Application of Machine-Learning Techniques to Understand the Nature of X-ray and Gamma-ray Sources

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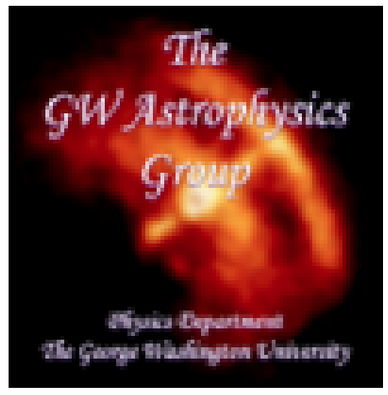
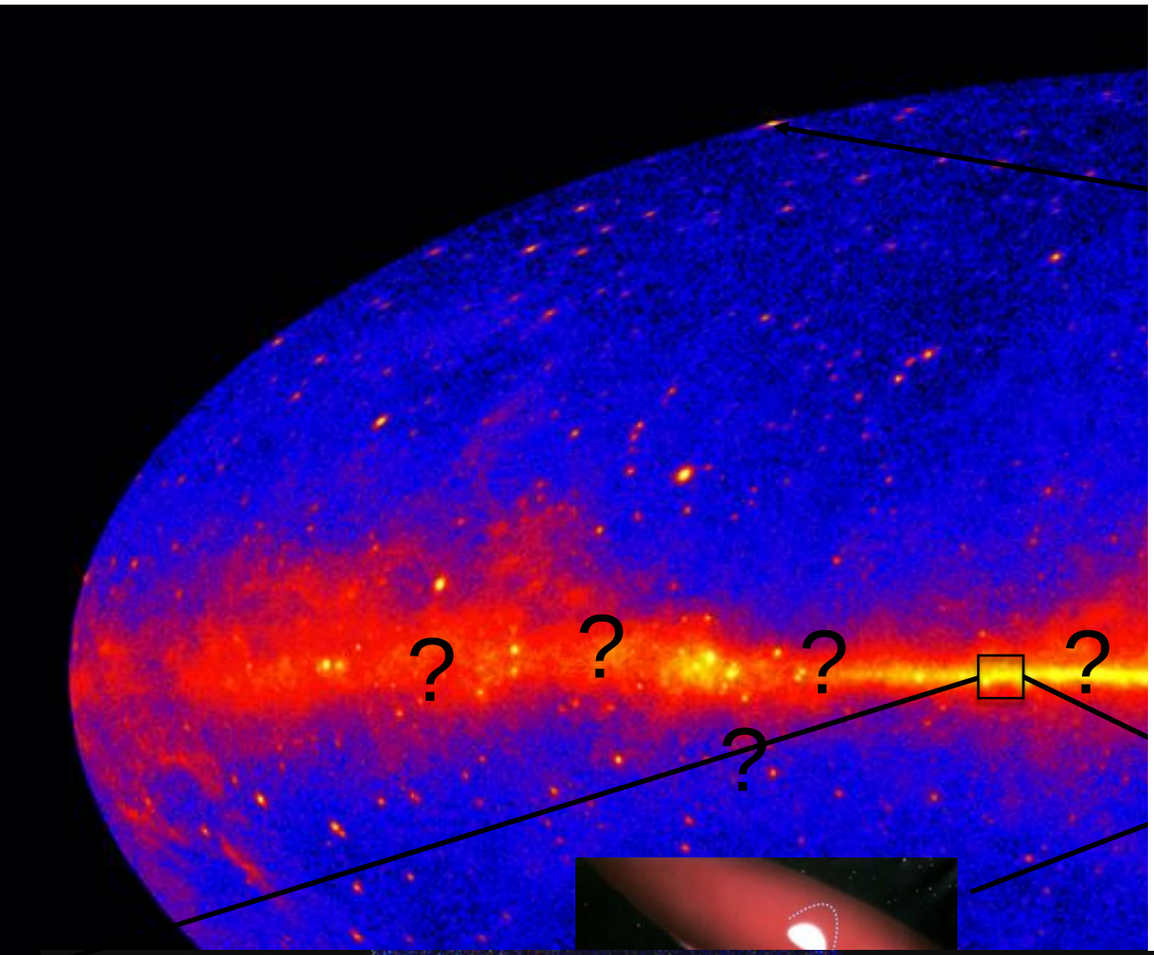
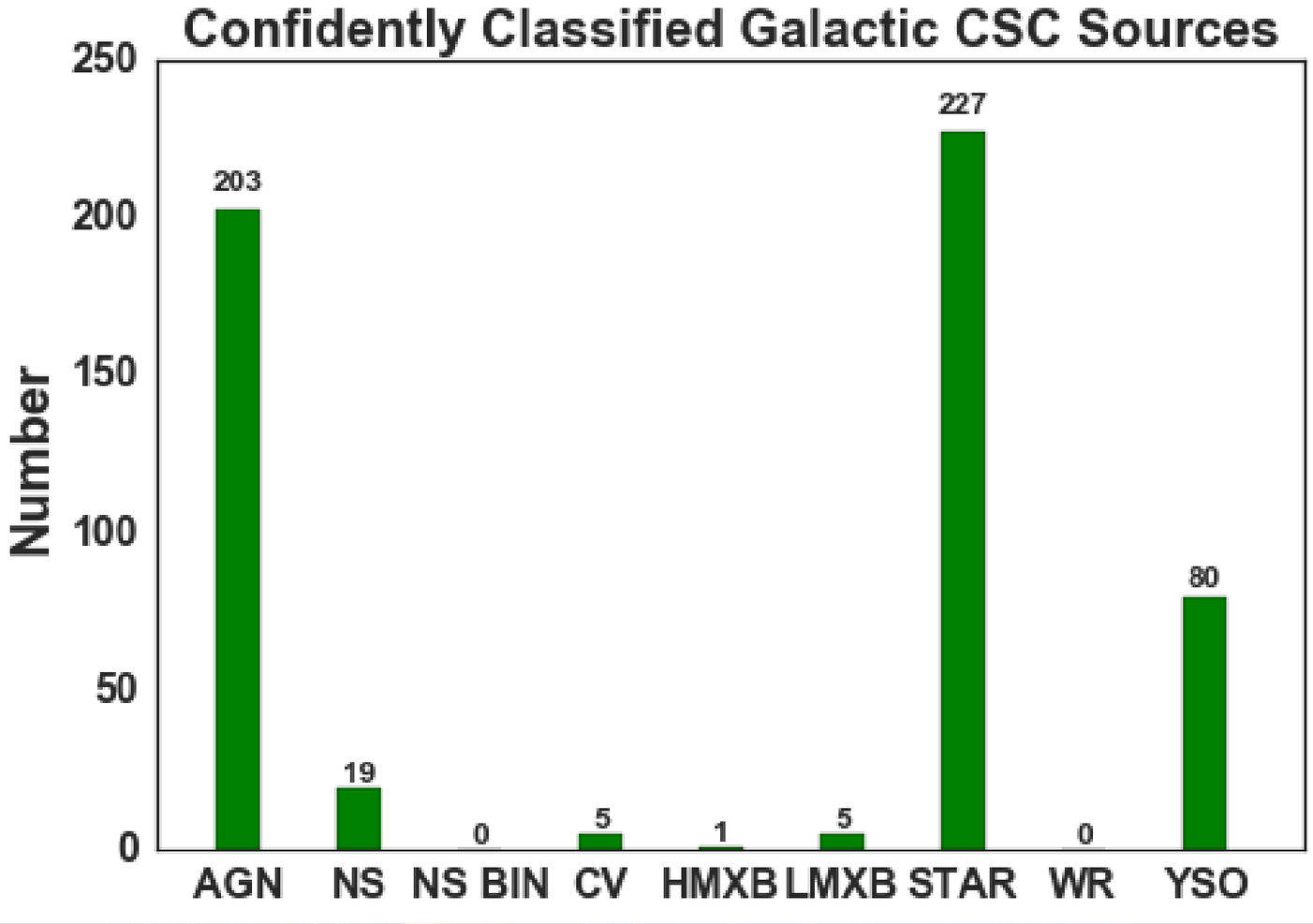
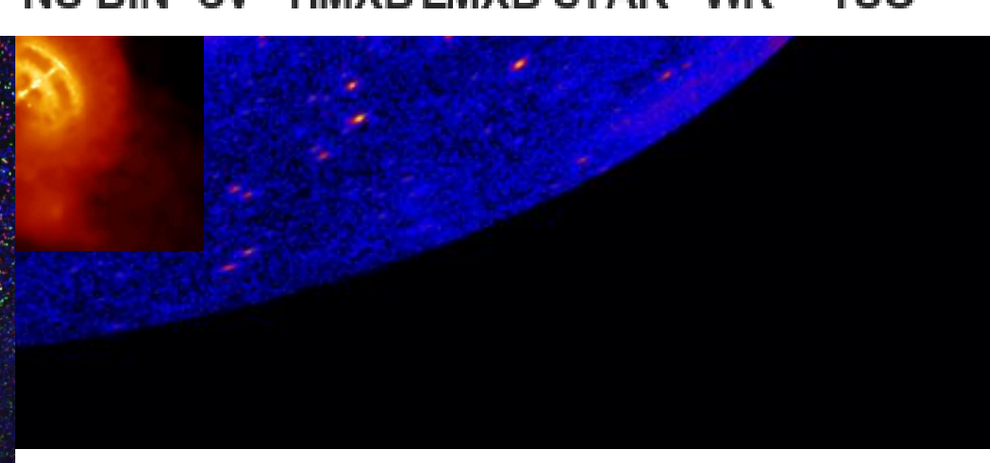
WASHINGTON, DC



IAU Symposium 325 Astroinformatics, October 20, 2016







-Ray Sky

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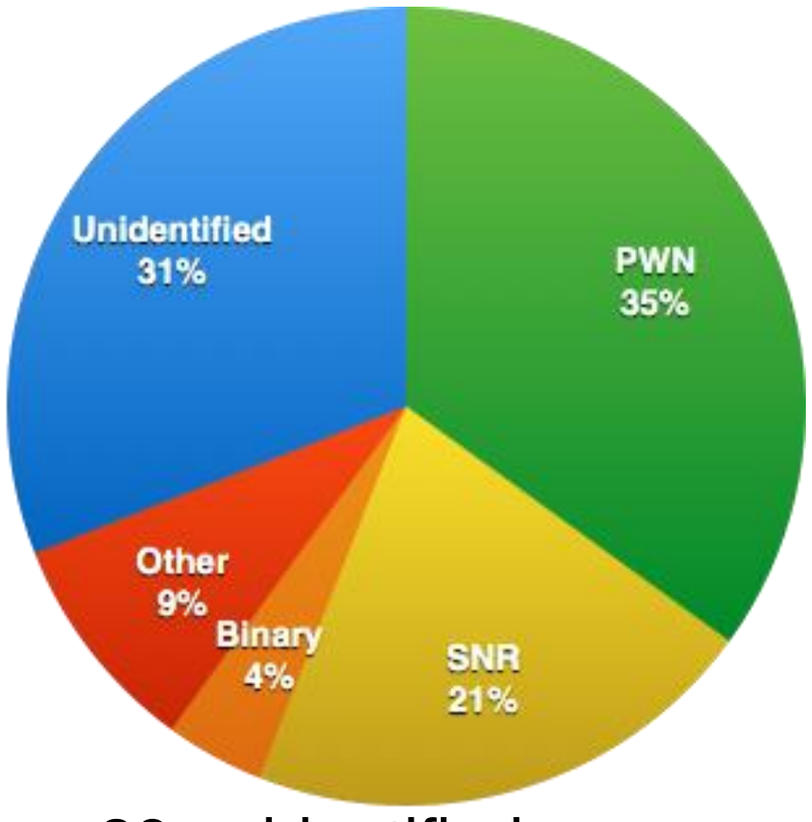
Defining the Problem

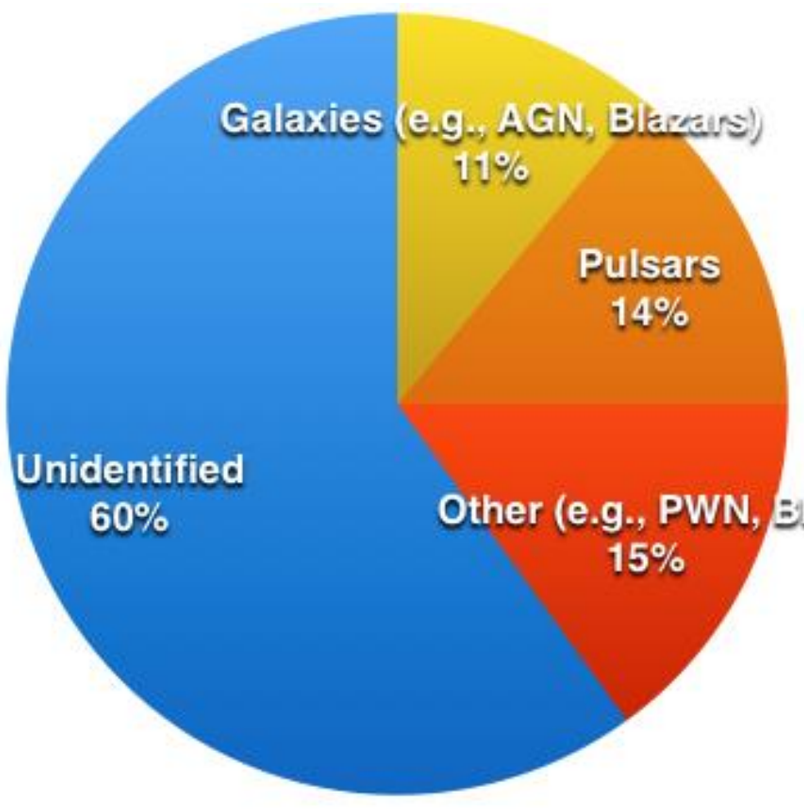
- Many unidentified very high energy sources

H.E.S.S. Galactic Source Breakdown



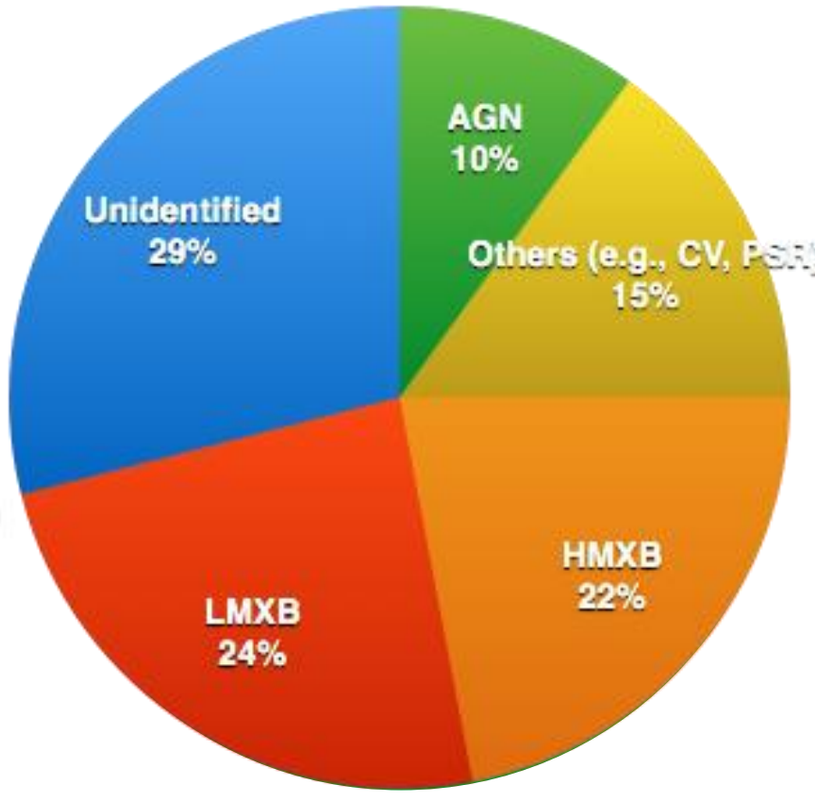
~20 unidentified sources

Fermi 3FGL Galactic Source Breakdown



~350 unidentified sources

Integral Galactic Source Breakdown

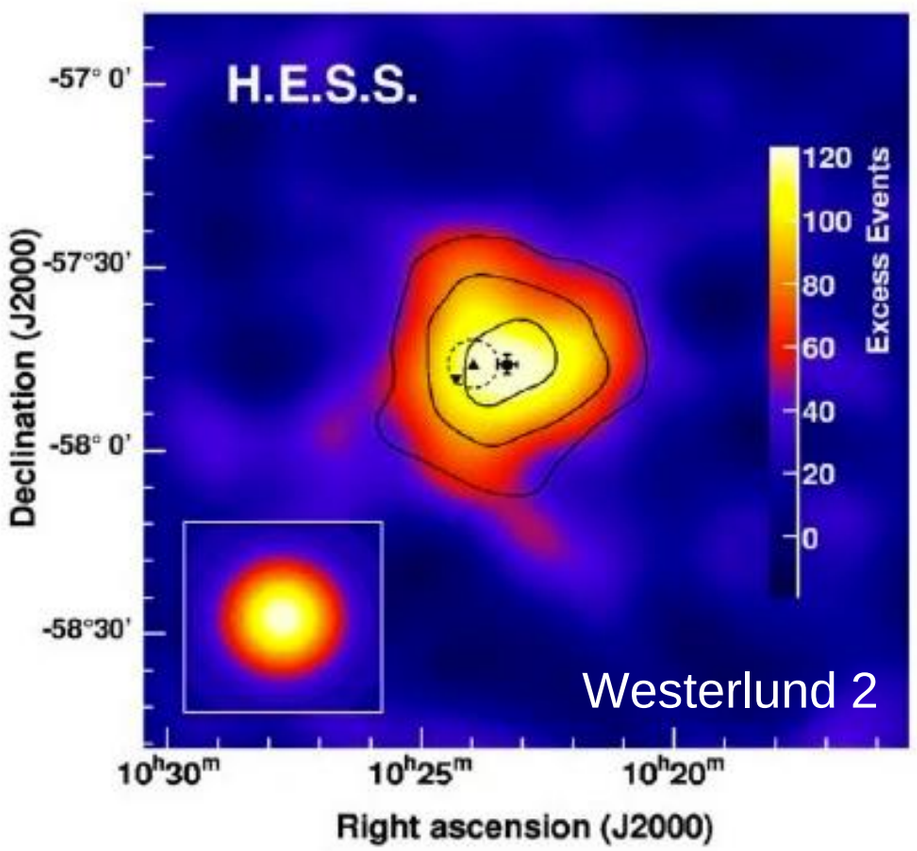


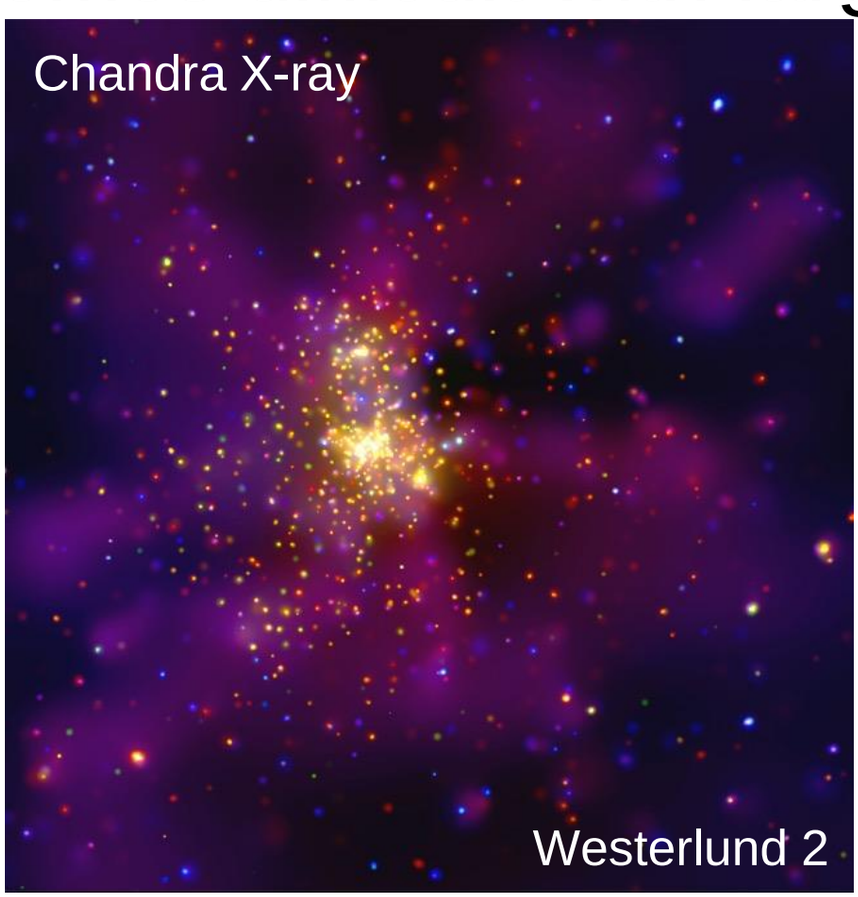
~50 unidentified sources

Defining the Problem

- MW counterparts can be used to classify these objects

- Identifying counterparts becomes difficult with larger error circles/ellipses





taken from https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2006/12/
Naze et al. (2008)
http://chandra.harvard.edu/photo/2008/wd2/

Defining the Problem

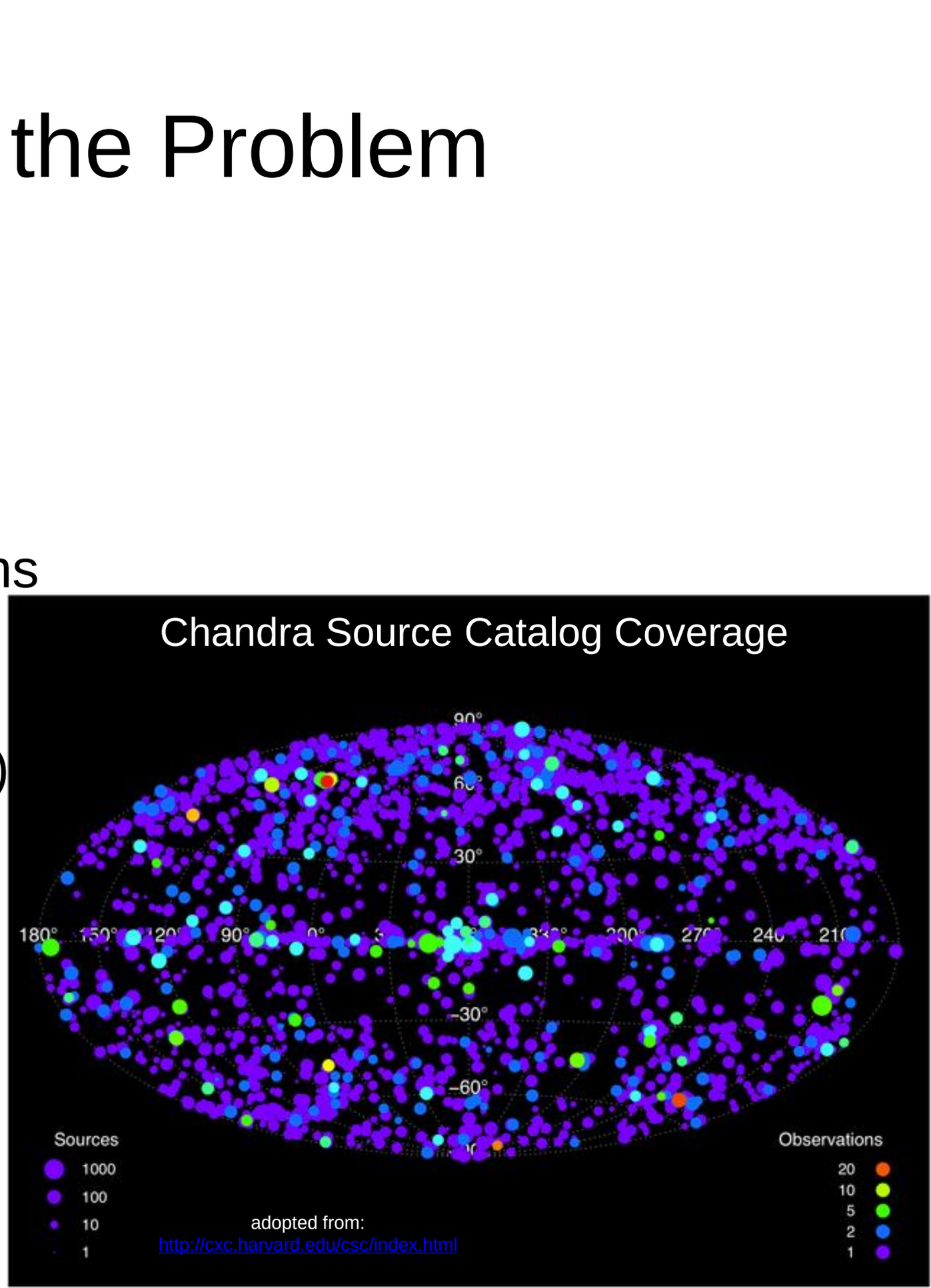
- Many X-ray archival images (many sources serendipitously observed >90% remain unidentified)

- First CSC data release contains ~95,000 sources

- 3XMM-DR6 (468,440 sources)

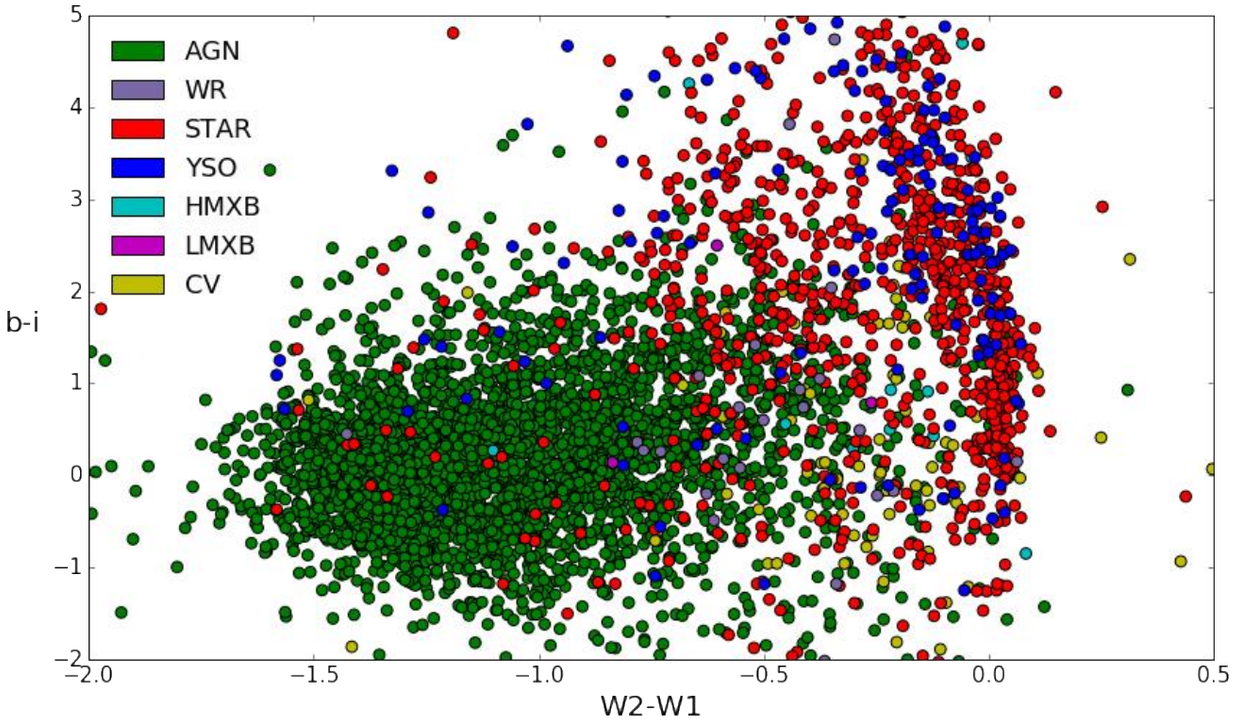
- CSCv2 ~400,000 sources (upcoming)

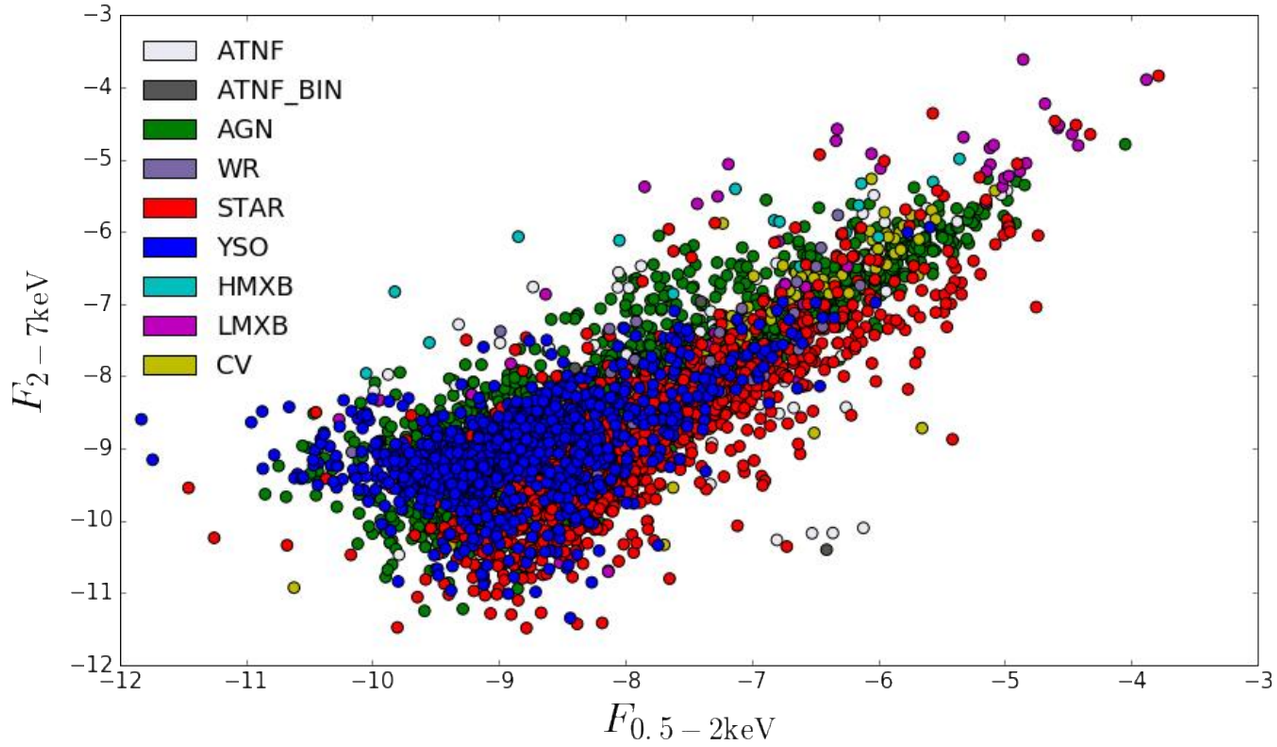
Color shows # of observations
Size shows # of sources

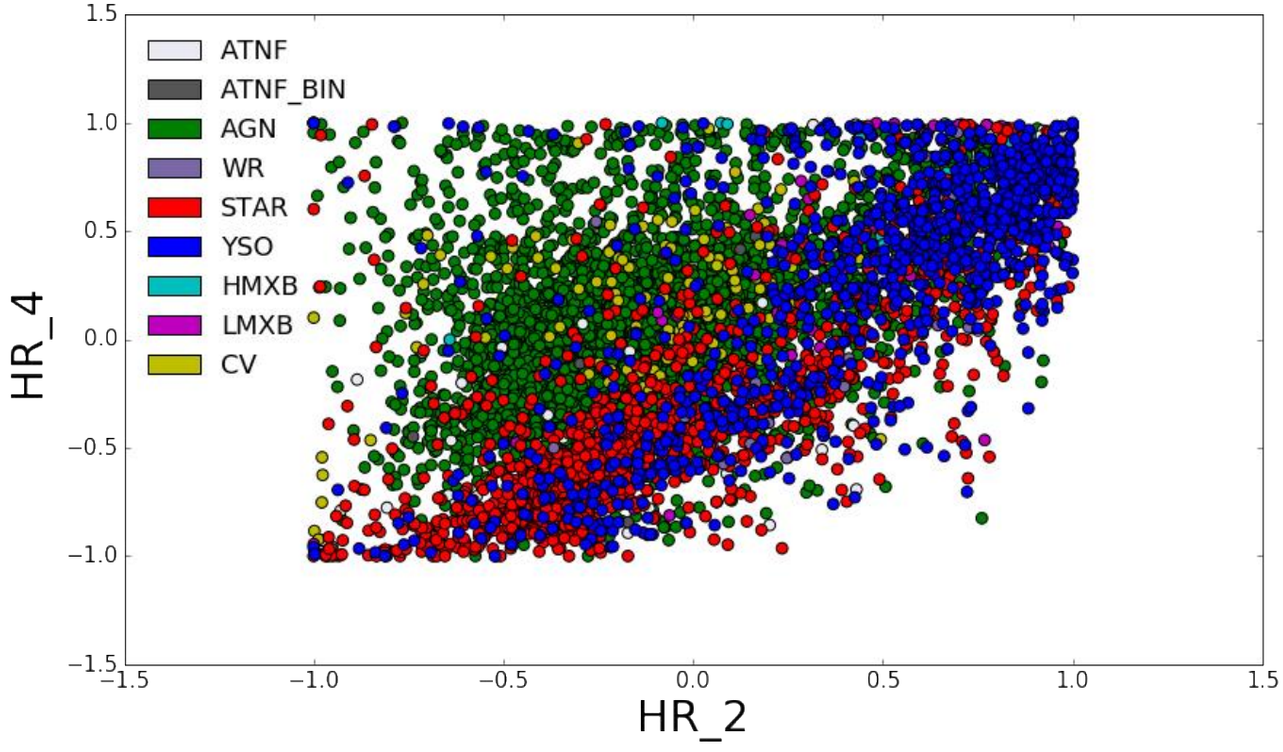


Defining the Problem

- Often X-ray data is not enough to classify sources
- Multi-wavelength data are needed
- Leads to high dimensionality problem


AGN
WR
STAR
YSO
HMXB
LMXB
CV
b-i
W2-W1


ATNF
ATNF_BIN
AGN
WR
STAR
YSO
HMXB
LMXB
CV
$F_{2-7\mathrm{keV}}$
$F_{0.5-2\mathrm{keV}}$


ATNF
ATNF_BIN
AGN
WR
STAR
YSO
HMXB
LMXB
CV
HR_4
HR_2

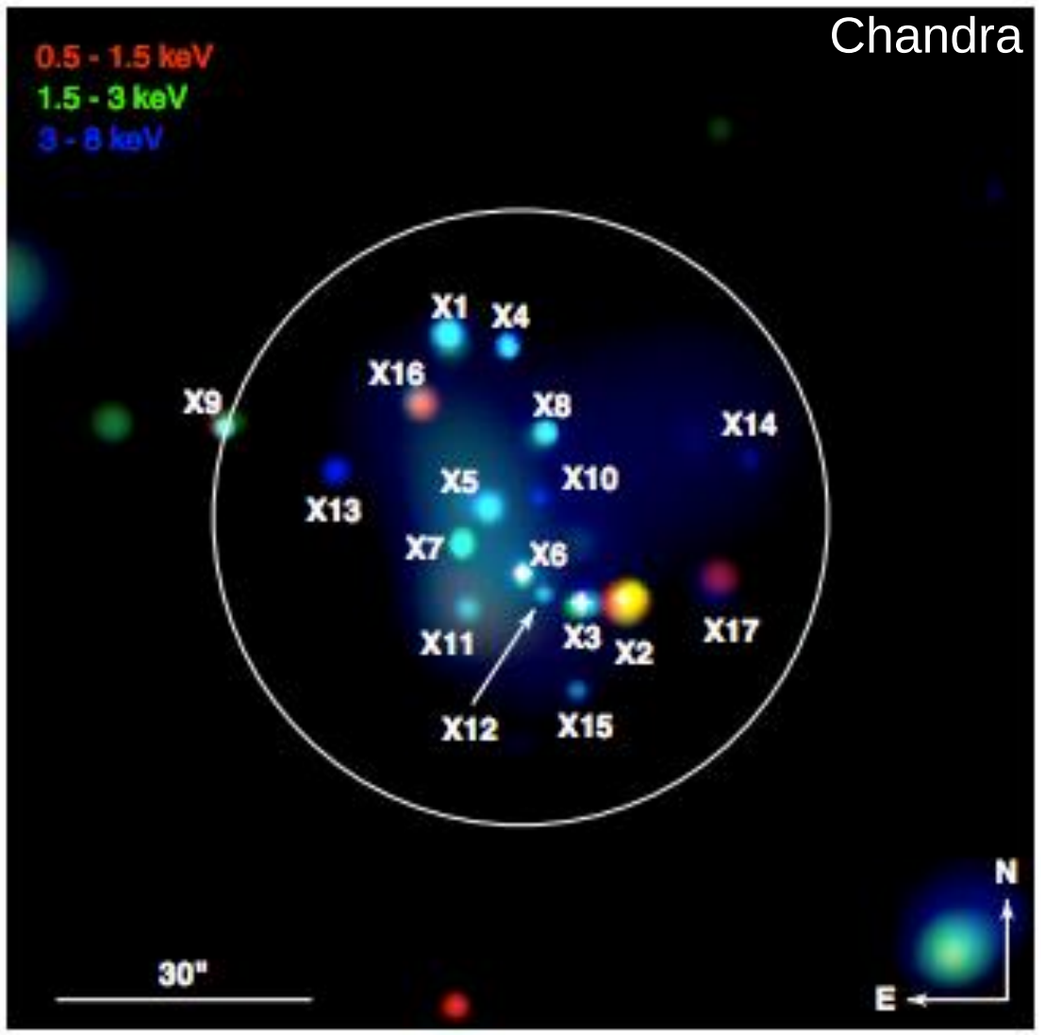
Astrophysical Importance: High Energy Sources

- Map out the population of GeV emitting compact objects in the galaxies (e.g., NS, BHs in binaries)
- Search for new and rare GeV and TeV emitting source classes (e.g., Colliding wind binaries)

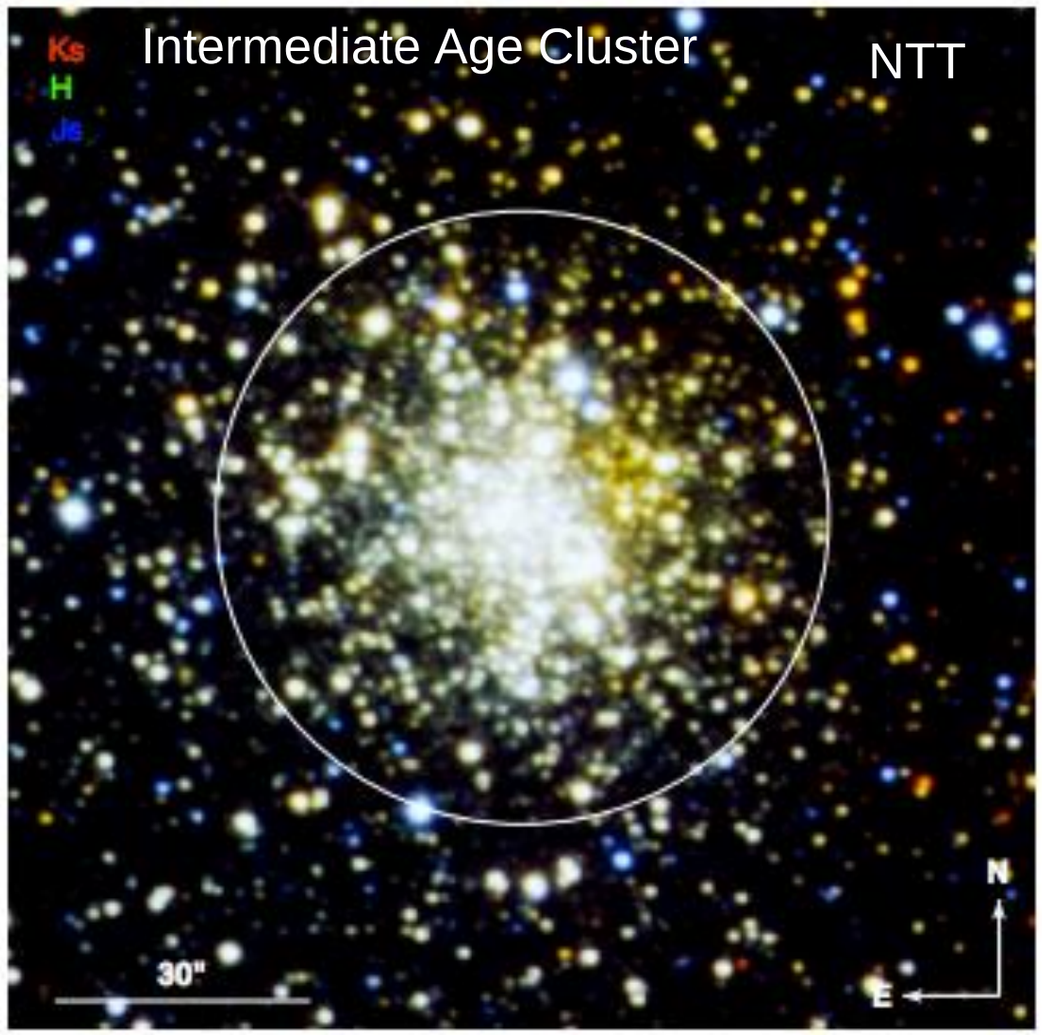
Astrophysical Importance: High Energy Sources

- Identifying compact objects in SNRs
- Understanding populations in galaxies/clusters

Pannuti et al. (2014)



Pooley et al. (2007)



Solution

- How can we efficiently classify all of these sources?
- Computers may eventually one day destroy us; however, until then we can take advantage of them!
- Machine learning can be used to handle large datasets and large numbers of parameters

Supervised Machine Learning

- Requires a training dataset
- Training dataset is used to teach the classifying algorithm how to make inferences about unclassified data

Training Dataset

- ~9,000 literature verified X-ray sources (from 8 catalogs, representing 9 source types)

Source Type	3XMM-DR6	CSC	Overlap
AGN	6526	1229	571
NS	88	33	32
NS BIN	10	5	4
CV	136	75	10
HMXB	21	8	5
LMXB	55	31	17
STAR	1380	514	291
WR	32	13	6
YSO	978	1152	221
Total	9226	3060	1157

Features=Measured Parameters

- Currently 19 features

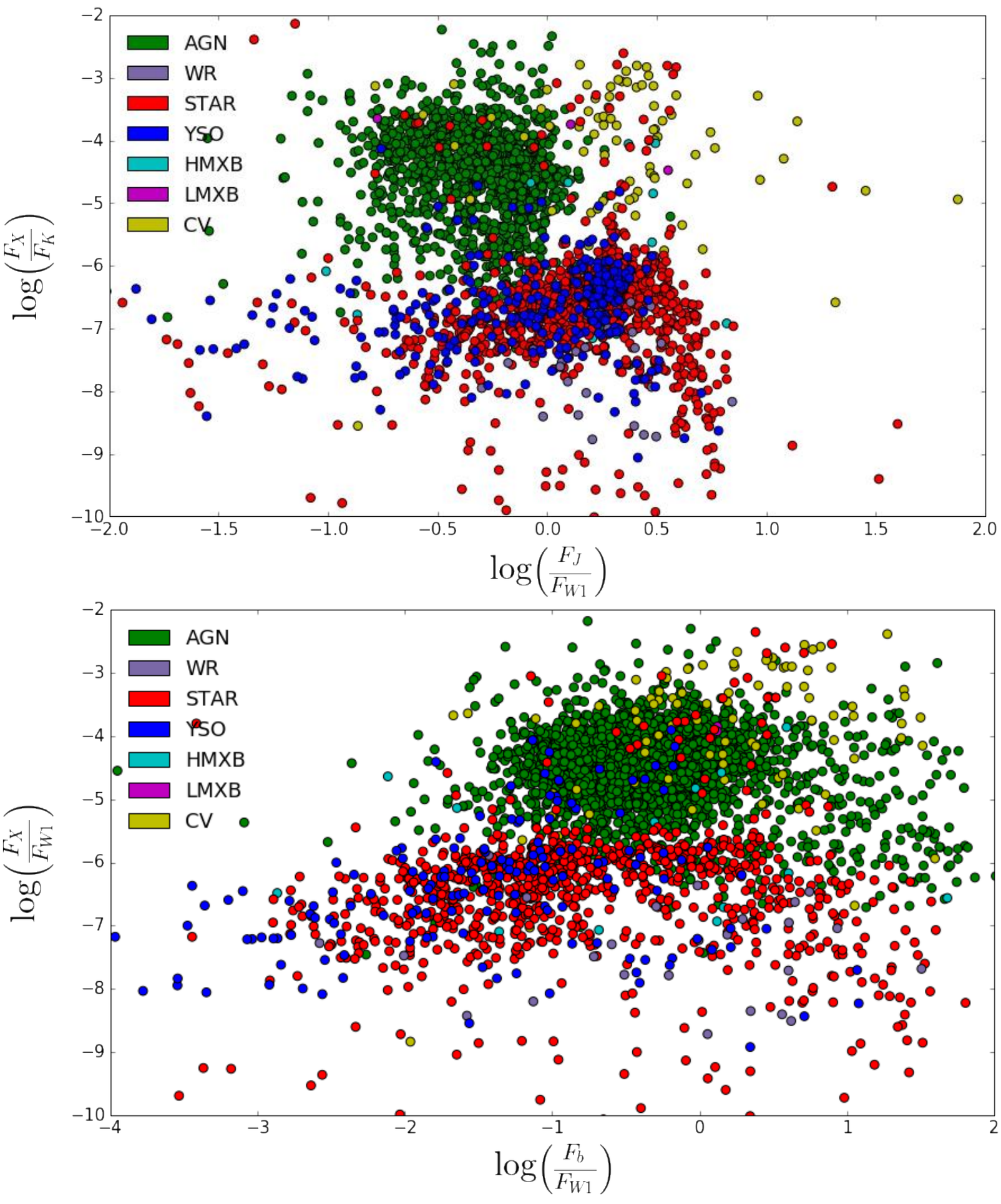
USNO-B

2MASS

WISE

All-Sky Catalogs

Feature	Description
EP052Flux	X-ray flux in the 0.5−2 keV band
EP27Flux	X-ray flux in the 2−7 keV band
HR2	Soft band hardness ratio defined in Section 2.2
HR4	Hard band hardness ratio defined in Section 2.2
Bmag	Magnitude of counterpart in B-band
Rmag	Magnitude of counterpart in R-band
Imag	Magnitude of counterpart in I-band
Jmag	Magnitude of counterpart in J-band
Hmag	Magnitude of counterpart in H-band
Kmag	Magnitude of counterpart in K-band
W1mag	Magnitude of counterpart in W1-band
W2mag	Magnitude of counterpart in W2-band
W3mag	Magnitude of counterpart in W3-band
coljk	Magnitude of J-band minus K-band
coljh	Magnitude of J-band minus H-band
colri	Magnitude of R-band minus I-band
colw12	Magnitude of W1-band minus W2-band
colw13	Magnitude of W1-band minus W3-band
colw2j	Magnitude of W2-band minus the J-Band

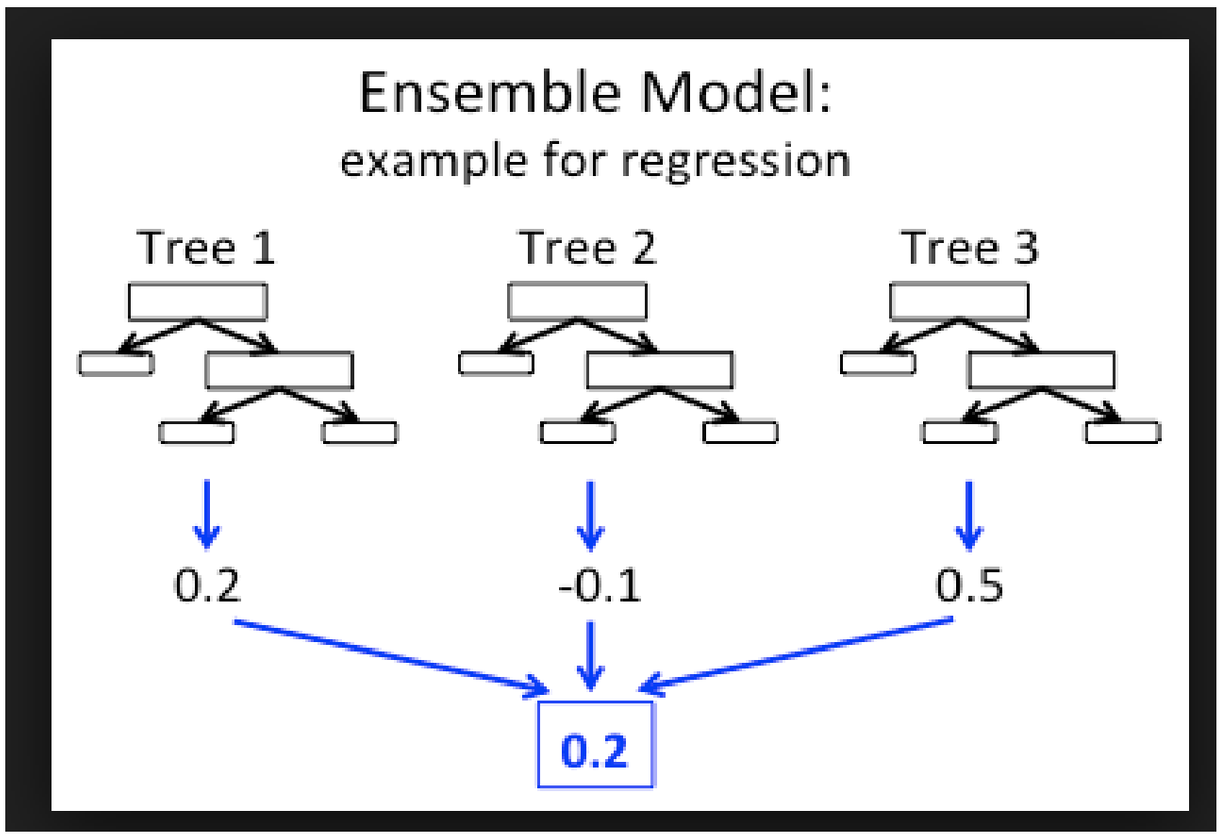

AGN
WR
STAR
YSO
HMXB
LMXB
CV
$\log\left(\frac{F_X}{F_K}\right)$
$\log\left(\frac{F_J}{F_{W1}}\right)$
AGN
WR
STAR
YSO
HMXB
LMXB
CV
$\log\left(\frac{F_X}{F_{W1}}\right)$
$\log\left(\frac{F_b}{F_{W1}}\right)$

Random Forest (RF)

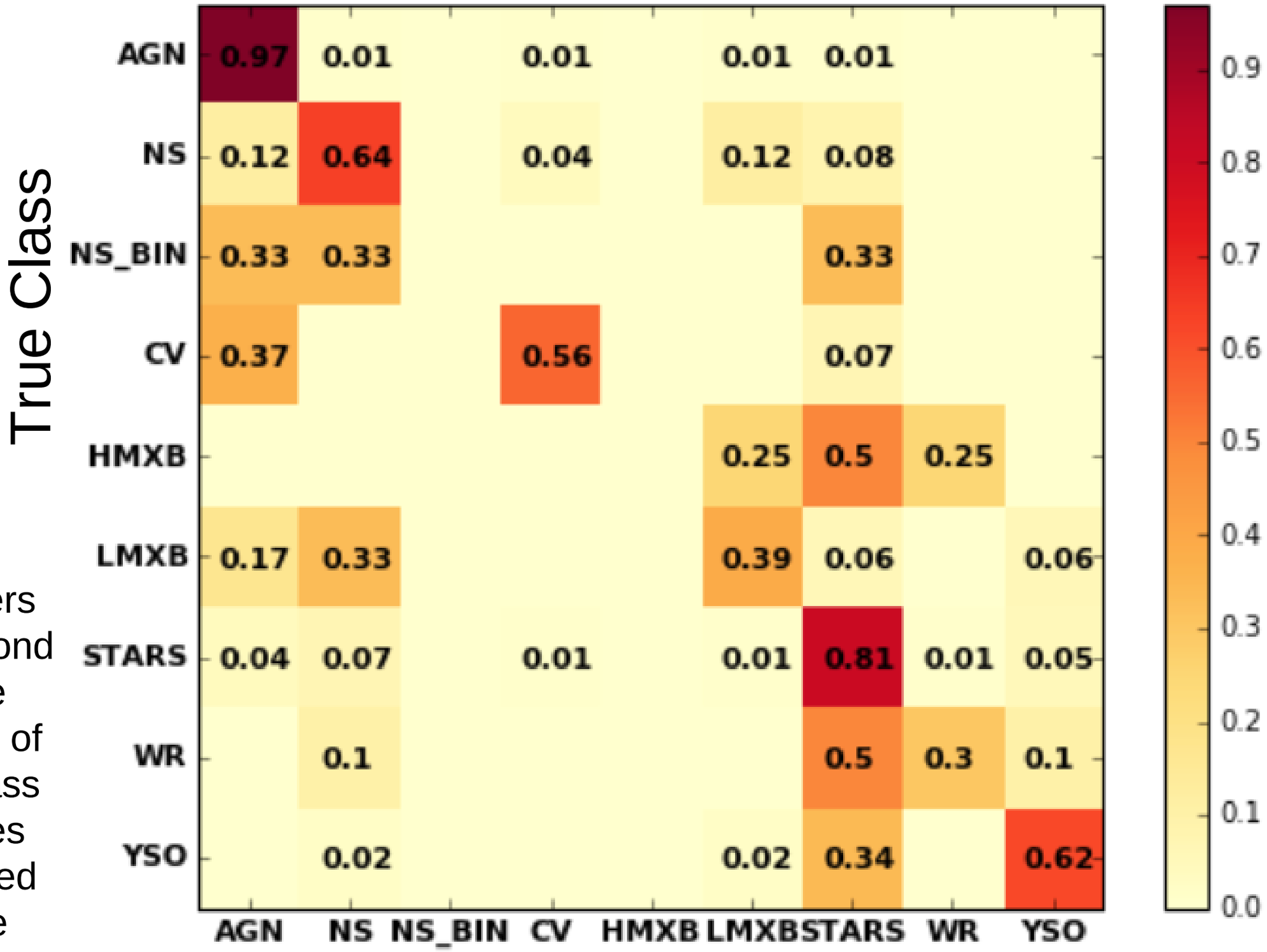
- Bootstraps training dataset
- Uses a random subset of features
- Reduces overfitting

Pedregosa *et al. (2011)*

- Not sensitive to uninformative features



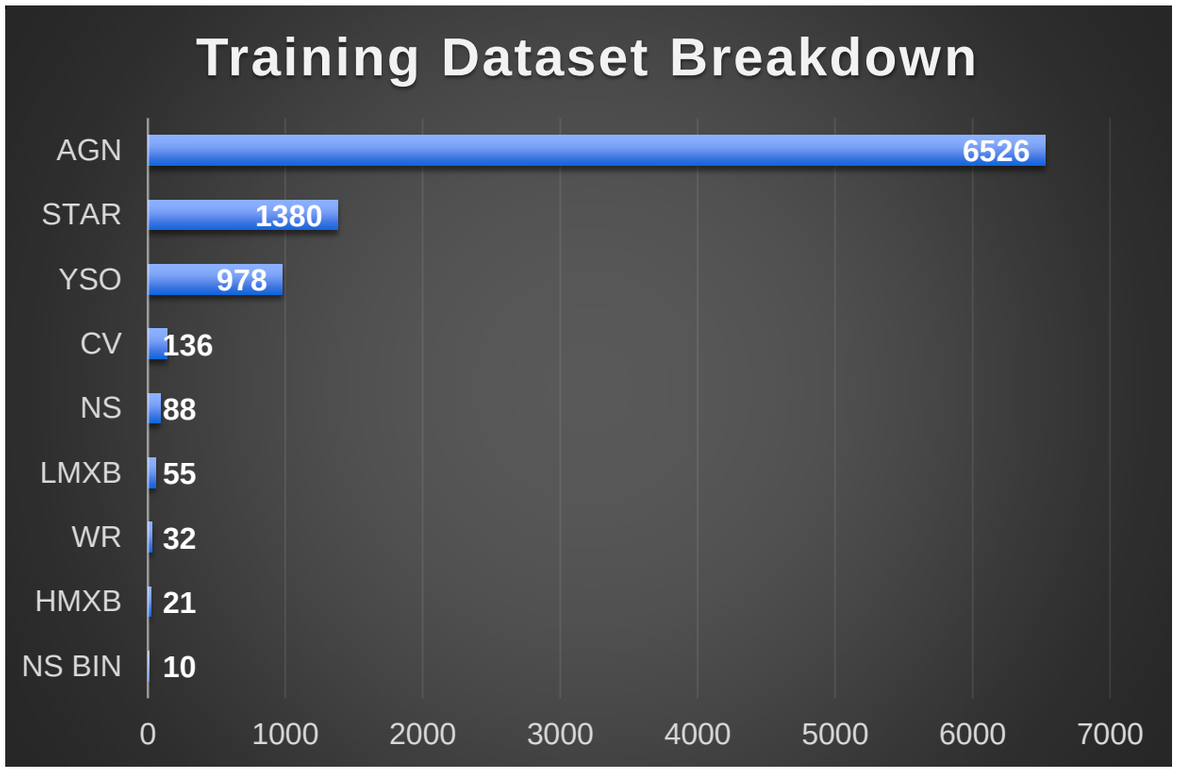
Confusion Matrix for Random Forest



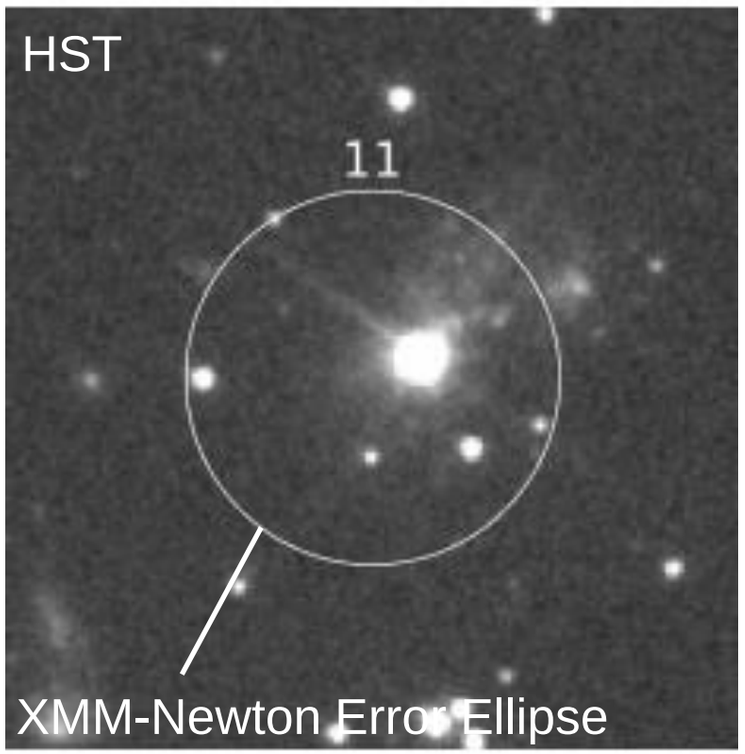
Numbers correspond to the fraction of true class sources classified as the predicted class

Current Issues

- Heavily Imbalanced Training Dataset
- Errors on features
- Confusion between sources and counterparts

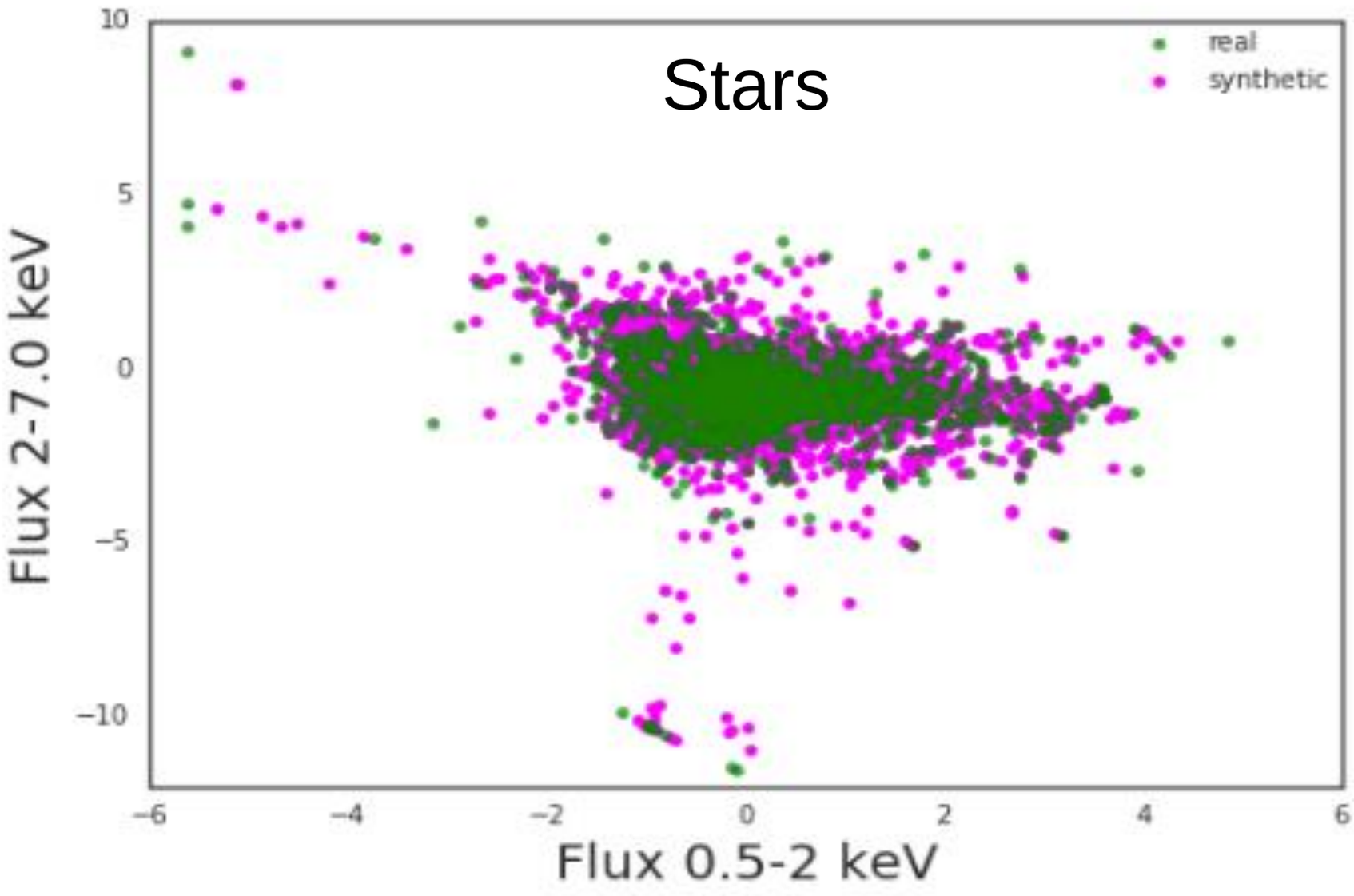


Sonbas et al. 2016



Imbalanced Training Data

- Currently we use the Synthetic Minority Over Sampling Technique (SMOTE; Chawla et al. 2011)

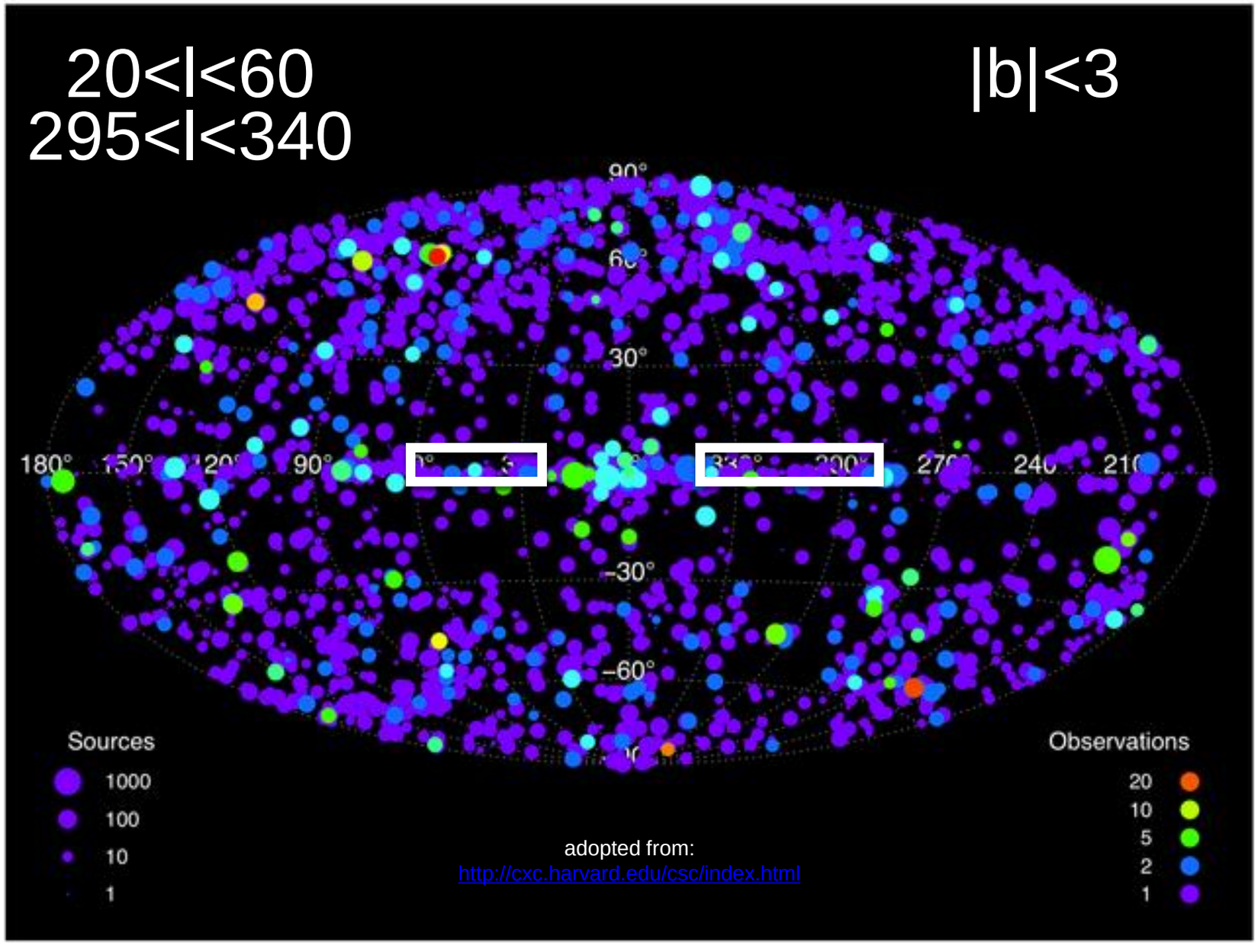


Biases and Missing Data

- Most of the classified AGN are off of the Galactic plane
- Must account for reddening through the plane
- Currently use a flag value for missing data

Chandra Source Catalog

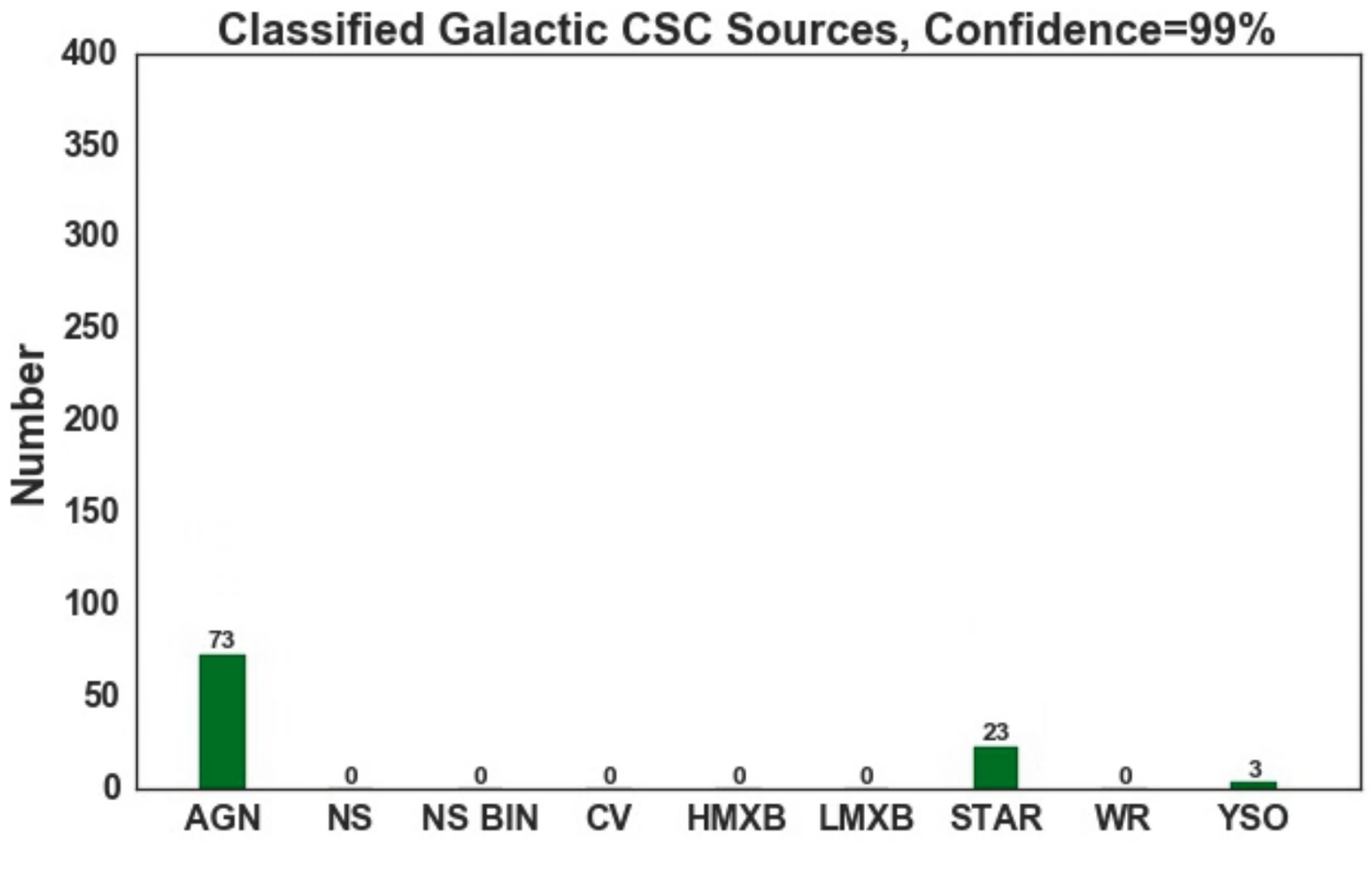
- Currently we are working to classify ~1,100 unclassified sources in the galactic plane



adopted from:
http://cxc.harvard.edu/csc/index.html

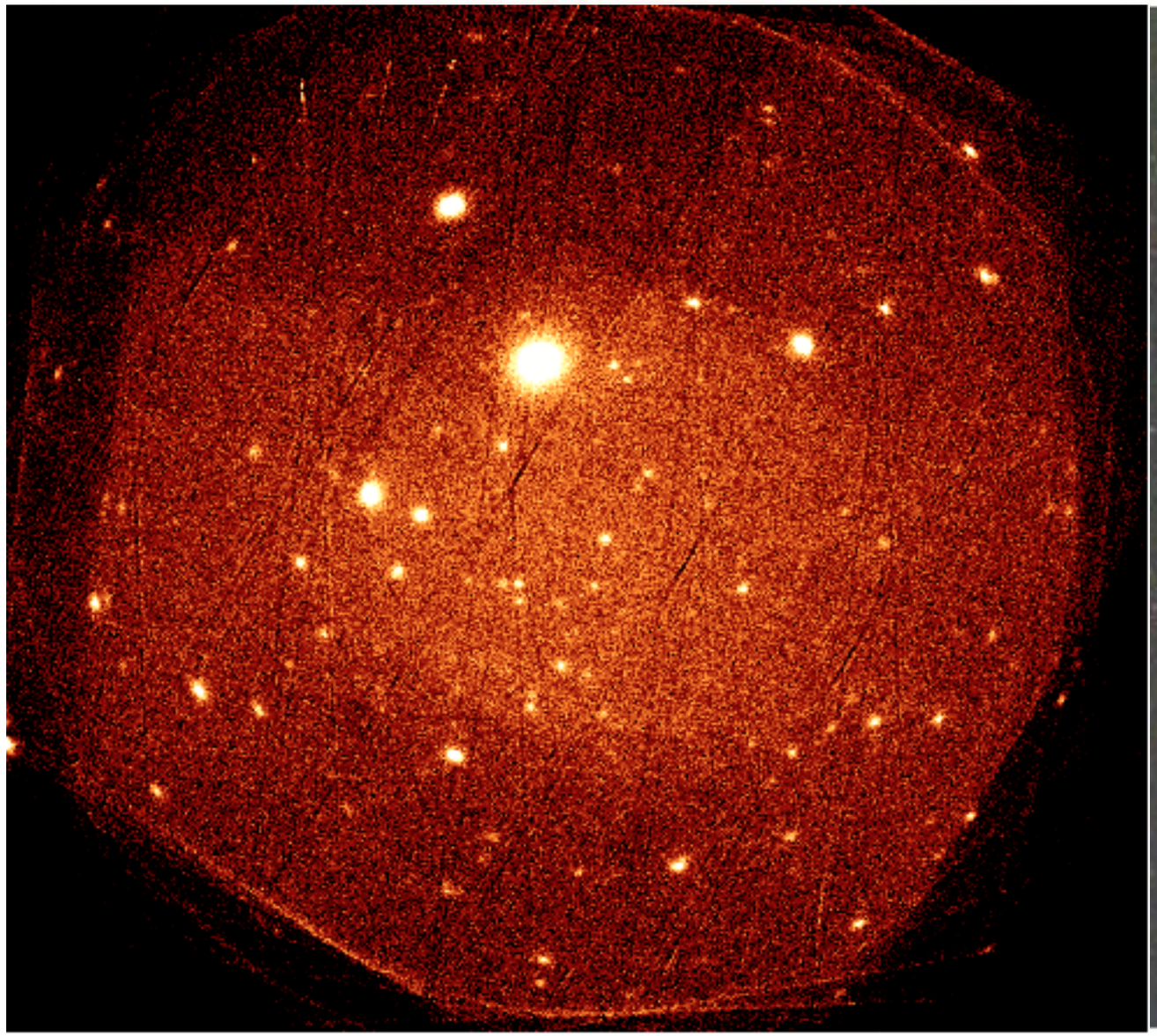
Preliminary Results

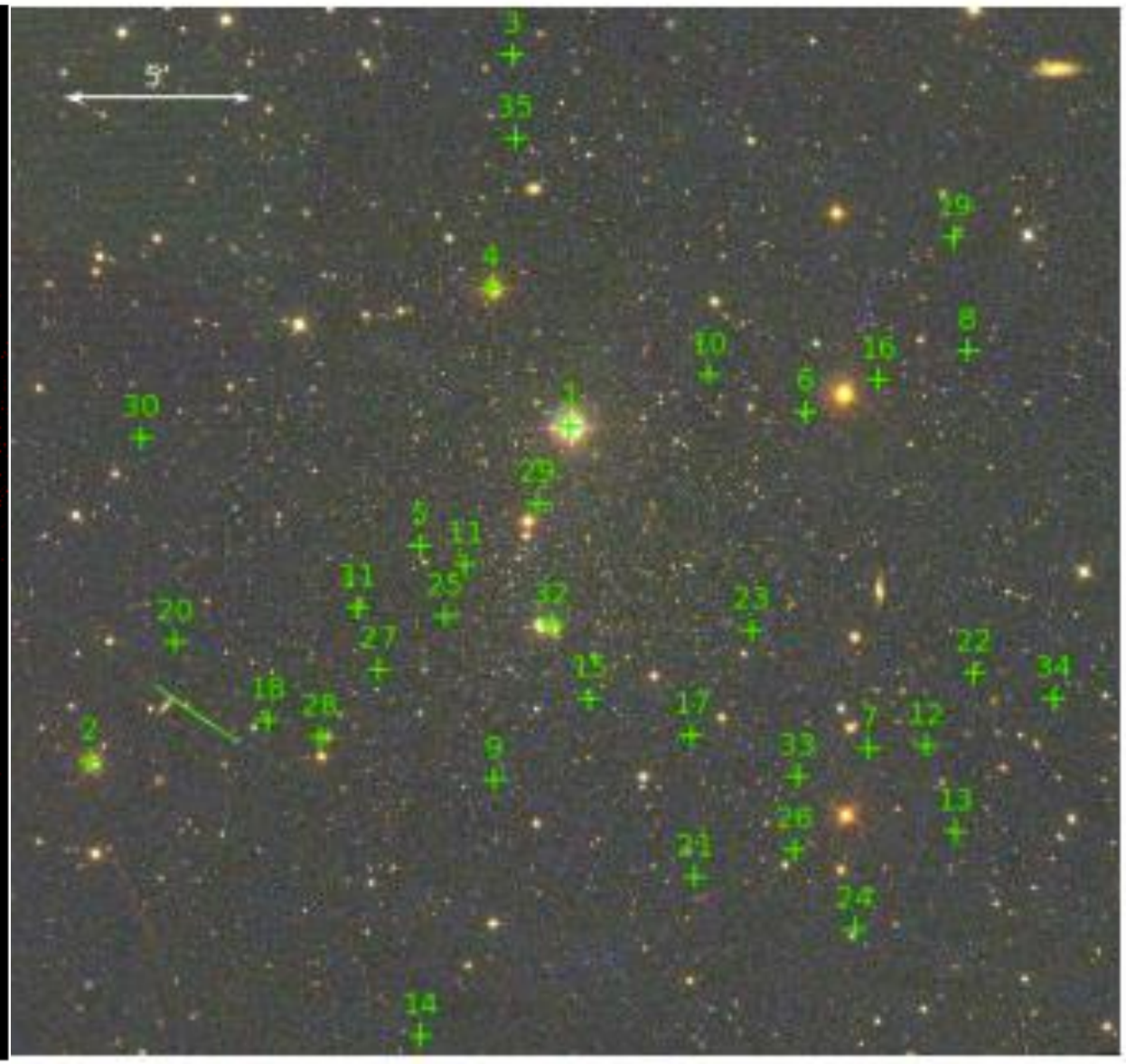
Class	P_{AGN}	P_{NS}	P_{NSBIN}	P_{CV}	P_{HMXB}	P_{LMXB}	P_{STAR}	P_{WR}	P_{YSO}	Source Name (CXO)	RA	DEC
STAR	0.0	0.0	0.0	0.0	0.02	0.0	0.89	0.06	0.03	CXO J185807.9+020411	284.53322509	2.06995874
STAR	0.03	0.0	0.0	0.12	0.0	0.03	0.82	0.0	0.0	CXO J184203.8-052331	280.51606568	-5.39194554
STAR	0.0	0.0	0.0	0.0	0.0	0.0	0.91	0.02	0.07	CXO J192318.7+140748	290.828027193	14.1302255582
AGN	0.97	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.02	CXO J163939.3-484513	249.91385475	-48.75383928
AGN	0.98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	CXO J193938.9+213337	294.91229638	21.56052764
STAR	0.0	0.0	0.0	0.0	0.0	0.01	0.8	0.03	0.16	CXO J164044.3-485101	250.18497892	-48.8504673
AGN	0.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	CXO J185812.4+020049	284.55194378	2.01373768
CV	0.0	0.0	0.0	0.65	0.05	0.08	0.22	0.0	0.0	CXO J194015.9+213513	295.06635999	21.58709821
LMXB	0.09	0.01	0.0	0.0	0.0	0.89	0.01	0.0	0.0	CXO J183316.2-102341	278.317621267	-10.3949345091



Draco

Sonbas et al. 2016



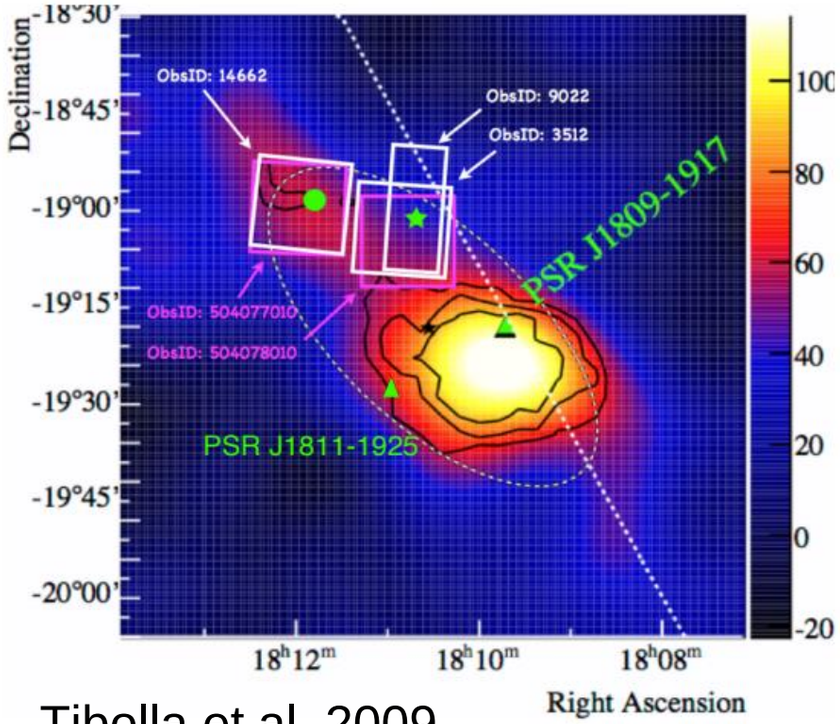


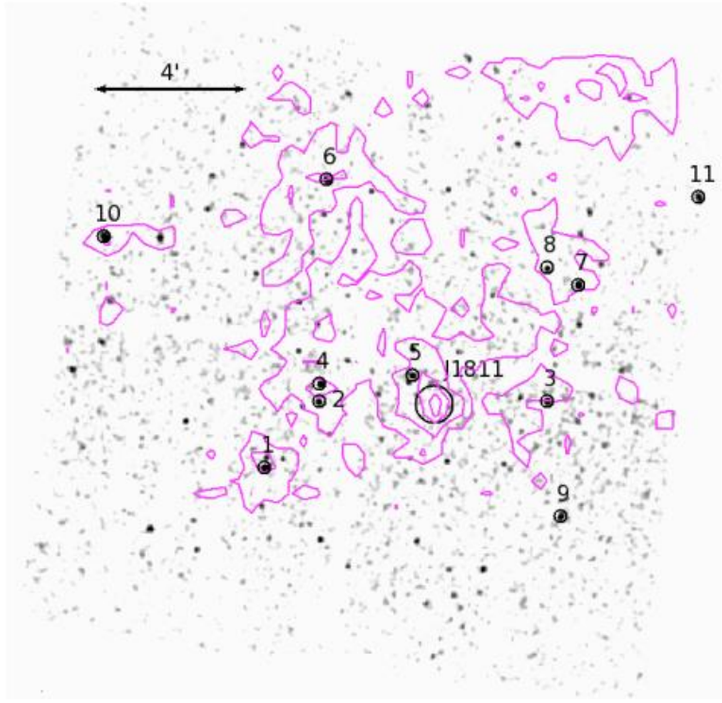
Found several possible qLMXB/CVs in Draco

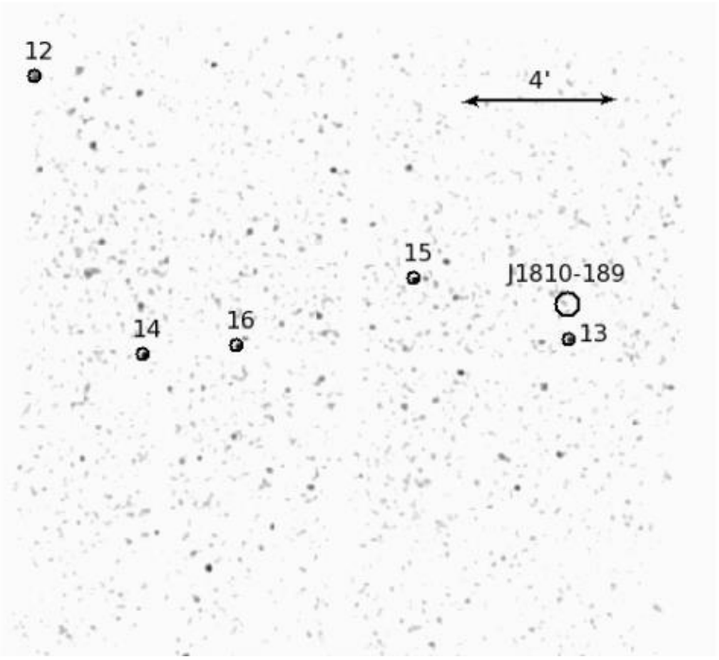
Classifications matched well with manual efforts by other teams

HESS J1809-193 & HESS J1741-302

Aharonian et al 2007

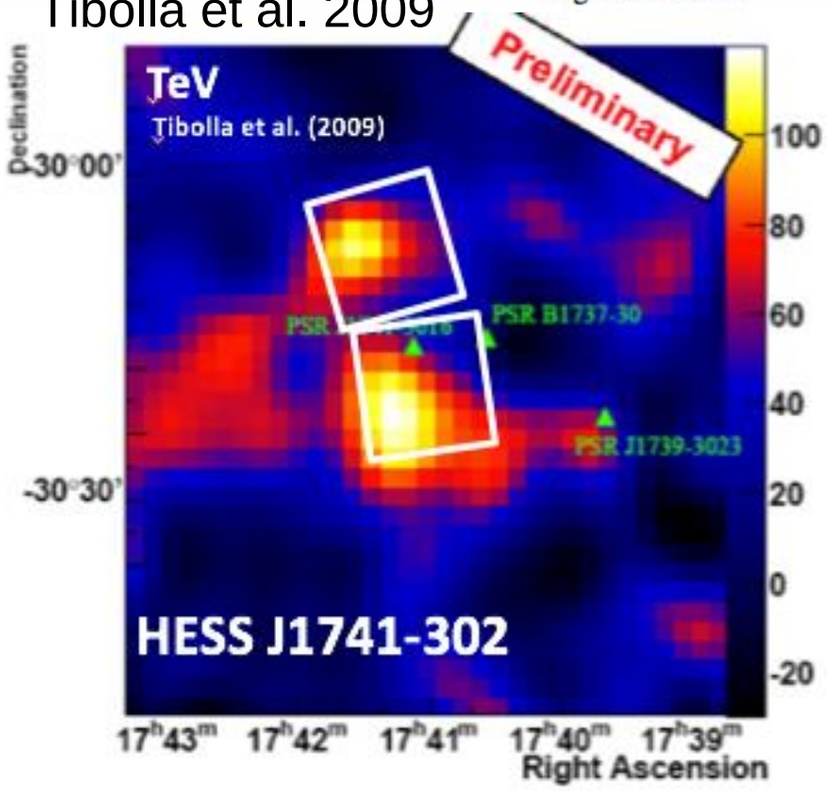




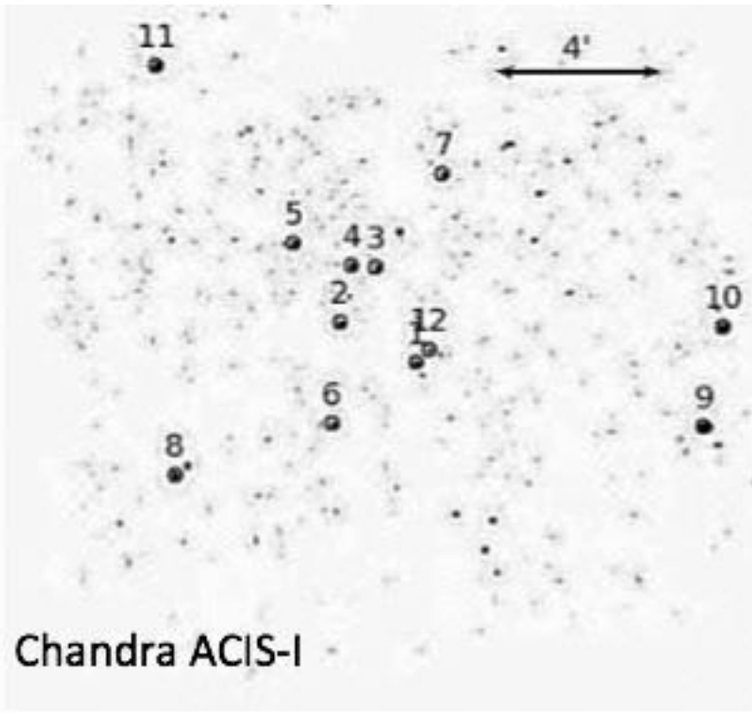


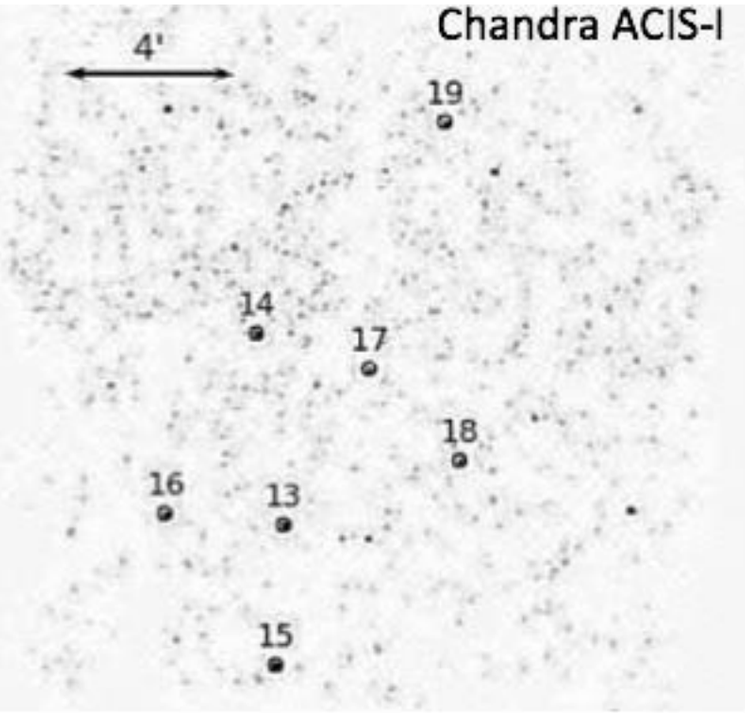
Rangelov et al. 2014

Tibolla et al. 2009



Hare et al. 2016

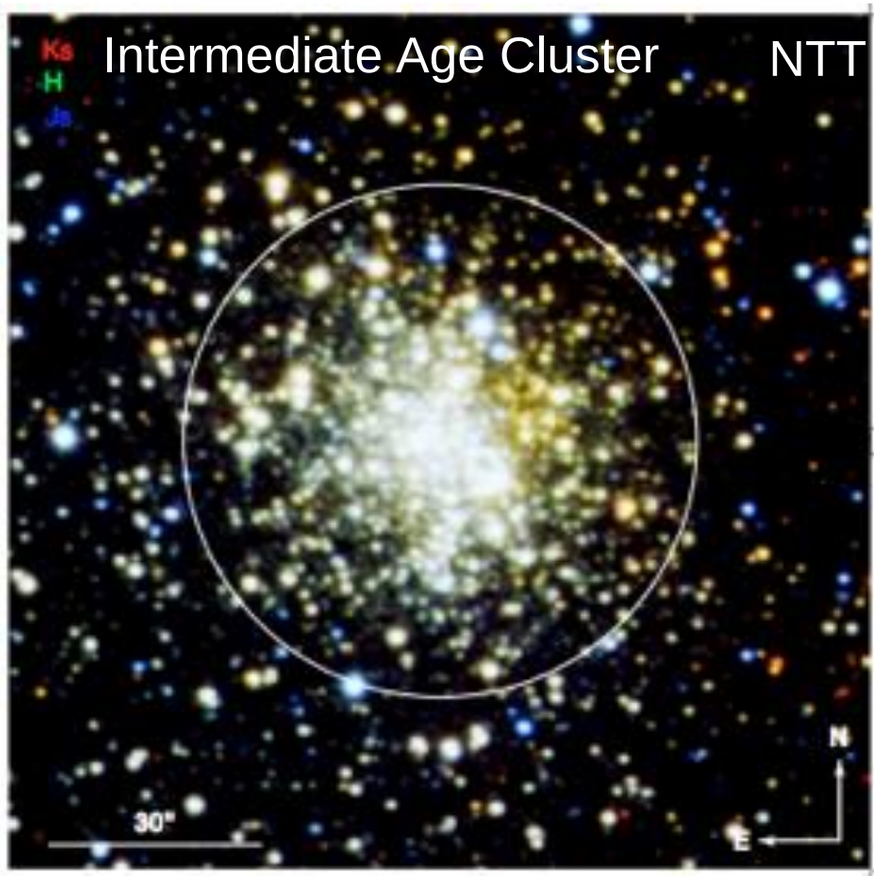




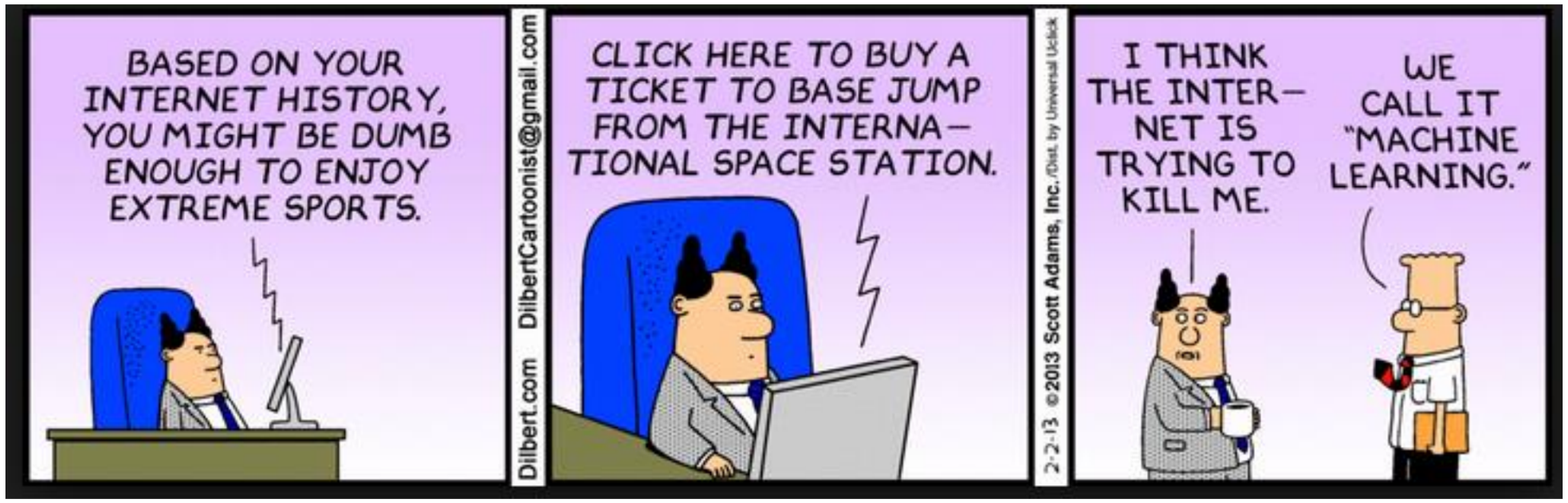
Future Work

- Add a more sophisticated cross-matching technique
- Include confusion into classification confidence in a robust way
- Include new catalogs to increase the number of underrepresented source types
- New MW features (e.g., radio, x-ray variability)
- Allow for use of catalogs that do not have full sky coverage (e.g., SDSS)

Pooley et al. (2007)



Thank You!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