Active Learning for the Cameras for All-sky Meteor Surveillance (CAMS) meteor orbit survey - Sahyadri Krishna[1], Siddha Ganju[2], Amartya Hatua[3], Chicheng Ren[4], Julia Nguyen[5], Surya Ambardar[6], Chad Roffey[7], Alfred Emmanuel[8], Jesse Lash[9], Meher Kasam[10] and Peter Jenniskens[11] - [1]Indian Institute of Science Education and Research (IISER), Tirupati; SpaceML (email: sahyadrikrishna@students.iisertirupati.ac.in), [2]Nvidia; Frontier Development Lab (FDL), NASA; SpaceML (email: sganju@nvidia.com), [3]Fidelity Investiments; SpaceML, [4]Square; SpaceML, [5]University of Florida; SpaceML, [6]University of Virginia; SpaceML, [7]DocuSign; SpaceML; [8]Federal University of Technology, Minna; SpaceML; [9]SpaceML; [10]Square; SpaceML; [11] SETI Institute

Introduction: Meteor showers are some of the most enigmatic events that illuminate the night sky. They offer an avenue to explore the often invisible components of our solar system. They may also provide clues to the origin of life, as meteors and related rocky objects may have brought water and amino acids, the building blocks of life, to Earth.

Traditionally meteor detection has required long hours of manual work, including visual inspection, cleaning and interpretation of data, led by domain experts. Scaling such manual procedures to large volumes of meteor data is problematic. Additionally, meteor detection has involved establishing expensive and elaborate observatories, severely limiting meteor shower coverage.

The Cameras for All-Sky Meteor Surveillance, or CAMS, project solves these problems. Founded in 2010 by Dr Peter Jenniskens of the SETI Institute, the NASA-funded CAMS project employs a global network of inexpensive low-light surveillance cameras to track nightly meteor showers [1]. With an extension into Asia in motion, the CAMS network has set up 16 camera sites across 6 continents, enabling 24x7 surveillance of the night sky.

The large volume of data generated by the extensive and continually expanding CAMS network necessitates techniques to scale meteor detection and characterization. We present an innovative approach of AI automation of the CAMS meteor detection network. We have developed a custom supervised learning neural network (CAMS-Net) to classify meteors from raw camera sensor data. CAMS-Net consists of a binary classifier with stacked Bidirectional LSTM layers followed by an attention layer and 4 Dense layers. Each layer has a RELU activation function, except for the last Dense layer, which has sigmoid activation suited for binary classification. The loss function used was binary cross-entropy, with an Adam optimizer. The model was trained on an NVIDIA TitanX GPU.

To augment training of the CAMS-Net model, we have developed a windowing technique based on advancements in the field of natural language processing. Augmentation leverages differences in duration of meteors and non-meteor objects such as birds, planes and satellites captured by CAMS cameras. Augmentation using this method can balance and mitigate the impact of data bias, all while increasing the number of positive and negative samples. With the windowing augmentation, our neural network achieved a precision and recall of 97% and 98% respectively when segregating meteors from non-meteor objects.

The CAMS-Net relies on readily available labeled meteor data for training. Annotating data however is a largely manual task that requires immense effort. To increase the quantity of unbiased training data, we used weak supervision active learning to label a decade's worth of data from only a year's worth of labeled data.

We also present features of an end-to-end cloud-based CAMS AI pipeline that integrates supervised and active learning with a data ingestion backend and visualization tool. The improved backend establishes a database system for CAMS that enables fast and rich querying. Fitting with the theme of improved scalability, the python CAMS AI pipeline was optimized using NumPy and NVIDIA Rapids. The performance optimizations yielded a 50% reduction in pipeline runtime, thereby eliminating any potential backlogs in meteor processing.

Finally, we present the CAMS web portal[1]. The interactive CAMS web portal uses a celestial sphere canvas and heliocentric ecliptic coordinate system to display meteor showers daily. The web portal displays data for any given meteor with a mouse click. With powerful querying, zoom and timeline features along with constellations as location aids, the CAMS portal assists discovery by allowing scientists to explore patterns in the CAMS data. The user-centered design features make the CAMS web portal easy-to-use for new and experienced users alike.

Since first light, the CAMS portal has detected 92 out of 112 established showers and recognized 323 out of 700 meteor showers on the IAU working list of meteor

1 CAMS web portal - https://meteorshowers.seti.org/

showers (as of Feb 2021)[2] [2][3]. In 2021 alone, the CAMS network discovered nine new showers, includ-

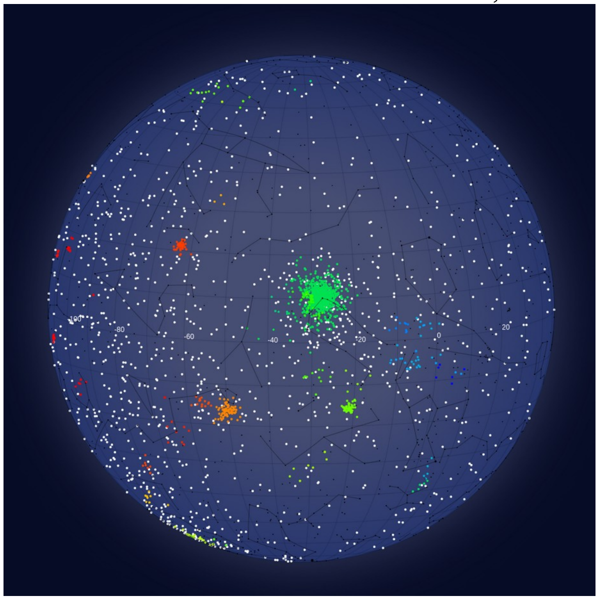

Figure 1: Celestial sphere of the CAMS web portal. Meteor showers are color coded while stars are white. Constellation stick figures can be seen with black.

ing the “Arids” meteor shower theorized to originate from the comet 15P/Finlay [4], and the June theta2 Sagittarids [5]. Data from the first instrumental detection of the delta Pavonids by CAMS cameras in New Zealand was used to refine orbital characteristics of comet C/1907 G1 (Grigg-Mellish) [6]. CAMS data of the phi Serpentid shower in April of 2020 was used to trace back the shower to the orbit of an unknown parent comet [7].

Besides expanding our understanding of meteor showers and their parent bodies, CAMS has encouraged public participation in meteor astronomy by enabling establishment of CAMS observatories by the public across the world. The CAMS web portal also encourages the public to play with meteor data. With a large body of work done on CAMS being done by citizen scientists pro bono, the CAMS project sets a precedent for citizen science in the backdrop of a global pandemic. Our efforts have pushed CAMS to NASA Technology Readiness Level (TRL) 9, the highest level of project readiness as described by the NASA Science Mission Directorate (SMD).

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Aditional Information: The CAMS project website is at http://cams.seti.org. The CAMS web portal is at https://meteorshowers.seti.org/. CAMS is supported and made possible by NASA’s Planetary Astronomy program.

2 IAU Meteor Data Center (MDC) - https://www.ta3.sk/IAUC22DB/MDC2007/index.php