Primordial Black Holes as Dark Matter: Constraints from the Milky Way

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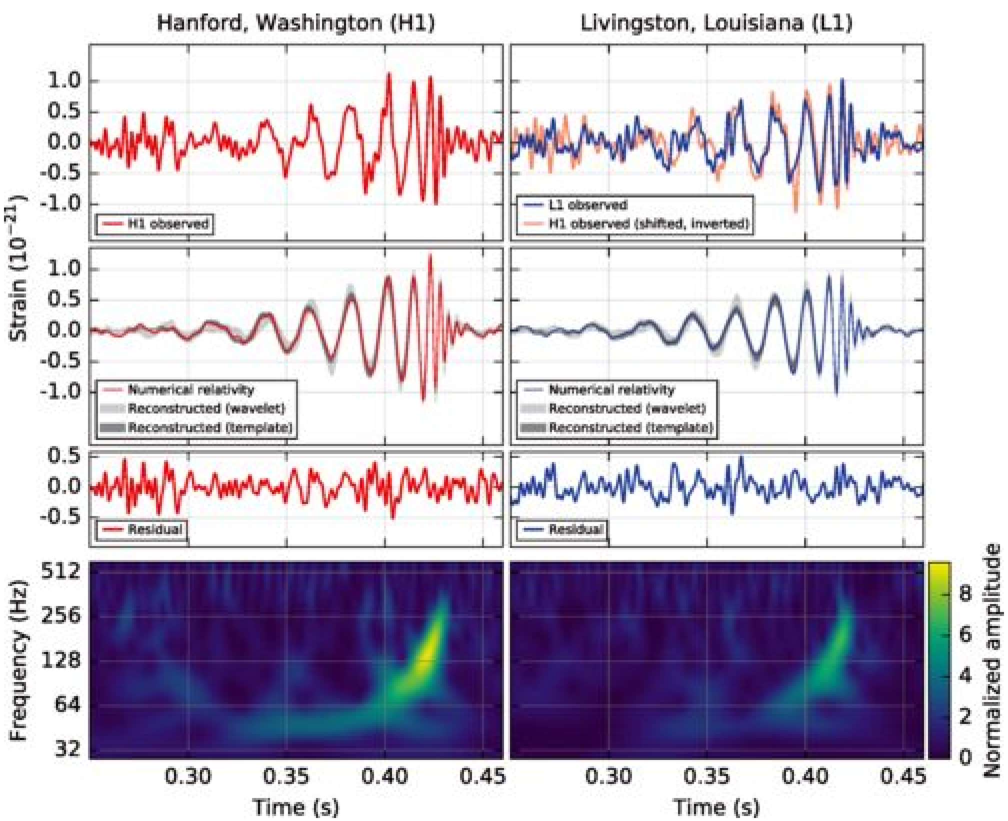
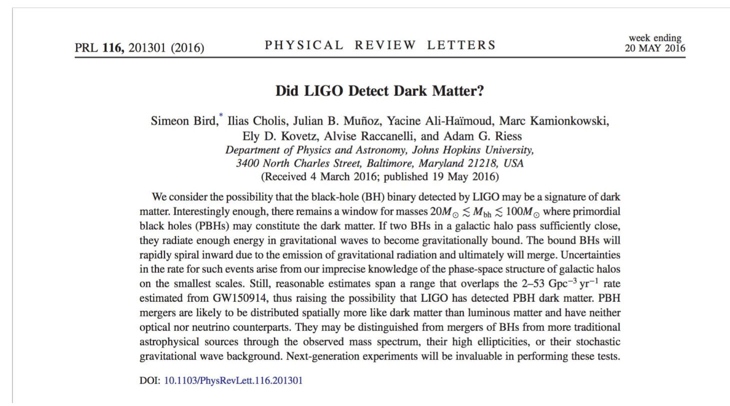
The Motivation

LIGO Detects Gravitational Waves from Black Holes



PRL 116, 061102 (2016)

Did LIGO detect DM??



PRL **116,** 201301 (2016) PHYSICAL REVIEW LETTERS week ending 20 MAY 2016

Did LIGO Detect Dark Matter?

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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 $20M_{\odot} \lesssim M_{\mathrm{bh}} \lesssim 100M_{\odot}$ 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 the emission of gravitational radiation and ultimately will 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 $\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$ 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 neither 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.

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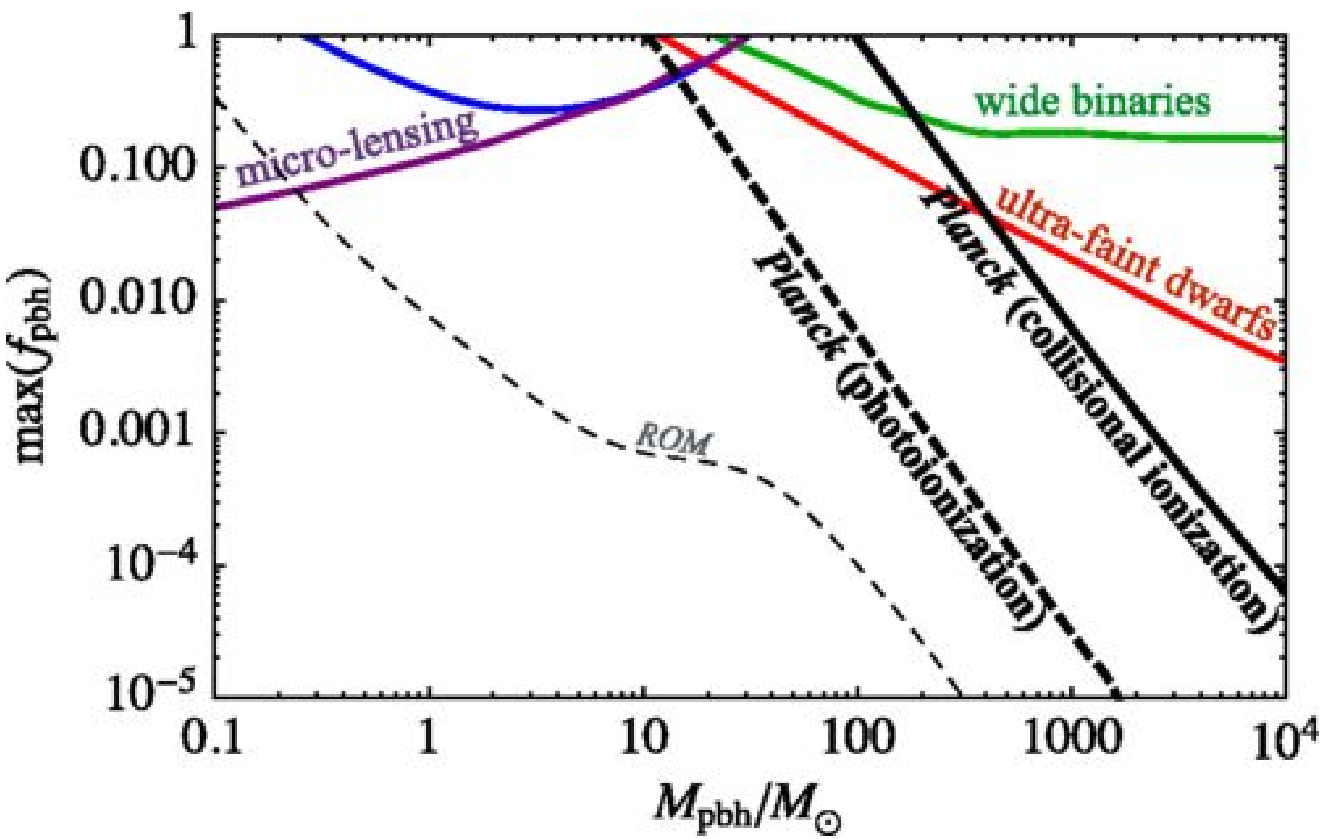
PRL 116, 201301 (2016)

Primordial Black Holes as Dark Matter

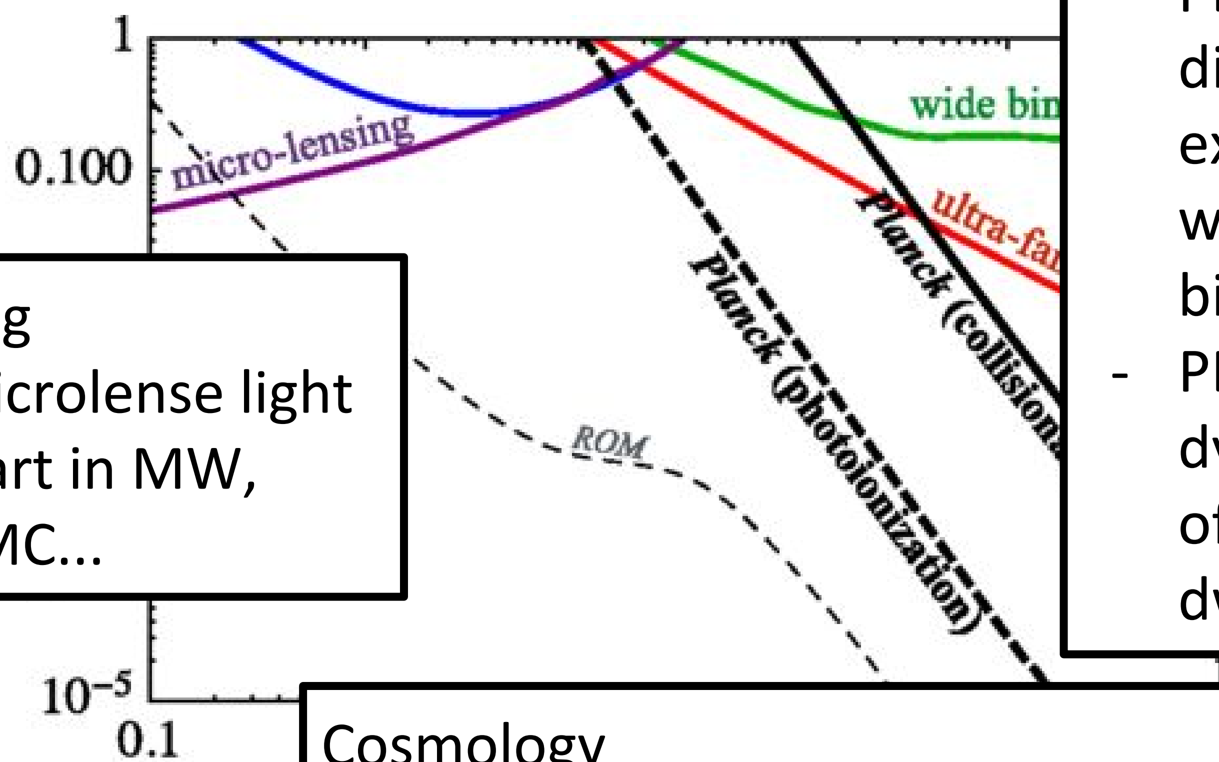
Constraints on PBH Mass



PRD 95, 043534 (2017)

Primordial Black Holes as Dark Matter

Constraints on PBH Mass



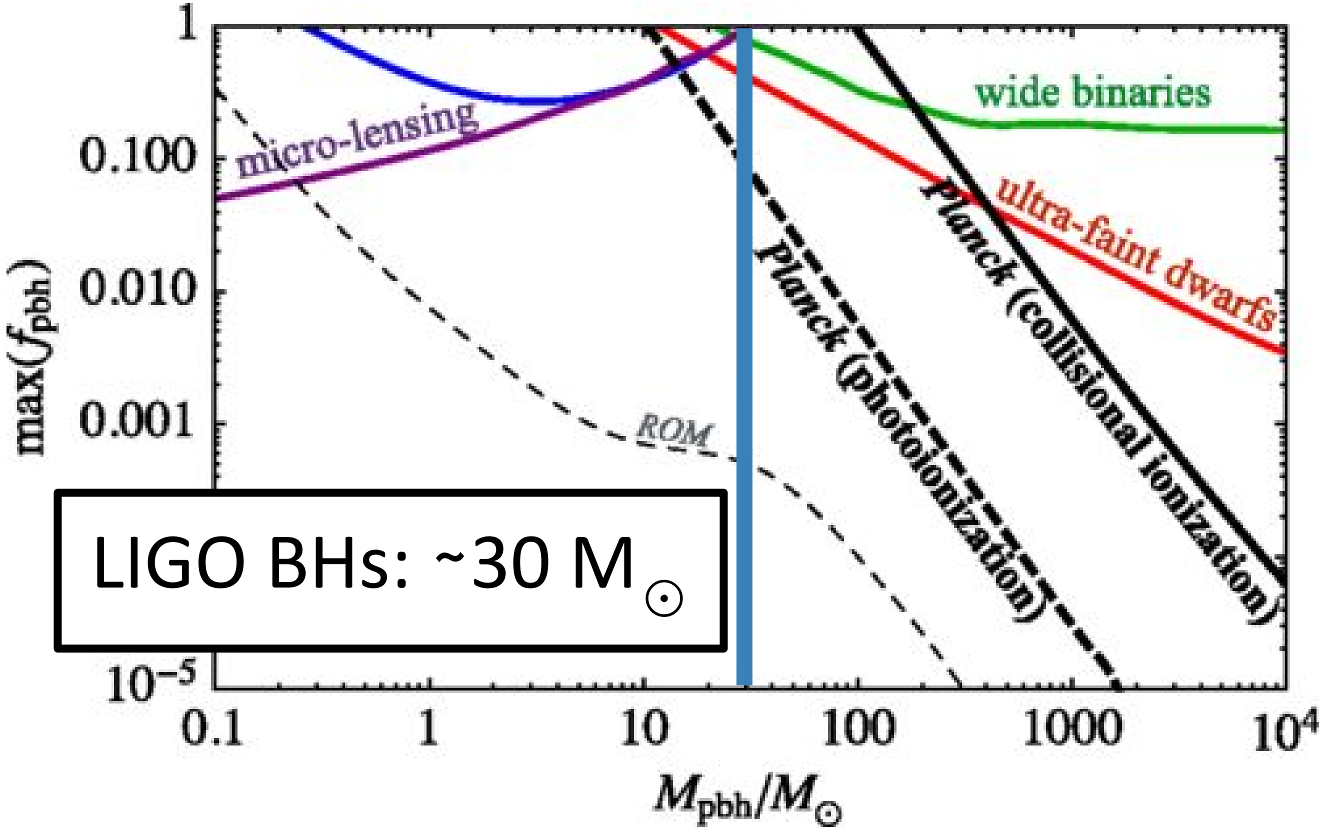
Microlensing
- PBHs microlense light from start in MW, LMC, SMC...

Dynamics
- PBHs disrupt existing wide binaries
- PBHs affect dynamics of stars in dwarfs

Cosmology
- PBHs in early universe heat up environment via accretion + radiation, changing the CMB

Primordial Black Holes as Dark Matter

Constraints on PBH Mass



PRD 95, 043534 (2017)

Primordial Black Holes in the Milky Way

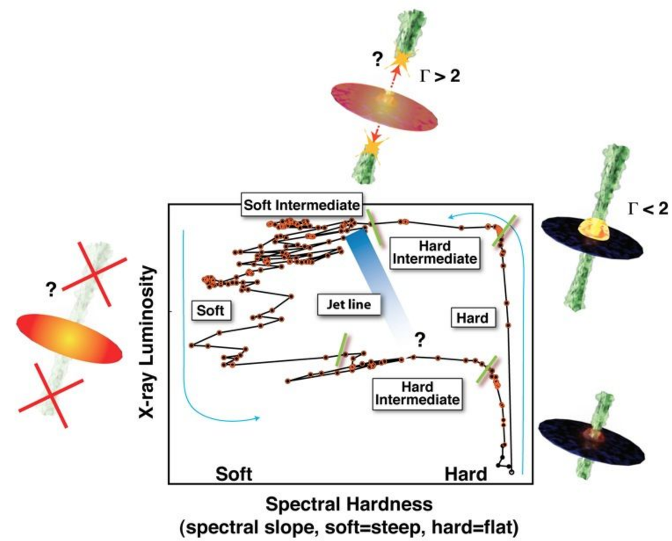
If PBHs are DM:

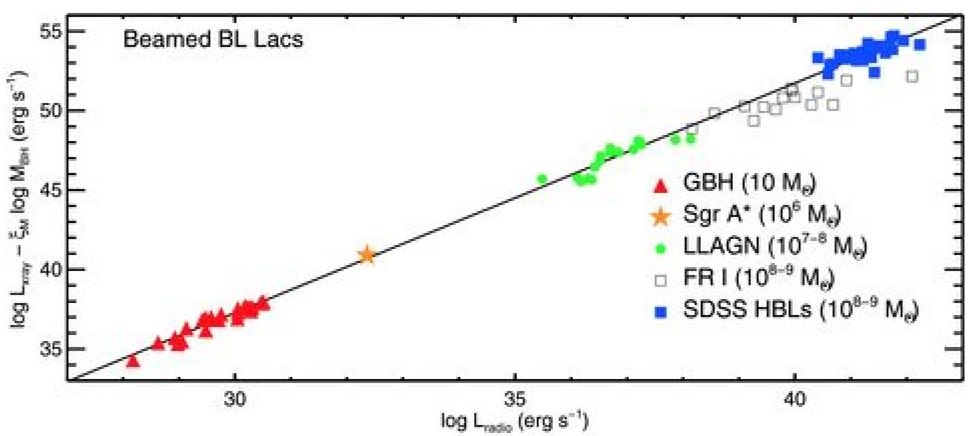
- MW halo contains 10^{11} 30 $M_\odot$ PBHs
  - 10^9 in the bulge

Can this many objects hide in the Milky Way?

The physics of accreting black holes

What we know about **astrophysical** black holes:
- They accrete gas, launch jets, and radiate X-ray and radio emission



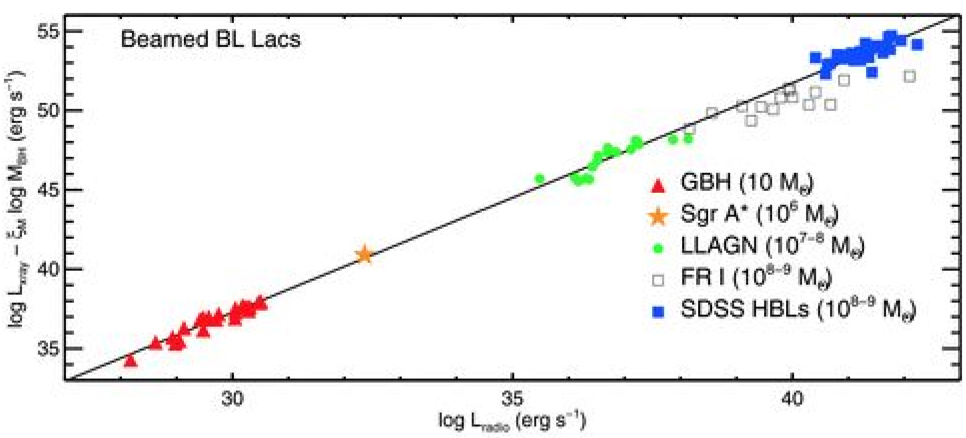


MNRAS 419:267 (2012)

Fundamental Plane for BHs with jets:
- Mass of BH
- Radio Luminosity
- X-ray Luminosity

The physics of accreting black holes

- Assume that **primordial** black holes will accrete gas and radiate emission
- Use FP to predict the radio and X-ray emission from PBHs + compare with observations



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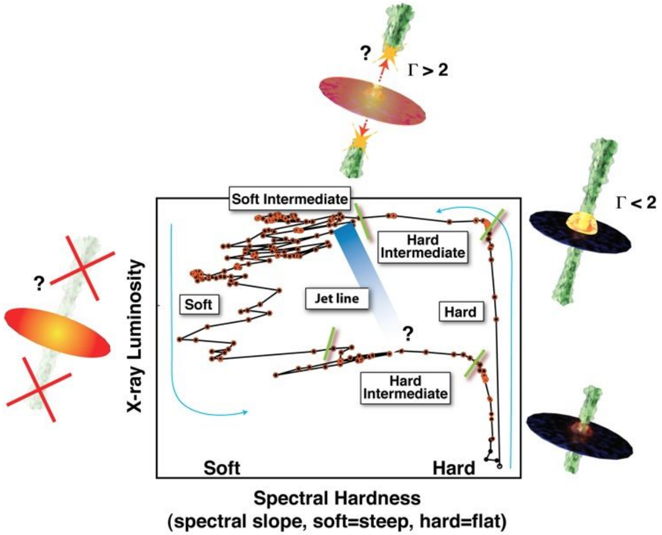
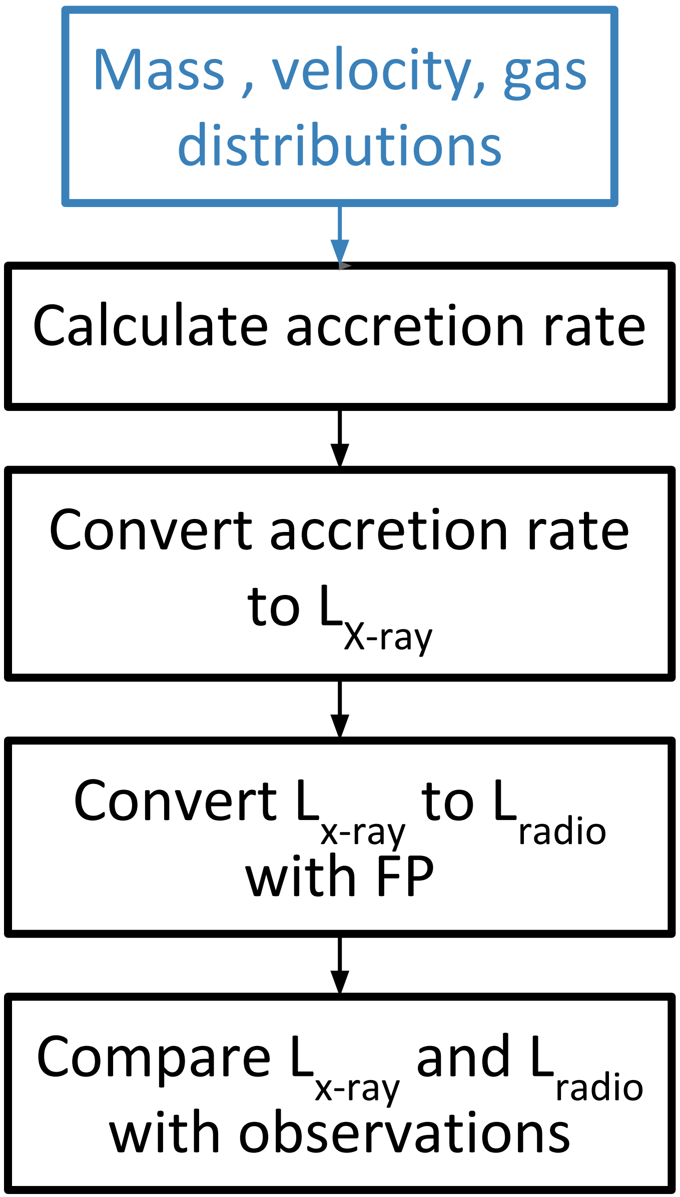


PBHs in the Milky Way: the plan



Flow chart inspired by Fig 1 in MNRAS 430:3 (2013)

PBHs in the Milky Way: the plan

Mass , velocity, gas distributions

NFW | Maxwell-Boltzmann distribution | 3D bulge model

Calculate accretion rate

Convert accretion rate to $L_{X\text{-ray}}$

Convert $L_{x\text{-ray}}$ to L_{radio} with FP

Compare $L_{x\text{-ray}}$ and L_{radio} with observations

Assume inefficient accretion:

- $L_{Bolometric} \propto \dot{M}^2$, $\dot{M} = \lambda \dot{M}_{Bondi}$
- $\dot{M} \propto v^{-3} \rightarrow$ small velocities drive constraints

Assume spectrum with index=0.6 to convert $L_{Bolometric}$ to $L_{X\text{-ray}}$

Assume flat radio spectrum

Chandra, NuSTAR, VLA, SKA

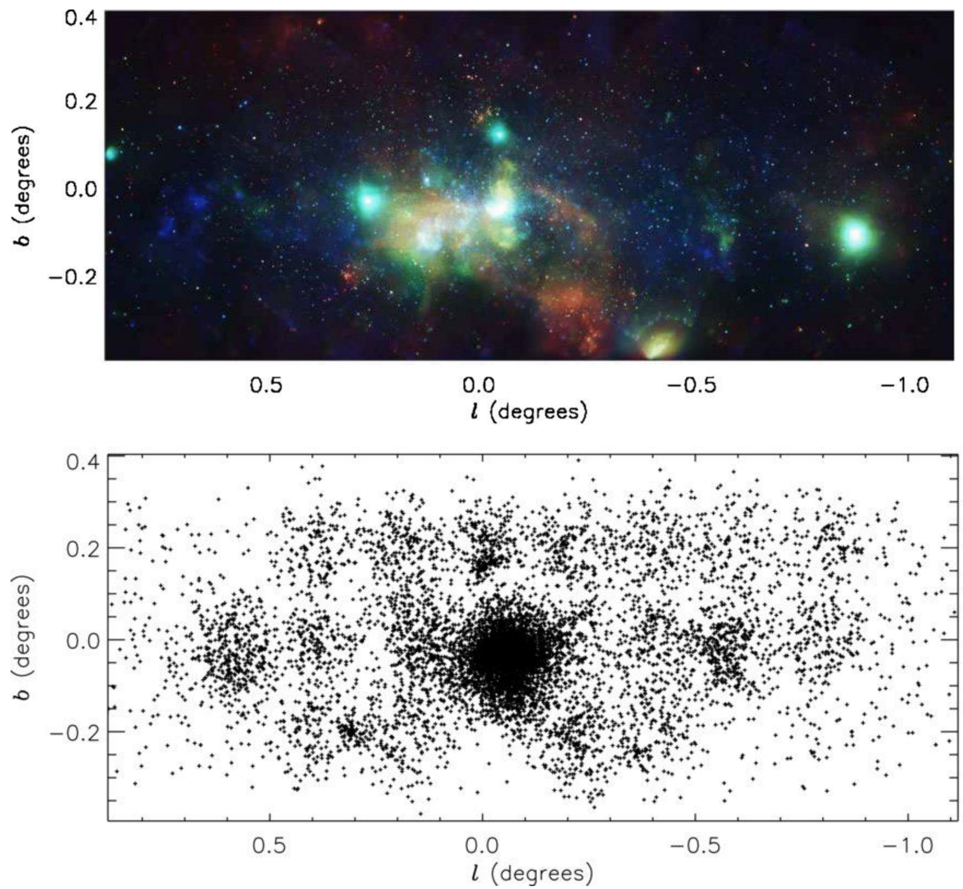
PBHs in the Milky Way: Observations

Chandra (0.5-8 keV)

L > 4e32 erg/s :

- 500 (likely Galactic) sources detected
- All 500 are candidate PBHs
- 2500±50 PBHs detectable in ROI

→ f_{DM}= 1 excluded at 40σ



ApJSS 181:110 (2009)

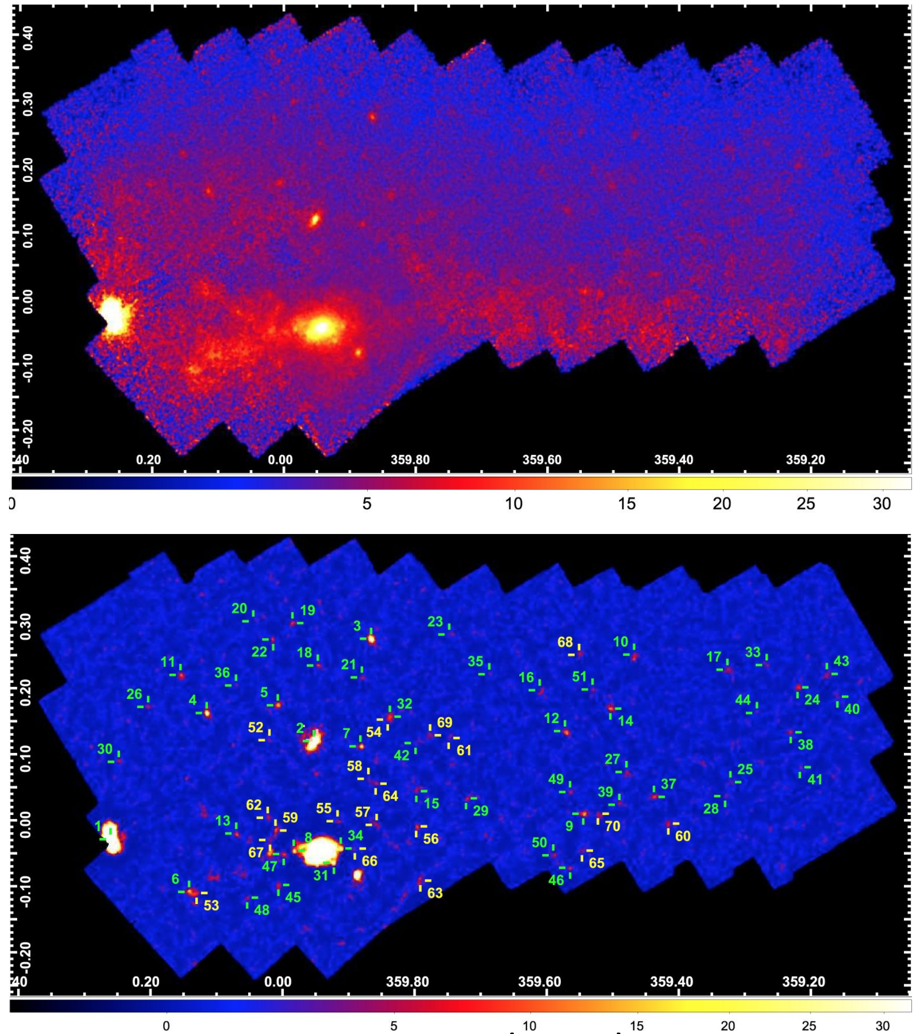
PBHs in the Milky Way: Observations

NuSTAR (10-40 keV)

L > 8e32 erg/s:

- 70 sources detected
- 30 candidate PBHs
- 160±12 PBHs detectable in ROI

→ $\mathbf{f_{DM} = 1}$ **excluded at 10σ**



ApJ 825:132 (2016)

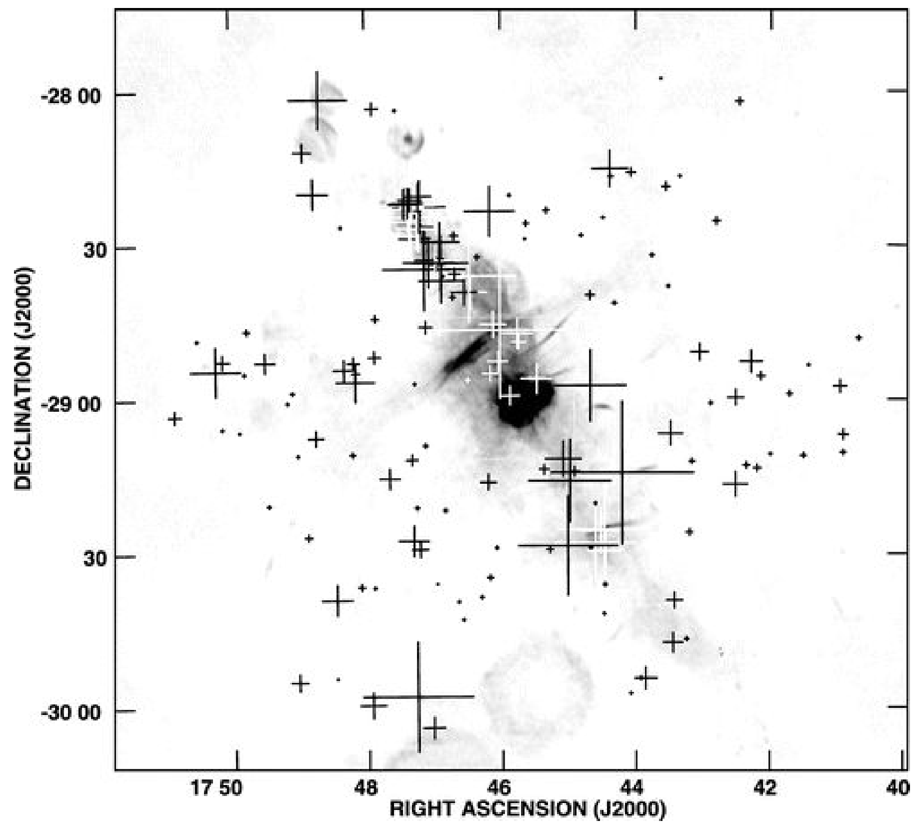
PBHs in the Milky Way: Observations

VLA (1.4 GHz)

flux > 1 mJy:

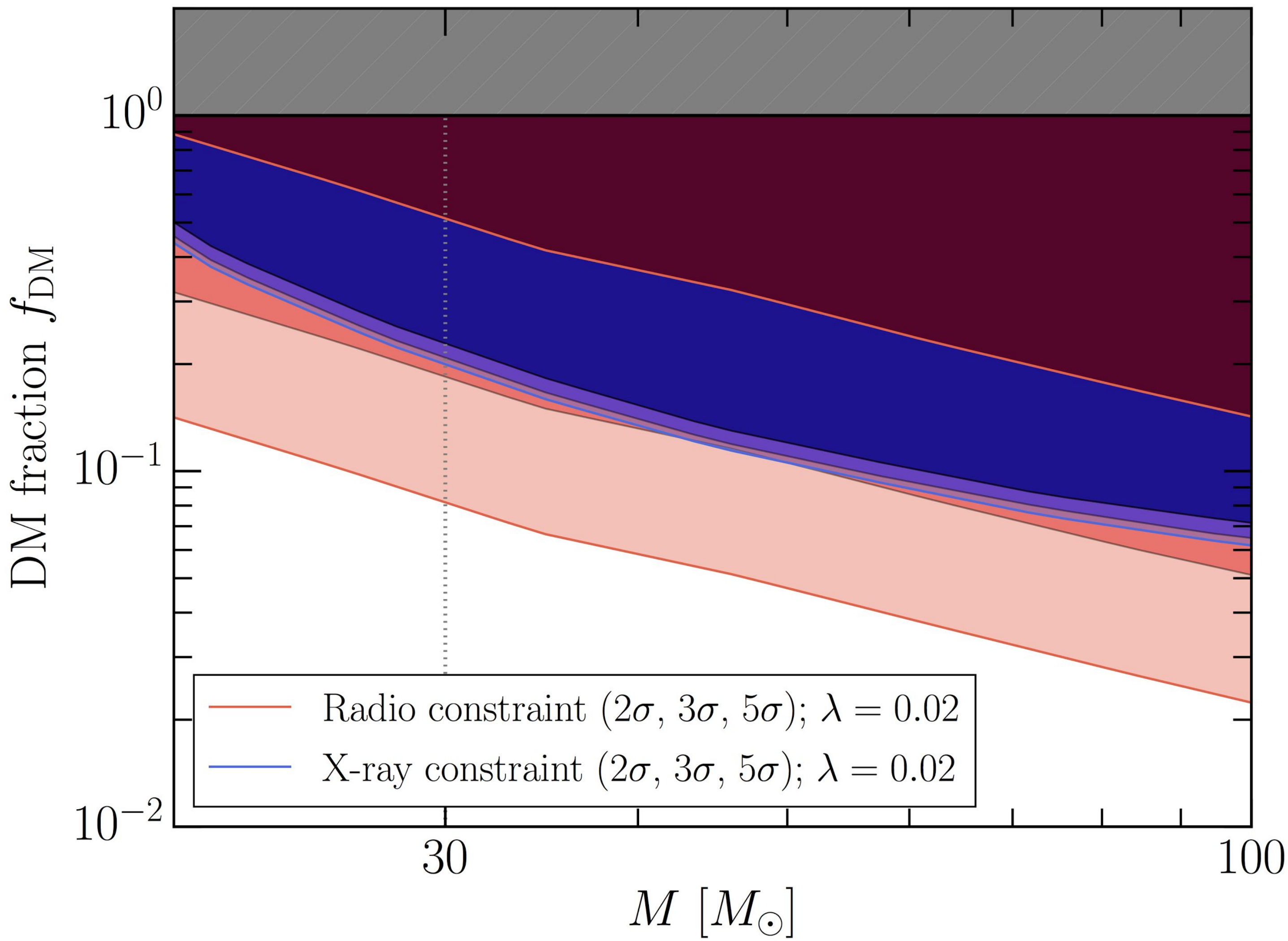
- 170 detected sources
- 0 candidate PBHs (from FP + Chandra)
- 40±6 PBHs detectable in ROI

→ **f_{DM}= 1 excluded at 6σ**



ApJSS 174:481 (2008)

PBHs in the Milky Way: Constraints



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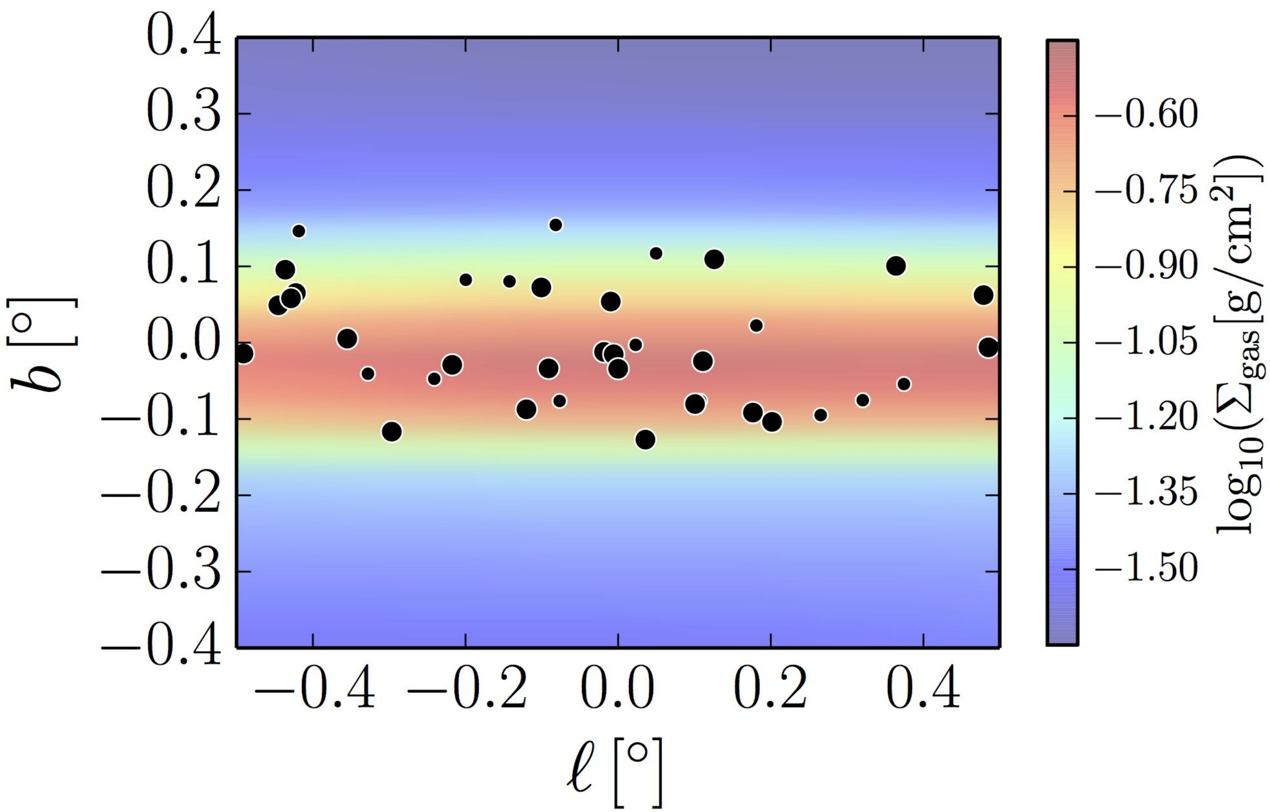
PBHs in the Milky Way: Radio Results

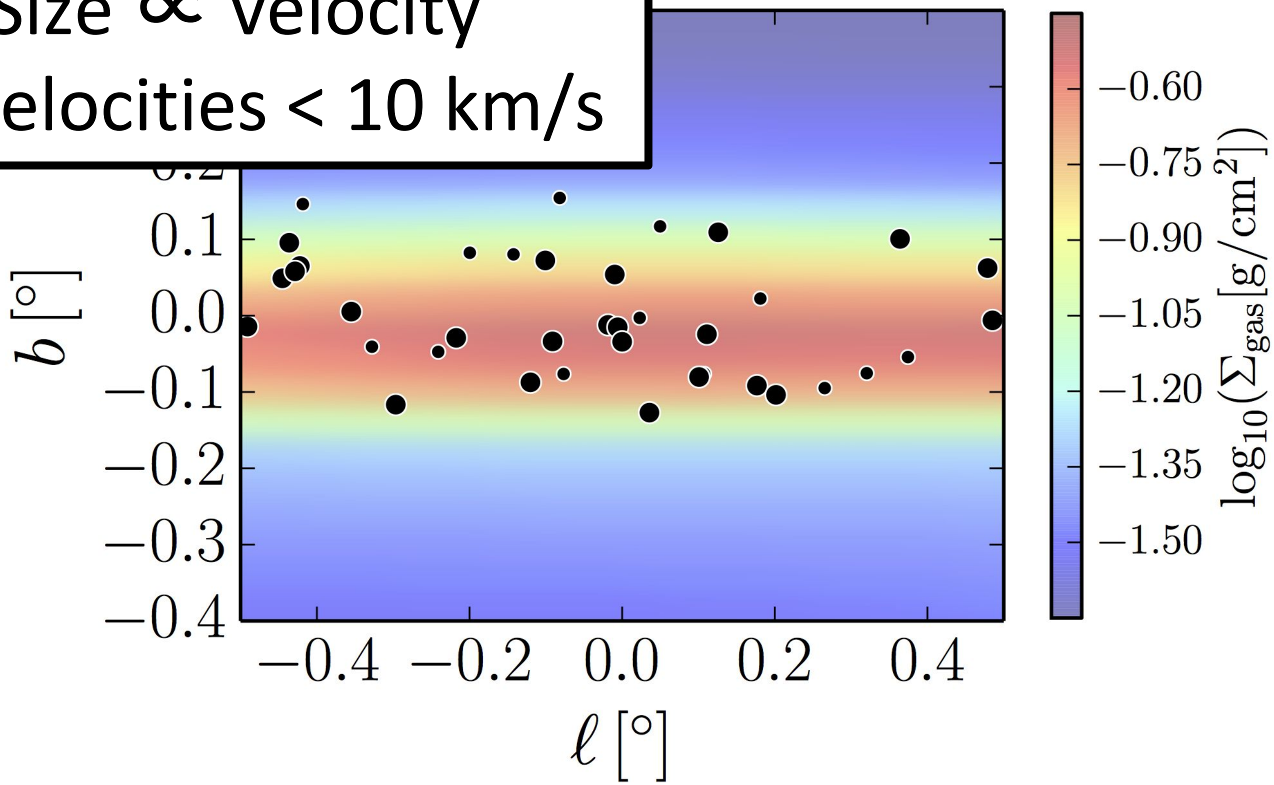


40±6 PBHs detectable with VLA

PRL 118, 241101 (2017)

PBHs in the Milky Way: Radio Results

Size ∝ velocity
All velocities < 10 km/s



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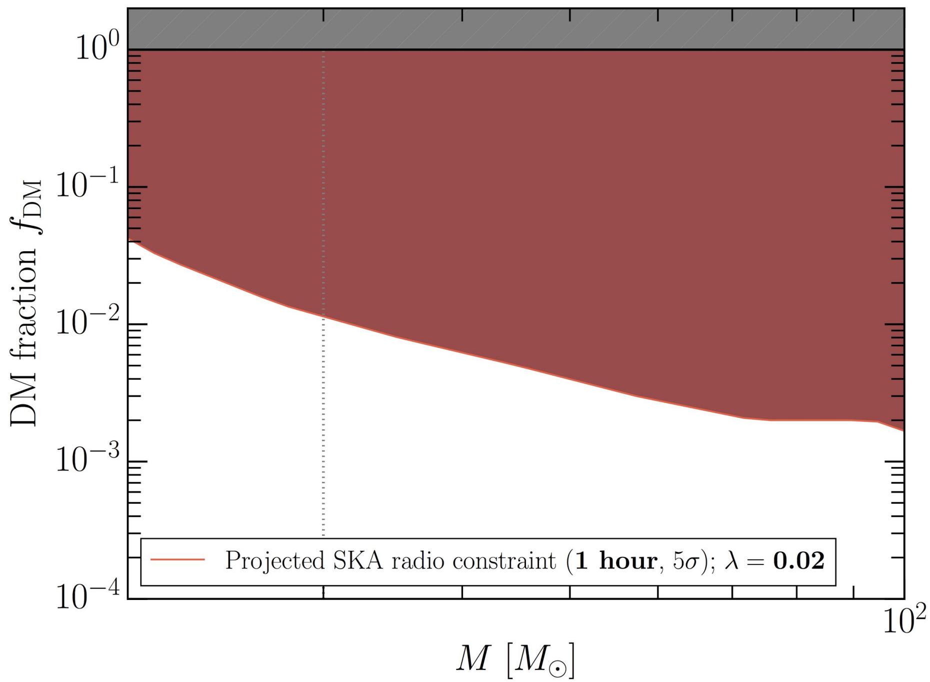
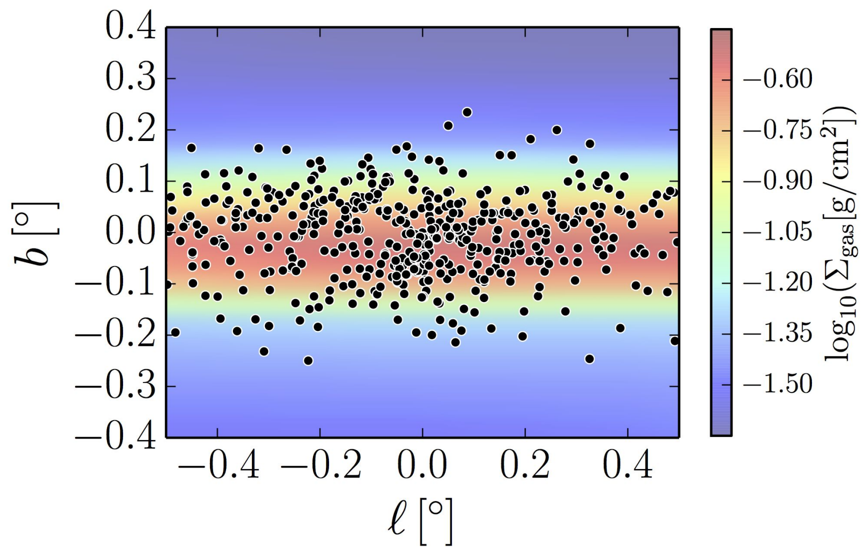
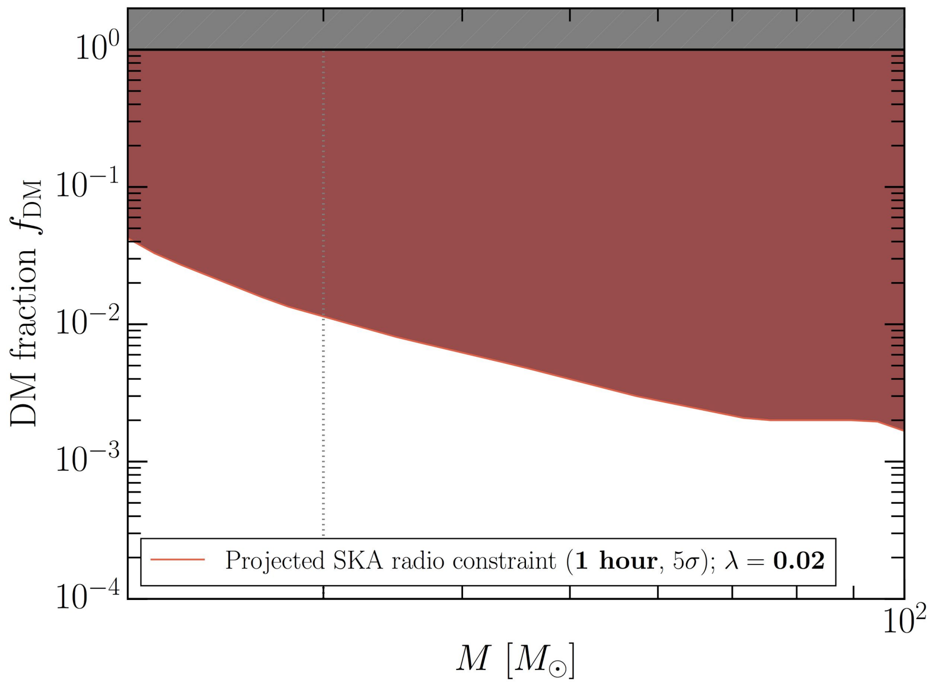
PBHs in the Milky Way: SKA predictions



Assuming PBHs are 1% of DM (!)



PBHs in the Milky Way: SKA predictions



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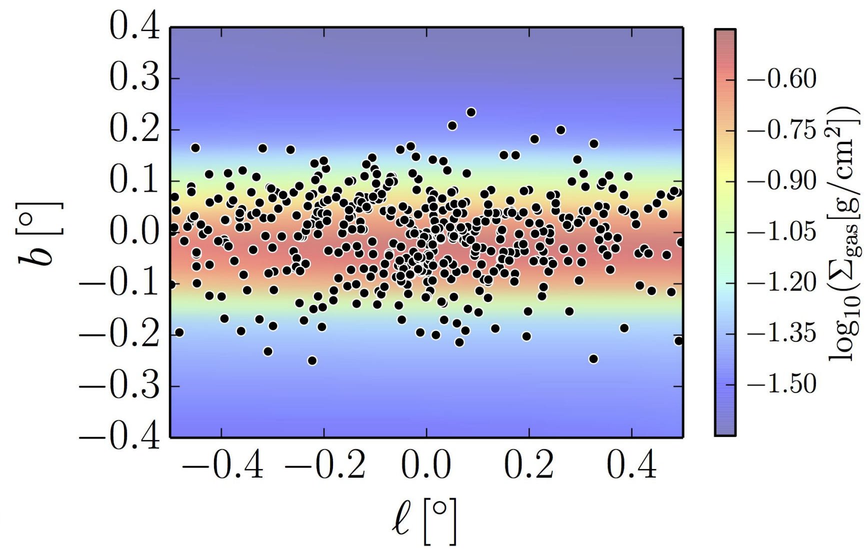
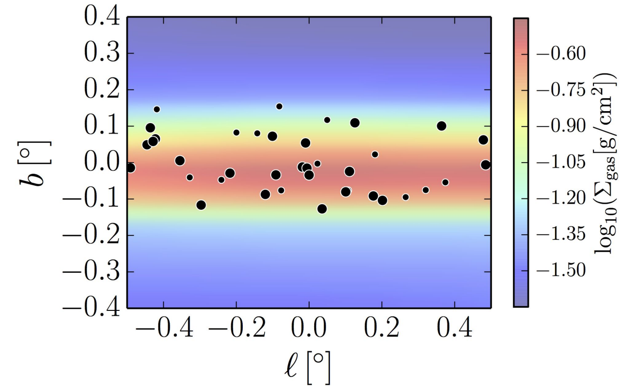


SKA will detect (or rule out) this population!

Searching for PBHs in Radio + X-ray

Can we hide a population of PBHs in the Milky Way? **NO**



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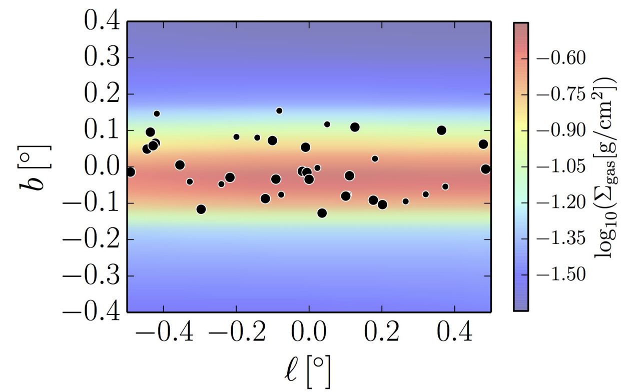
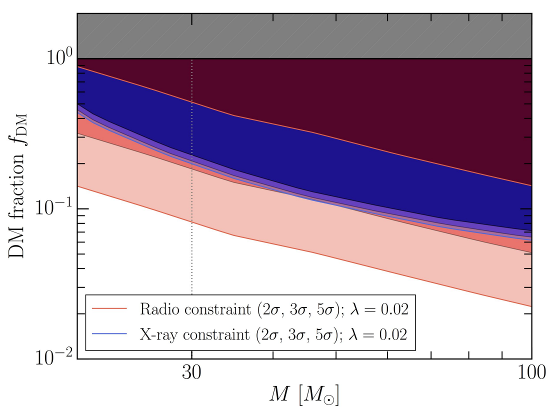




Constraints complement previous bounds, totally different method

SKA will detect (or rule out) this population!

Primordial Black Holes in the Milky Way

Back up slides

Primordial Black Holes in the Milky Way

Inefficient Accretion

$\dot{M} = \lambda \dot{M}_{bondi} = 4\pi\lambda(GM_{bh})^2\rho(v_{bh}{}^2+c_s{}^2)^{-3/2}$

$L = \eta\dot{M}$, $\eta = 0.1\dot{M}/\dot{M}_{crit}$ for $\dot{M}<\dot{M}_{crit}$; $\dot{M}_{crit} = 0.01\dot{M}_{edd}$

→ **$L \propto \dot{M}^2$**
We choose: $\lambda = 0.02 \rightarrow \dot{M}$ ~ Sgr A*

Primordial Black Holes in the Milky Way

Velocity Distribution

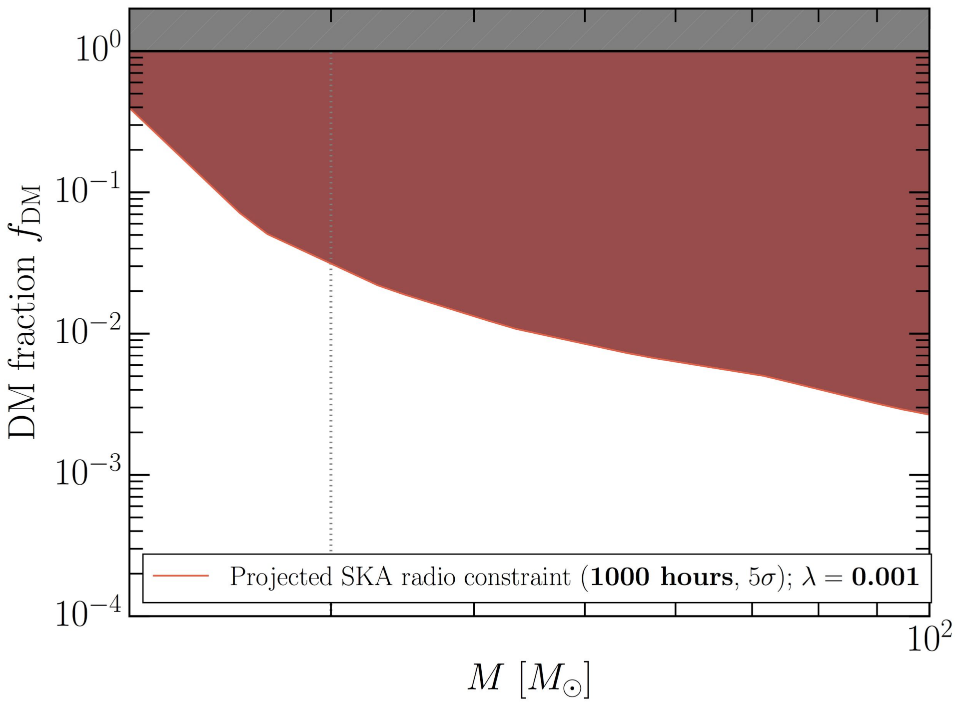
Gas model in the bulge:
Ferrière+2007, A&A, 467:611

Mass model in the bulge:
McMillan 2017, MNRAS, 465:76

Assume:

- Isotropic orbits
  - checked against Aquarius simulation
- $v(R) = v_{circ}(R)$
  - checked against phase-space calculation; valid for v<40km/s

PBHs in the Milky Way: SKA predictions



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