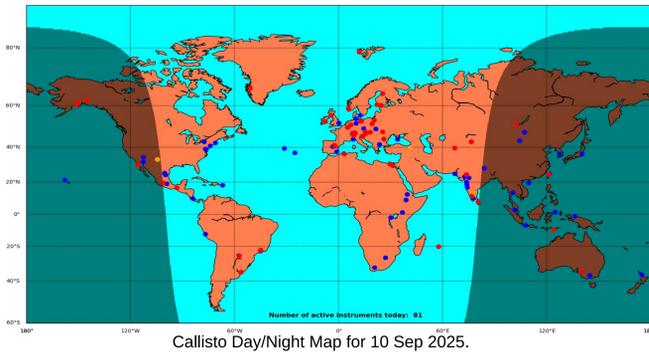


# Automated Classification of Solar Radio Bursts for Space Weather Forecasting

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## Context

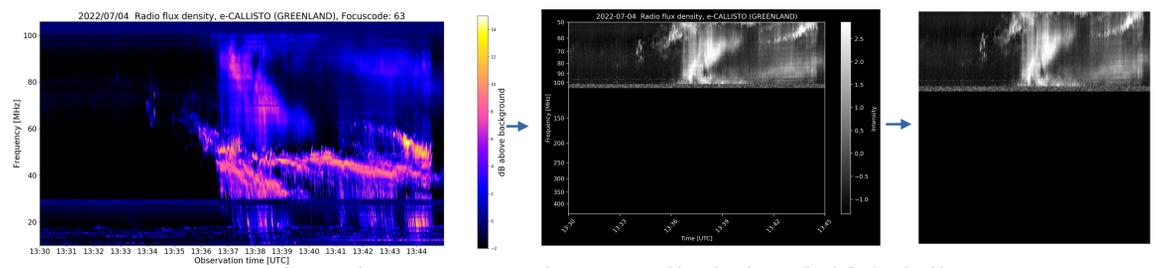


- **Solar radio bursts** (Type II, III, IV) are radio signatures of energetic solar eruptions such as flares and coronal mass ejections.
- They are visible in **spectrograms** (radio frequency vs. time), but interpretation is complex.
- **The e-CALLISTO network**, with ~80 stations worldwide, provides 24/7 coverage of solar activity.
- **Our Goal:** develop automated bursts detection and classification to support space weather forecasting.

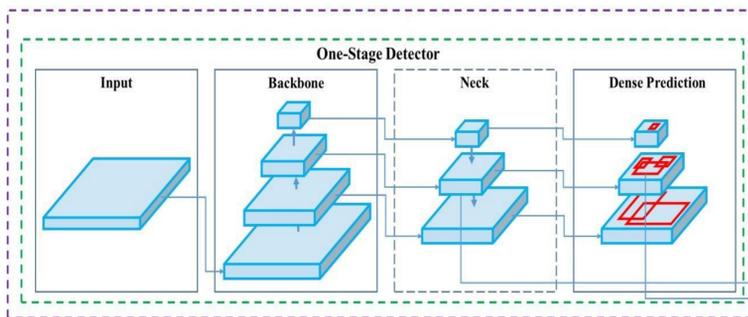
## Methods

**Deep Learning Approach:** YOLOv5, an image recognition algorithm, was used and adapted to radio spectrograms.

**Dataset:** 1,108 annotated bursts from 49 stations (2022-2024).

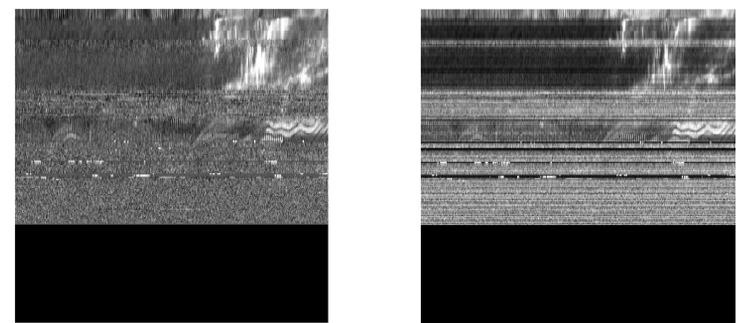


Main steps of spectrogram preprocessing: raw FITS, rebinned and normalized, final resized image.



### Improvements:

- Data augmentation,  $\rightarrow$  to increase robustness
- Merging categories  $\rightarrow$  to simplify classification
- Ensemble methods  $\rightarrow$  to improve performance

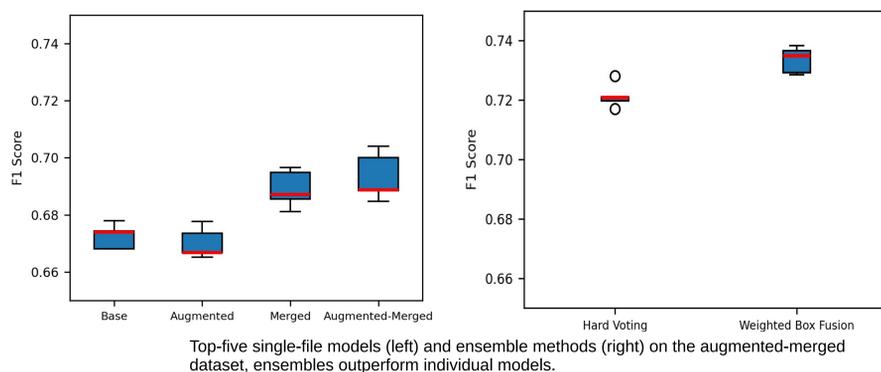


Data augmentation example: normalized spectrograms with Z-score or mean-max.

## Results

### Performance:

Ensemble methods improve detection across telescopes.



Top-five single-file models (left) and ensemble methods (right) on the augmented-merged dataset, ensembles outperform individual models.

- **Best setup:** Weighted Box Fusion augmentation + merged dataset
- **Achieved:** F1 score = 0.74  
Precision = 0.82  $\rightarrow$  most detections are correct  
Recall = 0.67  $\rightarrow$  some bursts still missed

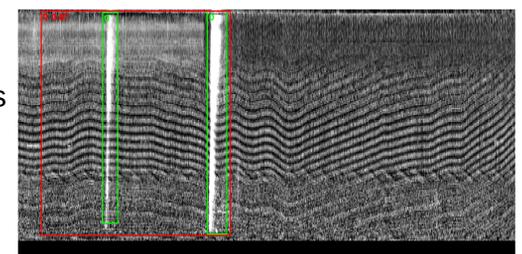
### Challenges:

#### Low recall for Type III / Group III:

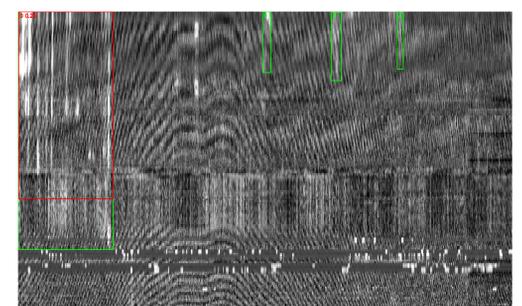
- Model often merges closely spaced bursts into one detection.
- This lowers the recall but is not physically incorrect.

#### Background noise:

- Faint Type III bursts are often missed, specially when instruments have noisy background.
- Stronger group events are detected more consistently.



Spectrogram with annotated Type III burst (green) and predicted merged group (red), where closely spaced bursts are detected as a single group.



Spectrogram with annotated Type III bursts (green) and predicted bursts (red), with faint single bursts blending into the background.

$\rightarrow$  Performance depends on the model, instrument noise, annotation consistency, and ensemble strategy.

## Implications

- Near-real time detection every 15 minutes.
- Supports operational space weather services.
- Reduce need and time for manual inspection.

## Future work

- Extend spectrogram time window for long-duration events.
- Refine annotations, especially for Type III bursts.
- Test performance on non-CALLISTO instruments to ensure generalization.

