Simulated Observations of Planet Formation with MROI

CAVENDISH ASTROPHYSICS

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ABSTRACT

We present simulated observations of protostars undergoing planet formation with the Magdalena Ridge Observatory Interferometer (MROI). The MROI [1] is a ten-telescope optical/near-IR interferometer currently under construction at a 10,000-feet altitude site in New Mexico. First fringes are expected in 2011. The MROI will offer the UK community a unique capability to perform model-independent near-infrared imaging on sub-milli-arcsecond scales. We show that the detection of gaps in the inner circumstellar disk is feasible with MROI using its phase 1 complement of six telescopes.

INTRODUCTION

A key component of the MROI science case is the characterization of protostellar disks in the near-infrared, including imaging of disk structures such as gaps due to forming planets.

Recent observational evidence supports flared disk models, both for Herbig Ae/Be [2], and more tentatively for T Tauri stars [3], rather than the geometrically flat disks common in earlier literature (Fig. 1). The flared disk models imply that most of the near-infrared continuum emission comes from a narrow annulus close to the dust sublimation radius. The consequent high contrast between the inner and outer disk (and even higher contrast between the central star and outer disk) makes detection of gaps very challenging.

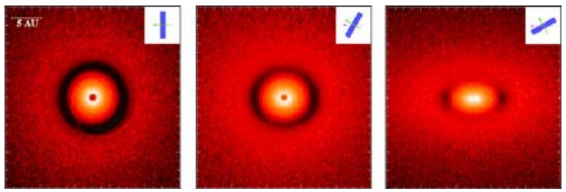

Figure 1:Figure from Wolf et al. [4], showing radiative transfer images of a protoplanetary disk at 700 µm wavelength derived from hydrodynamical simulations of a geometrically flat disk. A Jupiter-mass planet is orbiting at 5.2 AU from a solar-mass protostar.

References

[1] Creech-Eakman, M.J. et al., Proc. SPIE 7013, 70130X (2008).

[2] Millan-Gabet, R., et al. in Protostars and Planets V, ed. B. Reipurth et al., 539 (2007).

[3] Pinte, C., Ménard, F., Berger, J.P., Benisty, M., Malbet, F., ApJ 673, L63 (2008).

[4] Wolf, S., Gueth, S., Henning, T., Kley, W., ApJ 566, L97 (2002).

[5] Varniere, P., Quillen, A. C., Frank, A., ApJ 612, 1152 (2004).

[6] Pauls, T. A., Young, J. S., Cotton, W. D., Monnier, J. D., PASP 17, 1255 (2005).

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[8] Monnier, J.D., Millan-Gabet, R., ApJ 579, 694 (2002).

SIMULATED OBSERVATIONS

The NIR continuum emission from a Herbig Ae/Be star was modelled as a point source surrounded by a face-on disk, with a central cavity representing the dust sublimation region. Various ad-hoc power laws for the radial fall-off of disk intensity were adopted. A dark gap of width 0.7 AU was superimposed, as might be caused by a ~Jupiter-mass planet [5].

Simulated datasets in OIFITS format [6] were prepared by evaluating the discrete Fourier transform of the model image at spatial frequencies corresponding to the measured projected baselines, converting to optical interferometric observables (squared visibilities and bispectra), and adding Gaussian noise appropriate for bright (K ~ 5) targets. The YSO was assumed to be in the Taurus star forming region, and its brightness distribution was assumed wavelength-independent over the K band.

These simulated datasets were used as input to the BSMEM maximum entropy imaging code [7]. A point source default image was used. Further details of the simulations are given in the following table.

Parameter	Value	Note
MROI latitude	+33.98°	
No. of unit telescopes	6	Stations W0 W1 W4 N1 N3 S2
Baseline range	7.5–32 m	λ/B_{max} = 14mas; See Fig. 2
Spectral resolution	30	7 spectral channels in K
Calibration error	$\Delta V/V$=0.02	Assumed uncorrelated
Target declination	+25°	
Disk inner radius	0.5 AU (3.5 mas)	e.g. [8]
Gap radius	2.1 AU (15 mas)	
Gap width	0.7 AU (5 mas)	
Disk flux/star flux	3.35	[3]

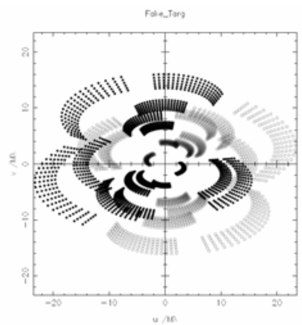

Figure 2: Fourier plane coverage of the simulated observations. A six hour observation duration was assumed, with a set of 42 visibility amplitude and 70 closure phase measurements captured every twenty minutes.

RESULTS & DISCUSSION

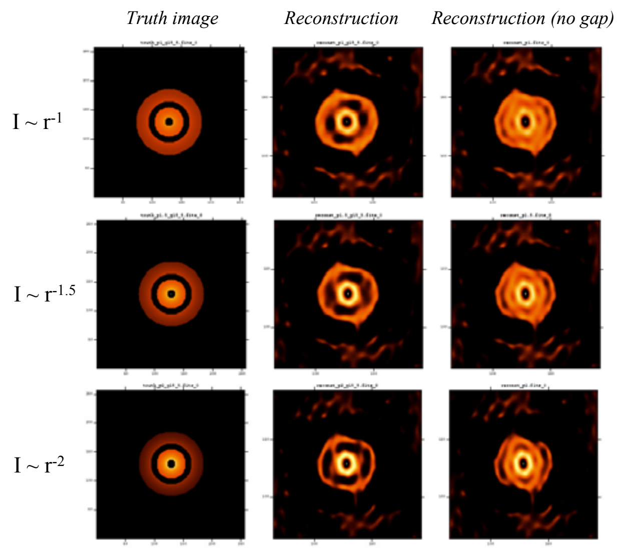

Figure 3: From left to right, the model image with a 0.7 AU gap, the reconstructed image, and an image reconstructed from an otherwise-identical model with no gap. Each row shows results for a different assumed disk radial brightness distribution. The colour scale is logarithmic, and covers only the range of intensities in the disk. The central point source is actually ~130 times brighter than the brightest pixels in the disk in the reconstructed images.

The dynamic range in the reconstructed images (Fig. 3) is excellent at ~1000:1. A degree of super-resolution has been obtained, as demonstrated by the resolution of the 7mas-diameter inner cavity. There is a clear difference between the reconstructed images for disks with and without a gap. For the cases presented here, the presence of a gap can be inferred straightforwardly from the reconstructed image.

The availability of 10 telescopes in the second phase of MROI will allow images with a wider range of spatial scales to be reconstructed, with greater potential for discerning structures at 5–10 AU radius.

CONCLUSIONS

•Imaging of gaps in the inner protoplanetary disk with MROI is feasible

•Detection depends critically on disk radial brightness function and radial location of gap

•Further simulations using physical models are needed

•ALMA is complementary to MROI for this application; MROI suited for inner-disk gap detection, ALMA for outer disk