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Applications in Medicine and Physics

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Characteristic sky background features around galaxy mergers

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7th June, 2024

Outline



Based on the work of:

Suelves, Pearson, & Pollo (2023) (published in A&A)

Life of a galaxy

The finding: Sky background error `skyErr`

Extension: deeper imaging in Subaru/HSC

Conclusions

Life of a galaxy

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Conclusions

Galaxies



NGC 1300



- Stars
- Gas
- Dust
- Planets

Credit: Hubble Space Telescope (HST), NASA/ESA

Galaxy Mergers



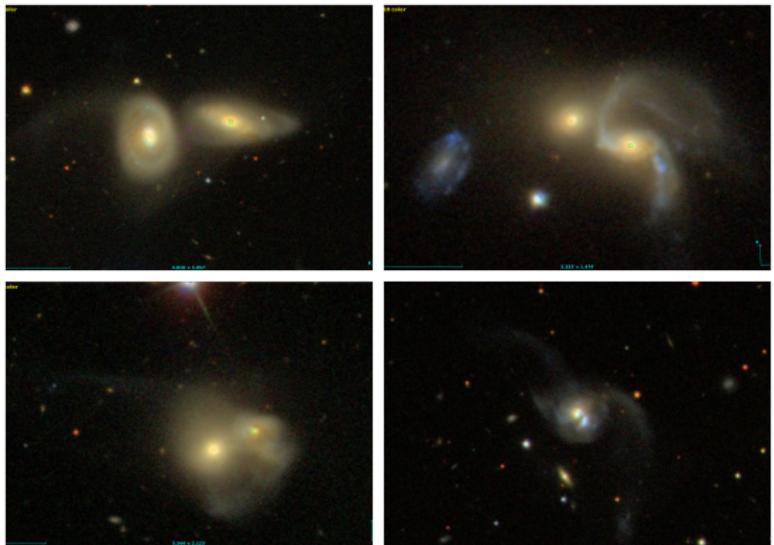
Credit: Hubble Space Telescope (HST), NASA/ESA

Galaxy Mergers



Credit: Hubble Space Telescope (HST), NASA/ESA

Why Galaxy Mergers



Drive galactic evolution?

- Early-Late type gal transformations:
Quenching and SF
- Growth of Structure
- Time scales
- Milky Way + Andromeda

Credit: SDSS

But first, we need to find them

But first, we need to find them

Merger Identification!!

Merger Identification Methods



Visual Inspection

Professionals look at astronomical frames

Close Pairs

Pairing sky-neighbours at similar radial distance

Morphological Analysis

Parameters that quantify shape distortions



Visual Inspection

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Morphological Analysis

Parameters that quantify shape distortions

Convolutional Neural Networks (CNN)

Models that learn properties that characterize pre-classified galaxies **from the images**



ML method using, only Photometry?



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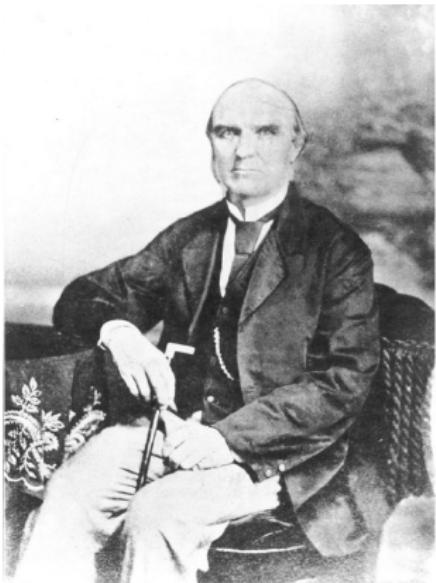
Saving time + resources
&
Learning new properties



Based on the work of: Suelves, Pearson, & Pollo (2023), A&A

What is photometry?

Magnitude Calculation



1856, Norman R. Pogson defined:
magnitude m from a flux F

$$m_{\text{source}} = -2.5 \log F_{\text{source}} .$$

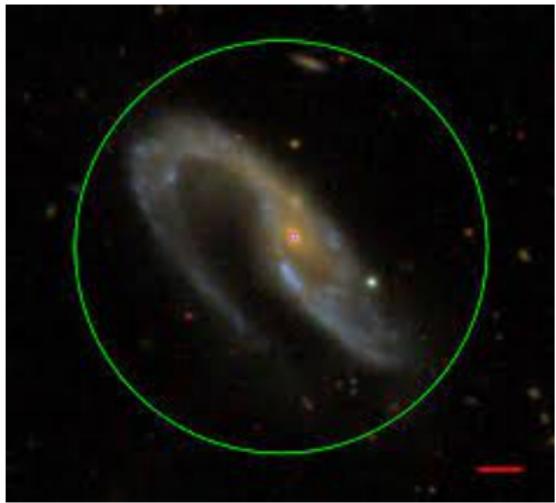
Credit: Wikipedia

Aperture Magnitudes

Surface Brightness



Sloan Digital Sky Survey (SDSS)



Counts in the pixels within the aperture



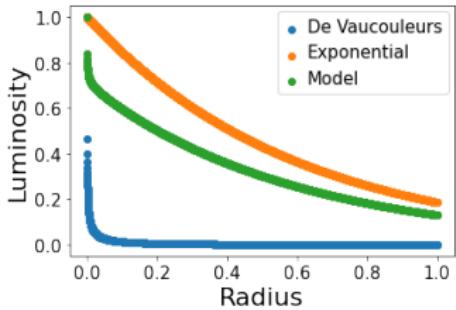
Magnitude inside the fiber's 3
arcsecs ϕ aperture

Model Magnitudes

Surface Brightness



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Model magnitude in SDSS Fluxes are calculated from integrating the Brightness Model (or Intensity Profile)

$$\frac{r_{DeV}}{r} = 0.3$$

$$F \sim 2\pi \int_0^r I(r) r dr . \quad (1)$$

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Citizen Science project for visual classification of galaxies
Result: merger vote fraction f_M

The screenshot shows the Galaxy Zoo.org homepage. At the top, there's a navigation bar with links: Hi starstryder, Home, The Science, How to Take Part, Galaxy Analysis, Forum, Press, Blog, FAQ, Links, Contact Us, Logout, and Profile. Below the navigation is a large "GALAXY ZOO.org" logo with a yellow sun-like icon. To the left, a sidebar titled "Galaxy Analysis" contains links: Galaxy Tutorial, Galaxy Analysis, Galaxy Zoo - Thank You, and Show My Galaxies. The main content area features a large image of a spiral galaxy with a central bright core. To the right of the image, the text "Galaxy Ref: 587729387677679742" is displayed, followed by the instruction "Choose the Galaxy Profile by clicking the buttons below". Below this are four profile buttons: "Spiral Galaxy" (selected), "Elliptical Galaxy", "Starburst Galaxy", and "Merger". At the bottom of the image area is a checkbox labeled "Show Grid Overlay on the next Image".

Training dataset

Source Selection



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Mergers

- from Darg et al (2010), confirming high f_M are mergers

Non-Mergers

- from Galaxy Zoo's low f_M

Class-Balanced Dataset

- Training: 2 680 Mergers + 2 680 Non-mergers
- Test: 250 + 250
- Distance: redshift $z \in [0.01, 0.1]$
- Nearest neighbour match (r -mag, spec-z)



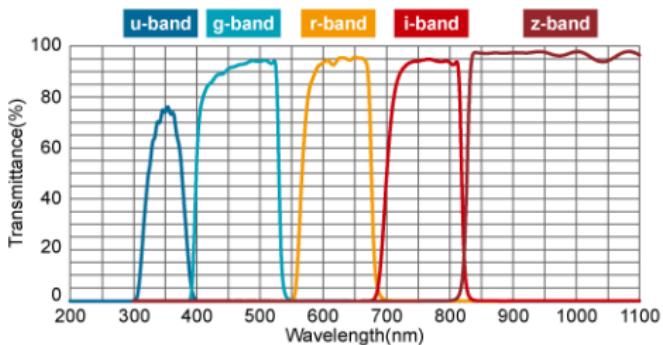
Credit: SDSS DR9, Aladin, Darg et al (2010)

Training dataset, Inputs



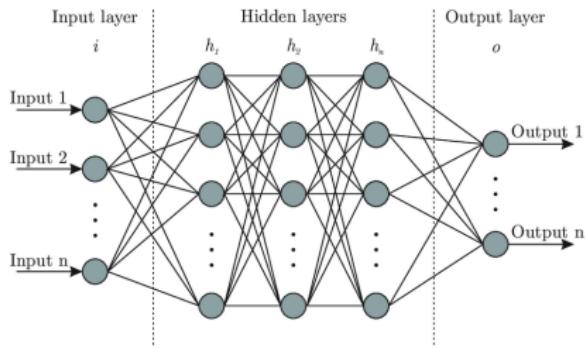
Input Information

- Magnitudes, colours, and errors
- Model and Aperture flux calc. methods
- Five optical bands



COLORS?! the subtraction between two bands' magnitude $\rightarrow r-g$

Neural Network



*Classification method using internal layers
of mathematical connections*

Input: Photometric information
→ Training Data

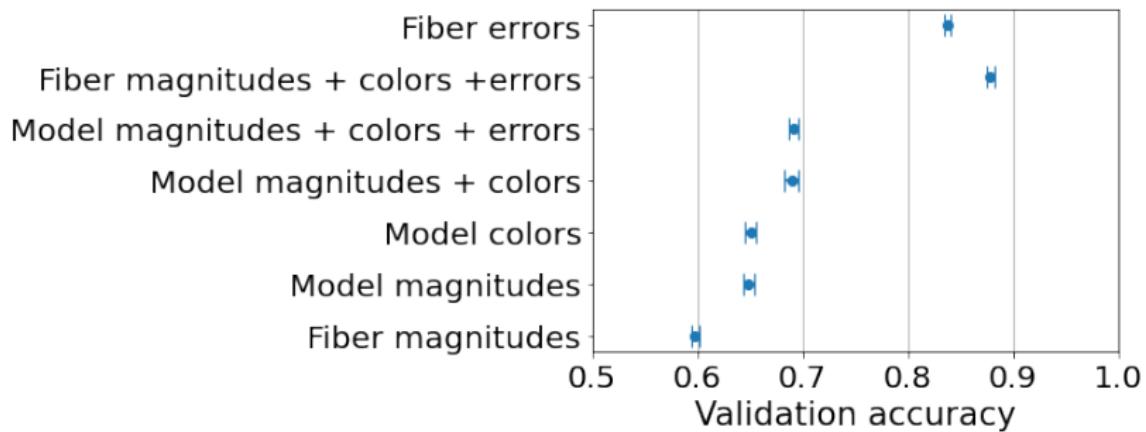
Internal layers: trained
parameters

Output: Binary Classification
→ Labels: Merger or Non-Merger

Photometric Results

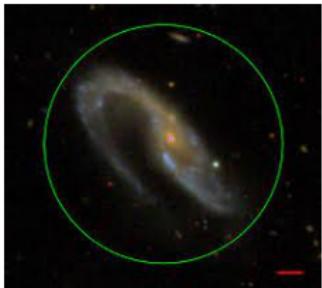
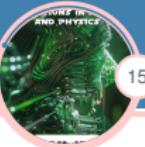


From k-fold cross-validation (k=5)



Credit: Suelves +23

Fiber magnitude and errors



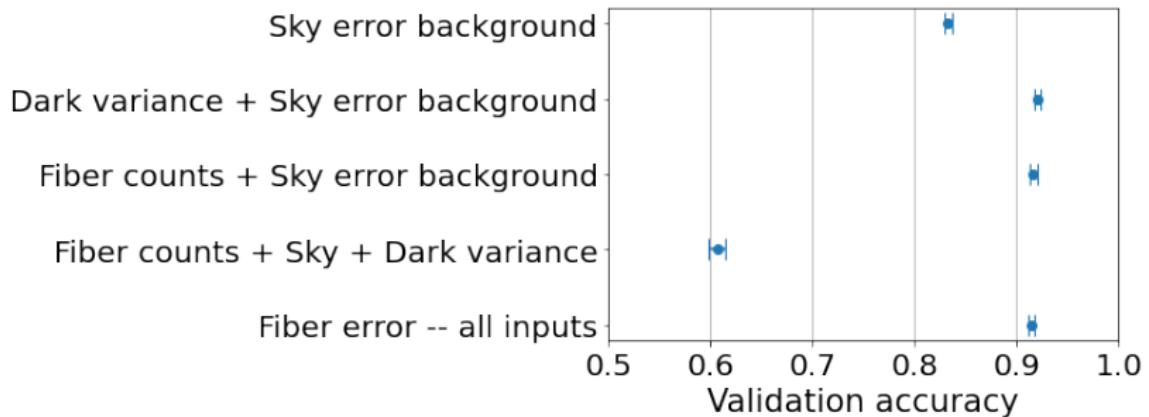
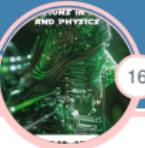
SDSS Fibers' 3 arcsec ϕ aperture

The fiber error depends on four variables:

- Aperture counts
- Dark current variance
- Sky background
- Sky background error

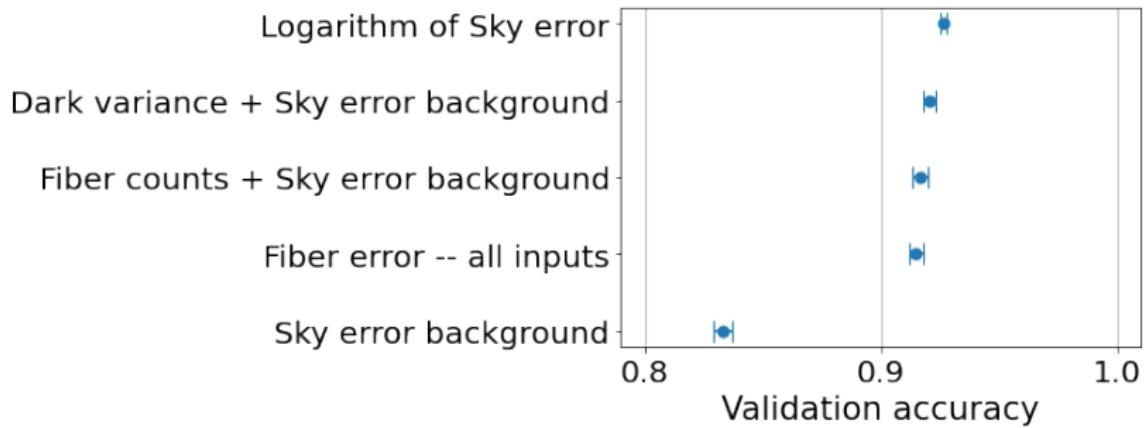
Fiber error input's results

SDSS's fibers



Credit: Suelves +23

Logarithmic skyErr

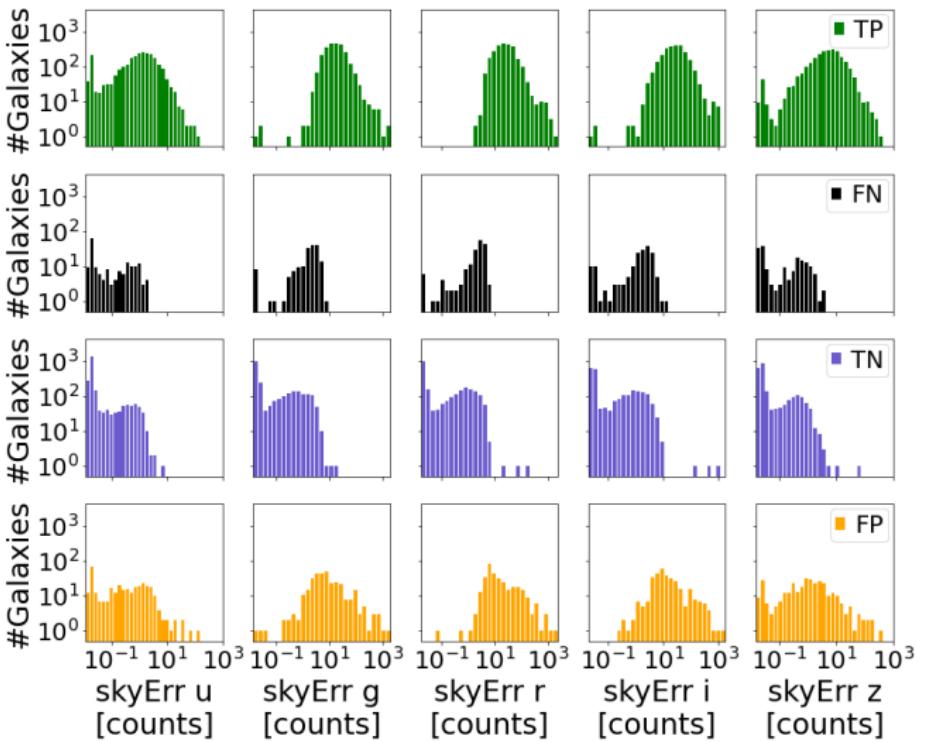


Credit: Suelves +23

Logarithmic 5-bands sky error accuracy:

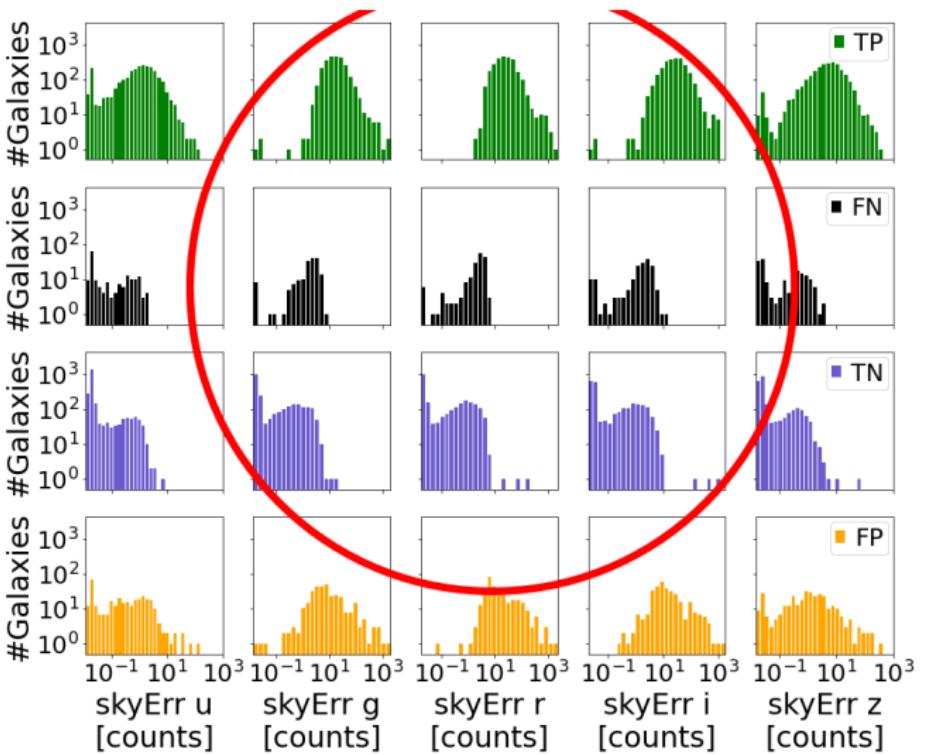
- Validation: $92.64 \pm 0.15\%$
- Test: $92.36 \pm 0.21\%$

Logarithmic skyErr, feature space



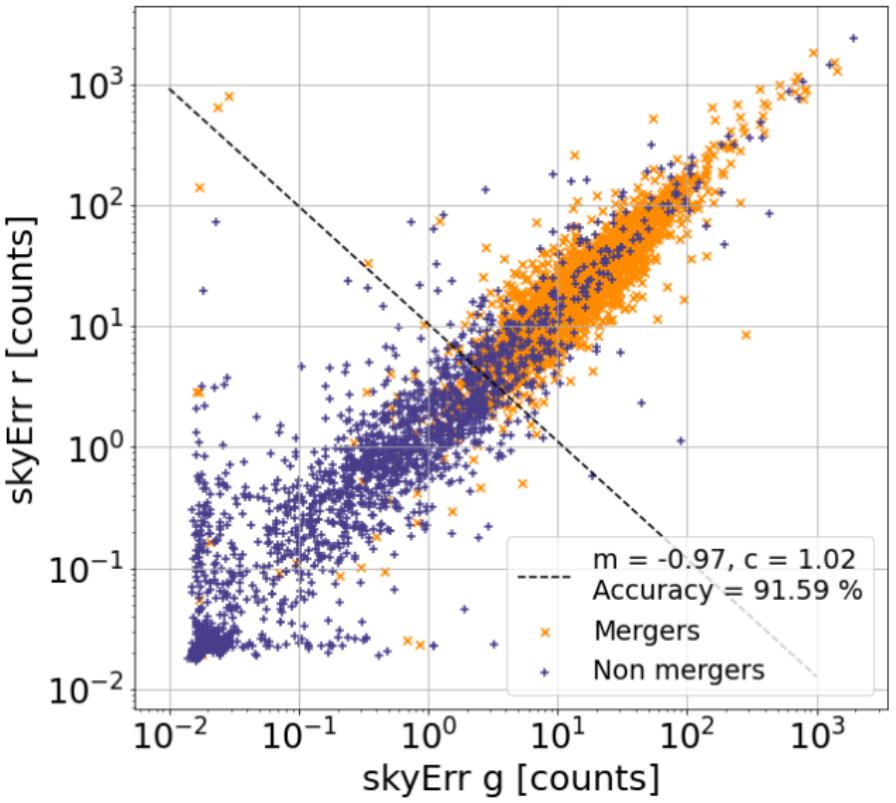
Credit: Suelves +23

Logarithmic skyErr, feature space



Credit: Suelves +23

Decision Boundary



Credit: Suelves +23

Sky background error



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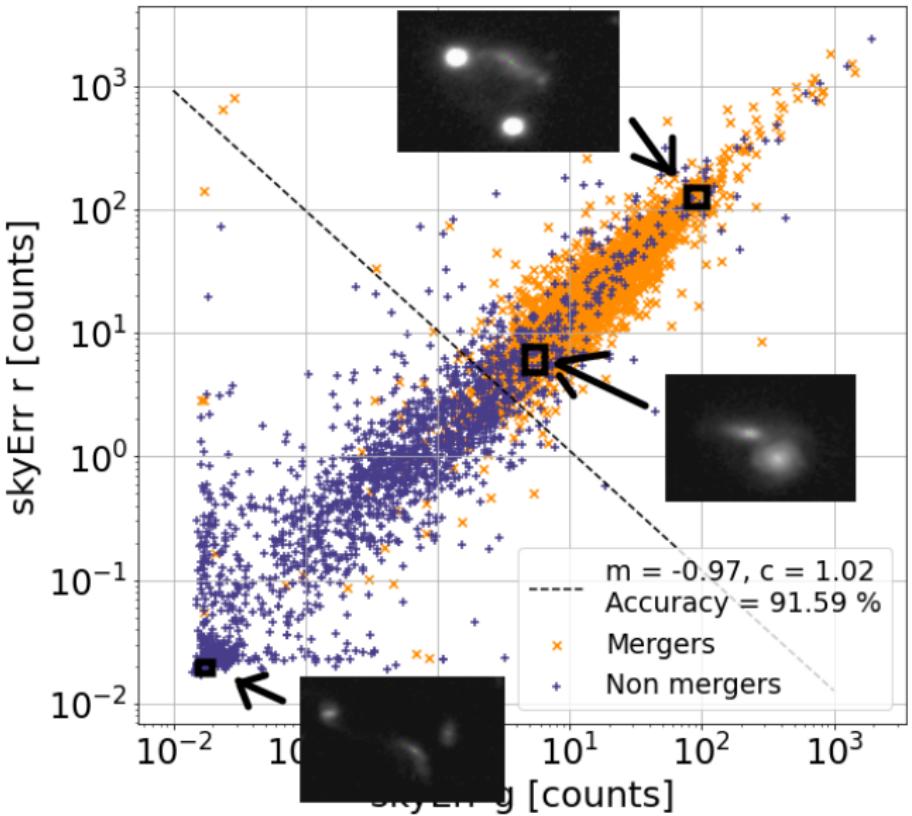
Physics: sky error traces (*low S/N?*) structures



Mergers along the diagram



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Conclusions

Subaru/HSC



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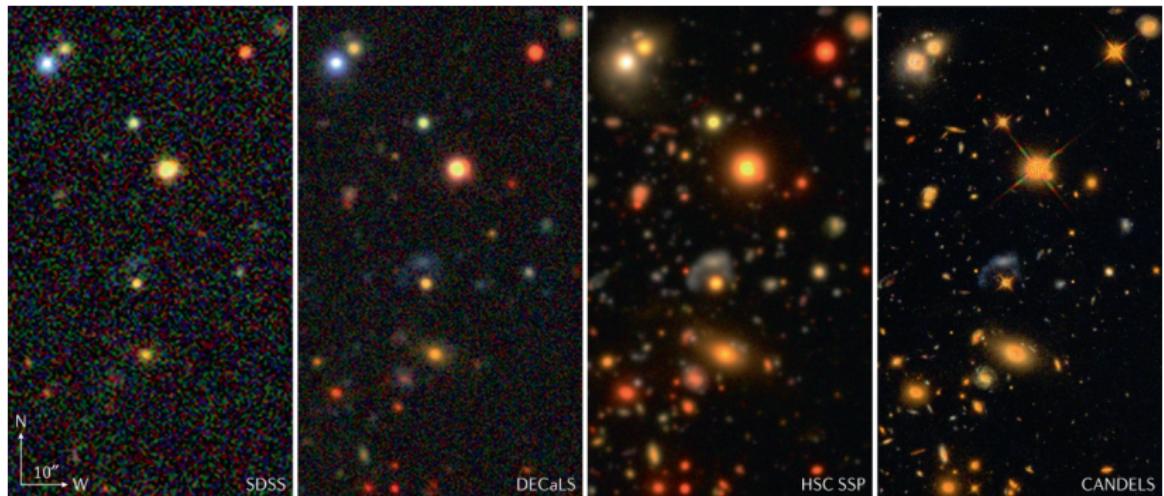


Credit: <https://www.subarutelescope.org/>

Image Depth in astronomy

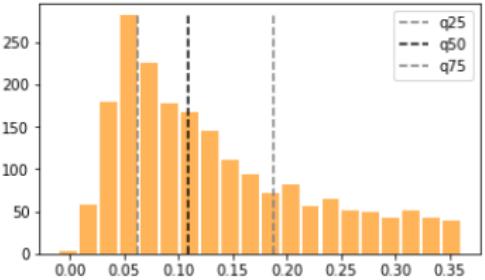
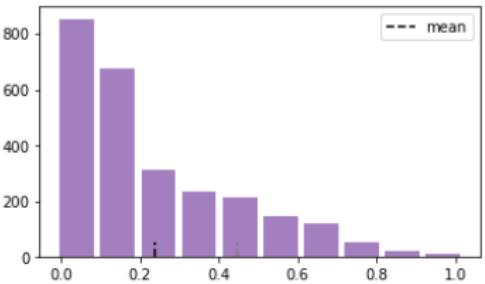
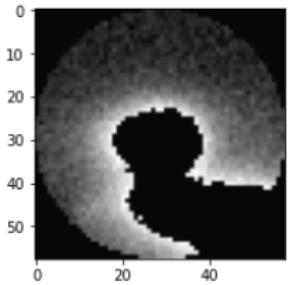
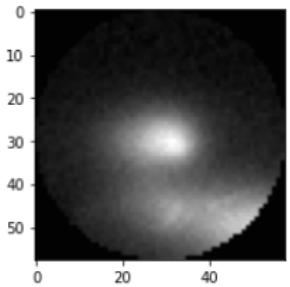


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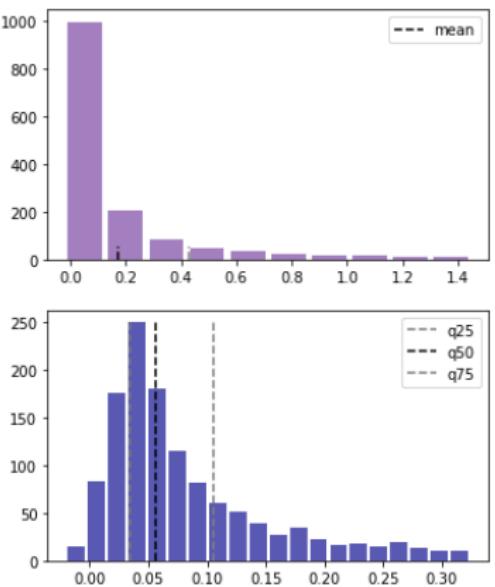
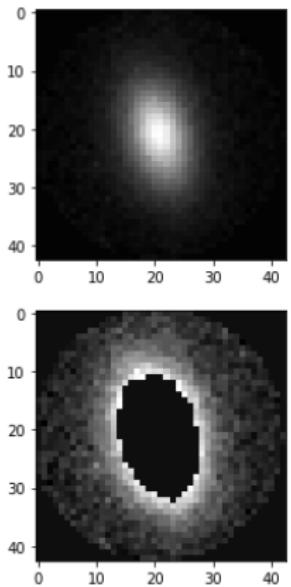


Credit: Melchior +21

HSC, low-surface brightness around mergers

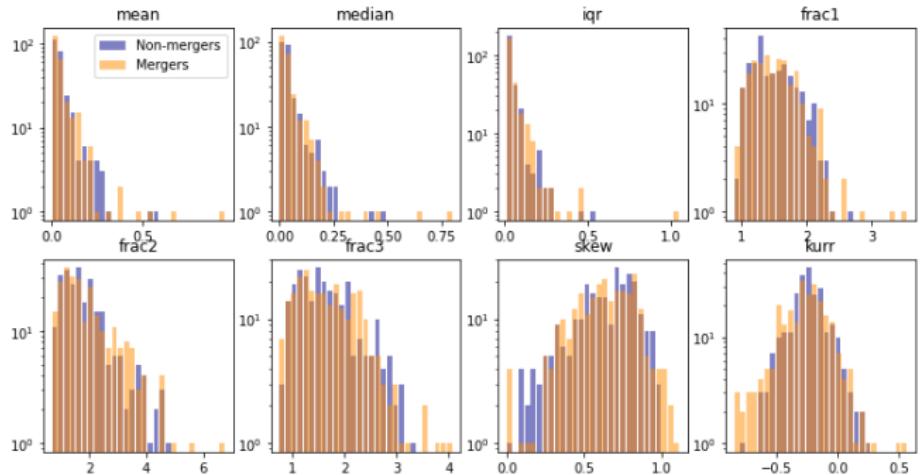


Low-surface brightness around non-mergers



New Parameter Space!

Usual HSC sky



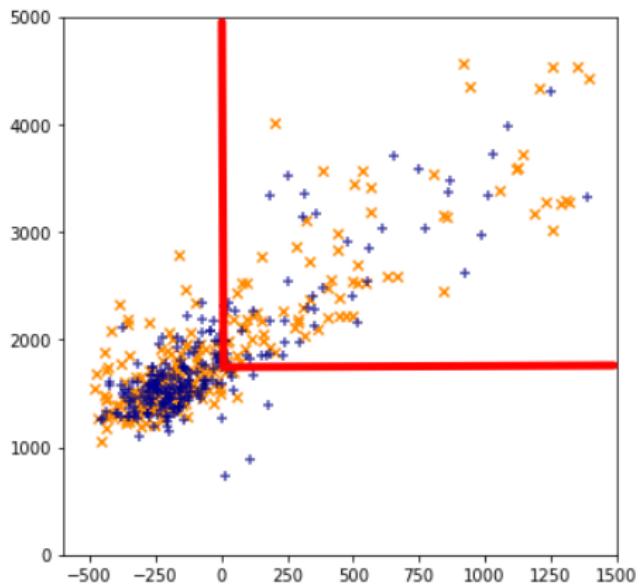
FINAL GOAL



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- Combine parameters
- Reduce dimensionality
- Find a region occupied by mergers

NCA (zoomed), All 8 parameters, My sky



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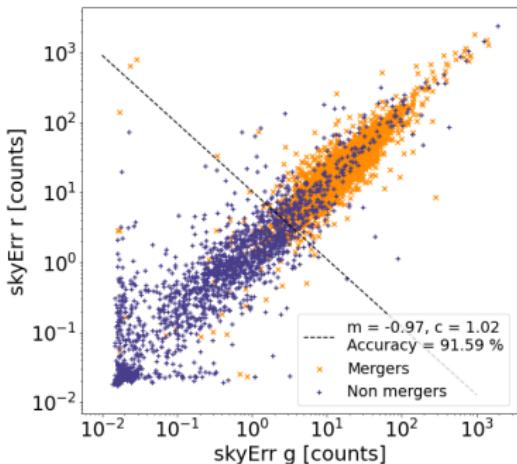


Future Work

- ▶ Extend it to deeper images:
Dimensionality Reduction helping to
find parameters
- ▶ Apply a CNN on galaxy residuals:
Dawid Chudy, from UJ, is testing it

Take-home message

- ▶ Sky error as trace of merging processes
- ▶ Neural Network (NN) led to discover an
unknown property! **By studying the
relation between NN input and
output-classification**



Thank you!



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Binary Classification: labels Merger or Non-Merger

- ▶ 2 Dense layers of 16 neurons
- ▶ ReLU activation function
- ▶ 0.2 dropout rate
- ▶ Output: softmax probability
- ▶ Min-max normalization $x_{norm} = (x - \min(x)) / (\max(x) - \min(x))$

```
class photo_model(tf.keras.Model):
    def __init__(self):
        ## I'm trying to name each layer and see if the loading is managed through it
        super(photo_model, self).__init__()
        self.drop_rate = 0.1

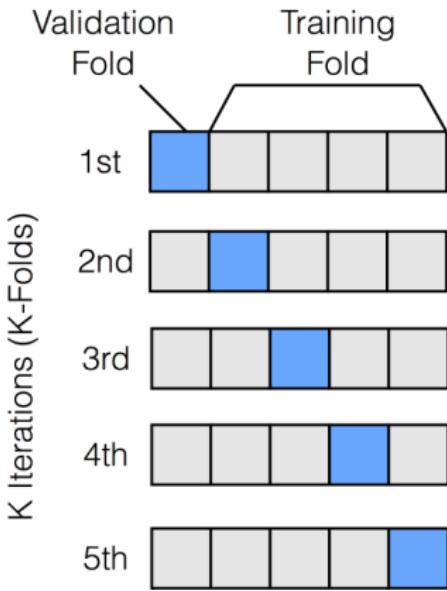
        self.fucol = tf.keras.layers.Dense(16, name='dens_1')
        self.batn1 = tf.keras.layers.BatchNormalization(name='btchn_1')
        self.drop1 = tf.keras.layers.Dropout(self.drop_rate, name='drop_1')

        self.fuc05 = tf.keras.layers.Dense(16, name='dens_2')
        self.batn5 = tf.keras.layers.BatchNormalization(name='btchn_2')
        self.drop5 = tf.keras.layers.Dropout(self.drop_rate, name='drop_1')

        self.y_out = tf.keras.layers.Dense(NO_CLASS, activation='softmax', name='out')
```

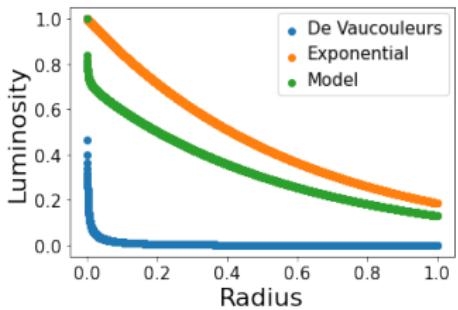


Adam training method 5-fold Validation



Model Magnitudes, Surface Brightness

Appendix 3



Model magnitude in SDSS

$$F_{\text{model}} = \textit{frac}_{DeV} F_{deV} + (1 - \textit{frac}_{DeV}) F_{exp},$$

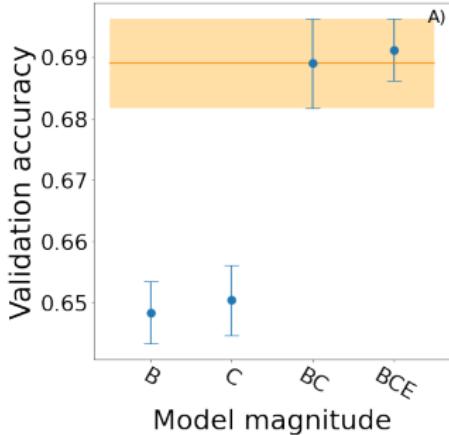
Fluxes are calculated from integrating the
Brightness Model (or Intensity Profile)

$$\textit{frac}_{DeV} = 0.3$$

$$F \sim 2\pi \int_0^r I(r) r dr .$$

NN training over different Inputs

Appendix 4



Credit: Suelves +23

