PLANTING COMPACT BINARIES IN COSMOLOGICAL SIMULATIONS

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Astrosim 2018
NEW FIELD IN ASTRONOMY

**Fundamental physics**
- Beyond GR
- Mass of graviton
- Hubble constant

**Gravitational waves from stellar remnants**
- (black holes, neutron stars, white dwarves)

**Nuclear physics**
- Neutron star equation of state
- R-process elements

**High energy astrophysics**
- Relativistic outflows
- BH formation
- Gamma-ray bursts

**Global star formation**
- Initial mass function
- Low-metallicity environments
- R-process elements
- Dwarfs galaxies
- Milky-Way structure

**Stellar/Binary evolution**
- Supernova kicks
- Common envelope
- Mass loss
- Cluster evolution

**And numerics for**
- Waveforms
- Data analysis

**And**
- Nuclear physics
- High energy astrophysics
- Global star formation
- Stellar/Binary evolution
- Fundamentals physics
- Gravitational waves from stellar remnants
FORMATION OF GW PROGENITORS

Dwarf galaxy  Milky Way

COMBINE MERGER MODELS WITH COSMOLOGICAL SIMULATIONS
FIRE SIMULATIONS

Feedback In Realistic Environments project (FIRE, Hopkins+14,17)

Ex: LATTE simulation Mass resolution : 7000 Msun
MAKING BINARY COMPACT OBJECTS
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- Binary population synthesis code (BSE, Hurley+2002): simplified stellar and binary model.

- Many free parameters: how to explore N-dimensional space?

- Input: Initial masses, periods, eccentricities: ~ million systems.

- Explore metallicity from 1% of Solar to Solar.

  => Create a dataset of compact object formation/merger properties.

- For black holes: mergers in clusters (CMC code, with Carl Rodriguez): N body code + stellar/binary interactions.

  => Create dataset of mergers from clusters, different masses, mass profiles, metallicities, stellar evolution
GROWING COMPACT BINARIES IN GALAXIES

Star formation history
Metallicity
Positions/Trajectory
Gas properties

Star cluster properties
(M. Grudic)

Binary population model
Metallicity dependent

Gravitational wave emission

cluster mergers
(C. Rodriguez)
IMPACT OF COMPLEX STAR FORMATION

Different populations found in different structures

>10^{10} stars  
1 million binary black holes  
100 million binary white dwarfs

Lamberts+18; Blunt, Lamberts+ in prep.
Impact of Dwarf Galaxies

1/3 of black holes were formed outside Milky Way, implying that dwarf galaxies matter. This requires high resolution in observational studies. Mean metallicity is approximately 20% of the Sun's metallicity.
"INDIVIDUAL" NUMERICAL REQUIREMENTS

FIRE simulations: MW-like galaxies:
- 10 runs with 1-5 million CPU (M~7000 Msun)
- 1 run with 25 million CPU in progress (M~900 Msun)
Outputs: 7-20 GB/snapshot x 600: 5-10 TB/run
National/European-scale supercomputers

Cluster evolution: 100,000 CPU hours, need ~20 models
scaling difficult beyond ~100 CPU, specific supercomputers

10 million binaries: ~24 CPU hours
Need ~100 models for white dwarfs
~700 models for black holes
Embarrassingly parallel, ok on local clusters, needs “bookkeeping”
BRINGING IT ALL TOGETHER

Star formation
Metallicity

Star clusters

Binary model

Gravitational waves

Public catalogue

Cluster model
BRINGING IT ALL TOGETHER

1) MW simulations for LISA predictions
Sampling issues: initial conditions need to be sampled properly (x10)

Galactic background in LISA

Missing binaries = underestimated background
BRINGING IT ALL TOGETHER

2) Communicating results and accessibility
Making a catalogue: accessible, durable, easy to use, advertised: how?
2D/3D visualisation

Mock GAIA catalogues (Sanderson + 2018)
5 billion stars

Week on local cluster:
Bottleneck: writing to disk
2TB / catalogue

In prep: double white dwarf catalogues (~100 million objects)
BRINGING IT ALL TOGETHER

3) LIGO/Virgo mergers from binaries and clusters
FIREBOX simulation. 15 Mpc/h, M~60 000 Msun
~50 MW galaxies, 1000 dwarf galaxies
5 million CPU (PRACE, R. Feldmann), 50 TBs, 200 GB/output

Needs for analysis:
Storage and high-memory computing (finding cloud properties,
Determine galactic tides, start particle history)
Flexible outputs, good time sampling (for gas evolution)
Intermediate data products: which formats?
Visualisation: tools?
Statistical tools to analyze different models