FUV and X-ray Irradiation

in Star-forming Regions

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WISH: Water In Star-forming regions with Herschel

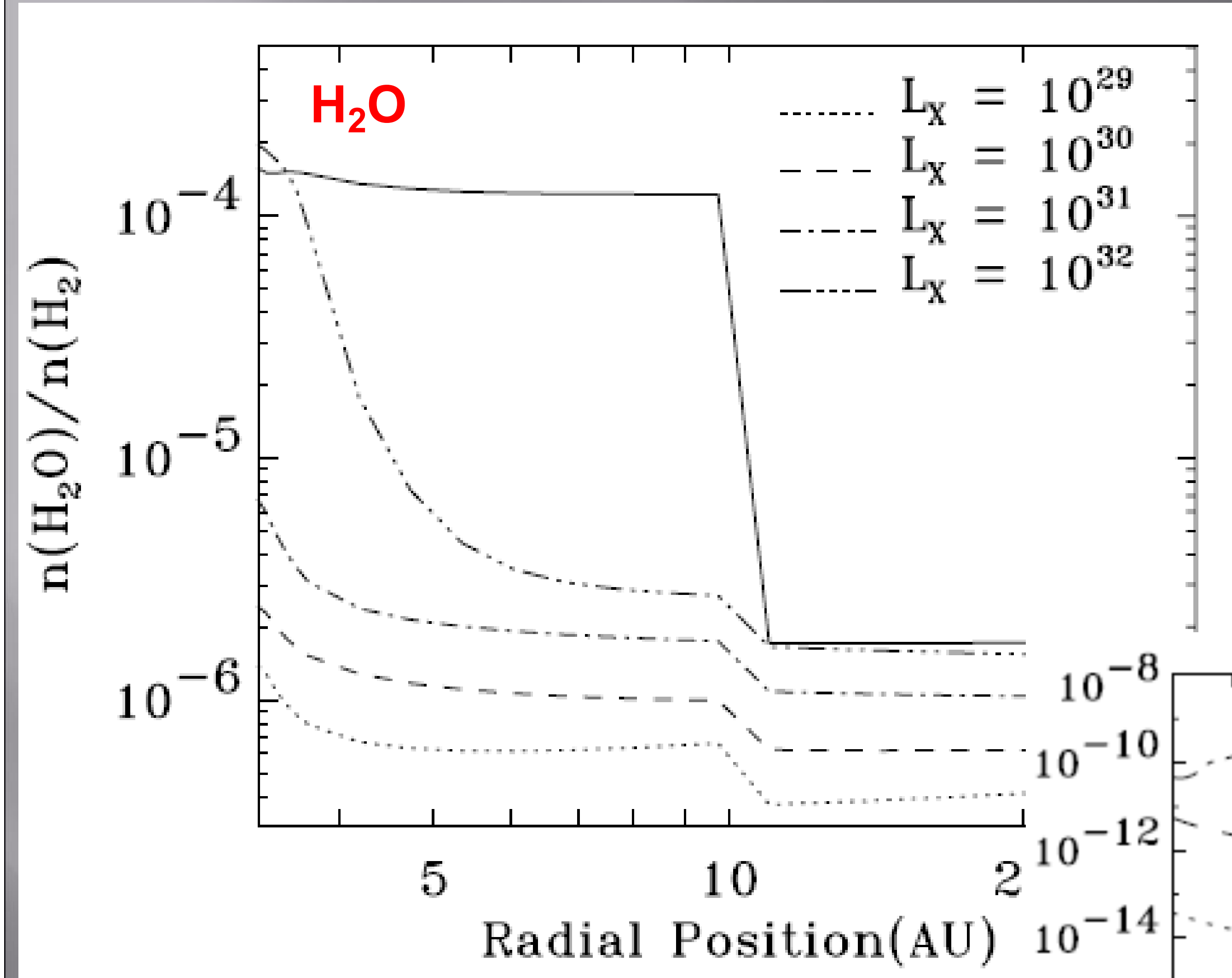
Goals

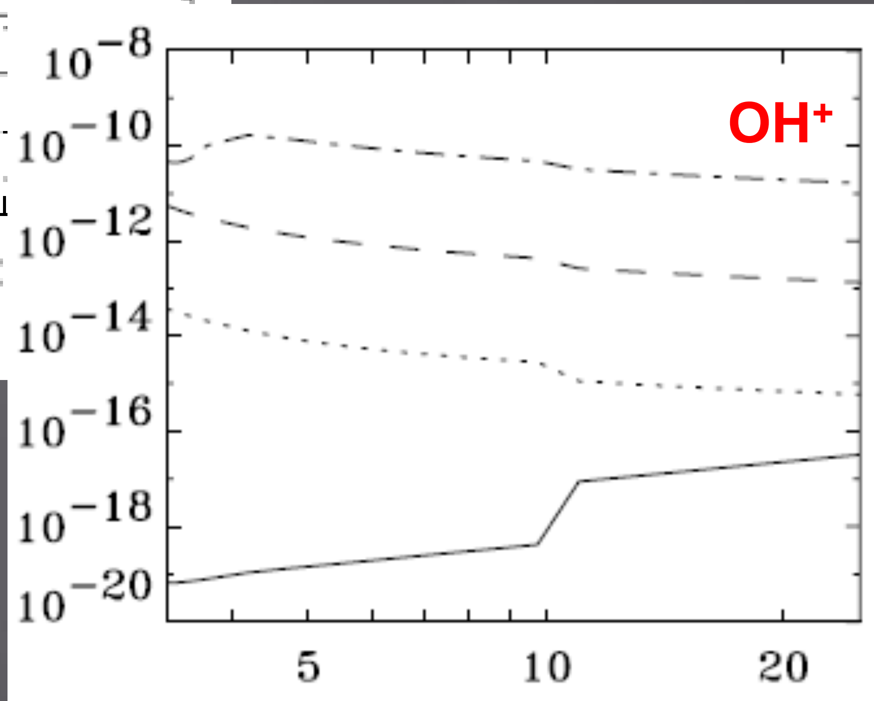
Radiation Diagnostics

1. Probe chemical network of water in YSO envelopes and outflows under far-UV and X-ray irradiation

2. Estimate ionizing far-UV and X-ray flux

Effects of internal ionizing radiation





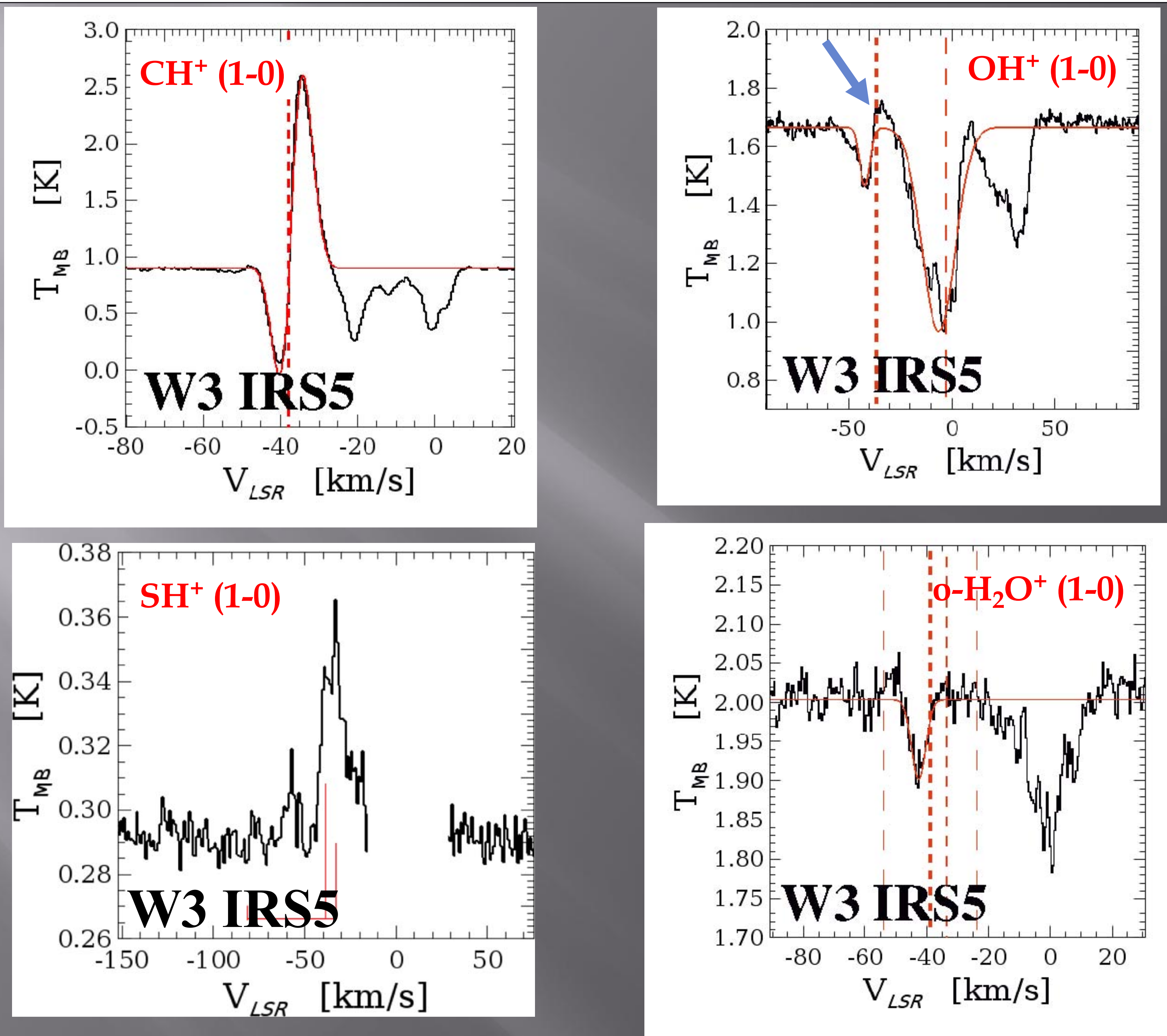
- Low-mass class I, 10^5 years
- 1D geometry, incl. cosmic rays

Stäuber+ 06

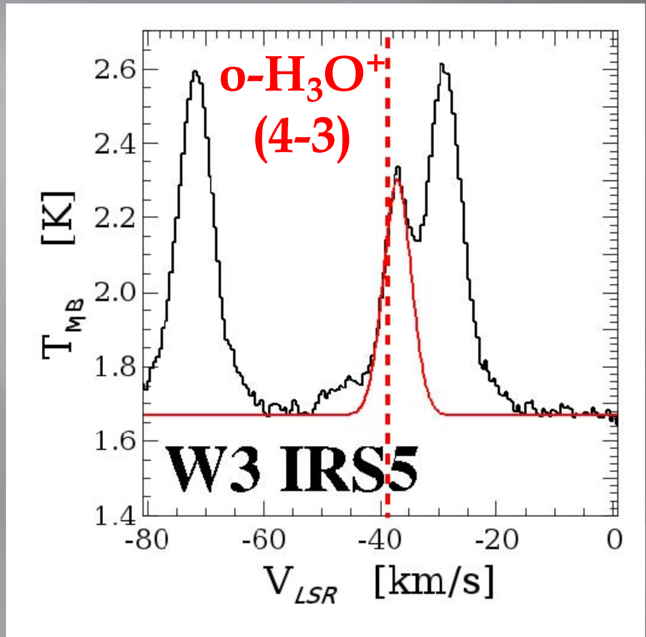
Herschel/HIFI Observations of hydrides

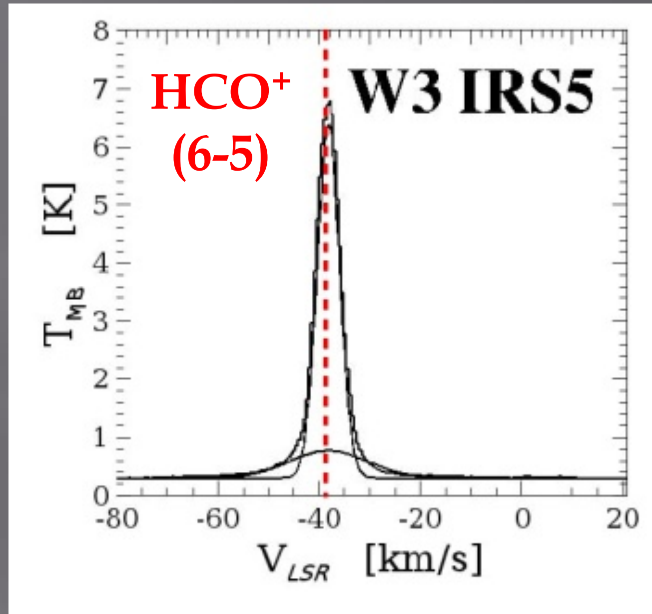
towards star-forming regions

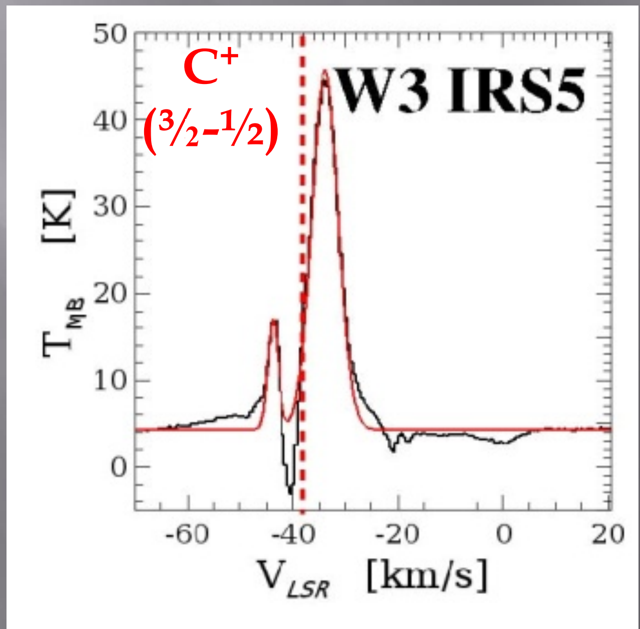
< 12 km/s relative to systemic velocity

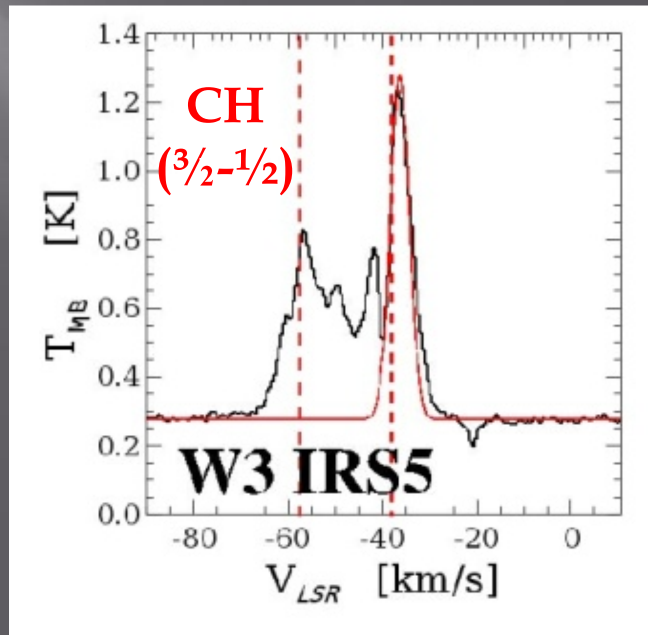

CH+ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
OH+ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
SH+ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
o-H2O+ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]

Benz+ 16


o-H3O+
(4-3)
W3 IRS5
TMB [K]
VLSR [km/s]
2.6
2.4
2.2
2.0
1.8
1.6
1.4
-80
-60
-40
-20
0


HCO+
(6-5)
W3 IRS5
TMB [K]
VLSR [km/s]
8
7
6
5
4
3
2
1
0
-80
-60
-40
-20
0
20


C+
(3/2-1/2)
W3 IRS5
TMB [K]
VLSR [km/s]
50
40
30
20
10
0
-60
-40
-20
0
20


CH
(3/2-1/2)
W3 IRS5
TMB [K]
VLSR [km/s]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-80
-60
-40
-20
0

Benz+ 16

Group I Molecules

(H_3O^+, SH^+, HCO^+, CH, OH, NH)

predominantly

- in emission
- narrow line width (< 5 km/s)
- unshifted relative to systemic velocity

comparable in line width to

- ^{13}CO (10-9) (San José Garcia et al. 2013)
- H_2O narrow component (Kristensen et al. 2013)

→ origin in envelope

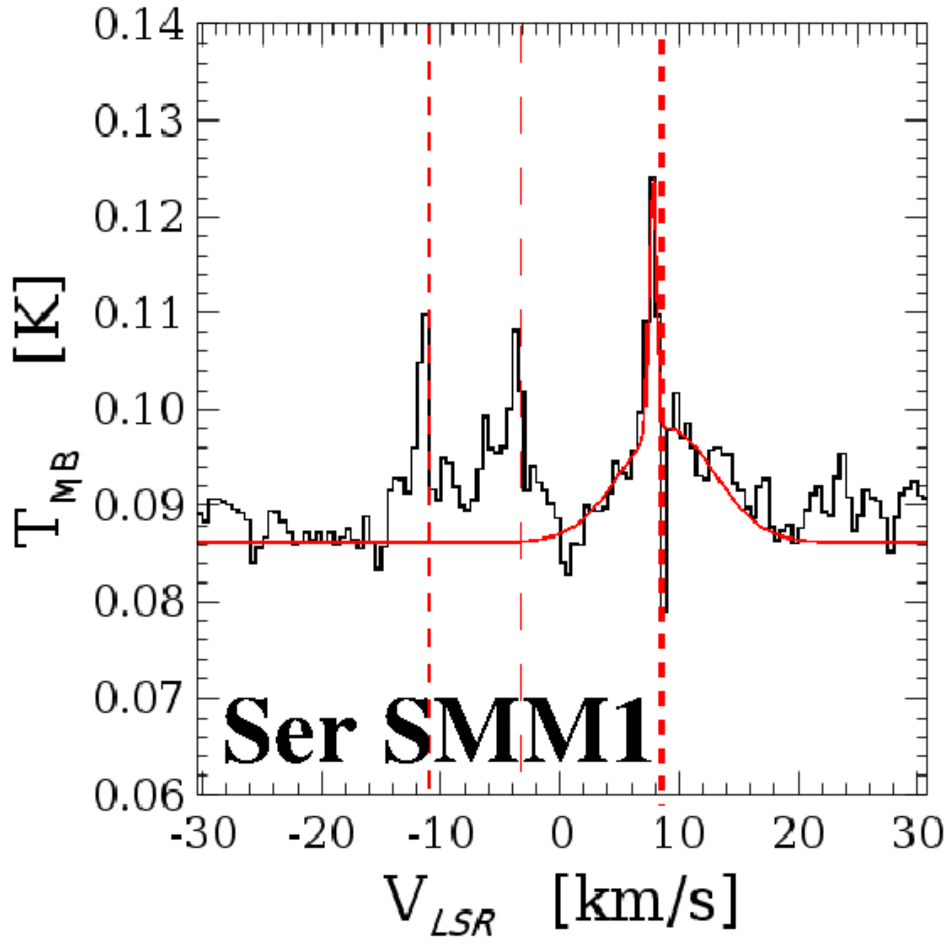
Group II Molecules

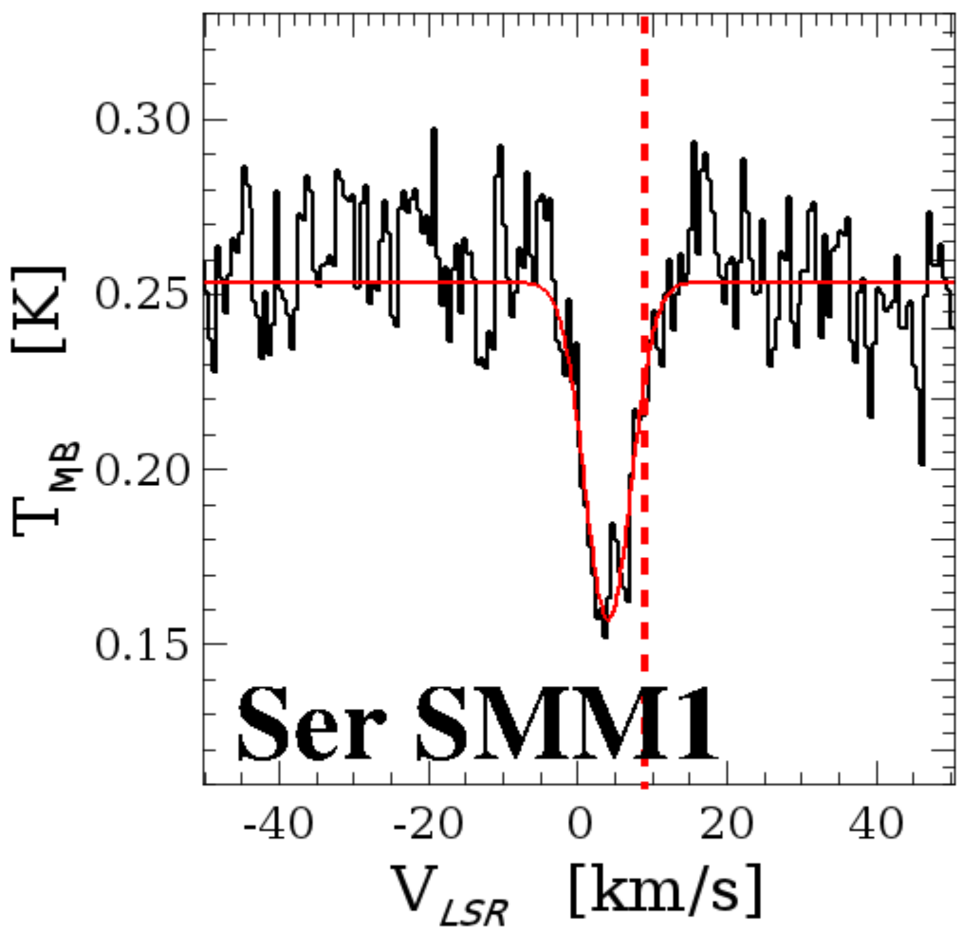
(CH^+, OH^+, H_2O^+, C^+)

predominantly

- **in absorption**
- **medium line width (5 – 10 km/s)**
- **blue-shifted**

→ origin in outflow wind or shock

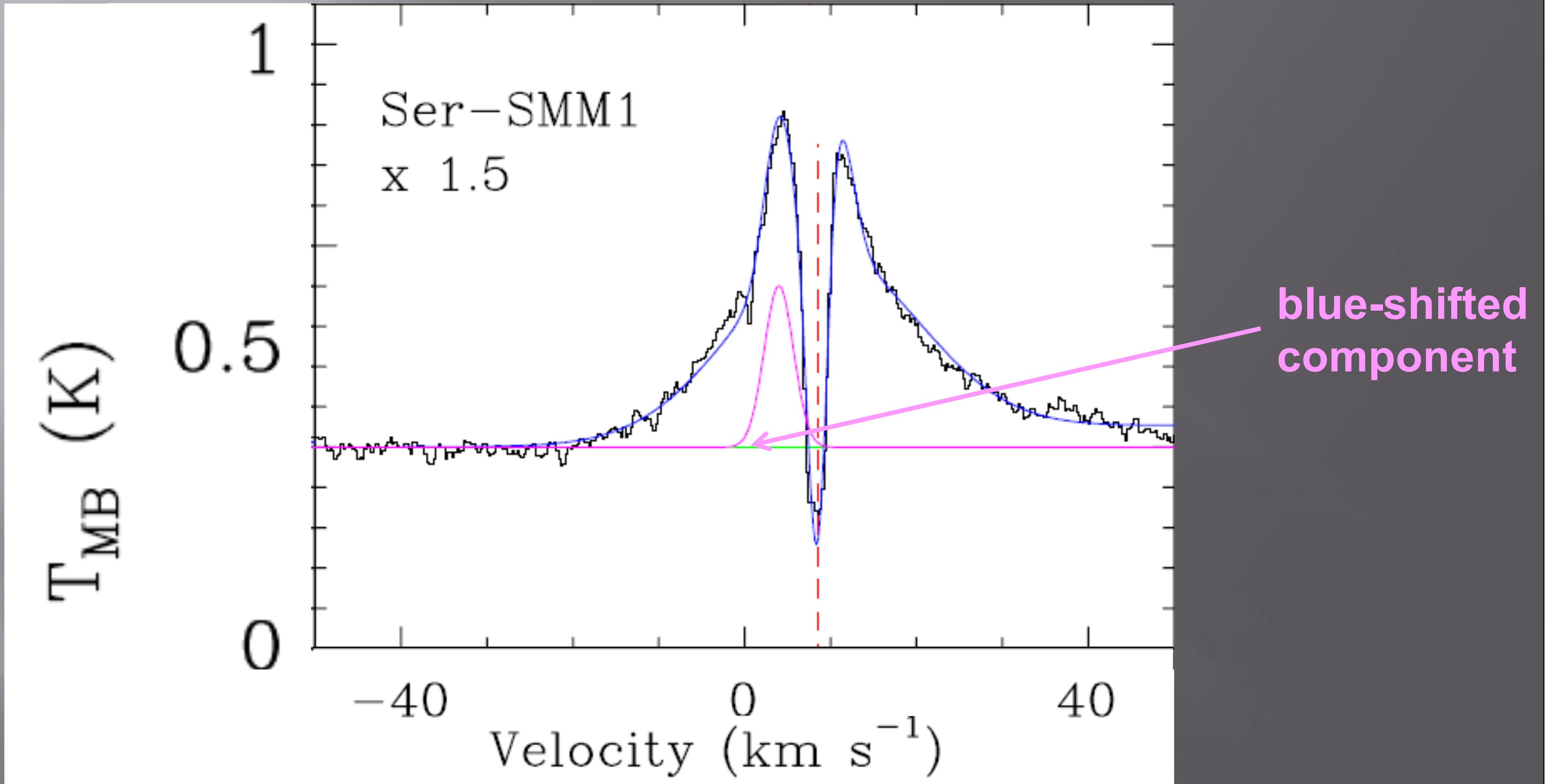




CH ($^3/_2$ - ½)
536 GHz
group I

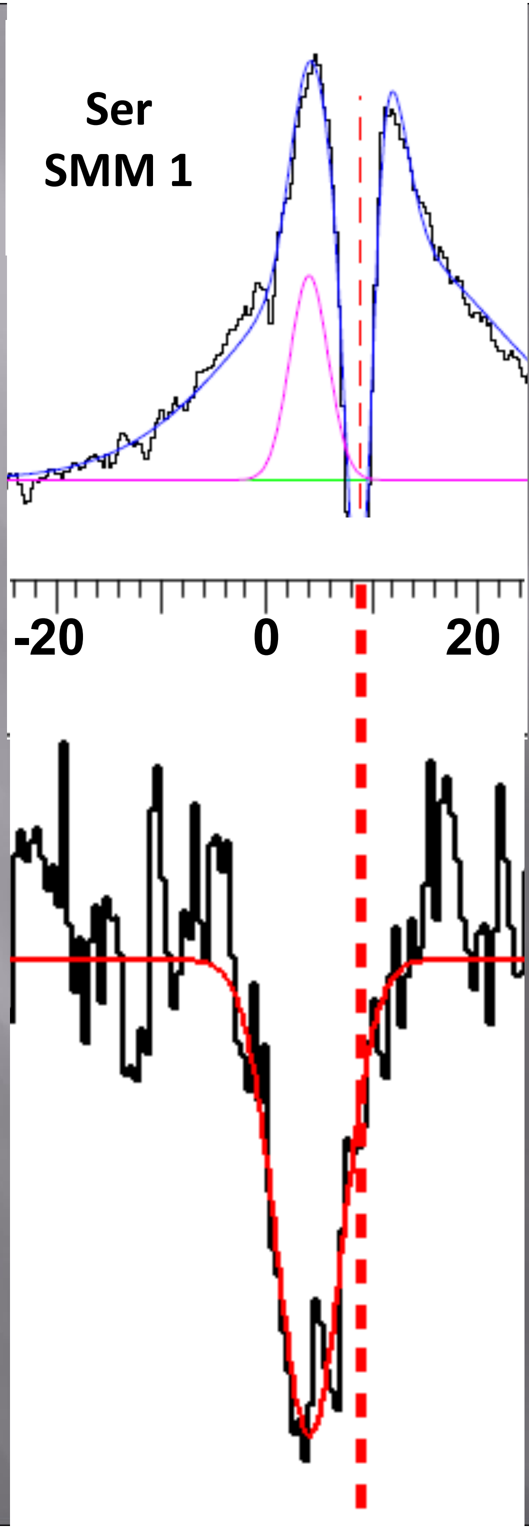
CH^+ (0-1)
835 GHz
group II

Benz+16



H_2O (1_{10}-1_{01})
557 GHz

Kristensen+ 13



H_2O (1_{10}-1_{01})

557 GHz

CH^+ (0-1)

835 GHz

group II

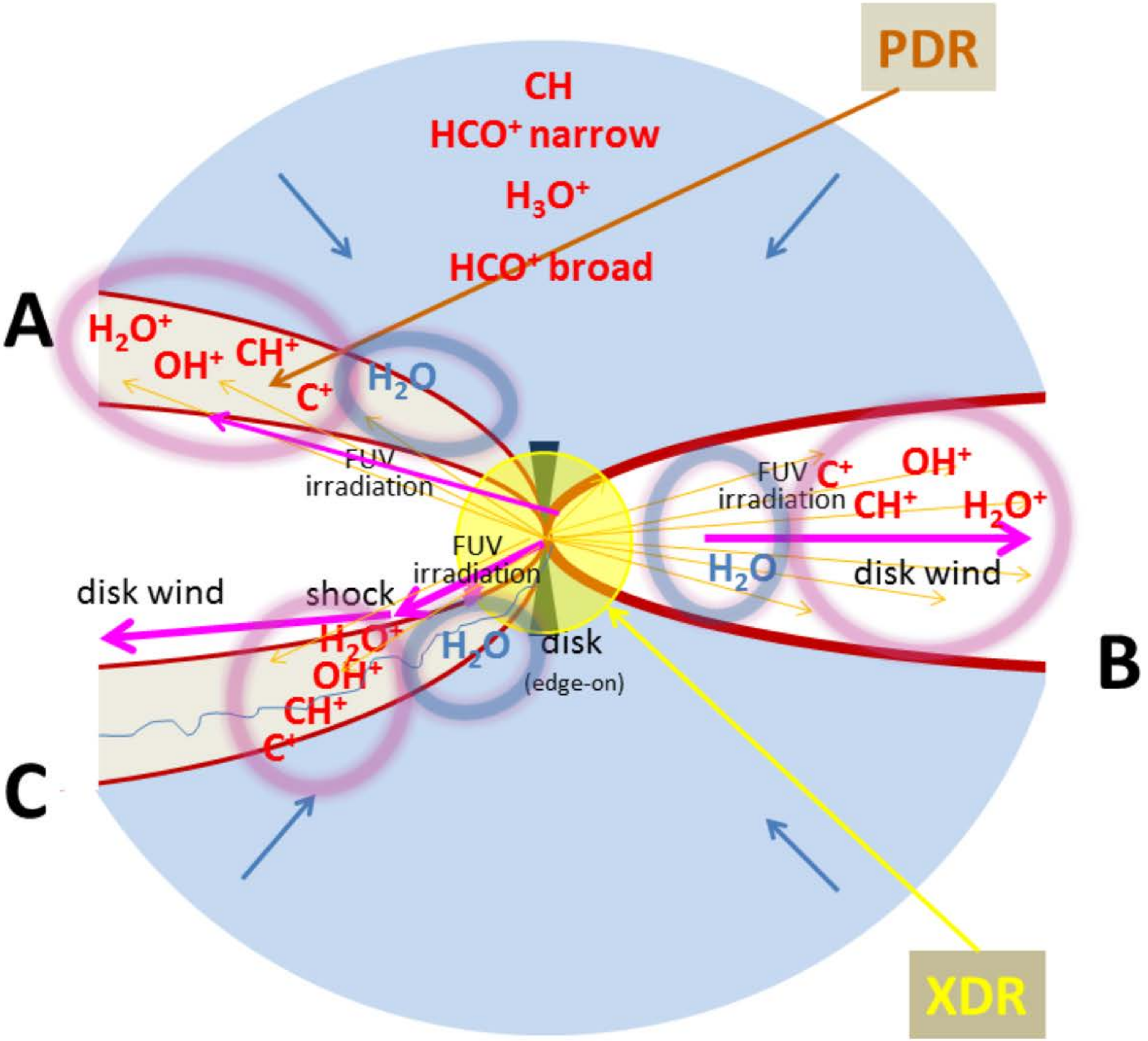
Possible Interpretation
(Group II)

medium line width (5-10 km/s) → shock or wind

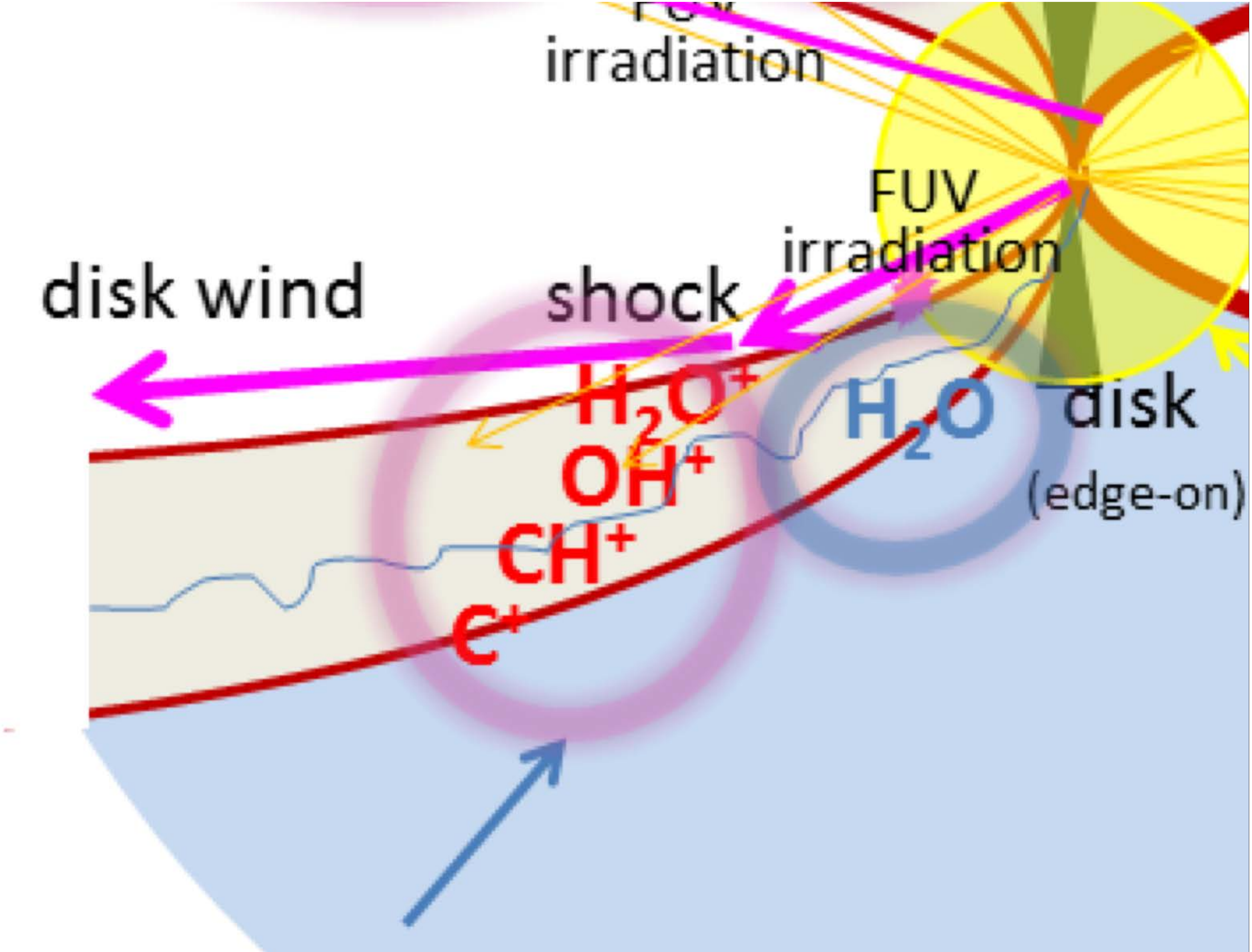
blue-shift (~10 km/s) → related to outflow

ionized → internal irraditation

Questions
- why absorption ?
- relation to H_2O ?

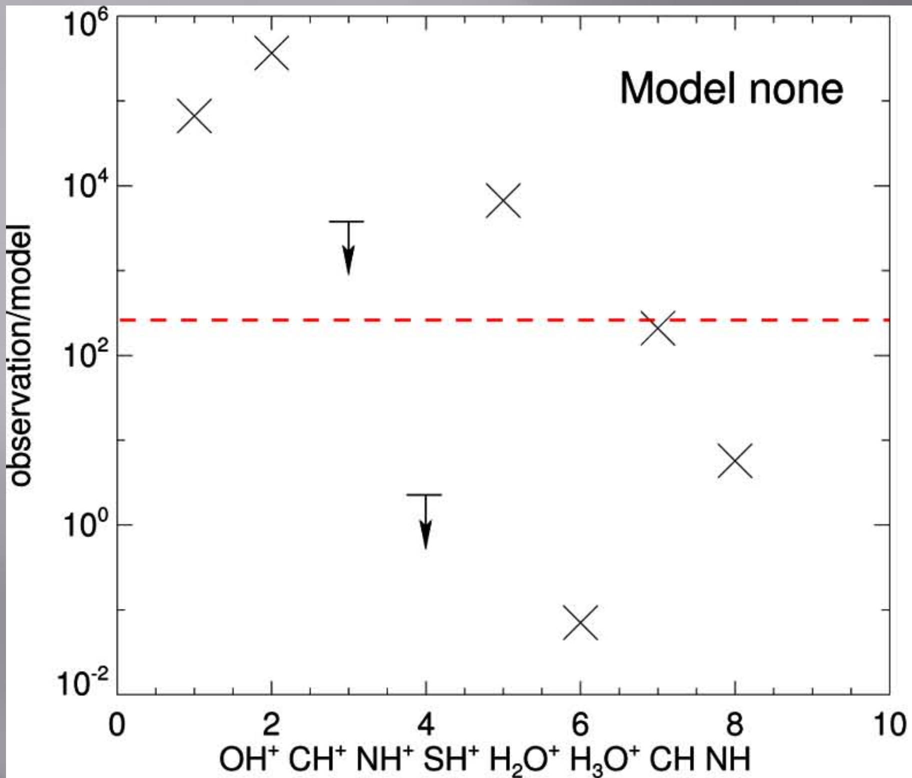

PDR
CH
HCO+ narrow
H3O+
HCO+ broad
A
H2O+
OH+
CH+
C+
H2O
FUV
irradiation
FUV
C+
OH+
irradiation
CH+
H2O+
H2O
disk wind
FUV
irradiation
disk wind
shock
H2O+
H2O
disk
(edge-on)
OH+
CH+
C+
B
C
XDR

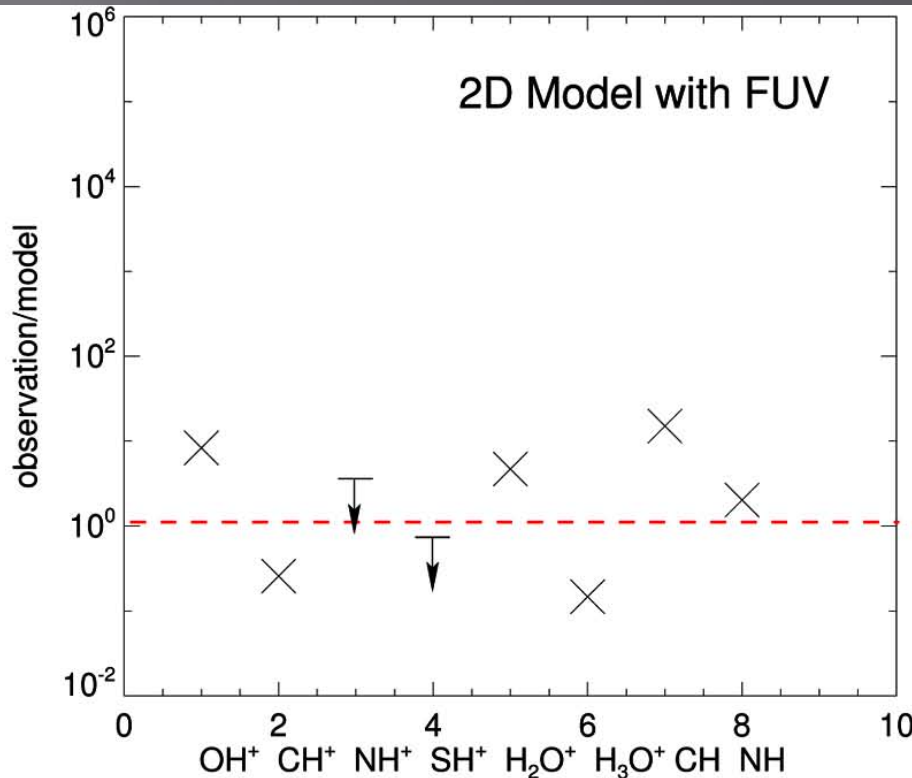
Benz+ 16


irradiation
FUV
irradiation
disk wind
shock
H_2O^+
OH^+
CH^+
C^+
H_2O
disk
(edge-on)

NOT irradiated

irradiated





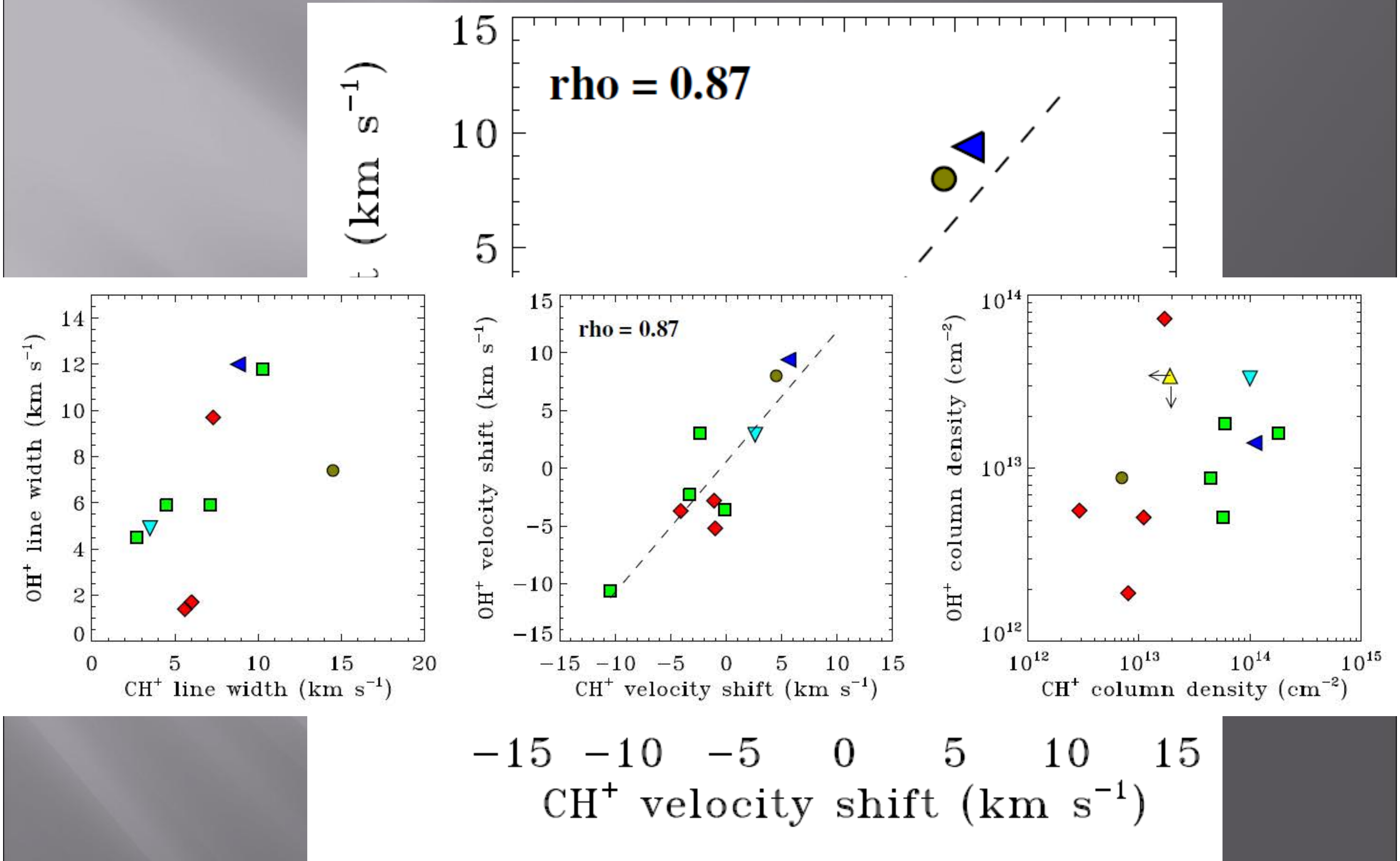
Comparison in column density: observations/theory

2D-model envelope with outflow cavity
(AFGL 2591)

Bruderer+ 10,
Benz+ 12

1. Probe chemical network of water in YSO envelopes and outflows under far-UV and X-ray irradiation

2. Estimate ionizing irradiation from CH^+/OH^+ ratio



Correlation of CH^+ and OH^+

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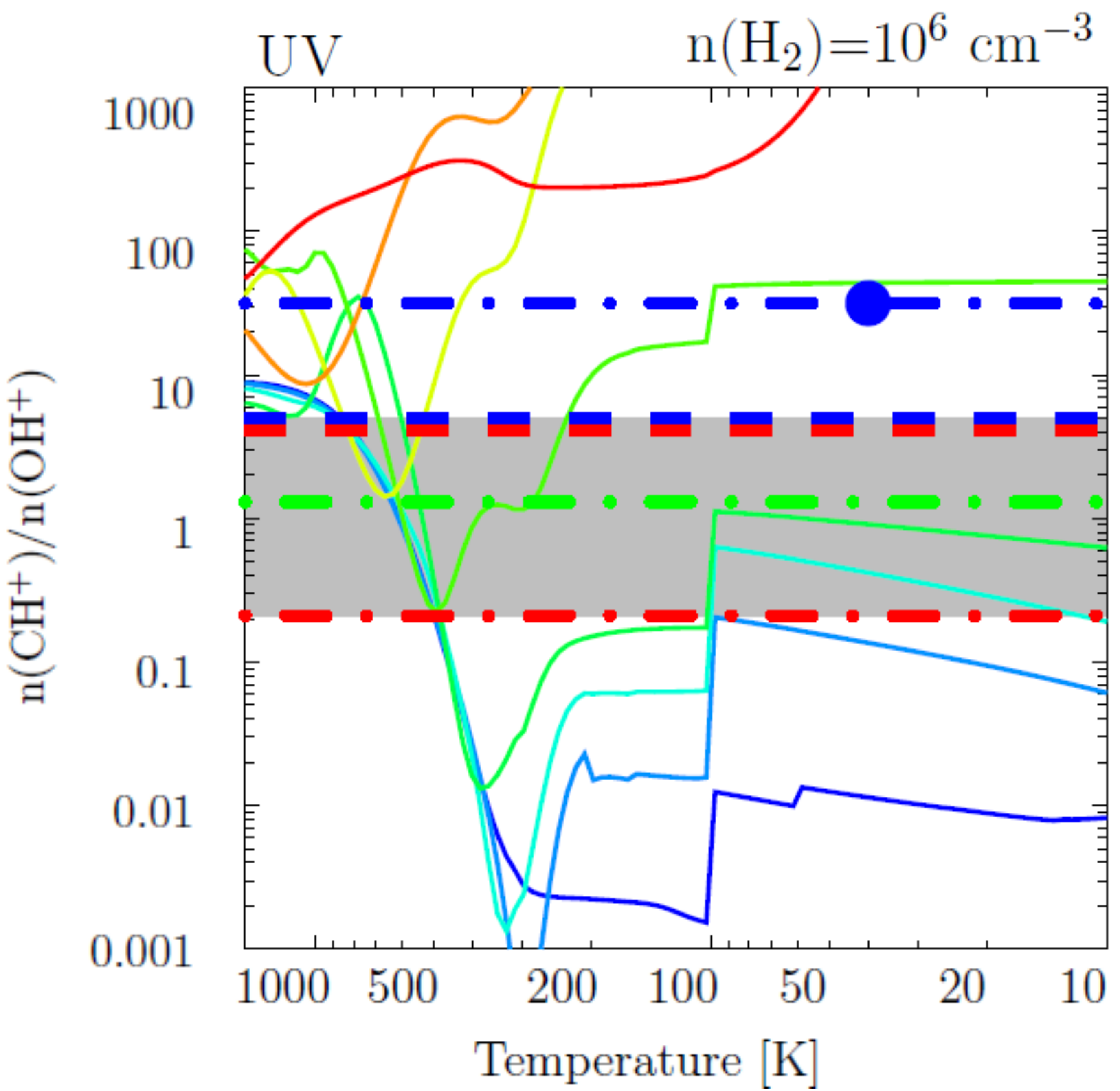
Object	$\frac{N(CH^+)}{N(OH^+)}$	$\frac{N(OH^+)}{N(H_2O^+)}$	$\frac{N(C^+)}{N(CH^+)}$
NGC1333 I2A	>2.1	–	43000
NGC1333 I4A	4.1	>0.39	≤16000
NGC1333 I4B	>0.48	–	<170000
Ser SMM1	0.21	≥15.5	3100
L 1489	–	–	–
NGC7129 FIRS2	0.75	>1.5	
W3 IRS5	5.0	2.7	>130000
W3 IRS5 emission	31.5	–	>580000
NGC6334 I	1.8	>124.0	
NGC6334 I(N)	1.4	>36.1	
AFGL 2591	1.3	19.4	>28000
S 140	1.8	>13.6	≥8800
NGC7538 IRS1	0.48	>24.5	



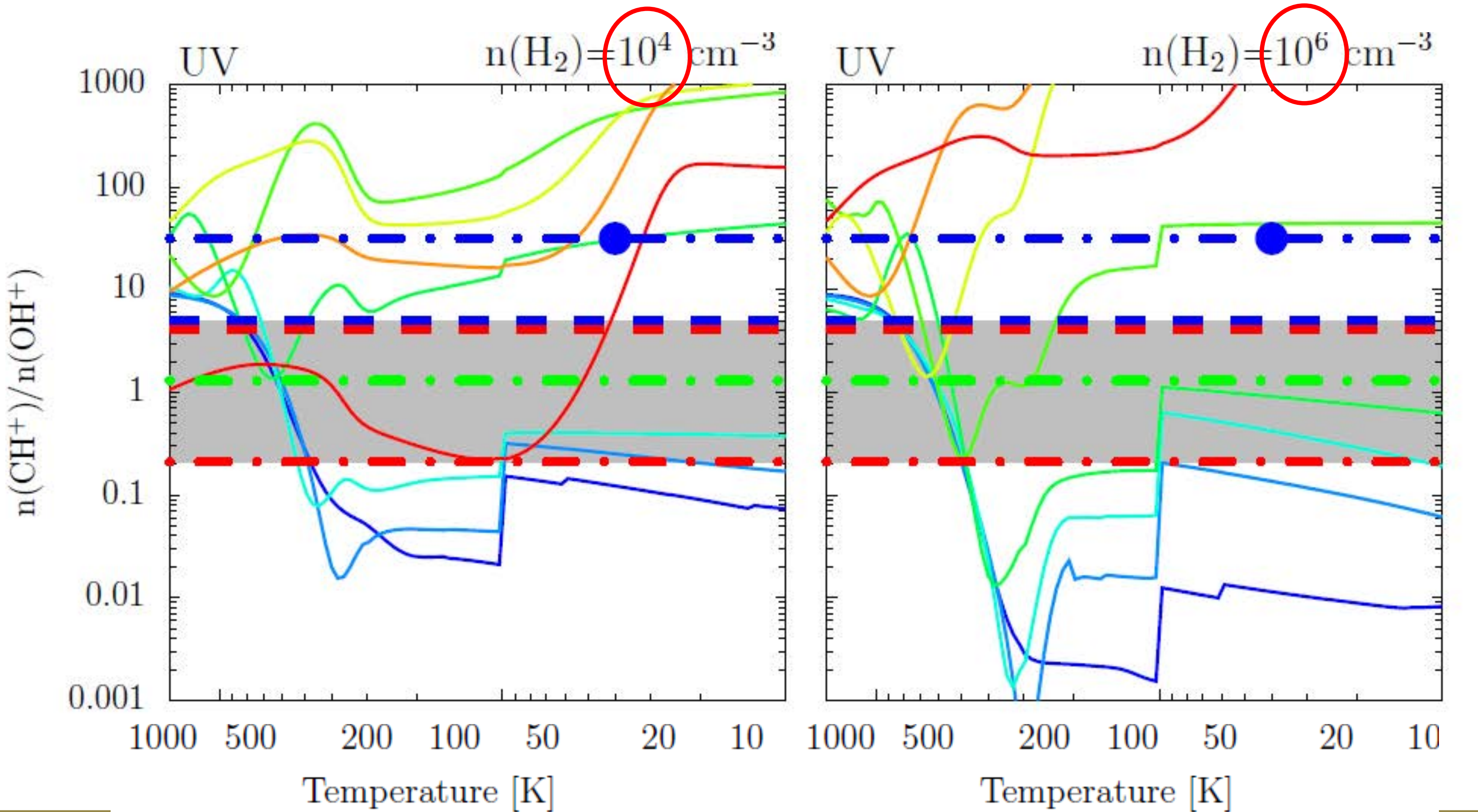
model

$G_0 = 0$ ISRF
$G_0 = 1$ ISRF
$G_0 = 10$ ISRF
$G_0 = 10^2$ ISRF
$G_0 = 10^3$ ISRF
$G_0 = 10^4$ ISRF
$G_0 = 10^5$ ISRF
$G_0 = 10^6$ ISRF

observations

Chemical model

no geometry (0D)
Variables:
T, FUV, n



lower H_2 density $\rightarrow$ lower irradiation requirement

FUV Irradiation at location of molecules from observed CH+/OH+ ratios

Object	radius [AU]	density [cm^{-3}]	line mode	G_0 ISRF
NGC1333 I4A	2500	1.3×10^6	abs.	200 - 400
Ser SMM1	4400	6.0×10^5	abs.	2 - 8
AFGL 2591	35000	7.0×10^4	abs.	20 - 80
W3 IRS5	21000	1.1×10^5	abs.	80 - 200
W3 IRS5	21000	1.1×10^5	em.	300 - 600

Assumptions:
- 0D chemical model
- FUV irradiation at Herschel beam radius
- density at Herschel beam radius
- gas temperature < 100 K

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What we have learnt

- Ionized hydrides detected in star-forming regions, but often in absorption
- CH^+ and OH^+ correlate in line shift, and have similar line width and column density
- CH^+/OH^+ is enhanced by internal irradiation and/or high temperature or low H_2 density
- X-ray signatures not detected (Herschel beam too large)
- Evidence for 2–400 ISRF FUV irradiation in low-mass class 0 objects, requiring up to 1.5 L_{sun} if source at protostar