An Information Theoretic study of Optical Synthesis Imaging

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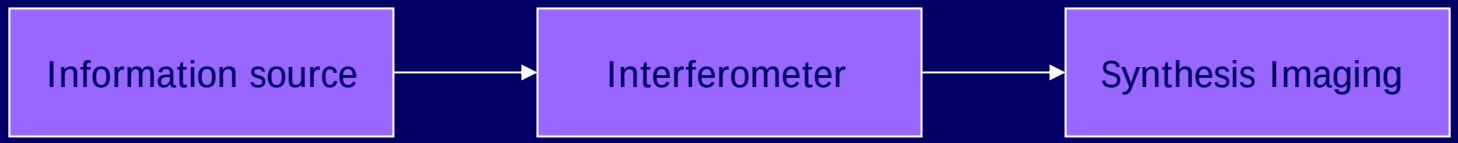
Synthesis Imaging as a Communication Channel

- Overview
  - Model as a communication channel (Shannon, 1948)



Class of objects
- Binary stars
- Stellar surfaces
- Circumstellar discs
- AGN

Information loss
- Limited UV coverage
- Photon counting noise
- detector noise
- calibration errors

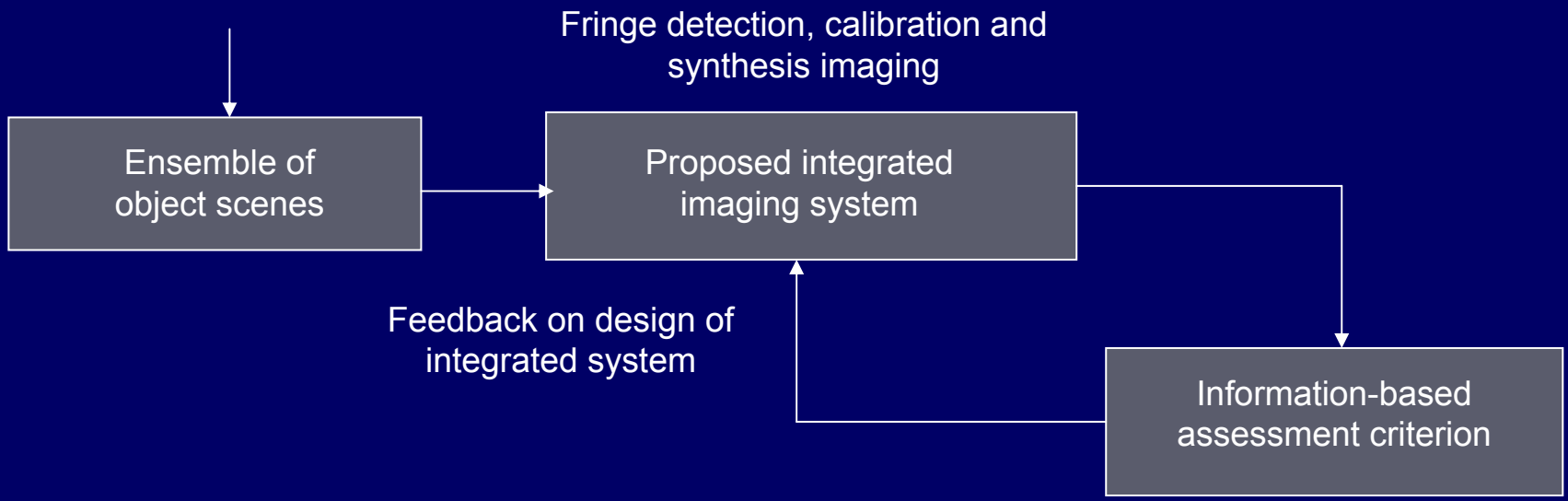
Information Gain
- closure phases
- self-calibration
- prior information from deconvolution MEM, CLEAN

- An interferometer is an Integrated Imaging System
  - Fringe measurement
  - Data Calibration
  - Synthesis imaging

- Information passed by system depends on each components

Motivation – Design of an Interferometer

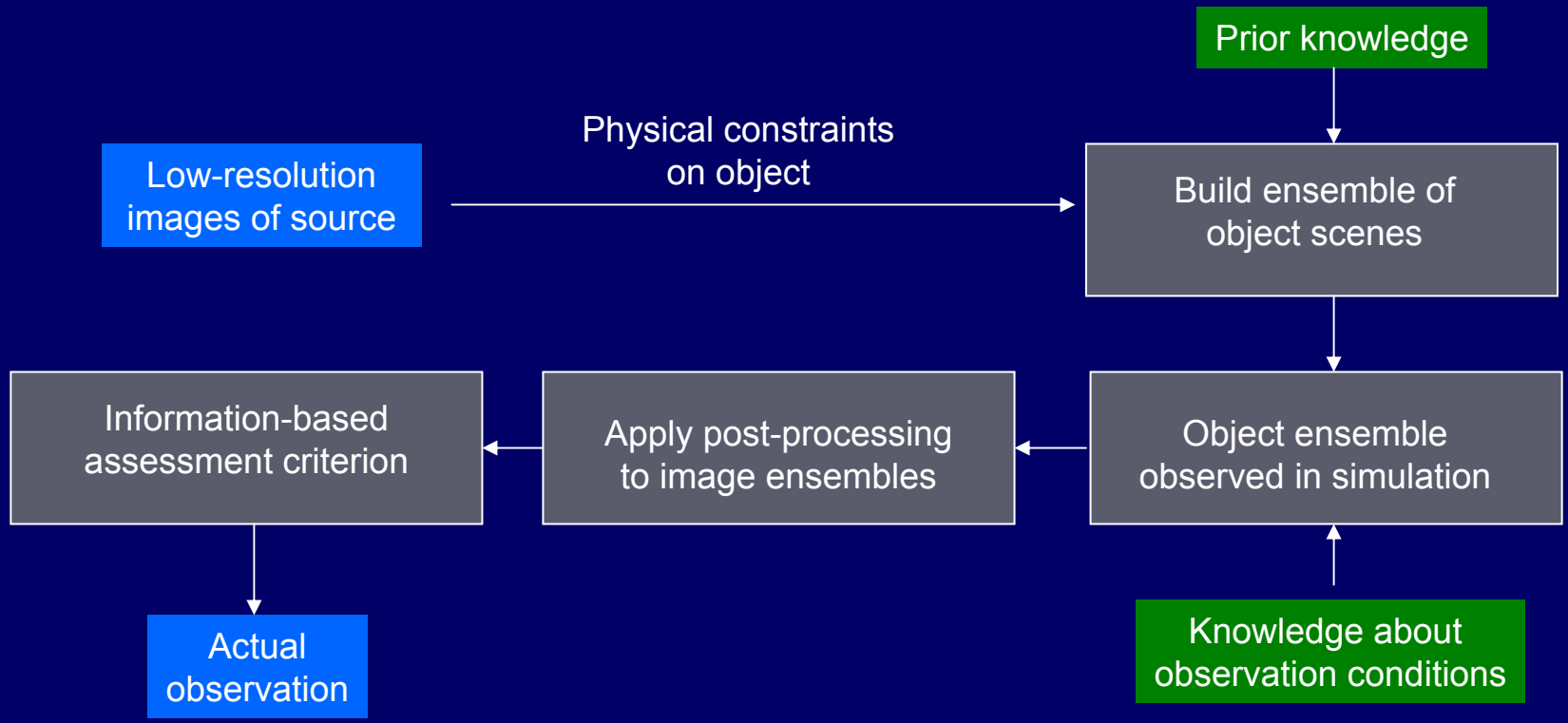
- Object class of interest
  - Binary stars
  - Stellar surfaces
  - Circumstellar discs
  - AGN and exo-plants



- Information metric – provides objective feedback
  - Fringe detection and synthesis imaging steps
  - System and post-processing can be optimized for a particular object class

Motivation – Assessment of Science Observations

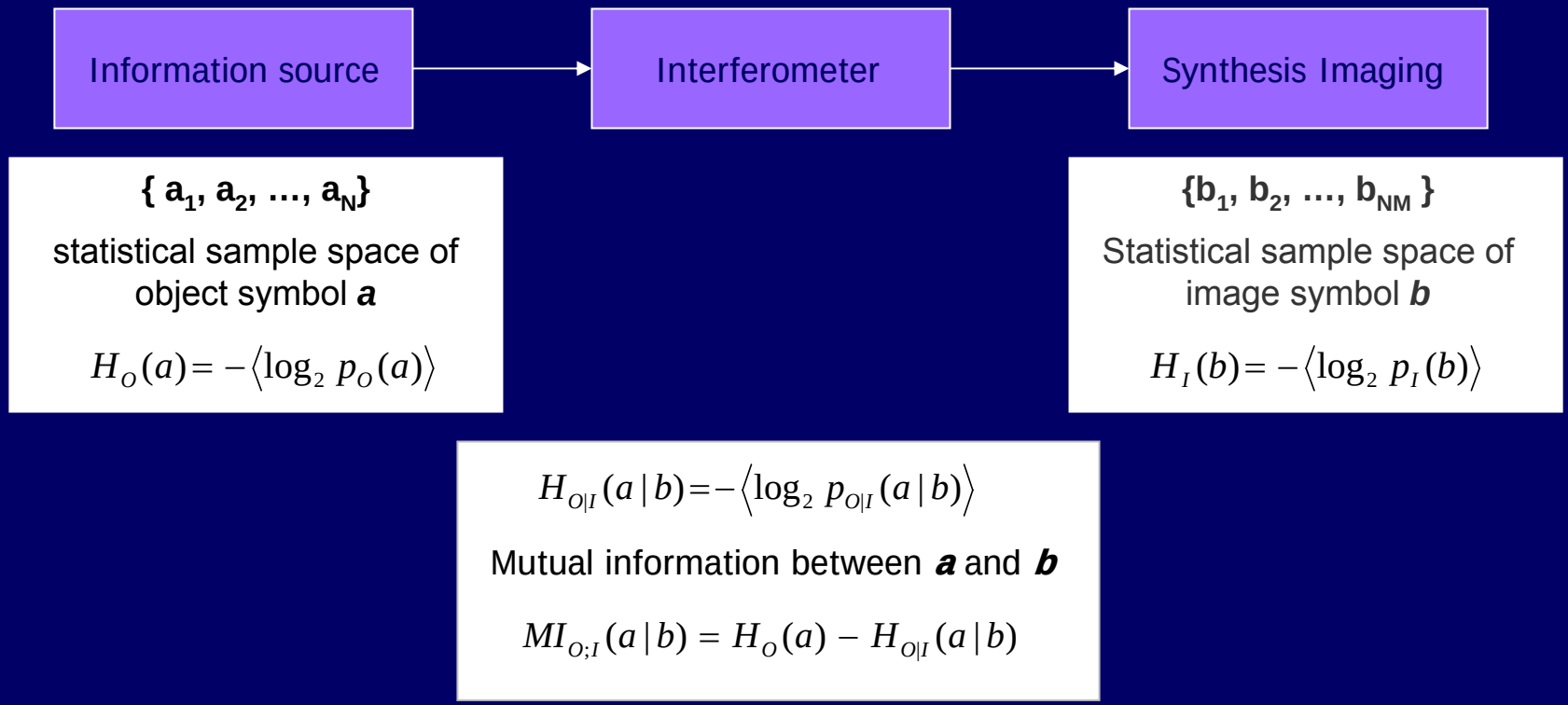
- Information metric is based on statistical prior knowledge



- Prior knowledge incorporated via the object ensemble
- Imaging process is simulated using actual observational conditions
- Supplements image post-processing

Synthesis Imaging as a Communication Channel

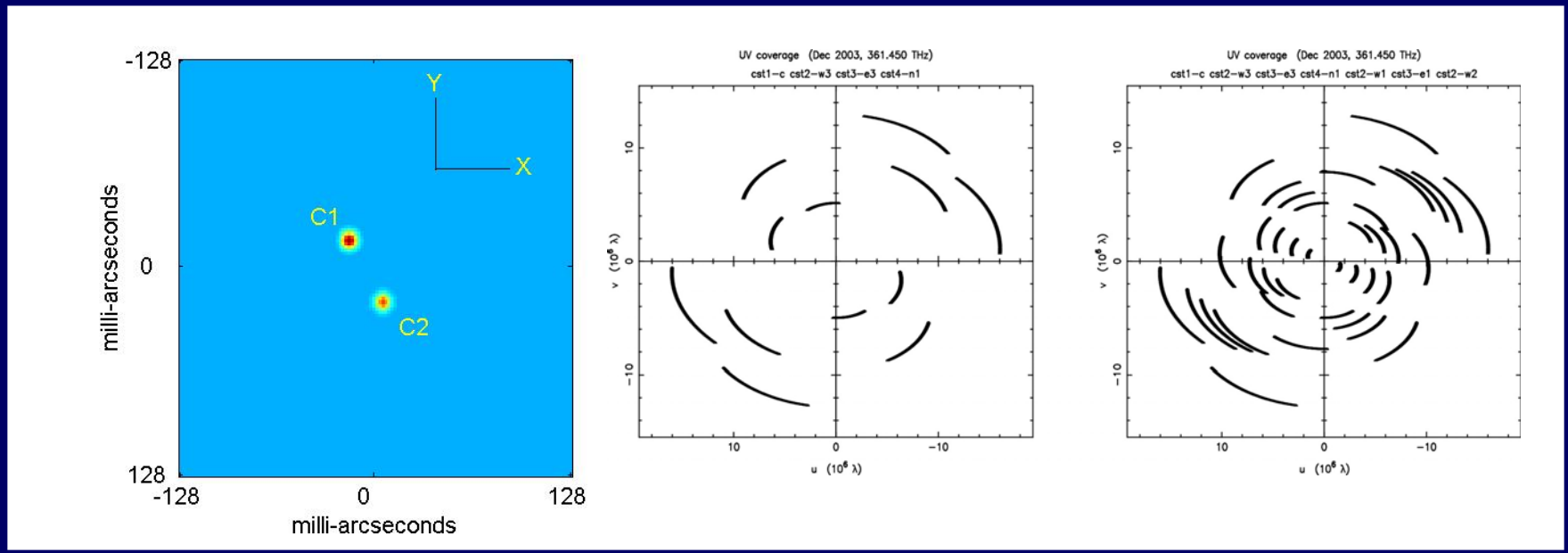
- Overview
  - Introduce object and image symbols



- Monitor MI at each step in self-calibration process

Information-based assessment of optical synthesis images

- Ensemble of binary stars
- Observed in simulation using two interferometer array configurations

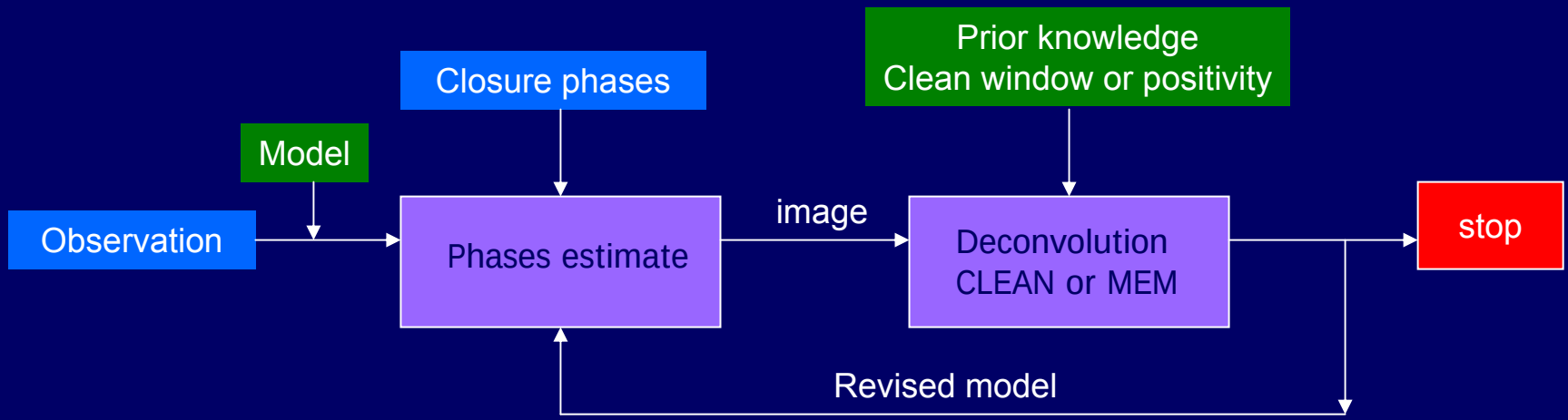


Information-based assessment of optical synthesis images

- Imaging using the Closure phases

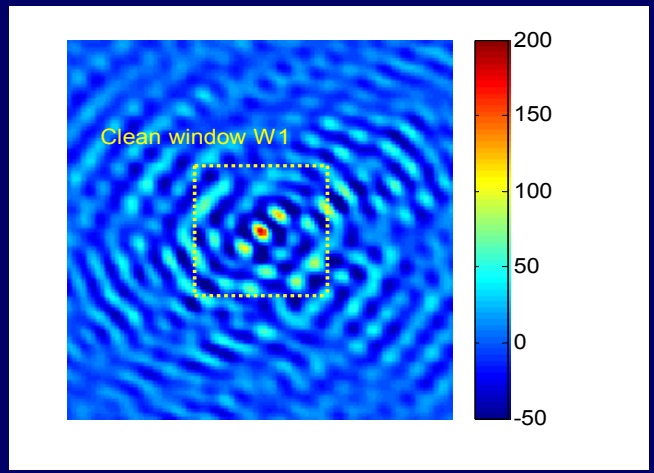
$$\begin{aligned}\psi_{ijk} &= \phi_{ij}^{obj} + \theta_i - \theta_j + \\ &\quad \phi_{jk}^{obj} + \theta_j - \theta_k + \\ &\quad \phi_{ki}^{obj} + \theta_k - \theta_i \\ &= \phi_{ij}^{obj} + \phi_{jk}^{obj} + \phi_{ki}^{obj}\end{aligned}$$

- Self-calibrate using closure phases and model phases



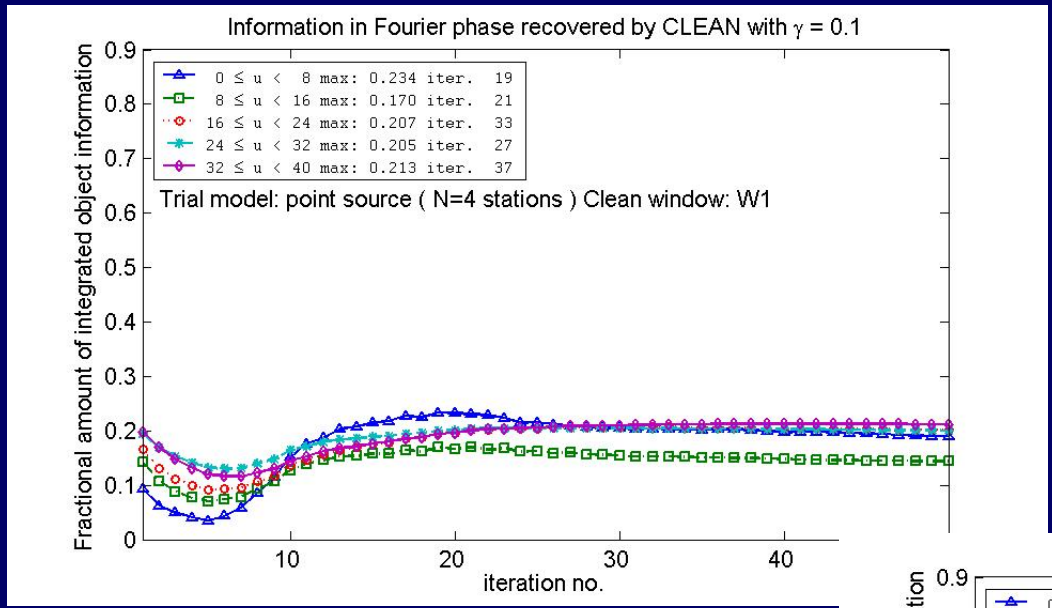
Information-based assessment of optical synthesis images

- Initial Model
  - Point source
  - Binary star
- UV coverage
  - N=4 apertures
  - N=7 apertures
- Deconvolution using CLEAN algorithm
- Effect of CLEAN windows on Information recovery
  - W1 – window around sources
  - W2 – window around each source

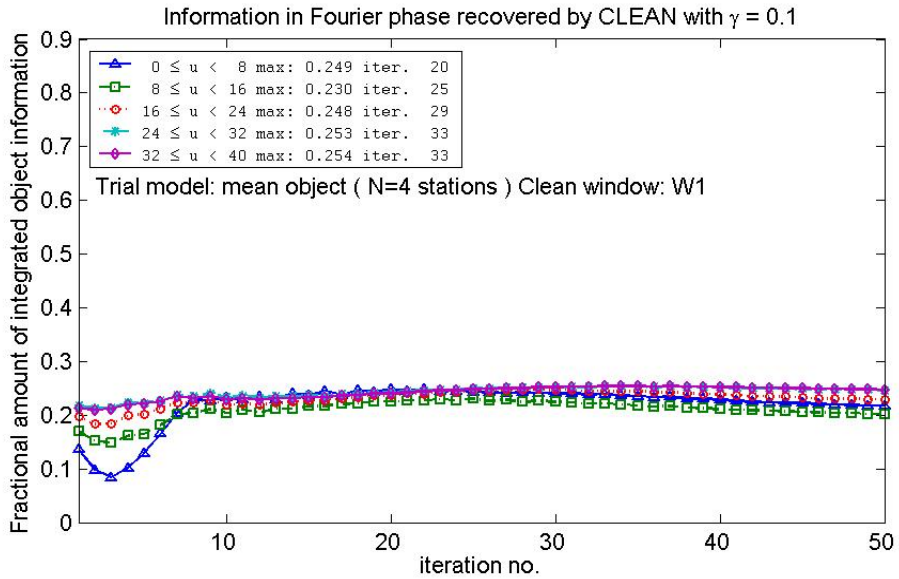


Information-based assessment of optical synthesis images

- Effect of Initial model on self-calibration
  - Object and image symbols are the Fourier phase (computed in frequency bands)

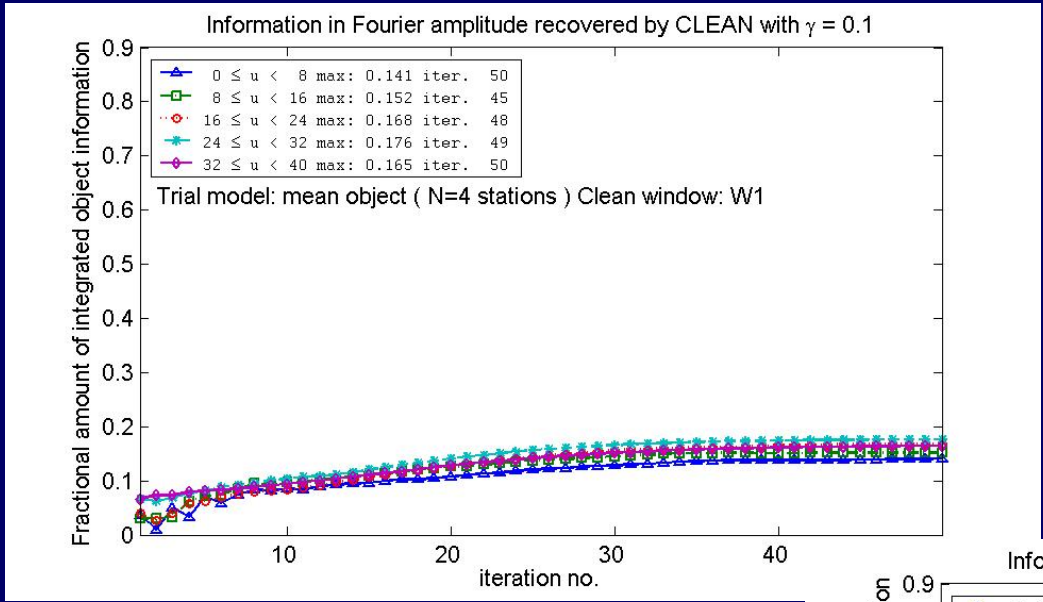


- Competition between phase information from the model and the closure phases
- Closure phases do not constrain the absolute position of the source
- Better initial model means more information recovery

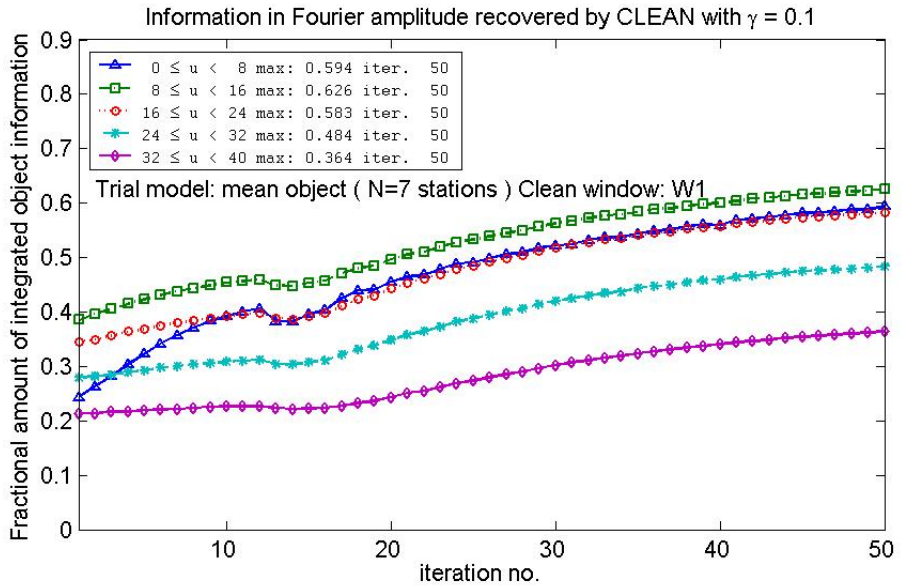


Information-based assessment of optical synthesis images

- Effect of UV coverage on information recovery

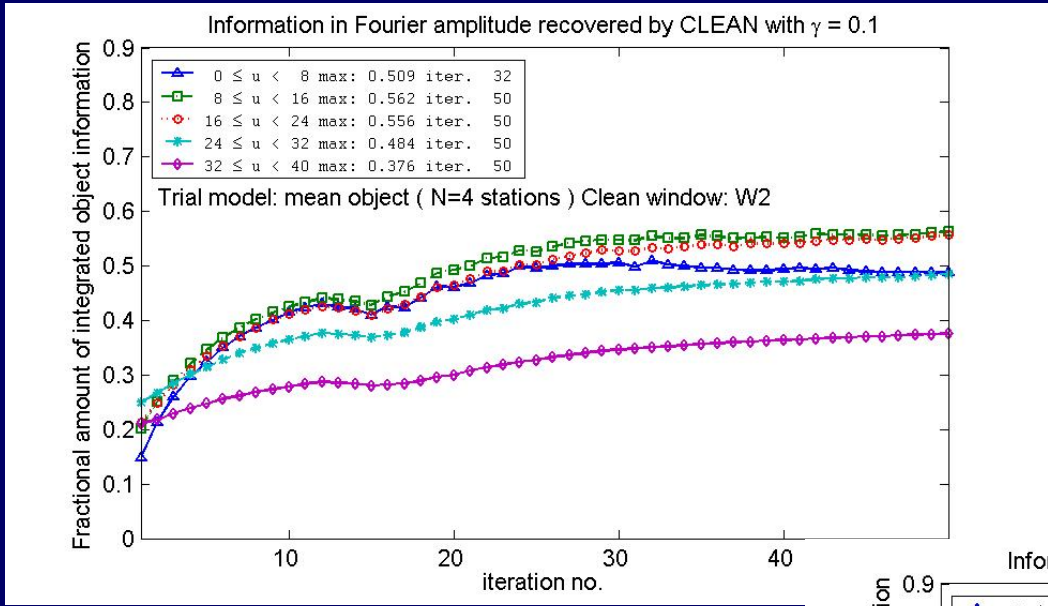


- Left: N=4 stations using W1
- Bottom: N=7 stations using W1
- MI recovered increases as UV coverage increases
- Appearance of noise-induced artifacts enhance discrimination ability – occurs at about iteration 15

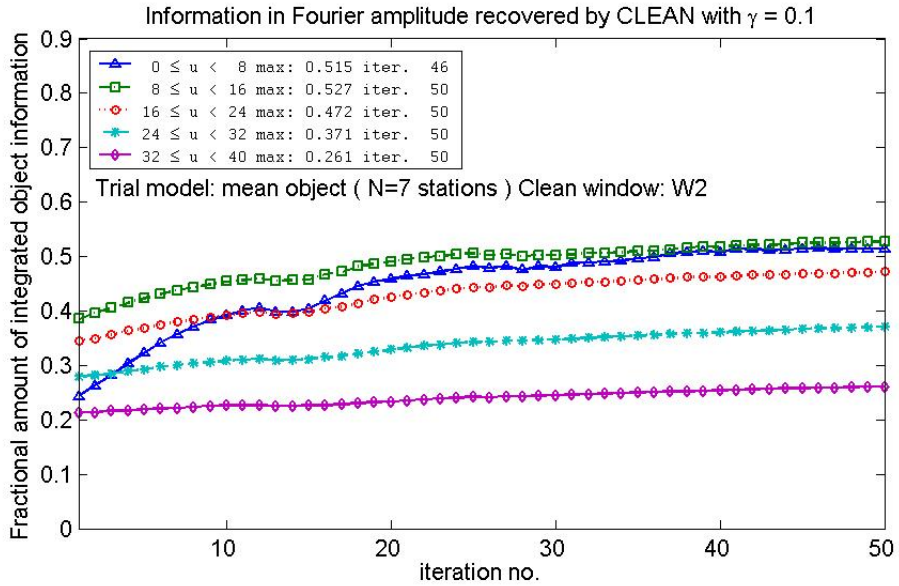


Information-based assessment of optical synthesis images

- Effect of CLEAN windows on information recovery



- Left: N=4 stations using tight CLEAN window around sources
- Below: N=7 stations using larger CLEAN window (weaker constraint) results in a smaller amount of information recovery
- Strong prior knowledge can compensate for limited UV-coverage



Summary and Conclusions

- Interferometer was modeled as a communication channel
- Mutual information
  - Objective metric based on prior knowledge
  - Can be used as a form of feedback on synthesis imaging
- How do aspects of self-calibration affect information recovery
  - Choice of initial model
    - Better choice implies more information recovery
  - UV coverage
    - More coverage results in more information recovery
  - CLEAN windows
    - Strong prior knowledge can compensate for limited UV-coverage
- Configure and optimize the instrument for a particular object class
  - UV-coverage
  - Self-calibration process