Science with SCORPIO on Gemini

SCORPIO

Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical

Scorpio: Latin for scorpion, a nocturnal arachnid with 8 legs

Scorpio: constellation passing overhead at Gemini South in winter

- New facility instrument at Gemini South for the 2020s
- Simultaneous optical-NIR multiband photometry (8 bands)
- Long-slit optical-NIR broadband spectroscopy (385 – 2350 nm)
- Time domain astronomy: fast response & high time resolution
- Uncovered region of observational space & highly efficient
- Work-horse instrument with broad range of science cases

The SCORPIO Team

Massimo Robberto
Principal Investigator

Alexander van der Horst
Project Scientist & Data Reduction Software

Marisa Garcia-Vargas – *OMT Manager*
Ernesto Sanchez-Blanco – *Optics*
Manuel Maldonado Medina – *Mechanical/Thermal*
Ana Perez – *OMT Systems Engineer*

Pete Roming – *Project Manager*
Susan Pope – *Systems Engineer*
Todd Veach – *Instrument Scientist*
Tonya Brody – *Deputy Systems Engineer*
Kelly Smith – *Visible Camera*
Ronnie Killough – *Control Software*
Kristian Persson – *Electronics*
Jason Stange – Electrical Engineer
Amanda Bayless – *Detectors*

Stephen Goodsell – *Project Manager*
Manuel Lazo – *Systems Engineer*
Morten Andersen – *Project Scientist*
Ruben Diaz – *Instrument Scientist*
Scot Kleinman – *Project Sponsor*
Arturo Nunez, Kathleen Labrie, Tom Hayward, …

Plus: large & diverse science team, covering broad range of science topics

SCORPIO Science Team

Álvaro Álvarez-Candal, Obs. Nacional
Morten Andersen, Gemini Observatory
Rodolfo Angeloni, University of La Serena
Stefano Bagnulo, Armagh Observatory
Franz Bauer, Pontificia Univ. Católica
Amanda Bayless, Southwest Research Inst.
Melina Bersten, Universidad de la Plata
Marcelo Borges Fernandes, Obs. Nacional
Tom Broadhurst, Univ. del País Vasco
Nat Butler, Arizona State University
Brad Cenko, Goddard Space Flight Center
Lydia Cidale, Obs. Astronomico de la Plata
Jesus Corral-Santana, Pontif. Univ. Católica
Vik Dhillon, University of Sheffield
Ruben Diaz, Gemini Observatory
René Duffard, Inst. de Astr. de Andalucía
Robert Fesen, Dartmouth College
Gastón Folatelli, Universidad de la Plata

Jonathan Fortney, UC Santa Cruz
Ori Fox, STScI
Anna Frebel, MIT
Bryan Gaensler, University of Toronto
Lluís Galbany, Universidad de Chile
Karl Glazebrook, Swinburne Univ. of Tec.
Stephen Goodsell, Gemini & Durham Univ.
Daryl Haggard, Amherst College
Eric Hintz, Bringham Young University
Julie Hlavacek-Larrondo, Univ. of Montreal
David Kaplan, Univ. of Wisconsin-Milwaukee
Oleg Kargaltsev, George Washington Univ.
Chryssa Kouveliotou, George Washington Univ.
Adam Kraus, University of Texas at Austin
Michaela Kraus, Akademie věd České rep.
Ho-Gyu Lee, Korea Astron. & Space Science Inst.
Teo Muñoz-Darias, Inst. de Astr. de Canarias
Jerome Orosz, San Diego State University

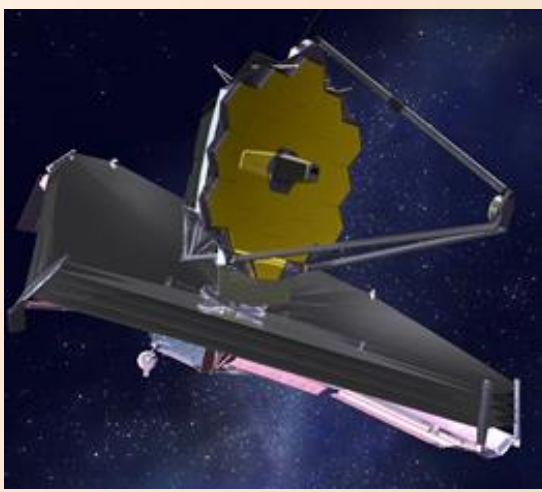
Thomas Pannuti, Morehead State Univ.
Jennifer Patience, Arizona State University
Daniel Perley, Liverpool John Moores Univ.
Noemí Pinilla-Alonso, Florida Space Inst.
Pete Roming, Southwest Research Institute
Brian Schmidt, Australian National Univ.
Steve Schulze, Pontificia Univ. Católica
Denise Stephens, Brigham Young University
Nicole St-Louis, University of Montreal
Rachel Street, Las Cumbres Observatory
Nial Tanvir, University of Leicester
Ezequiel Treister, Univ. de Concepción
Stefano Valenti, Univ. of California – Davis
Daniel Vanden Berk, St. Vincent College
Todd Veach, Southwest Research Institute
Sjoert van Velzen, Johns Hopkins University
Stefanie Wachter, Max-Planck-Inst. für Astr.

Today's Meeting

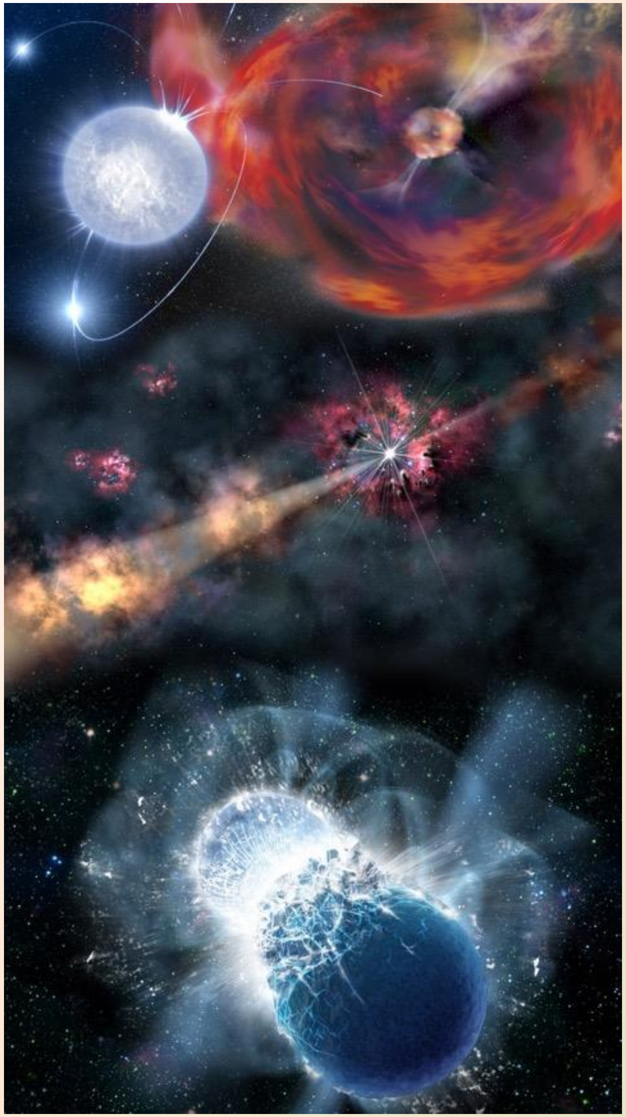
- Introduction
  - *Alexander van der Horst*
- Gemini status
  - *Morten Andersen*
- Gemini follow-up system
  - *Bryan Miller*
- SCORPIO science cases
  - *Alexander van der Horst*
- SCORPIO design status
  - *Massimo Robberto*

Scientific Needs of the 2020s

- New facilities, new role for Gemini: LSST, JWST, ELTs, ALMA, SKA, eROSITA, SVOM, BurstCube, aLIGO (A+), …
- Time-domain & multi-messenger astronomy
- SCORPIO: workhorse instrument to cover a broad range of science

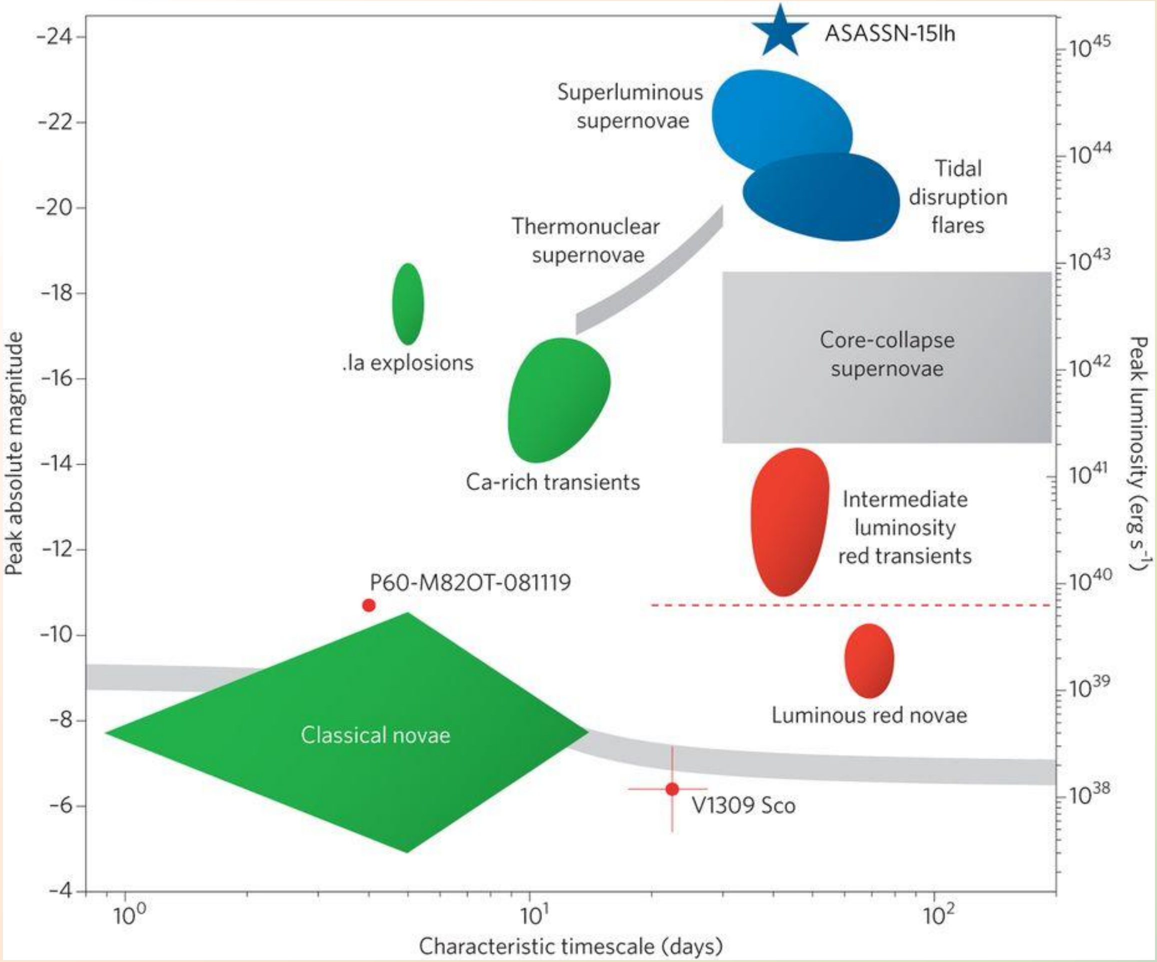


Science Drivers



- Transients discovered with high-cadence optical/radio/X-ray surveys (LSST, SKA, etc.)
- Gravitational wave counterparts
- First generation of stars and their environments through gamma-ray bursts
- Supernova explosion physics and dust evolution in the Universe
- Extreme physics of black holes, neutron stars and white dwarfs
- Origin of our solar system: comets, asteroids and trans-neptunian objects
- Characterize exoplanets, their stellar systems and atmospheres
- Evolution of the Universe since the first galaxies

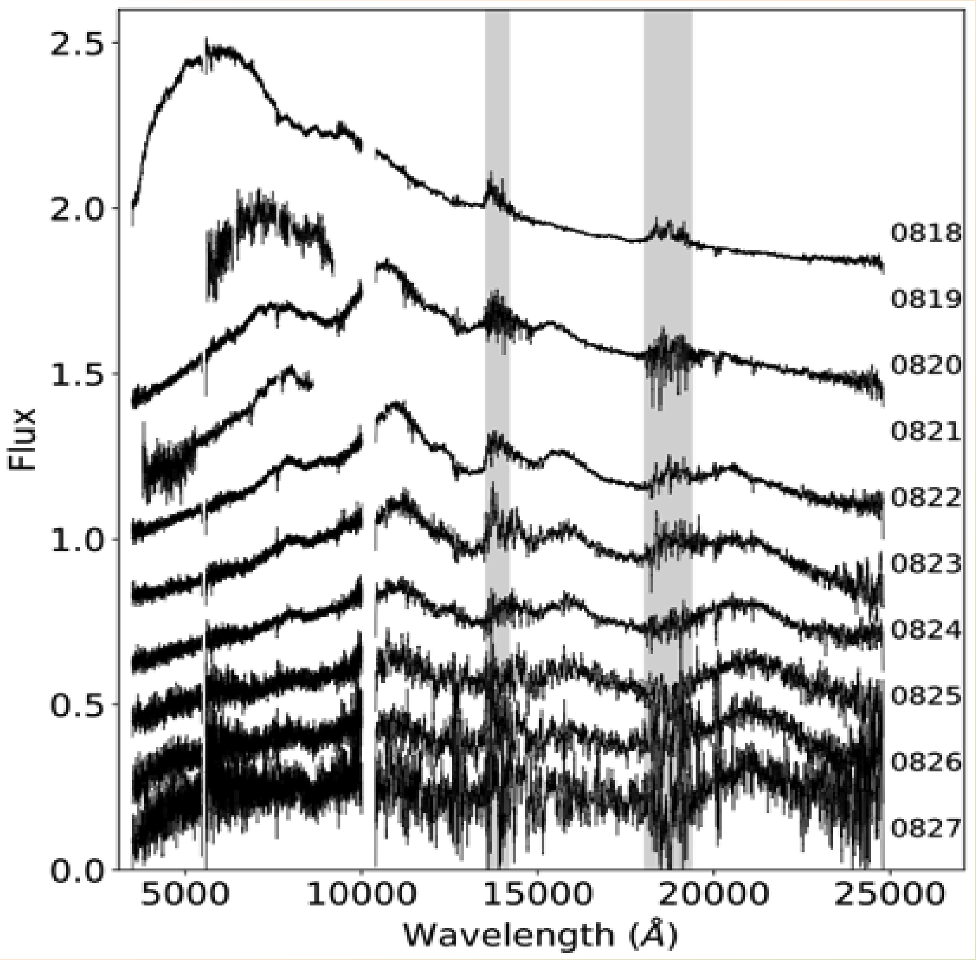
LSST Follow-Up



Cenko et al. 2017; Kasliwal et al. 2012

- LSST: new window in time-domain astronomy
- Time-scales from minutes to years, to unprecedented depth
- Known, predicted, and unknown sources
- SCORPIO: identification and characterization
- Broadband photometry, spectroscopy, and high time resolution
- Follow-up within minutes to hours

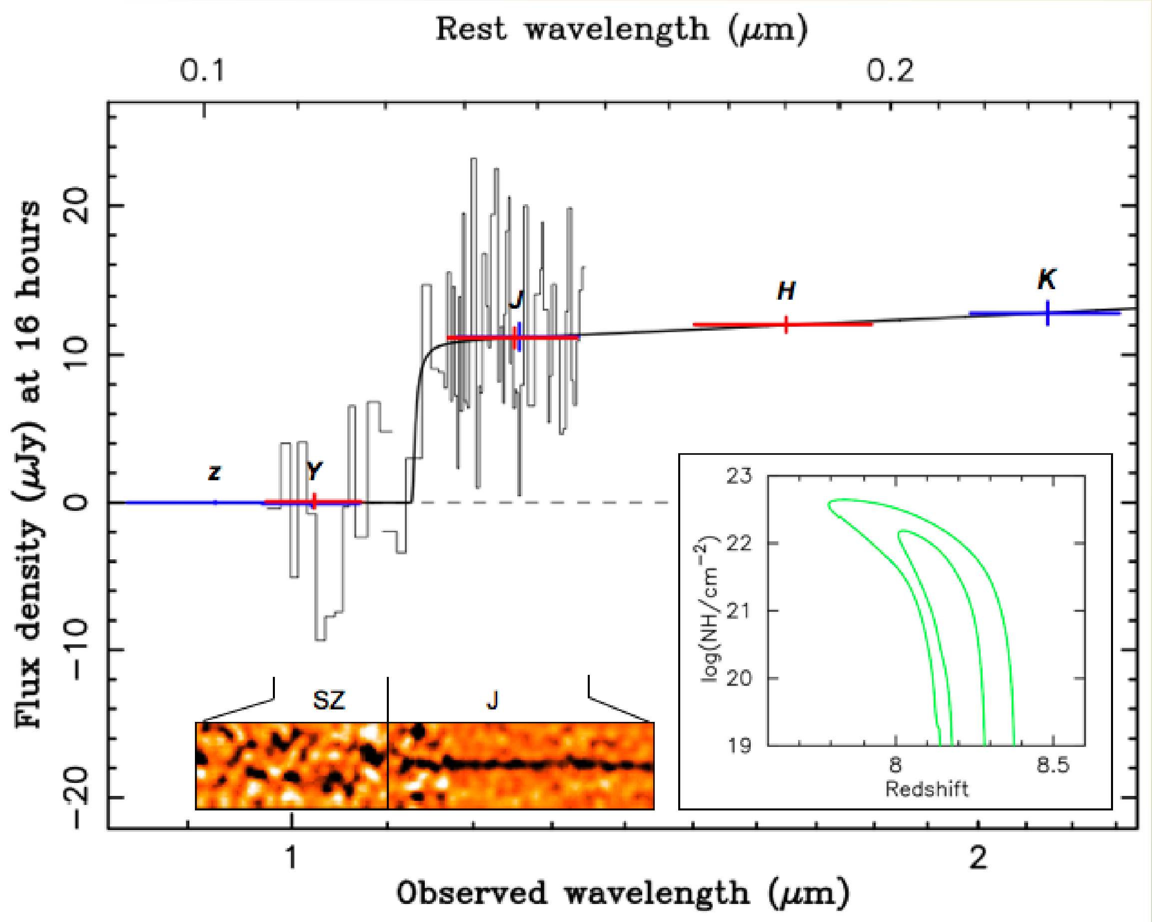
Gravitational Wave Sources



Pian et al. 2017

- First electromagnetic counterpart: GW 170817
- Rapidly evolving transient, in brightness and color
- Several spectral components
- SCORPIO: characterization
- Broadband photometry and spectroscopy
- Follow-up within hours

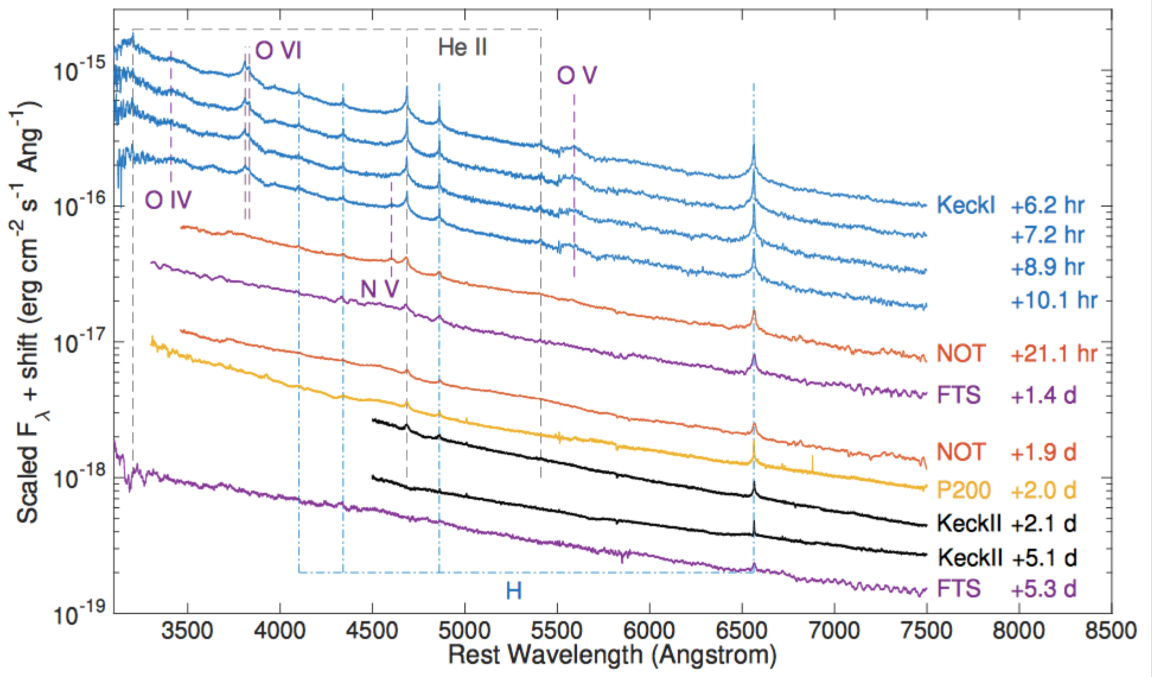
Gamma-Ray Bursts



Tanvir et al. 2009

- GRB jet physics: imaging & high time resolution
- Interstellar medium at high redshifts: broadband spectroscopy
- Characterization of high-redshift host galaxies: broadband imaging & spectroscopy
- Follow-up within minutes

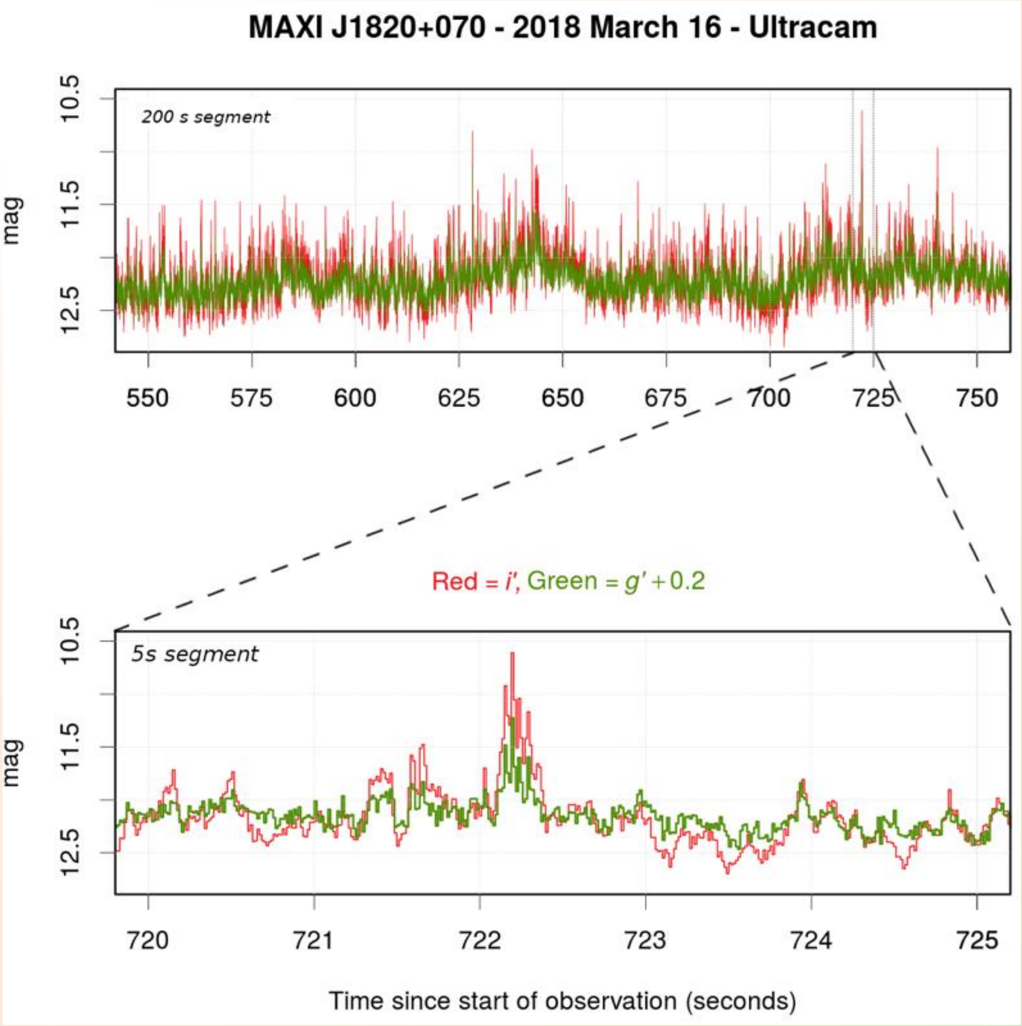
Supernovae



Yaron et al. 2017

- Mass-loss & progenitors: flash & late-time spectroscopy
- Evolution of dust in the Universe: NIR spectroscopy
- Push redshift limit of Hubble diagram: NIR photometry
- Type II possible standard candles: optical-NIR photometry
- Follow-up within hours

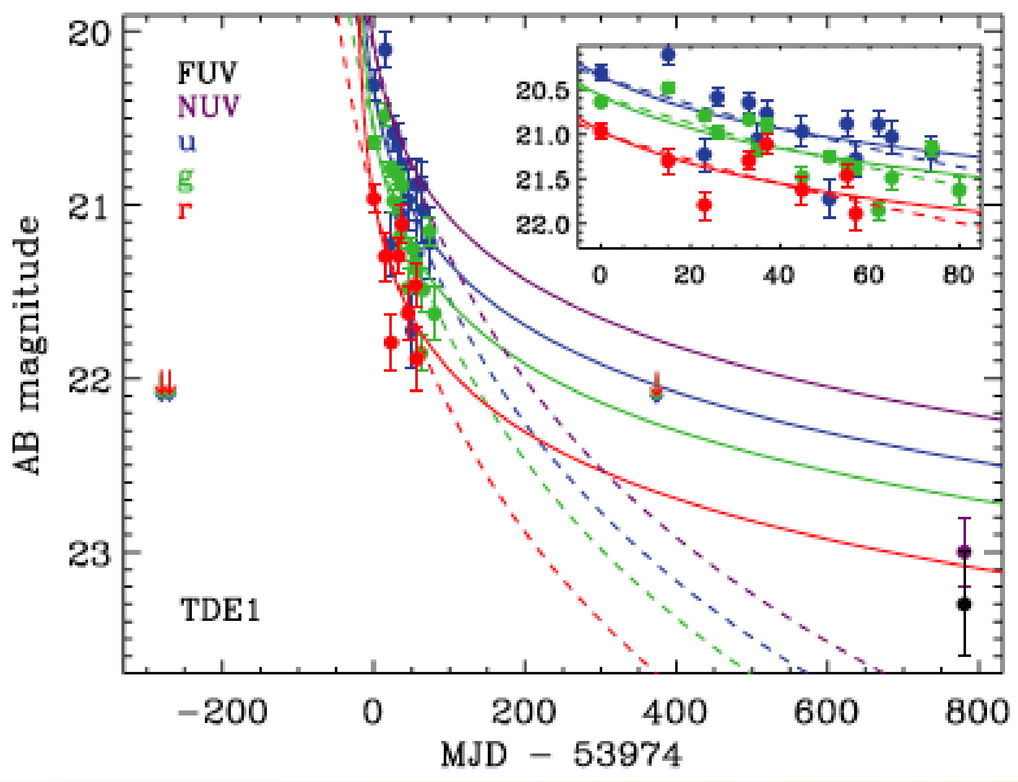
Black Holes



Gandhi et al. 2018

- Accretion physics near black hole event horizon
- Properties of jets
- Disentangle disk, jet & companion star
- Correlate inflow / outflow
- Compact object masses
- Properties disk & environment → progenitors
- Broadband photometry, spectroscopy, and high time resolution
- Follow-up within one day

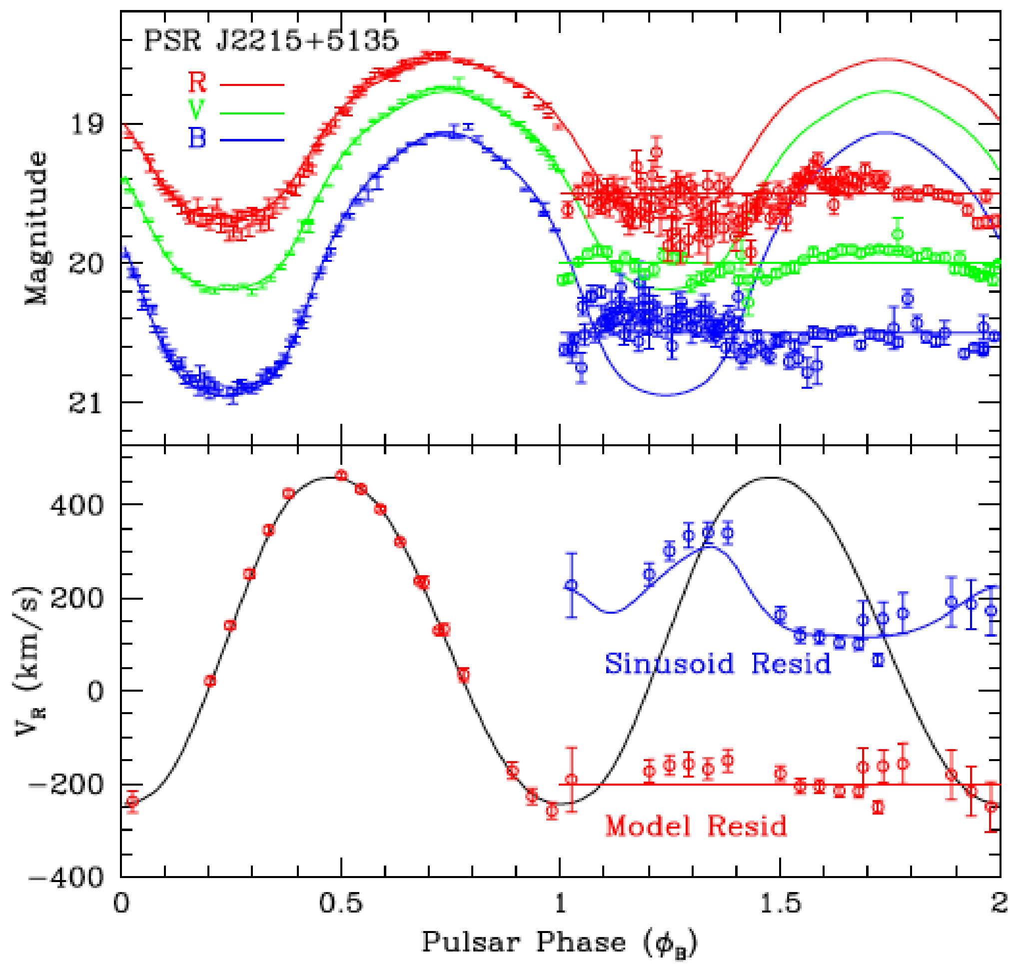
Tidal Disruption Events



Van Velzen et al. 2011

- Identification: broadband photometry
- Gas close to black hole: broadband spectroscopy
- Black hole mass: early & well-sampled photometry
- Disentangle disk & jet: photometry
- Follow-up within one day

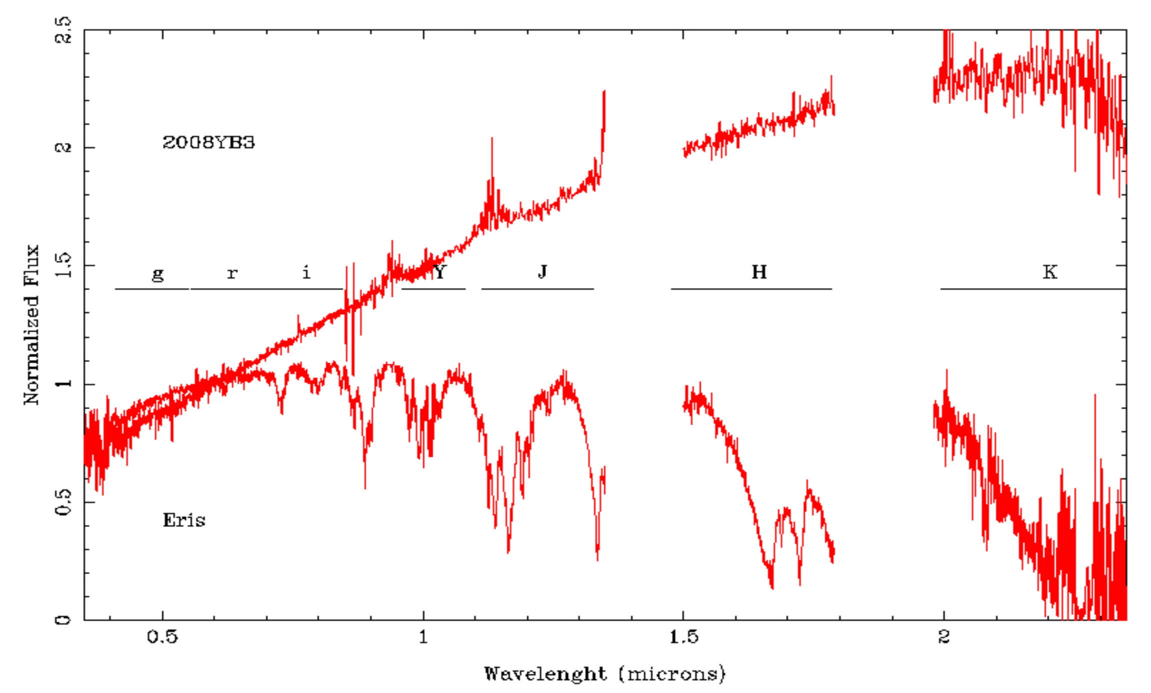
Neutron Stars



Romani et al. 2015

- Atmospheres & magneto-spheres of isolated neutron stars: phase-resolved broadband photometry
- Neutron star magnetic fields: spectroscopy
- Magnetar origin & emission mechanisms: NIR photometry
- Maximum mass & equation of state from millisecond pulsar binaries: photometry & time resolution
- Magnetars: follow-up within hours

Small Solar System Bodies



Alvarez-Candal et al. 2011, Pinilla-Alonso et al. 2013

- Most primitive objects: TNOs, Centaurs, etc.
- Existence of ices on surface: broadband spectroscopy & photometry
- Binary asteroids, rings & fast rotators: high time resolution
- Changes in activity: follow-up within hours

Fast Response

- One day:
  - X-ray binaries → outburst onset
  - Tidal disruption events → outburst onset
- Few hours:
  - Gravitational wave sources → fast spectral evolution
  - Supernovae → flash spectroscopy / shock breakout
  - Magnetars → high-energy outburst peak
  - Small Solar System Bodies → occultations, bursts
- Few minutes:
  - New transients → LSST fast follow-up & Fast Radio Bursts
  - Gamma-ray bursts → jet content & magnetic fields
  - Microlensing of exoplanets → confirmation & demographics

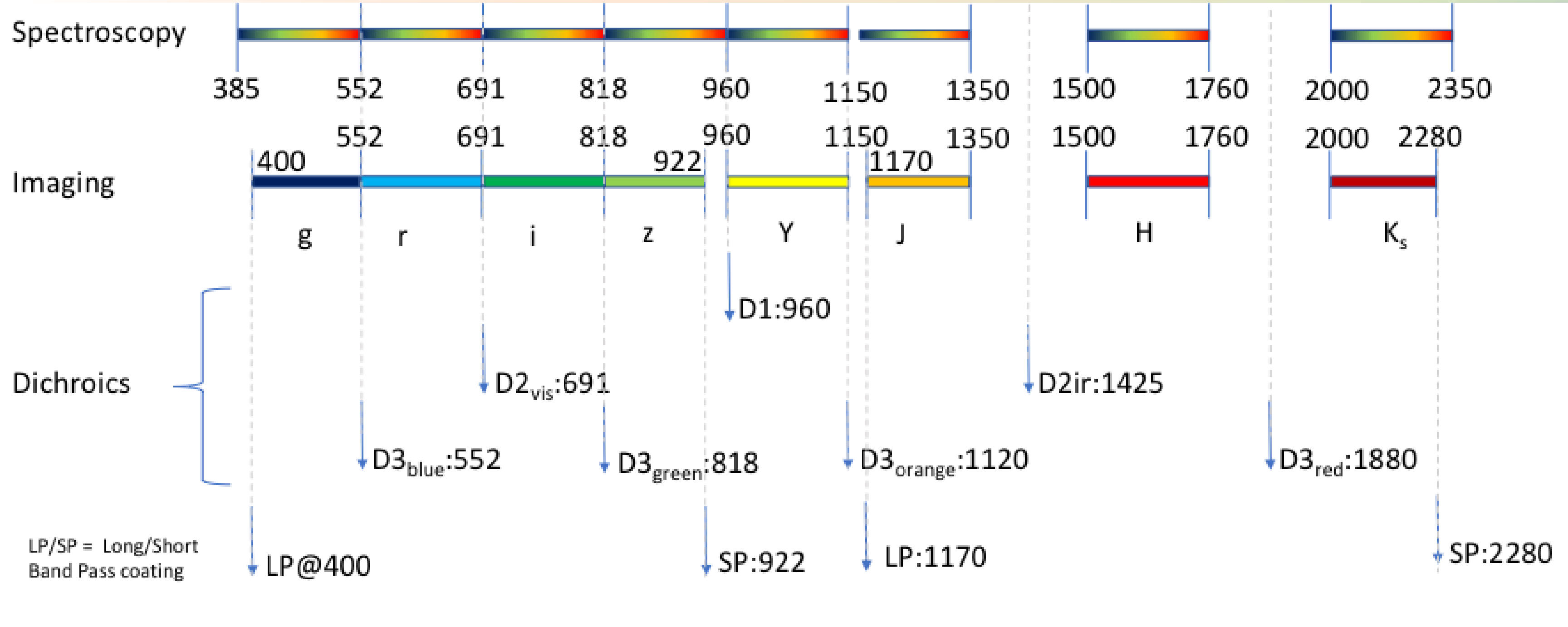
Data Reduction Software

- Software operates within Gemini framework (DRAGONS)
- Developed in Python using standard open source tools (no IRAF)
- Pipeline suitable for both fast and publication-worthy analysis
- Flexibility for various observational set-ups
- Data simulator: realistic simulated data and meta-data
- Observation monitoring tool & data quality assessment
- FITS files ingested by Gemini Observatory Archive
- Documentation for the community

Instrument Characteristics

- Simultaneous multiband photometry:
  - 400 – 2350 nm: *g, r, i, z, Y, J, H,* K_s
  - Field of View: 3'x3' square
- Long-slit broadband spectroscopy:
  - 385 – 2350 nm (except NIR atmospheric bands)
  - R > 4000 in NIR; 3500 – 4500 in VIS (0.54" slit)
  - Various slit sizes
- Plate scale
  - 0.18"/pixel for all 8 channels
- Temporal resolution:
  - 0.4 – 1 second full frame; 40 milliseconds subarray (180" x 18")
- Average throughput:
  - 0.46 / 0.52 imaging, 0.33 / 0.37 spectroscopy (ADC in / out)

Bandpasses



- Imaging: *griz* match LSST; *YJHK$_s$* avoid atmospheric bands
- Spectroscopy: continuum coverage except for atmospheric bands
- Good spectral resolution & continuous spectral coverage are crucial

Instrument Schematic