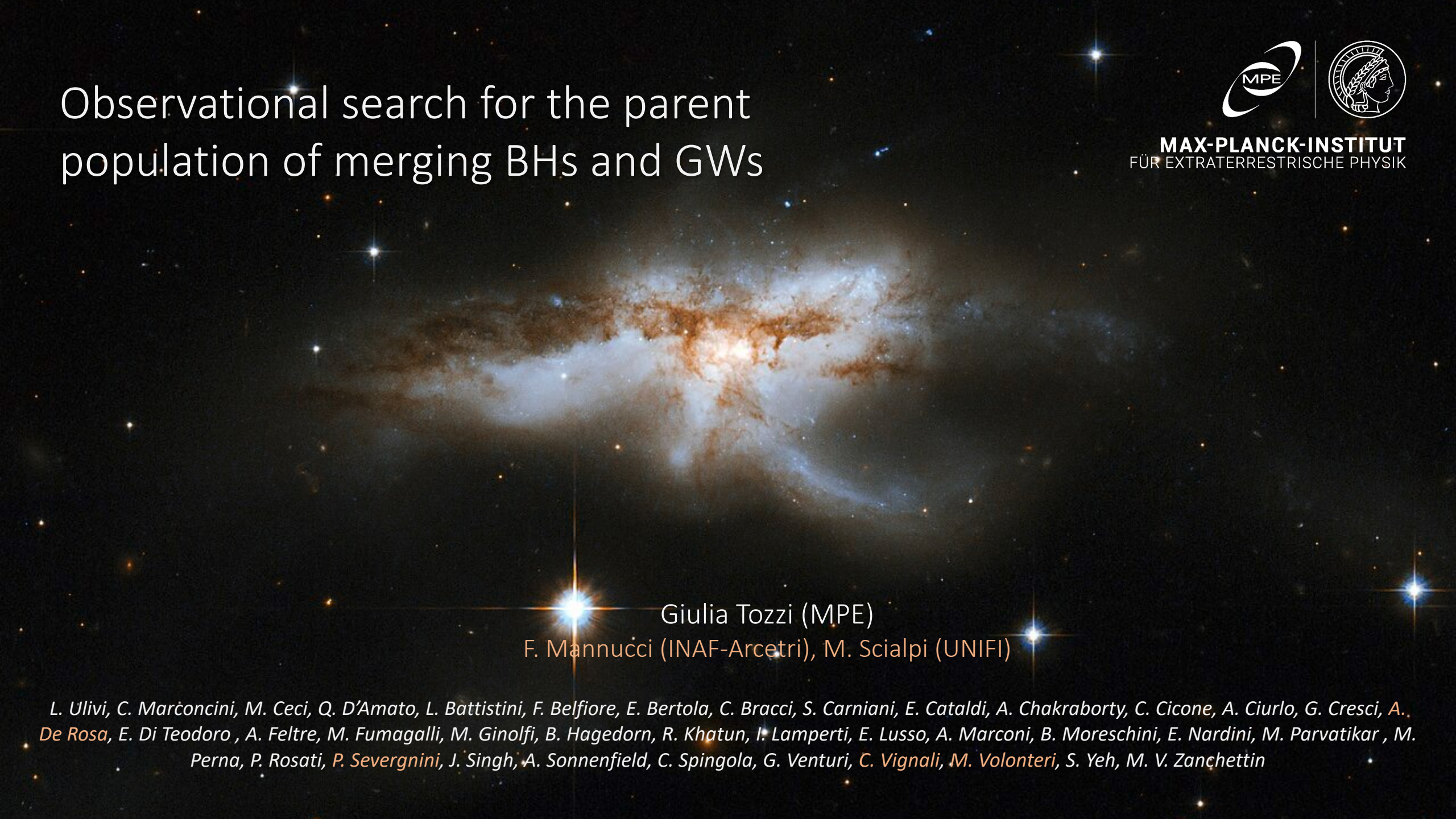
Observational search for the parent population of merging BHs and GWs



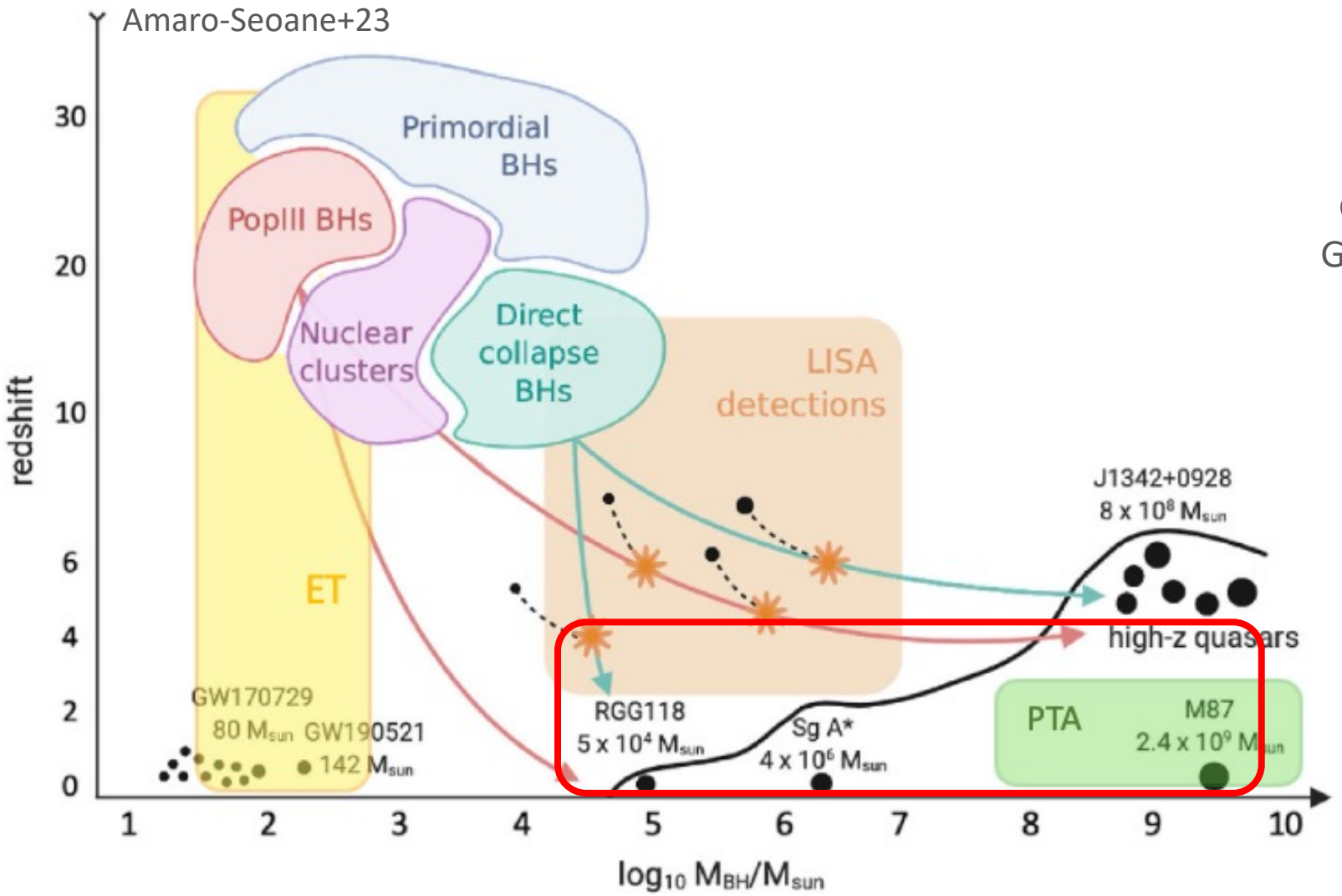
MAX-PLANCK-INSTITUT
FÜR EXTRATERRESTRISCHE PHYSIK

Giulia Tozzi (MPE)

F. Mannucci (INAF-Arcetri), M. Scialpi (UNIFI)

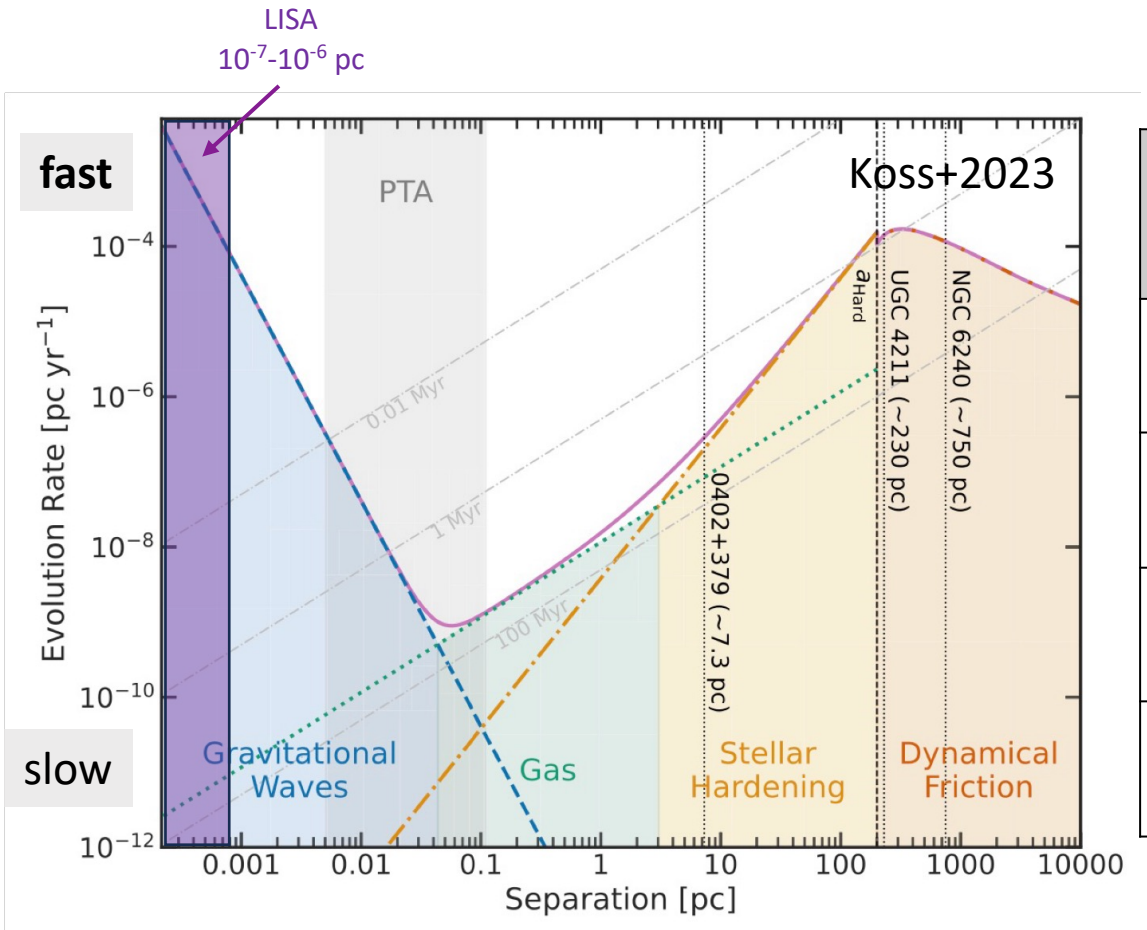
L. Ulivi, C. Marconcini, M. Ceci, Q. D'Amato, L. Battistini, F. Belfiore, E. Bertola, C. Bracci, S. Carniani, E. Cataldi, A. Chakraborty, C. Cicone, A. Ciurlo, G. Cresci, A. De Rosa, E. Di Teodoro , A. Feltre, M. Fumagalli, M. Ginolfi, B. Hagedorn, R. Khatun, I. Lamperti, E. Lusso, A. Marconi, B. Moreschini, E. Nardini, M. Parvatikar , M. Perna, P. Rosati, P. Severgnini, J. Singh, A. Sonnenfield, C. Spingola, G. Venturi, C. Vignali, M. Volonteri, S. Yeh, M. V. Zanchettin

Merging BHs and GWs emission



Giersz+15, Miller+02,Lousto+10, Gerosa+19, Dubois+14,Kulier+15, Smith+18, Arca Sedda+21

Long timescales of the in-spiralling of merging BHs

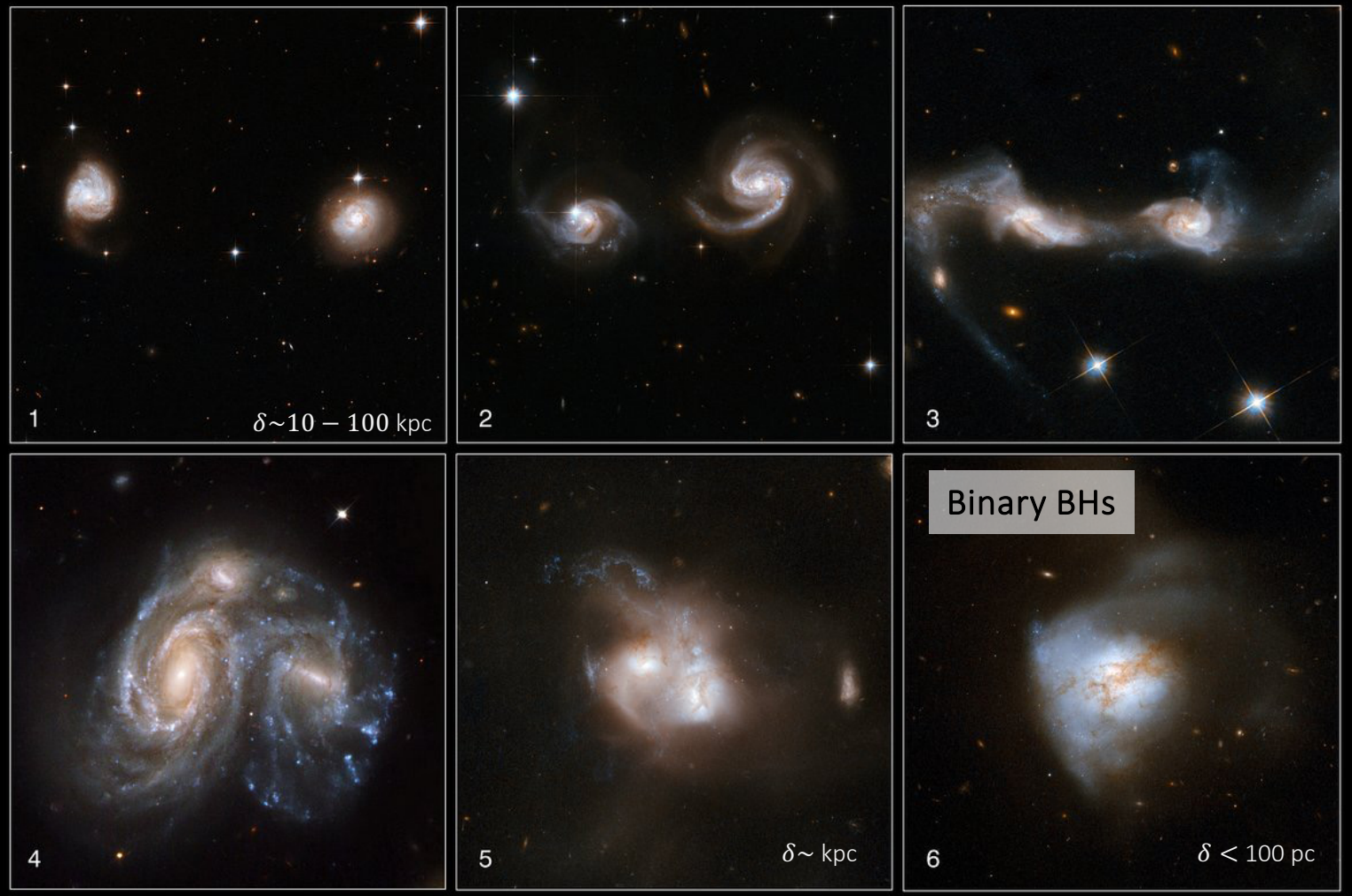


Process	Separation (pc)	Evolution rate (pc/yr)	Timescale (yr)
Dynamical friction of the stellar population	10^2-10^4	10^{-6}-10^{-4}	10^7-10^9
Stellar hardening	1-100	10^{-8}-10^{-4}	10^7-10^{10}
Gas friction	0.1-1	10^{-9}	10^7-10^{10}
GWs	<0.1		10^6-10^7

Long timescales (10^8-10^{10} yrs) → a widespread population of dual AGN at kpc separations

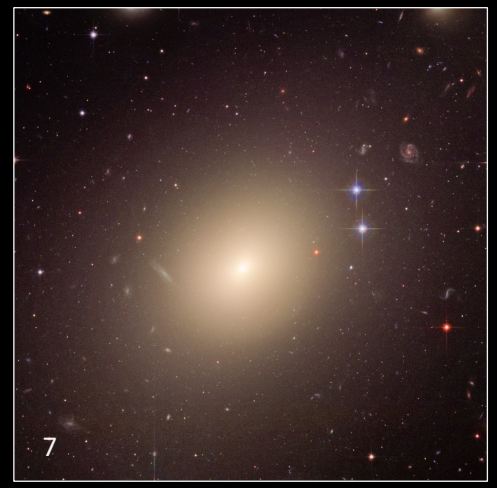
Dual AGN at subarcsec separations: Duets

Dual AGN - $\delta < 100$ kpc



HST/NASA/STScI/ESA

BH coalescence
Low-frequency GWs



Dual AGN at subarcsec separations: Duets

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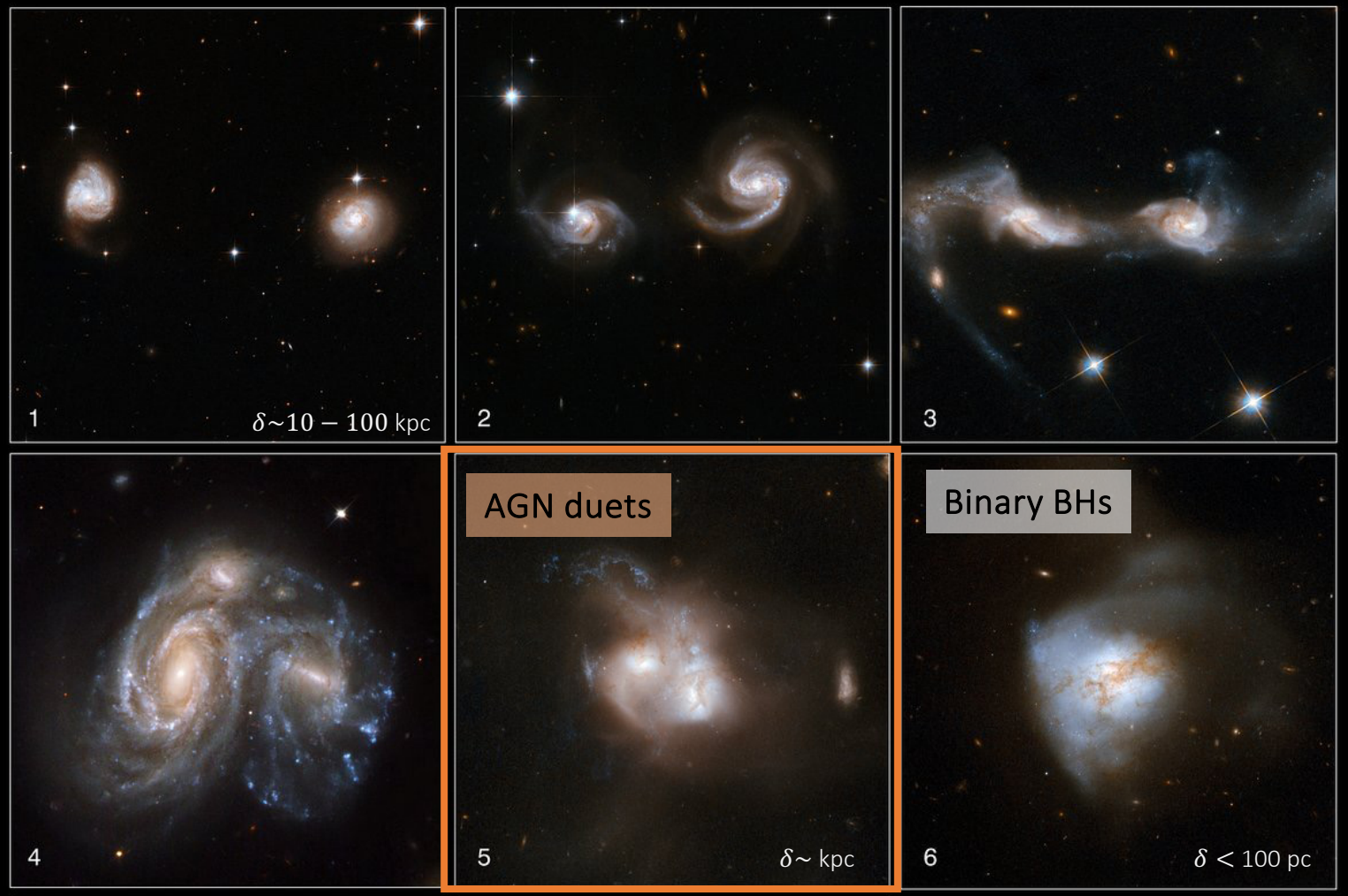

HST/NASA/STScI/ESA

BH coalescence
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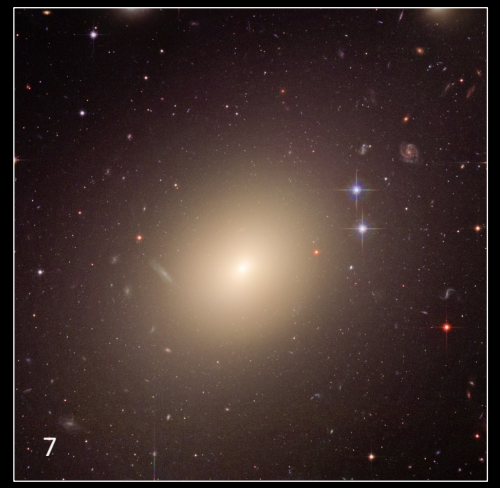


COSMIC DUETS

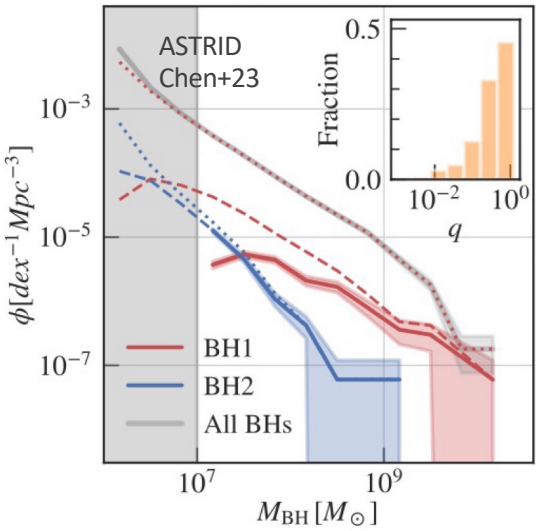
P114 MUSE LP, PI: M. Scialpi

Why is it important to study AGN duets?

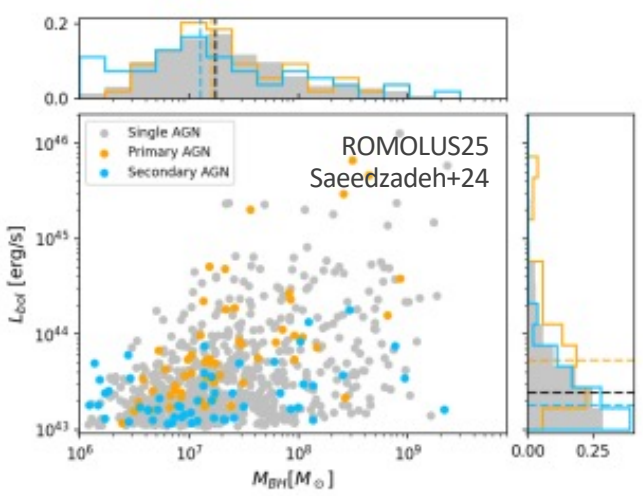
1. AGN duets are an ideal test bench of many never-tested model predictions on BH/galaxy evolution

- Effects of mergers on AGN activity, BH growth and host galaxy properties
- Co-evolution of BH and galaxy properties
- Physics of the BH in-spiralling

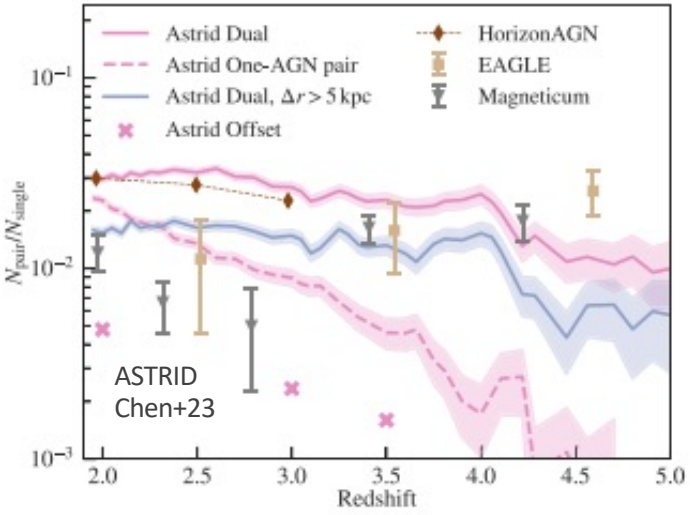
BH mass functions



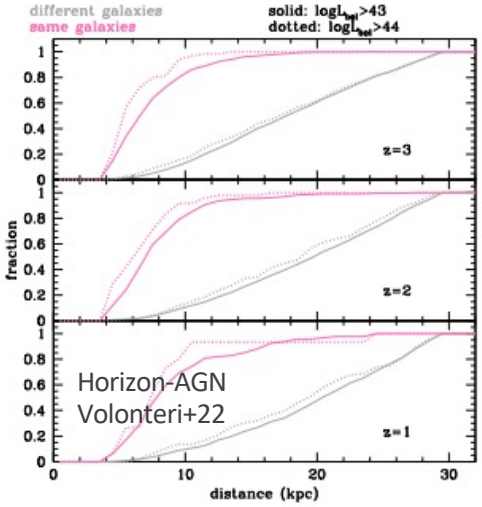
Bolometric luminosities



Dual fraction



Separation distribution



Tremmel+18, Ricarte+19, Rosas-Guevara+19, Silverman+20, Volonteri+20,22, Chen+22,23, Don-Paez+23, Izquierdo-Villalba+23,24, Koehn+23, Partman+23, Damiano+24, Saeedzadeh+24

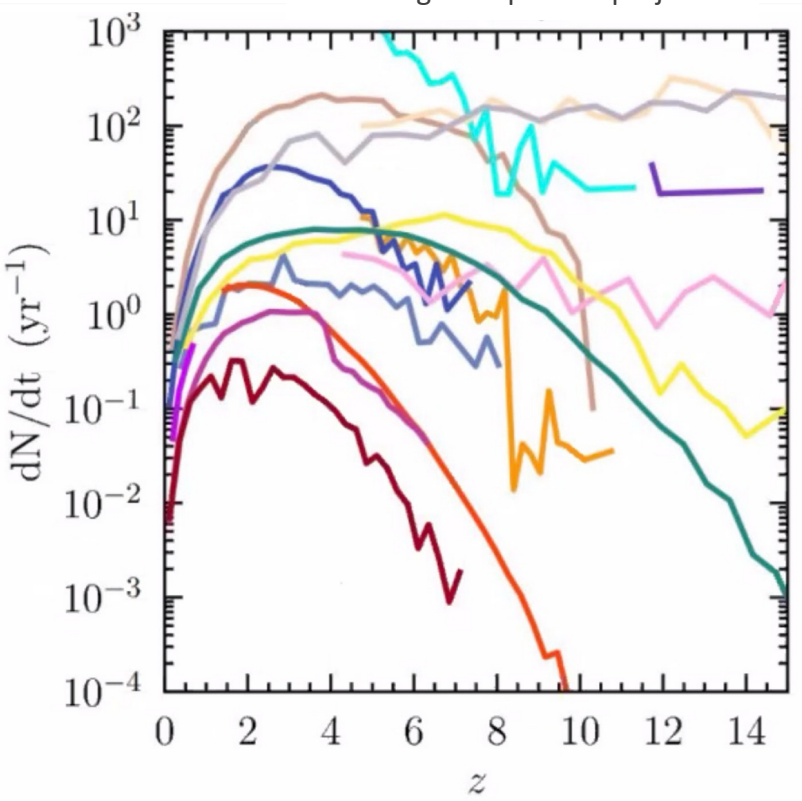
Why is it important to study AGN duets?

2. AGN duets are the parent population of merging BHs and GWs

Measurement of AGN duets properties
- Separation distributions
- Primary and secondary BH mass functions
- Mass ratios
- Eddington ratios
- Number density
- Dual-to-single AGN fraction
- Evolution in redshift

Crucial constraints on:
- the GW event rate currently predicted for LISA
- the merging BHs population: the longer the delay between galaxy and BH mergers → the lower the BH merger rate → the larger the number of AGN duets!

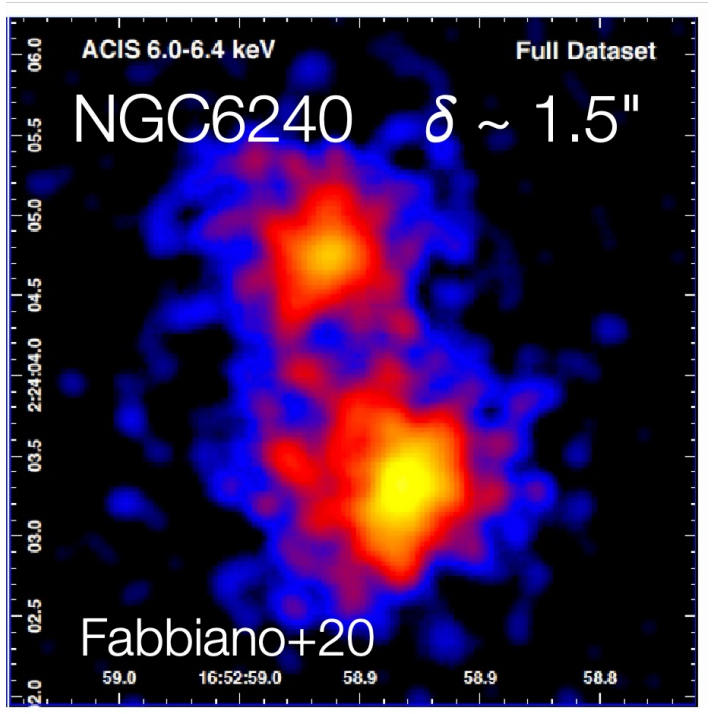
LISA MBH catalogs comparison project



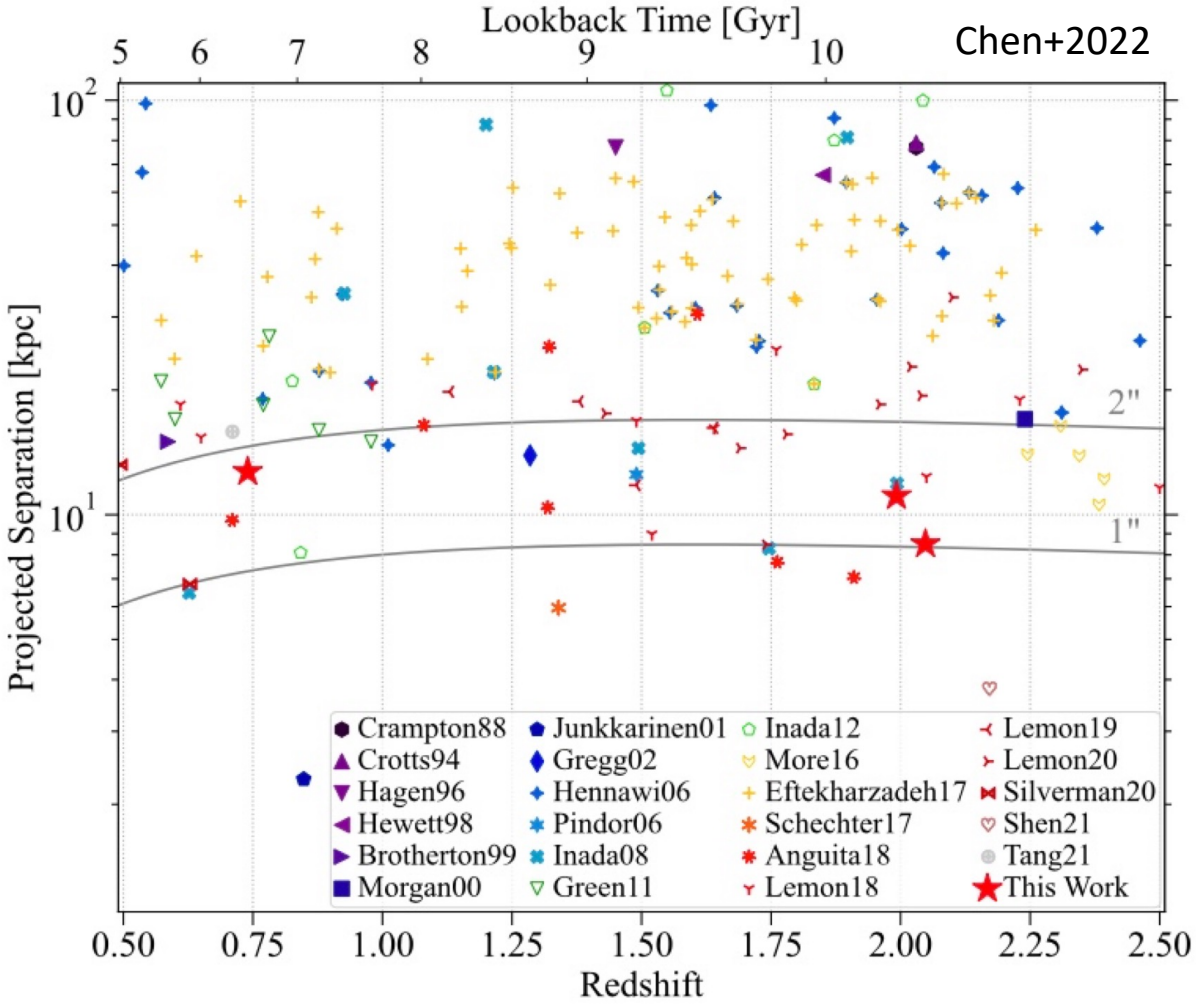
Colpi+14, Amaro-Seoane+17, Babak+17, Izquierdo-Villalba+22, Agazie+23, Di Matteo+23

Status of the observations in 2022

- A few known systems in the local Universe
- Distant ($z > 0.5$) systems at large separations
- Only 4 confirmed systems at $z > 1$ and $\delta < 7$ kpc



Chen+2022



Detection of AGN duets: an observational challenge!

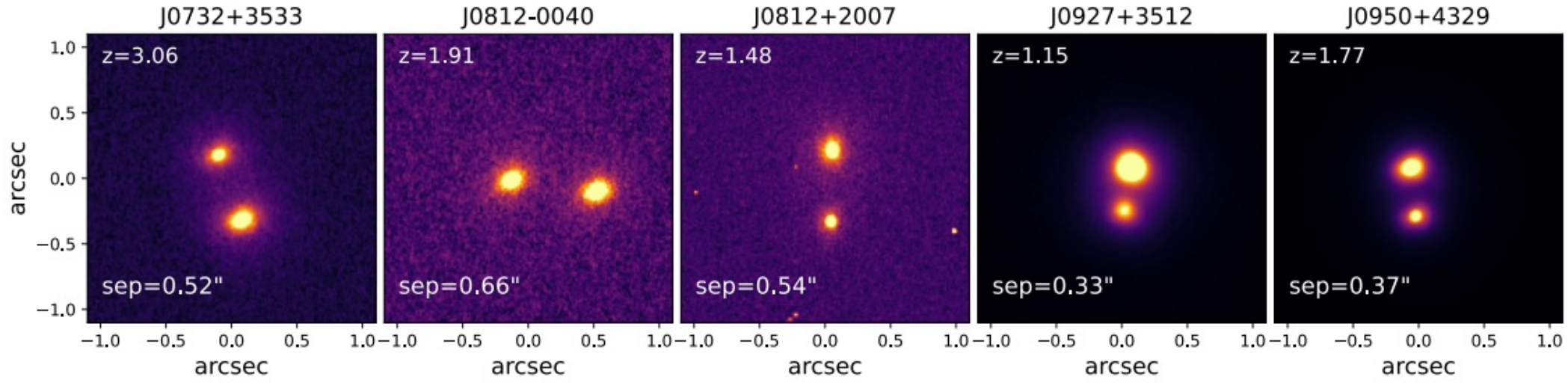
- Same host galaxy, $\delta < 7$ kpc $\sim 0.8''$ → **high spatial resolution**
- Rare systems → **large sky coverage**

Our strategy

1. Selection of candidates, i.e. known AGN at $0.5 < z < 3.5$ with close companions → **This talk**
2. Assessing their nature: 1) dual AGN, 2) lensed systems, 3) AGN+star
3. Measurement of dual AGN properties and comparison with models

} **see M. Scialpi's & F. Mannucci's talks!**

AO-assisted LBT $2'' \times 2''$ images (Mannucci[+GT]+2022)

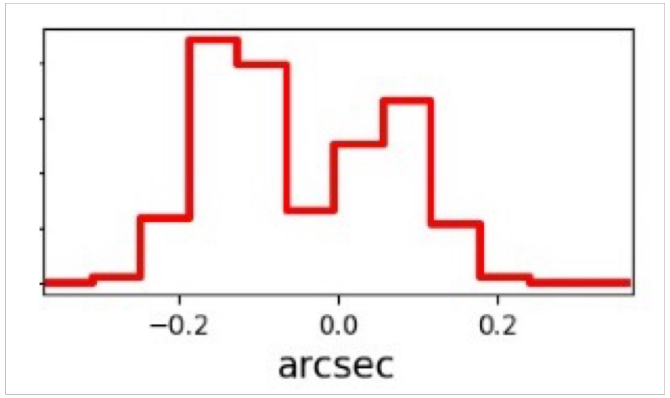


Selection of AGN duets candidates

GMP

Gaia Multi Peak

- all sky
- G<20.5 (L_{bol}>45.5 erg/sec)
- 0.15"<δ<0.7"
- L1/L2<15



Mannucci+22 [+GT, Nature Astr.], Ciurlo+23 [+GT], Scialpi+24 [+GT]

Selection of AGN duets candidates

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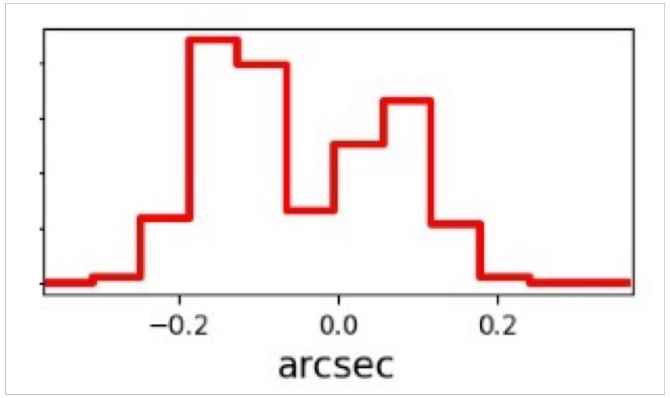
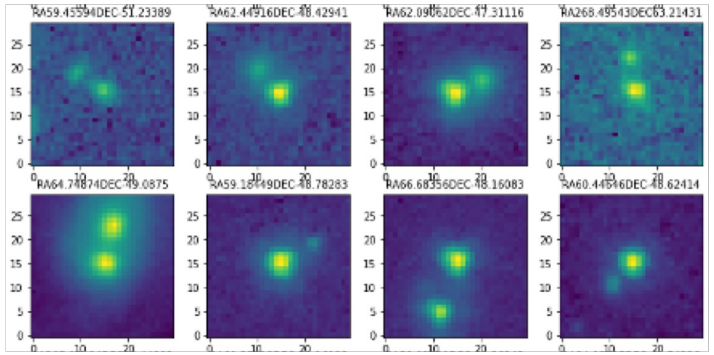


Mannucci+22 [+GT, Nature Astr.], Ciurlo+23 [+GT], Scialpi+24 [+GT]

PEACE

Probing Entwined AGN candidates with Euclid

- all extra-gal sky
- VIS I<25 (L_{bol}>43.5 erg/sec)
- 0.2"<δ<0.7"

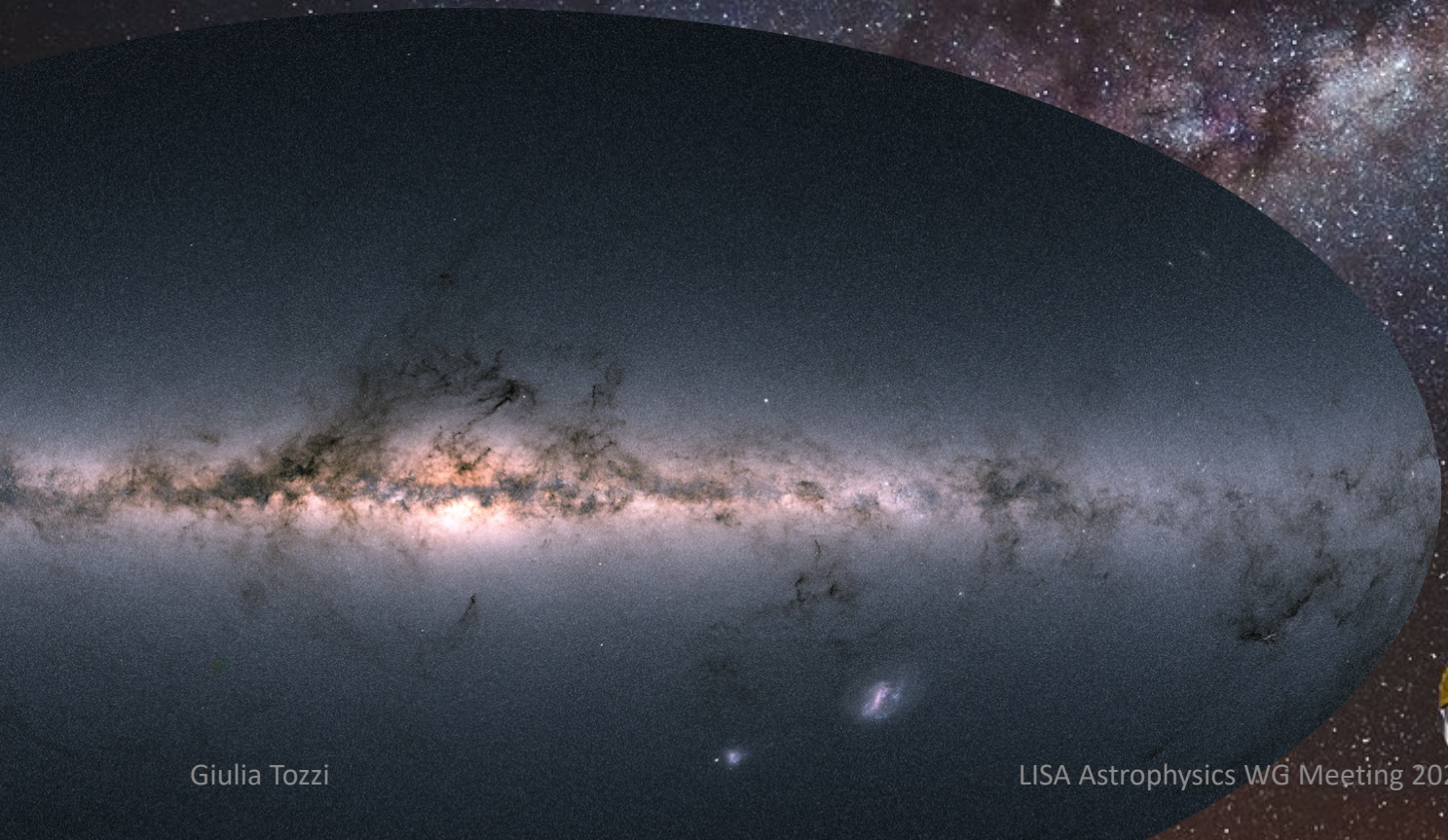


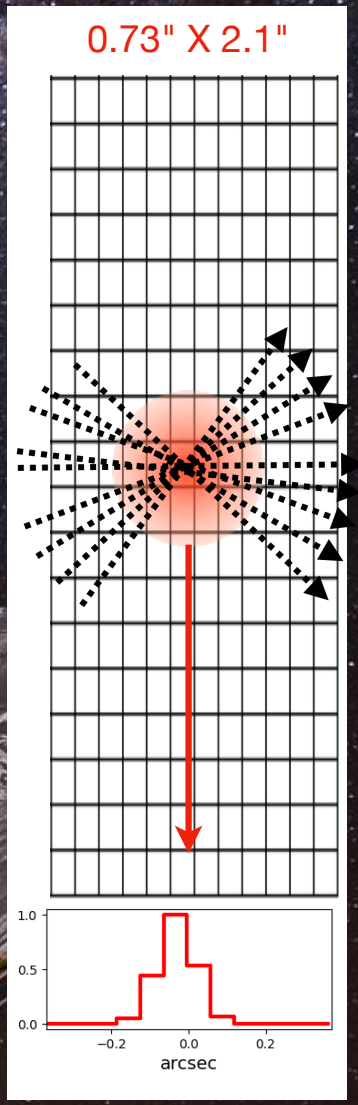
Cuillandre+24, Ulivi+in prep.

Gaia Multi Peak (GMP)

- All-sky survey
- PSF~0.11''
- G < 20.5

- No images, but 1D light profiles
- Multiple scans in different directions



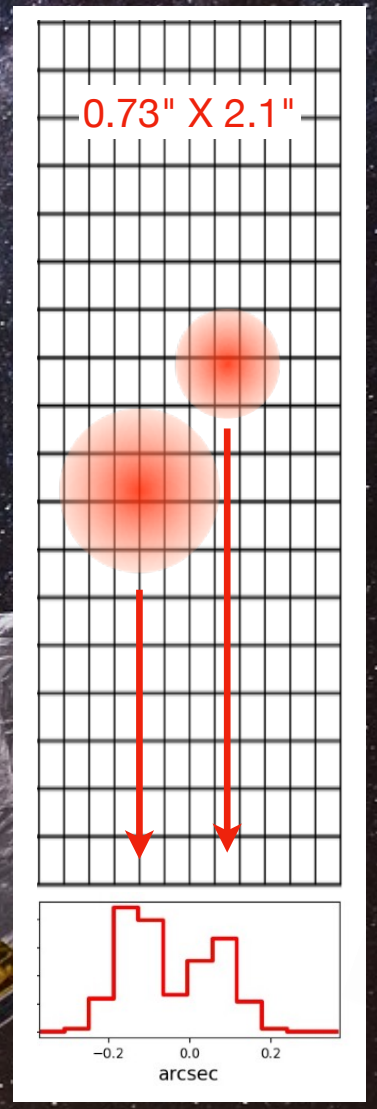


Gaia Multi Peak (GMP)

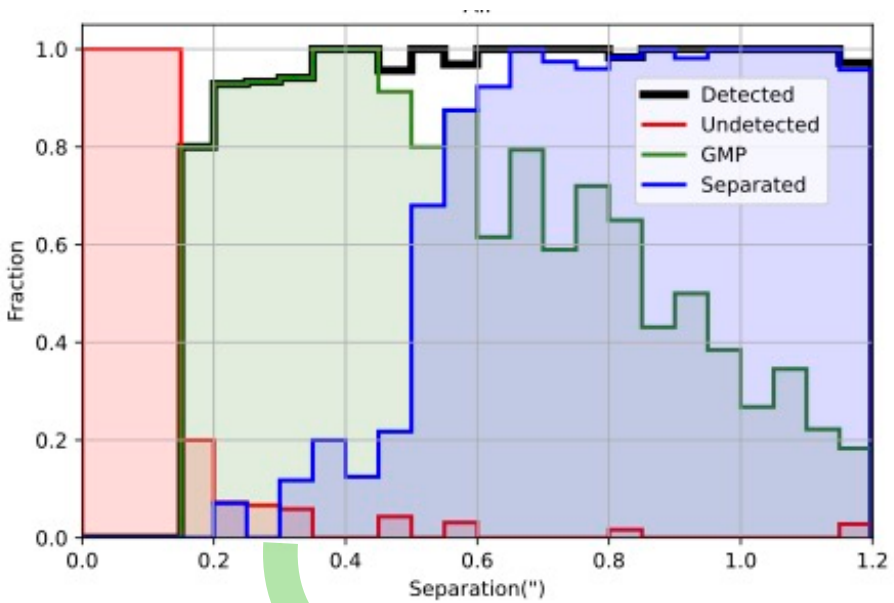
- All-sky survey
- PSF~0.11''
- G < 20.5

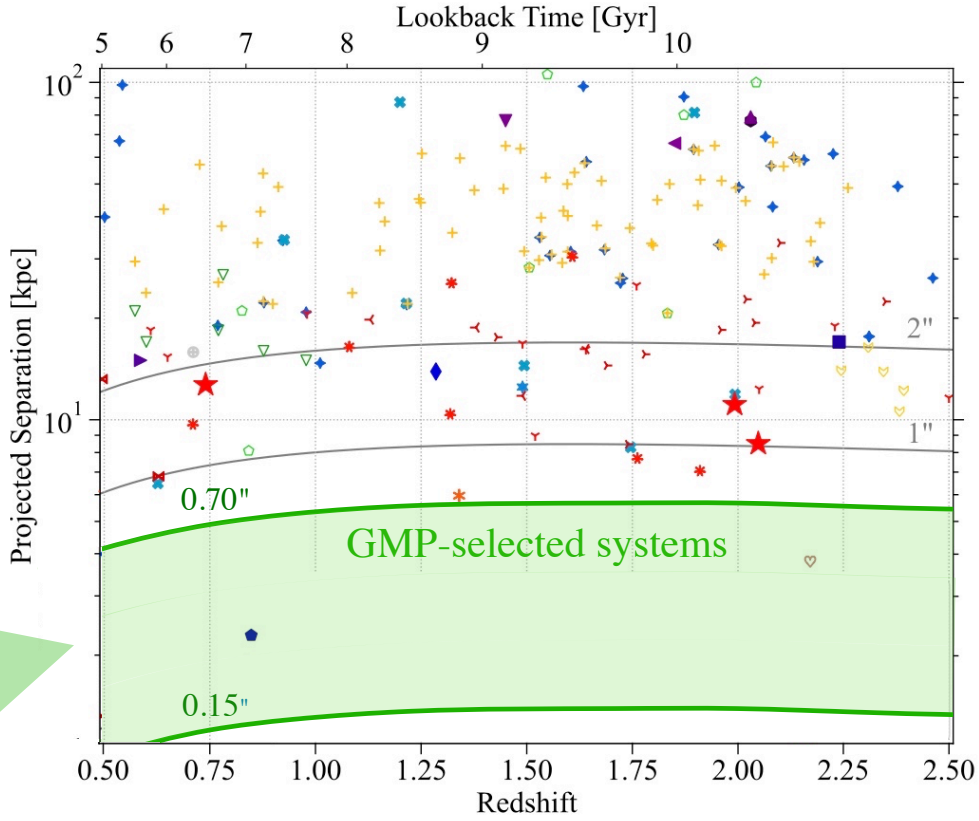
- No images, but 1D light profiles
- Multiple scans in different directions

GMP-selected systems
- Single catalogue entries
- Multi-peaky light profiles
- ~1000 candidates among spec/phot QSOs (~0.1%)



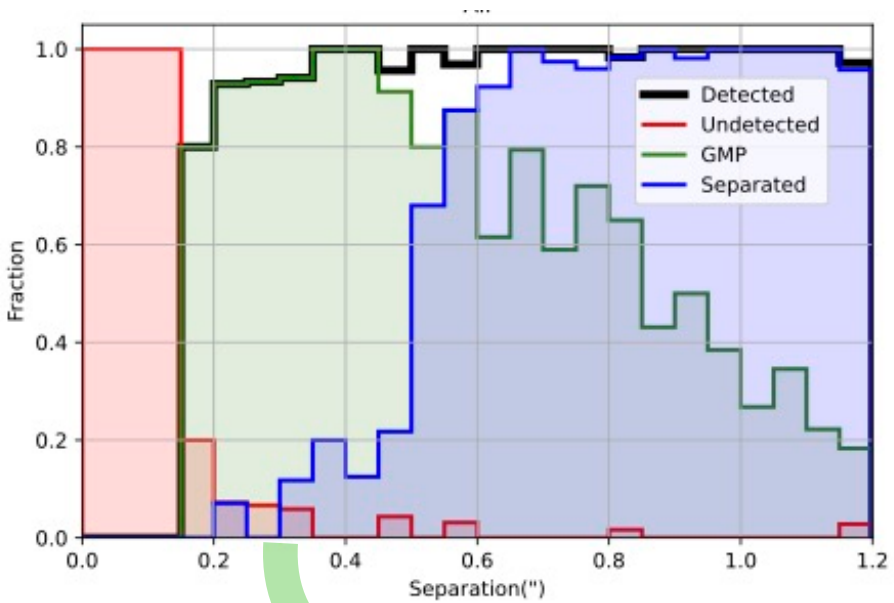
Efficiency of the GMP technique

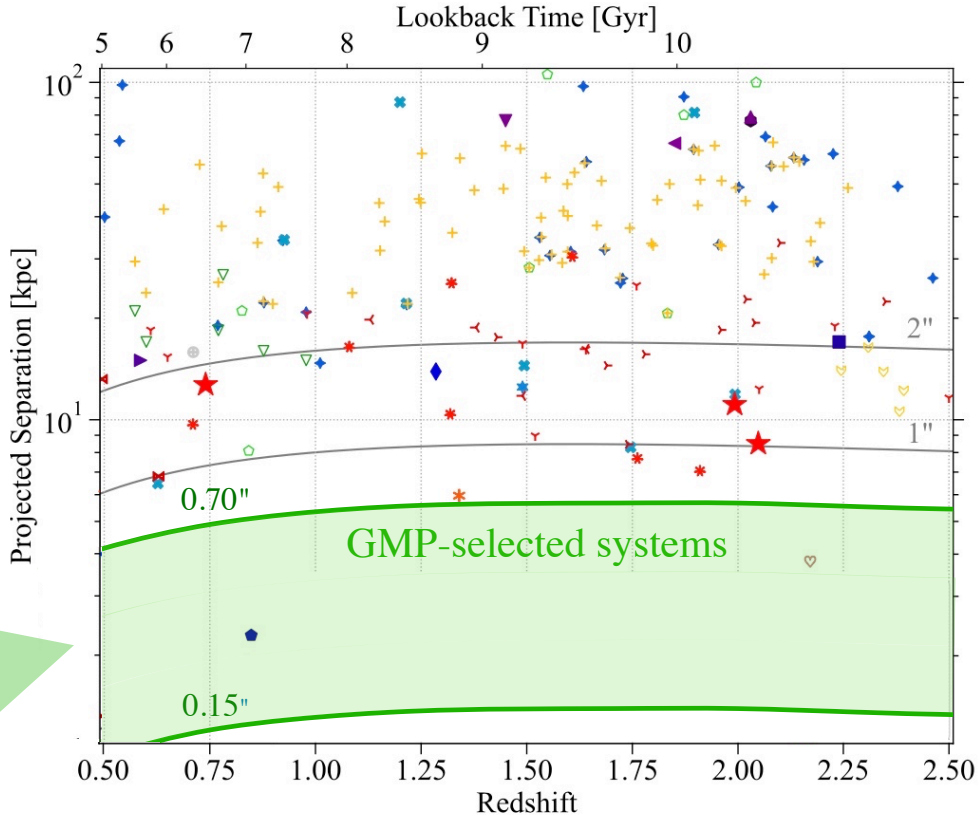




$0.15'' < \delta < 0.7''$
for sources Gaia-classified as 'single' objects

Efficiency of the GMP technique





$0.15'' < \delta < 0.7''$
for sources Gaia-classified as 'single' objects

Limitations

- small luminosity ratios (<15)
- low dust extinction

Euclid

- All (extragalactic) sky survey
- Real imaging
- High spatial resolution ($\sim 0.1''$)
- Stable PSF
- Much deeper than Gaia ($I_E \sim 25.5$)
  - Fainter AGN
  - Larger luminosity ratio

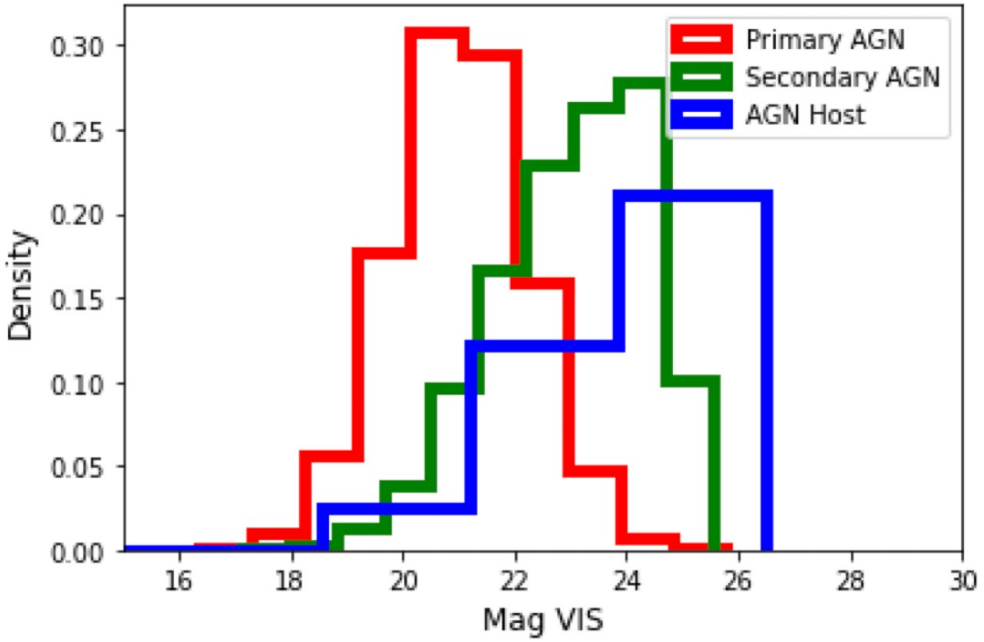
Machine Learning to select candidates

Lorenzo Ulivi

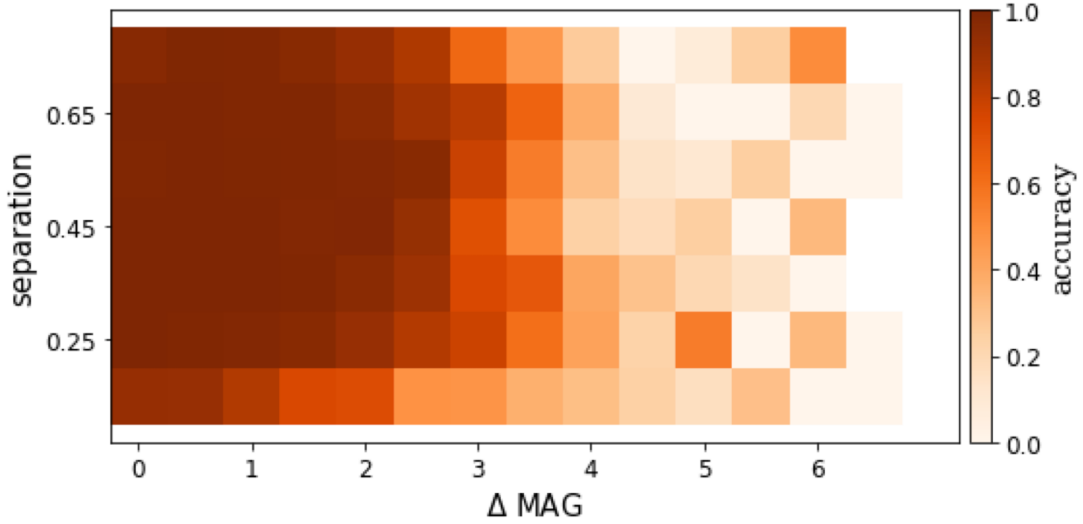
Selection of AGN duets candidates in Euclid via Machine Learning (ML):

- to distinguish real companions from bright clumps in the host
- to reach better resolution than that via standard techniques (e.g. Sextractor)

Magnitude distribution of our simulated dual AGN added to real Euclid optical images of galaxies



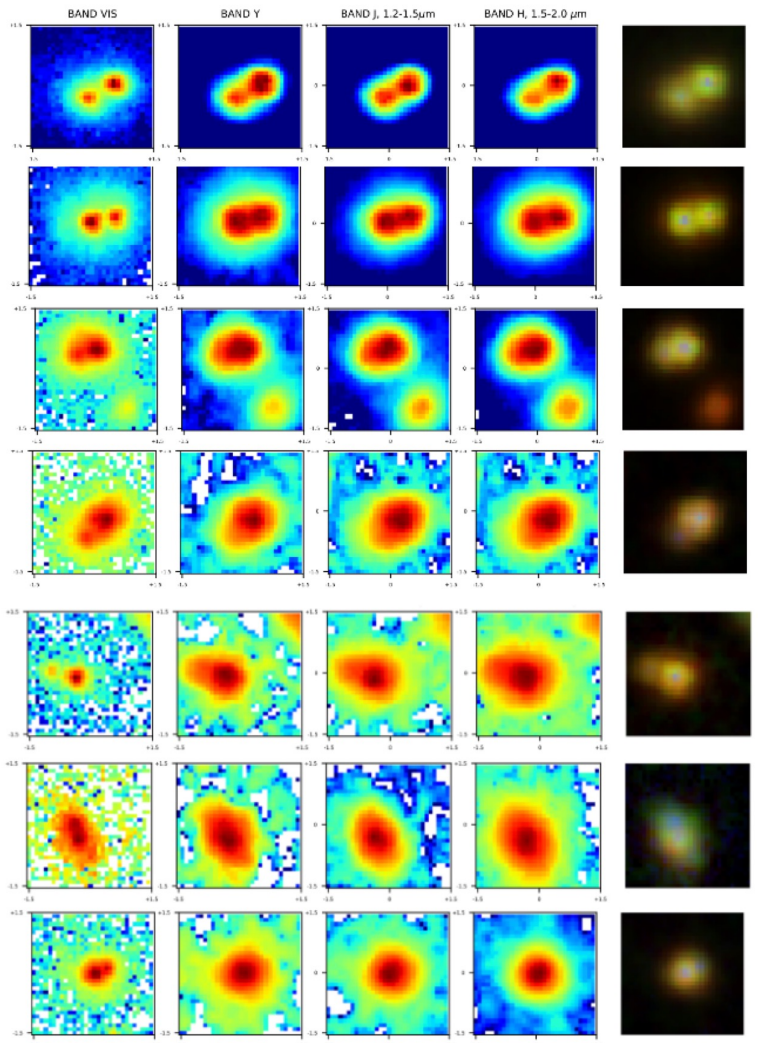
Efficiency of our ML-based selection

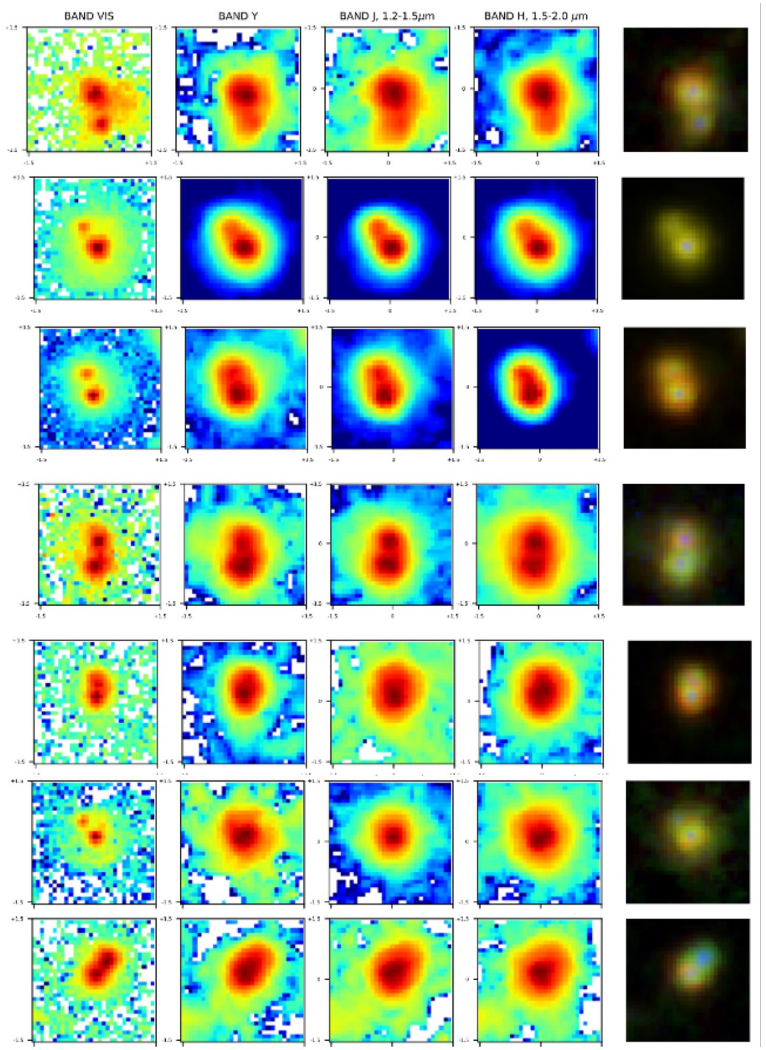


High completeness (~90%) for $\delta > 0.25$ and $\Delta L <\sim 40$

Ulivi+, in prep.

Results from Euclid-based ML selection





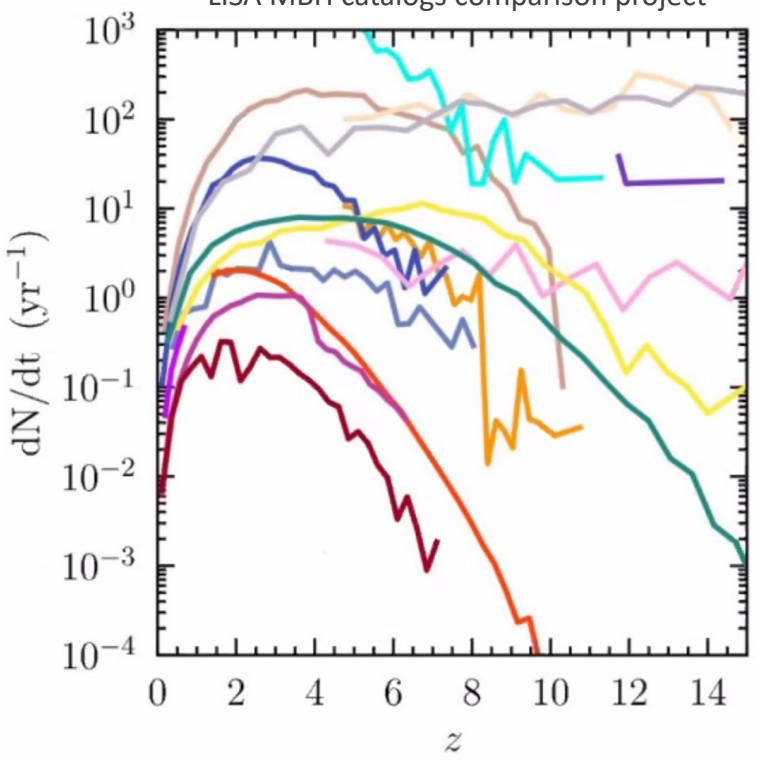
PRELIMINARY

Results obtained so far:
~100 good pair candidates (0.8% of 12,000 examined QSOs)

Ulivi+, in prep.

Summary & conclusions

LISA MBH catalogs comparison project



- Studying **AGN duets** is crucial to put constraints on model predictions: the GW event rate, the population of merging BHs and BH/galaxy evolution

- Successful selection of AGN duet candidates using **Gaia** and **Euclid** observations

- Need for extensive observational campaigns to:
  - ➢ confirm their duet nature candidates
  - ➢ ultimately gather a statistical significant sample of confirmed AGN duets, necessary to firmly constrain models

see M. Scialpi's & F. Mannucci's talks!