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Professor, Aerospace Engineering Sciences
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Education:

Ph.D. Physics 1977 University of California, Berkeley
B.S. Physics 1973 Massachusetts Institute of Technology

Positions:

1990-present Professor, Department of Astrophysical and Planetary Sciences
2009-present Professor, Department of Aerospace Engineering Sciences
1985-1990 Associate Professor, Dept. Astrophysical, Planetary and Atmospheric Sciences
1982-1985 Assistant Professor, Department of Astro-Geophysics
1979-1982 Research Associate, Laboratory for Atmospheric and Space Physics
Lecturer, Department of Astro-Geophysics, University of Colorado, Boulder
1978-1979 Assistant Research Physicist, University of California, Berkeley
1974-1977 Research Assistant, Department of Physics; University of California, Berkeley
1973-1974 Teaching Assistant, Department of Physics; University of California, Berkeley
1969-1973 Research Asst., Center for Space Research; Massachusetts Institute of Technology

Administrative Positions:

2007-2008 Chair, Department of Astrophysical and Planetary Sciences
2004-2007 Director, Center for Astrophysics and Space Astronomy
1986-1993 Associate Director, Center for Astrophysics and Space Astronomy
1985-present Fellow, Center for Astrophysics and Space Astronomy

Awards:

NASA Exceptional Technology Achievement Medal, 2008
Three-time Fellow, NASA Institute for Advanced Concepts

Professional Affiliations:

American Astronomical Society	International Astronomical Union
Optical Society of America	Phi Beta Kappa
High Energy Astrophysics Division, AAS	Sigma Xi

Research Interests:

My research centers on the design, fabrication, and implementation of instruments for visible, ultraviolet, and x-ray observations from space. A few years ago I invented the "Starshade", a device to enable spectroscopy of Earth-like planets and hence the search for life in the Universe. NASA has recently opened a starshade office to pursue building one.

Projects:

Principal Investigator	New Worlds Observer	2004-present
Principal Investigator	High Resolution Gratings for Con-X	2001-2010
Principal Investigator	X-ray Interferometry Development	1998-2007
Principal Investigator	X-ray Sounding Rocket Program	1981-2013
Principal Investigator	Next Generation X-ray Observatory	1995-1997
Co-Principal Investigator	Ultraviolet Sounding Rocket Program	1985-1999
Co-Investigator	The Far Ultraviolet Spectroscopic Explorer	1986-2010
Co-Investigator	Con-X High Resolution Spectrograph Study	1998-2000

Major Service Positions:

Member, NRC Technology Roadmap for NASA	2011-2012
Member, National Academy Astro2010 Infrastructure Panel	2009-2010
Member, Astrophysics Sounding Rocket Roadmap Committee	2006-2009
International X-ray Observatory Instrument Working Group	2008-2011
Constellation-X Working Group	1997-2008
Member, Sounding Rocket Working Group, NASA	2006-2009
Member, NRC Committee on Nuclear Energy for Space Astronomy	2003-2004
Chandra X-ray Center Users' Committee	1994-2000
Member, X-ray Astronomy Program Working Group, NASA	1998-1999
Member, NASA SEUS Technology Working Group	1999-2000
Member, Astrophysics Council (AMOWG), NASA	1988-1991
Member, Ultraviolet/Visible MOWG, NASA	1988-1991
Member, X-ray Astronomy Program Working Group, NASA	1989-1992
Associate Editor <i>Experimental Astronomy</i>	1988-1995
Member, Sounding Rocket Working Group, NASA	1986-1989
Member, Supernova Science Working Group, NASA	1987-1989
Executive Committee High Energy Astrophysics Division, AAS	1986-1988

Students Supervised:

<i>Name:</i>	<i>Thesis Title:</i>	
David Windt	Optical Properties of Thin Films in the EUV and Soft X-rays	1987
Stephan McCandliss	Analysis of Line Profile Variations: A Statistical Approach	1988
Timothy Cook	Far Ultraviolet Spectrophotometry of Hot Stars	1991
Erik Wilkinson	EUV Opacity Sources in the DA White Dwarf G191B2B	1993
Dennis Gallagher	The X-ray Scattering Halo Around Sco X-1	1997
Scott Sarlin	Ultraviolet Studies of Interstellar Molecular Hydrogen	1998
Randall McEntaffer	X-ray Spectroscopy of the Cygnus Loop	2007
Phil Oakley	Diffuse X-ray Spectroscopy	2011
Benjamin Zeiger	Spectroscopy of Supernova Remnants	...2012
Thomas Rogers	Diffuse X-ray Spectroscopy	2016
Anthony Harness	Starshade Development	2016

PUBLICATIONS:

1. Rappaport, S., W. Cash, R. Doxsey, G. Moore, and R. Borke, "Discovery of a central x-ray object in the Cygnus Loop," *Ap. J.(Letters)*, 186, L115, 1973.
2. Rappaport, S., W. Cash, R. Doxsey, J. McClintock, and G. Moore, "Possible detection of very soft x-rays from SS Cygni," *Ap. J.(Letters)*, 187, L5, 1974.
3. Cash, W., R. Malina, and R. Stern, "An observation of the soft x-ray/extreme ultraviolet background," *Ap. J.(Letters)*, 204, L7, 1976.
4. Cash, W., R.F. Malina, and R.S. Wolff, "A soft x-ray map of the Perseus Cluster of galaxies," *Ap. J.(Letters)*, 209, L111, 1976.
5. Cash, W., "Generation of confidence intervals for model parameters in x-ray astronomy," *Astr. Ap.* , 52, 307, 1976.
6. Lampton, M., W. Cash, R.F. Malina, and S. Bowyer, "Design, fabrication and performance of two grazing incidence telescopes for celestial extreme ultraviolet astronomy," *Proc. Soc. Photo-Opt. Instr. Eng.* , 106, 93, X-Ray Imaging, 1977.
7. Cash, W., S. Bowyer, J. Freeman, M. Lampton, and F. Paresce, "Possible detection of an extreme ultraviolet source at 500Å," *Ap. J.* , 219, 585, 1978.
8. Cash, W., S. Bowyer, and M. Lampton, "Extreme ultraviolet observation of Sirius: Evidence against a photospheric origin of the 0.25 keV flux," *Ap. J.(Letters)*, 221, L87, 1978.
9. Malina, R.F., and W. Cash, "Extreme ultraviolet reflection efficiencies of diamond-turned aluminum, polished nickel and evaporated gold surfaces," *Appl. Opt* , 17, 3309, 1978.
10. Cash, W., S. Bowyer, P.A. Charles, M. Lampton, G. Garmire, and G. Riegler, "The soft x-ray spectrum of Capella: Discovery of intense line emission," *Ap. J.(Letters)*, 223, L21, 1978.
11. Paresce, F., S. Bowyer, W. Cash, M. Lampton, and R. Malina, "Instrumentation for extreme ultraviolet astronomy," in *COSPAR: New Instrumentation for Space Astronomy*, p. 77, Pergamon Press, New York, 1978.
12. Schnopper, H.W., J.P. Delvaille, A. Epstein, W. Cash, P. Charles, S. Bowyer, R.M. Hjellming, F.N. Owen, and W.D. Cotton, "X-ray and radio emission from the compact galaxy III ZW2," *Ap. J.(Letters)*, 222, L91, 1978.
13. Charles, P., F. Walter, and W. Cash, "HEAO-1 observations of x-ray emission from RS CVn systems," *IAU COSPAR Symposium on X-ray Astronomy*, Innsbruck, 1978.
14. Cash, W., "Parameter estimation in astronomy through application of the likelihood ratio," *Ap. J.* , 228, 939, 1979.
15. Cash, W., P. Charles, and S. Bowyer, "Evidence for a massive x-ray halo around Markarian 541," *Astr. Ap.* , 72, L6, 1979.
16. Cash, W., S. Bowyer, and M. Lampton, "Interstellar absorption of the extreme ultraviolet flux from two hot white dwarfs," *Astr. Ap.* , 80, 67, 1979.
17. Cash, W., T.P. Snow, and P. Charles, "X-ray emission from an Ap star (ϕ Herculis) and a late B star (π Ceti)," *Ap. J.(Letters)*, 232, L111, 1979.
18. Cash, W., P. Charles, S. Bowyer, F. Walter, T.R. Ayres, and J.L. Linsky, "Discovery of x-rays from the 40 Eridani system," *Ap. J.(Letters)*, 231, L137, 1979.

19. Malina, R.F., S. Bowyer, D. Finley, and W. Cash, "Wolter-Schwarzschild optics for the extreme-ultraviolet: the Berkeley stellar spectrometer and the EUV explorer," *Proc. Soc. Photo-Opt. Instr. Eng.* , 184, 20, Space Optics, 1979.
20. Cash, W., D.L. Shealy, and J.H. Underwood, "Astronomical applications of grazing incidence telescopes with polynomial surfaces," *Proc. Soc. Photo-Opt. Instr. Eng.* , 184, 228, *Space Optics*, 1979.
21. Walter, F.M., W. Cash, P.A. Charles, and C.S. Bowyer, "X-rays from RS CVn systems: A HEAO-1 survey and the development of a coronal model," *Ap. J.* , 236, 212, 1980.
22. Cash, W., P. Charles, S. Bowyer, F. Walter, G. Garmire, and G. Riegler, "The x-ray superbubble in Cygnus," *Ap. J.(Letters)*, 238, L71, 1980.
23. Cash, W., P. Charles, and H.M. Johnson, "The coronae of 40 Eridani," *Ap. J.(Letters)*, 239, L23, 1980.
24. Johnson, H.M., and W.C. Cash, "A VLA sequel to HEAO-1 detections of main sequence stars," *Proceedings of the Workshop on Cool Stars, Stellar Systems and the Sun*, 137, 1980.
25. Cash, W., and P. Charles, "Stalking the Cygnus superbubble," *Sky and Telescope*, 59, 455, 1980.
26. Cash, W., and T.P. Snow, "HR976 and 4C34.13: An x-ray odd couple," *Astr. Ap.* , 91, L7, 1980.
27. Snow, T.P., W. Cash, and C.A. Grady, "The detection of x-ray variability in O stars," *Ap. J.(Letters)*, 244, L19, 1980.
28. Cash, W., "Requirements for high quality x-ray spectroscopy in an Explorer Class Mission," in *NASA Technical Memorandum 83848: X-ray Astronomy for the 1980's*, 403, 1982.
29. Cash, W., and R. Kohnert, "Very high x-ray efficiency from a blazed grating," *Appl. Opt* , 21, 17, 1982.
30. Cash, W., "Echelle spectrographs at grazing incidence," *Appl. Opt* , 21, 710, 1982.
31. McClintock, W.E., and W. Cash, "Grazing incidence optics: New techniques for high sensitivity spectroscopy in the space ultraviolet," *Proc. Soc. Photo-Opt. Instr. Eng.* , Instrumentation in Astronomy IV, 331, 321, 1982.
32. Cash, W., and T.P. Snow, Jr., "A study of x-ray emission from Ap and Am stars," *Ap. J.(Letters)*, 263, L59, 1982.
33. Cash, W., "X-ray superbubbles," *Highlights of Astronomy*, 6, 675, 1983.
34. Grady, C.A., T.P. Snow, and W. Cash, "Line profile variation in δ Ori A, ι Ori A, and 15 Mon," *Ap. J.* , 283, 218, 1984.
35. Cash, W., "X-ray spectrographs using radial groove gratings," *Appl. Opt* , 22, 3971, 1983.
36. Golub, L., Harnden, F.R., Maxson, C.W., Rosner, R., Vaiana, G.S., Cash, W., and Snow, T.P., "Einstein observations of x-ray emission from A stars," *Ap. J.* , 271, 264, 1983.
37. Culhane, J.L., Cash, W., Catura, R.C., "New applications of x-ray optical techniques," *Nuclear Inst. and Methods in Phys. Res.*, 221, 251-264, 1984.
38. Cash, W., "The Far Ultraviolet Spectroscopic Explorer," *Science and Technology Series of the American Astronautical Society*, 56, 107, 1984.
39. Windt, D., and W. Cash, "Laboratory Evaluation of Conical Diffraction Spectrographs," *Proc. Soc. Photo-Opt. Instr. Eng.* , 503, 98-105, 1984.

40. Cash, W., "Aspheric Concave Grating Spectrographs," *Appl. Opt.* , 23, 4518-4522, 1984.
41. Simon, T., W. Cash and T. Snow, "Ultraviolet and X-ray Observations of NGC 2264," *Ap. J.* , 293, 542-550, 1984.
42. Windt, W. and Cash W., "The Soft X-ray/EUV Calibration Facility at the University of Colorado," *Proc. Soc. Photo-Opt. Instr. Eng.* , 689, 167, 1986.
43. Scott, M., Arendt, P., Cameron, B., Cordi, R., Newman, B., Windt, D., and Cash W., "Metal Reflectors in the EUV", *Proc. Soc. Photo-Opt. Instr. Eng.* , 691, 20, 1986.
44. Cash, W., "X-ray optics: a technique for high resolution imaging", *Appl. Opt.* , 26, 2915-2920, 1987.
45. Windt, D., Cash, W., Scott, M., Arendt, P., Newman, B., Fisher, R., Swartzlander, A., "Optical Constants for Thin Films of Ti, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Hf, Ta, W, Re, Os, Ir, Pt, and Au from 24Å to 1216Å ," *Appl. Opt.* , 27, 246, 1988.
46. Windt, D., Cash W., Scott, M., Arendt, P., Newman, B., Fisher, R., Swartzlander, A., "Optical Constants for Thin Films of C, diamond, Al, Si, and CVD SiC from 24Å to 1216Å," *Appl. Opt.* , 27, 279, 1988.
47. Catura, R., Stern, R., Cash, W., Windt, D., Culhane, J. L., Lappington, J., Barnsdale, K., "X-ray Objective Grating Spectrograph", *Proc. Soc. Photo-Opt. Instr. Eng.* , 830, 204-216, 1988.
48. Cash, W., Cook, T., Chambellan, C., Heyse, D., Hofmockel, D., Snow, T., Windt, D., and Zaidins, C., "A Far-Ultraviolet Rocket-Borne Spectrograph," *Experimental Astronomy*, 1, 123-143, 1989.
49. Cook, T., Cash, W., and Snow, T., "Far Ultraviolet Spectrophotometry of Spica," *Ap. J.(Letters)*, 347, L81-84, 1989.
50. Cash, W., "X-ray Optics 2: A Technique for High Resolution Spectroscopy," *Appl. Opt.* , 30, 1749-1759, 1991.
51. Green, J. C., Cash, W., Cook, T. A., and Stern, S. A., "The Spectrum of Comet Austin from 910 to 1180 Å ", *Science*, 251, 408-410, 1991.
52. Cash, W., "FUV and EUV Spectrographs: Development in the 1980's for Astronomy in the 1990's", *Advances in Space Research*, 11, 171-179, 1991.
53. Stern, S. A., Green, J. C., Cash, W., Cook, T. A., "Helium and Argon Abundance Constraints and the Thermal Evolution of Comet Austin (1989c1)", *Icarus*, 95, 157-161, 1992.
54. Green, J., Cash, W., Cook, T., and Stern, S. A., "Response to Comment on the Spectrum of Comet Austin", *Science*, 253, 452-453, 1991.
55. Cook, T., Green, J., and Cash, W., "Far Ultraviolet Spectrophotometry of BD +28 4211", *Advances in Space Research*, 11, 29-32, 1991.
56. Green, J., Snow, T., Cook, T., Cash, W., and Poplawski, O., "The Anomalous Extinction Curve in the Direction of ρ Oph from 950 - 1180Å ", *Ap. J.* , 395, 289-294, 1992
57. Wilkinson, E., Green, J. C., and Cash, W., "Direct Observation of EUV Opacity Sources in the Hot, DA White Dwarf G191-B2B", *White Dwarfs: Advances in Observation and Theory*, Kluwer Academic, 171-176, 1993
58. Wilkinson, E., Green, J. C., and Cash, W., "The Extreme Ultraviolet Spectrograph: A Radial Groove Grating, Sounding Rocket Borne, Astronomical Instrument", *ApJ (Suppl.)*, **89**, 211-220, 1993.

59. Wilkinson, E., Green, J. C., and Cash, W., "Extreme Ultraviolet Spectroscopy of G191-B2B: Direct Observation of Ionization Edges", *ApJ (Letters)*, 397, L51-L54, 1992
60. Wilkinson, E., Green, J. C., Thomas R. Ayres and Cash, W., "Extreme Ultraviolet Spectroscopy of Capella", *ApJ (Letters)*, 397, L99-L102, 1992
61. Cash, W., "Ultraviolet Spectroscopic Instrumentation," *Proceedings of the 10th International Colloquium on UV and X-ray Spectroscopy of Astrophysical and Laboratory Plasmas*, Cambridge University Press, 270-279, 1993
62. Sarlin, S. P., Cash, W., and Green, J. C., "Optimized Holographic Grating Solutions for Rowland Circle Spectrographs", *Proc. Soc. Photo-Opt. Instr. Eng.* , **1945**, 361-364, 1993.
63. Cash, W., "Far Ultraviolet Spectrographs: Impact of Holographic Grating Design", *Appl. Opt.*, **34**, 2241-2246, 1995
64. Gallagher, D., Cash, W., Green, J. C., "A Search for an X-Ray Scattering Halo Around Scorpius X-1", *Ap. J.* , **439**, 976-982, 1995
65. Cash, W., "X-ray Diffraction Gratings", *Proceedings of the International School of Space Science*, 1995
66. Cash, W., "X-ray Interferometers", *Proceedings of the International School of Space Science*, 1995
67. Slater, D. C., Stern, S. A., Scherrer, J., Cash, W., Green, J. C., and Wilkinson, E., "The Extreme Ultraviolet Spectrograph Sounding Rocket Payload: Recent Modifications for Planetary Observations in the EUV/FUV", *Proc. Soc. Photo-Opt. Instr. Eng.* , **2518**, 1995.
68. Stern, S. A., Slater, D. C., Cash, W., Wilkinson, E., Green, and Gladstone, G. R., "Rocket FUV Observations of the Io Plasma Torus During the Shoemaker-Levy/9 Impacts", *GRL*, **22**, 1837, 1995
69. Stern, S. A., Slater, D. C., Gladstone, G. R., Wilkinson, E., Cash, W. C., Green, J. C., Hunten, D., Owen, T., and Paxton, L., "The 825-1110Å EUV Spectrum of Venus", *Icarus*, **122**, 200-204, 1996
70. Gallagher, D., Cash, W., Jelsma, S., Farmer, J., "Sub-Arcsecond X-ray Telescope for Imaging the Solar Corona in the 0.25-1.25keV Band", ", *Proc. Soc. Photo-Opt. Instr. Eng.* , **2805**, 121-132, 1996
71. Cash, Webster, "High Resolution X-ray Imaging", *The Next Generation of X-ray Observatories*, edited by MJL Turner and MG Watson, University of Leicester Report XRA97/02, pp 147-152, 1997
72. Cash, Webster, "The Mission Tree", *UV-Optical Space Astronomy Beyond HST*", edited by JA Morse, JM Shull, AL Kinney, Astronomical Society of the Pacific Conference Series, 164, 317-321, 1999
73. Cash, Webster, "X-ray Interferometry: Exciting Science and Feasible Technology", *Proceedings of the 16th IEEE Instrumentation and Measurement*, ed. V. Piuri and M. Savino, IEEE Press, 1123-1128, 1999
74. Cash, W., "High Resolution X-ray Imaging" in *Small Missions for Energetic Astrophysics*, S. P. Brumby editor, American Institute of Physics Press, 44-57, 1999
75. Cash, W., "High Uniformity Collimator for X-ray Proximity Lithography", *Proc. Soc. Photo-Opt. Instr. Eng.* , **3767**, 59-66, 1999

76. Shipley, A., Cash, W., Osterman, S., Joy, M., Carter, J., "Development of a Grazing Incidence X-ray Interferometer", *Proc. Soc. Photo-Opt. Instr. Eng.* , **3786**, 291-299, 1999.
77. Kahn, S. K., Paerels, F. B., Rasmussen, A., Schattenburg, M. L., Ricker, G. R., Bautz, M. W., Doty, J. P., Prighozin, G. Y., Nousek, J. A., Burrows, D. N., Hill, J. E., Cash, W. C., "Large Area Reflection Grating Spectrometer for the Constellation-X Mission", *Proc. Soc. Photo-Opt. Instr. Eng.* , **3765**, 94-103, 1999.
78. Shipley, A., Cash, W., Joy, M., "Grazing Incidence Optics for X-ray Interferometry", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 456-466, 2000.
79. Joy, M., Shipley, A., Cash, W., Carter J., Zissa, D., Cuntz, M., "Experimental Results from a Grazing Incidence X-ray Interferometer" *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 270-277, 2000.
80. Cash, W., White N., Joy, M., "The Maxim Pathfinder Mission: X-ray Imaging at 100 Micro-Arcseconds", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 258-269, 2000.
81. Windt, D., Cash, W., and Kahn, S., "The Scattering of X-rays by Interstellar Dust on the Micro-Arcsecond Scale", *Ap. J.*, **528**, 306-309, 2000.
82. Cash, W., Shipley, A., Osterman, S., and Joy, M., "Laboratory Detection of X-ray Fringes with a Grazing-Incidence Interferometer", *Nature*, **407**, 160-162, 2000.
83. Cash, W., "High Uniformity Collimator for X-ray Proximity Lithography", *Proc. Soc. Photo-Opt. Instr. Eng.* , **4144**, 228-237, 2000
84. Moos, H. W., Cash, W. C., et. al., "Overview of the Far Ultraviolet Spectroscopic Explorer", *Ap. J. (Letters)*, **538**, L1-L6, 2000.
85. Cash, W., White, N., and Joy, M., "The Maxim Pathfinder Mission: X-ray Imaging at 100 Micro-Arcseconds", ASP Proceedings, **234**, X-ray Astronomy 2000, 619-626 2001
86. Cash, W., "X-ray Interferometry", IAU Symposium 205, Galaxies and Their Constituents at the Highest Angular Resolutions, Schilizzi et al editors, ASP Press, 457-462, 2001
87. Cash, W., "A Twisted Look at the X-ray Sky", *Nature*, **411**, 644-647, 2001.
88. Cash, W., Shipley, A., and McEntaffer, R. L., "X-ray interferometry: ultra-high-resolution astronomy", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4506**, 127-135, 2001.
89. Shipley, A., and Cash, W., "Alignment of a Grazing Incidence X-ray Interferometer", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4444**, 17-28, 2001.
90. Cash, W., White, N., and Joy, M., "The Maxim Mission: X-ray Interferometry in the New Century", ASP Proceedings, **251**, New Century of X-ray Astronomy, 206-209, 2001
91. Cash, Webster, "X-ray Telescopes", in Encyclopedia of Imaging Science and Technology, Joseph P. Hornak editor, John Wiley and Sons, New York, 1495-1509, 2002.
92. Cash, W., "Maxim: The Micro-Arcsecond X-ray Imaging Mission", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4852**, 196-209, 2002.
93. Gendreau, K. C., Cash, W. C., White, N., Shipley, A. F., "MAXIM Pathfinder X-ray Interferometry Mission", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4851**, 353-364, 2002.
94. Lieber, M. D., Cash, W. C., Gallagher, D. J., Shipley, A. F., "System Performance Evaluation of the MAXIM Concept with Integrated Modeling", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4851**, 557-567, 2002.

95. Shipley, A. F., Cash, W. C., Gendreau, K. C., "MAXIM Interferometer Tolerances and Tradeoffs", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4851**, 568-577, 2002.
96. Gendreau, K. C., Leitner, J., Markley, L., Cash, W. C., Shipley, A. F., "Options and Requirements for a Stable Inertial Frame Reference for a 100 Microarcsecond Imaging Telescope", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4852**, 685-694, 2002.
97. R. McEntaffer, W. Cash, A. Shipley, "Off-plane gratings for Constellation-X", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4851**, 549-556, 2002.
98. Allred, D., Squires, M. B., Turley, R. S., Cash, W., and Shipley, A., "Highly Reflective Uranium Mirrors for Astrophysics Applications", *Proc. Soc. Photo-Opt. Instr. Eng.*, **4782**, 212-223 , 2002.
99. Gendreau, K., Cash, W., Shipley, A., "Maxim: The Black Hole Imaging Mission", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 420-434 , 2003.
100. Cash, W., Gendreau, K., Shipley, A., Gallagher, D., "MAXIM Pathfinder: A Practical Configuration", Gendreau, K., Cash, W., Shipley, A., "Maxim: The Black Hole Imaging Mission", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 435-445 , 2003.
101. Gallagher, D., Cash, W., Shipley, A., "Modeling the Optical Performance of Grazing Incidence X-ray Interferometers", Gendreau, K., Cash, W., Shipley, A., "Maxim: The Black Hole Imaging Mission", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 446-458 , 2003.
102. McEntaffer, R., Osterman, S., Shipley, A., Cash, W., "X-ray Performance of Gratings in the Extreme Off-plane Mount", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 492-498 , 2003.
103. McEntaffer, R., Hearty, F., Gleeson, B., Cash, W., "X-ray Test Facility for Diffraction Gratings", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 499-507 , 2003.
104. Rasmussen, A., Bookbinder, J., Cash, W., Heilmann, R., Kahn, S., Paerels, F., Schattenburg, M., "Grating Arrays for High-throughput Soft X-ray Spectrometers", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5168**, 248-259 , 2003.
105. Arzoumanian, Z., Gendreau, K., Cash, W., Shipley, A., Queen, S. Z., "Laboratory Testbeds for Broadband X-ray Interferometry", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 623-629, 2004
106. Cash, W. and Shipley, A., "Off-plane Grating Mount Tolerances for Constellation-X", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 335-340, 2004
107. Flanagan, K. A., et al, "The Constellation-X RGS Options: Status of the Grating Trade Study", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 515-529, 2004
108. Gendreau, K., Cash, W., Gorenstein, P., Windt, D., Kaaret, P., Reynolds, C., "Maxim: The Black Hole Imager", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 394-402 , 2004
109. Leitch, J., Lieber, M., Gallagher, D. J., Gendreau, K., Cash, W., Shipley, A., "System Performance Model and Error Budget for Maxim", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 593-600, 2004
110. McEntaffer, R., and Cash, W., "High Resolution X-ray Spectroscopy of Supernova Remnants and the Diffuse X-ray Background", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 136-147, 2004
111. Osterman, S., McEntaffer, R., Cash, W., Shipley, A., "Off-plane Grating Performance for Constellation-X", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5488**, 302-311, 2004
112. Cash, W., and Gendreau, K., "Maxim Science and Technology", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5491**, 199-211, 2004

113. Simmons, W. L., Cash, W., Seager, S., Wilkinson, E., Kasdin, N. K., Vanderbei, R. J., Chow, N., Gralla, E., Kleingeld, J., "The New Worlds Observer: A Mission for High-Resolution Spectroscopy of Extra-Solar Terrestrial Planets", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5487**, 1634-1645, 2004
114. Cash, W., "X-ray Interferometry", *Experimental Astronomy*, **16**, 91-136, 2004
115. Cash, W., "High Resolution X-ray Spectroscopy: Is It Interesting? Is It Possible?", *Advances in Space Science*, in press 2004.
116. Cash, W., "Imaging a Black Hole: MAXIM", *Advances in Space Research*, **35**, 122-129, 2005
117. Webster Cash, Jeremy Kasdin, Sara Seager, Jonathon Arenberg "Direct studies of exoplanets with the New Worlds Observer", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5899**, 0S1-0S12, 2005
118. Cash, W., "X-ray Interferometry", *Future Directions in High Resolution Astronomy: The 10th Anniversary of the VLBA*, Astronomical Society of the Pacific Conference Series, Romney, J., and Reid, M., **340**, 633-638, 2005
119. Randall L. McEntaffer, Webster Cash, Ann Shipley, "Sounding rocket payload development for x-ray observations of the Cygnus Loop" *Proc. Soc. Photo-Opt. Instr. Eng.*, **5900**, 1B1-1B12, 2005
120. Nishanth Rajan, Webster Cash, "Kirkpatrick-Baez optics for the Generation-X mission" *Proc. Soc. Photo-Opt. Instr. Eng.*, **5900**, 1F1-1F7, 2005
121. Schindhelm, E., Cash, W., Seager, S., "Science simulations for the New Worlds Observer", *Proc. Soc. Photo-Opt. Instr. Eng.*, **5905**, 455-463, 2005
122. Cash, W., "Detection of Earth-like planets around other stars using petal-shaped occulters", *Nature*, **442**, 51-53, (2006)
123. Shipley, A., Gleeson, B., McEntaffer, R., Cash, W., "Studies in thin diffraction gratings for flight applications", *Proc. Soc. Photo-Opt. Instr. Eng.*, **6273**, 3K, 1-10, 2006
124. McEntaffer R., Cash, W., Shipley, A., Schindhelm. E., "A sounding rocket payload for x-ray observations of the Cygnus Loop" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6266**, 44, 1-12, 2006
125. Osterman, O., Cash, W., "Kirkpatrick Baez spectrograph concepts for future space missions" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6266**, 38, 1-8, 2006
126. Arenberg, J., Lo, A., Cash, W., Polidan, R., "New Worlds Occulter performance: a first look" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6265**, 1W, 1-14, 2006
127. Cash, W., Schindhelm, E., Arenberg, J., Polidan, R., Kilston, S., Noecker, C., "The New Worlds Observer: using occulters to directly observe planets" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6265**, 1V 1-11, 2006
128. Cottam, J., Cash, W., Flanagan, K., Heilmann, R., Prigozhin, G., Rasmussen, A., Ricker, G., Schattenburg, M., Schindhelm, E., "The Constellation-X reflection grating spectrometer" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6266**, 1X, 1-8, 2006
129. Schindhelm, E., Arav, N., Cash, W., "High-resolution x-ray spectroscopy with the reflection grating spectrometer of Constellation-X" *Proc. Soc. Photo-Opt. Instr. Eng.*, **6266**, OC 1-11, 2006
130. Lillie, C. F., Cash, W. C., "High Resolution Soft X-ray Spectroscopy for Constellation-X", *Proc. Soc. Photo-Opt. Instr. Eng.*, **6686**, 2007
131. Cash, W., et al, "External occulters for direct observation of exoplanets: an overview", *Proc. Soc. Photo-Opt. Instr. Eng.*, **6687-12**, 1-14, 2007

132. Lyon, R., Lo, A., Cash, W., Starkman, G. D, Vanderbei, R., Kasdin, J., Copi, C., “Externally occulted terrestrial planet finder coronagraph: simulations and sensitivities“, *Proc. Soc. Photo-Opt. Instr. Eng.*, **6687**-19, 1-12, 2007
133. Shipley, A., Cash, W., Arenberg, J., Lo, A., “New Worlds Observer tolerances overview”, *Proc. Soc. Photo-Opt. Instr. Eng.*, **6687**-1A, 1-11, 2007
134. Leviton, D., Cash, W., Gleeson, B., Kaiser, M., Levine, S., Lo, A., Schindhelm, E., Shipley, A., “White-light demonstration of one hundred parts per billion irradiance suppression in air by new starshade occulters”, *Proc. Soc. Photo-Opt. Instr. Eng.*, **6687**-1B, 1-12, 2007
135. Schindhelm E.; Shipley; A. Oakley; P. Leviton; W. Cash; D. Card, G., “Laboratory studies of petal-shaped occulters”, *Proc. Soc. Photo-Opt. Instr. Eng.*, **6693**, 669305-669312 , 2007
136. McEntaffer, R. L., and Cash, W., “Soft X-ray Spectroscopy of the Cygnus Loop Supernova Remnant”, *ApJ*, **680**, 328-335, 2008
137. Skinner, G. K., Arzoumanian, Z., Cash, W. C., Gehrels, N., Gendreau, K. C., Gorenstein, P., Krizmanic, J. F., Miller, M. C., Phillips, J. D., Reasenberg, R. D., Reynolds, C. S., Sambruna, R. M., Streitmatter, R. E., and Windt, D. L., “The milli-arc-second structure imager (MASSIM): a new concept for a high angular resolution x-ray telescope”, *Proc. SPIE*, **7011**, 70110T, 11pp, 2008
138. McEntaffer, Randall, L., Cash, Webster, and Shipley, Ann, “Off-plane reflection gratings for Constellation-X”, *Proc. SPIE*, **7011**, 701107, 8pp, 2008
139. Gorenstein, Paul, Cash, Webster, Gehrels, Neil, Gendreau, Keith, Krizmanic, John, Miller, M. Coleman, Reynolds, Christopher, S., Sambruna, Rita M., Skinner, Gerald, K., Streitmatter, Robert E., and, Windt, David., L., “The future of high angular resolution x-ray astronomy”, *Proc. SPIE*, **7011**, 70110U, 9pp, 2008
140. Oakley, Phil, Cash, Webster and Turnbull, Margaret, “Analysis of exoplanet light curves with the New Worlds Observer”, *Proc. SPIE*, **7010**, 70103Y, 9pp, 2008
141. Howard, Joseph M., Noecker, Charlie, Kendrick, Steve, Kilston, Steve, Woodgate, Bruce, and Cash, Webster, “New Worlds Observer telescope and instrument optical design concepts”, *Proc. SPIE*, **7010**, 70103X, 9pp, 2008
142. Lo, Amy S., Glassman, Tiffany, Dailey, Dean, Lillie, Charles F., Cash, Webster, and Oakley, Philip, “New Worlds Observer: Minotaur to Ares V”, *Proc. SPIE*, **7010**, 70101W, 9pp, 2008
143. Arenberg, Jonathon, W., Shipley, Ann, Cash, Webster, Glassman, Tiffany, and Lo, Amy, “Sensitivity analysis of the New Worlds starshade's shadow”, *Proc. SPIE*, **7010**, 70101V, 11pp, 2008
144. Cash, W., Oakley, P., Turnbull, M., Glassman, T., Lo, A., Polidan, R., Kilston, S., and Noecker, C., “The New Worlds Observer: scientific and technical advantages of external occulters”, *Proc. SPIE*, **7010**, 70101Q, 9pp, 2008
145. McEntaffer, Randall L., Neil J. Murray, Andrew Holland, Charles Lillie, Suzanne Casement, Dean Dailey, Tim Johnson, Webster C. Cash, Phillip H. Oakley, Ted Schultz, and David N. Burrows, “Off-plane grating spectrometer for the International X-ray Observatory”, *Proc. SPIE*, **7437**, 74370H, 13pp, (2009)
146. Soummer, Rémi, Webster Cash, Robert A. Brown, Ian Jordan, Aki Roberge, Tiffany Glassman, Amy Lo, Sara Seager, and Laurent Pueyo, “A starshade for JWST: science goals and optimization”, *Proc. SPIE*, **7440**, 74400A 15pp, (2009)

147. Cash, Webster, and 48 co-authors of the New Worlds Study Team, “The New Worlds Observer: the astrophysics strategic mission concept study”, *Proc. SPIE*, **7436**, 743606 14pp (2009)
148. Oakley, Phil, Webster Cash, Randy McEntaffer, Ann Shipley, and Ted Schultz, “The EXOS sounding rocket payload”, *Proc. SPIE*, **7437**, 74370I 8pp (2009)
149. Glassman, Tiffany, Amy S. Lo, Jonathan Arenberg, Webster Cash, and Charley Noecker, “Starshade scaling relations”, *Proc. SPIE*, **7440**, 744013 10pp (2009)
150. McEntaffer, Randall L., Neil J. Murray, Andrew Holland, Chuck Lillie, Suzanne Casement, Dean Dailey, Tim Johnson, Webster Cash, and Phil Oakley, “Off-plane x-ray grating spectrometer for the International X-ray Observatory” *Proc. SPIE*, **7360**, 73600H 11pp (2009)
151. Oakley, P., and Cash, W., “Construction of an Earth Model: Analysis of Exoplanet Light Curves and Mapping the Next Earth with the New Worlds Observer”, *ApJ*, **700**, 1428-1439 (2009)
152. Oakley, Phil, Ben Zeiger, Michael Kaiser, Ann Shipley, Webster Cash, Randall McEntaffer, and Ted Schultz, “Results from the Extended X-ray Off-plane Spectrometer (EXOS) sounding rocket payload” *Proc. SPIE*, **7732**, 77321R, 10pp (2010)
153. Cash, W., T. Glassman, A. Lo, and R. Soummer, “Alternative starshade missions” *Proc. SPIE* **7731**, 77312J 10pp (2010)
154. Soummer, Rémi, Jeff Valenti, Robert A. Brown, Sara Seager, Jason Tumlinson, Webster Cash, Ian Jordan, Marc Postman, Matt Mountain, Tiffany Glassman, Laurent Pueyo, and Aki Roberge, “Direct imaging and spectroscopy of habitable planets using JWST and a starshade” *Proc. SPIE*, **7731**, 77312I 10pp (2010)
155. Zeiger, Benjamin R., Ann Shipley, Webster Cash, and Randall McEntaffer, “X-ray resolution tests of an off-plane reflection grating for IXO” *Proc. SPIE* **7732**, 773245 10pp (2010)
156. Lo, Amy S., Tiffany Glassman, Dean Dailey, Ken Sterk, James Green, Webster Cash, and Remi Soummer, “New Worlds Probe” *Proc. SPIE* **7731**, 77312E 10pp (2010)
157. Murray, Neil J., Andrew D. Holland, Richard D. Harriss, James H. Tutt, Simeon J. Barber, Peter Pool, James Endicott, David Burt, Dave Walton, Mat Page, Randall L. McEntaffer, Ted Schultz, Webster C. Cash, Chuck Lillie, and Suzanne Casement, “Off-plane x-ray grating spectrometer camera for IXO” *Proc. SPIE* **7742**, 77420X 10pp (2010)
158. Casement, Suzanne, Randall L. McEntaffer, Webster Cash, Tim Johnson, Charles Lillie, and Dean Dailey, “A tower concept for the off-plane x-ray grating spectrometer for the International X-ray Observatory” *Proc. SPIE* **7732**, 77323W 10pp (2010)
159. McEntaffer, R. L. et al. “Developments of the off-plane x-ray grating spectrometer for IXO” *Proc. SPIE* **7732**, 77321K 10pp (2010)
160. Oakley, Phillip, H. H., McEntaffer, Randall L., Cash, Webster, “A suborbital payload for soft X-ray spectroscopy of extended sources”, *Experimental Astronomy*, **30**, 22pp (2011)
161. Zeiger, B., A. Shipley, W. Cash, T. Rogers, T. Schultz, R. McEntaffer, and M. Kaiser “The CODEX sounding rocket payload”, *Proc. SPIE* **8076**, 6pp (2011)
162. Cash, W., “Compact Optics for high resolution spectroscopy of celestial x-ray sources”, *Proc. SPIE* **8076**, 6pp (2011)

163. Pina, L., Marsikova, V., Hudec, R., Inneman, A., Marsik, J., Cash, W., Shipley, A., Zeiger, B., “Full-aperture x-ray tests of Kirkpatrick-Baez modules: preliminary results” Proc. SPIE **8076**, 807609-1, 6pp (2011)
164. Cash, W., “Analytic Modeling of Starshades”, Ap. J., **738**, 76, 13pp (2011)
165. Cash, W., McEntaffer, R., Zhang, W., Casement, S., Lillie, C., Schattenburg, M., Bautz, M., Holland, A., Tsunemi, H., O’Dell, S., “X-ray optics for WHIMex: the Warm Hot Intergalactic Medium Explorer”, Proc. SPIE **8147**, 1J-1, 6pp (2011)
166. McEntaffer, R., Cash, W., Lillie, C., Casement, S., Zhang, W., Holland, A., Murray, N., O’Dell, S., Schattenburg, Heilmann, Ralf, M., Tsunemi, H., “Development of off-plane gratings for WHIMex and IXO”, Proc. SPIE **8147**, 1K-1, 11pp (2011)
167. Lillie, C., Cash, W., McEntaffer, R., et al, “The Warm-Hot Intergalactic Medium Explorer (WHIMex) mission Proc. SPIE **8147**, C-1, 14pp (2011)
168. Cash, W. and Lo, A., “Limits on achievable intensity reduction with an optical occulter: comment”, Journal of the Optical Society of America A, 29, 913-917, (2012)
169. Petre R., J. Bregman, M. Bautz, D. Burrows, W. Cash, C. Jones-Forman, S. Murray, P., Plucinsky, B. Ramsey, R. Remillard, C. Wilson-Hodge, A. Ptak, J. Bookbinder, M. Garcia, R., Smith, G. Daelemans, “The NASA X-ray Mission Concepts Study”, Proc. SPIE **8443**, 13pp (2012)
170. Bautz, Marshall W., Webster C. Cash, John E. Davis, Ralf K. Heilmann, David P., Huenemoerder, Mark L. Schattenburg, Randall McEntaffer, Randall Smith, Scott J. Wolk, William W. Zhang, Steven P. Jordan, Charles F. Lillie, “Concepts for High-Performance Soft X-ray Grating Spectroscopy in a Moderate-Scale Mission”, Proc. SPIE **8443**, 9pp (2012)
171. Margaret C. Turnbull, Tiffany Glassman, Aki Roberge, Webster Cash, Charley Noecker, Amy Lo, Brian Mason, Phil Oakley and John Bally, “The Search for Habitable Worlds. 1. The Viability of a Starshade Mission”, *Publications of the Astronomical Society of the Pacific*, Vol. **124**, pp. 418-447 (2012)
172. Oakley, P., McEntaffer, R., Cash, W., “Soft X-ray Spectroscopy of the Cygnus Loop Supernova Remnant”, ApJ, **766**, 6pp (2013)
173. Pina, L., R. Hudec, V. Tichy, A. Inneman, D. Cerna, L. Sveda, J. Marsik, V. Marsikova, W. Cash, A. F. Shipley, B. R. Zeiger, and T. D. Rogers, “Design of Novel X-ray Optical System for Rocket Experiment” SPIE **8448**, 12pp (2012)
174. Pina, L., R. Hudec, V. Tichy, A. Inneman, D. Cerna, J. Marsik, V. Marsikova, W. Cash, A. F. Shipley and B. R. Zeiger, T. D. Rogers, R. Melich “Novel design of a large X-ray optical system for astrophysical application” SPIE **8502**, 6pp (2013)
175. Pina, L., R. Hudec, V. Tichy, A. Inneman, D. Cerna, J. Marsik, V. Marsikova, W. Cash, A. F. Shipley and B. R. Zeiger, T. D. Rogers “Hybrid X-ray optical system for space astrophysics” SPIE **8777**, 8pp (2013)
176. DeRoo, Casey, Randall L. McEntaffer, Ted Schultz, William W. Zhang, Neil J. Murray, Stephen L. O’Dell, Webster Cash “Pushing the Boundaries of X-ray Grating Spectroscopy in a Suborbital Rocket” SPIE **8861**, 11pp (2013)
177. Lawson, P. R., R. Belikov, W. Cash, M. Clampin, T. Glassman, O. Guyon, N. J. Kasdin, B. D. Kern, R. Lyon, D. Mawet, D. Moody, R. Samuele, E. Serabyn, D. Sirbu, and J. Trauger “Survey of experimental results in high-contrast imaging for future exoplanet missions” SPIE **8864**, 8pp (2013)

178. Rogers, T., R. McEntaffer, T. Schultz, B. Zeiger, P. Oakley, W. Cash “The OGRESS sounding rocket payload” SPIE **8859**, 7pp (2013)
179. Harness, Anthony, Webster Cash, Ann Shipley, Tiffany Glassman, Steven Warwick “New Worlds Airship” SPIE **8864**, 8pp (2013)
180. L. Pina; D. Burrows; W. Cash; D. Cerna; P. Gorenstein; R. Hudec; A. Inneman; J. Jakubek; V. Marsikova; L. Sieger; V. Tichy, “X-ray monitoring for astrophysical applications”, SPIE **9207**, 8pp (2014)
181. James H. Tutt; Randall L. McEntaffer; Casey DeRoo; Ted Schultz; Drew M. Miles; William Zhang; Neil J. Murray; Andrew D. Holland; Webster Cash; Thomas Rogers; Steve O'Dell; Jessica Gaskin; Jeff Kolodziejczak; Anthony M. Evagora; Karen Holland; David Colebrook, “Developments in the EM-CCD camera for OGRE”, SPIE **9154**, 7pp (2014)
182. L. Pina; R. Hudec; A. Inneman; D. Cerna; J. Jakubek; L. Sieger; V. Dániel; W. Cash; L. Mikulickova; R. Pavlica; E. Belas; J. Polak, “X-ray monitoring for astrophysical applications on Cubesat”, SPIE **9510**, 9pp (2015)
183. Seager, S., et al., “The Exo-S Probe Class Starshade Mission” SPIE **9605**, 18pp, (2015)
184. Harness, A., Warwick, S., Shipley, A., Cash, W., “Ground-based Testing and Demonstrations of Starshades”, SPIE **9904**, 13pp (2016)
185. Deccia, C., Villalba, E., Parker, J., Cash, W., Born, G., and Noomen, R.. "Surfing the L2 gradient with the starshade in search of extraterrestrial life", AIAA/AAS Astrodynamics Specialist Conference, AIAA SPACE Forum, (AIAA 2016-5666) 9pp, (2016)
186. Harness, A., Cash, W., Warwick, S., “High Contrast Observations of Bright Stars with a Starshade”, *Experimental Astronomy*, submitted (2017) Harness, A., Cash, W. & Warwick, S. *Exp Astron* (2017) 44: 209. <https://doi.org/10.1007/s10686-017-9562-1> December 2017, Volume 44, **Issue 2**, pp 209–237
187. Harness, A., Shaklan, S., Cash, W., Dumont, P., “Advances In Edge Diffraction Algorithms”, *Journal of the Optical Society of America A*, J. **35**(2), 275-285 (2018)

Patents:

1. Cash, Webster C Jr, “Spherical Mirror Grazing Incidence X-ray Optics”, US Patent #5,604,782 (1997).
2. Cash, W. “X-ray Collimator for Lithography”, US Patent #6,049,588 (2000).
3. Cash, W. “Collimator for X-ray Proximity Lithography”, US Patent #6,108,397 (2000)
4. Cash, W. and Weil, M., “Pharmaceutically Enhanced Low-Energy Radiosurgery” US Patent #6,125,295 (2000)
5. Cash, W., “X-ray Interferometer” US Patent #6,195,410 (2001).
6. Cash, W., “Medical Uses of Focused and Imaged X-rays”, US Patent #6,359,963 (2002)
7. Cash, W., “Deep Shadow Occulter”, US Patent #7828451 (2010)