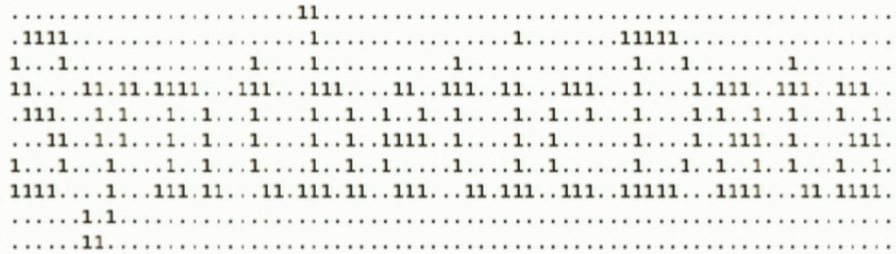
Title: Synthetic Data

Date: Nov 14, 2014 11:10 AM

URL: http://pirsa.org/14110111

Abstract: You've just finished running your code, and you're certain that you (and only you) know exactly what the region around a supermassive black hole looks like. You could lie back and wait for the accolades to roll in, but why not take an extra moment to make testable predictions that even the observers can understand? Synthetic data can help.



Synthetic Data

Vincent L. Fish

EHT 2014

Why produce synthetic data?

Simulations take models from the theoretical world and reformulate them in the language of observations

Useful for

- Making predictions for future observations
- Determining which potential features are observable
- Model parameter estimation

- Examining the impact of array upgrades (e.g., new sites)
- Testing imaging and analysis techniques

Simulating data

Simple in principle:

1. Fourier transform your image
2. Read visibilities at the appropriate locations in (u,v) space
3. Optionally construct other VLBI observables (with noise?)

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Lots of potential places to go wrong:

- Signs
  - Sky coordinates are left-handed! RA increases to the left.
  - (u,v) coordinates are left-handed
  - Conventions for visibility phase & closure phase
- Factors of 2π
- Polarization definitions
- Miscellaneous bugs

No matter how you simulate data, it is advised to validate your simulation with other pathways

MAPS

MIT Array Performance Simulator

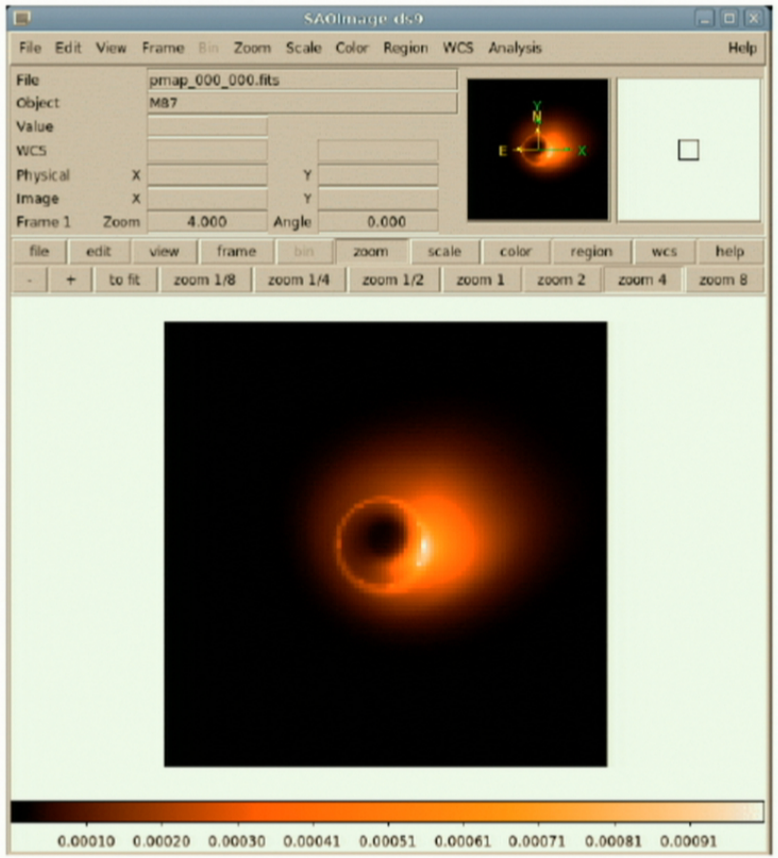
Produces simulated data for an interferometric array

Originally designed for low-frequency arrays (LOFAR, MWA), but usable for high-frequency VLBI as well

Source code for free download from the Haystack website

MAPS example inputs

FITS file of image



(courtesy A. Broderick)

MAPS example inputs

FITS file of image

Array file

Example_Input_File

File Edit Options Buffers Tools Help

```
#Telescope        X              Y              Z        Layout      Elevation:lo/hi   SEFD
Hawaii8     -5464523.400   -2493147.080    2150611.750   Hawaii8_20.8m_unpol  15 85   4900
SMTO        -1828796.200   -5054406.800    3427865.200   SMTO_10m_unpol       15 85  11900
CARMA8      -2397431.300   -4482018.900    3843524.500   CARMA8_26.9m_unpol   15 85   3500
LMT          -768713.9637  -5988541.7982   2063275.9472  LMT_50m_unpol        15 85    560
ALMA50       2225037.1851  -5441199.1620  -2479303.4629  ALMA50_84.7m_unpol   15 85    110
PV           5088967.9000   -301681.6000   3825015.8000  PV_30m_unpol         15 85   2900
PdBI         4523998.40      468045.240    4460309.760   PdBI_36.7m_unpol     15 85   1600
SPT                0.0            0.0     -6359587.3     SPT_12m_unpol        15 85   7300
GLT          1500692.0     -1191735.0      6066409.0     GLT_12m_unpol        15 85   4744
--:---  m87.array.txt.fordisplay   All L1     (Fundamental)-----------------------------------
Wrote /data1/MAPS_futz/demo/m87.array.txt.fordisplay
```

(courtesy R. Lu)

MAPS outputs

Visibilities in text or FITS formats

MAPS_Text_Output

File Edit Options Buffers Tools Help

UV data taken from visgen.

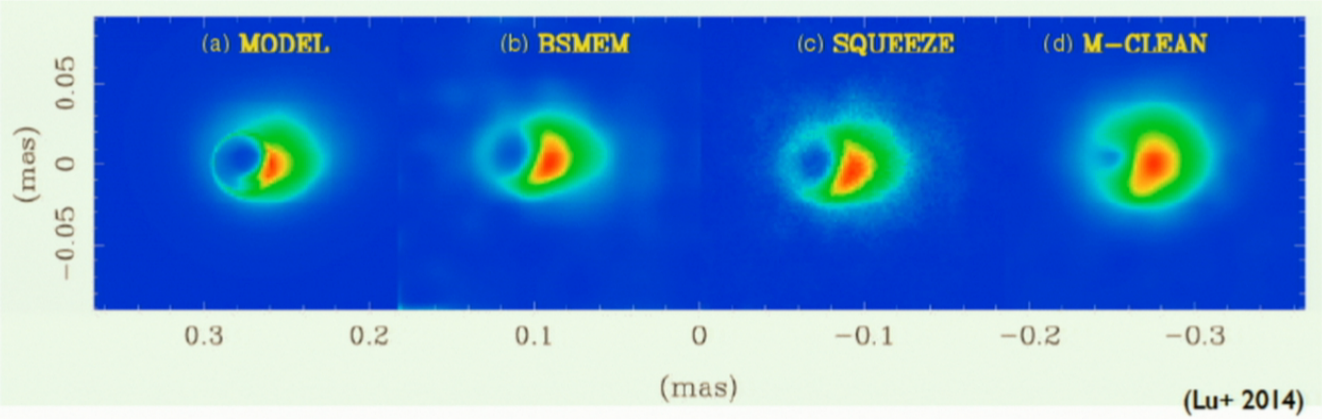
Scan Start (UT)	U(klam)	V(klam)	W(klam)	Baseline	Channel	Visibility (amp, phase)	Weight	Sigma
2015:095:00:00:00.00	-4117355.56	-4320334.37	-2810969.06	05-06	00	(0.036615, -166.628064)	49152	0.00180
2015:095:00:00:00.00	-4663767.80	-4899848.70	-2441799.88	05-07	00	(0.033922, -177.916597)	49152	0.00134
2015:095:00:00:00.00	-3185813.62	-6568121.23	-570672.18	05-09	00	(0.025689, -167.376333)	49152	0.00230
2015:095:00:00:00.00	-546412.24	-578706.32	369169.18	06-07	00	(0.346626, -14.201007)	49152	0.00687
2015:095:00:00:00.00	931541.94	-2247786.86	2240296.88	06-09	00	(0.129780, 37.918745)	49152	0.01183
2015:095:00:00:00.00	1477954.18	-1669080.54	1871127.70	07-09	00	(0.132035, 54.219866)	49152	0.00879
2015:095:00:00:12.00	-4118945.19	-4321187.64	-2807449.41	05-06	00	(0.039670, -166.045846)	49152	0.00180
2015:095:00:00:12.00	-4664933.04	-4899916.53	-2437813.41	05-07	00	(0.029142, -174.851992)	49152	0.00134
2015:095:00:00:12.00	-3185066.82	-6568719.37	-567949.68	05-09	00	(0.024064, -168.916548)	49152	0.00230
2015:095:00:00:12.00	-545987.85	-578808.89	369636.00	06-07	00	(0.346265, -14.869915)	49152	0.00687
2015:095:00:00:12.00	933878.36	-2247611.73	2239499.73	06-09	00	(0.113991, 36.083335)	49152	0.01183
2015:095:00:00:12.00	1479866.21	-1668802.84	1869863.73	07-09	00	(0.138641, 48.674399)	49152	0.00879
2015:095:00:00:24.00	-4120531.67	-4321881.22	-2803928.39	05-06	00	(0.039794, -164.917410)	49152	0.00180
2015:095:00:00:24.00	-4666094.71	-4900792.59	-2433825.93	05-07	00	(0.030904, -175.200210)	49152	0.00134
2015:095:00:00:24.00	-3184317.59	-6569317.37	-565227.82	05-09	00	(0.025062, -175.037937)	49152	0.00230
2015:095:00:00:24.00	-545563.04	-578911.37	370102.46	06-07	00	(0.336058, -13.847839)	49152	0.00687
2015:095:00:00:24.00	936214.08	-2247436.15	2238700.57	06-09	00	(0.142869, 43.852847)	49152	0.01183
2015:095:00:00:24.00	1481777.12	-1668524.78	1868598.11	07-09	00	(0.125307, 50.086366)	49152	0.00879
2015:095:00:00:36.00	-4122115.00	-4322655.09	-2800486.01	05-06	00	(0.039750, -166.030461)	49152	0.00180
2015:095:00:00:36.00	-4667252.81	-4901668.86	-2429837.46	05-07	00	(0.031860, -179.529081)	49152	0.00134
2015:095:00:00:36.00	-3183565.91	-6569915.23	-562506.60	05-09	00	(0.023390, -179.226592)	49152	0.00230
2015:095:00:00:36.00	-545137.81	-579013.77	370568.55	06-07	00	(0.353044, -15.525050)	49152	0.00687

--:--- pmap_000_000_UVdata.txt Top L1 (Text)

For information about GNU Emacs and the GNU system, type C-h C-a.

Using simulated data

Imaging



(Lu+ 2014)

OIFITS input (closure phases)

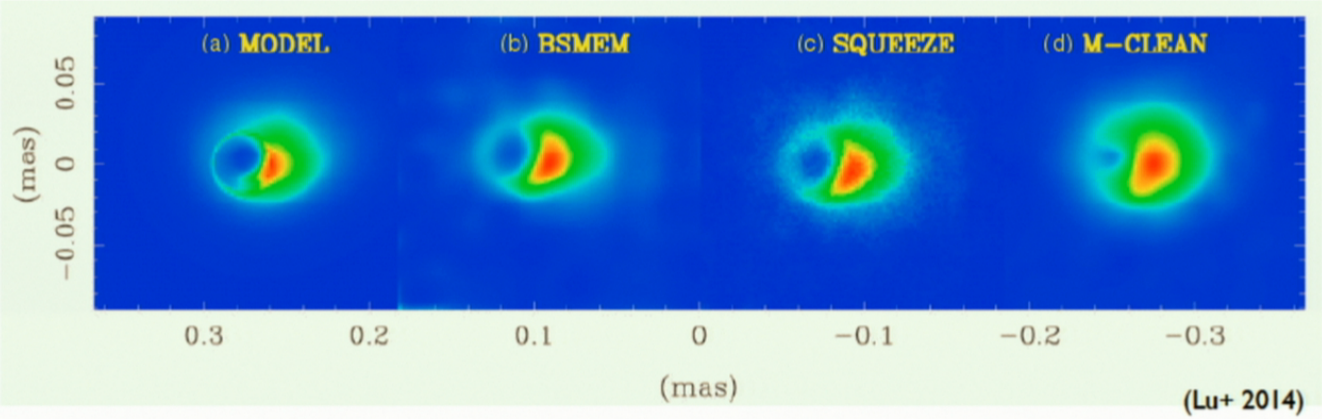
- BSMEM: Bispectral Maximum Entropy Method
- SQUEEZE: Markov Chain Imager

FITS-IDI/UVFITS input (visibility phases)

- (Multi-scale) CLEAN

Using simulated data

Imaging



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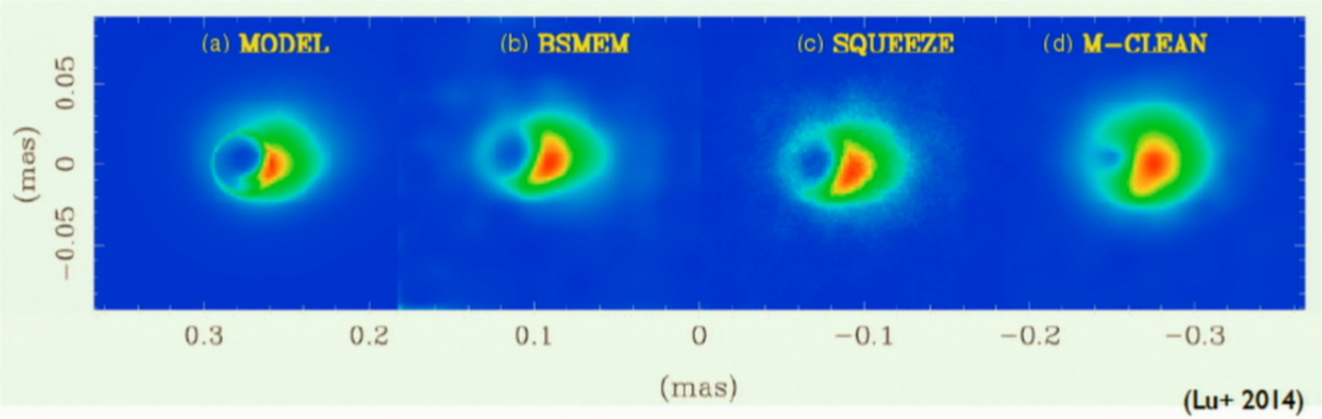

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Using simulated data

Imaging

VLBI observable quantities

- Visibility amplitudes

Using simulated data

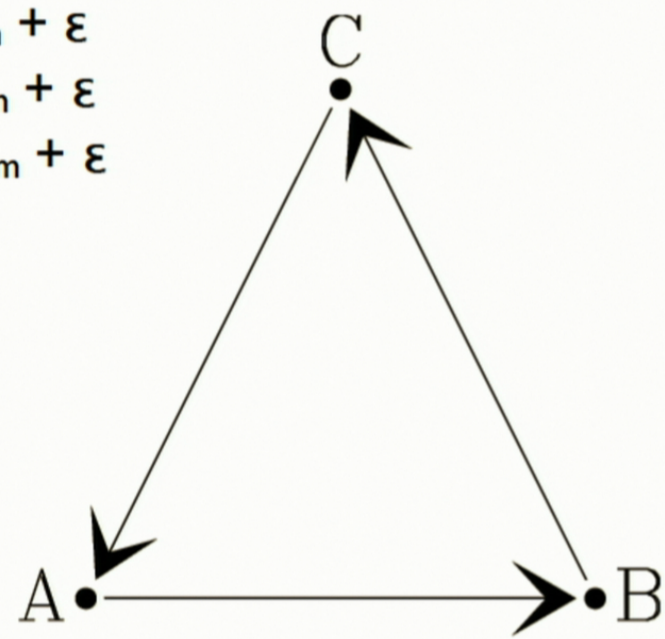
Imaging

VLBI observable quantities

- Visibility amplitudes
- Closure phases: robust against atmospheric phase errors

$$\varphi_{AB,\,obs} = \varphi_{AB,\,src} + \sigma_{A,\,atm} - \sigma_{B,\,atm} + \varepsilon$$
$$\varphi_{BC,\,obs} = \varphi_{BC,\,src} + \sigma_{B,\,atm} - \sigma_{C,\,atm} + \varepsilon$$
$$\varphi_{CA,\,obs} = \varphi_{CA,\,src} + \sigma_{C,\,atm} - \sigma_{A,\,atm} + \varepsilon$$

$$\varphi_{ABC,\,obs} = \varphi_{ABC,\,src} + \varepsilon$$



Using simulated data

Imaging

VLBI observable quantities

- Visibility amplitudes
- Closure phases: robust against atmospheric phase errors
- Closure amplitudes: robust against amplitude miscalibration
- Polarimetric ratios: robust against both

$$|V_{AB,\,src,RL}| = g_{A,R}\, g_{B,L}\, |V_{AB,\,obs,RL}|$$

$$|V_{AB,\,src,RL}|/|V_{AB,\,src,LL}| = (g_{A,R}/g_{A,L})|V_{AB,\,obs,RL}|/|V_{AB,\,obs,LL}|$$

$$\varphi_{AB,\,obs,\,RL} = \varphi_{AB,\,src,RL} + \sigma_{A,\,atm} - \sigma_{B,\,atm} + \varepsilon$$

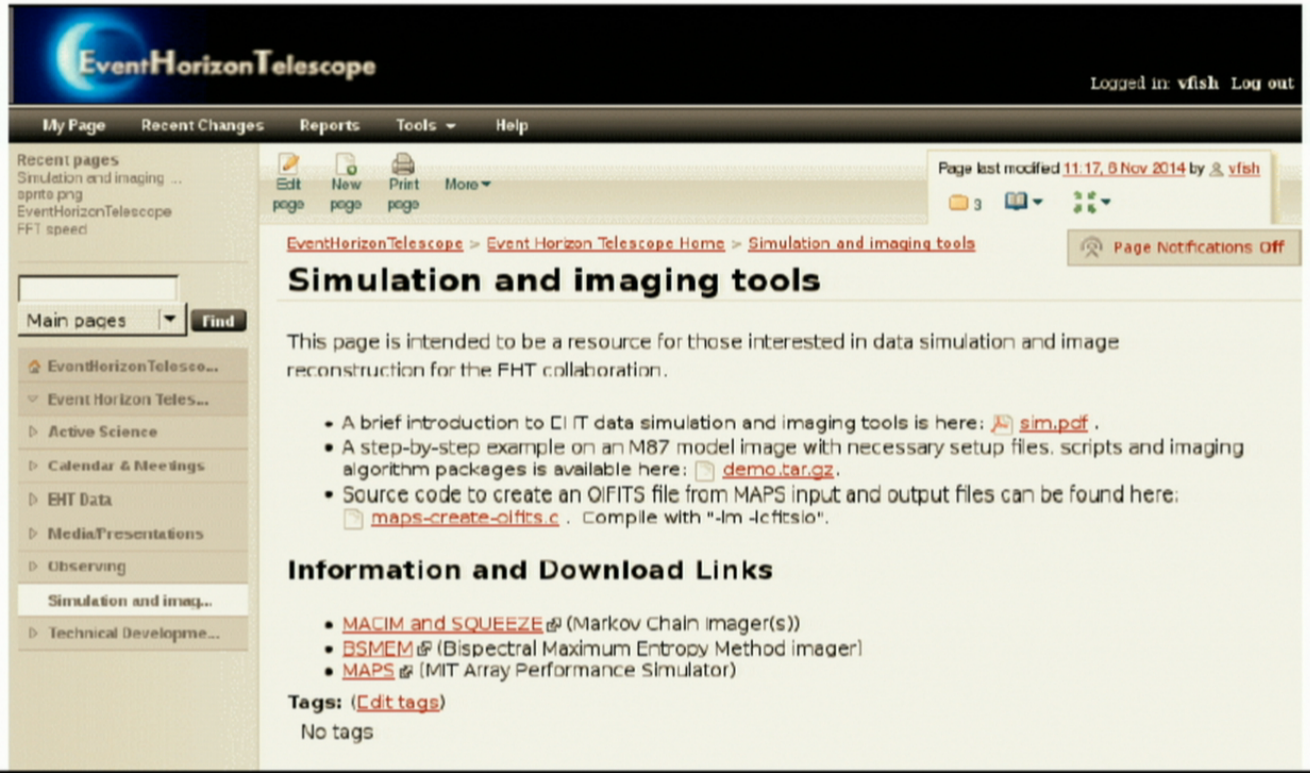
$$\varphi_{AB,\,obs,\,LL} = \varphi_{AB,\,src,LL} + \sigma_{A,\,atm} - \sigma_{B,\,atm} + \varepsilon$$

$$\varphi_{AB,\,obs,\,RL} - \varphi_{AB,\,obs,\,LL} = \varphi_{AB,\,src,RL} - \varphi_{AB,\,src,LL} + \varepsilon$$

Tools

MAPS demo available on the EHT Wiki (courtesy R. Lu)

Links to imaging tools



Coming soon

Web-based form for easy image reconstruction (courtesy Katie Bouman, MIT CSAIL)

Summary

Synthetic data are useful for theorists and observers alike

The EHT Wiki has examples and links to simulation and image-reconstruction software

It's good to cross-check your simulation against another

Do you have useful tools/scripts/software? Please share!