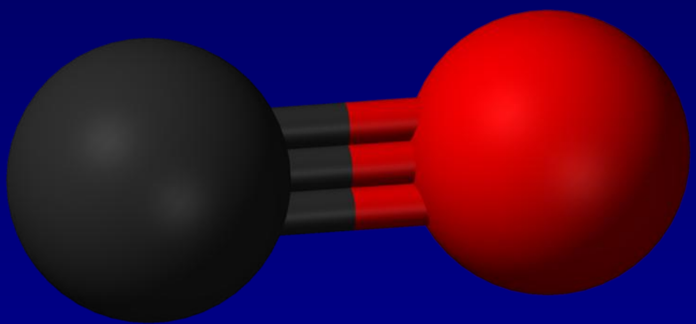
~~Water~~ in Star-forming Regions with Herschel (WISH)

CO



Ewine F. van Dishoeck
Leiden Observatory/MPE

www.strw.leidenuniv.nl/WISH

Water In Star-forming regions with Herschel
The WISH team

Leiden, December 2011

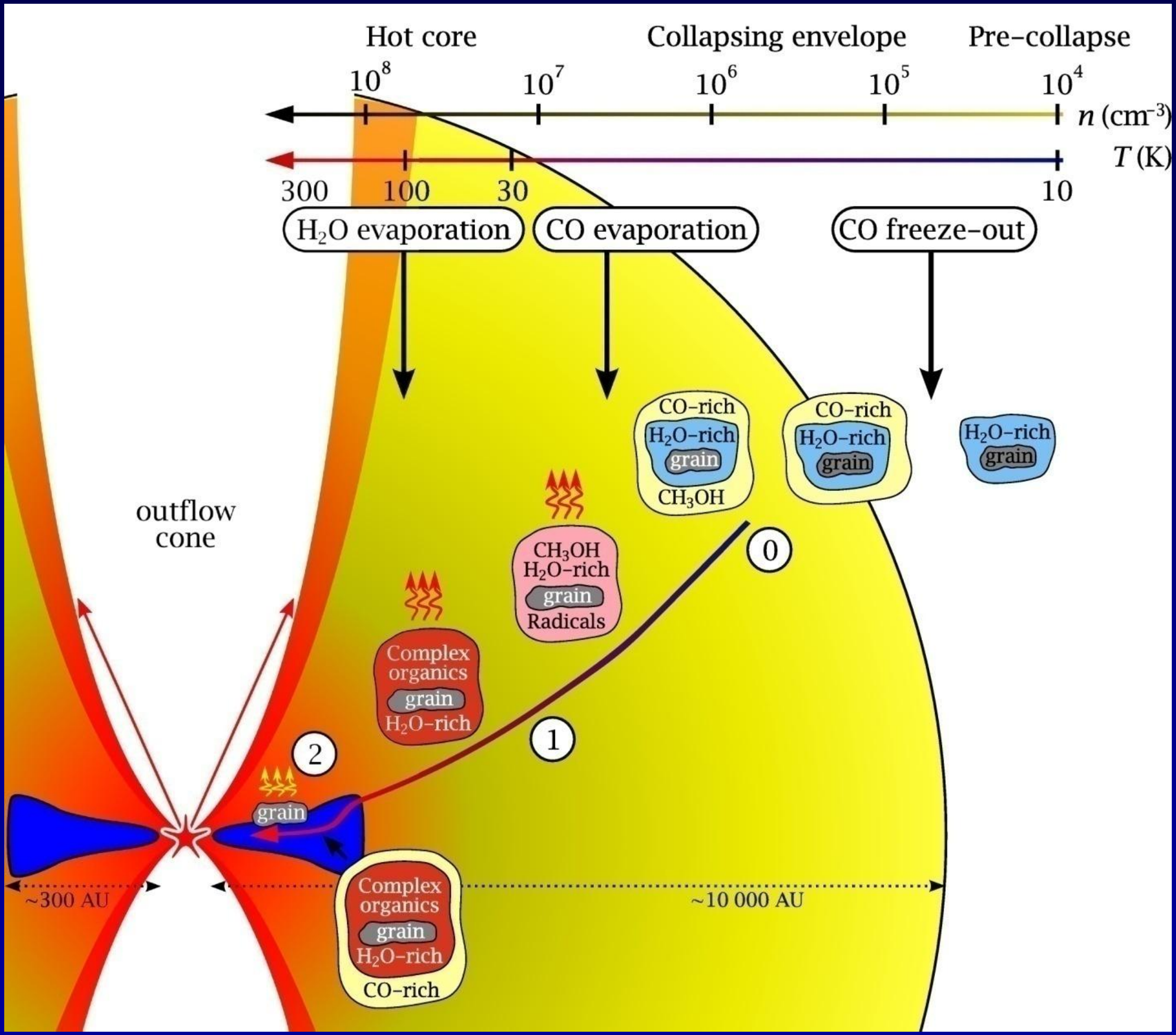
Toledo, June 2011

L. Kristensen
U. Yildiz
I. San Jose
M. Hogerheijde
R. Visser
S. Bruderer
A. Karska
G. Herczeg

70+ scientists from 30 institutions (PI: EvD)
15 papers in Herschel A&A first results issues,
25 papers total

Summary in van Dishoeck et al. 2011, PASP

Follow journey of parcel from cores to disk

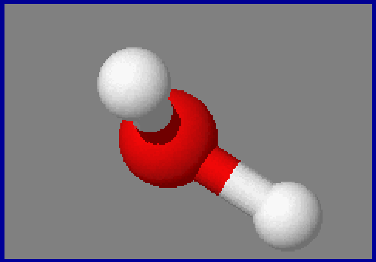


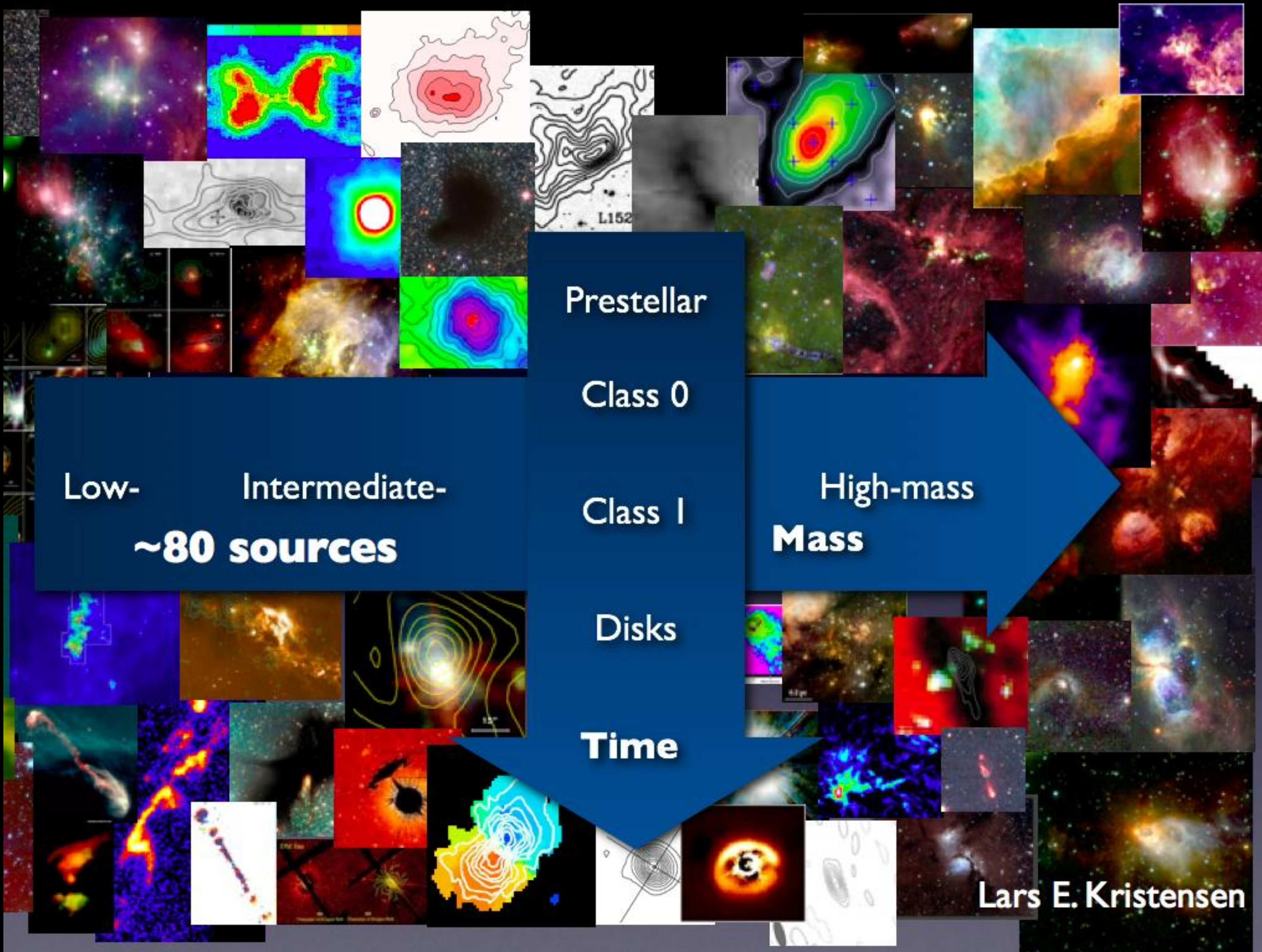
Visser et al. 2009, 2011
Herbst & vD 2009

WISH questions

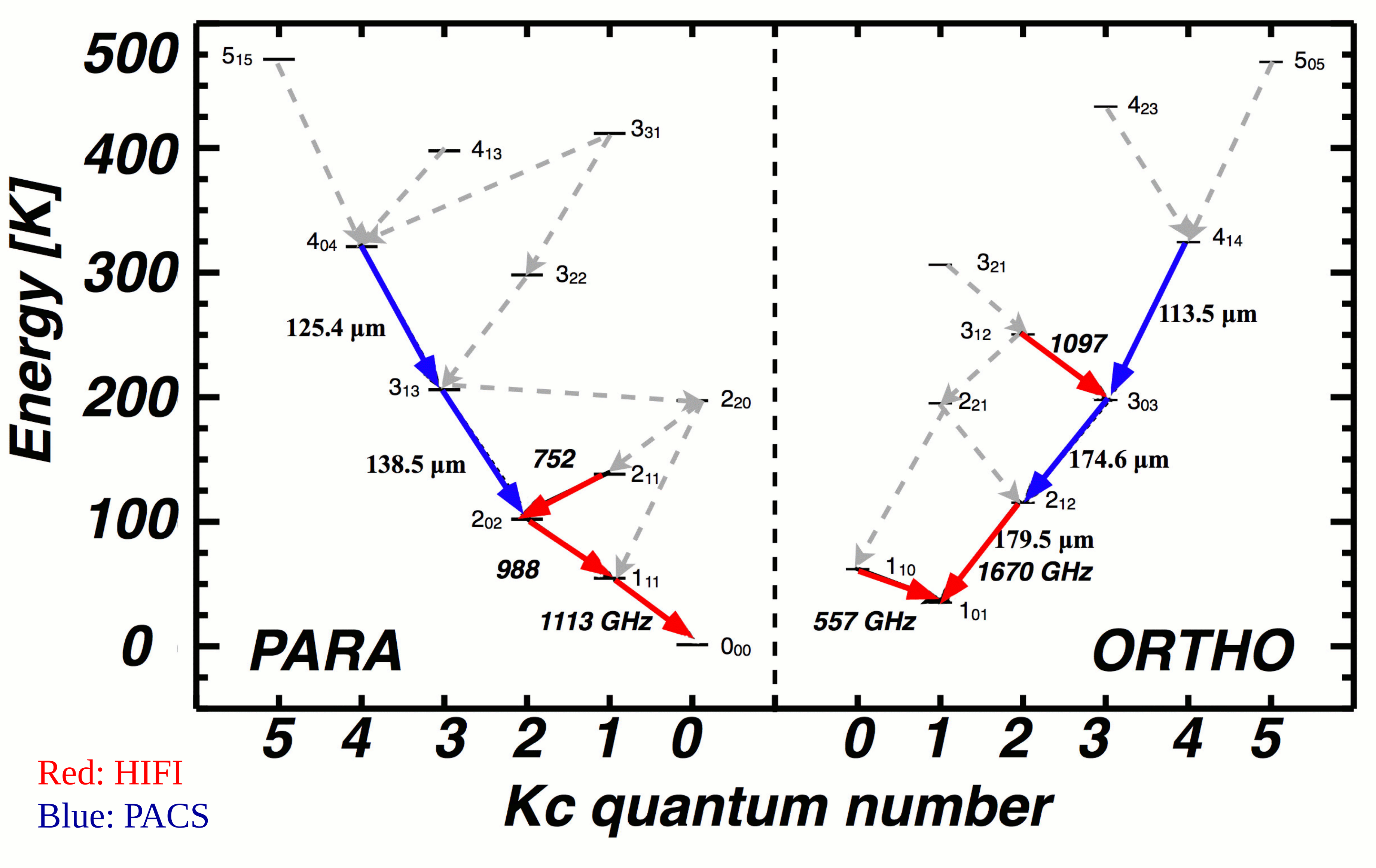
- Where is water formed in space and by which processes?
  - Gas vs grains
- Which physical components does water trace?
  - Quiescent envelope, hot core, outflows, disks, …
  - Cooling budget
- What is the water 'trail' from clouds to planets?
  - Origin of water on Earth

To do so, we also need to understand the physics => independent tracer CO



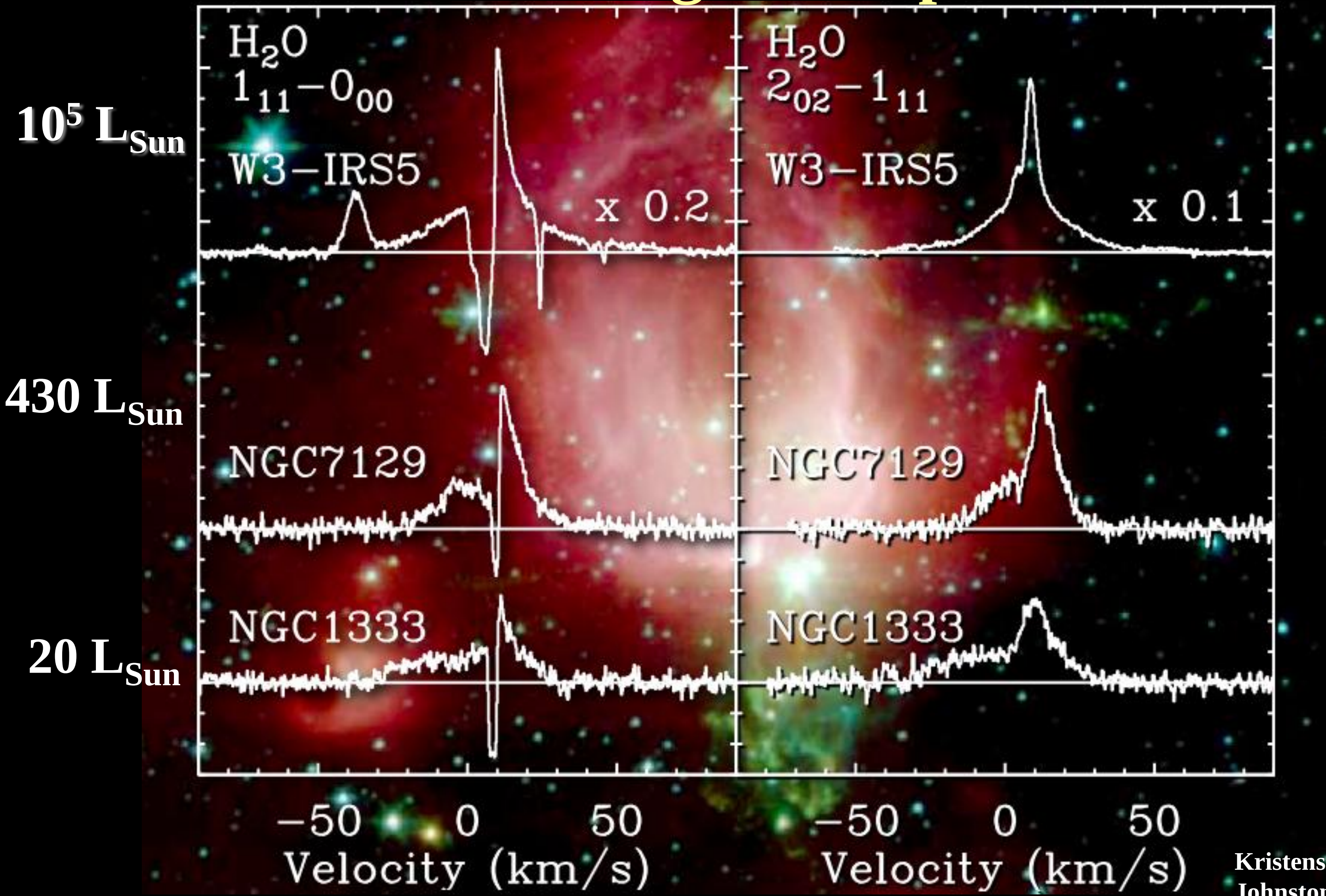

L152
Prestellar
Class 0
Class I
Disks
Time
Low-
Intermediate-
High-mass
~80 sources
Mass
Lars E. Kristensen

H_2O lines: HIFI and PACS



Observe mix of low- and high-excitation lines to probe cold and hot environments; Include ^{12}CO 10-9, ^{13}CO 10-9, $C^{18}O$ 9-8, PACS

Water reveals profile components
From low to high mass protostars

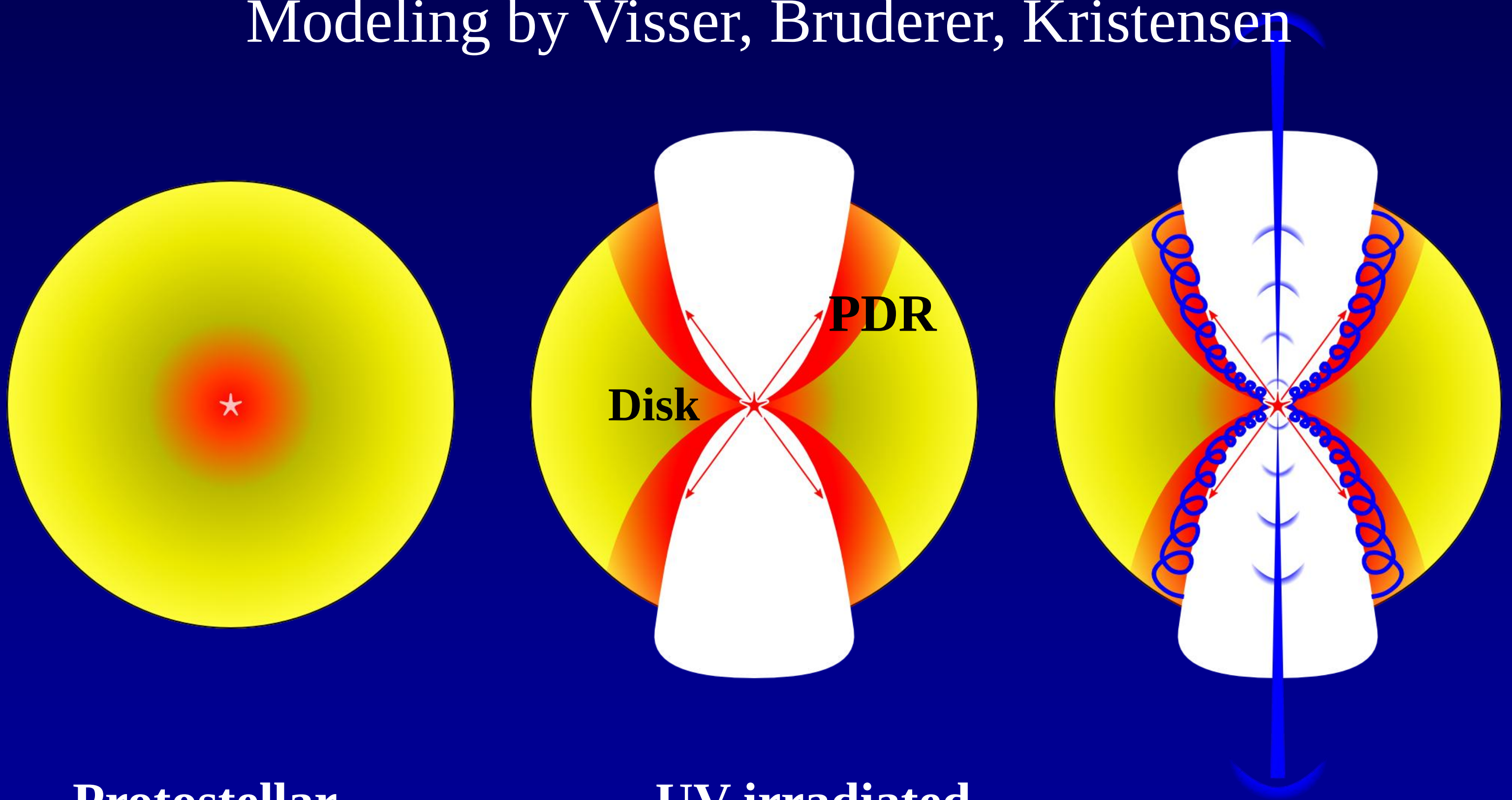


Kristensen et al. 2010
Johnstone et al. 2010
Chavarria et al. 2010

Note similar profiles: broad, medium and narrow

Which physical component dominates which lines?

Modeling by Visser, Bruderer, Kristensen

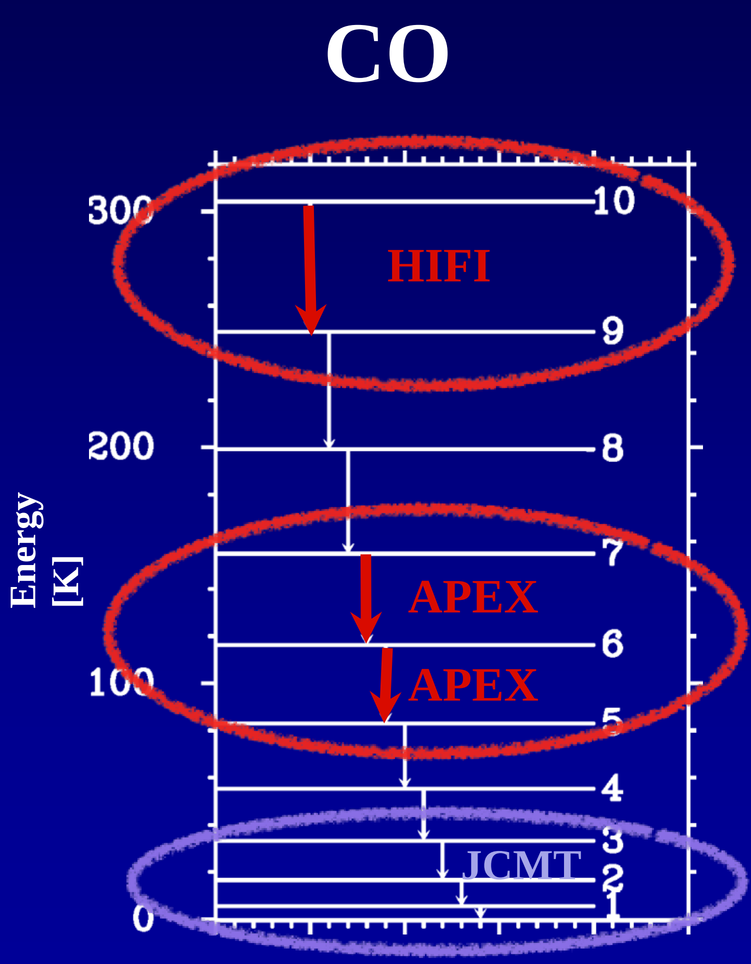


Protostellar envelope with hot core:
Low-J CO
Also swept-up outflow

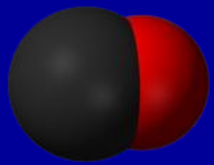
UV irradiated cavity walls, disk surface:
Mid-J CO
Hot water?

Outflow shocks:
High-J CO,
Hot water?
High velocity O I

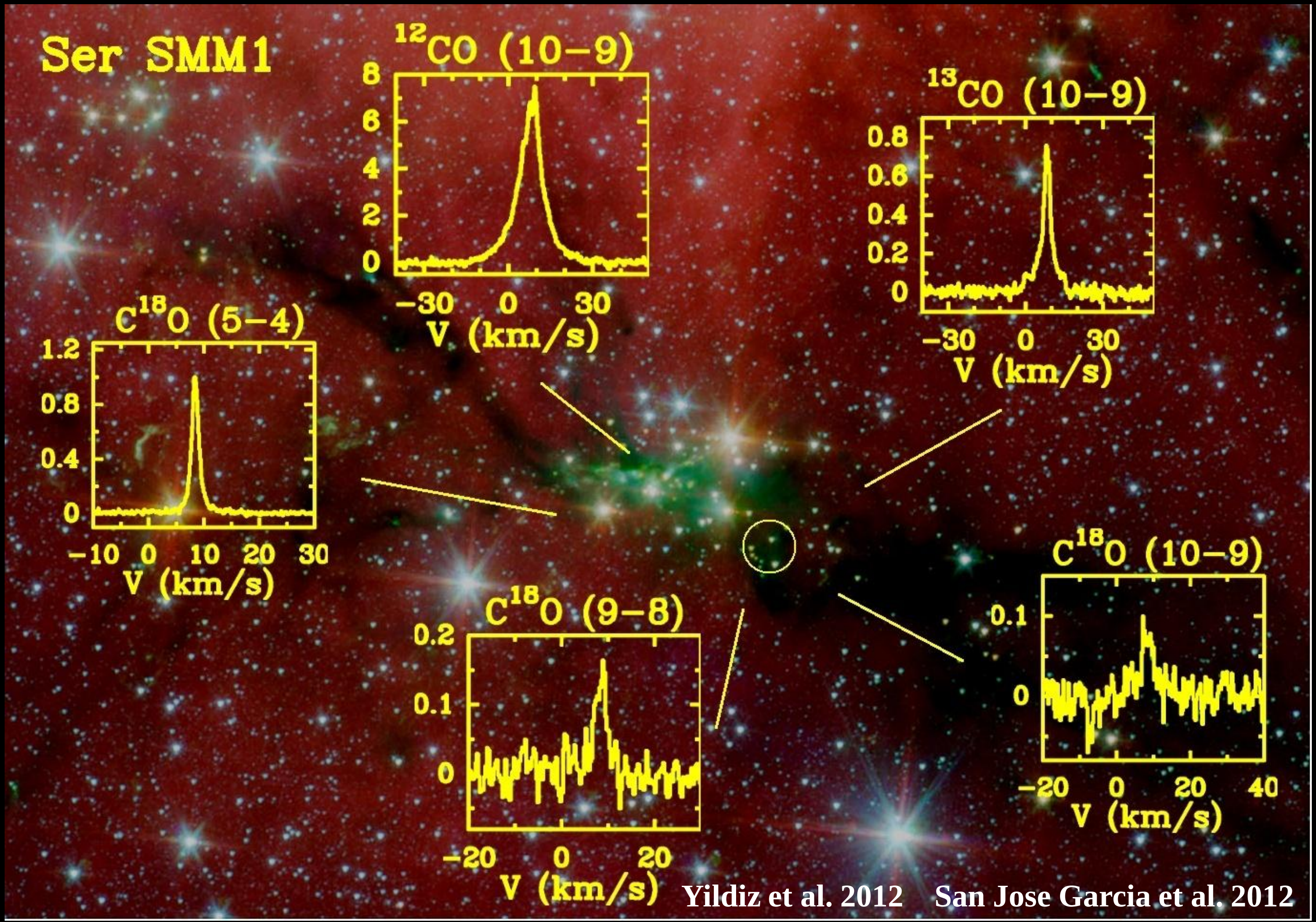
Velocity resolved CO lines



- **Combination of instruments allows full ladder up to *J*=10-9 to be observed; *J*=16-15 in one source**



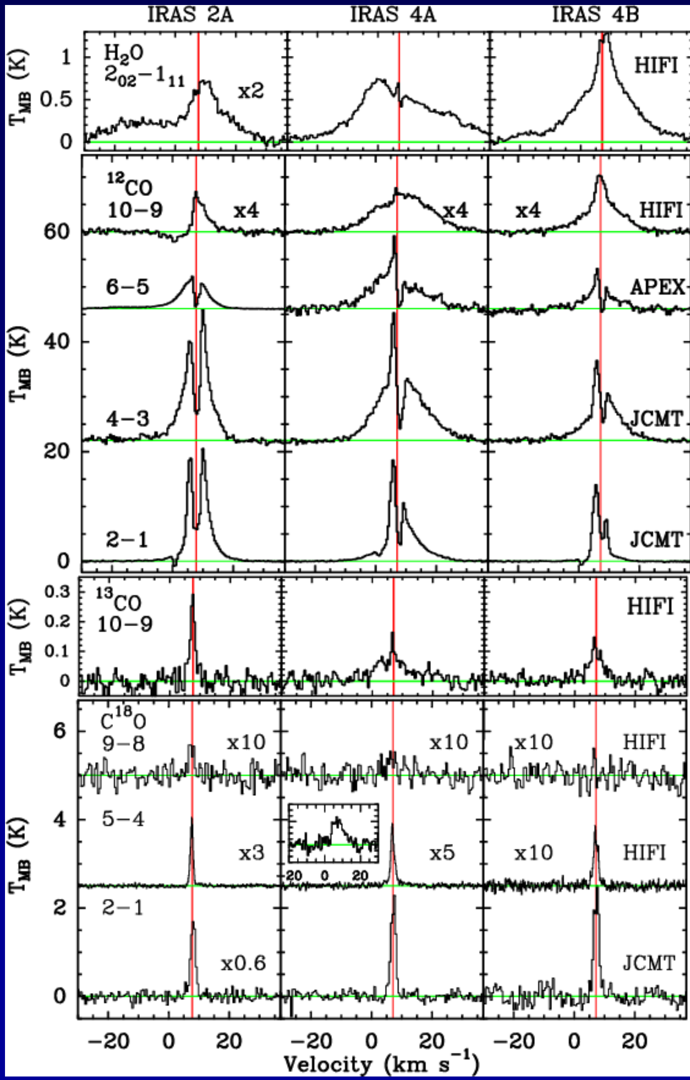
High-J CO lines



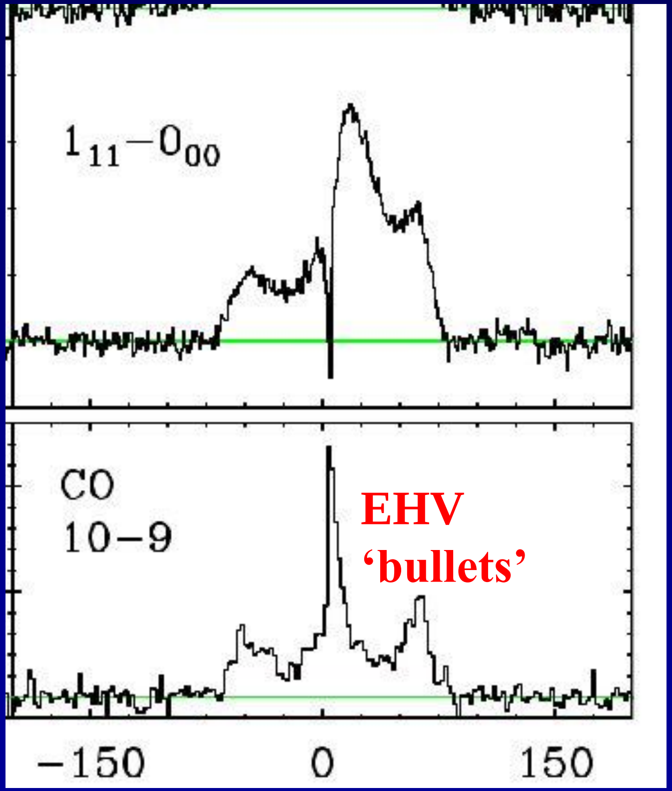
- Note mix of narrow and broad lines

From broad to narrow profiles

NGC 1333



L1448



Kristensen et al. 2011

Yildiz et al. 2010

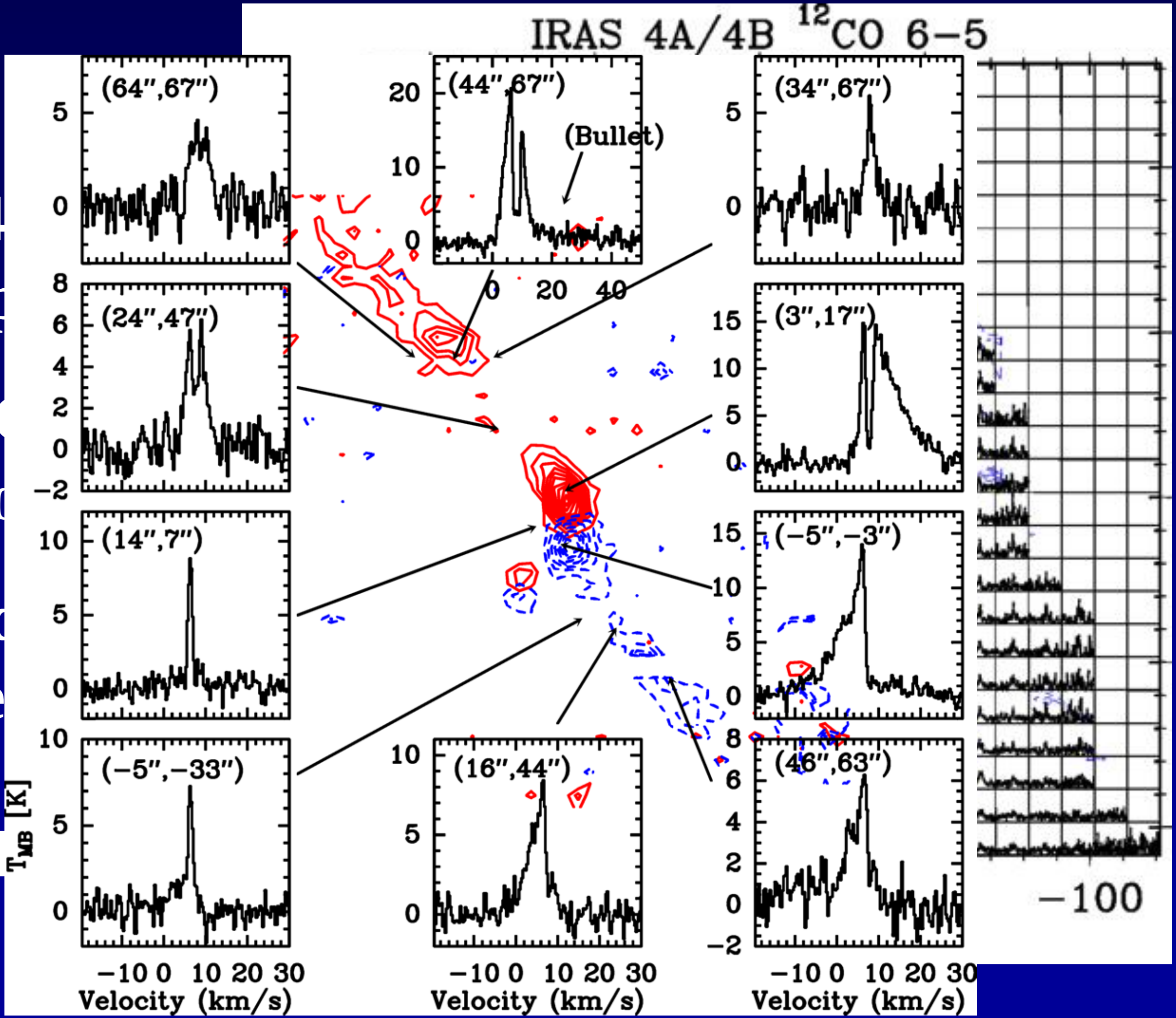
Points addressed here

- **Importance of velocity resolution**
- **Importance of isotopologues**
- **Importance of spatial information**

Focus here on low-mass sources

Examples: NGC 1333 IRAS 4A/B

- NGC 1333 IRAS 4
  protostars (*d*=235p
- APEX-CHAMP+ C
  5 map, 9” resolutio
- Spectrally resolved
  dynamics of the re
  Spatially resolved
  outflow (entrained



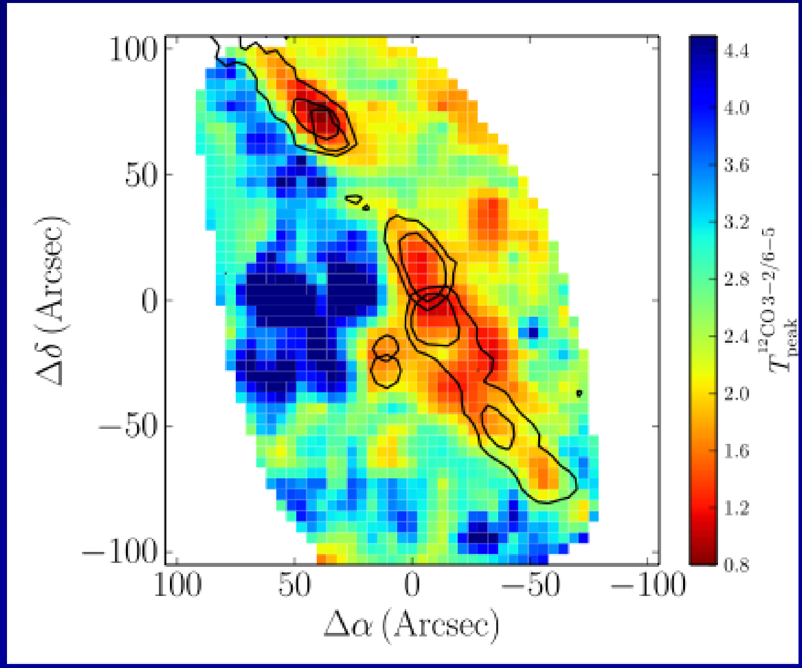
Yildiz et al., 2012

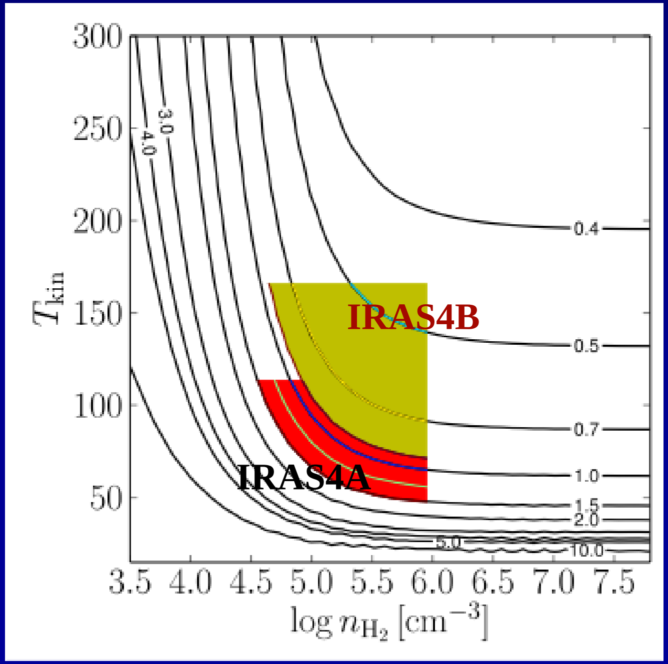
Extracting quantitative information

Temperatures inferred from CO 3-2/6-5 and 6-5/10-9 ratios in line profiles indicate 70-200 K for entrained outflow gas

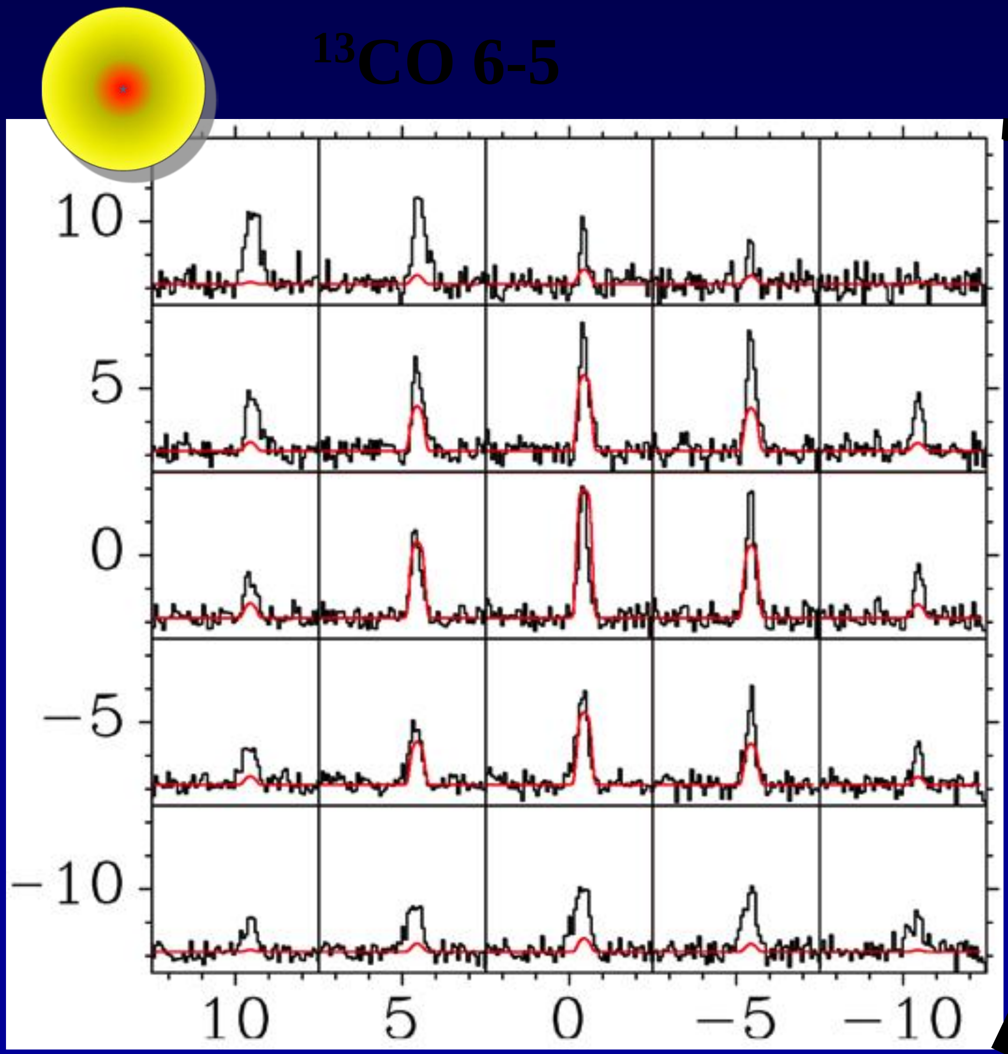
Unresolved ^{12}CO low-J lines primarily trace this outflow

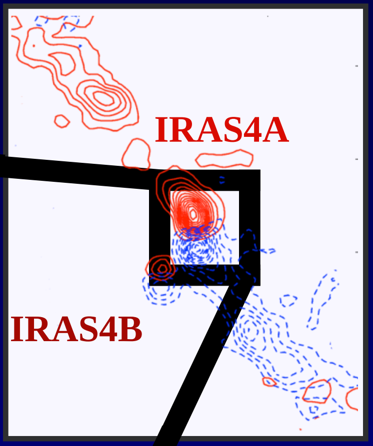
T via CO 3-2/6-5





^{13}CO: UV heating of cavity walls



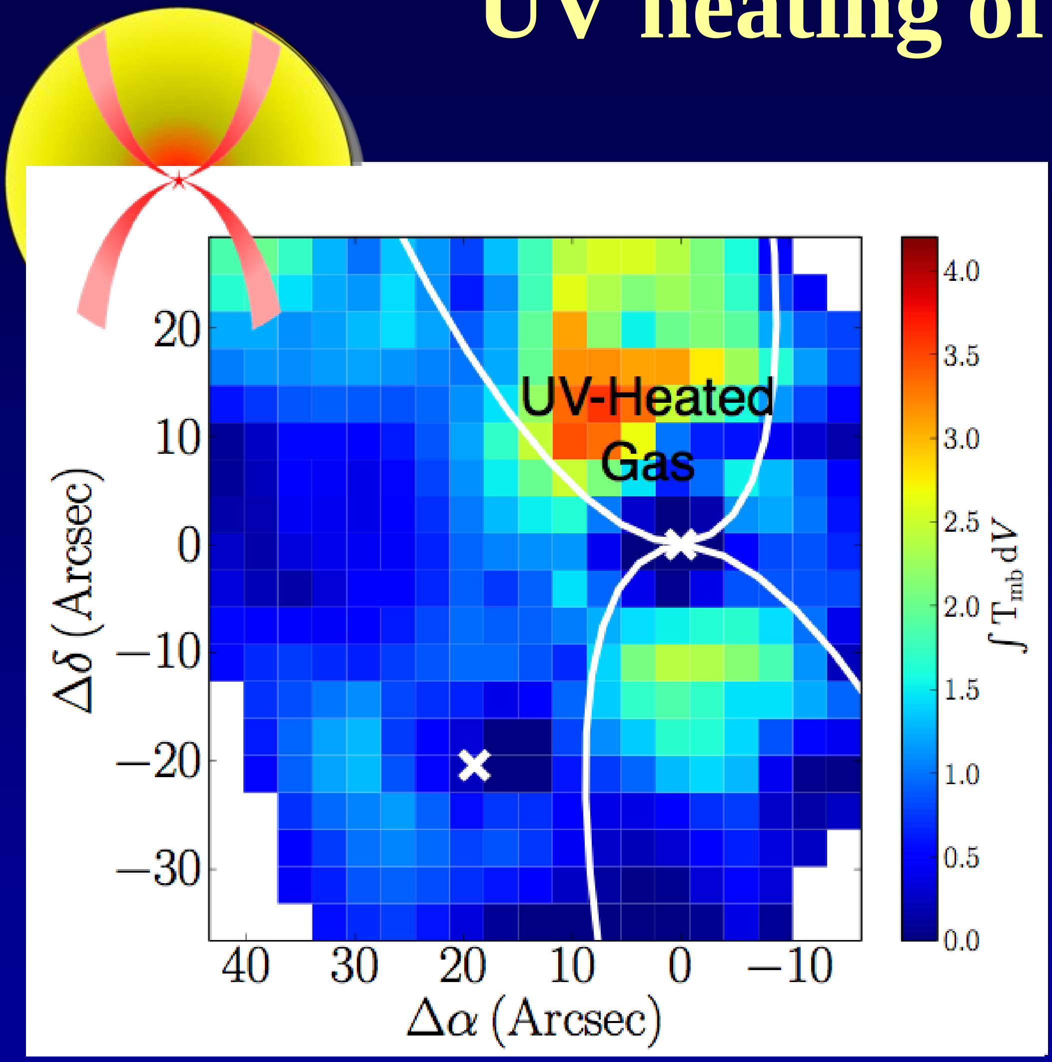


- ^{13}CO 6-5 narrow emission at source can be produced in the envelope.

Used $C^{18}O$ model to predict ^{13}CO

Yildiz et al., 2012

UV heating of cavity walls



^{13}CO 6-5

(Observed Spectra
– Outflow
– Envelope Emission)
= UV heated gas

- ^{13}CO 6-5 reveals the first direct observational evidence for the UV heated gas distribution
- For IRAS 4A, the mass of the UV-heated gas is at least comparable (even higher) to the mass of the outflow.

Note that Intensity Scale changes

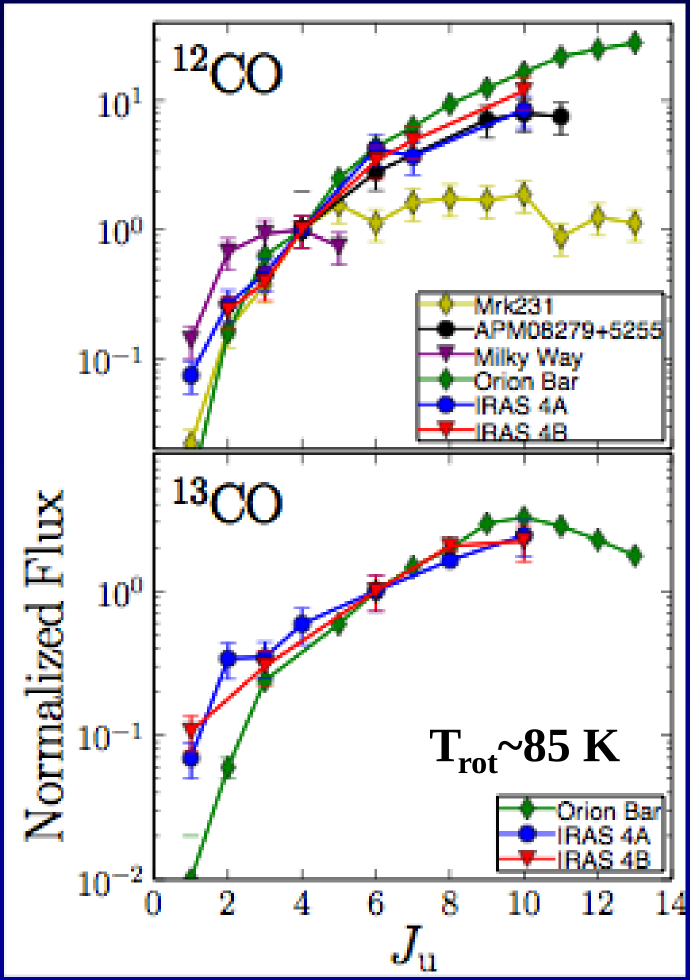
Yildiz et al., submitted; see also van Kempen et al. 2009, Spaans et al. 1995

Message 1

- ^{12}CO and ^{13}CO up to J~10 trace different physical components
  - ^{12}CO: entrained outflow gas
  - ^{13}CO: quiescent envelope + UV heated gas

→ Velocity-unresolved ^{12}CO/^{13}CO flux ratios are meaningless for protostars

Comparing CO ladders



- Protostars have ^{12}CO excitation
  - similar ⇒ a ULIRG, a PDR
  - different ⇒ Milky Way, a Quasar
- ^{13}CO excitation similar to PDR

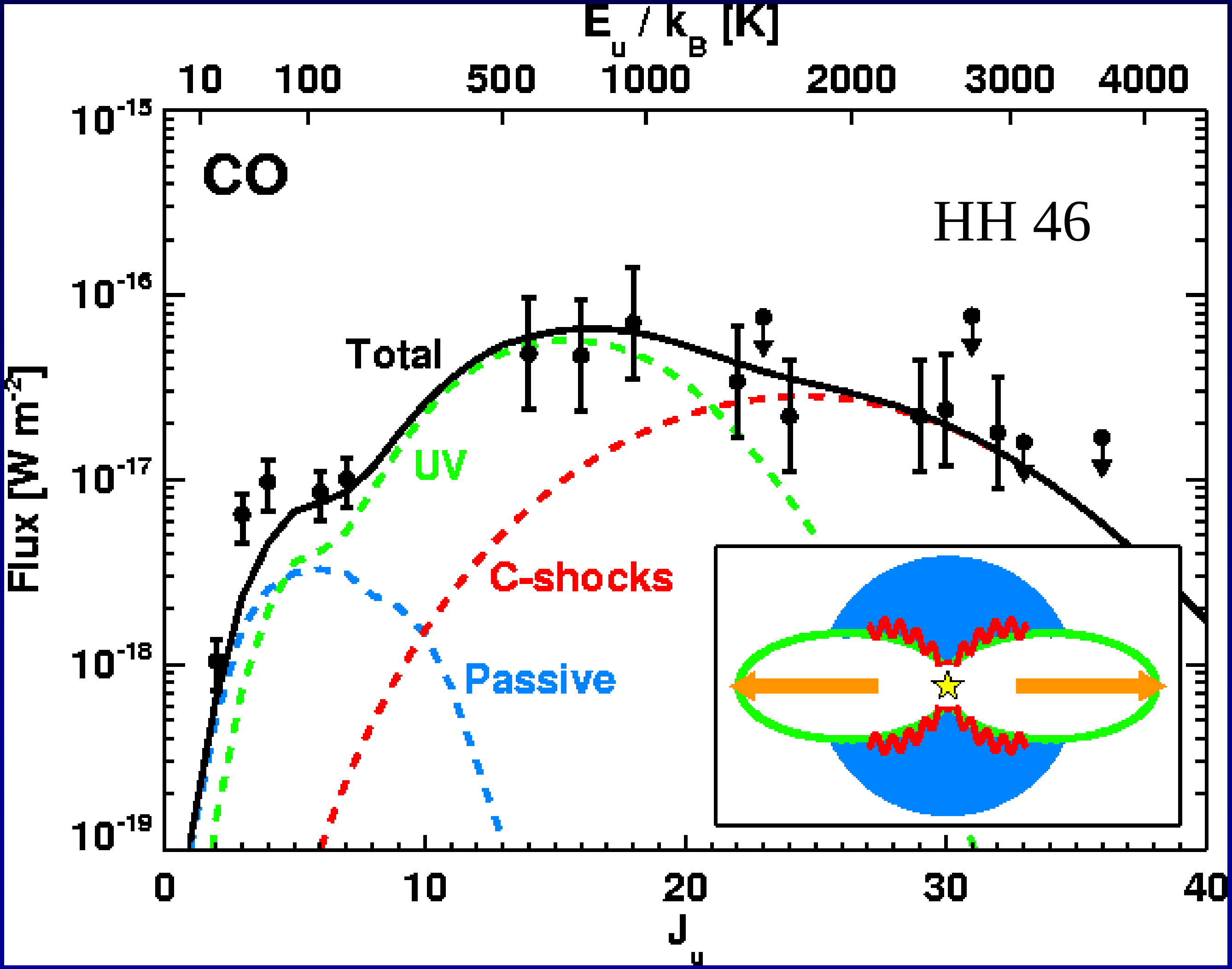
- Normalized relative to ^{12}CO 4-3 and ^{13}CO 6-5

Van der Werf et al., 2010; Wright et al., 1991; Habart et al., 2010; Weiss et al., 2007; Yildiz et al., 2012

Message 2

- **Only ^{12}CO *J*>10 probes same physical components as PACS**
  - **UV heated gas**
  - **Directly shocked gas**

Origin of hot CO



Only parameters: UV field G_o and v_{shock}

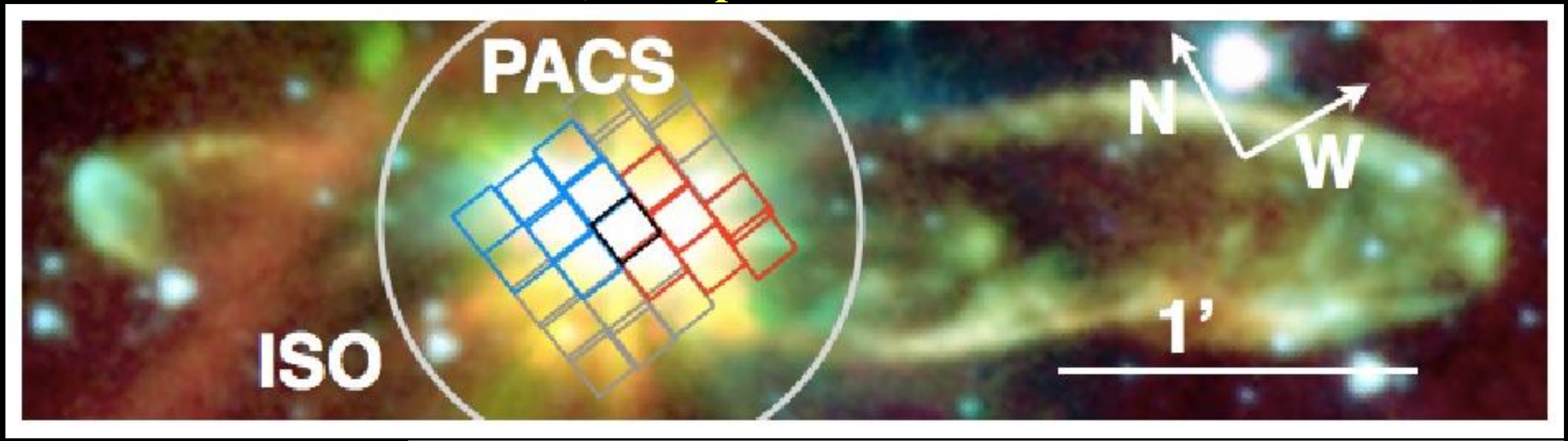
Visser, Bruderer, et al. 2012
van Kempen, Kristensen et al. 2010

Envelope and outflow of HH46

Spatially-resolved Herschel/PACS Spectroscopy

R=1500-4000, 9.4” pixels

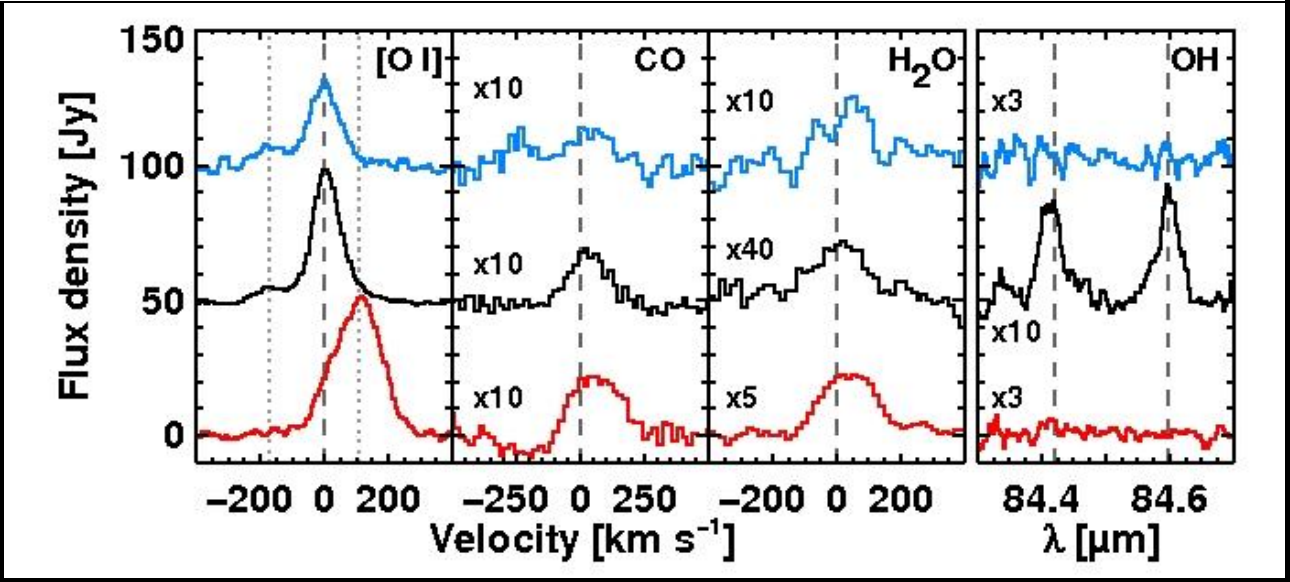
van Kempen,Kristensen, Herczeg et al. 2010



Blueshifted Outflow

Inner envelope

Red-shifted Outflow

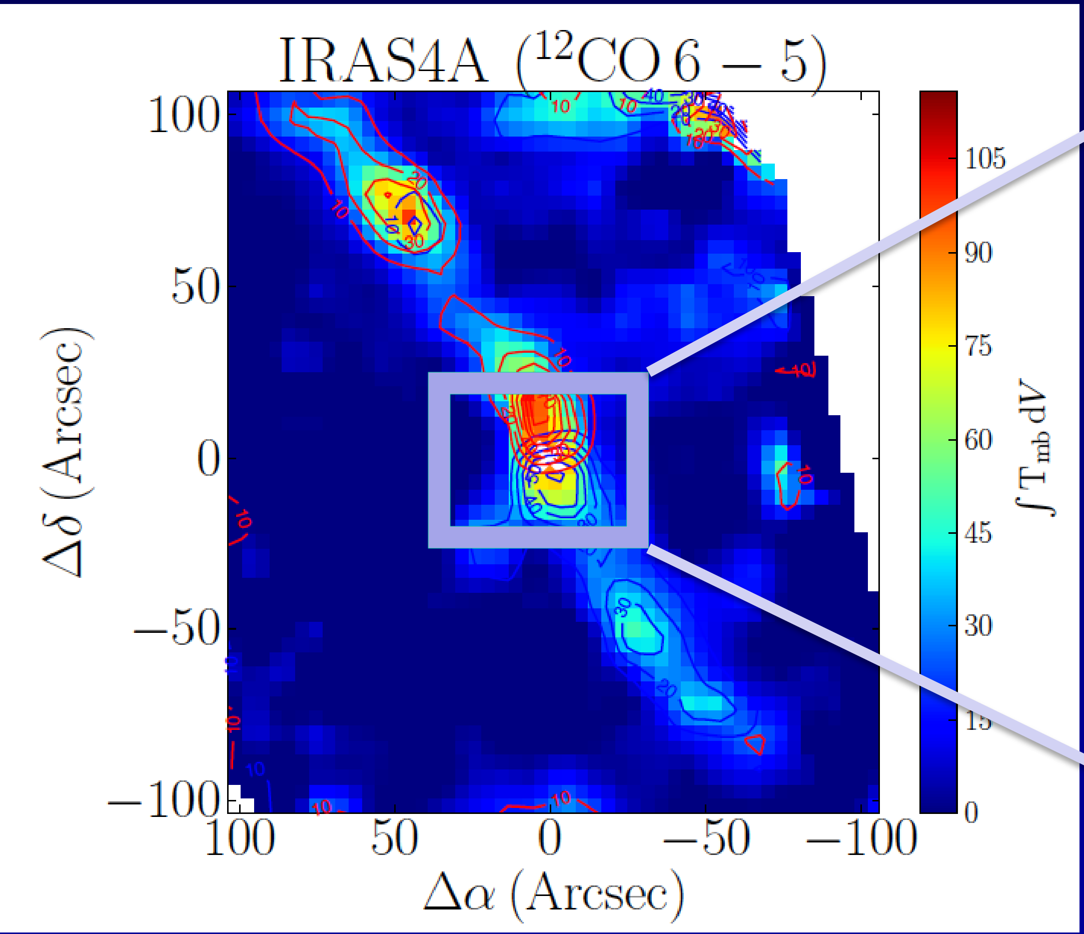


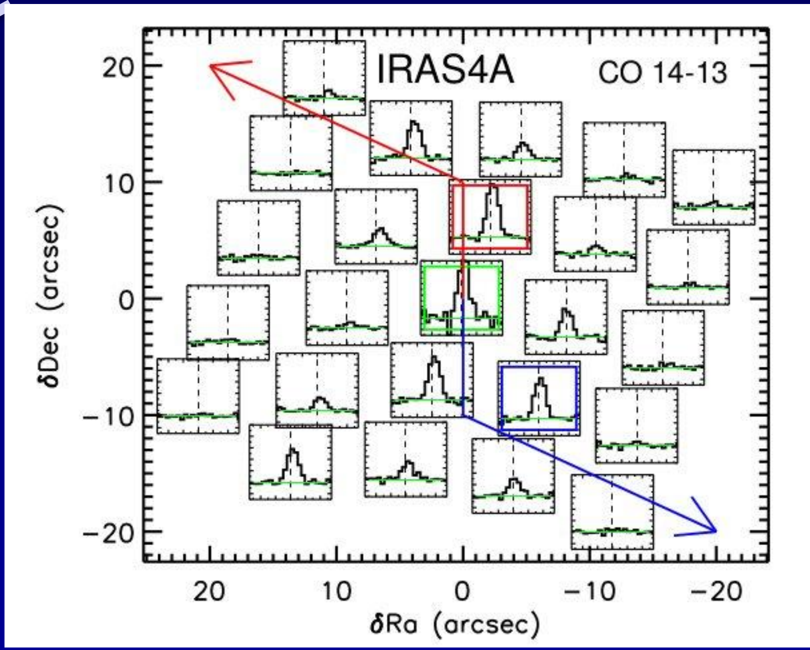
Note association of CO and H_2O with outflow

NGC1333 IRAS4A with PACS

APEX-CHAMP+ CO 6-5

Herschel/PACS
CO 14-13

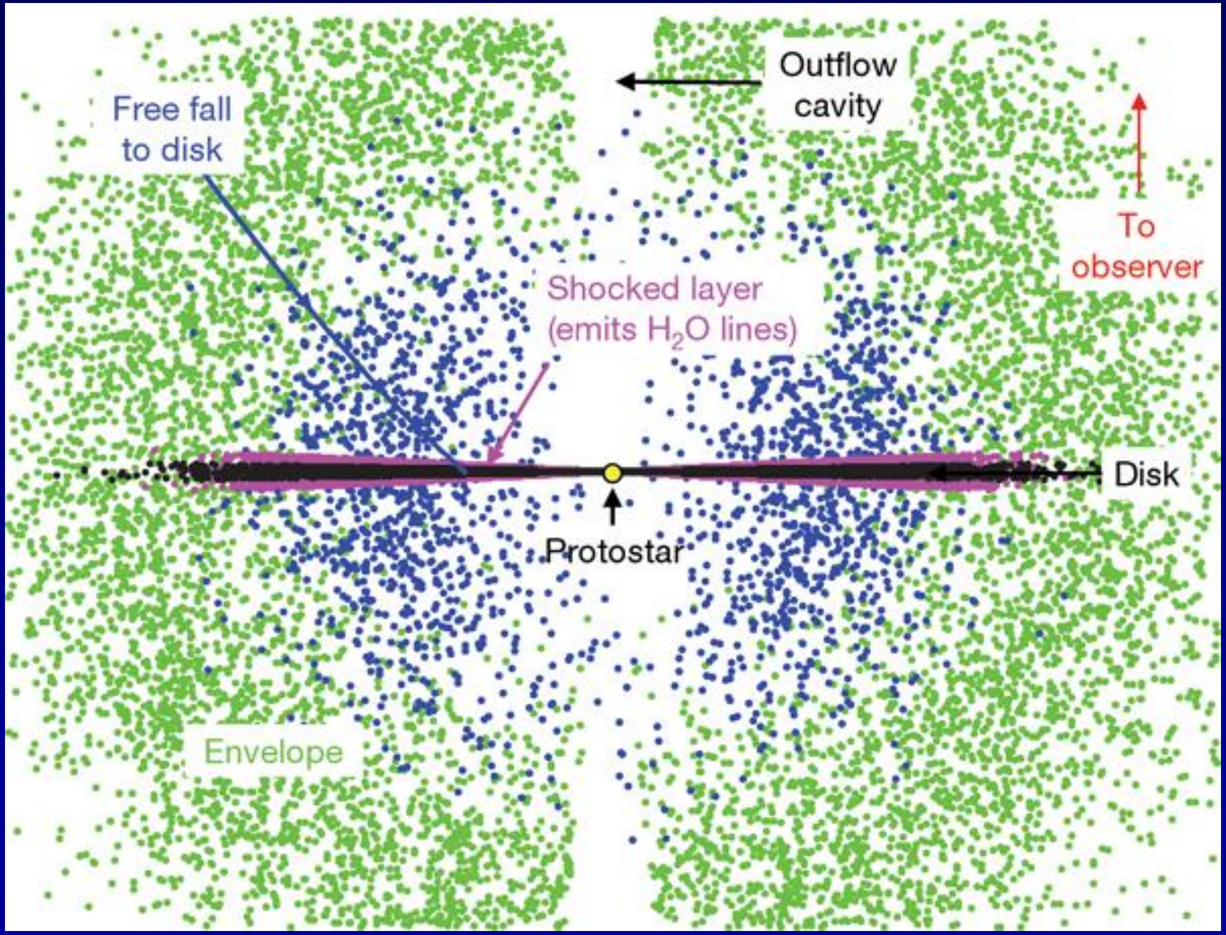




Karska+, in prep.

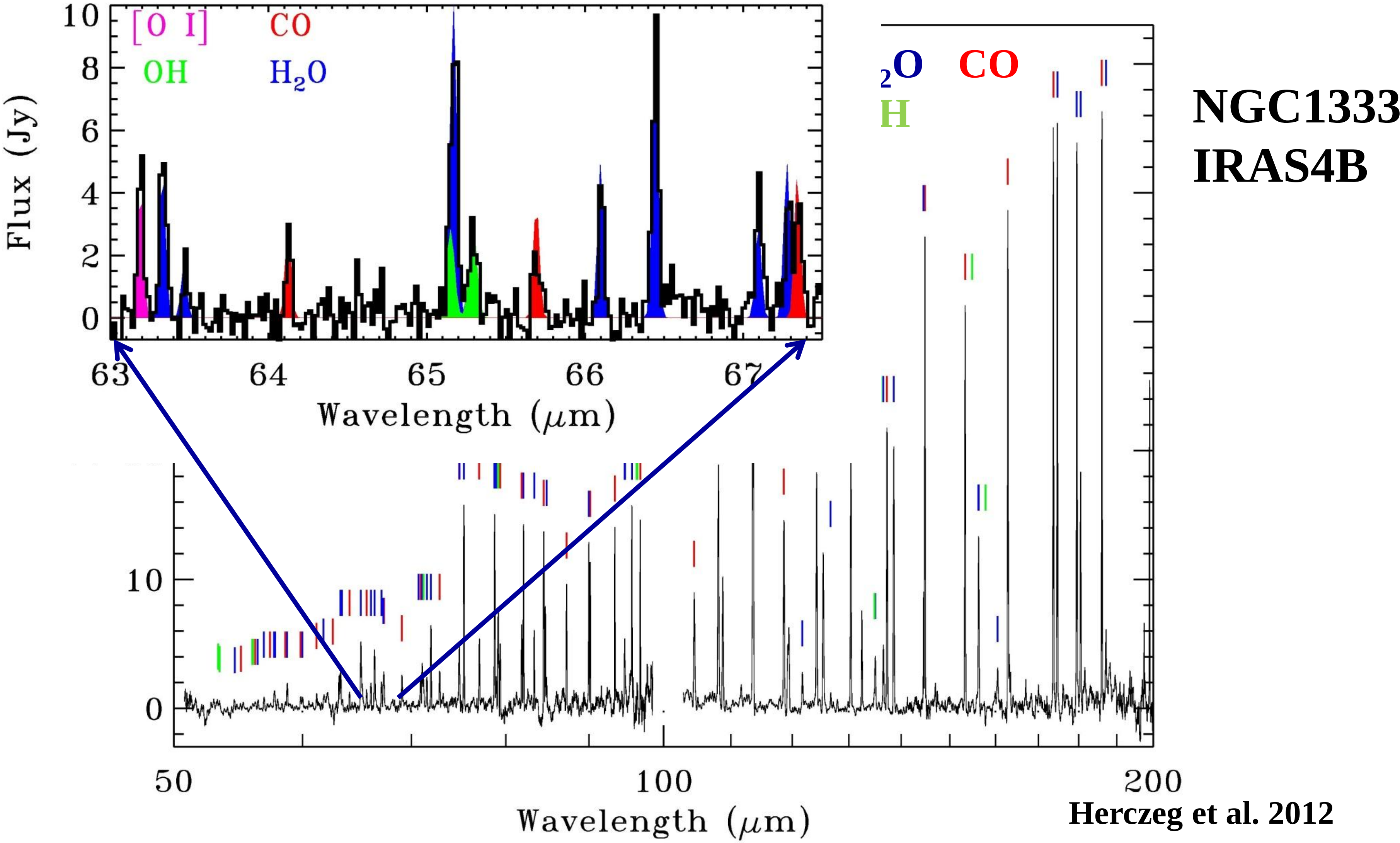
Yildiz+2012

Do hot water and CO trace accretion shock onto disk?



Watson et al. 2007, Nature

NGC1333 IRAS4B: PACS spectral scan

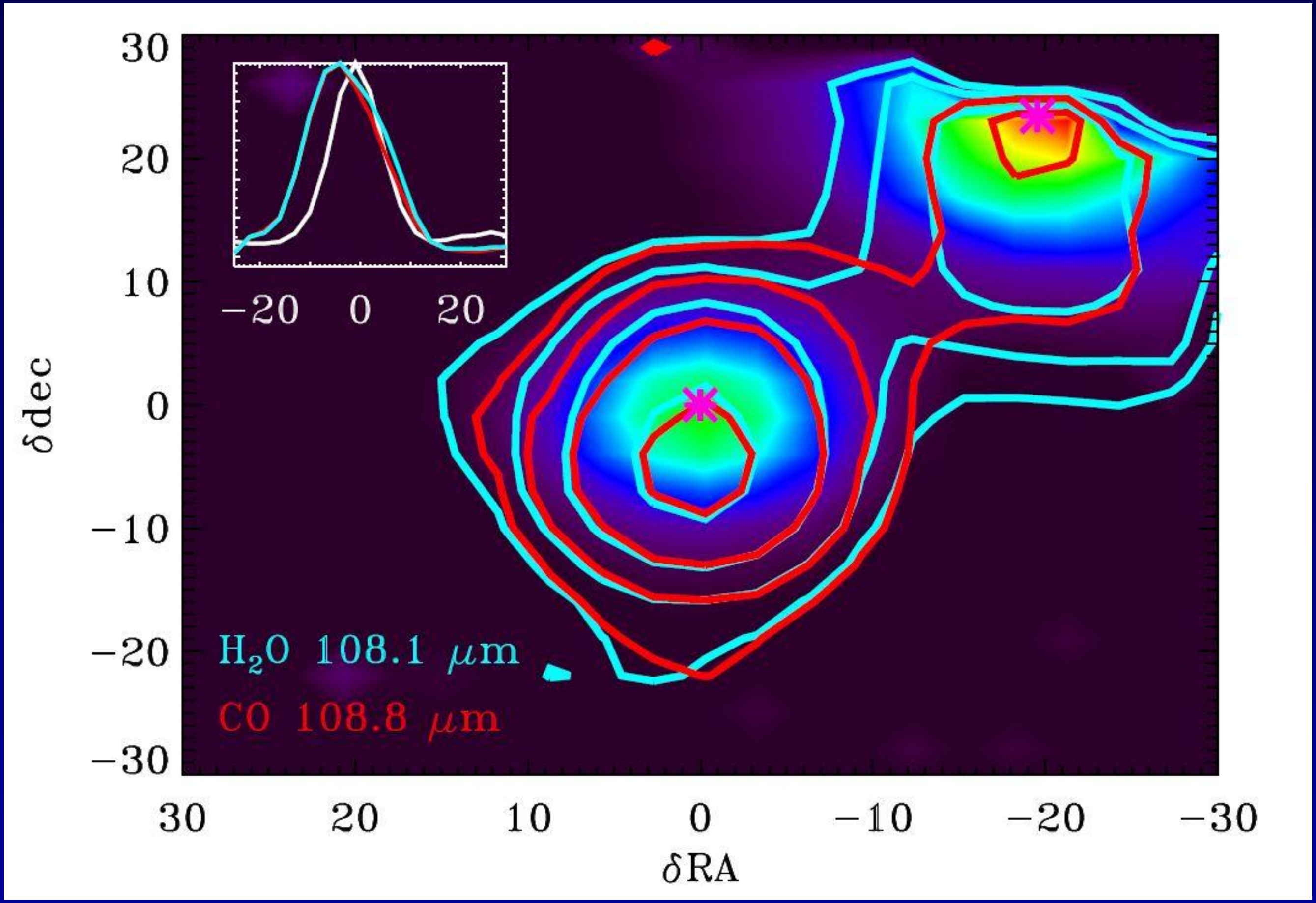


Herczeg et al. 2012

- One of the richest PACS spectral scans

H_2O and CO in outflow, not disk

Use PACS raster mode for fully sampled map



Herczeg et al. 2012

Hot CO and H_2O clearly displaced from far-infrared continuum → not disk

Message 3

- CO PACS lines spatially extended and associated with outflow direction
- Hot H_2O follows high-*J* CO, not low-*J* CO

WISH =

Water IS Hot

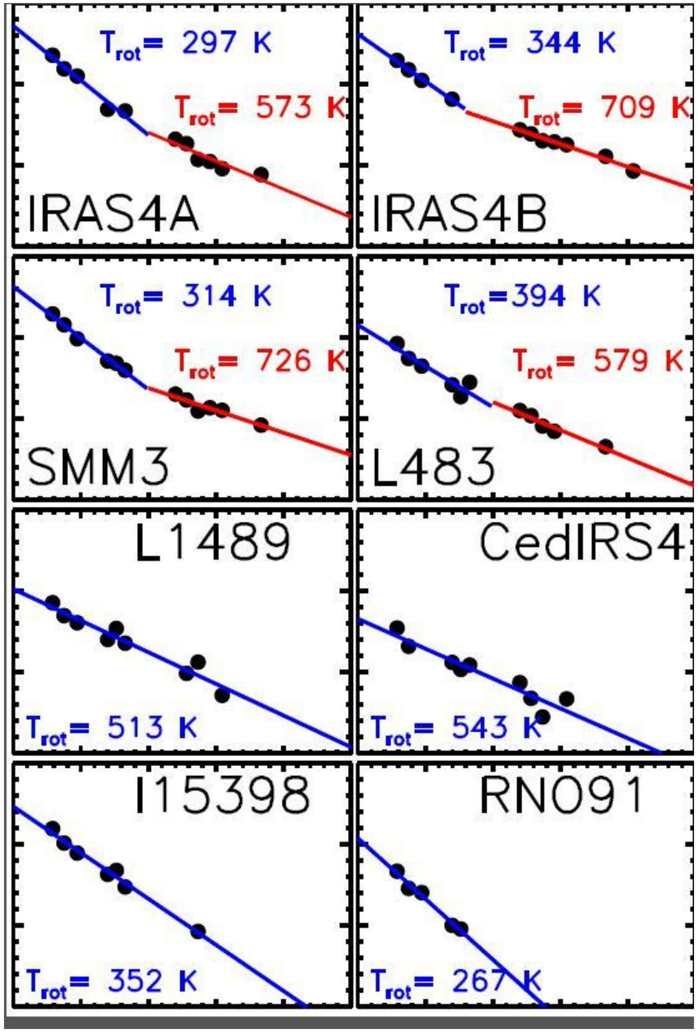
M. Tafalla

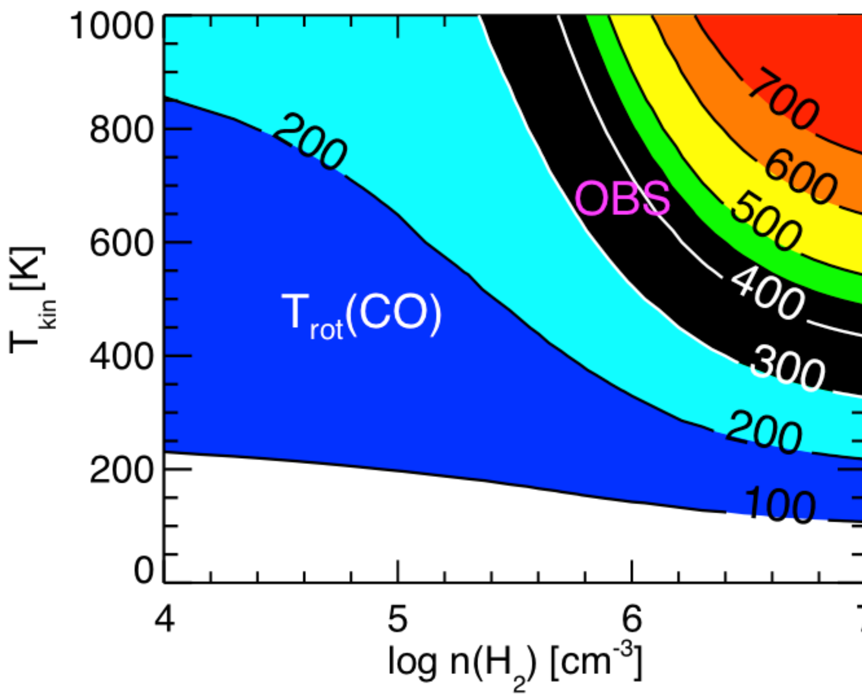
CO ladders for Class 0+I YSOs

Karska+, in prep.

Class 0

Class I

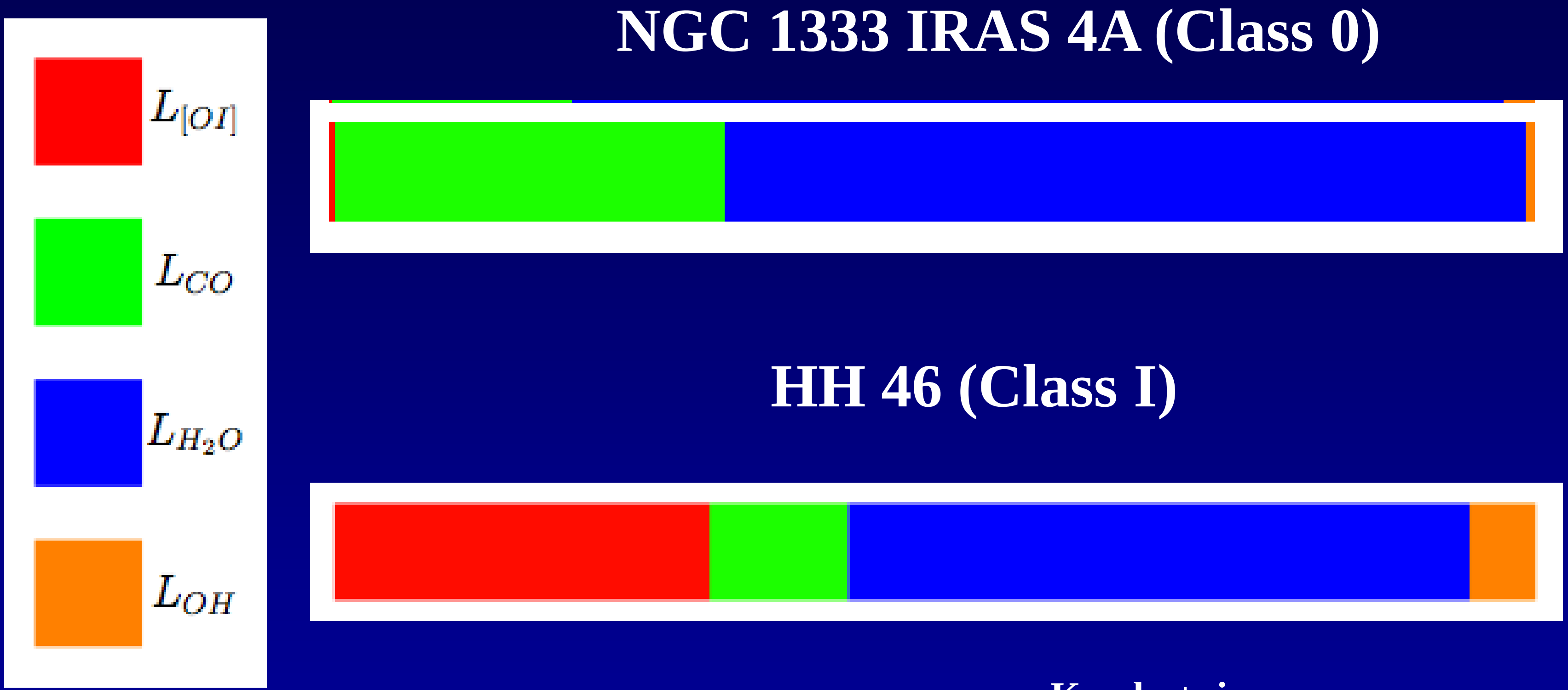




High-T and high-n required to explain observations

- ✧ "Warm" (T~300 K) and "hot" (T~700 K) components
- ✧ "Hot" component disappears for some Class I sources (TBC)?

Far-IR cooling budget



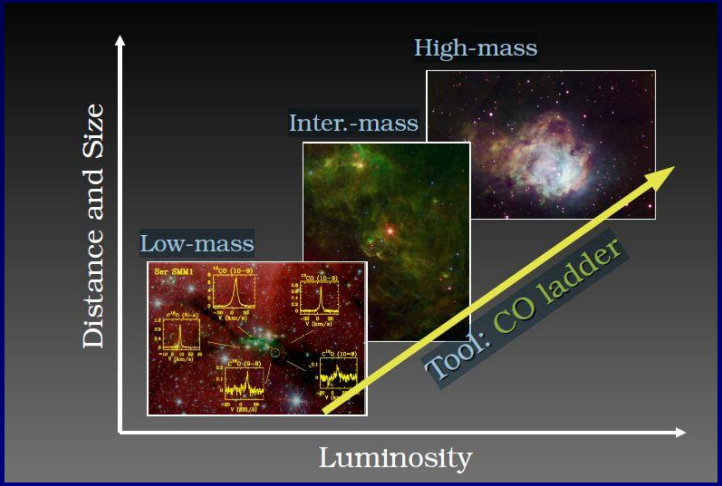
Karska+, in prep.

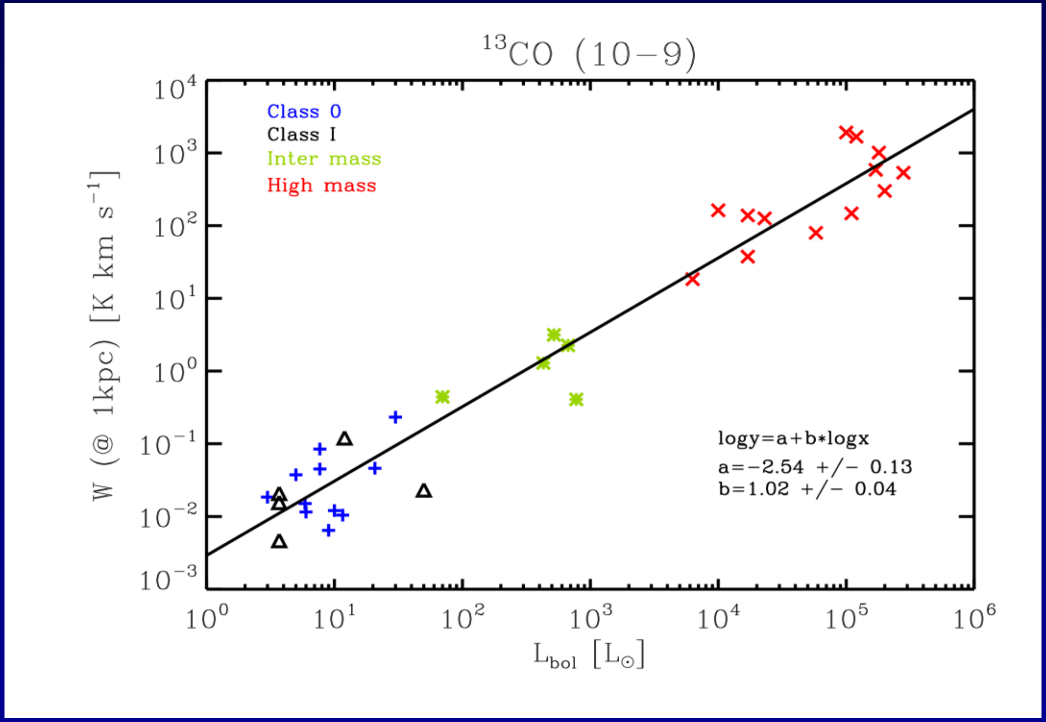
- ✧ Cooling by [OI] marginal in Class 0, but rises with evolution
- ✧ H_2O dominates far-IR cooling of deeply embedded YSOs

Message 4

- CO ladder can change from position to position
- CO ladder perhaps changes with evolution Class 0 to I (TBC)?
- CO significant coolant for Class 0 sources, but less for Class I

From low to high mass: ^{13}CO 10-9 as tracer of warm gas mass:



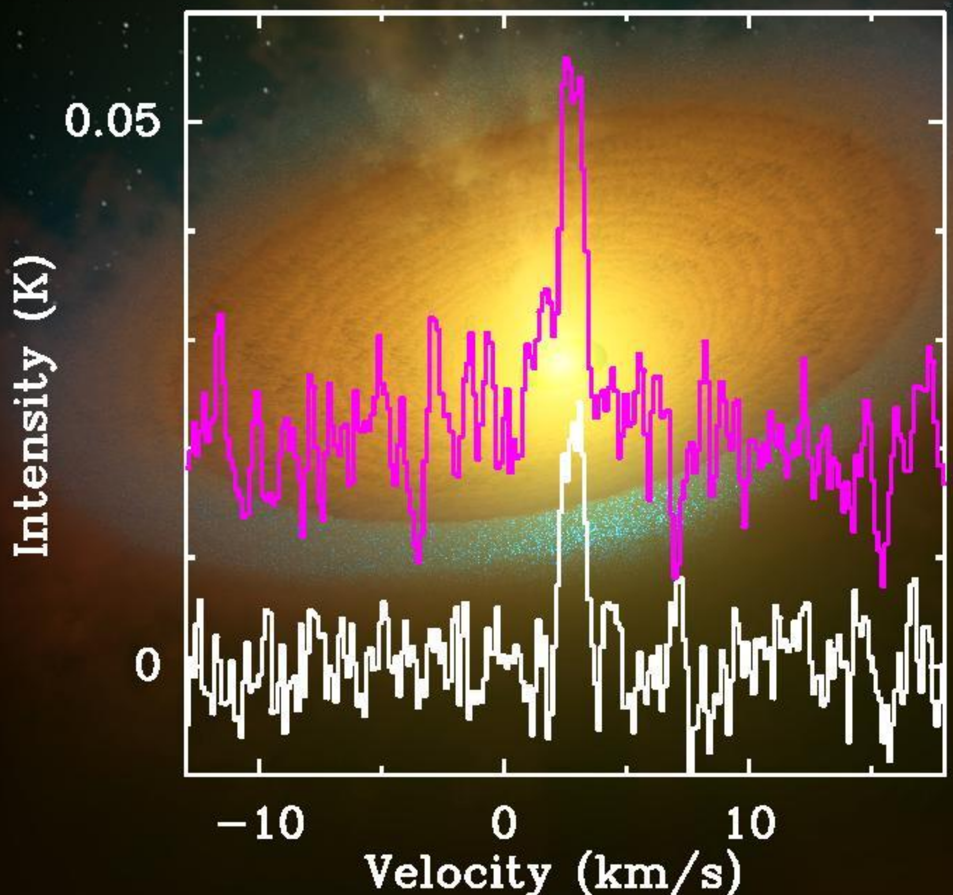


SanJose-Garcia et al. in prep
Yildiz et al. in prep

Message 5

- **Same conclusions hold from low to high-mass protostars (<1 to >10^5 L_{Sun})**

TW Hya ortho and para H_2O



p-H_2O 1_{11}-0_{00}
1113 GHz

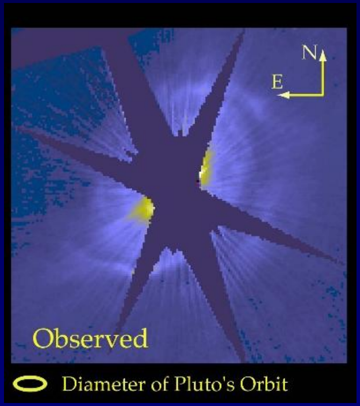
o-H_2O 1_{10}-1_{01}
557 GHz

Hogerheijde et al. 2011, Science

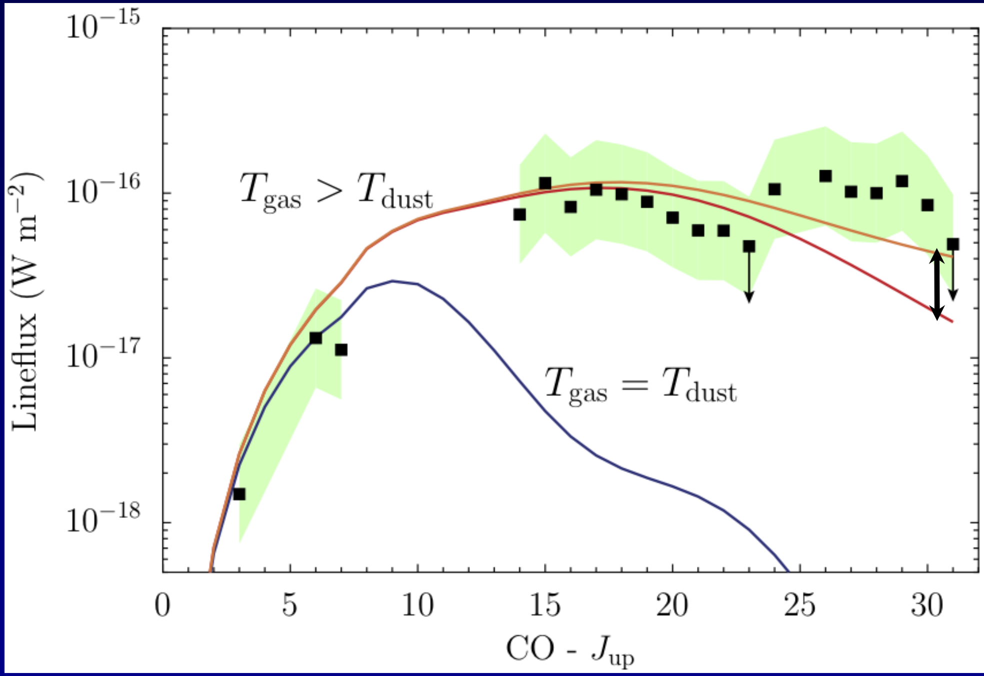
Points to water ice reservoir of 6000 oceans

Also CO 10-9 HIFI data for same sources

HD 100546 : CO ladder



HST: Grady et al. 2001



Different H_2 formation rates

Bruderer et al. 2012

Evidence that gas- and dust temperatures are decoupled in atmosphere

Message 6

- **High-*J* CO from disks readily reproduced by models with $T_{gas}>T_{dust}$**
- **Emission comes from a range of radii**

DIGIT, Bruderer et al. 2012

Conclusions

- CO is seen in cold, warm and hot components
- Importance of velocity resolution, isotopologues and spatial extent to assign physical components

CO
AWARENESS
Trust in us to help you understand the effects of
Carbon Monoxide and other products of combustion