UNIVERSITY of VIRGINIA | SCHOOL of DATA SCIENCE

Optimizing the ALMA Research Proposal Process with Machine Learning

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ALMA Observatory

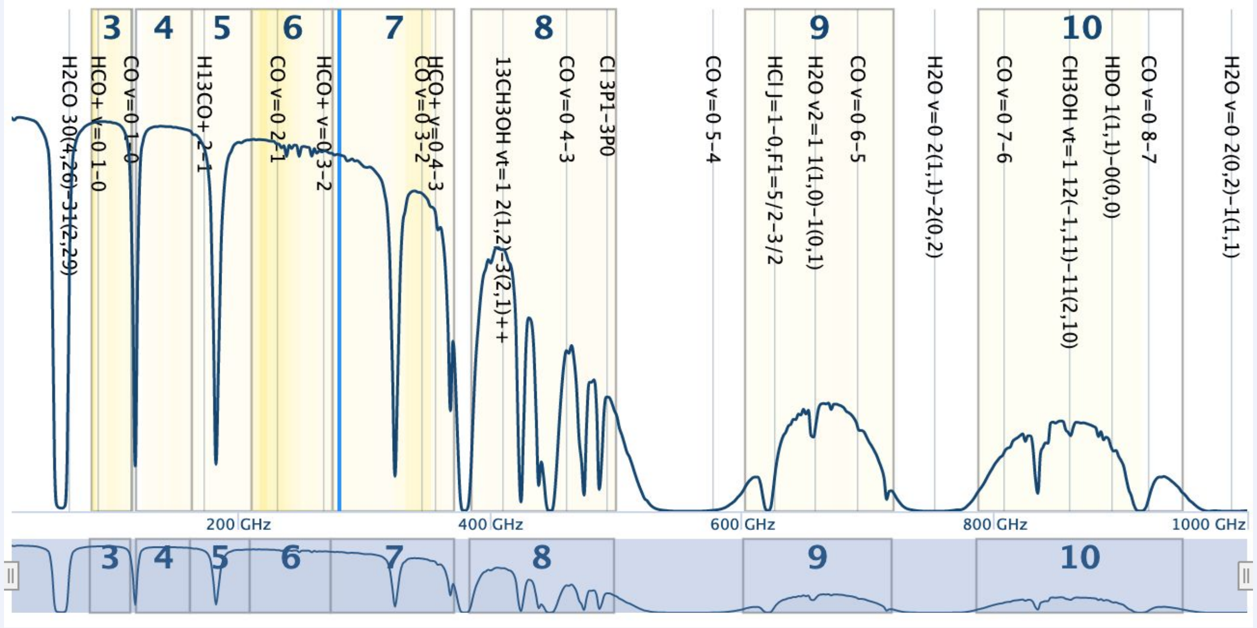
- The ALMA Observatory is located in the Atacama Desert in northern Chile
- The state-of-the-art radio telescope array consists of 66 high-precision antennas that observe electromagnetic radiation outside of visible light

Project Significance

- ALMA is open to anyone to use, based on a proposal process
- Reduce the time and effort required for researchers to prepare proposals
- Our work will help the astronomy community by simplifying the technical aspects of proposal writing, leading to more precise and effective observations

Data Discussion

- Two types of projects:
  - Spectral Line and Continuum
- Line projects require specific measurement setup



Spectral Line Measurements

Target Variable

Project Title and Abstract

Predictor Variable

4,586

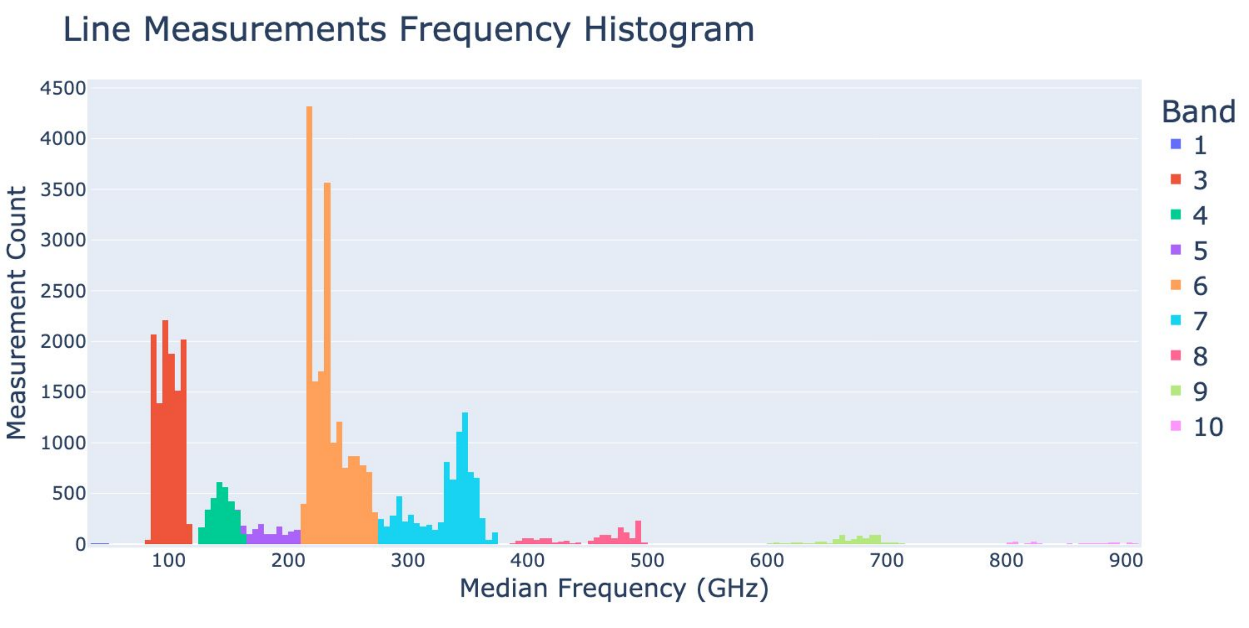
Previous Projects

67,439

Total Measurements

Data Discussion Cont.

- Distribution of measurements across band shows that the vast majority exist in band 3 and 6 and in the lower frequency ranges.



3,628

Line Projects

75%

Have fewer than 13 measurements

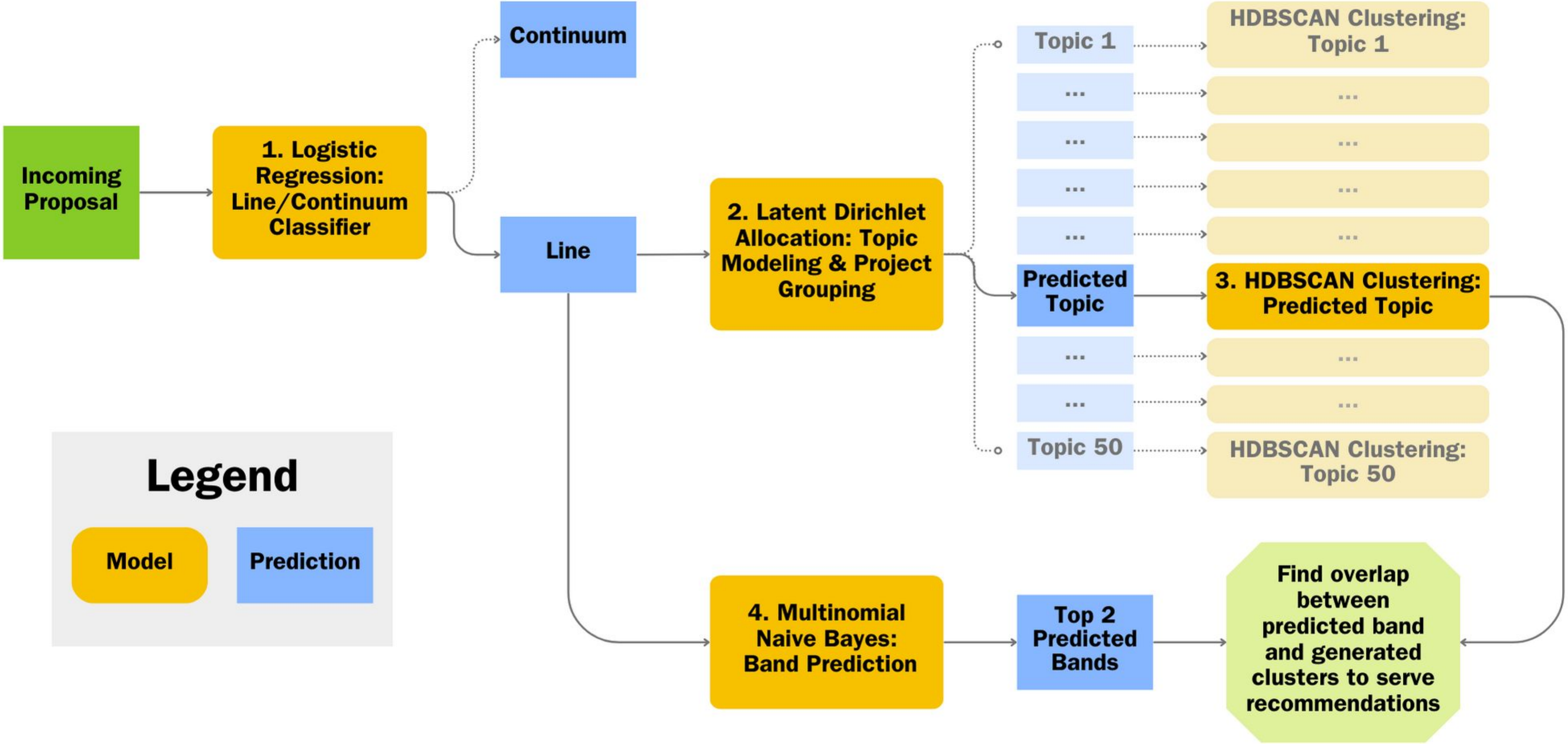
450

Outlier projects have more than 26 measurements

82%

Have measurements in only one frequency band

Model Prediction Pipeline



Incoming Proposal

1. Logistic Regression: Line/Continuum Classifier

Continuum

Line

2. Latent Dirichlet Allocation: Topic Modeling & Project Grouping

Topic 1

...

...

...

...

Predicted Topic

...

...

Topic 50

HDBSCAN Clustering: Topic 1

...

...

...

...

3. HDBSCAN Clustering: Predicted Topic

...

...

HDBSCAN Clustering: Topic 50

4. Multinomial Naive Bayes: Band Prediction

Top 2 Predicted Bands

Find overlap between predicted band and generated clusters to serve recommendations

Legend

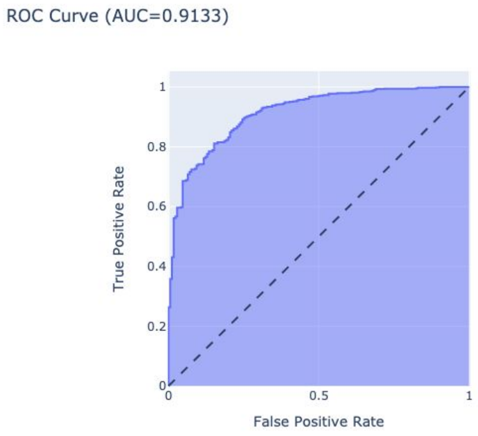
Model

Prediction

01 Project Classification: Logistic Regression

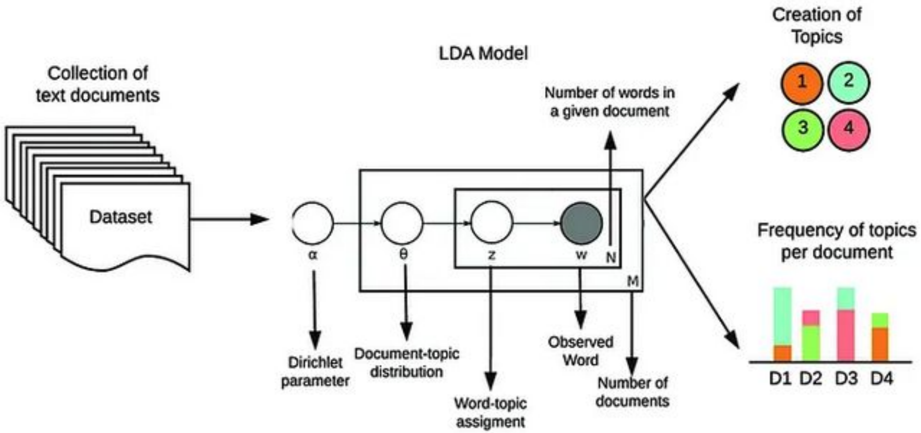
- Vectorize title and abstract using TF-IDF
- Vector used as features to classify a project as either line or continuum
- Only projects with line observations are of interest to us
- Accuracy of 90.02%
- Correctly predicted line 96.41% of the time
- Correctly predicted continuum 59.42% of the time

	Predicted Continuum	Predicted Line
True Continuum	104	71
True Line	26	699



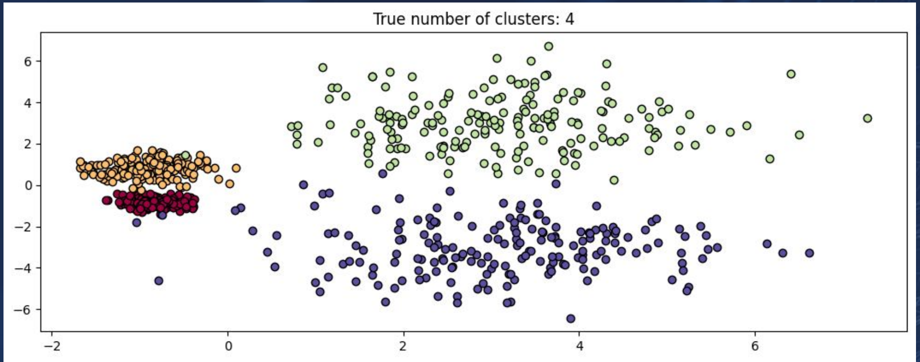
02 Project Grouping: LDA

- Generate 50 topics
- Group projects into topics generated by LDA
- Projects are assigned to their “max topic”
- Topic 25 most heavily weighted words: *bar, gmcs, molecular, spiral, galaxy*
- Topic 37 most heavily weighted words: *mass, chemical, chain, protostars, wccc*

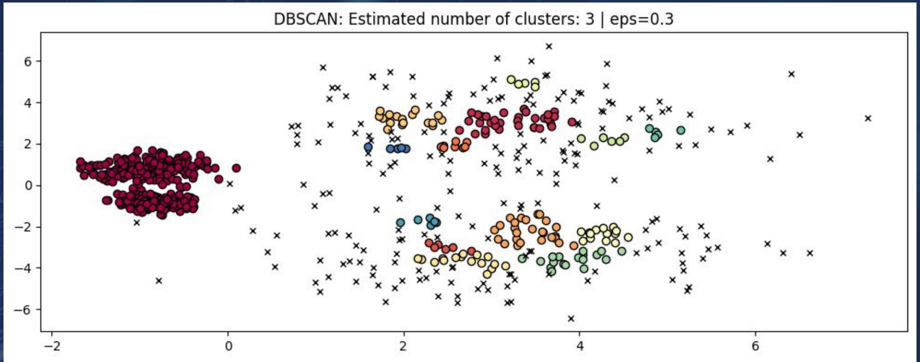


03 Measurement Clustering: HDBSCAN

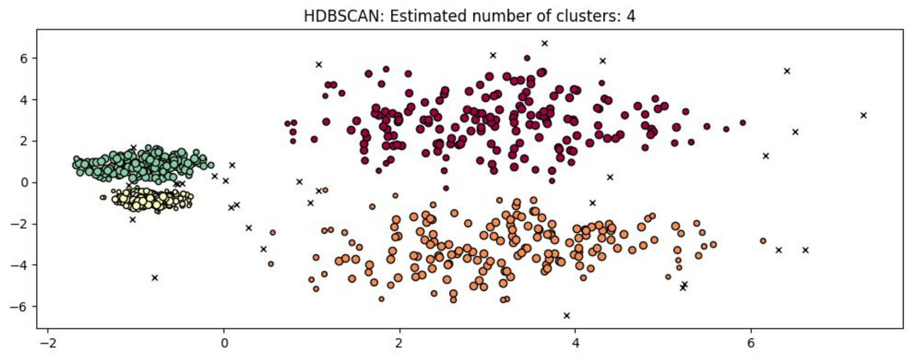
- Cluster measurements for projects within each LDA topic
- Accounts for different densities in measurement distribution
    - Keeps clusters representative of overall measurement distribution
- Ensure clusters are not too large
- Average noise 14.59 ± 0.05%
- Score clusters with count of measurements and projects



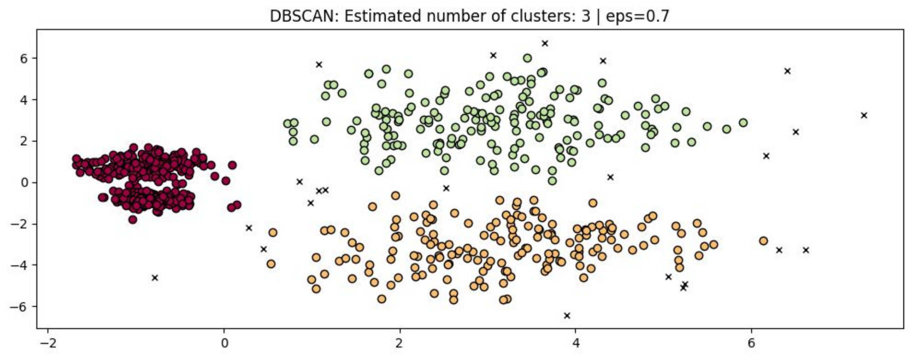
True number of clusters: 4



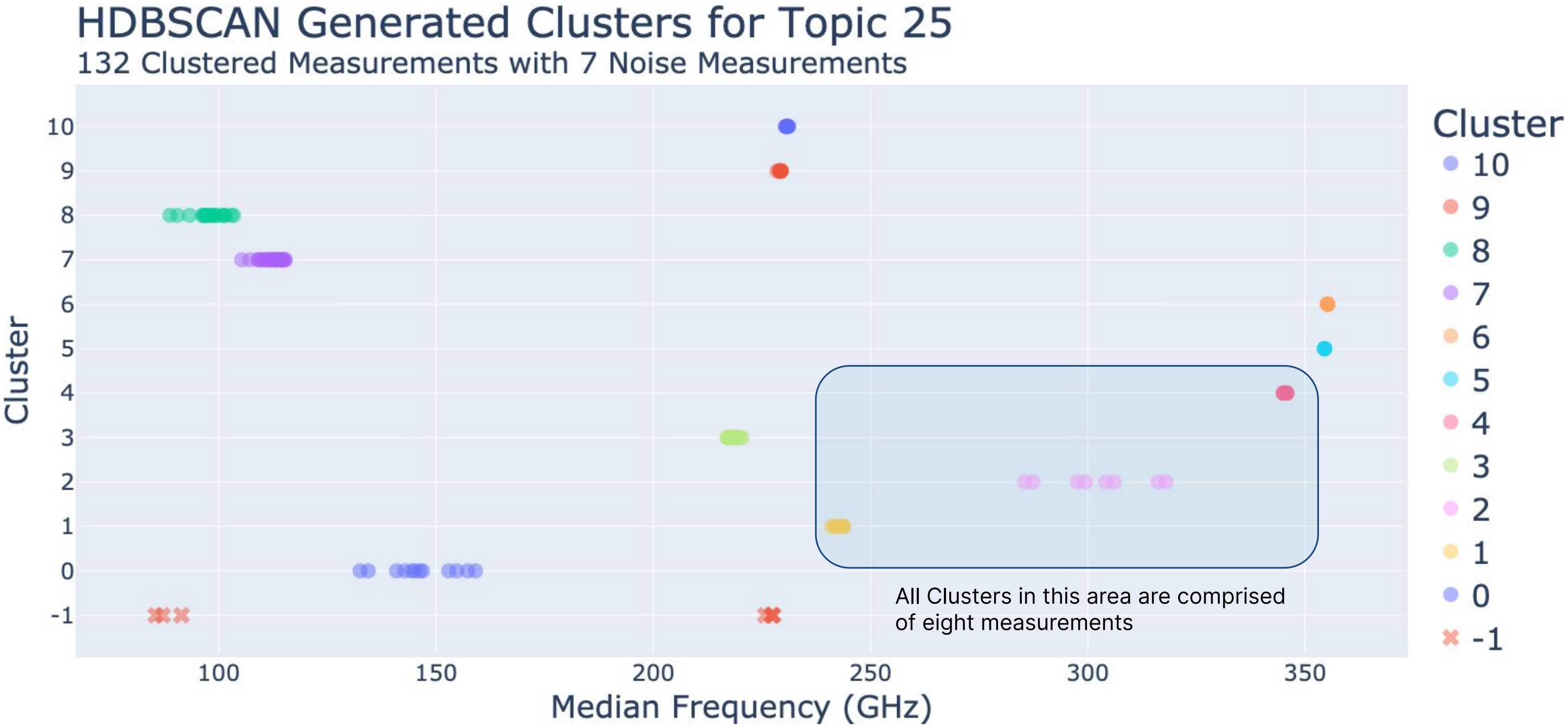
DBSCAN: Estimated number of clusters: 3 | eps=0.3



HDBSCAN: Estimated number of clusters: 4



DBSCAN: Estimated number of clusters: 3 | eps=0.7


HDBSCAN Generated Clusters for Topic 25

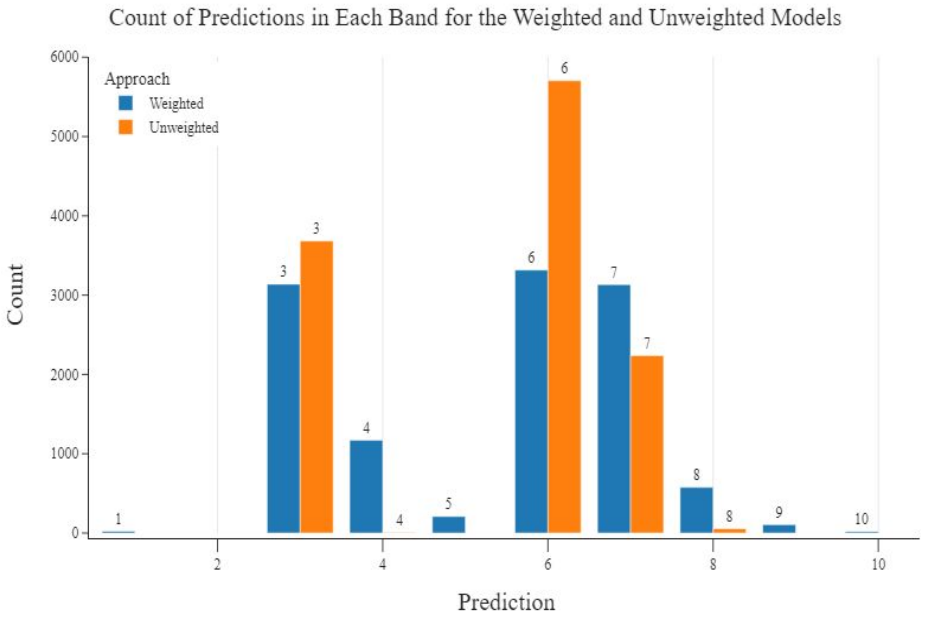
132 Clustered Measurements with 7 Noise Measurements

All Clusters in this area are comprised of eight measurements

04 Band Prediction: Multinomial Naïve Bayes

- Text Preprocessing:
  - Remove stop words
  - Lemmatize text
  - TF-IDF Vectorization
- Unweighted Model:
  - Fit the data according to the percent of instances of each band
- Weighted Model:
  - Specify prior probabilities to improve accuracy for less common bands

Unweighted Results	Weighted Results
73.55%	69.70%



05 Combined Method

- Combine HDBSCAN and Band Classification (weighted) to filter HDBSCAN's predictions with Band Classification predictions
- Yields more precise results, predicting fewer and narrower "areas of interest"

Combined Method	
Predicts >= 1 "Area of Interest" for Projects	Measurements Captured per Project
67.17%	44.72%

Project Code	***HDBSCAN* Prediction**	***Band Classification* (*weighted*) Prediction**	***Combined (unweighted)* Prediction**
2017.1.00786.S	Band: [Frequency Range] 3: [89.105 101.005] 3: [109.775 115.160] 6: [213.095 220.395] 6: [227.095 231.490] 7: [355.090 357.225] 7: [344.980 345.180] 7: [345.785 345.815]	Bands: 6 7	Band: [Frequency Range] 6: [213.095 220.395] 6: [227.095 231.490] 7: [355.090 357.225] 7: [344.980 345.180] 7: [345.785 345.815]

Limitations & Assumptions

- Limitations
  - Difficulty measuring success
  - Did not have full research papers to train on
- Assumption
  - All “areas of interest” already exist in the data
  - LDA topics are salient and discriminant
  - Optimal weights were calculated

Conclusions

- Combined (weighted) process is useful
  - Researchers submitting projects to ALMA
  - Proposal reviewers
  - Understanding of project proposals
  - Recommendations for proposed projects
- Applicable and adaptable to telescopes beyond ALMA
  - Expand Line/Continuum classification to Very Large Array (VLA) in New Mexico

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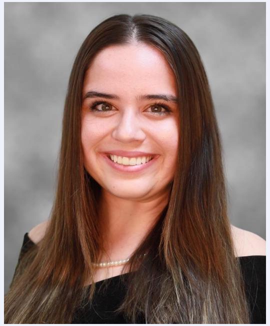

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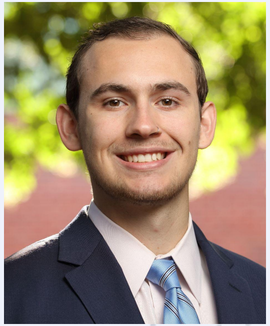

Citations

LDA Graphic:

M. Bakrey, "All About Latent Dirichlet Allocation (LDA) in NLP," Medium, 01-Nov-2020. [Online]. Available: https://mohamedbakrey094.medium.com/all-about-latent-dirichlet-allocation-lda-in-nlp-6cfa7825034e. [Accessed: 26-April-2024].

HDBSCAN Example Graph Code:

"HDBSCAN clustering with sklearn," Scikit-learn, [Online]. Available: https://scikit-learn.org/stable/auto_examples/cluster/plot_hdbscan.html#sphx-glr-auto-examples-cluster-plot-hdbscan-py. [Accessed: 26-April-2024].