

Searches of lensed Transients and Variables

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Time Domain Cosmology with Strong Gravitational Lensing, Jan 25, 2021

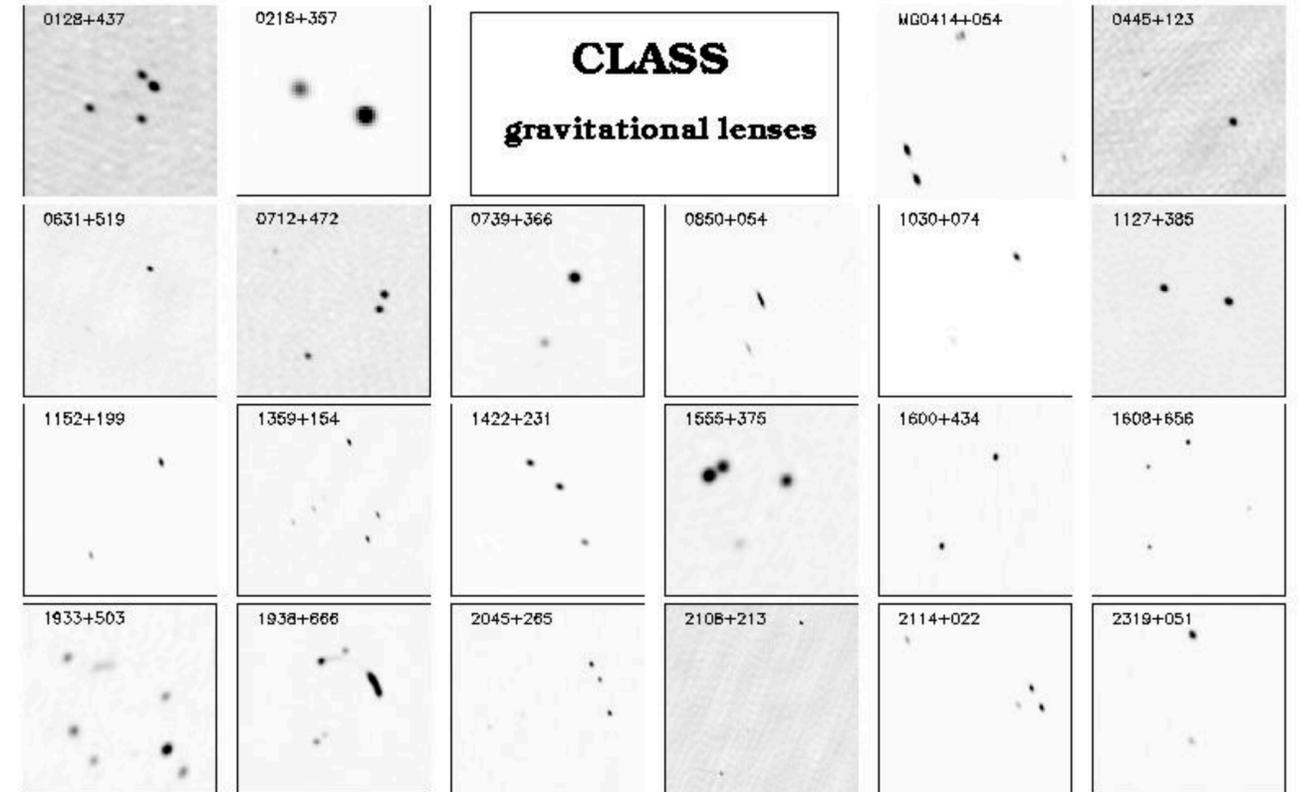
Overview

- Types of transient/variable sources
 - Quasars
 - Supernovae and GWs
 - Others - GRBs & FRBs
- Types of searches
 - (Machine Learning) Algorithms
 - Visual inspection / Citizen Science

Imaging/Continuum

Quasars

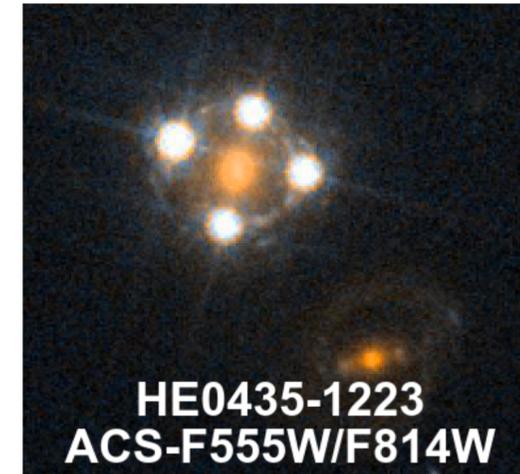
- Radio:
 - MIT-Greenbank Survey (Burke 1989)
 - JVAS (Patnaik et al. 1992, Browne et al. 1998)
 - CLASS (Myers et al. 2002)
- Optical:
 - HST Snapshot Survey (Bahcall, Maoz, et al. 1992)



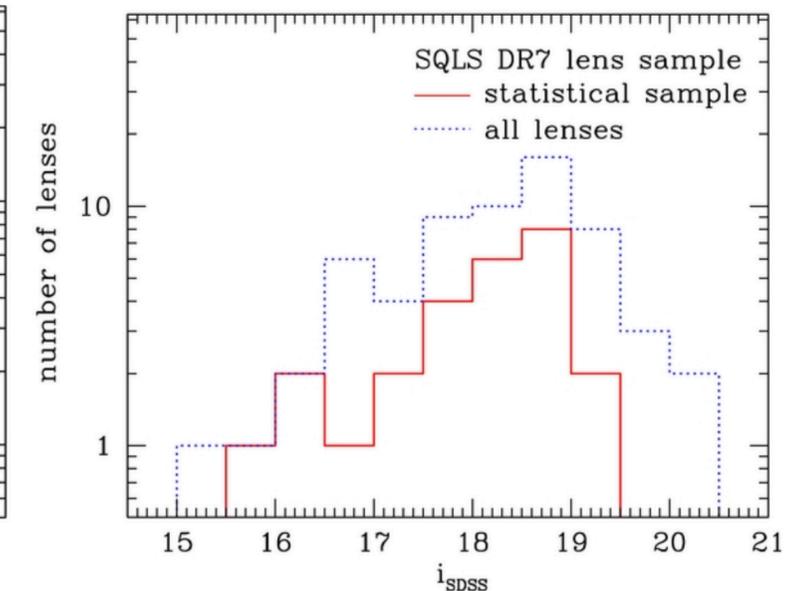
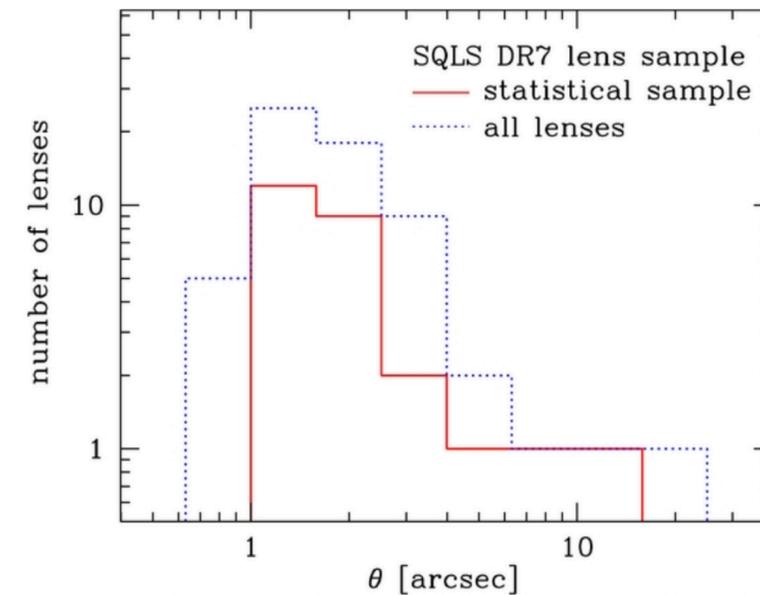
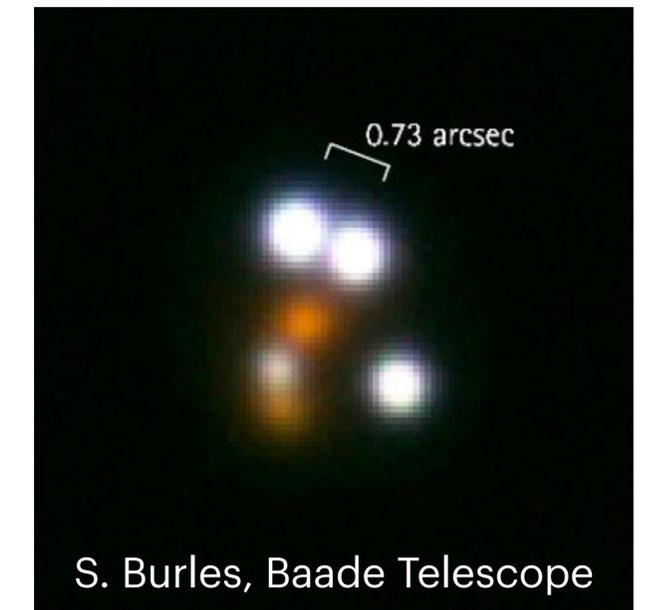
Other optical (HST-based) searches e.g. CANDELS, GEMS, GOODS and COSMOS - but for lensed galaxies

Imaging+Spectroscopy

- Hamburg - ESO Survey
 - e.g. Wisotzki et al. 1996, 2000, 2001
- SDSS/BOSS spectroscopy:
 - Oguri et al. 2006: SQLS morphology+colors+ modeling+ SDSS image visual inspection
 - AM et al. 2016: BQLS morphology+colors+BOSS image visual inspection
 - Jackson et al. 2012: MUSCLES visual inspection of all quasars visible in UKIDSS



Quasars



Inada et al. 2012

Imaging/Continuum

Quasars

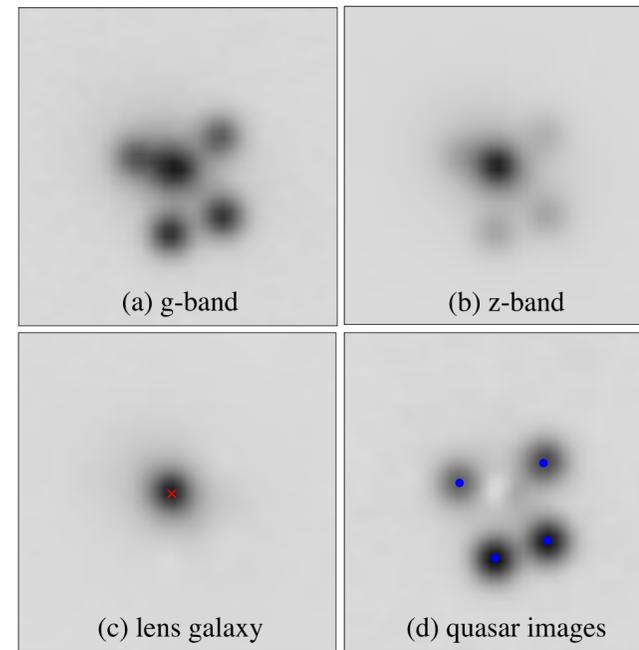
Catalog-based

- WISE +/- Gaia +/- DES (STRIDES)
 - Agnello, ...AM, et al. 2018: Color cuts + multiplets + visual inspection
 - Agnello & Spiniello 2019: 5 methods ; cuts based on morphology, multiplets, spectra, color, multi-wavelength
 - Lemon et al. 2017, 2018, 2019, 2020: GAIA based; comp. fitting+ variability (see next talk)
- PanSTARRS
 - Rusu, ...AM, et al. 2019: AGN catalog + cuts on parameters (color, magnitude, etc.)+ GAIA+ visual inspection

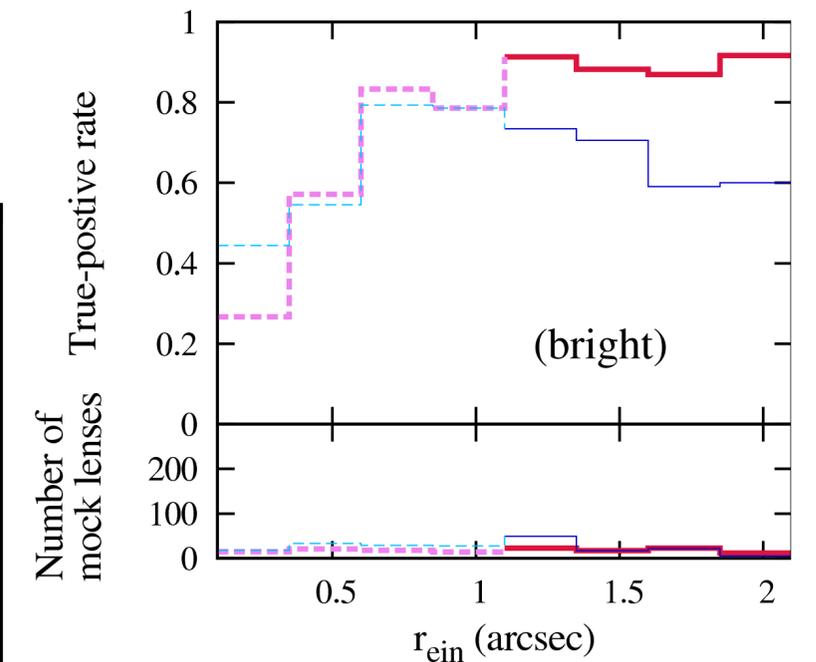
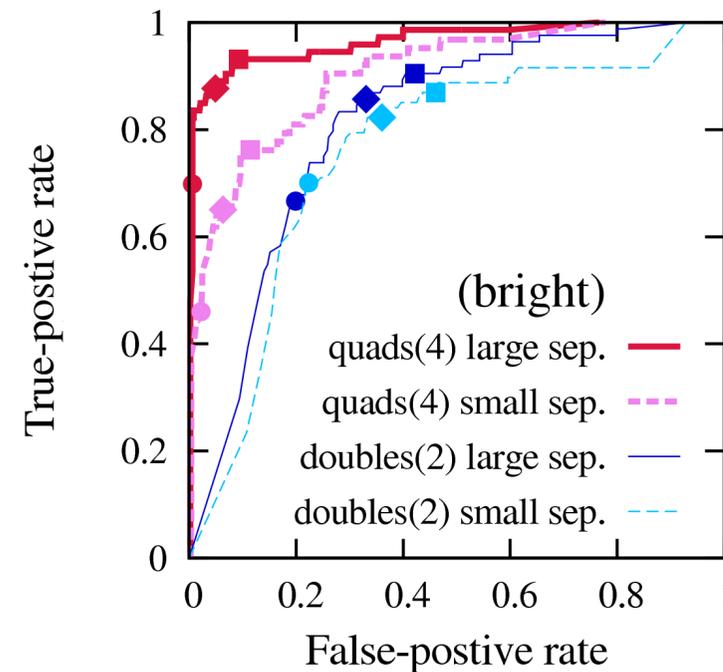
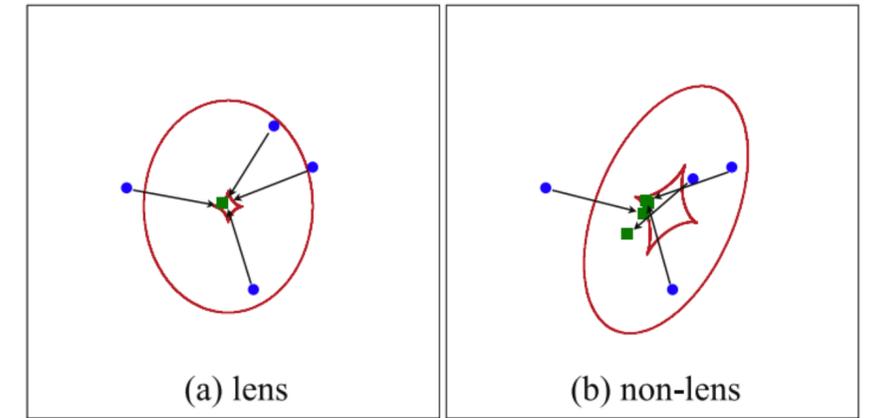
Imaging/Continuum

Modelling-based

- Chan, ..., AM, et al. 2015, 2020
 - CHITAH algorithm + trained on mock lenses from CFHTLS data
 - Applied to HSC-Wide for discovering quads, in particular



Quasars

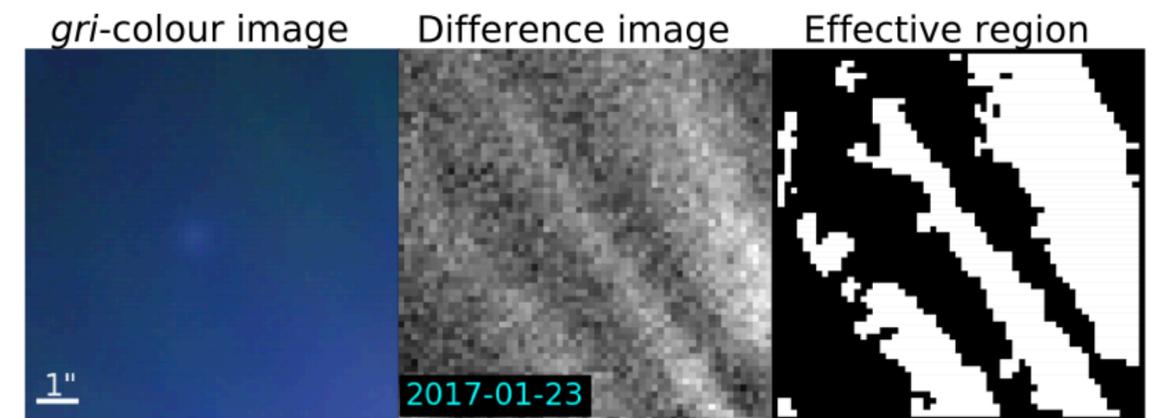
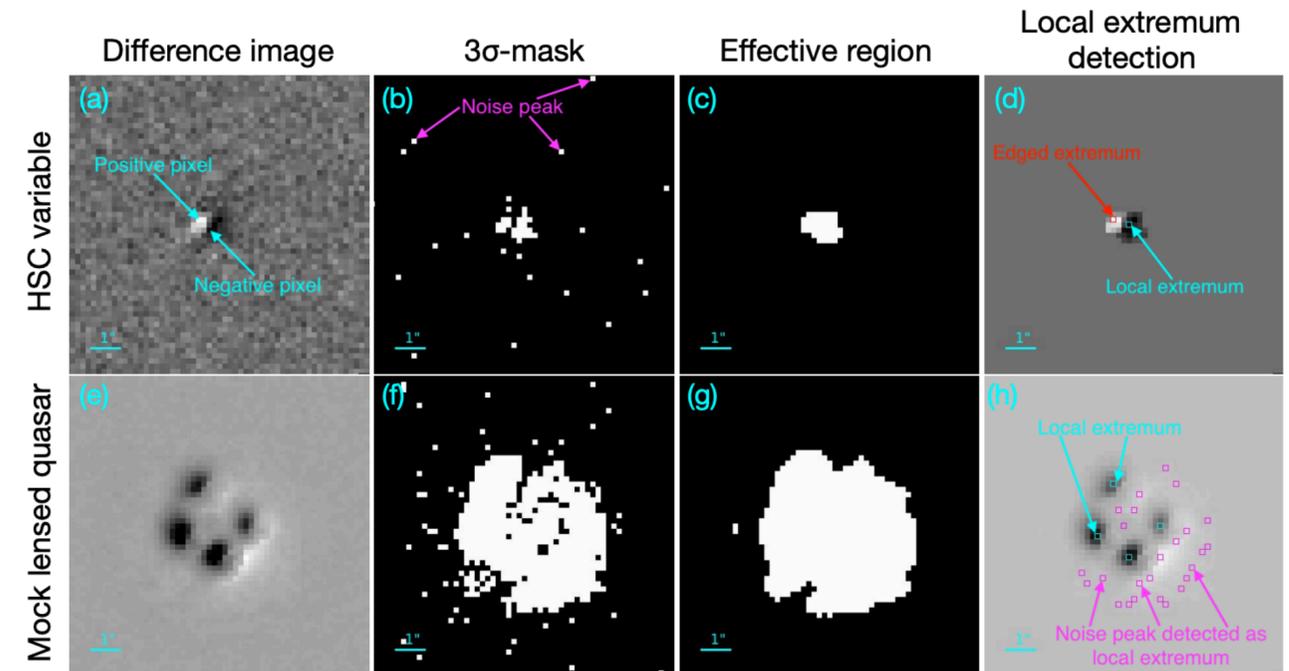


Training sample from SIMCT pipeline

Variability

- Method only:
 - Kochanek et al. 2006: Difference imaging
- Method+Application:
 - Lacki et al. 2009: SDSS Supernova Survey + SQLS
 - images+light curves; look for extended variable sources; success limited by the survey design
 - Chao, ..., AM et al. 2020a and 2020b: HSC-Transient Survey
 - Apply difference imaging to variables and mock lensed quasars
 - Images with large effective area and sufficiently large number of blobs are candidates

Quasars

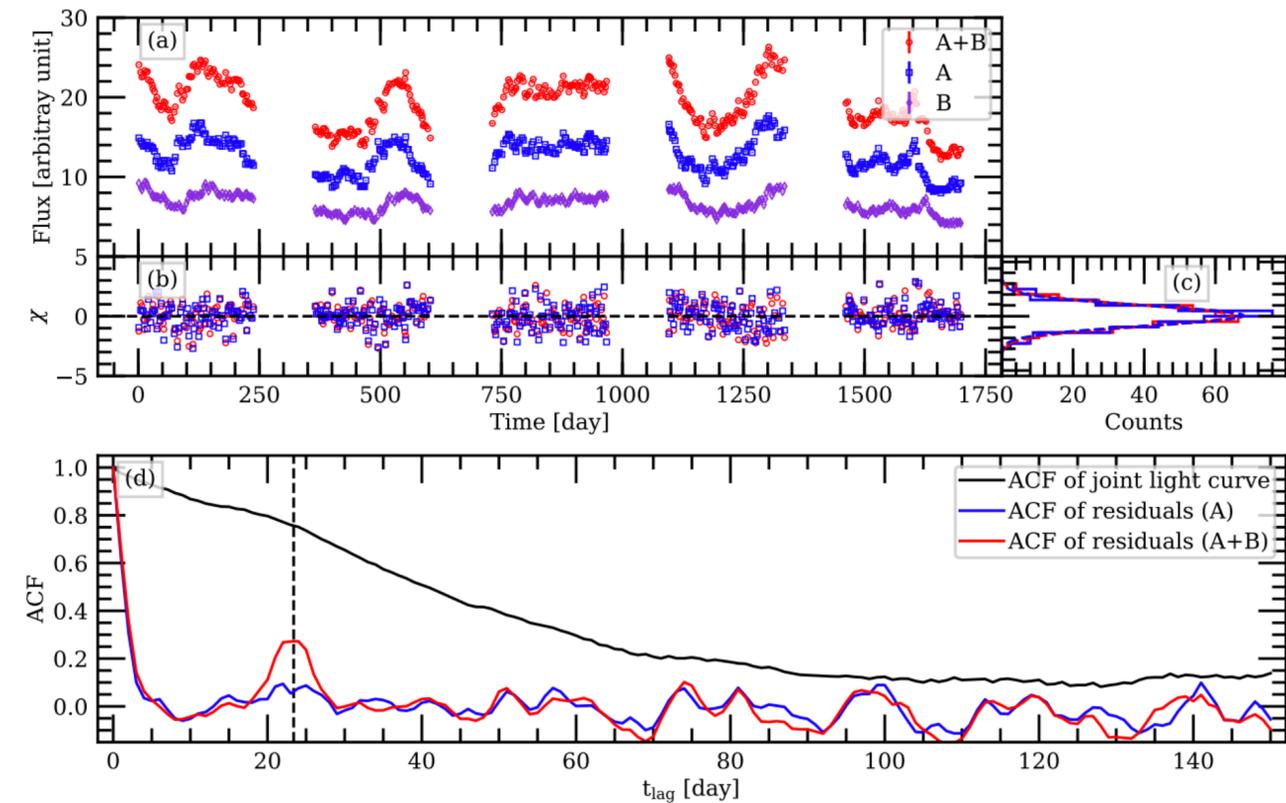


Chao et al.

Light curves

Quasars

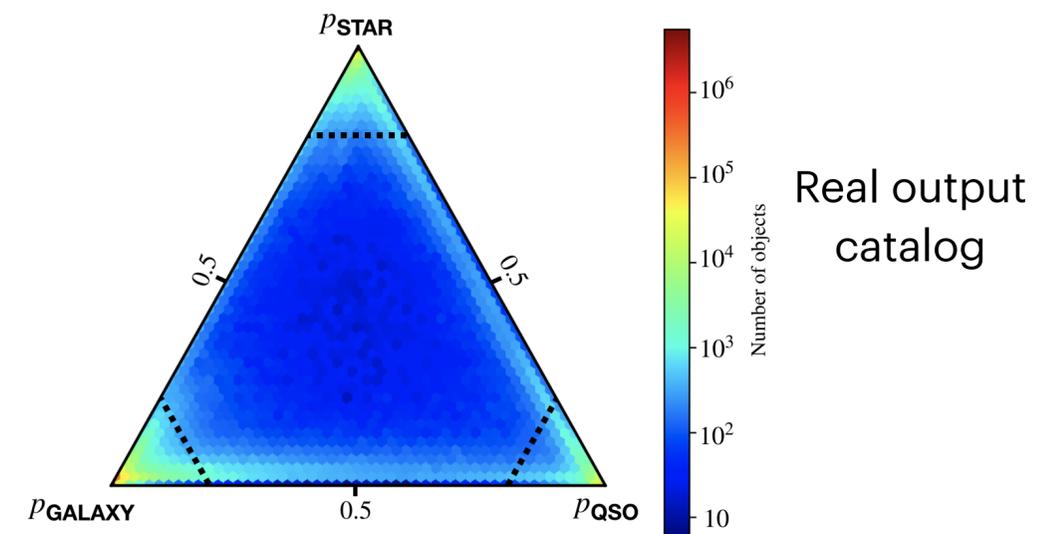
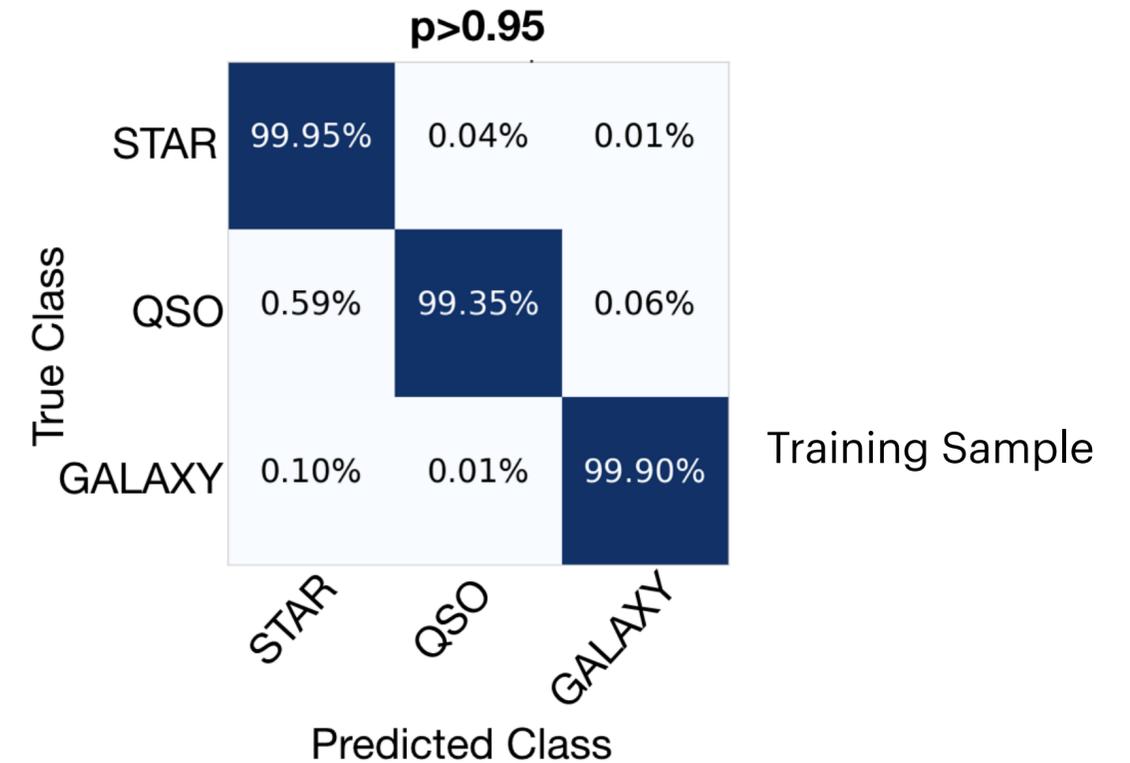
- Method primarily:
 - GRAL: Krone-Martins et al. 2019:
 - Quasar light curves + images from CRTS
 - Apply entropy and wavelet transforms method to select doubles
 - Shu et al. 2020
 - Autocorrelation of light curves
 - Tested on COSMOGRAIL curves of 22 CLASS lenses
 - improvements possible by including additional information such as multi-filter, morphological and astrometric data



Machine learning

- Method primarily:
 - Agnello et al. (2015): Preselect targets from catalogs with ANNs + Identify candidates with pattern recognition algorithm
 - Williams et al. (2017): Gaussian Mixture Models + color cuts + visual inspection
 - Khramtsov et al. (2019): Catboost (decision tree based algorithm) + KiDS

Quasars

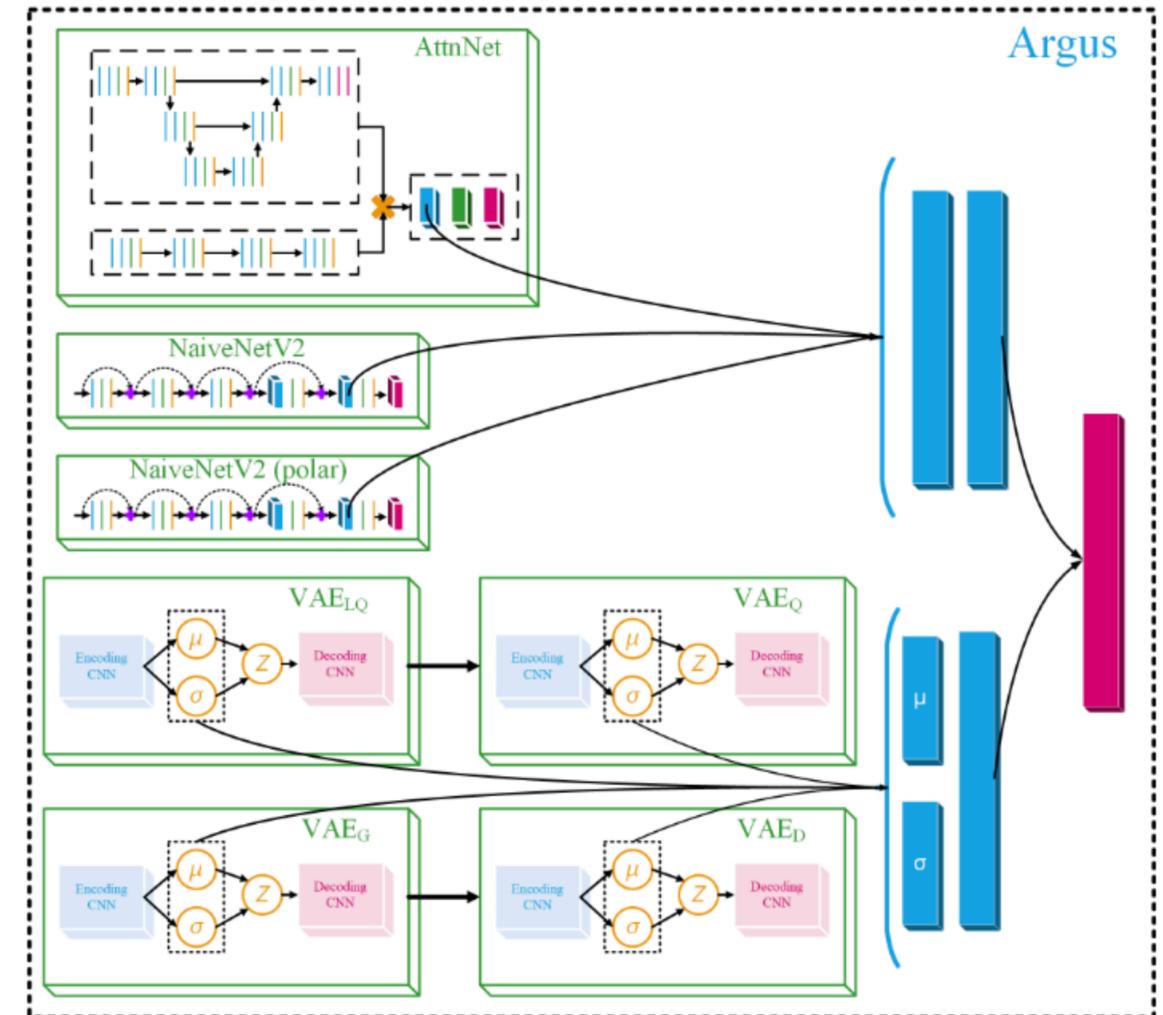


Khramtsov et al. 2019

Machine learning

Quasars

- Method+Application (for Quads):
 - GRAL - Krone-Martins et al. 2018, Delchambre et al. 2019
 - Extremely randomized Trees on GAIA DR2
 - Ablai, AM et al. (in prep)
 - Simulated lensed quasars with microlensing injected on real DES galaxies included in the Training sample
 - Novel techniques e.g. Polar convolution and architecture e.g. Argus



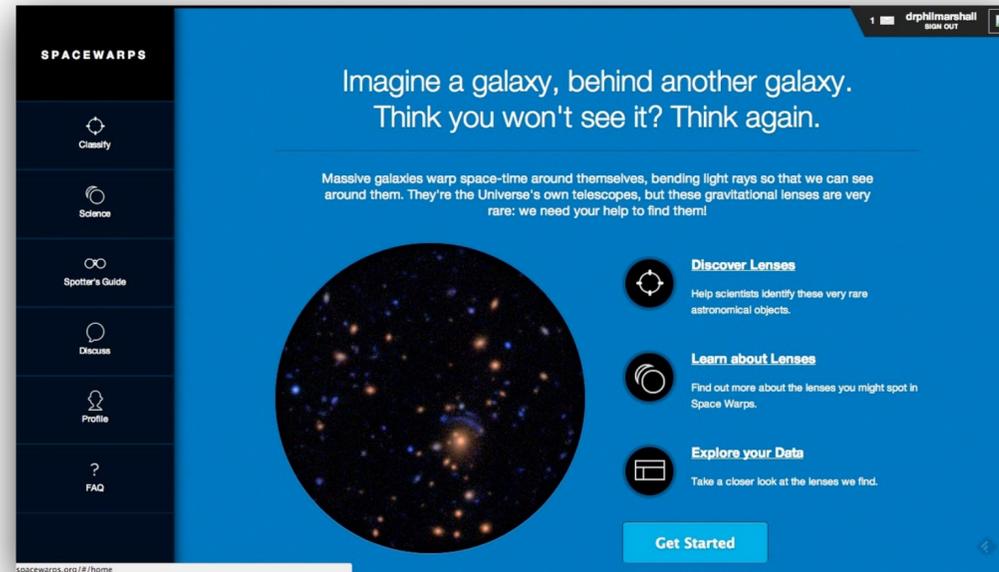
Ablai, AM et al. (in prep)

Citizen Science : Space Warps

spacewarps.org

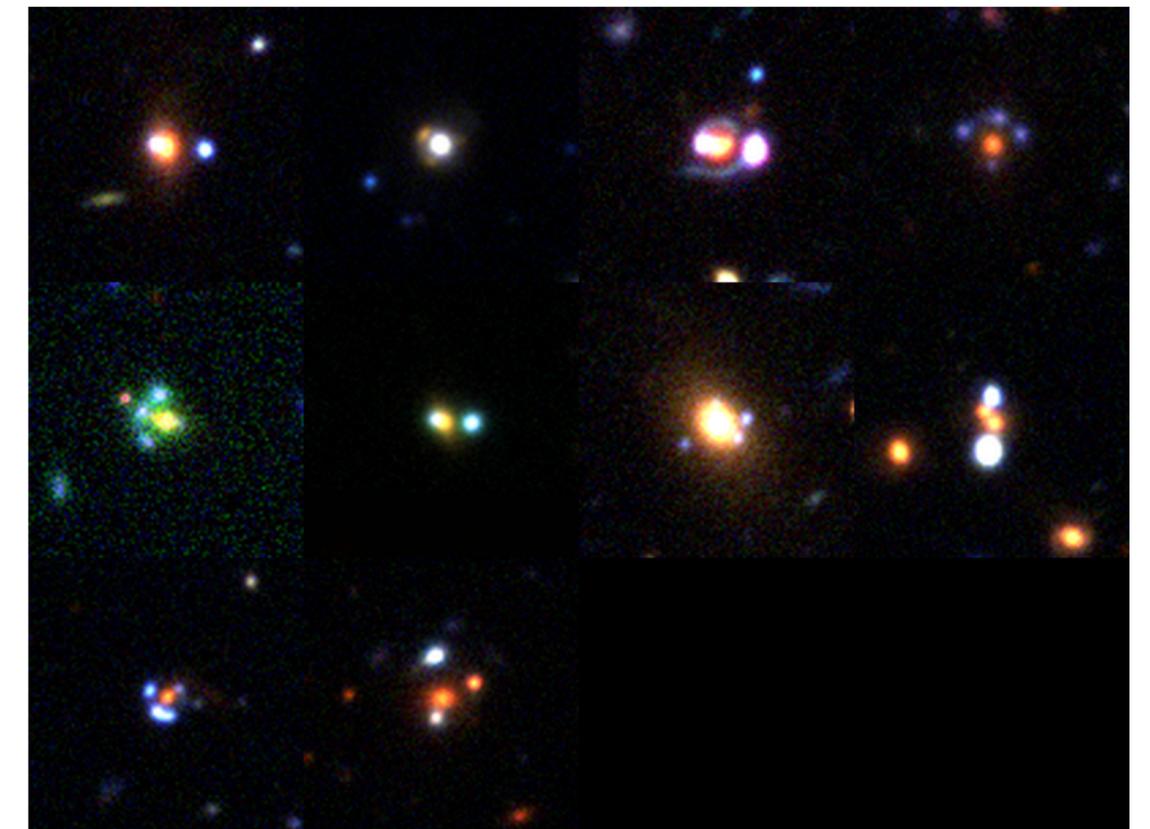
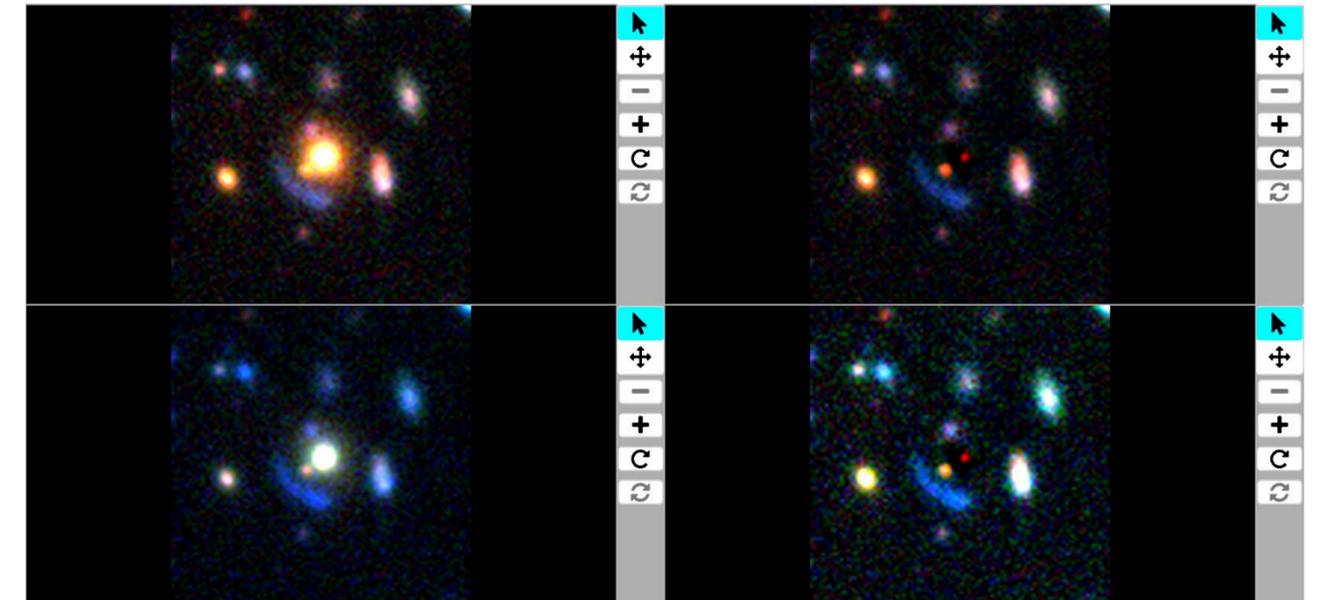
PIs: Marshall,
Verma, AM

Marshall et al. 2016,
AM et al. 2016



- Classification: Semi-automated or pure visual inspection
- Multiple classifications are combined in a Bayesian framework to assign probabilities to each image to contain a lens
- Candidate lensed quasars discovered in Hyper Suprime Cam survey while looking for lensed galaxies

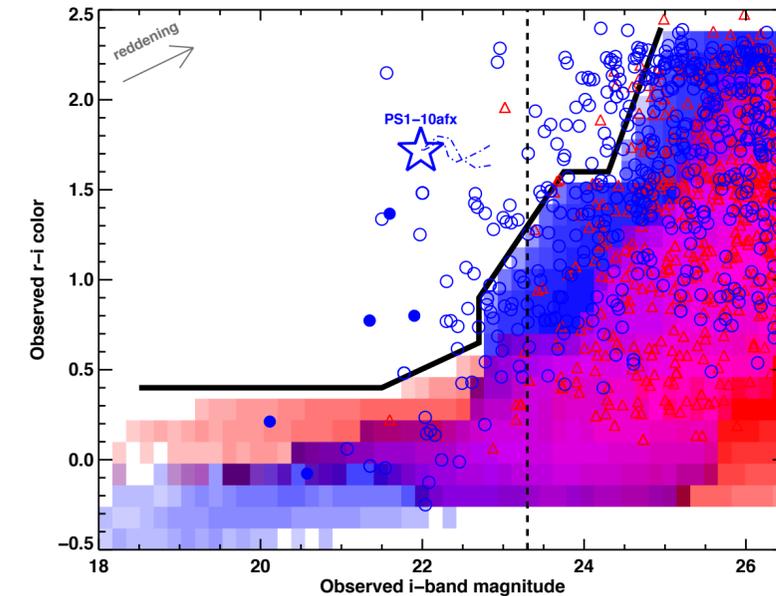
Classification Interface



Lensed SNe

Proposed Techniques

- Color-magnitude (Quimby, Oguri, AM et al. 2014)
- Lens photometry (Goldstein & Nugent 2016)
- Follow-up of cluster lenses (e.g. SN Refsdal from the GLASS program follow-up of clusters from MACS or CLASH program)
- Cross-matching of ZTF transients with existing samples of lenses
 - https://www.iucaa.in/~navin/ztf_alerts.html by Navin Chaurasia (IUCAA)



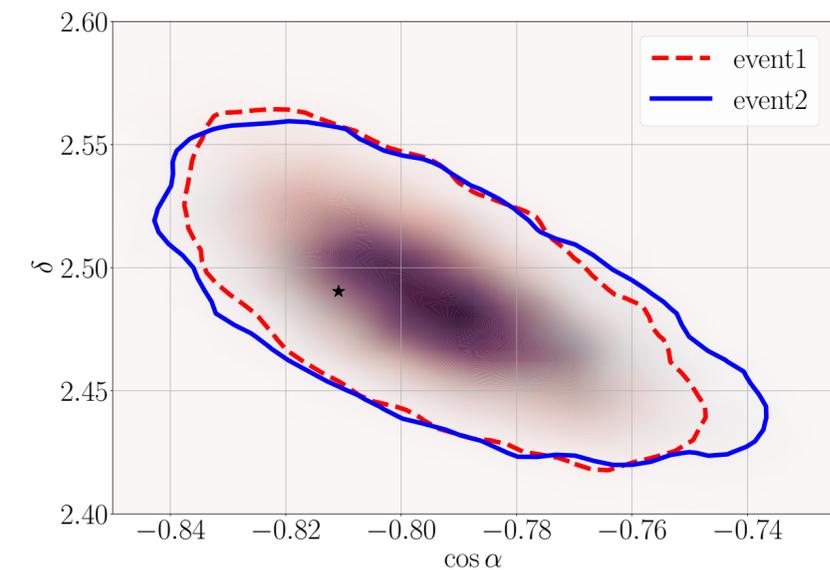
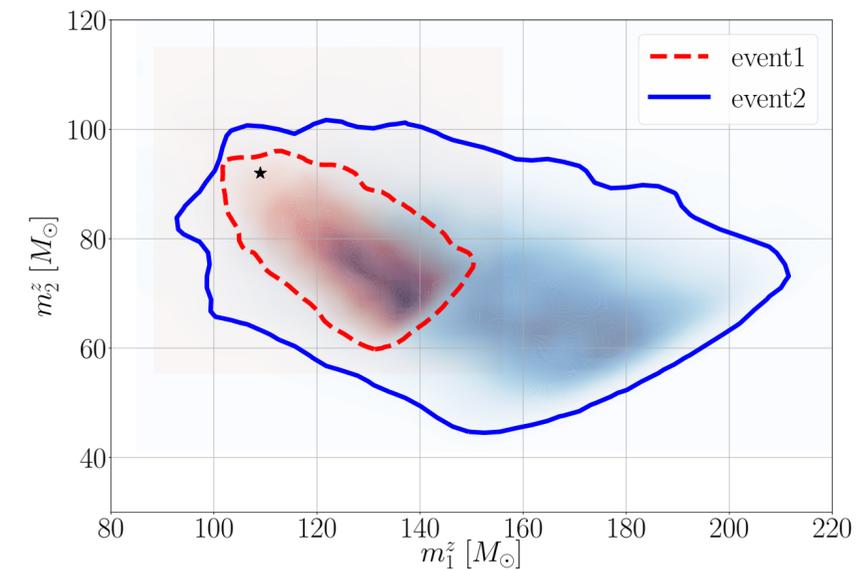
Quimby, Oguri, AM et al. 2020



SN Refsdal, HST/WFC3

Lensed GWs

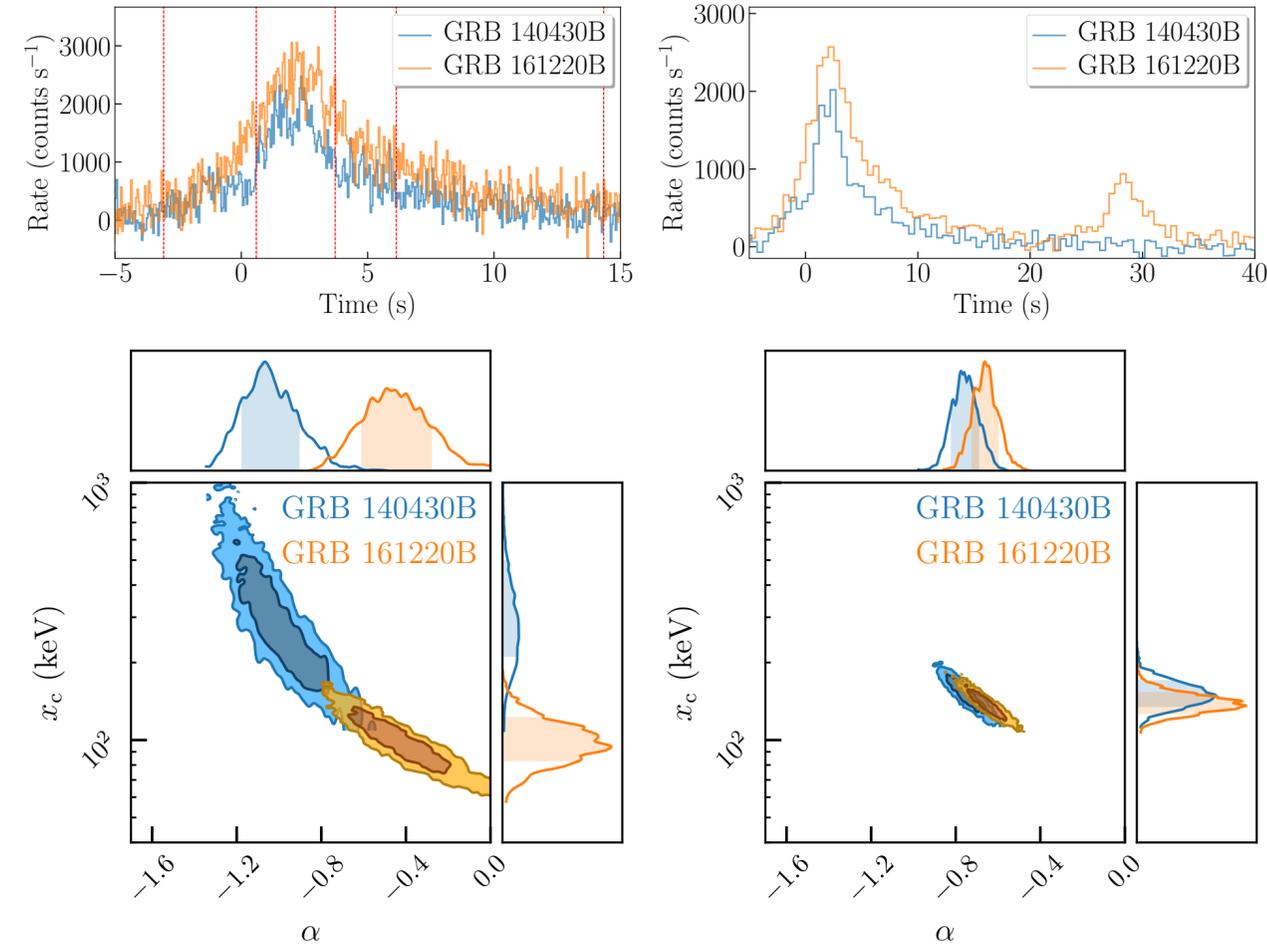
- Method primarily:
 - Posterior overlap of image pairs e.g. Haris et al. 2018
 - Sub-threshold searches e.g. Li et al. 2019
- Searches in real GW data:
 - First two observing runs LIGO/VIRGO
 - Work ongoing in more recent data



Haris et al. 2018

Lensed GRBs/FRBs

- GRBs:
 - Hurley et al. 2019: Data from Konus-Wind
 - sky localization, light curve similarities
 - comparison of energy spectra; blind and targeted search
 - Ahlgren et al. 2020: Data from Fermi-GBM
 - Cuts on position, time-averaged spectral properties, relative duration
 - cross-correlation of light curves
- FRBs:
 - See Adi Zitrin's talk



Ahlgren et al. 2020

Summary

- Imaging (multi-wavelength), Spectroscopy, Variability, Light curves, Modeling, Citizen Science and Machine learning
- New challenges in stage 4 surveys:
 - e.g. X-rays (eROSITA), Optical imaging (LSST, Euclid), Optical spectra (DESI,PFS), Radio (SKA,LOFAR), GW experiments