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Contents

Part One

- xxvii *Conference Committee*
- xxxi *High redshift galaxy surveys (Plenary Paper) [7016-500]*
M. Iye, National Astronomical Observatory (Japan)

HERSCHEL-PLANCK

- 7010 02 **Herschel mission overview and key programmes [7010-01]**
G. L. Pilbratt, European Space Agency (Netherlands)
- 7010 04 **The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI): instrument and pre-launch testing [7010-03]**
T. de Graauw, SRON Netherlands Institute for Space Research (Netherlands), Leiden Observatory, Leiden Univ. (Netherlands), and Joint Alma Observatory (Chile); N. Whyborn, SRON Netherlands Institute for Space Research (Netherlands) and Joint Alma Observatory (Chile); F. Helmich, P. Dieleman, P. Roelfsema, SRON Netherlands Institute for Space Research (Netherlands); E. Caux, Ctr. d'Etude Spatiale des Rayonnements (France); T. Phillips, California Institute of Technology (United States); J. Stutzki, KOSMA, Univ. of Köln (Germany); D. Beintema, SRON Netherlands Institute for Space Research (Netherlands); A. Benz, Astronomical Institute, ETH Zurich (Switzerland); N. Biver, Observatoire de Paris-Meudon (France); A. Boogert, NHSC, California Institute of Technology (United States); F. Boulanger, Institut d'Astrophysique Spatiale (France); S. Cherednichenko, Chalmers Univ., Onsala Observatory (Sweden); O. Coeur-Joly, Ctr. d'Etude Spatiale des Rayonnements (France); C. Comito, Max Planck Institut für Radio Astronomie (Germany); E. Dartois, Institut d'Astrophysique Spatiale (France); A. de Jonge, G. de Lange, SRON Netherlands Institute for Space Research (Netherlands); I. Delorme, Observatoire de Paris-Meudon (France); A. DiGiorgio, Institute of Physics of Interplanetary Space, INAF (Italy); L. Dubbeldam, SRON Netherlands Institute for Space Research (Netherlands); K. Edwards, SRON Netherlands Institute for Space Research (Netherlands) and Univ. of Waterloo (Canada); M. Fich, Univ. of Waterloo (Canada); R. Güsten, Max Planck Institut für Radio Astronomie (Germany); F. Herpin, Observatoire de Grenoble (France); N. Honingh, KOSMA, Univ. of Köln (Germany); R. Huisman, H. Jacobs, W. Jellema, SRON Netherlands Institute for Space Research (Netherlands); J. Kawamura, Jet Propulsion Lab. (United States); D. Kester, SRON Netherlands Institute for Space Research (Netherlands); T. Klapwijk, Delft Univ. (Netherlands); T. Klein, Max Planck Institut für Radio Astronomie (Germany); J. Kooi, California Institute of Technology (United States); J.-M. Krieg, Observatoire de Paris-Meudon (France); C. Kramer, KOSMA, Univ. of Köln (Germany); B. Kruijenga, Netherlands Organisation for Applied Scientific Research (Netherlands); W. Laauwen, SRON Netherlands Institute for Space Research (Netherlands); B. Larsson, Stockholm Observatory (Sweden); C. Leinz, Max Planck Institut für Radio Astronomie (Germany); R. Liseau, Stockholm Observatory (Netherlands); S. Lord, Observatoire de Paris-Meudon (France); W. Luinge, SRON Netherlands Institute for Space Research (Netherlands); A. Marston, SRON Netherlands Institute for Space Research (Netherlands) and European Space Astronomy Ctr. (Spain); H. Merkel, Chalmers Univ., Onsala Observatory (Sweden); R. Moreno, Observatoire de Paris-Meudon (France); P. Morris, NHSC, California Institute of Technology

(United States); A. Murphy, National Univ. of Ireland (Ireland); A. Naber, SRON Netherlands Institute for Space Research (Netherlands); P. Planesas, Joint Alma Observatory (Chile) and Observatorio Astronómico Nacional (Spain); J. Martin-Pintado, CSIC (Spain); M. Olberg, SRON Netherlands Institute for Space Research (Netherlands) and Chalmers Univ., Onsala Observatory (Sweden); P. Orleanski, Space Research Ctr. (Poland); V. Ossenkopf, SRON Netherlands Institute for Space Research (Netherlands) and KOSMA, Univ. of Köln (Germany); J. Pearson, Jet Propulsion Lab. (United States); M. Perault, Ecole Normale Supérieure (France); S. Phillip, Max Planck Institut für Radio Astronomie (Germany); M. Rataj, Space Research Ctr. (Poland); L. Ravera, Ctr. d'Etude Spatiale des Rayonnements (France); P. Saraceno, Institute of Physics of Interplanetary Space, INAF (Italy); R. Schieder, F. Schmuelling, KOSMA, Univ. of Köln (Germany); R. Szczerba, National Univ. of Ireland (Ireland); R. Shipman, SRON Netherlands Institute for Space Research (Netherlands); D. Teyssier, SRON Netherlands Institute for Space Research (Netherlands) and European Space Astronomy Ctr. (Spain); C. Vastel, Ctr. d'Etude Spatiale des Rayonnements (France); H. Visser, Netherlands Organisation for Applied Scientific Research (Netherlands); K. Wildeman, K. Wafelbakker, SRON Netherlands Institute for Space Research (Netherlands); J. Ward, Jet Propulsion Lab. (United States); R. Higgins, SRON Netherlands Institute for Space Research (Netherlands) and National Univ. of Ireland (Ireland); H. Aarts, SRON Netherlands Institute for Space Research (Netherlands); X. Tielsens, SRON Netherlands Institute for Space Research (Netherlands) and NASA Ames Research Ctr. (United States); P. Zaal, SRON Netherlands Institute for Space Research (Netherlands)

7010 05 **The Photodetector Array Camera and Spectrometer (PACS) for the Herschel Space Observatory** [7010-04]

A. Poglitsch, Max-Planck-Institut für extraterrestrische Physik (Germany); C. Waelkens, Katholieke Univ. Leuven (Belgium); O. H. Bauer, Max-Planck-Institut für extraterrestrische Physik (Germany); J. Cepa, Instituto de Astrofísica de Canarias (Spain); H. Feuchtgruber, Max-Planck-Institut für extraterrestrische Physik (Germany); T. Henning, Max-Planck-Institut für Astronomie (Germany); C. van Hoof, Interuniversity Microelectronics Ctr. (Belgium); F. Kerschbaum, Institut für Astronomie der Univ. Wien (Austria); O. Krause, Max-Planck-Institut für Astronomie (Germany); E. Renotte, Ctr. Spatial de Liège (Belgium); L. Rodriguez, Commissariat à l'Energie Atomique (France); P. Saraceno, Istituto di Fisica dello Spazio Interplanetario (Italy); B. Vandenbussche, Katholieke Univ. Leuven (Belgium)

7010 06 **Herschel-SPIRE: design, ground test results, and predicted performance** [7010-05]

M. Griffin, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); B. Swinyard, Rutherford Appleton Lab. (United Kingdom); L. Vigroux, Institut d'Astrophysique de Paris (France); A. Abergel, Institut d'Astrophysique Spatiale (France); P. Ade, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); P. André, Service d'Astrophysique, CEA (France); J. Baluteau, Observatoire de Marseille (France); J. Bock, Jet Propulsion Lab. (United States); A. Franceschini, Univ. di Padova (Italy); W. Gear, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); J. Glenn, Univ. of Colorado, Boulder (United States); M. Huang, National Astronomical Observatories of China (China); D. Griffin, K. King, Rutherford Appleton Lab. (United Kingdom); E. Lellouch, Observatoire de Paris (France); D. Naylor, Univ. of Lethbridge (Canada); S. Oliver, Univ. of Sussex (United Kingdom); G. Olofsson, Stockholm Observatory (Sweden); I. Perez-Fournon, Instituto de Astrofísica de Canarias (Spain); M. Page, Mullard Space Science Lab. (United Kingdom); M. Rowan-Robinson, Imperial College, Univ. of London (United Kingdom); P. Saraceno, Istituto di Fisica dello Spazio Interplanetario (Italy); E. Sawyer, Rutherford Appleton Lab. (United Kingdom); G. Wright, UK Astronomy Technology Ctr. (United Kingdom); A. Zavagno, Observatoire de Marseille (France); A. Abreu, Rutherford Appleton Lab. (United Kingdom);

G. Bendo, Imperial College, Univ. of London (United Kingdom); A. Dowell, Rutherford Appleton Lab. (United Kingdom); D. Dowell, Jet Propulsion Lab. (United States); M. Ferlet, Rutherford Appleton Lab. (United Kingdom); T. Fulton, Blue Sky Spectroscopy (Canada); P. Hargrave, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); G. Laurent, Univ. of Colorado, Boulder (United States); S. Leeks, Rutherford Appleton Lab. (United Kingdom) and Infrared Processing and Analysis Ctr. (United States); T. Lim, Rutherford Appleton Lab. (United Kingdom); N. Lu, Infrared Processing and Analysis Ctr. (United States); H. Nguyen, Jet Propulsion Lab. (United States); A. Pearce, Rutherford Appleton Lab. (United Kingdom); E. Polehampton, Rutherford Appleton Lab. (United Kingdom) and Univ. of Lethbridge (Canada); D. Rizzo, Imperial College, Univ. of London (United Kingdom); B. Schulz, Infrared Processing and Analysis Ctr. (United States); S. Sidher, D. Smith, Rutherford Appleton Lab. (United Kingdom); L. Spencer, Univ. of Lethbridge (Canada); I. Valtchanov, ESA Herschel Science Ctr., ESAC (Spain); A. Woodcraft, UK Astronomy Technology Ctr. (United Kingdom); K. Xu, L. Zhang, Infrared Processing and Analysis Ctr. (United States)

7010 07 **Herschel payload: straylight design and performance** [7010-06]
P. Martin, Thales Alenia Space (France); S. Idler, Astrium GmbH (Germany)

7010 08 **Performance evaluation of the Herschel/SPIRE instrument flight model imaging Fourier transform spectrometer** [7010-07]
L. D. Spencer, D. A. Naylor, B. Zhang, Univ. of Lethbridge (Canada); P. Davis-Imhof, T. R. Fulton, Blue Sky Spectroscopy, Inc. (Canada); J.-P. Baluteau, Lab. d'Astrophysique de Marseille (France); M. J. Ferlet, T. L. Lim, E. T. Polehampton, B. M. Swinyard, Rutherford Appleton Lab. (United Kingdom)

7010 09 **Preparing Herschel's commissioning phase: Ge:Ga detector tuning** [7010-08]
J. M. Stegmaier, S. M. Birkmann, U. Grözinger, O. Krause, D. Lemke, Max-Planck-Institut für Astronomie (Germany)

AKARI

7010 0A **The infrared astronomical satellite AKARI: overview, highlights of the mission** [7010-09]
H. Murakami, H. Matsuhara, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)

7010 0B **Mid-infrared all-sky survey with AKARI/IRC** [7010-10]
D. Ishihara, T. Onaka, Univ. of Tokyo (Japan); H. Katata, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); H. Fujiwara, Univ. of Tokyo (Japan); S. Takita, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan) and The Graduate Univ. for Advanced Studies (Japan); C. Alfrageme, European Space Astronomy Ctr. (Spain); M. Cohen, Univ. of California, Berkeley (United States); N. Fujishiro, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); P. Garcia-Lario, European Space Astronomy Ctr. (Spain); S. Hasegawa, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); Y. Ita, National Astronomical Observatory of Japan (Japan); W. Kim, T. Nakagawa, H. Matsuhara, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); T. Matsumoto, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan) and Seoul National Univ. (Republic of Korea); H. Murakami, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); Y. Ohyama, Institute of Astronomy and Astrophysics (Taiwan); S. Oyabu, Institute of Space and Astronautical Science, Japan

Aerospace Exploration Agency (Japan); J. Pyo, Seoul National Univ. (Republic of Korea); I. Sakon, Univ. of Tokyo (Japan); A. Salama, C. Stephenson, European Space Astronomy Ctr. (Spain); H. Shibai, Osaka Univ. (Japan); T. Tanabe, Institute of Astronomy, Univ. of Tokyo (Japan); K. Uemizu, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); M. Ueno, Univ. of Tokyo (Japan); F. Usui, T. Wada, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); H. Watarai, Space Applications Missions Directorate, Japan Aerospace Exploration Agency (Japan); C. Yamauchi, I. Yamamura, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)

7010 0C **The Infrared Camera (IRC) for AKARI: in-flight imaging performance and the post cryogen mission** [7010-11]

T. Wada, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); T. Onaka, The Univ. of Tokyo (Japan); H. Matsuhara, N. Fujishiro, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); H. Fujiwara, D. Ishihara, The Univ. of Tokyo (Japan); Y. Ita, National Astronomical Observatory of Japan (Japan); H. Kataza, W. Kim, T. Matsumoto, H. Murakami, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); Y. Ohyama, Institute of Astronomy and Astrophysics (Taiwan); S. Oyabu, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); I. Sakon, The Univ. of Tokyo (Japan); T. Tanabé, Institute of Astronomy, The Univ. of Tokyo (Japan); T. Tange, T. Takagi, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); S. Takita, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan) and The Graduate Univ. for Advanced Studies (Japan); K. Uemizu, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); M. Ueno, The Univ. of Tokyo (Japan); F. Usui, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); H. Watarai, Japan Aerospace Exploration Agency (Japan); M. Cohen, Radio Astronomy Lab., Univ. of California, Berkeley (United States); K. Enya, T. Ootsubo, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); C. P. Pearson, Rutherford Appleton Lab. (United Kingdom) and Univ. of Lethbridge (Canada); N. Takeyama, T. Yamamuro, Y. Ikeda, Genesis Corp. (Japan)

7010 0D **Slow-scan performance of the Far-Infrared Surveyor (FIS) onboard AKARI** [7010-12]

M. Sirahata, S. Matsuura, S. Hasegawa, T. Ootsubo, S. Makiuti, I. Yamamura, T. Nakagawa, H. Kaneda, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); Y. Doi, Univ. of Tokyo (Japan); M. Kawada, Nagoya Univ. (Japan); H. Shibai, Osaka Univ. (Japan); T. Müller, Max Plank Institute for Extraterrestrial Physics (Germany); M. Cohen, Univ. of California, Berkeley (United States)

7010 0E **Far-Infrared Surveyor on AKARI: in-orbit characterization of transient response and radiation effects of Ge:Ga array detectors** [7010-13]

H. Kaneda, ISAS, Japan Aerospace Exploration Agency (Japan); T. Suzuki, National Astronomical Observatory of Japan (Japan); A. Coulais, LERMA, Observatoire de Paris (France); Y. Doi, Univ. of Tokyo (Japan); B. Fouks, Institute of Radioengineering and Electronics (Russia); M. Kawada, Nagoya Univ. (Japan); S. Makiuti, S. Matsuura, ISAS, Japan Aerospace Exploration Agency (Japan); N. Murakami, Bisei Astronomical Observatory (Japan); T. Nakagawa, Y. Okada, ISAS, Japan Aerospace Exploration Agency (Japan);

H. Shibai, Osaka Univ. (Japan); M. Shirahata, ISAS, Japan Aerospace Exploration Agency (Japan); H. Takahashi, Gunma Astronomical Observatory (Japan); A. Yasuda, ISAS, Japan Aerospace Exploration Agency (Japan)

- 7010 0F **Imaging Fourier transform spectrometer with photoconductive detector arrays: an application to the AKARI far-infrared instrument** [7010-14]
M. Kawada, Nagoya Univ. (Japan); H. Takahashi, Gunma Astronomical Observatory (Japan); N. Murakami, Bisei Astronomical Observatory (Japan); Y. Okada, A. Yasuda, T. Ootsubo, H. Kaneda, Institute of Space and Astronautical Science, JAXA (Japan); H. Matsuo, National Astronomical Observatory of Japan (Japan); S. Matsuura, M. Shirahata, Institute of Space and Astronautical Science, JAXA (Japan); Y. Doi, The Univ. of Tokyo (Japan); M. Fujiwara, NICT (Japan); I. Yamamura, T. Nakagawa, Institute of Space and Astronautical Science, JAXA (Japan); H. Shibai, Nagoya Univ. (Japan) and Osaka Univ. (Japan)

SPICA-WISE

- 7010 0G **Wide-field Infrared Survey Explorer science payload update** [7010-15]
M. F. Larsen, H. Latvakoski, Space Dynamics Lab., Utah State Univ. (United States); A. K. Mainzer, Jet Propulsion Lab. (United States); S. Schick, Practical Technology Solutions, Inc. (United States); J. Drake, Space Dynamics Lab., Utah State Univ. (United States)
- 7010 0H **SPICA mission for mid- and far-infrared astronomy** [7010-16]
T. Nakagawa, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)
- 7010 0I **The European contribution to the SPICA mission** [7010-17]
B. Swinyard, Rutherford Appleton Lab. (United Kingdom); T. Nakagawa, H. Matsuhara, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); D. Griffin, M. Ferlet, P. Eccleston, Rutherford Appleton Lab. (United Kingdom); A. di Giorgio, INAF-Istituto Fisica Spazio Interplanetario (Italy); J. Baselmans, SRON National Institute for Space Research (Netherlands); J. Goicoechea, LERMA-LRA, CNRS, Observatoire de Paris et École Normale Supérieure (France); K. Isaak, P. Maukopf, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); L. Rodriguez, F. Pinsard, Service d'Astrophysique, DAPNIA, CEA Saclay (France); W. Raab, Max-Planck-Institut für Extraterrestrische Physik (Germany); L. Duband, N. Luchier, Service des Basses Temperatures, DRFMC, CEA Grenoble (France); N. Rando, A. Heras, T. Jagemann, ESA-Estec (Netherlands); N. Geis, Max-Planck-Institut für Extraterrestrische Physik (Germany); S. Vives, Observatoire Astronomique Marseille Provence (France)
- 7010 0J **Focal plane instruments onboard SPICA** [7010-18]
H. Matsuhara, H. Kataza, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)

JWST OVERVIEW

- 7010 0K **The scientific capabilities of the James Webb Space Telescope** [7010-19]
J. P. Gardner, NASA Goddard Space Flight Ctr. (United States)

- 7010 0L **Status of the James Webb Space Telescope (JWST)** [7010-20]
M. Clampin, NASA Goddard Space Flight Ctr. (United States)
- 7010 0M **Design status of the James Webb Space Telescope** [7010-21]
J. W. Arenberg, Northrop Grumman Space Technology (United States)
- 7010 0N **Applying HST lessons learned to JWST** [7010-23]
L. D. Feinberg, P. H. Geithner, NASA Goddard Space Flight Ctr. (United States)
- 7010 0O **Towards observing extrasolar giant-planet environments with JWST** [7010-24]
R. B. Makidon, Space Telescope Science Institute (United States); A. Sivaramakrishnan, R. Soummer, American Museum of Natural History (United States); J. Anderson, R. P. van der Marel, Space Telescope Science Institute (United States)

JWST: OTE VERIFICATION

- 7010 0P **Optical performance verification of the James Webb Space Telescope** [7010-25]
A. A. Barto, Ball Aerospace & Technologies Corp. (United States); C. Atkinson, Northrop Grumman Space Technologies (United States); J. Contreras, P. A. Lightsey, C. Noecker, Ball Aerospace & Technologies Corp. (United States); M. Waldman, T. Whitman, ITT Corp. (United States)
- 7010 0Q **Architecting a revised optical test approach for JWST** [7010-26]
C. Atkinson, J. Arenberg, Northrop Grumman (United States); G. Matthews, M. Waldman, A. Wertheimer, T. Whitman, ITT (United States); J. Oschmann, Ball Aerospace & Technologies Corp. (United States)
- 7010 0R **Development of interferometry for testing the JWST Optical Telescope Element (OTE)** [7010-112]
R. A. Keski-Kuha, NASA Goddard Space Flight Ctr. (United States); B. Saif, B. Eegholm, Space Telescope Science Institute (United States); P. Blake, NASA Goddard Space Flight Ctr. (United States)
- 7010 0S **Verification of the James Webb Space Telescope (JWST) wavefront sensing and control system** [7010-85]
A. R. Contos, D. S. Acton, A. A. Barto, Ball Aerospace & Technologies Corp. (United States); L. A. Burns, Space Telescope Science Institute (United States); J. Contreras, Ball Aerospace & Technologies Corp. (United States); B. Dean, NASA Goddard Space Flight Ctr. (United States); E. Elliott, Ball Aerospace & Technologies Corp. (United States); L. Feinberg, NASA Goddard Space Flight Ctr. (United States); K. Hansen, B. Hardy, Ball Aerospace & Technologies Corp. (United States); W. Hayden, NASA Goddard Space Flight Ctr. (United States); J. S. Knight, P. A. Lightsey, Ball Aerospace & Technologies Corp. (United States); C. Starr, Northrop Grumman Space Technologies (United States); J. Sullivan, Ball Aerospace & Technologies Corp. (United States)

JWST: INSTRUMENTS

- 7010 0T **Design and development of MIRI, the mid-IR instrument for JWST** [7010-28]
G. S. Wright, UK Astronomy Technology Ctr. (United Kingdom); G. Reike, Steward Observatory, Univ. of Arizona (United States); P. Barella, Jet Propulsion Lab. (United States);

T. Boeker, ESTEC (Netherlands); L. Colina, Instituto de Estructura de la Materia, CSIC (Spain); E. van Dishoeck, Sterrewacht Leiden (Netherlands); P. Driggers, NASA Goddard Space Flight Ctr. (United States); G. Goodson, Jet Propulsion Lab. (United States); T. Greene, NASA Ames Research Ctr. (United States); A. Heske, ESTEC (Netherlands); T. Henning, Max-Planck Institut für Astronomy (Germany); P.-O. Lagage, CEA Saclay Service d'Astrophysique (France); M. Meixner, Space Telescope Science Institute (United States); H. Norgaard-Nielsen, Danish Space Research Institute (Denmark); G. Olofsson, Stockholm Observatory (Sweden); T. Ray, Dublin Institute for Advanced Studies (Ireland); M. Ressler, Jet Propulsion Lab. (United States); J. Thatcher, EADS Astrium, Ltd. (United Kingdom); C. Waelkens, Katholieke Univ. Leuven (Belgium); D. Wright, EADS Astrium, Ltd. (United Kingdom); A. Zehnder, Paul Scherrer Institute (Switzerland)

7010 0U **Development approach and first infrared test results of JWST/Mid Infra-Red Imager Optical Bench [7010-29]**

J. Amiaux, F. Alouadi, J. L. Augueres, P. Bouchet, M. Bouzat, C. Cavarroc, C. Cloue, CEA, IRFU, SAp (France); P. De Antoni, CEA, IRFU, SIS (France); D. Desforges, CEA, IRFU, SEDI (France); A. Donati, CEA, IRFU, SIS (France); D. Dubreuil, CEA, IRFU, SAp (France); D. Eppelle, F. Gougnaud, CEA, IRFU, SIS (France); B. Hervieu, CEA, IRFU, SACM (France); P. O. Lagage, CEA, IRFU, SAp (France) and CNRS, Unité Mixte CEA, UP7 (France); D. Leboeuf, CEA, IRFU, SIS (France); I. Le Mer, CEA, IRFU, SAp (France); Y. Lussignol, P. Mattei, CEA, IRFU, SIS (France); F. Meigner, CEA, IRFU, SEDI (France); V. Moreau, E. Pantin, CEA, IRFU, SAp (France) and CNRS, Unité Mixte CEA, UP7 (France); P. Perrin, CEA, IRFU, SIS (France); S. Ronayette, CEA, IRFU, SAp (France); G. Tauzin, CEA, IRFU, SEDI (France); S. Poupard, CNRS, Unité Mixte CEA, UP7 (France); D. Wright, EADS Astrium, Ltd. (United Kingdom); A. Glasse, G. Wright, UK ATC, Royal Observatory (United Kingdom); E. Mazy, J. Y. Plessier, E. Renotte, Ctr. Spatial de Liège (Belgium); T. Ray, Dublin Institute for Advanced Studies (Ireland); A. Abergel, P. Guillard, Y. Longval, Institut d'Astrophysique Spatiale, Univ. Paris-Sud (France); M. Ressler, Jet Propulsion Lab. (United States); J. M. Reess, LESIA (France); R. Hofferbert, O. Krause, Max-Planck-Institut für Astronomie (Germany); K. Justtanont, G. Olofsson, Stockholm Observatory, SCFAB (Sweden)

7010 0W **First tests of the coronagraphic device of MIRI/JWST [7010-31]**

C. Cavarroc, J. Amiaux, CEA, IRFU/SAp (France); P. Baudoz, A. Boccaletti, Observatoire de Paris-Meudon (France); P. Bouchet, D. Dubreuil, P.-O. Lagage, V. Moreau, E. J. Pantin, CEA, IRFU/SAp (France); J.-M. Reess, Observatoire de Paris-Meudon (France); S. Ronayette, CEA, IRFU/SAp (France); G. S. Wright, Royal Observatory (United Kingdom)

7010 0X **The JWST tunable filter imager (TFI) [7010-32]**

R. Doyon, Univ. de Montréal (Canada); N. Rowlands, COM DEV, Ltd. (Canada); J. Hutchings, Herzberg Institute of Astrophysics, National Research Council (Canada); C. E. Evans, E. Greenberg, A. D. Scott, D. Touhari, COM DEV, Ltd. (Canada); M. Beaulieu, Univ. de Montréal (Canada); R. Abraham, Univ. of Toronto (Canada); L. Ferrarese, Herzberg Institute of Astrophysics, National Research Council (Canada); A. W. Fullerton, Space Telescope Science Institute (United States); R. Jayawardhana, Univ. of Toronto (Canada); D. Johnston, Herzberg Institute of Astrophysics, National Research Council (Canada); M. R. Meyer, Steward Observatory, The Univ. of Arizona (United States); J. Pipher, Univ. of Rochester (United States); M. Sawicki, St. Mary's Univ. (Canada)

- 7010 02 **Opto-mechanical test results for the Near Infra-red Camera on the James Webb Space Telescope** [7010-34]
E. T. Kvamme, M. Jacoby, L. Osborne, Lockheed Martin Advanced Technology Ctr. (United States)
- 7010 10 **Cryogenic test results of engineering test unit optical components of the Near Infrared Camera for the James Webb Space Telescope** [7010-35]
L. A. Ryder, Lockheed Martin Space Systems Co. (United States)
- 7010 11 **The Integral Field Unit on the James Webb Space Telescope's Near-Infrared Spectrograph** [7010-36]
M. F. Closs, EADS Astrium GmbH (Germany); P. Ferruit, Univ. de Lyon (France), Observatoire de Lyon, Univ. de Lyon 1 (France), and CNRS, Ctr. de Recherche Astrophysique de Lyon, Ecole Normale Supérieure de Lyon (France); D. R. Lobb, Surrey Satellite Technology, Ltd. (United Kingdom); W. R. Preuss, S. Rolt, R. G. Talbot, Durham Univ. (United Kingdom)

PLANETARY MISSIONS

- 7010 13 **NEOSSat: a Canadian small space telescope for near Earth asteroid detection** [7010-38]
D. Laurin, Canadian Space Agency (Canada); A. Hildebrand, R. Cardinal, Univ. of Calgary (Canada); W. Harvey, S. Tafazoli, Canadian Space Agency (Canada)
- 7010 15 **SPEX: an in-orbit spectropolarimeter for planetary exploration** [7010-40]
F. Snik, T. Karalidi, C. Keller, Sterrekundig Instituut Utrecht (Netherlands); E. Laan, TNO Science and Industry (Netherlands); R. ter Horst, R. Navarro, NOVA-ASTRON (Netherlands); D. Stam, Technische Univ. Delft (Netherlands) and SRON Netherlands Institute for Space Research (Netherlands); C. Aas, Technische Univ. Delft (Netherlands); J. de Vries, G. Oomen, Dutch Space (Netherlands); R. Hoogeveen, SRON Netherlands Institute for Space Research (Netherlands)
- 7010 16 **Novel TMA telescope based on ultra precise metal mirrors** [7010-41]
S. Risse, A. Gebhardt, C. Damm, T. Peschel, W. Stöckl, T. Feigl, Fraunhofer Institute for Applied Optics and Precision Engineering (Germany); S. Kirschstein, Jena-Optronik GmbH (Germany); R. Eberhardt, N. Kaiser, A. Tünnermann, Fraunhofer Institute for Applied Optics and Precision Engineering (Germany)
- 7010 17 **Design of a Fabry-Perot interferometer for the SO/PHI instrument on Solar Orbiter** [7010-42]
C. Trosseille, T. Appourchaux, J.-J. Fourmond, Institut d'Astrophysique Spatiale, Univ. Paris-Sud 11 (France)

JDEM

- 7010 18 **Summary of the DUNE mission concept** [7010-43]
A. Refregier, SAp CEA Saclay (France); M. Douspis, IAS CNRS, Univ. Paris-Sud (France)

- 7010 19 **An integral field spectrograph for SNAP** [7010-44]
E. Prieto, CNRS, INSU, LAM (France); A. Ealet, CNRS, IN2P3, CPPM (France); B. Milliard, CNRS, INSU, LAM (France); M.-H. Aumeunier, CNRS, INSU, LAM (France) and CNRS, IN2P3, CPPM (France); A. Bonissent, C. Cerna, P.-E. Crouzet, P. Karst, CNRS, IN2P3, CPPM (France); J.-K. Kneib, R. Malina, T. Pamplona, C. Rossin, CNRS, INSU, LAM (France); G. Smadja, CNRS, IN2P3, INPL (France); S. Vives, CNRS, INSU, LAM (France)
- 7010 1A **Setup and performances of the SNAP spectrograph demonstrator** [7010-45]
C. Cerna, CPPM (France); M. H. Aumeunier, CPPM (France) and LAM (France); E. Prieto, LAM (France); A. Ealet, P. Karst, CPPM (France); A. Castera, G. Smadja, IPNL (France); T. Soilly, P. E. Crouzet, CPPM (France)
- 7010 1B **The Observatory for Multi-Epoch Gravitational Lens Astrophysics (OMEGA)** [7010-46]
L. A. Moustakas, Jet Propulsion Lab. (United States); A. J. Bolton, Institute for Astronomy, Univ. of Hawaii at Manoa (United States); J. T. Booth, Jet Propulsion Lab. (United States); J. S. Bullock, Univ. of California, Irvine (United States); E. Cheng, Conceptual Analytics, LLC (United States); D. Coe, Jet Propulsion Lab. (United States); C. D. Fassnacht, Univ. of California, Davis (United States); V. Gorjian, C. Heneghan, Jet Propulsion Lab. (United States); C. R. Keeton, Rutgers Univ. (United States); C. S. Kochanek, The Ohio State Univ. (United States); C. R. Lawrence, Jet Propulsion Lab. (United States); P. J. Marshall, Univ. of California, Santa Barbara (United States); R. B. Metcalf, Max Planck Institute for Astrophysics (Germany); P. Natarajan, Yale Univ. (United States); S. Nikzad, Jet Propulsion Lab. (United States); B. M. Peterson, The Ohio State Univ. (United States); J. Wambsganss, Astronomisches Rechen-Institut (Germany)
- 7010 1D **The focal plane instrumentation for the DUNE mission** [7010-48]
J. Booth, Jet Propulsion Lab. (United States); M. Cropper, Mullard Space Science Lab., Univ. College London (United Kingdom); F. Eisenhauer, Max Planck Institute for Extraterrestrial Physics (Germany); A. Refregier, SAp CEA Saclay (France)

HUBBLE

- 7010 1E **Wide Field Camera 3: a powerful new imager for the Hubble Space Telescope** [7010-49]
R. A. Kimble, NASA Goddard Space Flight Ctr. (United States); J. W. MacKenty, Space Telescope Science Institute (United States); R. W. O'Connell, Univ. of Virginia (United States); J. A. Townsend, NASA Goddard Space Flight Ctr. (United States)
- 7010 1F **Wide Field Camera 3: science capabilities and plans for flight operation** [7010-50]
J. W. MacKenty, Space Telescope Science Institute (United States); R. A. Kimble, NASA Goddard Space Flight Ctr. (United States); R. W. O'Connell, Univ. of Virginia (United States); J. A. Townsend, NASA Goddard Space Flight Ctr. (United States)

CORONOGRAPHY

- 7010 1H **New perspectives in solar coronagraphy offered by formation flying: from PROBA-3 to Cosmic Vision** [7010-52]
P. Lamy, S. Vivès, Lab. d'Astrophysique de Marseille (France); L. Damé, Service d'Aéronomie du CNRS (France) and LESIA, Observatoire de Paris (France); S. Koutchmy, Institut d'Astrophysique de Paris (France)

- 7010 1I **In-orbit calibration of the polarization flat fields of the SOHO-LASCO coronagraphs** [7010-53]
A. Llebaria, P. Lamy, LAM-OAMP, CNRS, Univ. de Provence (France)
- 7010 1J **Laboratory experiments on the 8-octant phase-mask coronagraph** [7010-54]
N. Murakami, National Astronomical Observatory of Japan (Japan); R. Uemura, N. Baba, H. Shibuya, Hokkaido Univ. (Japan); J. Nishikawa, L. Abe, M. Tamura, National Astronomical Observatory of Japan (Japan); N. Hashimoto, Citizen Technology Ctr. Co. (Japan)
- 7010 1K **Terrestrial planet detection approaches: externally occulted hybrid coronagraphs** [7010-55]
R. G. Lyon, NASA Goddard Space Flight Ctr. (United States); J. A. Gulltieri, GST (United States); R. Belikov, NASA Goddard Space Flight Ctr. (United States)

TPF CONCEPTS

- 7010 1L **The Transit Characterization Explorer (TRACER)** [7010-56]
M. C. Clampin, NASA Goddard Space Flight Ctr. (United States)
- 7010 1N **Detecting biomarkers in exoplanetary atmospheres with a Terrestrial Planet Finder** [7010-58]
S. R. Heap, NASA Goddard Space Flight Ctr. (United States); D. Lindler, NASA Goddard Space Flight Ctr. (United States) and Sigma Space Corp. (United States); R. Lyon, NASA Goddard Space Flight Ctr. (United States)
- 7010 1O **Spectral characterization of Earth-like transiting exoplanets** [7010-59]
W. A. Traub, Jet Propulsion Lab. (United States) and Harvard-Smithsonian Ctr. for Astrophysics (United States); L. Kaltenegger, K. W. Jucks, Harvard-Smithsonian Ctr. for Astrophysics (United States)
- 7010 1P **Polarization analysis as a means of detecting exoplanets and measuring their objective spectra** [7010-60]
N. Zubko, N. Baba, Hokkaido Univ. (Japan); N. Murakami, National Astronomical Observatory of Japan (Japan)

NEW WORLDS OBSERVER

- 7010 1Q **The New Worlds Observer: scientific and technical advantages of external occulters** [7010-61]
W. Cash, P. Oakley, M. Turnbull, Univ. of Colorado, Boulder (United States); T. Glassman, A. Lo, R. Polidan, Northrop-Grumman Space Technologies (United States); S. Kilston, C. Noecker, Ball Aerospace (United States)
- 7010 1S **New Worlds Observer system architecture** [7010-63]
J. W. Arenberg, T. Glassman, A. S. Lo, Northrop Grumman Space Technology (United States); S. Benson, NASA Glenn Research Ctr. (United States)
- 7010 1T **Design reference mission construction for planet finders** [7010-64]
D. Savransky, N. J. Kasdin, Princeton Univ. (United States)

- 7010 1V **Sensitivity analysis of the New Worlds starshade's shadow** [7010-68]
J. W. Arenberg, Northrop Grumman Space Technology (United States); A. Shipley, W. Cash, Univ. of Colorado, Boulder (United States); T. Glassman, A. Lo, Northrop Grumman Space Technology (United States)
- 7010 1W **New Worlds Observer: Minotaur to Ares V** [7010-69]
A. S. Lo, T. Glassman, D. Dailey, C. F. Lillie, Northrop Grumman Corp. (United States); W. Cash, P. Oakley, Univ. of Colorado, Boulder (United States)
- 7010 1X **Performance of hybrid occulters using apodized pupil Lyot coronagraphy** [7010-70]
E. Cady, L. Pueyo, Princeton Univ. (United States); R. Soummer, American Museum of Natural History (United States); N. J. Kasdin, Princeton Univ. (United States)

MISSION CONCEPTS I

- 7010 1Y **Pupil mapping Exoplanet Coronagraphic Observer (PECO)** [7010-66]
O. Guyon, Steward Observatory, The Univ. of Arizona (United States) and Subaru Telescope, NAOJ (United States); J. R. P. Angel, Steward Observatory, The Univ. of Arizona (United States); D. Backman, R. Belikov, NASA Ames Research Ctr. (United States); D. Gavel, Univ. of California, Santa Cruz (United States); A. Giveon, Jet Propulsion Lab. (United States); T. Greene, NASA Ames Research Ctr. (United States); J. Kasdin, Princeton Univ. (United States); J. Kasting, Pennsylvania State Univ. (United States); M. Levine, Jet Propulsion Lab. (United States); M. Marley, NASA Ames Research Ctr. (United States); M. Meyer, G. Schneider, Steward Observatory, The Univ. of Arizona (United States); G. Serabyn, S. Shaklan, M. Shao, Jet Propulsion Lab. (United States); M. Tamura, National Astronomical Observatory of Japan (United States); D. Tenerelli, Lockheed Martin Space Corp. (United States); W. Traub, J. Trauger, Jet Propulsion Lab. (United States); R. Vanderbei, Princeton Univ. (United States); R. A. Woodruff, Lockheed Martin Space Corp. (United States); N. J. Woolf, Steward Observatory, The Univ. of Arizona (United States); J. Wynn, ITT Industries (United States)
- 7010 20 **CALISTO: the Cryogenic Aperture Large Infrared Space Telescope Observatory** [7010-72]
P. F. Goldsmith, M. Bradford, M. Dragovan, C. Paine, C. Satter, B. Langer, H. Yorke, K. Huffenberger, Jet Propulsion Lab. (United States); D. Benford, NASA Goddard Space Flight Ctr. (United States); D. Lester, Univ. of Texas, Austin (United States)

MISSION CONCEPTS II

- 7010 21 **Science with an 8-meter to 16-meter optical/UV space telescope** [7010-73]
M. Postman, T. Brown, A. Koekemoer, Space Telescope Science Institute (United States); M. Giavalisco, Univ. of Massachusetts, Amherst (United States); S. Unwin, W. Traub, Jet Propulsion Lab. (United States); D. Calzetti, Univ. of Massachusetts, Amherst (United States); W. Oegerle, NASA Goddard Space Flight Ctr. (United States); M. Shull, Univ. of Colorado, Boulder (United States); S. Kilston, Ball Aerospace & Technologies Corp. (United States); H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)
- 7010 22 **Design study of 8 meter monolithic mirror UV/optical space telescope (Invited Paper)** [7010-74]
H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

- 7010 23 **The challenges posed by future far-IR and sub-mm space missions: an overview** [7010-75]
R. Lindberg, A. Lyngvi, N. Rando, P. Verhoeve, F. Safa, European Space Agency (Netherlands)
- 7010 24 **VSOP-2 project** [7010-76]
M. Tsuboi, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)
- 7010 25 **Durham optical design of EUCLID, the merged SPACE/DUNE ESA Dark Energy Mission** [7010-78]
R. Content, Univ. of Durham (United Kingdom)
- 7010 26 **A wide-field Imaging FTS for the Molecular Hydrogen Explorer space mission (H2EX)** [7010-79]
J.-P. Maillard, Institut d'Astrophysique de Paris, CNRS, Univ. P. & M. Curie (France); F. Boulanger, Y. Longval, J.-J. Fourmond, M. Bouzit, C. Dumesnil, Institut d'Astrophysique Spatiale, CNRS, Univ. Paris-Sud (France)
- 7010 27 **GAME: Gamma Astrometric Measurement Experiment** [7010-80]
M. Gai, M. G. Lattanzi, S. Ligori, A. Vecchiato, Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Torino (Italy)

INTERFEROMETRY FROM SPACE: JOINT SESSION WITH CONFERENCE 7013

- 7010 28 **The Space Infrared Interferometric Telescope (SPIRIT): the mission design solution space and the art of the possible** [7010-77]
D. Leisawitz, T. T. Hyde, S. A. Rinehart, M. Weiss, NASA Goddard Space Flight Ctr. (United States)

TECHNOLOGIES: ACTIVE OPTICS

- 7010 29 **ACCESS: a NASA mission concept study of an Actively Corrected Coronagraph for Exoplanet System Studies** [7010-81]
J. Trauger, K. Stapelfeldt, W. Traub, C. Henry, J. Krist, D. Mawet, D. Moody, P. Park, L. Pueyo, E. Serabyn, S. Shaklan, Jet Propulsion Lab. (United States); O. Guyon, Subaru Telescope (United States) and Univ. of Arizona (United States); J. Kasdin, D. Spergel, R. Vanderbei, Princeton Univ. (United States); R. Belikov, NASA Ames Research Ctr. (United States); G. Marcy, Univ. of California, Berkeley (United States); R. A. Brown, Space Telescope Science Institute (United States); J. Schneider, Paris Observatory (France); B. Woodgate, NASA Goddard Space Flight Ctr. (United States); G. Matthews, R. Eggerman, ITT Space Systems Division (United States); R. Polidan, C. Lillie, Northrop Grumman Corp. (United States); M. Ealey, T. Price, Xinetics, Northrop Grumman (United States)
- 7010 2A **Virtual wavefront compensation and speckle reduction in coronagraph by unbalanced nulling interferometer (UNI) and phase and amplitude correction (PAC)** [7010-82]
J. Nishikawa, NAOJ (Japan); K. Yokochi, Tokyo Univ. of Agriculture and Technology (Japan); L. Abe, Univ. de Nice-Sophia Antipolis (France); N. Murakami, NAOJ (Japan); T. Kotani, LESIA, Observatoire de Paris (France); M. Tamura, NAOJ (Japan); T. Kurokawa, Tokyo Univ. of Agriculture and Technology (Japan); A. V. Tavrov, NAOJ (Japan); M. Takeda, Univ. of Electro-Communications (Japan)

- 7010 2E **NIRCam Long Wavelength Channel grisms as the Dispersed Fringe Sensor for JWST segment mirror coarse phasing** [7010-86]
F. Shi, B. M. King, N. Sigrist, S. A. Basinger, Jet Propulsion Lab. (United States)

Part Two

TECHNOLOGIES: STRUCTURES AND MATERIALS

- 7010 2G **Large aperture space telescope mirror fabrication trades** [7010-88]
S. E. Kendrick, Ball Aerospace & Technologies Corp. (United States); H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)
- 7010 2H **Assembly of a Large Modular Optical Telescope (ALMOST)** [7010-89]
D. W. Miller, S. Mohan, Massachusetts Institute of Technology (United States); J. Budinoff, NASA Goddard Space Flight Ctr. (United States)
- 7010 2I **Integrated modeling for determining launch survival and limitations for actuated lightweight mirrors** [7010-90]
L. E. Cohan, D. W. Miller, Massachusetts Institute of Technology (United States)
- 7010 2K **Large ultra-lightweight photonic muscle membrane mirror telescope** [7010-92]
J. M. Ritter, A. E. Baer, Univ. of Hawaii, Institute for Astronomy (United States); T. D. Ditto, DeWitt Brothers Tool Co. (United States)

TECHNOLOGIES: INSTRUMENTS

- 7010 2L **The Kepler photometer focal plane array** [7010-93]
V. S. Argabright, J. E. VanCleve, E. E. Bachtell, M. J. Hegge, S. P. McArthur, F. C. Dumont, A. C. Rudeen, J. L. Pullen, D. A. Teusch, D. S. Tennant, P. D. Atcheson, Ball Aerospace & Technologies Corp. (United States)
- 7010 2M **Lessons learned from SCUBA-2 for future cryogenic instrumentation in space** [7010-94]
A. L. Woodcraft, SUPA, Institute for Astronomy, Edinburgh Univ. (United Kingdom) and UK Astronomy Technology Ctr. (United Kingdom)
- 7010 2O **Pico meter metrology for the GAIA mission** [7010-97]
E. A. Meijer, J. N. Nijenhuis, R. J. P. Vink, F. Kamphues, TNO Science and Industry (Netherlands)
- 7010 2P **SPIDER: a balloon-borne large-scale CMB polarimeter** [7010-98]
B. P. Crill, Univ. of Toronto (Canada) and Canadian Institute for Theoretical Astrophysics, Univ. of Toronto (Canada); P. A. R. Ade, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); E. S. Battistelli, Univ. of British Columbia (Canada); S. Benton, Univ. of Toronto (Canada); R. Bihary, Case Western Reserve Univ. (United States); J. J. Bock, Jet Propulsion Lab. (United States) and California Institute of Technology (United States); J. R. Bond, Canadian Institute for Theoretical Astrophysics, Univ. of Toronto (Canada); J. Brevik, California Institute of Technology (United States) S. Bryan, Case Western Reserve Univ. (United States); C. R. Contaldi, Imperial College (United Kingdom); O. Doré, Canadian Institute for Theoretical Astrophysics, Univ. of Toronto (Canada); M. Farhang, L. Fissel, Univ. of Toronto (Canada); S. R. Golwala, California Institute of Technology (United States);

M. Halpern, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); G. Hilton, National Institute of Standards and Technology (United States); W. Holmes, Jet Propulsion Lab. (United States); V. V. Hristov, California Institute of Technology (United States); K. Irwin, National Institute of Standards and Technology (United States); W. C. Jones, Jet Propulsion Lab. (United States) and California Institute of Technology (United States); C. L. Kuo, Stanford Univ. (United States); A. E. Lange, California Institute of Technology (United States); C. Lawrie, Case Western Reserve Univ. (United States); C. J. MacTavish, Canadian Institute for Theoretical Astrophysics, Univ. of Toronto (Canada); T. G. Martin, Univ. of Toronto (Canada); P. Mason, California Institute of Technology (United States); T. E. Montroy, Case Western Reserve Univ. (United States); C. B. Netterfield, Univ. of Toronto (Canada); E. Pascale, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); D. Riley, J. E. Ruhl, Case Western Reserve Univ. (United States); M. C. Runyan, A. Trangsrud, California Institute of Technology (United States); C. Tucker, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); A. Turner, Jet Propulsion Lab. (United States); M. Viero, D. Wiebe, Univ. of Toronto (Canada)

POSTER SESSION: HERSCHEL-PLANCK

- 7010 2Q **The Herschel-SPIRE photometer data processing pipeline** [7010-99]
M. Griffin, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); C. D. Dowell, Jet Propulsion Lab. (United States); T. Lim, Rutherford Appleton Lab. (United Kingdom); G. Bendo, Imperial College, Univ. of London (United Kingdom); J. Bock, Jet Propulsion Lab. (United States); C. Cara, Service d'Astrophysique, CEA Saclay (France); N. Castro-Rodriguez, Instituto de Astrofísica de Canarias (Spain); P. Chaniel, D. Clements, Imperial College, Univ. of London (United Kingdom); R. Gastaud, Service d'Astrophysique, CEA Saclay (France); S. Guest, Rutherford Appleton Lab. (United Kingdom); J. Glenn, Univ. of Colorado, Boulder (United States); V. Hristov, California Institute of Technology (United States); K. King, Rutherford Appleton Lab. (United Kingdom); G. Laurent, Univ. of Colorado, Boulder (United States); N. Lu, Infrared Processing and Analysis Ctr. (United States); G. Mainetti, Univ. of Padua (Italy); H. Morris, Rutherford Appleton Lab. (United Kingdom); H. Nguyen, Jet Propulsion Lab. (United States); P. Panuzzo, Service d'Astrophysique, CEA Saclay (France); C. Pearson, Rutherford Appleton Lab. (United Kingdom); F. Pinsard, Service d'Astrophysique, CEA Saclay (France); M. Pohlen, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); E. Polehampton, Rutherford Appleton Lab. (United Kingdom) and Univ. of Lethbridge (Canada); D. Rizzo, Imperial College, Univ. of London (United Kingdom); B. Schulz, A. Schwartz, Infrared Processing and Analysis Ctr. (United States); B. Sibthorpe, UK Astronomy Technology Ctr. (United Kingdom); B. Swinyard, Rutherford Appleton Lab. (United Kingdom); K. Xu, L. Zhang, Infrared Processing and Analysis Ctr. (United States)
- 7010 2R **The ESA Herschel Telescope Tiger Team metrology review: test results** [7010-100]
B. E. Catanzaro, CFE Services (United States); D. Doyle, ESA Estec (Netherlands); J. Pfund, Optocraft (Germany); N. Ninane, Y. Houbrechts, LIEGE Science Park (Belgium); B. Braunecker, Braunecker Engineering GmbH (Switzerland)
- 7010 2S **The ESA Herschel Telescope Tiger Team metrology review: modeling** [7010-101]
B. E. Catanzaro, CFE Services (United States); D. Doyle, ESA Estec (Netherlands); B. Fransen, AOES Group B.V. (Netherlands); J. Prowald, ESA Estec (Netherlands); A. Koch, German Aerospace Ctr., Institute of Aerospace Medicine (Germany)

- 7010 2T **The data processing pipeline for the Herschel/SPIRE imaging Fourier Transform Spectrometer** [7010-102]
 T. R. Fulton, Blue Sky Spectroscopy, Inc. (Canada); D. A. Naylor, Univ. of Lethbridge (Canada); J.-P. Baluteau, Lab. d'Astrophysique de Marseille (France); M. Griffin, School of Physics and Astronomy, Cardiff Univ. (United Kingdom); P. Davis-Imhof, Blue Sky Spectroscopy, Inc. (Canada); B. M. Swinyard, T. L. Lim, Rutherford Appleton Lab. (United Kingdom); C. Surace, Lab. d'Astrophysique de Marseille (France); D. Clements, Imperial College (United Kingdom); P. Panuzzo, R. Gastaud, Lab. AIM, CEA-Saclay (France); E. Polehampton, Univ. of Lethbridge (Canada) and Rutherford Appleton Lab. (United Kingdom); S. Guest, Rutherford Appleton Lab. (United Kingdom); N. Lu, A. Schwartz, K. Xu, Infrared Processing and Analysis Ctr., California Institute of Technology (United States)
- 7010 2U **Characterisation of Herschel-SPIRE flight model optical performances** [7010-103]
 M. Ferlet, Rutherford Appleton Lab. (United Kingdom); G. Laurent, Univ. of Colorado, Boulder (United States); B. Swinyard, Rutherford Appleton Lab. (United Kingdom); J. Glenn, Univ. of Colorado, Boulder (United States); J. Bock, Jet Propulsion Lab. (United States) and California Institute of Technology (United States); K. Dohlen, Observatoire Astronomique de Marseille Provence (United States)

POSTER SESSION: AKARI-SPITZER

- 7010 2V **Stability of the Infrared Array Camera for the Spitzer Space Telescope** [7010-104]
 S. Carey, J. Surace, M. Lacy, W. Glaccum, P. Lowrance, California Institute of Technology (United States); J. L. Hora, S. Willner, Harvard-Smithsonian Ctr. for Astrophysics (United States)
- 7010 2W **Improving the photometric precision of IRAC Channel 1** [7010-105]
 K. J. Mighell, National Optical Astronomy Observatory (United States); W. Glaccum, California Institute of Technology (United States); W. Hoffmann, Steward Observatory, Univ. of Arizona (United States)
- 7010 2X **In-orbit focal adjustment of the AKARI telescope with and without liquid helium cryogen** [7010-106]
 T. Onaka, Univ. of Tokyo (Japan); H. Kaneda, T. Wada, Institute of Space and Astronautical Science, JAXA (Japan); I. Sakon, Univ. of Tokyo (Japan); Y. Ita, National Astronomical Observatory of Japan (Japan); T. Takagi, W. Kim, Institute of Space and Astronautical Science, JAXA (Japan)
- 7010 2Y **Data reduction techniques for slit and slit-less spectroscopy of diffuse emission with the Infrared Camera onboard AKARI** [7010-107]
 I. Sakon, T. Onaka, Univ. of Tokyo (Japan); T. Wada, Y. Ohyama, H. Matsuhara, Institute of Space and Astronautical Science, JAXA (Japan); N. Fujishiro, D. Ishihara, Univ. of Tokyo (Japan); Y. Ita, H. Kaneda, H. Kataza, W. Kim, T. Matsumoto, H. Murakami, T. Nakagawa, S. Oyabu, Institute of Space and Astronautical Science, JAXA (Japan); T. Tanabe, Institute of Astronomy, Univ. of Tokyo (Japan); T. Takagi, K. Uemizu, Institute of Space and Astronautical Science, JAXA (Japan); M. Ueno, Univ. of Tokyo (Japan); F. Usui, Institute of Space and Astronautical Science, JAXA (Japan); H. Watarai, Office of Space Applications, JAXA (Japan); M. Cohen, Univ. of California, Berkeley (United States)

POSTER SESSION: SPICA-WISE

- 7010 2Z **Mid-infrared coronagraph for SPICA** [7010-108]
K. Enya, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); L. Abe, Lab. Hippolyte FIZEAU, CNRS (Japan); K. Haze, S. Tanaka, T. Nakagawa, H. Kataza, S. Higuchi, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); T. Miyata, S. Sako, T. Nakamura, Institute of Astronomy, The Univ. of Tokyo (Japan); M. Tamura, J. Nishikawa, N. Murakami, National Astronomical Observatory of Japan (Japan); Y. Itoh, Kobe Univ. (Japan); T. Wakayama, T. Sato, N. Nakagiri, Nanotechnology Research Institute, Advanced Industrial Science and Technology (Japan); O. Guyon, Subaru Telescope, National Astronomical Observatory of Japan (Japan); M. Venet, Observatoire Astronomique de Marseille-Provence (France); P. Bierden, Boston Micromachines Corp. (Japan)
- 7010 30 **Cryogenic system for the infrared space telescope SPICA** [7010-109]
H. Sugita, Y. Sato, Aerospace Research and Development Directorate, Japan Aerospace Exploration Agency (Japan); T. Nakagawa, H. Murakami, H. Kaneda, K. Enya, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); M. Murakami, Univ. of Tsukuba (Japan); S. Tsunematsu, M. Hirabayashi, Sumitomo Heavy Industries, Ltd. (Japan)
- 7010 32 **Mid-infrared high-resolution spectrograph for SPICA** [7010-181]
N. Kobayashi, Institute of Astronomy, Univ. of Tokyo (Japan); Y. Ikeda, Photocoding (Japan); H. Kawakita, Kyoto Sangyo Univ. (Japan); K. Enya, T. Nakagawa, H. Kataza, H. Matsuhara, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan); Y. Hirahara, Nagoya Univ. (Japan); H. Tokoro, Nano-Optonics Research Institute, Inc. (Japan)

POSTER SESSION: JWST

- 7010 35 **The on-ground calibration of the Near Infrared Spectrograph (NIRSpec) instrument on-board the James Webb Space Telescope (JWST)** [7010-114]
G. Bagnasco, European Space Agency (Netherlands); P. Ferruit, Univ. de Lyon (France), Observatoire de Lyon, Univ. de Lyon 1 (France), and CNRS, Ctr. de Recherche Astrophysique de Lyon, Ecole Normale Supérieure de Lyon (France); T. Boeker, European Space Agency (Netherlands); M. Closs, EADS Astrium GmbH (Germany); B. Dorner, European Space Agency (Netherlands); X. Gnata, Univ. de Lyon (France), Observatoire de Lyon, Univ. de Lyon 1 (France), and CNRS, Ctr. de Recherche Astrophysique de Lyon, Ecole Normale Supérieure de Lyon (France); J. Koehler, M. Kolm, C. Kuechel, H. Langenbach, M. Melf, J.-F. Pittet, EADS Astrium GmbH (Germany); M. Te Plate, European Space Agency (Netherlands); T. Wetteman, EADS Astrium GmbH (Germany)
- 7010 36 **JWST fine guidance sensor: guiding performance analysis** [7010-115]
N. Rowlands, M. B. Vila, C. Evans, D. Aldridge, D.-L. Desaulniers, COM DEV, Ltd. (Canada); J. B. Hutchings, Herzberg Institute of Astrophysics (Canada); J. Dupuis, Canadian Space Agency (Canada)
- 7010 38 **JWST tunable filter imager: etalon prototype test results** [7010-118]
D. Touahri, P. Cameron, C. Evans, E. Greenberg, N. Rowlands, A. Scott, COM DEV, Ltd. (Canada); R. Doyon, M. Beaulieu, Univ. de Montréal (Canada); O. Djazovski, Canadian Space Agency (Canada)

- 7010 39 **MIRI Telescope Simulator** [7010-119]
 T. Belenguer, M. A. Alcacera, A. Aricha, A. Balado, J. Barandiarán, A. Bernardo, M. R. Canchal, M. Colombo, E. Díaz, V. Eiriz, I. Figueroa, G. García, A. Giménez, L. González, F. Herrada, A. Jiménez, R. López, M. Menéndez, M. Reina, J. A. Rodríguez, A. Sánchez, Instituto Nacional de Técnica Aeroespacial (Spain)
- 7010 3A **First results from MIRI verification model testing** [7010-120]
 T. Lim, Rutherford Appleton Lab. (United Kingdom); J. L. Alvarez, European Space Agency (Netherlands); E. Bauwens, Instituut voor Sterrenkunde Katholieke Univ. Leuven (Belgium); A. Garcia Bedregal, Instituto de Estructura de la Materia, CSIC (Spain); J. Blommaert, Instituut voor Sterrenkunde Katholieke Univ. Leuven (Belgium); H. Dannerbauer, Max-Planck Institut für Astronomie (Germany); P. Eccleston, M. Ferlet, Rutherford Appleton Lab. (United Kingdom); S. Fischer, M. Garcia-Marin, Institut Univ. zu Köln (Germany); A. Glasse, UK Astronomy Technology Ctr. (United Kingdom); A. M. Glauser, Paul Scherrer Institut (Switzerland); K. Gordon, Space Telescope Science Institute (United States); T. Greene, NASA Ames Research Ctr. (United States); T. Grundy, Rutherford Appleton Lab. (United Kingdom); M. Hennemann, U. Klaas, Max-Planck Institut für Astronomie (Germany); A. Labiano, Instituto de Estructura de la Materia, CSIC (Spain); F. Lahuis, SRON Netherlands Institute for Space Research (Netherlands) and Leiden Observatory, Leiden Univ. (Netherlands); J. R. Martínez-Galarza, Leiden Observatory, Leiden Univ. (Netherlands); B. M. Martin, European Space Agency (Netherlands); J. Morrison, The Univ. of Arizona (United States); T. Nakos, Sterrenkundig Observatorium, Univ. of Ghent (Belgium); B. O'Sullivan, Astrium, Ltd. (United Kingdom); B. Pindor, Univ. of Leicester (United Kingdom); M. Ressler, Jet Propulsion Lab. (United States); B. Shaughnessy, Rutherford Appleton Lab. (United Kingdom); B. Vandenbussche, Instituut voor Sterrenkunde Katholieke Univ. Leuven (Belgium); M. Wells, G. Wright, UK Astronomy Technology Ctr. (United Kingdom); J. Zuther, Institut Univ. zu Köln (Germany)
- 7010 3B **Optical ground support equipment for the alignment of JWST-NIRSpec** [7010-121]
 J. Schmoll, A. G. Basden, D. G. Bramall, P. Clark, Netpark Research Institute (United Kingdom); R. E. Cole, Mullard Space Science Lab., Univ. College London (United Kingdom); G. N. Dodsworth, S. J. Goodsell, Netpark Research Institute (United Kingdom); A. McCalden, Interface (United Kingdom); G. J. Murray, R. M. Myers, R. M. Sharples, Netpark Research Institute (United Kingdom); J. A. Tandy, P. Thomas, Mullard Space Science Lab., Univ. College London (United Kingdom)
- 7010 3C **Cryogenic pupil alignment test architecture for the James Webb Space Telescope integrated science instrument module** [7010-122]
 B. J. Bos, D. A. Kubalak, S. R. Antonille, R. G. Ohl, J. G. Hagopian, P. S. Davila, NASA Goddard Space Flight Ctr. (United States); J. Sullivan, M. Sánchez, D. Sabatke, Ball Aerospace & Technologies Corp. (United States); R. A. Woodruff, Lockheed Martin Space Systems Co. (United States); M. te Plate, ESA European Space Research and Technology Ctr. (Netherlands); C. Evans, COM DEV (Canada); V. Isbrucker, Isbrucker Consulting (Canada); S. Somerstein, Lockheed Martin Advanced Technology Ctr. (United States); M. Wells, UK Astronomy Technology Ctr., Royal Observatory (United Kingdom); S. Ronayette, CEA Saclay (France)

- 7010 3D **Microshutter arrays: high contrast programmable field masks for JWST NIRSpec** [7010-123]
A. S. Kutyrev, CRESST, UMd, NASA Goddard Space Flight Ctr. (United States); N. Collins, RSIS, NASA Goddard Space Flight Ctr. (United States); J. Chambers, S. H. Moseley, NASA Goddard Space Flight Ctr. (United States); D. Rapchun, GST, NASA Goddard Space Flight Ctr. (United States)
- 7010 3F **The Optical Telescope Element Simulator for the James Webb Space Telescope** [7010-126]
P. S. Davila, B. J. Bos, NASA Goddard Space Flight Ctr. (United States); E. S. Cheng, Conceptual Analytics (United States); B. Chang, Edge Space Systems (United States); W. L. Eichhorn, B. J. Frey, NASA Goddard Space Flight Ctr. (United States); M. Garza, Orbital Sciences Corp. (United States); Q. Gong, ATK Space Division (United States); B. W. Greeley, NASA Goddard Space Flight Ctr. (United States); J. Guzek, Design Interface, Inc. (United States); C. F. Hakun, NASA Goddard Space Flight Ctr. (United States); L. Hovmand, Northrop Grumman (United States); J. Kirk, Orbital Sciences Corp. (United States); D. A. Kubalak, D. Leviton, NASA Goddard Space Flight Ctr. (United States); A. Nagle, R. Nyquist, Ball Aerospace & Technologies Corp. (United States); T. Pham, NASA Goddard Space Flight Ctr. (United States); F. D. Robinson, Orbital Sciences Corp. (United States); D. Sabatke, J. F. Sullivan, P. Volmer, R. VonHandorf, R. N. Youngworth, Ball Aerospace & Technologies Corp. (United States)
- 7010 3G **Optical coating performance for heat reflectors of JWST-ISIM electronic component** [7010-127]
M. A. Quijada, NASA Goddard Space Flight Ctr. (United States); R. Bousquet, Genesis Engineering Solutions, Inc. (United States); M. Garrison, C. Perrygo, F. Threat, NASA Goddard Space Flight Ctr. (United States); R. Rashford, Genesis Engineering Solutions, Inc. (United States)
- 7010 3J **Performance results of the TFI coronagraphic occulting mask prototypes** [7010-130]
M. Beaulieu, R. Doyon, Univ. de Montréal (Canada); D. Lafrenière, Univ. of Toronto (Canada)
- 7010 3K **The JWST MIRI double-prism: design and science drivers** [7010-182]
S. Fischer, D. Moratschke, C. Straubmeier, A. Eckart, Univ. of Cologne (Germany); L. Rossi, J.-Y. Plesseria, E. Renotte, E. Mazy, Ctr. Spatial de Liège (Belgium); J. Amiaux, Commissariat à l'Energie Atomique, DAPNIA (France)
- 7010 3L **Fabrication and test of silicon grisms for JWST-NIRCam** [7010-183]
D. T. Jaffe, W. Wang, J. P. Marsh, C. P. Deen, Univ. of Texas at Austin (United States); D. Kelly, Steward Observatory, Univ. of Arizona (United States); T. P. Greene, NASA Ames Research Ctr. (United States)

POSTER SESSION: JDEM

- 7010 3M **Three mirror anastigmat survey telescope optimization** [7010-133]
M. J. Sholl, Univ. of California at Berkeley (United States); M. L. Kaplan, Ball Aerospace & Technologies Corp. (United States); M. L. Lampton, Univ. of California at Berkeley (United States)

- 7010 3N **First results for the spectro-photometry calibration of the SNAP spectrograph demonstrator in the visible range** [7010-134]
M.-H. Aumeunier, Lab. d'Astrophysique de Marseille (France) and Ctr. de Physique de Particules de Marseille (France); A. Ealet, Ctr. de Physique de Particules de Marseille (France); P. Prieto, Lab. d'Astrophysique de Marseille (France); C. Cerna, Ctr. de Physique de Particules de Marseille (France)

POSTER SESSION: CORNOGRAPHY

- 7010 3P **Design and demonstration of hybrid Lyot coronagraph masks for improved spectral bandwidth and throughput** [7010-139]
D. C. Moody, B. L. Gordon, J. T. Trauger, Jet Propulsion Lab. (United States)
- 7010 3Q **Diffraction effects in a giant saw-toothed edge externally occulted solar coronagraph** [7010-140]
E. Verroi, Univ. of Padova (Italy); F. Frassetto, G. Naletto, CNR, Istituto Nazionale per la Fisica della Materia, Lab. for Ultraviolet and X-ray Optical Research (Italy) and Univ. of Padova (Italy)
- 7010 3R **In-flight validation of the formation flying technologies using the ASPIICS/PROBA-3 giant coronagraph** [7010-141]
S. Vivès, P. Lamy, P. Levacher, M. Venet, J. L. Boit, Lab. d'Astrophysique de Marseille (France)
- 7010 3S **Planetscope: an exoplanet coronagraph on a balloon platform** [7010-142]
W. A. Traub, P. Chen, B. Kern, Jet Propulsion Lab. (United States); T. Matsuo, Jet Propulsion Lab. (United States) and Japanese Society for the Promotion of Science (Japan)

POSTER SESSION: TPF

- 7010 3T **Verification, validation, and testing the New Worlds Observer: first thoughts** [7010-143]
J. W. Arenberg, Northrop Grumman Space Technology (United States); M. C. Noecker, Ball Aerospace & Technologies Corp. (United States)
- 7010 3U **THESIS: terrestrial and habitable zone infrared spectroscopy spacecraft** [7010-144]
G. Vasisht, M. R. Swain, Jet Propulsion Lab. (United States); R. L. Akeson, California Institute of Technology (United States); A. Burrows, Princeton Univ. (United States); D. Deming, NASA Goddard Space Flight Ctr. (United States); C. J. Grillmair, California Institute of Technology (United States); T. P. Greene, NASA Ames Research Ctr. (United States)
- 7010 3X **New Worlds Observer telescope and instrument optical design concepts** [7010-147]
J. M. Howard, NASA Goddard Space Flight Ctr. (United States); C. Noecker, S. Kendrick, S. Kilston, Ball Aerospace & Technologies Corp. (United States); B. Woodgate, NASA Goddard Space Flight Ctr. (United States); W. Cash, Univ. of Colorado, Boulder (United States)
- 7010 3Y **Analysis of exoplanet light curves with the New Worlds Observer** [7010-148]
P. Oakley, W. Cash, Univ. of Colorado, Boulder (United States); M. Turnbull, Univ. of Colorado (United States) and Global Science Institute (United States)

POSTER SESSION: MISSION CONCEPTS

- 7010 3Z **The Star Formation Observatory (SFO) mission to study cosmic origins near and far** [7010-149]
P. A. Scowen, R. Jansen, SESE, Arizona State Univ. (United States); M. Beasley, CASA, Univ. of Colorado, Boulder (United States); B. Cooke, S. Nikzad, NASA-Jet Propulsion Lab. (United States); O. Siegmund, SSL, Univ. of California, Berkeley (United States); R. Woodruff, Lockheed Martin Coherent Technologies (United States); D. Calzetti, Univ. of Massachusetts (United States); S. Desch, SESE, Arizona State Univ. (United States); A. Fullerton, Space Telescope Science Institute (United States); J. Gallagher, Univ. of Wisconsin-Madison (United States); S. Malhotra, SESE, Arizona State Univ. (United States); M. McCaughrean, Univ. of Exeter (United Kingdom); R. O'Connell, Univ. of Virginia (United States); S. Oey, Univ. of Michigan (United States); D. Padgett, SSC, California Institute of Technology (United States); J. Rhoads, SESE, Arizona State Univ. (United States); A. Roberge, NASA Goddard Space Flight Ctr. (United States); N. Smith, Univ. of California, Berkeley (United States); D. Stern, NASA-JPL (United States); J. Tumlinson, Yale Univ. (United States); R. Windhorst, SESE, Arizona State Univ. (United States)

POSTER SESSION: ACTIVE OPTICS TECHNOLOGIES

- 7010 43 **Telescope multi-field wavefront control with a Kalman filter** [7010-153]
J. Z. Lou, D. Redding, N. Sigrist, S. Basigner, Jet Propulsion Lab. (United States)
- 7010 44 **Extraction of extrasolar planet spectra from realistically simulated wavefront-corrected coronagraphic fields** [7010-155]
J. E. Krist, S. B. Shaklan, M. B. Levine, Jet Propulsion Lab. (United States)
- 7010 45 **Extrasolar Planetary Imaging Coronagraph (EPIC): visible nulling coronagraph testbed results** [7010-156]
R. G. Lyon, M. Clampin, NASA Goddard Space Flight Ctr. (United States); G. Melnick, V. Tolls, Smithsonian Astrophysical Observatory (United States); R. Woodruff, G. Vasudevan, Lockheed-Martin Corp. (United States)
- 7010 46 **A SWIFTS operating in visible and near-infrared** [7010-157]
J. Ferrand, LAOG, UJF-CNRS (France); G. Custillon, IMEP-LAHC, INPG-UJF-CNRS (France); S. Kochtcheev, S. Blaize, LNIO, UTT (France); A. Morand, IMEP-LAHC, INPG-UJF-CNRS (France); G. Leblond, LNIO, UTT (France); P. Benech, IMEP-LAHC, INPG-UJF-CNRS (France); P. Royer, LNIO, UTT (France); P. Kern, E. Le Coarer, LAOG, UJF-CNRS (France)
- 7010 47 **Frequency stabilization of semiconductor lasers for onboard interferometers using both Rb-saturated absorption profiles and double-optical feedback systems** [7010-158]
K. Nakano, S. Maehara, M. Yanagisawa, A. Sato, K. Doi, T. Sato, M. Ohkawa, T. Maruyama, Niigata Univ. (Japan); S. Kawamura, National Astronomical Observatory (Japan)

POSTER SESSION: INSTRUMENTS TECHNOLOGIES

- 7010 48 **Programmable spectrometer using MOEMS devices for space applications** [7010-96]
T. Viard, C. Buisset, X. Rejeanier, Thales Alenia Space (France); F. Zamkotsian, Lab. d'Astrophysique de Marseille, CNRS (France); L. M. G. Venancio, European Space Agency (Netherlands)

- 7010 4A **Precision attitude determination for an infrared space telescope** [7010-160]
D. J. Benford, NASA Goddard Space Flight Ctr. (United States); T. R. Lauer, NOAO (United States); R. A. Woodruff, Lockheed Martin Space Systems Co. (United States); R. W. H. van Bezooijen, G. Vasudevan, Lockheed Martin Advanced Technology Ctr. (United States)
- 7010 4C **MicrOmega: a VIS/NIR hyperspectral microscope for in situ analysis in space** [7010-162]
V. Leroi, J. P. Bibring, M. Berthé, Institut d'Astrophysique Spatiale, Univ. Paris XI (France)
- 7010 4D **Optical design and in situ fabrication of large telescopes on the Moon** [7010-163]
P. C. Chen, R. G. Lyon, M. E. Van Steenberg, NASA Goddard Space Flight Ctr. (United States)
- 7010 4E **Durable silver coating for Kepler Space Telescope primary mirror** [7010-164]
D. A. Sheikh, S. J. Connell, R. S. Dummer, Surface Optics Corp. (United States)
- 7010 4F **Phase errors in gossamer membrane primary objective gratings** [7010-165]
T. D. Ditto, DeWitt Brothers Tool Co., Inc. (United States); J. M. Ritter, Institute for Astronomy, Univ. of Hawaii (United States)
- 7010 4G **Optimal analysis for segmented mirror capture and alignment in space optics system** [7010-166]
X. Zhang, X. Yu, X. Wang, L. Zhao, Beijing Institute of Technology (China)
- 7010 4H **The ST5000: a high-precision star tracker and attitude determination system** [7010-168]
J. W. Percival, K. H. Nordsieck, K. P. Jaehnig, Univ. of Wisconsin, Madison (United States)
- 7010 4I **Performance study of photon imaging system for space application** [7010-169]
L. Zhao, X. Zhang, Y. Chen, X. Hu, X. Yu, Beijing Institute of Technology (China)
- 7010 4J **Laboratory experiment of a coronagraph based on step-transmission filters** [7010-170]
J. Dou, National Astronomical Observatories, Nanjing Institute of Astronomical Optics and Technology (China) and Graduate School of the Chinese Academy of Sciences (China); Y. Zhu, National Astronomical Observatories, Nanjing Institute of Astronomical Optics and Technology (China); D. Ren, National Astronomical Observatories, Nanjing Institute of Astronomical Optics and Technology (China) and California State Univ., Northridge (United States); X. Zhang, National Astronomical Observatories, Nanjing Institute of Astronomical Optics and Technology (China) and Graduate School of the Chinese Academy of Sciences (China)
- 7010 4K **IMaX opto-mechanical integration: the AIV process for a magnetograph** [7010-172]
G. Ramos Zapata, M. L. González Fernandez, A. Sánchez Rodríguez, C. Pastor Santos, A. Álvarez-Herrero, Instituto Nacional de Técnica Aeroespacial (Spain)
- 7010 4L **Development of laser interferometric high-precision geometry monitor for JASMINE** [7010-173]
Y. Niwa, K. Arai, A. Ueda, National Astronomical Observatory of Japan (Japan); M. Sakagami, Kyoto Univ. (Japan); N. Gouda, Y. Kobayashi, National Astronomical Observatory of Japan (Japan); Y. Yamada, Kyoto Univ. (Japan); T. Yano, National Astronomical Observatory of Japan (Japan)

- 7010 4M **The proximity electronics of the optical system for the Medusa experiment** [7010-174]
C. Molfese, INAF-VSTceN (Italy); P. Palumbo, V. Della Corte, Univ. La Parthenope (Italy);
F. Esposito, L. Colangeli, INAF-Osservatorio Astronomico di Capodimonte (Italy)
- 7010 4N **Six movements measurement system employed for GAIA secondary mirror positioning system vacuum tests at cryogenic temperatures** [7010-175]
G. Ramos Zapata, A. Sánchez Rodríguez, D. Garranzo García-Ibarrola, T. Belenguer Dávila,
Instituto Nacional de Técnica Aeroespacial (Spain)
- 7010 4O **The design and experiment research on Ha and White Light Telescope** [7010-176]
Z. Chen, S. Yang, National Astronomical Observatories (China); J. Xue, Nanjing Institute of
Astronomical Optics and Technology (China)

POSTER SESSION: HUBBLE

- 7010 4P **Wide field camera 3 ground testing and calibration** [7010-178]
H. Bushouse, S. Baggett, H. Bond, T. Brown, S. Deustua, G. F. Hartig, B. Hilbert, Space
Telescope Science Institute (United States); R. J. Hill, NASA Goddard Space Flight Ctr.
(United States); J. Kim-Quijano, Space Telescope Science Institute (United States);
R. A. Kimble, NASA Goddard Space Flight Ctr. (United States); J. W. MacKenty, A. Martel,
P. McCullough, L. Petro, Space Telescope Science Institute (United States); S. Rinehart,
NASA Goddard Space Flight Ctr. (United States); M. Robberto, Space Telescope Science
Institute (United States)
- 7010 4Q **Technical aspects of the Advanced Camera for Surveys repair** [7010-179]
S. A. Rinehart, NASA Goddard Space Flight Ctr. (United States); E. Cheng, Conceptual
Analytics, LLC (United States); M. Sirianni, Space Telescope Science Institute (United States)
and European Space Agency (France); J. Mack, Space Telescope Science Institute
(United States); K. Boyce, M. Turczyn, NASA Goddard Space Flight Ctr. (United States);
R. Emerle, Ball Aerospace (United States); A. Waczynski, GST (United States); Y. Wen, MEI
(United States); I. Orłowski, Jackson & Tull (United States); G. Waligroski, L. Trubell, K. Albin,
Ball Aerospace (United States); M. Loose, R. Ricardo, Teledyne Imaging Sensors
(United States); H. Smith, NASA Goddard Space Flight Ctr. (United States); P. Alea, ATK
(United States); T. Meyer, Jackson & Tull (United States); J. Auyeung, Teledyne Imaging
Sensors (United States)
- 7010 4R **Technical aspects of the Space Telescope Imaging Spectrograph Repair (STIS-R)** [7010-180]
S. A. Rinehart, NASA Goddard Space Flight Ctr. (United States); J. Domber, Ball Aerospace
(United States); T. Faulkner, SGT (United States); T. Gull, R. Kimble, NASA Goddard Space
Flight Ctr. (United States); M. Klappenberger, Jackson & Tull (United States); D. Leckrone,
M. Niedner, NASA Goddard Space Flight Ctr. (United States); C. Proffitt, Space Telescope
Science Institute/Computer Science Corp. (United States); H. Smith, B. Woodgate, NASA
Goddard Space Flight Ctr. (United States)

ADDITIONAL PAPER

- 7010 4S **Offspring of SPACE: the spectrograph channel of the ESA Dark Energy Mission EUCLID**
[7010-184]
R. Content, Univ. of Durham (United Kingdom); A. Cimatti, Univ. di Bologna (Italy);
M. Robberto, Space Telescope Science Institute (United States); R. Grange, Lab.
d'Astrophysique de Marseille, CNRS, Univ. de Provence (France); P. Spanò, INAF,
Osservatorio Astronomico di Brera (Italy); R. M. Sharples, C. M. Baugh, Univ. of Durham
(United Kingdom); B. Garilli, INAF, IASF-Milano (Italy); L. Guzzo, INAF, Osservatorio
Astronomico di Brera (Italy); O. Le Fevre, Lab. d'Astrophysique de Marseille, CNRS, Univ. de
Provence (France); D. Maccagni, INAF, IASF-Milano (Italy); P. Rosati, European Southern
Observatory (Germany); Y. Wang, Univ. of Oklahoma (United States); G. Zamorani, INAF,
Bologna Astronomical Observatory (Italy); F. Zerbi, INAF, Osservatorio Astronomico di Brera
(Italy)

Author Index

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Session Chairs

- 1 **Herschel-Planck**
Mattheus W. M. de Graauw, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands)

- 2 AKARI
Takao Nakagawa, Japan Aerospace Exploration Agency (Japan)
- 3 SPICA-WISE
Jean-Pierre Maillard, Institut d'Astrophysique de Paris (France)
- 4 JWST Overview
C. Matt Mountain, Space Telescope Science Institute
(United States)
- 5 JWST: OTE Verification
Lee D. Feinberg, NASA Goddard Space Flight Center (United States)
- 6 JWST: Instruments
Richard W. Capps, Jet Propulsion Laboratory (United States)
Suzanne Casement, Northrop Grumman Corporation (United States)
- 7 Planetary Missions
Jean-Pierre Maillard, Institut d'Astrophysique de Paris (France)
- 8 JDEM
Lee D. Feinberg, NASA Goddard Space Flight Center (United States)
- 9 Hubble
C. Matt Mountain, Space Telescope Science Institute
(United States)
- 10 Coronagraphy
Daniel R. Coulter, Jet Propulsion Laboratory (United States)
- 11 TPF Concepts
H. Philip Stahl, NASA Marshall Space Flight Center (United States)
- 12 New Worlds Observer
James B. Breckinridge, Jet Propulsion Laboratory (United States)
Matthew J. Griffin, Cardiff University (United Kingdom)
- 13 Mission Concepts I
Howard A. MacEwen, ManTech SRS Technologies, Inc. (United States)
- 14 Mission Concepts II
Howard A. MacEwen, ManTech SRS Technologies, Inc. (United States)
- 15 Interferometry from Space I: Joint Session with Conference 7013
Howard A. MacEwen, ManTech SRS Technologies, Inc. (United States)
William C. Danchi, NASA Goddard Space Flight Center (United States)

- 16 Interferometry from Space II: Joint Session with Conference 7013
Jacobus M. Oschmann, Jr., Ball Aerospace & Technologies Corporation (United States)
Markus Schoeller, European Southern Observatory (Chile)
- 17 Technologies: Active Optics
David W. Miller, Massachusetts Institute of Technology (United States)
- 18 Technologies: Structures and Materials
Jacobus M. Oschmann, Jr., Ball Aerospace & Technologies Corporation (United States)
- 19 Technologies: Instruments
Suzanne Casement, Northrop Grumman Corporation (United States)

High redshift galaxy surveys

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ABSTRACT

A brief overview on the current status of the census of the early universe population is given. Observational surveys of high redshift galaxies provide direct opportunities to witness the cosmic dawn and to have better understanding of how and when infant galaxies evolve into mature ones. It is a much more astronomical approach in contrast to the physical approach of to study the spatial fluctuation of cosmic microwave radiation. Recent findings in these two areas greatly advanced our understanding of the early Universe. I will describe the basic properties of several target objects we are looking for and the concrete methods astronomers are using to discover those objects in early Universe. My talk starts with Lyman α emitters and Lyman break galaxies, then introduces a clever approach to use gravitational lensing effect of clusters of galaxies to detect distant faint galaxies behind the clusters. Finally I will touch on the status and prospects of surveys for quasars and gamma-ray bursts.

Keywords: gamma ray burst, high redshift, Lyman α emitter, Lyman break galaxy, quasar, survey

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1. INTRODUCTION

Since the discovery of the expansion of the Universe by Edwin Hubble in 1929, astronomers with ever more powerful telescopes surveyed the sky to find more and more distant galaxies. By studying distant galaxies, one can look back the early history of the Universe. Partridge and Peebles¹, in their classical 1967 paper, predicted the properties of primordial galaxies and pointed out that these galaxies with redshifted Lyman α emission are the targets observational astronomers should look for. Many attempts followed using 4m class telescopes for next three decades. This was, however, not an easy task².

Astronomers of this decade developed various techniques to isolate distant objects; narrow band imaging surveys for Lyman α emitting galaxies³⁻²⁸, multi-band photometric surveys for Lyman break galaxies²⁹⁻³⁸, searches for amplified images of gravitationally lensed galaxies³⁹⁻⁴⁷, quasars⁴⁸⁻⁵⁴ and studies of sporadic gamma ray bursts⁵⁵⁻⁵⁷ in high redshift galaxies. Galaxies up to redshift $z=6.96$ ¹⁸ were spectroscopically confirmed and there are additional candidate galaxies that appear to be at redshift $z > 7$ ^{34-37,41,44,45}.

The current picture of the big bang Universe indicates that the expanding universe cooled rapidly to form neutral hydrogen from protons and electrons at 380,000 years after the big bang. This is the epoch when the photons are decoupled from the matter. The density fluctuation of the dark matter and the matter grew by gravitational interaction and it is conceived that the first generation of stars were born at around 200 million years after the big bang. Initial set of formed stars contained wide range of mass spectrum. The absence of metal elements in the primordial gas helped to form massive stars. Due to the strong UV radiation from those newly formed massive hot stars, the surrounding intergalactic matter was gradually re-ionized. A kind of “Global Warming of the Universe”. When and how these re-ionization process took place is not observationally clarified yet but WMAP5 results⁵⁹ suggest $z \sim 11$ if the re-ionization was an instantaneous event. It is more likely that the cosmic re-ionization could have taken place in an extended period sometime during $6 < z < 17$.

Detailed observations deep into the era beyond $z=7$ is, therefore, crucial. Some of the recent number counts of galaxies at $5.7 < z < 7$ indicate significant decrease in the number density of Lyman α emitting galaxies¹⁶⁻¹⁸, which could either be

due to the evolution of galaxies possibly through merging processes or due to the increasing fraction of neutral hydrogen blocking Lyman α emitting galaxies at high redshift.

I will describe the target population of galaxies in the early Universe and the technique astronomers are employing to find those objects together with some recent results.

2. NARROW BAND SURVEY FOR LYMAN A EMITTERS

What are Lyman α emitters, that are often abbreviated as LAEs? They are thought to be star-forming young galaxies with star formation rate from 1 to 10 solar mass per year. Hot massive stars produce strong UV radiation field and ionize the interstellar gas. The ionized hydrogen recombines and cools by emitting a Lyman α photon to settle down to the lowest ground level. The amount of stars produced in these galaxies is not yet very large as the usual continuum radiation from stars is not necessarily conspicuous. The spectra of LAEs are therefore characterized by strong Lyman- α emission line as shown in Fig.1.

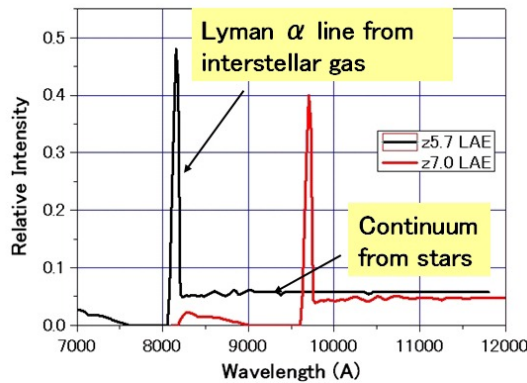


Fig. 1. Typical spectra of Lyman- α emitters showing conspicuous Lyman α emission lines.

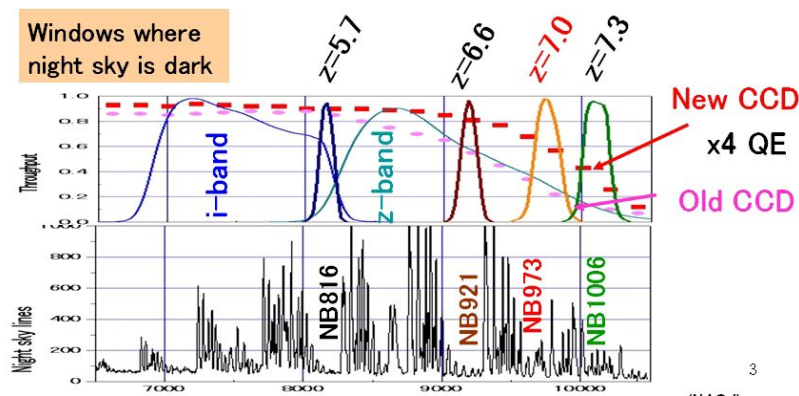


Fig. 2. OH night sky emission bands (lower panel) show a few gaps, which astronomers use as dark windows to study deep into the Universe. Narrow band filters whose transmission are matched to these dark windows are used to sample LAEs at $z=5.7$ (NB816), $z=6.6$ (NB921) and $z=7.0$ (NB973). The current CCD sensitivity falls rapidly toward 1000nm but recently developed high-resistivity, red-sensitive CCDs open a possibility to extend the accessible redshift limit up to $z=7.3$.

How to find those LAEs? It would be natural to catch the Lyman α emission line signal from these galaxies. Since these objects are so faint, one has to consider the properties of the sky background, actually foreground radiation from the Earth's atmosphere. The night sky glows ever brighter at longer wavelength. In the wavelength region below 1 micron, where Si-CCDs are sensitive, the night sky spectrum shows strong bands of OH emission lines as shown in the lowest panel of Fig.2. The gaps between these OH bands are nice dark windows to probe deep space.

Astronomers use narrow band filters whose transmittance bands are matched to one of these gaps to pick up light only in this gap to detect LAEs whose redshifted Lyman α emission enters in this gap. LAEs at appropriate redshift range are expected to show up brighter in the narrow band image than other broad band images. The narrow band (NB) survey is therefore trying to slice the universe in a narrow range of redshift. There are several such gaps, for instance, the narrow band filter NB816 that has the central wavelength at 816nm is suitable for isolating LAEs at redshift 5.7, NB921nm for redshift 6.6, etc. The most distant LAE at redshift 7.0 confirmed to date was also discovered using the narrow band imaging survey using a filter centered at 973nm. The sensitivity of current CCDs falls rapidly toward 1 micron but recent advent of red sensitive CCDs with thicker depletion layer will extend this redshift limit slightly up to about 7.3.

Let me talk on our discovery of the most distant galaxy. The red blob in the left panel of Fig. 3 shows the most distant galaxy, IOK-1¹⁸. This LAE was discovered among the 41,533 objects in the Subaru Deep Field through the narrow band filter NB973 for a total of 15 hours with SuprimeCam⁵⁸. All the objects were cross identified in images taken in other filters and only five photometric candidates for $z=7$ LAEs, which are visible only in this narrow band filter, were isolated (cf. Fig.4). Astronomers have a privilege to name their newly found objects and we took a liberty of naming them taking the initials of three main contributors to this survey, IOK-1 to IOK-5.

We have to be, however, careful as there are several types of possible contaminants in these 5-sigma photometric candidates. First, since the narrow band imaging observation was made 1-2 year after other broad band observations, some of the candidates may well be variable objects like AGNs or galaxies where supernovae added extra light when narrow band observation was made. Possibility for emission line objects at lower redshift is a common concern. To our surprise, simple statistics cautions us that there might be one or two 5 sigma noises as well, since there are millions of independent 2 arcsec apertures one can sample in the SuprimeCam field. Spectroscopic follow-up revealed that only one object, the brightest IOK-1, is a real LAE at redshift 6.96, with the characteristic asymmetric line profile as shown in the right panel of Fig.3.

Table 1 shows the top 10 list of high redshift galaxies with spectroscopic redshift measurement, to the best of my knowledge. You may notice that 9 out of 10 were discovered by Subaru/SuprimeCam survey in the single Subaru Deep Field. This is because Subaru/SuprimeCam enables observation of large survey volume with significant depth. Hubble Ultra Deep Field imaging survey with ACS probes much deeper than ground based observations, but has a much smaller survey volume. The wide field surveys to pick up scarce bright population and narrow field deep surveys to study fainter populations, are complementary to each other.

Subaru Deep Field surveys yielded several dozens of LAE candidates both at redshift 5.7 and 6.6 and about half of them are already confirmed spectroscopically to be LAEs. With this fair sample, one can derive the luminosity function of LAEs. The left panel of Fig.5 shows the UV continuum luminosity functions of LAEs at redshift 5.7 and 6.6 which are, more or less, identical. On the other hand, the right panel shows the Lyman α luminosity functions. We can see that the brighter population of LAEs at redshift 6.6 is significantly less abundant as compared to those at redshift 5.7.

This can be explained if the neutral hydrogen fraction of the intergalactic matter is increasing from redshift 5.7 to 6.6, as the neutral hydrogen selectively absorbs and scatters the Lyman α photons but not for UV continuum. The Ly- α luminosity functions, the UV luminosity functions, and the distribution of equivalent width of the LAEs can be reconciled with the presence of Pop III massive star formation followed by Pop II star formation to power Ly- α emission⁶⁰. Of course, the scarcity in LAEs at high redshift could also be due to the evolutionary history of those galaxies building from tiny proto galaxies. Cosmic variance could be another factor, if not significant to this level.

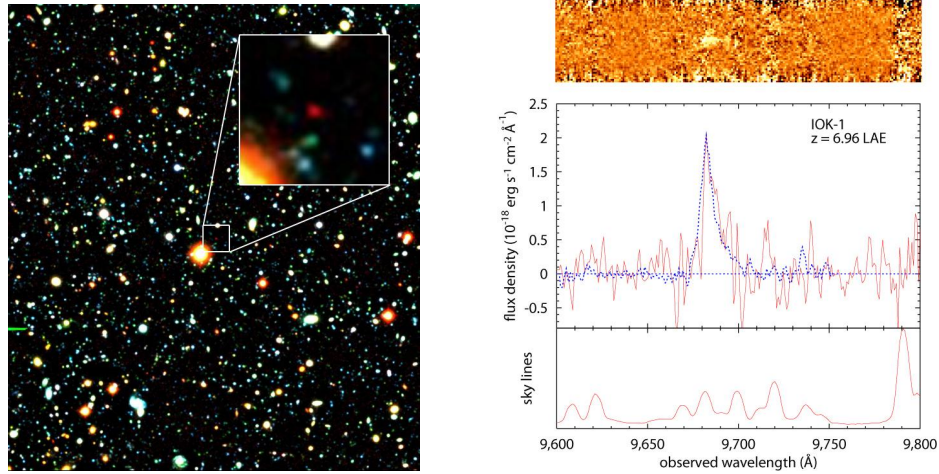


Fig. 3. (Left) The most distant galaxy IOK-1 is shown as a red blob in the inset panel. (Right) Spectrum of IOK-1 showing the characteristic Lyman α emission line with an asymmetric profile at 968nm indicating its redshift 6.96 (Right panel reproduced from Iye et al., 2006¹⁸).

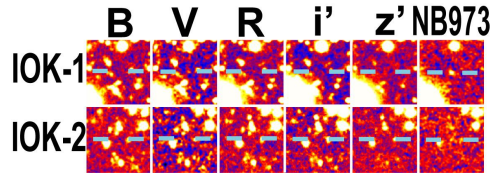


Fig. 4. Post stamp images of the NB973 objects IOK-1 and IOK-2. The latter was confirmed to be a 5-sigma noise (Edited from Ota et al., 2008²²).

Table 1: The most distant galaxies with measured redshift (as of June 6, 2008).

Rank	ID	Coordinates	z	Gyr [#]	Paper	Published date
1	IOK-1	J132359.8+272456	6.964	12.88	Iye et al.	Sep. 14, 2006
2	SDF ID1004	J132522.3+273520	6.597	12.82	Taniguchi et al.	Feb. 25, 2005
3	SDF ID1018	J132520.4+273459	6.596	12.82	Kashikawa et al.	Apr. 25, 2006
4	SDF ID1030	J132357.1+272448	6.589	12.82	Kashikawa et al.	Apr. 25, 2006
5	SDF ID1007	J132432.5+271647	6.580	12.82	Taniguchi et al.	Feb. 25, 2005
6	SDF ID1008	J132518.8+273043	6.578	12.82	Taniguchi et al.	Feb. 25, 2005
6	SDF ID1001	J132418.3+271455	6.578	12.82	Kodaira et al.	Apr. 25, 2003
8*	HCM-6A	J023954.7-013332	6.560	12.82	Hu et al.	Apr. 1, 2002
9	SDF ID1059	J132432.9+273124	6.557	12.82	Kashikawa et al.	Apr. 25, 2006
10	SDF ID1003	J132408.3+271543	6.554	12.82	Taniguchi et al.	Feb.25, 2005

Table 1. Top 10 list of the most distant galaxies. .

In order to identify LAEs at $z > 7$, quite a few projects to make narrow band imaging surveys with near infrared cameras are under way or planned²³⁻²⁸. The field of view of infrared cameras is still considerably smaller than that of, e.g., SuprimeCam and the increasing night sky background make the infrared imaging survey very challenging if the LAE luminosity function is further declining from $z=6.6$ to further redshift.

3. TWO COLOR DIAGNOSIS FOR LYMAN BREAK GALAXIES

Another population of galaxies searched for in the early Universe is called Lyman Break Galaxies, abbreviated as LBGs. LBGs are thought to be fairly massive galaxies with evolved stellar population. Stellar continuum is much stronger than LAEs. Lyman α emission is less conspicuous as compared with LAEs. The spectra of these galaxies show characteristic discontinuity at the blue side of Lyman α line caused by the intrinsic stellar atmospheric absorption and by the Intergalactic neutral hydrogen absorption. These galaxies, therefore, are visible at bands redward of Lyman α line but are not visible at bands blueward of the Lyman α line. One can select out LBG candidates at $z=6$ by i-band dropouts, $z=7$ by z' -band dropout, and $z=9$ by J-band dropouts.

Here again, one has to be careful for possible contaminants. Galactic T-dwarfs dwell in the similar region in two color diagram. One may be able to reject T-dwarfs by their point source images if the image quality is superb. Variable objects and 5 sigma noises are the common problems for this survey as well.

Hubble ACS and NICMOS imaging at Hubble Ultra Deep Field and GOODS field was used to identify faint z-dropouts at around $z=7.3$ and about 8 candidates were isolated. but similar attempt for J dropout didn't yield a candidate³⁷. Another group reported finding of 10 z-dropouts and 2 J-dropouts⁴⁶.

Unfortunately, many of these objects do not show strong Lyman α emission and spectroscopic confirmation of their genuine redshift is difficult.

4. SURVEY FOR STRONGLY LENSED GALAXIES

Let me turn to genius survey projects using the gravitational lensing effect of a massive cluster of galaxies to magnify and brighten the background faint galaxies. Cluster of galaxies are largest telescopes in the Universe with diameter about

1Mpc. They are nice telescopes for astronomers. You do not need to ask for funding agencies for construction budget and you do not need to ask engineers to design and build them. They are in situ and free of charge to use. Of course there are some drawbacks. You cannot point them to your favorite targets. Wavefront aberrations are bazaar. Although the images produced by cluster lensing are peculiarly deformed and enlarged, the largest advantage is the fact some of the lensed images are brightened considerably and when multiply lensed images are available they can be used to check for the consistency of their reconstructed source image.

Appropriate modeling of the gravitational field of the cluster enables the prediction of the location of critical lines for assumed source redshift slice where the magnification becomes infinity. Observers can look for lensed object along these critical lines and there are in fact several candidate galaxies found in this way³⁹⁻⁴⁷. For instance, a survey for strongly lensed LAEs in 9 clusters yielded six candidates⁴⁴. If any of these candidates are real, the number density of faint population of galaxies is much larger than previously considered and may well explain the necessary amount of re-ionizing source.

Fig.6 shows a promising z-dropout candidate at redshift 7.6 found behind the cluster Abel 1689 recently⁴⁵. Photometric results indicate better match to a galaxy at $z=7.6$, however, here again the possibility of galaxy at $z=1.7$ is hard to rule out just from imaging.

5. QUASARS AND GAMMA RAY BURSTERS

The last objects I am going to introduce are point sources, quasars and gamma ray bursts (GRBs), in the early Universe. The survey technique used to isolate high redshift quasar candidates is similar to that used for LBGs. Objects that match the expected spectral energy distribution of high redshift quasars are surveyed in the two color diagram or even a multi-dimension color manifold. Sloan Digital Sky Survey with its enormous data base is a nice test bed to apply this

approach. Many quasars beyond redshift 6 were found in this way⁴⁸⁻⁵². The most distant quasar to date is J1148+5251 at 6.42⁵¹. Gunn-Peterson test of quasars up to redshift 6 indicated strongly that the cosmic re-ionization ended by redshift 6.

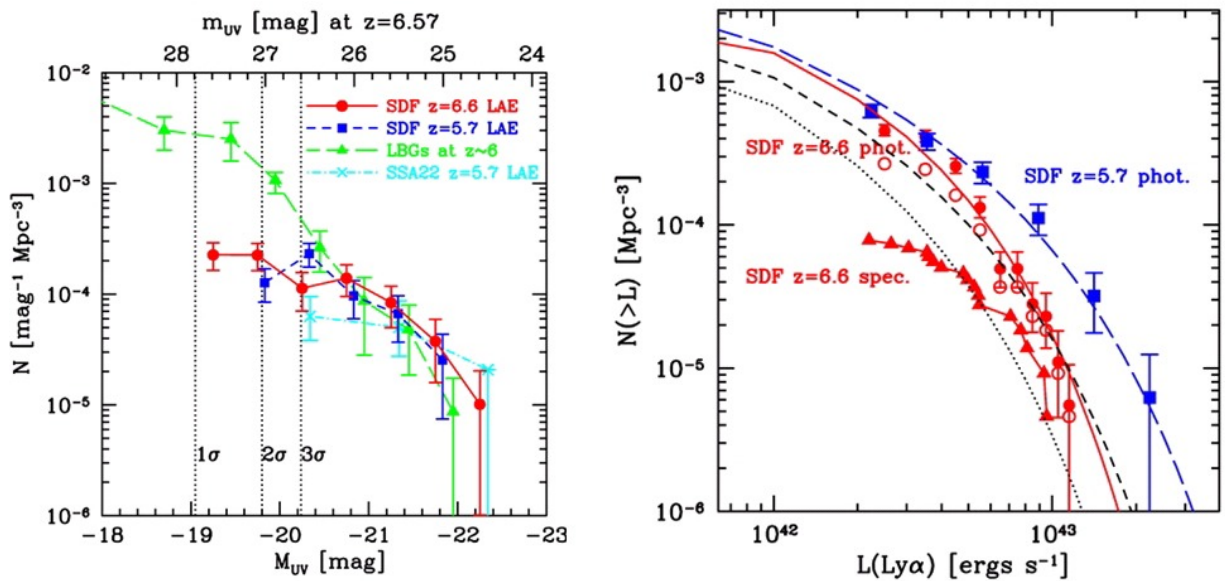


Fig. 5. (Left panel) UV continuum luminosity function of LAEs at $z=5.7$ (blue) and $z=6.6$ (red) which are more or less identical. (Right panel) Lyman α luminosity functions of LAEs at $z=5.7$ (blue) and $z=6.6$ (red). Note that the significant decrease in Lyman- α luminosity function at its bright end (Edited from Kashikawa et al., 2006¹⁷).

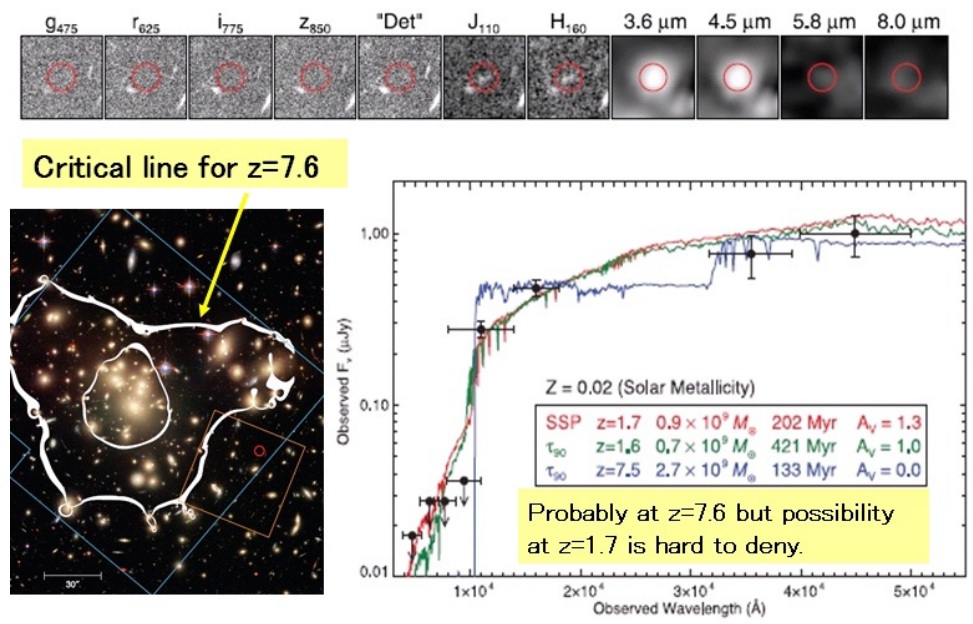


Fig.6. Lyman break galaxy candidate at $z\sim 7.6$ discovered behind the lensing cluster A1689 (Edited from Bradley et al. 2008⁴⁵).

The advent of the real time alert system of gamma ray burst increased the chance of optical and infrared astronomers to make prompt observations of these rapidly declining bursts. The most distant GRB observed to date is GRB050904 at $z=6.3$ ⁵⁵. GRBs at high redshift can be useful tools to probe the cosmic re-ionization through its Lyman- α damping wing⁵⁶.

GRB has a much simpler featureless continuum than the quasar spectra which has broad emission lines superposed on the non-thermal continuum. GRBs are, in a way, better probes to study the re-ionization history. Both quasars and GRBs are point sources, the advent of laser guide star adaptive optics makes the observation of fainter objects feasible and we expect many such observations if the observatories pay efforts for timely follow-up spectroscopy of long burst GRBs. GRBs may provide a new way to study even higher-redshift galaxies and first generation of stars.

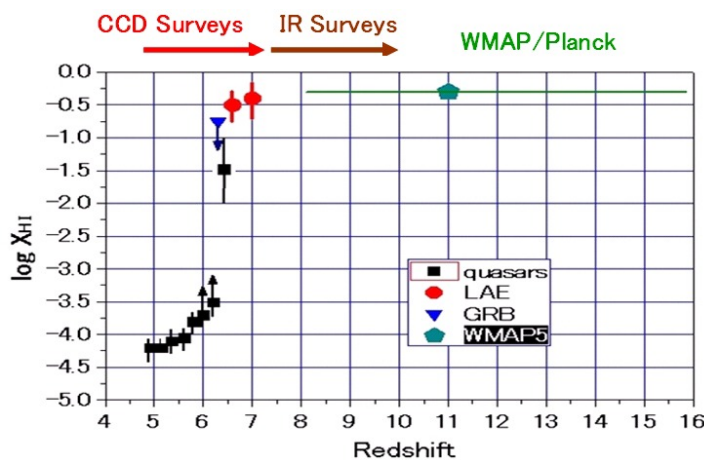


Fig. 7. Neutral hydrogen fraction of intergalactic matter as derived from Gunn-Peterson tests of $z > 5$ quasars (black squares), damped Lyman- α wing profile (blue triangle), and Lyman α luminosity function (red circles). Also plotted is the WMAP 5 year result, which predict $z=11$ for instantaneous re-ionization. Note, however, that WMAP cannot constrain when re-ionization started and how long it took to complete.

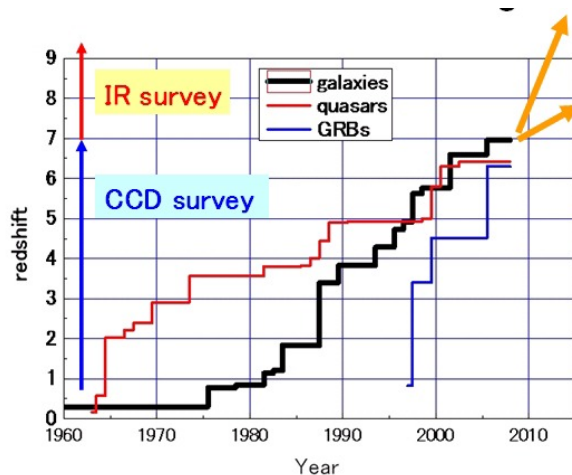


Fig.8. Growth history of largest redshift objects. Note that GRBs are catching up quickly (Based on Tanvir & Jakobsson, 2007⁵⁷)

Fig.7 shows the increase of the fraction of neutral hydrogen as measured from Gunn-Peterson tests⁵⁴ of quasars up to redshift 6.42 on the left hand. Our results from redshift 6.6 and 7.0 LAE is shown in red and an upper limit from redshift 6.3 GRB is shown in blue triangle. WMAP5 polarization study concludes that the cosmic re-ionization, if it took place instantaneously, would be at redshift around 11⁵⁹ However, WMAP results alone cannot pin down when the cosmic re-ionization started and how long it took to finish. Planck satellite may give more clue in 5 years time. Surveys for galaxies beyond redshift 7 up to 11 is, therefore, extremely important to elucidate what happened actually in this period and for that we need NIR deep surveys.

My last slide (Fig. 8) shows the annual growth of the records of highest redshift objects⁵⁷. The discovery of our $z=6.96$ galaxy was announced on Sep.14, 2006, 648 days ago. Simple statistical argument⁶¹ predicts that new record will come in, at 95% confidence level, at earliest in 17 days from today and at latest in 69 years. I am confident, however, that we do not need to wait so long as lots of new surveys are under way using near infrared cameras. Besides, observations of GRBs are catching up quickly, and considering the availability of innovated LGSAO, I would rather predict GRB will soon take over this race.

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