Sebastien Clesse (ULB, Brussels)
on behalf of the LISA-CosWG PBH group
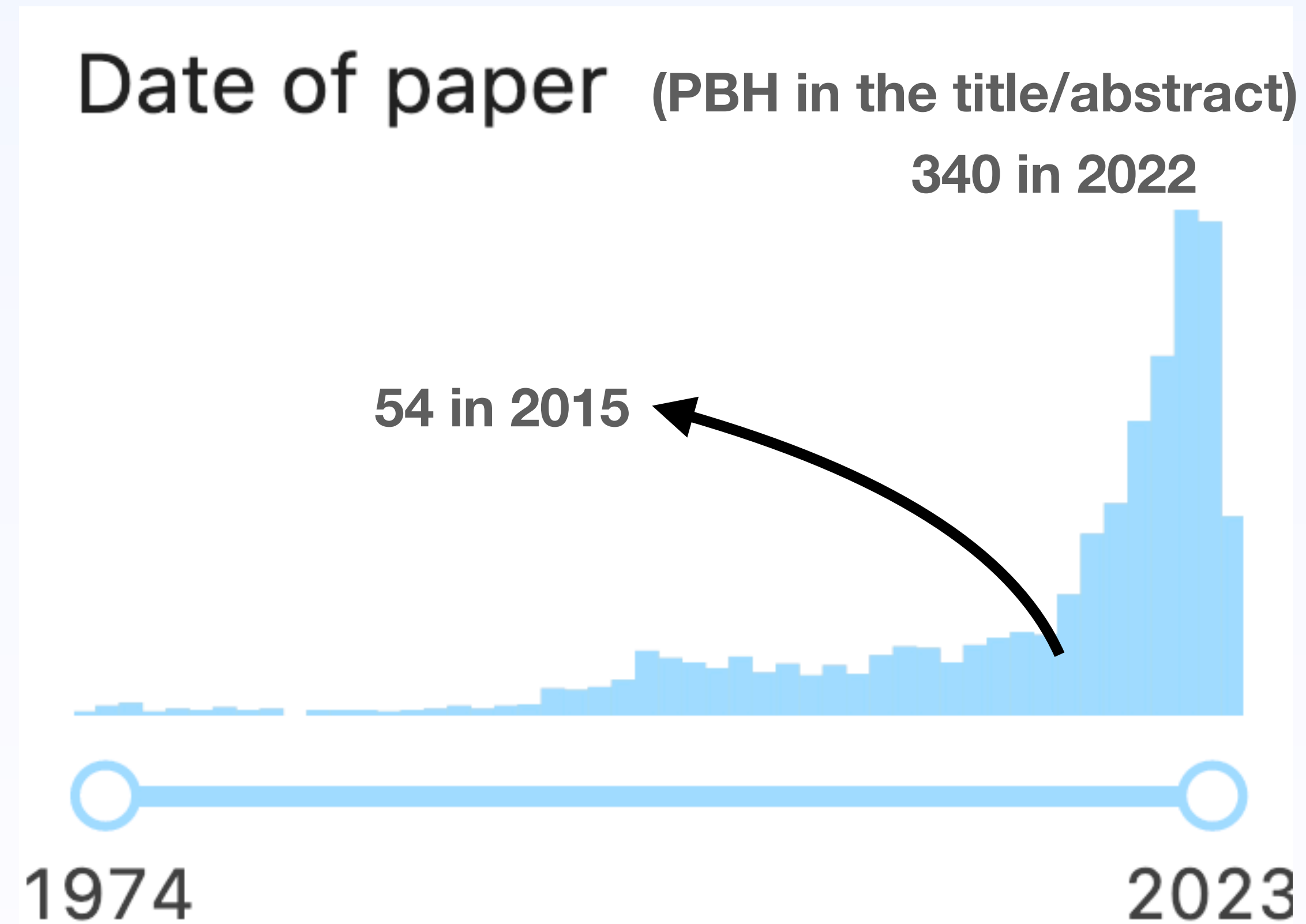
PrimBHoles

A public code for the computation of PBH abundances and GW signatures

Stavanger, LISA-CosWG meeting, 5-10 June 2023

Why developing `PrimBHoles` ?

Why developing **PrimBHoles** ?

1. Growth of interest in PBHs

2. Multi-disciplinary problem
   One cannot be expert in all aspects

3. Demand for the most recent prescriptions
   No need to re-invent the wheel…

4. PBHs may exist !

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing subsolar or high-z black holes

6. LISA can do both!
   and probe PBHs from 1g to 1 000 000 Msun
   with 10 different signals

Date of paper (PBH in the title/abstract)

340 in 2022

54 in 2015

1974   2023

3

Why developing `PrimBHoles` **?**

1. Growth of **interest** in PBHs

2. **Multi-disciplinary** problem
   One cannot be expert in all aspects

3. Demand for the most recent prescriptions
   No need to re-invent the wheel…

4. PBHs may exist !

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing subsolar or high-z black holes

6. LISA can do both!
   and probe PBHs from 1g to 1 000 000 Msun
   with 10 different signals

Why developing `PrimBHoles` ?

1. **Growth of interest in PBHs**

2. **Multi-disciplinary problem**
   One cannot be expert in all aspects

3. Demand for the most recent prescriptions
   No need to re-invent the wheel…

4. PBHs may exist !

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing subsolar or high-z black holes

6. LISA can do both!
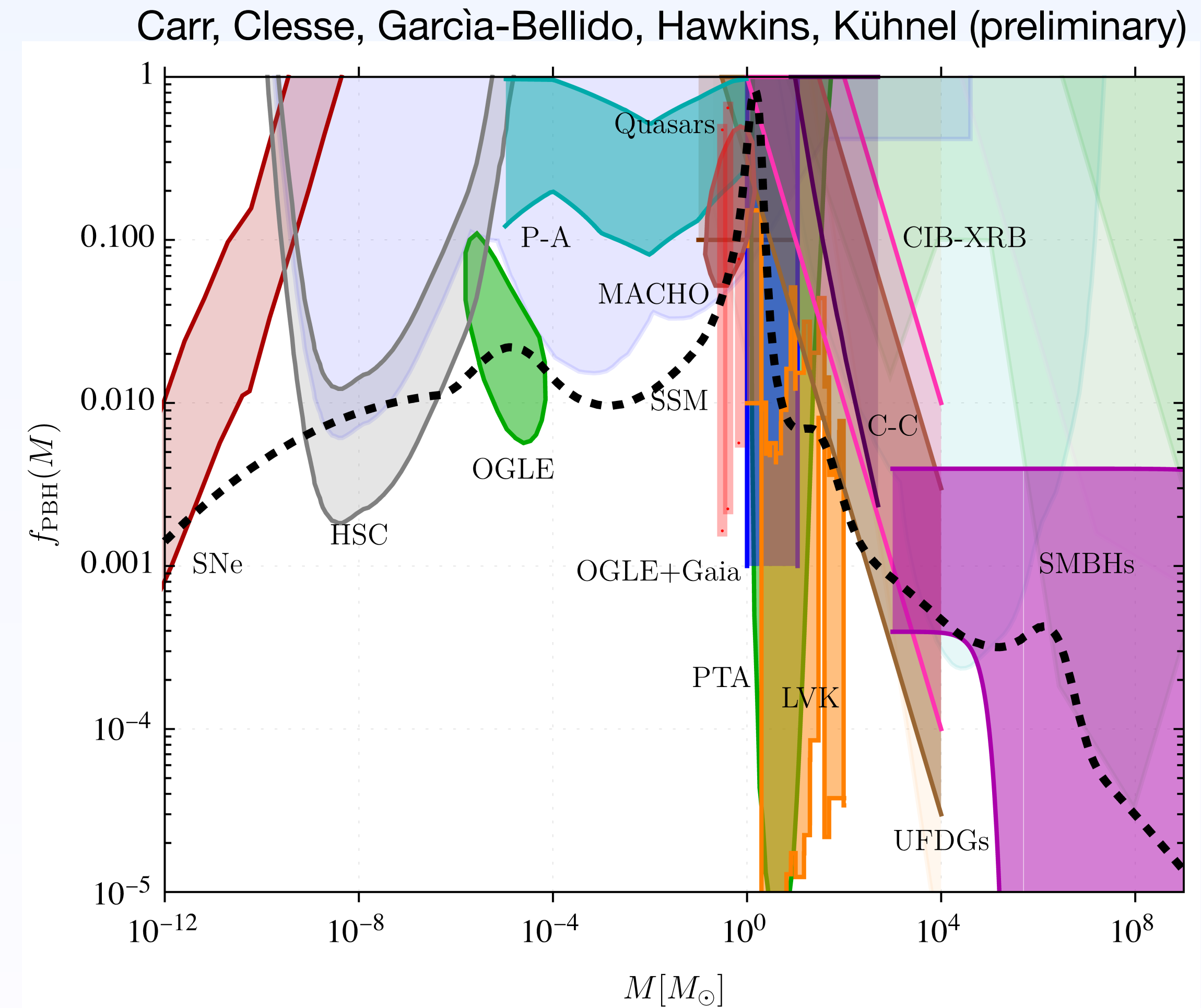   and probe PBHs from 1g to 1 000 000 Msun
   with 10 different signals

Which mass distribution ?

Let's ask PRIMBHoles ! !

What is their merger rate ?

How do they form ?

How to calculate their GWB ?

4

Why developing `PrimBHoles` ?

1. Growth of **interest** in PBHs

2. **Multi-disciplinary** problem
   One cannot be expert in all aspects

3. Demand for the **most recent prescriptions**
   No need to re-invent the wheel…

4. PBHs may exist !

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing subsolar or high-z black holes

6. LISA can do both!
   and probe PBHs from 1g to 1 000 000 Msun
   with 10 different signals

Why developing `PrimBHoles` ?

1. **Growth of interest in PBHs**

2. **Multi-disciplinary problem**
   One cannot be expert in all aspects

3. **Demand for the most recent prescriptions**
   No need to re-invent the wheel…

4. **PBHs may exist !**

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing subsolar or high-z black holes

6. LISA can do both!
   and probe PBHs from 1g to 1 000 000 Msun
   with 10 different signals

Carr, Clesse, Garcìa-Bellido, Hawkins, Kühnel (preliminary)

Why developing `PrimBHoles` ?

1. Growth of **interest** in PBHs

2. **Multi-disciplinary** problem
   One cannot be expert in all aspects

3. Demand for the **most recent prescriptions**
   No need to re-invent the wheel…

4. PBHs **may exist** !

5. Two 'unambiguous' ways
   to prove that PBHs exist:
   observing **subsolar** or **high-z** black holes

6. **LISA** can do both!
   and probe PBHs from 10 kg to 10^8 M$_\odot$
   with 12 different signals
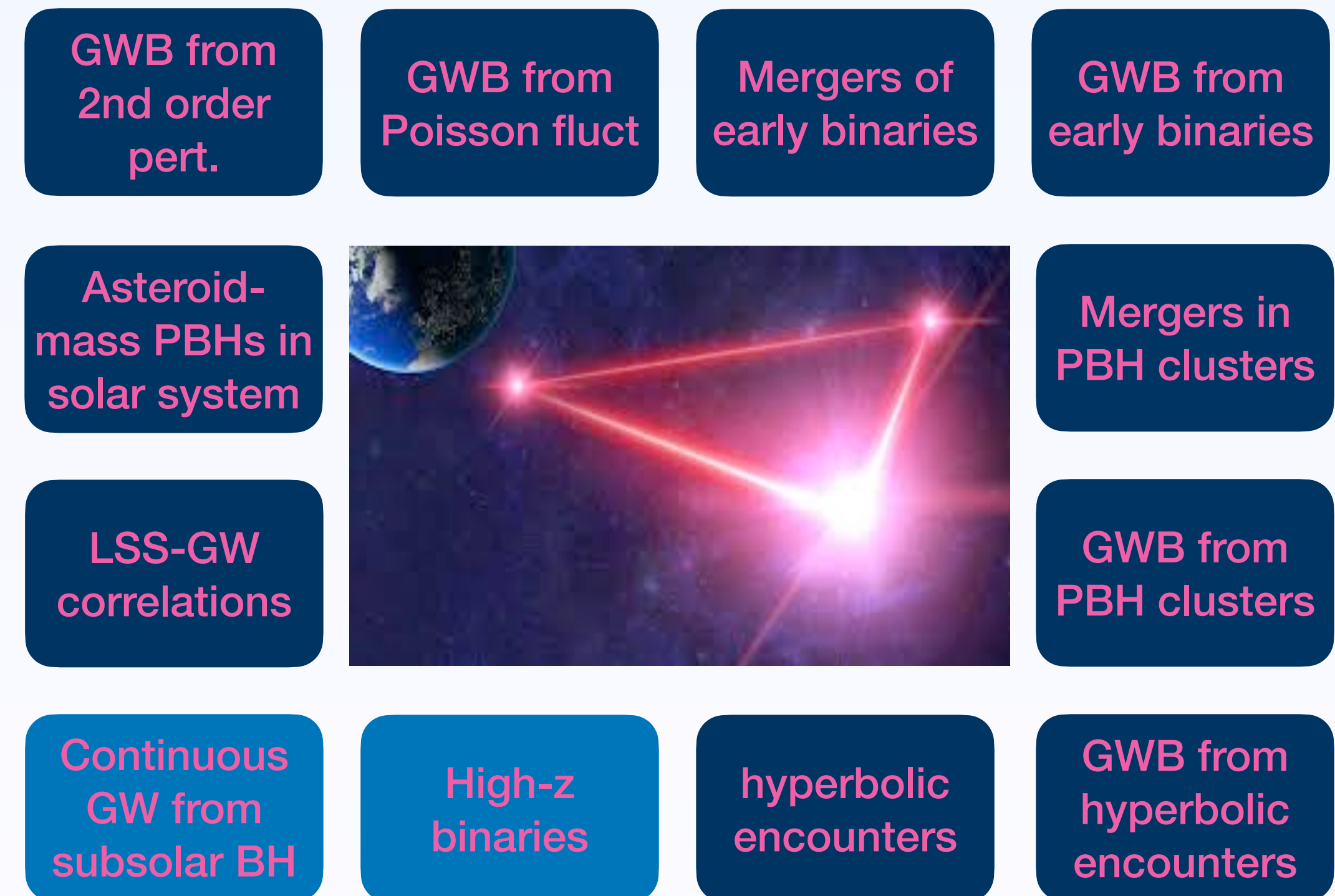
What is **PrimBHoles** ?

What is `PrimBHoles` ?

1. A **modular** code/toolbox

What is `PrimBHoles` ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

What is **PrimBHoles** ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

3. developed by a team of 20 PBH **experts,**

4. based on PBH **living review**

Sebastien Clesse (coord),
Juan Garcia-Bellido (coord),
Eleni Bagui,
Valerio De Luca,
Gabriele Franciolini,
Cristian Joana,
Rajeev Kumar Jain,
Sachiko Kuroyanagi,
Ilia Musco,
Theodoros Papanikolaou,
Marco Peloso,
Alvise Raccanelli,
Sebastien Renaux-Petel,
Antonio Riotto,
Ester Ruiz Morales,
Marco Scalisi,
Olga Sergijenko,
Caner Unal,
Vincent Vennin,
David Wands

What is `PrimBHoles` ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

3. developed by a team of 20 PBH **experts,**

4. based on PBH **living review**

5. with pre-implemented **models** and **scripts**

Sebastien Clesse (coord),
Juan Garcia-Bellido (coord),
Eleni Bagui,
Valerio De Luca,
Gabriele Franciolini,
Cristian Joana,
Rajeev Kumar Jain,
Sachiko Kuroyanagi,
Ilia Musco,
Theodoros Papanikolaou,
Marco Peloso,
Alvise Raccanelli,
Sebastien Renaux-Petel,
Antonio Riotto,
Ester Ruiz Morales,
Marco Scalisi,
Olga Sergijenko,
Caner Unal,
Vincent Vennin,
David Wands

What is `PrimBHoles` ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

3. developed by a team of 20 PBH **experts,**

4. based on PBH **living review**

5. with pre-implemented **models** and **scripts**

6. well **documented** and **up-to-date**

Sebastien Clesse (coord),
Juan Garcia-Bellido (coord),
Eleni Bagui,
Valerio De Luca,
Gabriele Franciolini,
Cristian Joana,
Rajeev Kumar Jain,
Sachiko Kuroyanagi,
Ilia Musco,
Theodoros Papanikolaou,
Marco Peloso,
Alvise Raccanelli,
Sebastien Renaux-Petel,
Antonio Riotto,
Ester Ruiz Morales,
Marco Scalisi,
Olga Sergijenko,
Caner Unal,
Vincent Vennin,
David Wands

What is `PrimBHoles` ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

3. developed by a team of 20 PBH **experts,**

4. based on PBH **living review**

5. with pre-implemented **models** and **scripts**

6. well **documented** and **up-to-date**

7. **public**

Sebastien Clesse (coord),
Juan Garcia-Bellido (coord),
Eleni Bagui,
Valerio De Luca,
Gabriele Franciolini,
Cristian Joana,
Rajeev Kumar Jain,
Sachiko Kuroyanagi,
Ilia Musco,
Theodoros Papanikolaou,
Marco Peloso,
Alvise Raccanelli,
Sebastien Renaux-Petel,
Antonio Riotto,
Ester Ruiz Morales,
Marco Scalisi,
Olga Sergijenko,
Caner Unal,
Vincent Vennin,
David Wands

What is PrimBHoles ?

1. A **modular** code/toolbox

2. for **end-to-end** computations of PBH **GW signatures**

3. developed by a team of 20 PBH **experts,**

4. based on PBH **living review**

5. with pre-implemented **models** and **scripts**

6. well **documented** and **up-to-date**

7. **public**

8. **easy** to install, to use and to modify

Sebastien Clesse (coord),
Juan Garcia-Bellido (coord),
Eleni Bagui,
Valerio De Luca,
Gabriele Franciolini,
<u>Cristian Joana,</u>
Rajeev Kumar Jain,
Sachiko Kuroyanagi,
Ilia Musco,
Theodoros Papanikolaou,
Marco Peloso,
Alvise Raccanelli,
Sebastien Renaux-Petel,
Antonio Riotto,
Ester Ruiz Morales,
Marco Scalisi,
Olga Sergijenko,
Caner Unal,
Vincent Vennin,
David Wands

How `PrimBHoles` works ?
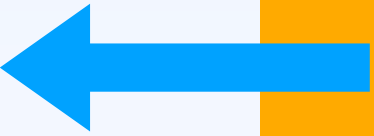
How `PrimBHoles` works ?

External codes or file

PBH theory

GW observable

Primordial curvature fluctuations
(Power spectrum, non-Gaussian tail…)

Fluct. Model

How **PrimBHoles** works ?

Primordial curvature fluctuations
(Power spectrum, non-Gaussian tail…)

Model

Parameters defined in: `user_params.py`
File: `power_spectrum.py`,
Mother class: `PS_Base`
Daughter classes: specific models

1. **Gaussian** curvature fluctuations - P(k)
   A. Amplitude + spectral index + running
   B. Log-normal (hybrid inflation)
   C. Gaussian
   D. Broken power law
   E. Others (axion, multi-field,…)
   F. From file or external method

2. **Non-Gaussian** curvature fluctuations - PDF
   A. Non-gaussian tail (critical higgs inflation)
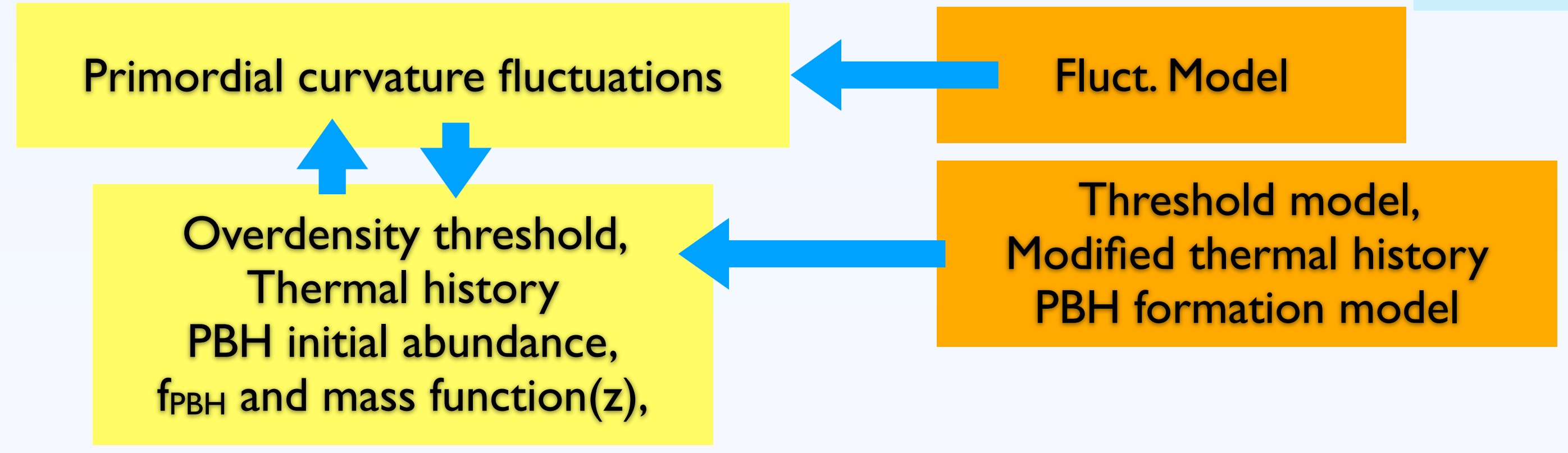   B. From file or external method

3. **Plots**
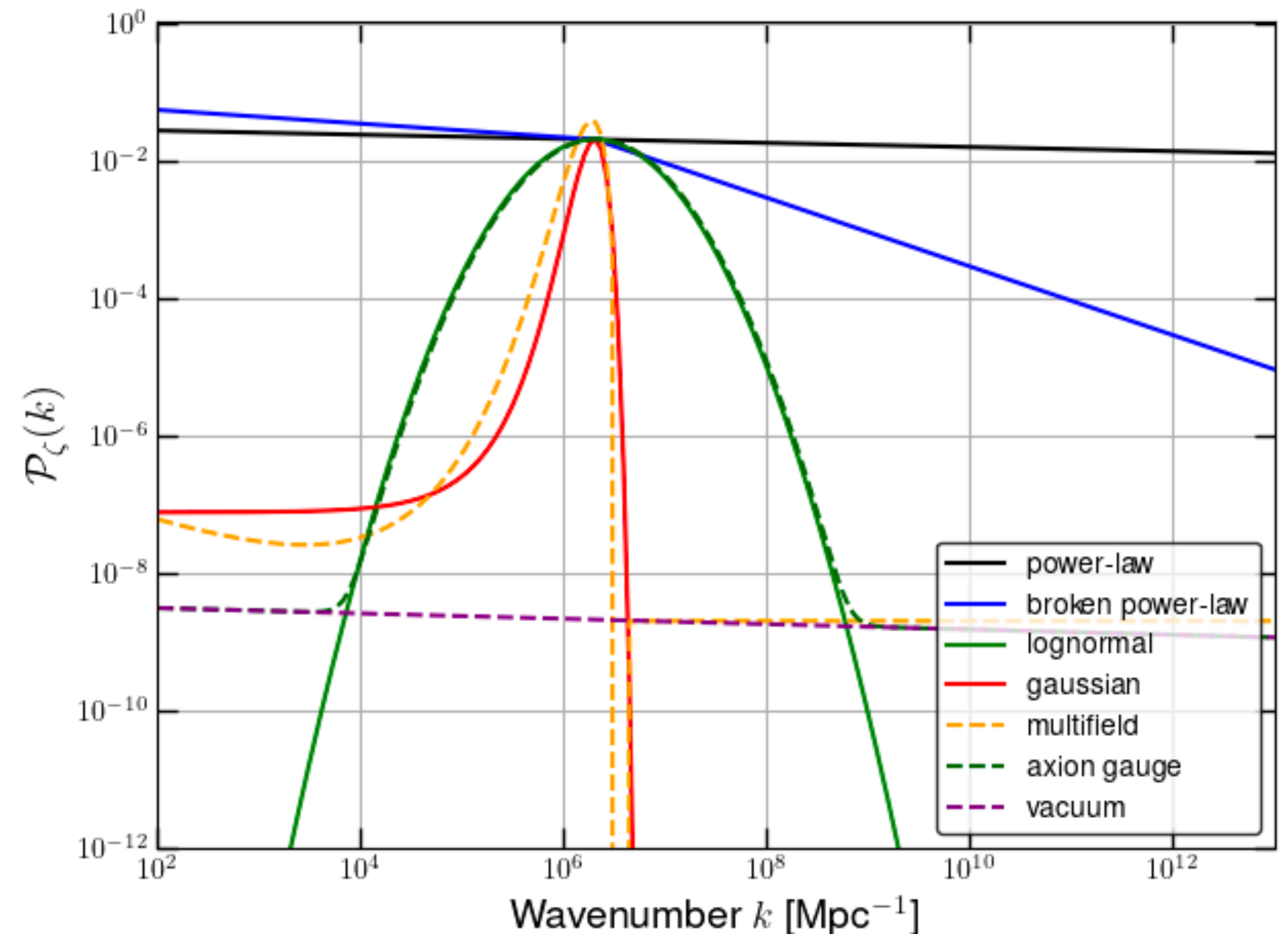
11

How `PrimBHoles` works ?

External codes or file

PBH theory

GW observable

Primordial curvature fluctuations

Fluct. Model

Overdensity threshold,
Thermal history
PBH initial abundance,
f_{PBH} and mass function(z),

Threshold model,
Modified thermal history
PBH formation model

How `PrimBHoles` works ?

Parameters defined in: `user_params.py`
File: `threshold.py` and `abundance.py`
Mother classes: `ClassDeltaCritical`, `CLASS_abundance`
Daughter classes: specific models

1. **Overdensity threshold**
   A. Single fixed value
   B. Elaborated algorithm from Musco et al.
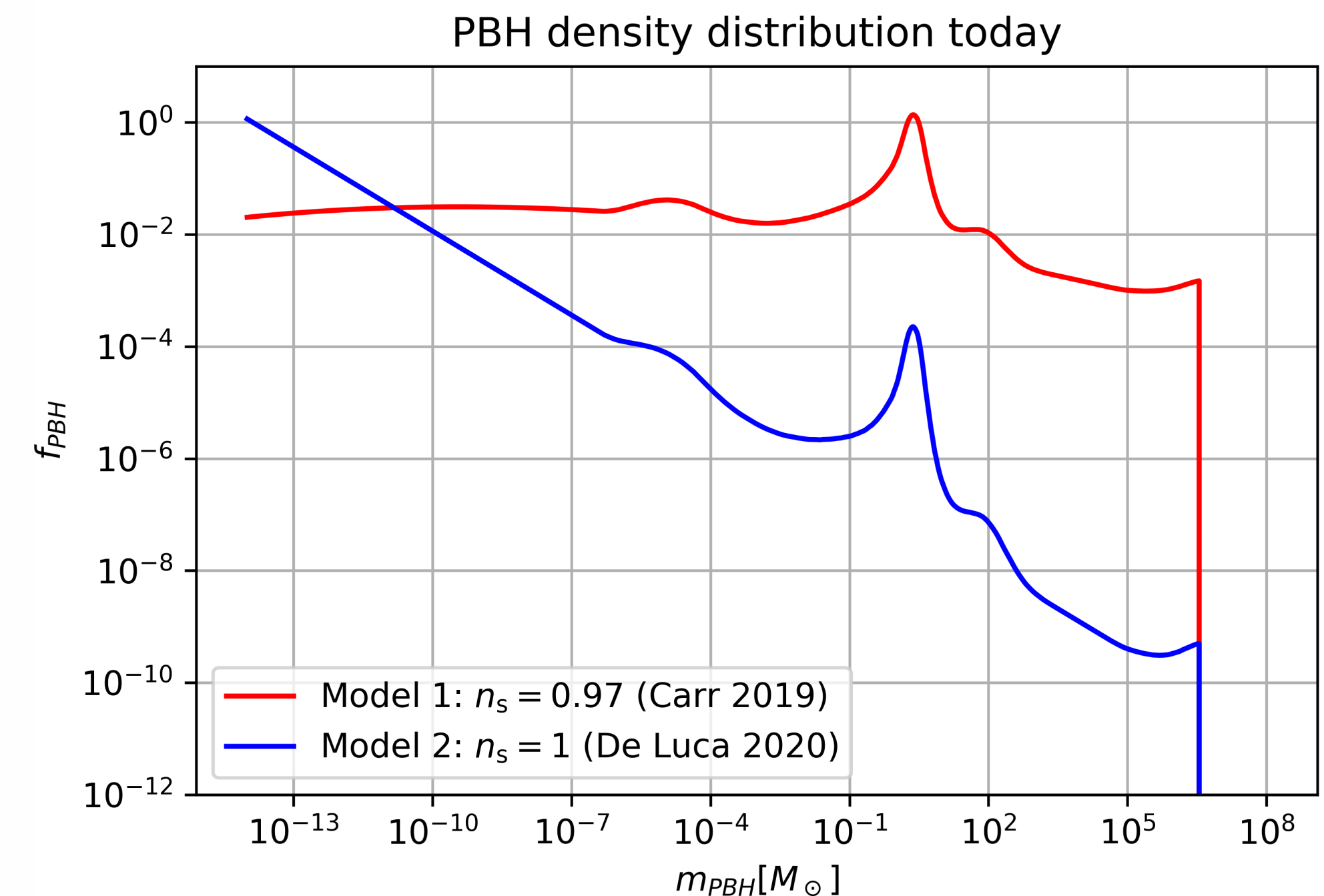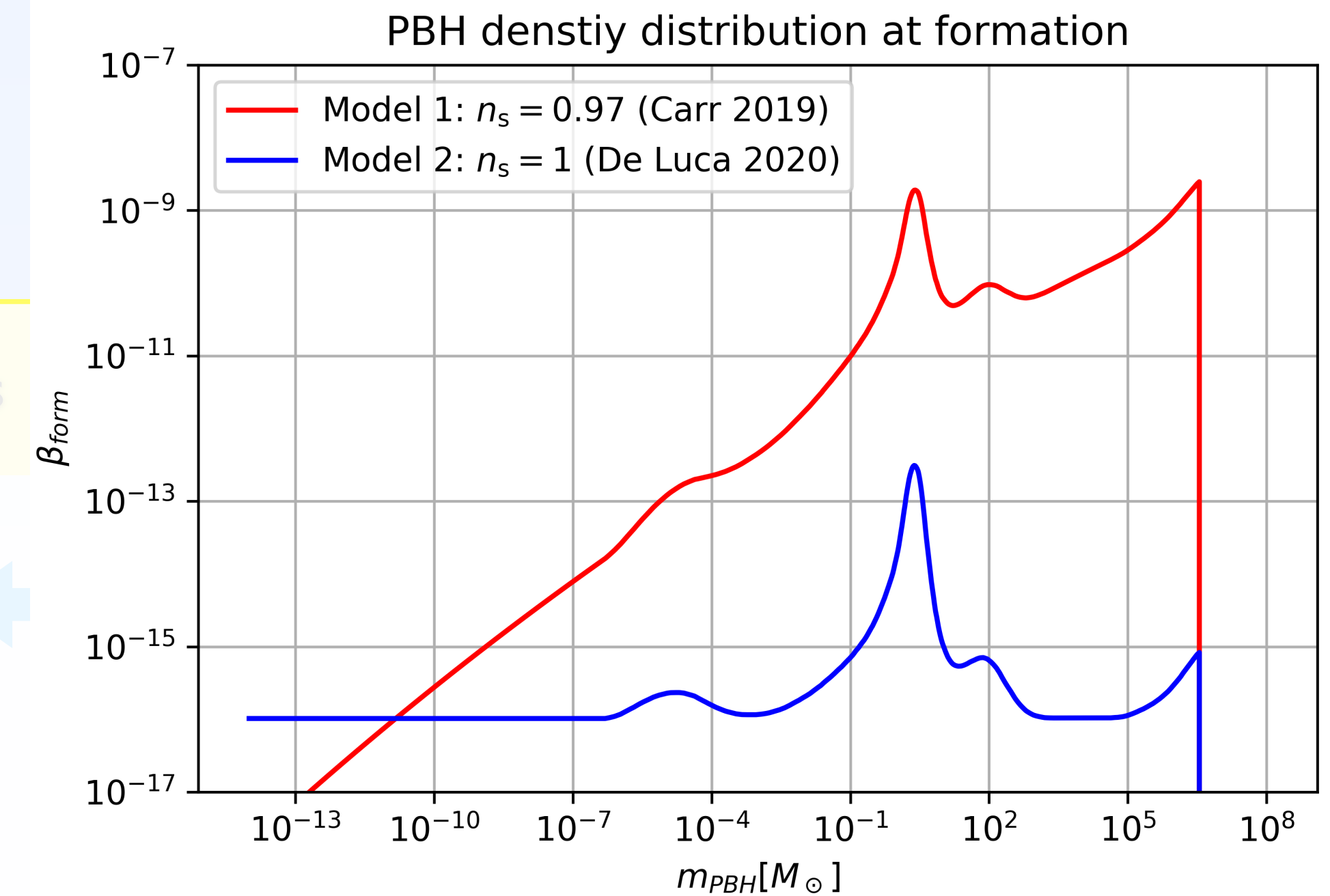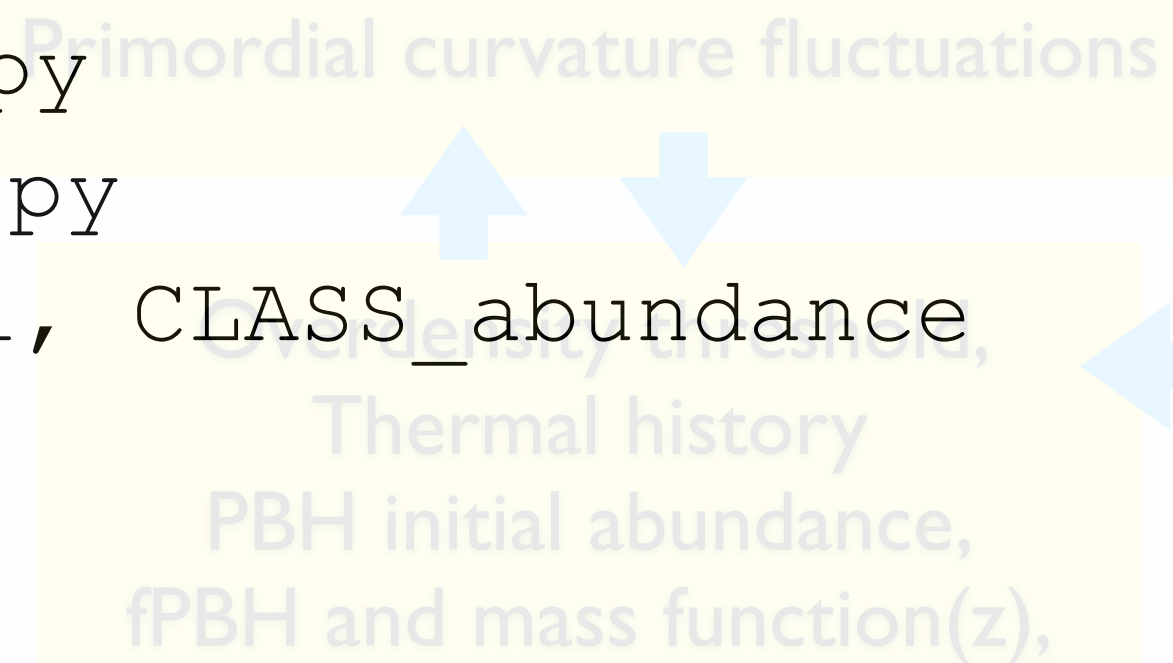   C. Thermal history (from file)
   D. From file or external method
2. **PBH initial abundance**
   E. Standard (naive) calculation
   F. More elaborated methods
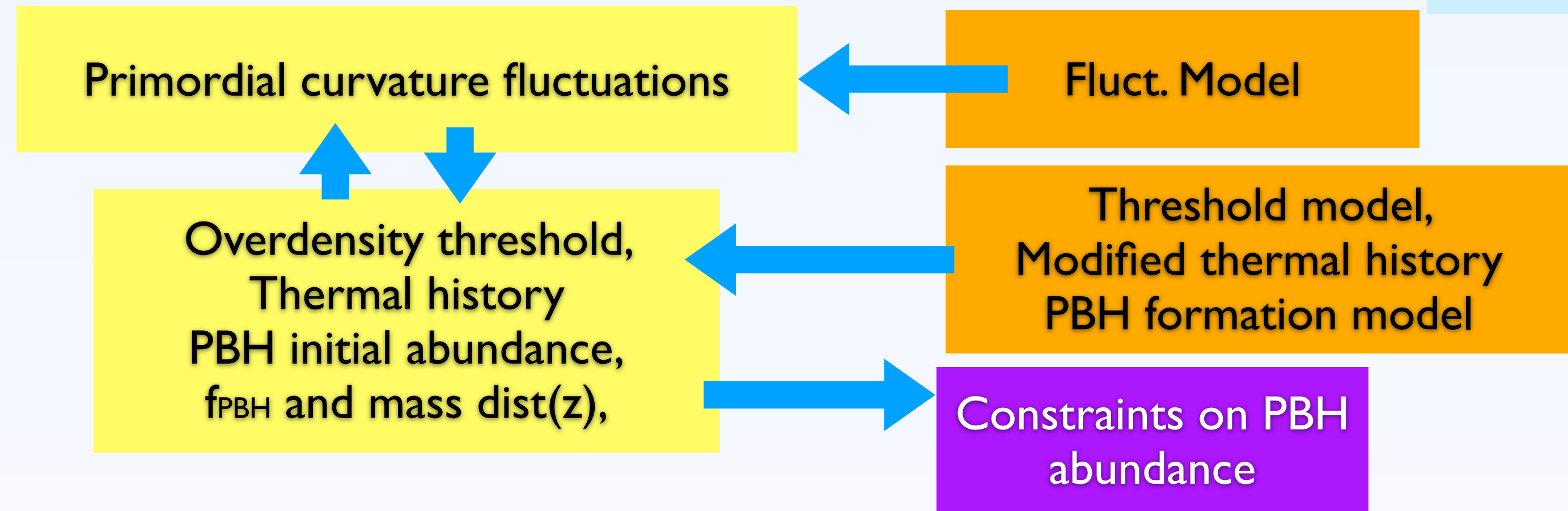   G. Non-Gaussian models
   H. From file or external method
3. f_{PBH} **and mass function + iterative method**
   I. Standard calculation
   J. Effect of accretion on PBH mass
4. Plots

Primordial curvature fluctuations

Overdensity threshold,
Thermal history
PBH initial abundance,
fPBH and mass function(z),

PBH denstiy distribution at formation

Model 1: $n_s = 0.97$ (Carr 2019)
Model 2: $n_s = 1$ (De Luca 2020)

β_{form}

$m_{PBH}[M_\odot]$

PBH density distribution today

f_{PBH}

Model 1: $n_s = 0.97$ (Carr 2019)
Model 2: $n_s = 1$ (De Luca 2020)

$m_{PBH}[M_\odot]$

How `PrimBHoles` works ?

External codes or file

PBH theory

GW observable

Primordial curvature fluctuations

Fluct. Model

Overdensity threshold,
Thermal history
PBH initial abundance,
fPBH and mass dist(z),

Threshold model,
Modified thermal history
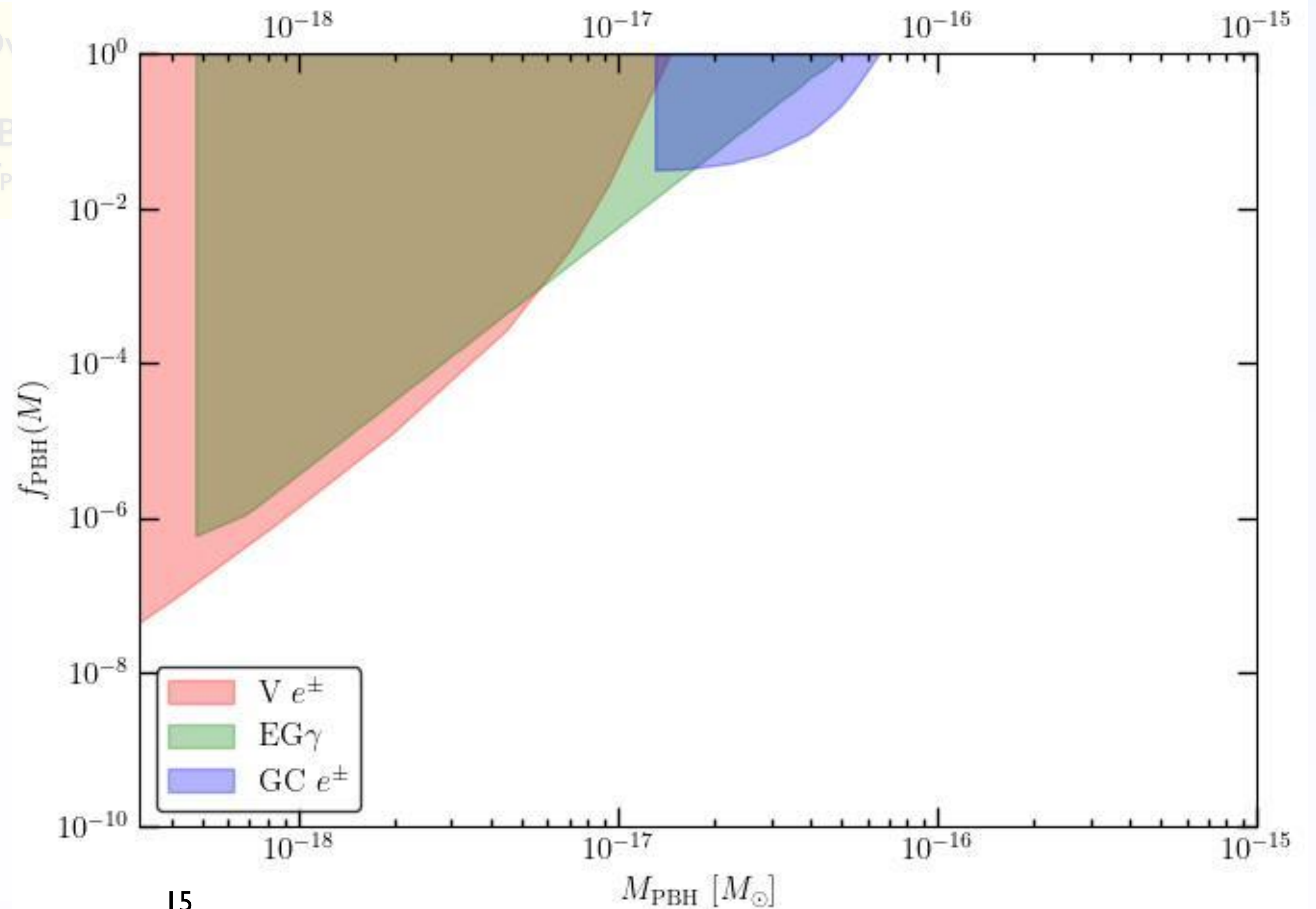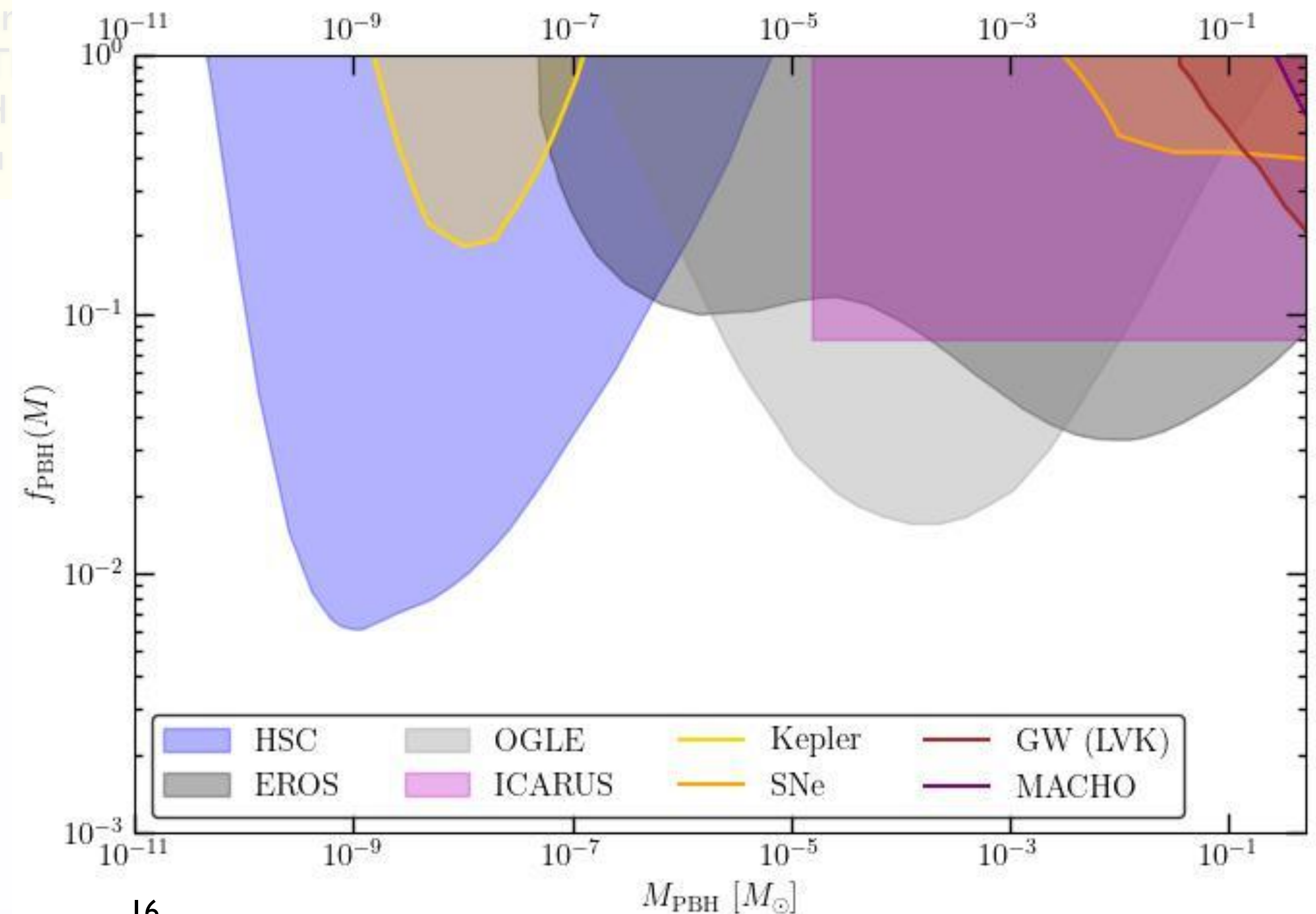PBH formation model

Constraints on PBH abundance

14

How `PrimBHoles` works ?

Choice of probes defined in: `bounds_params.py`
One data file + python dictionary entry, for each probe
File: `bounds.py`

1. **Read the necessary files**
with PBH constraints (monochromatic case)
2. **Make Plot(s)**
3. **include PBH evidence ?**

How `PrimBHoles` works ?
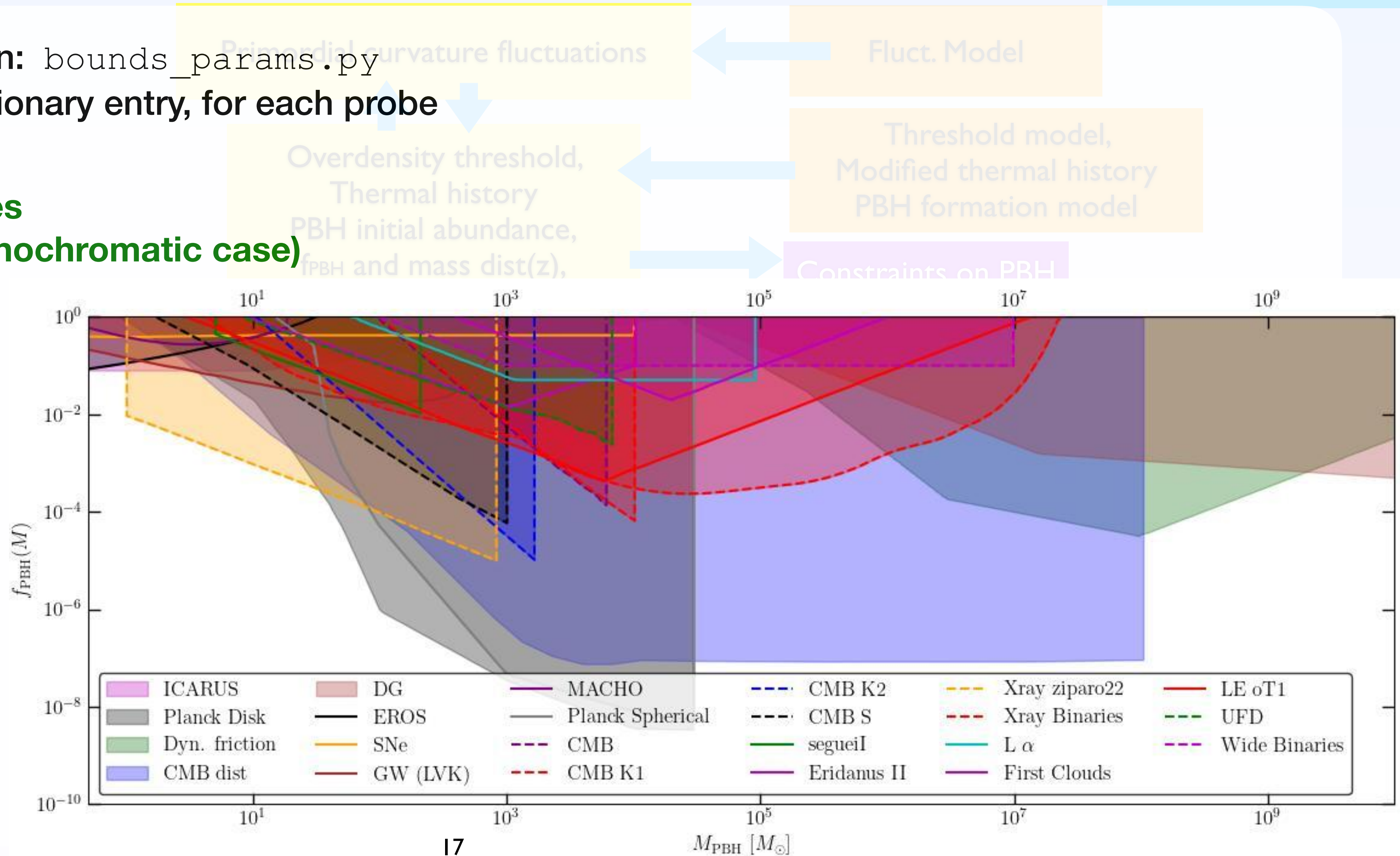
Choice of probes defined in: `bounds_params.py`
One data file + python dictionary entry, for each probe
File: `bounds.py`

1. **Read the necessary files**
with PBH constraints (monochromatic case)
2. Make Plot(s)
3. include PBH evidence ?

How **PrimBHoles** works ?
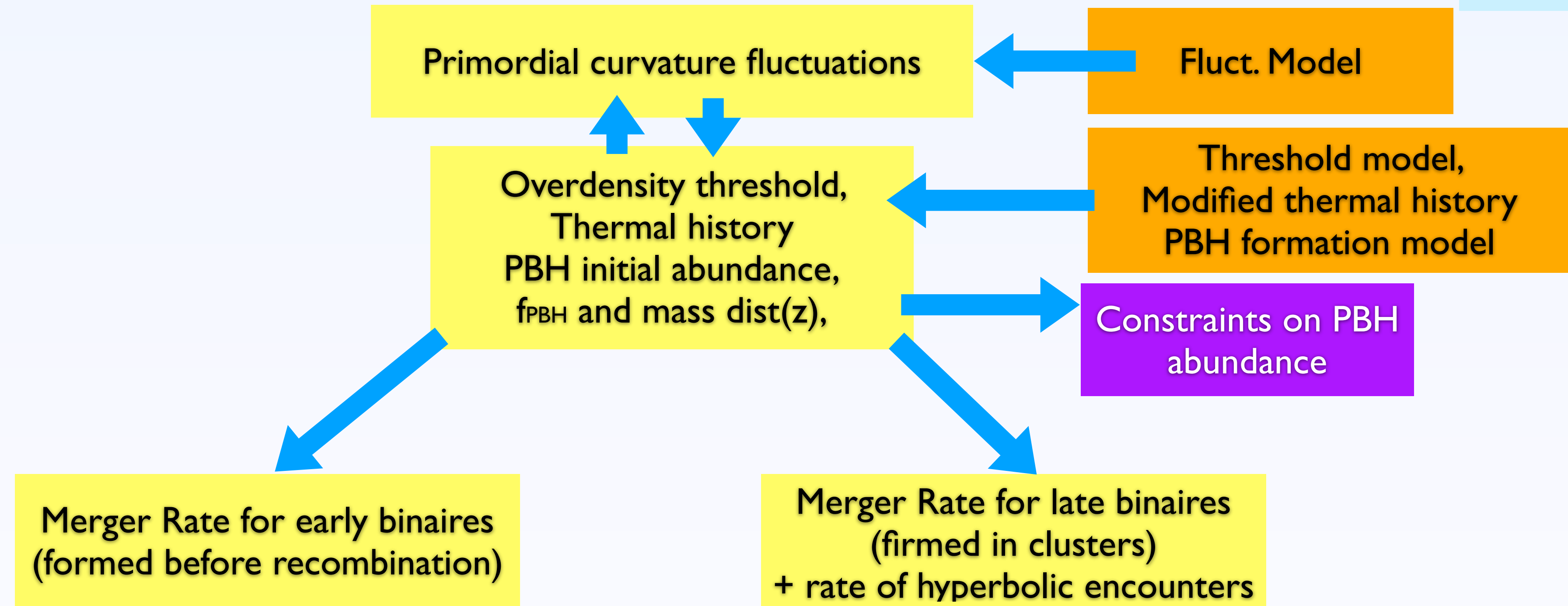
Choice of probes defined in: `bounds_params.py`
One data file + python dictionary entry, for each probe
File: `bounds.py`

1. **Read the necessary files**
with PBH constraints (monochromatic case)
2. **Make Plot(s)**
3. **Include PBH evidence ?**

17

How `PrimBHoles` works ?

External codes or file

PBH theory

GW observable

Primordial curvature fluctuations

Fluct. Model

Overdensity threshold,
Thermal history
PBH initial abundance,
f_{PBH} and mass dist(z),

Threshold model,
Modified thermal history
PBH formation model

Constraints on PBH abundance

Merger Rate for early binaires
(formed before recombination)

Merger Rate for late binaires
(firmed in clusters)
+ rate of hyperbolic encounters

18

How `PrimBHoles` works ?

Parameters defined in: `user_params.py`
File: `merger_rates.py`
Mother classes: `MergerRates`
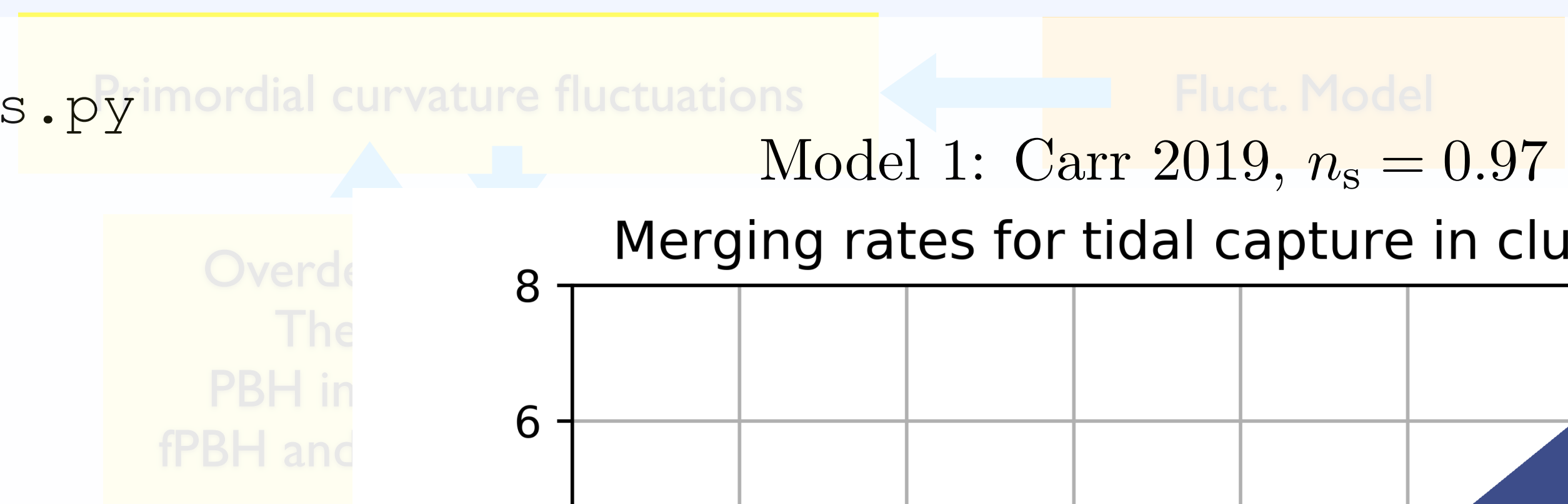Daughter classes: specific models

1. **Rate of early binaires**
   - A. Standard formula
   - B. Rate suppression factors (different models)
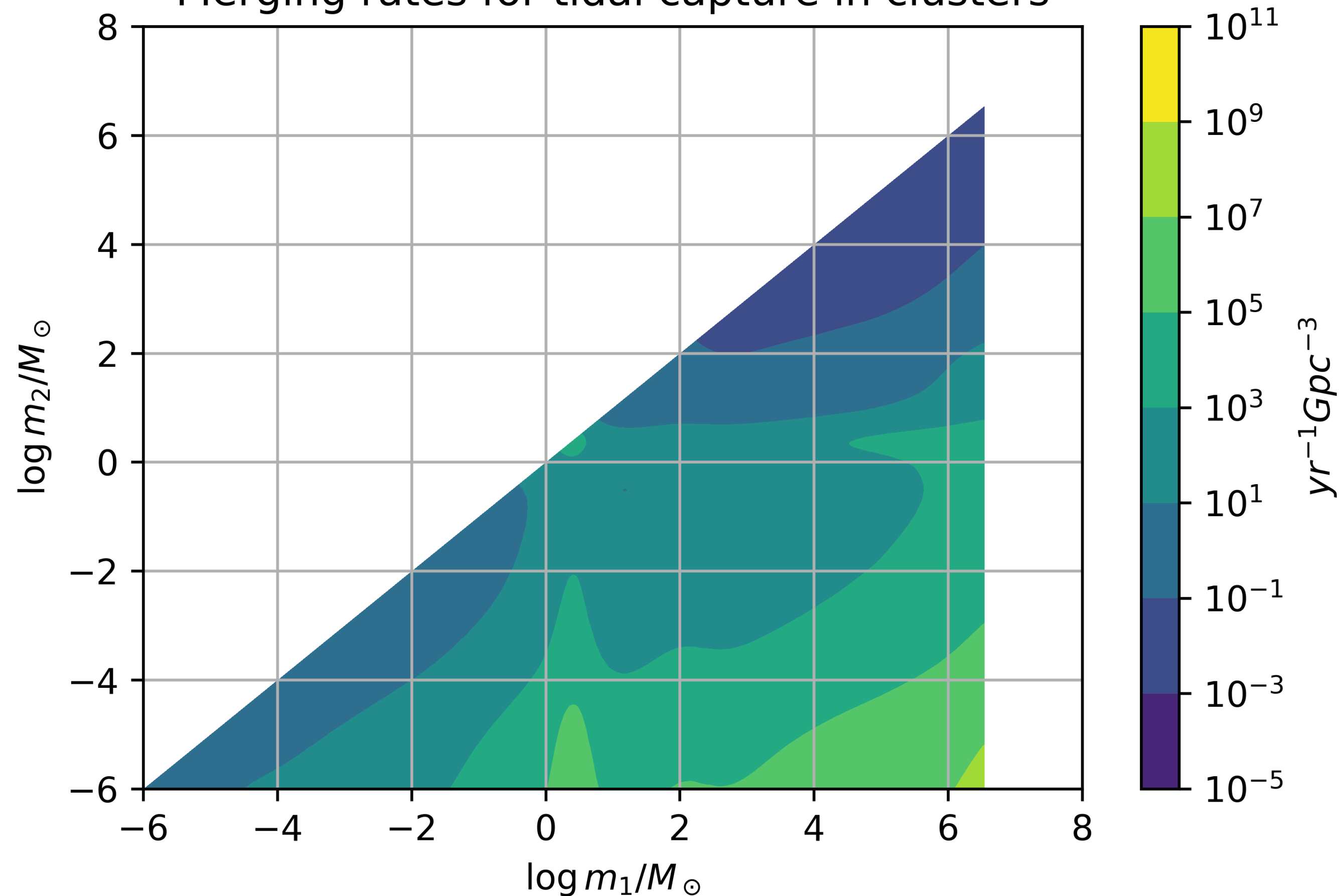
2. **Rate of late binaries (in clusters)**
   - C. Standard formula
   - D. Rate enhancement (Poisson clustering)
   - E. Redshift dependence
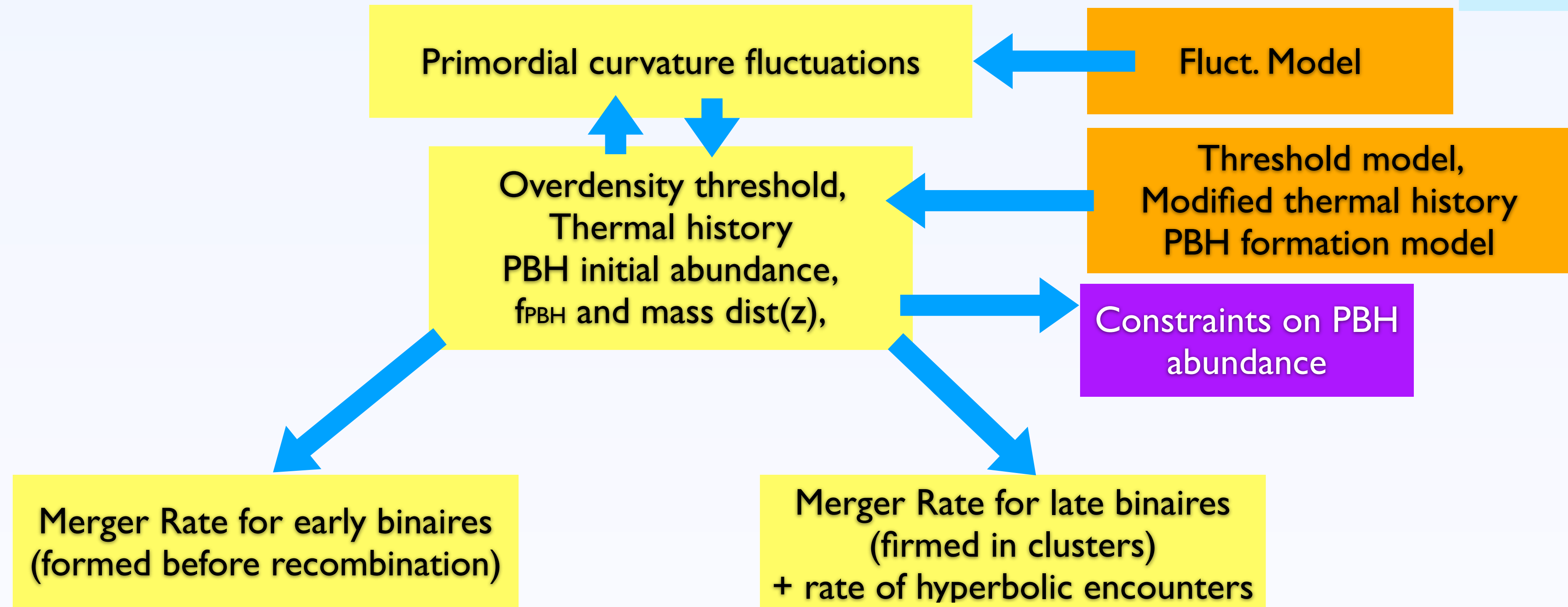   - F. Three-body capture

3. **Rate of hyperbolic encounters**

4. Plots

Model 1: Carr 2019, $n_s = 0.97$

Merging rates for tidal capture in clusters

How `PrimBHoles` works ?

External codes or file

PBH theory

GW observable

Primordial curvature fluctuations

Fluct. Model

Overdensity threshold,
Thermal history
PBH initial abundance,
f_{PBH} and mass dist(z),

Threshold model,
Modified thermal history
PBH formation model

Constraints on PBH abundance

Merger Rate for early binaires
(formed before recombination)

Merger Rate for late binaires
(firmed in clusters)
+ rate of hyperbolic encounters

20
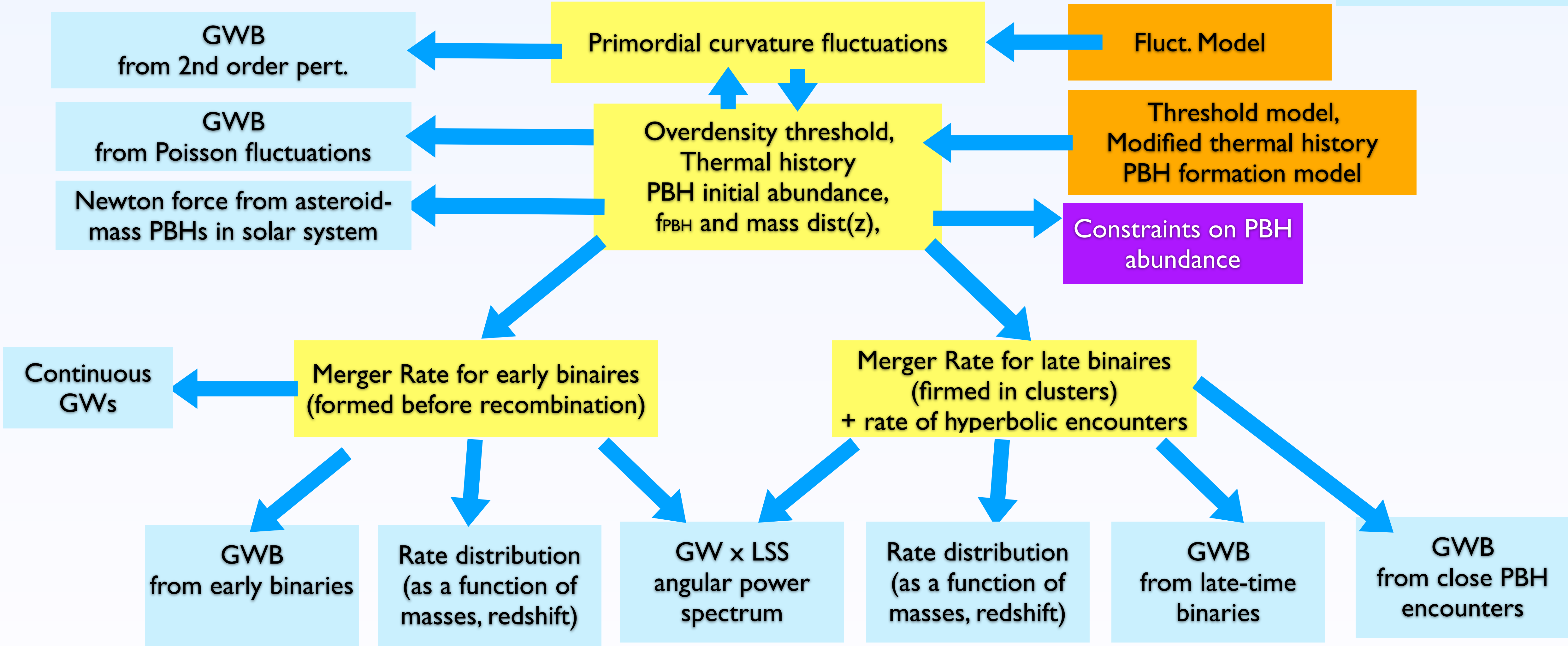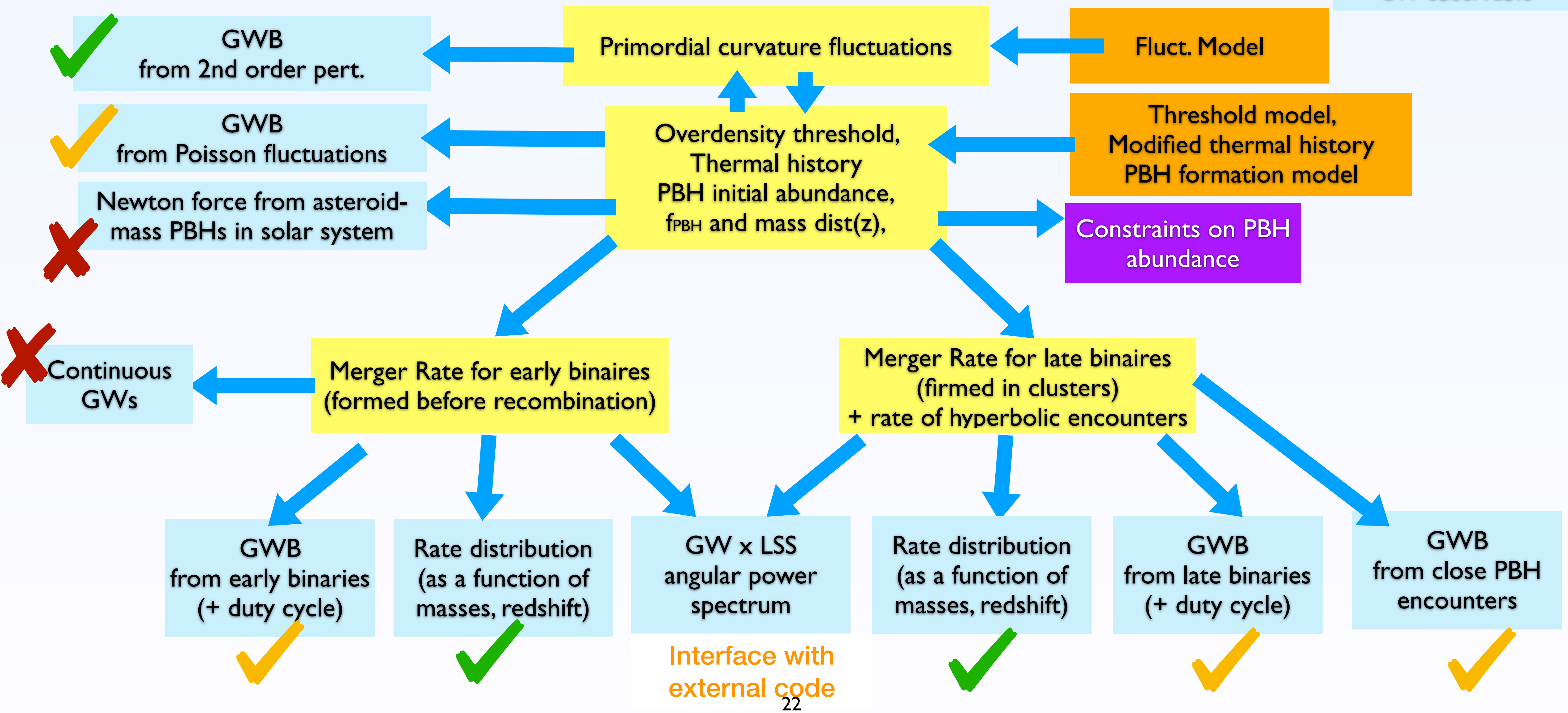
When will `PrimBHoles` be released ?

A few months after the living review
(October 2023…)

Perspective: interface with other (LISA) codes