

Essential Radio Astronomy Lecture Note

Renkun Kuang

September 5, 2019

Contents

1	Introduction to Radio Astronomy	2
1.1	Related links	2
1.2	Software Preparation	2
1.2.1	AIPS	3
1.2.2	CASA	8
1.3	Introduction to Radio Astronomy	10
1.3.1	The Radio Window	10
1.3.2	The low-frequency cut-off	11
1.3.3	The high-frequency cut-off (absorption)	11

Chapter 1

Introduction to Radio Astronomy

1.1 Related links

- <https://www.cv.nrao.edu/course/ast534/PDFnewfiles/IntroRadioastro.pdf>
- https://www.astron.nl/eris2017/Documents/ERIS2017_L1_McKean.pdf
2017 European Radio Interferometry School, a week of lectures and tutorials on how to achieve scientific results from radio interferometry.
Topics covered:
 1. Calibration and imaging of continuum, spectral line, and polarisation data;
 2. Low-freq. (LOFAR domain), high-freq. (ALMA/IRAM domain), and VLBI-interferometry;
 3. Extracting information from the data and interpreting the results;
 4. Choosing the most suitable array and observing plan for your project.
- <http://www.radio-astronomy.org/pdf/sara-beginner-booklet.pdf>
- http://egg.astro.cornell.edu/alfalfa/ugradteam/pdf12/radio_lecture_jess_uat12.pdf
- <http://www.jb.man.ac.uk/tob/course/radio2.html>
- SKA Shanghai 2018

1.2 Software Preparation

ref: [2017 European Radio Interferometry School](#).

Examples will be drawn from m-, cm- and mm-wave instruments such as LOFAR, JVLA, EVN, eMERLIN and ALMA.

1.2.1 AIPS

- [1996 The AIPsview Astronomy Visualization Tools, PDF](#)

AIPsview is a set of two new software tools for visual data analysis being developed by the radio astronomy group at the University of Illinois as part of the AIPS++ project. The tools provide a wide range of functionality for the display and analysis of 2D and 3D astronomical data sets. In this paper we describe how to obtain further information about AIPsview on the WWW including how to obtain executable and source code, and discuss the current functionality of AIPsview and future development plans.

- <http://www.aips.nrao.edu/index.shtml>

What is AIPS

The Astronomical Image Processing System is a software package for calibration, data analysis, image display, plotting, and a variety of ancillary tasks on Astronomical Data. It comes from the National Radio Astronomy Observatory.

Download install.pl via ftp and the "perl install.pl -n" to install the software.

ftp host website: <ftp://ftp.aoc.nrao.edu/pub/software/aips>

linux下登陆FTP

In terminal, using following command to login:

```
lftp ftp://ftp.aoc.nrao.edu/pub/software/aips
```

Download files:

要下载文件首先得设置用于存放下载文件的本地目录。

命令: lcd 本地目录

然后进入待下载文件的目录。根据下载文件类型的不同, 命令也不同。

单个文件

命令: get file

get -c file 可以进行断点续传

批量文件

命令: mget *.txt 批量下载目录下的txt文件

mget -c *.txt 断点续传加上批量下载

整个目录

命令: mirror aaa/

```
lftp ftp.aoc.nrao.edu:/pub/software/aips> lcd ./
lcd ok, local cwd=/home/anything/THU/astro/software/aips
lftp ftp.aoc.nrao.edu:/pub/software/aips> mirror 31DEC19
`31DEC19.tar.gz' at 1206184 (0%) 47.0K/s eta:58m [Receiving data]
[0] 0:lftp*
```

```

===== AIPS 31DEC19 Install Wizard=====

Screen 11: FINAL REVIEW before installing!
-----
This is your last, best hope for checking the settings before
committing to the install. Please check these settings, and
make sure they are what you want:

  AIPS_ROOT (screen 3): /home/anything/THU/astro/software/aips/31DEC19
    Group (screen 4): anything
  Group Write (screen 4): YES
Architecture (screen 5): LNX64
  Site name (screen 5): ANY
  AIPS hosts (screen 6): LOCALHOST
  Data areas (screen 7): /home/anything/THU/astro/software/aips/31DEC19/DATA/LOCALHOST_1
    Printers (screen 8): Paper type (screen 8): A4
  Tape drives (screen 9):
  Tape hosts (screen 9): 127.0.0.1
    Advanced (screen 10): (not listed here)

/home/anything/THU/astro/software/aips/31DEC19/31DEC19/LNX64/SYSTEM/ANY/MAKE.MNJ: 69: /home/anything/
THU/astro/software/aips/31DEC19/31DEC19/LNX64/SYSTEM/ANY/MAKE.MNJ: /opt/local/compilers/gcc-6/bin/gcc
: not found
MAKE.MNJ - UPDLSTDAT compiled
MAKE.MNJ - all .OLD files created
MAKE.MNJ - LAST*.DAT files created with begin date of 20190903.000000
MAKE.MNJ - Done.
MAKE.MNJ - The MNJ now uses cvs (http://www.cvshome.org) for updates;
MAKE.MNJ - looking to see if I can find a copy of it...
MAKE.MNJ - I can not seem to find it, either it is not here or it is
MAKE.MNJ - here, but it is installed in a place that is not in your
MAKE.MNJ - search path. If it is not here, you should install it and
MAKE.MNJ - run MAKE.MNJ again. Otherwise, please tell me where you
MAKE.MNJ - put it.
MAKE.MNJ - Full path to cvs: : |

```

install cvs: <http://www.cvshome.org>, [instruction](#)

installing AIPS failed.
[2019 install instruction](#)

[Installation instructions for Training Week 1](#)

Installation instructions for Training Week 1

There are two courses in training week 1: radio astronomy and telescope systems, and radio interferometry. Both of these have a hands-on component, and software should be pre-installed on laptops beforehand. The software packages needed are IPython for the IPython notebook component of the radio astronomy course, and AIPS or CASA for radio interferometry. Either MacOS or Linux is needed (i.e. **not Windows**). On Windows laptops or PCs it should be possible to install a VirtualBox <https://www.virtualbox.org/> with Linux as the guest operating system, or alternatively have Linux as a dual boot if you are planning to use it a lot.

1. Radio astronomy

This course uses IPython notebooks, so IPython is needed. On Linux systems with `pip`, you may be able to get and install IPython with `pip install ipython`. (IPython does run on Windows in theory, but we have not tested the notebooks with Windows, and MacOS/Linux is needed in any case for part 2).

Probably the easiest (and on some systems the only) way to install IPython is via the installation of Jupyter, which is available on

jupyter.readthedocs.org/en/latest/install.html

This installs without problems provided that at least Python 2.7 is present. If you do not have Python 2.7, then the best course is to install **anaconda** - a link to installation instructions for this is given on the same webpage. Once you have anaconda, any other packages can be installed with the `conda install` command. In some cases (e.g. `jupyter`) this can be done directly: `conda install jupyter`. In other cases, all you should need to do is to google `conda [package-name]` for any package that appears to be missing.

You can test your installation by downloading the file

<http://www.jb.man.ac.uk/~njj/test.ipynb>

and running it with `jupyter notebook test.ipynb`. You should get a cell of commands with a blue line to the left. Clicking inside the cell and then selecting `cell` and then `Run cell` should produce a plot with blue dots.

2. Radio interferometry

2.1 Major packages

There are currently two major software packages for radio interferometry, AIPS and CASA. AIPS is an older, Fortran-based system; CASA is a newer, C++/Python-based system which will eventually supersede AIPS. CASA has a fuller suite of imaging features, including much better wide-field mapping and imaging algorithms, but AIPS has some features useful for long-baseline interferometry.

AIPS is the primary software package for VLBI, e-MERLIN and LOFAR (long baselines). CASA, or CASA-based, systems are the primary system for LOFAR (other than long baselines), the JVLA, and ALMA. The syntax of the two packages is not hugely different, and there is a translation available on https://casaguides.nrao.edu/index.php?title=aips-to-casa_Cheat_Sheet.

The course will be bilingual (in AIPS and CASA!) so you can choose which one to install. Both are interoperable with Python: CASA natively, and AIPS by an interface (ParselTongue, which is not covered in the first week's course).

Both are distributed as binaries and should be relatively straightforward to install on any version of Linux or any version of MacOS. Please install and test one (or both) as below if you are intending to follow the course. **Note: neither AIPS nor CASA runs on Windows.**

Both packages are available as binary installations for MacOS and Linux. AIPS can be downloaded from

<http://www.aips.nrao.edu/install.shtml>

and CASA from

http://casa.nrao.edu/casa_obtaining.shtml

In both cases, the installation should be relatively painless. For CASA, the installation comes as a unix tar file, which can be unzipped in any desired directory. If you start the executable `casapy`, which should be in the top directory, this should start CASA and produce a log window.

For AIPS, the installation is slightly more complicated, but a Perl install wizard guides you through the steps. If you start the executable `START_AIPS`, which should be in the top directory, AIPS should start up and invite you to type in an AIPS number - any number larger than 10 should be fine. If you start it with the argument `tv=local`, then a black TV window should pop up as well.

2.2 Difmap

There is also a third useful package which does only some tasks in radio interferometry, but does them very well and very interactively. It is particularly useful for long-baseline interferometry. It's available from <ftp://ftp.astro.caltech.edu/pub/difmap/difmap.html>. It requires the plotting package PGPLOT, which is available from <http://www.astro.caltech.edu/~tjp/pgplot/>.

If there are any problems, I'm happy to try and help: neal.jackson@manchester.ac.uk although I may need to consult the local IT support here in complicated cases. Please forward screenshots and/or as much detail of error messages as possible in these cases.

- [天文博客](#)
- [How to build AIPS on Ubuntu](#)
- [The AIPS++ Project](#)

Finally successfully installed:

```
AipsWiz: =====> We're DONE!  Let's have a nice Banana Split! <=====
AipsWiz: ***** READ CAREFULLY *****
AipsWiz: ***** READ CAREFULLY *****
AipsWiz: Services should be defined either in /etc/services
        or your YP/NIS services map (all tcp services)
This may require sudo or root privileges
AipsWiz: ***** READ CAREFULLY *****
AipsWiz: Here are the final setup instructions for running AIPS

    1.  Reference the LOGIN.SH file in your .profile file
        or perhaps your .bashrc file
        (dot it now too, via ". ./LOGIN.SH")

    2.  Check that it works:

        aips notv tpok

        (this will not start a TV or tape servers).
        Try 'print 2 + 2' for a very basic test.

    3.  Make a cron entry for the do_daily.LOCALHOST file
        that the MAKE.MNJ created, so you can run the
        AIPS 'midnight job'.  This is optional but
        strongly recommended.

AipsWiz: That's it.  You should now have the latest AIPS!  Enjoy.

# anything @ anything-ThinkPad-E470c in ~/.aips [13:40:30]
$ |
```



```
# anything @ LOCALHOST in ~/.aips [13:48:17]
$ aips notv tpok
START_AIPS: Your initial AIPS printer is the
START_AIPS: - system name , AIPS type

START_AIPS: User data area assignments:
DADEVs.PL: This program is untested under Perl version 5.026
  (Using global default file /home/anything/.aips/DA00/DADEVs.PL)
  Disk 1 (1) is /home/anything/.aips/DATA/LOCALHOST_1

Tape assignments:
  Tape 1 is REMOTE
  Tape 2 is REMOTE

START_AIPS: Assuming TPMON daemons are running or not used (you said TPOK)
Starting up 31DEC18 AIPS with normal priority
Begin the one true AIPS number 1 (release of 31DEC18) at priority = 0
AIPS 1: You are NOT assigned a TV device or server
AIPS 1: You are NOT assigned a graphics device or server
AIPS 1: Enter user ID number
?2
AIPS 1:                               31DEC18 AIPS:
AIPS 1:      Copyright (C) 1995-2019 Associated Universities, Inc.
AIPS 1:      AIPS comes with ABSOLUTELY NO WARRANTY;
AIPS 1:      for details, type HELP GNUGPL
AIPS 1: This is free software, and you are welcome to redistribute it
AIPS 1: under certain conditions; type EXPLAIN GNUGPL for details.
AIPS 1: Previous session command-line history recovered.
AIPS 1: TAB-key completions enabled, type HELP READLINE for details.
AIPS 1: Recovered POPS environment from last exit
>print 2+2
AIPS 1:      4
>|
```

TWO VLBI TUTORIALS

From <http://www.aips.nrao.edu/index.shtml>

Two extensive tutorials on VLBI data reduction in AIPS have been prepared, complete with data sets, introductory material about AIPS, and detailed instructions. They are:

- [simple VLBA project including self-calibration](#)
- [spectral-line VLBA project plus astrometry](#)

Users new to, or rusty in, VLBI data reduction are encouraged to try these tutorials. Appendix C and Chapter 9 of the [AIPS CookBook](#) are also recommended.

1.2.2 CASA

[CASA-obtaining](#)

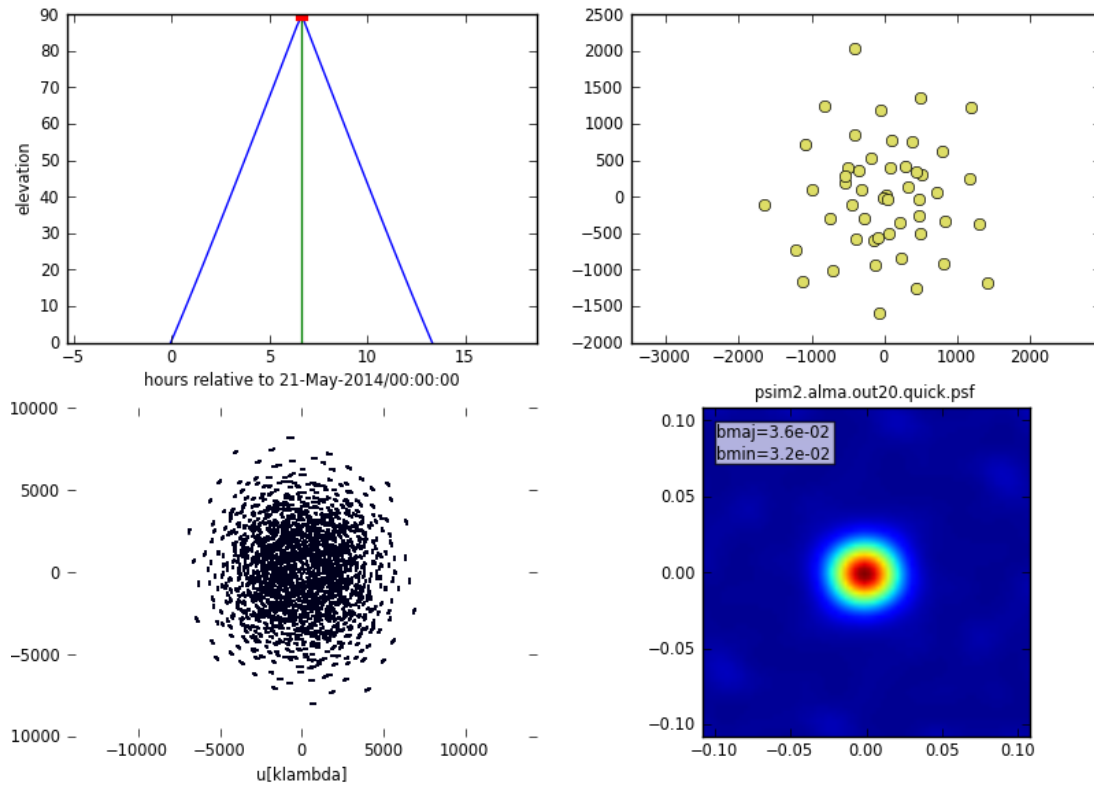
[CASA Documentation Homepage](#)

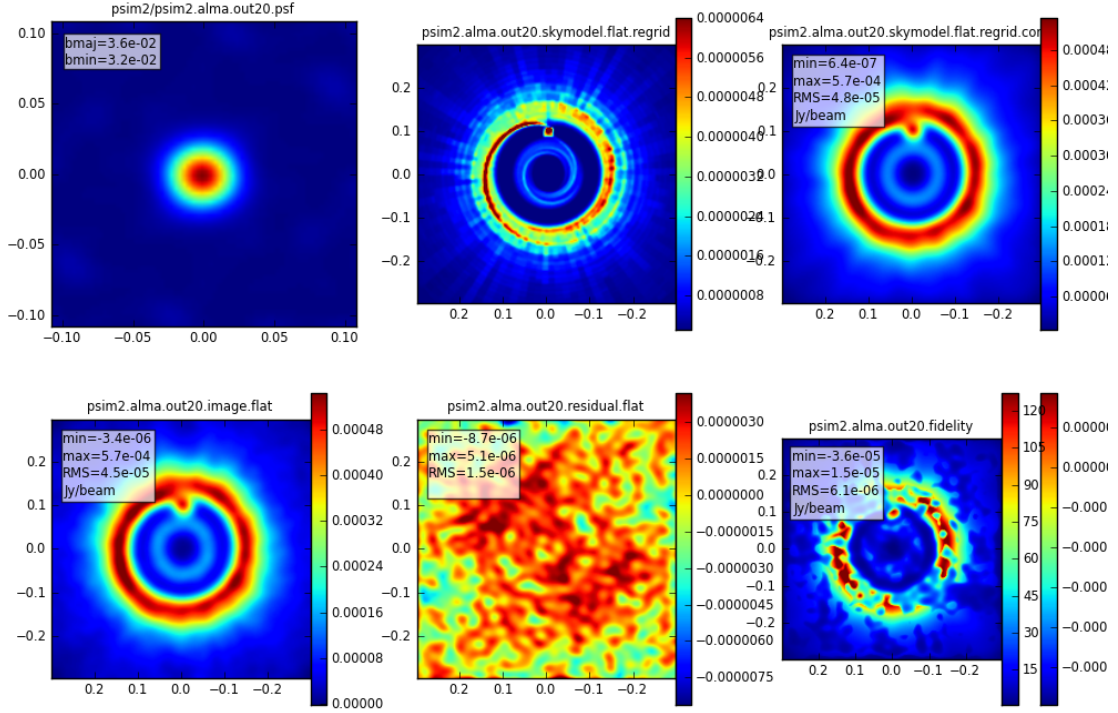
[CASA homepage](#)

[CASA Guides](#)

Protoplanetary Disk Simulation Using CASA

[Reference](#)





1.3 Introduction to Radio Astronomy

The following of this note file is mainly center on [2017 European Radio Interferometry School](#)(which aims to give a general introduction to radio astronomy, focusing on the issues that you must consider for single element telescopes that make up an interferometer) materials.

1.3.1 The Radio Window

$$\nu \sim 10^7 Hz - 10^{12} Hz, \quad \lambda \sim 10m - 0.1mm$$

The observing window is constrained by atmospheric absorption / emission and refraction.

1. Charged particles in the ionosphere reflects radio waves back into space at < 10 MHz.
2. Vibrational transitions of molecules have similar energy to infra-red photons and absorb the radiation at > 1 GHz (completely by ~ 300 GHz)

1.3.2 The low-frequency cut-off

The ionosphere consists of a plasma of charged particles (conducting layers), that has an effective refractive index of,

$$n^2 = 1 - \frac{\omega_p^2}{\omega^2} = 1 - \frac{\lambda^2}{\lambda_p^2}$$

where, the plasma frequency is defined as,

$$\nu_p[\text{Hz}] = \frac{\omega_p}{2\pi} = \left(\frac{N_e e^2}{4\pi^2 \epsilon_0 m}\right)^{1/2} = 8.97 \times 10^3 \sqrt{\frac{N_e}{[\text{cm}^{-3}]}}$$

when $\omega < \omega_p \rightarrow n^2 < 0$, there is no propagation, i.e. total reflection. (i.e. low-frequency cutoff)

Worked example: What is the cut-off frequency for LOFAR observations carried out when the electron density is $N_e = 2.5 \times 10^5 \text{cm}^{-3}$ (night time) and $N_e = 1.5 \times 10^6 \text{cm}^{-3}$ (day time)?

$$\nu_p[\text{Hz}] = 4.5 \text{ MHz (night time)}$$

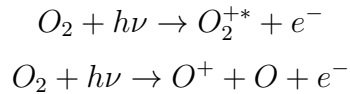
$$\nu_p[\text{Hz}] = 11 \text{ MHz (day time)}$$

(at night, the observable frequency by LOFAR can be lower)

At frequencies,

1. $\omega < \omega_p$: $n^2 < 0$, reflection ($\nu < 10 \text{MHz}$),
2. $\omega > \omega_p$: $n^2 > 0$, refraction ($10 \text{MHz} < \nu < 10 \text{GHz}$),
3. $\omega \gg \omega_p$: $n^2 \rightarrow 1$ ($\nu > 10 \text{GHz}$).

The observing conditions are dependent on the electron density, i.e. the solar conditions (space weather), since the ionisation is due to the ultra-violet radiation field from the Sun,



1.3.3 The high-frequency cut-off (absorption)