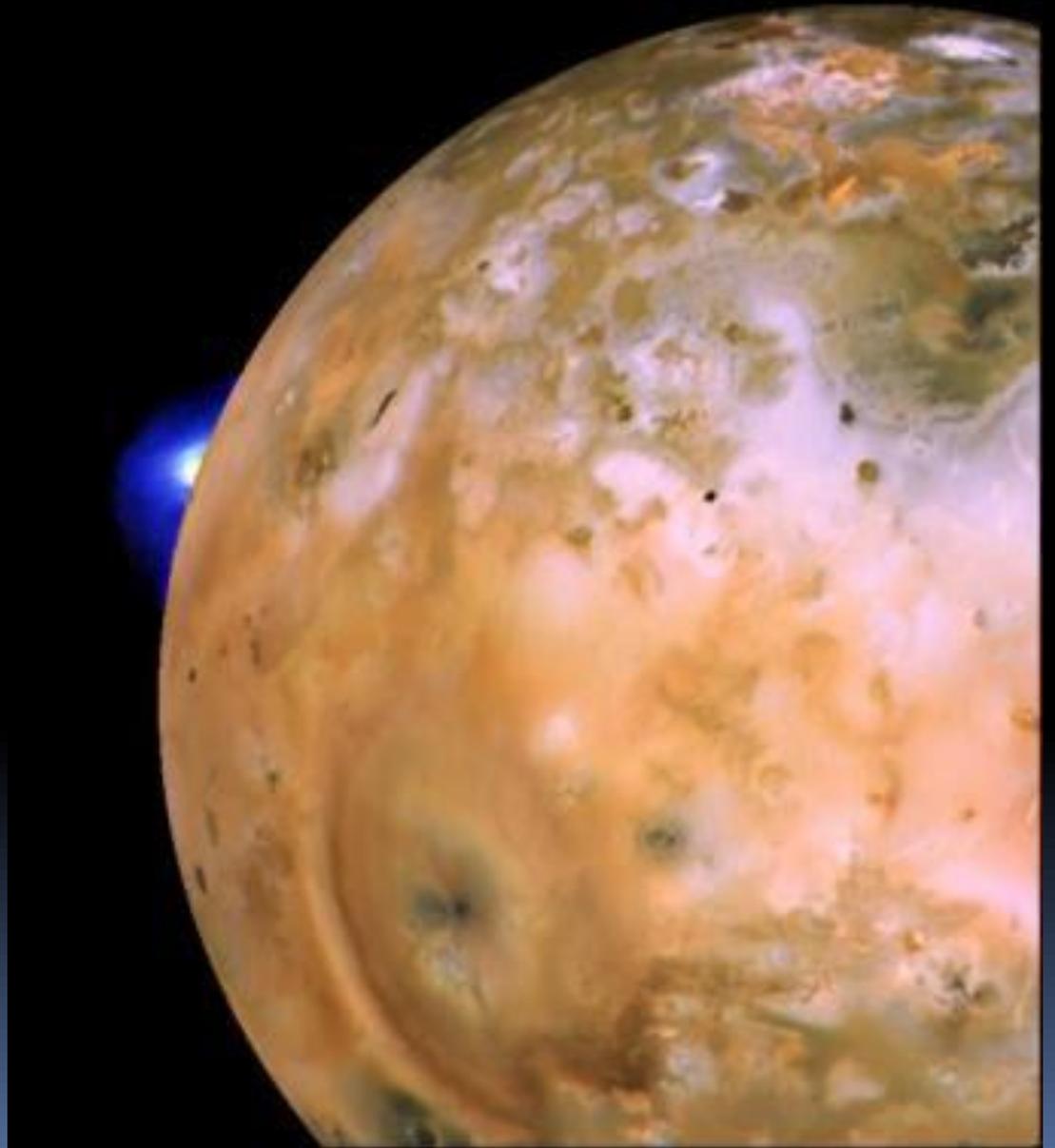
Masa \approx 300 Tierras



Io

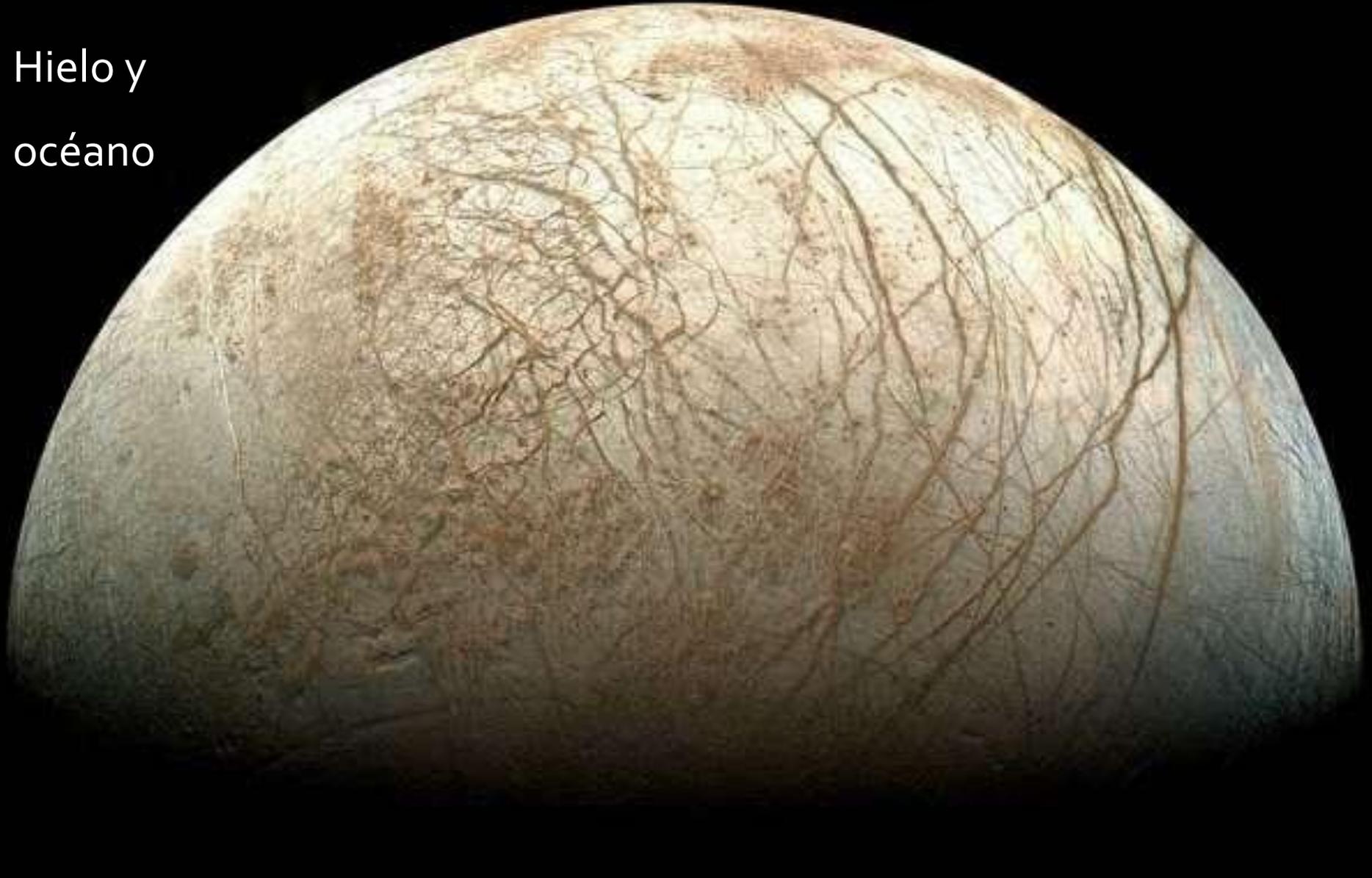
Volcanes activos

Mareas jovianas

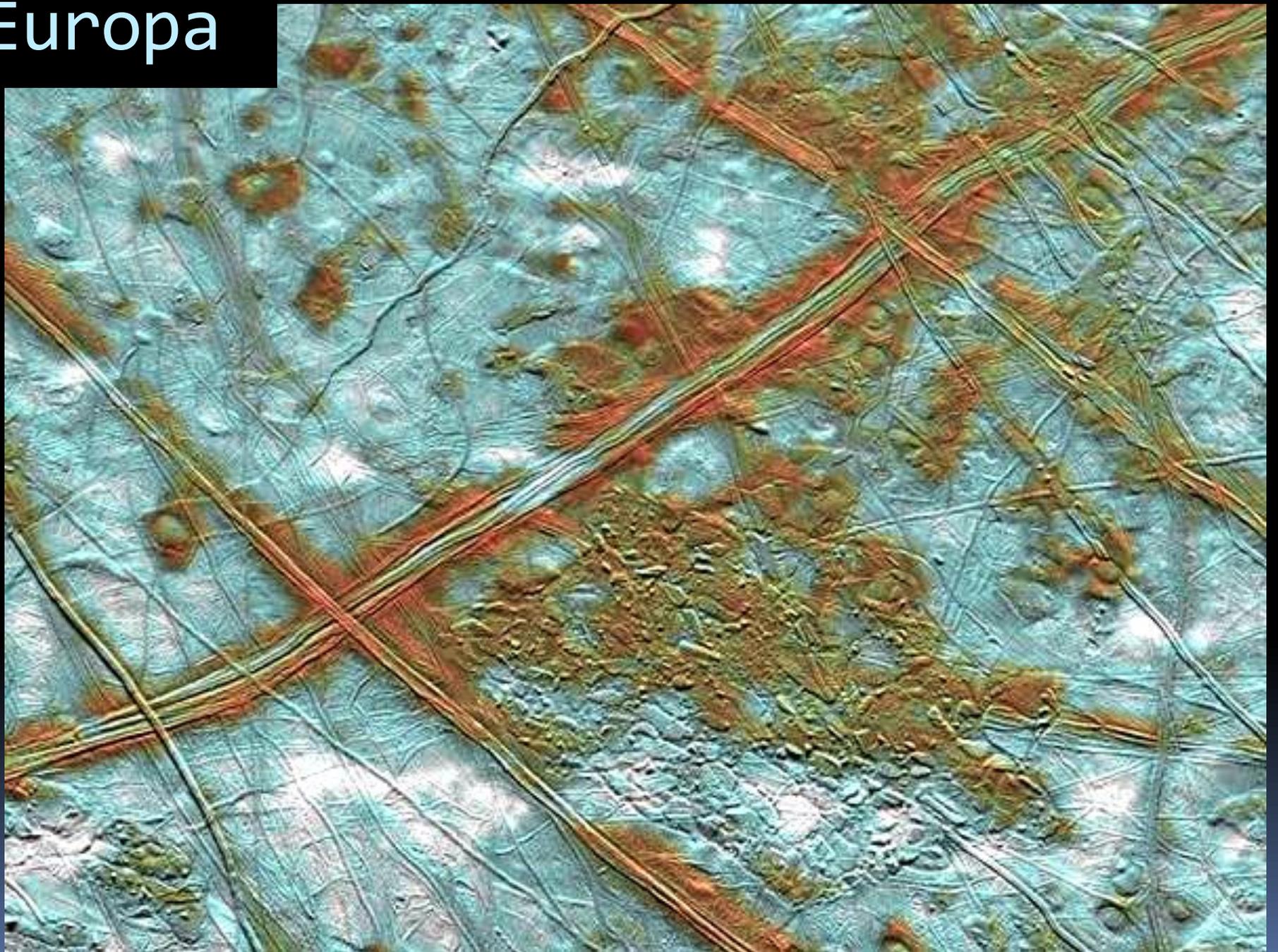


Europa (satélite)

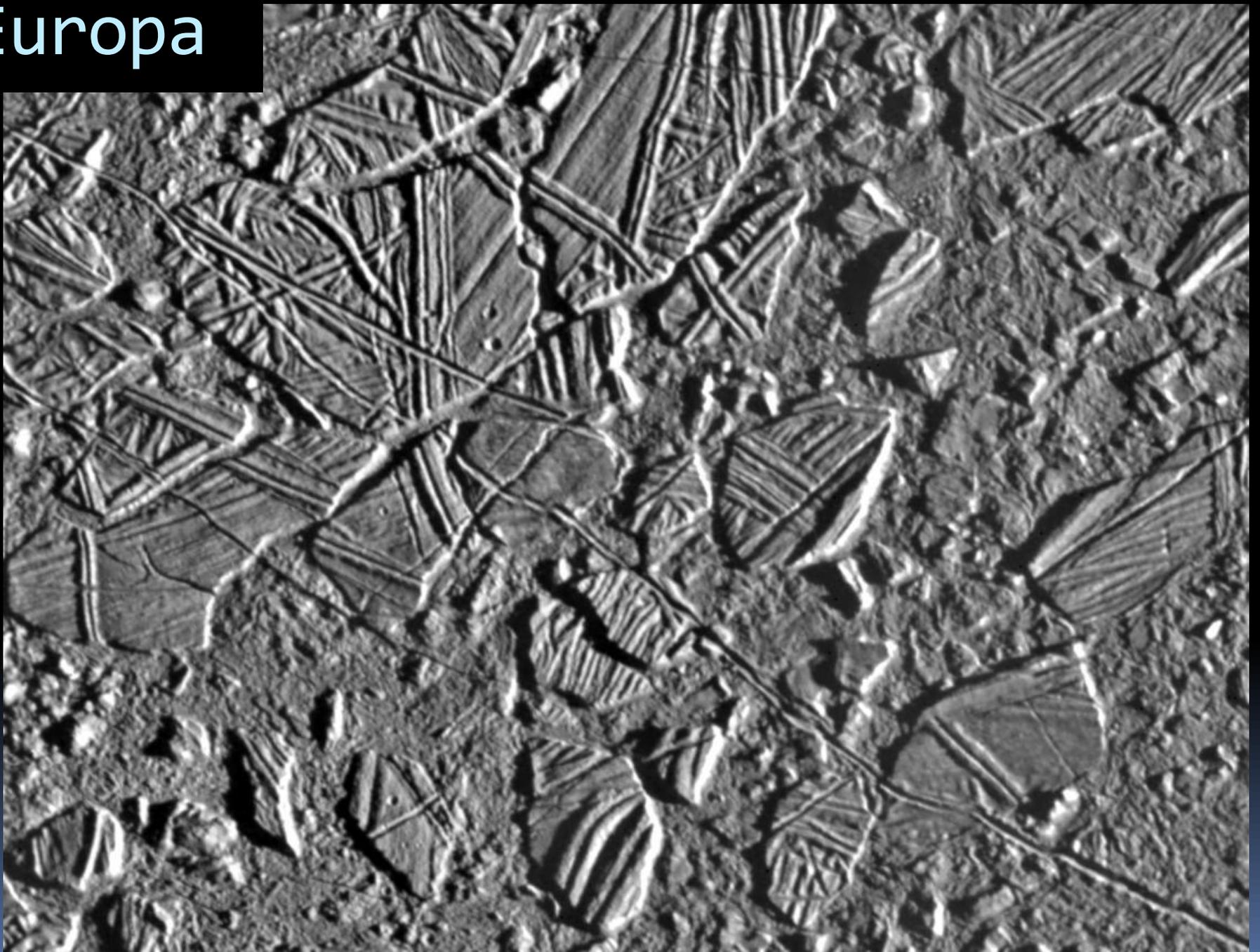
Hielo y
océano



Europa



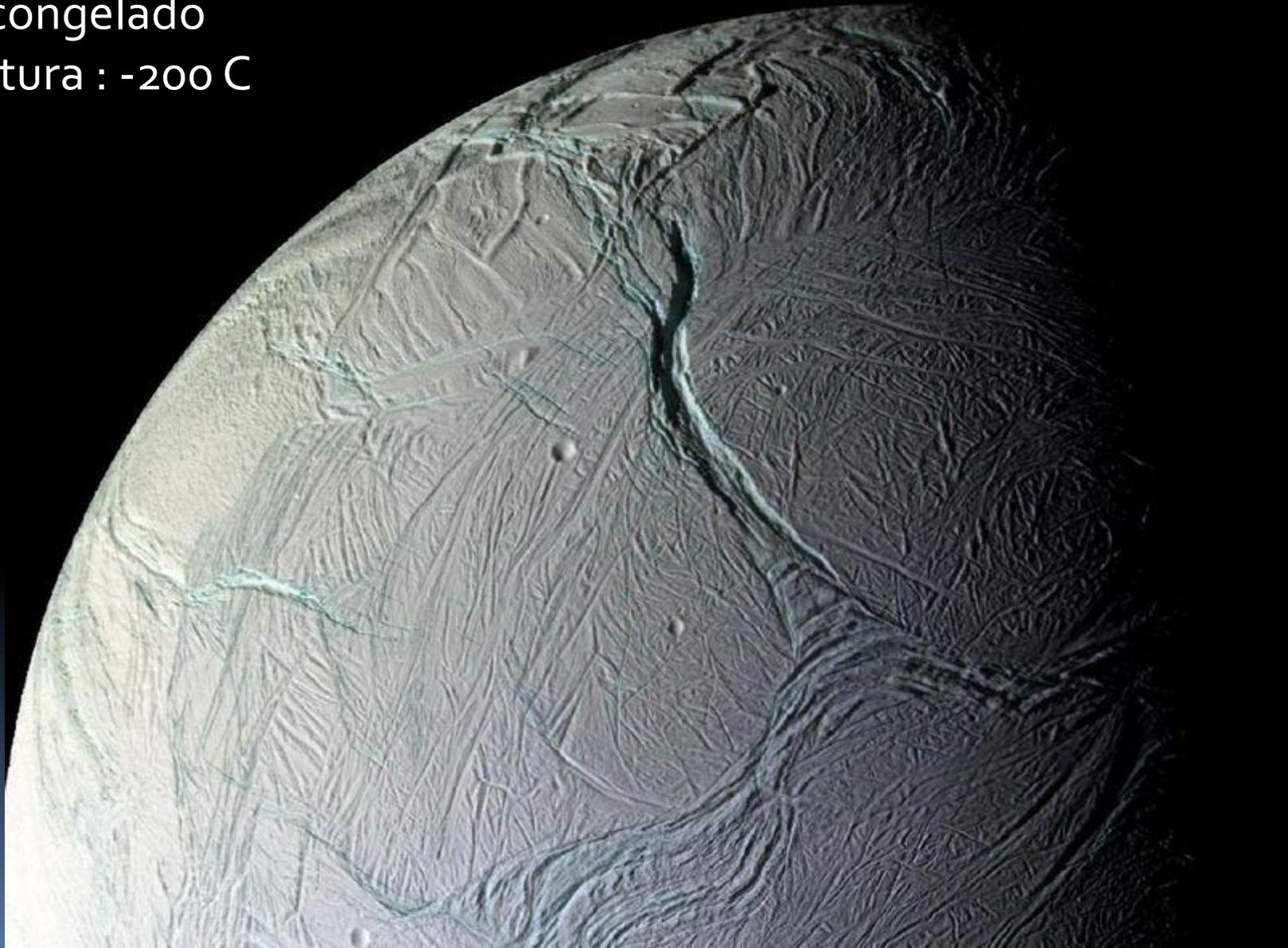
Europa



Encelado

Océano congelado

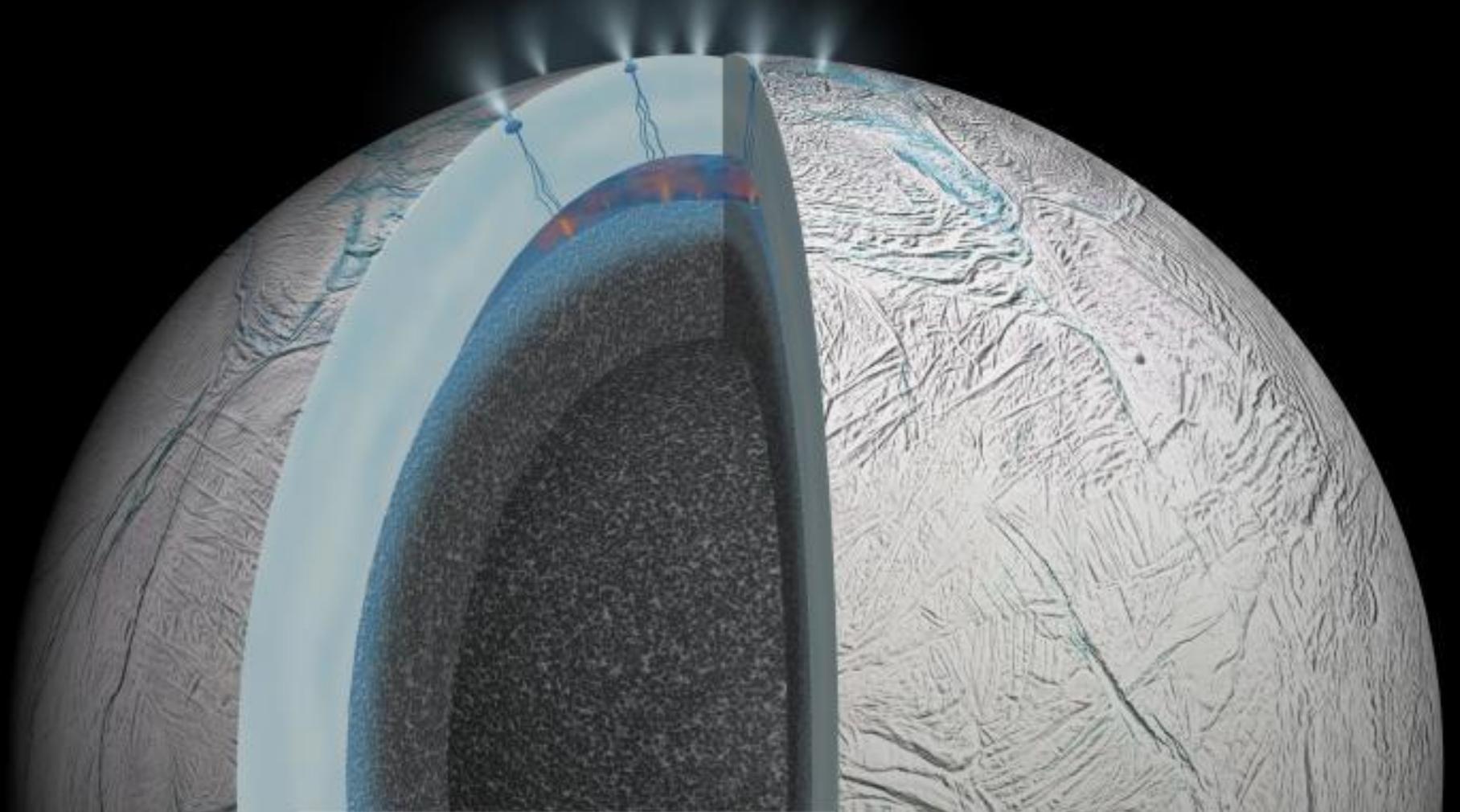
Temperatura : -200 C



Ence1ado



Encelado



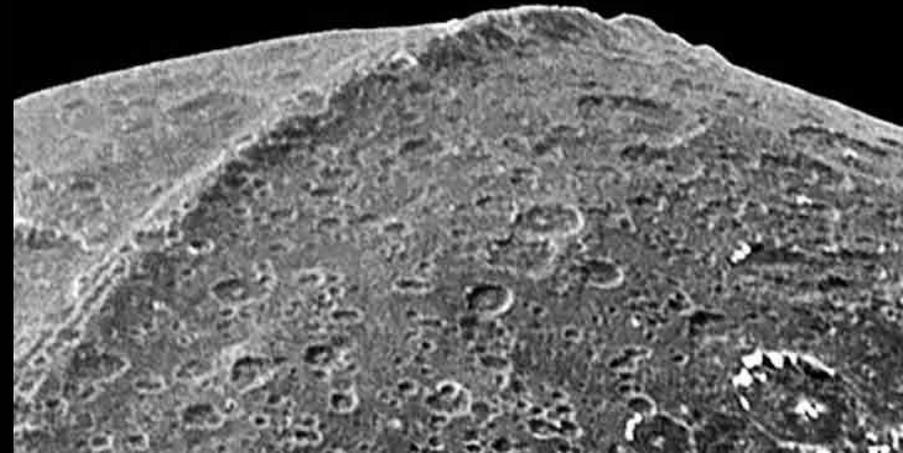
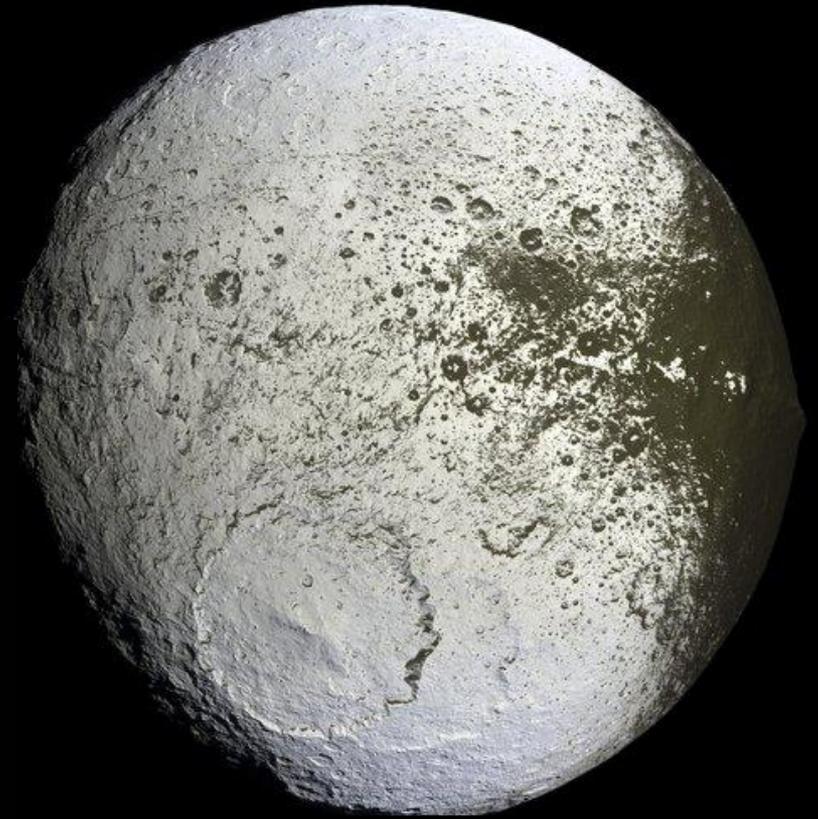
Titán

Atmósfera de Nitrógeno
Temperatura media = -170 C
Presión $> 1\text{ atm.}$
Metano sólido en superficie
Lagos de nitrógeno

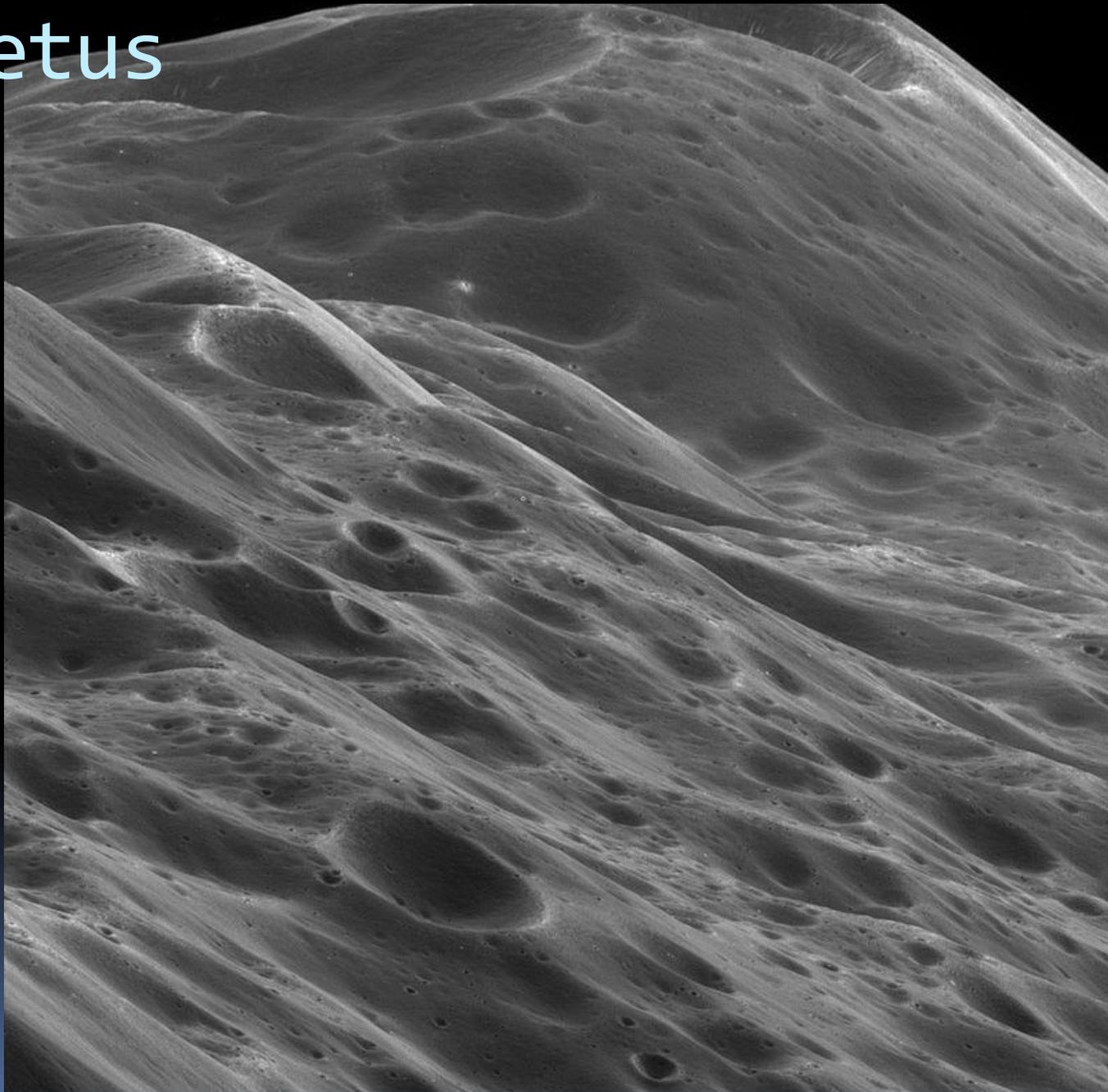


Iapetus

Compuestos de carbono



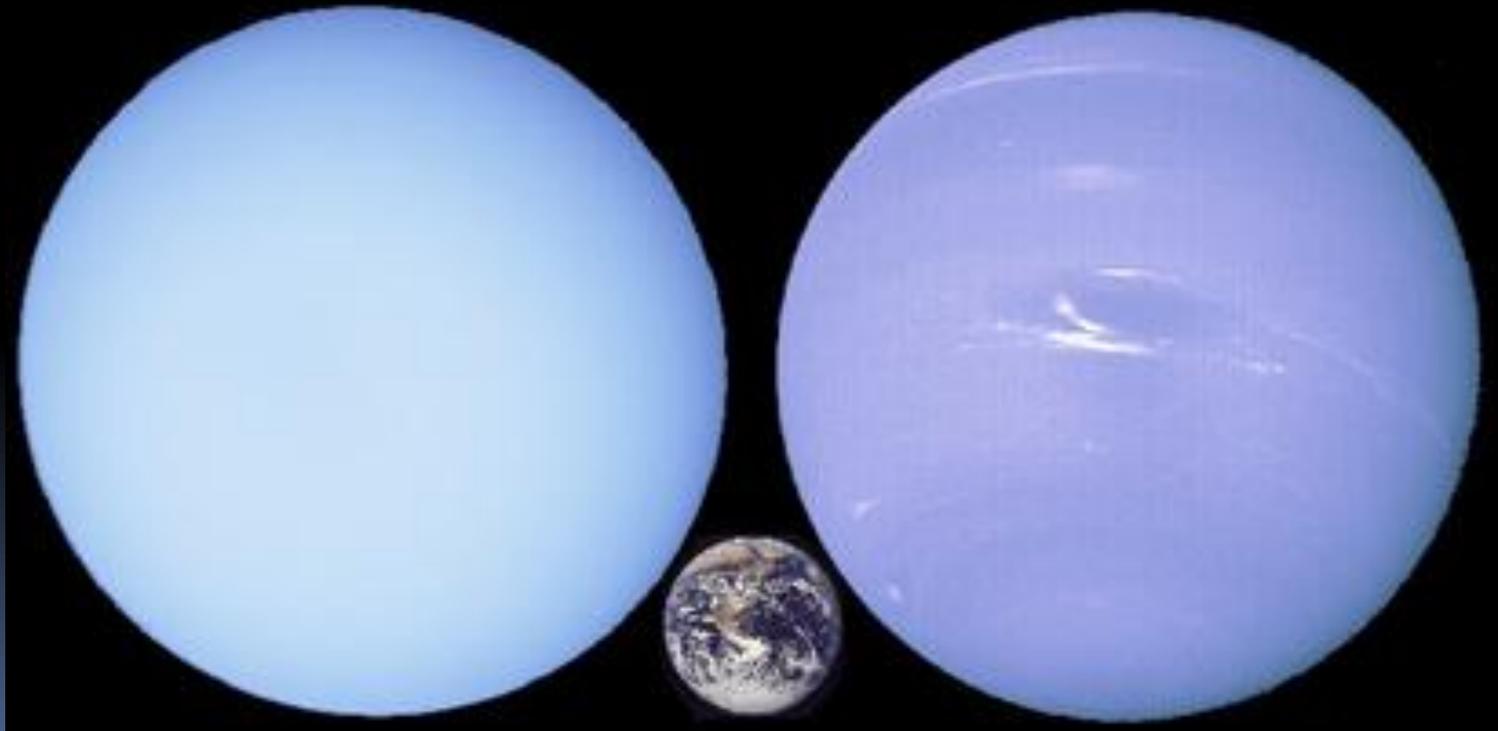
Iapetus



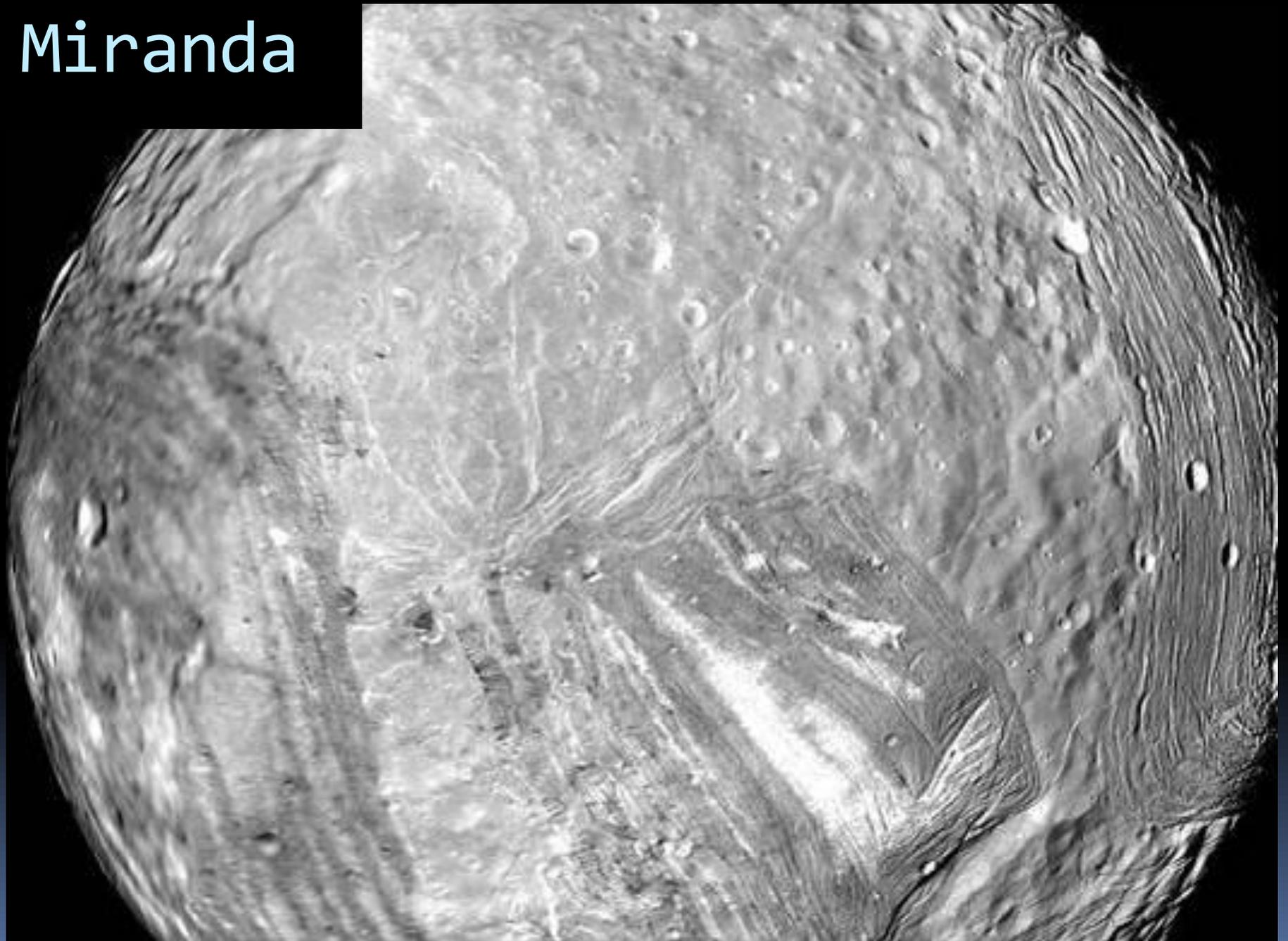
Urano y Neptuno

$\text{CH}_4 + \text{NH}_3$
Temp: -220 C

Masa ≈ 20 Tierras



Miranda



Plutón y Caronte

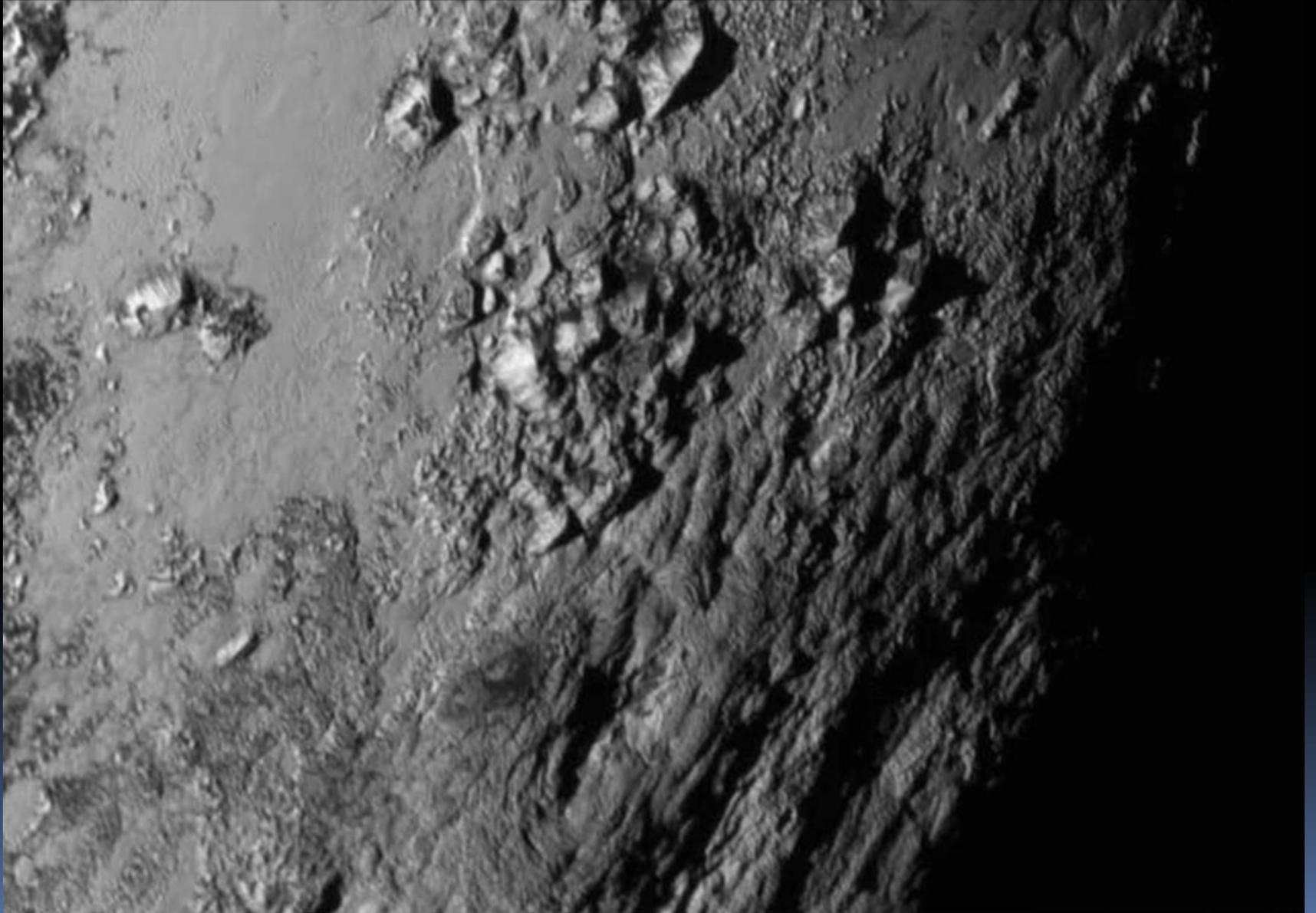


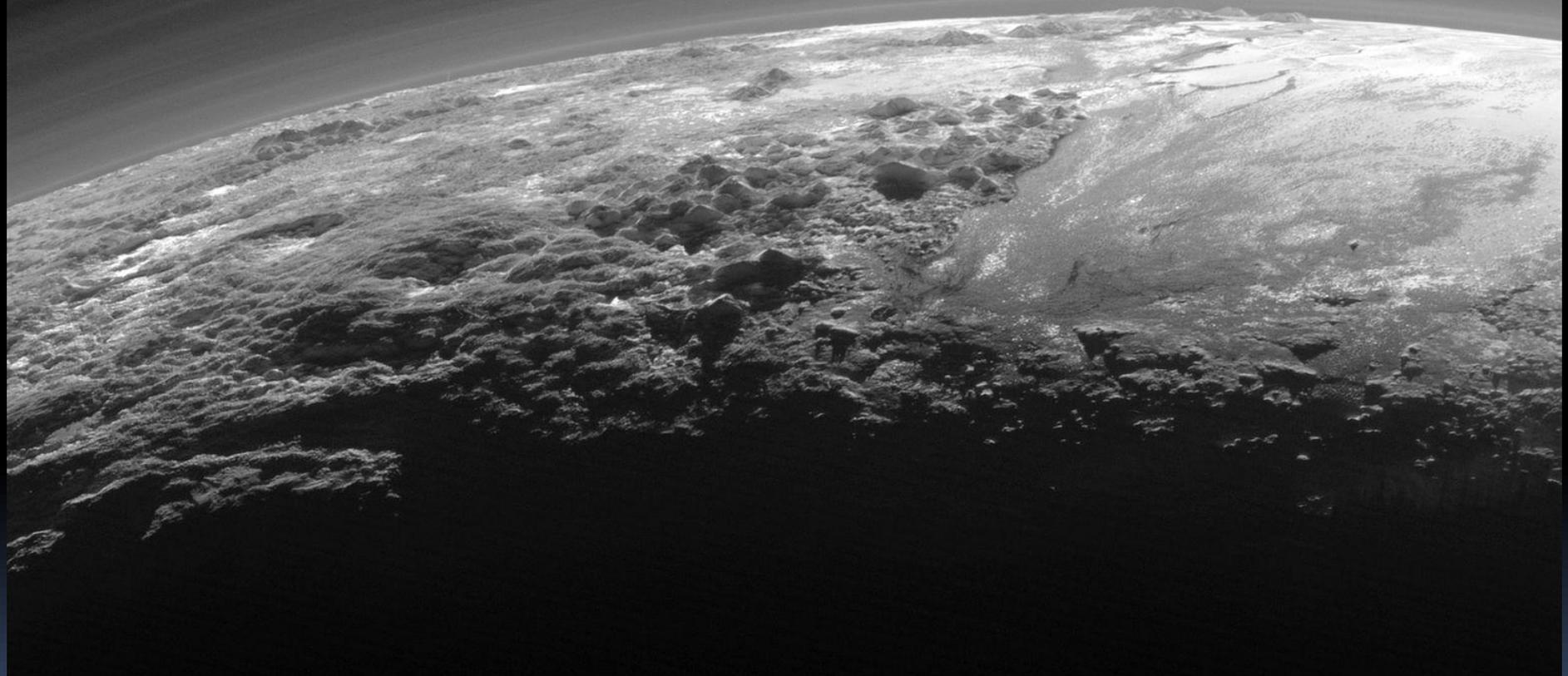
Plutón



False Color

Plutón





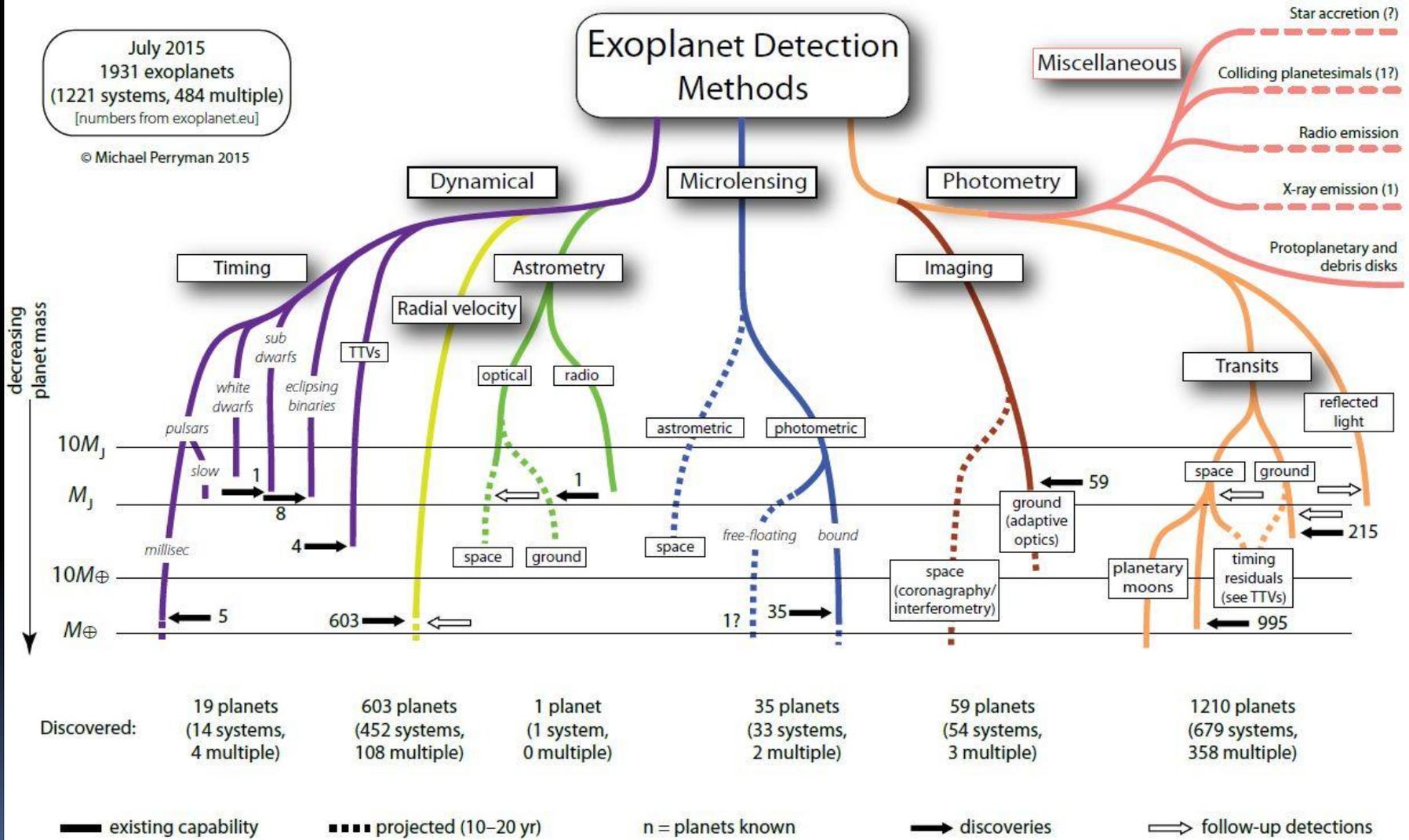
Jóvenes (100 millones de años...) montañas de hielo.

TECNICAS

July 2015
 1931 exoplanets
 (1221 systems, 484 multiple)
 [numbers from exoplanet.eu]

© Michael Perryman 2015

Exoplanet Detection Methods



1952

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

By Otto Struve

With the completion of the great radial-velocity programmes of the major observatories, the impression seems to have gained ground that the measurement of Doppler displacements in stellar spectra is less important at the present time than it was prior to the completion of R. E. Wilson's new radial-velocity catalogue.

I believe that this impression is incorrect, and I should like to support my contention by presenting a proposal for the solution of a characteristic astrophysical problem.

One of the burning questions of astronomy deals with the frequency of planet-like bodies in the galaxy which belong to stars other than the Sun.

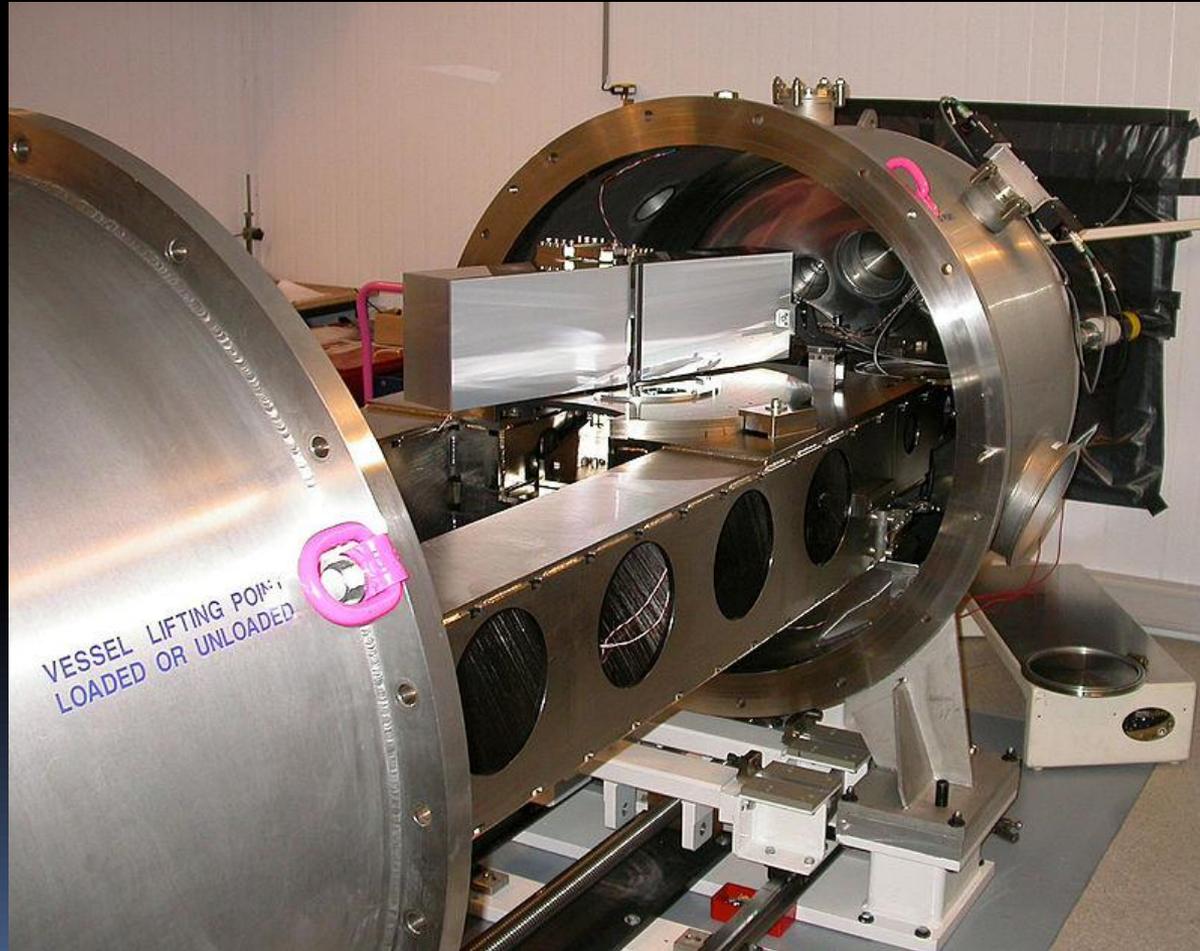
K. A. Strand's¹ discovery of a planet-like companion in the system of 61 Cygni, which was recently confirmed by A. N. Deitch² at Pulkovo.

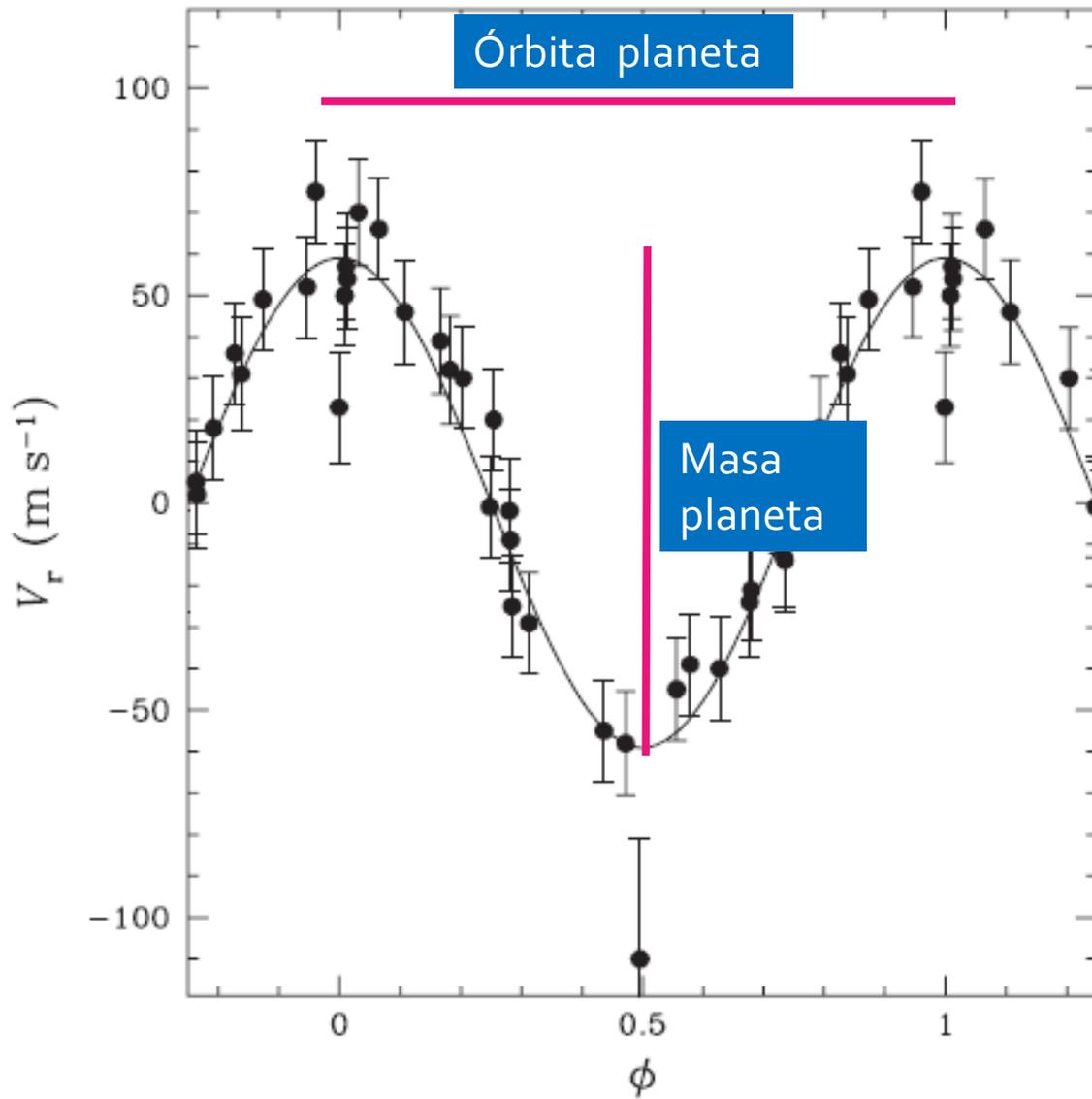
Variación de velocidad radial



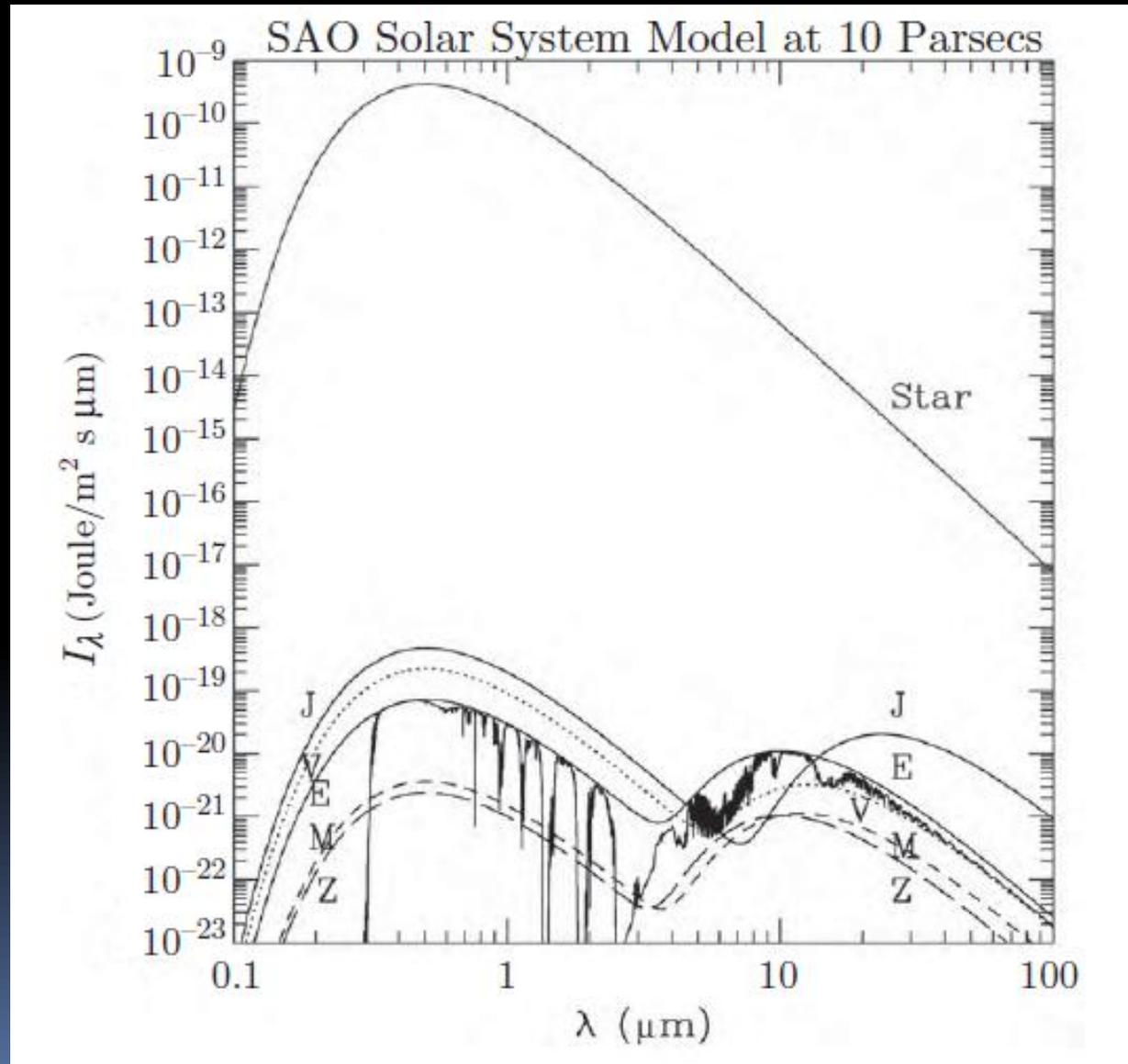
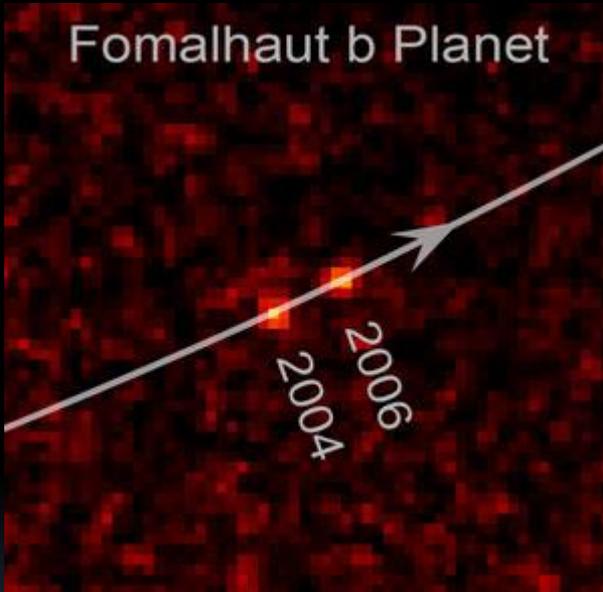
www.eso.org

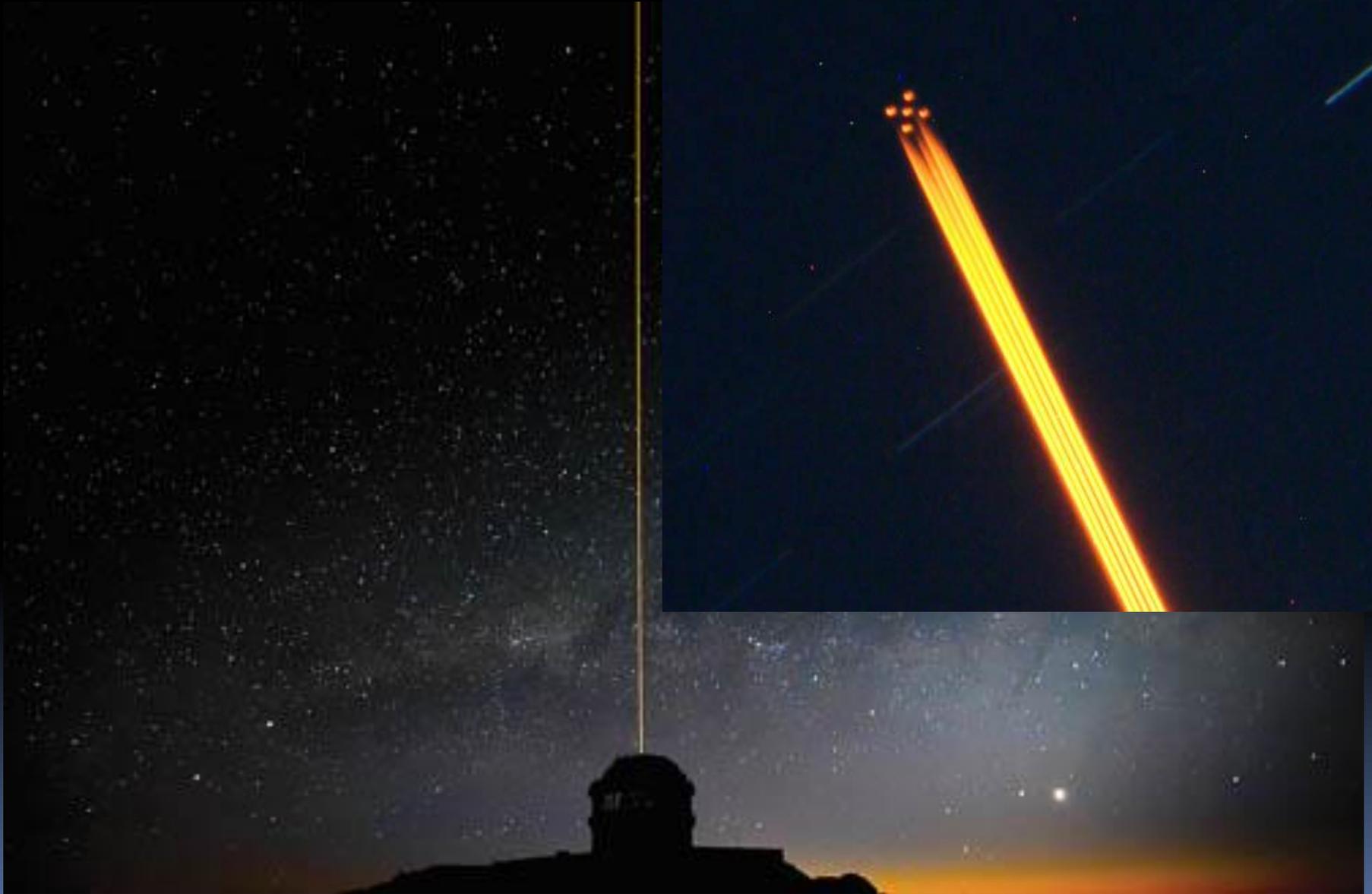
Espectrógrafo

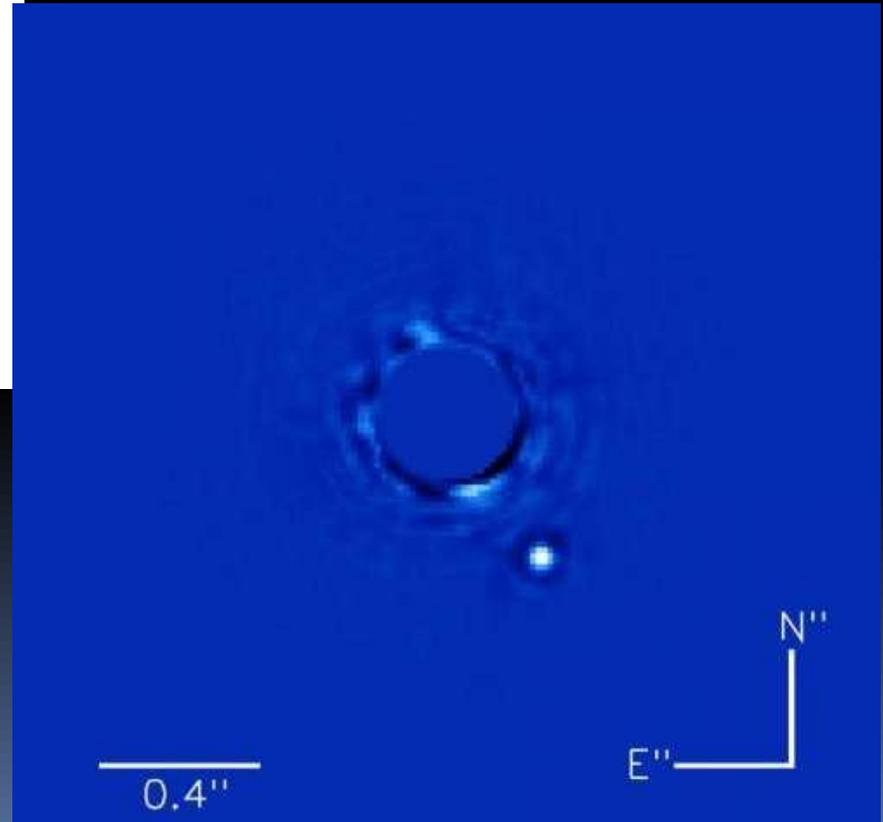
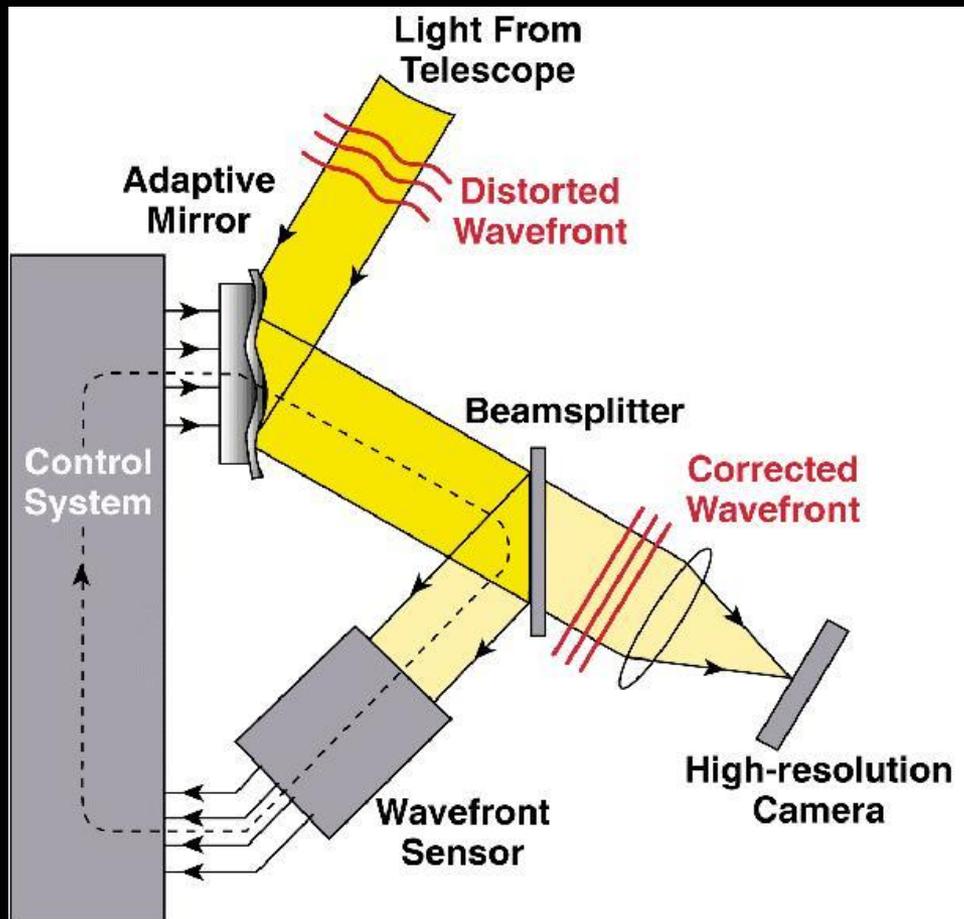


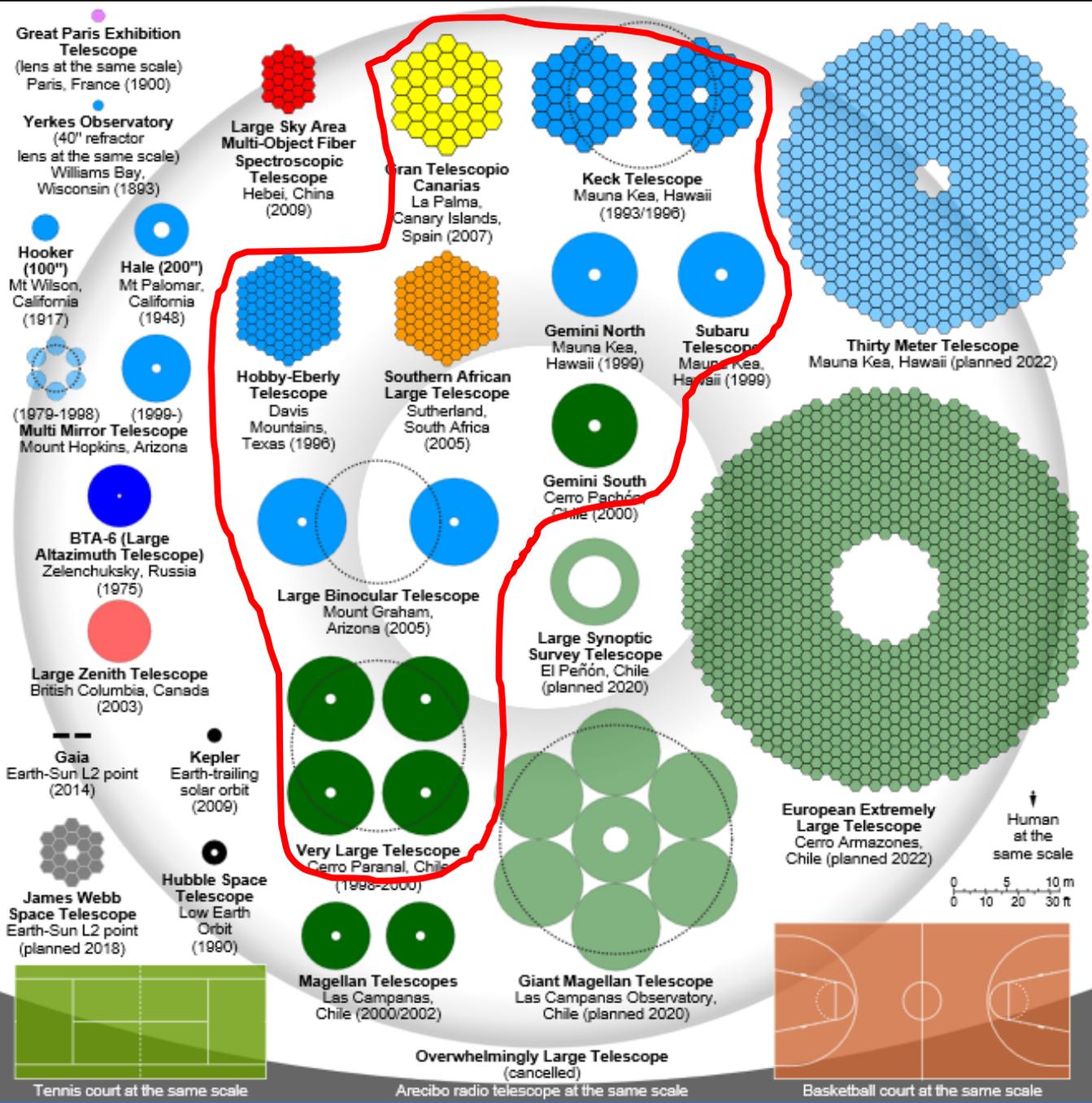


Observación directa









Great Paris Exhibition Telescope
 (lens at the same scale)
 Paris, France (1900)

Yerkes Observatory
 (40' refractor lens at the same scale)
 Williams Bay, Wisconsin (1893)

Hooker (100")
 Mt Wilson, California (1917)

Hale (200")
 Mt Palomar, California (1948)

Multi Mirror Telescope
 (1979-1998) Mount Hopkins, Arizona

(1999-)
 Mount Hopkins, Arizona

BTA-6 (Large Altazimuth Telescope)
 Zelenchuksky, Russia (1975)

Large Zenith Telescope
 British Columbia, Canada (2003)

Gaia
 Earth-Sun L2 point (2014)

Kepler
 Earth-trailing solar orbit (2009)

James Webb Space Telescope
 Earth-Sun L2 point (planned 2018)

Hubble Space Telescope
 Low Earth Orbit (1990)



Tennis court at the same scale

Large Sky Area Multi-Object Fiber Spectroscopic Telescope
 Hebei, China (2009)

Gran Telescopio Canarias
 La Palma, Canary Islands, Spain (2007)

Keck Telescope
 Mauna Kea, Hawaii (1993/1996)

Thirty Meter Telescope
 Mauna Kea, Hawaii (planned 2022)

Hobby-Eberly Telescope
 Davis Mountains, Texas (1996)

Southern African Large Telescope
 Sutherland, South Africa (2005)

Gemini North
 Mauna Kea, Hawaii (1999)

Subaru Telescope
 Mauna Kea, Hawaii (1999)

Large Binocular Telescope
 Mount Graham, Arizona (2005)

Gemini South
 Cerro Pachón, Chile (2000)

Large Synoptic Survey Telescope
 El Peñón, Chile (planned 2020)

Very Large Telescope
 Cerro Paranal, Chile (1998-2000)

Giant Magellan Telescope
 Las Campanas Observatory, Chile (planned 2020)

Magellan Telescopes
 Las Campanas, Chile (2000/2002)

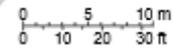
Giant Magellan Telescope
 Las Campanas Observatory, Chile (planned 2020)

Overwhelmingly Large Telescope
 (cancelled)

Arecibo radio telescope at the same scale

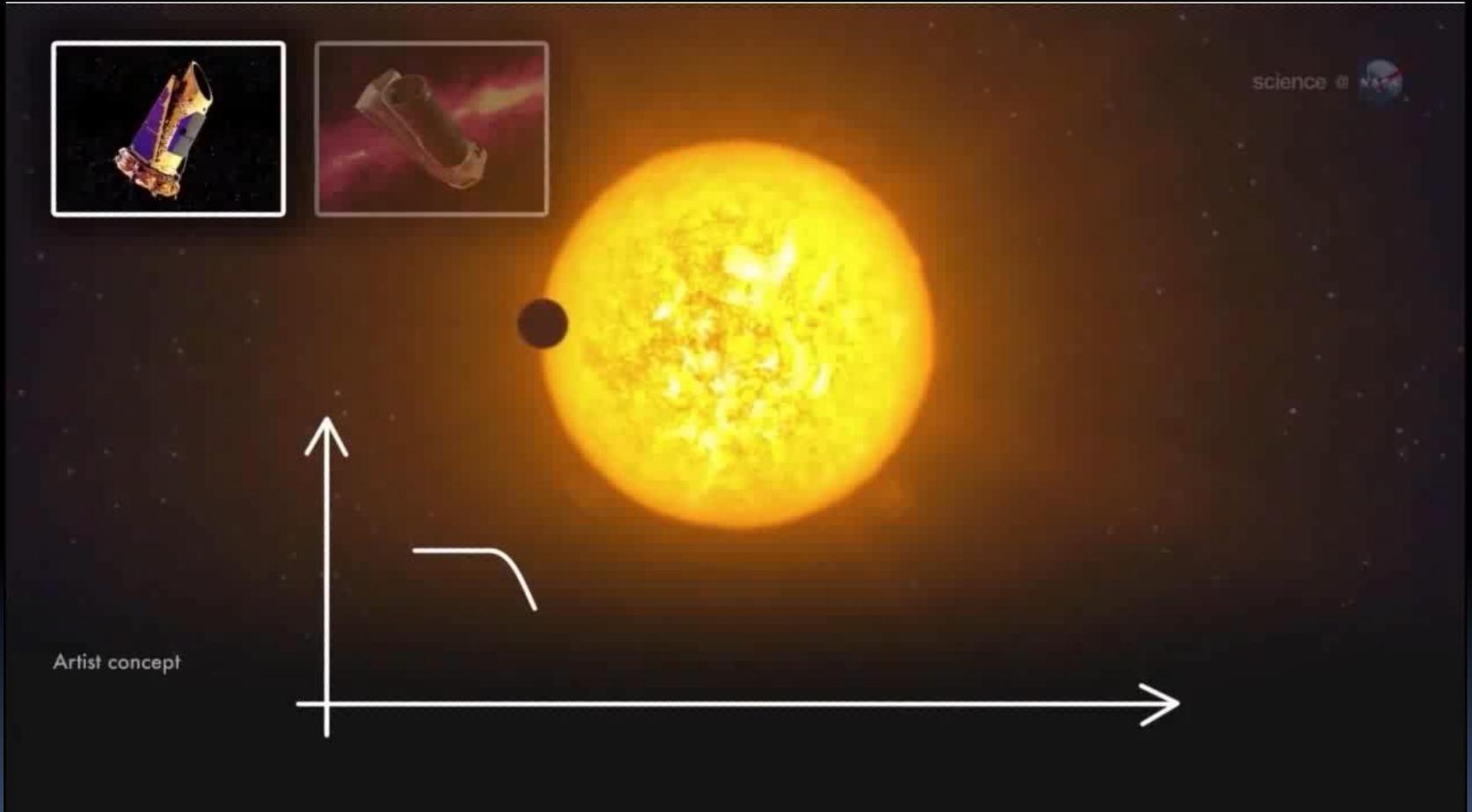
European Extremely Large Telescope
 Cerro Armazones, Chile (planned 2022)

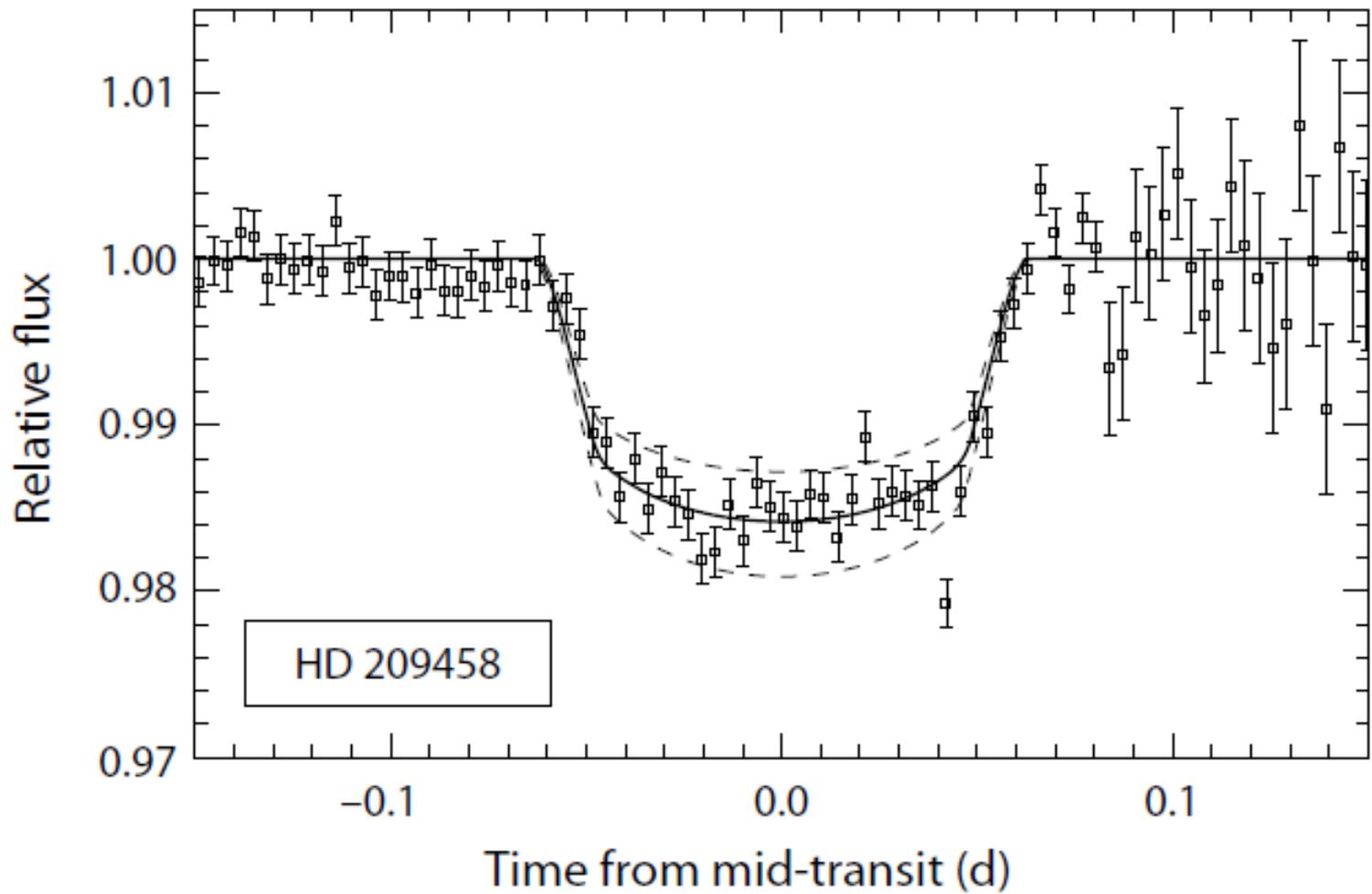
Human at the same scale



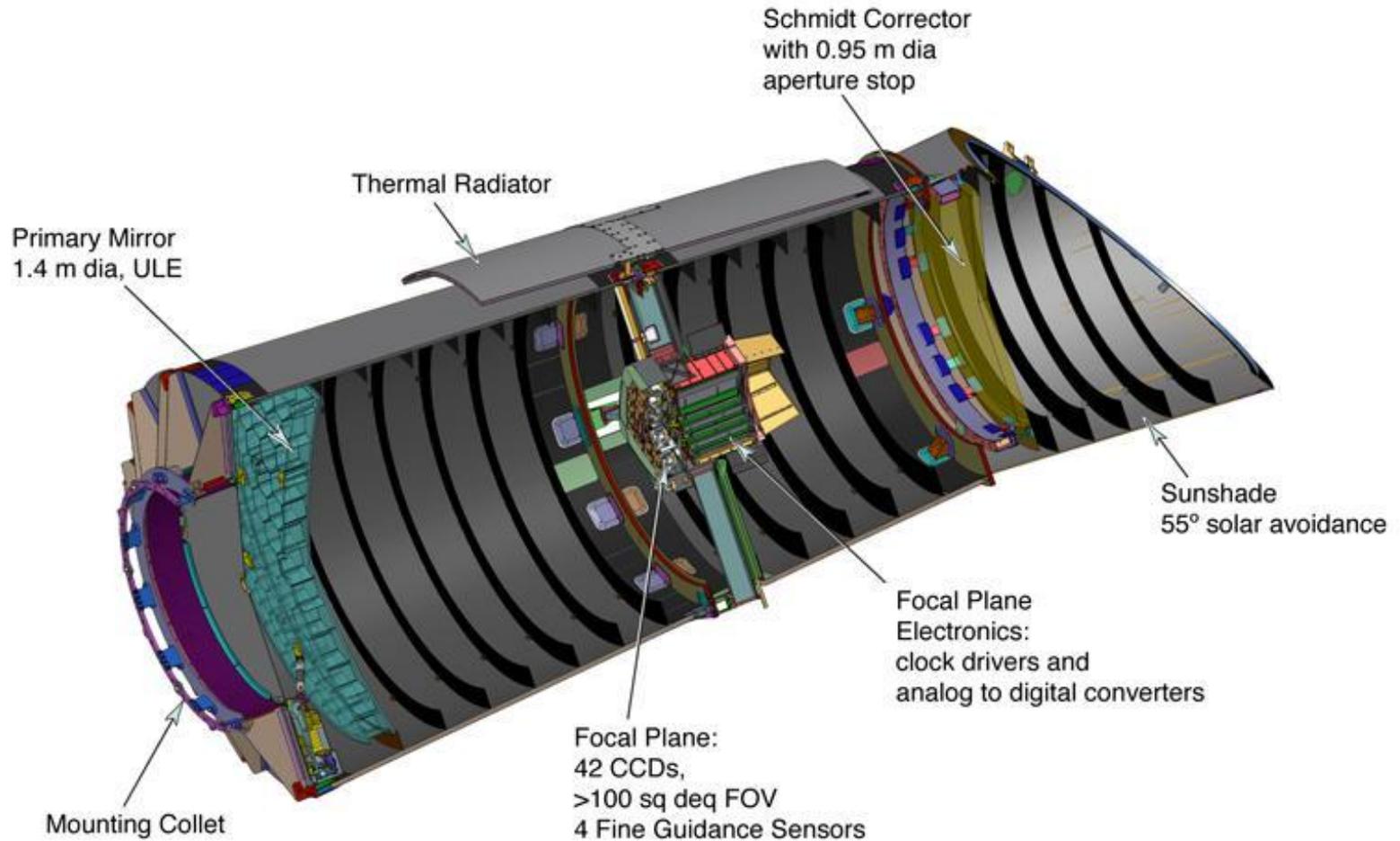
Basketball court at the same scale

Tránsitos: radios



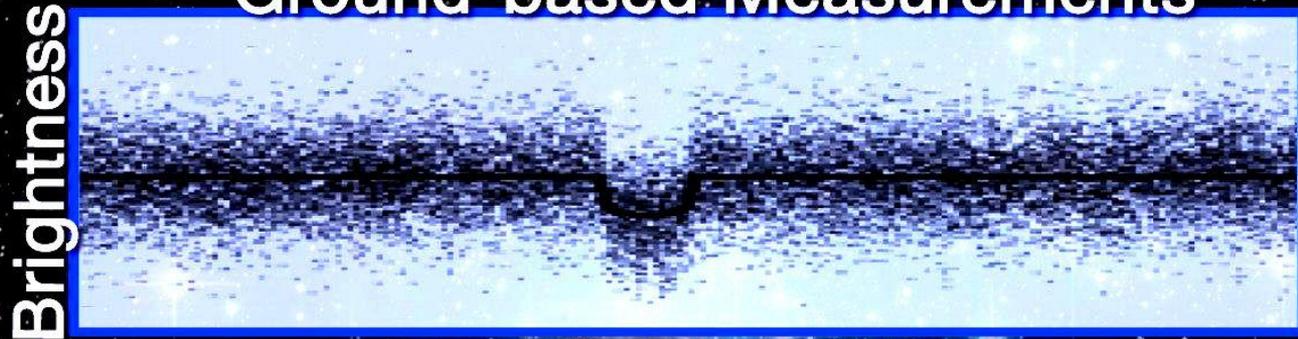


Kepler

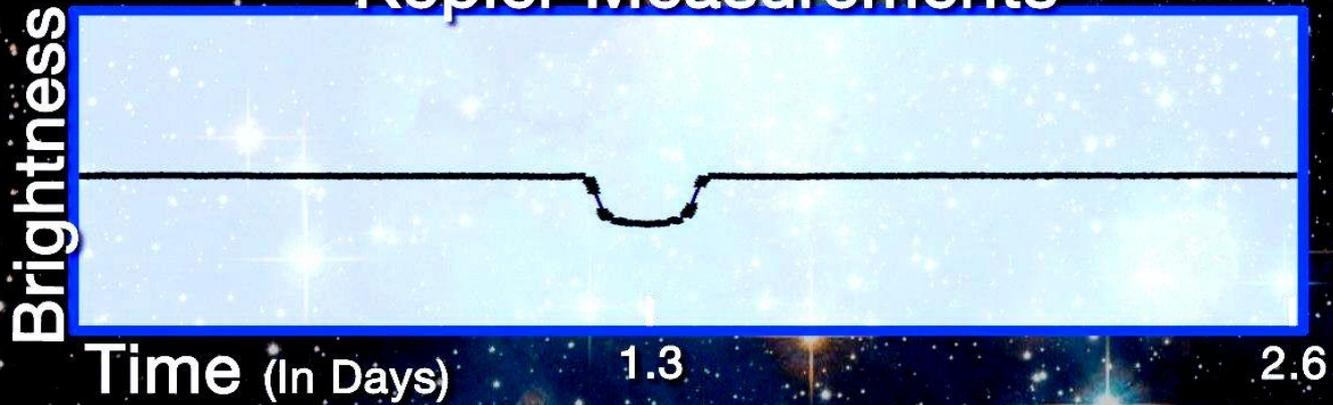


HAT-P-7 Light Curves

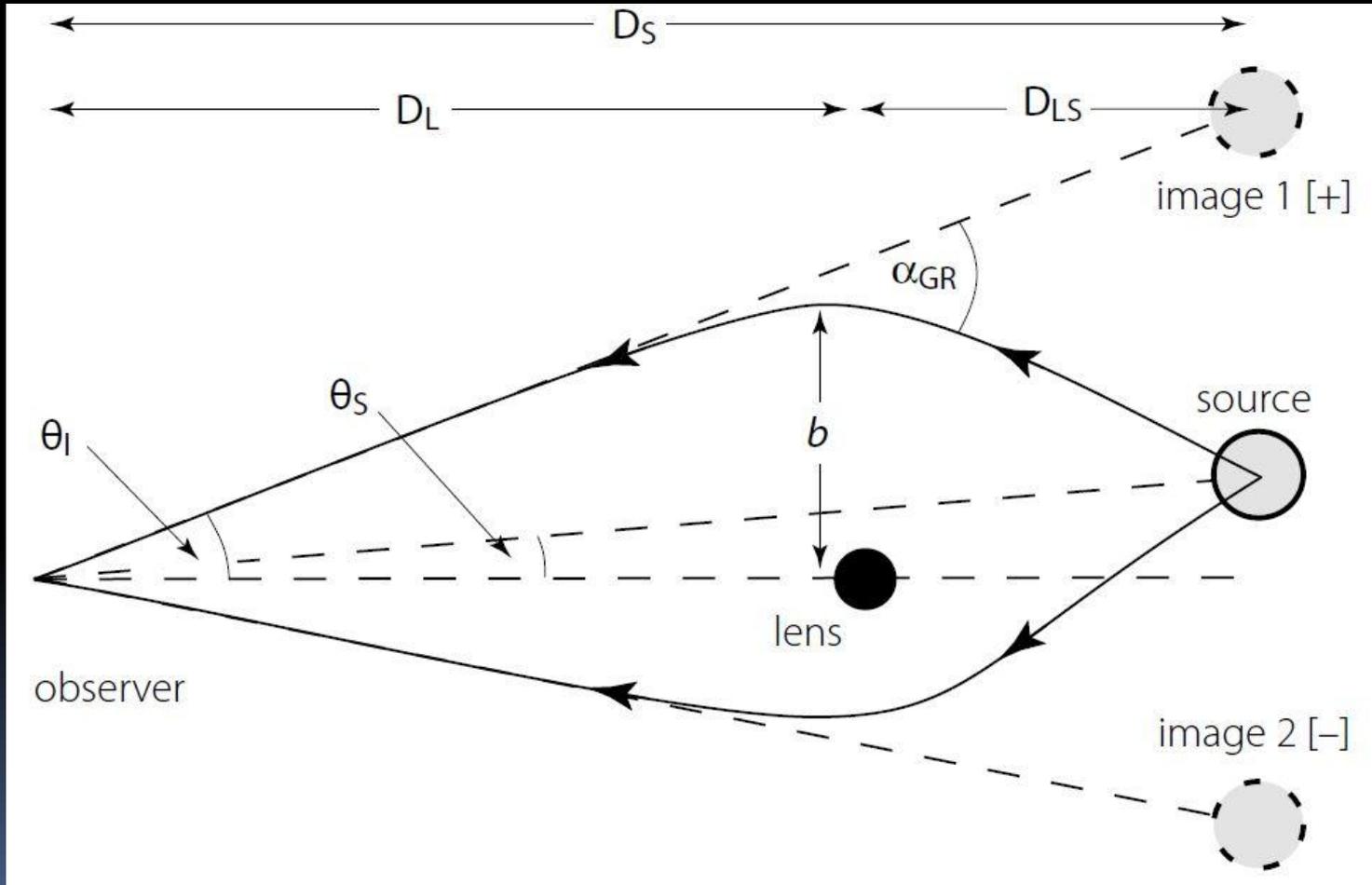
Ground-based Measurements



Kepler Measurements



Lentes gravitacionales



Exoplanet Missions

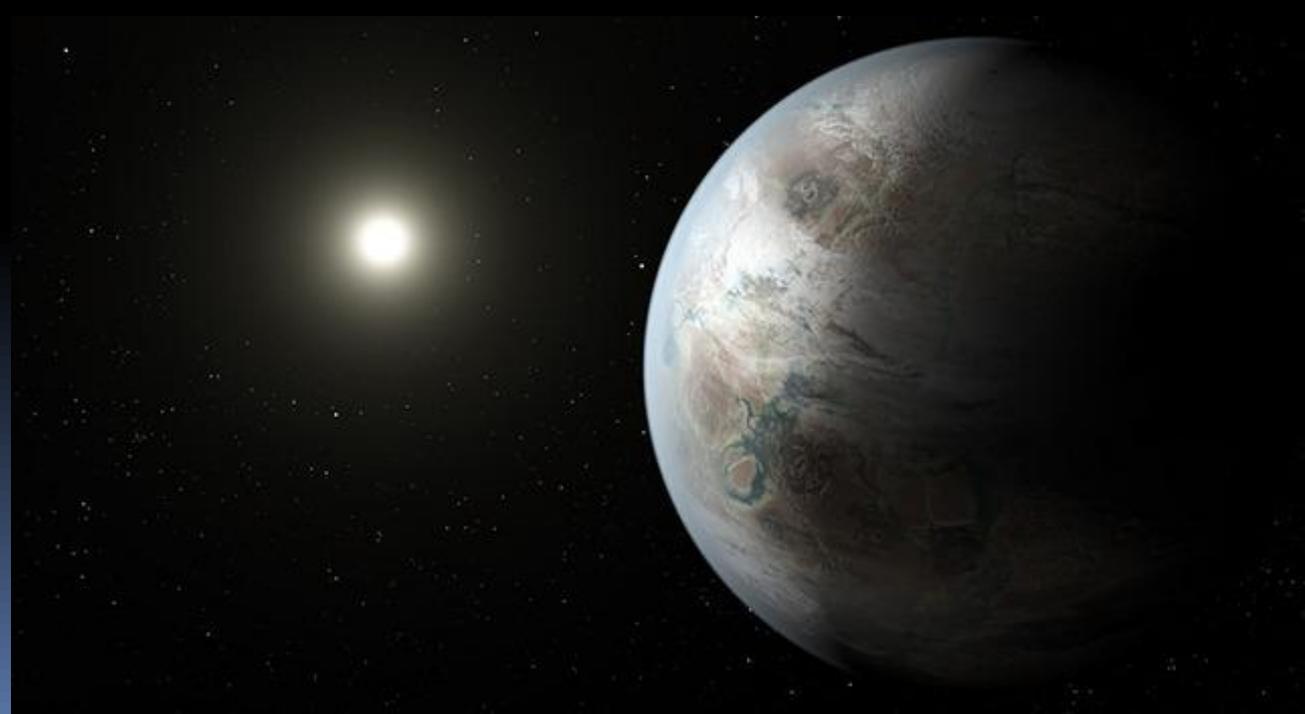


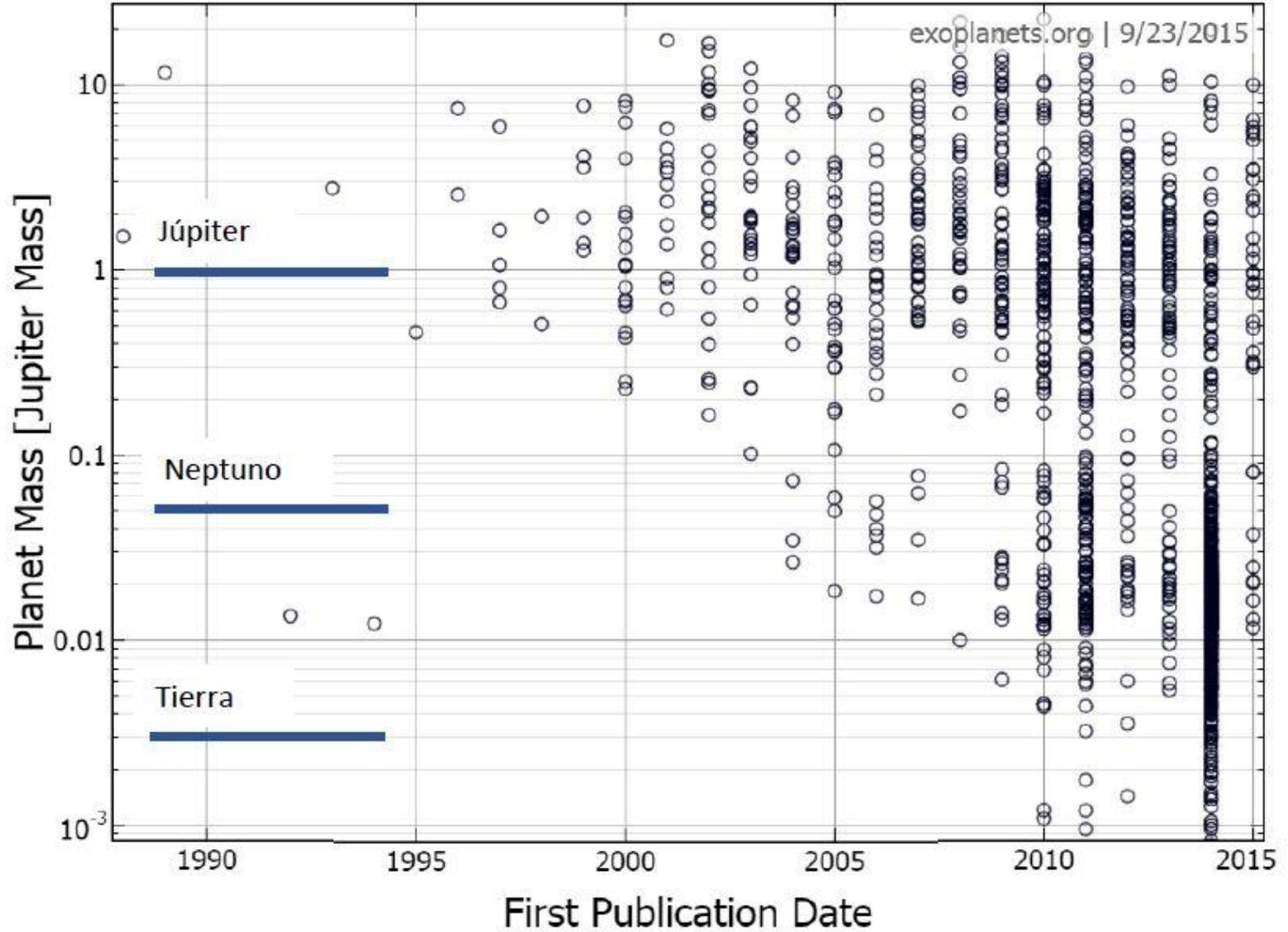
¹ NASA/ESA Partnership

² CNES/ESA

RESULTADOS:

A) Orbitas y masas

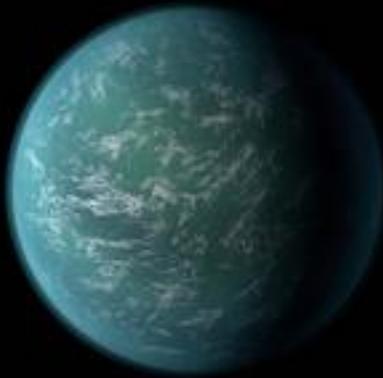




De planetas a estrellas

- Tierras y SuperTierras: hasta $10 M_{\text{Tierra}}$
- Neptunos
- Jupiters: hasta $13 M_{\text{Jup}}$
- Enanas marrones: fusión deuterio, masa $> 13 M_{\text{Jup}}$
- Estrellas: fusión de H, masa $> 80 M_{\text{Jup}}$

Kepler-22b



Kepler-69c



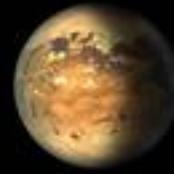
Kepler-452b



Kepler-62f

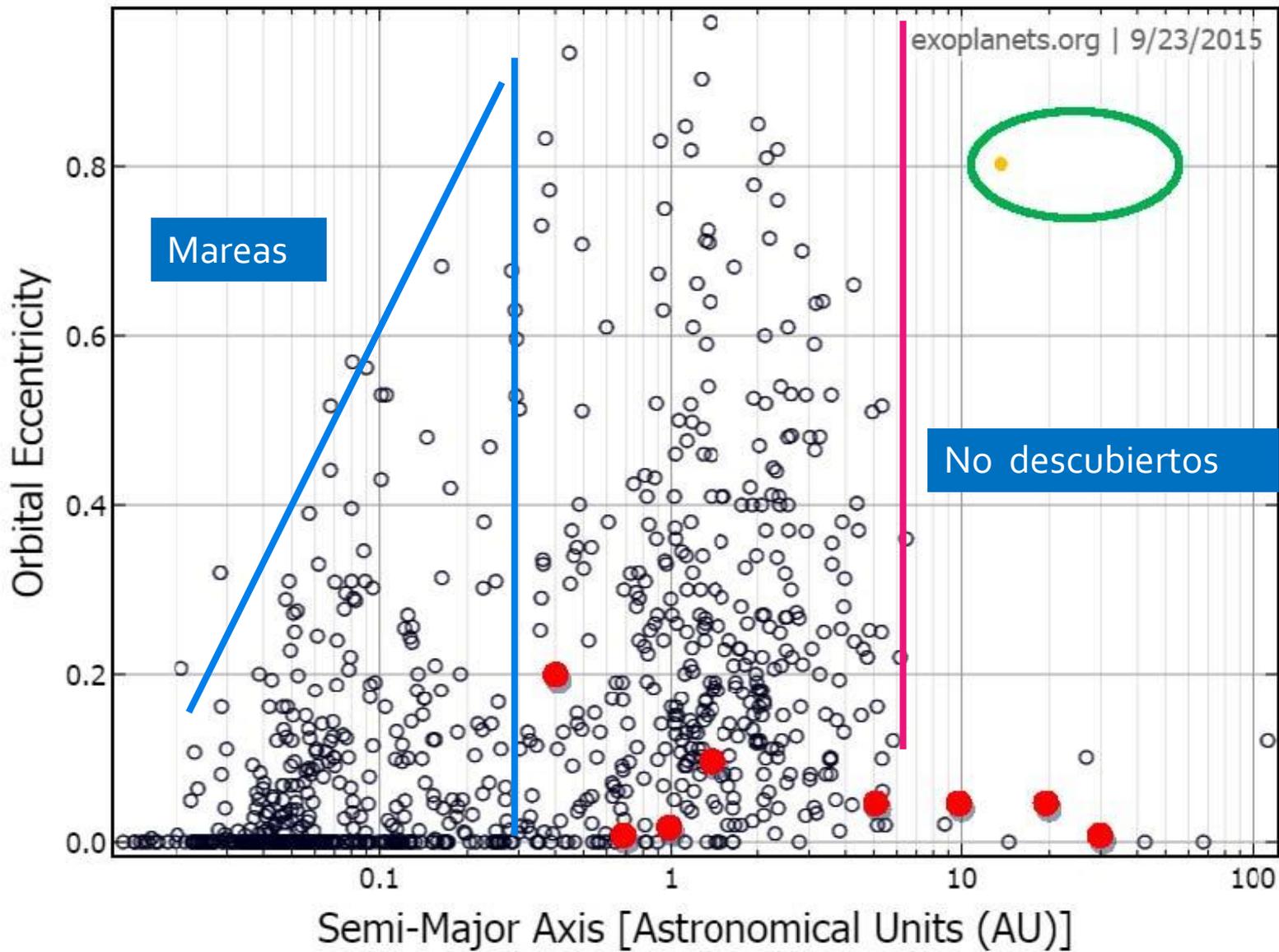


Kepler-186f



Earth





Evolución orbital por 2Ma

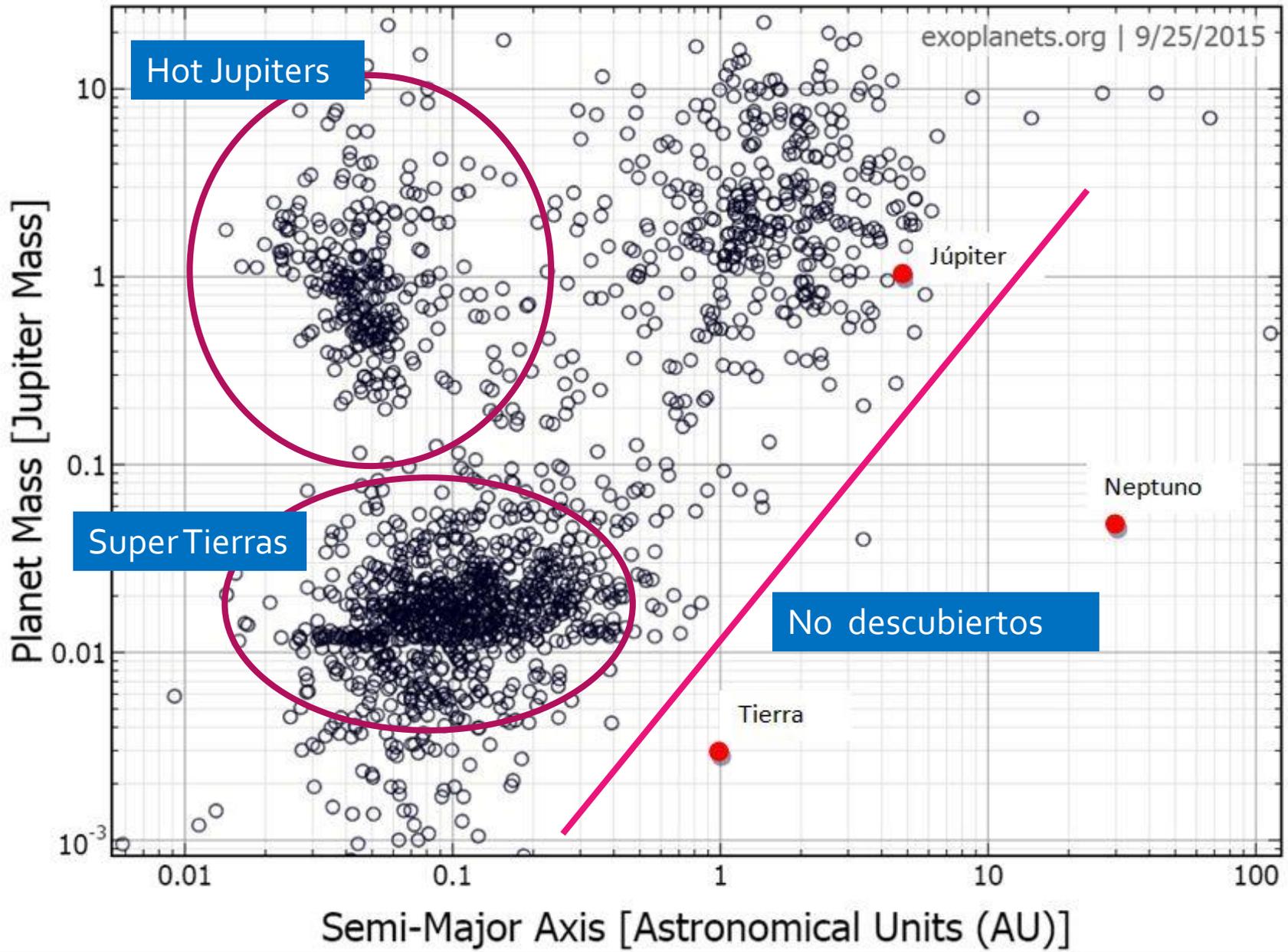
2.000.000 years of orbital evolution of
Mercury, Venus, Earth and Mars

Tabare Gallardo
Facultad de Ciencias
Uruguay

www.fisica.edu.uy/~gallardo

Órbitas muy excéntricas

- Prácticamente todas las teorías de formación planetaria previas a 1995 predecían sistemas planetarios en **órbitas cuasi circulares**.
- ¿Modelos muy crudos y sesgados al Sistema Solar?
- ¿(Auto)censura?



Hot Jupiters

Super Tierras

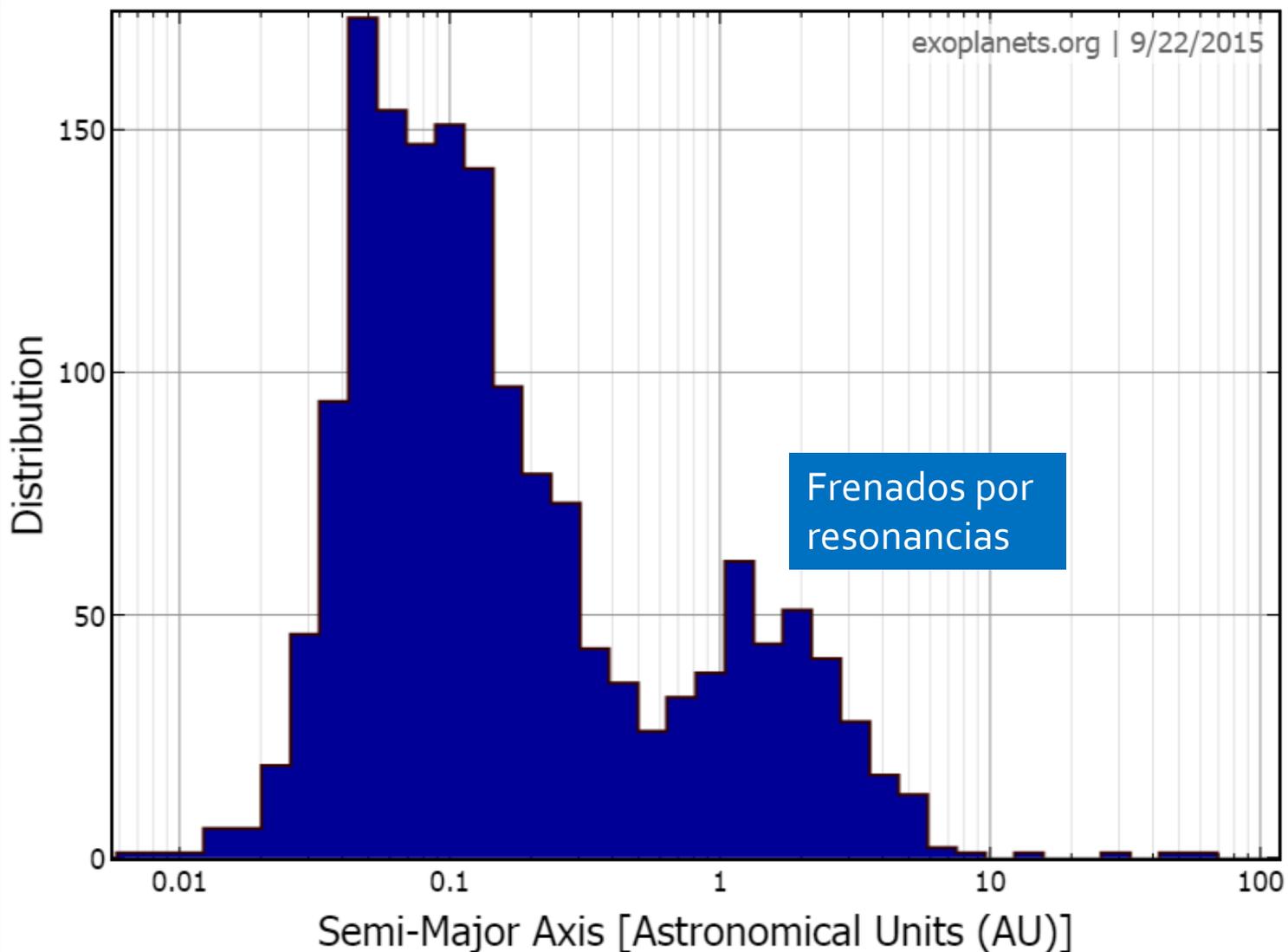
No descubiertos

Júpiter

Neptuno

Tierra

Semi-Major Axis [Astronomical Units (AU)]



Migración

THE ASTROPHYSICAL JOURNAL, 241:425–441, 1980 October 1

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DISK-SATELLITE INTERACTIONS

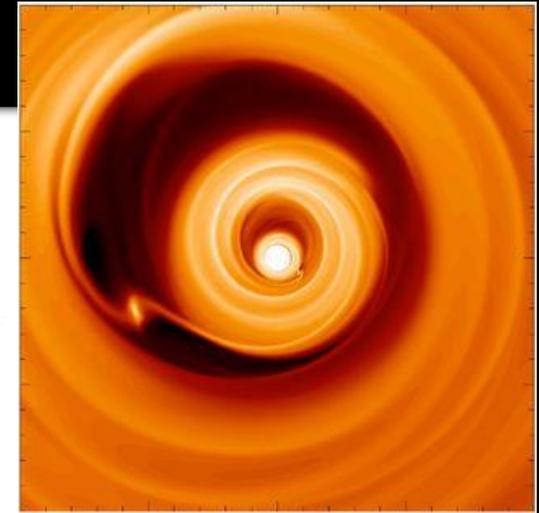
PETER GOLDREICH

California Institute of Technology

AND

SCOTT TREMAINE

Institute for Advanced Study, Princeton, New Jersey



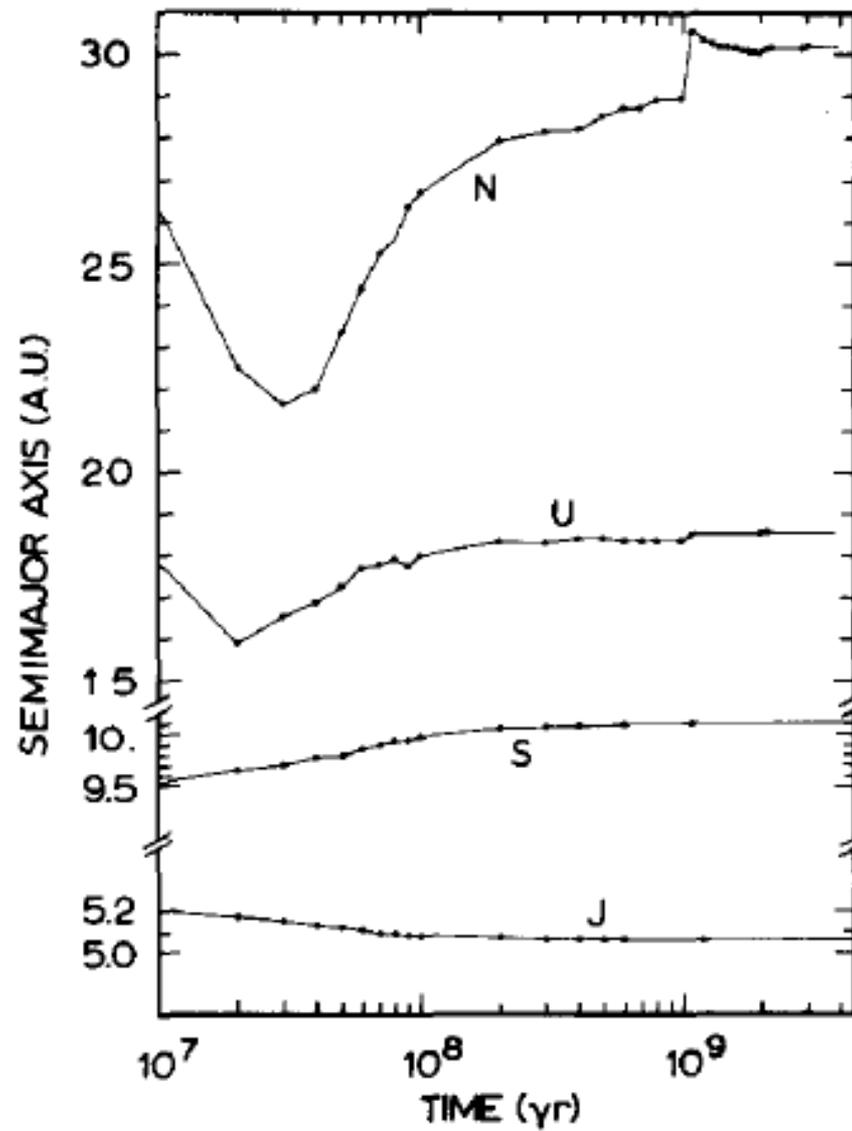
ICARUS 58, 109–120 (1984)

Some Dynamical Aspects of the Accretion of Uranus and Neptune: The Exchange of Orbital Angular Momentum with Planetesimals

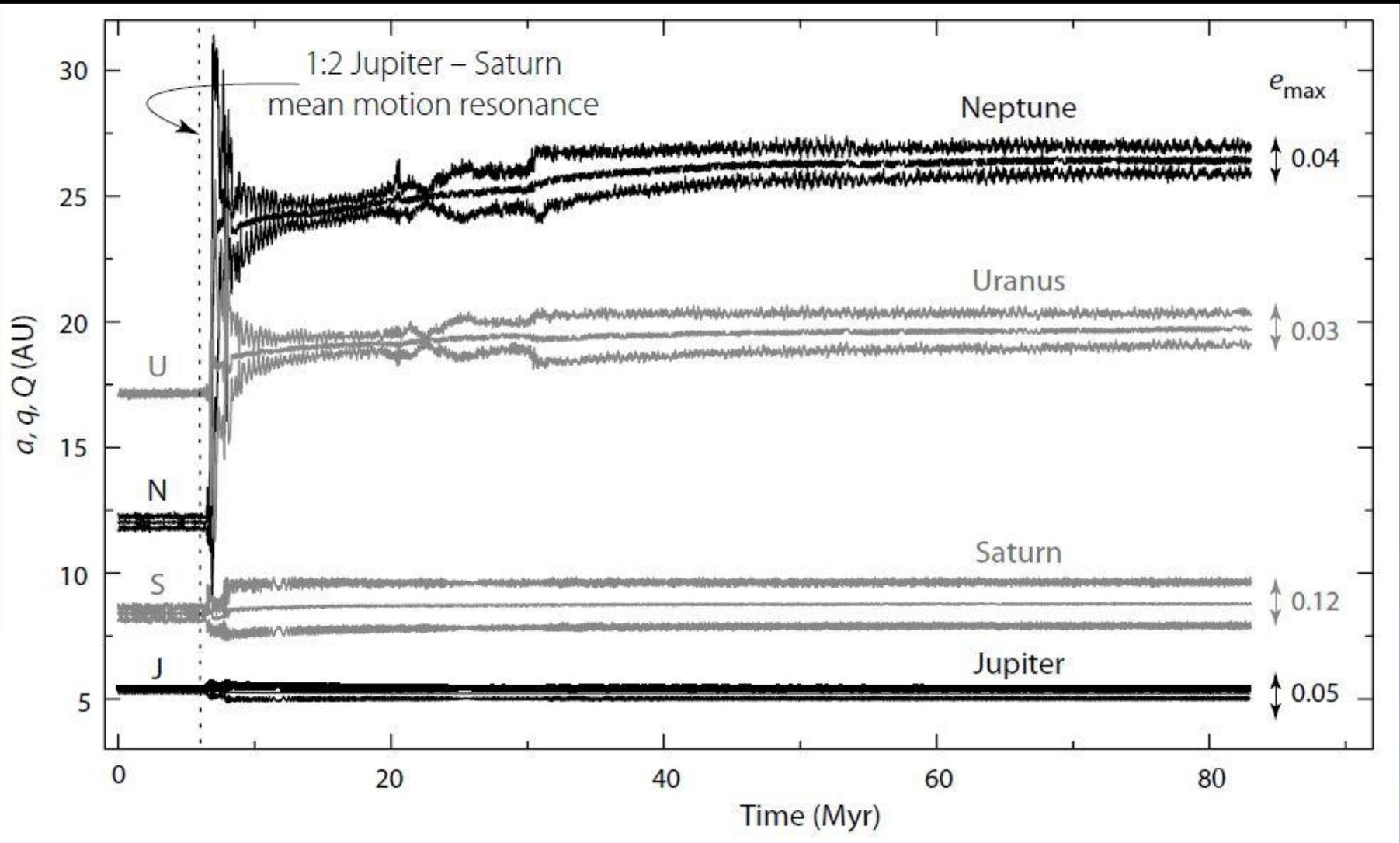
J. A. FERNÁNDEZ* AND W.-H. IP†

**Max-Planck-Institut für Kernphysik, 6900 Heidelberg, and †Max-Planck-Institut für Aeronomie,
3411 Katlenburg-Lindau, Federal Republic of Germany*

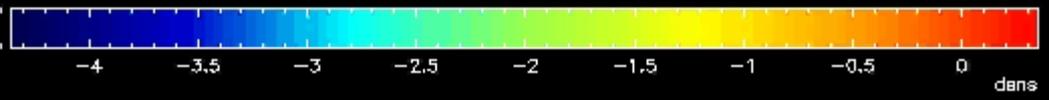
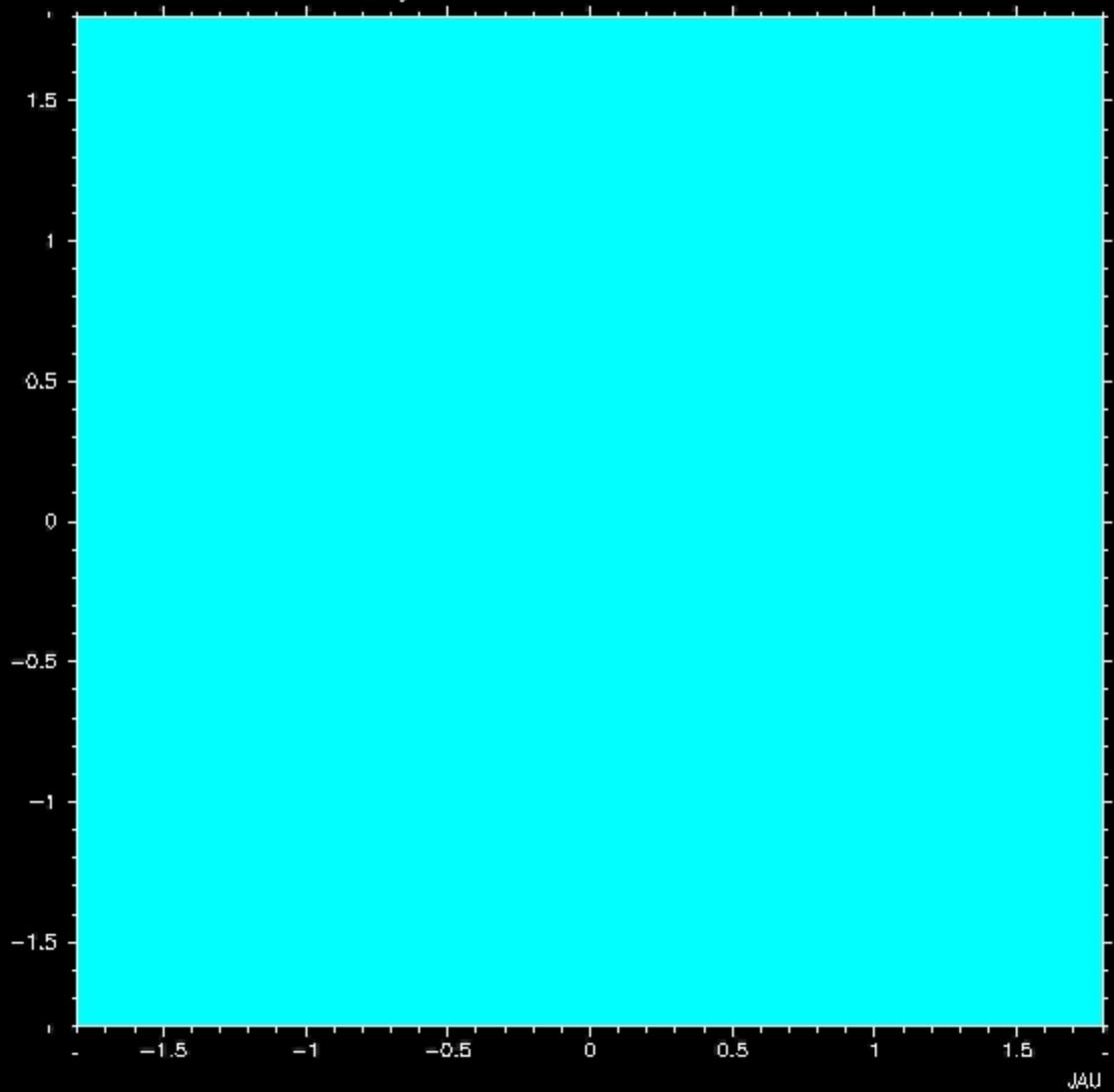
Received September 6, 1983; revised January 2, 1984



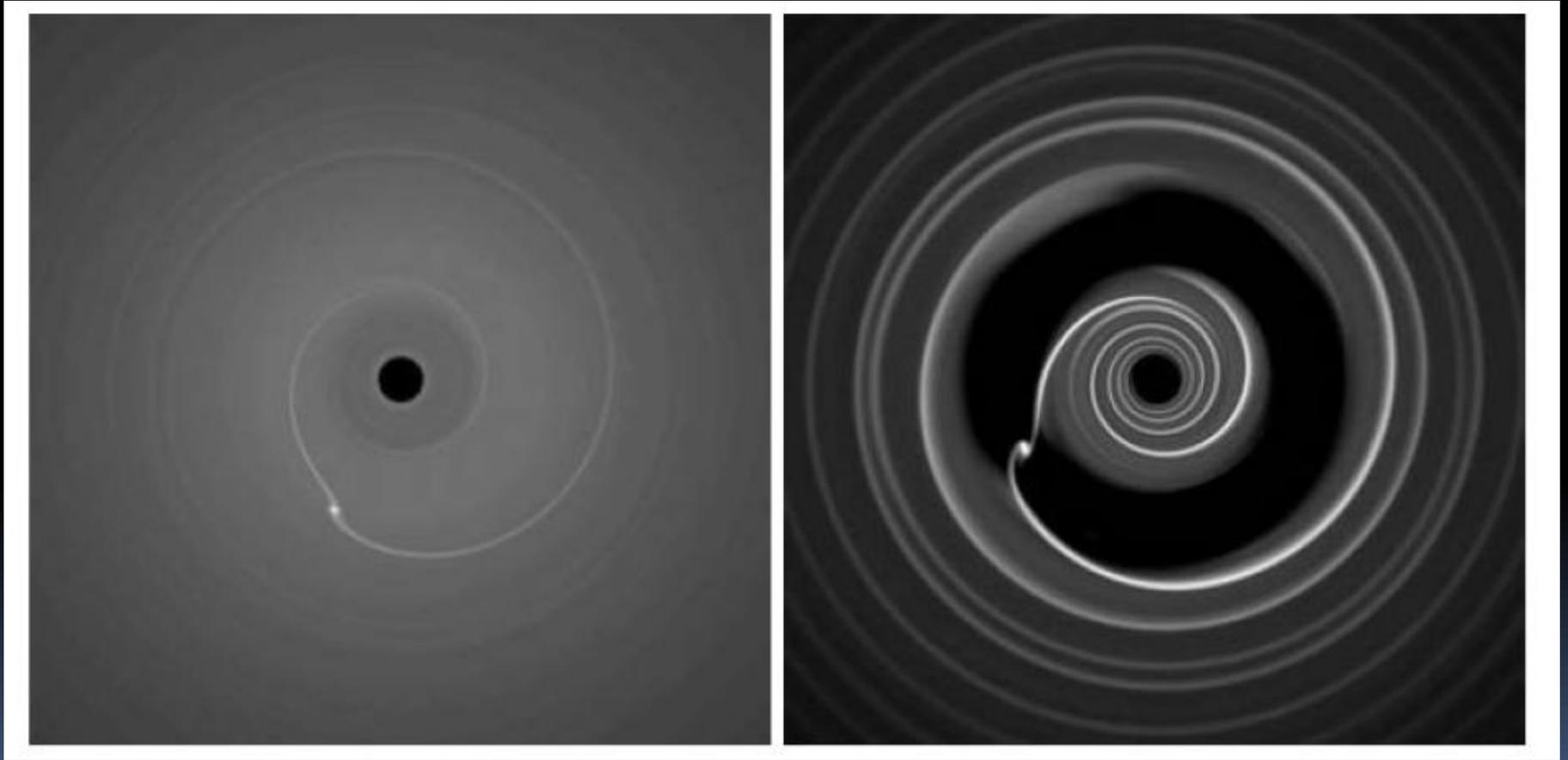
Modelo de Niza: migración + resonancias



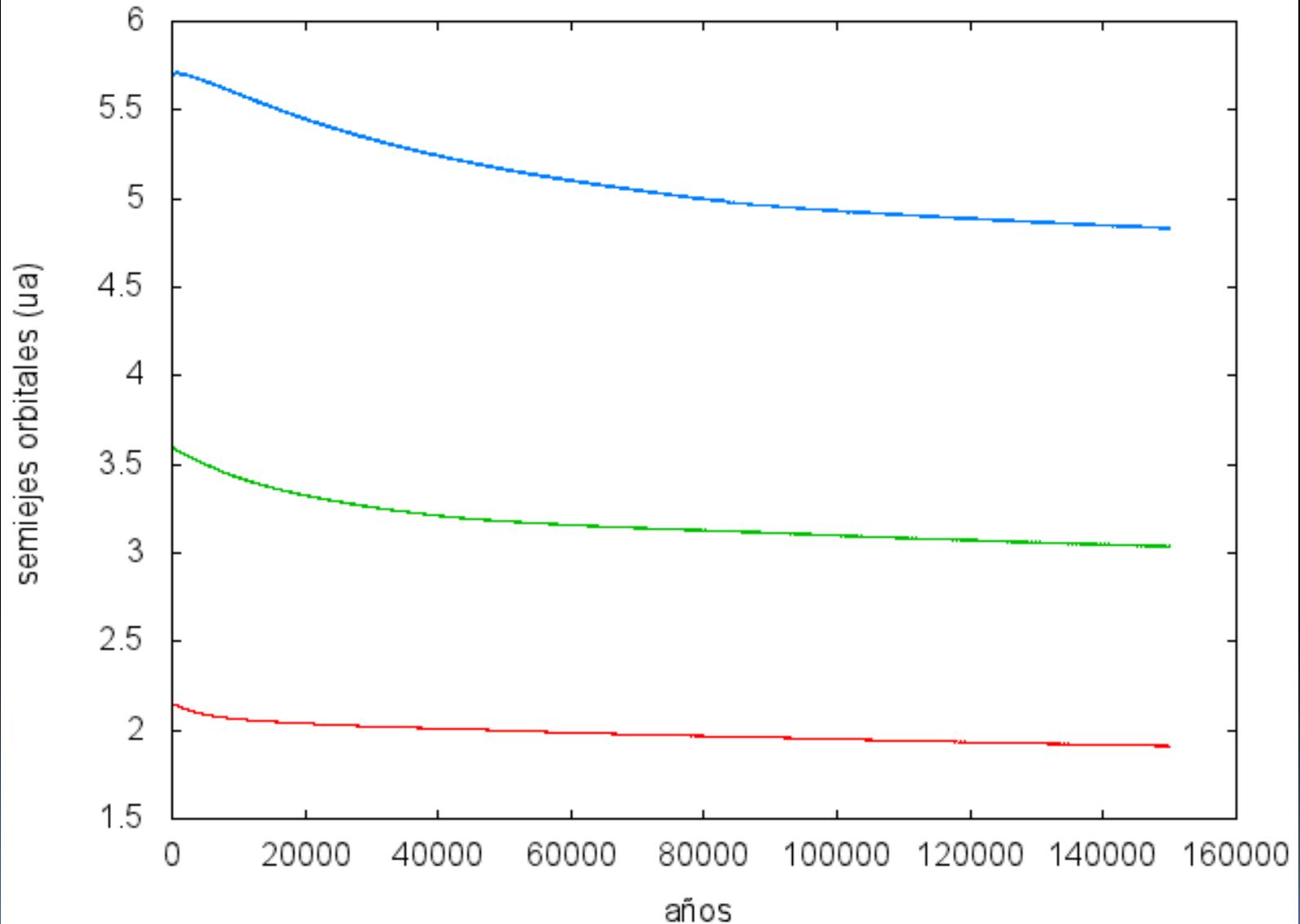
simulation time= 0.0000E+00 Jyr



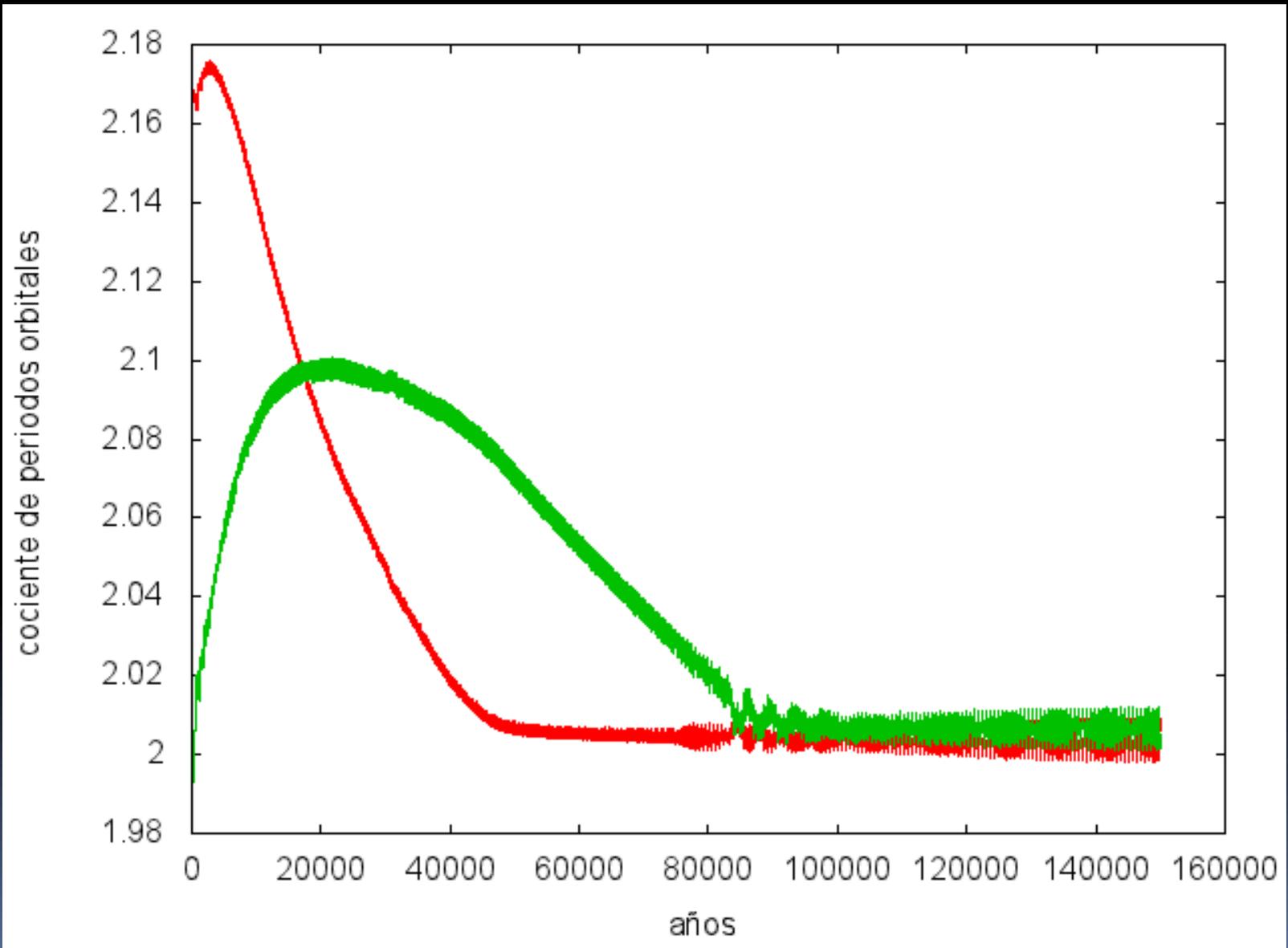
Interacción planeta-disco



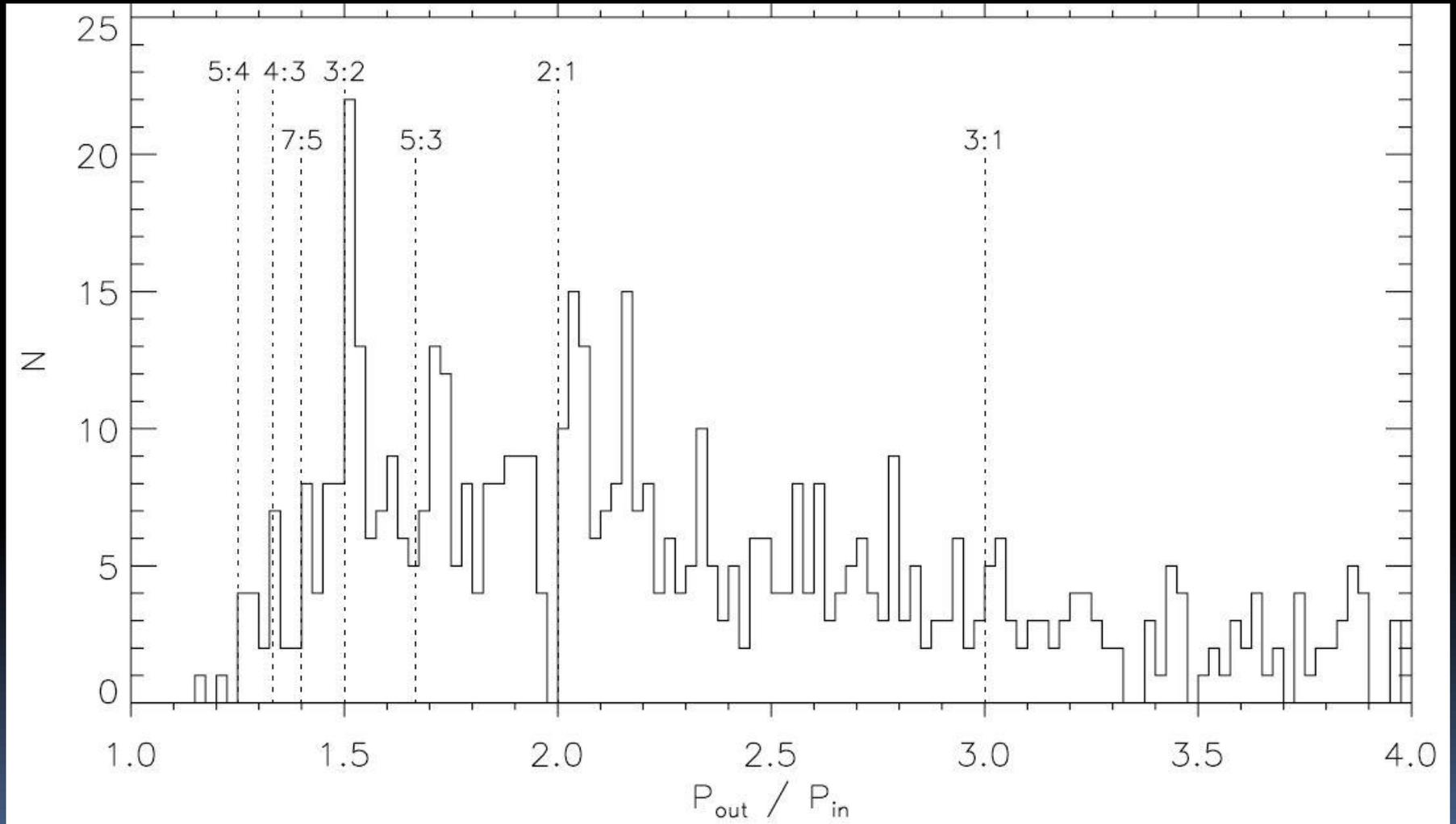
Tres planetas migrando



Relación entre períodos



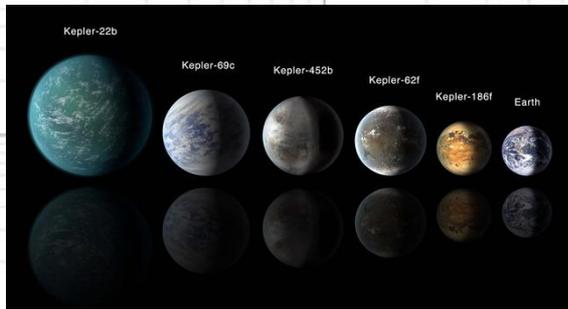
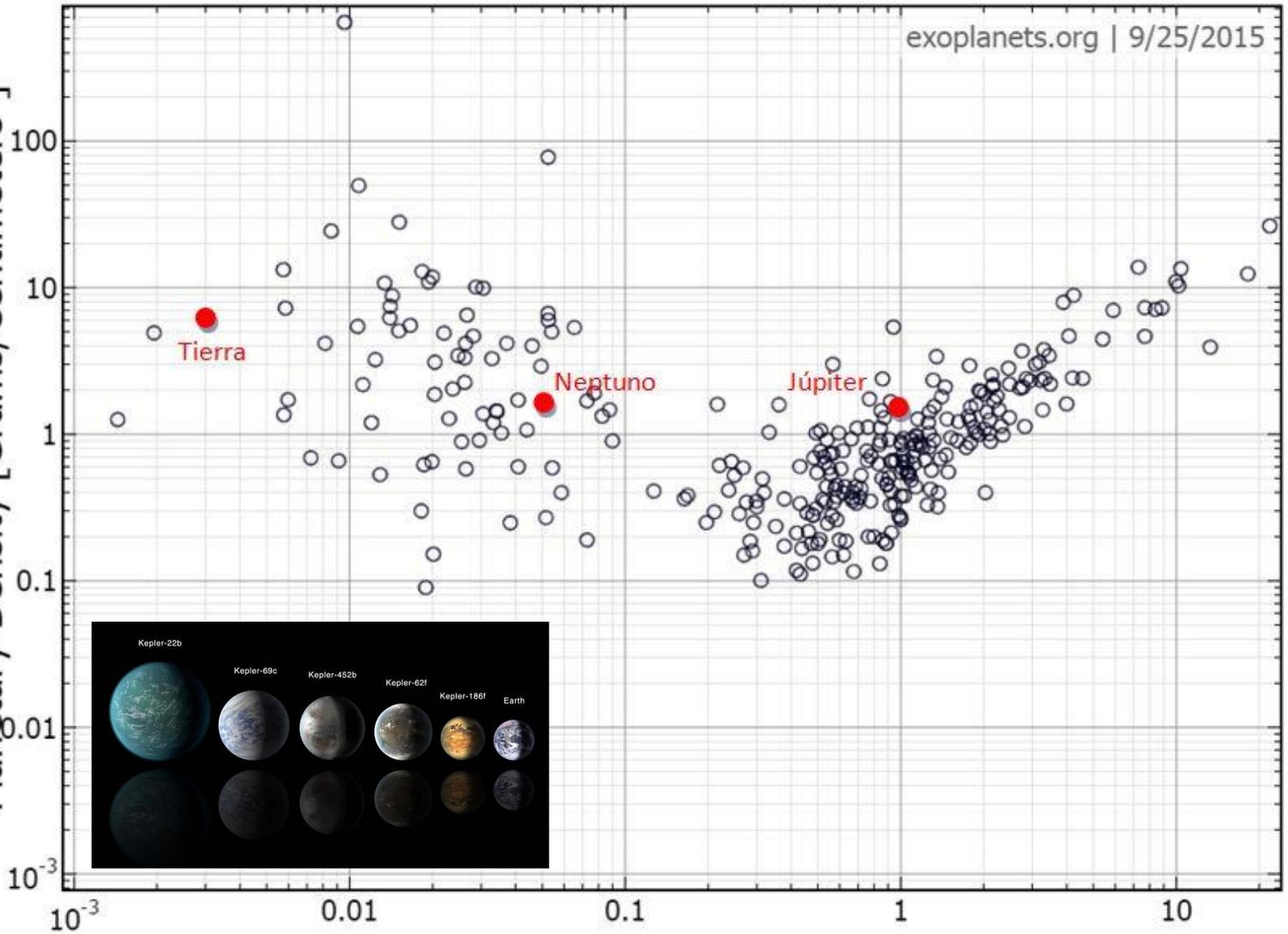
Exoplanetas: relación entre períodos



RESULTADOS:

B) Interiores y Atmósferas

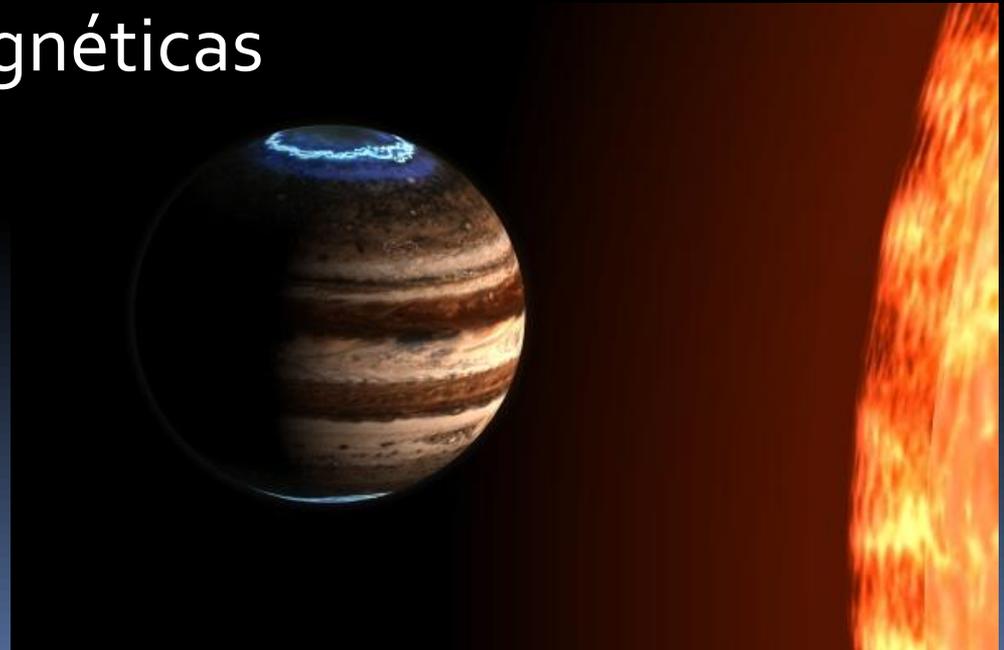
Planetary Density [Grams/Centimeters³]



Planet Mass [Jupiter Mass]

Hot Jupiters

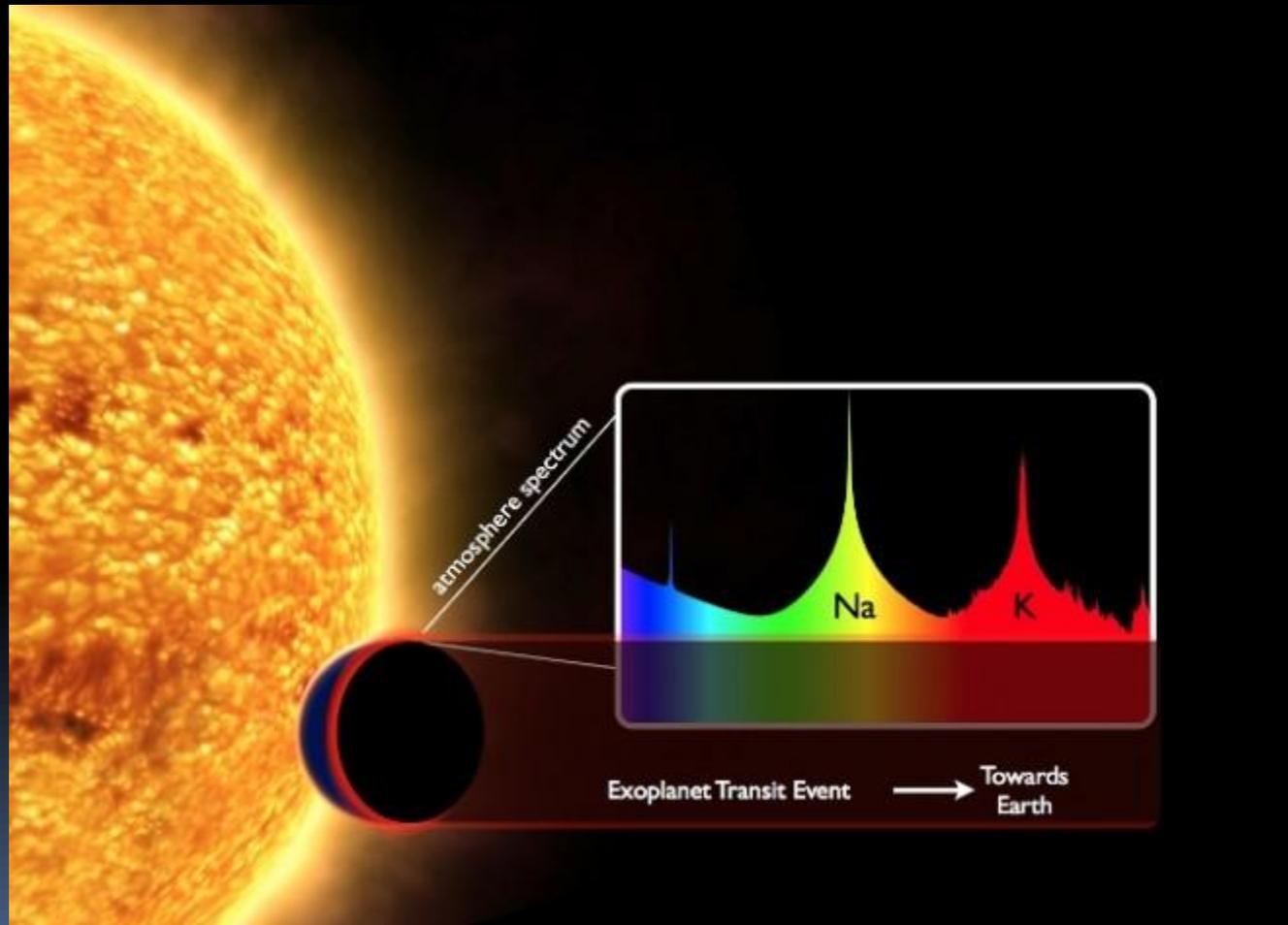
- Atmósferas extendidas
- Intensas mareas estelares
- Circulación atmosférica atípica
- Interacciones magnéticas



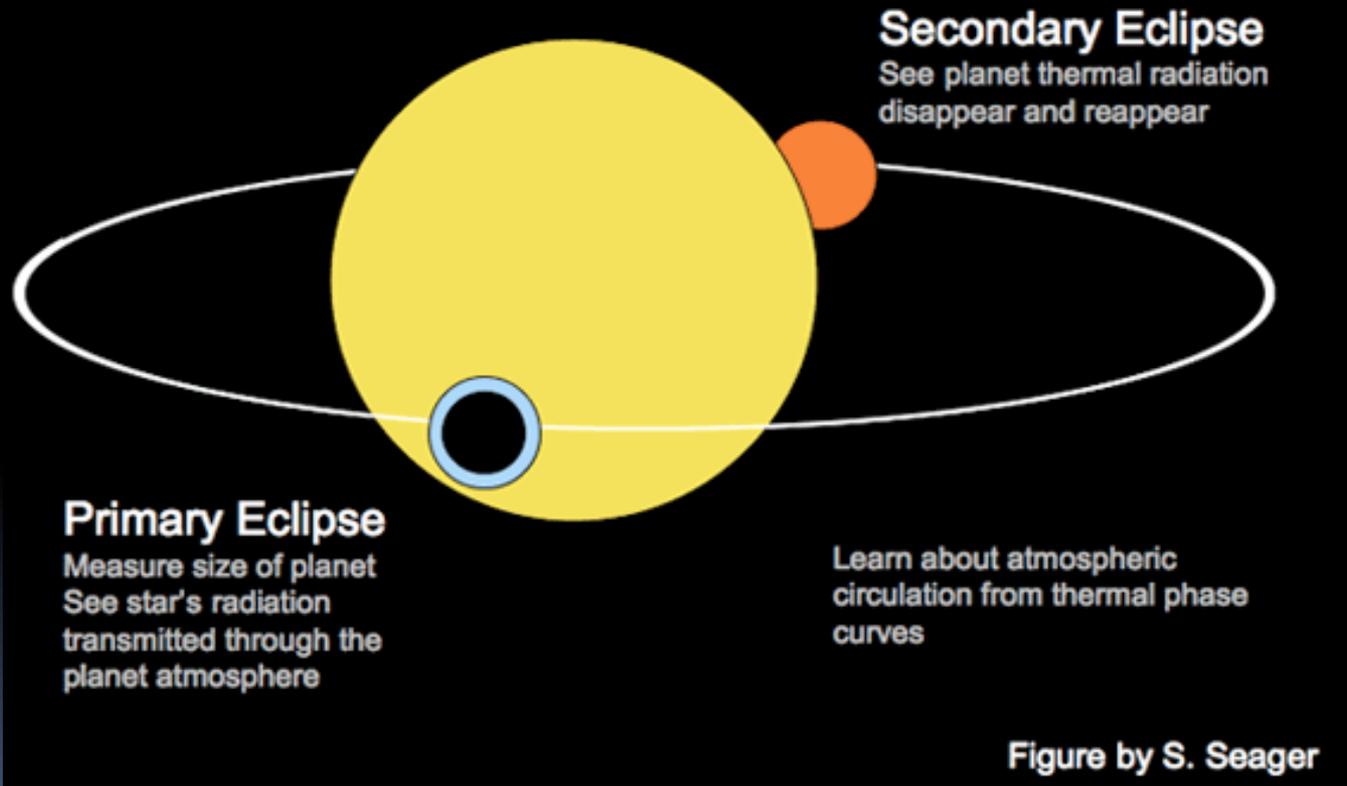
Tierras y SuperTierras

- Formados más allá de la línea de nieve: gran cantidad de agua ($> 10\%$)
- Formados más cerca de la estrella: ricos en rocas y metales
- ¿Planetas sin núcleo diferenciado?
- ¿Planetas con $C/O > 1$ ricos en SiC (en vez de SiO_2)?
- Tierras calientes: ¿ volátiles perdidos y nubes de Na y K?
- ¿Super Tierras como carozos de Neptunos?

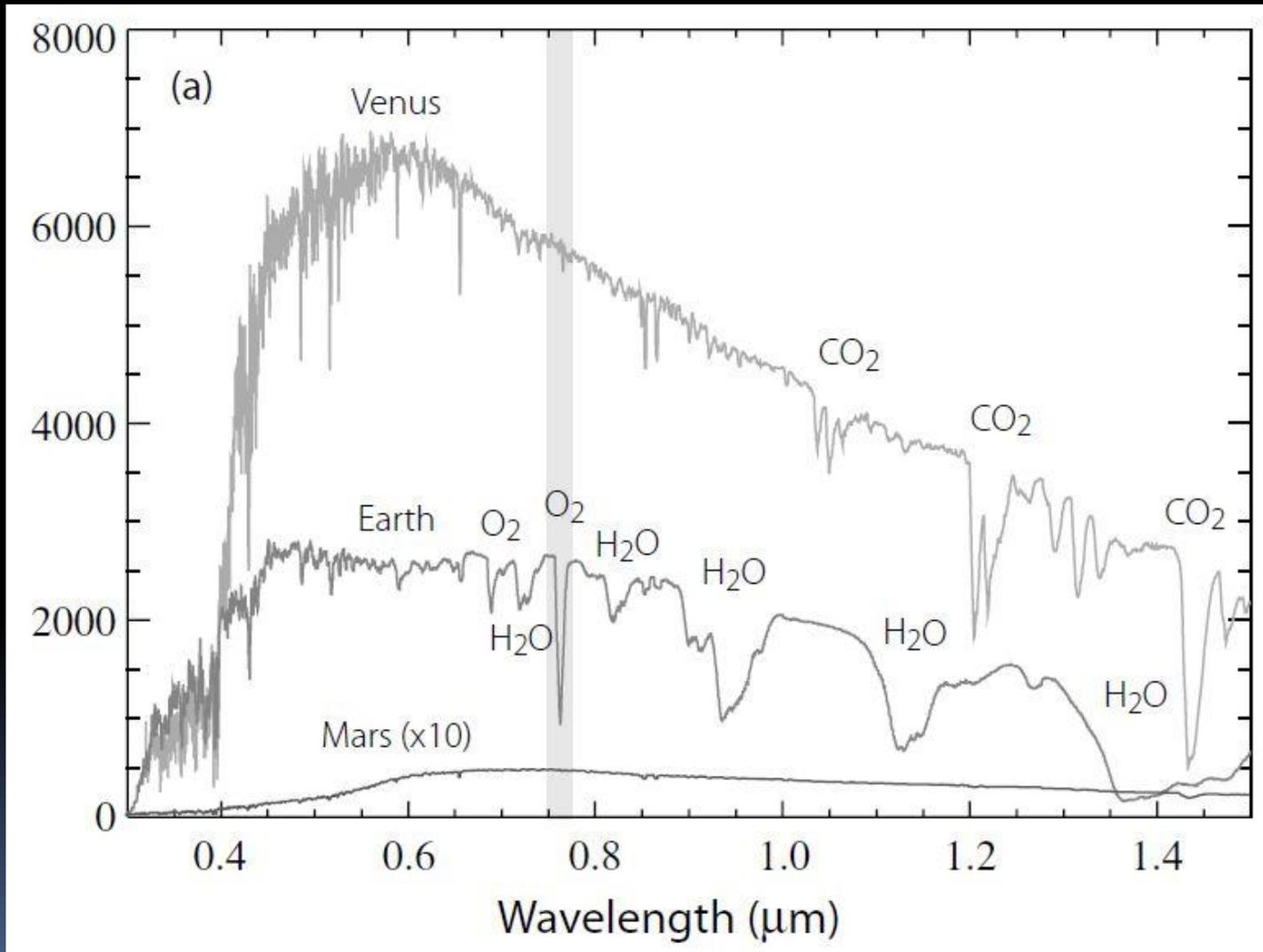
Atmósferas: primeras detecciones



Na, H, C, O, agua, nubes



Espectros: ¿bioseñales?



Campos magnéticos planetarios

- Campos magnéticos: modulación de la actividad de la estrella
- Mecanismo dínamo y constitución interna
- Escudo protector



Sara Seager
**EXOPLANET
ATMOSPHERES**
Physical Processes

Disciplinas emergentes

Invited Review for *Treatise on Geophysics*, 2nd Edition

Exoplanetary Geophysics – An Emerging Discipline

Gregory Laughlin

UCO/Lick Observatory, University of California, Santa Cruz, Santa Cruz, CA 95064, USA

Jack J. Lissauer

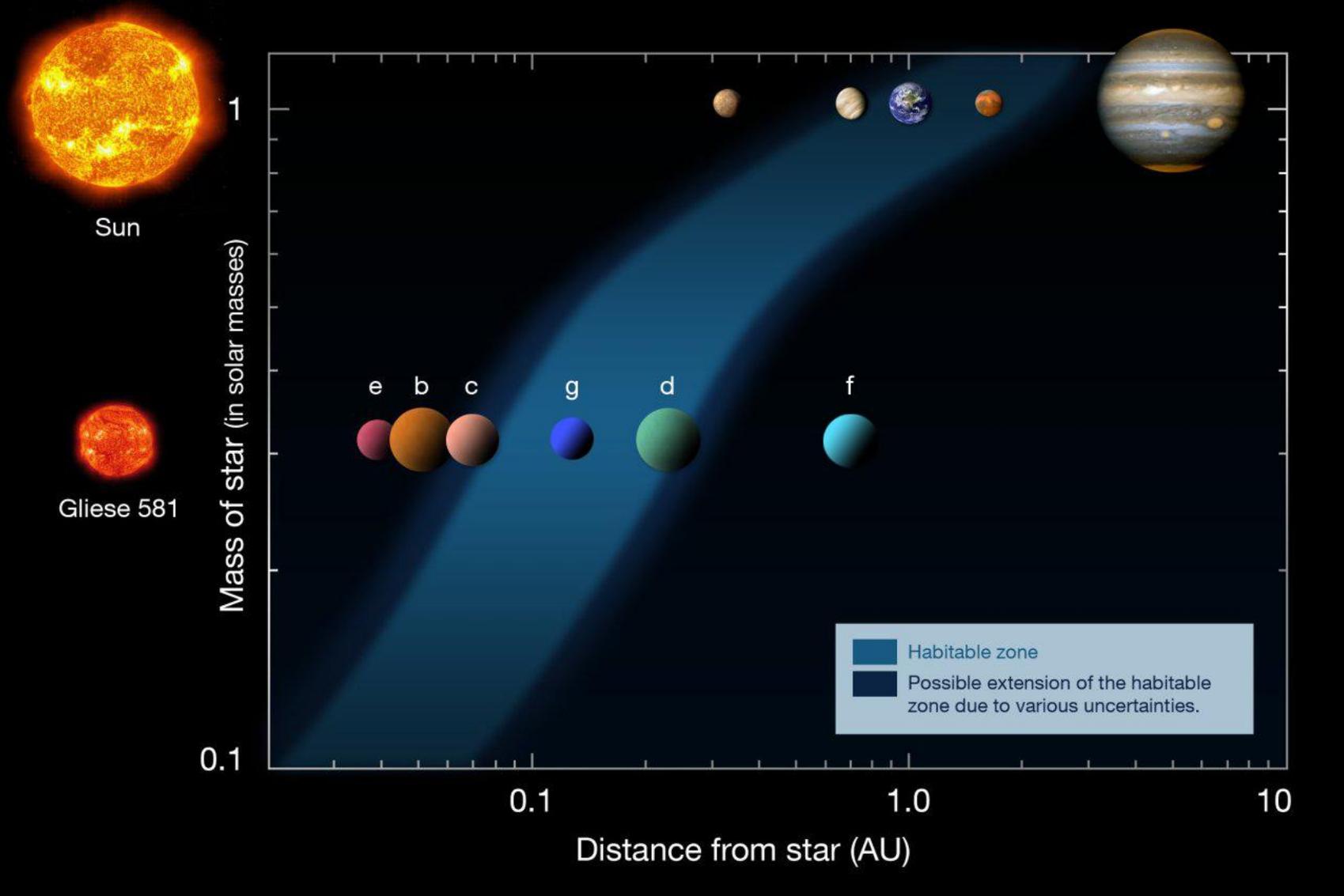
NASA Ames Research Center, Planetary Systems Branch, Moffett Field, CA 94035, USA

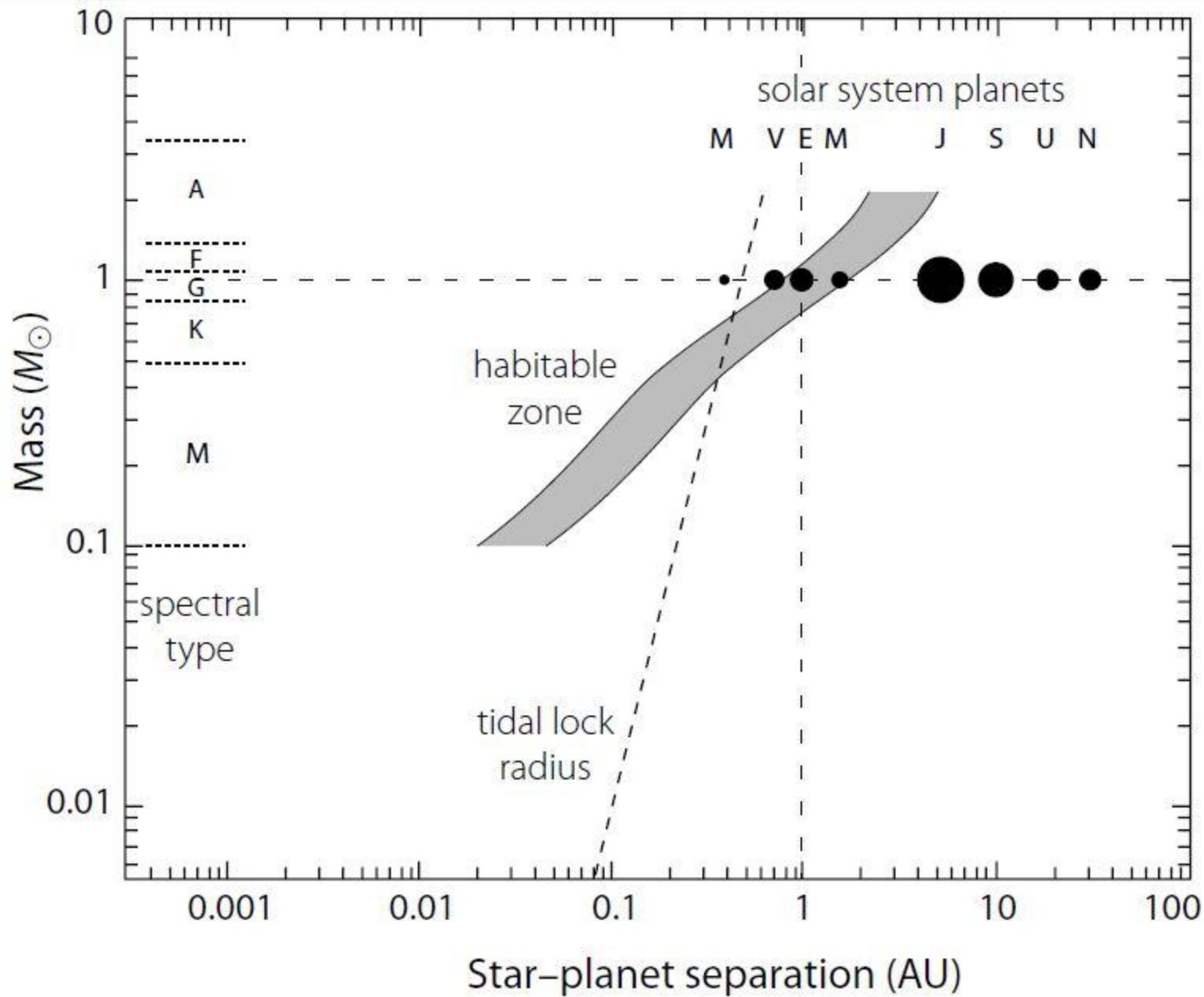
ASTROBIOLOGIA

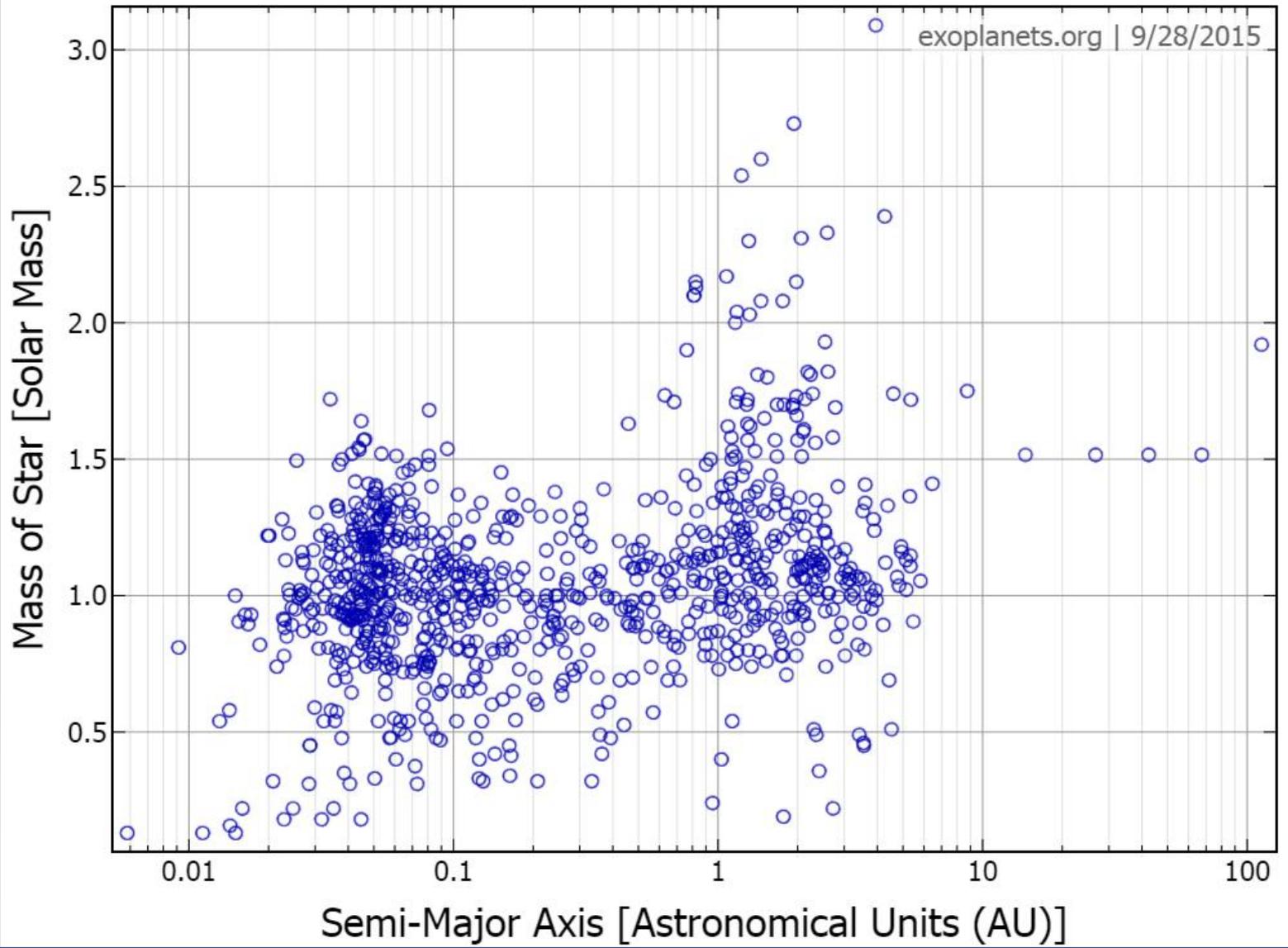
Astrobiología:

- Naturaleza y distribución de los entornos habitables
- Cómo emerge la vida a partir de los planetas u otros entornos (¿nubes?)
- Cómo evoluciona
- Límites ambientales para la vida
- Mecanismos que determinan su futuro
- Cómo detectar trazas de vida en otros mundos

Zona de Habitabilidad







SETI:

Search ExtraTerrestrial Intelligence

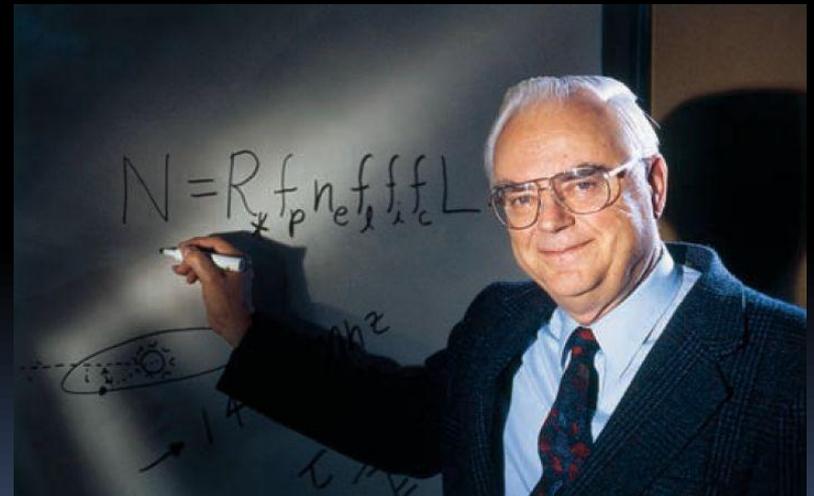
el gran silencio

Ecuación de Drake

$$N = N_{\text{planetas}} \times f_{\text{vida}} \times f_{\text{civilizacion}} \times f_{\text{ahora}}$$

$$N = 10^{12} \times 0.1 \times 0.1 \times 100/10.000.000.000$$

$$N \sim 100 \quad (???)$$



¿Por qué aún no las encontramos?

Arecibo



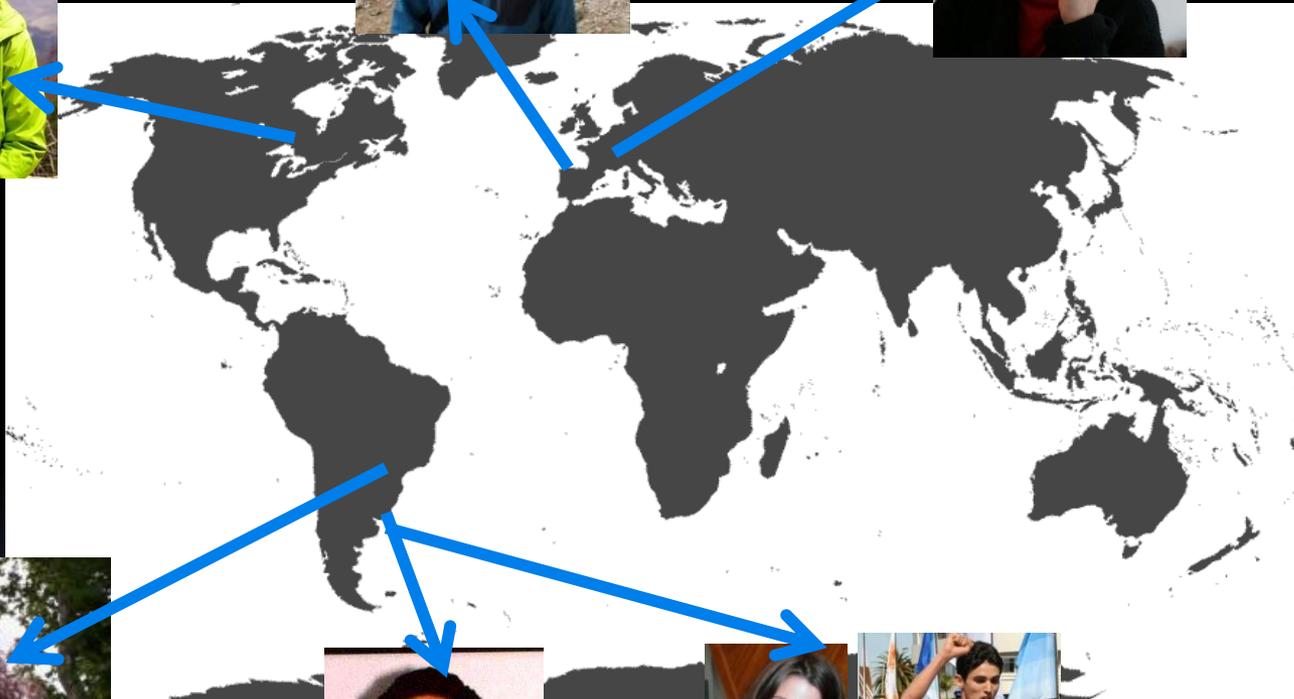
Allen Telescope Array



Desafíos

- Geofísica exoplanetaria: interiores, superficies, planetas helados, oceánicos
- Atmósferas: química y dinámica
- Astrobiología: diversidad de entornos
- Nuevas tecnologías: detección de planetas, atmósferas, campos magnéticos, actividad biológica
- Estudios dinámicos: poder de cómputo para procesar modelos más realistas

Uruguayos exoplanetarios



Hace 25 años...

Levante Confirmada por el Ejército 25-7-1996-74

Masiva presencia de ovnis en Chile

Se habla de secuestros y persecuciones

SANTIAGO DE CHILE, 25 de Julio. — Pasa un día extraordinario, una vez más, en Chile. Se habla de ovnis, de secuestros, de persecuciones. El Ejército confirma la presencia de estos aparatos voladores en el país.

LA PRENSA 025
Diario Ilustrado de la Mañana

¡PLATO VOLADOR EN LA CAPITAL!

Un Velocísimo y Extraño Aparato se Mantuvo Toda la Mañana Sobre el Aeropuerto Central

Un OVNI gigantesco

en jaque a la defensa española

El Ejército exige silencio a los testigos

NO CARDEÑOSA

se Aérea de Zaragoza despegada para identificar un que se encontraba sobre Jaca. siones de cuatro kilómetros y des superiores a los 6.500 rlar a los cazas. En el escua- aérea se niega todo, pero los «invitados» a guardar silencio.

silencio estamos por fin en condiciones de informar del episodio vivido en los cielos españoles durante la madrugada del 30 de noviembre de 1996.

NADA TAN GRANDE VUELA

02.30 HORAS. En las pantallas de los radares primarios de los escuadrones de vigilancia aérea EVA-1 (nombre militar *Siesta*) y EVA-2 (*Matador*), con sedes en El Frasno (Zaragoza) y Villatobas (Toledo), aparecen extrañas señales: tres ecos no identificados que presentan en el monitor, anómalamente, una coloración roja. Forman un perfecto triángulo equilátero y están unidos por una tenue línea amarilla. Las primeras consideraciones fueron inevitables: nada convencional podía ofrecer un eco semejante en los radares pero... el OVNI estaba allí, estático, aproximadamente sobre la vertical de Jaca (Huesca) y el tamaño del conjunto era gigantesco: ¡cerca de 4 kilómetros! No se conoce nada tan grande en la tierra

Hoy

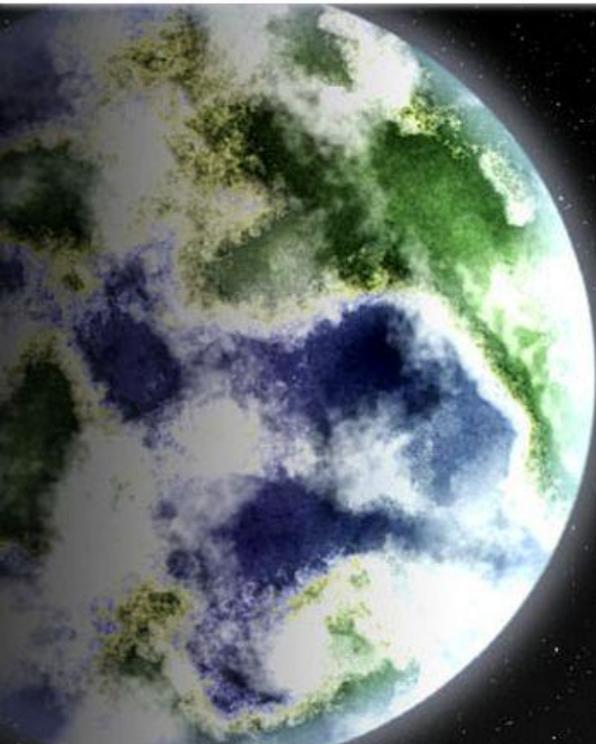
exoplanets.org

Exoplanets
Data Explorer

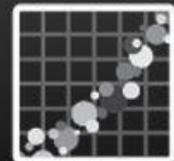
Methodology
and FAQ

Exoplanets
Links

California
Planet Survey



Table



Plots

1618

EOD Planets

Planets with good orbits listed in the Exoplanet Orbit Database

24

Other Planets

Including microlensing and imaged planets

1642

Total Confirmed Planets

3787

Unconfirmed Kepler Candidates

5429

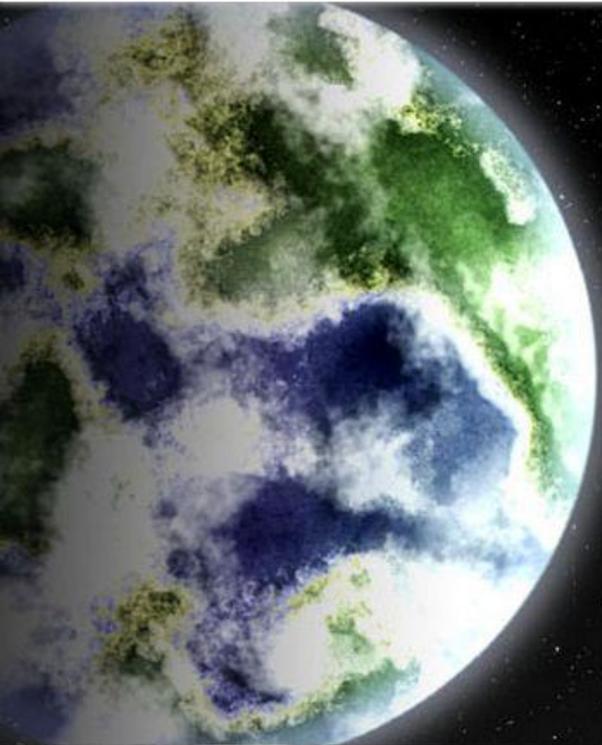
Total Planets

Confirmed planets + Kepler Candidates

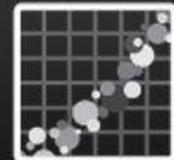
The Exoplanet Data Explorer is an interactive table and plotter for exploring and displaying data from the Exoplanet Orbit Database. The Exoplanet Orbit Database is a carefully constructed compilation of quality, spectroscopic orbital parameters of exoplanets orbiting normal stars from the peer-reviewed literature, and updates the Catalog of nearby

Dentro de 25 años... 😊

exomensajes.org



Table



Plots

1618

Mensajes
amistosos

24

Mensajes
belicosos

1642

Total mensajes
decodificados

3787

Mensajes
incomprensibles

5429

Total mensajes
recibidos

¡MUCHAS GRACIAS!