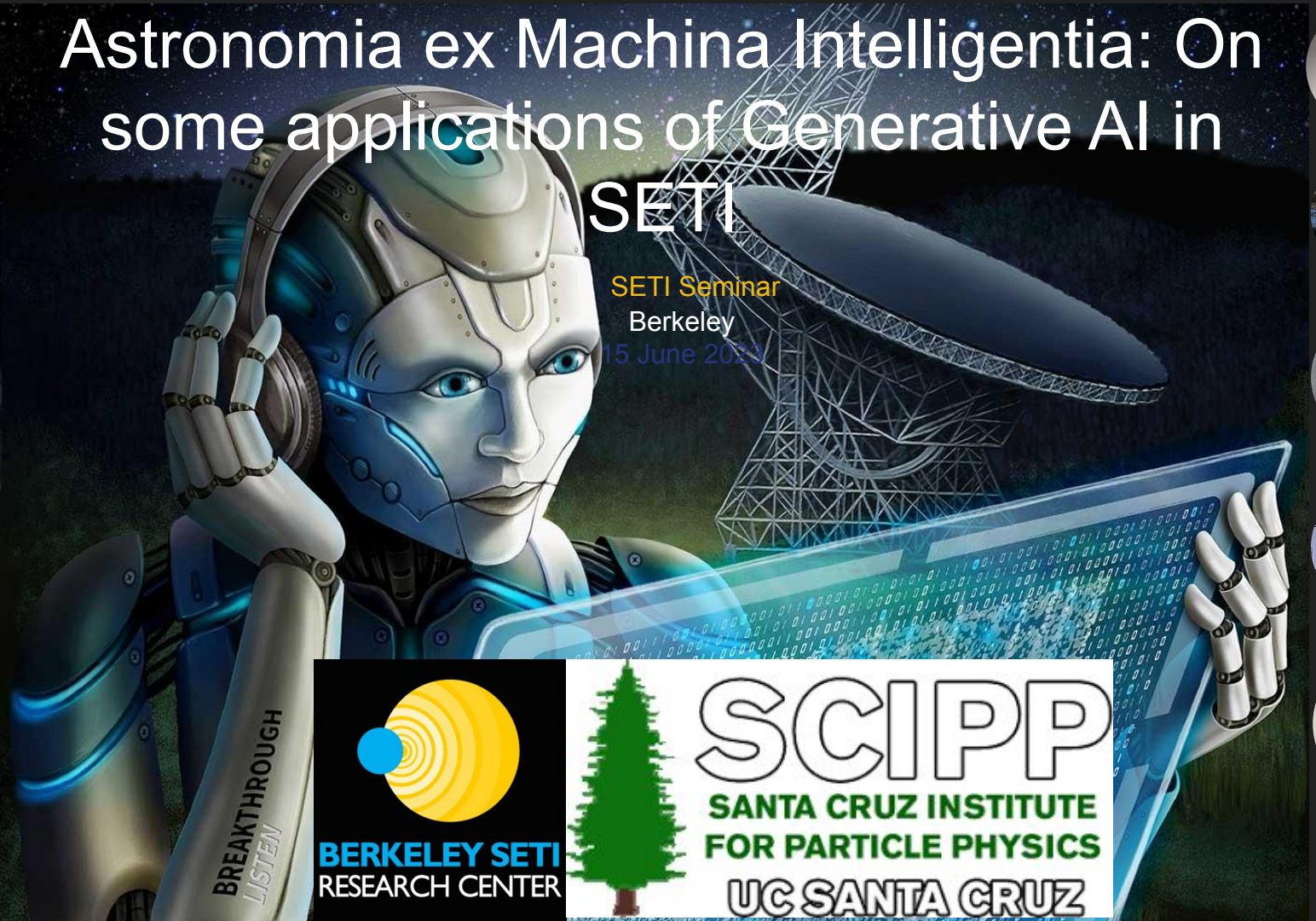
Astronomia ex Machina Intelligentia: On some applications of Generative AI in SETI

SETI Seminar
Berkeley
15 June 2023



BERKELEY SETI RESEARCH CENTER

SCIPP
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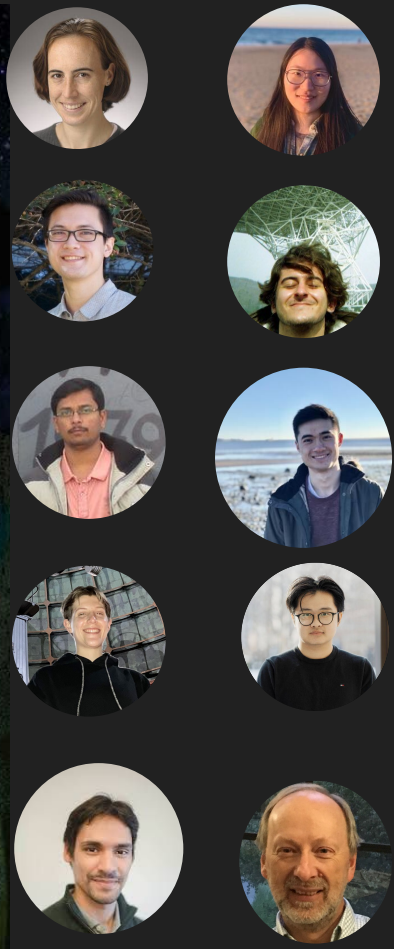

Partners in crime

What I **WON'T** talk about today

JO

How can we use ChatGPT to search for aliens?

While ChatGPT can provide information and insights on various topics, including space exploration, it is important to note that it is an AI language model and does not possess real-time or direct access to current scientific data. However, I can offer some general guidance on how scientists search for aliens, which you can use as a starting point:

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3. Exoplanet Studies: The discovery of exoplanets (planets orbiting stars outside our solar system) has opened up new possibilities for the search for alien life. Scientists study exoplanet atmospheres for chemical signatures that may indicate the presence of life, such as oxygen or methane.
4. Astrobiology Missions: Space agencies like NASA have launched missions specifically designed to search for signs of life in our solar system and beyond. For example, the Mars rovers and the upcoming Europa Clipper mission to Jupiter's moon Europa aim to investigate the potential for life in those environments.

To apply ChatGPT to the search for aliens, you can use it to gather information, discuss theories, brainstorm ideas, and explore different approaches to the search for extraterrestrial life. It can provide insights based on existing knowledge and scientific hypotheses. Remember to consult the latest scientific research and data to ensure you have the most up-to-date information.

What I **WILL** talk about today

1. SETI and Technosignatures
2. Astronomia ex Machina Intelligentia
   - Neural Nets & Latent space
   - Generative AI and GANs
3. Some applications
   - Radio spectra
   - Dyson swarm
   - Cherenkov data
4. Future applications
   - (A)nomaly detection and creation
   - Reverse-engineering anomalies
   - Transit spectroscopy with JWST
5. Q&A

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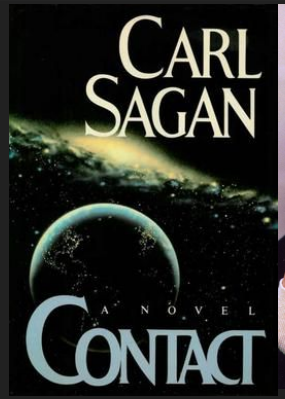
SETI: the great question



SETI: the great question

There are billions of stars in the Milky Way similar to the Sun.

Some of these stars have Earth-like planets in a circumstellar habitable zone.

Many of these stars, and hence their planets, are much older than the Sun. If Earth-like planets are typical, some may have developed intelligent life long ago.

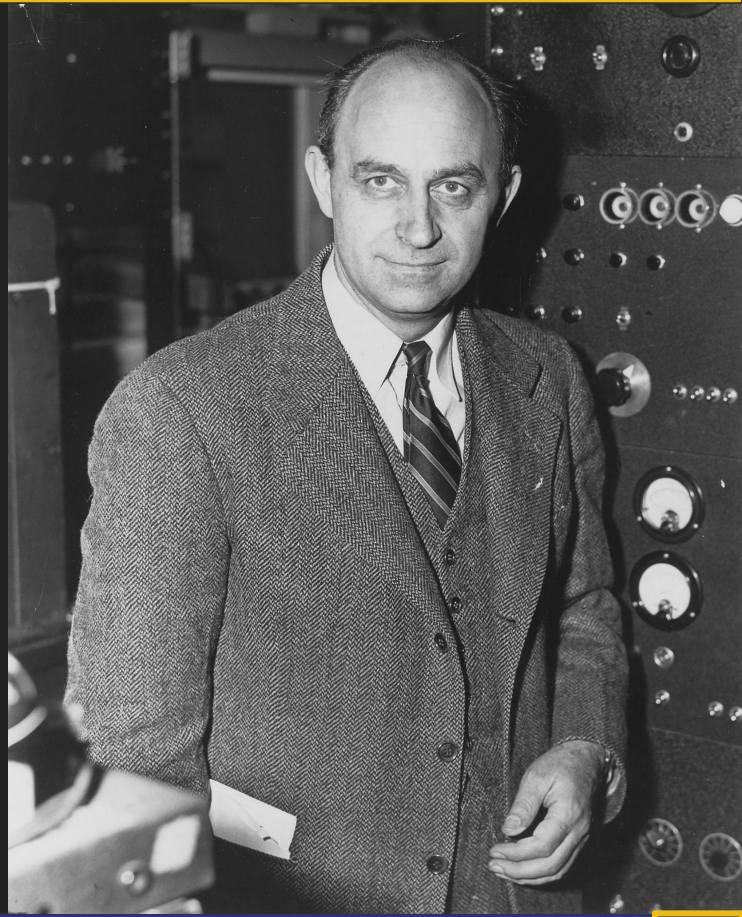
Some of these civilizations may have developed interstellar travel, a step humans are investigating now.

Even at the slow pace of currently envisioned interstellar travel, the Milky Way galaxy could be completely traversed in a few million years.

Since many of the Sun-like stars are billions of years older than the Sun, the Earth should have already been visited by extraterrestrial civilizations, or at least their probes

However, there is no convincing evidence that this has happened.

SO, WHERE IS EVERYBODY?



SETI: the great equation

$$N = R_* \cdot f_P \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

N = number of civilizations with which humans could communicate

R_* = mean rate of star formation

f_P = fraction of stars that have planets

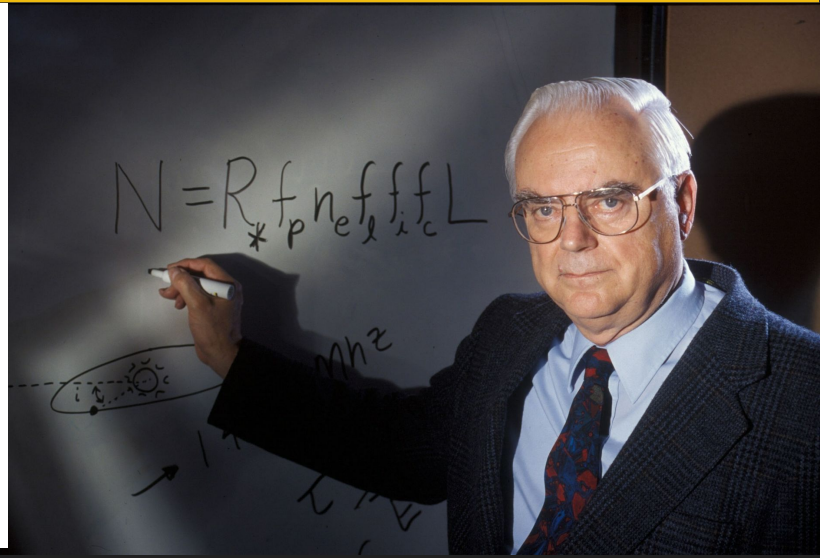
n_e = mean number of planets that could support life per star with planets

f_l = fraction of life-supporting planets that develop life

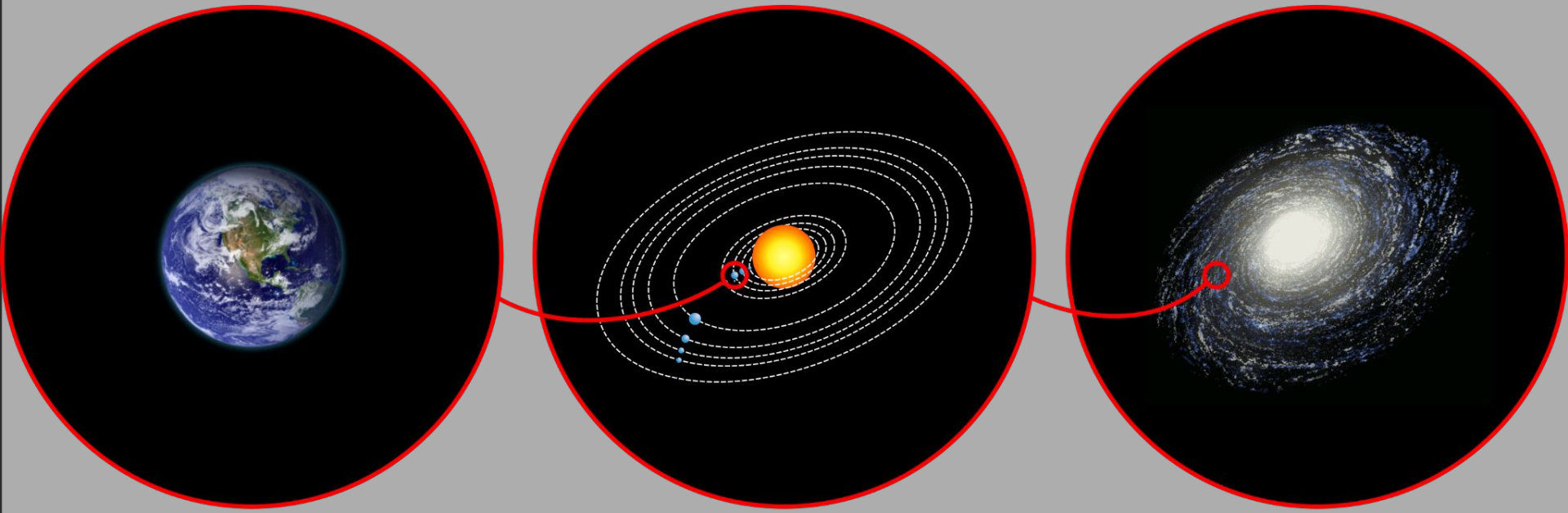
f_i = fraction of planets with life where life develops intelligence

f_c = fraction of intelligent civilizations that develop communication

L = mean length of time that civilizations can communicate



Technosignatures: Kardashev scale

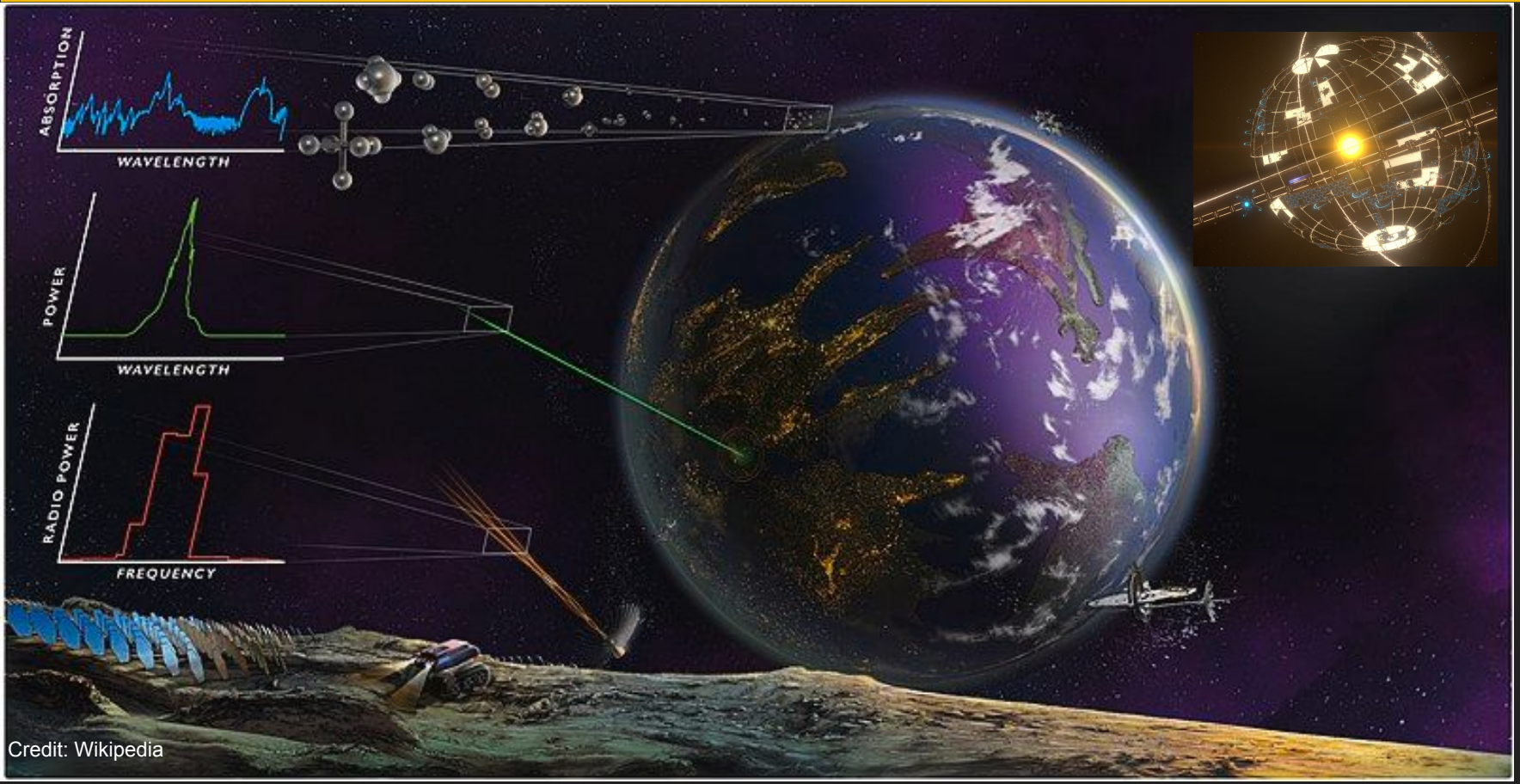


Type I: 10^{16} W

Type II: 10^{26} W

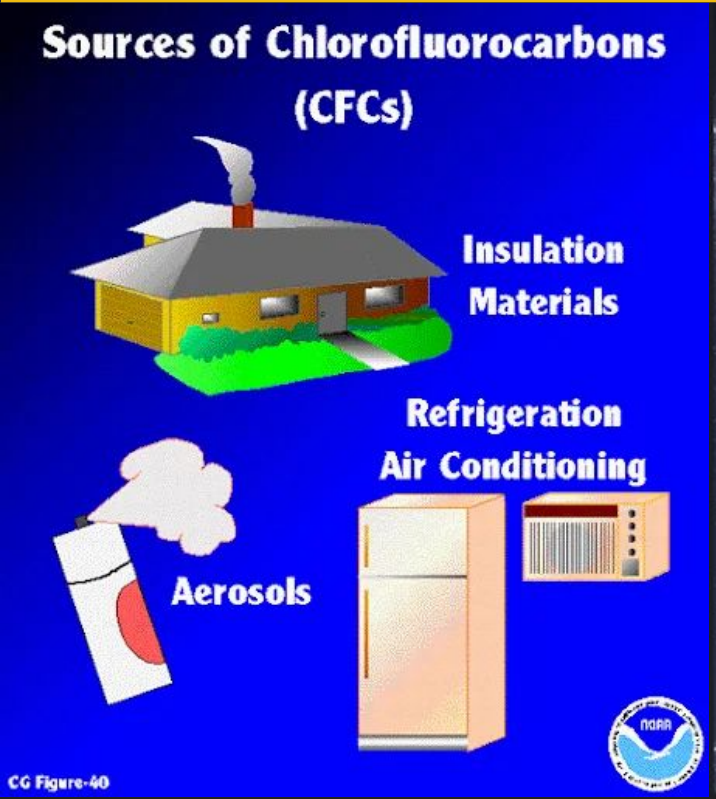
Type III: 10^{36} W

Technosignatures



Credit: Wikipedia

Technosignatures



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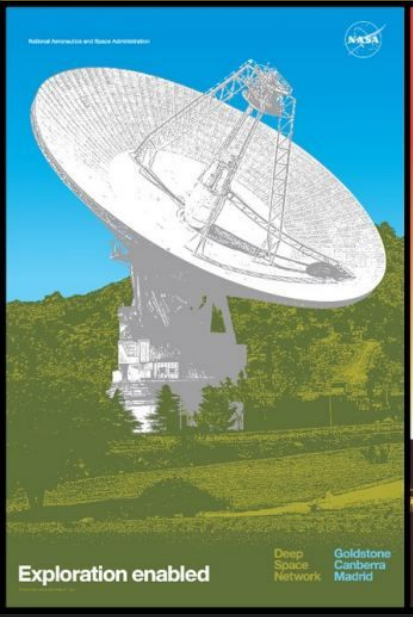

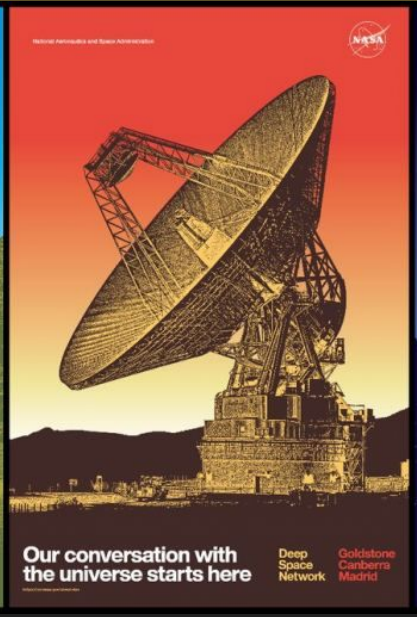

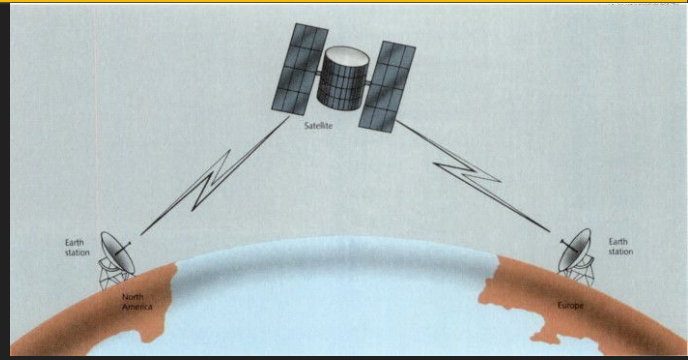

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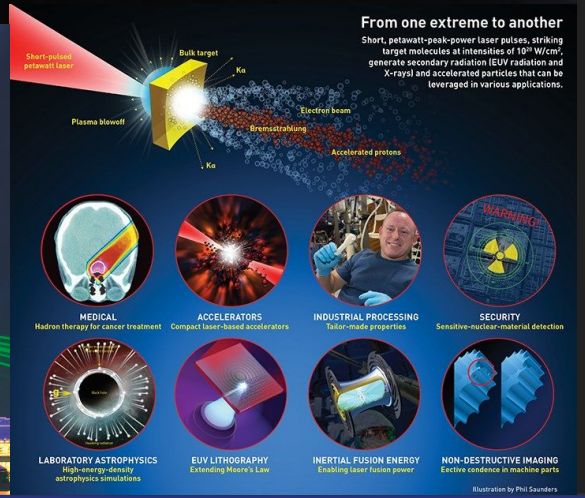

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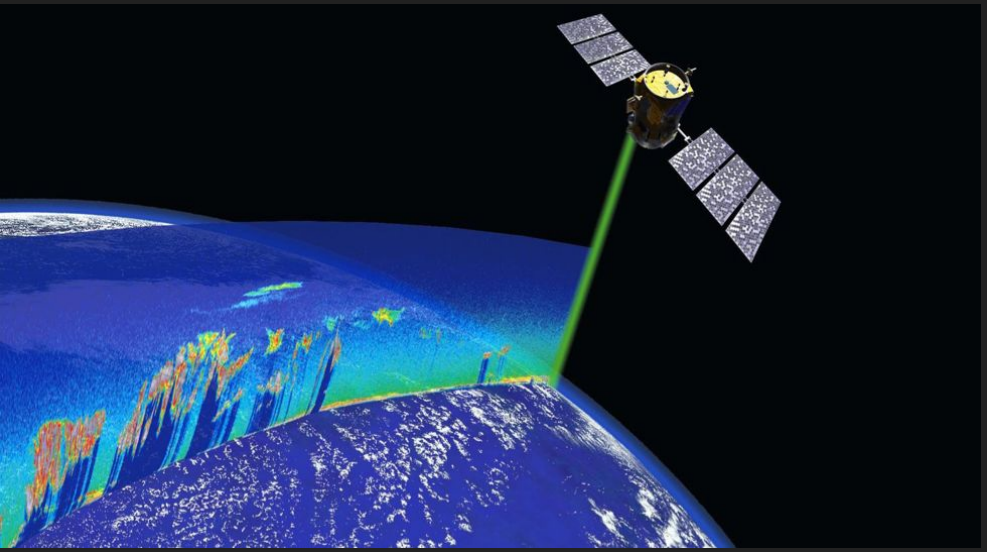

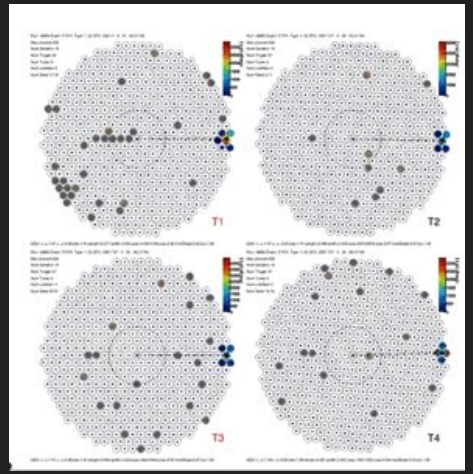

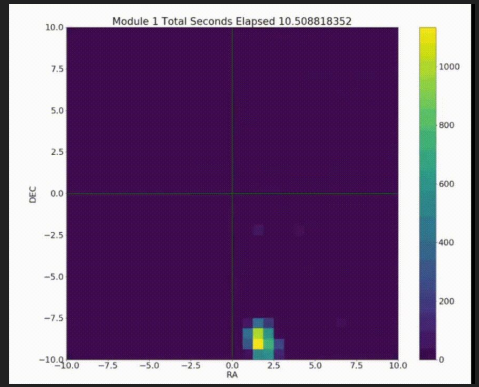

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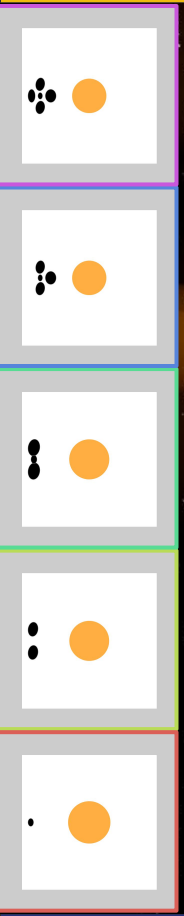
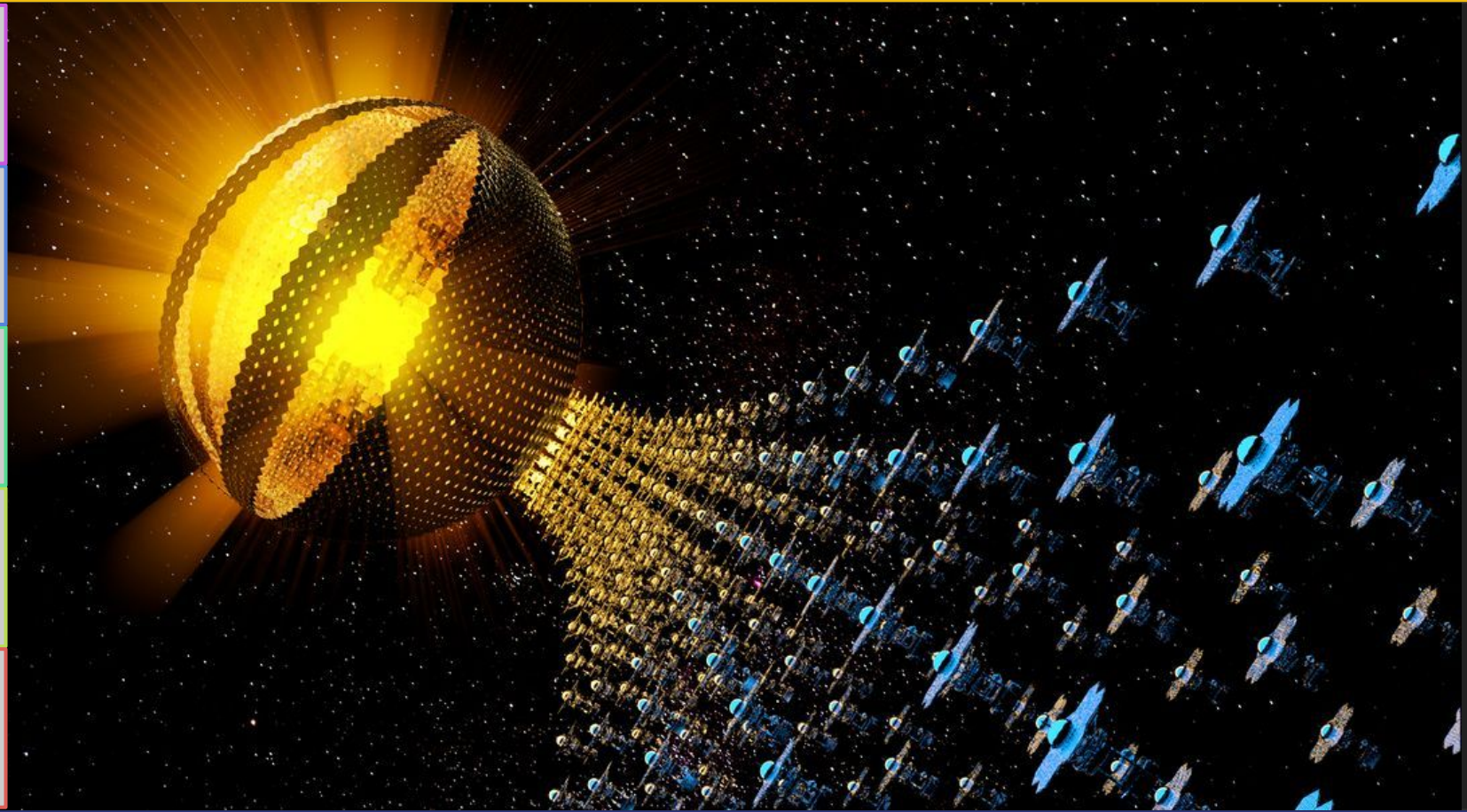
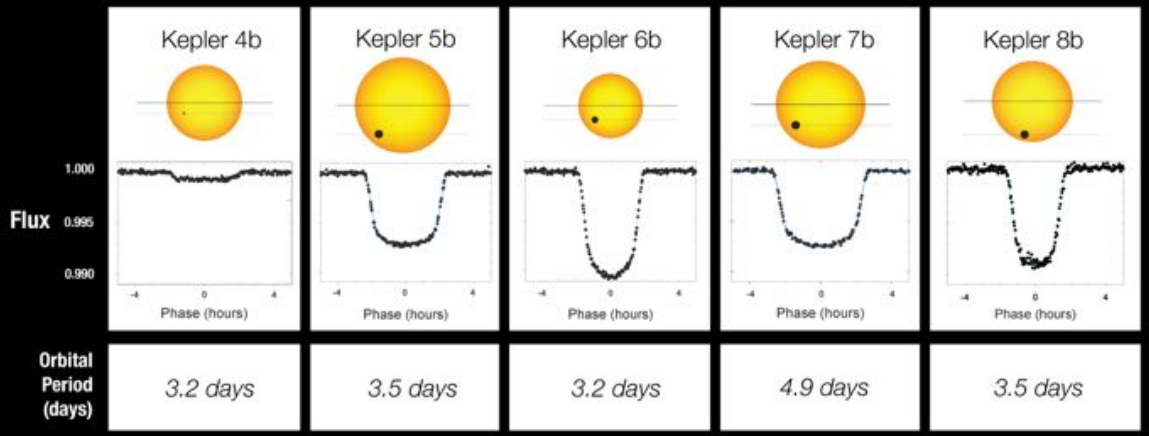


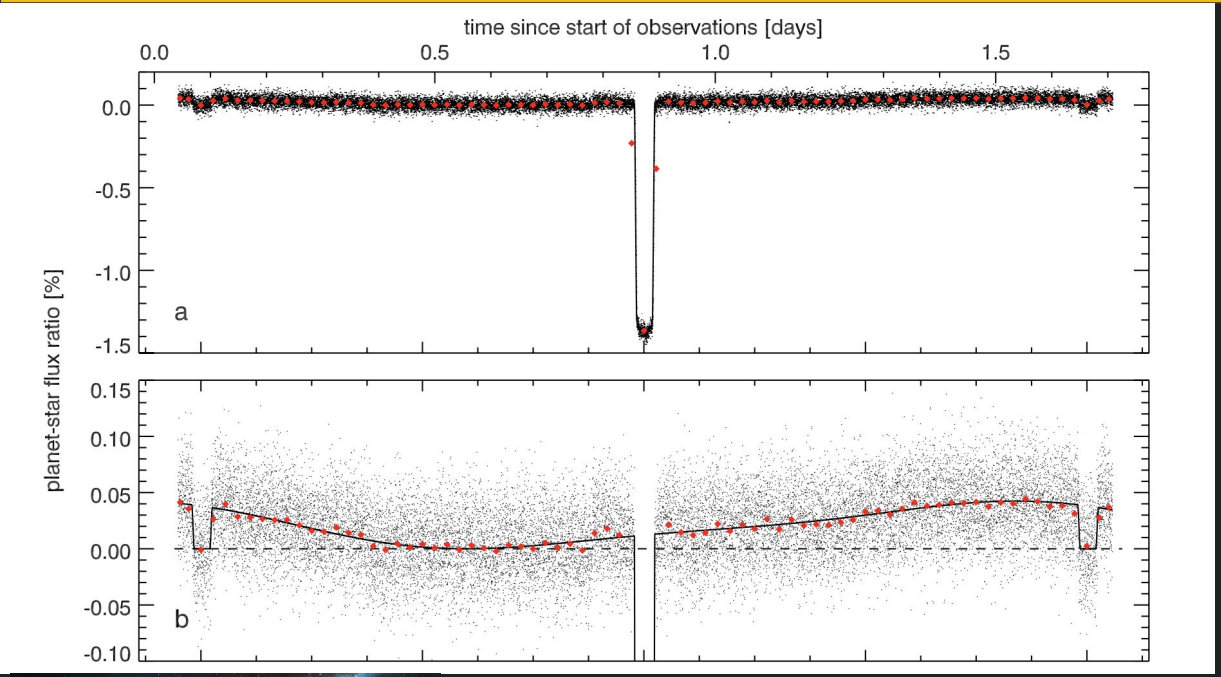


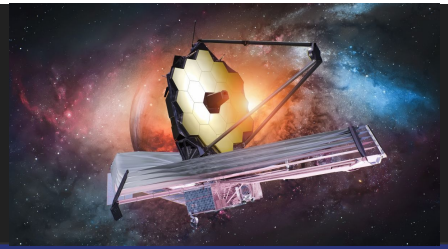
Technosignatures

Transit Light Curves

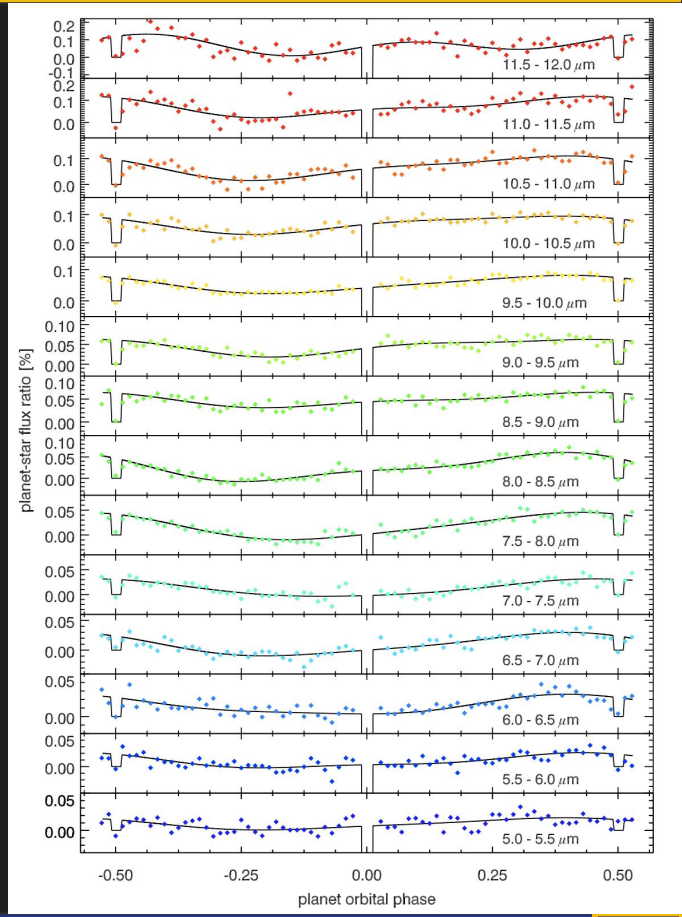


Future Direction: Spectrophotometric with JWST

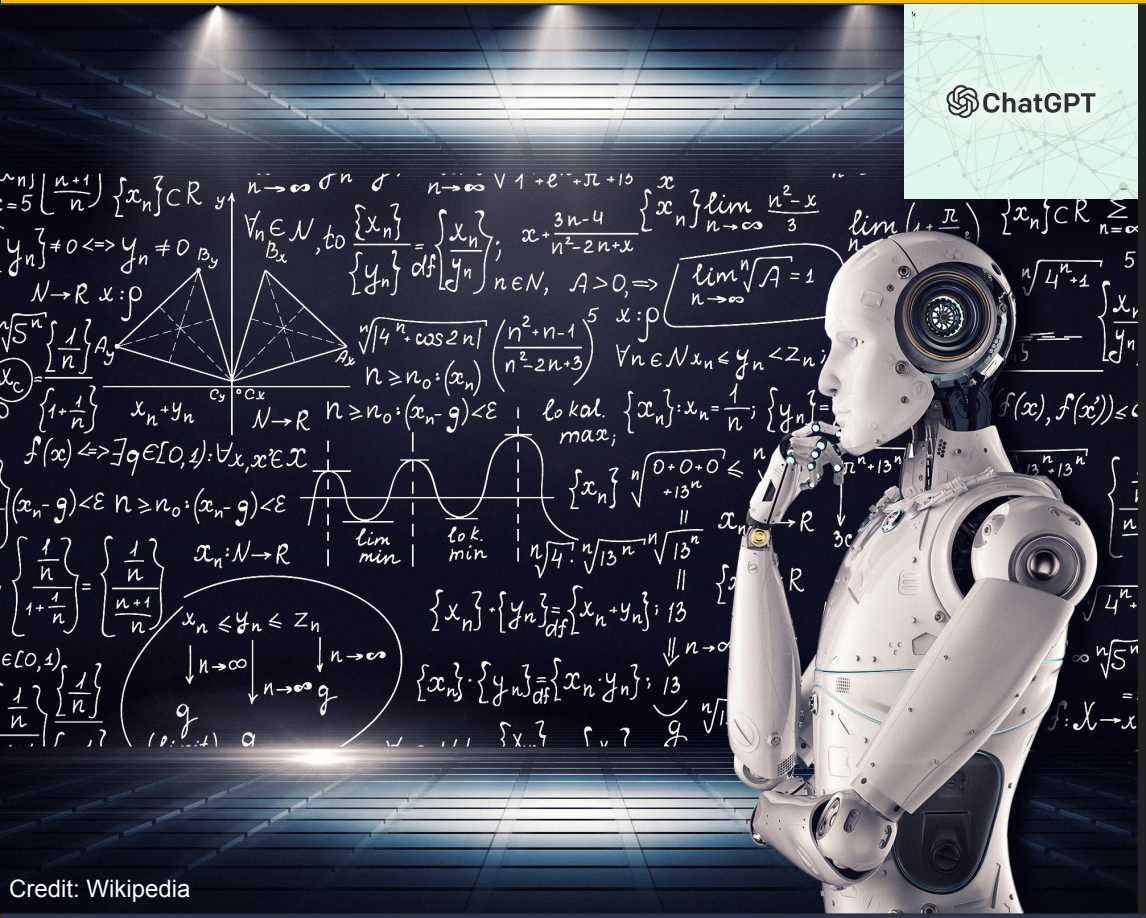




arXiv: 2305.06240 (Super Earth GJ 1214b)



Astronomia ex Machina Intelligentia



Credit: Wikipedia

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Astronomia ex Machina Intelligentia

1988ESOC.

AUTOMATED GALAXY RECOGNITION

Barry Rappaport, Computing Research Laboratory and Department of Astronomy, New Mexico State University, Box 3CRL, Las Cruces, New Mexico, 88003/USA

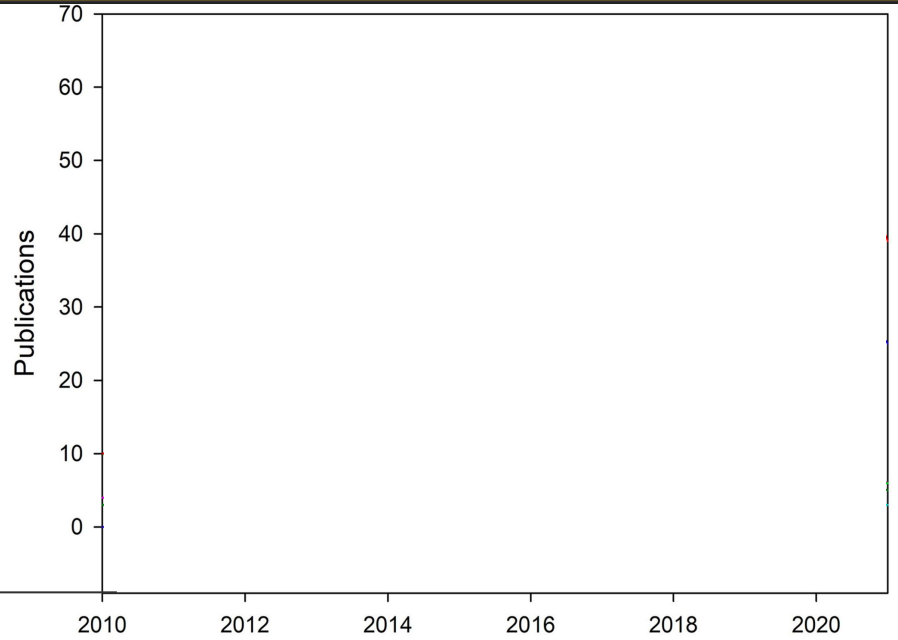
Kurt Anderson, Department of Astronomy, Box 4500, New Mexico State University, Las Cruces, New Mexico, 88003/USA

Abstract

Previous approaches to automated image processing have used both deterministic and non-deterministic techniques. These have not used any form of conceptual learning nor have they employed artificial intelligence techniques. Addition of such techniques to the task of image processing may significantly enhance the efficiencies and accuracies of the recognition and classification processes. In our application, the objects to be recognized and classified are galaxies.

1988: this paper

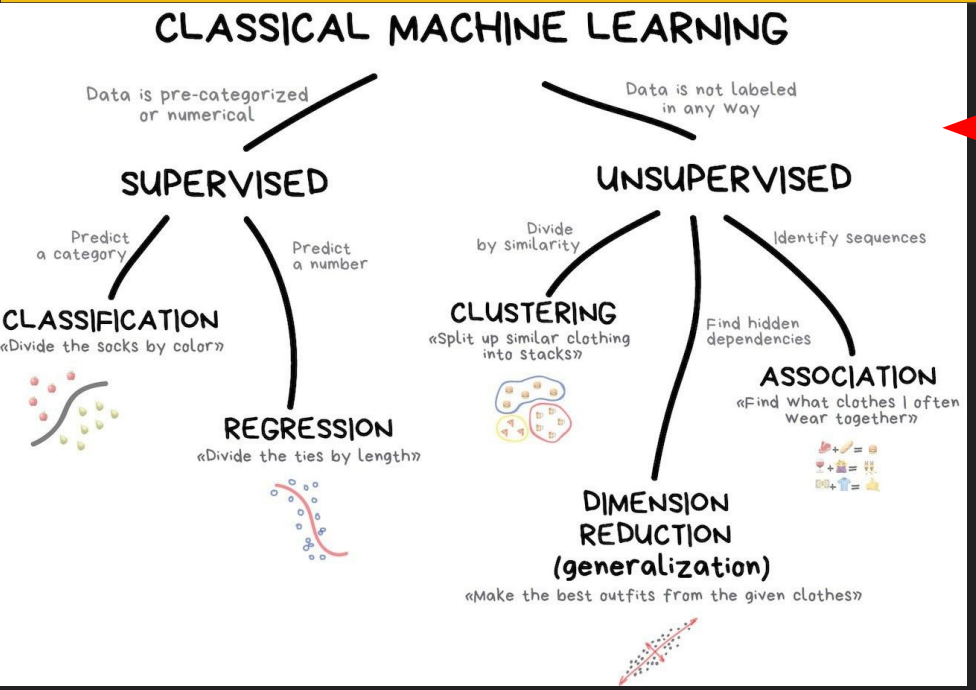
1990
John was born

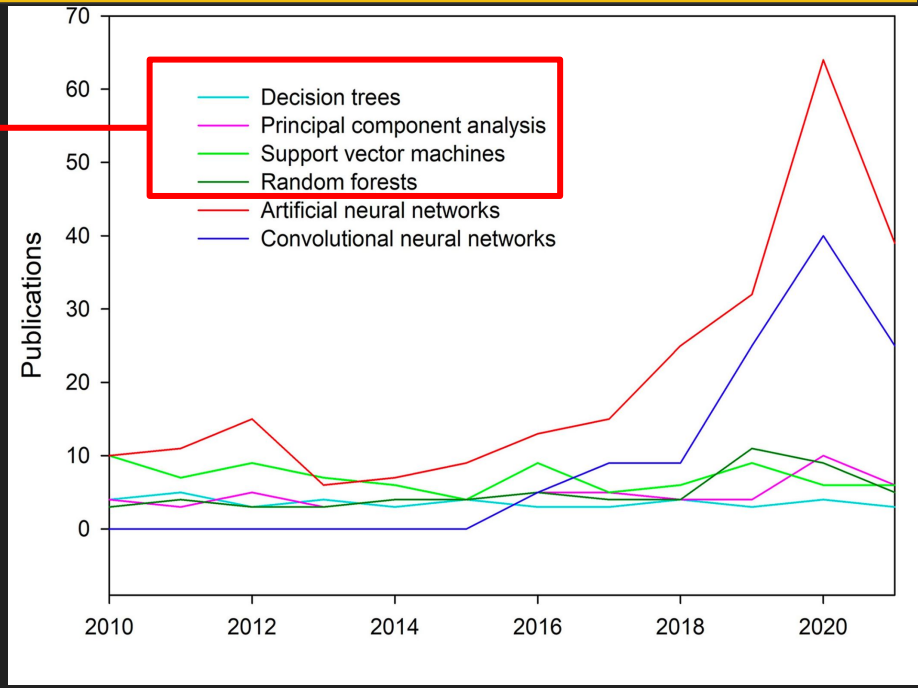


Connectionism is a collection of the models of algorithms which control the flow of a neural network (directed graph). The network contains input and output nodes. The input nodes are the observational quantities. The output nodes are decision points within the problem solving process. For example, if

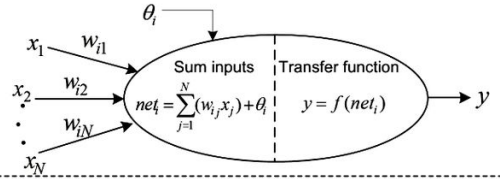
Credit: On the application of machine learning in astronomy and astrophysics: A text-mining-based scientometric analysis

Astronomia ex Machina Intelligentia





Why neural nets are useful? A mathematical perspective



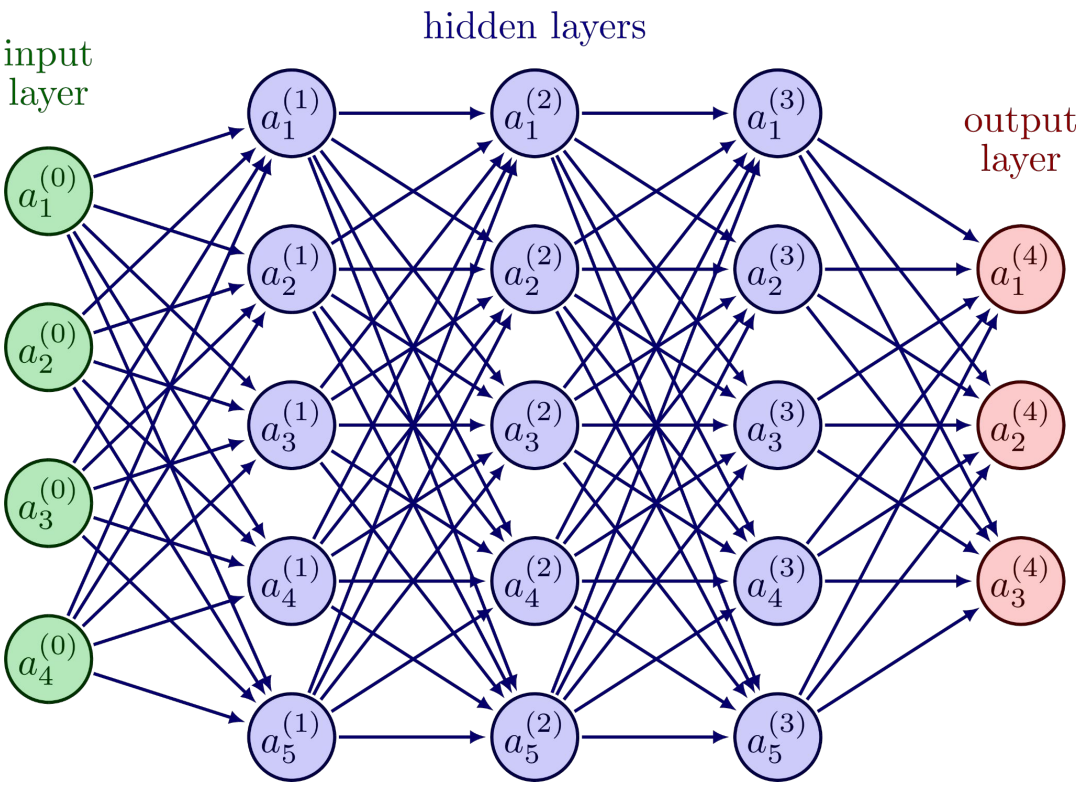
$x_i (i = 1,2,\ldots,N)$: *Set of inputs*

w_{ij} : *Connection weights*

θ_i : *Bias term*

Net_i : *Net input signal*

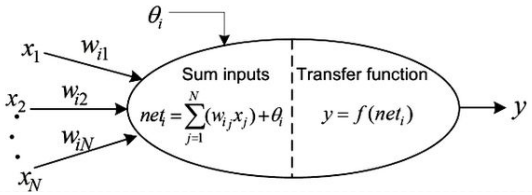
Transfer function : tangent *sigmoid function* $f(x) = \left[\frac{2}{1+e^{-2x}} - 1\right]$ *or linear function* $f(x) = x$



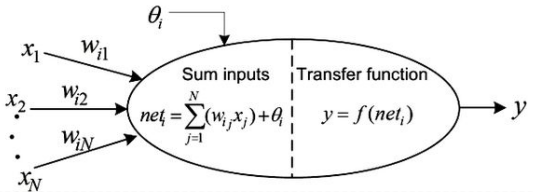
Why neural nets are useful? A mathematical perspective

Universal approximation theorem[19]**:** There exists an activation function σ which is analytic, strictly increasing and sigmoidal and has the following property: For any $f \in C[0,1]^d$ and $\varepsilon > 0$ there exist constants $d_i, c_{ij}, \theta_{ij}, \gamma_i$, and vectors $\mathbf{w}^{ij} \in \mathbb{R}^d$ for which

$$\left| f(\mathbf{x}) - \sum_{i=1}^{d_i} \gamma_i \sigma\left(\sum_{j=1}^{d} c_{ij} \sigma\left(\mathbf{w}^{ij} \cdot \mathbf{x} - \theta_{ij} \right) \right) \right| < \varepsilon$$



for all $\mathbf{x} = (x_1, \ldots, x_d) \in [0,1]^d$.



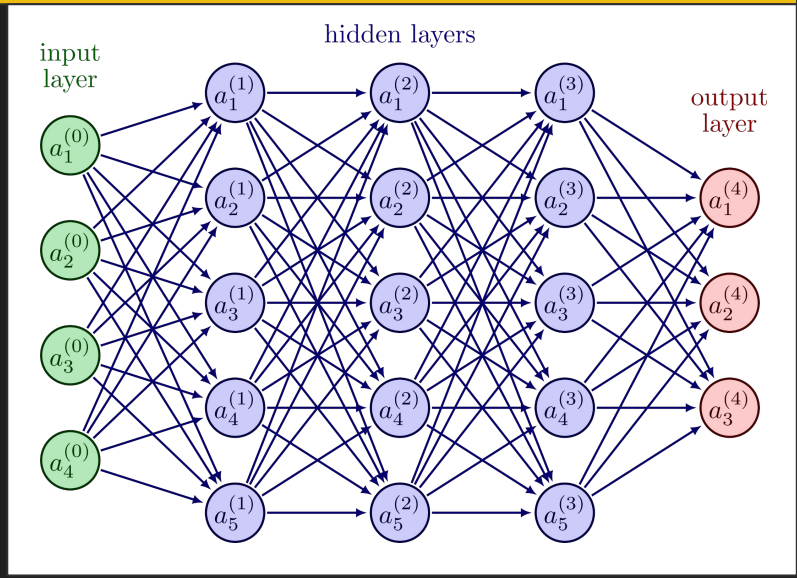
Weierstrass Approximation Theorem — Suppose f is a continuous real-valued function defined on the real interval $[a, b]$. For every $\varepsilon > 0$, there exists a polynomial p such that for all x in $[a, b]$, we have $|f(x) - p(x)| < \varepsilon$, or equivalently, the supremum norm $\|f - p\| < \varepsilon$.

Credit: Wikipedia

Why neural nets are useful? A mathematical perspective

Polynomial Approximation

Machine Learning



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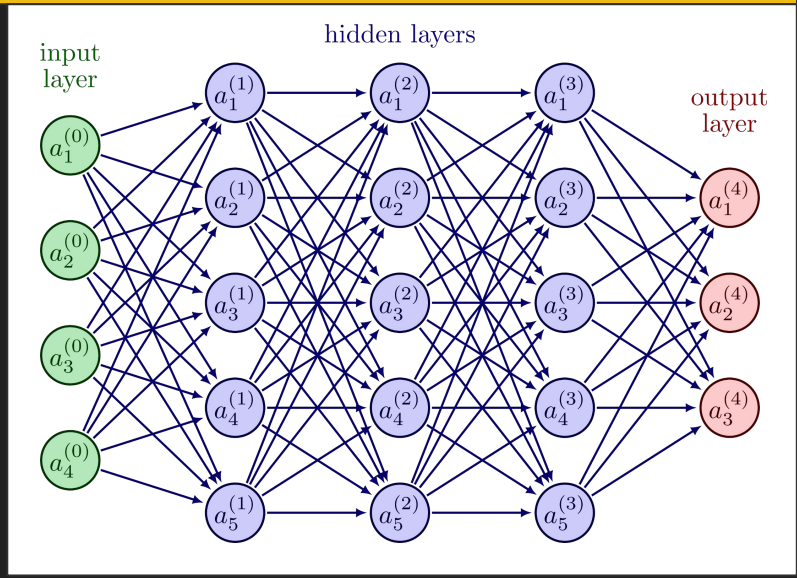
Why neural nets are useful? Latent space!

Polynomial Approximation

Machine Learning



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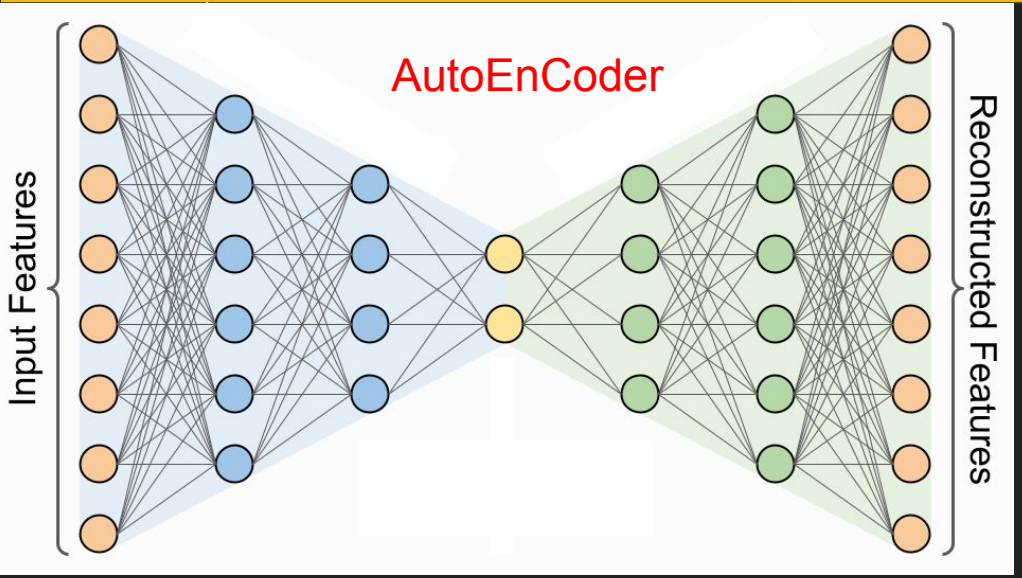
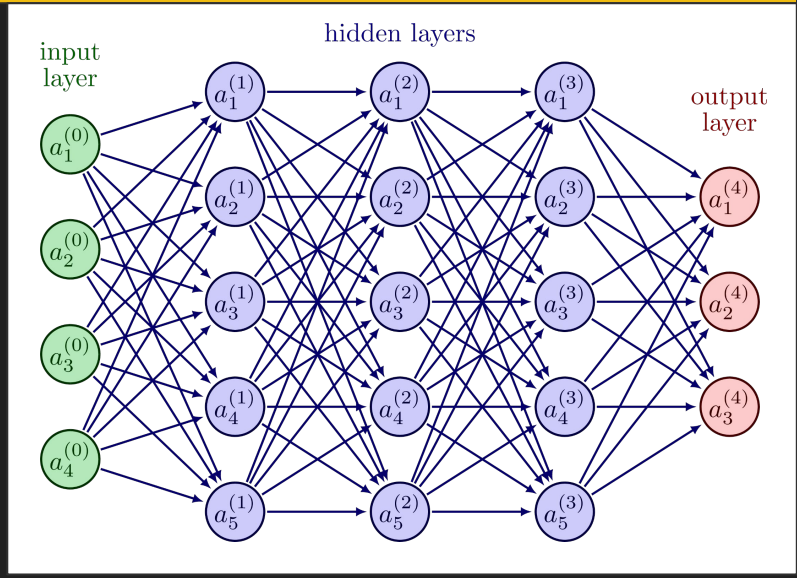
Why neural nets are useful? Latent space!





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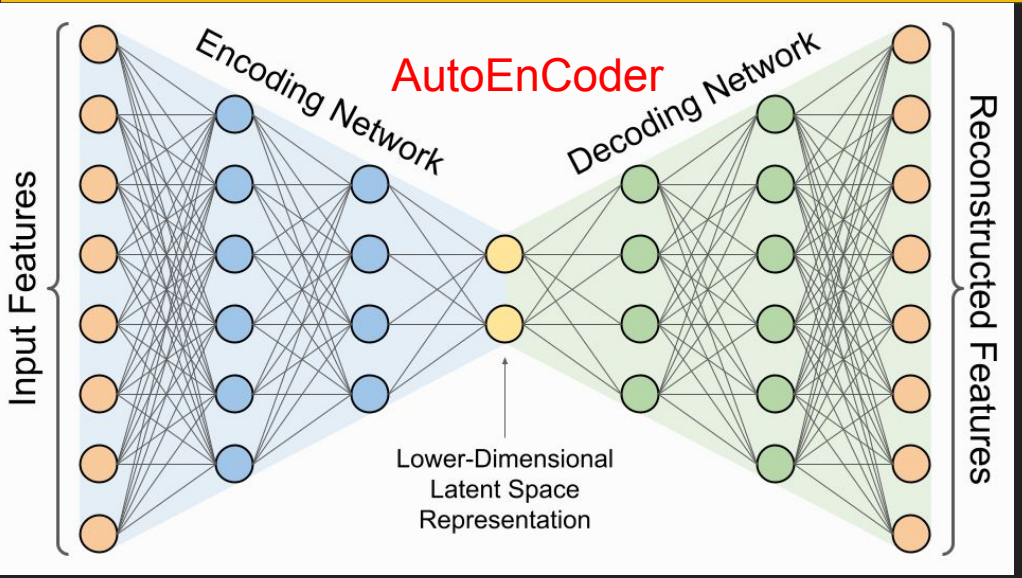

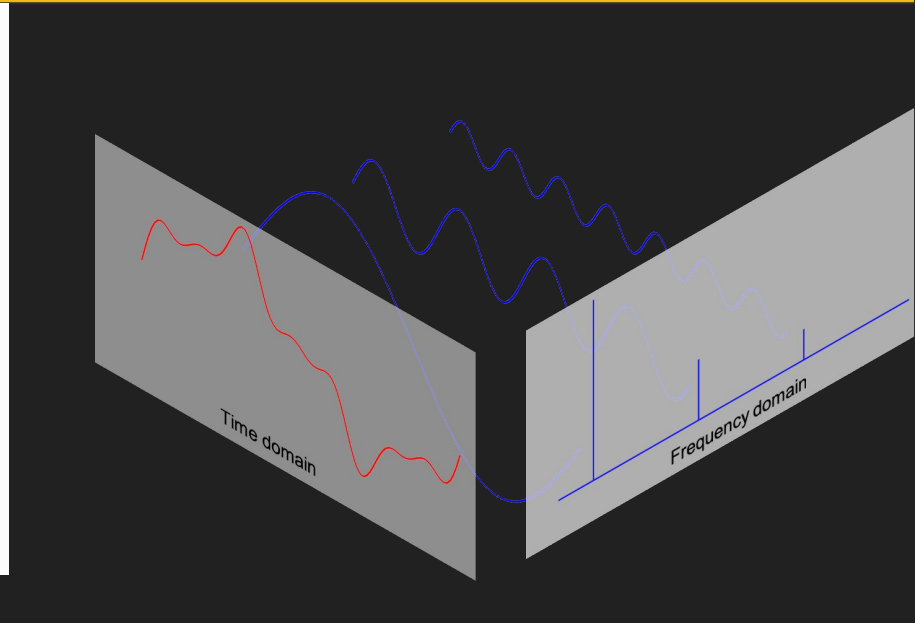

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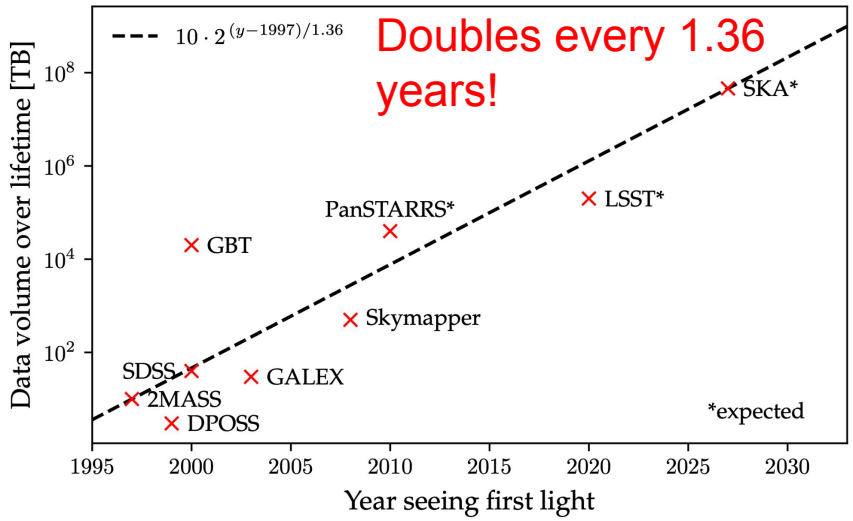
The Cambrian explosion



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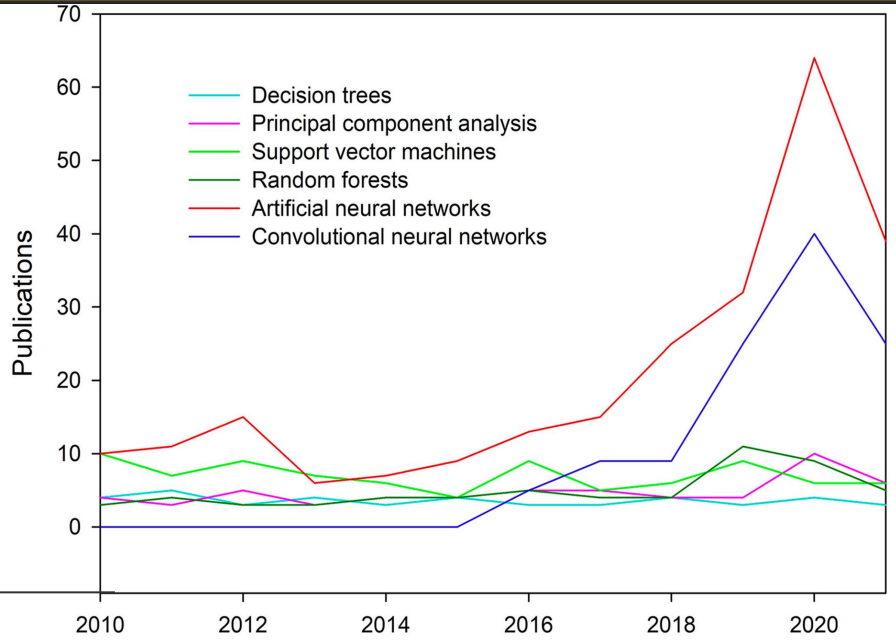
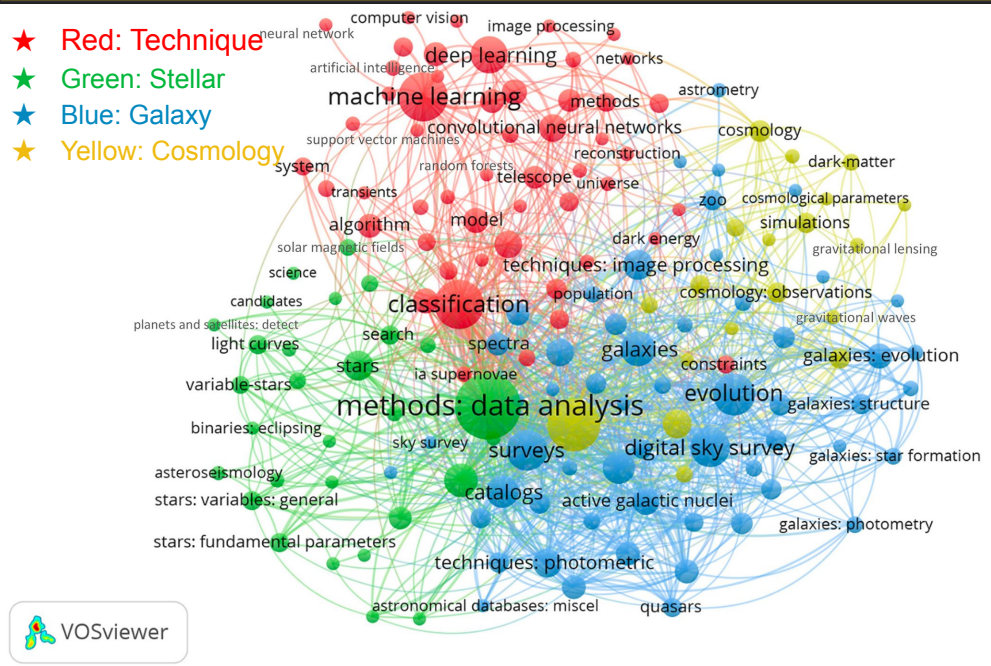
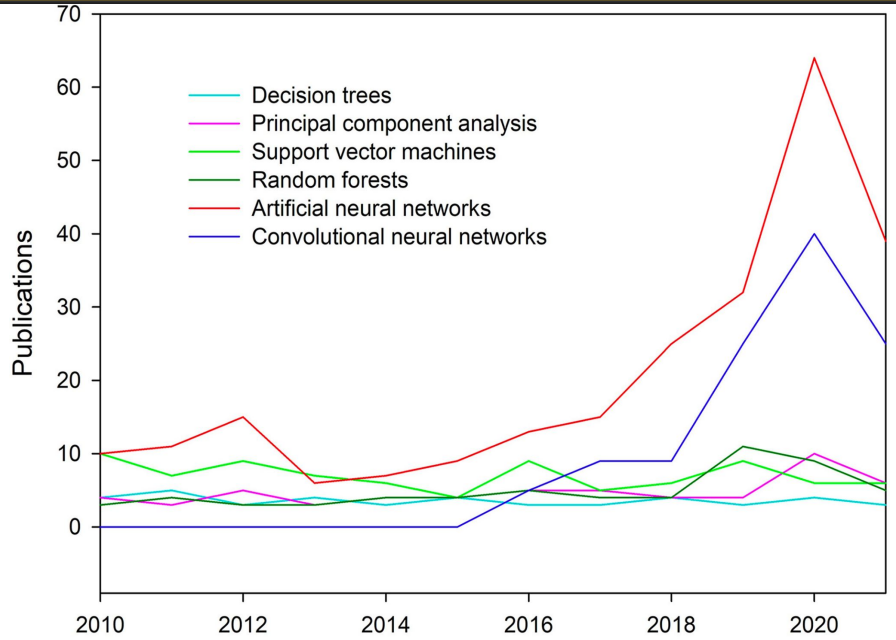
John was born



Credit: On the application of machine learning in astronomy and astrophysics: A text-mining-based scientometric analysis

The Cambrian explosion





Credit: On the application of machine learning in astronomy and astrophysics: A text-mining-based scientometric analysis

RGB: a flourishing industry

Image-based discovery and classification with Neural Nets is now a cottage industry.

A deep-learning search for technosignatures from 820 nearby stars

Peter Xiangyuan Ma, Cherry Ng, Leandro Rizk, Steve Croft, Andrew P. V. Siemion, Bryan Brzycki, Daniel Czech, Jamie Drew, Vishal Gajjar, John Hoang, Howard Isaacson, Matt Lebofsky, David H. E. MacMahon, Imke de Pater, Danny C. Price, Sofia Z. Sheikh & S. Pete Worden

THE ASTROPHYSICAL JOURNAL

Fast Radio Burst 121102 Pulse Detection and Periodicity: A Machine Learning Approach

Yunfan Gerry Zhang[1,2], Vishal Gajjar[2,3], Griffin Foster[1,2,4], Andrew Siemion[1,2,5,6,7], James Cordes[8], Casey Law[1], and Yu Wang[9]

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The Astrophysical Journal, Volume 866, Number 2

Citation Yunfan Gerry Zhang *et al* 2018 *ApJ* **866** 149

DOI 10.3847/1538-4357/aadf31

Outlier galaxy images in the Dark Energy Survey and their identification with unsupervised machine learning

Lior Shamir
Department of Computer Science, Kansas State University

Machine Learning Classification of SDSS Transient Survey Images

L. du Buisson[1,2*], N. Sivanandam[2†], Bruce A. Bassett[1,2,3‡] and M. Smith[4,5]

JOURNAL ARTICLE

Machine learning for transient discovery in Pan-STARRS1 difference imaging FREE

D. E. Wright, S. J. Smartt, K. W. Smith, P. Miller, R. Kotak, A. Rest, W. S. Burgett, K. C. Chambers, H. Flewelling, K. W. Hodapp ... Show more

Astroinformatics
Proceedings IAU Symposium No. 325, 2016
M. Brescia, S.G. Djorgovski, E. Feigelson, G. Longo & S. Cavuoti, eds.

© International Astronomical Union 2017
doi:10.1017/S1743921316012734

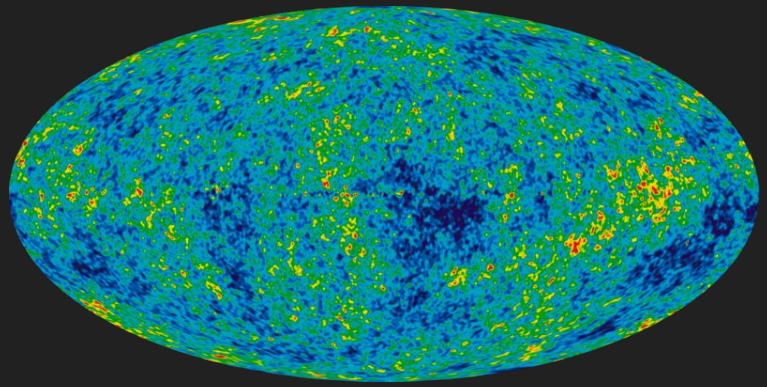
The analysis of VERITAS muon images using convolutional neural networks

Qi Feng[1,†], Tony T. Y. Lin[1]
for the VERITAS Collaboration[2]

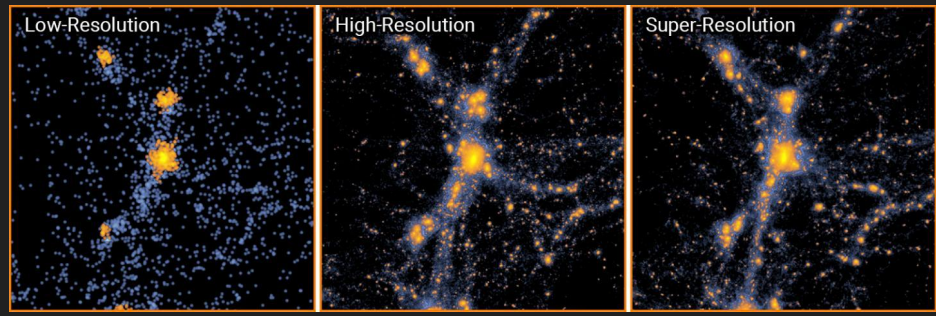
Y: Towards “simulation-based” inference

Two objectives in Cosmology

- ★ Parameter Inference: Find optimal constraints on cosmological parameters.
- ★ Posteriors/likelihoods/priors for intractable model.



- ★ Emulators for Statistics: cosmological simulation is an expensive affair.
- ★ Emulator at arbitrary points in parameter space by interpolating between points at which simulations are generated.

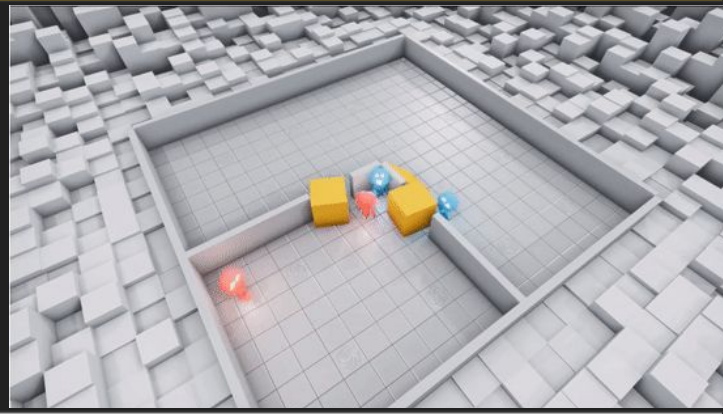


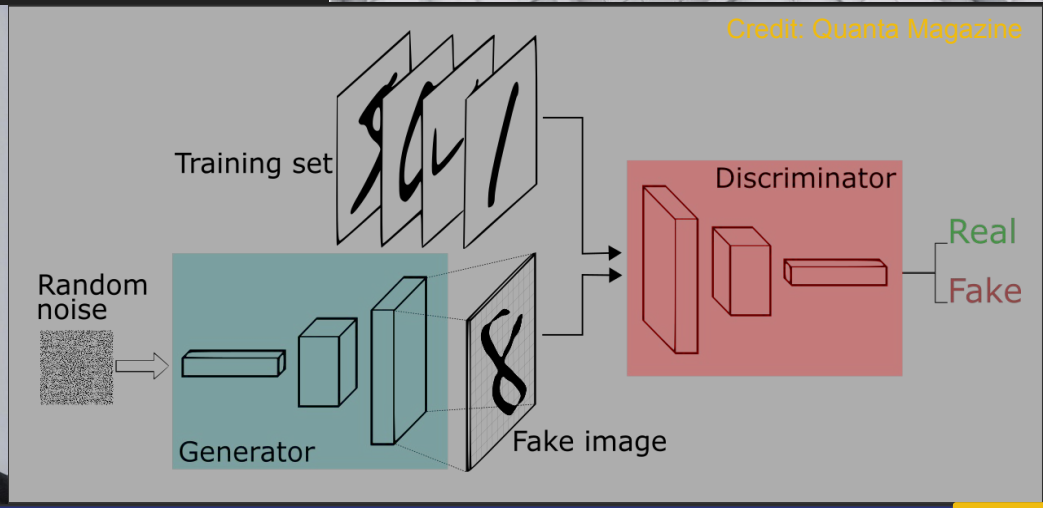
GANs

- ★ DeepFake: thispersondoesnotexist.com
- ★ GANs: Generative Adversarial Networks

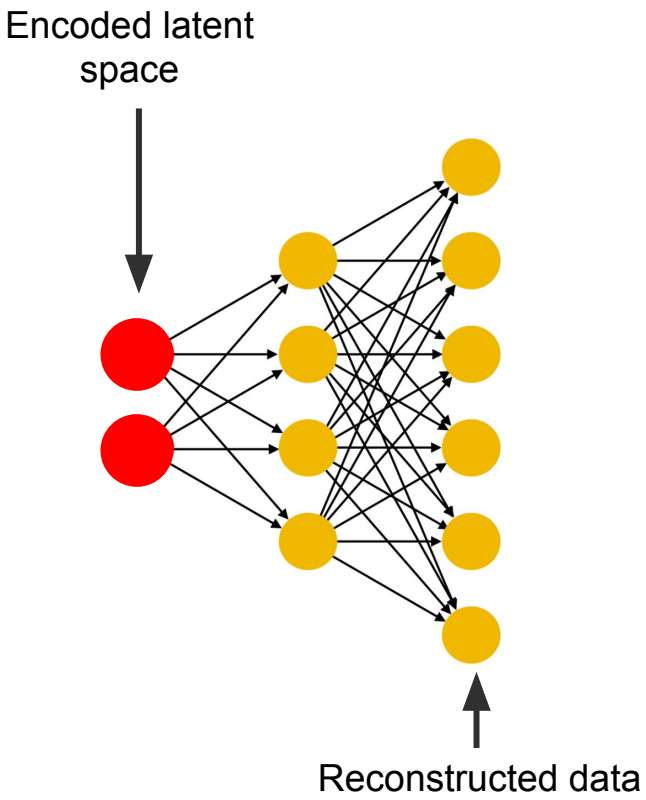
GANs

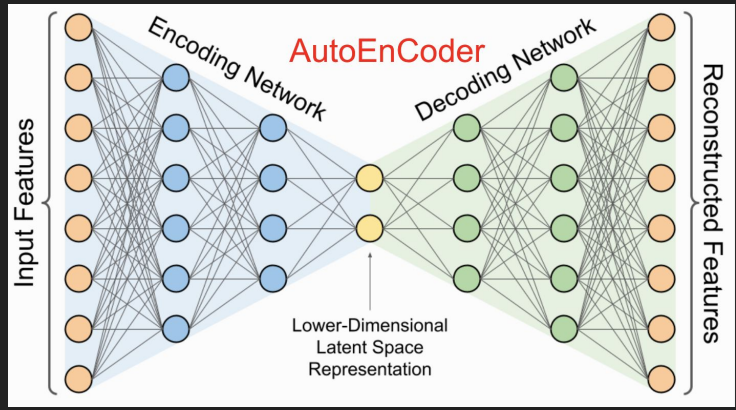
- ★ DeepFake: thispersondoesnotexist.com
- ★ GANs: Generative Adversarial Networks
- ★ 2 competing neural nets:
  - ○ **G**enerative network
  - ○ **A**dversarial network
- ★ Zero-sum game at equilibrium

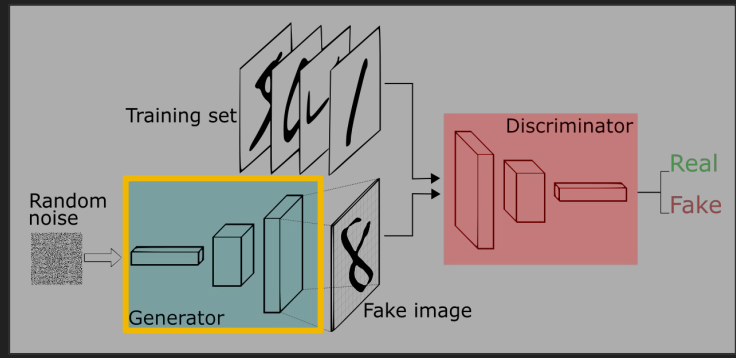




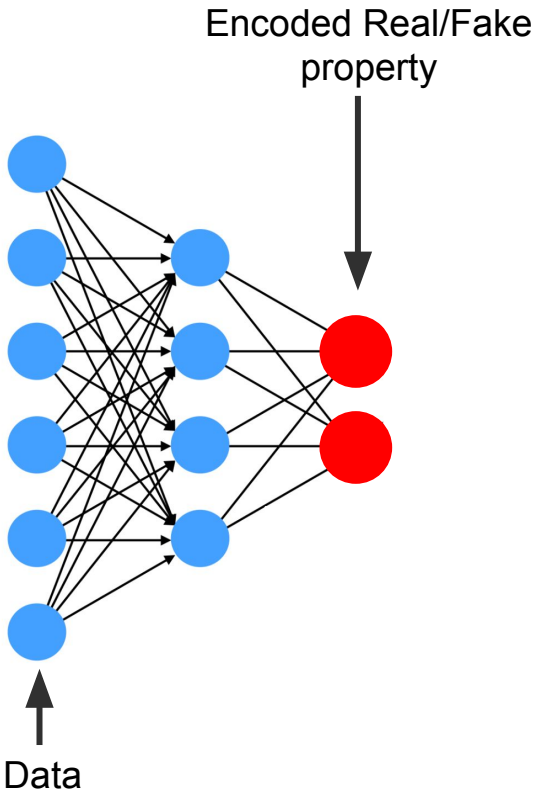
Generator: Forger, Artist, Decoder

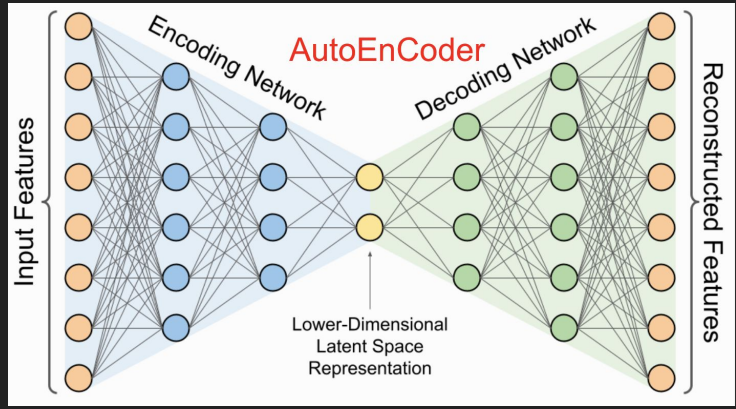


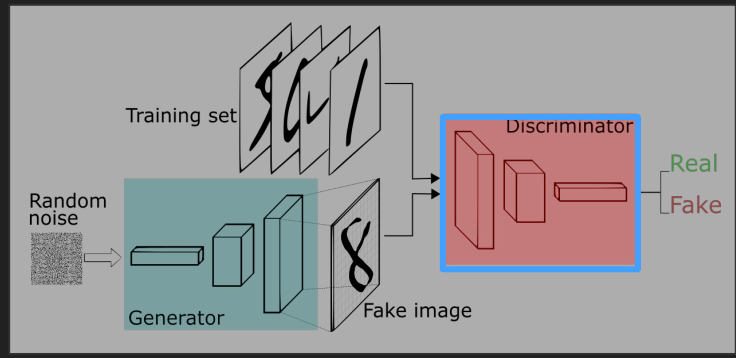




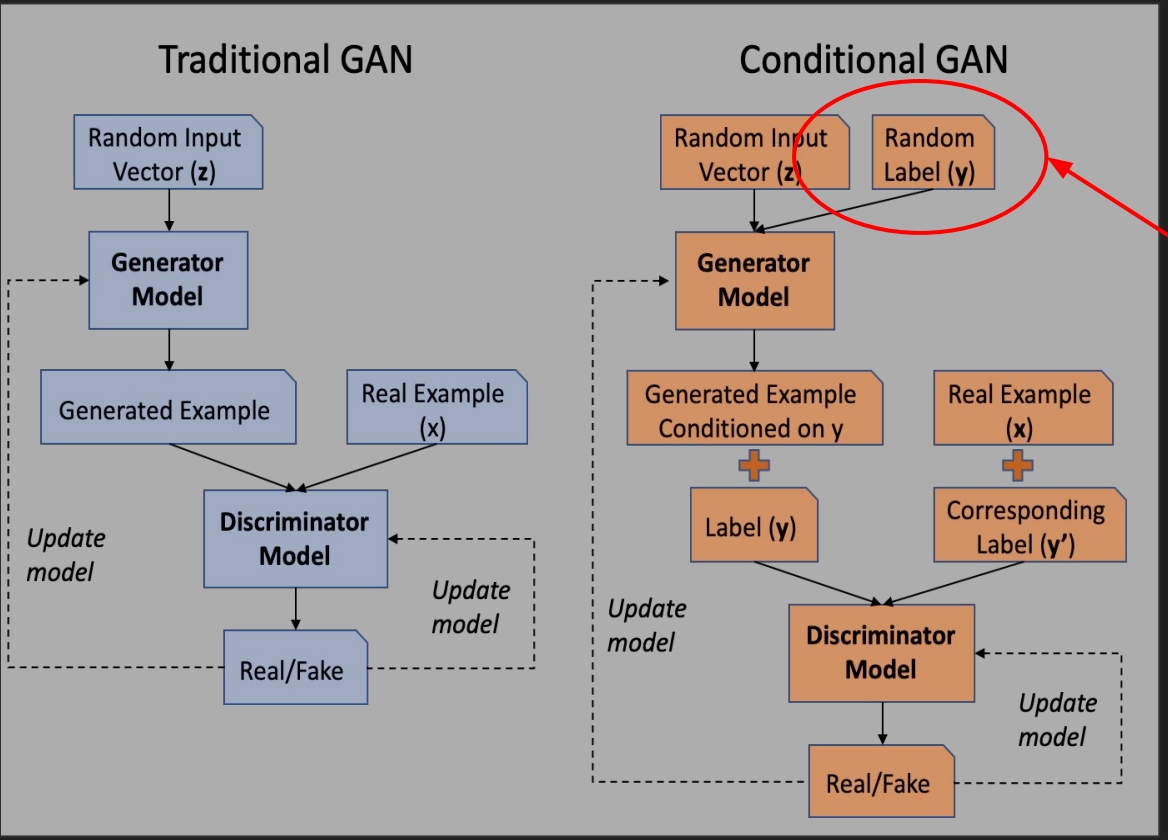
Discriminator: Critic, Detective, Encoder







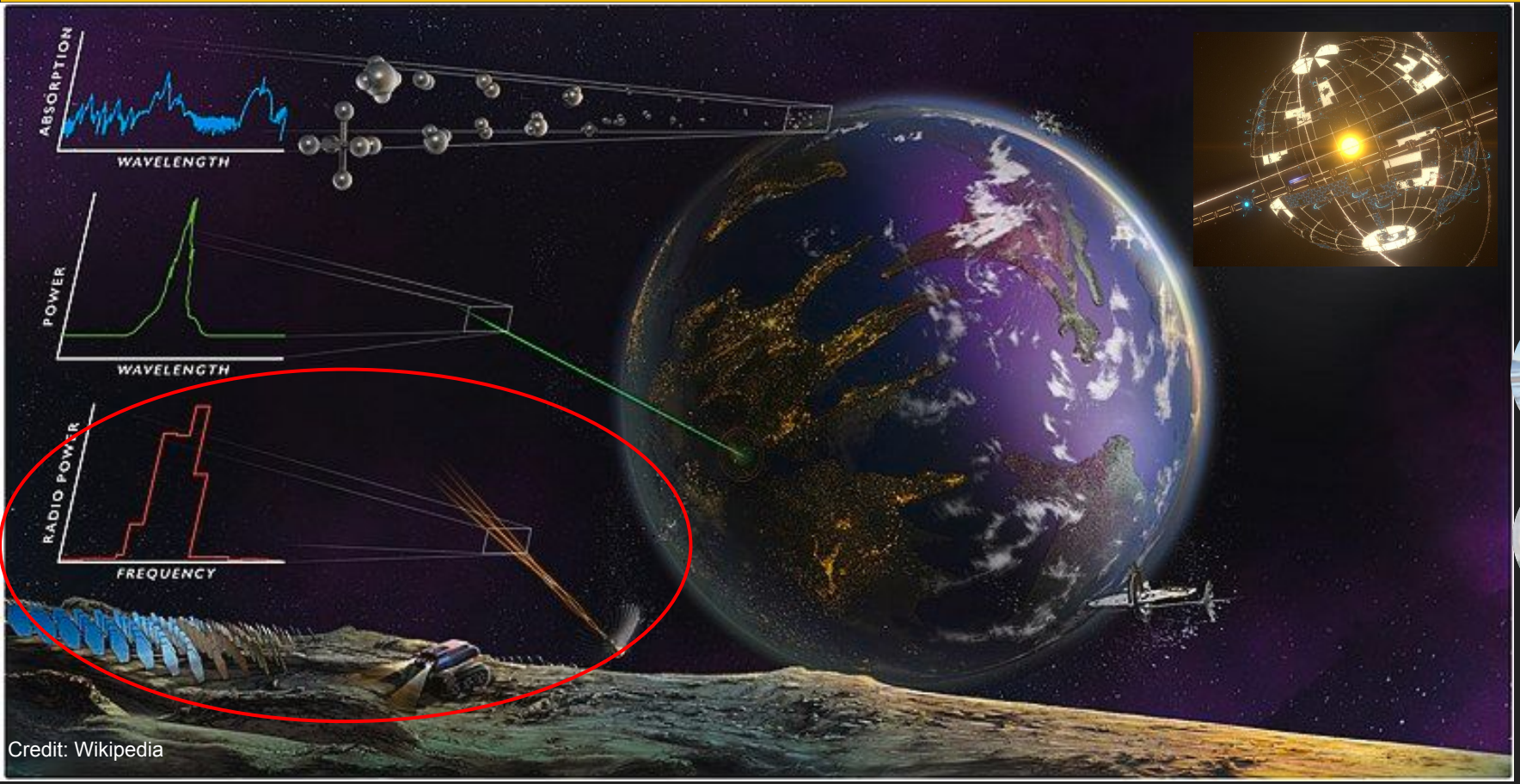
Conditional GANs



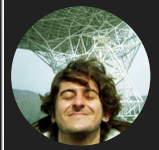
Credit: Z. Zheng

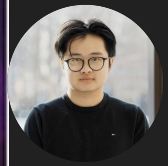
- ★ The trick: conditional GAN
- ★ Add known labels corresponding to known properties in training data

Technosignatures search



Credit: Wikipedia





cGANs with narrow-band radio spectra

THE ASTROPHYSICAL JOURNAL

Fast Radio Burst 121102 Pulse Detection and Periodicity: A Machine Learning Approach

Yunfan Gerry Zhang[1,2], Vishal Gajjar[2,3], Griffin Foster[1,2,4], Andrew Siemion[1,2,5,6,7], James Cordes[8], Casey Law[1], and Yu Wang[9]

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The Astrophysical Journal, Volume 866, Number 2

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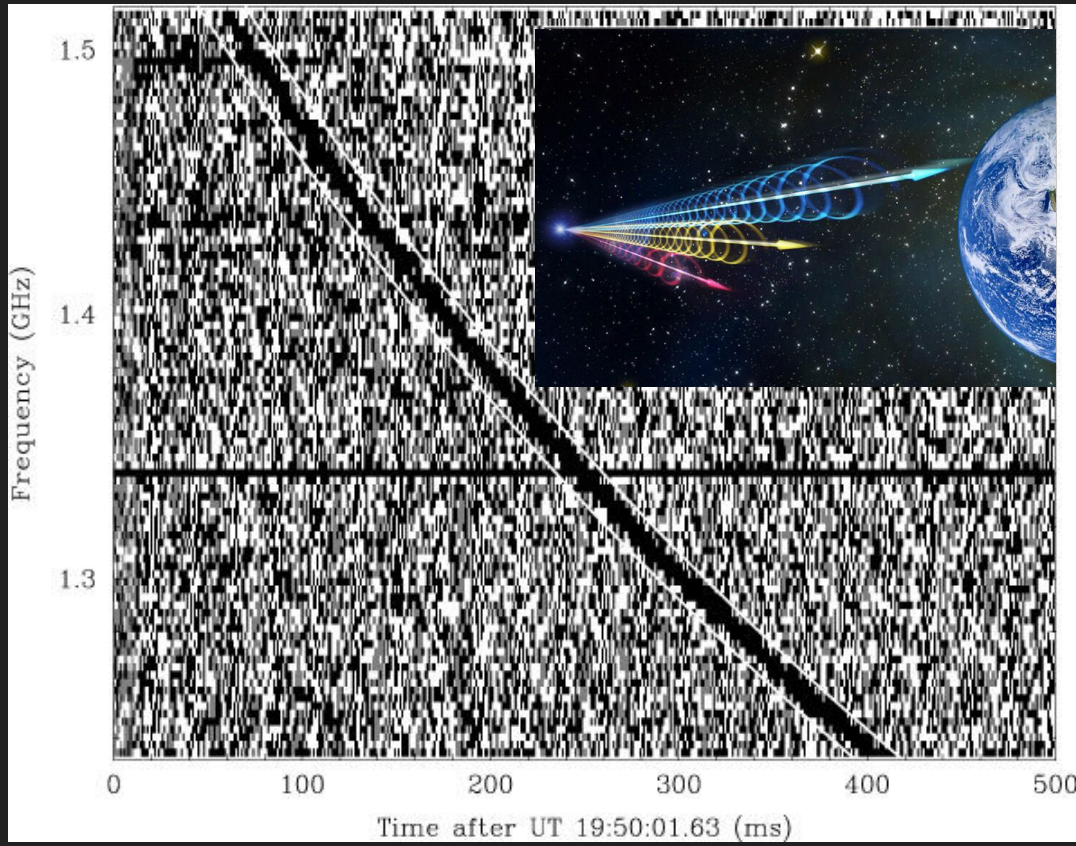
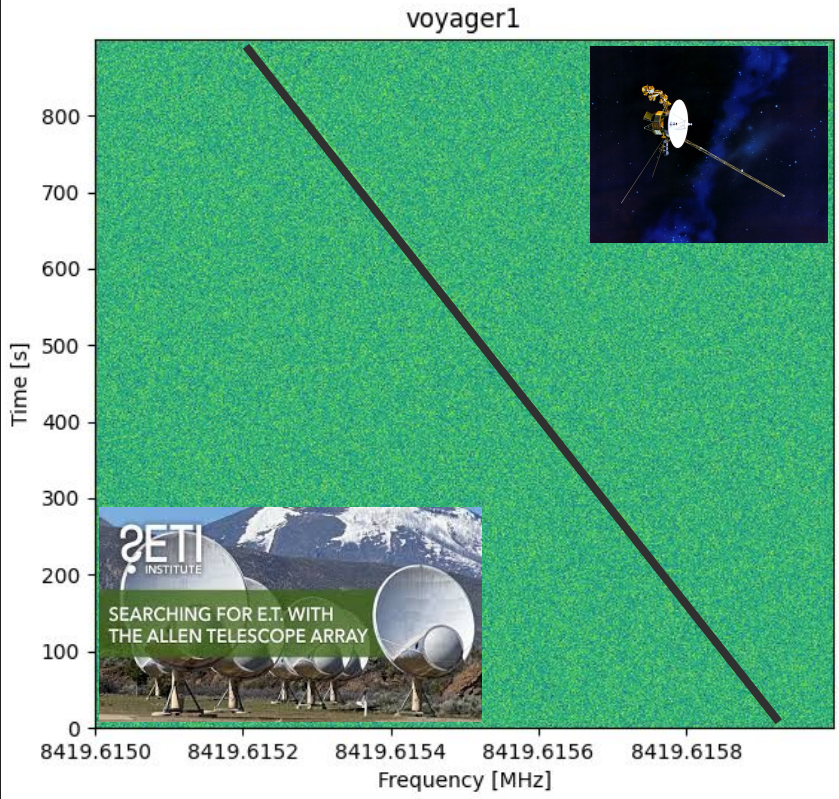
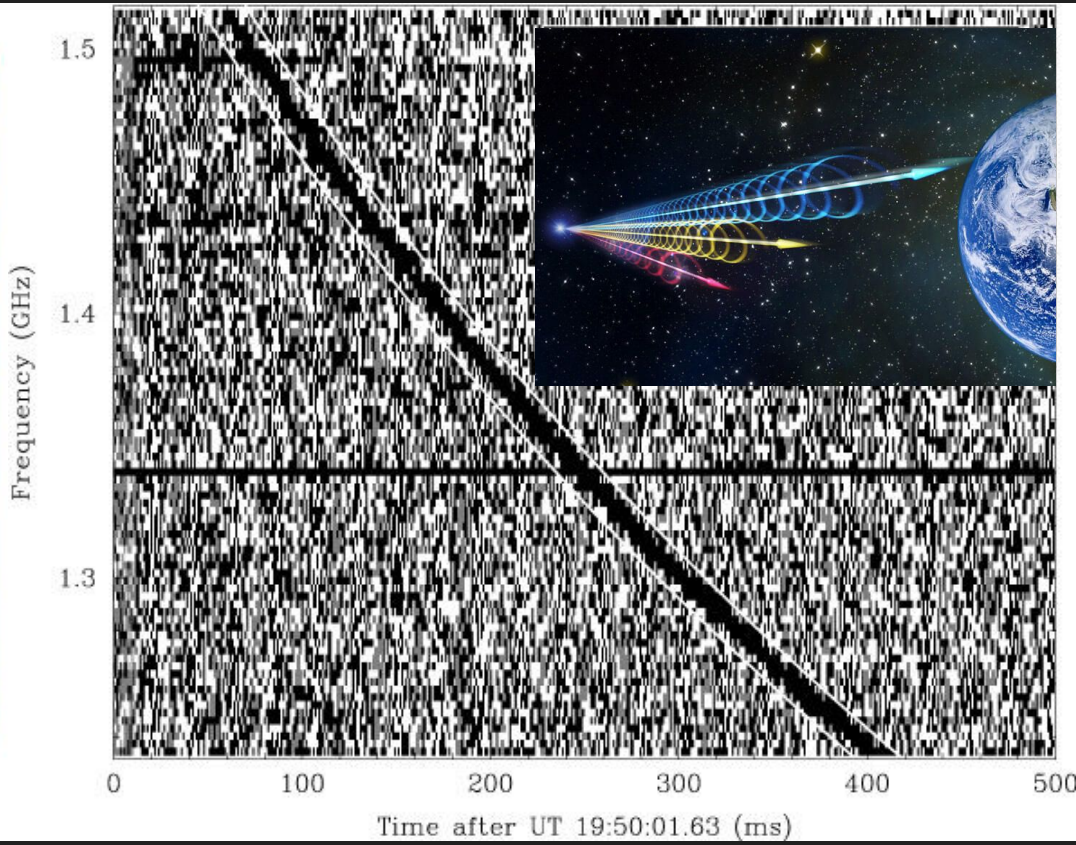
DOI 10.3847/1538-4357/aadf31



Credit: D. Lorimer

cGANs with narrow-band radio spectra





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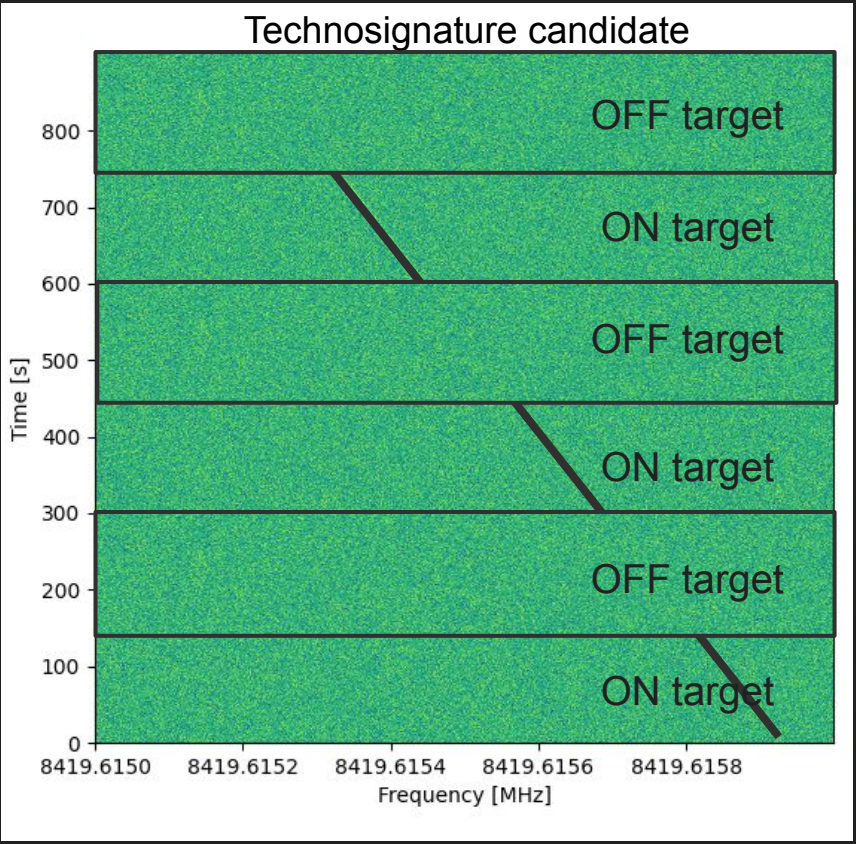
cGANs with narrow-band radio spectra

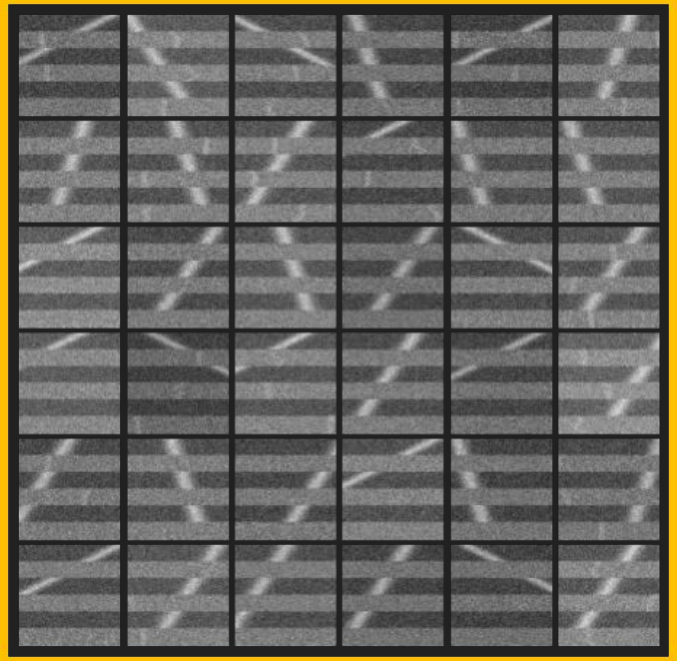


cGANs with narrow-band radio spectra

Random Waterfall Plot Generator (This Signal Does Not Exist)

Slope

Any

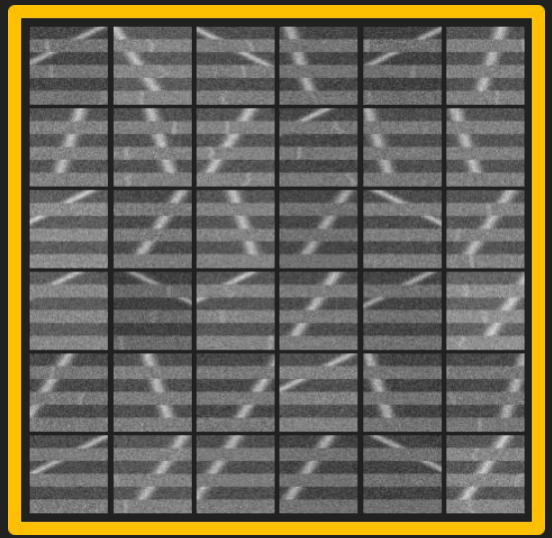


Random Face Generator (This Person Does Not Exist)

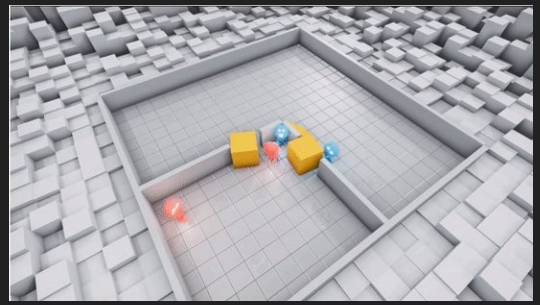
Generate random human face in 1 click and download it! AI generated fake person photos: man, woman or child.

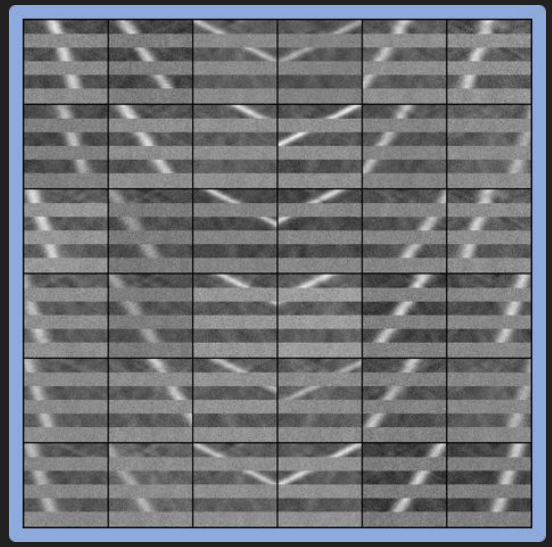
Gender: Any | Age: 50+ years old | Ethnicity: Any | Refresh Image

cGANs with narrow-band radio spectra



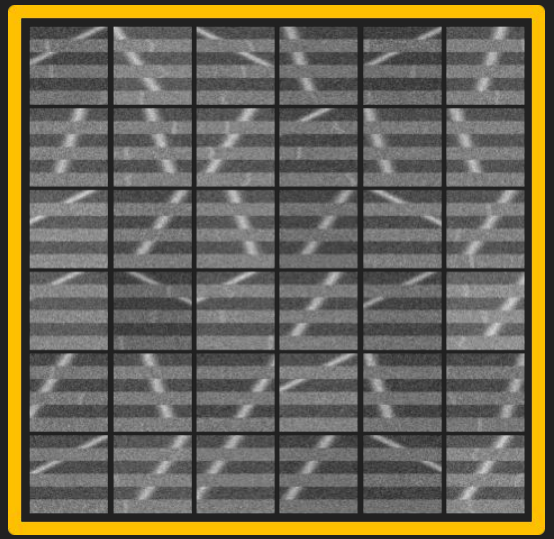
Training data



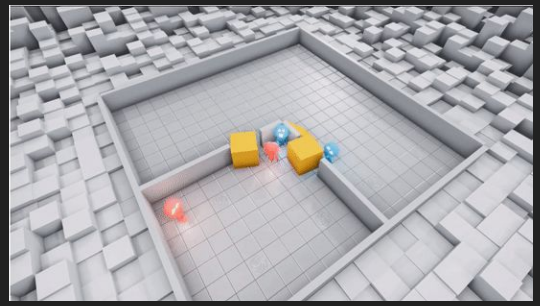


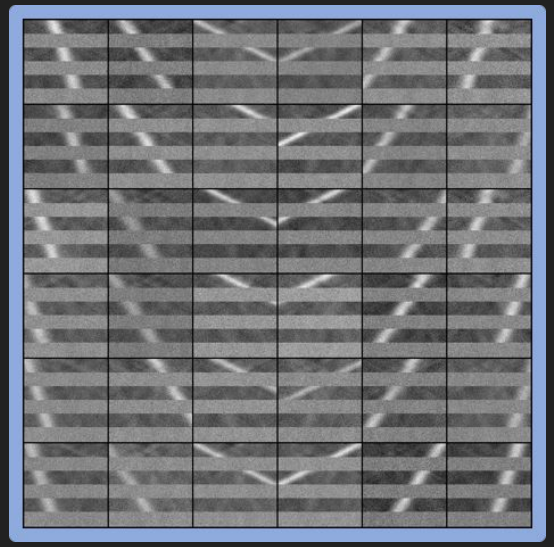
DeepFaked data

cGANs with narrow-band radio spectra



Training data

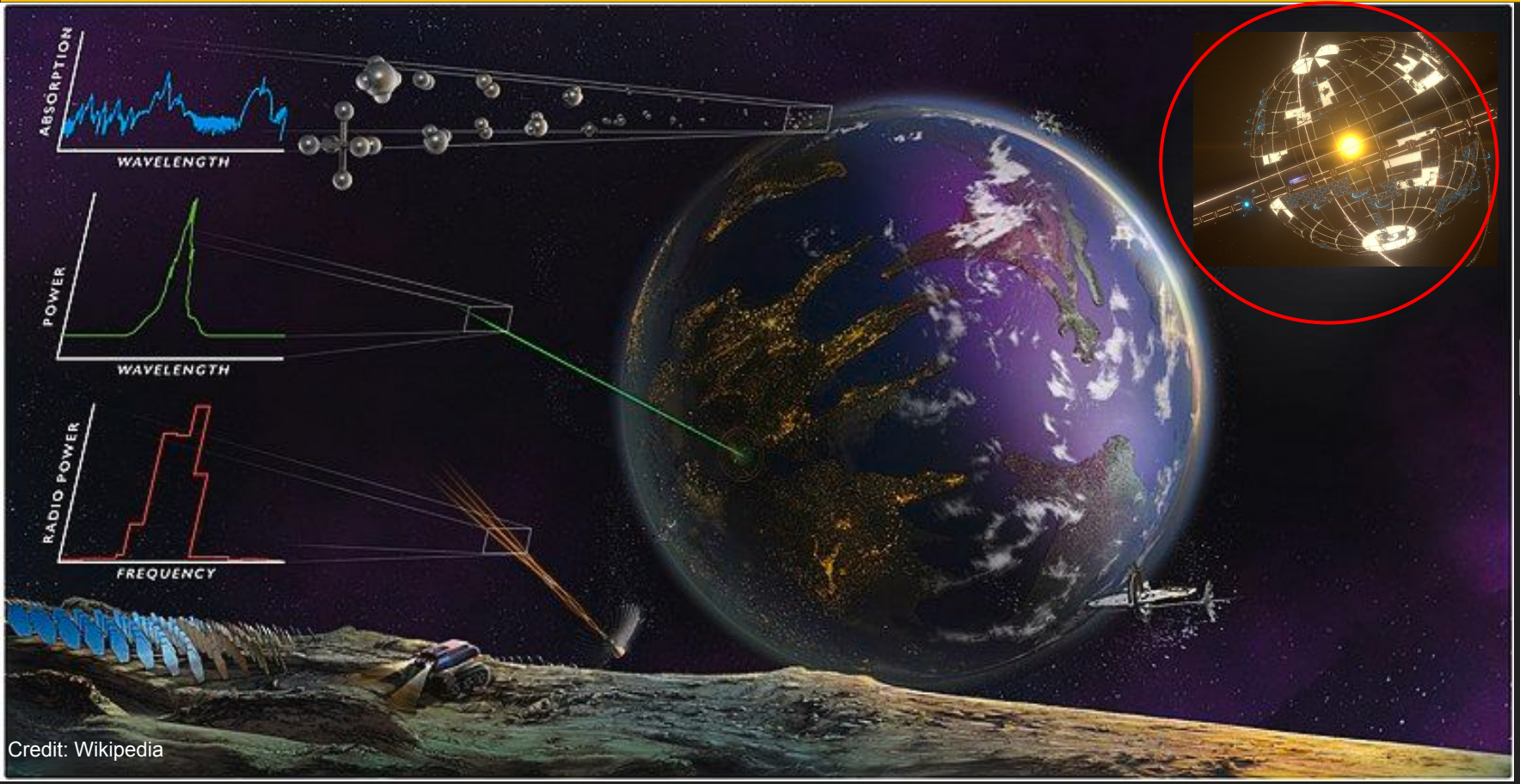




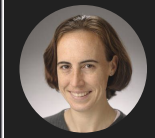
DeepFaked data

	SETIGEN			SETIGAN		
Events	File Size	Generate (s)	G+W (s)	File Size	Generate (s)	G+W (s)
10^2	12.5 MB	0.578	0.613	12.5 MB	3.335	3.378
10^3	125.3 MB	5.090	6.287	125.4 MB	3.784	4.181
10^4	1.2 GB	51.279	55.723	1.2 GB	3.807	7.742
10^5	12.2 GB	515.802	563.833	12.2 GB	4.358	95.597

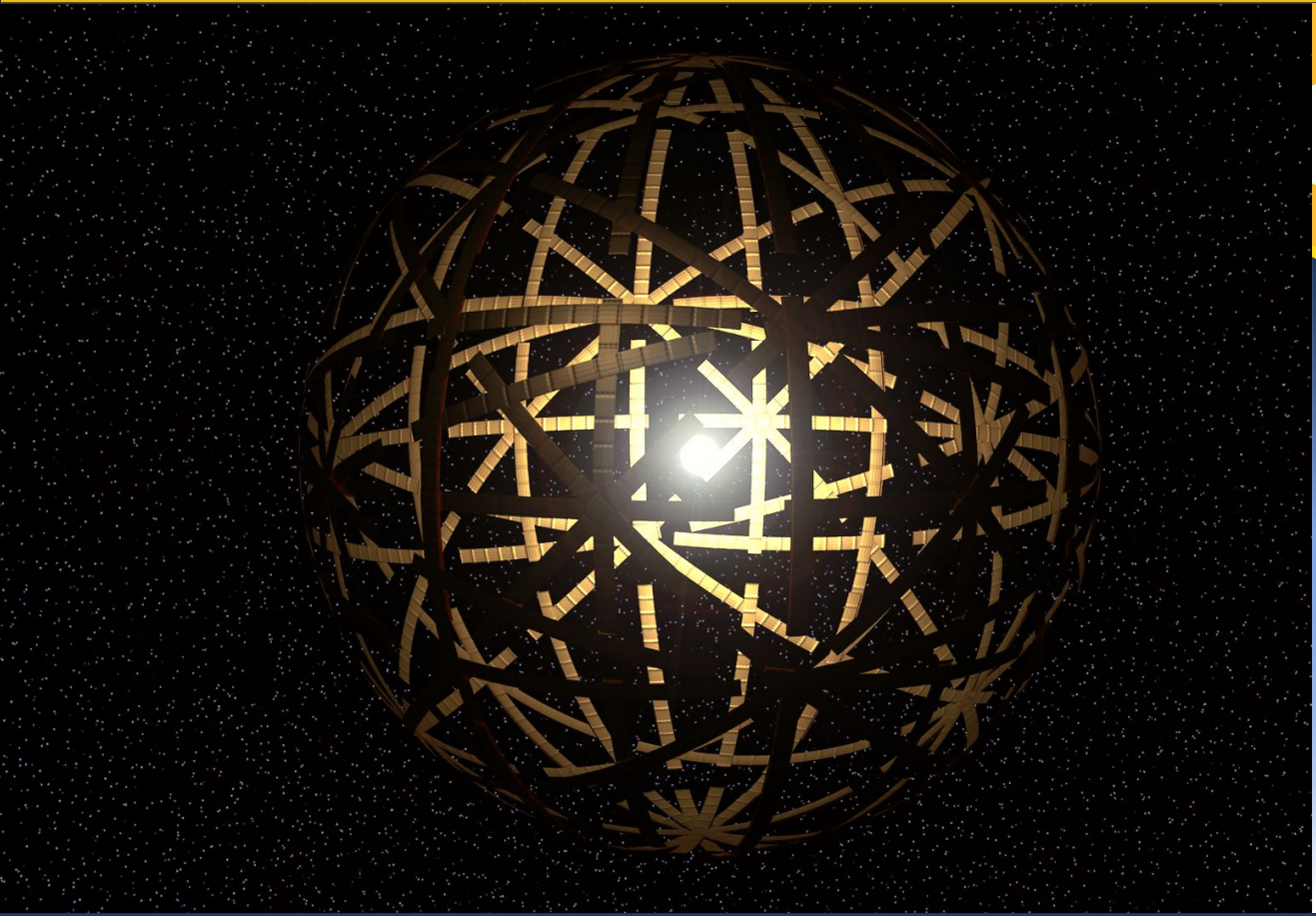
Technosignatures search



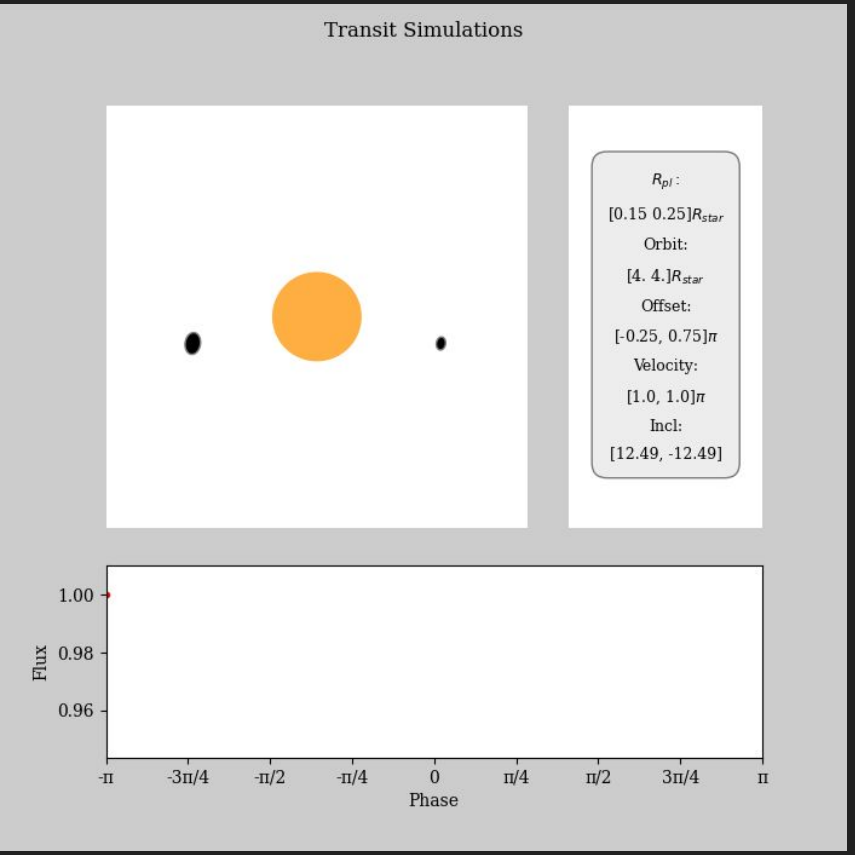
Credit: Wikipedia

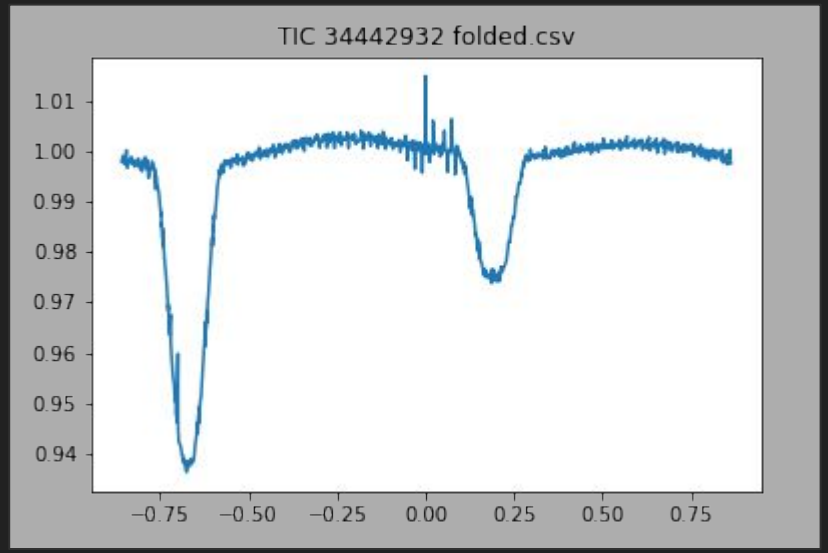


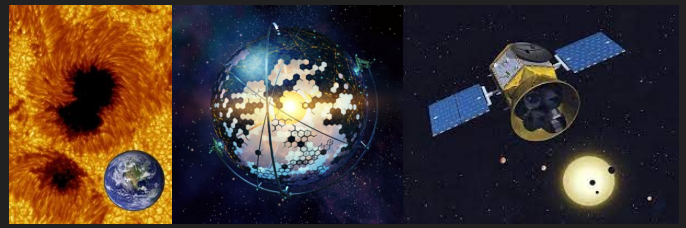
cGANs with Dyson swarm



cGANs with Dyson swarm







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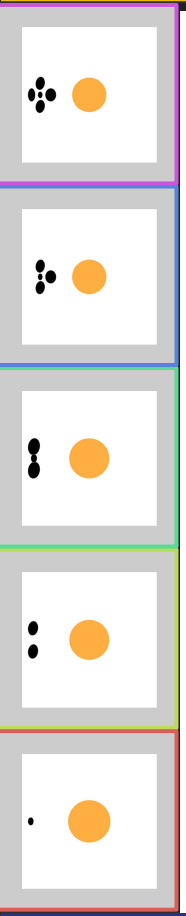
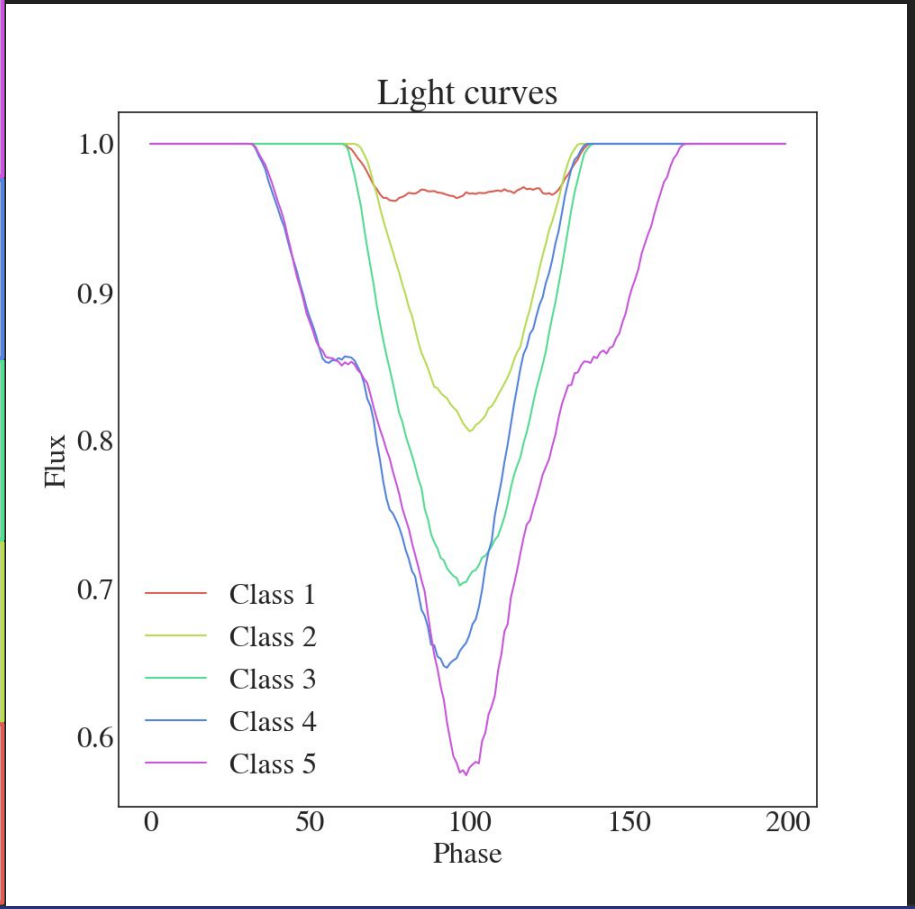
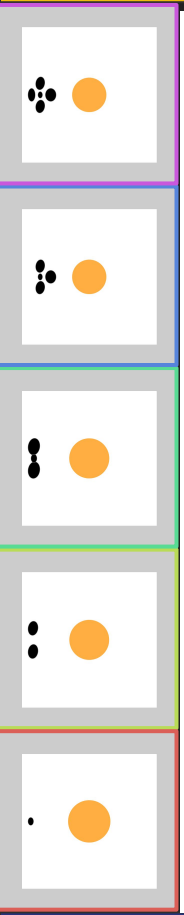
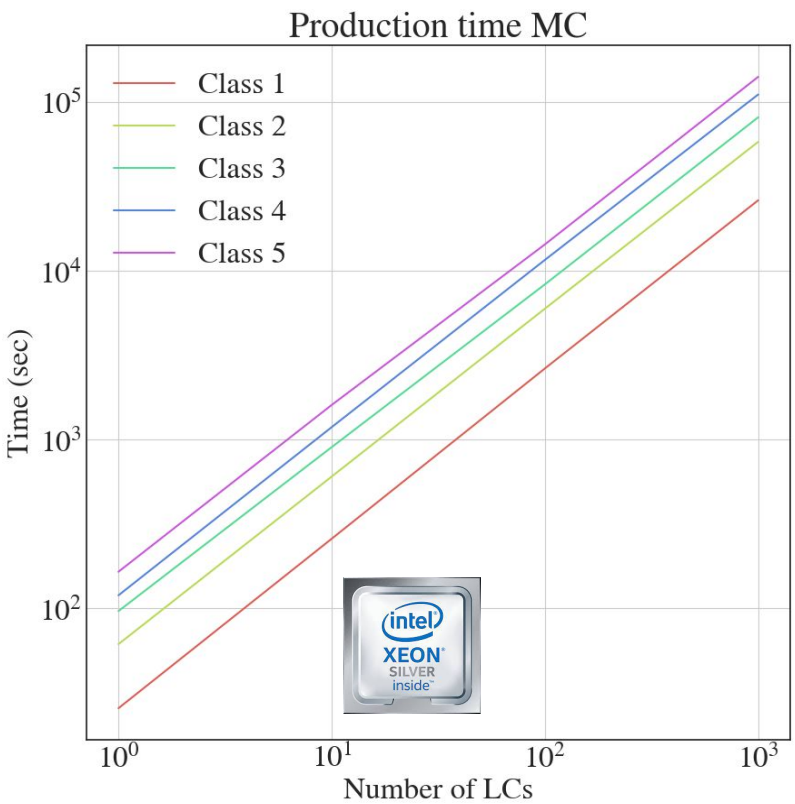


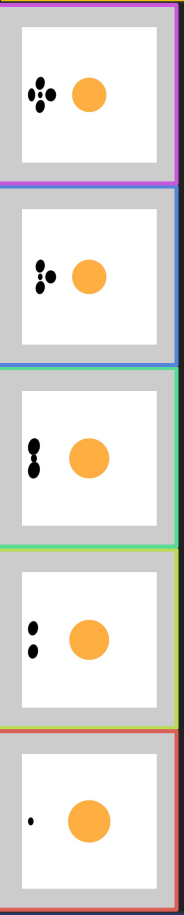


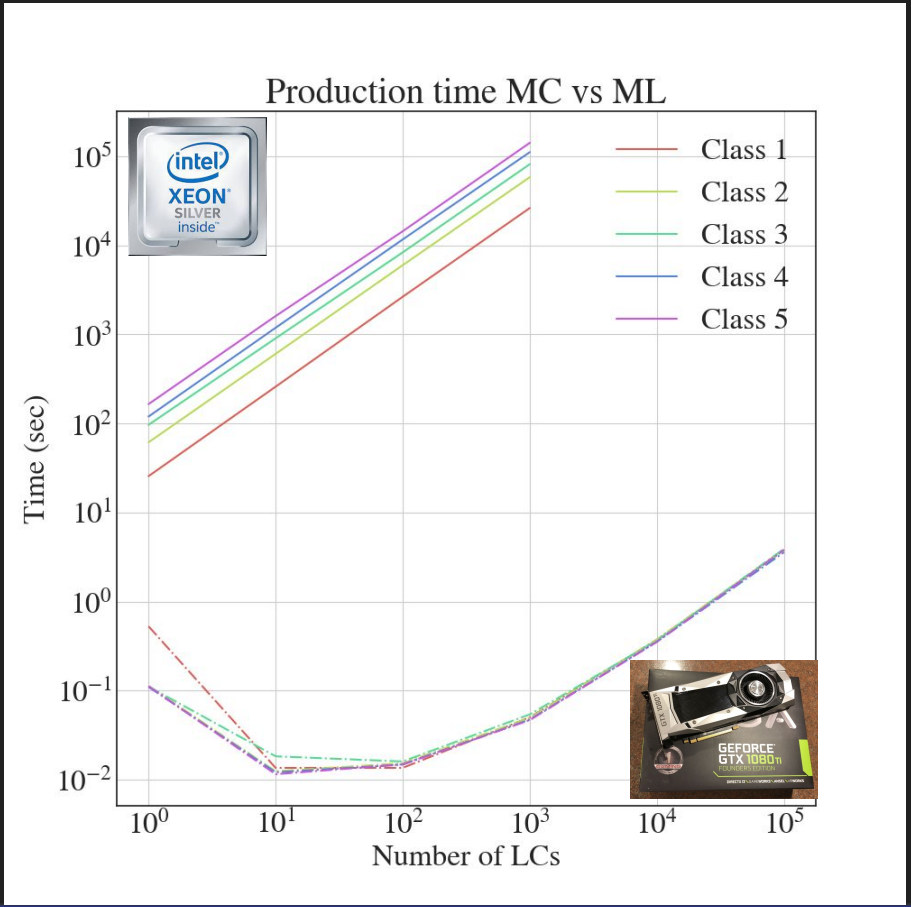
cGANs with Dyson swarm



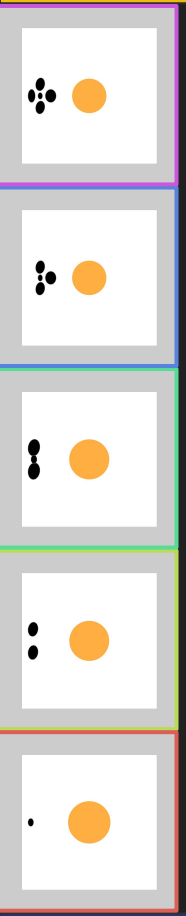


cGANs with Dyson swarm





Look Ma, no Physics!



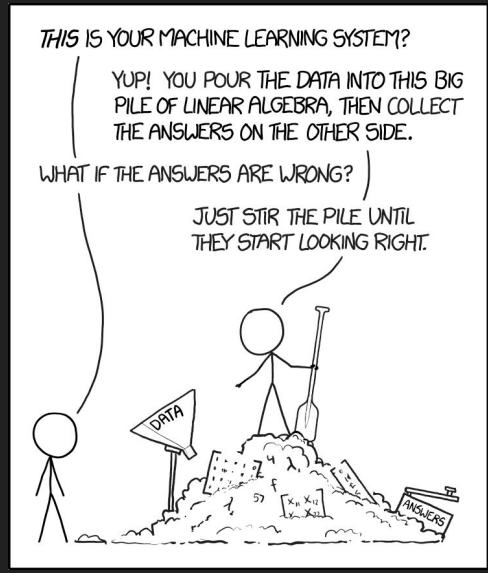
```python
import numpy as np
from tensorflow.keras.models import load_model

Generator = load_model("models/generator_model0120.h5") #Load trained model from .h5 file
z = np.random.randn(100000, 100) #100k random latent vectors, each 100D
c = np.random.randint(4, size=100000) #100k random class labels, each is an integer in range [0,4]

LCs = Generator.predict([z, c]) #Produce 100k LCs
```

3.7 MB!

$$[x]_{200D} = [G] \begin{bmatrix} z \\ \oplus \\ c \end{bmatrix}_{100D+5D}$$



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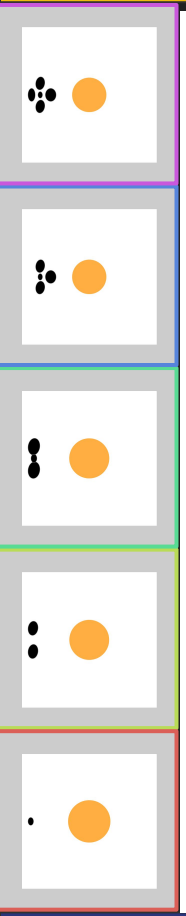
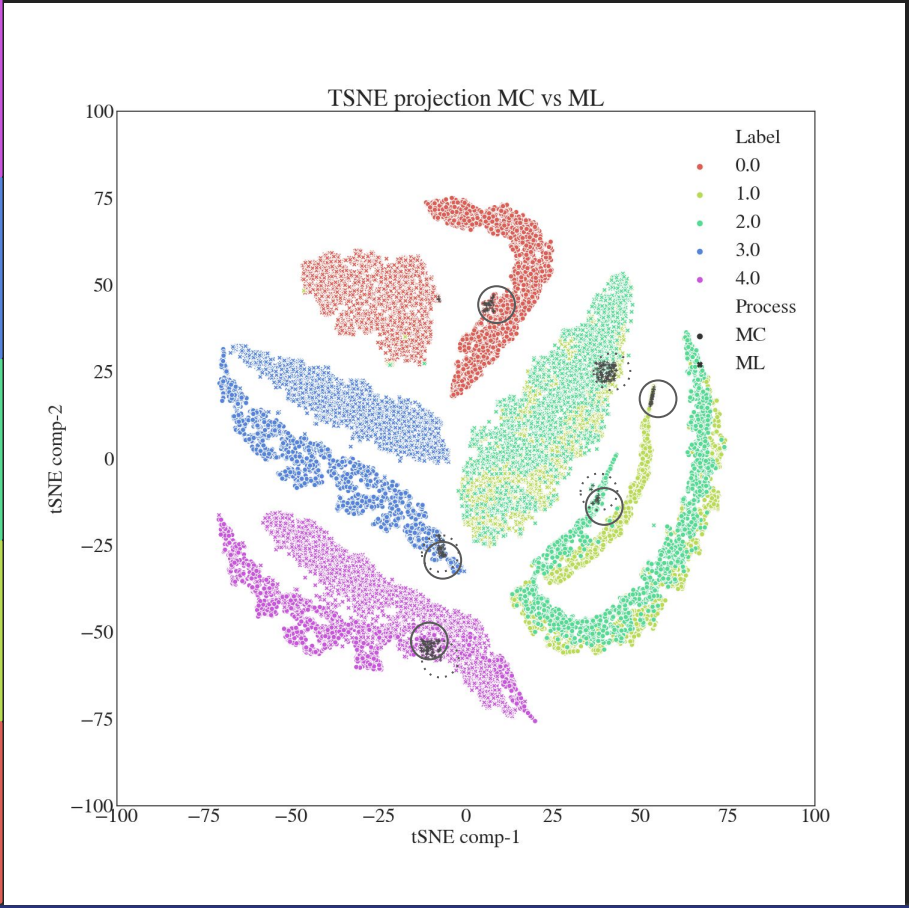
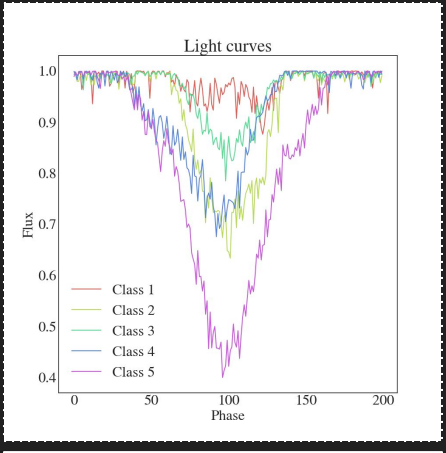
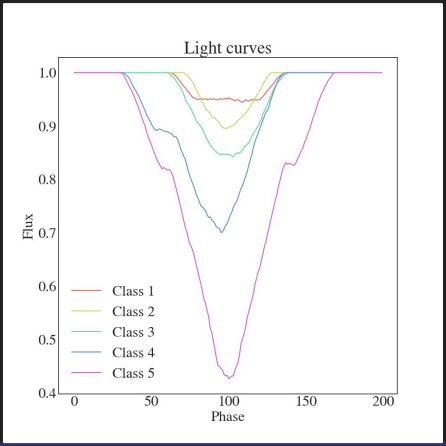
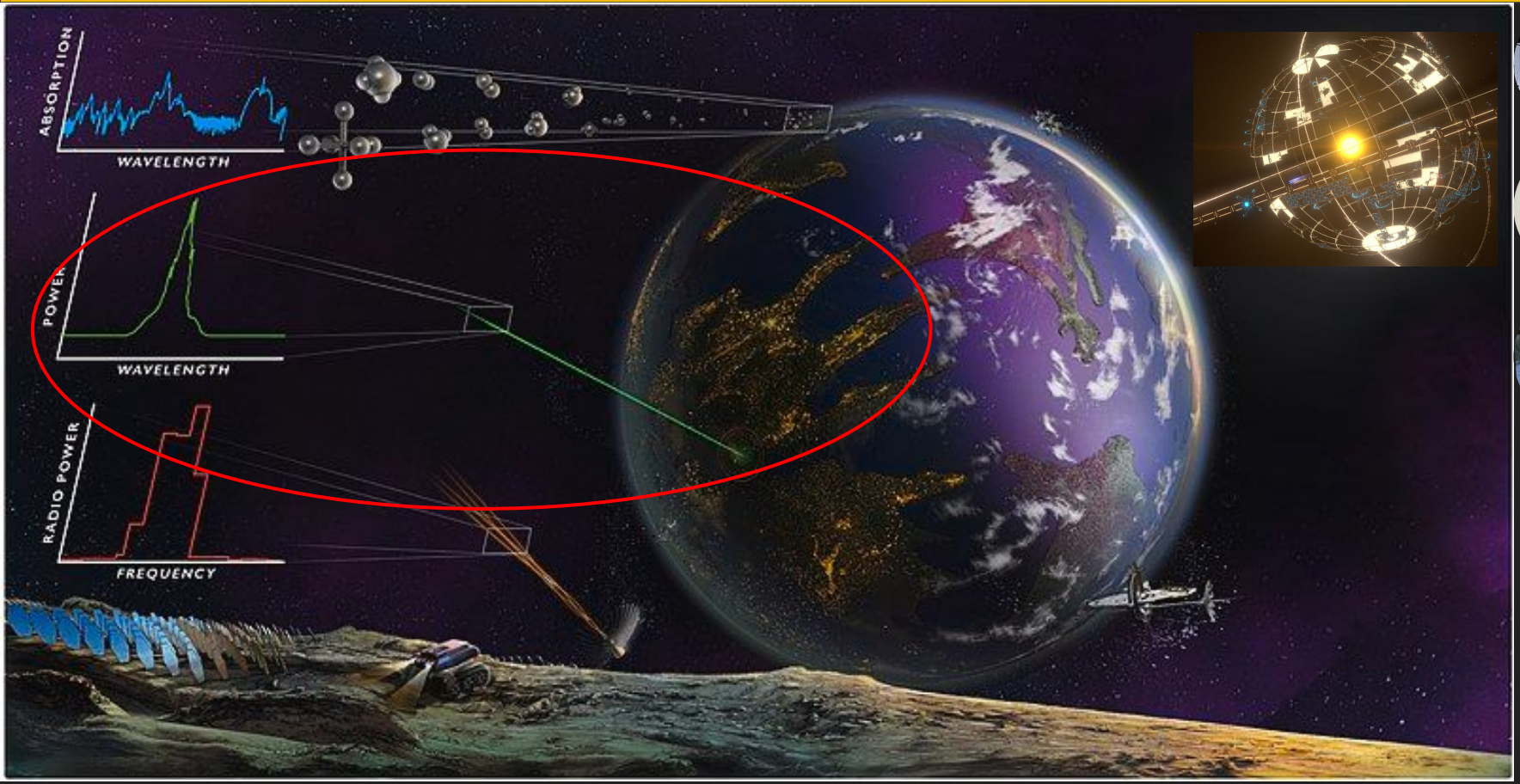


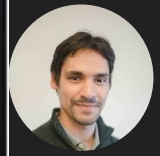




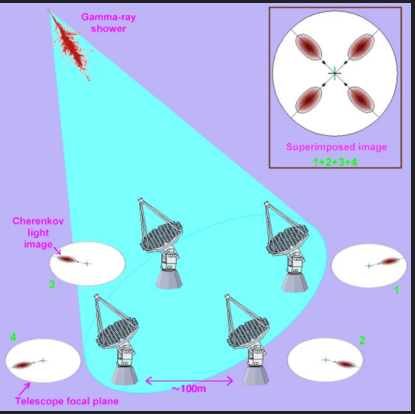


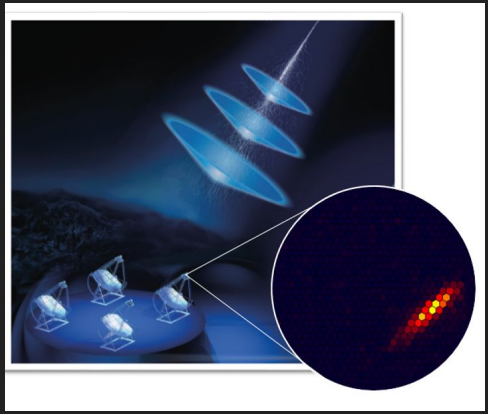
cGANs with Cherenkov Telescopes

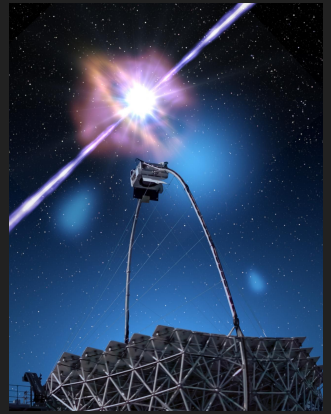




cGANs with Cherenkov Telescopes

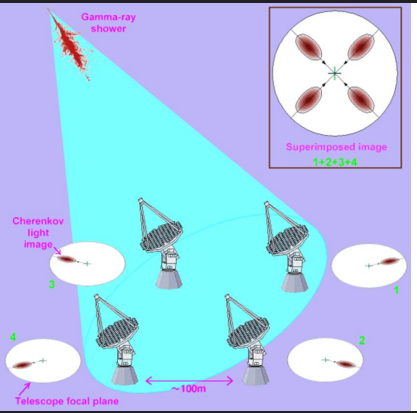


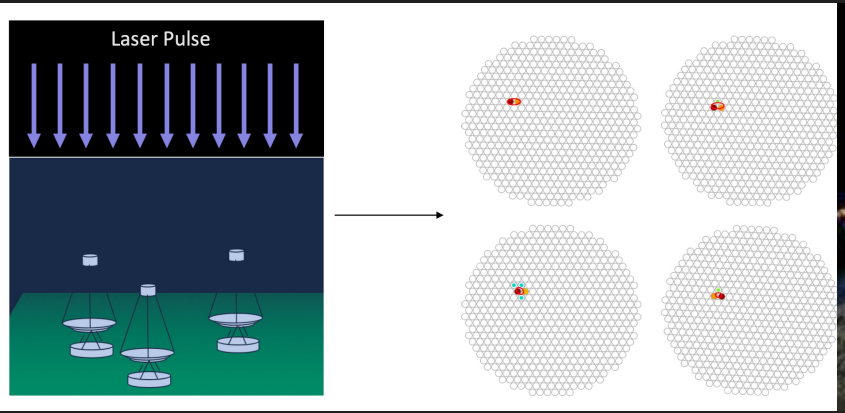


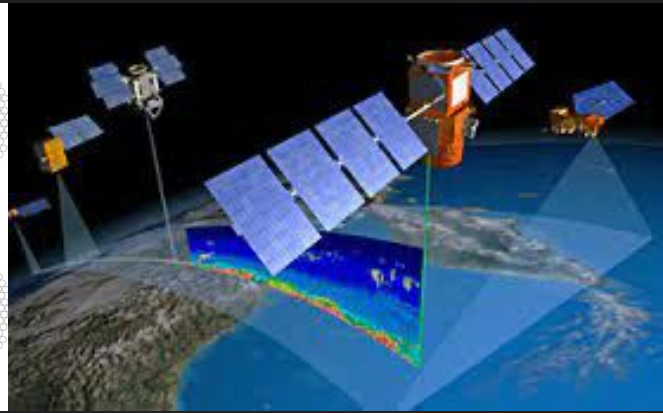


- ★ 10-m class “optical” telescopes => Huge photon buckets
- ★ Fast (ns) photosensors to detect Cherenkov photon showers from ~TeV gamma rays

cGANs with Cherenkov Telescopes



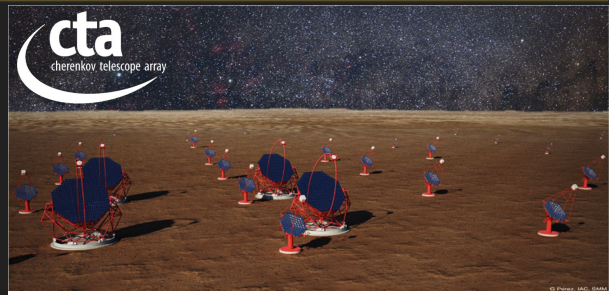


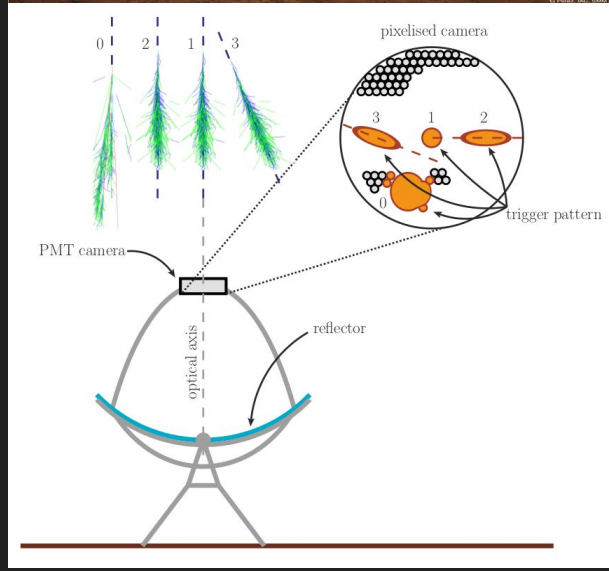


- ★ 10-m class “optical” telescopes => Huge photon buckets
- ★ Fast (ns) photosensors to detect faint laser communication signals.
- ★ Laser pulses should appear point-like with equal intensity and in the same position in each camera.

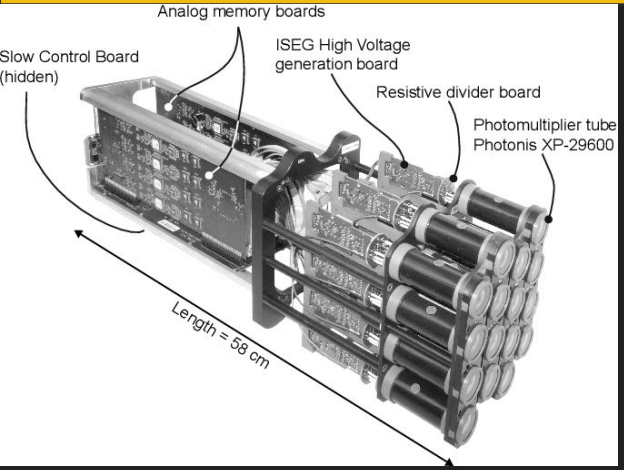
cGANs with Cherenkov Telescopes

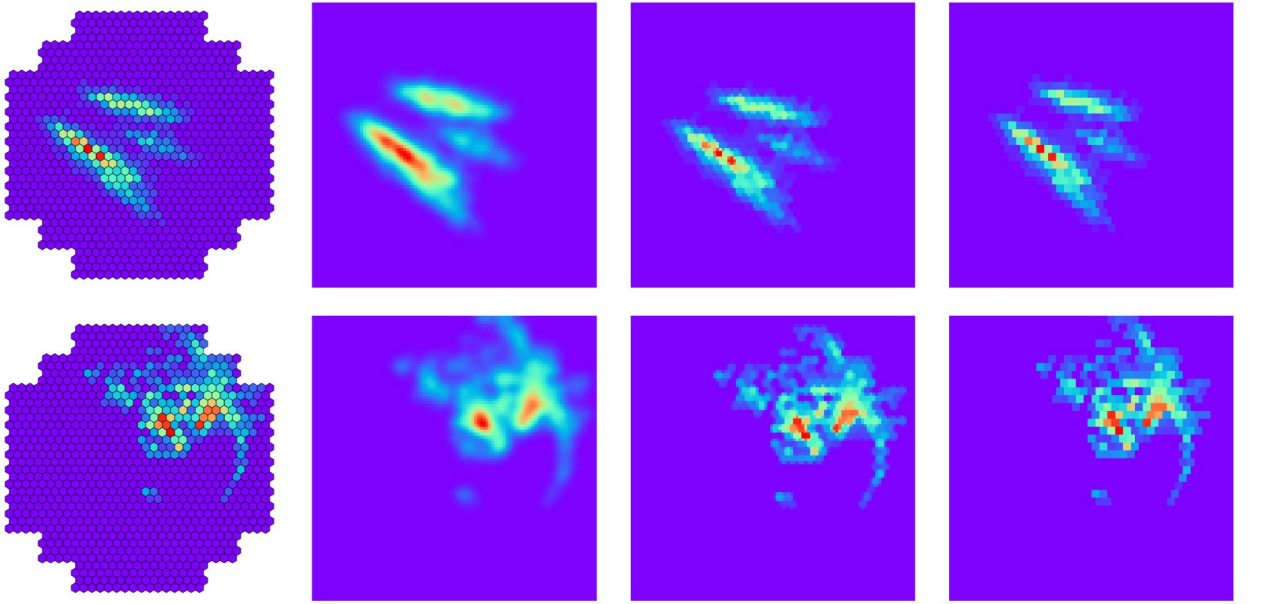
- ★ Intractable Physics
- ★ Simulation is expensive:
  - Each shower event: 10^9 Cherenkov photons are produced
  - 100 telescopes, > 1000 pixels each
  - <u>Every</u> simulation set: 10^9 gamma showers, 10^11 hadron showers
  - 10^7 HP CPU hours, ~100 TB of data



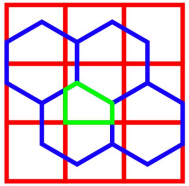


cGANs with Cherenkov Telescopes

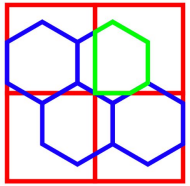




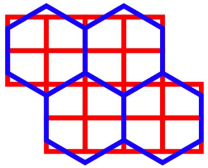
- ★ Needs conversion step
- ★ Needs padding at corners
- ★ Needs more storage space



(a) high resolution rebin

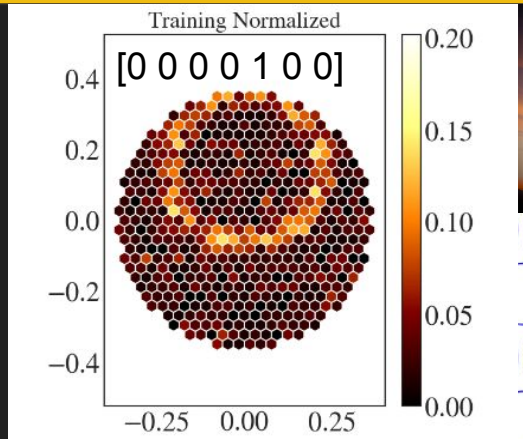


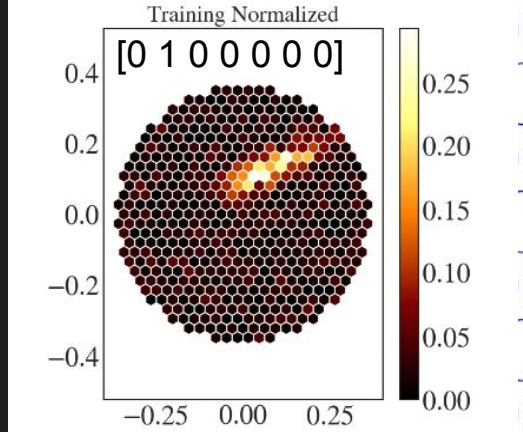
(b) low resolution rebin

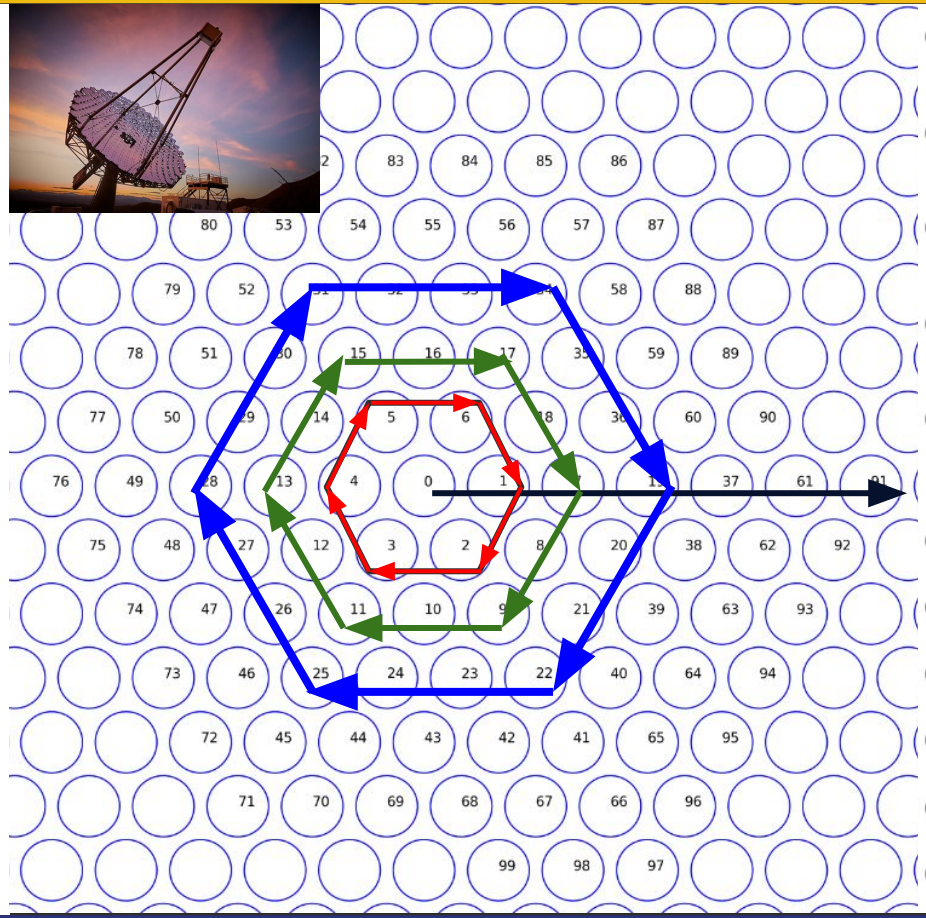


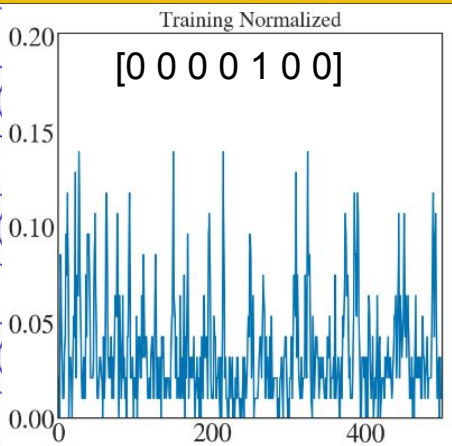
(c) oversampling

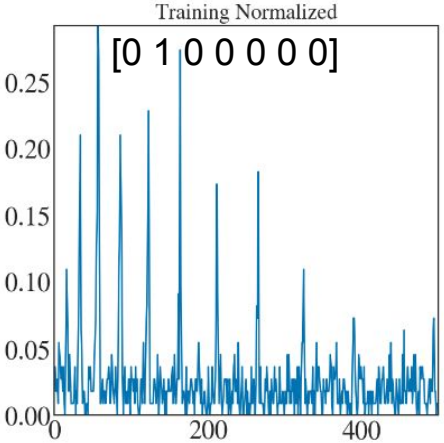
Time-series approach



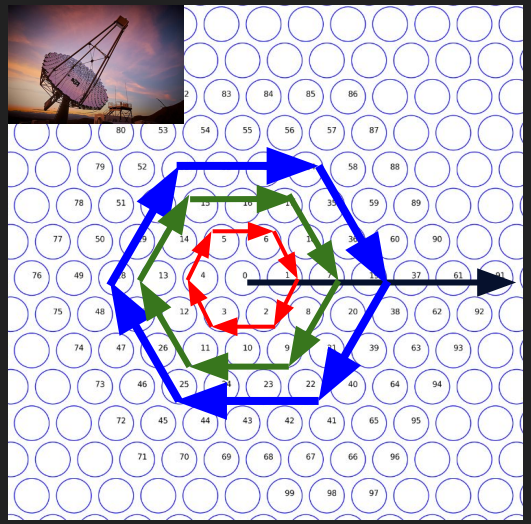


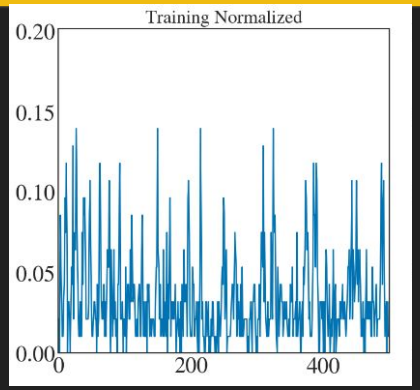


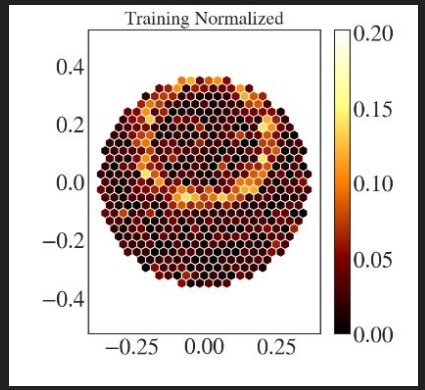




How does it work?

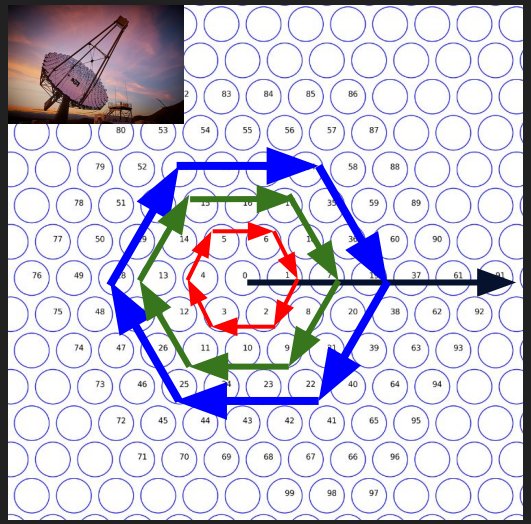


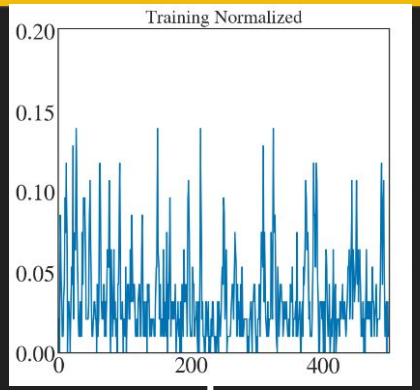




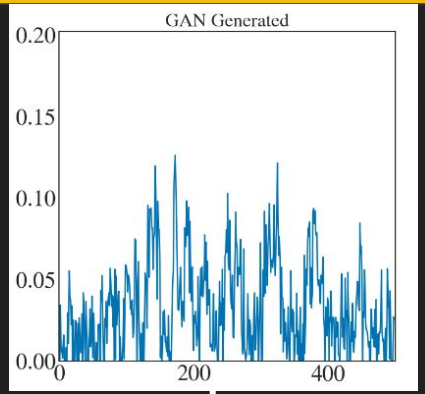
Non-trivial hidden correspondence between time-series and camera view representations

How does it work?

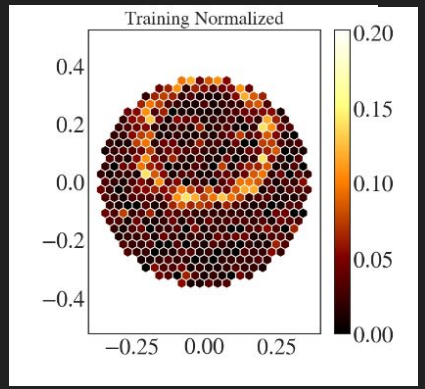




Machine “Learned”

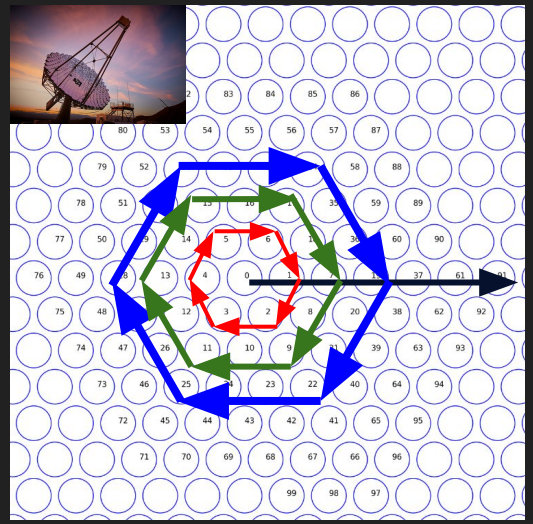


What they “see”: time series

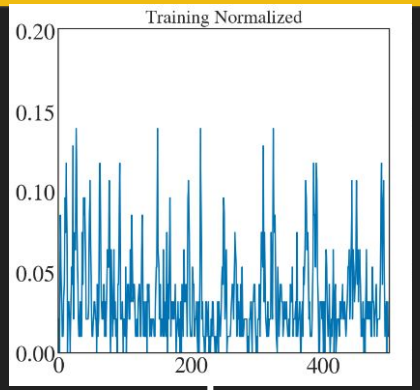


Non-trivial hidden correspondence between time-series and camera view representations

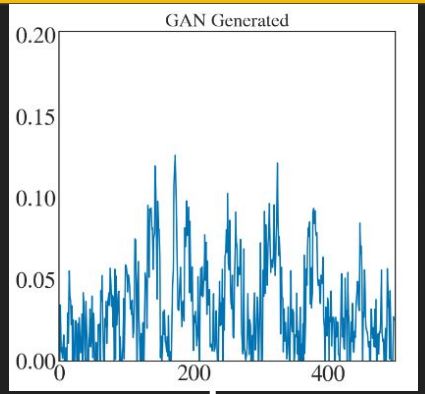
How does it work?



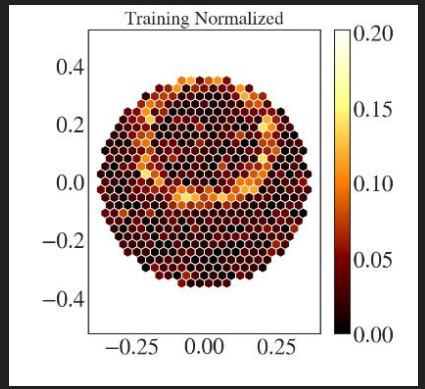
Non-trivial hidden correspondence between time-series and camera view representations

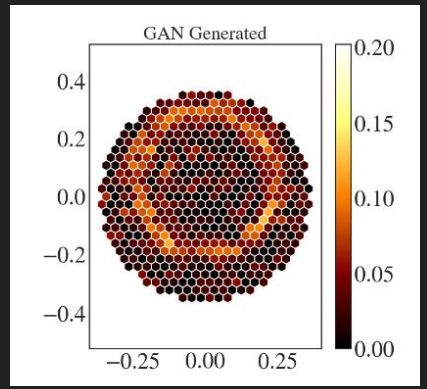


Machine “Learned”

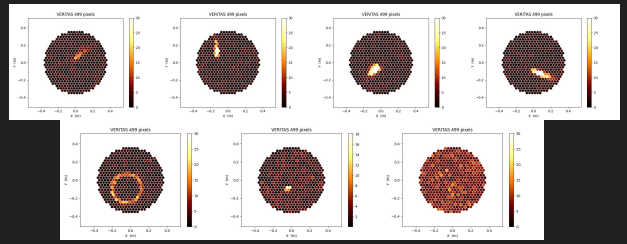


What they “see”: time series



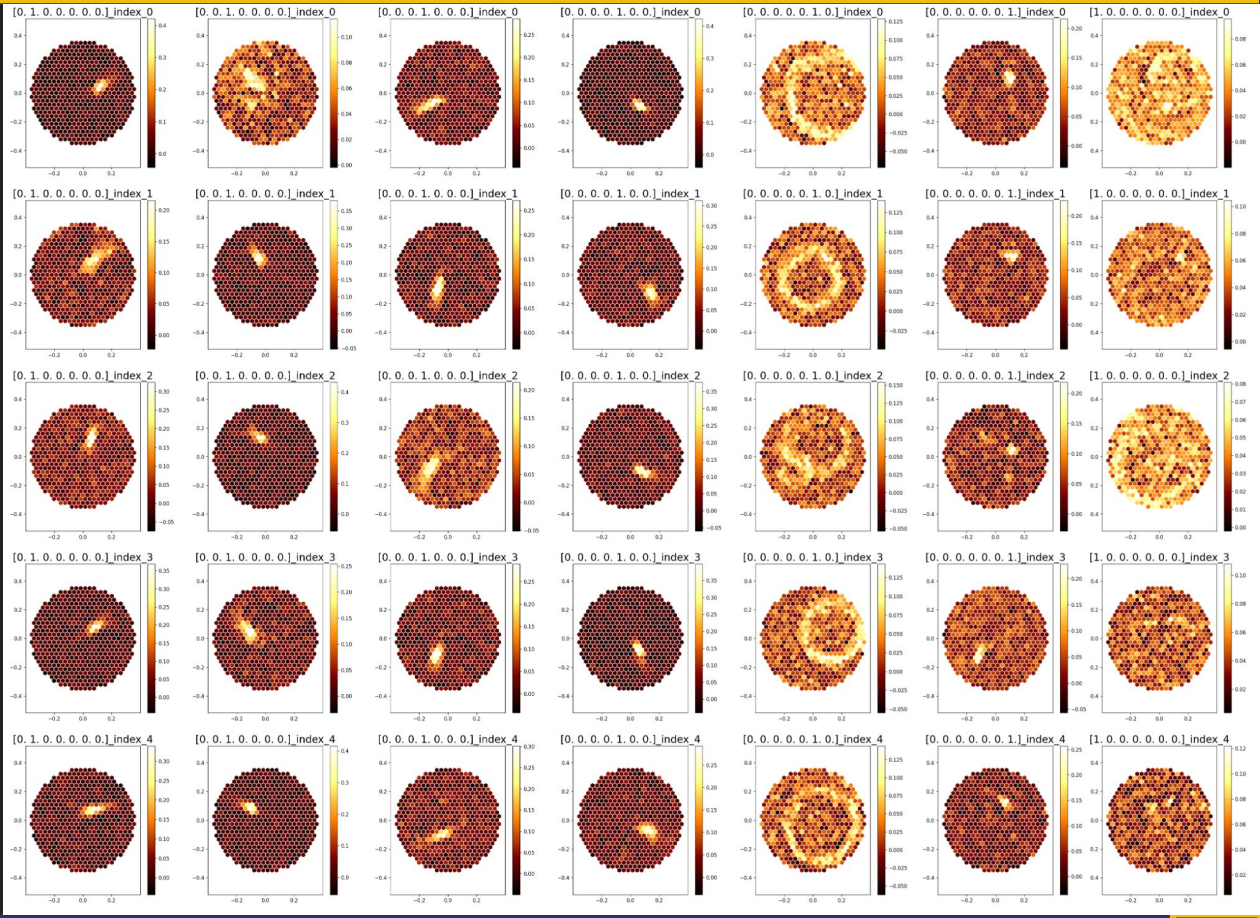


Let there be light!

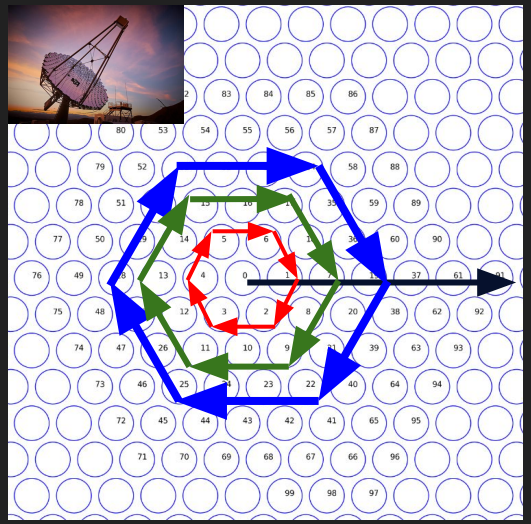


Training data

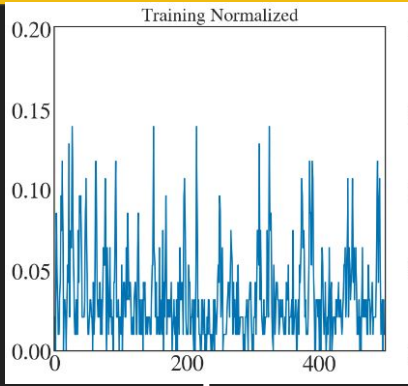
cGAN's reconstruction



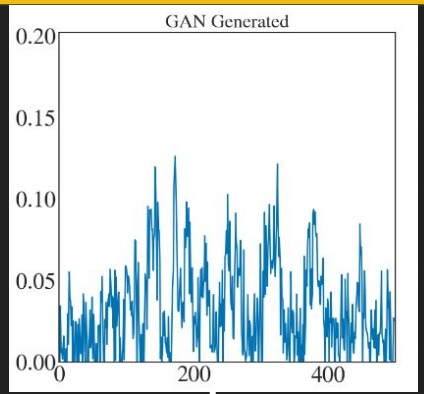
(in)Sanity check



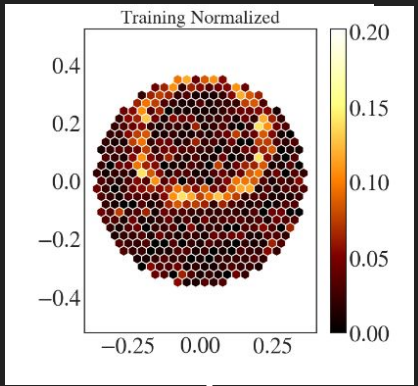
Non-trivial hidden correspondence between time-series and camera view representations

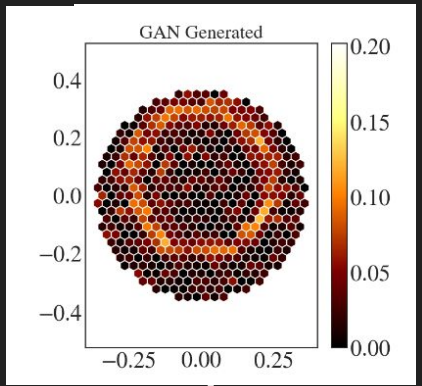


Machine “Learned”



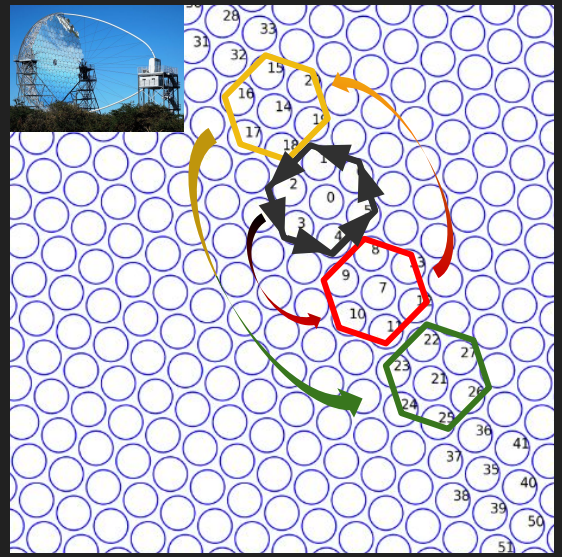
What they “see”: time series



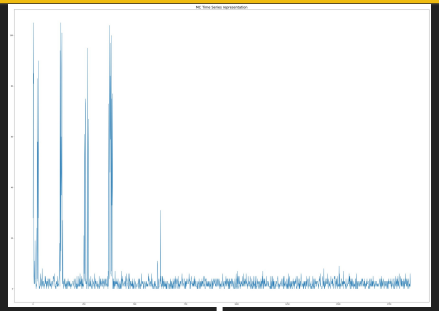


What we “see”: 2D camera with pixels

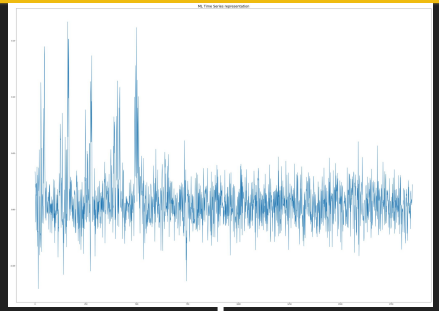
(in)Sanity check



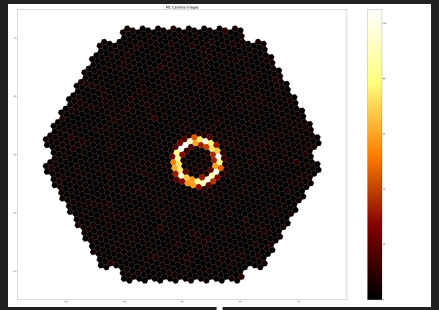
Non-trivial hidden correspondence between time-series and camera view representations

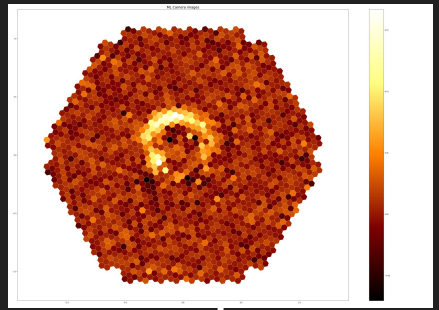


Machine “Learned”



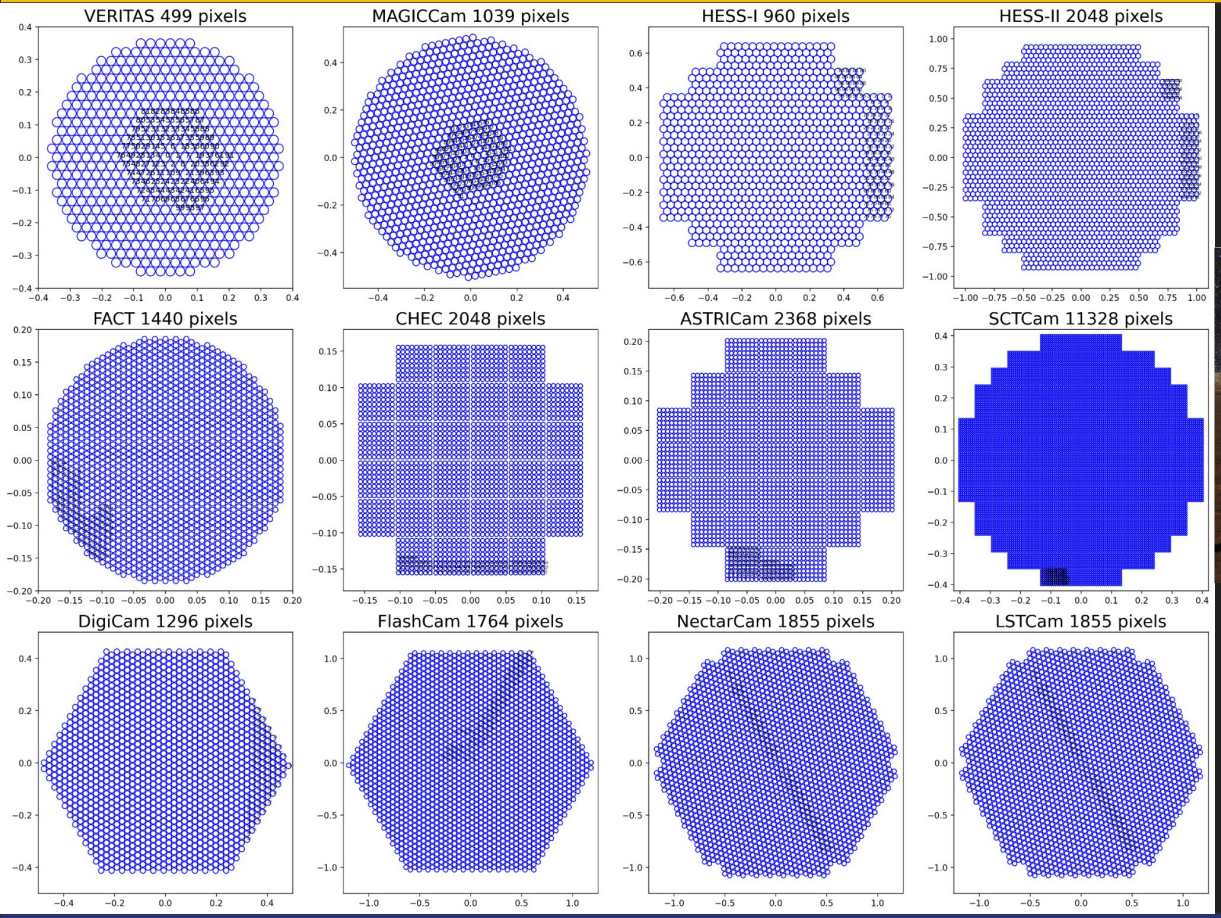
What they “see”: time series

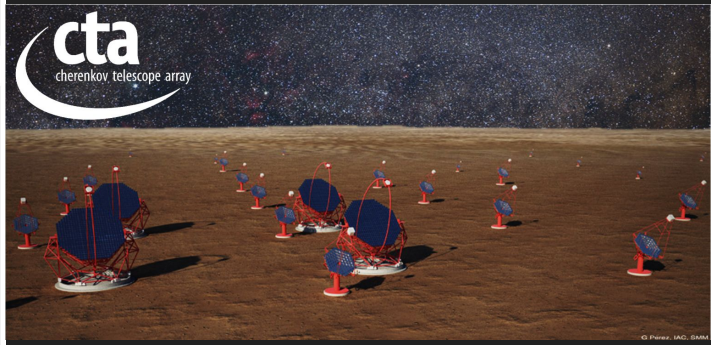




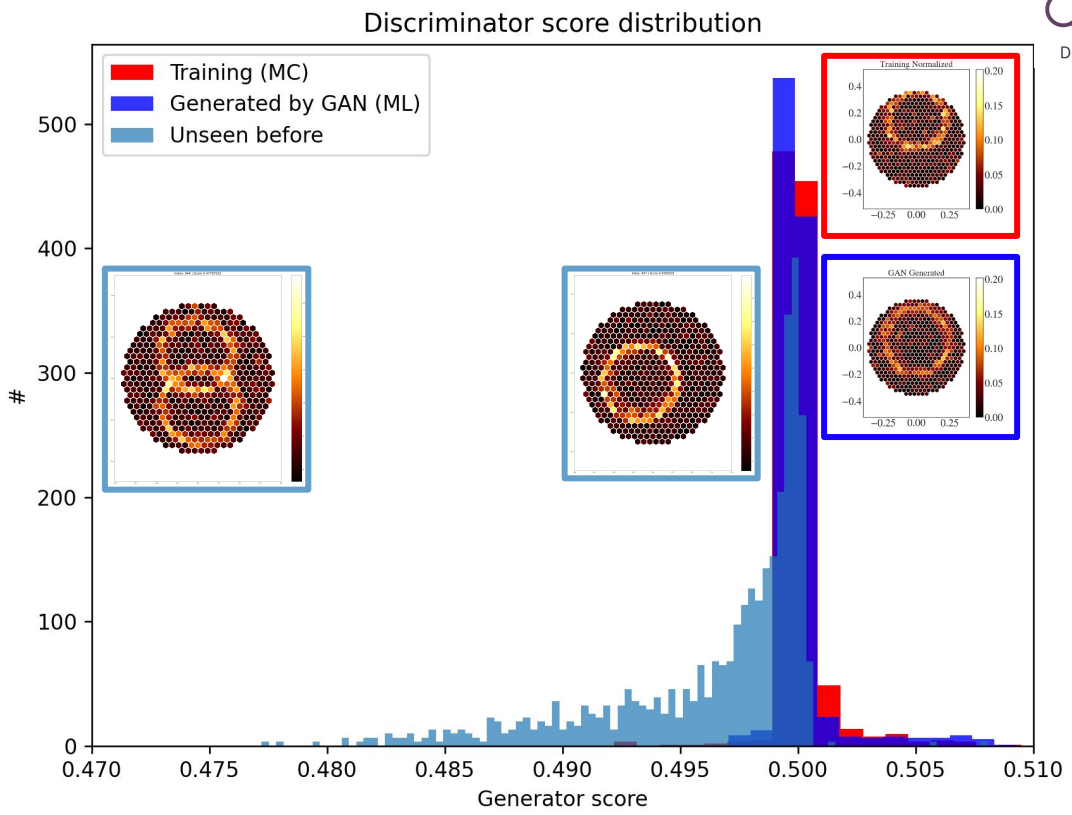
What we “see”: 2D camera with pixels

Highly generalizable



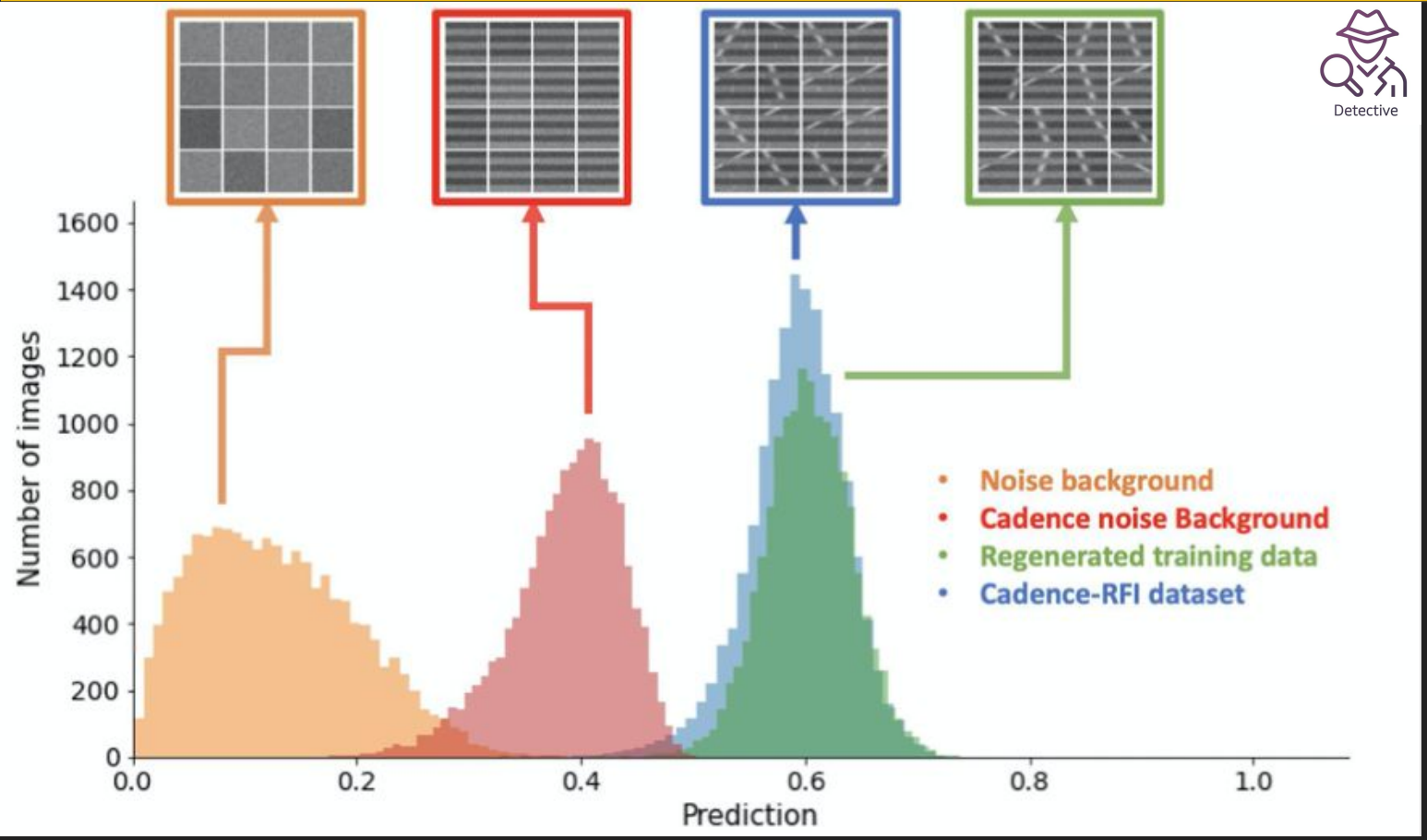


Future Direction: Generator as (A)nomaly Detector



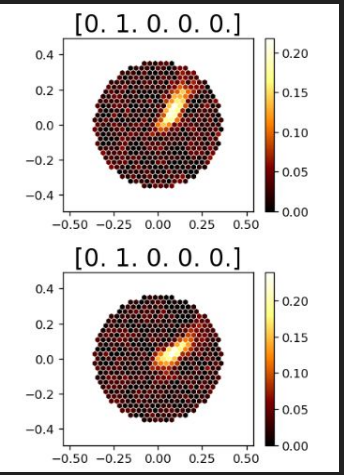
Detective

Future Direction: Generator as (A)nomaly Detector

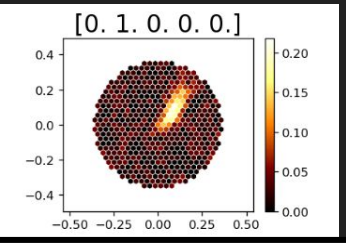


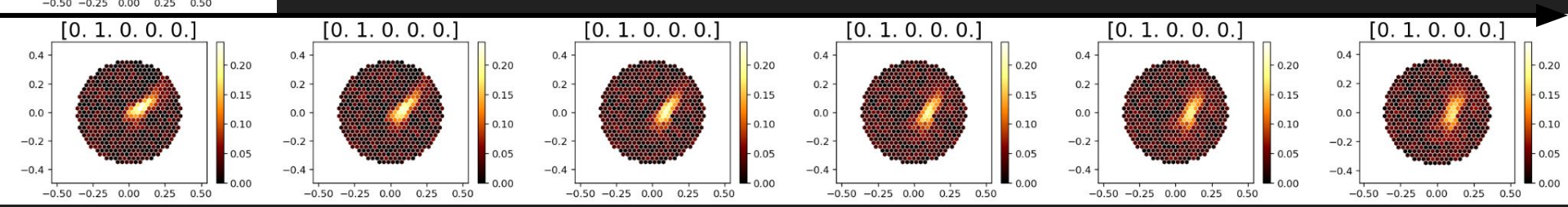
Z. Zheng
(zihe.zheng@yale.edu)

Future Direction: (A)nomaly Creator



Future Direction: (A)nomaly Creator





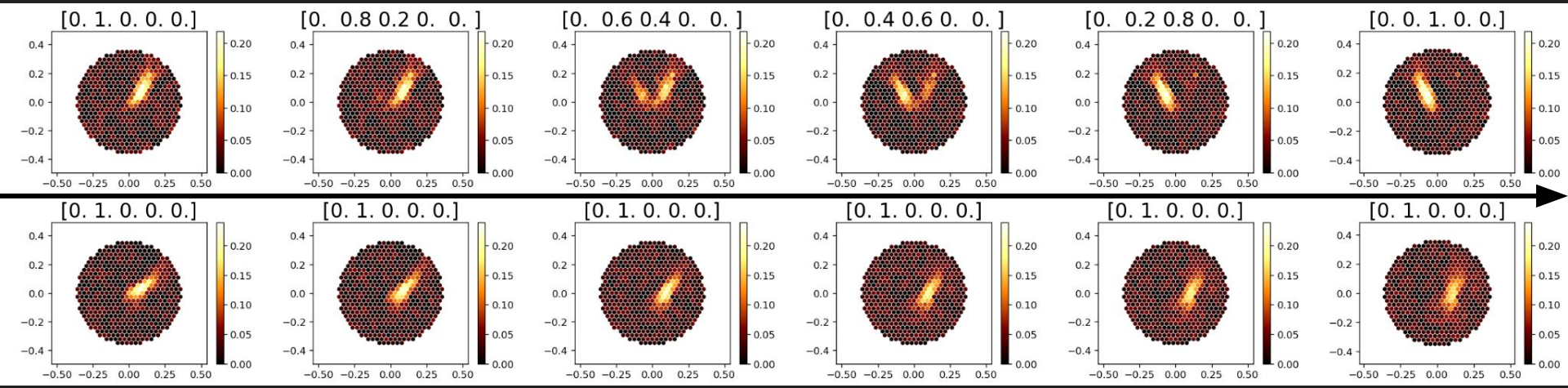
Linear walk in 100D latent space

$$[x]_{499D} = [G] \begin{bmatrix} z + \delta z \\ \oplus \\ c \end{bmatrix}_{100D+5D}$$

Future Direction: (A)nomaly Creator

Linear walk in 5D class space

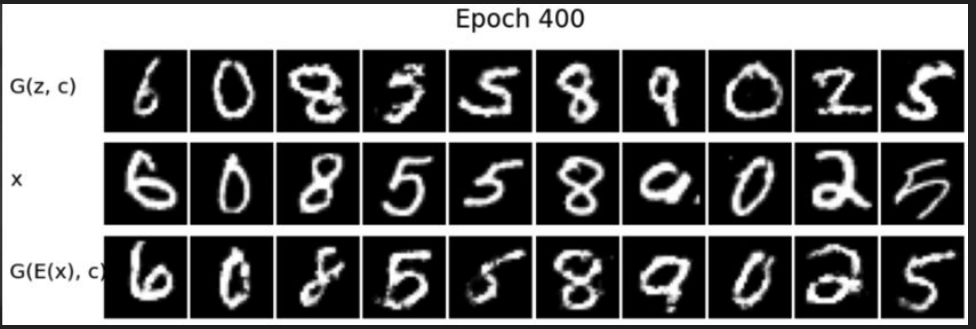
$$[x]_{499D} = [G] \begin{bmatrix} z \\ \oplus \\ c + \delta c \end{bmatrix}_{100D+5D}$$

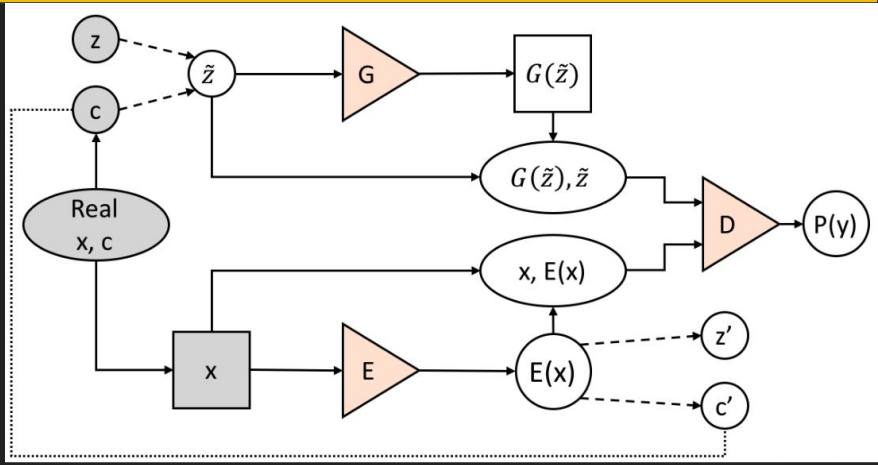


Linear walk in 100D latent space

$$[x]_{499D} = [G] \begin{bmatrix} z + \delta z \\ \oplus \\ c \end{bmatrix}_{100D+5D}$$

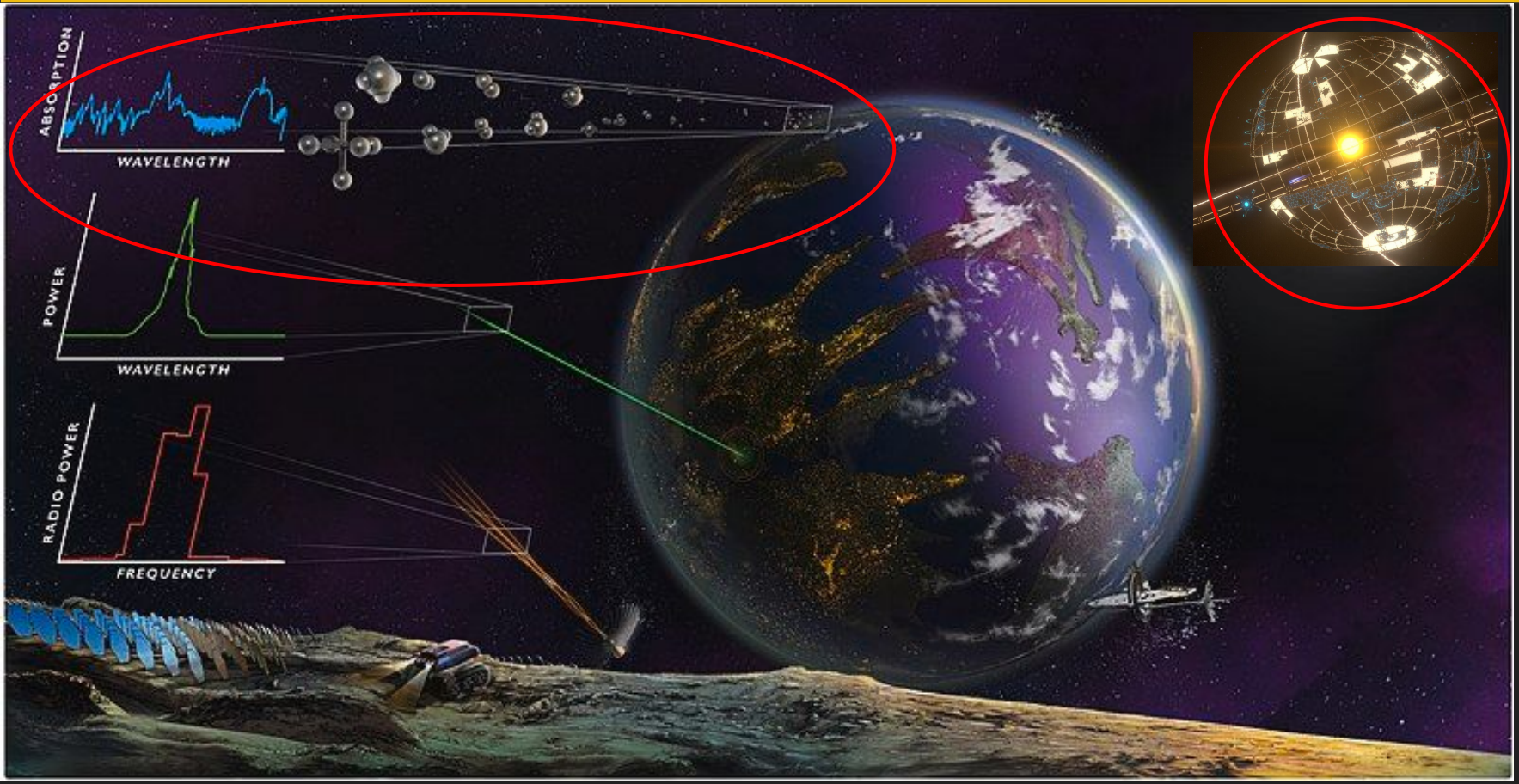
Future Direction: Reverse Engineering Anomaly





A.Zelakiewicz
(aidenzelak@gmail.com)

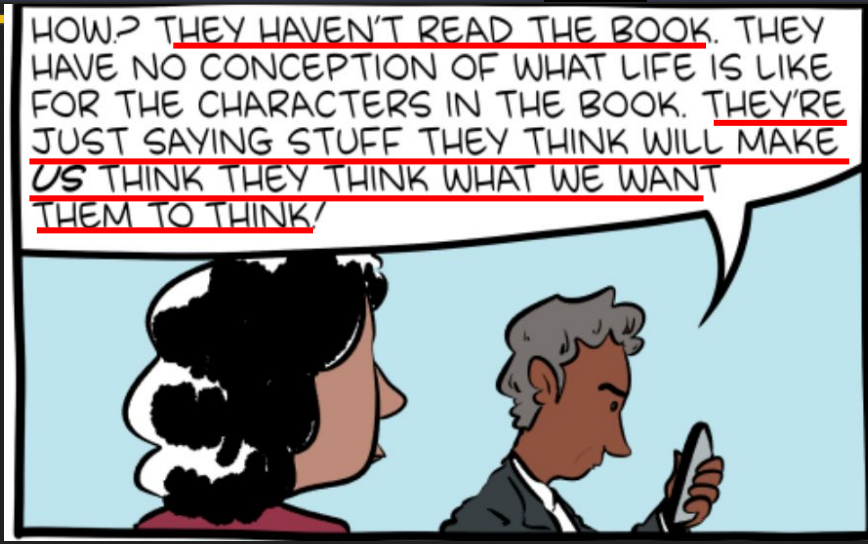
Future Direction: Spectrophotometric with JWST



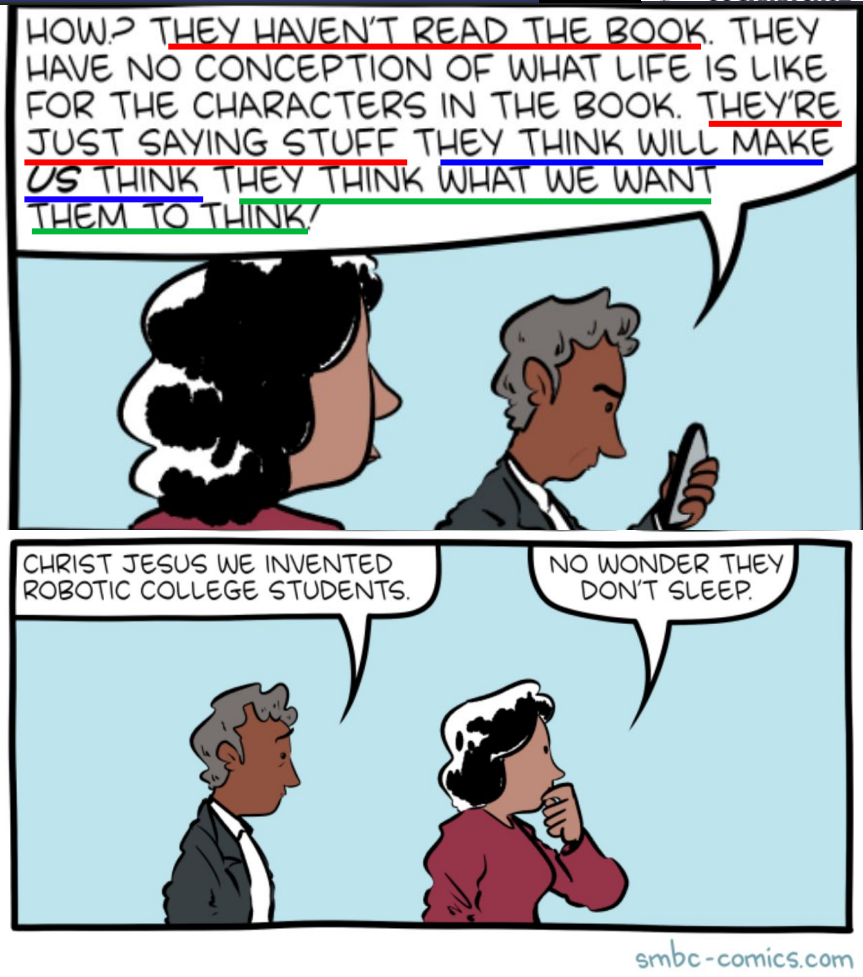
Summary

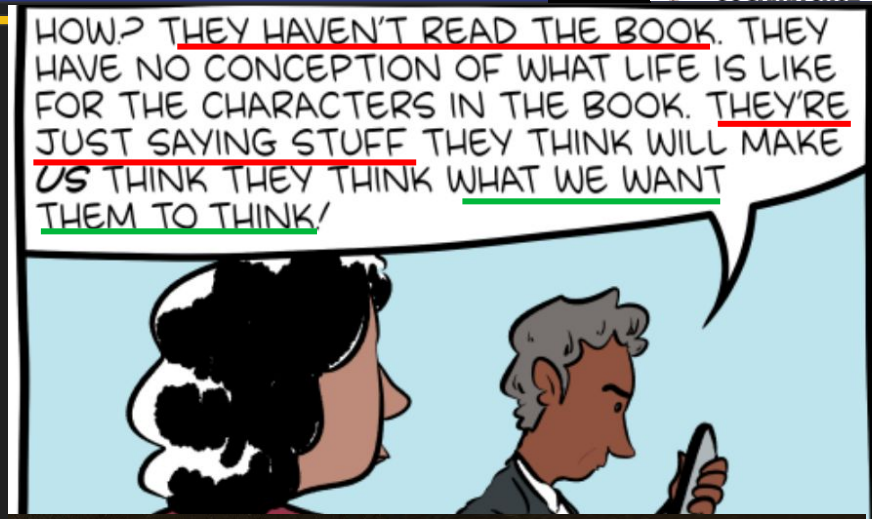
- ★ SETI and Technosignatures
- ★ Neural Net: Fancy polynomial approximator
  - ○ GANs: competing Generator and Discriminator
  - ○ cGANs: GANs with classes
- ★ Wide range of applications in SETI:
  - ○ Narrow-band waterfall plots (Radio)
  - ○ Light curves (TESS)
  - ○ Cherenkov images
- ★ Potential for more complex applications:
  - ○ Anomaly detection
  - ○ Anomaly creation (new physics)
  - ○ Reverse engineering anomalies
  - ○ Transit spectroscopy
  - ○ Your ideas here?

Food for thought: Who's doing the thinking now?



Food for thought: Who's doing the thinking now?



Q&A

- ★ Thinking is good. Keep thinking!
- ★ Thanks for your attention!