Elisabetta Ladu

Università degli studi di Cagliari – Osservatorio Astronomico di Cagliari- INAF

Ph.D Student

IC 485:
A new disk-maser galaxy?

A. Tarchi – INAF - OAC

G. Surcis – INAF - OAC

P. Castangia – INAF - OAC

J.A. Braatz – NRAO

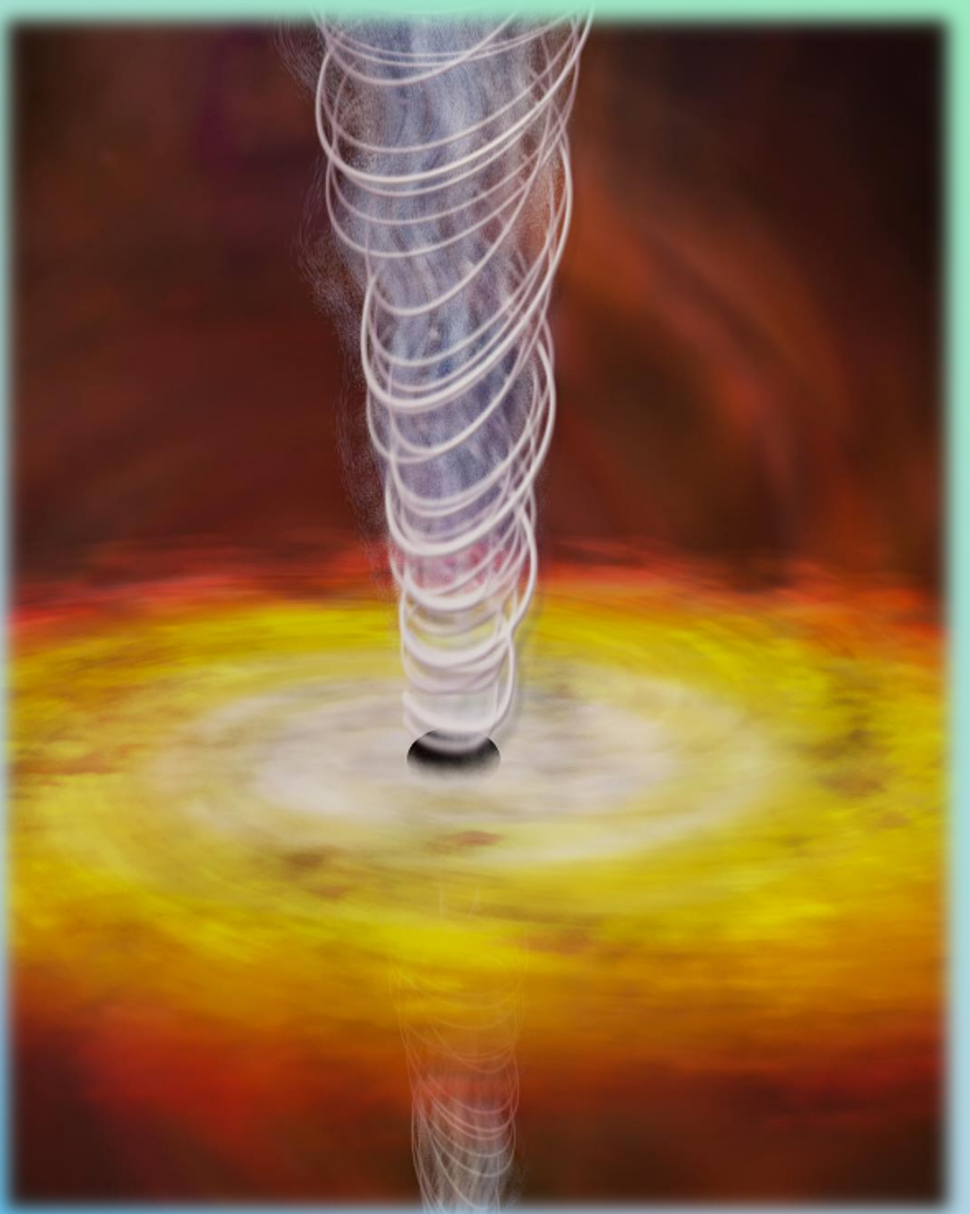
F. Panessa – INAF - IAPS

D. Pesce – CfA

15th EVN Symposium & Users Meeting:
Providing the Sharpest View of the Universe

Topics:

- The AGN;
- MASER phenomenon;
- The galaxy IC485;
- Results;
- Conclusions and follow-up.



AGN

Active Galactic Nuclei

Intense nuclear activities in all e.m. spectrum

Unified Model - Urry & Padovani

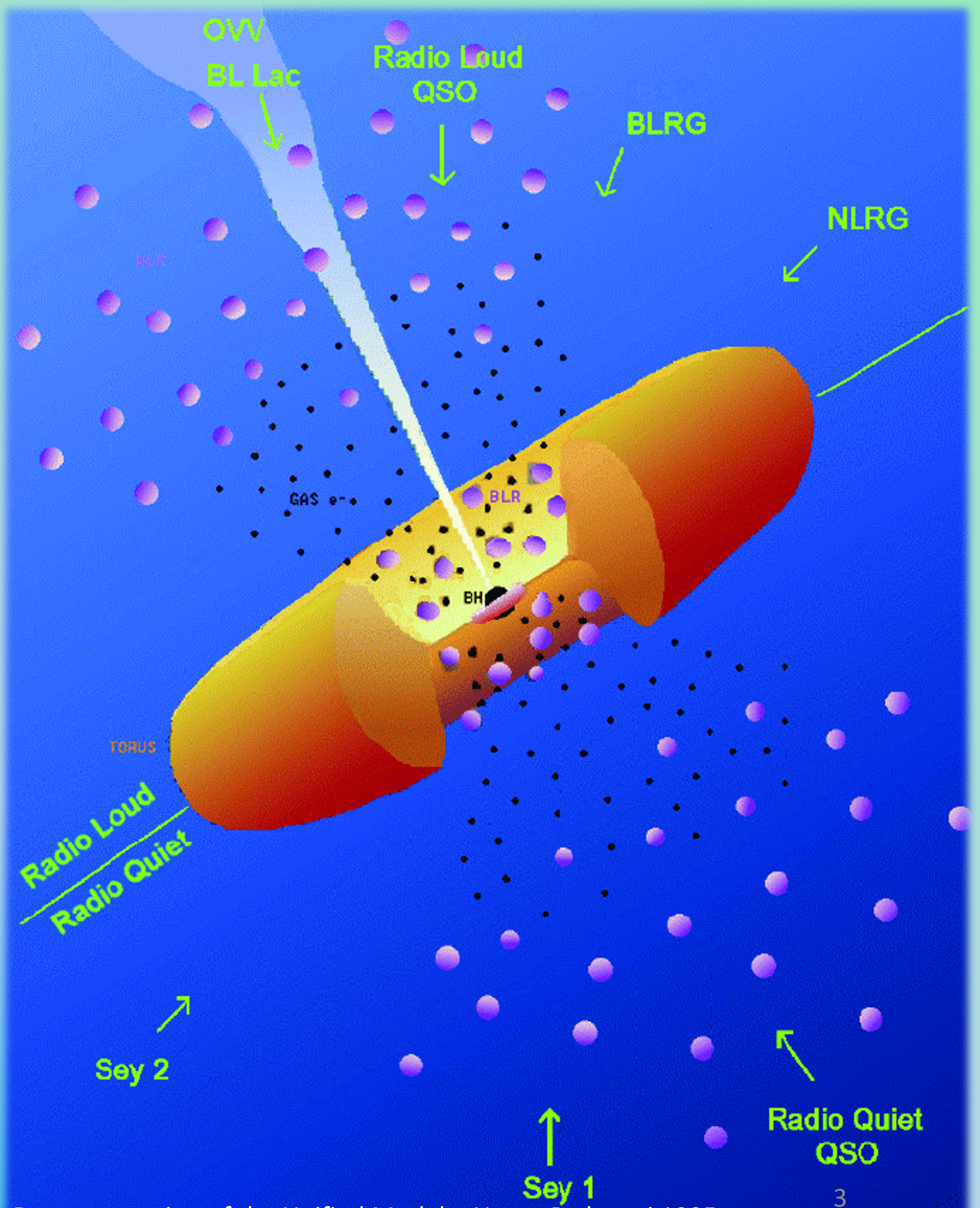
- SuperMassive Black Hole (SMBH - $10^6 \div 10^9 M_\odot$);
- Accretion disk;
- Torus of gas and dust;
- Broad Line Regions;
- Narrow Line Regions;

- Radio jets;

Radio quiet

Radio loud

The observation of each components depends on the orientation of the galaxy.



Rappresentation of the Unified Model - Urry e Padovani 1995

AGN: Seyfert and LINERs

AGN *radio-quiet*

Seyfert

Radiative-mode

Seyfert 1 (Sey1)

Morphology: Spiral

Orientation: «face-on»

Broad lines - FW$HM \geq 1000\ km\ s^{-1}$

Seyfert 2 (Sey2)

Morphology: Spiral

Orientation: «edge-on»

Narrow lines - FW$HM \approx 300 - 1000\ km\ s^{-1}$

LINERs

Jet-mode

Low – Ionization Nuclear Emission – line Regions

Morphology: Elliptical, rarely Spiral

Emission lines from low ionization species:
[OI], [OII], [NII], [SII]

Low X-ray luminosity

AGN ⟺ LINERs ⟺ «Normal» galaxies

MASER phenomenon

Microwave Amplification by Stimulated Emission of Radiation

Megamaser H_2O

K-band $\nu_0 = 22{,}2\ GHz$

Extragalactic maser source $\geq 10^4\ L_\odot$

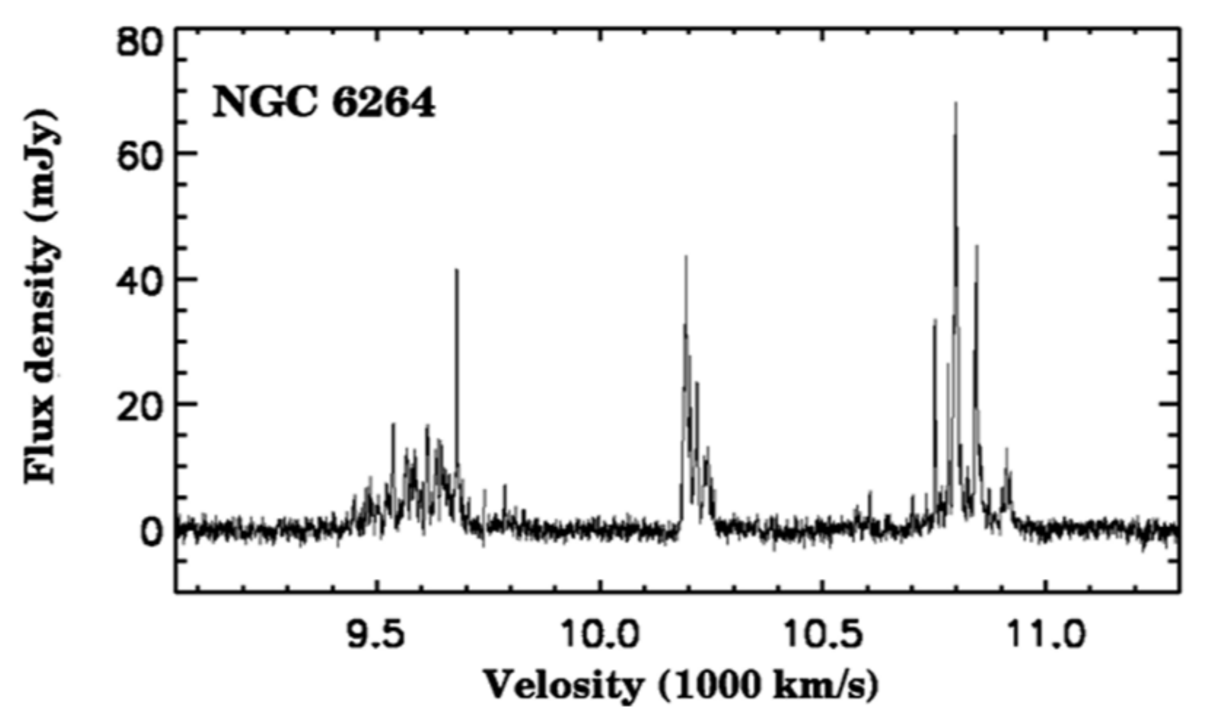
AGN: Sey2 and/or LINERs

Megamaser H_2O

Disk maser (edge-on)

- Systemic lines;
- Red-shifted lines ;
- Blue-shifted lines .

Maser spots allow us to map nuclear accretion disk and estimate the BH mass.



Kuo et al. (2011)

MASER phenomenon

Microwave Amplification by Stimulated Emission of Radiation

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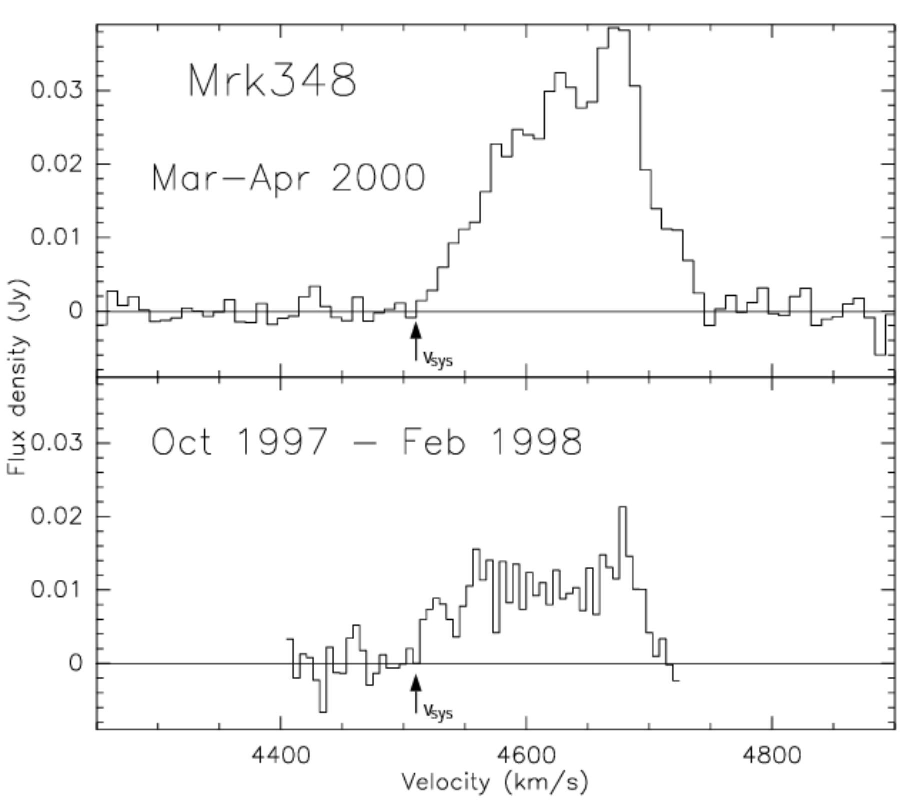
Jet/outflow Maser

- Single broad line
  - often red/blue-shifted w.r.t the systemic velocity.

Maser spots allow us to study geometry, dynamics and materials distribution of the jet/outflow.



Falcke et al. (2000)

MASER phenomenon

Microwave Amplification by Stimulated Emission of Radiation

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Inclined maser disk

(Darling J. 2017)

We detected maser emission thanks to geometry and gravitational lensing.

IC 485

RA: $8^h0^m19{,}765^s$
DEC: 26°42' 5,19''

Distance: 122 Mpc
Type: Sa Spiral Galaxy

Feature H_2O maser
(GBT - MCP*)

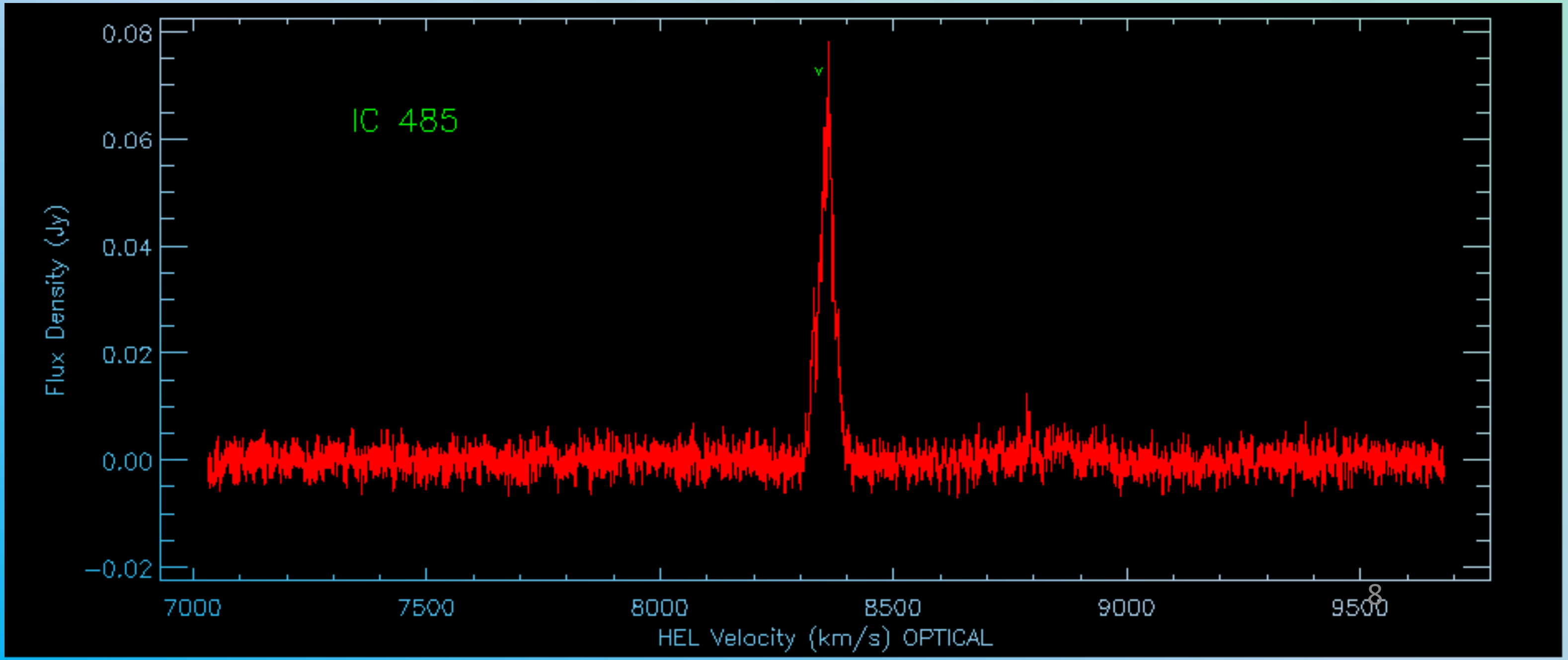
$(78 \pm 2) mJy$
$L_{iso} = (868 \pm 46) L_\odot$

Nuclear Radio Continuum
at 1,4 GHz : ~ 5 mJy (Darling 2017)

... see also Castangia's poster
(#19, in this symposium)

IC 485: Optical Survey Sloan Digital Sky Survey (SDSS)

*Spectrum GBT – MCP (Megamaser Cosmology Project)



IC 485

RA: $8^h0^m19{,}765^s$
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Distance: $122\ Mpc$

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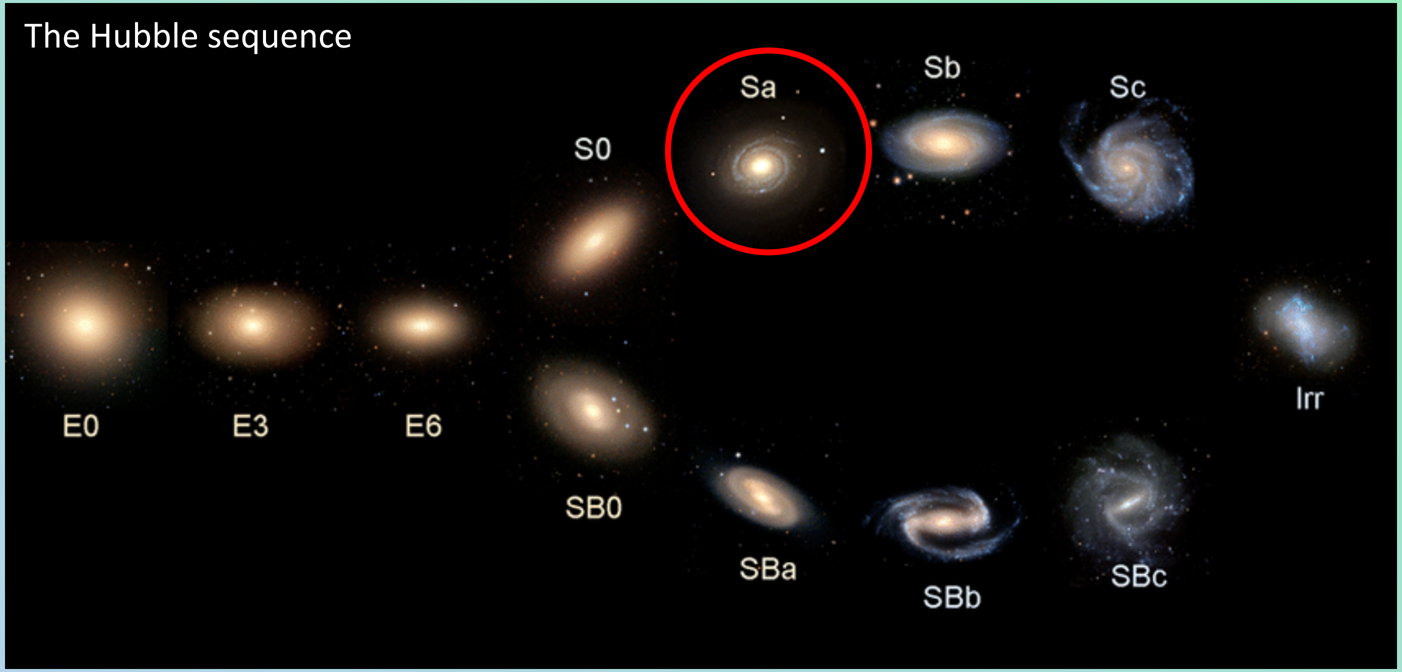


Classification to confirm:

- LINERs (Darling – 2017)
- Seyfert 2 (Kamali et al. – 2017)
- Candidate *inclined maser disk galaxy* (Darling -2017)

Aims of these observations:

- Detect maser emission;
- Position and
- Structure in relation to the galactic center;
- Clarify the classification.

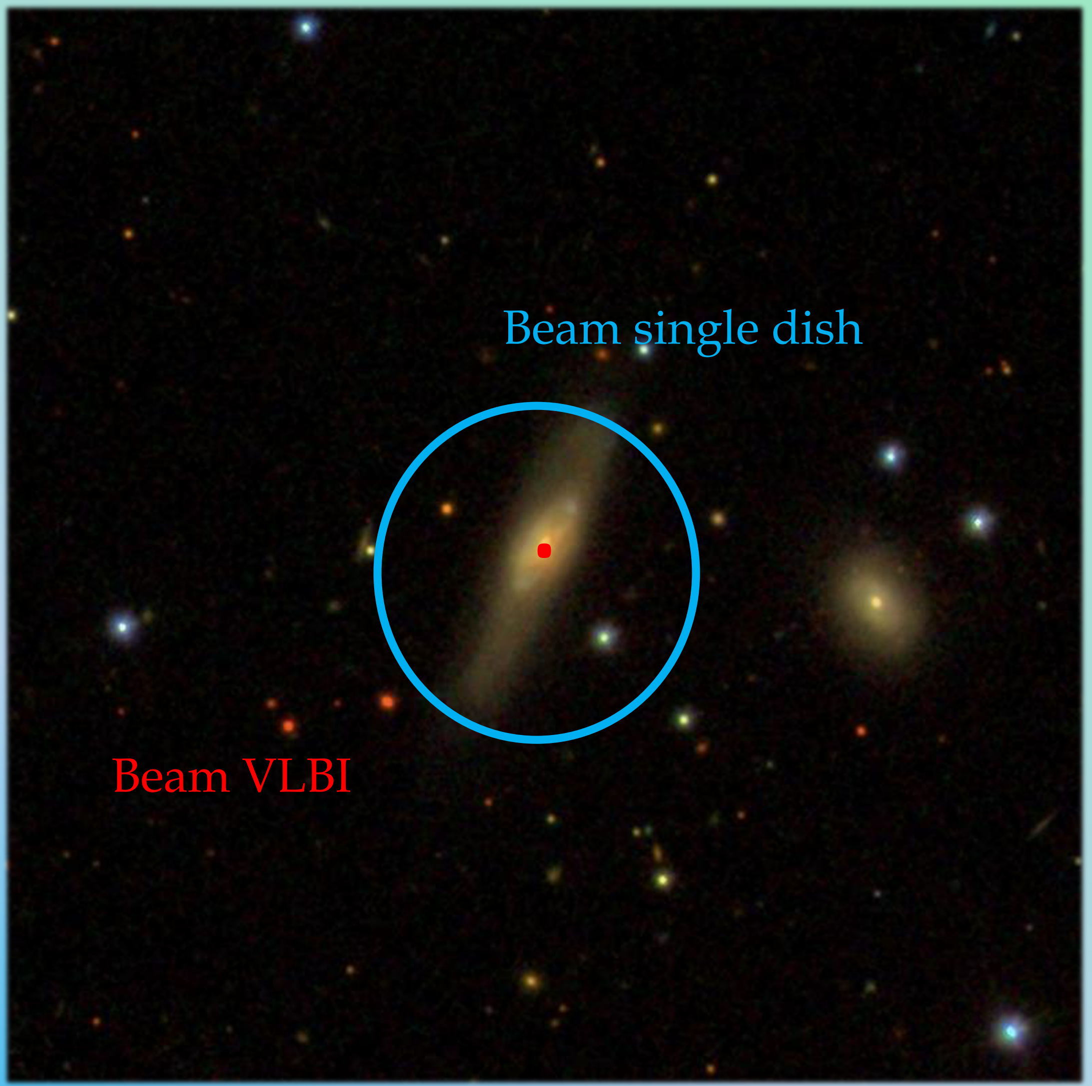
Why Interferometry?

High angular resolution needs to:

- Determine the location and distribution of the maser emission;
- Provide information about geometry and dynamic of the nuclear components.

$$\vartheta \approx \frac{\lambda_{K\ band}}{D_{S.D.}} \approx \frac{1{,}3\ cm}{100\ m} \approx 2\ arcsecond$$

$$\vartheta \approx \frac{\lambda_{K\ band}}{D_{VLBI}} \approx \frac{1{,}3\ cm}{9000\ km} \approx 0{,}2\ milliarcsecond$$



IC 485: Optical Survey Sloan Digital Sky Survey (SDSS)

Details observation

K – Band ($\lambda \sim 1,3\ cm$)

Number of dishes : 10
Dish sizes: 25 meter

Receiver frequencies: $(0,3\ GHz \div 96)\ GHz$

Resolution: $(0,17 \div 22)\ mas$

Target (T): IC 485 (LINERs/Sey2)

Phase reference (PR): J0802+2509

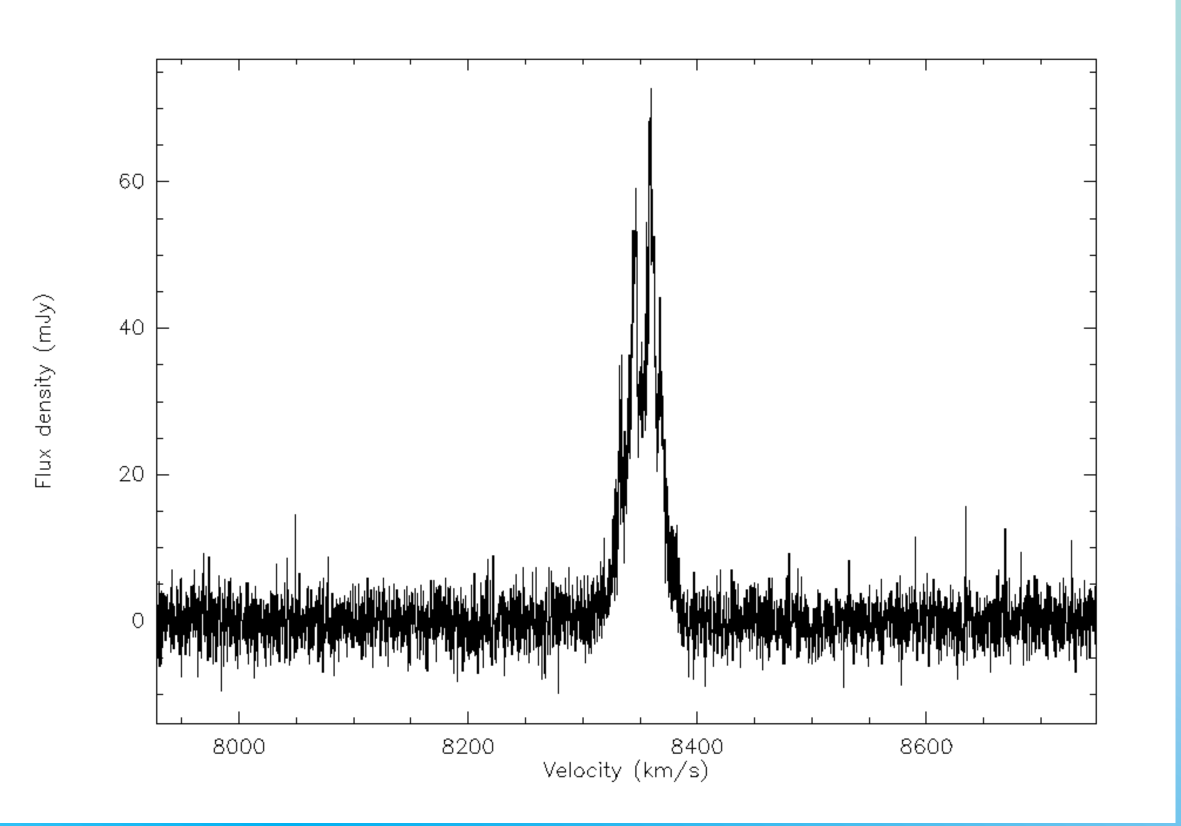
Project name	BT 142	BT 145
Date	26 February 2018	30 October 2018
Bandwidth	1 IF of 64 MHz, 2 pol	2 IF each of 64 MHz, 2 pol
Velocity resolution	$0,2\ km \cdot s^{-1}$ (4096 chans)	$0,2\ km \cdot s^{-1}$ (4096 chans)
On-source time	2,5 hours	3,5 hours
Sensitivity - rms	$10\ mJy/beam/chan$	$5\ mJy/beam/chan$

Software: AIPS (NRAO)

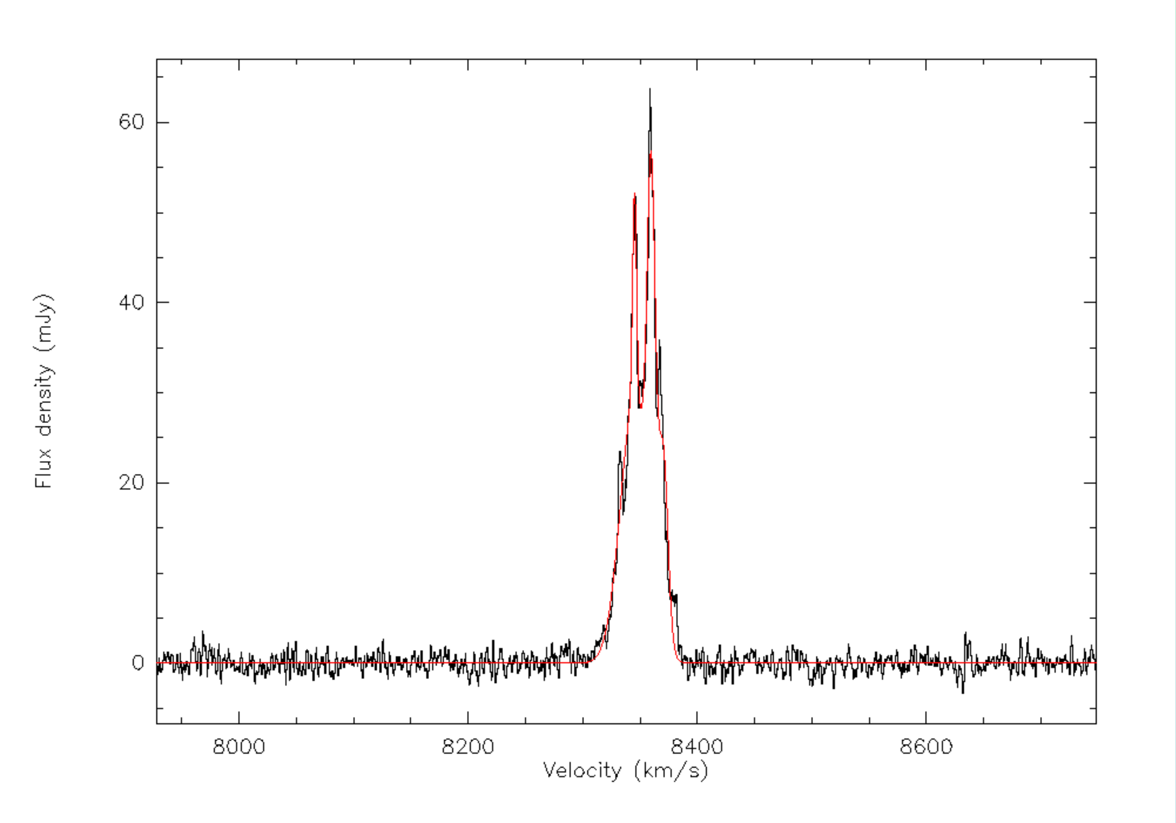
Results – Maser M1 (BT142)

IC 485: cube map

Smooth 8



Unsmooth



RA: $8^h\ 0^m\ 19{,}75253^s$
Dec: 26°42′ 5,0524″

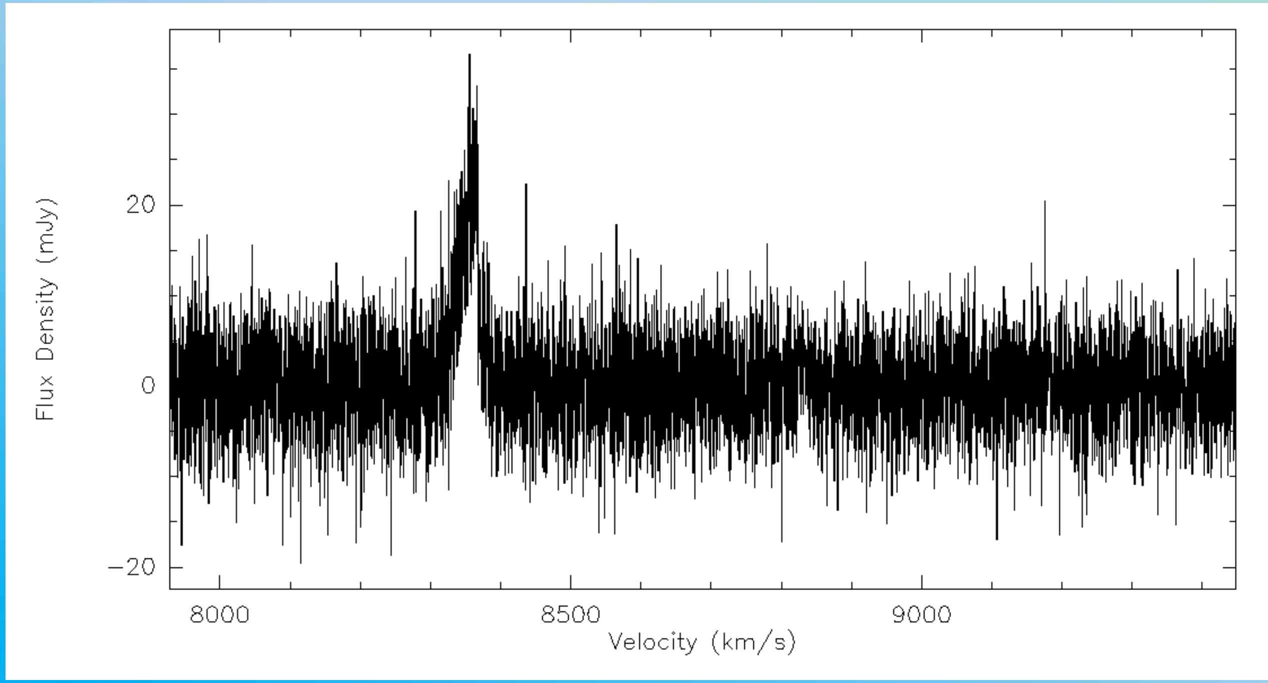
Peak Flux Density: $(68{,}8 \pm 0{,}2)\ mJy$
FWHM: $(35{,}35 \pm 0{,}5)\ km\ s^{-1}$
Velocity position: $(8361{,}0 \pm 0{,}5)\ km\ s^{-1}$

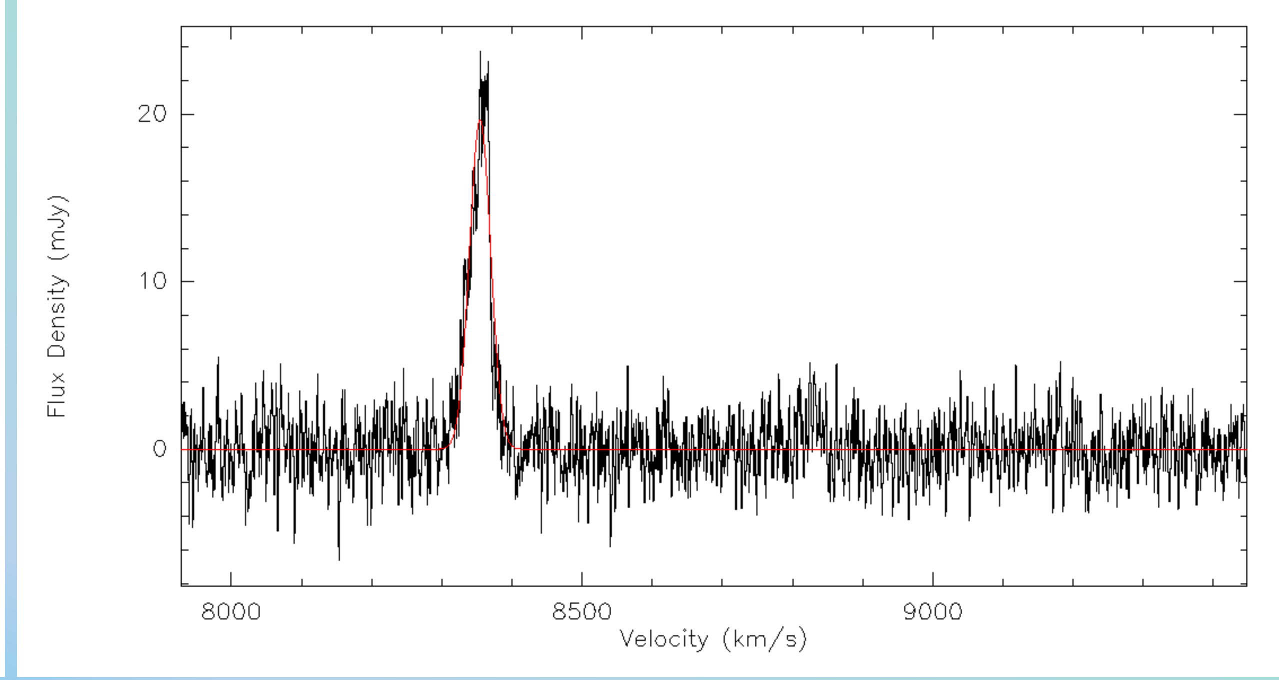
$L_{iso} = (833 \pm 89)\ L_{\odot}$

Results – Maser M1A (BT145)

IC 485: cube map

Smooth 8





Unsmooth

RA: $8^h\ 0^m\ 19{,}75252^s$
Dec: 26°42′ 5,0526′′

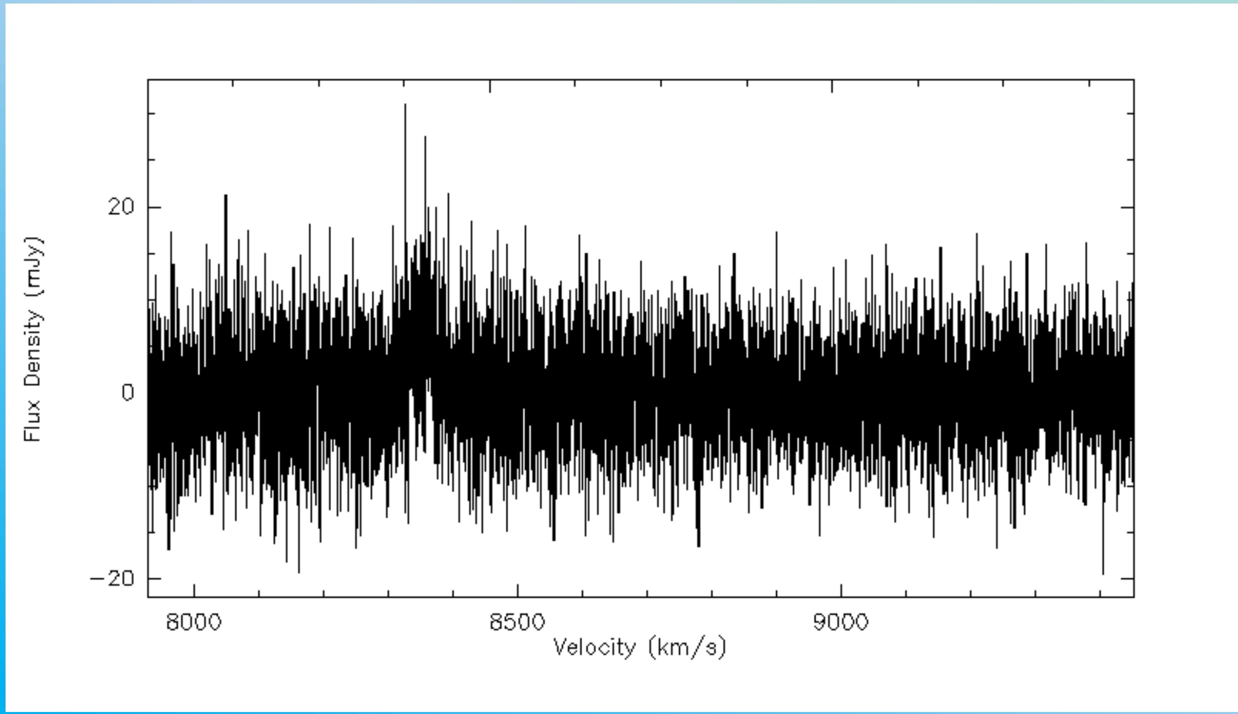
Peak Flux Density: $(19{,}7 \pm 0{,}9)\ mJy$
FWHM: $(35 \pm 1)\ km\ s^{-1}$
Velocity position: $(8354{,}8 \pm 0{,}5)\ km\ s^{-1}$

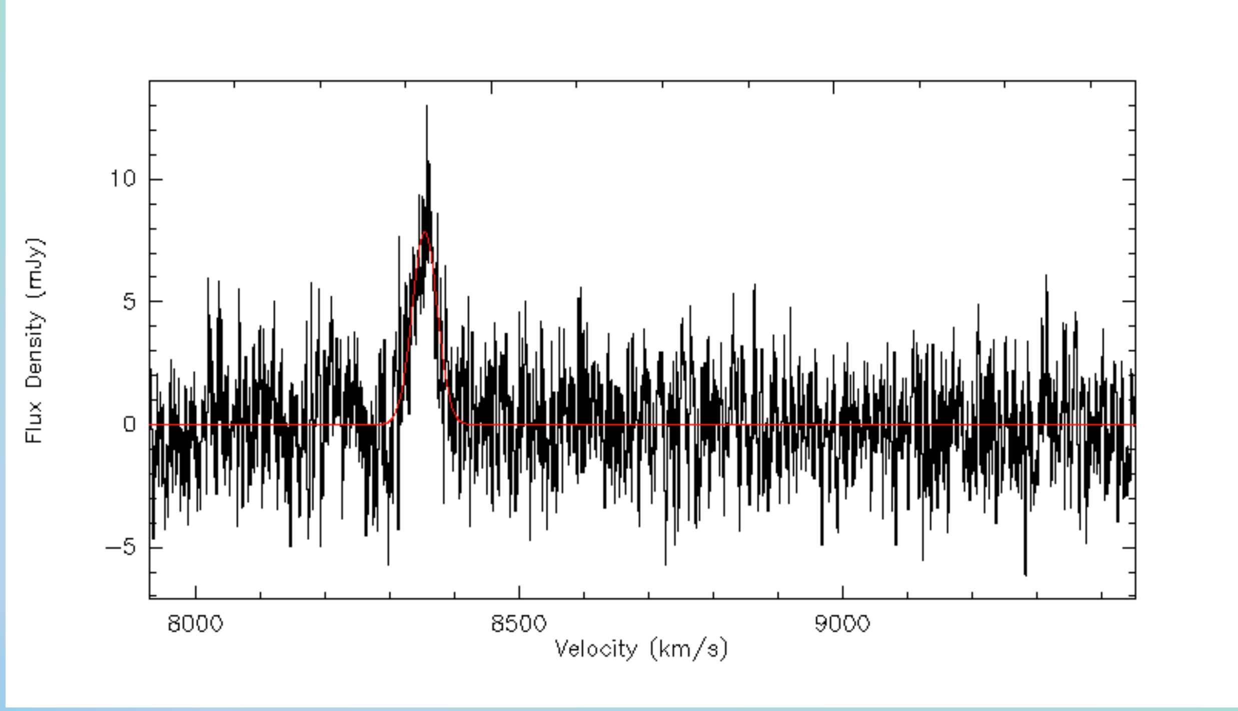
$L_{iso} = (239 \pm 28)\ L_\odot$

Results – Maser M1B (BT145)

IC 485: cube map

Smooth 8





Unsmooth

RA: $8^h\ 0^m\ 19{,}7546^s$
Dec: 26°42′ 5,0521′′

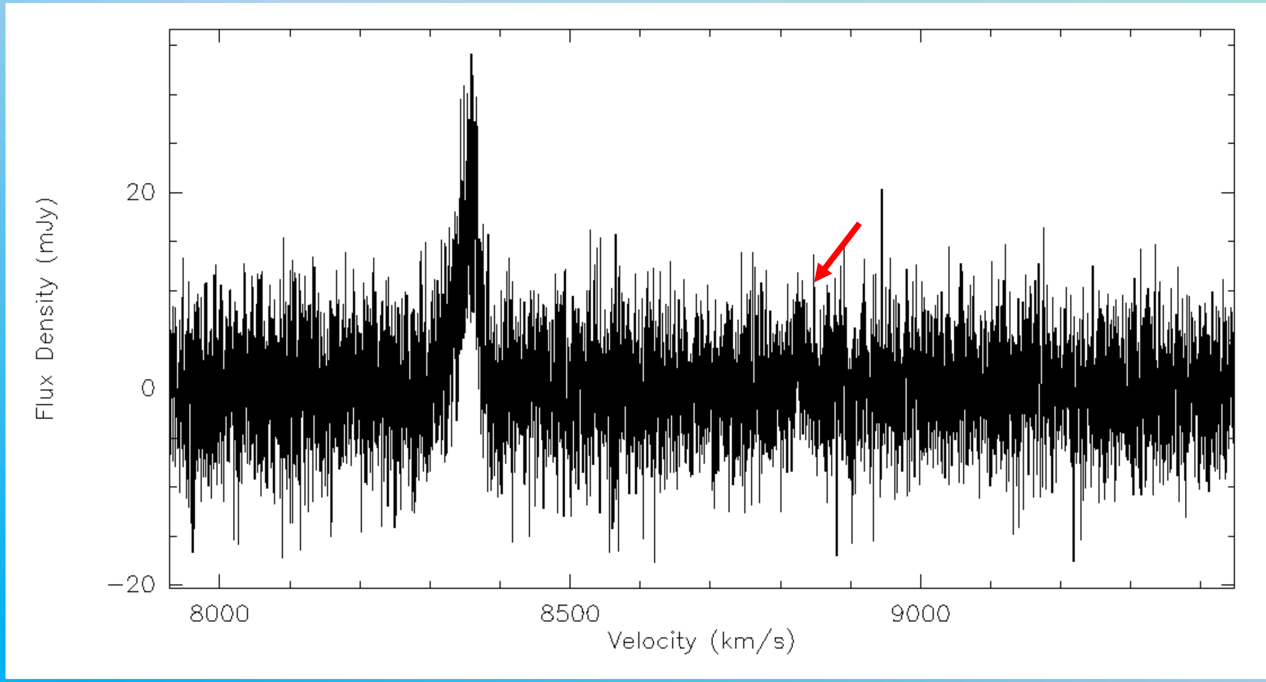
Peak Flux Density : $(5{,}0 \pm 0{,}8)\ mJy$
FWHM: $(45 \pm 6) km\ s^{-1}$
Velocity position : $(8355 \pm 2)\ km\ s^{-1}$

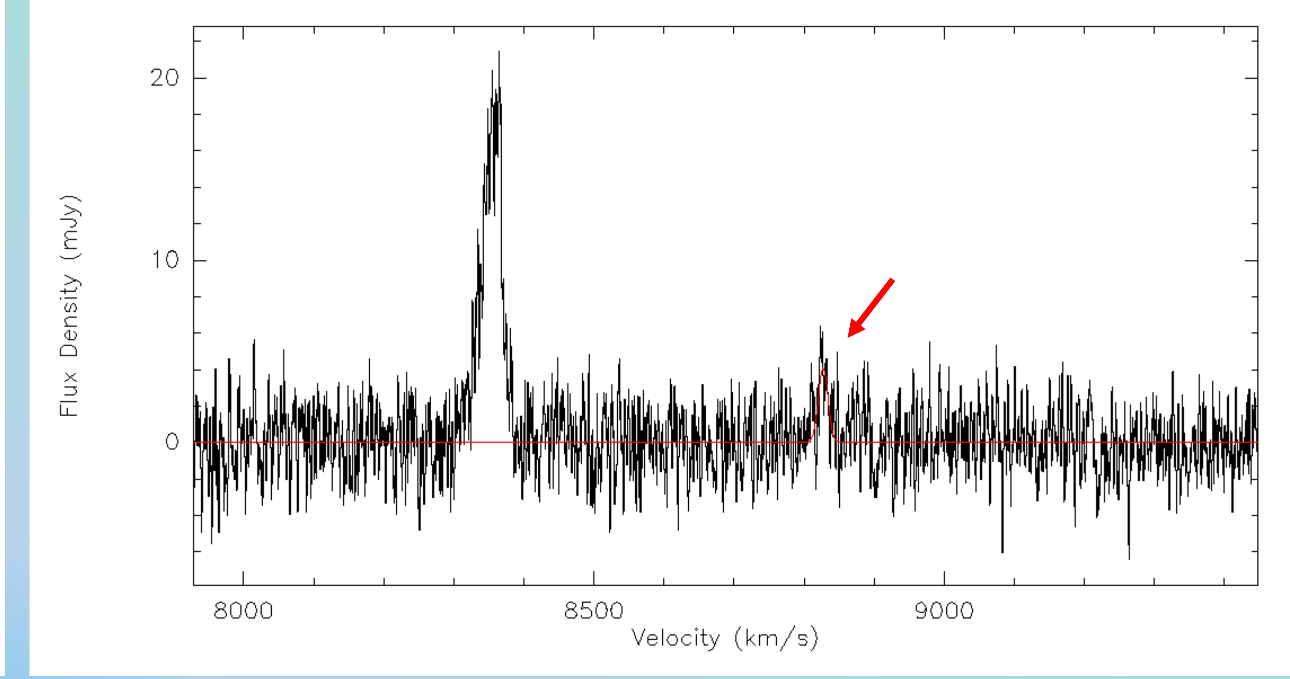
$$L_{iso} = (77 \pm 18)\ L_{\odot}$$

Results – Maser M2 (BT145)

IC 485: cube map

Smooth 8





Unsmooth

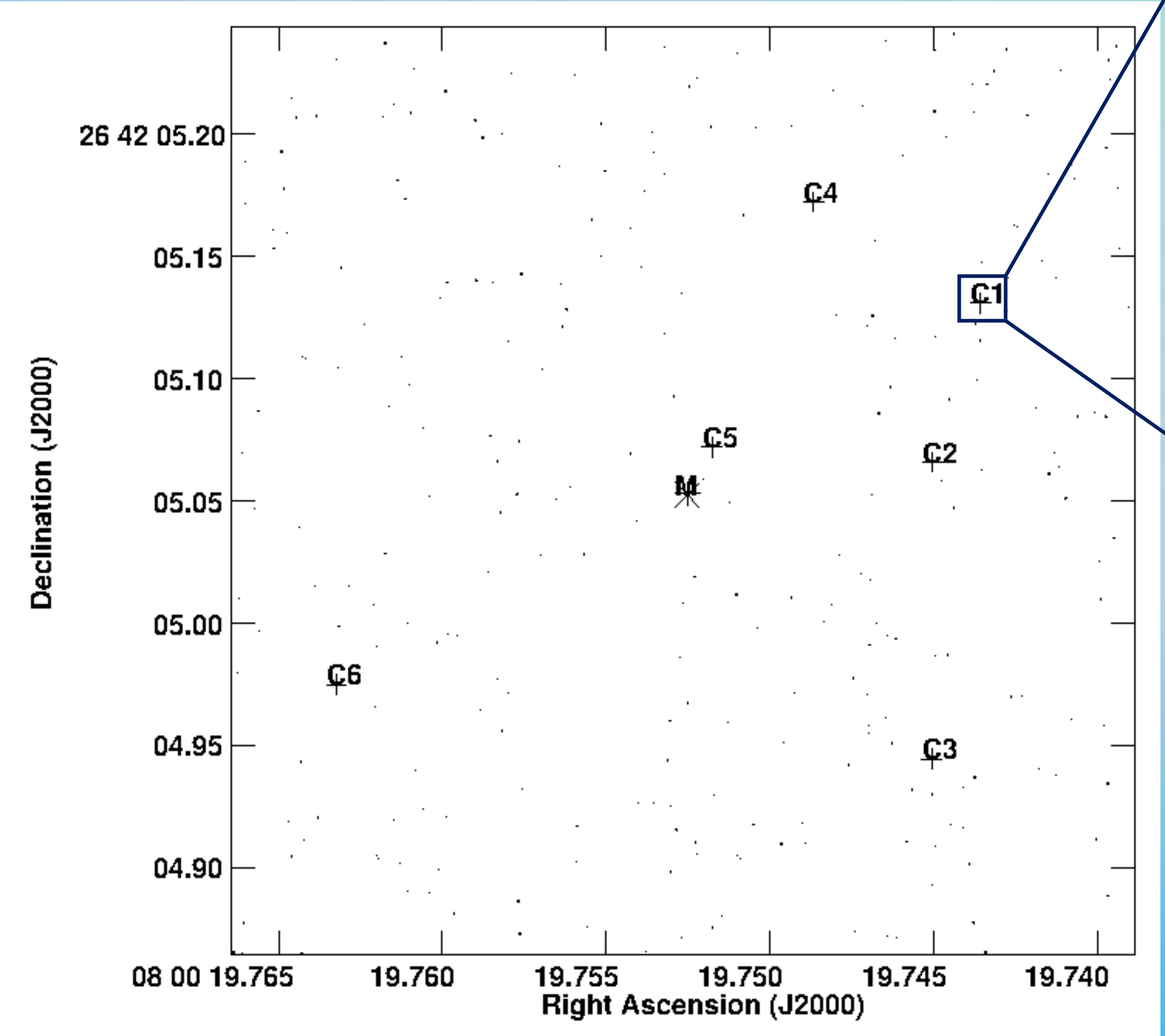
RA: $8^h\ 0^m\ 19{,}75252^s$
Dec: 26°42′ 5,0529″

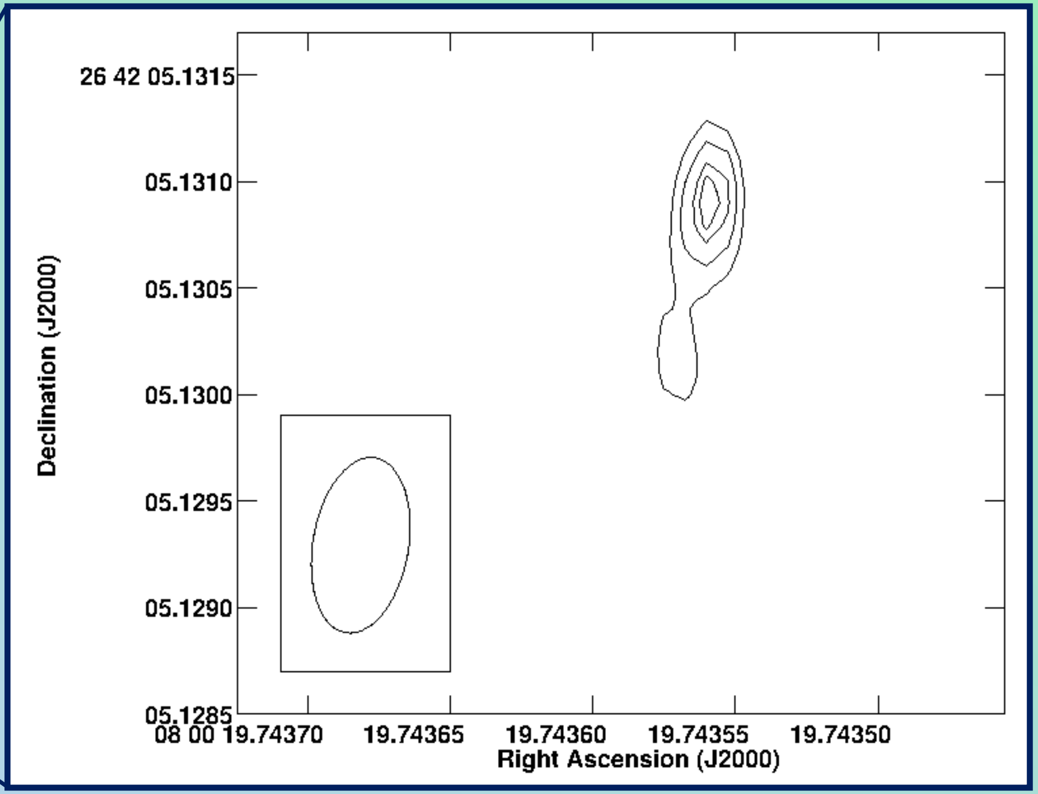
Peak Flux Density: $(4 \pm 2)\ mJy$
FWHM: $(18 \pm 7)\ km\ s^{-1}$
Velocity position: $(8827 \pm 1)\ km\ s^{-1}$

$$L_{iso} = (24 \pm 16)\ L_{\odot}$$

Results – Continuum

IC 485 – continuum map



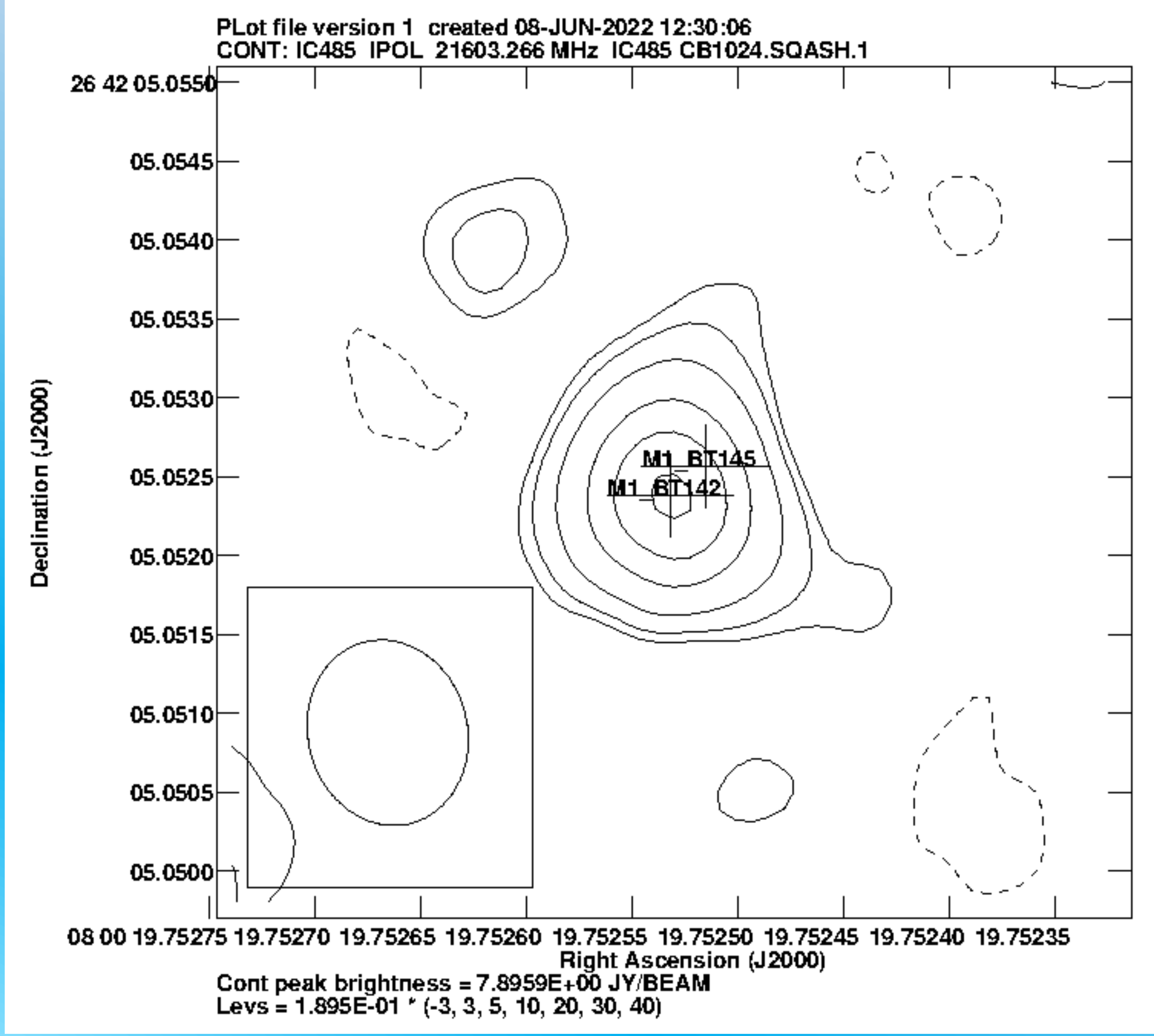


Noise: 65,14 μJy Levs: 65,14 $\mu Jy \times (-4\ ; 3; 4; 5; 5{,}5)$

All sources
are
Unresolved – slightly resolved

SNR $\geq 5\sigma$

Discussion – Maser position in the two data ~ set



Sqash maps

Thermal noise $\Delta\vartheta \approx 0,5\ \frac{BEAM}{SNR}$

Position error PR $\Delta RA = 0,09\ mas$

Position error PR $\Delta Dec = 0,13\ mas$

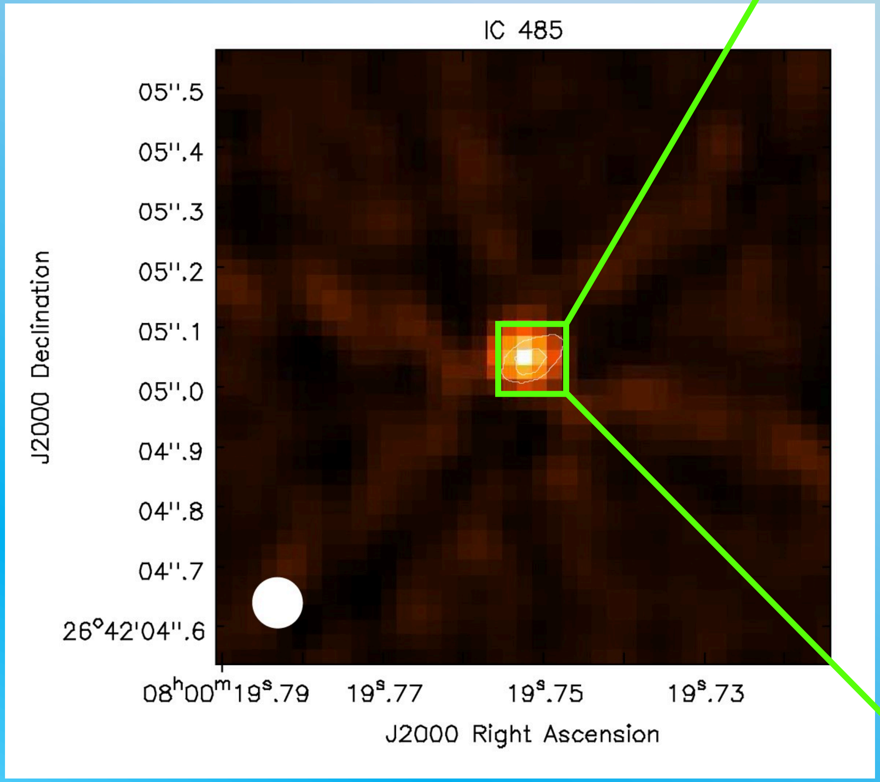
$$\Delta M1 = \sqrt{(\Delta\vartheta)^2 + (\Delta PR)^2} \approx 0,23\ mas$$

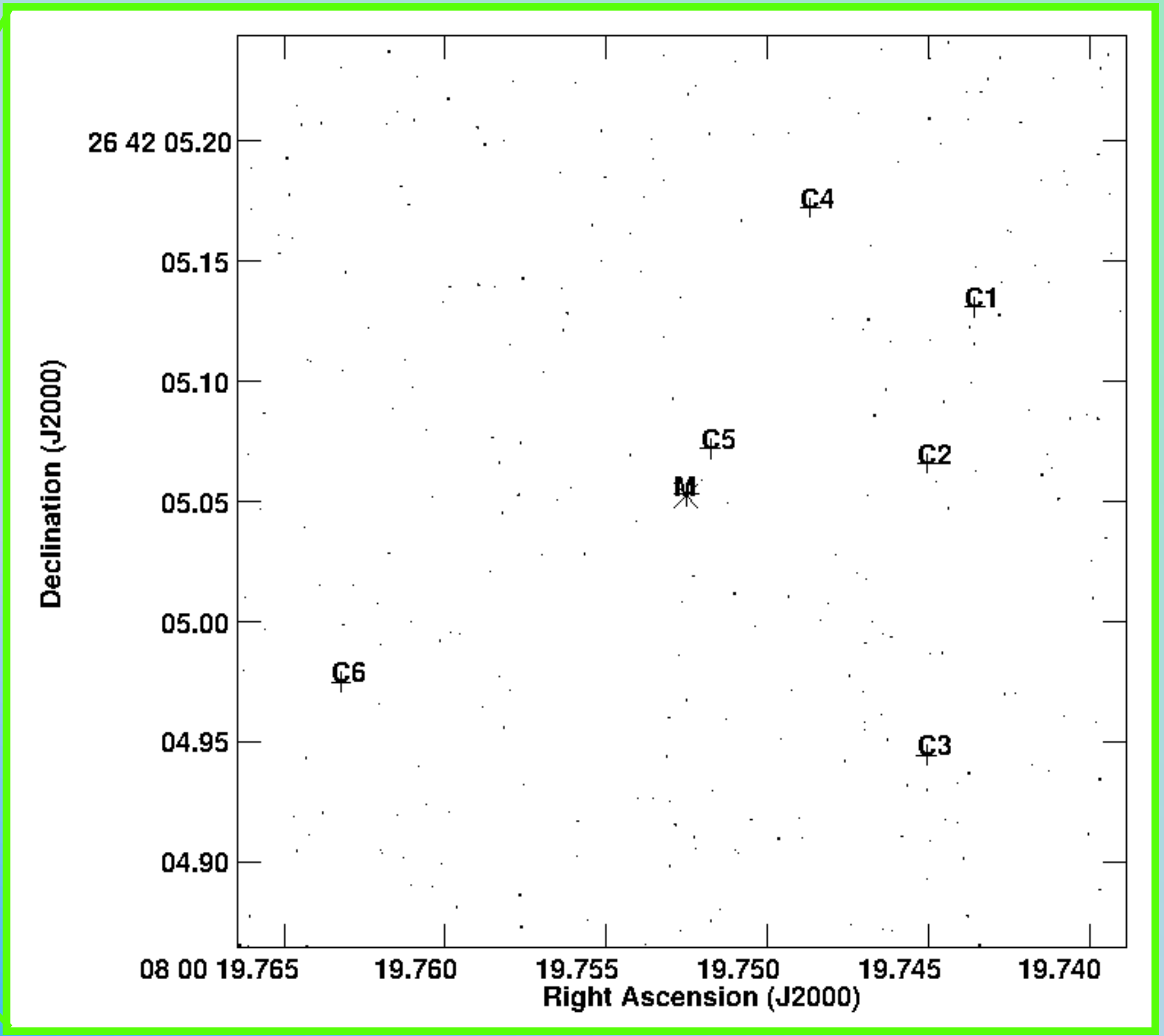
Maser position is consistent within the errors

$$M1A_{BT145} = M1_{BT142}$$

Discussion – Continuum and maser position

Darling (2017) - Continum map VLA
L - band (18 cm), resolution 0,1 *as*

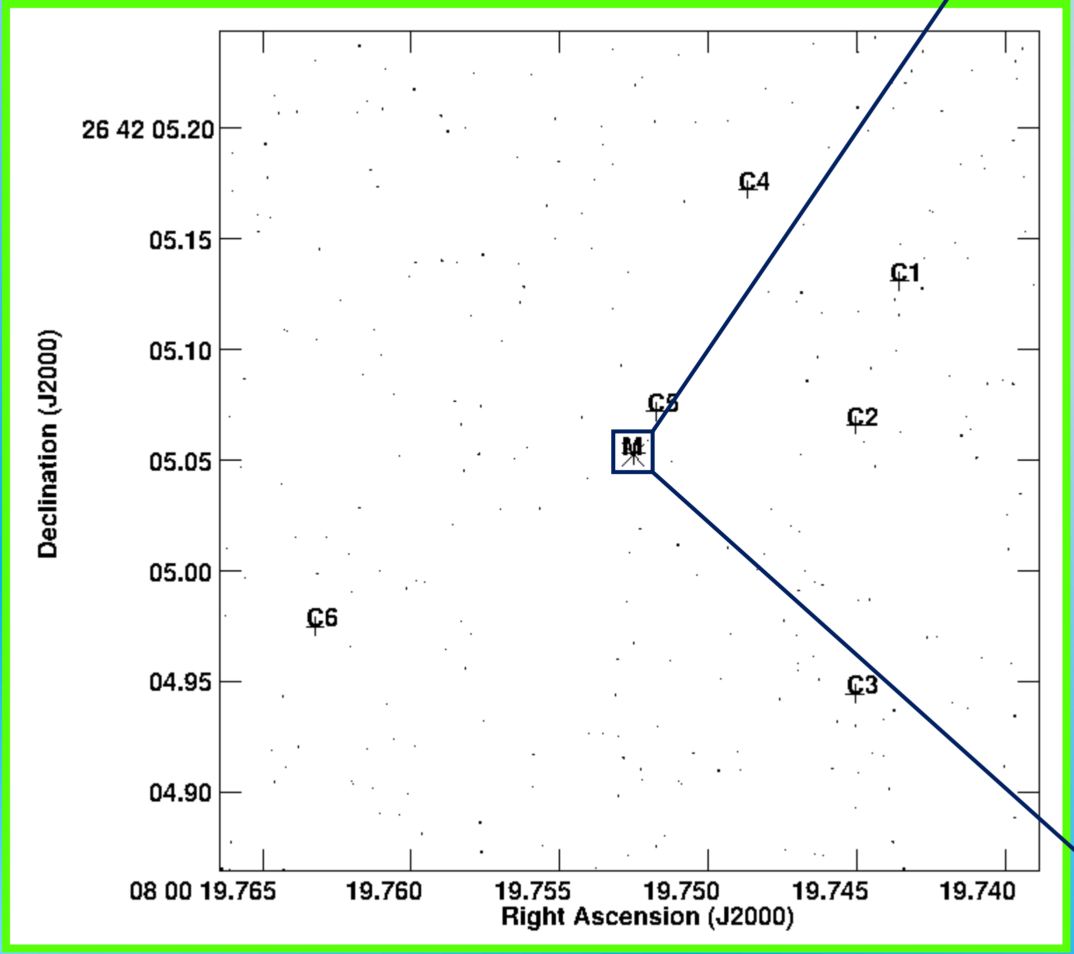


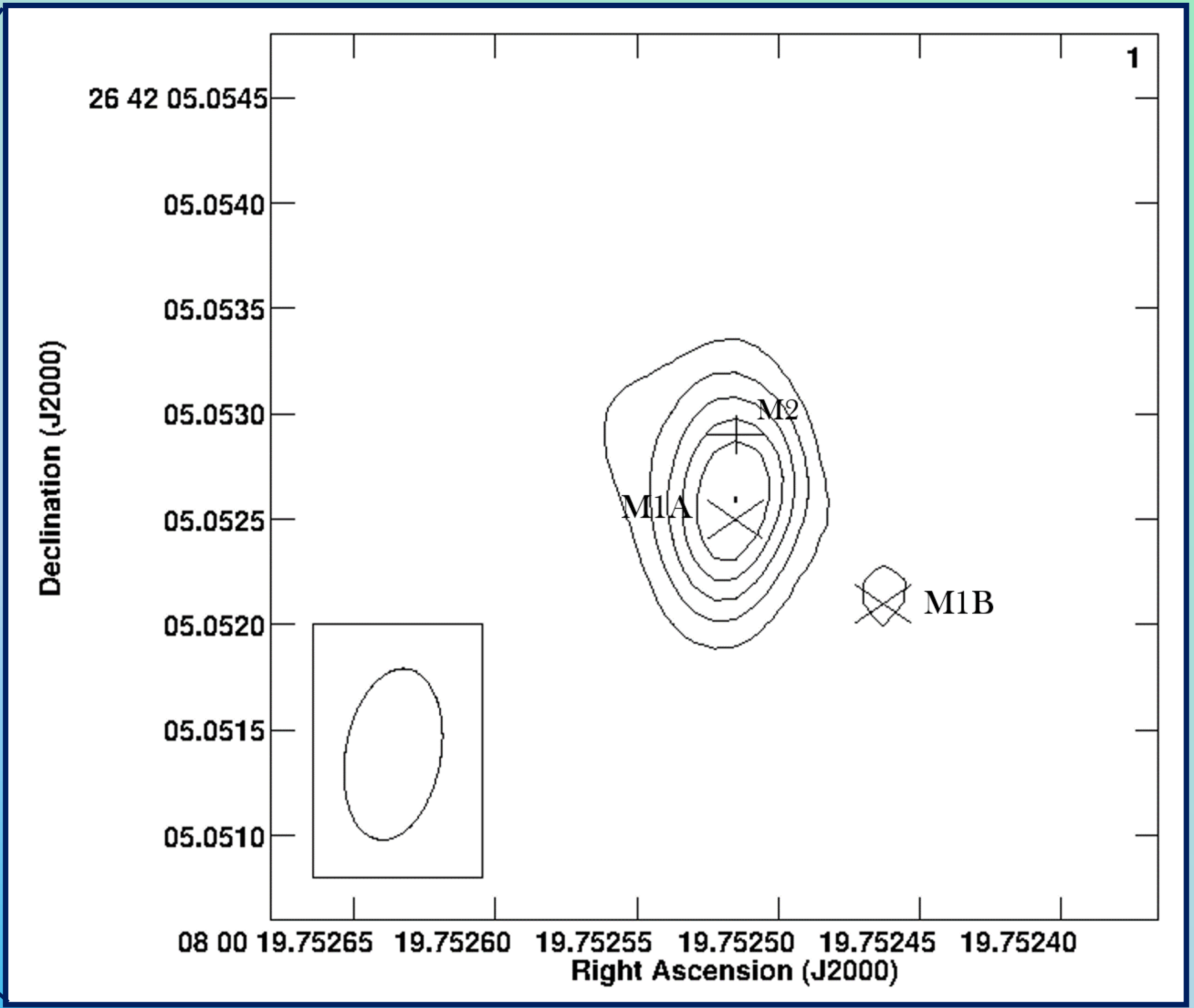


BT145 Our study - Continuum map
K - band (1,3 cm), resolution 0,001 *as*

Discussion – Continuum and maser position

BT145 Our study - Continuum map
K - banda (1,3 cm), resolution 0,001 *as*



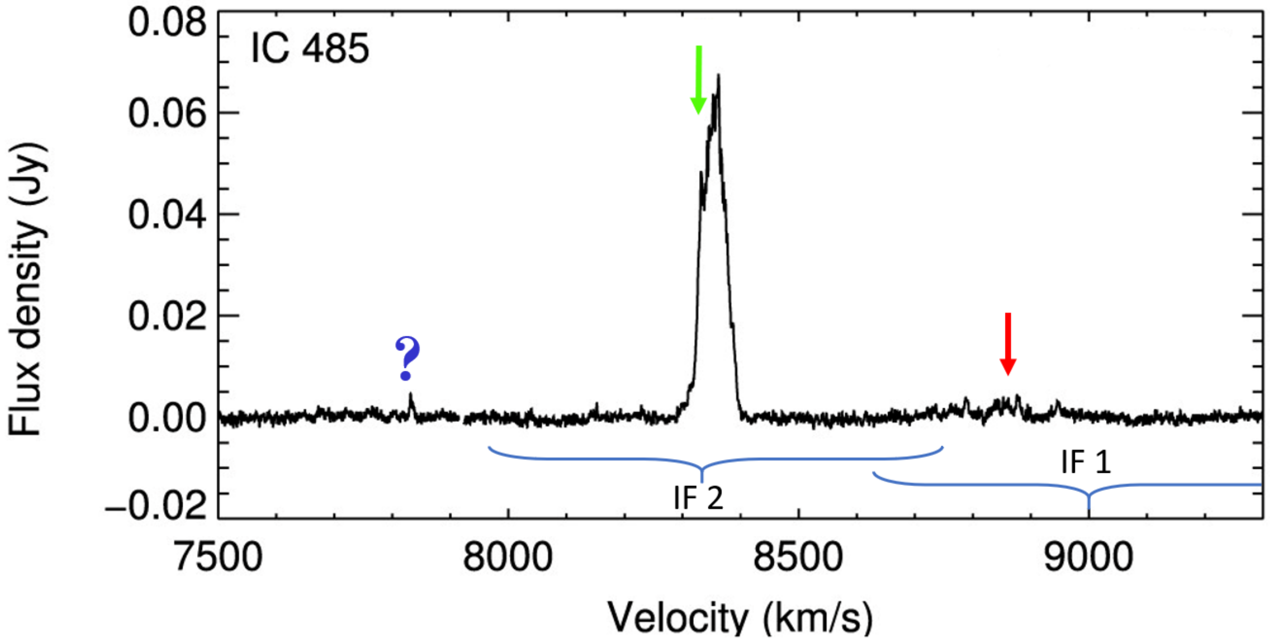


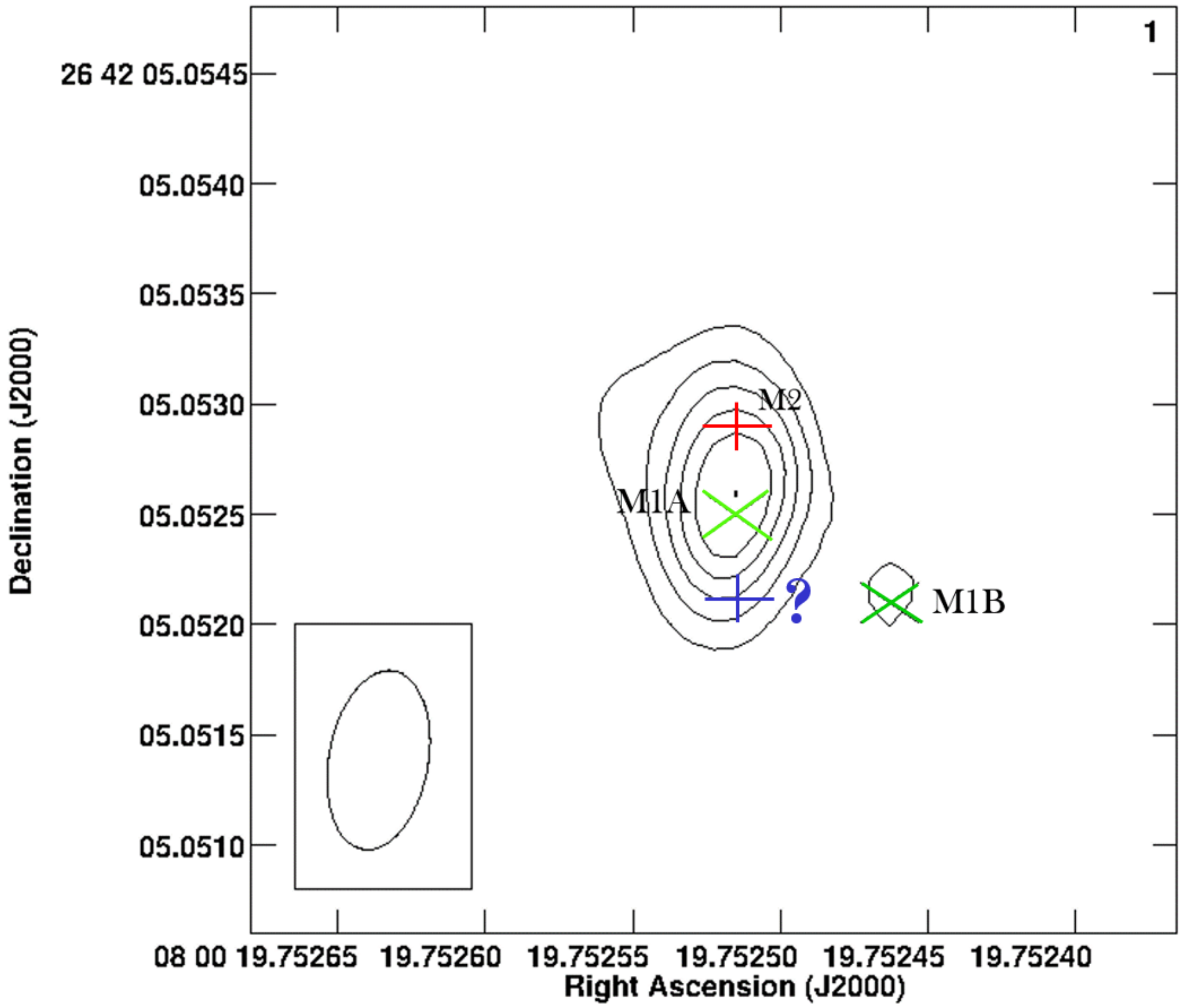
BT145 Our study - zeroth moment map

Discussion – the nature of the maser

Disk-maser!?

Pesce et al. (2015) – Spectrum multi - epoch average with GBT





BT145 – Our study

Discussion – the nature of the maser

Hypothesis of *edge-on* disk with keplerian rotation

$$\frac{M_{BH}}{M_\odot} = 1{,}12 \times \left[\frac{v_r}{km\ s^{-1}}\right]^2 \times \left[\frac{\vartheta}{mas}\right] \times \left[\frac{D}{Mpc}\right]$$

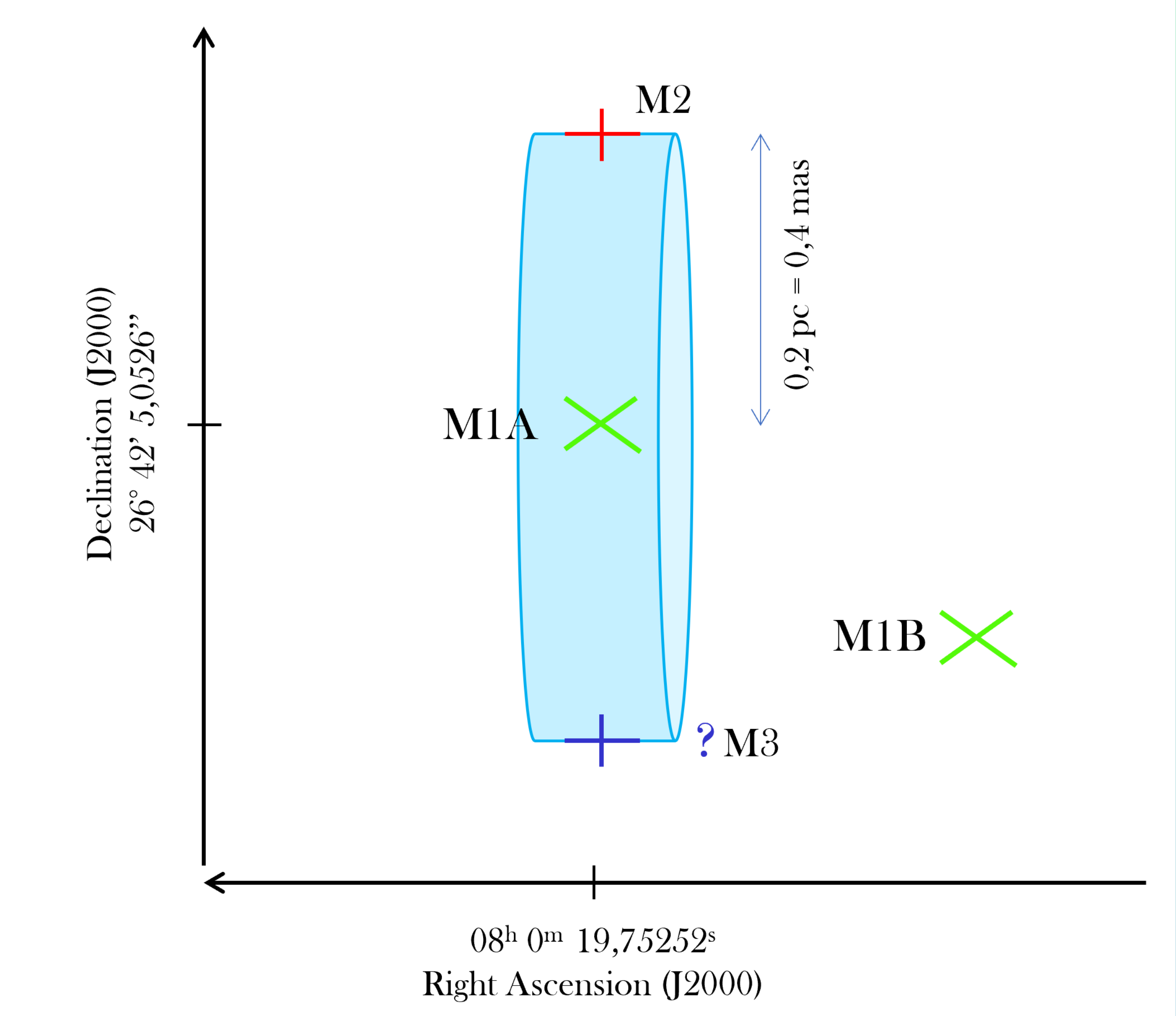
$v_r \cong 475\ km\ s^{-1}$ $\quad\quad$ $\vartheta = 0{,}4\ mas = 0{,}2\ pc$

$$D = 122\ Mpc$$

$$M_{BH} = 1{,}2\ \times 10^7 M_\odot$$

According to SMBH values for Seyfert and LINERs

The hypothesized model does not support the candidacy to *Inclined maser disk*



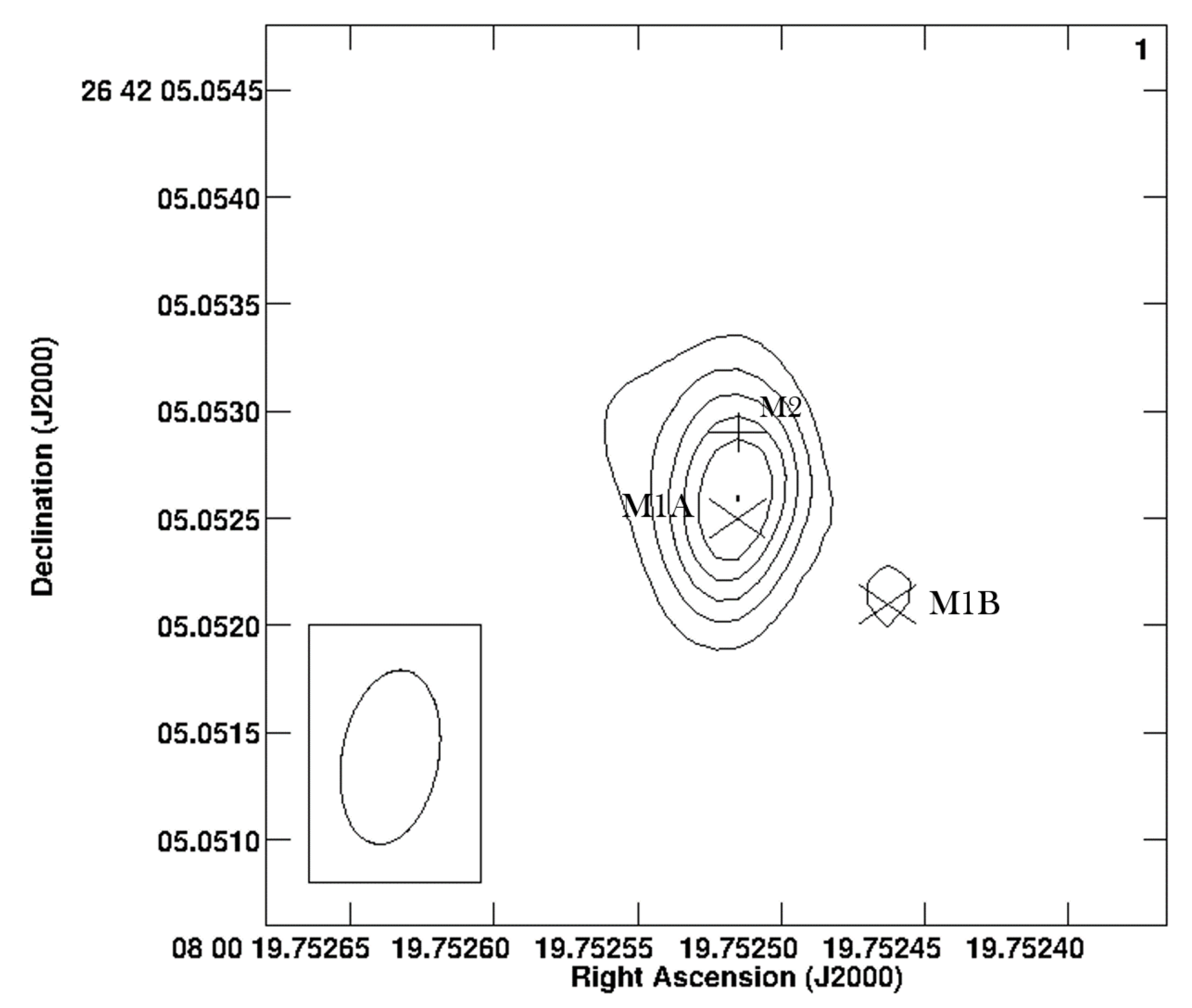
Discussion – the nature of the maser

The line width of M1A ($\sim 35\ km\ s^{-1}$) and the position of M1B

↓

Jet/outflow maser (!?)
- Broad line
- Red-shifted componet

Composite Maser (!?)
e.g. NGC 1068
(Gallimore et al. 1996)
- Disk
  - M1A
  - M2
- Jet/outflow M1B



Conclusions …

In this work:

- We define the **absolute position of the water maser** with an accuracy better than one milliarcsecond, **for the first time**. We improve by 2 orders of magnitude the Darling (2017) value;
- We observe the systemic and the red – shifted components at **high angular resolution** for the first time;
- We detect compact sources in the continuum map in the nuclear regions of the galaxy;
- We propose an hypothesis about the **nature of the maser** supported by **a VLBI map**, for the first time.

Our study suggests an edge-on disk with a North – South orientation and according to keplerian rotation, we estimate :

- A disk radius ≈ 0,2 pc;
- Black hole mass of $M_{BH} = 1{,}2 \times 10^7 M_{\odot}$

A
new disk -
maser galaxy!? 🤩

… and present and future works

To confirm the nature of the maser, the AGN classification and complete the analysis of IC485, our group is working on:

- Interferometric data EVN (*European VLBI Network)* in L – band (18 cm) e C – band (6 cm);
- VLBI data multi-epoch in K – band (1,3 cm).

see Castangia's Poster (#19, in this symposium)

Ladu et al. (in preparation)

Our group is also planning to carry out:

- a **single dish monitoring campagne** (with SRT, GBT or others...)
- and high sentivity VLBI measurements to detect and map all maser features including the blue – shifted one.

Thank you for your attention!