

Bridging the Gaps in Black Hole Demographics for the 2030s and Beyond

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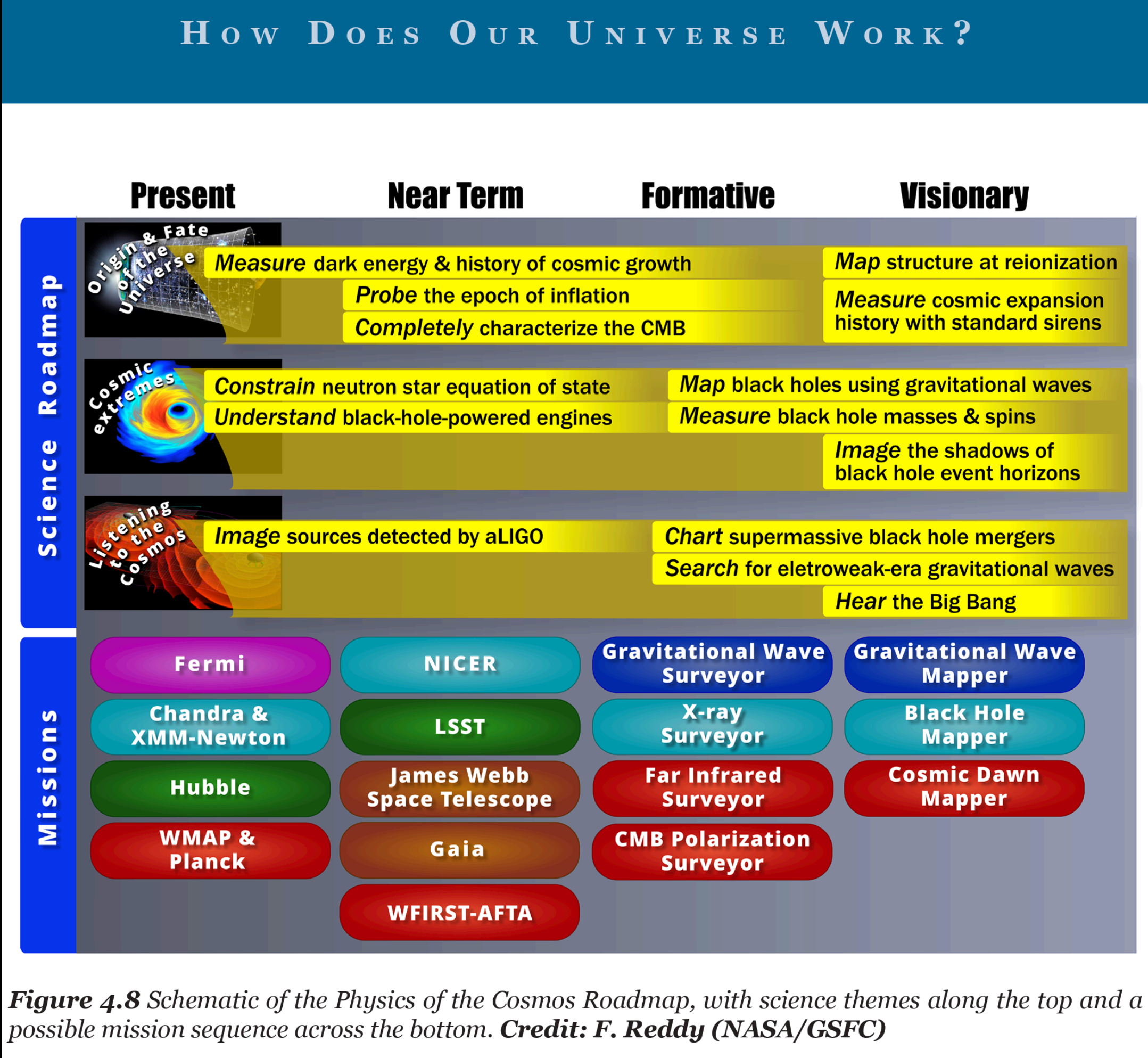
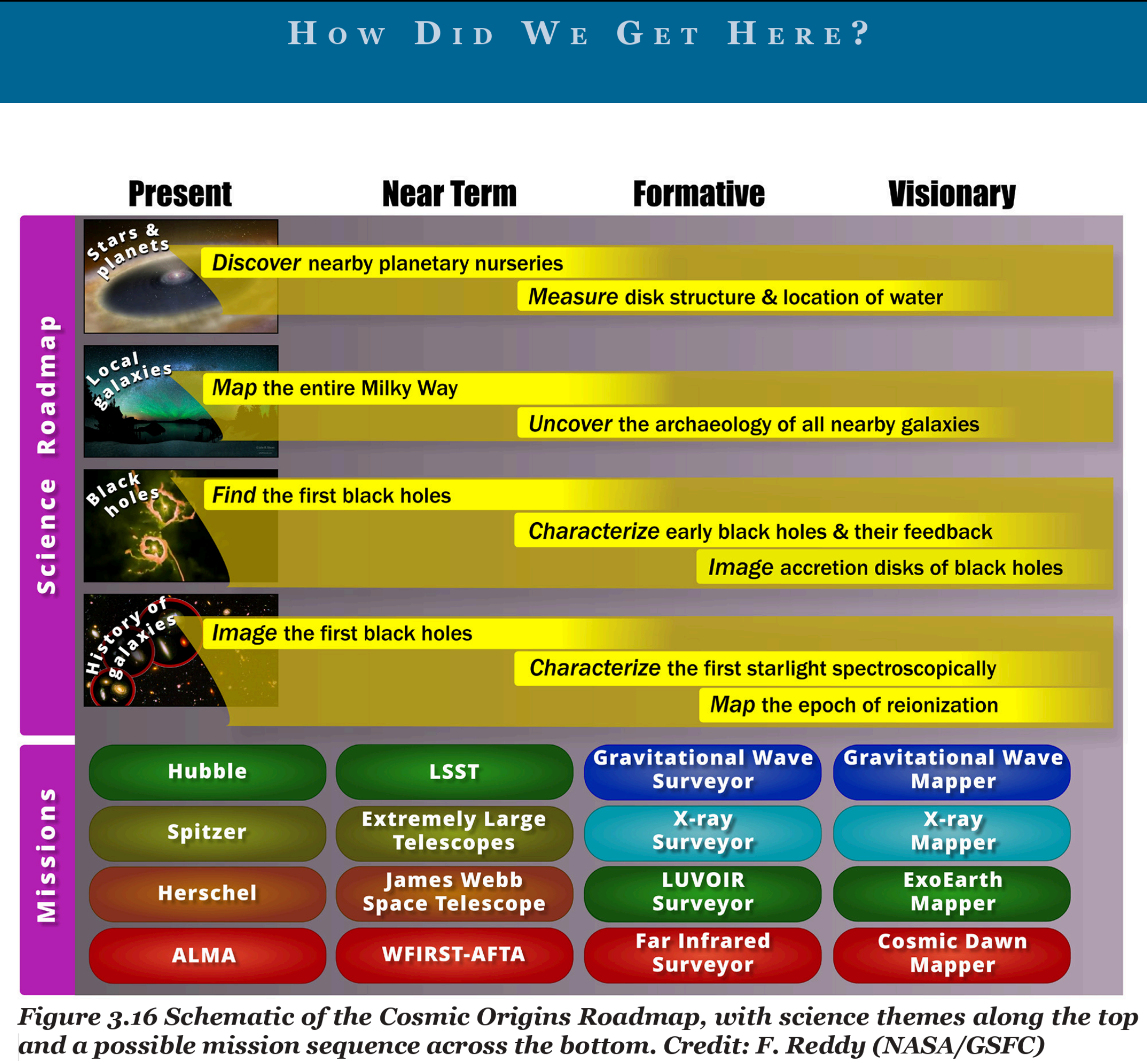


**Ad ASTRA Community Science Workshop
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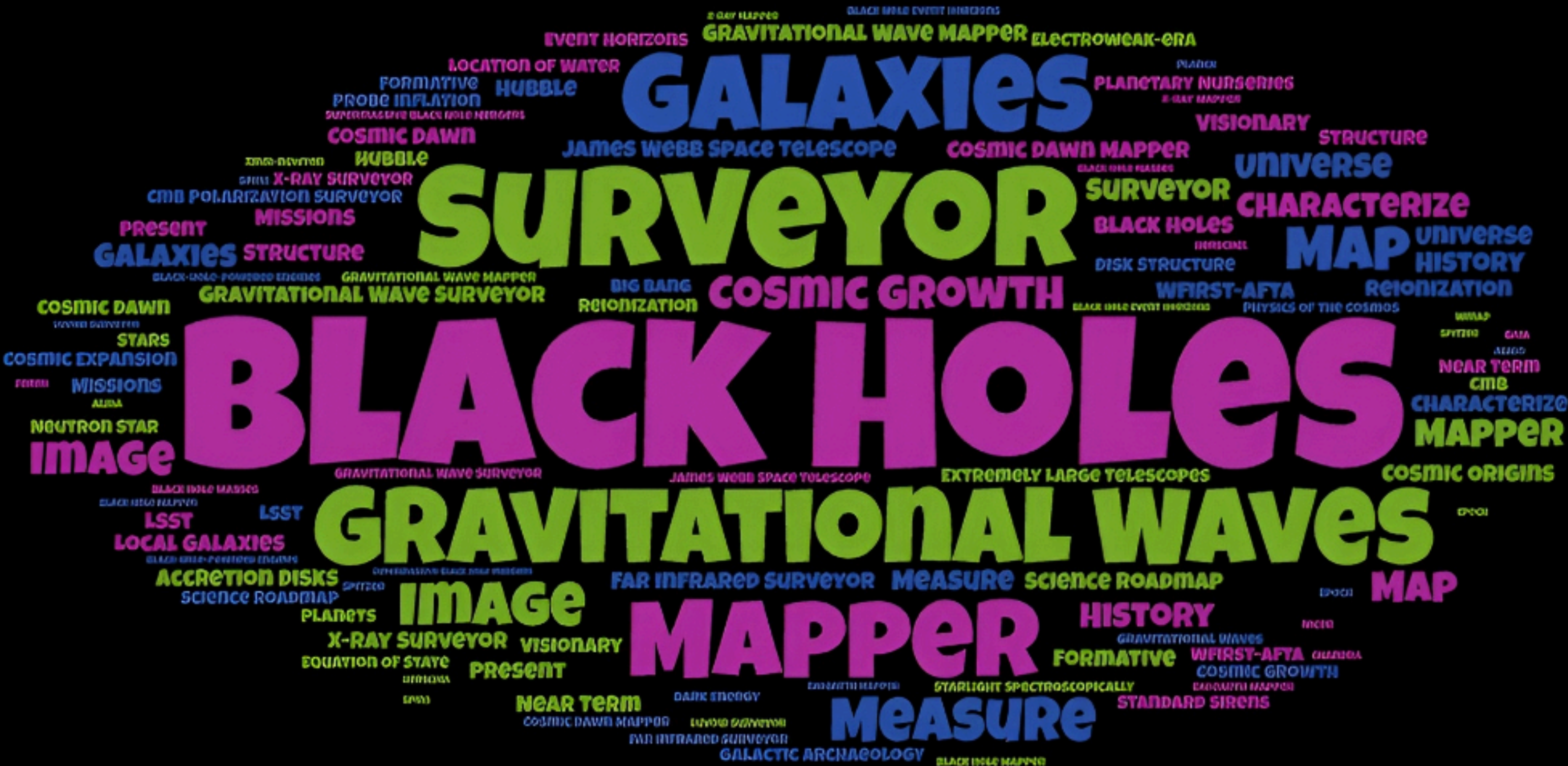
ASTRA initiative

- ✦ What is the big-picture billion dollar question?
- ✦ What instrument capabilities are needed to address the above?
- ✦ What current or planned missions are needed to complement the above?

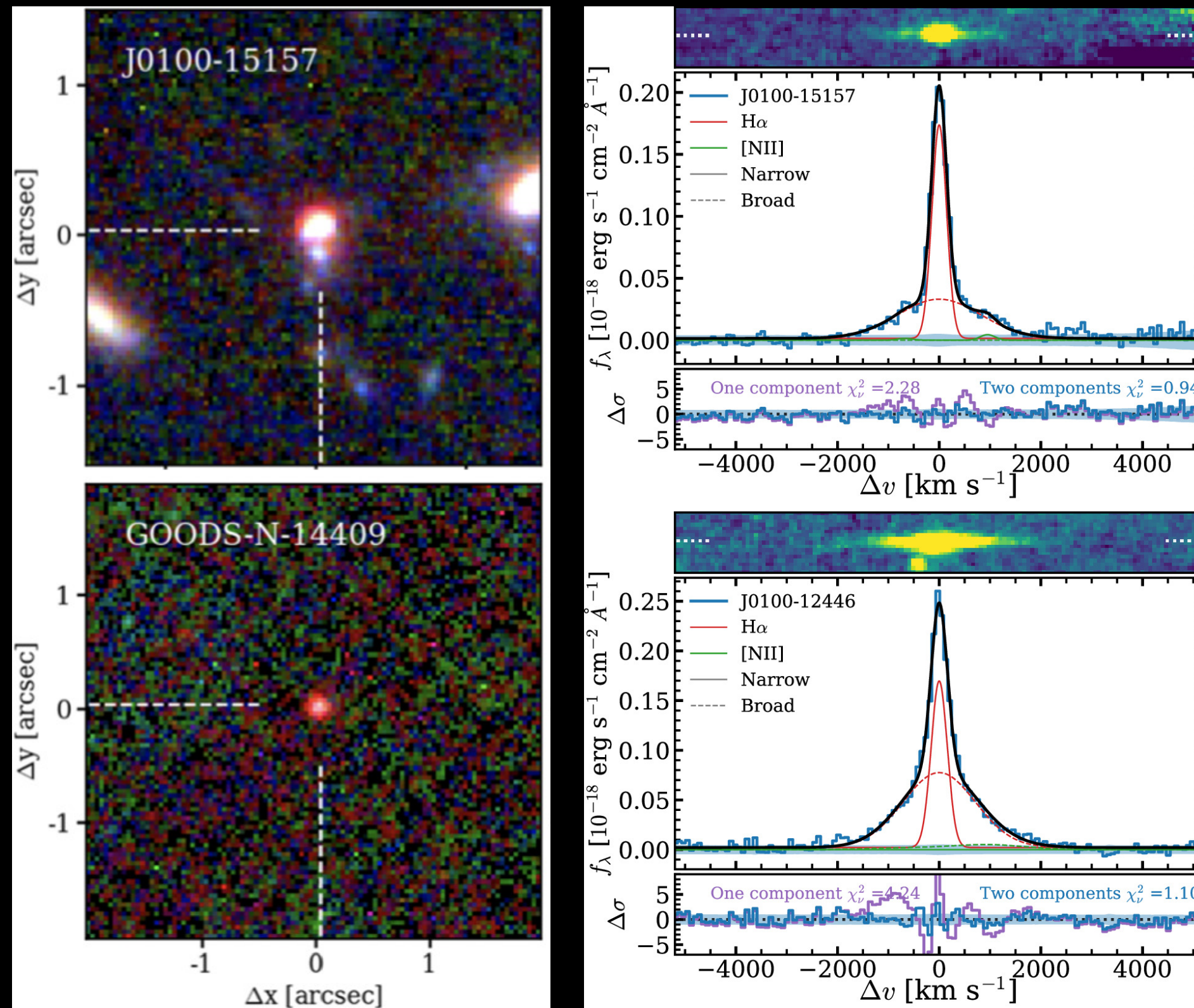
Cosmic Origins & Physics of the Cosmos Roadmaps



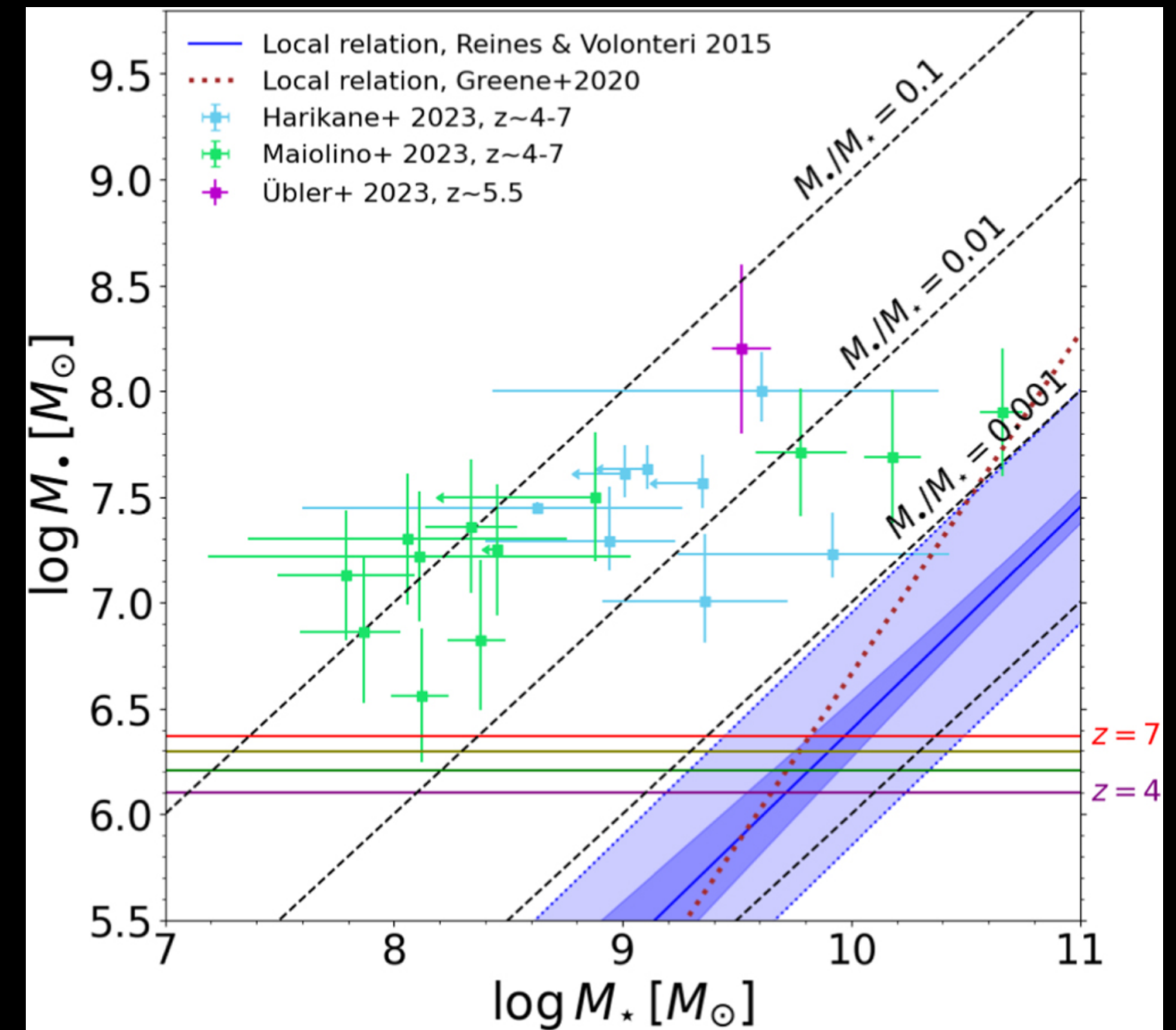
Cosmic Origins & Physics of the Cosmos Roadmaps



JWST Discovery of Little Red Dots



(see Matthee+24, Greene+24, and others)

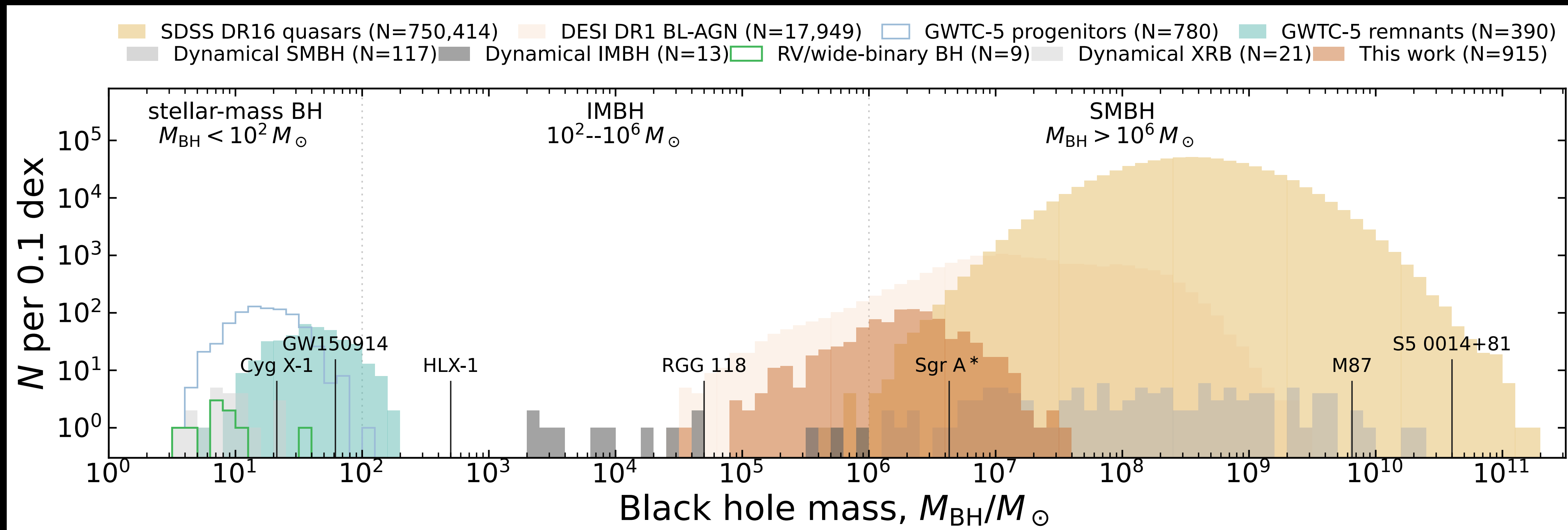
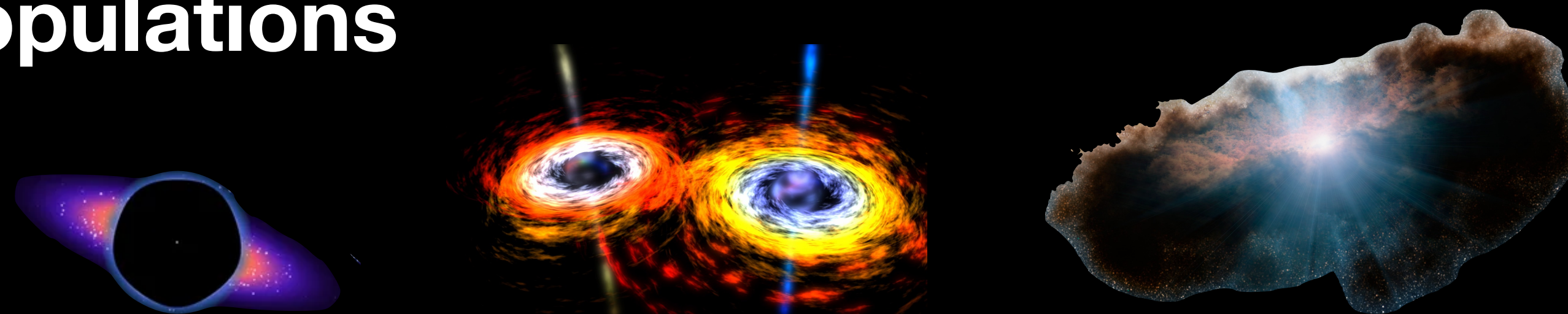


(see Pacucci+23, Bogdan+24, and others)

LRDs have exposed just how incomplete our picture of black hole growth really is.

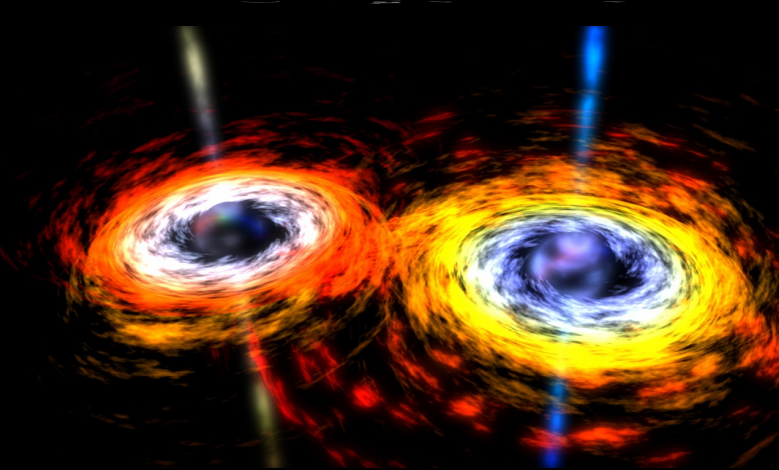
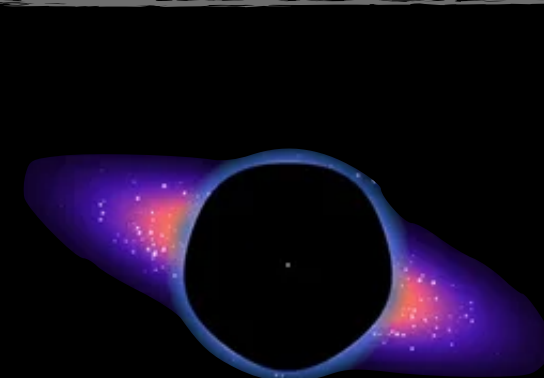
Black Hole Demographics

...and the missing populations



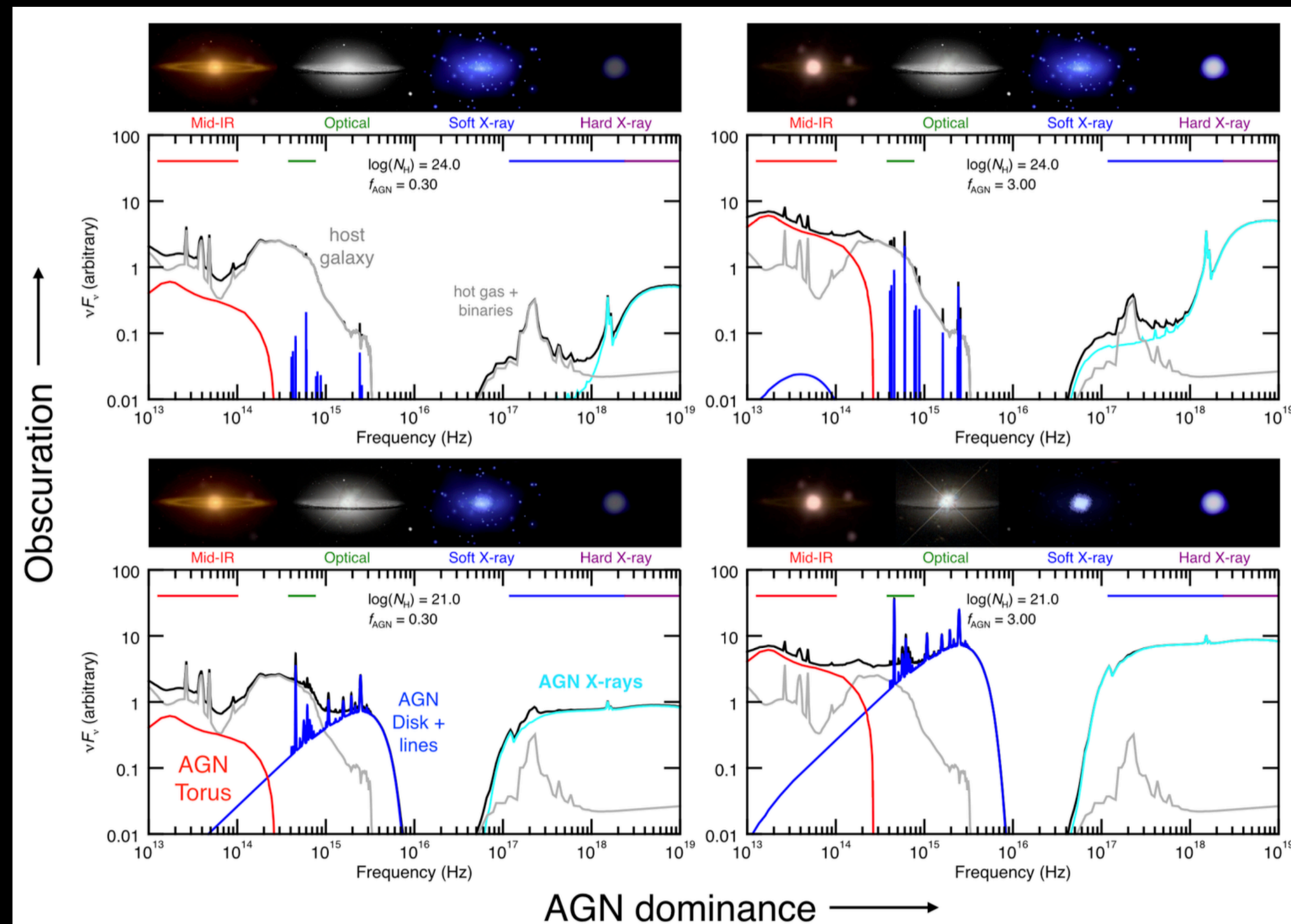
(Guo+ including VU, to be submitted; also see Burke and Natarajan 2026)

Bridging the Gaps

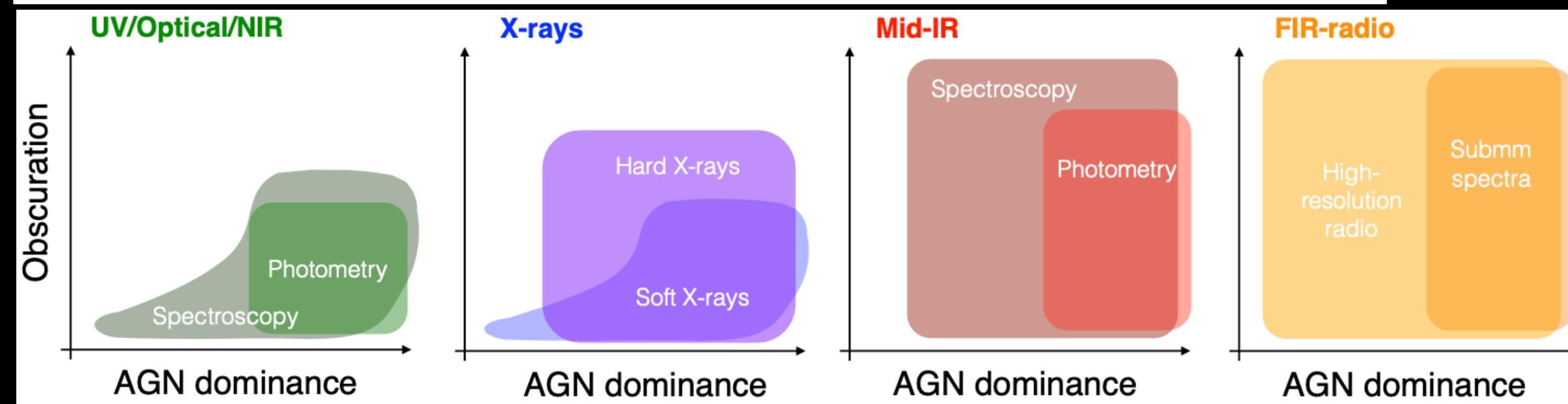


BH Source	IMBHs	Obscured AGN	Binary SMBHs
Evolutionary Stage	Missing Seeds	Hidden Accretion	Dynamical Endpoint
Challenge	Low-luminosity signature	Shrouded in dust	Close separation
Required Capability	UV/optical time-domain & high throughput spectroscopy	High spatial & spectral resolution mid-/far-IR (and sensitive hard X-ray)	Multimessenger GW / EM Follow-up

A Multiwavelength Perspective of Obscured AGN



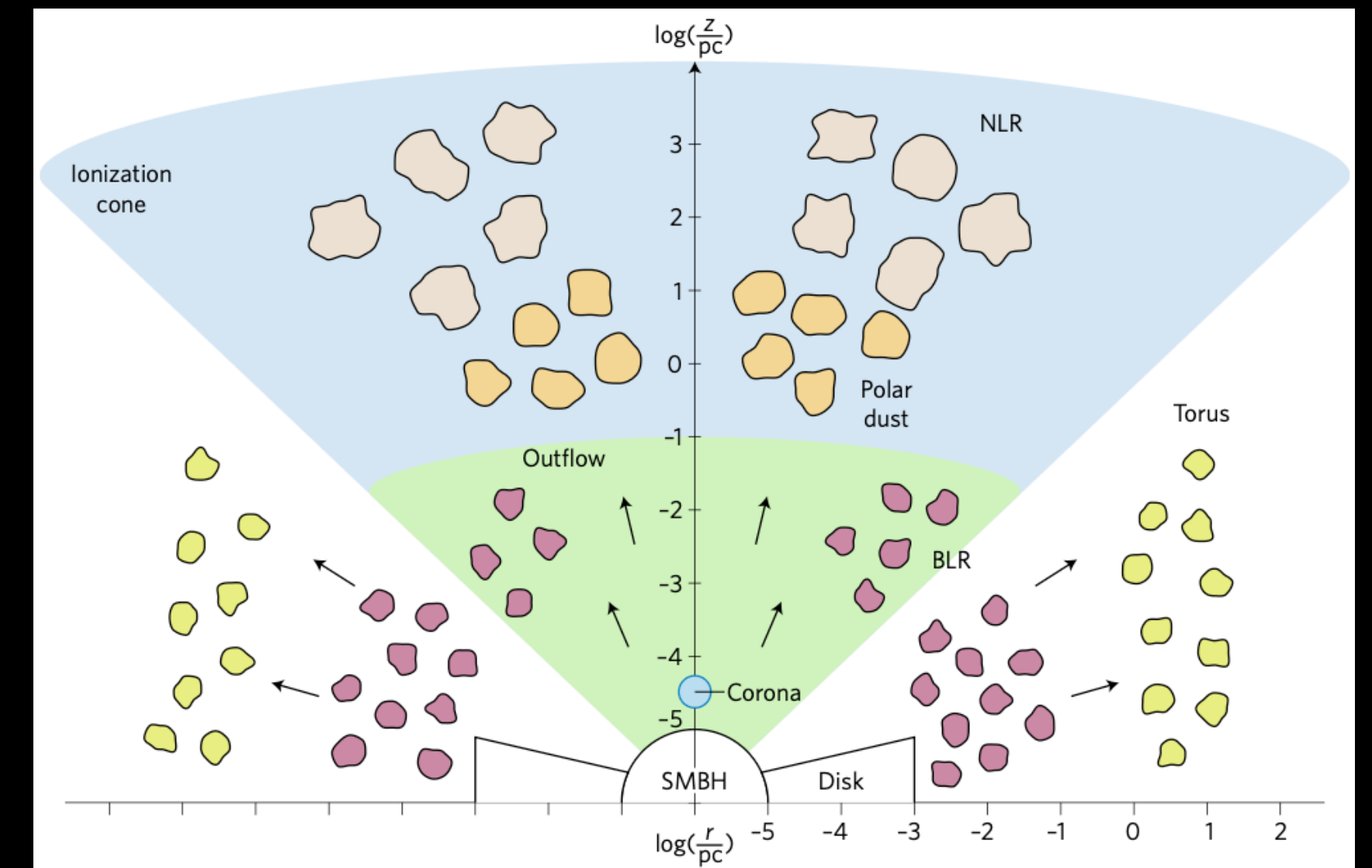
- Host starlight dominates UV / optical in high obscuration cases
- Hard X-rays penetrate gas; mid/far-IR traces reprocessed dust continuum
- Far-IR is essential for uncovering the most heavily dust-enshrouded AGN population



(Hickox and Alexander 2018)

STM: Recovering Obscured AGN in the FIR

- **Science Objective:** Identify obscured AGN to complete the BH census across cosmic time
- **Physical Parameters:** Detect and resolve compact sources to measure size, mass, number density, and kinematics
- **Observables:** IR continuum and high ionization emission lines (e.g. [O IV], [Ne V]) via line fluxes and velocity profiles
- **Potential Challenges:** Far-IR observations suffer source confusion driven by the diffraction limit



(Ramos Almeida and Ricci 2017)

From Mid-IR Breakthroughs to Far-IR Frontiers

The Mid-IR Benchmark

- JWST uncovered LRDs
- High spatial resolution isolates compact nuclear sources
- High spectral resolution ($R \gtrsim 3000$) enables line width characterization and kinematic diagnostics

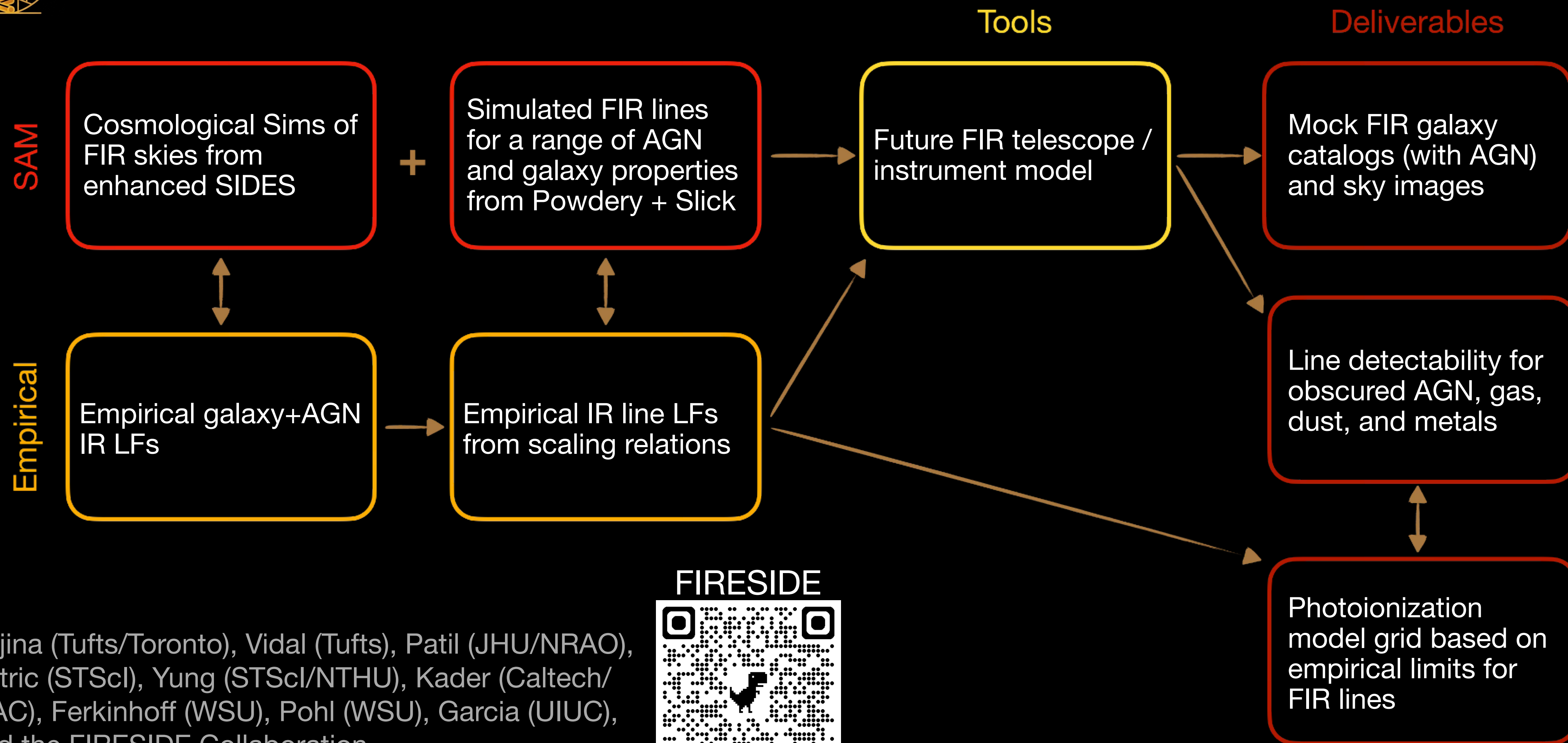
The Far-IR Imperative

- Probes cold dust and peak continuum
- Extends local studies to higher redshifts
- Motivates technical capabilities to enable high spatial and spectral resolution in the long wavelengths

Quantify FIR detection limits and AGN recovery rates to inform the design and requirements of future missions



Far-InfraRed Extragalactic Survey and Instrument Design Exploration



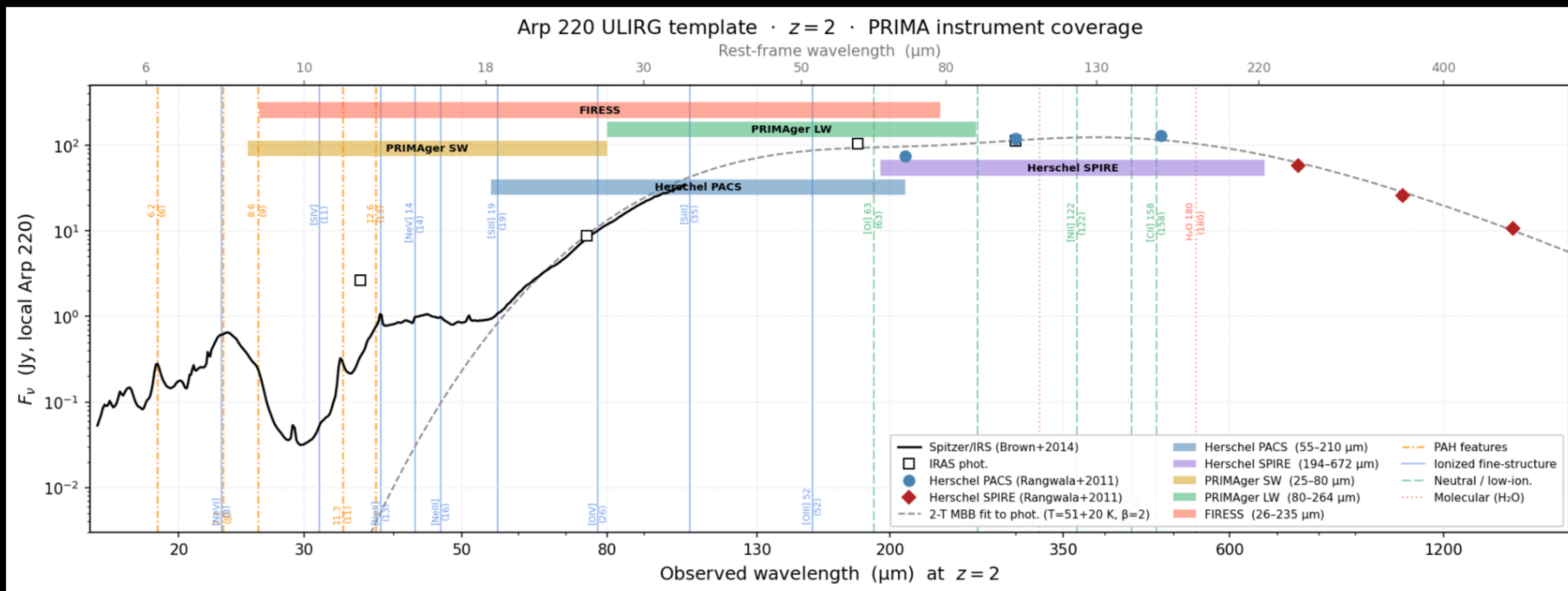
Sajina (Tufts/Toronto), Vidal (Tufts), Patil (JHU/NRAO), Petric (STScI), Yung (STScI/NTHU), Kader (Caltech/IPAC), Ferkinhoff (WSU), Pohl (WSU), Garcia (UIUC), and the FIRE SIDE Collaboration





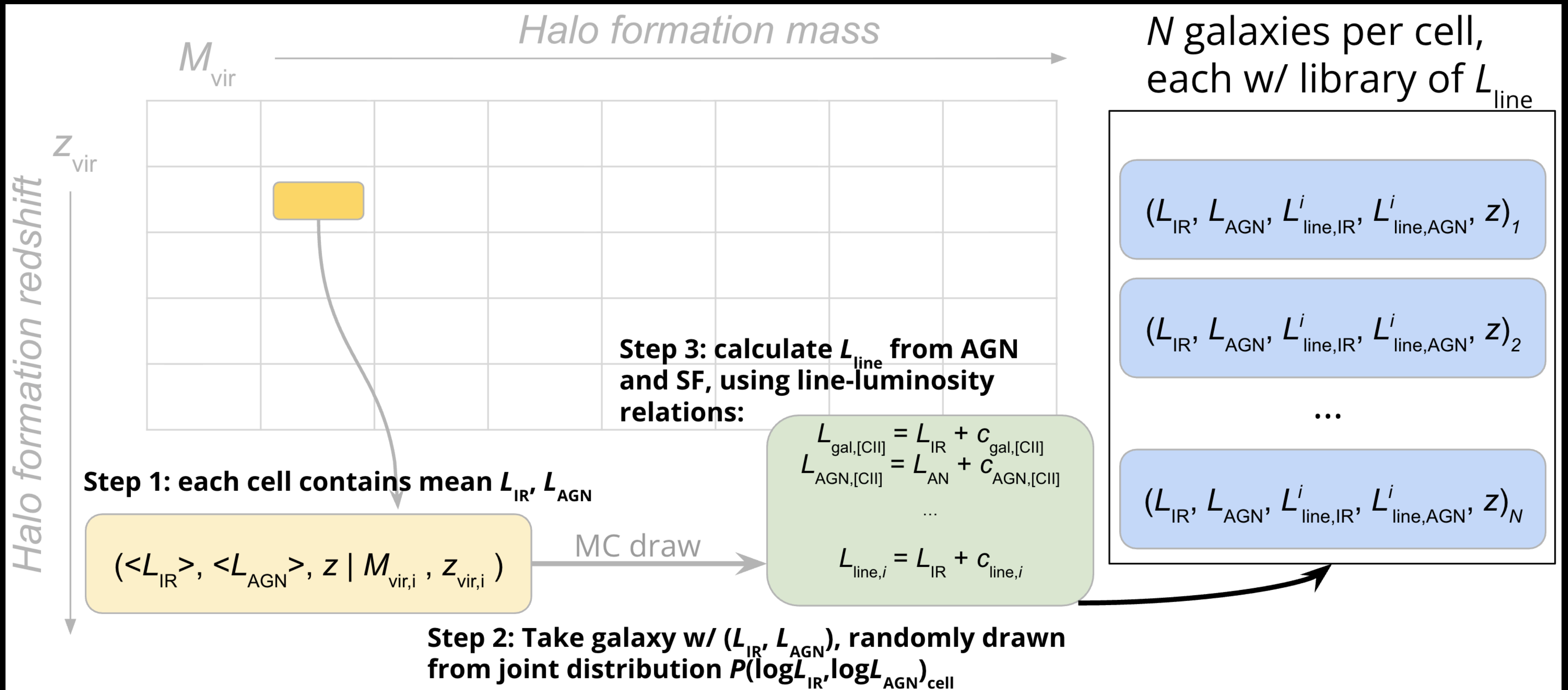
FIRE SIDE enables FIR mission concept tradeoff studies

FIR lines probe understudied regimes of SF and SMBH growth across cosmic time.
FIRE SIDE will provide FIR predictions for various mission concepts & survey designs.



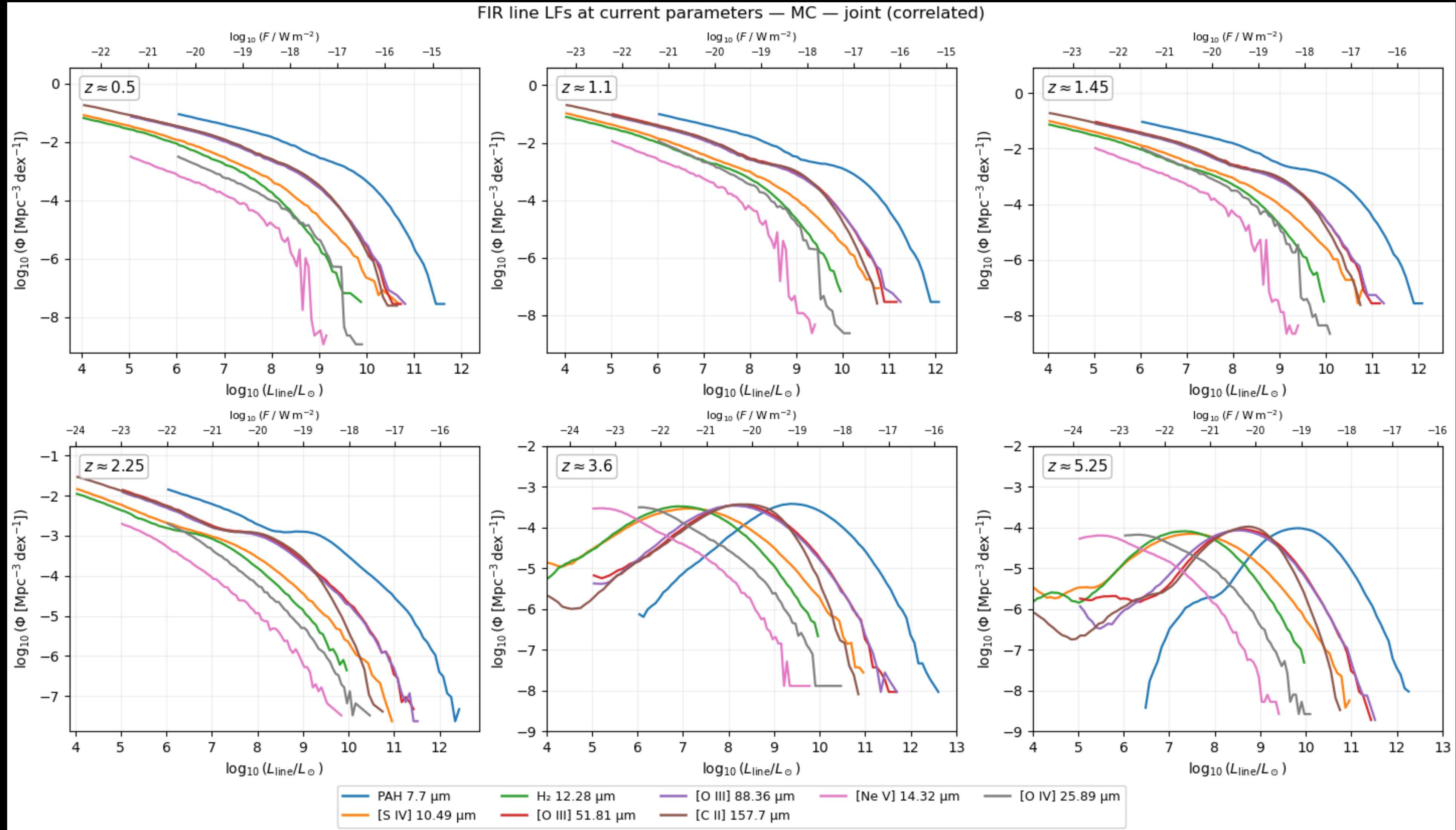


A New Approach toward Line LF: Joint Multi-line Lum per Galaxy





Preliminary Results: MC-sampled (correlated) line LFs

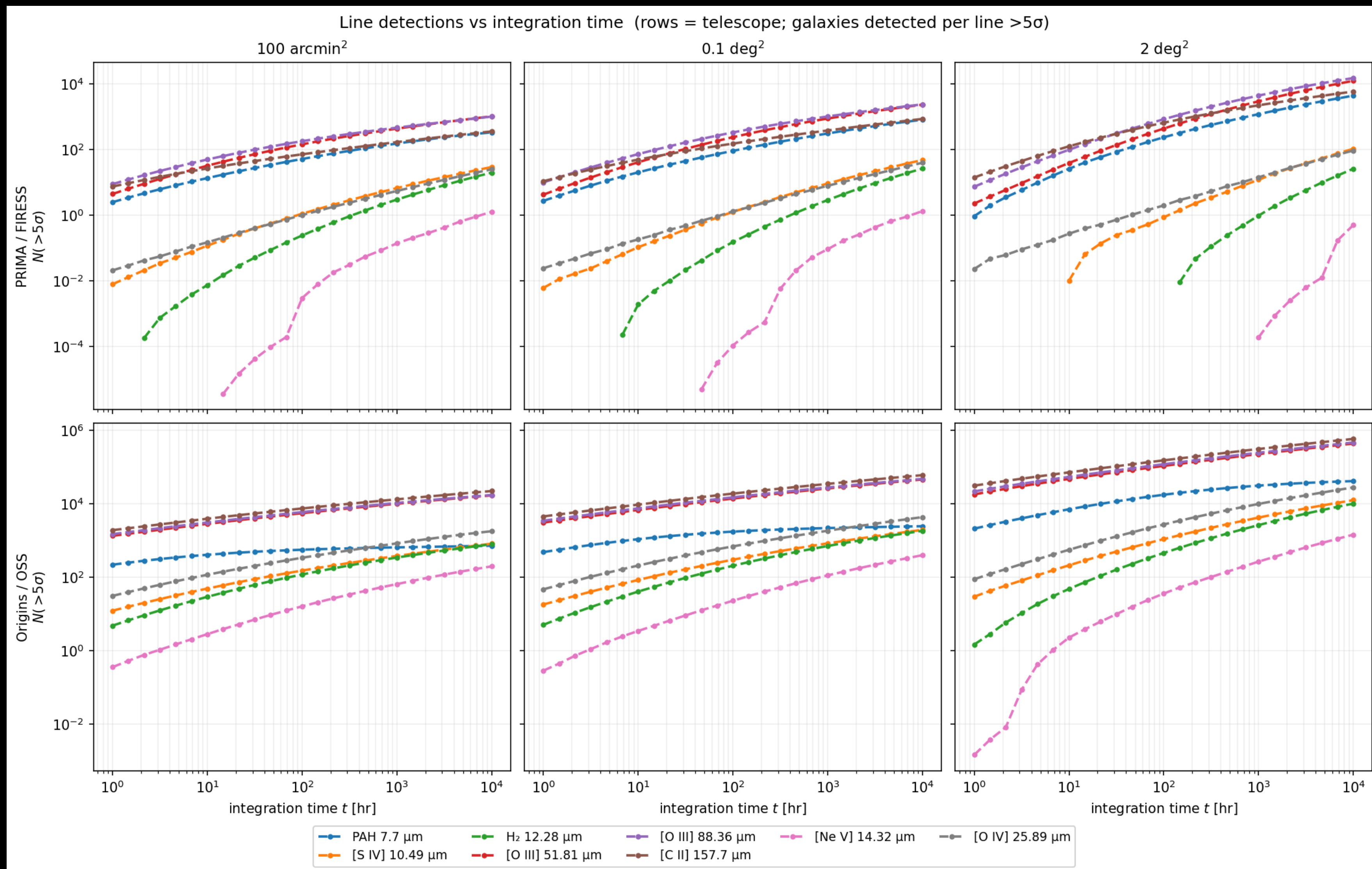




Preliminary Results: N sources detected w/ $F_{\text{line}} > F_{5\sigma}$

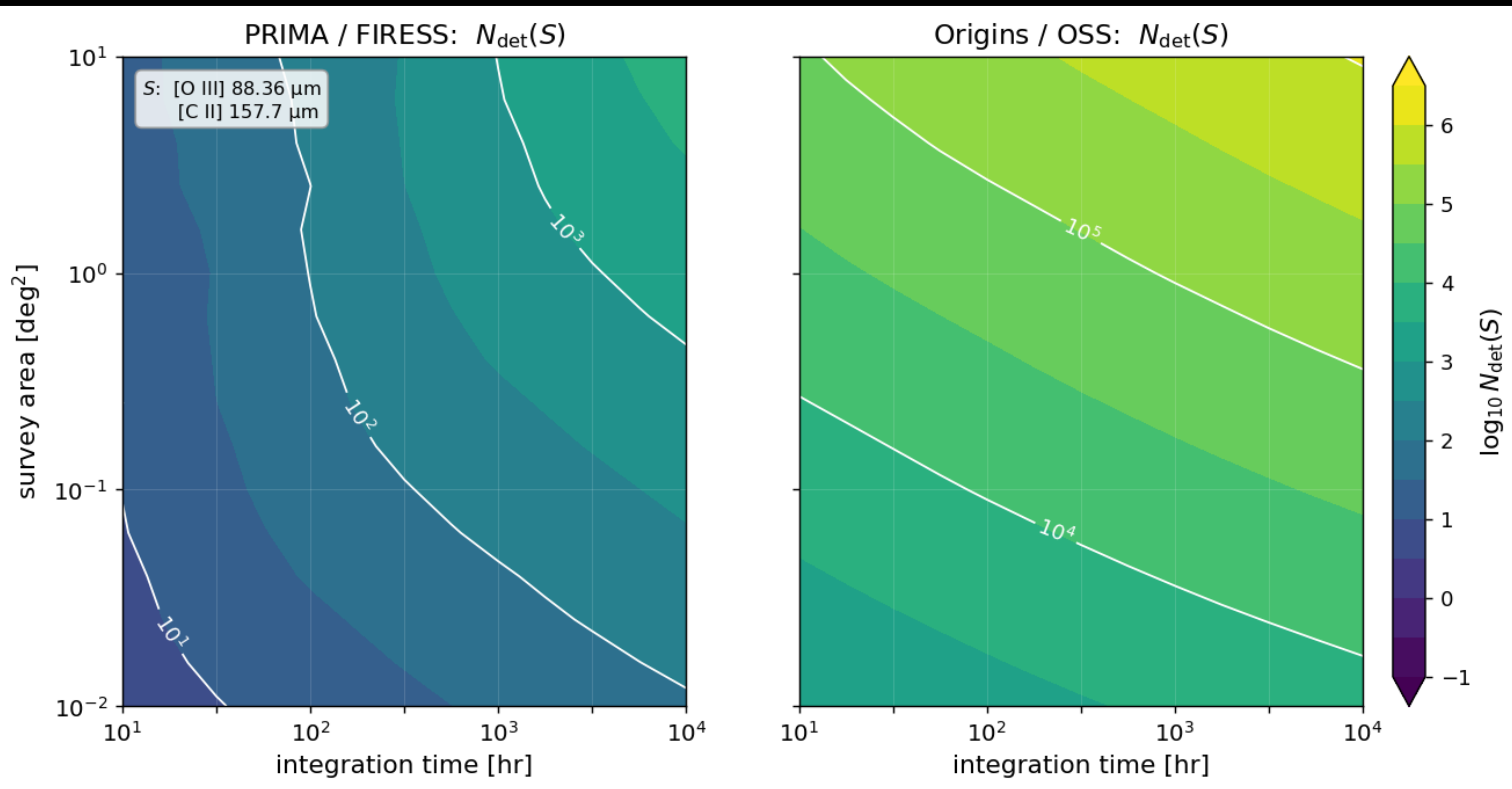
PRIMA

Origins





Preliminary Results: N sources detected in ALL lines of a set S



The 2030s Multi-Messenger and Multi-Wavelength Landscape

- ◆ What is the big-picture billion dollar question?

How do SMBHs seed and grow?

- ◆ What instrument capabilities are needed to address the above?

The synergy of gravitational wave detectors, high UV sensitivity large aperture-mirror with stable PSF, high spatial and spectral resolution in the FIR

- ◆ What current or planned missions are needed to complement the above?

LISA / PTA, HWO, and a far-infrared flagship mission