INAF – Osservatorio Astronomico di Padova

Formation pathways of BH-BH binaries: HPC friends and foes

Mario Spera (mario.spera@oapd.inaf.it) (mario.spera@live.it)
Postdoctoral fellow at Astronomical Observatory of Padova

Collaborators: Michela Mapelli

What about computing @ INAF?
June 20-21, INAF sede centrale, Rome (Italy)

Outline

1. Research aim
   Constraining the formation pathways of GW150914/GW151226 and future GW events

2. Achievements so far
   Up-to-date black hole mass spectrum

3. Direct N-body simulations
   Studying the dynamical evolution of compact objects in dense stellar environments

4. High Performance Computing: means-and-needs analysis
   Graphics Processing Units, as a must

5. Summary

Origin of GW150914/GW151226

We know

GW150914: first detection

$m_1 = 36^{+5}_{-4}\ \mathrm{M}_\odot$ $m_2 = 29^{+4}_{-4}\ \mathrm{M}_\odot$

✓ Massive BHs exist ($m > 25\ \mathrm{M}_\odot$)

✓ Binary BHs exit

✓ They can merge within a Hubble time

Origin of GW150914/GW151226

We know

GW150914: first detection

$m_1 = 36^{+5}_{-4}\ \mathrm{M}_\odot$ $m_2 = 29^{+4}_{-4}\ \mathrm{M}_\odot$

✓ Massive BHs exist ($m > 25\ \mathrm{M}_\odot$)

✓ Binary BHs exit

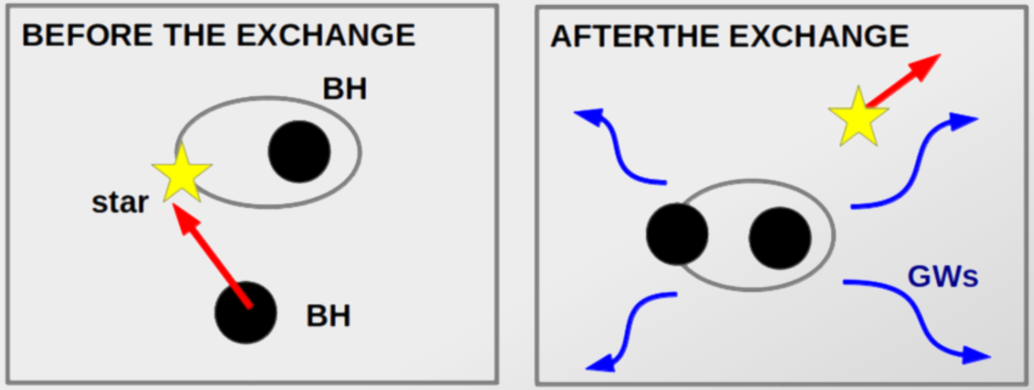
✓ They can merge within a Hubble time

We don't know

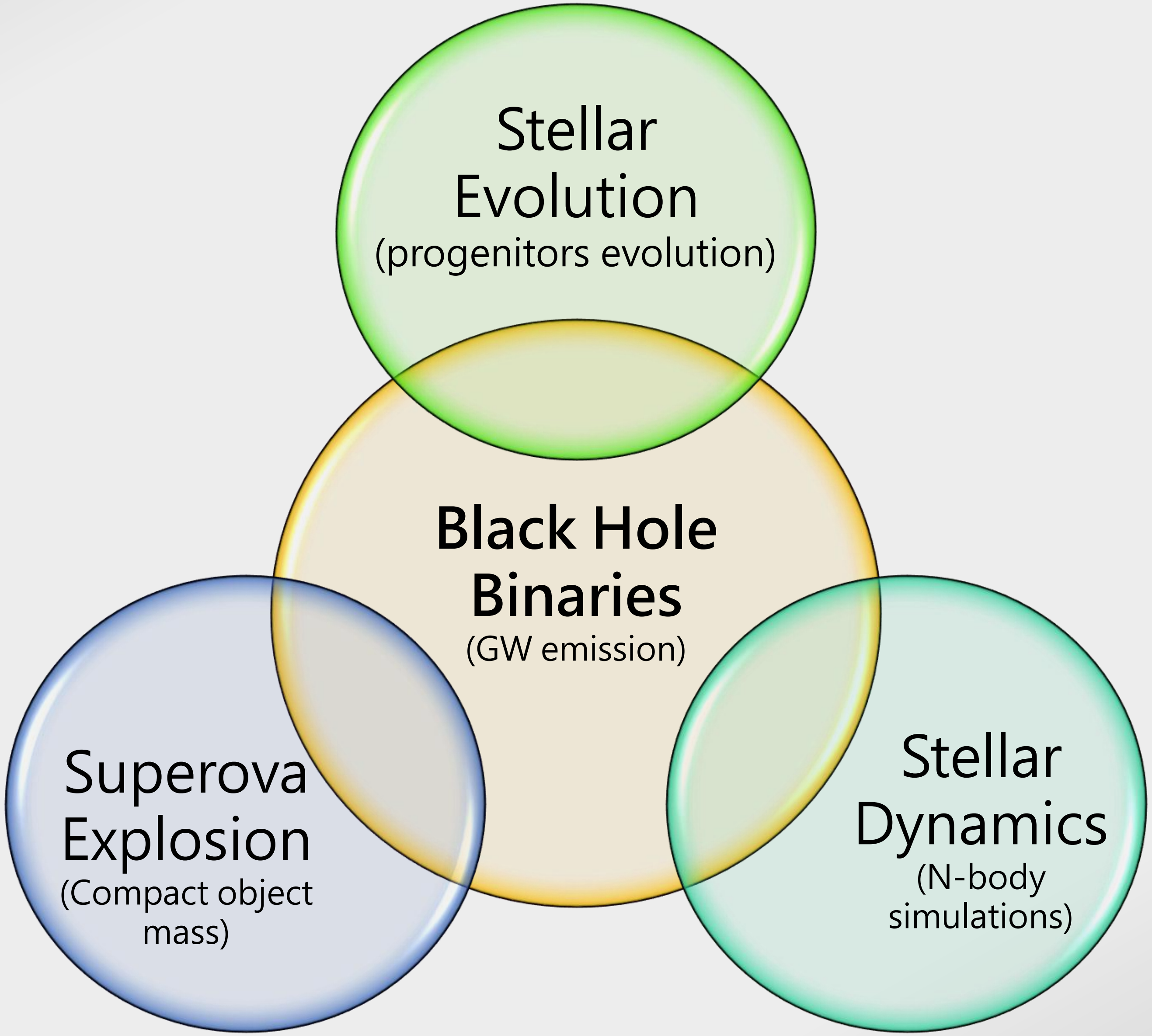
Primordial or dynamical origin?

My main research interest

Example of dynamical origin



Understanding the origin of GW events: ingredients



Main achievement: SEVN

Up-to-date stellar evolution recipes

Up-to-date SN models

Simple C++ interface for N-Body codes

SEVN: Stellar Evolution for N-body codes

Spera, Mapelli, Bressan 2015 MNRAS, 451, 4086

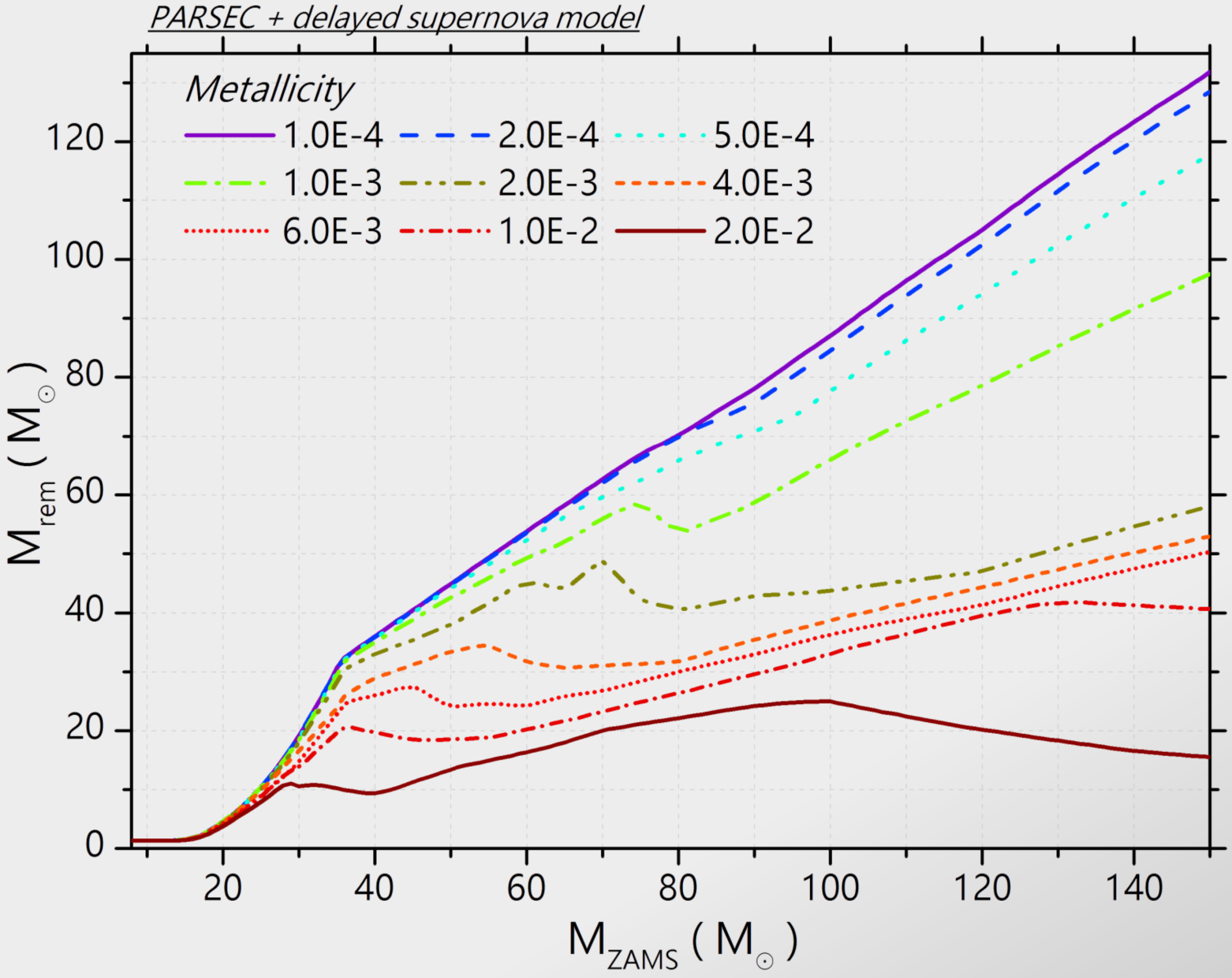
✓ It can be easily coupled with N-Body codes (currently implemented in HiGPUs and StarLab)

✓ SEVN interpolates stellar evolution tables (versatile approach instead of fitting formulas)

(change stellar evolution → just change input tables, without modifying the code)

BHs mass spectrum: results (SEVN)

Spera, Mapelli, Bressan 2015 MNRAS, 451, 4086



BHs mass spectrum: results (SEVN)

Spera, Mapelli, Bressan 2015 MNRAS, 451, 4086

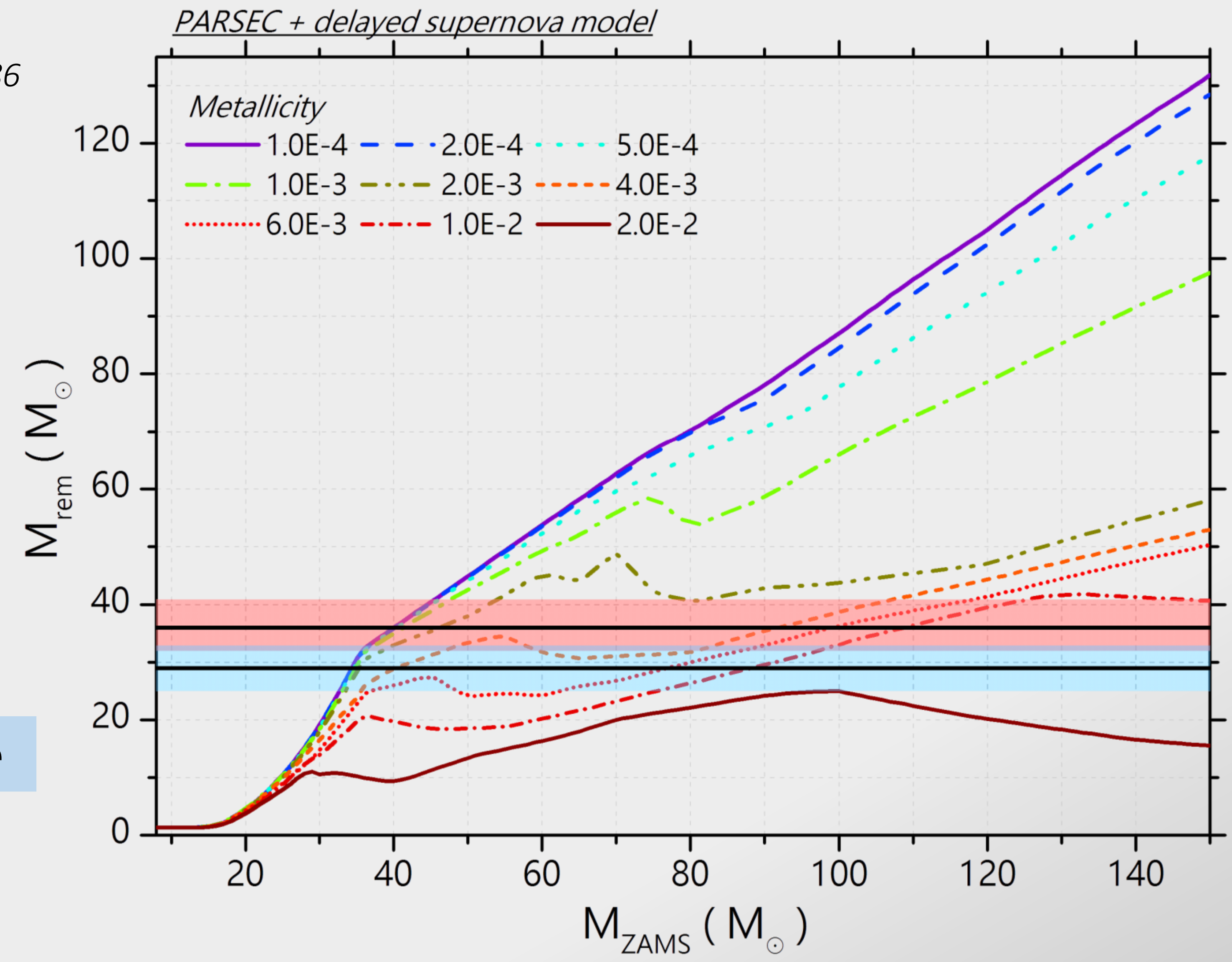
Abbott+ 2016 ApJL, 818, L22 (Fig. 1)

GW150914 estimated metallicity

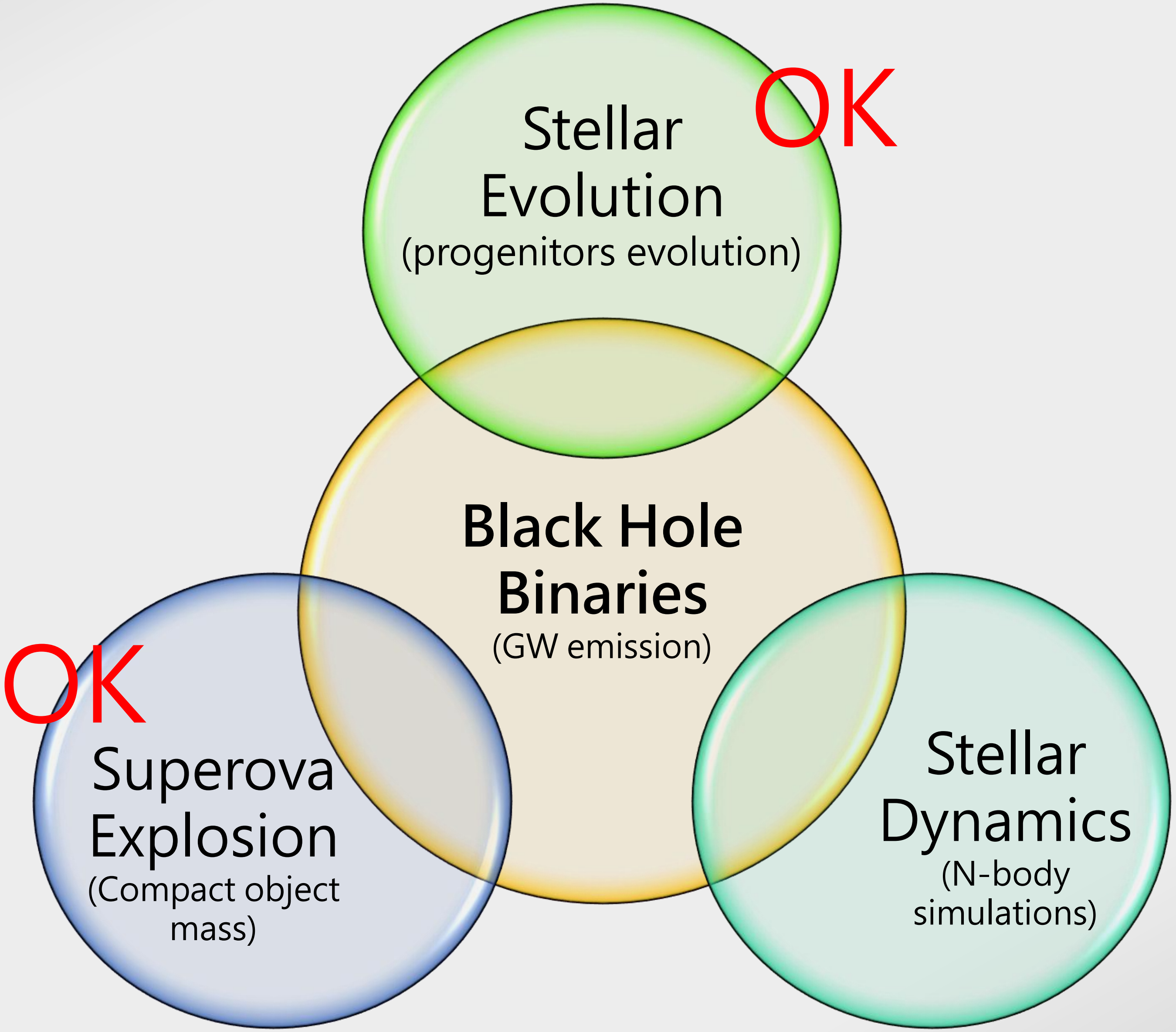
Below $Z \simeq 0.5 Z_{\odot}$ and possibly below $Z \simeq 0.25 Z_{\odot}$

High metallicity stars lose more mass than metal poor stars

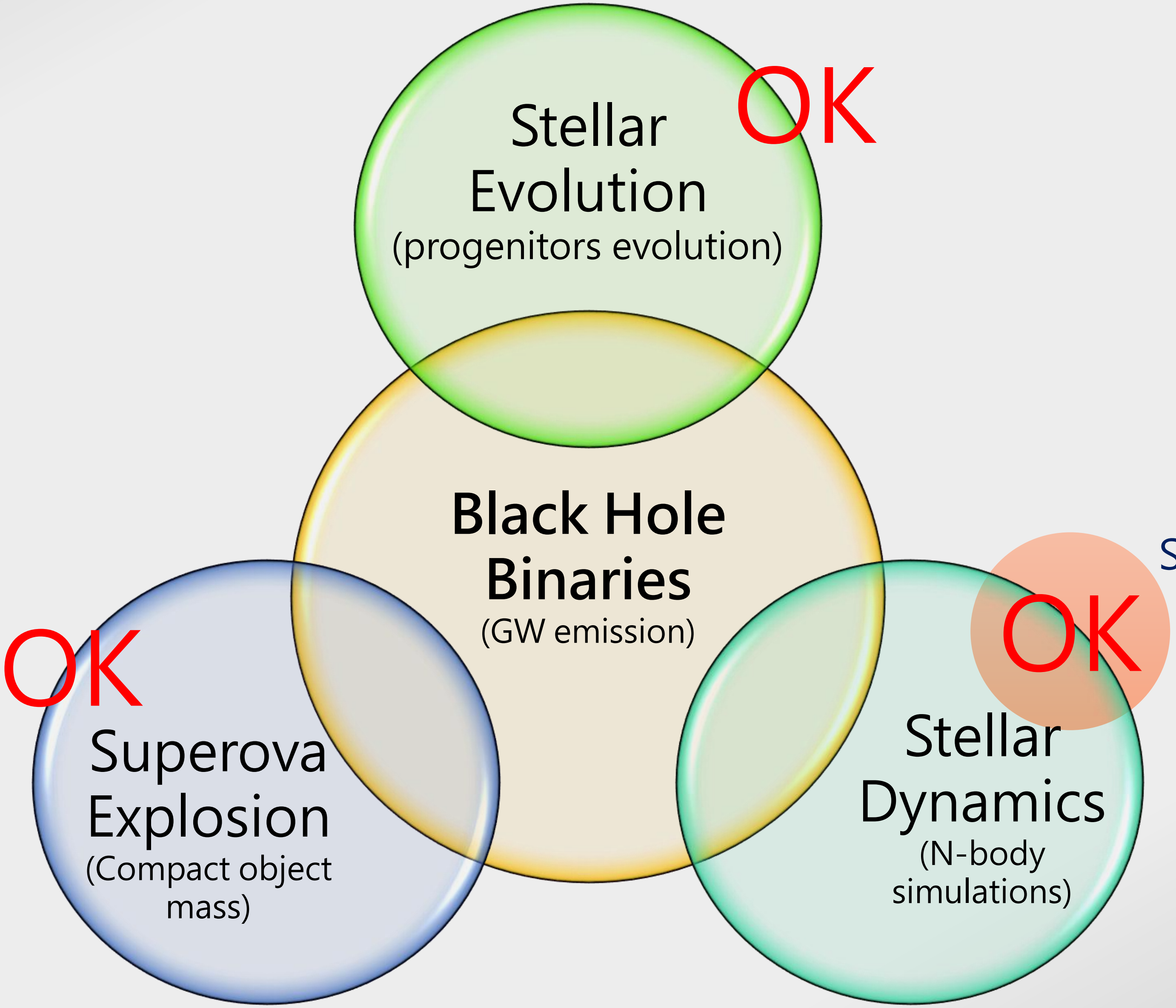
Key points: low Z + direct collapse



Understanding the origin of GW events: ingredients



Understanding the origin of GW events: ingredients



We have already linked SEVN with N-body codes

What’s missing?

N-body simulations of different environments including the new physics implemented in SEVN

Target N-body simulations: codes

Pros

Very high accuracy

1 star : 1 body (real SC)

Maximum resolution

Cons

Computational complexity $O(N^2)$

DIRECT N-BODY SIMULATIONS

Target N-body simulations: codes

Pros

Very high accuracy

1 star : 1 body (real SC)

Maximum resolution

Cons

Computational complexity $O(N^2)$

DIRECT N-BODY SIMULATIONS

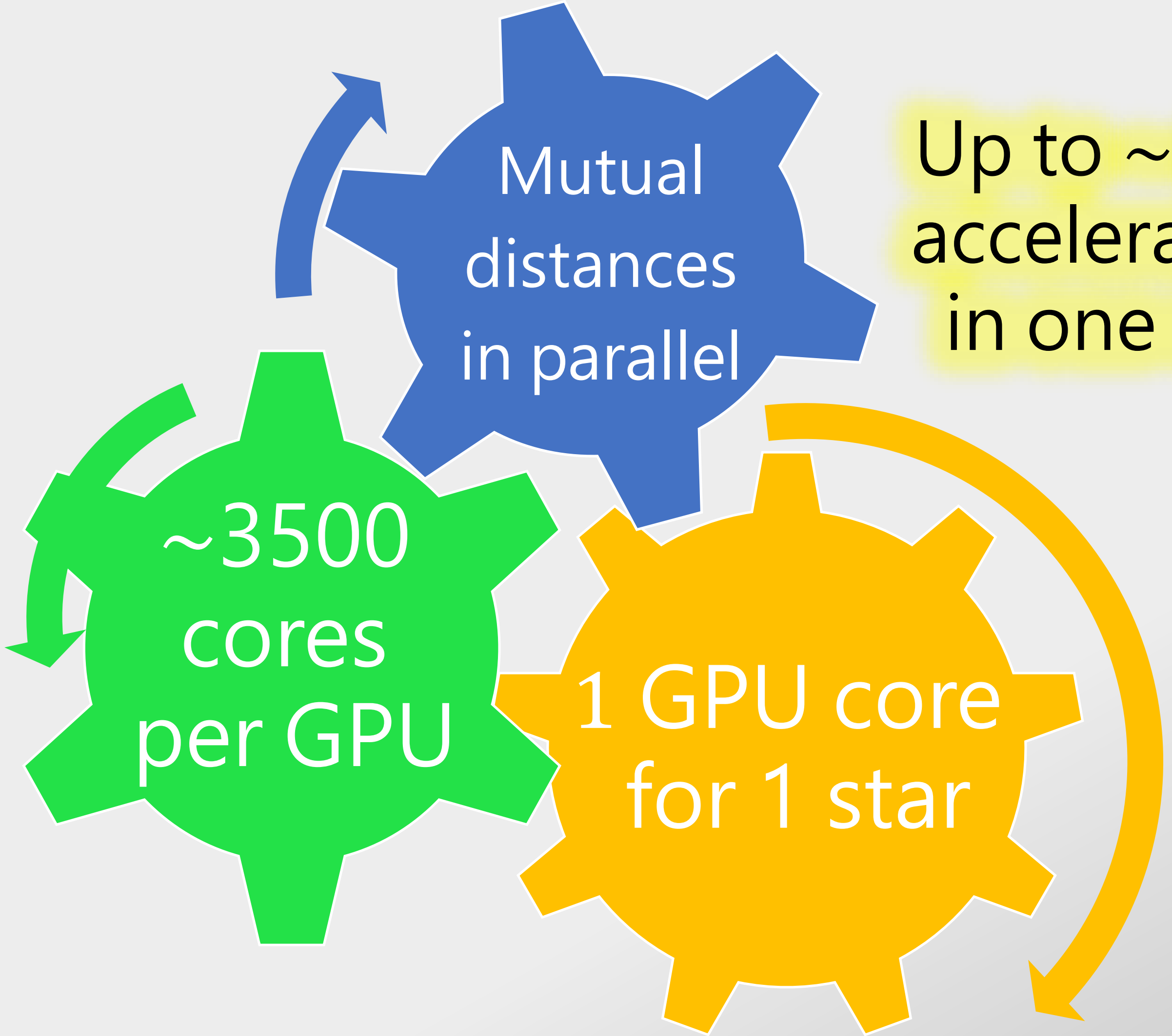
KEY POINT

We can follow the formation and dynamical evolution of binary systems

Direct N-body codes are a MUST for our research

Target N-body simulations

A perfect marriage with GPUs



Up to ~ 3500 accelerations in one shot

Some numbers

GPU performance (Pascal arch., GP100)

- ✓ *Up to 10000 GFLOPS (32bit)*
- ✓ *Up to 5000 GFLOPS (64bit)*

Real N-body apps 8000 GFLOPS (32bit) (expected)

CPU → not more than 500 GFLOPS (32bit)

The big IF: computing resources availability

NO GPU clusters to run our simulations: we do have primacy, we cannot keep it!

CINECA supercomputers

- **PLX**, 548 GPUs M2070 (not active)
- **EURORA**, 64 GPUs K20 + Xeon Phi (not active)
- **GALILEO**, 20 GPUs K80 + Xeon Phi
- **MARCONI**, NO GPUs, Xeon Phi

N-body codes on Xeon Phi?

Not worth it

- Lower peak performance (3000 GFLOPS vs 10000 GFLOPS)
- Less number of cores (70 vs 3500)
- Very hard to get a real speedup on Xeon Phi
- Efficient porting requires (almost) a professional programmer

WE NEED GPUs