A Quick MIRI Survey of the HUDF
5.6 – 25.5 μm

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A JWST/MIRI Program in the HUDF and on Searching for AGNs in ULIRGs
A Quick MIRI Survey of the HUDF

- All bands, 5.6 – 25.5μm
- Integration times/depths optimized for identification of AGN
- 30 square arcmin, 55 hours of time
- Expect to detect 30 – 50 AGNs
- About 2000 SF galaxies

At z = 2:
- SF galaxies to 5 M_☉/yr
- AGN down to 1 – 2 X 10^{10} L_☉
Goal 1: Obtaining a Complete AGN Sample

- The problem
  - Different selections yield different samples of AGNs
  - Even very deep X-ray (4 Msec) does not detect all of the bright embedded AGNs found through infrared methods (mostly IRAC power law searches) – e.g., DelMoro et al. 2016, MNRAS, 456, 2105
  - And vice versa – deep X-rays detect AGNs that are not identified in the IR

- Focus on HUDF
  - 7 Msec = 2000 hours of Chandra
  - 1 Msec = 280 hours of HST/ACS
  - 0.7 Msec = 200 hours of JWST/NIRCam to come
  - 0.7 Msec = 200 hours of Herschel
  - 0.6 Msec = 180 hours of JVLA (and more coming)
  - Lots of followup (e.g., spectroscopy)
Color-color selection with IRAC is powerful means to find AGN.

AGNs bright in the infrared can be found with MIRI from color-color plots similar to those developed for IRAC (and WISE) photometry.

Figure from Karina Caputi

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MIRI enables a better strategy than previous work

With the additional photometric bands available with MIRI, we can utilize the spectral minimum in star forming galaxies between 3.5 and 5.5 μm.

• It is hard for an AGN to hide if one can observe this rest wavelength
• As an example, here is WISE photometry of NGC 4945 (a highly obscured local AGN with 2 – 10 keV reduced by X 35), normalized to the spectrum of Arp 220

• We will get more complete identifications of AGNs with many MIRI bands that let us isolate the 3.5 – 5.5 μm (rest) spectral region

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The MIRI “ultra-ultra low resolution spectrometer”

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A Test Case

Flux density vs wavelength (microns)

- Main sequence pure star formation
- Plus 0.03 Eddington AGN2 on Magorrian mass BH
Combination of NIRCam and MIRI Colors Achieves Good Separation
Goal 2: Complete Measurement of Embedded Star Formation to $z = 2$

- The same survey will measure obscured SFRs to $z \sim 2$ and down to $5 \, M_\odot/\text{yr}$, $5$-$\sigma$, based on the MIRI 21 $\mu$m imaging.

- A critical part of the strategy is the imaging in the shorter wavelength MIRI bands to let us model PAH feature strengths.

- Very deep 6 GHz JVLA image is also key.
Accurate SFRs can be determined from 24\(\mu\)m (and MIRI 21\(\mu\)m) photometry up to \(z \sim 2\) (from Rujopakarn et al. 2013, ApJ, 767, 73)

Behavior of local LIRGs/ULIRGs

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IR galaxies are \( \sim 4 - 6 \) kpc in diameter by \( z > 1 \)


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Because IR galaxies are more extended than locally, the suppression of the aromatic bands characteristic of local ULIRGs is shifted to higher luminosities.
Metallicity effects are reasonably well understood for local galaxies

- And are similar at $z \sim 2$: Shivaei et al. 2017
- Multiple bands will allow accurate modeling of PAH features

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But what can be done about the compact ULIRGs??

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For local (ultra-compact) ULIRGs, even Br $\alpha^*$ is not a good SFR indicator

* At 4.05 $\mu$m!!

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For them, we have ultradeep 6 GHz images of the region

- 100 sources down to 0.35 μJy rms (Wiphu Rujopakarn et al. 2016, ApJ, 833, 12)
  - Reaches ULIRGs at $z = 2$ at a minimum of $\sim 5 \sigma$
  - Deeper for star formation than deep ALMA mosaic of same region
- Get SFRs from radio/IR relation
- Also will help interpret ultra-deep (but confused) Herschel FIR data

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Goal 3: Searching for AGNs in ULIRGs

(c) Interaction/“Merger”
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG
- galaxies coalesce: violent relaxation in core
- gas inflows to center:
  - starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback,
  but, total stellar mass formed is small

(e) “Blowout”
- BH grows rapidly; briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO:
  - recent/ongoing SF in host,
  - high Eddington ratios
- merger signatures still visible

(f) Quasar
- dust removed; now a “traditional” QSO
- host morphology difficult to observe:
  - tidal features fade rapidly
- characteristically blue/young spheroid

(b) “Small Group”
- halo acquires similar-mass companion(s)
- can occur over a wide mass range
- $M_{200}$ still similar to before:
  - dynamical friction merges the subhalos efficiently

(g) Decay/K+A
- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant redden rapidly (E+A/K+A)
- “hot halo” from feedback
- sets up quasi-static cooling

(a) Isolated Disk
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- “Seyfert” fueling (AGN with $M_b$ $>$ 23)
- cannot redden to the red sequence

(h) “Dead” Elliptical
- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to “large group” scales:
  - mergers become inefficient
- growth by “dry” mergers

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[Ne VI] 7.65 \( \mu m \) (ionization potential 158 eV) falls within a broad minimum in interstellar extinction.

\[
\frac{A_{\lambda}}{A_{Ks}} = f(\lambda)
\]

\( \lambda = (2, 5, 10, 20, 30) \mu m \)

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Mid-IR spectroscopy is competitive with hard X-rays (HX) for obscured AGN studies.

Optical depth at [Ne VI] (7.65 μm) is no more than that at about 8 keV. As a forbidden line, [Ne VI] will have an extended emission region, facilitating its escaping. From Corrales et al. 2016, MNRAS, 458, 1345
[NeV] (used widely with Spitzer) and [Ne VI] are of similar flux.

data from Veilleux et al. (2009)

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Are ULIRGs really the nurseries for active galactic nuclei??

• 1 hour with JWST could detect an AGN with a luminosity of \( \sim 10^7 \, L_\odot \)
• This is \(< 10^{-5} \) the luminosity in young stars

Arp 220 (HST): prototypical Ultraluminous Infrared Galaxy (ULIRG) with \( > 10^{12} \, L_\odot \) from young stars.
Are ULIRGs really the nurseries for active galactic nuclei???

- A very efficient program can use a single channel of the MIRI spectrometer to search for embedded AGNs
  - Includes [Ne VI] 7.65 μm
  - Also includes aromatic features at 7.7, 11.3 μm as star formation indicators
  - Reduced equivalent widths of aromatic bands signals an AGN continuum
  - Plus [Ne II], 12.8 μm for star formation
  - Plus can detect CO fundamental bands in red giants just short of 5 μm
    - Reduced equivalent widths signals an AGN continuum

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Key Points

• MIRI survey enabled by advances in:
  • Sensitivity (of course): 21 µm survey depth reached > 100 times faster than MIPS 24 µm
  • High resolution: MIPS 24 µm confusion limited at about 15 times JWST 21 µm depth in survey discussed
  • Versatility: Multiple filters allow improved AGN identification and aromatic band modeling strategies

• Exploiting these advantages can yield a lot of science in a survey requiring only a modest time investment

• Also demonstrated MIRI capabilities for AGN studies centered on 7.65µm [NeVI] line

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