

## Julian B. Muñoz

Clay Fellow

Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138

(443) 683-4277; julianmunoz@cfa.harvard.edu; [www.julianbmunoz.com](http://www.julianbmunoz.com)

### RESEARCH INTERESTS

---

I am a broadly trained physicist working at the intersection of astrophysics and particle physics. I am best known for my work on 21-cm cosmology. I have developed theoretical models to probe the dark sector with data from cosmic dawn and reionization, and used them to search for dark matter within the HERA collaboration as well as Hubble Space Telescope high- $z$  galaxies. My work also uses other astrophysical data sets, such as the large-scale structure and fast radio bursts, to learn about new physics in our universe.

### RESEARCH EXPERIENCE

---

**2020-**      **Clay Fellow**, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA.

**2017-20**    **Postdoctoral Fellow**, Department of Physics, Harvard University, Cambridge, MA.

### EDUCATION

---

**2017**      **Ph.D. in Physics**, Johns Hopkins University. “*New Cosmological Probes for Old Fundamental Questions*”. Advisor: Marc Kamionkowski.

**2013**      **Graduado en Física** (B.A. in Physics), Complutense University of Madrid, Spain.

### PRESENTATIONS

---

#### Colloquia

“Cosmic Dawn: The Next Frontier”, Dartmouth, EuCAPT review talk (2021).

“Cosmology with the 21-cm line”, ETH Zurich (2020).

“Did LIGO detect dark matter?” Harvard BHI (2017).

#### Selected Invited Talks

“Light Relics beyond  $N_{\text{eff}}$ ”, GGI workshop, APS April meeting, Aspen Summer (2021).

“Small scales and high- $z$  with the 21-cm line”, Seminar at Cornell, CERN, YITP, PSU, Perimeter, Yale, NYU, IFT, Weizmann, MIT, UT Austin, USC, BGU, Cambridge, Geneva, Stanford, Caltech, BSM Pandemic (2020-21).

“Velocity-induced Acoustic Oscillations”, 234<sup>th</sup> AAS, 21-cm at Pisa, HERA Meeting UK, UTokyo (2019).

“Searching for dark matter at cosmic dawn”, Seminar at Fermilab, Mainz, TUM, Dartmouth, UCR, KIAS, Elusives network. Plenary talk at IDM Brown, DM18 Santander, CIPANP18, and Aspen Winter (2018-19).

### FUNDING

---

NASA Hubble Fellowship Program (PI) “*Improving Our Understanding of Cosmic Dawn*”  
\$300k (2020, declined in favor of Clay)

XSEDE (Co-I) “*Unveiling Cosmic Dawn with HERA*” (PI Murray)  
2M core hours (2020)

NASA Hubble Space Telescope (Co-I) “*Quasars with small proximity zones*”  
11 orbits (2021)

## FELLOWSHIPS & AWARDS

---

5-year Clay Fellowship, MIT Kavli Fellowship (declined), NASA Hubble Fellowship (declined).  
Dan David Prize Scholar 2017 (\$15k).  
EJ Rhee travel award 2016 (\$1k)  
Pitt PACC travel award 2017 (\$0.5k).  
Spanish Ministry of Education Research Fellowship 2012 (€4k).  
Summer Fellowship at the Instituto Astrofisico de Canarias 2012 (€2k).

## TEACHING & ADVISING EXPERIENCE

---

### Teaching Assistant, Johns Hopkins University

Responsibilities included grading, supervising group discussions and laboratories, holding office hours, and developing assignments and exams.

- Physics 103. Fall 2013 (taught by David E. Kaplan).
- Physics 104. Spring 2014 (taught by Tim Heckman).
- Graduate Quantum Mechanics. Fall 2015 (taught by Marc Kamionkowski).
- Stars and the Universe. Spring 2016 (taught by Adam Riess).

### Guest lecturer

*Basics of 21-cm cosmology*, Ay98 at Harvard, Fall 2018 and 2019 (taught by Xingang Chen). Substitute lectures for Quantum Mechanics and Cosmology at JHU and Harvard, respectively.

### Advising Experience

W. Linda Xu (graduate student at Harvard Physics->Postdoc Berkeley), since 2018, 3 papers.  
Nick Deporzio (graduate student at Harvard Physics), since 2018, 2 papers.  
Nash Sabti (graduate student at King's College London), since 2019, 3 papers.  
Misha Rashkovetskyi (graduate student at Harvard Astronomy), since 2020, 1 paper.  
Xiaohan Wu (graduate student at Harvard Astronomy), since 2020, 1 paper.

### Outreach

Member of the graduate-student outreach group at JHU. Lead lectures at Pikesville High, participated in the JHU physics fair, and contributed demonstrations at Coppin State and local high schools.  
Contributor to the Boston non-profit Science for the Public, and Astronomy on Tap.

## PROFESSIONAL SERVICE

---

### Reviewing

Panelist for NSF AAG (USA), and reviewer for ERC *Synergy* (EU) and *FONDECYT* (Chile).  
*PRL, PRD, ApJ, ApJ Lett., JCAP, MNRAS, Phys. Rept., Nature Astronomy, & Communications.*

### White Papers

Contributor to the CMB-S4 science book and thirteen Astro2020 decadal papers.  
Contact person for four LOIs, one RFI, and speaker in the community meeting of Snowmass 2021.

### Professional Duties

Organizer, high-energy physics seminar, Harvard University (2018-2019).  
Member, ITC postdoctoral selection committee (2021).  
Coordinator, DM theory group, Hydrogen epoch of reionization array (HERA) experiment.  
Develop and maintain the codes 21cmvFAST, RelicFast, GALLUMI, and 21cmFAST(v3).

## PUBLICATIONS

---

Total number of publications: 40

Number of first-author publications: 19

Total number of citations: 2142 (including preprints: 3502)

h-index: 24; citations/paper = 58 (including preprints: 57)

Most-cited first-author publication: Muñoz and Loeb, Nature 2018 (192 citations)

### Selected

1. **J. B. Muñoz**, Y. Qin, A. Mesinger, S. Murray, B. Greig, and C. Mason  
The Impact of the First Galaxies on Cosmic Dawn and Reionization.  
Submitted to *MNRAS*. [ArXiv: 2110.13919](#).
2. HERA collaboration (Including **J. B. Muñoz**. I led Sections 4 and 7)  
HERA Phase I Limits on the Cosmic 21-cm Signal: Constraints on Astrophysics and Cosmology  
During the Epoch of Reionization  
*MNRAS*, in press (2021). [ArXiv: 2108.07282](#).
3. **J. B. Muñoz**  
A Standard Ruler at Cosmic Dawn  
*Phys. Rev. Lett.* 123, 131301 (2019). [ArXiv: 1904.07868](#) – **Editor’s Choice**.
4. **J. B. Muñoz** and A. Loeb  
*A small amount of mini-charged dark matter could cool the baryons in the early Universe.*  
*Nature* 557 no.7707, 684 (2018). [ArXiv: 1802.10094](#).
5. **J.B. Muñoz**, E.D. Kovetz, L. Dai, and M. Kamionkowski  
*Lensing of Fast Radio Bursts as a Probe of Compact Dark Matter.*  
*Phys. Rev. Lett.* 117, 091301 (2016). [ArXiv: 1605.00008](#) – **Editor’s Choice**.

### Additional (\* Student co-supervised)

6. N. Sabti\*, **J. B. Muñoz**, and D. Blas  
Measurements of the Clustering of Matter with the High-Redshift Galaxy UVLF.  
Submitted to *PRL*. [ArXiv: 2110.13161](#).
7. N. Sabti\*, **J. B. Muñoz**, and D. Blas  
GALLUMI: A Galaxy Luminosity Function Pipeline for Cosmology and Astrophysics.  
Submitted to *PRD*. [ArXiv: 2110.13168](#).
8. X. Wu\*, **J. B. Muñoz**, and D. J. Eisenstein  
A fully Lagrangian, non-parametric bias model for dark-matter halos  
Submitted to *JCAP*. [ArXiv: 2109.13948](#).
9. M. Rashkovetskyi\*, **J. B. Muñoz**, D. J. Eisenstein, and C. Dvorkin  
Small-scale Clumping at Recombination and the Hubble Tension  
*PRD*, in press (2021). [ArXiv: 2108.02747](#).
10. W.L. Xu\*, **J. B. Muñoz**, and C. Dvorkin  
Cosmological Constraints on Light (but Massive) Relics  
Submitted to *PRL*. [ArXiv: 2107.09664](#).

11. S. Hotinli, T. Binnie, **J. B. Muñoz**, B. Dinda, and M. Kamionkowski  
Probing compensated isocurvature with the 21-cm signal during cosmic dawn  
*Phys.Rev.D* 104 6, 063536 (2021). [ArXiv: 2106.11979](#).
12. A. Ray, R. Laha, **J. B. Muñoz**, and R. Caputo  
Closing the gap: Near future MeV telescopes can discover asteroid-mass primordial black holes  
*Phys.Rev.D* 104 2, 023516 (2021). [ArXiv: 2102.06714](#).
13. **J. B. Muñoz**, S. Bohr, F.Y. Cyr-Racine, J. Zavala, and Mark Vogelsberger  
ETHOS: Impact of Dark Acoustic Oscillations on Cosmic Dawn  
*Phys.Rev.D* 103 4, 043512 (2021). [ArXiv: 2011.05333](#).
14. S. Murray, B. Greig, A. Mesinger, **J. B. Muñoz**, Y. Qin, J. Park, and C. Watkinson  
21cmFASTv3: A Python-integrated C code for 3D realizations of the cosmic 21cm signal.  
*JOSS* 5(54), 2582. [ArXiv: 2010.15121](#).
15. N. Sabti\*, **J. B. Muñoz**, and D. Blas  
First Constraints on Small-Scale Non-Gaussianity from UV Galaxy Luminosity Functions.  
*JCAP* 01 010 (2021). [ArXiv: 2009.01245](#).
16. J. Flitter, **J. B. Muñoz**, and E. Kovetz  
Outliers in the LIGO Black Hole Mass Function from Coagulation in Dense Clusters.  
*MNRAS* 507 1, 743 (2020). [ArXiv: 2008.10389](#)
17. W.L. Xu\*, N. Deporzio\*, **J. B. Muñoz**, and C. Dvorkin  
Accurately Weighing Neutrinos with Cosmological Surveys.  
*Phys.Rev.D* 103 2, 023503 (2021). [ArXiv: 2006.09395](#).
18. N. Deporzio\*, W.L. Xu\*, **J. B. Muñoz**, and C. Dvorkin  
Finding eV-scale Light Relics with Cosmological Observables.  
*Phys.Rev.D* 103 2, 023504 (2021). [ArXiv: 2006.09380](#).
19. **J. B. Muñoz** and F.Y. Cyr-Racine  
Cosmic Variance of the 21-cm Global Signal.  
*Phys.Rev.D* 103 2, 023512 (2021). [ArXiv: 2005.03664](#).
20. R. Laha<sup>^</sup>, **J. B. Muñoz**<sup>^</sup>, and T. Slatyer<sup>^</sup> (<sup>^</sup>Alphabetical)  
INTEGRAL constraints on primordial black holes and particle dark matter  
*Phys.Rev.D* 101, 123514 (2020). [ArXiv: 2004.00627](#). – **INTEGRAL picture of the month.**
21. Y. Qin, A. Mesinger, J. Park, B. Greig, and **J. B. Muñoz**  
A tale of two sites I: Inferring the properties of minihalo-hosted galaxies from current observations.  
*MNRAS* 495 1, 123 (2020) [ArXiv: 2003.04442](#).
22. **J. B. Muñoz**, C. Dvorkin, and F.Y. Cyr-Racine  
Probing the Small-Scale Matter Power Spectrum with Large-Scale 21-cm Data.  
*Phys.Rev. D* 101, 063526 (2020). [ArXiv: 1911.11144](#).
23. **J. B. Muñoz**, V. Ravi, and A. Loeb  
Periodic Fast Radio Bursts from Young Neutron Stars.  
*ApJ* 890 162 (2020), [ArXiv: 1909.00004](#).

24. D. Jyoti, **J. B. Muñoz**, R. Caldwell, and M. Kamionkowski  
Cosmic Time Slip: Testing Gravity on Supergalactic Scales with Strong-Lensing Time Delays  
*Phys.Rev. D* 100, 043031 (2019). [ArXiv: 1906.06324](#).
25. **J. B. Muñoz**  
Robust Velocity-induced Acoustic Oscillations at Cosmic Dawn  
*Phys.Rev. D* 100, 063538 (2019). [ArXiv: 1904.07881](#) – **Editor’s Choice**.
26. C. Zeng, E.D. Kovetz, X Chen, Y. Gong, **J. B. Muñoz**, and M. Kamionkowski  
Searching for Oscillations in the Primordial Power Spectrum with CMB and LSS Data  
*Phys.Rev. D* 99, 043517 (2019). [ArXiv: 1812.05105](#).
27. **J. B. Muñoz** and A. Loeb  
Finding the Missing Baryons with FRBs and Sunyaev-Zeldovich Maps  
*Phys.Rev. D* 98, 103518 (2018). [ArXiv: 1809.04074](#).
28. **J. B. Muñoz** and C. Dvorkin  
Efficient Computation of Galaxy Bias with Neutrinos and Other Relics.  
*Phys.Rev. D* 98, 043503 (2018). [ArXiv: 1805.11623](#).
29. **J. B. Muñoz**, C. Dvorkin and A. Loeb  
21-cm Fluctuations from Charged Dark Matter.  
*Phys. Rev. Lett.* 121, 121301 (2018). [ArXiv: 1804.01092](#).
30. A.M. Dizgah, H. Lee, **J. B. Muñoz** and C. Dvorkin  
Galaxy Bispectrum from Massive Spinning Particles.  
*JCAP* 1805, 013 (2018). [ArXiv: 1801.07265](#).
31. **J. B. Muñoz** and A. Loeb  
Constraints on Dark Matter-Baryon Scattering from the Temperature Evolution of the Intergalactic Medium.  
*JCAP* 1711, 043 (2017). [ArXiv: 1708.08923](#).
32. **J.B. Muñoz** and M. Kamionkowski  
Large-Distance Lens Uncertainties and Time-Delay Measurements of  $H_0$ .  
*Phys.Rev. D* 96, 103537 (2017). [ArXiv: 1708.08454](#).
33. T. L. Smith, **J.B. Muñoz**, R. Smith, K. Yee, and D. Grin  
Baryons still trace dark matter: probing CMB lensing maps for hidden isocurvature.  
*Phys.Rev. D* 96, 083508 (2017). [ArXiv 1704.03461](#).
34. **J.B. Muñoz**, E. D. Kovetz, A. Raccanelli, M. Kamionkowski, and J. Silk  
Towards a measurement of the spectral runnings.  
*JCAP* 1705, 032 (2017). [ArXiv 1611.05883](#).
35. P.D. Meerburg, M. Münchmeyer, **J.B. Muñoz**, and X. Chen  
Prospects for Cosmological Collider Physics.  
*JCAP* 1703, 050 (2017). [ArXiv: 1610.06559](#).

36. I. Cholis, E.D. Kovetz, Y. Ali-Haïmoud, S. Bird, M. Kamionkowski **J.B. Muñoz**, and A. Raccanelli.  
Orbital eccentricities in primordial black holes binaries.  
*Phys. Rev. D* 94, 084013 (2016). [ArXiv: 1606.07437](#).
37. A. Raccanelli, E.D. Kovetz, S. Bird, I. Cholis, and **J.B. Muñoz**  
Determining the progenitors of merging black-hole binaries.  
*Phys. Rev. D* 94, 023516 (2016). [ArXiv: 1605.01405](#).
38. M. Shiraishi, **J.B. Muñoz**, M. Kamionkowski, and A. Raccanelli  
Violation of statistical isotropy and homogeneity in the 21-cm power spectrum.  
*Phys.Rev. D* 93, 103506 (2016) .[ArXiv: 1603.01206](#).
39. S. Bird, I. Cholis, **J.B. Muñoz**, Y. Ali-Haïmoud, M. Kamionkowski  
E.D. Kovetz, A. Raccanelli, and A.G. Riess.  
Did LIGO detect dark matter?  
*Phys. Rev. Lett.* 116, 201301 (2016). [ArXiv: 1603.00464](#) – **Featured in Physics**.
40. **J.B. Muñoz**, D. Grin, L. Dai, M. Kamionkowski, and E.D. Kovetz  
Search for Compensated Isocurvature Perturbations with Planck Power Spectra.  
*Phys.Rev. D* 93, 043008 (2016). [ArXiv: 1511.04441](#).
41. **J.B. Muñoz**, E.D. Kovetz, and Y. Ali-Haïmoud  
Heating of Baryons due to Scattering with Dark Matter During the Dark Ages.  
*Phys.Rev. D* 92, 083528 (2015). [ArXiv: 1509.00029](#).
42. **J.B. Muñoz**, Y. Ali-Haïmoud, and M. Kamionkowski  
Primordial non-gaussianity from the bispectrum of 21-cm fluctuations in the dark ages.  
*Phys.Rev. D* 92, 083508 (2015). [Arxiv: 1506.04152](#) – **Editor’s Choice**.
43. **J.B. Muñoz** and M. Kamionkowski  
Equation-of-State Parameter for Reheating.  
*Phys.Rev. D* 91, 043521 (2015). [ArXiv: 1412.0656](#).
44. **J. Muñoz Bermejo**, A. Asensio Ramos, and C. Allende Prieto  
A PCA approach to stellar effective temperatures.  
*Astronomy & Astrophysics* 553, A95 (2013). [ArXiv: 1303.7218](#).  
(Undergraduate project as summer intern at the Instituto Astrofisico de Canarias.)

### **Selected white papers**

45. A. Loeb and **J.B. Muñoz**  
The First Stars May Shed Light on Dark Matter (Invited viewpoint for PRL, [arXiv:1807.01531](#)).
46. K.A. Abazajian et al. (including **J.B. Muñoz**, I lead one of the parameter-forecasting teams)  
CMB-S4 Science Book, First Edition ([arXiv:1610.02743](#)).
47. V. Ravi et al. (including **J.B. Muñoz**)  
Fast Radio Burst Tomography of the Unseen Universe ([arXiv:1903.06535](#)).
48. A. Liu et al. (including **J.B. Muñoz**)  
Cosmology with the Highly Redshifted 21cm Line ([arXiv:1903.06240](#)).
49. S. Furlanetto et al. (including **J.B. Muñoz**)

- Fundamental Cosmology in the Dark Ages with 21-cm Line Fluctuations ([arXiv:1903.06240](#)).
50. V. Gluscevic et al. (including **J.B. Muñoz**)  
Cosmological Probes of Dark Matter Interactions: The Next Decade ([arXiv:1903.05140](#)).
  51. C. Dvorkin et al. (including **J.B. Muñoz**)  
Neutrino Mass from Cosmology: Physics Beyond the Standard Model ([arXiv:1903.03689](#)).
  52. J.O. Burns et al. (including **J.B. Muñoz**)  
Dark Cosmology: Investigating Dark Matter & Exotic Physics in the Dark Ages using the Redshifted 21-cm Global Spectrum ([arXiv:1902.06147](#)).