C/O Ratios in Exoplanetary Atmospheres

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Observations

Theory

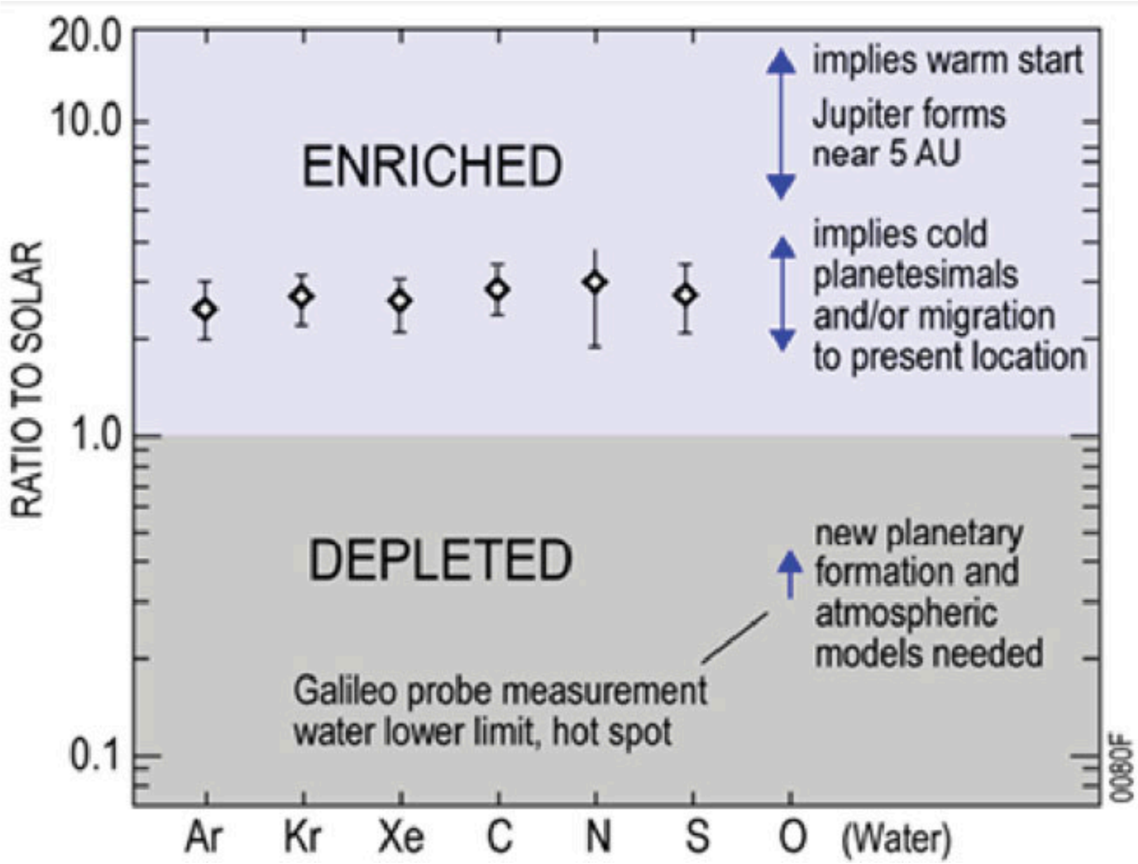
Collaborators: Drake Deming (U. Maryland), Joseph Harrington (UCF), Kevin Stevenson (UCF), Sarah Nymeyer (UCF), Christopher Campo (UCF), Peter Wheatley (WASP), Jasmina Blecic (UCF), Ryan Hardy (UCF), Nate Lust (UCF), David Anderson (WASP), Andrew Collier-Cameron (WASP), Christopher Britt (UCF), William Bowman (UCF), Leslie Hebb (WASP), Coel Hellier (WASP), Pierre Maxted (WASP), Don Pollacco (WASP), Richard West (WASP), Olivier Mousis (FNRS, France), Jonathan Lunine (Cornell), Torrence Johnson (JPL), Kevin Heng (ETH, Zurich), Julianne Moses (Space Sci. Inst), Channon Vischer (LPI), Erik Petigura (Berkeley), Geoff Marcy (Berkeley), Brice Demory (MIT), Kaspar von Braun (NExScI), Sukrit Ranjan (Harvard), David Charbonneau (Harvard)

Special thanks: Sara Seager, Adam Burrows, Marc Kuchner

Extreme Solar Systems II

Jackson Hole, WY. September 11-17, 2011

The Giant Planet Story is the Story of the Solar System



Owen et al 1999; Bolton et al. 2010

C/O = 0.5

(Working Hypothesis)

C/O ≥ 1

(Strange Territory)

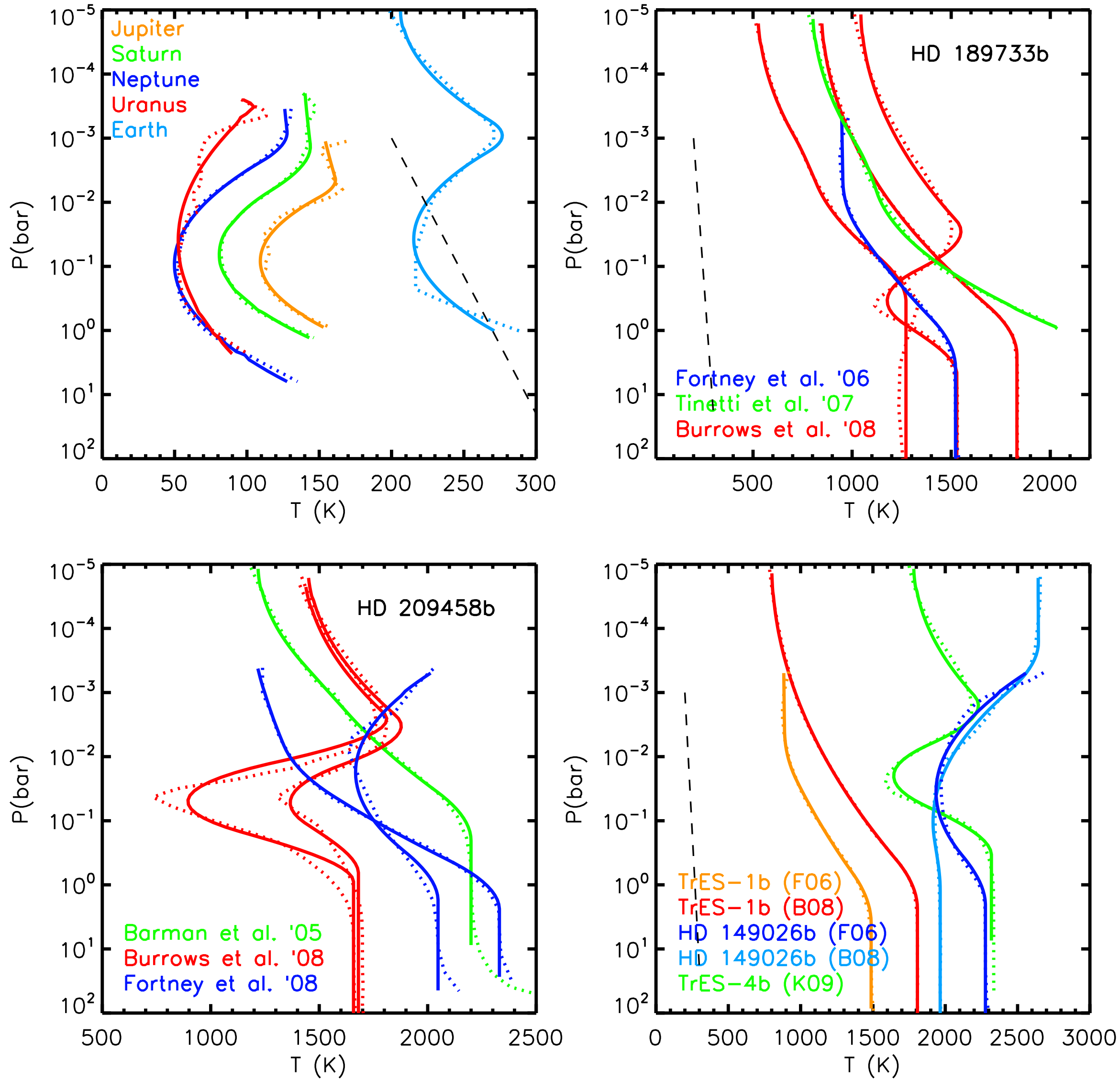
Lodders 2004; Kuchner & Seager 2005; Madhusudhan et al. 2011b, in press.

JUNO Mission

Launch - August 5, 2011, Cape Canaveral, Florida
Mission: To Understand the Origin and Evolution of Jupiter
Journey: 1.7 billion miles, 5 years

Goal #1: "Juno will determine how much water is in Jupiter's atmosphere, which helps determine which planet formation theory is correct (or if new theories are needed)"

Temperature Profiles of Planetary Atmospheres



Madhusudhan & Seager 2009

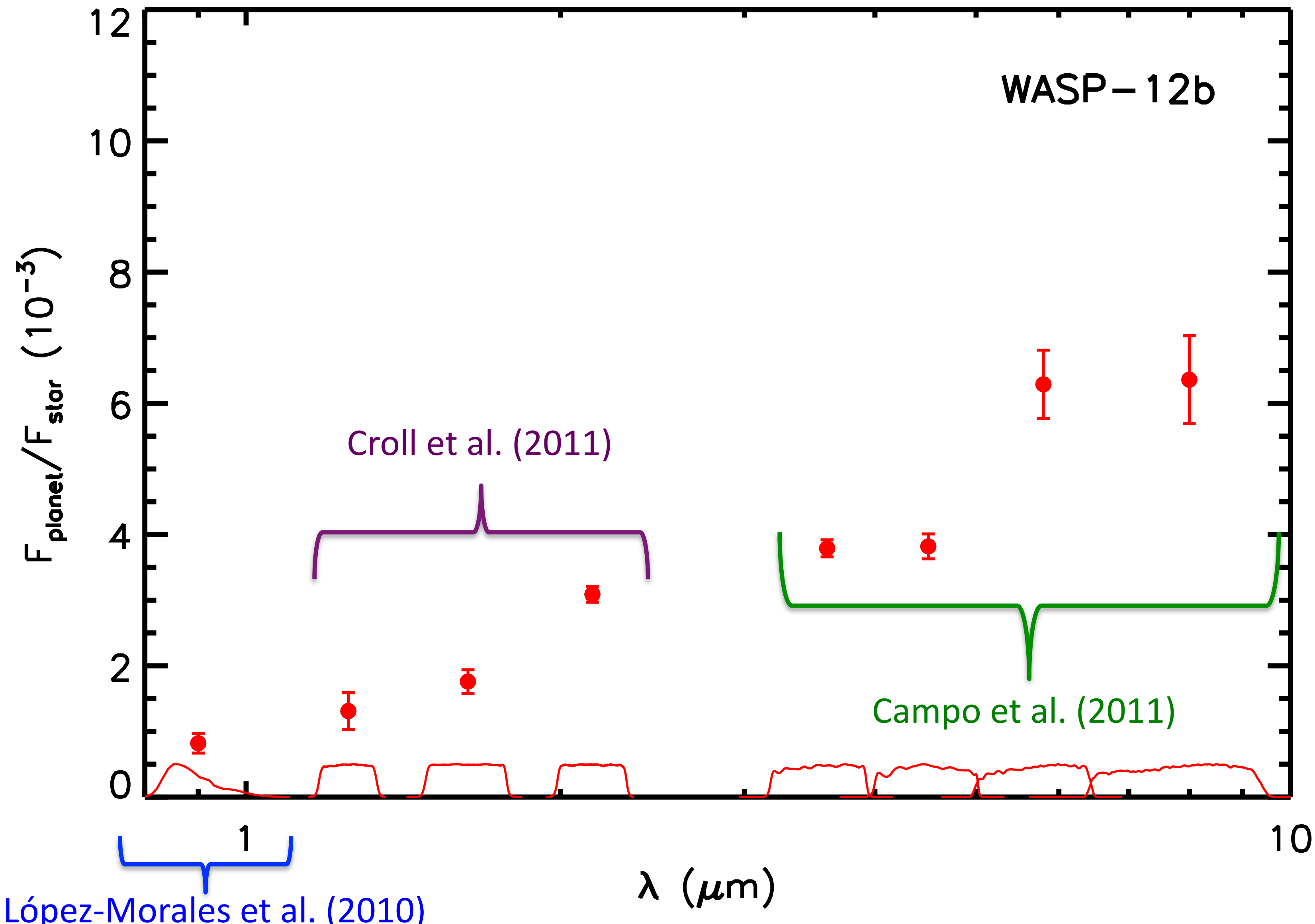
First Stringent Constraint on the C/O ratio of a Giant Planet Atmosphere

Surprises in the dayside atmosphere of hot Jupiter WASP-12b

A high C/O ratio and weak thermal inversion in the atmosphere of exoplanet WASP-12b

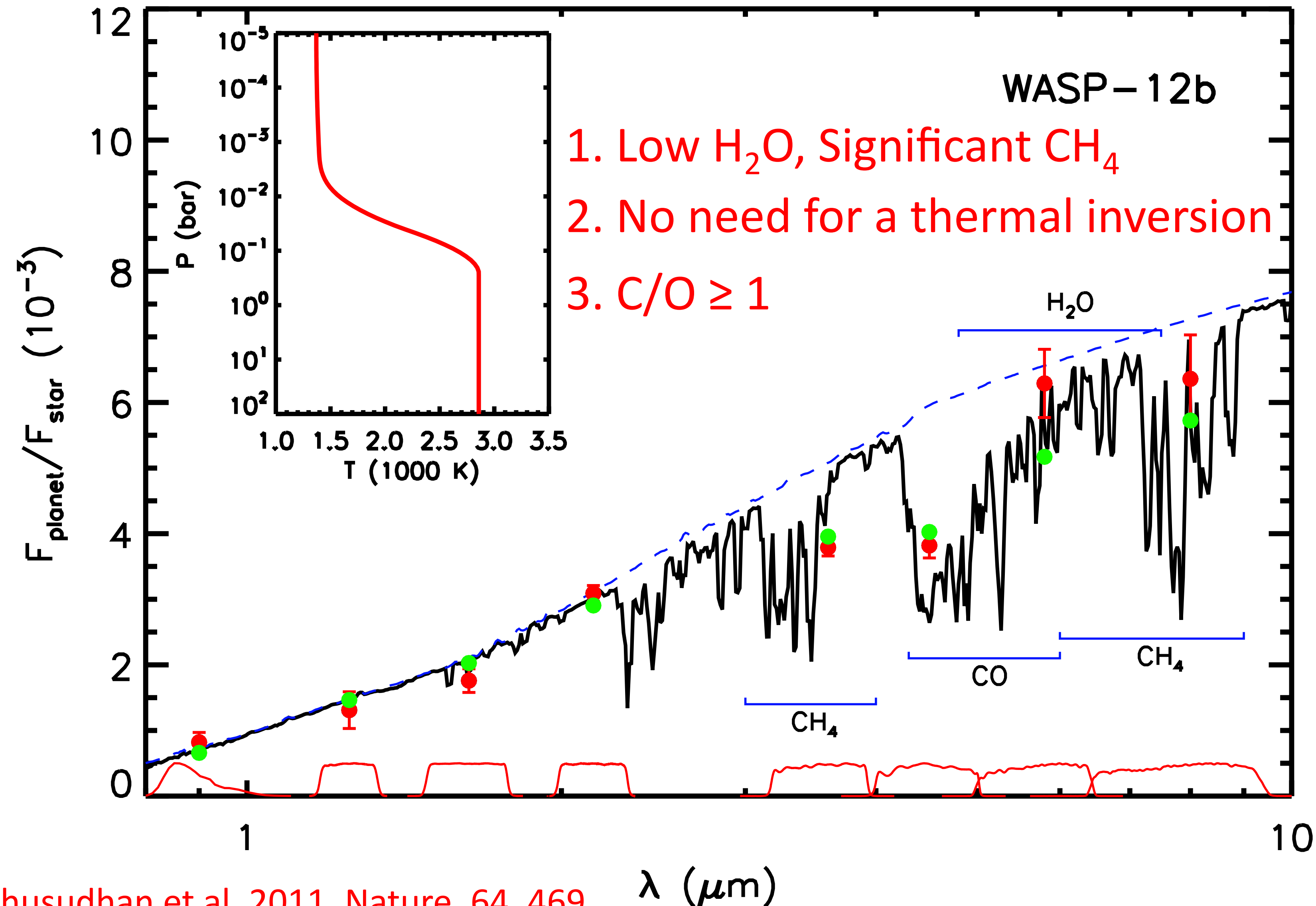
Nikku Madhusudhan (MIT/Princeton), Joseph Harrington (UCF), Kevin Stevenson (UCF), Sarah Nymeyer (UCF), Christopher Campo (UCF), Peter Wheatley (WASP), Drake Deming (NASA GSFC), Jasmina Blecic (UCF), Ryan Hardy (UCF), Nate Lust (UCF), David Anderson (WASP), Andrew Collier-Cameron (WASP), Christopher Britt (UCF), William Bowman (UCF), Leslie Hebb (WASP), Coel Hellier (WASP), Pierre Maxted (WASP), Don Pollacco (WASP), Richard West (WASP), 2011, Nature, 64, 469

Dayside spectrum of WASP-12b



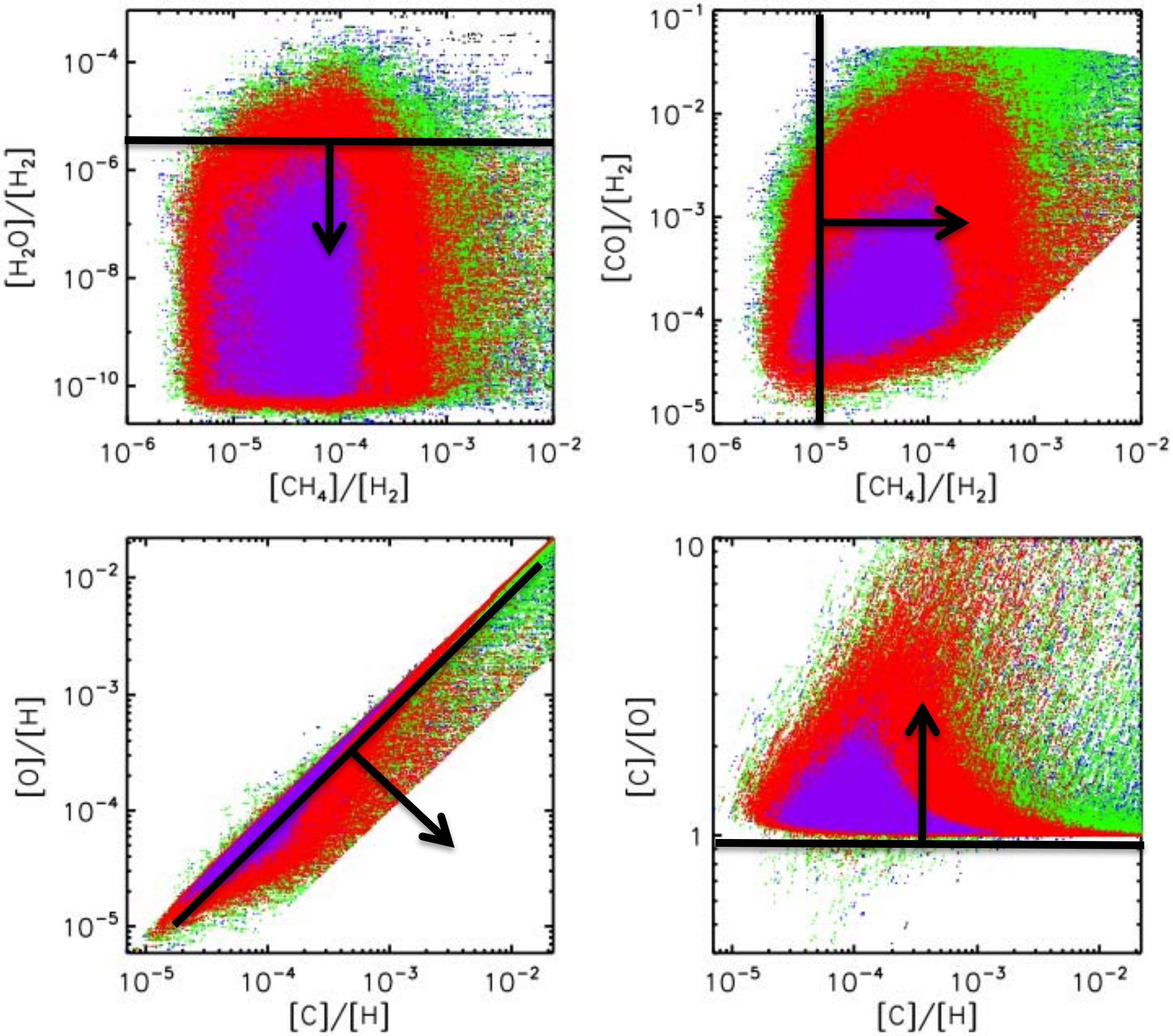
Talk by Nick Cowan. Poster by Ian Crossfield

Fit requires non-solar abundances



Madhusudhan et al. 2011, Nature, 64, 469

A Carbon-rich Atmosphere



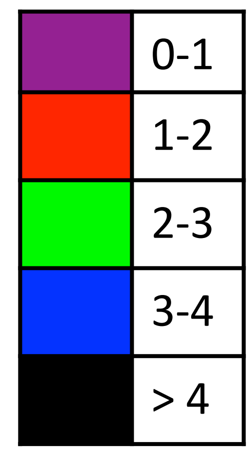
Madhusudhan et al. 2011, Nature, 469, 64

Key Molecular Constraints

- $H_2O/H_2 \leq 6 \times 10^{-6}$
- $CH_4/H_2 \geq 8 \times 10^{-6}$

C/O ≥ 1

$\xi^2 = X^2/N_{obs}$



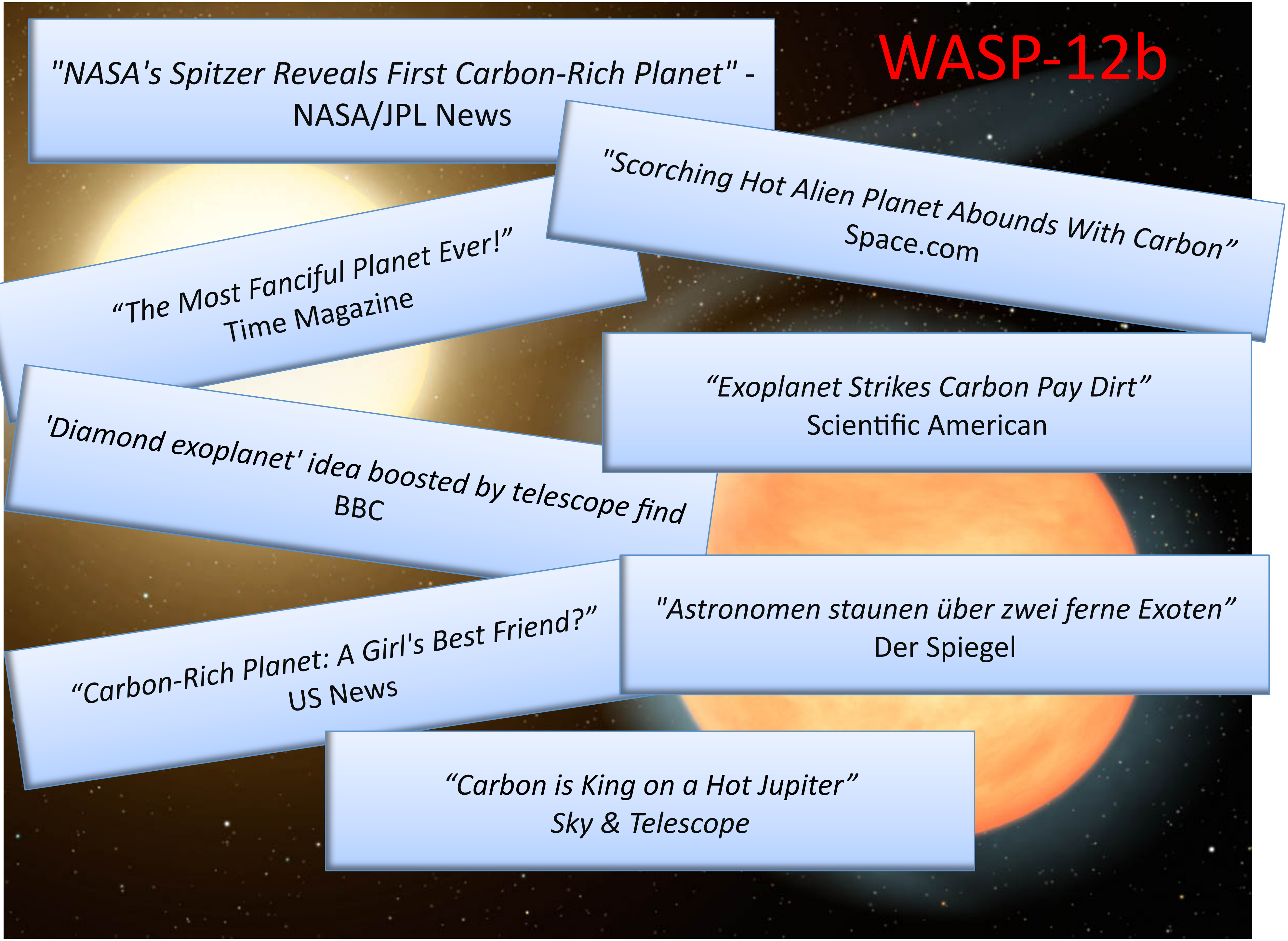
Atmospheric Retrieval Techniques

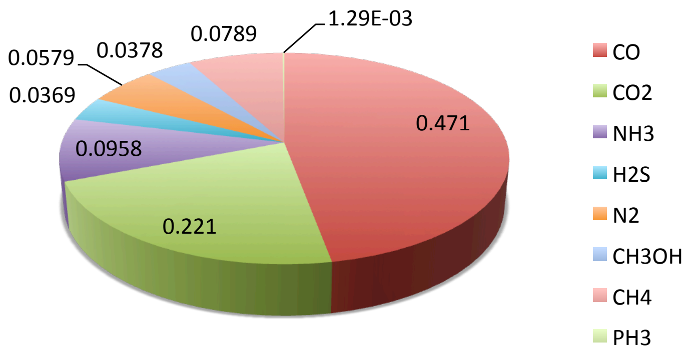
Bayesian:

(Madhusudhan & Seager 2010 & 2011)

Grid-based:

(Madhusudhan & Seager 2009)


WASP-12b
"NASA's Spitzer Reveals First Carbon-Rich Planet" - NASA/JPL News
"Scorching Hot Alien Planet Abounds With Carbon" Space.com
"The Most Fanciful Planet Ever!" Time Magazine
"Exoplanet Strikes Carbon Pay Dirt" Scientific American
'Diamond exoplanet' idea boosted by telescope find BBC
"Carbon-Rich Planet: A Girl's Best Friend?" US News
"Astronomen staunen über zwei ferne Exoten" Der Spiegel
"Carbon is King on a Hot Jupiter" Sky & Telescope



Extreme depletion of water-ice in planetesimals

Madhusudhan et al. 2011b, in press; Lodders 2004

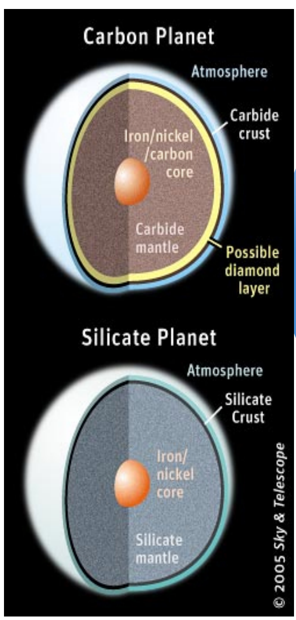
(See poster by E. Petigura)

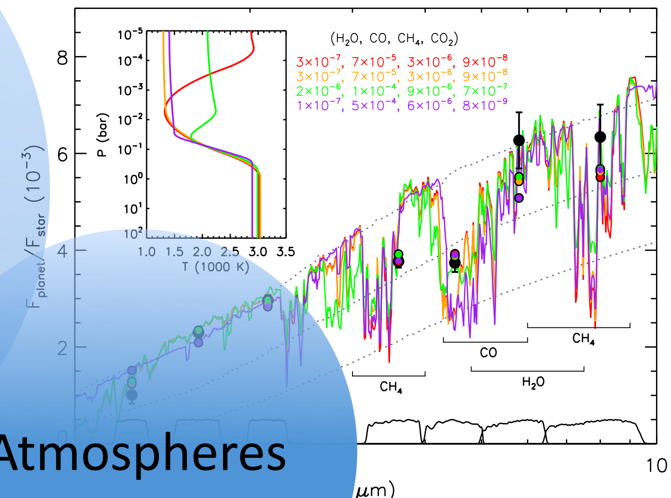
Planet Formation

C/O ≥ 1

Interiors & Surfaces

Atmospheres





Water-poor, C-rich Chemistry

Predominance of non-silicate rocks and interiors, water-poor

Madhusudhan 2011 (submitted), Poster by J. Moses, Talk by K. Heng

Gaidos (2000), Kuchner & Seager (2005), Bond et al. (2010)

New Candidate Carbon-rich Atmospheres

Potential solutions to two outstanding problems

Observational and Theoretical Efforts

Summary

- We have no idea if H_2O should be abundant in exoplanetary atmospheres? We don't even know the H_2O abundance in Jupiter!
- C/O ratio controls the H_2O abundance and has major implications for planet formation, interiors, atmospheres, and for the search for life as we know it.
- We CAN measure C/O ratios for hot Jupiters better than for Jupiter. Hot Jupiters are abundant in gaseous H_2O, whereas Jupiter is below freezing.
- Latest observations are indicating C/O ≥ 1 in some hot Jupiter atmospheres. Need detailed follow-up and verification.

Most Profound Question