EPSC Abstracts
Vol. 8, EPSC2013-230, 2013
European Planetary Science Congress 2013

Titanium and vanadium oxides as possible tracers of C/O in protoplanetary disks

M. Ali Dib(1), **O. Mousis(1)**, G. S. Pekmezci(2), J. I. Lunine(3), N. Madhusudhan(4) and J.-M. Petit(1)
(1) Institut UTINAM, CNRS-UMR 6213, Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France (mdib@obs-besancon.fr), (2) Dipartimento di Astronomia, Universita' di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy, (3) Center for Radiophysics and Space Research, Space Sciences Building, Cornell University, Ithaca, NY 14853, USA, (4) Department of Physics and Department of Astronomy, Yale University, New Haven, CT 06511, USA

Abstract

The observation of carbon-rich disks have motivated several studies questioning the influence of the C/O ratio on their gas phase composition in order to establish the connection between the metallicity of hot-Jupiters and that of their parent stars. These observations strongly motivate the need for a method that allows characterization of the adopted C/O ratio in protoplanetary disks independently from the determination of the host star composition. Here we use the HSC chemistry commercial package based on the Gibbs energy minimization technique to compute the titanium and vanadium equilibrium chemistries in protoplanetary disks for C/O ratios ranging from 0.05 to 20. We find that the vanadium nitride/vanadium oxide and titanium hydride/titanium oxide gas phase ratios strongly depend on the degree of the C/O ratio in the hot parts of disks. Our calculations suggest that these ratios can be used as tracers of the C/O value in protoplanetary disks.

1. Introduction

The recent detection of carbon-rich planets (hereafter CRPs), with C/O ratios ≥ 1 in their envelopes [4], have stimulated researches on their physical properties and the scenarios that may lead to their formation [5, 8, 7]. Carbon-rich disks have also been observed in the last years [9] and motivated several studies on the influence of the C/O ratio on their gas phase composition [6, 2]. The formation scenario of CRPs is still poorly understood, in particular when considering the recent observation of Wasp-12b, a CRP orbiting a carbon-poor star, leading to the conclusion that the disk's C/O ratio might be different from that of the host star [4]. More recently, [7] proposed the formation of Jupiter through the accretion of condensed volatiles in the cold outer part of an oxygen-depleted primordial nebula. All these models and observations outline a non trivial relation between the C/O ratios of the host stars, their protoplanetary disks and eventually their planets. For this reason it is important to establish a reliable probe of the C/O ratio. Here, we investigate the influence of the C/O ratio on the chemistry of Ti– and V–bearing species in protoplanetary disks. We find that the TiH/TiO and VN/VO gas phase ratios are reliable tracers of the C/O ratio in the inner and hot parts of disks.

2. Methods

We have used the HSC chemistry commercial package based on the Gibbs energy minimization method in order to obtain the disk's Ti and V bearing species solid and gaseous composition for different C/O ratios. we chose to use the entire HSC Chemistry database of elements relevant to solar elemental abundances totalizing 1224 gases and solids (excluding C_nH_m for n>3). We made the reasonable assumption that the gas phase composition of the disk under study has the same elemental composition as that of the host star, in the exception of the Oxygen abundance varied to achieve different C/O ratios, with C/O=0.55 corresponding to the canonical nebula. Here, all our calculations are based on the solar photosphere abundances taken from [1] at 1700 K and for a global disk's pressure of 10^{-4} bar.

3. Results

Figure 2 represents the VN/VO and TiH/TiO gas phase ratios computed as a function of C/O ranging between 0.1 and 20 in protoplanetary disks. These molecules have been selected because their abundance ratios heavily depend on the value of the adopted C/O ratio.

One can note the strong dependence of VN/VO and TiH/TiO gas phase ratios with the adopted value of

Table 1: Elemental abundances used as inputs in the HSC Chemistry software for the solar C/O case.

Element	Solar abundance in Kmol	X/H_2
H	1.0×10^9	
He	9.5×10^7	1.90×10^{-1}
N	7.4×10^4	3.71×10^{-5}
O	5.37×10^5	2.69×10^{-4}
C	2.95×10^5	1.48×10^{-4}
Na	1.9×10^3	9.53×10^{-7}
Mg	4.3×10^4	2.18×10^{-8}
Al	3.0×10^3	1.55×10^{-6}
Ni	1.8×10^3	9.11×10^{-7}
Si	3.5×10^4	1.77×10^{-5}
P	2.8×10^2	1.41×10^{-7}
S	1.45×10^4	7.23×10^{-6}
Ca	2.4×10^3	1.20×10^{-6}
Ti	9.7×10^1	4.89×10^{-8}
Cr	4.7×10^2	2.39×10^{-7}
Fe	3.4×10^4	1.73×10^{-5}
V	9.3×10^0	4.67×10^{-9}

C/O ratio. For example, a growth of the C/O ratio from 0.1 to 2 induces a steep increase of the TiH/TiO and VN/VO ratios by $\sim$10 orders of magnitudes, respectively. Beyond C/O = 2, the two molecular ratios continue to increase slightly linearly. Our calculations suggest that these ratios can be used as tracers of the C/O ratio in protoplanetary disks.

4. Discussions and Conclusions

We have performed computations of equilibrium chemistry describing the fate of Ti– and V–bearing species in protoplanetary disks as a function of different values of C/O ratios, and using the Gibbs energy minimization method. This allowed us to find that the VN/VO and TiH/TiO gas phase ratios strongly depend on the degree of the C/O ratio in the hot parts of disks. Finally, observations of gaseous TiO and VO in disks must be spatially resolved in order to eliminate any confusion from stellar emissions. Such a high resolution should be attained with the new generation sub-millimetric instruments such as ALMA, from which several spatially resolved observations of different types of disks have been recently reported with angular resolutions of $\sim$0.1 AU. The detection of TiO and TiO_2 in the cooler region of late-type stars, implies that other small transition metal–bearing molecules such as VO, might be found with sensitive interferom-

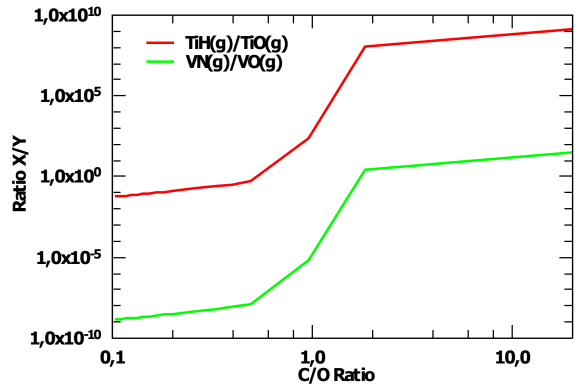

Figure 1: VN/VO_2 and TiH/TiO molecular gas phase ratios as a function of C/O in protoplanetary disks.

eters in the submillimeter wave band ([3]).

Acknowledgements

O. Mousis acknowledges support from CNES. JIL acknowledges support from the JWST program through a grant from NASA Goddard.

References

[1] Asplund, M., Grevesse, N., Sauval, A. J., & Scott, P. 2009, ARAA, 47, 481

[2] Johnson, T. V., Mousis, O., Lunine, J. I., & Madhusudhan, N. 2012, ApJ, 757, 192

[3] Kamiński, T., Gottlieb, C. A., Menten, K. M., et al. 2013, A&A, 551, A113

[4] Madhusudhan, N., Harrington, J., Stevenson, K. B., et al. 2011a, Nature, 469, 64

[5] Madhusudhan, N., Mousis, O., Johnson, T. V., & Lunine, J. I. 2011b, ApJ, 743, 191

[6] Marboeuf, U., Mousis, O., Ehrenreich, D., et al. 2008, ApJ, 681, 1624

[7] Mousis, O., Lunine, J. I., Madhusudhan, N., & Johnson, T. V. 2012, ApJL, 751, L7

[8] Öberg, K. I., Murray-Clay, R., & Bergin, E. A. 2011, ApJL, 743, L16

[9] Roberge, A., Feldman, P. D., Weinberger, A. J., Deleuil, M., & Bouret, J.-C. 2006, Nature, 441, 724