Machine Learning Frameworks for next-generation Cosmology Surveys

Nikhel Gupta

ML/AI Future Science Platform (MLAI FSP)
CSIRO Space & Astronomy, Australia

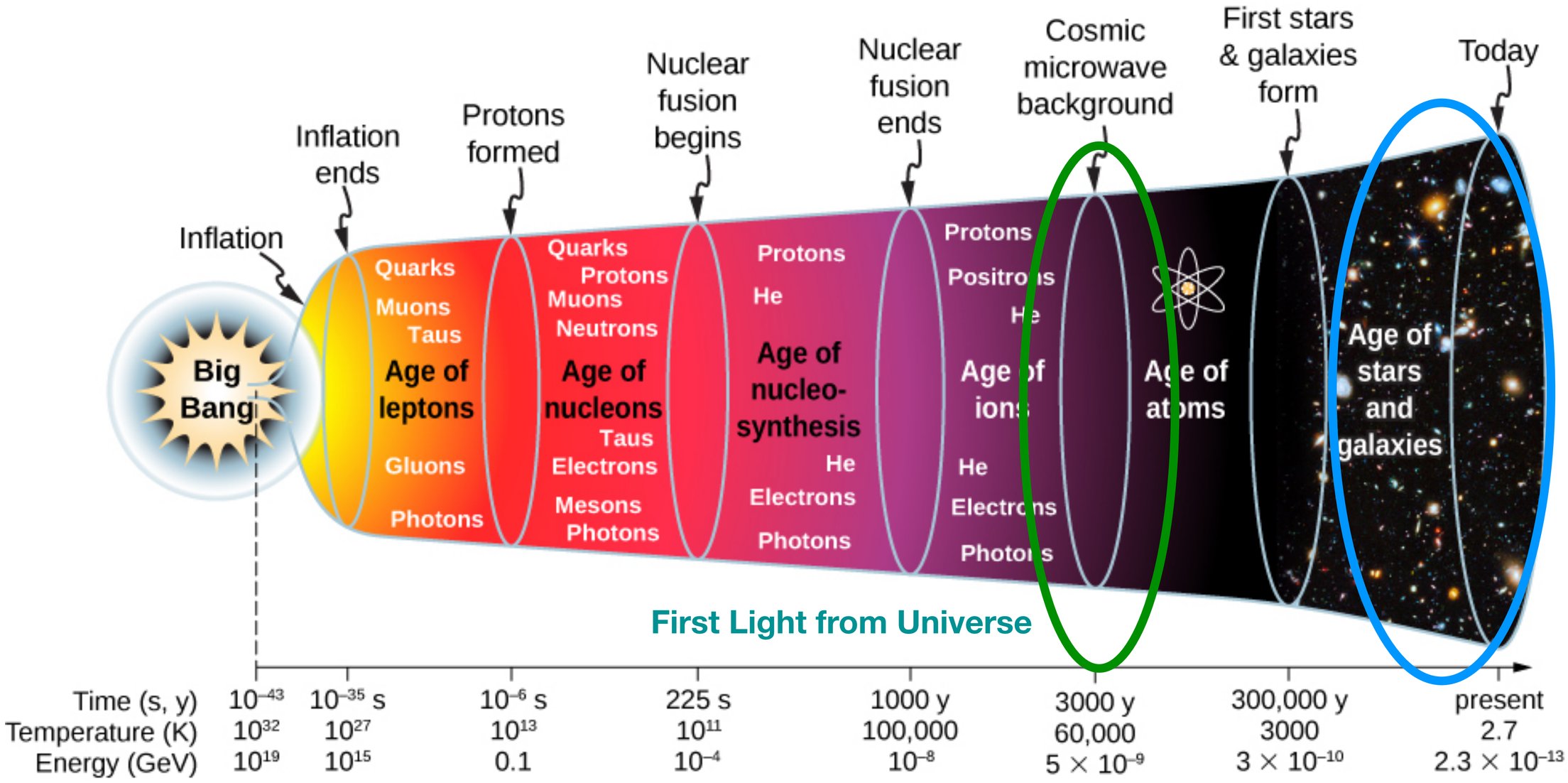
Collaborators:
Minh Huynh, Ray P. Norris, Zeeshan Hayder, Lars Petersson, Rosalind Wang, Vivien Rolland

Nikhel.Gupta@csiro.au

XXV DAE-BRNS HEP Symposium 2022

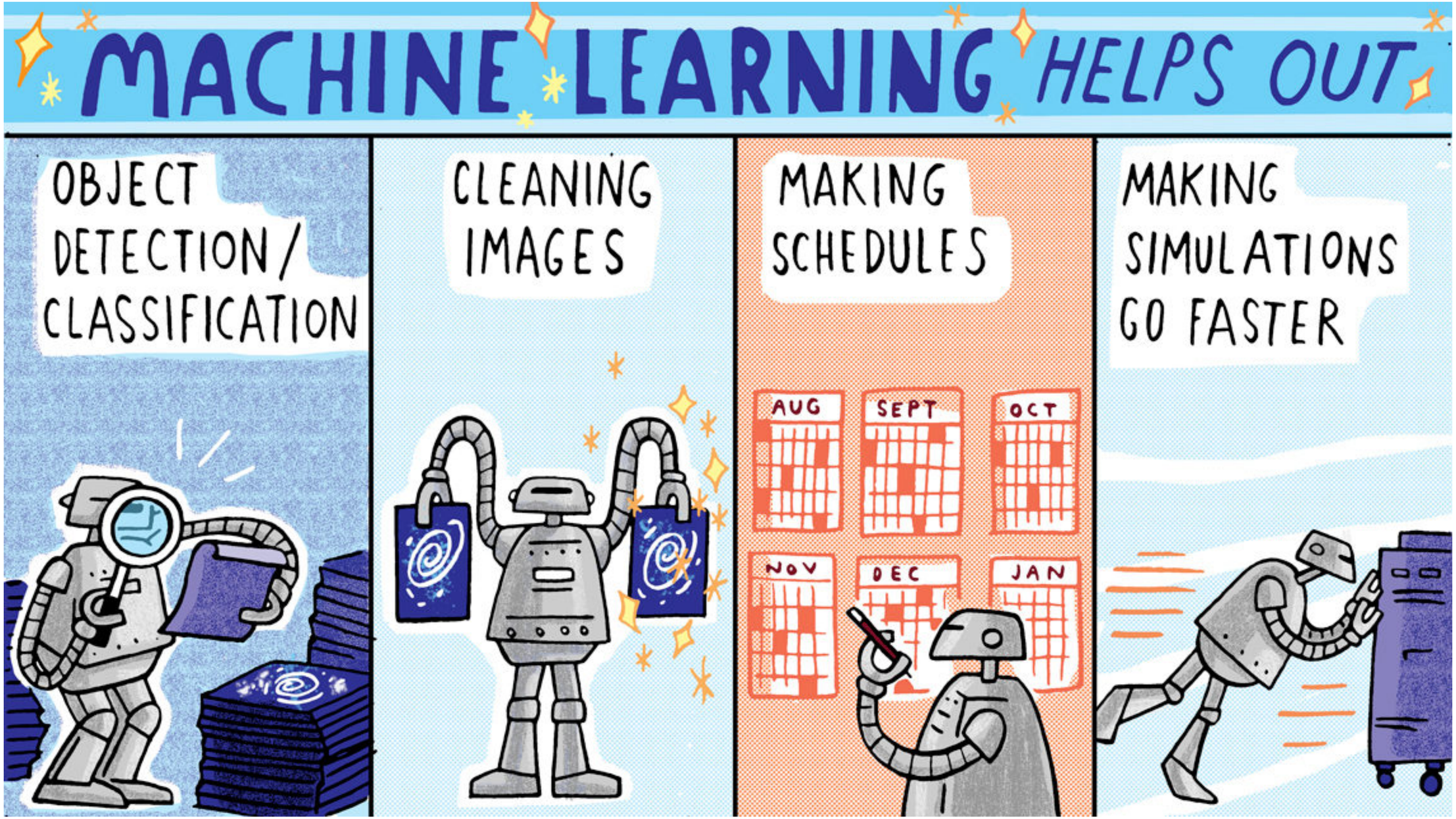
Image Courtesy : ASKAP

Evolution of Universe

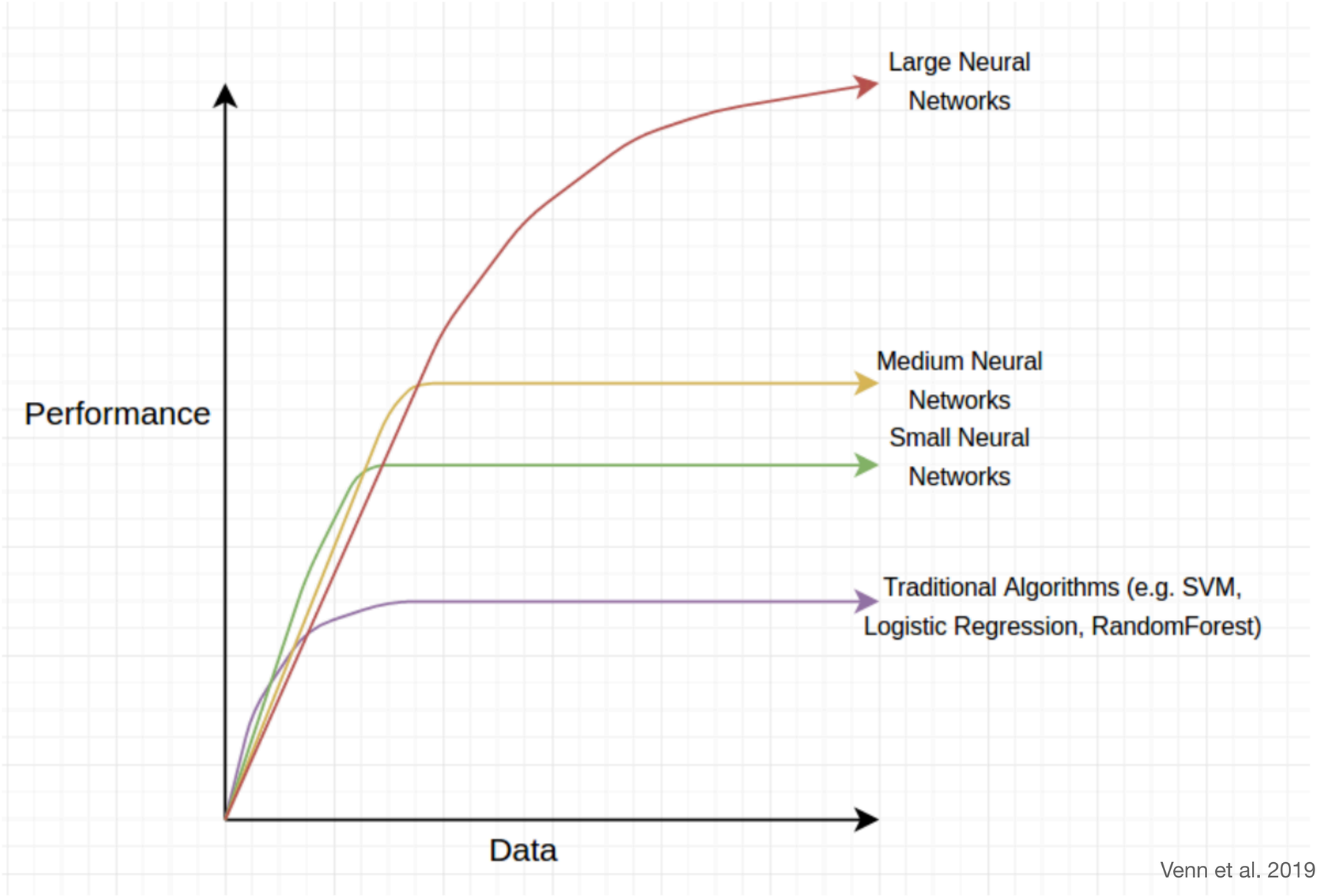


Credit: Physics Libretexts

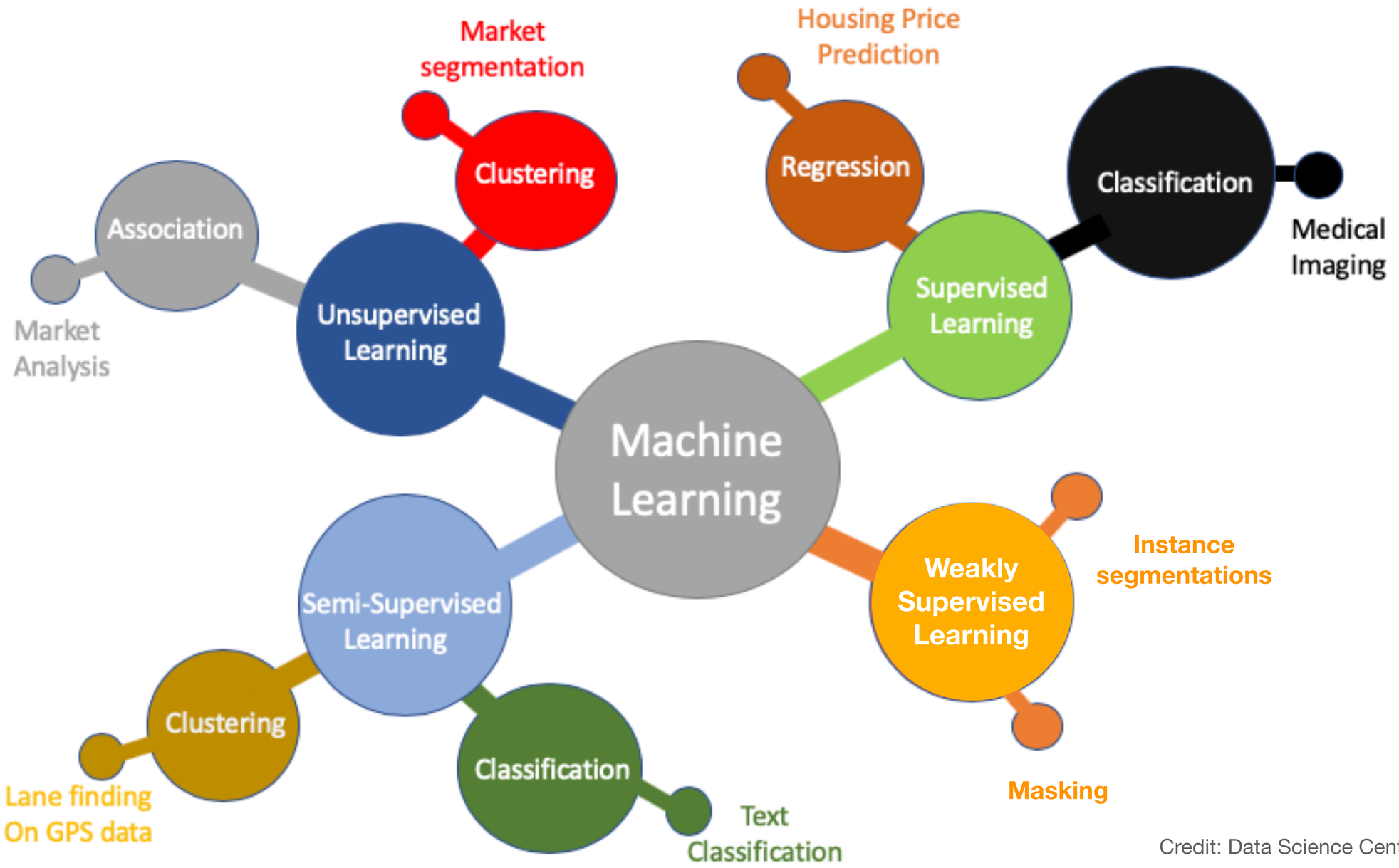
Nikhel.Gupta@csiro.au



Nikhel.Gupta@csiro.au



Venn et al. 2019



Credit: Data Science Central

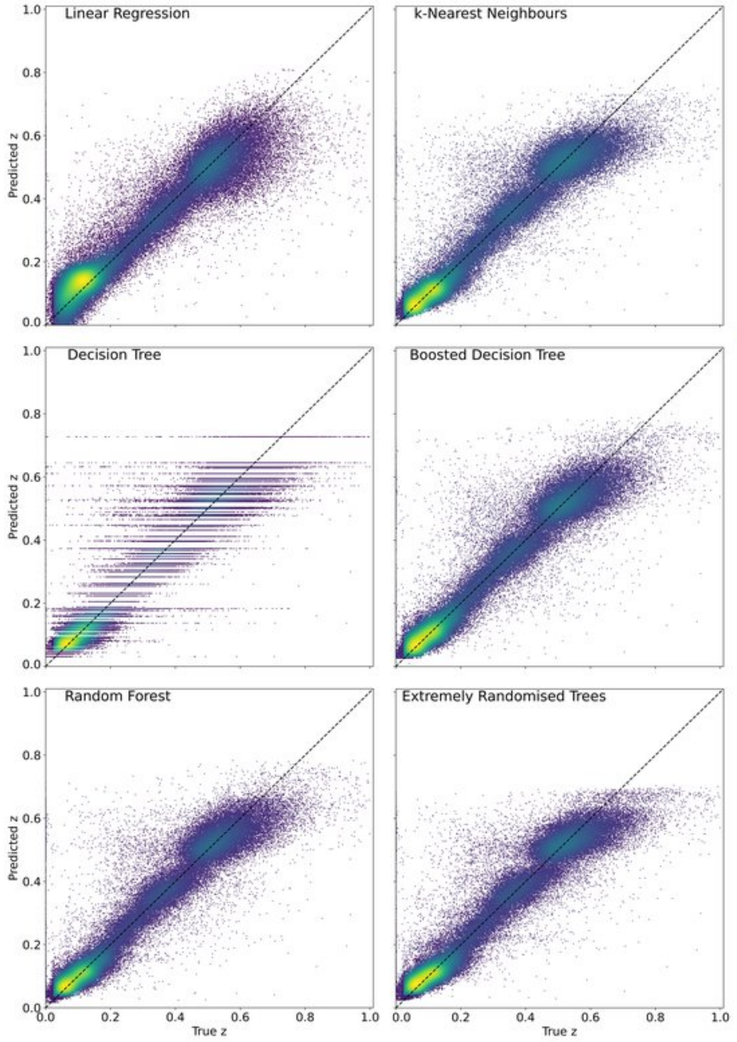
Machine Learning Frameworks

- **Supervised Learning**
  Complete information of truth-labels is available for all images
- **Self-supervised Learning**
  No information about truth-labels is available for all images
- **Weakly-supervised Learning**
  Some information about truth-labels is available for all images
- **Semi-supervised Learning**
  Complete information of truth-labels is available for some images

Nikhel.Gupta@csiro.au

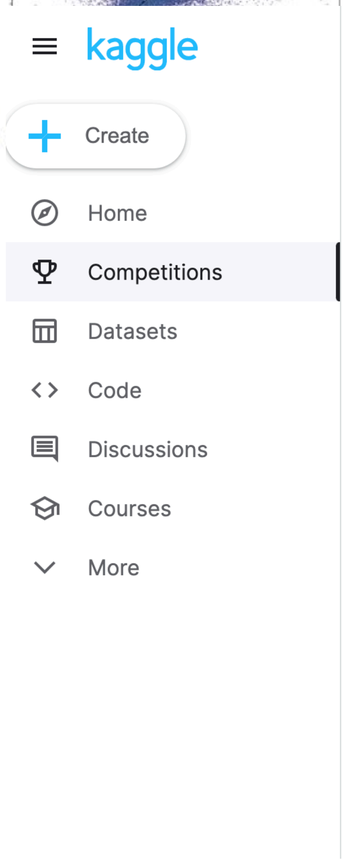
Courtesy : EMU

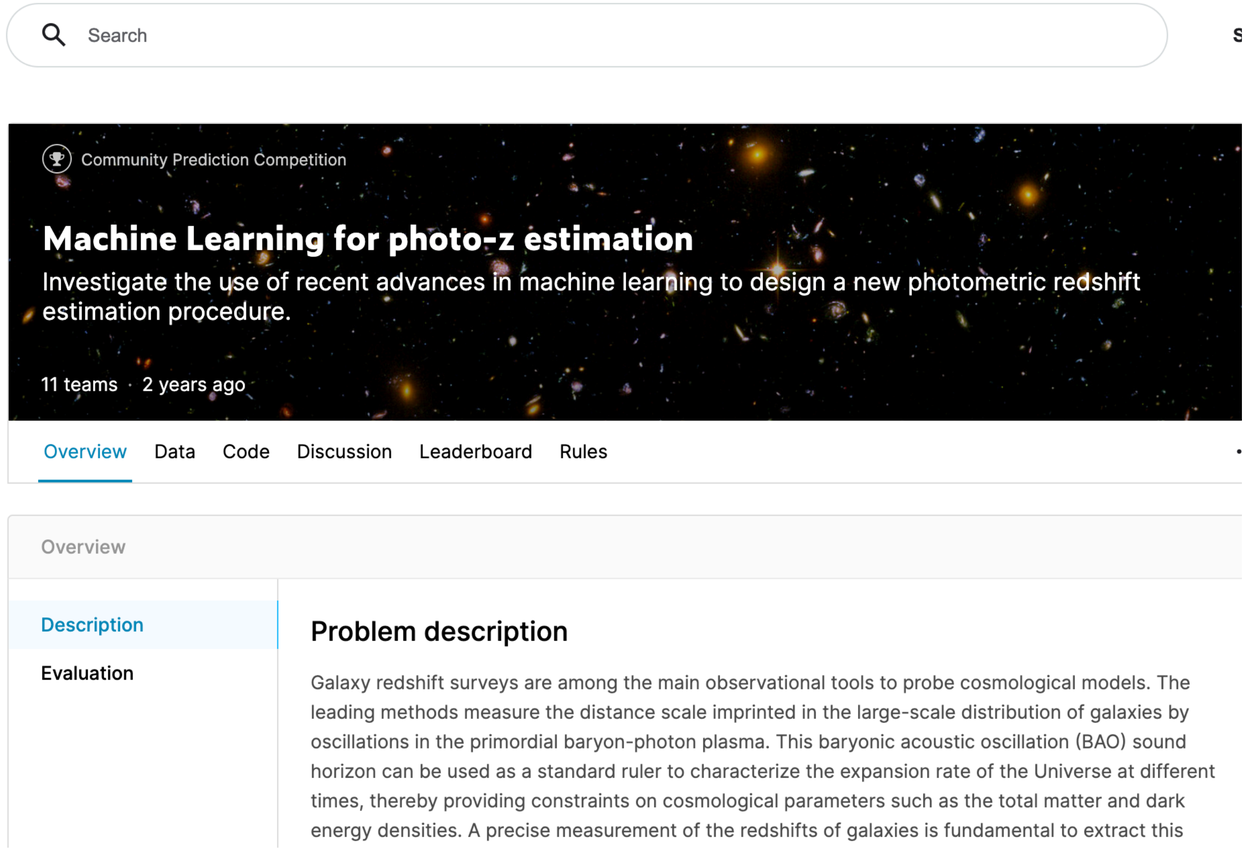
Redshift Estimations



Henghes et al. 2021

Redshift estimations
Catalog space i.e. using tables

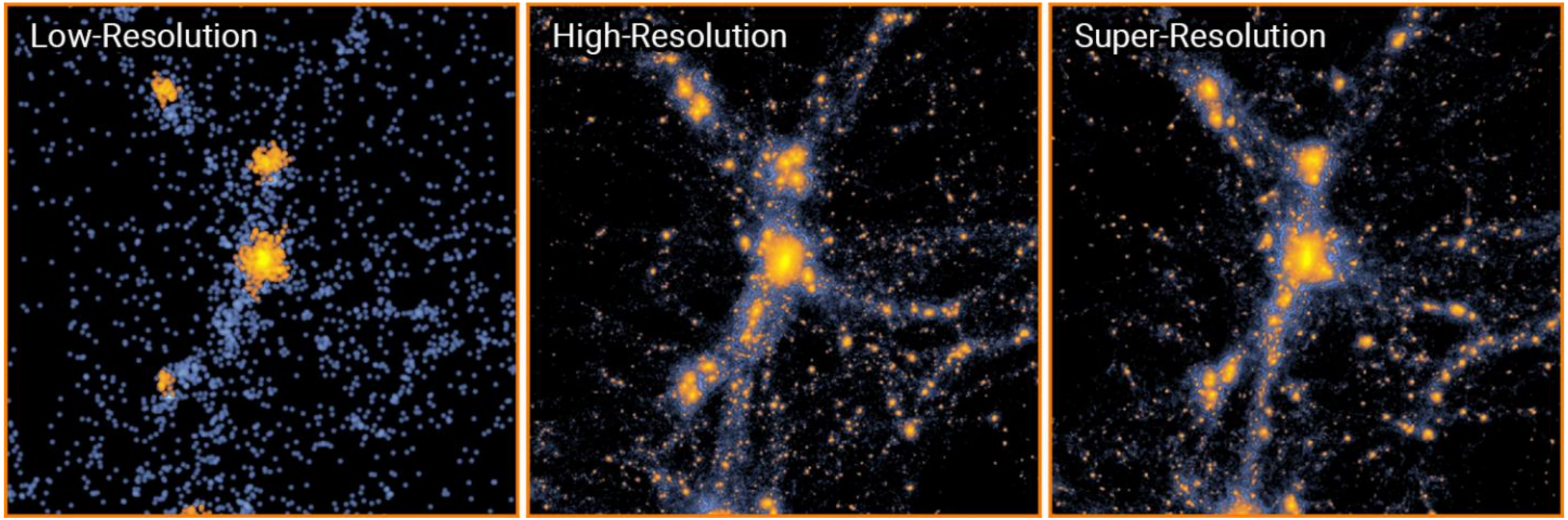




Nikhel.Gupta@csiro.au

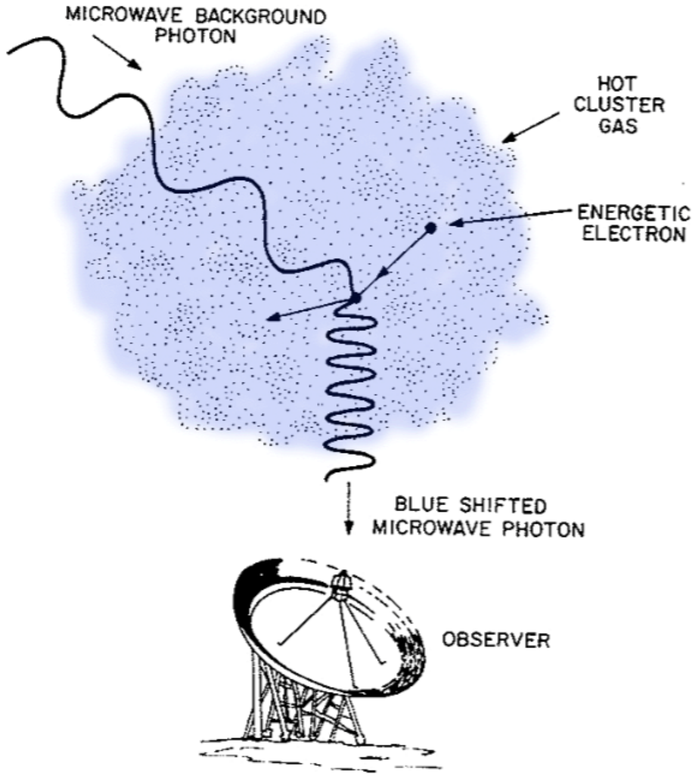
Making High Resolution Simulations

Y. Li et al. 2021

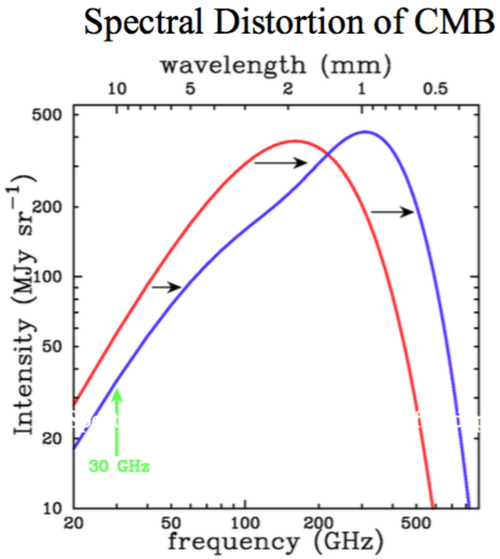


Nikhel.Gupta@csiro.au

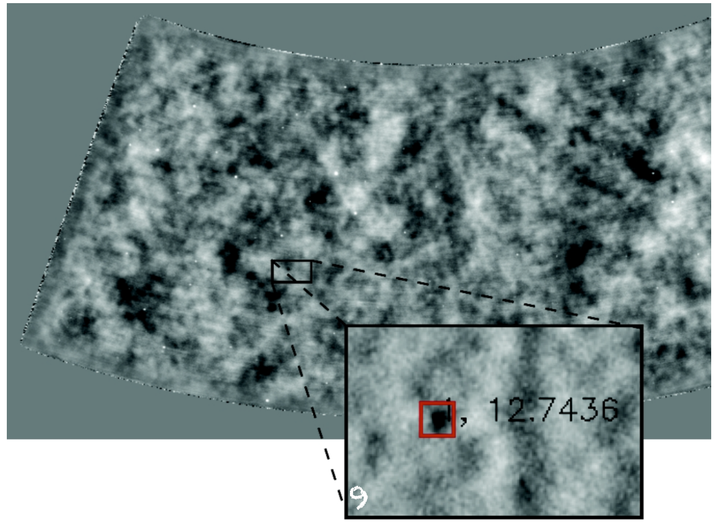
Sunyaev Zel'dovich (SZ) Effect

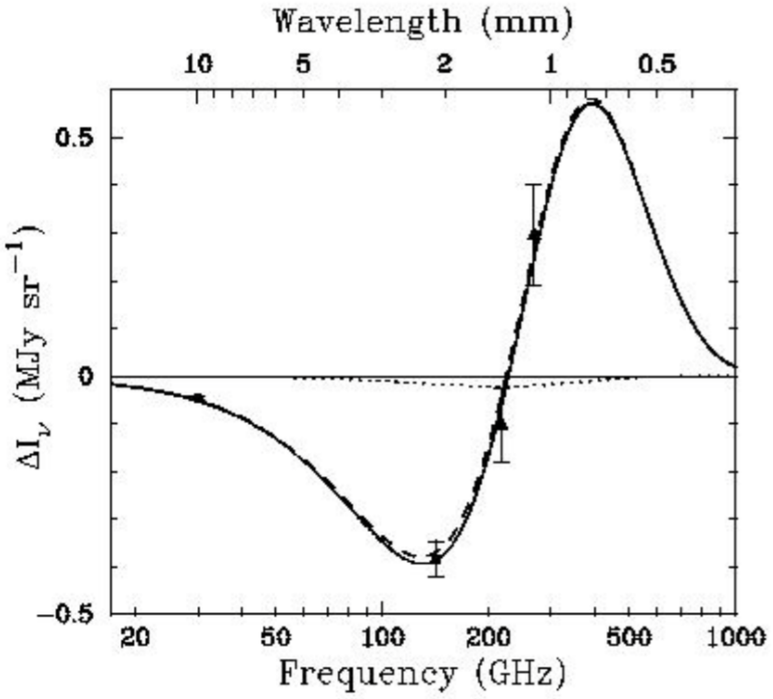


Adapted from L. Van Speybroeck



Sunyaev & Zel'dovich 1970, 1972

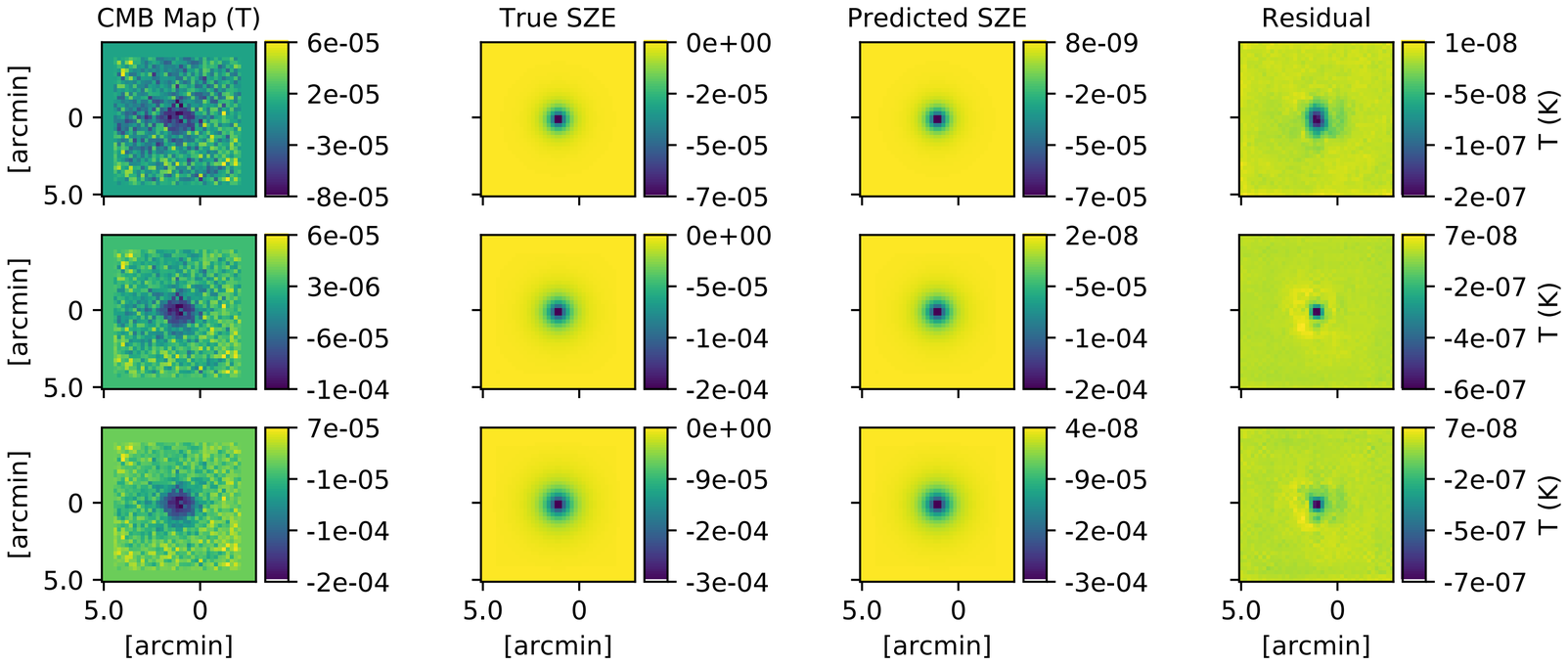


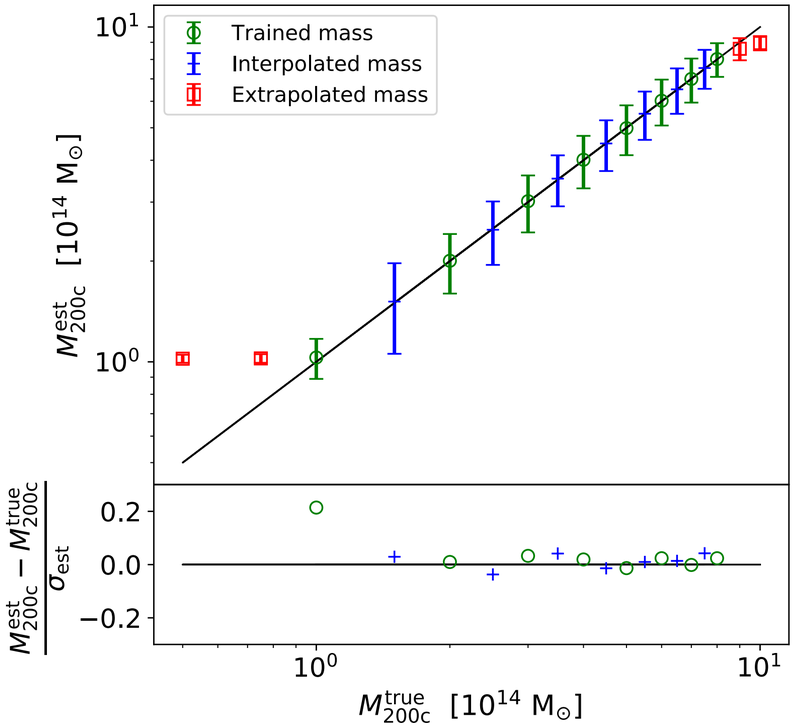


Nikhel.Gupta@csiro.au

SZ Profile & Mass Predictions with Supervised Machine Learning

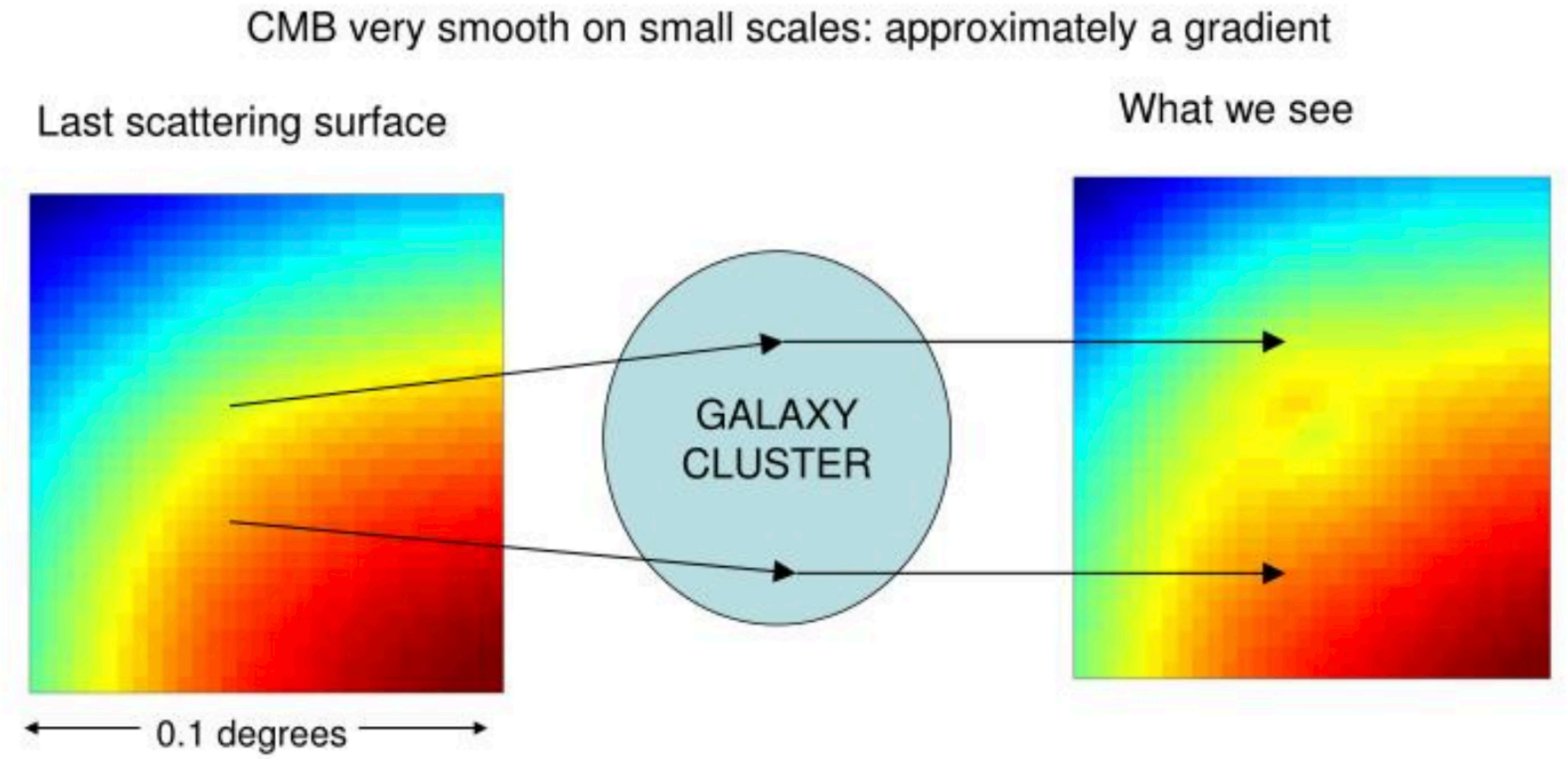
Gupta et al. (2020b)





Nikhel.Gupta@csiro.au

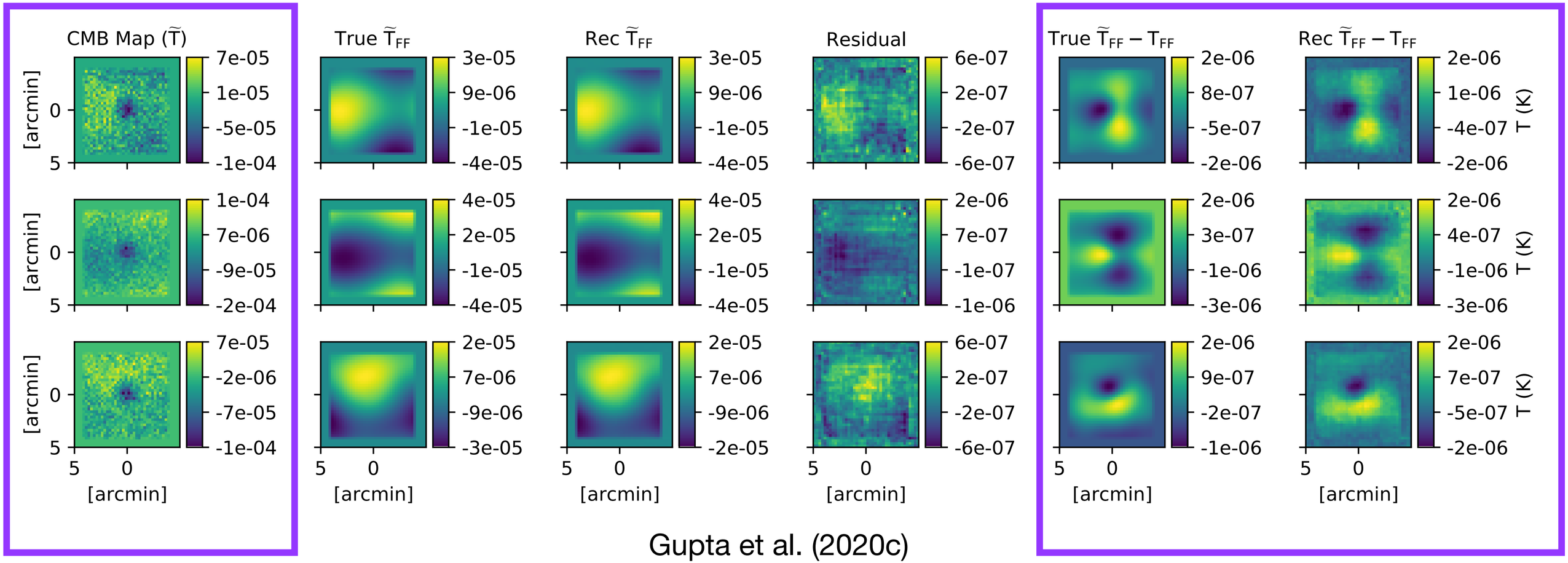
Cosmic Microwave Background (CMB) — Galaxy Cluster Lensing



Credit: Lewis et al.

Cosmic Microwave Background (CMB) — Galaxy Cluster

Convergence Profiles Predictions with Machine Learning leads to cluster masses!!



Gupta et al. (2020c)

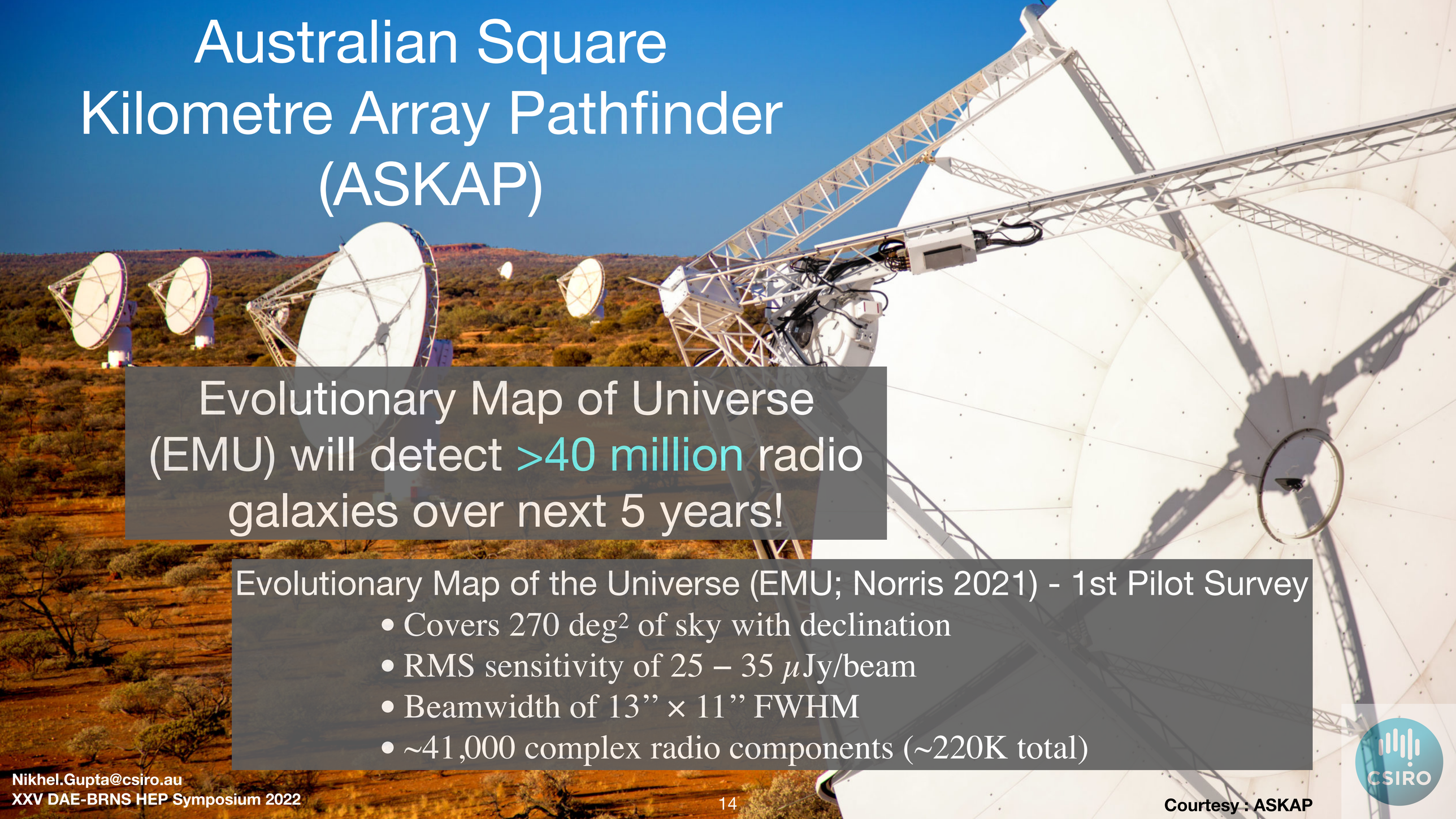
Machine Learning Frameworks

- **Supervised Learning**
  Complete information of truth-labels is available for all images
- **Self-supervised Learning**
  No information about truth-labels is available for all images
- **Weakly-supervised Learning**
  Some information about truth-labels is available for all images
- **Semi-supervised Learning**
  Complete information of truth-labels is available for some images

Nikhel.Gupta@csiro.au

Courtesy : EMU

Australian Square Kilometre Array Pathfinder (ASKAP)



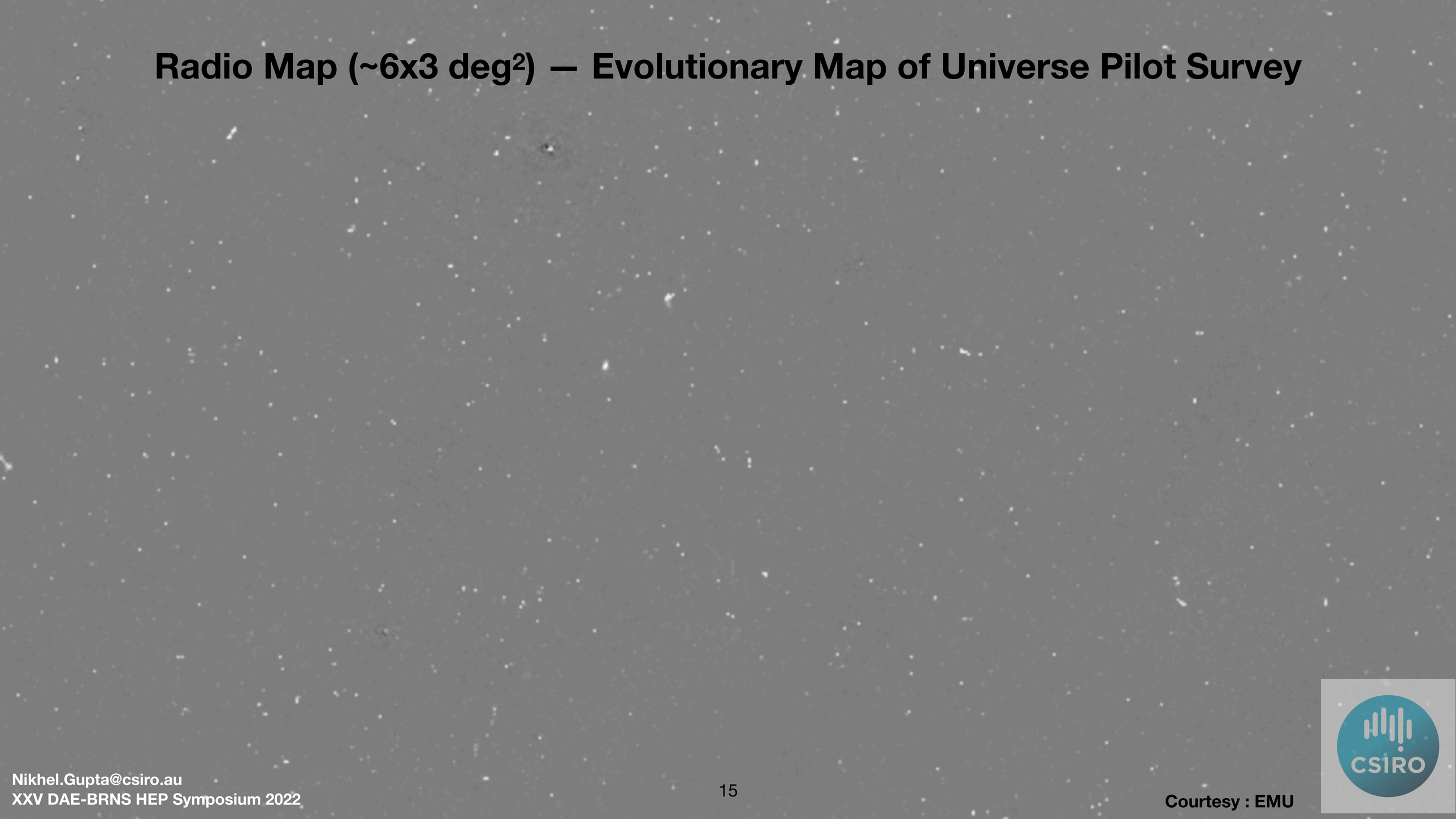
Evolutionary Map of Universe (EMU) will detect >40 million radio galaxies over next 5 years!

Evolutionary Map of the Universe (EMU; Norris 2021) - 1st Pilot Survey

- Covers 270 deg^2 of sky with declination
- RMS sensitivity of 25 – 35 μJy/beam
- Beamwidth of 13” × 11” FWHM
- ~41,000 complex radio components (~220K total)

Courtesy : ASKAP

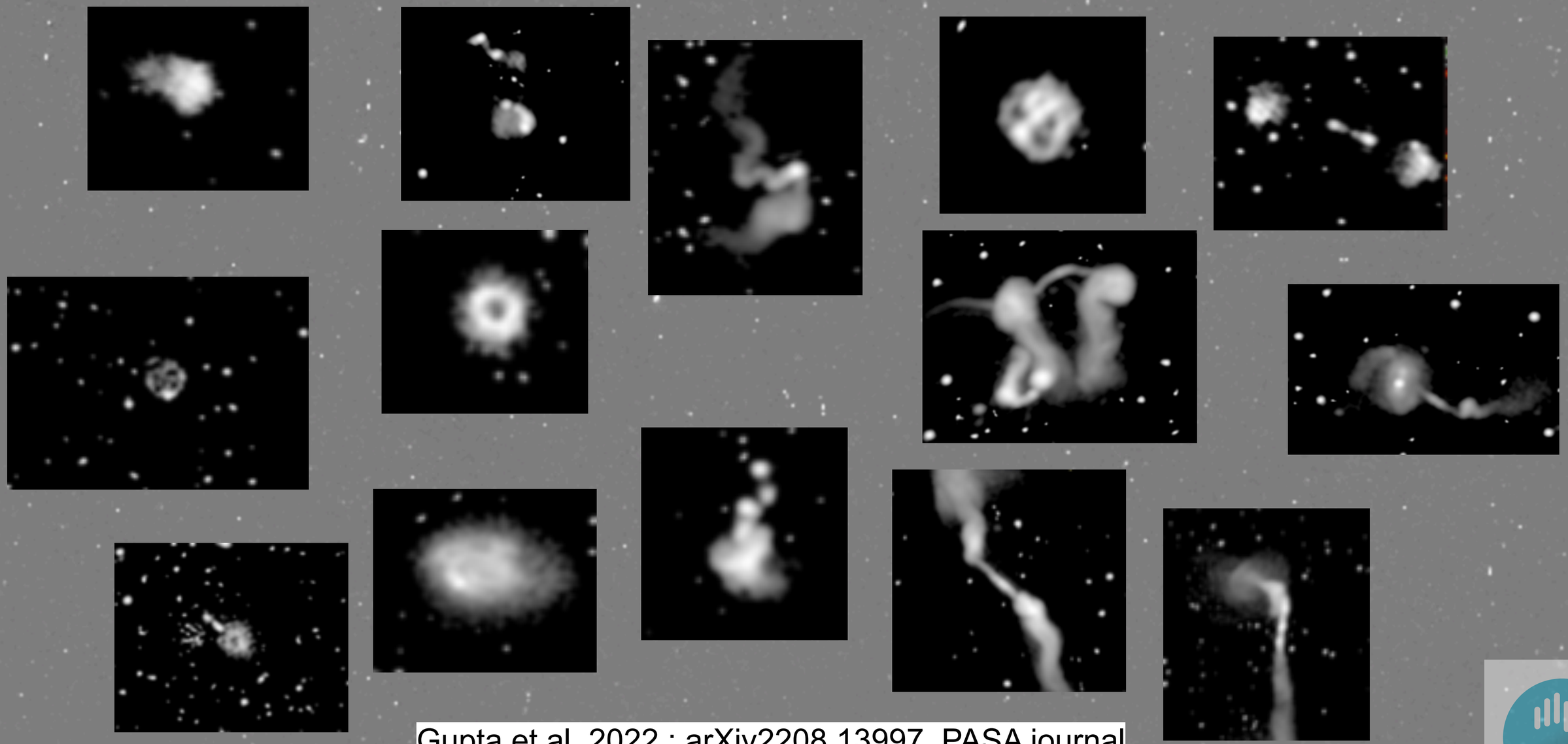
Radio Map (~6x3 deg^2) — Evolutionary Map of Universe Pilot Survey



Nikhel.Gupta@csiro.au

Courtesy : EMU

Radio Map (~6x3 deg^2) — Evolutionary Map of Universe Pilot Survey



Gupta et al. 2022 : arXiv2208.13997, PASA journal

Nikhel.Gupta@csiro.au

Courtesy : EMU

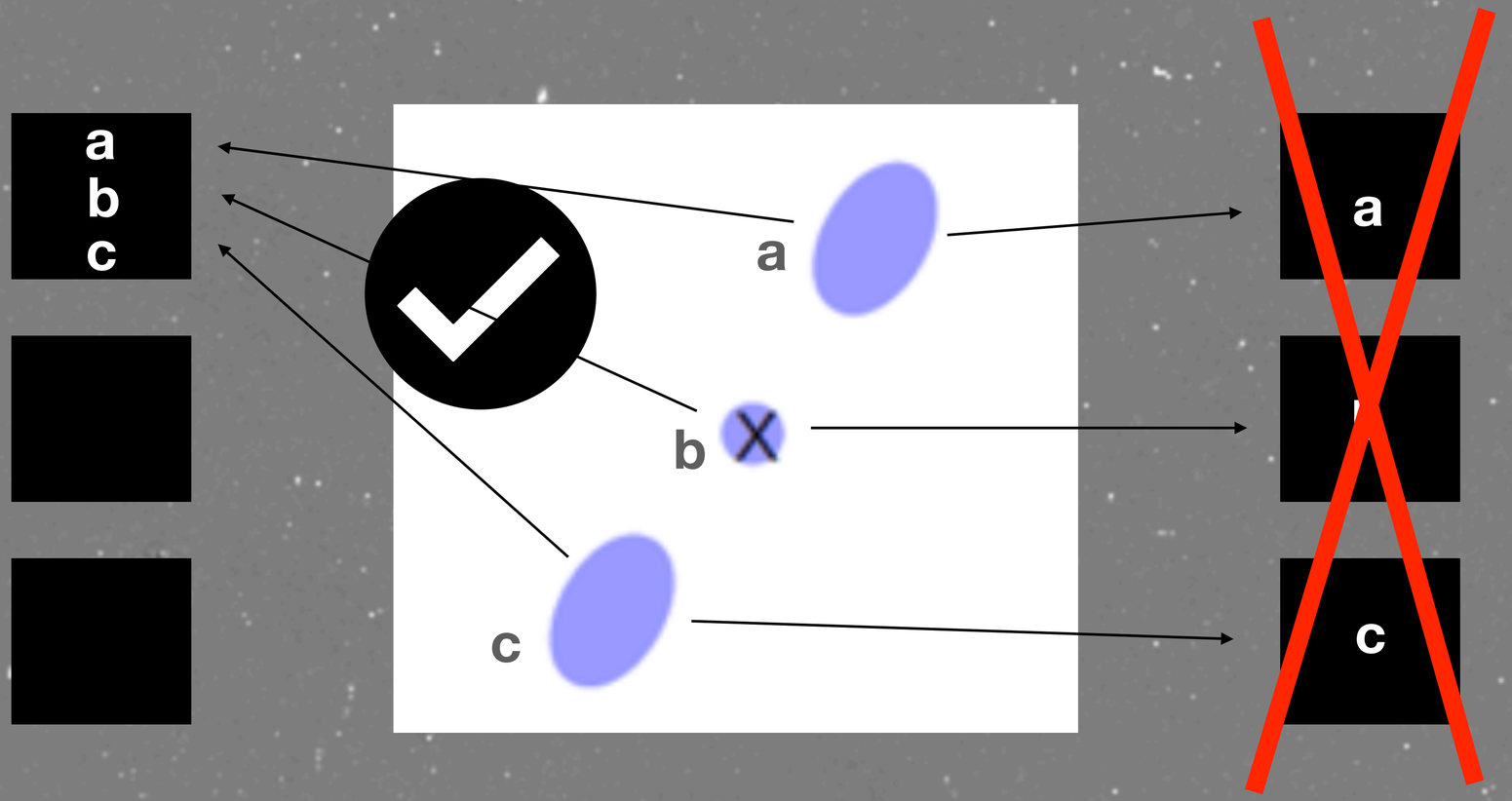
Machine Learning Frameworks

- **Supervised Learning**
  Complete information of truth-labels is available for all images
- **Self-supervised Learning**
  No information about truth-labels is available for all images
- **Weakly-supervised Learning**
  Some information about truth-labels is available for all images
- **Semi-supervised Learning**
  Complete information of truth-labels is available for some images

Nikhel.Gupta@csiro.au

Courtesy : EMU

Can we group components of Radio Galaxies using ML?

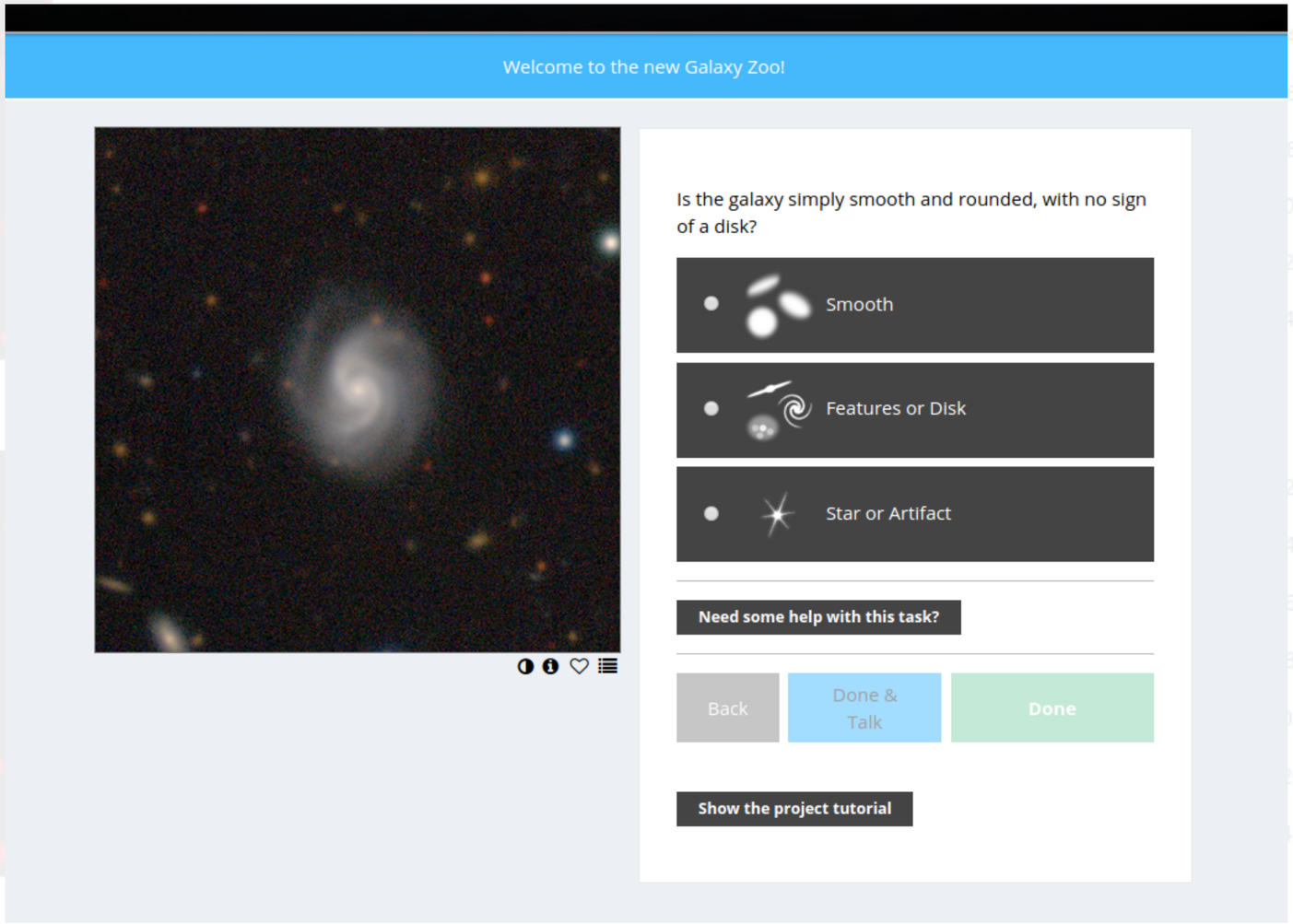


Nikhel.Gupta@csiro.au

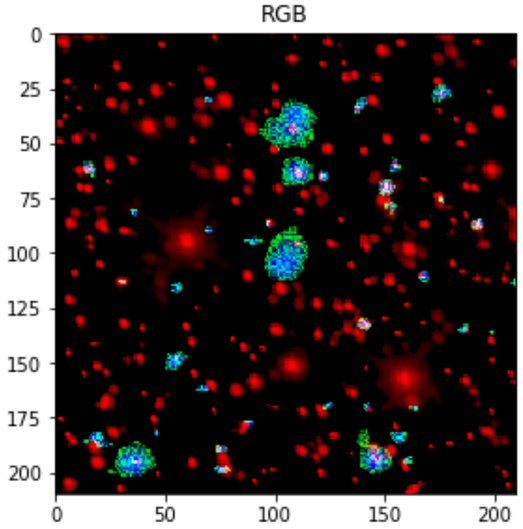
Courtesy : EMU

Weakly-supervised Learning

Citizen Science



Weakly-supervised Learning

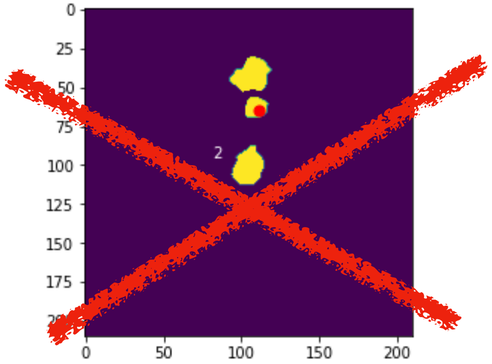


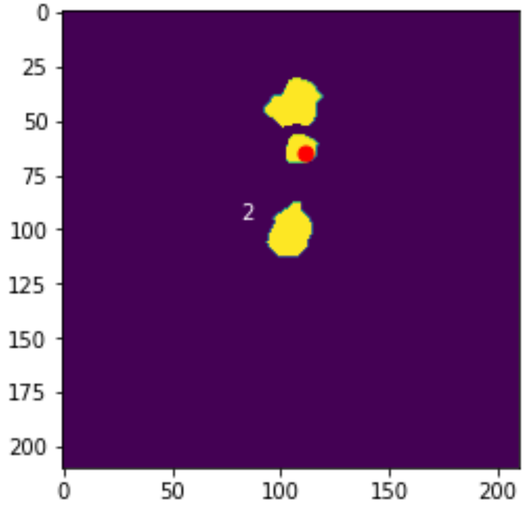
+

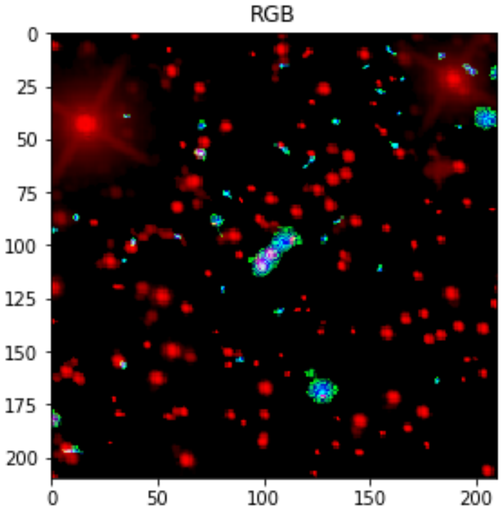
Class-level label

FRII

Segmentation Mask & Keypoints





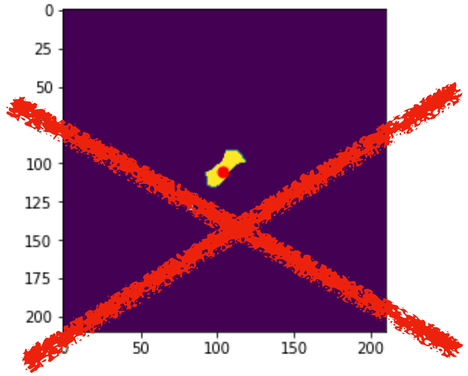


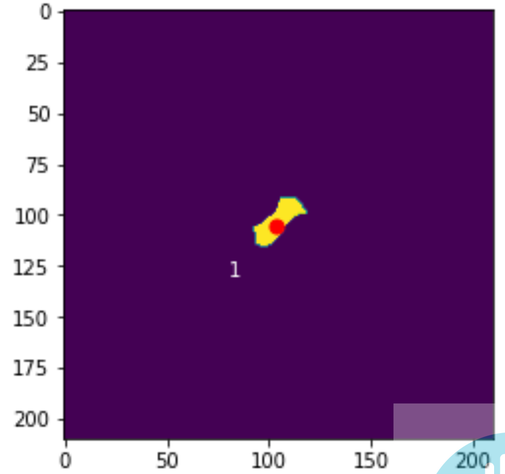
+

Class-level label

FRI

Segmentation Mask & Keypoints





Gupta et al. (in prep)

Nikhel.Gupta@csiro.au

Machine Learning Frameworks

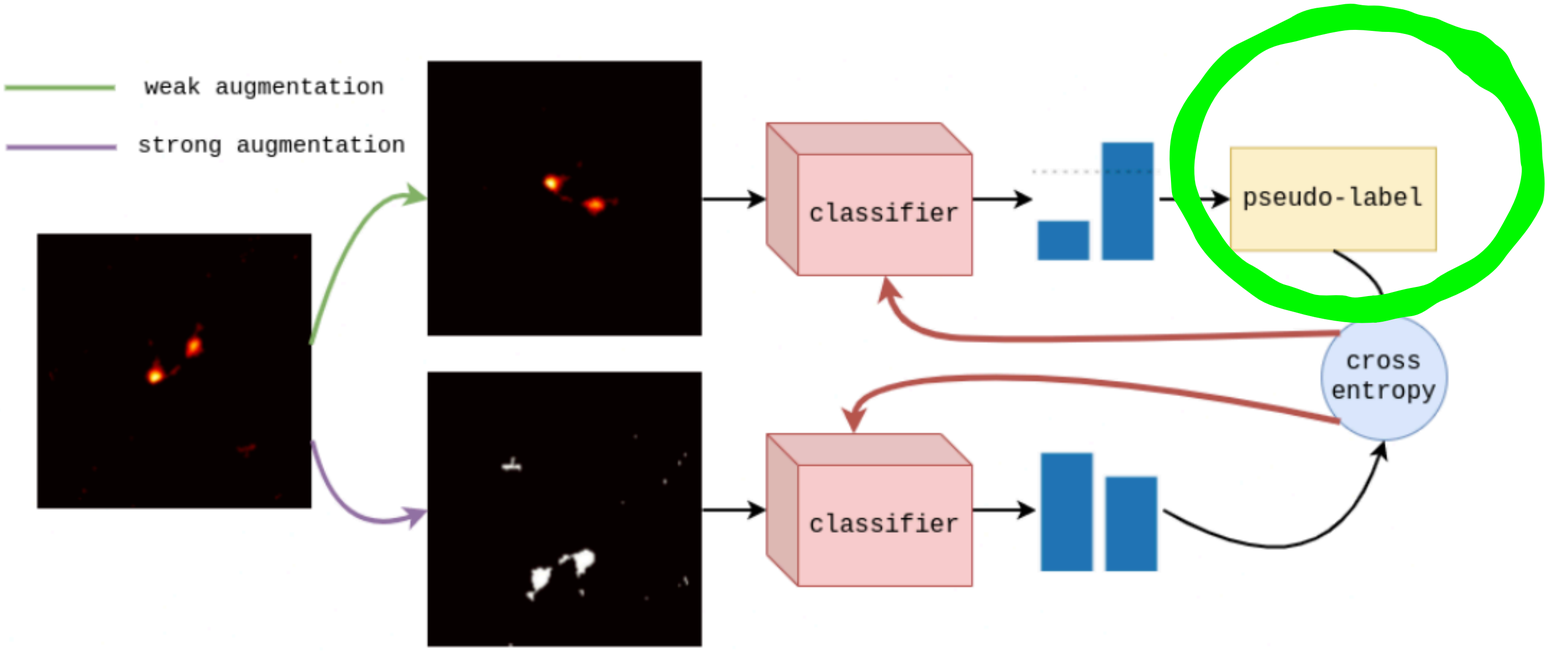
- **Supervised Learning**
  Complete information of truth-labels is available for all images
- **Self-supervised Learning**
  No information about truth-labels is available for all images
- **Weakly-supervised Learning**
  Some information about truth-labels is available for all images
- **Semi-supervised Learning**
  Complete information of truth-labels is available for some images

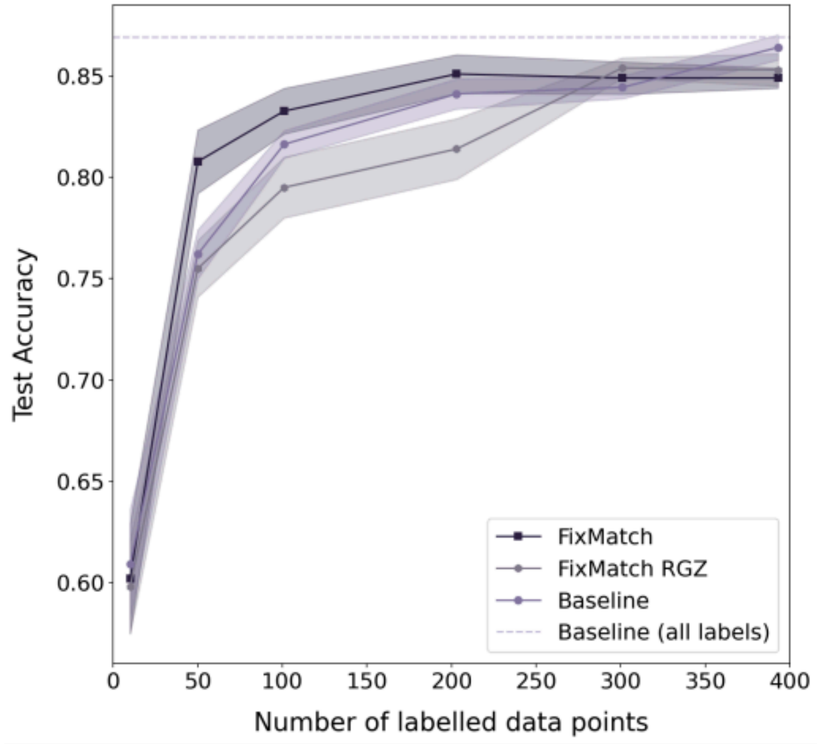
Nikhel.Gupta@csiro.au

Courtesy : EMU

Semi-supervised Learning in Astronomy Examples

(1) feature extraction, (2) clustering/classification (few labels), (3) visual representation

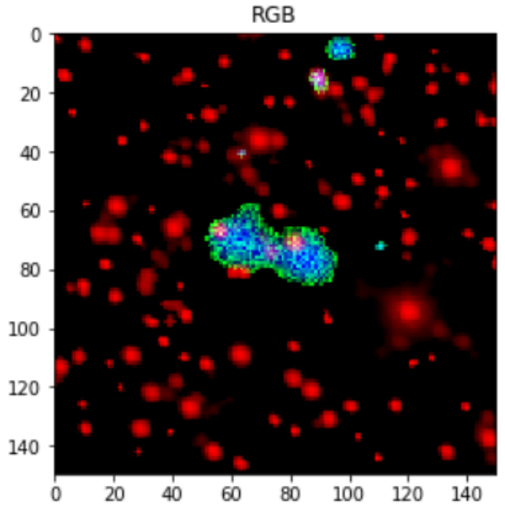




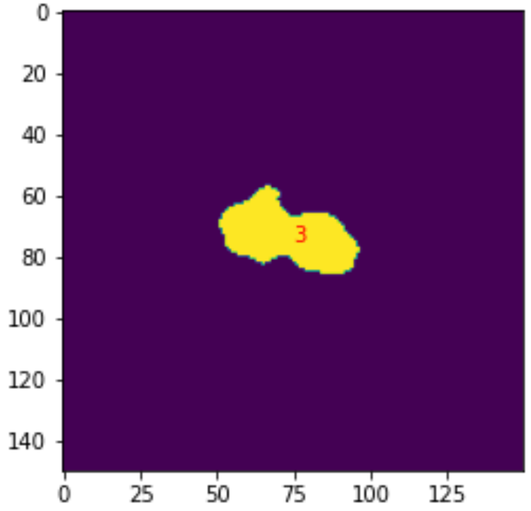
Slijepcevic et al. 2021

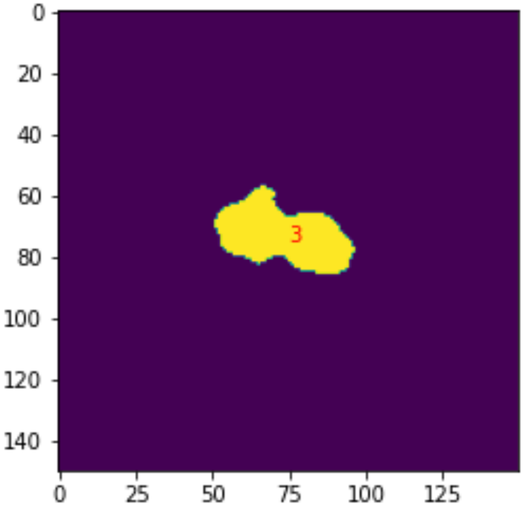
Nikhel.Gupta@csiro.au

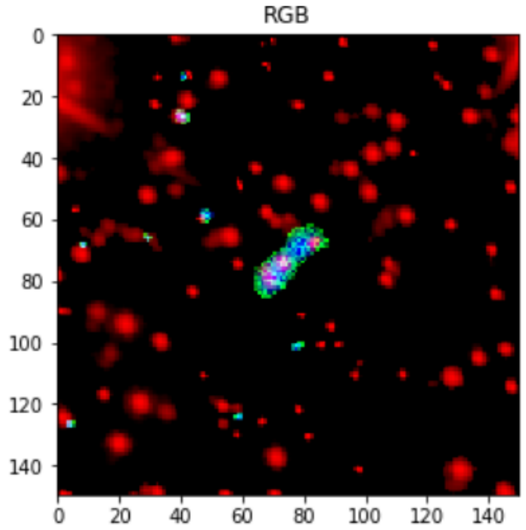
Semi-supervised Learning



+

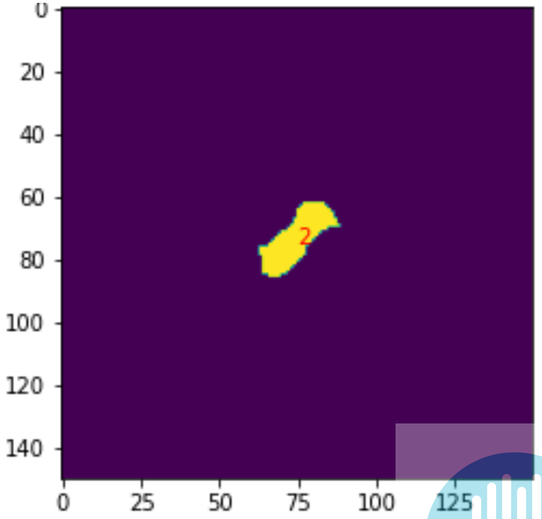






+

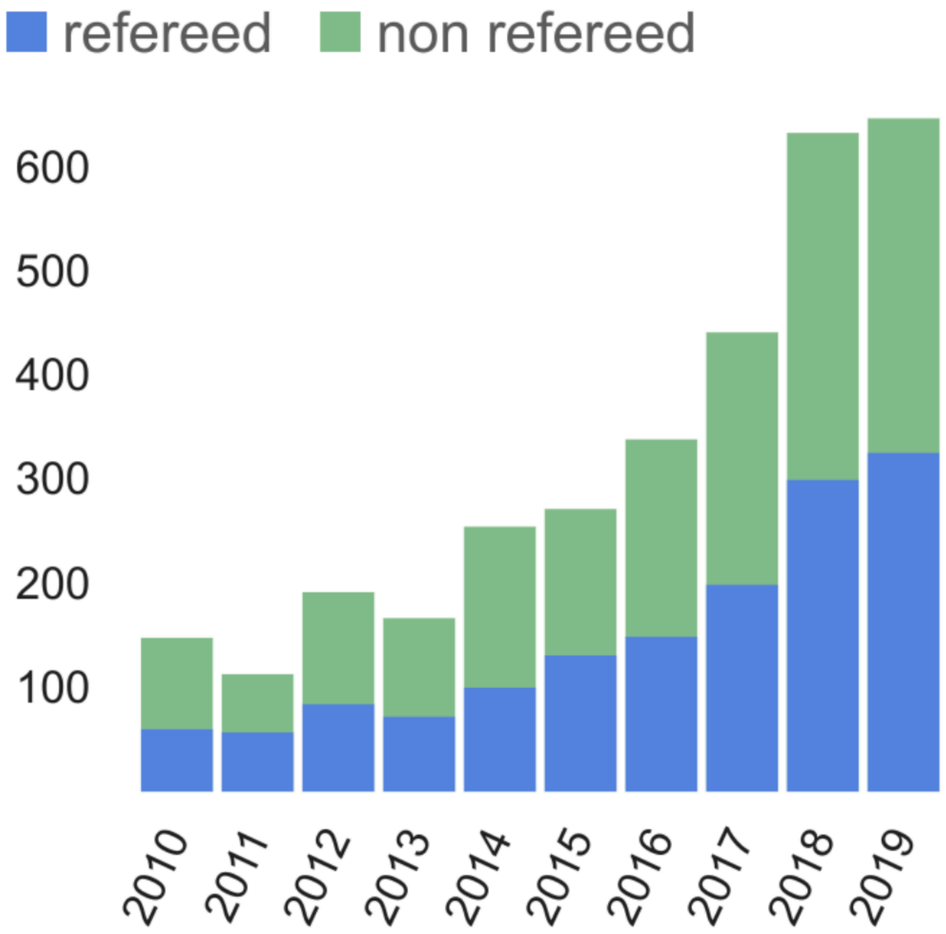
No label
Or
Class-label



Gupta et al. (in prep)

Nikhel.Gupta@csiro.au

Cosmology papers that include machine learning methods in the abstract or title!



Thanks!

See you later for discussions!

Nikhel.Gupta@csiro.au