Radiation Diagnostics in Massive Star-forming Regions Using Hydrides

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Goals

1. **Chemical network of water** in star forming regions under far UV (FUV) and X-ray irradiation

2. **Ionizing radiation** produced by young stars and protostars (hydrides)

Many hydrides have a high activation energy (up to several 1000 K)

Form at high temperature or by reactions with ions → tracers of strong FUV or X-ray fields

Irradiation W3 IRS 5

FUV Radiation

$N_{mfp} = 2\ 10^{21}\ cm^{-2}$ → surface effect

$L_{bol} = 3\ 10^{5}\ L_{\odot}$

assume $L_{FUV} \approx 3\ 10^{38}$ erg/s

$G_0 = 3\ 10^{6}\ (r_{10000AU})^{-2}$ ISRF

X-rays

$N_{mfp} = 10^{24}\ cm^{-2}$ (7 keV) → volume effect

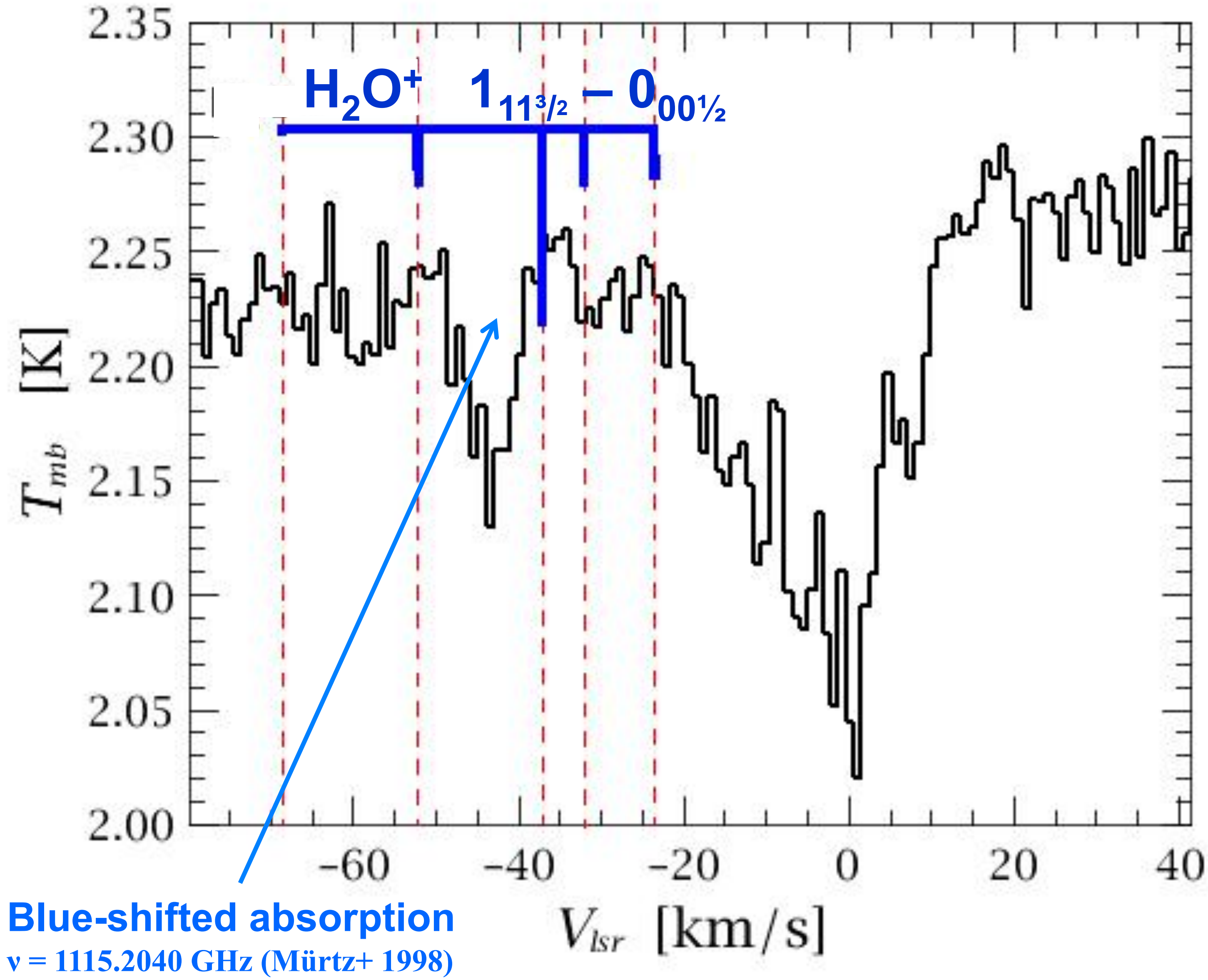
$L_X \approx 5\ 10^{30}$ erg/s

$\zeta_x > \zeta_{cr}$ for $r < 1000$ AU

Hydrides in Young Stellar Objects

	Transition	Frequency GHz	E_{up} [K]	Detected w. HIFI/Herschel in W3 IRS5
OH	½, ³/₂ – ½,½	1834.7	269.8	emission
CH	$1_{-1} – 1_1$	536.7611	25.8	emission
NH	$1_1 – 0_1$	999.9734	48.0	absorption
SH	$3_1 – 2_{-1}$	1447.0123	640.6	not detected
OH^+ NEW!	$1_1 – 0_1$	1033.1186	49.6	absorption
CH^+	1 – 0	835.1375	40.1	emission
NH^+	$1_{3/2+} – 1_{1/2-}$	1012.5400	48.6	not detected
SH^+ NEW!	$1_2 – 0_1$	526.0479	25.3	emission
H_2O	many			emission
H_2O^+ NEW!	$1_{11\,3/2} – 0_{00\,1/2}$	1115.204	53.5	absorption
H_3O^+	many		emission	

W3 IRS5

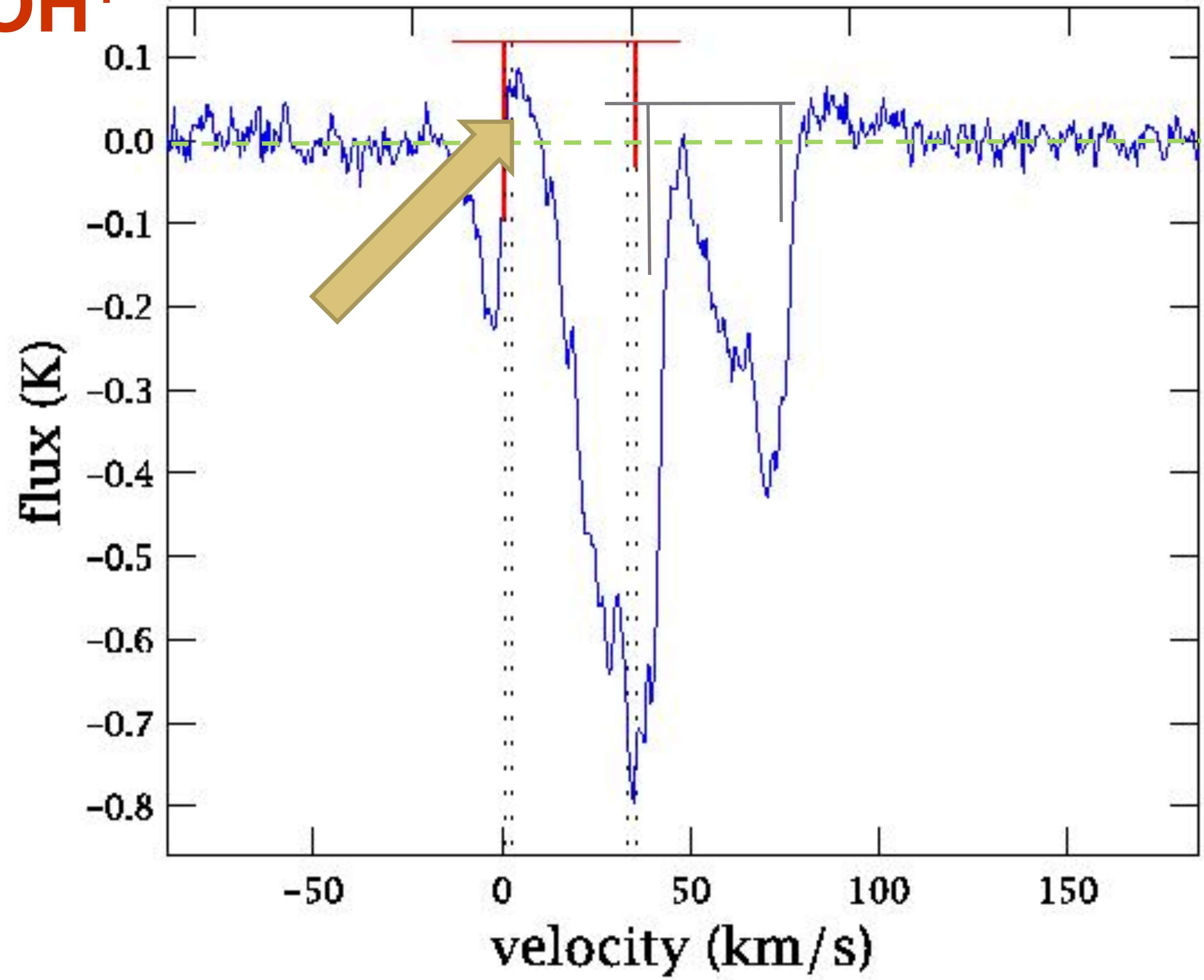


Benz et al. 2010
Bruderer et al. 2010
Gerin et al. 2010
Gupta et al. 2010
Neufeld et al. 2010
Ossenkopf et al. 2010
Schilke et al. 2010
Van der Werf et al. 2010
Weiss et al. 2010
Wyrowski et al. 2010

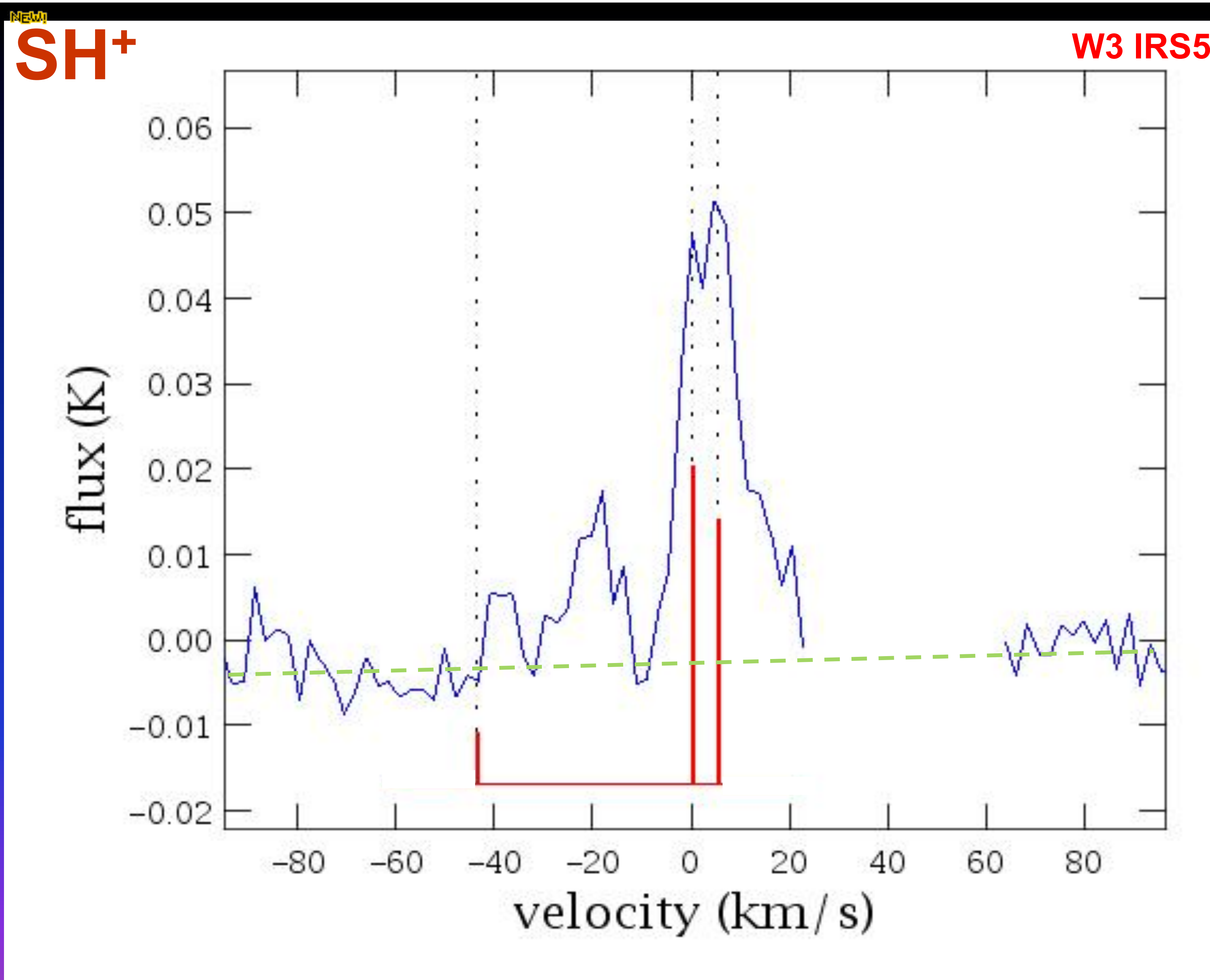
Excitation ? Collision rate? Frequencies J ≠ 1-0 ?

OH^+

W3 IRS5



Components at systemic velocity of W3 IRS5 OH^+/H_2O^+ = 12

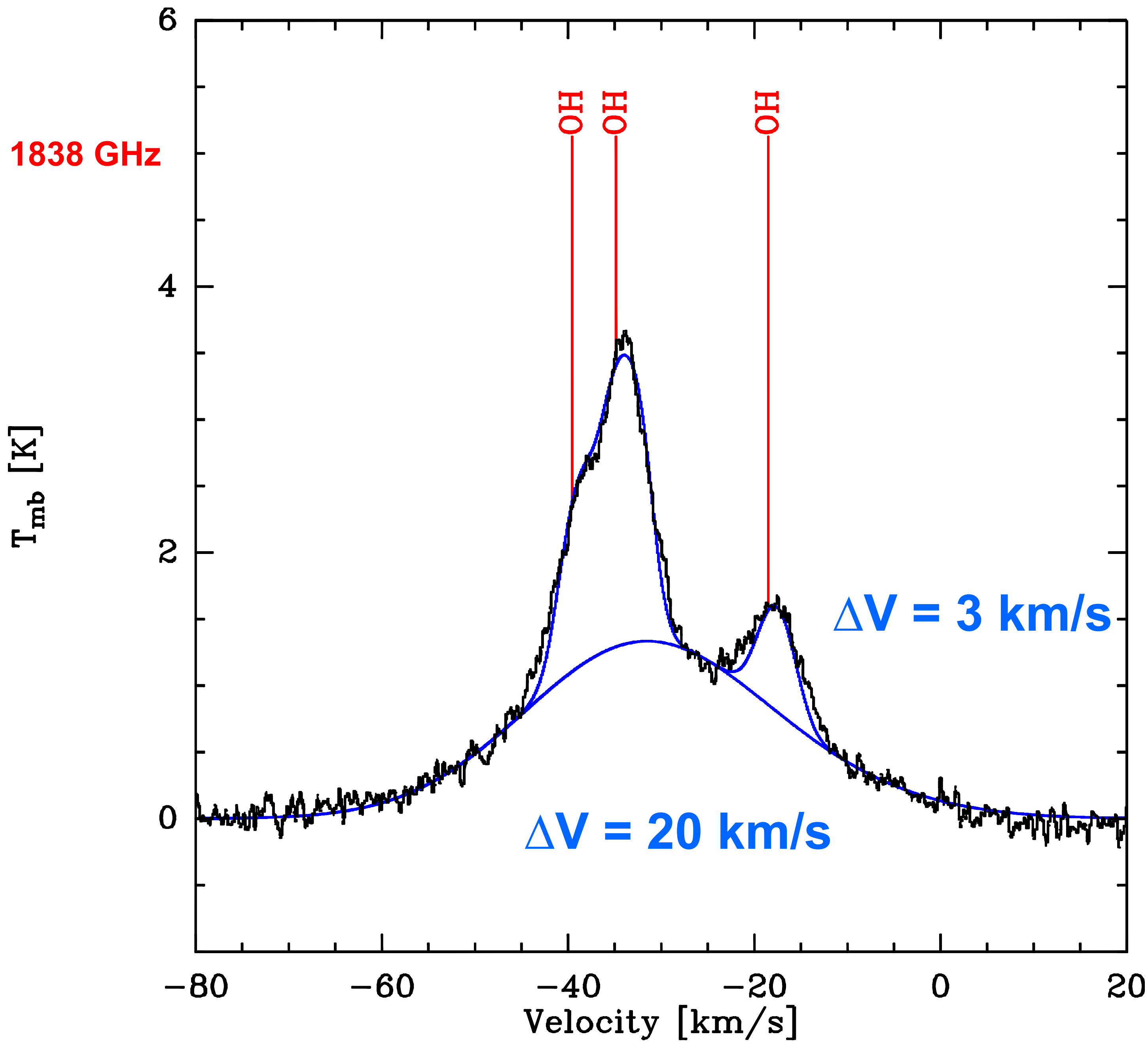


NEW!
SH+
W3 IRS5
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
flux (K)
−80
−60
−40
−20
0
20
40
60
80
velocity (km/s)

OH

163 µm/ 1838 GHz

W3 IRS5



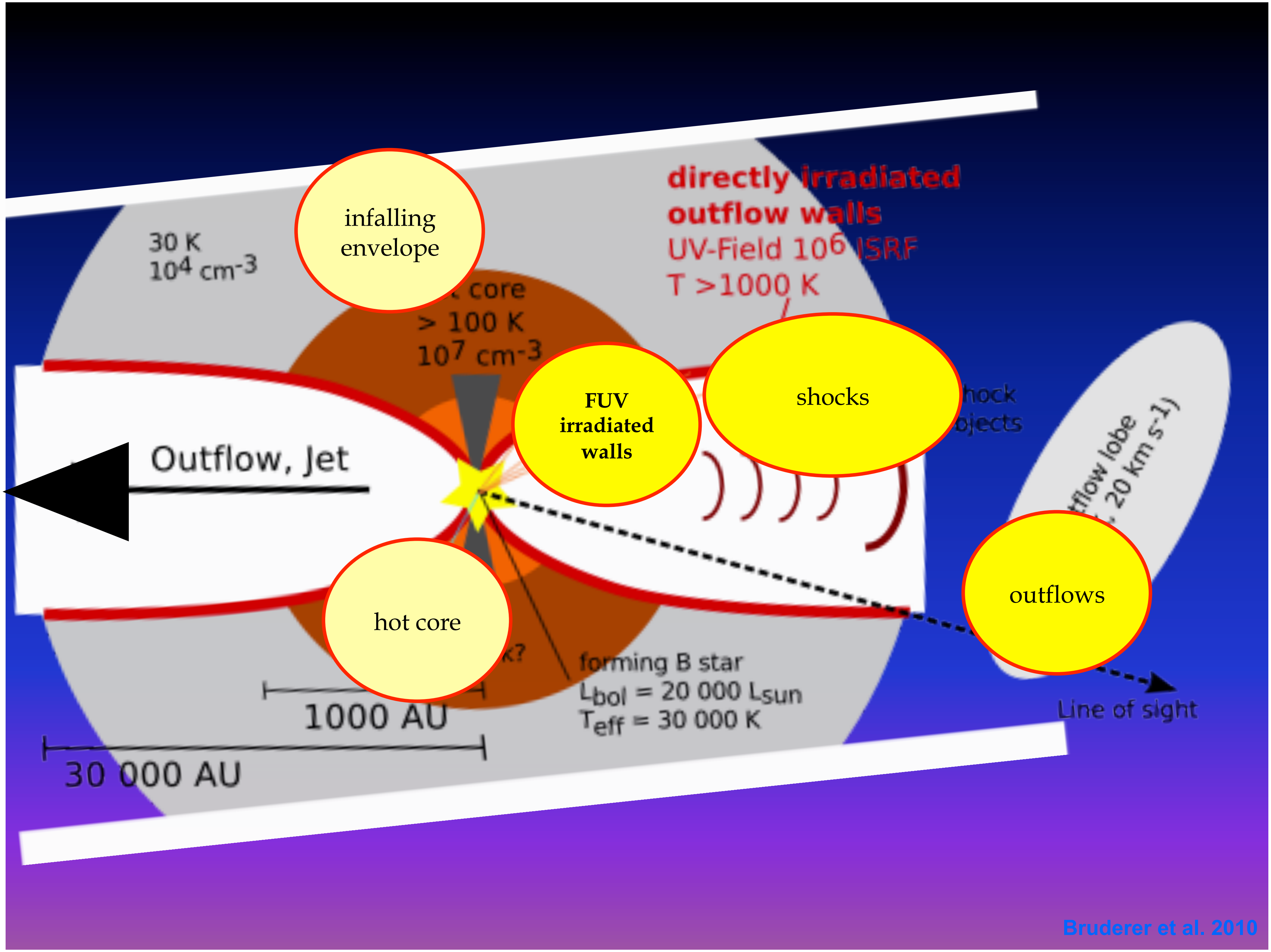
Hyperfine structure first time resolved

Wampfler et al. 2010

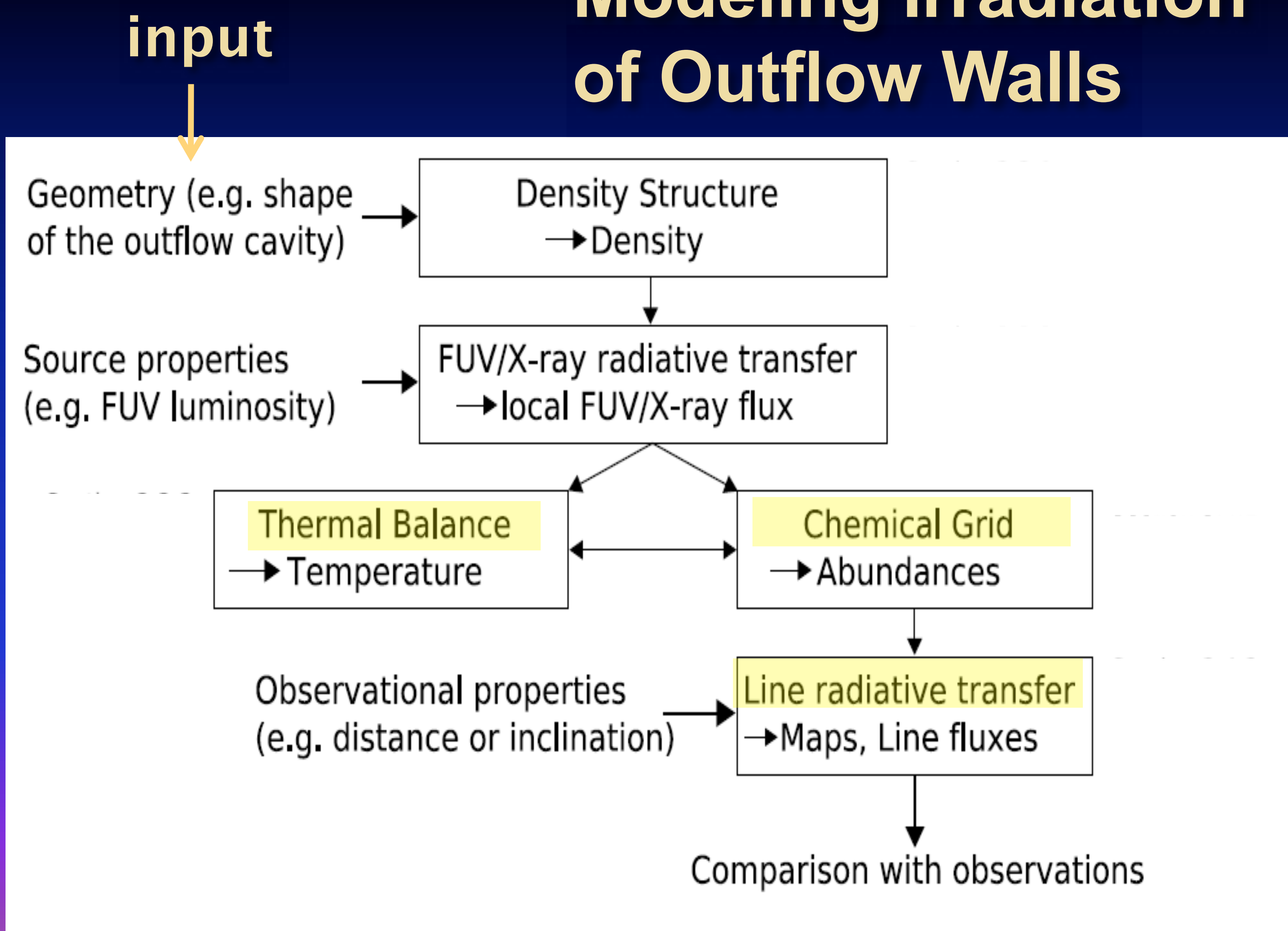
Summary Spectral Features

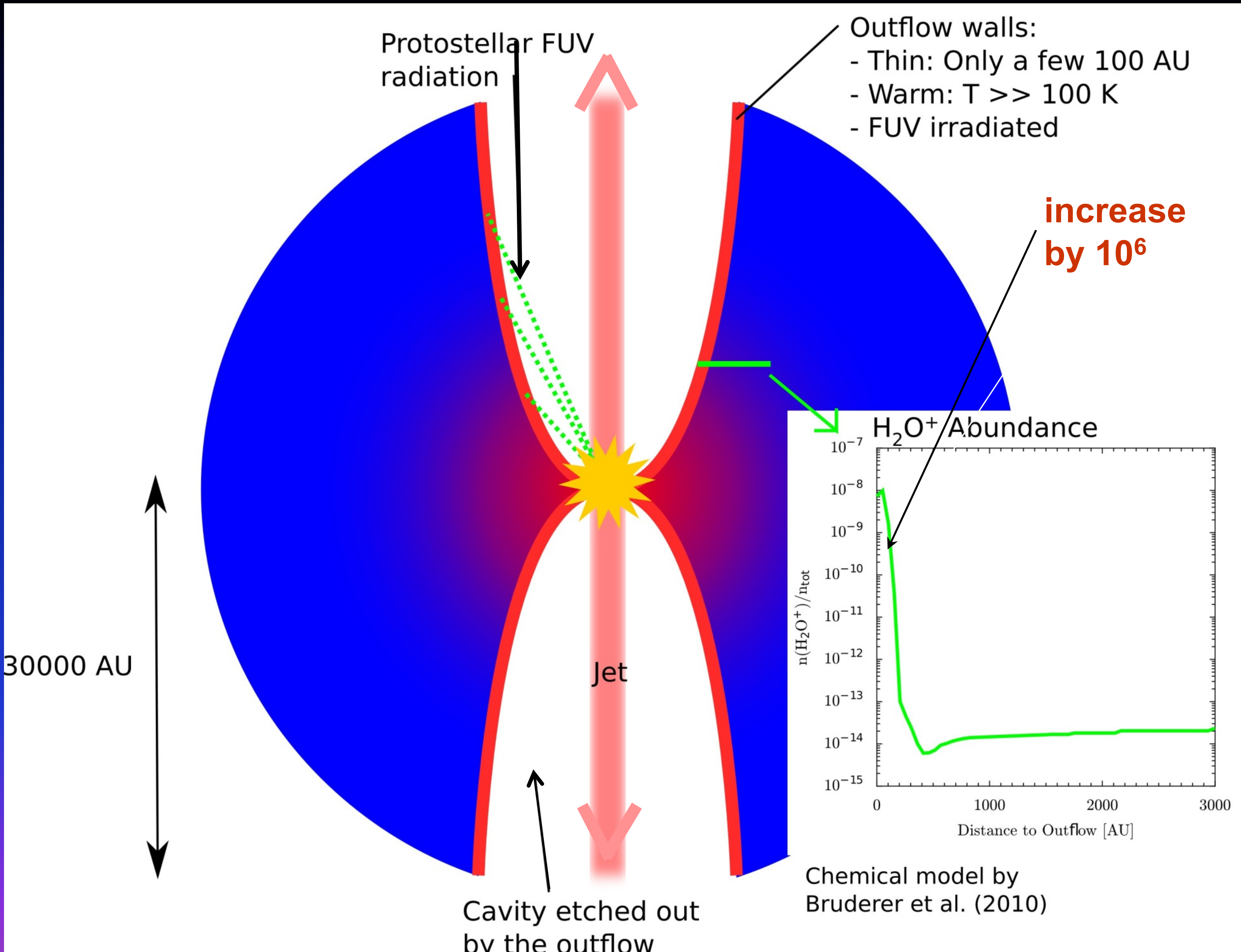
(high-mass star-forming regions)

Narrow emission lines (3-5 km/s)	SH^+, NH, OH^+, H_3O^+, OH
Broad line component (20 km/s)	OH, H_2O, OH^+(S140 IRS1)
Blue-shifted absorption (10 km/s)	CH^+ (AFGL 2591, P Cyg), OH^+ (W3 IRS5, P-Cyg), H_2O, H_2O^+, NH (?)

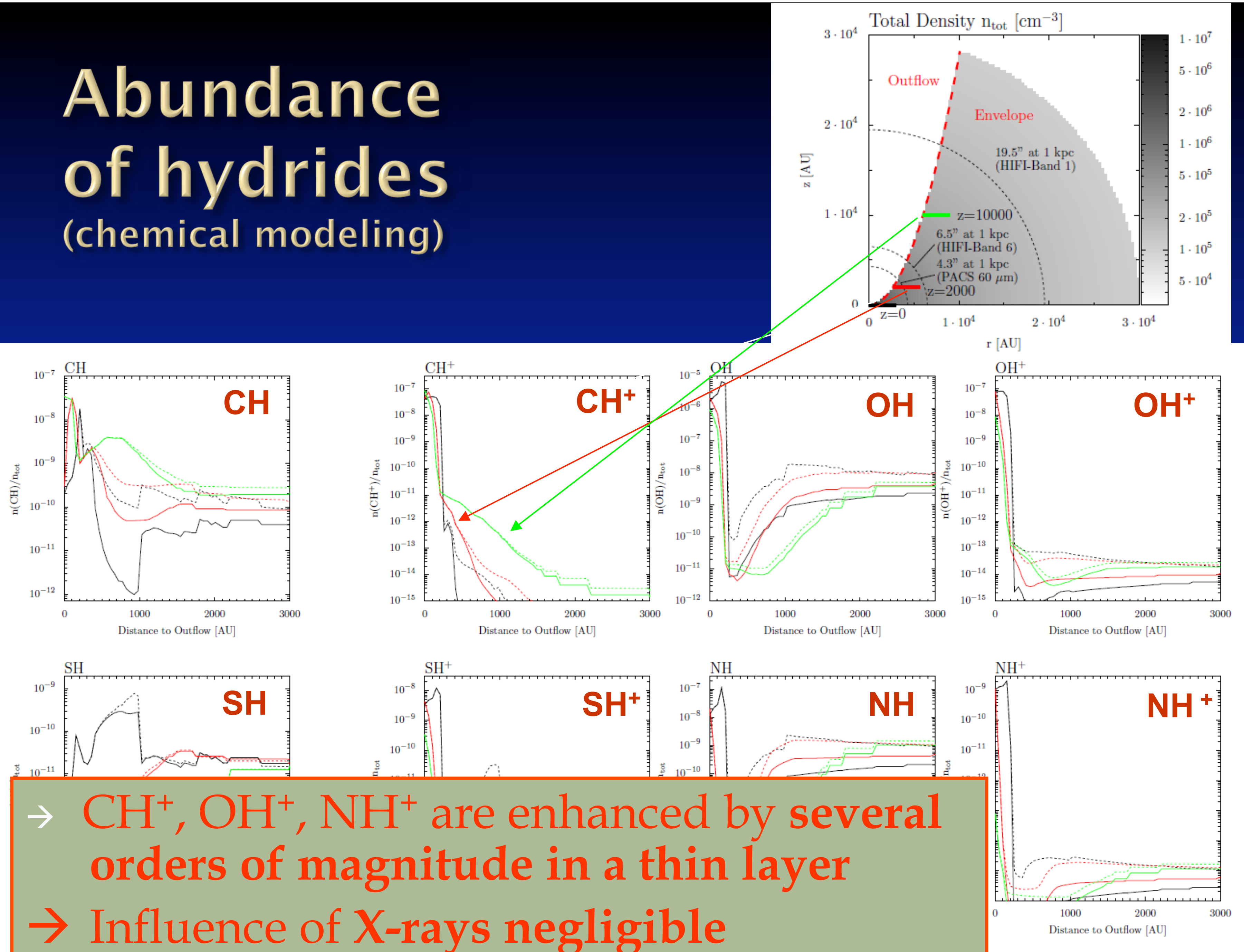

infalling envelope
30 K
10^4 cm-3
directly irradiated outflow walls
UV-Field 10^6 ISRF
T >1000 K
> 100 K
10^7 cm-3
FUV irradiated walls
shocks
Outflow, Jet
outflows
hot core
forming B star
L_{bol} = 20 000 L_{sun}
T_{eff} = 30 000 K
1000 AU
30 000 AU
Line of sight
Bruderer et al. 2010

Modeling Irradiation of Outflow Walls




Protostellar FUV radiation
Outflow walls:
- Thin: Only a few 100 AU
- Warm: T >> 100 K
- FUV irradiated
increase by 10^6
H2O+ Abundance
n(H2O+)/ntot
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
0
1000
2000
3000
Distance to Outflow [AU]
30000 AU
Jet
Cavity etched out by the outflow
Chemical model by Bruderer et al. (2010)

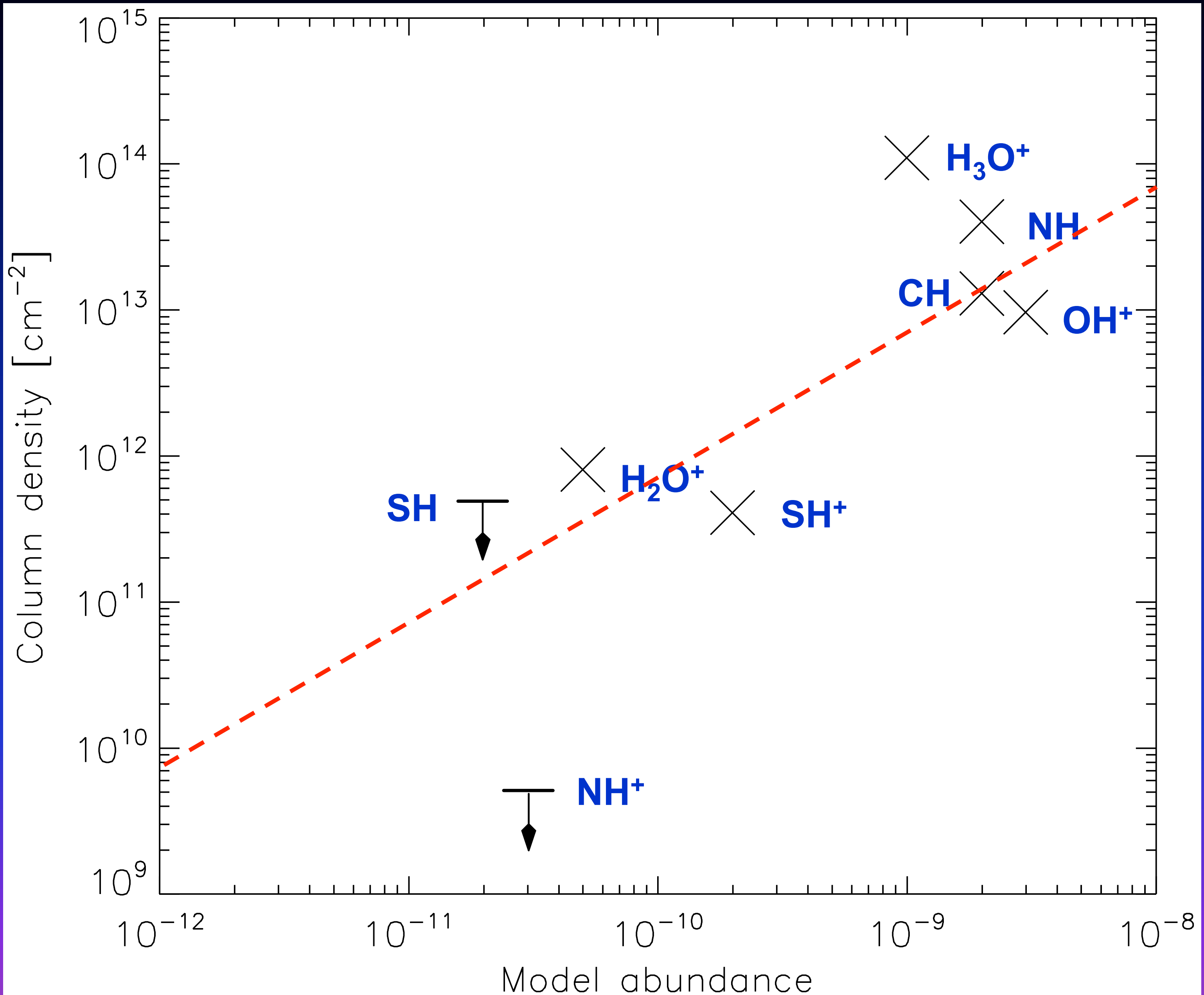
Abundance of hydrides
(chemical modeling)



→ CH^+, OH^+, NH^+ are enhanced by **several orders of magnitude in a thin layer**

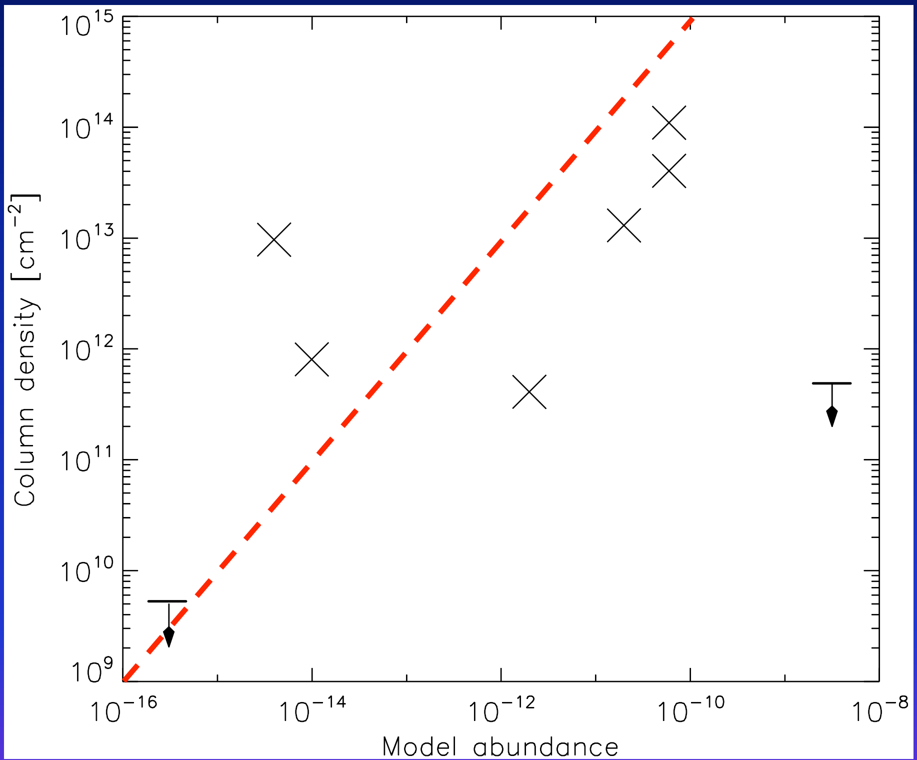
→ Influence of **X-rays negligible**

Bruderer et al. 2010

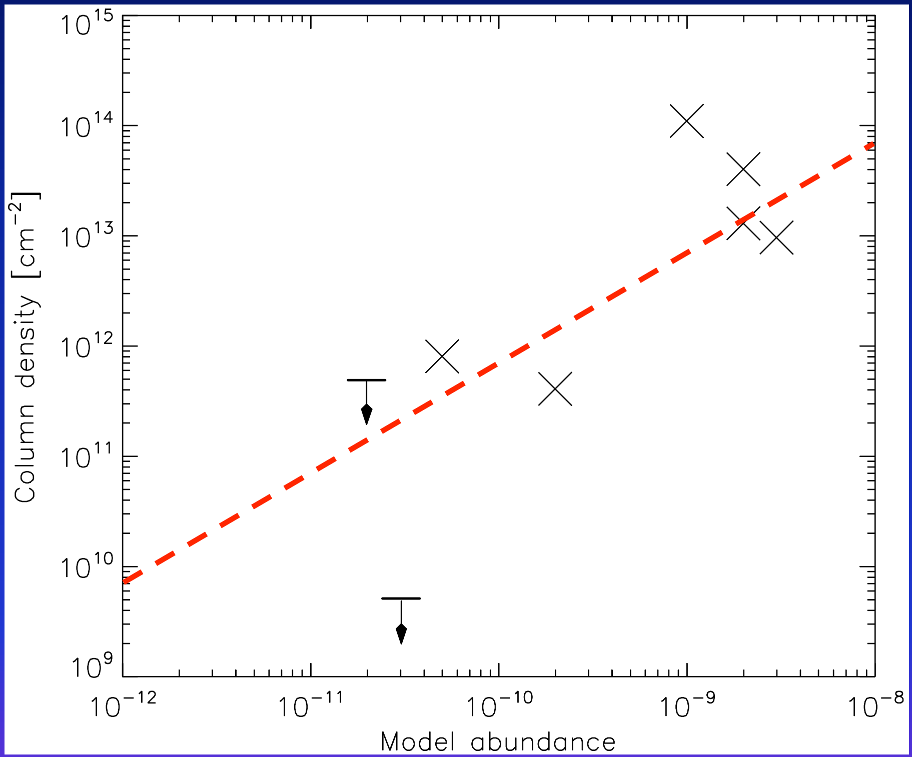


2 dimensional with UV irradiation

No UV irradiation



With UV irradiation

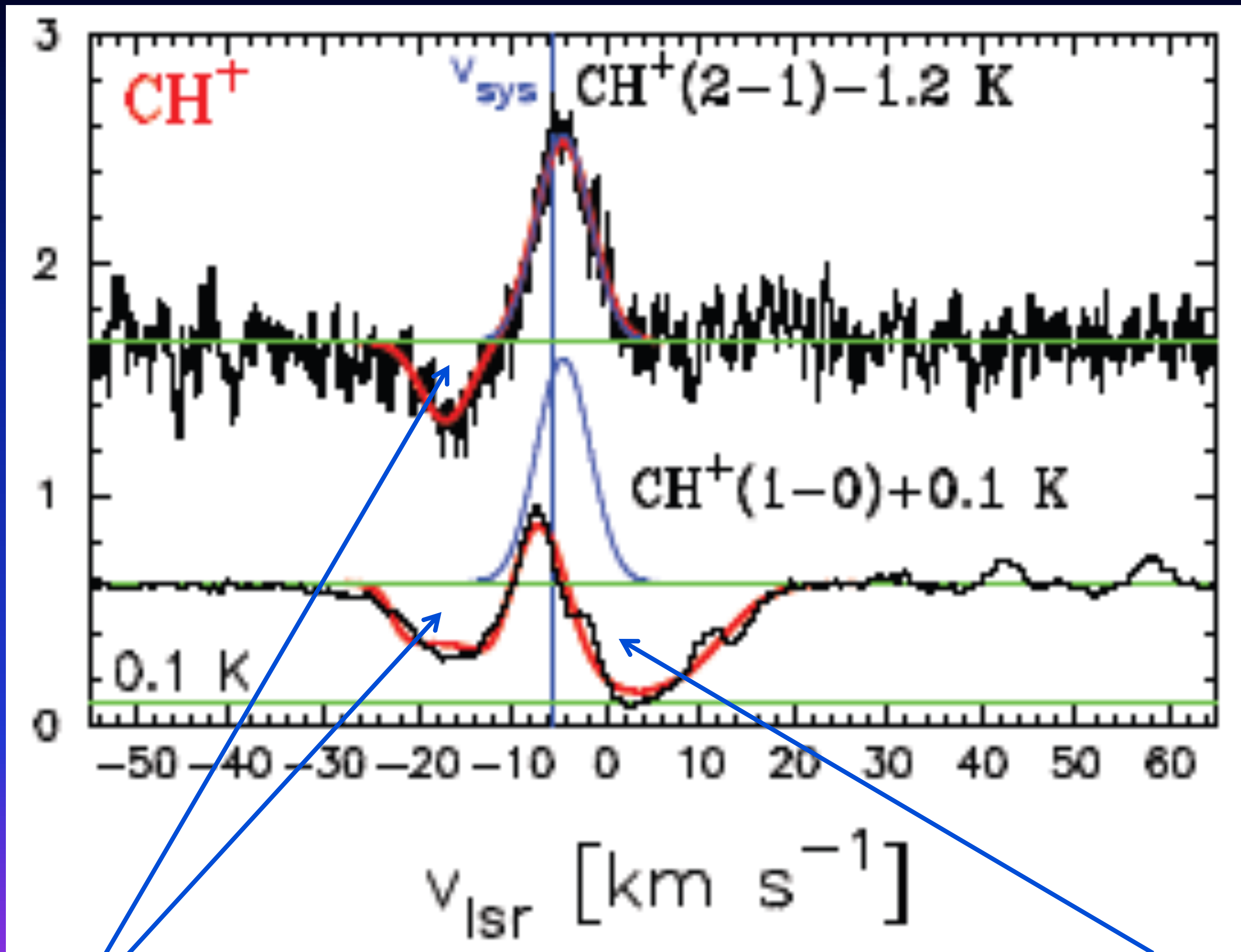


Model with UV irradiation fits better

Detailed Modeling of Outflow Wall

(AFGL 2591)

AFGL 2591

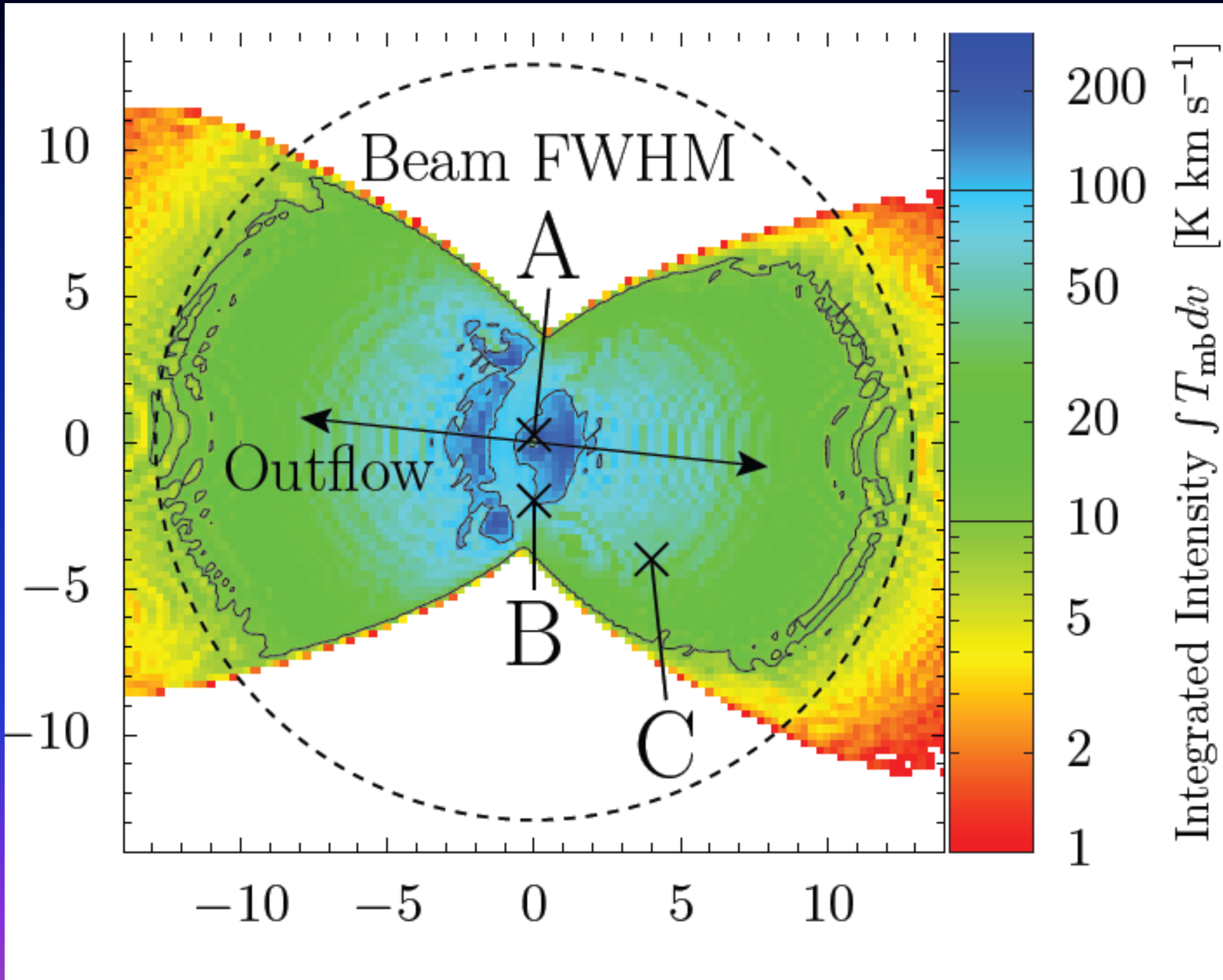


Foreground absorption

Blue-shifted absorption (P Cyg), ν = 835.1375 GHz (Amano)

Bruderer et al. 2010

Map of modeled CH^+ (1-0) emission in AFGL 2591



Bruderer et al. 2010

Model vs Theory

AFGL 2591

CH^+ Beam averaged abundance

1D	2D
$5\ 10^{-16}$	$9\ 10^{-11}$

Irradiated outflow walls enhance beam averaged CH^+

Bruderer et al. (2010) A+A special issue

Model vs Theory
AFGL 2591

CH^+	Line flux [K km/s]	
	2D	**observed**
1-0	**4.3**	**0.91±0.03**
2-1	**8.9**	**3.7 ± 0.2**

Shape of outflow, UV flux, outflow density influence!!

Bruderer et al. (2010) A+A special issue

Radiation Diagnostics Summary

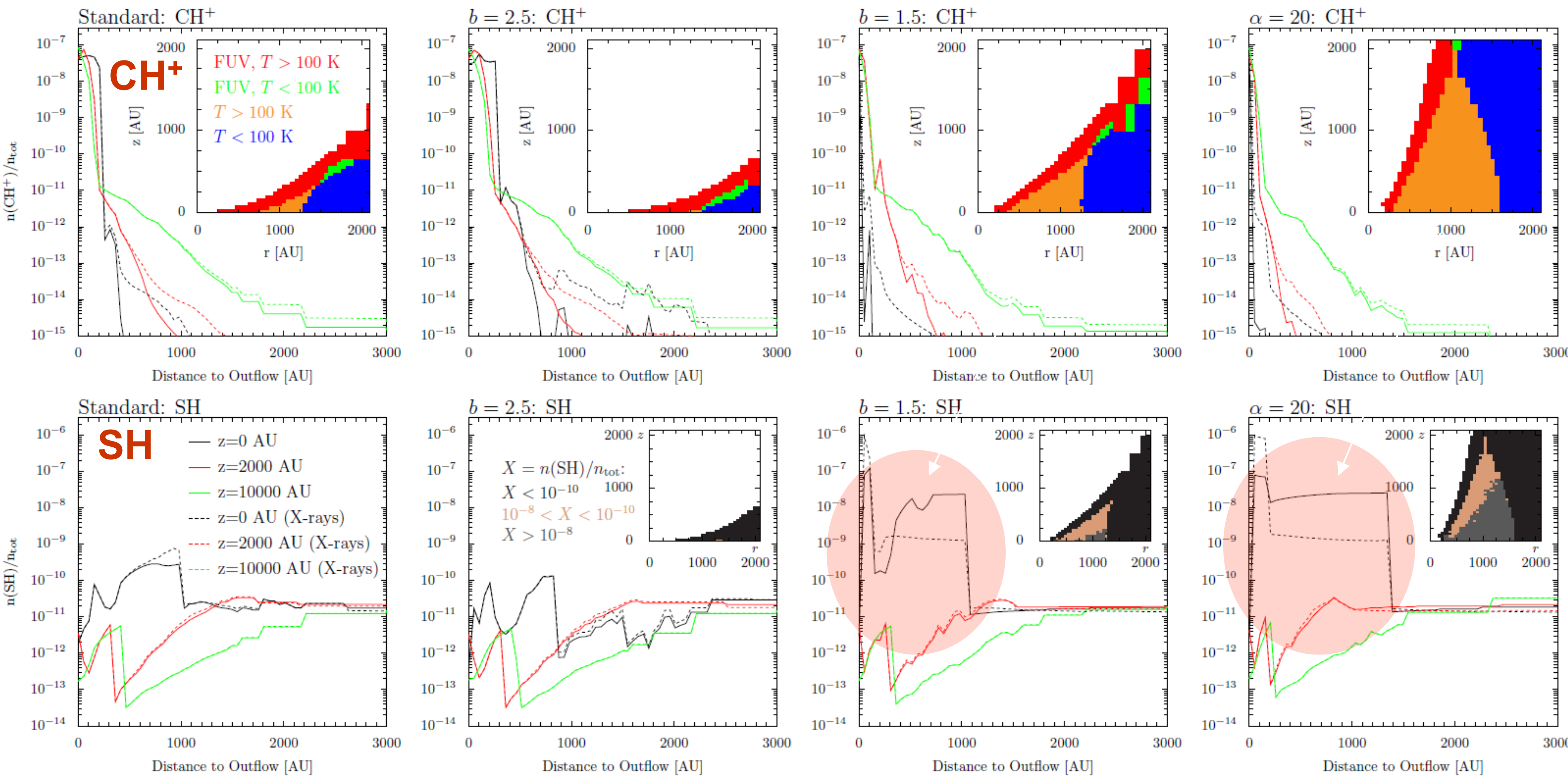
1. The effect of FUV emission by massive YSO can be detected in hydrides.

2. FUV irradiation is most clearly demonstrated in ionized diatomic hydrides such as CH^+.

3. Three components in hydrides in star-forming regions:

- Narrow lines → FUV irradiated outflow walls
- Blue shifted absorption in OH^+, CH^+, H_2O^+, NH (?) , some are P Cyg shaped. Outflow associated ?
- Some emission lines (H_2O, OH, OH^+) have a broad component possibly due to shocks

Influence of outflow geometry



- → **FUV enhanced species little affected (red region): CH^+ and OH^+**
- → **FUV destroyed species evaporating in the hot-core (yellow) depend strongly on geometry: SH and H_2O!**

Bruderer et al. 2010