RT5: The nature of compact objects

Ferrari, Pani, Vincent

1) What alternatives to Kerr? And to BHs? New exotic sources?
2) EM observables VS GW observables
3) Is the probe “astrophysically-clean”?

STRONG GRAVITY UNIVERSE
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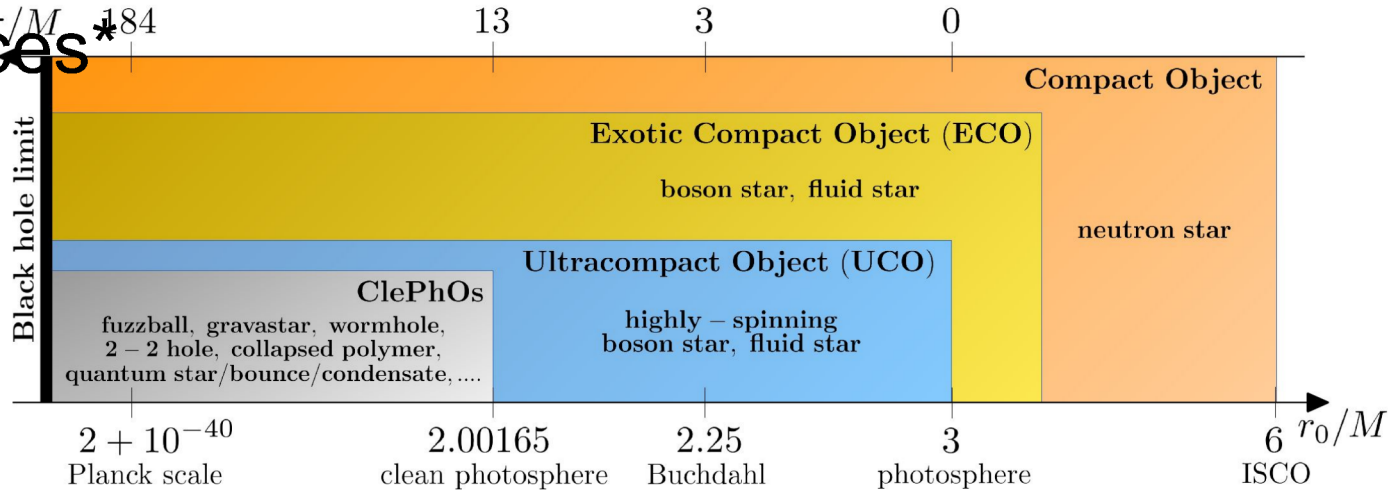
Beyond the Kerr BH paradigm

1) BH alternatives to Kerr

- Metric deformations: Ad-hoc / Generic
- Specific BHs in alternative theories
- Specific BHs within GR (exotic matter)

2) non-BH alternatives and/or novel exotic sources*



*(not all exotic compact objects are BS!)

EM tests of BHs

EM probes:

- Interfero: imaging; centroid / GRAVITY, EHT
- Spectro: continuum;line / X-ray satellites
- Timing: QPO / eXTP
- Polarisation / XIPE, IXPE

Big questions:

- Target: event horizon / apparent horizon / dark area on sky / photon ring ...
- Narayan-Broderick argument on event horizon detection
- EHT / BHCam (shadows): horizon or photon sphere? GRAVITY: which tests?
- Specific observable features for horizon-less spacetimes?
- Future of EM tests in the realm of GW tests? Specific EM tests? Multi-messenger
- Mass/spin (quadrupole?) measurements: which method? Astro systematics?
- Polarisation: less studied than others?

GW tests of BHs: big questions

- Merger templates beyond GR: *where do we stand*?
- Ringdown: fully under control?
- Fluid modes?
- Inspiral tests: which SNR to probe current models? Need LISA?
- EMRIs: which tests with only first-order SF? Bumpy BHs?

		BH	ECO	ClePhO
ringdown	GW echoes	✗	✓(only UCOs)	✓($\tau_{\rm echo} \sim M\|\log\epsilon\|$)
	Modified prompt ringdown	✗	✓	✗
	Extra modes	✗	✓	✓
inspiral	Multipolar structure (2PN)	$\delta M_l = \delta S_l = 0$	$\delta M_l \neq 0,\ \delta S_l \neq 0$	$\delta M_l \simeq 0,\ \delta S_l \simeq 0$
	Tidal heating ($2.5-4$PN)	✓	✗	✗
	Tidal Love number (5PN)	$k = 0$	$k \lesssim \mathcal{O}(k_{\rm NS})$	$k \sim [\log\epsilon]^{-1}$
	Resonances	✗	77 93	$\omega M \sim [\log\epsilon]^{-1}$

Theoretical questions

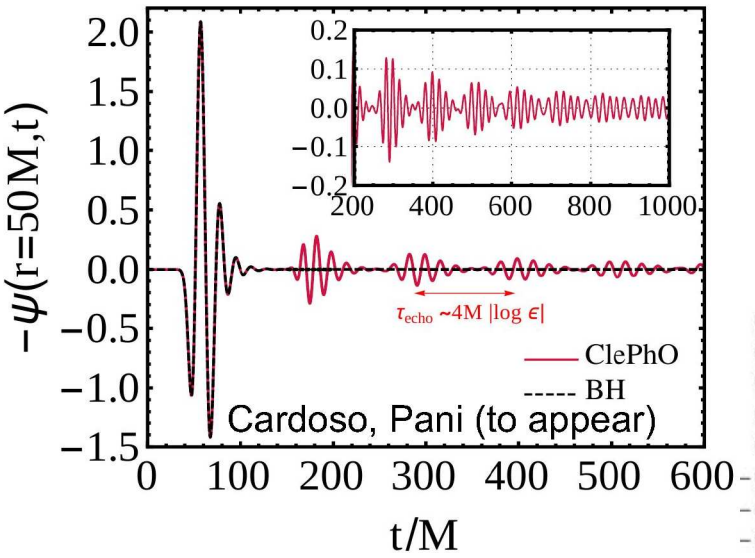
Theoretical constraints:

- Formation / stability (lesson from pulsars!)
- Motivation / models

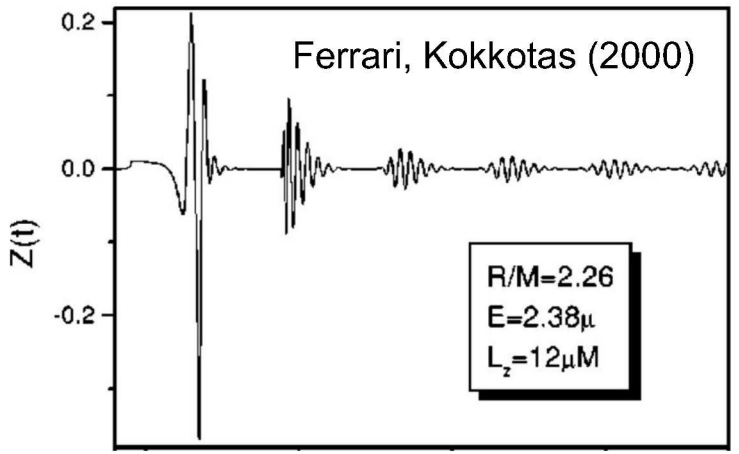
- **Big questions:**
  - What's the Target: Event horizon, Apparent horizon, Photon sphere?
  - Can ClePhOs/ECOs form dynamically?
  - ClePhO+ClePhO → ClePhO ? (ECO+ECO → ECO?)
  - BHs with boson hair: stability, observational constraints

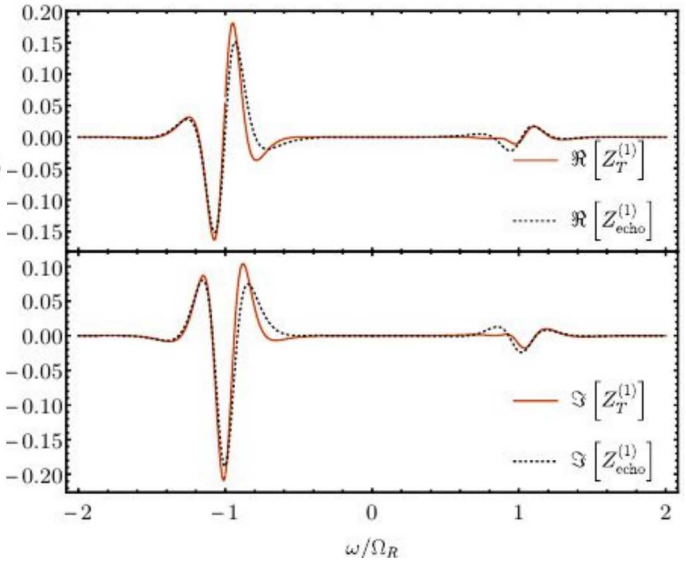
GW echo modelling

ClePhOs: R~2M+epsilon



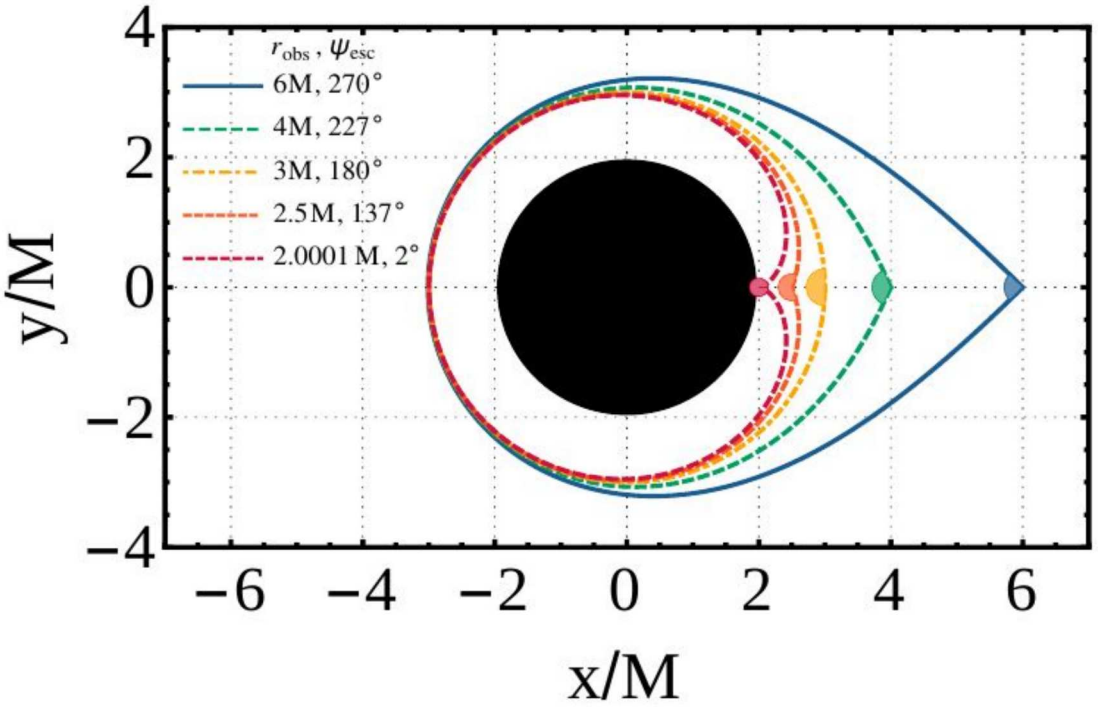
Ultracompact stars R>~9/4 M

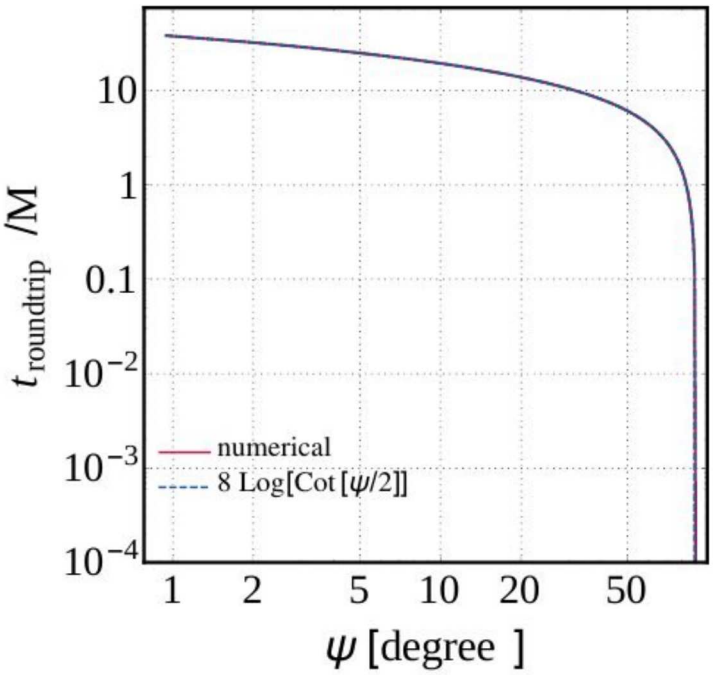




Mark, Zimmerman+ (2017)
overlap~0.969

Model	Taxonomy	Formation	Stability	EM signatures	GWs
Fluid stars	UCOs	✗	✓ [15, 50–54]	✓	✓ [15, 25, 50, 53, 54]
Anisotropic stars	ClePhOs [55–57]	✗	✓ [58, 59]	✓ [57, 60, 61]	✓ [60, 61]
Boson stars & oscillatons	UCOs, (ClePhOs?) [62–69]	✓ [65, 68, 70–72]	✓ [67, 73–77]	✓ [78–80]	✓ [21, 44, 49, 81–85]
Gravastars	COs – ClePhOs [4, 86]	✗	✓ [76]	✓ [87–89]	∼ [20, 21, 44, 49, 89, 94]
AdS bubbles	UCOs – ClePhOs [95]	✗	✓ [95]	∼ [95]	✗
Wormholes	ClePhOs [96–100]	✗	✓ [101, 102]	✓ [103–106]	∼ [20, 44, 49]
Fuzzballs	ClePhOs [5, 6]	✗	✗ (but see [107–110])	✗	∼ (but see [20, 21, 111])
Superspinars	COs – ClePhOs [112]	✗	✓ [32, 113]	✗ (but see [114])	∼ [20, 21]
$2-2$ holes	ClePhOs [115]	✗	✗ (but see [115])	✗ (but see [115])	∼ [20, 21]
Collapsed polymers	ClePhOs [116, 117]	✗	✗ (but see [116, 118])	✗	∼ [118]
Quantum bounces / black stars	ECO – ClePhOs [7, 119–121]	✗ (but see [119])	✗	✗	∼ [121]
Quantum stars*	UCOs – ClePhOs [122, 123]	✗	✗	✗	✗
Fire-walls*	ClePhOs [124–126]	✗	✗	✗	∼ [21, 127]





$$\dot{E} \sim 10^{-17} \left(\frac{\epsilon}{10^{-16}} \right) \left(\frac{\delta M}{M} \right)$$