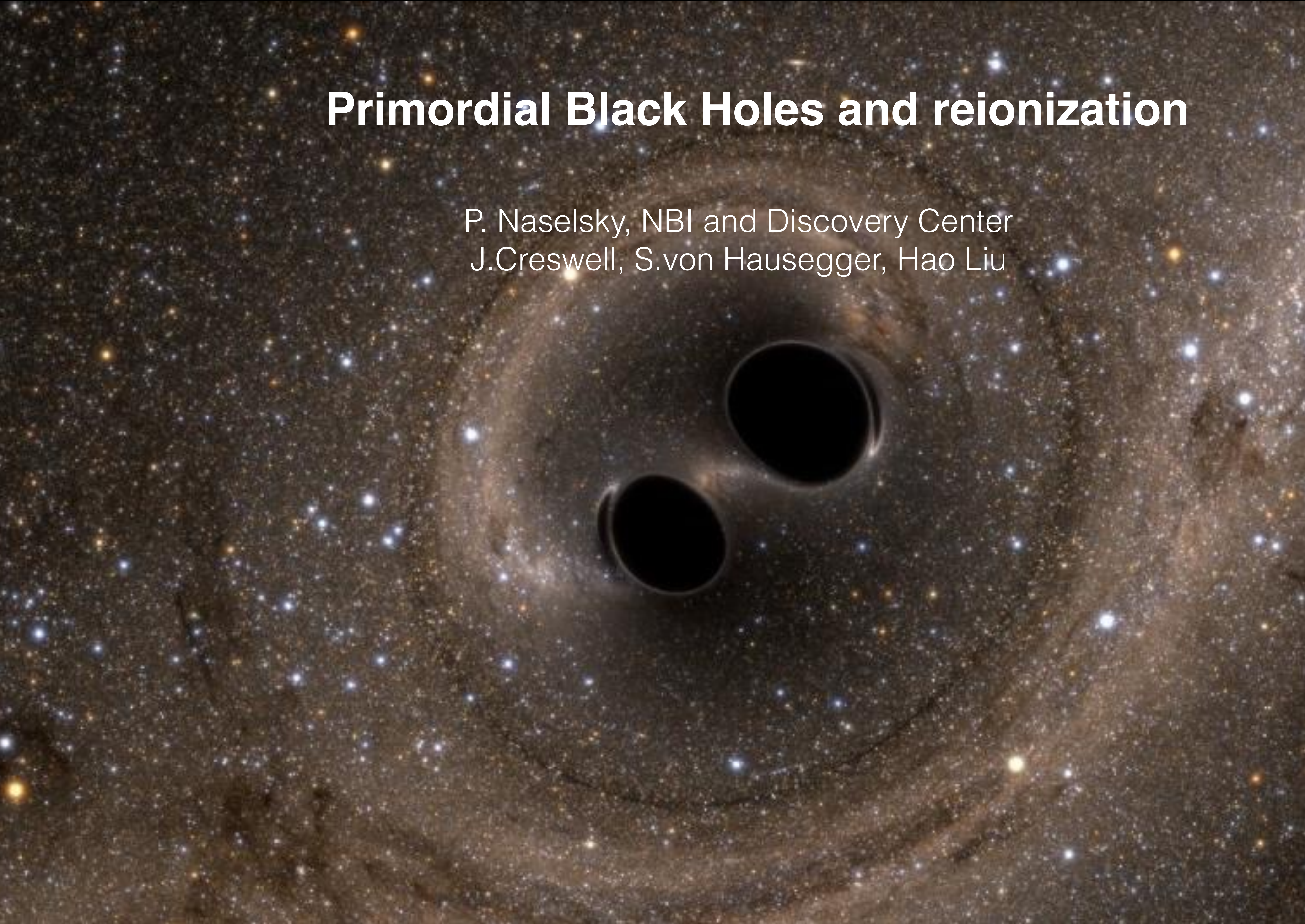
# Primordial Black Holes and reionization

P. Naselsky, NBI and Discovery Center
J.Creswell, S.von Hausegger, Hao Liu



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*1. "Cosmological consequences of PBH's evaporation" , 1979* ,**PHD**

**Y.Zeldovich**

**I.Novikov**

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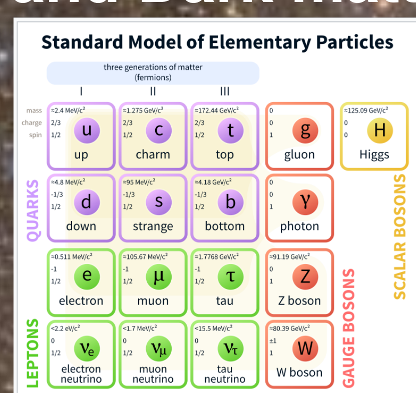


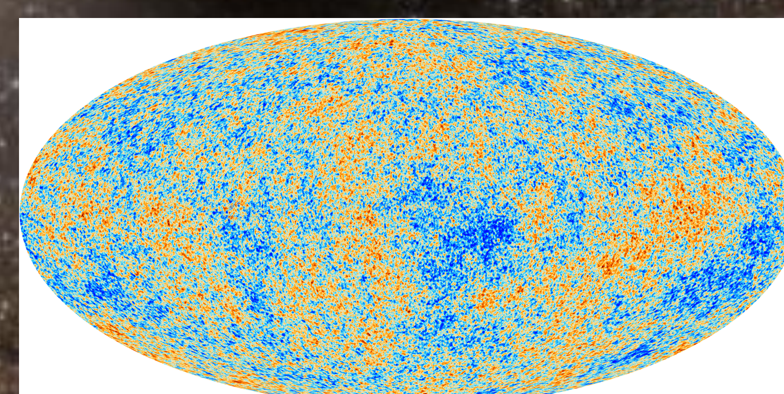

$$\tau_{re} \simeq 0.05 - 0.08$$

**PBH's ?**

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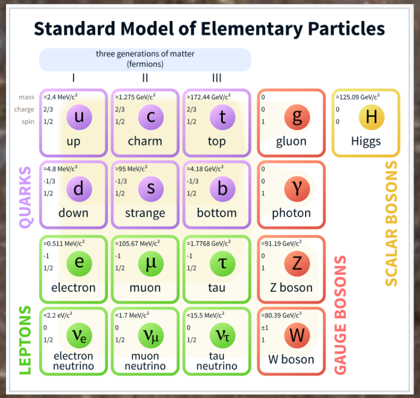
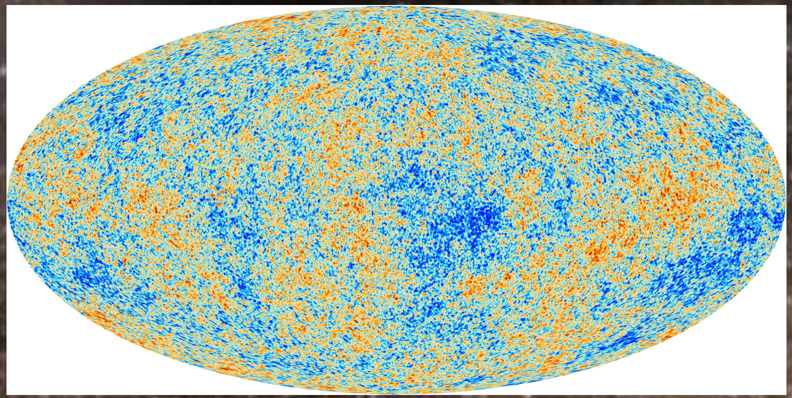
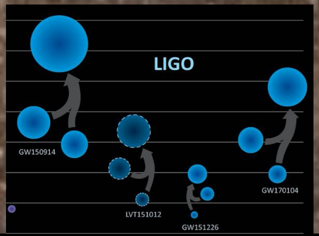


$$\tau_{re} \simeq 0.05 - 0.08$$

**PBH's ?**

3. LIGO events




$$M_{pbh} \sim 10 - 30\, M_{\odot}$$

# Primordial Black Holes and re-ionisation

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## Outline

* PBH and LIGO GW events

*Observational constrains

* Scalar perturbations and PBH formation

*PBH and re-ionisation of the cosmic plasma

**Can PBH's escape from accretion of the baryons ?**

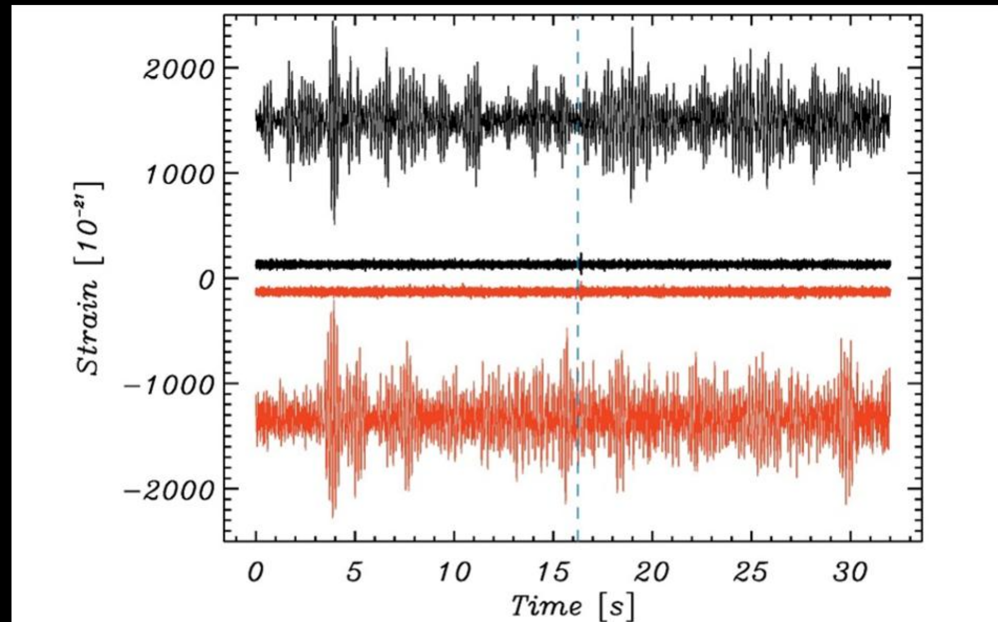
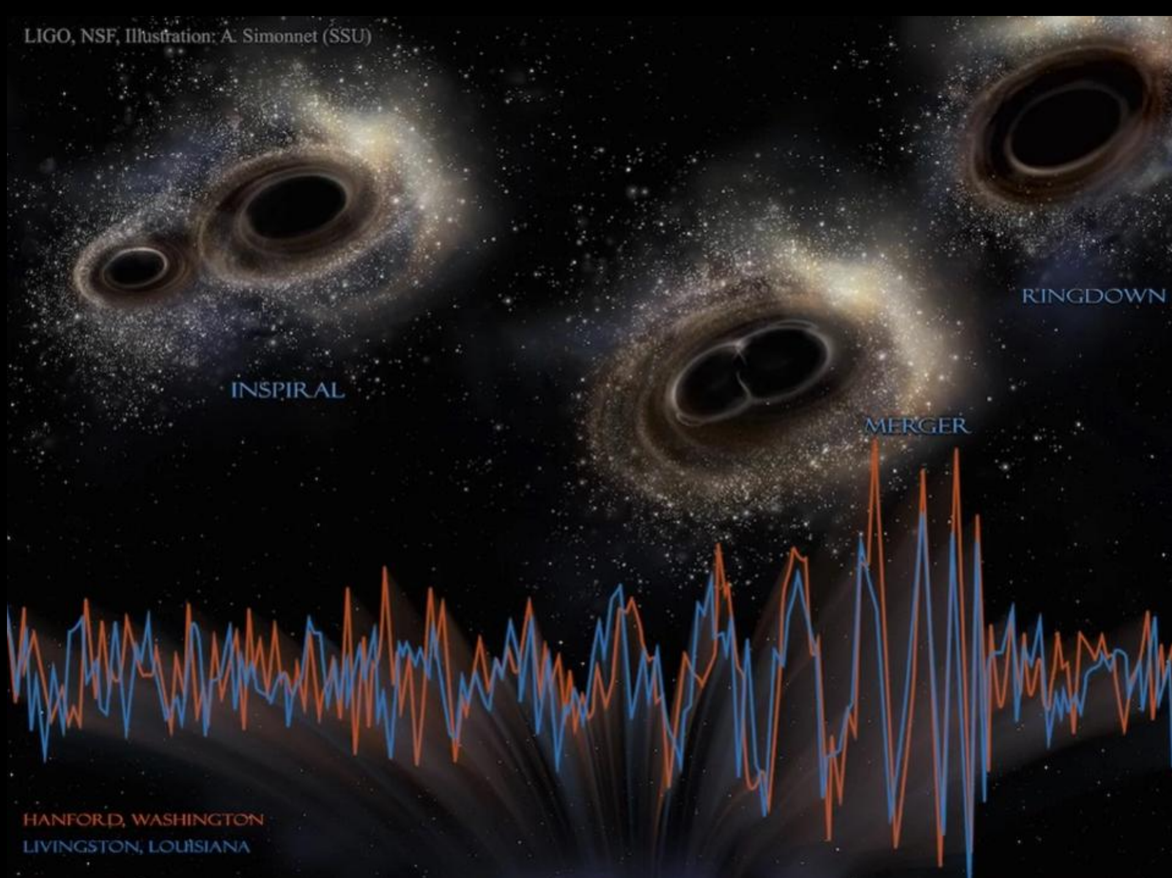
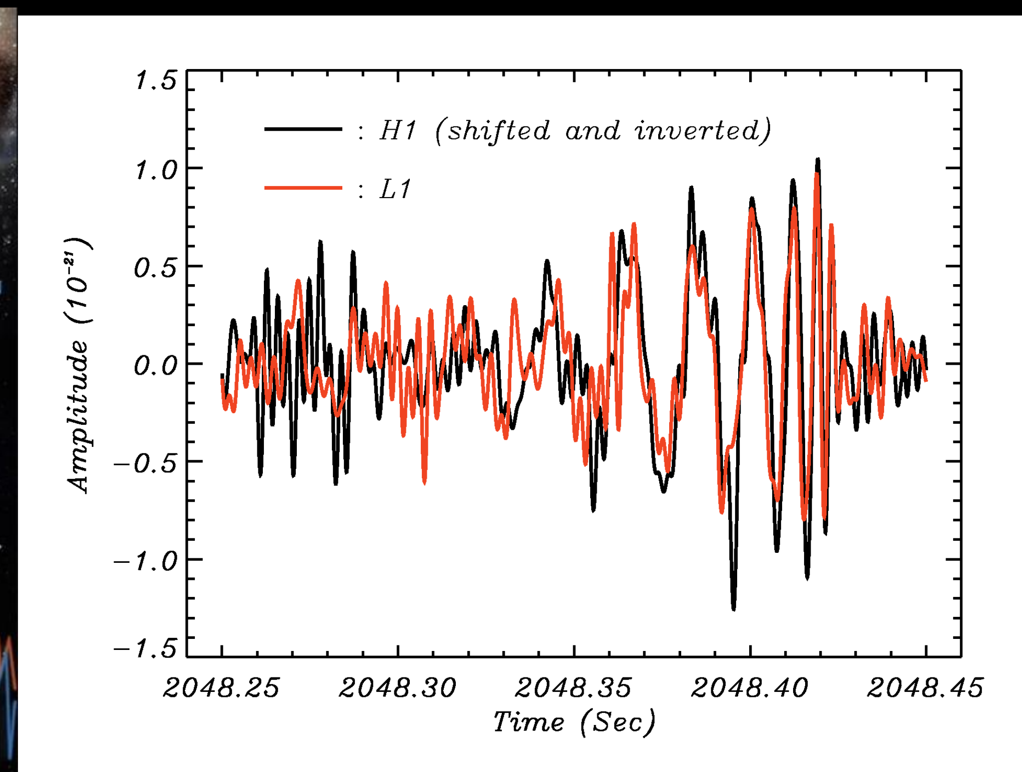
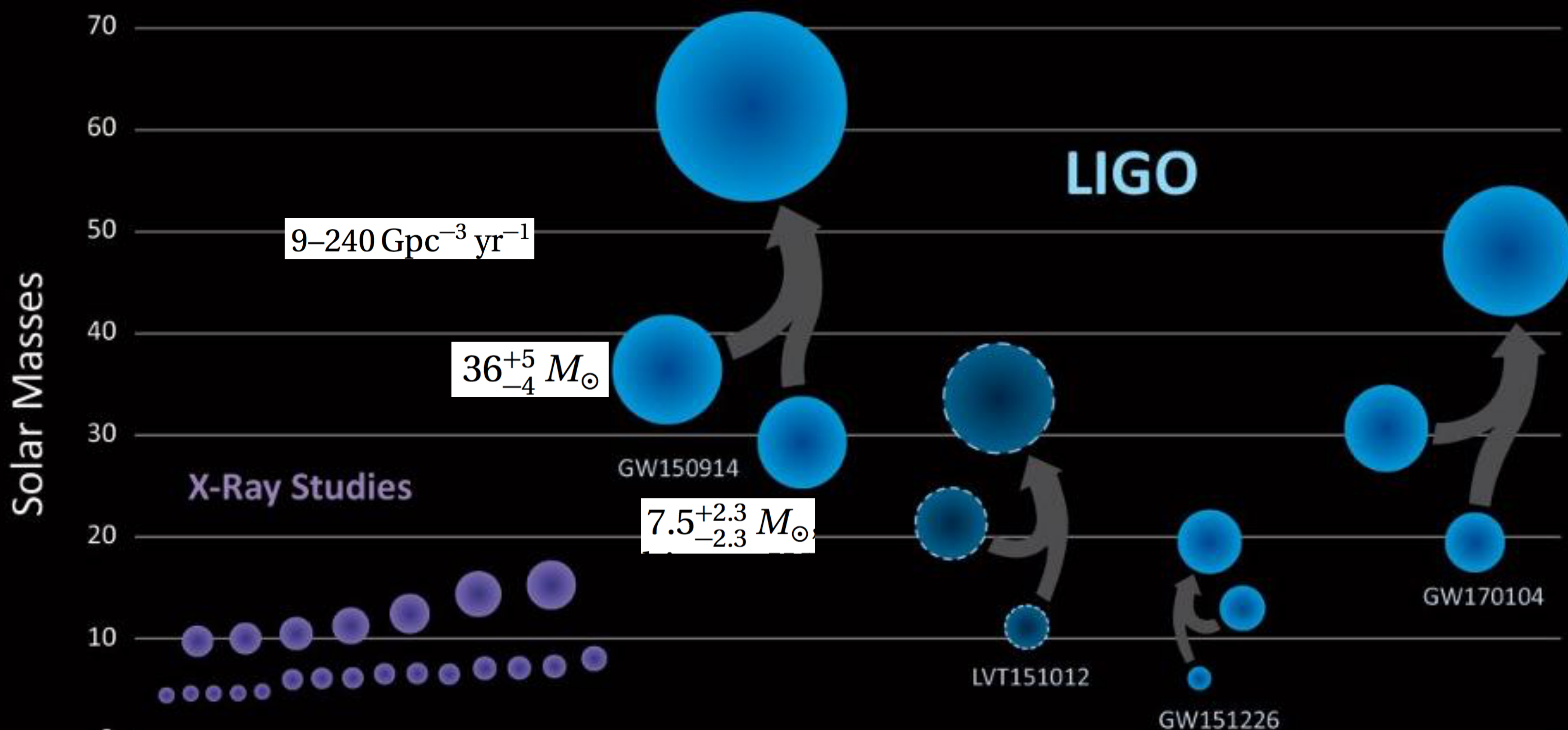



**Figure 1**. Comparison of the LIGO 32 s data (black for Hanford and red for Livingston). The top and bottom records are raw data, the middle records have been band-passed and cleaned (as described in the text), then amplified by a factor of 100 for visibility. All four curves have been manually shifted vertically for ease of comparison.

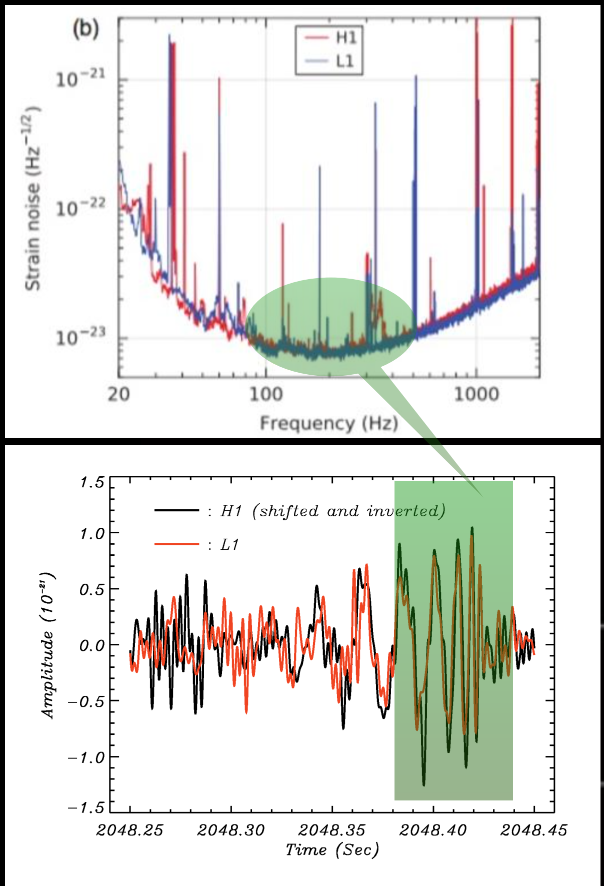


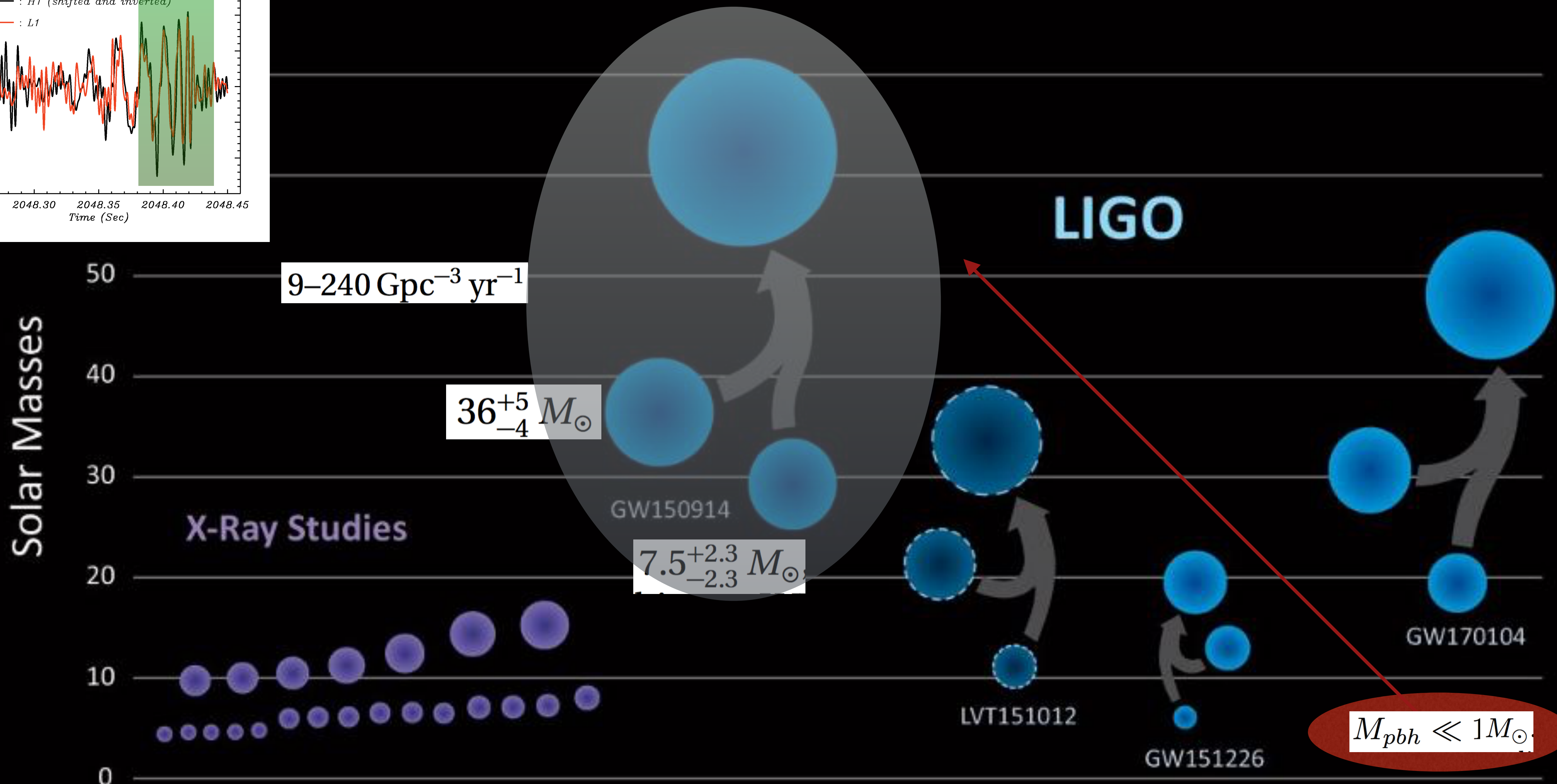



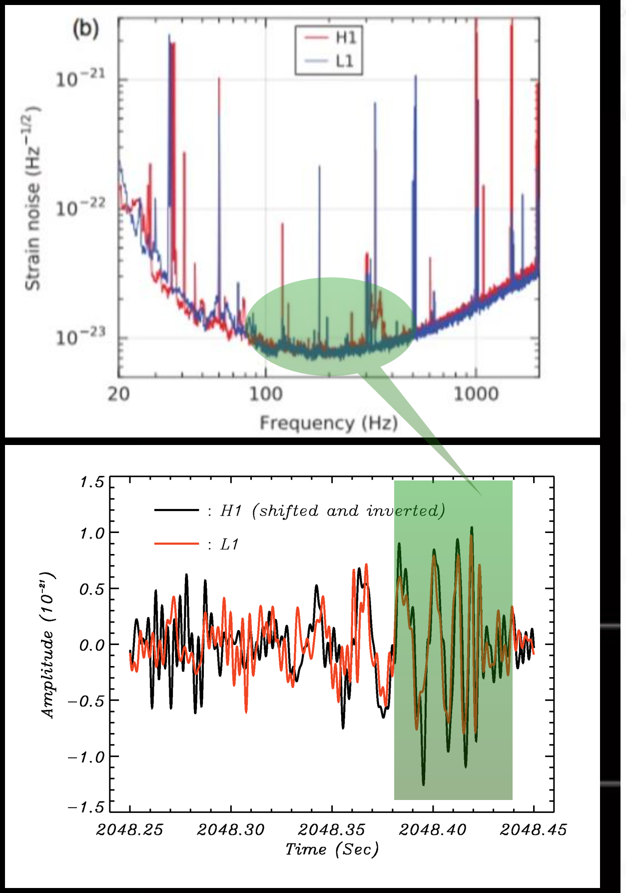
# Black Holes of Known Mass

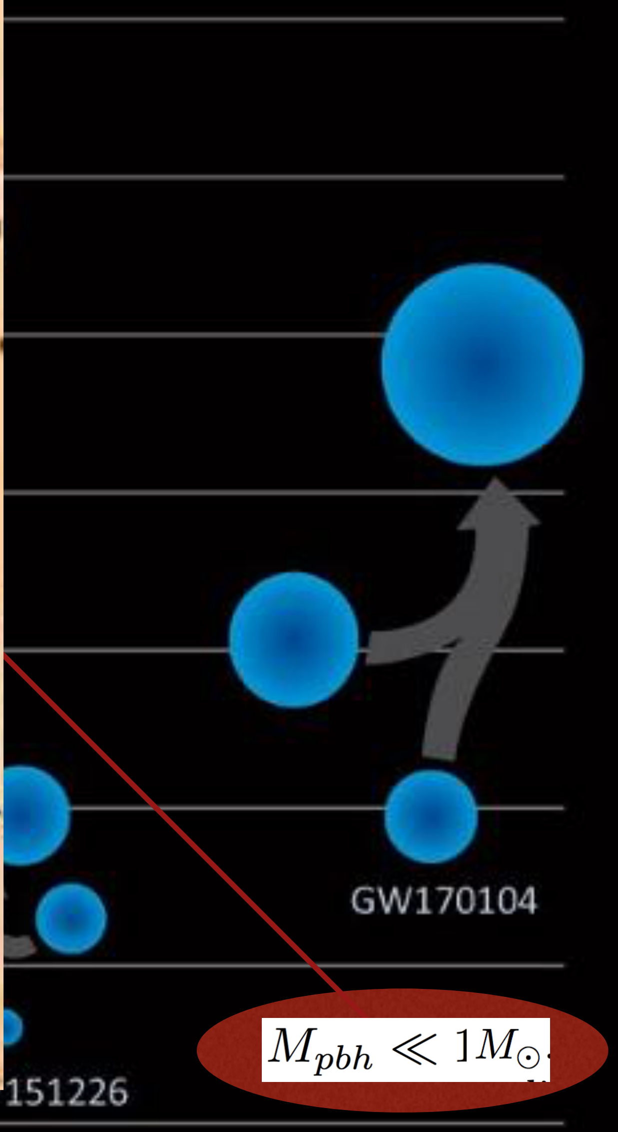


# Black Holes of Known Mass

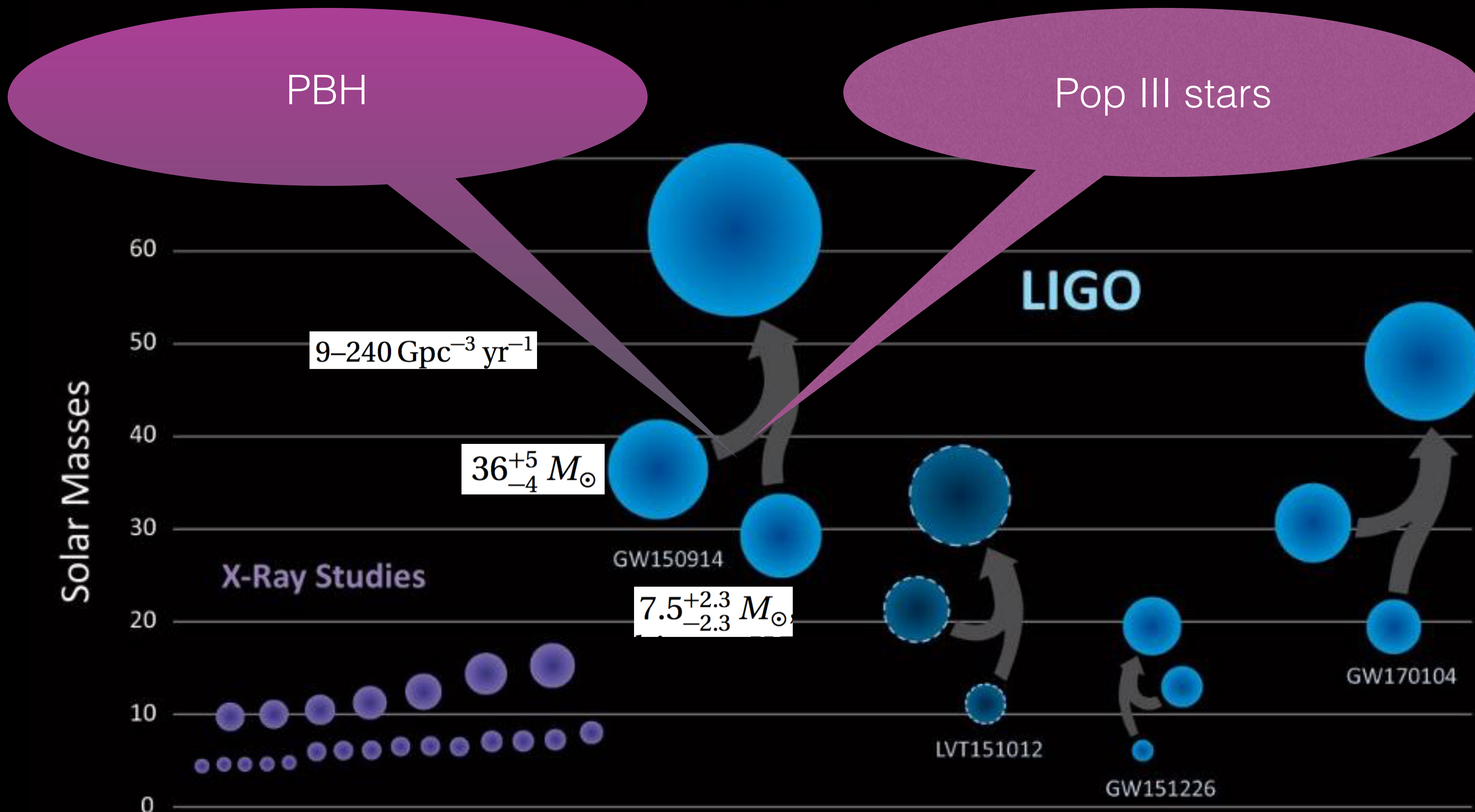


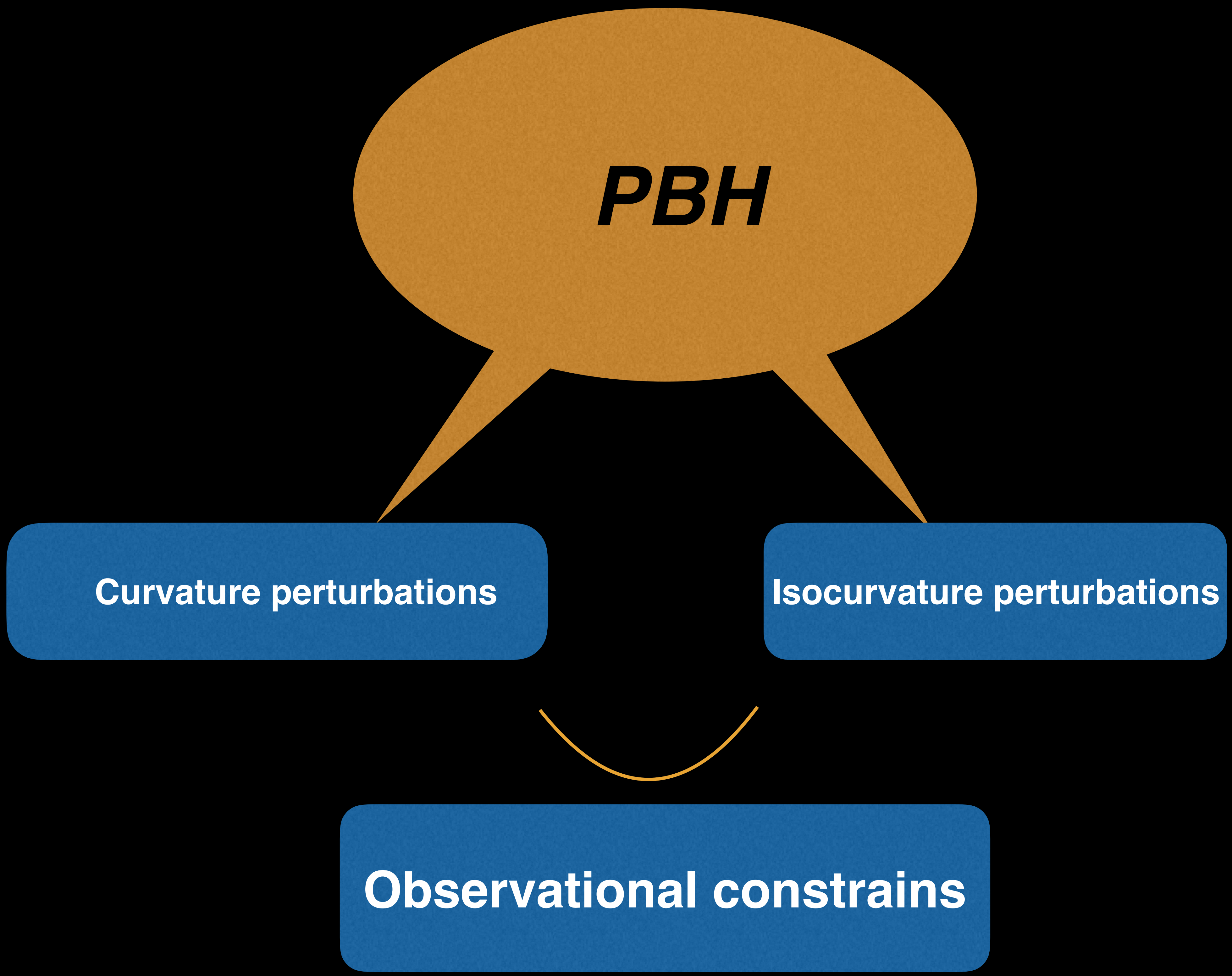



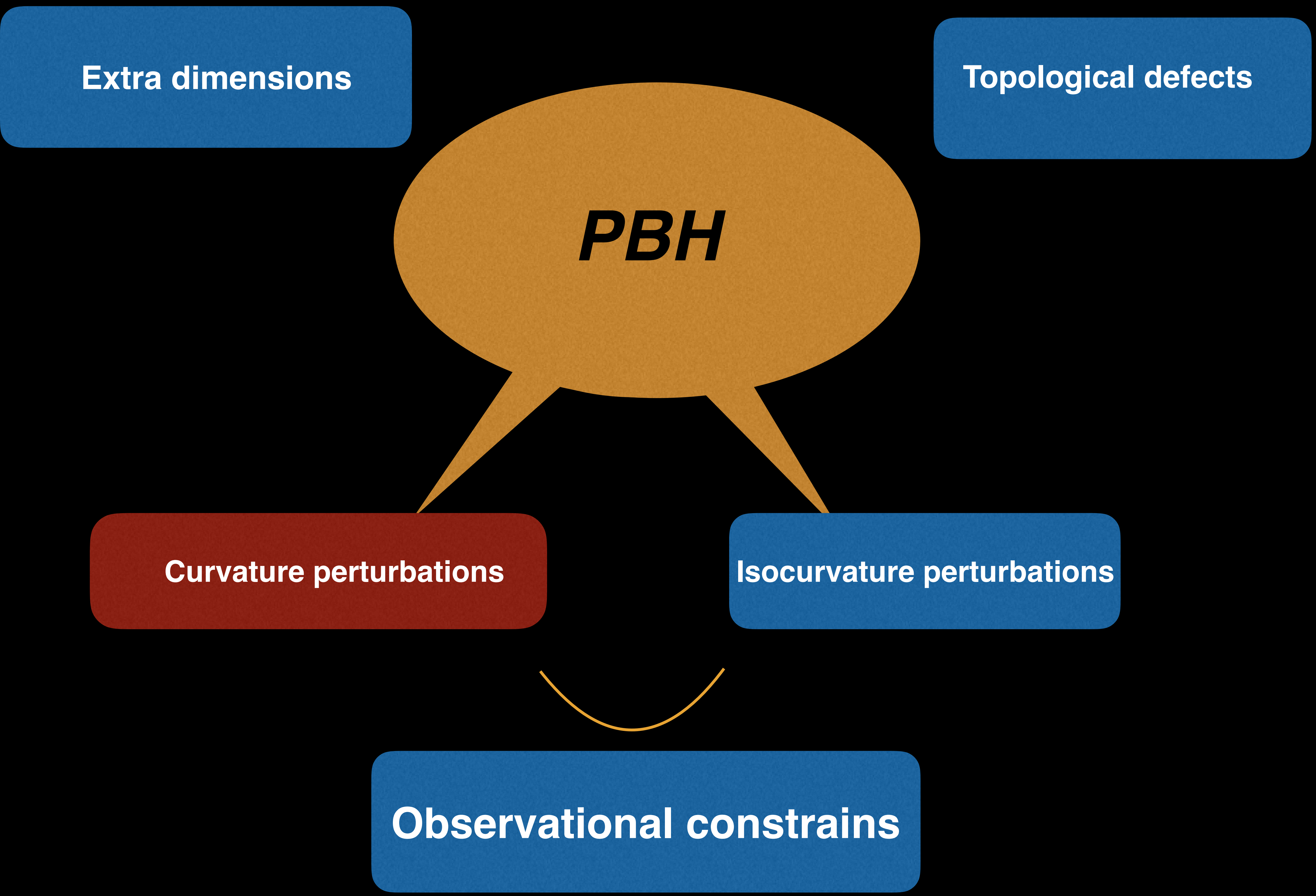

(b)
H1
L1
Strain noise (Hz$^{-1/2}$)
Frequency (Hz)
: H1 (shifted and inverted)
: L1
Amplitude ($10^{-21}$)
Time (Sec)


Solar Masses
X-Ray
GW170104
GW151226
$M_{pbh} \ll 1 M_\odot$

# Black Holes of Known Mass

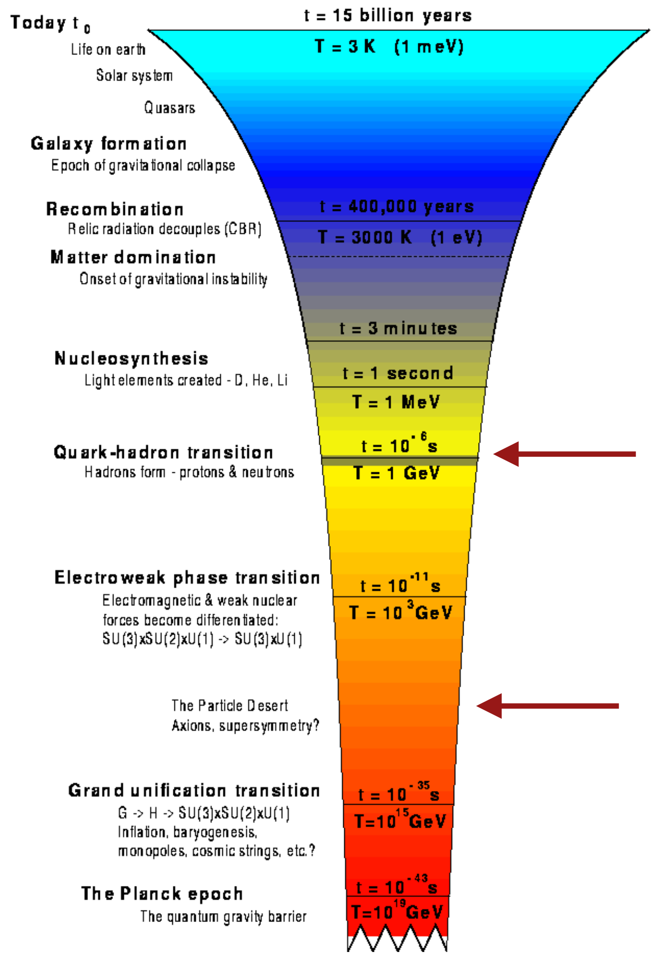



PBH
Curvature perturbations
Isocurvature perturbations
Observational constrains



Extra dimensions
Topological defects
PBH
Curvature perturbations
Isocurvature perturbations
Observational constrains

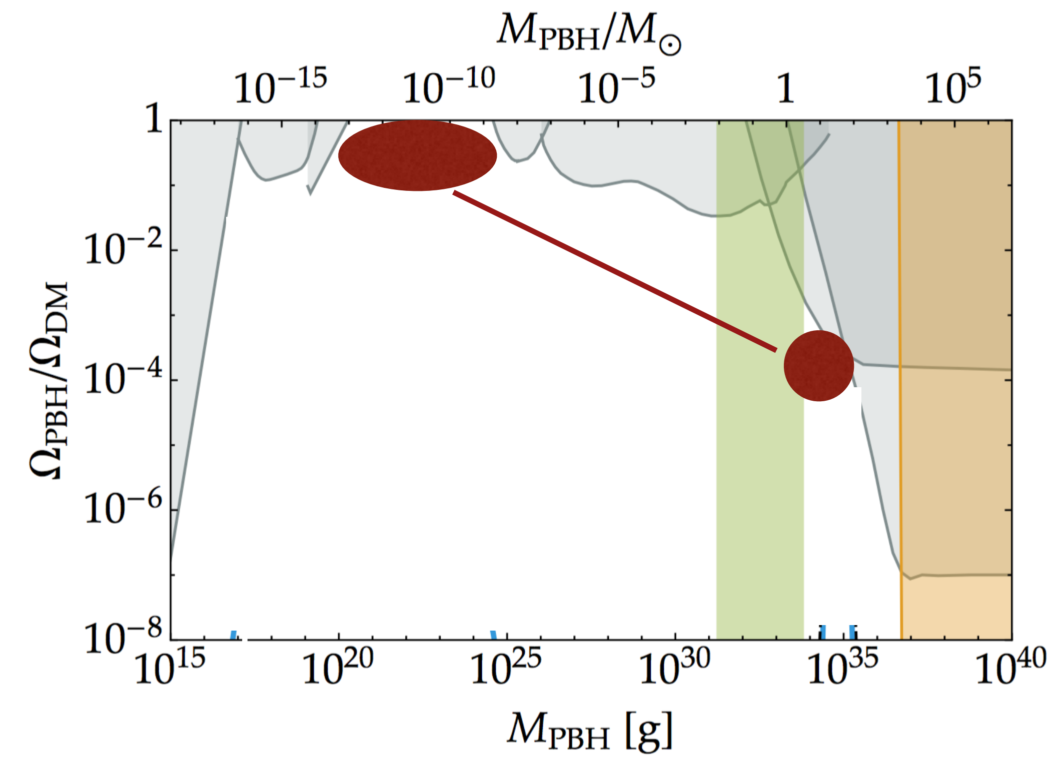
# Random Gaussian curvature perturbations




$$t_{pbh} \sim \frac{M}{M_{pl}} t_{pl}$$

$$M_{pbh} \sim 10\, M_{\odot}$$

$$M_{pbh} \sim 10^{20} g$$




**gray-shaded regions:** extragalactic gamma rays from Hawking radiation [49], femtolensing of known gamma ray bursts [50], white dwarfs existing in our local galaxy [51], Kepler micro/millilensing [52], EROS/MACHO microlensing [53], and accretion constraints from CMB [54]

**green-shaded region:** the current $\mu$ distortion constraint $|\mu| < 9 \times 10^{-5}$

$$\frac{\Omega_{\rm PBH}(M)}{\Omega_c} \simeq \frac{\rho_{\rm PBH}}{\rho_m}\bigg|_{\rm eq}\frac{\Omega_m}{\Omega_c} = \left(\frac{T_M}{T_{\rm eq}}\frac{\Omega_m}{\Omega_c}\right)\gamma\beta(M)$$

$$\simeq \left(\frac{\beta(M)}{1.84\times10^{-8}}\right)\left(\frac{\gamma}{0.2}\right)^{\frac{3}{2}}\left(\frac{10.75}{g_*(T_M)}\right)^{\frac{1}{4}}\left(\frac{0.12}{\Omega_c h^2}\right)\left(\frac{M}{M_\odot}\right)^{-\frac{1}{2}},$$

$$\beta(M) = \int_{\delta_c} \frac{{\rm d}\delta}{\sqrt{2\pi\sigma^2(M)}}\, e^{-\frac{\delta^2}{2\sigma^2(M)}} \simeq \frac{1}{\sqrt{2\pi}}\frac{1}{\delta_c/\sigma(M)}\, e^{-\frac{\delta_c^2}{2\sigma^2(M)}}.$$

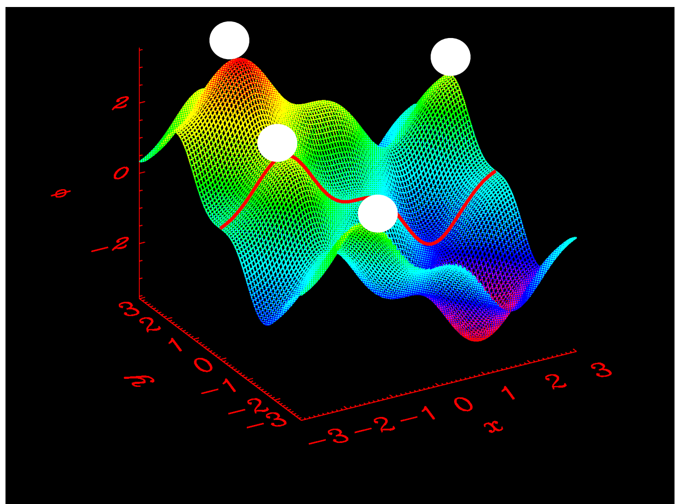
$$\sigma^2(M(k)) = \int {\rm d}\ln q\, W^2(qk^{-1})\frac{16}{81}(qk^{-1})^4\mathscr{P}_\zeta(q).$$

**Inflationary primordial black holes for the LIGO gravitational wave events and pulsar timing array experiments**


Keisuke Inomata,[1,2] Masahiro Kawasaki,[1,2] Kyohei Mukaida,[2] Yuichiro Tada,[1,2] and Tsutomu T. Yanagida[2]

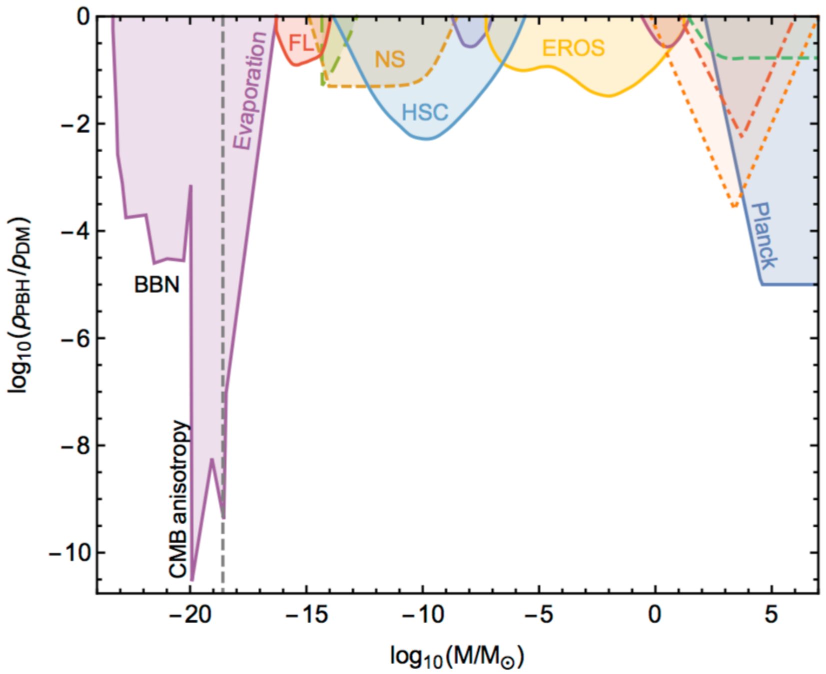


**ArXive:1611.06130**

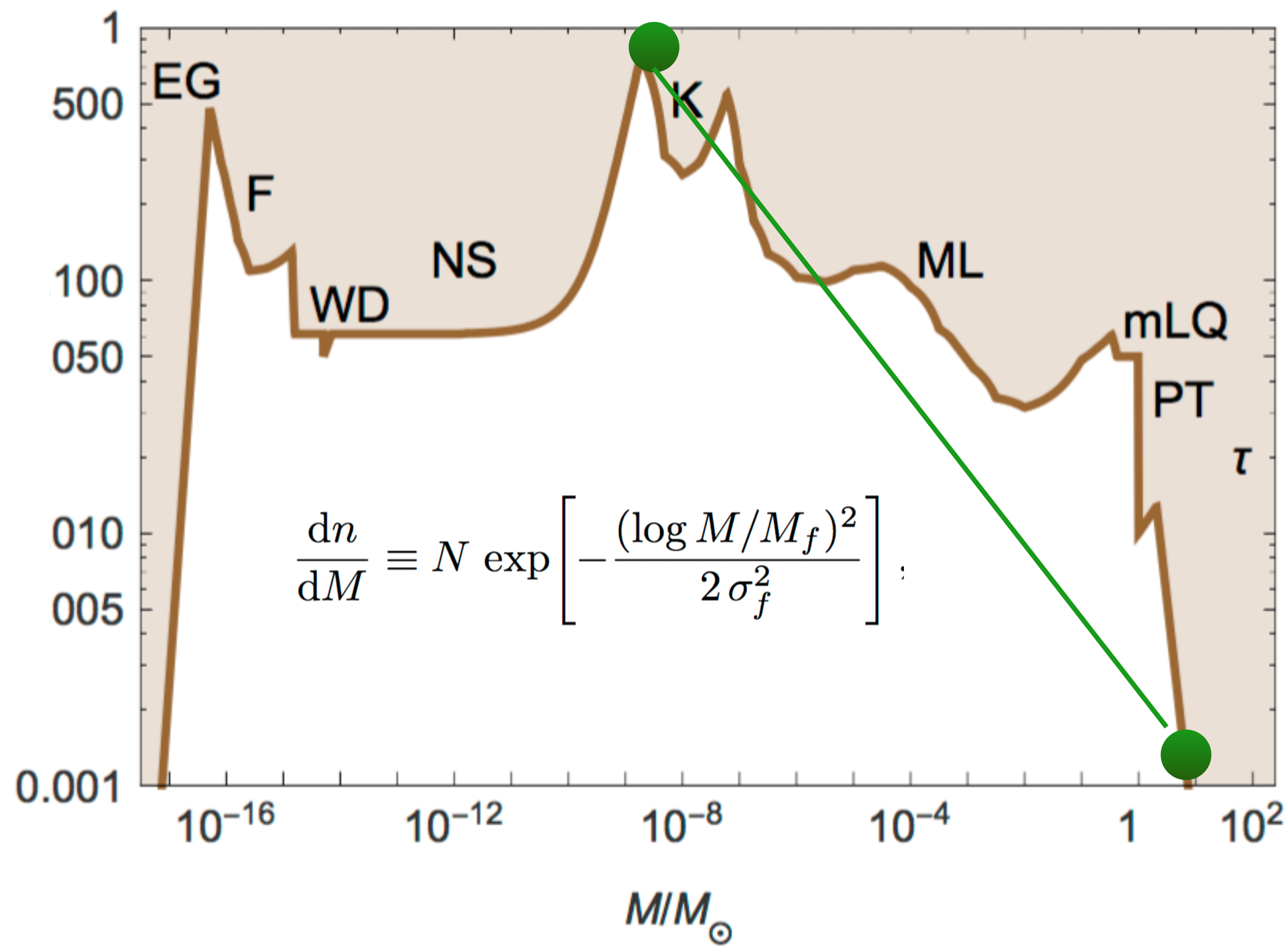



# Constraints on Primordial Black Holes with Extended Mass Functions

Florian Kühnel[1, 2, *] and Katherine Freese[3, 1, †]




B.J.Carr, T. & Tenkanen V. Vaskonen, arXiv:1706.03746

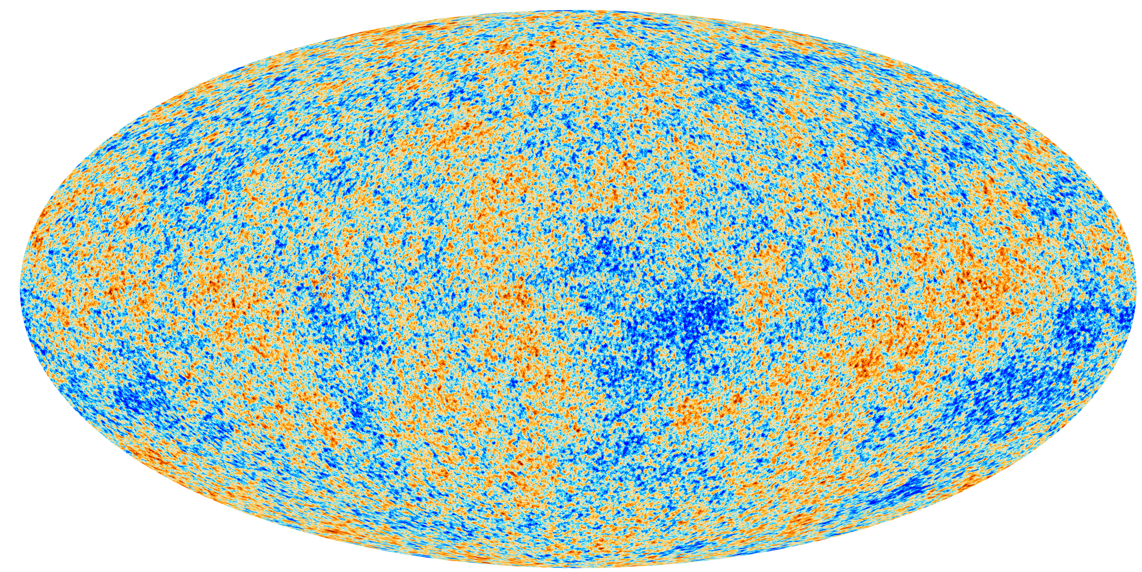


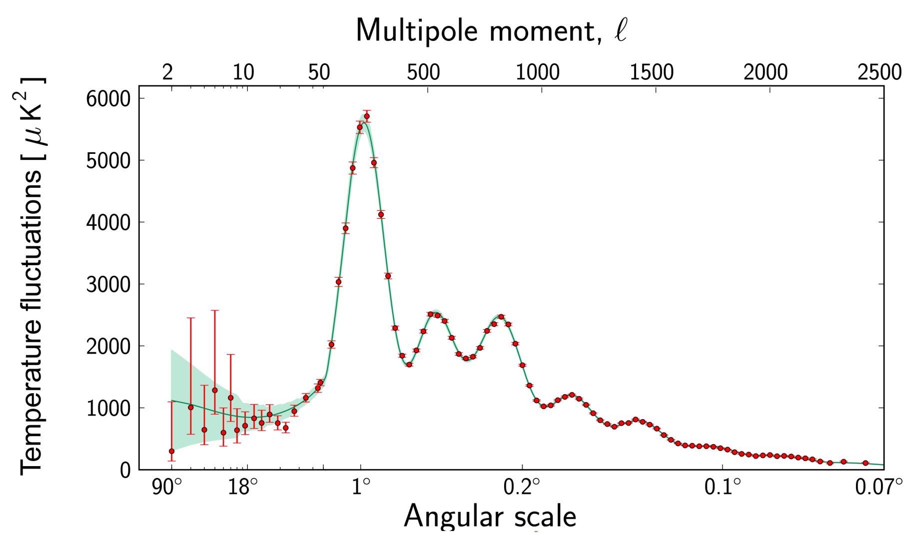

We confirm the results of Ref. [17] that there still is a window in the mass range $10^{-10}\,M_\odot$ to $10^{-8}\,M_\odot$ which can accommodate for 100% PBH dark matter. Apart from the possibility of Planck-mass relics, to pose new constraints in the mentioned mass window seems to be crucial for providing an answer to the question whether primordial black holes can constitute the entirety of the dark matter.

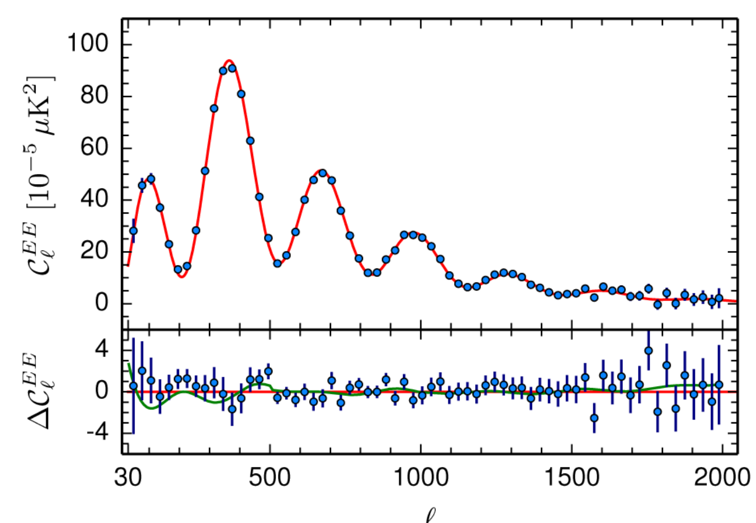
FIG. 1: Summary of previous literature for the idealised case in which the entire PBH dark matter consists of PBHs of a single mass $M$ (mono-chromatic mass function): Constraint "curtain" on the dark-matter fraction $f \equiv \rho_{\rm PBH}/\rho_{\rm DM}$ for a variety of effects associated with PBHs of mass $M$ in units of solar mass $M_\odot$. Only strongest constraints are included. We show constraints from extragalactic $\gamma$-rays from evaporation (EG) [31], femtolensing of $\gamma$-ray bursts (F) [32], white-dwarf explosions (WD) [33], neutron-star capture (NS) [28], Kepler microlensing of stars (K) [11], MACHO/EROS/OGLE mi-

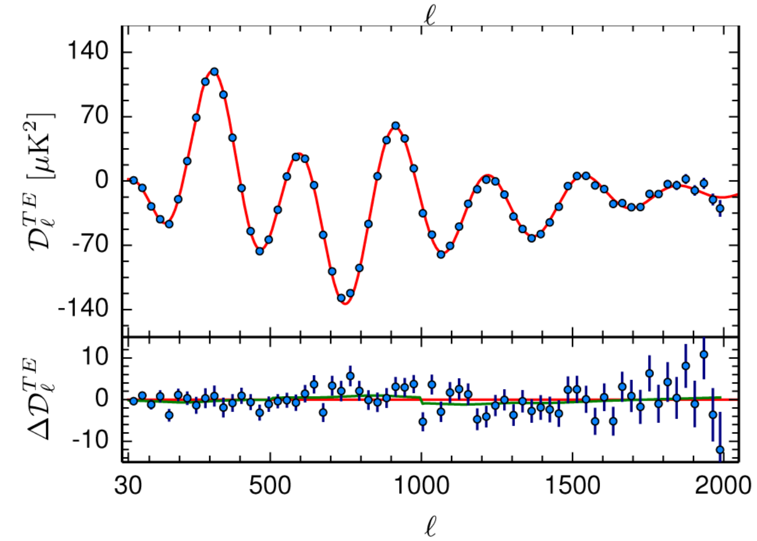
# PBH and Inflation

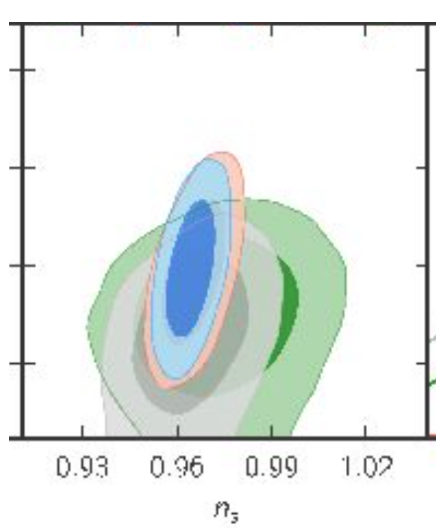
$$\beta_0(M) \approx \delta(M) \exp\left(-\frac{\gamma^2}{2\delta^2(M)}\right)$$

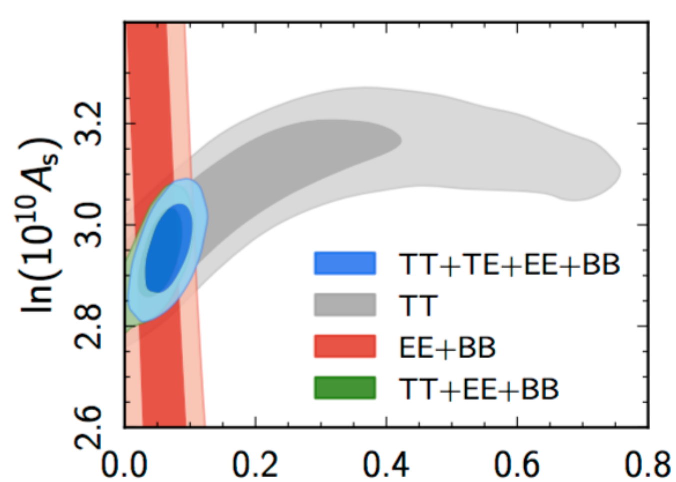




# PBH and Inflation

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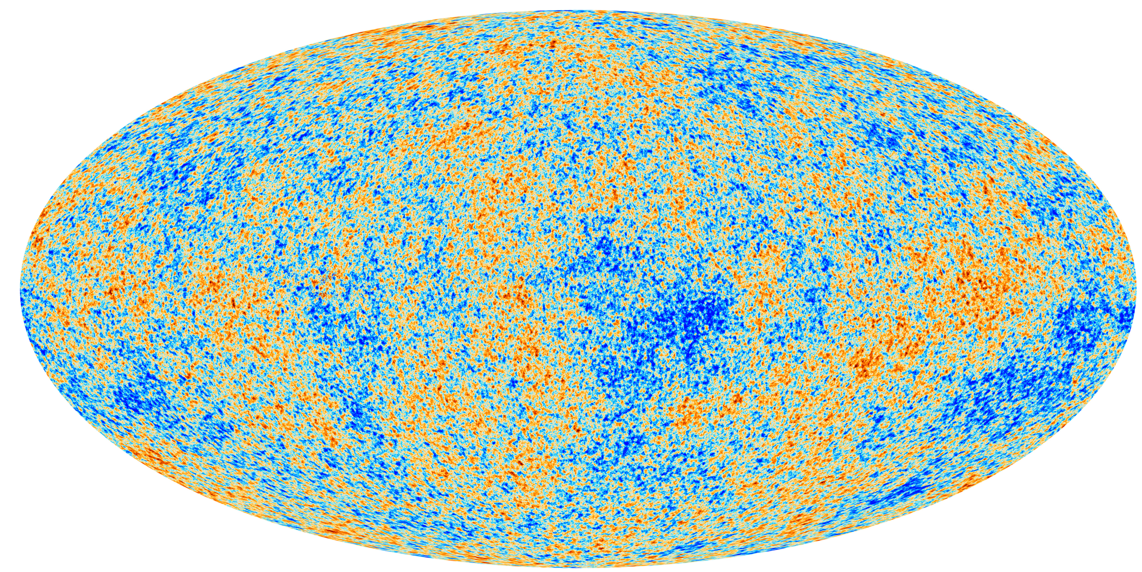
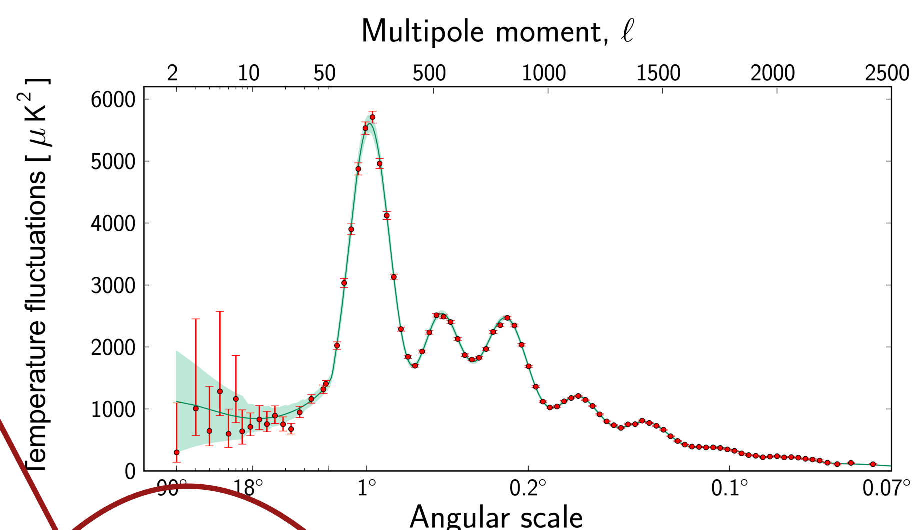
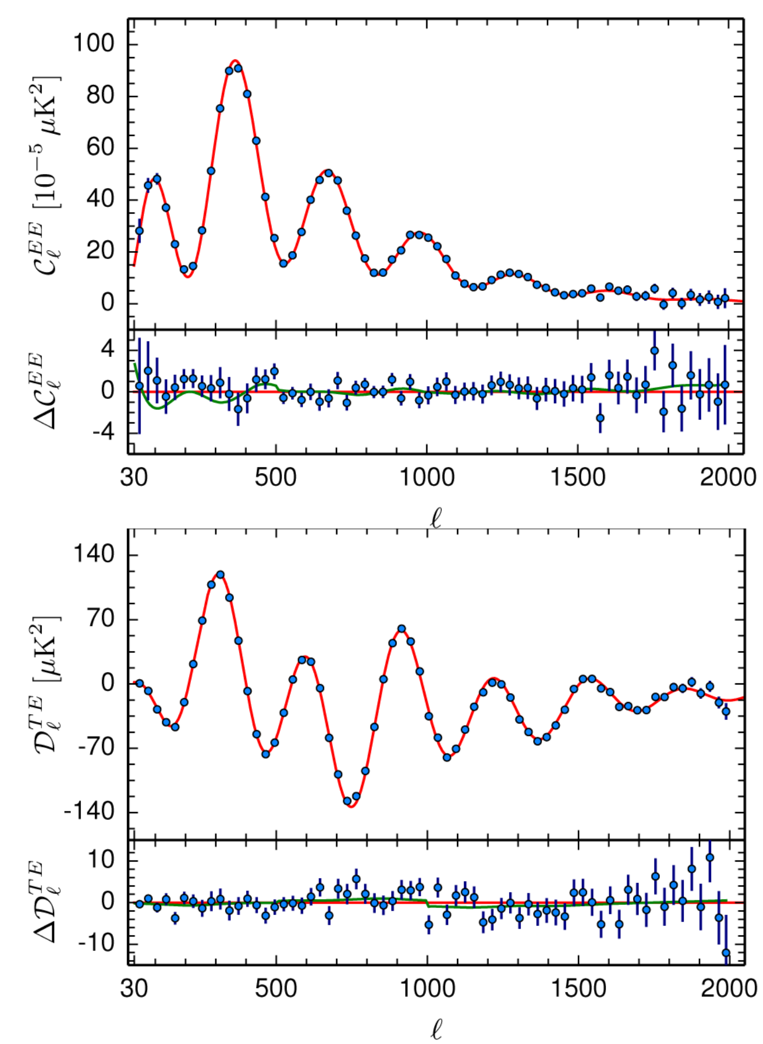


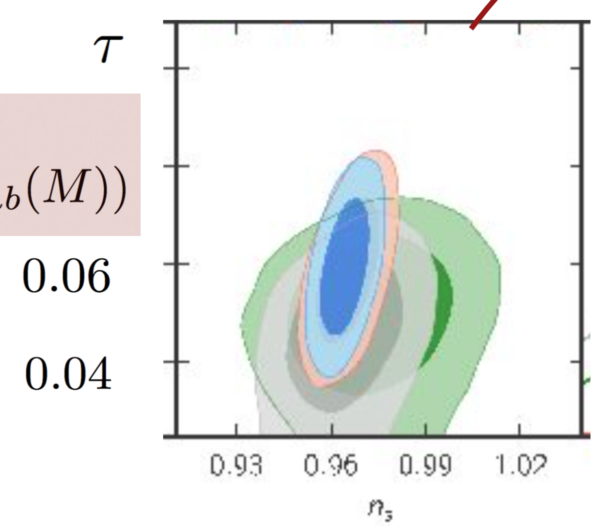
$$\beta \ll 10^{-10^8}$$

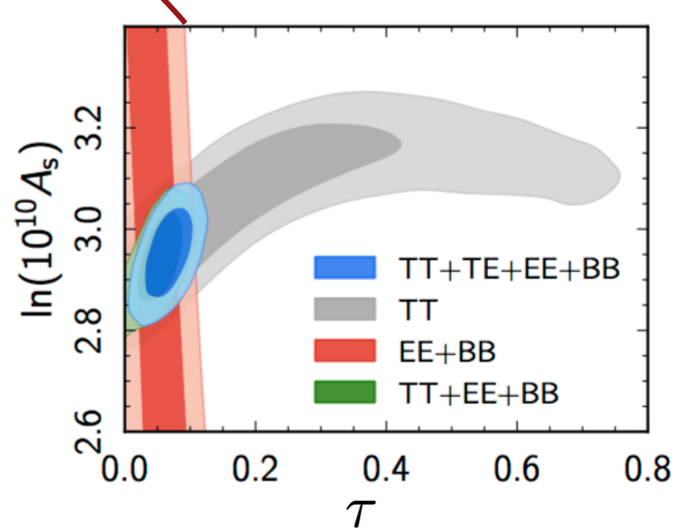
$$\beta \simeq 10^{-7}$$




$$\delta(M) \simeq 0.1(\sim 10^4 \delta_{cmb}(M))$$

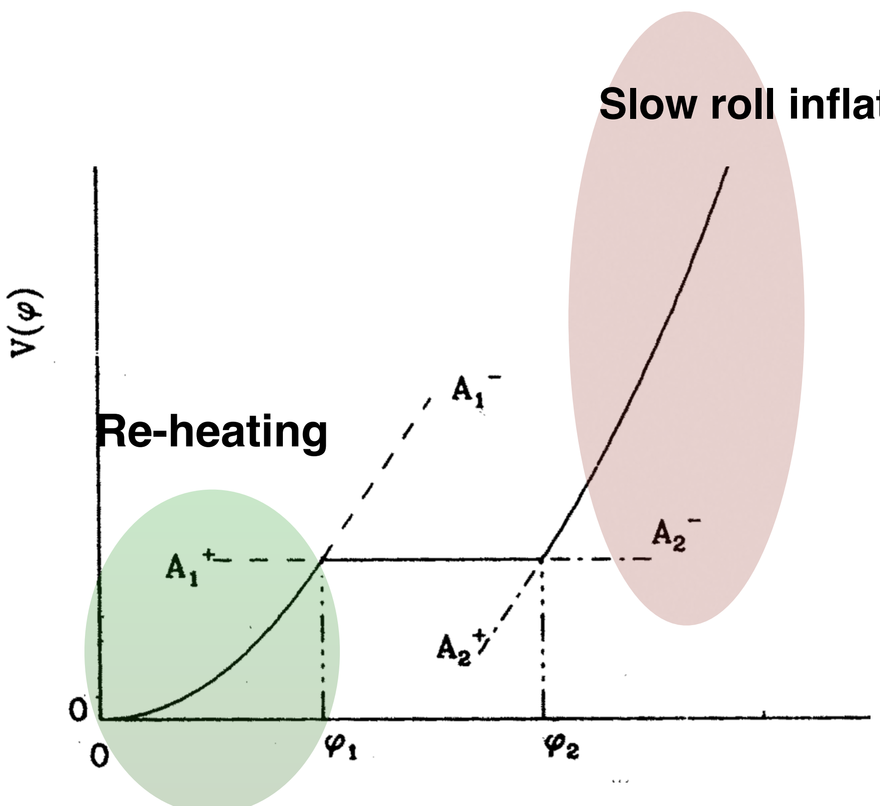


# Peculiarities of the scalar field potential and PBH

PHYSICAL REVIEW D VOLUME 50, NUMBER 12 15 DECEMBER 1994

Inflation and primordial black holes as dark matter




$$P(k) = A^2 k D(k),$$

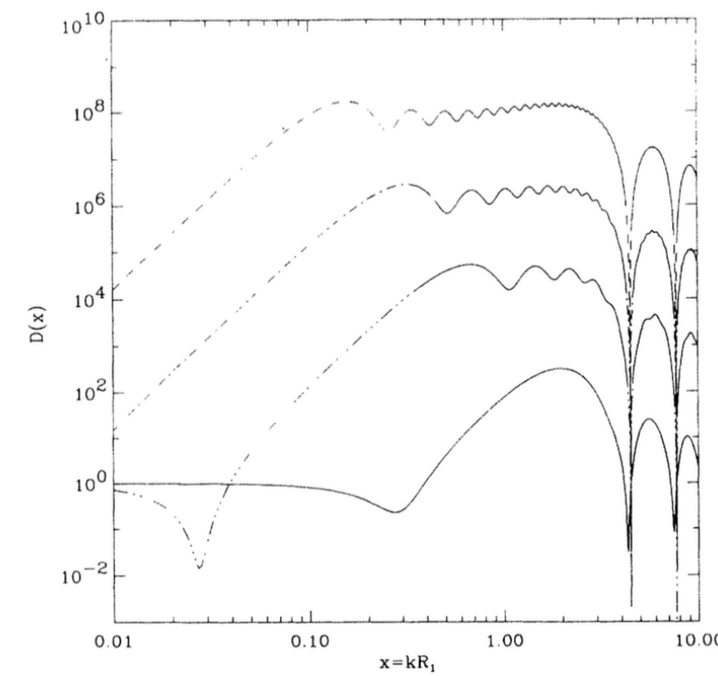
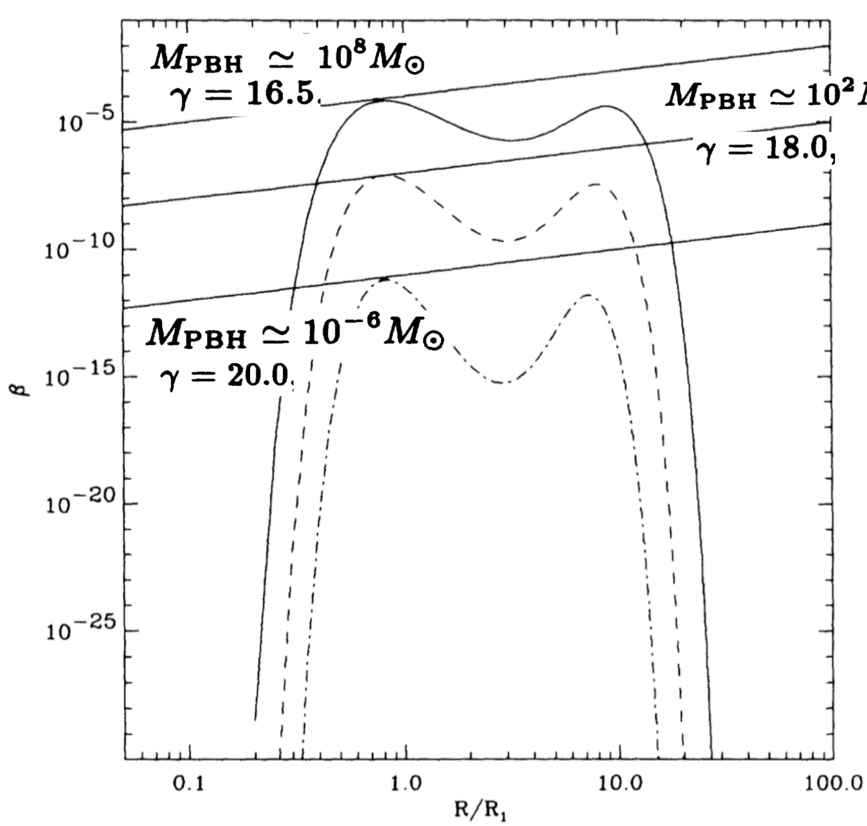



FIG. 2. Result of the computations of $D(x)$, $x = kR_1$. The dashed, dashed-dotted, dashed-triple-dotted, and solid lines correspond to $\gamma = 20$, $\gamma = 10$, $\gamma = 5$, and $\gamma = 2$, respectively.




## Running spectral index

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1 + \frac{1}{2}\, dn_s/d\ln k \ln(k/k_*) + \frac{1}{6}\, d^2 n_s/d\ln k^2 (\ln(k/k_*))^2 + \ldots}$$

$$\eta_V = \frac{M_{pl}^2 V_{\phi\phi}}{V}\,. \quad \epsilon_V = \frac{M_{pl}^2 V_\phi^2}{2V^2}\,,$$

$$n_s - 1 \approx 2\eta_V - 6\epsilon_V,$$

$$n_t \approx -2\epsilon_V,$$

$$dn_s/d\ln k \approx +16\epsilon_V\eta_V - 24\epsilon_V^2 - 2\xi_V^2,$$

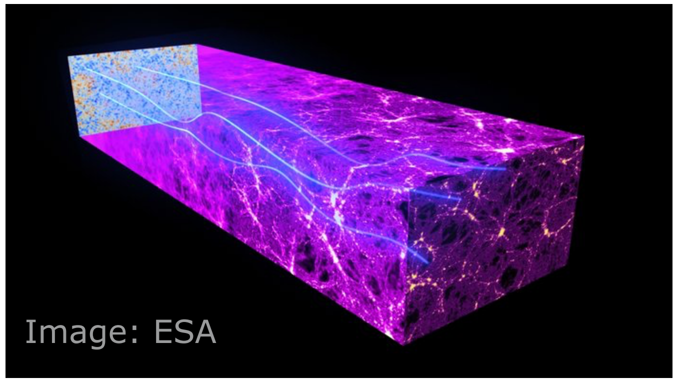
$$dn_t/d\ln k \approx +4\epsilon_V\eta_V - 8\epsilon_V^2,$$

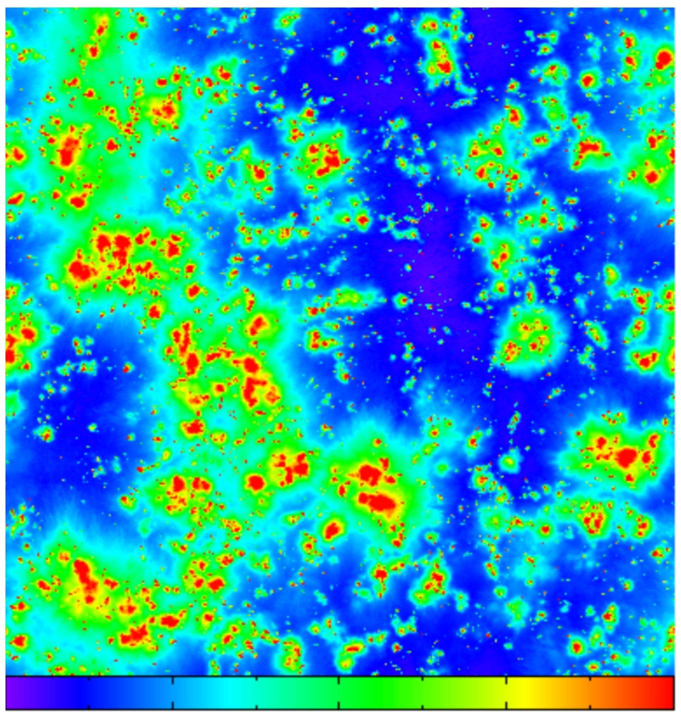
$$d^2 n_s/d\ln k^2 \approx -192\epsilon_V^3 + 192\epsilon_V^2\eta_V - 32\epsilon_V\eta_V^2 - 24\epsilon_V\xi_V^2 + 2\eta_V\xi_V^2 + 2\varpi_V^3,$$

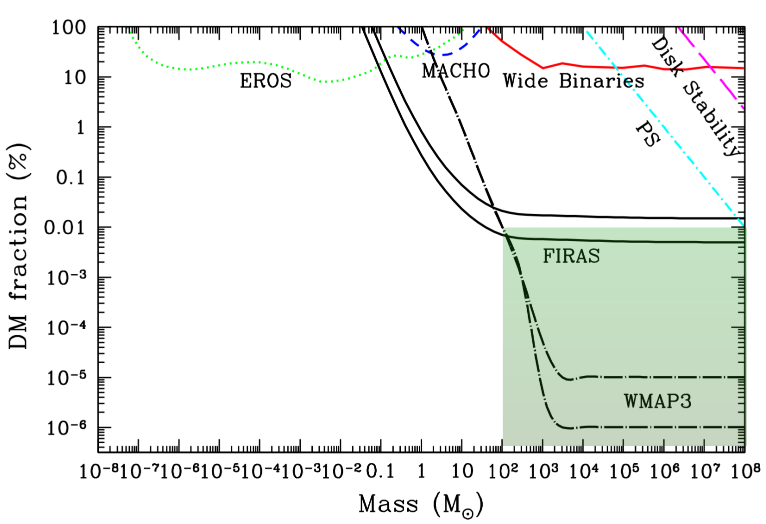
$$V_{\phi\phi} > \frac{3}{2}\frac{V_\phi^2}{V}$$

$$V(\phi) \propto \lambda\phi^{-q},\ q > 2$$

# Ionisation history of the cosmic plasma with PBH






EFFECT OF PRIMORDIAL BLACK HOLES ON THE COSMIC MICROWAVE BACKGROUND AND COSMOLOGICAL PARAMETER ESTIMATES

MASSIMO RICOTTI
Department of Astronomy, U of Maryland, College Park, MD 20742

JEREMIAH P. OSTRIKER AND KATHERINE J. MACK
Department of Astronomy, Princeton University;
*Draft version February 1, 2008*

$$\dot{M}_{\rm b} = \lambda 4\pi m_H n_{gas} v_{eff} r_B^2, \qquad (1)$$

where $r_B \equiv GMv_{eff}^{-2}$ is the Bondi-Hoyle radius

$$v_{eff} \equiv (v^2 + c_s^2)^{1/2}$$

**The numerical values of the Bondi-Hoyle radius and accretion rate are:**

$$r_B \approx 1.3 \times 10^{-4}\ \mathrm{pc} \left(\frac{M}{1\ M_\odot}\right) \left(\frac{v_{eff}}{5.7\mathrm{km\ s^{-1}}}\right)^{-2}, \qquad (2)$$

$$\dot{M}_{\rm b} \approx 2 \times 10^{12}\ \mathrm{g\ s^{-1}} \lambda n_{gas} \left(\frac{M}{1\ M_\odot}\right)^2 \left(\frac{v_{eff}}{5.7\mathrm{km\ s^{-1}}}\right)^{-3} \qquad (3)$$

$$n_{\rm gas} \simeq 200\ \mathrm{cm}^{-3} \left(\frac{1+z}{1000}\right)^3. \qquad (4)$$

**properties of the baryonic component :**

$$T_{\rm gas} = (2730\ K)\left(\frac{z+1}{1000}\right)\frac{a_{dec}}{(a^{\beta}+a_{dec}^{\beta})^{1/\beta}};\ (5)$$

where $a \equiv 1/(1+z)$ is the scale parameter, $a_{dec}$ is the scale parameter at decoupling where $z_{dec} \simeq 132(\Omega_b h^2/0.022)^{2/5}$ and $\beta = 1.72$. The gas sound speed is $c_s = (5.7\ \mathrm{km\ s^{-1}})(T_{gas}/2730)^{1/2}$. Thus, from equation (5) we have

$$c_S \simeq (5.7kms^{-1})\left(\frac{1+z}{1000}\right)^{\frac{1}{2}},\ for\ z \gg z_{dec} \sim 132,$$

$$c_S \simeq (5.7kms^{-1})\left(\frac{1+z}{1000}\right)^{\frac{1}{2}}\left(\frac{1+z}{z_{dec}}\right)^{\frac{1}{2}},\ for\ z \ll z_{dec}$$

# peculiar velocities

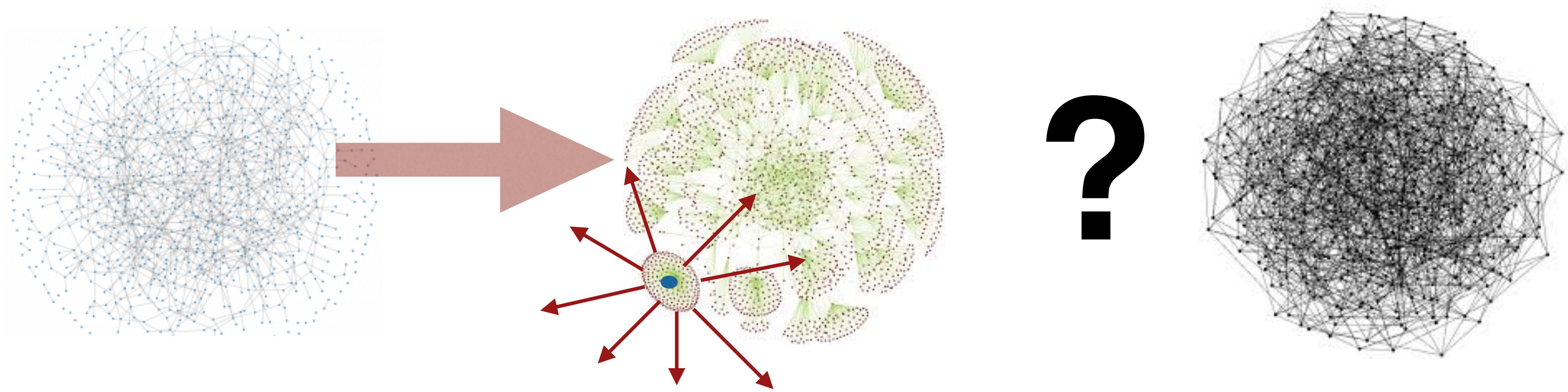
$$\langle V_i \rangle^2 = \frac{\Omega_m^{1.2} H^2}{2\pi^2} \int_0^\infty P_i(k) w_s^2(k,a) w_l^2(k,r_0) dk,$$

where $\Omega_m$ is the cosmological density parameter, $w_s$ and $w_l$ are window functions (here we use "top hat" window functions) and $a$ is a small scale smoothing of the perturbations. The choice of the value of $a$ is not critical as long as $a \ll r_0$. The index $i = dm, bm$ refers to dark matter and baryons, respectively. The ensemble average of the velocity variance within a patch of comoving radius $r_0$ is calculated in a similar fashion:

$$\langle \sigma_i \rangle^2 = \frac{\Omega_m^{1.2} H^2}{2\pi^2} \int_0^\infty P_i(k) w_s^2(k,a)[1 - w_l^2(k,r_0)] dk.$$

The "cosmic Mach number," $\mathcal{M}_i = \langle V_i \rangle / \langle \sigma_i \rangle$

$$\mu_{bh} = \frac{< V_{bh} >}{c_s}$$



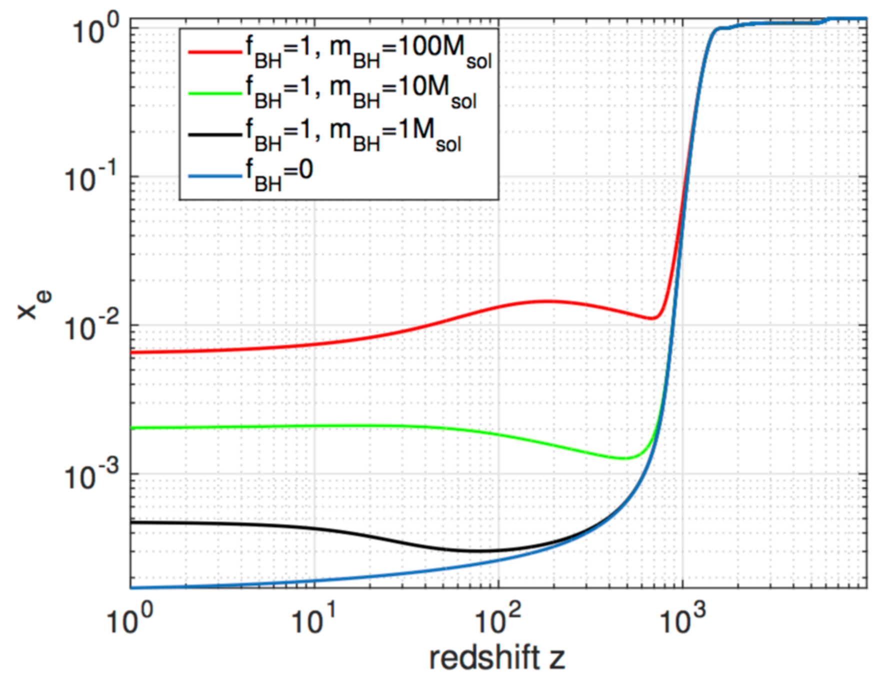

$$\frac{dM}{dt}\Big|_{cdm} \propto c_s^{-3},\ v_{ef} \sim c_s$$

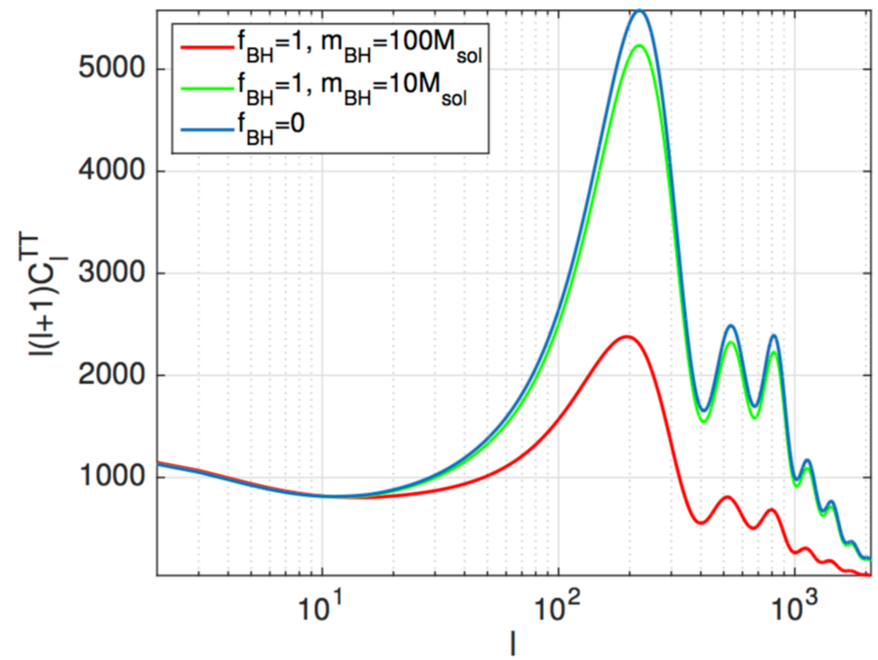
$$\frac{dM}{dt}\Big|_{pbh} \simeq \frac{dM}{dt}\Big|_{cdm} \mu_{bh}^{-3},\ \mu_{bh} \gg 1$$

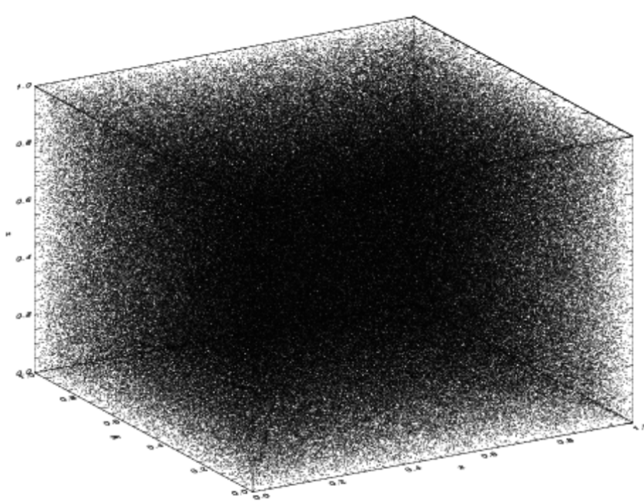
**Cosmic microwave background constraints on primordial black hole dark matter**

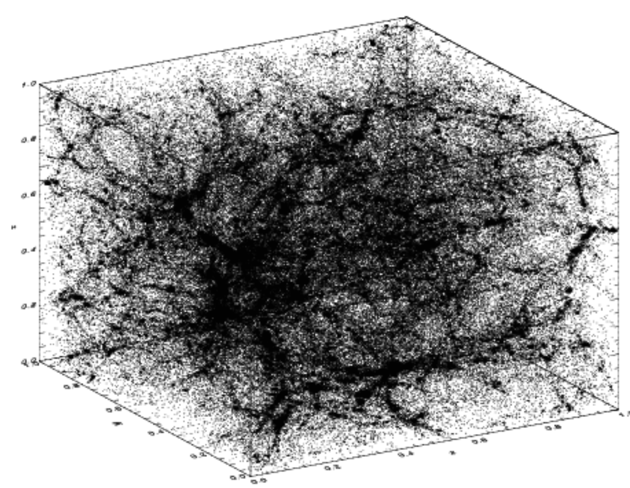
Daniel Aloni[1], Kfir Blum[1], and Raphael Flauger[2]

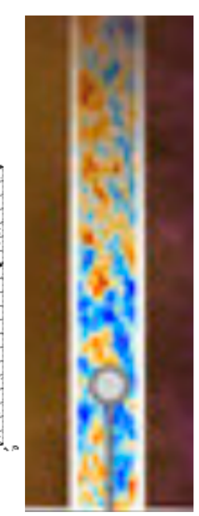
astroph:1612.06811

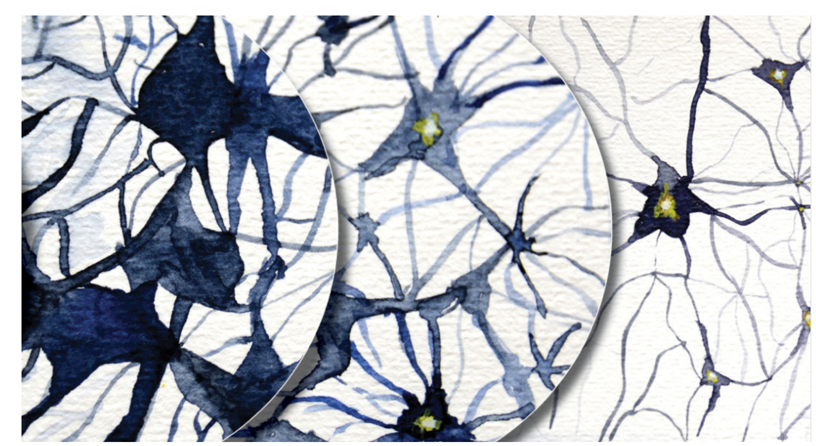






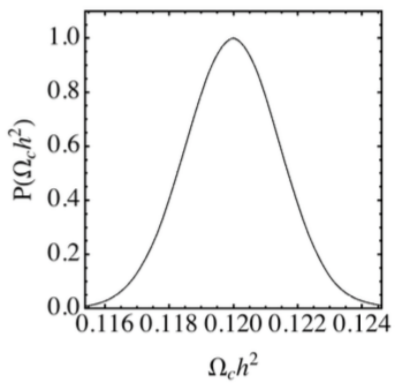


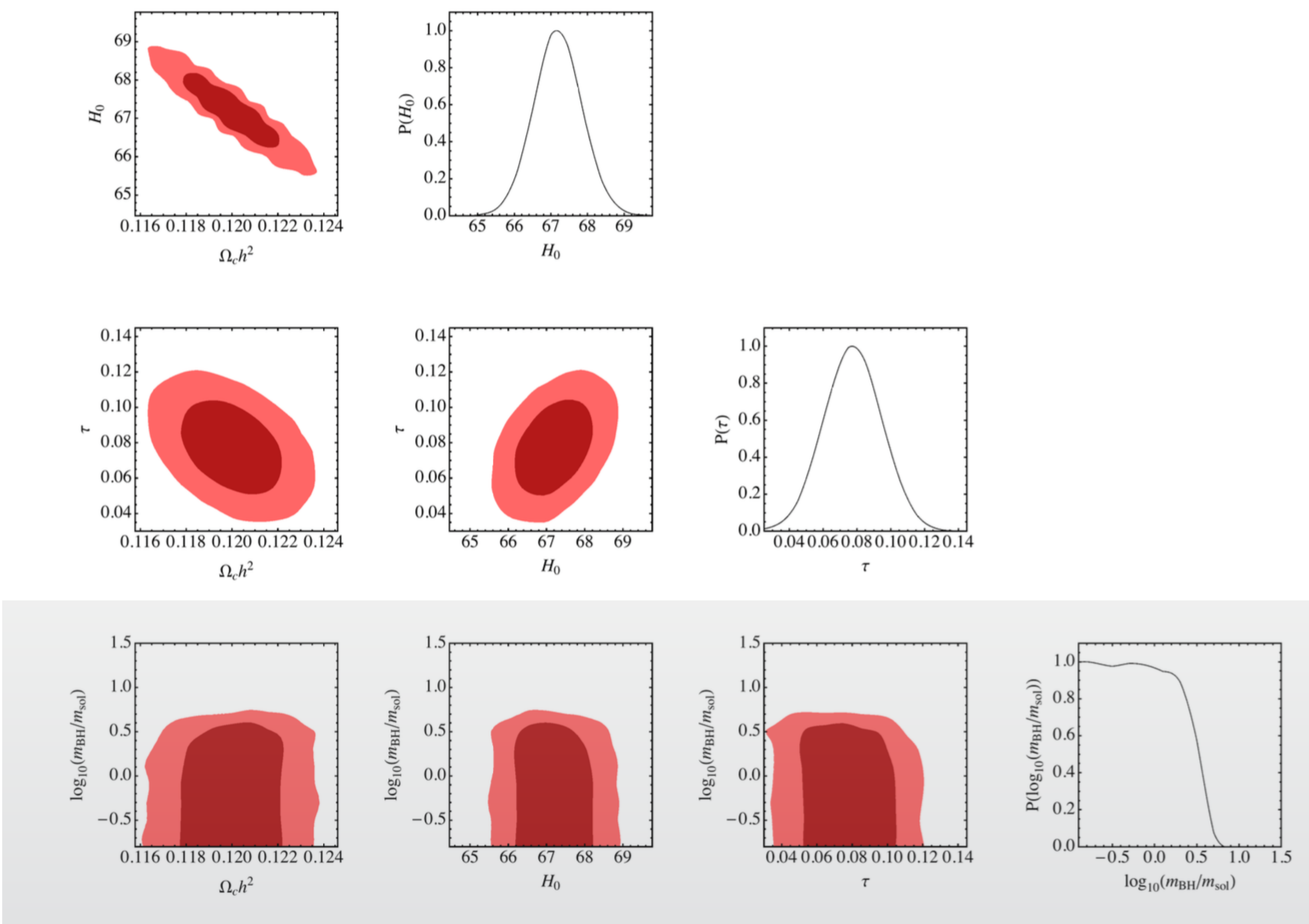
$t_{bh}(M)$ $t_{eq}$ $t_{rec}$ $t_U$

Aloni, Blum and Flauger,2016 $(\Lambda_{pbh} - \ model)$

**Planck TT, TE, EE data**

We revisit cosmic microwave background (CMB) constraints on primordial black hole dark matter. Spectral distortion limits from COBE/FIRAS do not impose a relevant constraint. Planck CMB anisotropy power spectra imply that primordial black holes with $m_{BH} \gtrsim 5\ M_\odot$ are disfavored. However, this is susceptible to sizeable uncertainties due to the treatment of the black hole accretion process. These constraints are weaker than those quoted in earlier literature for the same observables.



# Conclusion:

In adiabatic scenario of PBH's formation the effect of modulation leads to almost negligible re-ionization of the cosmic plasma.

The model is characterised by very intensive dark haloes formation.

**The critical test is related to the spectral distortion**

# Conclusion:

**In adiabatic scenario of PBH's formation the effect of modulation leads to almost negligible re-ionization of the cosmic plasma.**

**The model is characterised by very intensive dark haloes formation.**

**The critics test is the analysis of the spectral distortion**

# Thanks !