Constraints on Black Holes as Dark Matter

Phys. Rev. D 87, 023507 [arXiv:1209.6021]
Phys. Rev. D 87, 123524 [arXiv:1301.4984]

Fabio Capela

In collaboration with P. Tinyakov, M. Pshirkov

COSMO 2013 September 1, 2013

Outline

1. Dark Matter
   - Observational Signatures
   - Properties
2. Primordial Black Holes
   - Dark Matter?
3. Constraints on Primordial Black Holes
   - from Star Formation
   - from Neutron Star Capture
4. Discussion and Conclusions

Dark Matter

26.8 % of our Universe

Observational signatures

- Galaxies rotation curves
- CMB anisotropies
- Bullet Cluster

…

Properties

- $\Omega_{\text{DM}} = 0.27$
- electrically neutral (Dark)
- cold - dissipationless
- collisionless
- stable enough

Candidates

Axions, WIMPs, basically BSM physics...

Remark: we don't see BSM physics so far ...

Primordial Black Holes

Can they be dark matter ?...

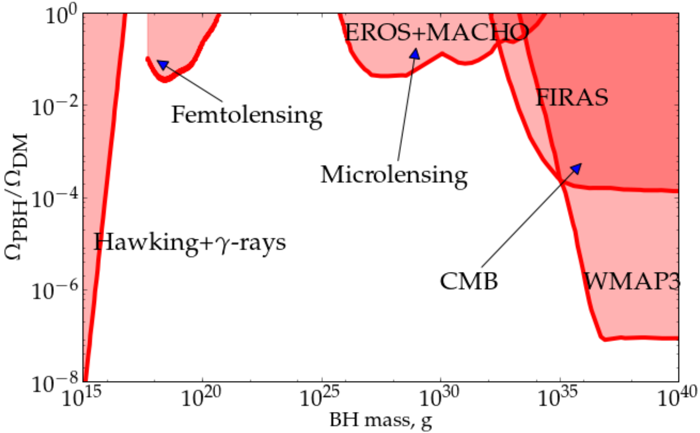
- Formation: density fluctuations w/ high initial amplitude collapse
- Dark Matter ?
  1. non relativistic, heavy: cold
  2. can have a subatomic size $r_g \sim 10^{-8}\text{cm}\left(\frac{m_{\text{BH}}}{10^{20}\text{g}}\right)$
  3. collisionless
  4. tend to be electrically neutral

No need for BSM physics ...

Question: $\Omega_{\text{BH}} = ?$

Primordial Black Holes

Existing Constraints



Constraints on Primordial Black Holes

from Star Formation

Idea:

- During star formation, DM follows the change of the potential
- *Eventually* some part of DM is captured by the pre-Main sequence star
- if DM $=$ PBHs, does not affect evolution of the star, (low dens)
- Some fraction of PBHs sink to the radius of the final star's compact remnant (high densities)
  - accretion time $\ll$ lifetime of visible star's remnants

Conclusion: observation of White Dwarfs/Neutron stars put constraints on $\Omega_{\rm BH}/\Omega_{\rm DM}$

Constraints on Primordial Black Holes

from Star Formation

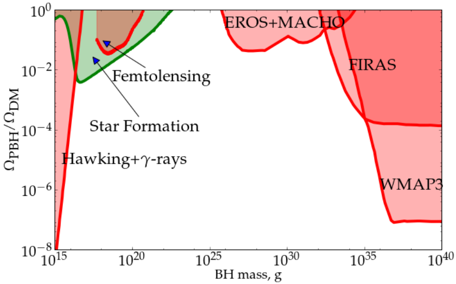
Adiabatic Contraction

- Take a baryonic distribution
- Inject DM particles @ $t = 0$
- Evolve the baryonic cloud

Result: $\rho_{\mathrm{DM}} = \frac{1}{2}\bar{\rho}_{\mathrm{DM}} \left(\frac{\bar{R}}{r}\right)^{3/2}$

Dynamical Friction

Some fraction of DM trapped inside the star sink until the final remnant's radius in enough time, due to dynamical friction force: $\mathbf{f} = -m_{\mathrm{BH}}\gamma(v; \rho(r))\mathbf{v}$



Constraints on Primordial Black Holes

from Neutron Star capture

Idea:

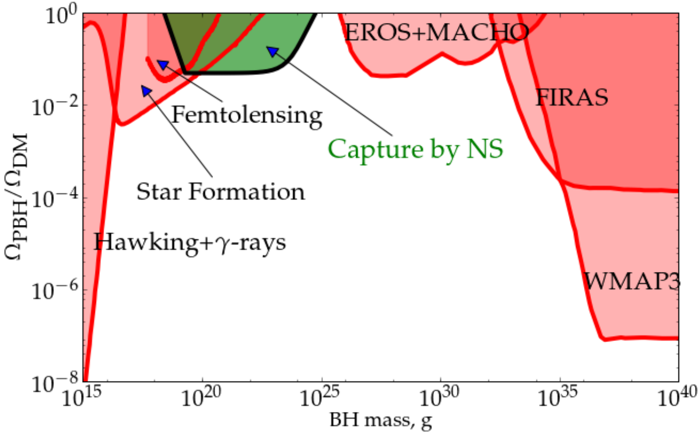
- Capture of a PBH by a Neutron Star
- As before, if so: accretion time $\ll$ lifetime of visible neutron star

How to proceed:

1. Compute the energy loss. Two contributions for high densities:
   - Dynamical Friction
   - Accretion
2. Compute time needed for full capture (and see if shorter than NS lifetime)
3. Compute the capture rate

Constraints on Primordial Black Holes

from Neutron Star capture



Discussion and Conclusions

1. Constraints on PBHs as dark matter for 10^{16}g $- 4 \times 10^{24}$g
   - Hypothesis: globular clusters are of primordial origin;
   - Question: What about Planck mass PBHs?
2. The profile of dark matter obtained & the amount of dark matter trapped by a star : not specific to any particular form of dark matter.
3. Observations of compact objects: powerful way to constraint dark matter properties

Constraints on Primordial Black Holes

from Neutron Star capture

- **Energy Loss**

$$\frac{dE}{dr} = 4\pi\rho\frac{G^2 m_{\mathrm{BH}}^2}{v^2}\ln\Lambda(r)$$

where

$$\ln(\Lambda(r)) = v^4\gamma^2\frac{b_{\mathrm{crit}}^2}{R_{\mathrm{g}}^2} + v^4\gamma^2\frac{2}{R_g^2}\int_{b_{\mathrm{crit}}}^{b_{\mathrm{max}}} bdb(1-\cos\phi(b))$$

- **Time needed for full capture**

$$t_{\mathrm{loss}} \simeq 4.1\times 10^4\mathrm{yr}\left(\frac{m_{\mathrm{BH}}}{10^{22}\mathrm{g}}\right)^{-3/2}$$

- **Capture Rate**

$$F = \sqrt{6\pi}\frac{\rho_{\mathrm{DM}}}{v_\infty m_{\mathrm{BH}}}\frac{R_g R}{1-R_g/R}\left[1-\exp\left(-\frac{3E_{\mathrm{loss}}}{m_{\mathrm{BH}}v_\infty^2}\right)\right]$$