Intermediate-mass black holes and their host galaxies

Chilingarian et al. 2018, ApJ 863 1

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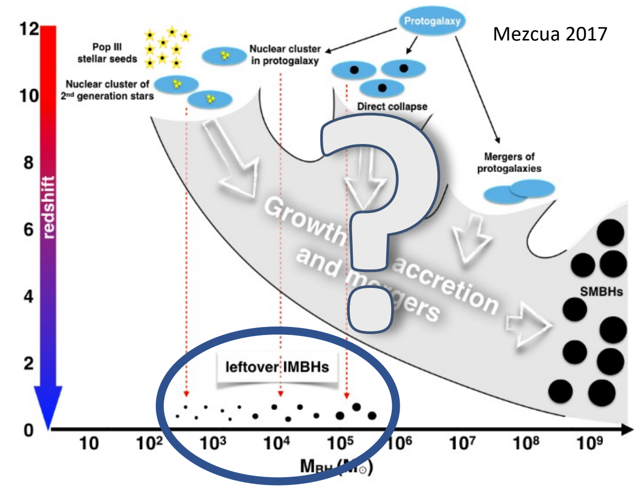
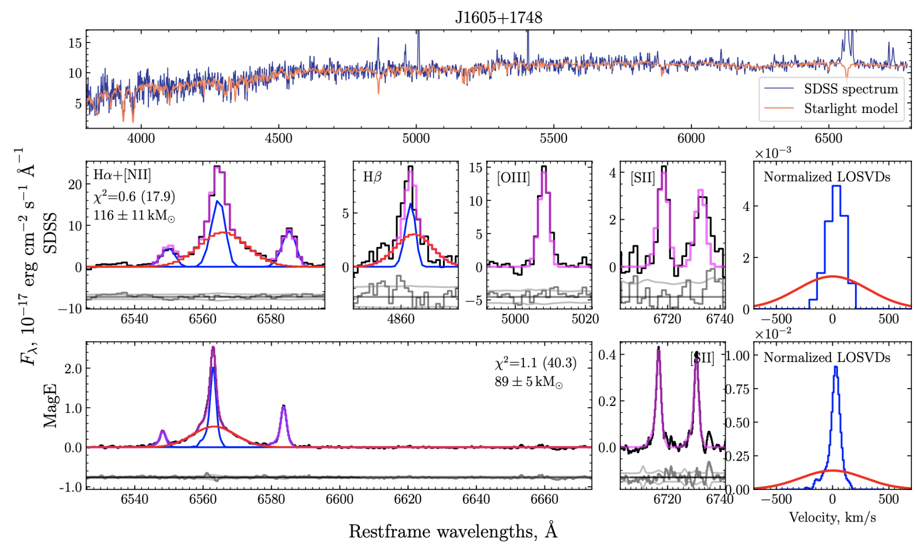
Introduction

- The ultimate questions: **what are the SMBH seeds and how did they grow into SMBHs**?
  - IMBHs in the local Universe can help if (we assume that) they evolve now similarly to high-z IMBHs
  - Search for low-z type-I AGN powered by IMBHs in SDSS
- What makes our IMBH search different from Greene & Ho?
  - We start from a full SDSS galaxy sample: no ”dwarf galaxy” bias
  - Non-parametric shape for narrow lines: better sensitivity for faint broad Hα
  - Homogeneous data; RCSED: http://rcsed.sai.msu.ru/
- Results (Chilingarian et al. 2018):
  - 305 optically selected candidates ($M_{BH}<2*10^5\ M_\odot$)
  - 10 confirmed in X-ray (24 as of now)
  - Most host galaxies live in sparse environments

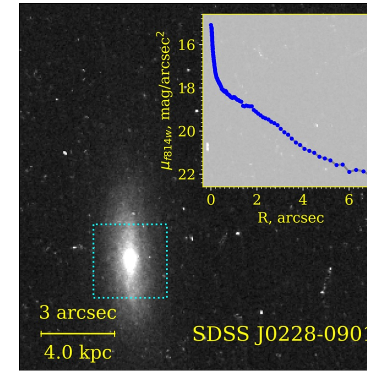


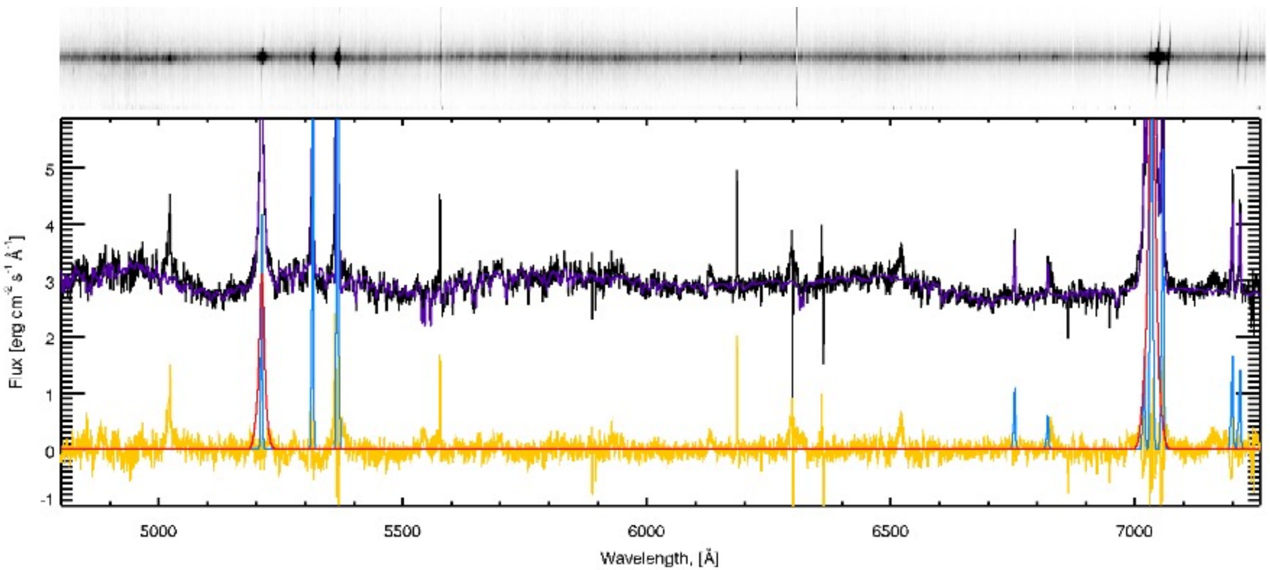
Mezcua 2017

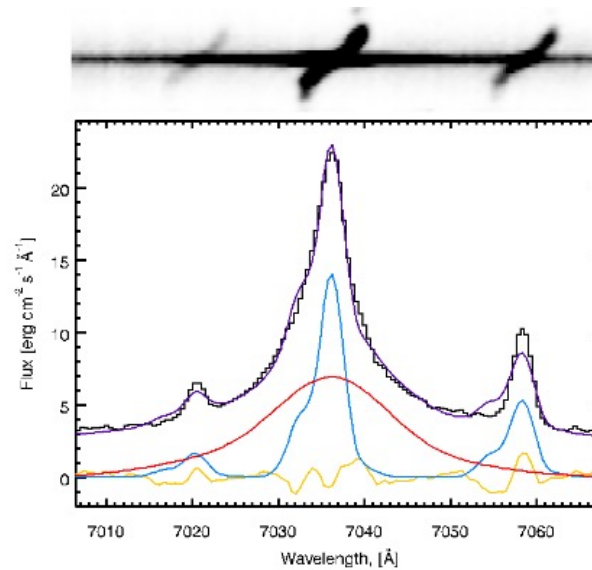


Data analysis: BLR/NLR decomposition

- The approach is conceptually similar to Greene & Ho: estimating BLR parameters, but we use a more general and stable technique for the BLR/NLR decomposition
  - Non-parametric NLR via linear inverse problem with regularisation
  - Parametric (Gauss-Hermite or Lorentzian) BLR





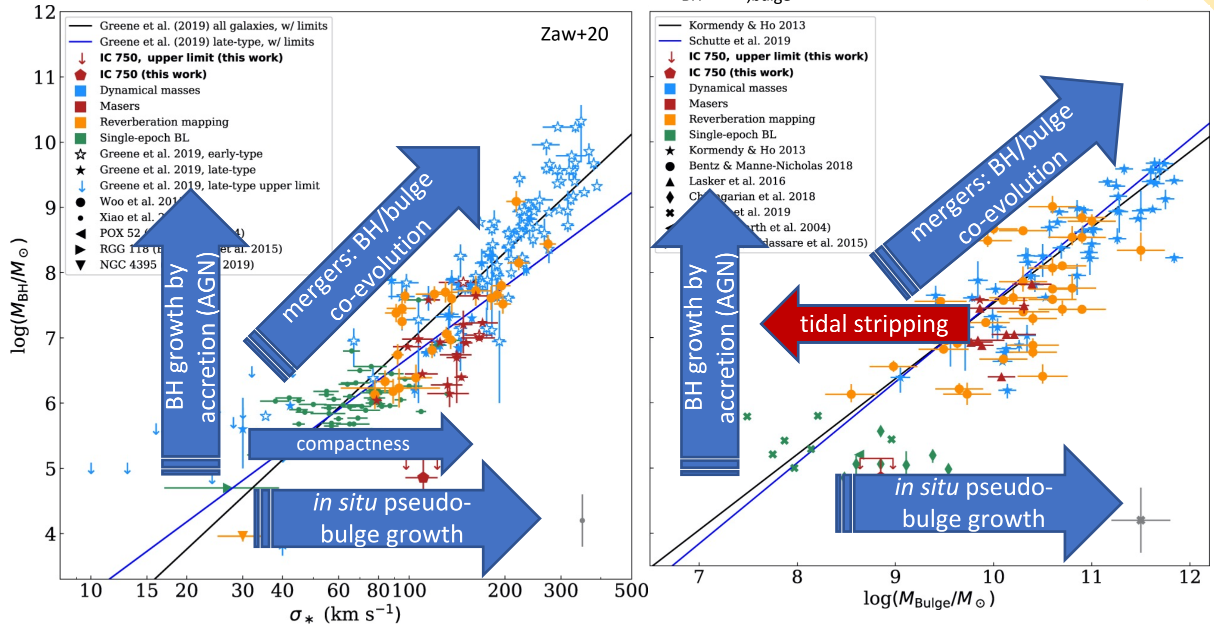


SMBH growth in the IMBH regime

SMBHs are thought to co-evolve with spheroids of their host galaxies and grow via mergers as suggested by the M_{BH}–σ_* and M_{BH}–$M_{*,bulge}$ relations, ***however***

- A bulge can be a pseudo-bulge growing *in situ* (Kormendy & Kennicutt'04)
- BH growth by accretion during the AGN phase will push a BH to higher M_{BH}
- The combination of the latter two factors might drag a BH back back on the relation: correlation vs causation
  - *If we pre-select dwarf galaxies we will miss oversized (pseudo-)bulges*
- Tidal stripping can reduce $M_{*,bulge}$ by orders of magnitude (UCDs) but would barely affect σ_*

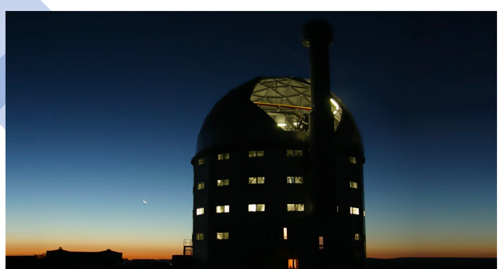
M_{BH}–σ_* (Ferrarese & Merritt'00; Gebhardt+00) M_{BH}–$M_{*,bulge}$ (Häring & Rix'04; Kormendy & Ho'13)

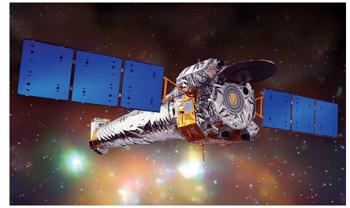


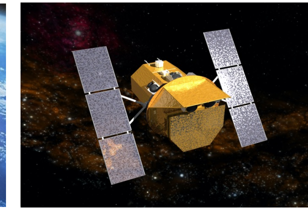
- ➢ If accretion was the dominant SMBH growth channel at high-z then LISA will not likely to see gravitational wave signals from IMBH mergers because they were rare, but Athena/Lynx will see signs of intense accretion in X-ray
- ➢ If galaxy mergers and central BH coalescences dominated the SMBH growth even at low masses, then LISA will see a lot of events, but Athena/Lynx might not see any high-z "dwarf AGN"

Follow-up campaign

- Expanding the X-ray sample
  - New XMM-Newton observations
  - New Chandra and Swift observations
  - Chandra/XMM/Swift archives
- Populating M_{BH}–σ_* (optical spectra)
  - Magellan MagE (R=7000)
  - Keck ESI (R=8000)
  - SALT RSS (R=4000)
    - BLR Balmer gradient to eliminate dust effects on M_{BH}
    - Improved virial M_{BH} thanks to higher resolution and depth
- Populating M_{BH}–$M_{*,bulge}$ (images)
  - Magellan FourStar (NIR)
  - HST/CFHT/Subaru archives (optical)

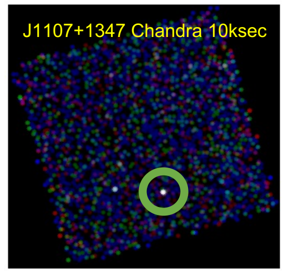


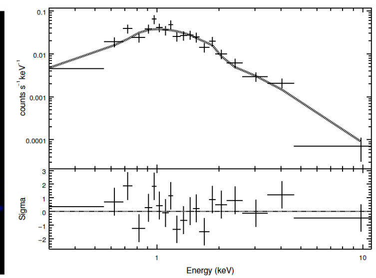


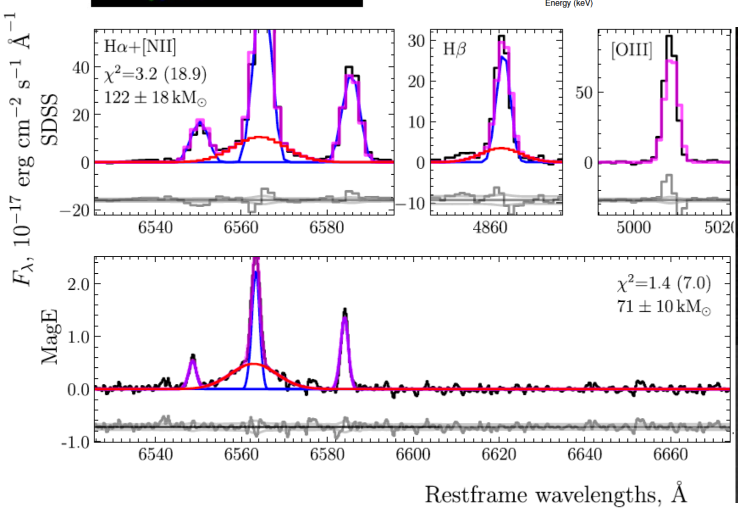


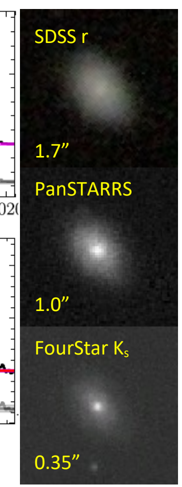
Confirmed in X-ray as of now:

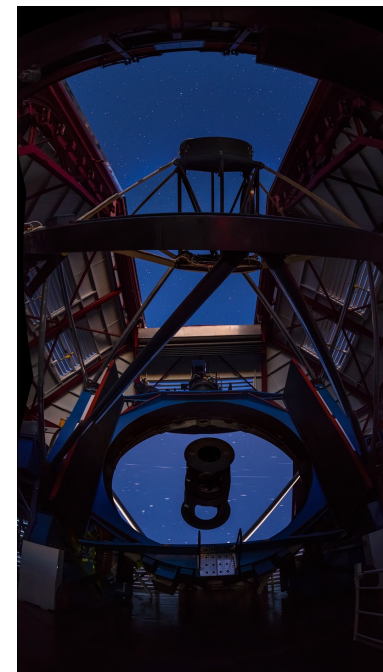
- 30 IMBHs ($M_{BH}<2*10^5\ M_\odot$)
- 170+ low-mass BHs ($M_{BH}<10^6\ M_\odot$)





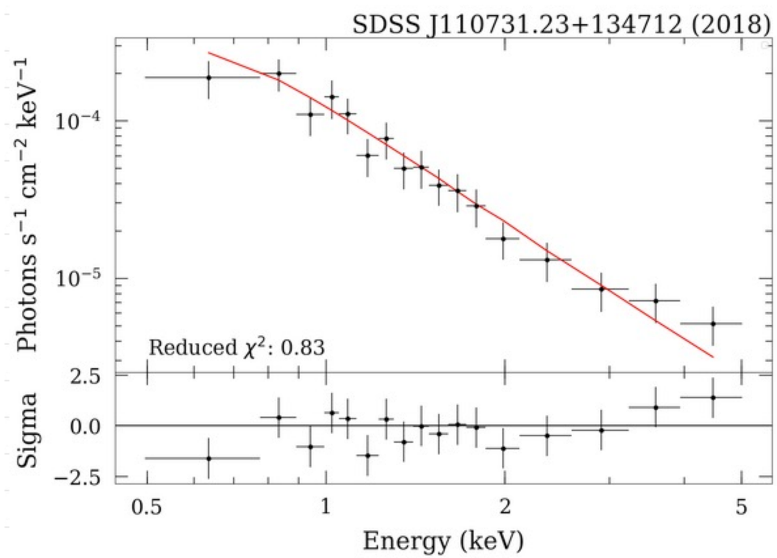


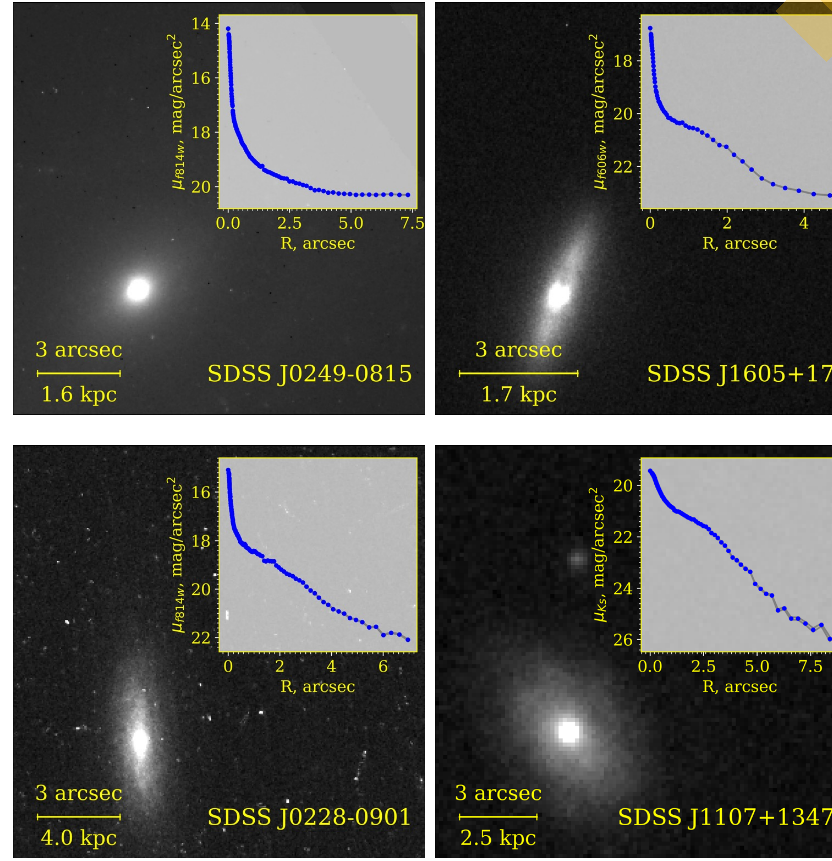




Eddington-limited IMBH growth

- 10 out of 30 IMBHs have soft X-ray luminosity of at least 3% of L_{Edd} that translates the L_{bol}>0.4L_{Edd}; and soft X-ray spectra (Γ>2.5) atypical for ”normal” AGN
  - J1107+1347: L_X(0.2-10 keV) = 2.7×10^{42} erg/s = 0.2-0.3 L_{edd}; Γ=2.5; no variability on 1d-1m-1y timescales
- They are growing fast and can increase their mass tenfold in 120–300 Myr if the accretion rate persists
- They show signs of ratiative outflows in the [OIII] line however, the feedback is probably too weak to affect star formation in their hosts: more data is needed (JWST)

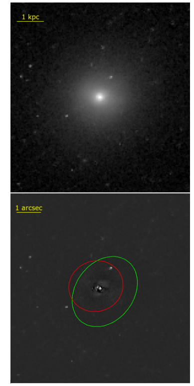


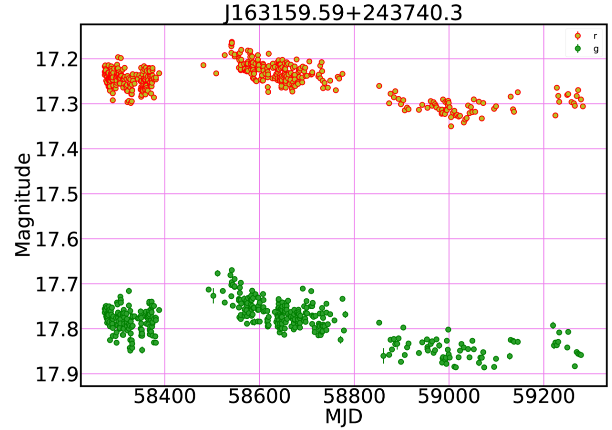


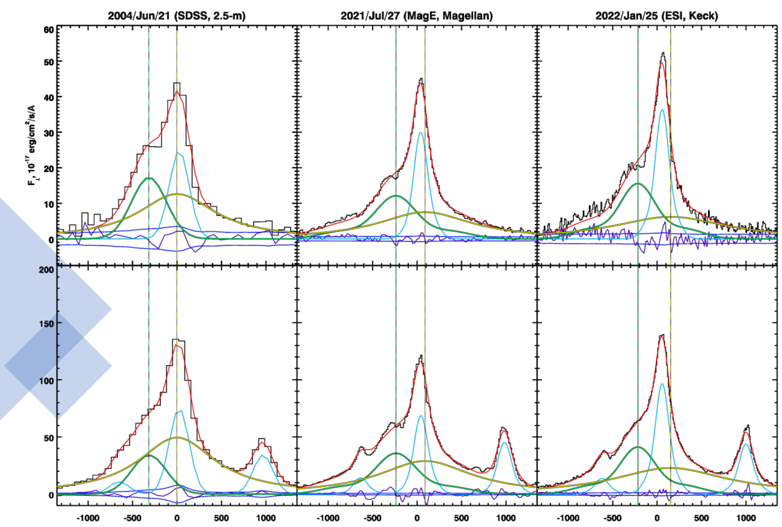
J1631+24: a 13:1 mass ratio binary IMBH candidate

One object in the 1M sample caught our attention

- Asymmetric broad Balmer lines with a blue "hump"
- Low-mass elliptical host galaxy; HST data analysis reveal disturbed morphology: a recent dry minor merger?
- Strong variability revealed from a light curve generated by Zwicky Transient Facility
- Secure X-ray identification with Chandra and XMM







Follow-up observations with Magellan and Keck (HST is coming)

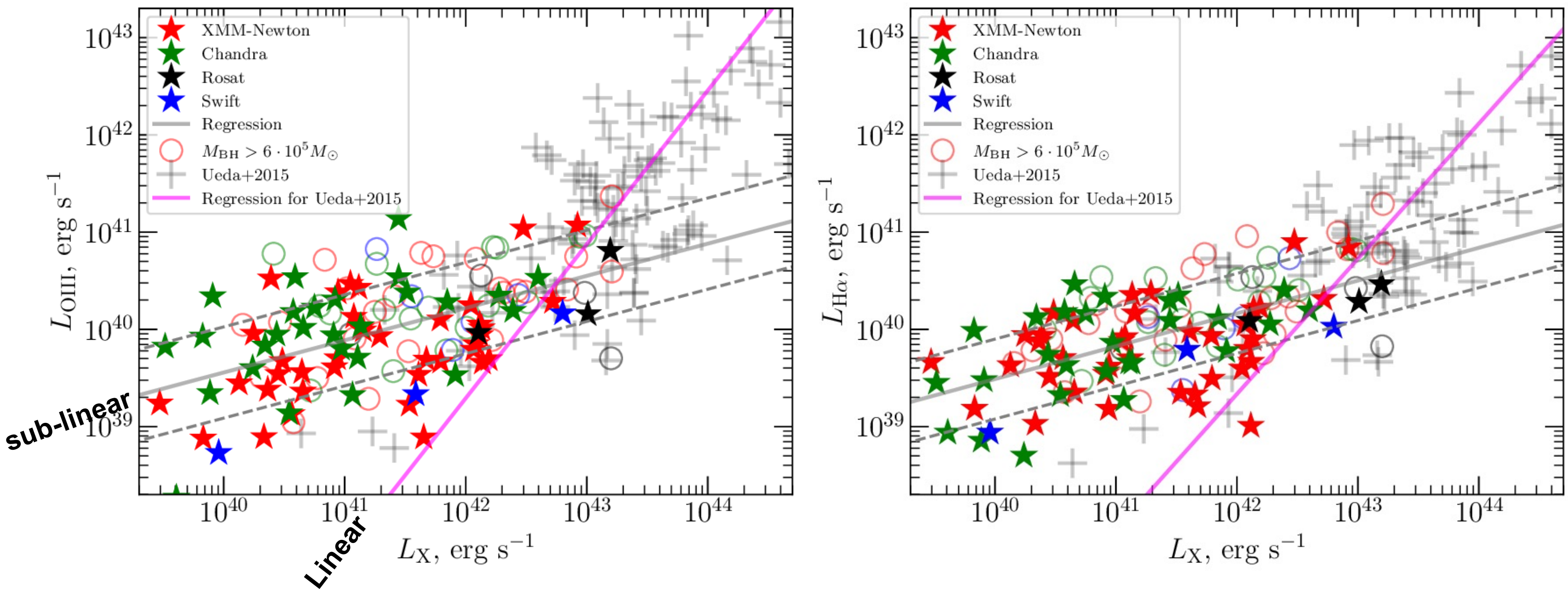
- "Hump" is persistent for 17 years, can be decomposed into two broad-line profiles in Hα, Hβ, Hγ, Hδ: it is not an outflow-related variability of a broad line profile
- Velocity separation between the components stay the same, about 300 km/s, intensities change over time
- HeI/II and Paschen lines also display the same two-component structure although helium lines are broader (as expected): this is not an effect of dust extinction in the torus

Viable explanation: a 0.05pc-separated binary IMBH

- Virial masses of $6*10^4$ and $8*10^5$ M_{Sun}; orbital period ~1000 yr

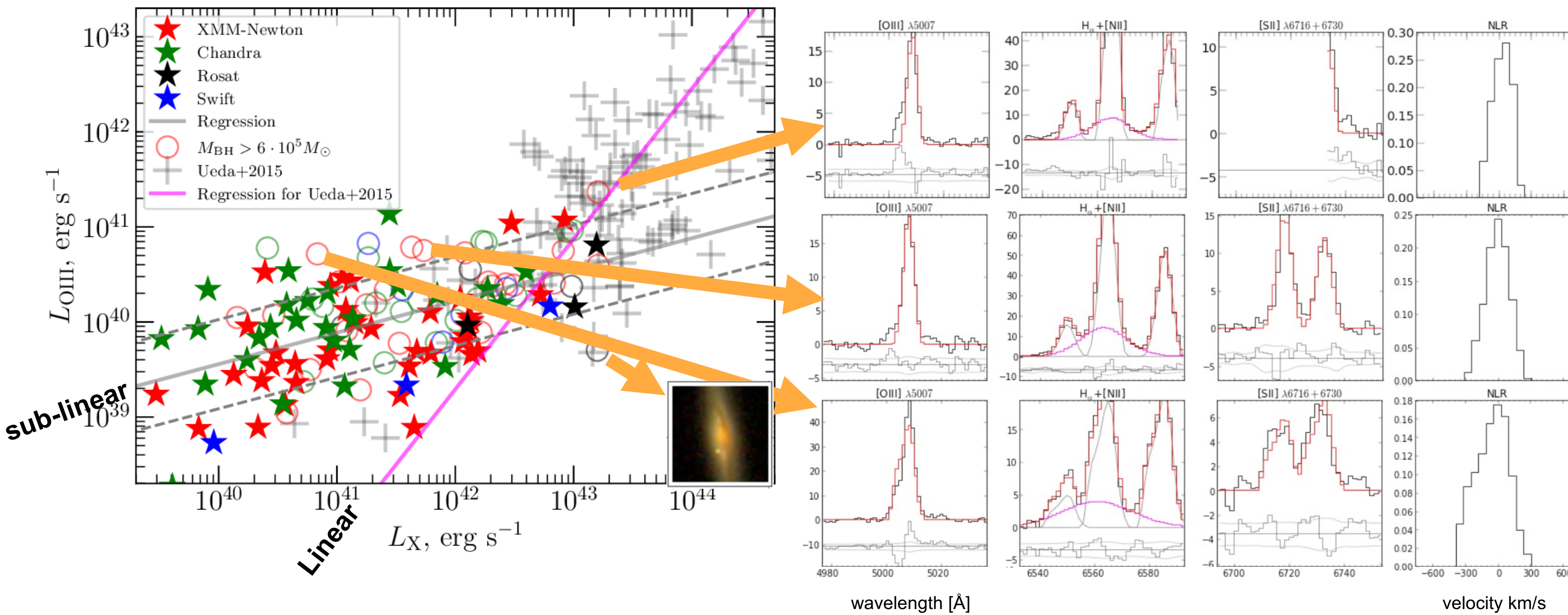
The $L_{[OIII]} - L_X$ and $L_{bH\alpha} - L_X$ relations for light-weight SMBHs

- We found that for $M_{BH}<10^6 M_\odot$ the relation is different
  - sub-linear: $L_{OIII} \sim L_X^{0.33}$ and much tighter (0.35 dex); similar story for the $L_{bH\alpha} - L_X$ relation
  - puffs up and steepens when including more massive BHs
  - not connected to SFR or total stellar mass; **broad Hα originate from the SMBH vicinity**



The $L_{[OIII]} - L_X$ and $L_{bH\alpha} - L_X$ relation for light-weight SMBHs

- Objects deviating “up” (higher [OIII]) exhibit outflows
  - asymmetric and broad forbidden line profiles with a “blue wing”
- Objects deviating “down” are dusty star-forming galaxies

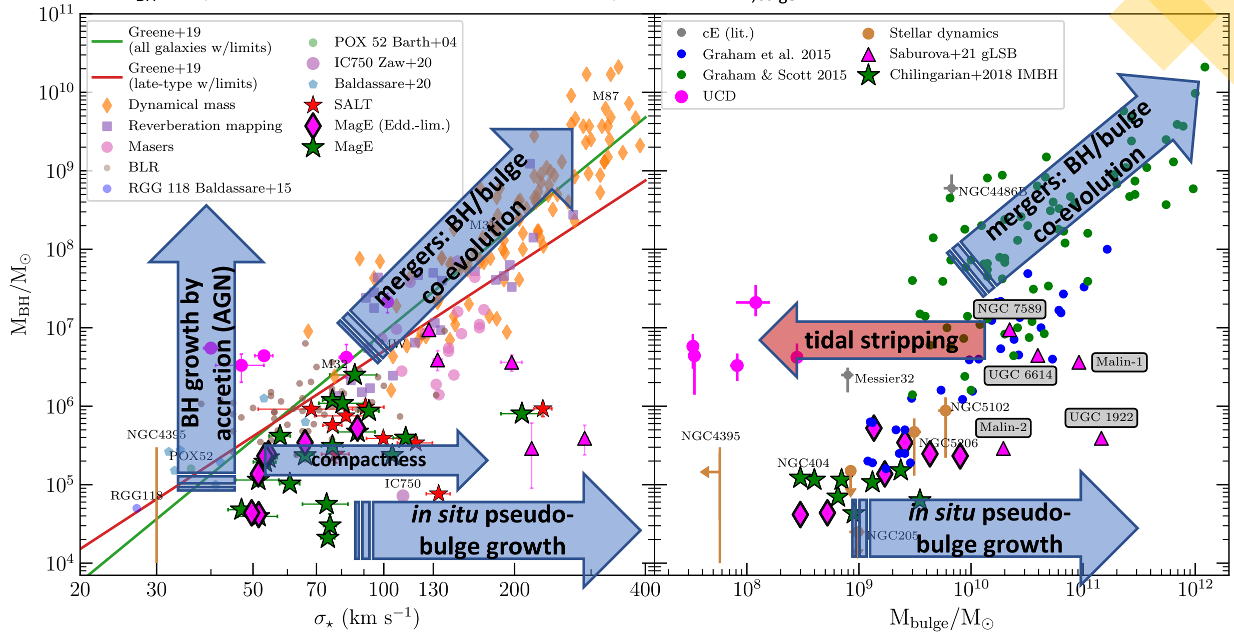


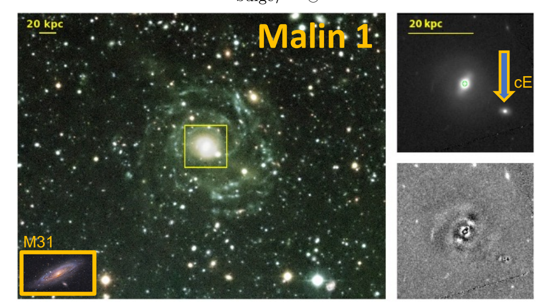
SMBH growth in the IMBH regime: new data

What can we learn from new data?

- Co-evolution is important for massive bulges, which assembled their mass via mergers
- gLSB galaxies grow their massive bulges secularly in sparse environment and, hence, become strong outliers below the BH-host scaling relations
- Compact stellar systems are outliers (above)
- Many IMBHs and light-weight SMBHs are offset to the bottom/right:
  - Dwarf early-type galaxies are subject to morphological transformation by environment, which heats them up and increases velocity dispersion
  - We can sometimes miss a low-mass bulge in a dE and consider the whole galaxy as a bulge: this will also offset it to the right
  - If these hypothesis is right, then there should be an environmental dependence of the position of a galaxy on the diagrams in the low-mass regime
- Eddington-limited BHs are almost exactly on the relation: perhaps this is because most of them live in relatively poor environment

M_{BH}–σ_* (Ferrarese & Merritt'00; Gebhardt+00) M_{BH}–$M_{*,bulge}$ (Häring & Rix'04; Kormendy & Ho'13)





Summary

- We conclude that a population of IMBHs in AGN with $M_{BH} < 10^5\ M_\odot$ exists and this fact disfavors massive SMBH seeds
- IMBHs in the nearby Universe do not seem to co-evolve with their host galaxies: they grow by accretion, while their hosts grow secularly (even though the gas supplies may be connected)
- If the same happens at high redshifts, then the (super-)Eddington accretion is the dominant SMBH growth mechanism at low masses, and we expect to see high-z IMBHs in X-ray with the next generation facilities Athena and Lynx
- There are still a lot of things to explore at the low-mass end of the SMBH properties, e.g. X-ray vs optical, feedback, environment

Thank you