Cosmic Duets and Where to Find Them

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M. Scialpi


G. Tozzi


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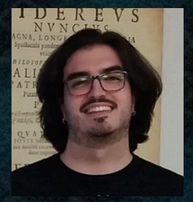
A. Feltre


M. Ceci

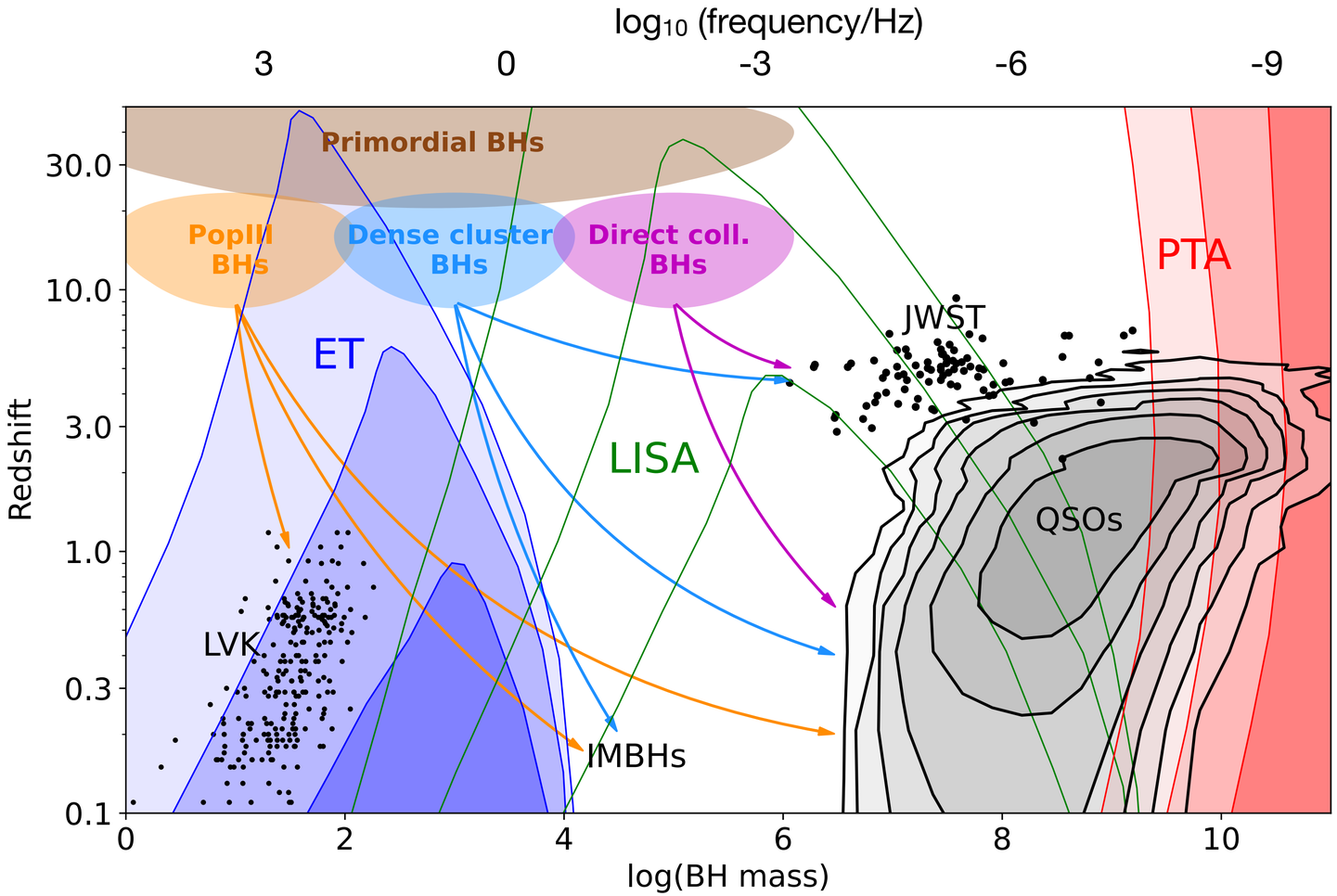

I. Lamperti

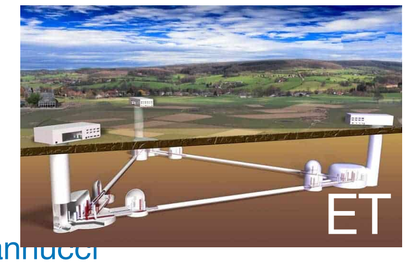

M. Zanchettin

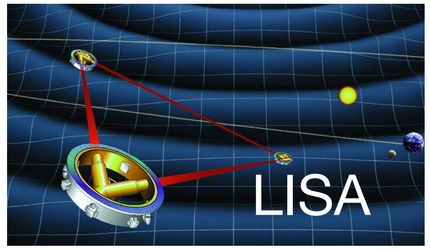
M. Perna, A. Ciurlo, S. Yeh, C. Cicone, E. Pancino, A. Chakraborty, E. Cataldi, C. Bracci, P. Severgnini, M. Volonteri, C. Vignali, G. Venturi, A. Marconi, G. Cresci, F. Belfiore, S. Carniani, M. Ginolfi, E. Lusso, E. Nardini, A. De Rosa, K. Rubinur, A. Sonnenfeld, P. Rosati, C. Spingola. +

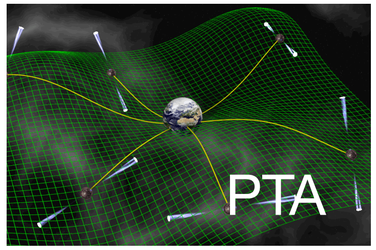
1

The cosmic journey of black holes







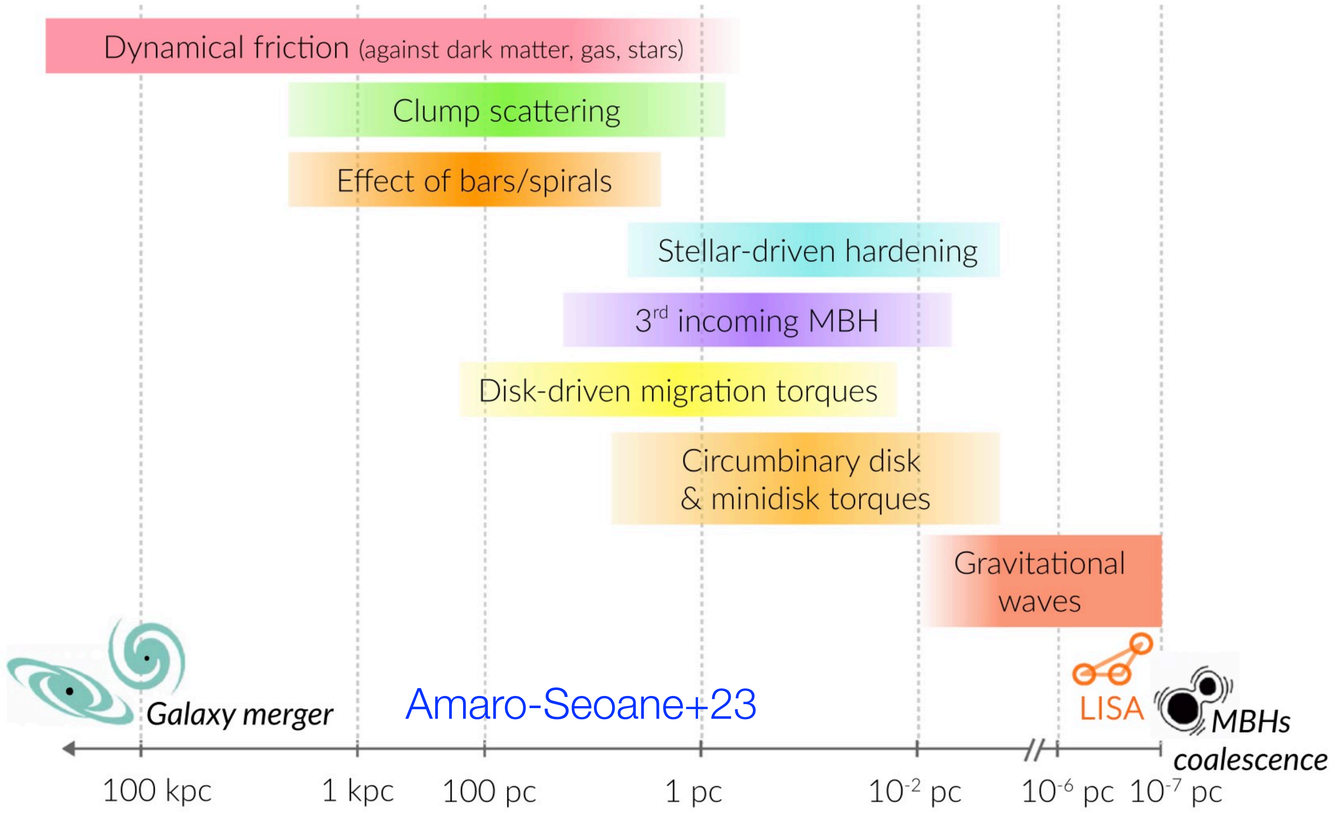


1. Gas accretion
2. Merging

Giersz+15, Miller+02, Lousto+10, Gerosa+19, Dubois+14,Kulier+15, Smith+18, Latif & Ferrara 16, Schneider+23, Di Matteo 23, Arca Sedda+21, Wu & Shen 22, Abbott+23, Juodžbalis+25, Zhuang+25

Merging SMBHs and dual AGN

physical processes affecting coalescening massive BHs



- Long merging timescales (~10^8-10^{10} yr)
- Merger-induced accretion

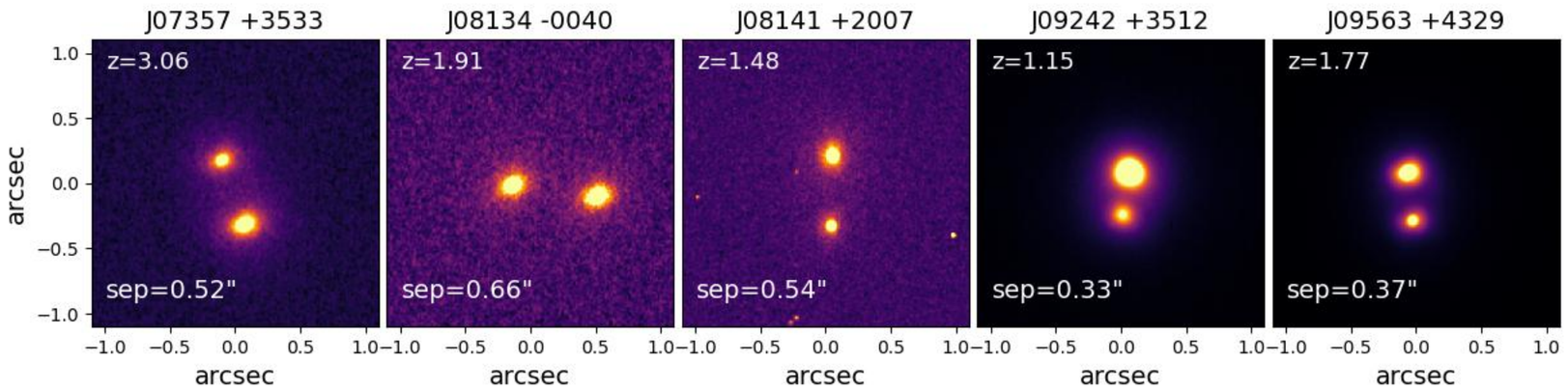
→ Multiple active SMBHs at 1-100 kpc separation: : **Dual AGN**

common host galaxy: **Cosmic Duets**

Progenitors of merging SMBHs

Begelman80, Yu02, Tremmel+17, Rosa-Guevara+19, Volonteri+21, Chen+23.....

The role of cosmic duets

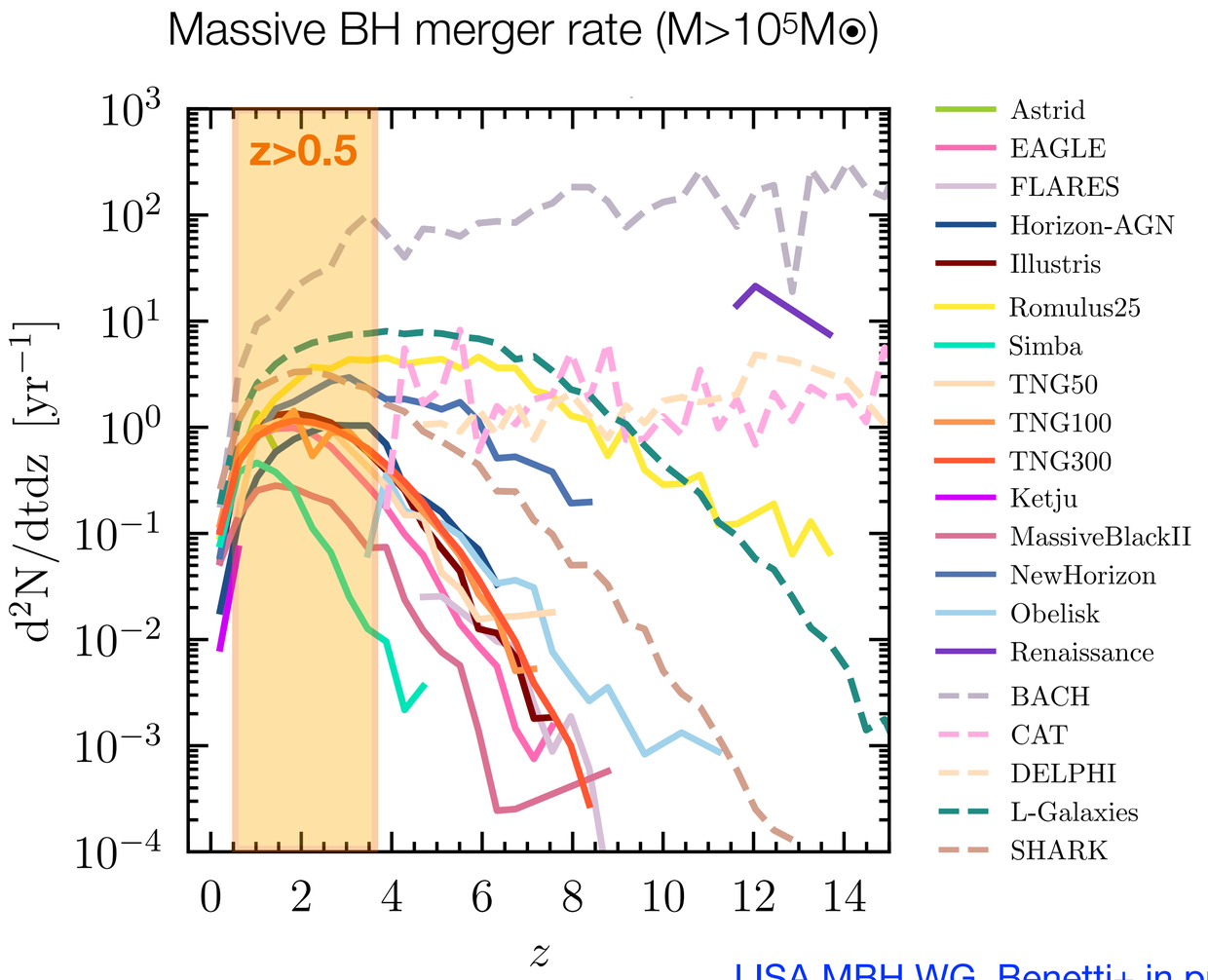


Mannucci+22, Nat. Astr.

Importance of the "duet" phase:

1. test of BH seeding
2. Role of merging in SMBH growth
3. Physics of in-spiraling and orbital shrinking
4. Test on models of Galaxy/SMBH co-evolution
5. Effect of merging on AGN activity
6. Feedback, effect on host galaxy
7. Predictions of the GW event rate in LISA and PTA

GW event rate

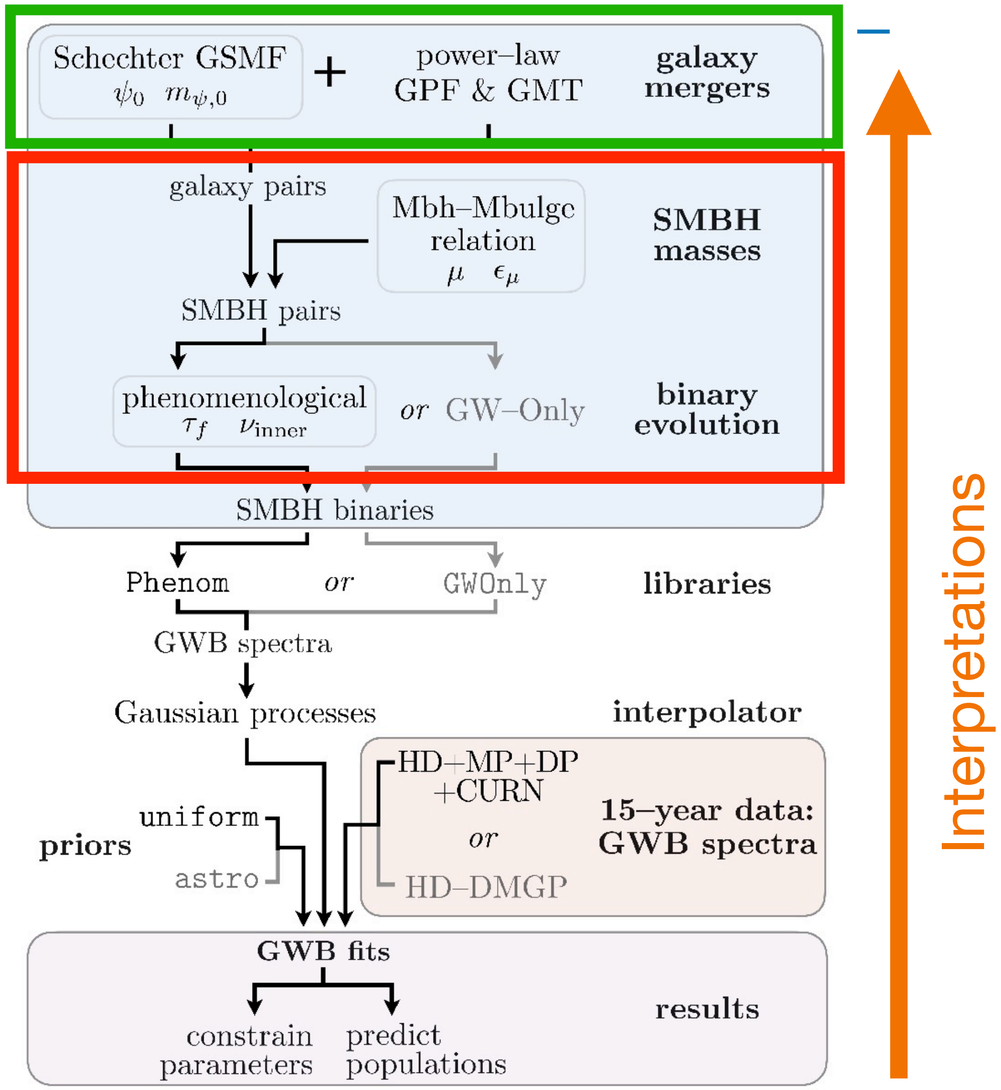


LISA MBH WG, Benetti+ in prep.

Duets at kpc separ.

Predictions

Calibration: LF, M-σ, ...



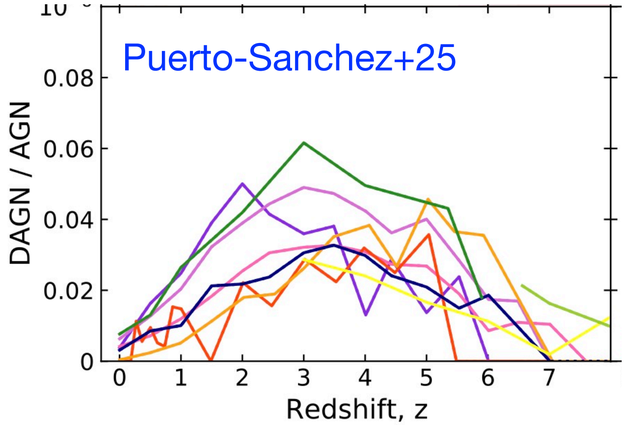
Agazie+23

Interpretations

Colpi+14, Amaro-Seoane+17,Babak+17, Izquierdo-Villalba+22, Agazie+23

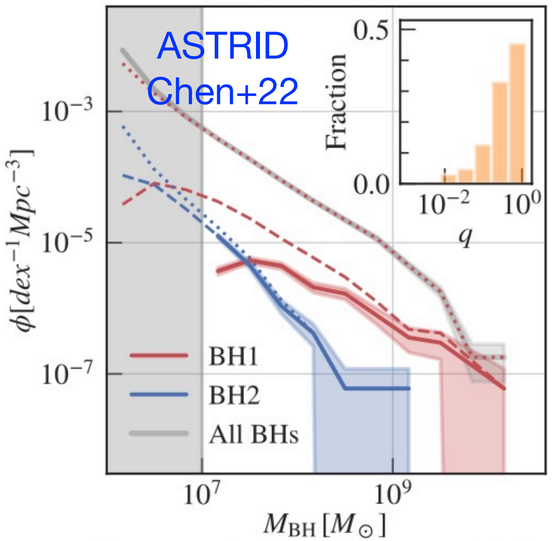
Never tested model predictions

Dual Fraction

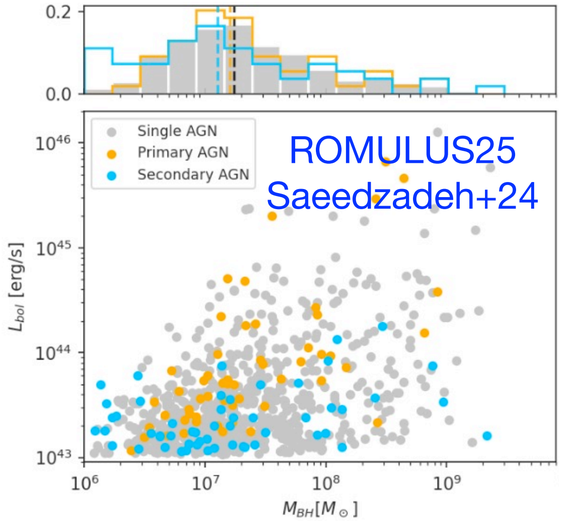


1. Dual Fraction
2. BH mass function, mass ratios
3. Separation distribution
4. Lbol + Ledd
5. Host properties
6. Feedback
7. .....

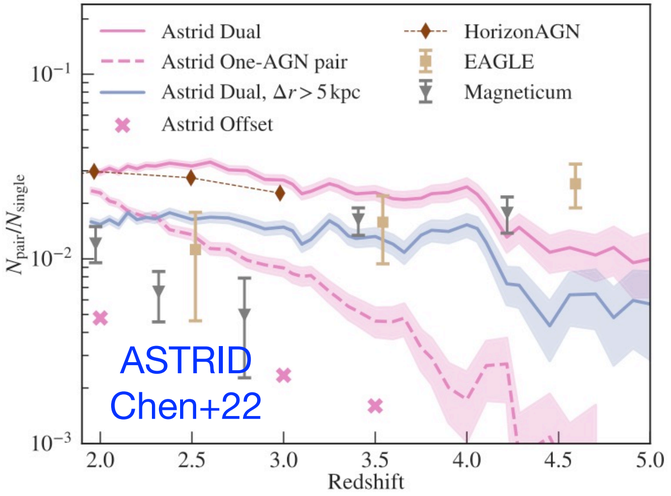
BH mass distribution



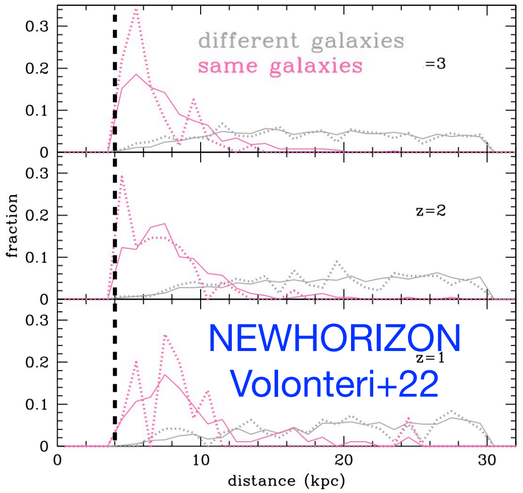
Bolometric luminosities



Dual Fraction

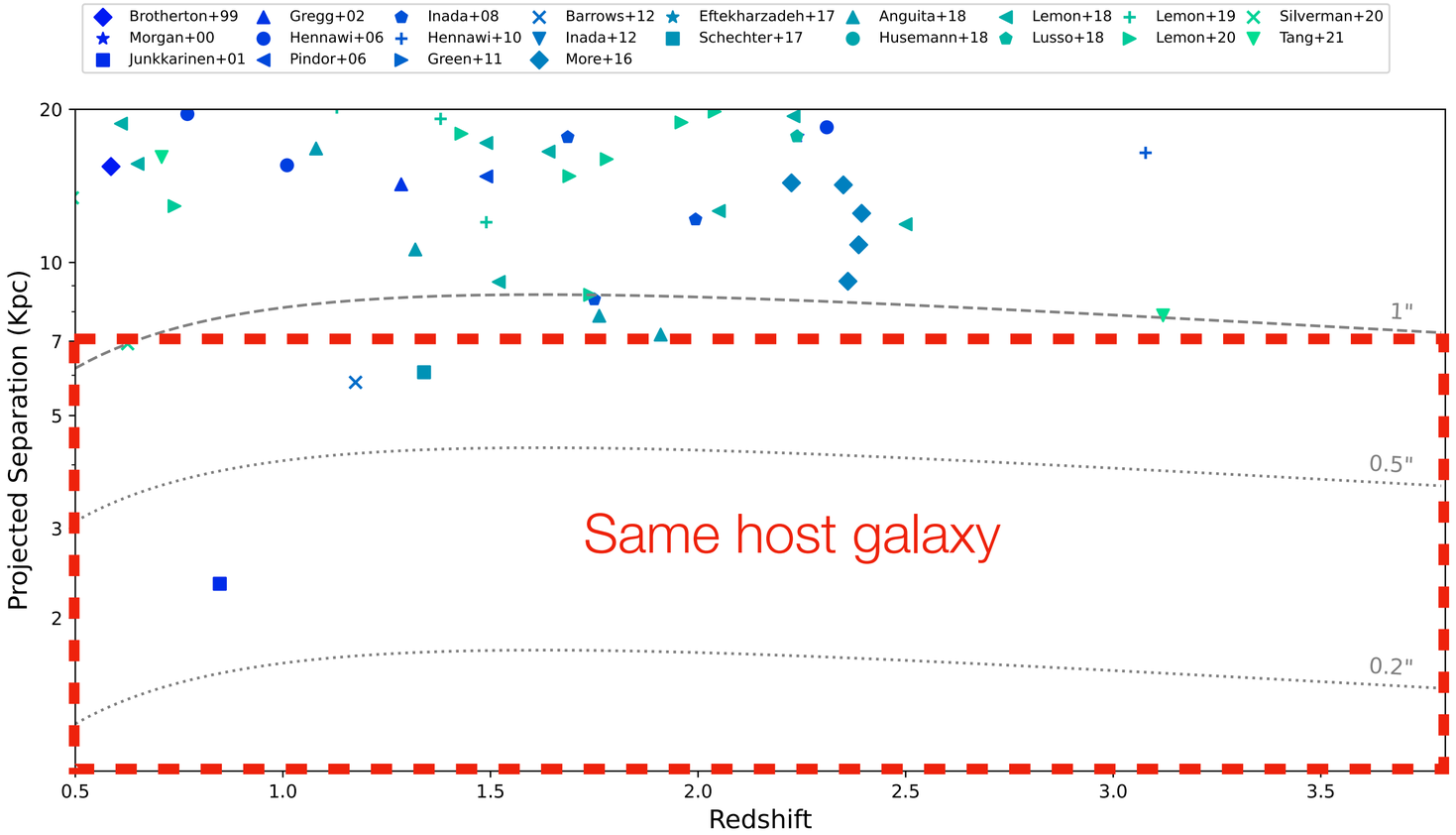


Separation distribution



Tremmel+18, Ricarte+19,Rosas-Guevara+19, Silverman+20, Volonteri+20,22, Chen+22, Dong-Paez+23, Koehn+23, Partman+23, Damiano+24, Saeedzadeh+24, Izquierdo-Villalba+23,24, Puerto-Sanchez+24 et al.

Few duets up to 2022....



Aim:

1. Select, confirm, and study the properties of a large number of duets at z>0.5 and sep<7kpc (~1")
2. uniform and well-understood selection function
3. Compare their properties with model predictions
4. Compute an accurate MBH merger rate

Strategy and instruments

multiple QSOs → redshift/contamination → classification/properties

Selection:
Multiple QSOs from large sky-coverage, high spatial resolution surveys

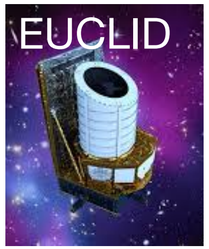
1. Gaia Multi peak (GMP)
2. Euclid
3. LOFAR

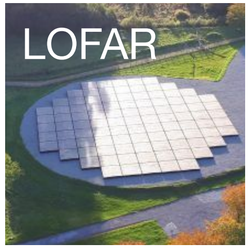
Integrated spectroscopy:
- confirm the QSO
- measure redshift
- presence of a star

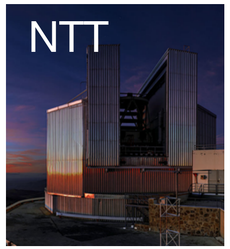
1. Archive: SDSS+DESI+...
2. New observation: VLT, NTT, TNG, ...

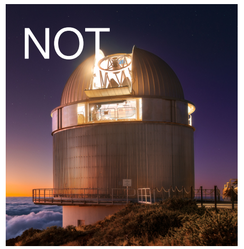
Spatially-resolved spectroscopy
nature and properties

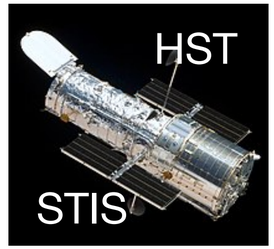
Follow-ups:
X-ray, midIR, submm, Radio

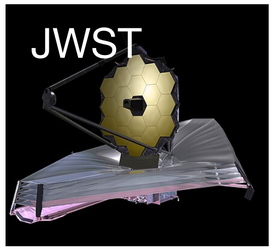


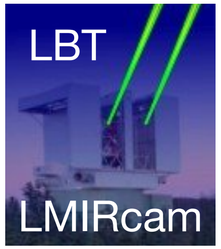


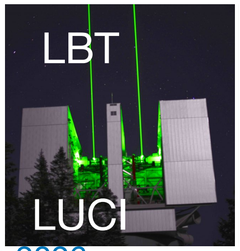


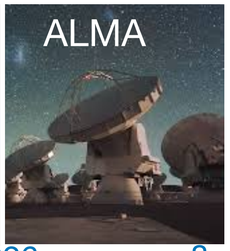












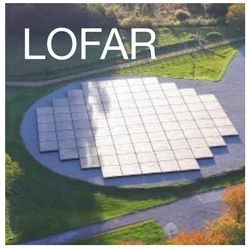
Strategy and instruments

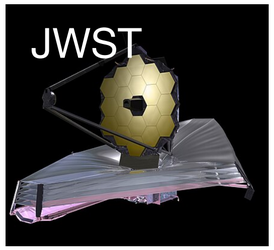
multiple QSOs → redshift/contamination → classification/properties

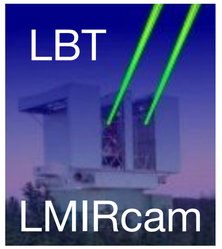
ESO GTO 115hr

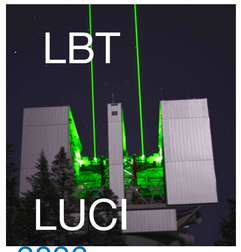
ESO LP 138hr, PI: M. Scialpi

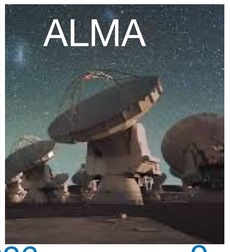
several tens of nights



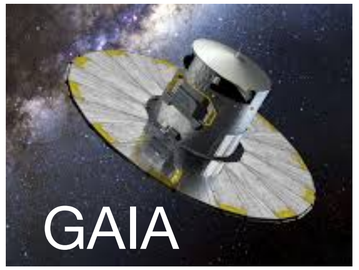




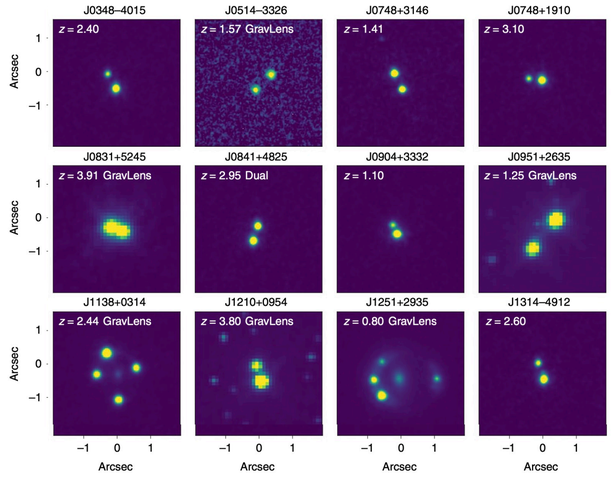




Multiple QSO selection

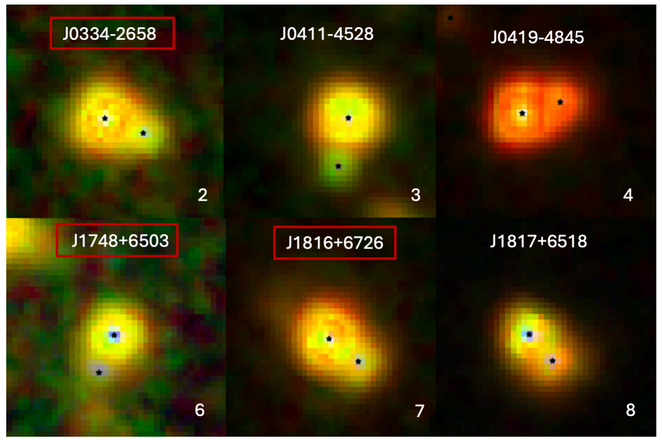


Gaia multi peak (GMP)
60 confirmed QSO pairs
24 dual AGN



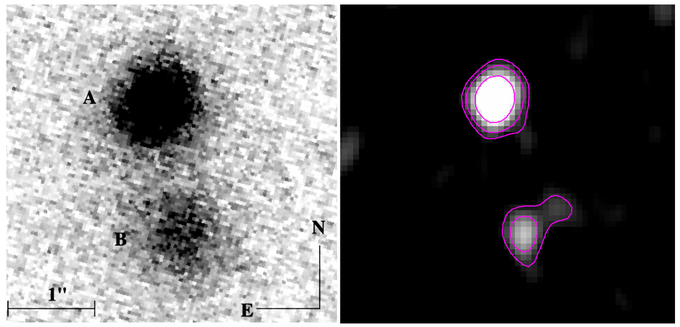
Mannucci+22, Ciurlo+23,
Mannucci+23, Scialpi+24, Wu+24

ML-based detection
Ie<25.5 sep>0.2"
Q1 data (63 sq.deg): 12 cand.
Wide Survey (14,000 sq.deg): ~ 2500



Cuillandre+24, Ulivi+25

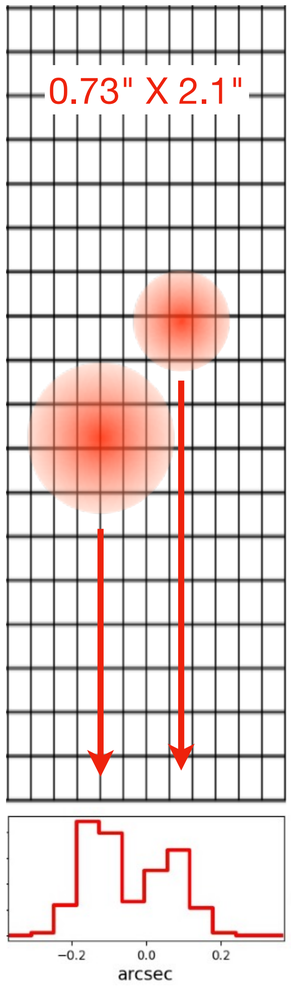
144MHz, ~80μJy/beam
sep>0.3"
LoTTS survey (20,000 sq.deg)
~1000 dual AGN



D'Amato (in prep.)

Gaia Multi peak (GMP)

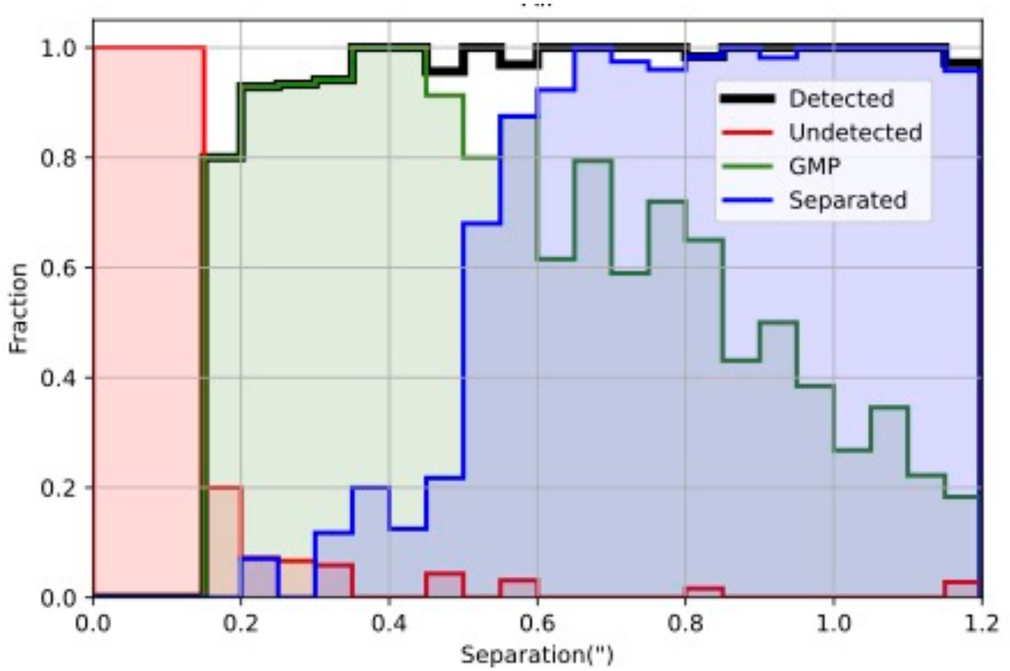
SCAN DIRECTION →

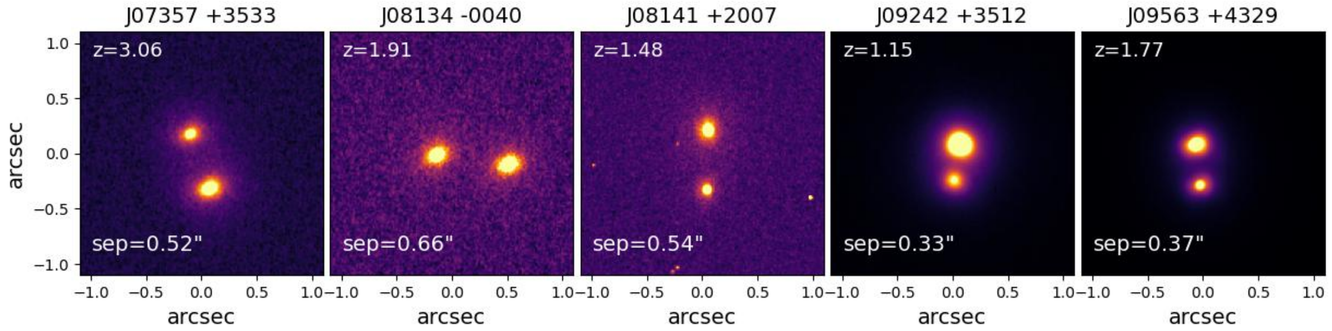


G<20.5

0.15"<sep<0.6"

~2000 candidates





Strong points:

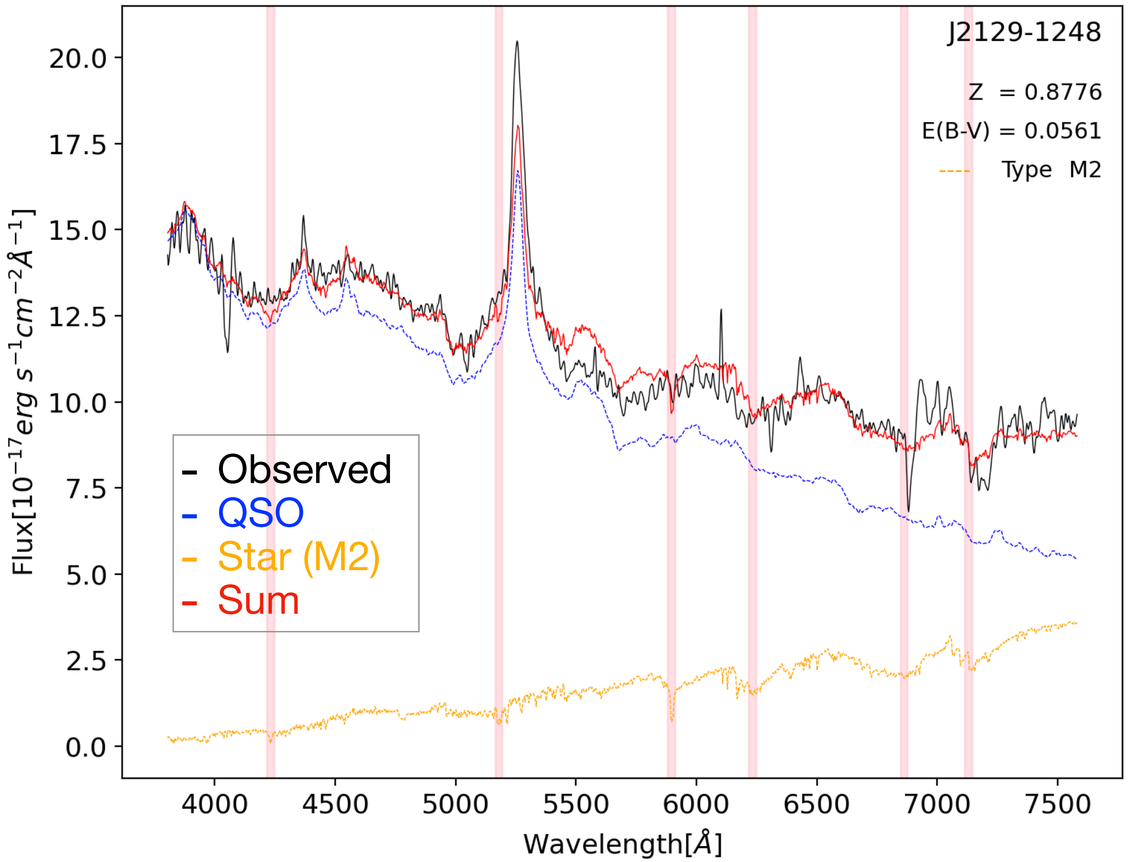
1. All sky, millions of QSO
2. high spatial resolution, stable PSF
3. very effective, no false positive

Limitations:

1. high luminosities log(L)>45.5
2. low luminosity ratio (<15)
3. low extinction
4. no host galaxy

Mannucci+22,23, Ciurlo+23, Scialpi+24, Wu+24

GMP: integrated spectroscopy



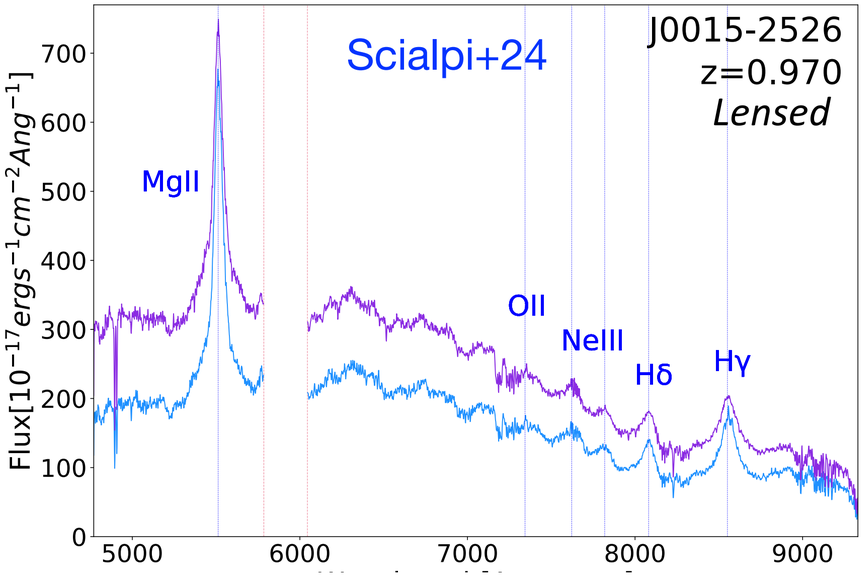
- confirm photometric classification
- measure redshift
- QSO/star deconvolution

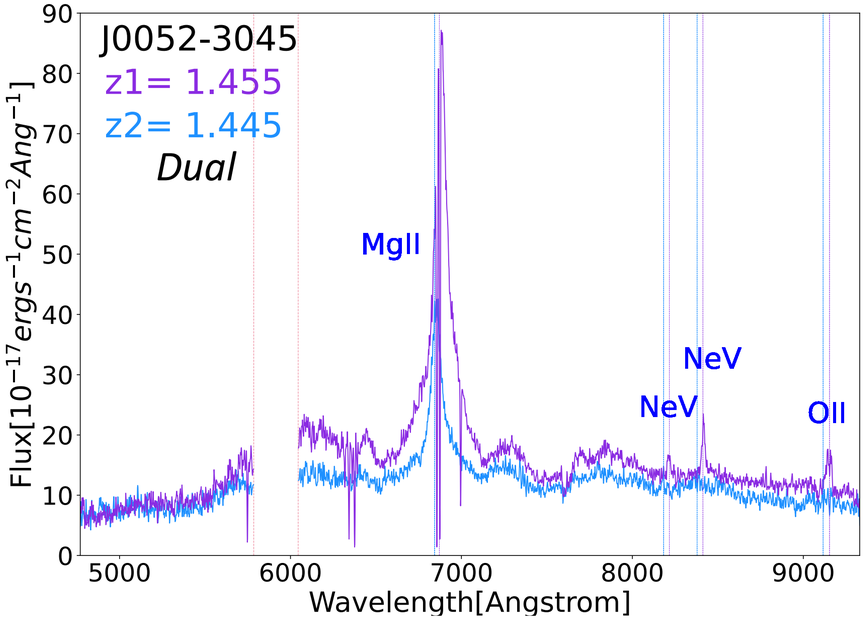
  → dual fraction

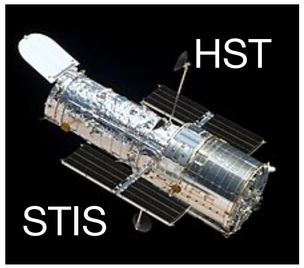
~1200 spectra:

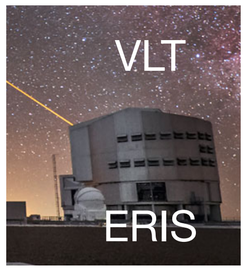
- ~600 from archive (SDSS, DESI...)
- ~600 proprietary data

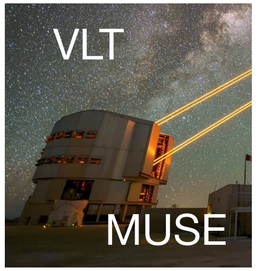
GMP: spatially-resolved spectroscopy

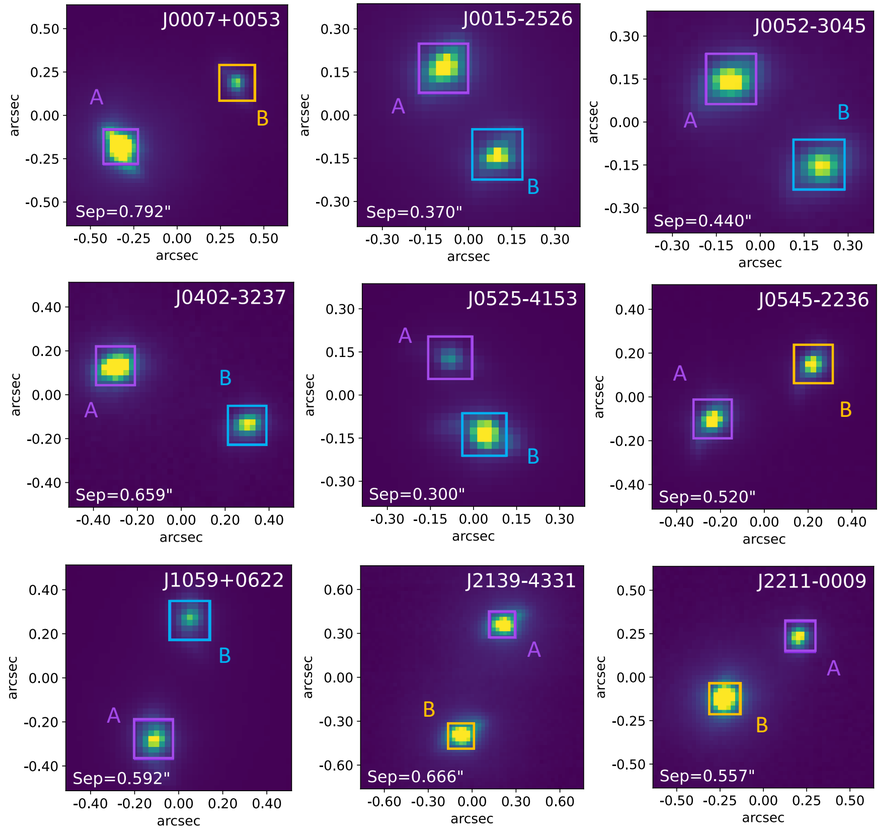












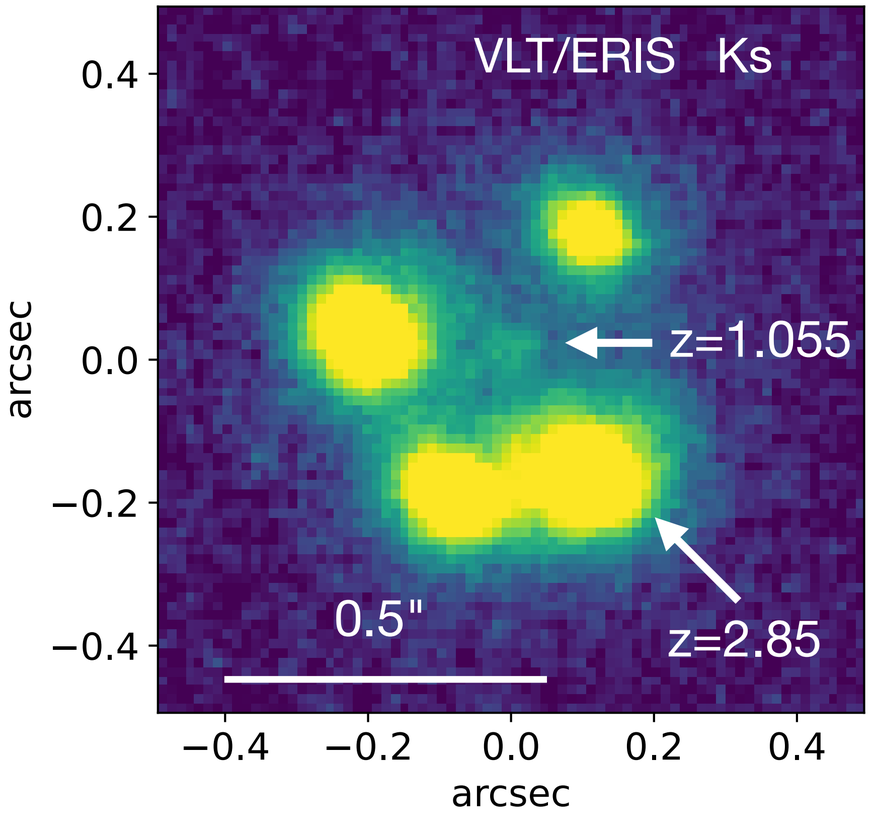
COSMIC DUETS

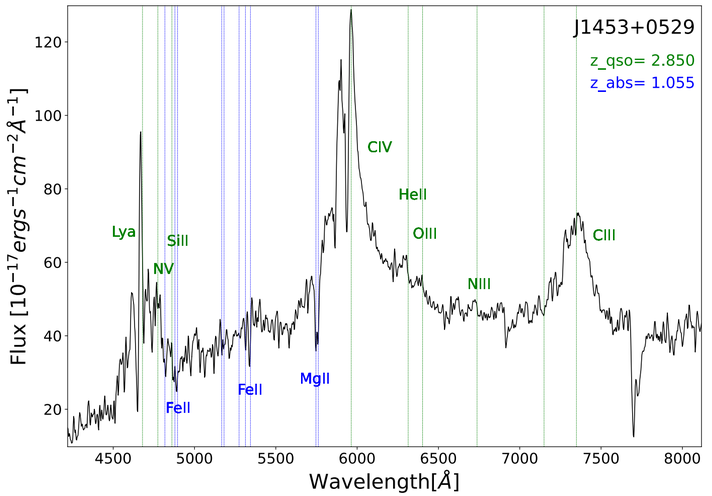
ESO
Large Program
VLT/MUSE-NFM
136hr, 2 yrs
PI: M. Scialpi

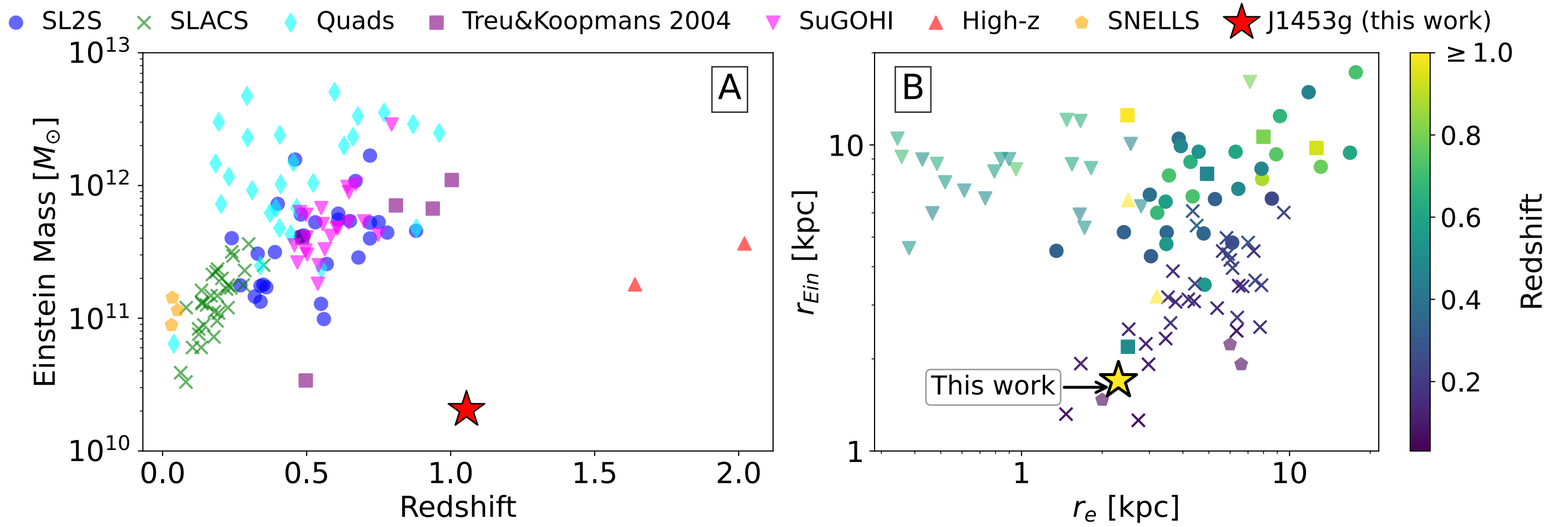
GMP: lensed QSO

Lensed QSOs

Most compact quad QSO known (R_{ein}~0.2")







D'Amato+26, Nature Astr.

Status:

All Spectroscopically-confirmed dual AGN at sep<20kpc

GMP:

~200 QSO pair candidates

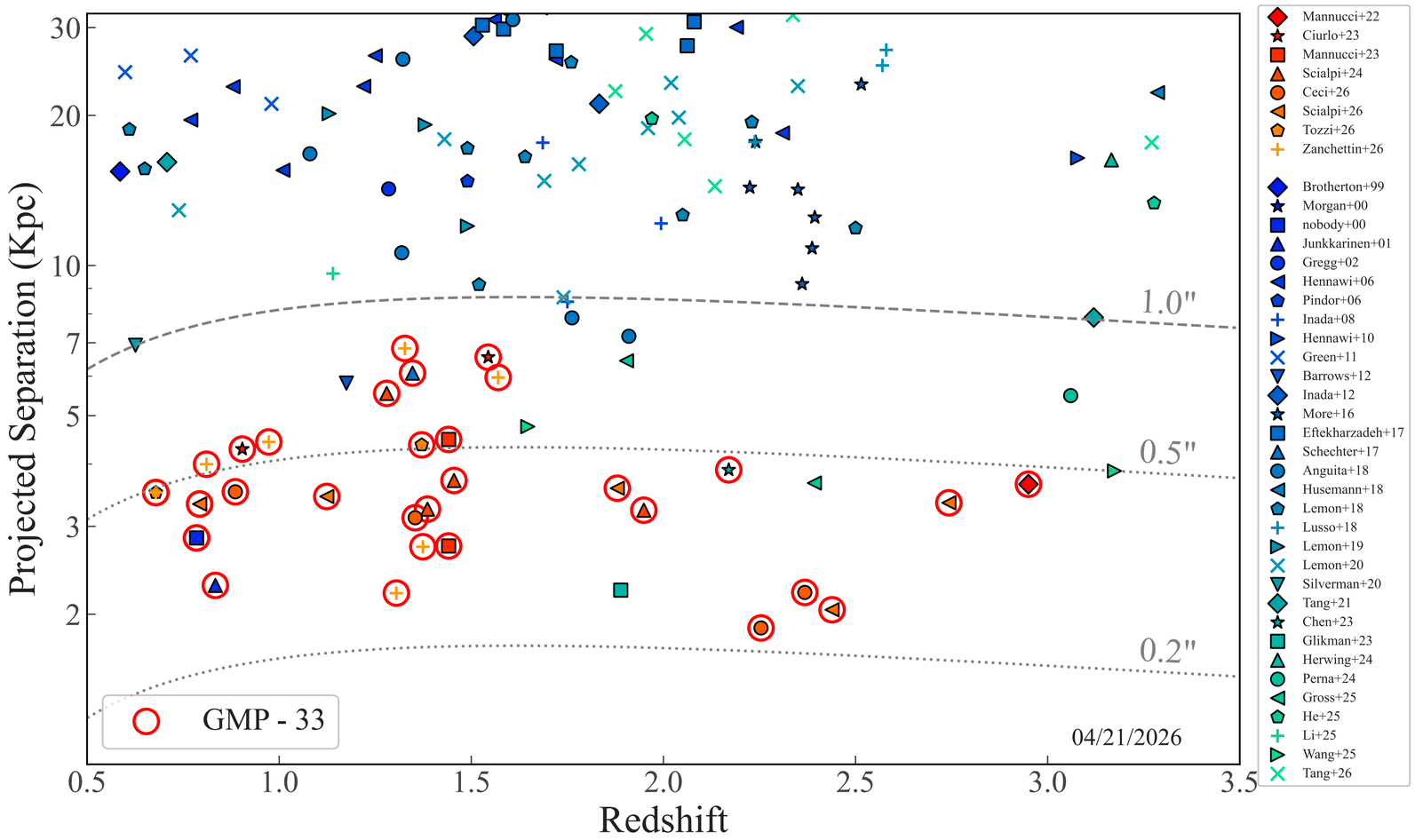
~70 with resolved spec.

~60 confirmed QSO pairs

33 confirmed duets

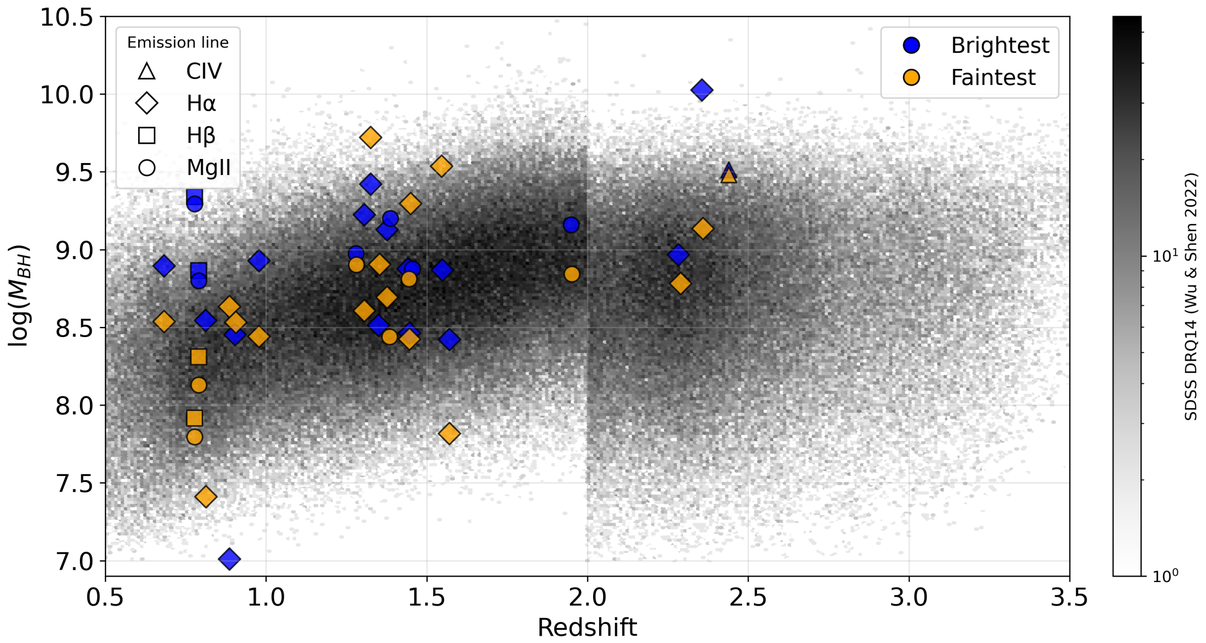
22 Confirmed lensed QSO

5 "pairs"



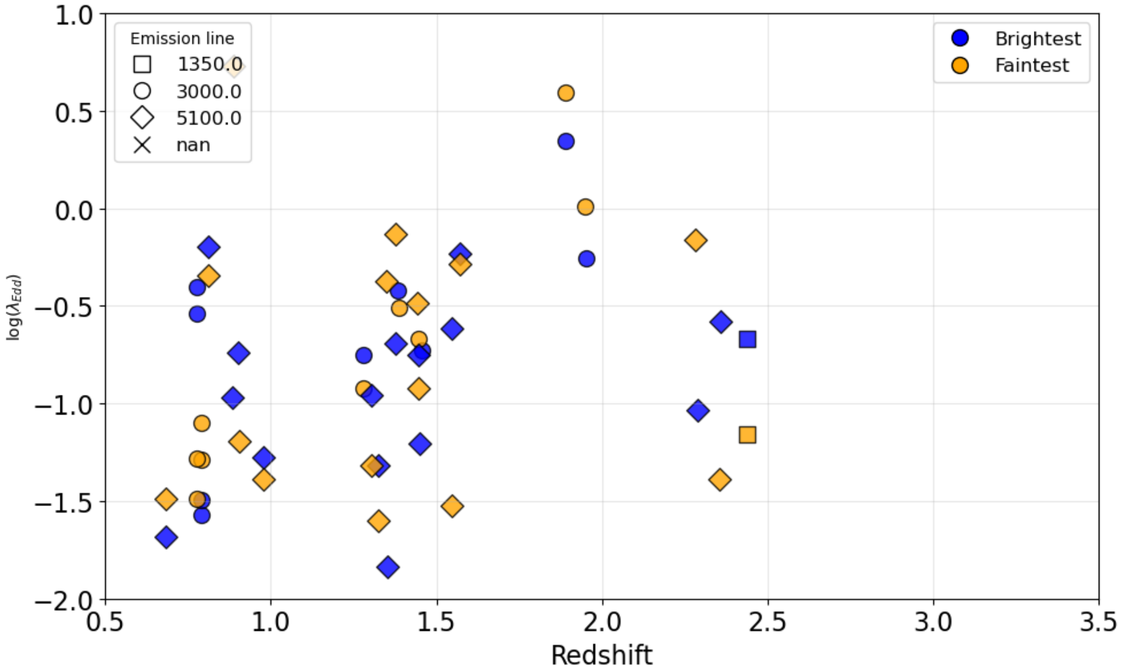
Physical properties

Single-epoch BH masses



$$\log\left(\frac{M_{BH}}{M_\odot}\right) = a + b\log\left(\frac{\lambda L_\lambda}{10^{44}\ erg/s}\right) + A\ log\left(\frac{FWHM}{10^3\ km/s}\right)$$

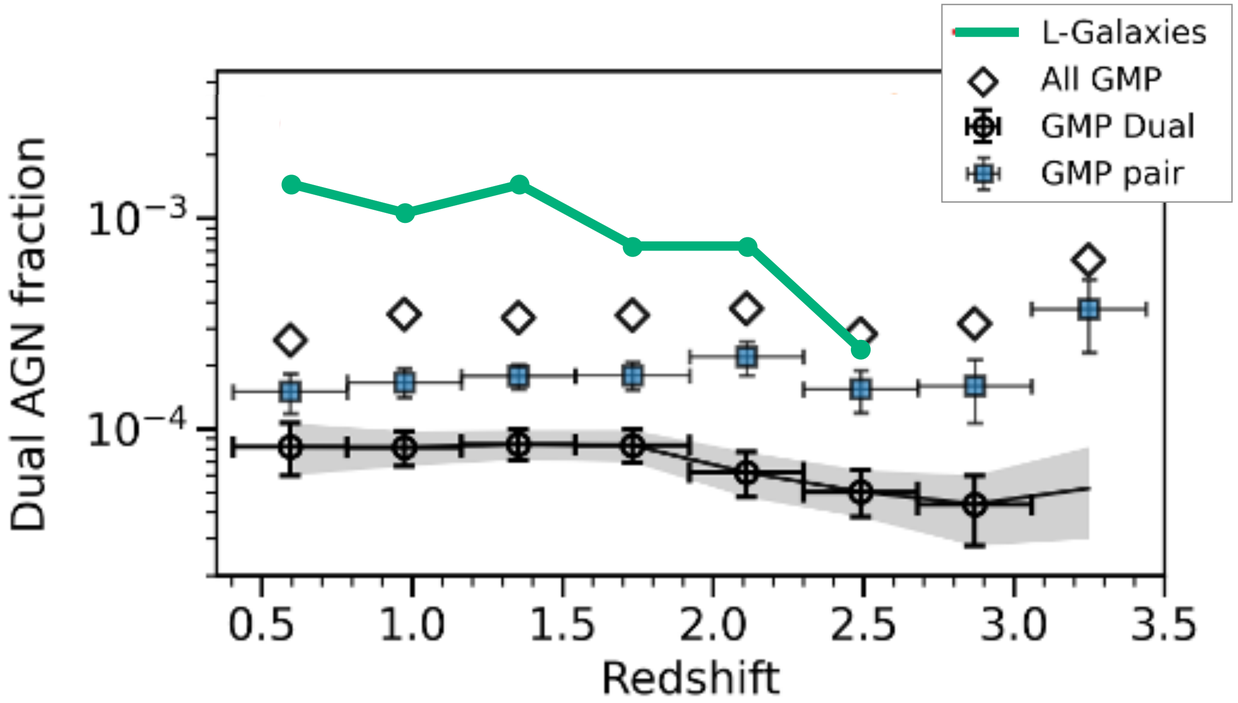
Eddington ratios



Dual fraction (how many duets?)

From:

- spectral deconvolution of ~1200 integrated spectra
- Lens fraction from resolved spectra

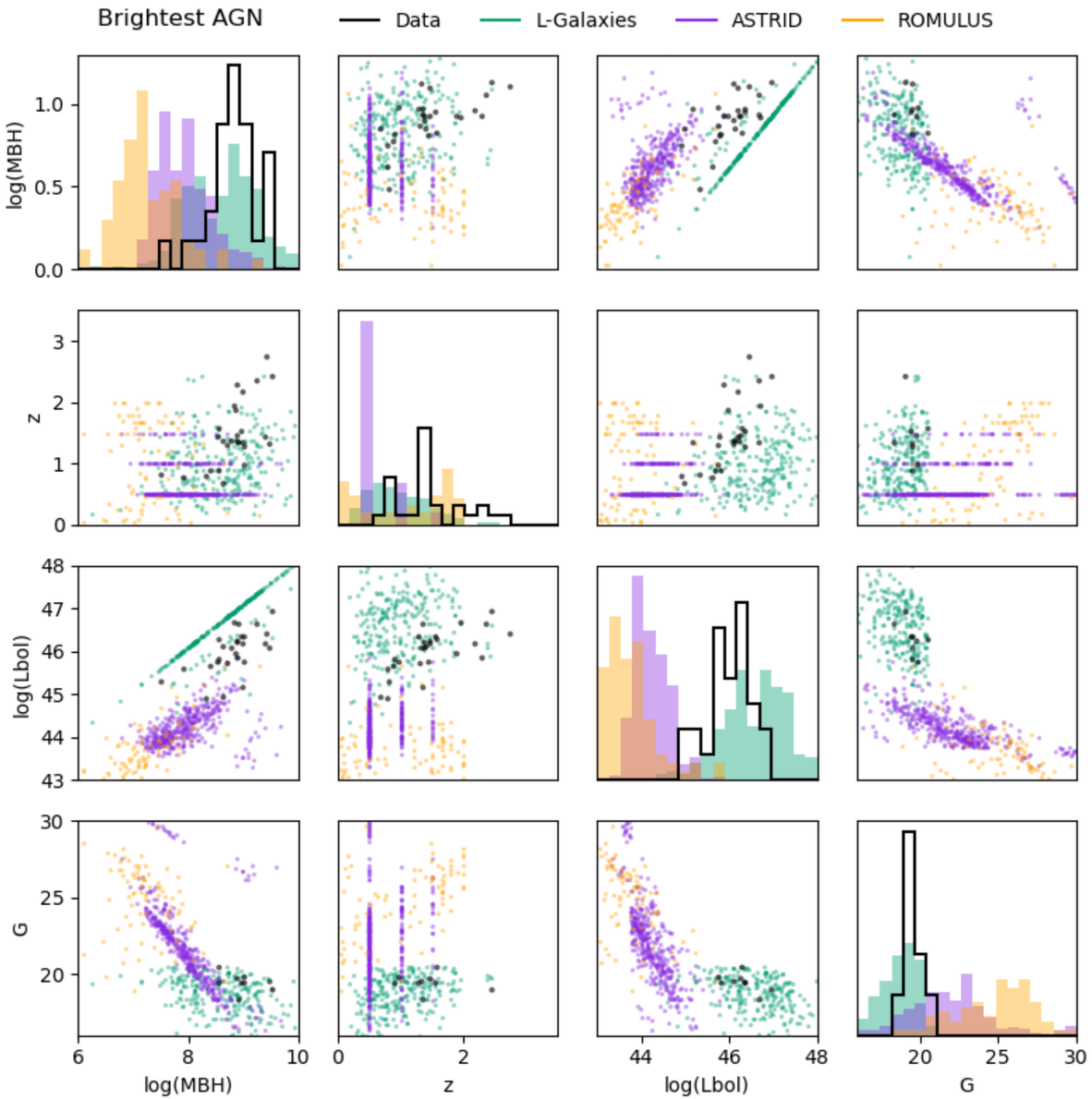


Comparison with models

Model	Ref	N duest
L-galaxiesBH	Izquierdo-Villalba+22 Bonoli+25	225
Astrid	Chen+23 Ni+25	31
Romulus	Tremmel+17 Saeidzadeh+24	0
Horizon-AGN	Volonteri+16	2
Illustris-TNG	Marinacci+17	0
Fables	Buttegieg+25	4

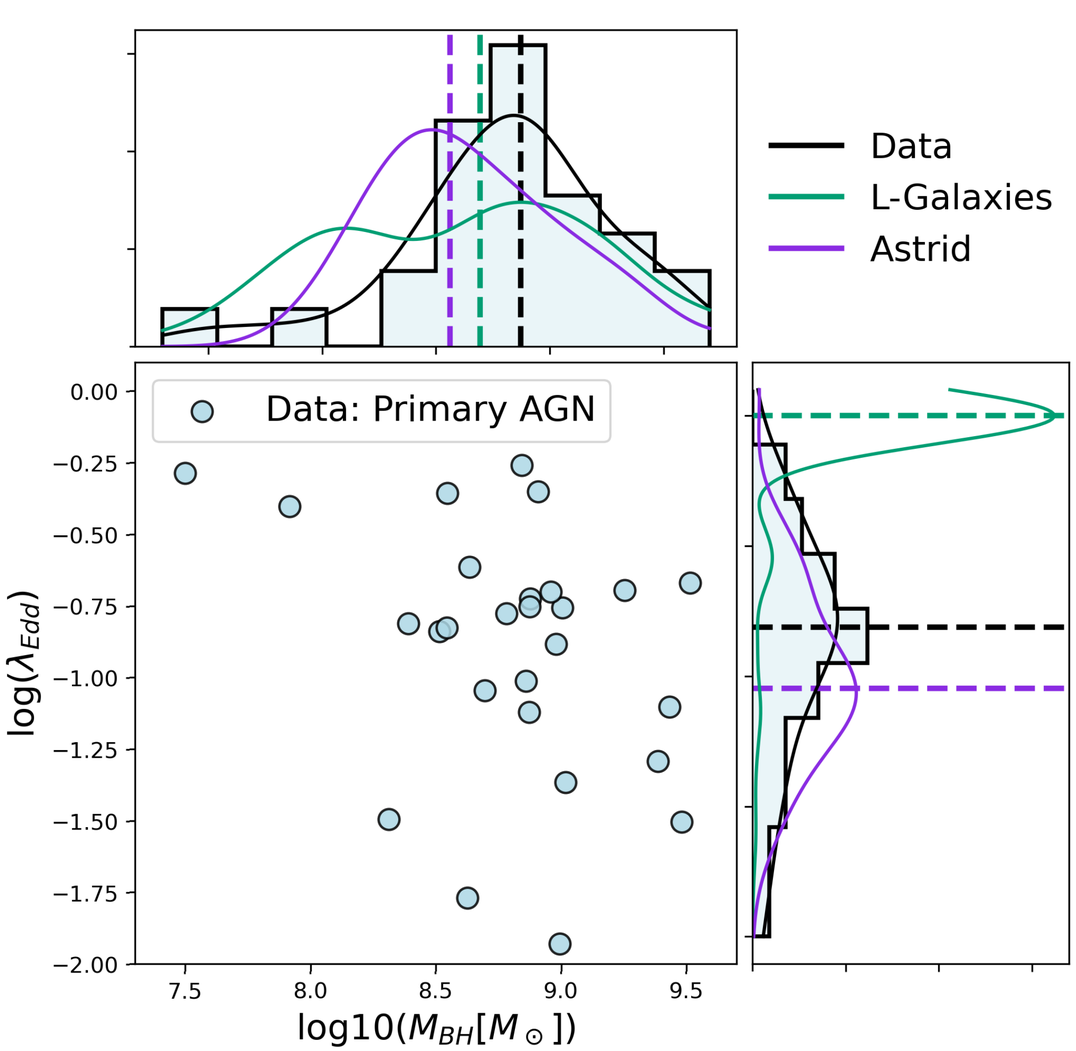
Apply the same selections:

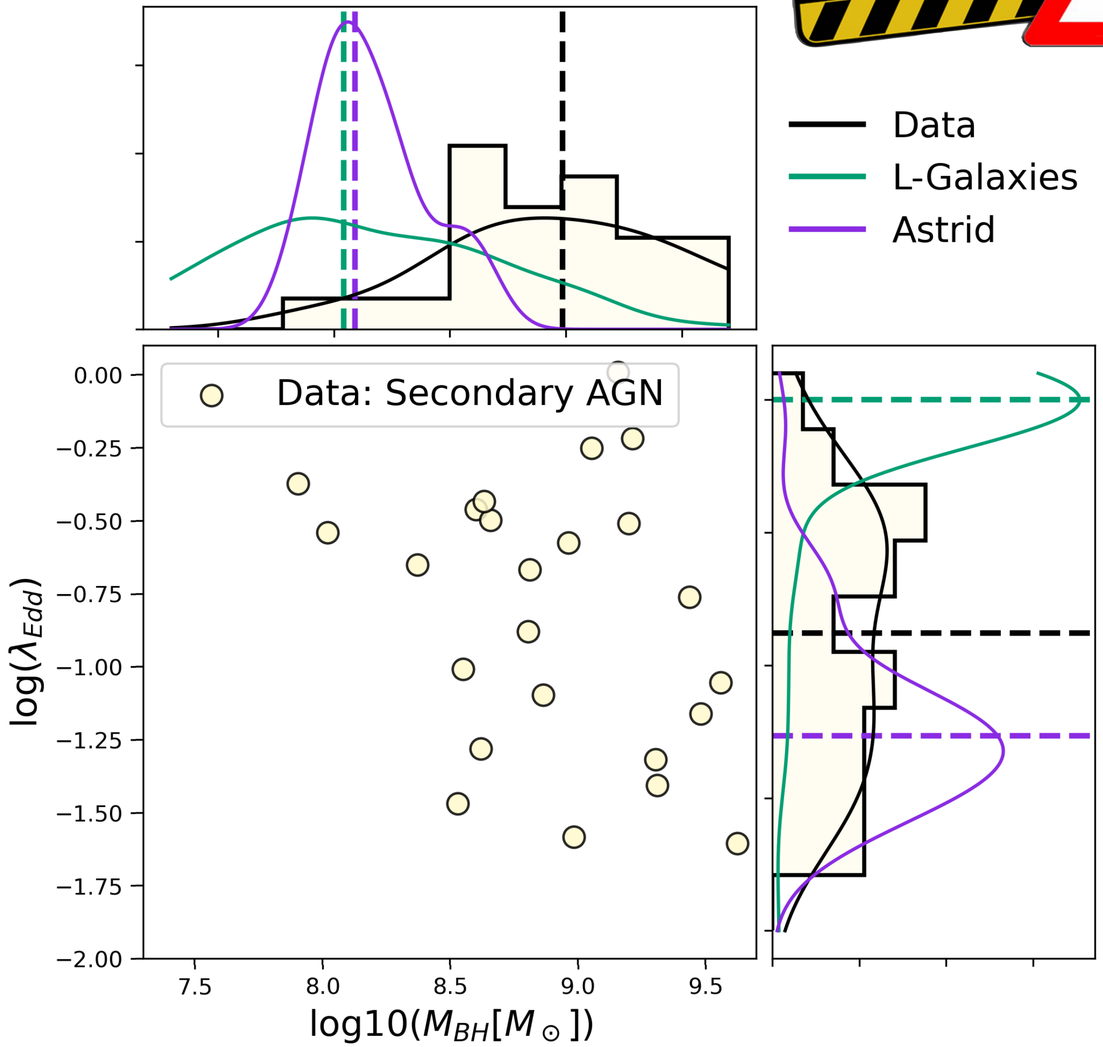
redshift, separation, mag



Need for larger simulations with higher resolution

BH mass and Eddington ratios

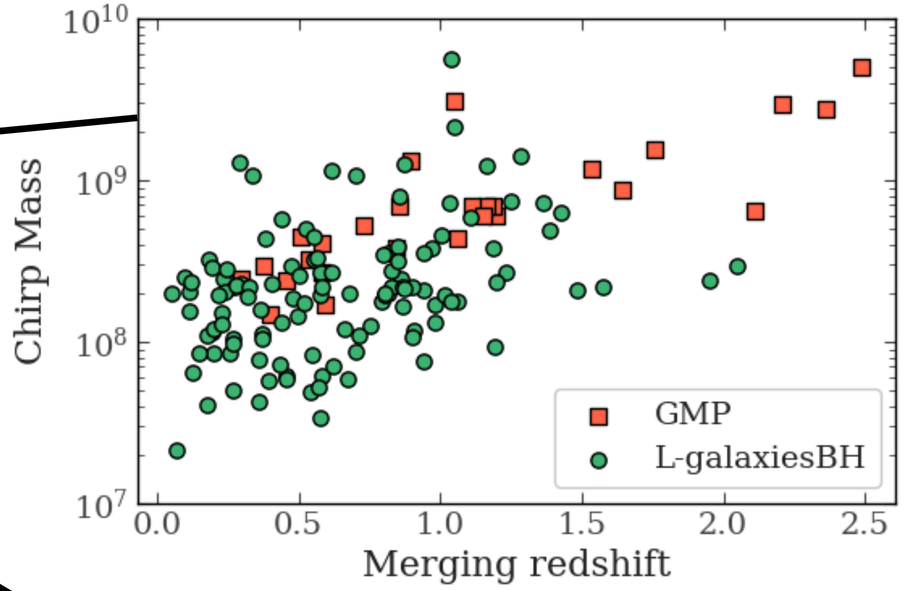


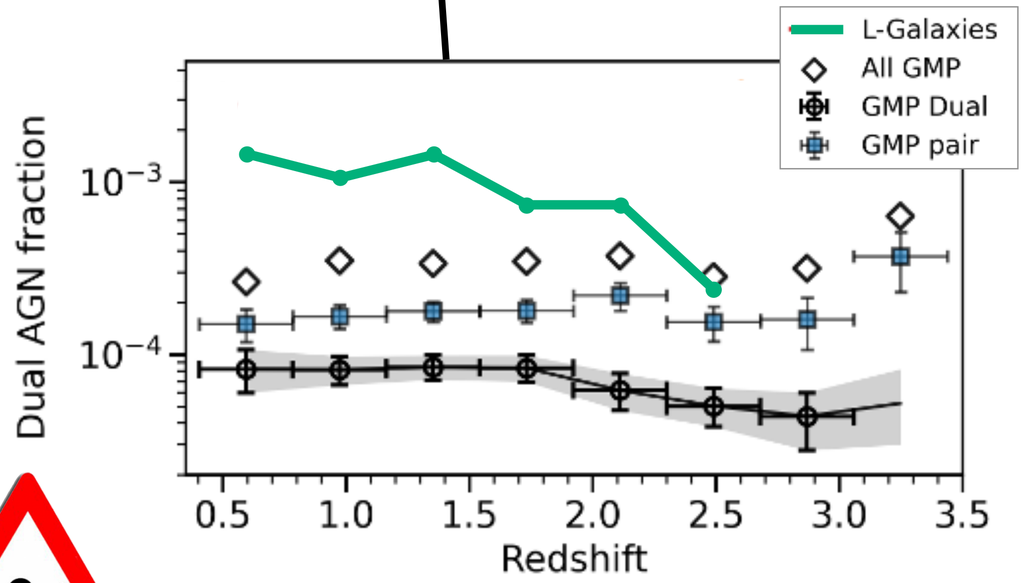


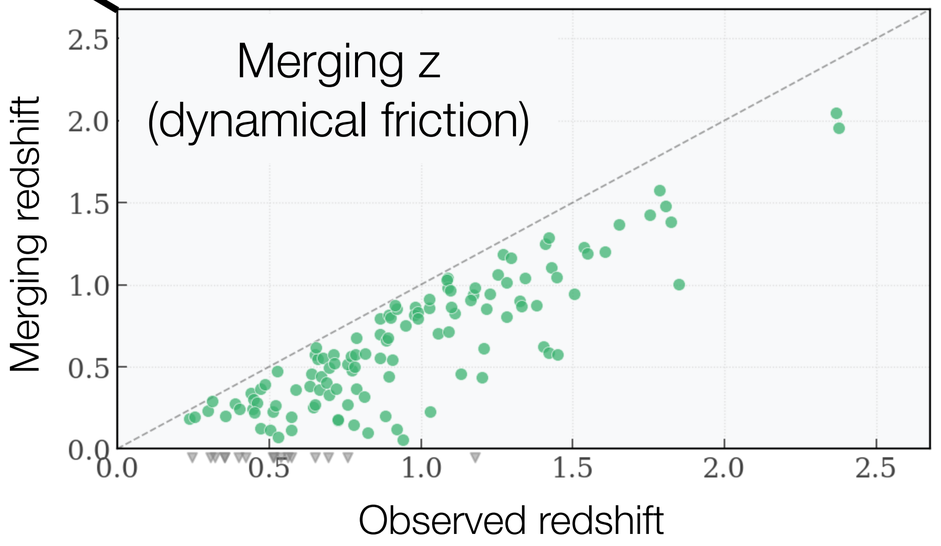
Predictions on GW background at PTA frequencies

$$h_c^2(f) = \frac{4G^{5/3} f^{-4/3}}{3c^2\pi^{1/3}} \int\int \frac{d^2n}{dz d\mathcal{M}} \frac{\mathcal{M}^{5/3}}{(1+z)^{1/3}} dz\, d\mathcal{M},$$

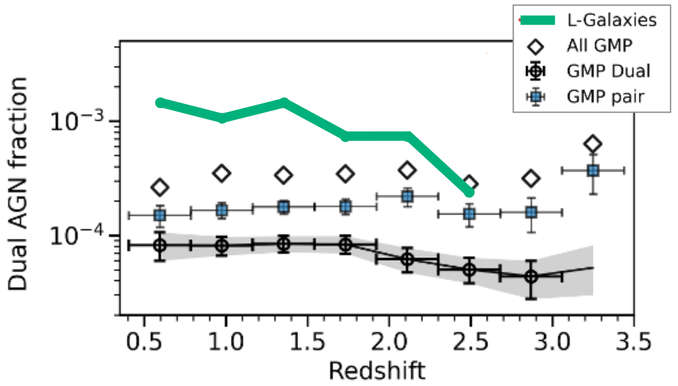
Bonoli+25

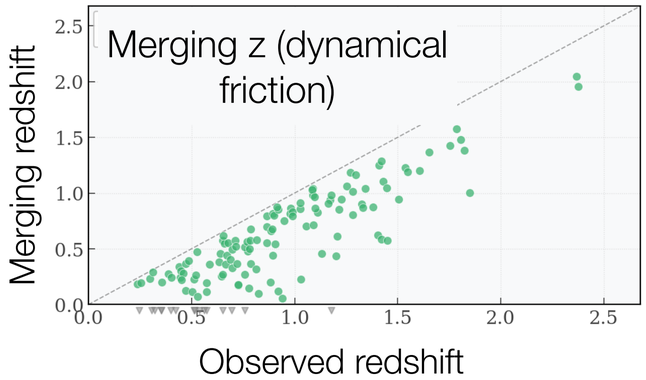


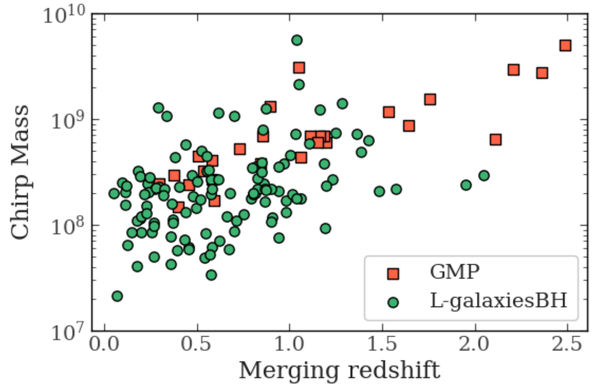


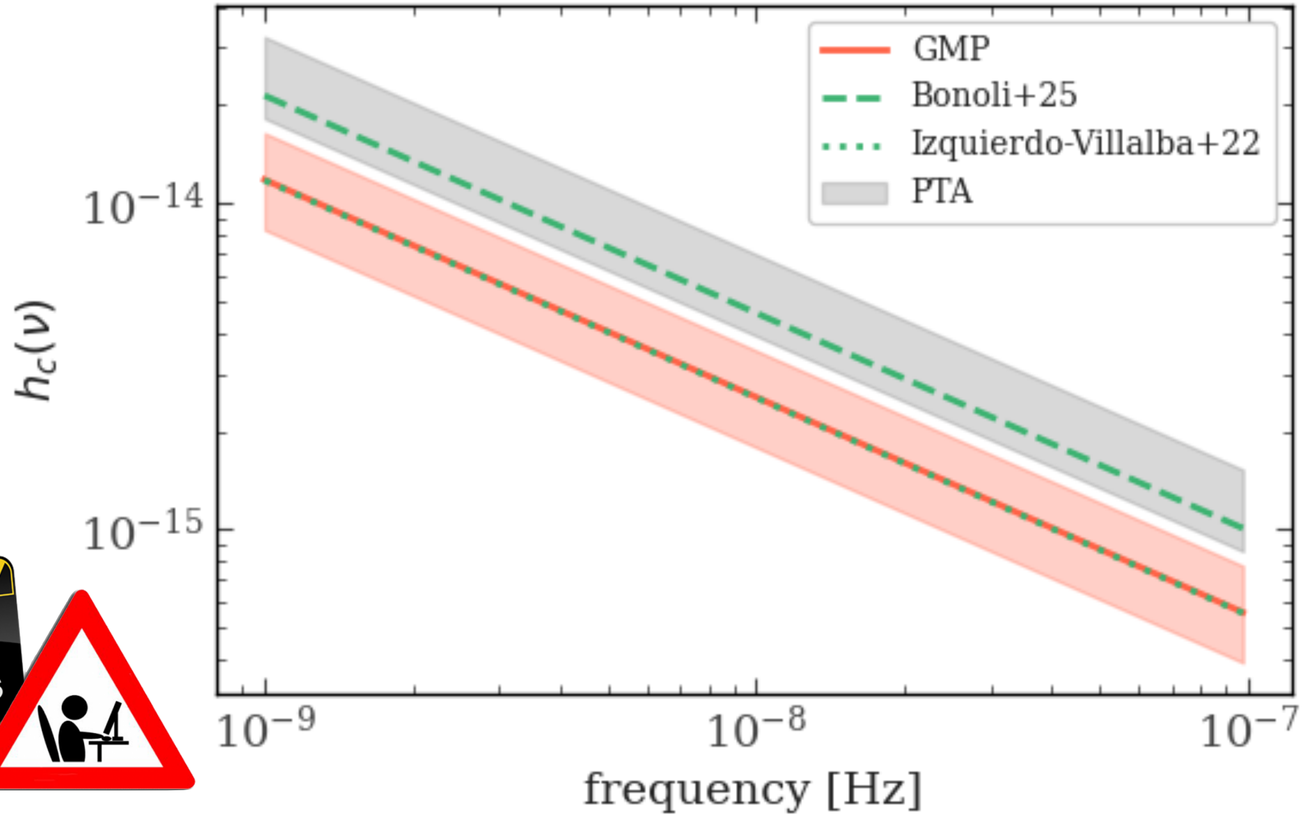


Predictions on GW background at PTA frequencies









Comparison with L-GalaxiesBH:

- larger chirp masses (larger M2)
- lower dual fraction
- ~X2 lower GW background

- ~X2 lower than PTA

Checking selection effects

Conclusions

- Using ~20 telescopes/instruments to build a large sample of duets at sub-arcsec separations (common host galaxy) and z>0.5
- First statistical sample of duets with a well defined selection function
- Physical quantities: BH mass, Lbol, dual fraction ....
- Comparison with models
- (Temporary) results on GW background: lower number of more powerful events, X2 lower GW background than PTA