Assessing massive black hole cosmic history through gravitational waves

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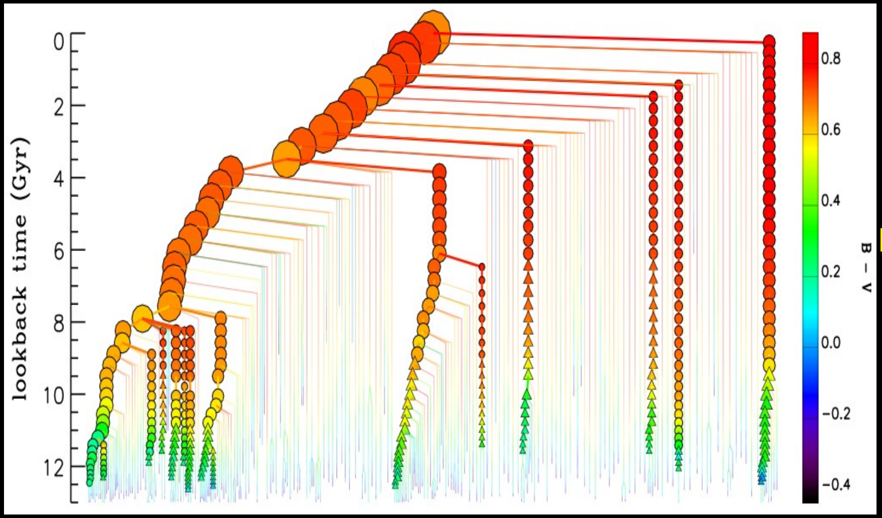
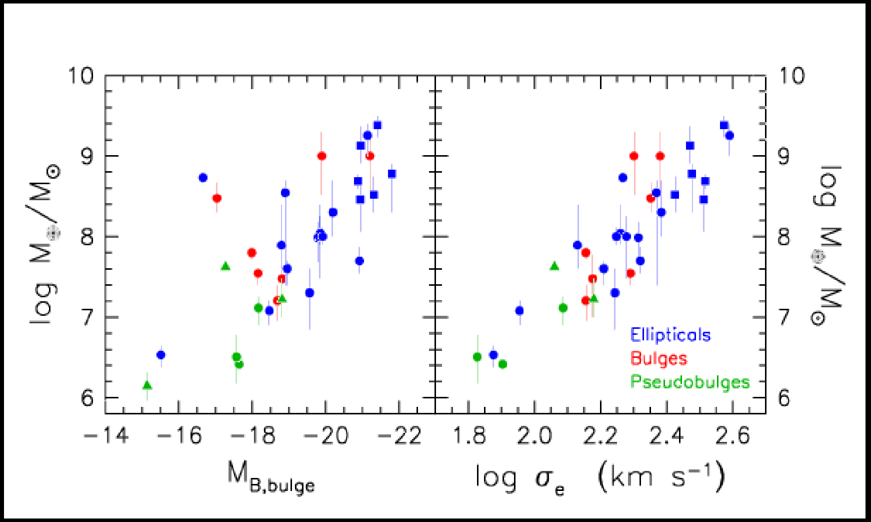
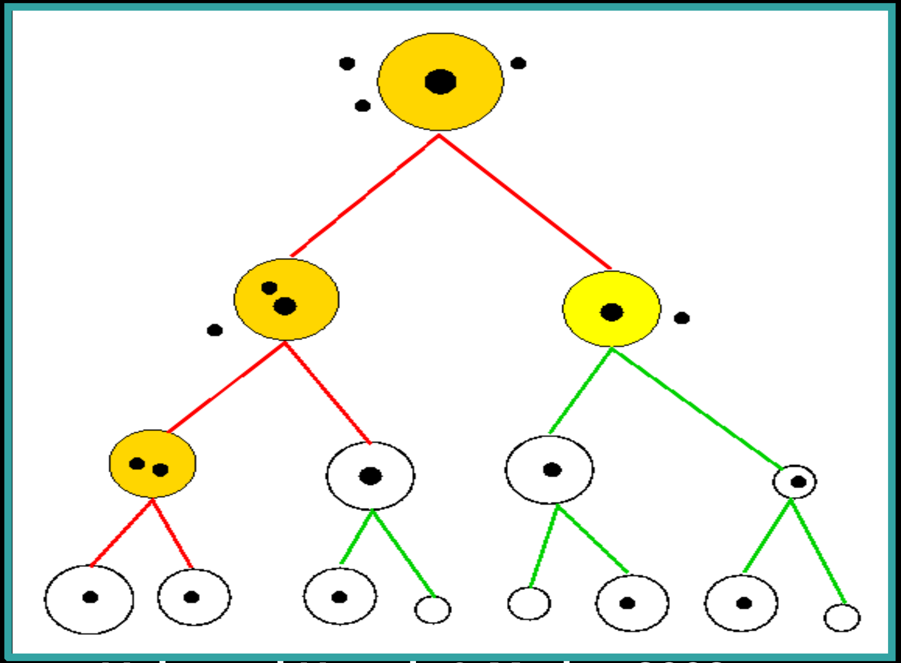
MBHBs are a natural consequence of the hierarchical formation of cosmic structures



From De Lucia et al 2006



Ferrarese & Merritt 2000, Gebhardt et al. 2000



Volonteri Haardt & Madau 2003

Question:
Given a set of observed massive black hole coalescences,
What information can be extracted about the underlying massive black hole population model?

We consider 10 different formation models differing in:

1- MBH seeding mechanism (heavy vs light seeds)
2- Metallicity feedback (metal free vs all metalliticies)
3- Accretion efficiency (Eddington vs. Merloni & Heinz)
4- Accretion geometry (coherent vs. chaotic)

Name	i	Seeding	Metallicity	Accretion model	Accretion geometry	$\bar{N}_i$ $[yr^{-1}]$
VHM-noZ-Edd-co	1	POPIII	$Z = 0$	Eddington	coherent	86
VHM-noZ-Edd-ch	2	POPIII	$Z = 0$	Eddington	chaotic	81
VHM-Z-Edd-co	3	POPIII	all Z	Eddington	coherent	108
VHM-Z-Edd-ch	4	POPIII	all Z	Eddington	chaotic	113
BVR-noZ-Edd-co	5	Quasistar	$Z = 0$	Eddington	coherent	26
BVR-noZ-Edd-ch	6	Quasistar	$Z = 0$	Eddington	chaotic	24
BVR-Z-Edd-co	7	Quasistar	all Z	Eddington	coherent	22
BVR-Z-Edd-ch	8	Quasistar	all Z	Eddington	chaotic	29
BVR-noZ-MH-co	9	Quasistar	$Z = 0$	Merloni & Heinz	coherent	33
BVR-noZ-MH-ch	10	Quasistar	$Z = 0$	Merloni & Heinz	chaotic	33

PROCEDURE

a-Construct the detector transfer function (takes into account for the adopted waveform and for the detector performance)

b-Filter the theoretical distribution through the transfer function to produce the “theoretically observable” distribution

c-Perform Montecarlo realizations of the MBH population

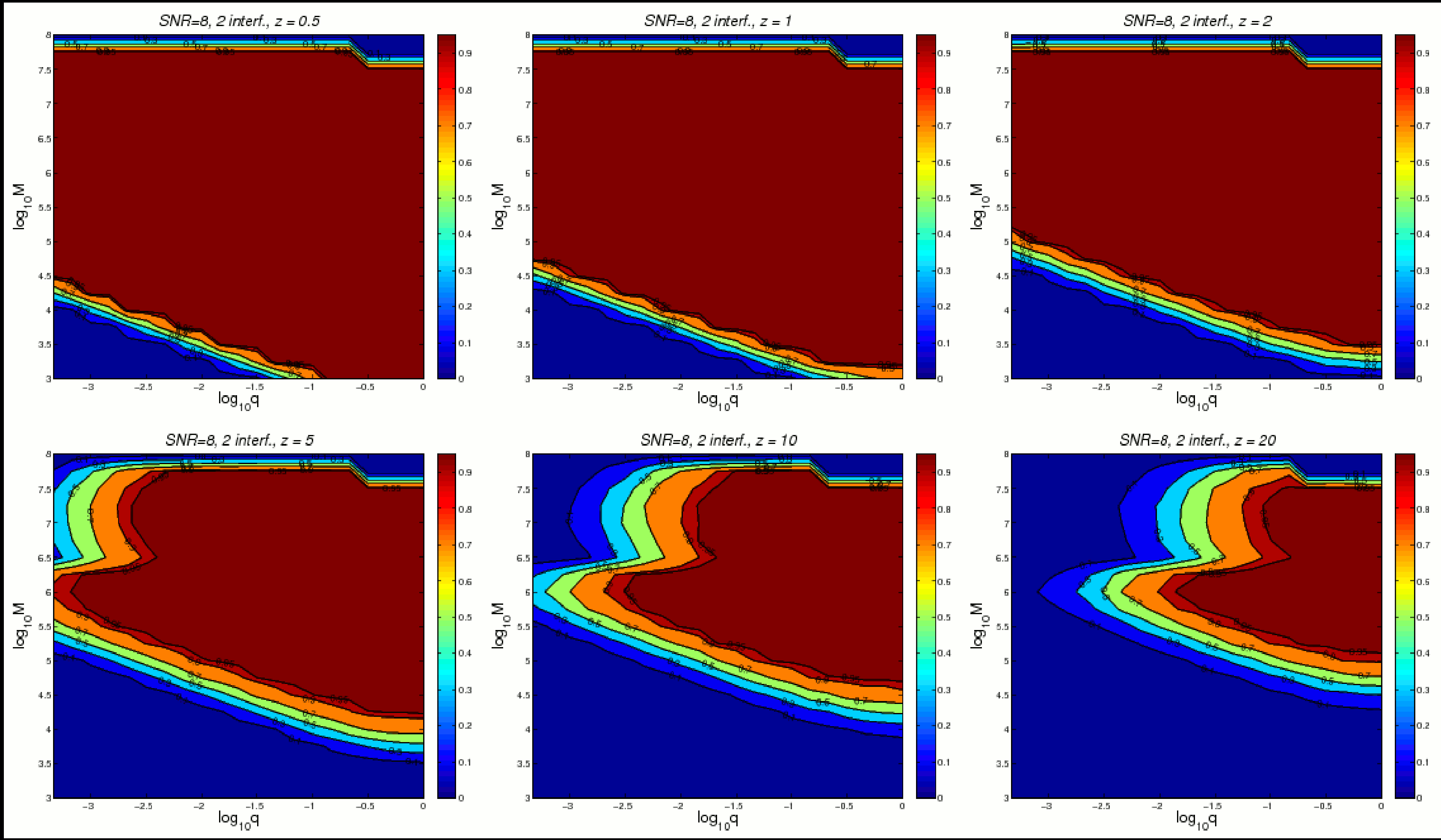
d-Create catalogs of observed binaries including FIM errors

We compare:

- the 10 pure models described before through the odds ratio
- artificially mixed models of the form $N_{mix} = f_1 N_1 + ... + f_n N_n$ f

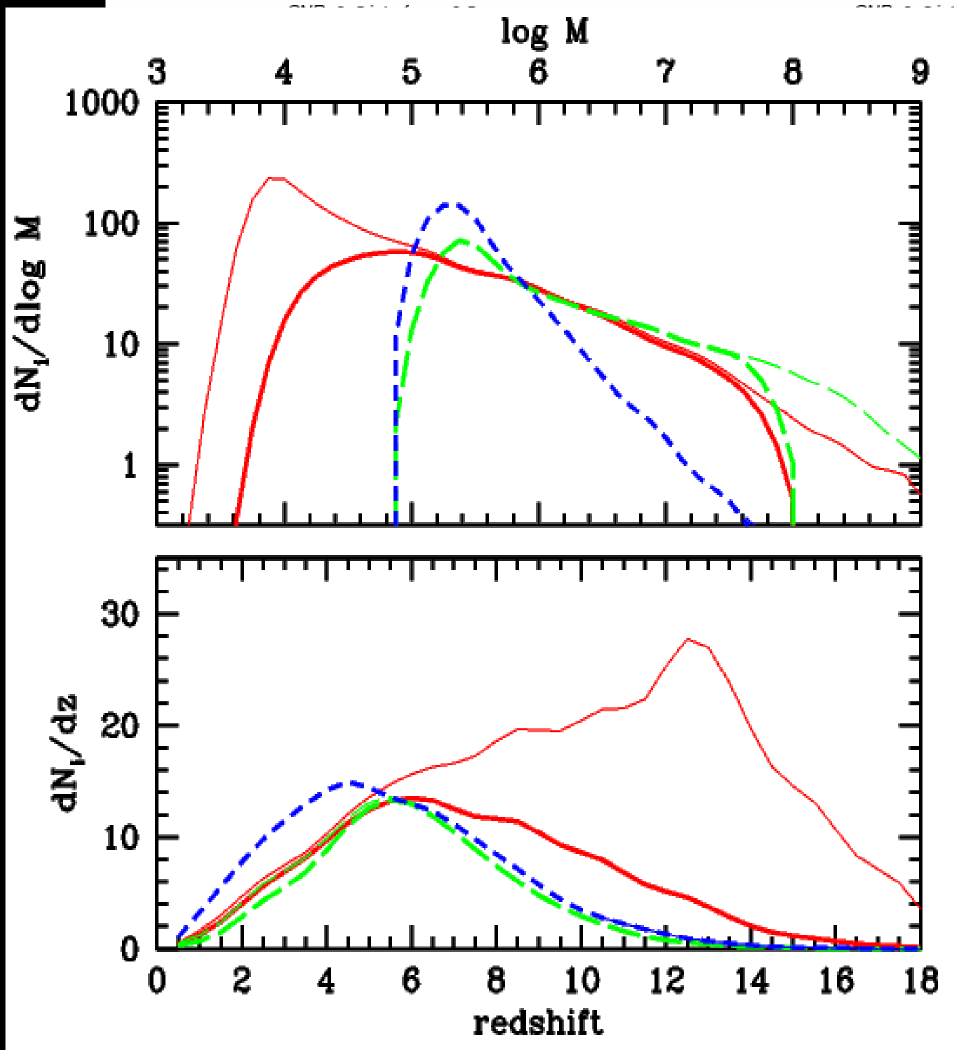
  we find the maximum of the posterior distribution in the mixing parameter space
- consistently mixed models, again finding the maximum of the Posterior distribution

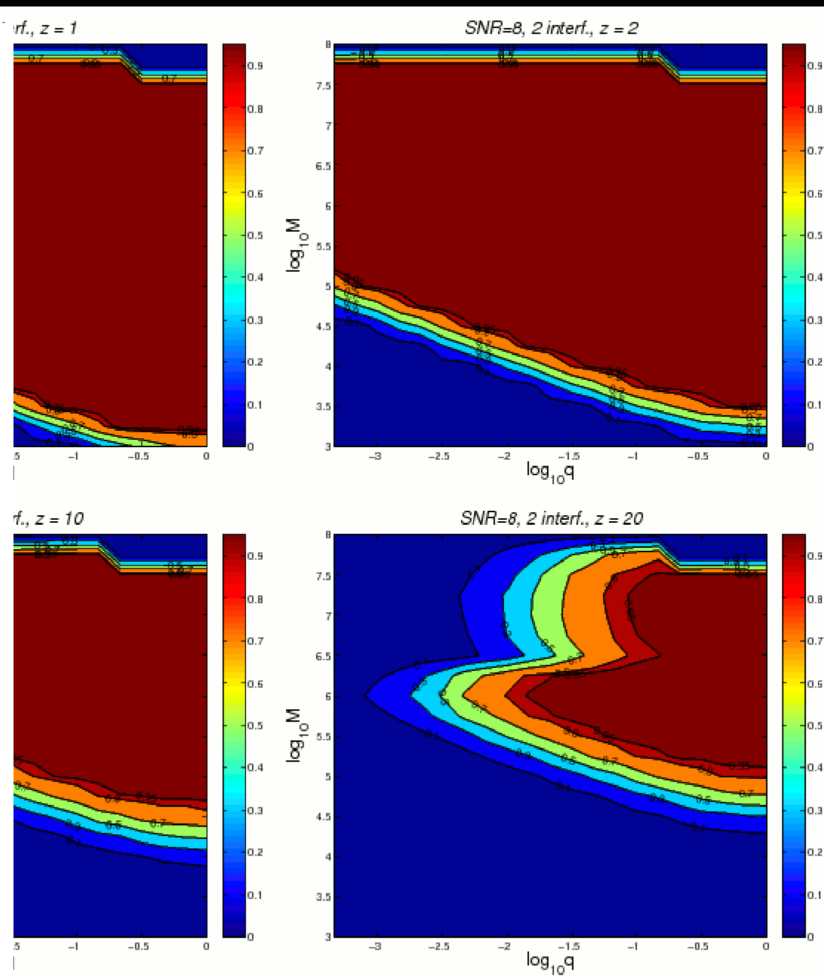
We consider the distribution $d^3N/dMdqdz$, we ignore spins.
We use 2PN circular binary waveforms, no merger, no ringdown



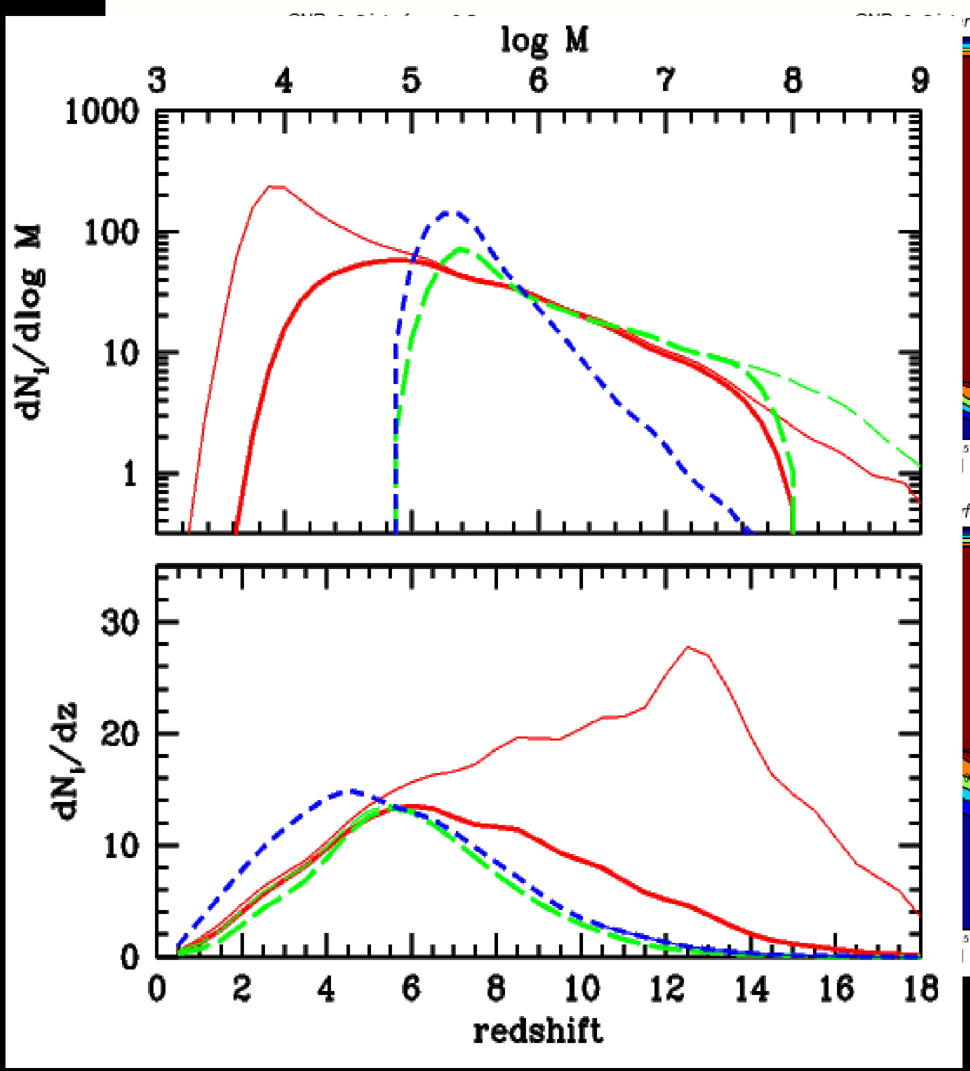
SNR=8, 2 interf., z = 0.5
SNR=8, 2 interf., z = 1
SNR=8, 2 interf., z = 2
SNR=8, 2 interf., z = 5
SNR=8, 2 interf., z = 10
SNR=8, 2 interf., z = 20
log10M
log10q

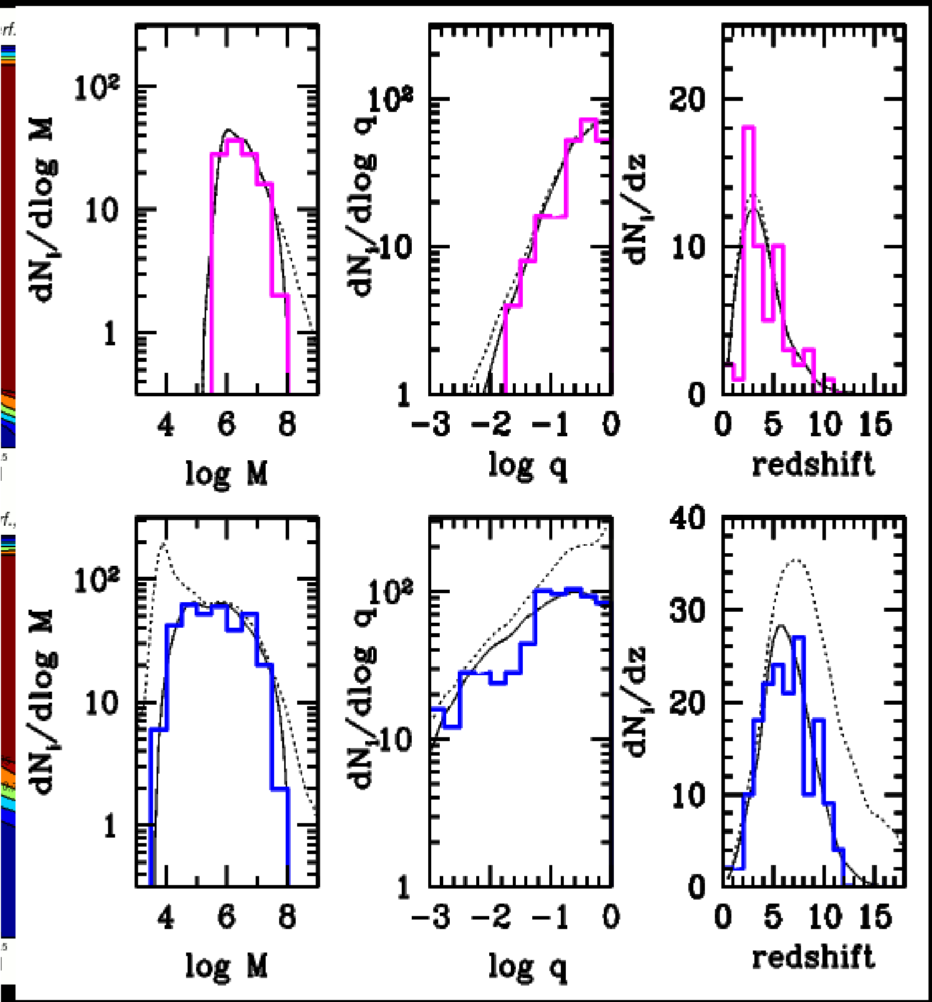
$$N_{T_{i,j}}(z, M, q) = \frac{d^3 N_i}{dz dM dq} \times T_j(z, M, q)$$





$$N_{T_{i,j}}(z, M, q) = \frac{d^3 N_i}{dz dM dq} \times T_j(z, M, q)$$





Likelihood of the dataset for a given choice of the parameters

$$p(D|\vec{\lambda}, M) = \prod_{i=1}^{K} \frac{(r_i(\vec{\lambda}))^{n_i} \mathrm{e}^{-r_i(\vec{\lambda})}}{n_i!}$$

PURE MODEL COMPARISON: compute the odds ratio

$$O_{AB} = \frac{p(D|A)}{p(D|B)} \frac{P(A)}{P(B)}$$

We assign confidence

$p_A = p(D|A)/(p(D|A)+p(D|B))$ to model *A*

$p_B = 1 - p_A$ to model *B*

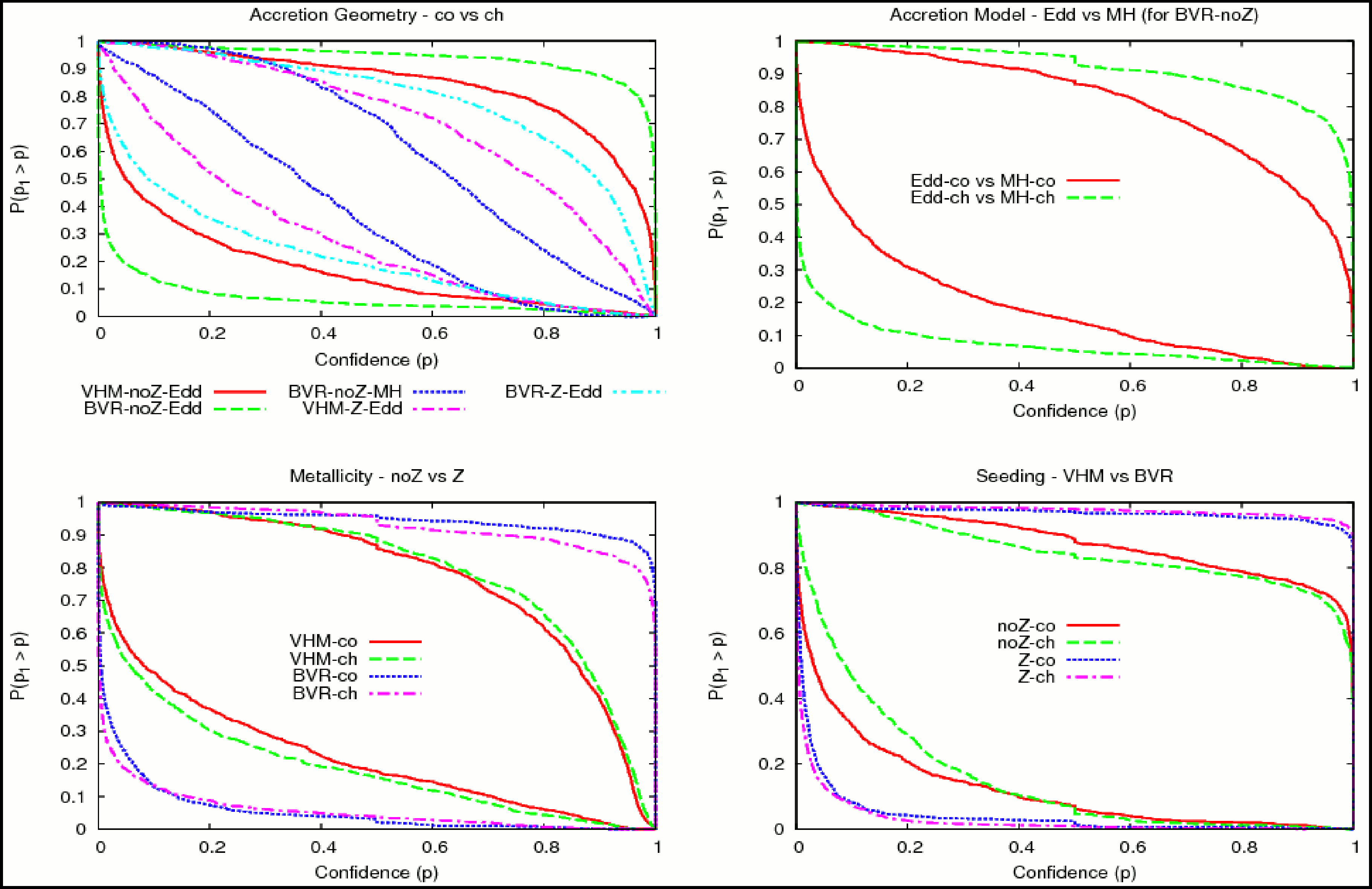
We build probability CDF over 1000 MC realization of the observed population

MIXED MODELS: find the maximum of the posterior

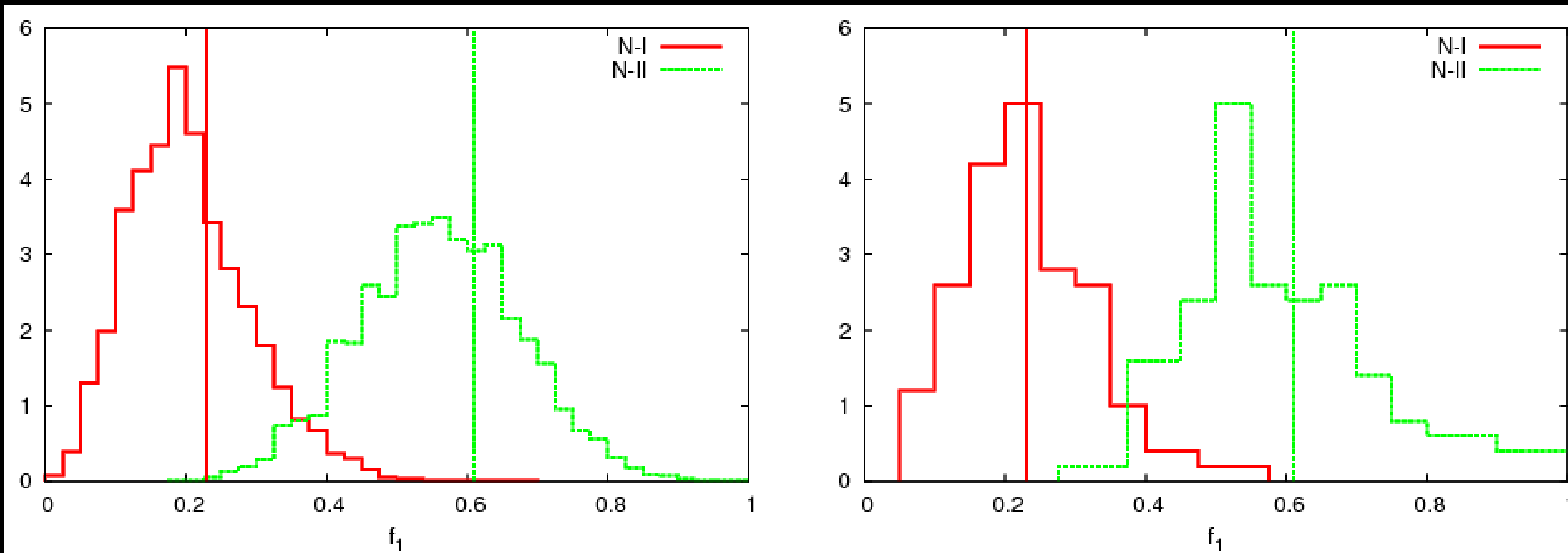
$$p(\vec{\lambda}|D, M) = \frac{p(D|\vec{\lambda}, M)\, \pi(\vec{\lambda})}{\mathcal{Z}},$$

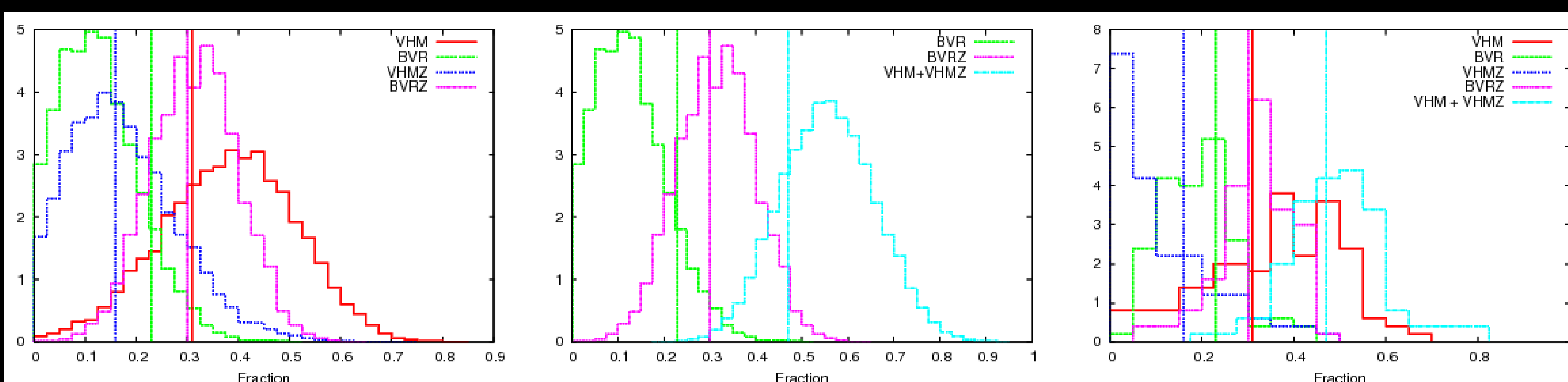
$$\mathcal{Z} = \int p(D|\vec{\lambda}, M)\, \pi(\vec{\lambda}) \mathrm{d}^N \lambda$$

Pure models:
Cumulative distribution function for the confidence



Mixed models:
evaluation of the posterior probability distribution function





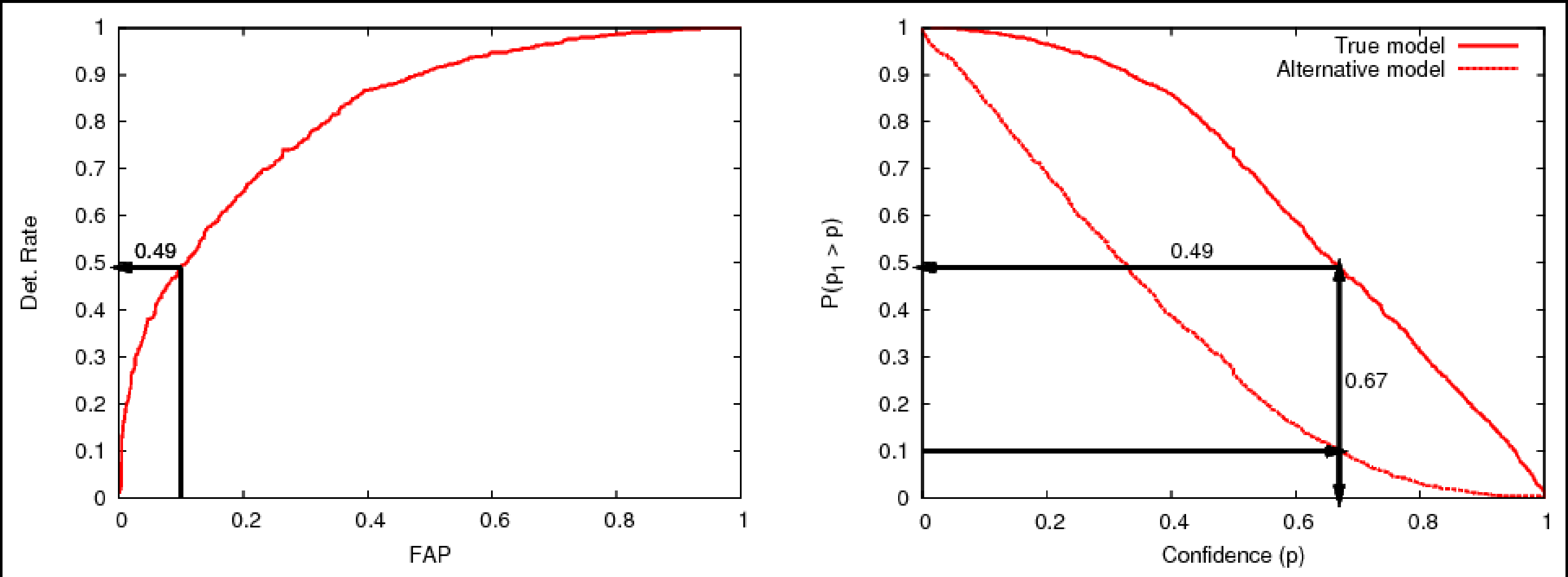
CONCLUSIONS:

-LISA is a powerful instrument to assess MBH cosmic history

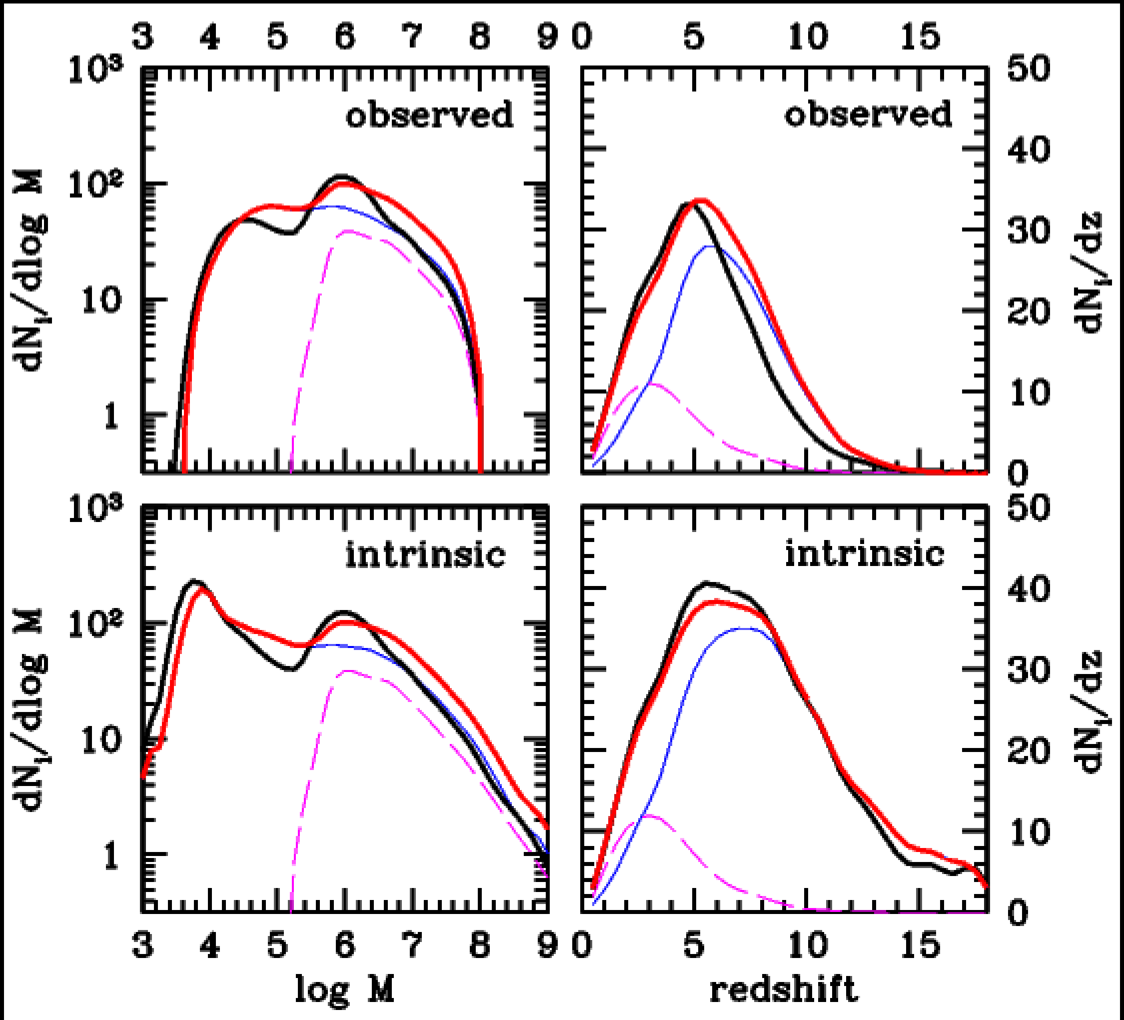
-assuming 3yr observation we can virtually distinguish any pair of pure models at a 95% confidence level or more

-when we mix different pure models, the mixing parameters can be recovered with 0.05-0.1 accuracy

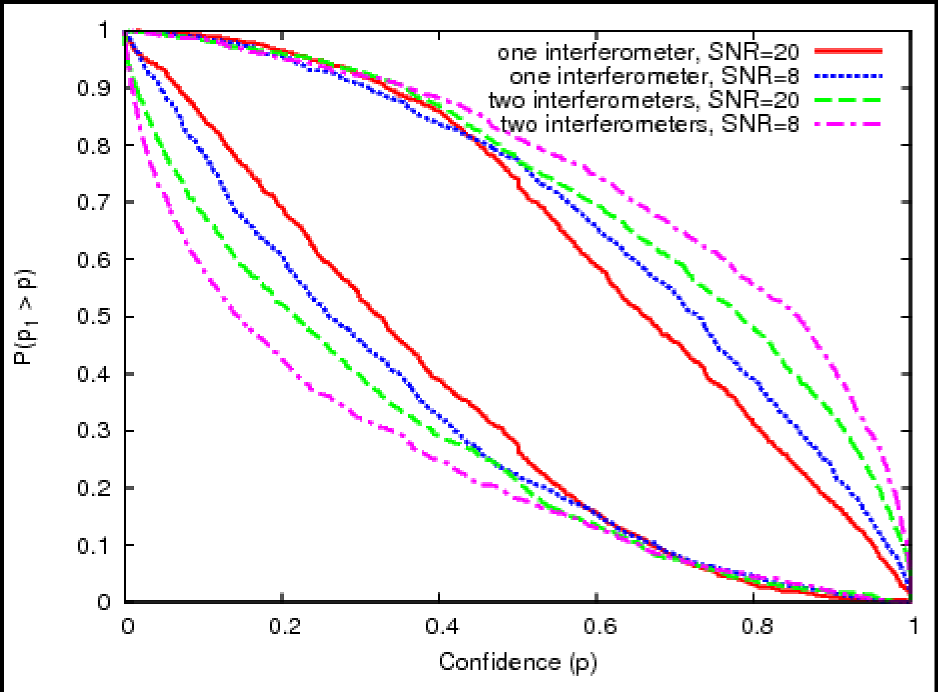
-we can also 'express' consistently mixed models as a combination of pure models.

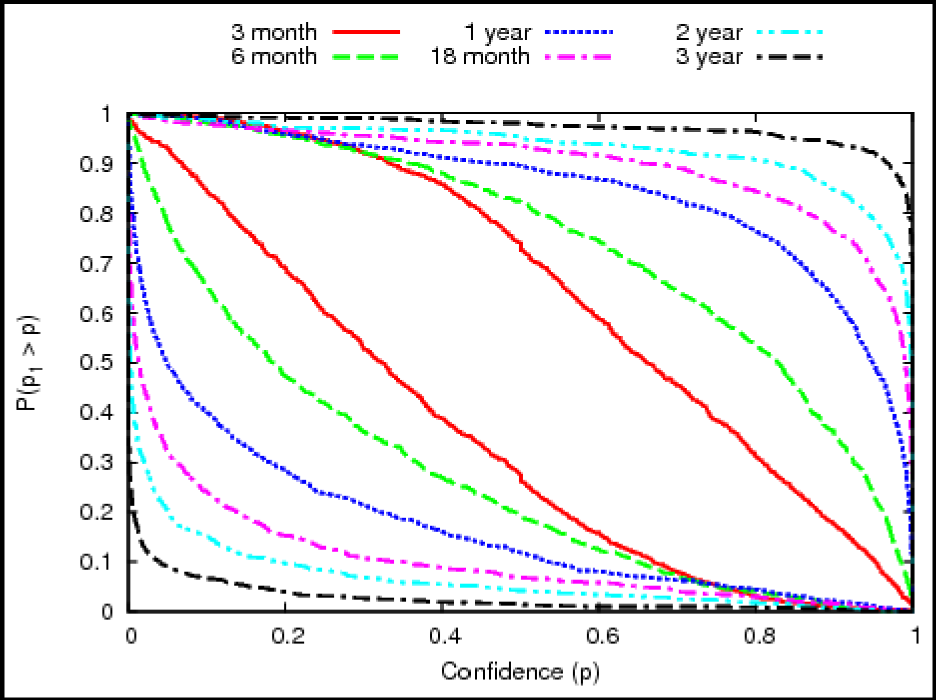


Det. Rate
FAP
0.49
P(p_1 > p)
Confidence (p)
True model
Alternative model
0.49
0.67



observed
observed
intrinsic
intrinsic
dN_l/dlog M
dN_l/dz
log M
redshift


one interferometer, SNR=20
one interferometer, SNR=8
two interferometers, SNR=20
two interferometers, SNR=8
$P(p_1 > p)$
Confidence (p)


3 month
6 month
1 year
18 month
2 year
3 year
$P(p_1 > p)$
Confidence (p)