Machine Learning and AI technics to model planetary atmospheres: contribution of IAP in the French landscape

Virginie Batista

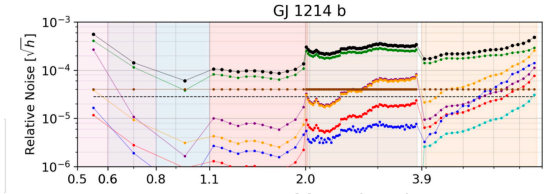
Journée ARIEL France - Jeudi 18 janvier 2024 at Institut d'Astrophysique de Paris

AI in the context of ARIEL and its applications to Planetary Atmospheres

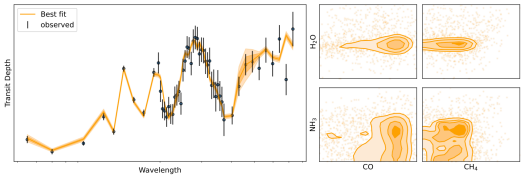
Use of AI has increased drastically within the last few years in astrophysics.

In the context of exoplanet and Ariel, among many other things, AI can be useful for:

- Data de-trending (instrumental noise)
- Instrument noise simulations
- Faster retrievals for atmospheric characterization
- Generative models (e.g. chemistry, radiative transfer, etc)

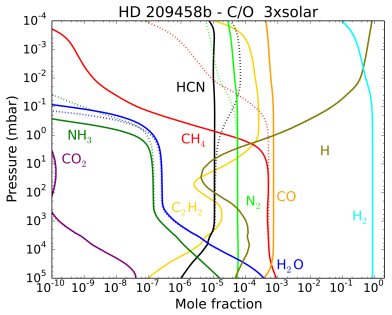


Mugnai et al. 2023



Yip et al. 2022

Yip et al. 2022



Venot et al. 2019

CNES supporting AI developments in French labs

- Monthly meeting between CNES, IAP, IAS, LISA, LESIA, CEA in 2022 to discuss AI applications for ARIEL activities

- **February 16th, 2023: AI training day**

  organized at IAP with Orphée Faucoz and Denis Standarovski (CNES AI experts)

Ariel School: Biarritz Ares III School 2023

Increasing AI content in the Ariel School organized by Pierre Drossart, and J.-P. Beaulieu in coordination with CNES, focused on atmospheric retrievals and Machine Learning:

- **4 AI lectures** given by:

  Orphée Faucoz and Denis Standarovski (CNES),

  Ingo Waldmann (UCL),

  Katia Matcheva (University of Florida).

- **1 training session** by Orphée Faucoz and Denis Standarovski.

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IAP AI working group

IAP new working group in 2023 with common interest in developing AI technics in the context of the ARIEL mission:

- **3 researchers**: J.-P. Beaulieu, Pierre Drossart, Clément Ranc
- **2 PhD Students**: Emilie Paneck and Alice Maurel
- **1 research engineer**: Virginie Batista
- **1 engineering internship from June to October 2023** dedicated to the Ariel Data Challenge 2023: Saad Taleb
- **Next: Master 2 internship + PhD** focused on de-trend systematics from the astrophysical signal, using AI (e.g.GAN).

Keeping up to date with the literature

Explainable Artificial Intelligence (XAI): Concepts, Taxonomies, Opportunities and Challenges toward Responsible AI

Random Forests applied to High Precision Photometry Analysis

ExoGAN: Retrieving

To Sample or Not To Sample:
Retrieving Exoplanetary Spectra with Variational Inference and Normalising Flows

Searching for Exoplanets

Kyle A. Pearson

Transit

Hands-on

Accurate Machine Learning Atmospheric Retrieval via a Neural Network Surrogate Model for Radiative Transfer

Michael D. Himes, Joseph Harrington, Adam D. Cobb, Atilim Güneş Baydin, Frank Soboczenski, Molly D. O'Beirne, Simone Zorzan, David C. Wright, Zacchaeus Scheffer, Shawn D. Domagal-Goldman and Giada N. Arney

Kai Hou

An Ensemble

Adam D. Cobb, Atilim Güneş Baydin, Yarin

Bovino, G. Picogna, and B. Ercolano

Retrievals

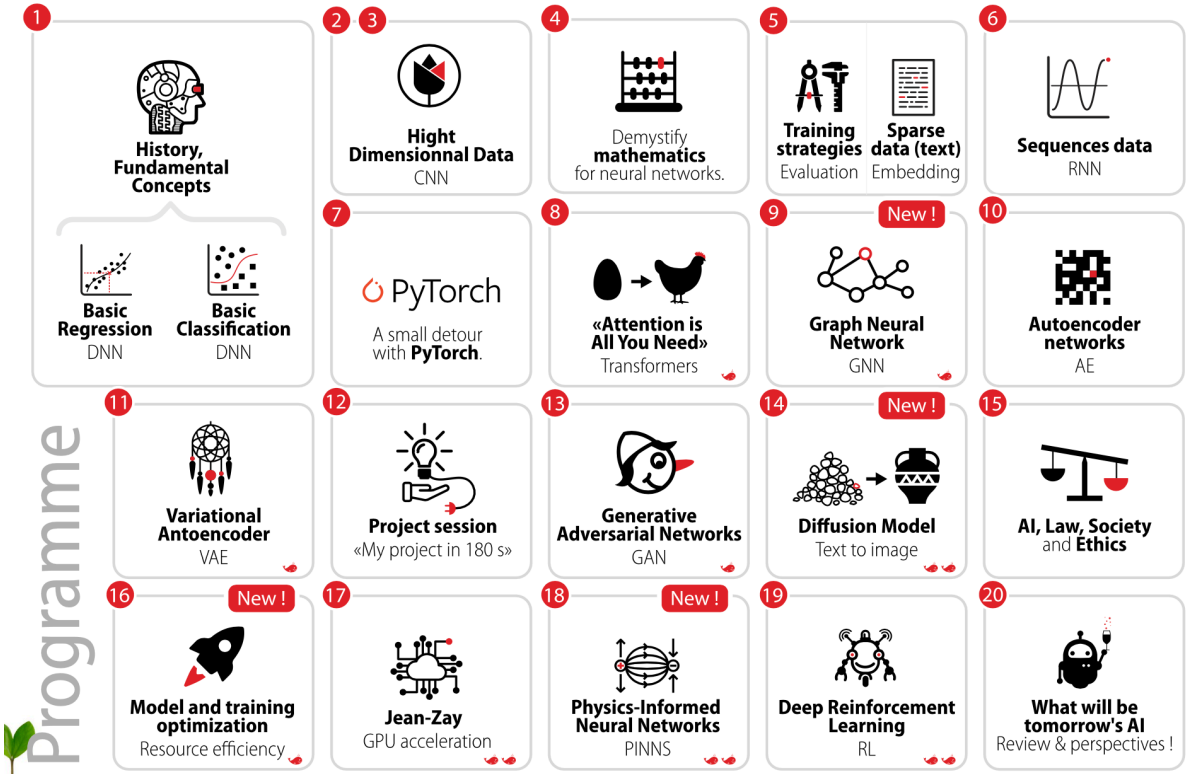
ate Model

Ariel FRANCE

Online courses with Fidle CNRS Univ. of Grenoble

Following online Fidle course + training sessions:

https://gricad-gitlab.univ-grenoble-alpes.fr/talks/fidle/-/wikis/home



Formation
Introduction
Deep Learning

Présentation de saison, 2022/23

FIDLE
https://fidle.cnrs.fr

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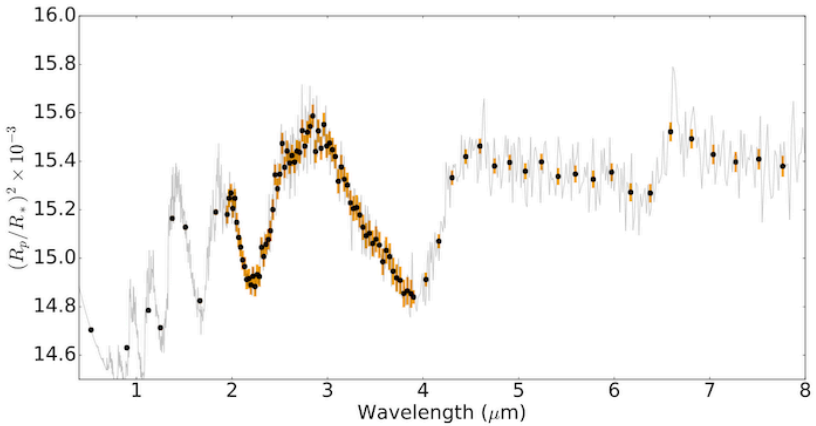
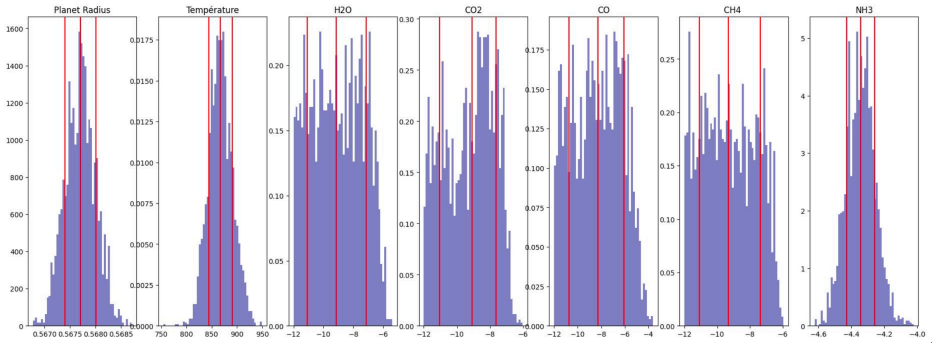
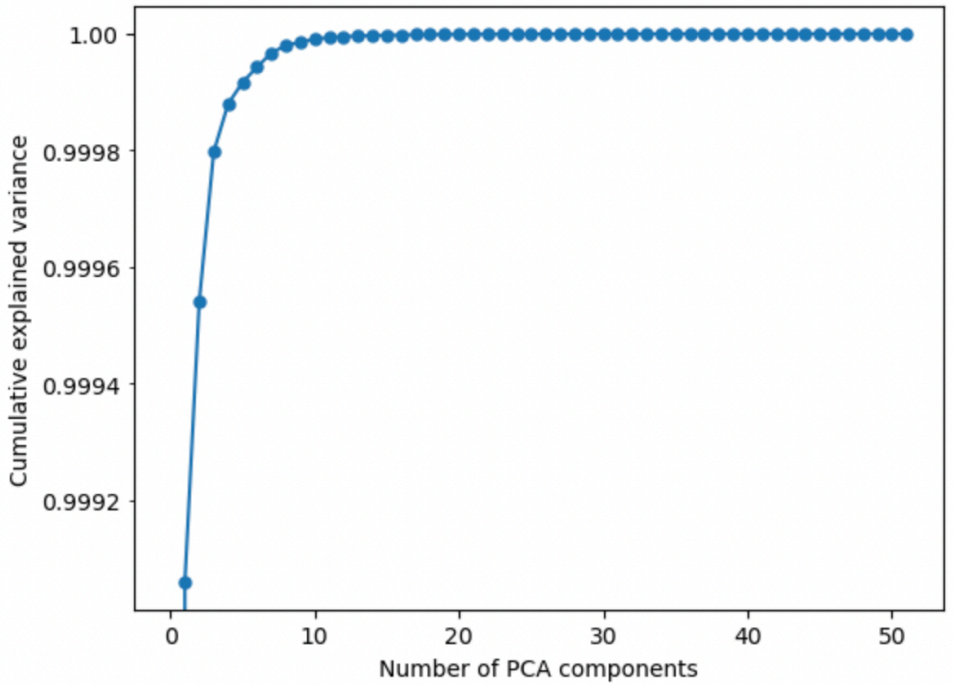
Training sessions: e.g. PCA analysis on ADC2023 database

6766 supervised data (Yip et al. 2022)





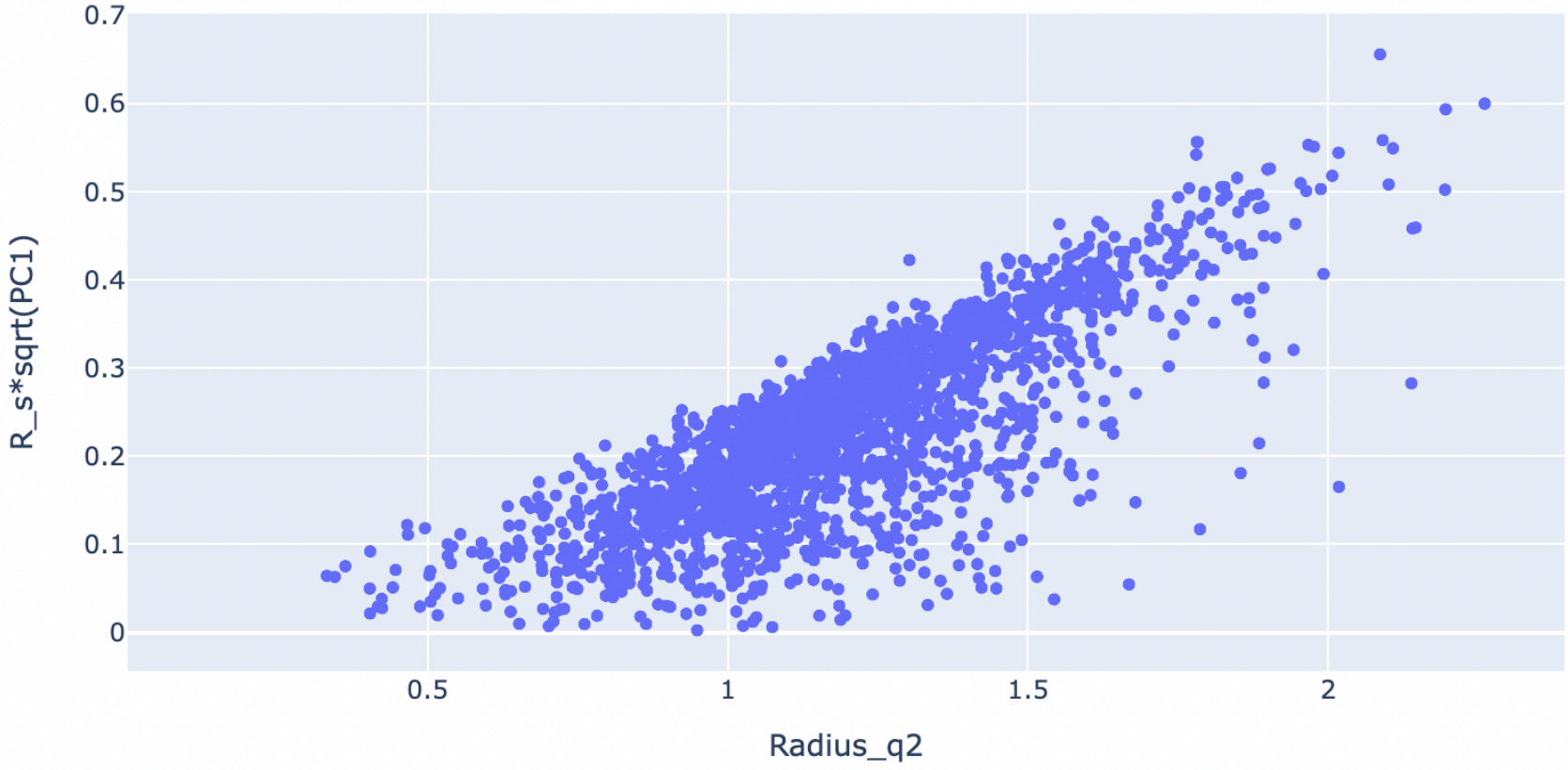


PC1 = 0.99905
PC2 = 0.0005
PC3 = 0.00025

1st component strongly dominates

PCA analysis on ADC2023 database: 1st component PC1

$$R_S\sqrt{PC1} \sim R_P$$



PCA analysis on ADC2023 database: other components

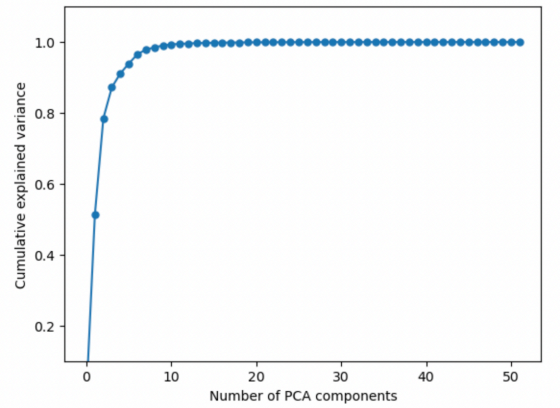
To express other PCA components, remove PC1 from the spectrum and do a second PCA on the residuals:

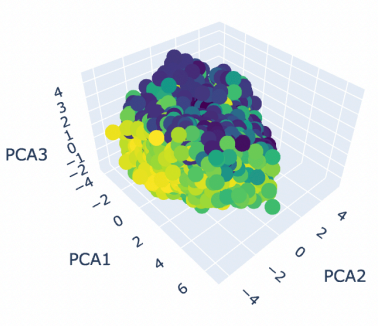
New components

PC1 = 0.513

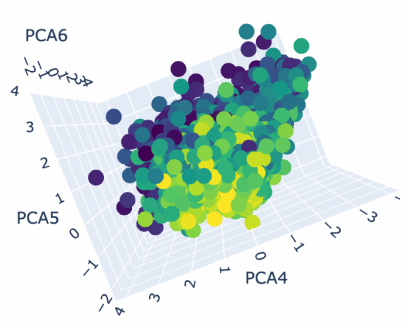
PC2 = 0.272

PC3 = 0.088

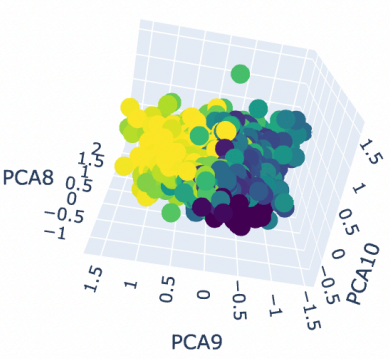




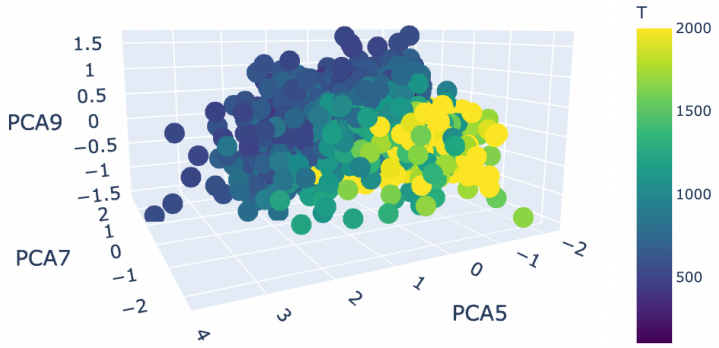
H2O



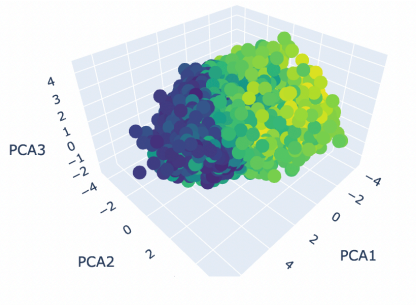
CO2



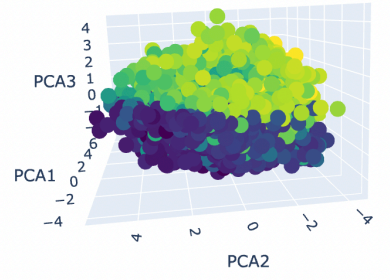
CO



Temperature



CH4

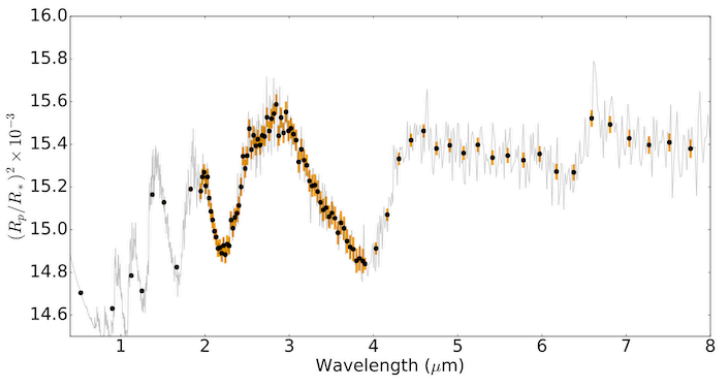


NH3

Participation to the Ariel Data Challenge 2023 (ADC23)

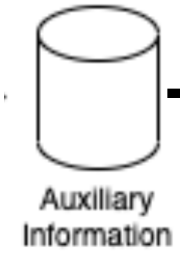
Engineering internship from June to October 2023 with **Saad Taleb (INSA Haut de France)**

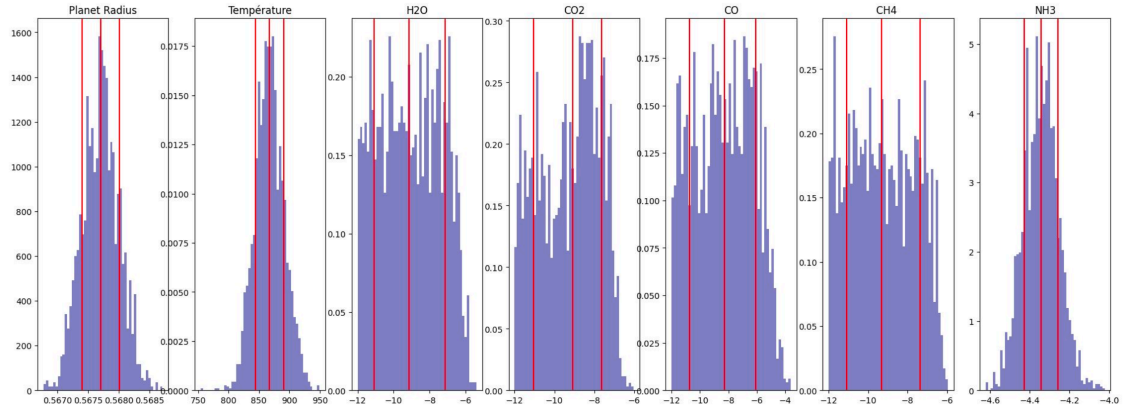
to work on **Ariel Data Challenge 2023 -** Deadline June 18th => Short !



Inputs

+

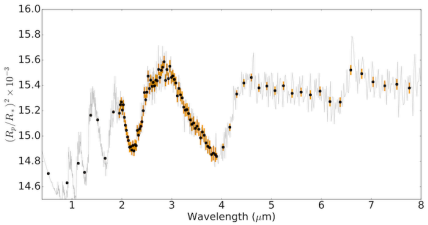




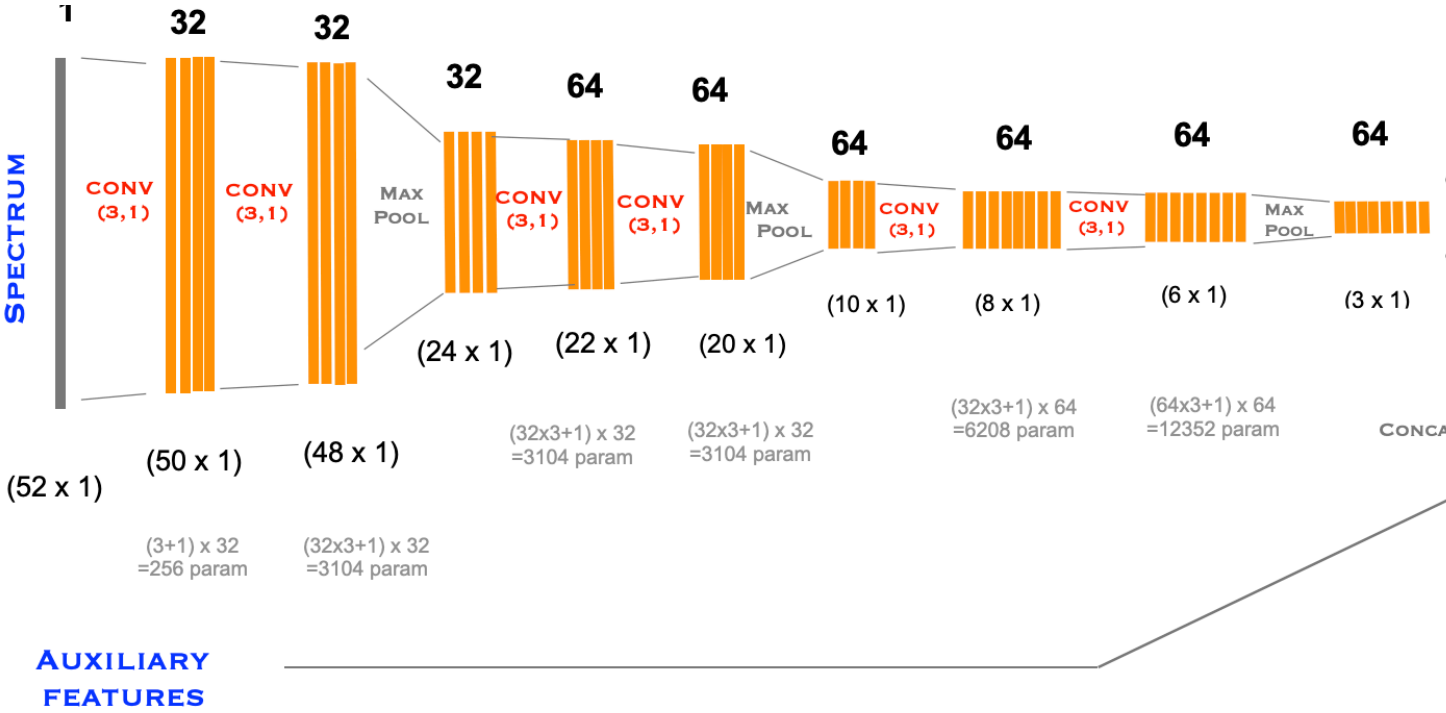
Radius **Temp** **H2O** **CO2** **CO** **CH4** **NH3**

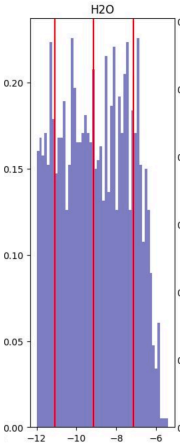
Outputs

Starting from the Ariel Data Challenge Baseline



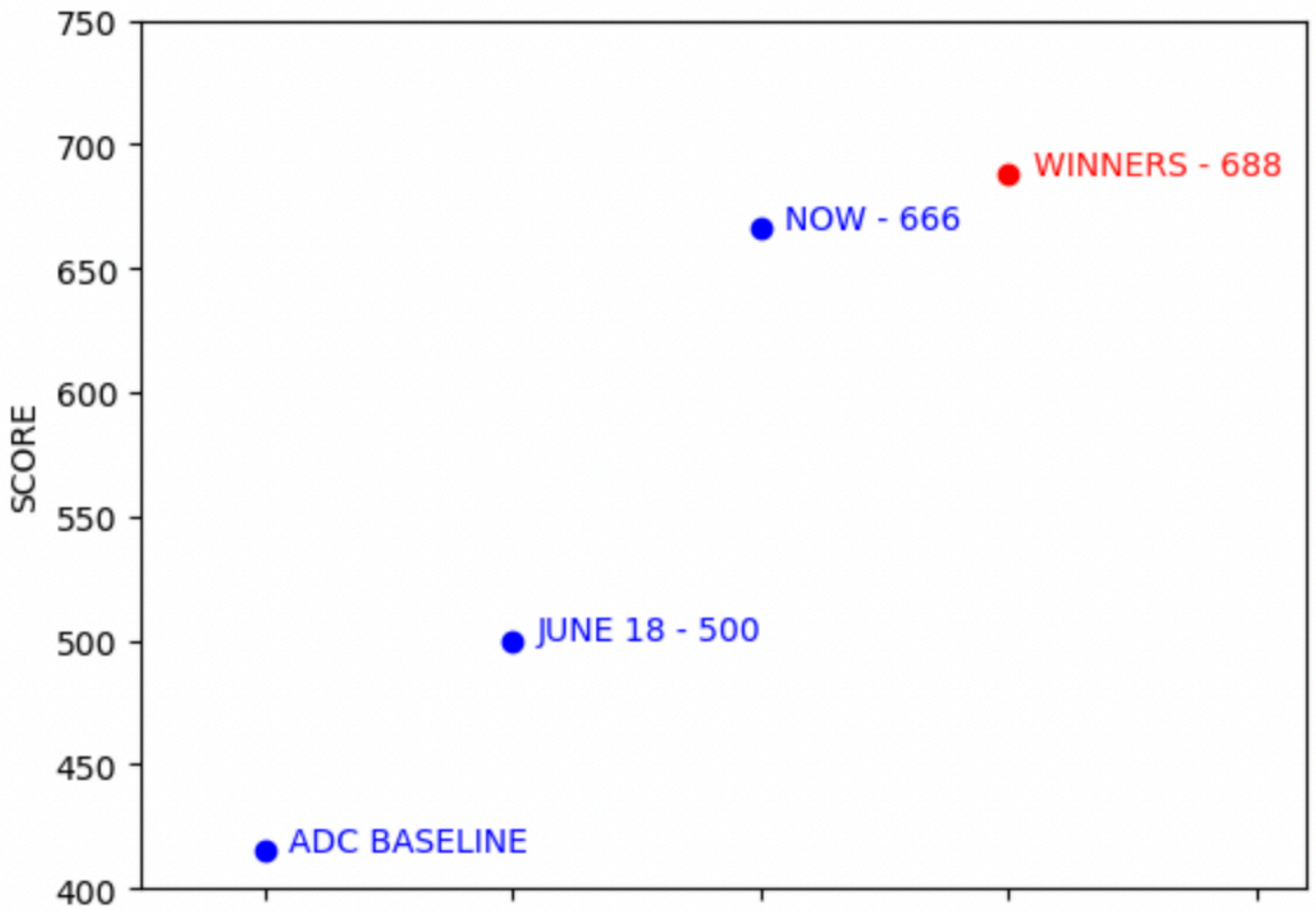
Convolutional Neural Network (CNN) + DNN





Score on test data between 0 and 1000 - Baseline score ~ 415

Score


750
700
650
600
550
500
450
400
SCORE
WINNERS - 688
NOW - 666
JUNE 18 - 500
ADC BASELINE

Conclusion and future projects

- **The Ariel Data Challenge provided a very useful Database for practicing**
- **IAP/CNES project to create a new Data Challenge in 2024** for French universities.
- **Master M2 internship + PhD starting in 2024 at IAP** under the supervision of Pierre Drossart, J.-P. Beaulieu and Orphée Faucoz (CNES):
  - Exploring AI approaches to de-trend systematics associated with the instrumental and astrophysical noise (e.g. variability of the host star, cosmic rays, jitter, photon noise, etc)
  - Generating Ariel L3 data with GANs
  - Testing Deep Learning approaches on a large sample of JWST/NIRSPEC data.