MONITORING WATER MASERS
in star-forming regions

Empirical results

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Collaborators

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Palagi

Various ways to monitor

Statistics

Many sources, only once: Wouterloot et al. 1995
Fewer sources, repeatedly: Arcetri/Bologna; Pushchino

Statistics & Individual object-studies

Wide range in L_{bol}: Valdettaro et al. 2002; Brand et al. 2003
Narrow range in L_{bol}: Wilking et al. 1994; Furuya et al. 2003
High time-resolution: Boboltz et al. 1998; Liljeström & Gwinn 2000
High frequency resolution: Boboltz et al. 1998

Observations

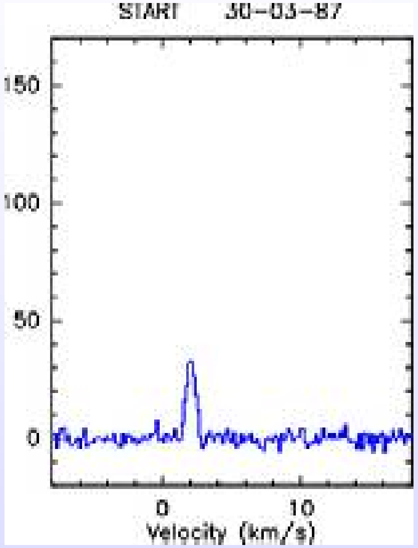
Since 1987
4-5 observations/yr

Sample of 53 YSOs;
first analysis on 14.

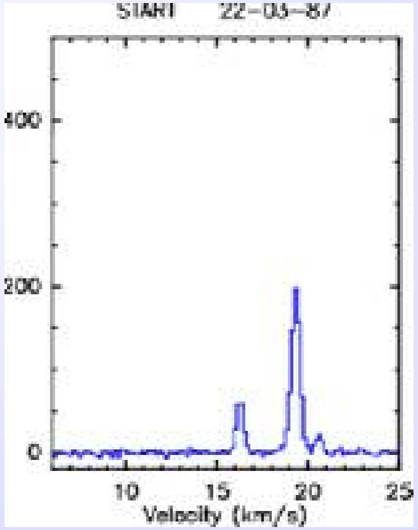
T_{sys} ≈ 120 K
$\eta \approx$ 30%
AC, 1024 channels,
10 MHz band
[0.132 km/s]

Medicina 32-m

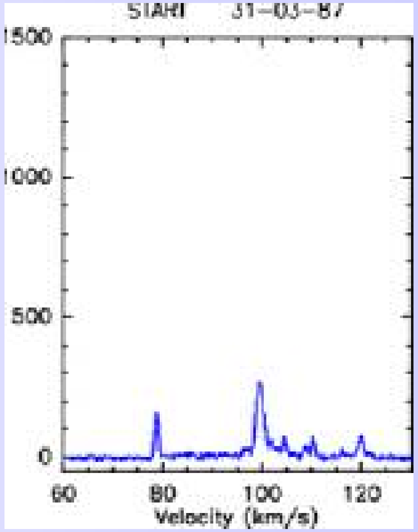
Time sequences maser emission



L1455 IRS1



S269 IRS2



W43 Main3

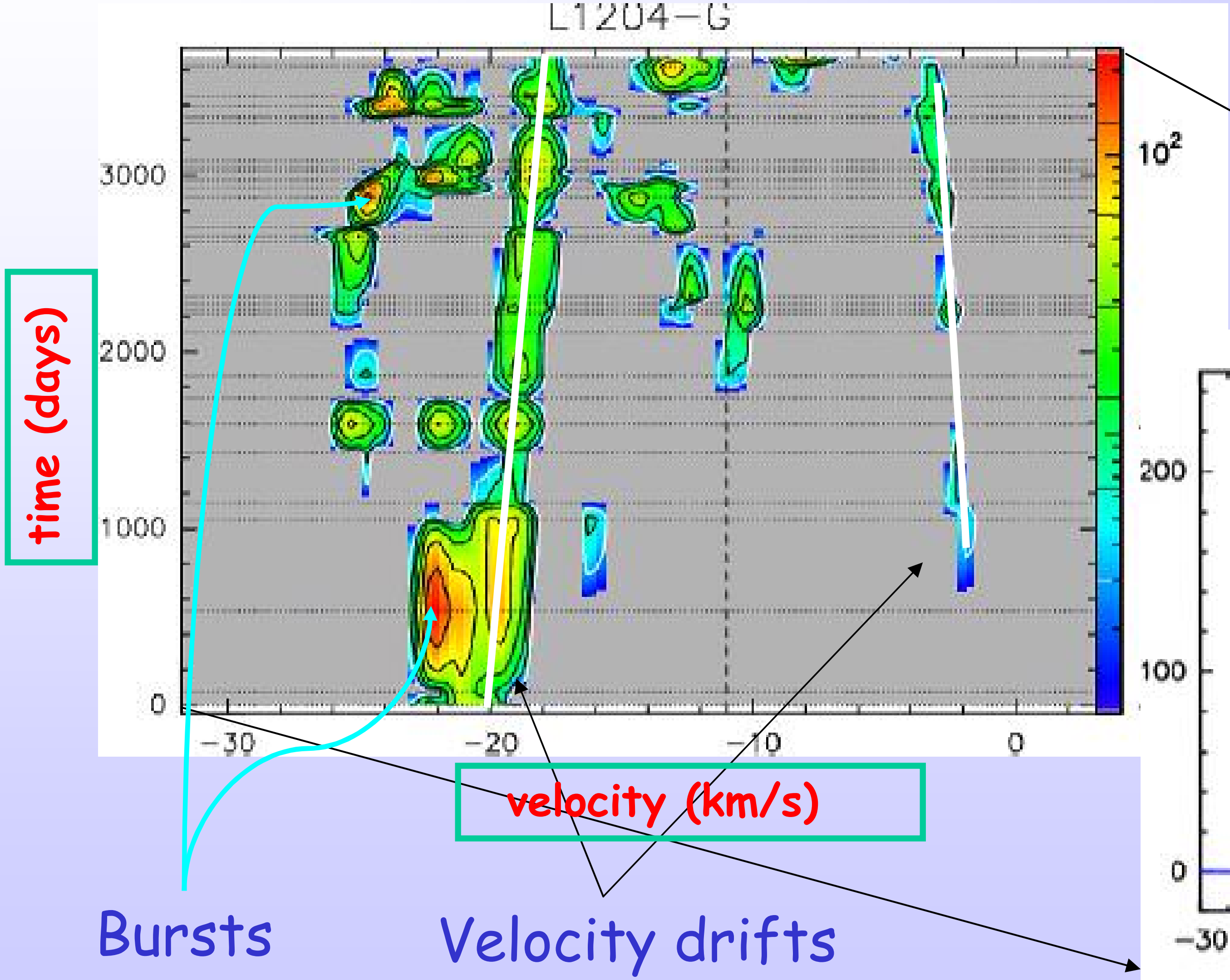
How to organize and display 10-15 years of data?

Ways of managing & studying the data

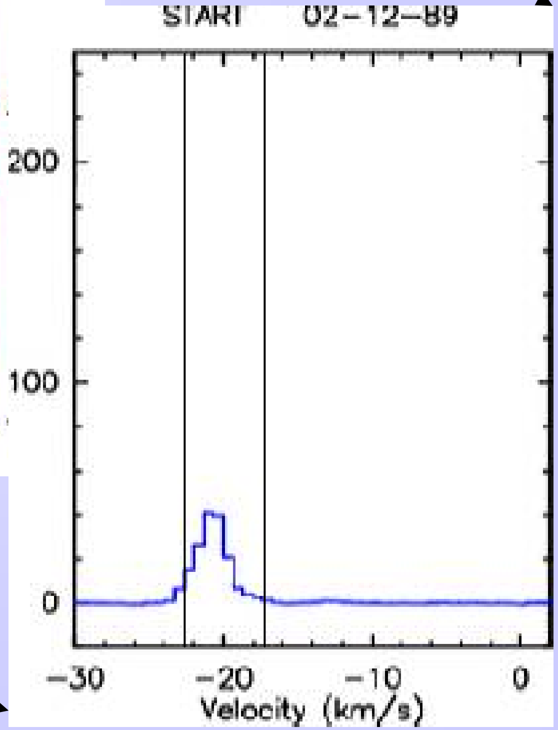
➔Flux density F as function of V, t

overall description maser activity;
visual identification possible velocity-drifts

Flux density – Velocity – Time diagrams

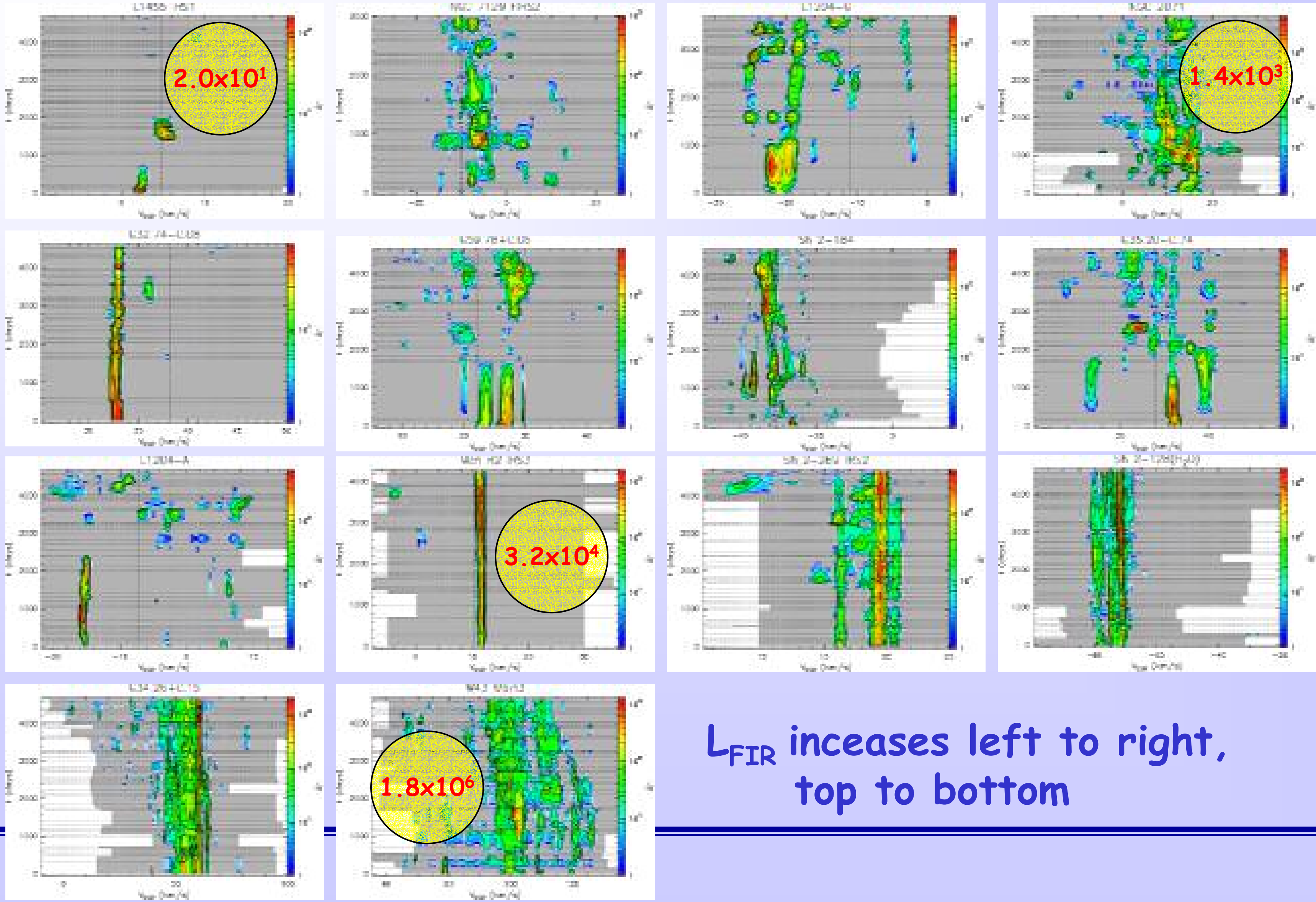


L1204-G



(Used 10-day averages and linear interpolation)

Flux density – Velocity - Time



L_{FIR} inceases left to right,
top to bottom

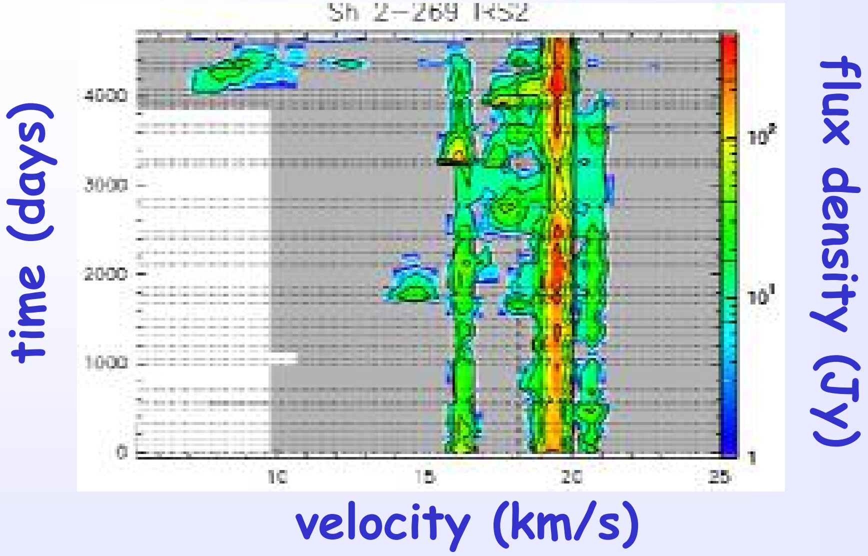
Ways of managing & studying the data

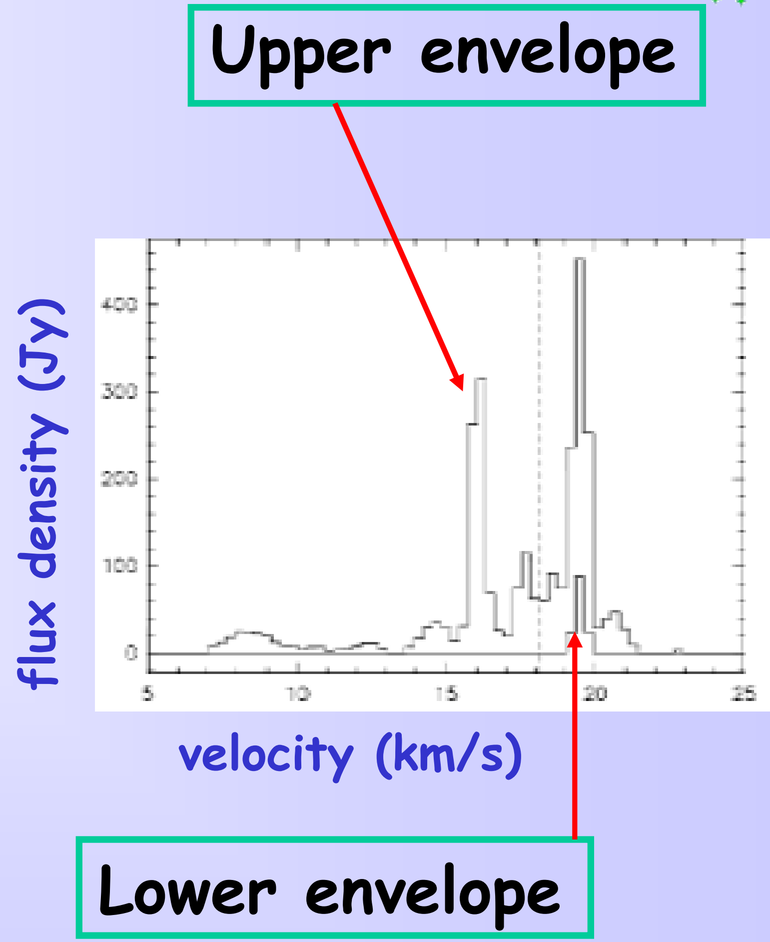
- ➔Flux density F as function of V, t
- ➔Integrated flux density S as function of time

  describes variation of total maser emission

- ➔Upper & Lower envelopes

  Shows maximum & minimum signal detected in each channel during monitoring period (5σ-level).
  What maser spectrum would look like *if* all velocity components were to emit *at their maximum/minimum level* and *at the same time*.

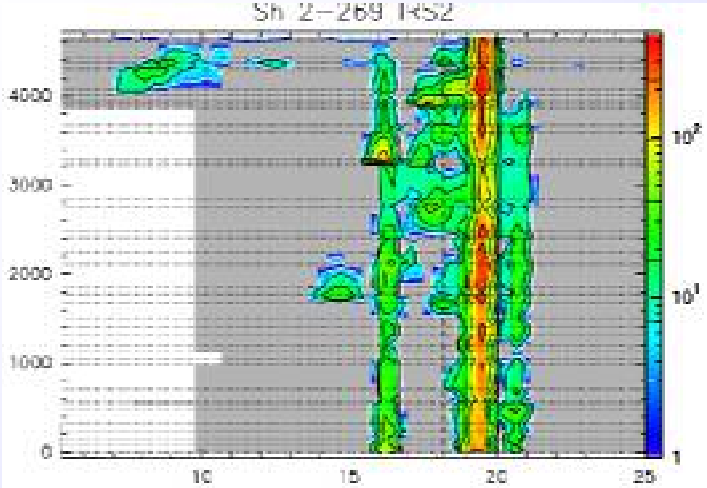

Sh 2–269 IRS2
time (days)
flux density (Jy)
velocity (km/s)


Upper envelope
flux density (Jy)
velocity (km/s)
Lower envelope

Ways of managing & studying the data

- ➔Flux density F as function of V, t
- ➔Integrated flux density S as function of time
- ➔Upper & Lower envelopes
- ➔Frequency-of-occurrence histogram

  percentage of time flux density in a channel was greater than 5σ-level

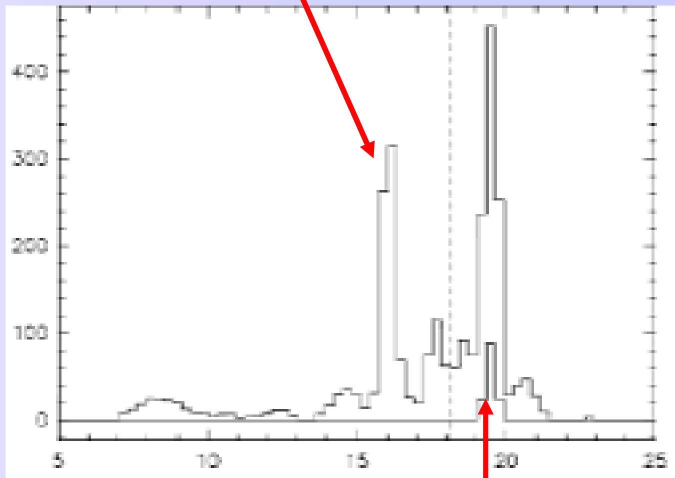


time (days)

flux density (Jy)

velocity (km/s)

Upper envelope

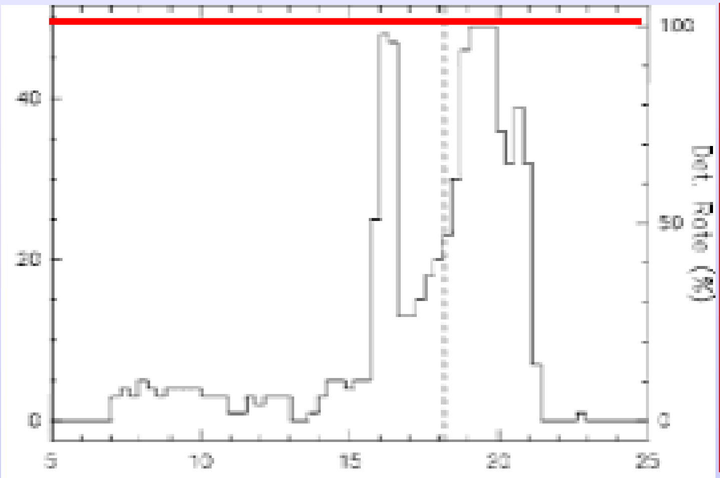


flux density (Jy)

velocity (km/s)

Lower envelope

100%



number

detection rate (%)

velocity (km/s)

Frequency-of-occurrence histogram

Ways of managing & studying the data

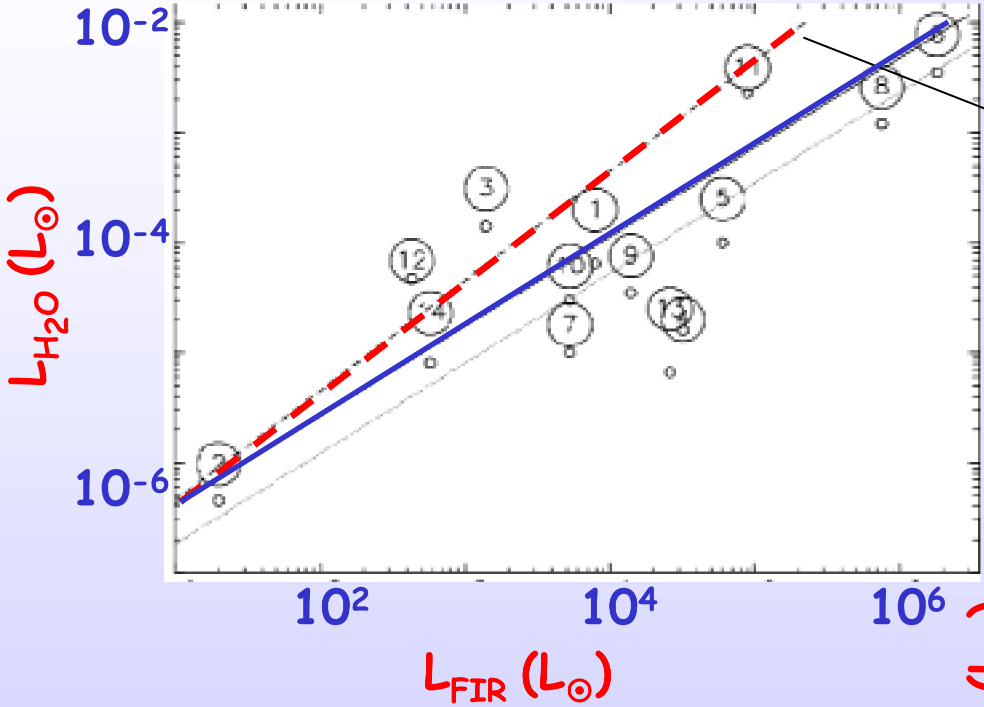
- ➔Flux density F as function of V, t
- ➔Integrated flux density S as function of time
- ➔Upper & Lower envelopes
- ➔Frequency-of-occurrence histogram
- ➔Potential maximum maser luminosity $L_{H_2O}^{up}$

  Integral of upper envelope;
  Maximum output source could produce *if* all velocity components were to emit *at their maximum level* and *at the same time*
- ➔Actually *observed* maximum maser luminosity $L_{H_2O}^{max}$

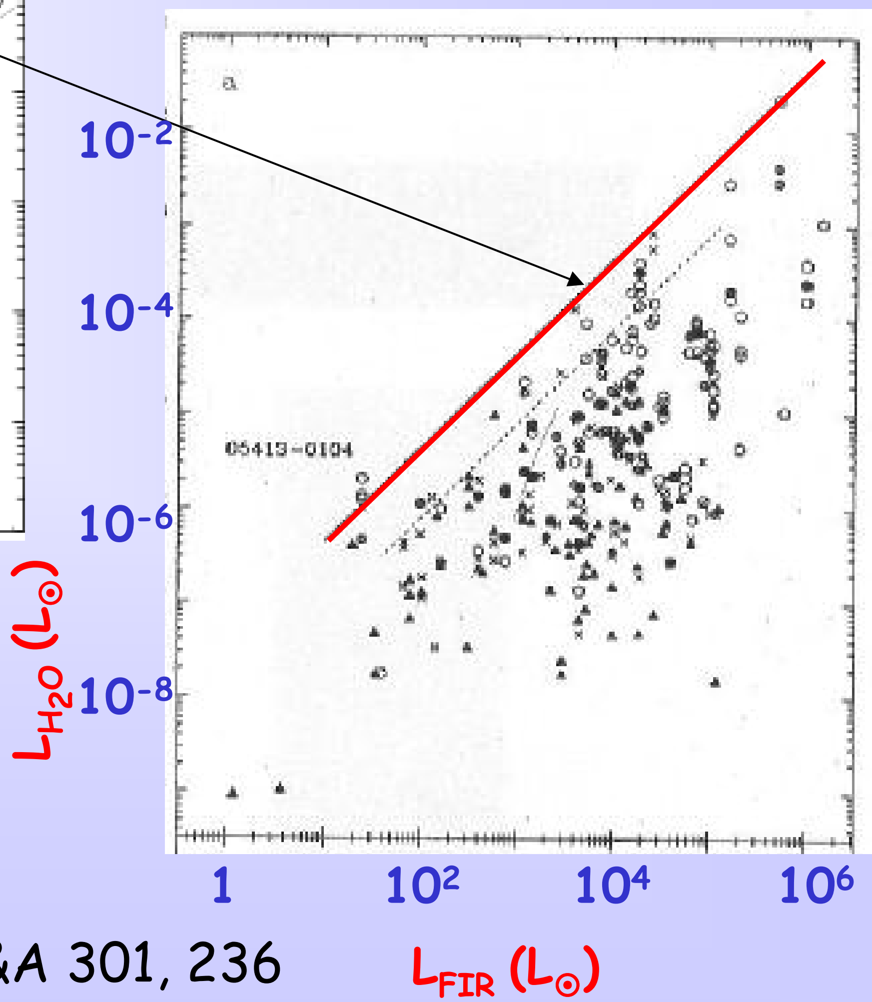
  Derived from spectrum with highest S
- ➔First, second moment of upper envelope, V_{up}, ΔV_{up}

  average velocity, weighted by flux density
  similarly: V_{fr} and ΔV_{fr}

Maser- vs- YSO luminosity



$L_{H_2O} \propto L_{FIR}^{0.81 \pm 0.07}$



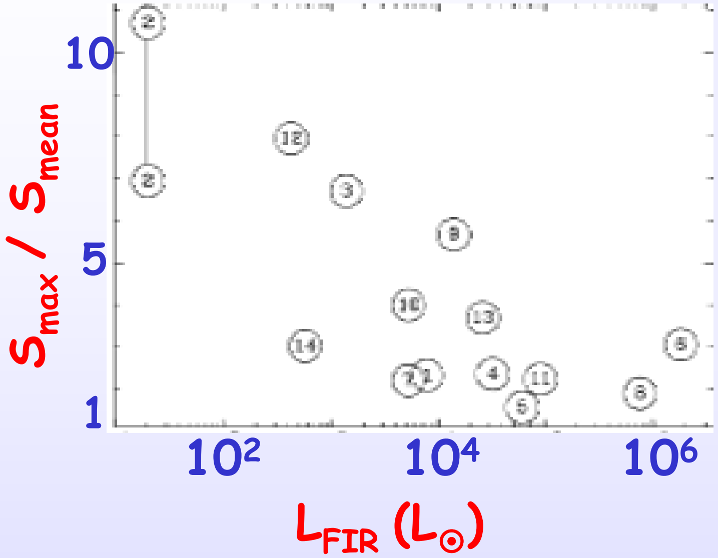
Wouterloot et al. 1995, A&A 301, 236

Maser velocity

$V_{up} \approx V_{fr}$ → most intense where most often

$V_{up} - V_{cl} = -0.4 \pm 3.5$ → max. emission for zero projected velo: maser emission max. when plane of shock along l.o.s.

Maser variability index



S_{max} / S_{mean}

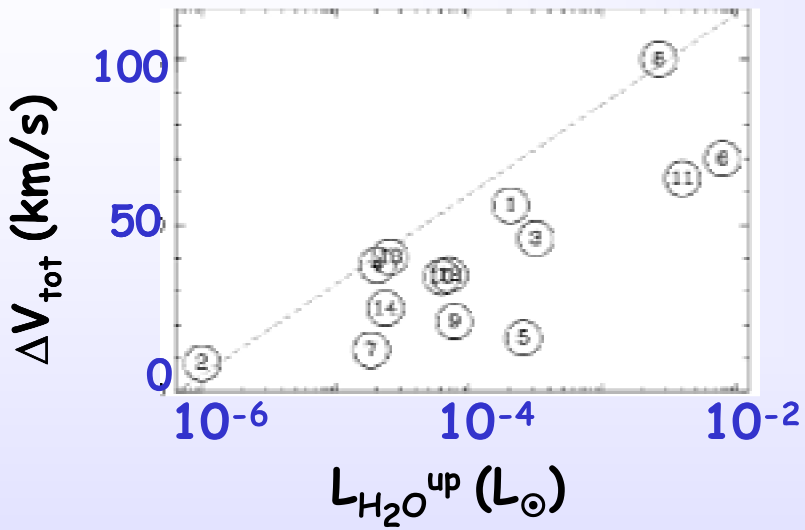
High-luminosity sources tend to be associated with more stable masers

Low-luminosity YSOs: fewer maser components excited; intrinsic time-variability dominates output.

High-luminosity YSOs: larger number of components simultaneously excited; effect of individual time-variability reduced.

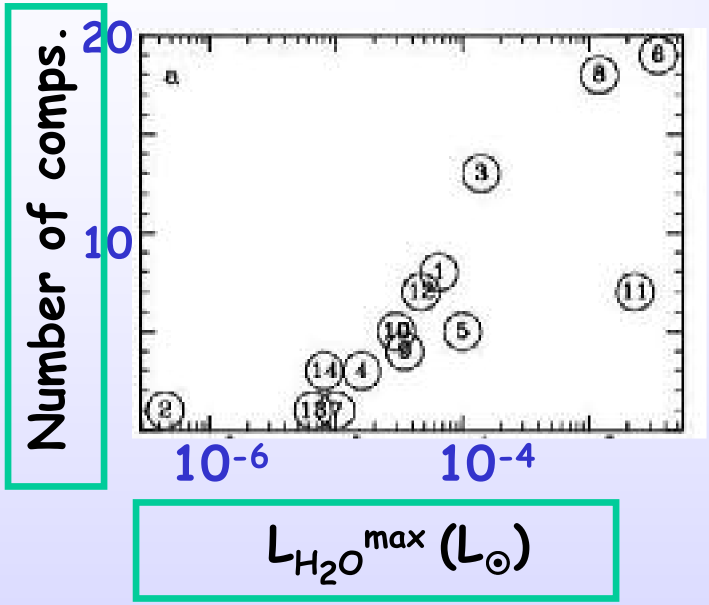
AND: lower L_{FIR} YSOs may work closer to threshold conditions, hence more unstable emission.

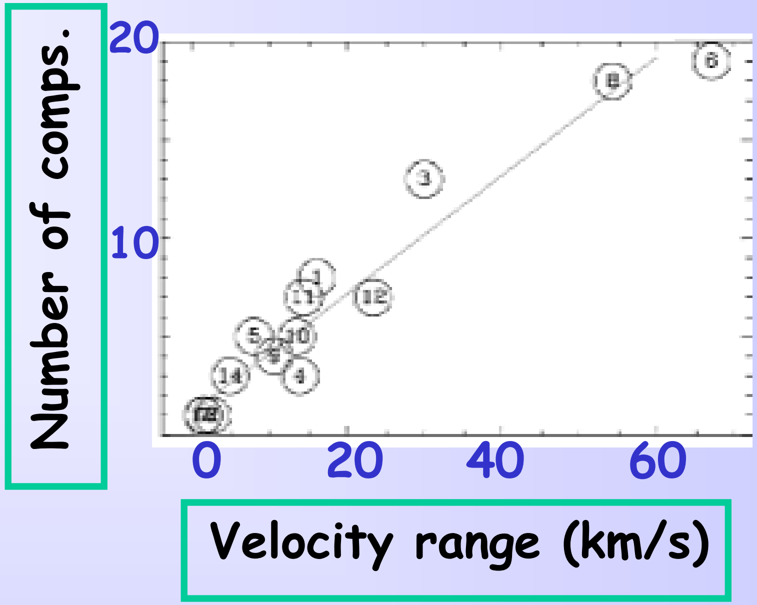
Maser velocity range



More luminous YSOs *can* excite maser emission over larger velocity range, but does not necessarily always do so.

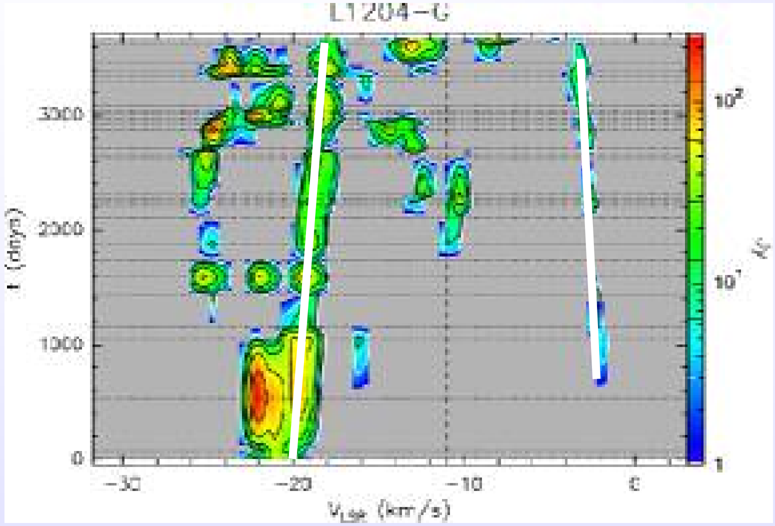
Distribution velocity components





Higher maser power goes into more emission channels, that are spread over a larger range in velocity.

Velocity drifts & bursts



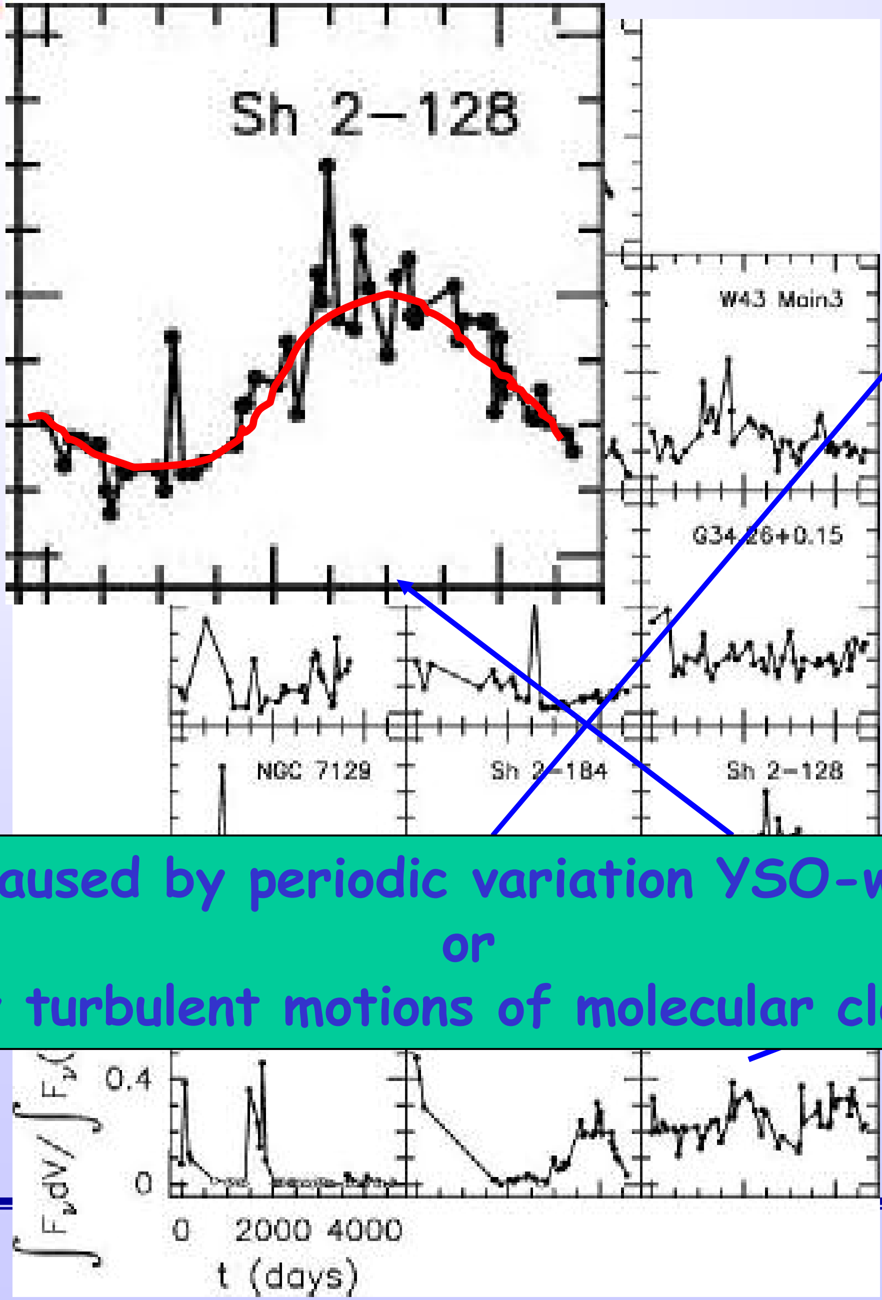
VLBI: 3 types of maser comps.

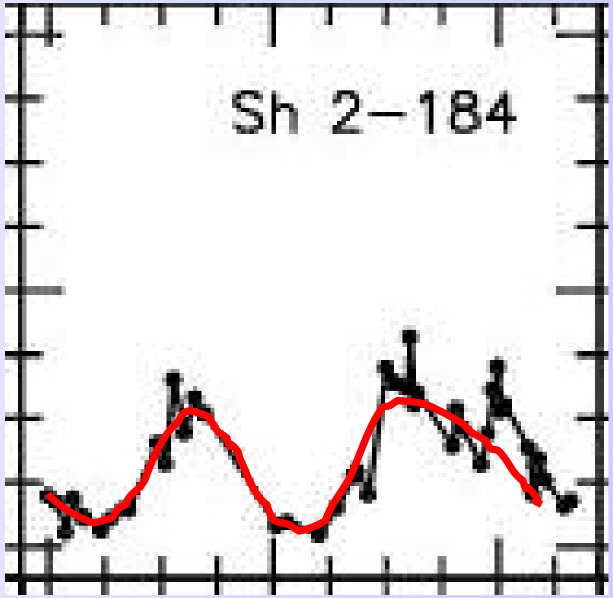
- In rotating disk around YSO
- In hi-velo collimated outflow perpendicular to disk
- At bow shocks produced by outflows

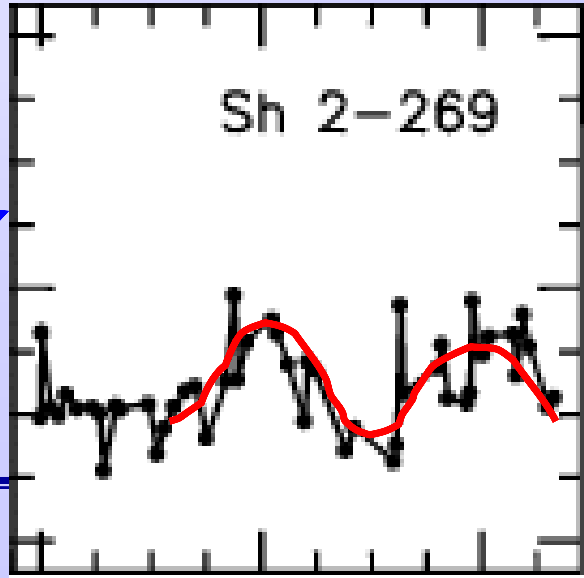
Analyzed 15 components for velo-drifts:
Gradients between 0.02 and 1.8 km/s/yr
9/15 negative, 6/15 positive

Analyzed 14 bursts in 9 components in 6 sources:
ΔF = 40 - >1840%; Δt = 63 – ~900 days
ΔF, Δt smaller at large velocities from V_{cloud}

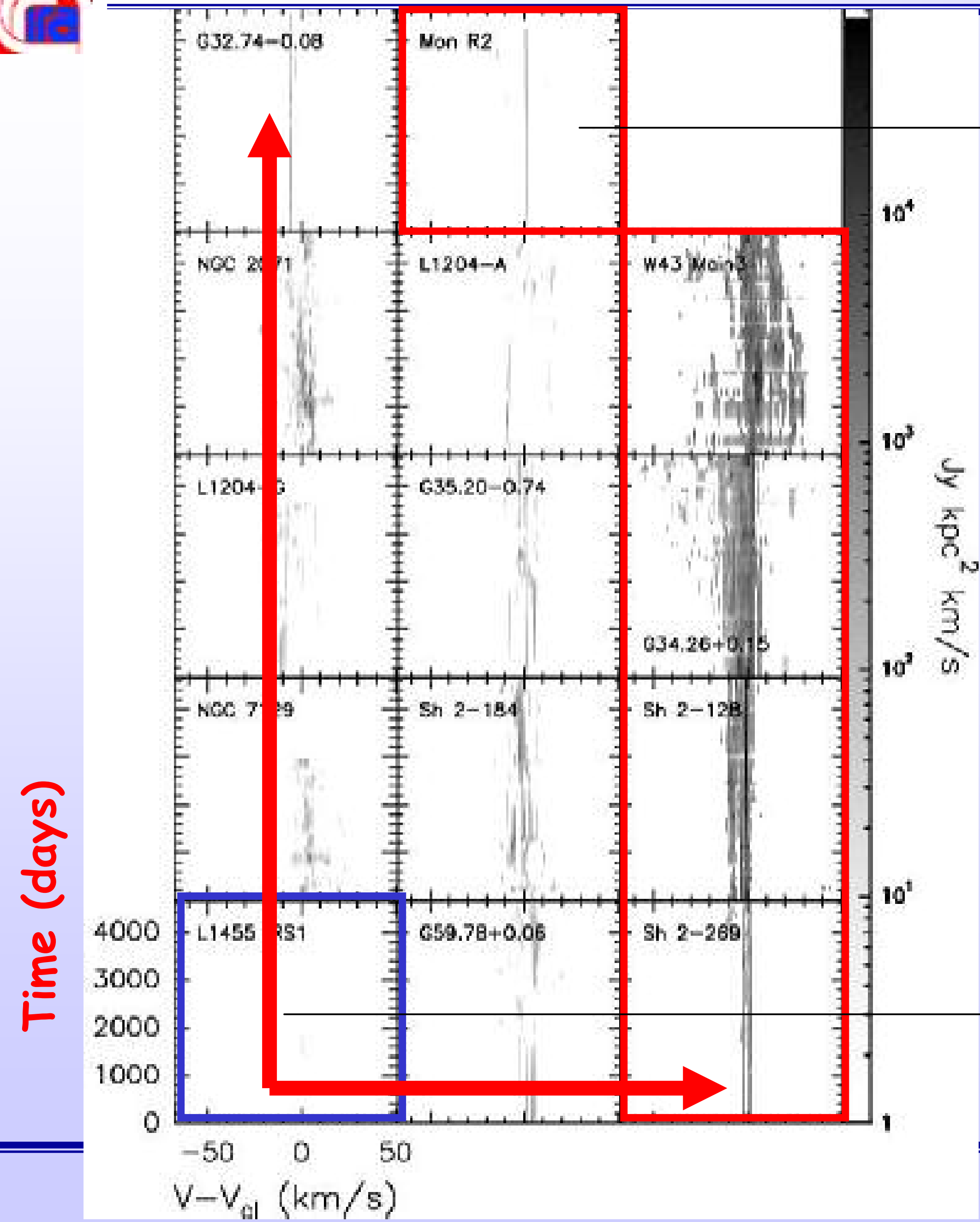
"Super variability"







Caused by periodic variation YSO-wind
or
by turbulent motions of molecular cloud?



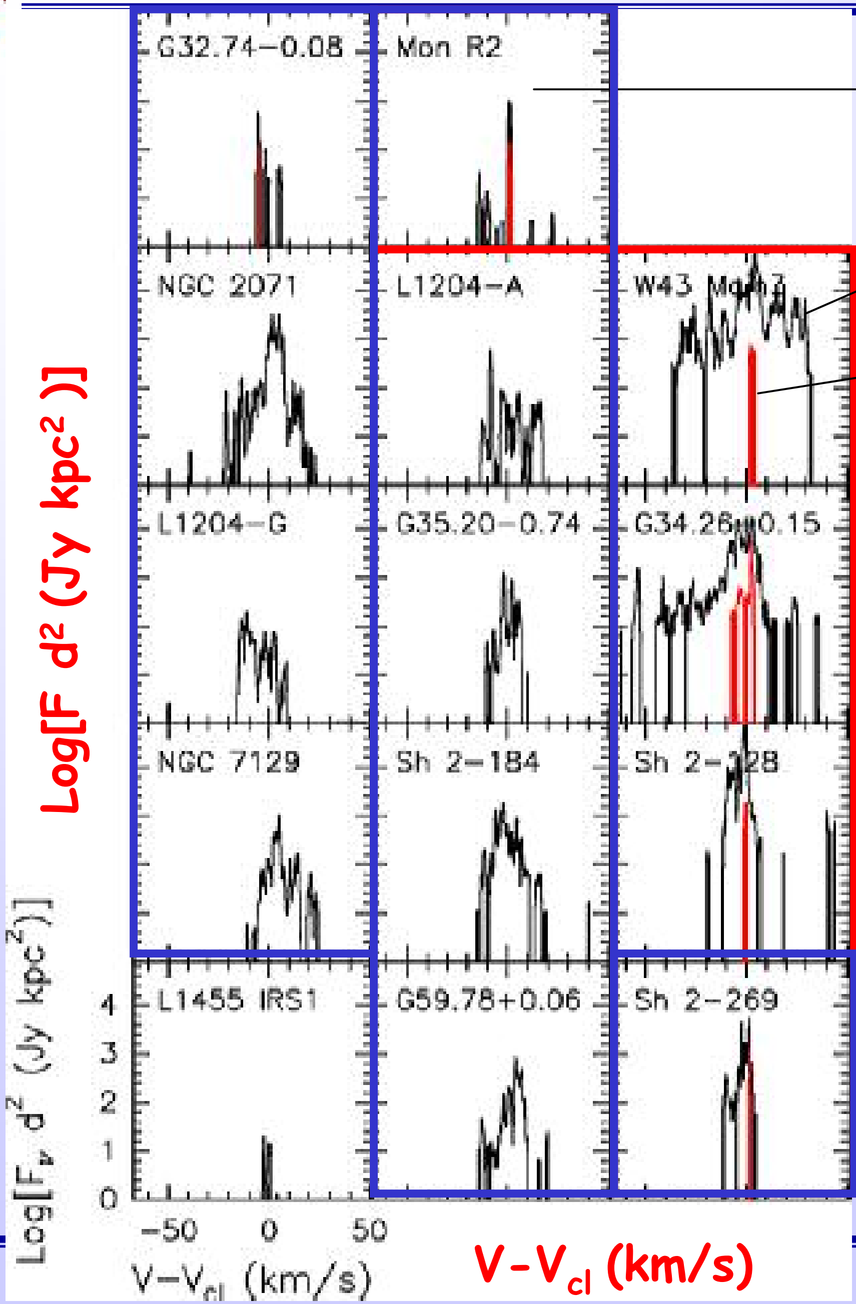
$3 \times 10^4\ L_\odot$

Complexity increases with L_{FIR} above $3 \times 10^4\ L_\odot$

Most of the time not visible Below L_{FIR} ~25 $L_\odot$

$20\ L_\odot$

Log[F d^2 (Jy kpc^2)]



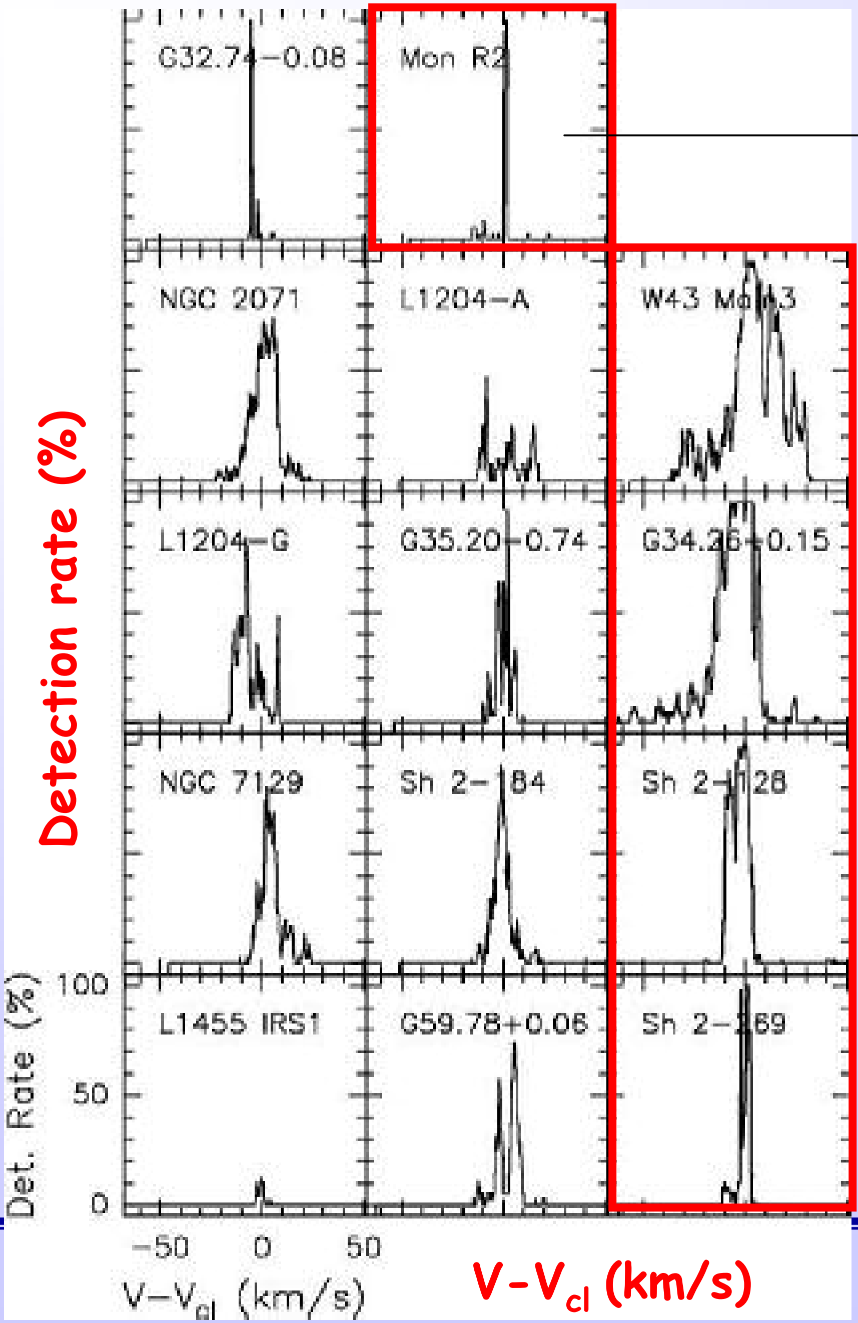
$3 \times 10^4\ L_\odot$

Upper envelope

Lower envelope

Only high-luminosity YSOs (L_{FIR} above $3 \times 10^4\ L_\odot$) are capable of maintaining certain level of emission at given velocity for extended periods of time.

Aspects of upper envelopes may reflect 3 different regimes of maser excitation



$L > 3 \times 10^4 L_\odot$:

Maser always detected

Velocity range increases with L_{FIR}.

Steep decline histograms:

the more blue- & red-shifted components have shorter lifetimes than components near cloud velocity

Tails in histograms:

Info on outflow orientation

CONCLUSIONS

- Mean velocity of maser emission close to V_{cloud}
- Maser emission is strongest where it also occurs most often
- $L_{H_2O}^{up} \propto L_{FIR}^{0.81 \pm 0.07}$
- High-luminosity sources associated with more stable masers
- Higher maser power goes into more emission channels, that are spread over a larger range in velocity
- Isolated component analysis shows occasional velocity-drifts; find both acceleration and deceleration (0.02 – 1.8 km/s/yr)
- Masers-bursts: 60 – 900 days duration. Flux density incease 40 - ≥1840%
- Several masers show “super-variability” on scales of 5-12 yrs

CONCLUSIONS, cont'd

- $L_{FIR} \approx 3 \times 10^4\ L_\odot$ defines a threshold:

  $L_{FIR} \geq 3 \times 10^4\ L_\odot$ at least one maser comp. always present at 1-20% level; $V \approx$ upper envelope peak, $\approx V_{cloud}$
  Below $\leq 430\ L_\odot$ maser not detectable most of time

- There are 3 regimes of maser excitation, function of L_{FIR} :

  $L_{FIR} < 4 \times 10^2\ L_\odot$ and $4 \times 10^2\ L_\odot \leq L_{FIR} \leq 6 \times 10^4\ L_\odot$
  maser excitation depends mostly on strength outflow and density surrounding molecular cloud

  $L_{FIR} \geq 6 \times 10^4\ L_\odot$ YSO-luminosity is determining factor

- Maser emission is function not only of YSO-luminosity but also of beaming properties outflow w.r.t. observer

Read about it in Valdettaro et al., 2002, A&A 383, 244
Brand et al., 2003, A&A 573, 587