eht-imaging Roadmap

Renkun Kuang

September 29, 2019

Contents

Python modules for simulating and manipulating VLBI data and producing images with regularized maximum likelihood methods by Andrew Chael from CfA of Harvard.

1 Introduction

ehtim (eht-imaging) is a Imaging, analysis, and simulation software for radio interferometry.

1.1 Related links

https://achael.github.io/
https://github.com/achael/eht-imaging
documentation
第一张黑洞照片全靠VLBI，这个Github项目教你用Python实现.

2 Installation

Download the latest version from the GitHub repository, change to the main directory and run:
sudo pip3 install .

If you want to use fast fourier transforms, you will also need to separately install NFFT and its pynfft wrapper. The simplest way is to use conda to install both:
conda install -c conda-forge pynfft

{conda is not installed on my computer, so I go to Anaconda 镜像使用帮助 and install the miniconda3 from this link by downloading and executing the Miniconda3-4.7.10-Linux-x86_64.sh file.}

3 eht-imaging tutorial/documentation

3.1 Documentation

documentation

3.2 Some ways to learn to use the code

1. Start with the script examples/example.py, which contains a series of sample commands to load an image and array, generate data, and produce an image with various imaging algorithms.
   After I run the example.py, there are some errors:

```
$ python3 example.py
Warning: No NFFT installed! Cannot use nfft functions
Warning: No NFFT installed!
Warning: No NFFT installed! Cannot use nfft functions
Warning: No NFFT installed! Cannot use nfft functions
Welcome to eht-imaging! v  1.1.1
Loading text image:  ../models/avery_sgra_eofn.txt
Generating empty observation file . . .
WARNING: failed to download http://maia.usno.navy.mil/ser7/finals2000A.all and http://toshi.nofs.navy.mil/ser7/finals2000A.all, using local IERS-
B: <urlopen error [Errno -3] Temporary failure in name resolution>;<urlopen error [Errno -3] Temporary failure in name resolution> [astropy.utils
.iers.iers]
```

(The command of conda install seems to be not working) So first I need to install: NFFT and its pynfft wrapper

- The NFFT:
  depends on the FFTW library, So I run: sudo apt-get install fftw-dev
  git clone https://github.com/NFFT/nfft.git

- pyfftw:
  sudo pip3 install pyfftw

2. Slides(not available anymore, but I found it here) from the EHT2016 data generation and imaging workshop contain a tutorial on generating data with the vlbi imaging VLBI Reconstruction Dataset website, loading into the library, and producing an image. Note that this presentation used a previous version of the code – some function names and prefixes may need to be updated.

4 Some publications that use ehtim

4.1 The Size, Shape, and Scattering of Sagittarius A* at 86 GHz: First VLBI with ALMA, Issaoun et al. 2019

The Galactic Center supermassive black hole Sagittarius A* (Sgr A*) is one of the most promising targets to study the dynamics of black hole accretion and outflow via direct imaging with very long baseline interferometry (VLBI). At 3.5 mm (86 GHz), the emission from Sgr A* is resolvable with the Global Millimeter VLBI Array (GMVA). **We present the first observations of Sgr A* with the phased Atacama Large Millimeter/submillimeter Array (ALMA) joining the GMVA.** Our observations achieve an angular resolution of 87μas, improving upon previous experiments by a factor of two. We reconstruct a first image of the unscattered source structure of Sgr A* at 3.5 mm, mitigating effects of interstellar scattering. The unscattered source has a major axis size of $120 \pm 34\mu$as (12 ± 3.4 Schwarzschild radii), and a symmetrical morphology (axial ratio of 1.2+0.30.2), which is further supported by closure phases[Methods of using closure phases in radio aperture synthesis] consistent with zero within 3σ. We show that multiple disk-dominated models of Sgr A* match our observational constraints, while the two jet-dominated models considered are constrained to small viewing angles. Our long-baseline detections to ALMA also provide

new constraints on the scattering of Sgr A*, and we show that refractive scattering effects are likely to be weak for images of Sgr A* at 1.3 mm with the Event Horizon Telescope. **Our results provide the most stringent constraints to date for the intrinsic morphology and refractive scattering of Sgr A*, demonstrating the exceptional contribution of ALMA to millimeter VLBI.**

We employ the eht-imaging library, a regularized maximum likelihood imaging software package, to image our sources (Chael et al. 2016, 2018b).
Due to the elevated noise level for the VLBA in our observations and the scattering properties of Sagittarius A*, standard imaging software packages like AIPS (Greisen 2003) or Difmap (Shepherd et al. 1995) do not offer the flexibility and necessary tools to obtain an unscattered image of the source.
The eht-imaging library is a Python based software package that is easily scriptable, flexible and modular.
It is able to make images with various data products (closure phase and amplitude, bispectra, visibilities), and it contains a suite of image "regularizers" such as maximum entropy and sparsity regularization. The library also possesses a routine for "stochastic optics", a regularized implementation of scattering mitigation presented in Johnson (2016), making it a natural choice for our analysis. In this section we present our imaging methods for both calibrators (Section 4.1) and for Sgr A (Section 4.2).