Problem: BHAR- M_{\star} relation does not explain why M_{BH} - M_{bulge} relation is tight



Morphology might be the key!



Galaxy morphology (shape)





Does BH and bulge coevolve?

- Aim: study BHAR vs. **bulge SFR**
- Problem: infeasible to separate bulge SFR from the total SFR
- Solution: focus on bulge-dominated galaxies, where bulge SFR ~ total SFR

CANDELS: Deep HST Imaging

Bulge-dominated (~25%)

BD. f _{SPH} =0.87	BD. f _{SPH} =0.81	BD. <i>f</i> _{SPH} =0.94
f _{DISK} =0.47,f _{IRR} =0.01	f _{DISK} =0.16,f _{IRR} =0.00	<i>f</i> _{DISK} =0.38, <i>f</i> _{IRR} =0.00
<i>z</i> =1.24 log <i>M</i> ★=9.9	$z=0.89$ $\log M_{\star}=9.7$	z=1.88 logM _★ =10.6
X. Undet. logSFR=1.5	X. Undet. $\log SFR=-0.6$	X. Undet. logSFR=0.4
BD. f _{SPH} =0.94	BD. f _{SPH} =0.90	BD. f _{SPH} =0.86
f _{DISK} =0.36,f _{IRR} =0.00	f _{DISK} =0.23,f _{IRR} =0.00	f _{DISK} =0.45,f _{IRR} =0.00
$z=1.37$ log $M_{\star}=10.1$	$z=0.68$ $\log M_{\star}=10.6$	$z=1.49$ log $M_{\star}=10.0$
X. Undet. logSFR=-0.7	X. Undet. $\log SFR=-1.1$	X. Undet. logSFR=-0.8
BD. f _{SPH} =0.87	BD. f _{SPH} =0.98	BD. f _{SPH} =1.00
f _{DISK} =0.57,f _{IRR} =0.00	f _{DISK} =0.39,f _{IRR} =0.00	f _{DISK} =0.57,f _{IRR} =0.00
$z=2.38$ log $M_{\star}=11.2$	$z=1.16$ log $M_{\star}=10.4$	$z=1.55$ log $M_{\star}=10.9$
X. Undet. logSFR=0.4	X. Undet. logSFR=1.1	X. Undet. logSFR=-0.4

Comparison (~75%)

Comp. f _{SPH} =0.10	Comp. f _{SPH} =0.42	Comp. f _{SPH} =0.13
f _{DISK} =0.97,f _{IRR} =0.04	f _{DISK} =1.00,f _{IRR} =0.00	f _{DISK} =1.00,f _{IRR} =0.07
<i>z</i> =1.59 log <i>M</i> _* =10.8	$z=1.17$ $\log M_{\star}=10.7$	<i>z</i> =1.11 log <i>M</i> ★=10.1
X. Undet. logSFR=-0.2	X. Undet. $\log SFR=1.2$	X. Undet. logSFR=1.2
Comp. f _{SPH} =0.55	Comp. f _{SPH} =0.52	Comp. f _{SPH} =0.07
f _{DISK} =1.00,f _{IRR} =0.11	f _{DISK} =0.91,f _{IRR} =0.21	f _{DISK} =0.70,f _{IRR} =0.48
$z=0.73$ $\log M_{\star}=10.1$	$z=1.96$ log $M_{\star}=10.7$	z=2.24 log <i>M</i> *=10.3
X. Undet. $\log SFR=1.2$	X. Undet. logSFR=1.9	X. Undet. logSFR=0.7
Comp. f _{SPH} =0.78	Comp. f _{5PH} =0.24	Comp. f _{SPH} =0.29
f _{DISK} =0.73,f _{IRR} =0.00	f _{DISK} =0.94,f _{IRR} =0.08	f _{DISK} =0.82,f _{IRR} =0.11
$z=0.88$ log $M_{\star}=11.3$	$z=0.94$ log $M_{\star}=9.8$	$z=1.55$ log $M_{\star}=10.3$
X. Undet. logSFR=-1.2	X. Undet. logSFR=1.1	X. Undet. logSFR=1.4

Machine-learning based classification (Huertas-Company 2015)

Yang et al. (submitted)

Bulge-dominated sample

- BHAR-SFR: **significant** (10σ)
- BHAR- M_{\star} : not significant (2 σ)
- Best-fit BHAR/SFR ~ $10^{-2.5}$, similar to local $M_{\rm BH}/M_{\rm bulge} = 10^{-2.5}-10^{-2.3}$



Comparison sample (not bulge-dominated)

- BHAR: mainly related to M_★ not SFR (Yang et al. 2017)
- BHs co-evolve with bulges, not entire galaxies!



Summary

BH and bulge growth are in lockstep



Yang et al. (submitted)