PROCEEDINGS OF SPIE

Techniques and Instrumentation for Detection of Exoplanets VIII

Stuart Shaklan
Editor

8–10 August 2017
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 10400

Proceedings of SPIE 0277-786X, V. 10400

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Techniques and Instrumentation for Detection of Exoplanets VIII, edited by Stuart Shaklan, Proc. of SPIE
Vol. 10400, 1040001 · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2298430

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:
Author(s), "Title of Paper," in *Techniques and Instrumentation for Detection of Exoplanets VIII*, edited by Stuart Shaklan, Proceedings of SPIE Vol. 10400 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510612570
ISBN: 9781510612587 (electronic)

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org
Copyright © 2017, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is $18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/17/$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

SPIEDigitalLibrary.org

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B … 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

Contents

ix *Authors*
xiii *Conference Committee*

SESSION 1 WFIRST CORONAGRAPH I

10400 03 **The WFIRST coronagraph instrument optical design update** [10400-2]

10400 04 **WFIRST coronagraph optical modeling** [10400-4]

10400 05 **Wavefront control performance modeling with WFIRST shaped pupil coronagraph testbed** [10400-5]

10400 06 **Sensitivity of WFIRST coronagraph broadband contrast performance to DM actuator errors** [10400-6]

SESSION 2 WFIRST CORONAGRAPH II

10400 07 **Sensitivity of the WFIRST coronagraph performance to key instrument parameters** [10400-7]

10400 09 **Current science requirements and planned implementation for the WFIRST-CGI Integral Field Spectrograph (IFS)** [10400-9]

10400 0B **Simulating the WFIRST coronagraph Integral Field Spectrograph** [10400-11]

SESSION 3 WFIRST CORONAGRAPH III

10400 0C **Fabrication of coronagraph masks and laboratory scale star-shade masks: characteristics, defects, and performance** [10400-12]

10400 0D **Dynamic testbed demonstration of WFIRST coronagraph Low Order Wavefront Sensing and Control (LOWFS/C)** [10400-13]

10400 0E **Shaped pupil coronagraphy for WFIRST: high-contrast broadband testbed demonstration** [10400-14]

10400 0F **Hybrid Lyot coronagraph for WFIRST: high-contrast broadband testbed demonstration** [10400-15]

SESSION 4 SEGMENTED APERTURE CORONAGRAPHS

10400 0G **Capabilities of ACAD-OSM, an active method for the correction of aperture discontinuities** [10400-16]

10400 0H **Coronagraph design optimization for segmented aperture telescopes** [10400-17]

10400 0J **Performance and sensitivity of vortex coronagraphs on segmented space telescopes** [10400-19]

10400 0M **Sensitivity analysis for high-contrast missions with segmented telescopes** [10400-22]

10400 0N **Design, fabrication, and testing of stellar coronagraphs for exoplanet imaging** [10400-64]

10400 0O **Shaped pupil coronagraph design improvements for the WFIRST Coronagraph Instrument** [10400-73]

SESSION 5 CORONAGRAPH DESIGN, COMPONENTS, AND ANALYSIS I

10400 0P **Electric field conjugation in the presence of model uncertainty** [10400-23]

10400 0Q **Wavefront control methods for high-contrast integral field spectroscopy** [10400-24]

10400 0R **Improved high-contrast wavefront controllers for exoplanet coronagraphic imaging systems** [10400-25]

10400 0S **Adaptive estimation of line-of-sight jitter disturbance** [10400-26]

10400 0T **Tip/tilt optimizations for polynomial apodized vortex coronagraphs on obscured telescope pupils** [10400-27]

10400 0U **Patterned liquid-crystal optics for broadband coronagraphy and wavefront sensing** [10400-28]

SESSION 6 CORONAGRAPH DESIGN, COMPONENTS, AND ANALYSIS II

10400 0V **Optimal design of apodizing phase plate coronagraphs** [10400-29]

10400 0W **High contrast imaging in multi-star systems: progress in technology development and lab results** [10400-30]

10400 0Y **Utilizing active single-mode fiber injection for speckle nulling in exoplanet characterization** [10400-32]

10400 0Z **Baseline requirements for detecting biosignatures with the HabEx and LUVOIR mission concepts** [10400-33]

10400 10 **Optical tolerances for the PICTURE-C mission: error budget for electric field conjugation, beam walk, surface scatter, and polarization aberration** [10400-34]

SESSION 7 DEFORMABLE MIRRORS

10400 11 **Characterization of low mass deformable mirrors and ASIC drivers for high-contrast imaging** [10400-35]

10400 13 **Design of the deformable mirror demonstration CubeSat (DeMi)** [10400-37]

10400 14 **Fundamental limits to high-contrast wavefront control** [10400-80]

SESSION 8 GROUND-BASED INSTRUMENTS

10400 15 **Combining angular differential imaging and accurate polarimetry with SPHERE/IRDIS to characterize young giant exoplanets** [10400-38]

10400 16 **First light of the CHARIS high-contrast integral-field spectrograph** [10400-39]

10400 18 **NIRPS: an adaptive-optics assisted radial velocity spectrograph to chase exoplanets around M-stars** [10400-41]

SESSION 9 STARSHADES

10400 19 **Modeling and performance predictions for the Princeton Starshade Testbed** [10400-42]

10400 1A **Optical demonstration of a starshade at flight Fresnel numbers** [10400-43]

10400 1B **Precise starshade stationkeeping and pointing with a Zernike wavefront sensor** [10400-44]

10400 1C **Starshade mechanical design for the Habitable Exoplanet imaging mission concept (HabEx)** [10400-45]

10400 1D **Prospects for exoplanet imaging in multi-star systems with starshades** [10400-46]

SESSION 10 ASTROMETRY

10400 1E **Gaia and exoplanets: a revolution in the making (Invited Paper)** [10400-47]

10400 1G **Results of the astrometry and direct imaging testbed for exoplanet detection** [10400-49]

SESSION 11 INTERFEROMETRIC CORONAGRAPHY

10400 1I **Segmented Aperture Interferometric Nulling Testbed (SAINT) II: component systems update** [10400-51]

10400 1J **Phase-shifting coronagraph** [10400-59]

SESSION 12 MISSION AND DATA ANALYSIS

10400 1K **ExEP yield modeling tool and validation test results** [10400-53]

10400 1L **Multi-mission modeling for space-based exoplanet imagers** [10400-54]

10400 1N **Quantifying the impact of small statistics on planet detectability at small inner working angles** [10400-56]

10400 1O **Planet signal extraction from direct imaging using common spatial pattern filtering** [10400-57]

POSTERS SESSION

10400 1P **Commissioning and performance results of the WFIRST/PISCES integral field spectrograph** [10400-58]

10400 1Q **Development status and performance of the evanescent wave coronagraph testbed** [10400-60]

10400 1S **Simulation of realistic images for Starshade missions** [10400-62]

10400 1T **Shape accuracy requirements on starshades for large and small apertures** [10400-63]

10400 1U **Starshade orbital maneuver study for WFIRST** [10400-65]

10400 1V **Line profile analysis of the laser frequency comb in FOCES** [10400-66]

10400 1X **Optimization of high-inclination orbits using planetary flybys for a zodiacal light-imaging mission** [10400-68]

10400 1Y **Detected exoplanet population distributions found analytically** [10400-69]

10400 1Z **The low-order wavefront control system for the PICTURE-C mission: preliminary testbed results from the Shack-Hartmann sensor** [10400-70]

10400 20 **The low-order wavefront control system for the PICTURE-C mission: high-speed image acquisition and processing** [10400-71]

10400 21 **Post-processing of the HST STIS coronagraphic observations** [10400-72]

10400 22 **Optimizing the regularization in broadband wavefront control algorithm for WFIRST coronagraph** [10400-74]

10400 24 **Focal plane based wavefront sensing with random DM probes** [10400-76]

10400 26 **The automated data processing architecture for the GPI Exoplanet Survey** [10400-78]

10400 27 **Optimization of pyKLIP's forward model matched filter for the GPI Exoplanet Survey** [10400-79]

10400 28 **Identification of the focal plane wavefront control system using E-M algorithm** [10400-81]

10400 29 **A fiber injection unit for the Keck Planet Imager and Characterizer** [10400-82]

Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Agolli, Jack, 1I
Alagao, Mary Angelie, 1Q
Allan, Gregory, 13
Amiri, Nikta, 04
An, Xin, 0D
Arriaga, Pauline, 26
Artigau, E., 18
Arya, Manan, 1C
Balasubramanian, Kunjithapatham, 0C, 0D, 0E
Bandy, T., 18
Barnes, Derek, 13
Bartos, R. D., 29
Belikov, Ruslan, 0W, 1D, 1G, 1N, 24
Bendek, Eduardo A., 0W, 1D, 1G, 24
Bender, Ralf, 1V
Benz, W., 18
Beuzit, Jean-Luc, 15
Blind, N., 18
Boisse, I., 18
Bolcar, Matthew R., 1I
Bottom, Michael, 1B
Bouchy, F., 18
Bovay, S., 18
Bradford, S. Case, 1C
Brandt, Timothy, 0B, 16
Brewer, John, 0N
Broeg, Ch., 18
Brousseau, D., 18
Bryson, Stephen T., 1N
Buisset, Christophe, 1Q
Burke, Elliot, 1I
Cabral, A., 18
Cady, Eric J., 05, 0B, 0C, 0D, 0E, 0F, 0Q, 1B, 1P, 1T
Cahoy, Kerri L., 0B, 13
Carlotti, Alexis, 1J
Chakrabarti, Supriya, 10, 1Z, 20
Chilcote, Jeffrey K., 16, 26
Choquet, Élodie, 0Y, 21
Conod, U., 18
Cook, Timothy A., 10, 1Z, 20
Corsetti, James, 1I
Currie, Thayne, 16
Debes, John H., 21
de Boer, Jozua, 15
Dekany, R., 0Y
de Kok, Remco J., 15
Delabre, B., 18
Delacroix, Christian, 1K, 1L, 1U
Delfosse, X., 18
Delorme, Jacques-Robert, 0Y, 0Z, 29
de Medeiros, J. R., 18
Demers, Richard, 03
De Rosa, Robert J., 26
DeVries, John, 1I
Dillon, Thomas, 1I
Doelman, David S., 0U
Douglas, Ewan S., 0B, 13
Doyon, R., 18
Dudinov, Vladimir N., 24
Dumont, Philip, 19
Eberhardt, Andrew, 1I
Echeverri, D., 0Y
Echternach, Pierre, 0C
Egron, Sylvain, 0G
Eldorado Riggs, A. J., 0O
Escuti, Michael J., 0U
Figueira, P., 18
Figura, Joseph S., 13
Finan, Emily, 1G
Finn, Susanna C., 10, 1Z, 20
Fitzgerald, M., 29
Fogarty, Kevin, 0G, 0T
Freebury, Gregg, 1C
Fregoso, Santos, 0C
Fucik, J., 0Y
Fusco, Thierry, 0M
Galvin, Michael, 16, 1A
Garrett, Daniel, 1K, 1L, 1U, 1Y
Genolet, L., 18
Gersh-Range, Jessica, 0E
Ginski, C., 15
Girard, Julien H., 15
Gong, Qian, 09, 0B, 0Q, 1P
González Hernández, J. I., 18
Gordon, Brian, 0F
Graham, James R., 26
Groff, Tyler D., 09, 0B, 0Q, 0R, 16, 1P
Grogan, Keith, 1X
Grupp, Frank, 1V
Gubner, Jennifer N., 13
Gull, Jamie, 1C
Gutt, Gary, 04
Guyon, Olivier, 0N, 0Q, 16, 1G
Hagelberg, J., 18
Hamilton, Ryan, 0N
Harness, Anthony D., 19, 1A, 1S
Haughwout, Christian A., 13
Hayashi, Masahiko, 16

Helmbrecht, Michael A., 1I
Hénault, François, 1J
Hernandez, O., 18
Hewawasam, Kuravi, 10, 1Z, 20
Hicks, Brian A., 1I
Hilgemann, Evan, 1C
Holte, Elias, 1D
Hopp, Ulrich, 1V
Howe, Glenn A., 10, 1Z, 20
Hu, Mengya (Mia), 1A, 1S
Hu, Renyu, 0Z
Jewell, Jeffrey, 0H, 0J
Johnson, Lee, 1G
Jovanovic, Nemanja, 16, 29
Kasdin, N. Jeremy, 0E, 0R, 0S, 16, 19, 1A, 1S, 28
Kasper, Markus, 15
Käufl, U., 18
Keller, Christoph U., 15
Kellermann, Hanna, 1V
Kern, Brian, 05, 06, 0D, 0E, 0F, 0P, 22
Kim, Yunjong, 19, 1A, 1S
Klimovich, Nikita, 0Y, 0Z, 29
Knapp, Gillian, 16
Knight, Justin M., 0N, 1G
Knoedler, Alex A., 13
Krist, John E., 03, 04, 05, 07, 0B, 0O
Lam, Raymond, 0D, 0E, 0F
Langlois, Maud, 15
Lea, Andrew, 1I
Leboulleux, Lucie, 0G, 0M
LeClair, Sarah, 13
Lepine, Thierry, 1Q
Lilley, S., 29
Lisman, P. Douglas, 1C
Liu, Xiang Cate, 1K
Llop Sayson, Jorge, 1P
Lloyd, James, 1X
Loomis, Craig, 16
Lowrance, Patrick, 1K
Lozi, Julien, 16
Lupu, Roxana, 09
Macintosh, Bruce, 1O, 26, 27
Malo, L., 18
Mandell, Avi M., 09, 0B, 0Q, 1P
Marchen, Luis, 04, 1T
Marois, Christian, 26
Martel, Jason, 10, 1Z, 20
Martin, Stefan, 1B
Marx, David, 04, 0D, 0F, 0P, 22
Mawet, Dimitri, 0H, 0J, 0Y, 0Z, 29
Mazoyer, Johan, 0G, 0T, 14
McCabe, Tyler, 1I
McElwain, Michael W., 09, 0B, 0Q, 1P
McGown, James, 1C
McGuire, James, 03, 04
Mejia Prada, Camilo, 0B, 0C, 0D, 0E, 0F, 0Q, 11, 1P
Melo, C., 18
Mendillo, Christopher B., 10, 1Z, 20
Mennesson, Bertrand, 07, 0Y
Merck, John, 13
Metzman, Jacob, 0C
Millar-Blanchaer, Maxwell A., 26
Milster, Thomas, 0N, 1G
Moody, Dwight, 0D, 0E, 0F
Morgan, Rhonda, 1K
Mouillet, David, 15
Muller, Richard, 0C, 0F
Murphy, Thomas J., 13
N'Diaye, Mamadou, 0G, 0M, 0T
Nemati, Bijian, 04, 05, 06, 07, 0O, 0P, 22
Norman, Colin, 0G
Nunez, Paul, 1K
Opperman, Roedolph A., 13
Patterson, Keith, 0D, 0E, 0F
Pellicori, Samuel, 1I
Pepe, F., 18
Perrin, Marshall D., 21, 26
Petrone, Peter, III, 1I
Pluzhnik, Eugene, 0W, 1G, 24
Poberezhskiy, Ilya, 05, 06, 0D, 0E, 0F, 0P, 22
Por, Emiel H., 0V
Poshyachinda, Saran, 1Q
Pueyo, Laurent, 0G, 0M, 0T, 14, 21, 27
Rabbia, Yves, 1Q
Rameau, Julien, 26
Randolph, M., 0Y
Ranganathan, Nikhil, 1O
Rasilla, J. L., 18
Rebolo, R., 18
Redding, Dave, 0H
Ren, Bin, 21
Reshetov, V., 18
Riggs, A. J. Eldorado, 04, 0B, 0C, 0E, 0R, 1D
Rizzo, Maxime Jean, 09, 0B, 0Q, 16, 1P, 1S
Roberge, Aki, 0B, 1S
Roberts, Lewis C., Jr., 11
Rodack, Alexander, 1G
Ruane, Garreth, 0H, 0J, 0Y, 0Z, 29
Rud, Mayer, 03
Ruffio, Jean-Baptiste, 1O, 26, 27
Ryan, Daniel, 0C
Saddlemyer, L., 18
Saini, Navtej, 04
Santos, N. C., 18
Sarajlic, M., 18
Sauvage, Jean-François, 0M
Savransky, Dmitry, 1K, 1L, 1O, 1U, 1X, 1Y, 26
Saxena, Prabal, 09, 0B, 0Q, 1P
Segovilla, A., 18
Seo, Byoung-Joon, 06, 0C, 0D, 0E, 0F, 0P, 22
Serabyn, E., 0Y
Seubert, Carl, 1B
Shaklan, Stuart B., 0H, 0J, 19, 1A, 1B, 1C, 1D, 1T
Shapiro, Jacob, 1O, 26
Sheets, Teresa, 1I
Shelton, Chris, 11
Shi, Fang, 0C, 0D, 0E, 0F
Shields, Joel, 0D
Shiri, Ron, 1I

Sidick, Erkin, 04, 06, 0D, 0F, 0P, 22
Sinha, Amlan, 1U, 1X
Sirbu, Dan, 0W, 1A, 1D, 24
Skouloudis, Nikolaos, 13
Snik, Frans, 0U, 15
Soonthornthum, Boonrucksar, 1Q
Sordet, M., 18
Soto, Gabriel, 1U, 1X
Soummer, Rémi, 0M
Sozzetti, Alessandro, 1E
St. Laurent, Kathryn, 0M
Stam, Daphne M., 15
Steeves, John, 1C
Subedi, Hari, 0S
Sun, He, 0R, 28
Takato, Naruhisa, 16
Tang, Hong, 03, 04, 0D, 0E
Thibault, S., 18
Thomson, Mark, 1C
Trauger, John T., 06, 0D, 0E, 0F
Trease, Brian, 1C
Truong, Tuan, 0D
Turmon, Michael, 1K
Vallée, Ph., 18
van Holstein, Rob G., 15
Vanderbei, Robert J., 0R, 1A, 1S, 28
Varnai, Peter, 0S
Vasisht, G., 0Y
Vérinaud, Christophe, 1J
Vigan, Arthur, 15
Wallace, J. K., 0Y, 29
Wang, Jason J., 26, 27
Wang, Ji, 0Y, 0Z, 29
Wang, Liang, 1V
Ward, Karen, 0N
Warriner, Nathaniel Z., 0U
Warwick, Steve, 1C
Webb, David, 1C
White, Victor, 0C, 0D
Wildi, F., 18
Wilson, Daniel, 0C, 0D, 0F
Wilson, Robert Casey, 0C
Wizinowich, P. L., 29
Wolff, Schuyler G., 26
Wu, Xingtao, 11
Wu, Yuqian, 11
Xin, Y., 0Y, 29
Xuan, W., 0Y
Yao, Li, 11
Yee, Karl, 0C
Zareh, Shannon Kian, 1B
Zhao, Feng, 03
Zhou, Hanying, 04, 05, 0D, 0E
Zimmermann, Neil T., 09, 0B, 0E, 0O, 0Q
Zurlo, Alice, 15

Conference Committee

Conference Chair

Stuart Shaklan, Jet Propulsion Laboratory (United States)

Program Track Chair

Oswald H. Siegmund, University of California, Berkeley (United States)

Conference Program Committee

Olivier Guyon, Subaru Telescope, National Astronomical Observatory of Japan (United States) and Research Corporation of University of Hawaii (United States) and The University of Arizona (United States)
Lucas Labadie, University of Cologne (Germany)
Bruce A. Macintosh, Stanford University (United States)
Dimitri P. Mawet, California Institute of Technology (United States)
M. Charley Noecker, Jet Propulsion Laboratory (United States)
Rémi Soummer, Space Telescope Science Institute (United States)

Conference Review Committee

Howard A. MacEwen, Reviresco LLC (United States)
James Breckinridge, California Institute of Technology (United States)
Tony B. Hull, The University of New Mexico (United States)
Dae Wook Kim, College of Optical Sciences, The University of Arizona (United States)
Pascal Hallibert, European Space Research and Technology Center (Netherlands)

Session Chairs

1 WFIRST Coronagraph I
Stuart Shaklan, Jet Propulsion Laboratory (United States)

2 WFIRST Coronagraph II
Garreth Ruane, California Institute of Technology (United States)

3 WFIRST Coronagraph III
Stuart Shaklan, Jet Propulsion Laboratory (United States)

4 Segmented Aperture Coronagraphs
Eric Cady, Jet Propulsion Laboratory (United States)

5 Coronagraph Design, Components, and Analysis I
Lucas Labadie, Universität zu Köln (Germany)

6 Coronagraph Design, Components, and Analysis II
A. J. Eldorado Riggs, Jet Propulsion Laboratory (United States)

7 Deformable Mirrors
Garreth Ruane, California Institute of Technology (United States)

8 Ground-based Instruments
Michael Bottom, Jet Propulsion Laboratory (United States)

9 Starshades
Stuart Shaklan, Jet Propulsion Laboratory (United States)

10 Astrometry
A. J. Eldorado Riggs, Jet Propulsion Laboratory (United States)

11 Interferometric Coronagraphy
A. J. Eldorado Riggs, Jet Propulsion Laboratory (United States)

12 Mission and Data Analysis
Lucas Labadie, Universität zu Köln (Germany)