SKA1-Low低频大视场高动态范围成像

--Wideband Widefield Imaging for SKA1-Low

张利
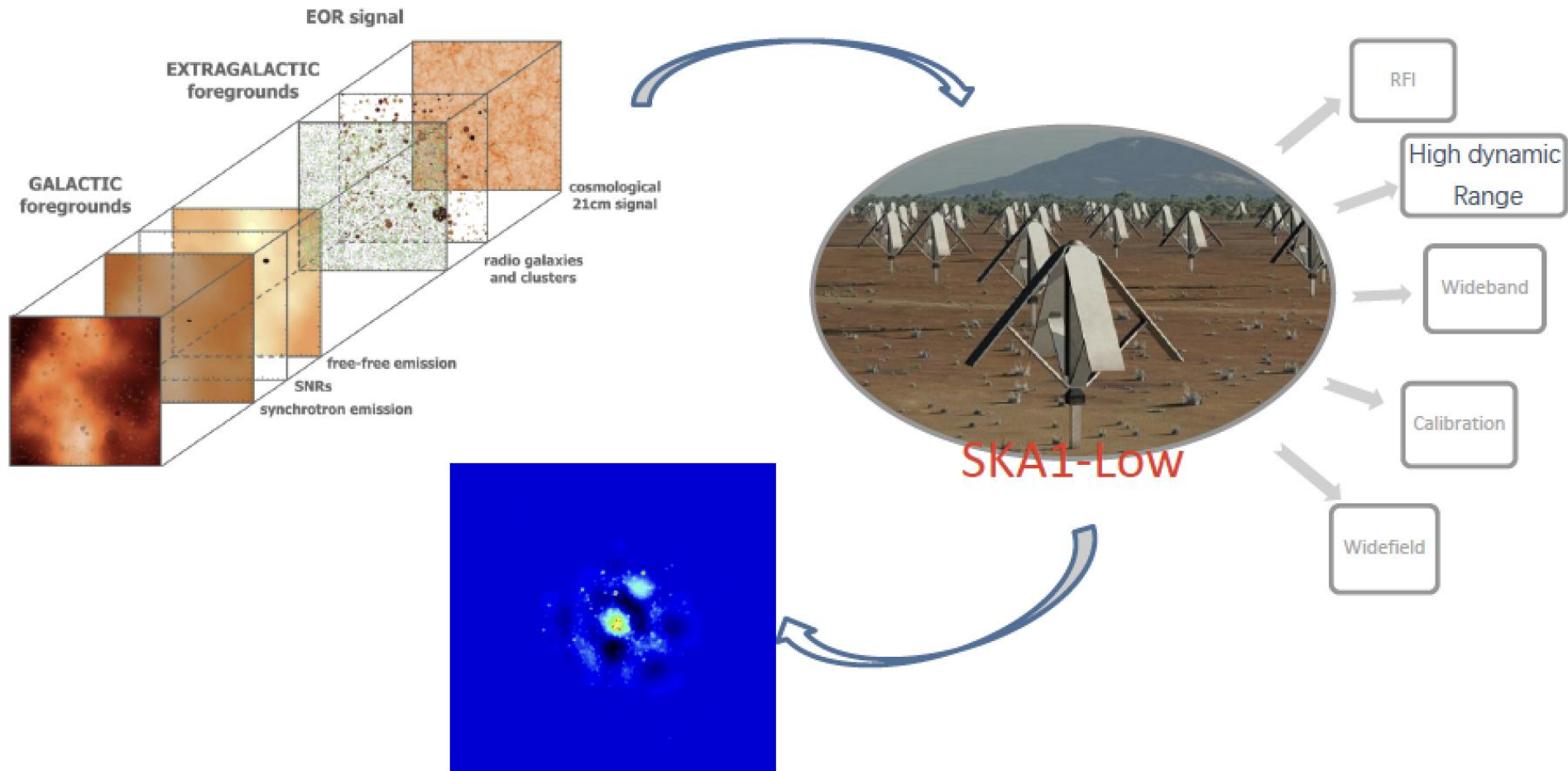
lizhang.science@gmail.com

贵州大学

欢迎引用论文

Challenge: Imaging & Recon
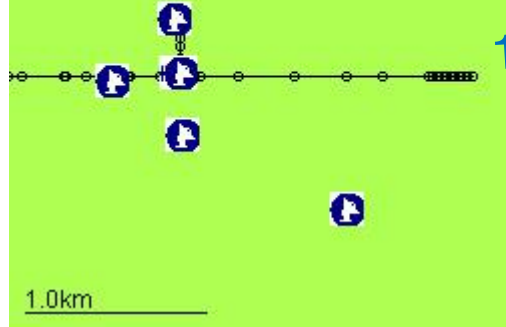
EoR ~ 1-10mK,

比前景信号低4-5个数量级

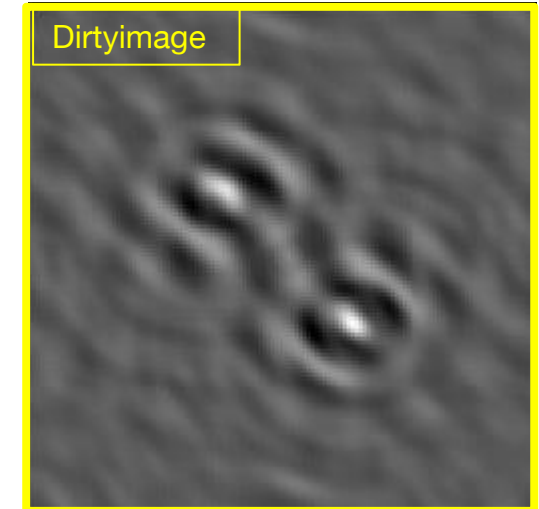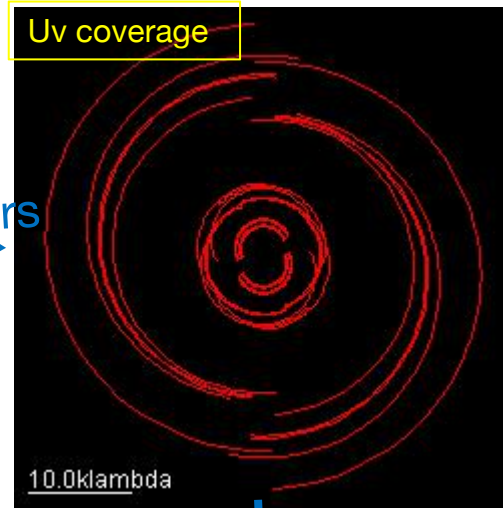# Radio Interferometry

Latitude:-30°minimum elevation:12°
D=22m,number=6,Frequ=4800MHz
Bandwidth=100MHz   ATCA

1.0km

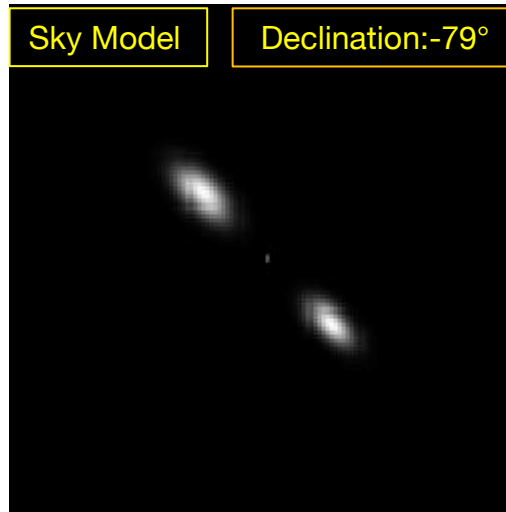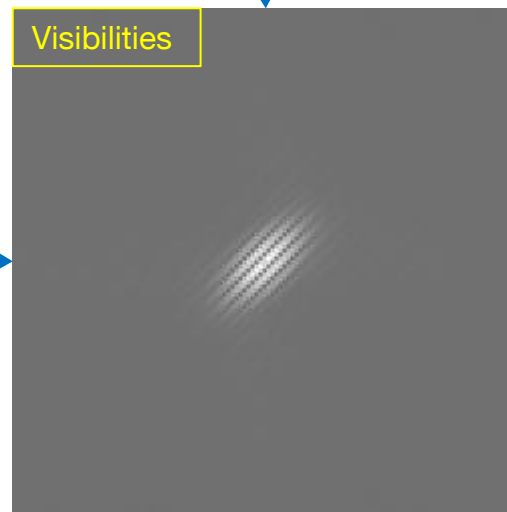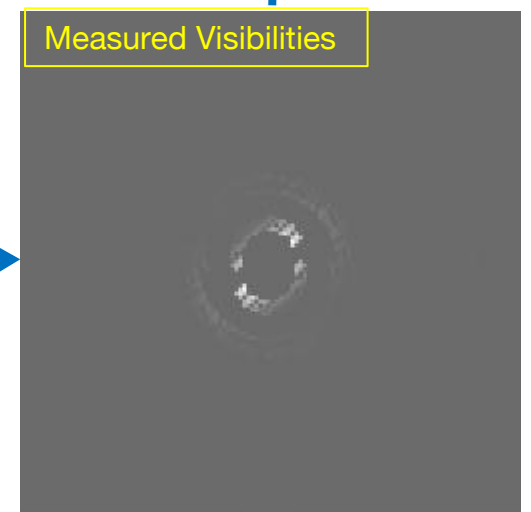Uv coverage

10.0klambda

12 hours

sampling

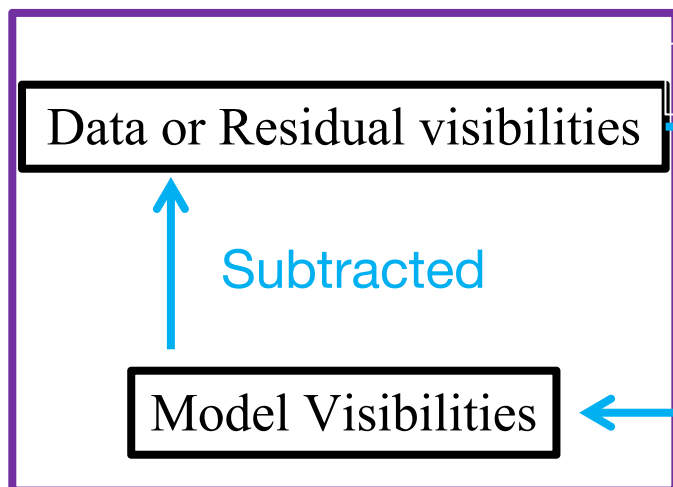Dirtyimage

iFFT

Sky Model   Declination:-79°

Visibilities

Measured Visibilities

FFT

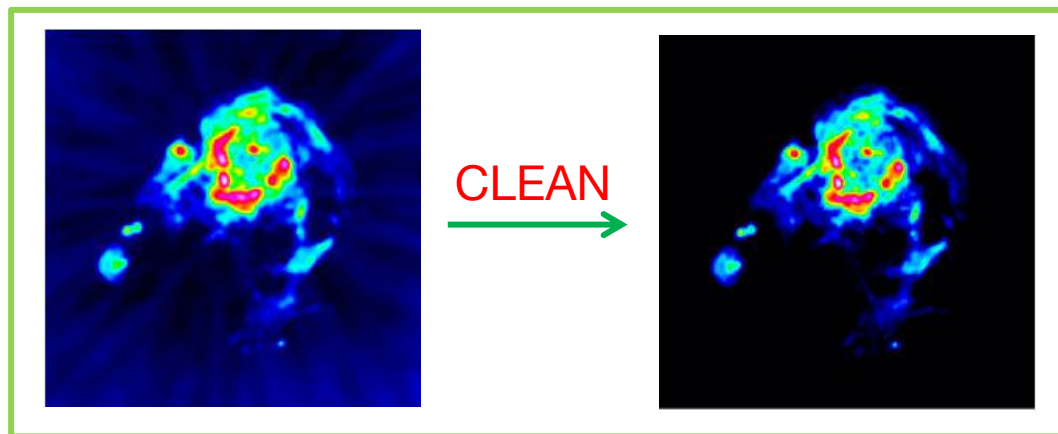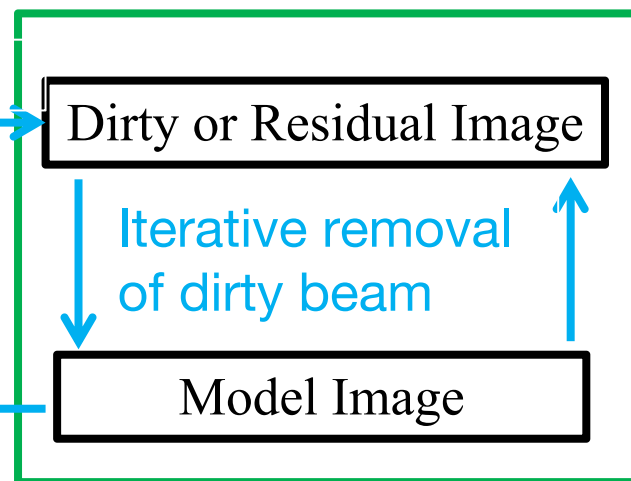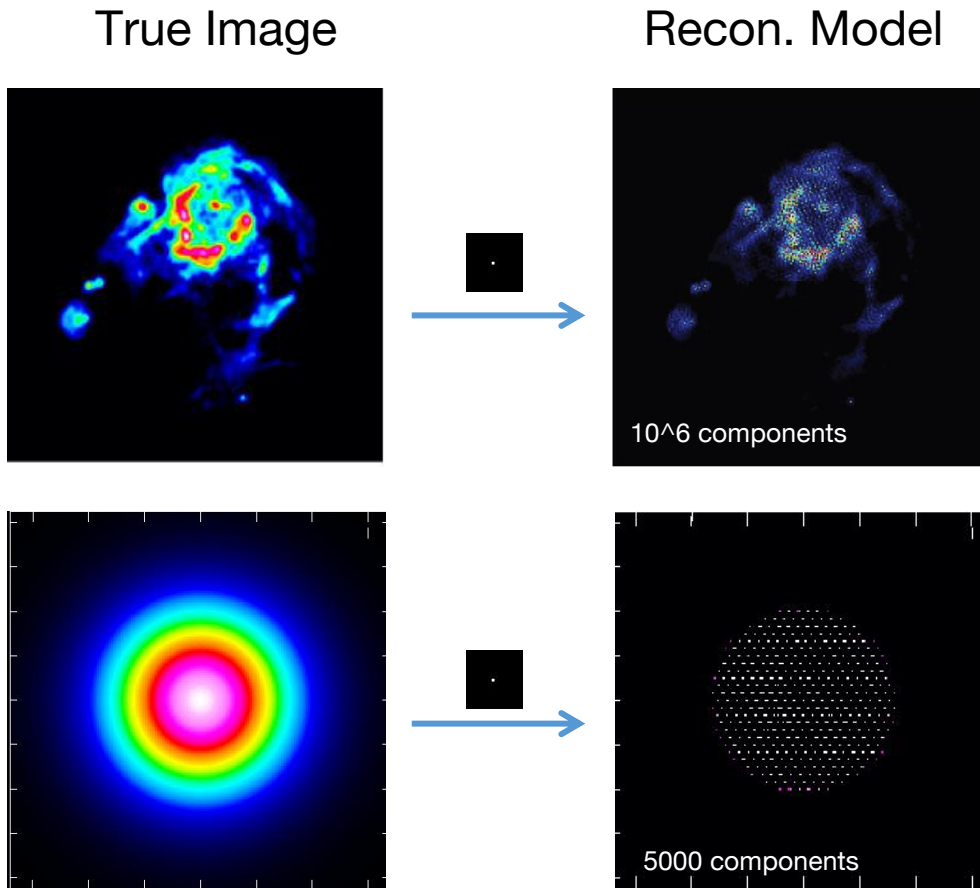# Model-driven Methods

CLEAN Framework

Problems of Scale-less Reconstruction

The original CLEAN algorithm is proposed by Högbom in 1974

Cs-Clean

True Image

Recon. Model

10^6 components

5000 components
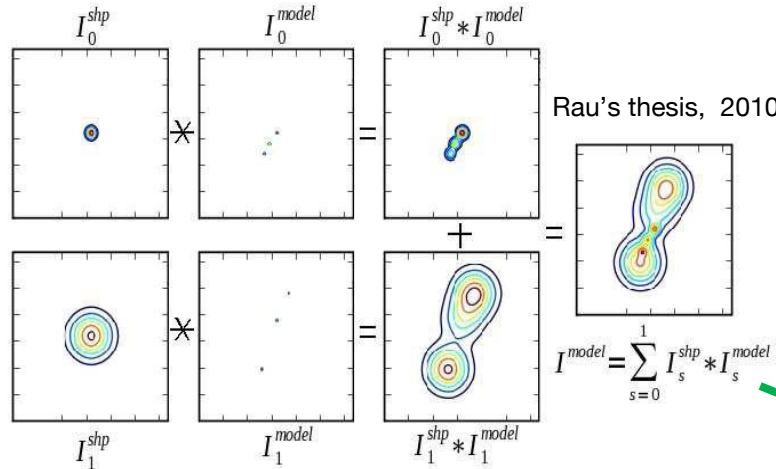
Peak of residual

↓

A loop gain

Peak of residual

↓

component

↓

Point sources: effective
Extended: bad model &
physically inaccuracy
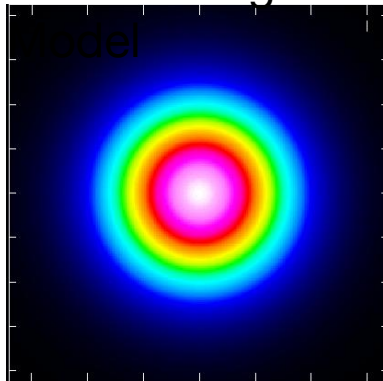
Problems of Ms-Reconstruction

SKA Organisation Staff

Tim Cornwell
SKA Architect

I_0^{shp} I_0^{model} $I_0^{shp} * I_0^{model}$

Rau's thesis, 2010

I_1^{shp} I_1^{model} $I_1^{shp} * I_1^{model}$

$$I^{model} = \sum_{s=0}^{1} I_s^{shp} * I_s^{model}$$

Ms-Clean

Matched Filtering

Truncated Paraboloids
+
Residual/Dirty Image

True Image

Model

Recon.

100 components
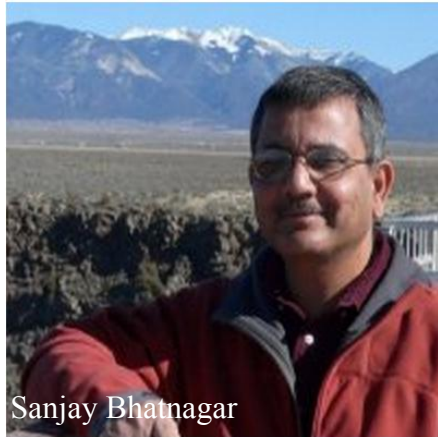
1. good for extended emissions
2. But with limited scales

Enumerated scales : limited performance
&
Complicated Images: computational expensive
&
More scales: prohibitive memory cost
&
Large Images: prohibitive memory cost

Problems of Asp-Reconstruction

Sanjay Bhatnagar

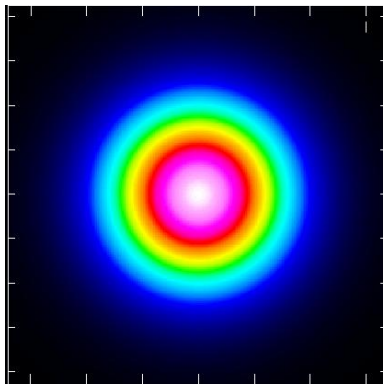Gradient-based minimization

Asp-Clean

Constrianed Optimization
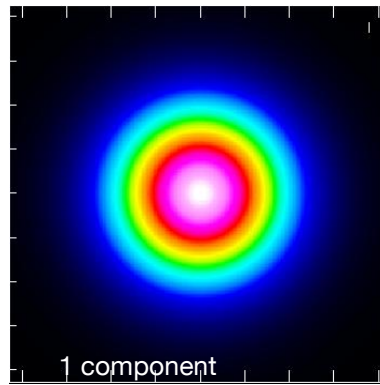
Initial Gaussian
Components
+
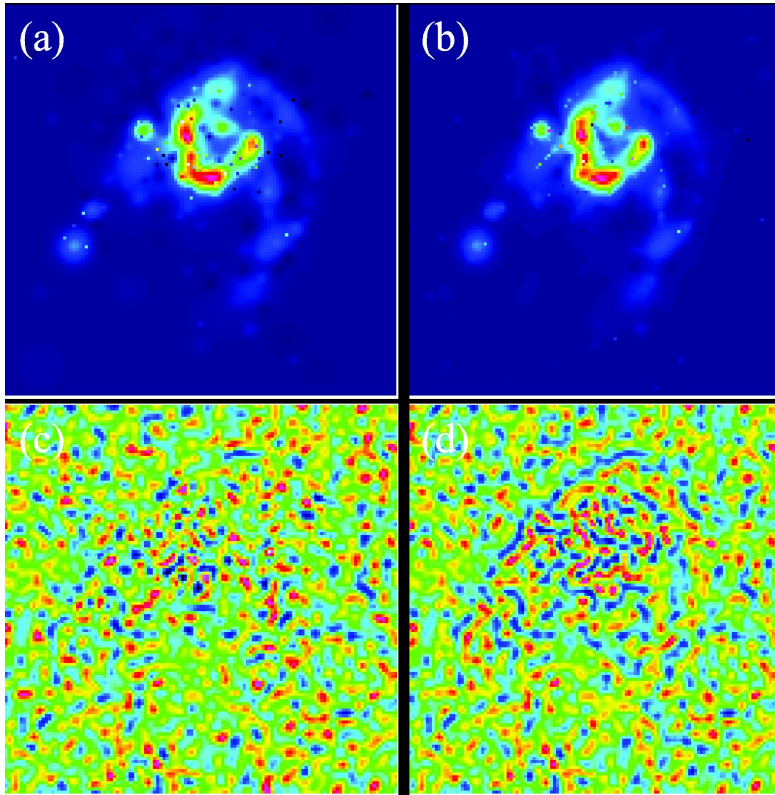Residual/Dirty Image

Iterative

True Image

Recon. Model

1 component

Best for extended emission
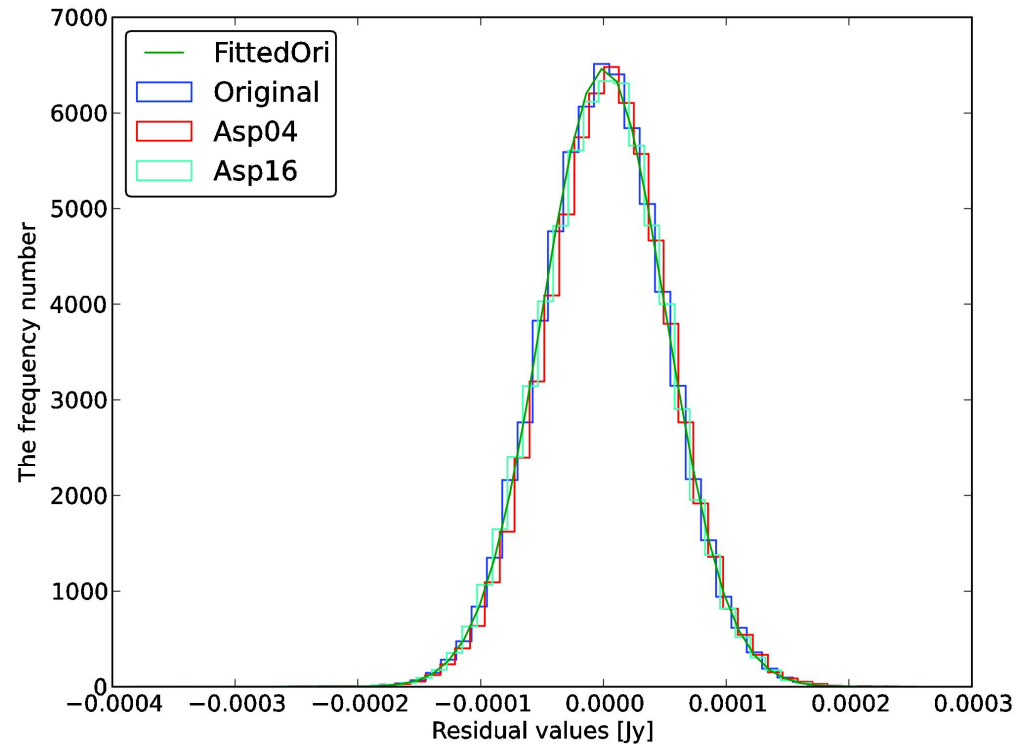
Small images: Computational expensive
&
large images: Comp. Prohibitive
&
Complicated images: Comp. Prohibitive
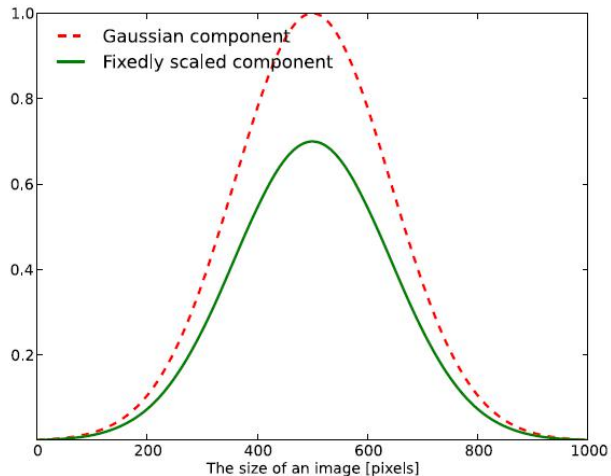
研究进展1： Asp *vs* Our (asp2016)

(a) (b) (c) (d)

A little worse residuals, but
Residual noise profile is closer to the input Gaussian noise →
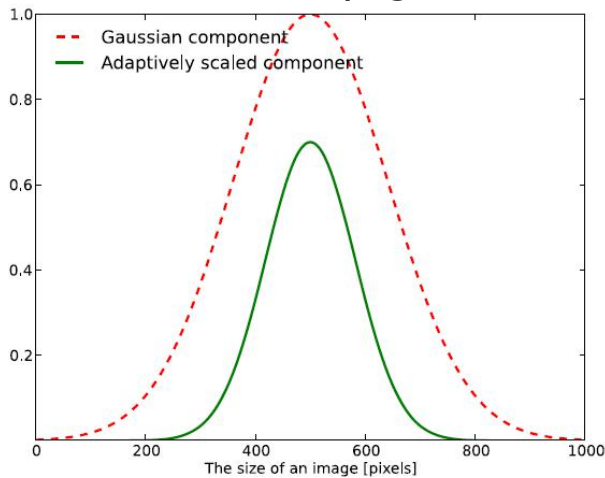Sufficient extraction of the signal

Asp vs Our: Comparable
Model: a little better
Residual: a little worse

Zhang, A&A, 2016

研究进展2： Adaptive Loop Gain Scheme

Fixed loop gain

Adaptive loop gain

The formula for adaptive Loop gain scheme:

$$g(x) = \sqrt{a(1 - f(x)) + bf(x)}$$
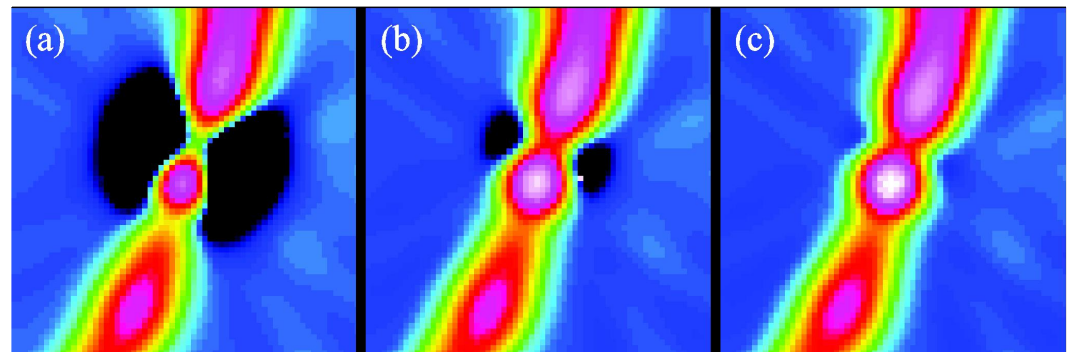
where

$$f(x) = \frac{x - C_{min}}{C_{max} - C_{min}}$$

g_{min} and g_{max} are the minimum and maximum values of adaptive loop gain $g(x)$; C_{min} and C_{max} are the minimum and maximum values of component's amplitude
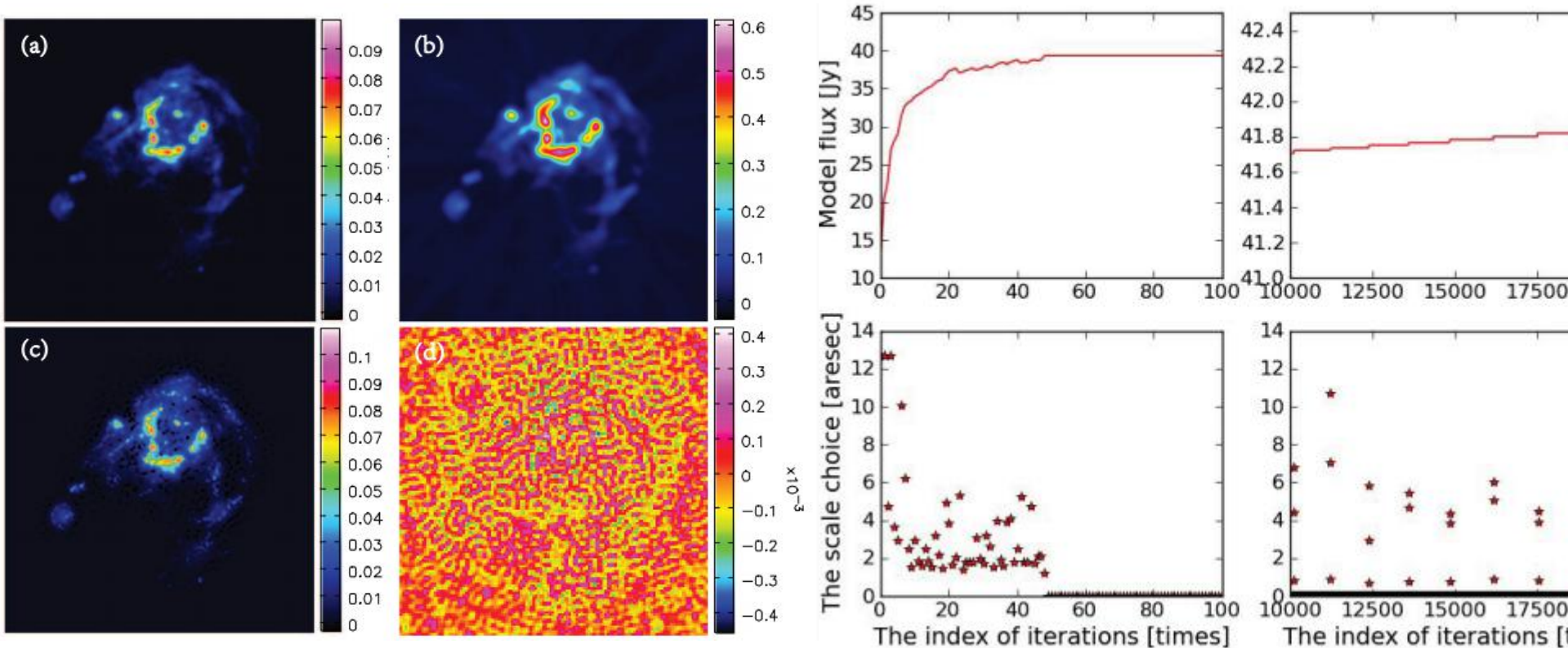
Zhang PASP, 2016

Without loop gain   Fixed loop gain   Adaptive loop gain

Asp-Clean2016 + Hg-Clean ➤ Fused CLEAN

Zhang A&A, 2018

研究进展4: SKA Widefield Imaging
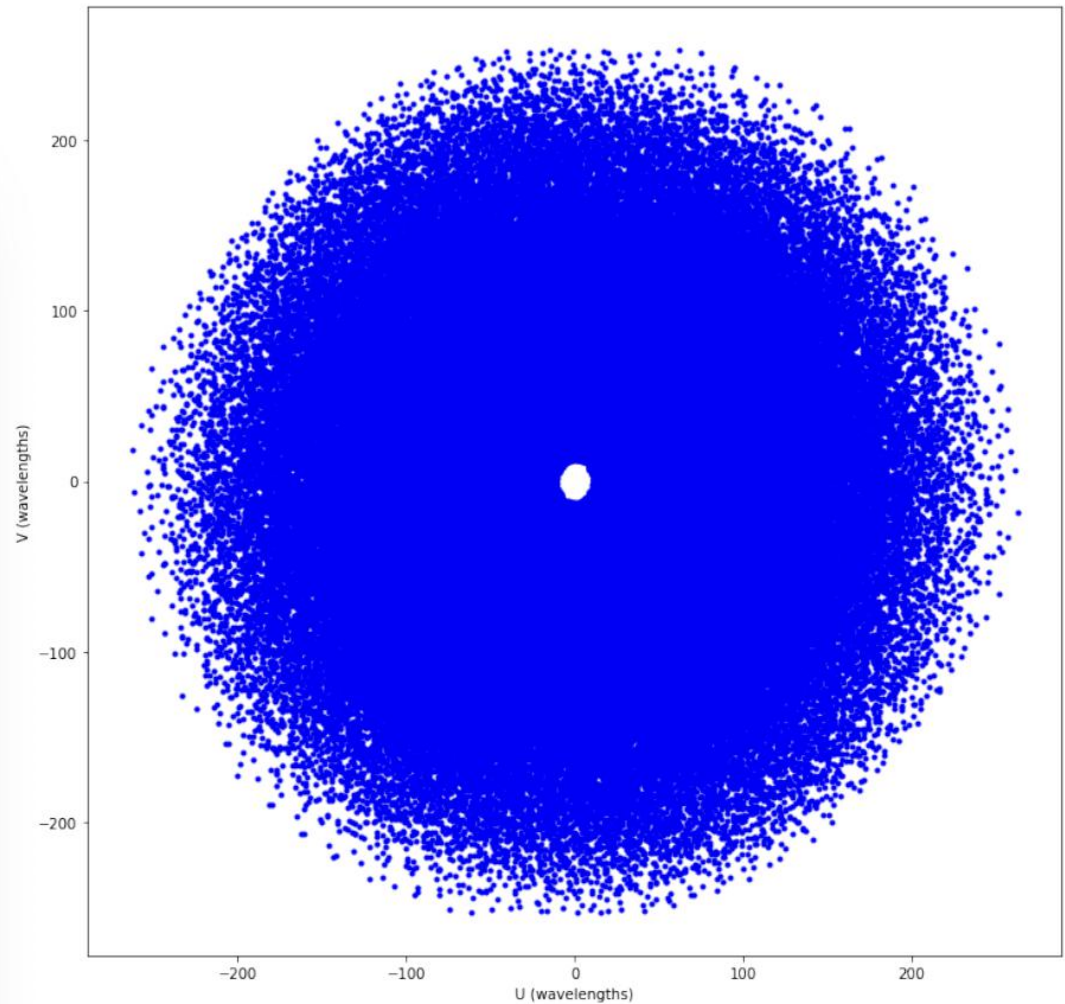
SKA simulation：

1. SKA1-LOW core

2. at 100 MHz

Fig. 1. Uv coverage for the SKA simulation, recorded as seven snapshots whose time distribution is in $[-3.0, -2.0, -1.0, 0.0, 1.0, 2.0, 3.0] * (\pi/12.0)$.

研究进展4: SKA模拟数据验证

$$V^{\text{sky}}(u, v, w) = V^{\text{sky}}(u, v, w = 0) * K(u, v, w),$$

1. Our imager
    = adaptive scale deconvolution
    + Widefield Correction

2. Tests： Simulated SKA data
    + JVLA observation data

4. Plan：
   Test for SKA EoR Imaging

Fig. 3. Reconstruction results from our imager. *Left*: model image. *Right*: restored image.

研究进展4: JVLA实测数据验证（首次）

$$V^{sky}(u, v, w) = V^{sky}(u, v, w = 0) * K(u, v, w),$$

1. Our imager
   = adaptive scale deconvolution
   + Widefield Correction

2. Tests： Simulated SKA data
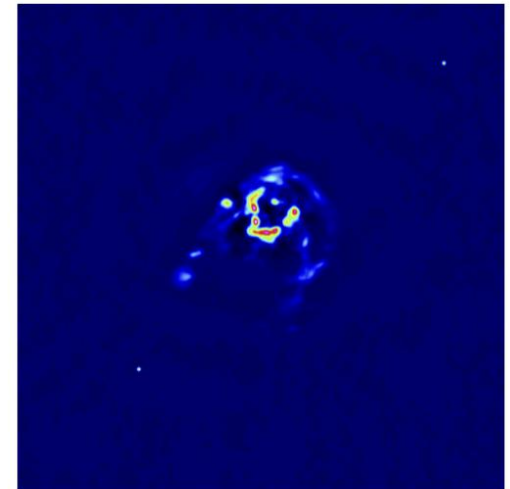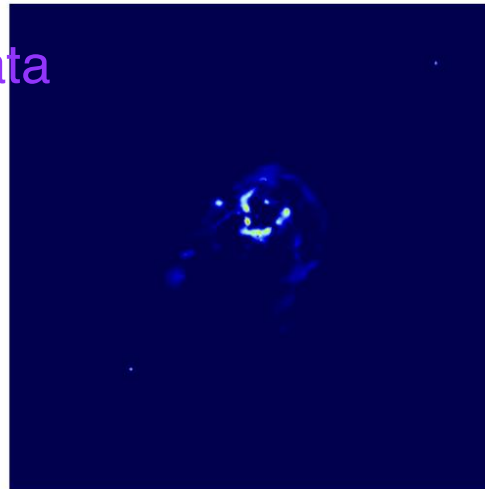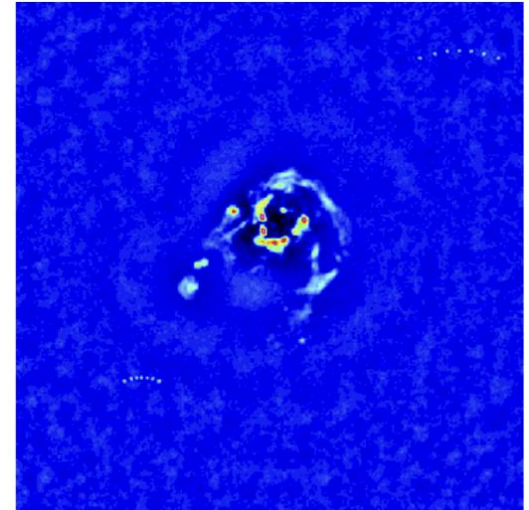   + JVLA observation data
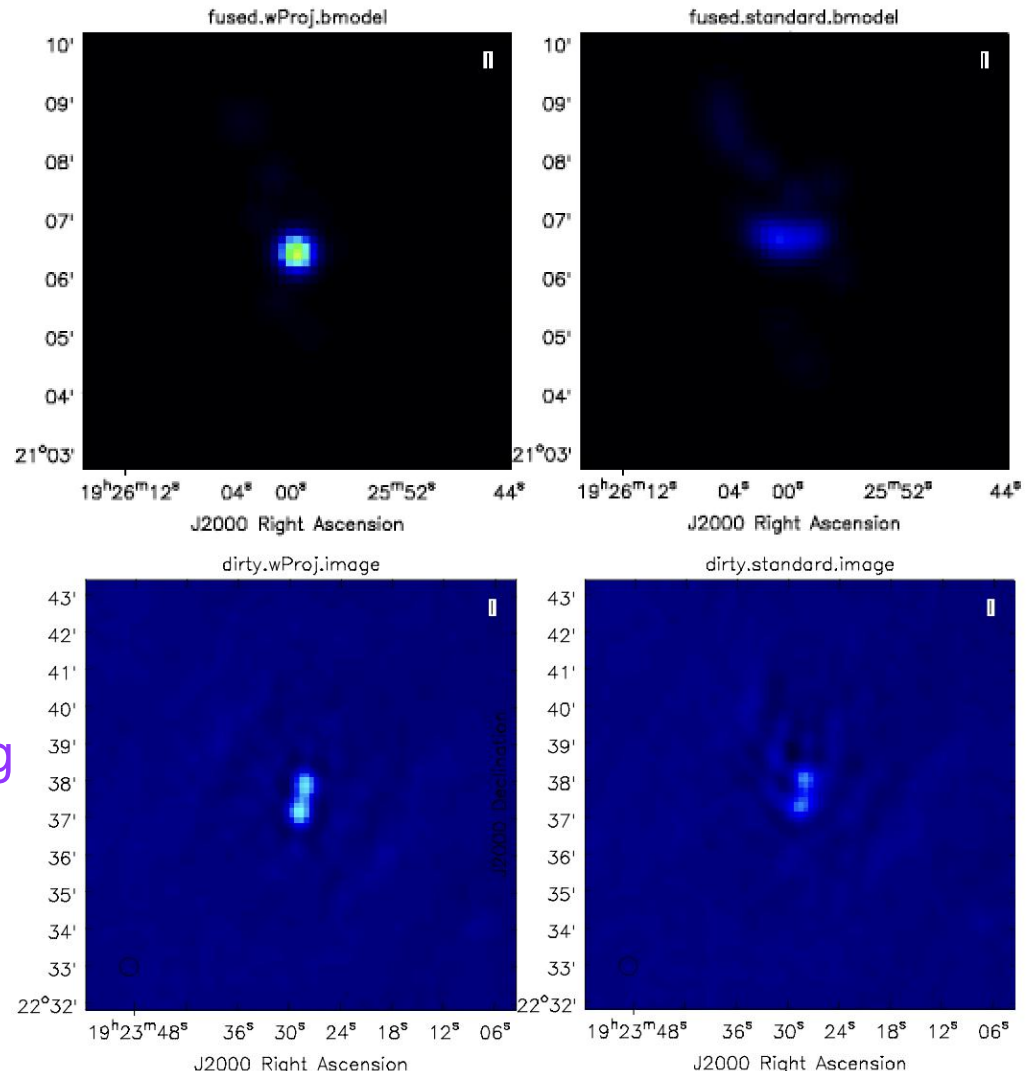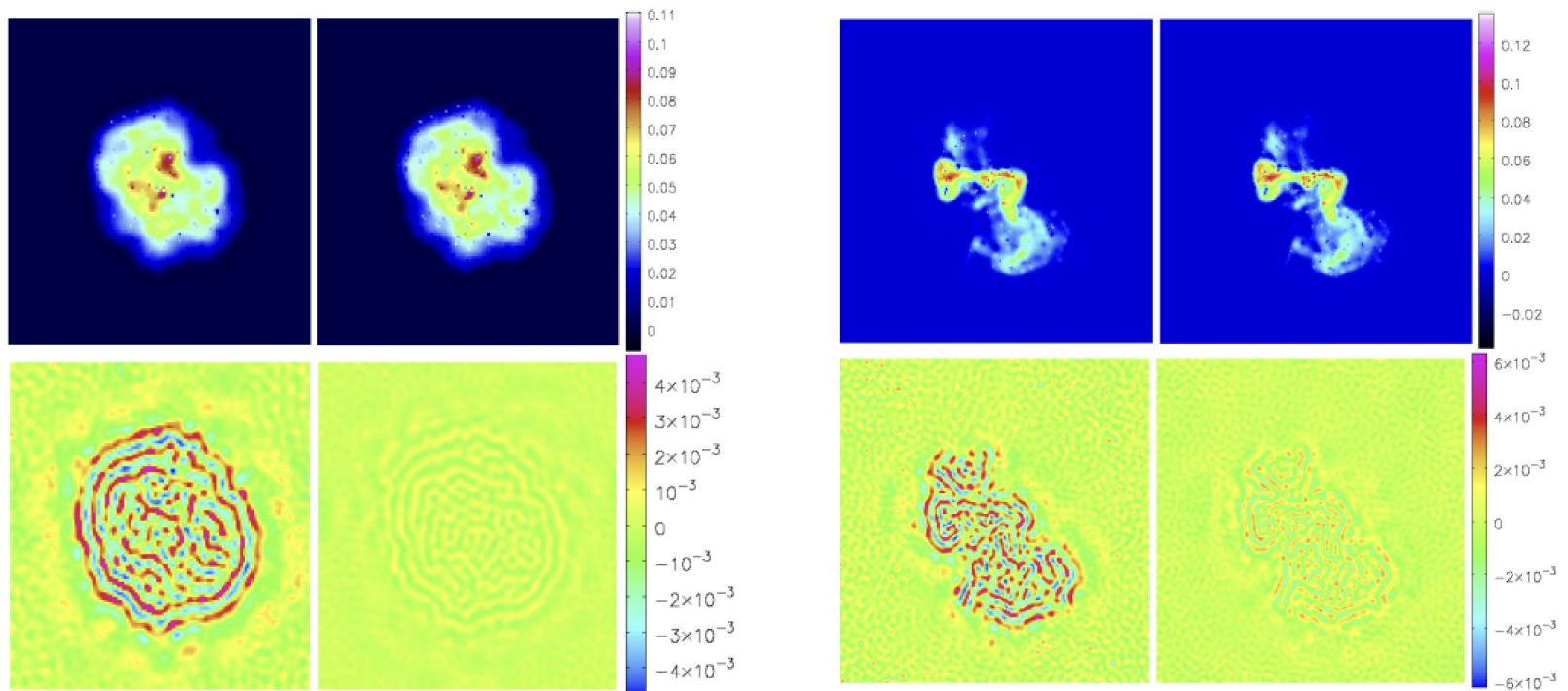
3. Plan： test for SKA EoR Imaging

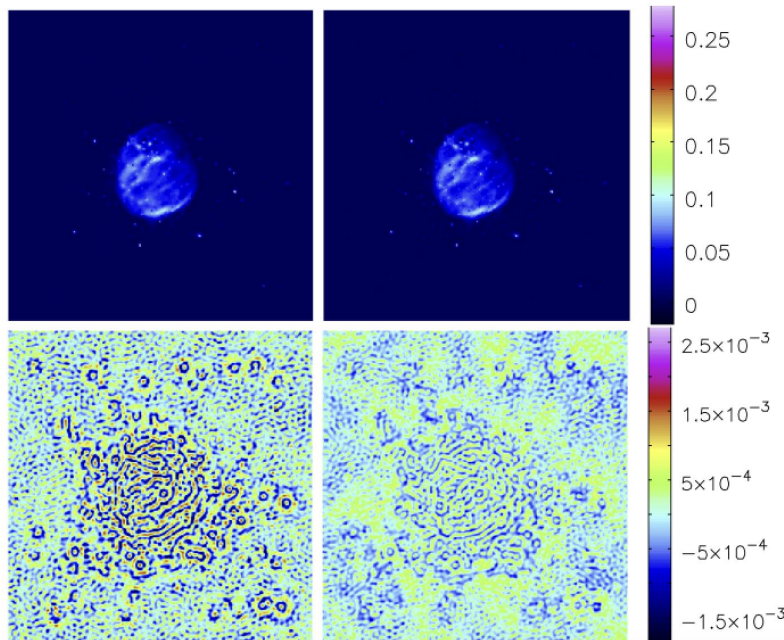(A&A，2020)

Our imager   Standard imager

Specified scale lists	Algorithms	Off-source rms (10^{-4})	Full rms (10^{-4})	Dynamic range (10^3)
[0, 4, 8, 16, 32]	MS-Clean	1.887	2.819	7.674
	RMS-Clean	0.871	1.084	19.957
[0, 3, 10, 30, 60]	MS-Clean	4.025	7.514	2.878
	RMS-Clean	3.022	5.133	4.212
[0, 6, 12, 18, 24]	MS-Clean	4.129	7.894	2.739
	RMS-Clean	1.012	1.354	15.974

(AA，2021)

研究进展6：Deconv with Hybrid Parameterization

Scale Lists	Algorithms	Runtime (s)	Off-source RMS (10^{-4})	Full RMS (10^{-4})	Dynamic Range (10^3)
$[0, 3, 6, 12, 24]$	MsClean	88.659	8.075	9.967	2.675
	Our	79.346	3.256	3.243	6.635
$[0, 3, 10, 20, 40]$	MsClean	312.679	3.544	3.527	6.093
	Our	104.610	3.284	3.231	6.575
$[0, 6, 12, 18, 32]$	MsClean	216.191	4.199	4.561	5.145
	Our	76.164	3.240	3.336	6.668

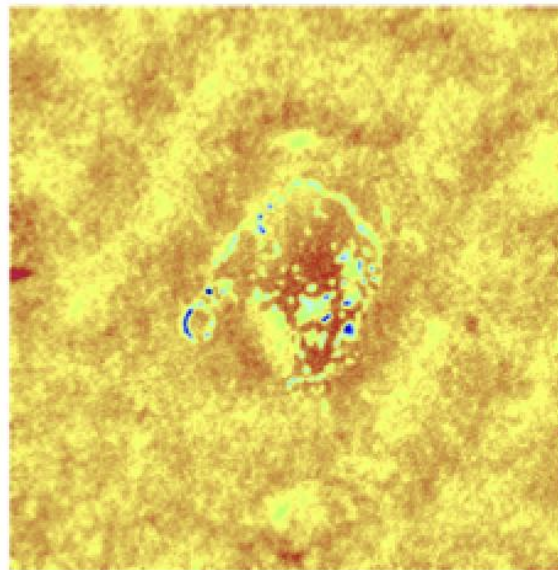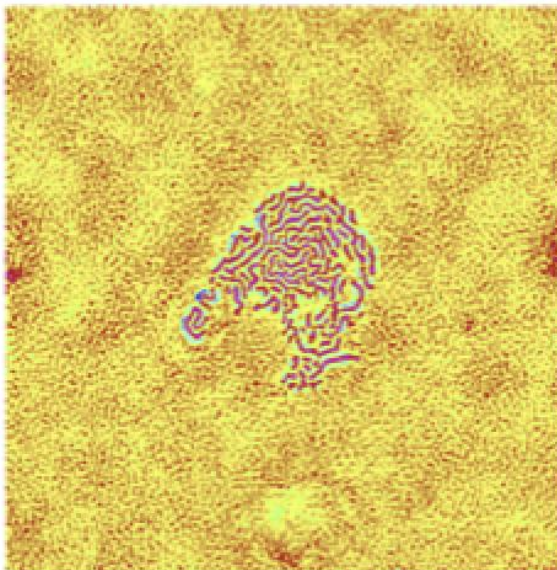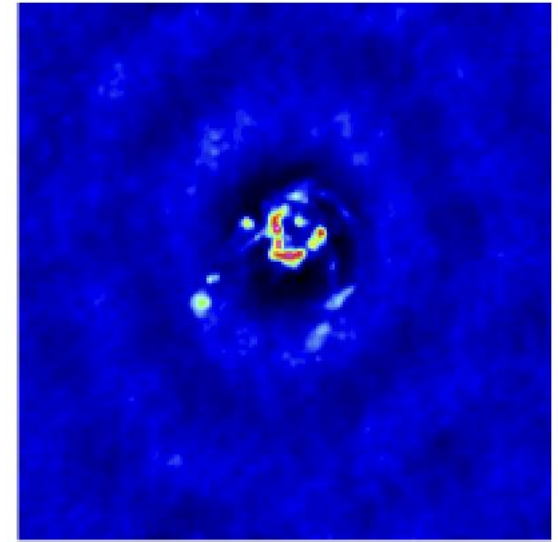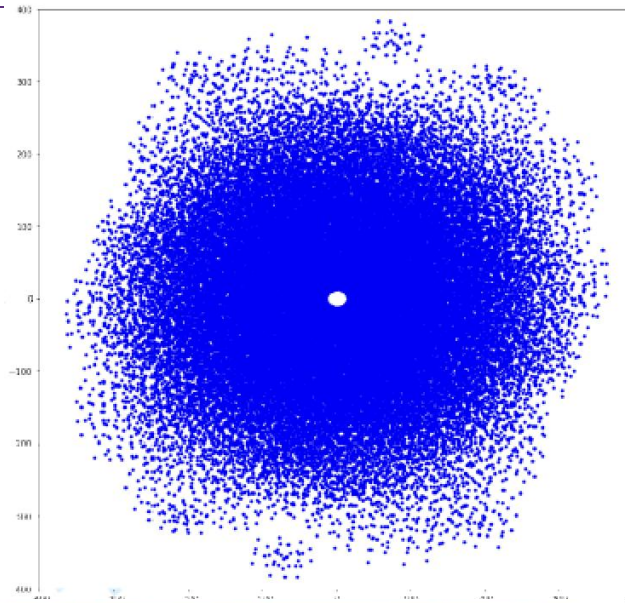| Diffuse	Compact
Ms-Clean	Hg-Clean

(RAA，2021)

研究进展7: SKA Wideband Imaging

SKA simulation:

1. SKA1 'LOWBD2'

2. at 100 MHz
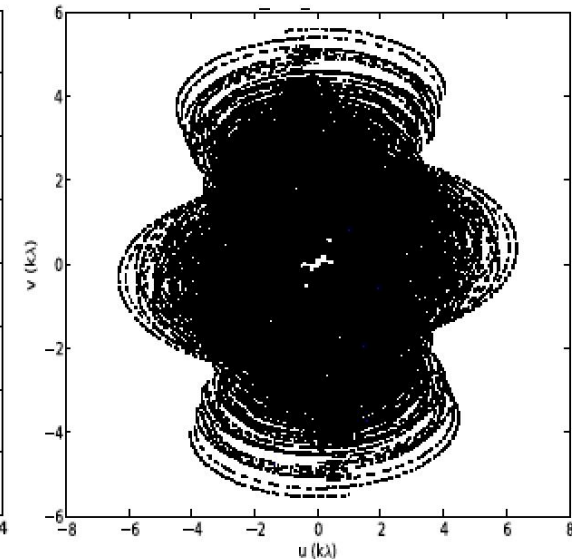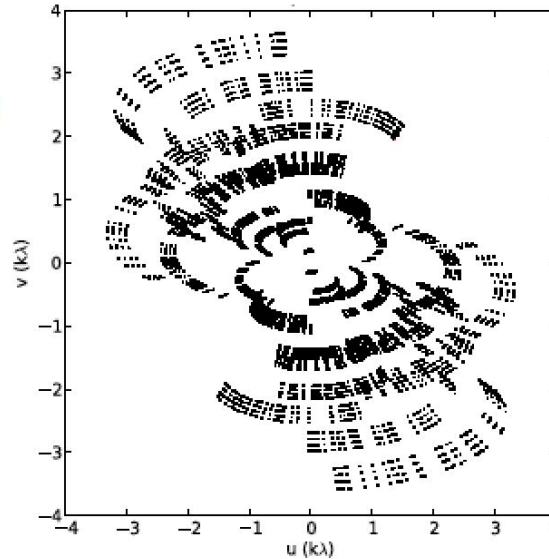

UV coverage | dirty image

Ms-Clean | Asp-Clean

(RAA，2021)

SKA wideband widefield imaging

$$I^{obs} = F^{-1} \sum_{0}^{N-1} S_v V^{sky}$$

1. Our imager
= adaptive scale deconvolution
   + Wideband Correction

2. Tests： Simulated SKA data
          + JVLA observation data

4. Plan： test for SKA EoR Imaging

JVLA D, supernova remnants,
G55.7+3.4, 1-2GHz, 2MHzChannel,
time 1s

SKA wideband widefield imaging

$$V^{sky}(u, v, w) = V^{sky}(u, v, w = 0) * K(u, v, w),$$

= adaptive scale deconvolution
+ Widefield Correction
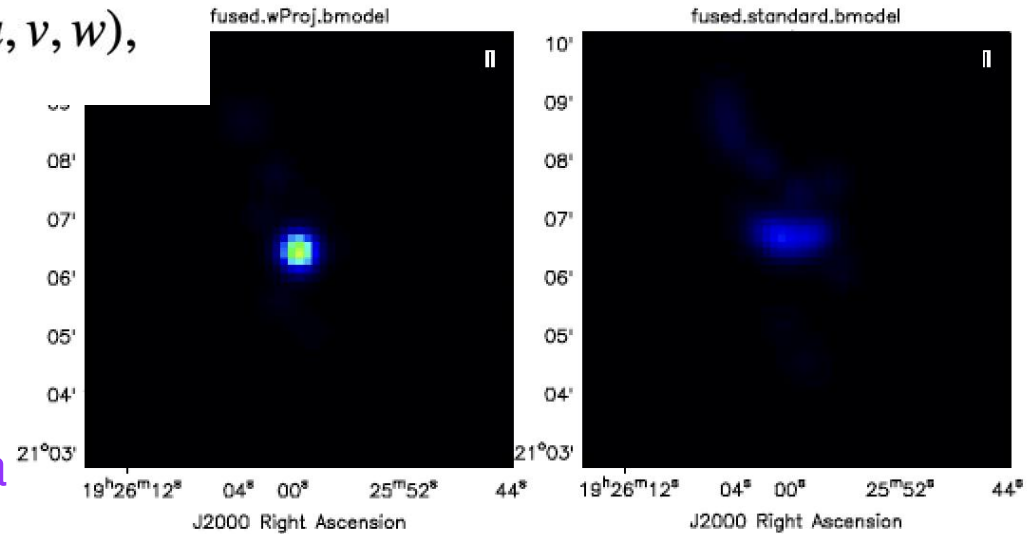+ Wideband Correction

2. Tests： Simulated SKA data
+ JVLA observation data

3. We proposed 4 algorithms for accurate deconvolution
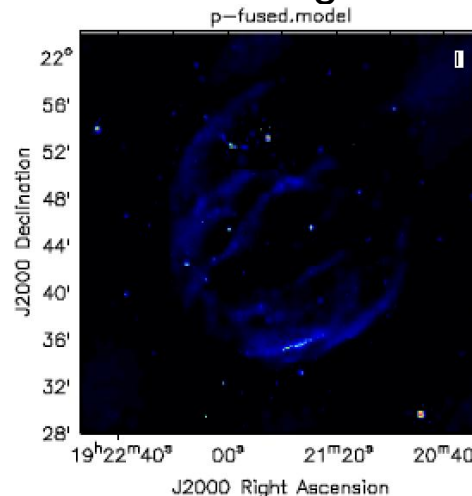+ imagers for wideband widefield Imaging

4. Plan： test for SKA EoR Imaging
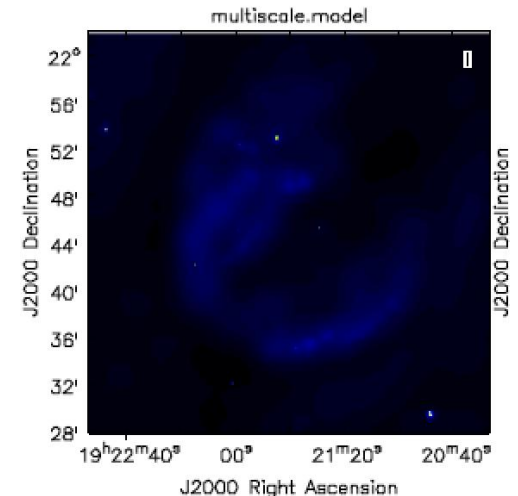
(A&A，2020，A&A 2021，RAA，2021a, RAA, 2021b)

eld imaging for JVLA observation data

Our imager   Standard imager

Wideband imaging for JVLA observation data

Data-driven Methods

研究进展1: Deep Learning for SKA imaging

1. deepDeconv for accurate reconstruction of compact emission + PSF Correction
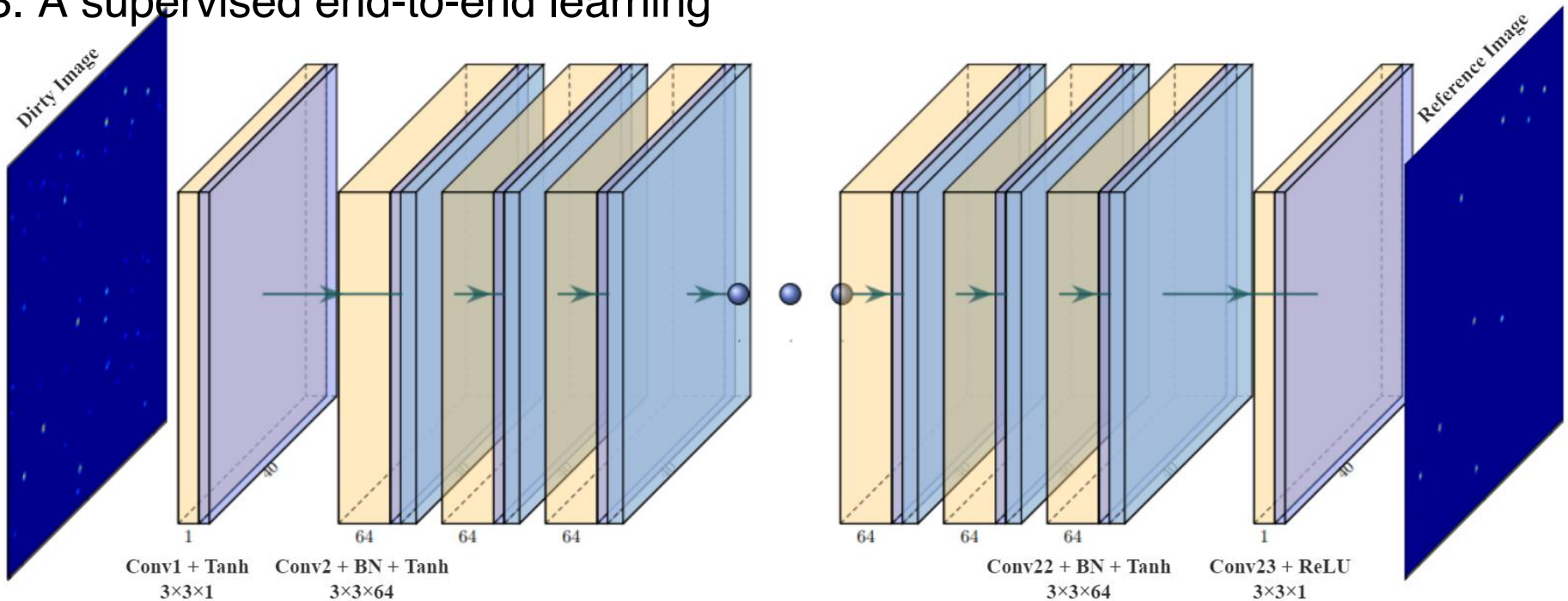
2. Tests： Simulated SKA data

3. A supervised end-to-end learning
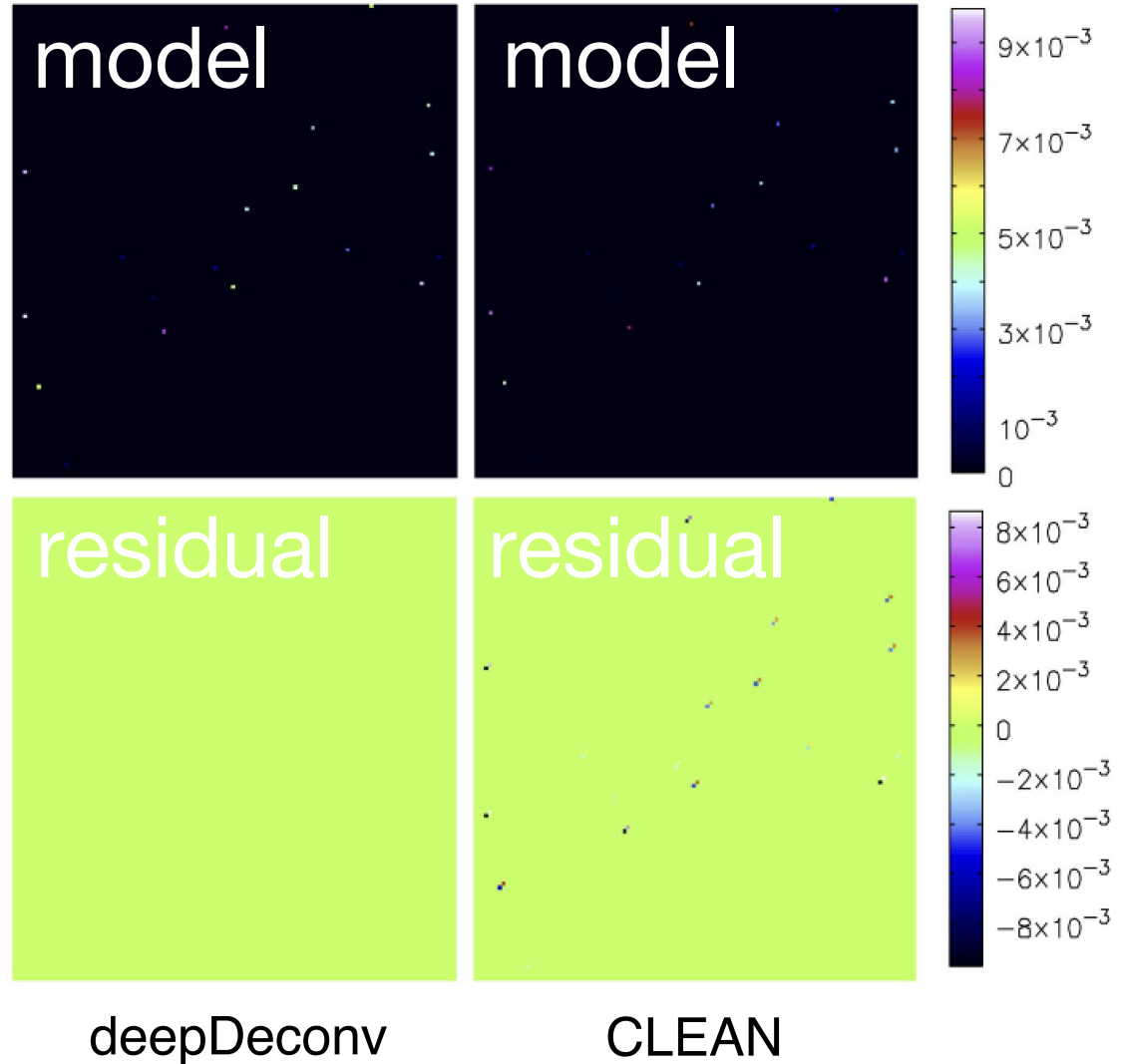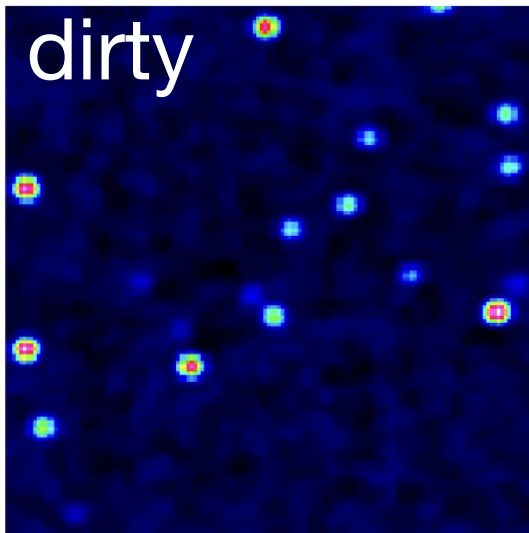
4. Activation function scheme: tanh + ReLU

5. data-driven VS model-driven

6. Plan: Test for SKA EoR Imaging

研究进展1: Deep Learning for SKA imaging

Reconstruction results for sparse-distributed compact emission.

Thanks for listening