~Find the Gap~

New Physics and the Black Hole Mass Gap

Samuel D. McDermott

work with Djuna Croon + Jeremy Sakstein: PotDU & 2007.00650 [hep-ph], PRD & 2007.07889 [gr-qc]

&/+ Maria Straight and Eric Baxter: PRL & 2009.01213 [gr-qc]

&/+ Eric Baxter: @ApJL & 2104.02685 [astro-ph.CO]

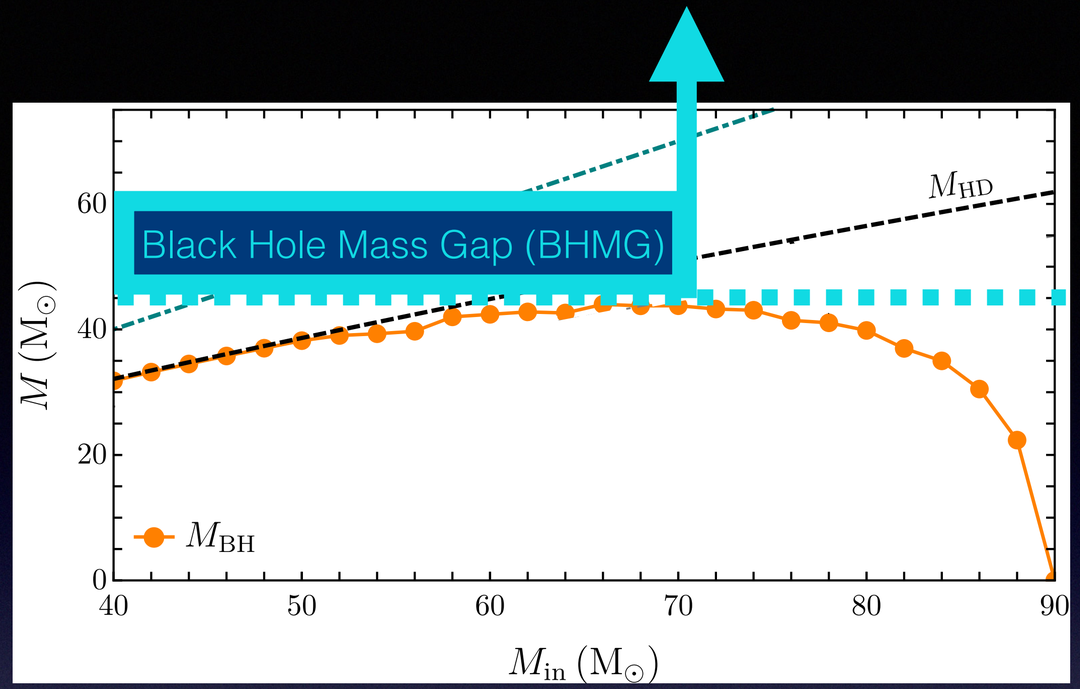
+ code development in progress (email me for updates/release info)

Fermilab

sammcd00@fnal.gov

Sam McDermott

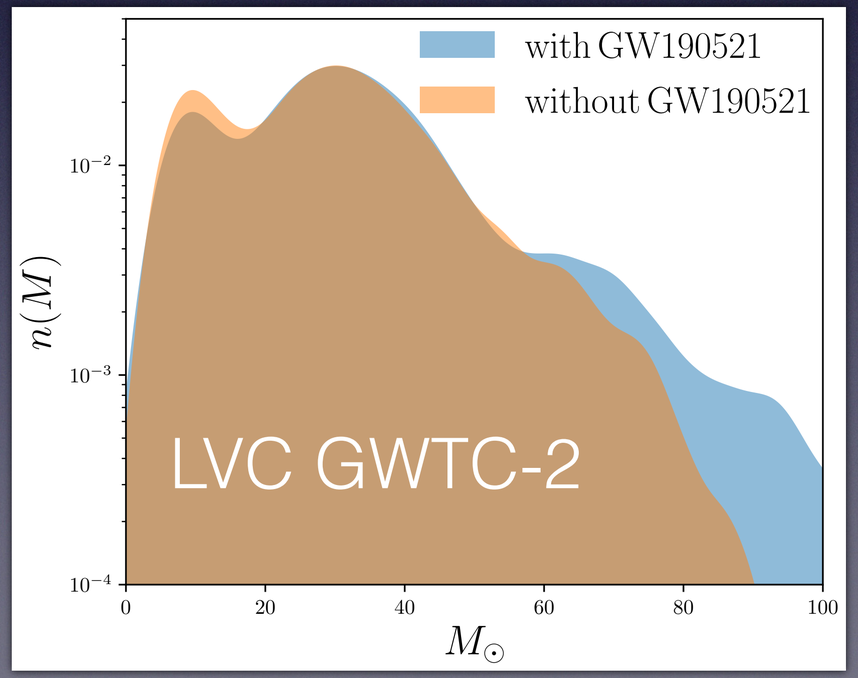
"Find the Gap" 2104.02685/@ApJL



$$\frac{dN^{(1g)}}{dM_{\rm BH}} \sim \int d\theta \frac{dN_*}{dM_*} \frac{1}{dM_{\rm BH}(\theta)/dM_*}$$

$$p\left(m_1, m_2 \mid \vec{\theta}\right) \propto \frac{dN^{(1g)}}{dM_{\rm BH}} + \lambda \frac{dN^{(2g)}}{dM_{\rm BH}}$$

+



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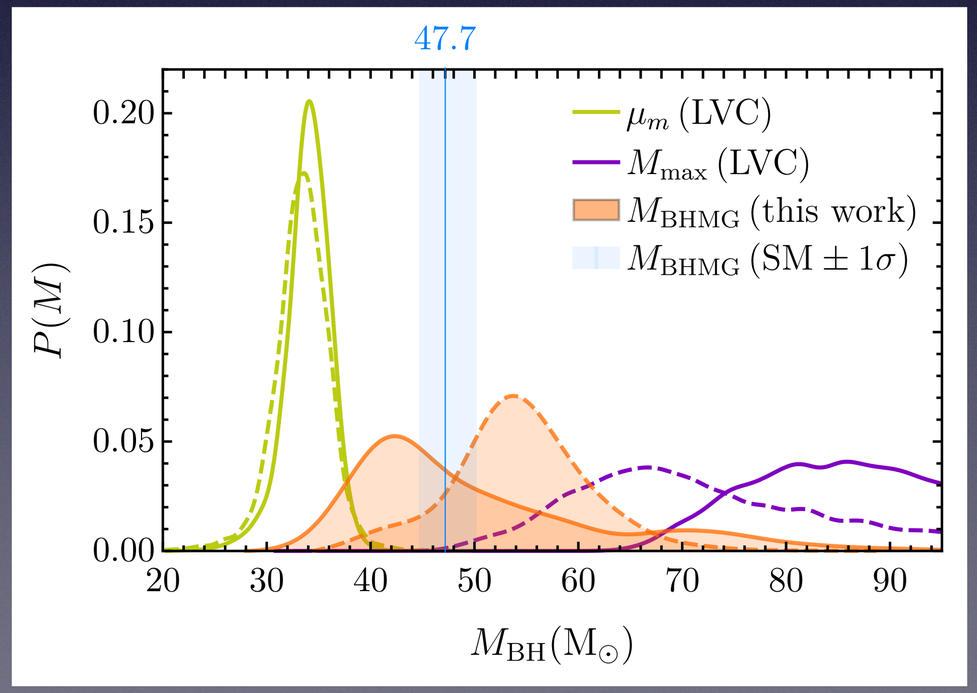

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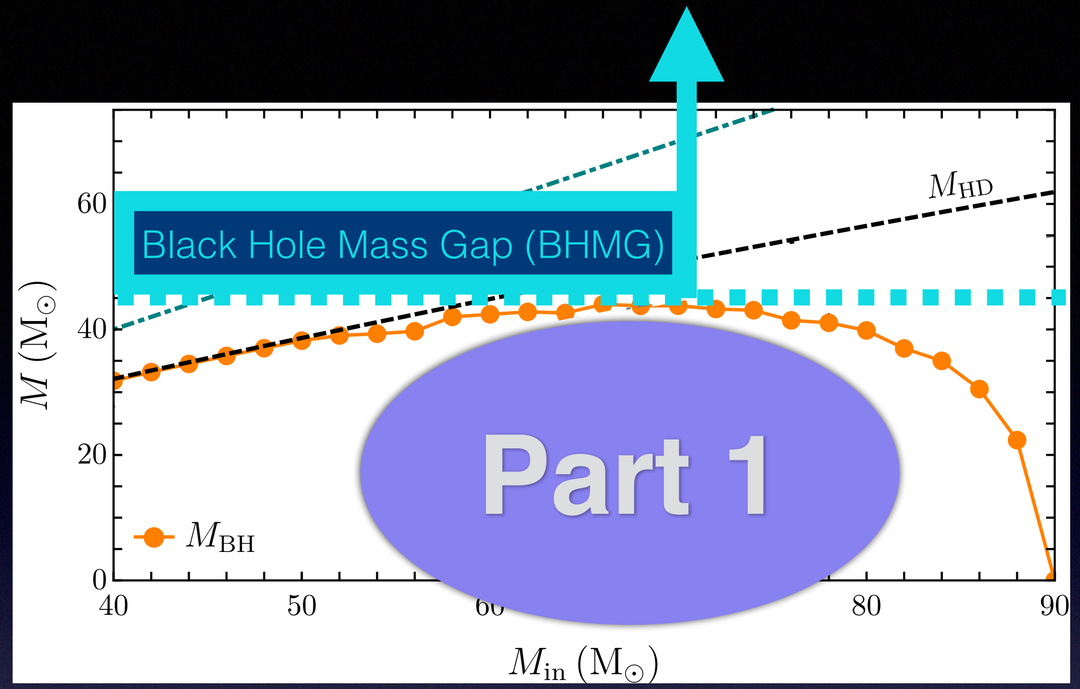

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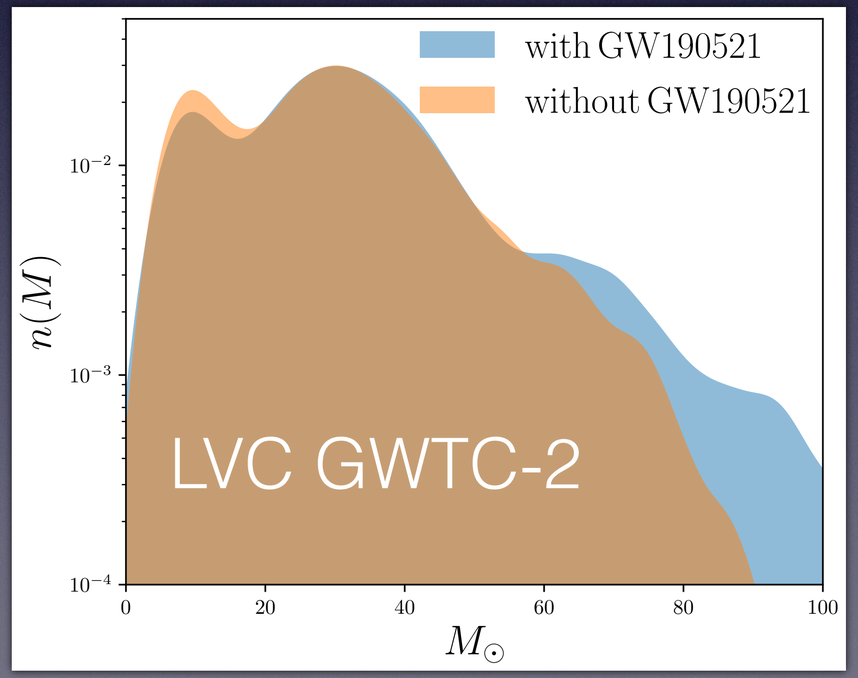

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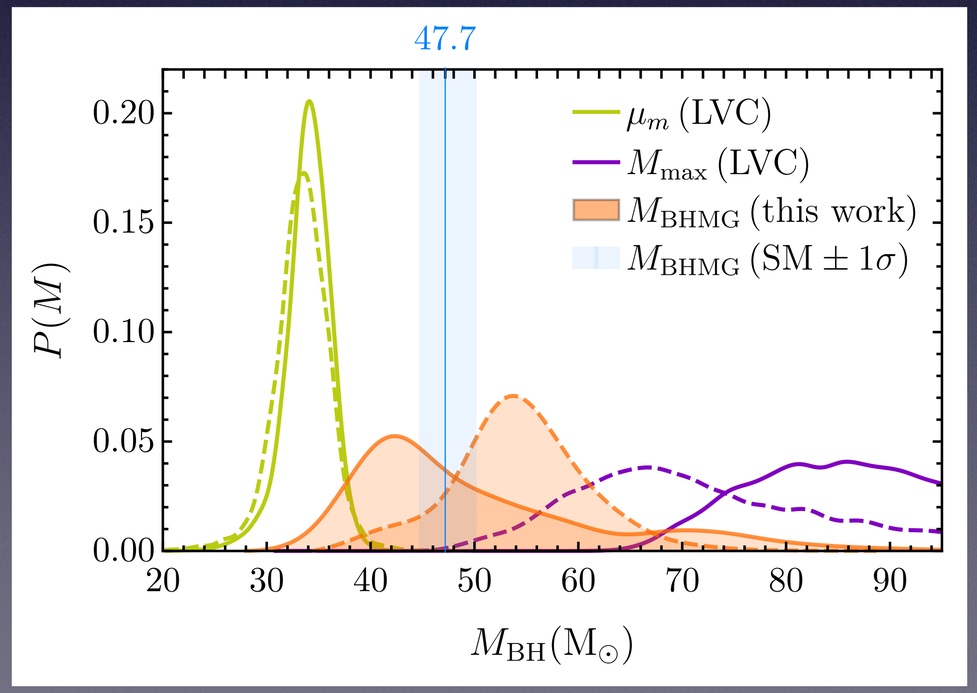

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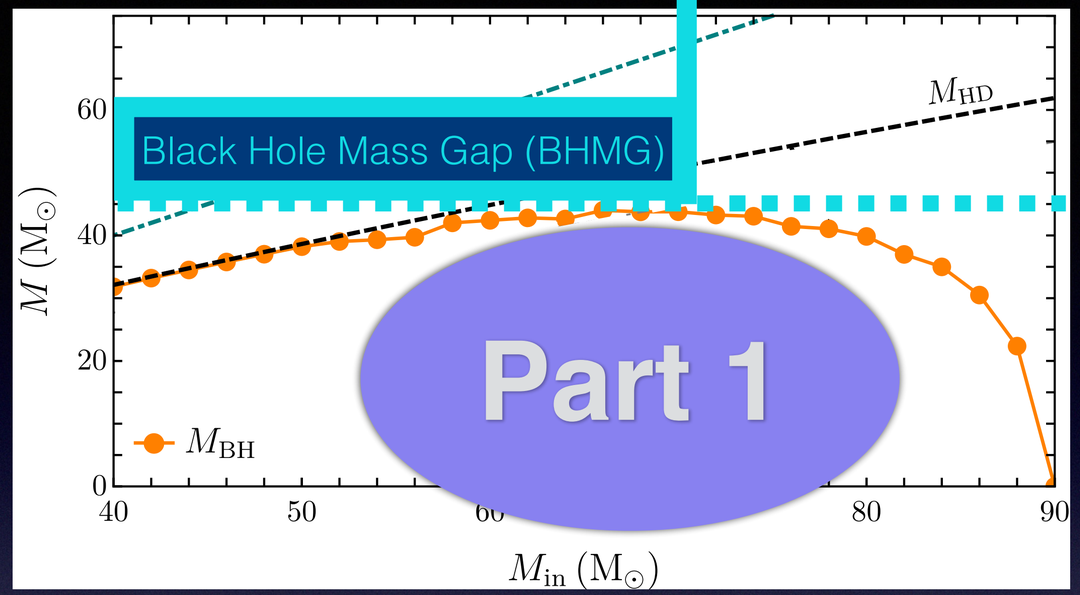

Part 1

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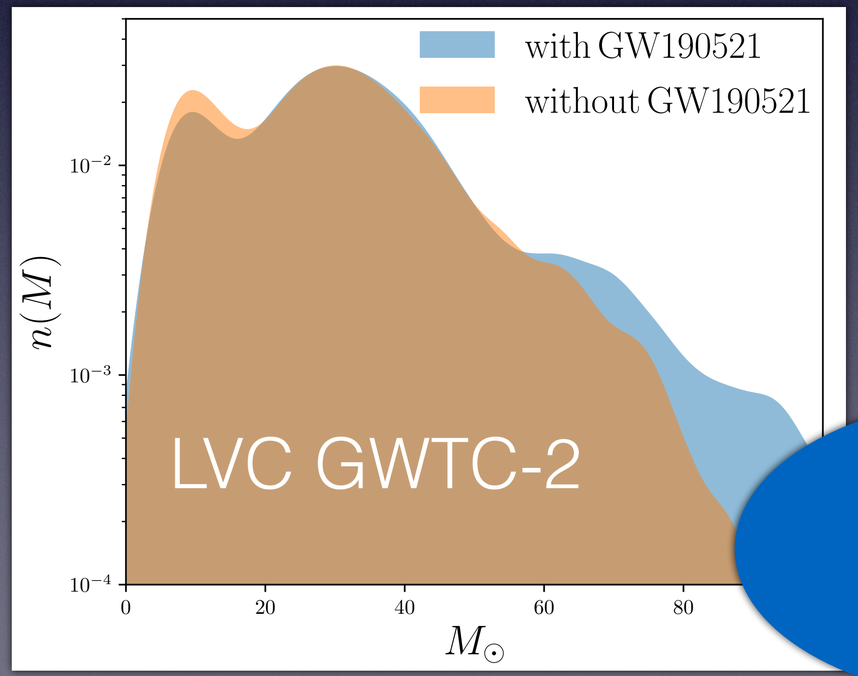

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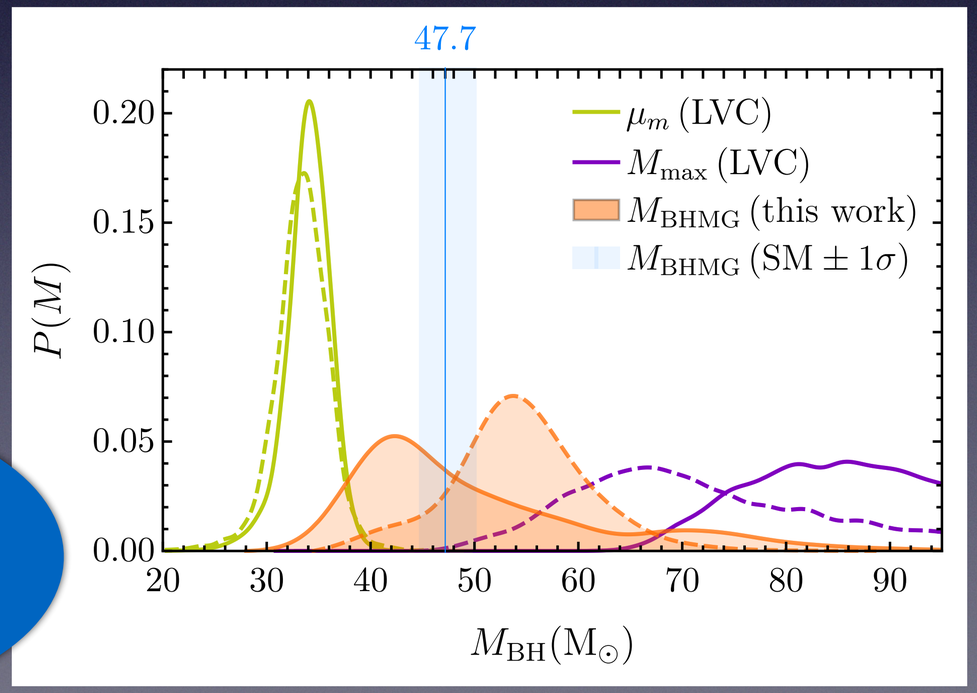
Part 2



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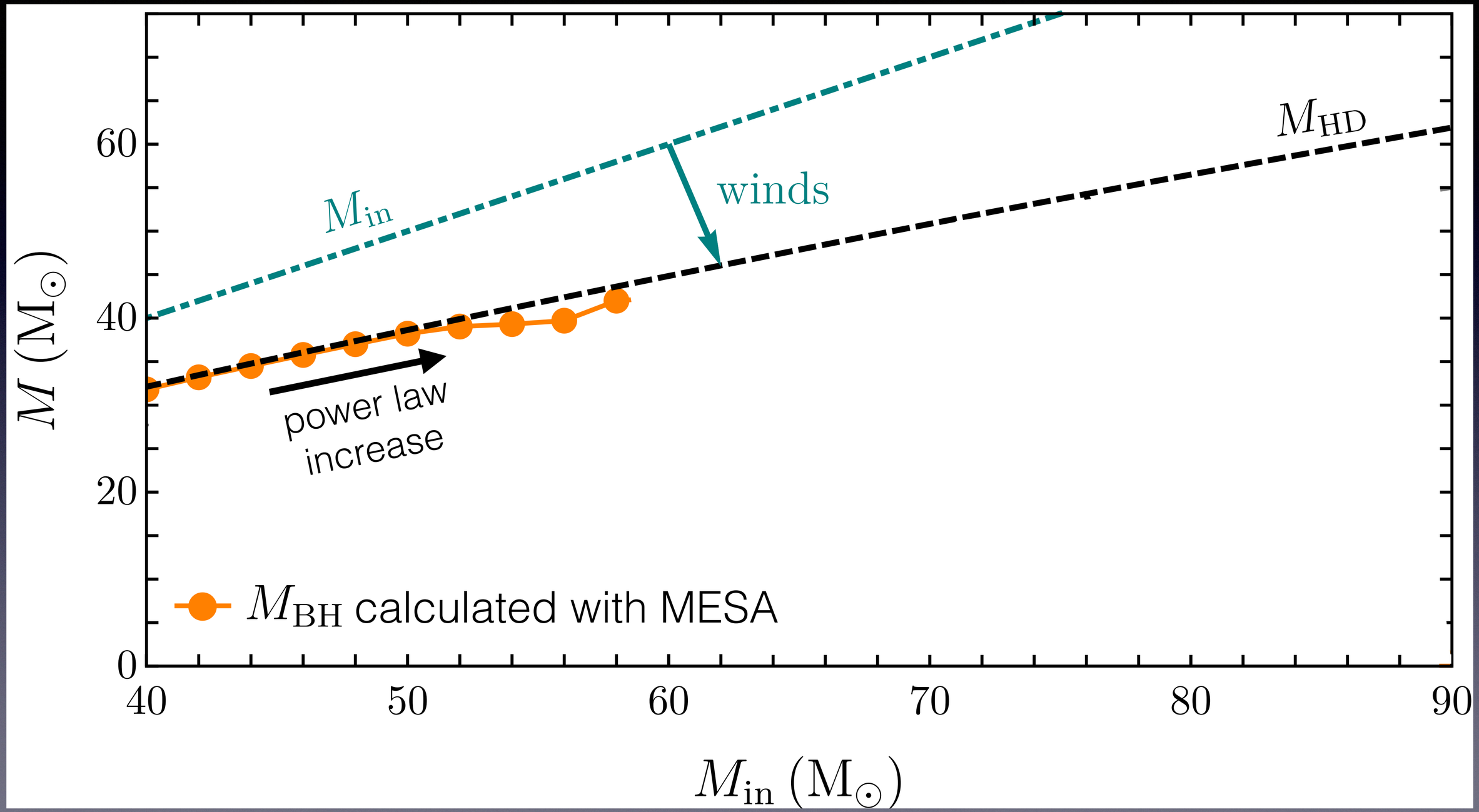
PRD & 2007.07889



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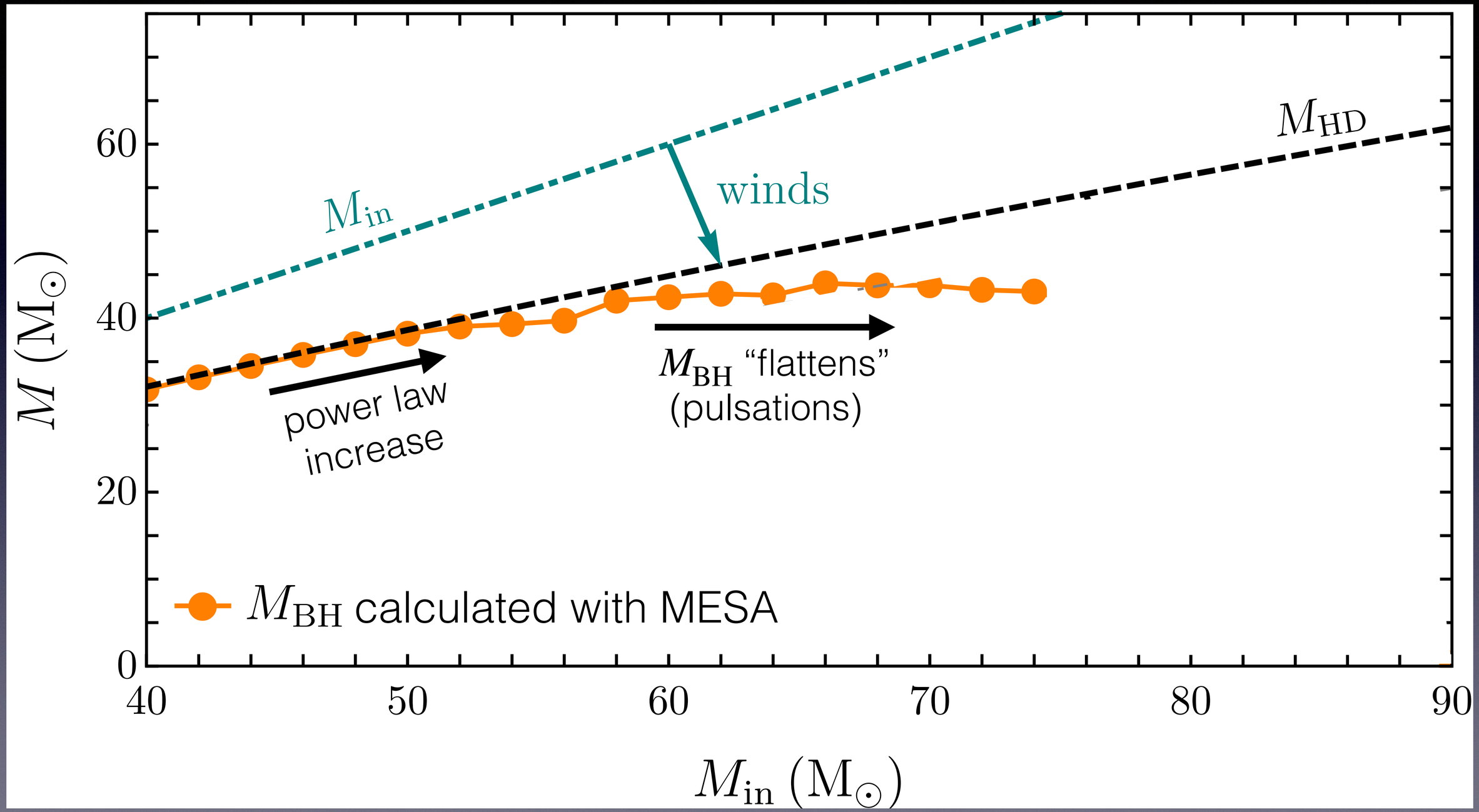

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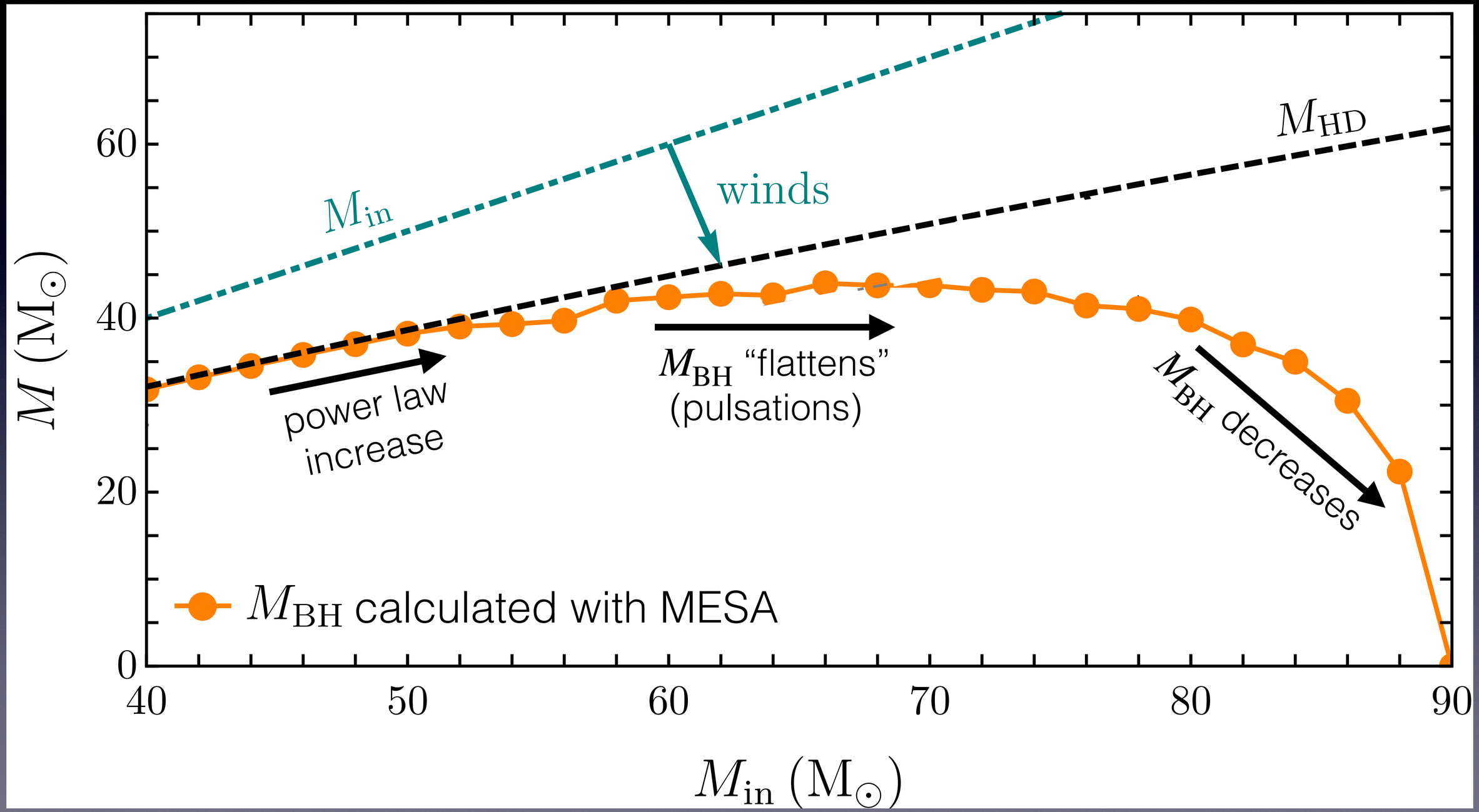

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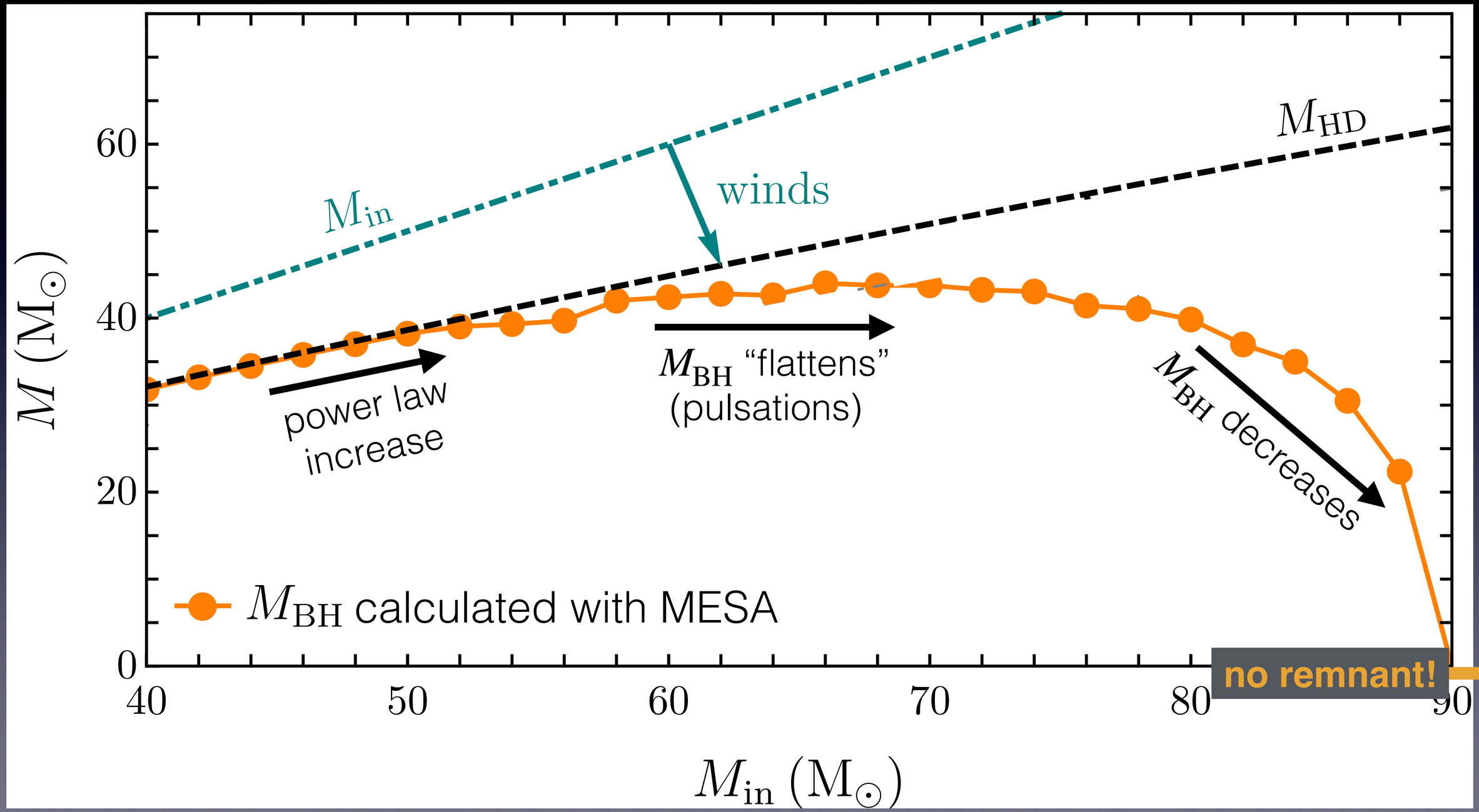

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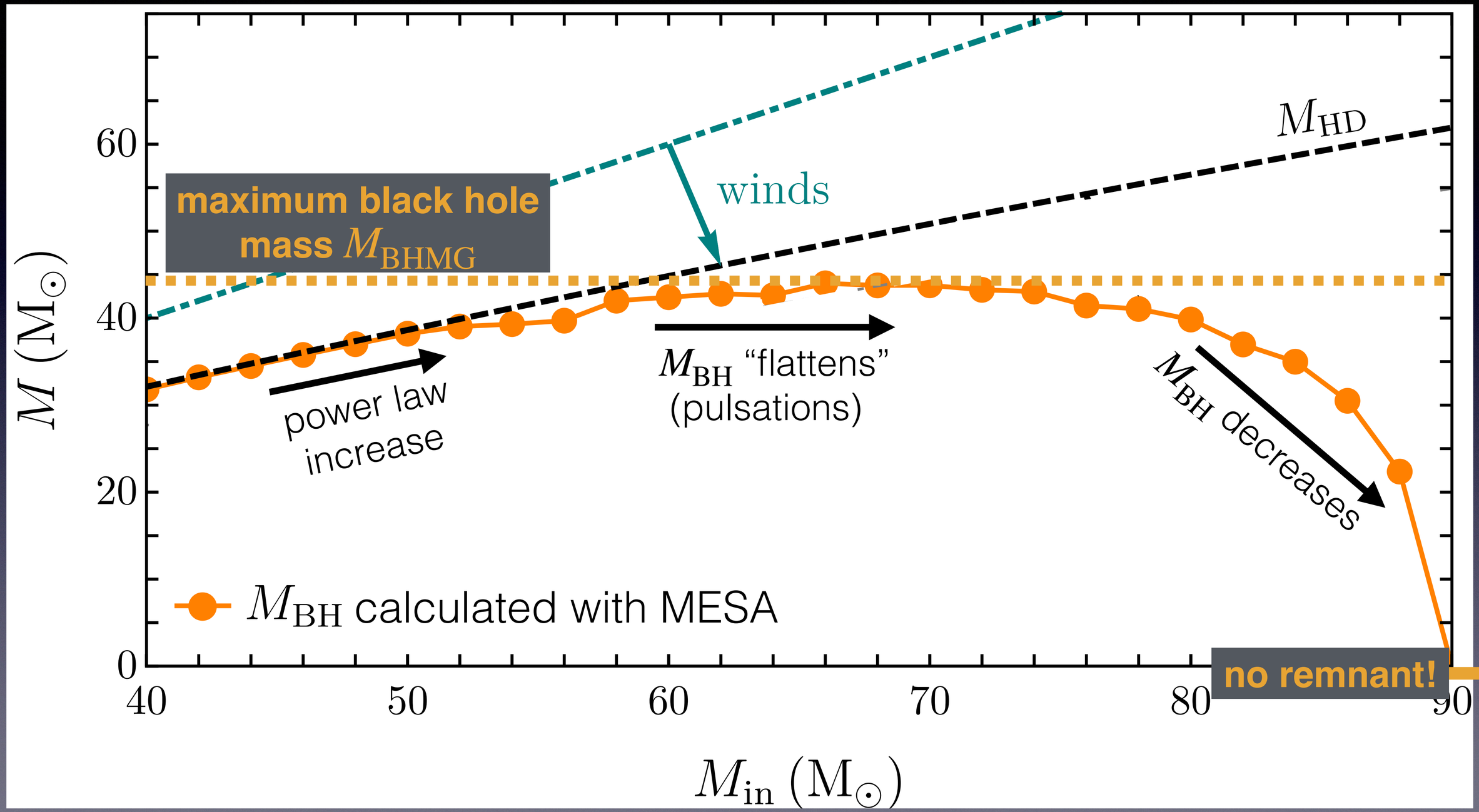

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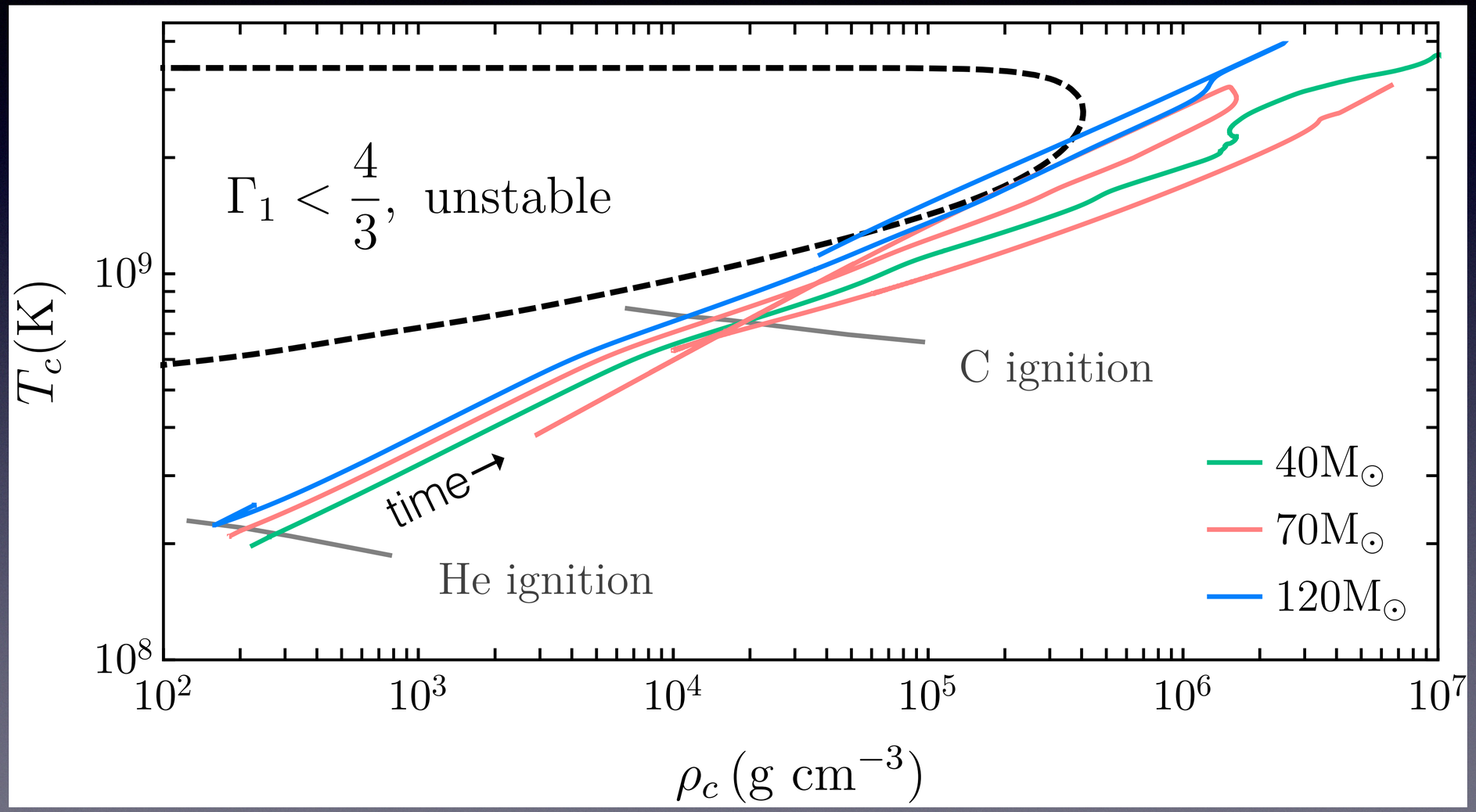
Evolution* of Pop III Stars



*MESA v12778 Paxton et al, arXiv:1710.08424 [astro-ph.SR]

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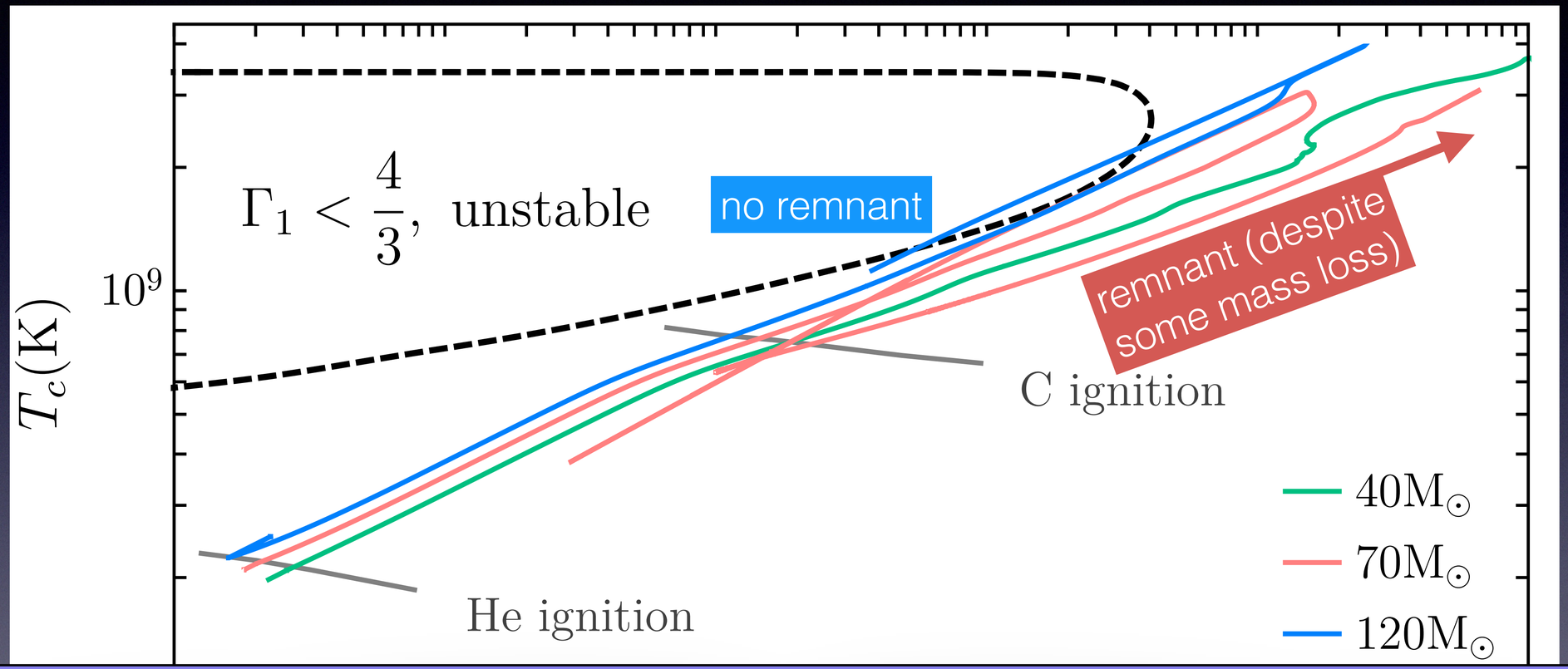
Outcome of Pulsations



$70\mathrm{M}_\odot \lesssim M_{\mathrm{in}} \lesssim 100\mathrm{M}_\odot$ — pulsational pair instability supernova (PPISN)

vs

$100\mathrm{M}_\odot \lesssim M_{\mathrm{in}} \lesssim 250\mathrm{M}_\odot$ — pair instability supernova (PISN)

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Can we Change the BHMG?

- New light degree(s) of freedom are **produced in the core** of a massive star during helium burning
- This additional loss channel causes the star to **consume fuel more quickly** and **end helium burning earlier**
- This **reduces** the amount of **^{16}O** available **during pulsations**
- Explosions are less violent $\Longrightarrow$ mass loss is less pronounced $\Longrightarrow$ a **heavier black hole**

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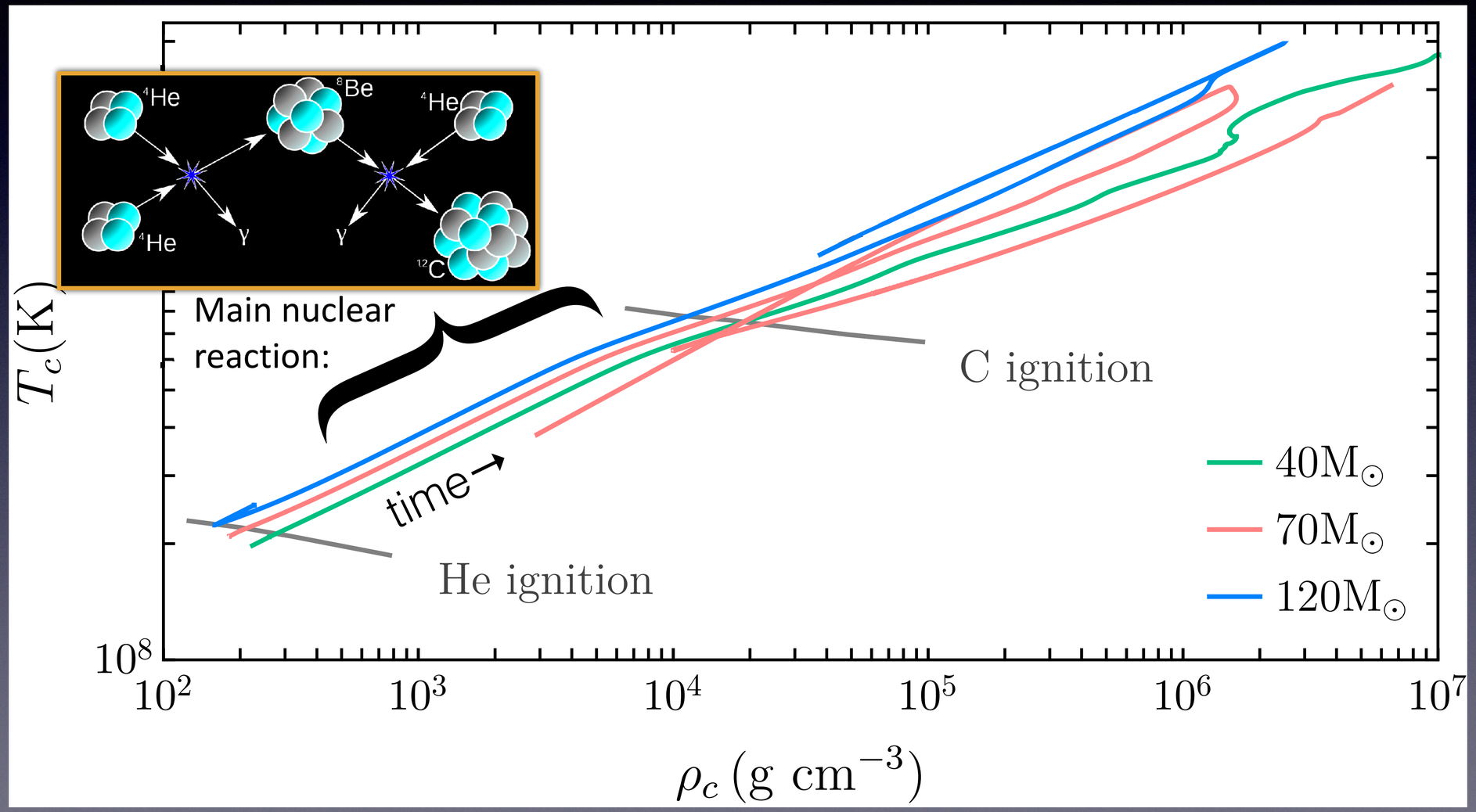
Reactions in Pop III Stars



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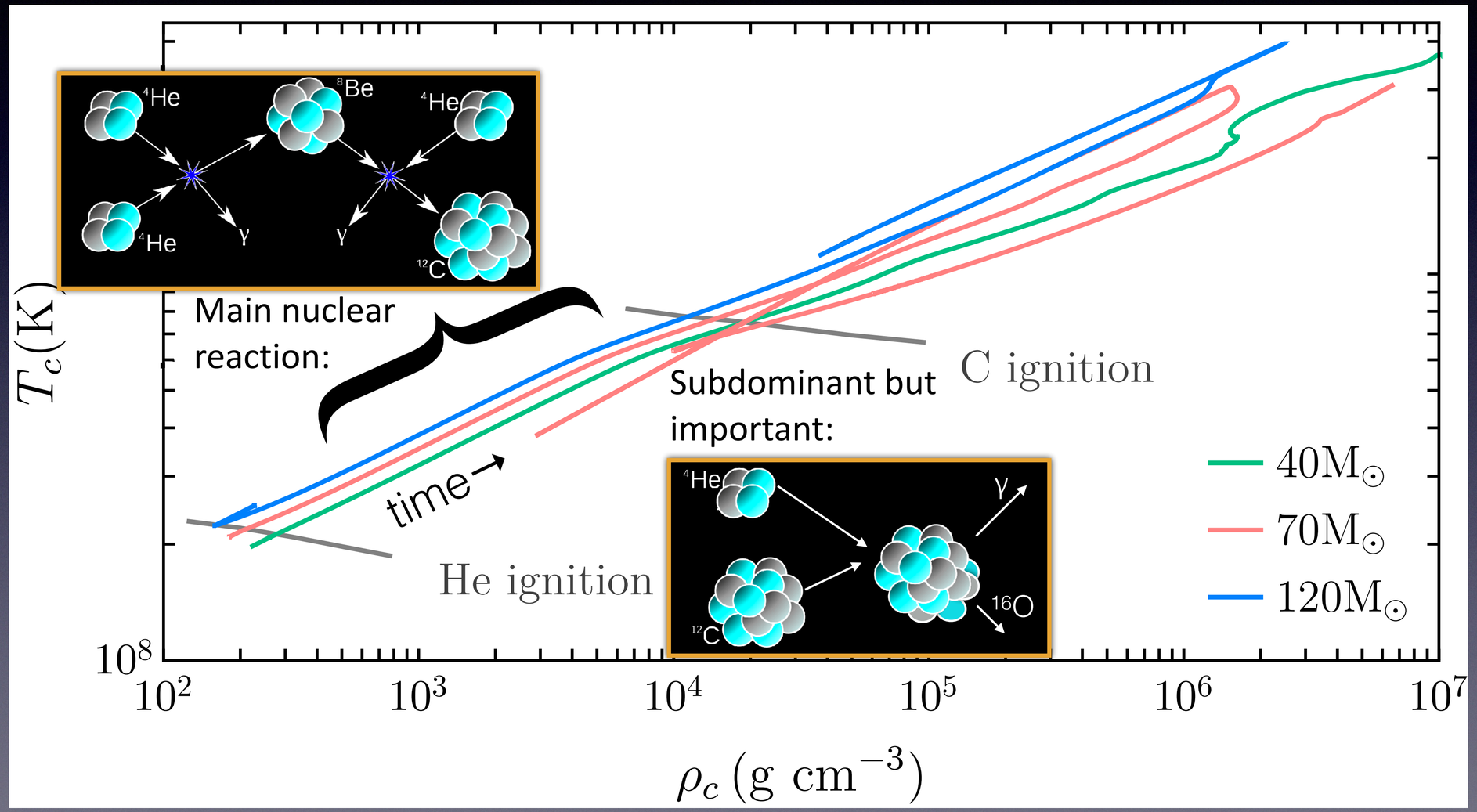

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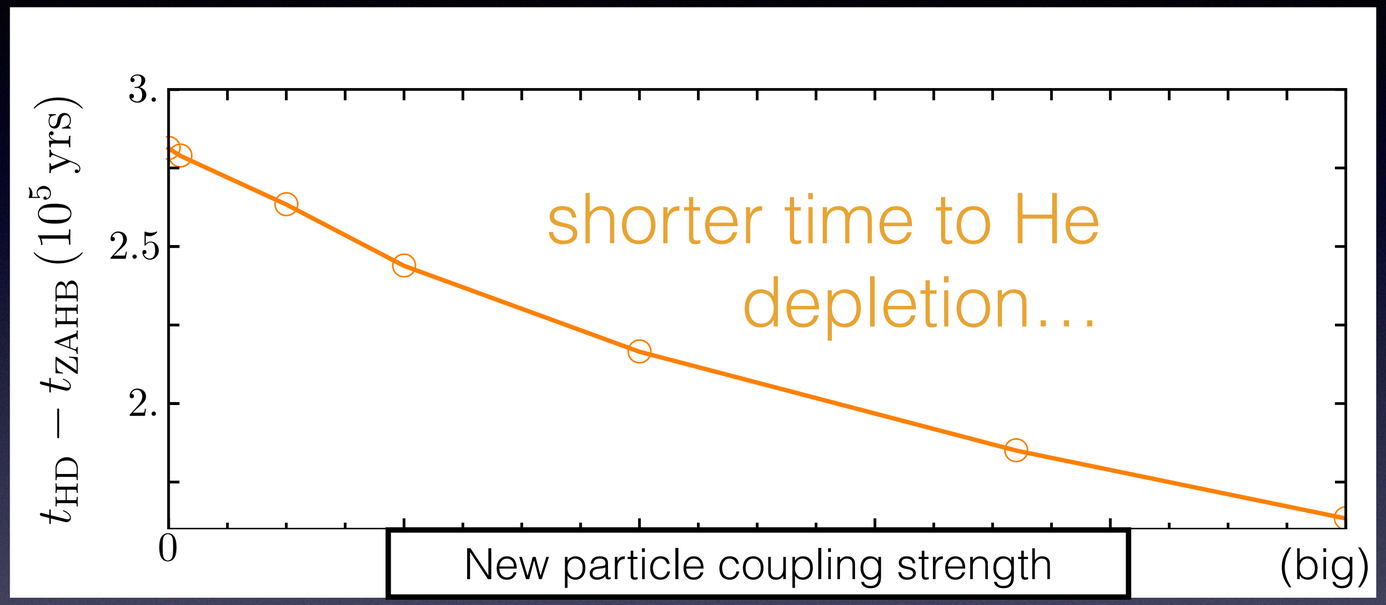
Implications for Oxygen Production



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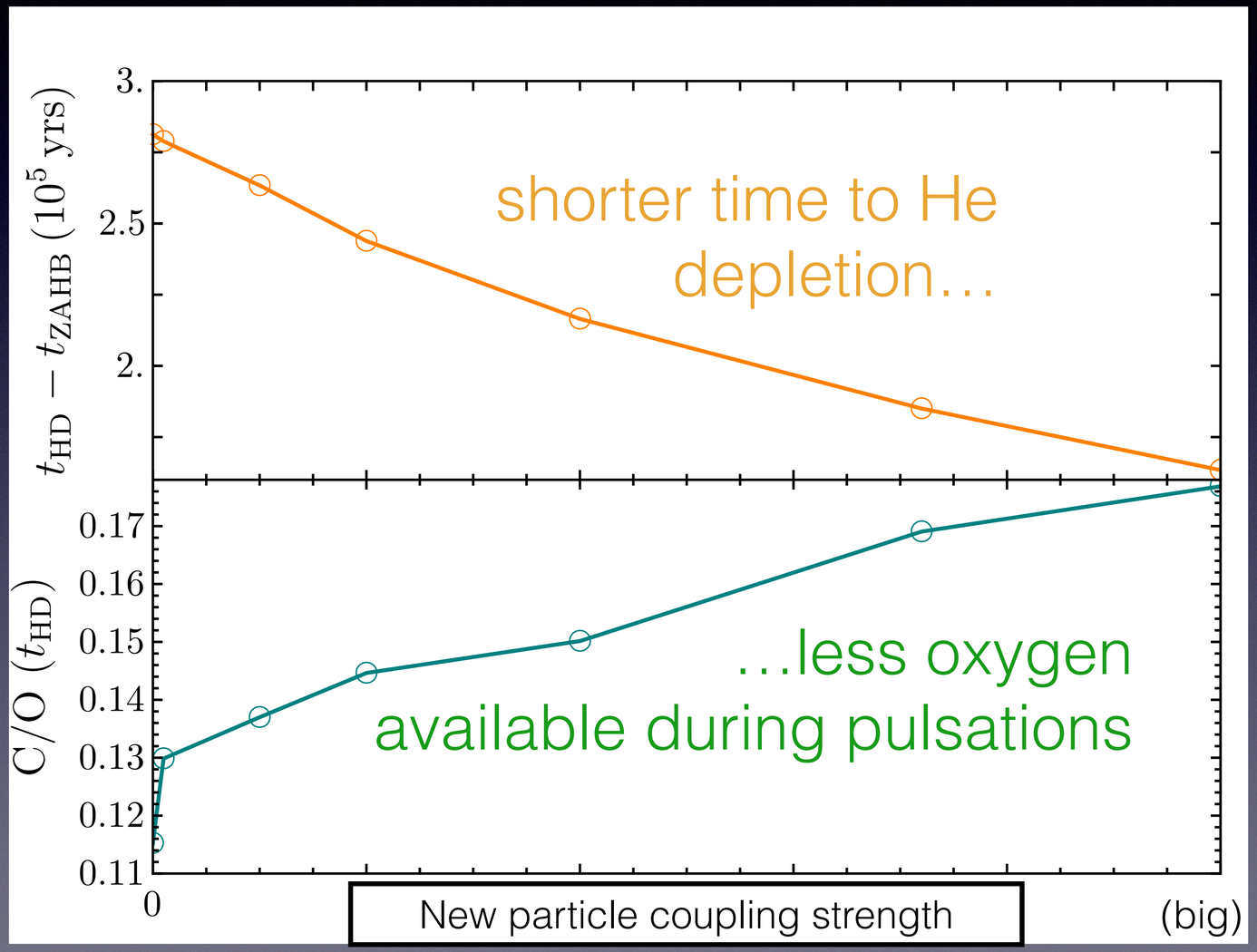

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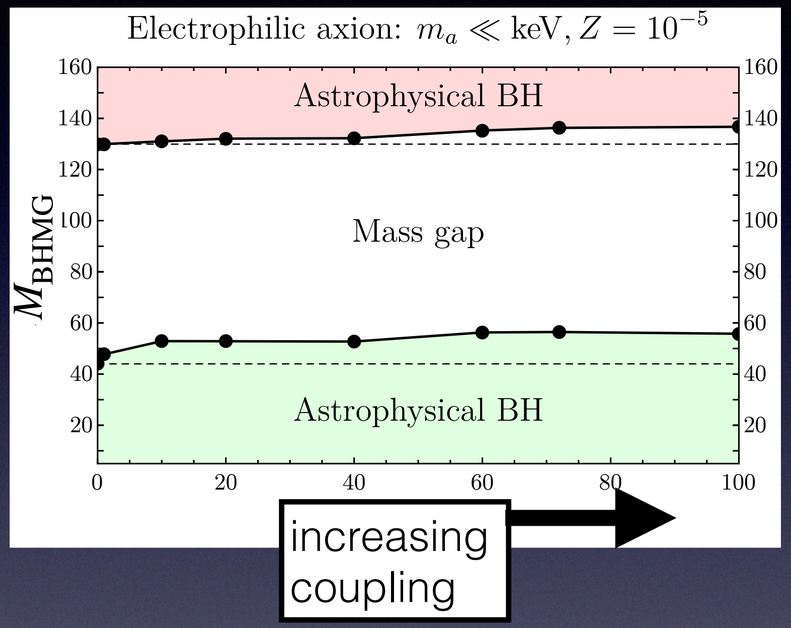
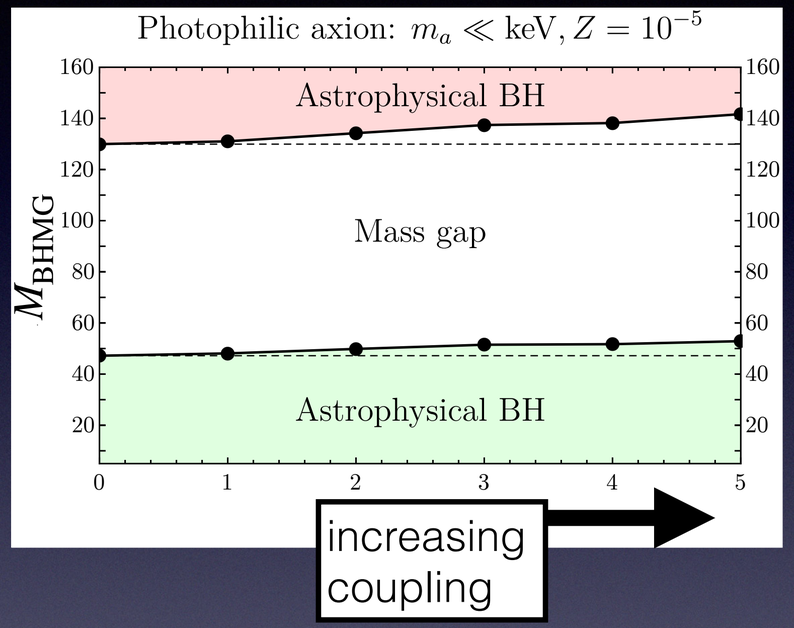
Implications for Black Hole Masses



increasing coupling



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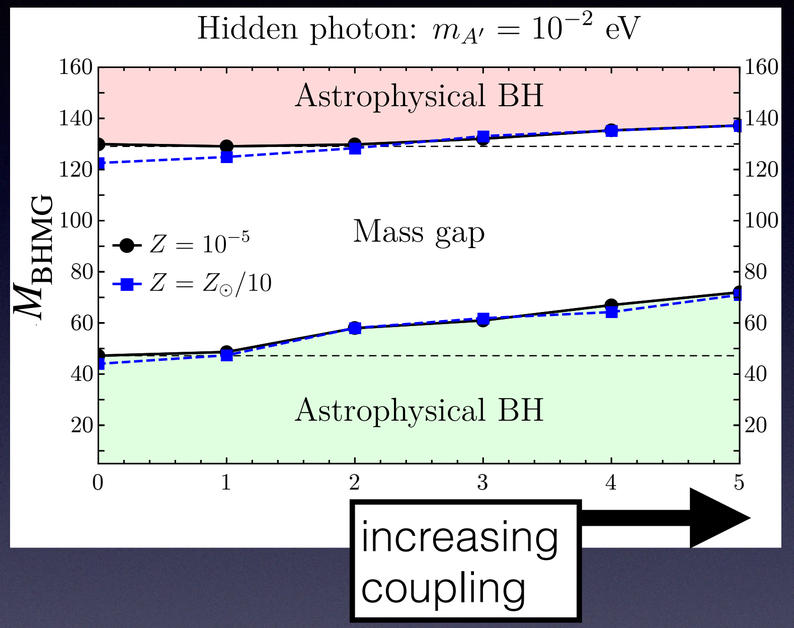
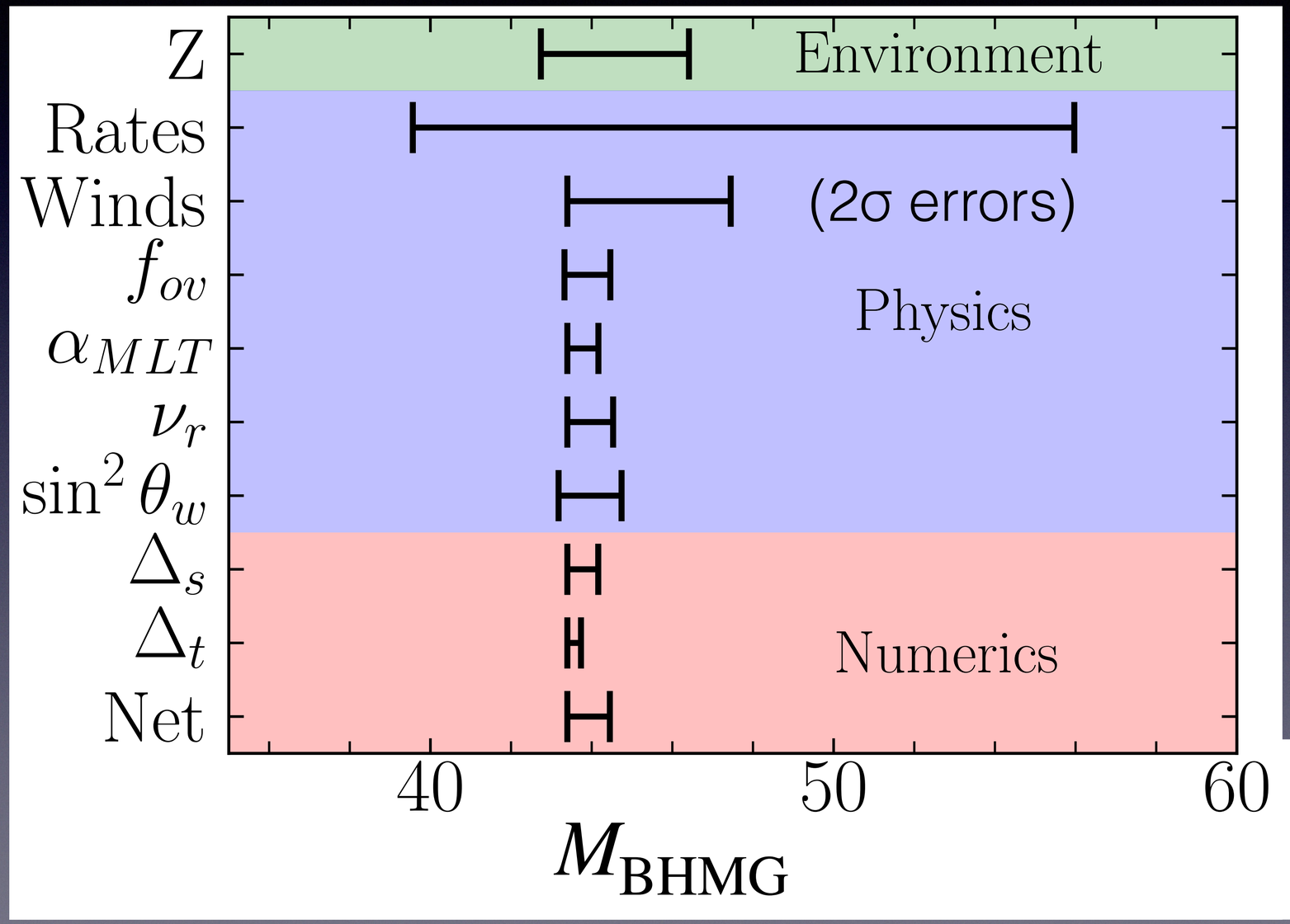


increasing coupling

larger coupling to new physics $\Longrightarrow$ larger black hole mass

SM Uncertainties



also rare events:

- pre-/post-collapse merger
- accretion after formation
- retention of H envelope
- binarity
- rotation
- …

Farmer et al., 1910.12874

Surprisingly Massive: SM vs BSM

SM physics

- M_{BHMG} is at the value predicted by the SM-only calculation*

*unless ~5σ deviations from nuclear rates or major differences in stellar physics wrt to MESA

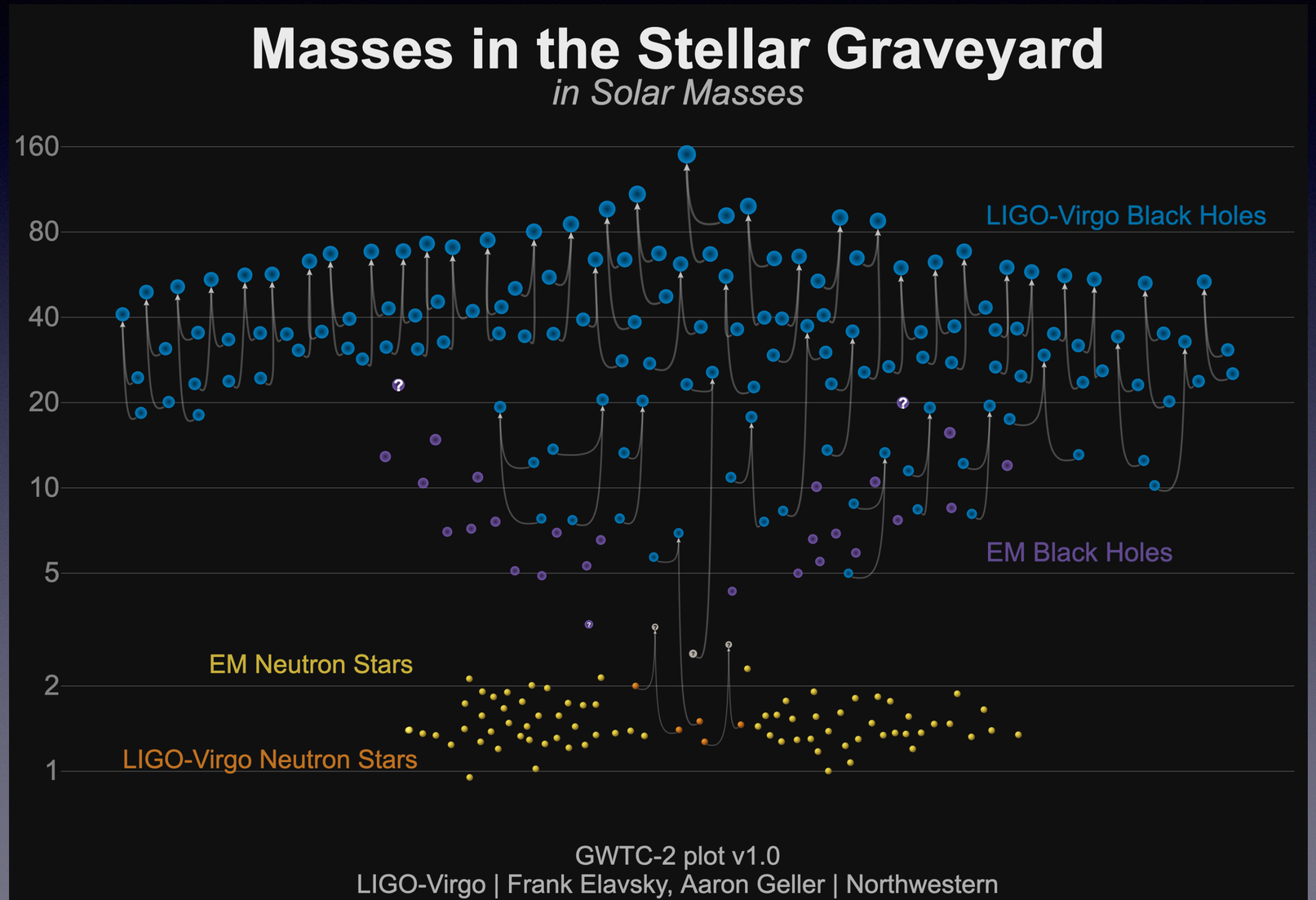
- Continuous distribution of M_{BH} up to **expected value of** M_{BHMG} due to isolated stars, plus **rare excursions** to $M_{\mathrm{BH}} > M_{\mathrm{BHMG}}$ ("pollutants")

BSM physics

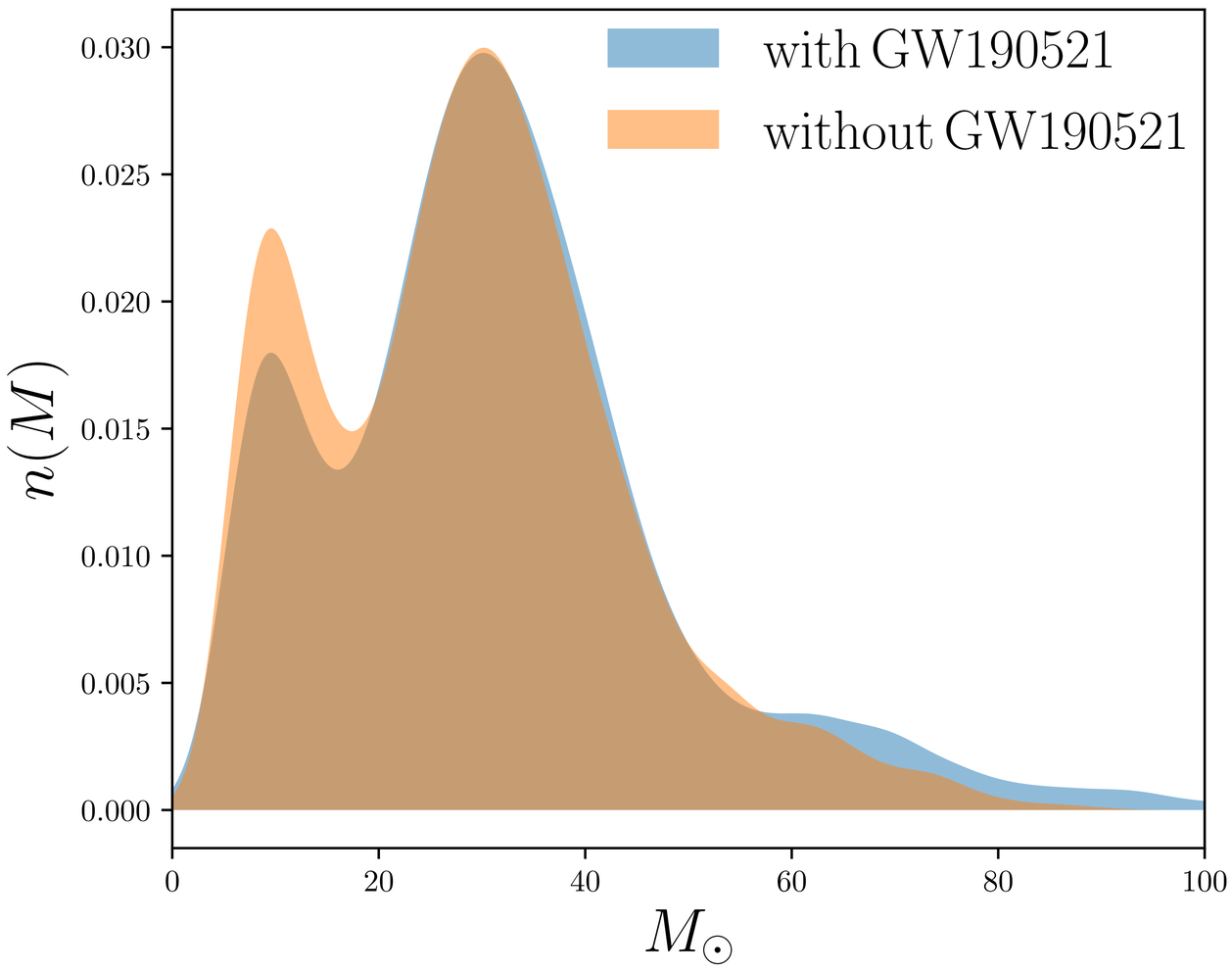
- M_{BHMG} is **not** as expected from SM-only calculation: objects "in the (SM) mass gap" form from isolated evolution, no rare process required

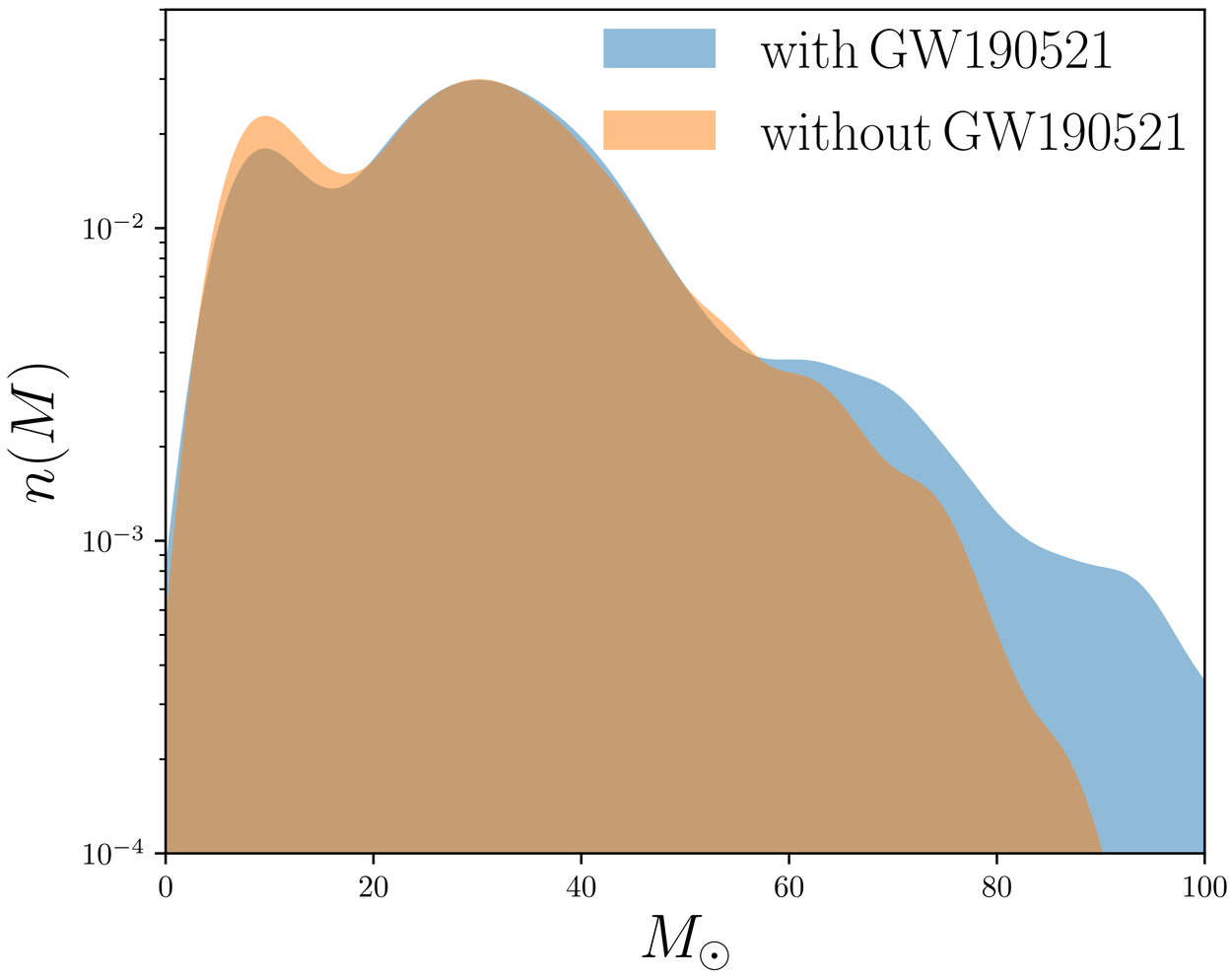
- Implies a continuous distribution of BH masses up to a **new, higher value of** M_{BHMG}

LIGO Observations: Oct 2020



Black Hole Population Statistics



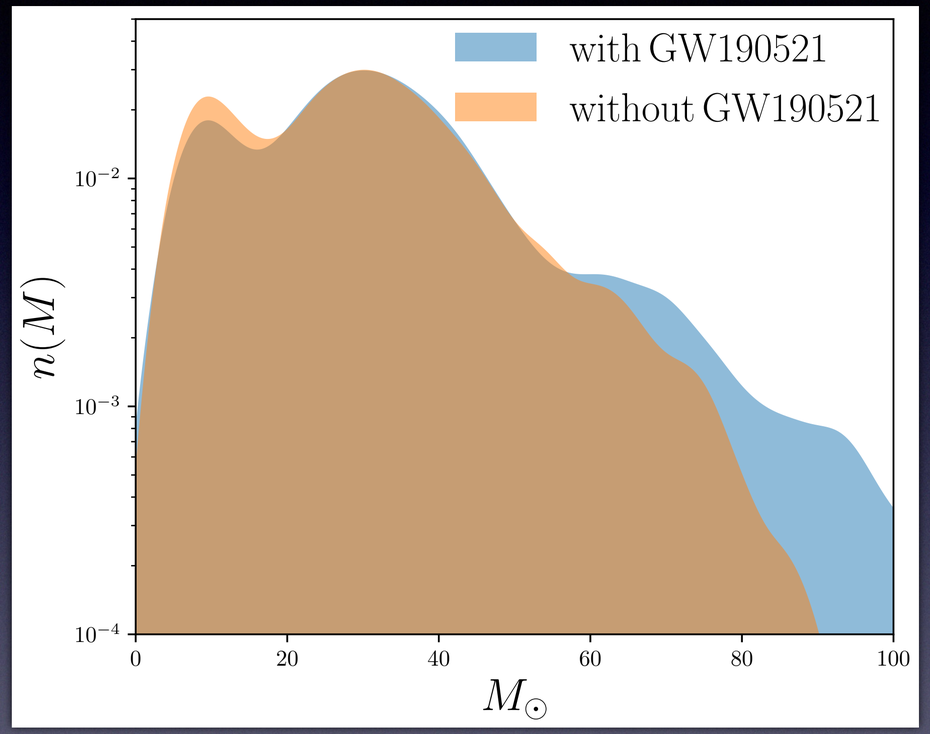


Black Hole Population Statistics

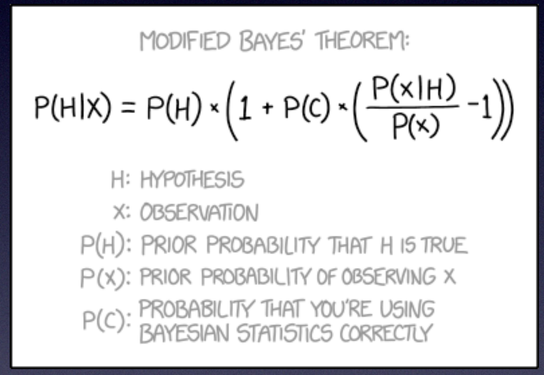
$$p\left(m_1, m_2 \mid \vec{\theta}\right) \propto \frac{dN^{(1g)}}{dM_{\rm BH}} + \lambda \frac{dN^{(2g)}}{dM_{\rm BH}}$$

BHs formed from isolated stellar evolution

"pollutants" (λ<1)



Baxter, Croon, SDM, Sakstein @ApJL & 2104.02685



xkcd.com/2059/

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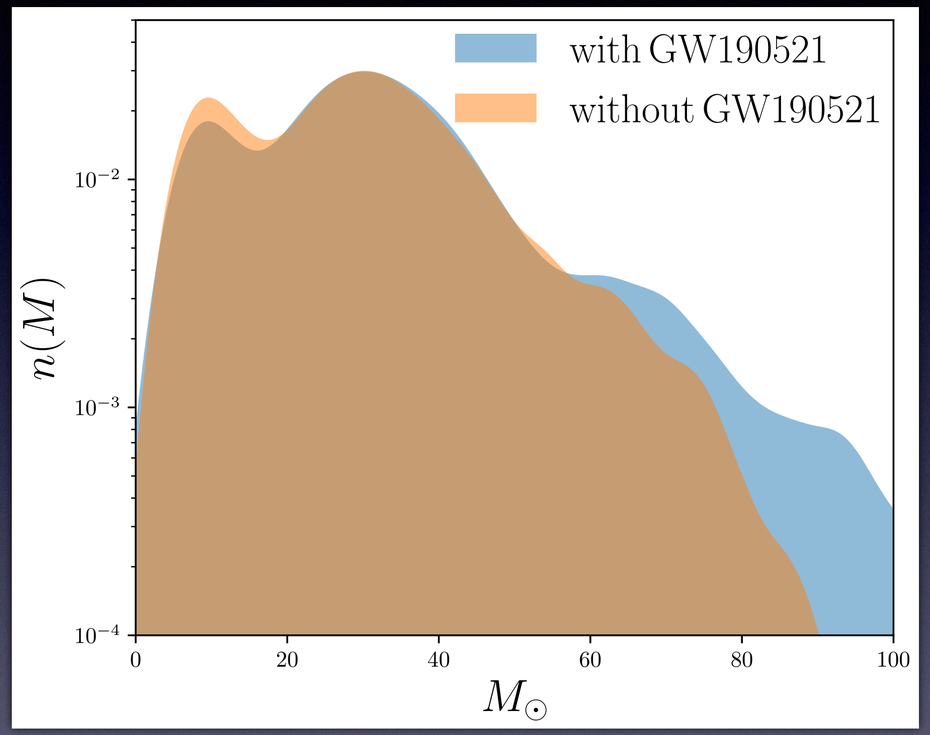

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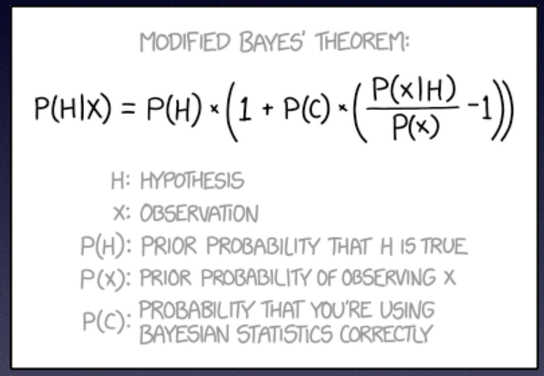


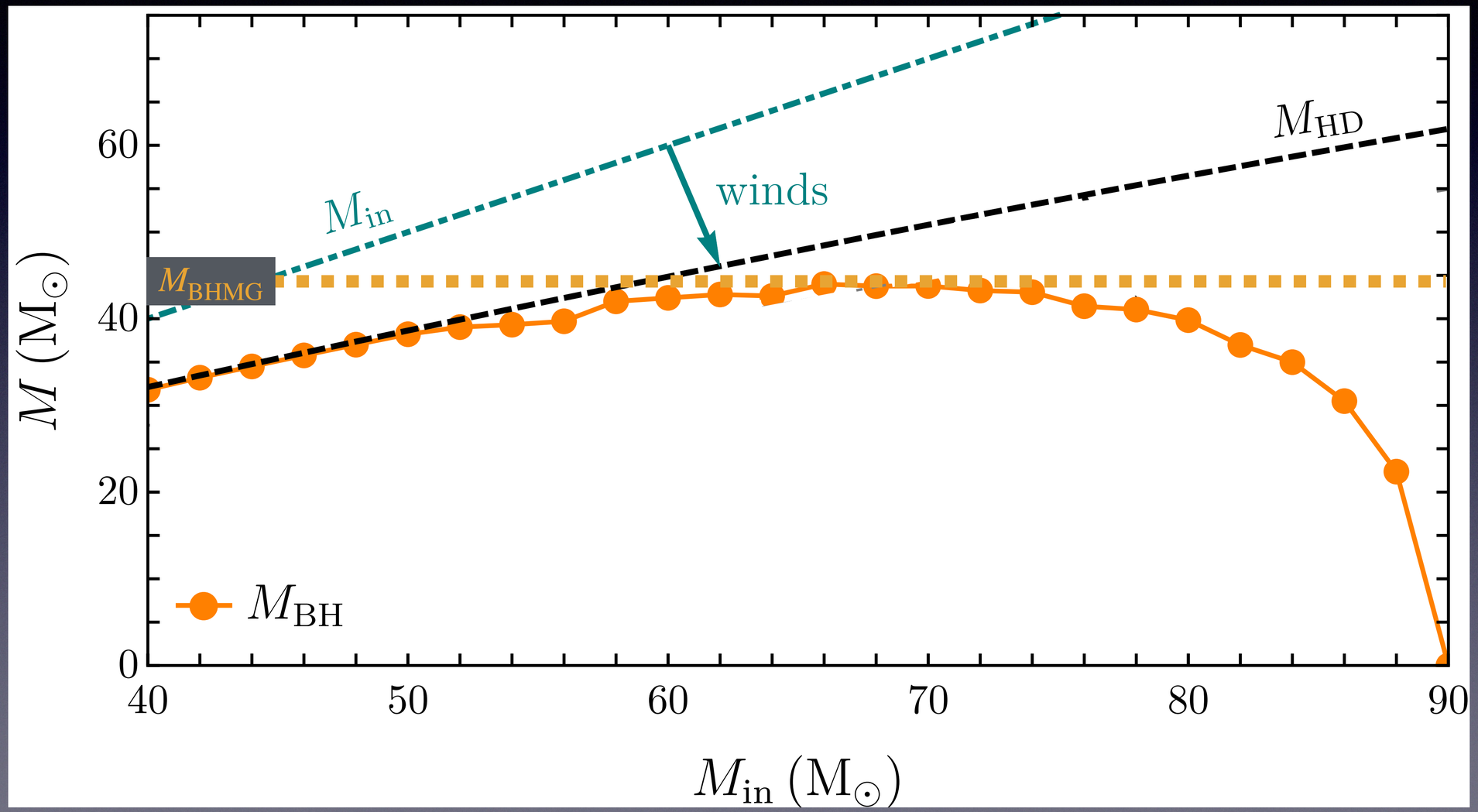
xkcd.com/2059/

$$\frac{dN^{(1g)}}{dM_{\rm BH}} \sim \int d\vec{\alpha}\, \frac{dN_*}{dM_*} \frac{1}{dM_{\rm BH}(\vec{\alpha})/dM_*}$$

this is exactly what we get from MESA!

Croon, McDermott, Sakstein PRD & 2007.07889
&/+ Baxter @ApJL & 2104.02685

$dM_{\rm BH}/dM_*$



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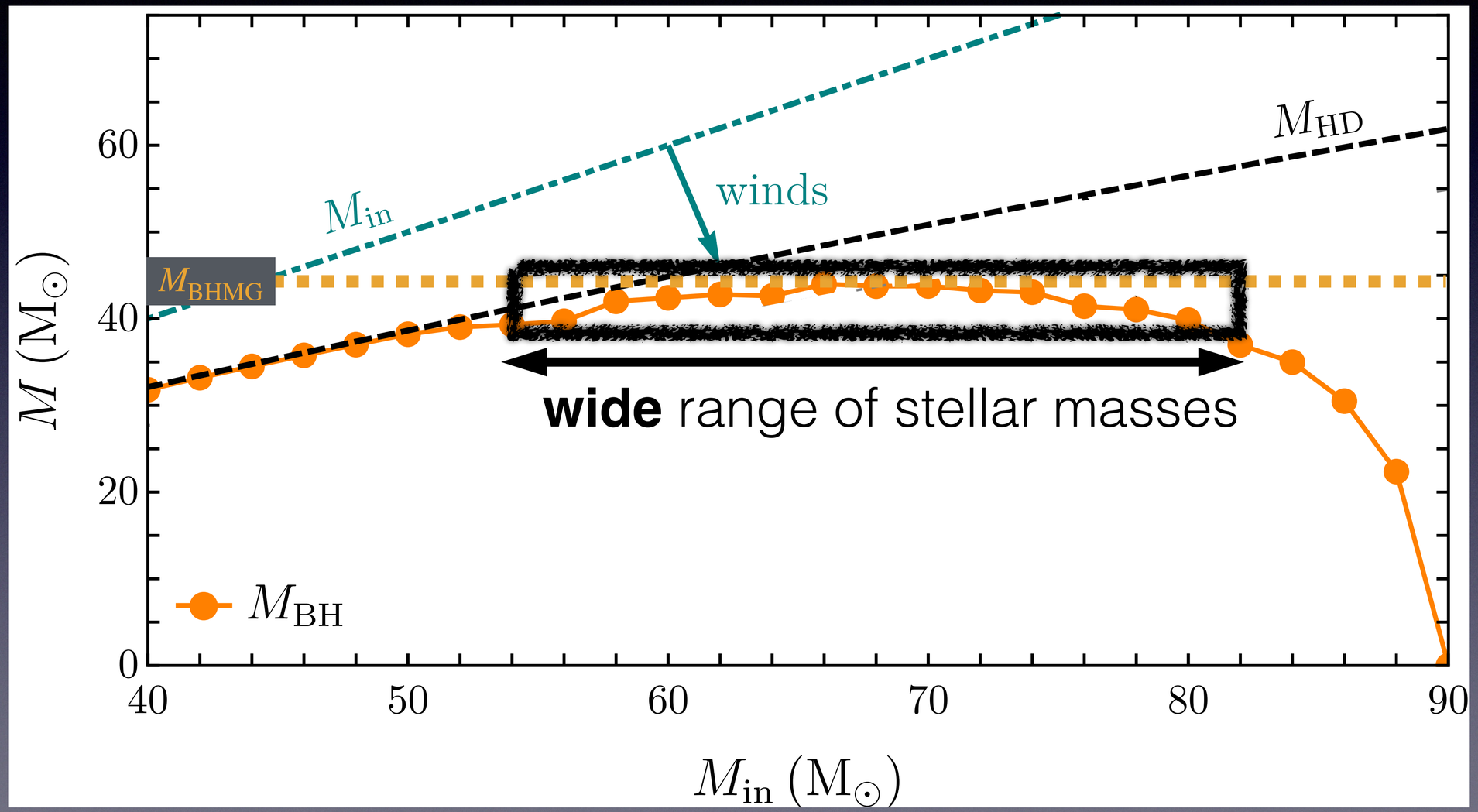

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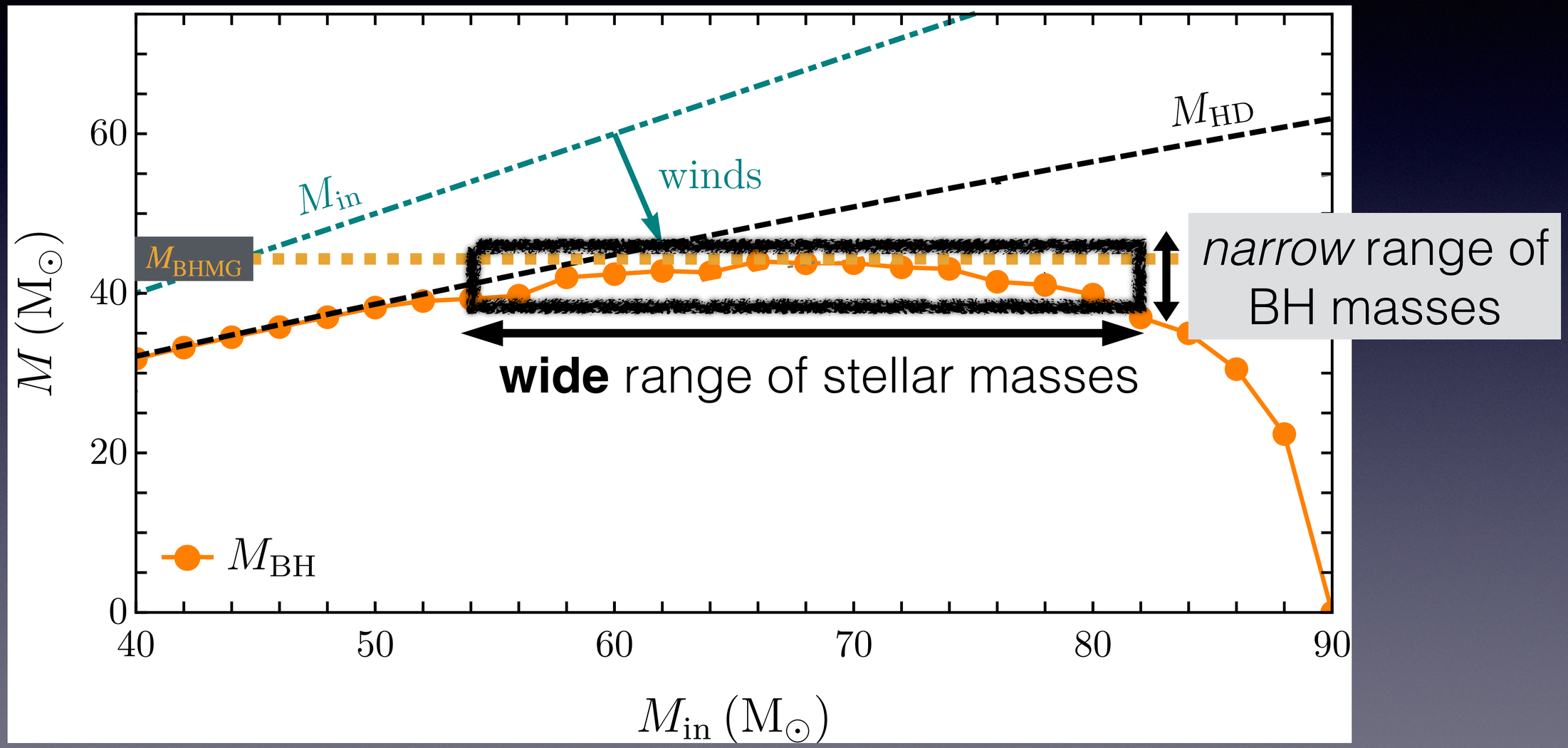

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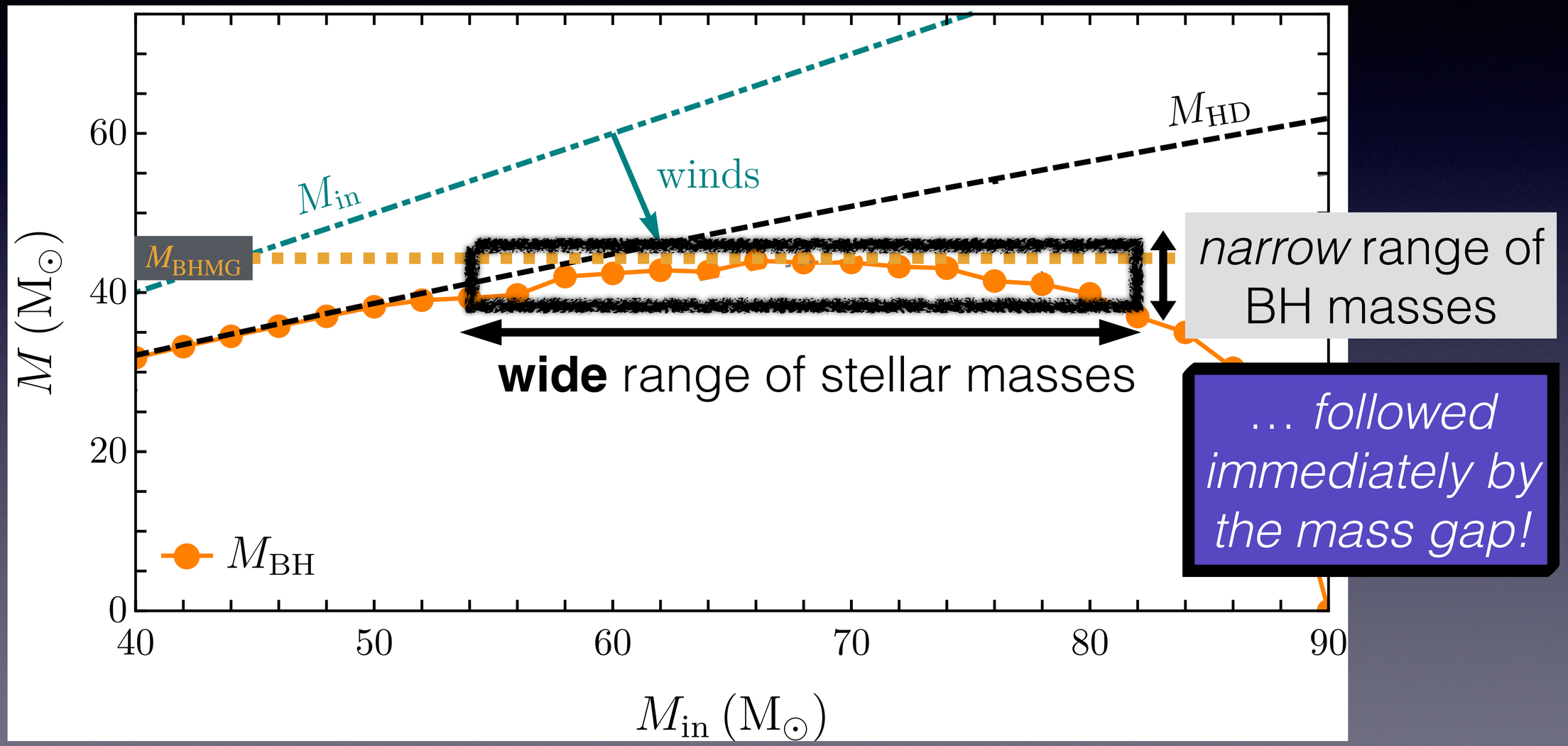

Black Hole Population Statistics

after GWTC-2

$$p\left(m_1, m_2 \mid \vec{\theta}\right) \propto \frac{dN^{(1g)}}{dM_{\rm BH}} + \lambda \frac{dN^{(2g)}}{dM_{\rm BH}}$$

Baxter, Croon, SDM, Sakstein @ApJL + 2104.02685

flexible fitting function with a sharp peak followed by a gap:

$$\frac{dN_{\rm BH}^{(1g)}}{dM_{\rm BH}} \propto \left[1 + 2a^2\sqrt{\frac{M_{\rm BH}}{M_{\rm BHMG}}}\left(1 - \frac{M_{\rm BH}}{M_{\rm BHMG}}\right)^{a-1}\right]\Theta(M_{\rm BHMG} - M_{\rm BH})$$

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$$\frac{dN^{(2g)}}{dM_{\rm BH}} \sim \int dM_a \frac{dN^{(1g)}(M_a)}{dM_a}\frac{dN^{(1g)}(M_{\rm BH} - M_a)}{dM_a}$$

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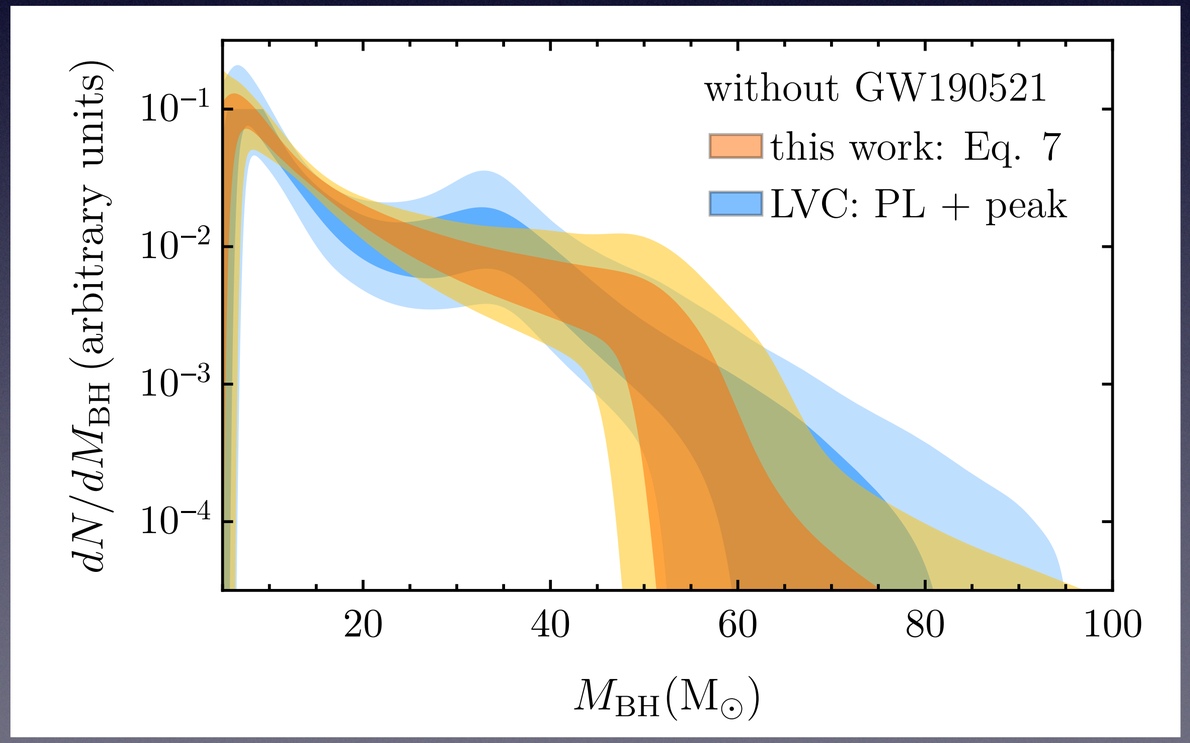
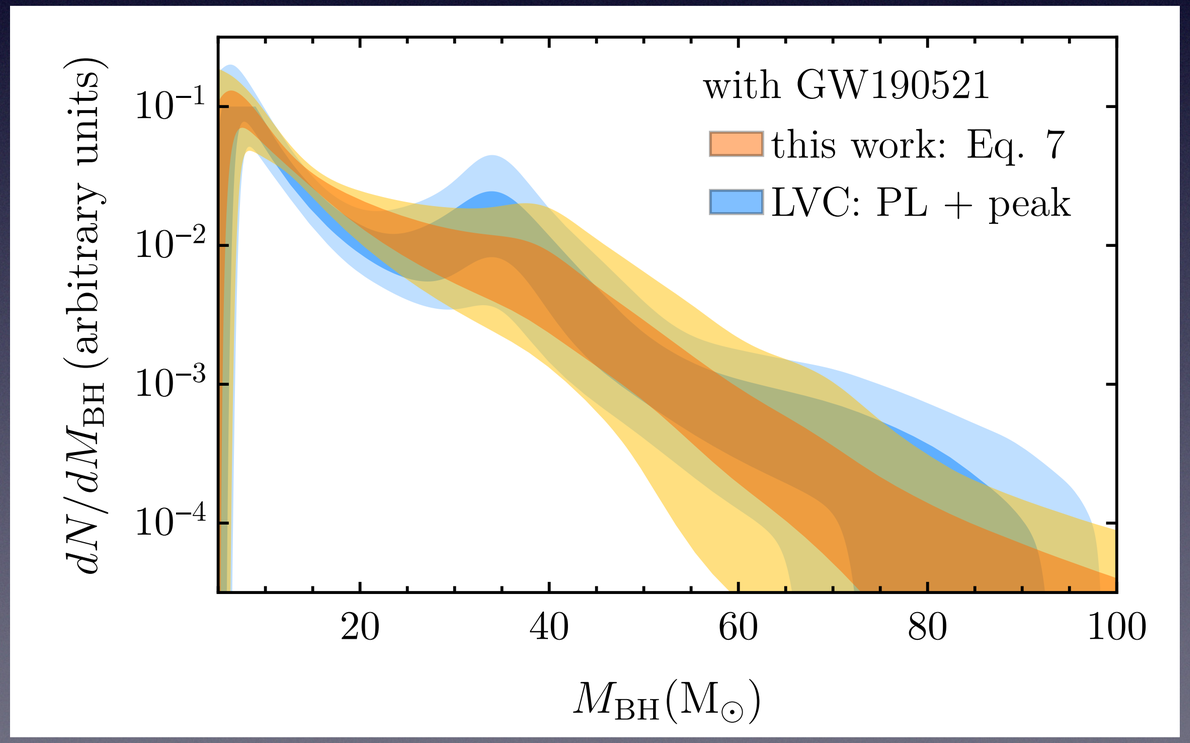
Baxter, Croon, SDM, Sakstein
@ApJL + 2104.02685v2





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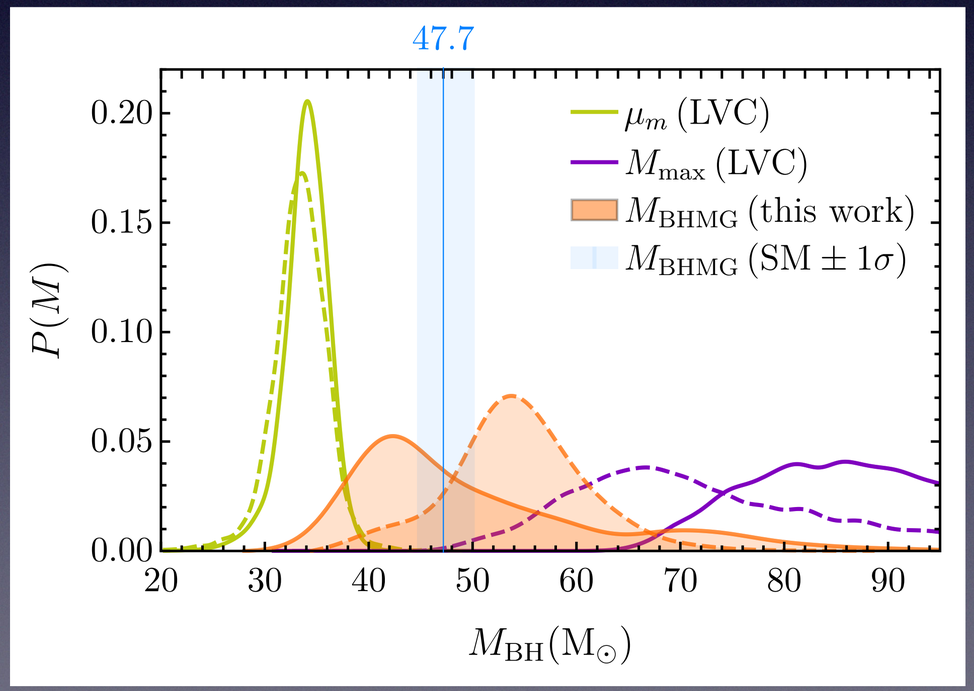

Conclusions

xkcd.com/1022/

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xkcd.com/1022/

- LIGO is in the middle of its “discovery bump” — we are learning so much more about the Universe all the time!
- Physically motivated mass functions will soon reveal intimate details of the black hole creation mechanism
- The future is exciting!

Thanks!

sammcd00@fnal.gov

home.fnal.gov/~sammcd00/