SAG19: Signal Detection Theory and Rigorous Performance Metrics for Exoplanet Imaging

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• Methods papers:
  – *Jensen-Clem et al. 2018*: letting the threshold hold change with separation to give the desired # of false positives
  – *Ruffio et al. submitted*: setting up a Bayesian framework for detection and non-detection

• Application papers:
  – *Ruane et al. 2017*: using varying thresholds to place mass upper limits on planets in the disk gaps of TW Hydra
  – *Mawet et al. submitted*: using the Bayesian framework to combine HCI and RV data to constrain the mass and orbital parameters of Eps Eri b

• The next step: data challenge!
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Bayesian upper limits for direct imaging

Jean-Baptiste Ruffio (Stanford University)
GPIES et al.
Consider a non-detection where the planet’s location is known

- Placing a “5σ” upper limit makes use of the noise at the planet’s separation, but not the realization at the planet’s exact location

- Instead, let’s place a Bayesian upper limit where the likelihood is a Gaussian centered on the observed flux at the planet’s location
\[ \mathcal{P}(\tilde{F}_x|F) \]

\[ \mathcal{P}(F|\tilde{F}_x) \]

\[ \tilde{f}_x = 0 \]

98%
\begin{align*}
\mathcal{P}(\tilde{f}_x | F) \\
\mathcal{P}(F | \tilde{f}_x)
\end{align*}

\(\tilde{f}_x = 3\)

98%
Bayesian upper limits for direct imaging

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The paper also covers scenarios in which the planet’s orbit is known, but not its precise location, as well as combining HCI and RV data (see also Mawet et al. submitted).
The exoplanet direct detection data challenge

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Context

- An **open-source** data challenge, welcoming broad participation
- Directly supported by the **Grenoble Alpes Data Institute** (France).
- **Feedback gathered** from a large team of researchers (O. Absil, JB. Ruffio, J. Wang, M. Bottom, D. Mawet, C. Marois, O. Guyon, D. Mouillet, others)
- See our website: [https://carlgogo.github.io/exoimaging_challenge/](https://carlgogo.github.io/exoimaging_challenge/).
- Workshop on “image processing for HCI” linked to the challenge.
Goals of the data challenge

- To benchmark image processing algorithms for exoplanet detection (extended structures are not included).
- Building a benchmark/standard library of HCI datasets.
- Agreeing on meaningful metrics for comparison and validation of current and new algorithms.
- Sharing knowledge, sparking collaborations.
Data sets

- Observing techniques: pupil tracking (ADI) and multispectral (ASDI).
- About 10 datasets (different targets) per HCI instrument.
- Several instruments: SPHERE, GPI, NACO, NIRC2, SCEXAO, NICI, others?
- 0 to 5 injected companions per dataset.
- Standard injection (no smearing, no variable photometry, etc).
Detection metrics

- Outputs: *detection maps* and critical thresholds
- Source counting by thresholding the detection map
- Receiver operating characteristic (ROC) curves
- Mapping the true positive rate vs # of false positives trade-off
- All at multiple separation regimes
Open questions

- Exact kick-off date (fall 2018)
- Exact detection metrics
- Optional submission of astrometry and photometry of companions
- Multispectral ASDI: real spectra or model for planet injection
- Storage solution for the HCI benchmark library
- Usage of metadata (atm. profiling, AO-telemetry, etc)
- Taking advantage of pre-constructed RDI libraries (e.g. GPI survey)
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• The next step: data challenge and close out