EPSC Abstracts
Vol. 12, EPSC2018-541, 2018
European Planetary Science Congress 2018

# An experimental approach to investigate carbon rich exoplanets interior

**Francesca Miozzi** (1), Guillaume Morard (1) Daniele Antonangeli (1) Alisha N Clark (2) Caroline Dorn (3) Antoine Rozel (4) Mohamed Mezouar (5) Marzena A Baron (1) Anna Pakhomova (6) Guillaume Fiquet (1)

(1)Sorbonne Université, Muséum National d'Histoire Naturelle, UMR CNRS 7590, IRD, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, IMPMC, 75005 Paris, France (francesca.miozzi@upmc.fr) (2) Department of Earth and Planetary Sciences, Northwestern University, Evanston, IL, USA, 60208. (3) University of Zurich, Institute of Computational Sciences, Winterthurerstrasse 109, CH-8057 Zurich. (4) Institute of Geophysics, Department of Earth Sciences, ETH Zurich, Sonneggstrasse 5, CH-8092 Zurich, Switzerland. (5) European Synchrotron Radiation Facility (ESRF). Grenoble, France. (6)Deutsches Elektronen-Synchrotron (DESY). Hamburg, Germany

## Abstract

We experimentally determined properties (i.e. phase assemblage, thermal equation of state, melting temperature) of carbides (Si-C, Fe-Si-C) under extreme pressure and temperature conditions to constrain internal properties of carbon-rich exoplanets. By expanding the P-T-X range of these measurements, we can tightly constrain the phase diagram of binary and ternary carbide systems, and establish accurate P-V-T equation of state. Our experimental results are critically important for building reliable direct models for the interiors of exoplanets as well for interpreting observational data from recently launched survey missions such as TESS.

## Introduction

An exciting recent development in space science has been the advancement of the exoplanet survey and the quest of an Earth's analog in other stellar systems. The launch of Kepler telescope in 2009 strongly contributed to the field, discovering more than a thousand exoplanets and for some also enabling to measure mass and radius. To further characterize those planets, the chemical composition can be inferred, though indirectly, by the elements distribution of the host star [1]. Knowledge of bulk composition and mineralogy of planetary interiors is central to understand their formation, present and past dynamics, including generation of magnetic field and surface processes, formation and sustainment of an atmosphere, all fundamental parameters to define the habitability of a planet.

Notably, some of the confirmed exoplanets have been observed orbiting around stars with an unusual chemical composition enriched in carbon instead of oxygen. This suggests that their mineralogical assemblages are potentially dominated by carbides instead of oxides. Carbon-rich planets are defined by a C/O ratio >0.8, and 55 Cancri e has been an archetype for this particular planets [2][3][4]. The TESS mission, with its scan range more than 20 times greater than Kepler, is likely to find also exoplanets orbiting around stars with exotic chemical composition. Accordingly, updated and diversified models are required for the interpretation of observational data.

Interiors of carbon-rich exoplanets were first modeled by computational methods using the mass and radius of 55 Cancri e as a reference [2]. The results of this study highlight how a mineralogy based on the Fe-Si-C system leads to multiple interior structures that all match the observed M/R. This clearly calls for an improved understanding of the properties of the Fe-Si-C system at relevant P-T conditions. Calculations by Wilson and Militzer [5] focused on the Si-C binary system up to 40 Mbar, and proposed possible planets interior made by SiC with different amount of C. In recent years further experimental studies on the Si-C system were published, however limited below 100 GPa [6]

In this contribution we will present experimental data collected on two different systems: 1) the binary Si-C and 2) the ternary Fe-Si-C, both investigated between 30 and 200 GPa and at temperatures up to 3300 K. The obtained results, provide insight on the stability and properties at high pressure of components that are candidates as constituent of carbon rich exoplanets.

## Method

Experiments were performed at the European synchrotron radiation facility (ESRF) and at the Petra

III ring of the Deutsches Elektronen-Synchrotron (Desy), employing laser heated diamond anvil cells, coupled with *in-situ* x-ray diffraction. Samples were few micron thick layers of non-stoichiometric SiC and FeSiC sandwiched between KCl, used as a pressure medium, thermal insulator and pressure calibrant. Recovered samples were sectioned by FIB (focused ion beam) to expose the center of the heating spot, and chemical and textural analyses were performed by electron microscopy.

## Results

The large amount of data collected on Si-C compounds allowed defining the exact P-T location and Clapeyron slope of the transition to the cubic rock salt structure, solving an on-going controversy. Furthermore the data collected for the high pressure structure were used to determine its thermal equation of state, still unknown, but of fundamental importance for the modelling of planetary interior. Finally, the phase diagram was examined, highlighting the strong dichotomy between the low melting temperature of the Si-rich side and the high melting temperature of the C-rich side, as well as the absence of intermediate compound between diamond and SiC (Miozzi et al., JGR Planets, under review). The Fe-Si-C ternary system has been probed using samples of different starting composition. Multiple eutectic melting curves were detected, together with changes in the phase assemblages and the solid liquid composition. The changes in the phase diagram affect the solid liquid composition and phase stability.

## Application to Exoplanets Interiors

Two possible carbon rich exoplanets were modelled, both with SiC mantles and pure Fe cores. The first is a model of a planet with an iron core that make up for 1/3 of the mass. In the second model, the proportions of Fe and Si are chosen so as the bulk composition of the planet matches solar Fe/Si abundances. As shown in Figure 1, the first model yields to a mass-radius relationship very similar to the Earth-like planets. Thus there is a range of mass and radius for which is almost impossible to discriminate between and Earth-like interior or a carbon rich interior on the sole basis of the mass and radius.

This demonstrates the importance of having reliable models, coming from both computational and experimental studies, which can be used to interpret observational data for exoplanets.

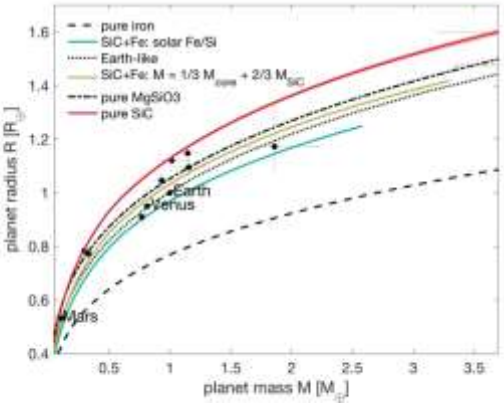

Figure 1: Mass radius relation for different idealized exoplanets interior, together with the standard comparison curves (e.g. pure Fe, $MgSiO_3$ and Earth-like).

## Acknowledgements

This project and F.M., G. M. and G. F. have received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation Programme (grant agreement No 670787). C.D. is funded by the Swiss National Science Foundation under the Ambizione grant PZ00P2_174028. A.B.R received founding from the European Research Council under the European Unions Seventh Framework Programme (FP/20072013)/ERC grant agreement number 320639 project iGEO and from ETH Zürich.

## References

[1] Hinkel, Natalie, and Cayman Unterborn. 2017. "The Star-Planet Connection I: Using Stellar Composition to Observationally Constrain Planetary Mineralogy for the Ten Closest Stars.

[2] Madhusudhan, N., Lee, K. K. M. & Mousis, O. A POSSIBLE CARBON-RICH INTERIOR IN SUPER-EARTH 55 Cancri e. *Astrophys. J.* **759,** L40 (2012).

[3] Delgado Mena, E., Israelian, G., Gonzalez Hernandez, J. I., Bond, J. C., Santos, N. C., Udry, S. & Mayor, M. CHEMICAL CLUES ON THE FORMATION OF PLANETARY SYSTEMS : C / O VERSUS Mg / Si FOR HARPS GTO SAMPLE. 2349–2358 (2010). doi:10.1088/0004-637X/725/2/2349

[4] Teske, J. K., Cunha K, Smith V.V, Schuler S.C., & Griffith C.A. C/O Ratios of Stars with Transiting Hot Jupiter Exoplanets. Astrophysical Journal 788 (1) (2013).

[5] Wilson, H. F. & Militzer, B. Interior Phase Transformations and Mass-Radius Relationships of Silicon-Carbon Planets. *Astrophys. J.* **793,** 34 (2014).

[6] Kidokoro, Y., Umemoto, K., Hirose, K. & Ohishi, Y. Phase transition in SiC from zinc-blende to rock-salt structure and implications for carbon-rich extrasolar planets. *Am. Mineral.* **102,** 2230–2234 (2017).