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Observing protoplanetary discs with the Square Kilometre Array – I. Characterizing pebble substructure caused by forming planets

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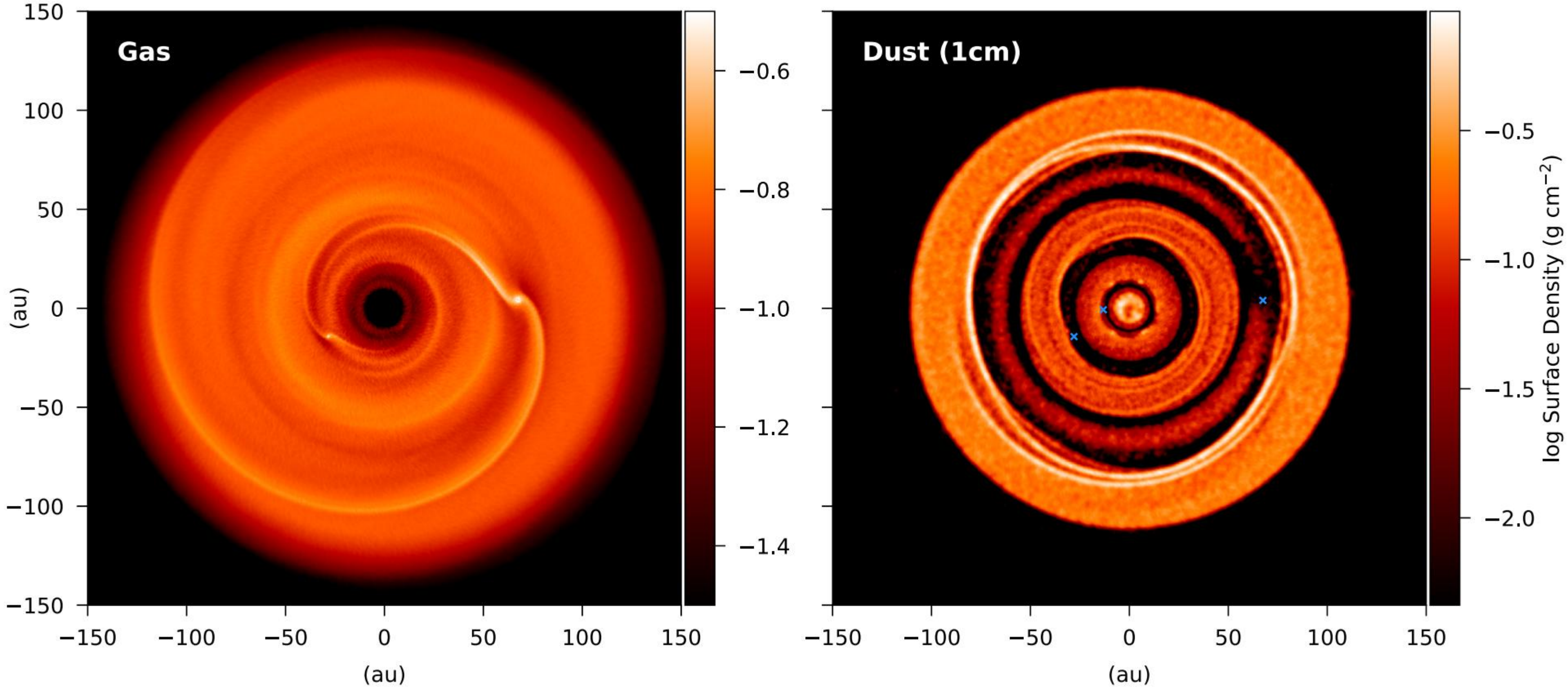
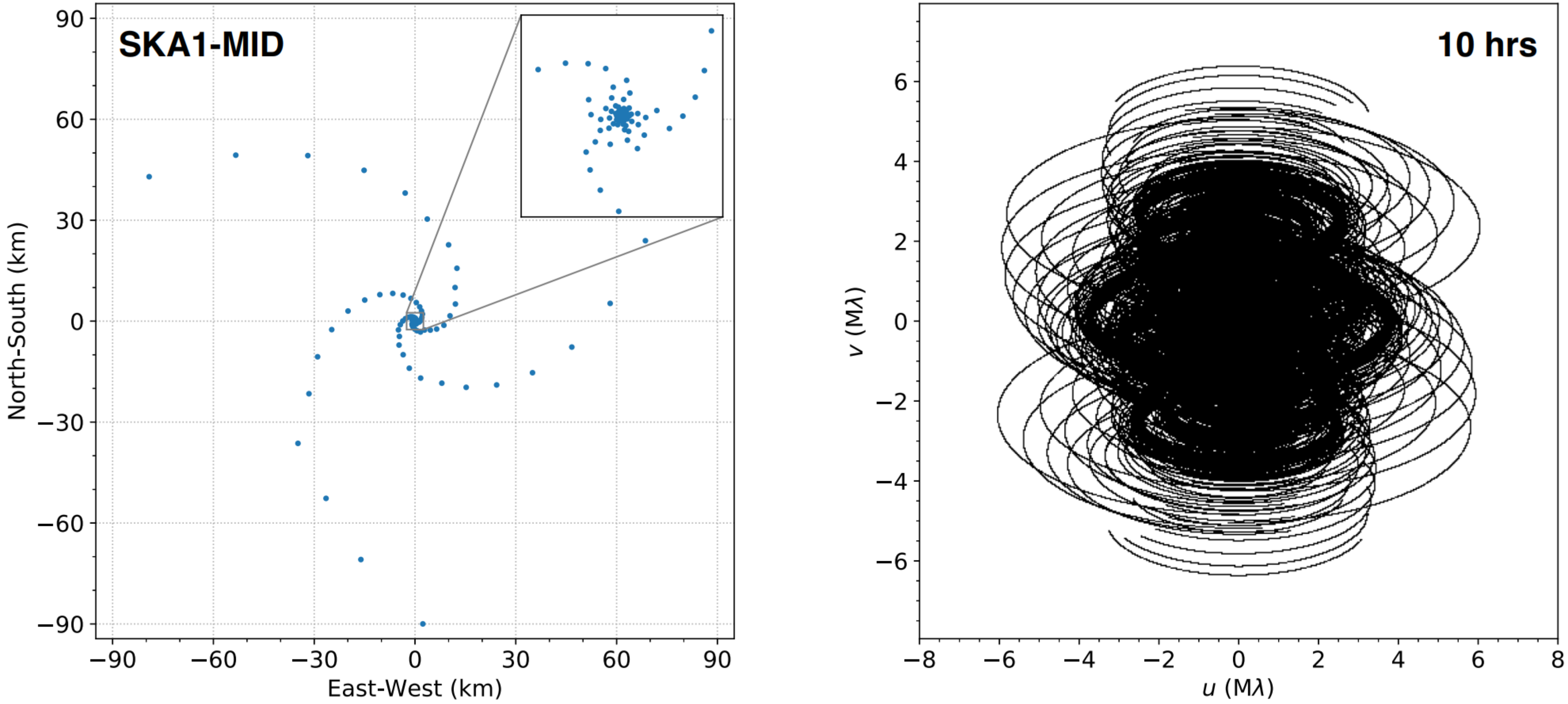
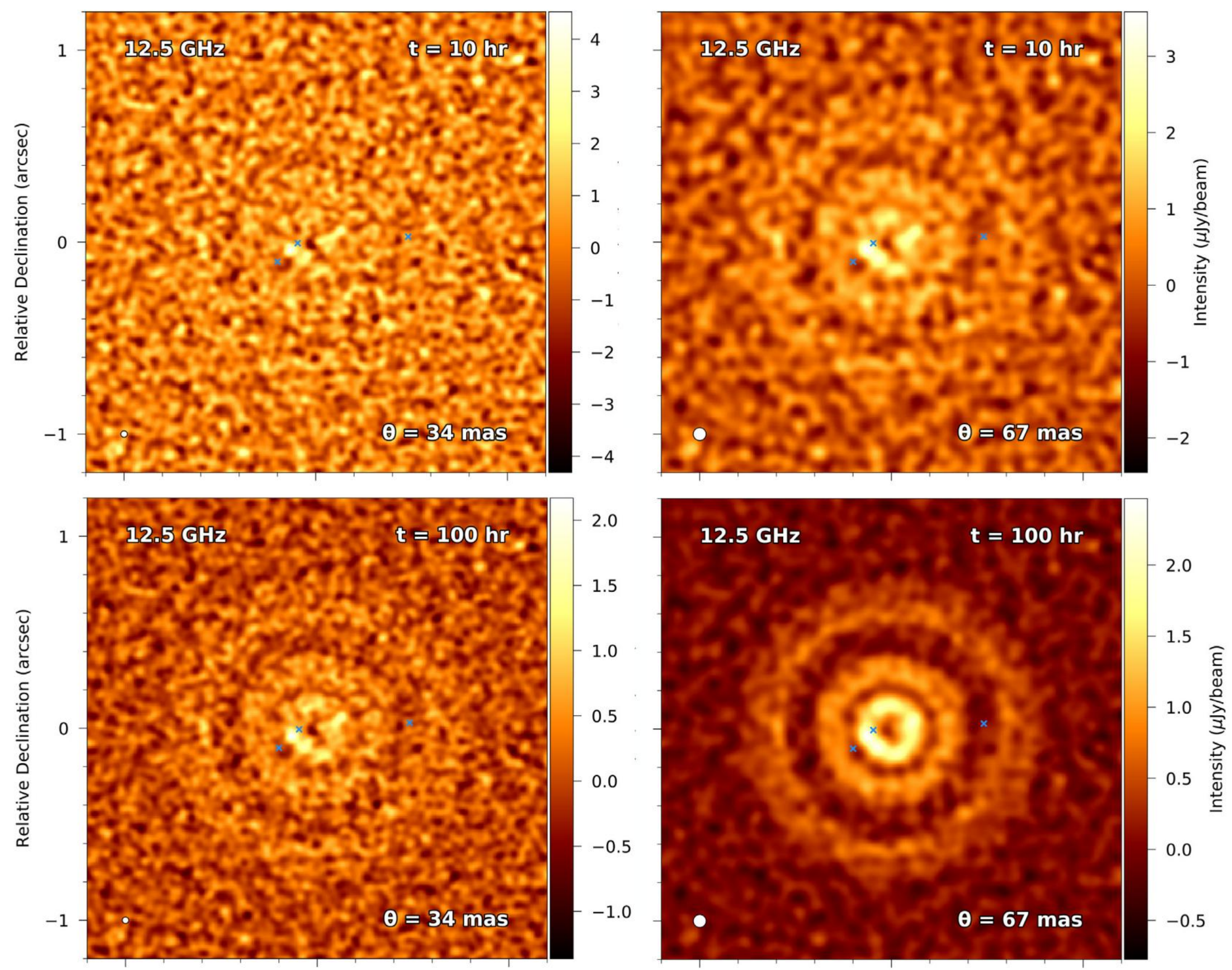


1.e6 SPH particles, and 2.5e5 dust particles
20 orbital periods for the outermost planet (~ 12000 yr)
0.20/0.25/0.55 MJ
13.2/32.3/68.8 au

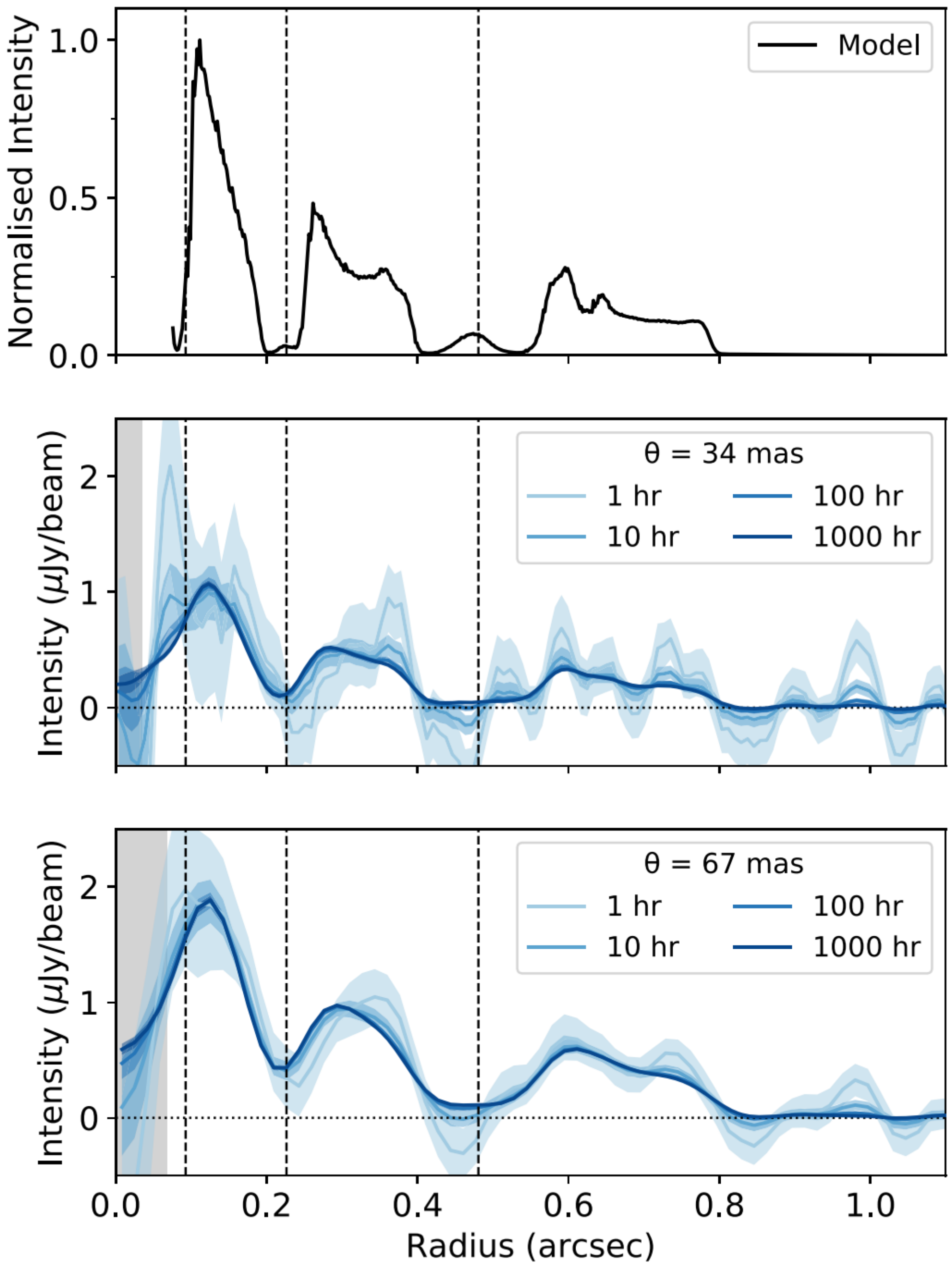


AA4, 133 dishes

Frequency ν (GHz)	Angular resolution θ (mas)	Sensitivity σ_{c} (μJy beam^{-1})	Visibility noise σ_{v} (mJy)
12.5	34	2.4	0.56
12.5	67	1.2	0.28



12.5 GHz
t = 10 hr
θ = 34 mas
12.5 GHz
t = 10 hr
θ = 67 mas
12.5 GHz
t = 100 hr
θ = 34 mas
12.5 GHz
t = 100 hr
θ = 67 mas
Relative Declination (arcsec)
Intensity (μJy/beam)



Normalised Intensity
Model
Intensity (μJy/beam)
θ = 34 mas
1 hr
10 hr
100 hr
1000 hr
θ = 67 mas
Radius (arcsec)
0.0
0.2
0.4
0.6
0.8
1.0
0.5
2
1
0

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Observability of Substructures in the Planet-forming Disk in the (Sub)centimeter Wavelength with SKA and ngVLA

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Abstract

Current imaging observations of protoplanetary disks using the Atacama Large Millimeter/submillimeter Array (ALMA) primarily focus on the submillimeter wavelength, leaving a gap in effective observational approaches for centimeter-sized dust, which is crucial to the issue of planet formation. The forthcoming Square Kilometre Array (SKA) and ngVLA may rectify this deficiency. In this paper, we employ multifluid hydrodynamic numerical simulations and radiative transfer calculations to investigate the potential of SKA1-Mid, ngVLA, and SKA2 for imaging protoplanetary disks at subcentimeter/centimeter wavelengths. We create mock images with ALMA/SKA/ngVLA at multiwavelengths based on the hydrodynamical simulation output and test different sensitivity and spatial resolutions. We discover that both SKA and ngVLA will serve as excellent supplements to the existing observational range of ALMA, and their high resolution enables them to image substructures in the disk's inner region (∼5 au from the stellar). Our results indicate that SKA and ngVLA can be utilized for more extended monitoring programs in the centimeter wave band. While in the subcentimeter range, ngVLA possesses the capability to produce high-fidelity images within shorter observation times (∼1 hr on source time) than previous research, holding potential for future survey observations. We also discuss for the first time the potential of SKA2 for observing protoplanetary disks at a 0.7 cm wavelength.

Unified Astronomy Thesaurus concepts: Protoplanetary disks (1300); Planet formation (1241); Hydrodynamics (1963); Astronomical simulations (1857); Astrophysical fluid dynamics (101)

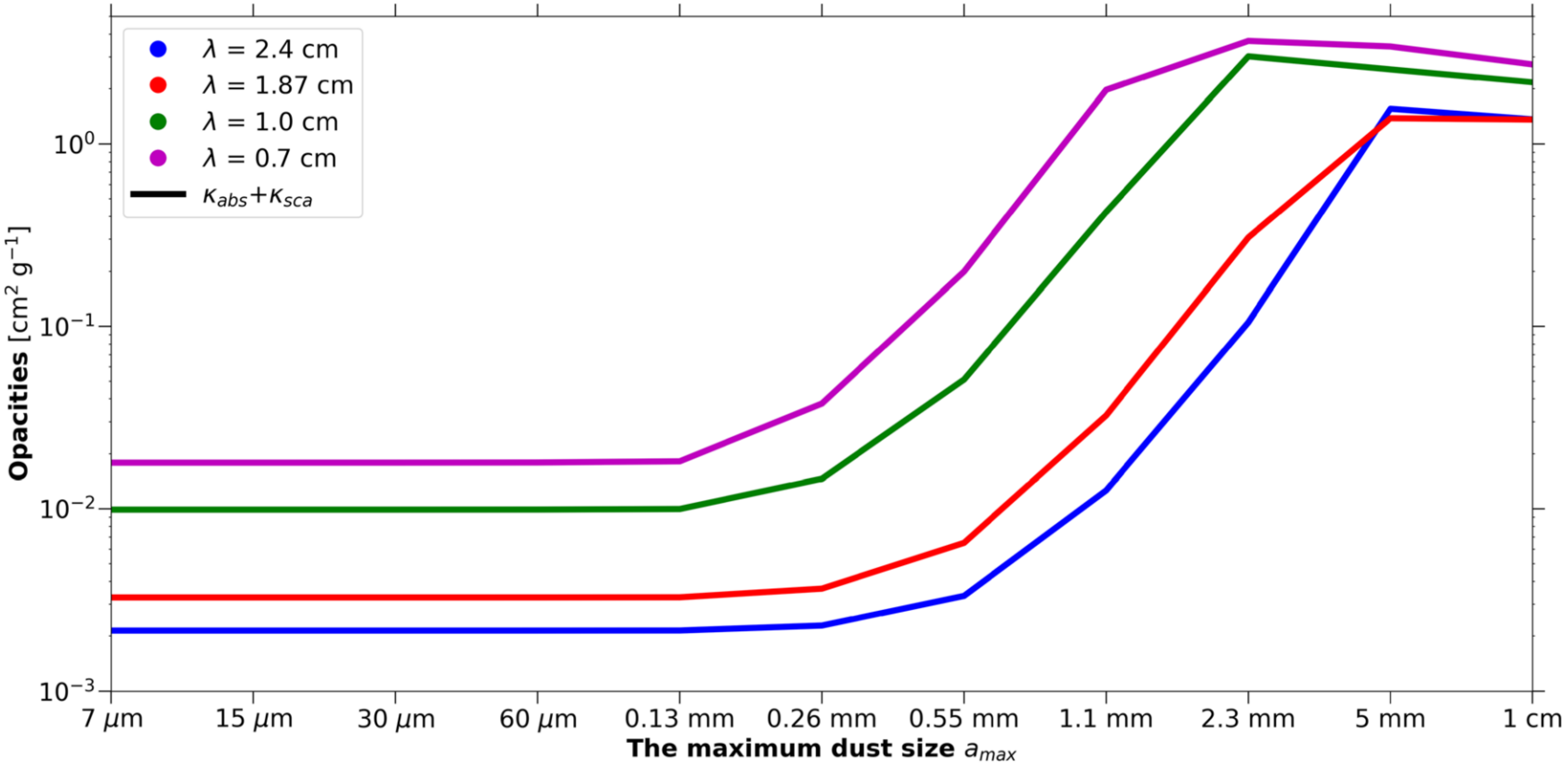
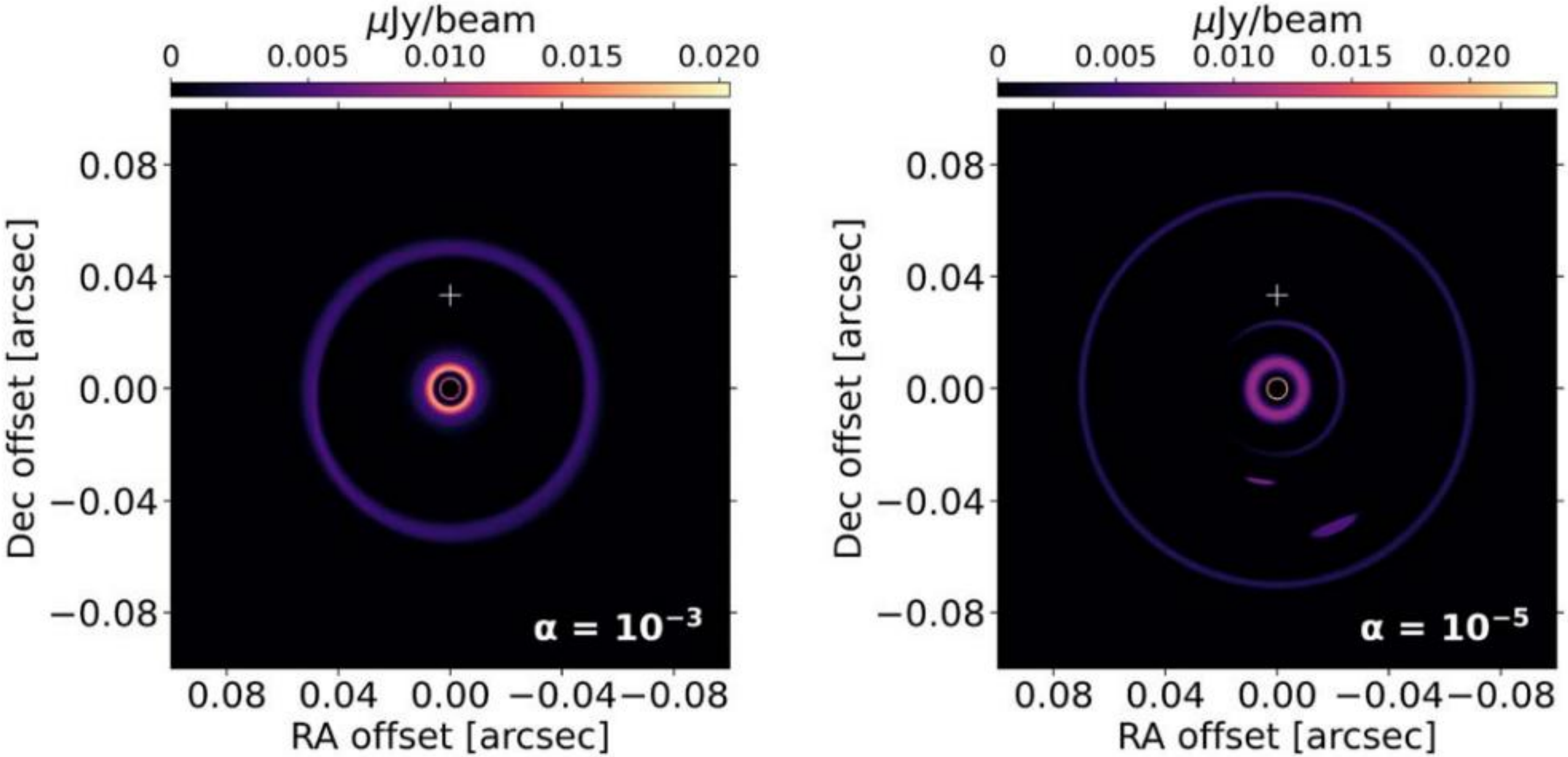
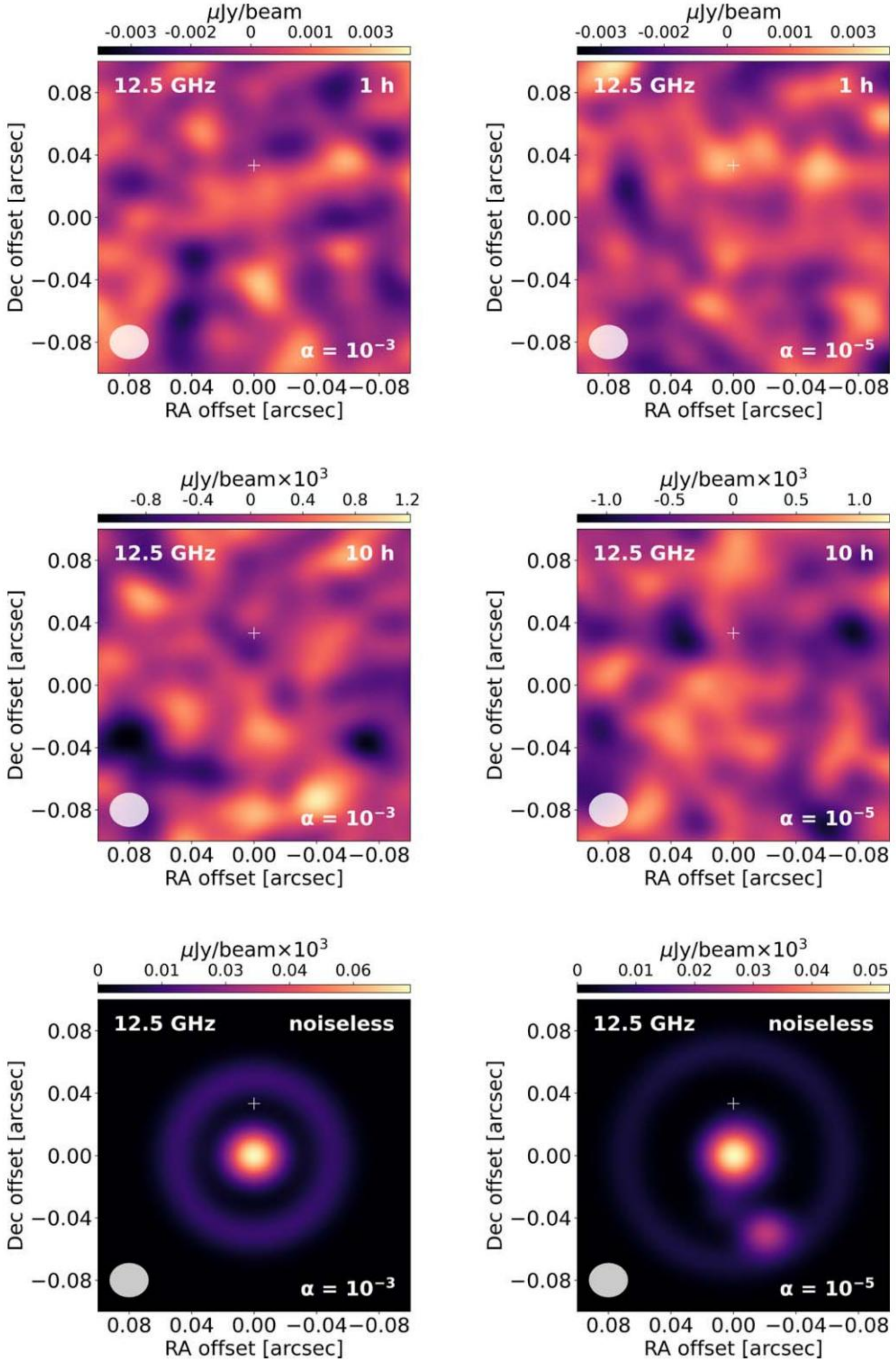


Figure 1. The total (absorption + scattering) optical depth ($\kappa_{\mathrm{abs}} + \kappa_{\mathrm{sca}}$) vs. the maximum dust are used in our radiation transfer calculations. Different colors indicate different observation wavelengths.



1536 (r) * 1024 (θ)
1 MJ at 5 au, 1500 orbits, ~ 18000 yr



μJy/beam
12.5 GHz
1 h
α = 10⁻³
α = 10⁻⁵
μJy/beam×10³
10 h
noiseless
Dec offset [arcsec]
RA offset [arcsec]

AA*, 88 dishes

Summary	Ilee et al. 2020	Wu et al. 2024
Code	PHANTOM (SPH)	FARGO3D (grid-based)
Planets	0.20/0.25/0.55 MJ 13.2/32.3/68.8 au	1.0 MJ 5.0 au
Disk	1~120 au	0.5~60 au
Simulating observations	CASA	SKAO Sensitivity Calculator + Python
Resolution and Sensitivity (1h)	0.034 arcsec with 2.4μJy/beam 0.067 arcsec with 1.2μJy/beam (AA4, 12.5 GHz with 5 GHz Bandwidth)	0.025 * 0.022 arcsec with 14.5μJy/beam (AA*, 12.5 GHz with 2.4 GHz Bandwidth)
Source Distance	140 pc	150 pc
Viscousity	5.e-3	1.e-3 and 1.e-5
Dust Opacity	Draine & Lee 1984	DSHARP opacity (Birnstiel et al. 2018), made by OpTool (Dominik et al. 2021)

Discussion:

Target source: **~150 au**? **Taurus** (Loinard et al. 2007), **Ophiuchus** (Ortiz-León et al. 2017), **Chamaeleon** (Whittet et al. 1997), and **Lupus** (Lombardi et al. 2008). Or ‘**Young Cluster Deep Field**’ SKA Key Science Project (Hoare et al. 2015), which contains 18 sources detected in the cm ranging from Class 0 to III (Coutens et al. 2019).

Code: **FARGO3D**? In multi-fluid simulations, the disk can be evolved to near **steady-state**, allowing the modeling of substructures caused by massive planets, such as **gaps**, **rings**, **vortices**, and even **spiral arms**.

Scripts: **CASA** + **SKAO Sensitivity Calculator** + **Radmc3D** (if use FARGO3D) + **OpTool**?

The focused region: 20 au? Similar to **DSHARP** source, also is **planet-forming** region.

Opacity: **DSHARP**?

Planet(s): Single or multi?