POST PROCESSING WITH RDI:
RDI FOR SPHERE

A review of *Reference-star differential imaging on SPHERE/IRDIS* (Xie et al. 2022)

Data and Methodology

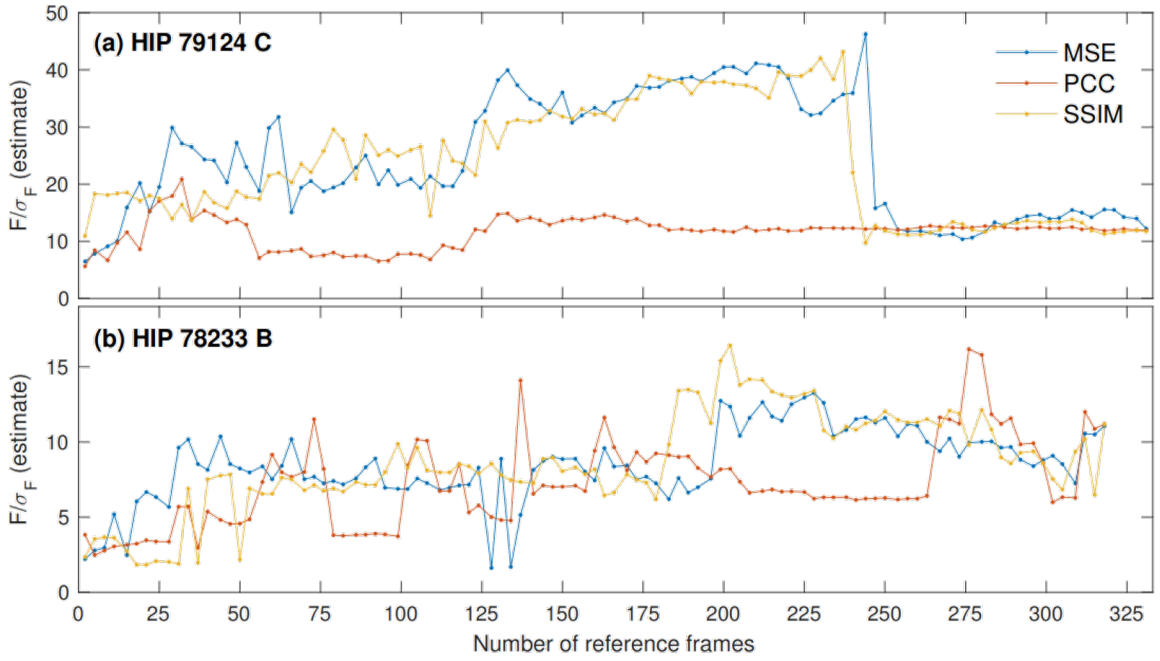
- IRDIS DB H23 observations.
- Total of 2.6×10^5 coronographic images for the two bands.
- Each image aligned to a reference template: an arbitrary bright star (HD121156) observed with a clear AO correction radius ring.
  - Reference template in H3 scaled and aligned to that in H2 to ensure images in the different bands were also aligned.
  - ~12% images failed the alignment and are excluded from the study.
- ADI and RDI performed on a selected sample of targets using PCA to construct and subtract the stellar PSF.
- 5σ contrast of reduced images calculated in order to quantify performance of ADI and RDI for point source detection*.

* Reductions performed for a grid of parameters -reference library size (number of science images for ADI) and number of principal components- with contrast curves using best contrast at each angular separation.

Assembling a reference library

- Targets analysed to identify poor reference stars (containing point/extended sources) after performing ADI on the aligned images.
  - RDI performed using master reference library obtained after ADI to further remove poor reference targets not identified with ADI.
  - Final master reference library containing ~70,000 images per band from 725 observations.

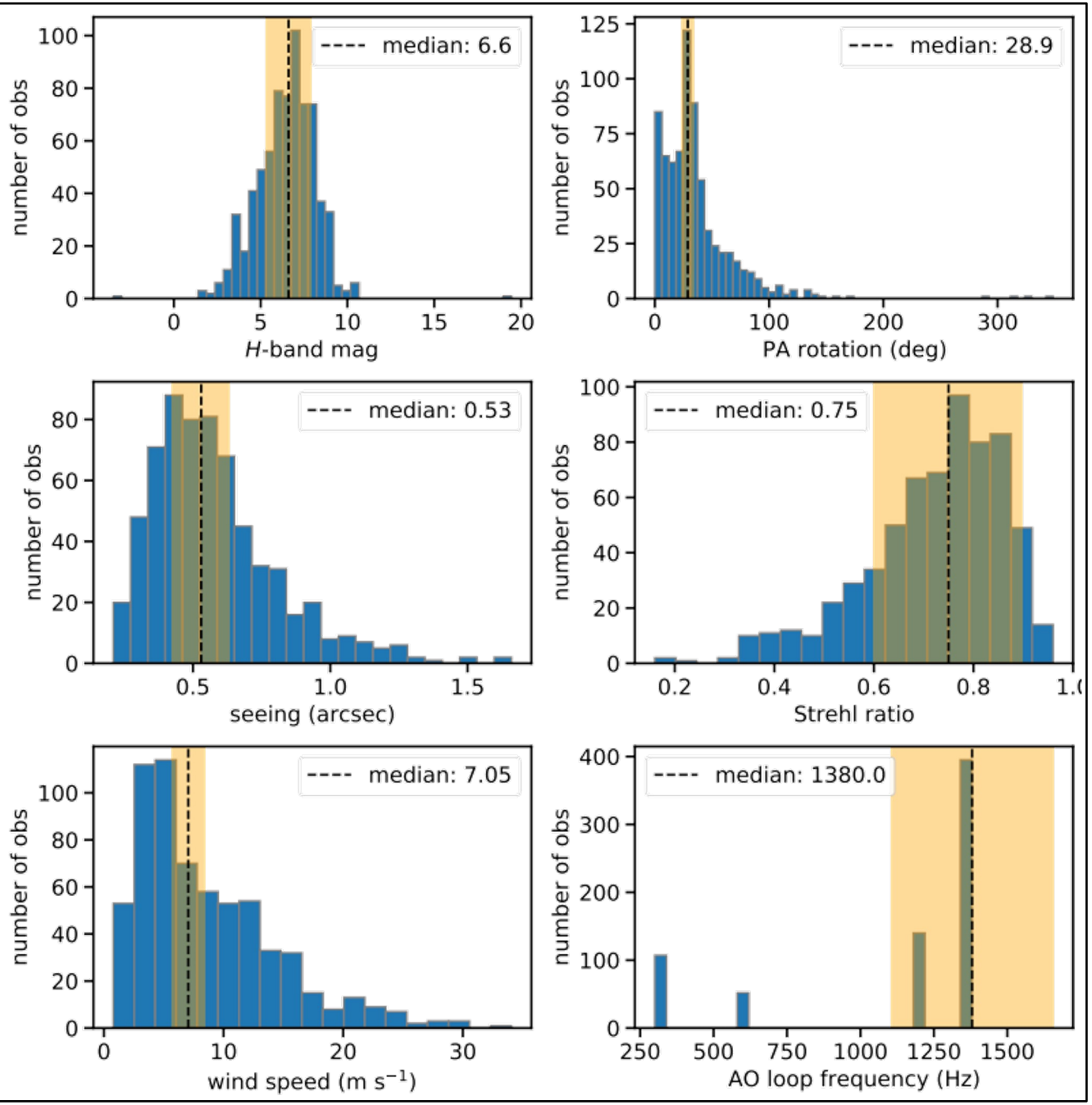
- For each science frame, an optimal reference library was constructed using the MSE between normalised science and reference frames.



Estimated photometric SNR of RDI reduction as a function of reference library size using three methods of frame selection (Ruane et al. 2019)

Target Sample

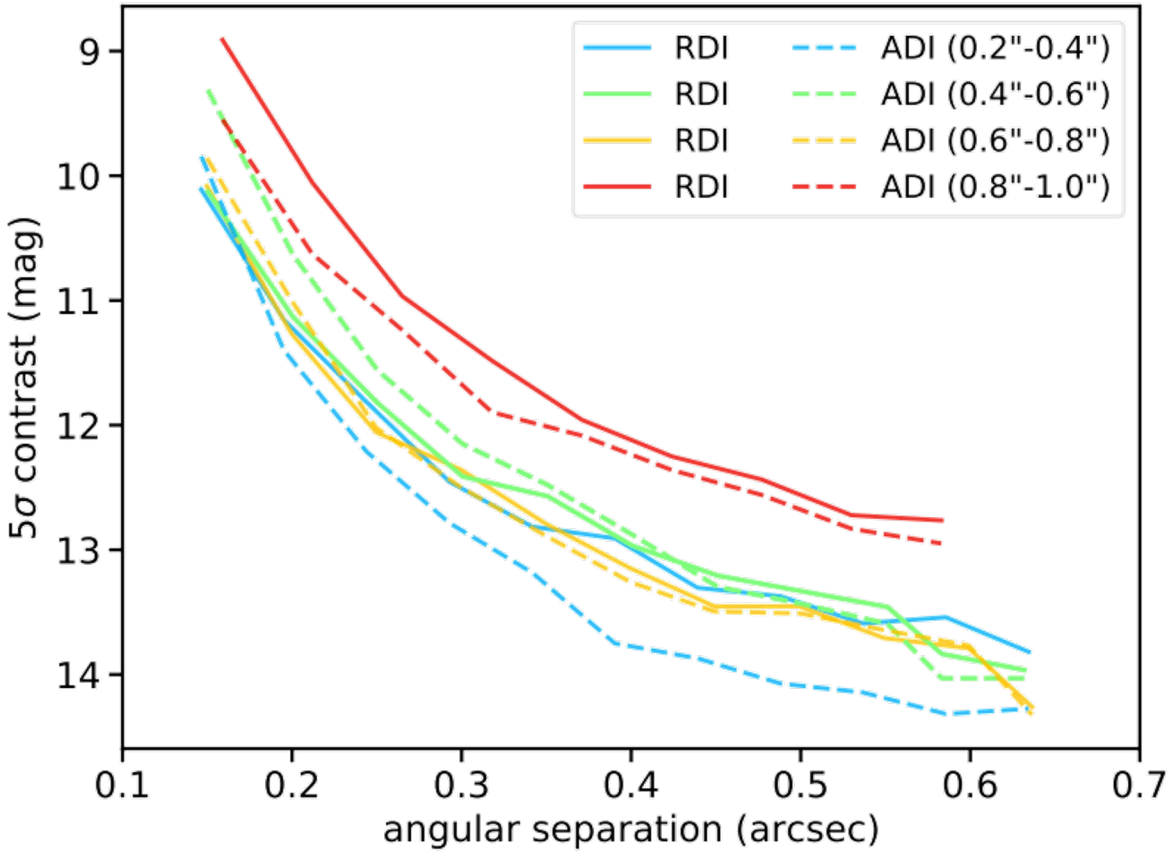
- A subsample of target observations from the master reference library were selected to explore the effect of seeing condition and PA rotation.
- Seeing conditions were explored in bins of 0.2”, 0.4”, 0.6”, 0.8”, and 1.0”, and PA rotation in bins of 5˚, 20˚, 30˚, 40˚, 60˚, and 80˚.
- Wind speed, Strehl ratio, H band magnitude, AO loop frequency, and the parameter (seeing or PA rotation) not being explored of selected targets were within 20% of the mean value for the master reference library.

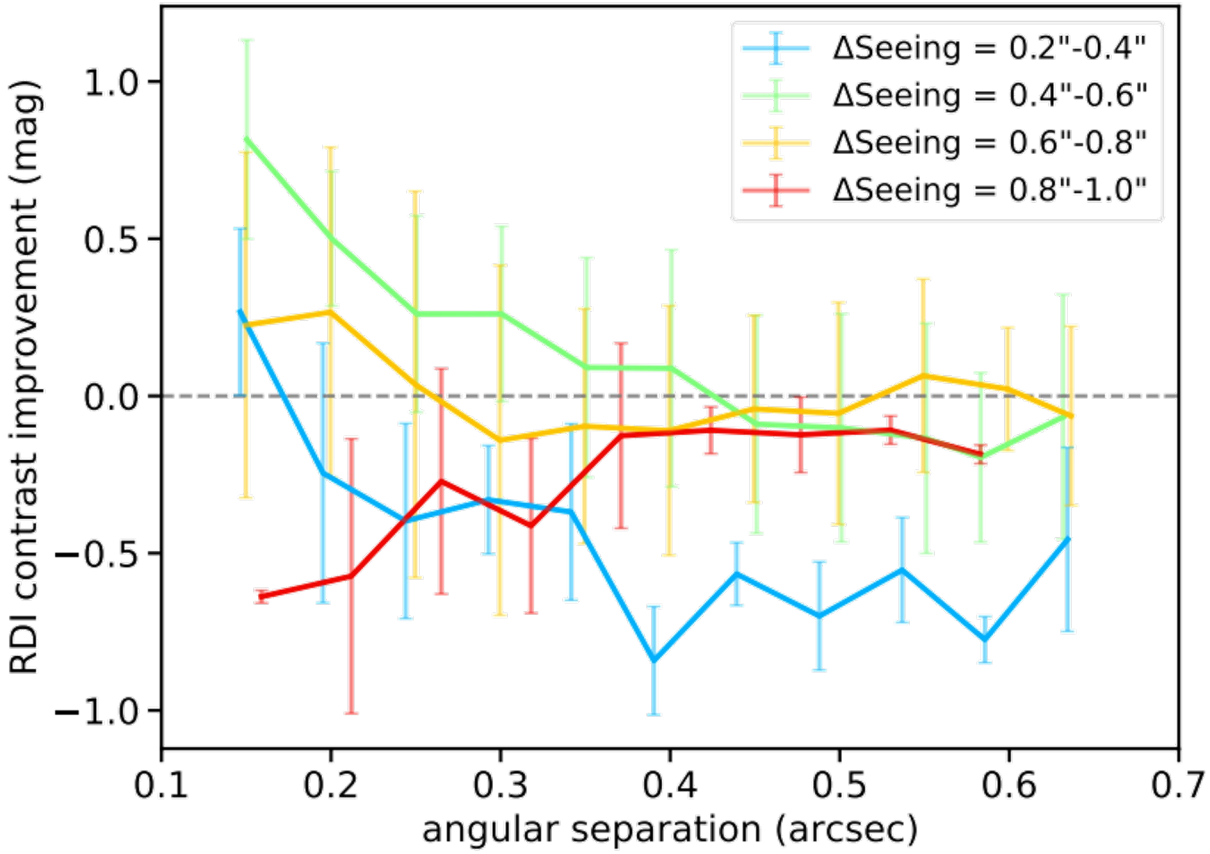


RDI PERFORMANCE: POINT-SOURCE DETECTION

RDI performance as a function of various parameters (where applicable; compared to ADI).

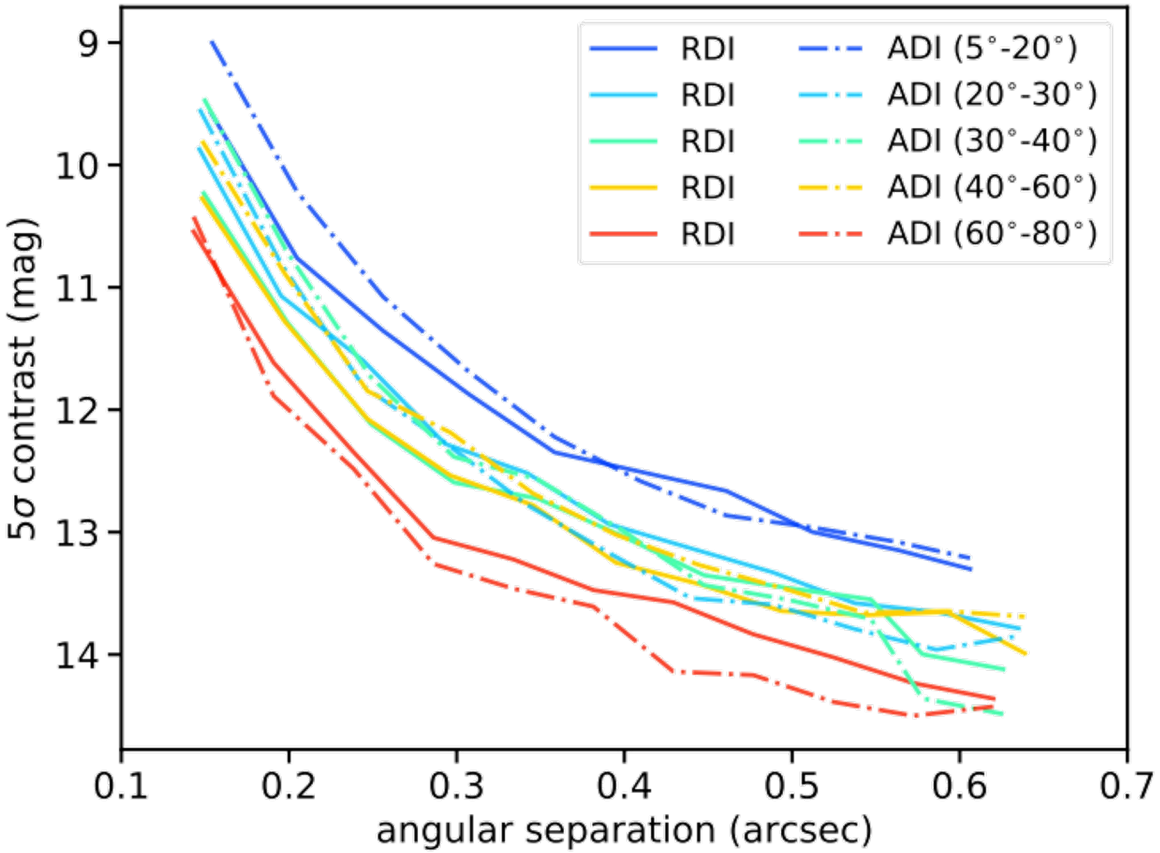
Seeing conditions

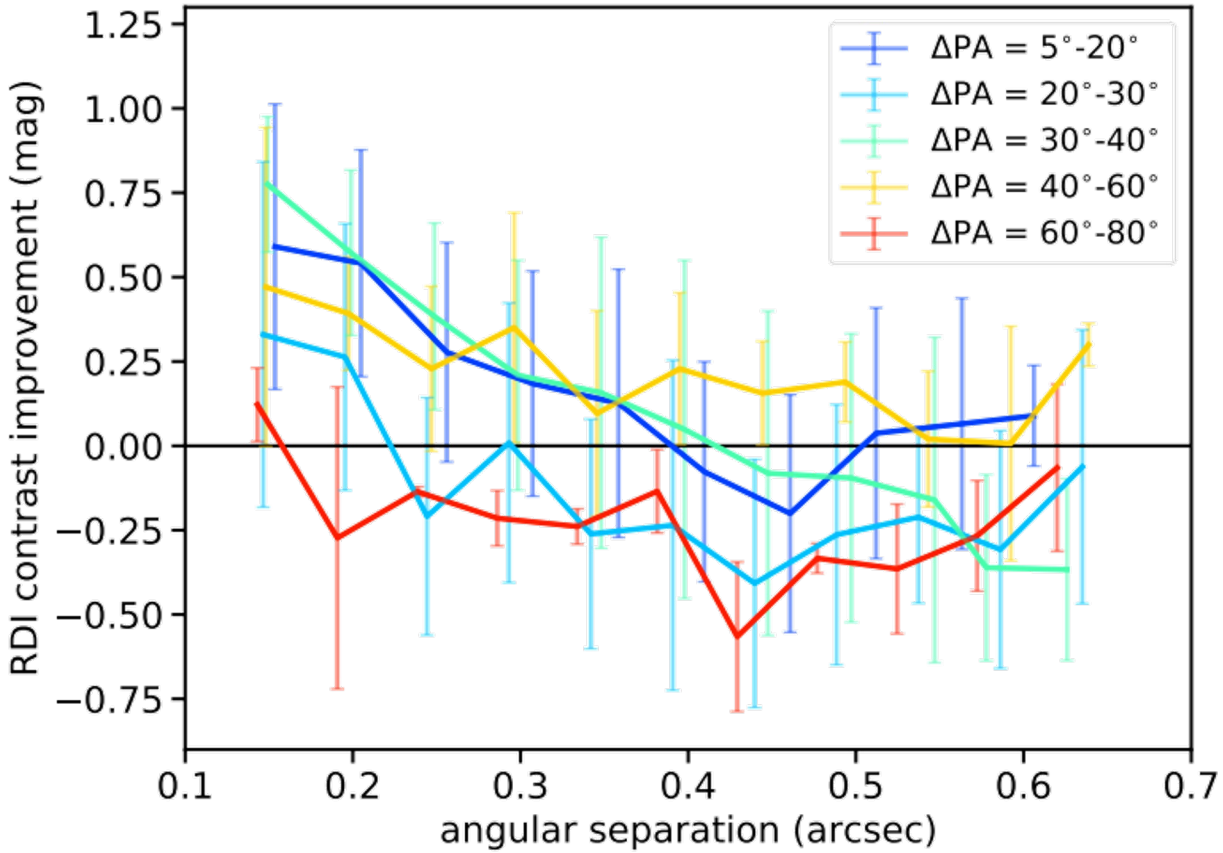




- RDI outperforms ADI at small separations (<0.4”) for observations with median seeing (0.4”-0.6”)
- For observations with extreme conditions (0.4”< seeing <0.8”), ADI outperforms RDI at almost all separations (fewer well matching reference images available for RDI)

PA rotation

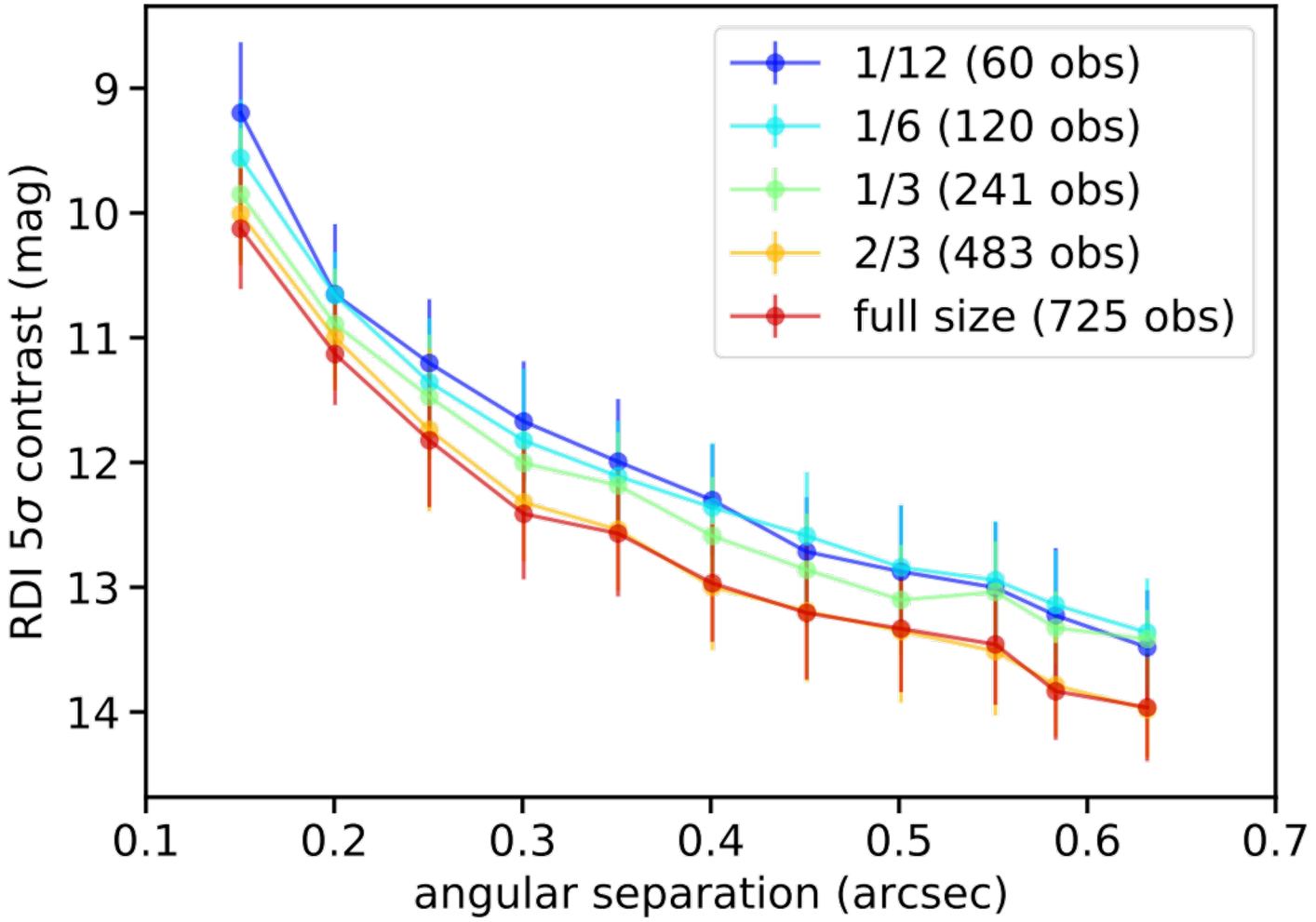




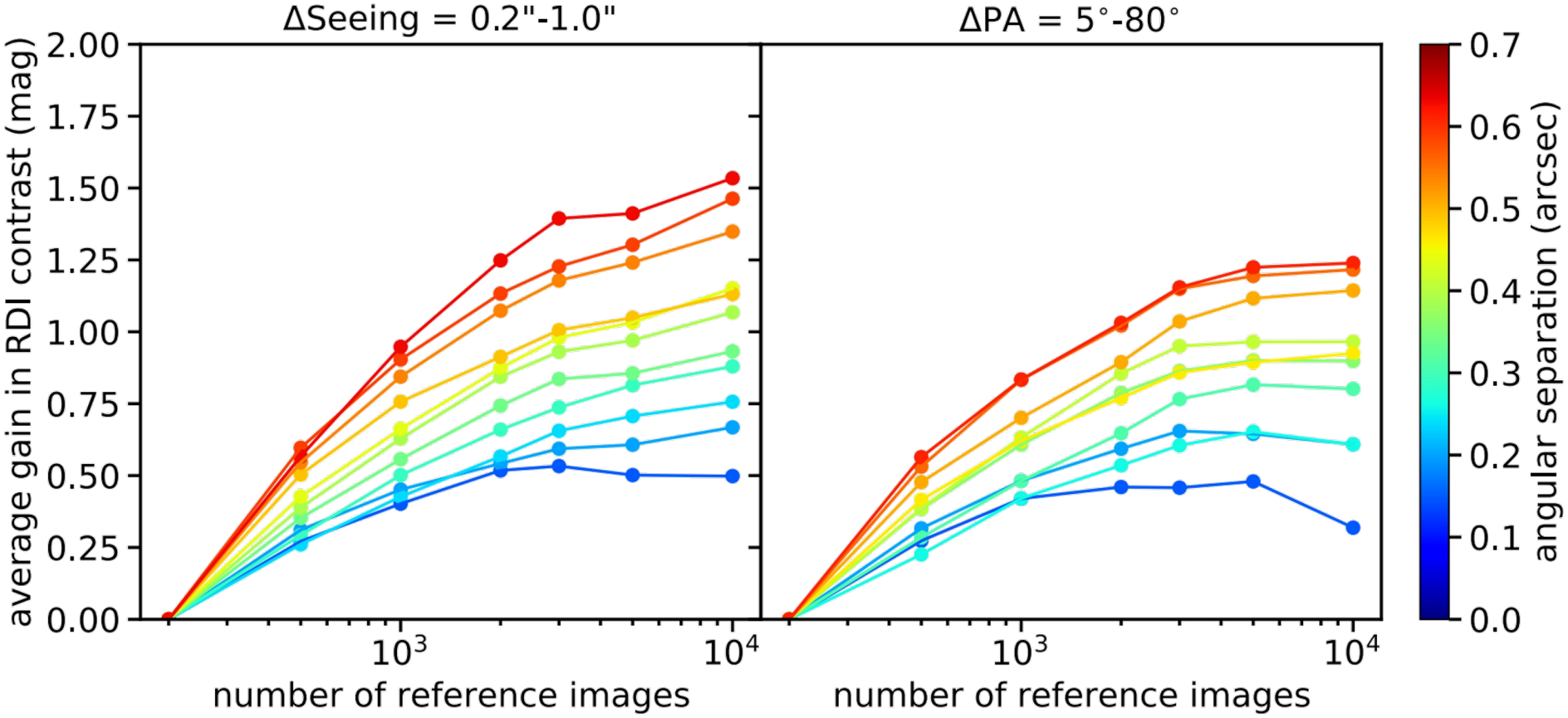
- Better contrast is achieved for observations with larger PA rotations with both RDI and ADI.
  - Observations with larger PA rotations tend to have longer exposure times and more science frames which leads to noise which is closer to a Gaussian distribution, and hence better contrast.
- RDI can mostly outperform ADI at small separations (<0.4") for PA rotations between 5˚- 60˚.

Master reference library

- Observations randomly extracted from the master reference library in different sized subsets.
- Larger sized libraries are statistically likely to contain more well matching reference frames, hence a better PCA subtraction and achieved contrast



Selected reference library

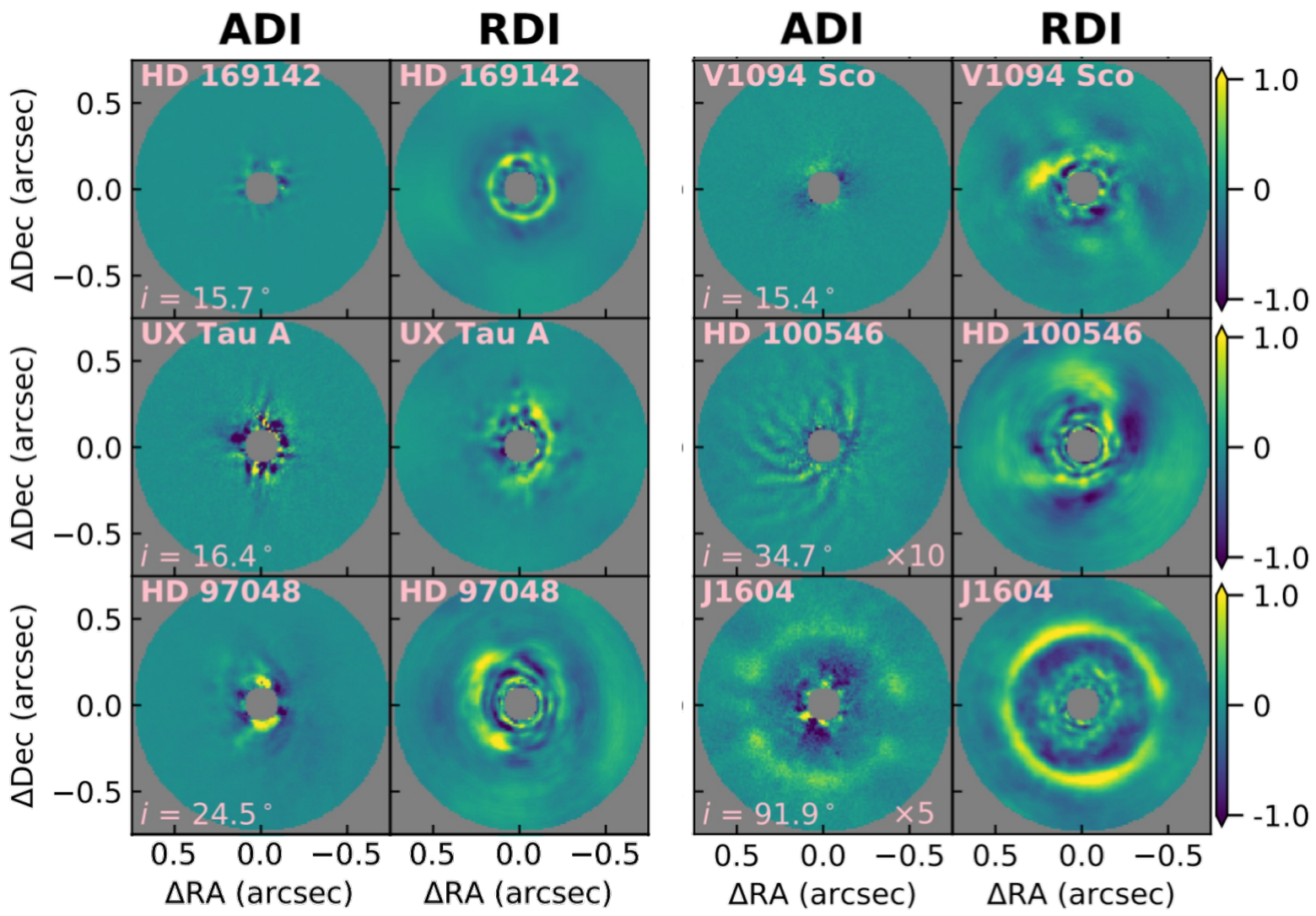


- Increasing the number of reference frames used in the PCA reduction improves the achieved contrast until ~3000-5000 frames. The inclusion of too many less correlated frames can worsen the contrast at short separations.
- The best correlation is achieved using only ~5% of the master reference library.

RDI PERFORMANCE: CIRCUMSTELLAR DISKS

Advantages of RDI over ADI for detection and characterisation of disks.

Disk detection



- 33 circumstellar disks were detected in total intensity in this study.
  - The disks of DG Tau A and HD 131488 were resolved in scattered light for the first time.
  - The disks of V1094 Sco, UX Tau A, and SZ Cha were most likely detected in total intensity for the first time.
- RDI provides a more robust detection of disk features which may be lost or altered due to self-subtraction with ADI.
- Unlike with ADI, disk features in RDI images were insensitive to increasing the number of PCs.
- RDI is more likely to detect ow inclination (<50°) disks which may be non-detections with ADI.
  - 4 of the 33 disks were only detected using RDI and not ADI.

Summary

- For small separations (<0.4”), RDI can outperform ADI for point-source detection given observations with median seeing (0.4-0.6”) and PA rotation <60°.
- The size of the master reference library plays a role in the contrast achieved, as a larger master library is statistically likely to have more well correlated reference images.
- Increasing the number of reference frames used in the RDI reduction improves the contrast until ~3000-5000 frames, after which it plateaus.
- RDI is capable of detecting disk features which may be biased or not detected due to self-subtraction with ADI.
- 33 circumstellar disks were detected; 4 disks with inclination <50° were only detected in RDI.