Atmospheric Remnants as Propellant for Space Electric Propulsion

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Electric **P**ropulsion **I**nnovation & **C**ompetitiveness
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Abstract

♣ **4CDGM**, a volume averaged **detailed global model** with four initial components (**O**, **O_2** , **N**, **N_2**), meant to **analyze** the functioning of **Air-Breathing Electric Thrusters (ABET)**, is used to **foresee** the plasma constitution and to **diagnose** it by **Optical Emission Spectroscopy (OES)**.

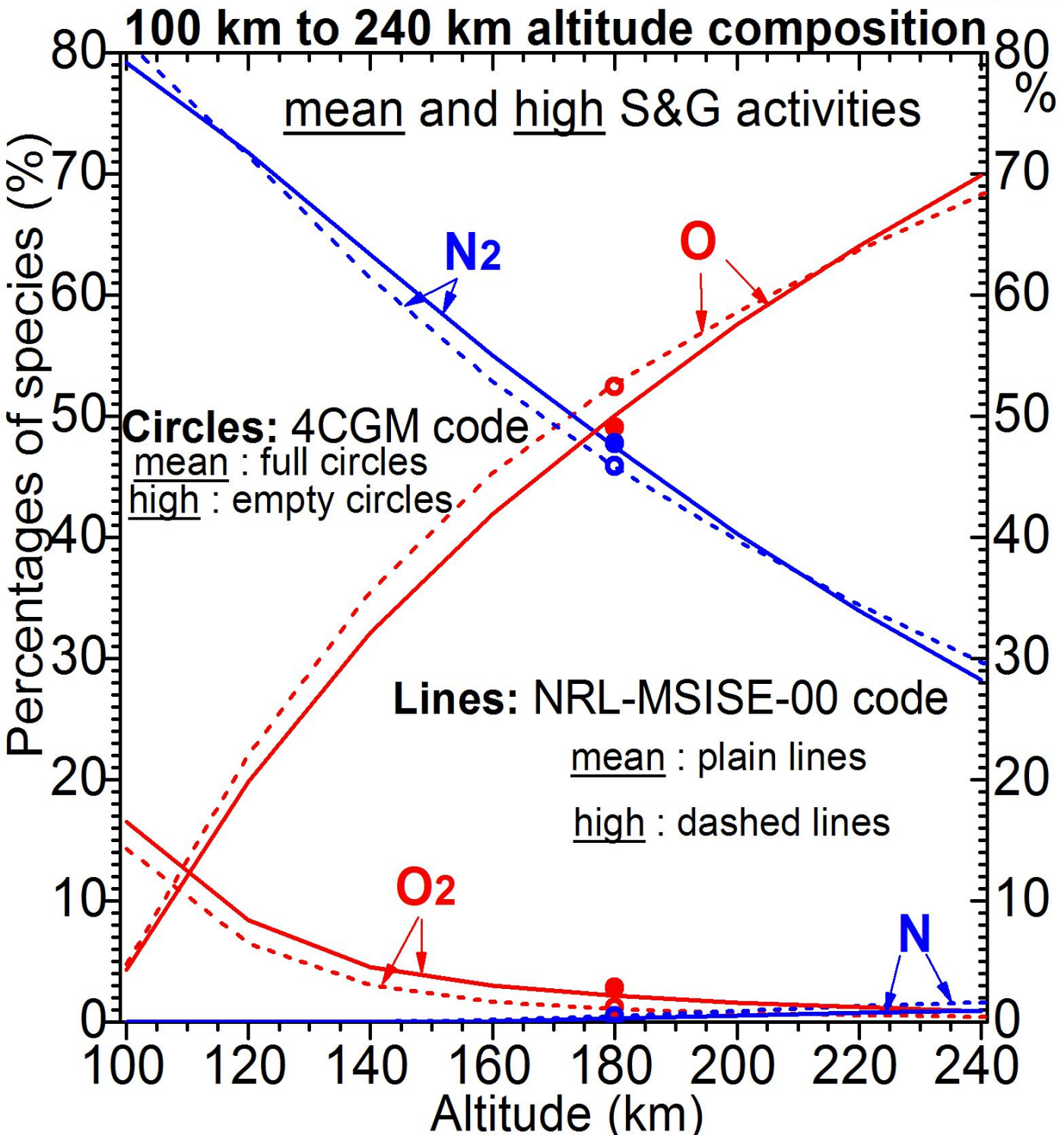
♣ **4CDGM** can also evaluate the **Atmospheric Remnants** (**AtmRems**) in altitudes exceeding the Karman line (in about 100 km altitude) up to 240 km (see **Fig. 1**) on the basis of existing empirical models **[1]**.

♣ Towards this aim, **4CDGM** provides **Plasma Component Composition (PCC) diagrams**, **Functioning Diagrams (FD)** and also theoretical spectra **emission line intensities**, thus allowing for **OES** diagnostics

Fig. 1.

Species percentages in the ***AtmRems*** *in case of mean & high S&G activities*

100 km *to* ***240 km*** *altitude*



Summary of the Presentation

1. Introduction

Presentation of **4CDGM** results, consisting in :

2. PCCs containing **densities of species** followed by their **percentages** in concomitant diagrams. Only results concerning mean Solar and Geomagnetic (**S&G**) activities are presented in the following.

3. FD, illustrating the thruster functioning.

4. Oxygen O I / O II & **nitrogen N I / N II theoretical emission spectra**, allowing for **OES** diagnostics.

5. Conclusions

1. Introduction (1/2)

♣ **4CDGM** supports the ***In Situ*** **Resource Utilization** (**ISRU**) disruptive technology for various types of thrusters, when their propellant is harvested from the **AtmRems**, see **Refs. [2 - 5]**, next slide.

♣ The main consistence of the **AtmRems** in the region of interest, i.e. **O**, $\mathbf{O_2}$, **N**, $\mathbf{N_2}$, was shown in **Fig. 1** as a function of the altitude, in case of mean and high **S&G** activities.

♣ We address here propulsion for **satellites** revolving **around Earth** and for **spacecrafts** traveling in its vicinity, where the atmosphere allows for direct feed. Whenever the breathed propellant is conveniently stored, **ISRU** technology may also serve for exploration of more distant regions.

REFERENCES

[1] Picone, J.M., Hedin, A.E., Drob, D.P. & Aikin, A.C. (**2002**). *NRL-MSISE-00 Empirical Model of the Atmosphere: Statistical Comparisons and Scientific Issues*, J. Geophys. Res. **107**, 1468

[2] Berenguer, Ch. & Katsonis, K. (**2022**). *Modeling and Diagnostics of ISRU Technology Electric Thrusters meant for Extremely Low Earth Orbits Propulsion,* EPIC 2022 Workshop, Cologne, Germany, 4 - 8 April 2022

[3] K. Katsonis, Ch. Berenguer, J. Gonzalez del Amo (**2022**). *Electric Propulsion for Extremely Low Earth Orbits*, SP2022_**041**, 8th Space Propulsion Conference, Estoril, Portugal, May 2022

[4] Berenguer, Ch., Katsonis, K. & Gonzalez del Amo, J. (**2018**). *Air Breathing Electric Thruster Characterization and Diagnostics by a Four Components Detailed Global Model*, 6th Space Propulsion Conference, Paper ID SP2018_**345**, Seville, Spain, May 2018

[5] Katsonis, K., Berenguer, Ch. & Gonzalez del Amo, J. (**2015**). *Characterization of Air Breathing Plasma Thrusters Fuelled by Atmospheric Mixtures Encountered in Earth Atmosphere at an Altitude of About 200 km*, 34th IEPC Conference, IEPC-2015-**268**, Kobe, Japan, July 2015.

Related information :

[6] Berenguer & Katsonis, presented **in the poster session**

[7] Berenguer, Ch. & Katsonis, K. (**2023**). *Earth atmosphere remnants as an electric propulsion*, AEC Conference, Lausanne, Switzerland, July 2023

1. Introduction (2/2)

♣ **Electron temperature T_e , pressure *p*** and **absorbed power P_{ABS}** are the main parameters in the presented **PCC**s in Figs. 2, 4 and concomitant diagrams giving the plasma composition and components percentages correspondingly, while **FD** gives the plasma ionization percentages. The latter shows results illustrated by isothermal, isoenergetic and isobaric curves.

♣ In the chosen altitude of 180 km, main AtmRems constitution is of about 50.1 % O / 47.5 % N2 / 2.16 % O2 / 0.28 % N for mean S&G activity. The addressed **flow rate Q_{TOT}** is of 40 sccm.

♣ **OES diagnostics** pertains here to **ET** plasma neutral / ionized species created by the propellant harvested from the AtmRems. Extended sets of data belonging to oxygen and nitrogen main levels have been included in **4CDGM**.

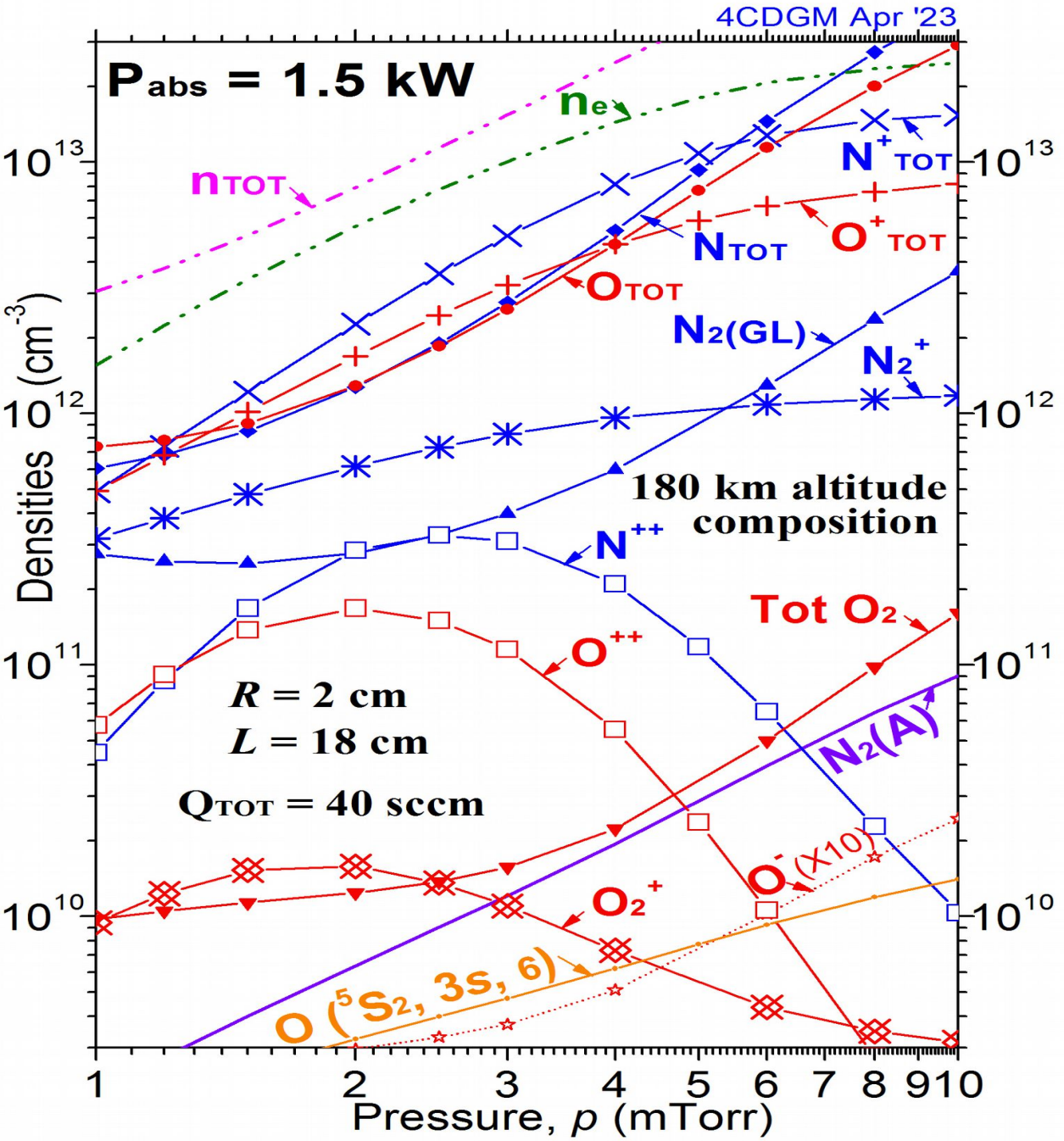
2. Density of Species PCC

Fig. 2.
Pressure dependent PCC

P_{abs} = 1.5 kW

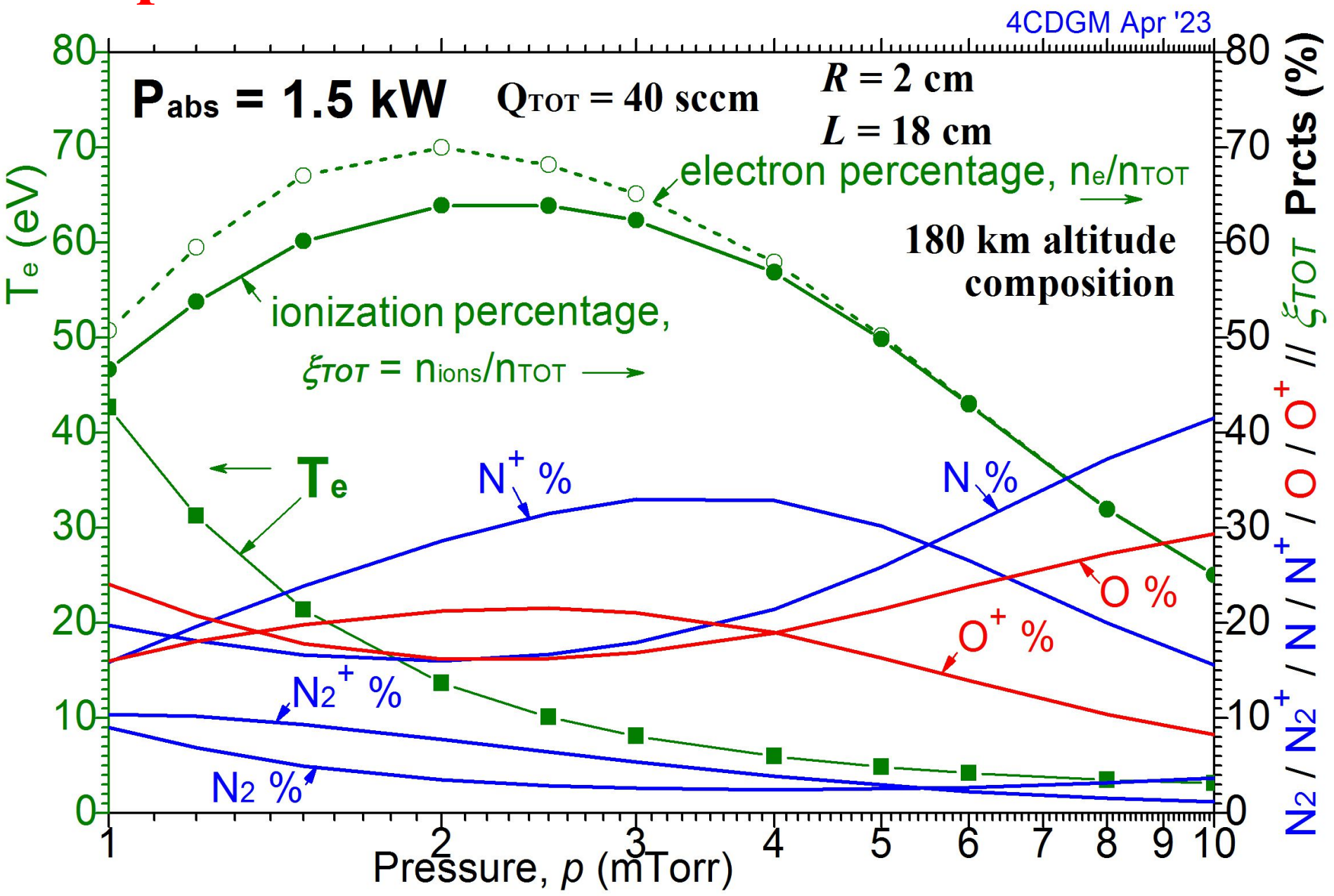
AtmRems feed of 40 sccm in 180 km altitude

Form factor for all figures : R=2 cm, L=18 cm



2. Density of Species PCC

Fig. 3. Concomitant of Fig. 2



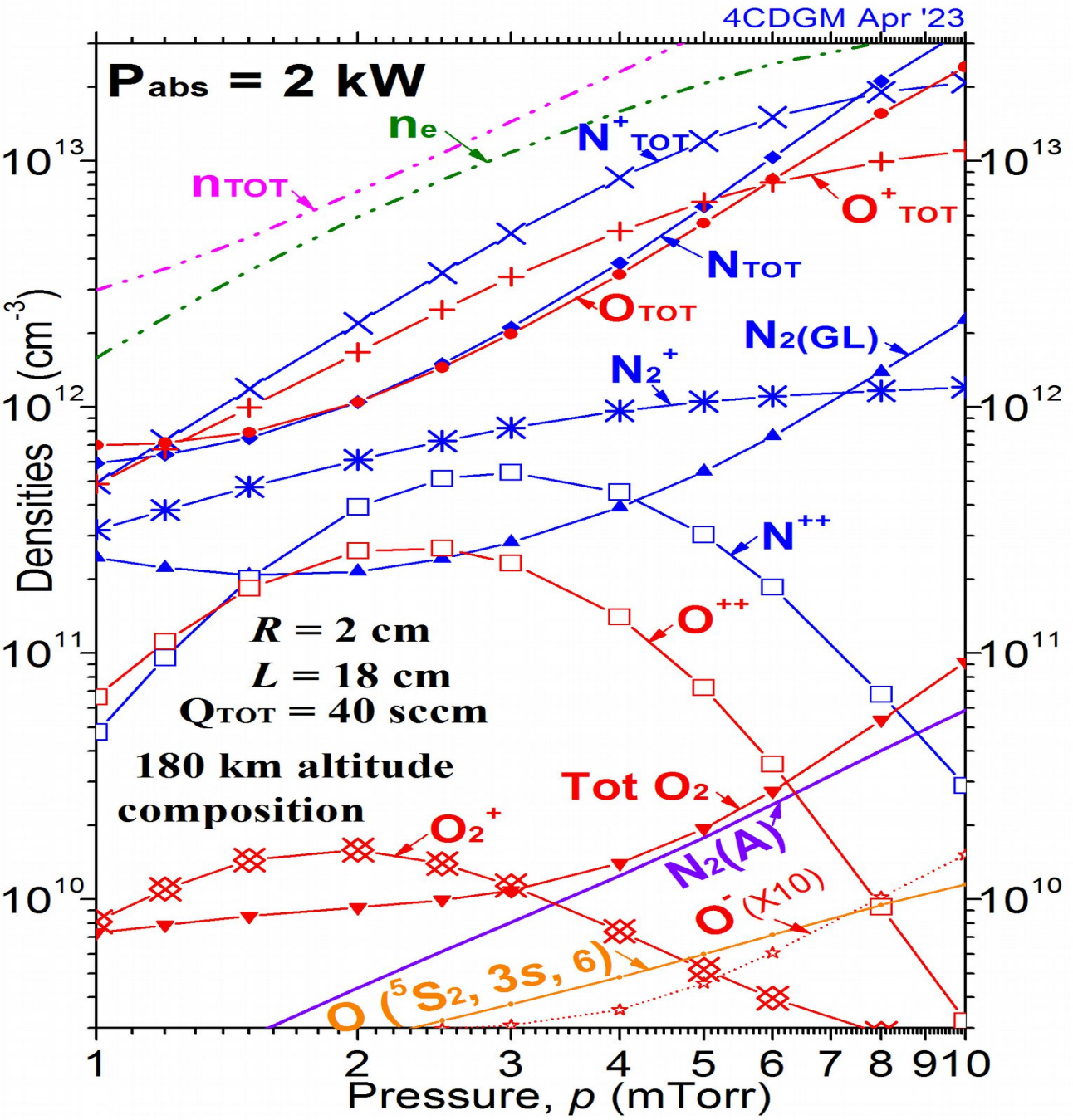
2. Density of Species PCC

Fig. 4.
Pressure dependent PCC

P_{abs} = 2 kW

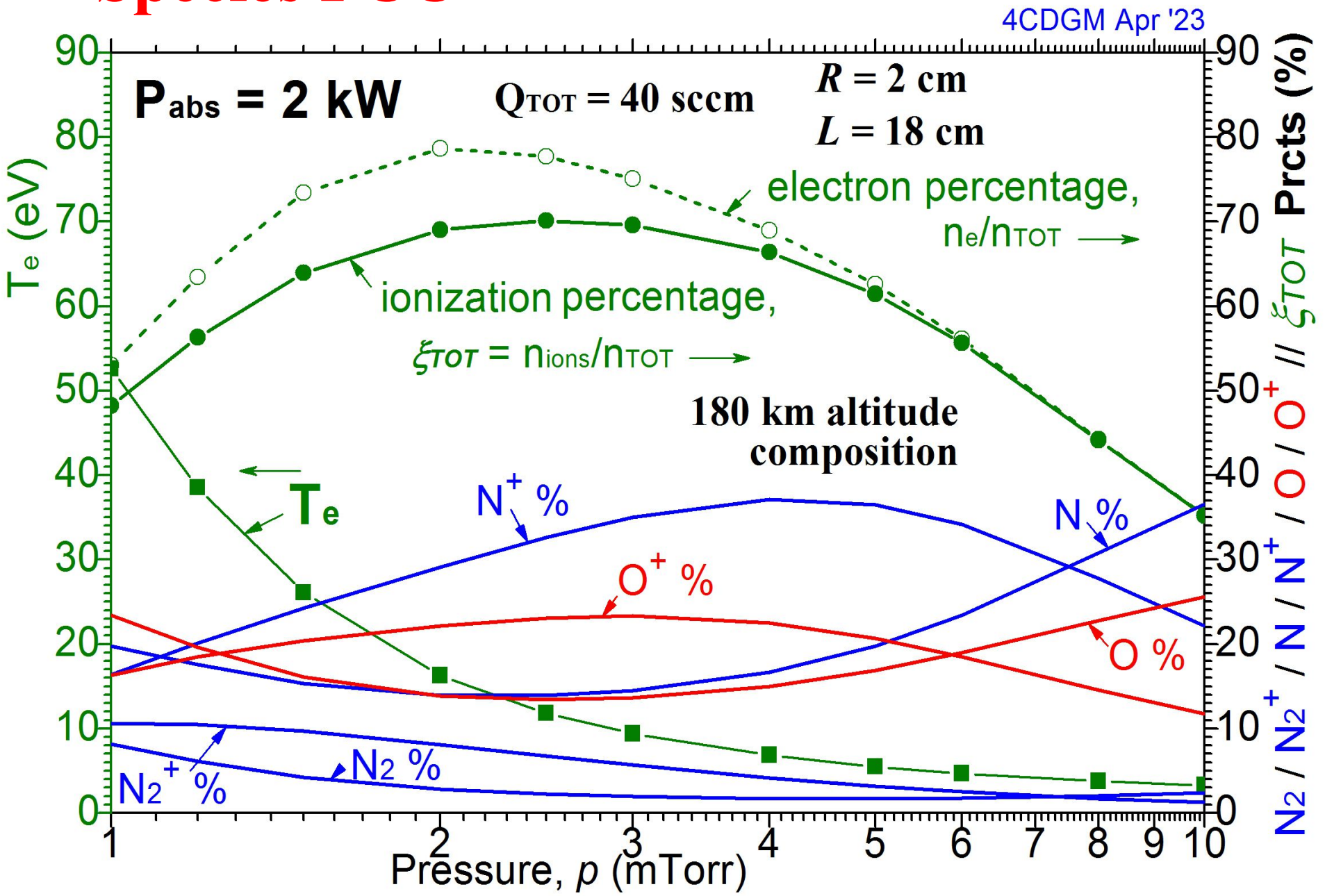
AtmRems feed of 40 sccm in 180 km altitude

Form factor for all figures : R=2 cm, L=18 cm



2. Density of Species PCC

Fig. 5. Concomitant of Fig. 4



3. Functioning Diagram, FD

Fig. 6.

FD for

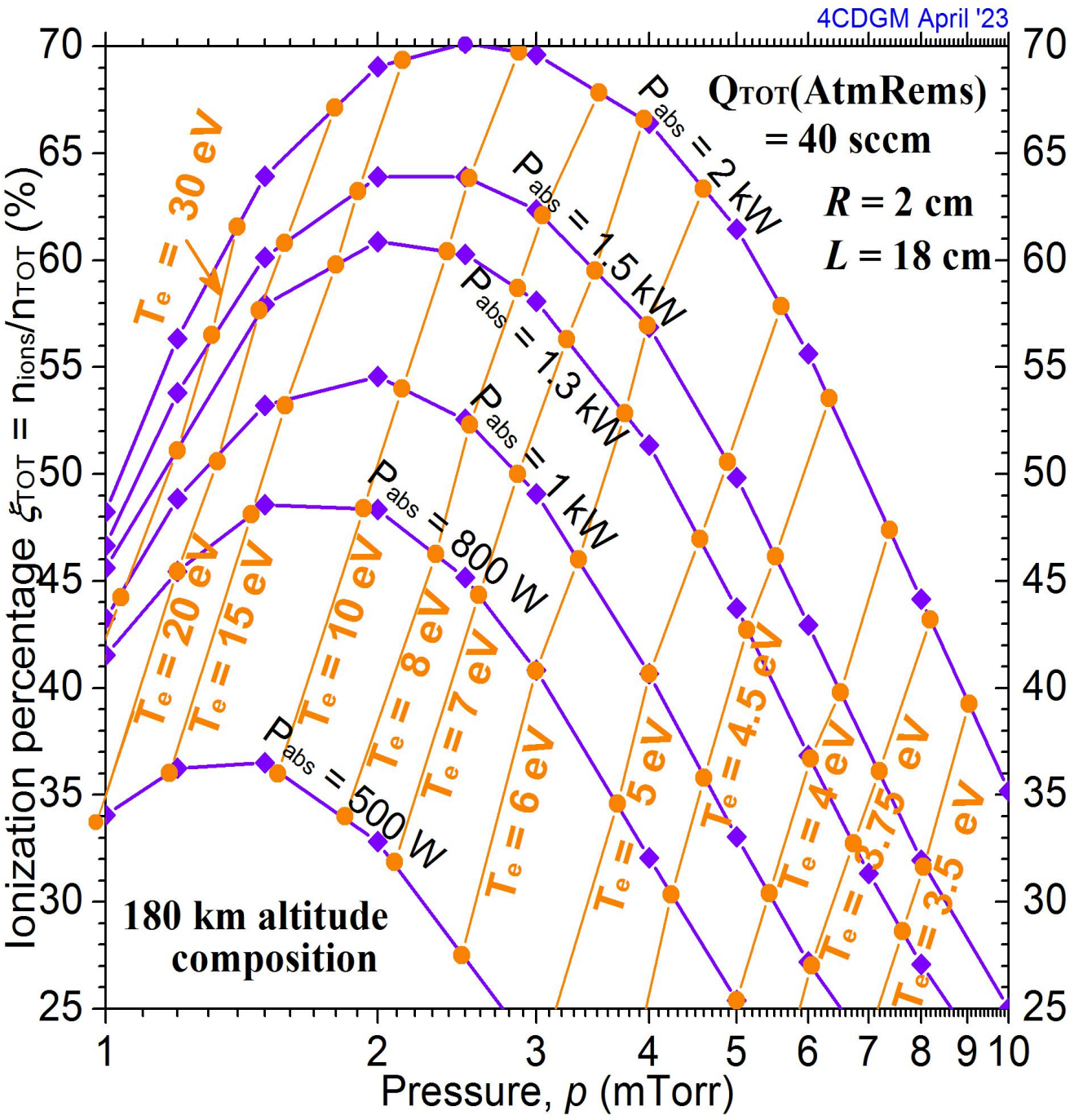
P_{ABS} = 0.5 kW to 2 kW

AtmRems feed of

Q_{TOT} = 40 sccm

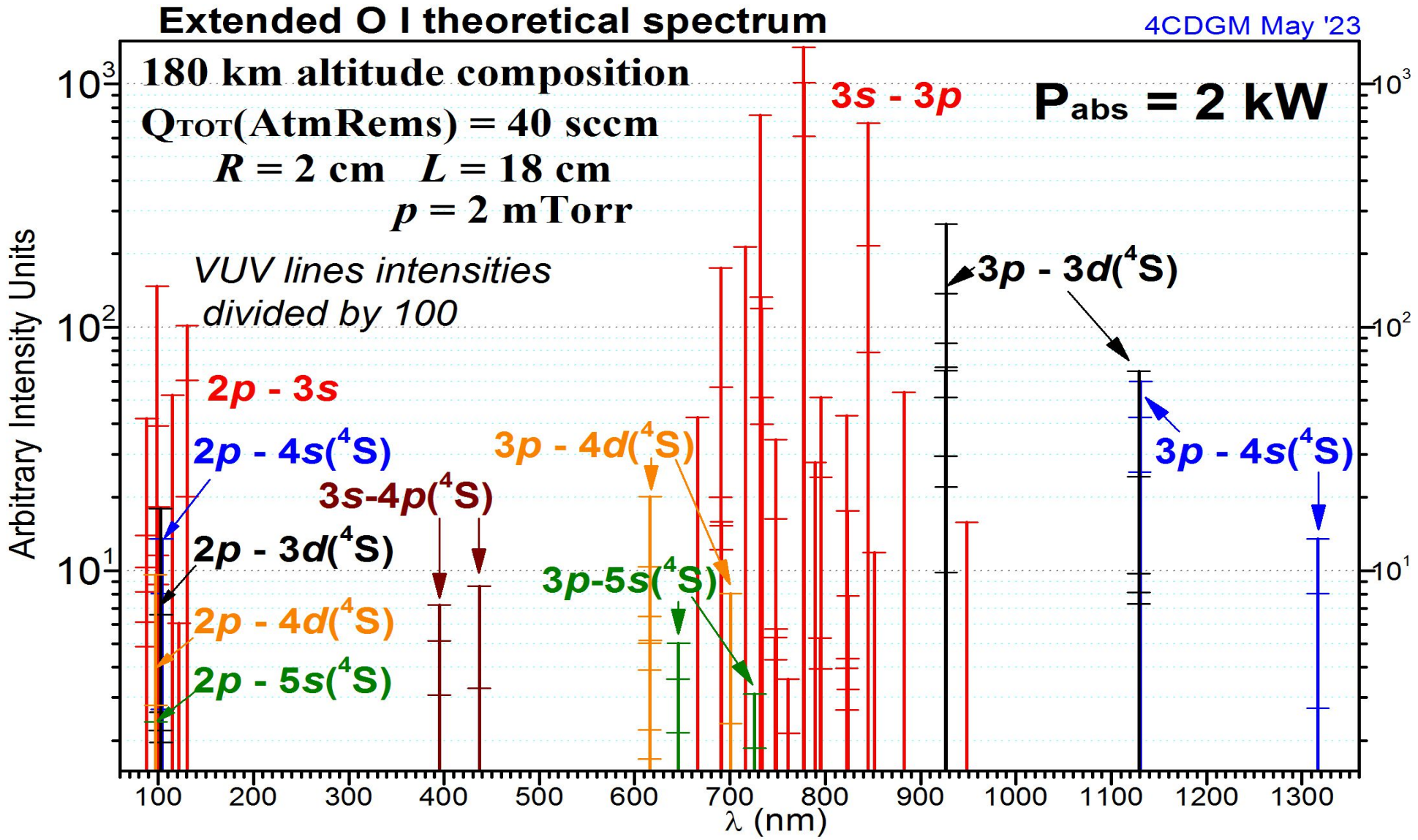
in 180 km altitude

T_e = 3.5 eV to 30 eV



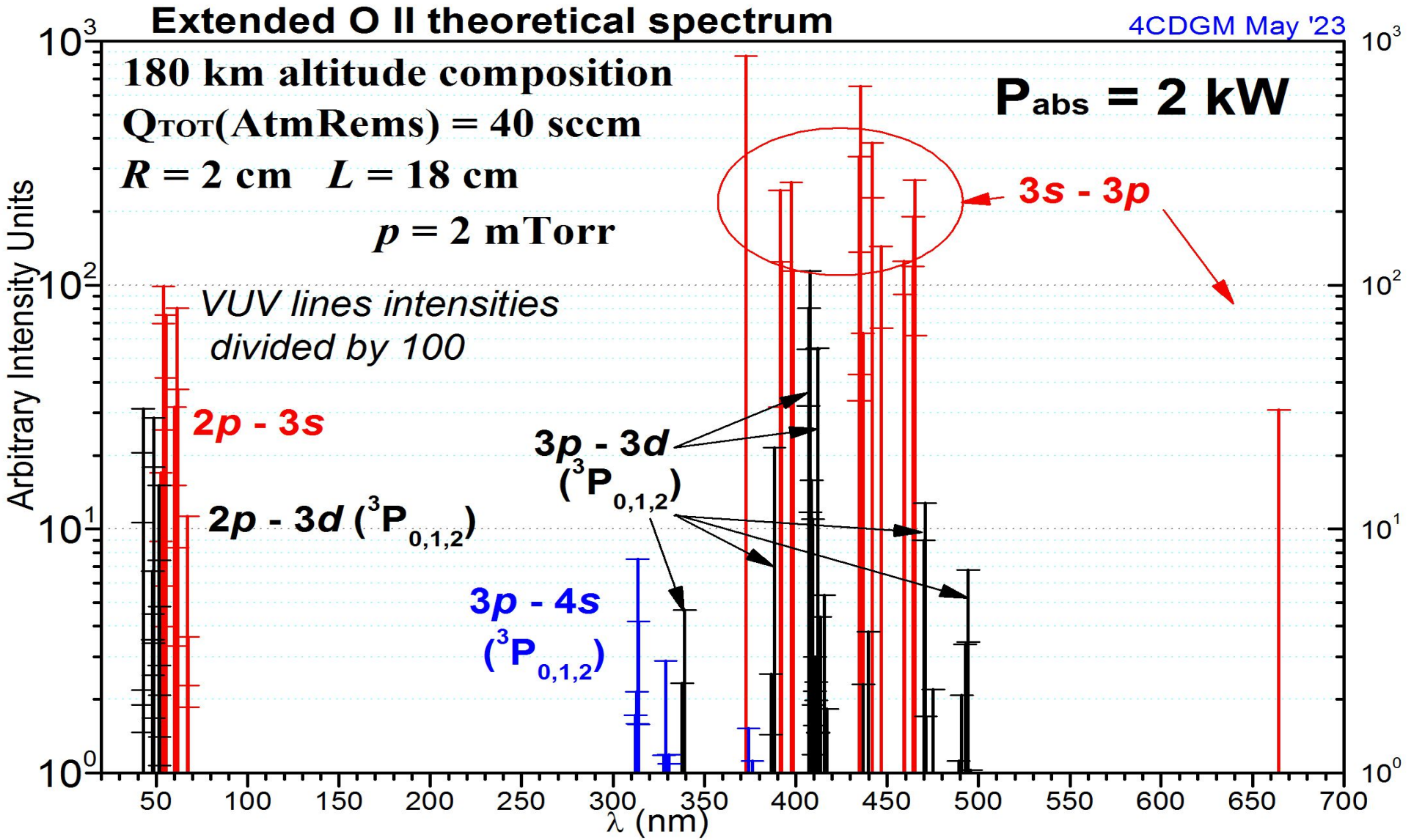
4. Theoretical spectra, OES

Fig. 7. AtmRems O I theoretical spectrum for P_{ABS}= 2 kW



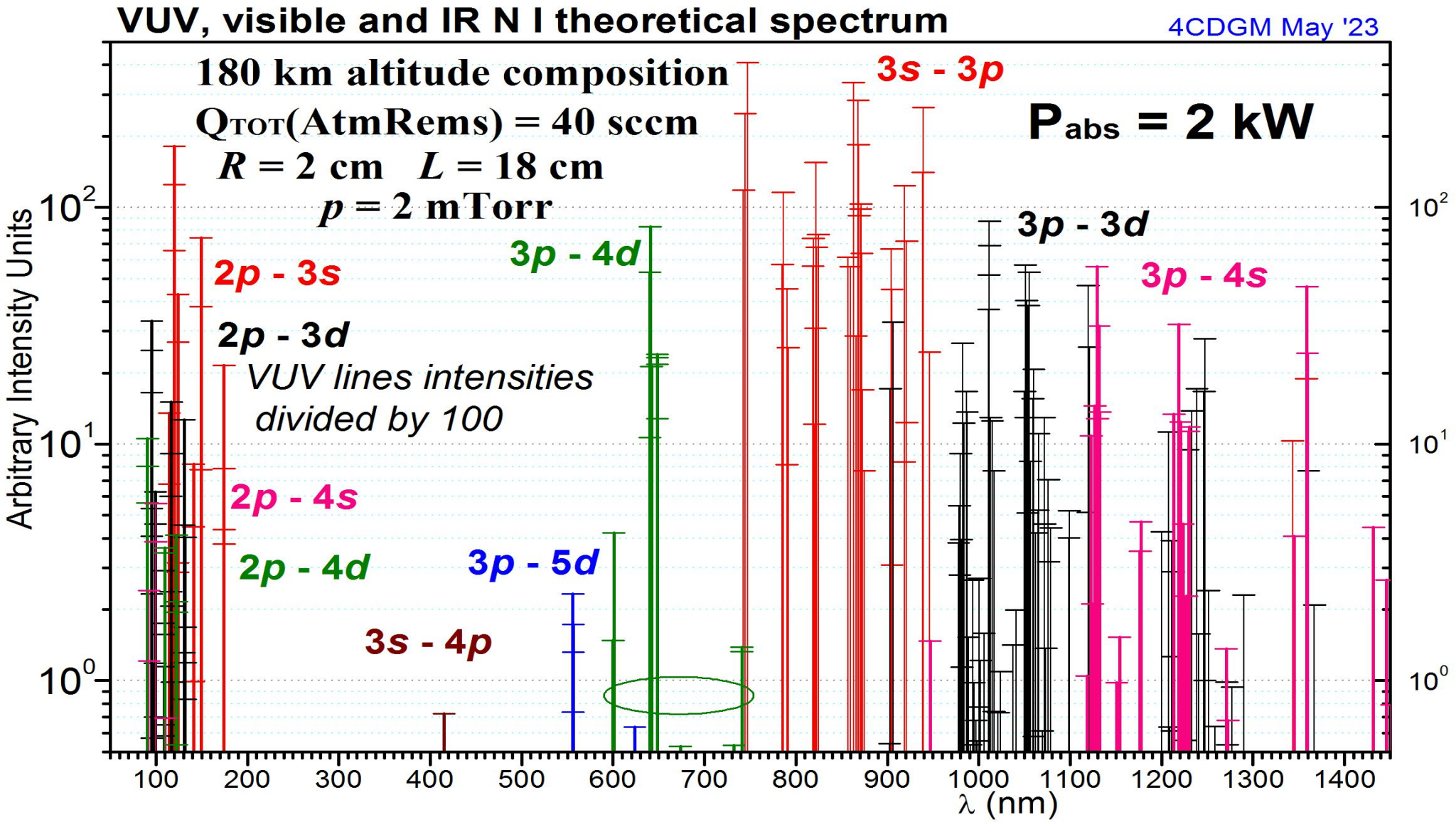
4. Theoretical spectra, OES

Fig. 8. AtmRems O II theoretical spectrum for P_{ABS} = 2 kW



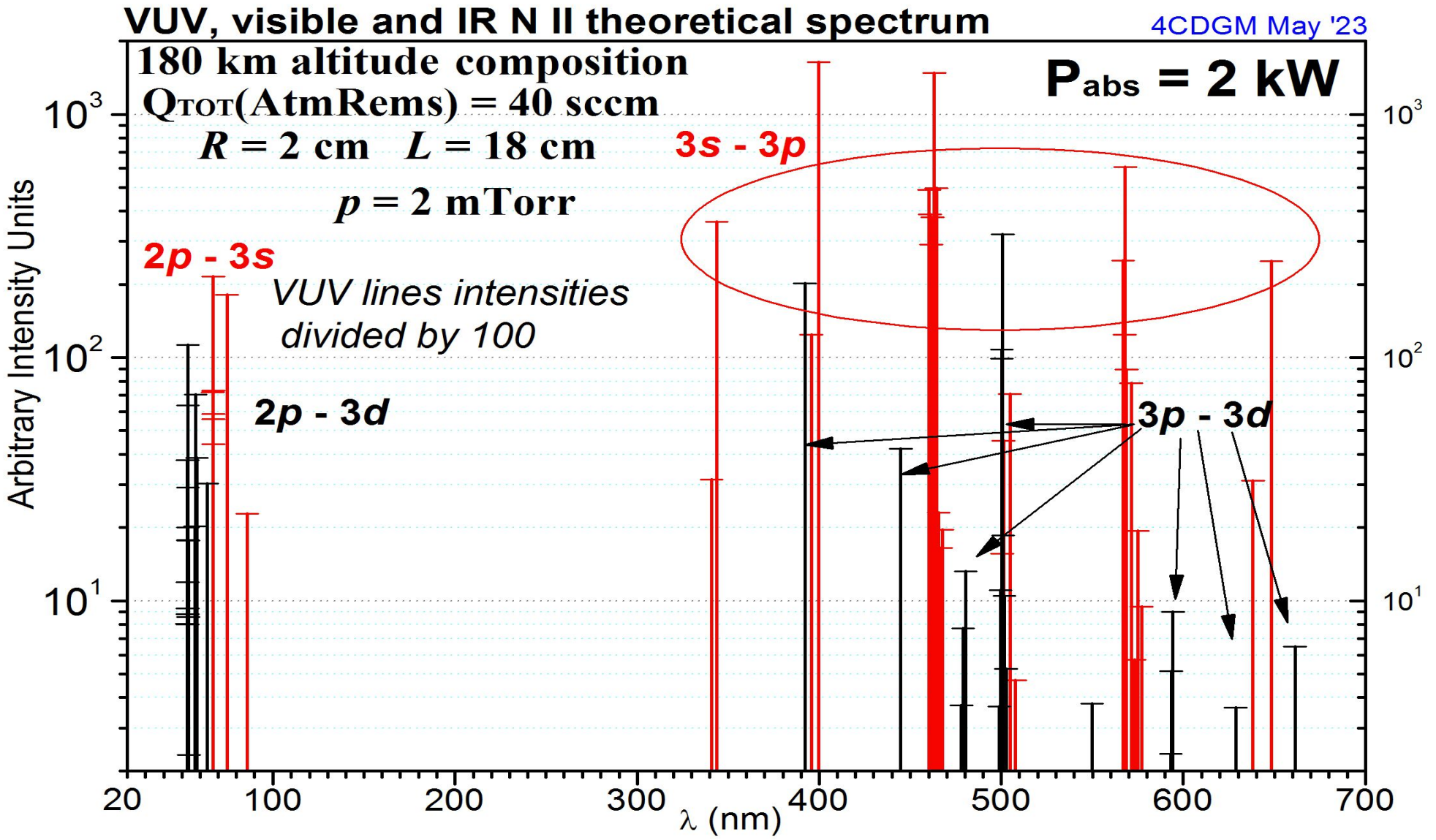
4. Theoretical spectra, OES

Fig. 9. AtmRems N I theoretical spectrum for P_{ABS}= 2 kW



4. Theoretical spectra, OES

Fig. 10. AtmRems N II theoretical spectrum for P_{ABS}= 2 kW



5. Conclusions

♣ We presented results obtained by **4CDGM**. They pertain to **ISRU** electric propulsion in the 180 km altitude region for mean S&G activities.

♣ **4CDGM** allows for detailed calculation of the ET plasma components densities and contributes to evaluation of the thruster functioning.

♣ **4CDGM** results to calculation of theoretical spectra belonging to the main plasma components created in case of **ETs** fed by **AtmRems**. Comparison with experimental spectra of neutral and ionized species allows for **OES**.

Thank you for your attention