Francesco and Masers

Francesco's Legacy

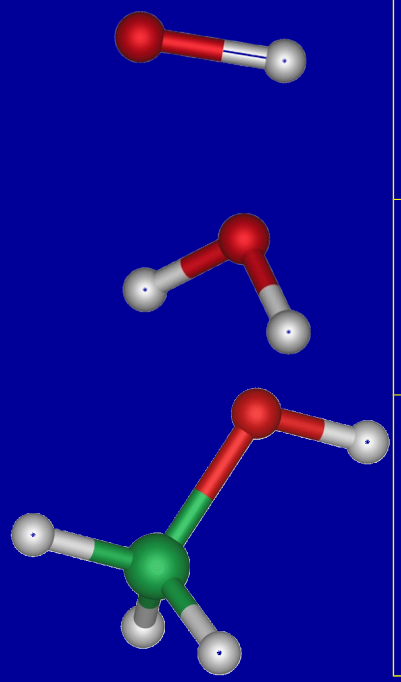
Florence, 2017 June 7

Francesco and Masers

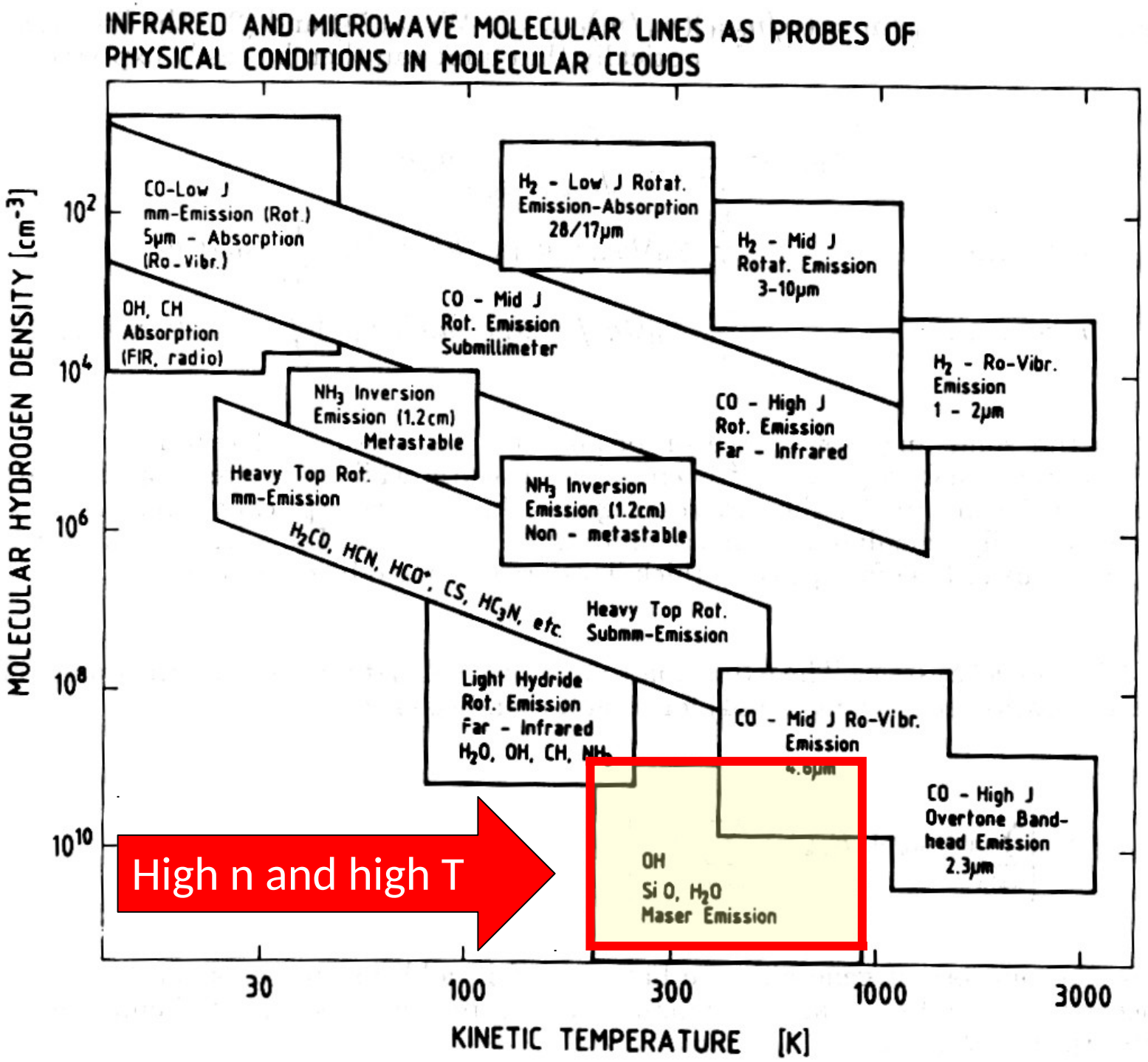
Francesco's Legacy

Florence, 2017 June 7

Common Strong Interstellar Masers:

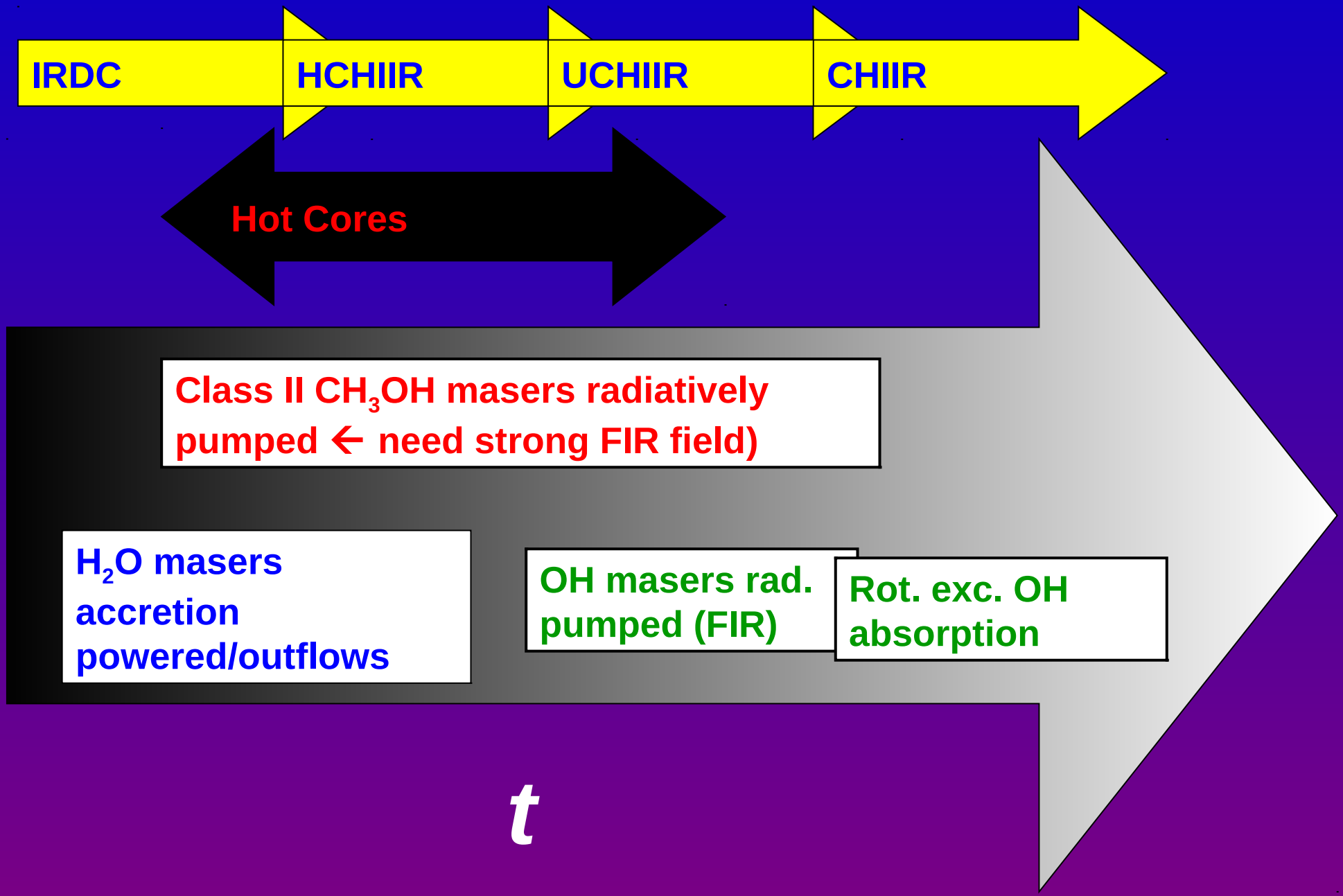


		First found	Where	Pump	# known
OH	Hydroxyl	1965	UCHIIRs	R (FIR)	many
H_2O	Water vapor	1969	L+HM YSOs	C	very many
CH_3OH	Methanol	1971 (I) 1986 (II)	Class I outflows Class II HMYSOs	Cl. I: C Cl. II: R (FIR)	Class I: many Class II: very many


INFRARED AND MICROWAVE MOLECULAR LINES AS PROBES OF PHYSICAL CONDITIONS IN MOLECULAR CLOUDS
MOLECULAR HYDROGEN DENSITY [cm⁻³]
KINETIC TEMPERATURE [K]
10²
10⁴
10⁶
10⁸
10¹⁰
30
100
300
1000
3000
CO-Low J mm-Emission (Rot.) 5μm - Absorption (Ro.-Vibr.)
OH, CH Absorption (FIR, radio)
H₂ - Low J Rotat. Emission-Absorption 28/17μm
CO - Mid J Rot. Emission Submillimeter
H₂ - Mid J Rotat. Emission 3-10μm
H₂ - Ro-Vibr. Emission 1 - 2μm
CO - High J Rot. Emission Far - Infrared
NH₃ Inversion Emission (1.2cm) Metastable
Heavy Top Rot. mm-Emission
NH₃ Inversion Emission (1.2cm) Non - metastable
H₂CO, HCN, HCO⁺, CS, HC₃N, etc.
Heavy Top Rot. Submm-Emission
Light Hydride Rot. Emission Far - Infrared H₂O, OH, CH, NH₃
CO - Mid J Ro-Vibr. Emission
CO - High J Overtone Band-head Emission 2.3μm
OH Si O, H₂O Maser Emission
High n and high T

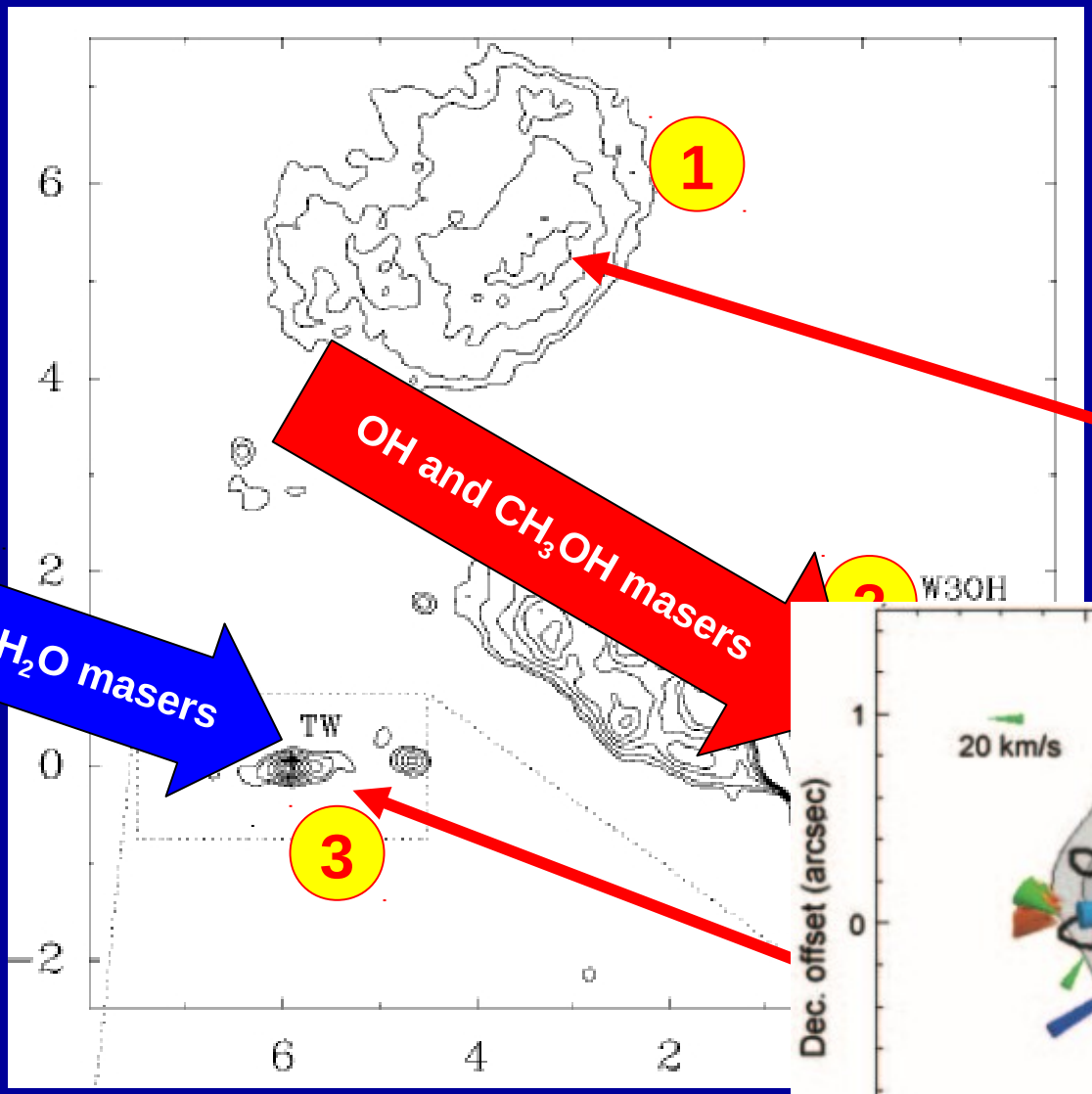
Genzel 1988

Masers in Regions of High Mass Star Formation

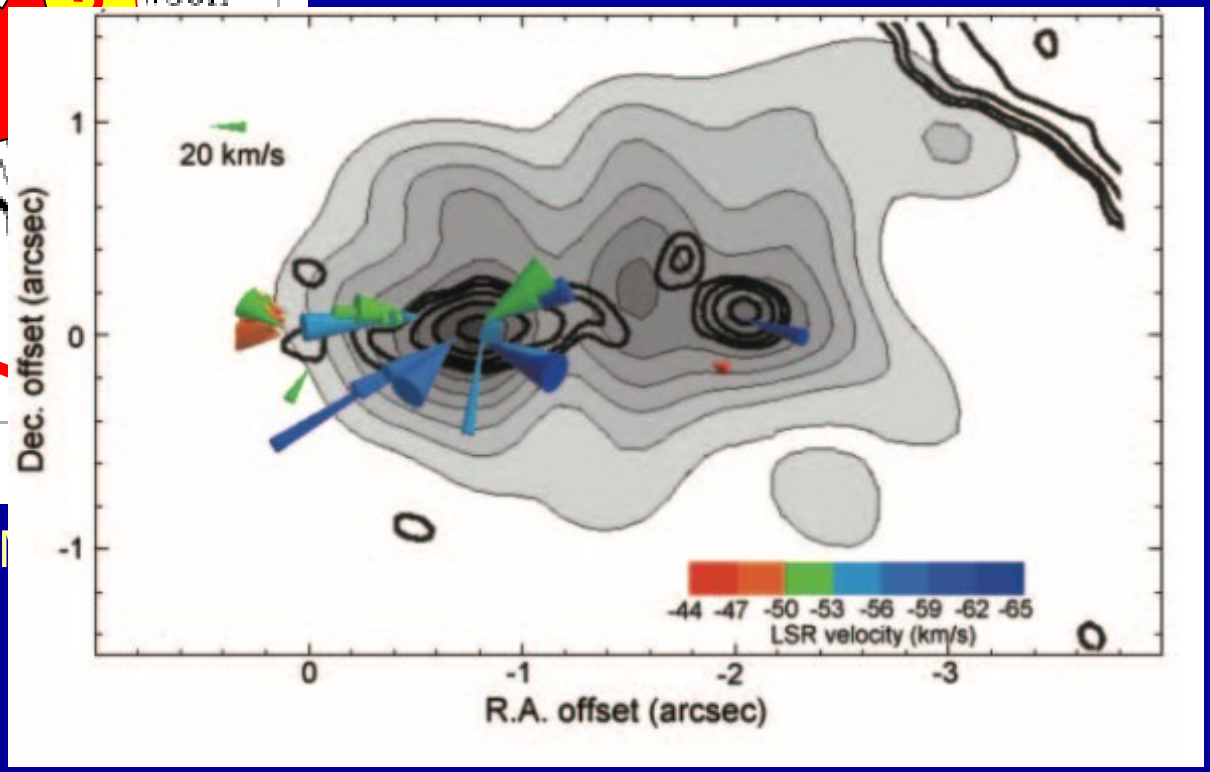


The W3OH region – different stages of high-mass star formation

1) CHII region: dynamical age ~ 5000 yr



Wilner, Reid, & I



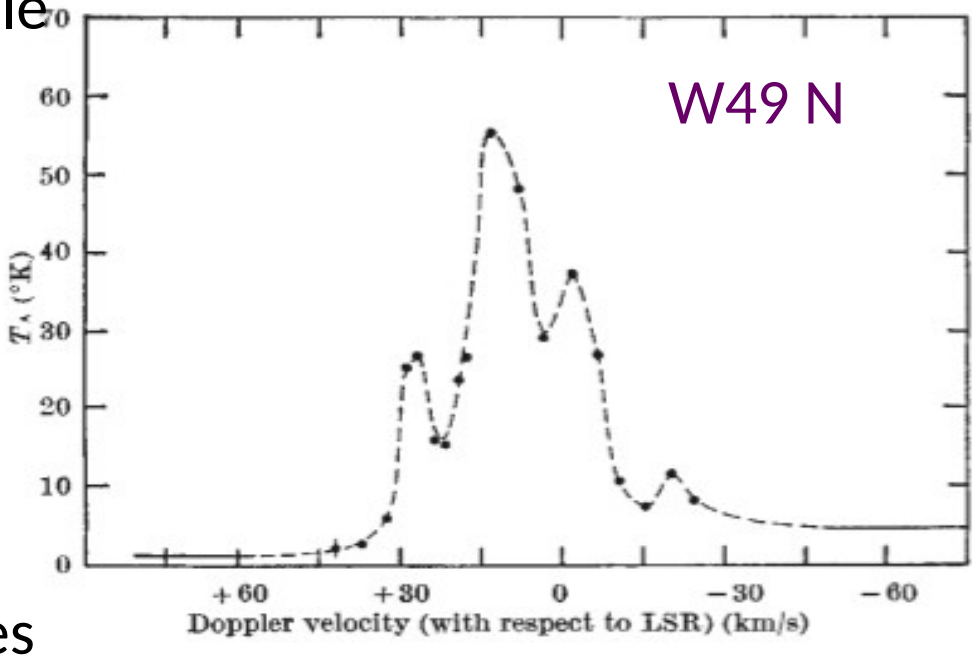
Hachisuka+ 2006/VLBA

The 22.2 GHz H_2O line

- Discovered 1969 by Cheung … Townes …
  - First triatomic interstellar molecule
  - In Orion, Sgr B2, W49 N
  - Very intense emission/ strongest radio line: W 49 N ~ 1 $L_\odot$
- Level energies 643 K above ground
- Very wide velocity spread
- **VLBI:**
  - Very compact, variable emission
  - Very high brightness temperatures

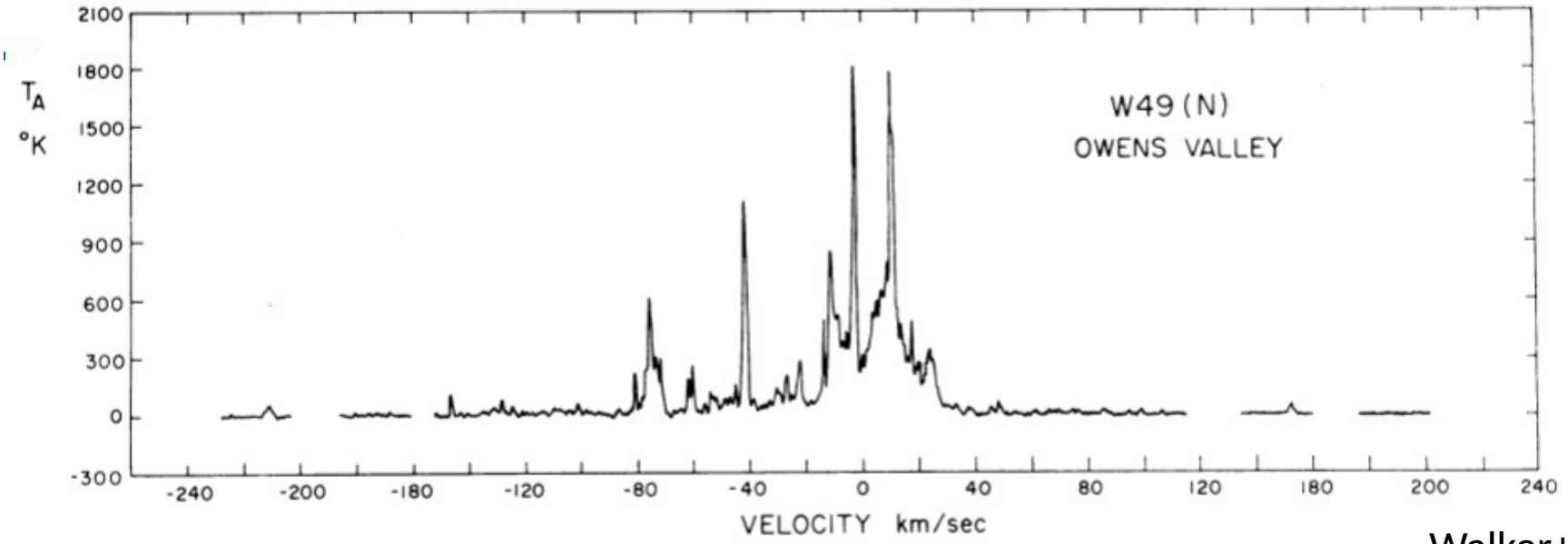
  → Maser
  - Collisonally pumped in post-J shock gas

    Neufeld & Melnick 1991, Hollenbach+ 2013

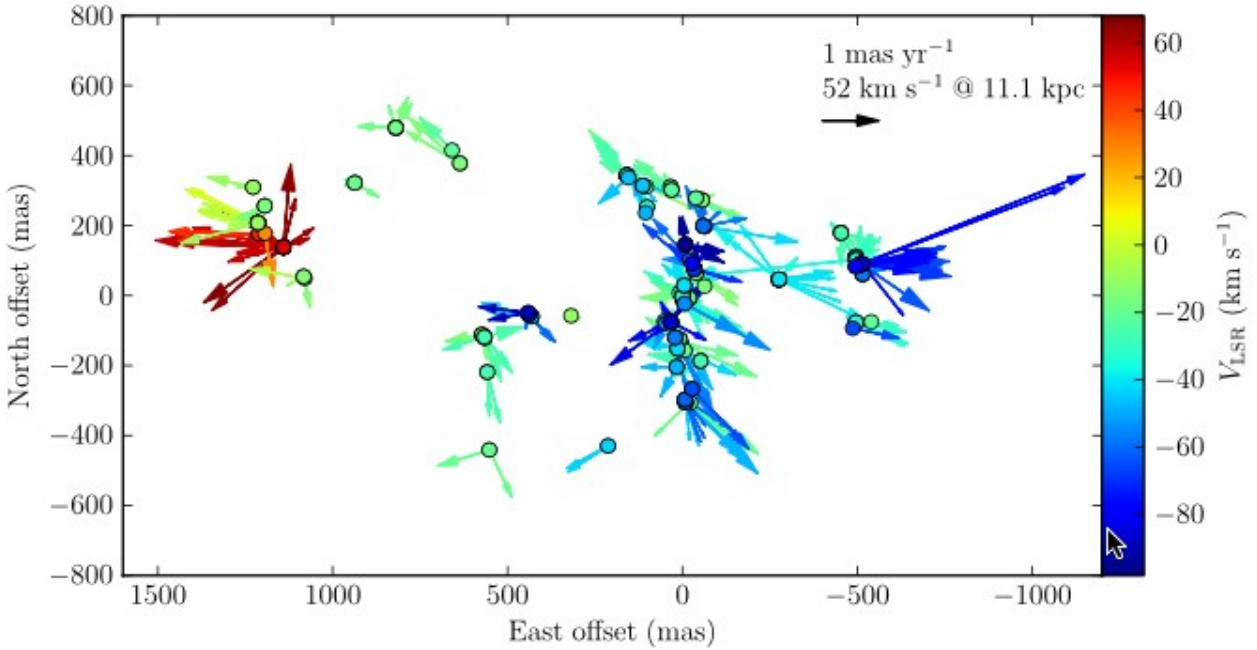


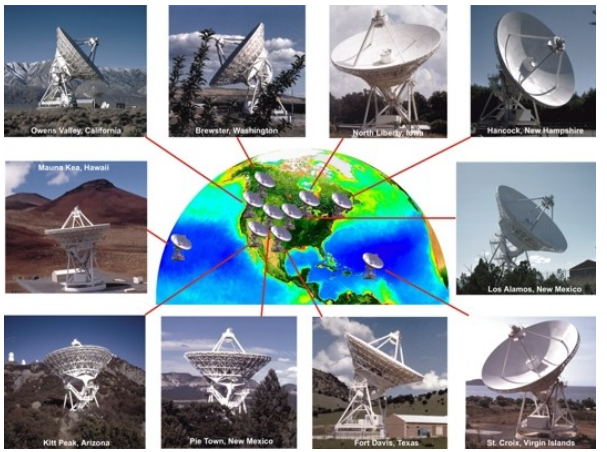
Cheung+ 1969

H_2O Maser motions in W49 N



Walker+ 1977





Luminosity in 22.2 GHz H_2O line ~1 $L_\odot$

Zhang+ 2013/
BeSSeL survey

Interstellar H_2O Masers

- are always associated with outflows → trace accretion
- are signposts for energy sources
- Variability marks energetic events

Interstellar H_2O Masers

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- **are signposts for energy sources**
- Variability marks energetic events

Astron. Astrophys. 223, 267–270 (1989)

ASTRONOMY AND ASTROPHYSICS

Research Note

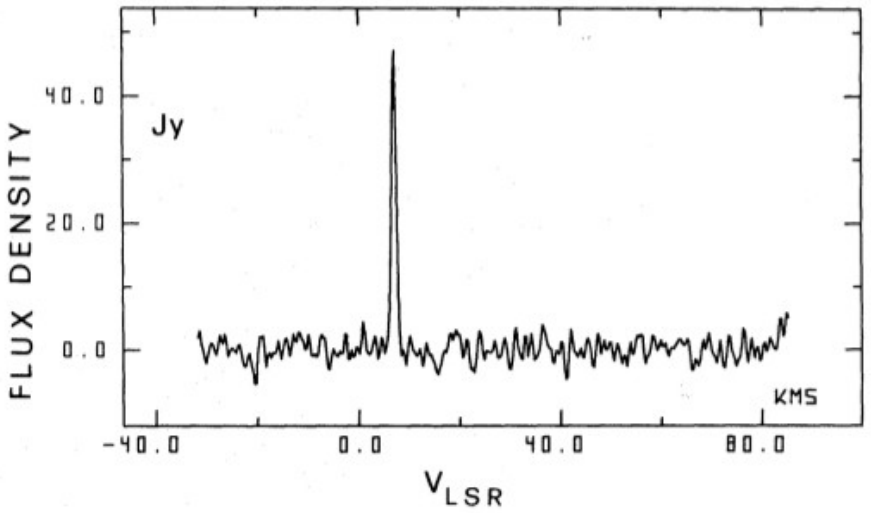
A search for H_2O maser emission in the Serpens region

F. Palla [1,2] **and C. Giovanardi** [1,2]

[1] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[2] Centro di Astronomia Infrarossa, C.N.R., Largo E. Fermi 5, I-50125 Firenze, Italy

Summary. We present the results of repeated H_2O maser line observations (22.2 GHz) in the Serpens region obtained with the 32 m parabola of the Medicina Station over a period of 16 months. Several positions coincident with pre-main-sequence (PMS) objects and far-infrared (FIR) sources were observed, with no positive detection at an average rms = 1.5 Jy. We have also mapped three regions: the cloud molecular core, the Ser/G3–G6 complex, and the strong IRAS source 18278+O111. Only within the core, and only in one out of six observing runs a feature of 48 Jy was observed. This line coincides in position and velocity with one of the two masers once reported (Blair et al., 1975), but never detected since then.

Key words: interstellar medium: clouds: Serpens – masers – radio lines: molecular – stars: pre-main-sequence



1. Introduction

Water vapor masers in the Serpens cloud are sneaky objects. This

Astron. Astrophys. 223, 267–270 (1989)

ASTRONOMY AND ASTROPHYSICS

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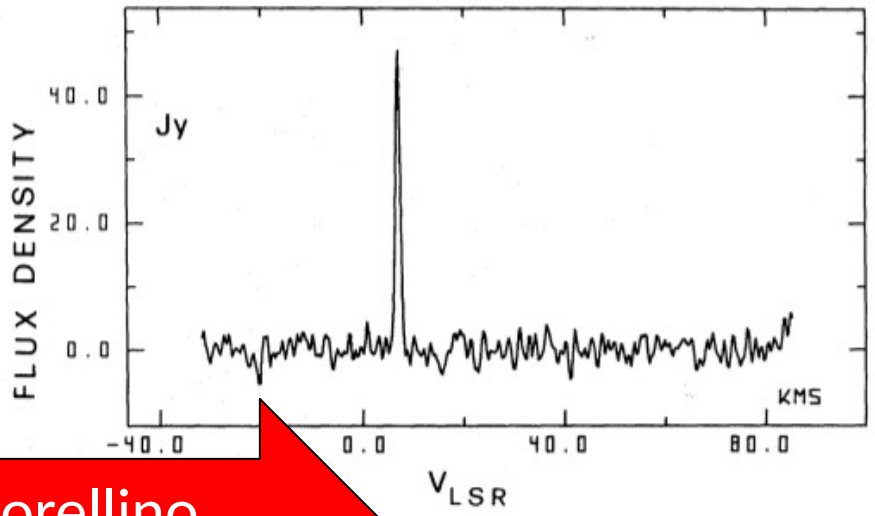


Poster 41 on Serpens/Herschel by E. Fiorellino

Ke
lin

1. Introduction

Water vapor masers in the Serpens cloud are sneaky objects. This

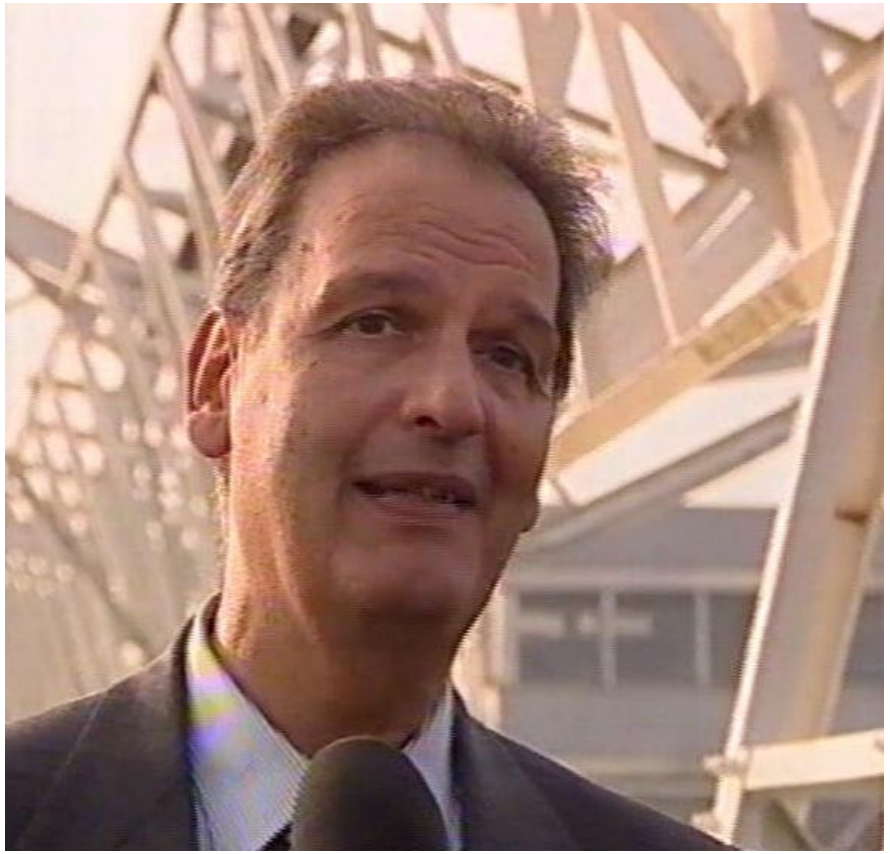
Amazing bandwidth!

13	☐ 1989A&AS...77..157G	1.000	02/1989	A	F G		R C	
	Giovanardi, C.; Palla, F.	Revision and extension to low temperature of numerical estimates of the electron collisional rates for atomic hydrogen						
14	☐ 1989A&A...223..267P	1.000	10/1989	A	F G		R C	S
	Palla, F.; Giovanardi, C.	A search for H2O maser emission in the Serpens region						

The 32 meter telescope of Medicina Radio Observatory

- **Built in 1983**

EVN – the European VLBI Network

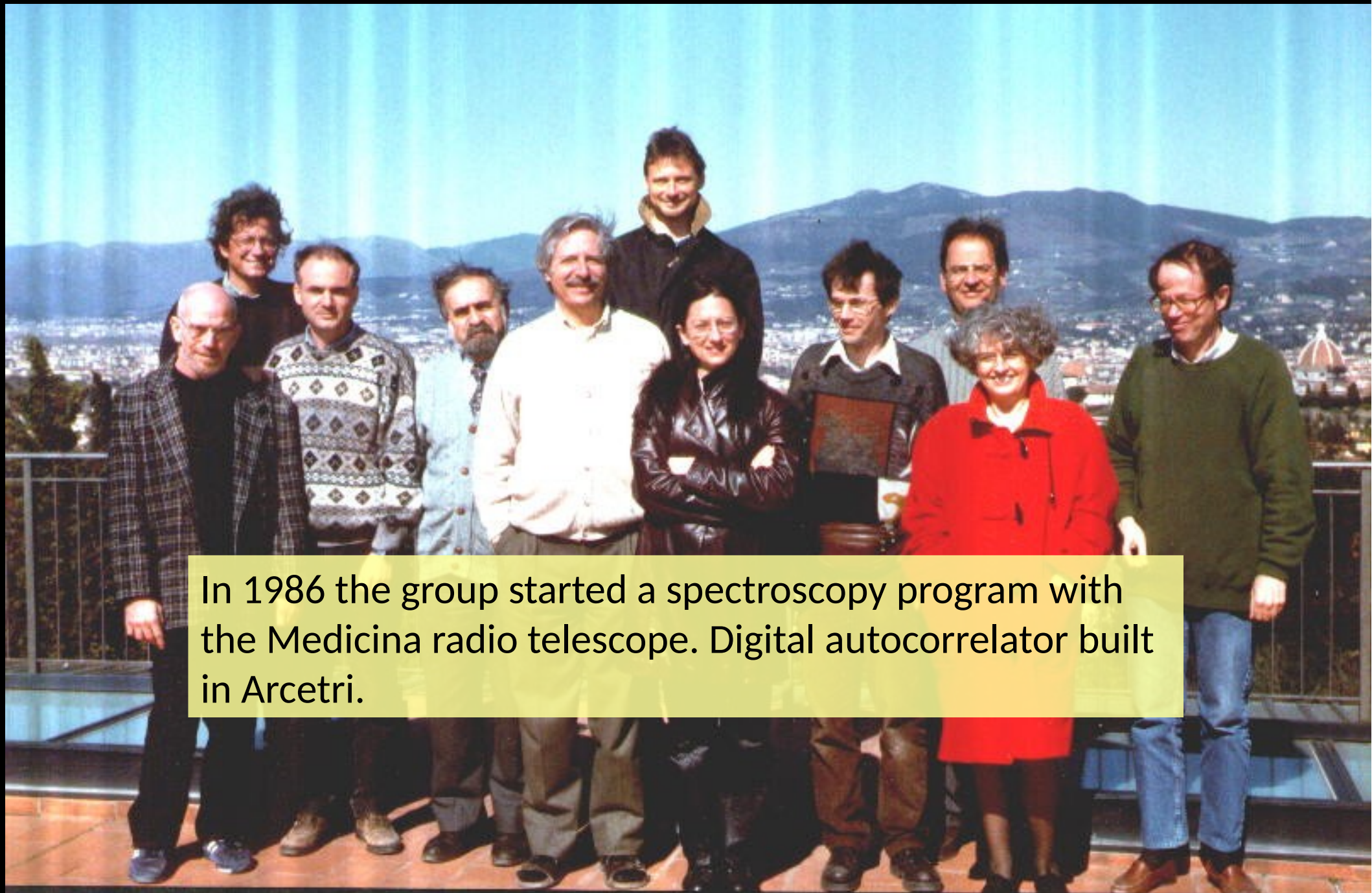


Gianni Tofani
1938–2015

Marcello Felli

(A somewhat later edition of) il gruppo radioastronomia di Arcetri

(A somewhat later edition of) il gruppo radioastronomia di Arcetri



In 1986 the group started a spectroscopy program with the Medicina radio telescope. Digital autocorrelator built in Arcetri.

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

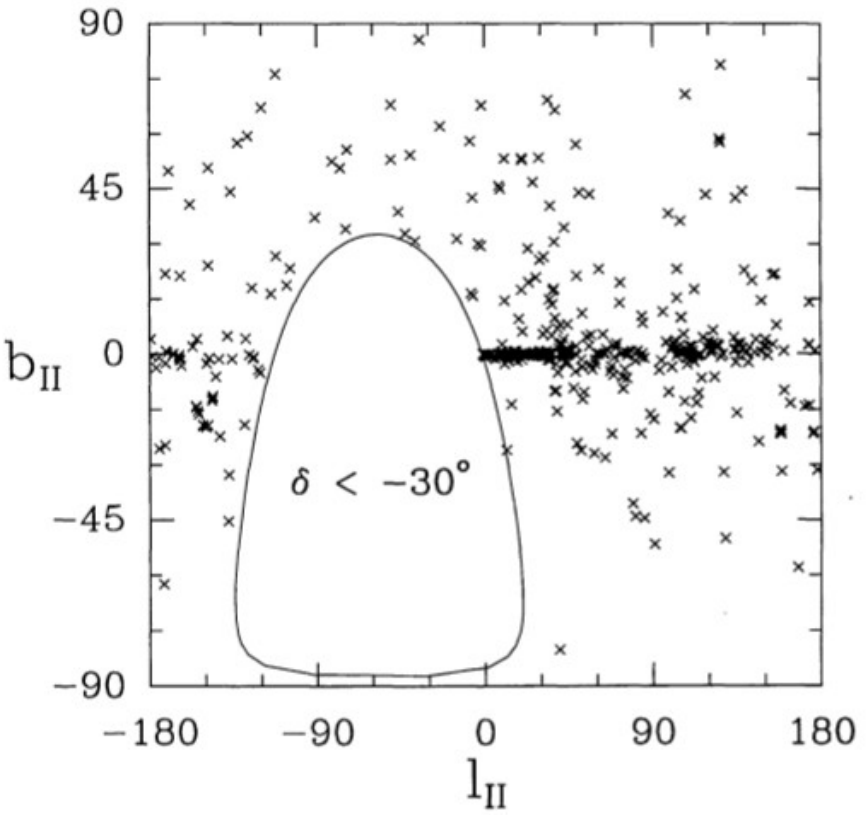
DECEMBER **1988,** PAGE 445

Astron. Astrophys. Suppl. Ser. **76,** 445-458 (1988)

A catalogue of H_2O maser sources north of $\delta = -30^\circ$

R. Cesaroni (1), F. Palagi (2), M. Felli (3), M. Catarzi (3), G. Comoretto (3), S. Di Franco (1), C. Giovanardi (3) and F. Palla (3)

(1) Istituto di Astronomia, largo E. Fermi 5, 50125, Florence, Italy
(2) C.N.R., Gruppo Nazionale Astronomia, U.d.R. Arcetri, largo E. Fermi 5, 50125, Florence, Italy
(3) Osservatorio Astrofisico di Arcetri, largo E. Fermi 5, 50125, Florence, Italy



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(3) Osservatorio Astrofisico di Arcetri, largo E. Fermi 5, 50125, Florence, Italy

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
Astron. Astrophys. Suppl. Ser. **84,** 179-225 (1990)

JULY **1990,** PAGE 179

The Arcetri atlas of H_2O maser sources

G. Comoretto (3), F. Palagi (2), R. Cesaroni (1), M. Felli (3), A. Bettarini (3), M. Catarzi (3), G. P. Curioni (3), P. Curioni (3), S. Di Franco (1), C. Giovanardi (3), M. Massi (3), F. Palla (3), D. Panella (3), E. Rossi (3), N. Speroni (2) and G. Tofani (3)

(1) Istituto di Astronomia, Largo E. Fermi 5, 50125, Firenze, Italy
(2) C.N.R., Gruppo Nazionale Astronomia, U.d.R. Arcetri, Largo E. Fermi 5, 50125, Firenze, Italy
i 5, 50125, Firenze, Italy

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
Astron. Astrophys. Suppl. Ser. **103,** 541-572 (1994)

MARCH **1994,** PAGE 541

The Arcetri catalogue of H_2O maser sources update*

J. Brand[1,2], R. Cesaroni[1], P. Caselli[3], M. Cat
S. Di Franco[5], M. Felli[1], C. Giovanardi[4], L. O
N. Speroni[4] and G. Tofani[1]

[1] Osservatorio Astrofisico di Arcetri, Florence, It
[2] Istituto di Radioastronomia CNR, Via Gobetti
[3] Dipartimento di Astronomia, Univ. di Bologna
[4] C.N.R., Gruppo Naz. Astronomia, U.d.R., Arc
[5] Dipartimento di Astronomia e Scienza dello Sp

A&A 368, 845–865 (2001)
DOI: 10.1051/0004-6361:20000526

2001

Astronomy & Astrophysics

The Arcetri Catalog of H_2O maser sources: Update 2000*,**

R. Valdettaro[1], F. Palla[1], J. Brand[2], R. Cesaroni[1], G. Comoretto[1], S. Di Franco[3], M. Felli[1], E. Natale[4], F. Palagi[4], D. Panella[1], and G. Tofani[1]

[1] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy
[2] Istituto di Radioastronomia CNR, Via Gobetti 101, 40129 Bologna, Italy
[3] Dipartimento di Astronomia e Scienza dello Spazio, Largo E. Fermi 5, 50125 Firenze, Italy
[4] CAISMI, C.N.R., Largo E. Fermi 5, 50125 Firenze, Italy

Osservatorio Astrofisico di Arcetri

1992

INAF - IASF BOLOGNA

ISTITUTO DI ASTROFISICA SPAZIALE
E FISICA COSMICA - BOLOGNA

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

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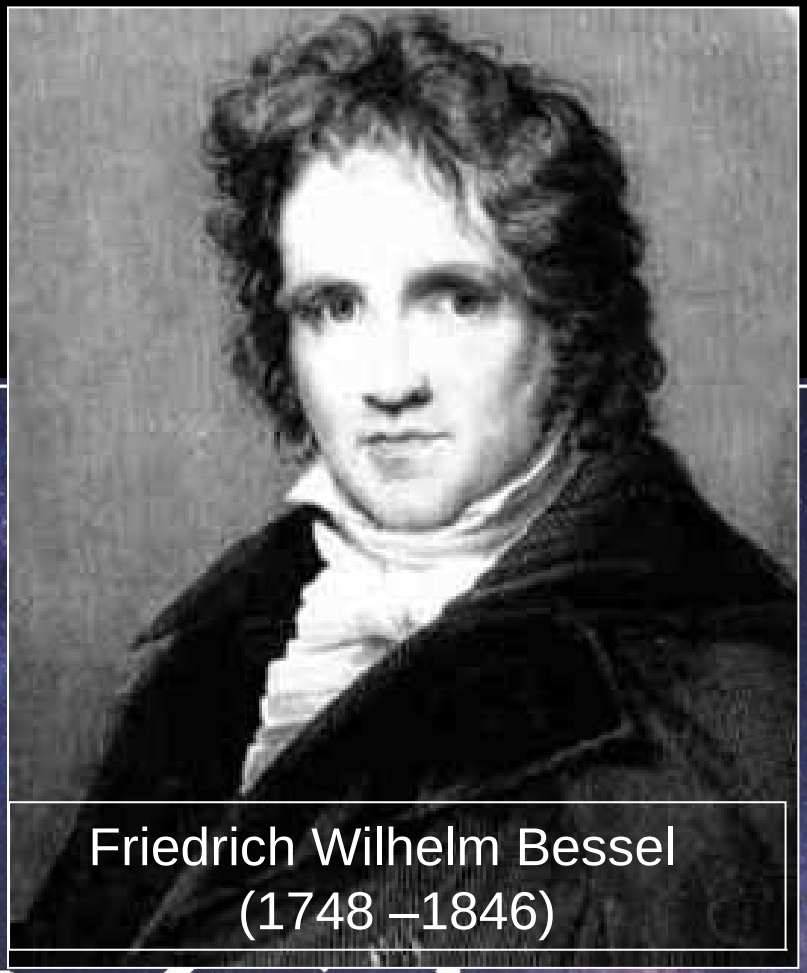
(3) Osservatorio Astrofisico di Arcetri, largo E. Fermi 5, 50125, Florence, Italy

TABLE I.

Right Asc.	Declinat.	Name	Class	Gal. Long.	Gal. Lat.	Flux (Jy)	V (km/s)	Reference
00 00 45.0	+55 24 21.0	Y CAS	STAR	116.144	-6.552	3.80	2.4	271,272,280,288
00 05 3.4	-25 46 21.0	SY SCL	STAR	39.914	-80.045	13.80	22.6	276
00 11 44.6	+64 12 4.0	IRAS00117+6412	HII	118.961	1.893	6.00	-30.0	259
00 11 44.9	+64 11 50.0	IRAS00117+6412	HII	118.961	1.889	2.00	-38.0	259
00 21 9.6	+65 49 26.0	IRAS00211+6549	HII	120.153	3.378	16.00	-38.0	259
00 33 53.3	+63 12 32.0	IRAS00338+6312	HII	121.301	0.659	0.50	-29.0	259
00 34 5.4	+62 51 32.0	TY CAS	STAR	121.303	0.308	16.70	-58.9	266,276
00 34 16.1	+63 47 30.0	IRAS00342+6347	HII	121.377	1.238	9.00	-20.0	259
00 34 17.2	+63 47 5.0	IRAS00342+6347	HII	121.378	1.231	5.00	-20.0	259
00 37 58.7	+62 48 21.0	IRAS00379+6248	HII	121.744	0.233	5.00	-18.0	259
00 42 50.0	+68 54 36.0	IRC+70012	STAR	122.445	6.317	1.40	-25.0	271
00 46 51.2	+65 27 19.0	IRAS00468+6527	HII	122.779	2.856	0.50	-51.0	259
00 49 29.2	+56 17 36.0	NGC 281	HII	123.071	-6.307	26.00	-32.0	41
01 03 49.0	+12 18 42.0	CIT 3	STAR	128.653	-50.126	6.60	22.2	271,272,280,288
01 04 35.7	+65 05 21.0	IRAS01045+6505	HII	124.645	2.539	5.00	-84.0	259

Medicina survey data provide targets

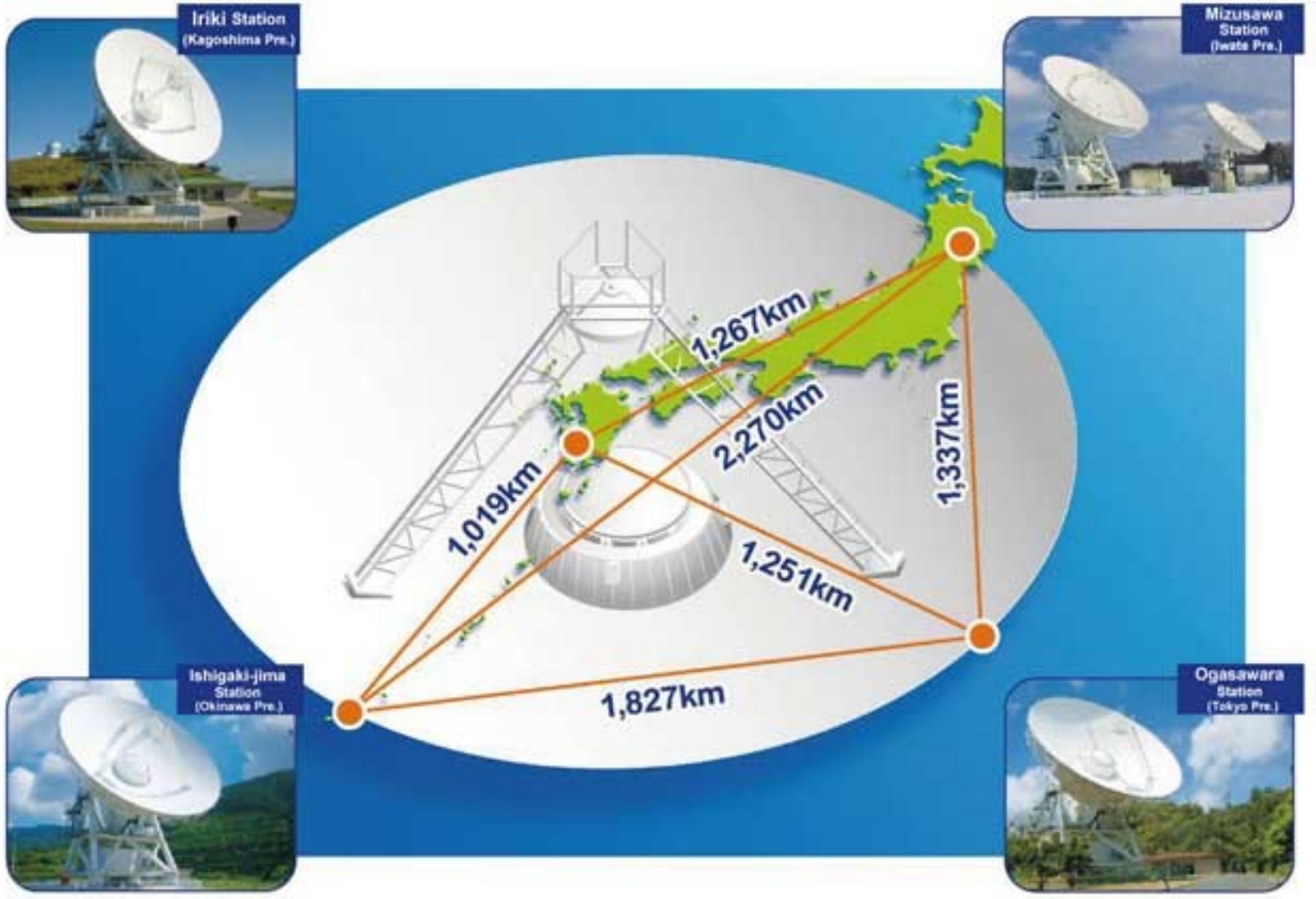


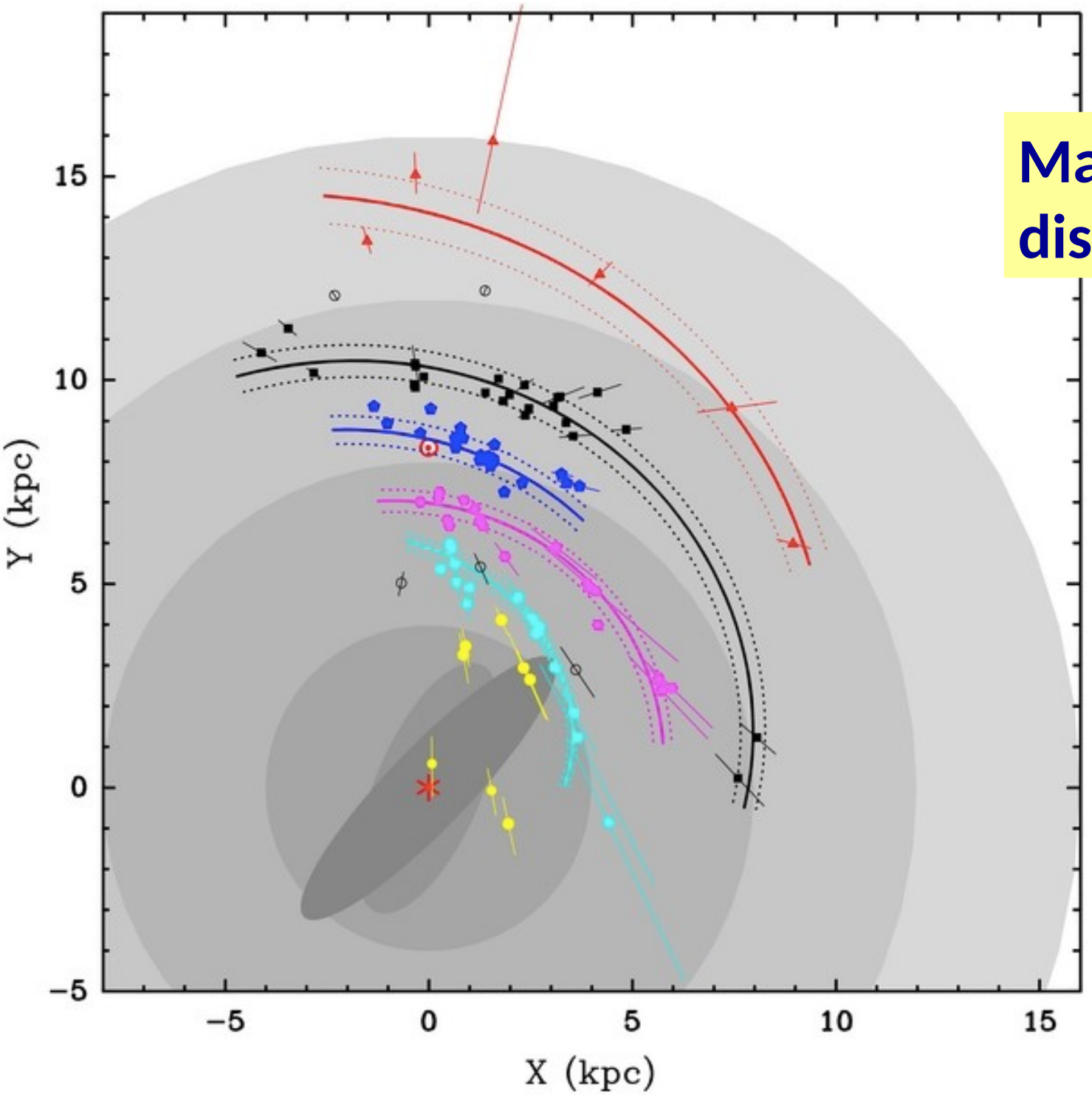
Friedrich Wilhelm Bessel
(1748 –1846)

BESSEL

Bar and Spiral Structure Legacy Survey,
a VLBA Key Science Project

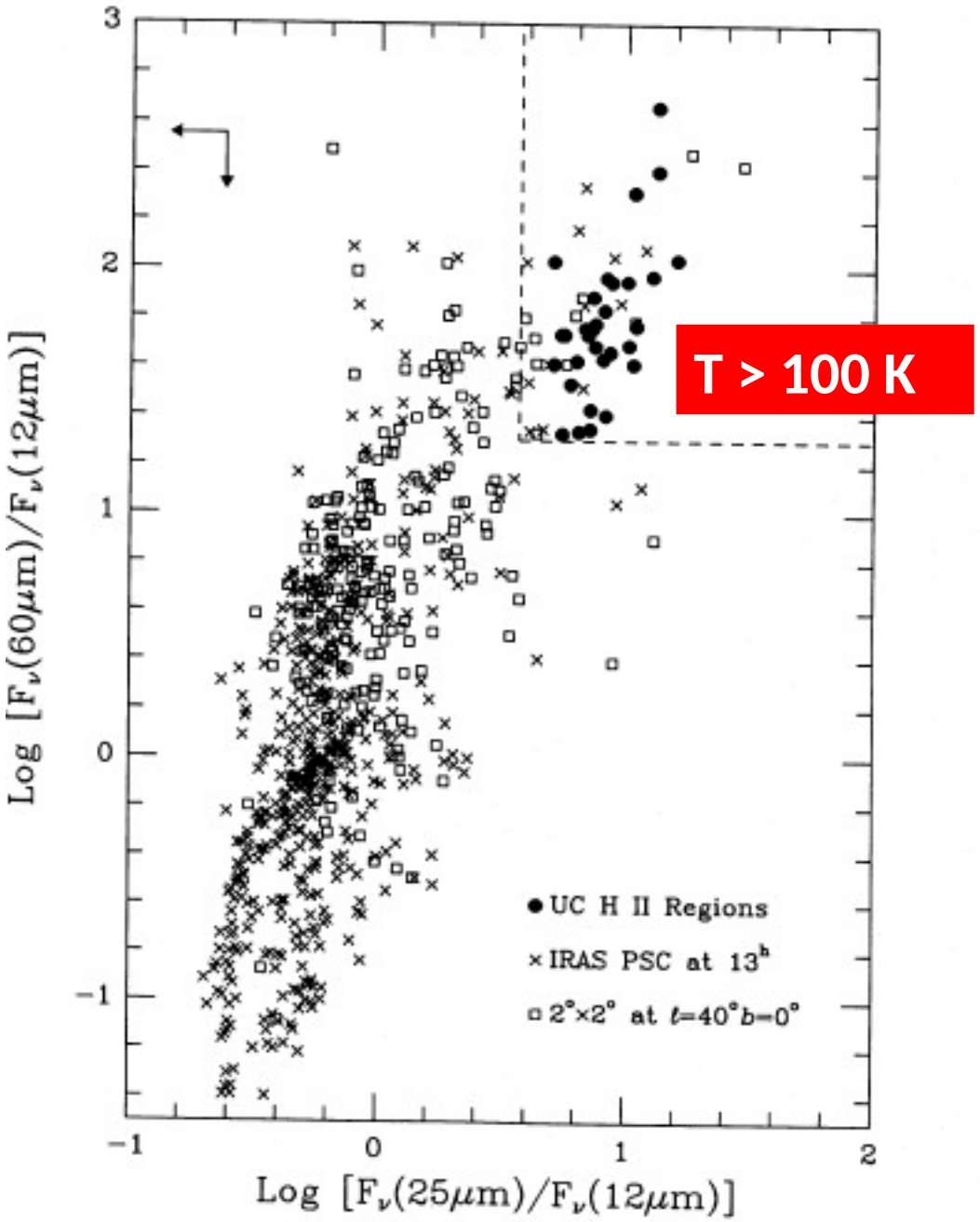
VERA: VLBI Exploration of Radio Astronomy





Maser parallax distances

Reid+ 2014



Finding embedded high mass young stellar objects

IRAS Point Source Catalog
12 + 25 + 60 + 100 μm

Wood & Churchwell 1989

Astron. Astrophys. 246, 249–263 (1991)

ASTRONOMY AND ASTROPHYSICS

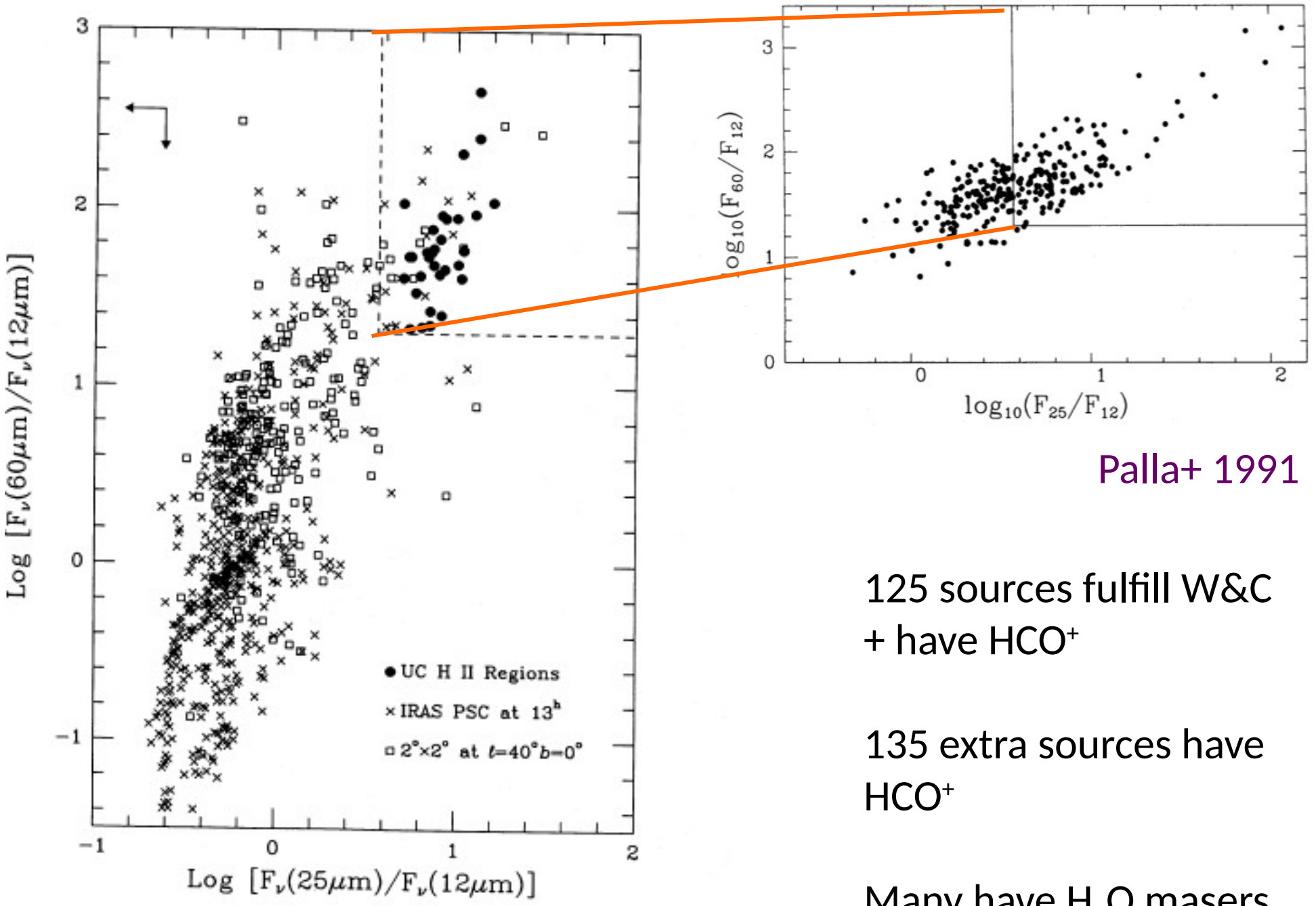
Water masers associated with dense molecular clouds and ultracompact H II regions

F. Palla [1], J. Brand [1], R. Cesaroni [2], G. Comoretto [1], and M. Felli [1]

[1] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D(West)-5300 Bonn 1, Federal Republic of Germany

The RLTH sample was derived according to the following criteria:
(1) sources with galactic latitude $|b| \leqq 10°$;
(2) FIR colours: $0.61 \leqq [60-25] \leqq 1.74$, and $0.087 \leqq [100-60] \leqq 0.52$;
(3) no upper limits for the flux at 25, 60, and 100 μm;
(4) no positional coincidence with known H II regions;
(5) $F_{60} \geqq 100$ Jy, to select sources with higher expected H_2O flux and limit the sample to a manageable number;

In the definition of our sample we added a further instrumental constraint:
(6) declination $\delta \geqq -30°$.



Wood & Churchwell 1989

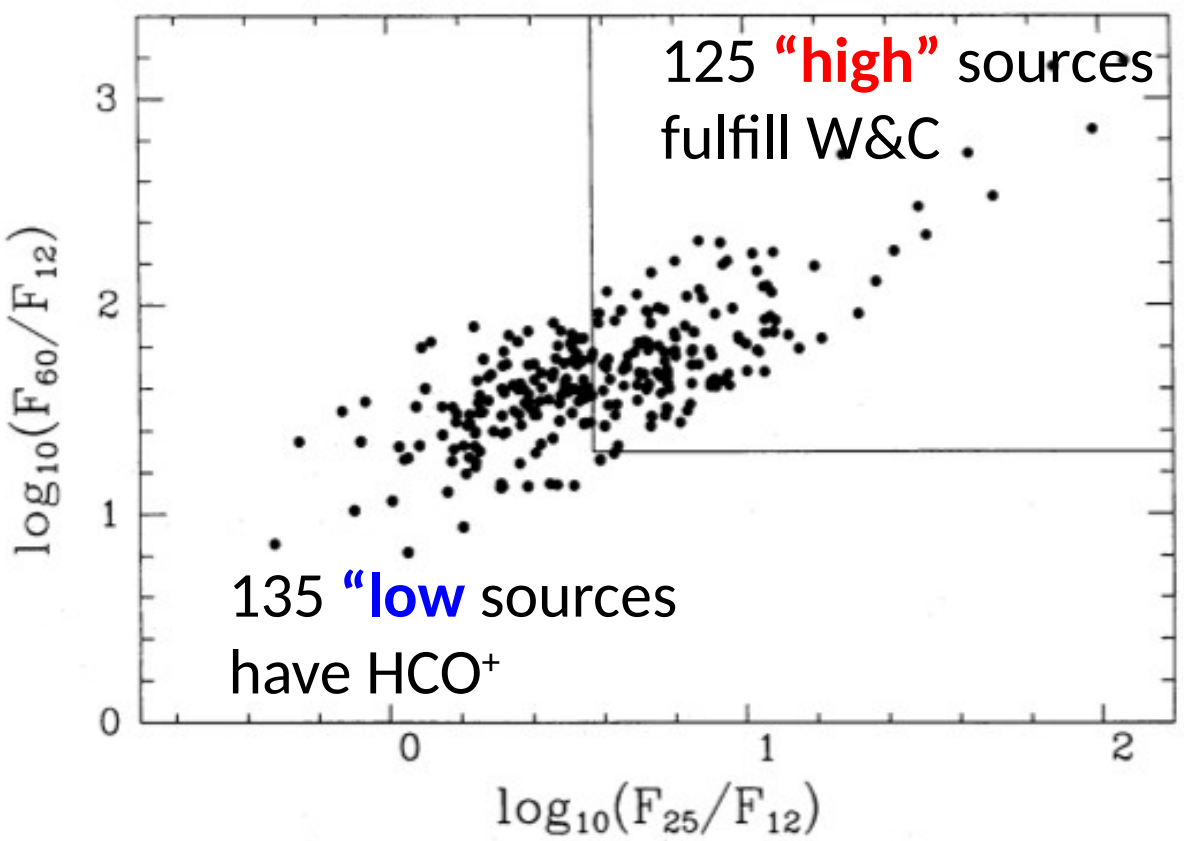
Palla+ 1991

125 sources fulfill W&C + have HCO^+

135 extra sources have HCO^+

Many have H_2O masers

A Sample of Massive Young Stellar Objects



Talk by Sergio Molinari

"high" sources:

- More active
  - UCHII, but also younger → MP/YSO
- More H_2O masers (29%)

135 "low sources have HCO^+

"low" sources:

- less active
  - UCHII, but also younger
- fewer H_2O (9%) masers

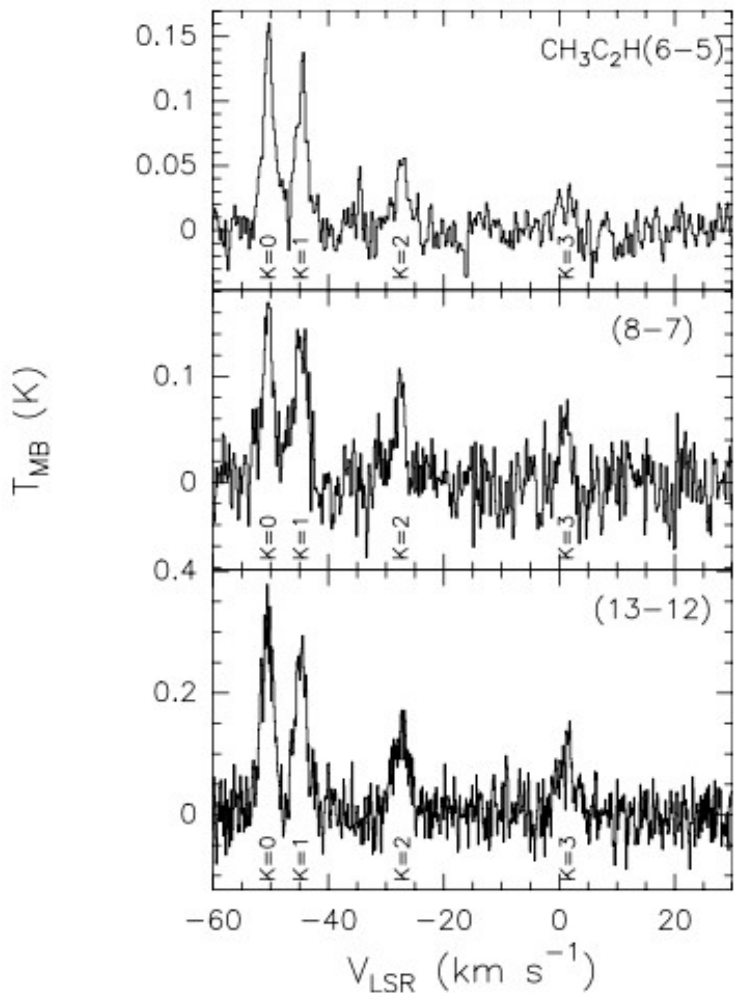
Palla+ 1991, 1993
Molinari+ 1996, 1998, 2000

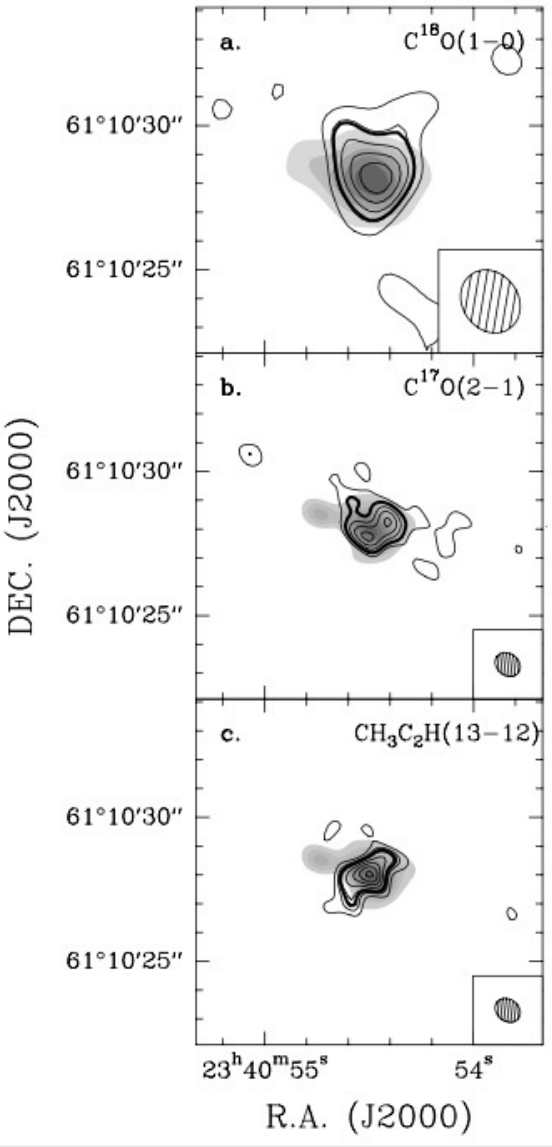
Very many follow-up studies of Molinari+ sample

Example: **IRAS 23385+6053: A candidate protostellar massive object**⋆

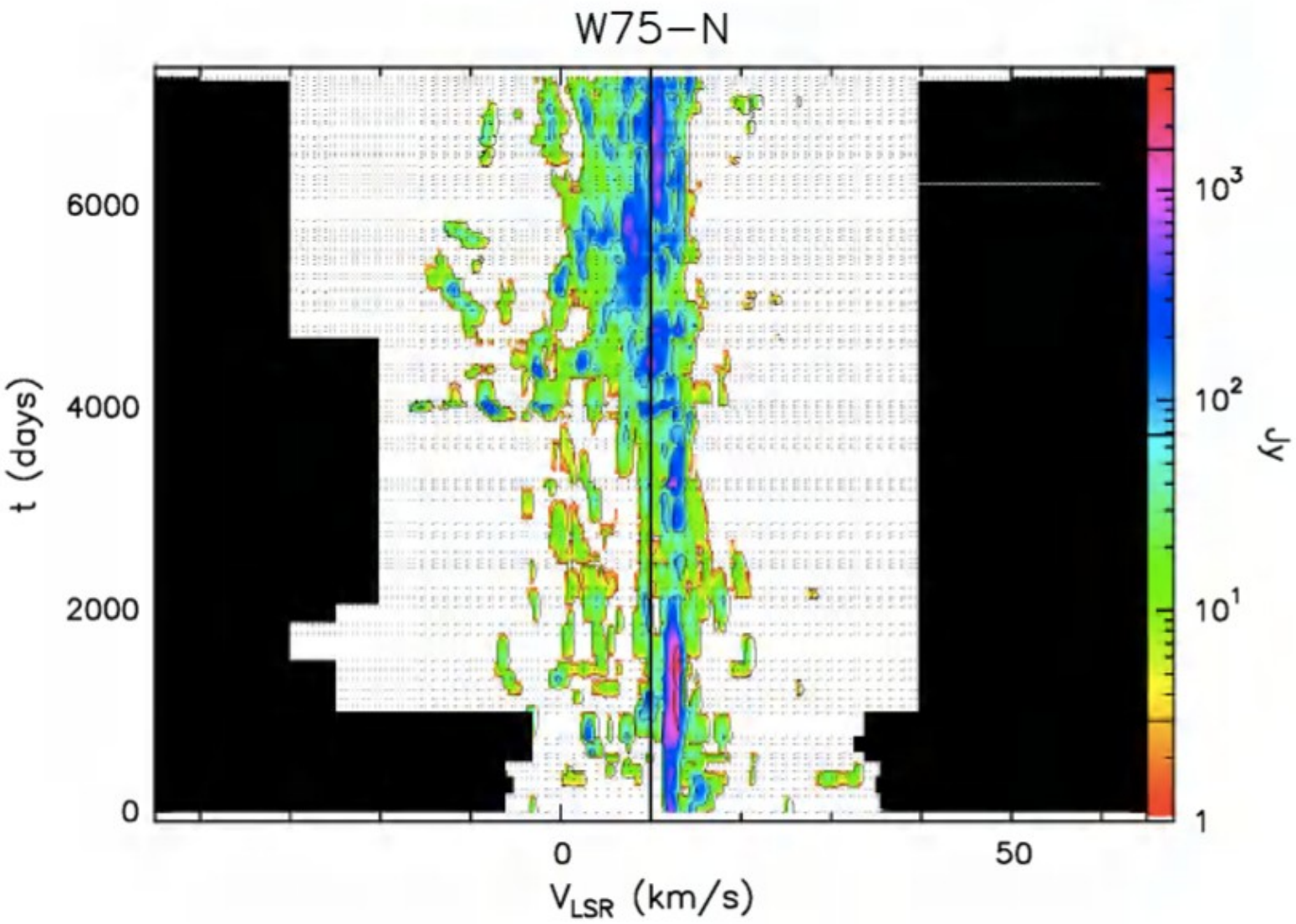
F. Fontani[1], R. Cesaroni[2], L. Testi[2], C. M. Walmsley[2], S. Molinari[3], R. Neri[4], D. Shepherd[5], J. Brand[6], F. Palla[2], and Q. Zhang[7]

A&A **414**, 299 (2004)





20 y monitoring of ~40 H_2O masers with Medicina

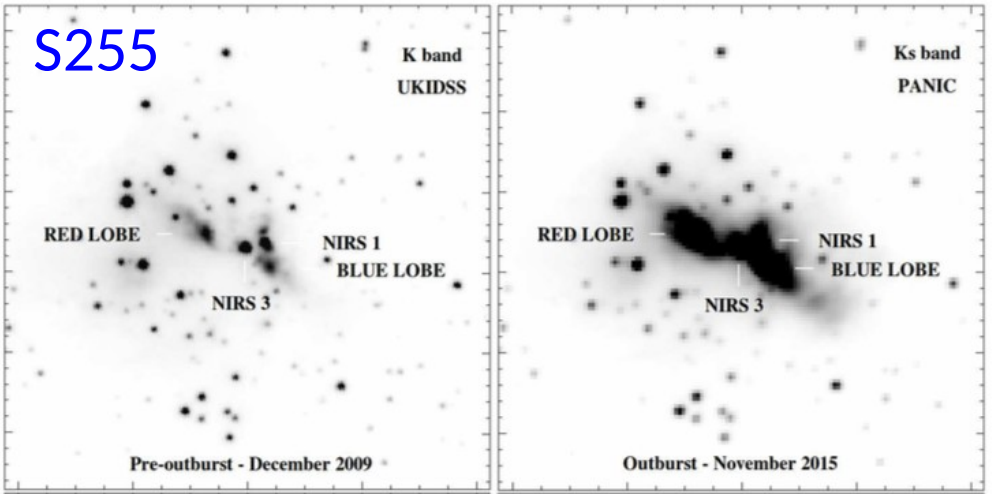


Valdettaro+ 2002
Brand+ 2003, 2005
Felli+ 2007

Maser monitoring can have big pay-off!!

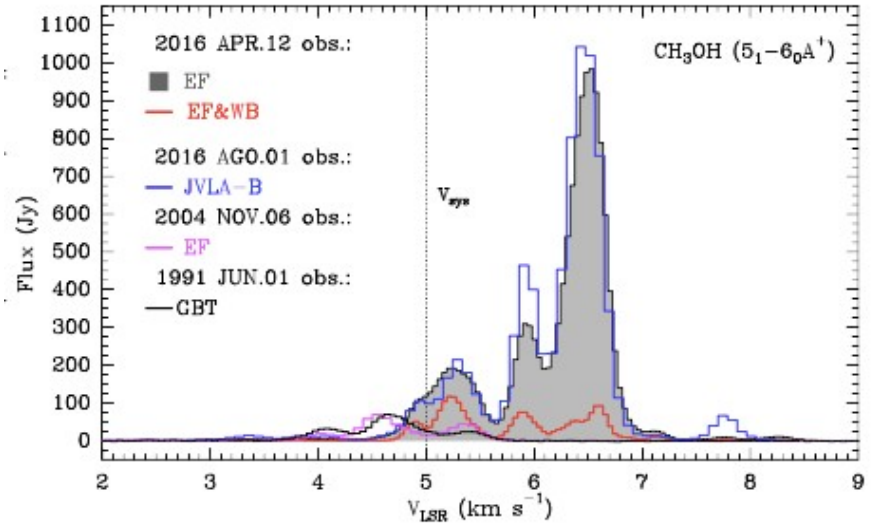
Recently discovered strong outburst of high mass YSO were accompanied (even preempted?) by very strong maser outbursts

Scaled up FUOR accretion episodes?



Factor ~10 luminosity increase

Caratti o Garatti+ 2017

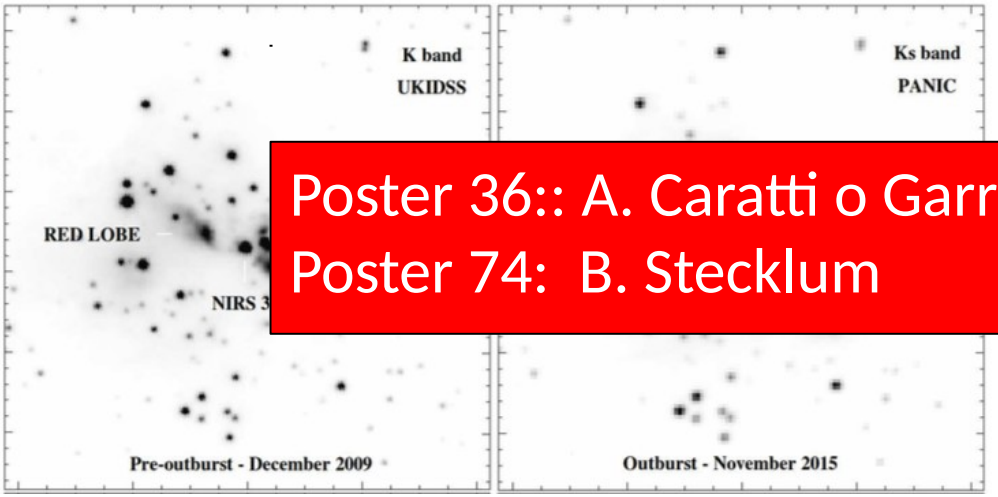


Moscadelli+ 2017

The value of maser monitoring

Recently discovered strong outburst of high mass YSO were accompanied (even preempted?) by very strong maser outbursts

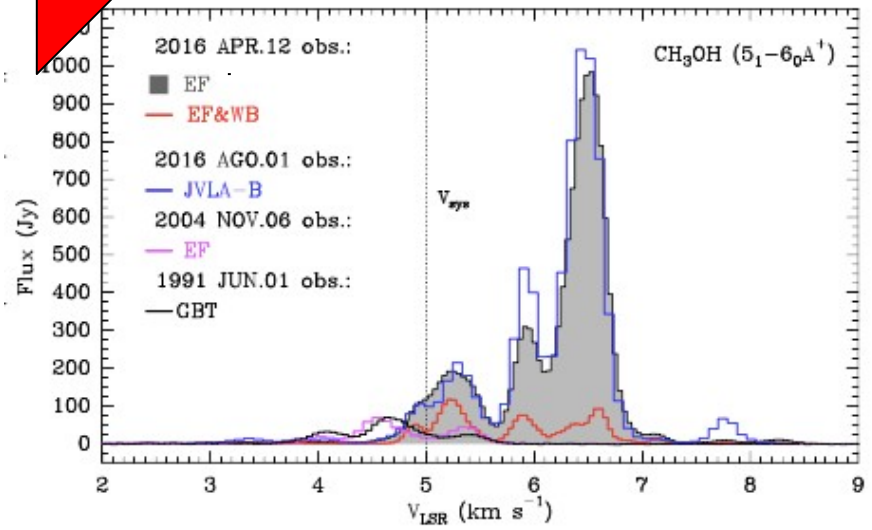
Scaled up FUOR accretion episodes?



Poster 36:: A. Caratti o Garrati

Poster 74: B. Stecklum

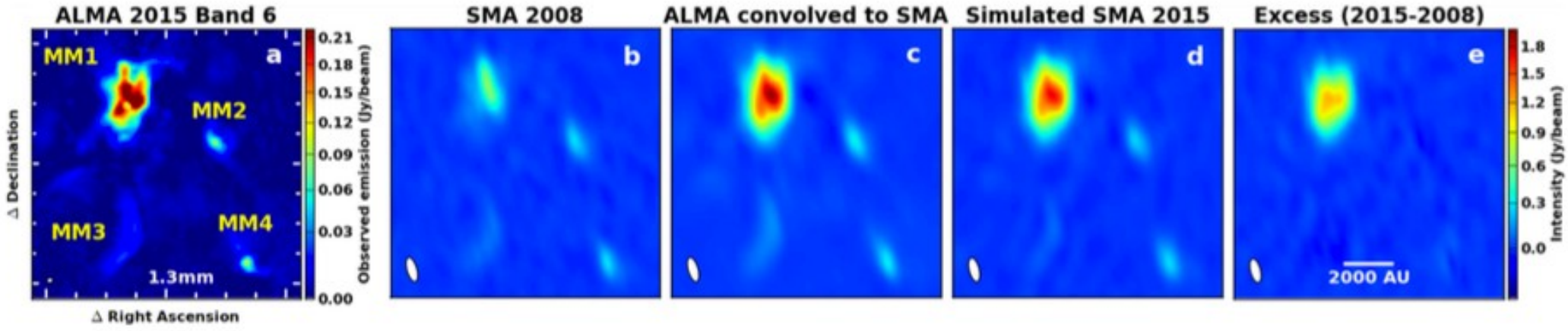
Moscadelli+ 2017



An Extraordinary Outburst in the Massive Protostellar System NGC 6334I-MM1: Quadrupling of the Millimeter Continuum

T. R. Hunter[1], C. L. Brogan[1], G. MacLeod[2], C. J. Cyganowski[3], C. J. Chandler[4], J. O. Chibueze[5,6,7], R. Friesen[8], R. Indebetouw[1,9], C. Thesner[7], and K. H. Young[10]

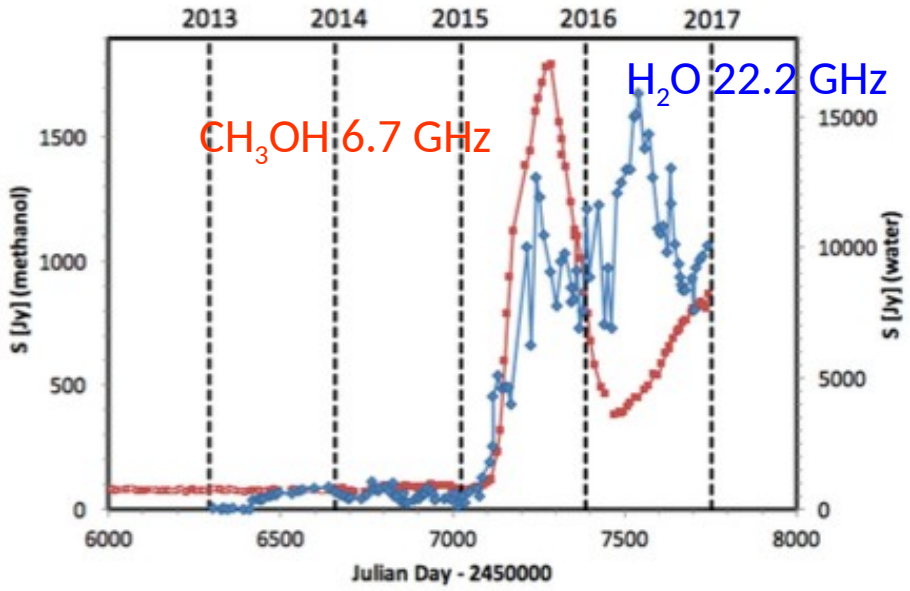
ApJ 2017 March

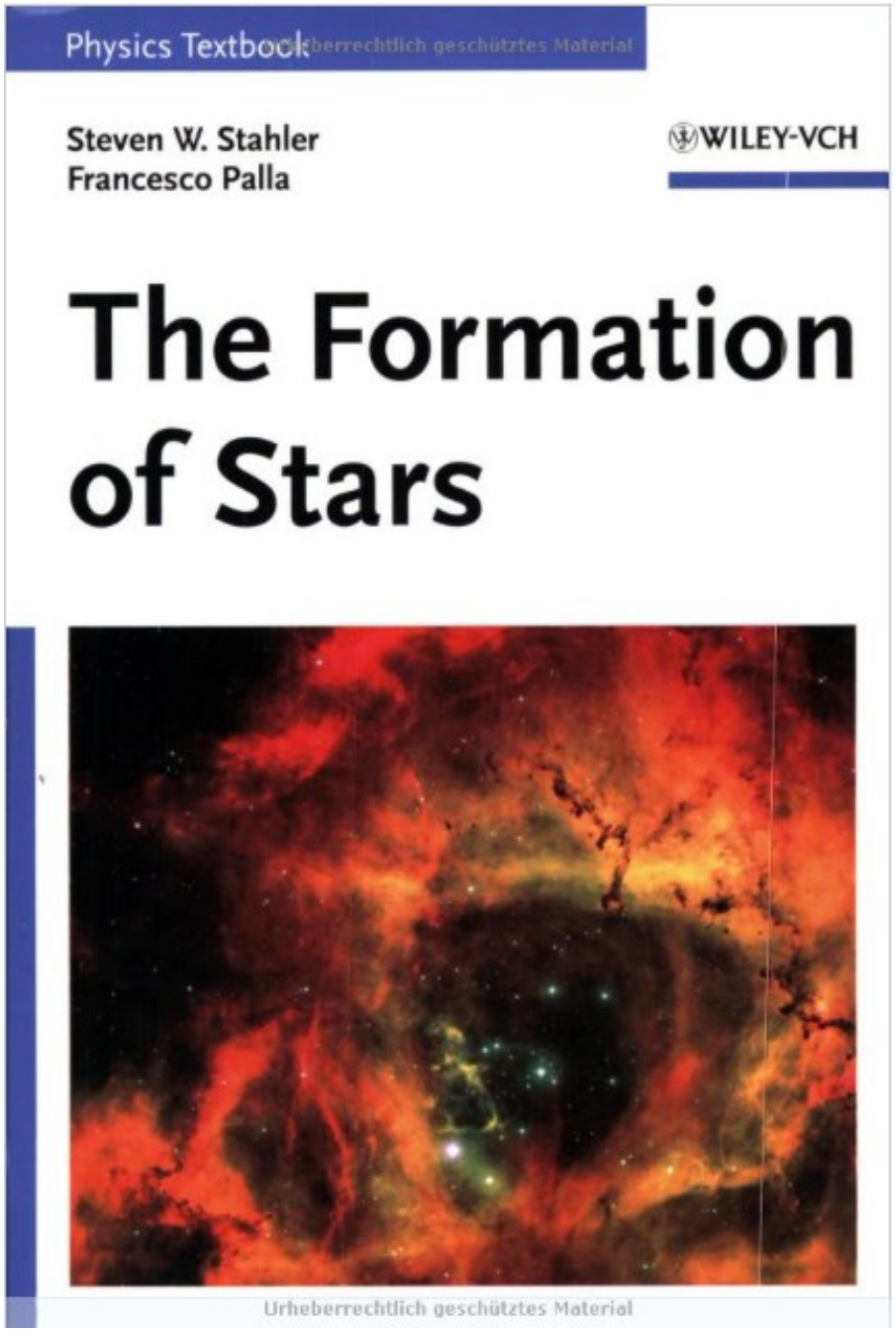


Luminosity surge by a factor ~70
← Sudden accretion event?

Persistent, long-term monitoring

Hartebeesthoek Radio Observatory 26m telescope





Chapter 15: Interstellar Masers

Water maser research is a **significant** part of Francesco's legacy

- The Medicina data, taken for themselves, provide valuable targets for
  - searches for embedded, active, accreting very young stellar objects
  - trigonometric parallax Galactic structure surveys
- They also were are the starting point of a large scale program to systematically study high-mass young stellar objects
- Future, closely spaced, rapidly reduced variability surveys may point to key objects for the study of episodic accretion events