# Searching for Strong Gravitational Lenses in the Dark Energy Survey

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OSG

Department of Physics
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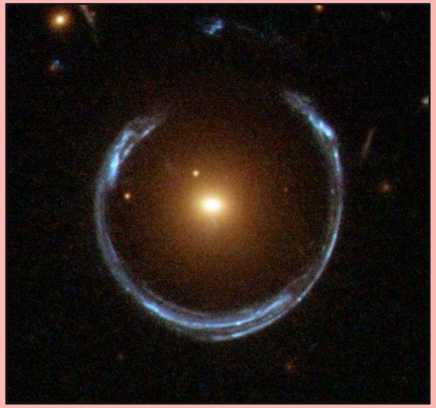
DARK ENERGY SURVEY

# OUTLINE

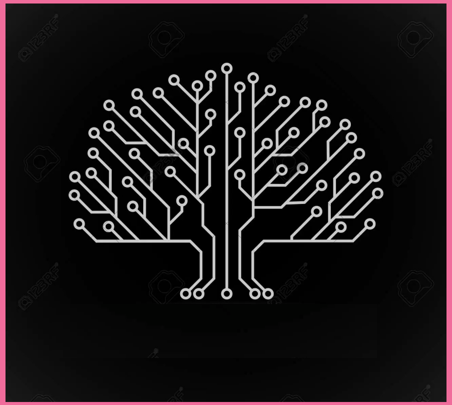
## INTRODUCTION

- Strong lensing
- Science applications
- Challenge context



## PROJECT WORKFLOW

1 - Training sample
2 - Machine Learning Training
3 - Complete Search



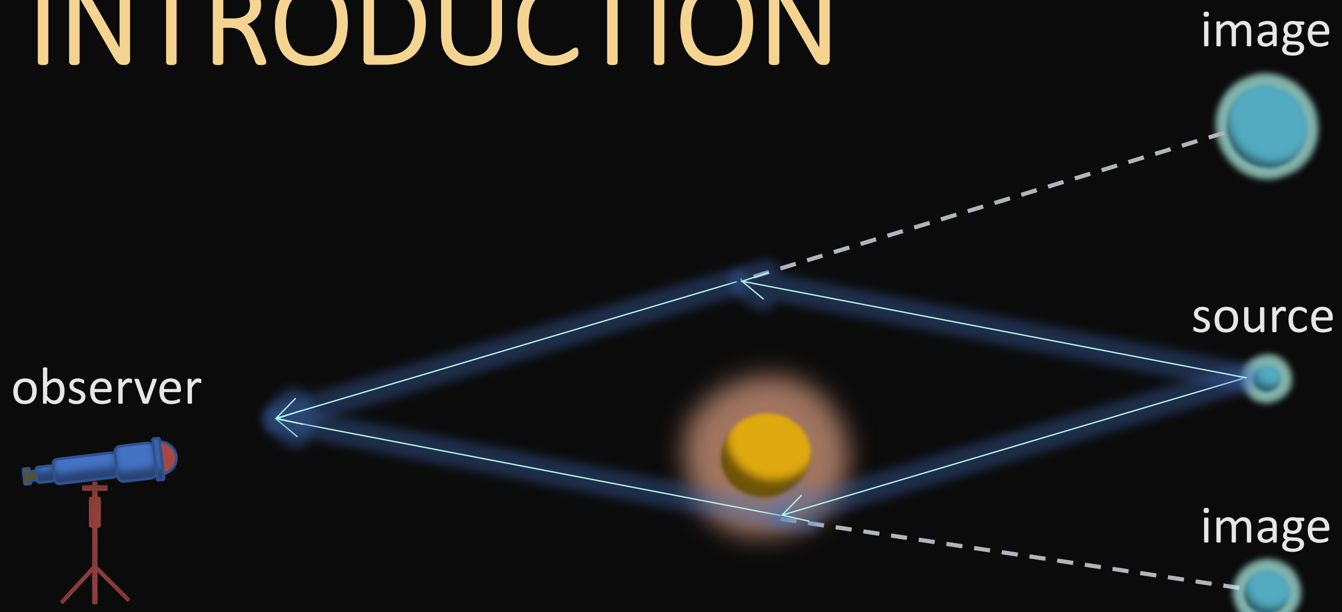
## IMPLEMENTING HTC & OSPOOL

- Before attending the OSG school
- Transition & challenges

## IMPACT OF HTC & OSG

- Quantitative impact
- Pushing the limits

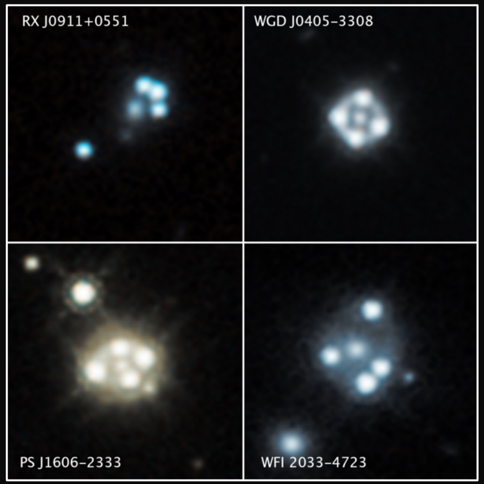
# INTRODUCTION




## Strong Lensing Observables:

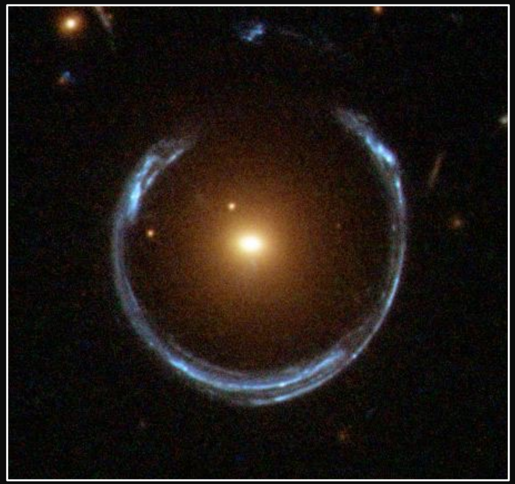
- Image positions
- Relative magnifications
- Time delays between images

Point Source




Credit: Forbes

Extended Source

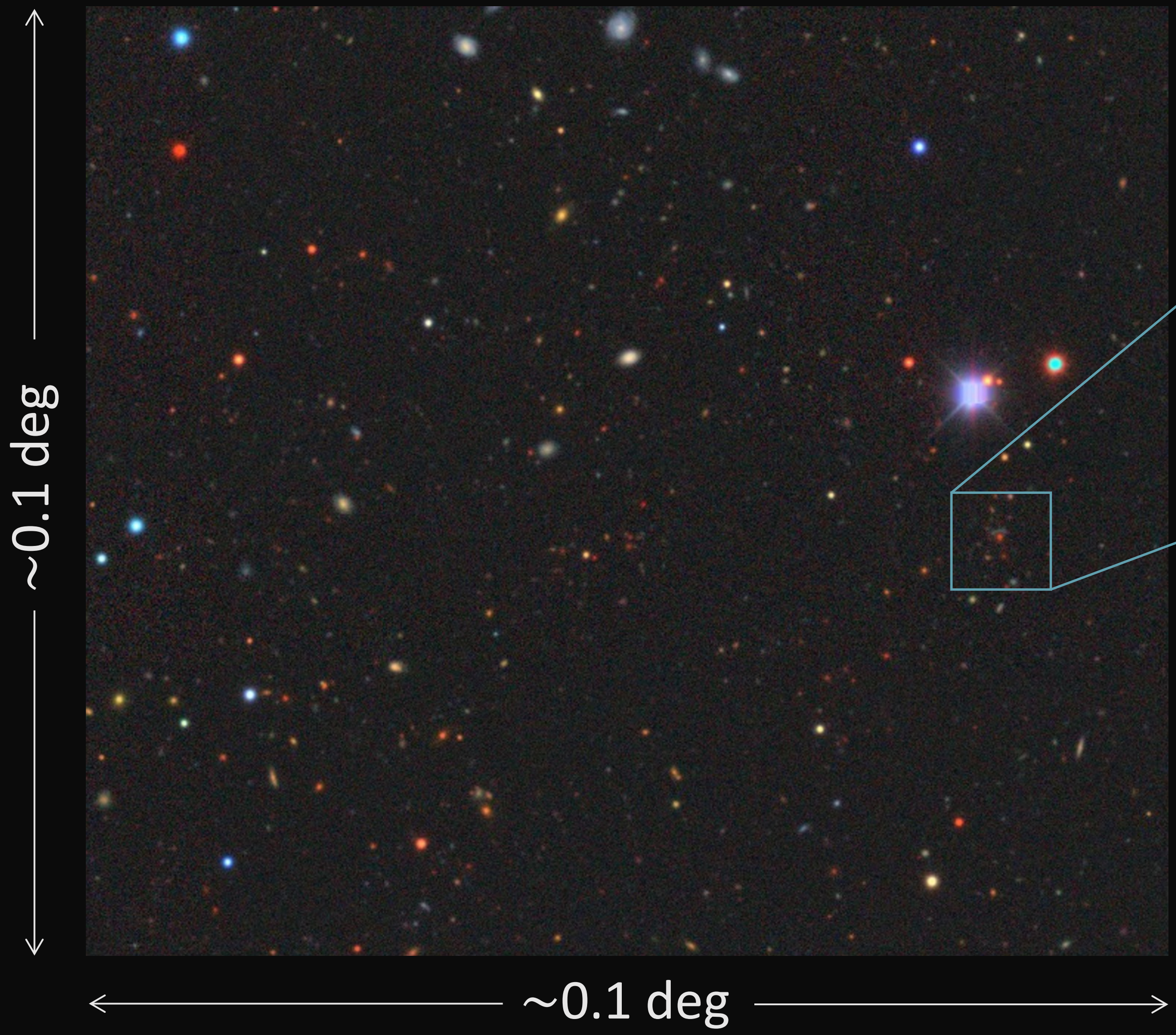


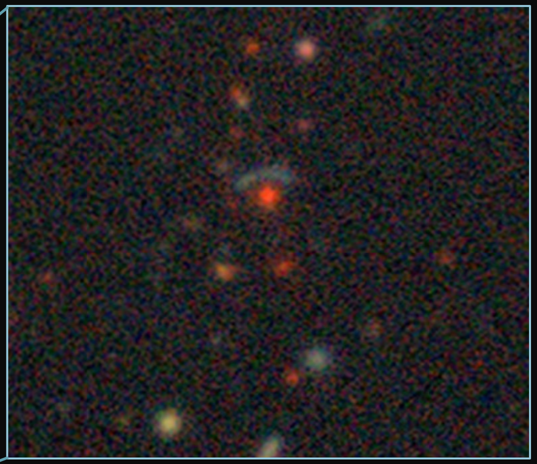
Credit: Wikipedia

## Science Applications:

| Elliptical Galaxies | Cosmology |
|---|---|
| Mass Structure | Dark Energy |
| Formation | Dark Matter |
| Evolution | Expansion History |

# STRONG LENSING IN THE DARK ENERGY SURVEY



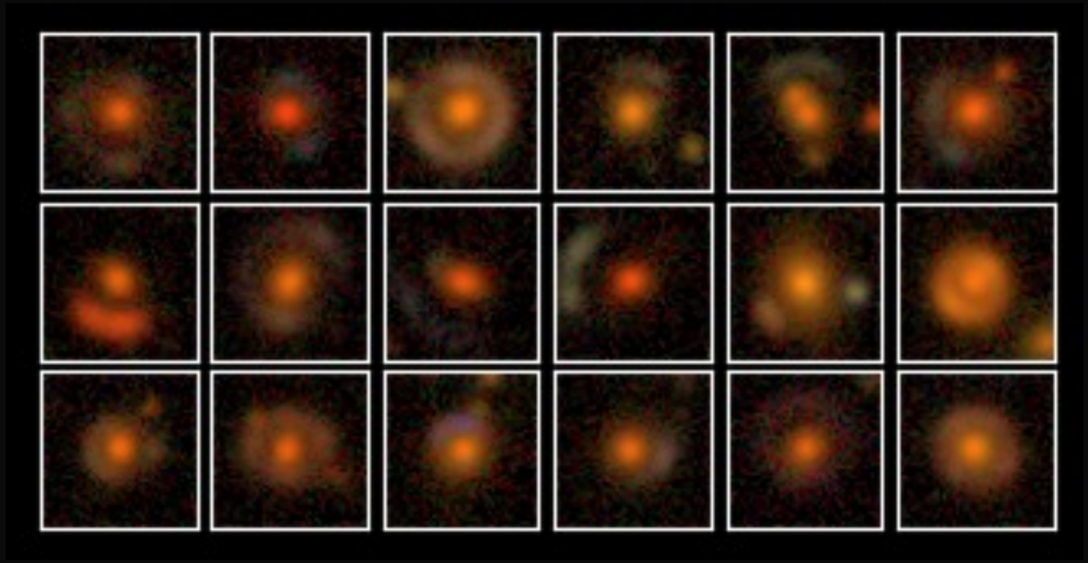



DES covers 5,000 sq deg. -> 500,000 times larger than the image shown.

Expectation: hundreds of strong lenses in complete data.

# 1- TRAINING SAMPLE: POSITIVE CLASS

## Simulations



We control the quality of the simulations by setting constraints on simulation properties.

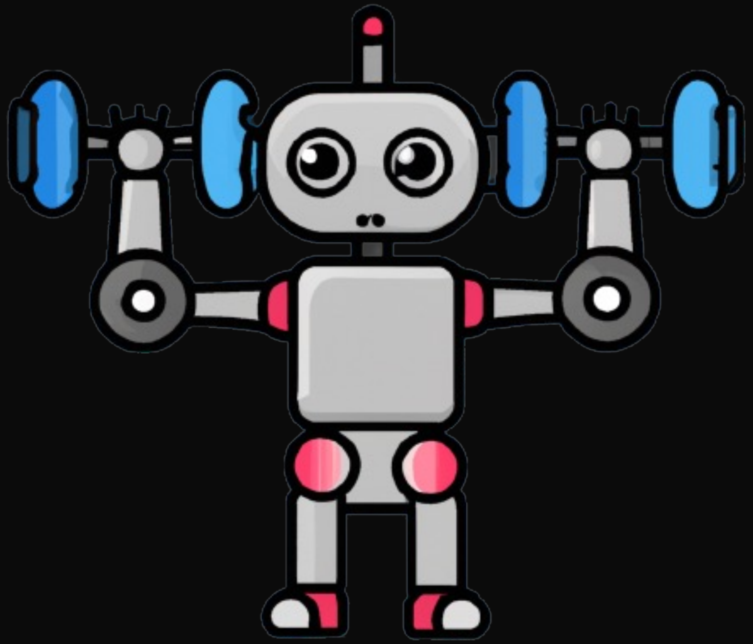
Created with Lenstronomy (Birrer & Amara 2018, Birrer et al. 2021)

## Computational Limits:

- Need thousands of simulations: ~2 days (for 15,000 simulations)
- Tighter constraints require more time: 2 days -> 4 days

➜ Couldn't experiment much with simulations with different properties.

# 2- MACHINE LEARNING TRAINING



## Machine learning model:

- Vision Transformer (ViT): 86 million parameters.

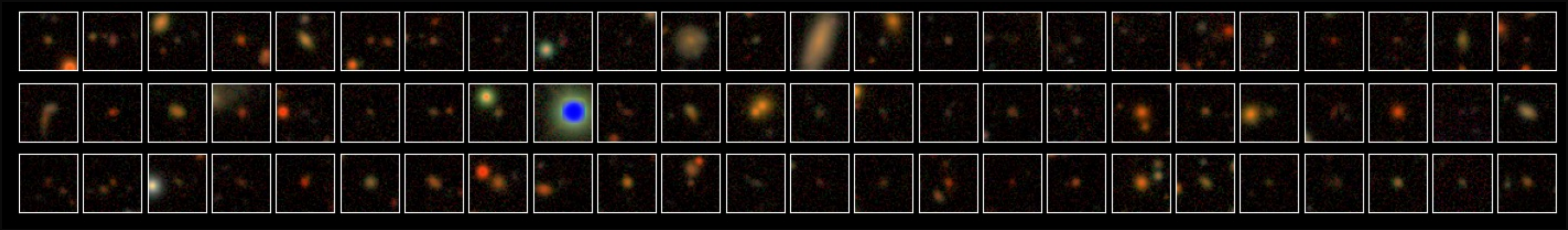
## Computational Limits:

- Training is time consuming: ~3 days on personal laptop.
- The larger the training sample, the more time is needed.

➜ Each training run is a big commitment.

# 3- COMPLETE SEARCH

Search: Must process 320 million images (1 TB)



Representation of 72 images

## Computational Limits:

- On personal laptop: 7 years
- On a cluster running in series: 4.5 years

→ When am I going to graduate?

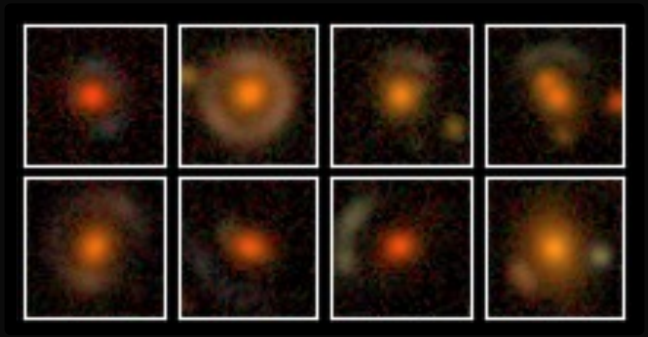
# CONTEXT: BEFORE THE OSG-USER SCHOOL

- Mostly doing simulations, and training. Taking ~2 weeks.
- Applying search to some images (80,000) to understand results. ~2 days
- Spending my time mostly waiting.
- Errors were expensive.

Elephant in the room: search on all the data.

# IMPLEMENTING HTC: 1 - SIMULATIONS

## How this task is parallelizable:



- Simulations are independent of each other.
- Each simulation only takes ~2 seconds.

## Implementing HTC: straight forward

- Organization: input files, output files and software.
- Modify code to receive important information as arguments. Example: number of simulations & random seed.
- Lots of testing!

# MOVING TO OSG: 2 - TRAINING

Challenge: Not easily parallelizable

- The learning process can't be divided into independent tasks.

OSG resources useful:

- A GPU made a large impact.

# IMPLEMENTING HTC: 3 - TOTAL SEARCH

## How this task is parallelizable:

- Images are independent of each other.
- The DES imaging data is divided into ~10,000 pieces (tiles), each containing 24,000 images.
- Processing each tile takes only 4 hours.

## Implementing HTC:

- Challenge: All input data is heavy and not public.
- Solution: implementing HTC with the resources I had available: FermiGrid. Same concepts, just different syntax.

# QUANTITATIVE IMPACT OF THE OSG SCHOOL

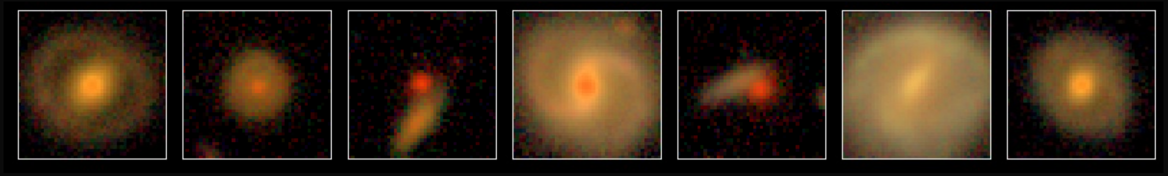
## 1- Simulations:


## 2- Training:

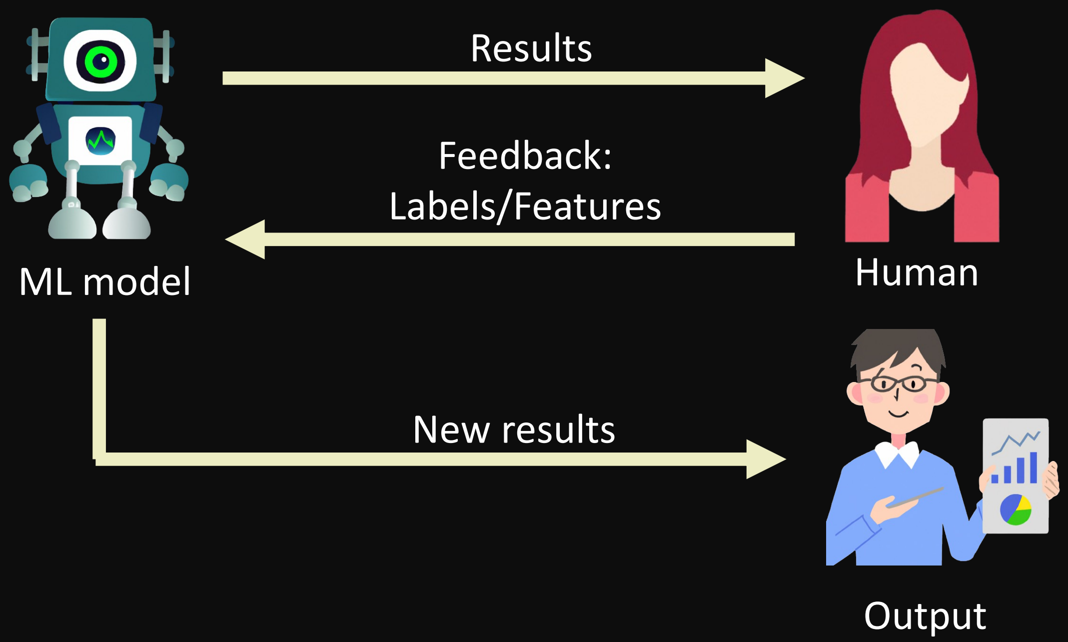

## 3- Complete Search

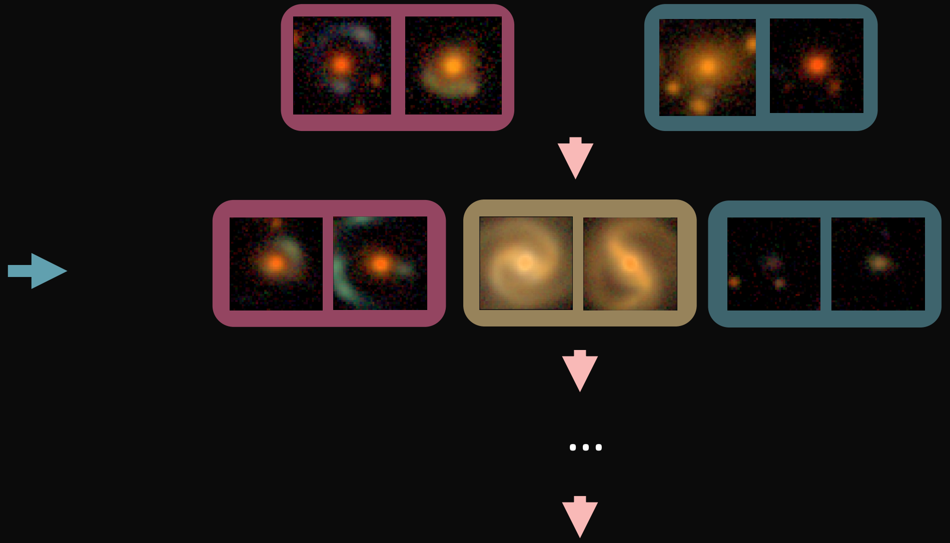
# PUSHING THE LIMITS

Challenge for these searches:
Purity rate of automatic searches: 1%



Possible to implement Interactive Machine Learning to improve our training sample:



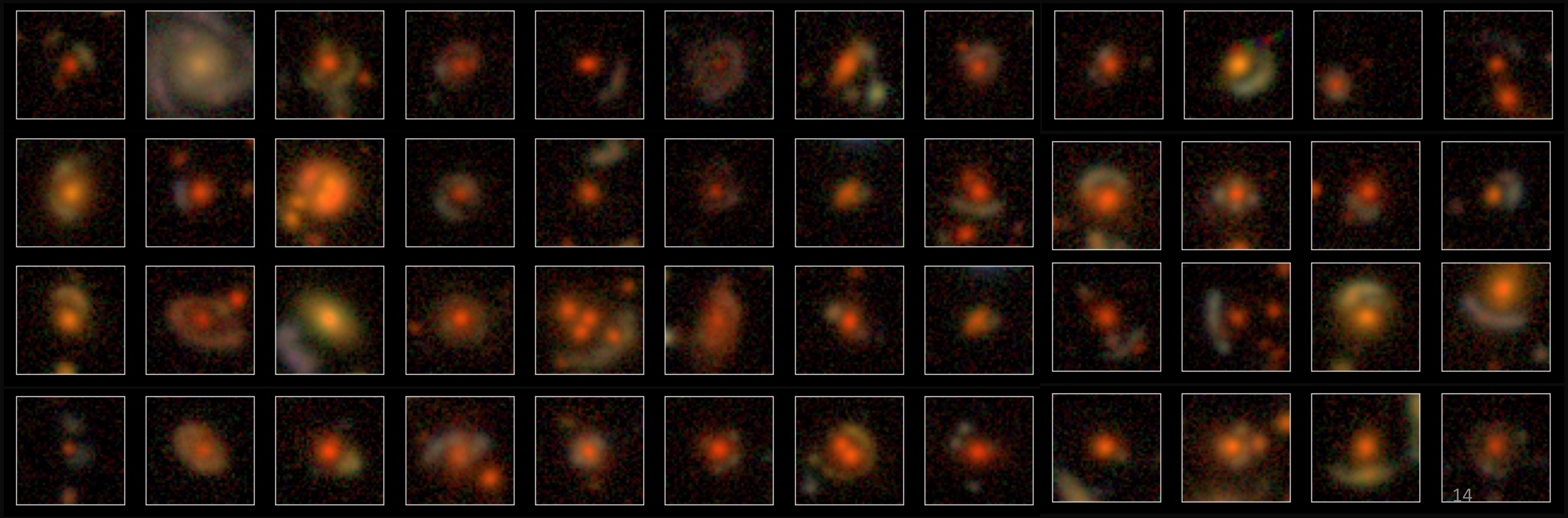




9 categories!

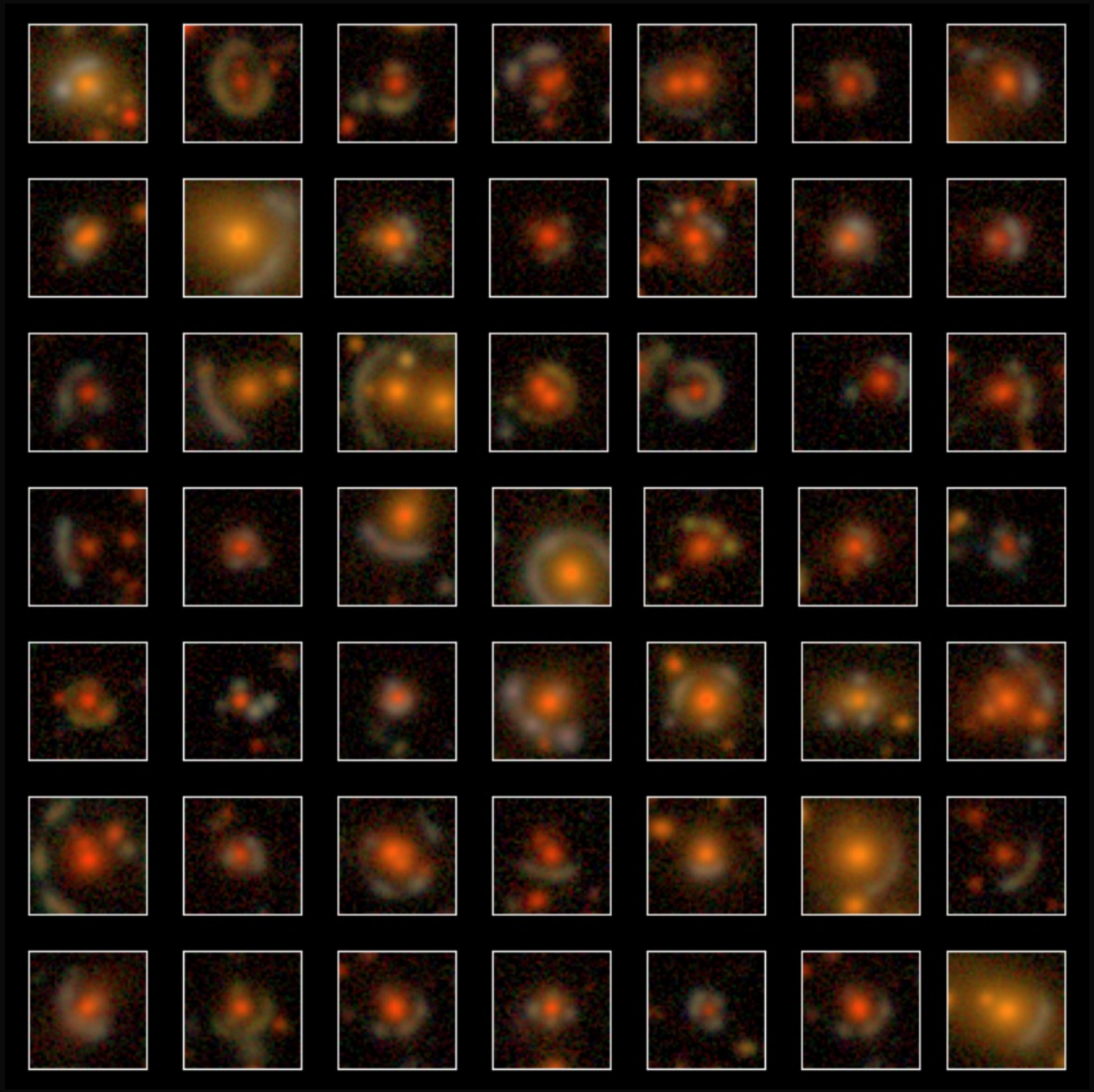
# SEARCH RESULTS

~230 million images → ViT trained model → 20,600 candidates

Random sample of candidates with probability ~1 (~900):



# CONCLUSION



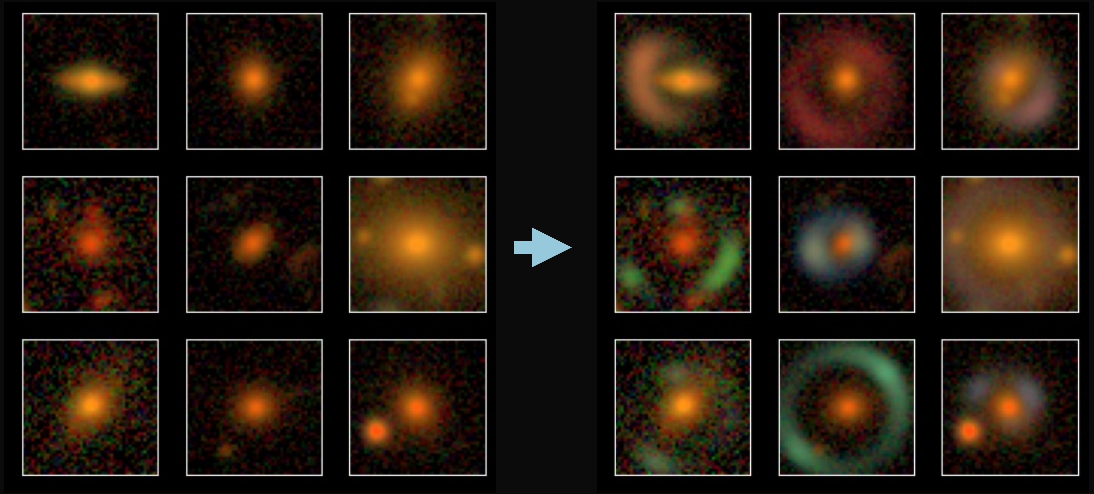
State of the project:

- Preparing a crowdsourcing project in Zooniverse to extract the compelling candidates.
- More plans with OSG: characterizing the final candidates.

Thanks to the OSG consortium for allowing me to focus on the science, instead of the computational limitations.

# EXTRA SLIDES: TRAINING SAMPLE

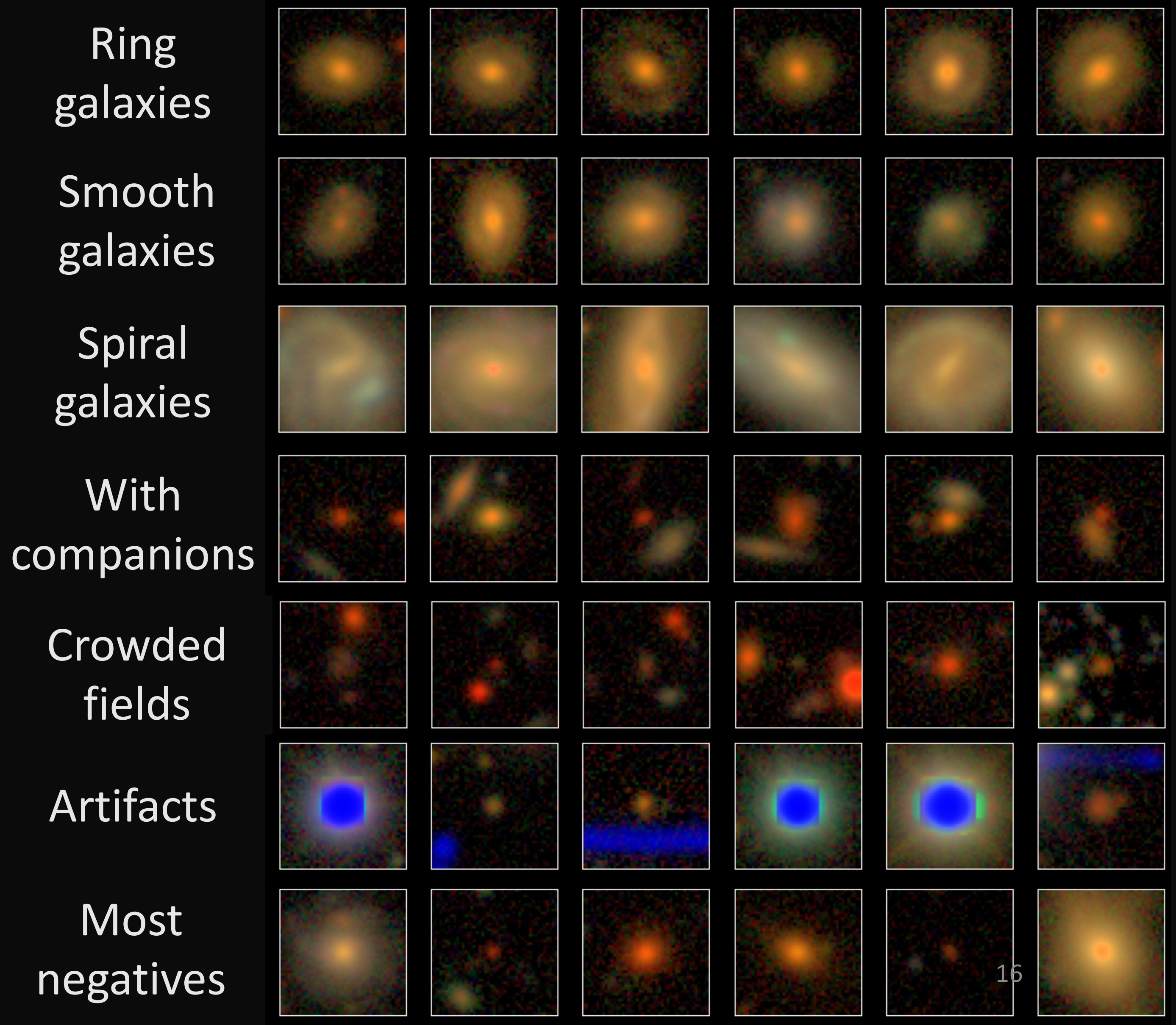
## Positive training sample “Single”:



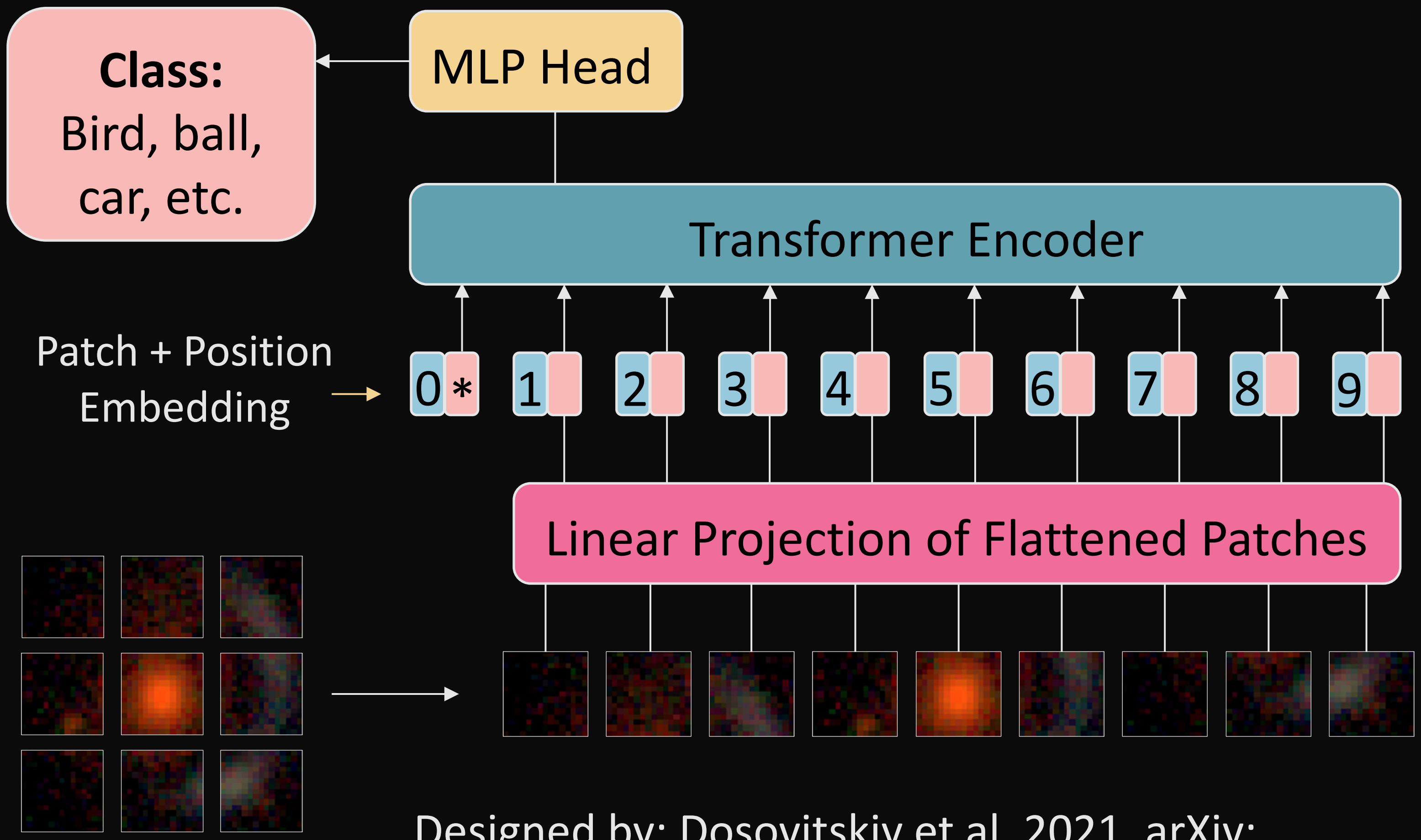
Created with Lenstronomy (Birrer & Amara 2018, Birrer et al. 2021)

We control the “quality” of the simulations by setting constraints: Magnification, position of the images, contrast of arc simulation, etc.

## Negative training sample:



# EXTRA SLIDES: THE VISION TRANSFOMER (ViT)

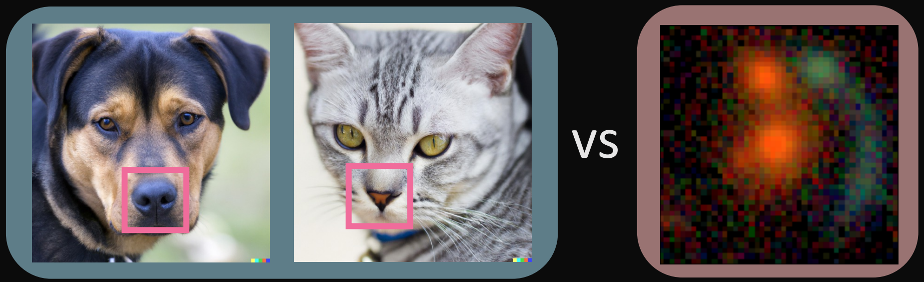



Designed by: Dosovitskiy et al. 2021. arXiv: 2010.11929

## CHARACTERISTICS:

Larger receptive field

→ Better for global features




Performs the same or better than state of the art CNN models when pre-trained on large datasets.