Hierarchical galaxy merger estimate using machine-learning algorithm and MUSE galaxy catalogues for massive black hole merger detection with LISA

Delpech Rémi (IRAP)
Thierry Contini (IRAP)
Sylvain Marsat (L2IT)

LISA Astrophysic WG
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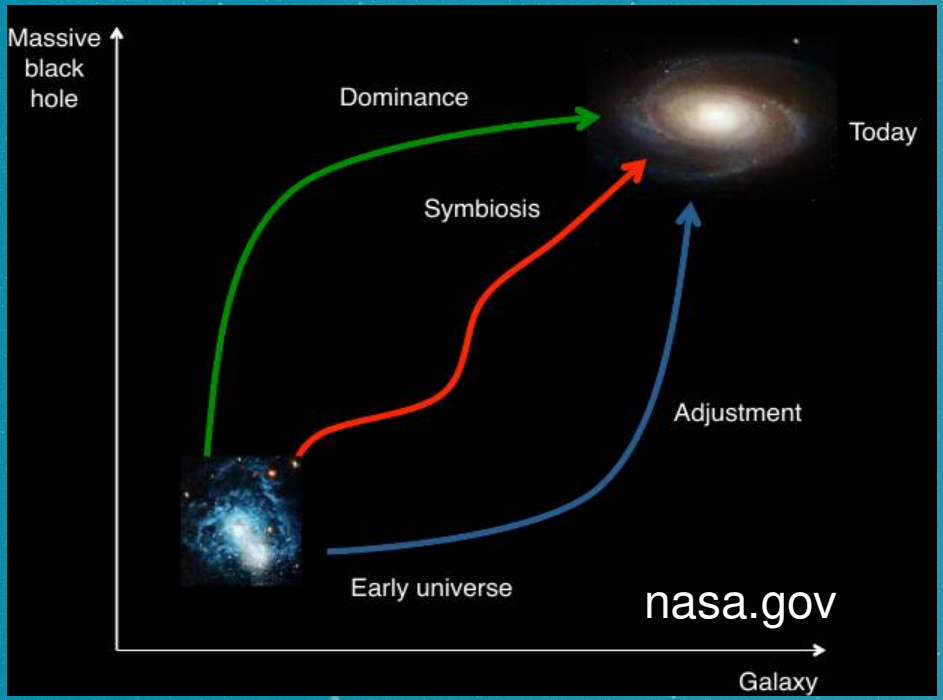
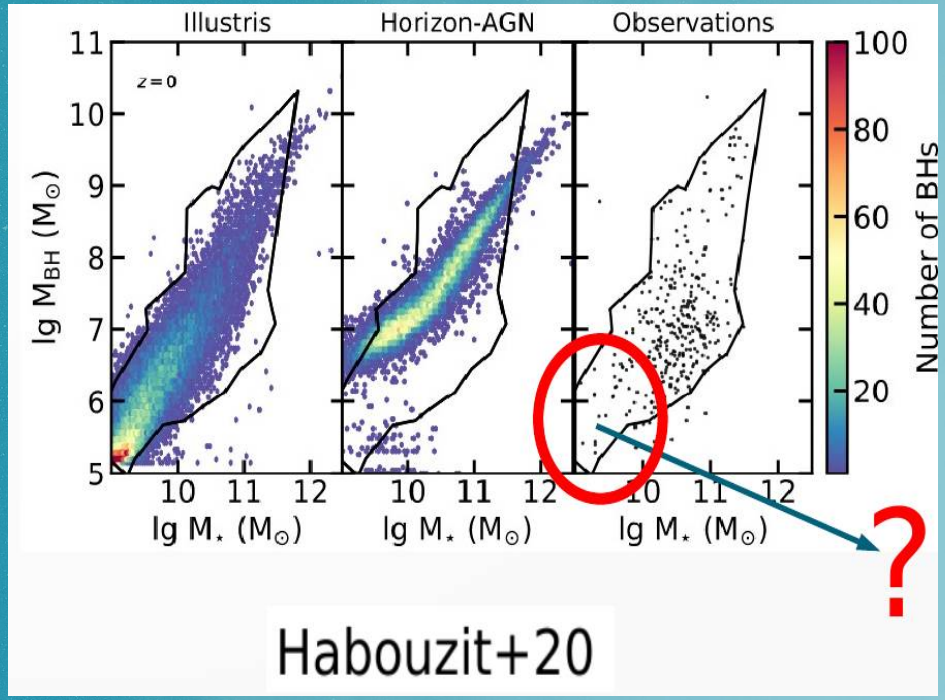
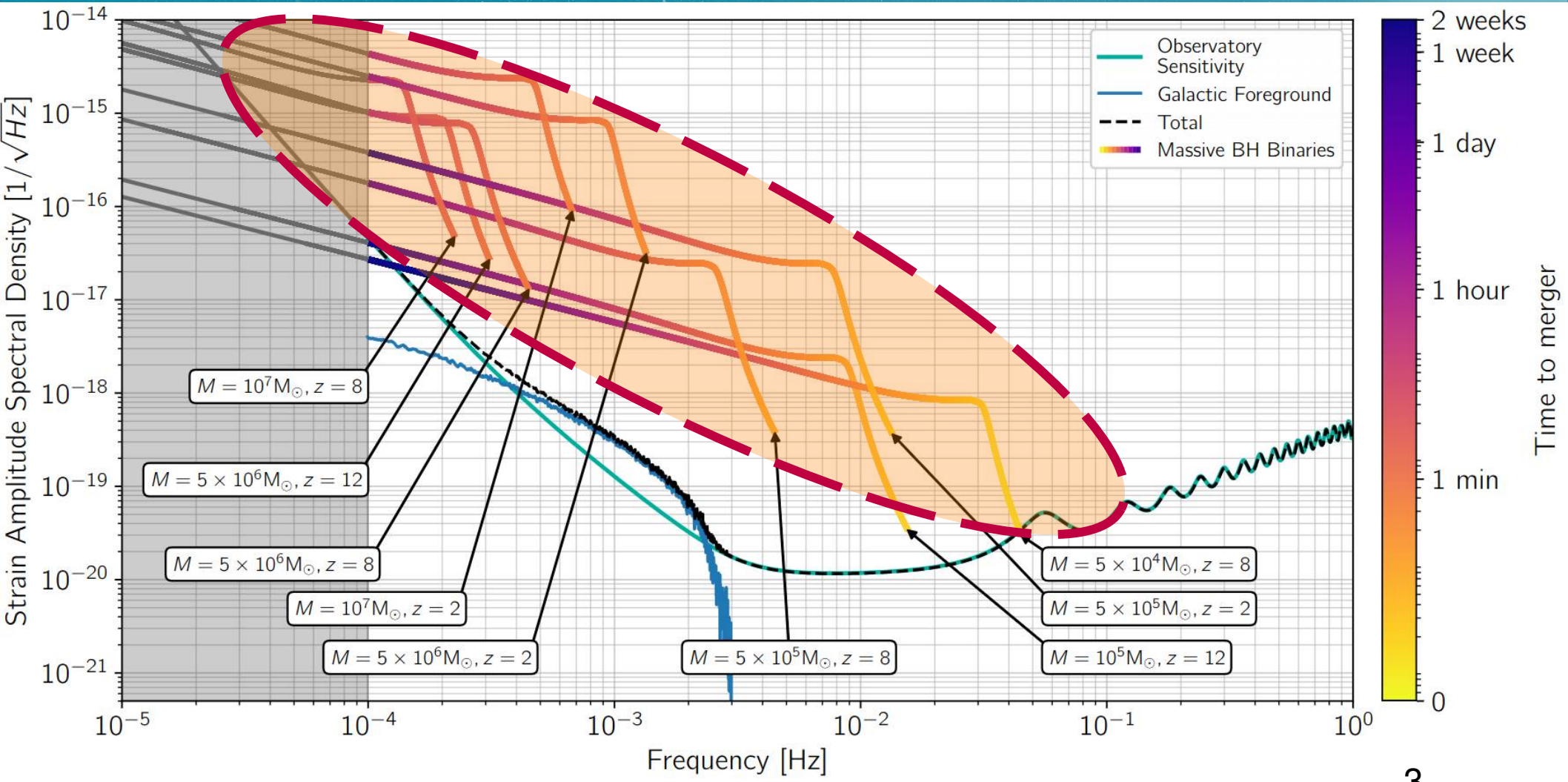
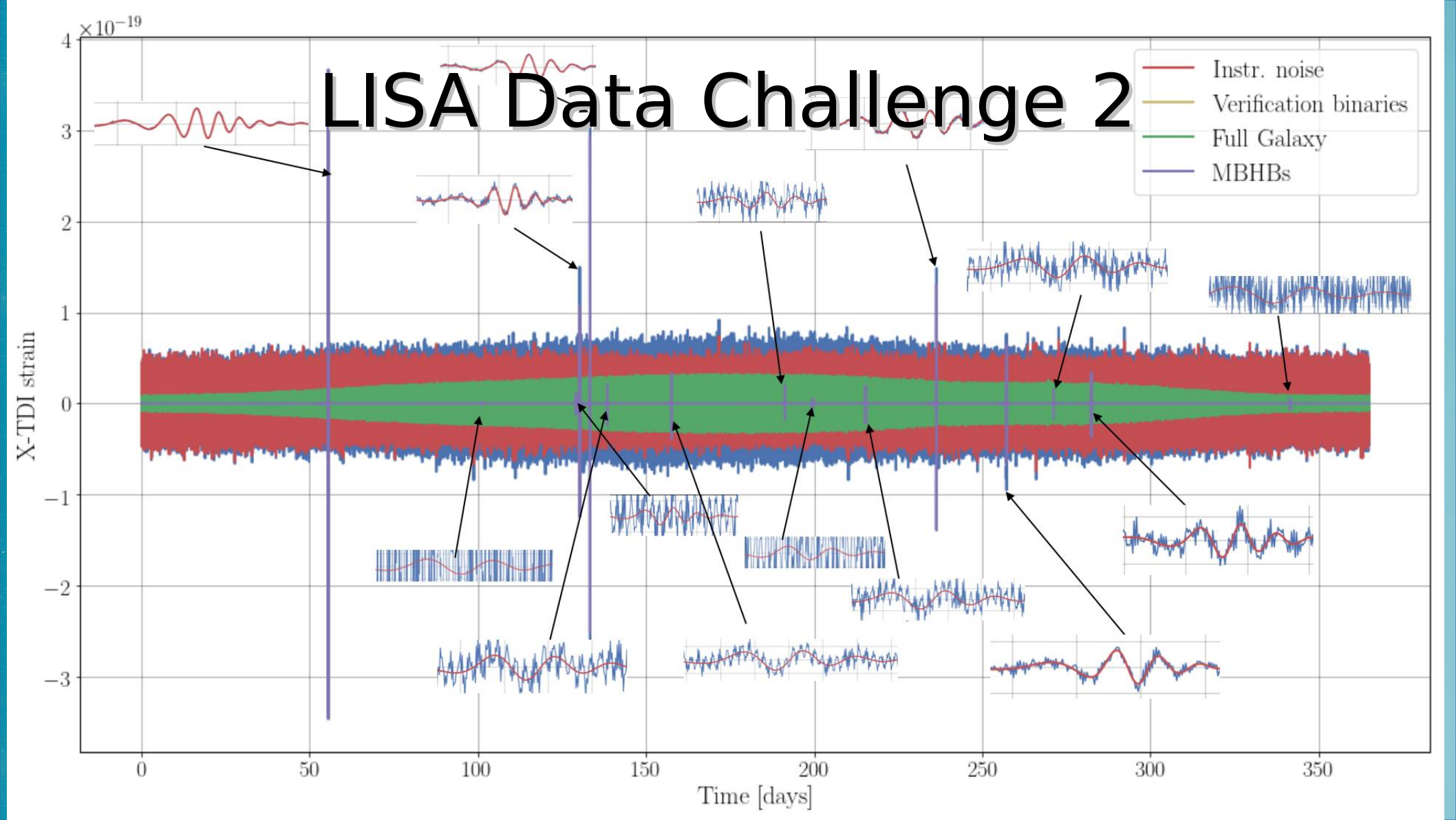
How MBH have grown during the history of galaxies?





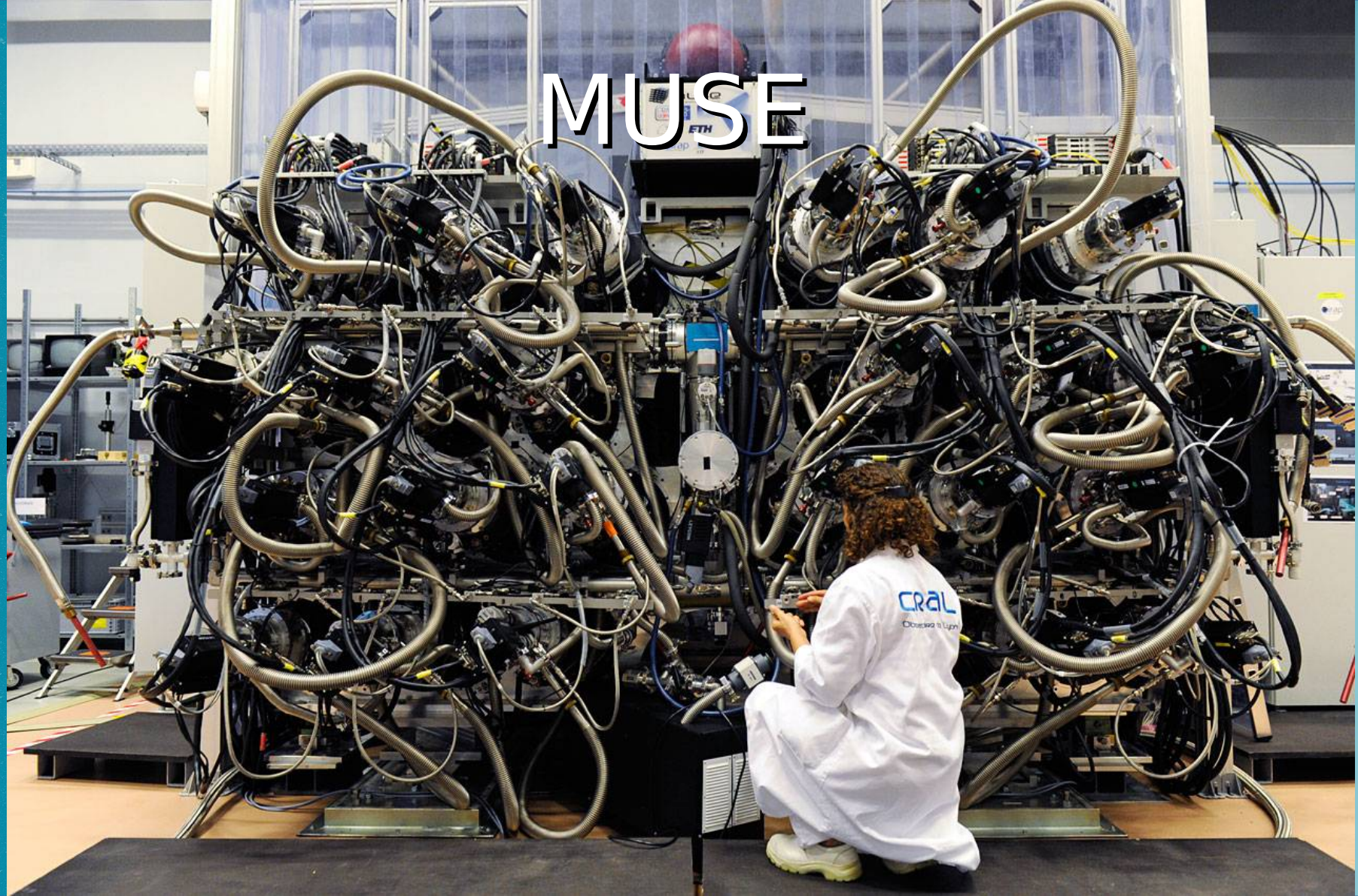

Observatory Sensitivity
Galactic Foreground
Total
Massive BH Binaries
$M = 10^7 M_\odot, z = 8$
$M = 5 \times 10^6 M_\odot, z = 12$
$M = 5 \times 10^6 M_\odot, z = 8$
$M = 10^7 M_\odot, z = 2$
$M = 5 \times 10^6 M_\odot, z = 2$
$M = 5 \times 10^5 M_\odot, z = 8$
$M = 5 \times 10^4 M_\odot, z = 8$
$M = 5 \times 10^5 M_\odot, z = 2$
$M = 10^5 M_\odot, z = 12$
Strain Amplitude Spectral Density $[1/\sqrt{Hz}]$
Frequency [Hz]
Time to merger
2 weeks
1 week
1 day
1 hour
1 min
0


LISA Data Challenge 2
Instr. noise
Verification binaries
Full Galaxy
MBHBs
×10⁻¹⁹
X-TDI strain
Time [days]
4
3
2
1
0
−1
−2
−3
0
50
100
150
200
250
300
350

Main goal

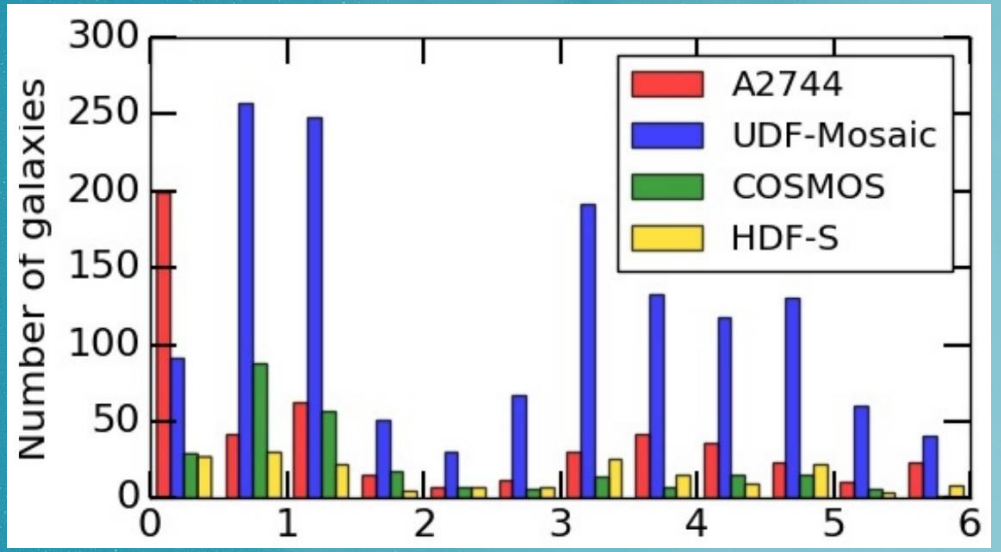
Evaluate the MBH binary merger detection rate of LISA **based** on galaxy populations observed with **MUSE**

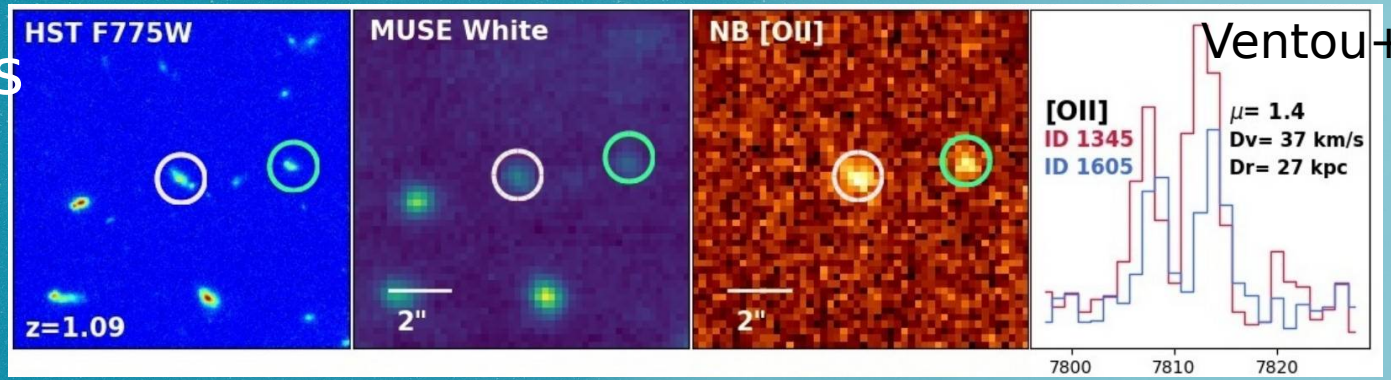
MUSE



MUSE Dataset

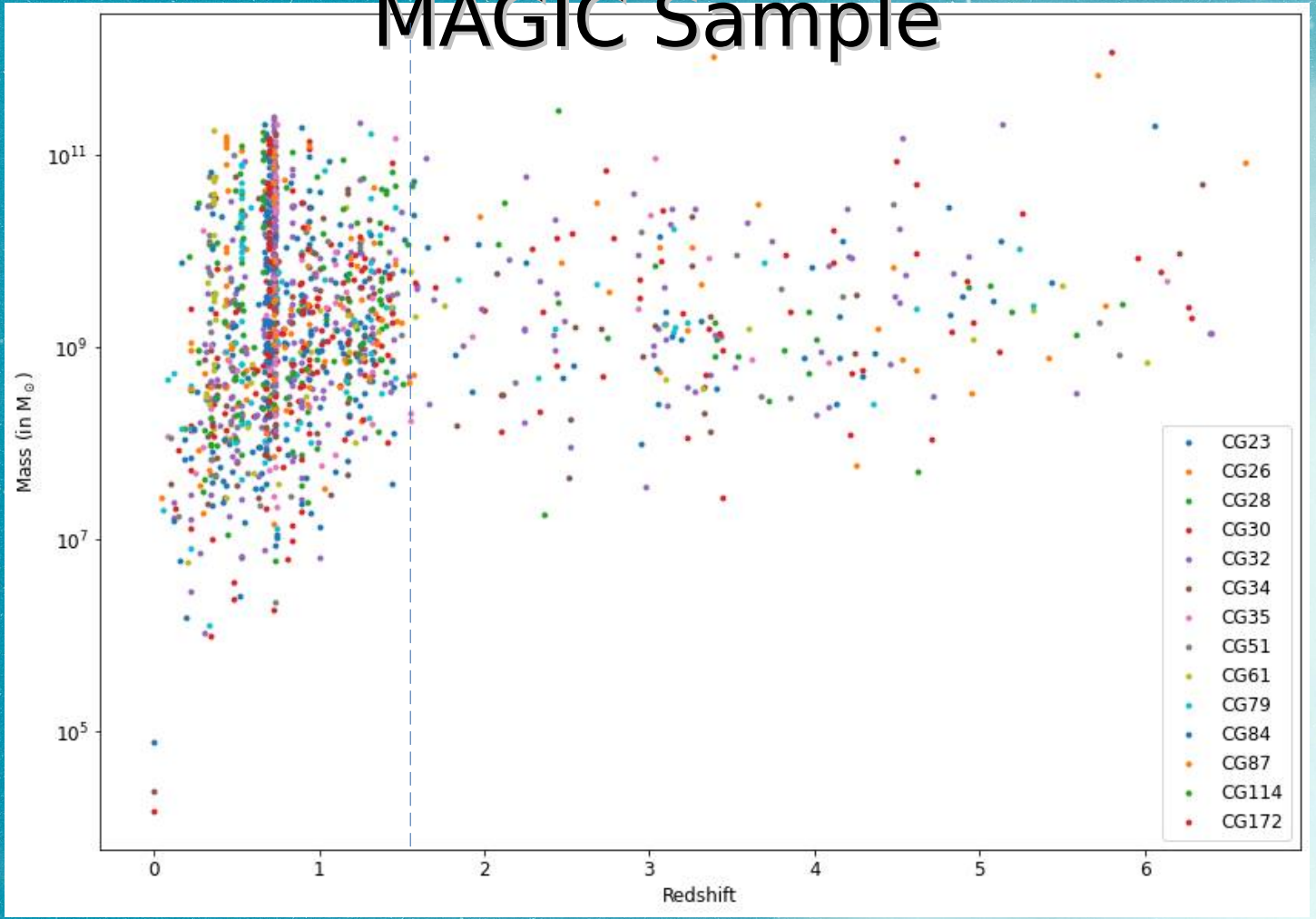
- **More than 2000 selected galaxies**
- Precise z_{spec}
- Accurate estimate of pairs separation (projected distance & velocity) and galaxy masses



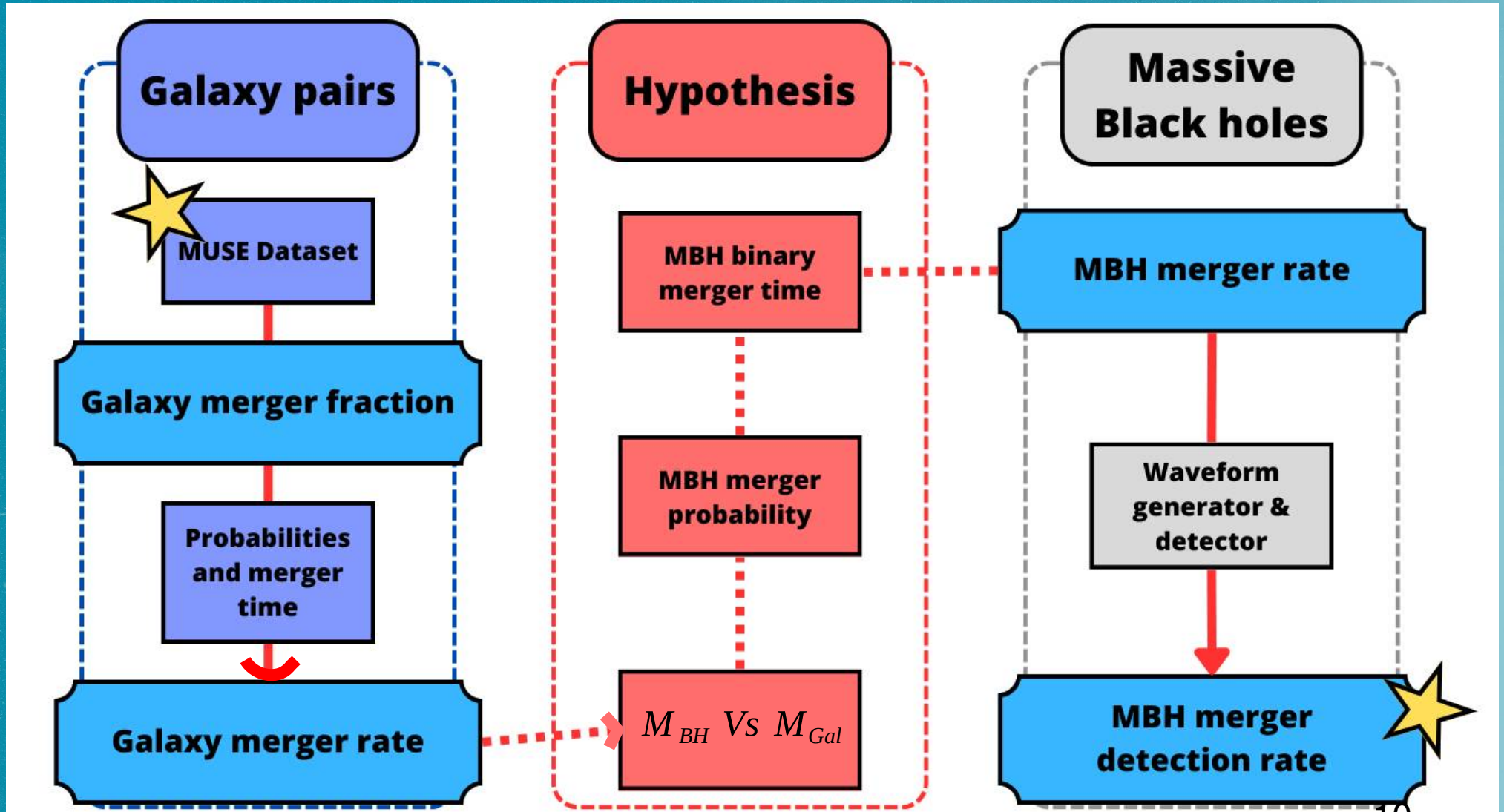


Ventou+19

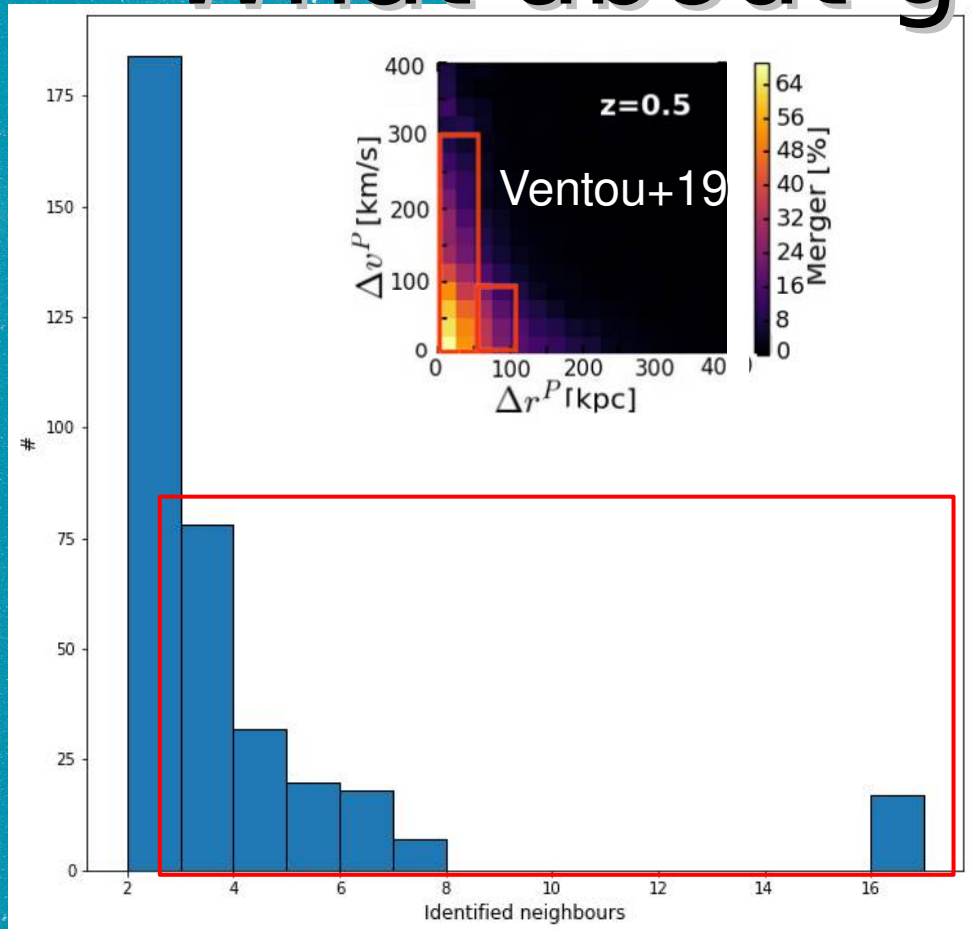
MAGIC Sample



From close pairs to MBH mergers


Galaxy pairs
MUSE Dataset
Galaxy merger fraction
Probabilities and merger time
Galaxy merger rate
Hypothesis
MBH binary merger time
MBH merger probability
M_{BH} Vs M_{Gal}
Massive Black holes
MBH merger rate
Waveform generator & detector
MBH merger detection rate

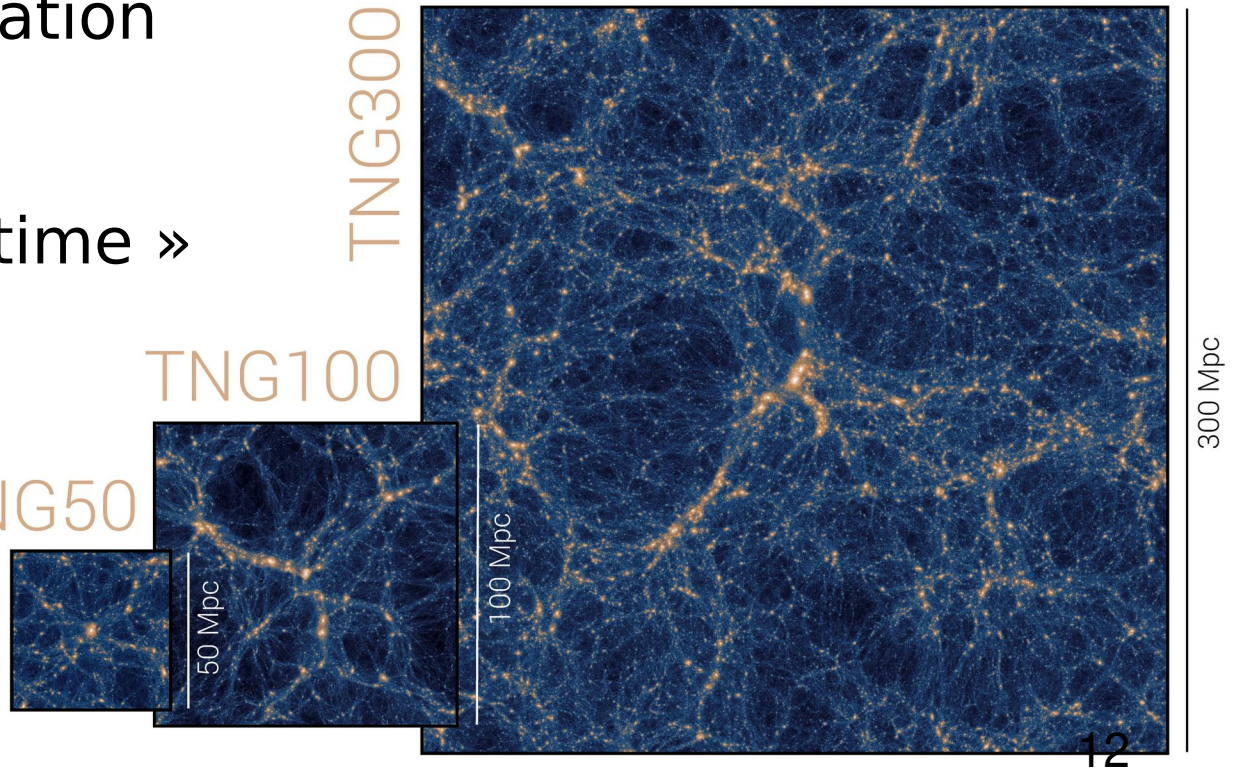
What about galaxy groups ?



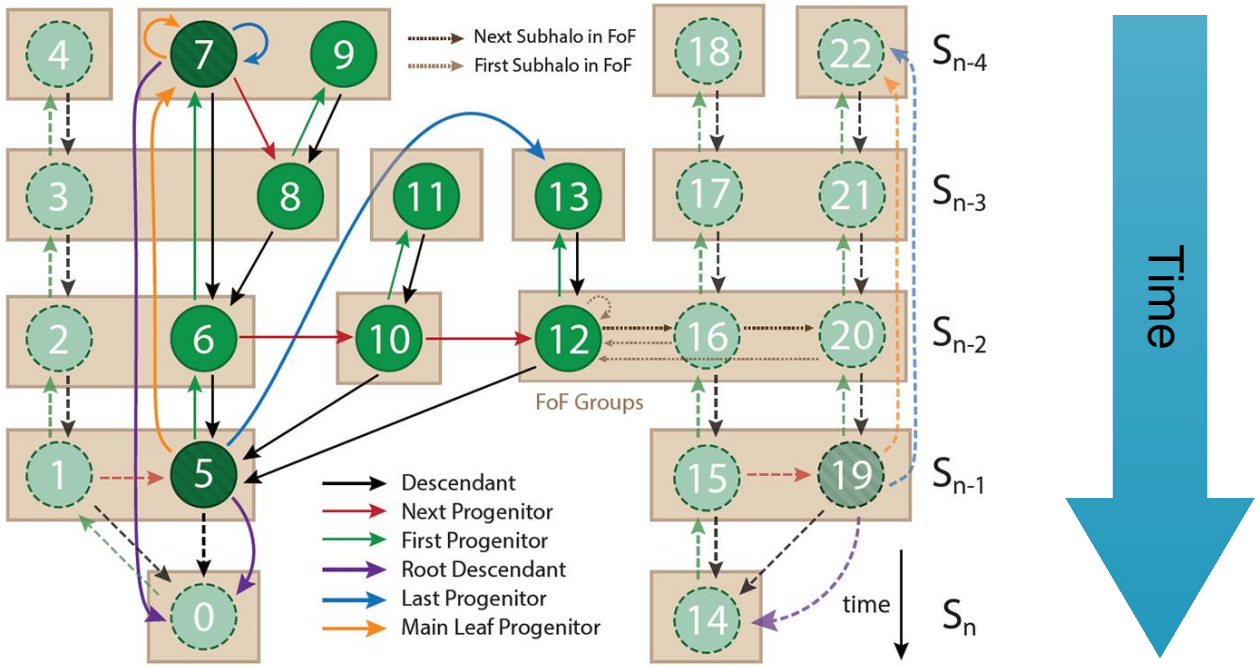
- More than 50 % ot the sample had more than 1 potential neigbour
- What is the merger hierarchy

Illustris – TNG for the ML protocol

- Hydrodynamical cosmological simulation
- ≈300Mpc wide
- High spatial and « time » resolution
- We use it only for galaxy dynamics



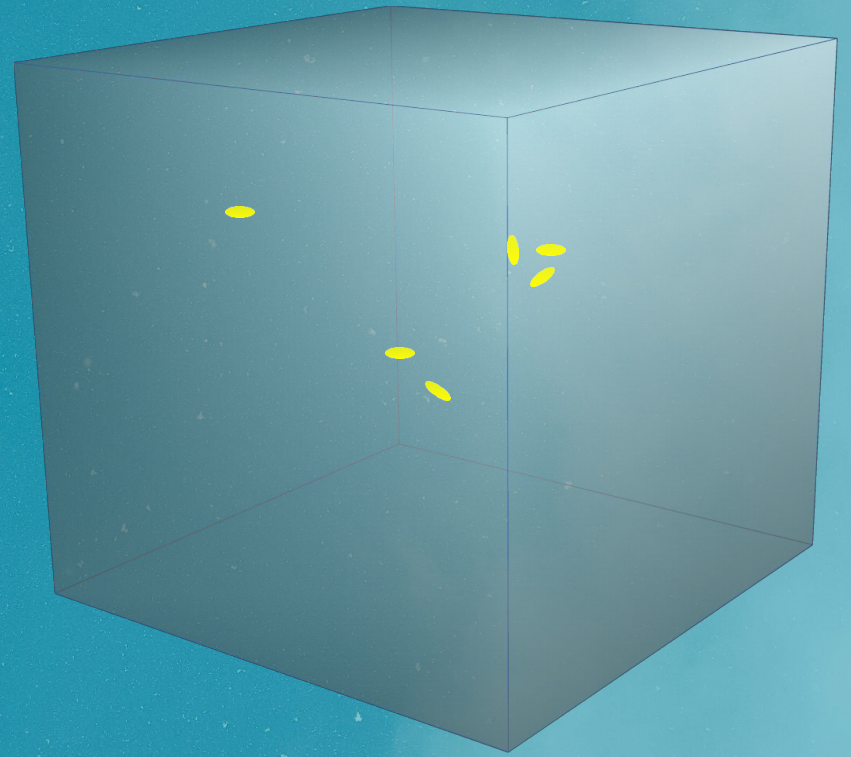
Merger Trees



tng-project.org

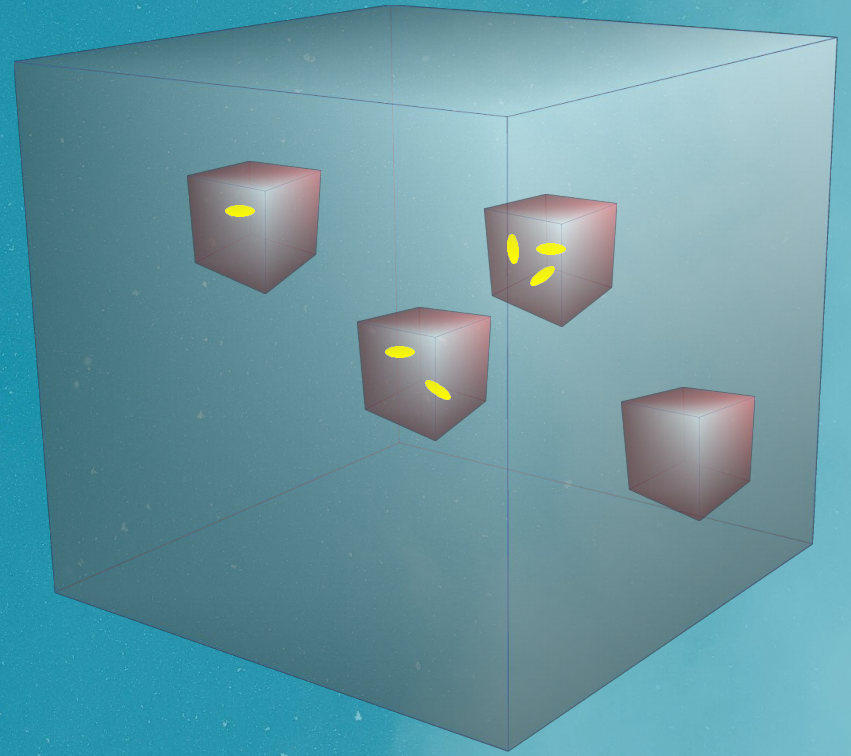
ML Protocol – Dataset

- Random sampling of galaxies in TNG Illustris



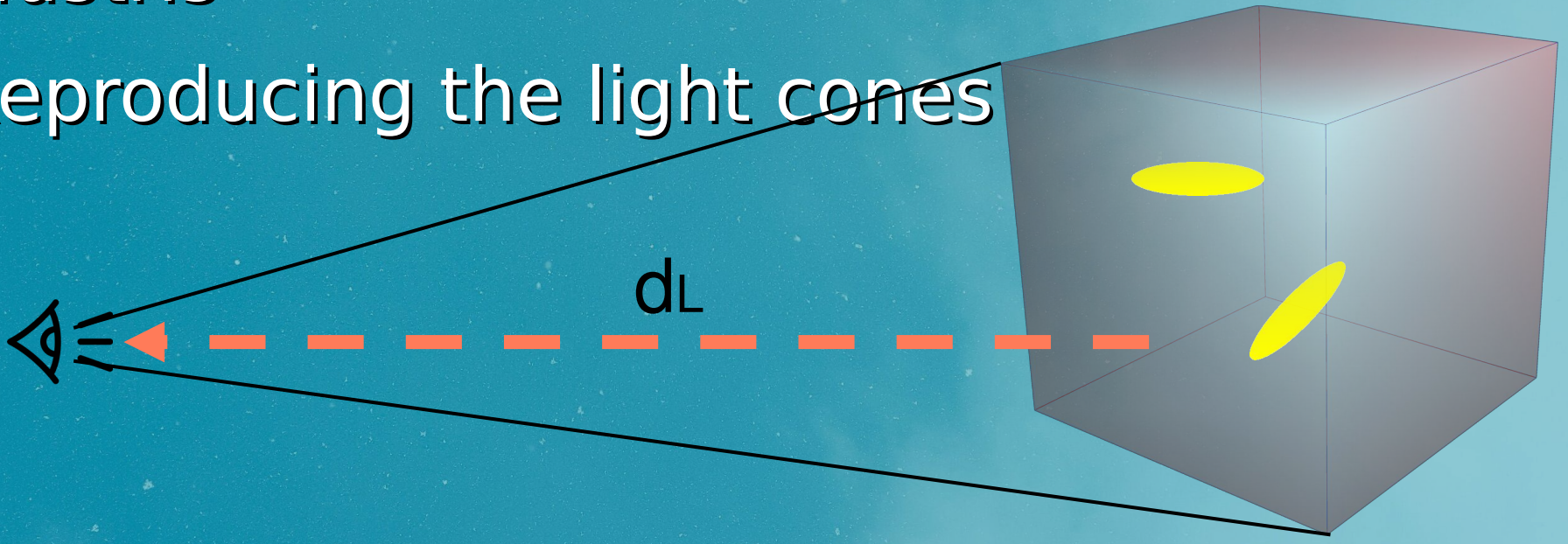
ML Protocol – Dataset

- Random sampling of galaxies in TNG Illustris



ML Protocol – Dataset

- Random sampling of galaxies in TNG Illustris
- Reproducing the light cones

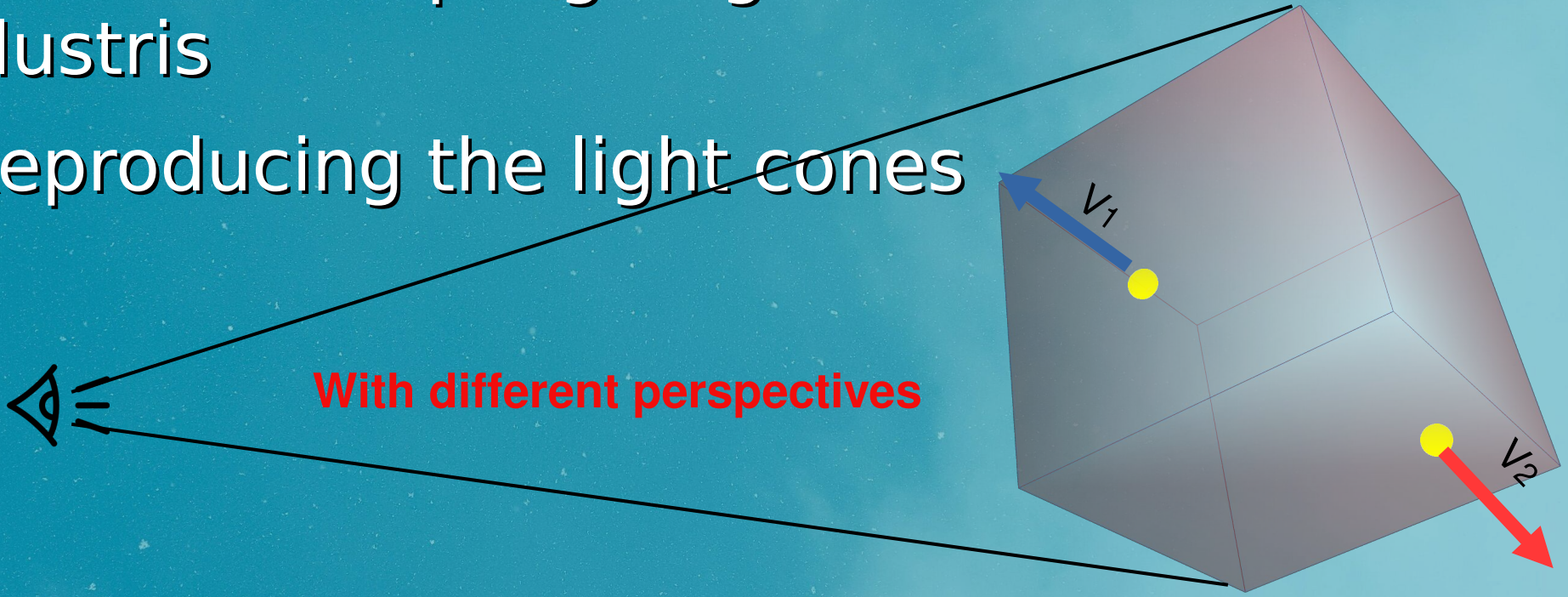


ML Protocol – Dataset

- Random sampling of galaxies in TNG Illustris
- Reproducing the light cones

ML Protocol – Dataset

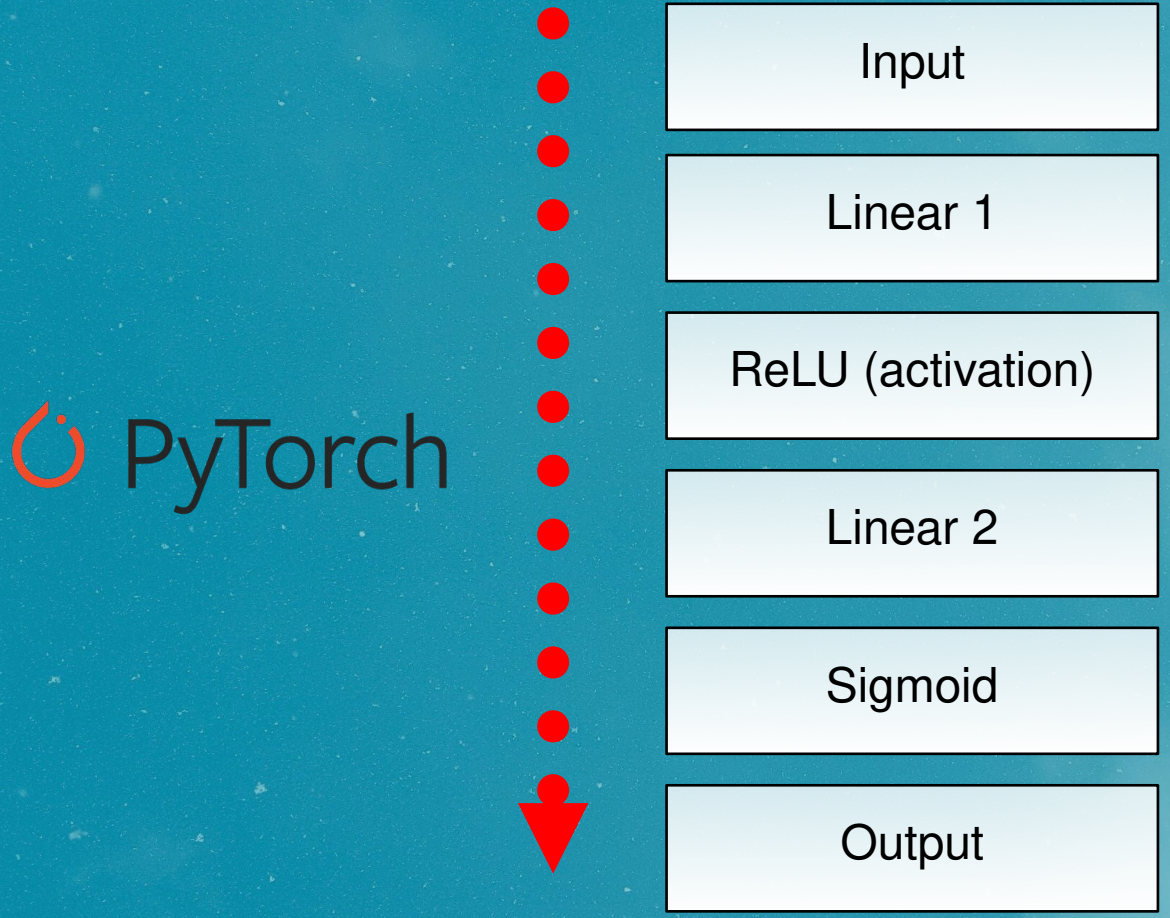
- Random sampling of galaxies in TNG Illustris
- Reproducing the light cones



ML Protocol – Dataset

- Random sampling of galaxies in TNG Illustris
- Reproducing the light cones
- Identifying merging states for sampled galaxies with merger tree

ML Protocol – Step 1



ReLu :

$f(x) = \max(0,x)$

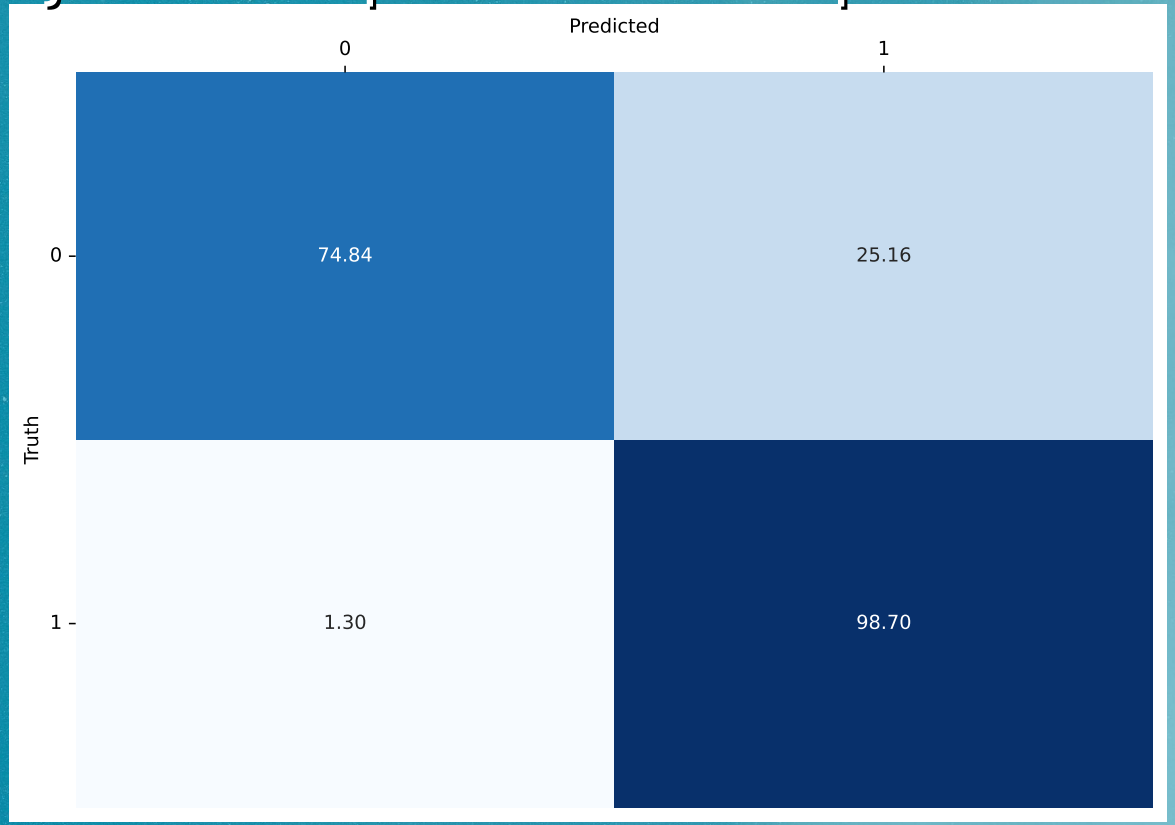
ML Protocol – Step 1

Accuracy : 98 % - Physical separation

Average time scale : 150 Myr

ML Protocol – Step 1

With projected separation : drop to 85 %

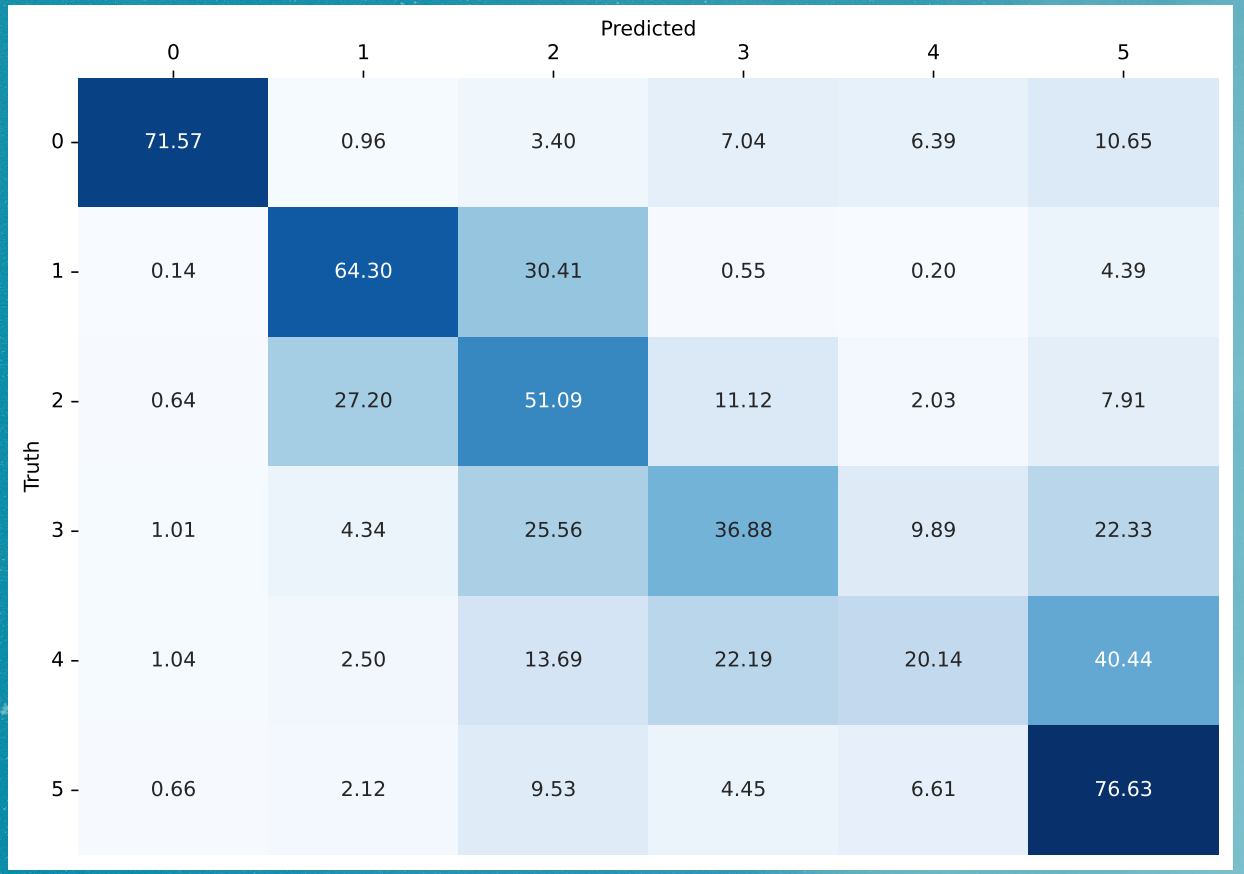


ML Protocol – Step 1

- Δt_{max} about 150 milions years
- High reliability of more than 98 % with physical separation
- Drop up to 85 % with projected separation

ML Protocol – Step 1

Time intervals : [-1, 0, 150, 3380, 6600, 9800, Tmax]

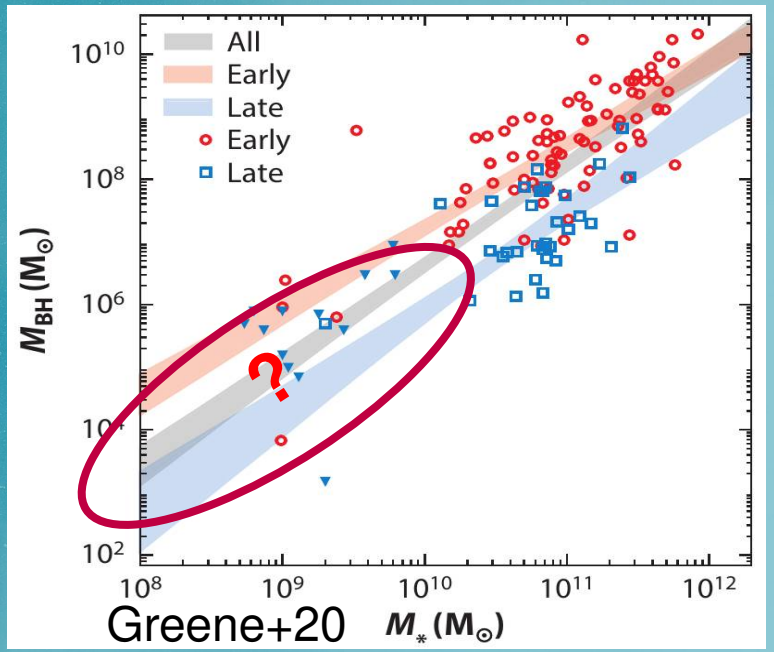


ML Protocol – Step 2

- Adapt the protocol for the groups ✓
- Merging timescale increase ✓
- Apply the protocol for the groups :
  - Work in progress…

Further steps

- LISA AstroWG : MBH Catalogue study
  - Better Mgal-MBH relation?
- MBH merger probability ?
- SMBH Merging timescales ?
- LISA detectability ?

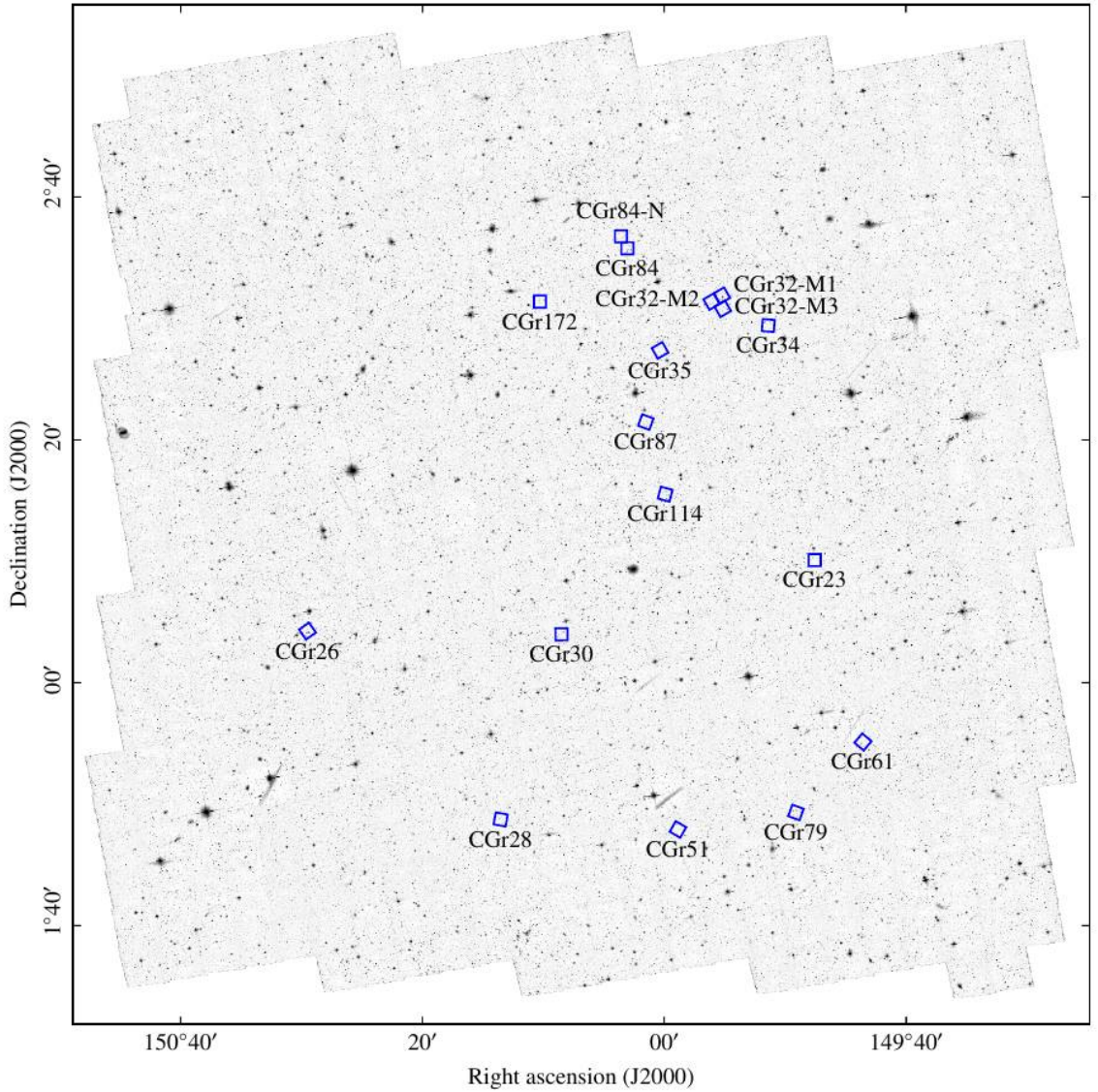


Takeway message

- Galaxy and MBH growth pathways are still debated.
- Necessary to estimate the MBH merger rate for LISA data analysis.
- Estimates galaxy merger is a N body problem
- The ML protocol can gives interesting results for galaxy pairs for short timescales.

Thank you for your attention

Backup Slides



Data set -

Cosmos Field

Dense regions

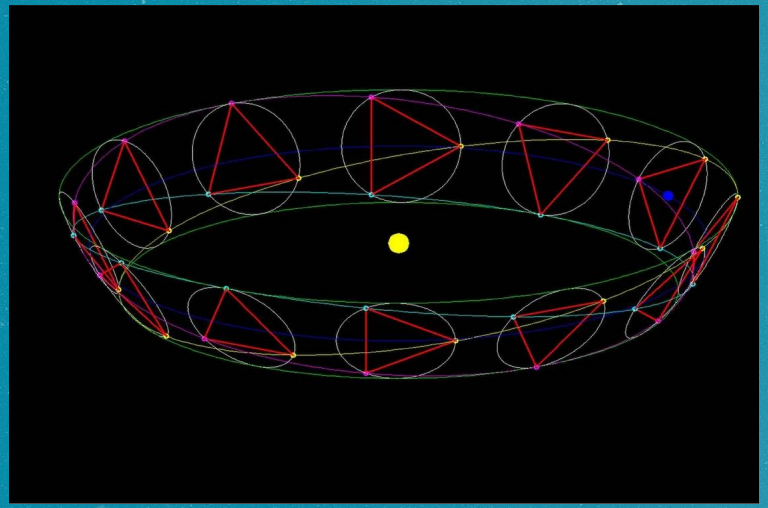
*

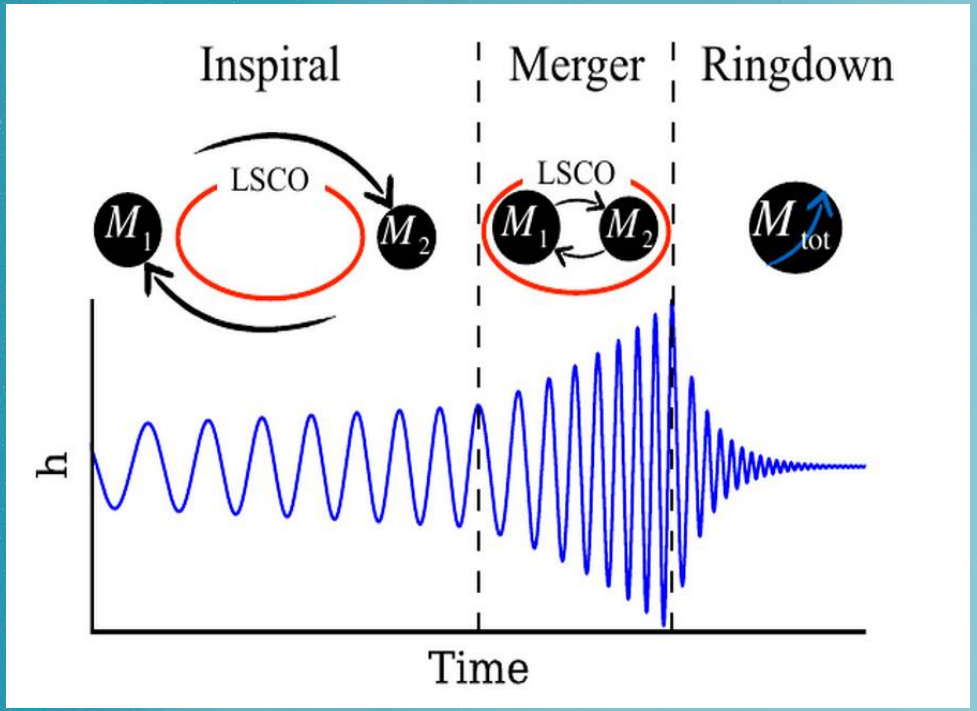
Epinat +23

LISA Mission

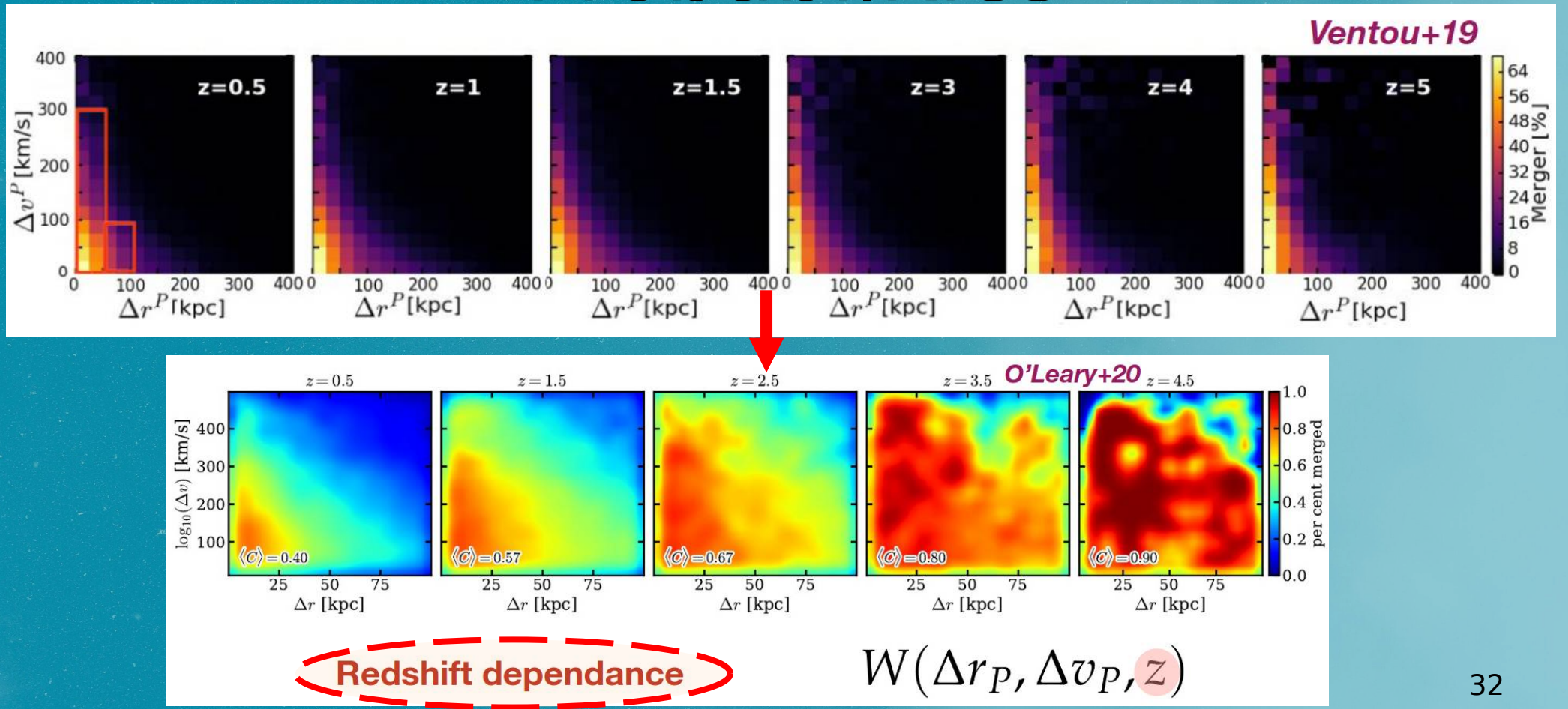
Gravitational wave detector

- Informations on positions, masses, inclination...
- In the frequency domain of MBH masses of intermediate masses galaxies

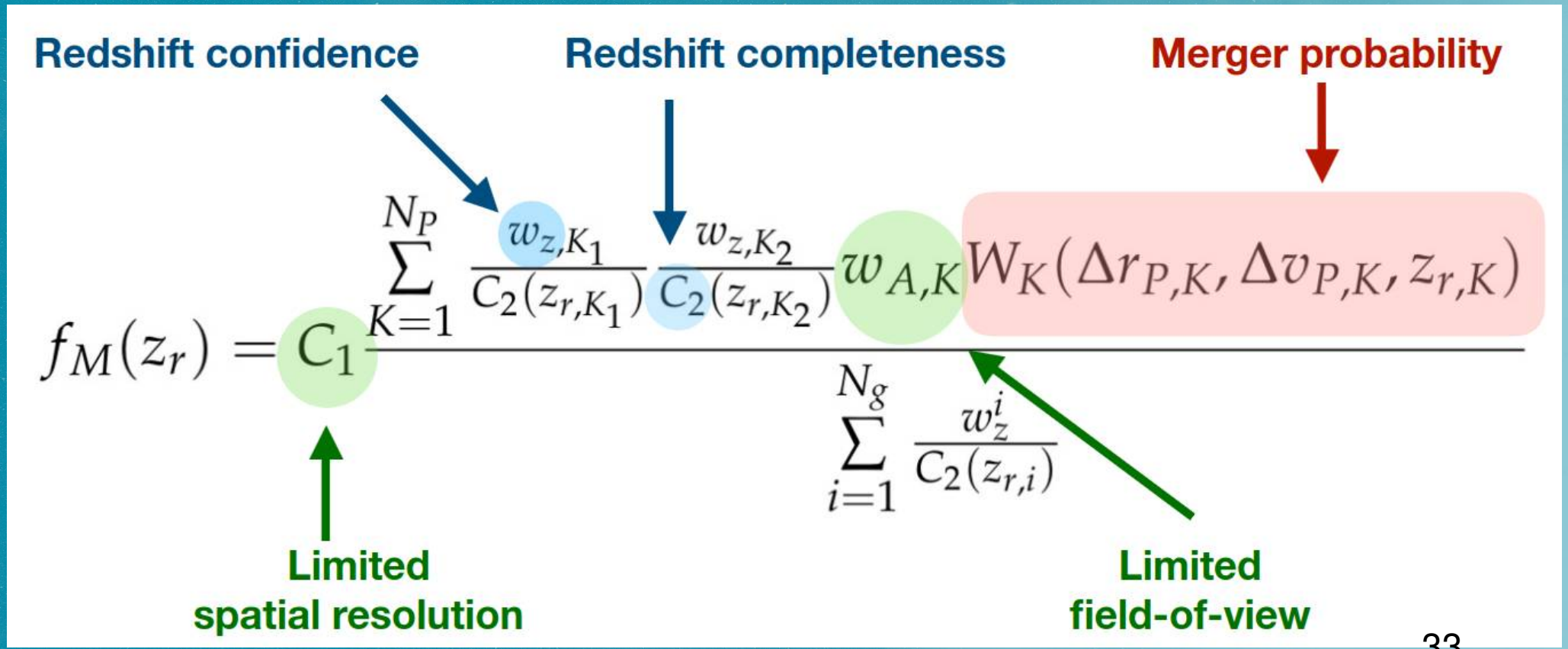




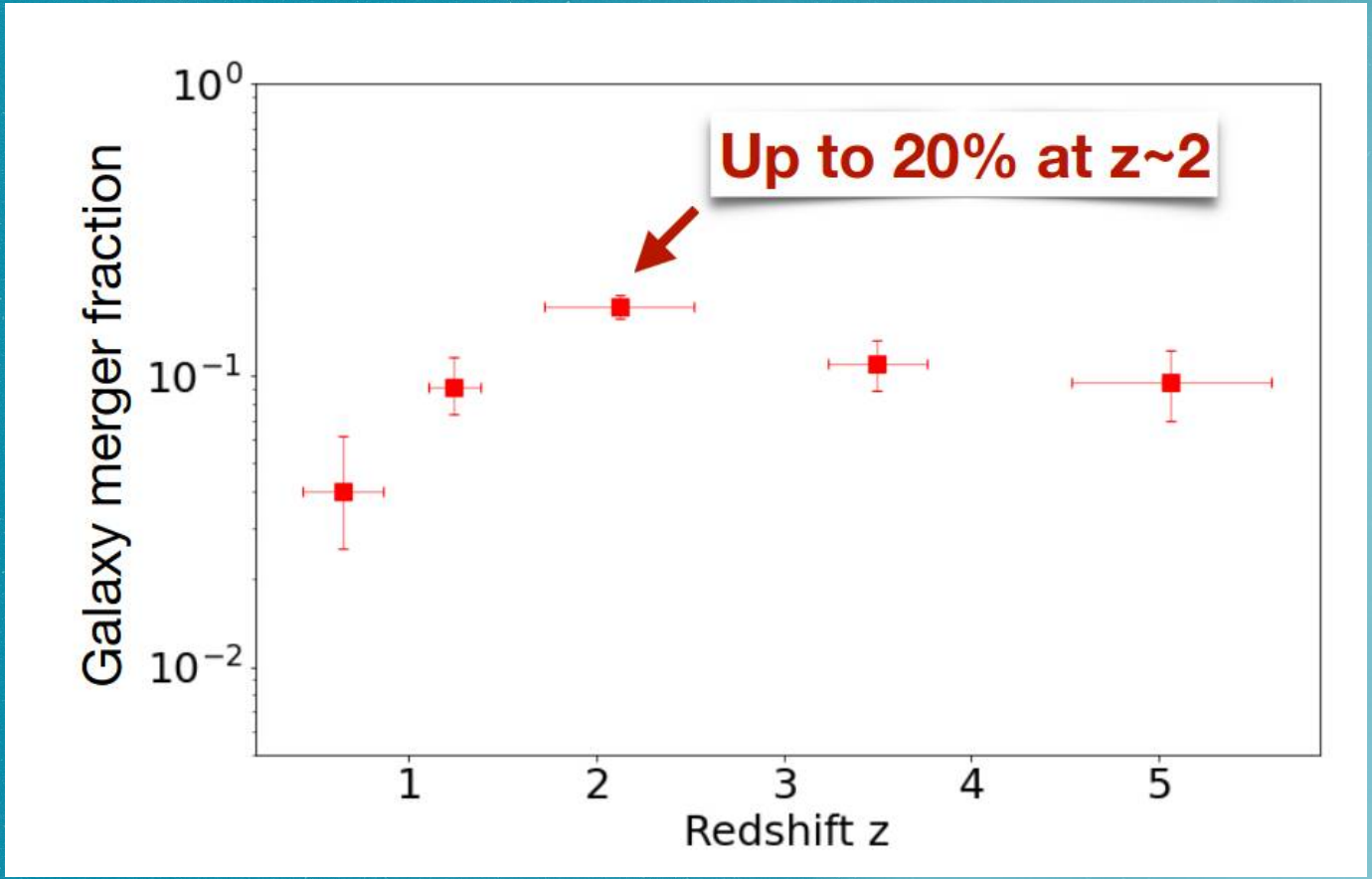
Probabilities



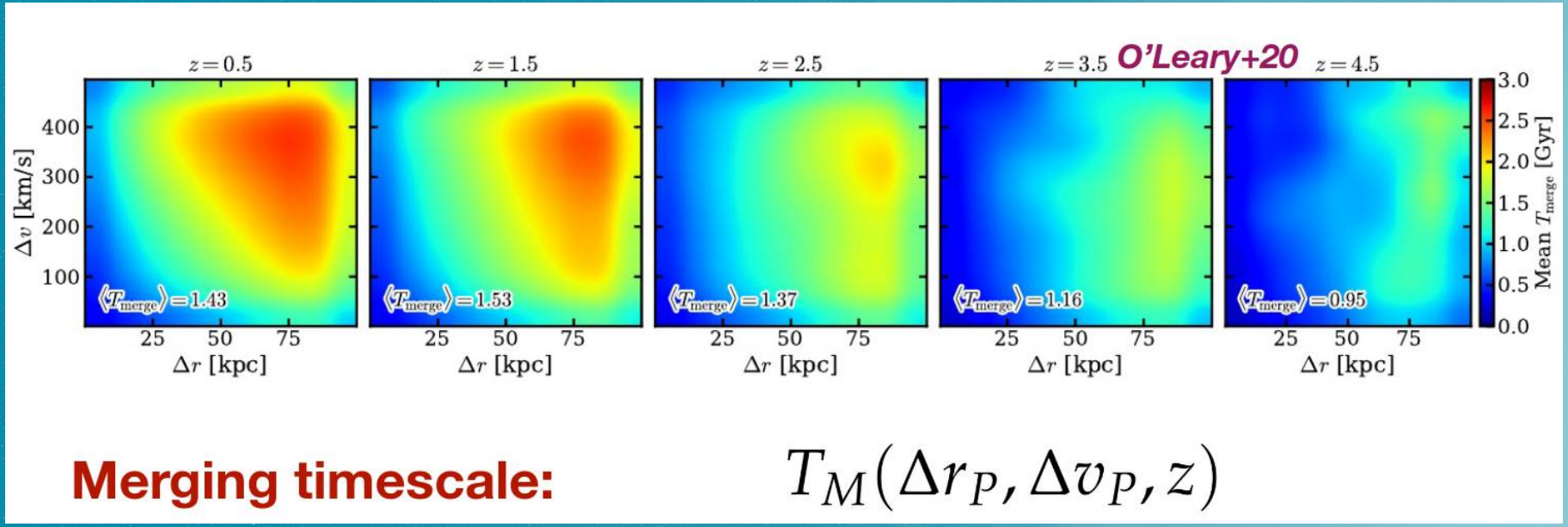
Fraction of galaxy merger



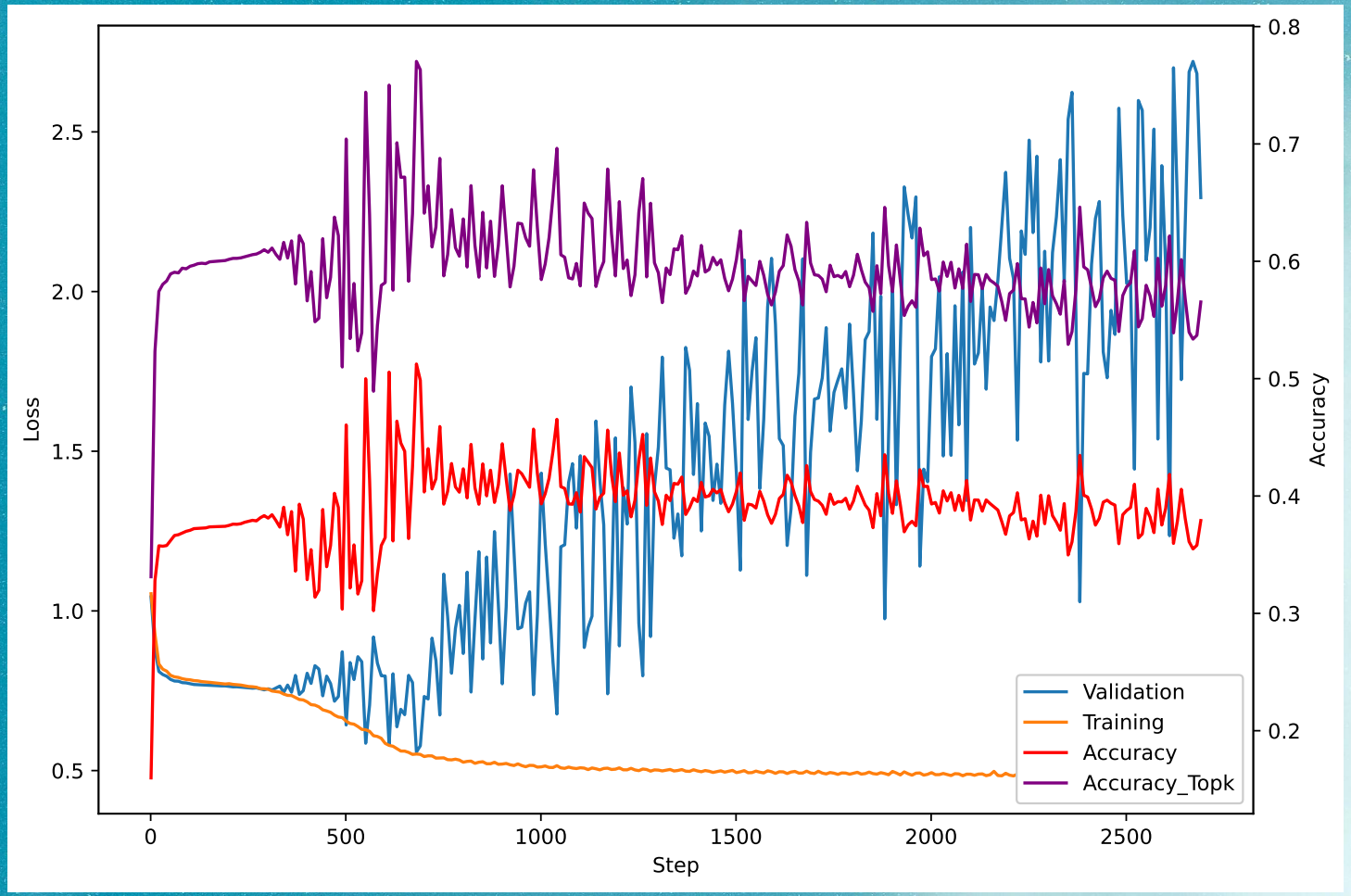
Fraction of galaxy merger



Galaxy merger rate



Merging timescale: $T_M(\Delta r_P, \Delta v_P, z)$


Loss
Accuracy
Step
0
500
1000
1500
2000
2500
0.5
1.0
1.5
2.0
2.5
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Validation
Training
Accuracy
Accuracy_Topk