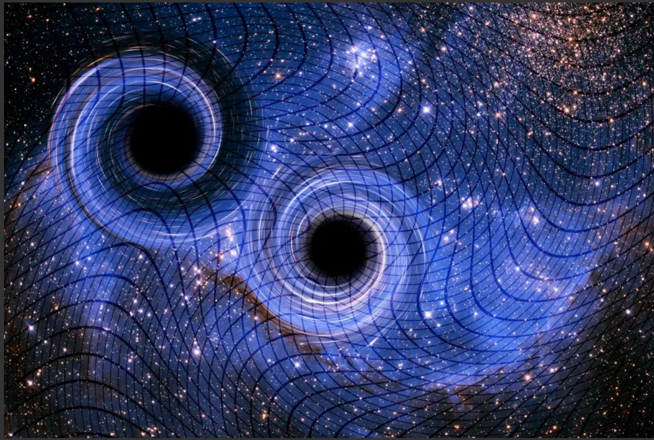
Light-curve models of radiation counterparts to the merger of compact objects in AGNs

Juan Carlos Rodriguez-Ramirez
Centro Brasileiro de Pesquisas Fisicas (CBPF)



Fink-Brazil Workshop
May 2024

Collaborators:
Clecio Roque De Bom, CBPF
Bernardo Fraga, CBPF
Rodrigo Nemmen, IAG-USP

Virgo Collaboration

Credit:Fermilab

Outline

- Introduction

- Predictions of EM counterparts to binary black hole mergers in AGNs:

  ->Flares driven by jet-in-disc propagation

  ->Flares driven by Hyper-Eddington winds

- Conclusions

Multi-Messenger Astronomy

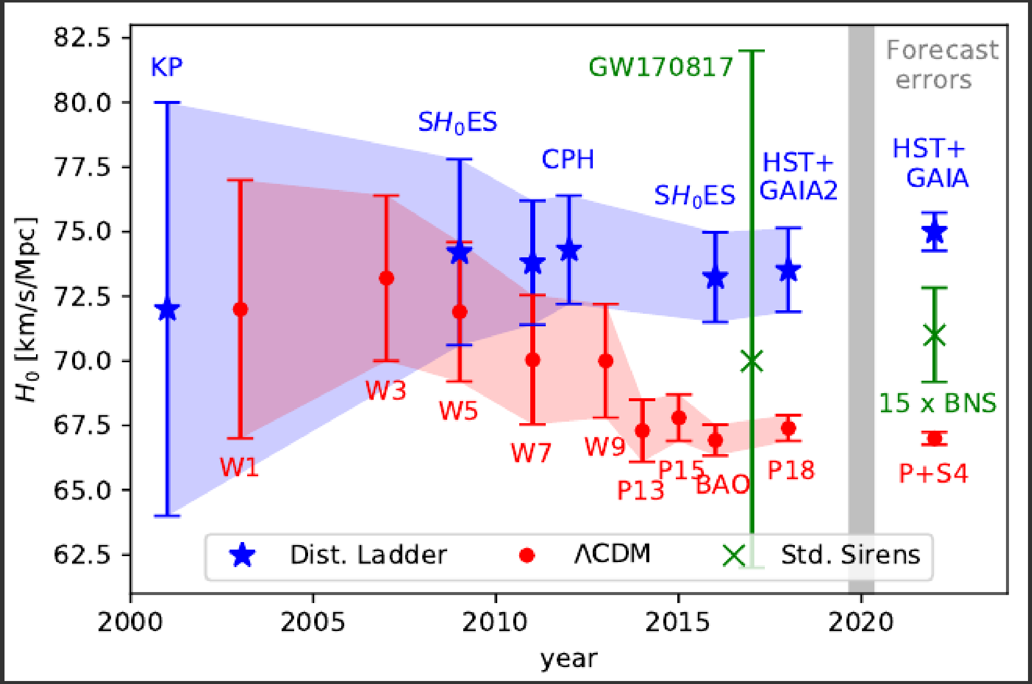
- GRBs can be produced in NS-NS collisions: GW 170817

- Alternative measure of Hubble constant.

Multi-Messenger Astronomy

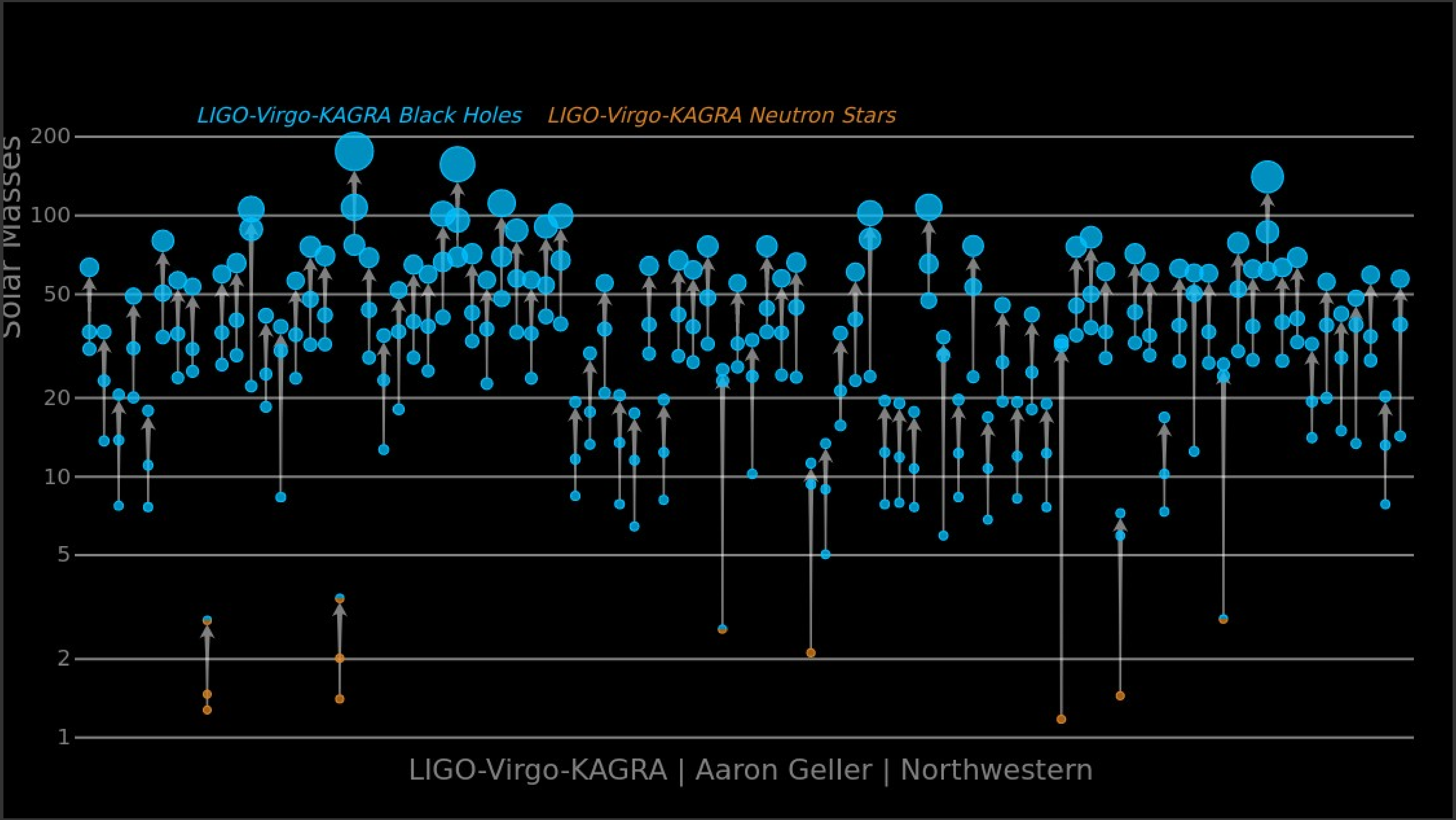
- GRBs can be produced in NS-NS collisions: GW 170817

- Alternative measure of Hubble constant.



Ezquiaga et al. (2018)
See also Palmese, De Bom et al. (2021)

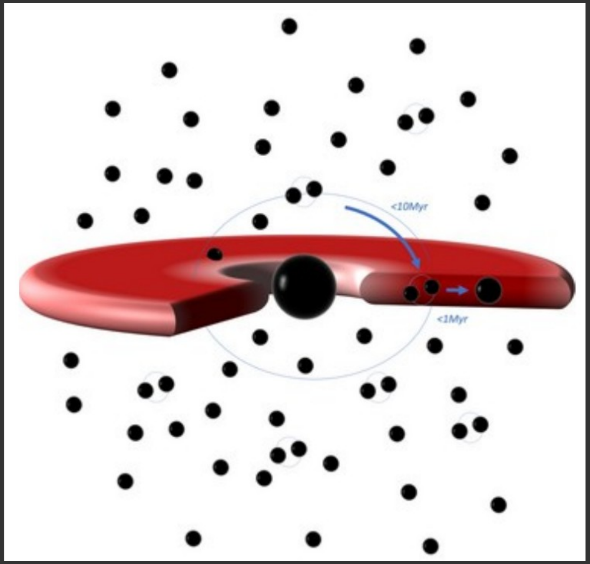
GW detections by LVK experiment, since September 2015



What is(are) the astrophysical site(s) where the observed BBH GWs come from?

- Star clusters

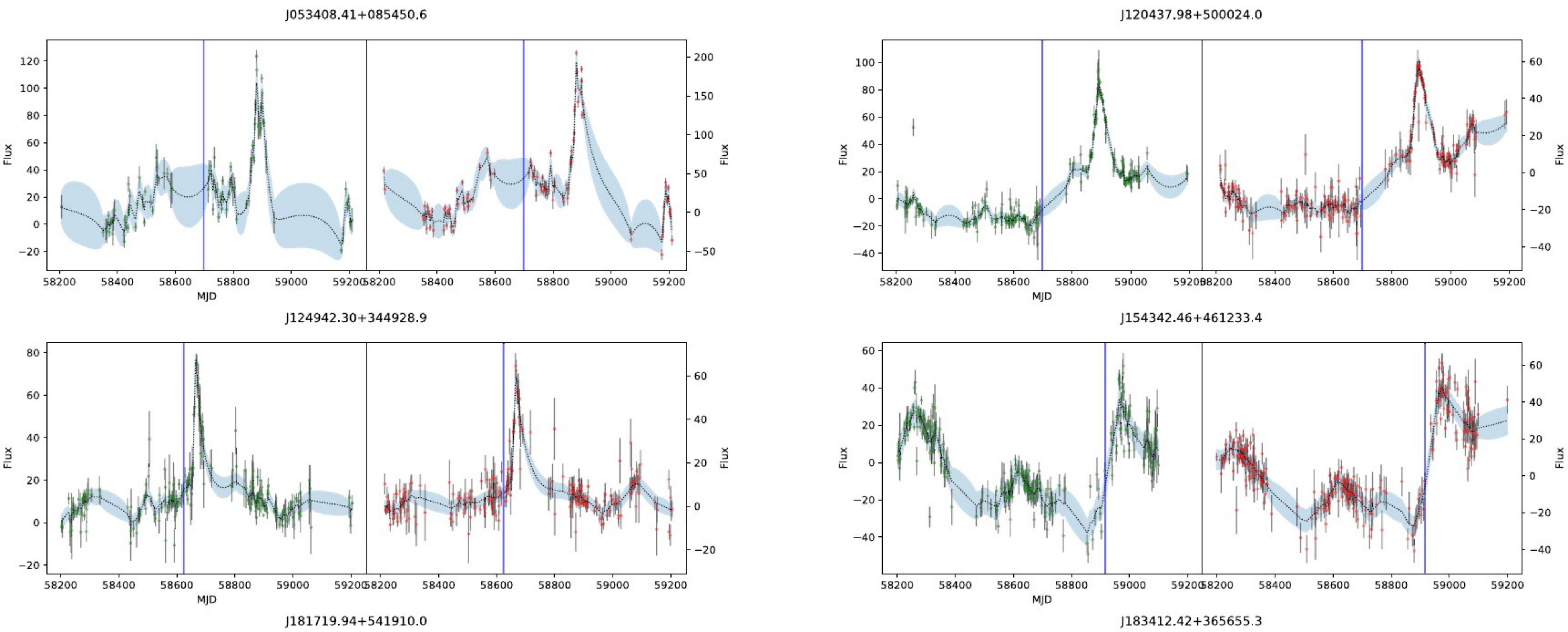
Rodriguez et al. (2016, 2017)



- Active galactic nuclei (AGNs)

McKernan et al. (2012)

The rate of BBH GWs is much higher than mergers involving NSs. Can we observe MM events form BBH mergers?

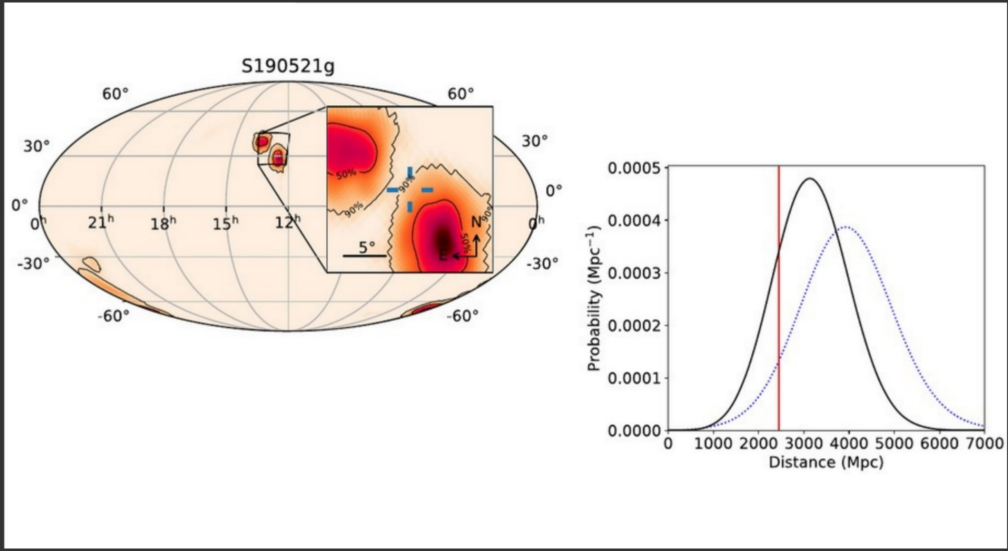


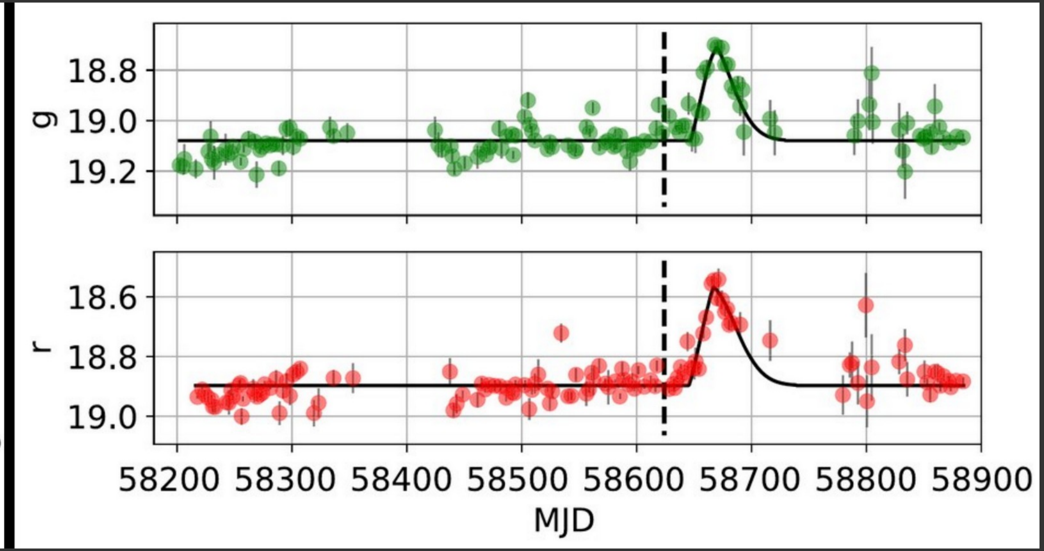
ZTF *g*- and *r*-band light curves, possibly associates with LIGO/Virgo events

Seven candidates reported in Graham et al. (2023). ApJ 942,99

The optical flare from the AGN J1249+3449 is perhaps the most discussed EM counterpart to a BBH GW.

Graham et al.(2020), De Paulis et al.(2020)
Ashton et al.(2021), Palmese et al.(2021)
Chen et al.(2022)





Graham et al.(2020)

GW190521: A Binary Black Hole Merger with a Total Mass of 150 $M_\odot$

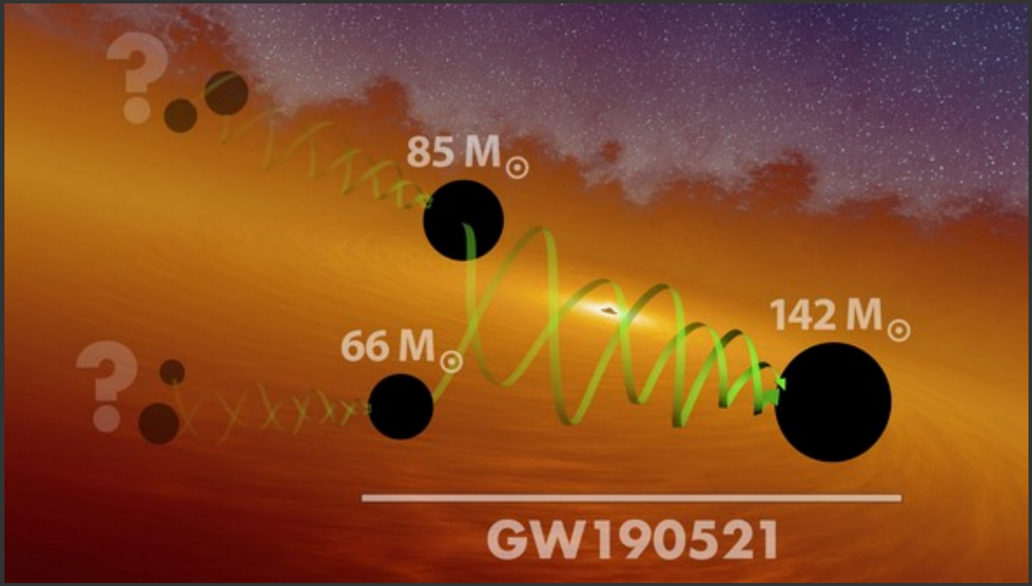
R. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 30 May 2020; revised 19 June 2020; accepted 9 July 2020; published 2 September 2020; corrected 23 October 2020)

What is the origin of high mass BBH remnants?

- The explosive deaths of massive stars do not produce BHs > 50 $M_\odot$ due to pair instability (Woosley 2017)

- Can such IMBHs remnant form in hierarchical sequences?



EM counterpart to BBH mergers with IMBH remnants.

The proposed multi-messenger model is based on the following considerations:

- The BBH merger occurs in the vecinity of an AGN thin disc.

- The merger occurs outside the disc (second, or higher generation).

  Different to the previous works of

  McKernan et al. (2019), Kimura et al. (2021),

  Wang et al. (2021), Tagawa et al. (2023).

- A highly spining remnant drives an efficient relativistc jet quasi-parallel to the plane of the disc.

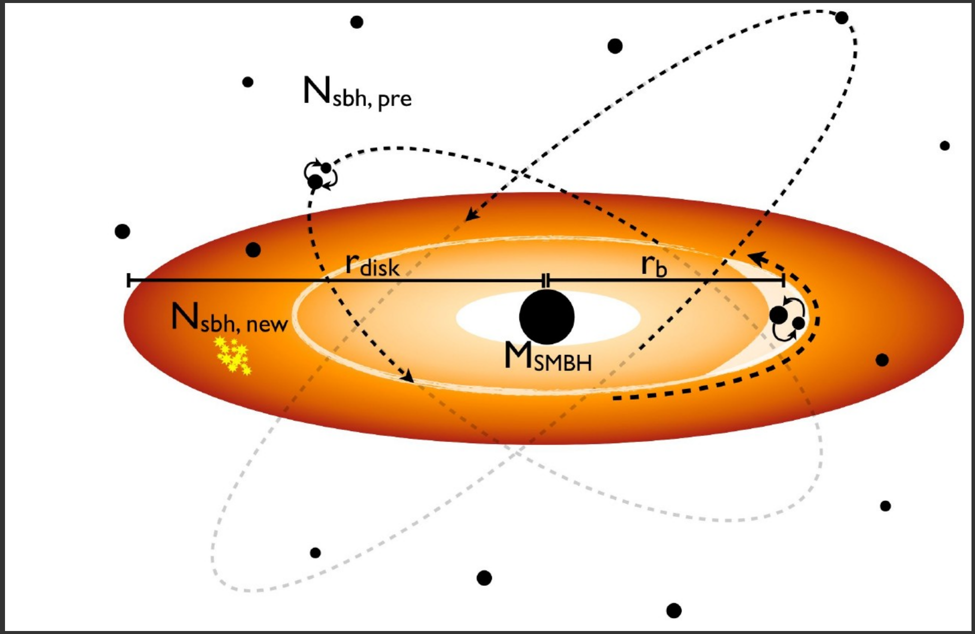
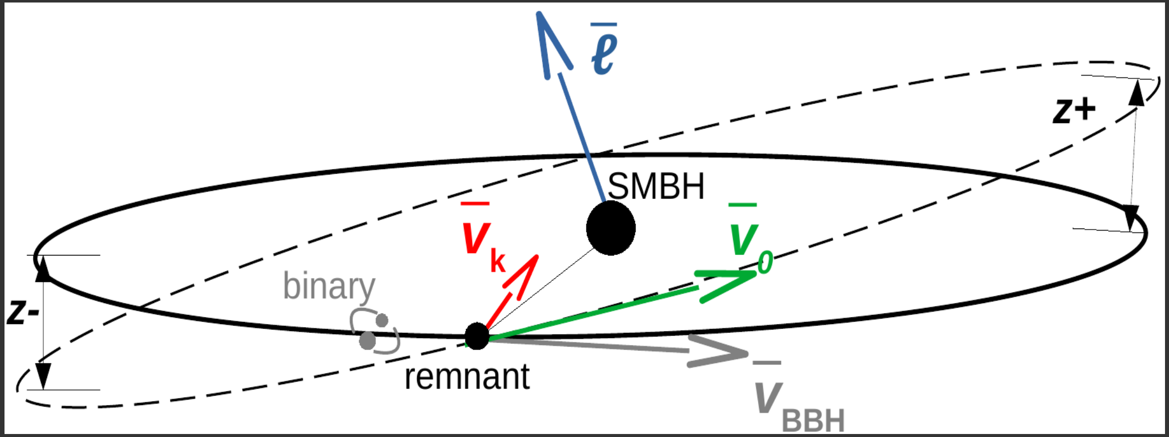
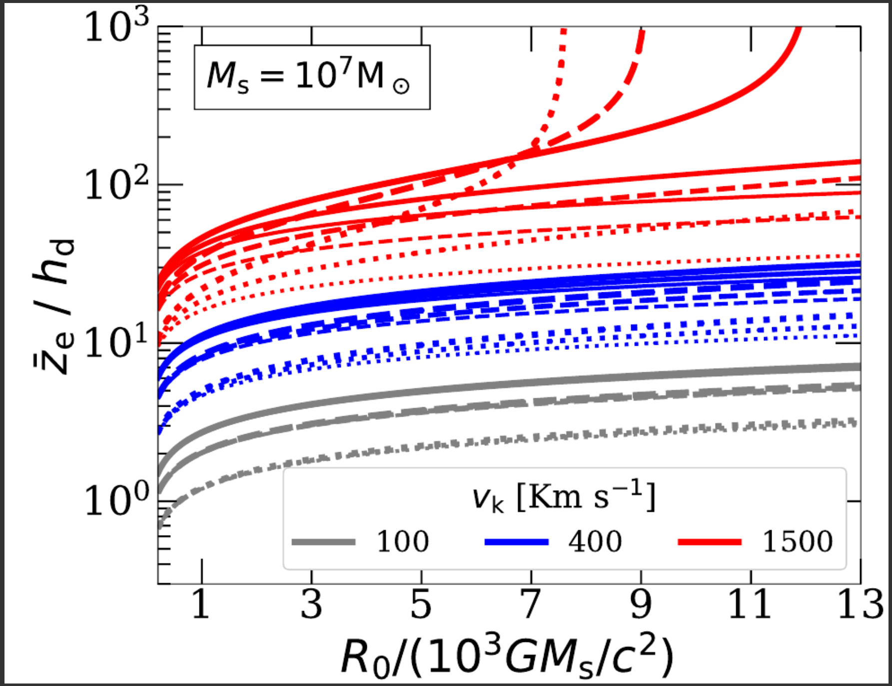


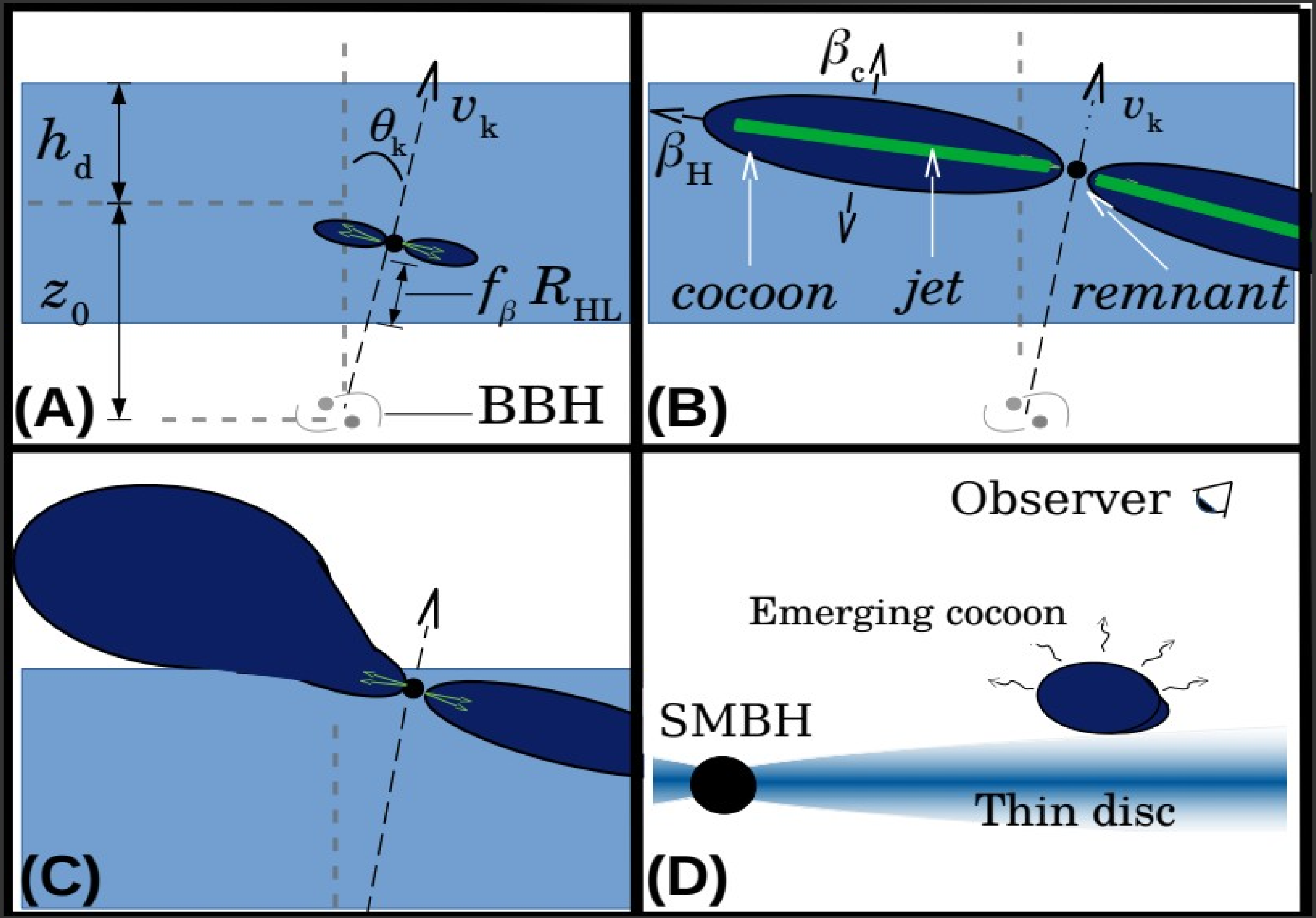
Image credit: O'Dowd

BH remnants tend to orbit outside the AGN thin disc



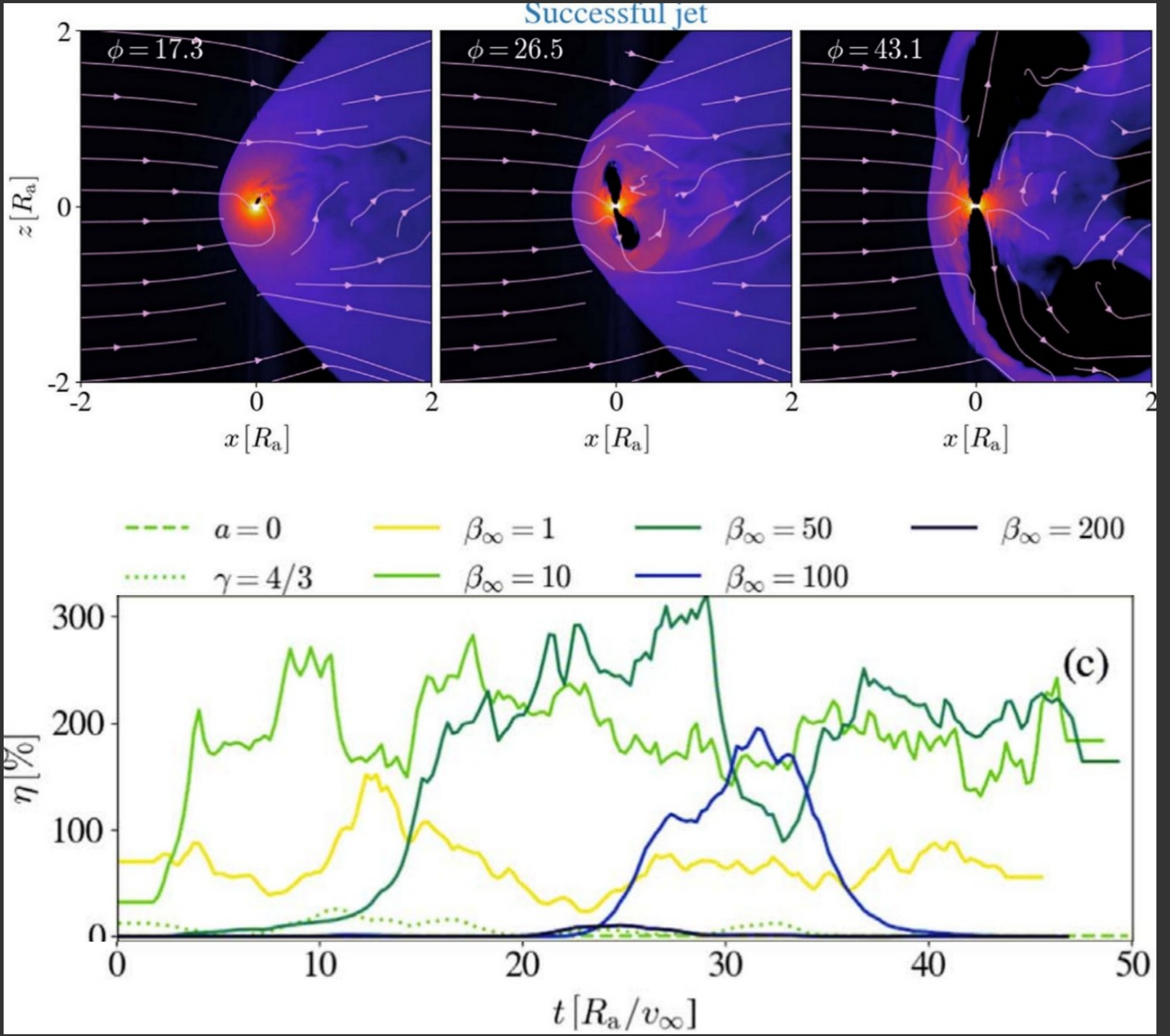


Emission scenario appropriate for second, or higher order BBH mergers in a hierarchical sequence (Rodriguez-Ramirez et al. 2023) arXiv:2304.10567

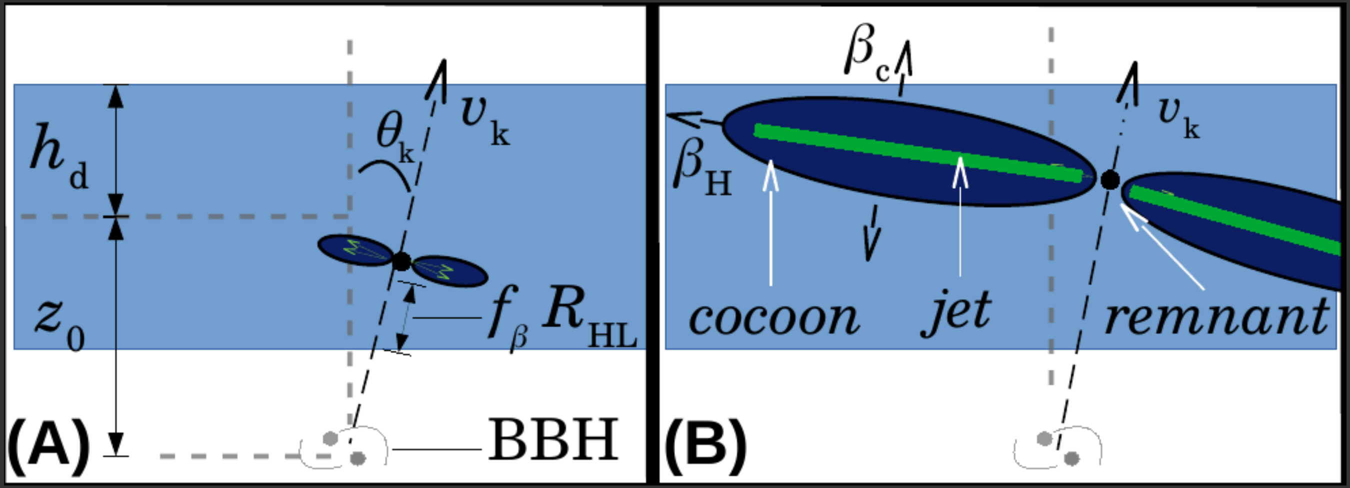


Relativistic jets with ~200% efficiency can be driven in Bondi-Hoyle-Lyttletton accretion of a spinning BH travelling through a magnetised environment of beta plasma ~10

GRMHD simulations performed by Kaaz et al. (2023).



The "emerging cocoon" has the oportunity of collecting mass while the remnant crosses the thin disc.



Rodriguez-Ramirez et al. (2023)

$$2h_{\rm d} - f_\beta R_{\rm HL}\cos\theta_{\rm k} = [\cos\theta_{\rm k}]^{-1}\int_0^{\Delta t_c} dtc\beta_{\rm c}(t) + \sin\theta_{\rm k}\left[\int_0^{\Delta t_c} dtc\beta_{\rm H}(t) - \tan\theta_{\rm k}\int_0^{\Delta t_c} dtc\beta_{\rm c}(t)\right] + \Delta t_{\rm c} v_{\rm k}\cos\theta_{\rm k},$$

$$\beta_{\rm H}(t) = \left[1 + \tilde{L}(t)^{-1/2}\right]^{-1}, \quad \beta_{\rm c}(t) = \frac{\theta_0}{2}\tilde{L}(t)^{1/2}, \quad \tilde{L} = A\left(\frac{L_{\rm j}}{\rho_{\rm d}\theta_0^4 c^5}\right)^{2/5} t^{-4/5},$$

Bromberg et al. (2011)

The flare mostly emmits in EUV and optical

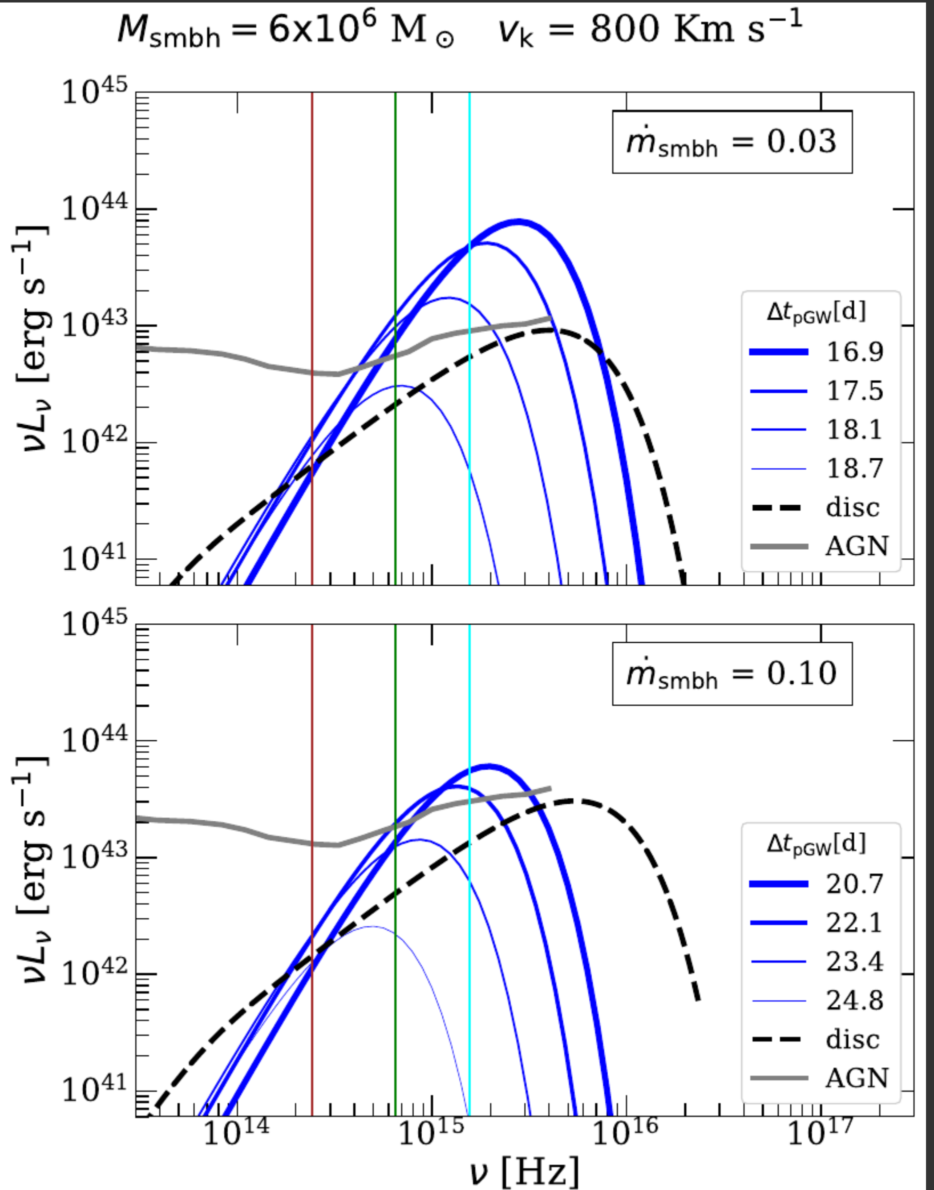
- We follow a time-dependent “Arnett-like” photon difussion model.

- Decribes the thermal evolution of an homolougous expansion sphere:

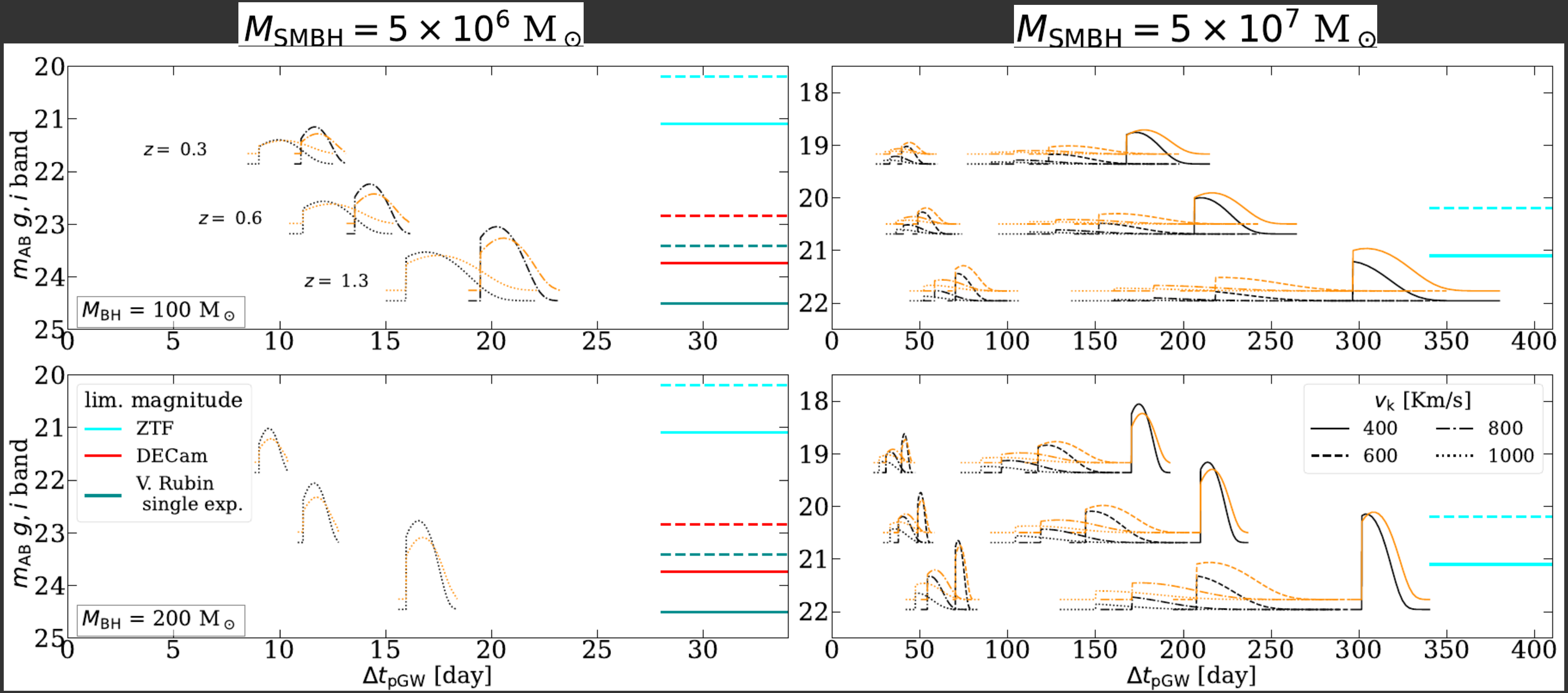
  Arnett (1980, 1996),

  Chatzopoulos et al. (2012)

$$4T^4\left(\frac{\dot{T}}{T}+\frac{\dot{V}}{V}\right)=\frac{1}{r^2}\frac{\partial}{\partial r}\left(\frac{c}{3\kappa\rho}r^2\frac{\partial T^4}{\partial r}\right)$$



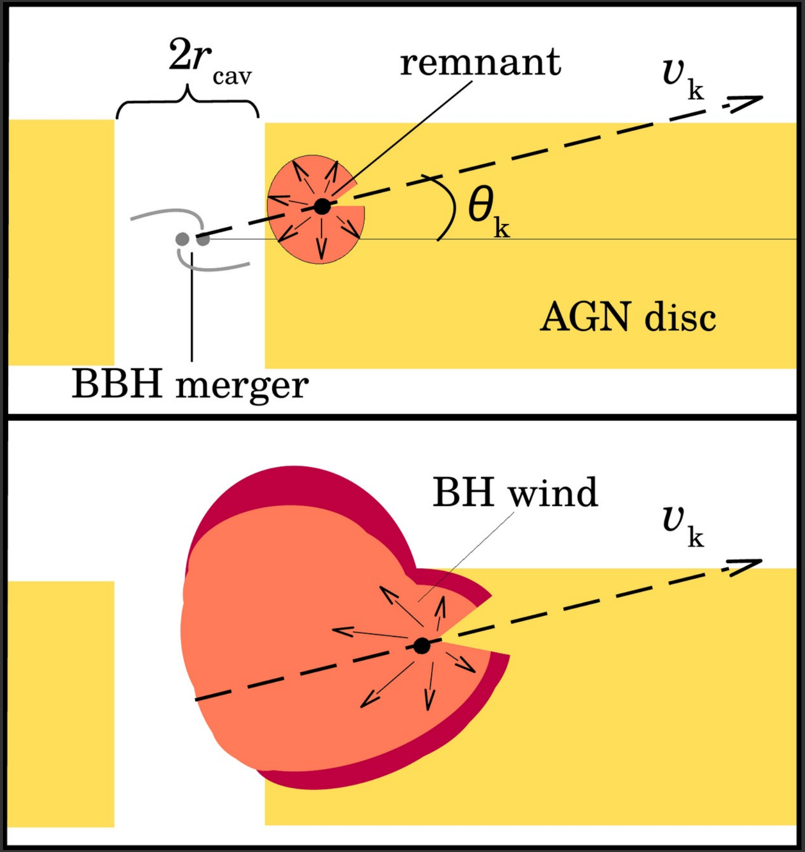
Optical time-domain surveys capable to capture these transients



Rodriguez-Ramirez et al. (2023) *MNRAS*

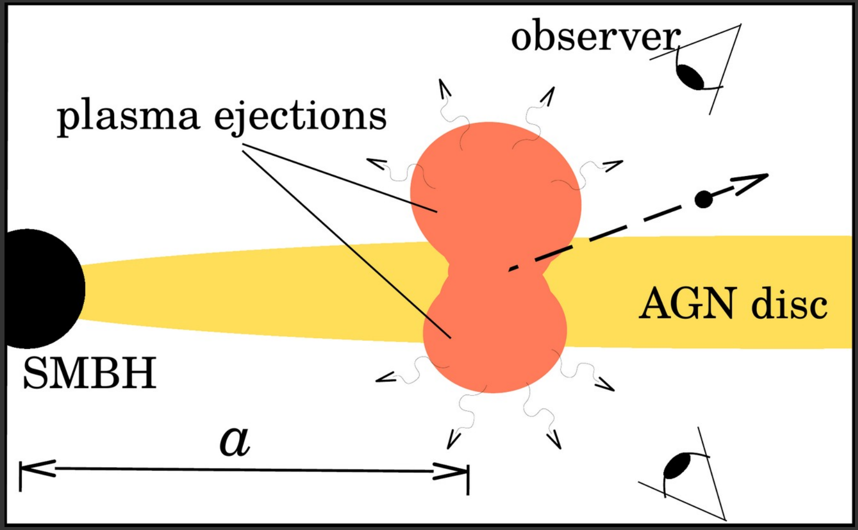
New MM model for stellar mass BBH mergers: time delay, duration, and LC profiles

Emission scenario appropriate for stellar mass BBHs within the AGN thin disc based on the scenario proposed by Kimura et al. (2021)



- The counterpart energised by a radiation driven, hyper-Eddington wind

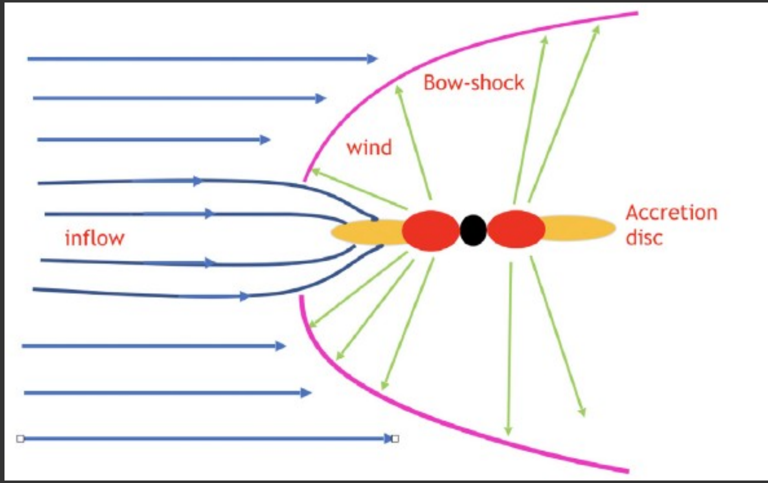
- We derive “upper” and “lower” observer solutions.

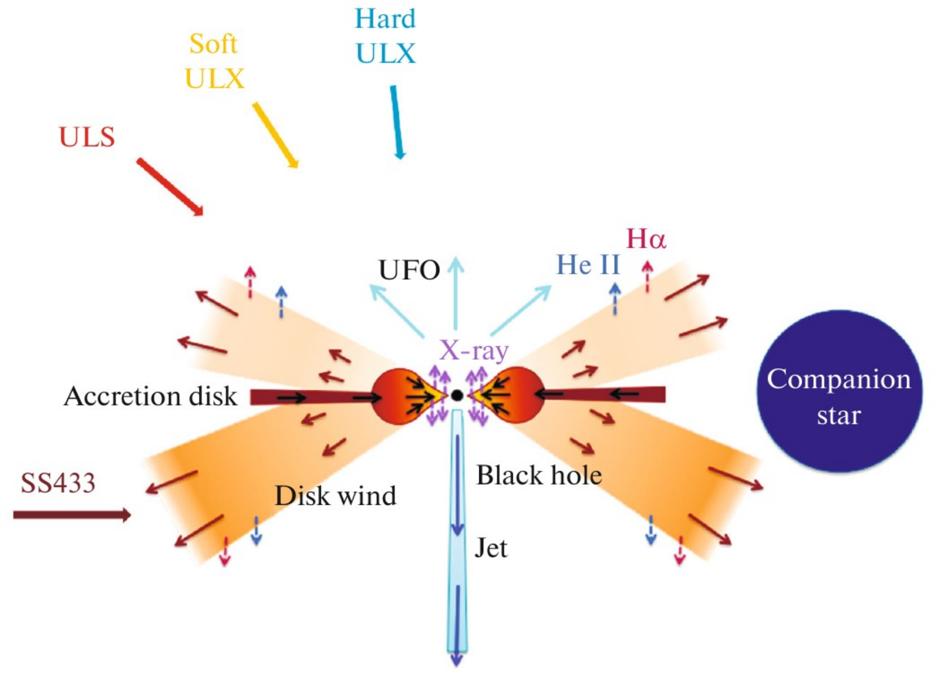


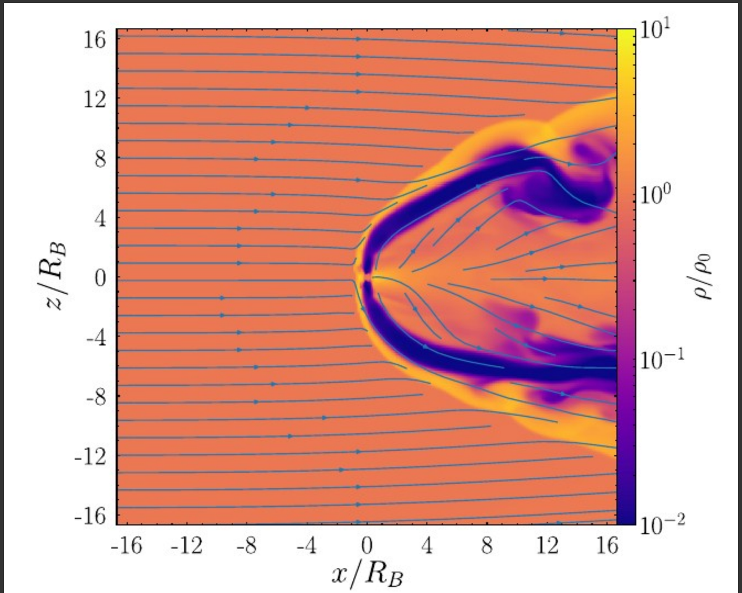
The inflow-outflow scenario is motivated by:

- Observations e interpretation of ULXs
  Fabrika et al. (2021)

- Theory and simulations of B-H-L accretion with outflows
  Gruzinov et al. 2019, Li et al. (2020).

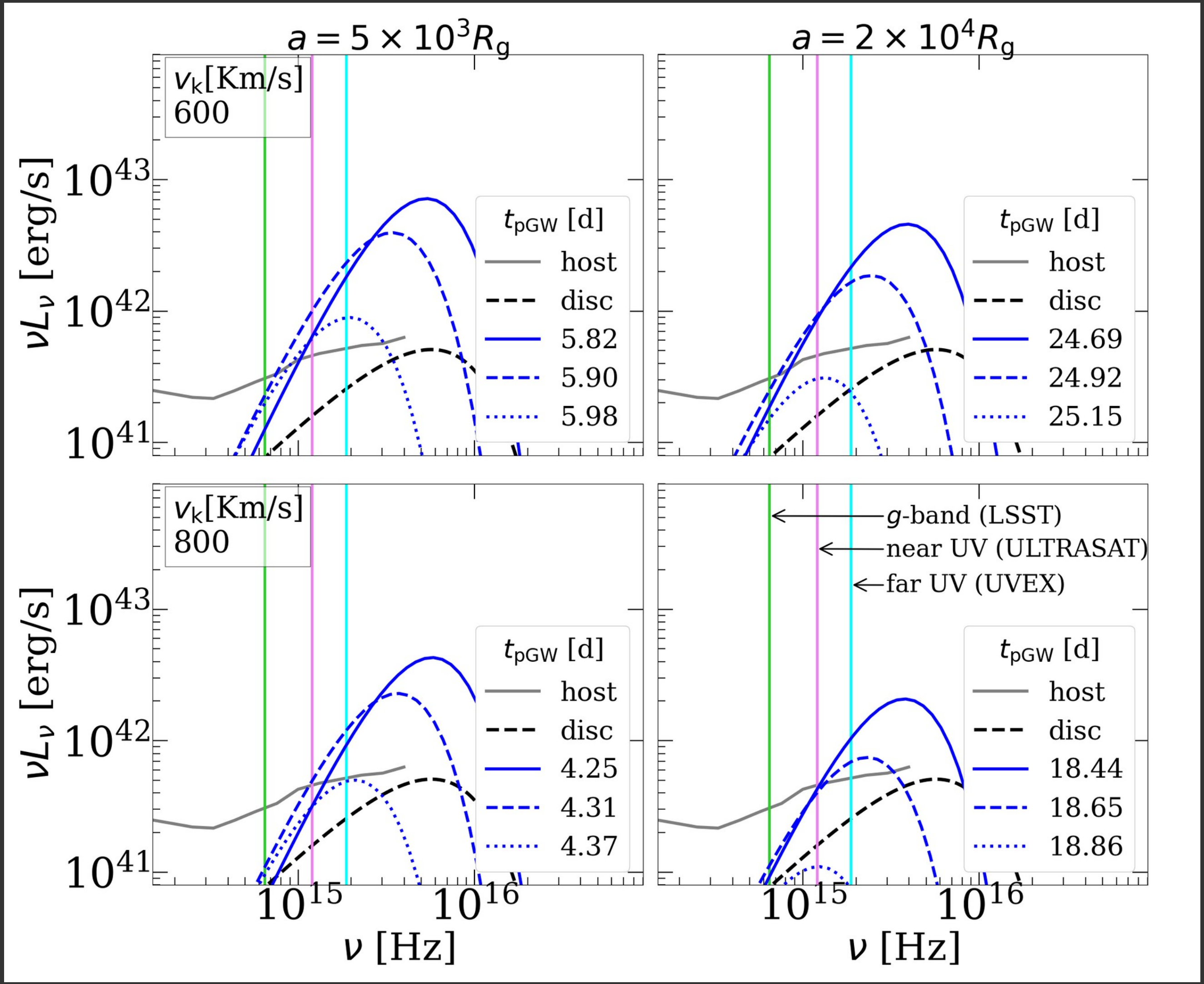






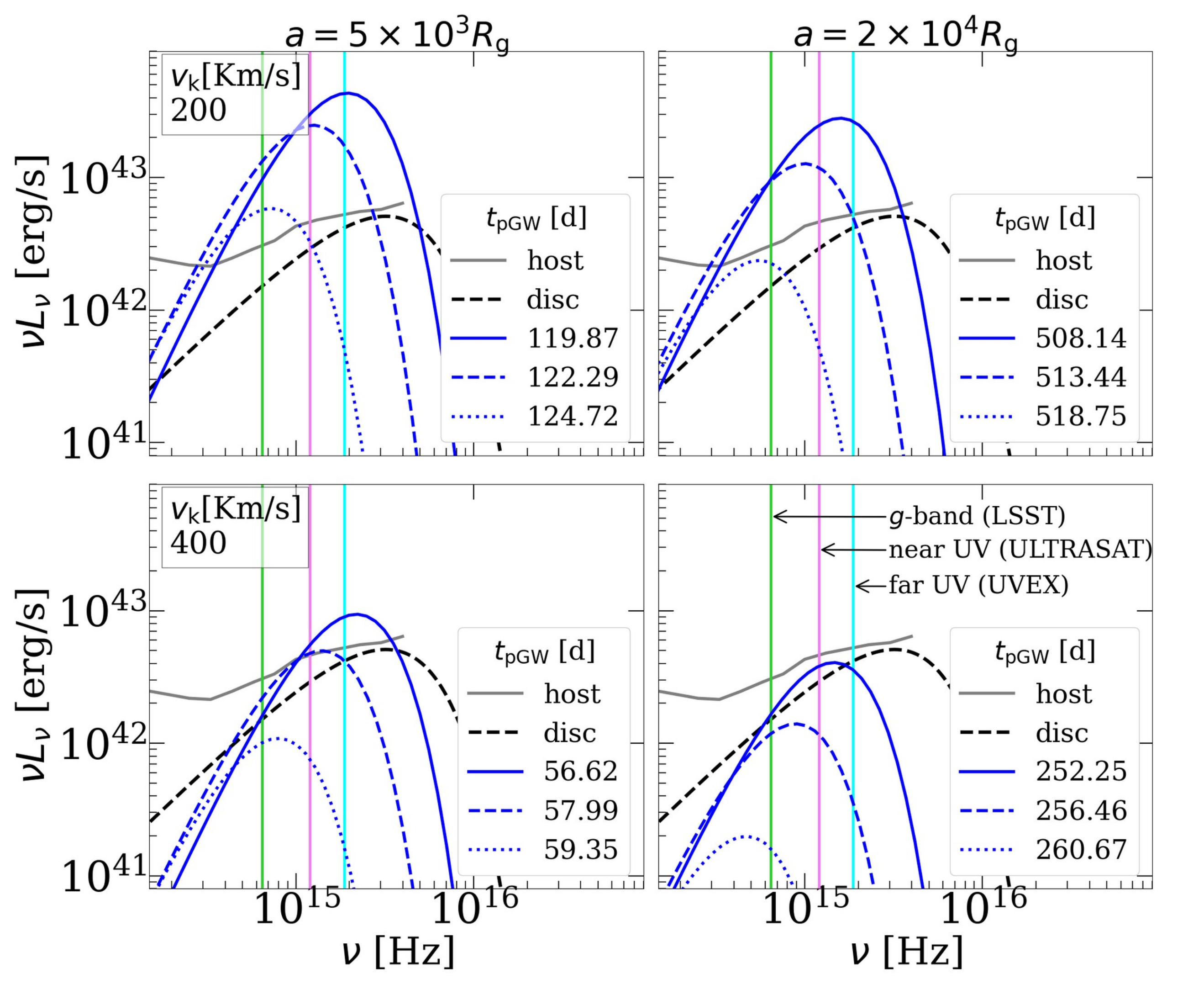
Central SMBH of 10^6 $M_\odot$:

The flare peaks between UV and X-rays

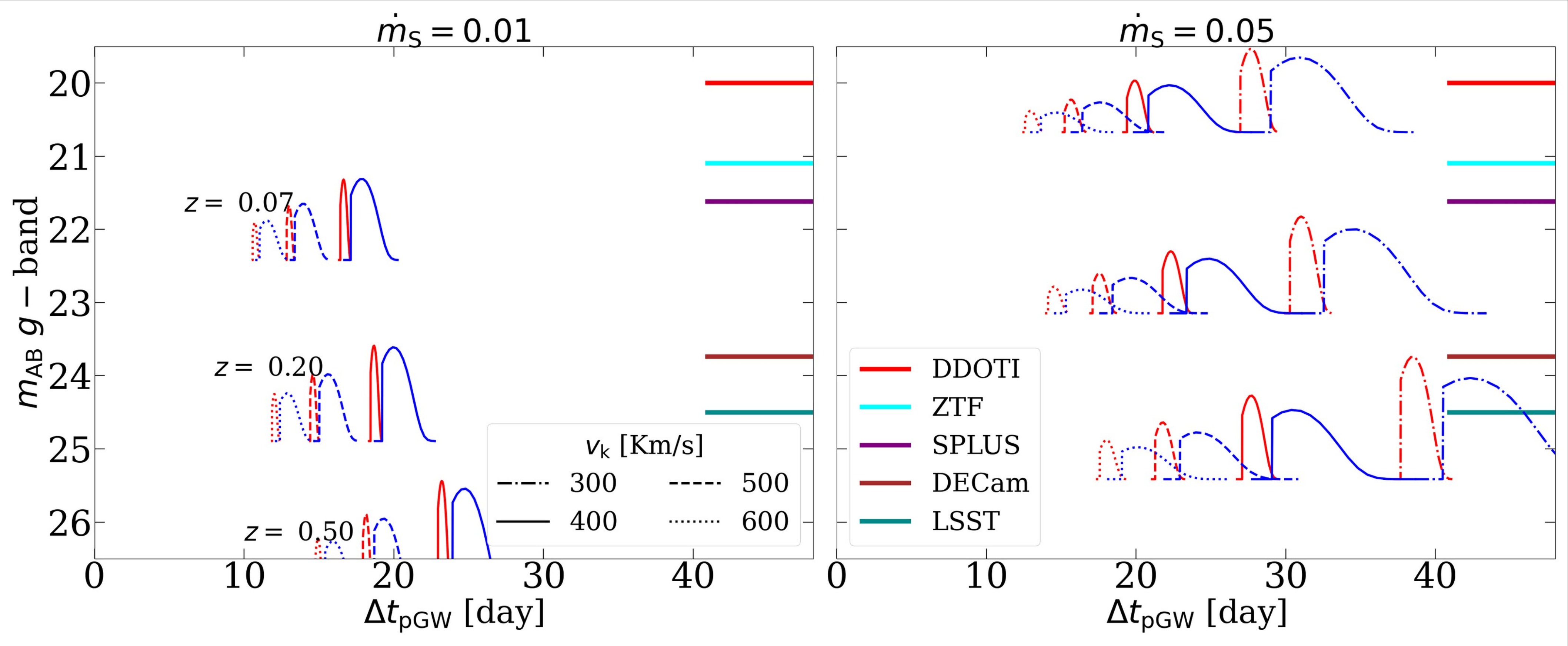


Central SMBH of 10^7 $M_\odot$:

The flare peaks optical - UV

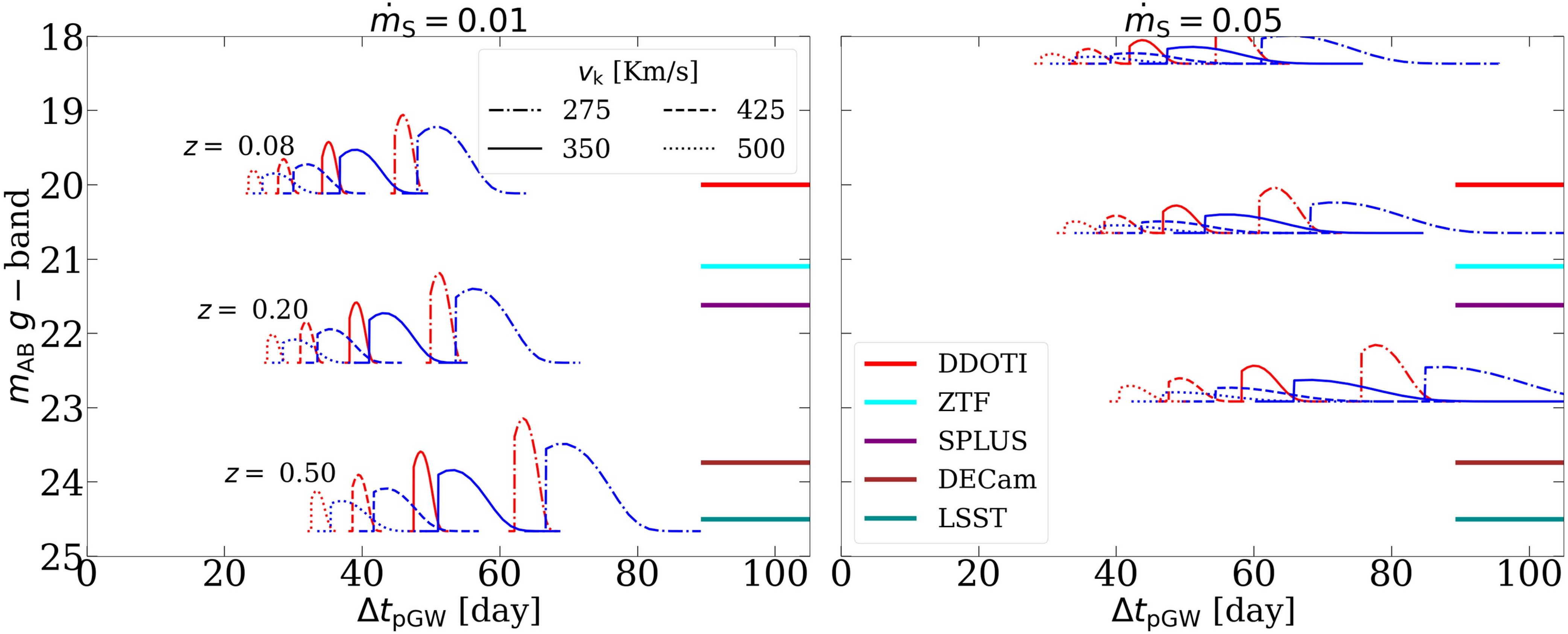


Optical time-domain surveys capable to capture these transients



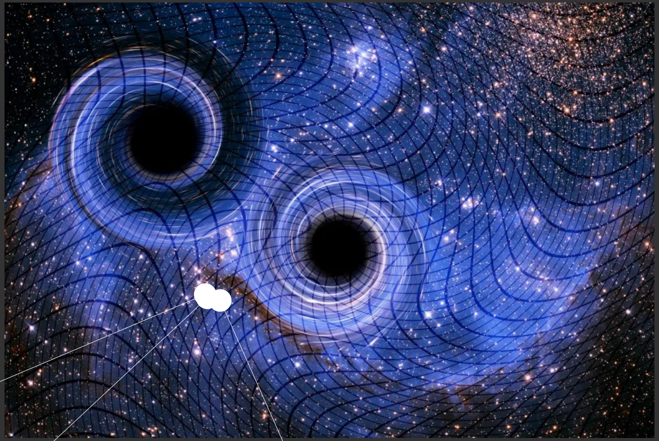
Rodriguez-Ramirez et al. (2024) *in prep.*

Optical time-domain surveys capable to capture these transients



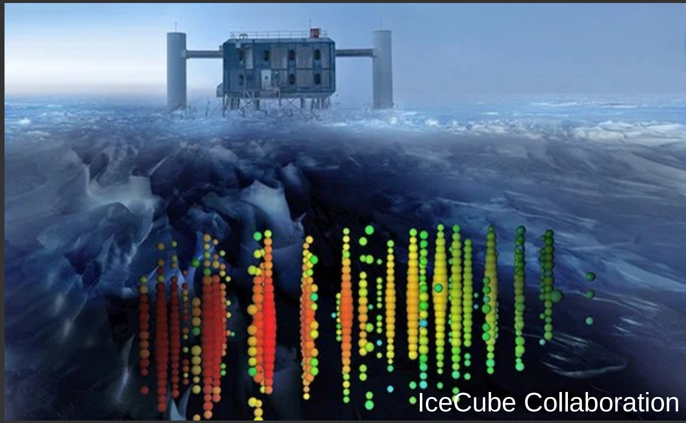
Rodriguez-Ramirez et al. (2024) *in prep.*

Are the EM counterpart mechanisms discussed here able to produce high energy neutrinos?



Virgo Collaboration

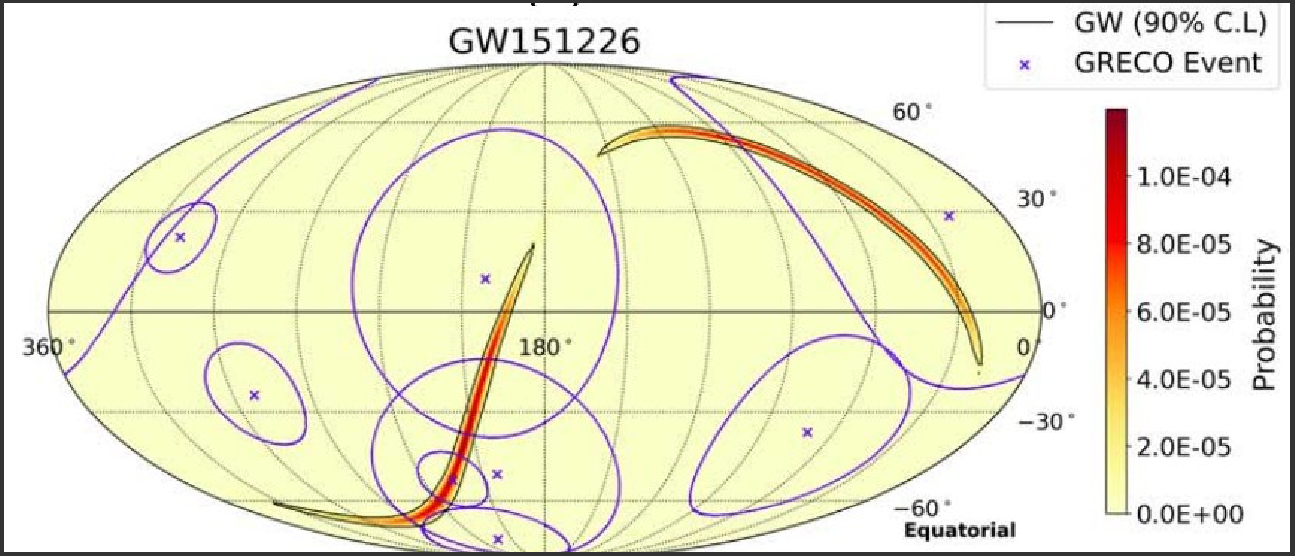
Credit:Fermilab



IceCube Collaboration

Search for HE neutrinos correlated with LIGO/Virgo events. Abassi et al. (2023)

- Several neutrinos are spatially compatible with the direction of GW events.
- However, the associations are not statistically significant.
- IceCube Upgrade will improve such localisations.



Conclusions

- We developed **physical emission models** appropriate for **localising EM** counterparts to **BBH mergers**.

- The predicted **flares** produce emission **comparable** or **exceeding** that of **the hosting AGN**, for mergers occurring at radii > $4000R_g$.

- We suggest that **flares** in our model with **|m|>0.5 mag,** in AGNs with SMBHs **smaller than 5×10^6 $M_\odot$**, can be better **associated to GW** events, as they have **lags of few weeks.**