Contents

1 Main conclusions

1.1 Burst duration

Cline papers have burst durations in the ¡100ms range, which is smaller than we are trying to fit. We can really only go down to 1e-3s time resolution with the GBM, so that puts us in the same searching domain as BATSE. With a much larger catalogue, we could do the same thing as the Cline and potentially replicate/extend his results. I think that would be big, in and of itself. BATSE data is just as easily searchable as Fermi, so we could start with that datset and extend it to the present.

It’s worth mentioning that they determine burst duration independently from the T90 which I am using to overview the data. As such, we can probably expect more sources to be hidden in our candidates for the LAT, however I’ll need to go through them manually to find out.

1.2 Hardness

Our hardness numbers using the GBM/LAT energy ranges are actually somewhat consistent with Cline's. The way that they tend to get 'softer' with higher burst duration is also consistent with expectation.

1.3 Rise time

Cline quotes a rise time of ¡1 microsecond. There are a few sources we have seen now that have quite aggressive rise times. This can be an easy way for us to quickly determine whether a source is a good candidate by eye.

1.4 Isotropy/angular distribution

This is where I think we have a good chance of making progress: if we can collect a healthy group of candidates apply the same arguments for angular distribution, and we discover the same 'anomalous region' that Cline did, it would reinforce the argument quite a bit – at the very least with the argument to classify short GRBs separately. Mainly, though, we want to see if they are distributed independently from the galactic center/plane.

If we also notice sources coming from that anomalous region/close to the average rate in other regions that fit the correct shape but don't fit the correct burst duration, we could argue that these are PBHs too. But they would be closer. Applying volumetric scaling to their norms, we could see if the density is consistent/isotropic.

I think this is what they did with the V/Vmax parameter, but I don't fully understand that yet.

1.5 Afterglow

The original paper quotes the radio afterglow arriving weeks years afterwards. I figure that the PBH could also have this late of a remnant – maybe when sorting the sources angularly, we can find those afterglows which come from the same spot.

2 Individual paper notes

2.1 Possibility of unique detection of PBH GRBs - Sep '92

- Components of a PBH explosion in order of 'uniqueness': neutrino burst, short time duration & hardness of photon spectrum

- Additionally, they must occur $\lesssim 10pc$ from Earth
- They expect durations on ¡1s, 'upper limit' in 50ms
- Luminosity for 10e14g PBH between 10^{33} to $10^{34} ergs$ corresponding to $M_{PBH} \in [6.3, 7] \times 10^{13} g$ in fireball stage
- Bursts would be isotropic but not homogeneous – correlated with Galactic/halo BUT needing to occur near Earth, the bursts would appear anisotropic
- number of emitting particle states grows exponentially with mass $\rho(m) \approx m^{-\beta} e^{\frac{m}{\Lambda}}$ for $\beta \in [5/2, 7/2]$ and $\Lambda \in [140, 160]$MeV
- Hagedorn-type models (Carter, 1976): "medium" (0.5 and 140 MeV) γ-rays lasting $10^{-8}s$
- DURATION corresponds to "order of time required for light to cross the photosphere radius"

2.2 Very short GRBs and PBH evaporation - Mar '96

- Hardness ratio versus burst duration (in ¡200ms GRBs):
- Hardness is (fluence in 100-300 keV)/(fluence in 50-100 keV) [fluence: erg/cm^3]
  - Increasing hardness with shorter GRB – expected with PBH evap (see Figure 2)
  - Hardness ratio in the limit of pure Hawking is 250
  - "Thus a hard y-ray spectrum is a natural consequence of a PBH origin!" though the pure Hawking hugely overestimates the actual hardness.
- Some comments on spatial distribution – namely homogeneity due to near-Earth requirement.

2.3 Further evidence for some GRBs consistent with PBH evaporation - Mar '97

- Very short rise time $\leq \mu s$
- Fitting BATSE events

  - Determination of time duration with Time Tagged Event of Gaussian 4th-order polynomial
  - Polynomial fit background
  - Short duration bursts of $T_{90} < 250ms$
  - Require single spike data peak countrate at least 2x background
  - They specifically required ¿100ms
  - Distribution is 'reasonably' isotropic
  - 1-2s bursts would be 'soft' in comparison to the shorter ones

2.4 Evidence for a galactic origin of very short GRBs and PBH sources - Sep '02

- There are 20 excess sources in one region
- I want to better understand this argument for GRBs being non-cosmological through the V/Vmax parameter
- Conclusion: distributed isotropically 3.7 with an extra source providing 16 in the anomalous region
- No excess from galactic center or plane – independent from stellar processes!!
- The anomalous region could be clumping of the halo distribution

2.5 Afterglow response from adiabatic blob expansion - '21

- Afterglow peak for blazars occurs weeks to years after the initial jet (GeV 'leads' the radio) – observed 40 days for Mrk421, longest 140 days in another
- Applies 'convolution' of gamma-ray lightcurves into afterglow response
- This afterglow from the jet is a bit of a blob of ejecta expanding – would the same shaped curve occur with a presumably spherical shell of ejecta centered on the PBH itself? Could the PBH produce an asymmetrical shell due to rotation, charge, etc.?

2.6 PBHs as DM: Carr and Kuhnel

- Except PBHs $< 10^15$g to have evaporated right now – slightly contrasts with the PBHmodels (Ukwatta et al.) paper which argues for evap to be on $5 \times 10^11 kg$
- PBHs could provide seeding to SMBHs
- Could generate large-scale structure "through Poisson fluctuations" (Meszaros Primeval black holes and galaxy formation 1975) – could look into this to see where we "expect" signals to come from? Are there any possible clusters in our immediate vicinity (prob not)?
- PBHs will only be a fraction of mass range from $10^{-7} M_{\odot} to 10 M_{\odot}$
- Constrained mass ranges:
  - Asteroid-mass: 10^16g to 10^17g
  - Sublunar-mass: 10^20g to 20^26g
  - Intermediate mass range: 10 to $10^3 M_{\odot}$
- LIGO detected some merging BHs in 10-50$M_{\odot}$ which is bigger than expected, could have been PBHs or just Pop3 stars collapsing (those are the 1st-gen high-hydrogen & helium stars)
- Formation mechanisms:
  - Primordial inhomogeneity: primordial density fluctuations with anything ¿Jeans mass collapsing to a BH:

    $$\beta \approx \mathrm{Erfc}[\frac{\delta_c}{\sqrt{2}\sigma}]$$

    for fluctuations of Gaussian distribution with dispersion σ, δ_c the density-contrast threshold for PBH formation ($\delta_c \approx 1/3 = 0.45$ in Radiation-dominated;)
  - Collapse from Scale-Invariant Fluctuations: form from 'cosmic loops' (str theory) ((don't get this one))
  - Collapse in a Matter-Dominated Era: if the universe was matter-dominated at some point (don't get this one)

  - Collapse from Inflationary Fluctuations: fluctuations in the inflation period which means there's a cutoff at the mass where inflation ends (CMB) so they have to be ¿1g
  - Quantum diffusion: inflaton (lol)
  - Critical collapse: lower & broad mass spectrum of PBHs (I think I get it)
  - Collapse at the QCD phase transition: I'm just gonna read that other paper on this
  - Collapse of cosmic loops: see last one – what's the diff?
  - Collapse through Bubble Collisions: Fermiballs

- PBH mass fcn could have multiple spikes

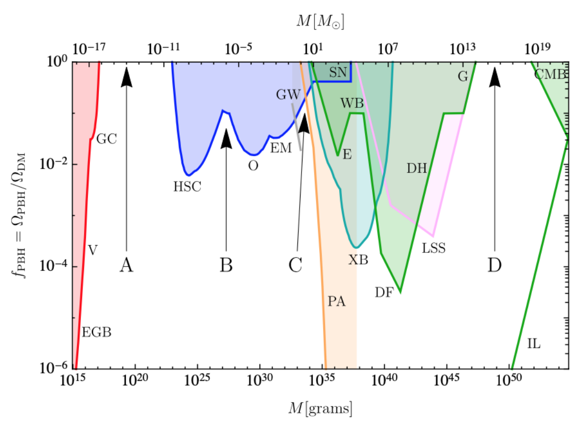

FIG. 1. Constraints on $f(M)$ for a monochromatic mass function, from evaporations (red), lensing (blue), gravitational waves (GW) (gray), dynamical effects (green), accretion (light blue), CMB distortions (orange) and large-scale structure (purple). Evaporation limits come from the extragalactic γ-ray background (EGB), the Voyager positron flux (V) and annihilation-line radiation from the Galactic centre (GC). Lensing limits come from microlensing of supernovae (SN) and of stars in M31 by Subaru (HSC), the Magellanic Clouds by EROS and MACHO (EM) and the Galactic bulge by OGLE (O). Dynamical limits come from wide binaries (WB), star clusters in Eridanus II (E), halo dynamical friction (DF), galaxy tidal distortions (G), heating of stars in the Galactic disk (DH) and the CMB dipole (CMB). Large-scale structure constraints derive from the requirement that various cosmological structures do not form earlier than observed (LSS). Accretion limits come from X-ray binaries (XB) and Planck measurements of CMB distortions (PA). The incredulity limits (IL) correspond to one PBH per relevant environment (galaxy, cluster, Universe). There are four mass windows (A, B, C, D) in which PBHs could have an appreciable density. Possible constraints in window D are discussed in Section VI but not in the past literature.

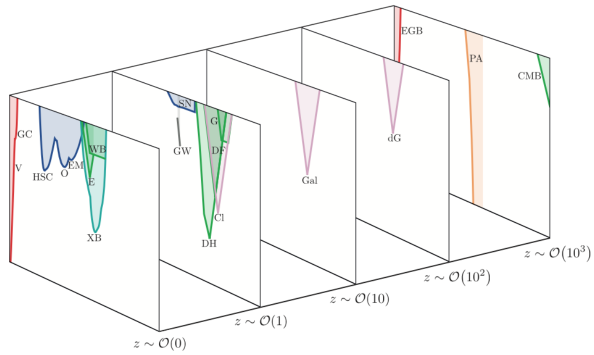

FIG. 2. Sketch of the limits shown in Figure 1 for different redshifts. Here, we break down the large-scale structure limit into its individual components from clusters (Cl), Milky Way galaxies (Gal) and dwarf galaxies (dG), as these originate from different redshifts (cf. Reference [145]). Further abbreviations are defined in the caption of Figure 1.

- So in our RS window, we are pinned btw Voyager positron flux (V) & annihilation-line radiation from galactic center (GC) and lensing of stars in M31 (HSC) but mostly the former

- There is a strong constraint on $f(M_*)$ from observations of the extragalactic γ-ray background where $M_* \approx 5 \times 10^14$g is the evaporating mass (Hawking, Gamma rays from primordial black holes)

- PBHs in the band $M_* < M < 1.005M_*$ have not yet completed evap but are below $M_q \approx 0.4M_*$ where quark and gluon jets can be emitted (HOW MUCH do JET PHOTONS affect our spectrum? Worth looking into?)

$$f(M) < 2 \times 10^{-8}(\frac{M}{M_*})^{3+\epsilon} \text{ for } (M > M_*)$$

- Galactic gamma-ray bkg could give stronger limit BUT depends on PBH mass fcn (EGB)

- Positron data from Voyager 1 constrains PBHs of $M < 10^16$g to $f < 0.001$

- Gonna skip the rest of the constraints in favor of more relevant stuff

2.7 Evidence for Primordial Black Hole Final Evaporation - Cline '09

- Only survival time of 1s to 1ms would allow for a detectable GRB with existing space detectors (LAT launched in 2008)

- Clear asymmetry in VSB locations; local galactic source – WHAT COORDS SPECIFICALLY? looks to be RHS octant
- I want to figure out Stefano's method for the burst duration, so that we can back-calculate Cline's fascination with 10ms bursts

2.8 Fermi Collaboration Search for GRBs from EBHs (Ritz, Atwood, Omodei)

Note: Arne Christian Johnson's PhD thesis has some more description of methodology (73, pg 91 in the pdf)

- Temperature of 20MeV for EBHs evaporating rn
- Distance to which a PBH of 16GeV can be detected is ≤ 0.02pc
- Fermi-LAT is sensitive to a PBH evap rate of $6 \times 10^4 pc^{-3} yr^{-1}$