GSpyNetTree-O: An Extension to *GSpyNetTree*'s Signal vs. Glitch Classification Algorithm for Overlapping Compact Binary Coalescence Signals

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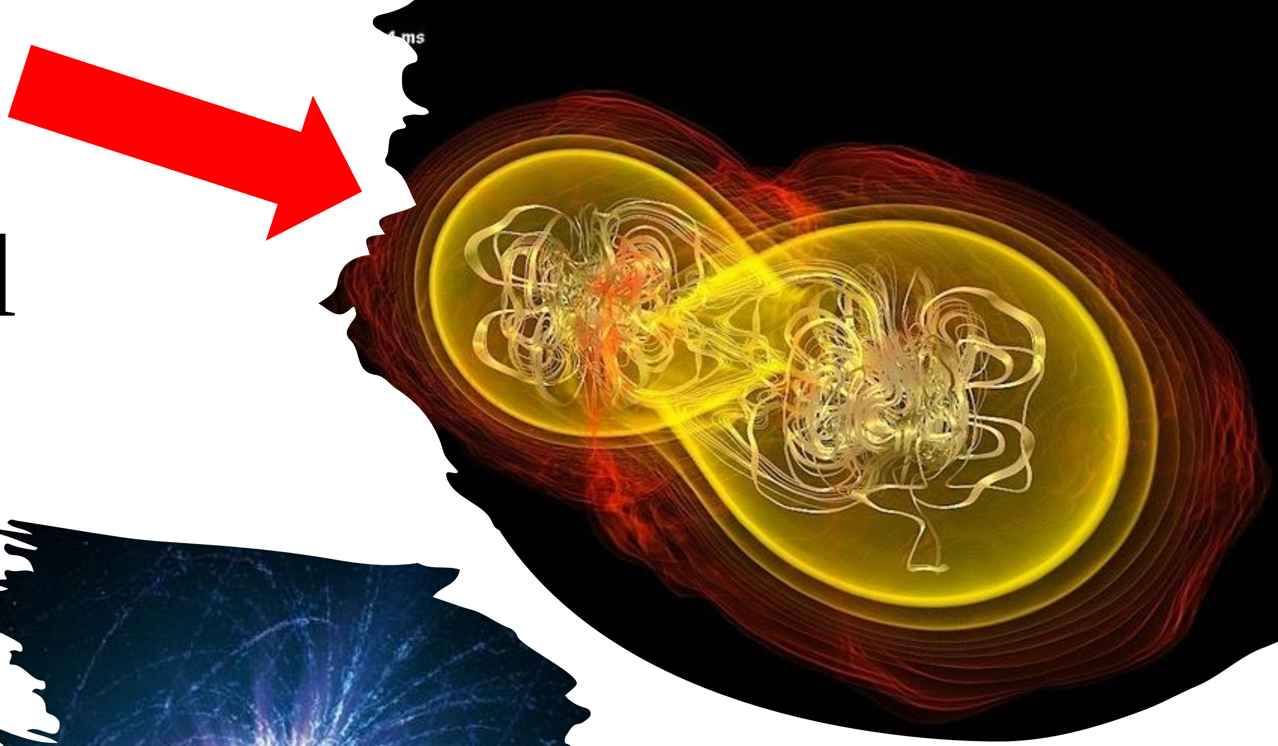
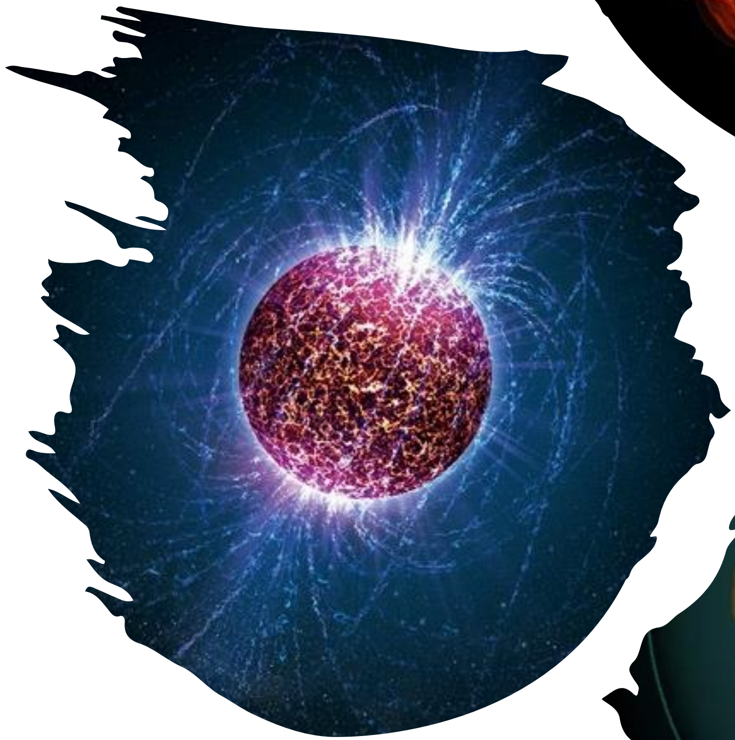
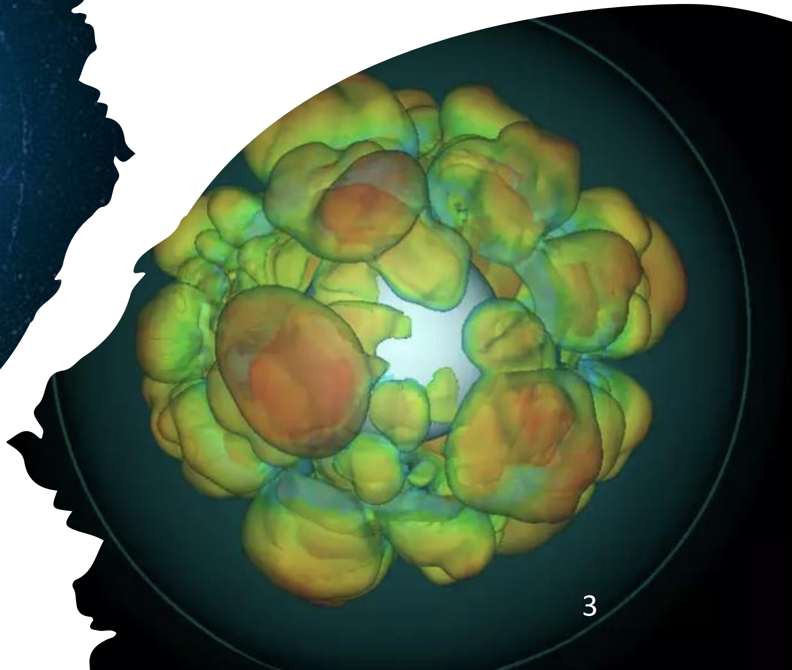
What are Gravitational Waves (GW)?



- “Ripples” in spacetime
- Can originate from various sources
- Very hard to detect
  - Thousands time smaller than diameter of proton



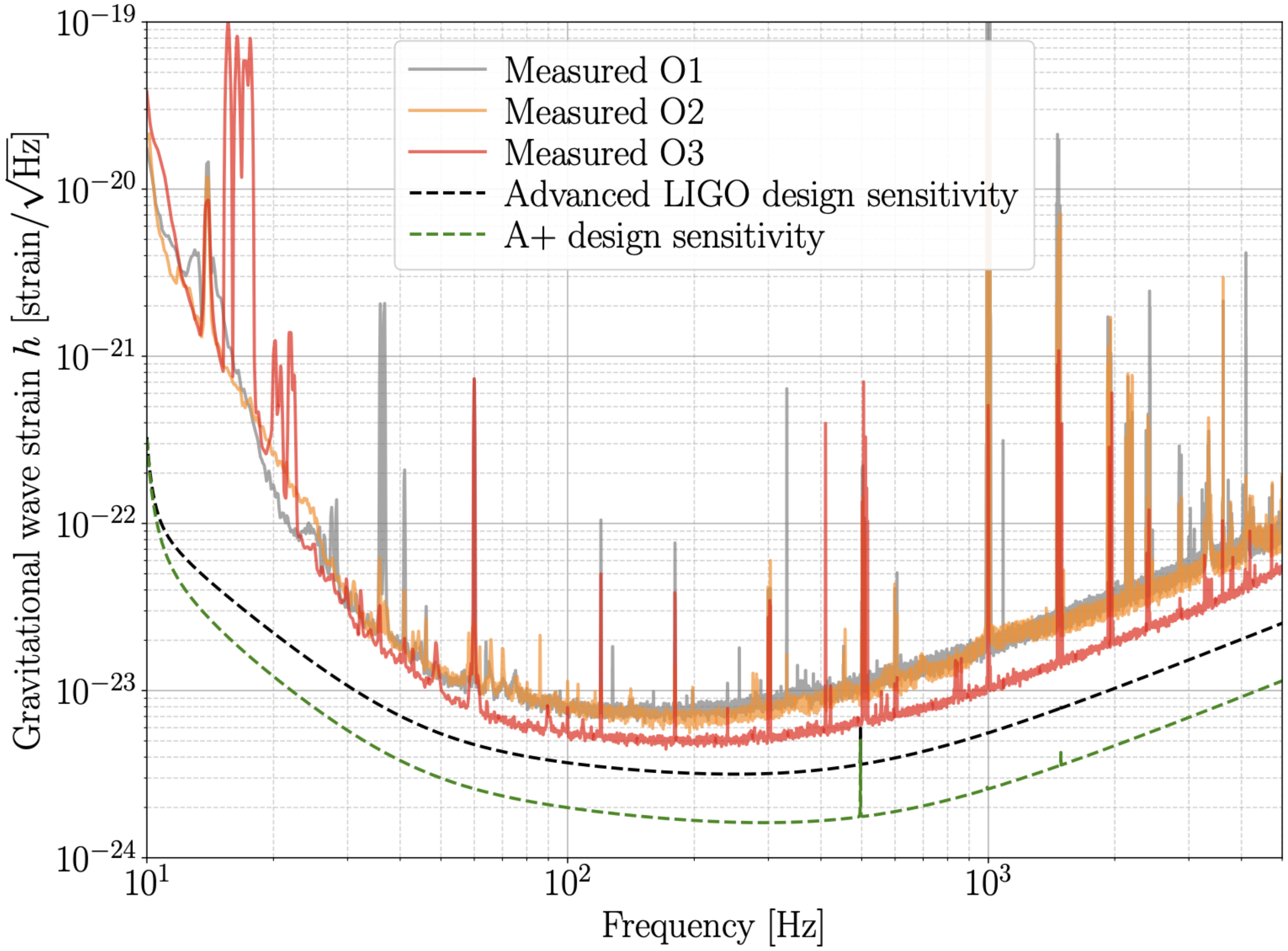


Figures adapted from [2], [3]

Motivation – O4 and Sensitivity Range

- Fourth Observation Run (O4) scheduled to start in May 2023
- Detector Sensitivity Upgrades
  - Lower noise floor
  - Frequency range approximately 10-2000 Hz

Motivation – O4 and Sensitivity Range



C. Cahillane and G. Mansell., 2022 [4]

Motivation – Probability of Overlapping in O4

- Projected O4 detection rate = ~1 event per day

- Example for a very conservative estimate:

  - 1s in duration, 1.5s for offset for second event

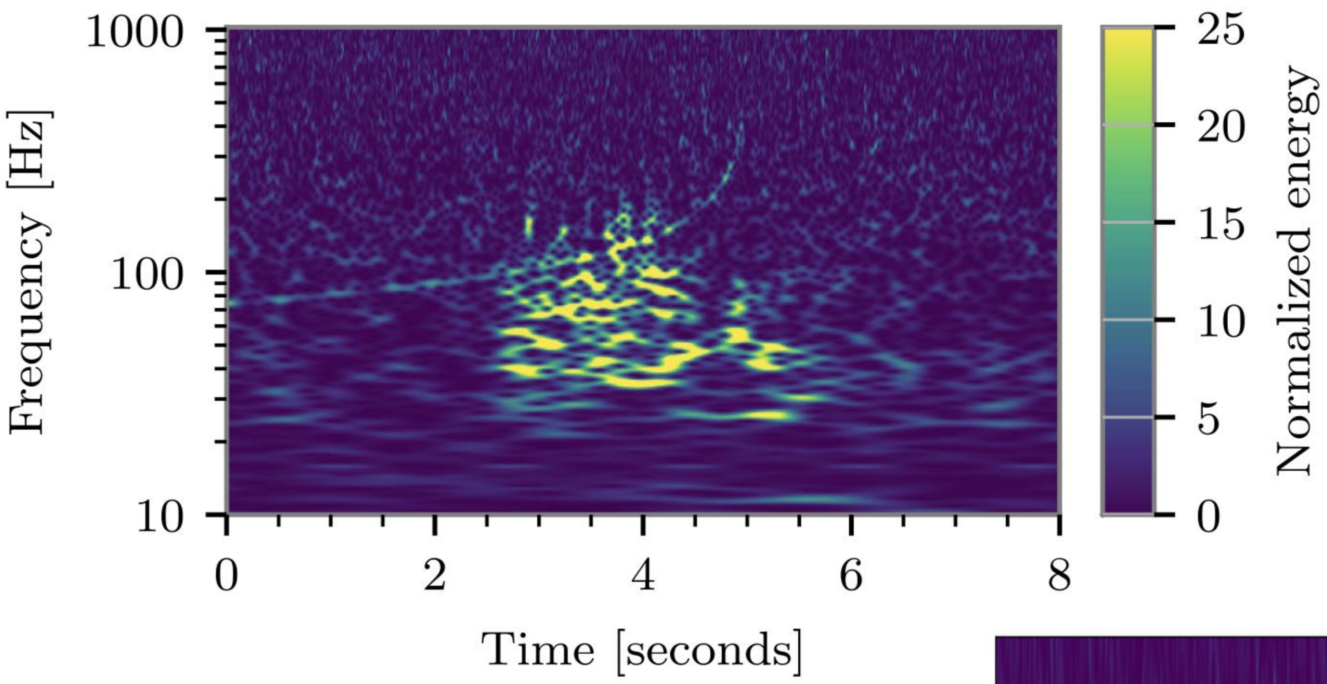
  - 0.0012% and 0.0035% separately

  - Not accounting for other possible observation (Low SNR, long event time)

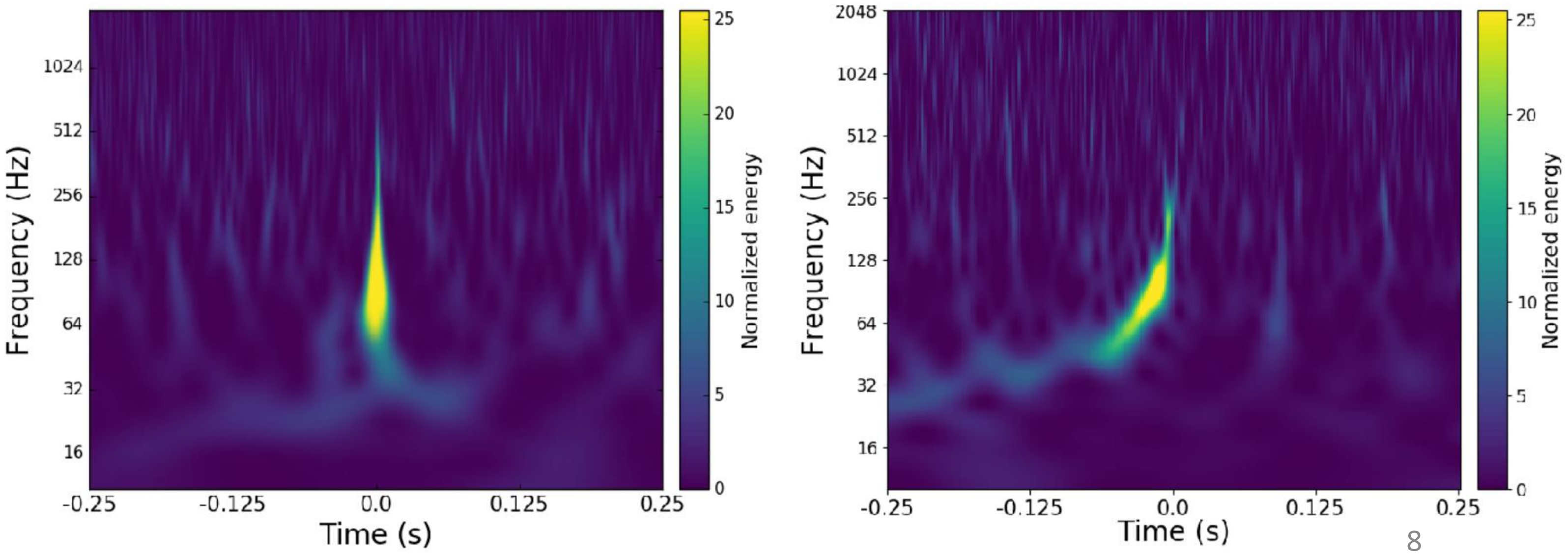
Motivation – *GravitySpy* and *GSpyNetTree*

- Data collection → impossible to validate all candidates by human
- *GravitySpy*
  - Combined **Machine Learning** (ML) techniques and citizen science to develop algorithm
  - Categorize glitches - transient, non-Gaussian noise artifacts

Motivation – Glitches & Event Detection



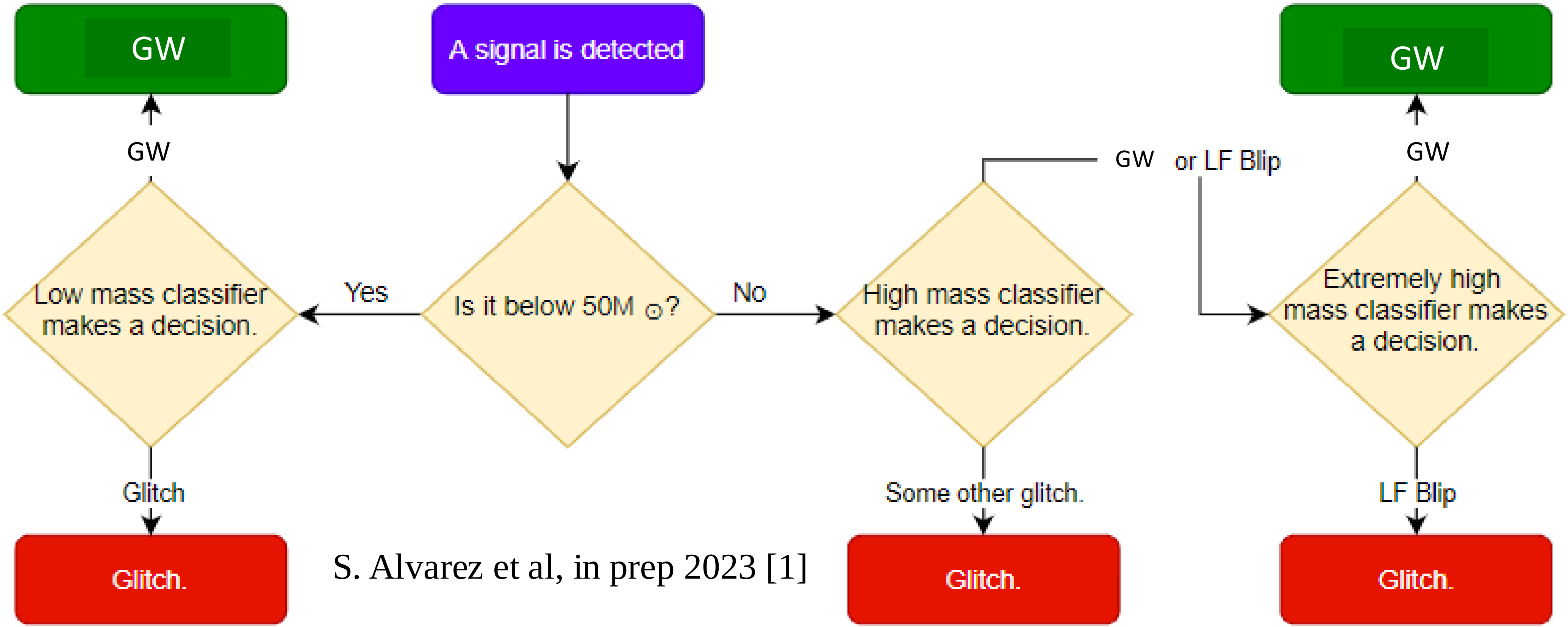
R. Macas, J. Pooley, et al., 2022 [6]



R. Mesuga and B. J. Bayanay., 2022 [5]

Motivation – *GravitySpy* and *GSpyNetTree*

- *GSpyNetTree* is an extension to *GravitySpy*



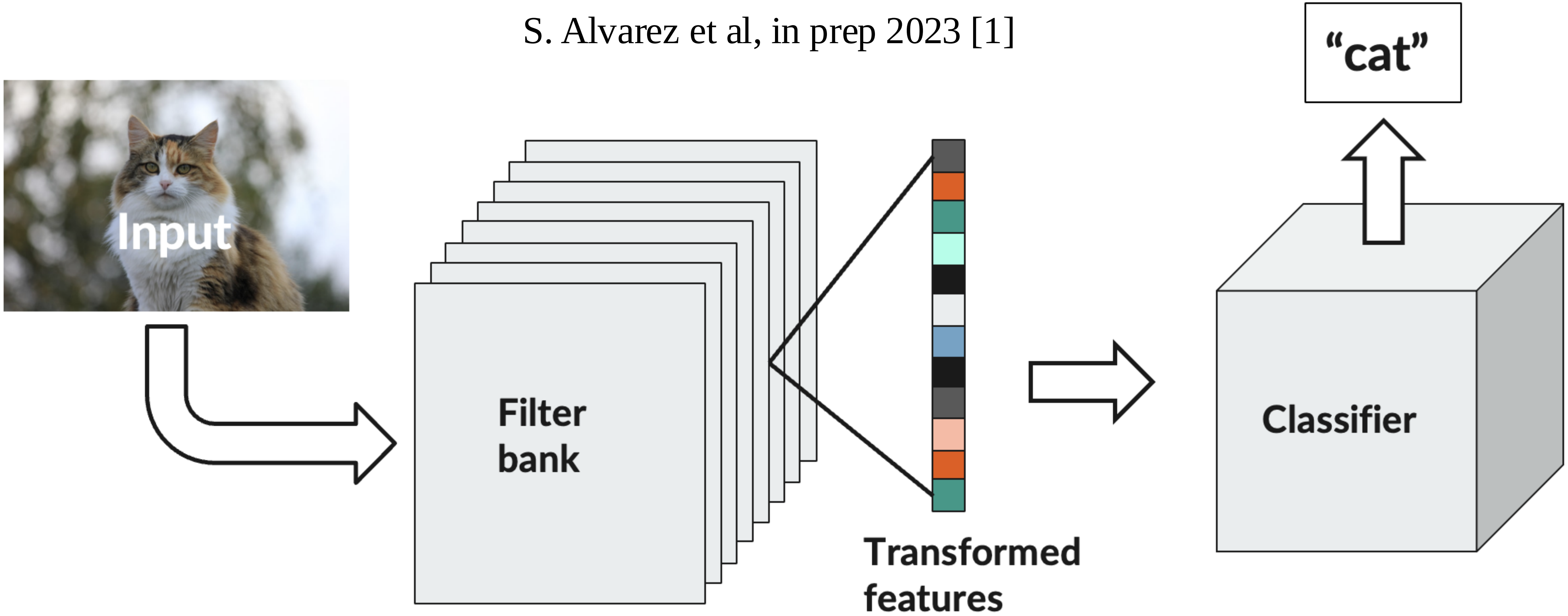
S. Alvarez et al, in prep 2023 [1]

Motivation – *GravitySpy* and *GSpyNetTree*

- Not trained with an implicit assumption of overlapping signals
- May lead to rejection of real astrophysical candidate
- Goal: develop a ML model that is robust to the presence of overlapping signals – *GSpyNetTree-O*

Theory – **Convolutional Neural Network** (CNN)

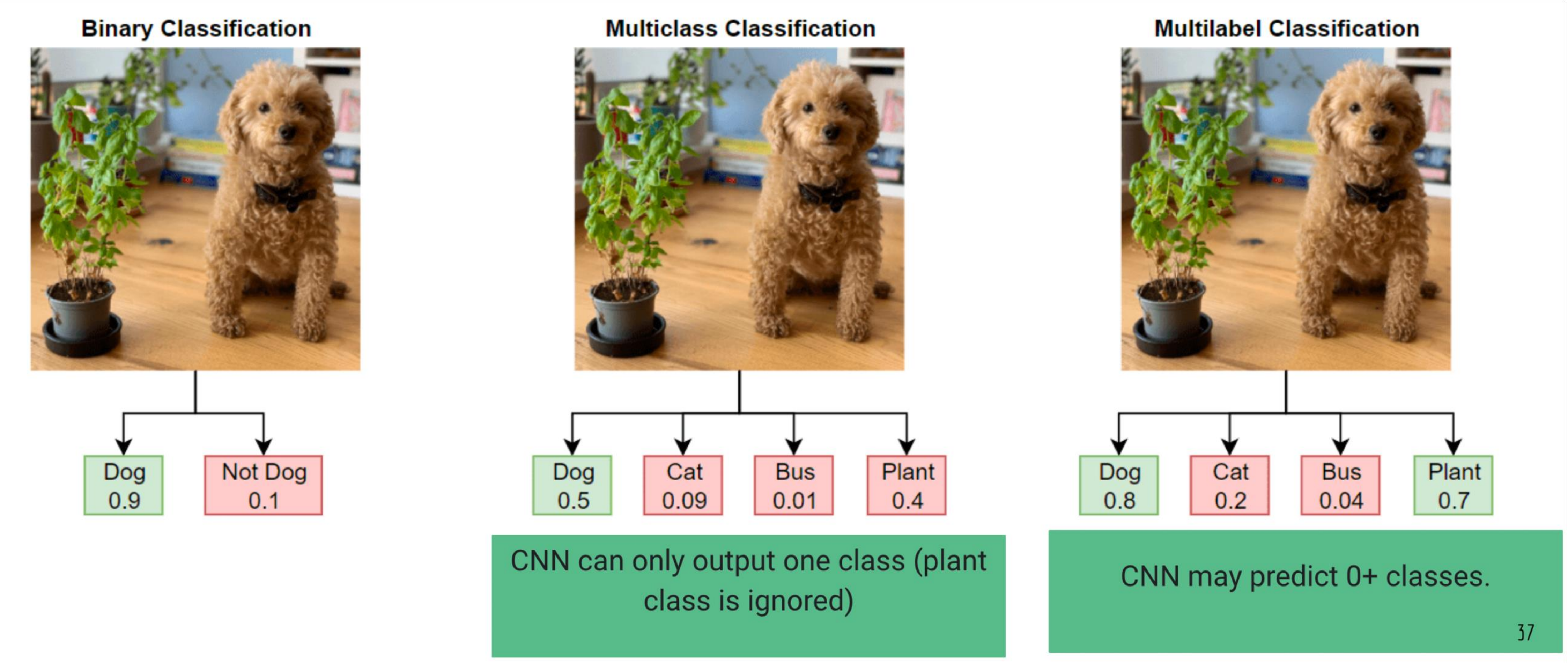
S. Alvarez et al, in prep 2023 [1]



Theory – CNN

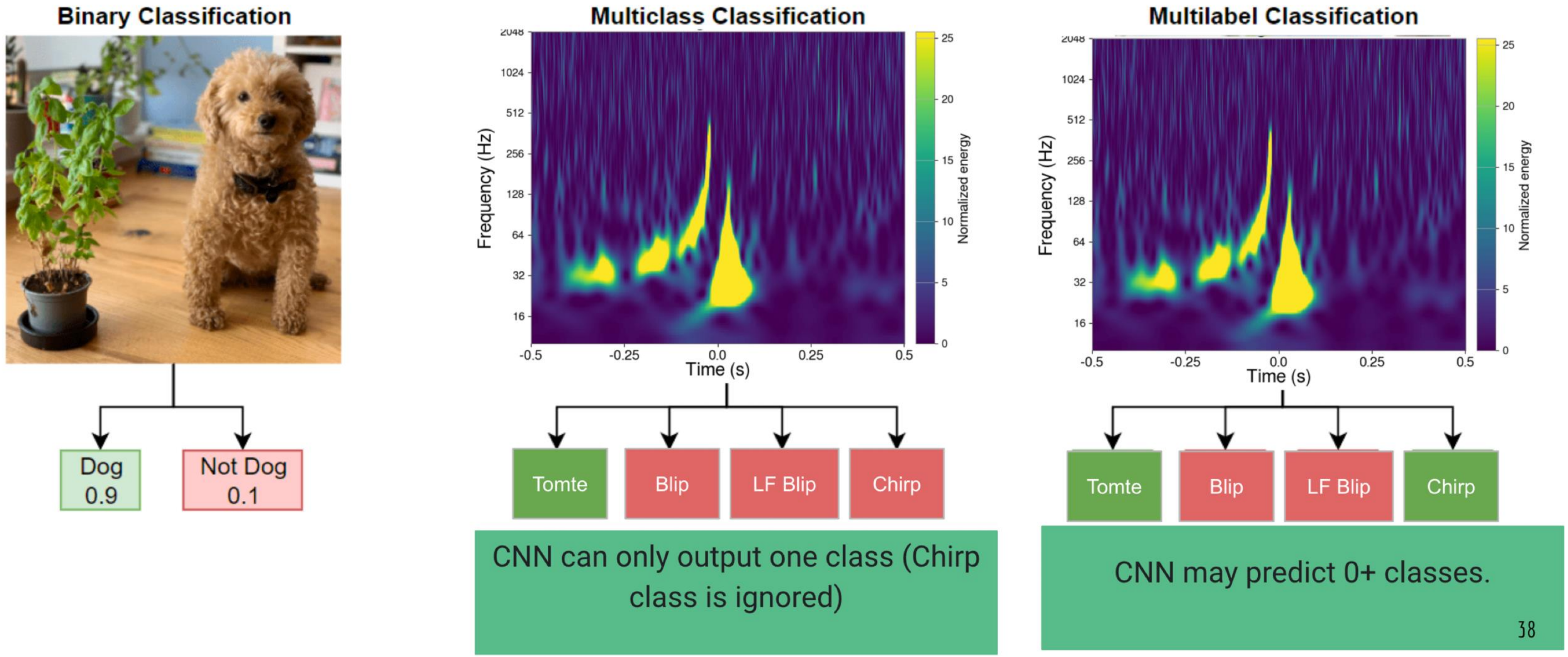
- *GravitySpy* & *GSpyNetTree* employs CNN
- Advantages:
  - Computationally cheap
  - Sensitive to feature in input data (such as shapes)

Theory – *Multi-Class* vs *Multi-Label*



Permission from S. Alvarez

Theory – *Multi-Class* vs *Multi-Label*

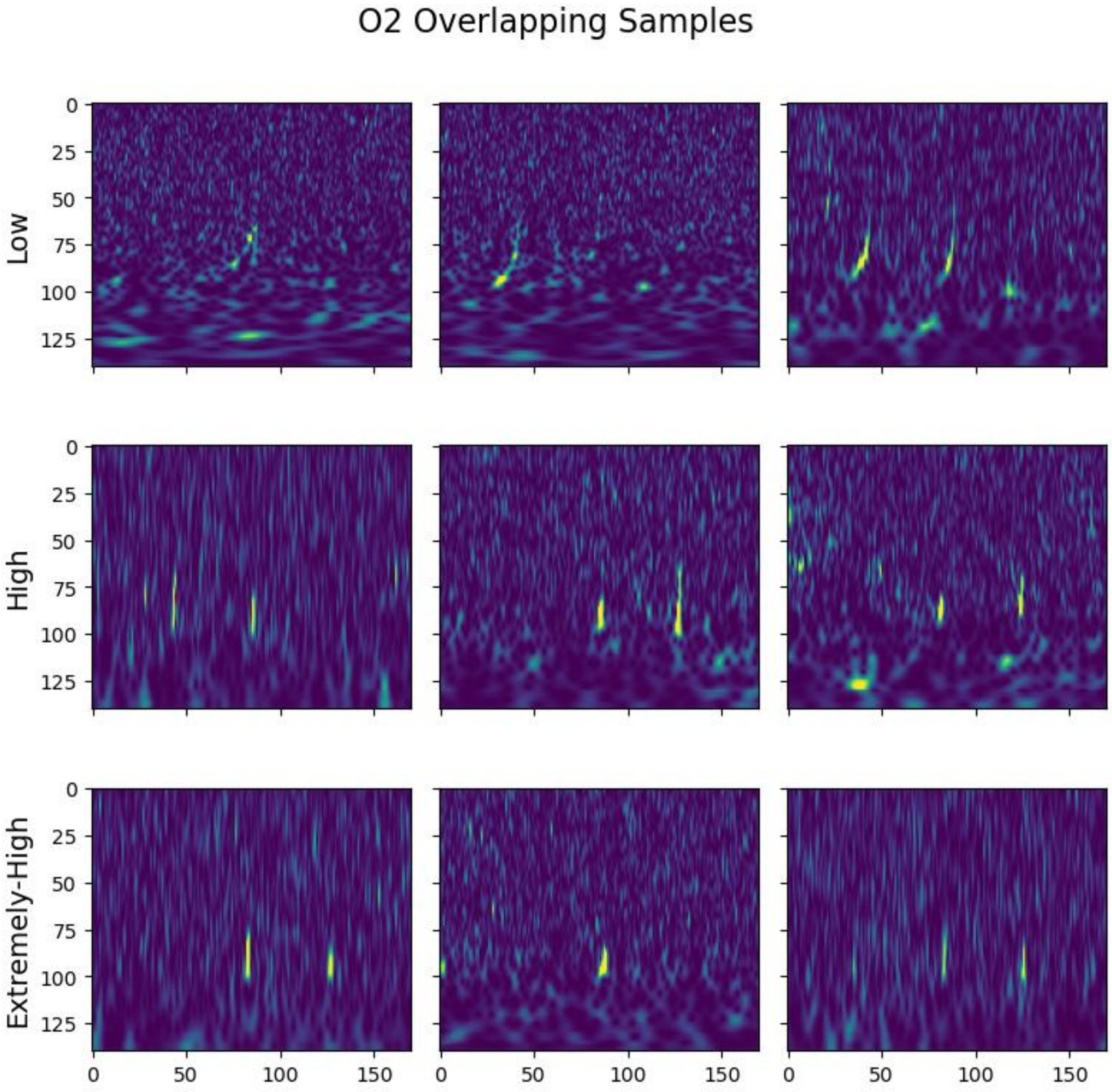


Permission from S. Alvarez

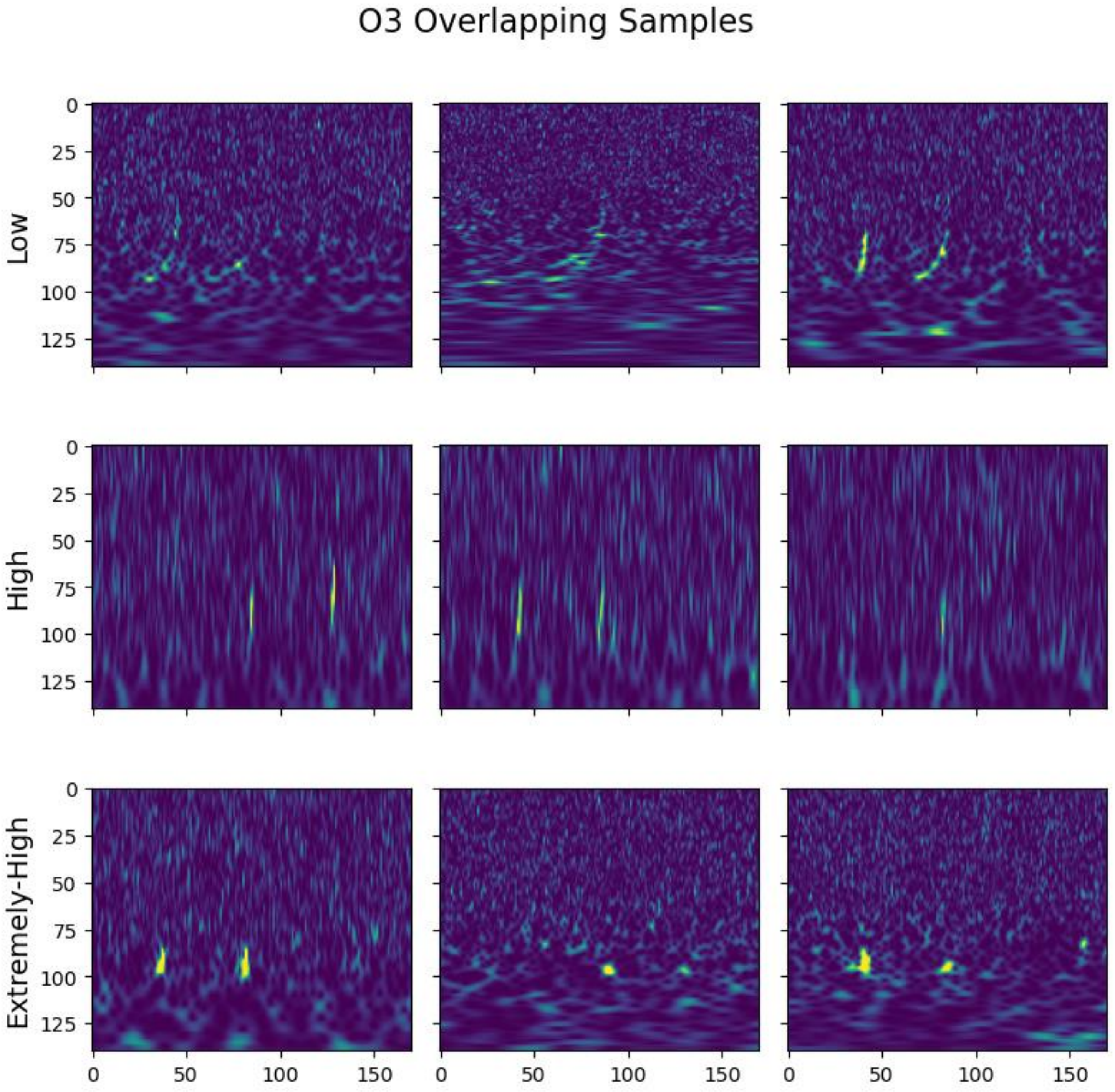
Methods - Simulation

- Modifying the existing scripts to generate overlapping signals
- Two overall training sets: O2 and O3
- Each overall set has three individual sets for each classifier
  - Low-mass (LM), High-mass (HM), Extremely-high-mass (EH)

Methods - O2 Simulated Samples



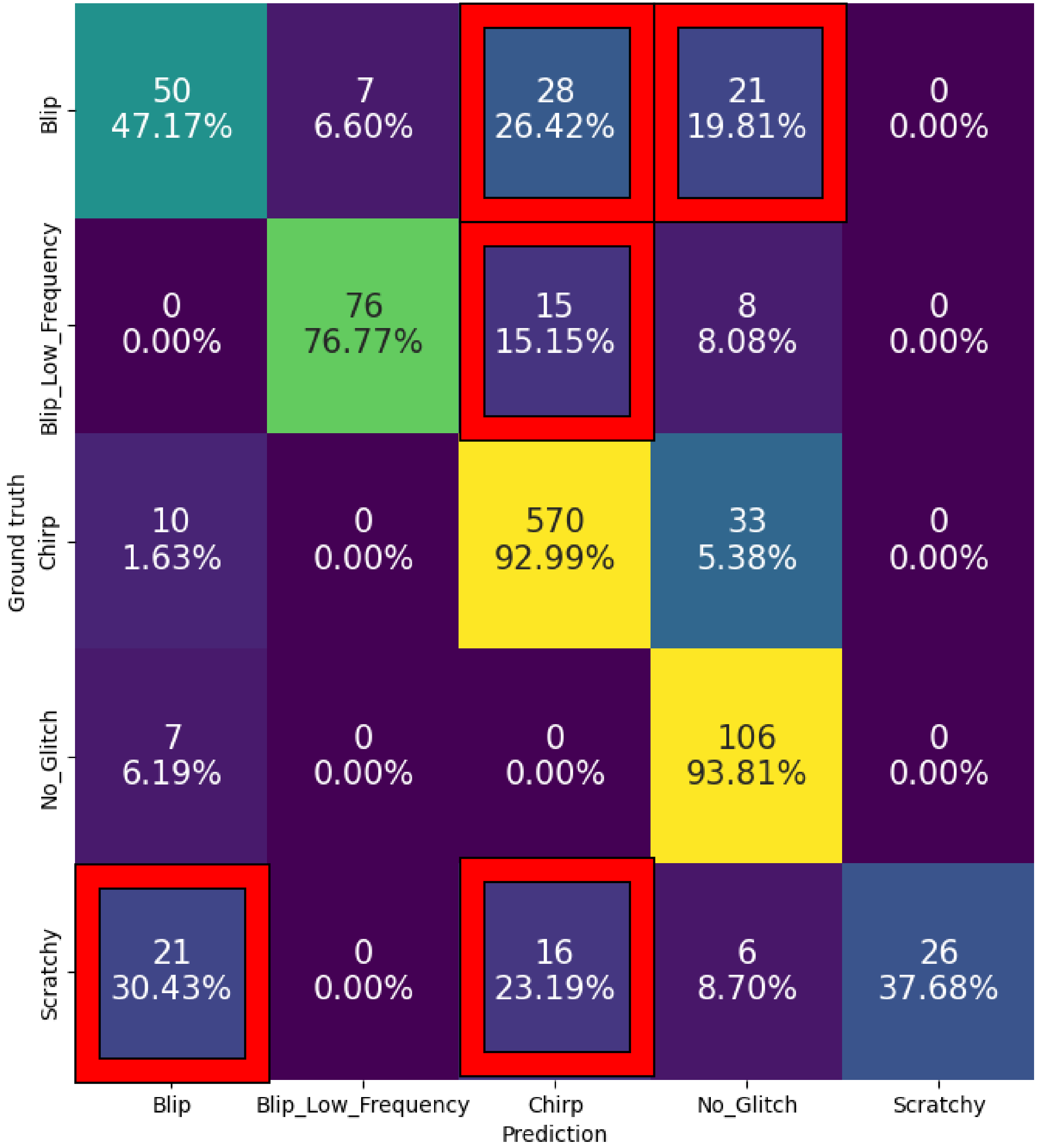
Methods - O3 Simulated Samples



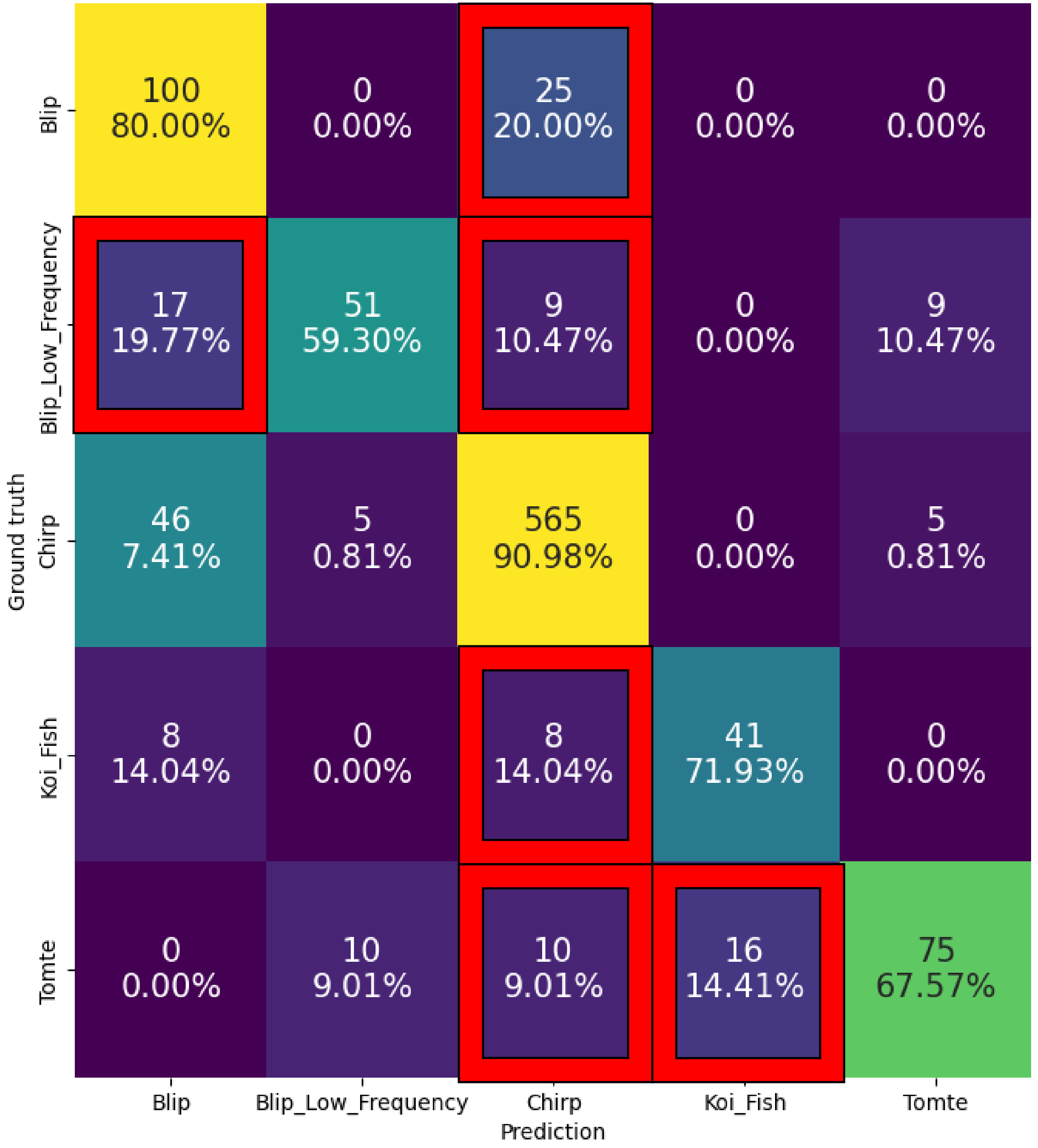
Methods – Training

- Training with Mutli-Class Model (MCM)
- Training with trained Multi-Label Model (MLM)
  - This model is developed by S. Alvarez, J. Ding, A. Liyanage, F. Herbst, et al.
- The following results are the **initial performance** against the test set

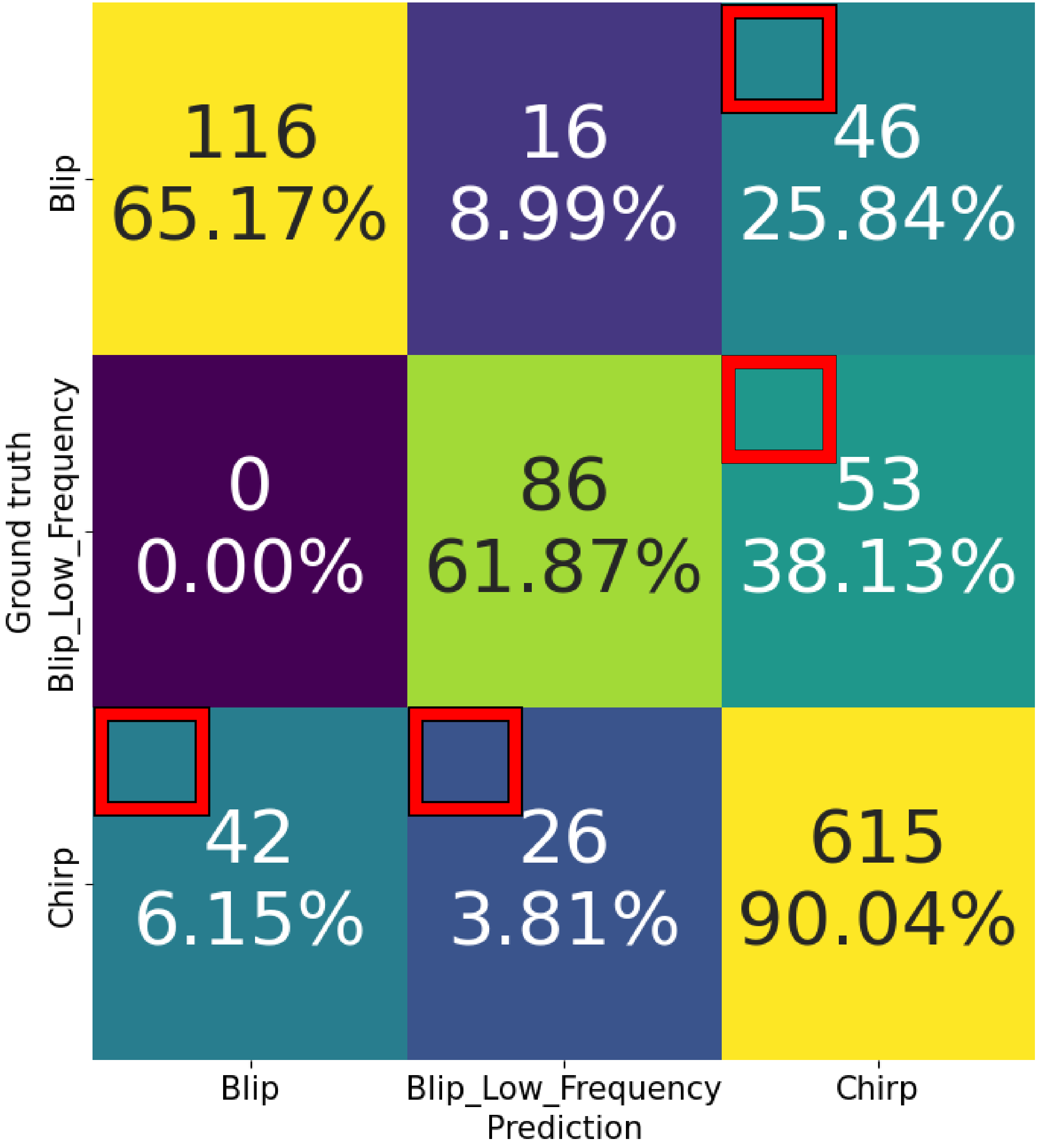
Result – O2 MCM Performance (LM)



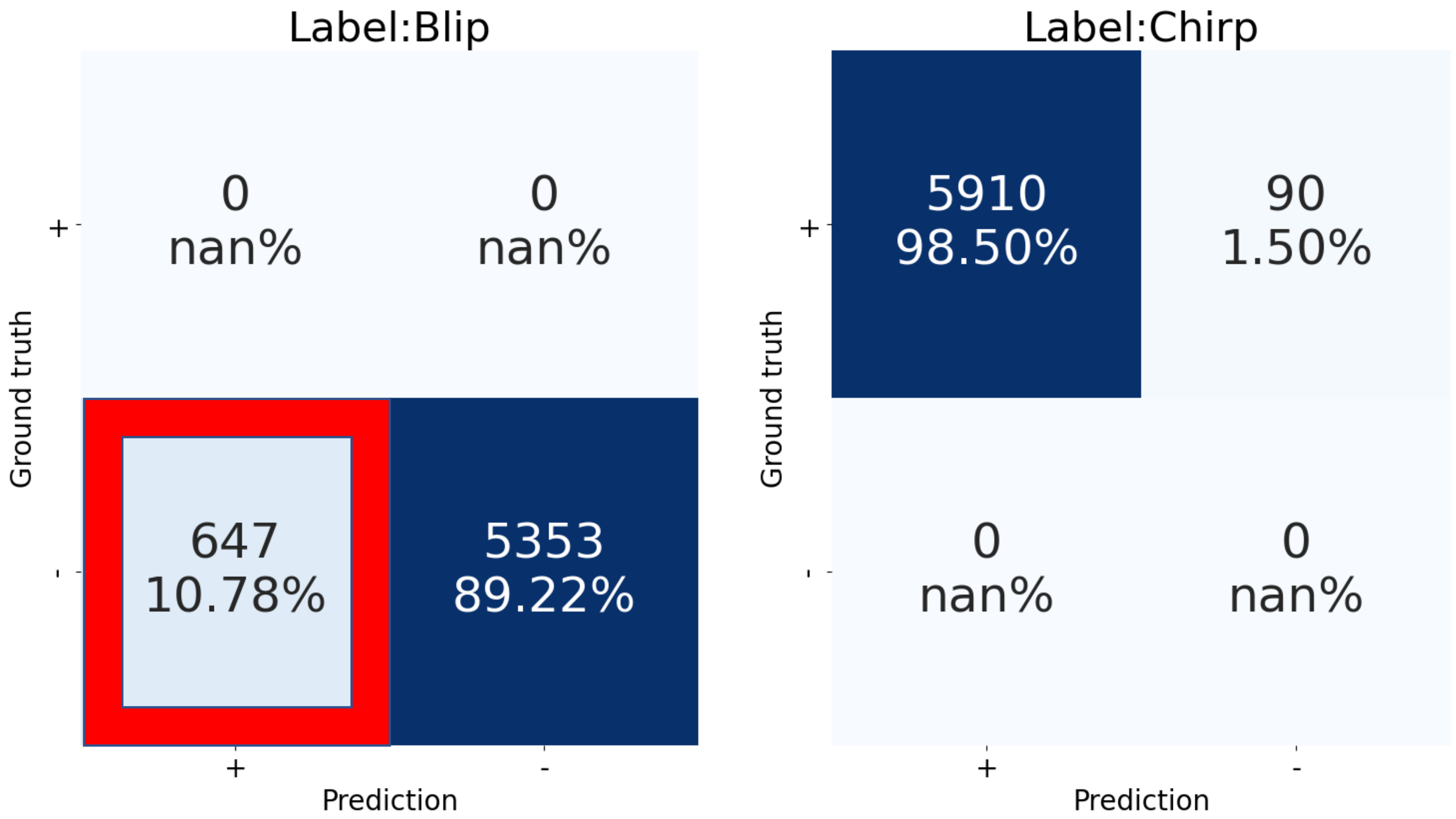
Result – O2 MCM Performance (HM)



Result – O2 MCM Performance (EH)

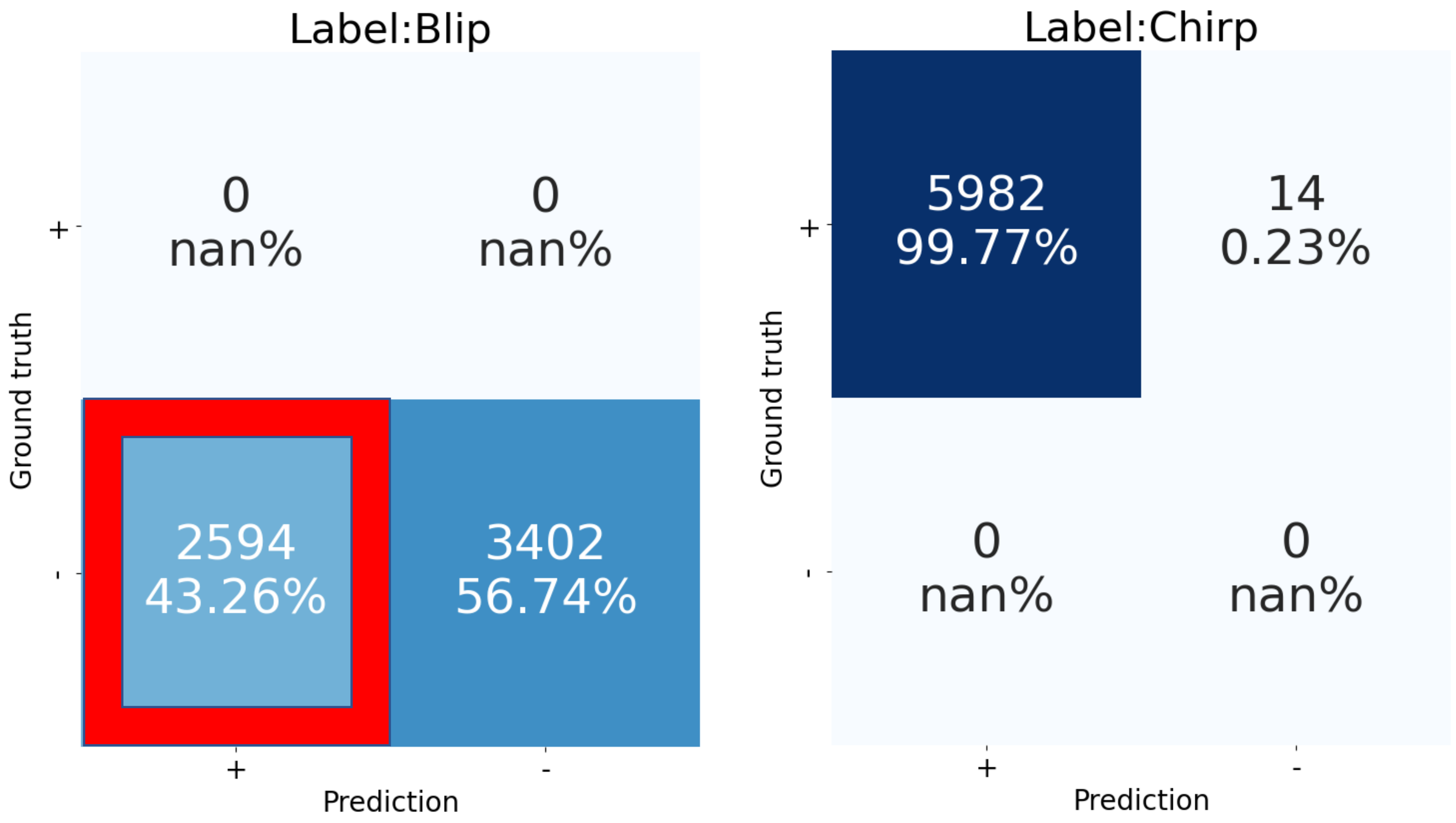


Result – O2 MLM Performance (LM)



Permission and modified from S. Alvarez

Result – O2 MLM Performance (HM)



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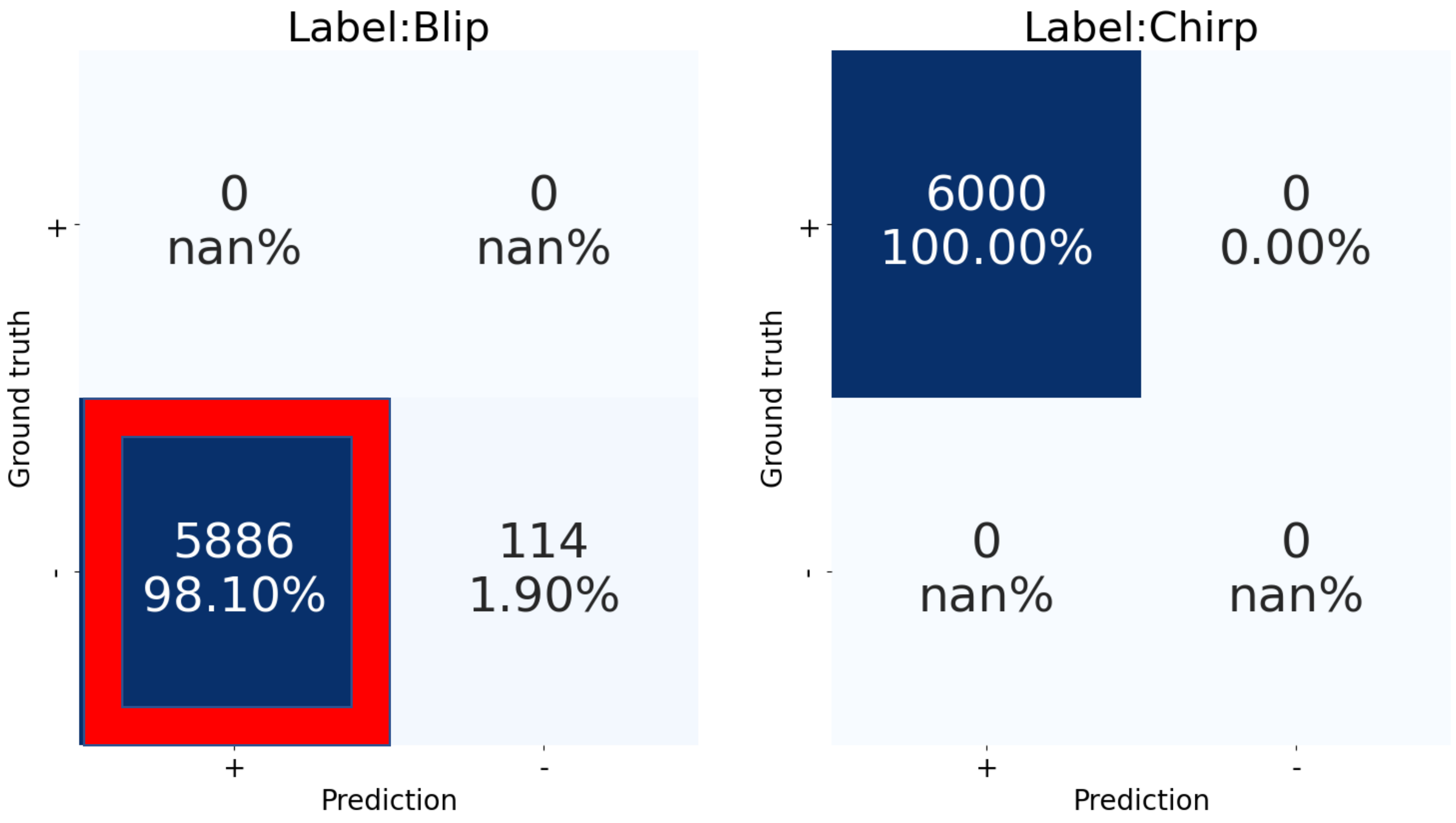
Result – O2 MLM Performance (EH)



Permission and modified from S. Alvarez

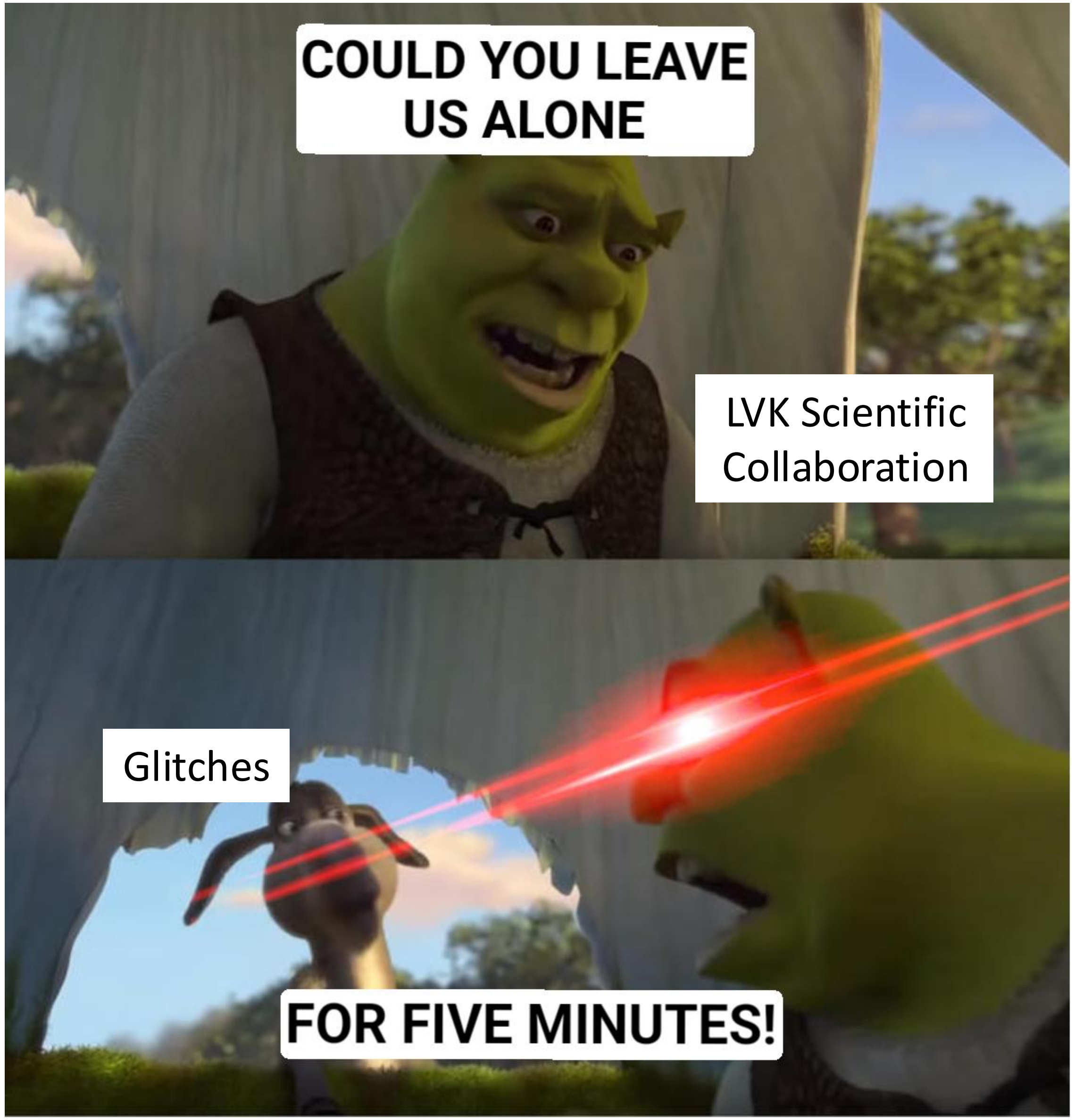
Discussion and Analysis

- Both MCM and MLM shows confidence in categorizing GW
  - Potentially due to high volume of GW samples
- Both MCM and MLM shows trouble in HM and EH
  - In particular with “Blip” glitch class
  - For MCM, other glitches also get misinterpret as GW

Future Work

- Obtain the initial performance against O3 test set
- Retrain both MCM and MLM for improvements
- Obtain the post-trained performance against test sets
- Compare the result between MCM and MLM

Thank you for listening



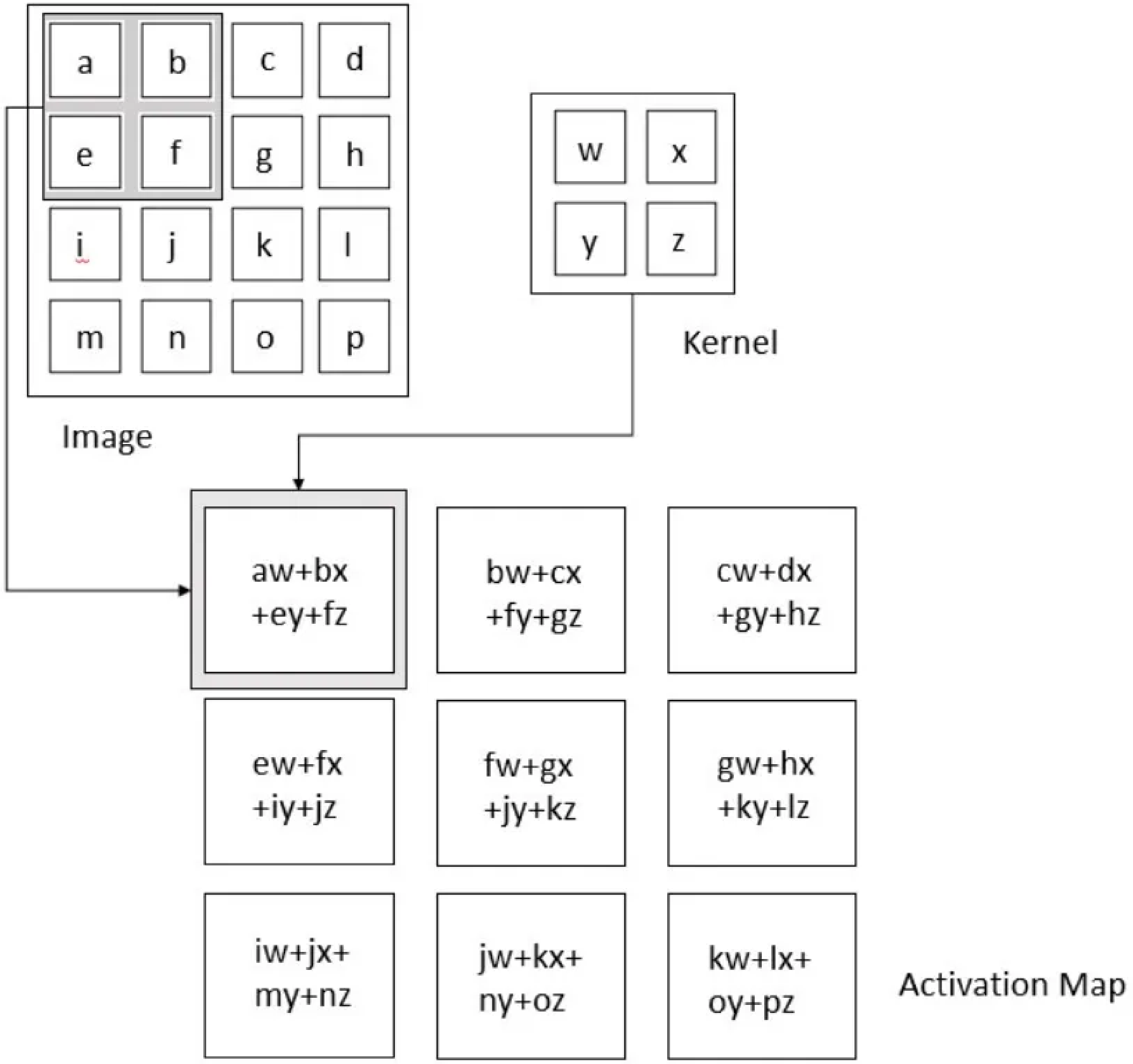
Reference

- [1] Ding, J., Alvarez, S., Liyanage, A. GSpyNetTree Presentation to DetChar. August 2022, https://wiki.ligo.org/DetChar/Telecon20220808. Power-Point Presentation.
- [2] Sources and types of gravitational waves. Caltech. (n.d.). Retrieved November 27, 2022, from https://www.ligo.caltech.edu/page/gw-sources
- [3] Core-collapse supernovae. Max Planck Institute for Astrophysics. (n.d.). Retrieved November 28, 2022, from https://www.mpa-garching.mpg.de/84411/Core-collapse-supernovae
- [4] C. Cahillane and G. Mansell. Review of the advanced ligo gravitational wave observatories leading to observing run four. Galaxies, 10(1):36, 2022. doi:10.3390/galaxies10010036
- [5] Mesuga and B. J. Bayanay. A deep transfer learning approach on identifying glitch wave-form in gravitational wave data. 2022. doi:10.36227/techrxiv.19687590.v1
- [6] R. Macas, J. Pooley, L. K. Nuttall, D. Davis, M. J. Dyer, Y. Lecoeuche, J. D. Lyman, J. McIver, and K. Rink. Impact of noise transients on low latency gravitational-wave event localization. Physical Review D, 105(10), 2022. doi:10.1103/physrevd.105.103021

Extra Slides - *GSpyNetTree*

- We can still detect signals that cannot see
  - There are other components within the network
- CNN can pick up pattern that human can’t, but not always reliable and still requires some human analysis
- A multi-label architecture, different from *GravitySpy*
  - One input can have more than one label

Extra Slides – CNN in-depth



Extra Slides – CNN in-depth