The Most Luminous Dust-Obscured Galaxies at Cosmic Noon

The BlueDOG at Cosmic Noon: A Possible Analog to Little Red Dots?

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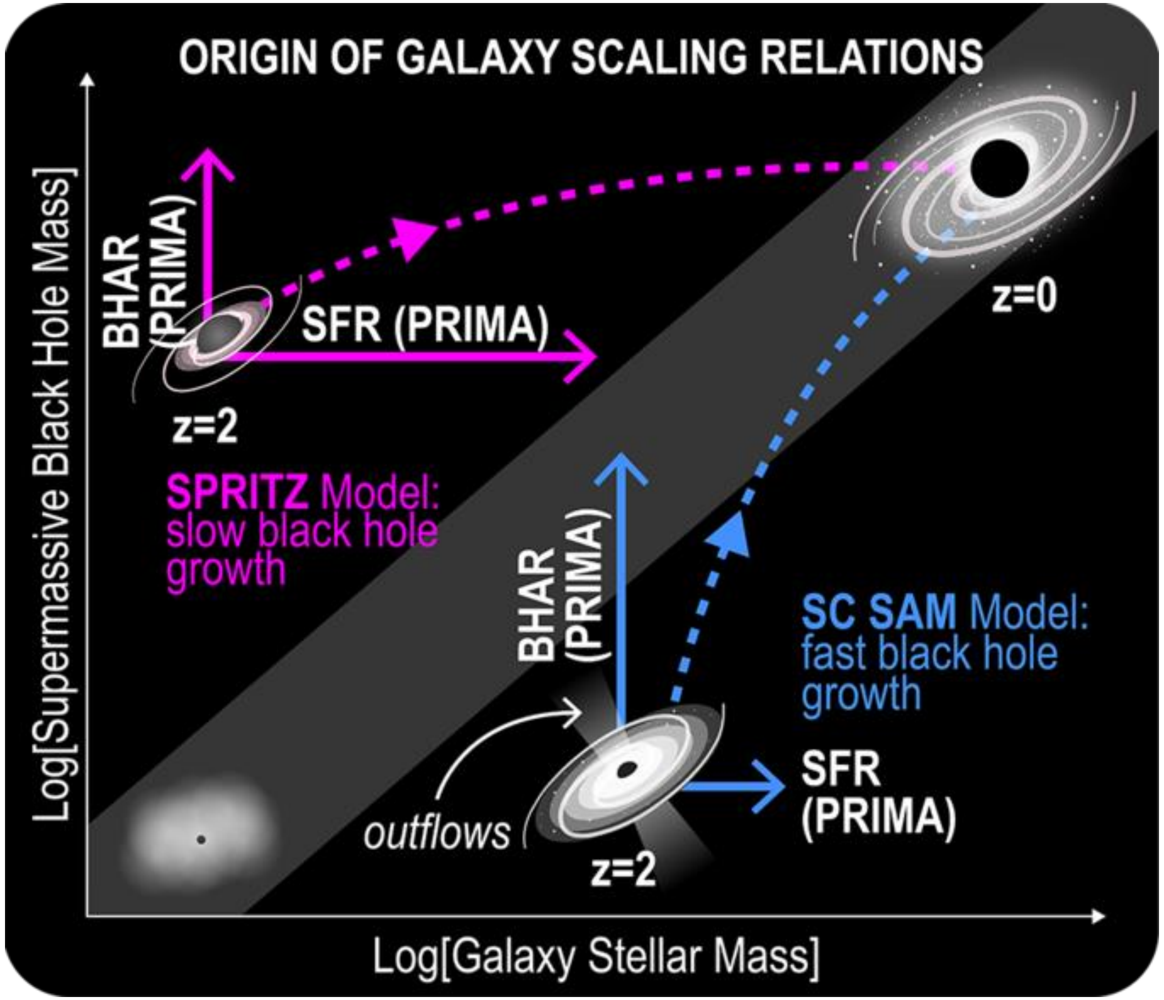
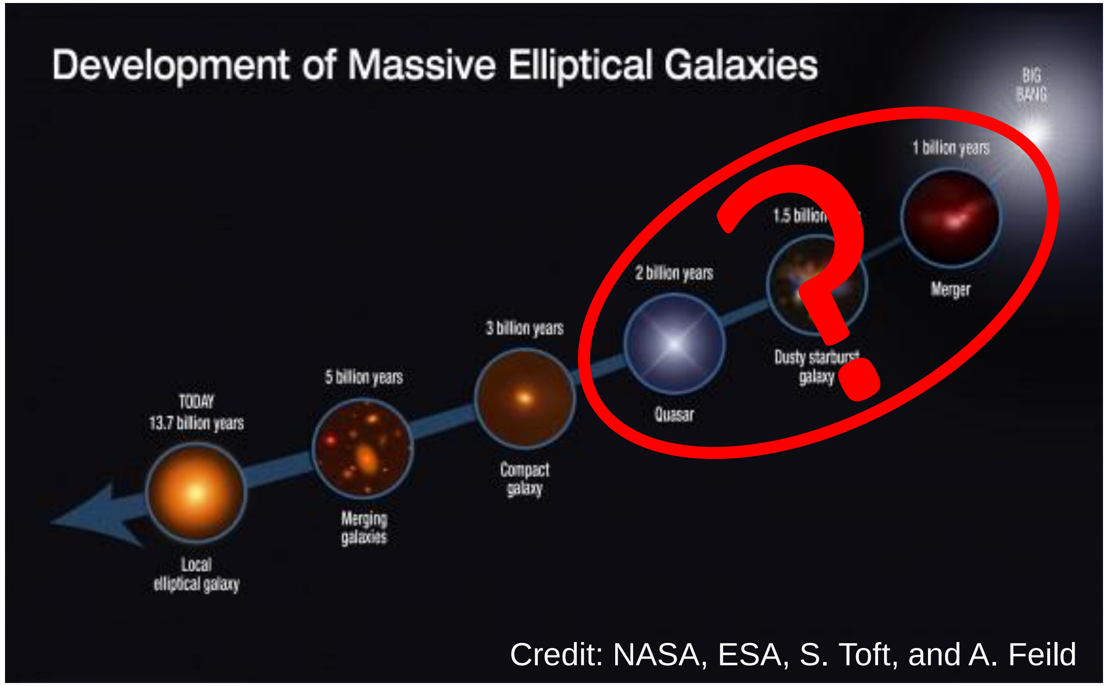
Dusting off the secrets of the cosmos with PRIMA
space IR telescope conference at Marseille

March 31, 2025

Coevolution of SMBH and Host galaxy

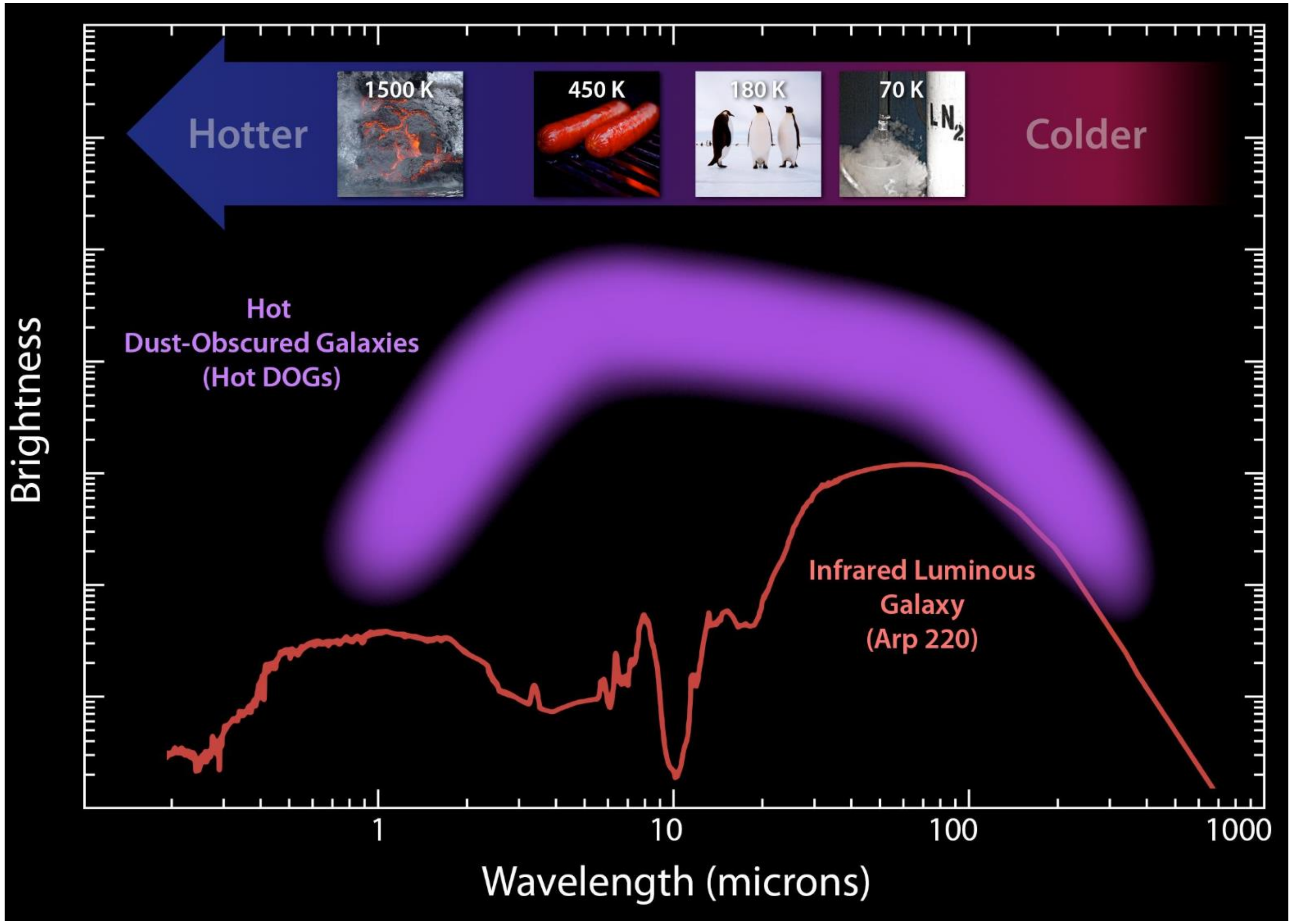


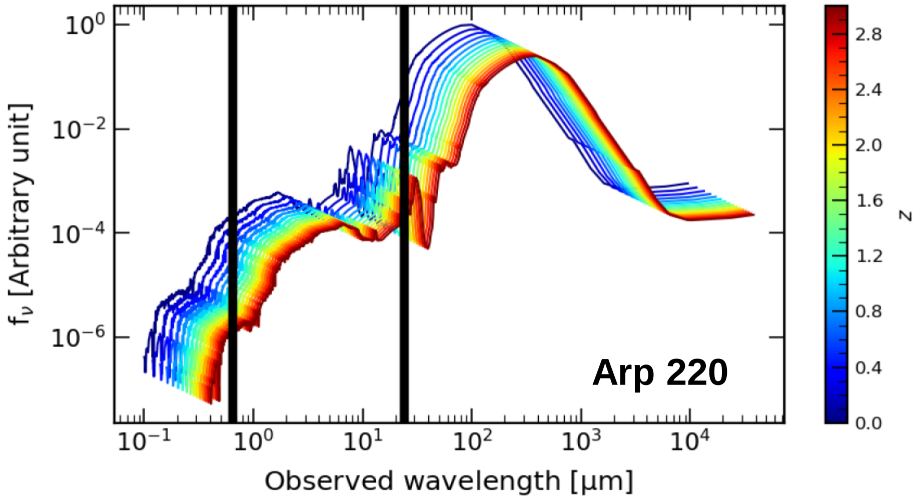


- It is known that supermassive black holes (SMBHs) and their host galaxies co-evolve. (Kormendy & Ho 2013)

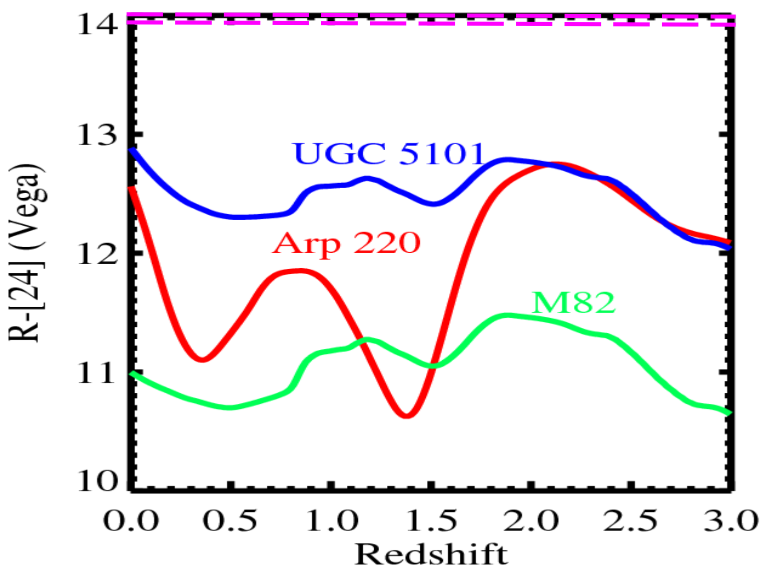
- However, the snapshot of massive SMBH formation and evolution at cosmic noon evolving into local massive ellipticals is still puzzling.

What are Dust-Obscured Galaxies? (1)





$F_{24\mu m}/F_R \gtrsim 10^3$



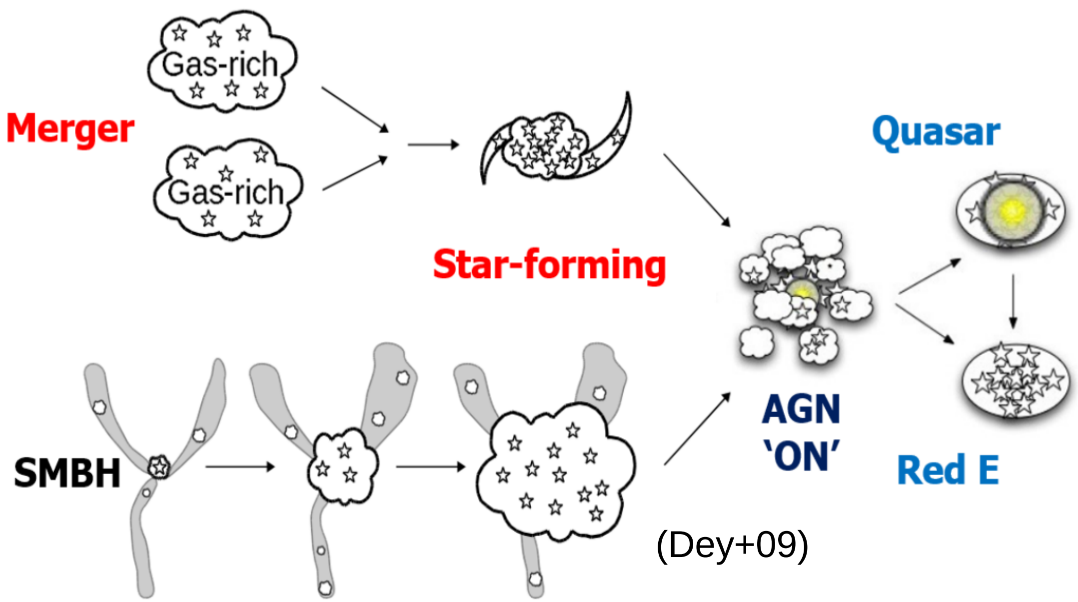
(Dey+08)

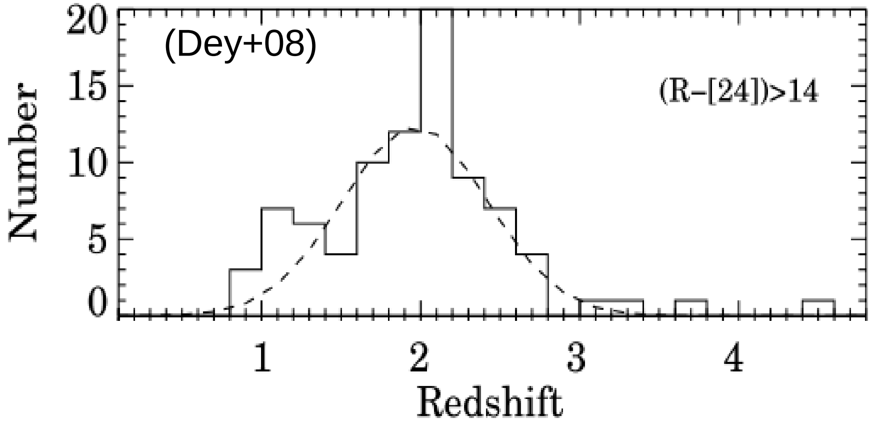
- After *Spitzer Space Telescope* was launched, this type of galaxies was newly discovered with IR-bright and optically-faint source selection.
- How? → Find redder color than local dusty galaxies/AGNs!

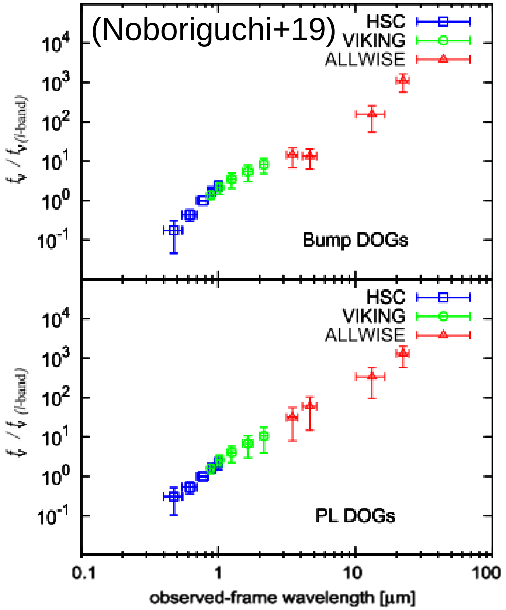
What are Dust-Obscured Galaxies? (2)

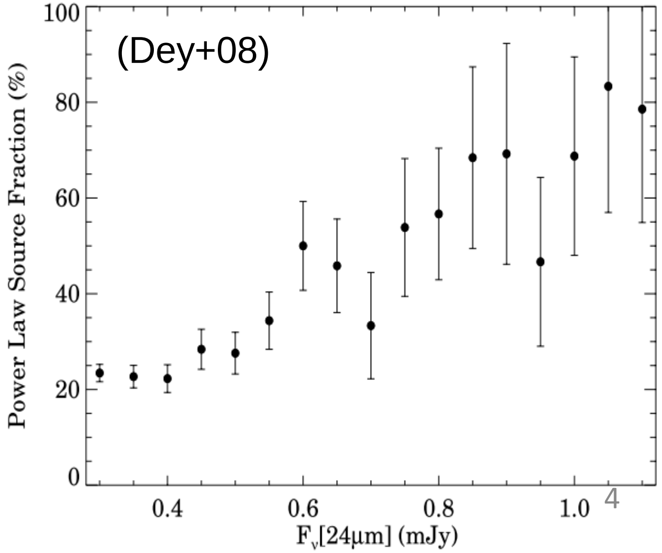
Dust-Obscured Galaxies (DOGs)

- DOG criteria: $F_{24\mu m}/F_R \gtrsim 10^3$
- Features of DOG
  - $z \sim 2 \pm 0.5$ @ cosmic noon: IRLD~10-40%
  - Type: bump (SF), power-law DOG (AGN)
  - 24μm bright DOGs: AGN-dominated (PL DOG) & more luminous.
  - Merger → SMG → **DOG** → QSO / Elliptical



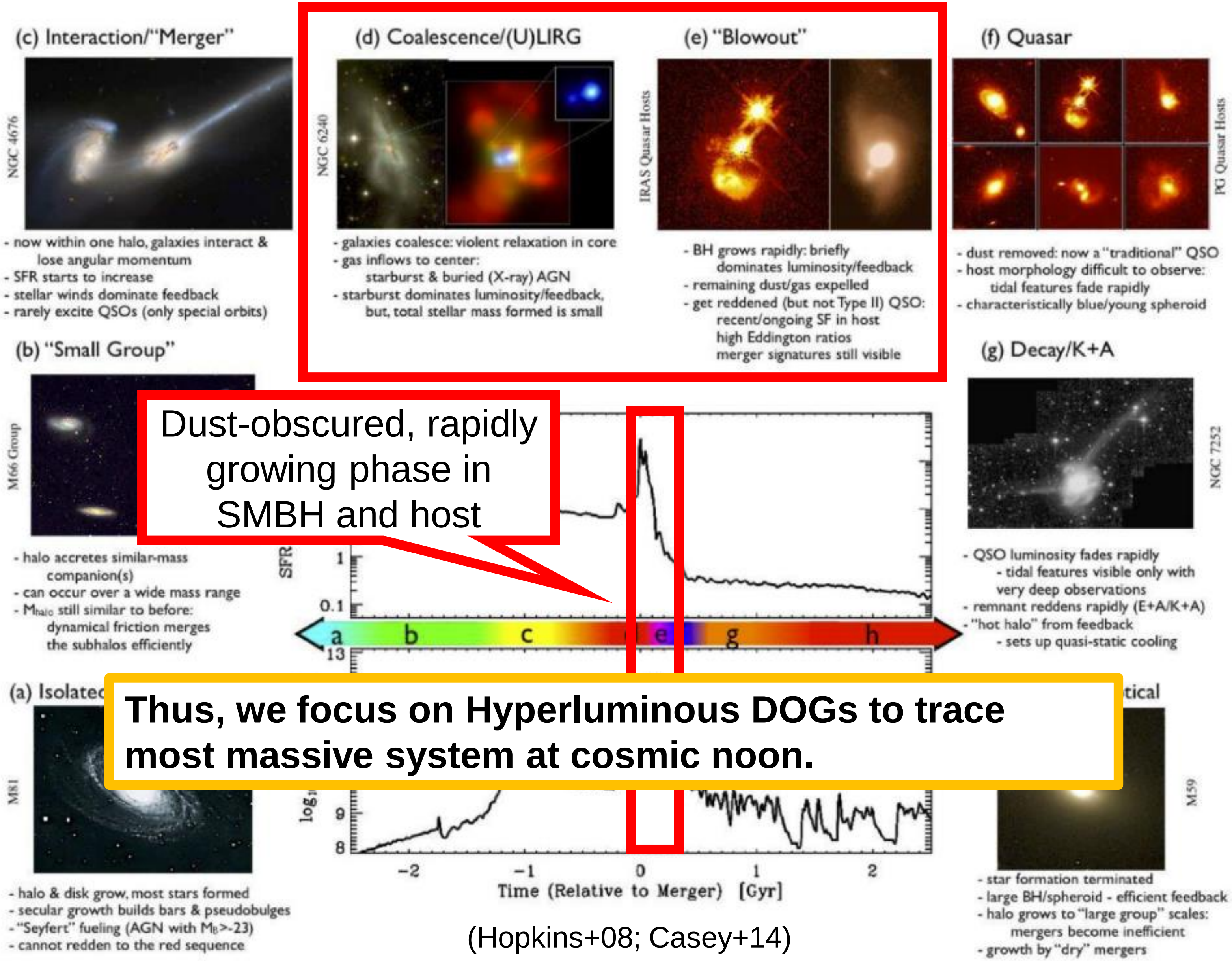






HyLIRG: $L_{IR} > 10^{13} L_{\odot}$

Why Hyperluminous Dust-Obscured Galaxies?

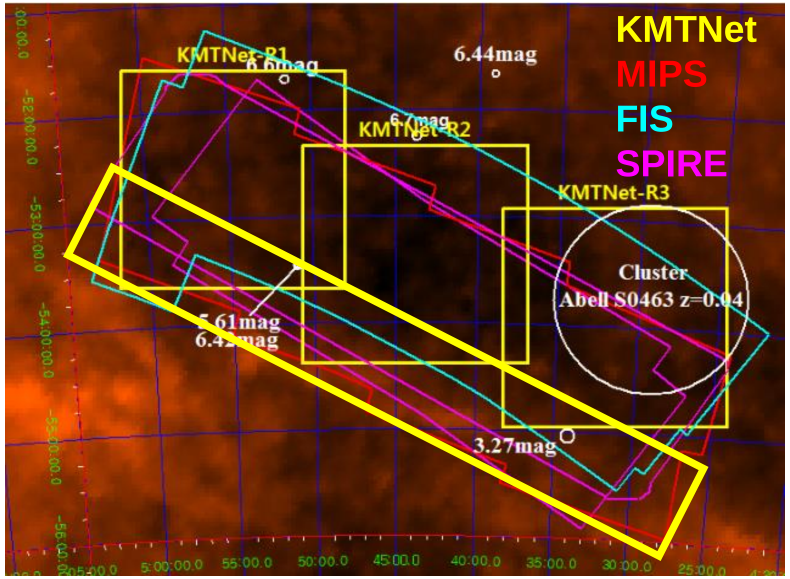


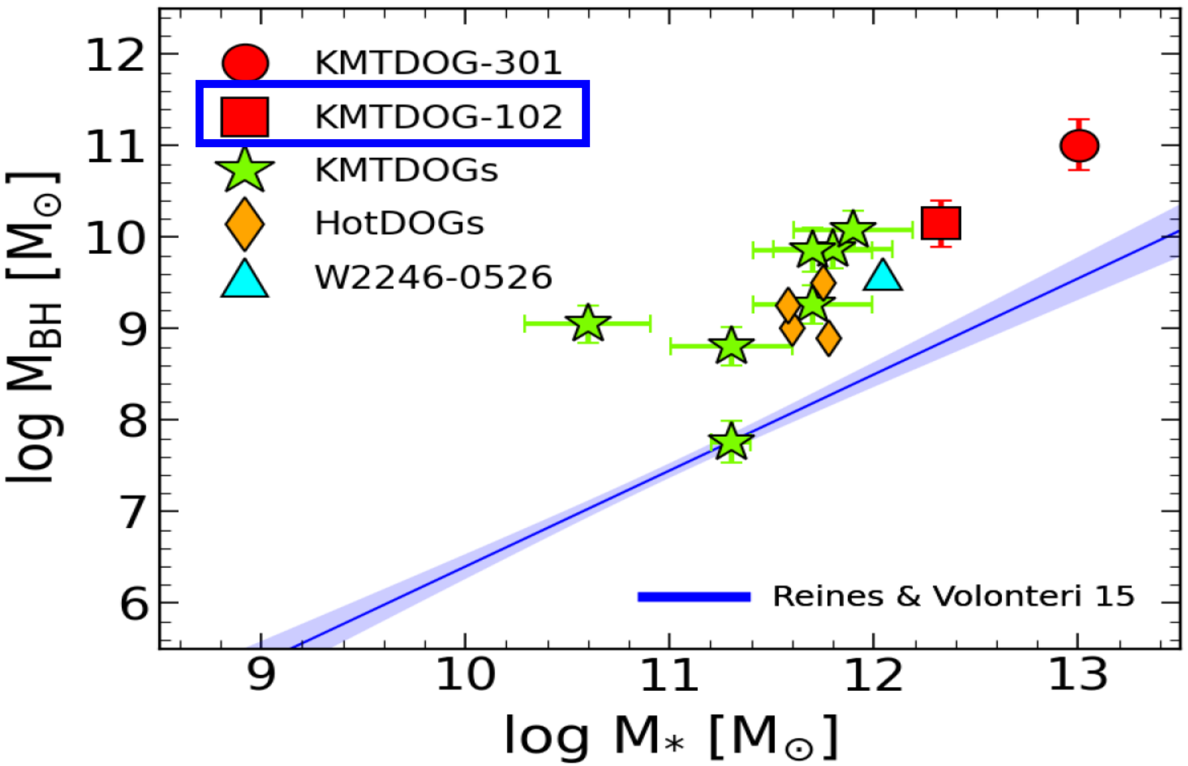
Dust-obscured, rapidly growing phase in SMBH and host

Thus, we focus on Hyperluminous DOGs to trace most massive system at cosmic noon.

(Hopkins+08; Casey+14)

NIR Spectroscopic Follow-up for Black Hole Mass

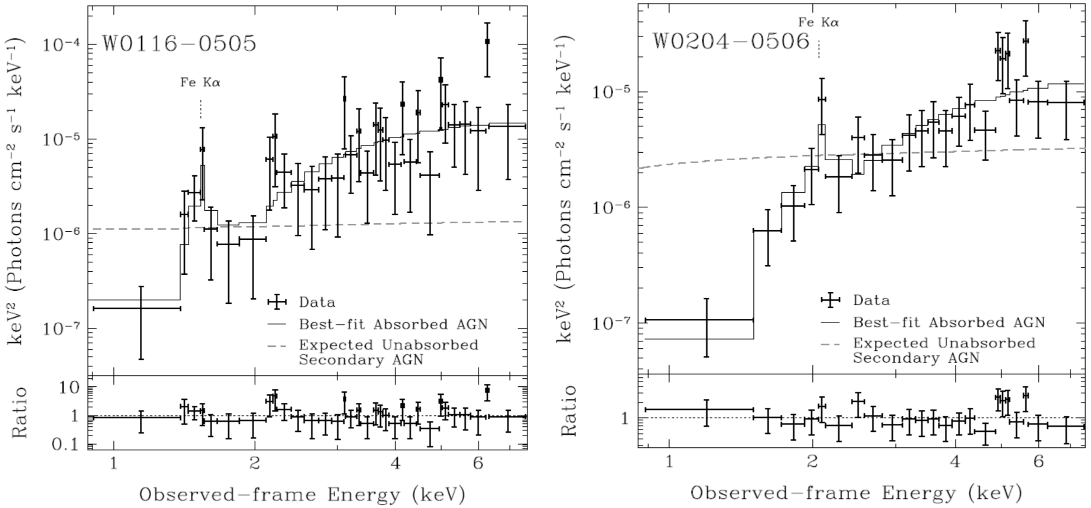




(Jeong et al. 2025, to be submitted)

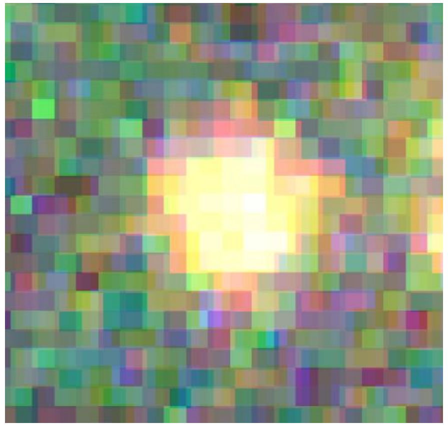
- Parents sample: Herschel SPIRE-detected hyperluminous DOGs (N~100) in AKARI Deep Field – South (ADF-S), one of the HerMES fields
- Most of our samples
  → broad Hα FWHM of 1,000-10,000 km s^{-1} : Broad line AGN signature
- Above local relation of broad line AGNs (Reines & Volonteri 15)

Blue-Excess Dust-Obscured Galaxies: What are BlueDOGs?

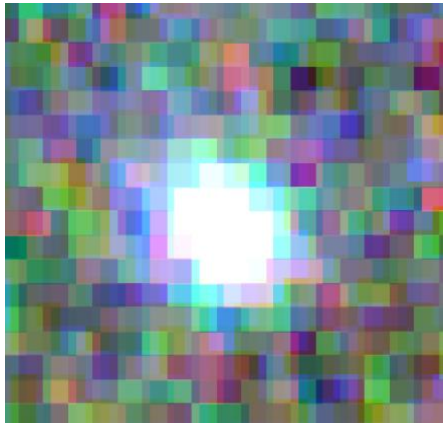


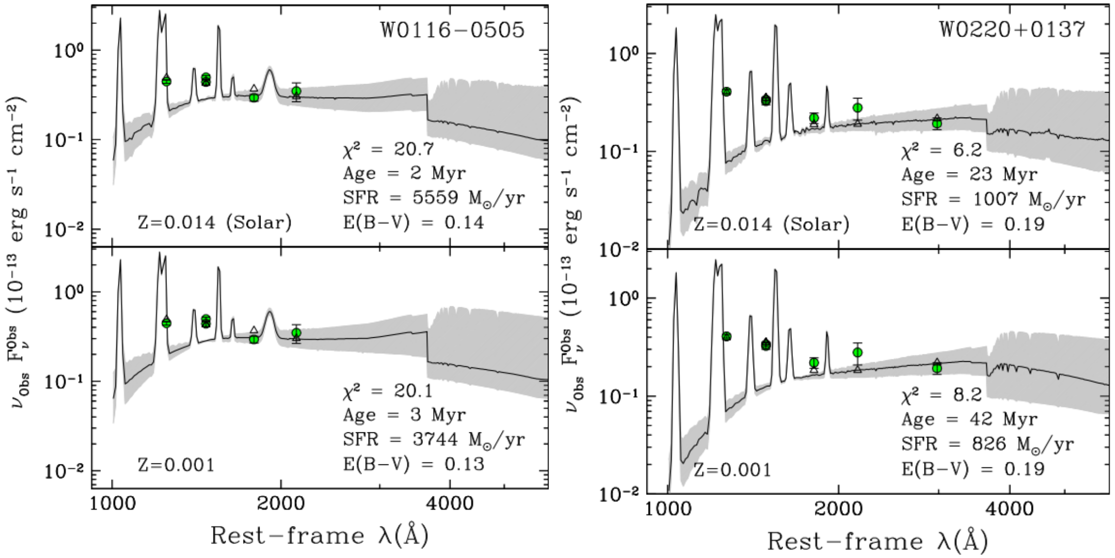
(Assef+20)

Typical DOG



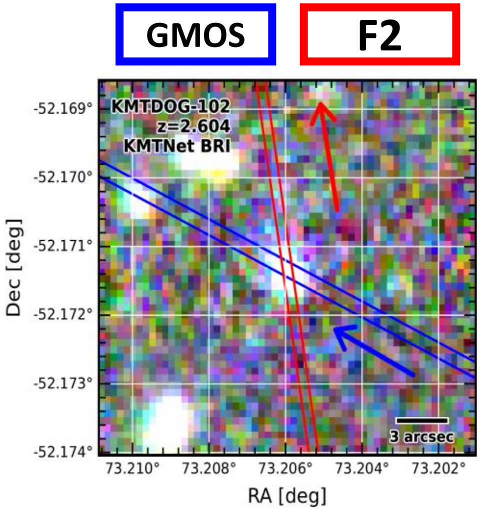
BlueDOG



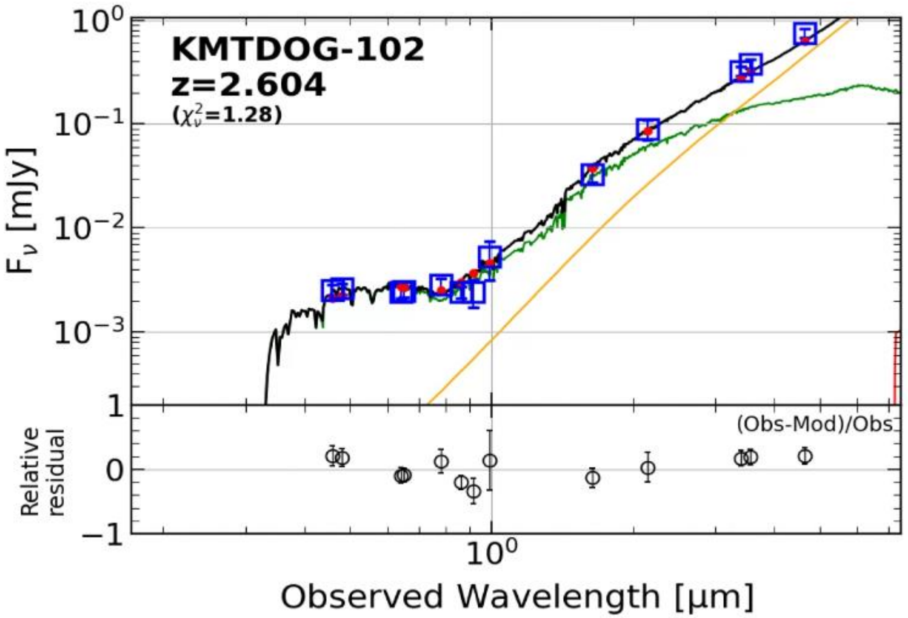


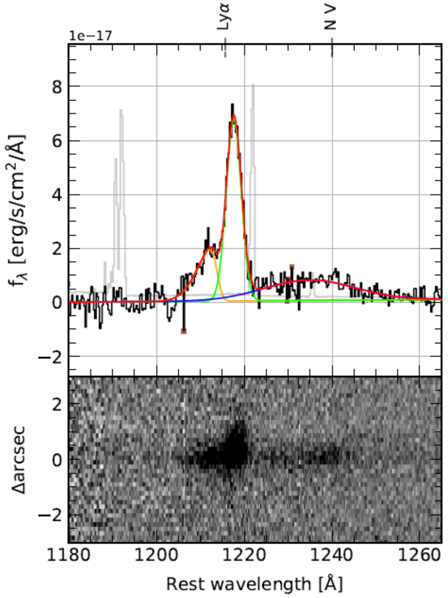
- Weird optical (rest-frame UV) color?!
- First sample reported by Assef+16. (Blue HotDOG: BHD)
- Scenario (Assef+20)
  ~~1) Extreme star-formation~~
  ~~2) Dual AGN~~
  3) Leaked AGN light

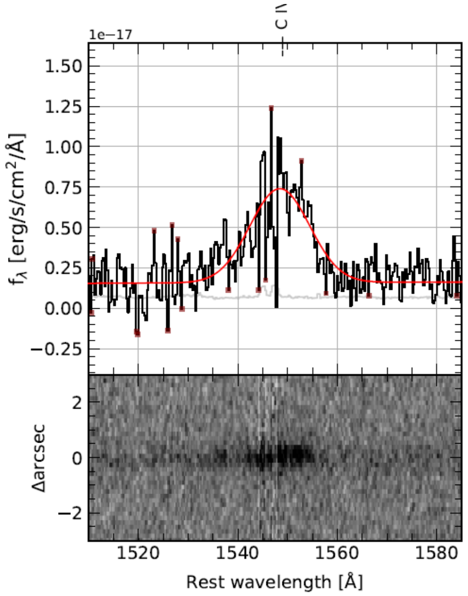
Hyperluminous BlueDOG: Spectroscopic Analysis (1)

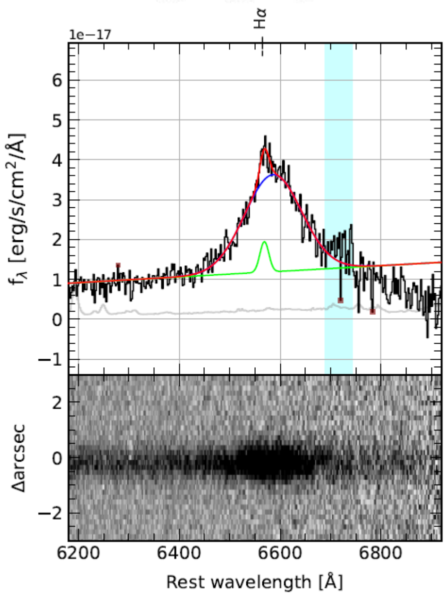


(F2 PI: Jeong;
GMOS PI: Kim)



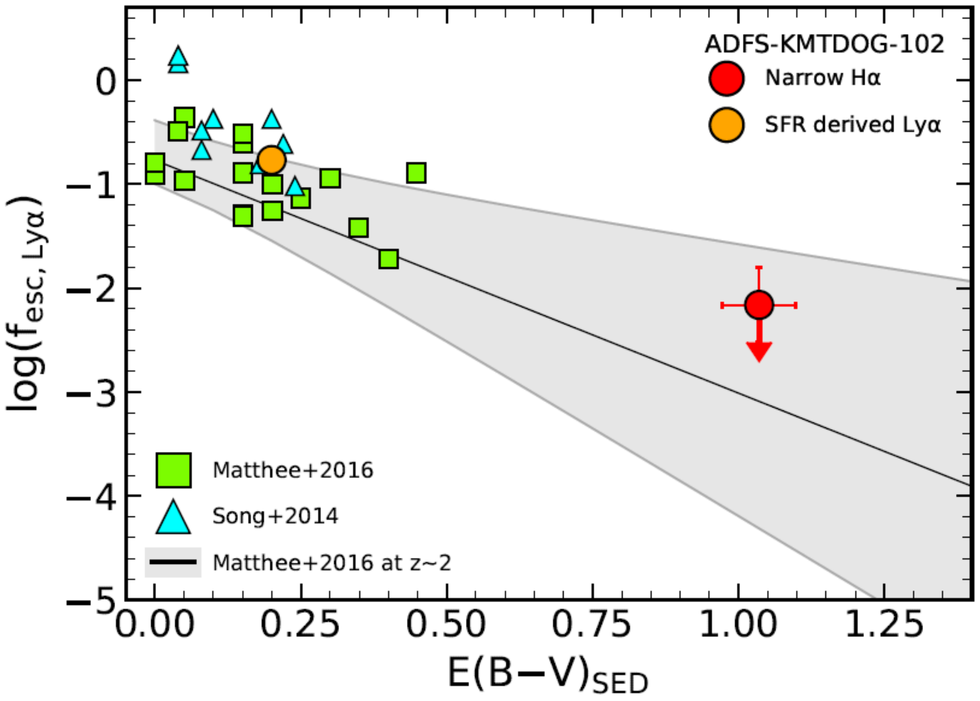






- A BlueDOG among our sample (cf., Assef+2016, 2020; Noboriguchi+2022)
- $\log(M_{SMBH,\,H\alpha}/M_\odot) = 10.15 \pm 0.25$
  $\lambda_{Edd} = 0.15 \pm 0.06$
  $\log(M_*/M_\odot) = 12.33 \pm 0.04$
- UV line ratio suggests UV emission lines originated from AGN.
  ($Ly\alpha/NV_{BlueDOG} = 2.04 \pm 0.15$,
  $Ly\alpha/NV_{LBG} \sim 15$, $Ly\alpha/NV_{SFG} \sim 100$,
  $Ly\alpha/NV_{NL} \sim 11.86$)
- The contribution of Lyα+N V to B-band is ~60%. (continuum~40%).
  → However, it cannot explain for other UV continuum excess.

Hyperluminous BlueDOG: Spectroscopic Analysis (2)



If an AGN is present,
SFR-derived Lyα escape fraction

→ can be overestimated

Lyα escape fraction ($f_{\mathrm{esc,\,Ly\alpha}}$)

1) All Lyα comes from star-formation

$$\mathrm{SFR}\,[M_\odot\,yr^{-1}] = 0.68 \times 7.9 \times 10^{-42} L_{\mathrm{H}\alpha}\,[\mathrm{erg\,s^{-1}}]$$

$$286\ M_\odot\,yr^{-1} = 0.68 \times 7.9 \times 10^{-42} \times L_{\mathrm{Ly}\alpha}/8.7\,[\mathrm{erg\,s^{-1}}]$$

(Kennicutt & Evans 12)

$$f^{\mathrm{Ly}\alpha}_{\mathrm{esc,\,SF}} = L_{\mathrm{Ly}\alpha,\,\mathrm{obs}}/L_{\mathrm{Ly}\alpha,\,\mathrm{int}}$$

$$= 17.1 \pm 3.1\%$$

2) AGN aspect

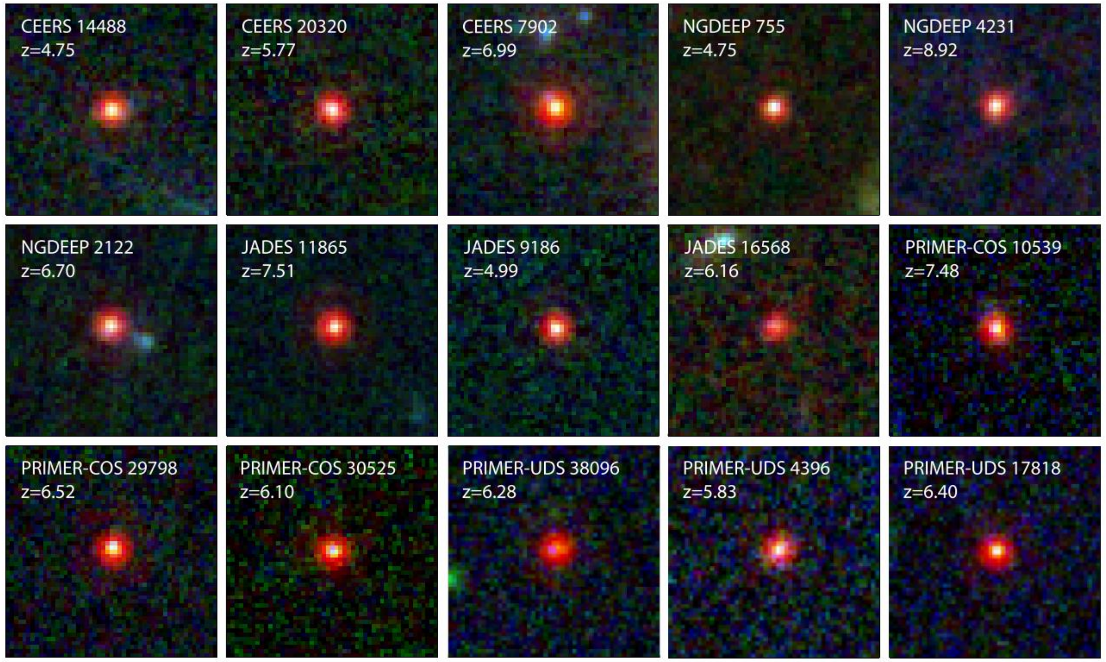
Intrinsic Lyα/Hα ratio around BLR
→ uncertain due to collisional excitation at Lyα
➔ Case B does not work!

Gaskell & Ferland (1984): Lyα/Hα ~ 11-16 in NLR

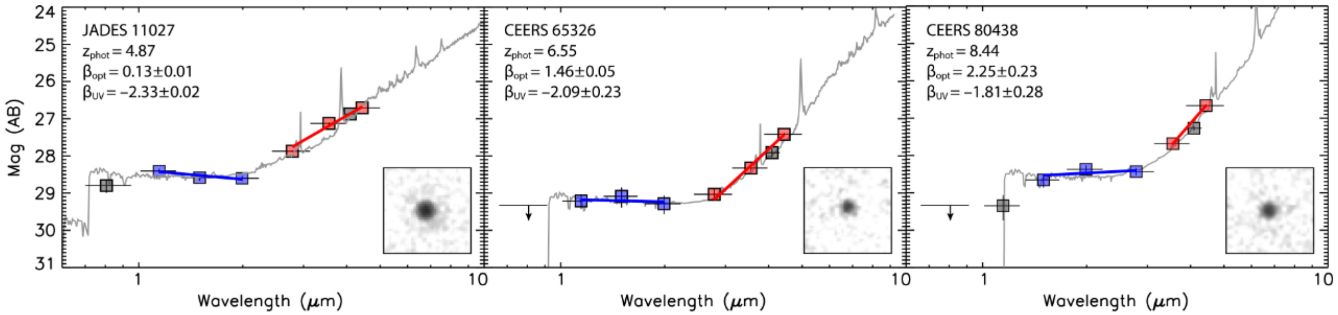
$$f^{\mathrm{Ly}\alpha}_{\mathrm{esc,\,AGN}} = L_{\mathrm{Ly}\alpha,\,\mathrm{obs}}/(11 L_{\mathrm{H}\alpha,\,\mathrm{narrow,\,corr}})$$

$$\leq 0.7 \pm 0.6\%$$

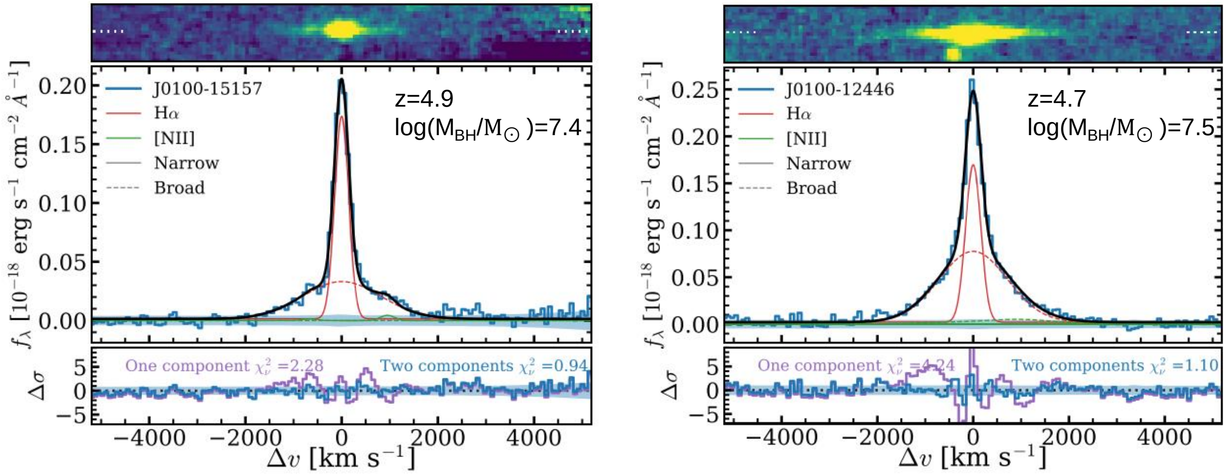
Similarity to Little Red Dots Discovered by JWST?



(Kocevski+2024)



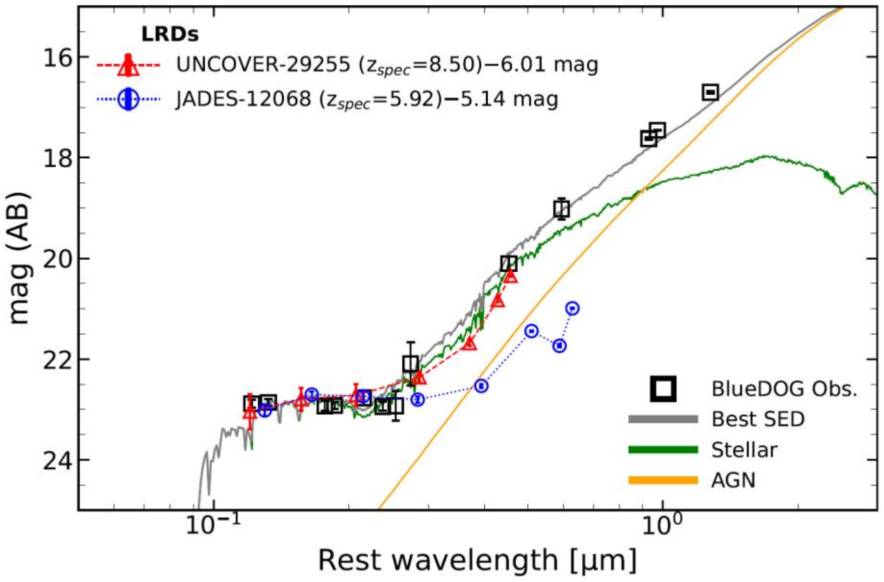
(Kocevski+2024)

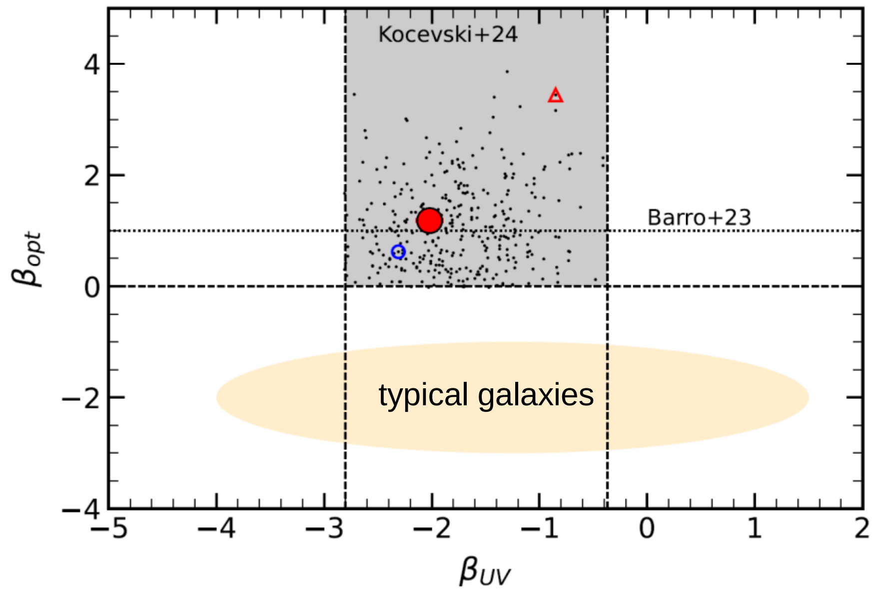


(Matthee+2024)

- Little Red Dots (LRDs) recently have been discovered by JWST at z~4-8.
- The masses of SMBHs were measured with broad Hα emission.
- It is hot topic whether the UV excess comes from AGN (direct/scattered) or starburst (Balmer break was confirmed on few sources!).

UV & Optical Slope Compared to Little Red Dots





- Normalized mags of LRDs
  → similar SED shape to the SED of BlueDOG.

$$m_i = -2.5\,(\beta+2)\,\log(\lambda_i) + c$$ (Kocevski+2024)

UV: rest-frame wavelength < 3,645Å
optical: 3,645Å < rest-frame wavelength < 10,000Å

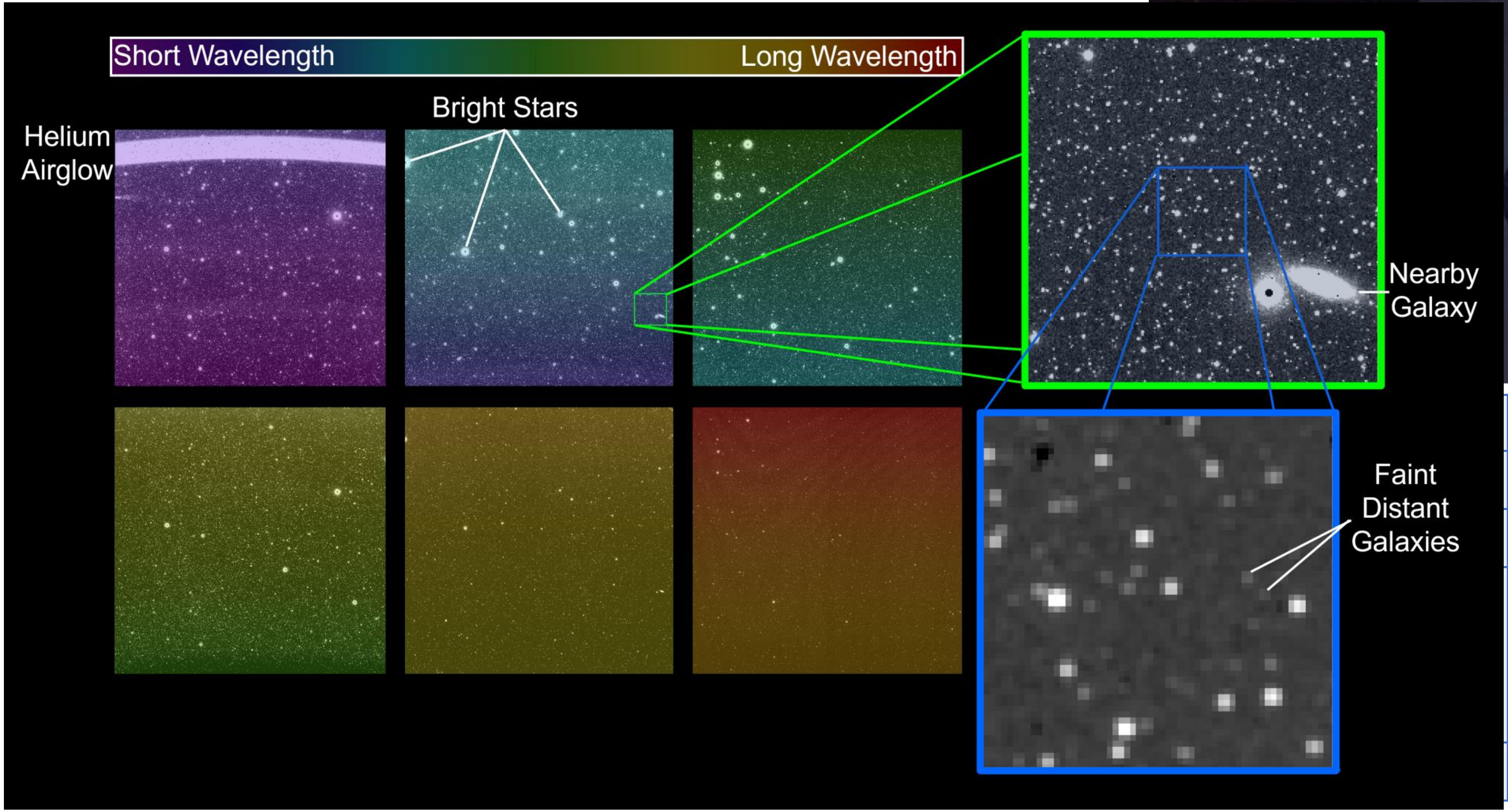
- BlueDOG ➔ satisfy LRD criteria
- λ_{Edd} ~ 0.07 – 0.4 (typically 0.16) from LRDs (Matthee+24) (cf., BlueDOG's $\lambda_{Edd,\,H\alpha}$ = 0.15 ± 0.06)
- Suggesting similar accretion status at their central SMBH.
- Combining those similarities between the BlueDOG and LRDs
  → Origin of UV continuum excess: starburst activity?

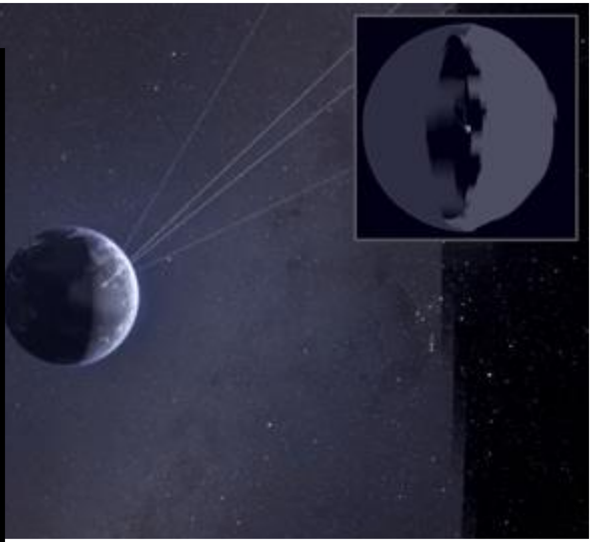
  ($sSFR_{10Myr}$ = 0.17±0.02 Gyr^{-1}, $sSFR_{100Myr}$ = 0.02±0.02 Gyr^{-1} at the BlueDOG)

(Kim et al. 2025, submitted to ApJ)

SPHEREx All Sky Survey

First Light - Released yesterday!





20cm (effective)
6.2" x 6.2"
3.5° x 11.3°
λ= 0.75 - 2.42 μm (R=41) λ= 2.42 - 3.82 μm (R=35) λ= 3.82 - 4.42 μm (R=110) λ= 4.42 - 5.00 μm (R=130)
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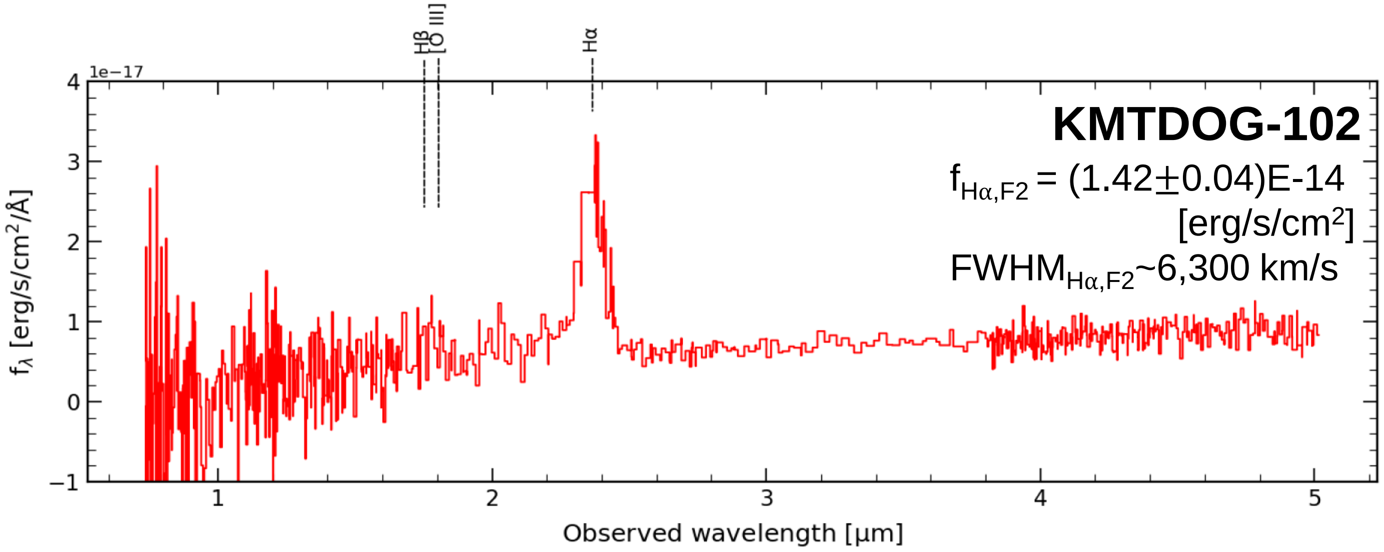
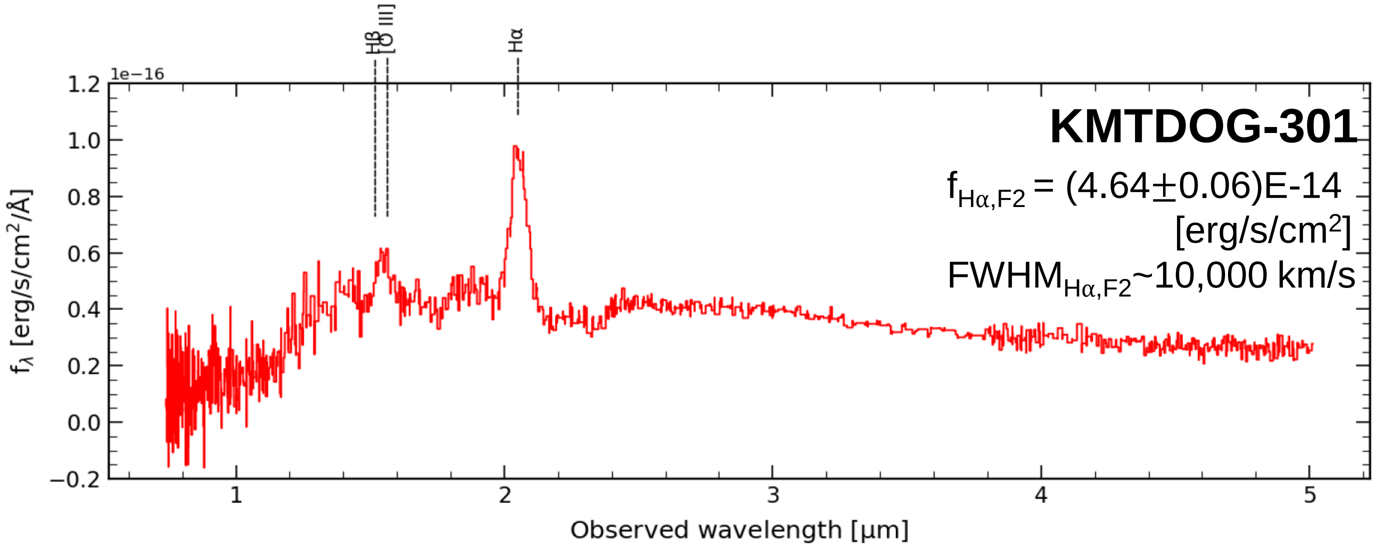
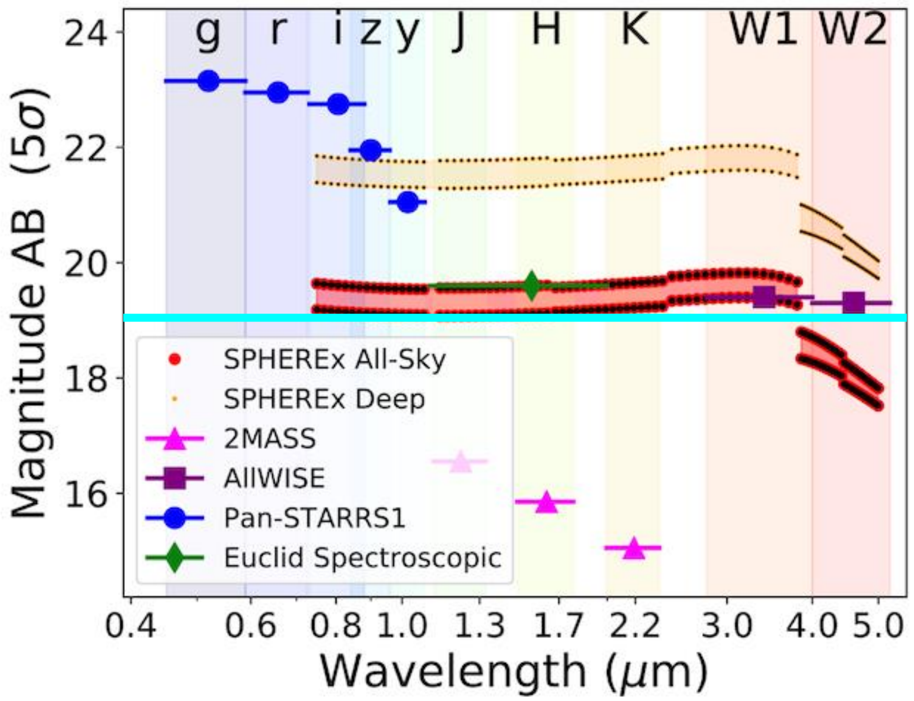
Hyperluminous DOGs Seen by SPHEREx

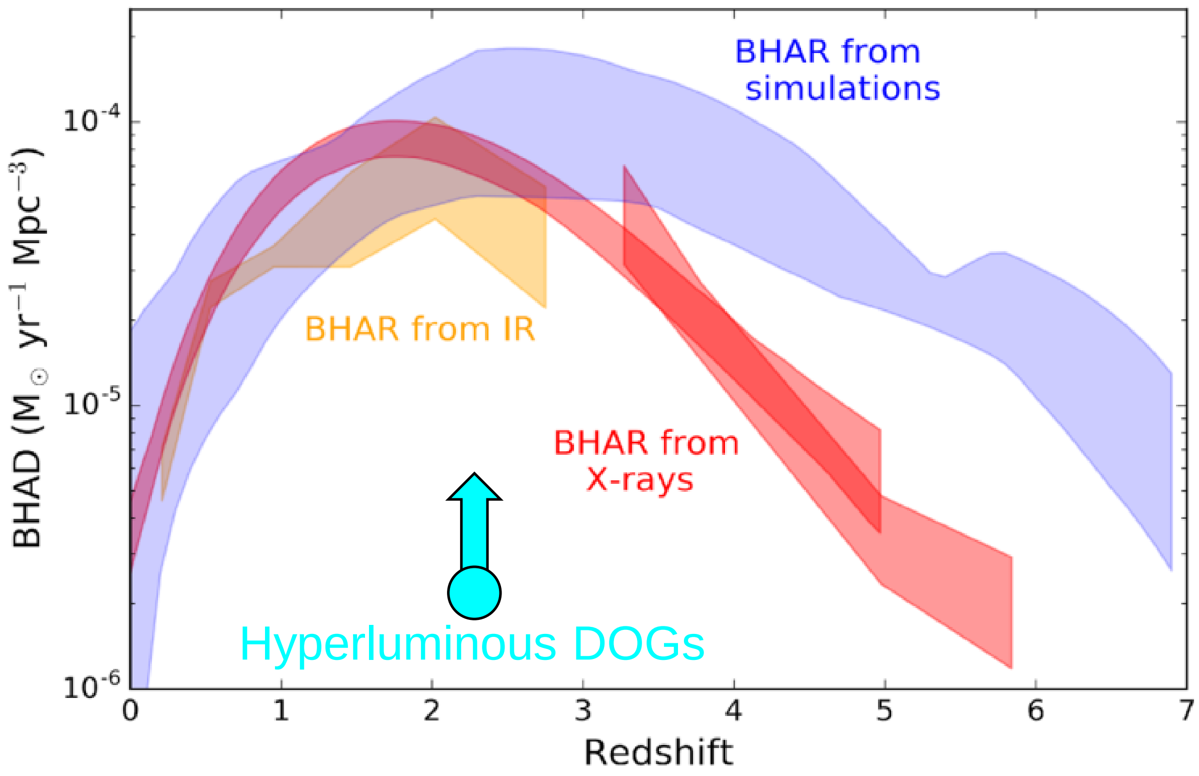






- Hyperluminos DOGs ~19 AB mag @ NIR → Expect new highly obscured AGNs (M_{BH} > 10^{10-11} $M_\odot$) even in SPHEREx All-Sky Survey. (N~4,000)

Synergy with PRIMA and Massive BH Samples

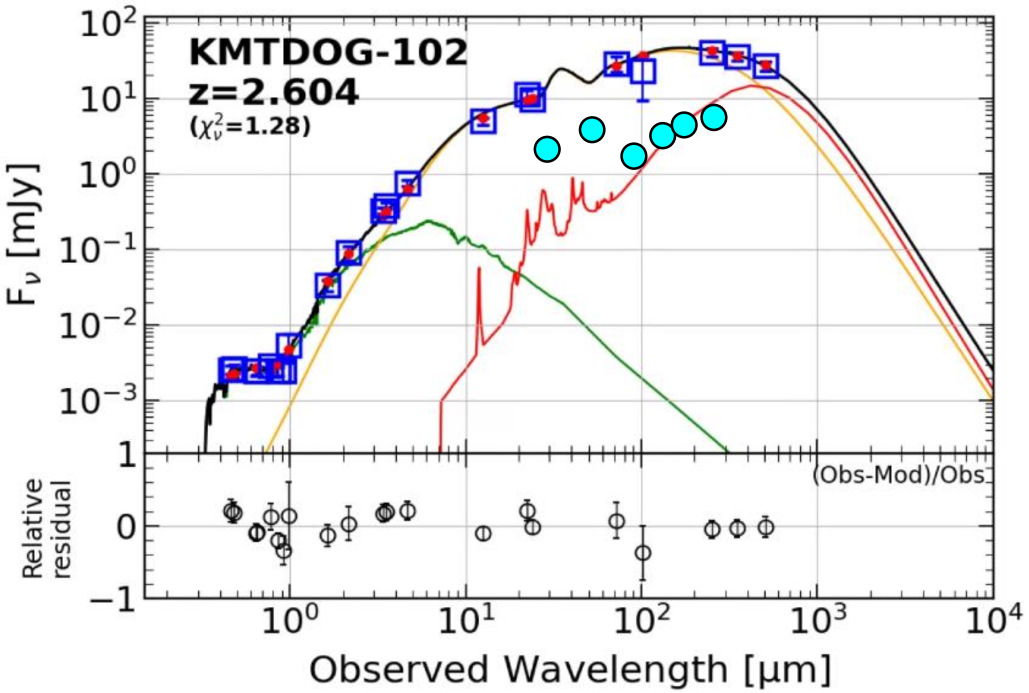


(PRIMA GO vol. 1 Book; Barchiesi et al.)

- Our spectroscopic survey in ground is not complete (~15%).
- We expect that we can provide massive BH samples obtained by SPHEREx All Sky Survey.
- How much massive BHs (>$10^{10\text{-}11}$ $M_\odot$) contribute to total BHARD?

➔ Combining PRIMA observations and massive BH samples will answer for this question.

Synergy with PRIMA and Massive BH Samples



- L_{bol} estimation with FIR photometric points using PRIMAger for massive BH sample
  ➔ Massive BH contribution to BHARD

- Targeted FIRESS observation
  ➔ Can PAH survive around hyperluminous obscured AGN?

	PRIMA Hyperspectral Imager		PRIMA Polarimetry Imager			
Source type	PHI1	PHI2	PPI1	PPI2	PPI3	PPI4
Wavelength [μm]	24–45	45–84	92	126	172	235
Point Source Flux Density (total, F_ν; mJy)	1.18–2.2	2.2–4.1	1.77	2.56	3.39	4.59

Conclusion & Summary

- The M_* and M_{BH} relation in our hyperluminous DOGs might supports the upper track of BH-host co-evolution.
- The BlueDOG exhibits a similar SED shape to recently discovered Little Red Dots (LRDs) at z~5-8.
- Eddington ratio of the BlueDOG (λ_{Edd}=0.15) is comparable to that of LRDs (λ_{Edd}~0.16), suggesting similar accretion state. However, note that the BH mass of the BlueDOG is 2-3 orders of magnitude more massive.
- UV line ratio suggest UV lines originate primarily from the central AGN.
- SED fitting suggests that a recent starburst event ($sSFR_{10Myr} \sim 8 \times sSFR_{100Myr}$).
  ➔ Blue excess UV continuum originates from stellar emission rather than leaked AGN continuum.
  ➔ Confirming Balmer break or WR stars (narrow $He\ II_{4686}$) with JWST in future work?
- How much massive BHs ($>10^{10-11}\ M_\odot$) contribute to total BHARD?
  ➔ Approximately 4,000 SMBHs ($M_{BH} > 10^{10-11}\ M_\odot$) are expected in the SPHEREx All Sky Survey.
  ➔ Combining PRIMA observations and massive BH samples will answer for this question.

Thank you!

Q&A