COL-OSSOS: Z-BAND PHOTOMETRY REVEALS THREE DISTINCT TNO SURFACE TYPES

IDENTIFYING COLD CLASSICAL TNO SURFACES

Rosemary E. Pike

Wesley Fraser; Megan Schwamb; J.J. Kavelaars; Michael Marsset; Michele Bannister; Ruth Murray-Clay; Katheryn Volk; Matthew Lehner; Shiang-Yu Wang; Aurelie Guilbert; Nuno Peixinho; Mike Alexandersen; Ying-Tung Chen; Brett Gladman; Stephen Gwyn; Jean-Marc Petit

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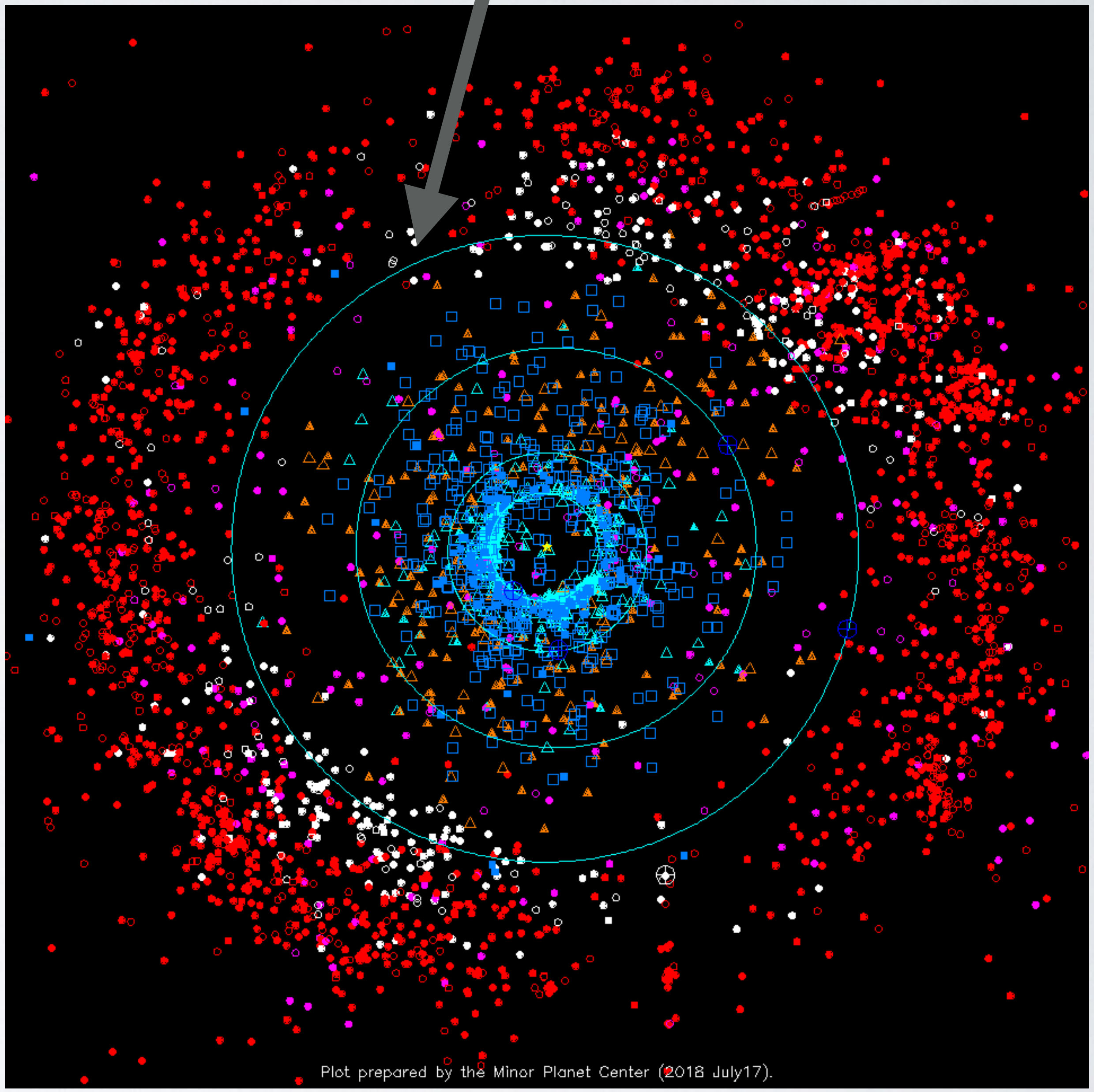
TNO SURFACES: WHAT & WHY

THE KUIPER BELT

- TNOs were distributed into the outer Solar System during giant planet migration
- The orbital distribution of TNOs provides constraints on the dynamics of scattering
- The surface properties of TNOs provide constraints on the surface properties of the initial proto-planetesimal disk
- Surface properties result from composition and evolution

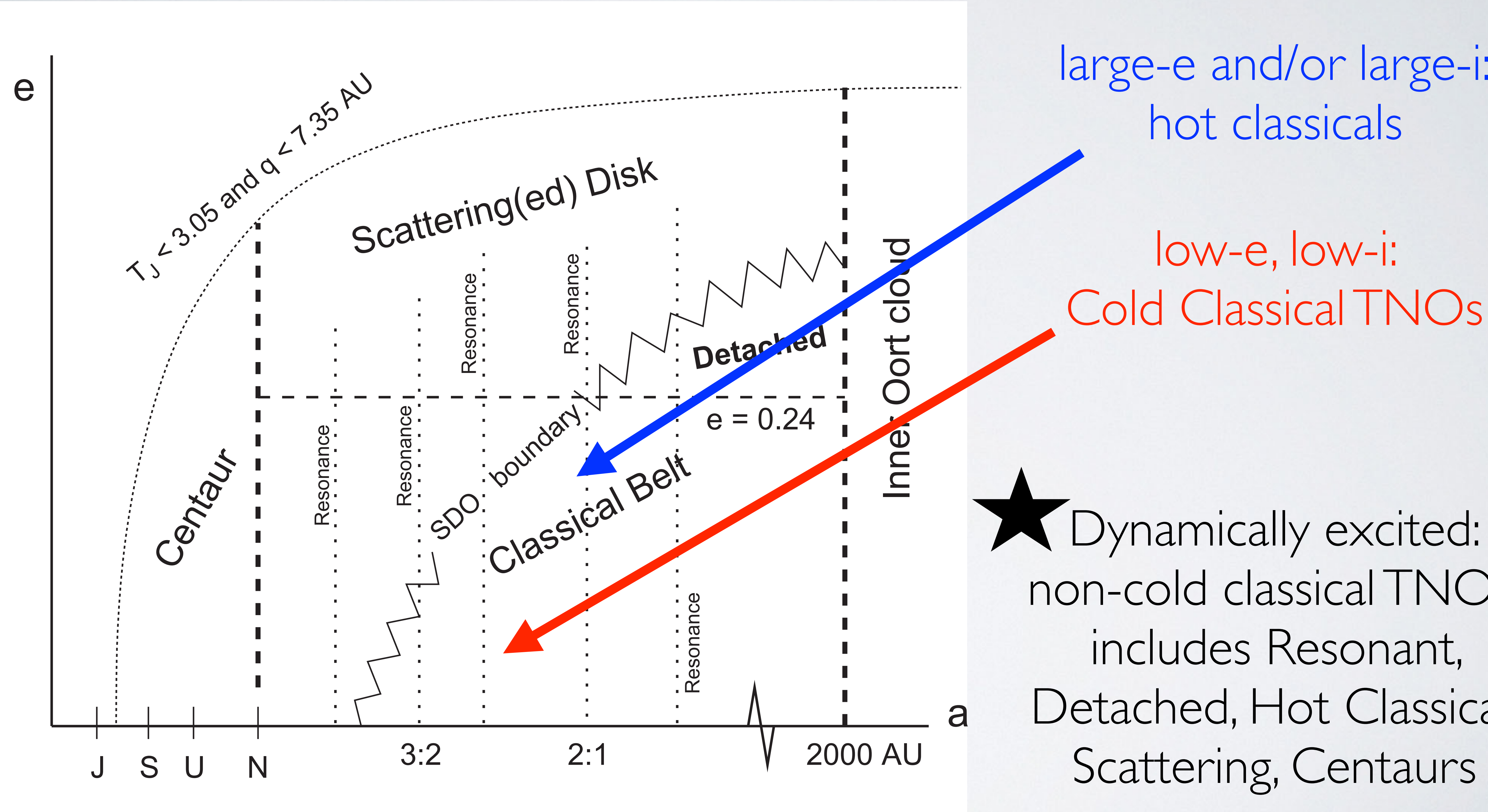
Neptune



Minor Planet Center: Outer Solar System

TNO SURFACES: WHAT & WHY

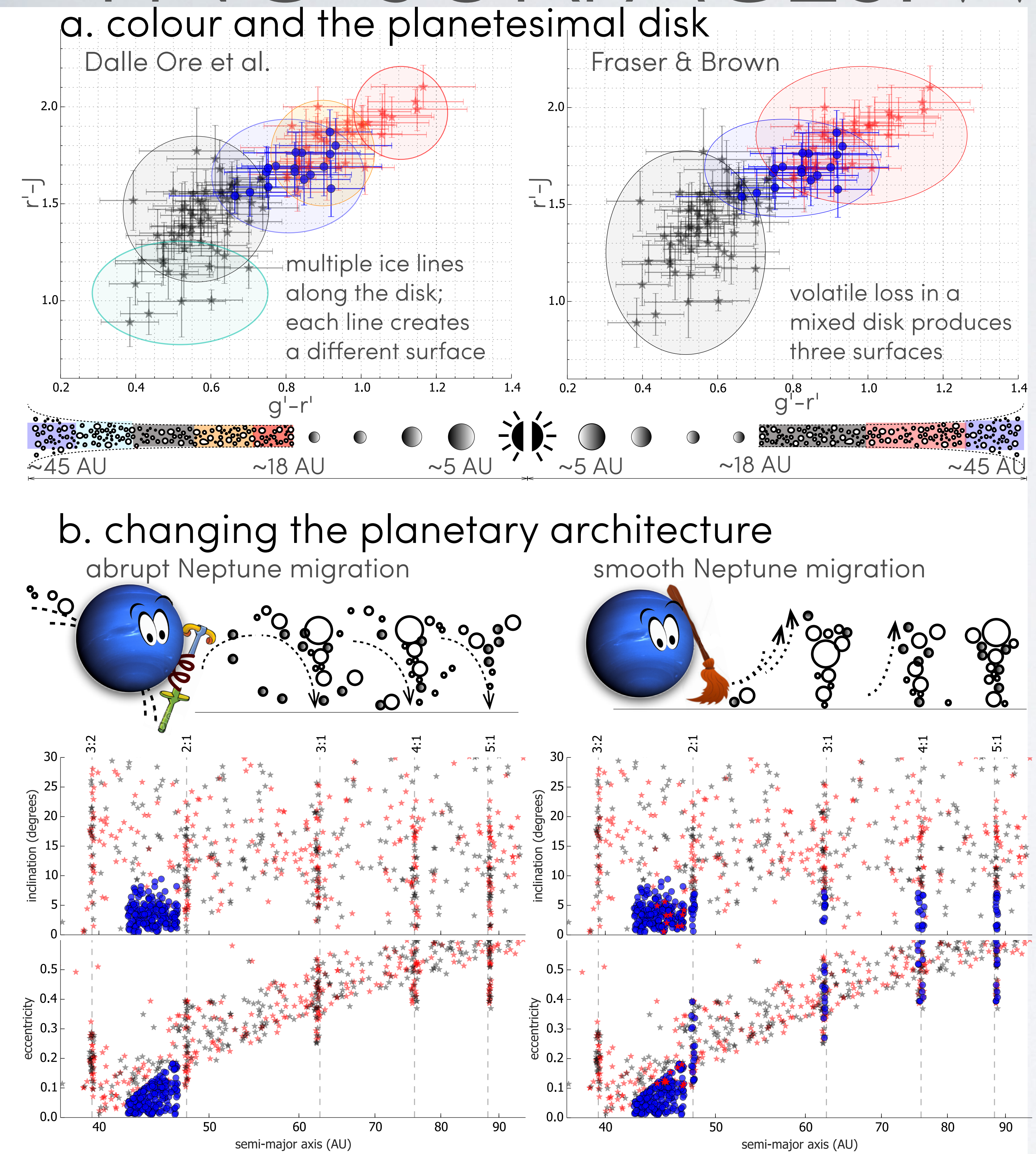
TNO DYNAMICAL CLASSIFICATIONS



Gladman et al. 2008, SSBN

Dynamically excited: non-cold classical TNOsl includes Resonant, Detached, Hot Classical, Scattering, Centaurs

TNO SURFACES: WHAT & WHY



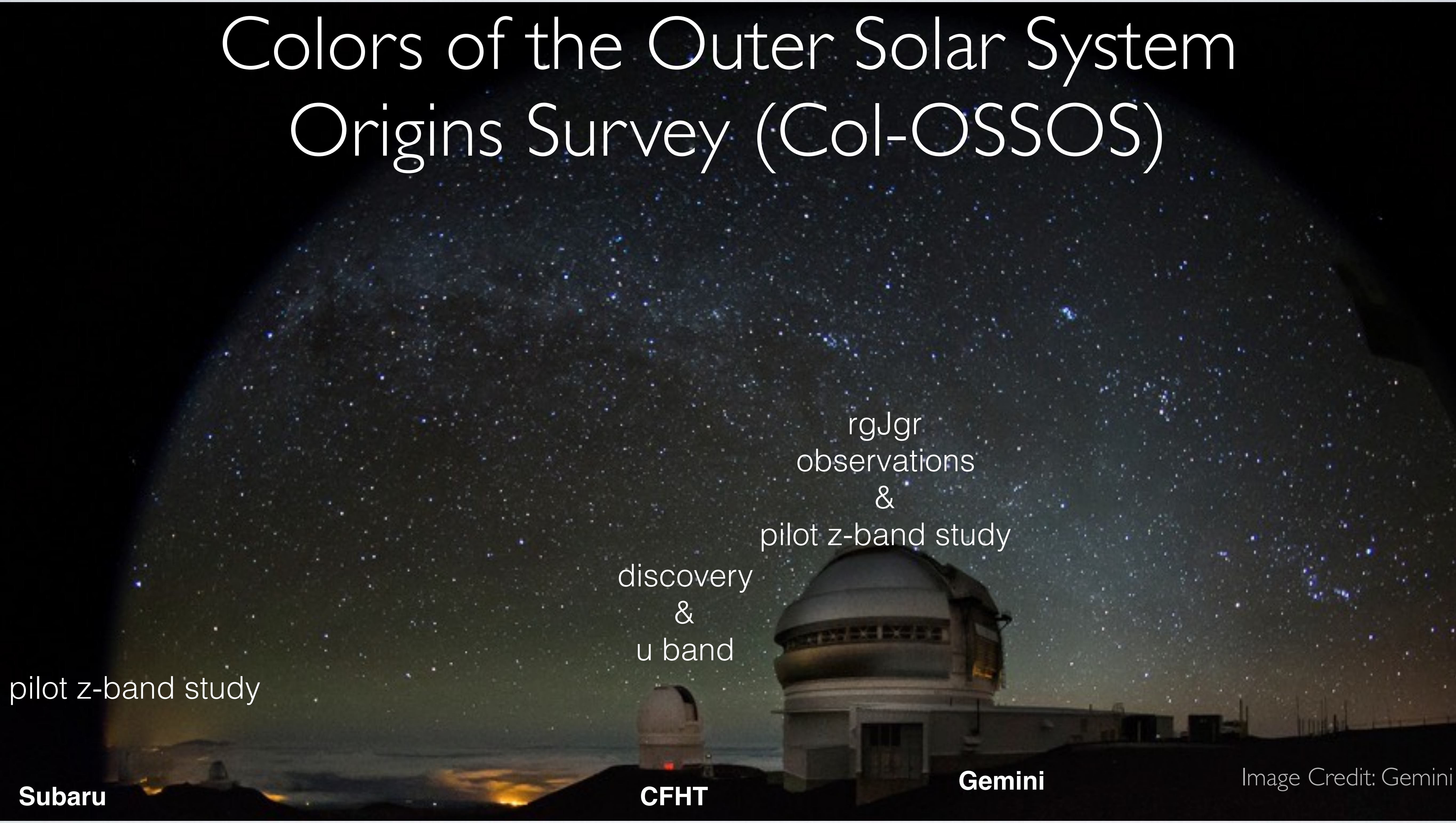
The Col-OSSOS Project

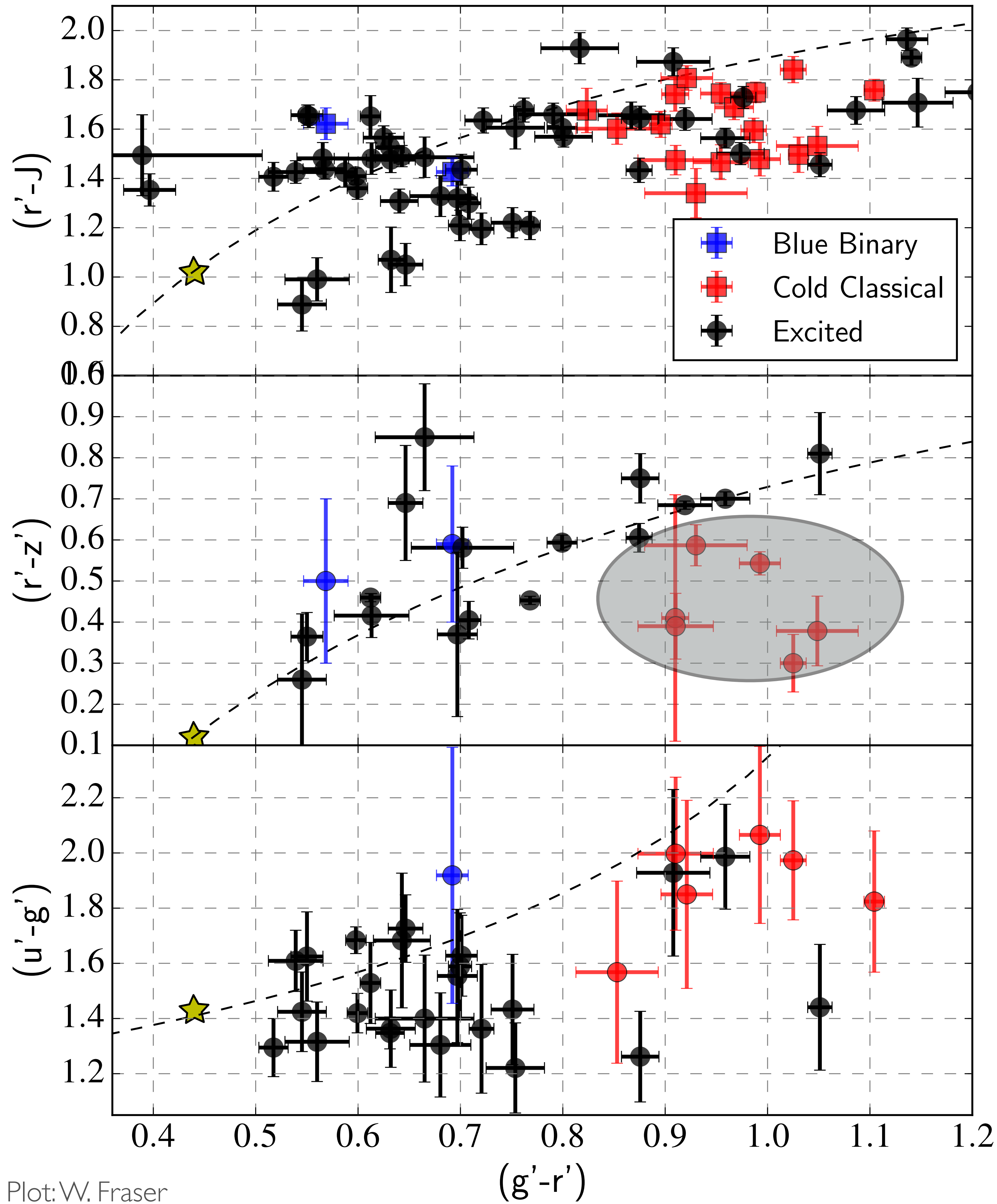
- Sample is from a characterized survey
- Follow-up photometry of a magnitude limited sub-sample of the Outer Solar System Origins Survey discoveries

Colossos Science Goals

- Determine the number of surface types
- Determine the intrinsic population fraction of these surface types
- Dependence between color and dynamics?
- Dependence between color and size?

Colors of the Outer Solar System Origins Survey (Col-OSSOS)

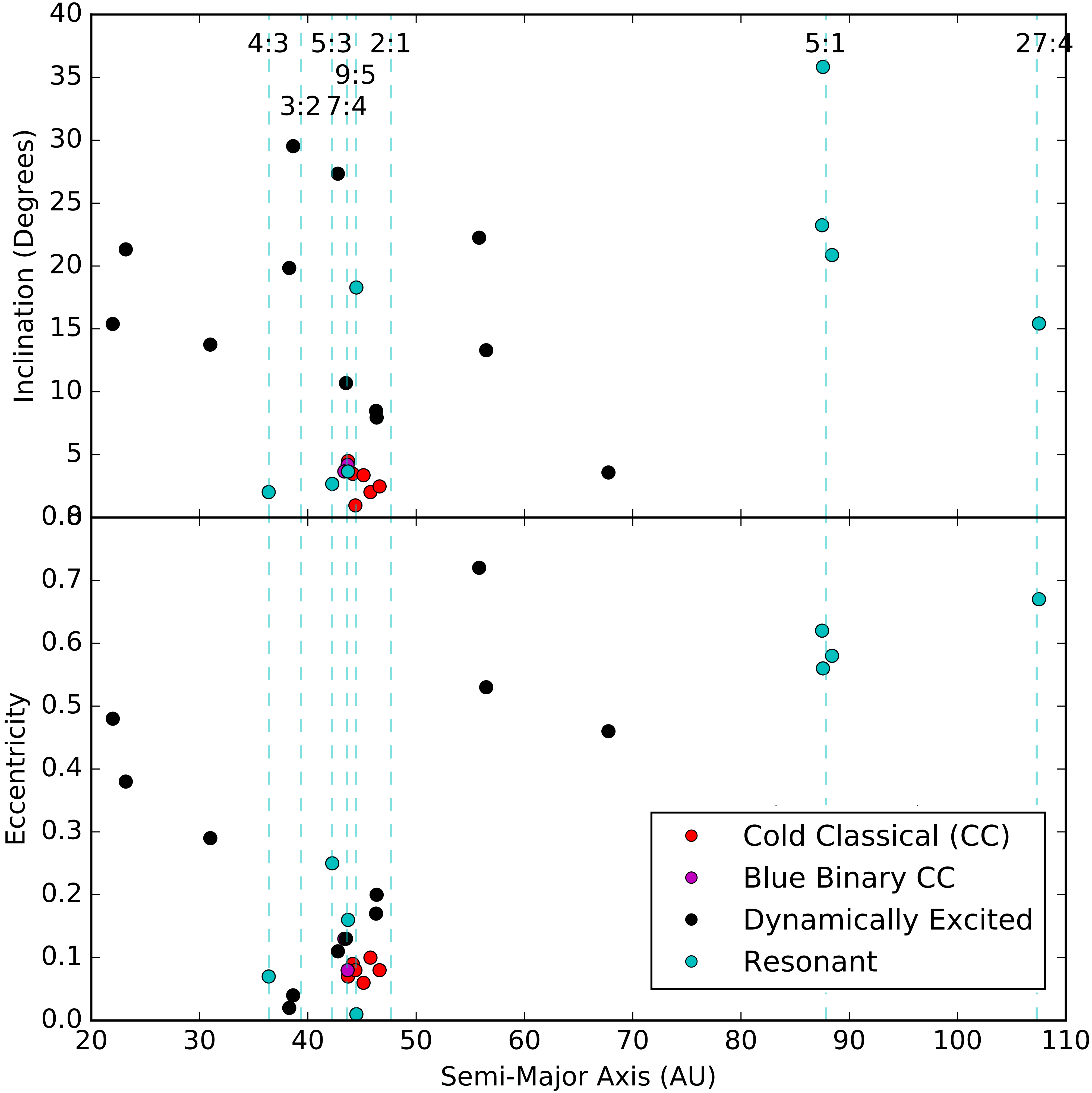




Plot: W. Fraser

Col-OSSOS Photometry

OUTER SOLAR SYSTEM
OSSOS
ORIGINS SURVEY

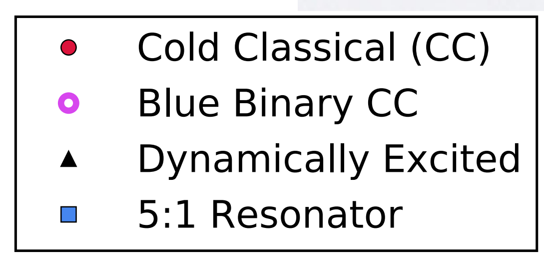


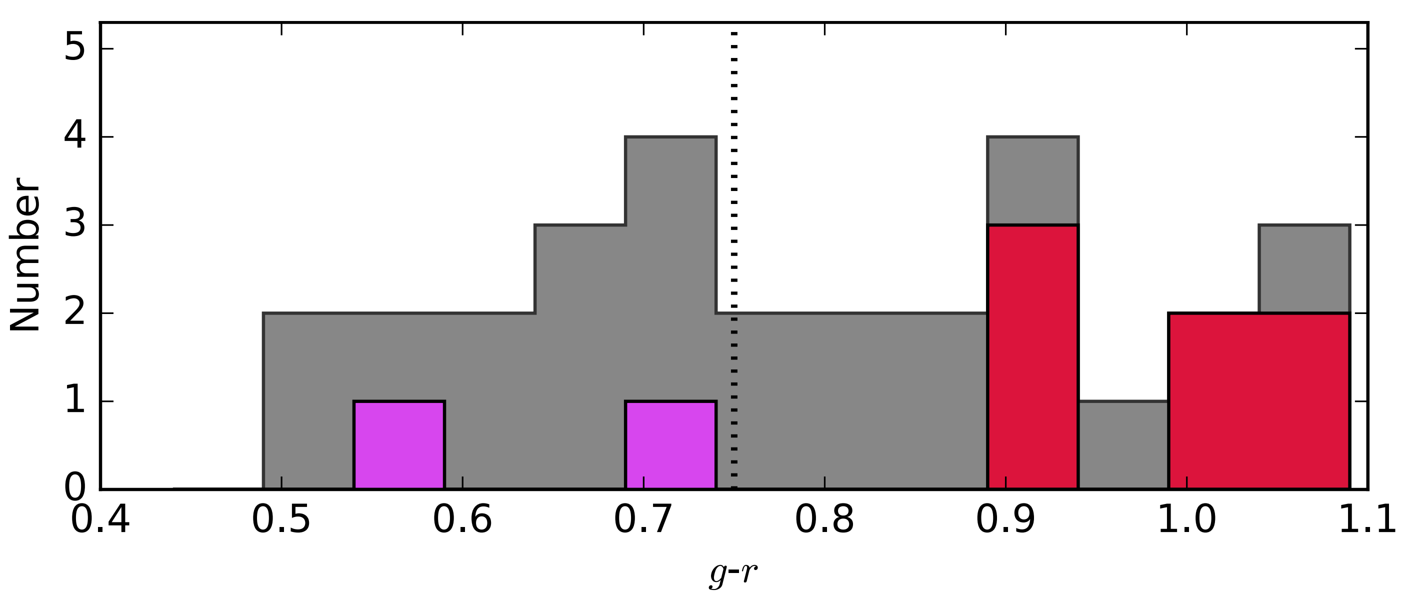
z-Band Sample

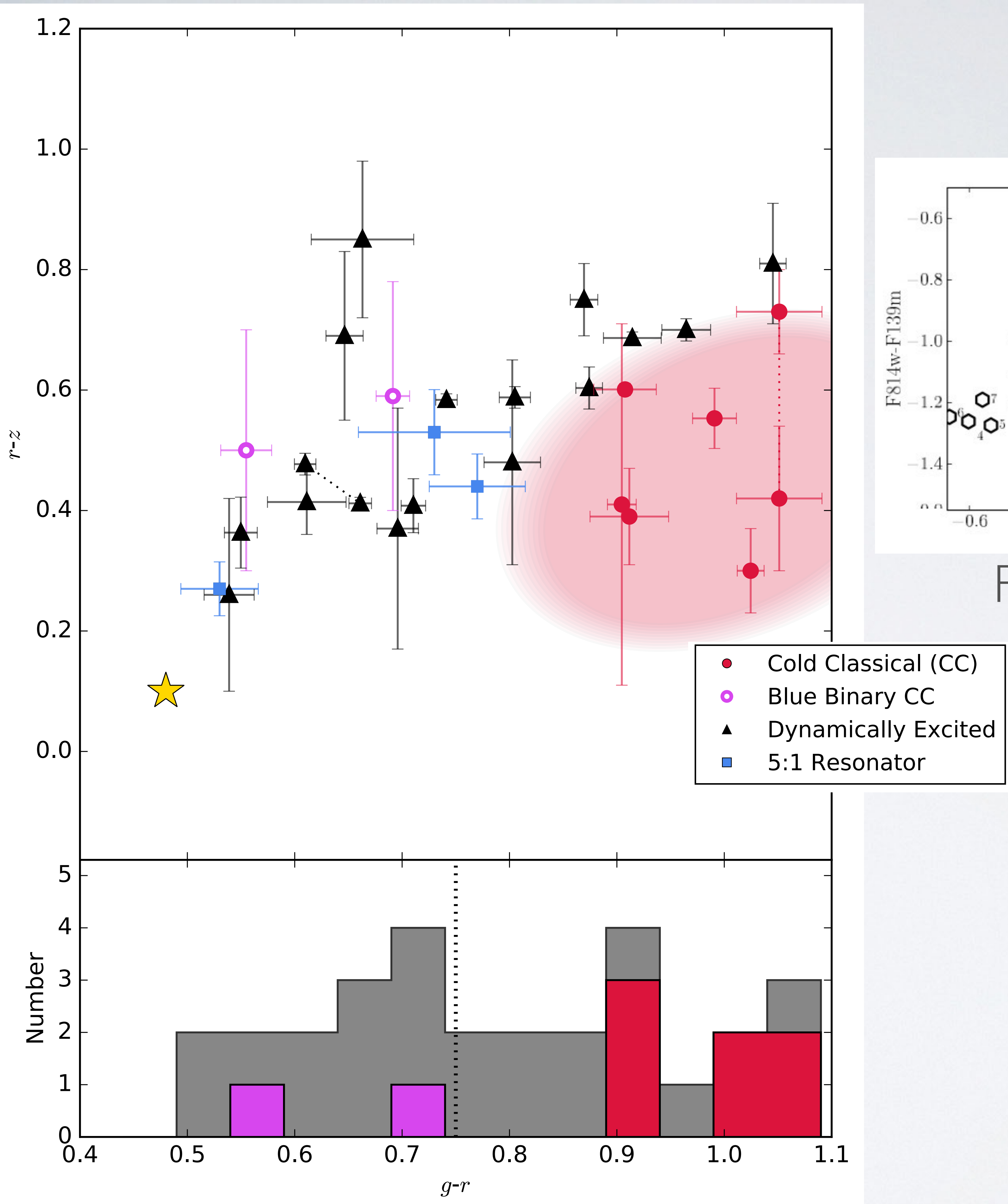
z-Band Photometry

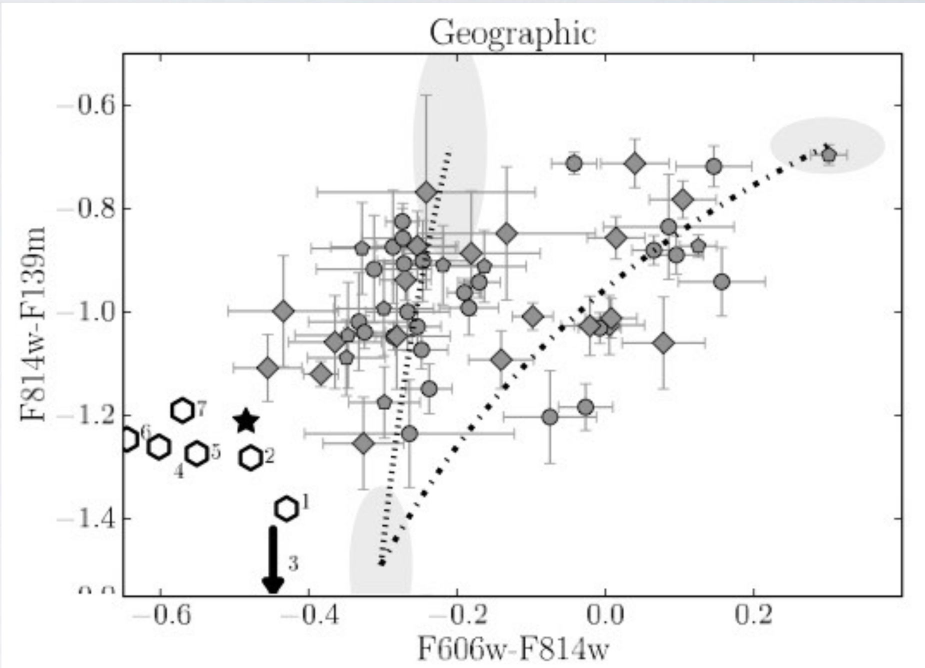
Pike et al. 2017, AJ

Tegler & Romanishin 2003
Peixinho et al. 2003, 2012, 2015
Tegler et al. 2003, 2016
Barucci et al. 2005
Fraser & Brown 2012
Dalle Ore et al. 2013
Wong & Brown 2017
. . .





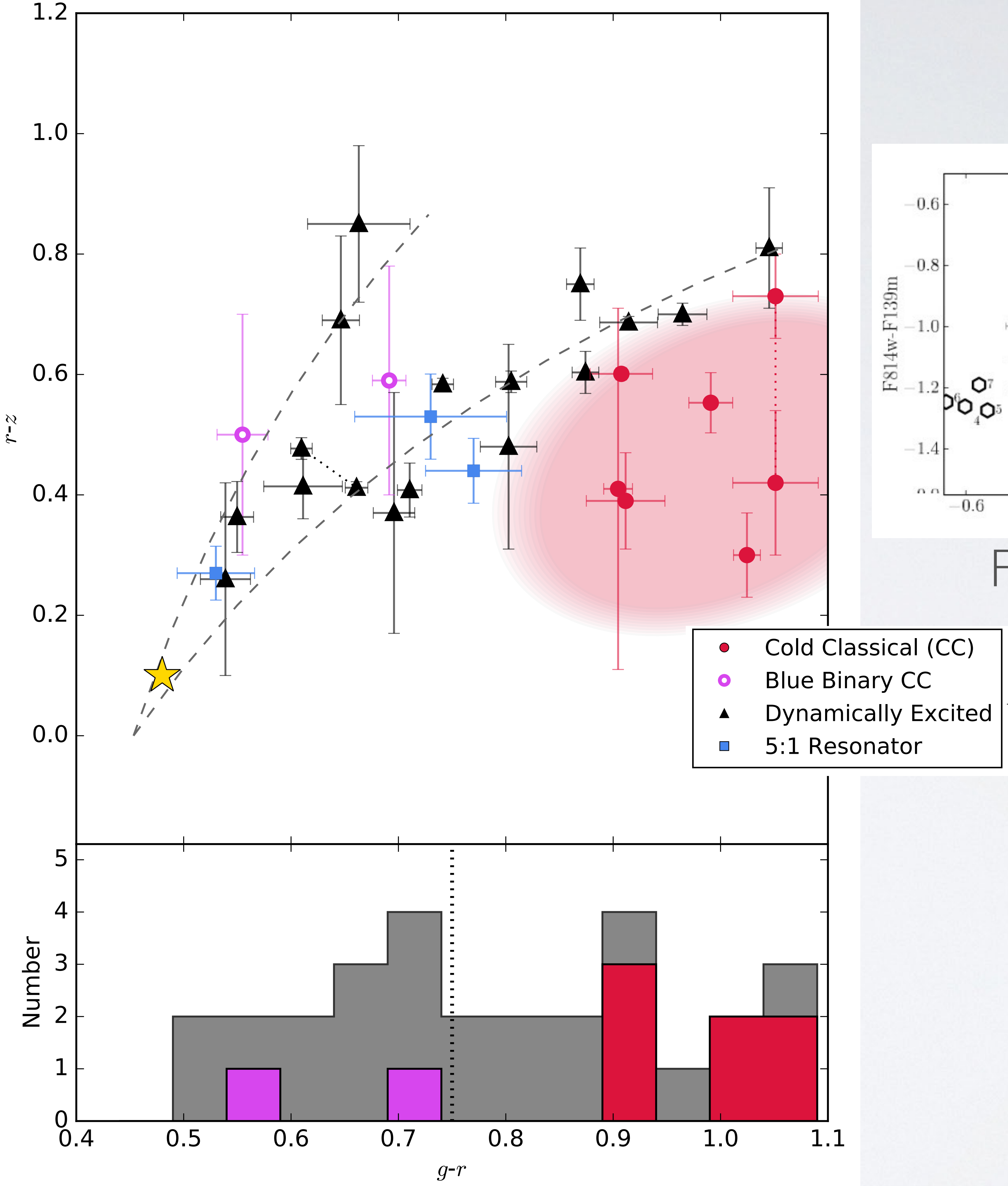


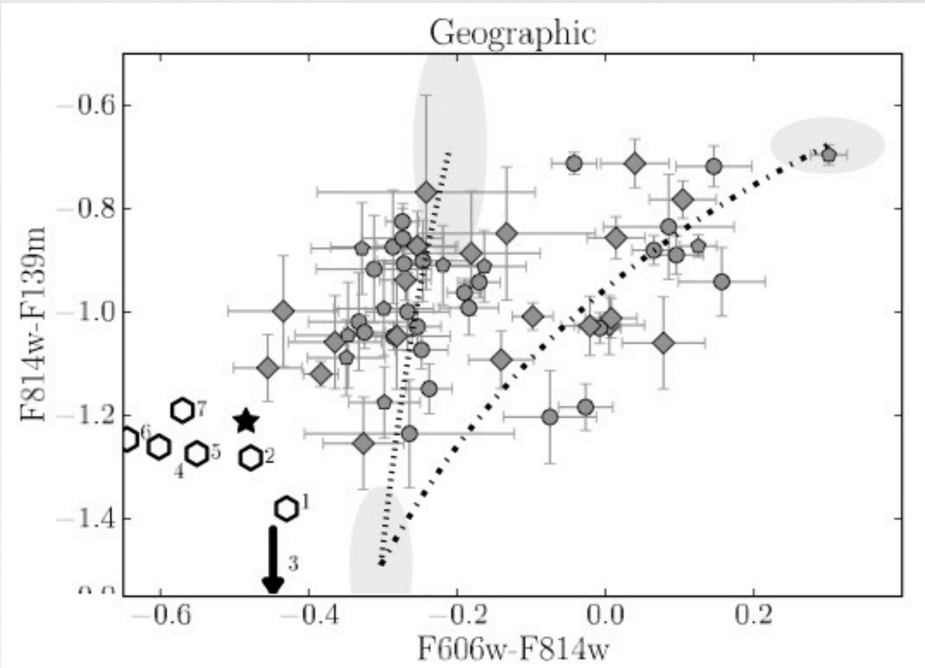


Fraser & Brown 2012

z-Band Photometry

Pike et al. 2017, AJ

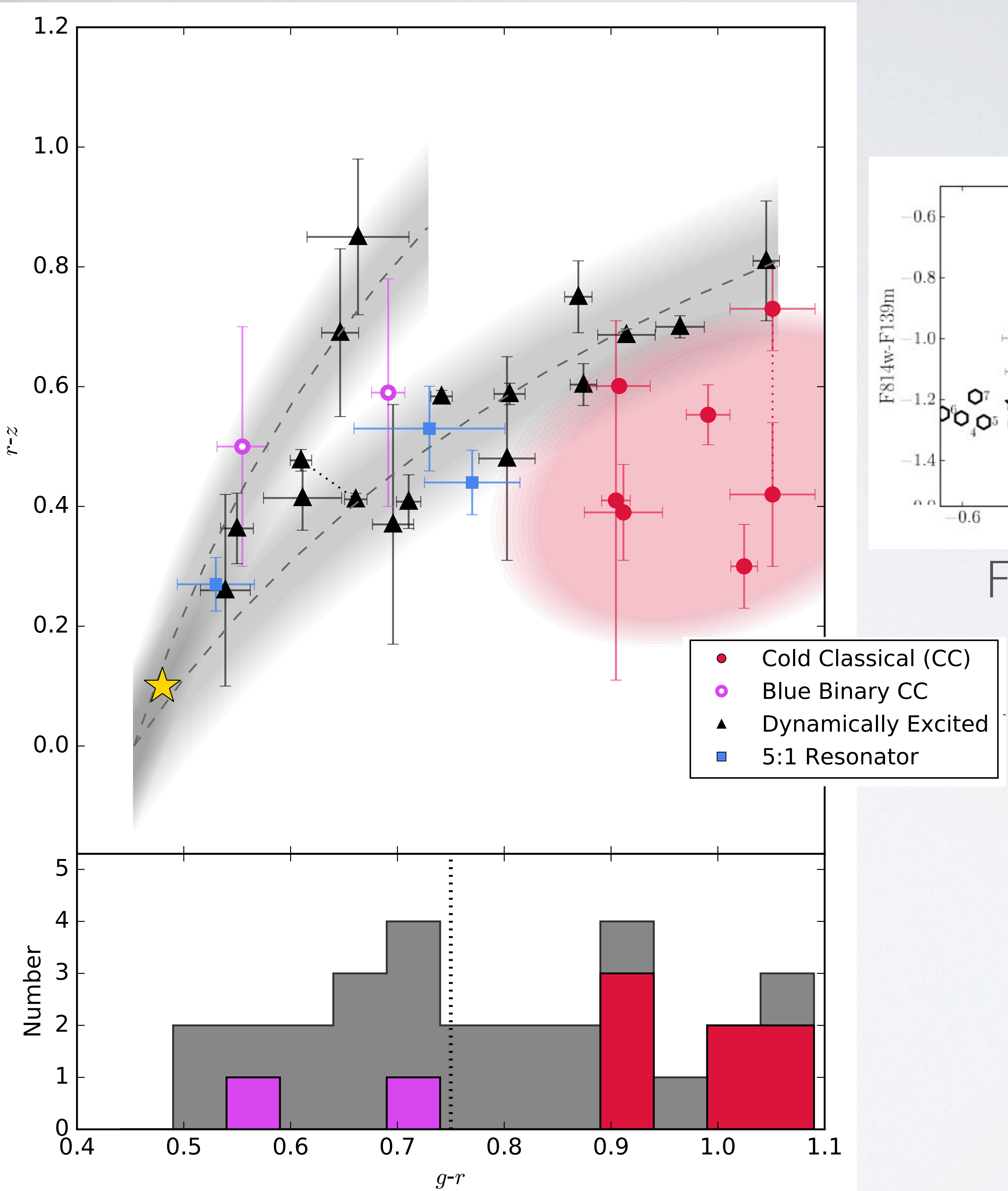


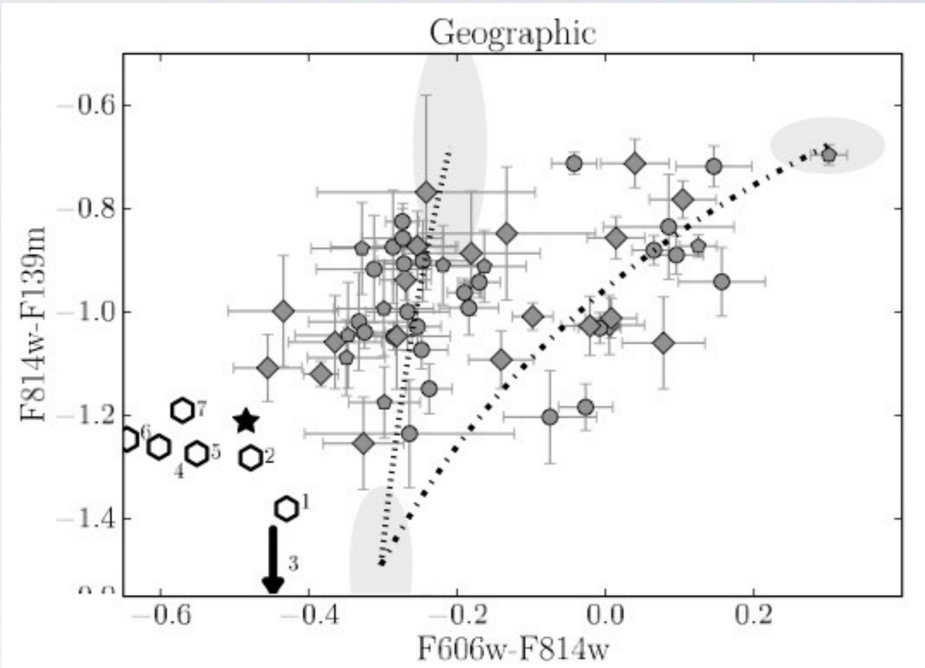


Fraser & Brown 2012

z-Band Photometry

Pike et al. 2017, AJ



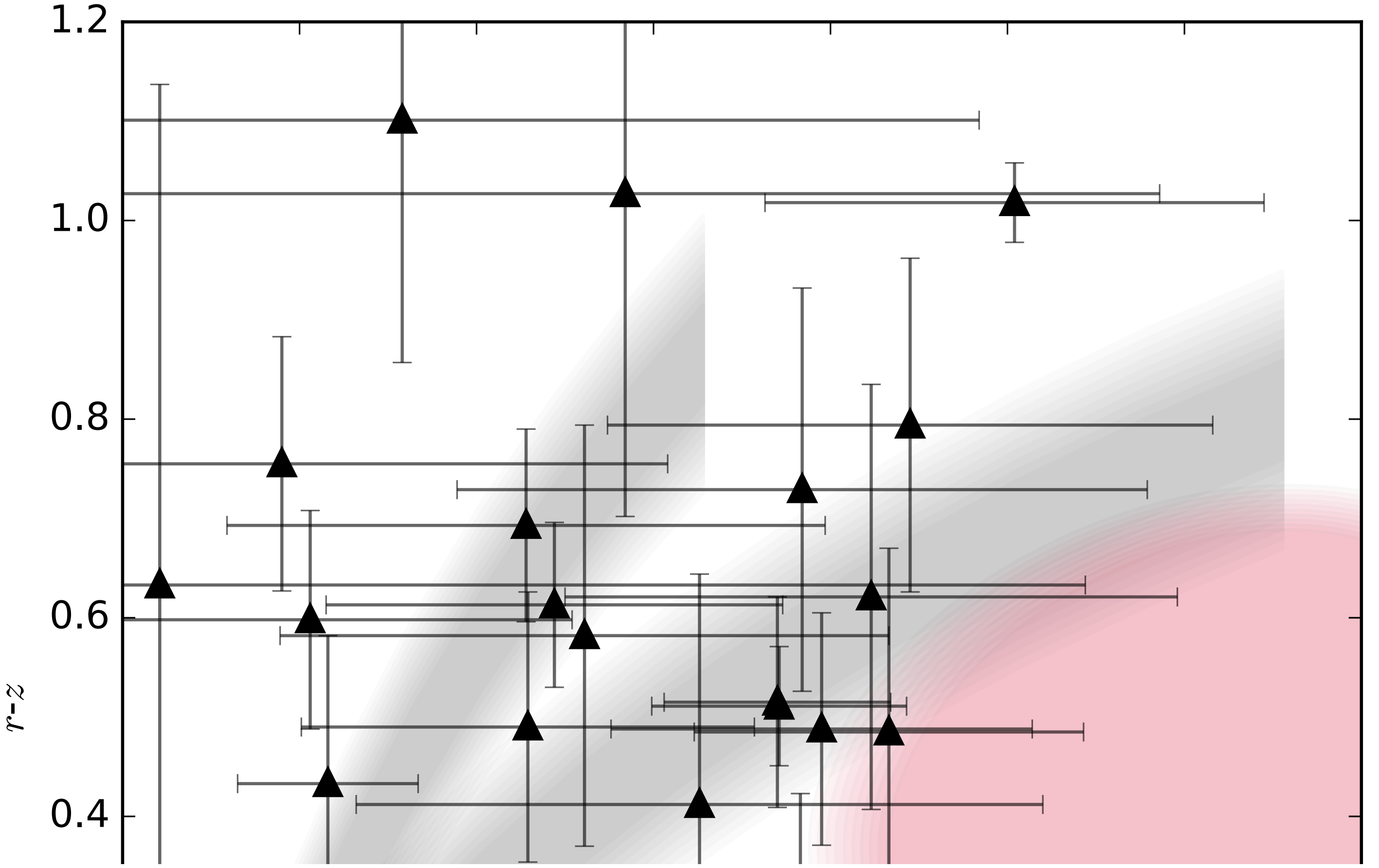


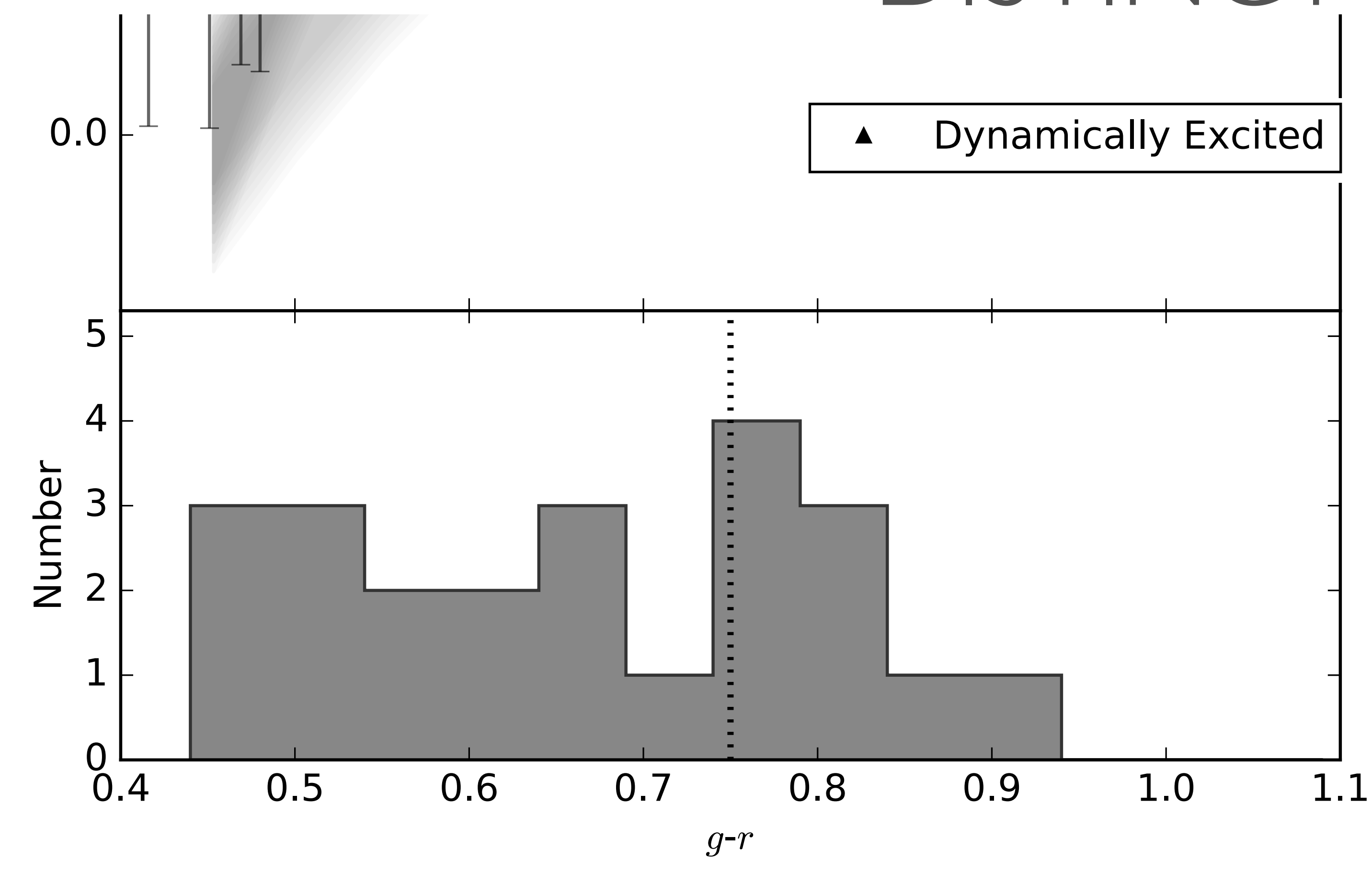
Fraser & Brown 2012

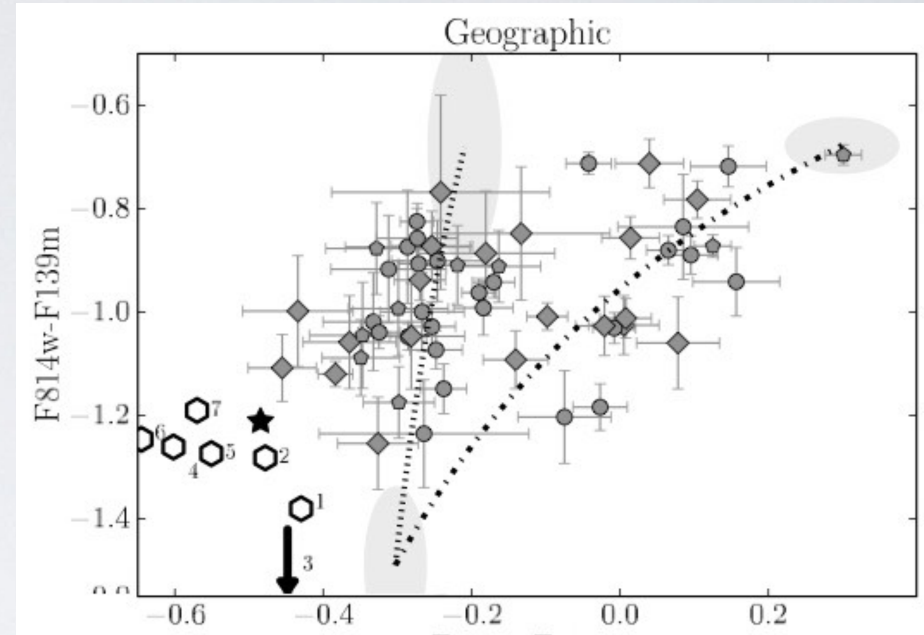
z-Band Photometry

Pike et al. 2017, AJ

CONCLUSION: COLD CLASSICAL SURFACES ARE DISTINCT IN *g*, *r*, *z*







z-Band Photometry from Ofek 2012

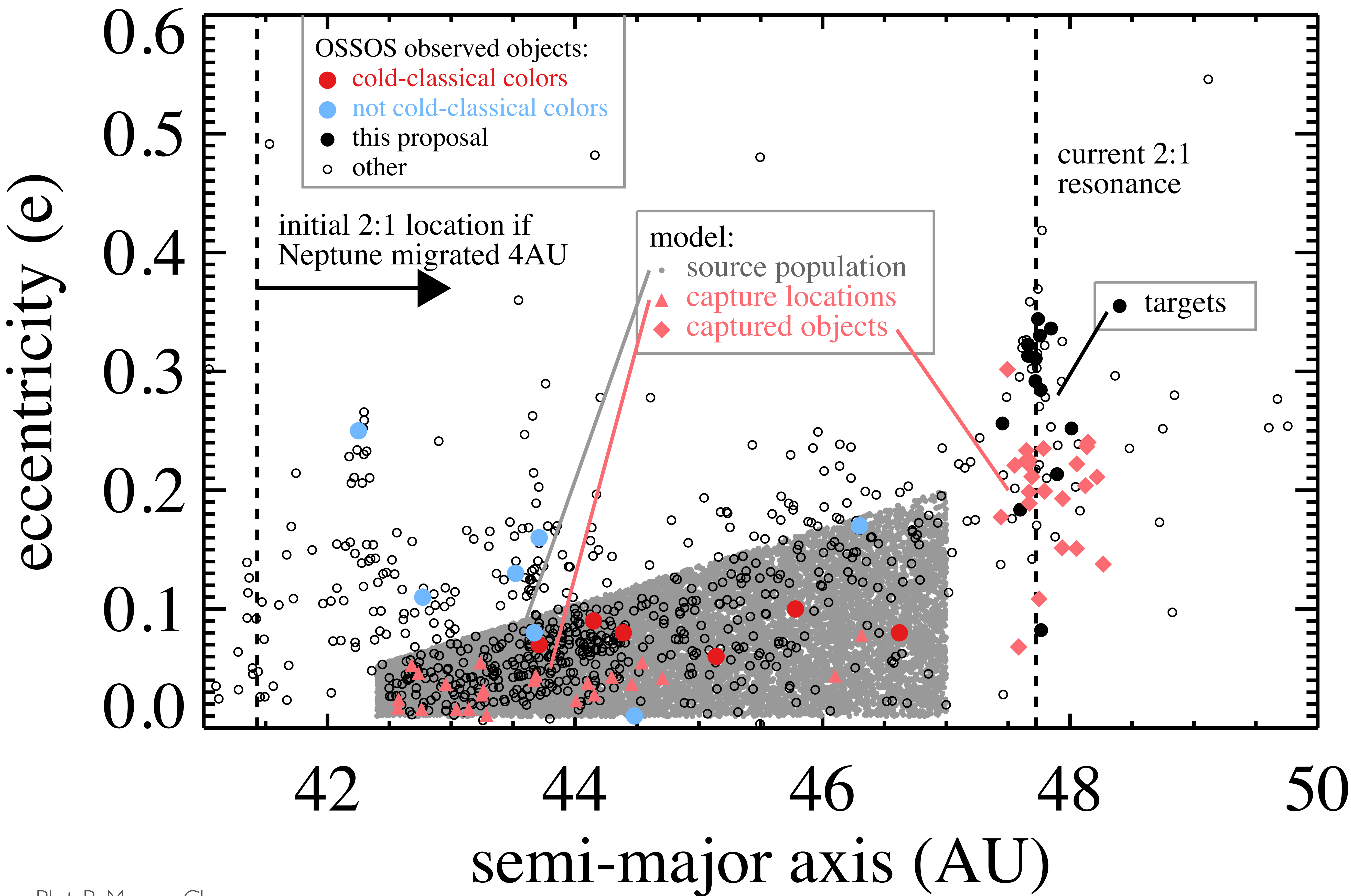
Pike et al. 2017, AJ

Col-OSSOS Expansion

Constraining Neptune's Migration: Surfaces of Resonant TNOs

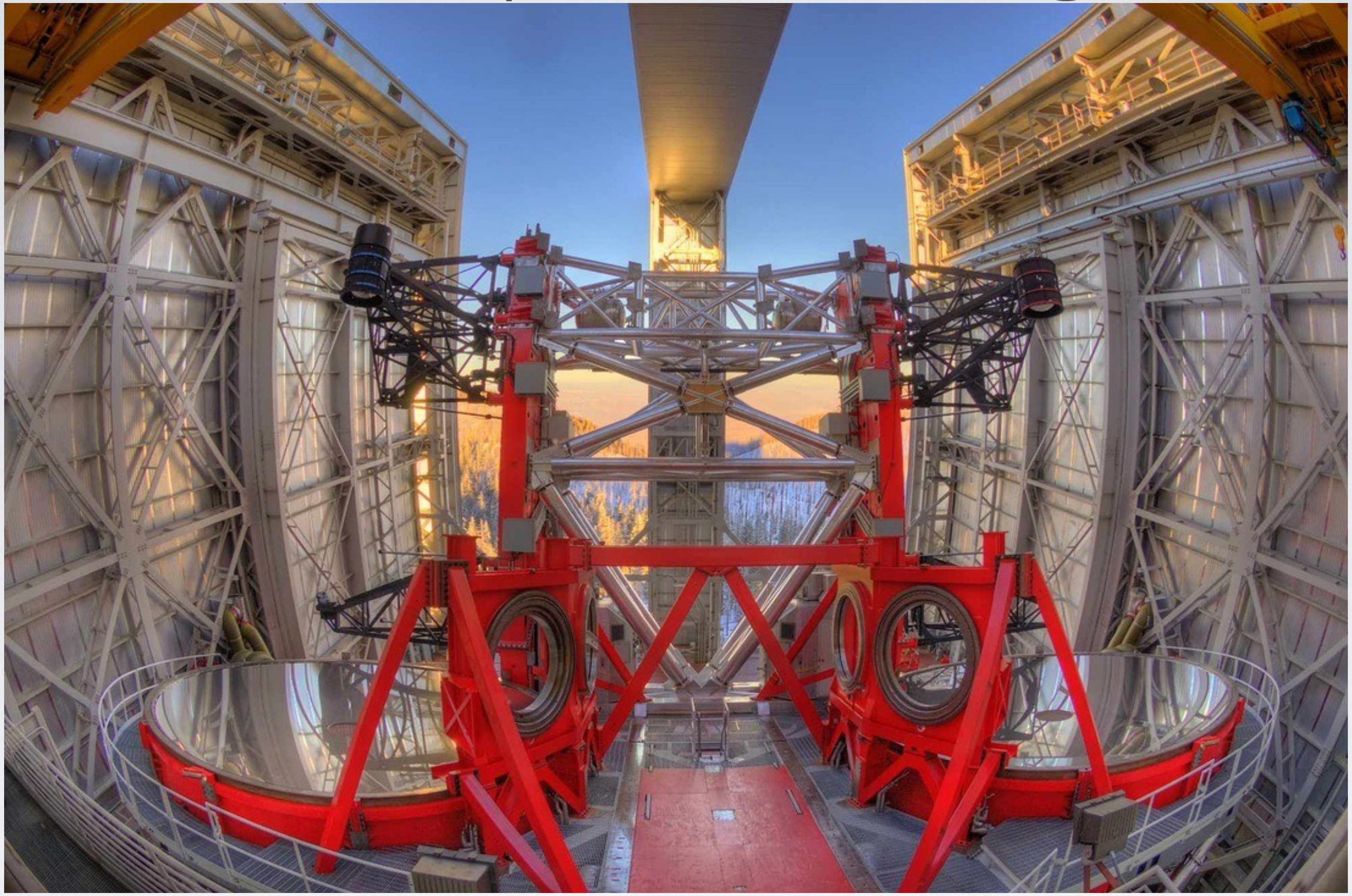
Rosemary Pike, Kat Volk, Ruth Murray-Clay, Wes Fraser, Michele Bannister, Michael Marsset, Meg Schwamb, Matt Lehner, Aurelie Gulibert

- Dynamical simulations of Neptune's migration to predict the number of cold classicals in the 2:1
- Photometry of a complete sample of 2:1 TNOs from the OSSOS Ensemble characterized surveys in *g*, *r*, and *z* bands



Plot: R. Murray-Clay
K. Volk

Col-OSSOS Expansion Program on LBT



- LBT in Mount Graham, AZ
- 34 TNOs in the 2:1, mr≤24.5
- *z* band using LBC Red
- g and r using LBC Blue
- 34 TNOs in the 2:1, mr≤24.5
- April 2018: 2/3 nights lost to weather
- 5 2:1s and 2 Cold classicals observed
- 2018B: 3.5 nights awarded by NOAO

CONCLUSIONS

- Red Cold Classical TNO surfaces are distinct from dynamically excited TNO surfaces in the combination of *g*, *r*, and *z*-bands.
- Separating TNOs based on a bimodal distribution is not sufficient to correctly identify red and neutral TNO surfaces classes.
- Simultaneous or near-simultaneous photometry is necessary to distinguish the red dynamically excited TNOs from the neutral dynamically excited TNOs.
- Photometry in *grz* can be used to identify TNOs with cold classical surfaces outside the cold classical dynamical region, such as the 2:1 resonance. We target this resonance in our current LBT program.

COL-OSSOS RESULTS

Additional papers by the Col-OSSOS Team

TRIPPy: TRAILED IMAGE PHOTOMETRY IN PYTHON

Wesley Fraser[1], Mike Alexandersen[2], Megan E. Schwamb[2], Michaël Marsset[3], Rosemary E. Pike[4], J. J. Kavelaars[5], Michele T. Bannister[4], Susan Benecchi[6], and Audrey Delsanti[7]

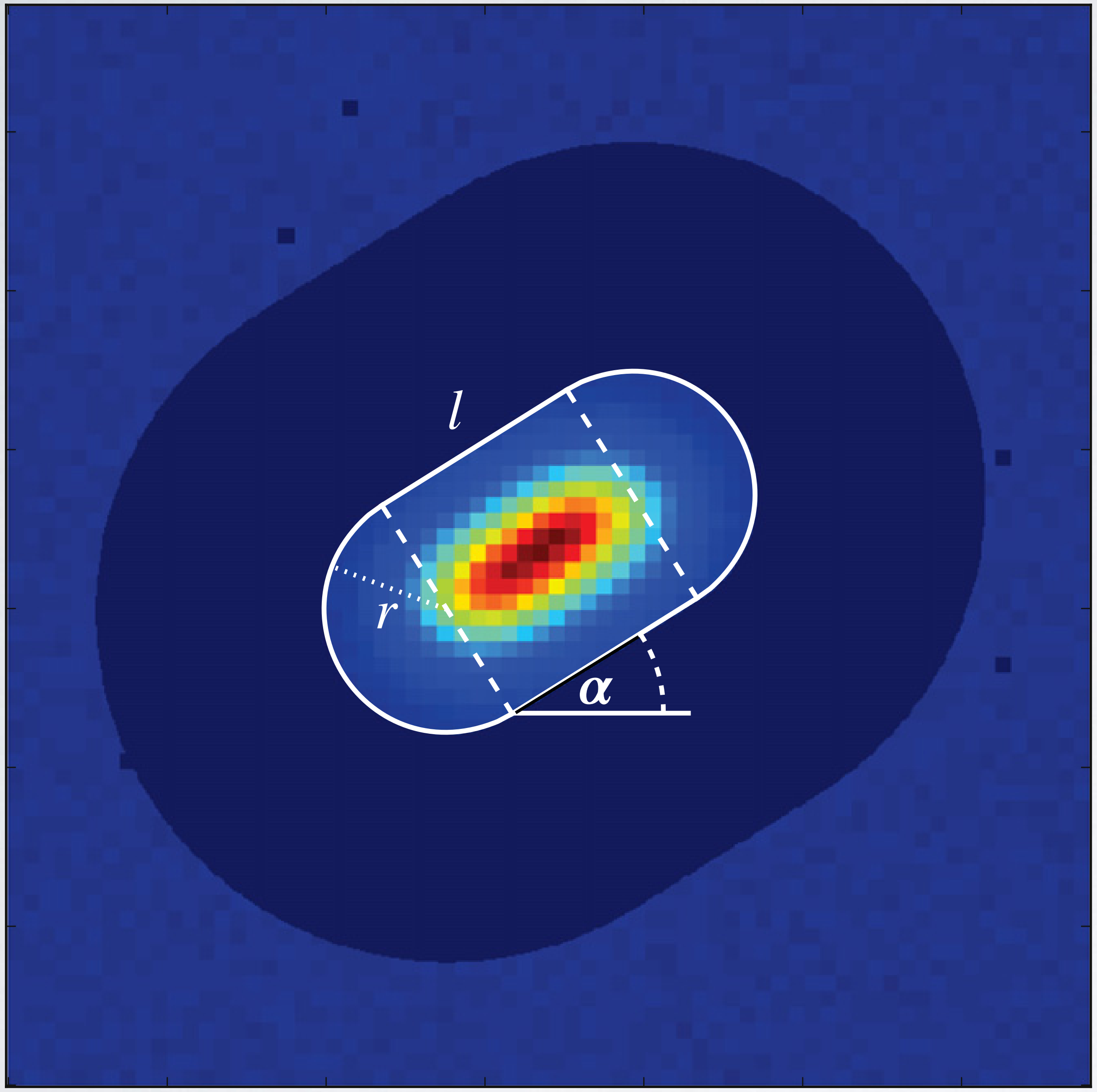
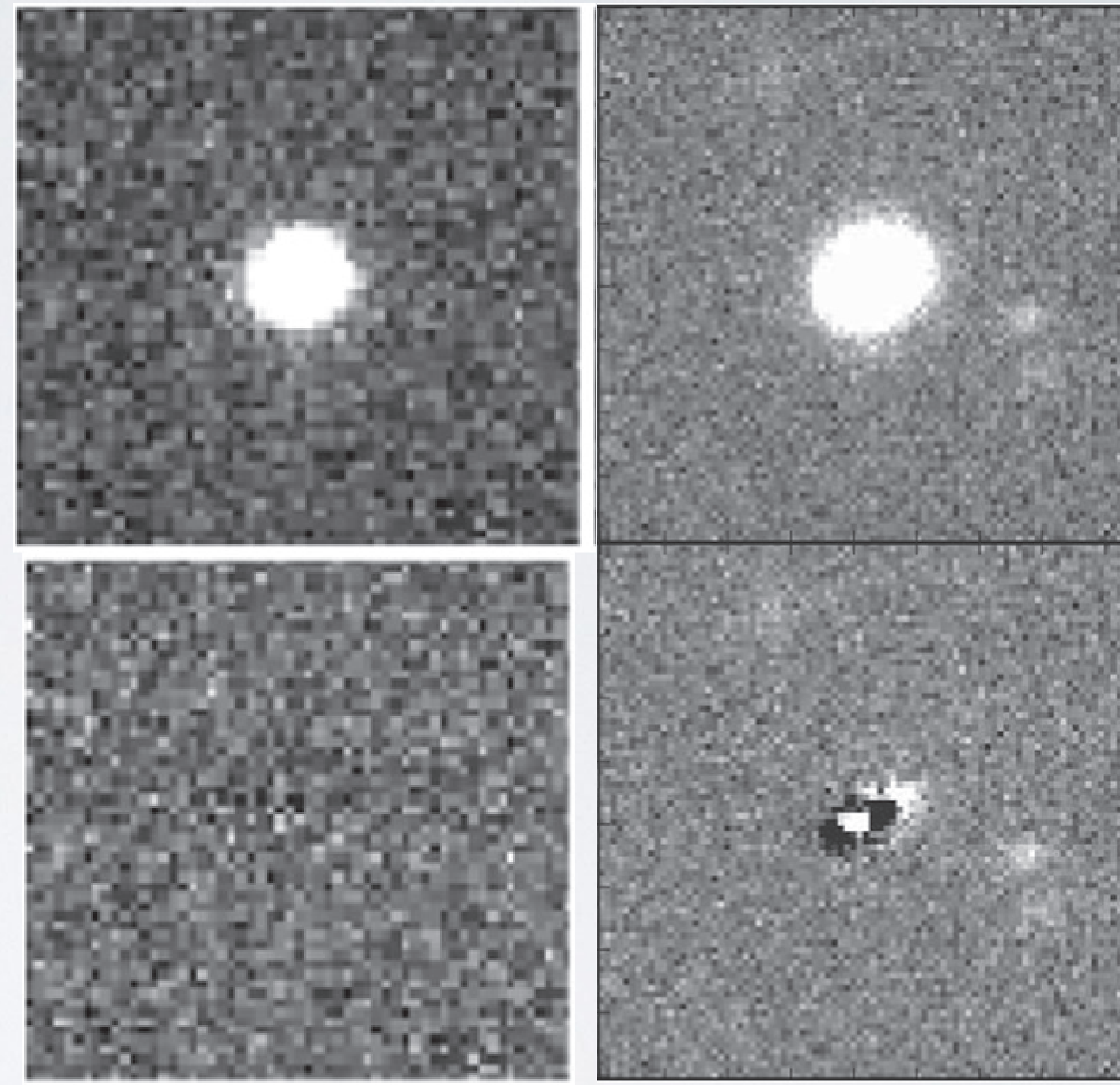


Figure 2. Example of a pill aperture. The full aperture, outlined in solid white, is the combination of a rectangle of length l, and width $2r$, with two semicircular end-caps of radius r, all rotated at angle α. For aperture photometry, the background is measured inside a user specified box, and outside a pill aperture with larger r (but the same l). The image is a 480 s exposure of asteroid 2006, Polonskaya, taken on 2008 January 15 14:40:25 UTC when the asteroid had a rate of motion of $19\overset{\prime\prime}{.}04$ hr^{-1} at angle $30\overset{\circ}{.}9$. The peak pixels are nearly 9000 ADU brighter than the background.



Star PSF subtraction

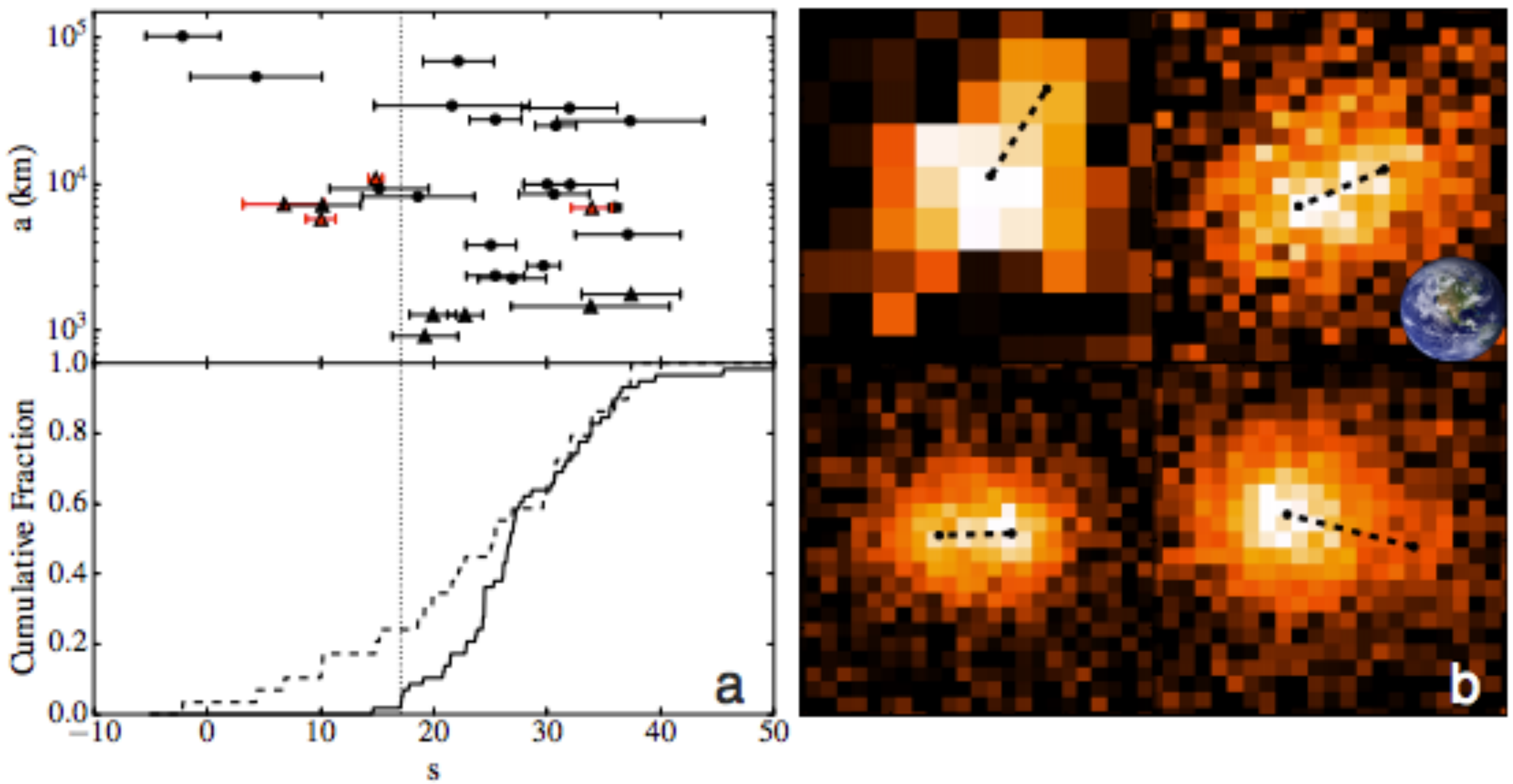
Asteroid PSF subtraction

Published in AJ 2016

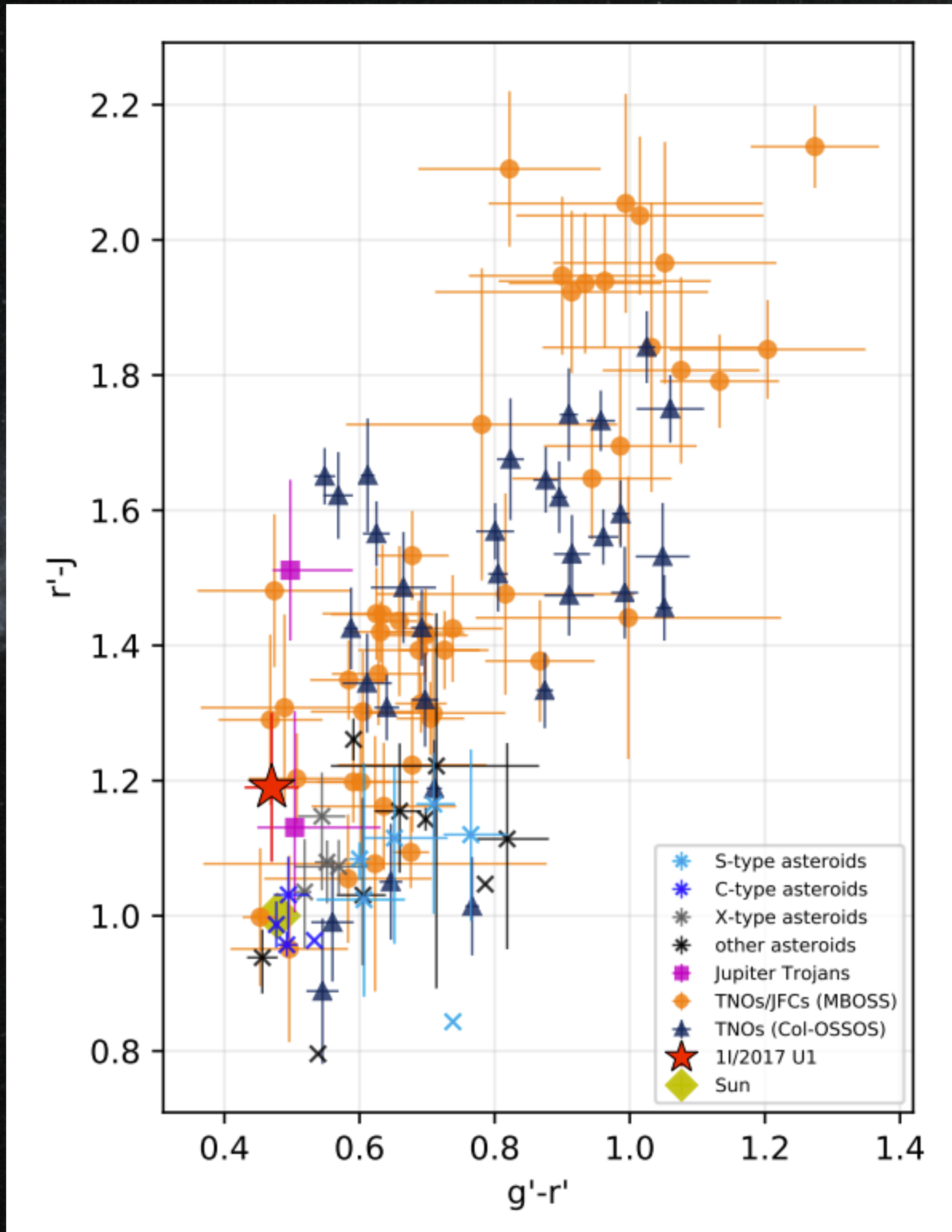
nature astronomy

All planetesimals born near the Kuiper belt formed as binaries

Wesley C. Fraser, Michele T. Bannister, Rosemary E. Pike, Michael Marsset, Megan E. Schwamb, J. J. Kavelaars, Pedro Lacerda, David Nesvorný, Kathryn Volk, Audrey Delsanti, Susan Benecchi, Matthew J. Lehner, Keith Noll, Brett Gladman, Jean-Marc Petit, Stephen Gwyn, Ying-Tung Chen, Shiang-Yu Wang, Mike Alexandersen, Todd Burdullis, Scott Sheppard & Chad Trujillo



Published in Nature Astronomy, 2017



First arrival from afar: the interstellar planetesimal 'Oumuamua

- Gemini DD Award
- Calibrated images released to the public within 5 weeks of observations http://doi.org/10.11570/17.0010

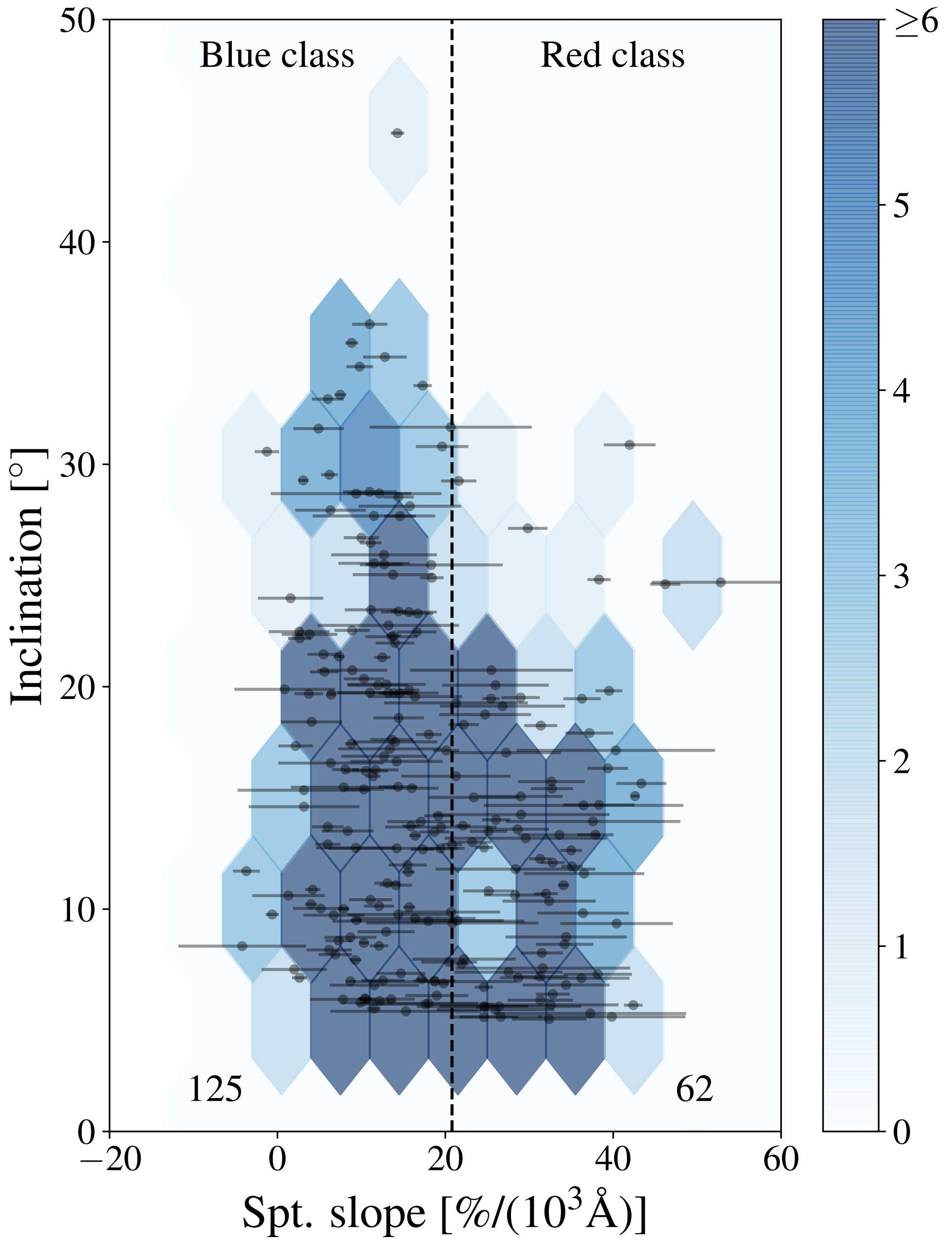
Michele Bannister, M. E. Schwamb, W. C. Fraser, M. Marsset, A. Fitzsimmons, S. Benecchi, P. Lacerda, R. E. Pike, JJ Kavelaars, A. B. Smith, S. O. Stewart, S.-Y. Wang (王祥宇), M. J. Lehner

Published in ApJL 2017

Col-OSSOS: Color and Inclination are Correlated Throughout the Kuiper Belt

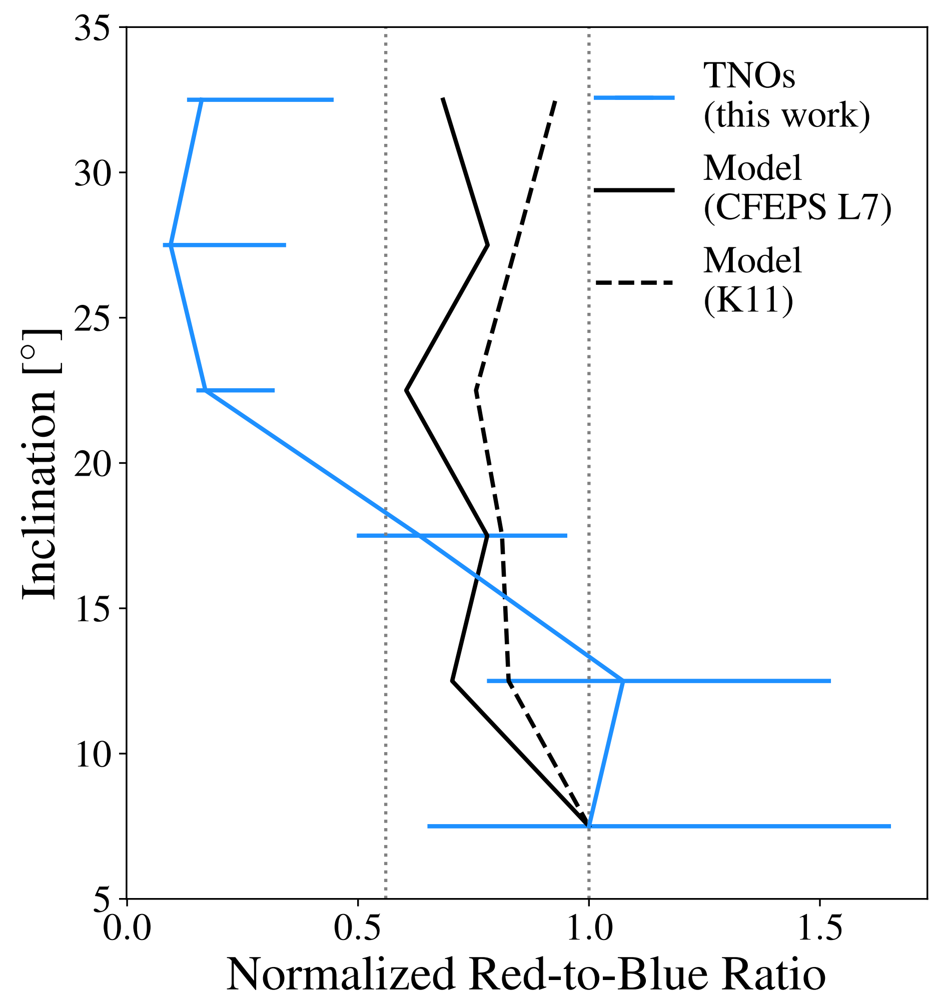
Michael Marsset, Wesley C. Fraser, Rosemary E. Pike, Michele T. Bannister, Megan E. Schwamb, Kathryn Volk, J. J. Kavelaars, and OSSOS Core (In prep.)

"Blue" TNOs have larger orbital inclinations than "red" objects (dynamically hot populations)



OSSOS Survey Simulator:

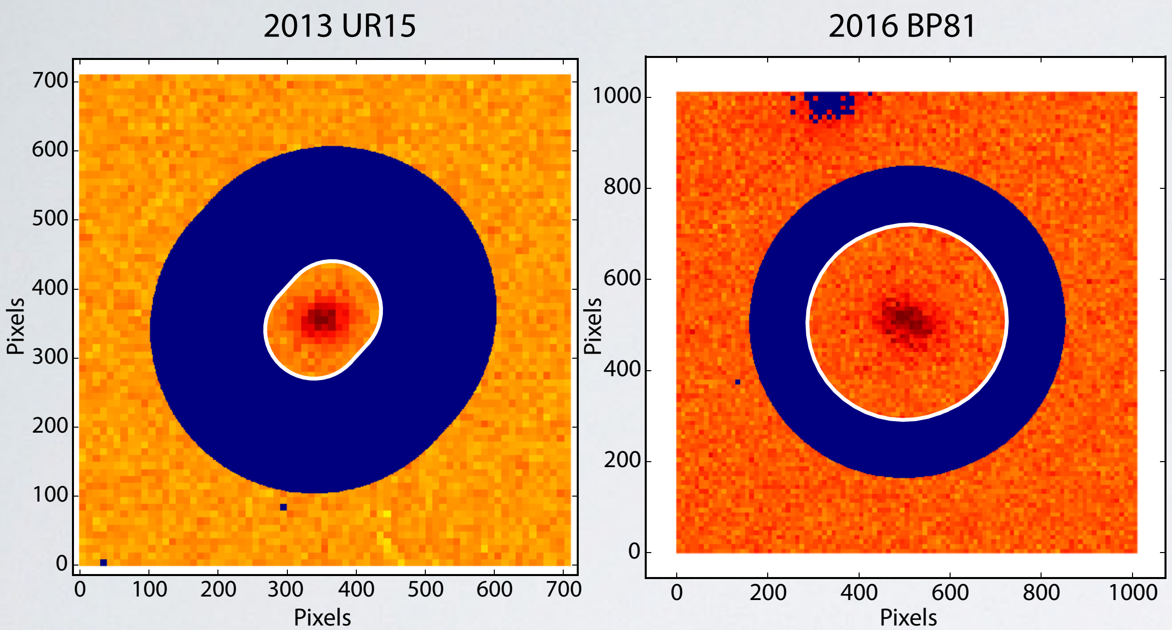
Not an effect of discovery biases



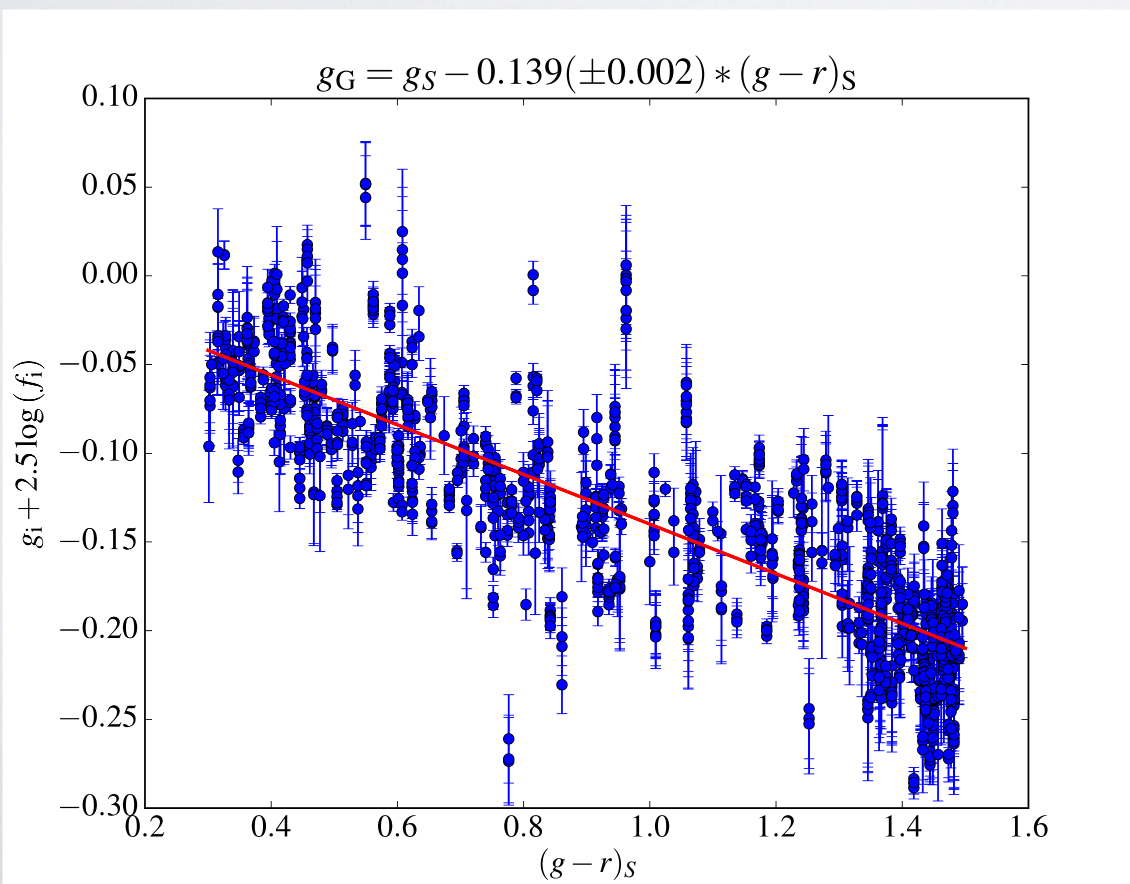
Implications: TNO surfaces are primordial and formed in a heterogeneous protoplanetary disk

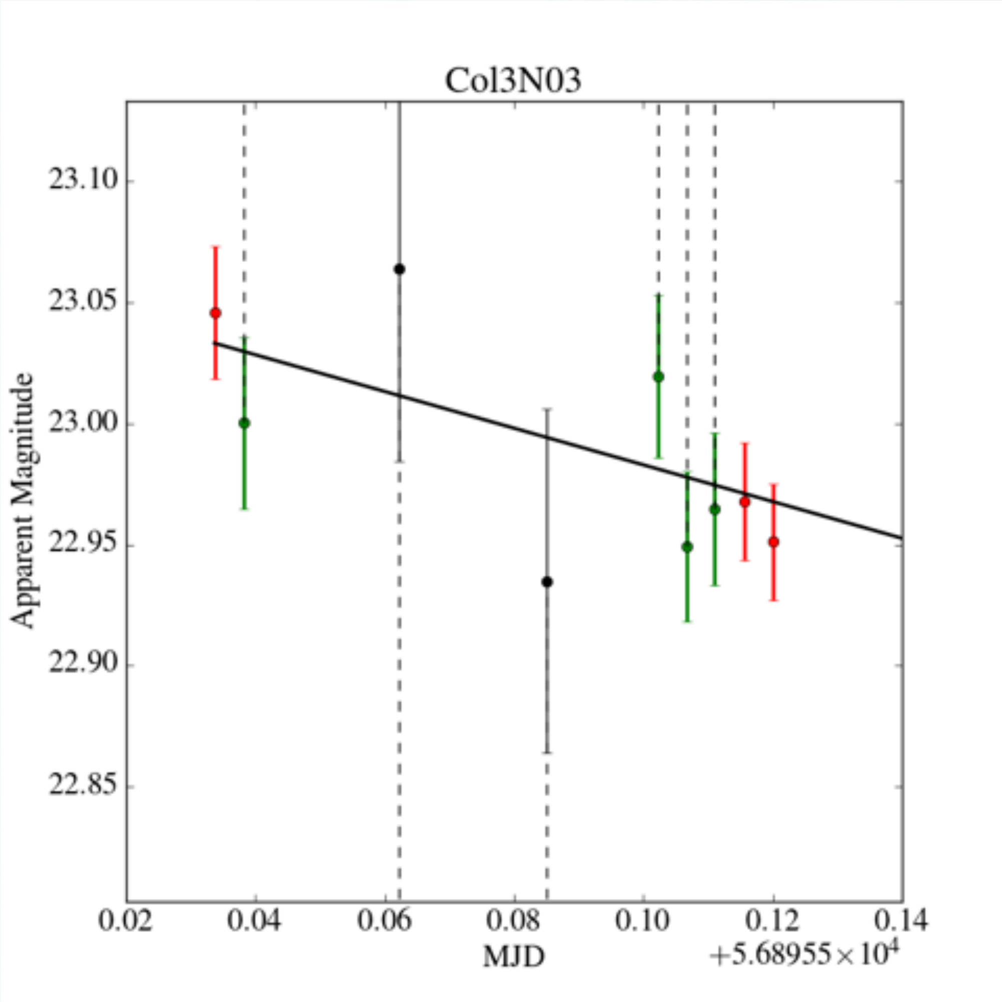
Col-OSSOS: The Colours of the Outer Solar System Origins Survey

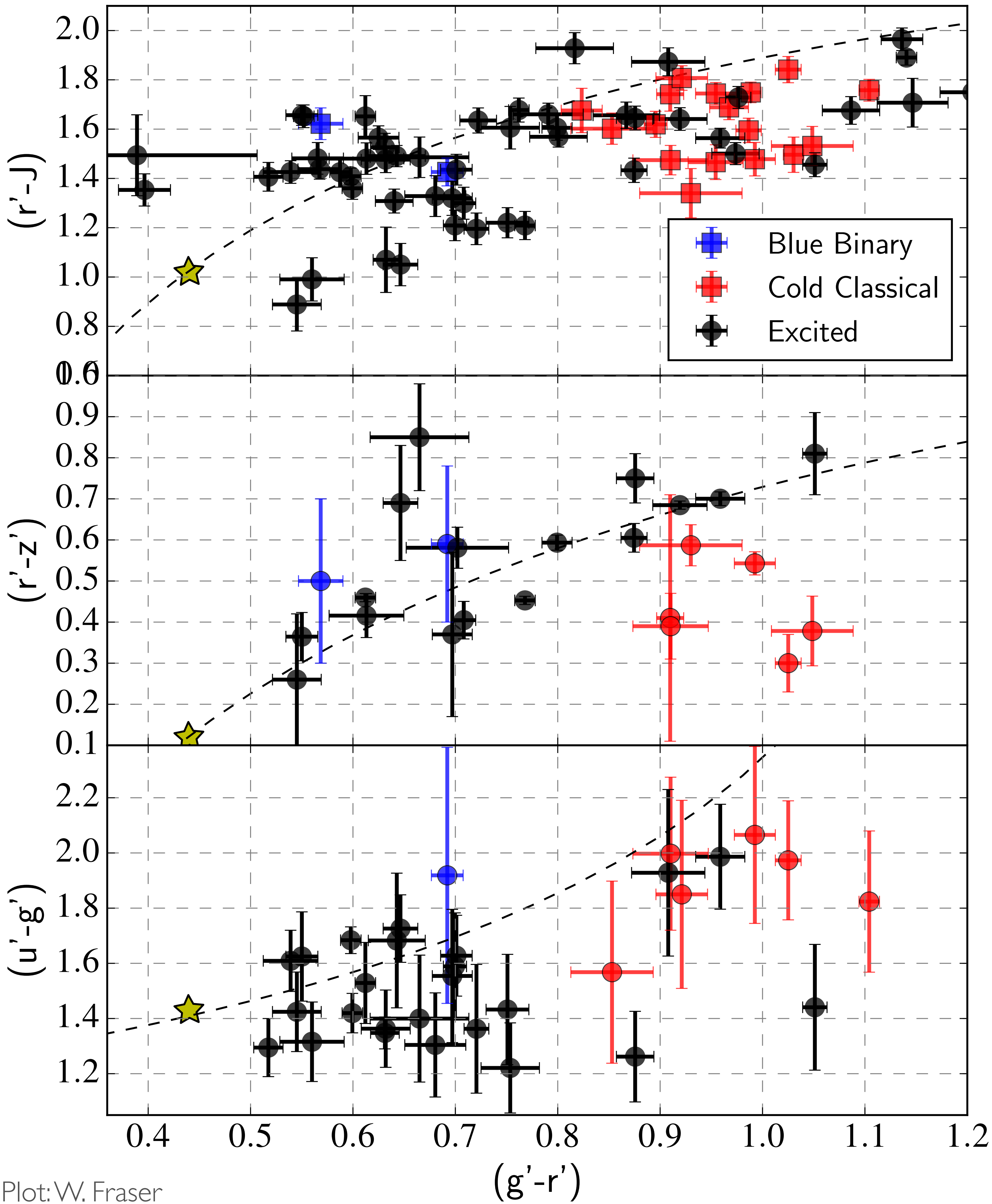
M. Schwamb, M. Bannister, W. Fraser, M. Marsset, R. Pike, J.J. Kavelaars, S. Benecchi, M. Lehner, S.Y. Wang, A. Thirouin, A. Delsanti, N. Peixinho, M. Alexandersen, Y.T. Chen, B. Gladman, S. Gwyn, J.M. Petit, K. Volk



Release of Photometry from:
- H block (17 objects)
- L block (18 objects)







Plot: W. Fraser

Col-OSSOS Photometry

www.colossos.net

OUTER SOLAR SYSTEM
OSSOS
ORIGINS SURVEY

~THANK YOU~

Col-OSSOS: www.colossos.net

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Rosemary E. Pike et al.

AJ 2017