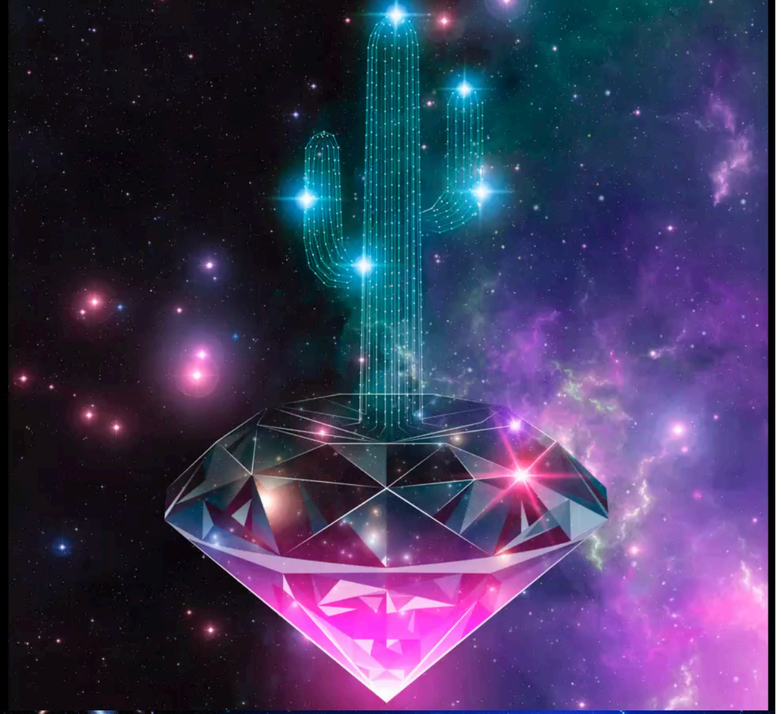
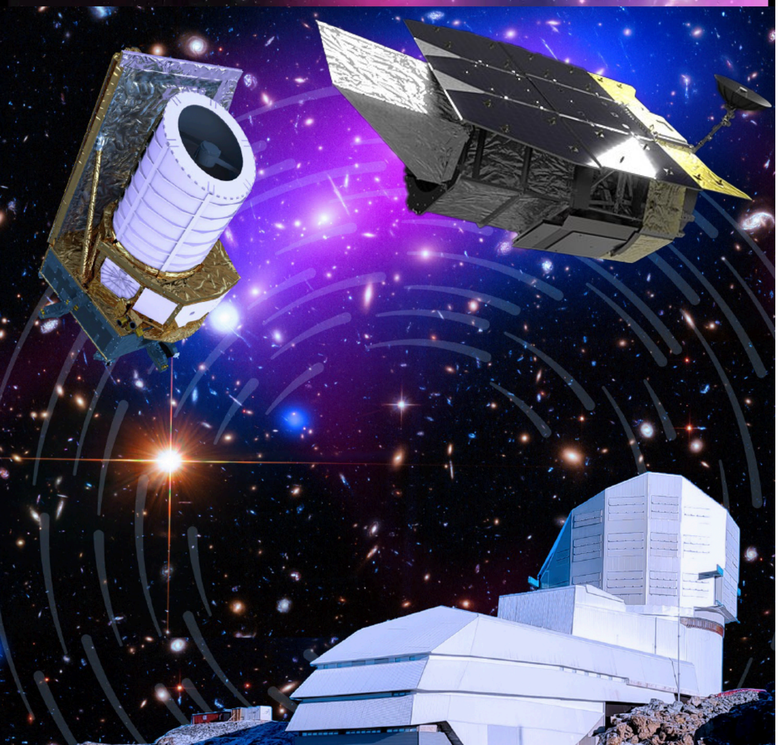
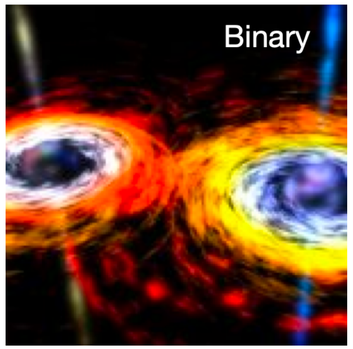




Rare Gems in Big Data: Exploring the Uncharted



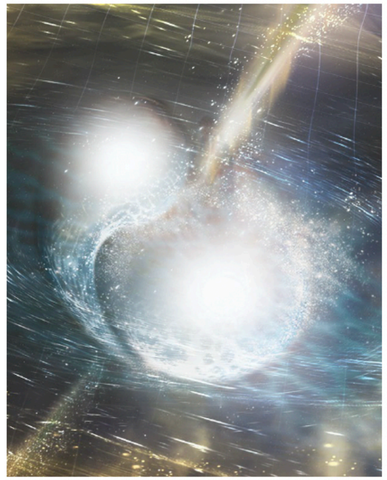
Grant Merz
Astronomy PhD Student
LSSTC Data Science Fellow
LINCC Incubator PI

Xin Liu (UIUC/NCSA)
May 23, 2024

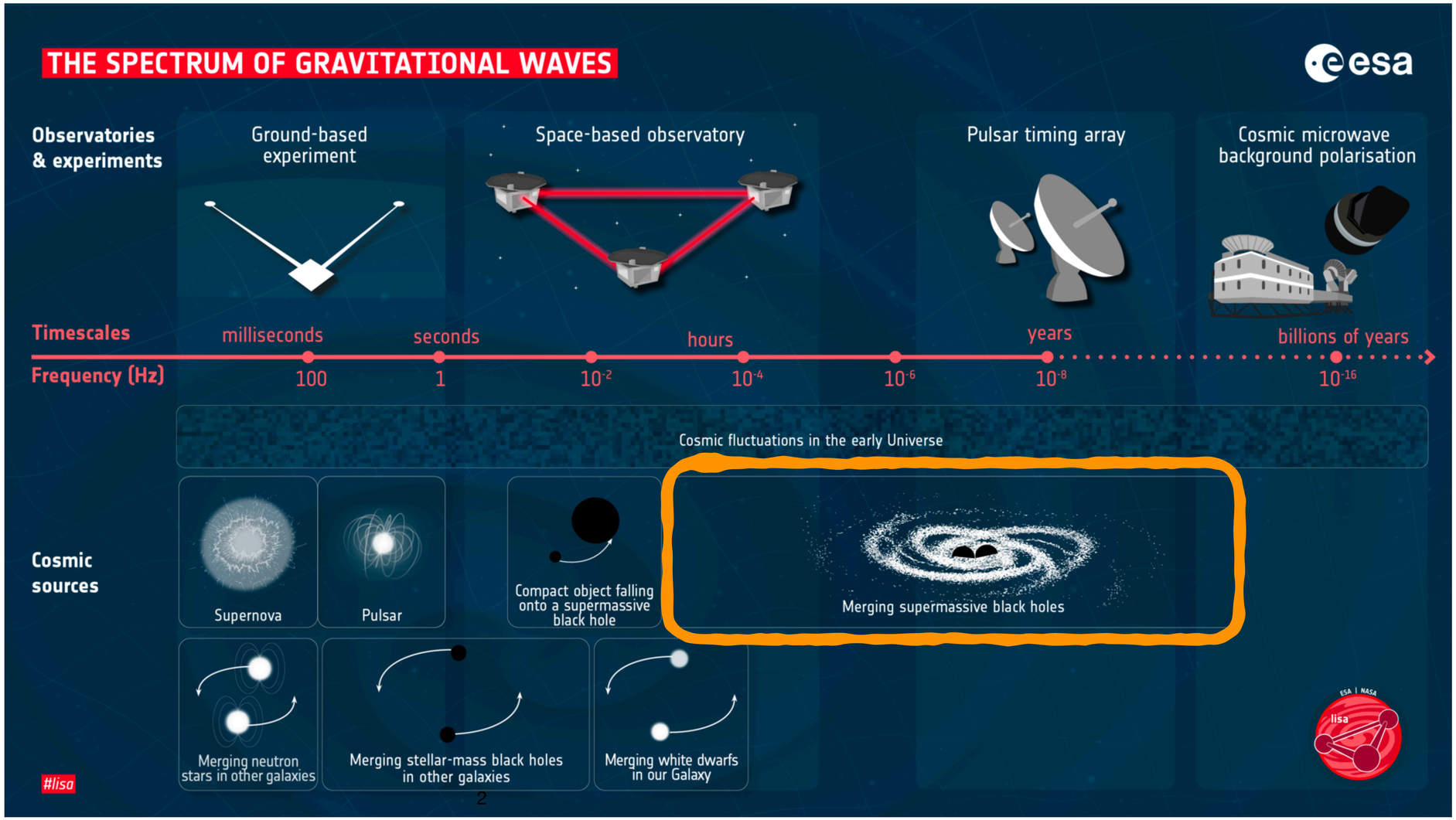
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
NCSA SPIN Students Pushing Innovation
LSST Discovery Alliance
NSF
AST-2108162
AST-2206499
AST-2308174

Science Theme: New Messengers and New Physics

Priority Area: New Windows on the Dynamic Universe



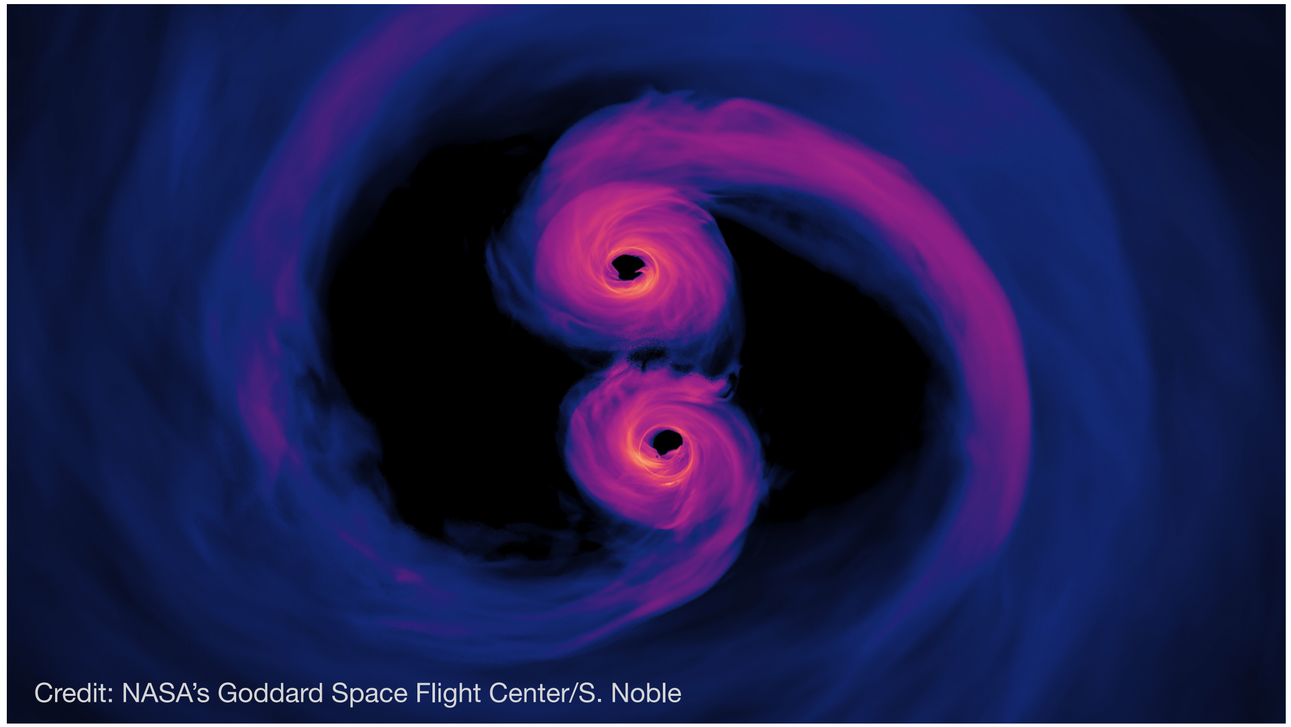
Discovery space for the coming decade: multi-messenger and time domains



Synergy between GW and EM facilities

Major differences between LISA and LIGO BBH observations:

- **Coalescing MBHs expected in gas-rich environments: EM signals expected**
- **LISA designed to detect inspiraling MBHs in “slow motion”: provide forewarnings to EM and particle detectors for MMA**



Credit: NASA’s Goddard Space Flight Center/S. Noble

EM observations help LISA localize sources and measure redshifts

- **Efficient EM observations and data analysis tools needed for realizing the full discovery potential in the multi-messenger and time domains**

EM Searches of Dual/Binary MBHs: Analogy with Exoplanets

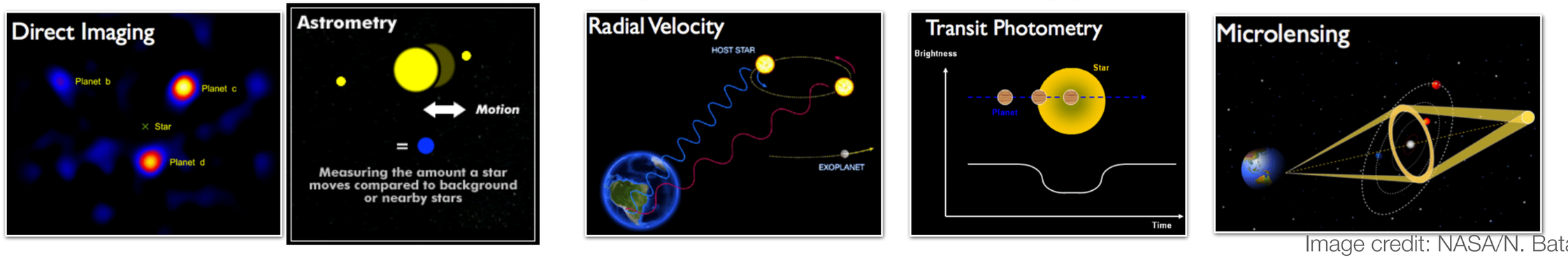
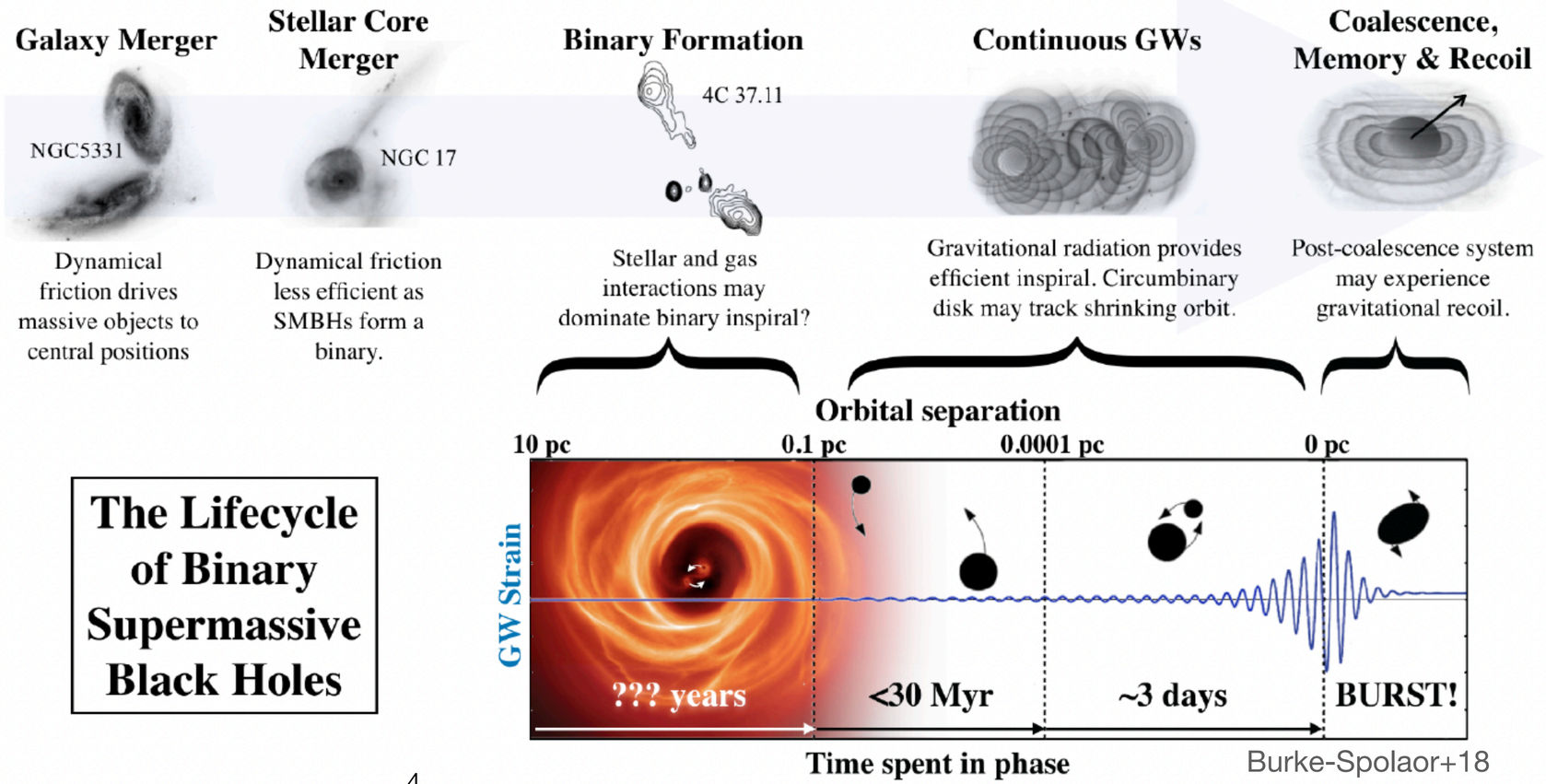


Image credit: NASA/N. Batalha

A multi-scale interdisciplinary problem: connecting cosmology, galaxy evolution, dynamics, accretion disk physics, GRMHD, and multi-messenger astronomy

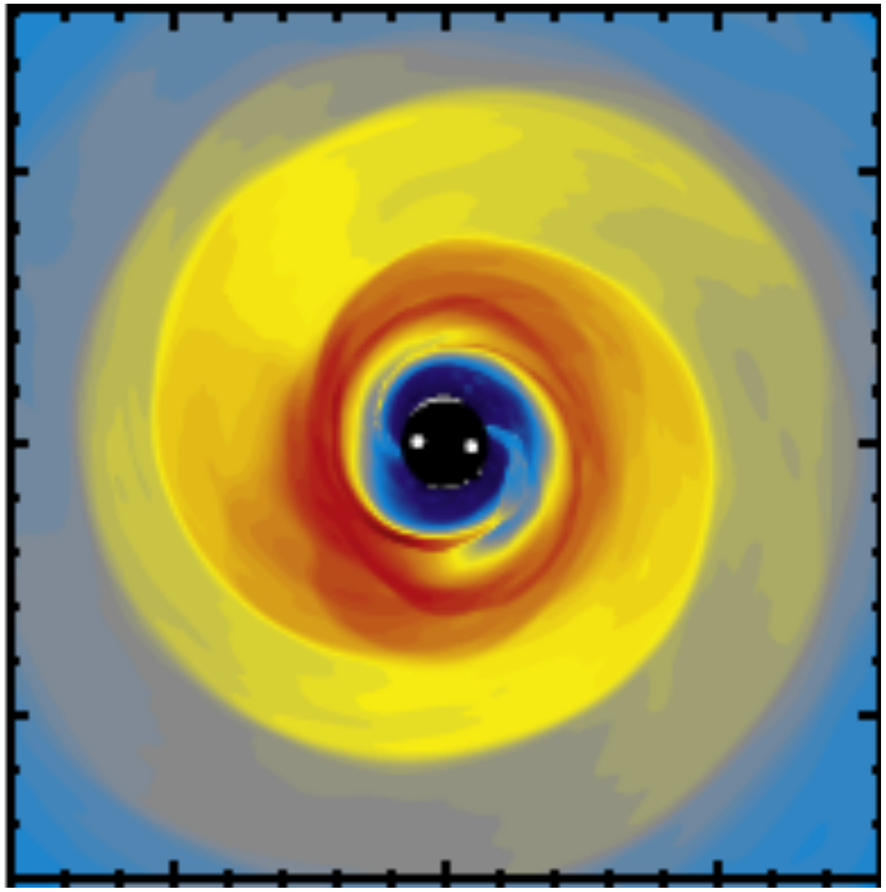


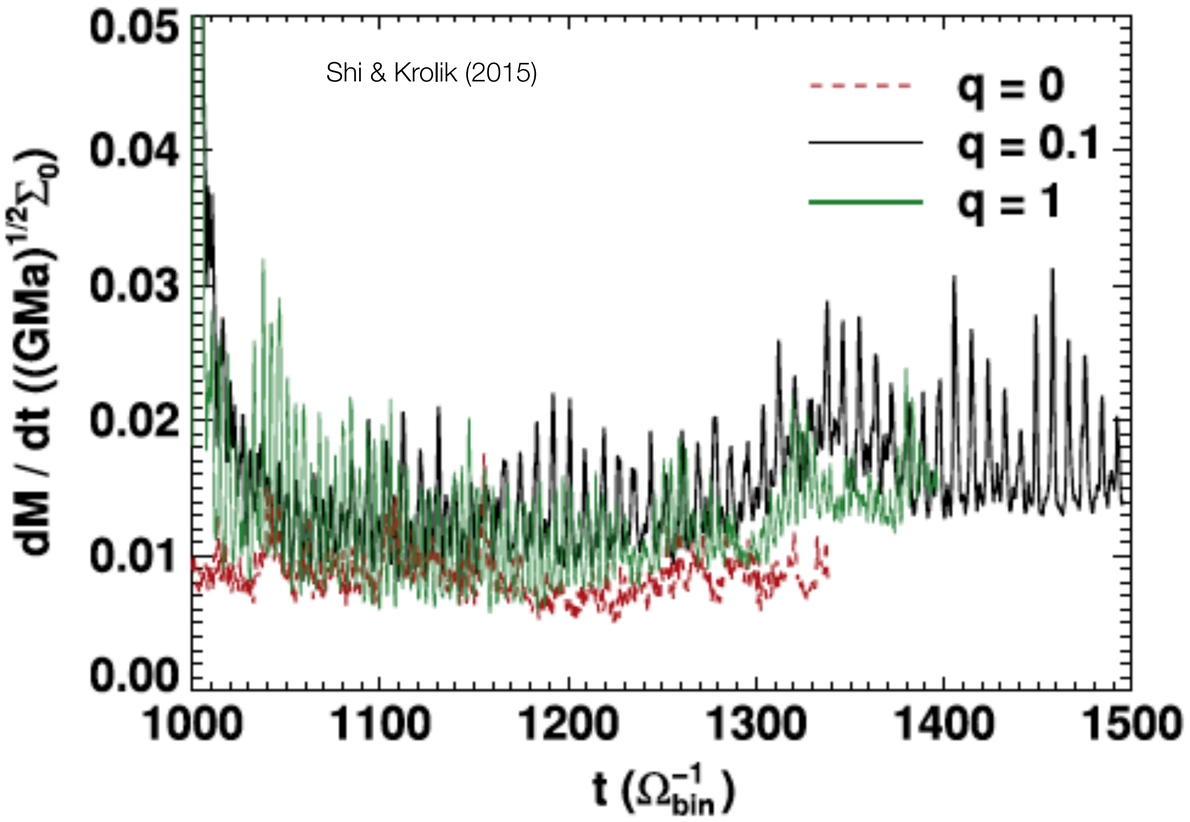
The Lifecycle of Binary Supermassive Black Holes

Burke-Spolaor+18

The Importance of Combined Datasets

- **Candidate Milli-pc MBBHs from Periodic Light Curves w/ SDSS+DES+DECam+LSST Long-Term Monitoring**





The Importance of Combined Datasets

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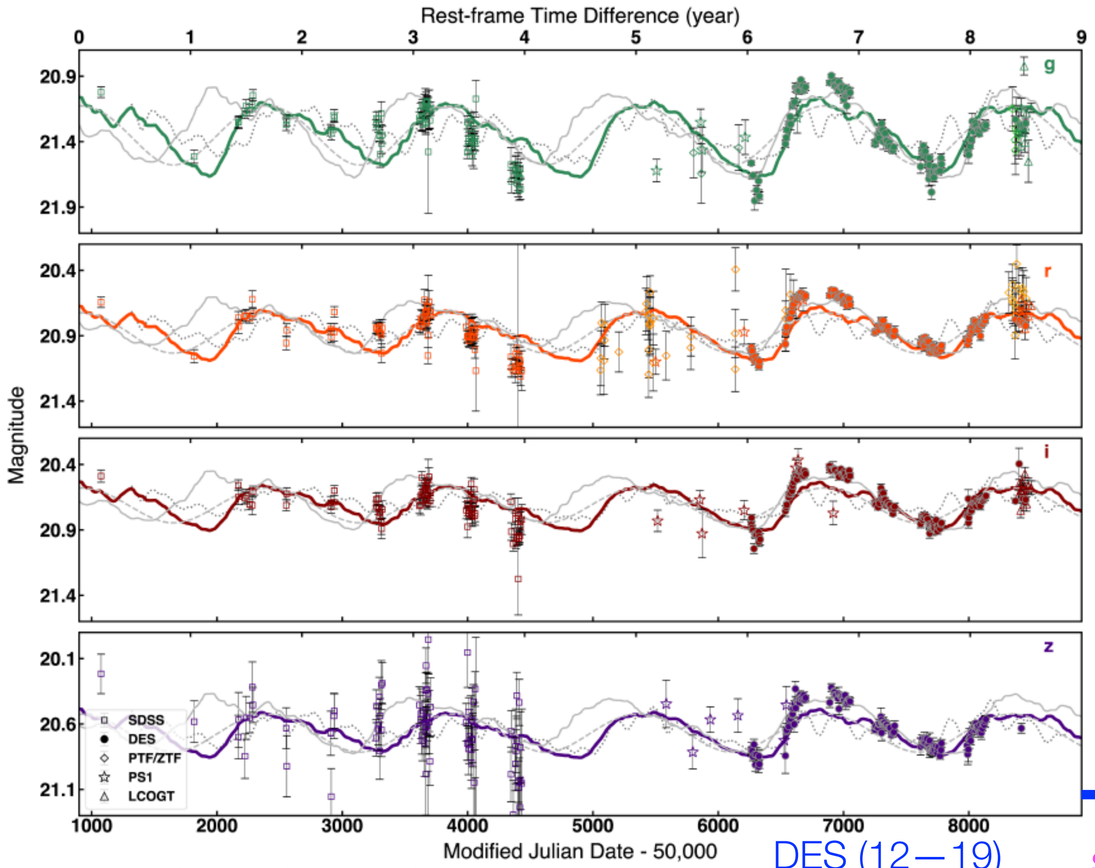
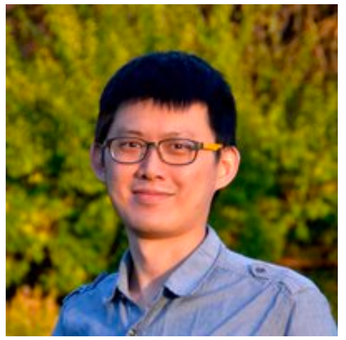


SDSS (98—07)

DES (12—19)

Liao et al. 2021, MNRAS, 500, 4025 (see also Chen+20)

1. **Continued monitoring to test red noise (DECam Long-term Programs)**
   Luo et al. in prep
2. **Multi-wavelength follow-ups (VLA, XMM, NuSTAR) to test alternatives**
   Chen+21b, Foord+22



Tony Chen (Postdoc Fellow@JHU)

DECam (19-25) LSST (25+)

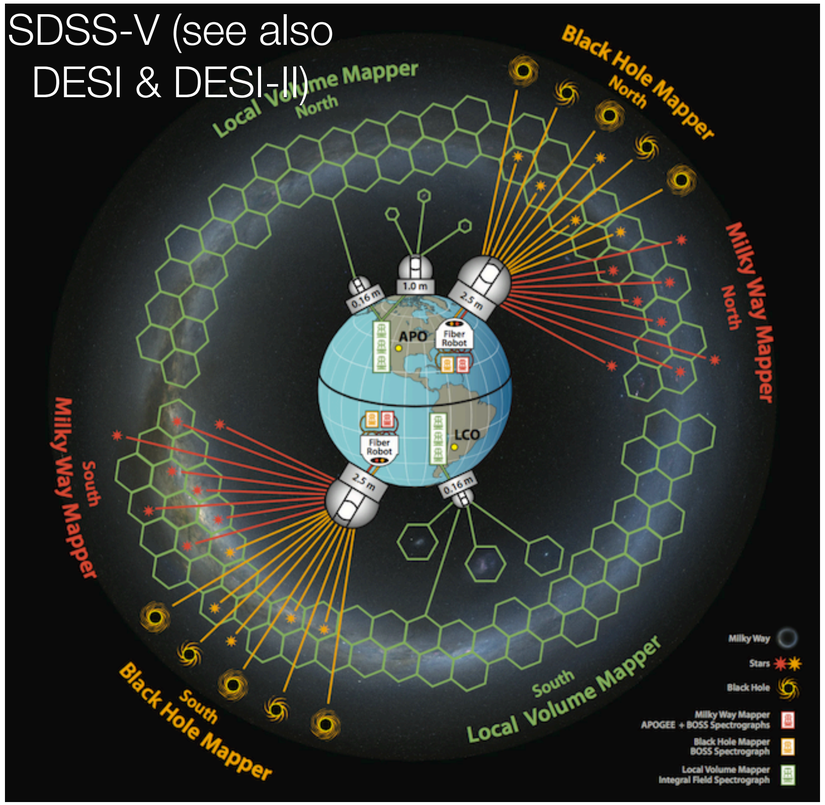
See also e.g., Vaughan et al. (2016), Barth & Stern (2018), and talk by Uros Seljak

AST-2206499

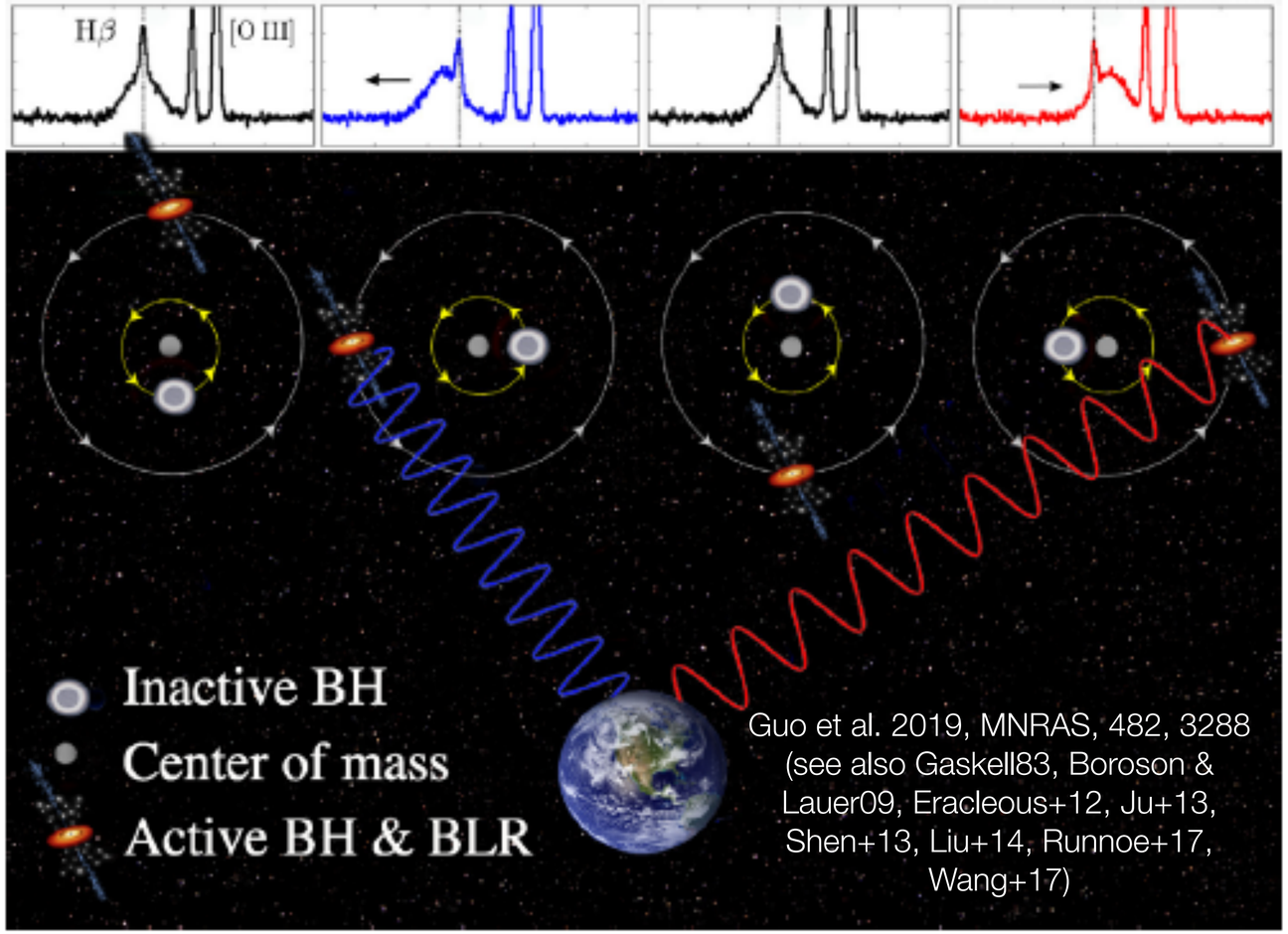
The Importance of Combined Datasets

- **Candidate Sub-pc MBBHs from Radial Velocities w/ SDSS Muti-Epoch Spectroscopy**

SDSS-V (see also DESI & DESI-II)



See also work by Antonella Palmese and talk by Stephanie Juneau

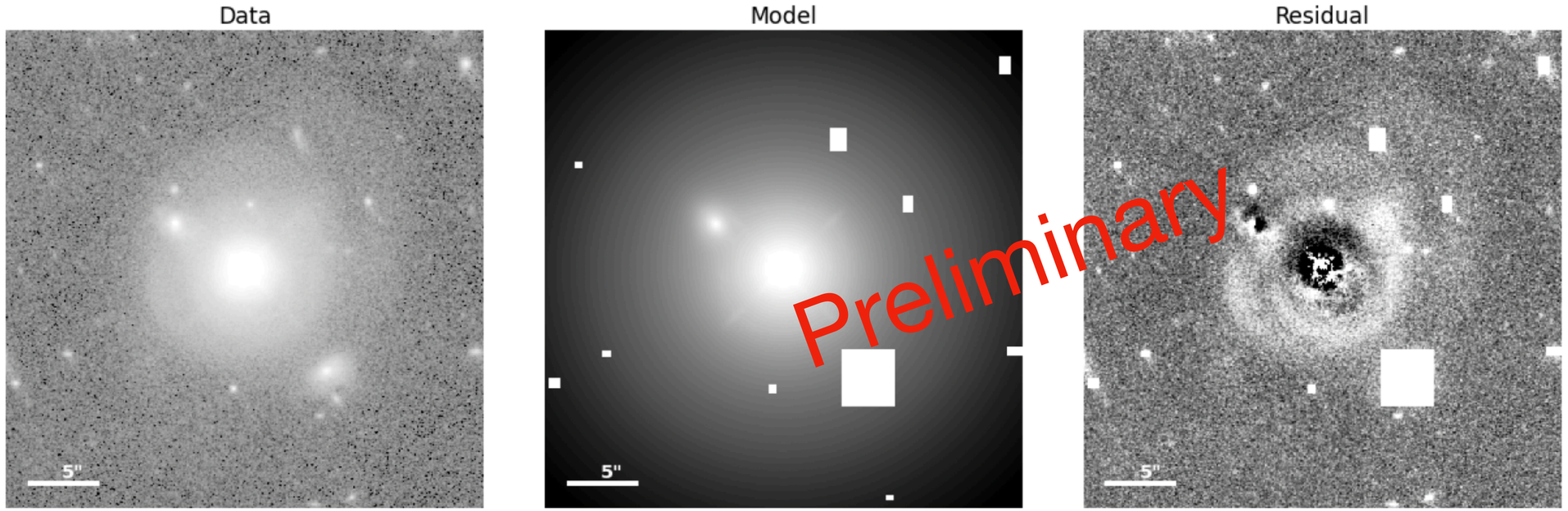


Guo et al. 2019, MNRAS, 482, 3288 (see also Gaskell83, Boroson & Lauer09, Eracleous+12, Ju+13, Shen+13, Liu+14, Runnoe+17, Wang+17)

The Importance of Combined Datasets

- **Candidate Sub-pc MBBHs from Radial Velocities w/ SDSS Muti-Epoch Spectroscopy**

HST Imaging: Complementary Test of the Binary Hypothesis



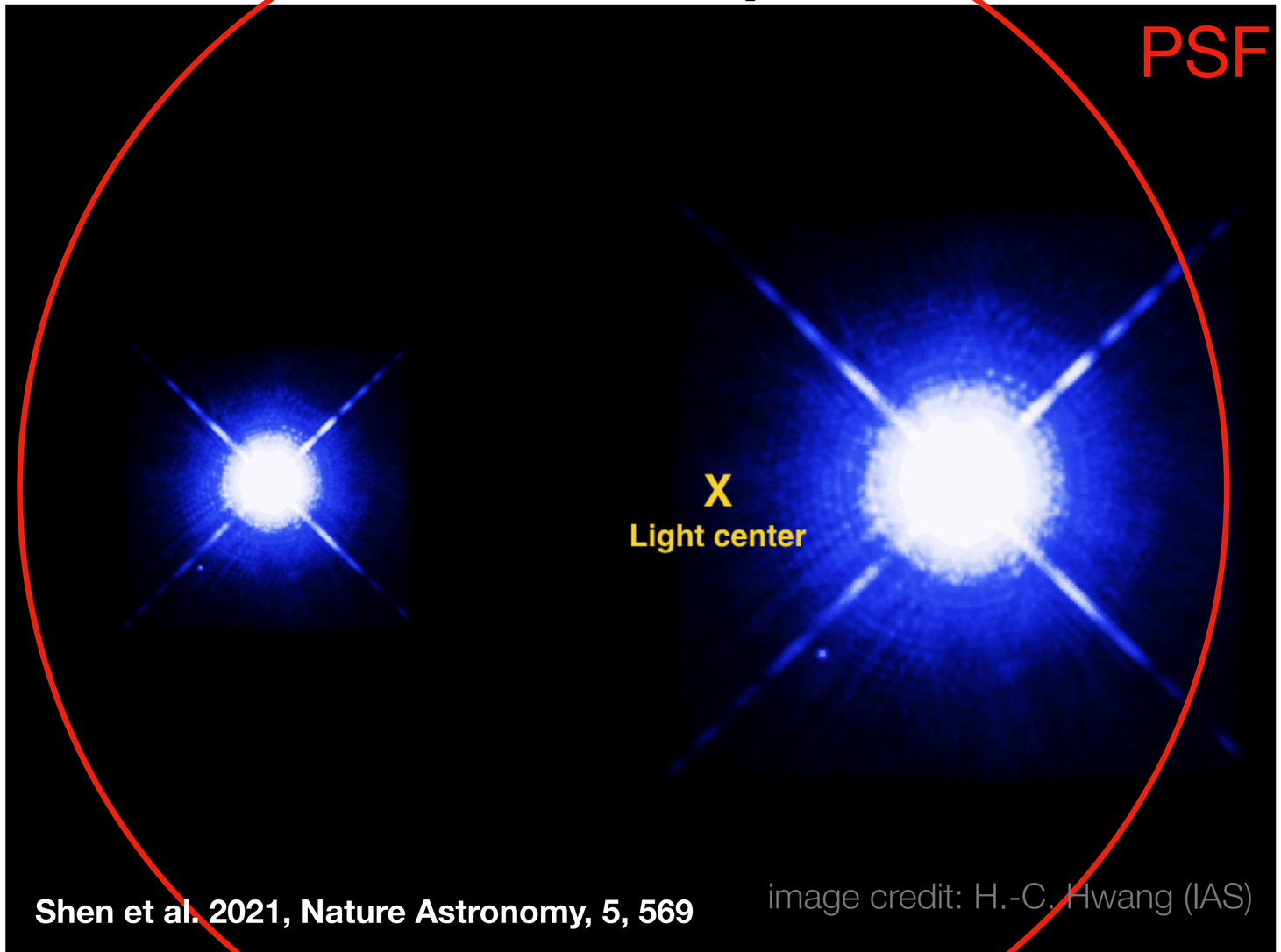
Liam Nolan
(NSF GRFP Fellow@UIUC)

Nolan et al. in prep

AST-2206499

Varstrometry for Off-nucleus and Dual sub-Kiloparsec AGN (VODKA); PI: Y. Shen (UIUC)

Discover sub-arcsec dual/lensed quasars at cosmic noon



Shen et al. 2021, Nature Astronomy, 5, 569

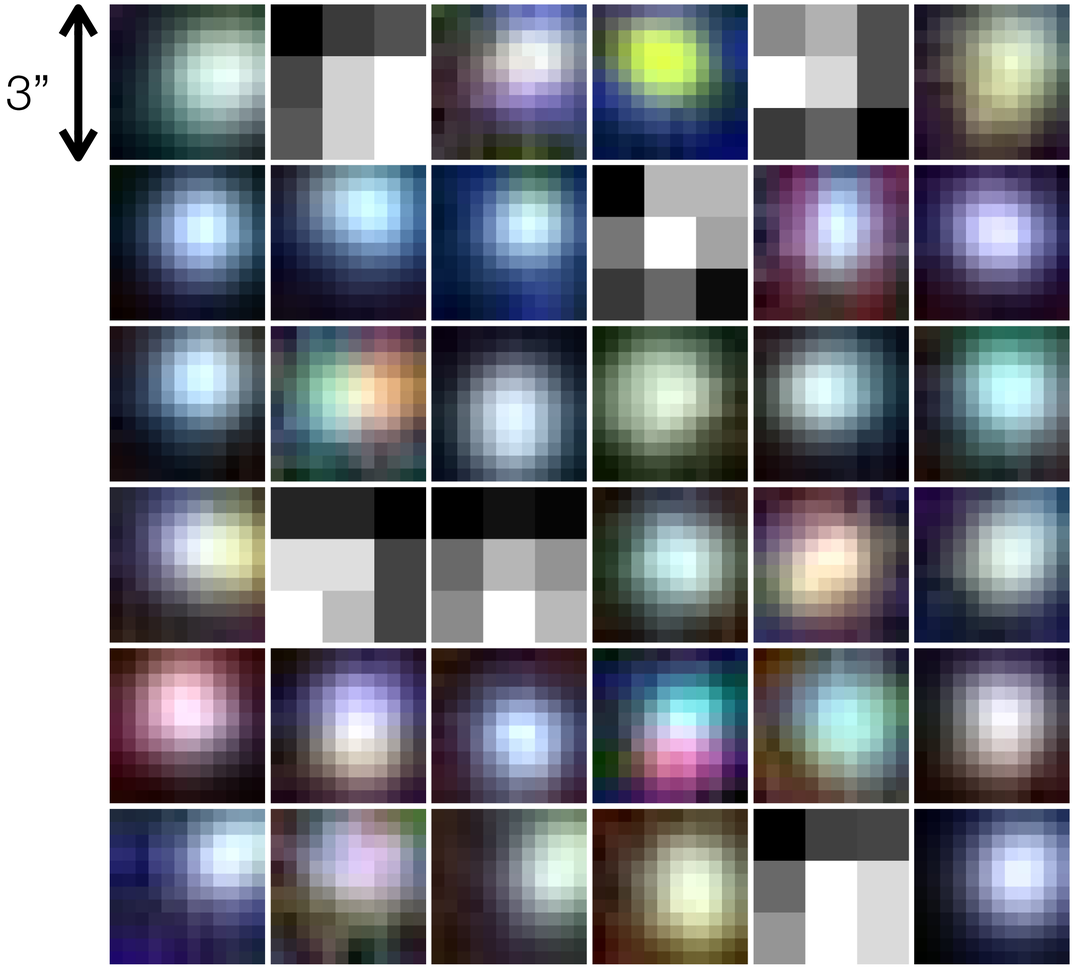
image credit: H.-C. Hwang (IAS)

AST-2108162

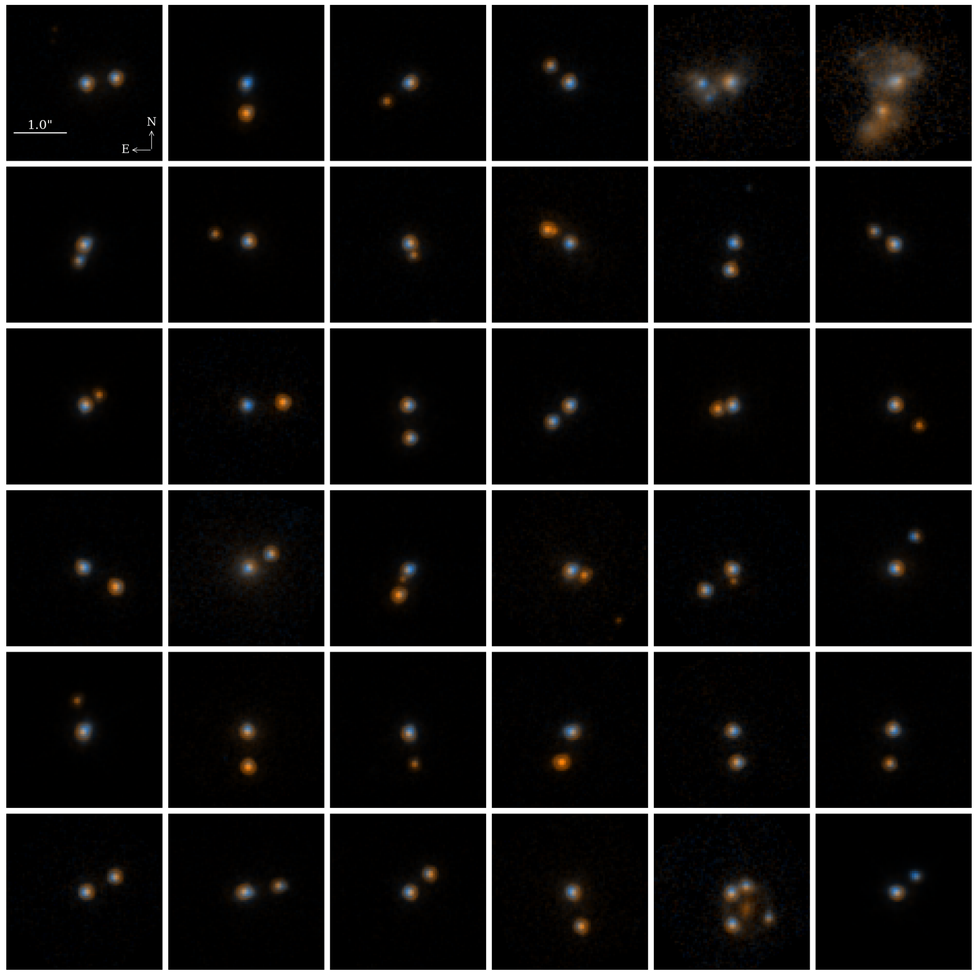
Varstrometry for Off-nucleus and Dual sub-Kiloparsec AGN (VODKA); PI: Y. Shen (UIUC)

Discover sub-arcsec dual/lensed quasars at cosmic noon

Hsiang-Chih Hwang (Postdoc Fellow@IAS)



HST SNAP 15900 (PI Hwang)



Chen, Hwang et al. 2022, ApJ, 925, 162

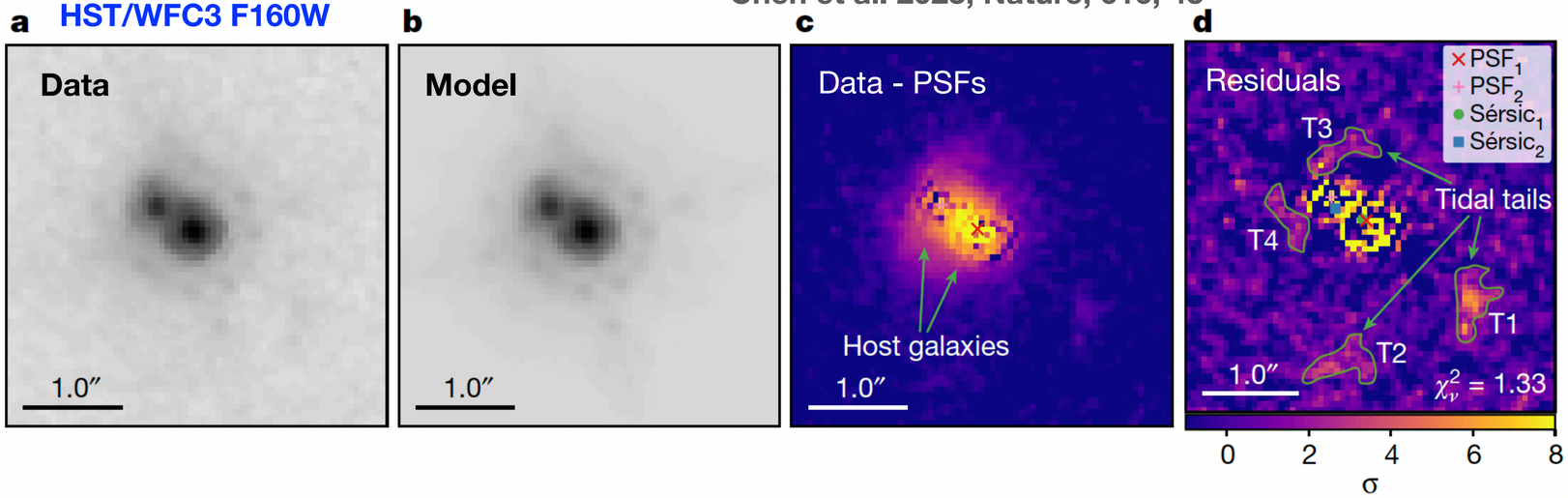
Varstrometry for Off-nucleus and Dual sub-Kiloparsec AGN (VODKA); PI: Y. Shen (UIUC)

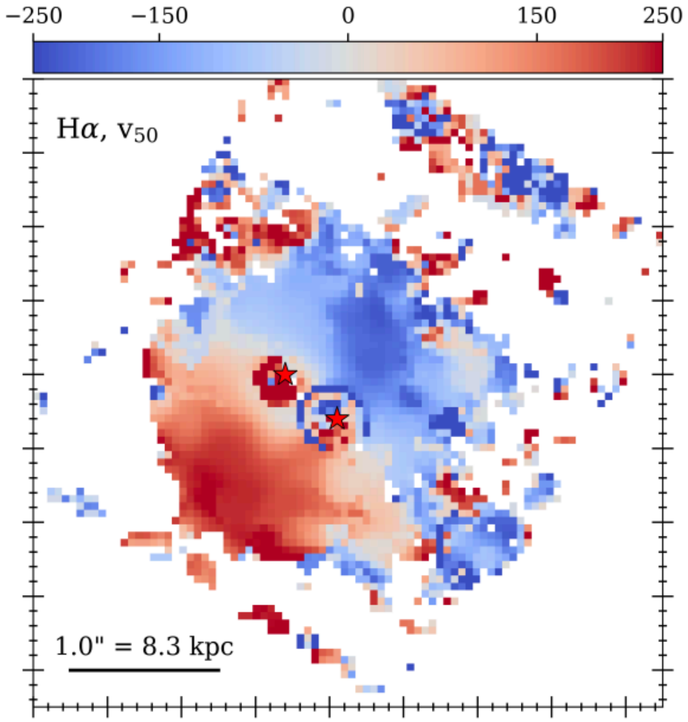
Discover sub-arcsec dual/lensed quasars at cosmic noon

Yuzo Ishikawa
(PhD Student@JHU)

A Close Quasar Pair in a Disk-Disk Galaxy Merger at z=2.17

Chen et al. 2023, Nature, 616, 45





JWST NIRSpec IFU

PIs: Yuzo Ishikawa, N. Zakamska (JHU)

Ishikawa et al. arXiv: 2403.08098

Varstrometry for Off-nucleus and Dual sub-Kiloparsec AGN (VODKA); PI: Y. Shen (UIUC)

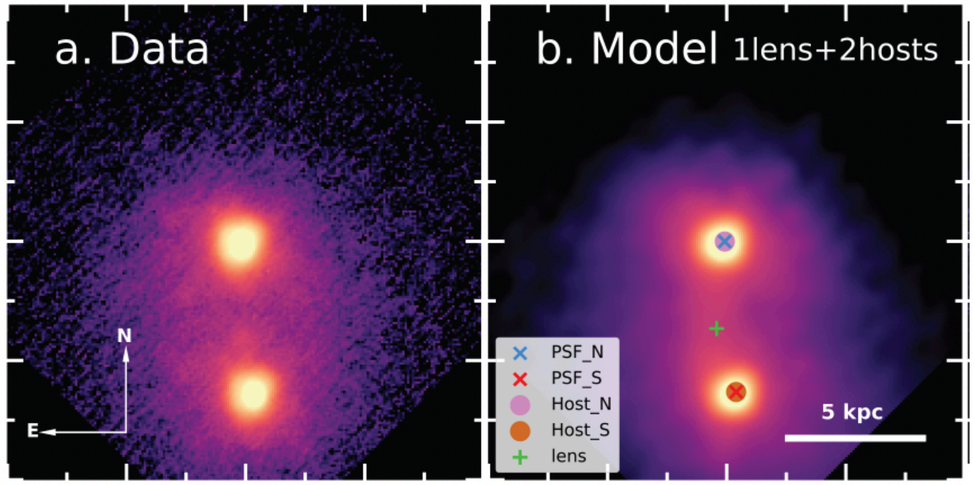
Discover sub-arcsec dual/lensed quasars at cosmic noon

Arran Gross (Postdoc Felllow@UIUC)

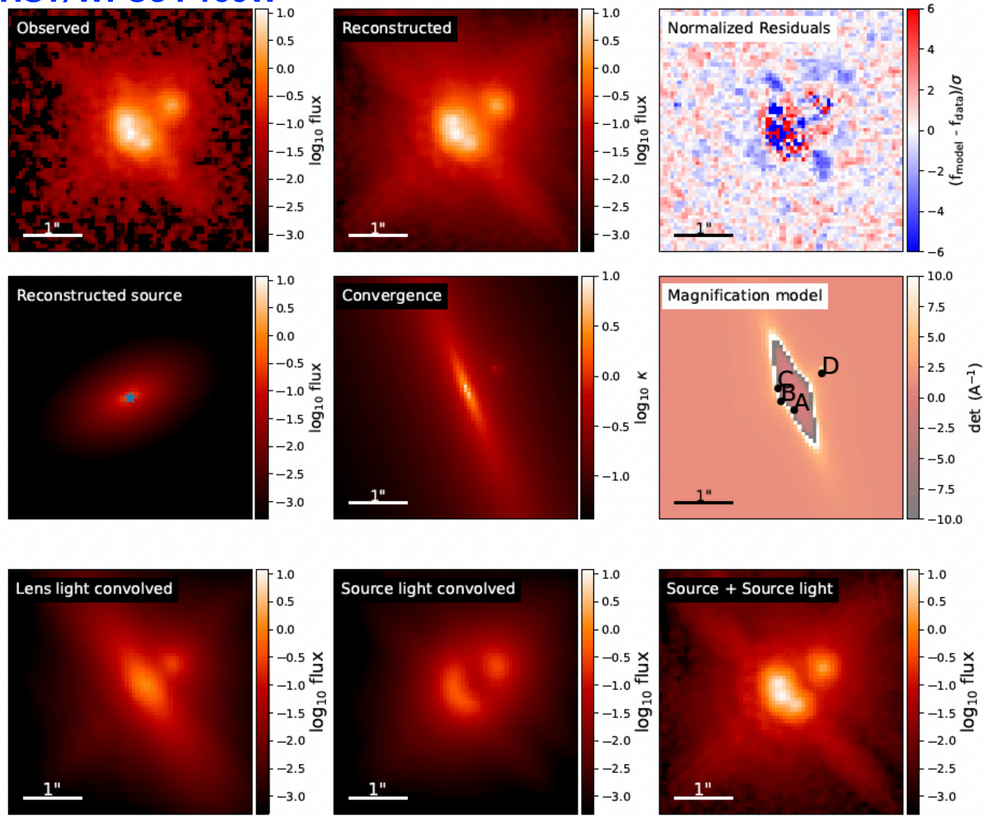
Gross et al. 2023, ApJ, 956, 117

VODKA: SDSS J0823 at z=1.81: A Likely Lensed Quasar

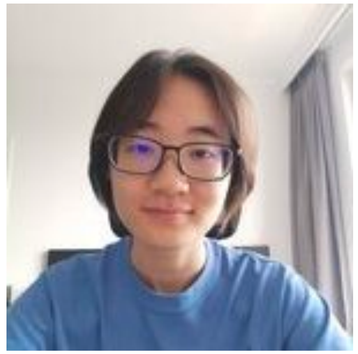
HST/WFC3 F160W



HST/WFC3 F160W



Surprisingly nontrivial to distinguish dual and lensed quasars: high-resolution deep IR imaging is key



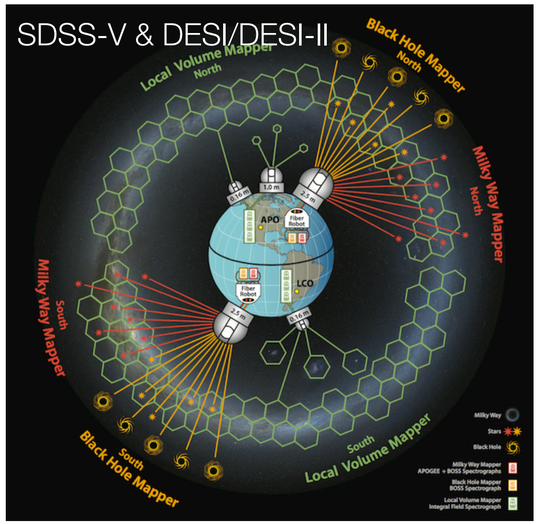
Junyao Li (Postdoc Fellow@UIUC)

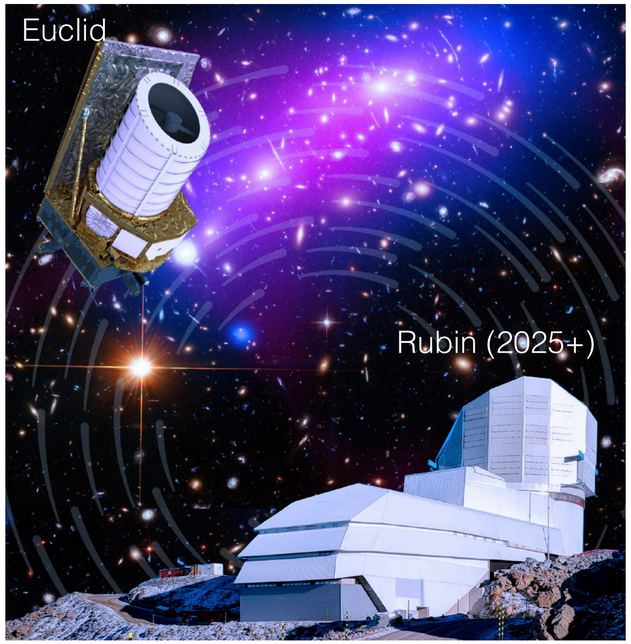
Li et al. (2023) ApJL, 955, 16

VODKA: SDSS J1608: A Sub-arcsec Quadruply Lensed Quasar at z=2.58

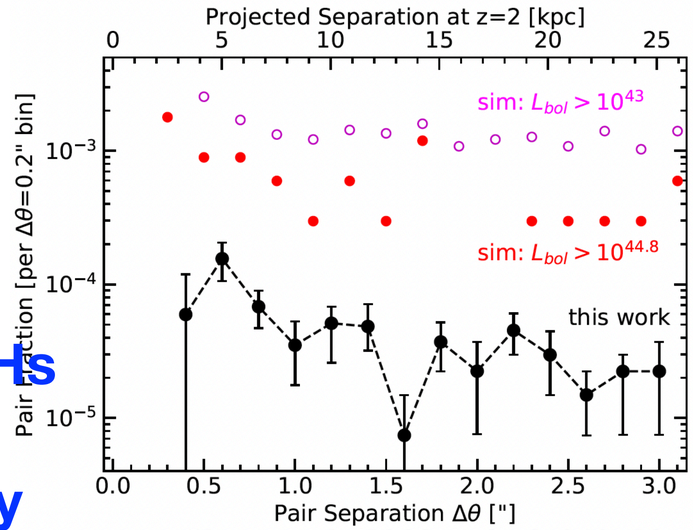
Looking Forward & Takeaways

Euclid/Rubin/Roman will revolutionize the field in synergy w/ PTA & LISA, but only their combined power can maximize the discovery potential for Rare Gems!





Dual/lensed/offset MBHs from high-res deep photometry & variability

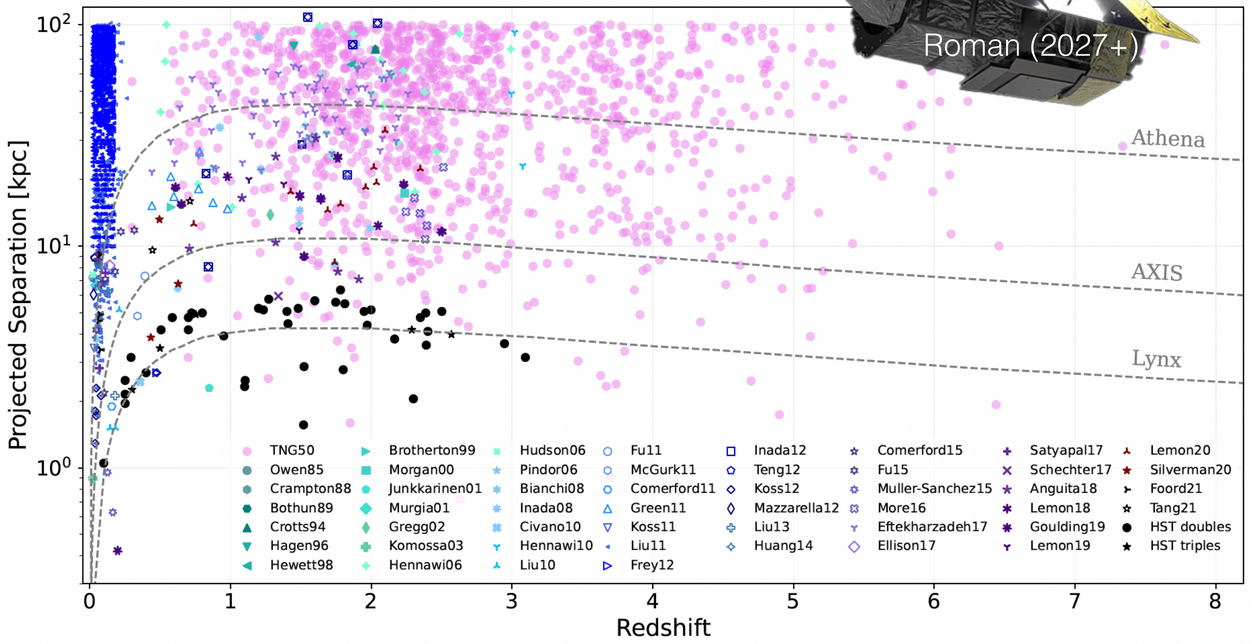


Shen et al. (2023a), ApJ, 943, 38

Sub-pc binary MBH candidates from long-term spectroscopic monitoring (VLTI/ Gravity+)

Milli-pc binary MBH/IMBH candidates from periodic variables/transients (also partial TDEs, EMRIs)

Roman Core Community Survey White Papers
Binary MBH: Haiman et al. arXiv:2306.14990
Dual MBH: Shen et al. arXiv: 2306.15527



Shen et al. (2023b); figure adapted from Puerto-Sanchez, Habouzit et al. in prep.

See also Guy et al. (2022) for Euclid-Rubin synergy

Building the Astro+AI community@Illinois

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **490,** 3952–3965 (2019) doi:10.1093/mnras/stz2845
Advance Access publication 2019 October 10

Deblending and classifying astronomical sources with Mask R-CNN deep learning

Colin J. Burke [1,2★] Patrick D. Aleo [1,3] Yu-Ching Chen,[1,2] Xin Liu,[1,2]
John R. Peterson,[4] Glenn H. Sembroski[4] and Joshua Yao-Yu Lin[5]

[1]*Department of Astronomy, University of Illinois at Urbana-Champaign, 1002 West Green Street, Urbana, IL 61801, USA*
[2]*National Center for Supercomputing Applications, 1205 West Clark Street, Urbana, IL 61801, USA*
[3]*Advanced Visualization Laboratory, National Center for Supercomputing Applications, 1205 West Clark Street, Urbana, IL 61801, USA*
[4]*Department of Physics and Astronomy, Purdue University, 525 Northwestern Avenue, West Lafayette, IN 47907, USA*
[5]*Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, IL 61801, USA*

Colin J. Burke, PhD

NSF AAPF Postdoctoral Fellow, Department of Astronomy, Yale University

Patrick D. Aleo, PhD

Problem & Significance

- Efficient (real-time) and robust deblending techniques are necessary in the era of upcoming massive, deep surveys (LSST, Roman)

SDSS

HSC (LSST-like)

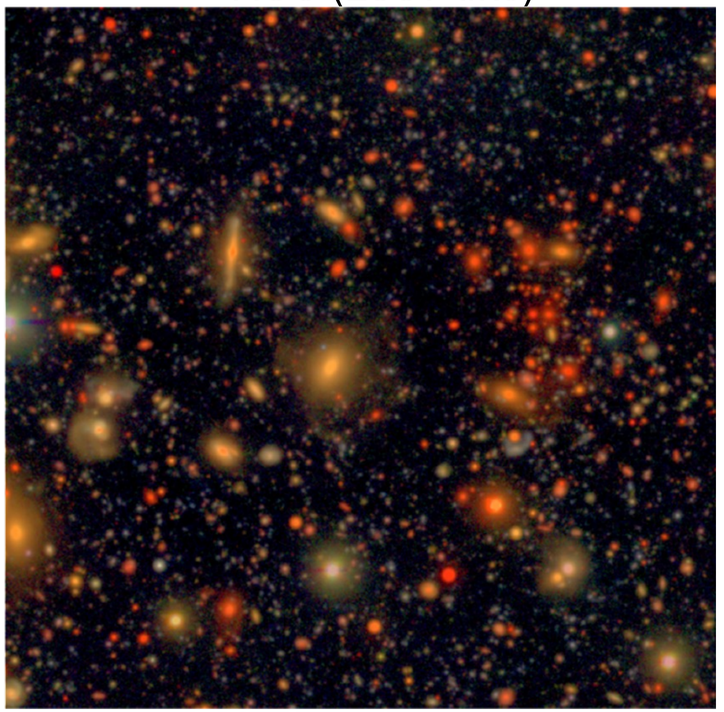


Image Credit: Robert Lupton

Image credit:
https://github.com/facebookresearch/detectron2

See also Melchior (2021)

From proof of principle to production-level codebase

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **526,** 1122–1137 (2023) https://doi.org/10.1093/mnras/stad2785
Advance Access publication 2023 September 14

Detection, instance segmentation, and classification for astronomical surveys with deep learning (DEEPDISC): DETECTRON2 implementation and demonstration with Hyper Suprime-Cam data

Grant Merz [1]★ Yichen Liu [1] Colin J. Burke [1] Patrick D. Aleo [1] Xin Liu,[1,2,3]
Matias Carrasco Kind [1,2] Volodymyr Kindratenko [2,3,4,5] and Yufeng Liu[6]

[1]*Department of Astronomy, University of Illinois at Urbana-Champaign, 1002 West Green Street, Urbana, IL 61801, USA*
[2]*National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, 1205 West Clark Street, Urbana, IL 61801, USA*
[3]*Center for Artificial Intelligence Innovation, University of Illinois at Urbana-Champaign, 1205 West Clark Street, Urbana, IL 61801, USA*
[4]*Department of Computer Science, University of Illinois at Urbana-Champaign, 201 North Goodwin Avenue, Urbana, IL 61801, USA*
[5]*Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, 306 North Wright Street, Urbana, IL 61801, USA*
[6]*Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, IL 61801, USA*

See also: Merz et al. (2024), DeepDISC photo-z , in prep

Check out Grant's talk at: https://www.youtube.com/watch?v=1HgyugrV0xA&list=PLnaABBT-hhFb0c_Hp2rbO6EC4JDxEkstz&index=14

Grant Merz
Astronomy PhD Student
LSSTC Data Science Fellow
LINCC Incubator PI

Yichen Liu
Astro Undergraduate Student
NCSA SPIN Intern
Incoming PhD student at U Arizona

AST-2308174

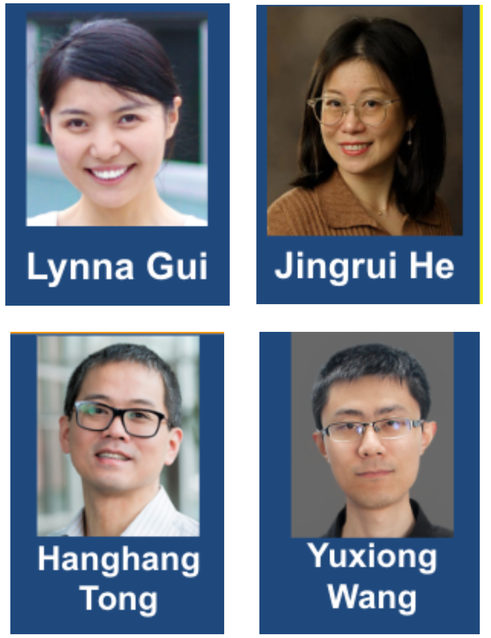
Looking Forward & Takeaways

Expecting the Unexpected: AI/ML for Anomaly Detection

- Self-supervised algorithms for more versatile hierarchical representations to intricately encode the scene-object-part compositions inherent in complex images and time series
- Harness multimodal data
- Address complex data structures
- Handle highly imbalanced data
- Enhance interpretability
- Leverage “open-world” AI, adapting to previously unknown objects
- Enable real-time analysis & decision-making for time-sensitive follow-ups

See also talk by Alex Razim

Key Collaborators from CS & iSchool @UIUC:



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