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A Black Hole Star at Cosmic Noon: Extreme Balmer break, photospheric continuum, and broad absorption by thick winds in a Little Red Dot at z = 1.7

Alberto Torralba [1], Jorryt Matthee [1], Andrea Weibel [2], Rohan P. Naidu [3], Yilun Ma [4], Aidan P. Cloonan [5,*], Aayush Desai [1], Anna de Graaff [6,7,†], Jenny E. Greene [4], Christian Kragh Jespersen [4], Ivan G. Kramarenko [1], Sara Mascia [1], Pascal A. Oesch [2,8,9], Wendy Q. Sun [3], and Christina C. Williams [10,11]

1.Introduction

Little Red Dots

- z~3-9
  - z=4-7 : number density >1e-5 Mpc^3 / few % of galaxies
  - Numbers of LRDs confirmed at z.8
  - Z_photo>10
  - Steep decline at z<4 : 1e-6Mpc^3 @z=2, 1e-10Mpc^3@z=0.3
- Characterization
  - Compact rest-optical morphology
  - Broad Emission Lines
  - V-shape UV-opt continuum
  - Non-AGN-like features
    - Faint in X-ray
    - Faint M-FIR dust emission
    - Faint radio emission
  - Strong Balmer break that cannot reproduced with stellar continuum => Dense neutral gas

2.Observations

- Target : PAN-BH*-1
- JWST PANORAMIC survey (0.3deg^2)
- Selected using "black hole star" template, instead of V-shaped selection
- VLT/X-Shooter 8.9hr obs => zspec=1.731

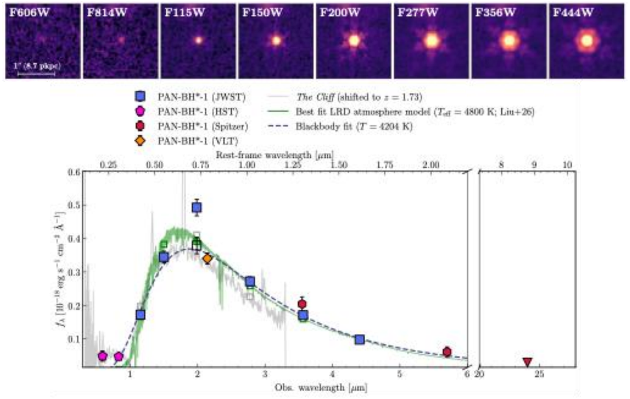

Figure 1. SED of PAN-BH*-1 Top: Cutouts from all the HST and JWST images in which PAN-BH*-1 is covered. It shows a remarkably

Table 2. HST, JWST, VLT and Spitzer photometry of PAN-BH*-1.

Telescope/Instrument	Filter	λ_{obs} [μm]	λ_{rest} [μm]	m_{AB}
HST/ACS	F606W	0.591	0.216	$27.02^{+0.29}_{-0.40}$
HST/ACS	F814W	0.831	0.304	$26.31^{+0.15}_{-0.18}$
JWST/NIRCam	F115W	1.154	0.423	$24.19^{+0.05}_{-0.06}$
JWST/NIRCam	F150W	1.501	0.550	$22.87^{+0.05}_{-0.06}$
JWST/NIRCam	F200W	1.988	0.728	$21.87^{+0.05}_{-0.06}$
VLT/HAWK-I	K_s	2.146	0.785	$22.11^{+0.05}_{-0.05}$
JWST/NIRCam	F277W	2.776	1.017	$21.79^{+0.05}_{-0.06}$
Spitzer/IRAC	IRAC1	3.551	1.298	$21.6^{+0.1}_{-0.1}$
JWST/NIRCam	F356W	3.565	1.306	$21.75^{+0.05}_{-0.06}$
JWST/NIRCam	F444W	4.402	1.612	$21.90^{+0.05}_{-0.06}$
Spitzer/IRAC	IRAC3	5.730	2.095	$21.8^{+0.3}_{-0.2}$
Spitzer/MIPS	24μm	23.68	8.658	> 19.5†

Note— Rest wavelengths calculated assuming $z = 1.731$. †3σ limit.

3. Properties of PAN-BH*-1

- SED shape
  - Similar to "The Cliff"
  - Extreme Balmer break of 7:1 : stronger than typical
  - Blue UV slope : β ~-0.1
  - 4204K single blackbody
- Hα : blueshifted absorption feature
  - Model fitting : 2 gaussian emission + absorption (EW=-148A)
- Hβ : marginal detection + absorption
- No [OIII] observation : due to atmospheric window.
- High Balmer decrement (Ha/Hb>9.4)
- Morphology : slightly resolved, reff=1kpc

4. Absorber Kinematics

- Central velocity=-94km/s, blue edge=-520km/s, red edge=267km/s
- Unstable gas flow scenario (a, b in Fig 5)
  - Required turbulent velocity dispersion ~120km/s
  - Dynamically unstable (free fall time ~3yr), and may show variability at same time scale
- Disk wind hypothesis (c in Fig 5)
  - Stable
  - Align with BAL-AGN disk wind model
  - Photosphere of disk is the source of continuum
  - Thick disk may show single-peak emission-line
  - Balmer lines are broaden by electron scattering

Table 1. Properties of PAN-BH*-1.

Parameter	Value	Unit
Width (FWHM; Hα)		
Exponential	1257 ± 27	km s^{-1}
Intermediate	687 ± 43	km s^{-1}
Narrow	184 ± 12	km s^{-1}
Absorption	283 ± 8	km s^{-1}
Flux (Hα)		
Exponential	643 ± 7	10^{-18} erg s^{-1} cm^{-2}
Intermediate	19 ± 5	10^{-18} erg s^{-1} cm^{-2}
Narrow	38 ± 3	10^{-18} erg s^{-1} cm^{-2}
Total	522 ± 7	10^{-18} erg s^{-1} cm^{-2}
General properties		
$\log_{10}(L_{H\alpha}/ergs^{-1})$	43.046 ± 0.006	–
EW_0(Hα)	520 ± 20	Å
SFR(Hα, narrow)†	2.1 ± 0.2	$M_\odot$ yr^{-1}
SFR(Hα, narrow)*	3.3 ± 0.3	$M_\odot$ yr^{-1}
$r_{eff,UV}$ (F606W+F814W)	$1.0^{+0.5}_{-0.3}$	kpc
$r_{eff,opt}$ (F200W)	< 0.047	kpc
Hα/Hβ (Total)	> 9.4	–
Hα/Hβ (Narrow)	5 ± 1	–

5. Implication for the Galaxy and BH Mass

- SFR(Ha)=2~3Msun/yr
- SFR(UV)=0.18 Msun/yr => some dust extinction?
- Mdyn=1e10Msun => M*=1e8.3Msun, assuming Mdyn/M*~40
- BH mass
  - Assuming Lbol/Ledd=1, Mbh=1e6Msun
  - Photosphere density => surface gravity => Mbh=1e5Msun
- Mbh/M*=1e-4~1e-2

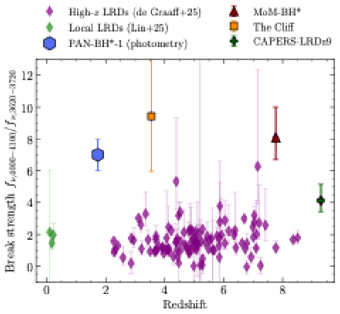

Figure 2. Spectroscopic sample of LRDs by redshift and Balmer

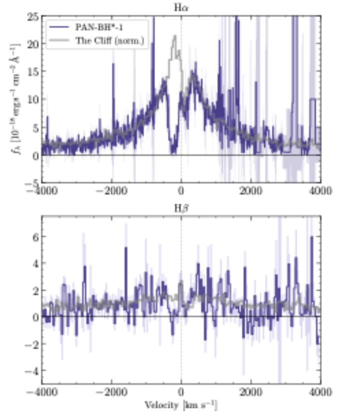

Figure 3. X-Shooter spectrum of Hα and Hβ of PAN-BH*-1

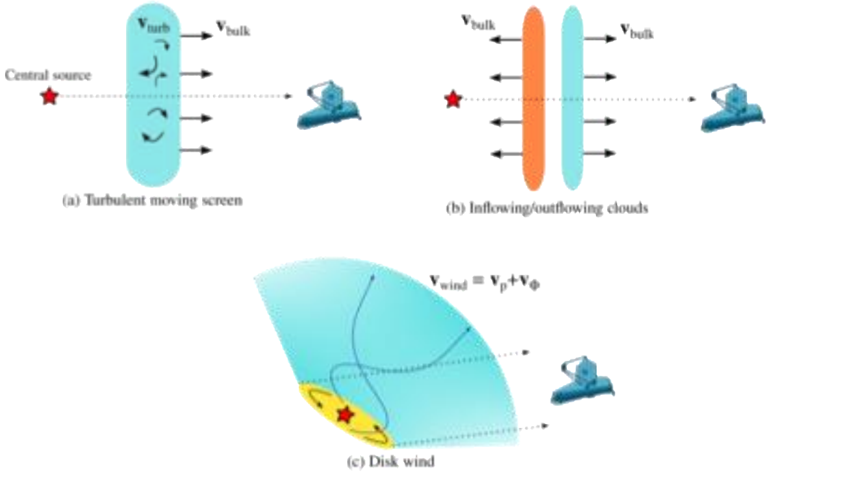

Figure 5. Geometric configurations for the absorber. We illustrate three scenarios that could give rise to the observed Balmer absorption