

# Multi-epoch VLBI of a double maser super-burst

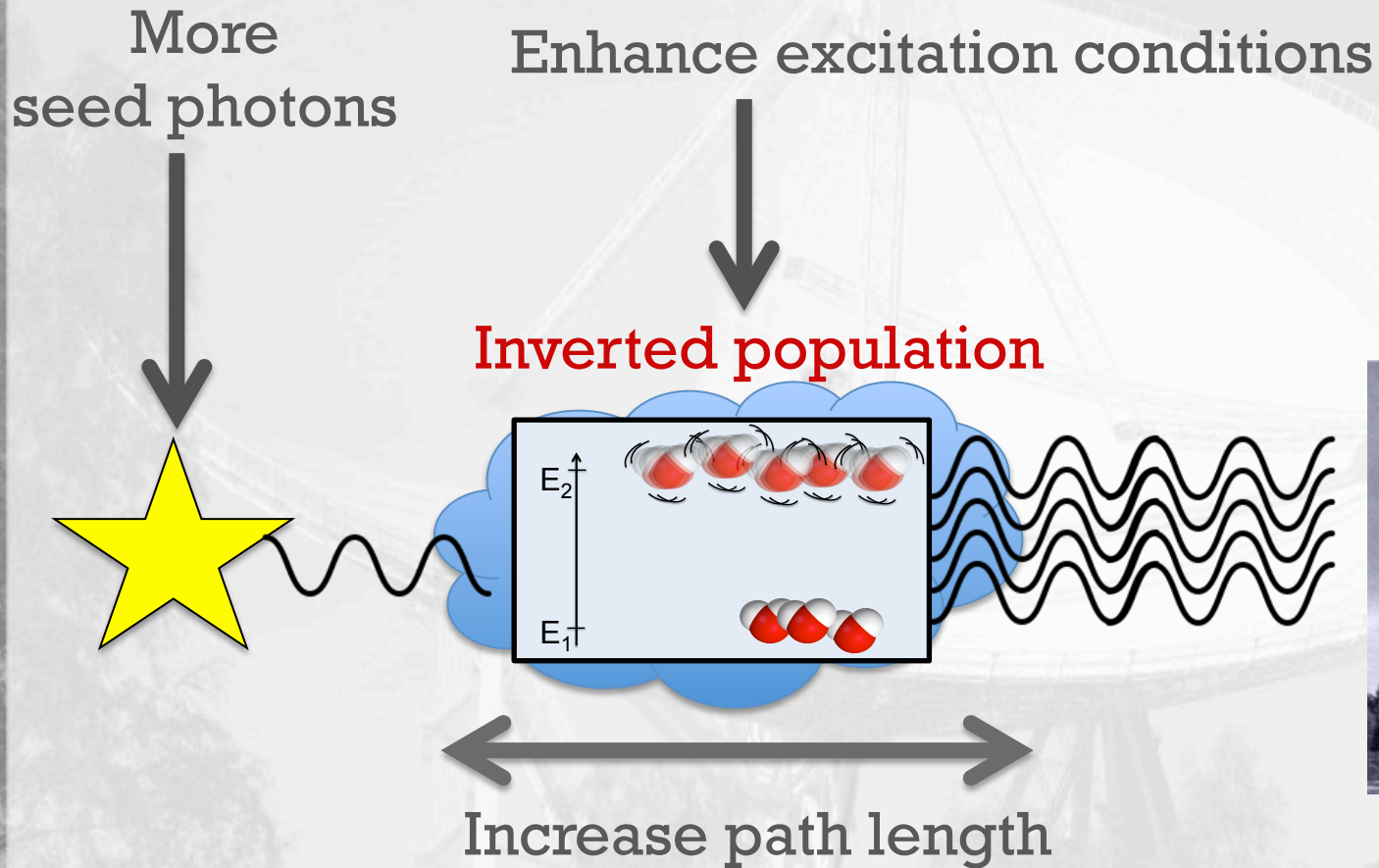
Ross Burns  
Joint Institute for VLBI ERIC (JIVE)

EVN Symposium  
10<sup>th</sup> October 2018

## M20-VLBI

Jungha Kim, Koichiro Sugiyama, Kazuhito Motogi, Tomoya Hirota, Kee-Tae Kim, Gabor Orosz, Olga Bayandina, Irina Val'tts, Nadya Shakhvorostova, Georgij Rudnitskij, Alexandr Volvach, Gordon MacLeod, James O. Chibueze, Mateusz Olech, Pawel Wolak, Anna Bartkiewicz, Gabriele Surcis, Busaba Kramer, Alex Kraus, Karl Menten, Ross Burns, Huib van Langevelde, Katherina Immer, Willem Baan, Crystal Brogan, Todd Hunter, Stan Kurtz

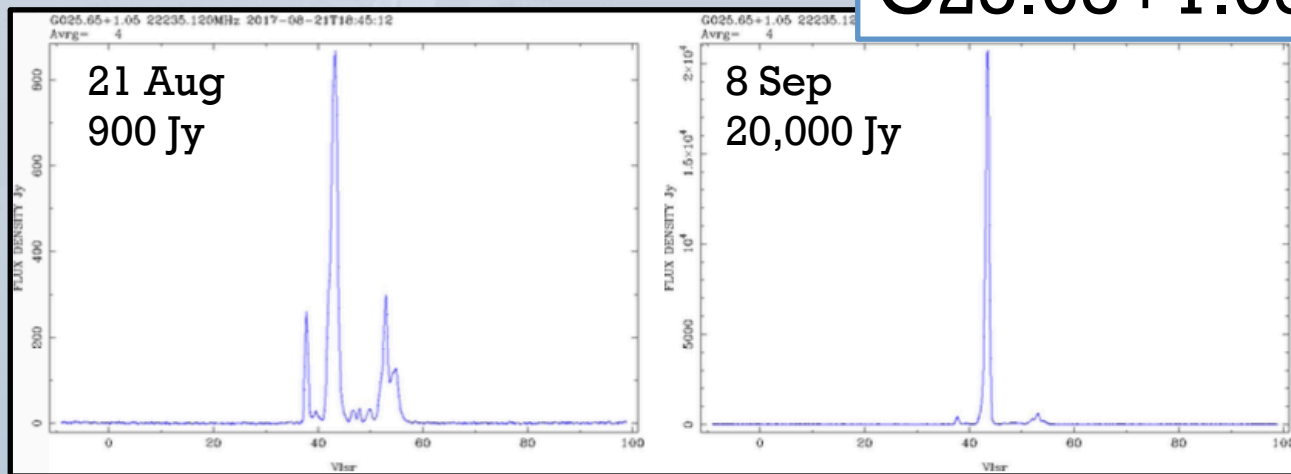
# Masers



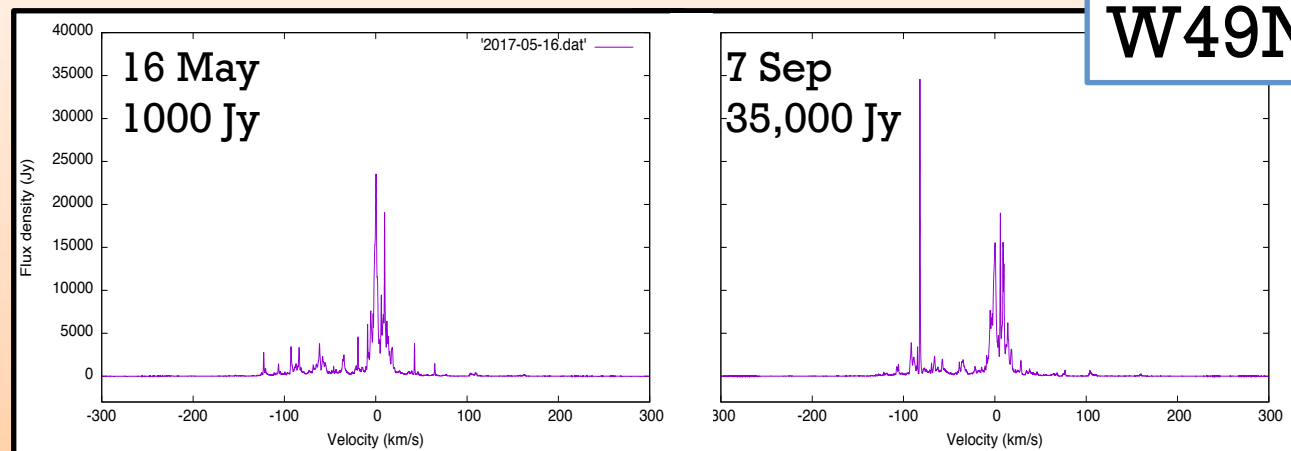
# Double maser super burst: Sep 2017



**G25.65+1.05**



**W49N**

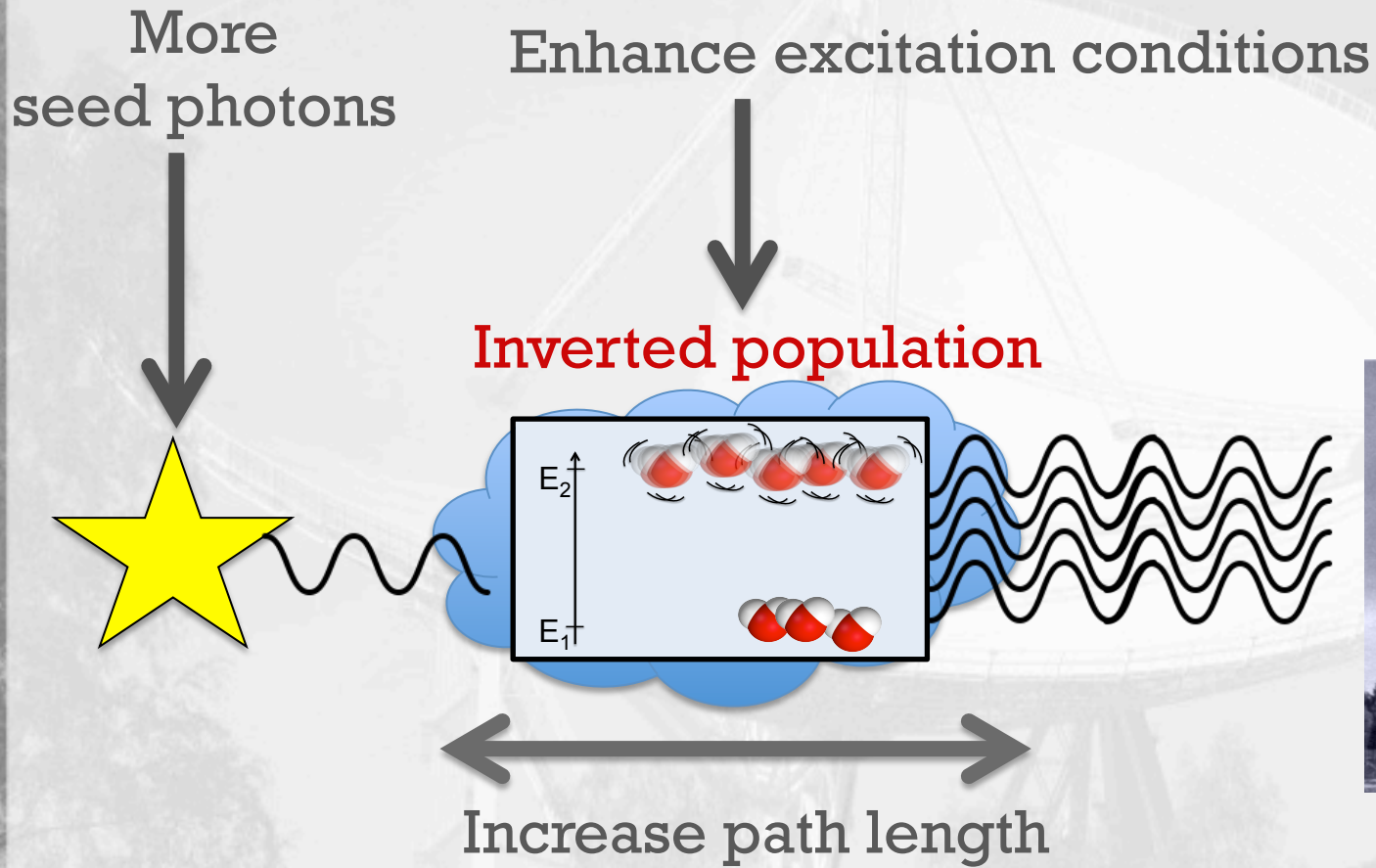


Maser Monitoring Organisation - See Poster



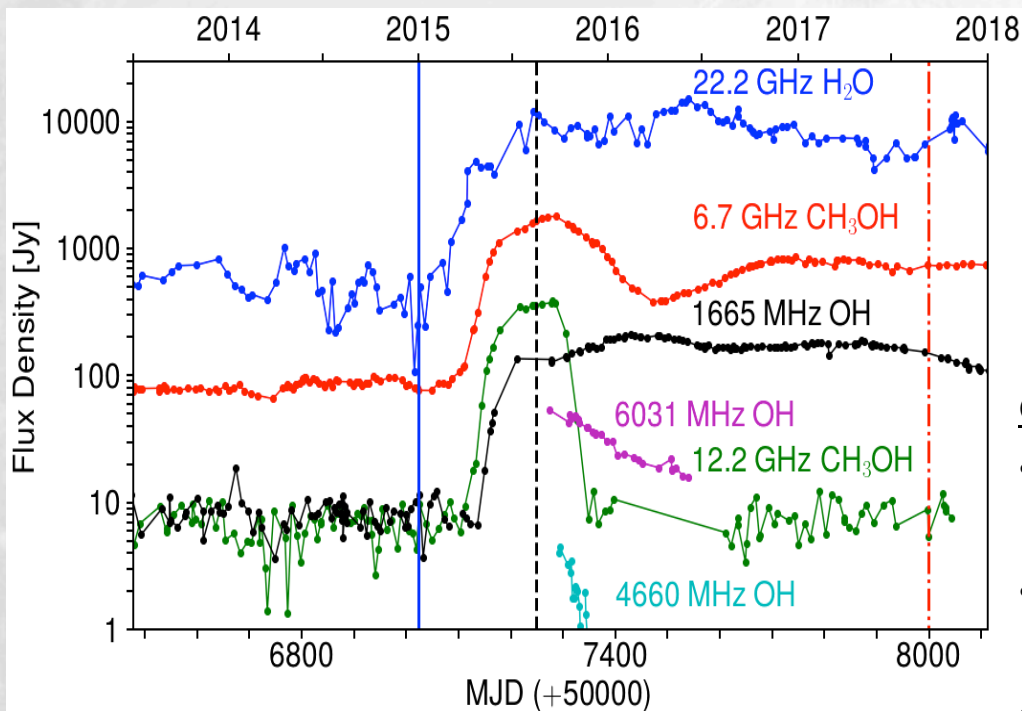


**But how?**



# Case study 1 – seed photons

## NGC6334I – Massive star forming region



McCleod et al., 2017, MNRAS, 478, 1077

## Mechanism of action

Accretion burst

v

Enhanced continuum

v

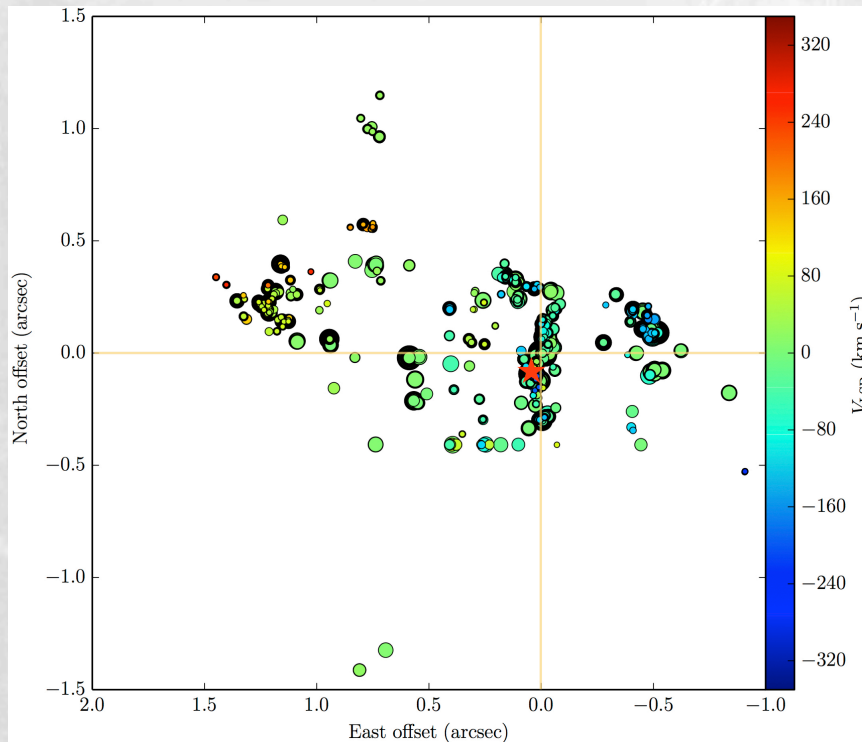
Enhanced masers

## Observational signatures

- Location:
  - near continuum
- Affected spectral features:
  - all foreground (many)
- Temporally:
  - 'slow' (weeks - years)
- Structure:
  - independent

# Case study **2** – pumping

## W49N – Massive star forming region



Kramer et al. (in prep)

## Mechanism of action

Shock formation

$v$

Enhanced pumping

$v$

Enhanced masers

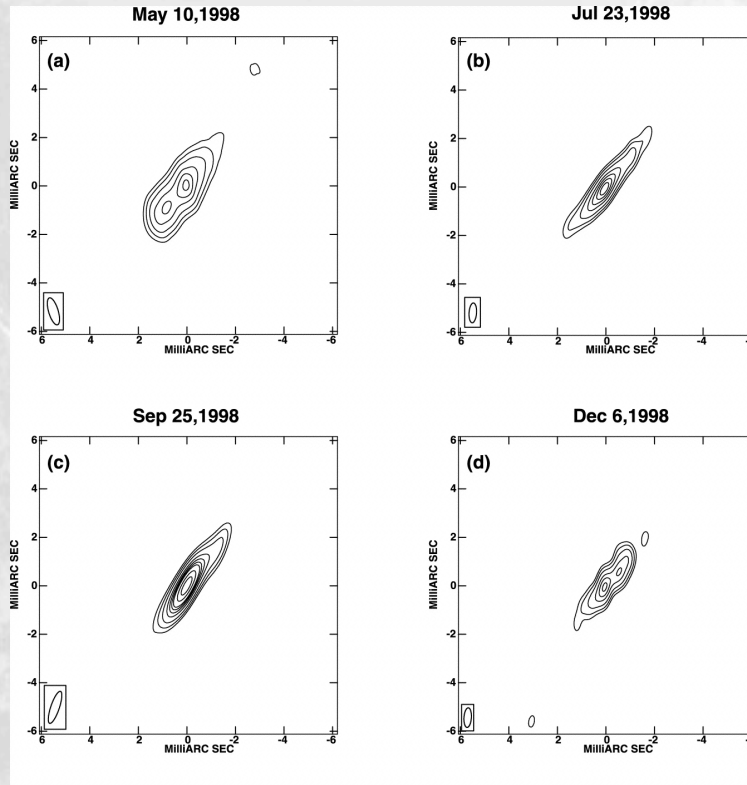
## Observational signatures

- Location:  
shocks
- Affected spectral features:  
several
- Temporally:  
`slow' (weeks - years)
- Structure:  
independent



# Case study **3** – Overlap

## OrionKL – Massive star forming region



Shimoikura et al. 2005, ApJ, 634, 459

## Mechanism of action

L.O.S. alignment

v

Increase path length

v

Enhanced masers

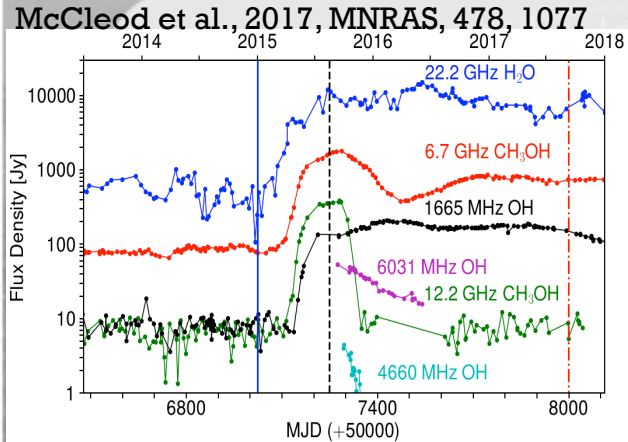
## Observational signatures

- Location:  
independent
- Affected spectral features:  
~one or two
- Temporally:  
`fast' (overlap duration)
- Structure:  
Highly compact

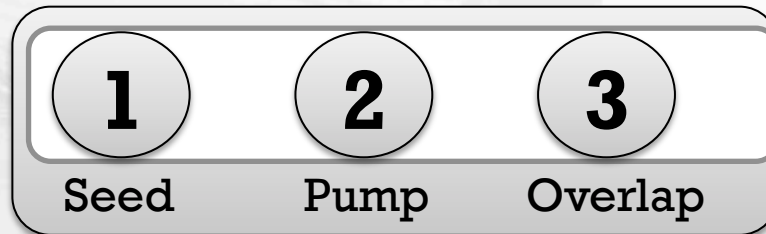
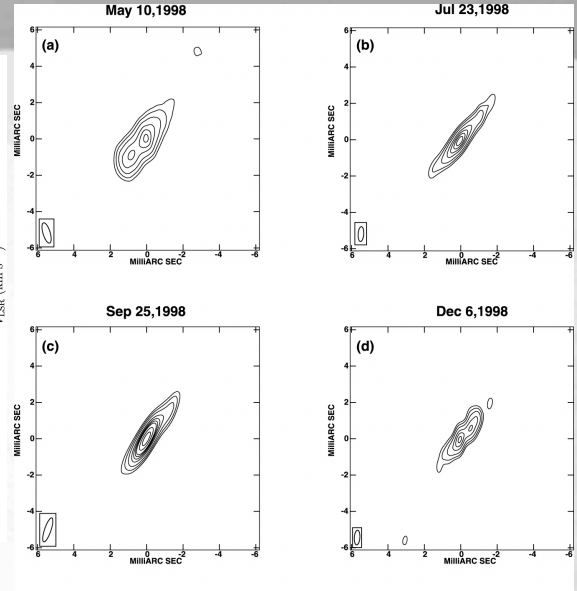
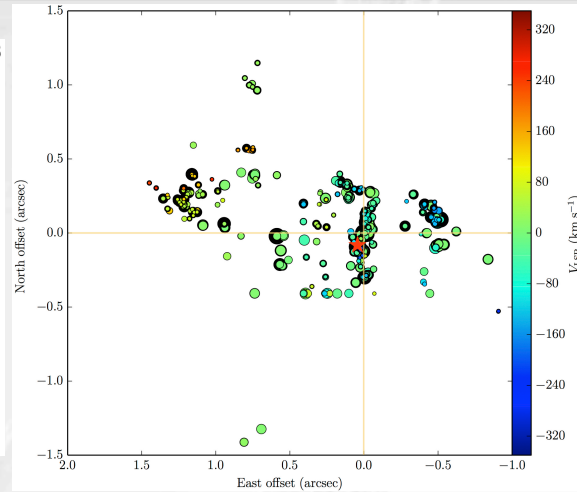


# Super Burst mechanisms

Shimoikura et al. 2005, ApJ, 634, 459



Kramer et al. (in prep)



Need **imaging** to distinguish between scenarios

# Maser Super Burst

7th Sep '17

**Single-dish detections**

**ToO proposals**

**+ RadioAstron**

Poster by  
Olga Bayandina

**EVN (K)**  
2<sup>nd</sup> Oct '17

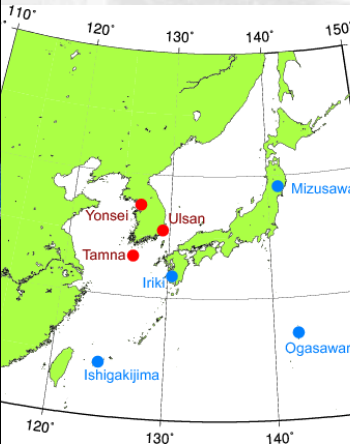
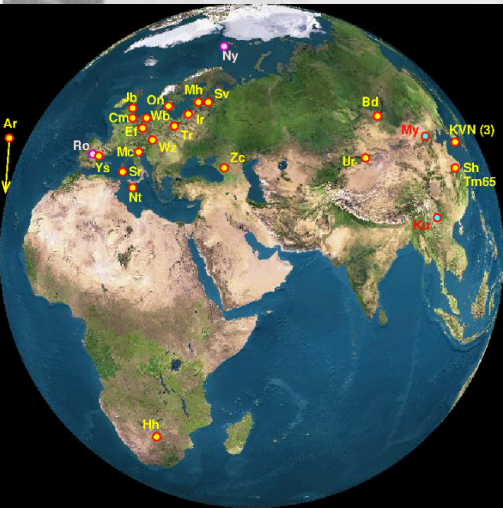
+Polarisation

**KaVA (K,Q)**  
11<sup>th</sup> Oct '17

**VLBA (K)**  
28<sup>th</sup> Oct '17

+Polarisation

**VLA**  
(C,Ku,K,Q)  
9<sup>th</sup> Dec '17





**EVN results**



1

Seed

2

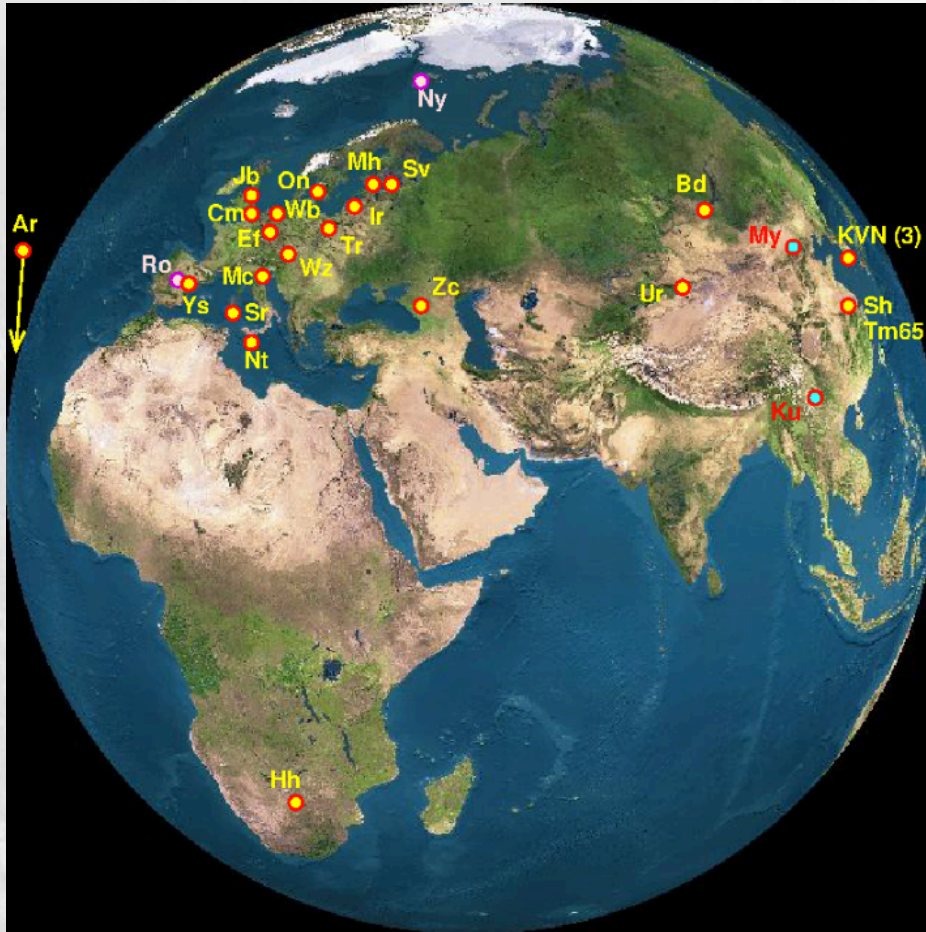
Pump

3

Overlap

# Results #1

## EVN - European VLBI Network



Date: 2 Oct 2017

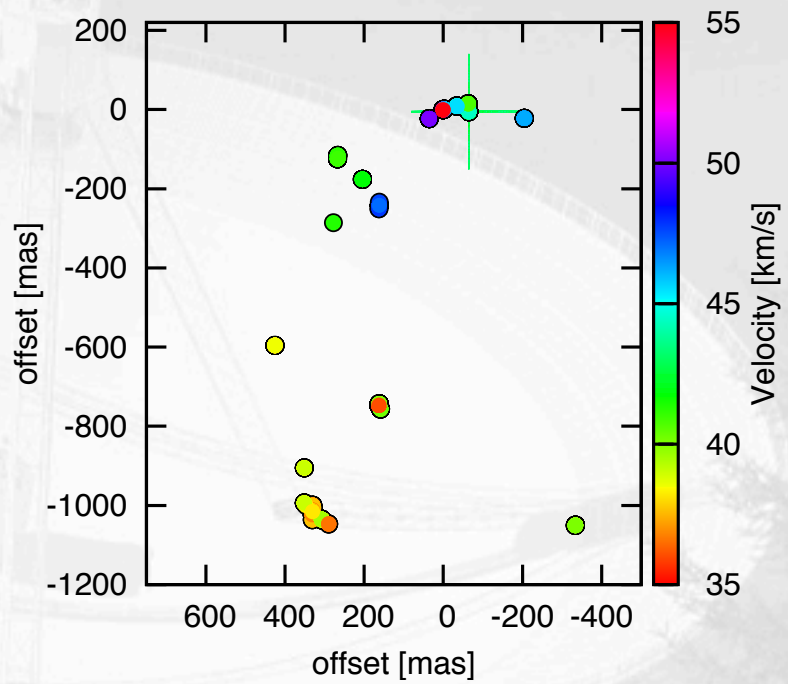
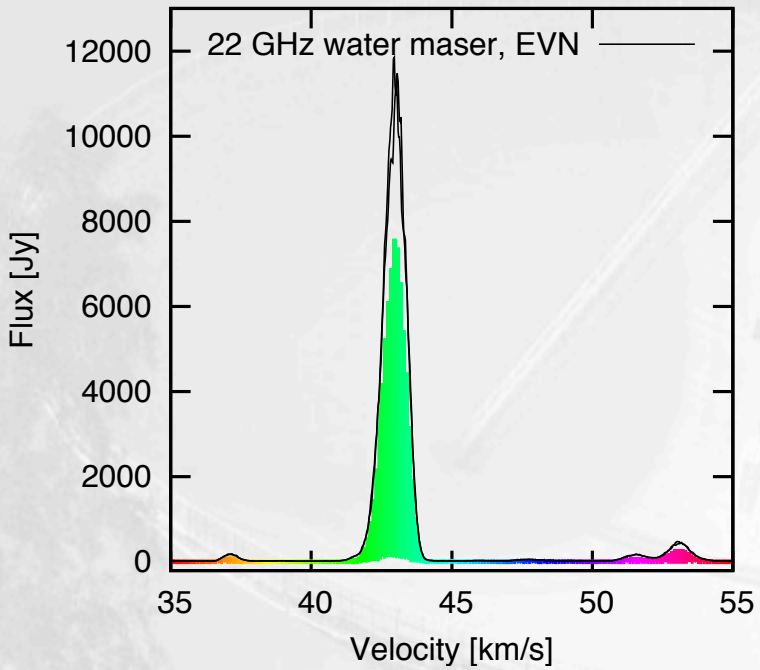
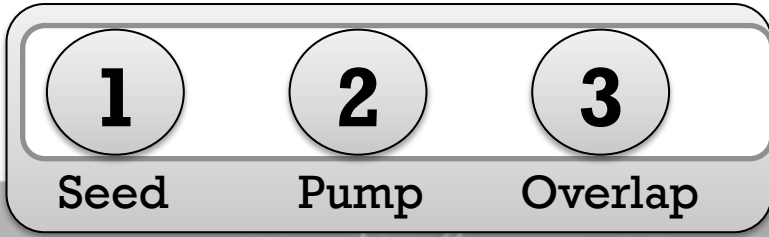
Duration: Full track

Targets: W49N, G25

Participating stations:

1. Effelsberg, Germany
2. Yebes, Spain
3. Jodrell Bank, UK
4. Torun, Poland
5. Onsala, Sweden
6. Hartebeesthoek, S.Africa



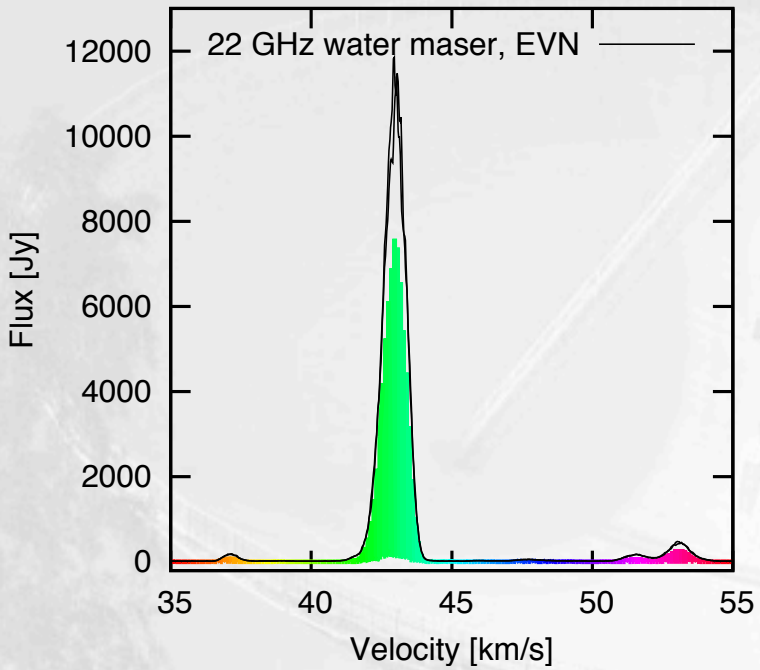
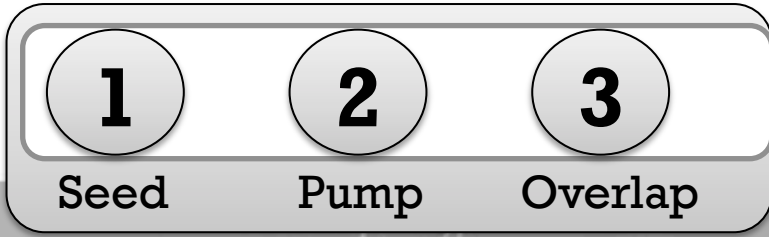


**Observation**

- VLBI: ~12,000 Jy
- Single dish: ~15,000 Jy

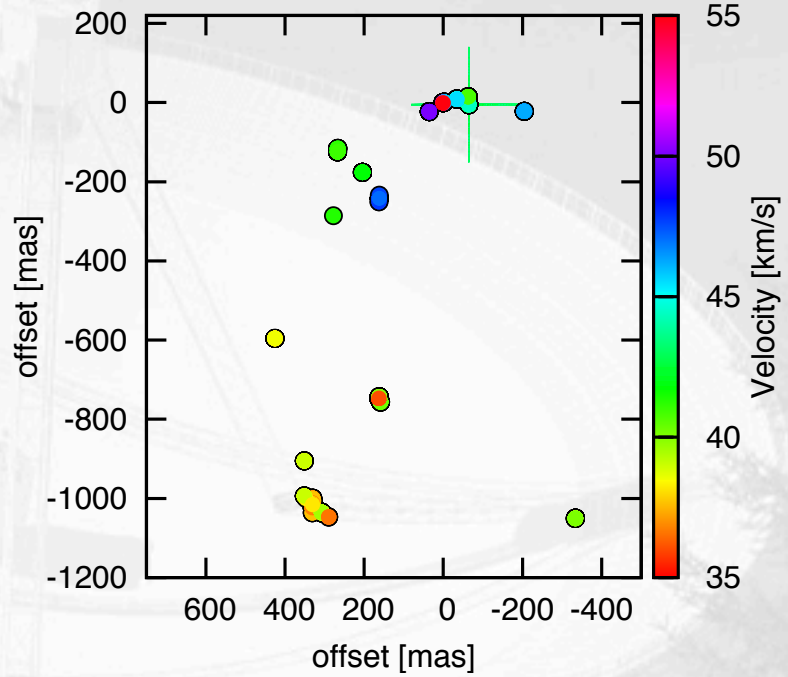
**Interpretation**

← Burst maser is highly compact (mas)



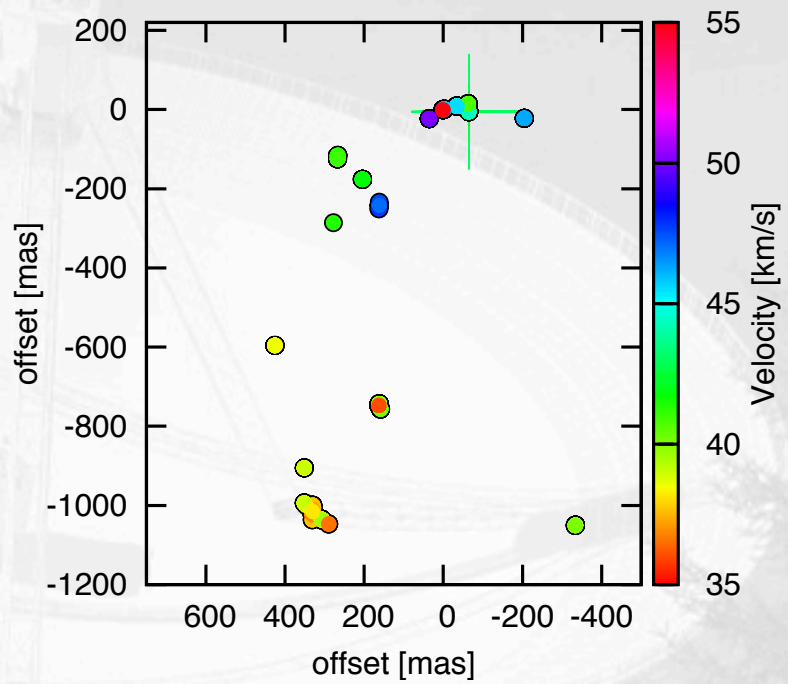
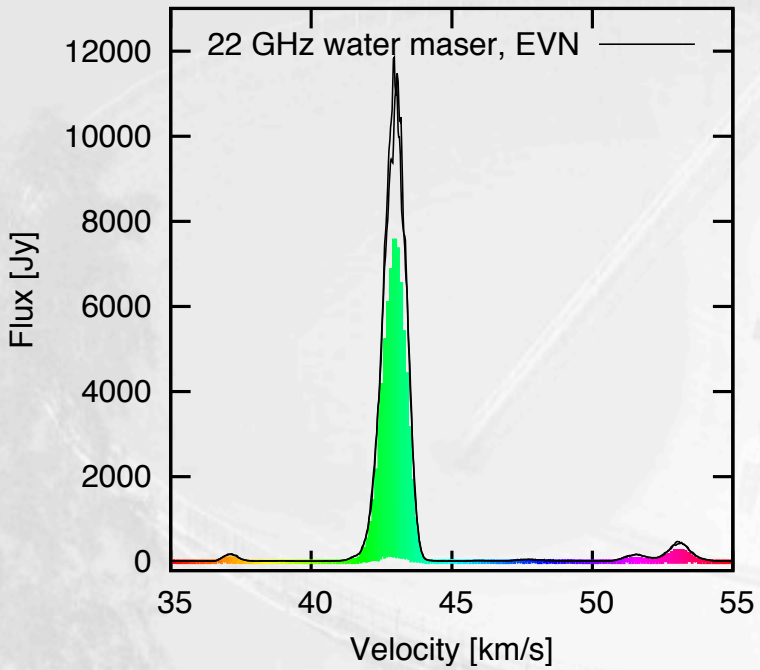
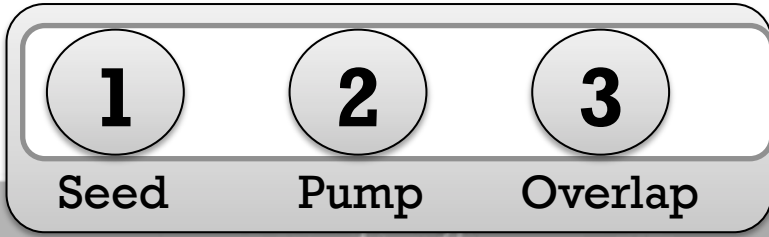
**Observation**

- VLBI: ~12,000 Jy
- Single dish: ~15,000 Jy
- Masers form arcs



**Interpretation**

- ← Burst maser is highly compact (mas)
- ← Burst occurs in shocked surface



**Observation**

**Interpretation**

- VLBI: ~12,000 Jy ← Burst maser is highly compact (mas)
- Single dish: ~15,000 Jy
- Masers form arcs ← Burst occurs in shocked surface
- Maser arcs associate with continuum ← Source of seed photons



# **KaVA results**



**1**

Seed

**2**

Pump

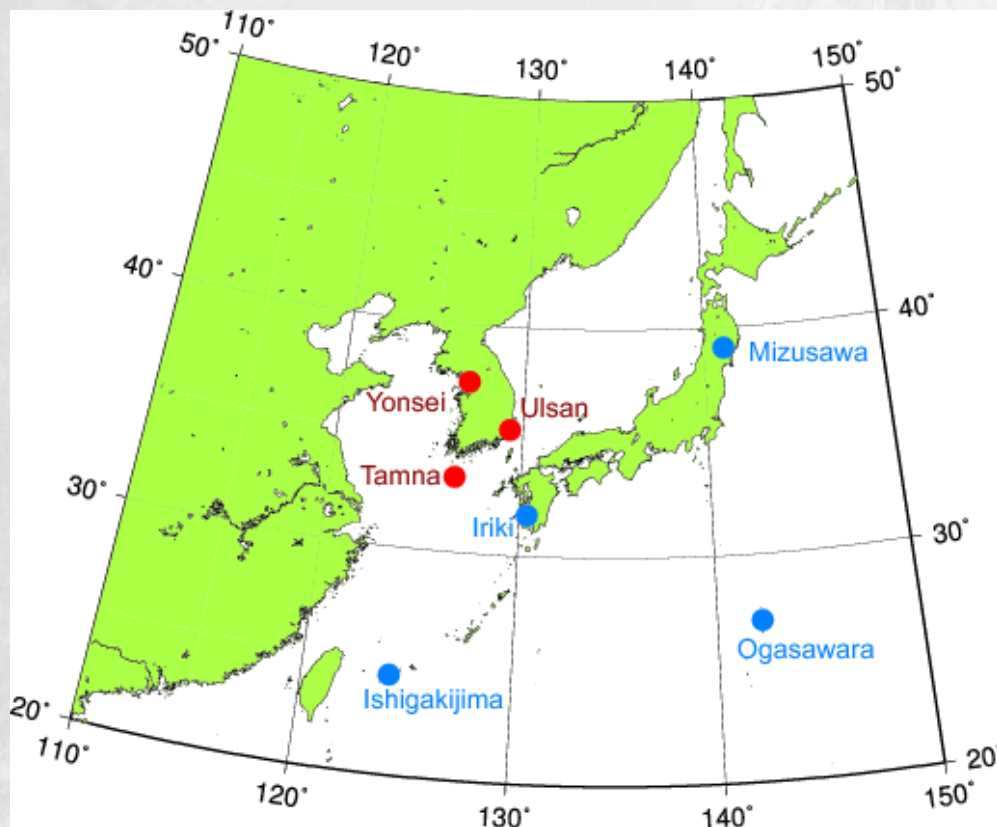
**3**

Overlap

**G25.65+1.05**  
**Results #2**

Happy Birthday  
1yr

## KaVA – KVN and VERA Array



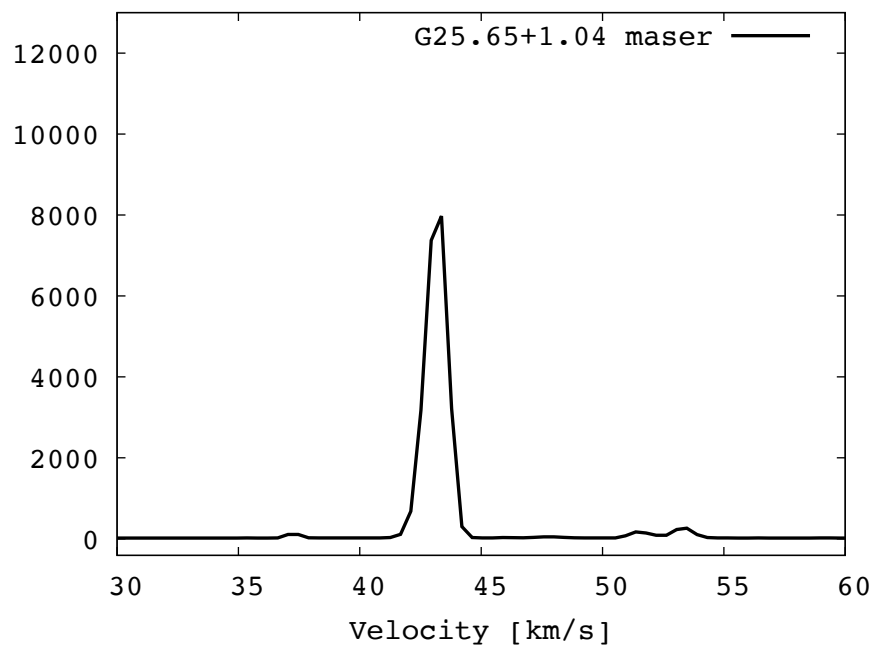
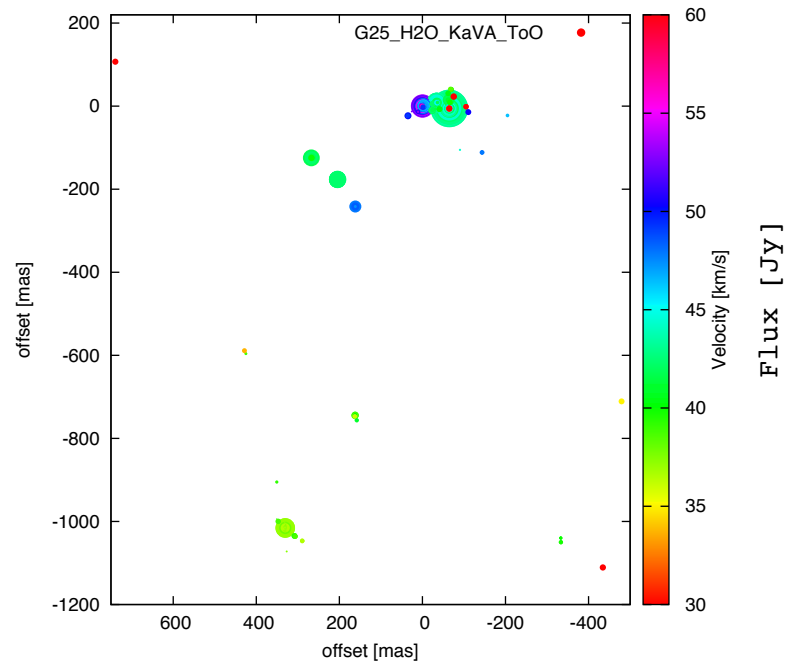
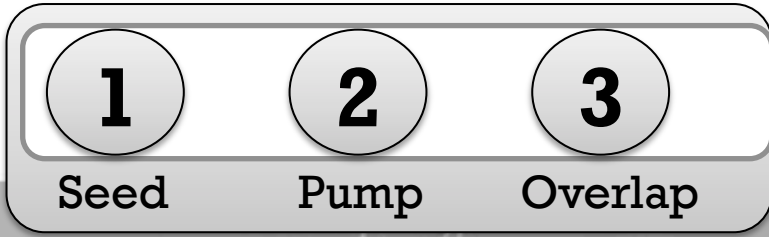
Date: 11 Oct 2017

Duration: Full track

Targets: W49N, G25

Participating stations:

1. Tamna, Korea
2. Yonsei, Korea
3. Ulsan, Korea
4. Mizusawa, Japan
5. Iriki, Japan
6. Ogasawaras, Japan



**Observation**

- VLBI: ~8,000 Jy
- Single dish: ~26,000 Jy
- Spectral peak widening
- Consistent with EVN

**Interpretation**

- ← Burst maser is less compact
- ← Multiple features?
- ← No masers created / destroyed



**VLBA results**



**1**

Seed

**2**

Pump

**3**

Overlap

**G25.65+1.05**  
**Results #3**

## VLBA - Very Long Baseline Array

Date: 28 Oct 2017

Duration: Full track

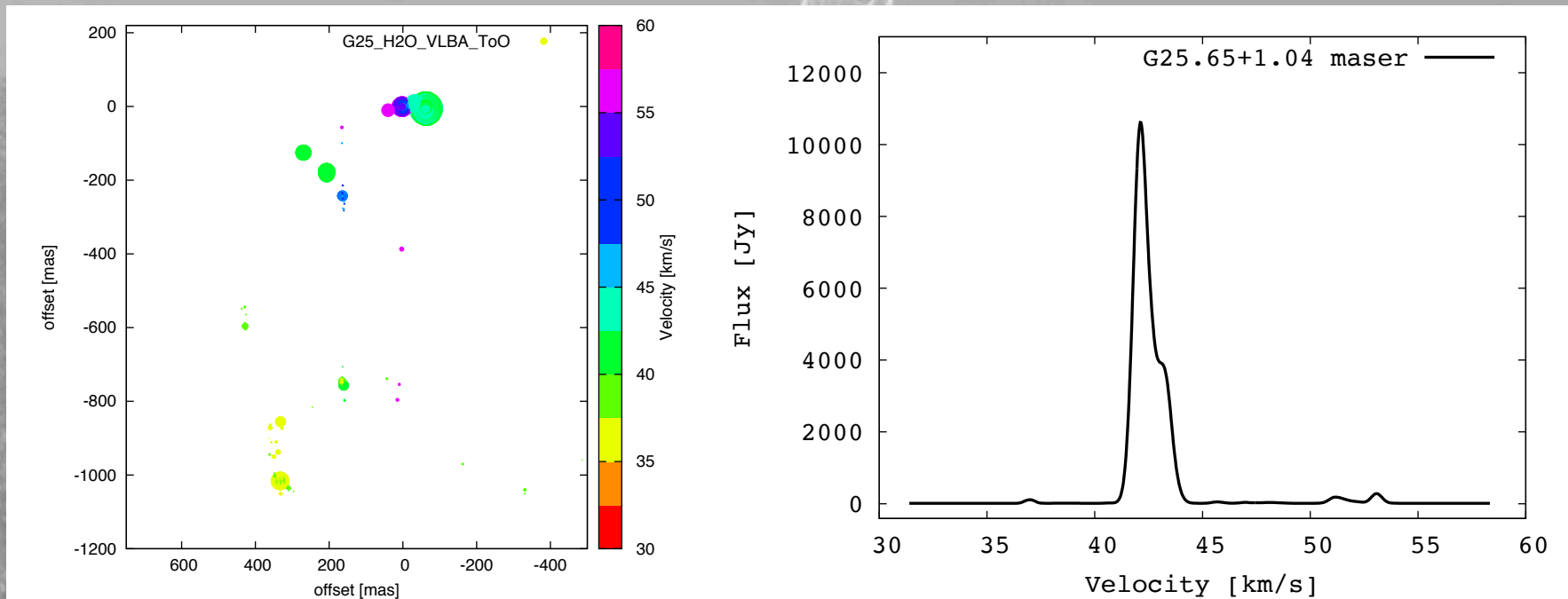
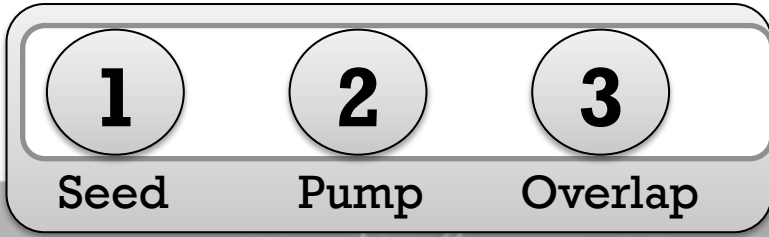
Targets: W49N, G25

Participating stations:

1. Brewster
2. Fort Davis
3. Kitt Peak
4. Los Alamos
5. Mauna Kea
6. North Liberty
7. Owens Valley
8. Pie Town







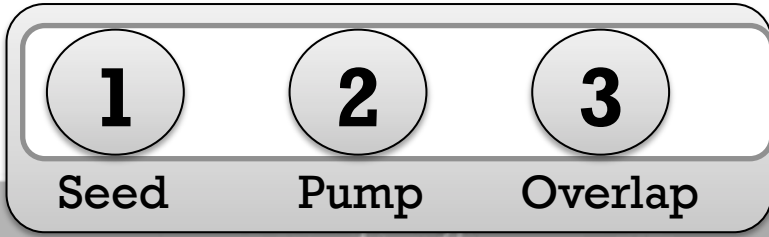
### Observation

- VLBI: ~10,000 Jy      ← Burst maser is highly compact  
 Single dish: ~10,000 Jy
- Spectrum exhibits “shoulder”      ← Multiple features? Interacting?
- Consistent with EVN+KaVA      ← No masers created / destroyed

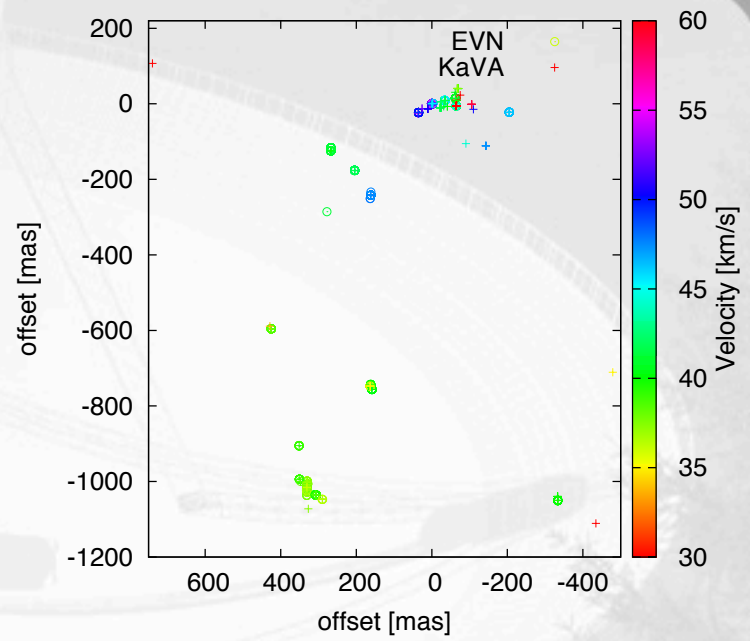
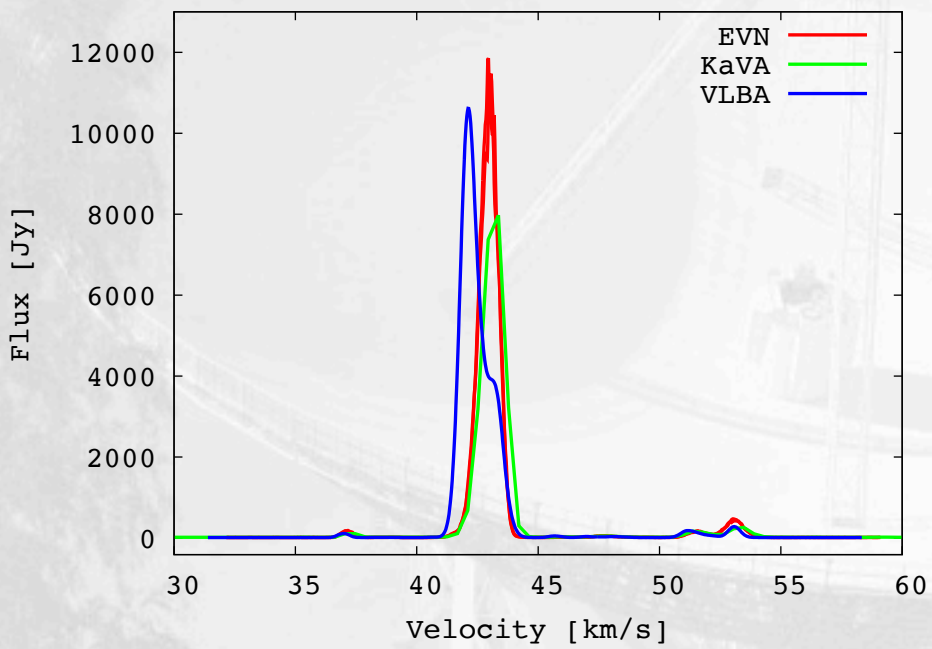
### Interpretation



**All results**



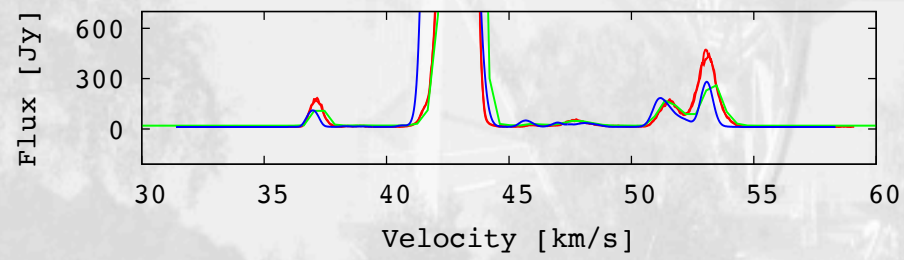
**Multi-epoch**  
**spectra and spotmap**



**Non-burst features  
 remain constant**

**Burst feature migrates**

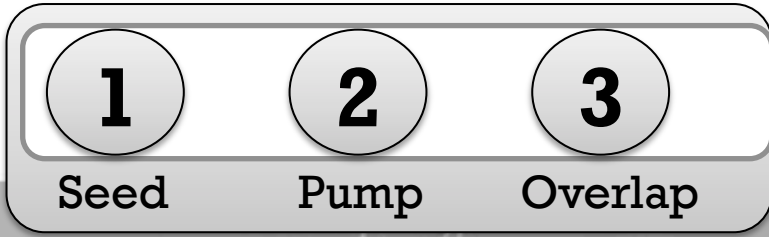
**Wing or “Shoulder”**



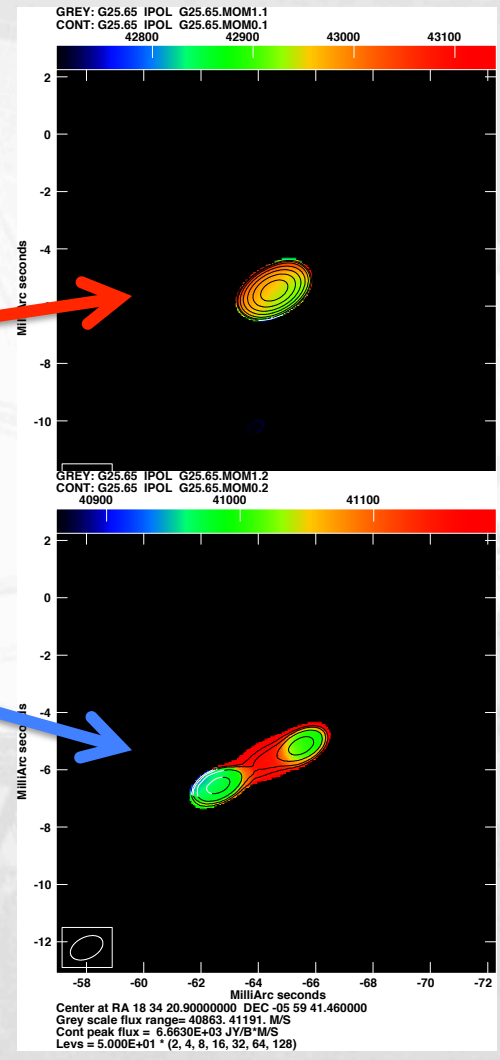
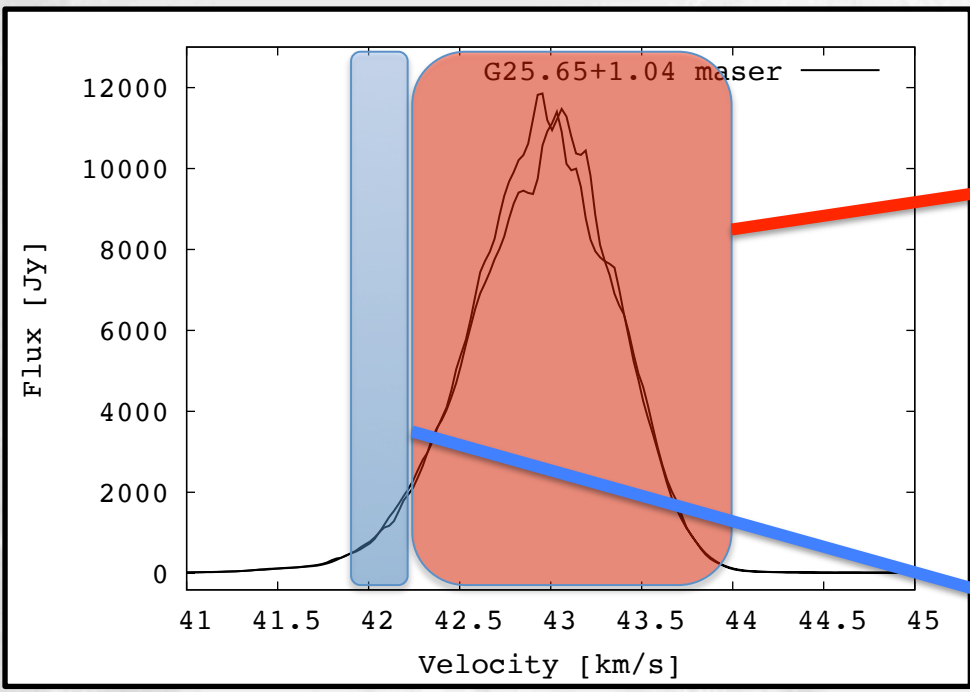


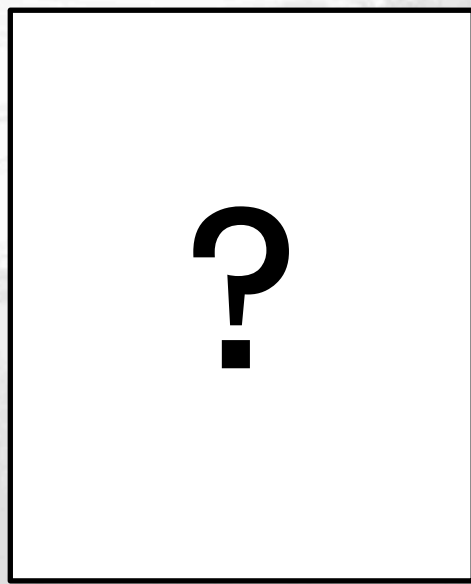
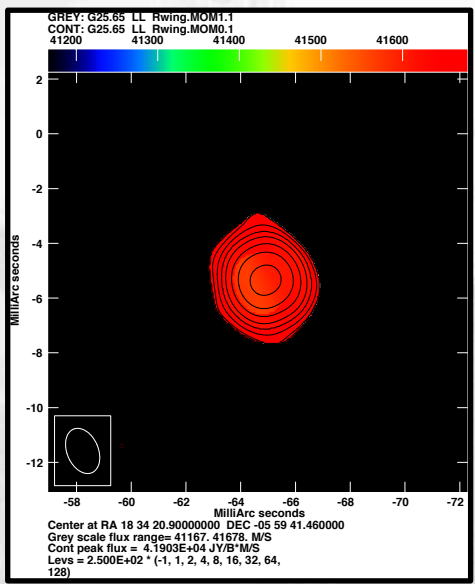
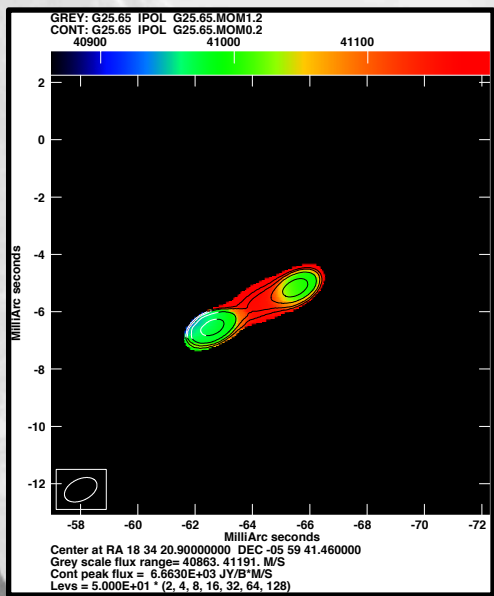
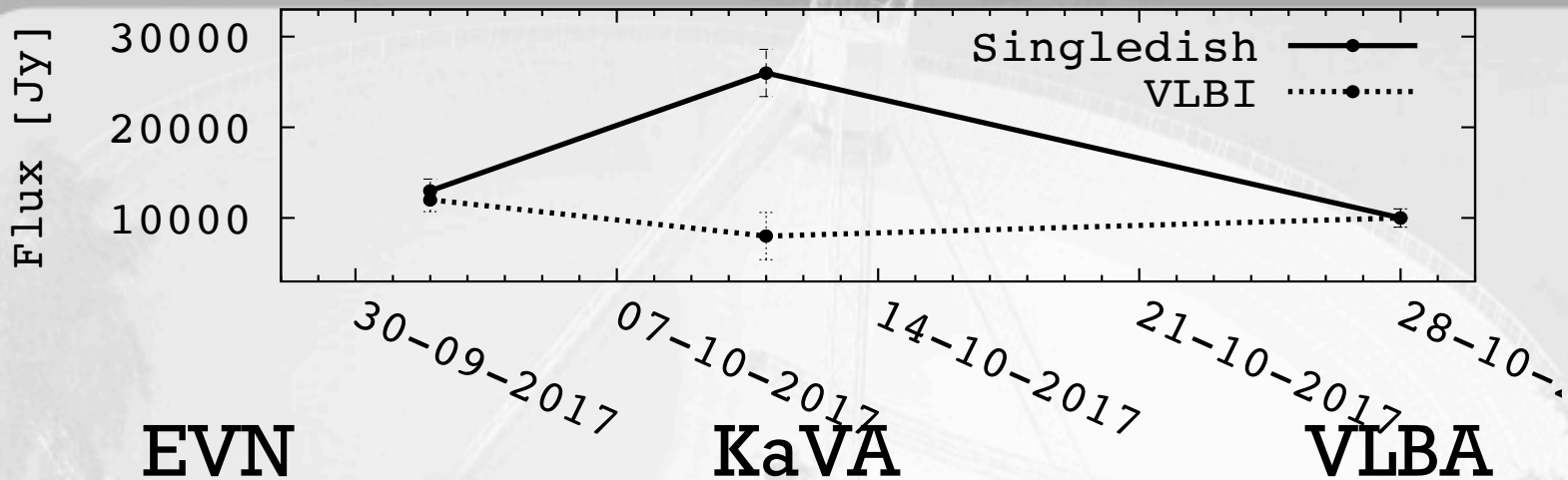
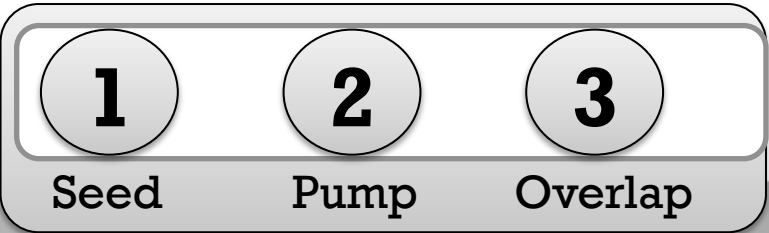


**Return to AIPS**

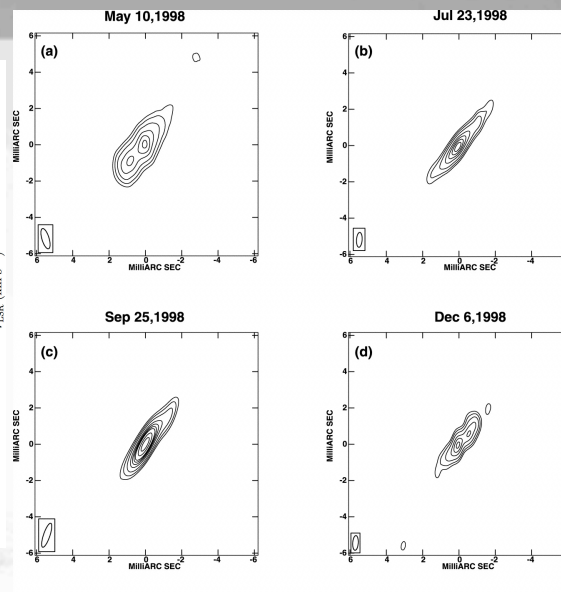
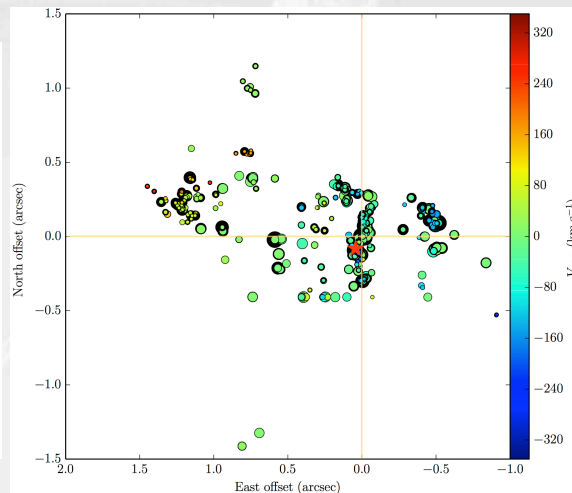
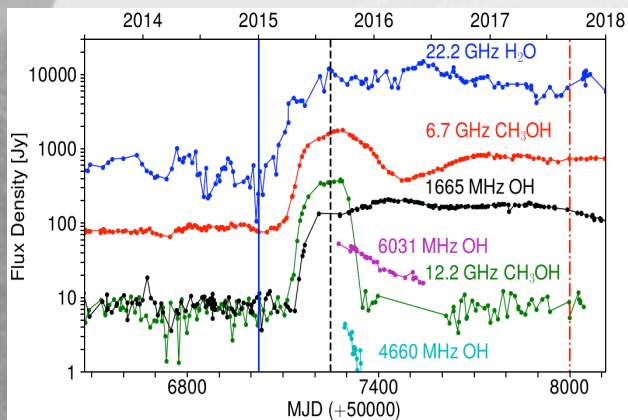


# “Shoulder” emission (EVN)









## More seed photons

- Location:  
near continuum ✓
- Affected spectral features:  
all foreground (many)
- Temporally:  
'slow' (days - years)
- Structure:  
independent

## Enhanced pumping

- Location:  
shocks ✓
- Affected spectral features:  
several
- Temporally:  
'slow' (days - years)
- Structure:  
independent

## L.O.S. overlap

- Location:  
independent ✓
- Affected spectral features:  
~one or two ✓
- Temporally:  
'fast' (hours - days) ✓
- Structure:  
Highly compact ✓

# Conclusions

We can confidently attribute the maser super burst in G25 to the overlapping of two maser features on the plane of the sky

There is still much more information to be extracted from this multi-epoch data set

Insights into the maser mechanism, and star formation



**Other business**



## Finding maser super bursts

- Rare
- Short-lived
- Unexplained

## Maser Monitoring Organisation (M2O)

- To coordinating single-dish maser monitoring programs worldwide.

## Understanding maser super bursts

- Quick-response observations
- Multi-scale
- Multi-epoch

## M2O-VLBI

- To obtain quick VLBI follow-up observations in quick response to M2O burst alerts

We can confidently attribute the maser super burst in G25 to the overlapping of two maser features on the plane of the sky

There is still much more information to be extracted from this multi-epoch data set

Insights into the maser mechanism, and star formation

M2O established to identify new bursts (see Poster)

M2O-VLBI established for follow up imaging of more bursts

To Questions



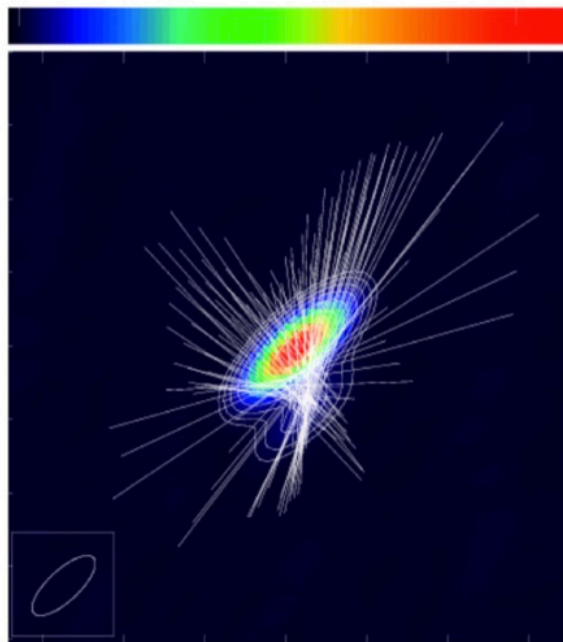
**Polarisation  
(preliminary)**



# Polarisation: Calibration (cont.)

## Before

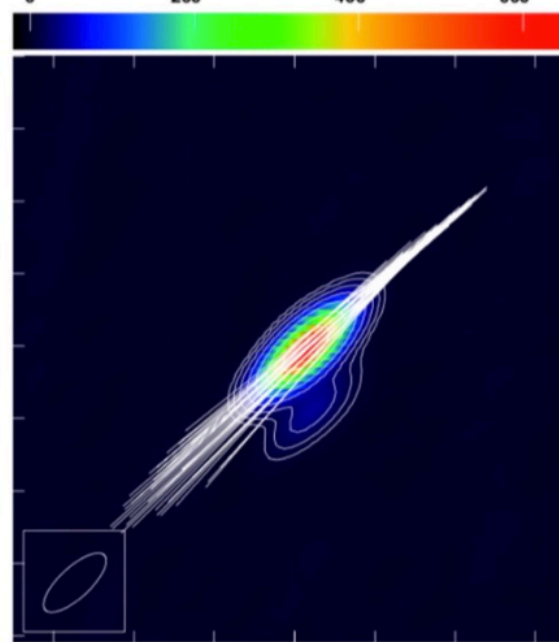
Lot file version 1 created 08-JUN-2018 12:12:28  
 .LL: J2202+42 IPOL 22235.089 MHz J2202+4216.ICL001.1  
 0 200 400 600



.2920 43.2918 43.2916 43.2914 43.2912 43.2910 43.2908  
 Right Ascension (J2000)  
 Grey scale flux range = -17.1 688.2 MilliJY/BEAM  
 Cont peak flux = 6.8822E-01 JY/BEAM  
 Levs = 3.579E-03 \* (2, 4, 8, 16, 32, 64, 128, 256, 512)  
 Pol line 1 milli arcsec = 1.5625E-04 JY/BEAM  
 Pol. line rotated by 88.0 degrees

## After

Plot file version 1 created 07-JUN-2018 21:58:57  
 ALL: J2202+42 IPOL 22235.089 MHz J2202+4216.ICL001.2  
 0 200 400 600



3.2920 43.2918 43.2916 43.2914 43.2912 43.2910 43.2908  
 Right Ascension (J2000)  
 Grey scale flux range = -17.1 688.2 MilliJY/BEAM  
 Cont peak flux = 6.8822E-01 JY/BEAM  
 Levs = 3.579E-03 \* (2, 4, 8, 16, 32, 64, 128, 256, 512)  
 Pol line 1 milli arcsec = 6.2500E-04 JY/BEAM  
 Pol. line rotated by 88.0 degrees

J2202+4216  
 (BL Lac)

D-term calibrator

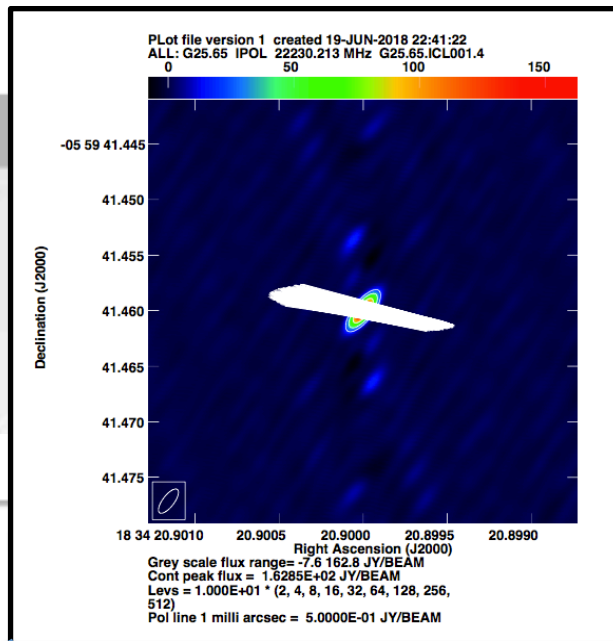
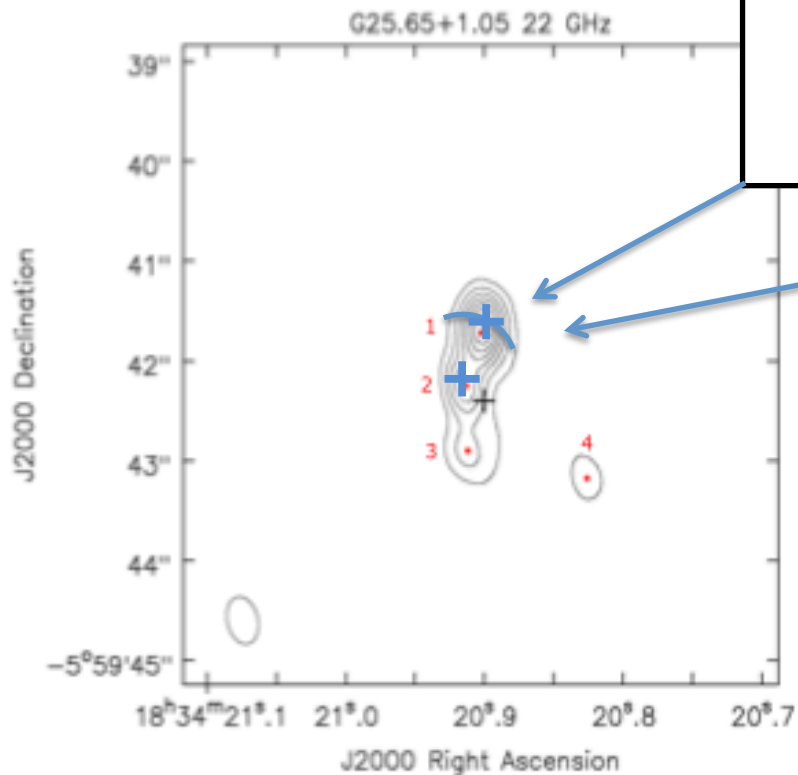
Delay calibrator

Gain selfcal

No EVPA cal yet

EVN pol. cal.  
successful

## 22 GHz water maser polarisation in the North group

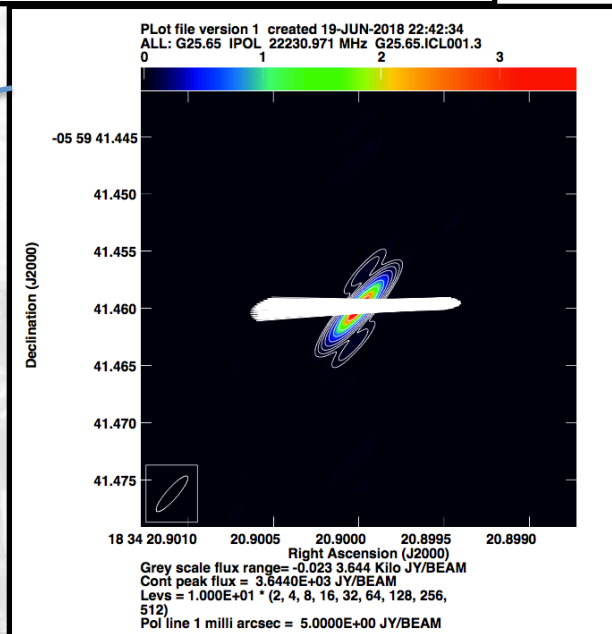


### Regular maser

Stokes Q  
8 Jy

Stokes I  
160 Jy

5% Linear  
polarisation



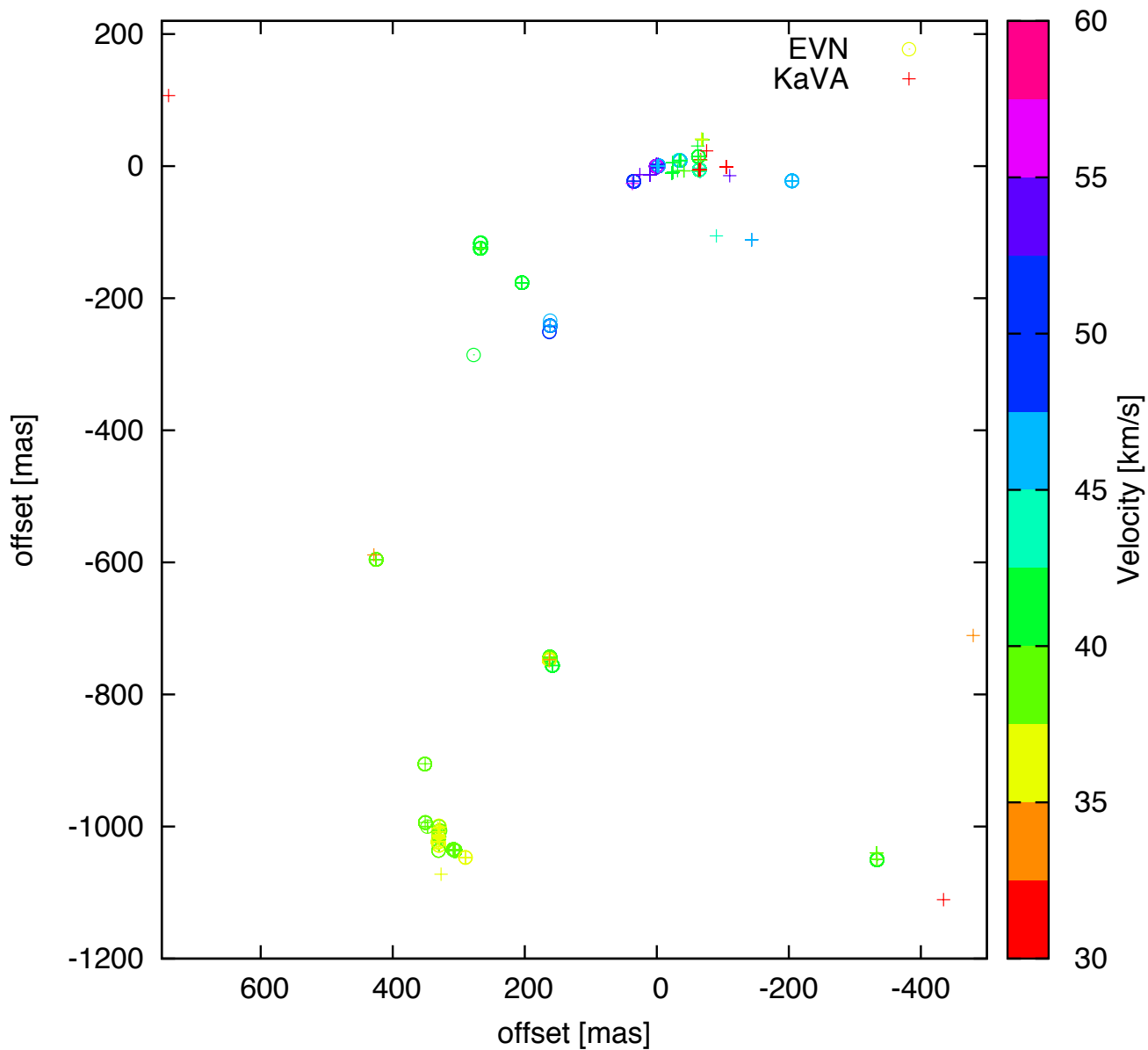
### Super burst

Stokes Q  
90 Jy

Stokes I  
3600 Jy

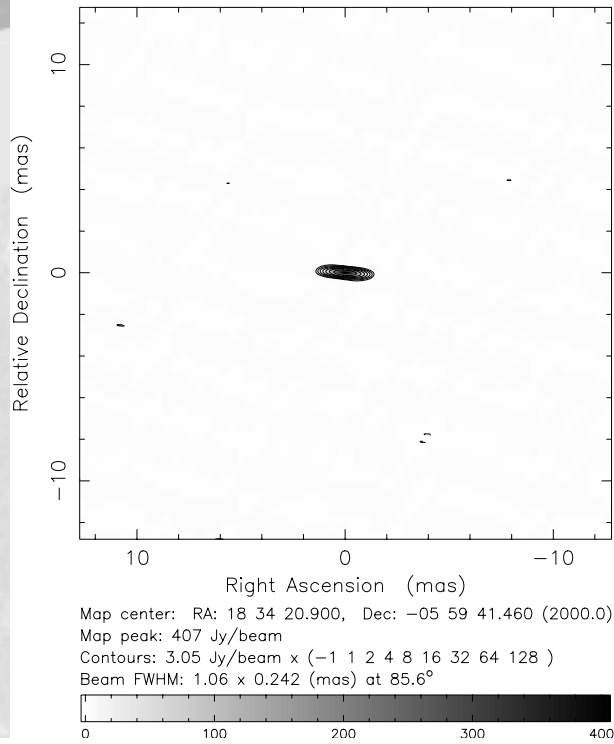
2.5% Linear  
polarisation

# Maser Super Burst

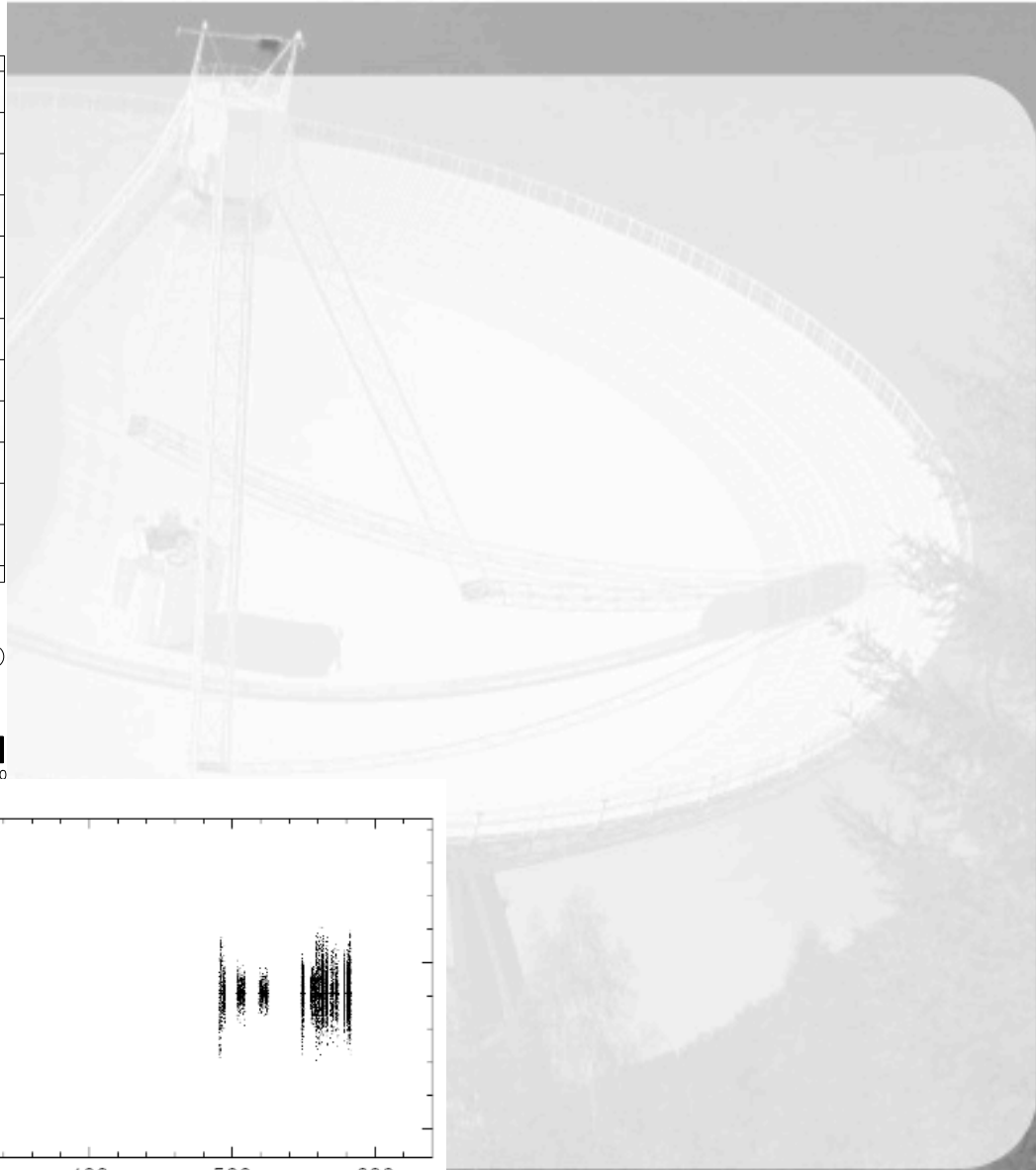
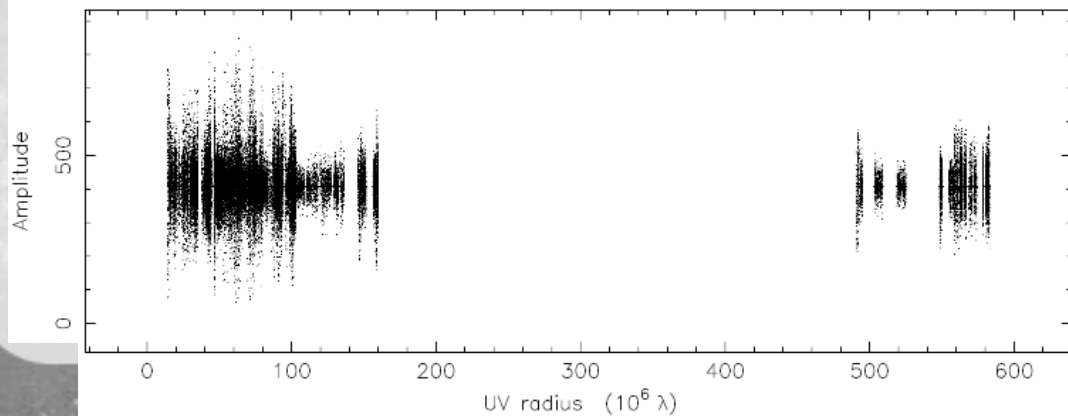


# Results #1

Clean RR map. Array: EVN  
G25.65 at 22.230 GHz 2017 Oct 02

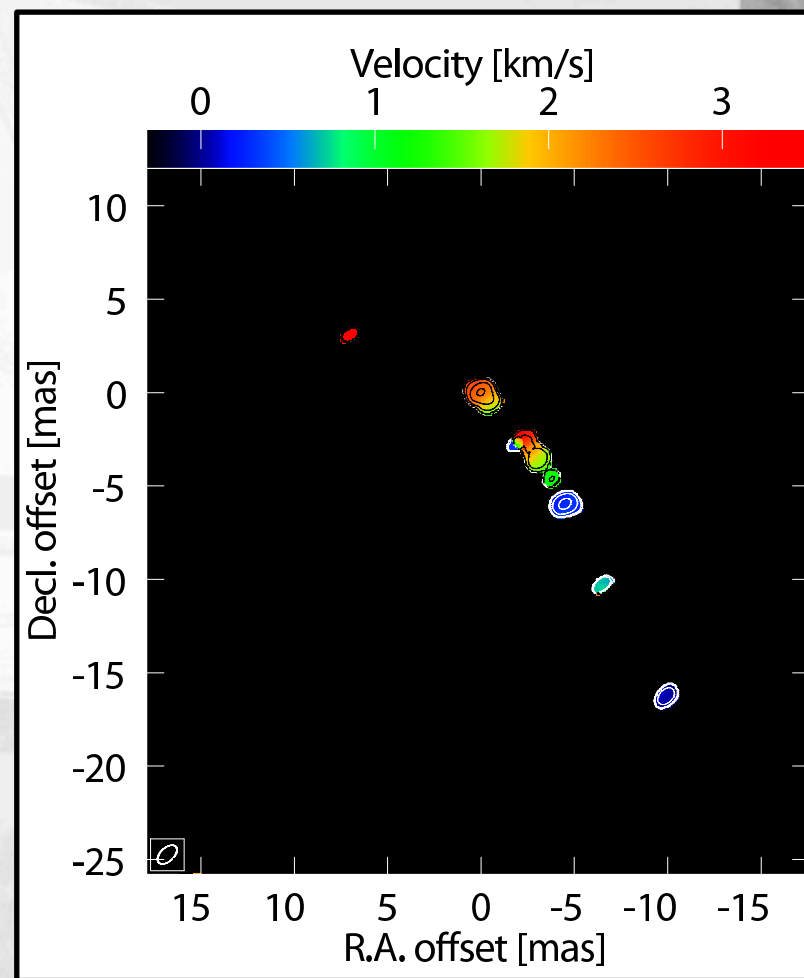
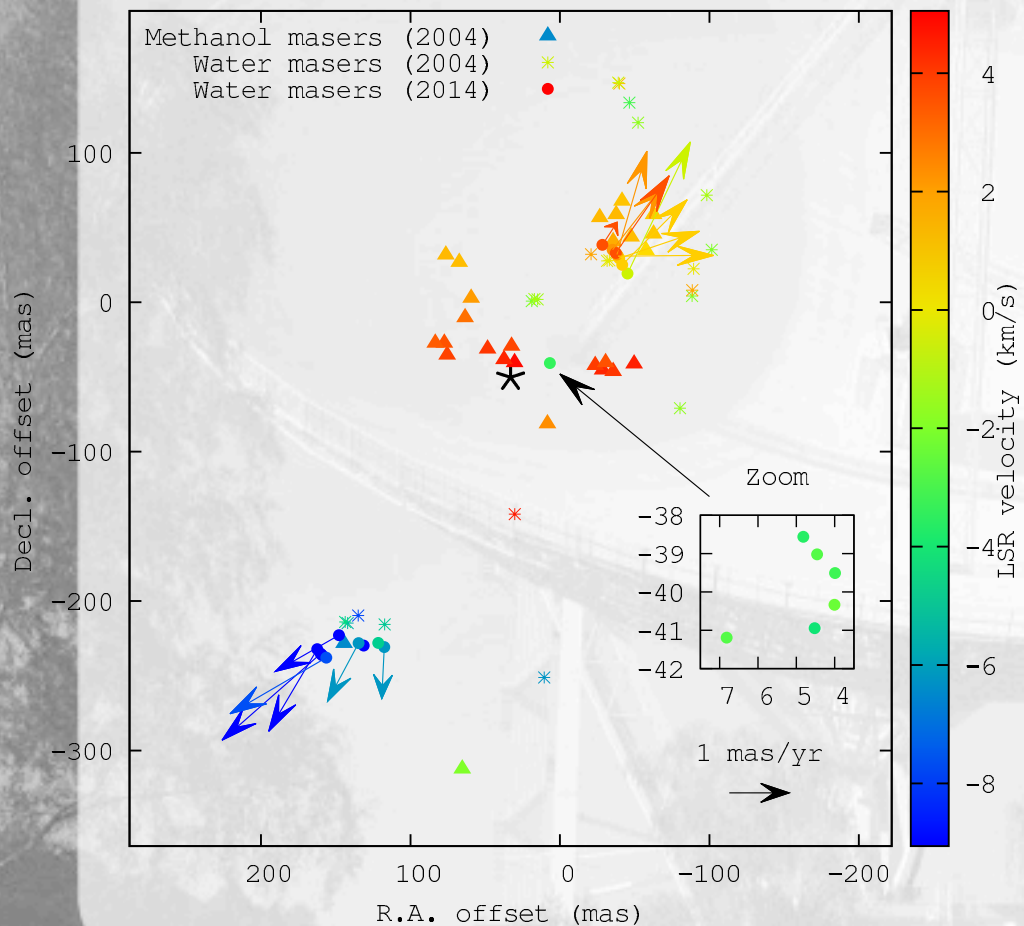


G25.65 at 22.230 GHz in RR 2017 Oct 02

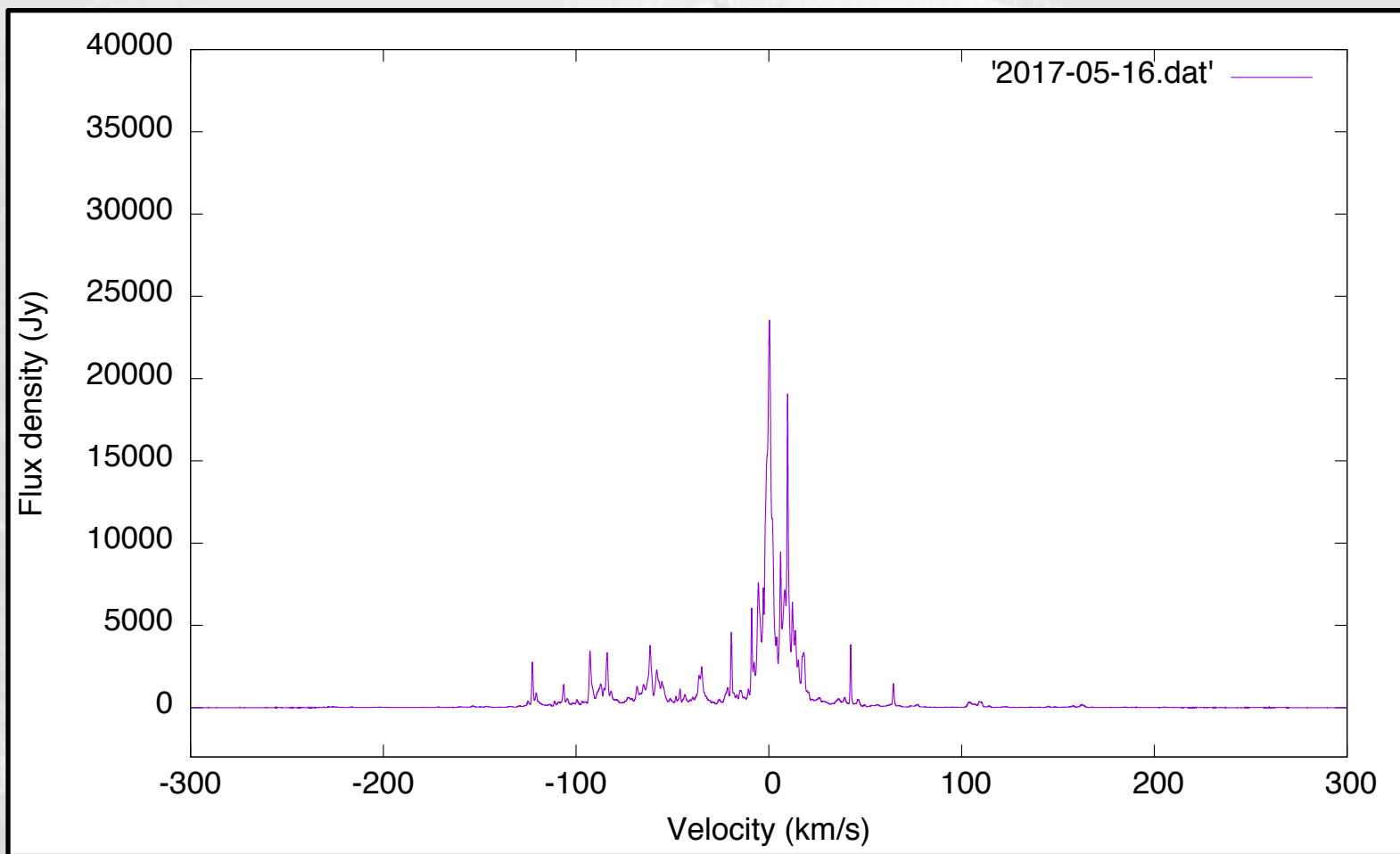




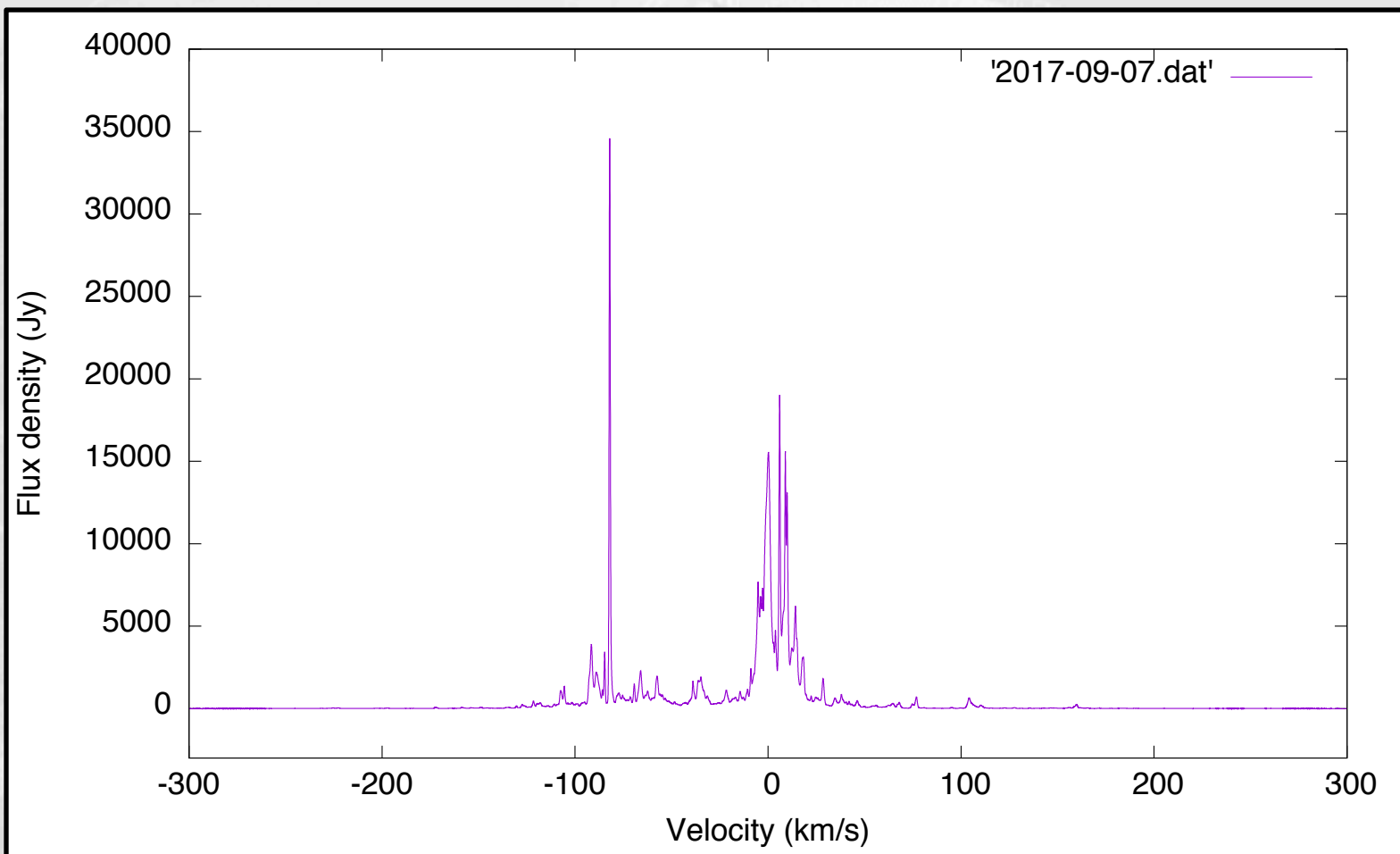
# Regular masers

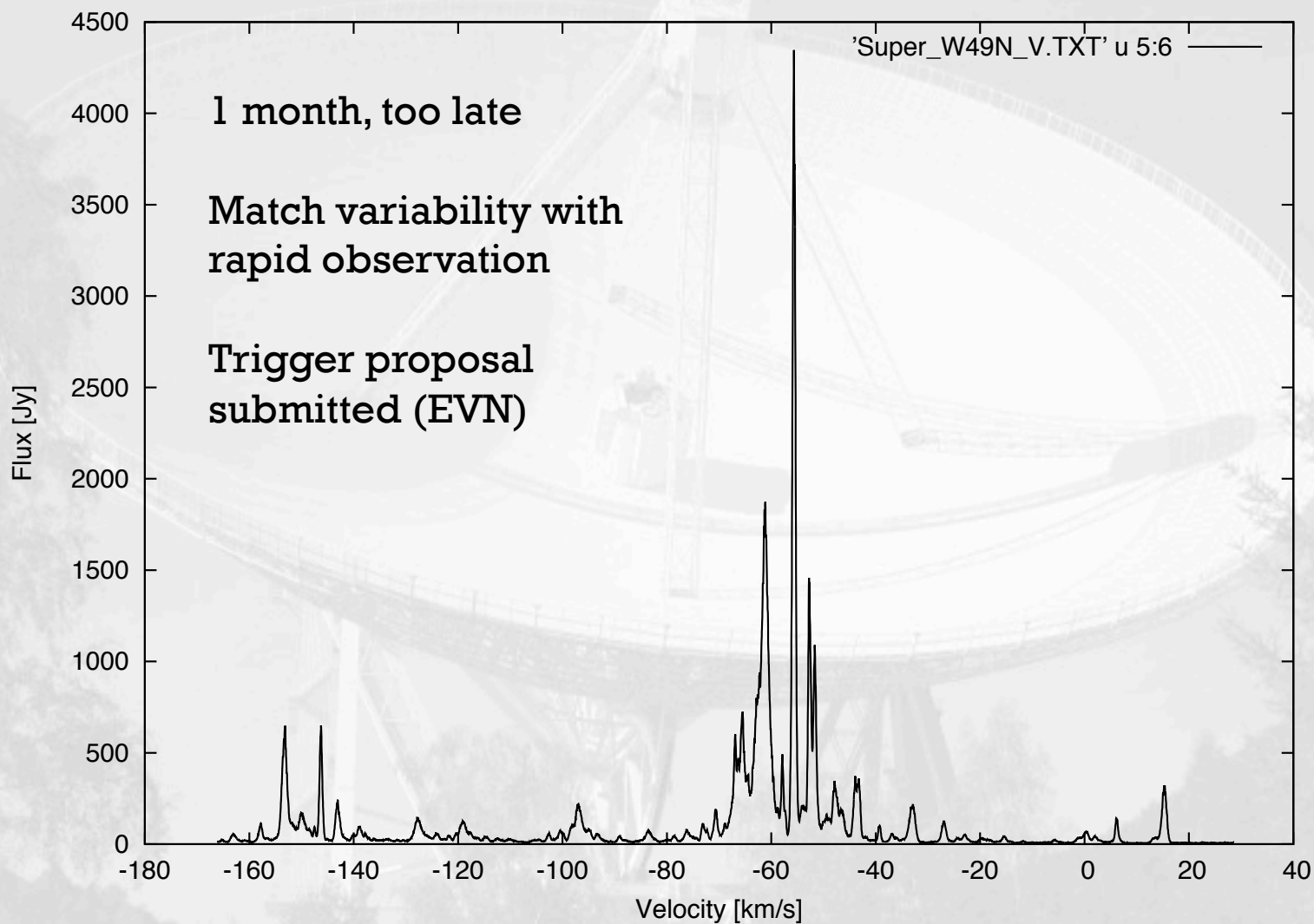


W49N



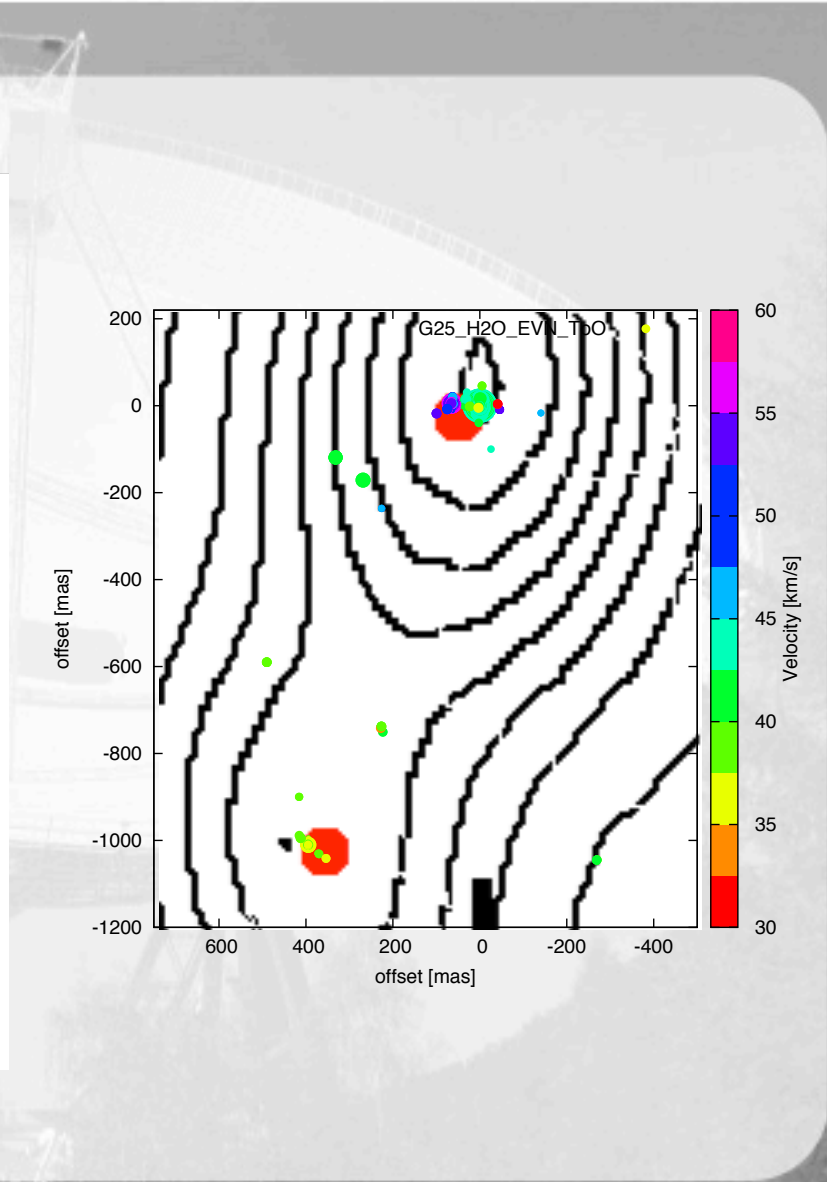
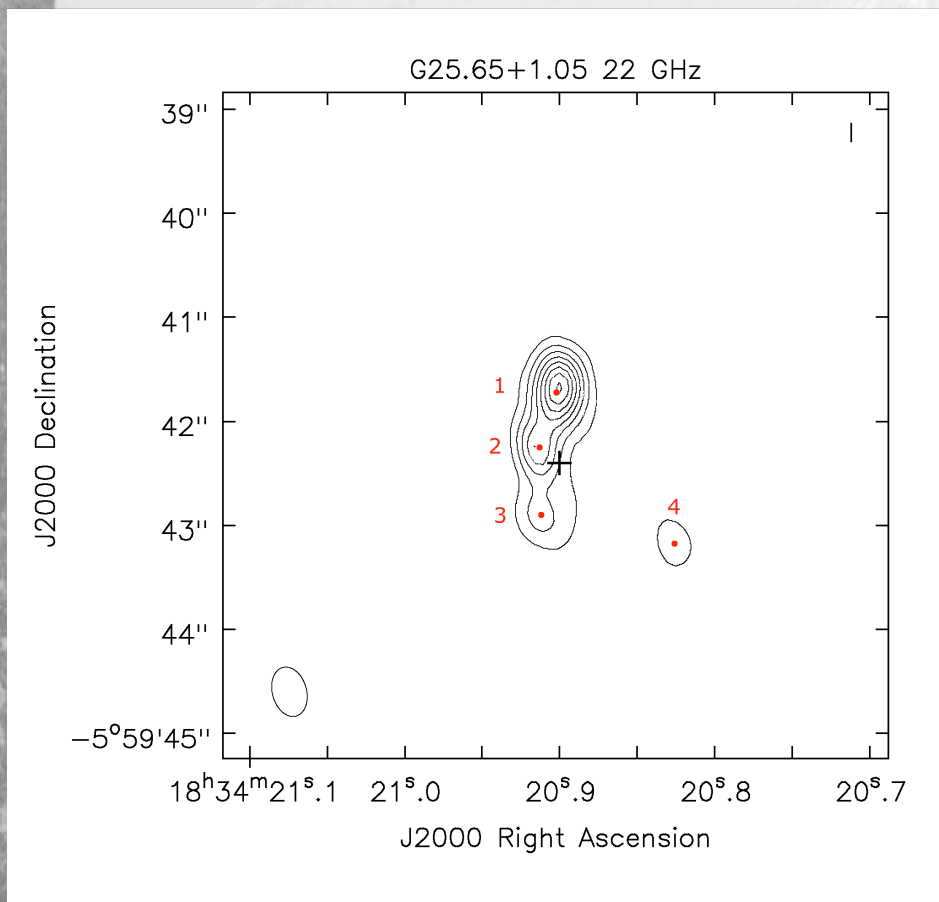
W49N



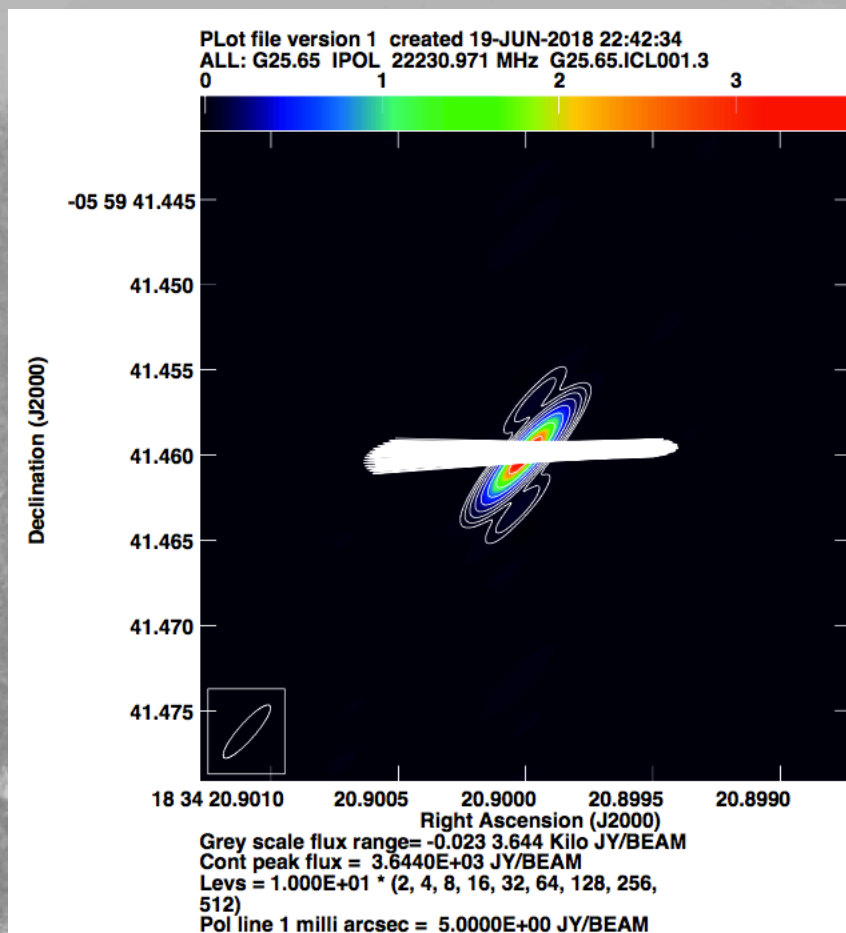




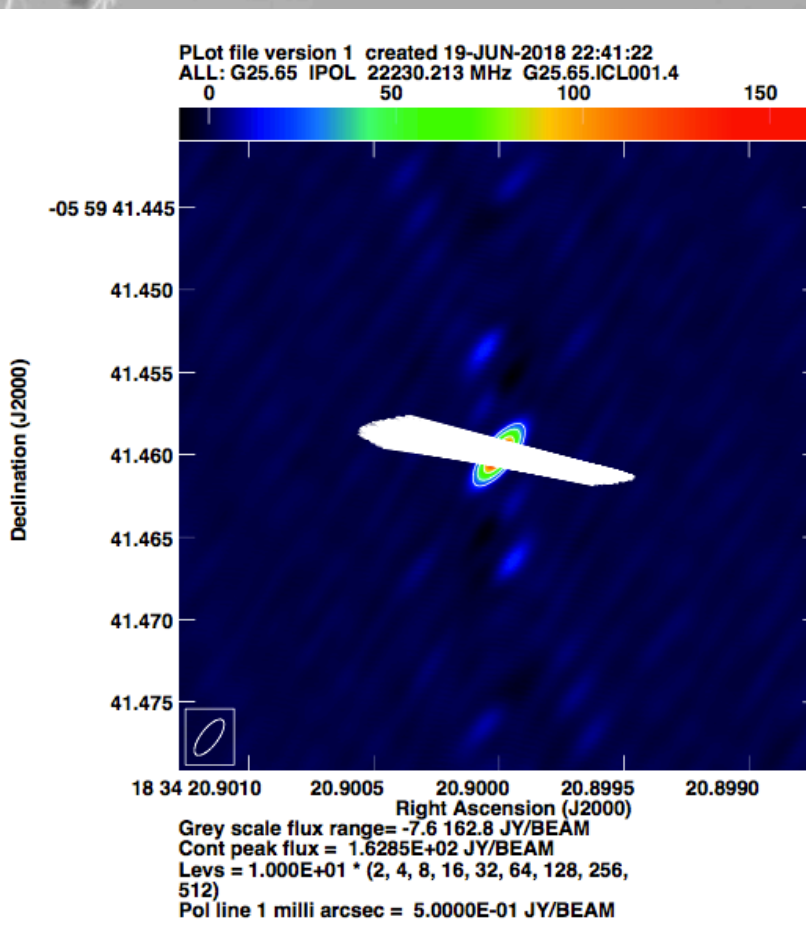
# G25 continuum - VLA



# Polarisation: Maser features



Stokes Q = 90 Jy  
 Stokes I = 3600 Jy  
 2.5% Linear polarisation



Stokes Q = 8 Jy  
 Stokes I = 160 Jy  
 5% Linear polarisation