Neutrino and positron constraints on primordial blackhole dark matter: role of angular momentum

1912.01014

Anupam Ray

Work in collaboration with: Basudeb Dasgupta & Ranjan Laha

WHEPP-XVI , IITG , 04.12.19

- Primordial black holes (PBHs): one of the earliest proposed DM candidate.
- There is still enough region in parameter space where PBHs can contribute entire DM density.

- Neutrino (positron) emission from PBHs and subsequent detection by SUPER-K (INTEGRAL) can put stringent constraints in the lower mass window.
- Angular momentum is a fundamental property of black holes. There exist viable cosmological scenarios where PBHs are born with very high spin and it is crucial to explore the effect of spin.

PBH can be DM

Did LIGO detect dark matter?

Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski, Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess[1]

[1] *Department of Physics and Astronomy, Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21218, USA*

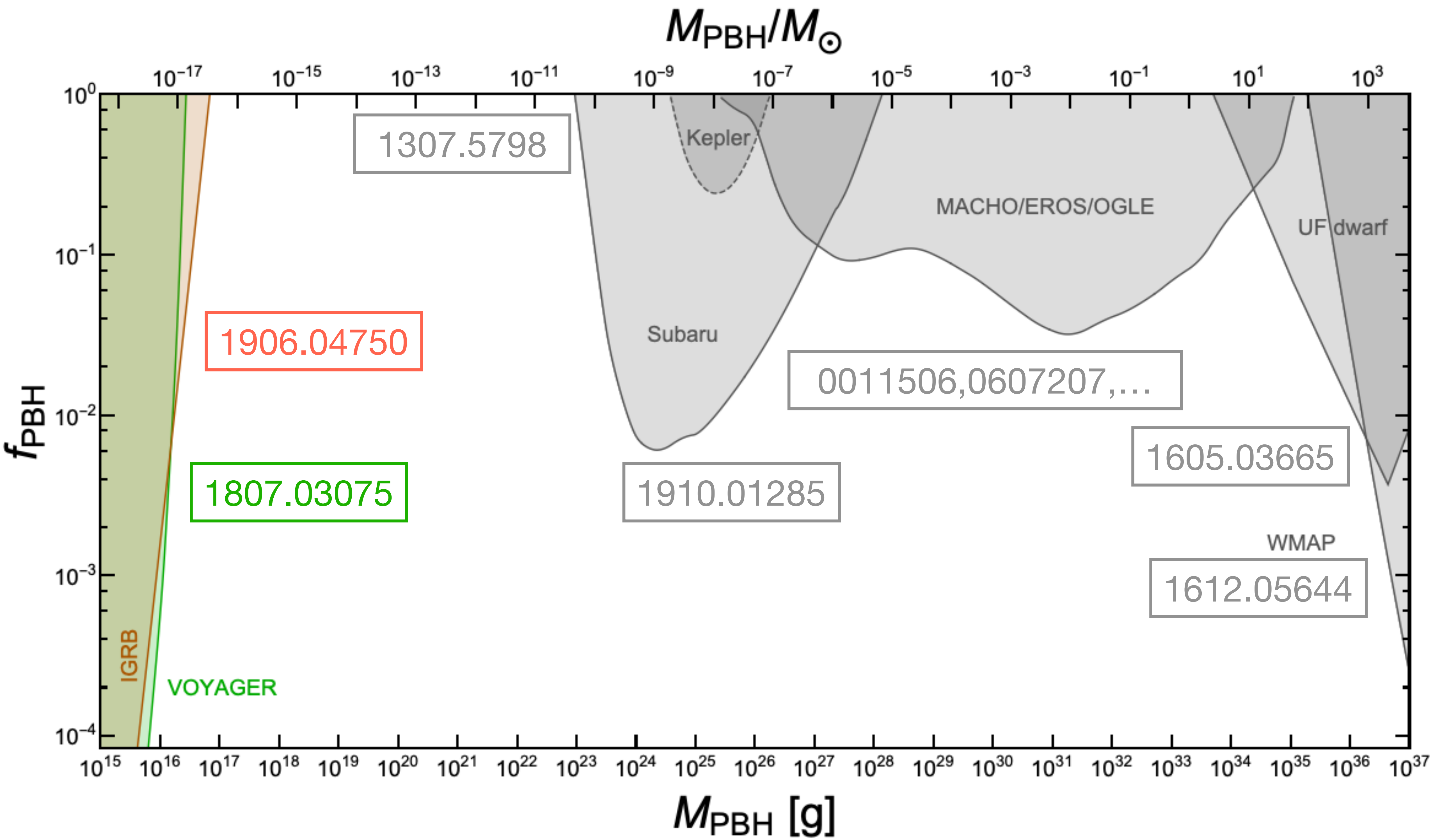
We consider the possibility that the black-hole (BH) binary detected by LIGO may be a signature of dark matter. Interestingly enough, there remains a window for masses $20\,M_\odot \lesssim M_{\rm bh} \lesssim 100\,M_\odot$ where primordial black holes (PBHs) may constitute the dark matter. If two BHs in a galactic halo pass sufficiently close, they radiate enough energy in gravitational waves to become gravitationally bound. The bound BHs will rapidly spiral inward due to emission of gravitational radiation and ultimately merge. Uncertainties in the rate for such events arise from our imprecise knowledge of the phase-space structure of galactic halos on the smallest scales. Still, reasonable estimates span a range that overlaps the $2-53$ Gpc^{-3} yr^{-1} rate estimated from GW150914, thus raising the possibility that LIGO has detected PBH dark matter. PBH mergers are likely to be distributed spatially more like dark matter than luminous matter and have no optical nor neutrino counterparts. They may be distinguished from mergers of BHs from more traditional astrophysical sources through the observed mass spectrum, their high ellipticities, or their stochastic gravitational wave background. Next generation experiments will be invaluable in performing these tests.

PBH can be DM

- After the detection of gravitational waves in LIGO and the subsequent proposal that these black holes are primordial in nature rekindled the idea of PBH as DM.

- Multiple techniques have been advocated in order to probe PBHs in various mass ranges. Some of the techniques put stringent constraint on some specific mass window.

- Still, there are regions in parameter space where PBH can form large fraction of DM or even entire fraction!



$M_{PBH}/M_\odot$
10^{-17} 10^{-15} 10^{-13} 10^{-11} 10^{-9} 10^{-7} 10^{-5} 10^{-3} 10^{-1} 10^{1} 10^{3}
f_{PBH}
10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4}
1307.5798
Kepler
MACHO/EROS/OGLE
UF dwarf
Subaru
1906.04750
0011506,0607207,...
1605.03665
1807.03075
1910.01285
WMAP
1612.05644
IGRB
VOYAGER
10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22} 10^{23} 10^{24} 10^{25} 10^{26} 10^{27} 10^{28} 10^{29} 10^{30} 10^{31} 10^{32} 10^{33} 10^{34} 10^{35} 10^{36} 10^{37}
M_{PBH} [g]

- In this work, we probe the DM fraction of PBH by considering neutrino and positron emission (Hawking radiation) and subsequent detection by Super-Kamiokande and INTEGRAL respectively.
- Angular momentum is a fundamental property of black holes and there exist viable cosmological scenarios where PBHs are born with very high spin. (1707.03595, 1810.03490, 1906.10987,….)
- Hence, it is crucial to explore the implication of angular momentum of PBHs. (1511.05642, 1906.04750,…).

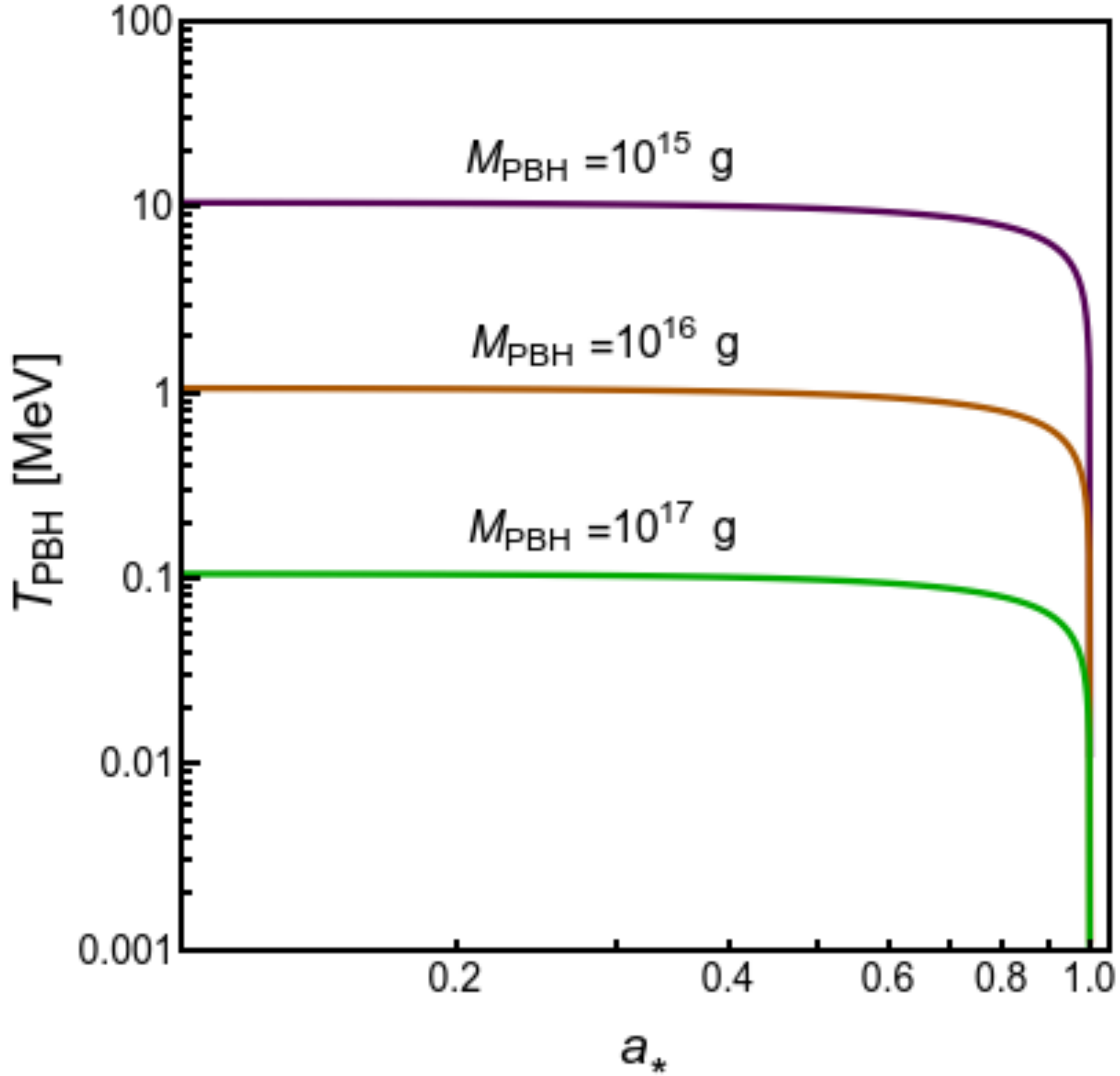
Formalism

- PBH emit particle by Hawking radiation and spectrum of these particles follow the distribution:

$$\frac{d^2N}{dEdt} = \frac{1}{2\pi} \frac{\Gamma_s(E, M_{\rm PBH}, a_*)}{\exp\left[E'/T_{\rm PBH}\right] - (-1)^{2s}}$$

- The temperature of a primordial blackhole is given by its mass (M_{PBH}):

$$T_{\rm PBH} = \frac{1}{4\pi G_N M_{\rm PBH}} \frac{\sqrt{1 - a_*^2}}{1 + \sqrt{1 - a_*^2}}$$



Variation of temperature with spin parameter

- For DSNB, the galactic and extragalactic contribution to the flux:

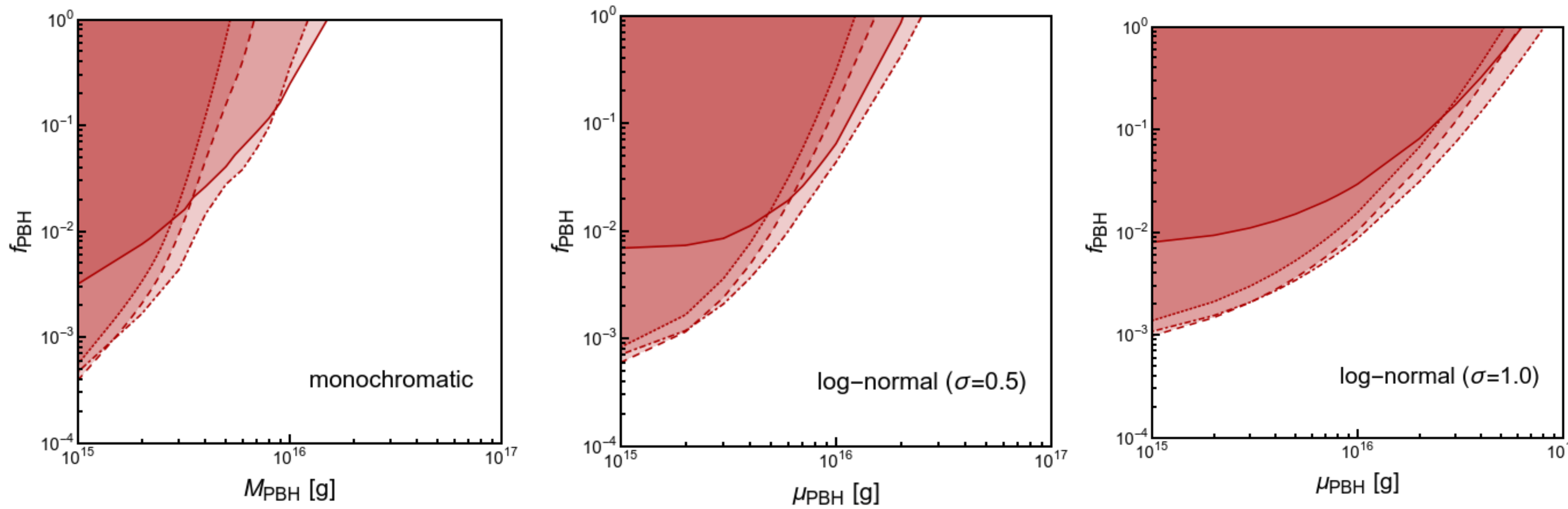
$$F_{\mathrm{Gal}} = \int d\Omega \int dE \frac{d^2N}{dEdt} \int dl \, \frac{f_{\mathrm{PBH}} \, \rho_{\mathrm{MW}} \left(r(l, \psi) \right)}{M_{\mathrm{PBH}}}$$

$$F_{\mathrm{EG}} = \int \int dt \, dE \, (1 + z(t)) \frac{f_{\mathrm{PBH}} \rho_{\mathrm{DM}}}{M_{\mathrm{PBH}}} \frac{d^2N}{dEdt} \bigg|_{E=(1+z(t))E}$$

- The limit on dark matter fraction of PBH can simply be obtained by comparing the total flux with the current upper limit on the DSNB flux from different experiments.

- Current upper limits on the DSNB flux are 2.9 $\bar{\nu}_e\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (139 $\bar{\nu}_e\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) in the energy range of 17.3 MeV to 91.3 MeV (8.3 MeV to 31.8 MeV) from Super-K (KamLAND).

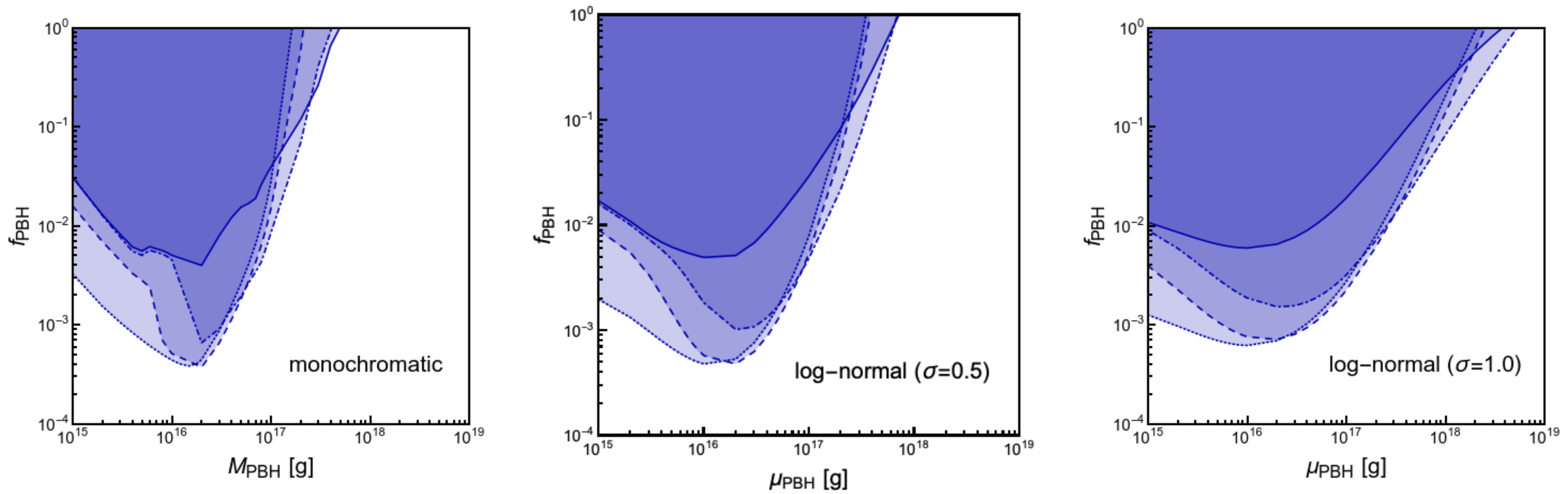
- SUPER-K and KamLAND data helps us to probe the dark matter fraction of PBH. Though the results obtained from SUPER-K data is stronger at all PBH masses we consider.



Upper limit on dark matter fraction of PBHs, from DSNB searches at Super-Kamiokande.

- For INTEGRAL, the total positron injection rate from the PBHs is compared with the total production rate of positrons within the Galactic bulge in order to get the limit:

$$f_{\mathrm{PBH}} \leq \frac{10^{50}\ \mathrm{yr}^{-1}}{\int dE \int dM_{\mathrm{PBH}} \frac{dN_{\mathrm{PBH}}}{dM_{\mathrm{PBH}}} \frac{d^2N}{dEdt} \int \frac{d^3r\, \rho_{\mathrm{MW}}(r)}{M_{\mathrm{PBH}}}}$$



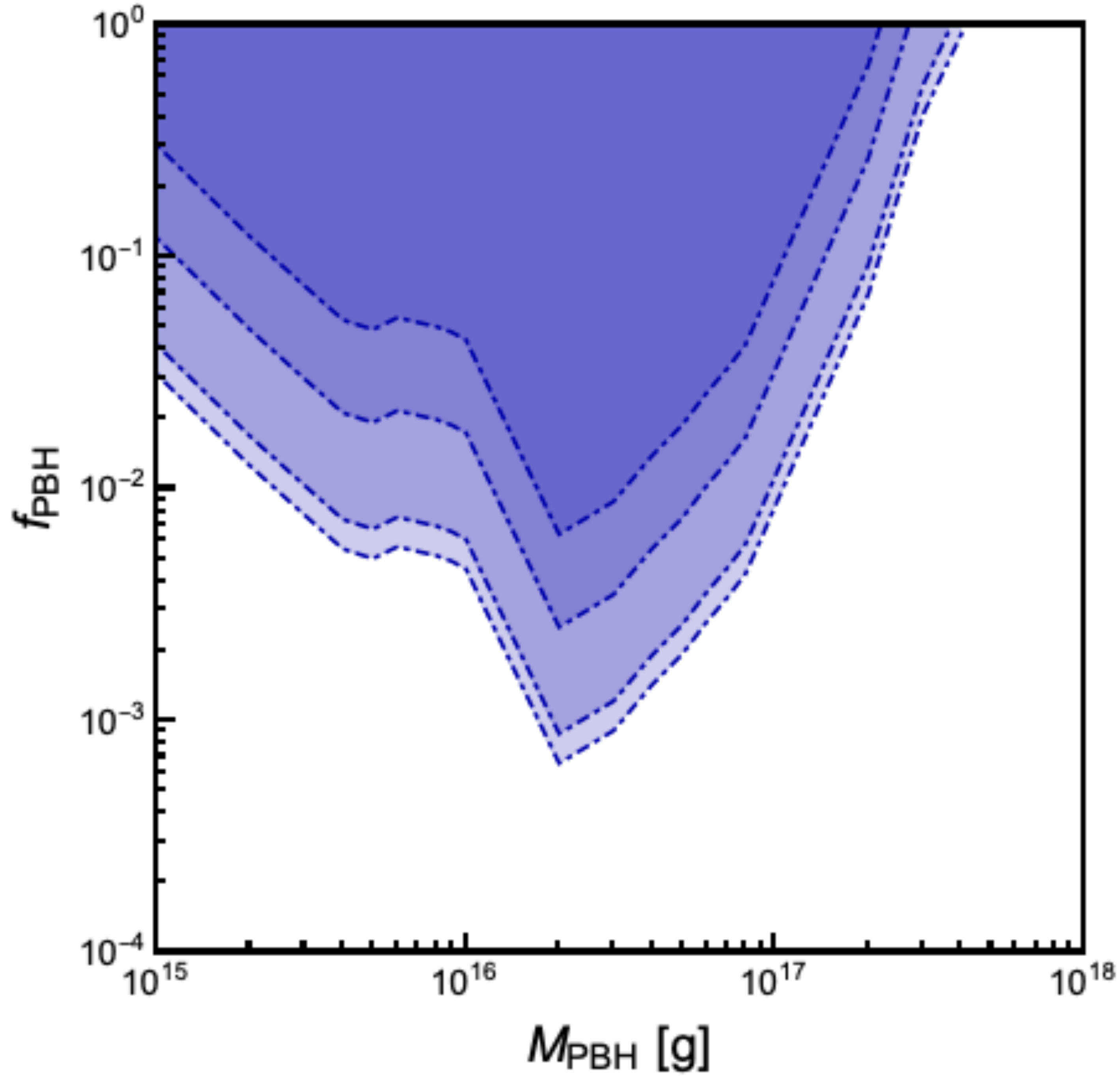
Upper limit on dark matter fraction of PBHs, from INTEGRAL 511 keV gamma-ray line measurement.

- Source of uncertainty in the positron constraints:

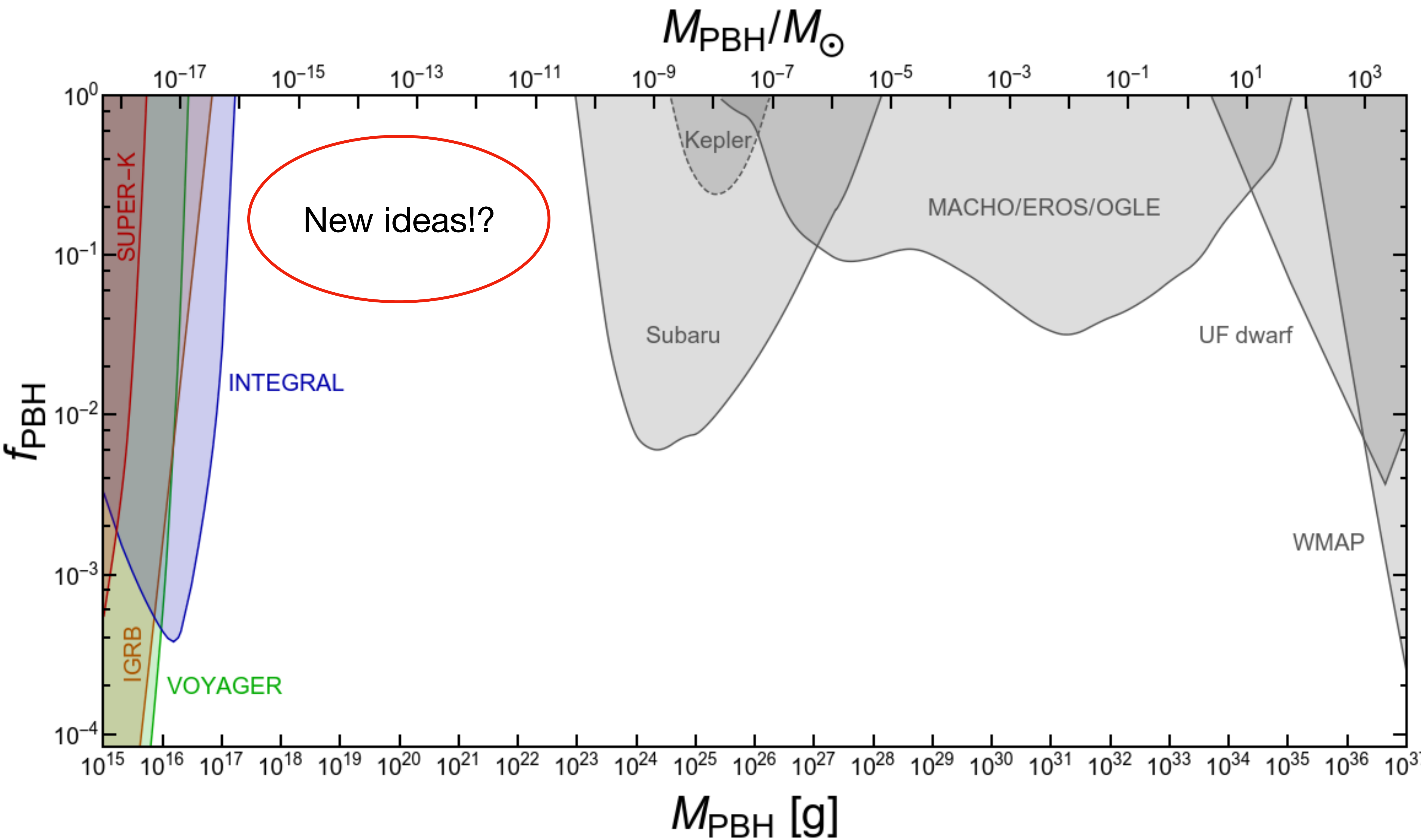
- Unknown propagation distance of positrons in the Galactic centre.
- Choice of DM density profile.

- All positrons within 1.5 kpc and 80% positrons within 3.5 kpc of the Galactic centre is taken in order to account for the positron propagation uncertainty.

- NFW and Isothermal DM profile is taken to show the variation of our constraints.



Variation in the upper limit on dark matter fraction of PBH due to astrophysical uncertainty



$M_{PBH}/M_\odot$
10^{-17}
10^{-15}
10^{-13}
10^{-11}
10^{-9}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
f_{PBH}
SUPER-K
INTEGRAL
IGRB
VOYAGER
New ideas!?
Kepler
MACHO/EROS/OGLE
Subaru
UF dwarf
WMAP
10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22} 10^{23} 10^{24} 10^{25} 10^{26} 10^{27} 10^{28} 10^{29} 10^{30} 10^{31} 10^{32} 10^{33} 10^{34} 10^{35} 10^{36} 10^{37}
M_{PBH} [g]

Conclusions

- Our results are maximally conservative, robust, and model independent.
- It chops a region of the mass window where PBHs can form entire fraction of dark matter.

- It can be improved a lot by doing improved modelling of the galactic positrons.
- Near future loading of Gadolinium in Super-Kamiokande and Hyper-Kamiokande will enhance their capability to search for the DSNB and increase the prospect of PBH discovery via neutrinos.

- Still enough mass window remains open for PBHs to be DM. Many more ideas to come.

Thanks!