Water in star-forming regions with Herschel (WISH):
Recent results and emerging trends

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www.strw.leidenuniv.nl/WISH
Water In Star-forming regions with Herschel
The WISH team

Leiden, December 2011

Toledo, June 2011

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

Summary in van Dishoeck et al. 2011, PASP
WISH questions

- Which physical components does water trace?
  - Quiescent envelope, hot core, outflows, disks, ...
  - Gas cooling budget

- Where is water formed in space and by which processes?
  - Gas vs grains

- What is the water ‘trail’ from clouds to planets?
  - Origin of water on Earth
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 diverse kinematic components
From low to high mass protostars

\[ \text{H}_2\text{O} \quad 1_{11} - 0_{00} \quad \text{W3-IRS5} \times 0.2 \]
\[ \text{H}_2\text{O} \quad 2_{02} - 1_{11} \quad \text{W3-IRS5} \times 0.1 \]

Note similar profiles: broad, medium and narrow
Even \( \text{H}_2^{18}\text{O} \) lines dominated by broad emission for low mass

Kristensen et al. 2010
Johnstone et al. 2010
Chavarria et al. 2010
CO 10-9 from low to high mass

Note similarity profiles

San Jose-Garcia et al.
Trends across mass and time

- Similar profiles from low to high mass protostars except for scale
- Water only bright in embedded phase, not in cores or disks
Where is the water?

- ‘Streaming’ along the walls?
- Inside the cavity?
- As ice in the envelope?
Physical components

- Quiescent envelope
  - Narrow absorption/emission
- UV-heated cavity walls
  - Narrow emission CO mid-$J$
- Currently shocked gas
  - $\text{H}_2\text{O}$ broad, CO high-$J$
- Entrained outflow gas
  - CO low-$J$

Talks Lars Kristensen
and Ruud Visser, Poster Joe Mottram
Spatial distribution CO vs $\text{H}_2\text{O}$

APEX-CHAMP$^+$ CO 6-5

Herschel/PACS
CO 14-13 vs $\text{H}_2\text{O} \ 2_{12}-1_{01}$

N1333 IRAS4A ($^{12}\text{CO} \ 6-5$)

Poster Yildiz+2012

Water follows outflow and high-$J$ CO, not low-$J$ CO
Shocking water lines

- Lower excitation lines trace higher velocities

Poster Santangelo et al.

Santangelo et al. 2011
Vasta et al. 2011

E_{up} < 80 K
E_{up} > 130 K

PACS image 179 \mu m line

L1448 R4

Water
Rich far-IR shock spectra

- All lines assigned to 4 species, from levels up to several thousand K
Cooling by [OI] marginal in Class 0, but rises with evolution

H$_2$O dominates far-IR cooling of deeply embedded YSOs
Conclusion 1

- Water reveals different physical components of protostellar environment more effectively than does CO
  - Kinematic information crucial!
- Emission dominated by high $n (>10^5 \text{ cm}^{-3})$, high $T (>400 \text{ K})$ shocks
- Far-IR cooling budget being quantified
- Processes similar from low- to high-mass YSOs

WISH = Water IS Hot

M. Tafalla
H$_2$O chemistry: three routes

Low T

- OH$^+$
- H$_2$O$^+$
- H$_3$O$^+$

High T

- O
- OH
- H$_2$

Ice

- H$_2$
- e

H$_2$O:gr

O:gr
Pre-stellar cores: where is water formed?

H$_2$O gas ring

$\text{H}_2\text{O} \text{gas= Ice formation}$

Photodesorption

$2.10^{4} - 5.10^{6} \text{ cm}^{-3}, T=10 \text{ K}$

Layer of water gas where ice is photodesorbed

Alves et al. 2001
Bergin et al. 2002

Lab + Theory
A&vD2008
Öberg et al. 2009
- Emission requires high central density $\sim 10^7$ cm$^{-3}$
- Profile indicates infall of 0.1 km/s at 1000 AU

1.3 mm continuum map from Ward-Thompson et al. (1999)
How much water is where?

Visser et al. 2009
Herbst & vD 2009
Cold outer envelope

- Outer envelope abundance ~$10^{-8}$ - $10^{-9}$
Deep 5 hr integration on excited line reveals narrow H$_2^{18}$O
- Abundance only ~few ×10$^{-6}$

Talk Herpin, poster Choi
Warm and cold water abundances

- Why is warm abundance not $> 10^{-4}$?
- What causes variations from source to source?
How much water is where?

Visser et al. 2009
Herbst & vD 2009

~10^{-5}

<10^{-9}

~10^{-6}

~10^{-8}

<10^{-9}

~10^8 10^7 10^6 10^5 10^4
n (cm^{-3})

T (K)

H_2O evaporation

H_2O ice formation

outflow cone

H_2O gas

H_2O gas

H_2O-rich grain

CO-rich grain

CH_3OH

Complex organics

Complex organics

CO-rich
Detection of cold water in disks

$p$-H$_2$O $1_{11}$-$0_{00}$
1113 GHz

$o$-H$_2$O $1_{10}$-$1_{01}$
557 GHz

Talk Michiel Hogerheijde

Hogerheijde et al. 2011, Science
Conclusions 2

- Water is formed mostly on grains
  - Some in shocks at high $T$
- Photodesorption controls gas-phase water abundance in cold clouds and disks
- Water abundance in hot cores is lower than expected
  - Both low- and high-mass sources
- Water is transported into disks mostly as ice

Stay tuned for more water stories during the day