Outflow chemistry

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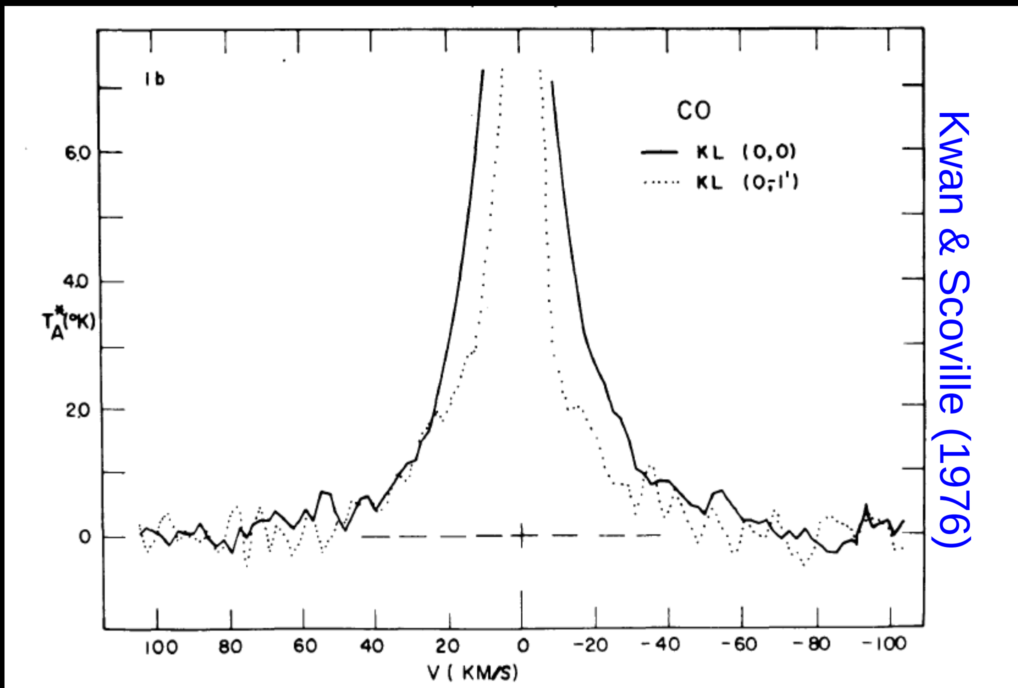
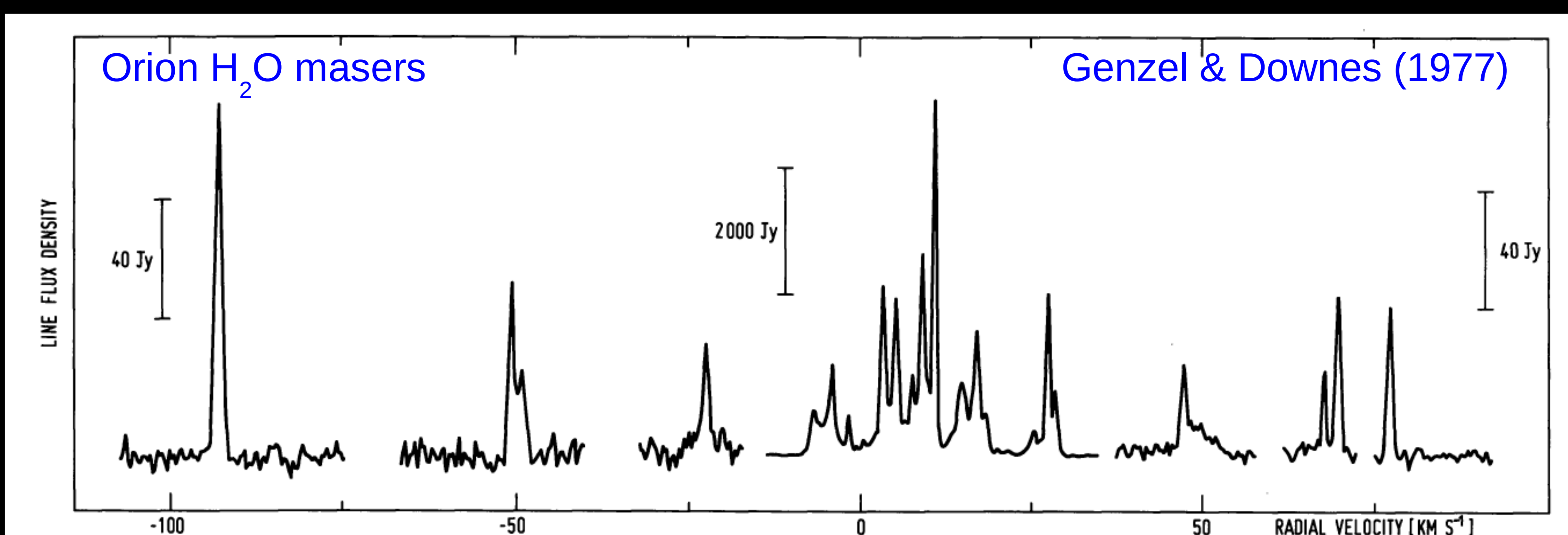
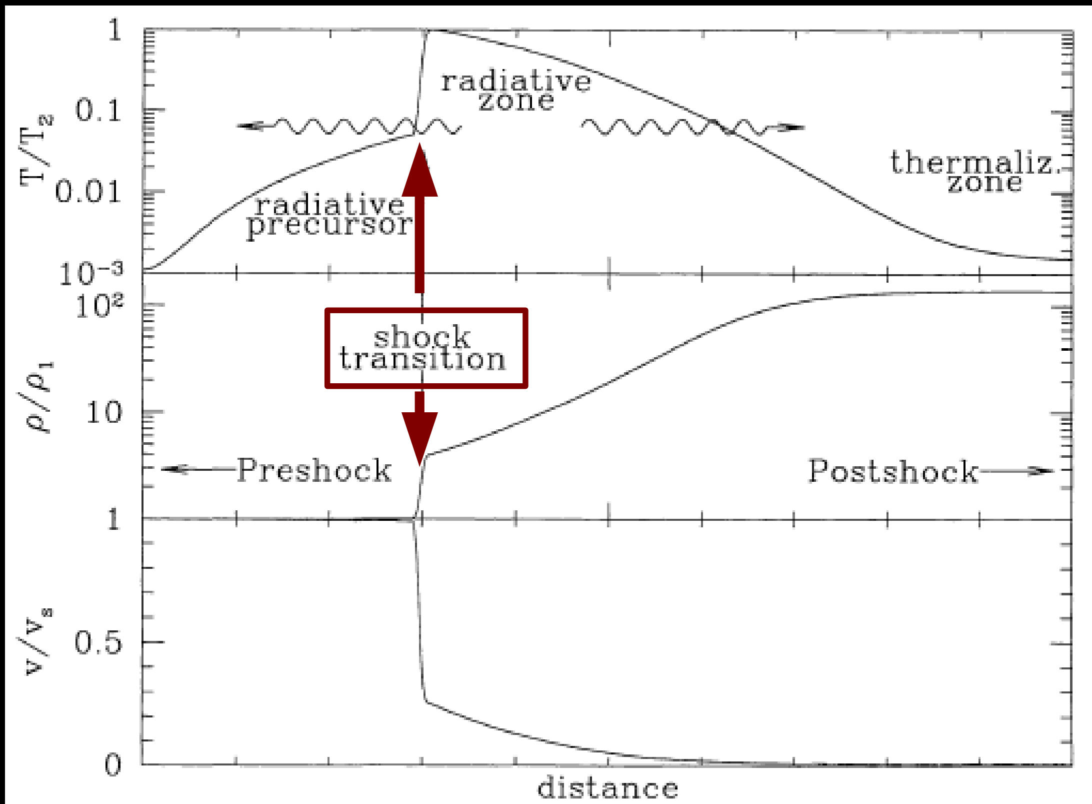
“Know your tracers”

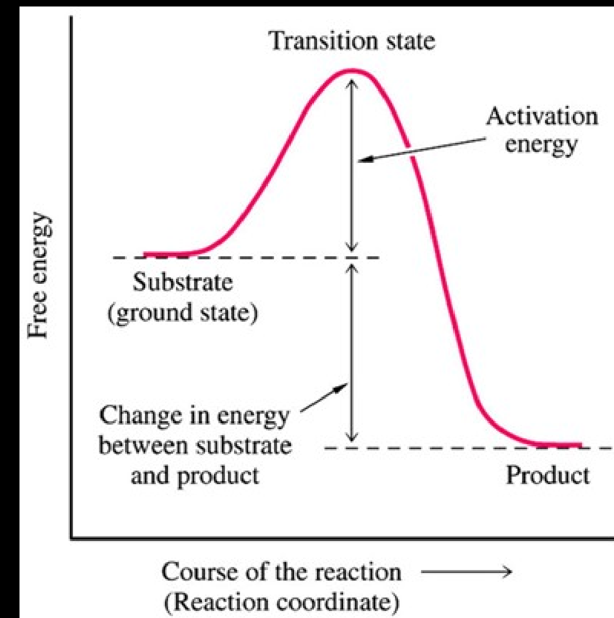


- Youngest outflows: molecules
- CO wings up to 40 km/s
- H_2O masers up to 100 km/s
- sound speed @ 10 K is 0.2 km/s
- M_A = 200 - 500
- How did molecules get to those velocities ?



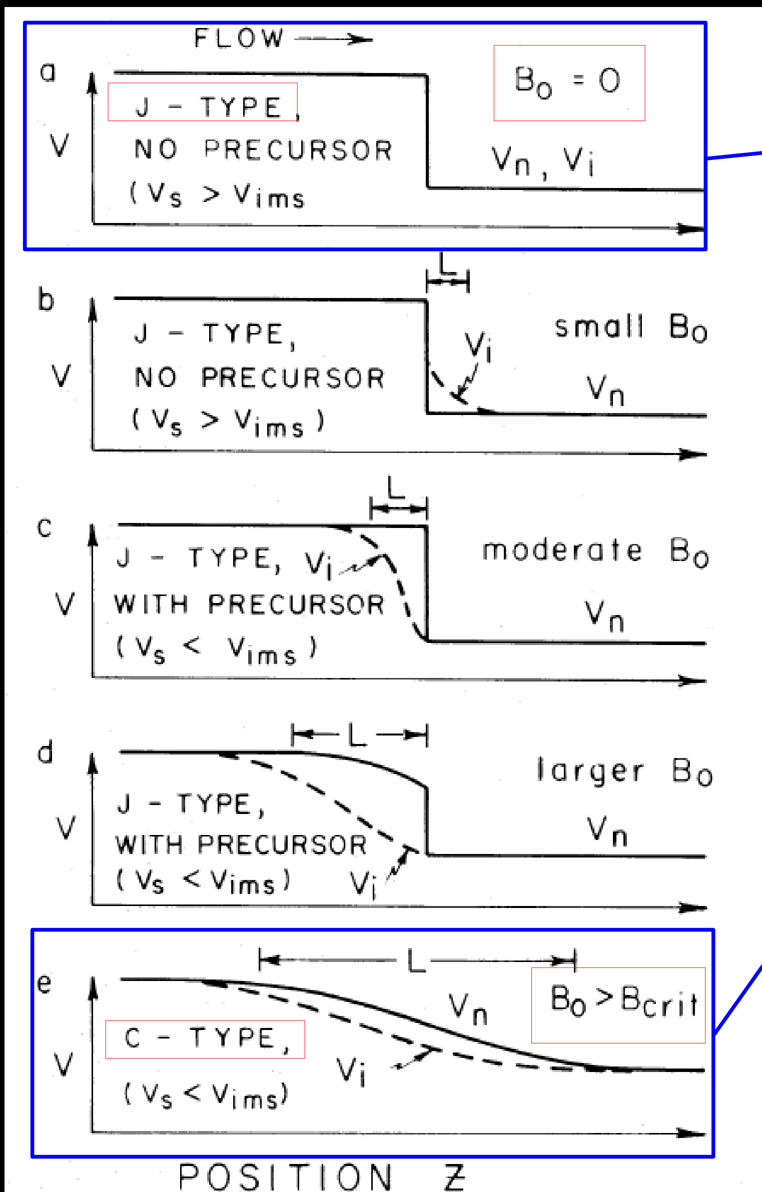
Outflow chemistry is shock chemistry



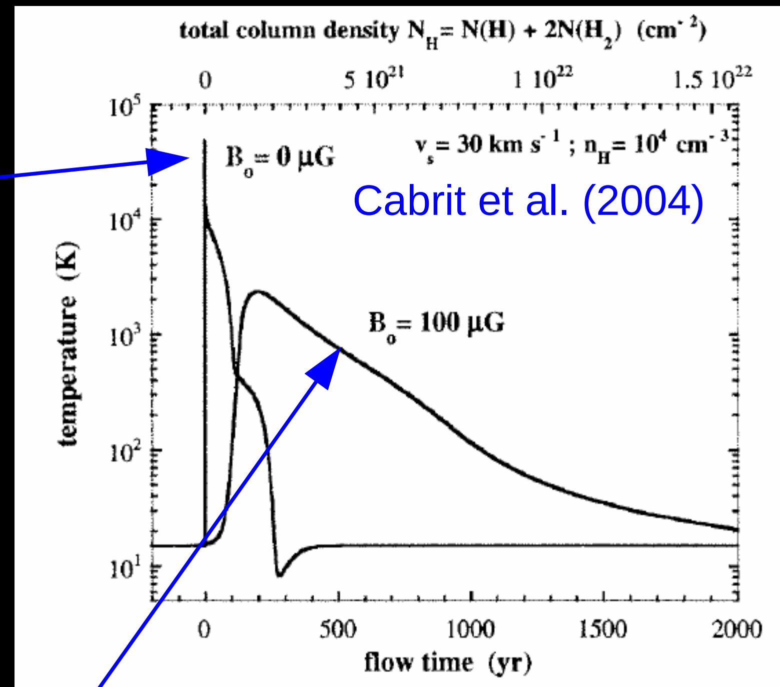


- Sudden acceleration and temperature increase in gas
  - open new reaction channels by overcaming activation energies (esp. neutral-neutral). Complex chemistry
- Dust grain disruption (via grain-grain coll. & sputtering)
  - release of molecules from ice mantles

Shock types: J(ump) and C(ontinuous)



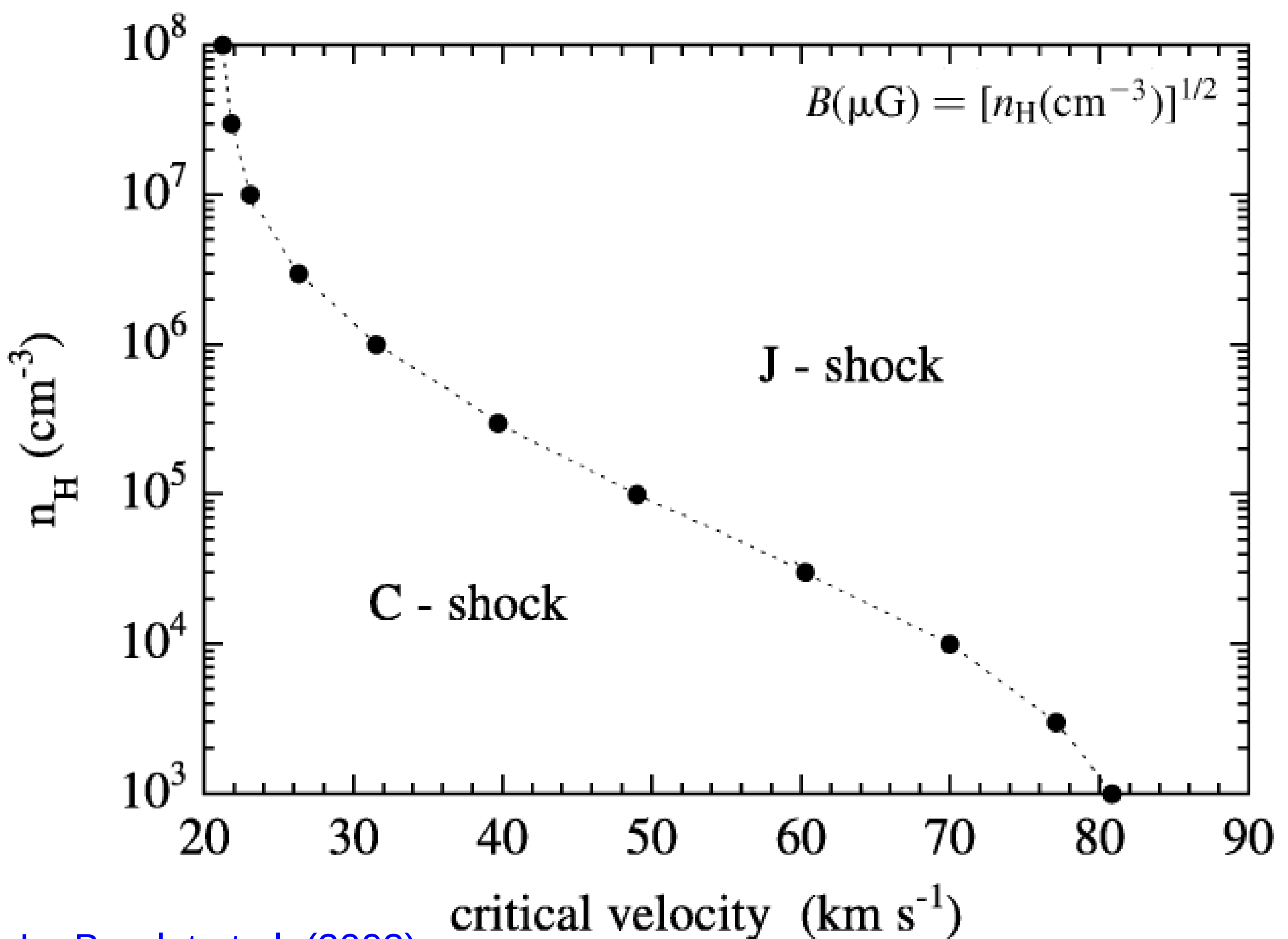
Draine (1980)



Cabrit et al. (2004)

- J-type: sharp increase, high T, narrow post-shock. Molecule destruction
- C-type: gradual increase, lower T, broad post-shock. Molecule survival

J-shock / C-shock transition



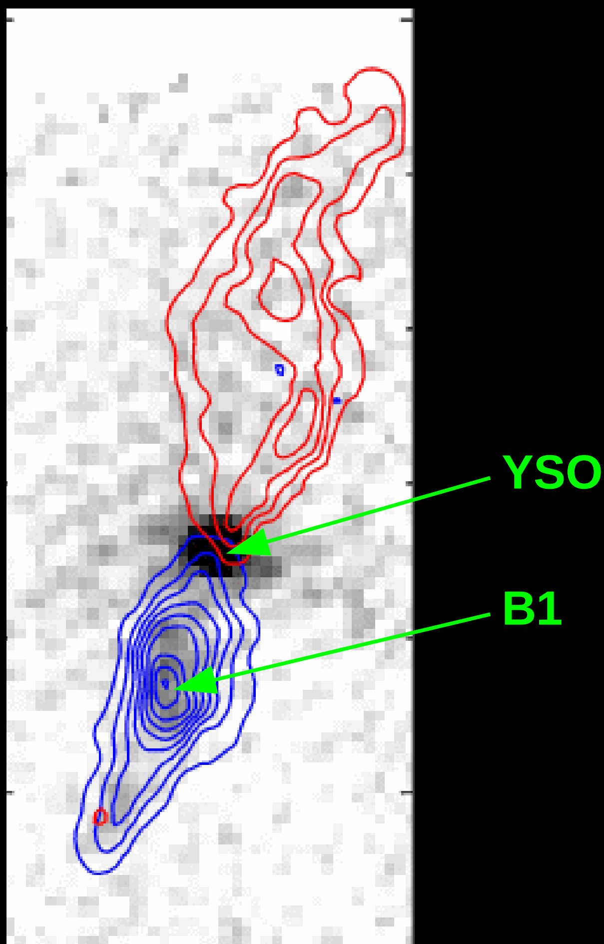
Le Bourlot et al. (2002)

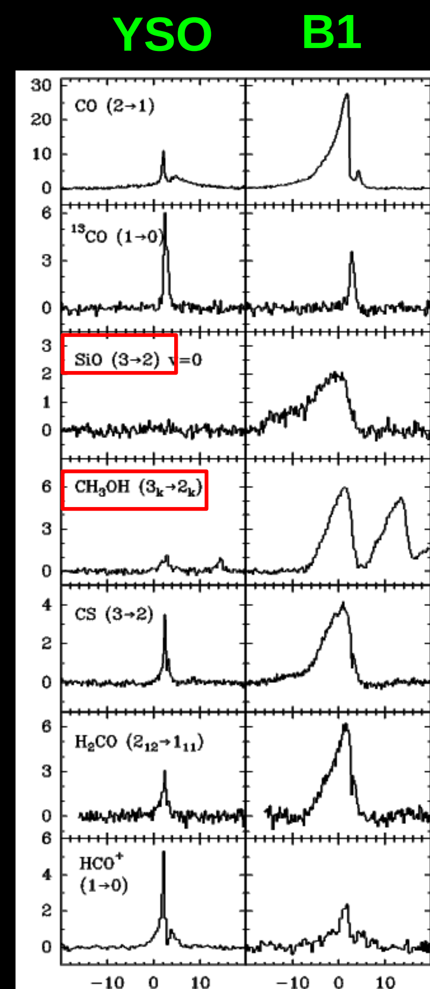
- **C-J transition depends on collisional dissociation of H_2**
- **Shock physics and chemistry are coupled**
- **Molecule survival to high speeds**

“Chemically active” outflows

- Most outflows: emission dominated by CO
  - Supersonic but T = 10-20 K (radiative post-shock)
  - No (detectable) emission from “exotic” species
- Small group of outflows
  - Strong lines of SiO, CH_3OH, etc. (at some spots)
  - “Chemically active”
  - Class 0 driving engine
- Chemical memory is short (-er than kinematic) [or most acceleration is chemically inactive]

Chemically active L1157 outflow

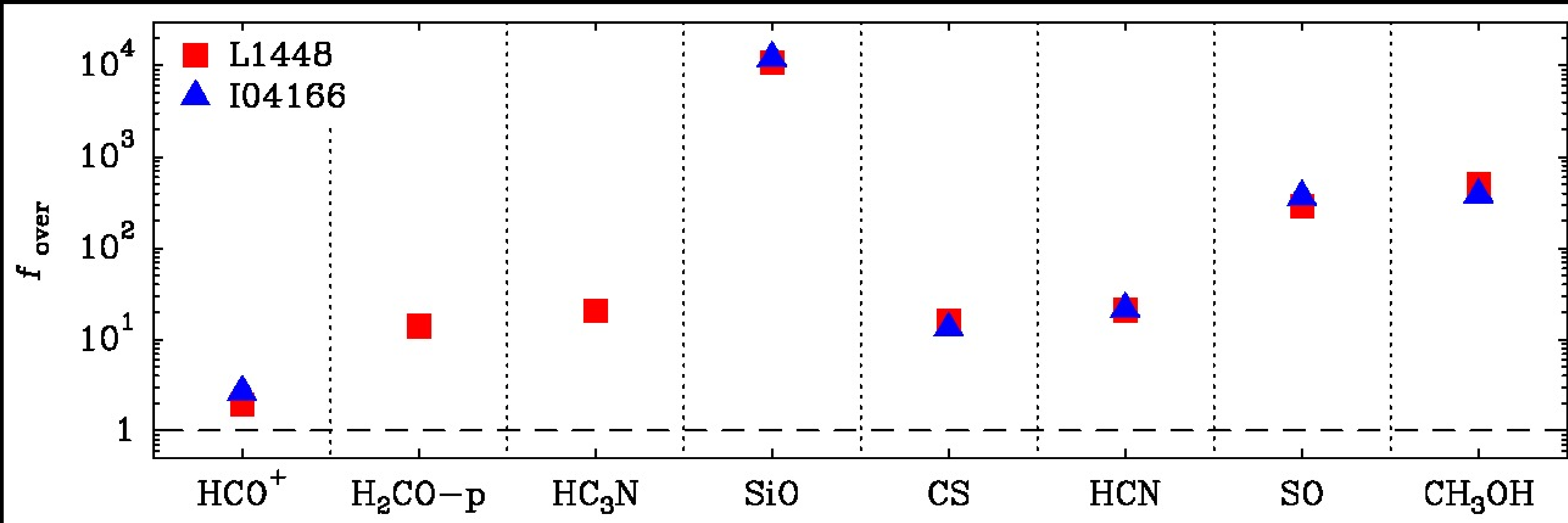




Bachiller & Perez-Gutierrez (1997)

- Powered by Class 0 source IRAS 20386+6751
  - L = 11 Lo
- Several "chemical spots"
  - B1, B2, R
- Prototype of chemical studies
  - target for searches
- Line surveys on-going (Nobeyama, IRAM 30m, Herschel)

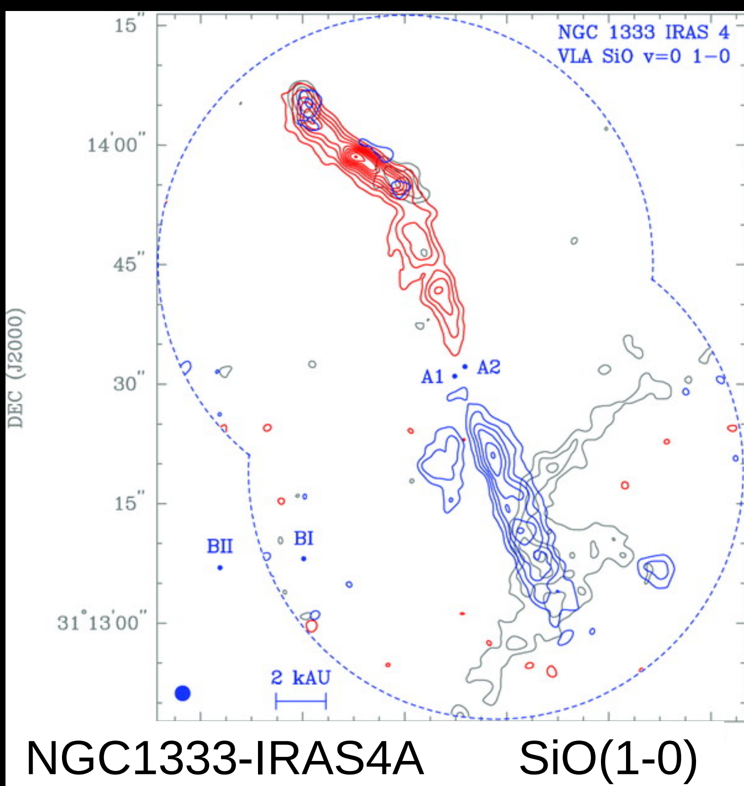
Large abundance enhancements



Tafalla et al. (2010)

- L1448 & IRAS 04166: Class 0
- Most molecules are enhanced
- CH_3OH & SO: ~ 300
- SiO > 10^4

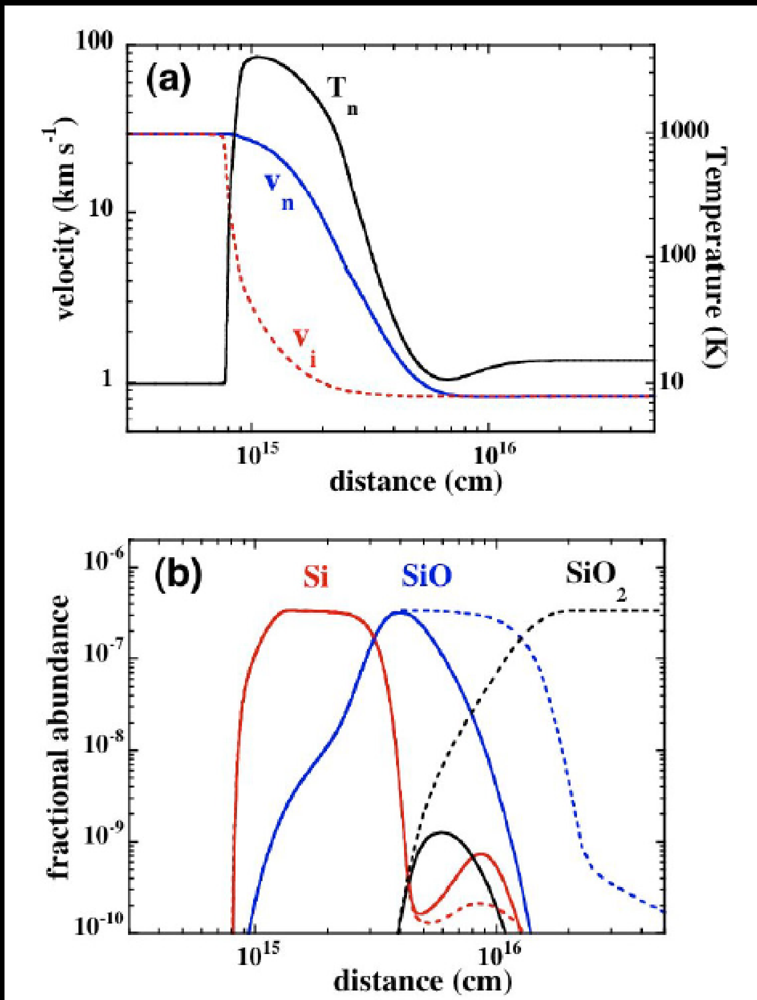
SiO



Choi et al. (2005)

- **Most selective shock tracer**
  - **mm-wavelength lines (obs. ground)**
  - **$X(SiO)_{amb}$ < 5 10^{-12} (Ziurys et al. 1989)**
  - **observed enhancements > 10^4**
- **Detection guarantees abundance enhancement**

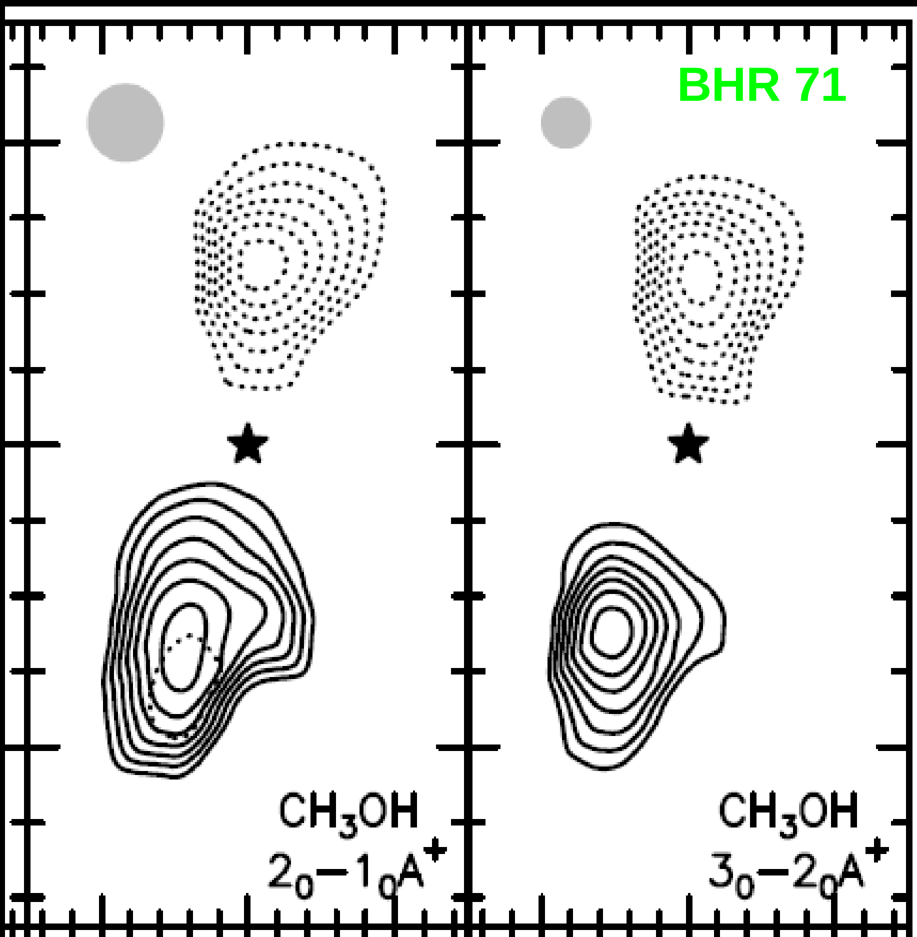
SiO



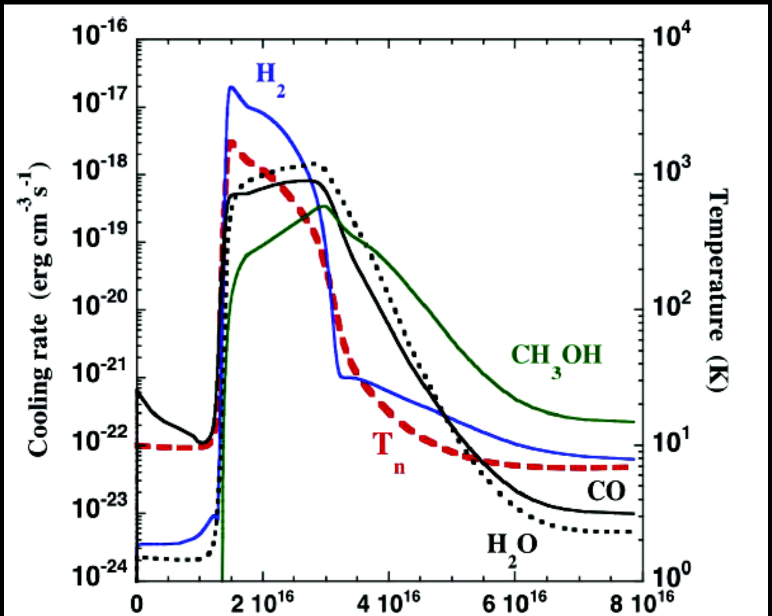
Gusdorf et al. (2008)

- Si released from core grains
- C-shocks
  - sputtering of (charged) grains by heavy neutral particles (Schilke et al. 1997, Gusdorf et al. 2008a)
  - grain-grain collisions (Caselli et al. 1997)
- J-shocks
  - dust vaporization (Guillet et al. 2009)
- SiO released from mantles (Gusdorf et al. 2008b)
- Overall
  - models explain abundances
  - problems with line shapes (later)

CH_3OH



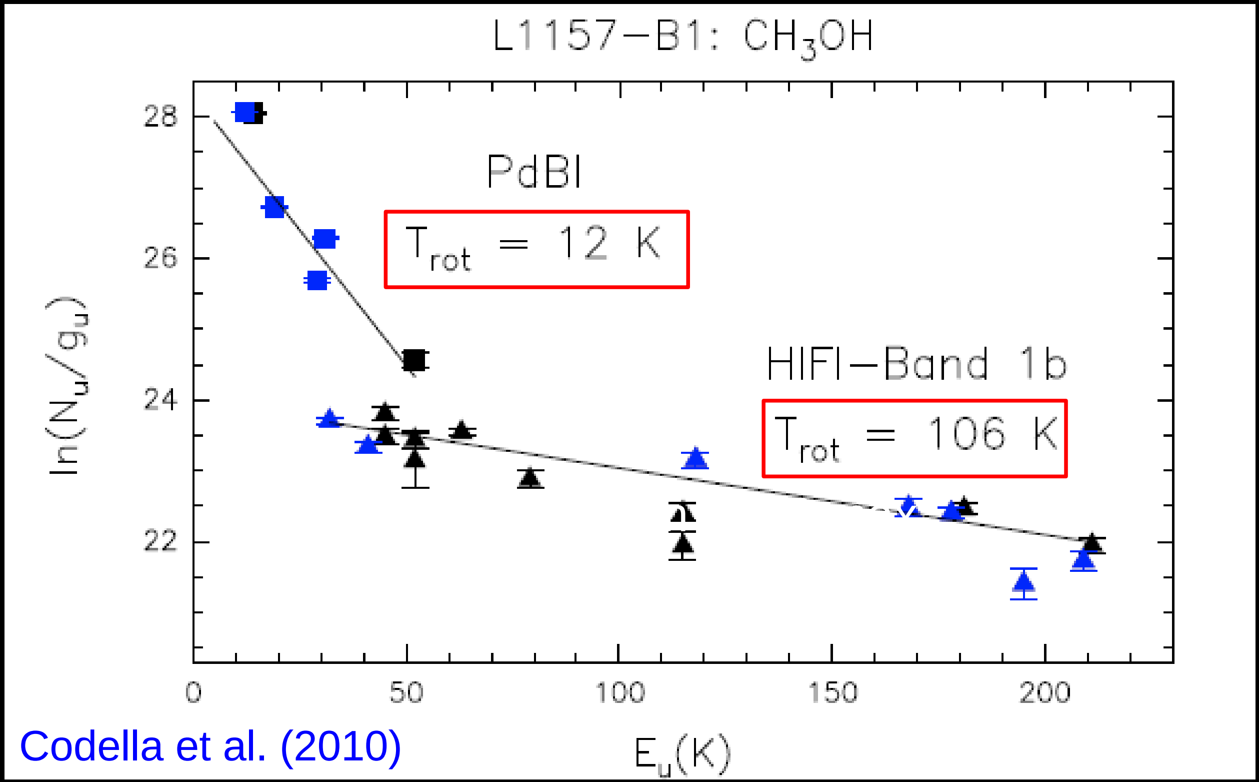
Garay et al. (1998)



Flower et al. (2010)

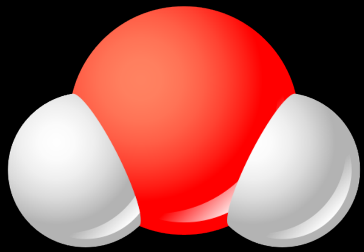
- Released **directly** from grain mantles
  - main ice component
- Threshold v_s = 15 km/s (Flower et al. 2010)

Warm CH_3OH



- **Cold (T$_{rot}$ = 12 K) component known from ground observations**
- **Warm (T$_{rot}$ = 106 K) component identified with Herschel**

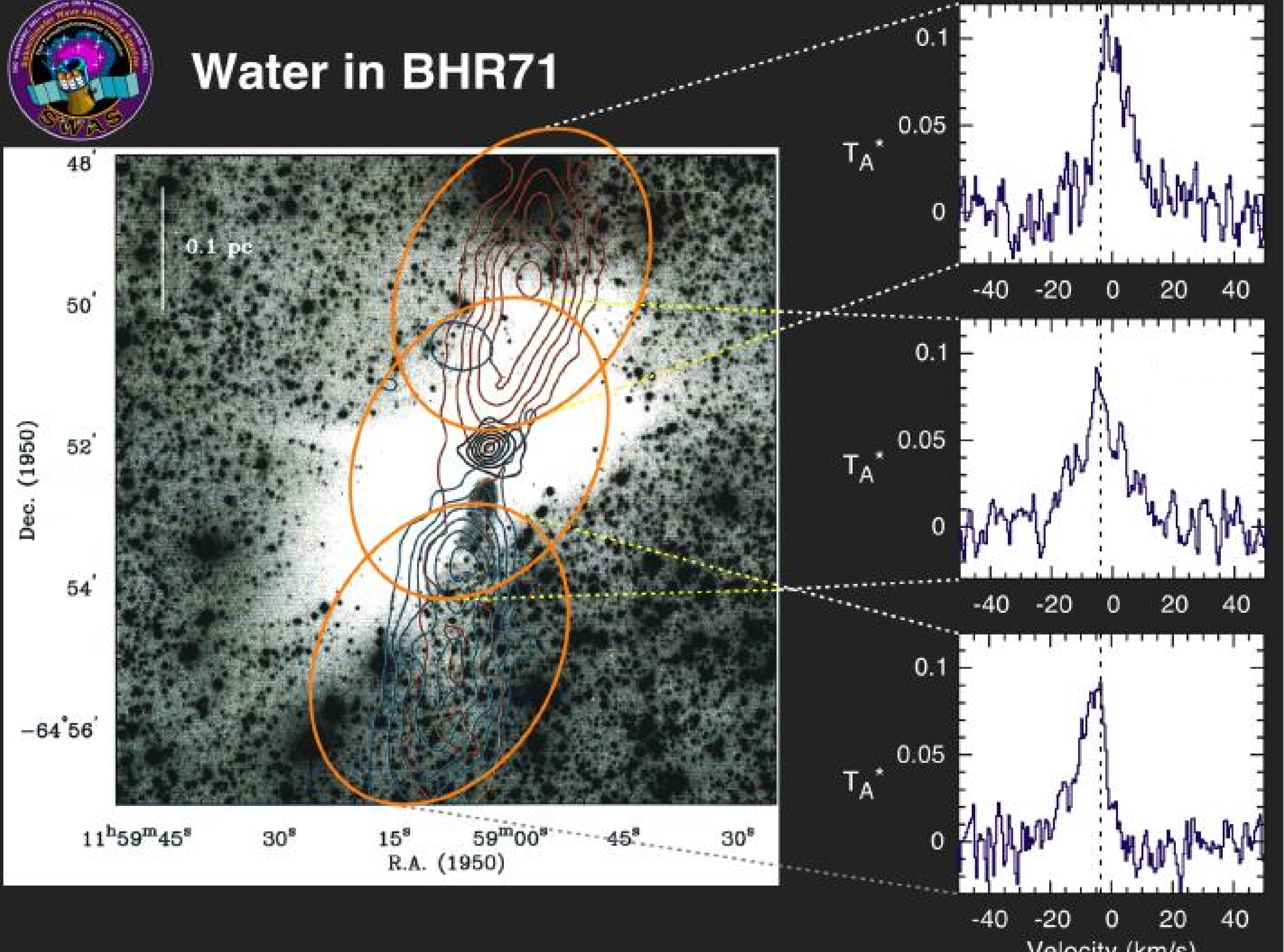
H_2O



- Sensitive outflow tracer
- Low ambient abundance (< 7 10^{-8}, Snell et al. 2000)
- Strong shock enhancement
  - evaporation from mantles (main ice)
  - gas-phase production (all O to H_2O for few 100 K)

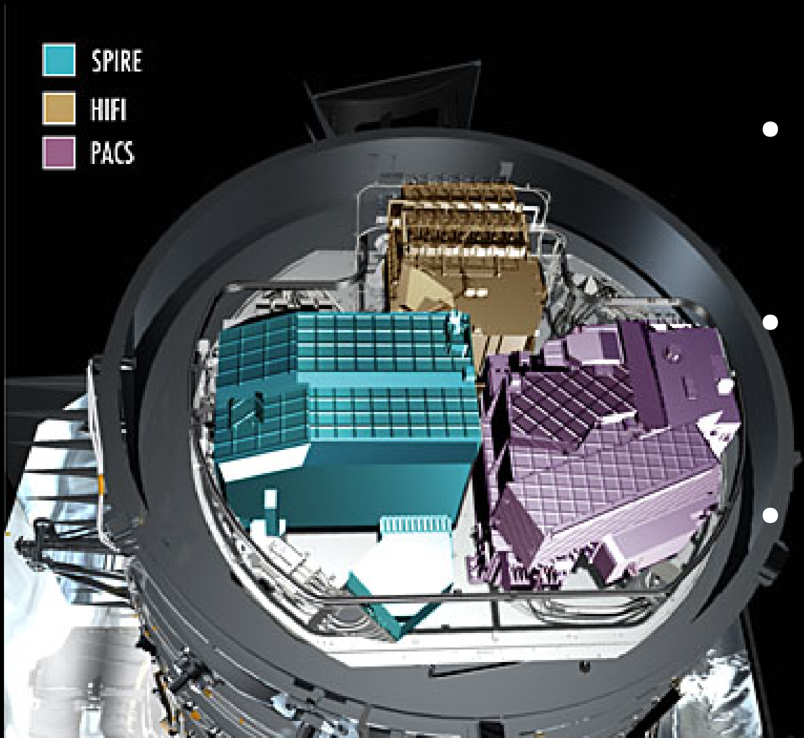
- Well known maser emission (Cheung et al. 1969)
- Thermal emission: ISO, SWAS, Odin

Water in BHR71

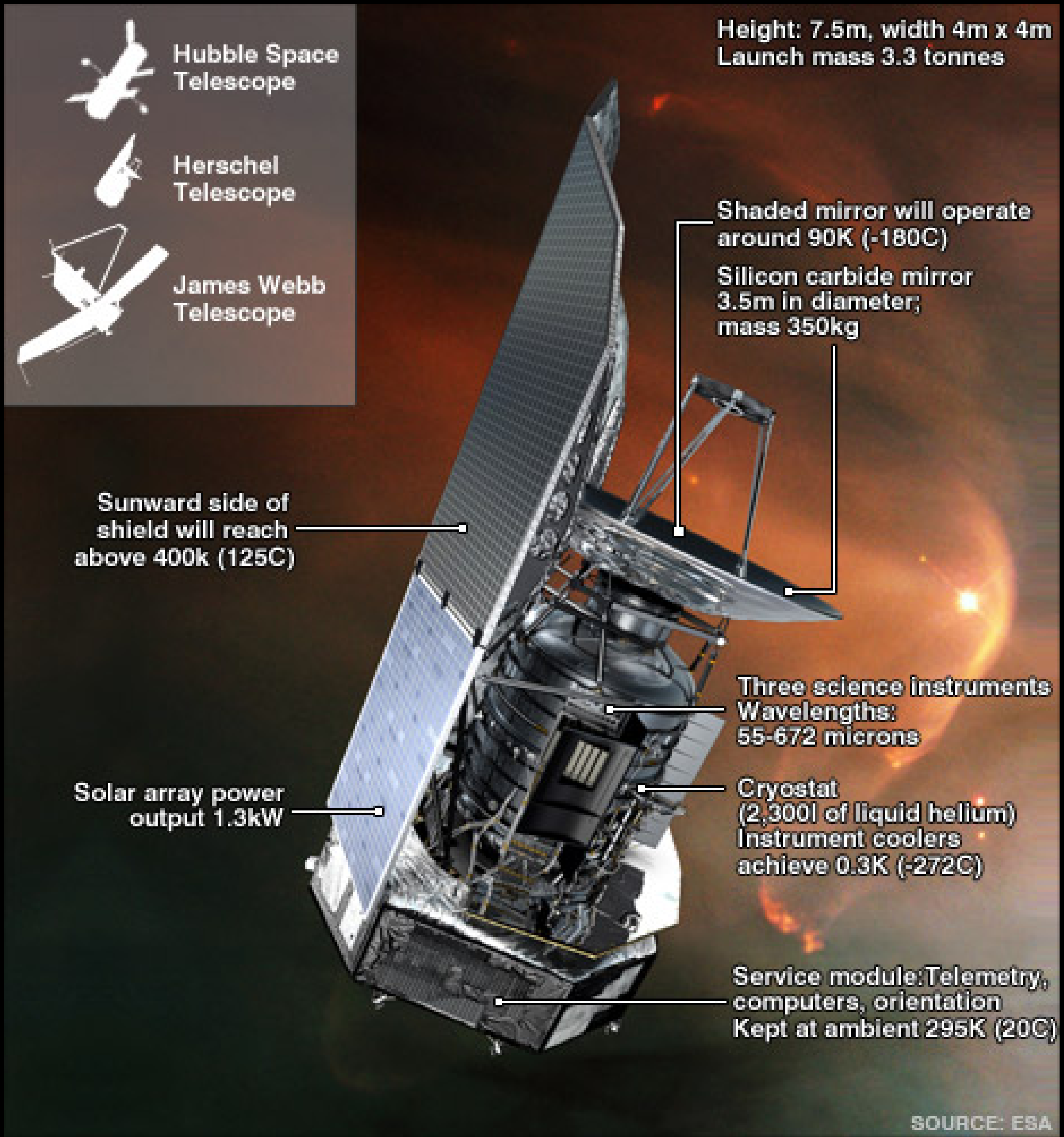


H_2O & Herschel Space Observatory

- **PACS**
  - **60-200 mu / R=1500**
- **SPIRE**
  - **200-670 mu / R=1000**
- **HIFI**
  - **150-600 mu / R=10^7**

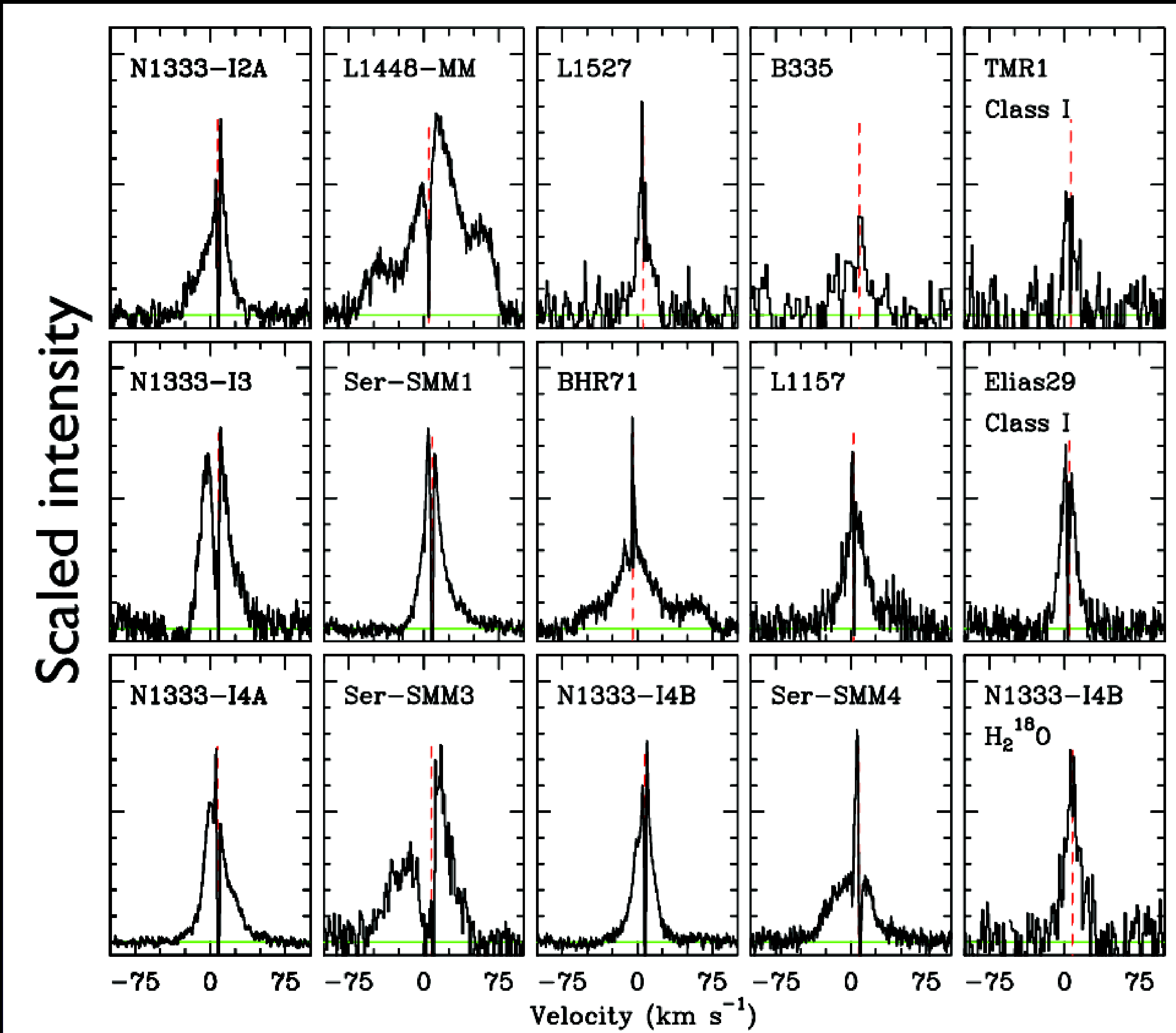


- **CHESS**
  - **Chemical HErschel Surveys of SF regions**
- **HEXOS**
  - **Herschel/HIFI Obs. of EXtraOrdinary Sources**
- **WISH**
  - **Water in Star forming regions with Herschel**

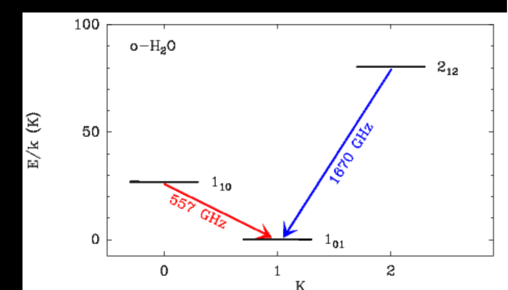


Hubble Space Telescope
Herschel Telescope
James Webb Telescope
Height: 7.5m, width 4m x 4m
Launch mass 3.3 tonnes
Shaded mirror will operate around 90K (-180C)
Silicon carbide mirror 3.5m in diameter; mass 350kg
Sunward side of shield will reach above 400k (125C)
Three science instruments Wavelengths: 55-672 microns
Solar array power output 1.3kW
Cryostat (2,300l of liquid helium) Instrument coolers achieve 0.3K (-272C)
Service module:Telemetry, computers, orientation Kept at ambient 295K (20C)
SOURCE: ESA

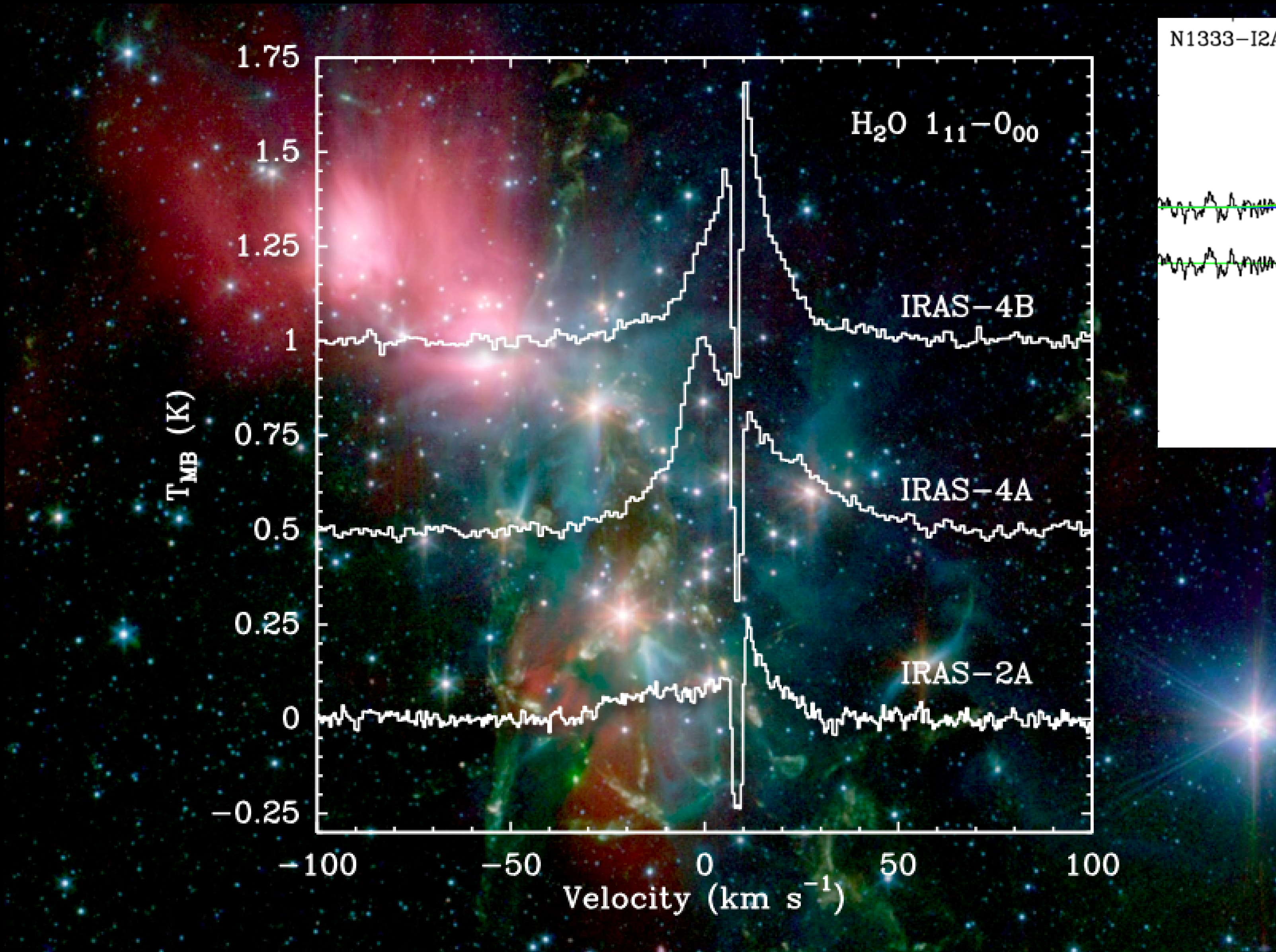
$H_2O(1_{10}-1_{01})$ survey of low-mass YSOs

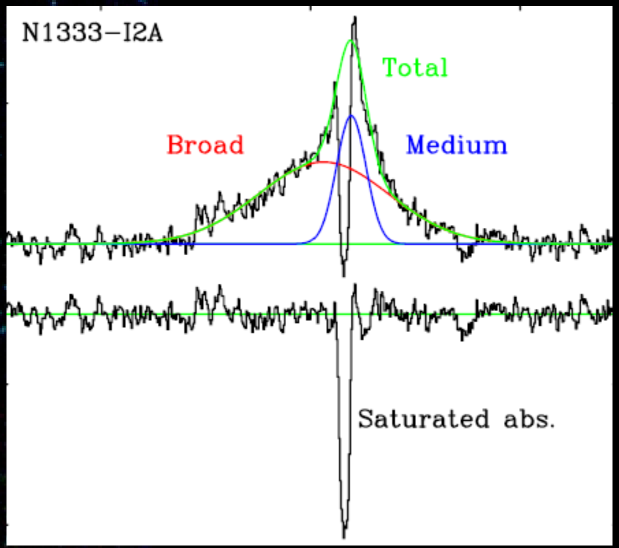


Kristensen et al. (2012)

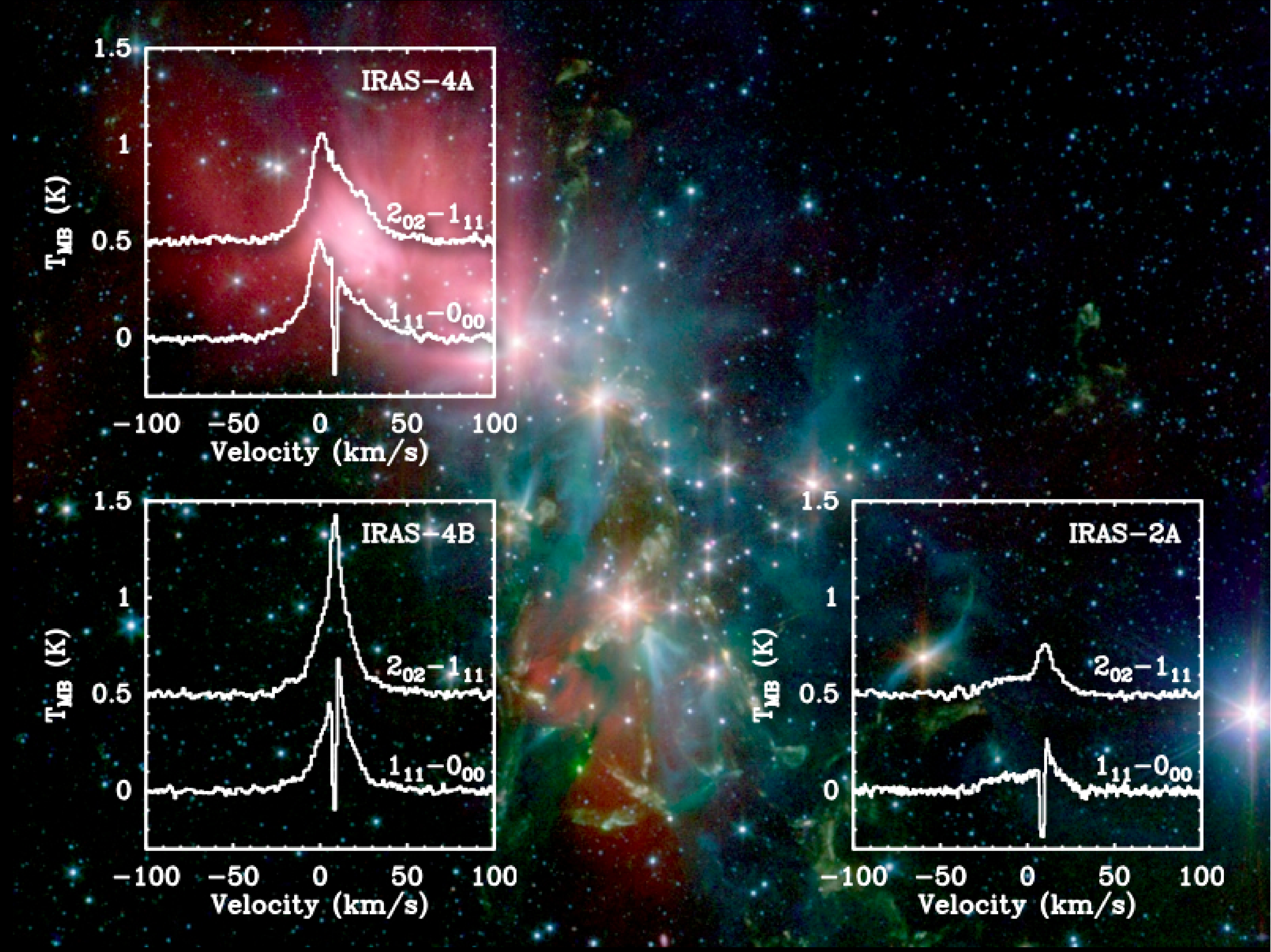


Multiple outflow components?



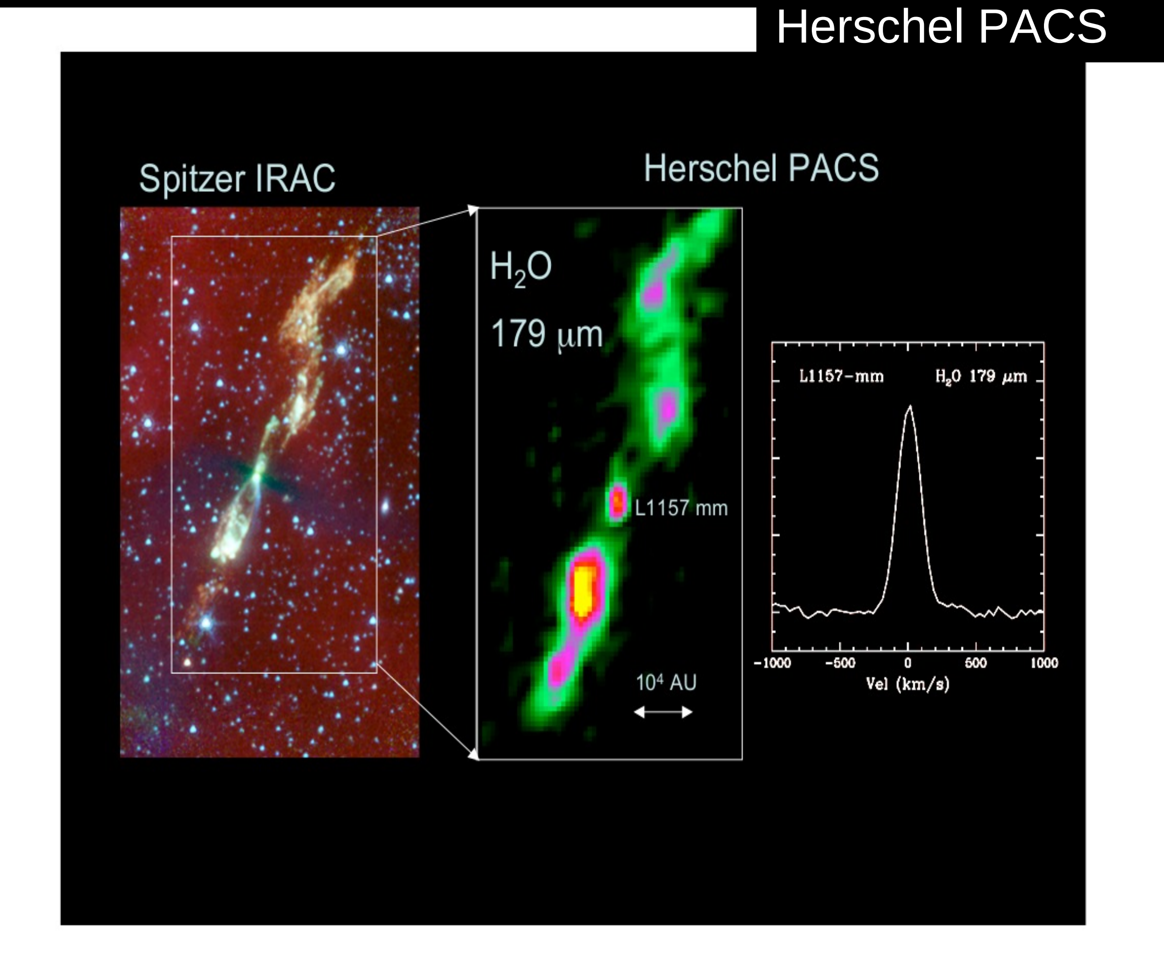


Kristensen et al. (2010)

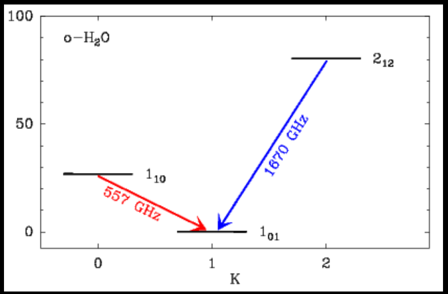


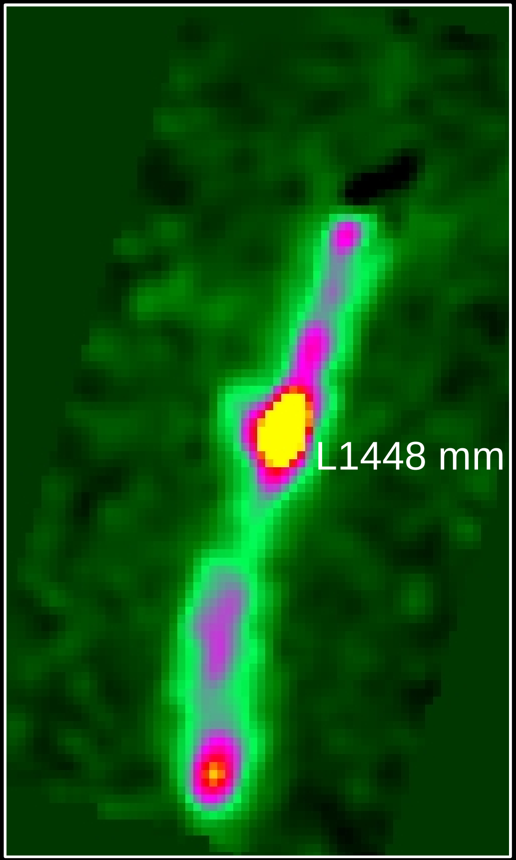
IRAS-4A
IRAS-4B
IRAS-2A
$2_{02}-1_{11}$
$1_{11}-0_{00}$
T_{MB} (K)
Velocity (km/s)
1.5
1
0.5
0
−100
−50
0
50
100

$H_2O(2_{12}-1_{01})$ maps of L1157 & L1448



Nisini et al. (2010)

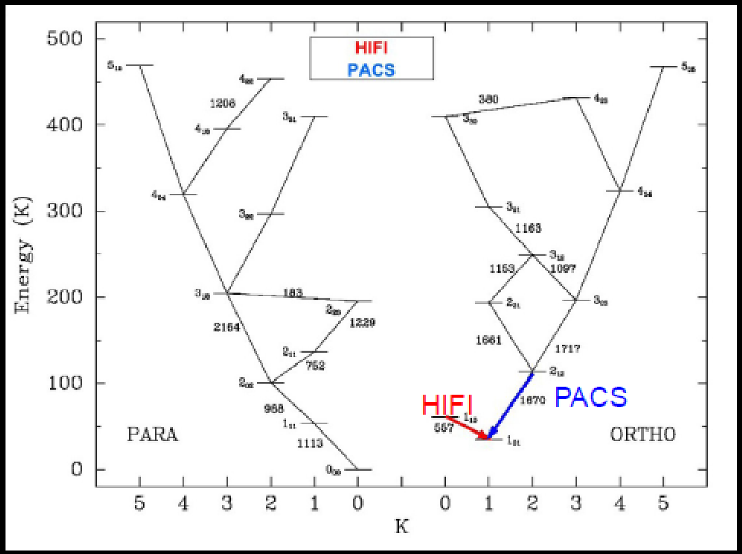


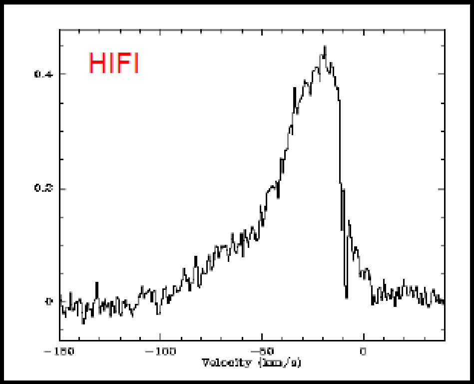


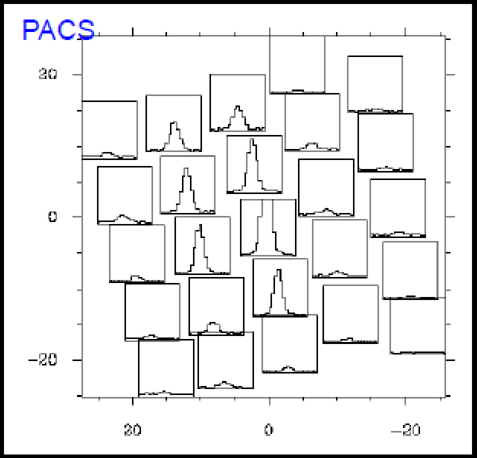
Nisini et al. (2012)

H_2O survey of outflows

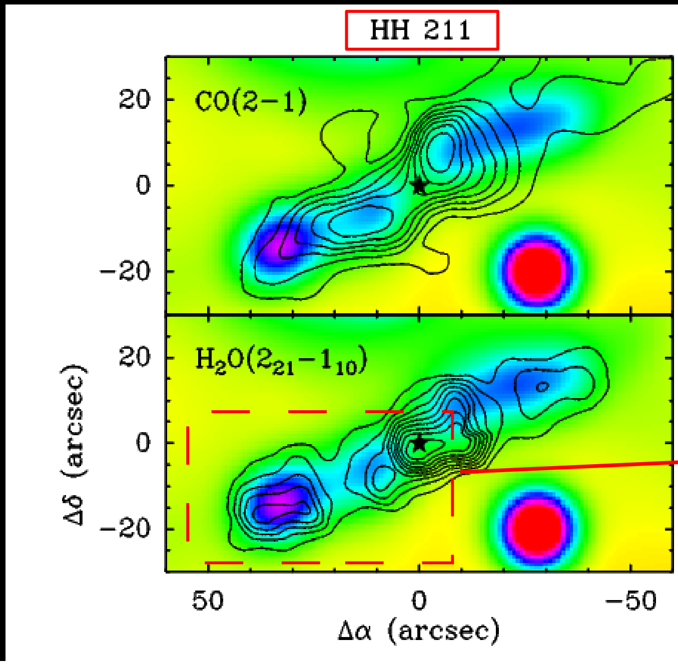
- Goal: sample a large number of outflows
- Sample of 25 objects
- ~ 2 positions each
- 2 ortho-H_2O lines
  - 557 GHz (HIFI)
  - 1670 GHz (PACS)

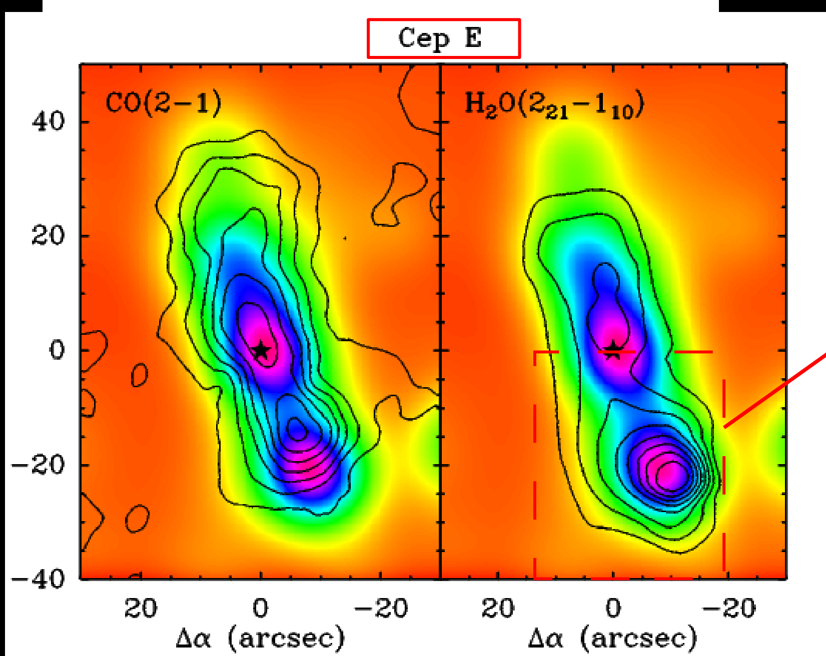


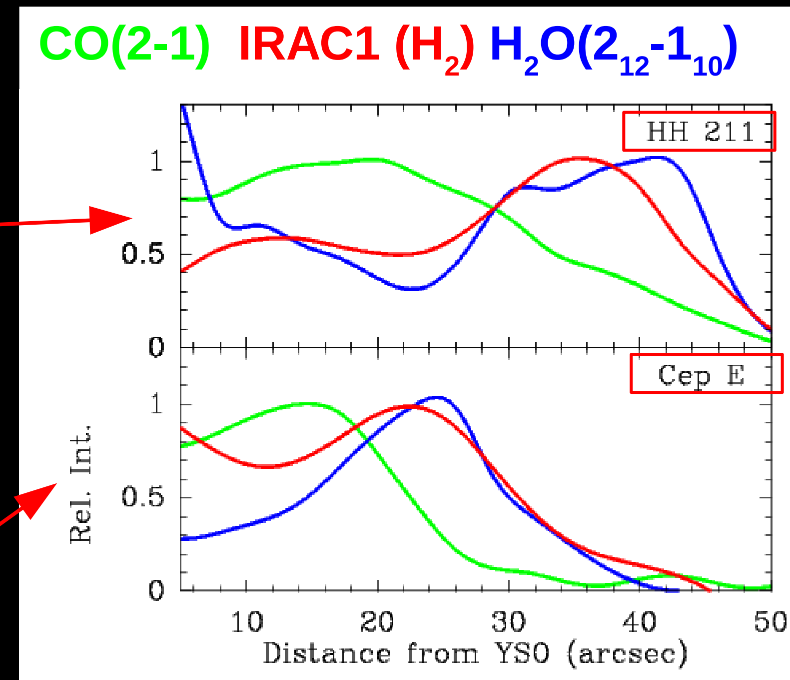




What gas is traced with H_2O?

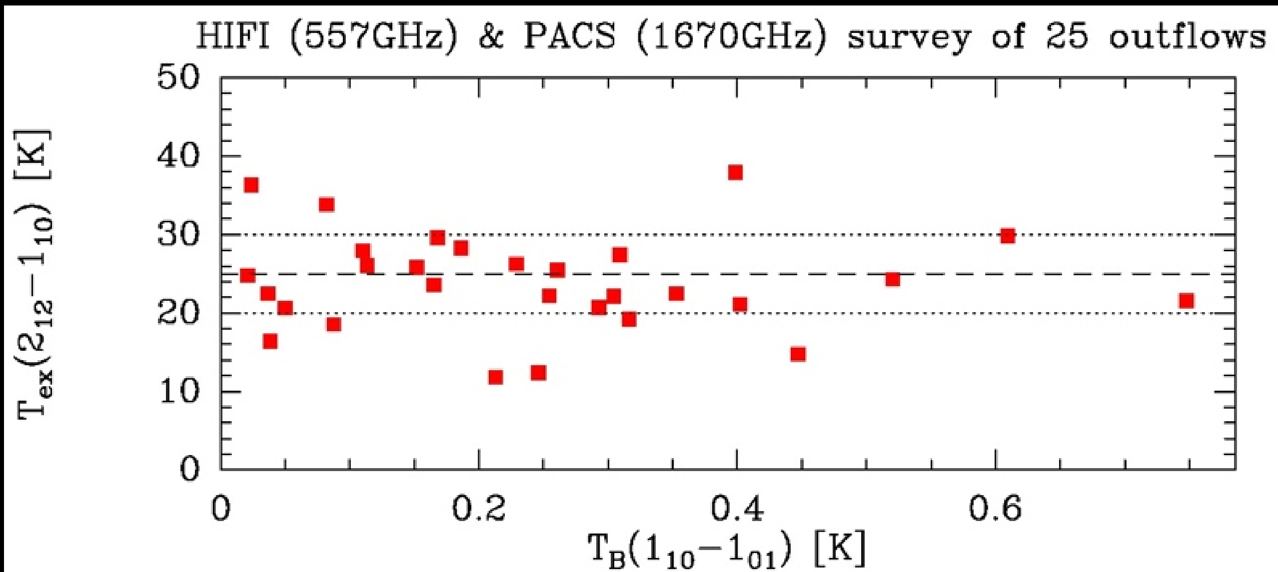


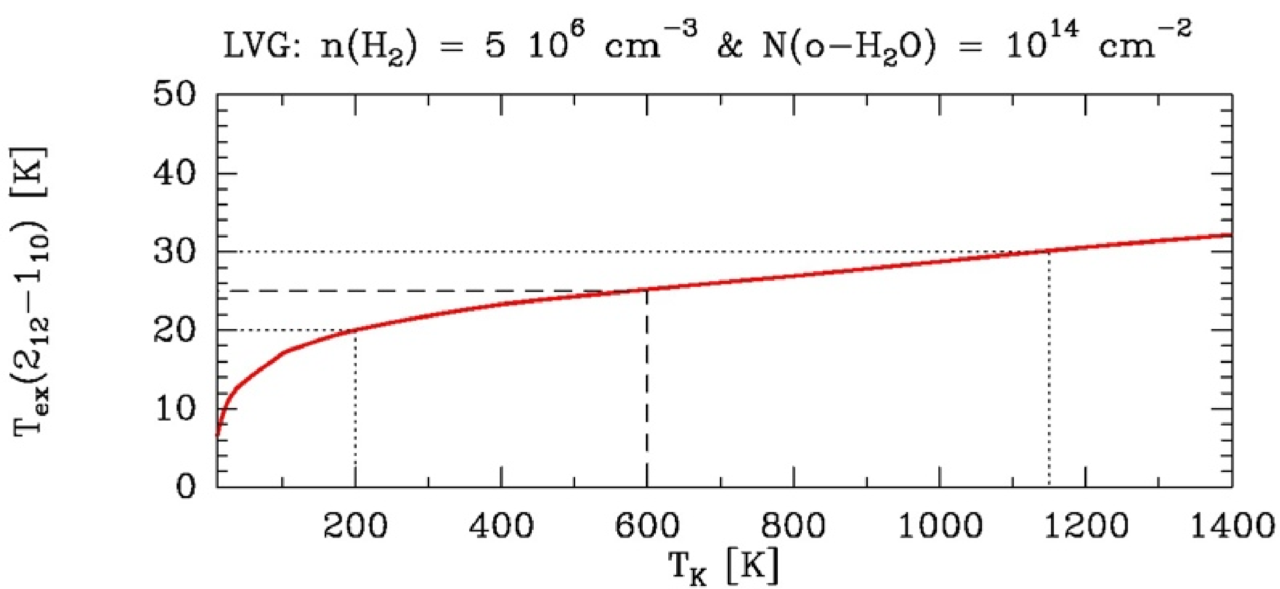


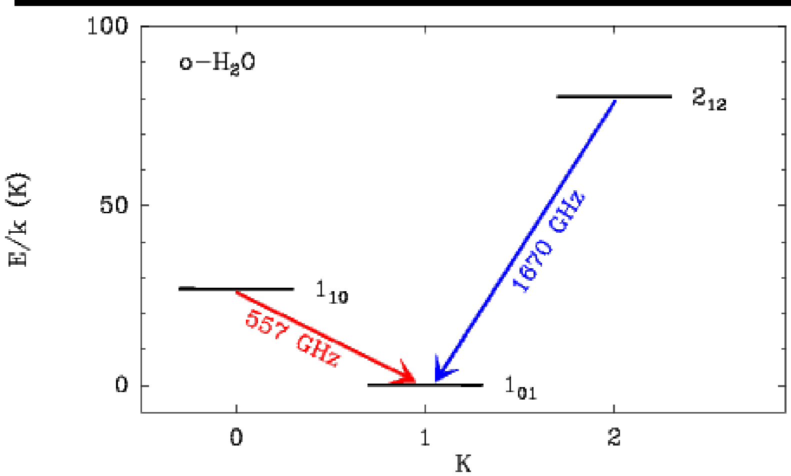


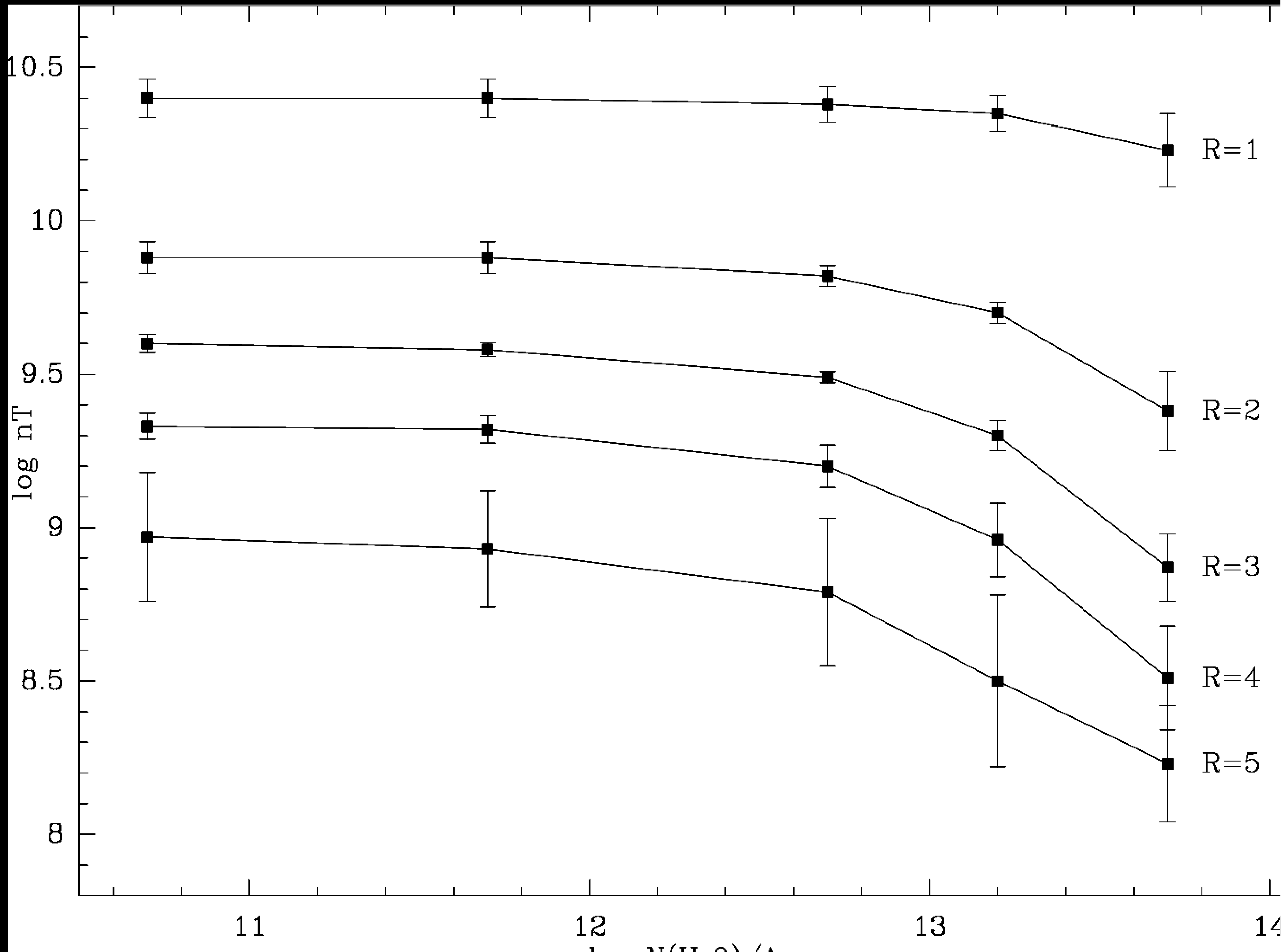
- H_2O emission
  - different from CO(2-1)
  - similar to H_2
- H_2O traces hot/warm gas

High pressure H_2O





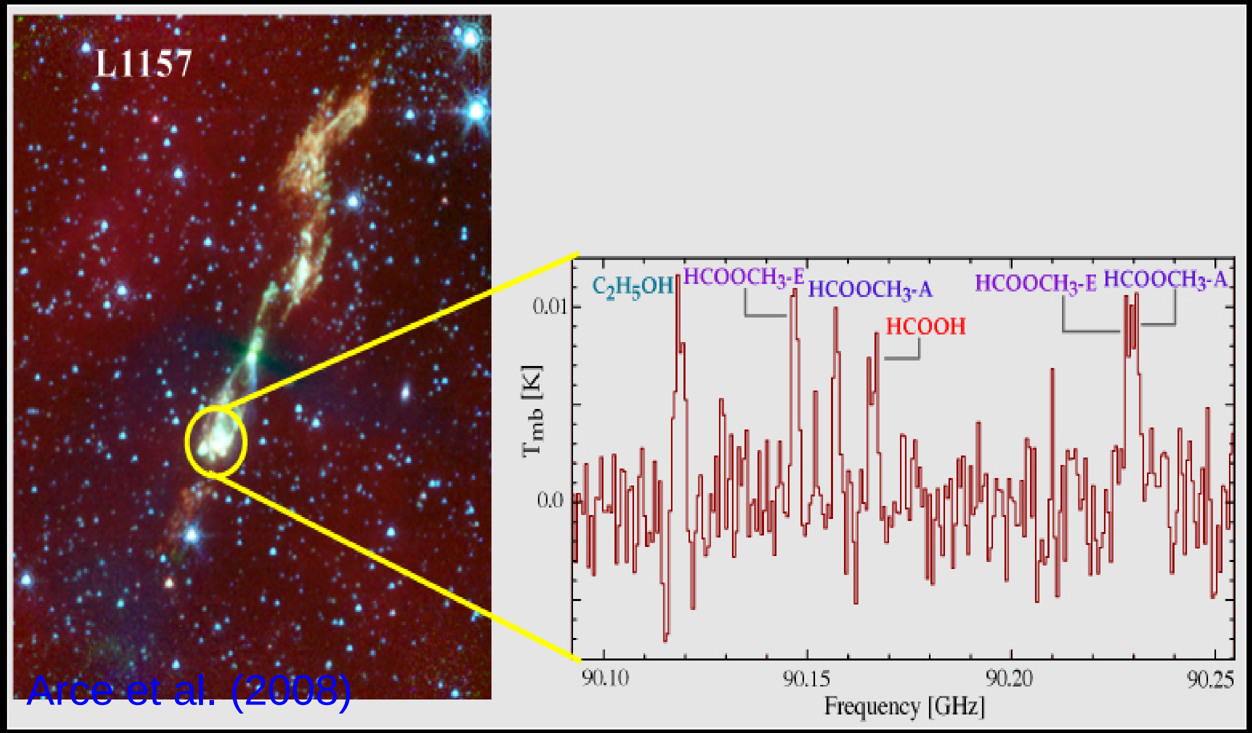




10.5
10
9.5
9
8.5
8
log nT
11
12
13
14
R=1
R=2
R=3
R=4
R=5

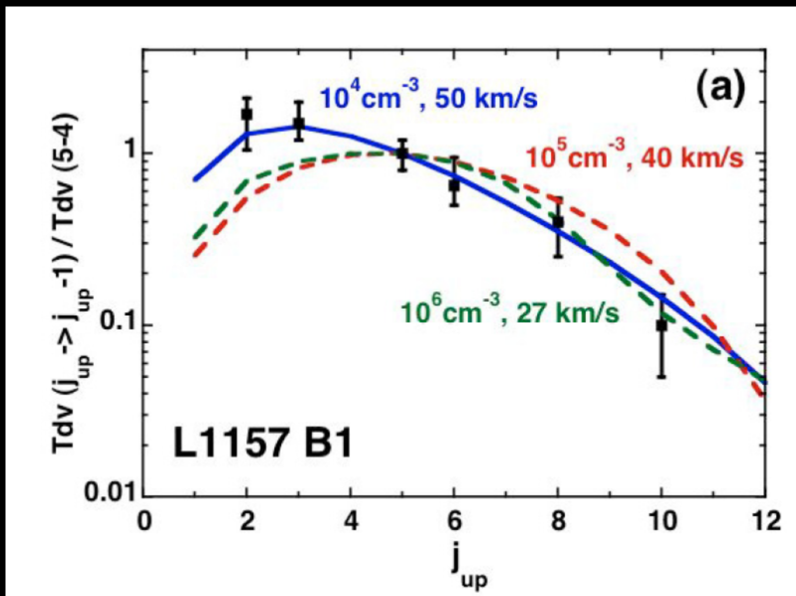
Complex organic molecules

L1157-B1

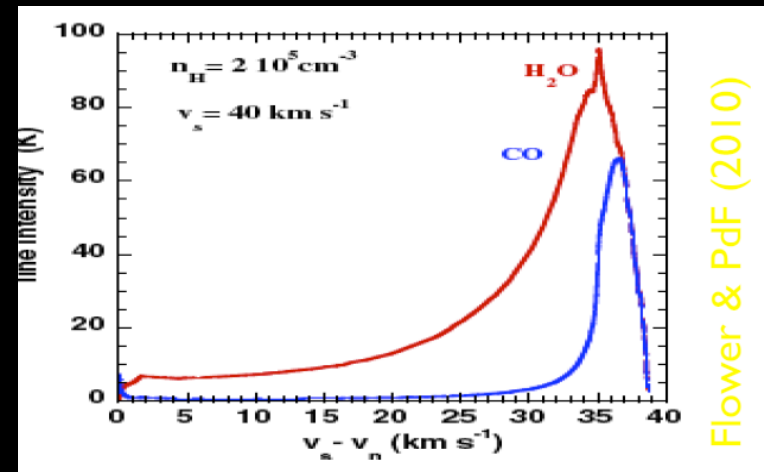


- Methyl formate, ethanol, formic acid in L1157-B1
- Imply processing of dust mantles
- Previously only detected in hot cores/corinos
- Lower ratio wrt to CH_3OH (Sugimura et al. 2011)

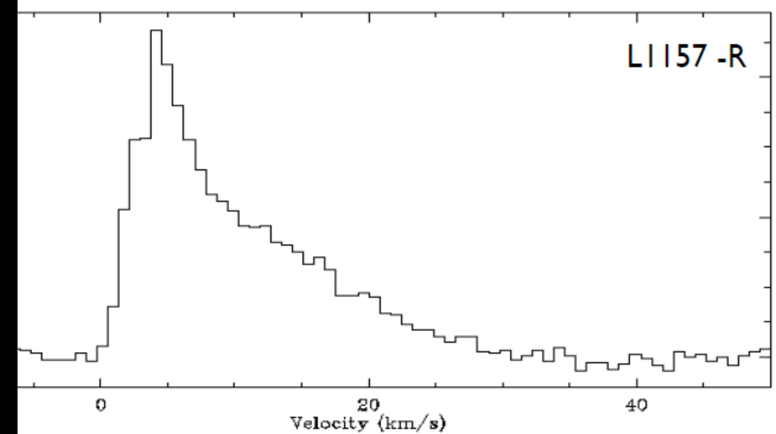
The “problem” with chemical models



Gusdorf et al. (2008)



Flower & PdF (2010)



- Plane parallel single velocity shock models
  - explain abundance enhancements
  - fit integrated intensities

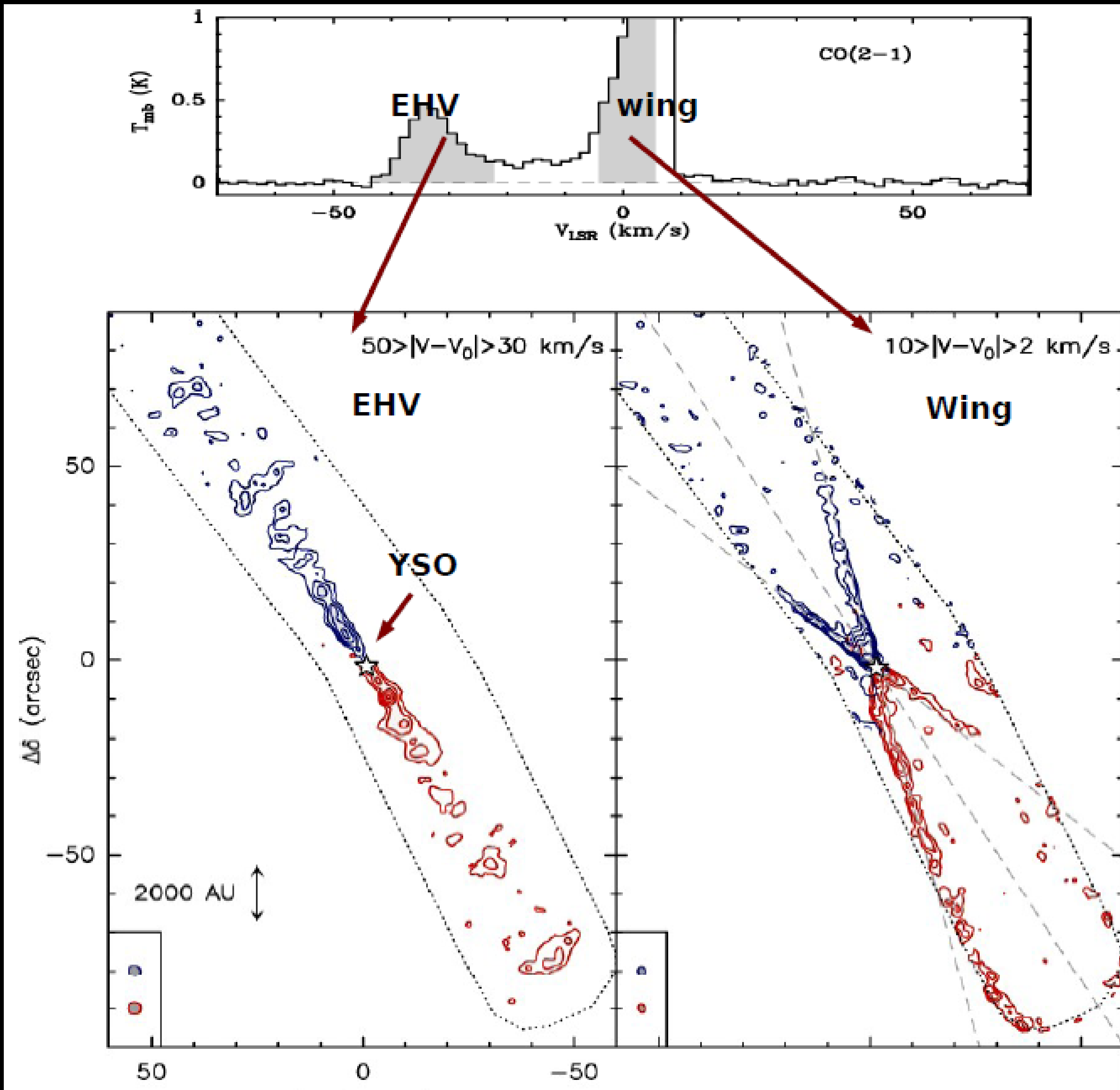
- Wrong line profile
  - no wing: spike at vs
- Optical depth overestimated (~x10)

Why do outflows have “wings”?

- Molecular spectra characterized by “wing”
  - Most emission is at the lowest velocities
- Plane parallel shocks produce “spikes”
  - Post-shock gas piles up at v_s
  - Slower gas most recently shocked
- Bow shocks can mix velocities
  - But requires a bow shock at each position
- What is the kinematic history of outflow gas?

Outflow chemistry
vs
jet chemistry

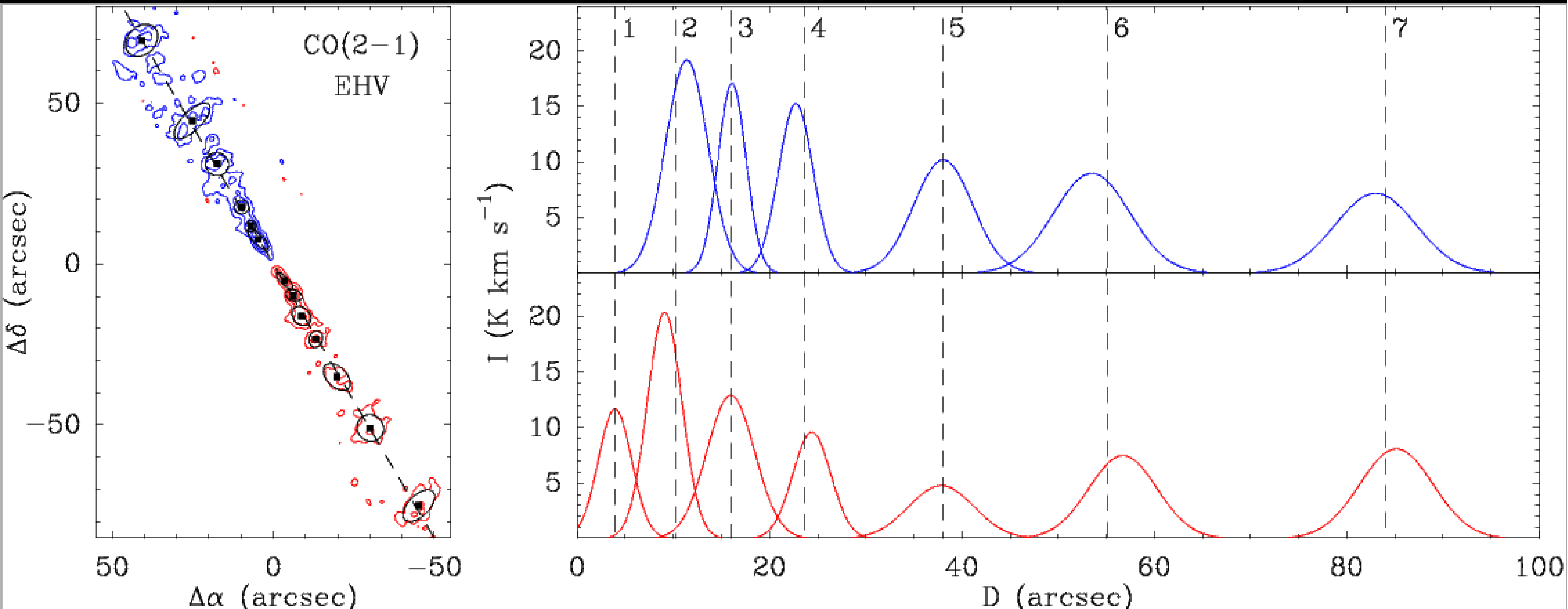
Extremely High Velocity component



Santiago-Garcia et al. (2009)

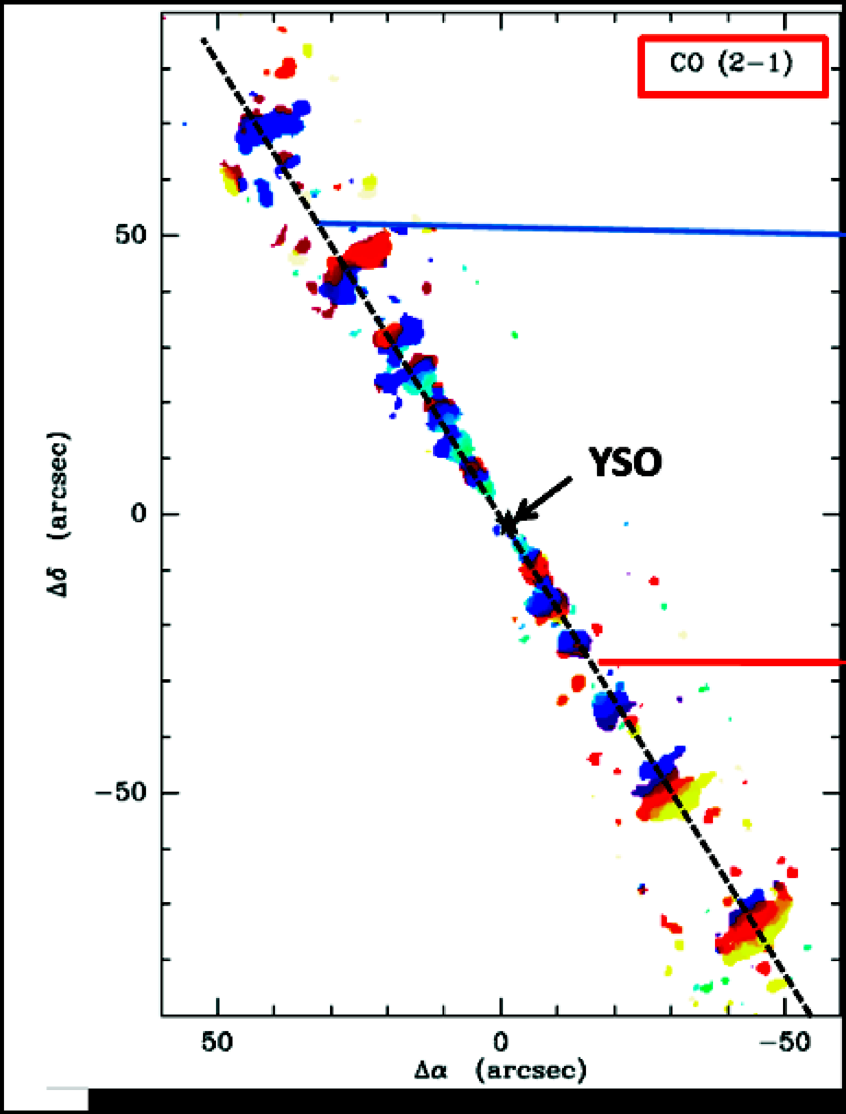
- IRAS 04166+2706
  - Taurus
  - class 0
  - 0.4 Lo
- Wing
  - ambient
  - accelerated
- EHV
  - jet
  - clumpy

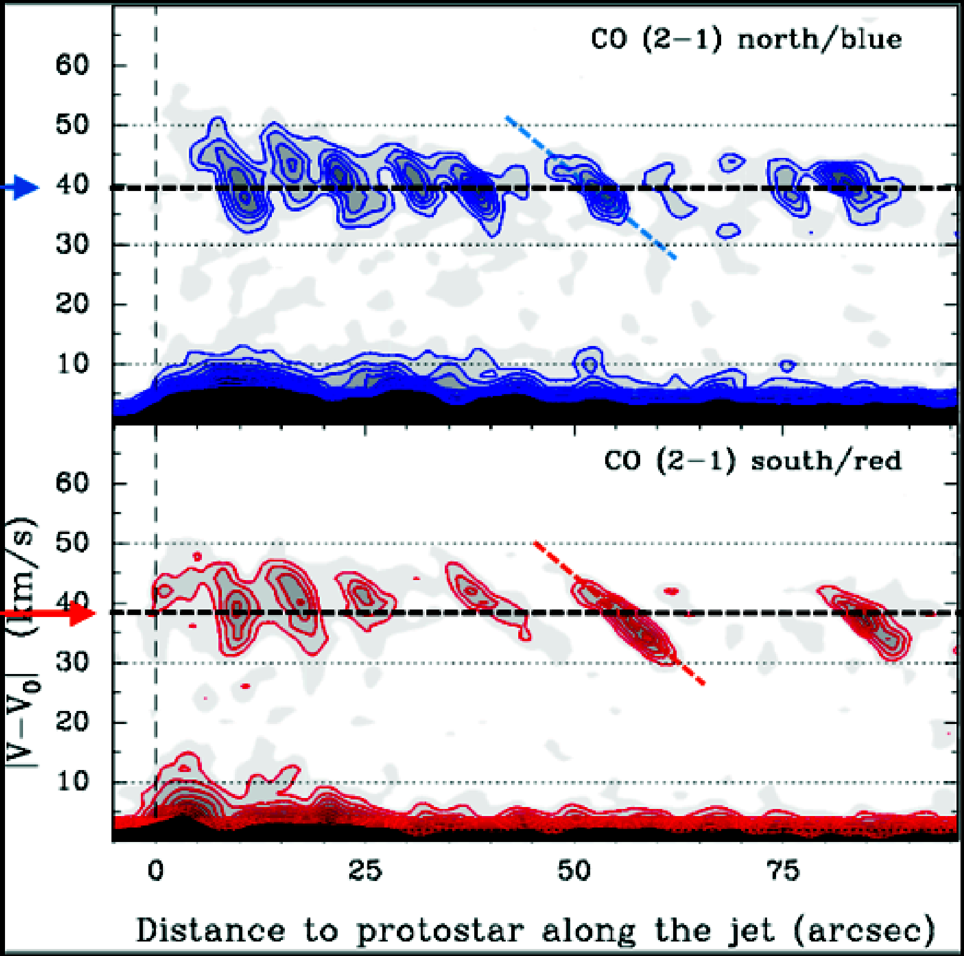
Point symmetry: YSO origin



- EHV peaks are symmetric wrt to YSO
  - location, intensity, and width
- Too far apart and moving too fast to communicate
  - symmetry originates at launching point

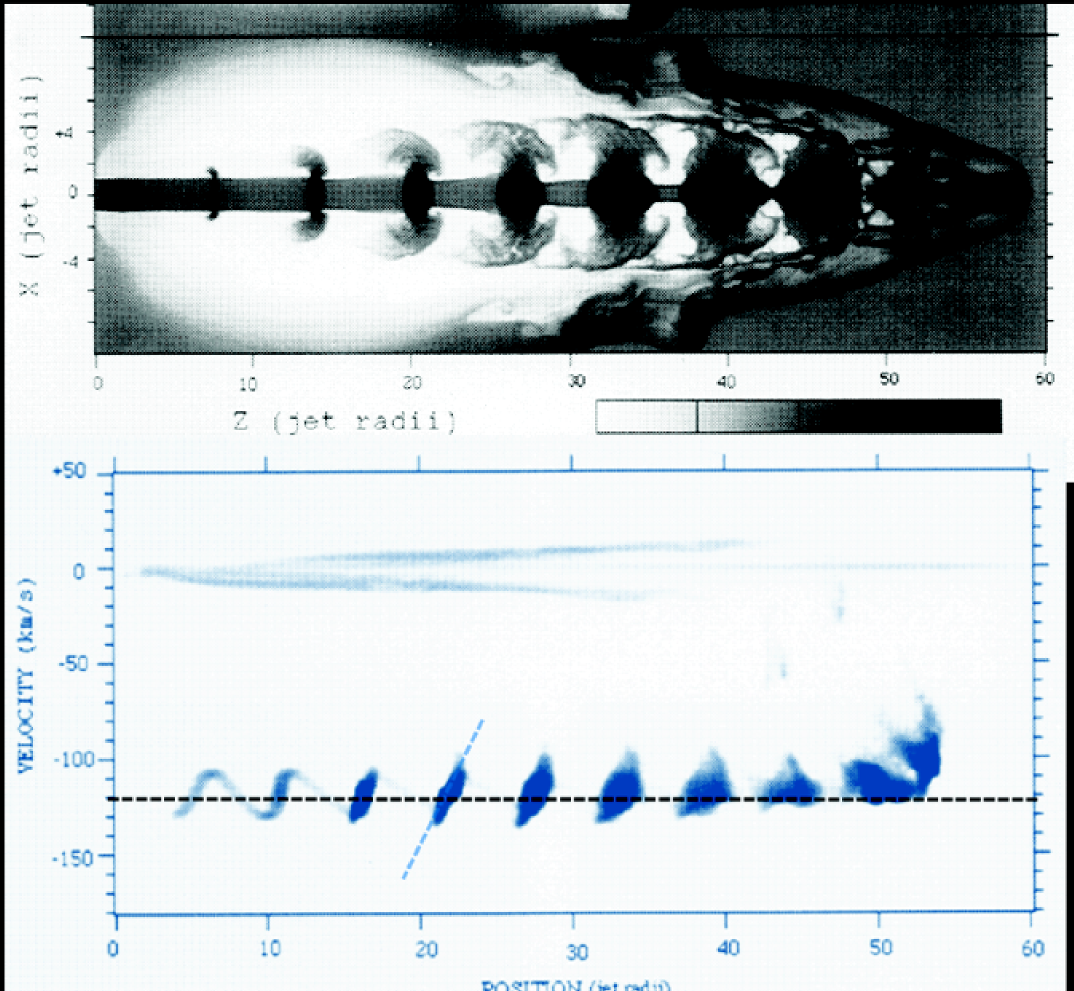
Saw-tooth velocity pattern





- EHV gas: constant mean 40 km/s + sawtooth
  - Each EHV peak: fastest gas lies upstream

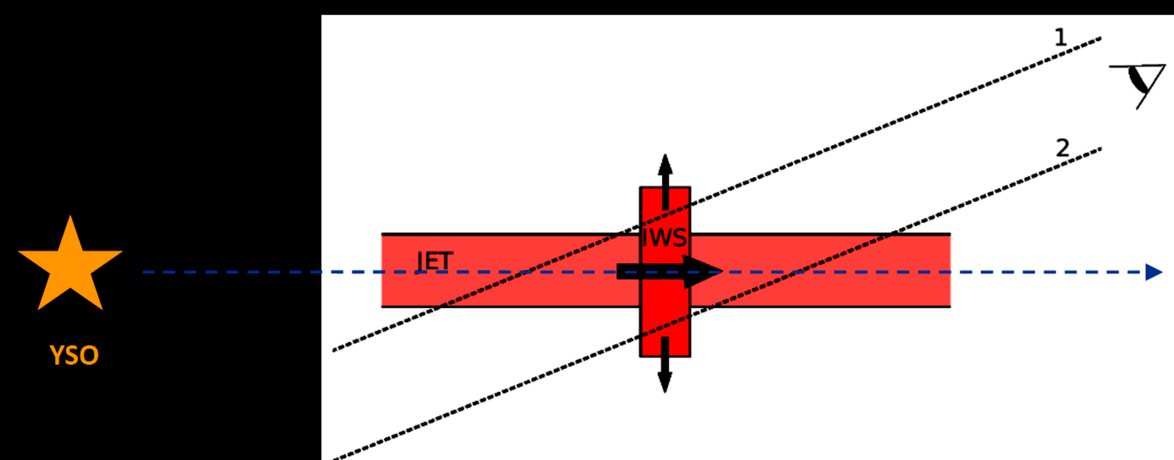
Internal working surfaces



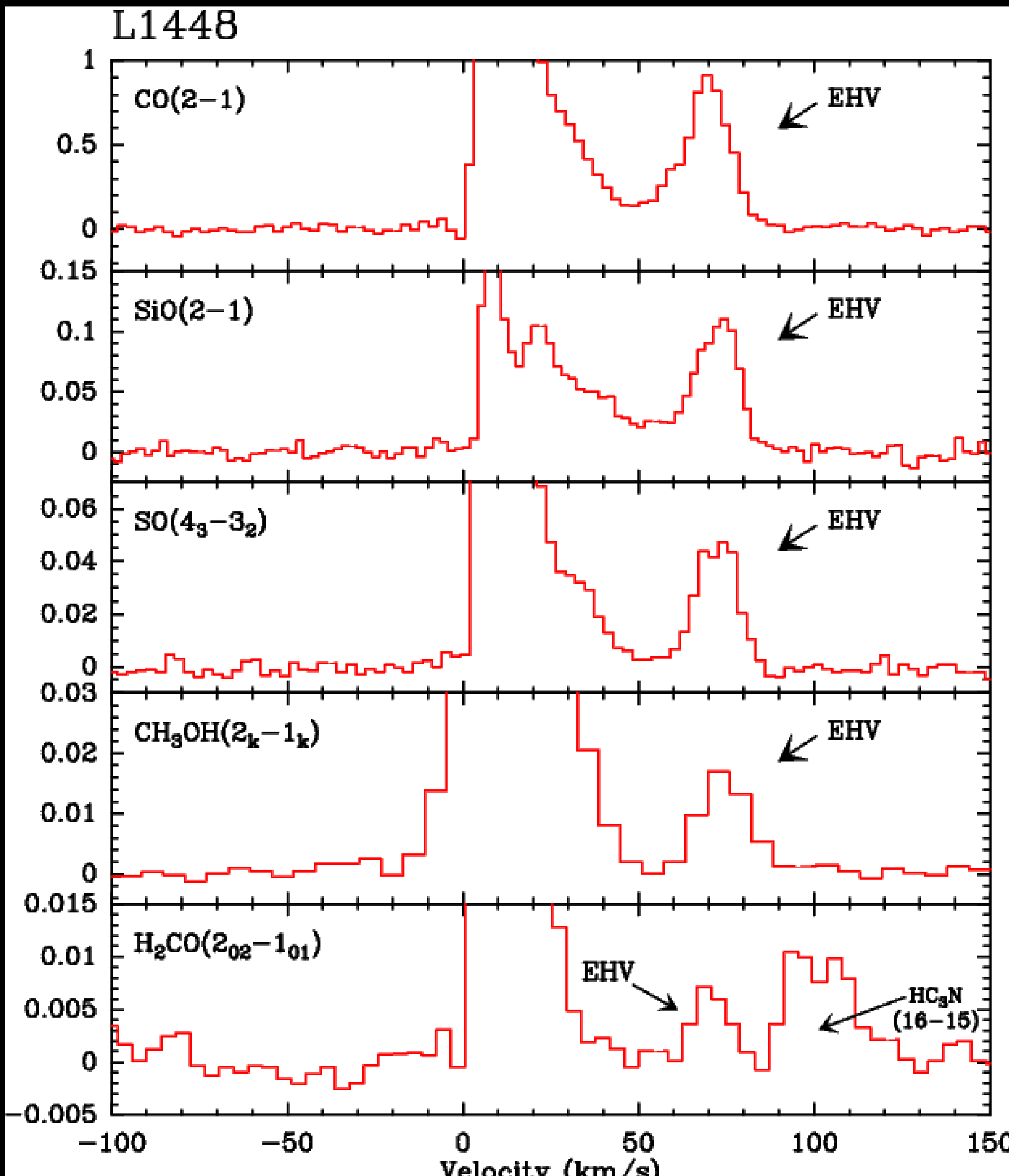
Stone & Norman. (1993)

- Numerical **simulation** of pulsating jet
  - **Saw-tooth** velocity pattern

- Projection of **lateral expansion** with jet velocity



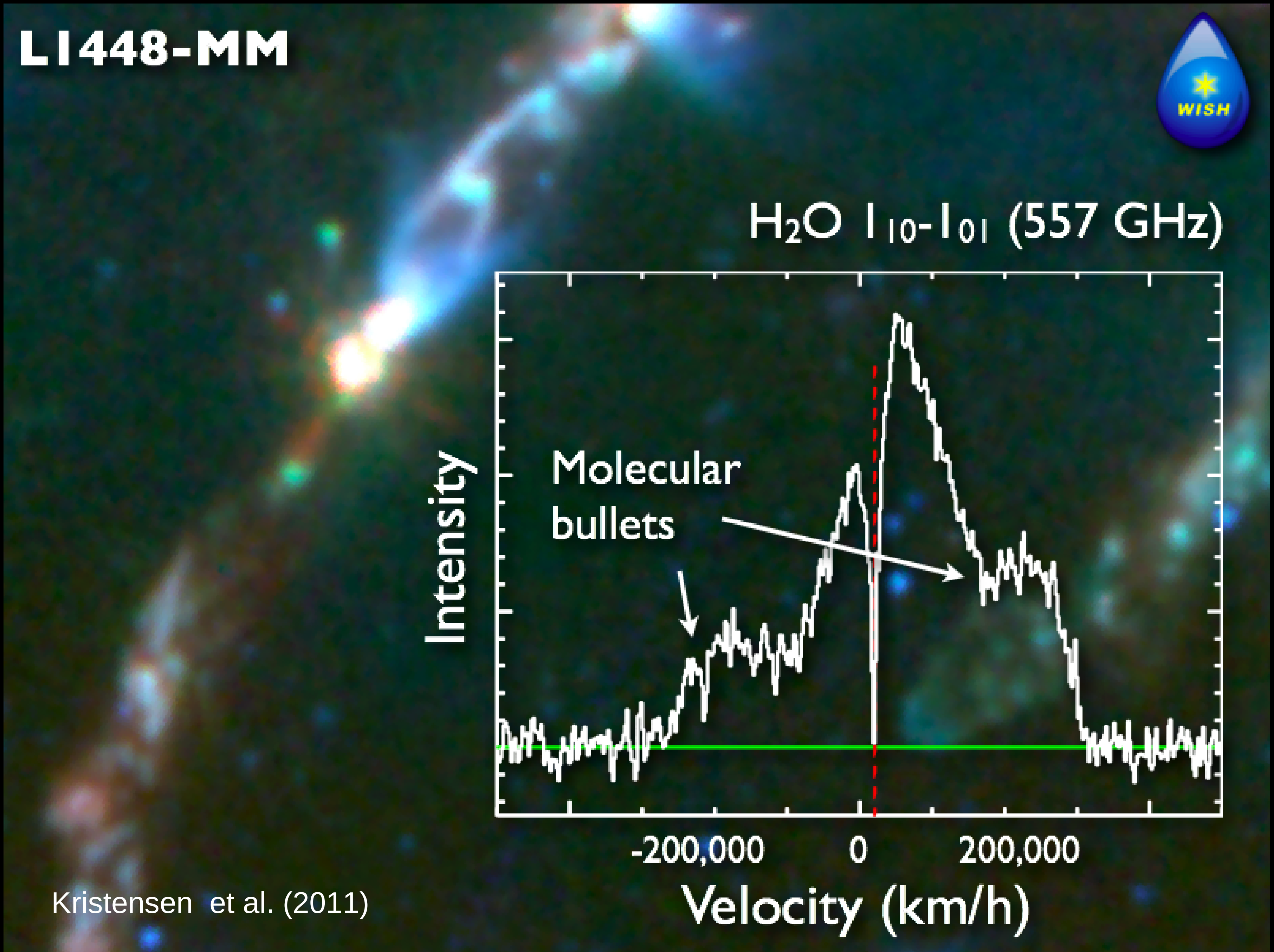
Chemical composition of EHV gas



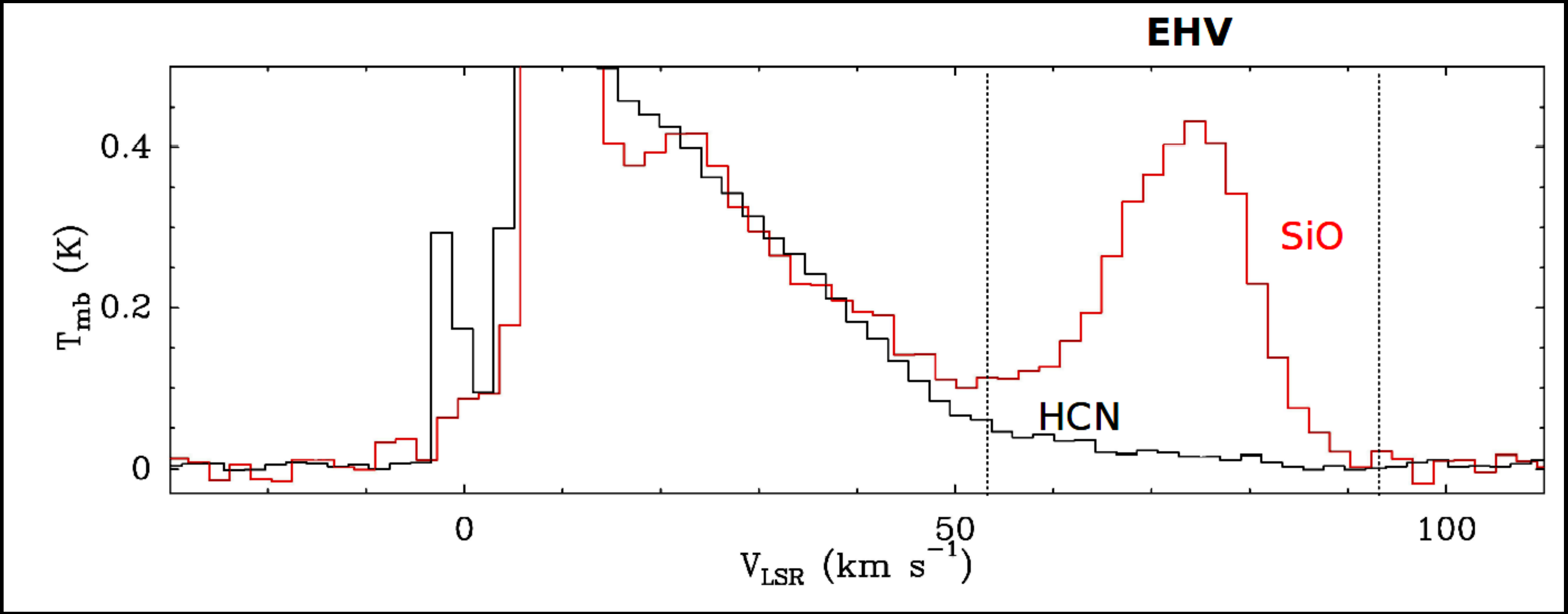
Tafalla et al. (2010)

- Is jet composition like "outflow" (shocked ambient) gas composition?
  - chemistry reflects thermal history of gas
  - clues on jet launching mechanism
- First survey of EHV gas
  - L1448 & IRAS 04166
  - CO, SiO, SO, CH_3OH, H_2CO
  - Large range of intensities

H_2O in EHV gas with Herschel



EHV gas is oxygen-rich



Tafalla et al. (2010)

- **All detected species in EHV gas are oxygen-bearing**
- **C-bearing molecules are significantly depleted**
  - **HCN/SiO ratio drops by 20 between wing and EHV**
- **Atomic protostellar wind (Glassgold et al. 1991)**
  - **C locked in CO**
  - **How do you produce CH_3OH? (needs grains)**
- **Disk wind (Panoglou et al. 2012)**
  - **No SiO production. Unclear C/O ratio**

Conclusions

- Chemical activity is signature of outflow youth
- Boom in molecular tracers of outflow gas
  - chemical and thermal complexity
- Outflow wing composition: shocked ambient gas
  - problems: need for global models of chemistry plus better velocity structure
- New chemistry of EHV gas component
  - differences with wing chemistry
  - need for jet/wind models