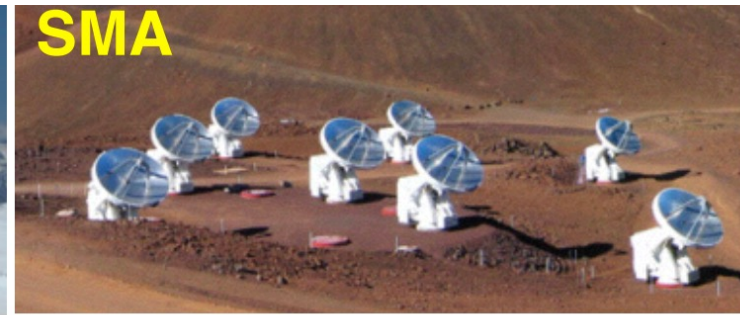# An Introduction to Radio Interferometry (Archival data I)
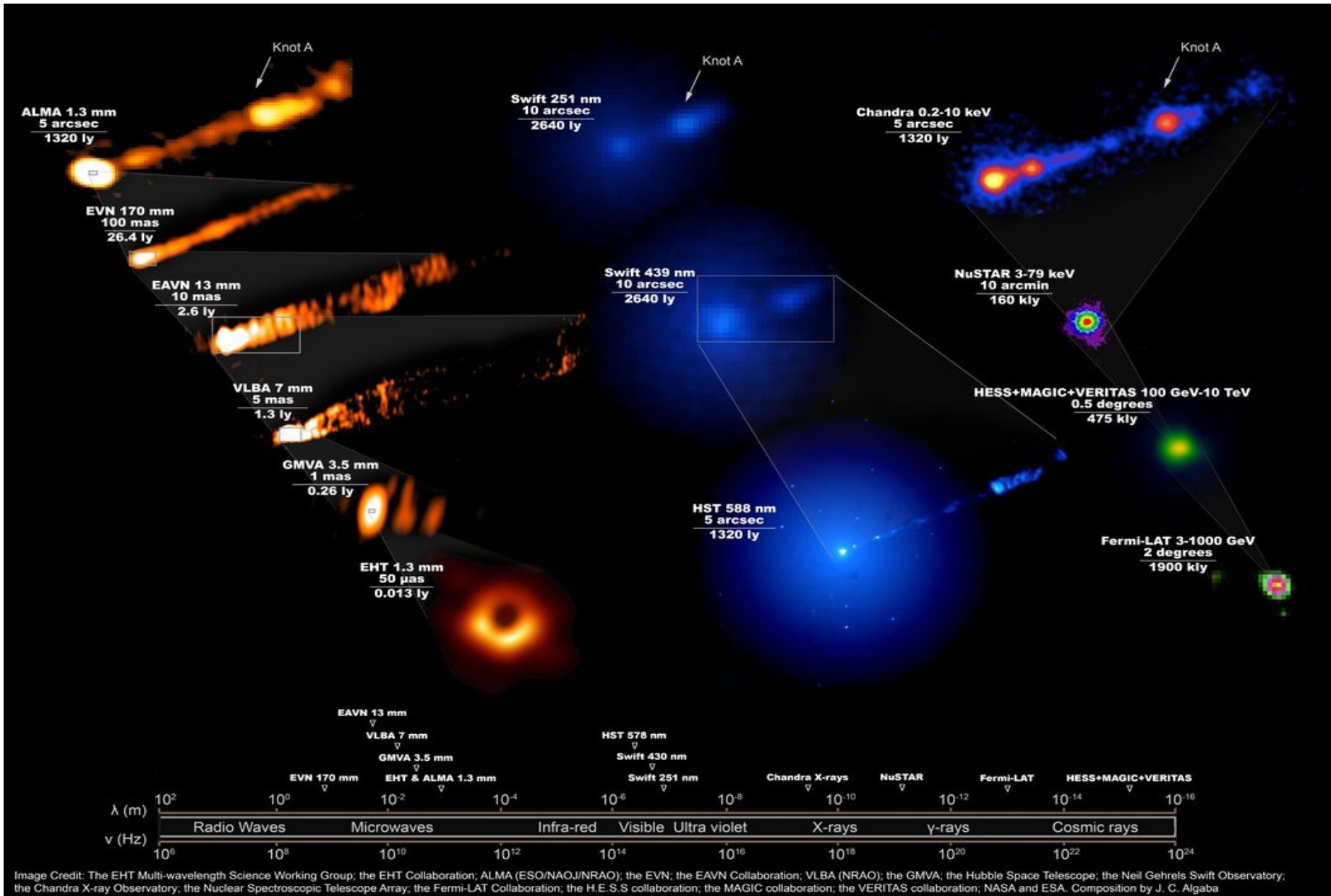
Nguyen Thi Phuong
Department of Astrophysics - Vietnam Nam National Space Center
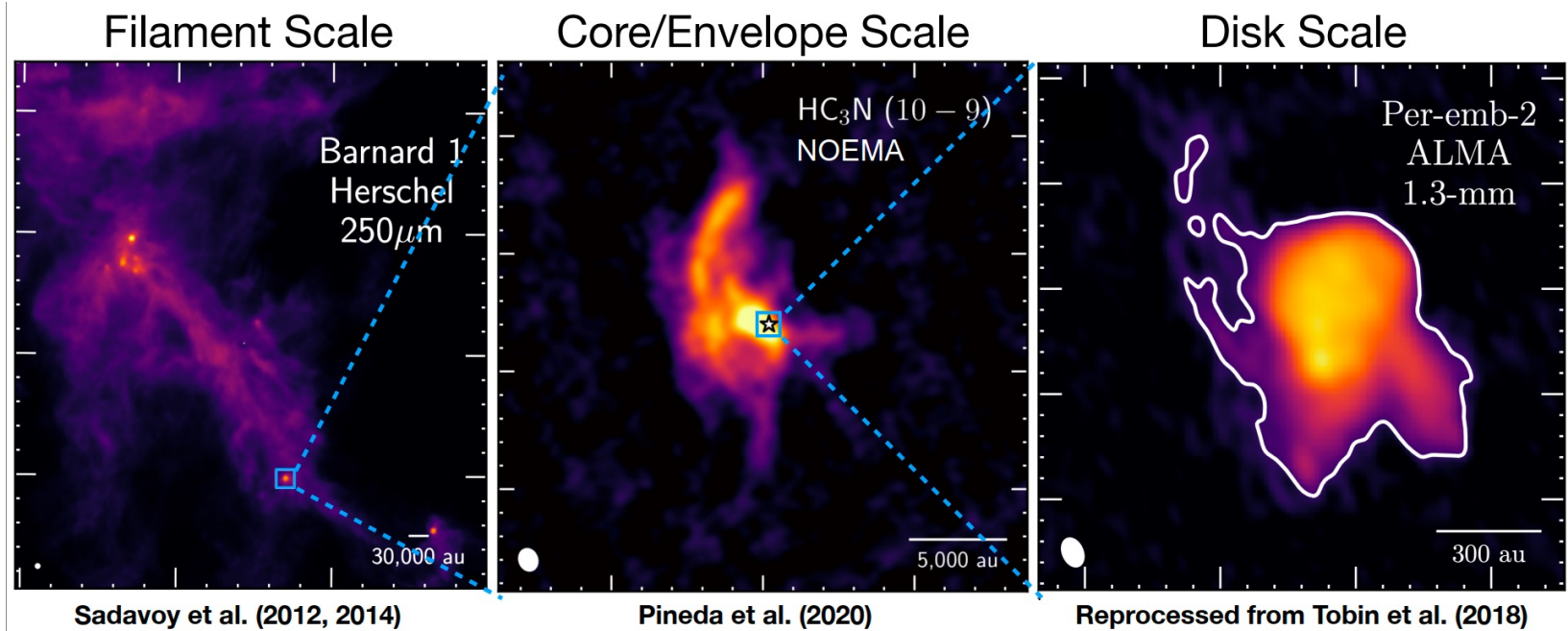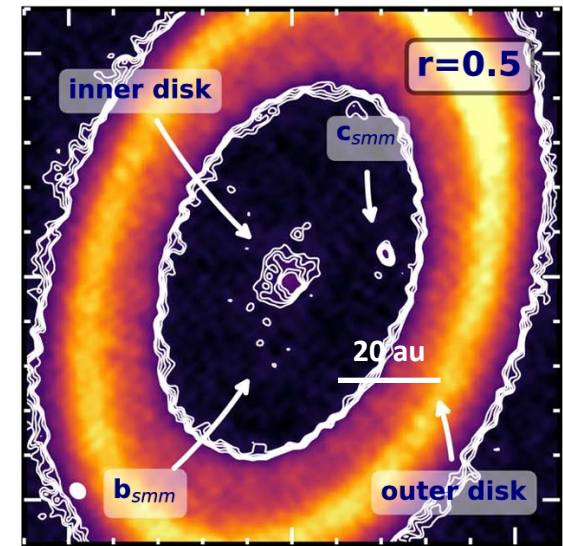Simon Astrophysics Group at IFIRSE/ICISE

Multi-scale and multi-wavelength observations
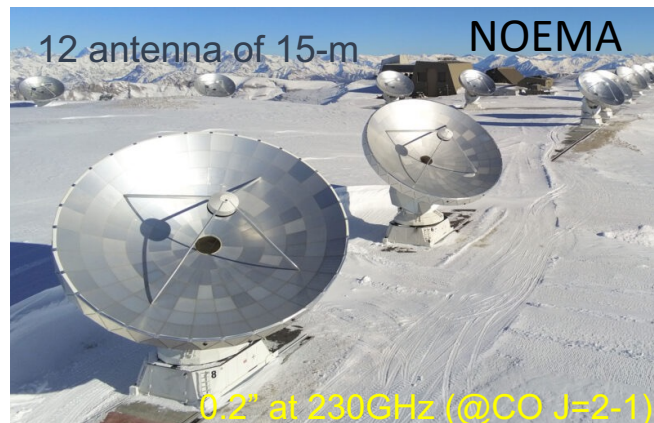

Knot A

ALMA 1.3 mm
5 arcsec
1320 ly

EVN 170 mm
100 mas
26.4 ly

EAVN 13 mm
10 mas
2.6 ly

VLBA 7 mm
5 mas
1.3 ly

GMVA 3.5 mm
1 mas
0.26 ly

EHT 1.3 mm
50 µas
0.013 ly

Knot A

Swift 251 nm
10 arcsec
2640 ly

Swift 439 nm
10 arcsec
2640 ly

HST 588 nm
5 arcsec
1320 ly

Knot A

Chandra 0.2-10 keV
5 arcsec
1320 ly

NuSTAR 3-79 keV
10 arcmin
160 kly

HESS+MAGIC+VERITAS 100 GeV-10 TeV
0.5 degrees
475 kly

Fermi-LAT 3-1000 GeV
2 degrees
1900 kly

	EAVN 13 mm ▽			HST 578 nm ▽					
	VLBA 7 mm ▽			Swift 430 nm ▽					
	GMVA 3.5 mm ▽								
EVN 170 mm ▽	EHT & ALMA 1.3 mm ▽			Swift 251 nm ▽		Chandra X-rays ▽	NuSTAR ▽	Fermi-LAT ▽	HESS+MAGIC+VERITAS ▽

λ (m)	10^2	10^0	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-14}	10^{-16}
	Radio Waves		Microwaves		Infra-red	Visible	Ultra violet	X-rays	γ-rays	Cosmic rays
v (Hz)	10^6	10^8	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}	10^{24}

Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

Why interferometry? Angular resolution! $\theta = \lambda/D$

Filament Scale

Barnard 1
Herschel
250μm

30,000 au

Sadavoy et al. (2012, 2014)

Core/Envelope Scale

HC$_3$N (10 − 9)
NOEMA

5,000 au

Pineda et al. (2020)

Disk Scale

Per-emb-2
ALMA
1.3-mm

300 au

Reprocessed from Tobin et al. (2018)

Many objects need resolution < 1 arcsec to be resolved
→ impossible to build a giant single dish!

JCMT: 15m

20" at 230 GHz

12 antenna of 15-m   NOEMA

0.2" at 230GHz (@CO J=2-1)

r=0.5
inner disk
c$_{smm}$
20 au
b$_{smm}$
outer disk

Benisty et al. 2021

(Sub)-mm interferometry

Array	Year in operation	Number (diameter) of antenna	Frequency (wavelength)
NOEMA	1988 - present	12 (15m)	80 – 370 GHz (3 – 0.8 mm)
Nobeyama	1994 - present	6 (10m)	22 – 350 GHz (13.6 – 0.8 mm)
SMA	2000 - present	8 (6m)	230 –345 GHz (1.3 – 0.9 mm)
ATCA	2002 - present	6 (22m)	1.1 –105 GHz (160 – 3 mm)
CARMA	2006 - 2015	6 (10.4 m) 9 (6.1 m) 8 (3.5 m)	80 – 270 GHz (3 – 1 mm)
ALMA	2011 - present	54 (12m) 12 (7m)	31 – 1000GHz (0.32 – 3.6 mm)
JVLA	2012 - present	27 (25m)	74 MHz – 50 GHz (4000 – 0.7 cm)
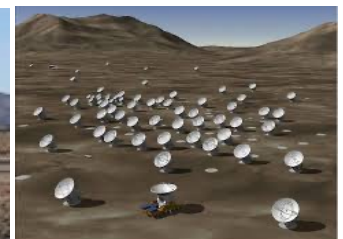
(Sub)-mm Sciences

Study of "cosmic origins"

➤ Cosmology and the high redshift universe

➤ Galaxies and galactic nuclei

➤ ISM, star formation and astrochemistry

➤ Planet-forming disks

➤ Stellar evolution

➤ Solar system
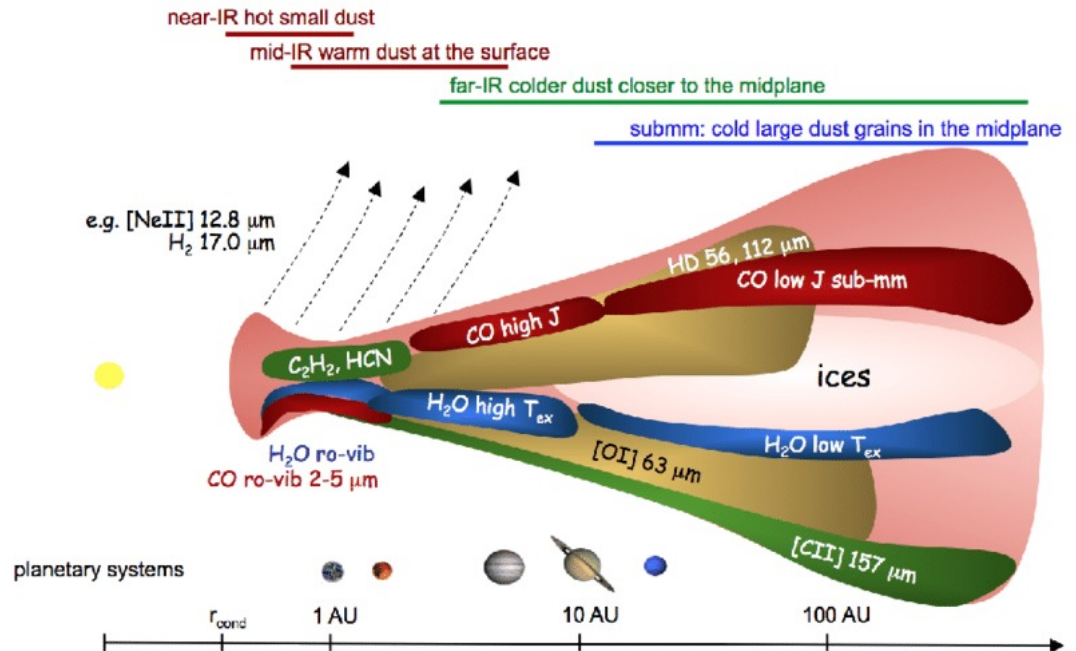
Interferometry observations and data reduction

Observations

An interferometer measures the interference pattern produced by two apertures.

The interference pattern is directly related to the source brightness.

The measured complex visibility, *V(u,v)*, is the 2D Fourier transform of the source brightness on the sky, *T(x,y)*.
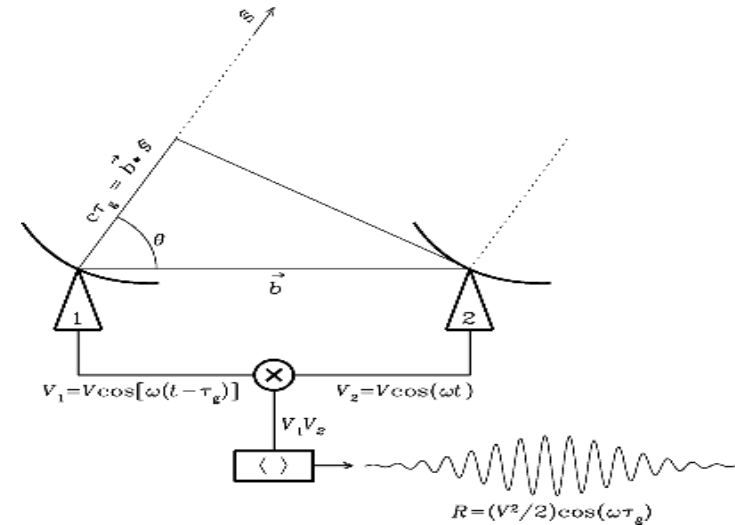
Calibrations

At any given time *t*, the interferometer provides:
V(ν, t) = spectrum OR V(t) = continuum data = spectrum average
(Here we do not consider (u, v) dependence)
We need various calibrations because:
- Electronics have variable gains (both amplitude and phase, frequency and time)
- Atmosphere absorption and path length fluctuations.

Observed visibility   True visibility

$$V_{obsij}(\nu,t) = G_{ij}(\nu,t) V_{ij}(\nu,t) + \text{noise}$$

Complex gain (phase + amp)

Imaging

(inverse) Fourier transform of observation gives the dirty image

$$T^D\ (x,y) = FT^{-1}\ \{B(u,v) \times V(u,v)\ \times W(u,v)\}$$

Which is the convolution of the true image by the dirty beam

$$T^D(x, y) = b(x, y) \otimes T(x, y)$$
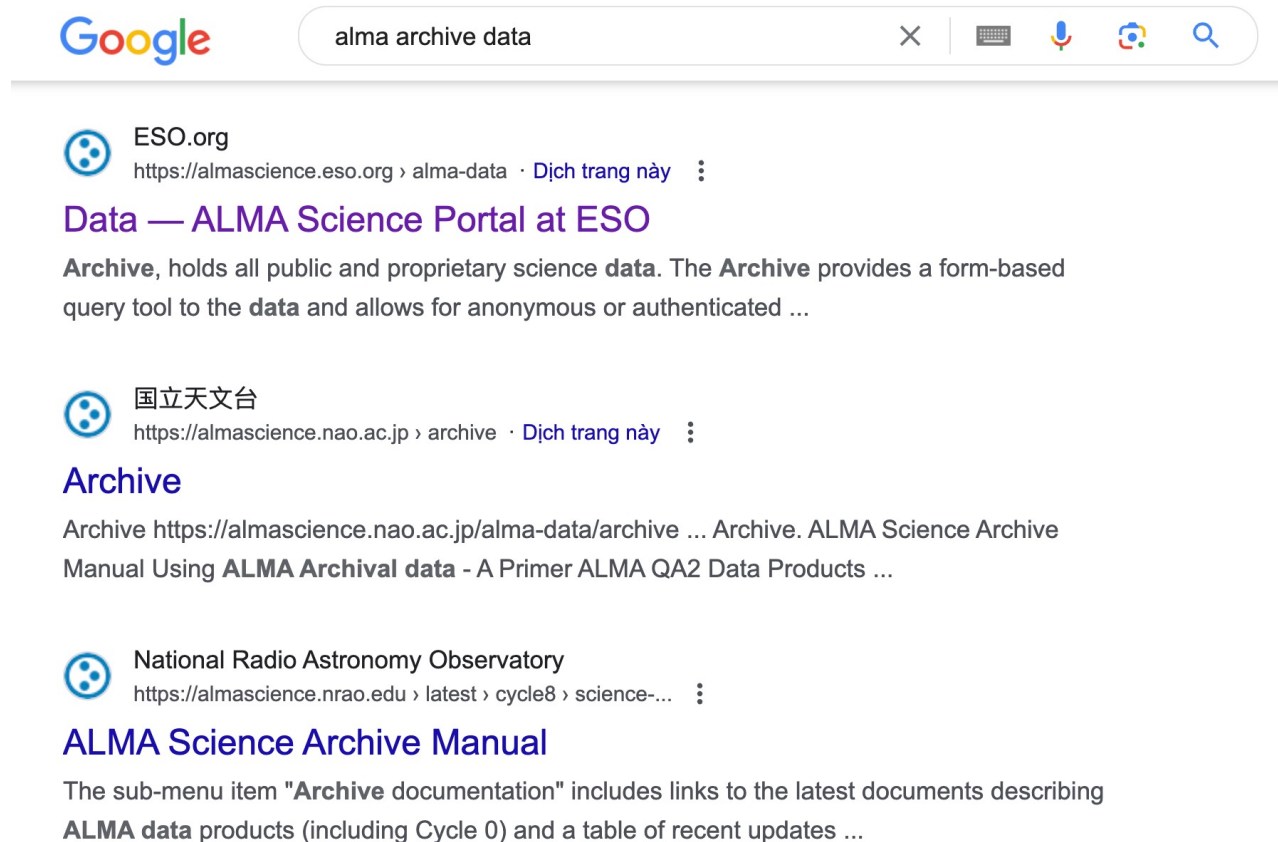
Deconvolution of the dirty beam yeilds the clean image
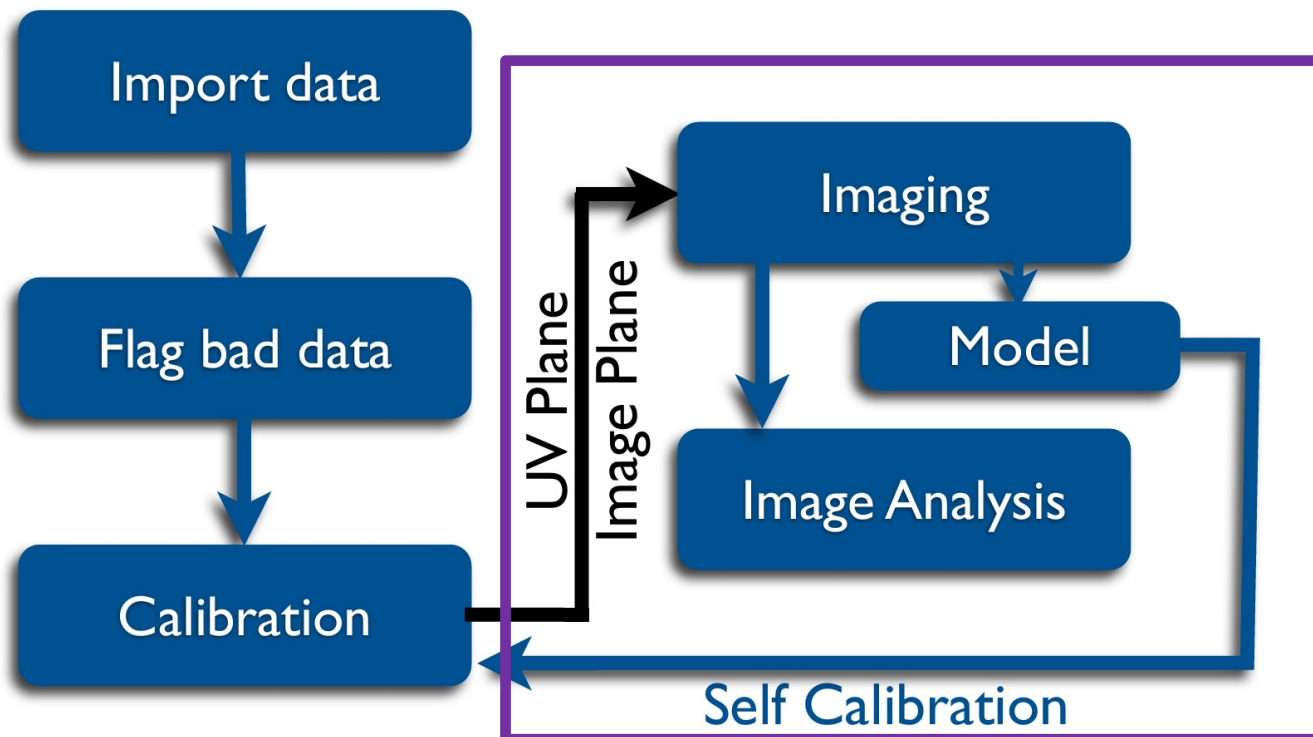
Archival Data

JVLA provides the archive fits images in ~ 1 year after the observations: on the website
NOEMA provides the archive data in ~ 2-3 years after the observations: upon your request
Nobeyama provides the archive fits images ….
ALMA provides everything to the public in ~1 year after delivering the data to PI

ALMA Archival Data

【How to request the calibrated visibility】

1. Log in to Helpdesk https://help.almascience.org/
2. Create a new ticket by clicking "Submit Helpdesk Ticket"
3. Choose "Archive and Data Retrieval (EA)" as Department
4. Put "Request of calibrated MS" as Subject
5. Choose "Data request (calibrated MS, stale data, calibrator data, or suggestions)" as Sub-category
6. Provide the following information in the box of "Message", then "Submit" the ticket

****

Message
****

a. Your affiliation
[example: University of Tokyo] (so that we can check if the institute does not have a network issue with NAOJ etc.)
b. Project Code and SB name of the data [please split Project Code and SB name with a space]
2013.1.00010.S NGC253_a_04_TM1
2013.1.00010.S NGC253_a_07_TM1
2014.1.00020.S NGC1068_a_06_TM1

Download data (link sent)
Install CASA (ver 6.5 is recommended)
Task: listobs, plotms, tclean, immoments, impv