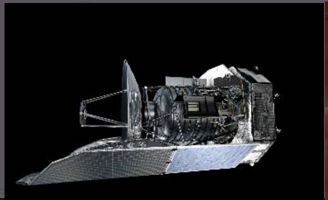
# Hydride Ions and Ionizing Irradiation

## in Young Stellar Objects

**Arnold O. Benz**
**Simon Bruderer**
**Ewine F. van Dishoeck**
**Pascal Stäuber**

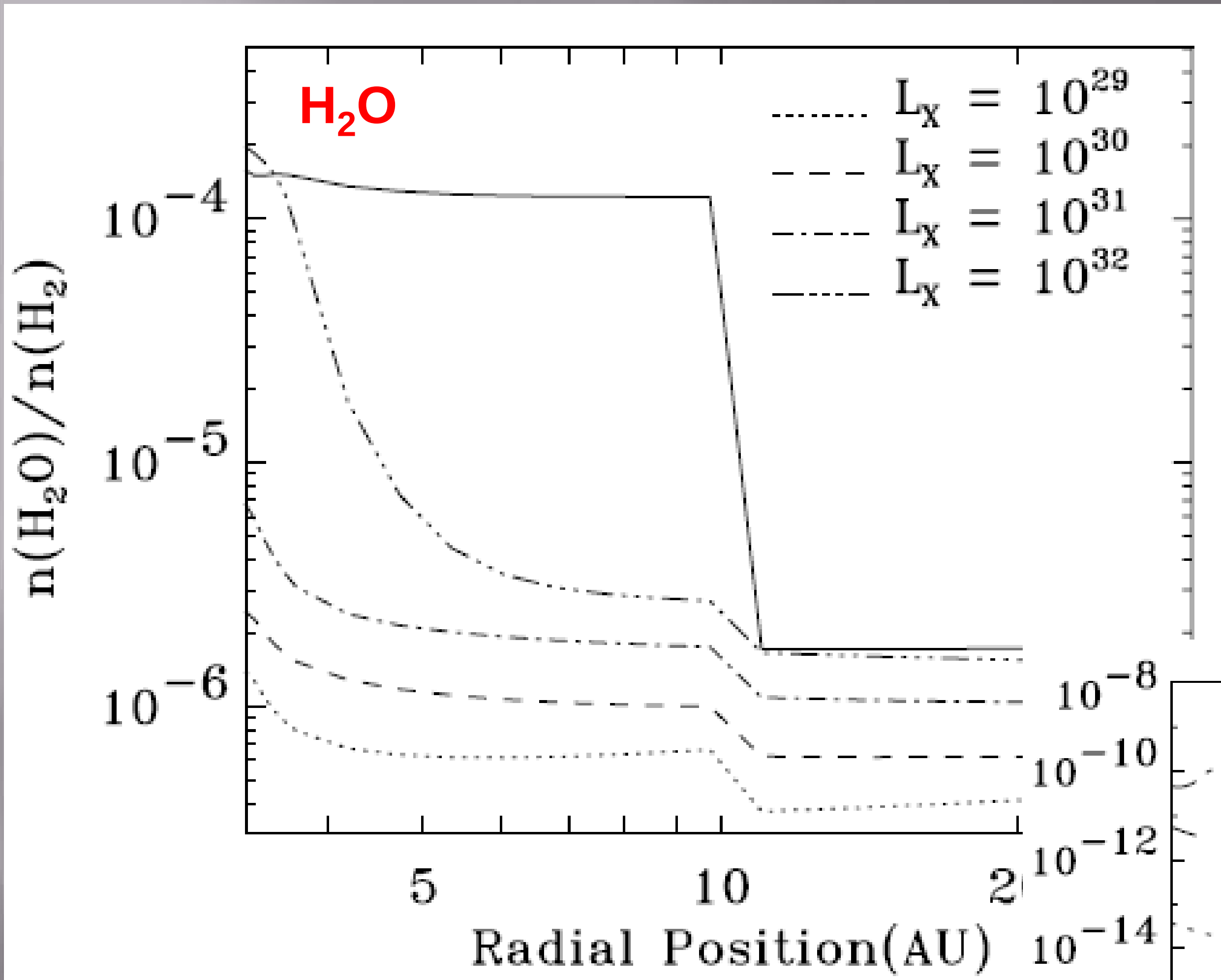
ETH Zurich

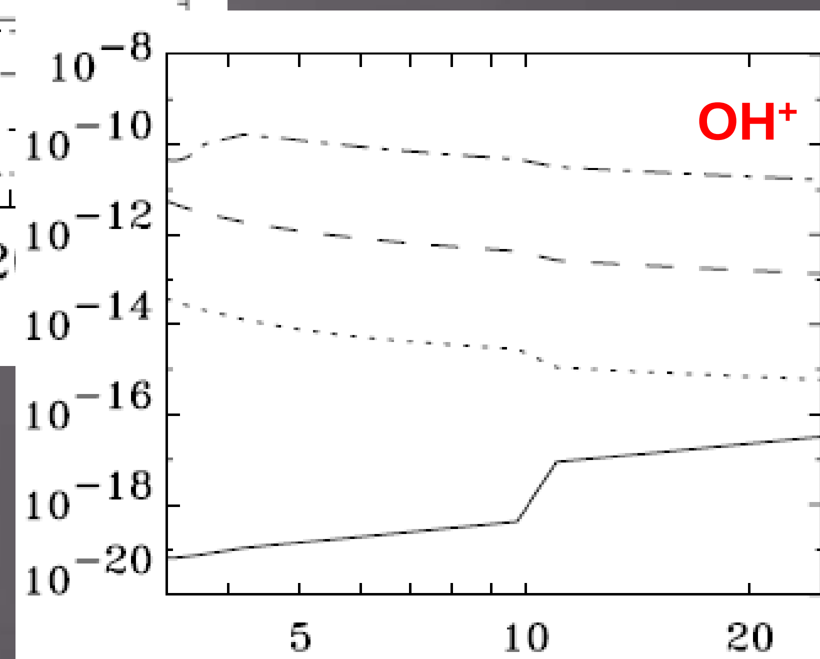


1. **Hydride Observations by Herschel/HIFI towards star-forming regions**

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

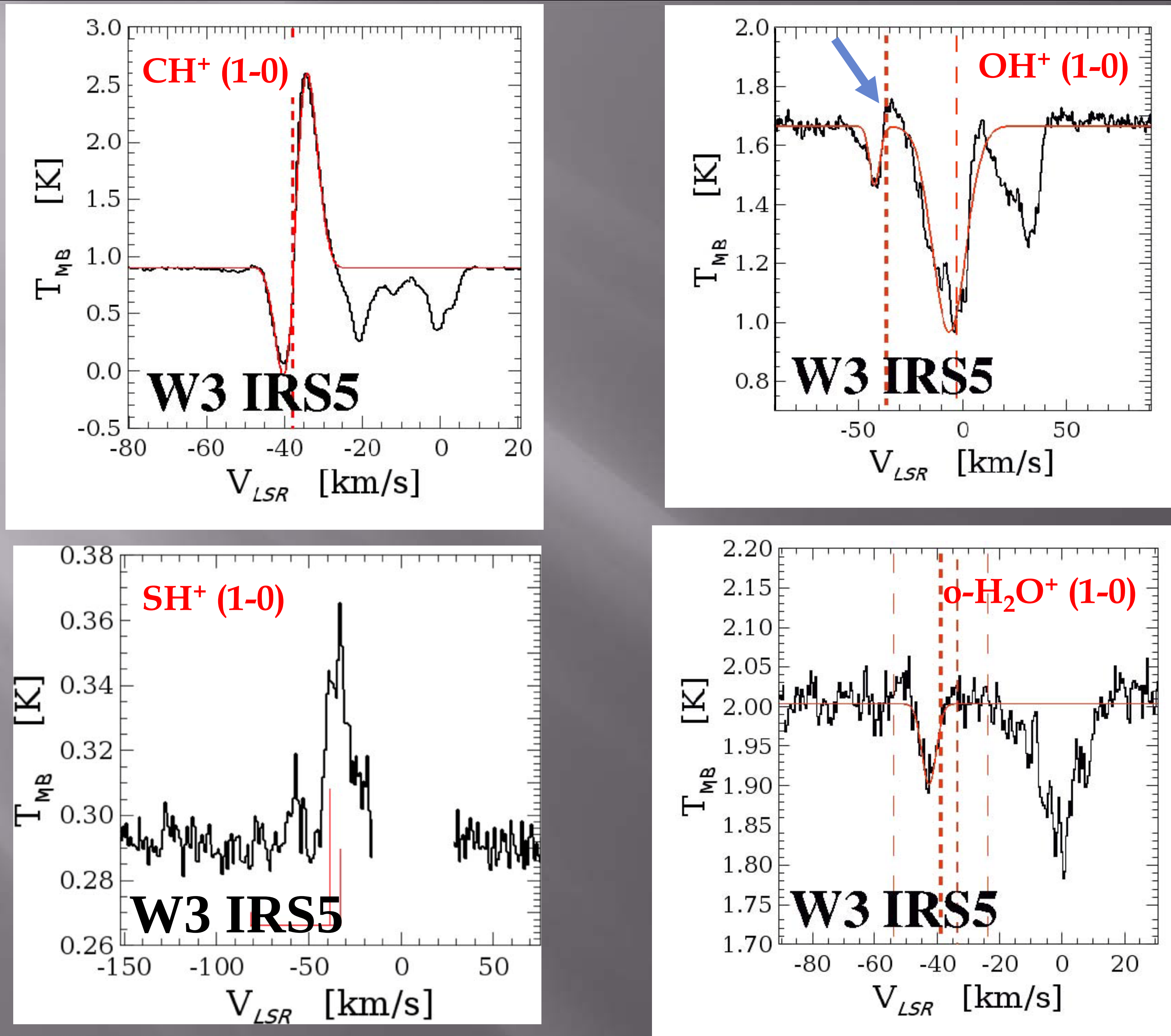
# Effects of internal ionizing radiation



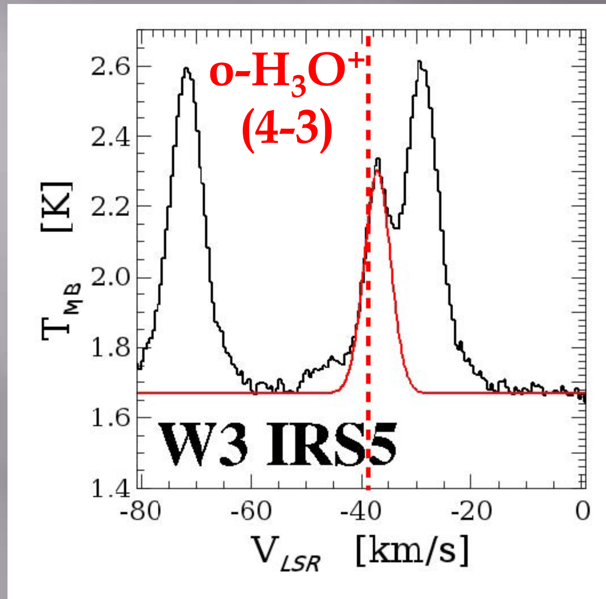



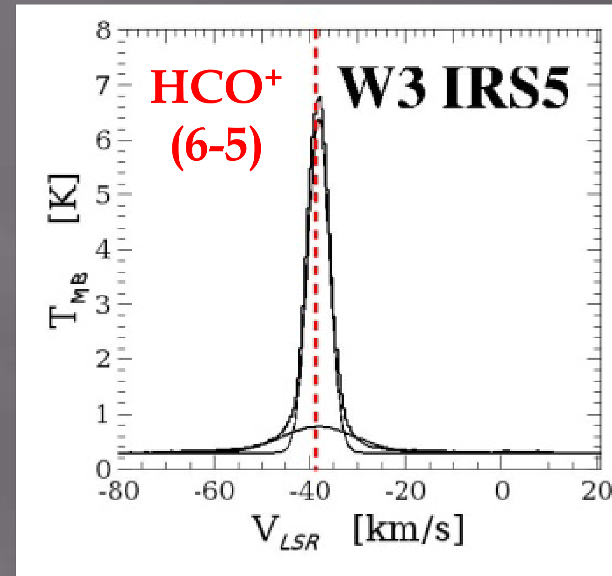

- Low-mass class I, $10^5$ years
- 1D geometry, incl. cosmic rays

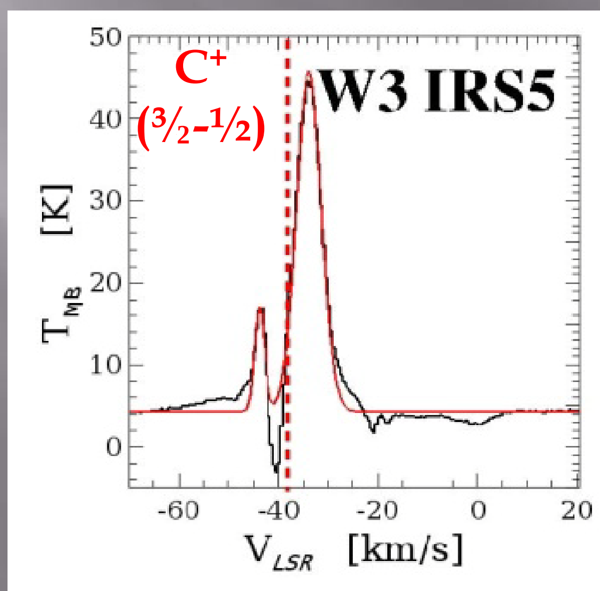
Stäuber+ 06

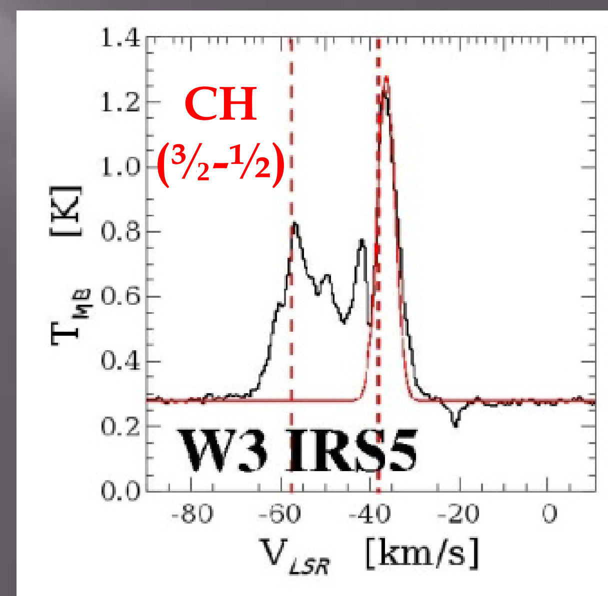

CH⁺ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
OH⁺ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
SH⁺ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]
o-H₂O⁺ (1-0)
W3 IRS5
T_MB [K]
V_LSR [km/s]

Benz+ 16

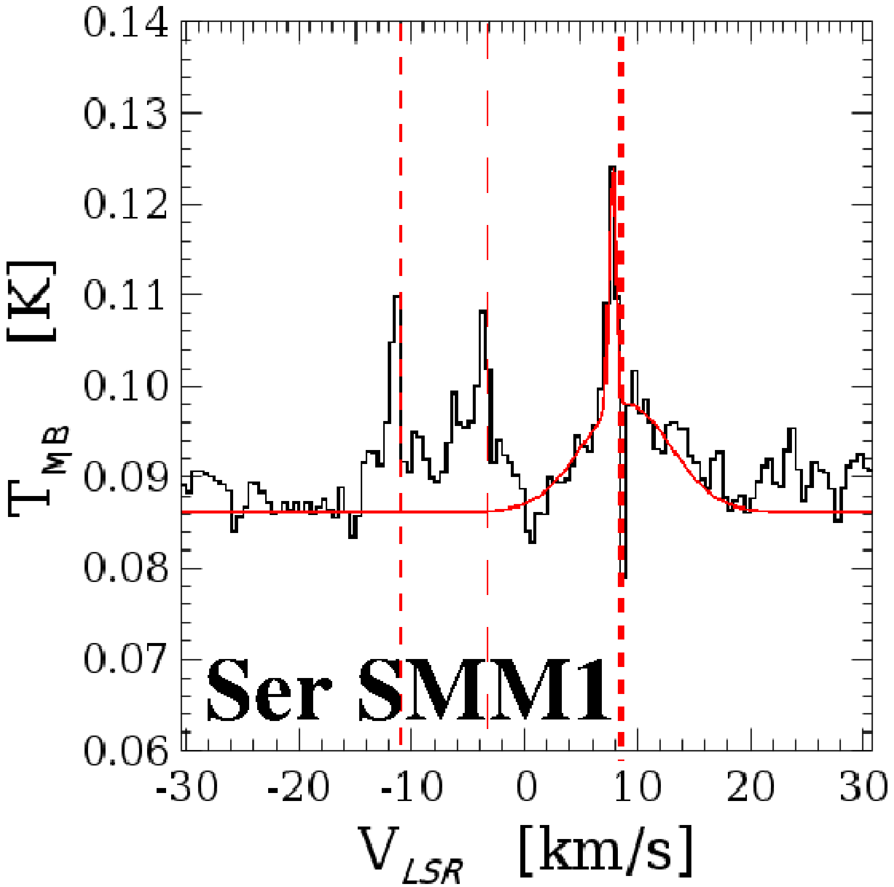

o-H3O+
(4-3)
W3 IRS5
TMB [K]
VLSR [km/s]
2.6
2.4
2.2
2.0
1.8
1.6
1.4
-80
-60
-40
-20
0

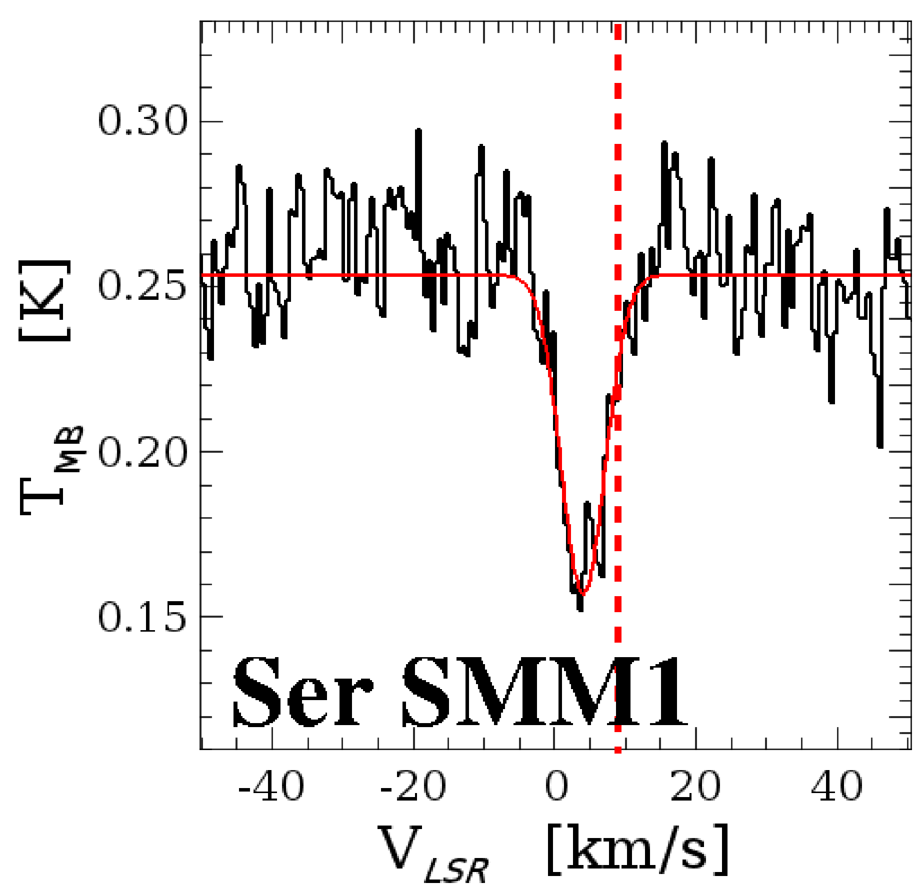

HCO+
(6-5)
W3 IRS5
TMB [K]
VLSR [km/s]
8
7
6
5
4
3
2
1
0
-80
-60
-40
-20
0
20


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




**CH ($^3/_2$ - ½)**
**536 GHz**
**group I**

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

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)

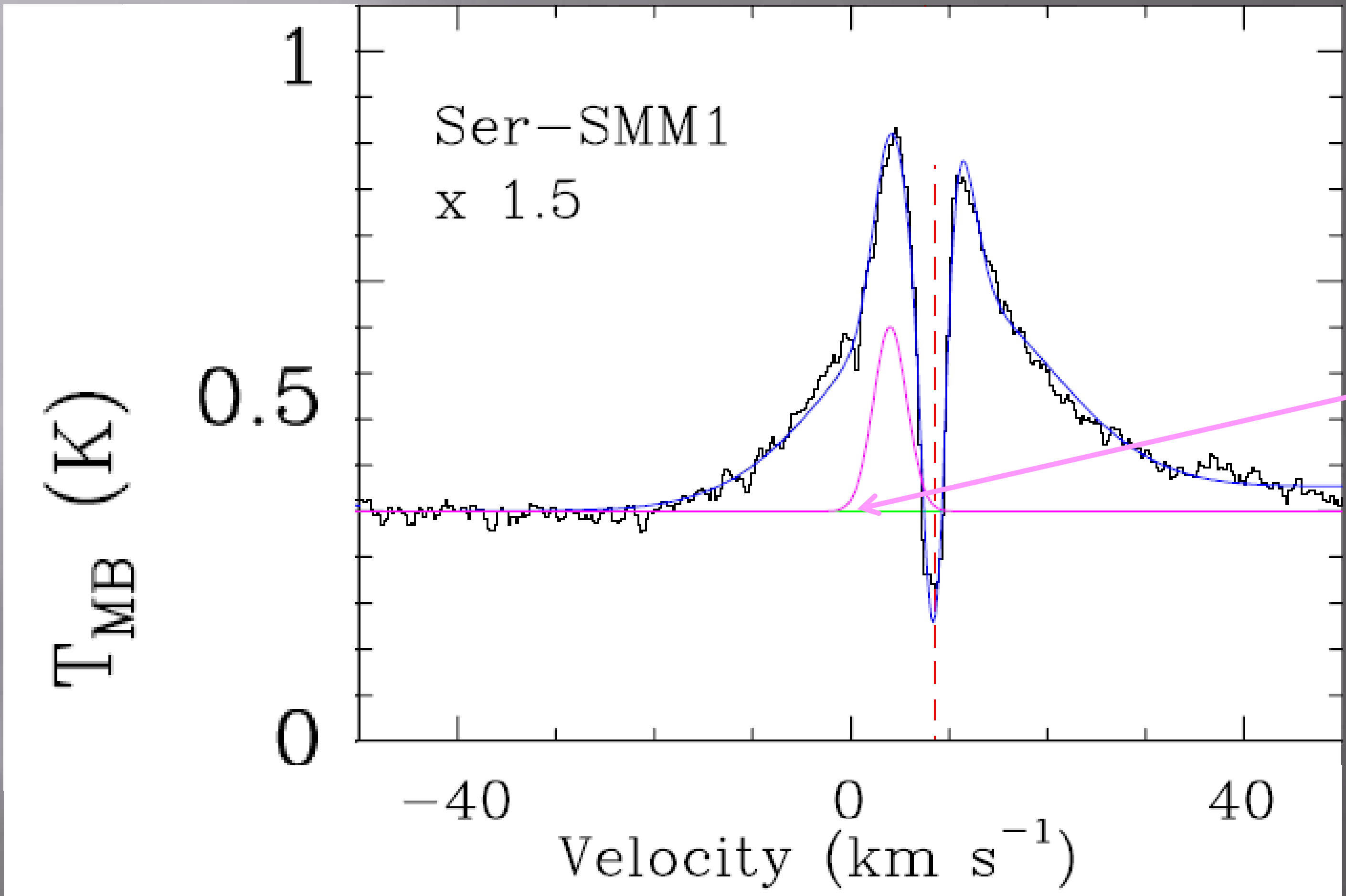
→ origin in envelope

# Group II Molecules

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

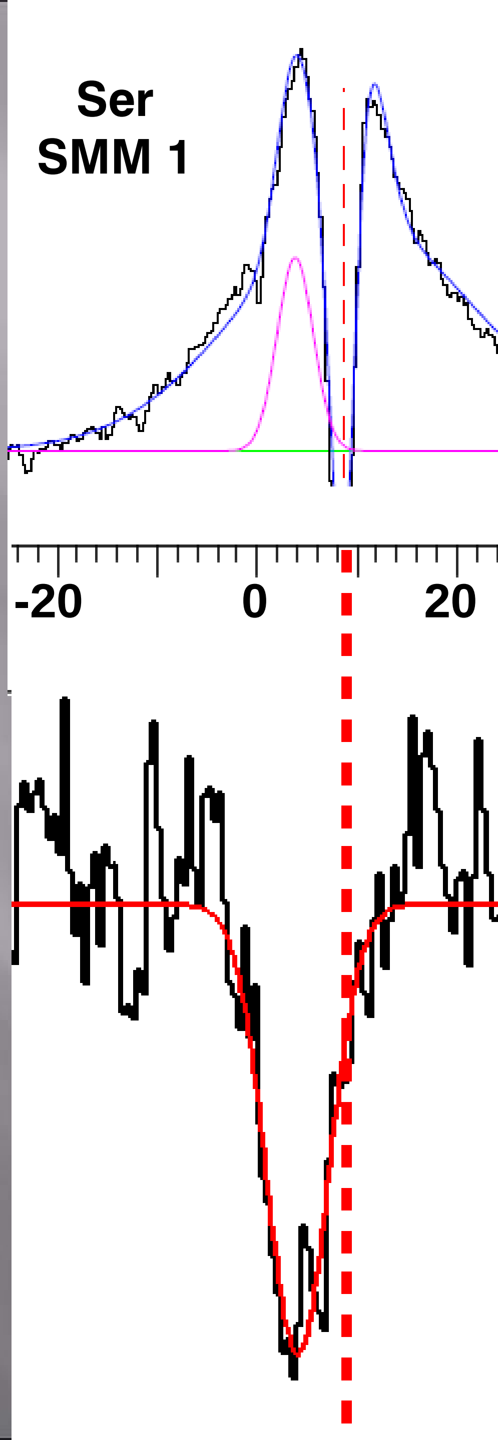
predominantly

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




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

Kristensen+ 13




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

557 GHz

## $CH^+$ (0-1)

835 GHz

group II

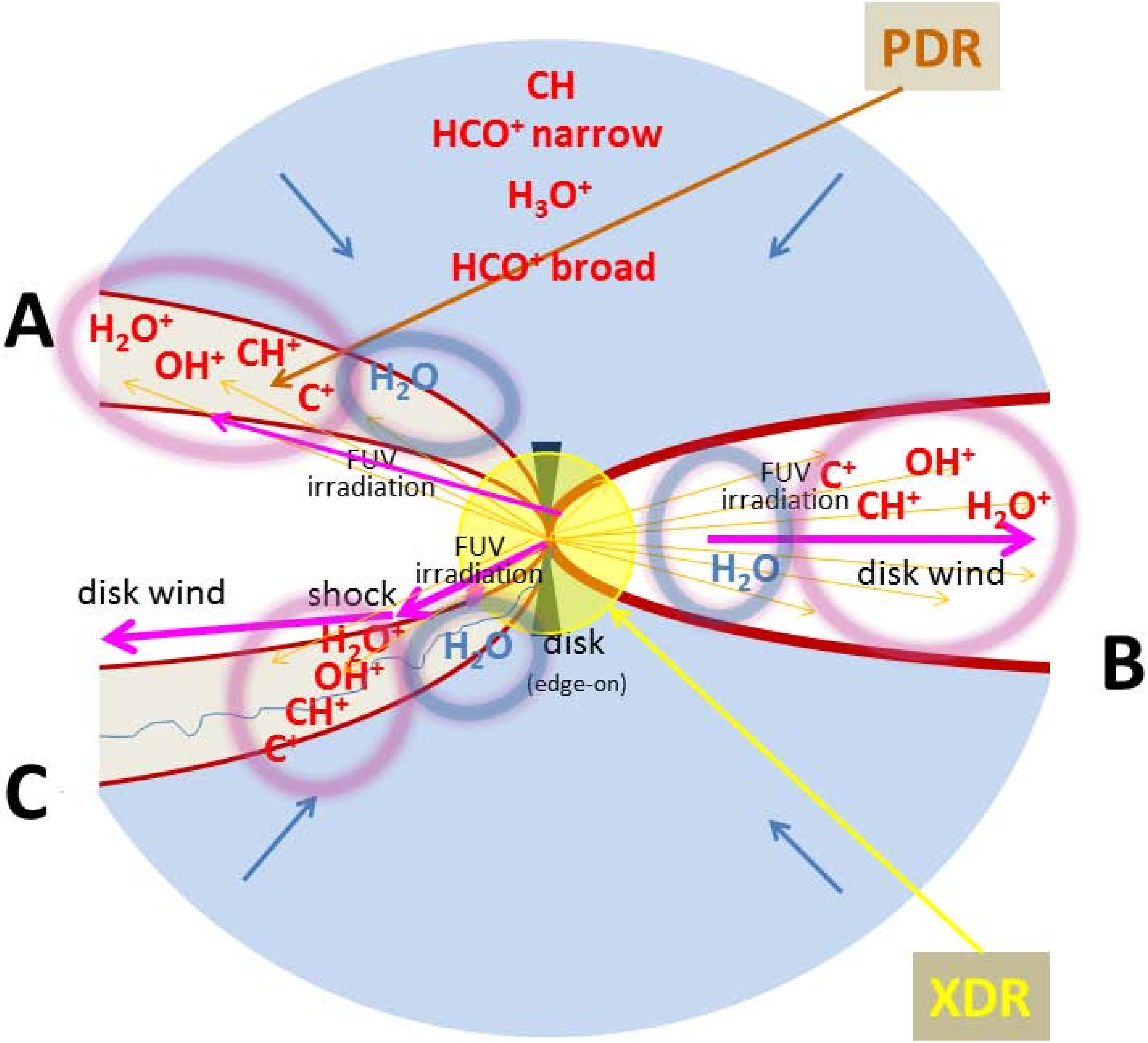
# Possible Interpretation
## (Group II)

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

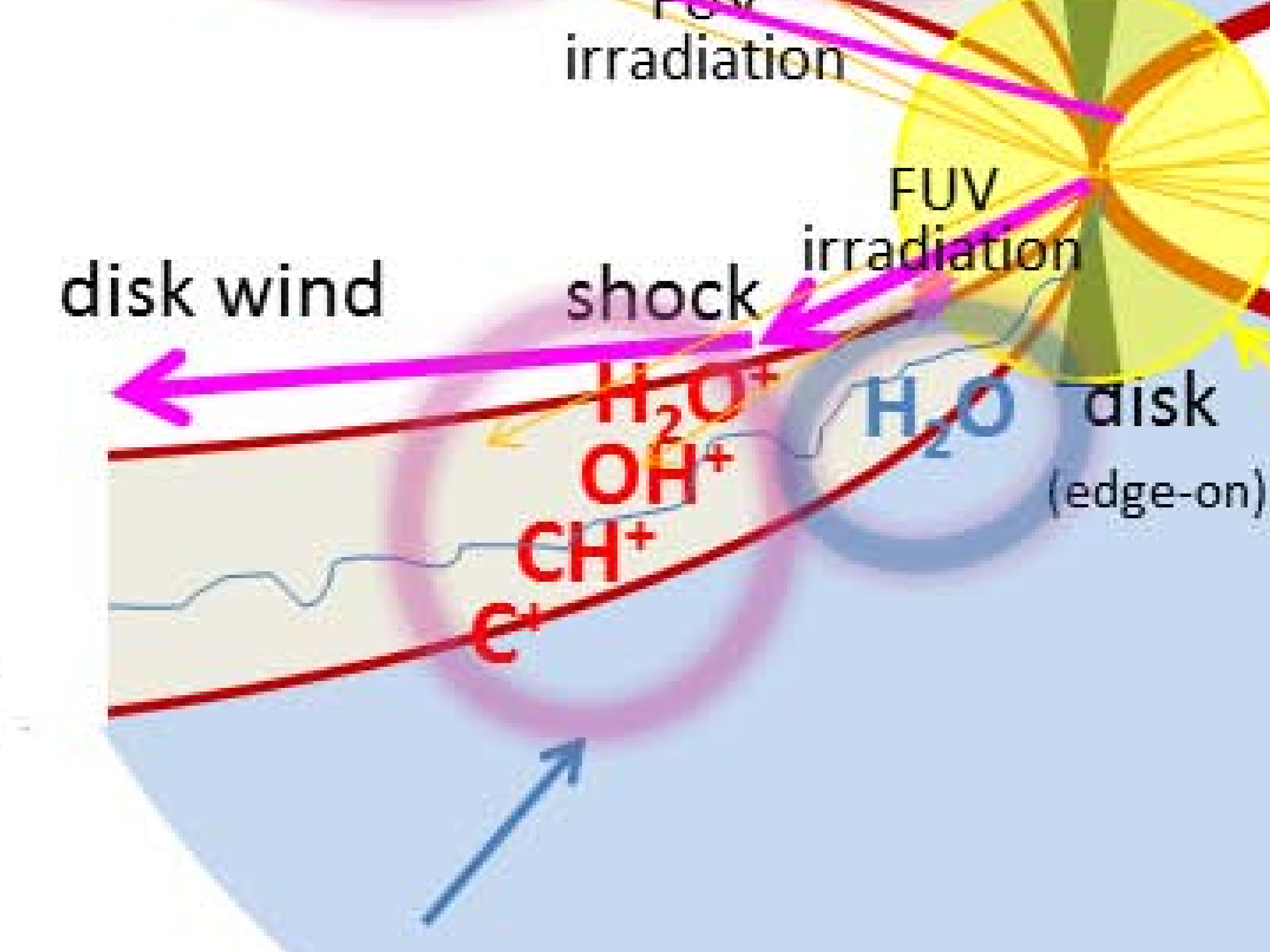
blue-shift (~10 km/s) → related to outflow

ionized → internal irraditation

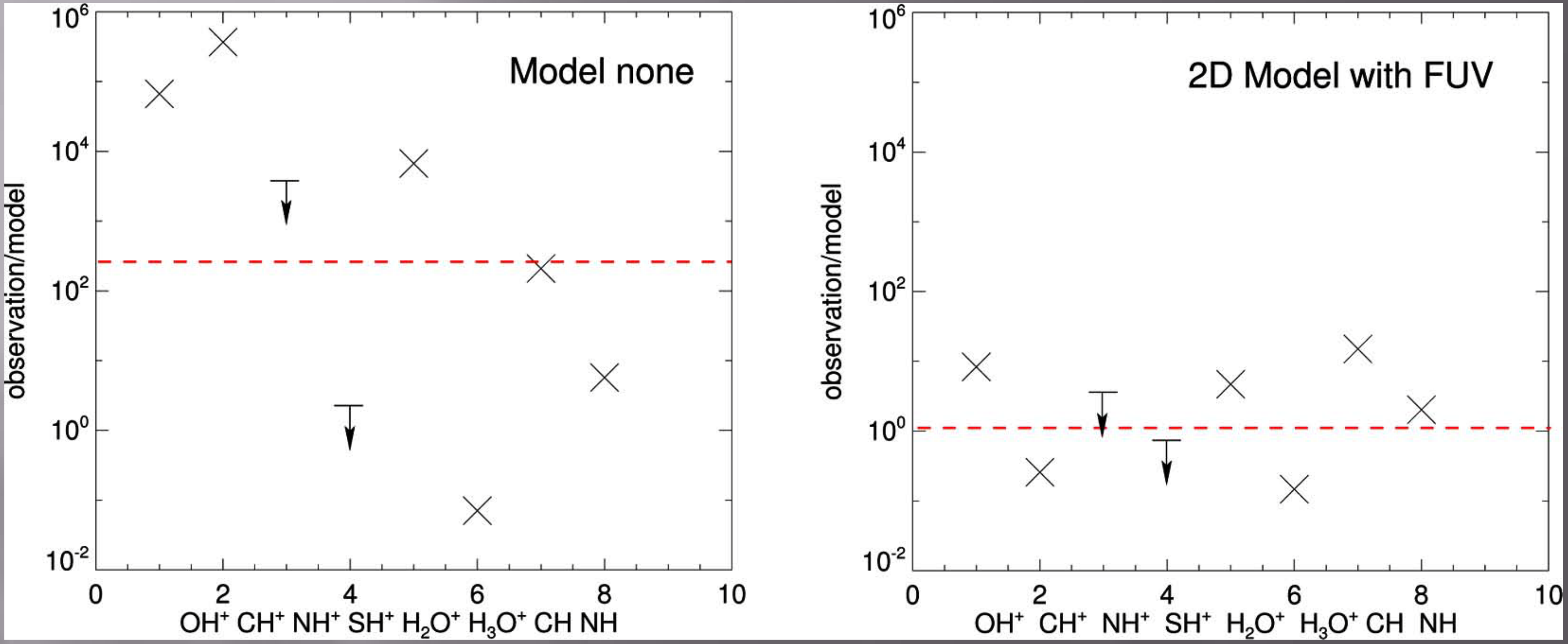
Questions
- why absorption ?
- relation to $H_2O$ ?


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

Benz+ 16



FUV
irradiation
FUV
irradiation
disk wind
shock
H2O+
OH+
CH+
C+
H2O
disk
(edge-on)

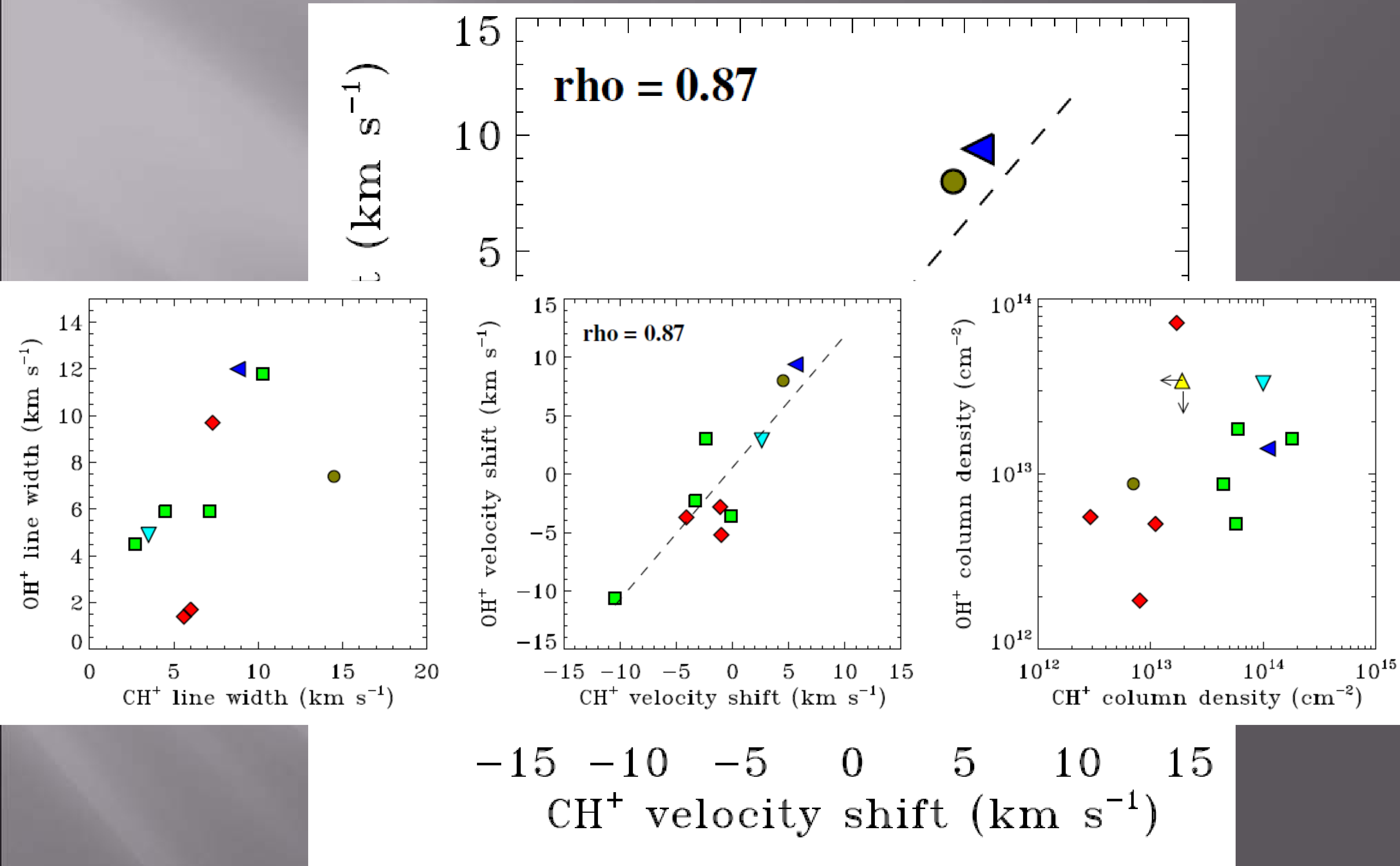



**Comparison in column density observations/2D-model (AFGL 2591)**

Bruderer+ 10, Benz+ 12

1. Hydride Observations by Herschel/HIFI towards star-forming regions

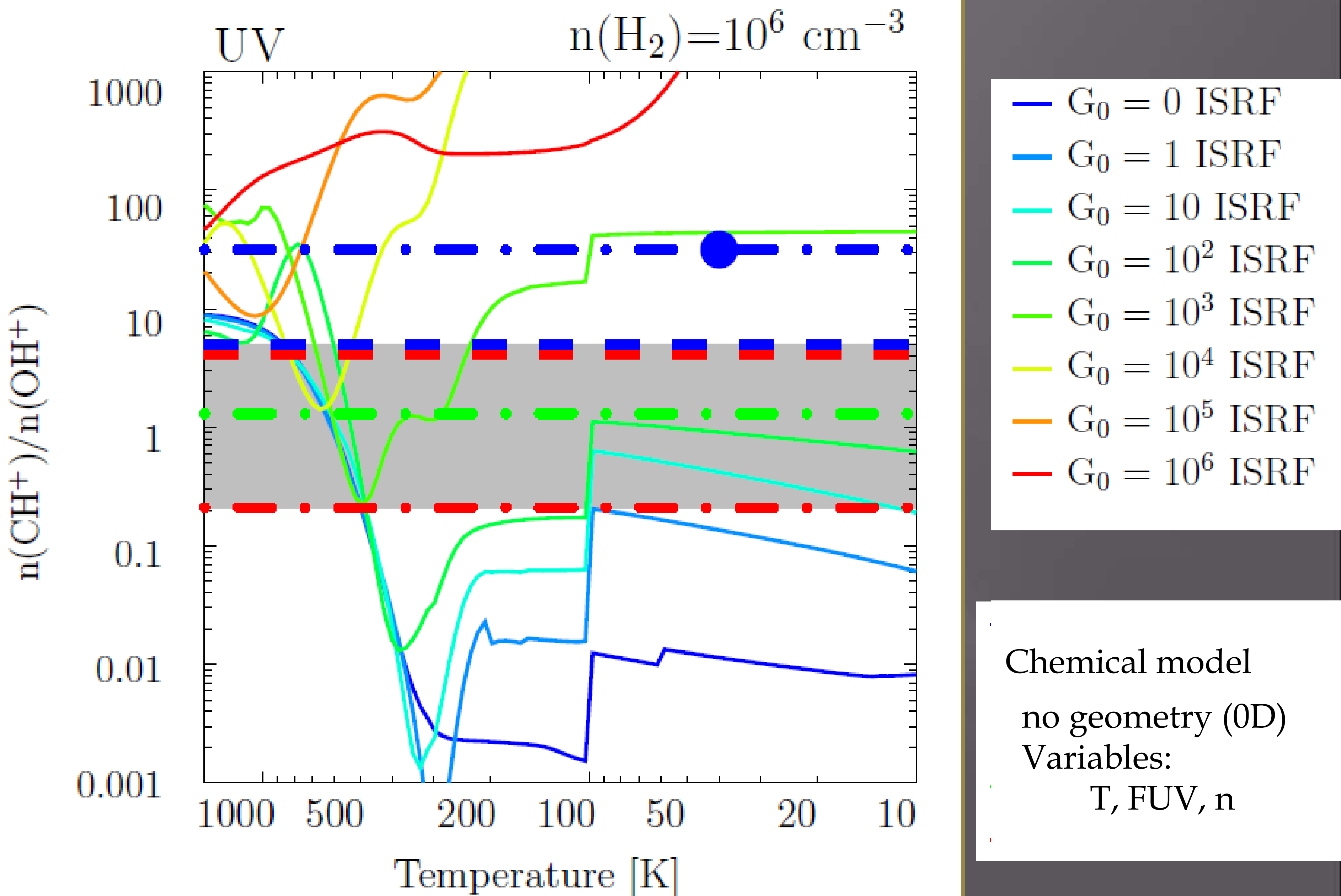
2. Estimate ionizing irradiation from $CH^+/OH^+$ ratio




# Correlation of $CH^+$ and $OH^+$

Benz+ 16

| 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 em. | 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 | |



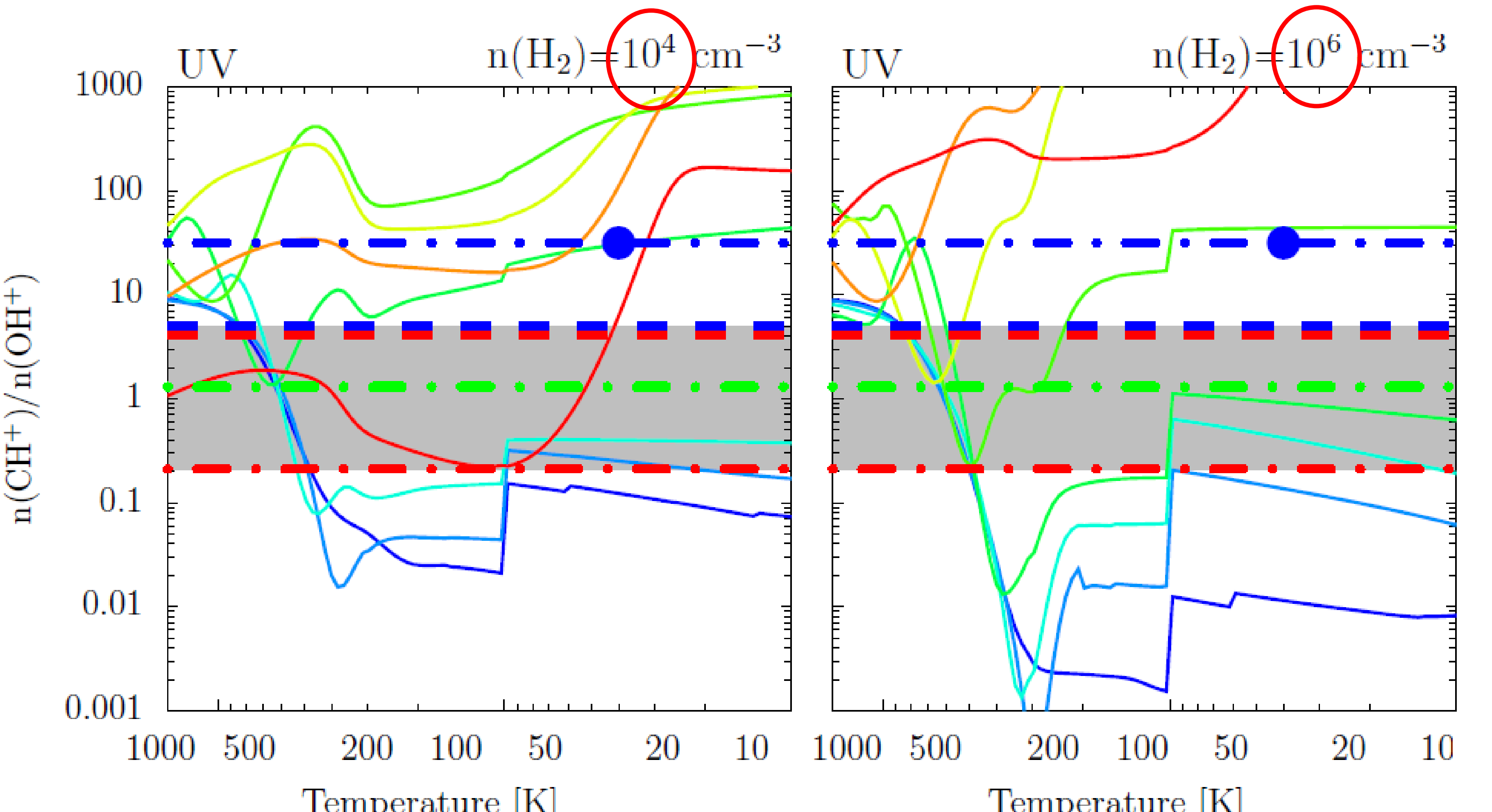

Chemical model

no geometry (0D)

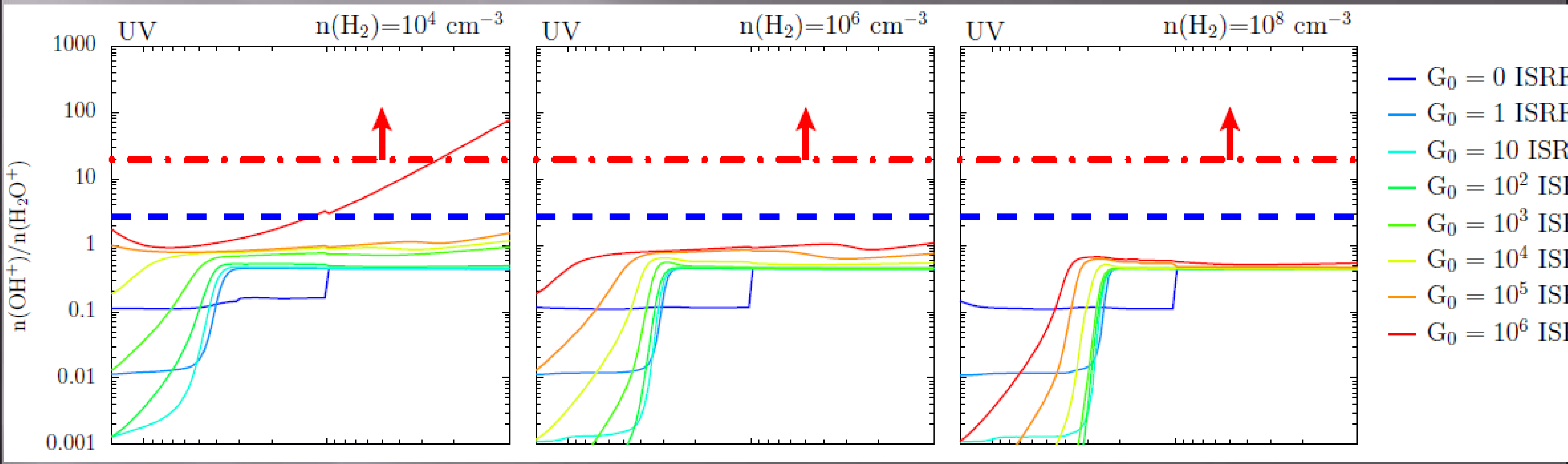
Variables:

T, FUV, n

Benz+ 16




**lower $H_2$ density → lower irradiation requirement**


UV
n(H2)=10^4 cm^-3
UV
n(H2)=10^6 cm^-3
UV
n(H2)=10^8 cm^-3
1000
100
10
1
0.1
0.01
0.001
n(OH+)/n(H2O+)
G0 = 0 ISRF
G0 = 1 ISRF
G0 = 10 ISR
G0 = 10^2 ISI
G0 = 10^3 ISI
G0 = 10^4 ISI
G0 = 10^5 ISI
G0 = 10^6 ISI

# 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 | $1.3\times10^6$ | abs. | 200 - 400 |
| Ser SMM1 | 4400 | $6.0\times10^5$ | abs. | 2 - 8 |
| AFGL 2591 | 35000 | $7.0\times10^4$ | abs. | 20 - 80 |
| W3 IRS5 | 21000 | $1.1\times10^5$ | abs. | 80 - 200 |
| W3 IRS5 | 21000 | $1.1\times10^5$ | em. | 300 - 600 |

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

Benz+ 16

# 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 low $H_2$ density
- X-ray signatures not detected (Herschel beam too large)
- Evidence for 2–400 ISRF FUV irradiation in low-mass objects, requiring 1.5 $L_{sun}$ if source at protostar

**Thanks !**