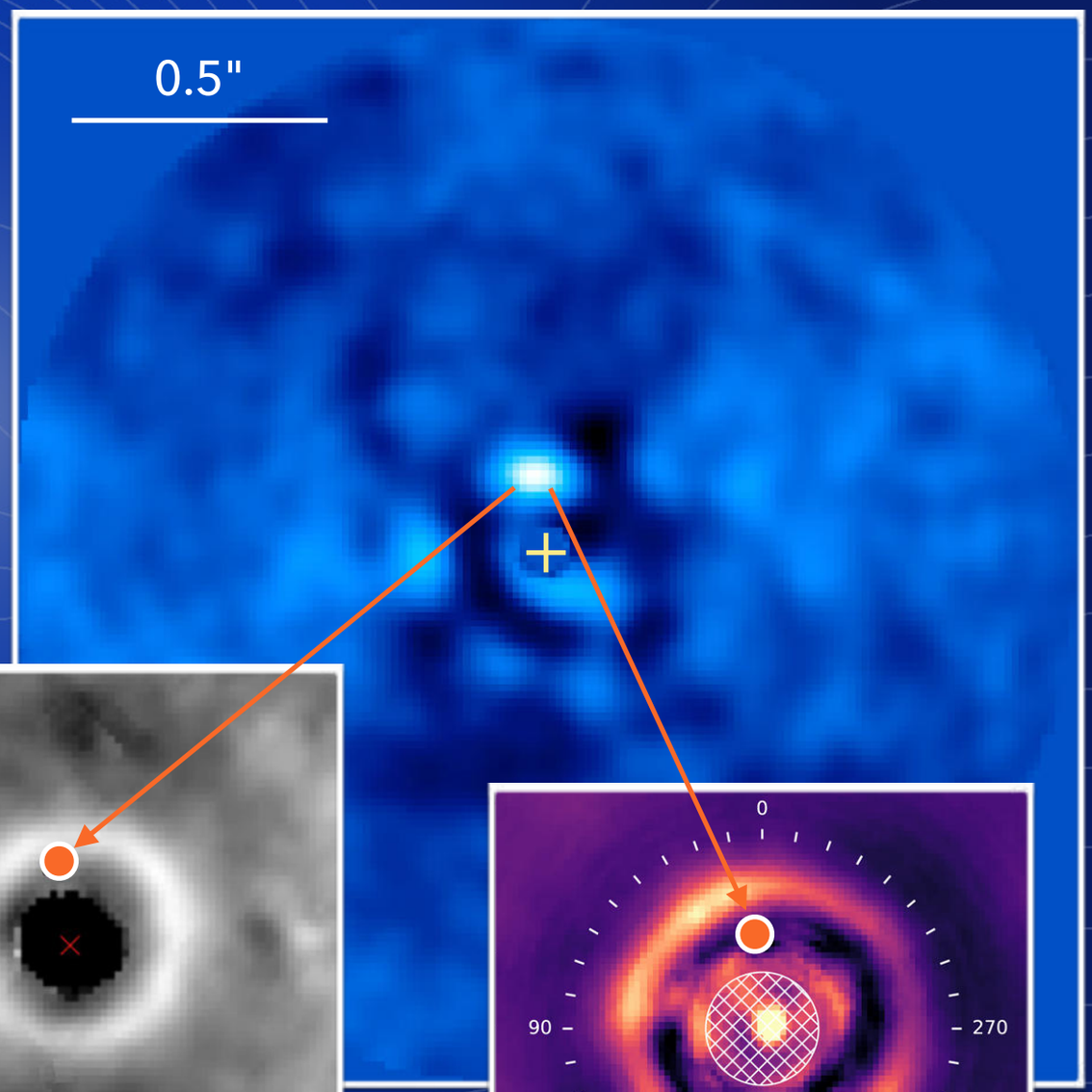
VORTEX

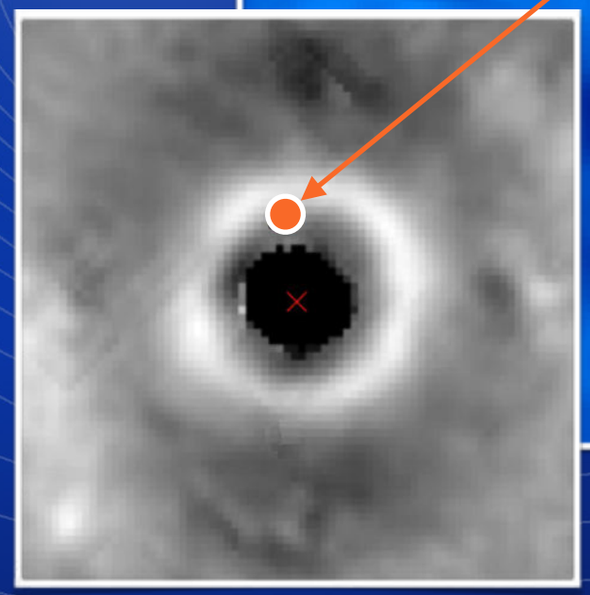
SCIENTIFIC RESULTS

EARLY SCIENCE @ VLT/NACO: HD 169142

- point-like source at 0.15" from Herbig Ae star, inside H-band PDI inner cavity
- not detected at J band (GPI) nor H-K bands (MagAO)
- possible explanations
  - accreting protoplanet?
  - disk feature?

Biller et al. 2014, Reggiani et al. 2014





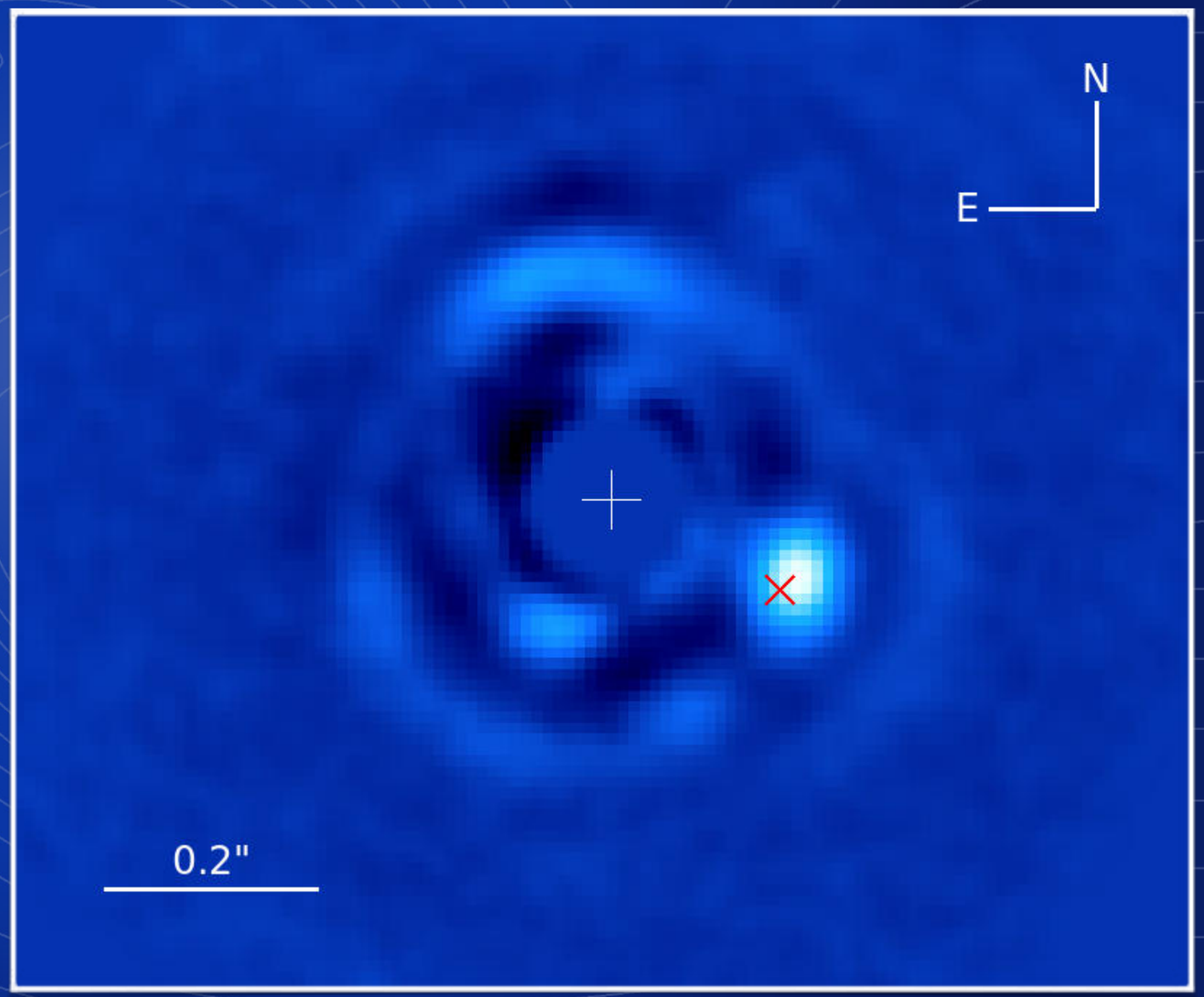
Quanz et al. 2013

Ligi et al. 2018

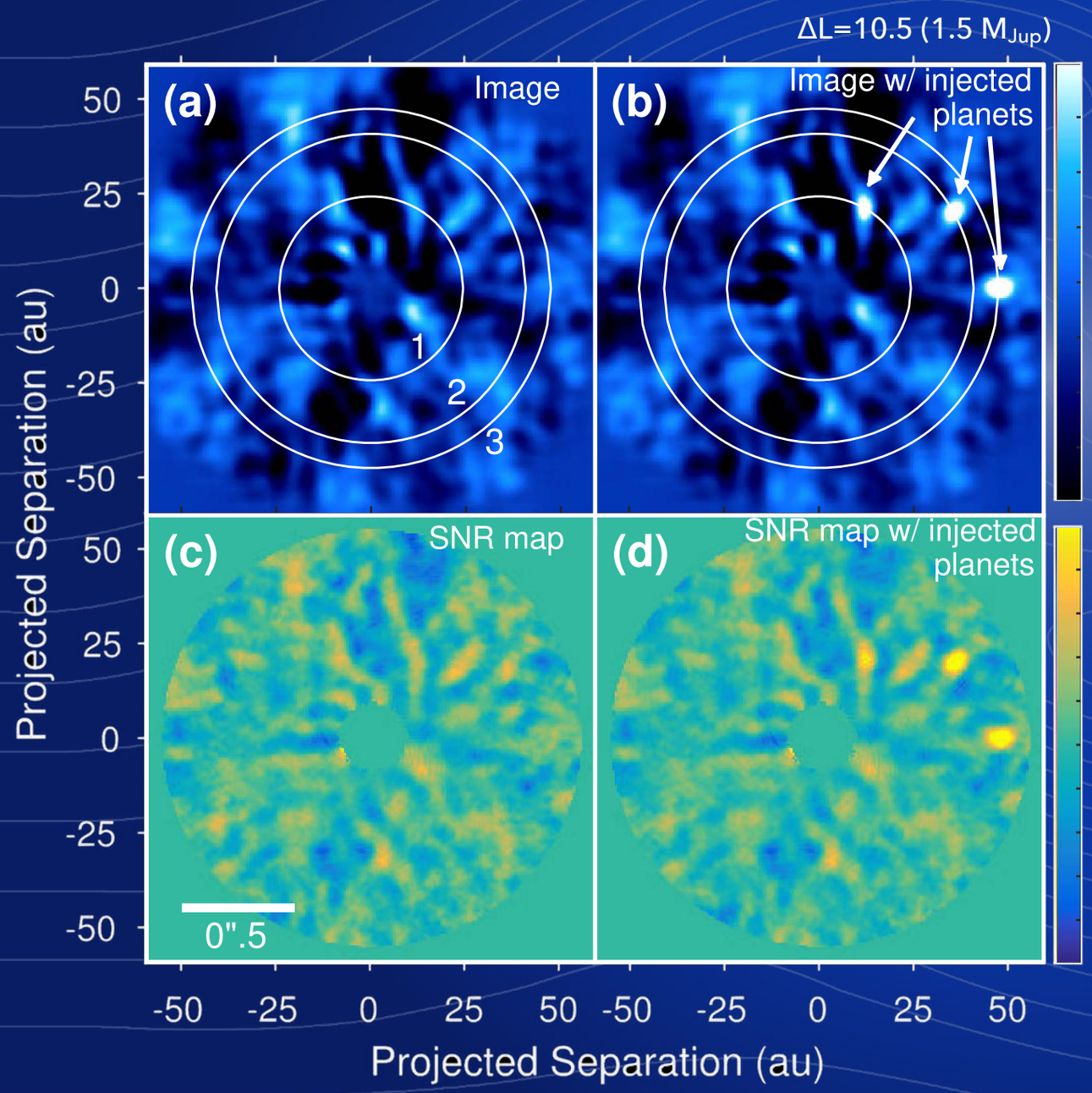
FIRST LIGHT @ KECK/NIRC2: HIP 79124

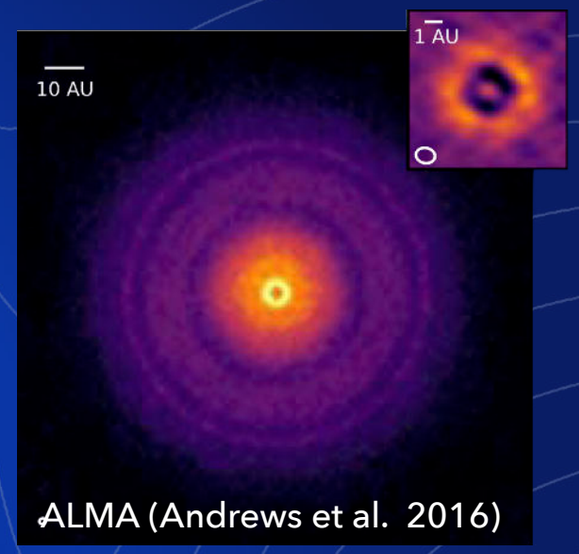
- brown dwarf around Sco-Cen A0 star
- 177 mas, ΔL=4.3
- only detected with aperture masking so far
- recovered with NIRC2+vortex during commissioning

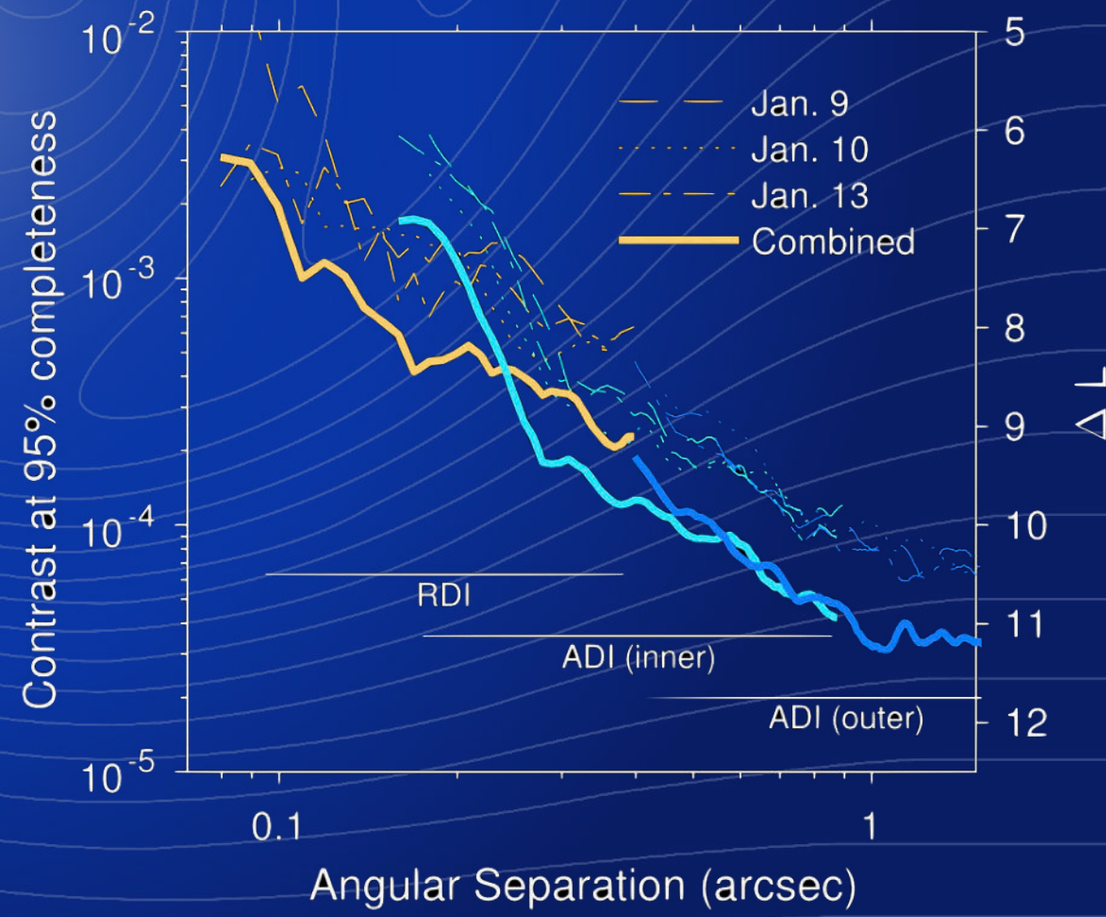
Serabyn et al. (2017)



KECK CORONAGRAPHIC DEEP FIELD: TW HYA



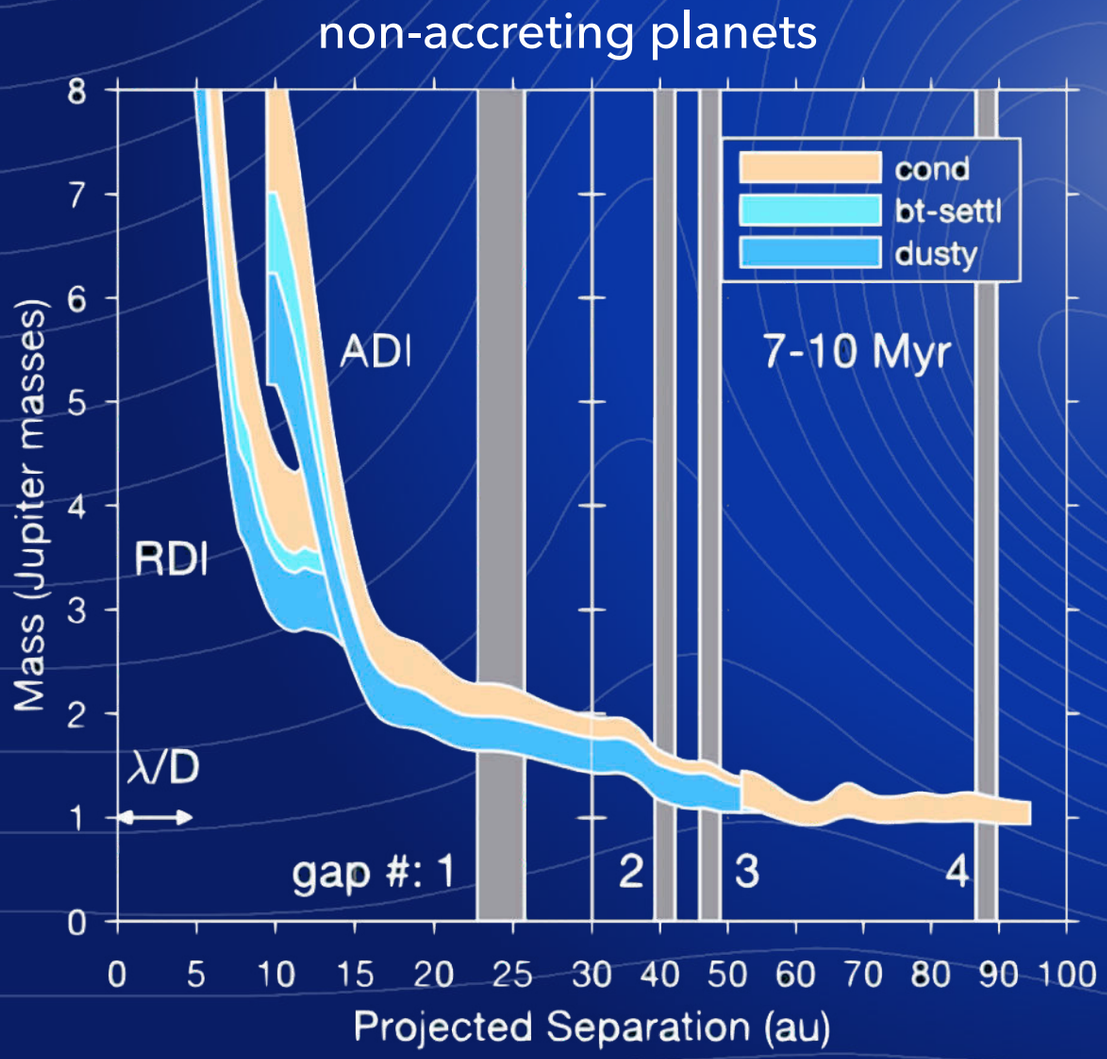


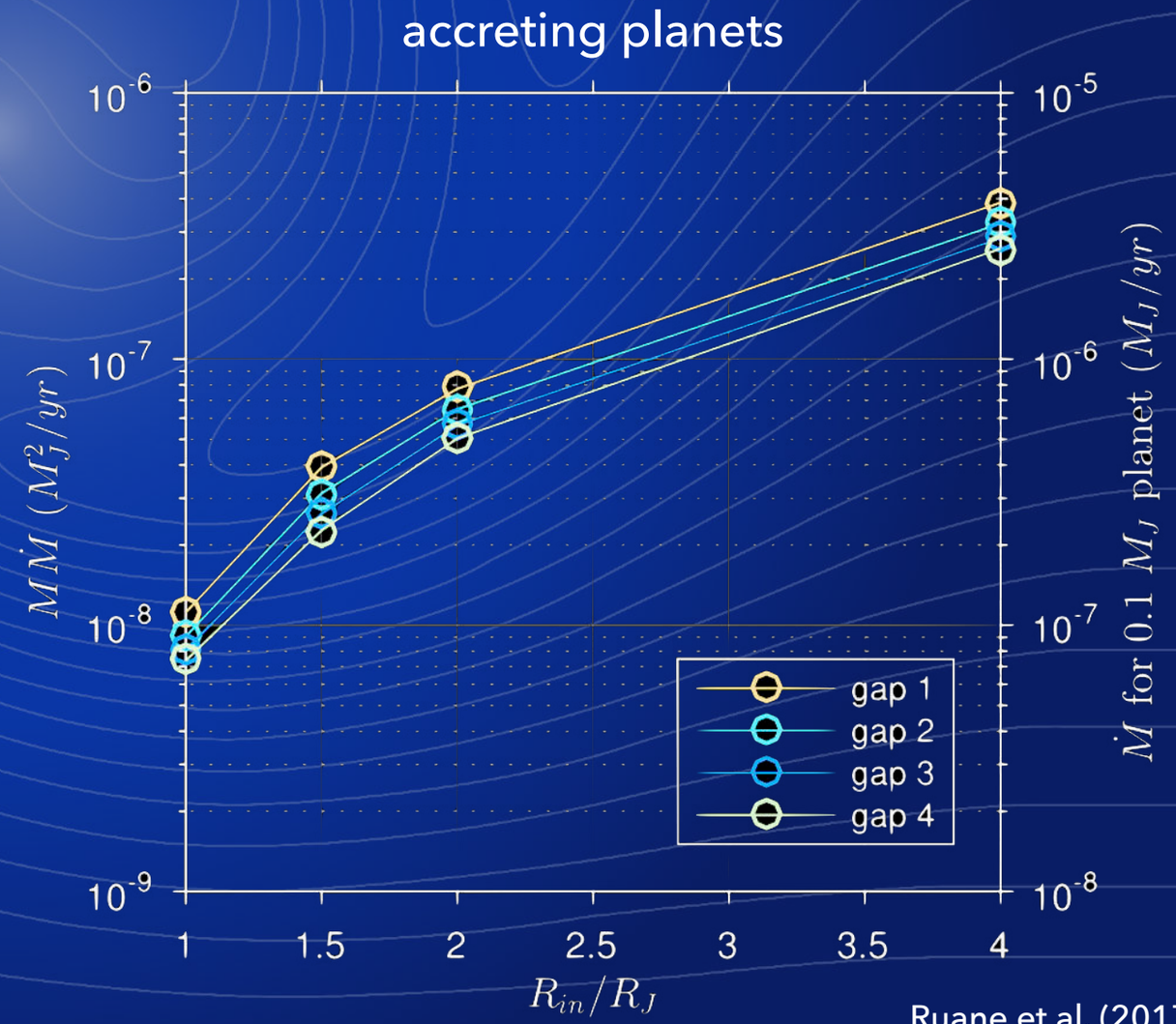


Ruane et al. (2017)

CONSTRAINING (PROTO)PLANETS IN TW HYA DISK

- protoplanet with circumplanetary disk truncated at ~1R_{Jup} presently accreting at a rate insufficient to form a Jupiter-mass planet

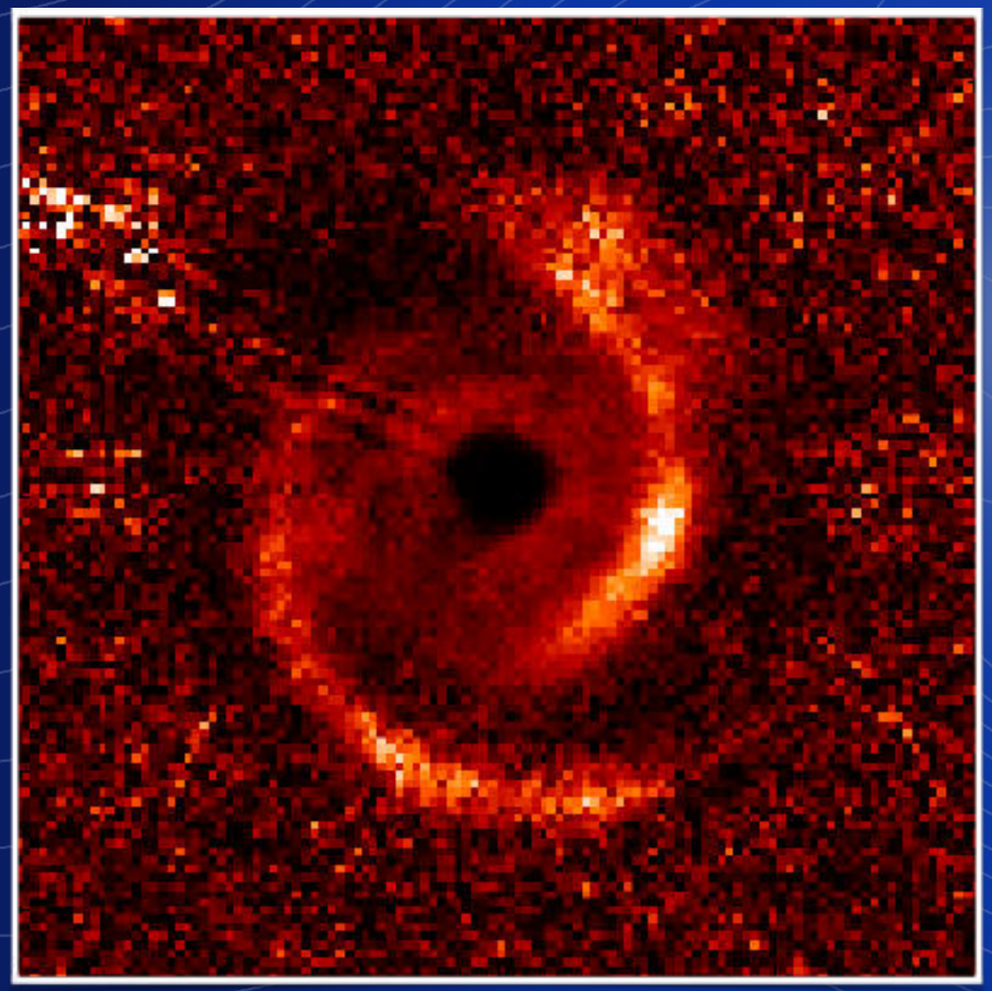




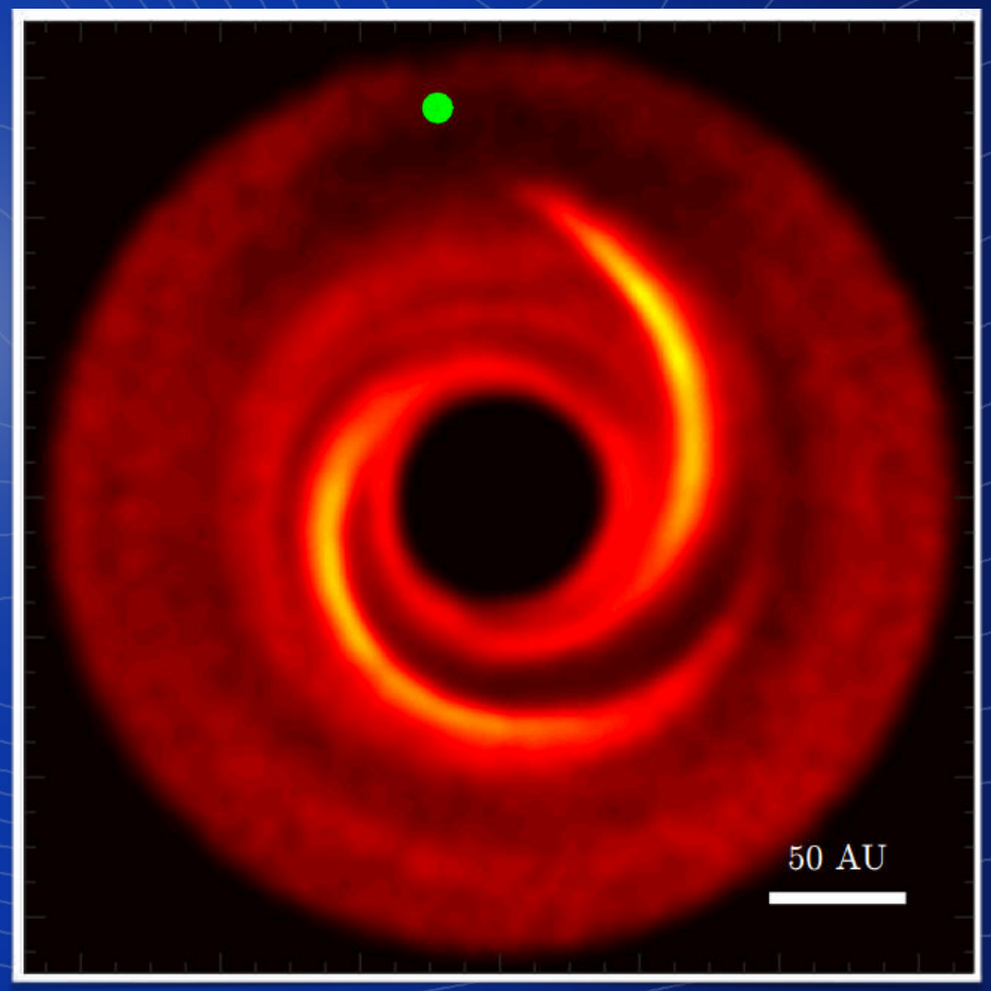
Ruane et al. (2017)

TRANSITION DISK SURVEY (NIRC2 & NACO)

SPHERE/IRDIS Y band polarimetry (Benisty et al. 2015)

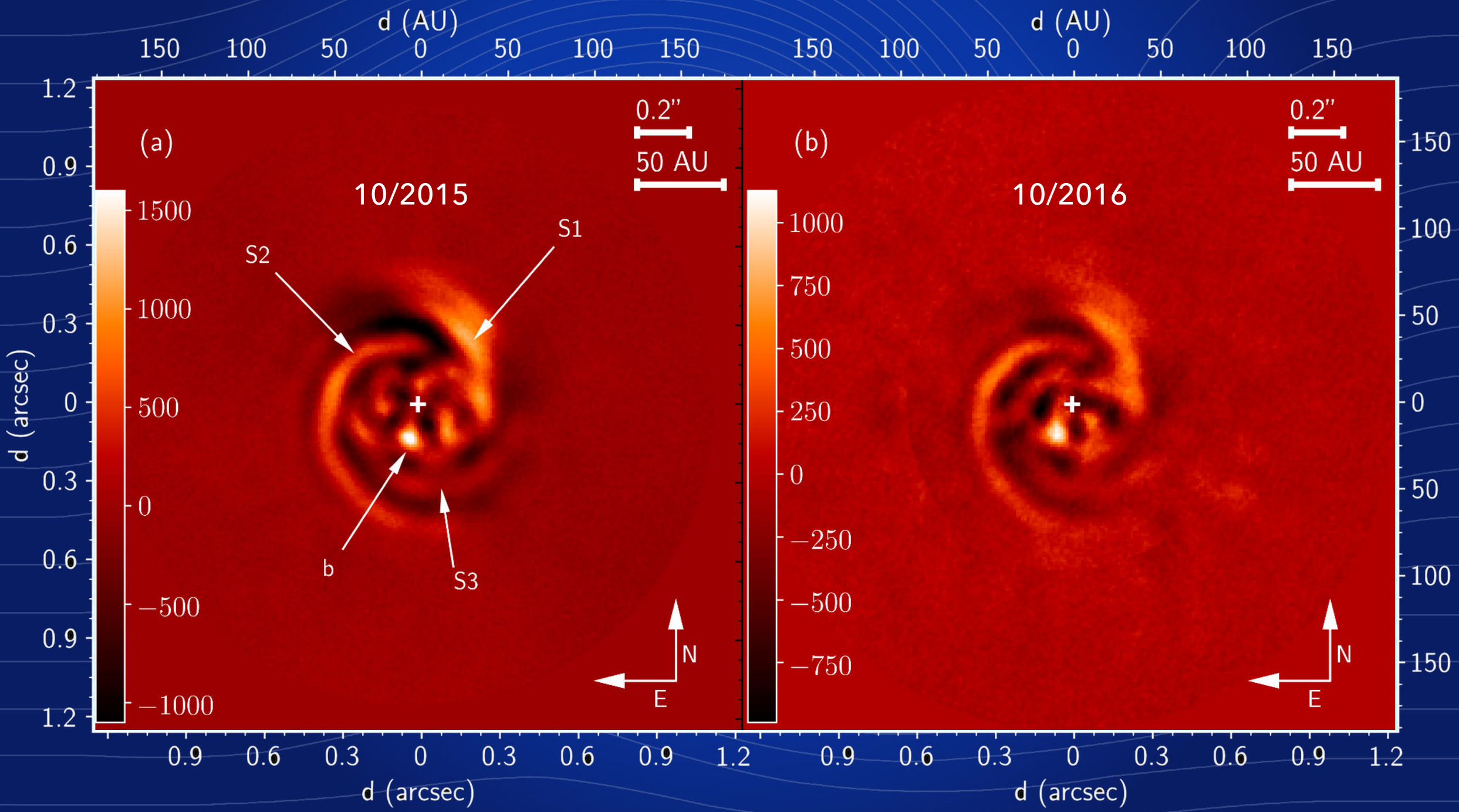


Protoplanet prediction (Dong et al. 2015)



goal: search for protoplanets at the origin of disk structures

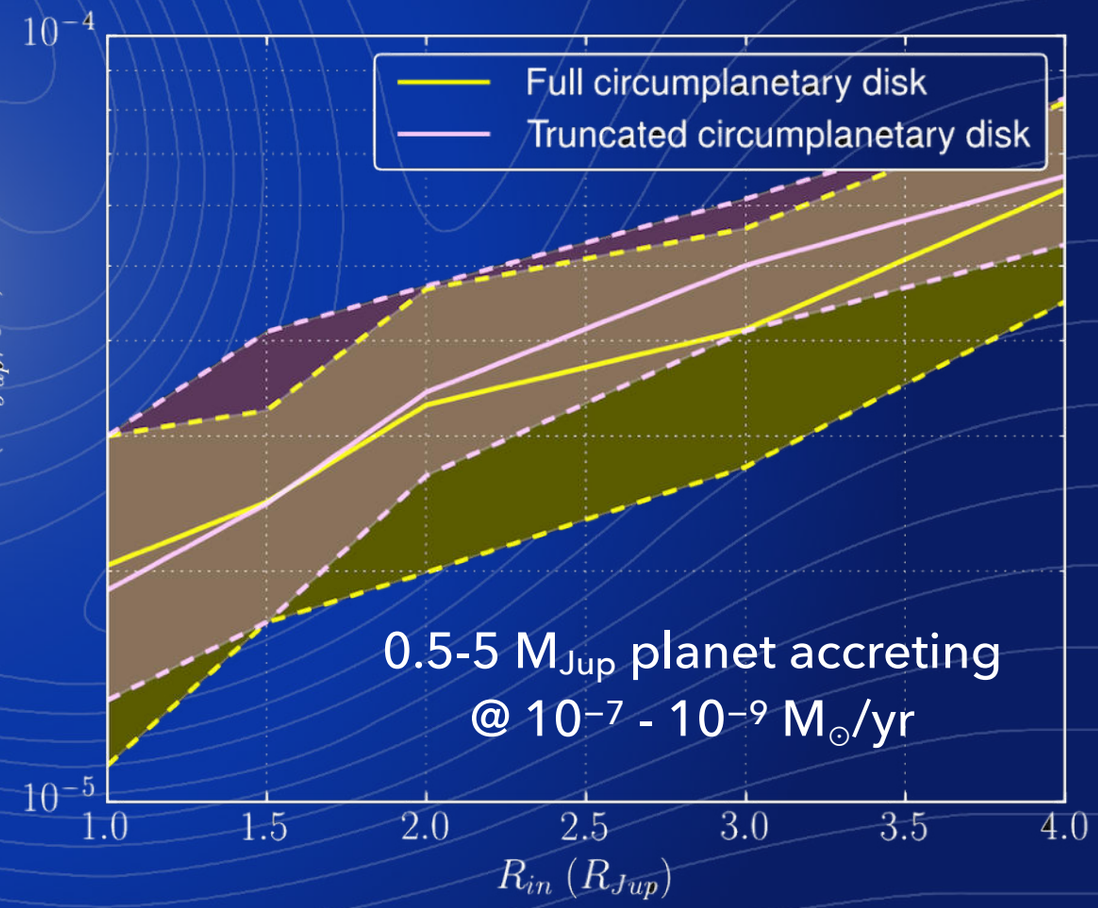
THE KECK/NIRC2 + VORTEX VIEW OF MWC758



Reggiani et al. (in press)

MWC758: YET ANOTHER PROTOPLANET CANDIDATE?

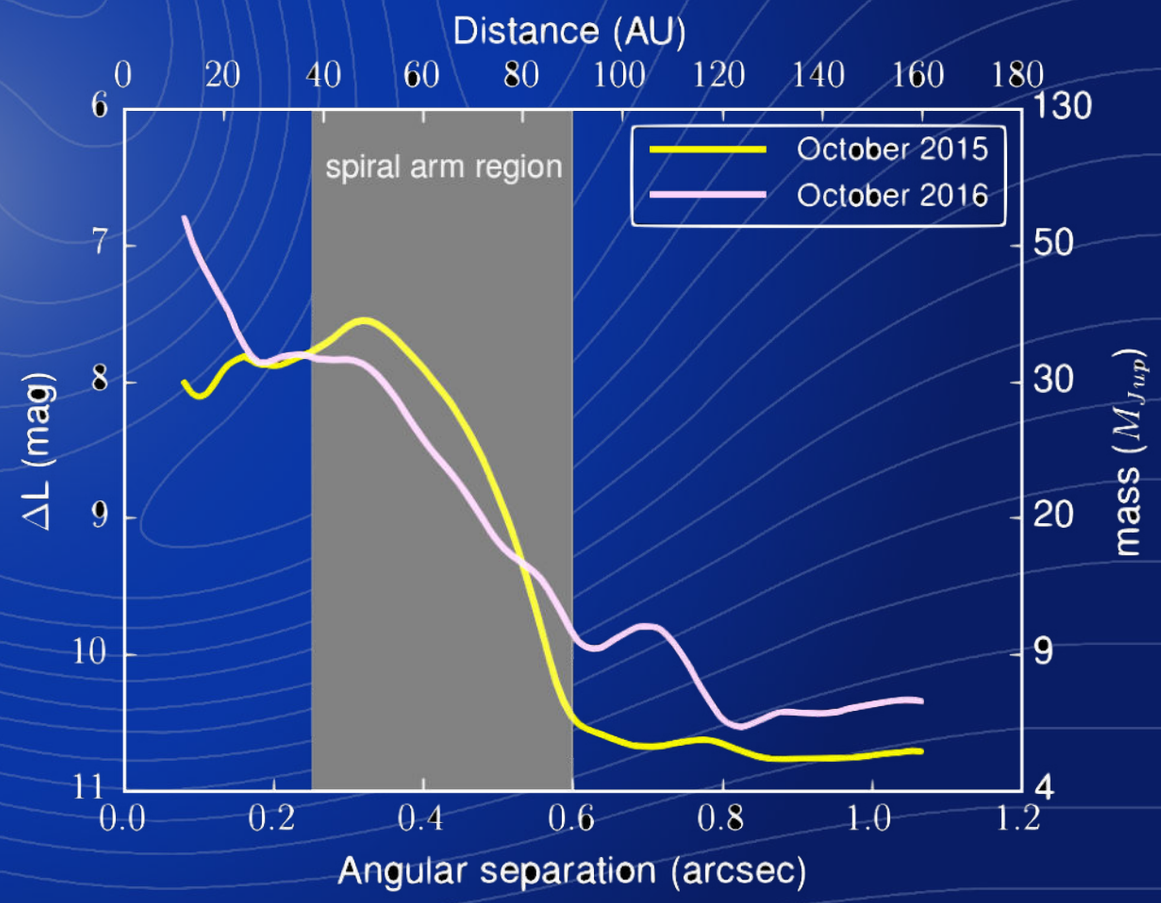
- main properties
  - ✳ 0.1″ separation (20 au), ΔL = 7
  - ✳ two epochs: PA difference consistent with Keplerian rotation in 1 yr
- low probability for bckg star
- companion? needs to be <6 M_{Jup}
  → not purely photospheric emission
- conclusion: accreting protoplanet or disk feature?
  - ✳ no polarized disk emission there!



Reggiani et al. (in press)

MWC758: ORIGIN OF THE SPIRALS?

- now three spiral arms to reproduce with models
- driven by protoplanet?
  - outer planet? most likely explanation based on models, but strong constraints from observations (< 6 M_{Jup})
  - inner planet? might explain one spiral, but not all three

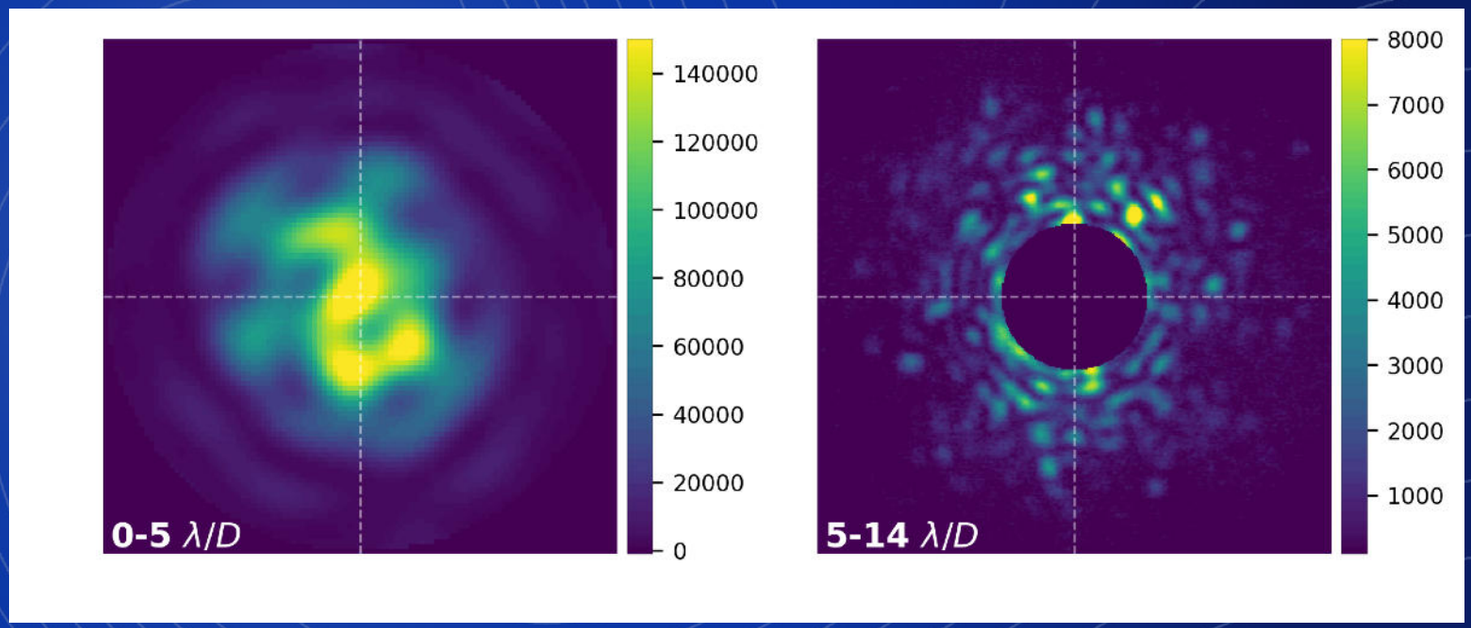


Reggiani et al. (in press)

HOW TO BETTER EXPLOIT THE DATA?

- interesting science at 1-3 λ/D
  - ✳ strongly affected by residual speckles
  - ✳ non-Gaussian noise –> more false positives
  - ✳ hard to validate candidates

NIRC2+vortex image sequence



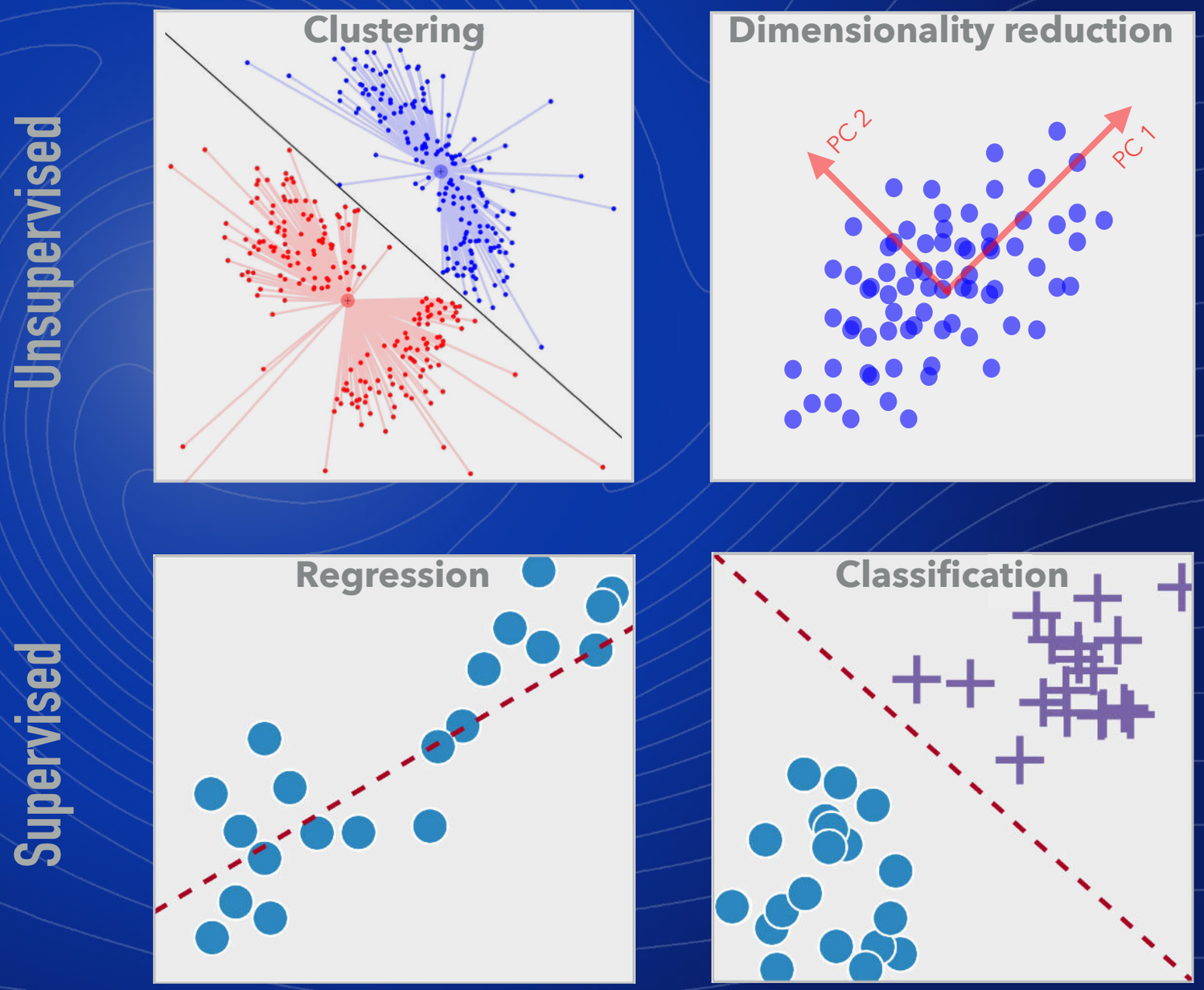
- ADI-based techniques produce SNR, but do not inform on nature of the source
- machine learning can help

VORTEX

IMAGE PROCESSING WITH MACHINE LEARNING

MACHINE LEARNING IN A NUTSHELL

- construction of algorithms that can learn from, and make predictions on data



SUPERVISED LEARNING

- goal: learn function f mapping input samples $\mathcal{X}$ to labels $\mathcal{Y}$ given a labeled dataset $(x_i, y_i)_{i=1,\ldots,n}$:

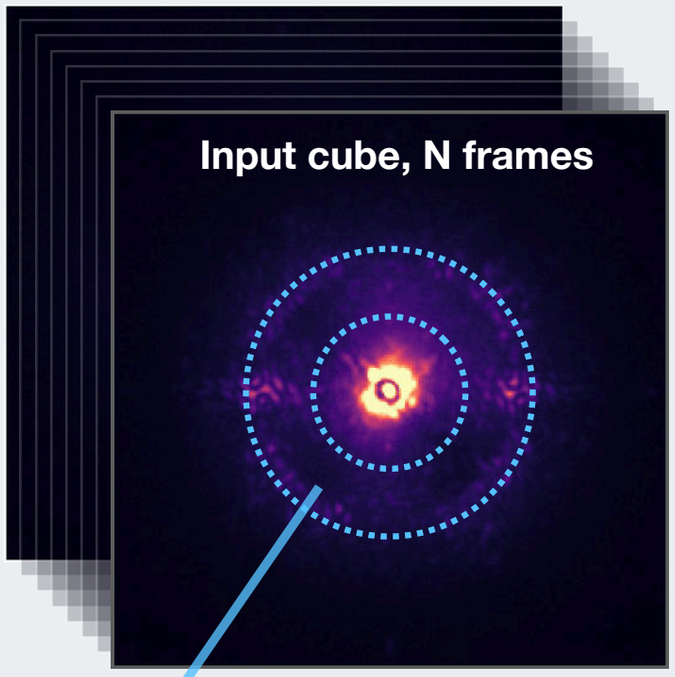
$$\min_{f \in \mathcal{F}} \frac{1}{n} \sum_{i=1}^{n} \mathcal{L}(y_i, f(x_i)) + \lambda \Omega(f)$$

- mapping function f based on (deep) neural network
  - layers of neurons whose parameters can be tuned to approximate a complex function
  - DNN can be trained with labeled datasets
- problem: need labels & large training sample!

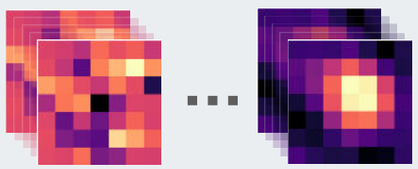
SUPERVISED DETECTION OF EXOPLANETS

Gomez Gonzalez et al. (in press)

1. generation of labeled data



N x P_{ann} → *k* SVD low-rank approximation levels → *k* residuals, back to image space



X : MLAR samples

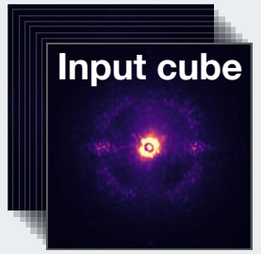
0 … 1 **y** : Labels

2. training the DNN

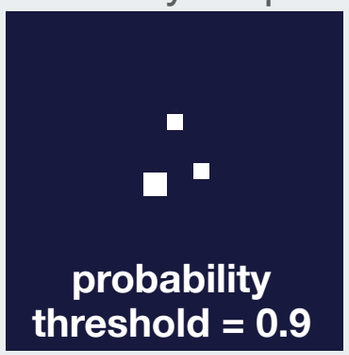
X and **y** to train/test/validation sets

- Convolutional LSTM layer *kernel=(3x3), filters=40*
- 3d Max pooling *size=(2x2x2)*
- Convolutional LSTM layer *kernel=(2x2), filters=80*
- 3d Max pooling *size=(2x2x2)*
- Dense layer *units=128*
- ReLU activation + dropout
- Output dense layer *units=1*
- Sigmoid activation

3. prediction



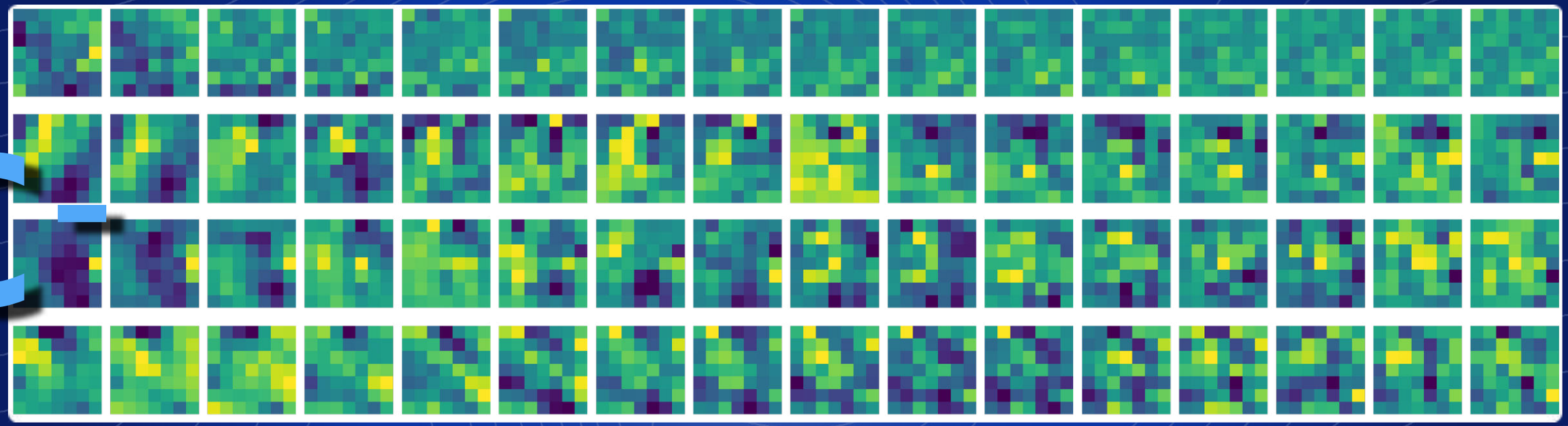
MLAR patches → Trained classifier → Probability of positive class → Binary map



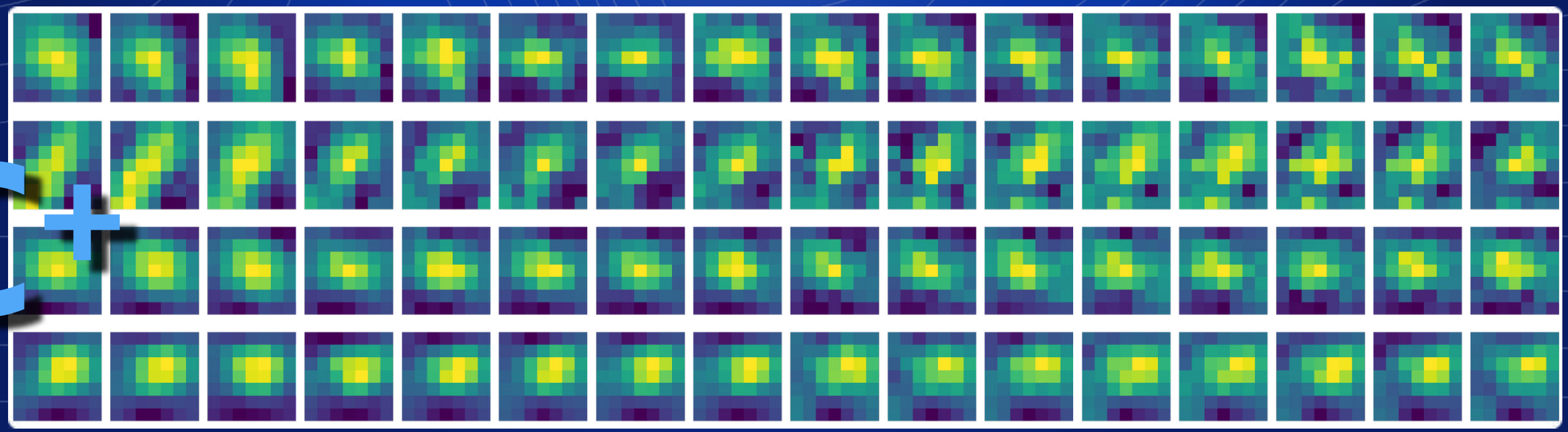
LABELED DATASET

Labels: $y \in \{c^-, c^+\}$

c^-



c^+



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Gomez Gonzalez et al. (in press)

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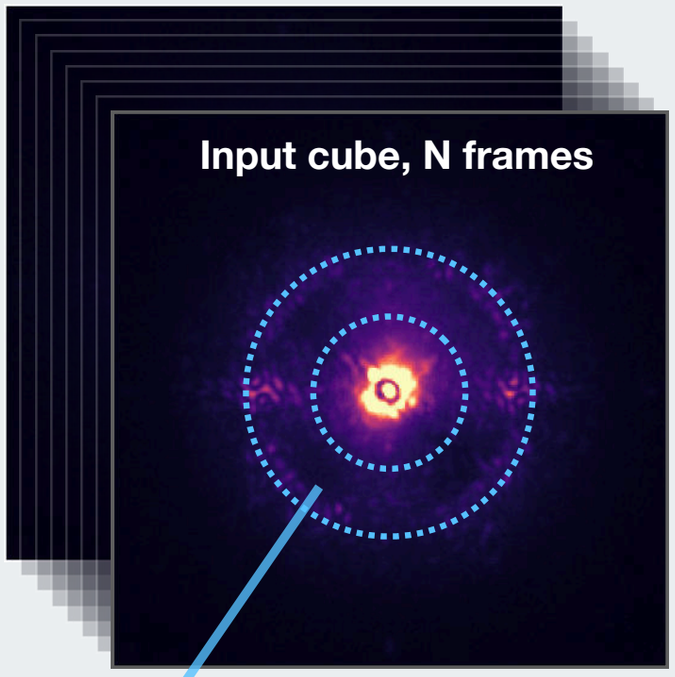

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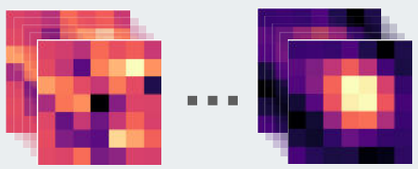

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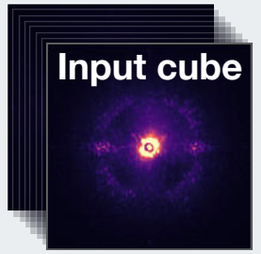

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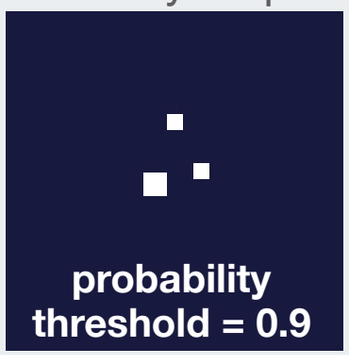
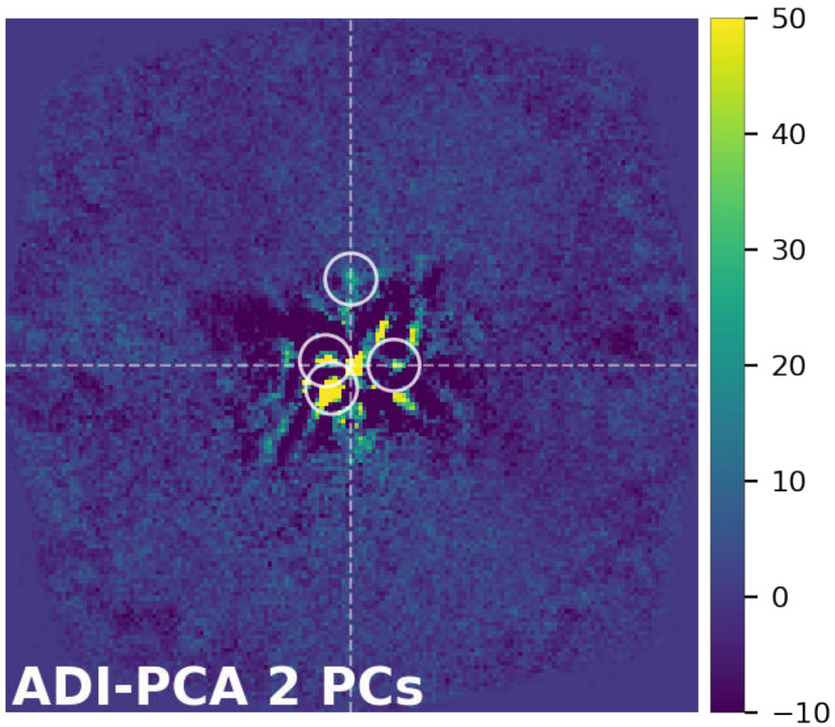
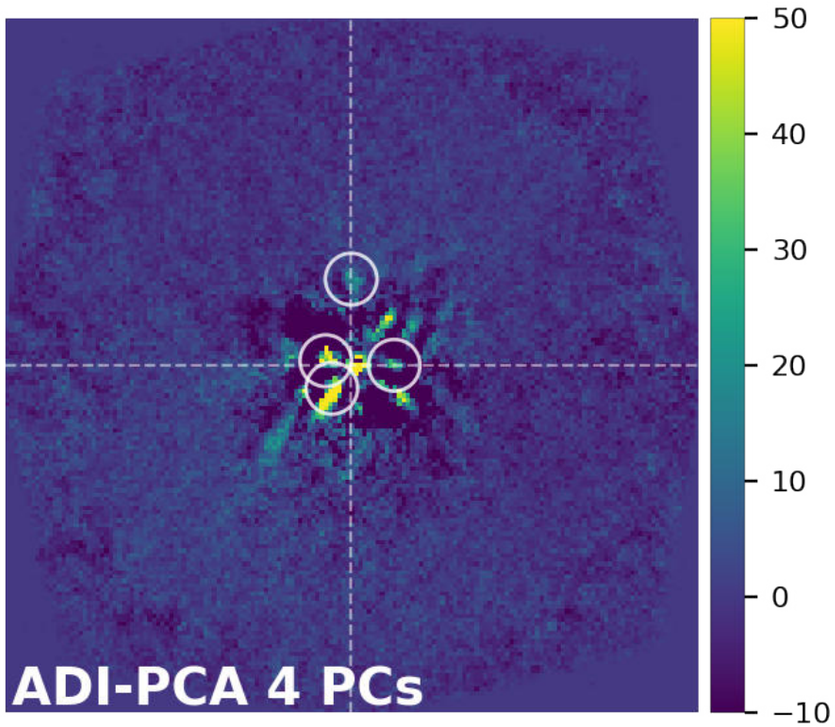
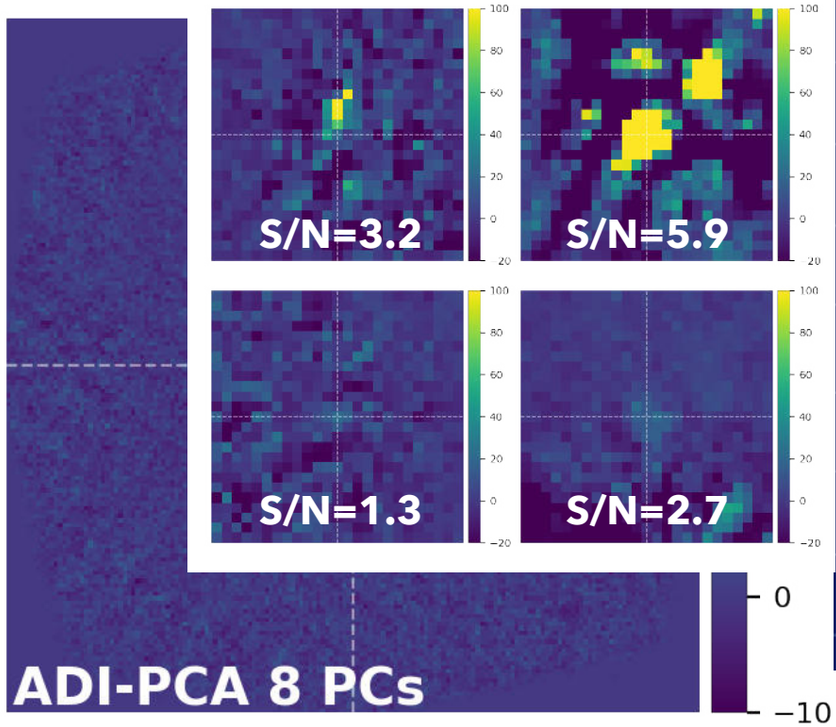
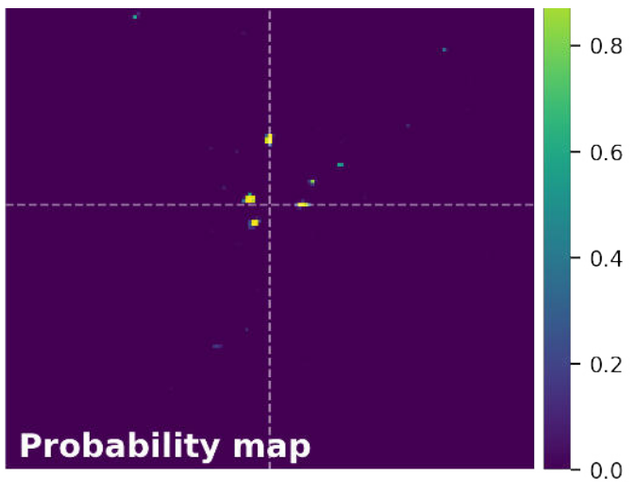


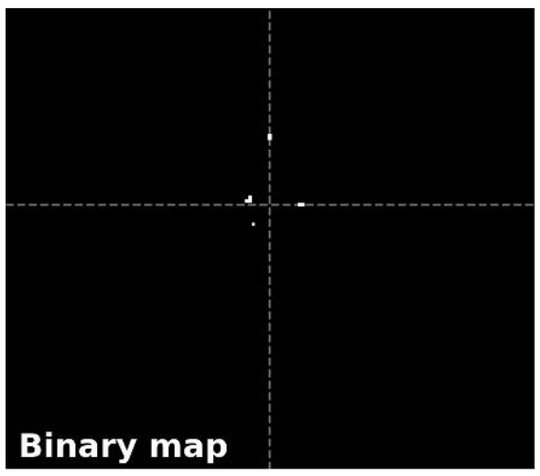
TEST WITH INJECTED COMPANIONS (SPHERE/IRDIS)

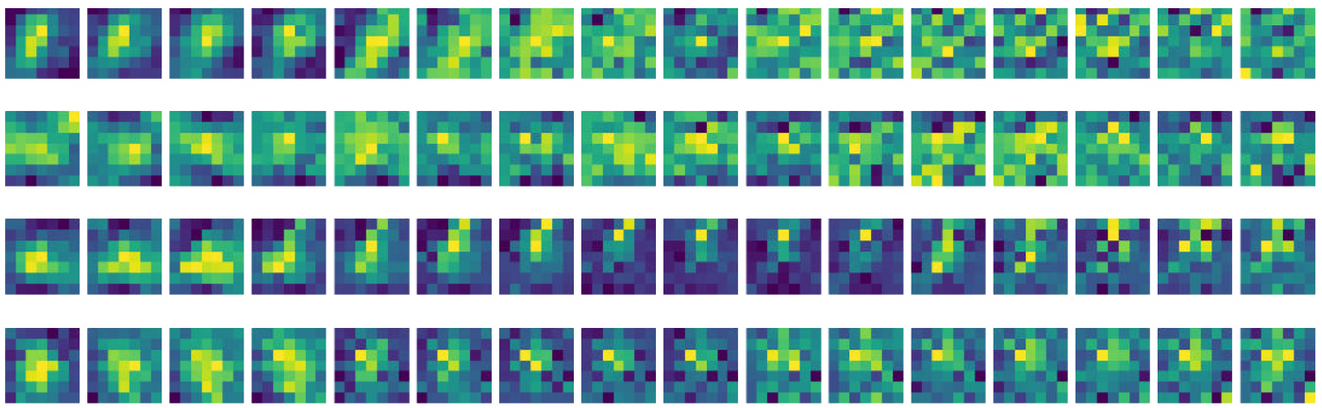












MLAR patches of 4 fake companions

Gomez Gonzalez et al. (in press)

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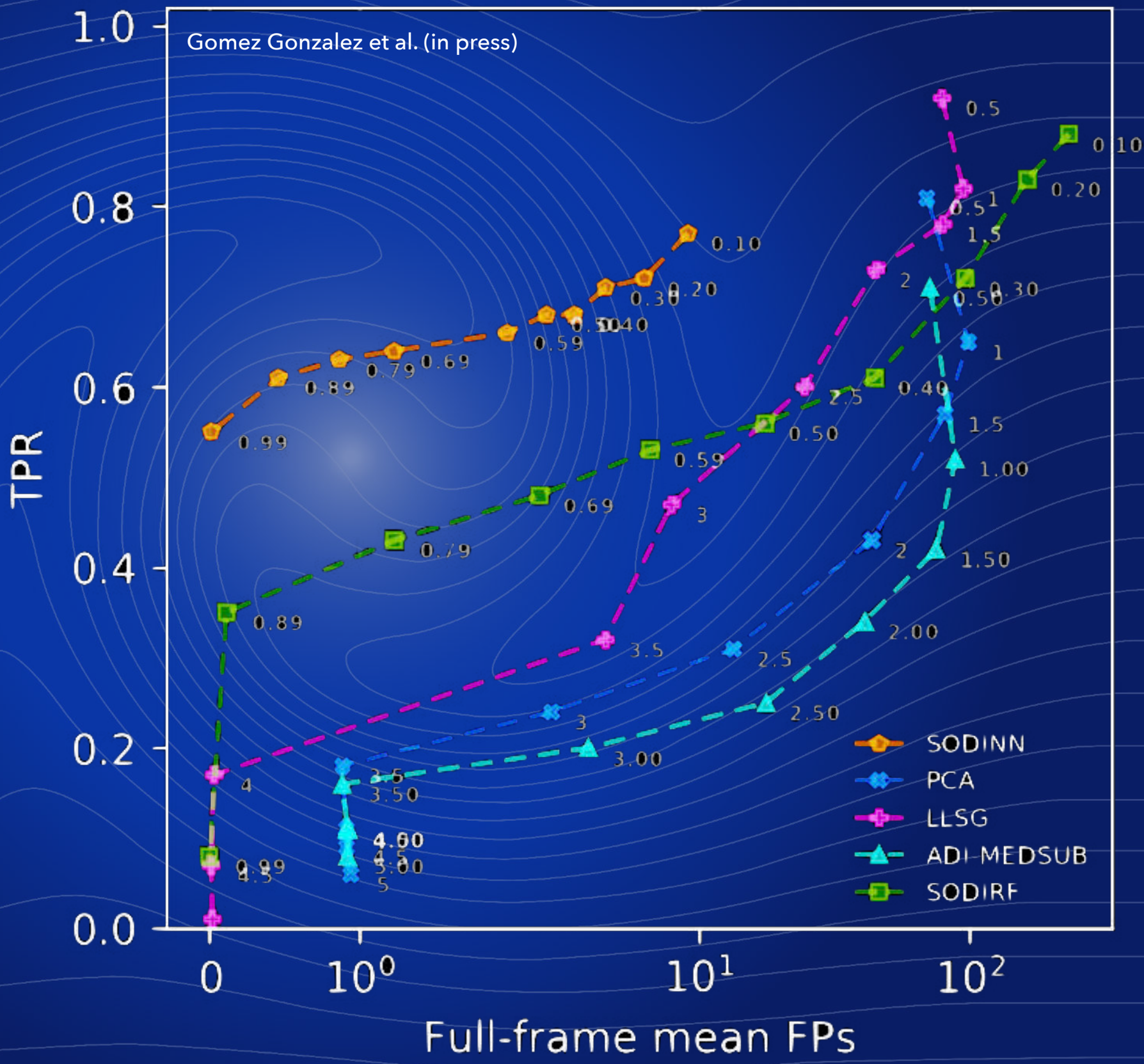
ROC CURVES

- Separation
  - ✳ 2 - 3 λ/D
- Contrasts
  - ✳ 2.9×10^{-5} to 1.4×10^{-4}



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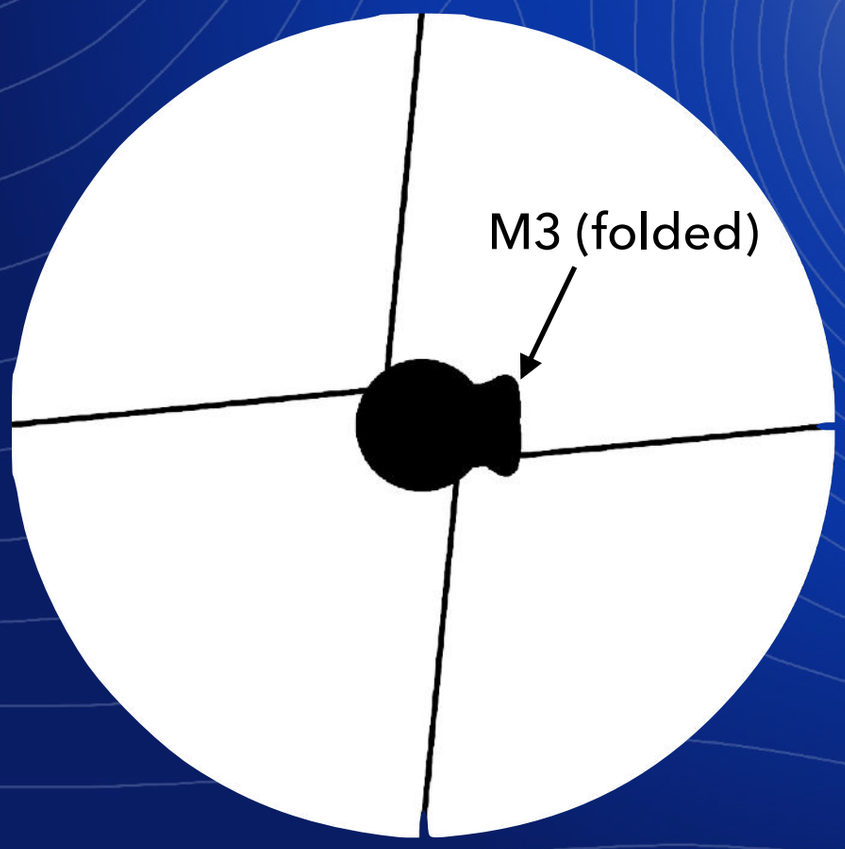
FUTURE PROJECTS

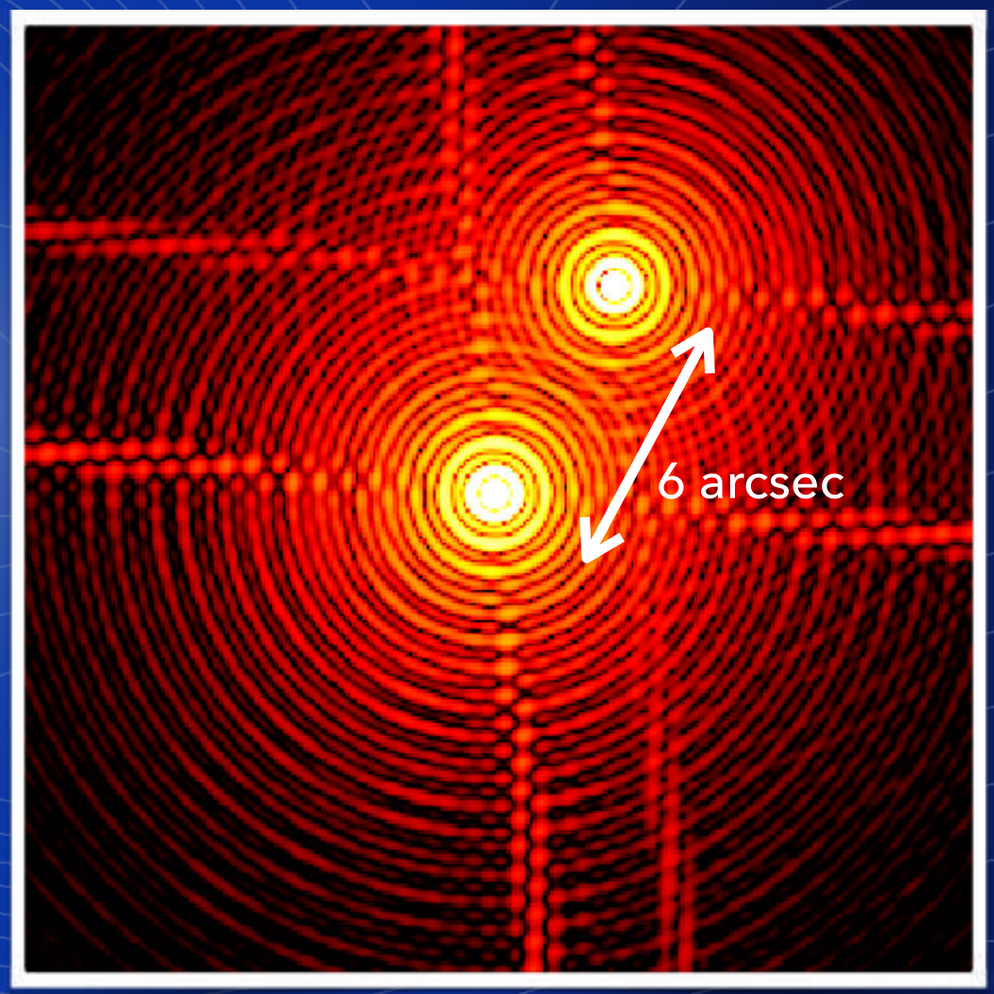
NEAR – NEW EARTH IN THE ALPHA CENTAURI REGION

- ESO project funded by Breakthrough Watch
  - what? search for rocky planets around α Cen A&B
  - how? refurbish VISIR and put it behind UT4+AOF
  - when? 100h observing campaign in mid-2019
- vortex team contribution
  - provide optimized AGPM for 10-12.5μm filter
  - design optimized Lyot stop
  - develop closed-loop pointing control with QACITS

NEAR LYOT STOP: TWO CHALLENGES

- binary target star
  - need to dim secondary star
- complicated pupil



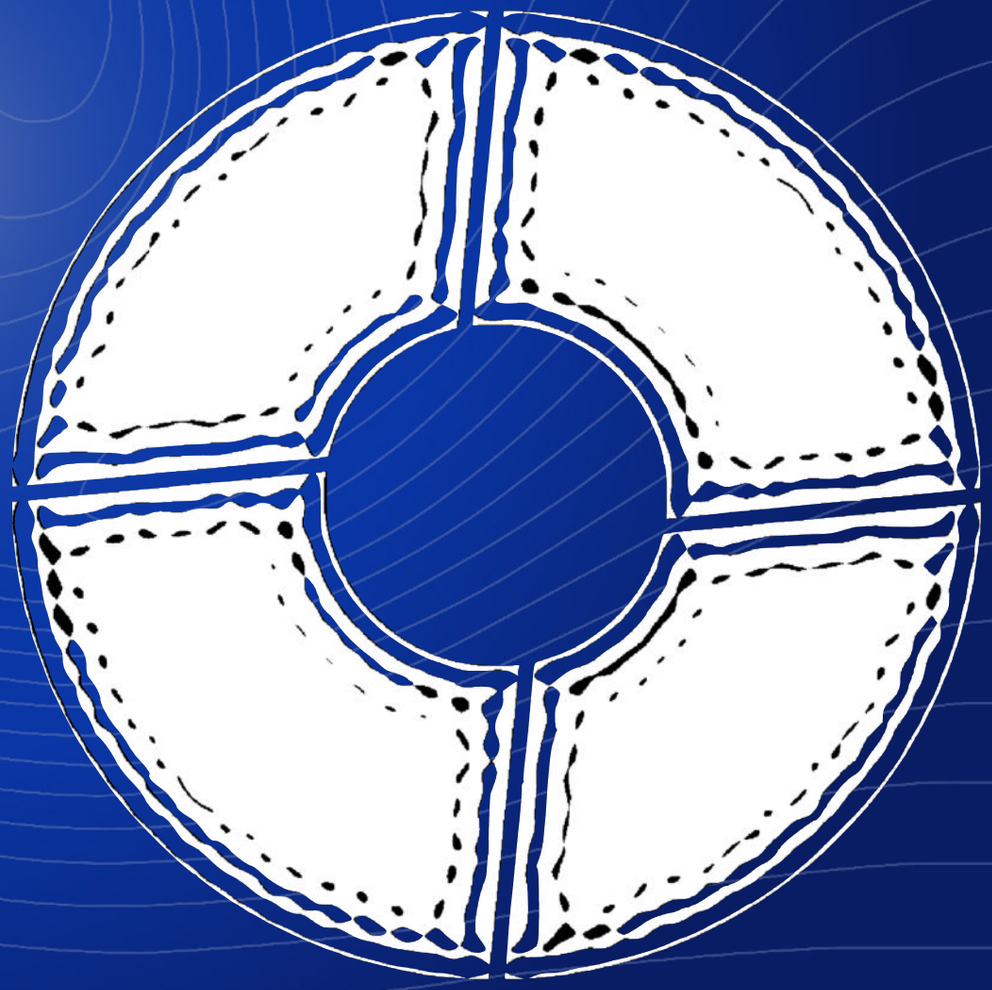


AN APODIZED LYOT STOP

- shaped-pupil: induce dark hole from 3″ to 8″ around B

Lyot stop

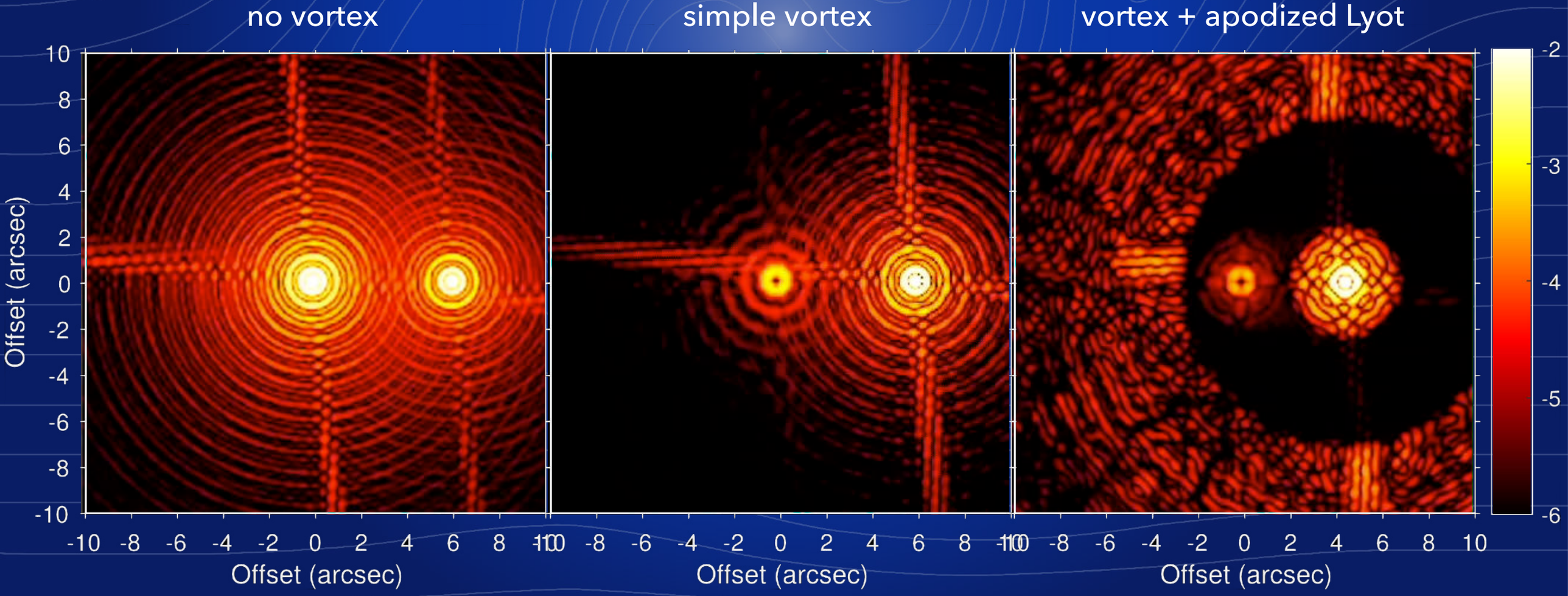
apodized Lyot stop



courtesy G. Ruane, AJ Riggs

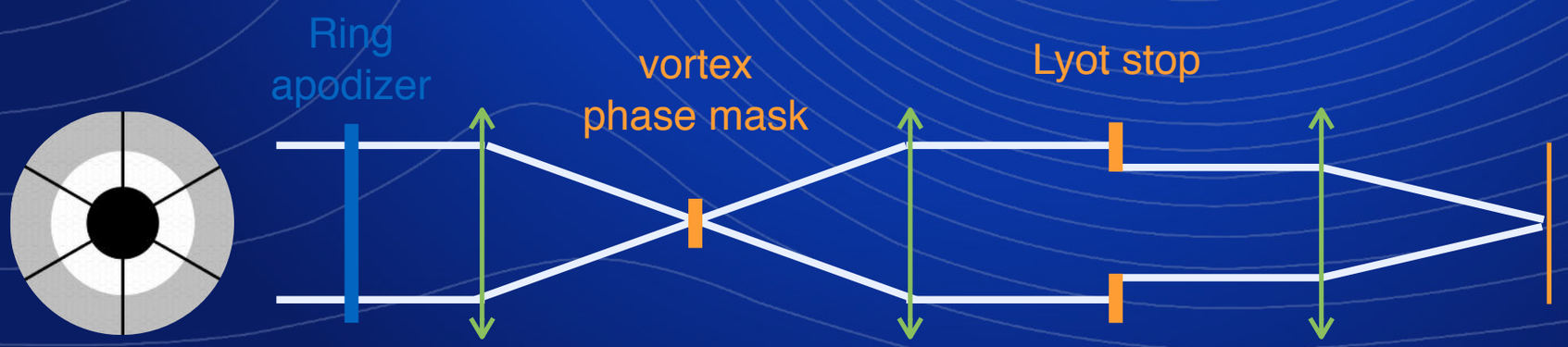
NOTIONAL IMAGES OF ALPHA CENTAURI SYSTEM

- habitable zone at 0.8″ - 1.1″ (A) or 0.5″ - 0.65″ (B)
- contrast around 10^{-6} for 2 $R_\oplus$ planet

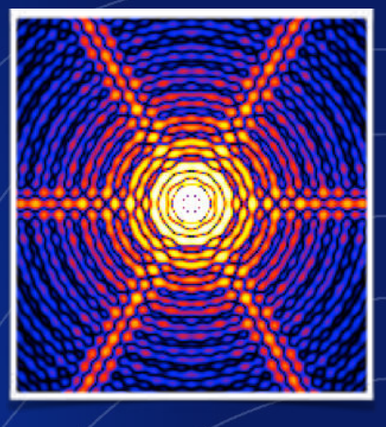


NEXT STEPS: VLT/ERIS AND ELT/METIS

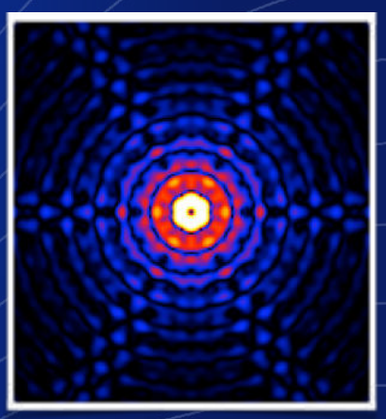
- ERIS: L & M band AGPMs
  - standard vortex coronagraph with simple Lyot stop
- METIS: L, M & N band AGPMs
  - ring-apodized vortex coronagraph: cancels diffraction from huge central obstruction



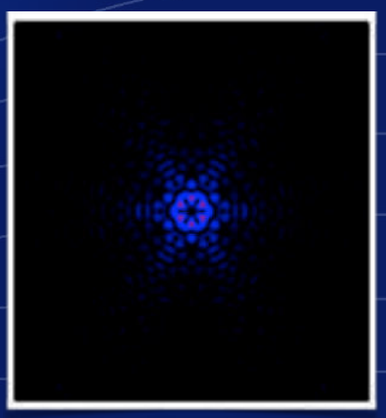
ELT



ELT+VC

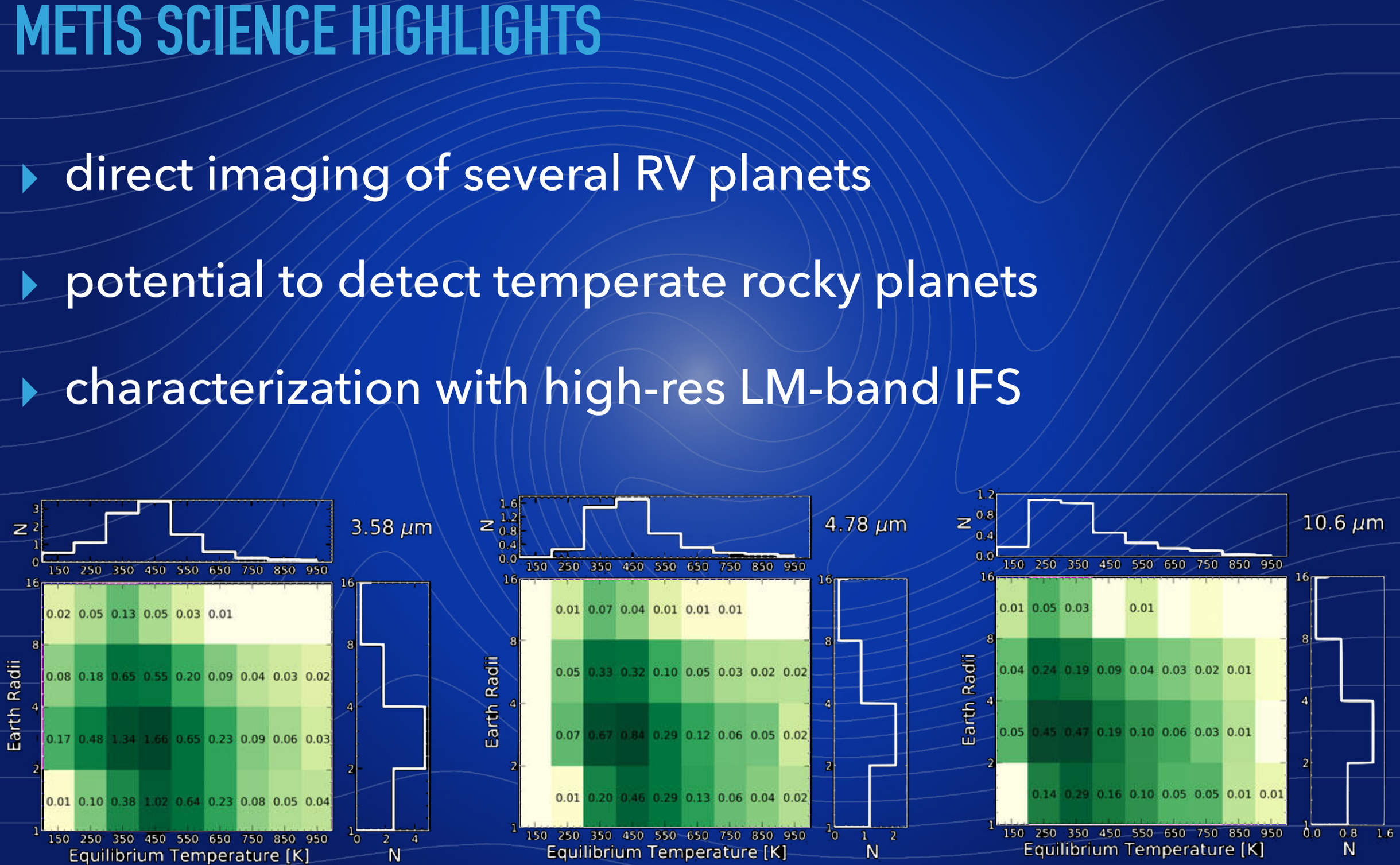


ELT+RAVC



METIS SCIENCE HIGHLIGHTS

- direct imaging of several RV planets
- potential to detect temperate rocky planets
- characterization with high-res LM-band IFS



Quanz et al. (2015)

A VORTEX UPGRADE FOR SPHERE?

- goal: open the 1-3 λ/D parameter space
  - ✶ increase number of detections
  - ✶ access a few RV planets
- need to identify main limitations to FQPM performance
  - ✶ component degradation?
  - ✶ effect of dead actuators?
  - ✶ low-order wavefront aberrations?
- K-band AGPM performance being evaluated

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THANKS FOR YOUR ATTENTION