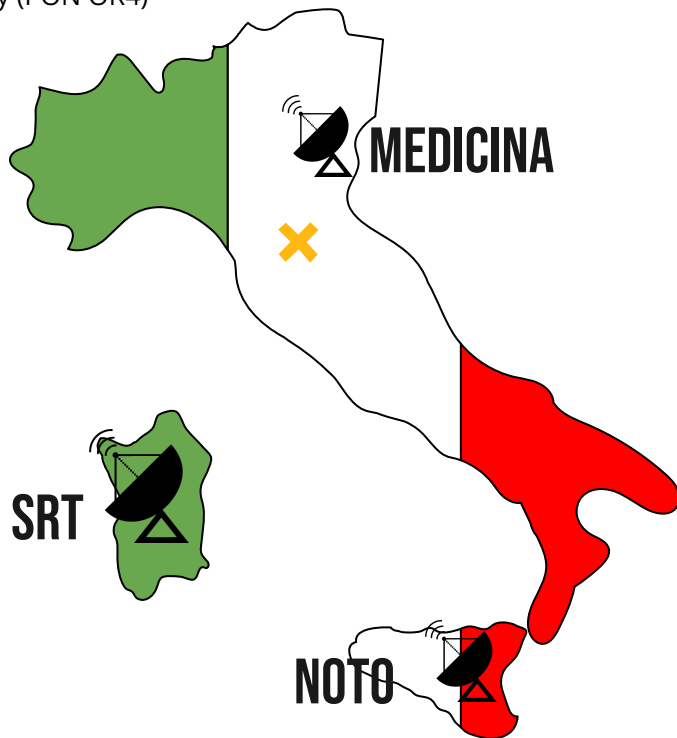


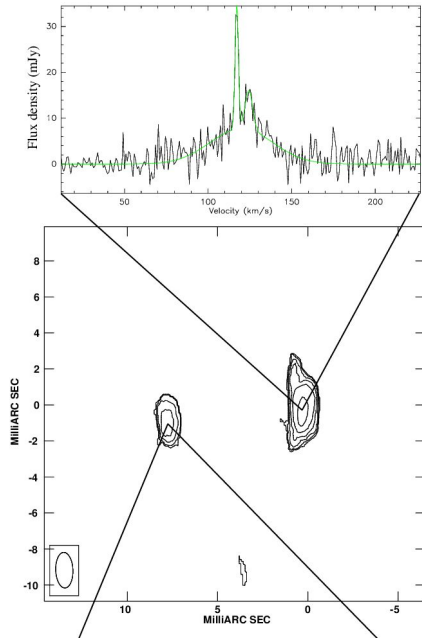
Lecture 9: Spectral line processing

Olga Bayandina

Installation of tri-band receivers to the INAF VLBI array (PON OR4)

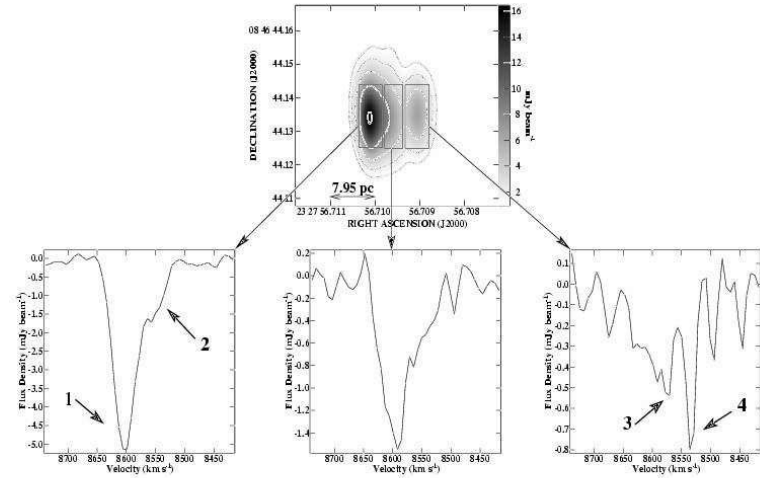


Spectral line



Brunthaler+2009

✗ Maser



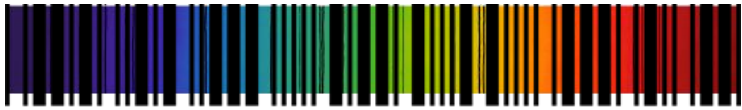
Momjian+2003

HI absorption

~1M_☉



Ingredients: hydrogen, helium,
oxygen, carbon, neon, iron



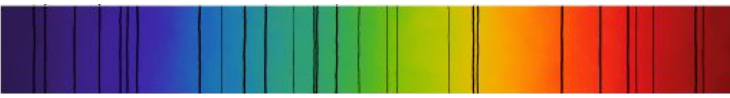
12345678

>8M_☉

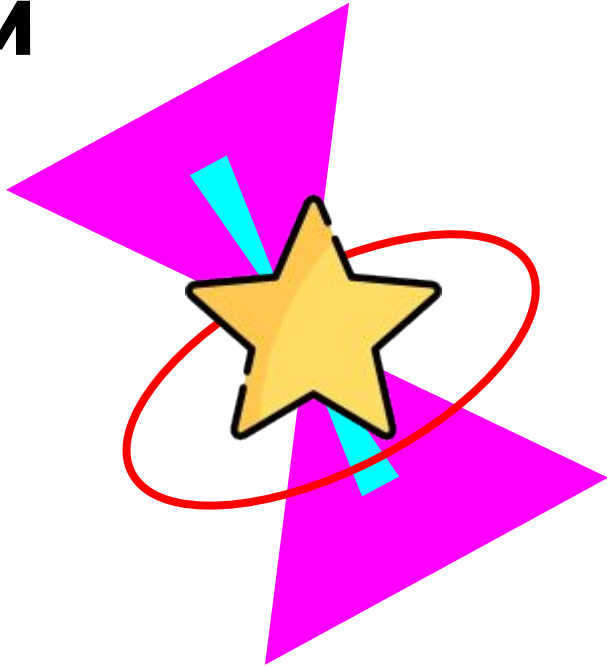


12345678

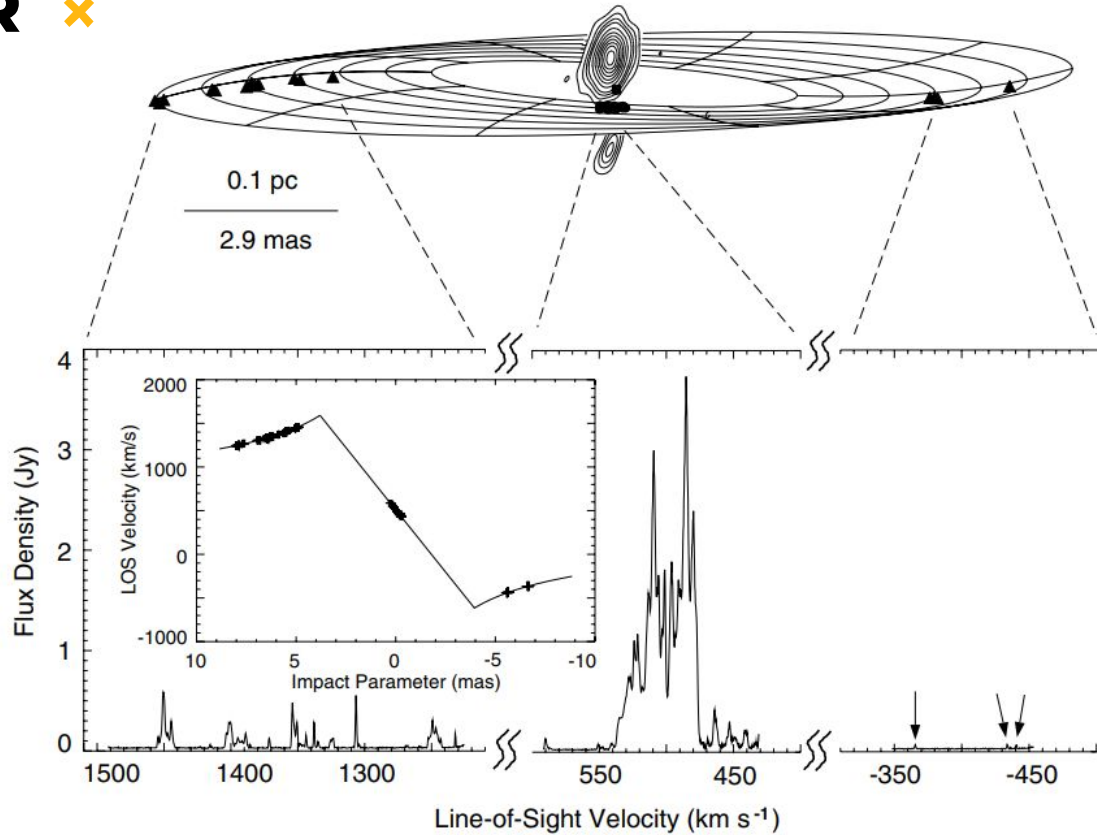
$\sim 1M_{\odot}$



$> 8M_{\odot}$

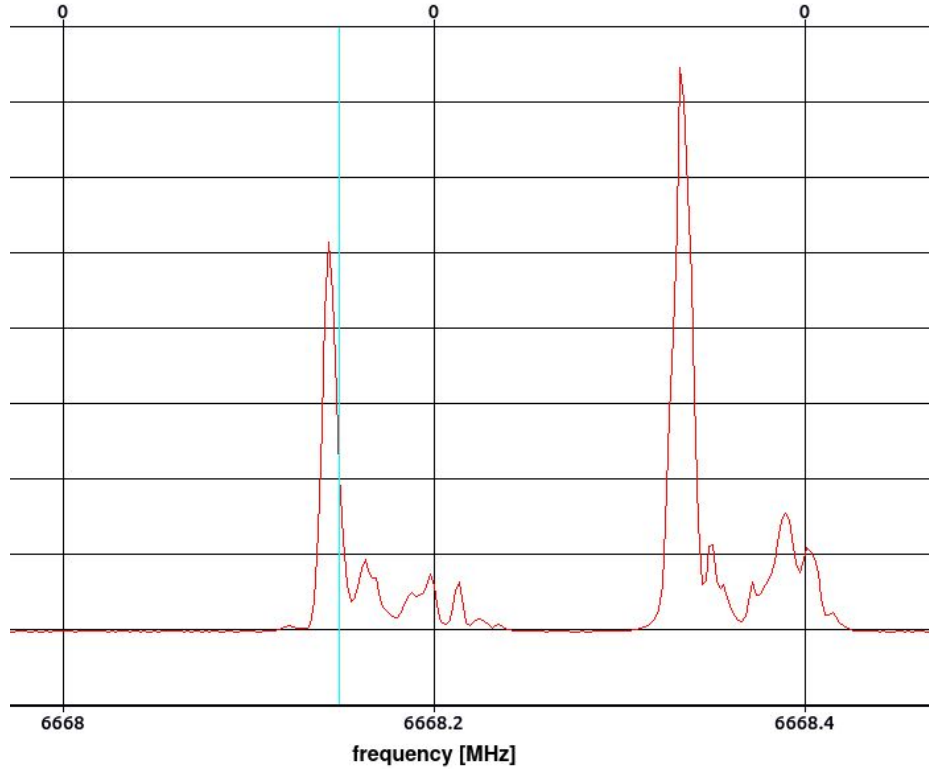


MASER ×

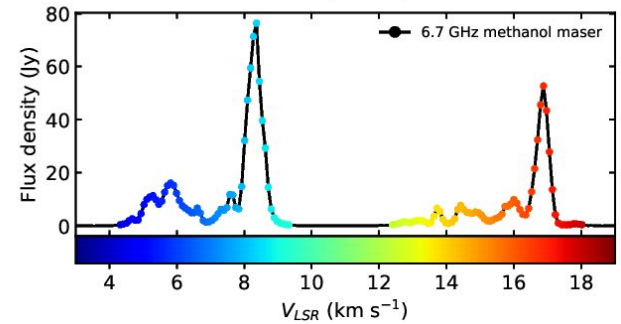
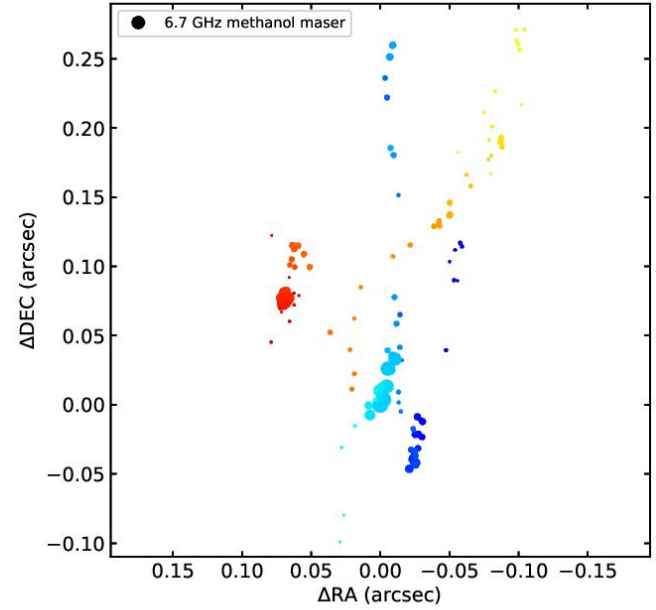


Brunthaler & Falcke 2004

MASER ✕

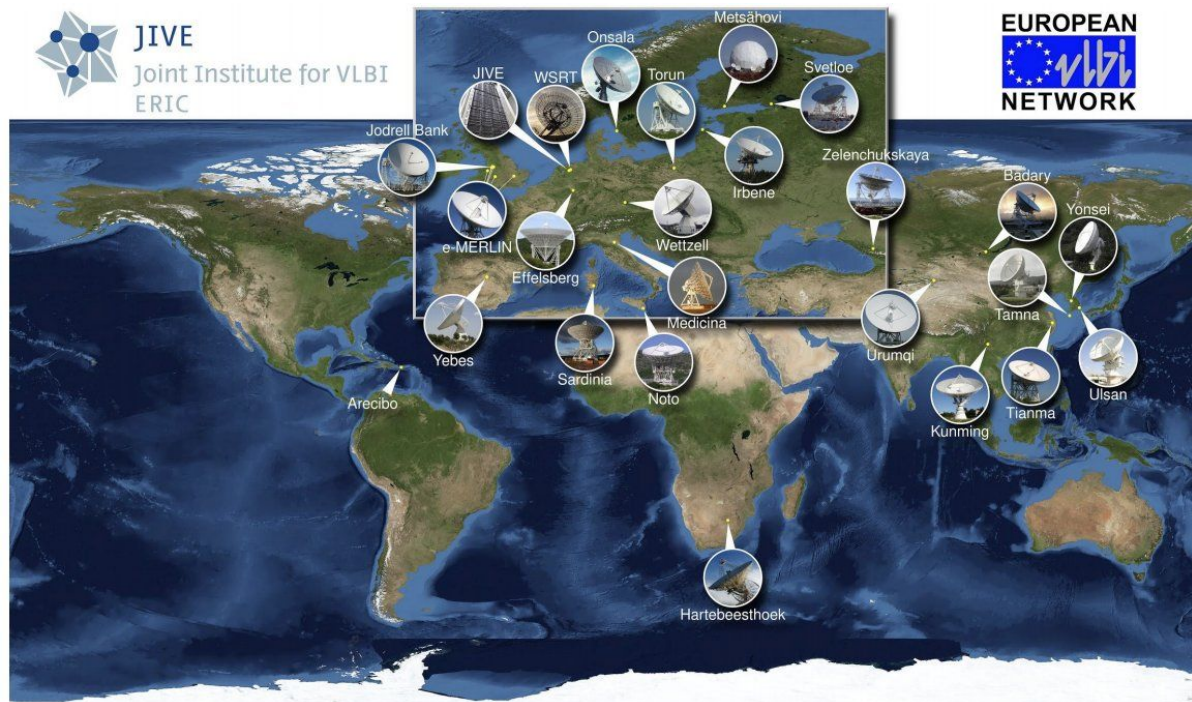


G11.497-1.485 6.7 GHz methanol maser



00x

Observation
Scheduling



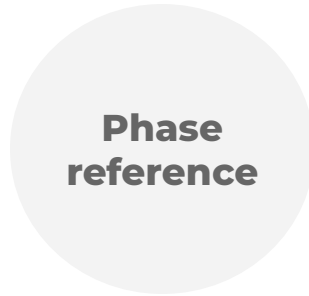
SCHEDULING



SOURCES



Continuum
source

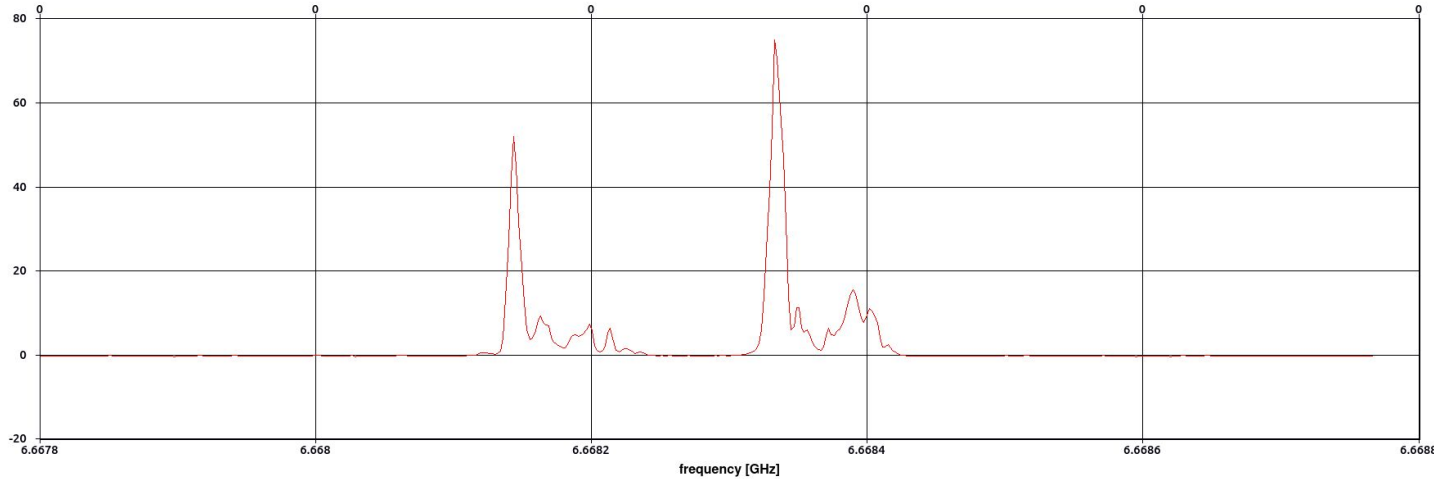


Continuum
source



Maser
source

SCHEDULING



Spectral resolution

Maser lines are narrow
(at least 3 channels)

Central Frequency

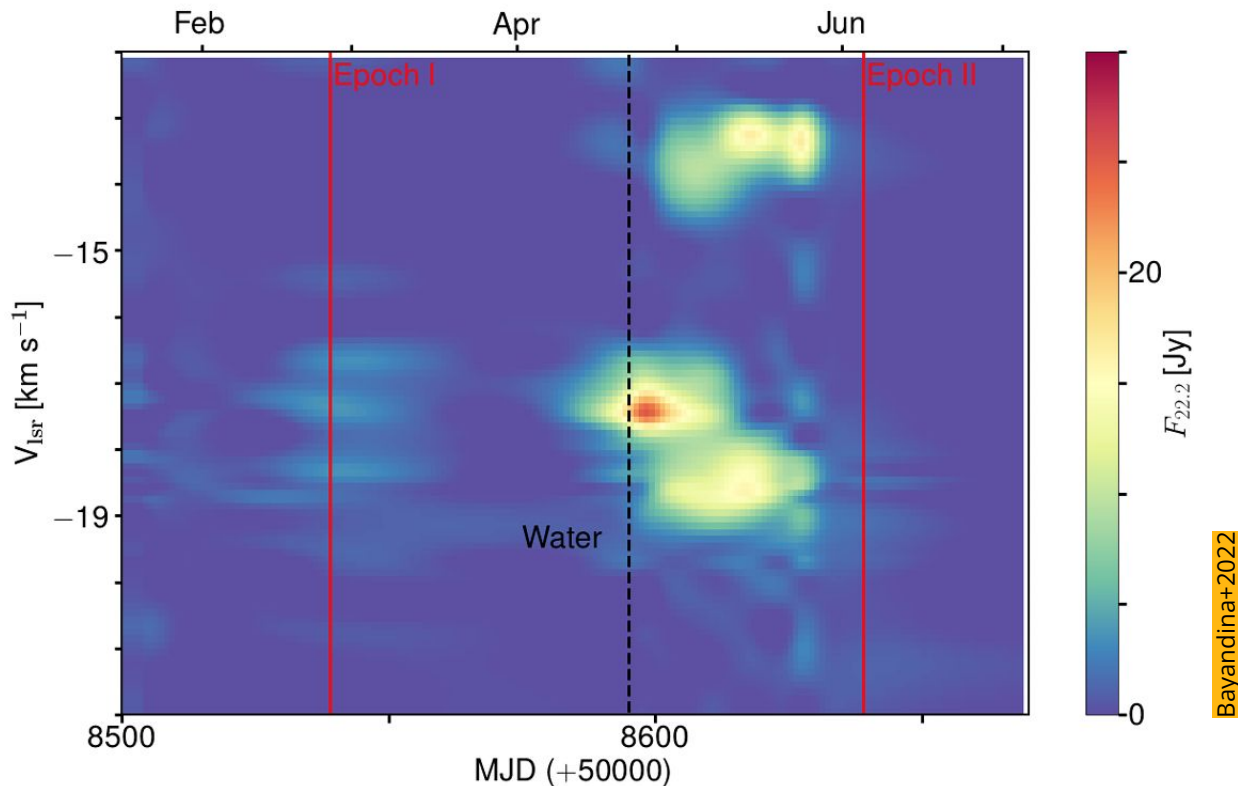
Rest frequency of a
particular maser

Müller+2004

Bandwidth

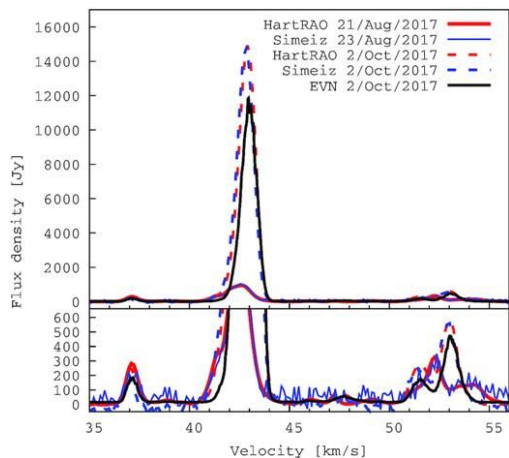
To include all the
spectral features

SCHEDULING

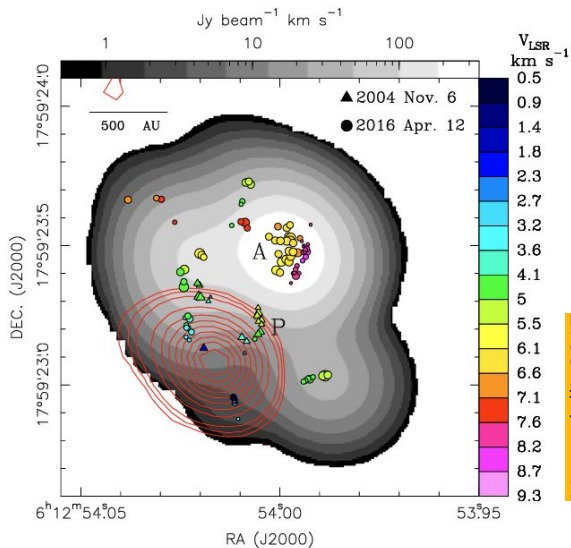


Flux density variability
Especially profound for water masers

SCHEDULING



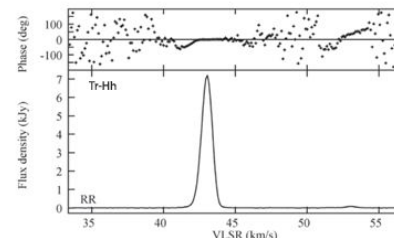
Burns+2019



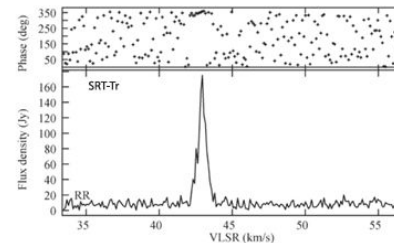
Moscadelli+2017

Extended vs Compact emission

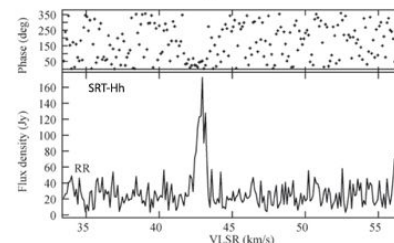
Masers consist of core+halo



(a)



(b)



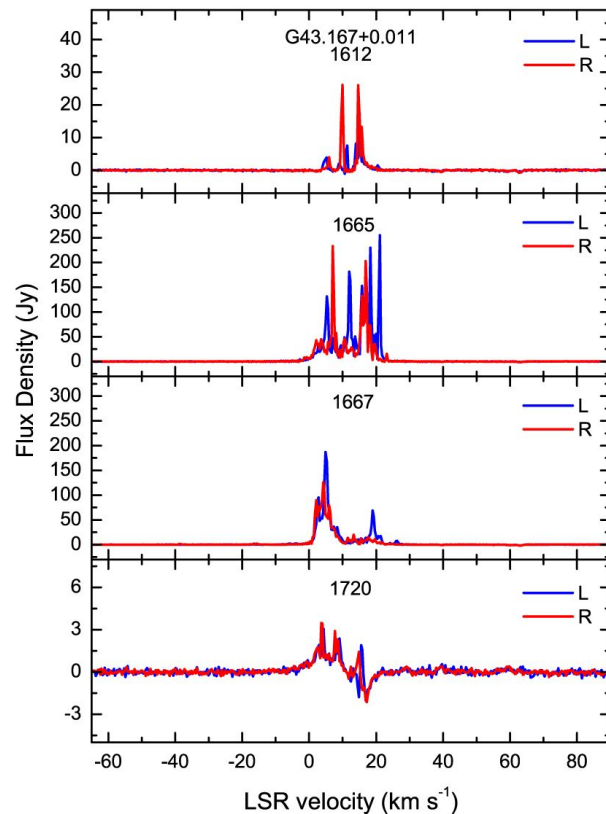
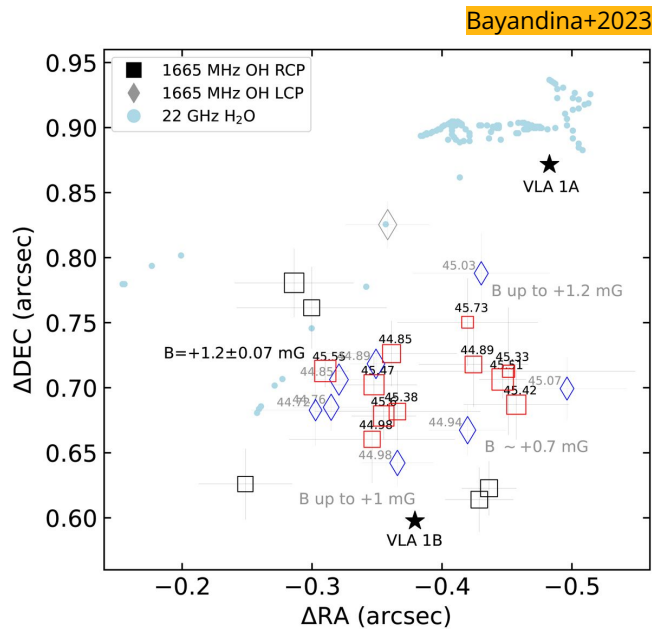
Bayandina+2020

SCHEDULING



Polarization

Different flux density in RCP vs LCP



Bayandina+2021

01 ×

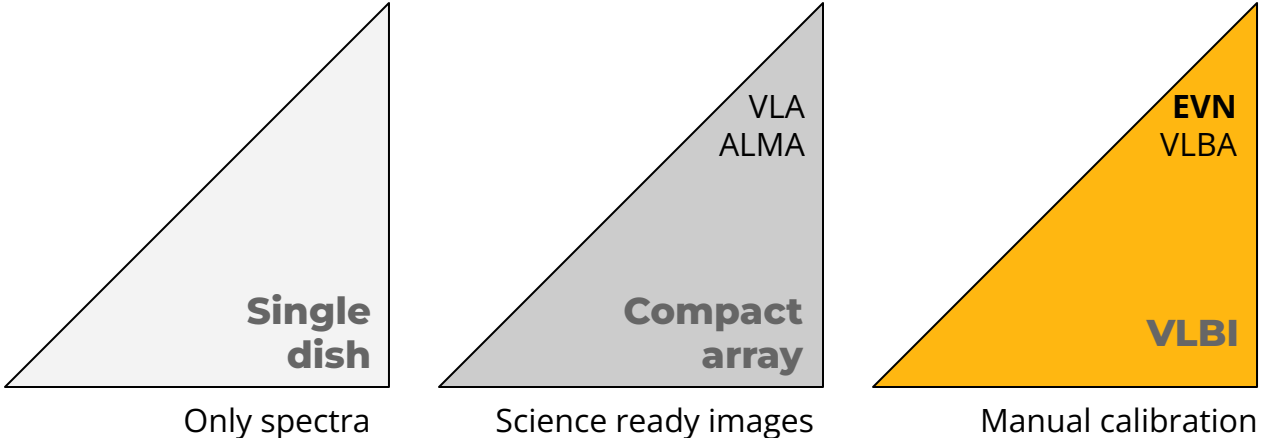
DATA REDUCTION

Loading data...



DATA REDUCTION

All can observe spectral lines

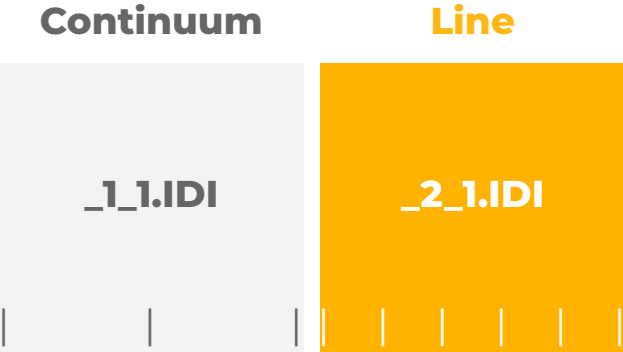


But data reduction is different

DATA REDUCTION

✘ EVN archive

- **Low spectral resolution**
(e.g. 64 channels)
- Finge-finder +
phase reference



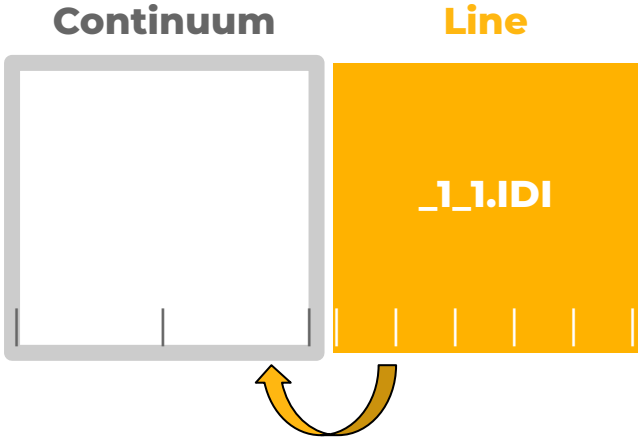
- **High spectral resolution**
(e.g. 2048 channels)
- Target

Both contain
- all sources -
but with **different** spectral resolution

DATA REDUCTION

✘ EVN archive

- **Low spectral resolution**
(e.g. 64 channels)
- Finge-finder +
phase reference



- **High spectral resolution**
(e.g. 2048 channels)
- Target

SPLIT

width - N chan to average

02 ×

DATA REDUCTION

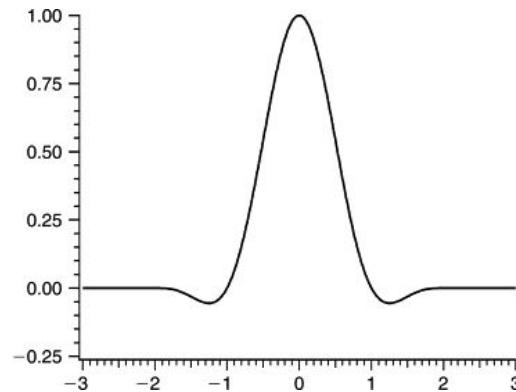
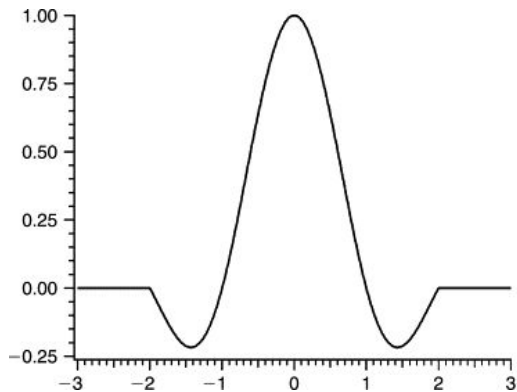
Data Inspection



DATA REDUCTION

✘ Smoothing

RFIs and strong spectral lines cause ringing across the frequency channels (the Gibbs phenomenon)



Thévenaz+2009

x2 lower spectral resolution

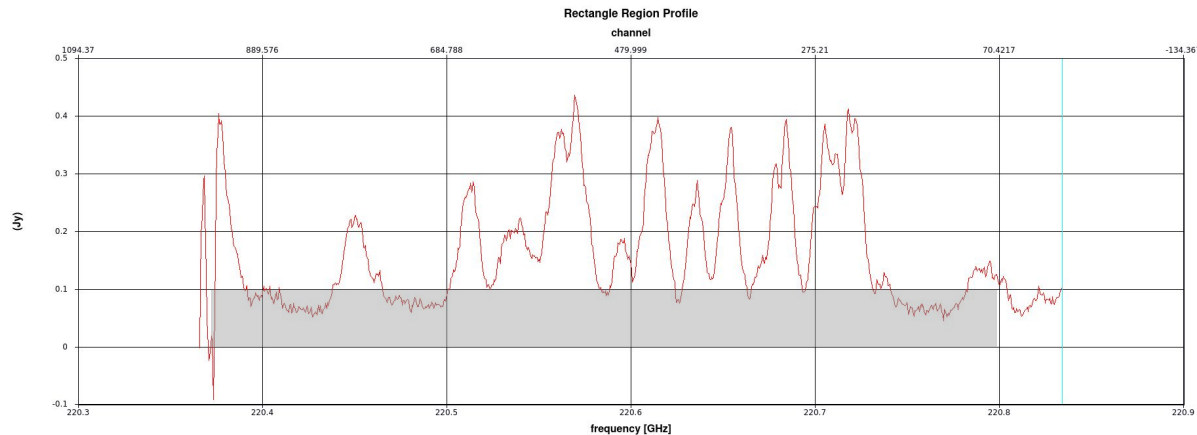
DATA REDUCTION

✘ Continuum subtraction

`imcontsub`

or

`uvcontsub`

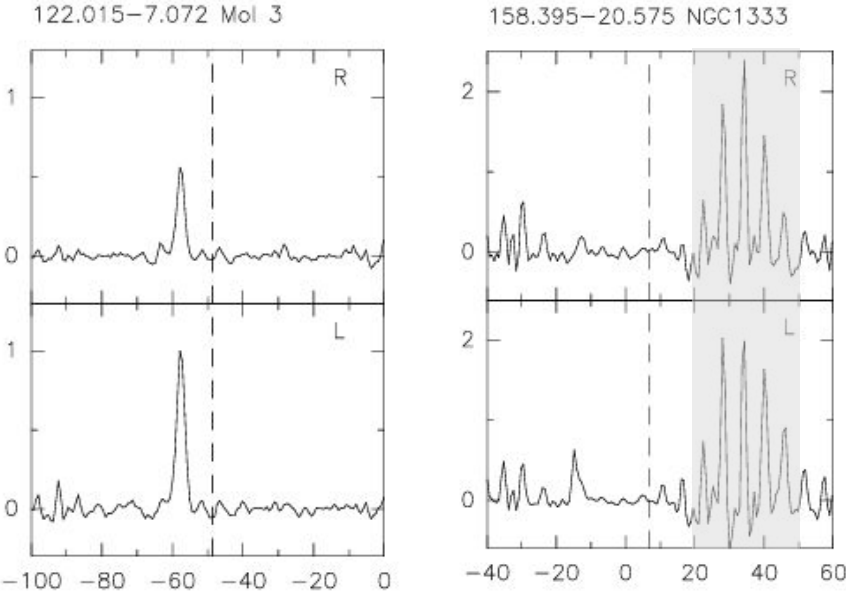


2 datasets =
1 continuum
+
1 spectral line

DATA REDUCTION

✘ Flagging

Strong and narrow spectral lines are confused with RFI by automatic flagging algorithms



comb-type RFI

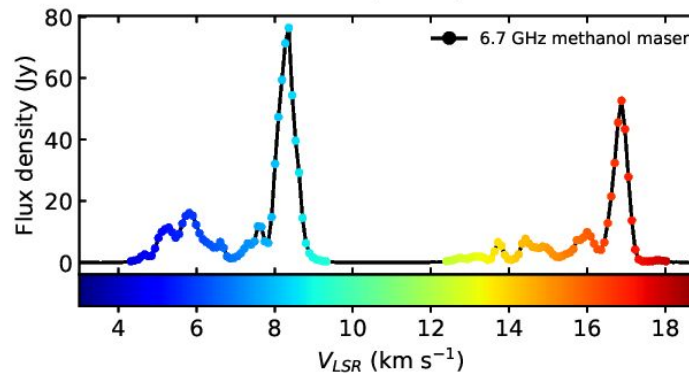
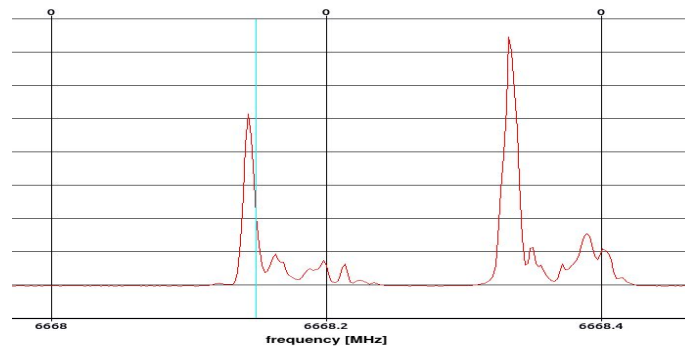
Litovchenko+2012

DATA REDUCTION

✗ Frequency -> Velocity

CVEL

```
field = 'target'  
mode = 'velocity'  
outframe= 'LSRK'  
veltype= 'radio'  
restfreq = XXX GHz
```



Bayandina+202? in prep.

03 ×

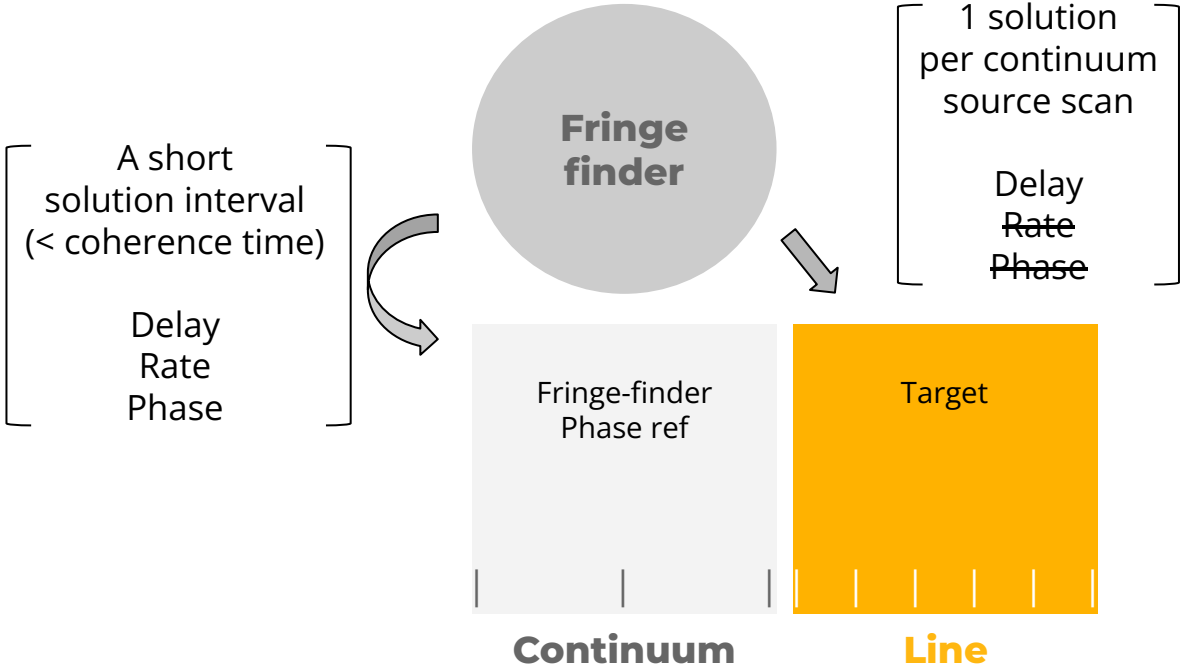
DATA REDUCTION

Calibration



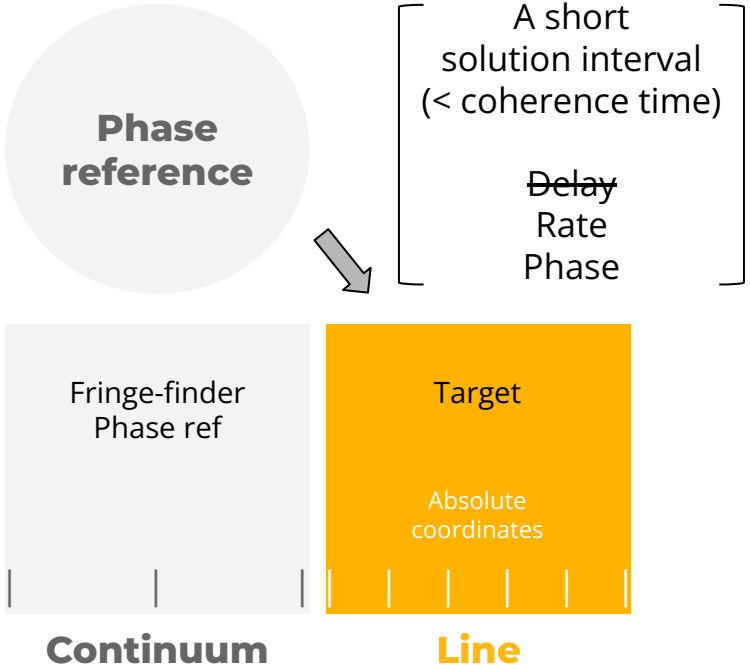
DATA REDUCTION

× Delay



DATA REDUCTION

✗ Rate + Phase

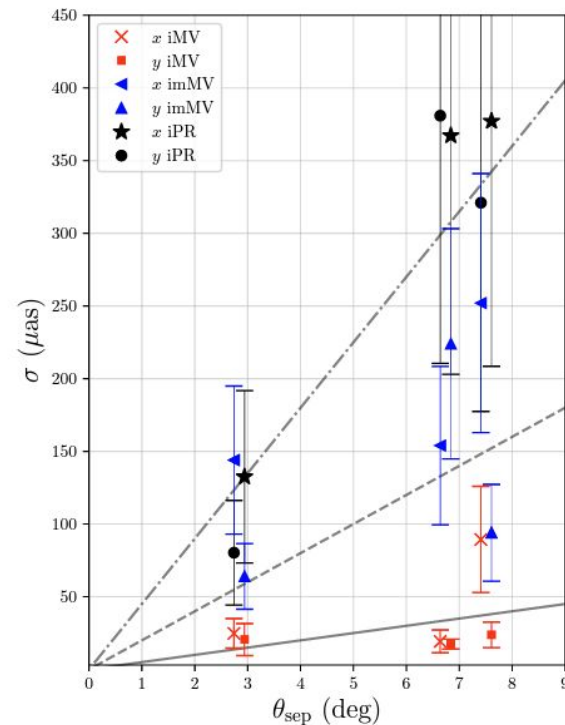


DATA REDUCTION

✕ Phase

Inverse phase referencing

- Target is strong but the phase reference calibrator is too weak
- The phase of the target is transferred to the calibrator (not other way around)
- The measured offset of the phase ref calibrator is used to determine the position of the target



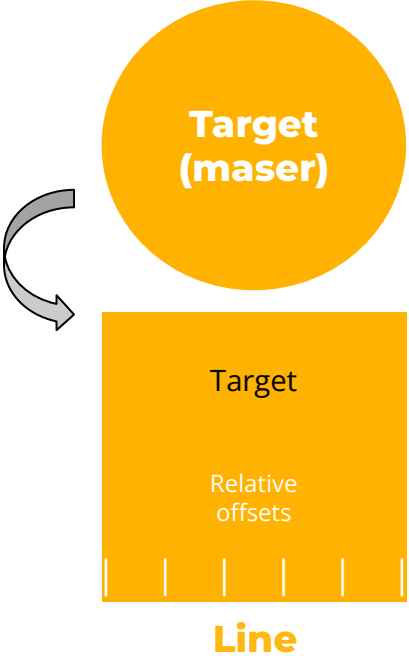
DATA REDUCTION

✘ Self-calibration

A short solution interval (< coherence time)

The strongest channel (compact maser feature)

~~Delay~~
Rate
Phase



A few times increase in flux density

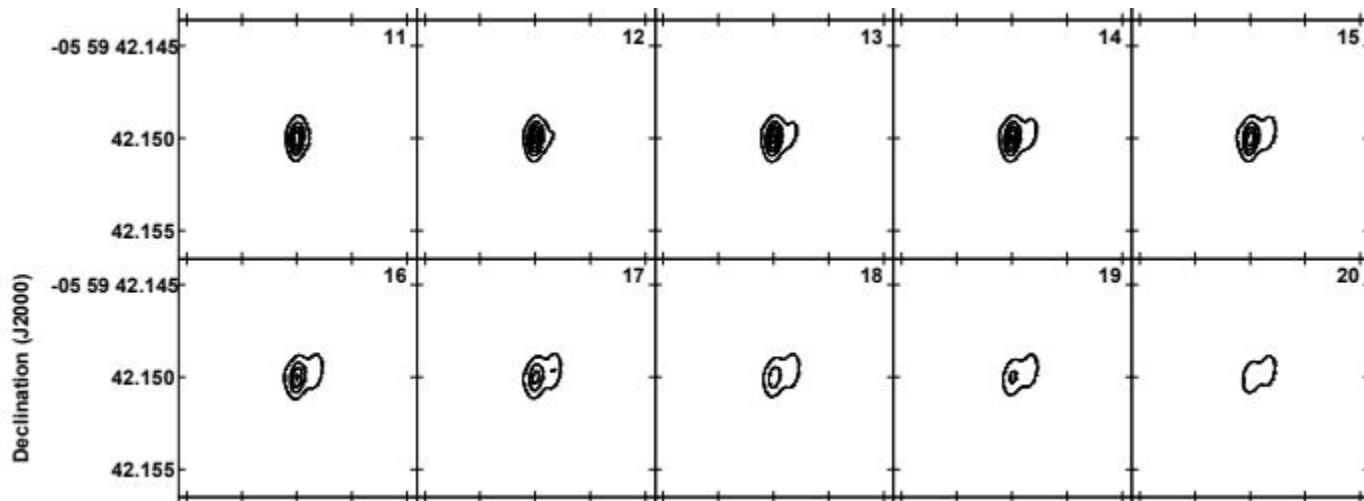
Keep an eye on the beam size!

DATA REDUCTION

✗ Self-calibration

The **self-calibration channel** must contain **a single point-like feature**

If the strongest channel shows double-structure, choose another channel
(but still a strong one!)

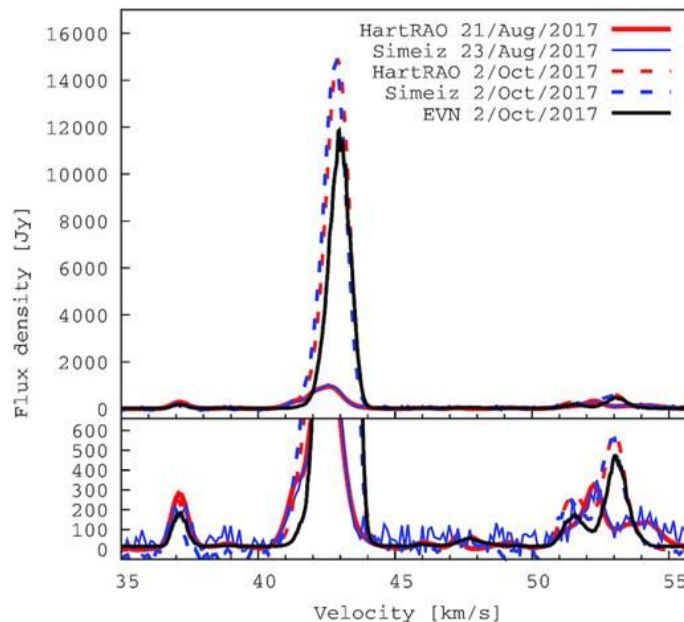


DATA REDUCTION

✗ Bandpass

- Important for auto-correlation spectra
- Amplitude only (phase)
- Calibrated on
fringe-finder (bright continuum source)
or
line-free channels of target source

Burns+2019



04^x

DATA REDUCTION

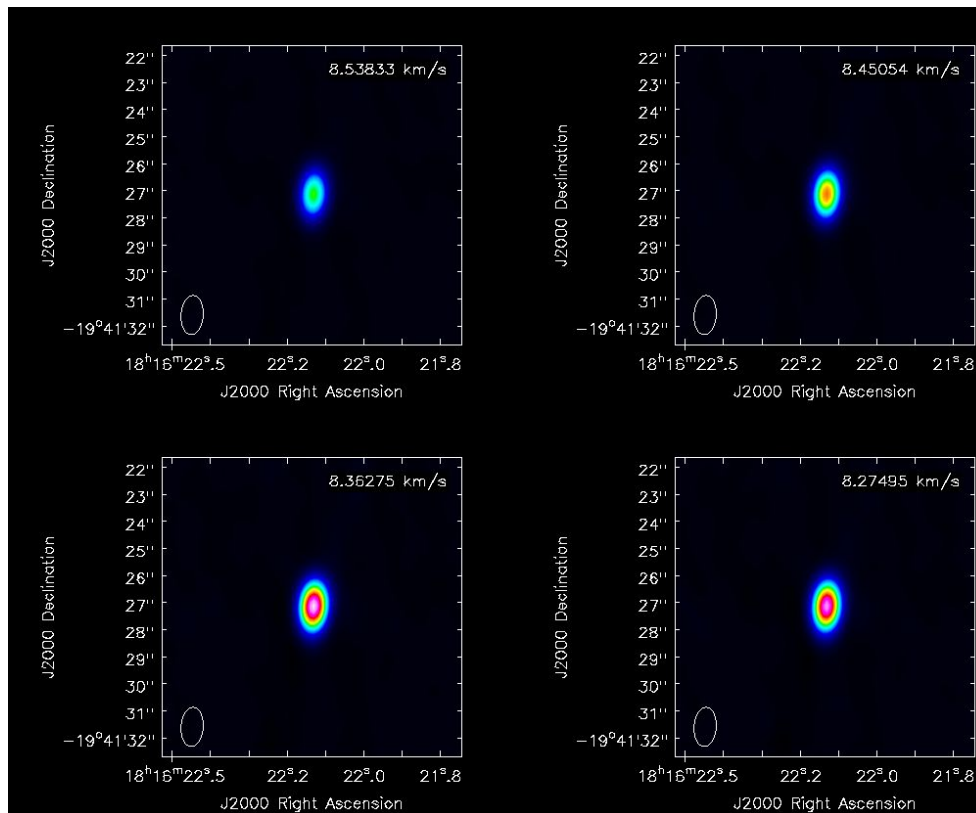
Imaging



DATA REDUCTION

✘ Data cube

```
tclean  
(vis='.ms',  
  field='X',  
  spw='X',  
  specmode='cube',  
  deconvolver='hogbom',  
  start='0',  
  nchan=XXX,  
  outframe='LSRK',  
  veltype='radio',  
  restfreq='XXX MHz',  
  imsize=[XXX],  
  cell=['XXX'],  
  weighting='briggs/natural',  
  gridder='mosaic')
```



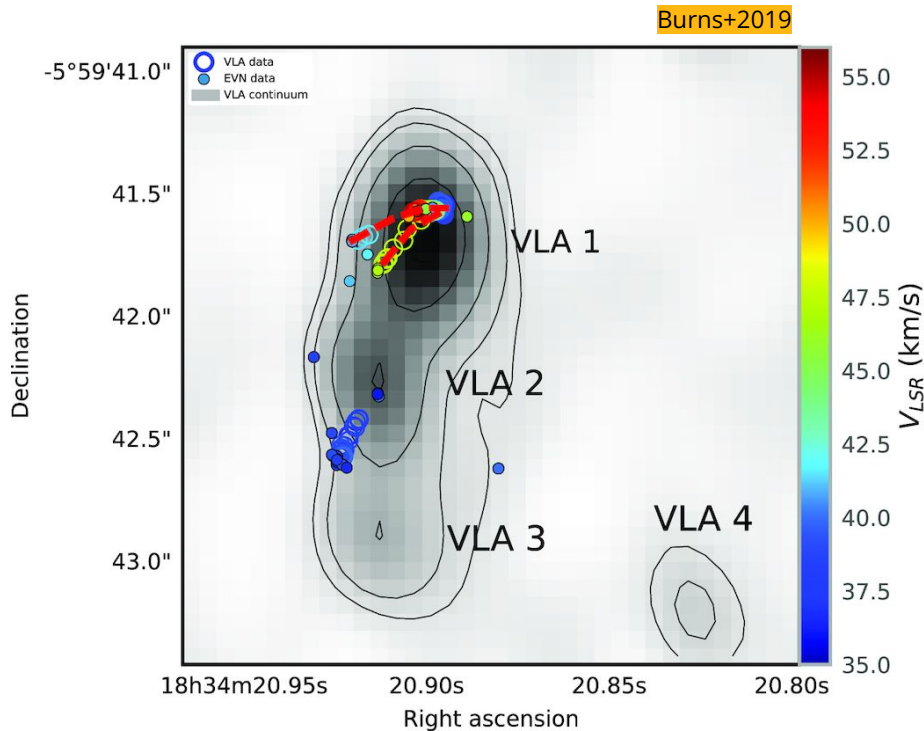
DATA REDUCTION

✘ Spot map

```
image = raw_input("Enter image name:")
sch = int(raw_input("Enter 1st channel:"))
fch = int(raw_input("Enter last channel:"))
nfch = fch + 1

for iii in range(sch,nfch):

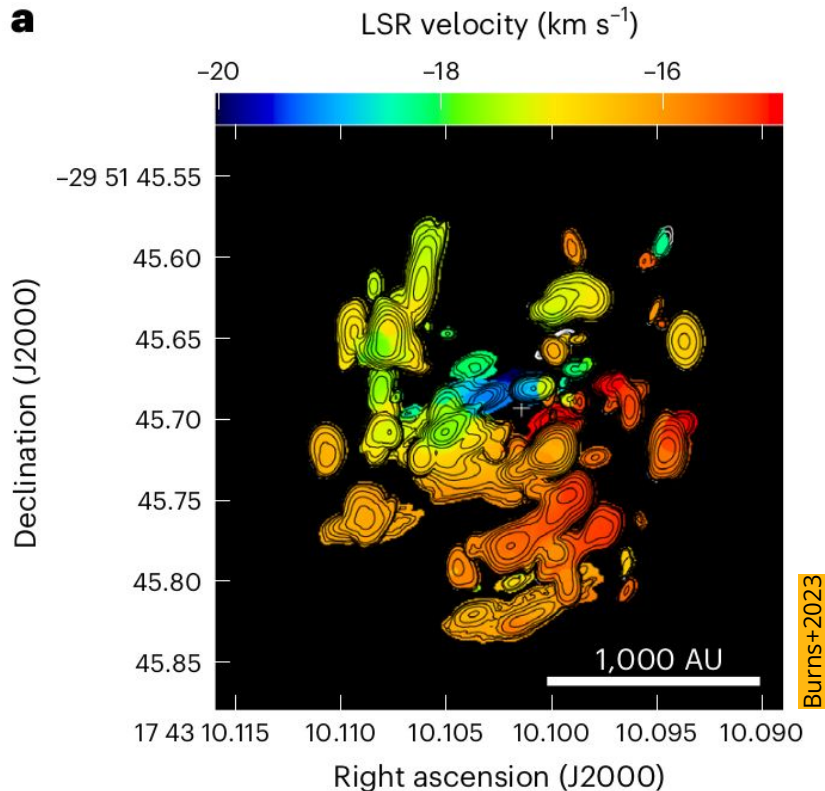
    imfit(
        imagename = image,
        box = '',
        chans = str(iii),
        stokes = 'I',
        logfile = str(iii) + '.txt',
        append = False)
```



DATA REDUCTION

✘ Moments

```
immoments  
(imagename='',  
moments=[0],  
axis='spectral',  
region='',  
chans='XX~XX',  
includepix=[XX,XX],  
outfile='',  
stretch=False)
```

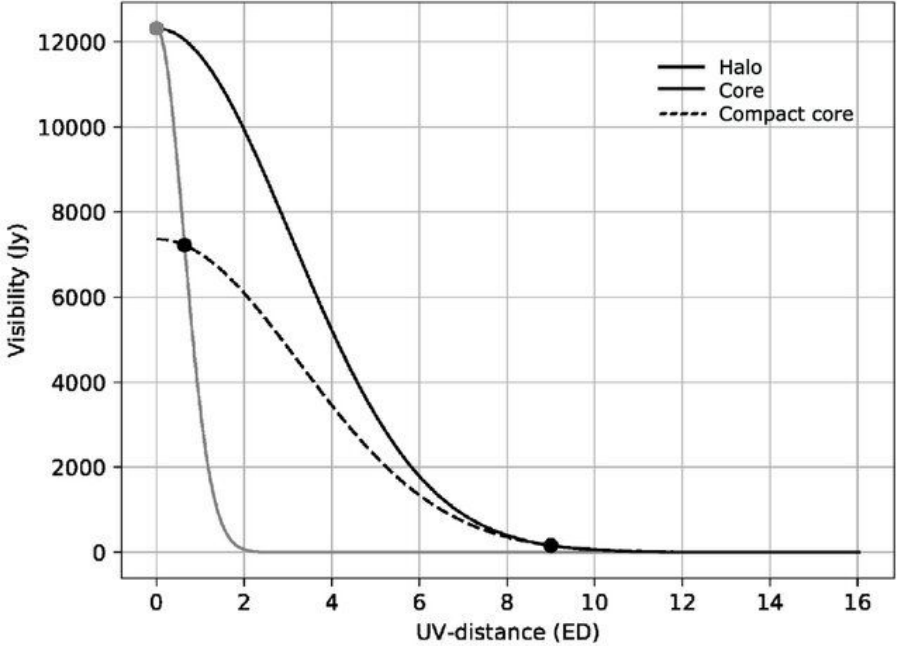


DATA REDUCTION

✘ Poor uv coverage

The size of the compact maser emission feature can be studied based on the angular resolution and recovered flux density

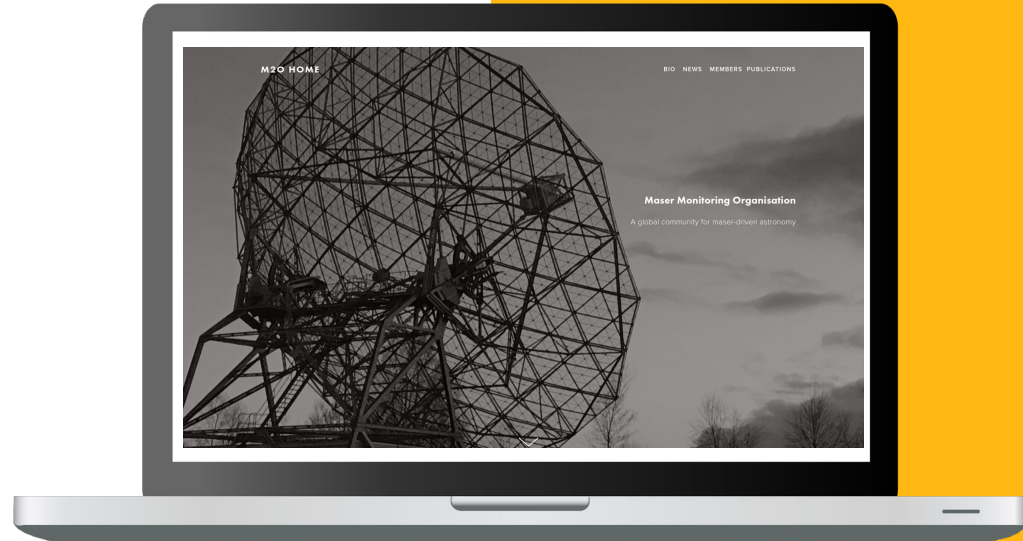
Bayandina+2020



05 ×

RESOURCES

Some links to click

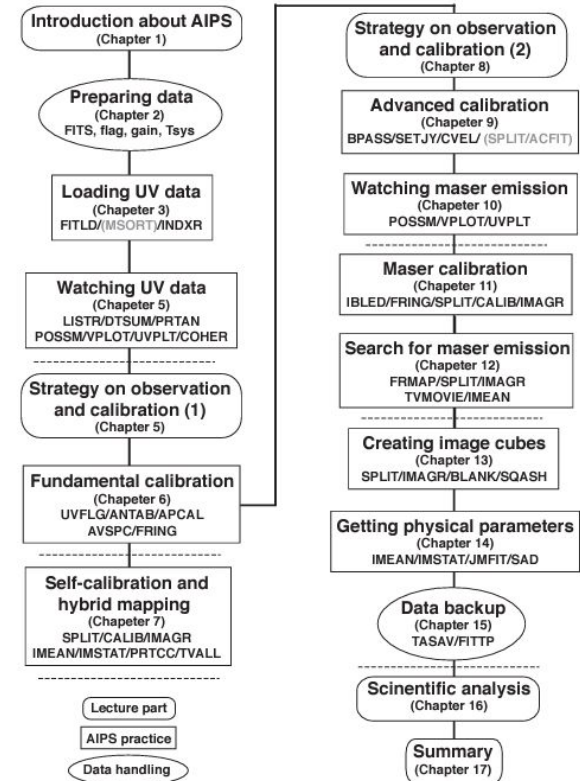


Tutorial AIPS(!)



AIPS Data Analysis Training

- Core philosophy of spectral line data reduction
- Can be translated to CASA with [AIPS-CASA Dictionary](#)

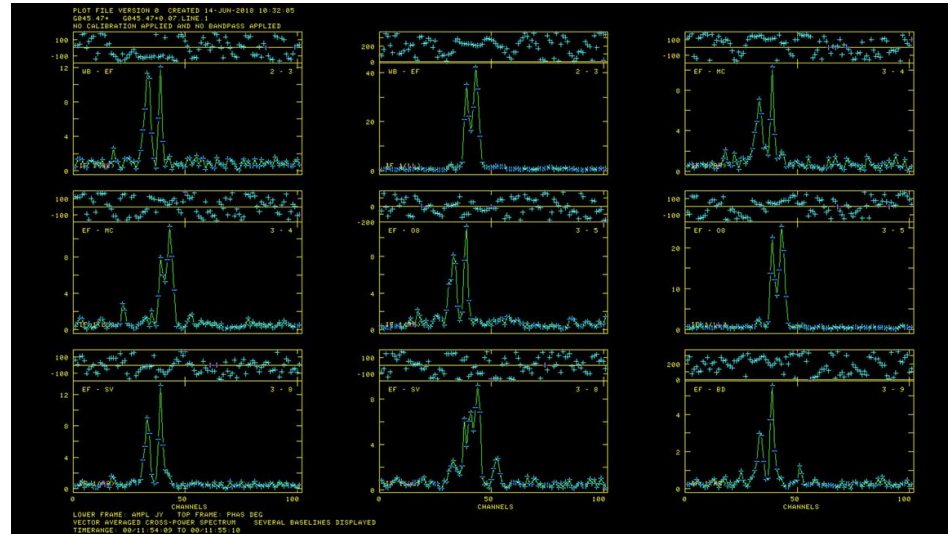


Tutorial AIPS(!)



Reducing EVN spectral line data

- Simple tutorial
- EVN OH maser data - [EB063C](#)

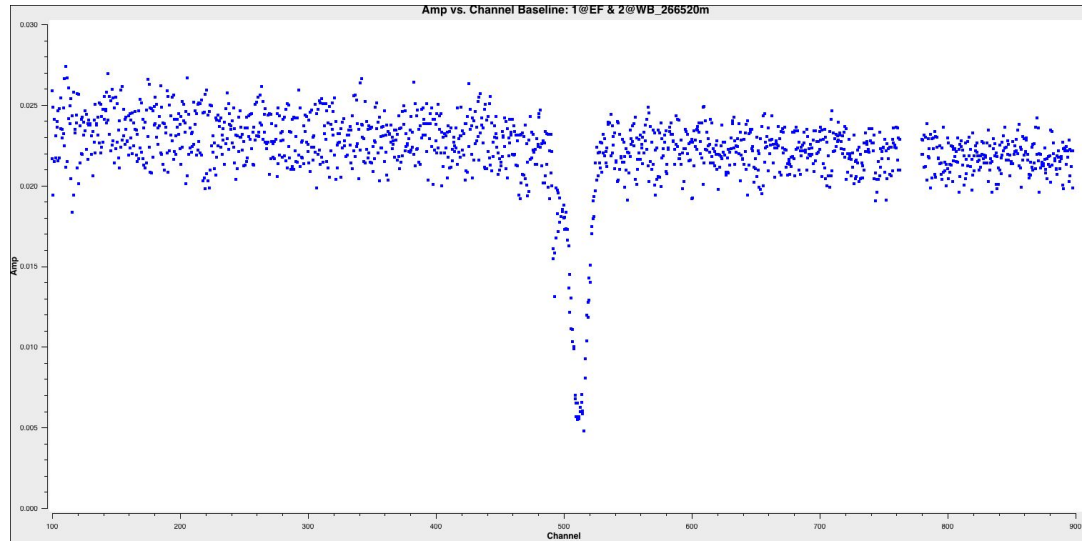


Tutorial CASA



EVN HI Spectral Line

- HI absorption data
- EVN data - [NGC660.FITS](#)



Tutorial CASA



ALMA guides

- Compact array!
- + Imaging of a spectral line
- + Moment creation and basic image analysis



Maser database

A database and multi-purpose tool for analyzing maser data

Maser object G208.993-19.385

Mean object RA, Dec: 05 35 14 -05 22 29 (83.8103330 -5.3748770)

Other names: 05302-0537 (Ori KL), 053249.8-052507, KL IRC 2, KL IRC 4, Ori KL, Orion-A, Orion-KL, ZOL 996-19.386, G208.996-19.386, Ori KL, Ori-KL, Orion KL, G208.99-19.38, G208.99-19.38(ORION-A), OMC-1, OMC-1 (25.0 GHz), OMC-1 (25.1 GHz), Orion, Orion-KL, Ori IRC2, ORION-IR.

Mean object l, b: 208.9927 -19.3843

Detected/non-detected masers in the object: +H₂O +CH₃OH I +CH₃OH II +OH +SiO

✘ Find your source!

Source G208.993-19.385 (83.8103330, -5.3748770)

Maser observations

Tip: Green is detection, Red is non-detection

[Hide](#) / [Show](#) individual components

H₂O maser observations in object G208.993-19.385

Line	Source	Peak	Vpeak	Dist.	Beam	ΔV (km/s)	Ref
22 GHz	KL IRC 2	3000 Jy	5.3 km/s	0.1" Ga	7"		[CES88]
22 GHz	KL IRC 4	3000 Jy	3.3 km/s	0.4" Ga	7"		[CES88]
22 GHz	053249.8-052507	84954 (579) Jy	7.3 km/s	60.0" Ga 114"	0.33		[CCD94] 9003/05
22 GHz	053249.8-052507	7280 (89) Jy	10 km/s	60.0" Ga 114"	0.33		[CCD94] 9003/06
22 GHz	053249.8-052507	58848 (729) Jy	19.3 km/s	60.0" Ga 114"	0.33		[CCD94] 9003/07
22 GHz	053249.8-052507	140200 (878) Jy	7.3 km/s	60.0" Ga 114"	0.33		[CCD94] 9004/08
22 GHz	053249.8-052507	53848 (579) Jy	7.3 km/s	60.0" Ga 114"	0.33		[CCD94] 8951/08
22 GHz	053249.8-052507	134380 (1204) Jy	7.3 km/s	60.0" Ga 114"	0.33		[CCD94] 9007/10
22 GHz	KL IRC2	110000	9.00 km/s	0.3" Ga	6"		[WIL07]
22 GHz	Ori KL	80000 Jy image	7.3 km/s	0.1" Ga 114"	0.33		[FEL03] 900200
22 GHz	05302-0537 (Ori KL)	1450 Jy image	8 km/s	0.2" Ga	7"		[MIG99] 1996 June, October
22 GHz	KL IRC 2	248300 0 Jy	7.5 km/s	0.1" Ga 114"	0.33		[PAL93B]
22 GHz	Orion-A	4740.230 Jy	8.8" Ga	73"	0.3		[GUM07] 30.05.2005
22 GHz	Orion-A	2875.8 Jy	12.8 km/s	8.0" Ga	62"		[GUM07] 30.05.2005
22 GHz	Orion-A	2350.40 Jy	7.7 km/s	8.0" Ga	73"	0.5	[GUM07] 25.09.2004
22 GHz	Orion-KL	15450 1 Jy image	10.6 km/s	9.0" Ga	138"		[WAT99] 1997 08 11

OH maser observations in object G208.993-19.385

Line	Source	Peak	Vpeak	Dist.	Beam	ΔV (km/s)	Ref
4600 MHz	ORION-IR	14.4 km/s	3.0" Ga	7"			[GMB3; QIAL1]
6035 MHz	G208.99-19.38 0.290	4.7" Ga	7"				[CV90; QIAL1]

SiO maser observations in object G208.993-19.385

Line	Source	Peak	Vpeak	Dist.	Beam	ΔV (km/s)	Ref
J=1-0 v=1	Ori IRC2 J40 K	5 km/s	1.0" Ga	7"			[NRO; BE; MGC]
Ori IRC2 1110 Jy	16.2 km/s	0.8" Ga	7"				[NEW91; ENG; SIO]

CH₃OH I maser observations in object G208.993-19.385

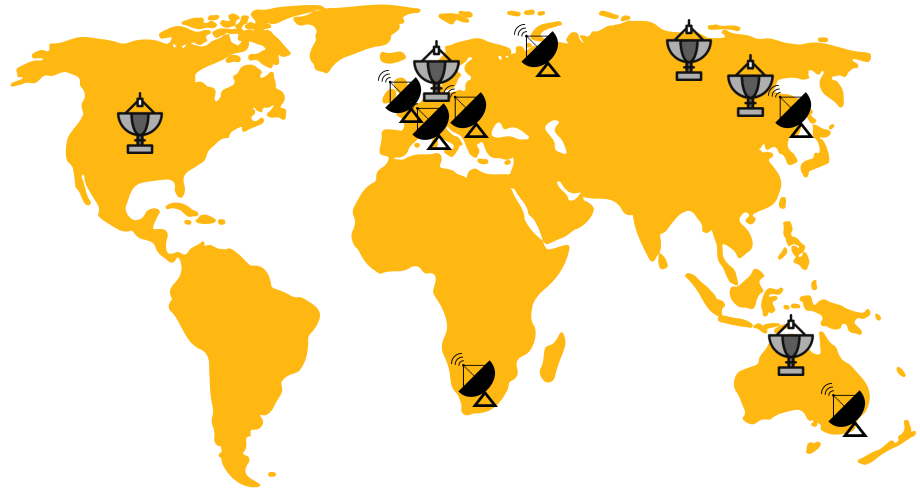
Line	Source	Peak	Vpeak	Dist.	Beam	ΔV (km/s)	Ref
9.93 GHz	Orion-KL	0.25 (0.04) Jy	8.7 (0.2) km/s	3.0" Ga	204"		[SLY93]
9.97 GHz	Orion-KL	<0.11b		3.0" Ga	204"		[SLY93]
10.00 GHz	Orion-KL	<0.11		3.0" Ga	204"		[SLY93]

maserdb.net

M2O: Maser Monitoring Organisation

A global community for maser-driven astronomy

- monitoring stations report new maser flares ->
- confirmation by other radio observatories ->
- follow up VLBI and IR observations



Want to join?

masermonitoring.org



THANKS

Do you have any questions?

olga.bayandina@inaf.it
masermonitoring.com



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