UNIVERSITY OF CALGARY

RESULTS FROM THE HEXOS FULL-BAND SPECTRAL SURVEY OF ORION SOUTH

René Plume & Kianoosh Tahani - U. of Calgary
Ted Bergin - U. Michigan
The HEXOS Team

The Universe Explored by Herschel - ESTEC - Oct 2013

HEXOS Team:

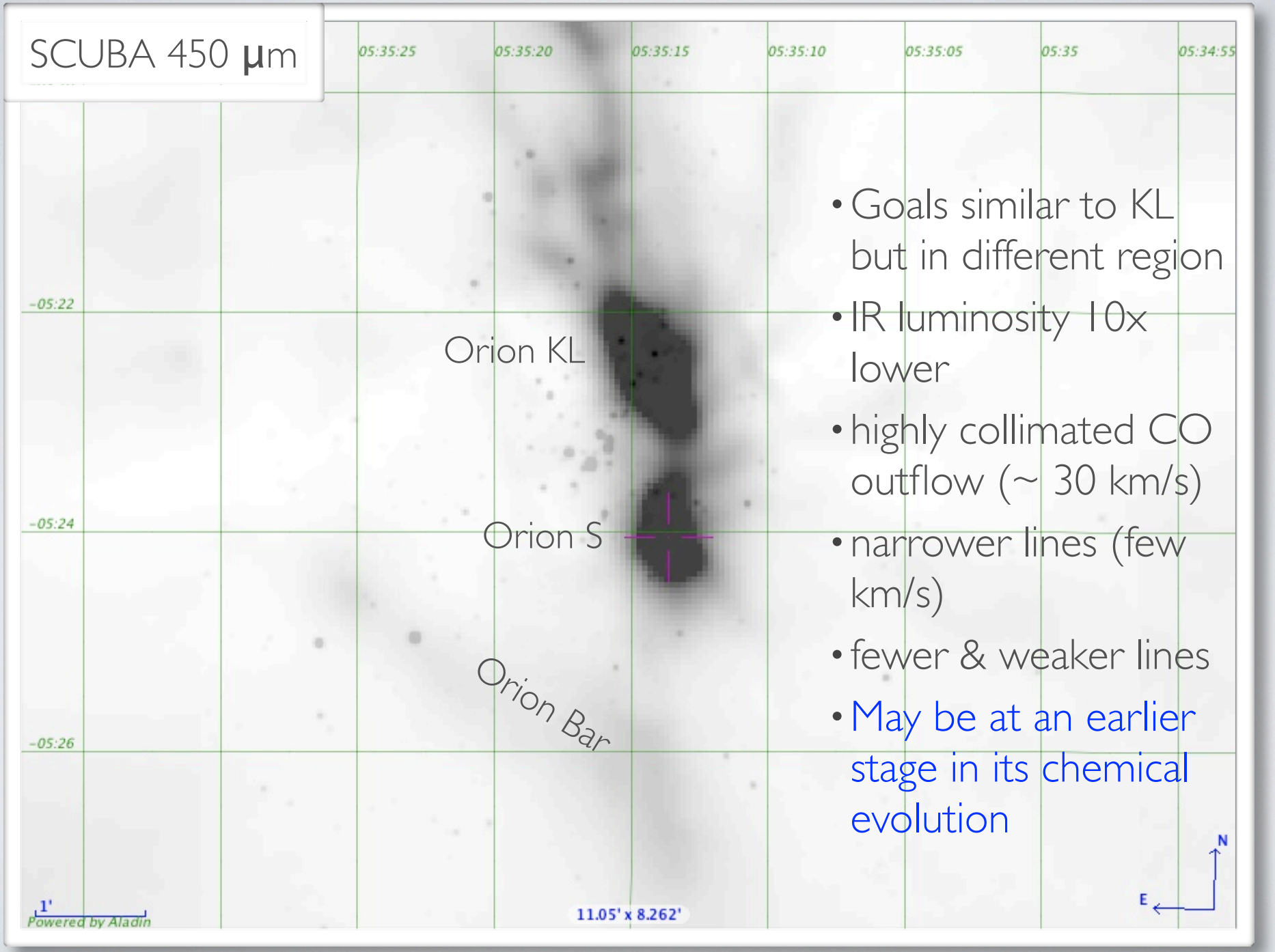
Edwin A. Bergin (PI)
Gisela Banos
Tom A. Bell
Arnaud Belloche
Olivier Berne
Geoffrey A. Blake
Paola Caselli
Emmanuel Caux
Cecilia Ceccarelli
José Cernicharo
Claudia Comito
Nathan Crockett
Fabien Daniel
Marie-Lise Dubernet
Martin Emprechtinger
Pierre Encrenaz
Maryvonne Gerin
Thomas Giesen
Javier R. Goicoechea
Paul Goldsmith
Harschal Gupta
Martin Harwit
Eric Herbst
Martin Houde
Willem Jellema
Christine Joblin
Doug Johnstone
Michael J. Kaufman
Di Li
Dariusz C. Lis
Steven D. Lord
Giuliano Malloci
Sébastien Maret
Peter G. Martin
Gary Melnick
Karl M. Menten
Giacomo Mulas
Holger Muller
J. Anthony Murphy
David A. Neufeld
Volker Ossenkopf
Juan R. Pardo
John C. Pearson
Michel Pérault
Thomas G. Phillips
Poalo Piller
René Plume
Sheng-Li Qin
Markus Röllig
Peter Schilke
Stephan Schlemmer
Robert Simon
Juergen Stutzki
Belen Tercero
Neil Trappe
Charlotte Vastel
Shiya Wang
Harold W. Yorke
Shanshan Yu
Jonas Zmuidzinas

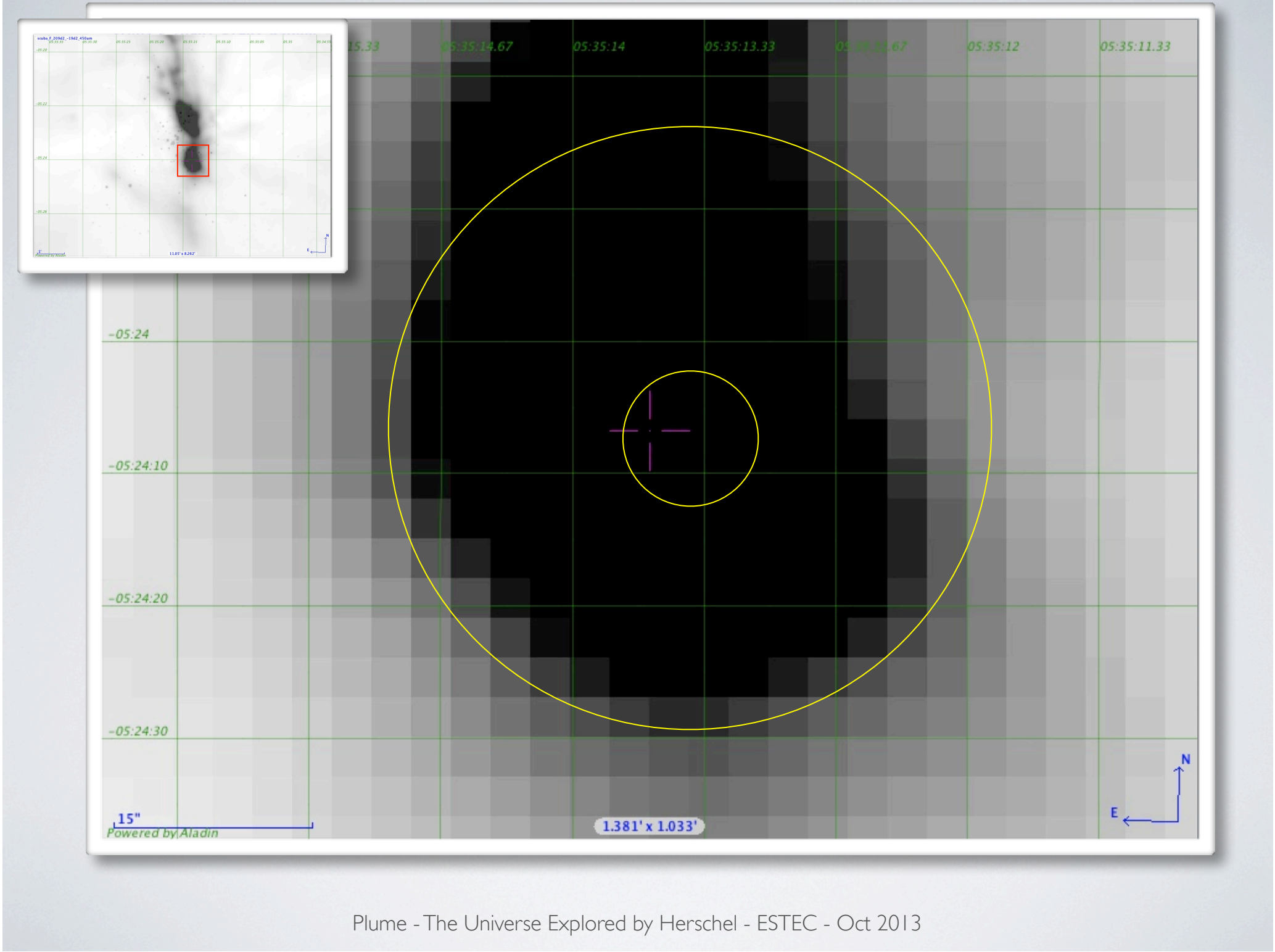
BROAD PERSPECTIVE

- Stars are born in molecular clouds that exhibit a high degree of chemical complexity - clearly dominated by water, carbon monoxide, and carbon dioxide etc but there are many complex organics

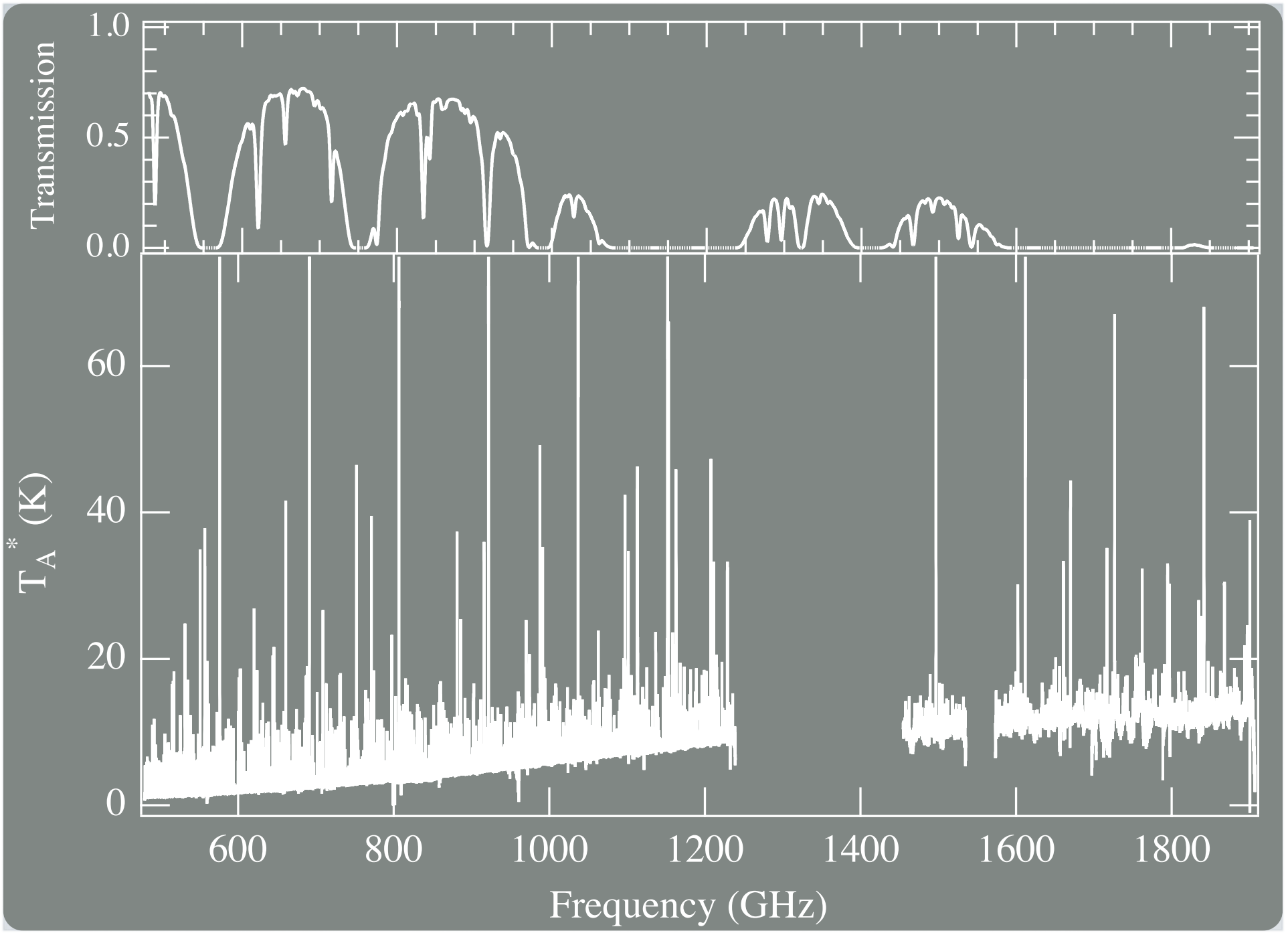
- How this complexity develops is uncertain -- gas phase? catalytic chemistry on grain surfaces? What are the reaction rates and branching ratios of the first key reactions? What are the abundances of the key species?

- We can use the rich variety of chemical species to provide key understandings of the physical conditions in molecular clouds.

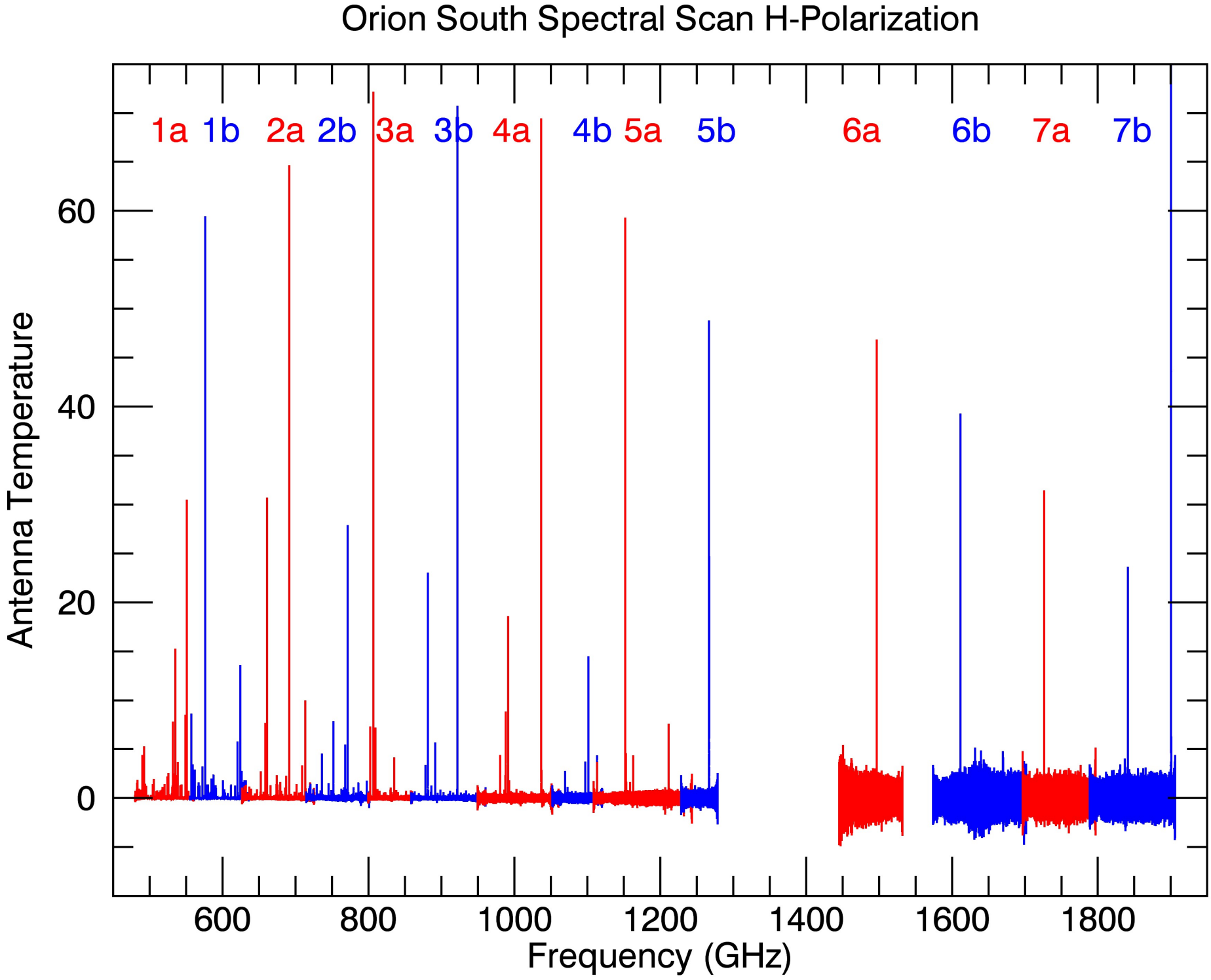

SCUBA 450 μm
05:35:25
05:35:20
05:35:15
05:35:10
05:35:05
05:35
05:34:55
-05:22
-05:24
-05:26
Orion KL
Orion S
Orion Bar
• Goals similar to KL but in different region
• IR luminosity 10x lower
• highly collimated CO outflow (~ 30 km/s)
• narrower lines (few km/s)
• fewer & weaker lines
• May be at an earlier stage in its chemical evolution
1'
Powered by Aladin
11.05' x 8.262'
N
E



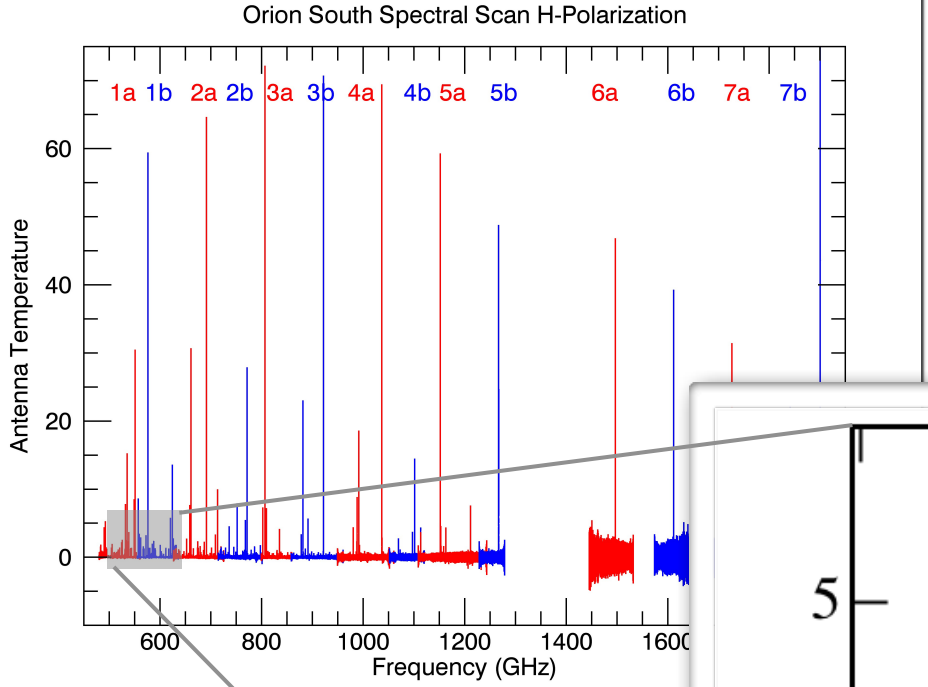
Plume - The Universe Explored by Herschel - ESTEC - Oct 2013

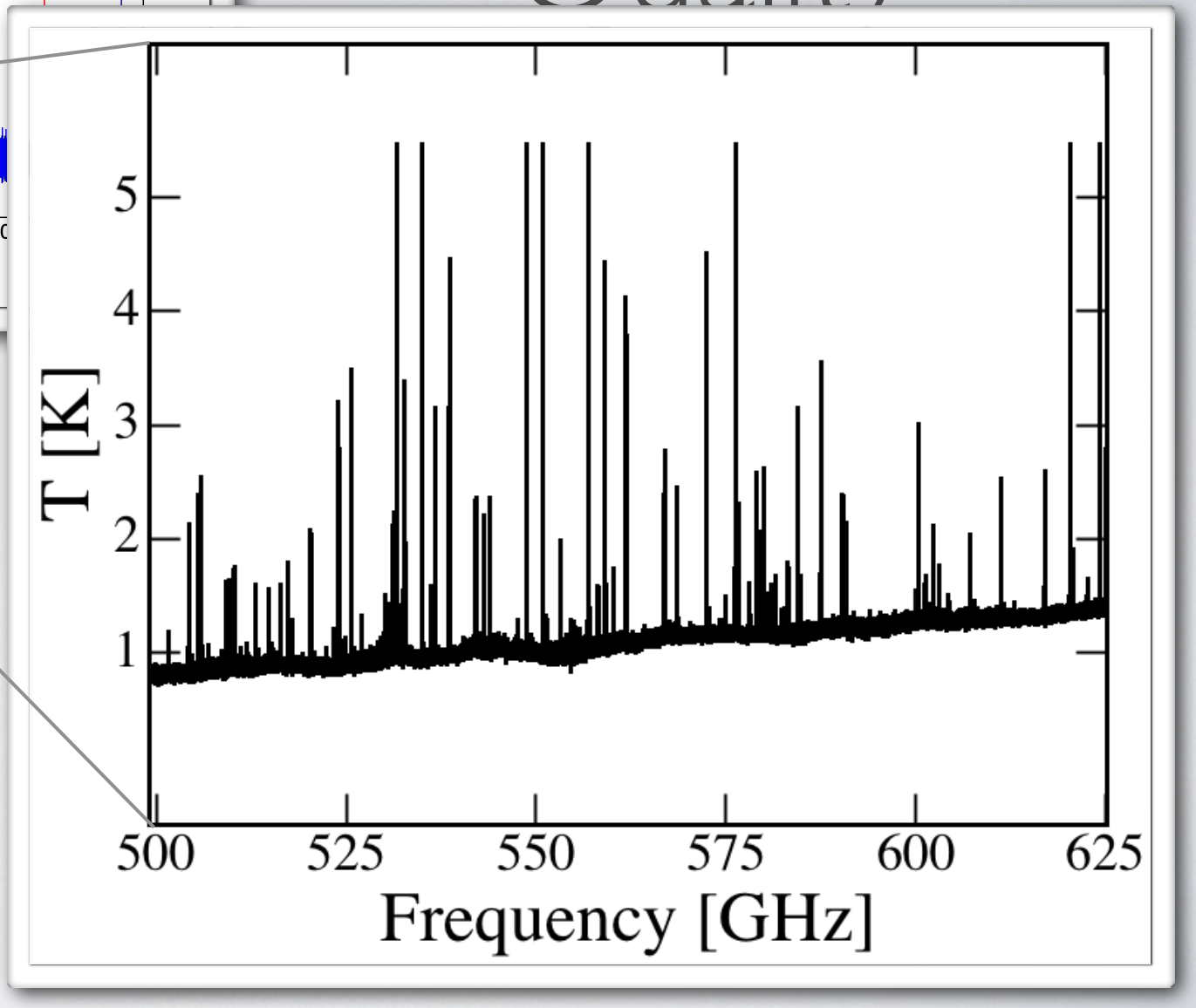

Transmission
1.0
0.5
0.0
T_A^* (K)
60
40
20
0
600
800
1000
1200
1400
1600
1800
Frequency (GHz)

E. Bergin

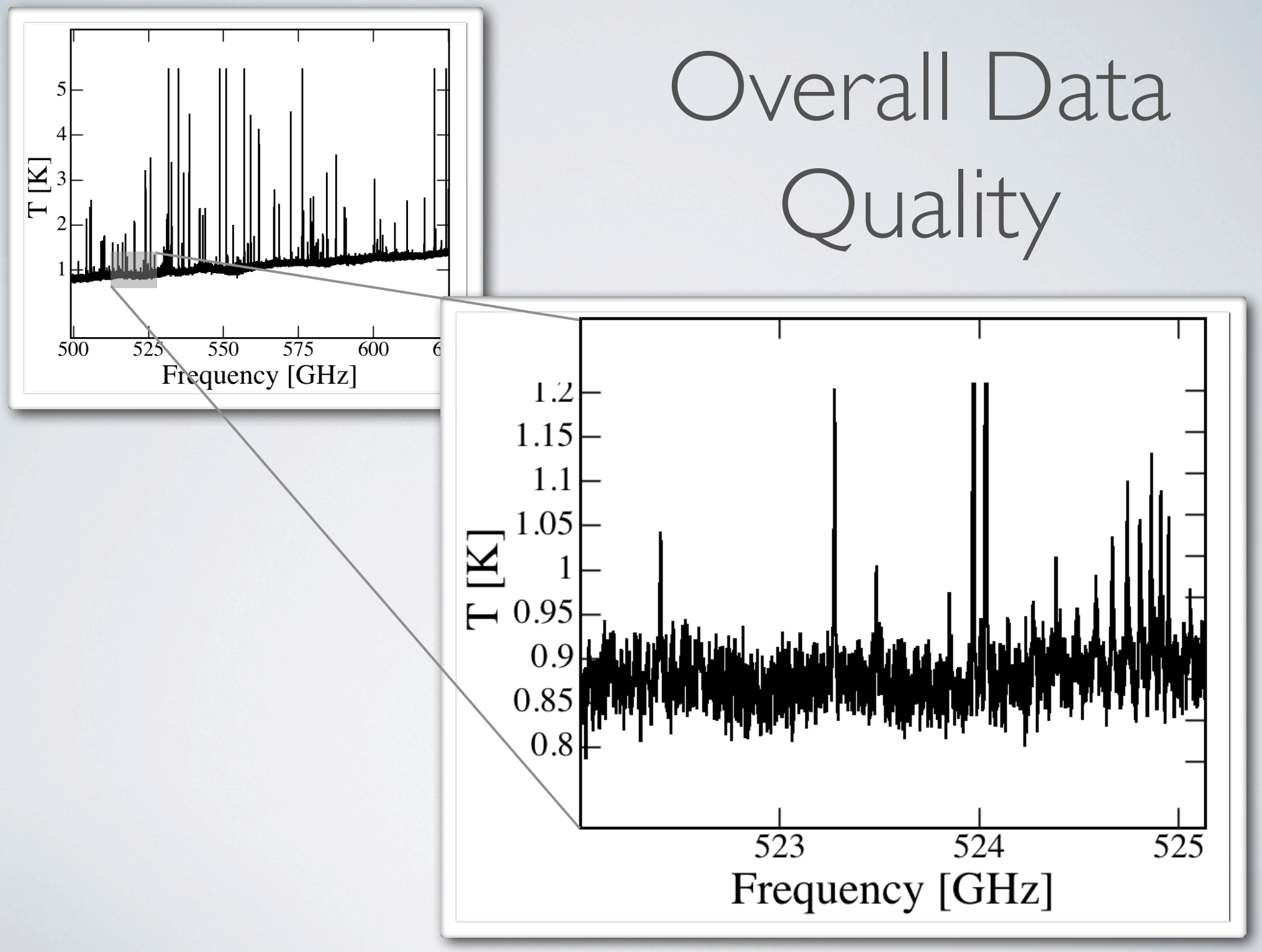

Orion South Spectral Scan H-Polarization
1a 1b 2a 2b 3a 3b 4a 4b 5a 5b 6a 6b 7a 7b
Antenna Temperature
0
20
40
60
600
800
1000
1200
1400
1600
1800
Frequency (GHz)

Overall Data Quality

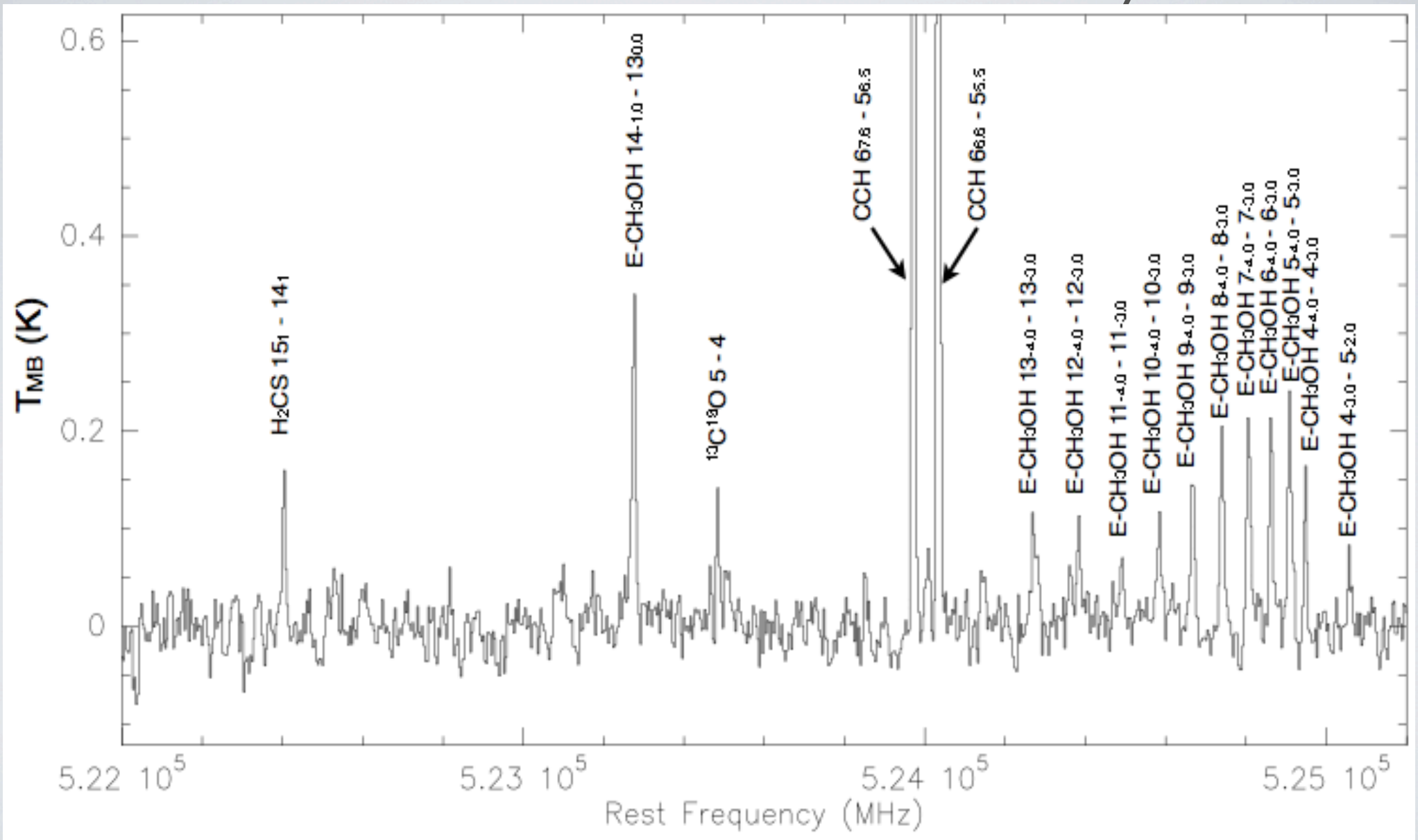


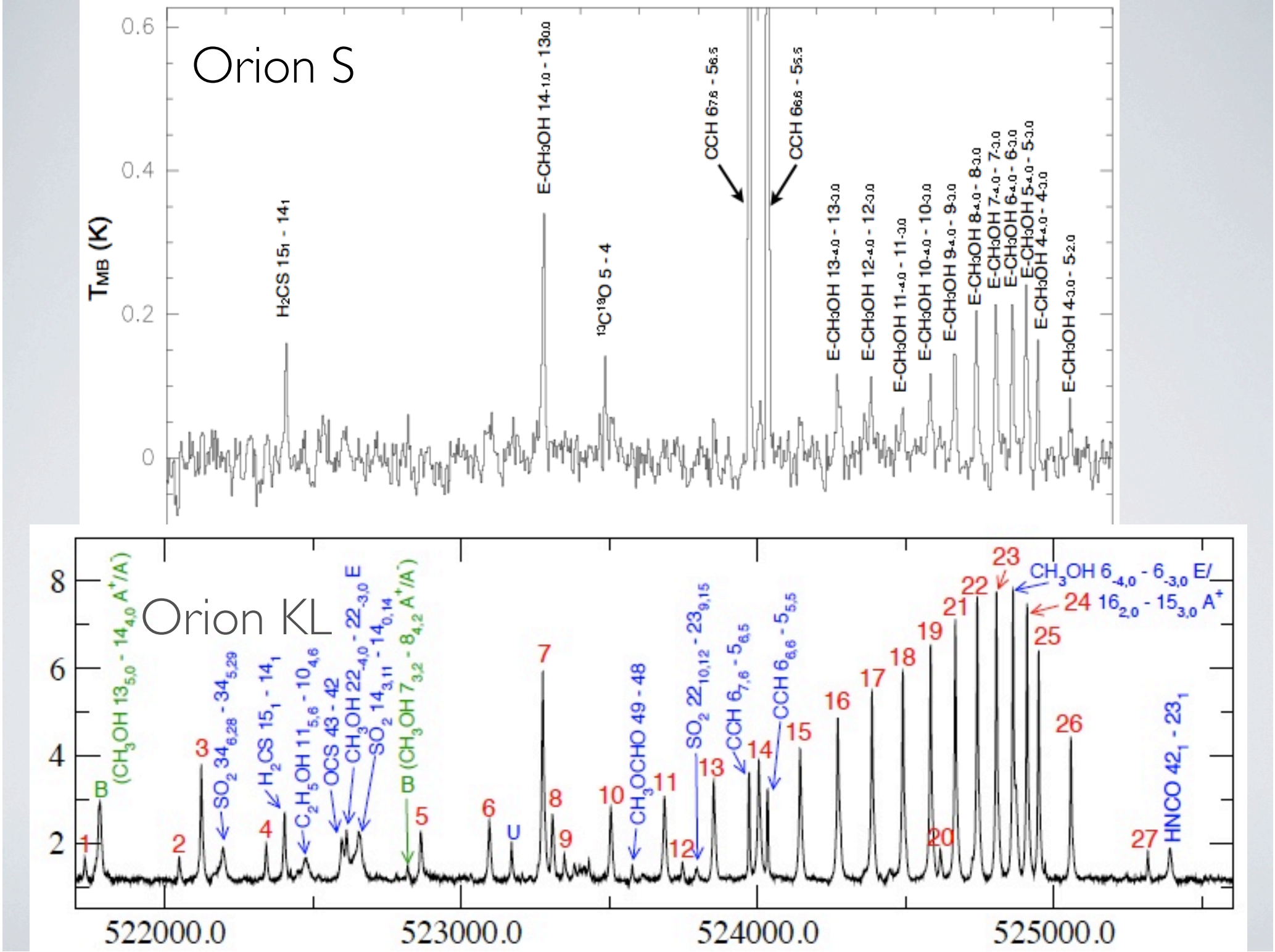


Overall Data Quality



Overall Data Quality




Orion S
T_{MB} (K)
0.6
0.4
0.2
0
H_2CS 15_1 - 14_1
E-CH_3OH $14_{1,0}$ - $13_{0,0}$
$^{13}C^{18}O$ 5 - 4
CCH $6_{7,6}$ - $5_{6,5}$
CCH $6_{6,6}$ - $5_{5,5}$
E-CH_3OH $13_{-4,0}$ - $13_{-3,0}$
E-CH_3OH $12_{-4,0}$ - $12_{-3,0}$
E-CH_3OH $11_{-4,0}$ - $11_{-3,0}$
E-CH_3OH $10_{-4,0}$ - $10_{-3,0}$
E-CH_3OH $9_{-4,0}$ - $9_{-3,0}$
E-CH_3OH $8_{-4,0}$ - $8_{-3,0}$
E-CH_3OH $7_{-4,0}$ - $7_{-3,0}$
E-CH_3OH $6_{-4,0}$ - $6_{-3,0}$
E-CH_3OH $5_{-4,0}$ - $5_{-3,0}$
E-CH_3OH $4_{-4,0}$ - $4_{-3,0}$
E-CH_3OH $4_{-3,0}$ - $5_{-2,0}$
Orion KL
8
6
4
2
B (CH_3OH $13_{5,0}$ - $14_{4,0}$ A^+/A^-)
SO_2 $34_{6,28}$ - $34_{5,29}$
H_2CS 15_1 - 14_1
C_2H_5OH $11_{5,6}$ - $10_{4,6}$
OCS 43 - 42
CH_3OH $22_{-4,0}$ - $22_{-3,0}$ E
SO_2 $14_{3,11}$ - $14_{0,14}$
B (CH_3OH $7_{3,2}$ - $8_{4,2}$ A^+/A^-)
CH_3OCHO 49 - 48
SO_2 $22_{10,12}$ - $23_{9,15}$
CCH $6_{7,6}$ - $5_{6,5}$
CCH $6_{6,6}$ - $5_{5,5}$
CH_3OH $6_{-4,0}$ - $6_{-3,0}$ E/
$16_{2,0}$ - $15_{3,0}$ A^+
HNCO 42_1 - 23_1
1
2
3
4
5
6
U
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
522000.0
523000.0
524000.0
525000.0

Line Identification

- Using CASSIS we have identified, and fit Gaussians to over ~ 400 transitions from 45 species
- Plus an additional ~100 U lines
- Focusing on the strong (S/N > 4-5) lines
- There are ~ 800 lines from ~47 species if we include lines w S/N ~ 3-4
- few complex molecules

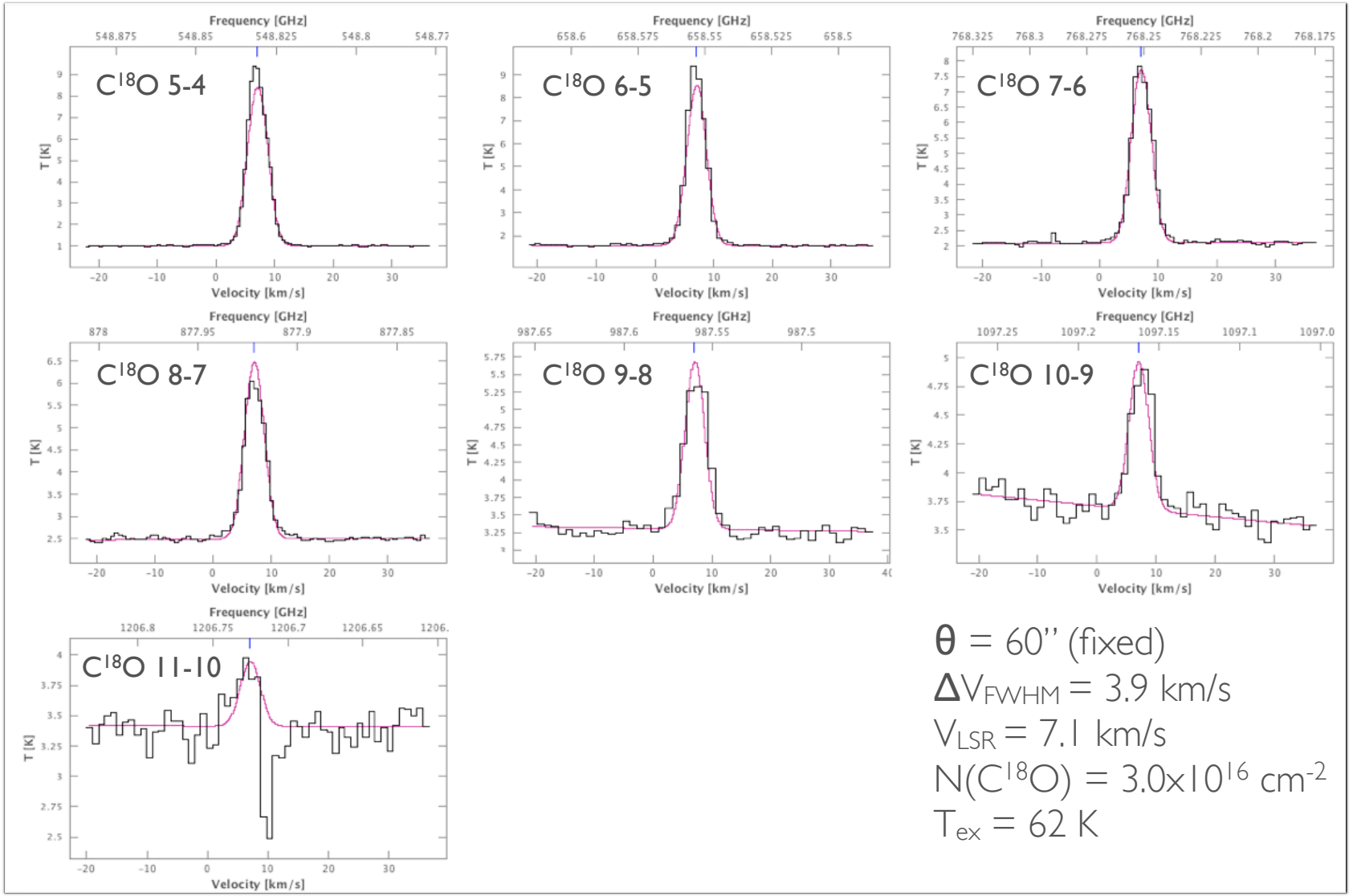
- Tahani et al 2014

C^0	$C^{18}O$	p-H_2O	$H^{13}CO^+$
C^+	$^{13}C^{18}O$	o-H_2O	$HC^{18}O^+$
CCH	$C^{17}O$	$H_2{}^{18}O$	DCO^+
CCD	CS	HDO	HNC
CH^+	$C^{34}S$	p-H_2S	N_2H+
CH	^{13}CS	o-H_2S	o-NH_3
E-CH_3OH	HCl	$H_2{}^{34}S$	p-NH_3
A-CH_3OH	$H^{37}Cl$	HCN	NO
CN	p-H_2CO	$H^{13}CN$	SH^+
CO	o-H_2CO	DCN	SO
^{13}CO	H_2CS	HCO^+	SO_2
			SiO

CASSIS
A free interactive spectrum analyser

http://cassis.irap.omp.eu

Spectral Line Fitting

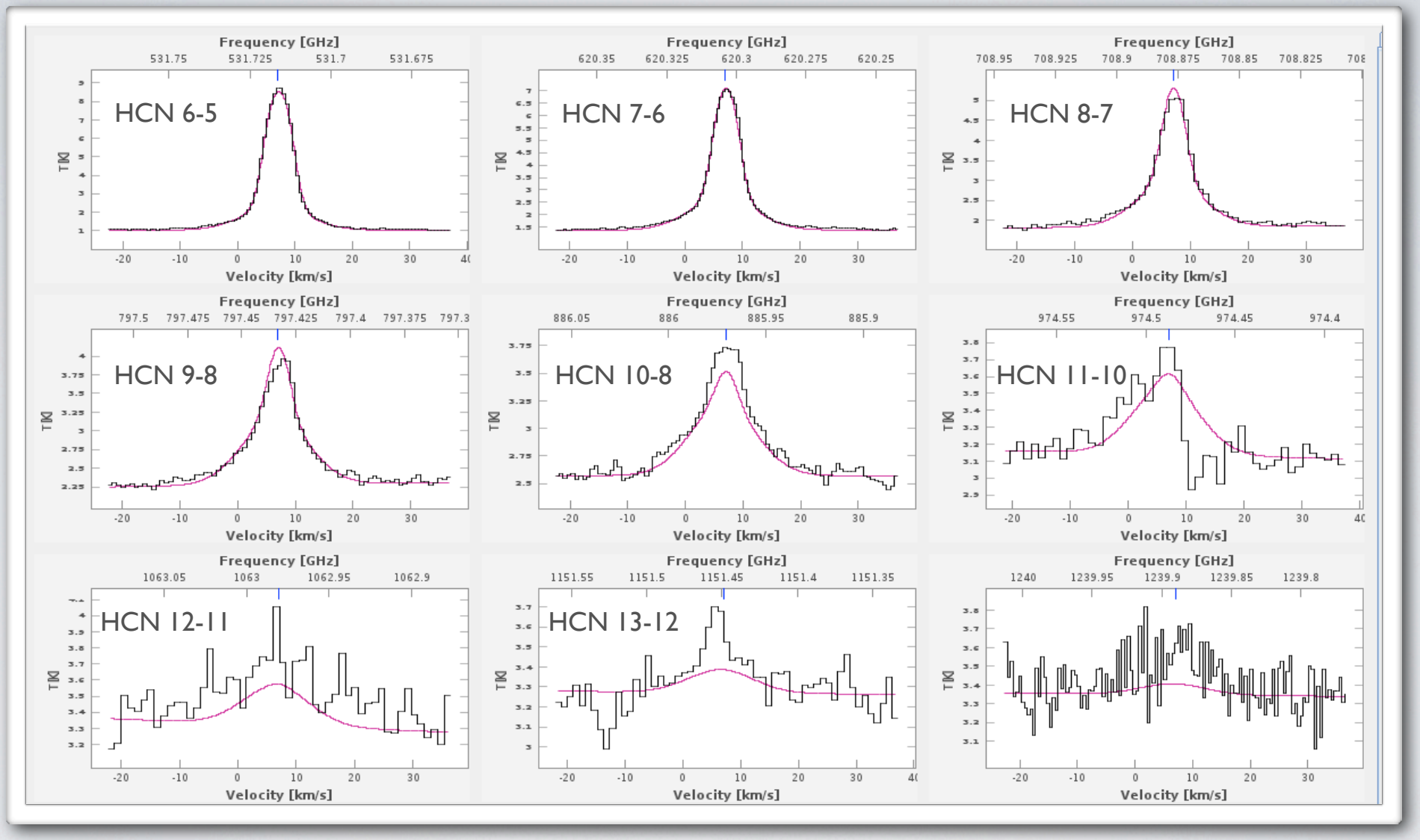


θ = 60'' (fixed)
ΔV_{FWHM} = 3.9 km/s
V_{LSR} = 7.1 km/s
$N(C^{18}O) = 3.0 \times 10^{16}$ cm^{-2}
T_{ex} = 62 K

CASSIS
A free interactive spectrum analyser

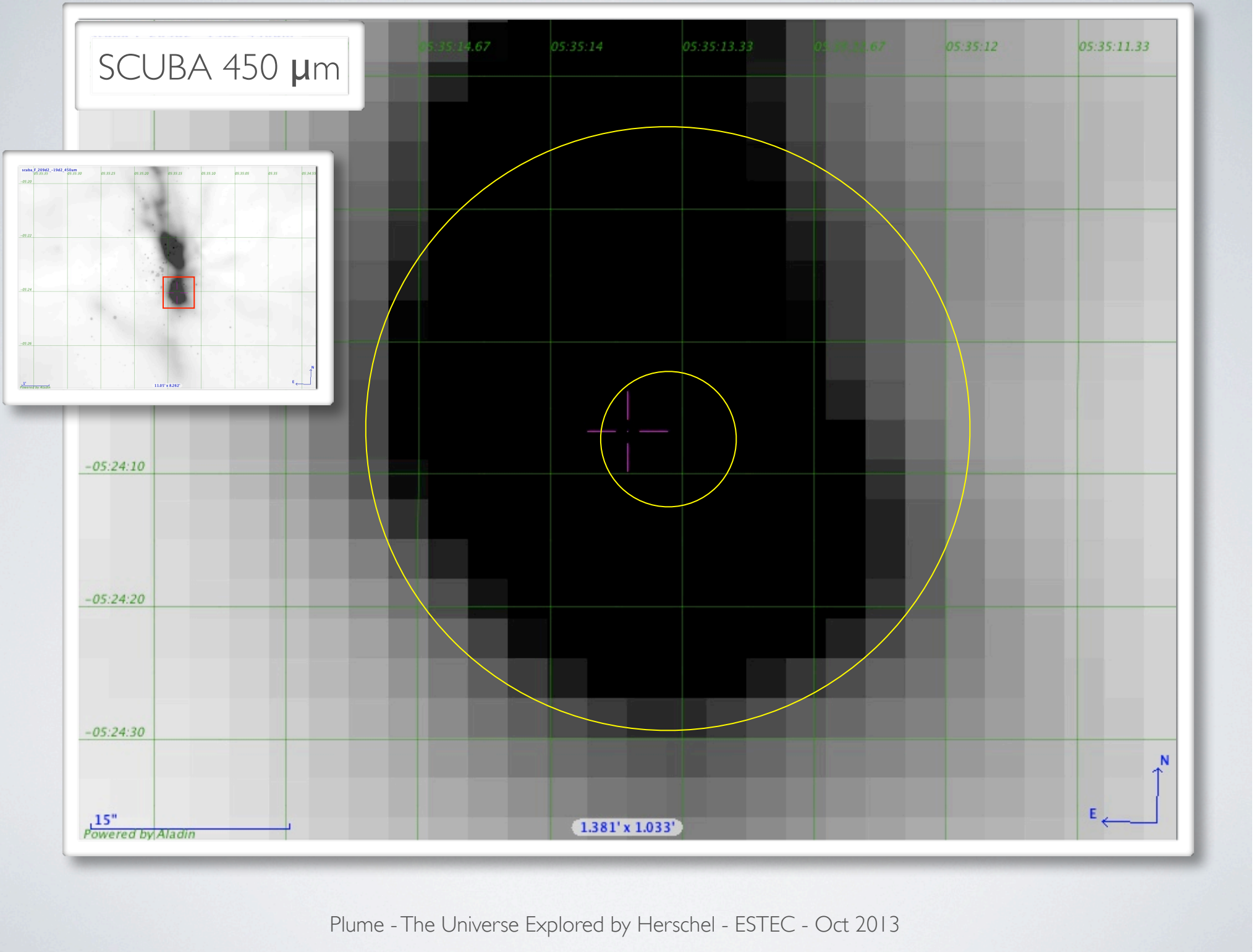
http://cassis.irap.omp.eu

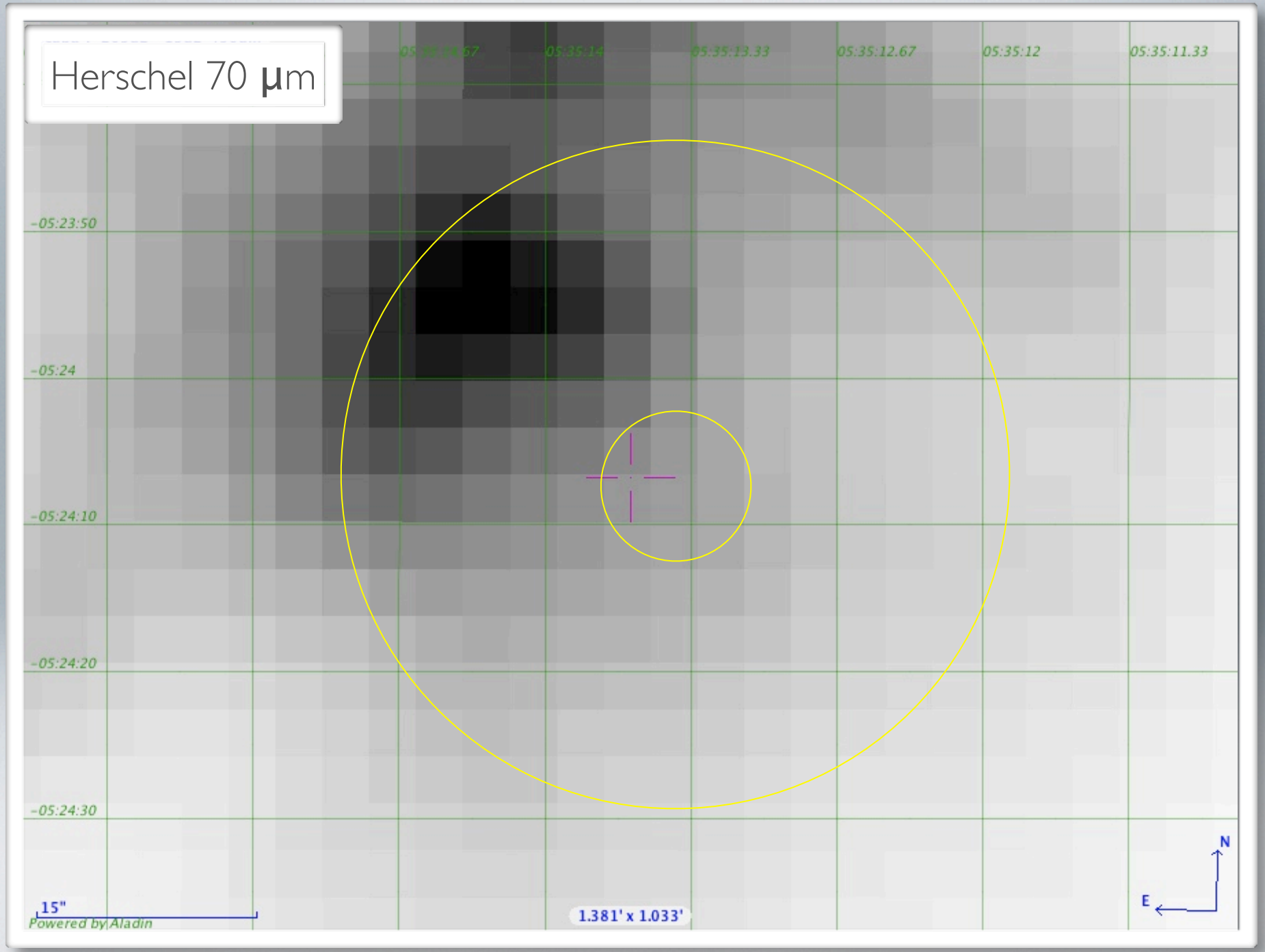
Spectral Line Fitting



θ = 30'' , ΔV_{FWHM} = 13.7 km/s, V_{LSR} = 6.6 km/s, N = 2.8×10^{13} cm^{-2}, T_{ex} = 74 K

θ = 60'' (fixed), ΔV_{FWHM} = 4.4 km/s, V_{LSR} = 7.1 km/s, N = 1.9×10^{14} cm^{-2}, T_{ex} = 32 K


SCUBA 450 µm
05:35:14.67
05:35:14
05:35:13.33
05:35:12
05:35:11.33
-05:24:10
-05:24:20
-05:24:30
15"
Powered by Aladin
1.381' x 1.033'
N
E



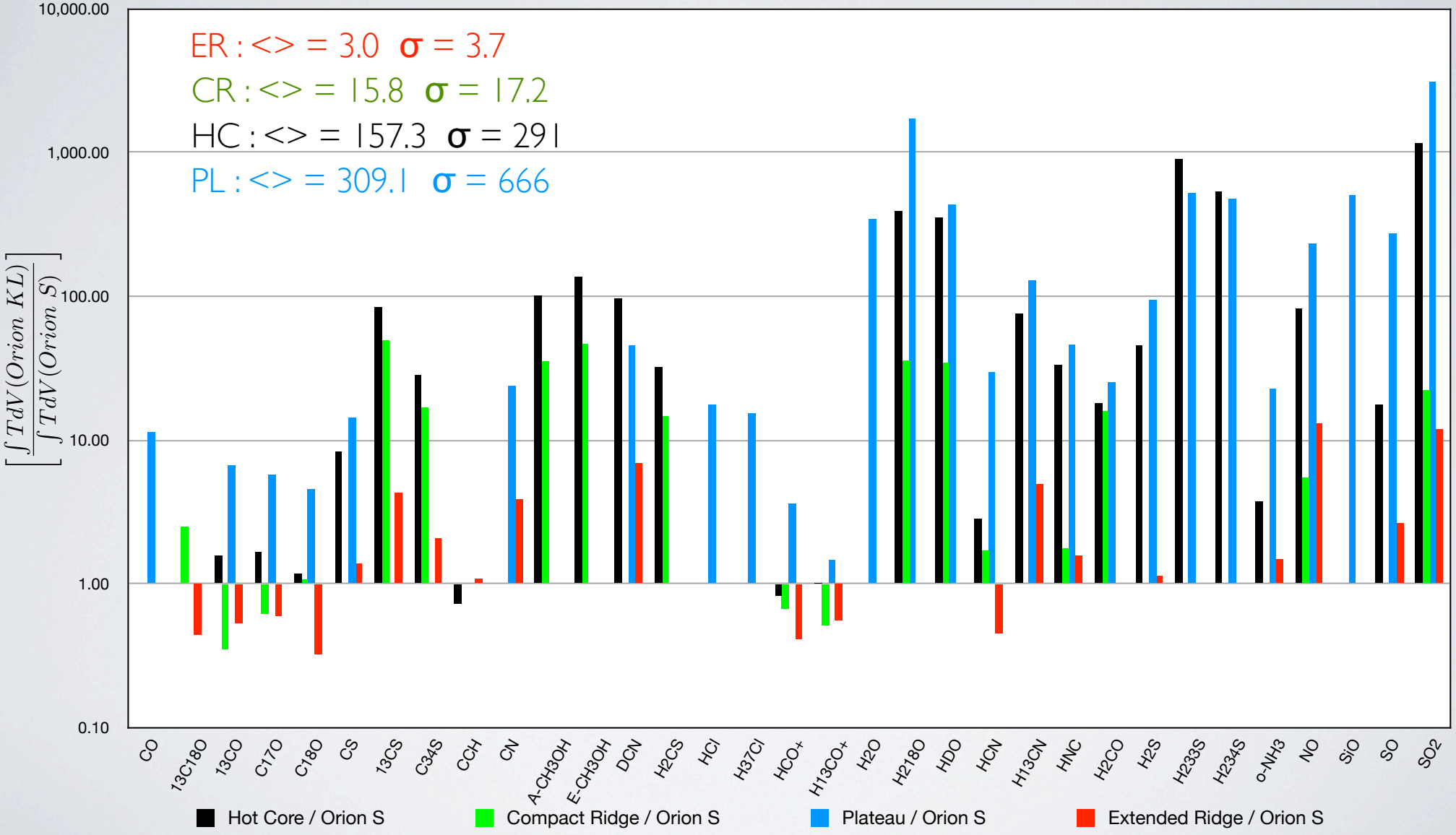
Courtesy of P. André and the Herschel Gould Belt survey (HGBS) project (A&A, 518, L102)
http://gouldbelt-herschel.cea.fr/archives

Polychroni et al., in prep.

16

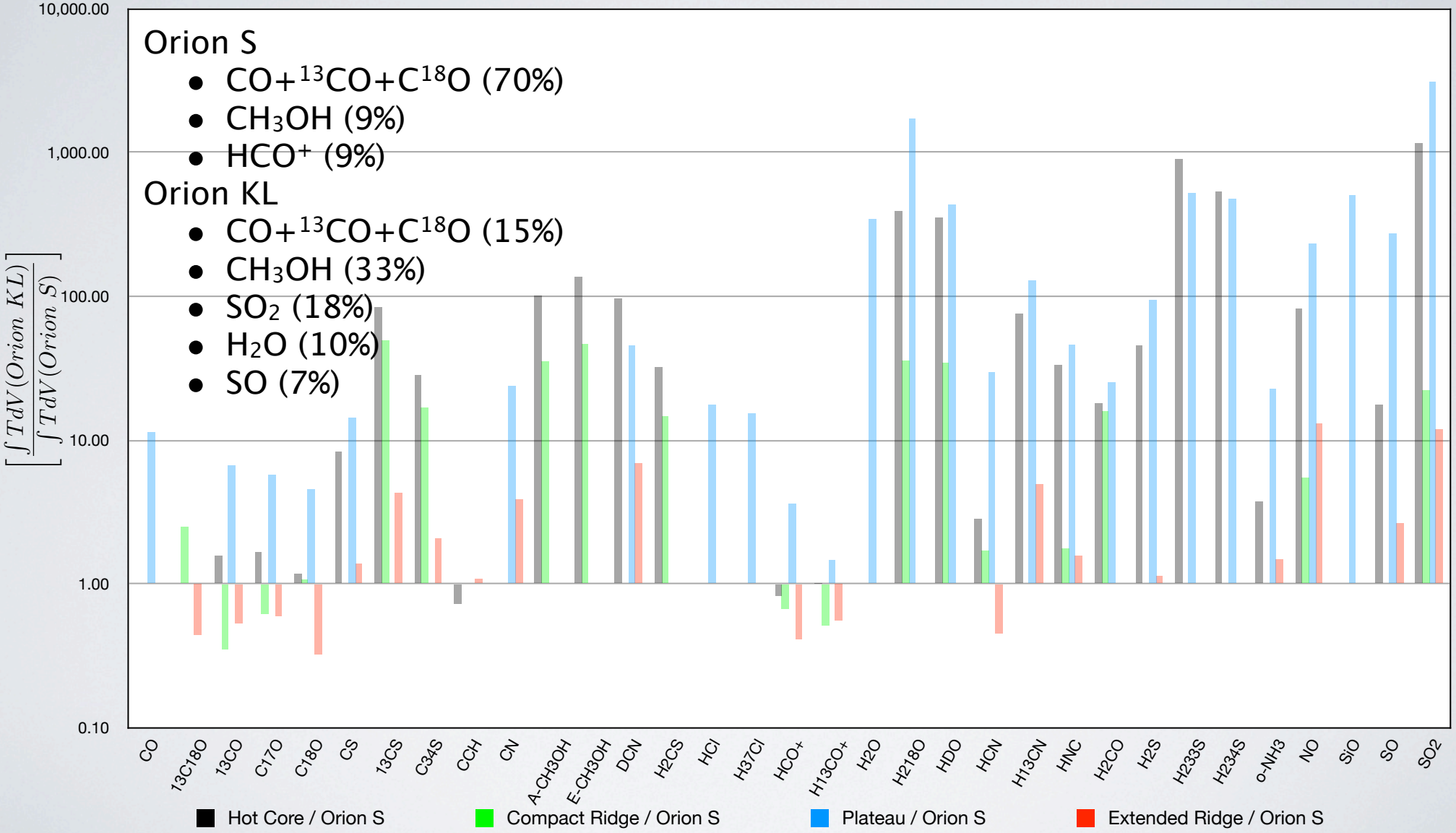
Emission Properties

Comparison with Orion KL (N. Crockett et al. 2013)



Emission Properties

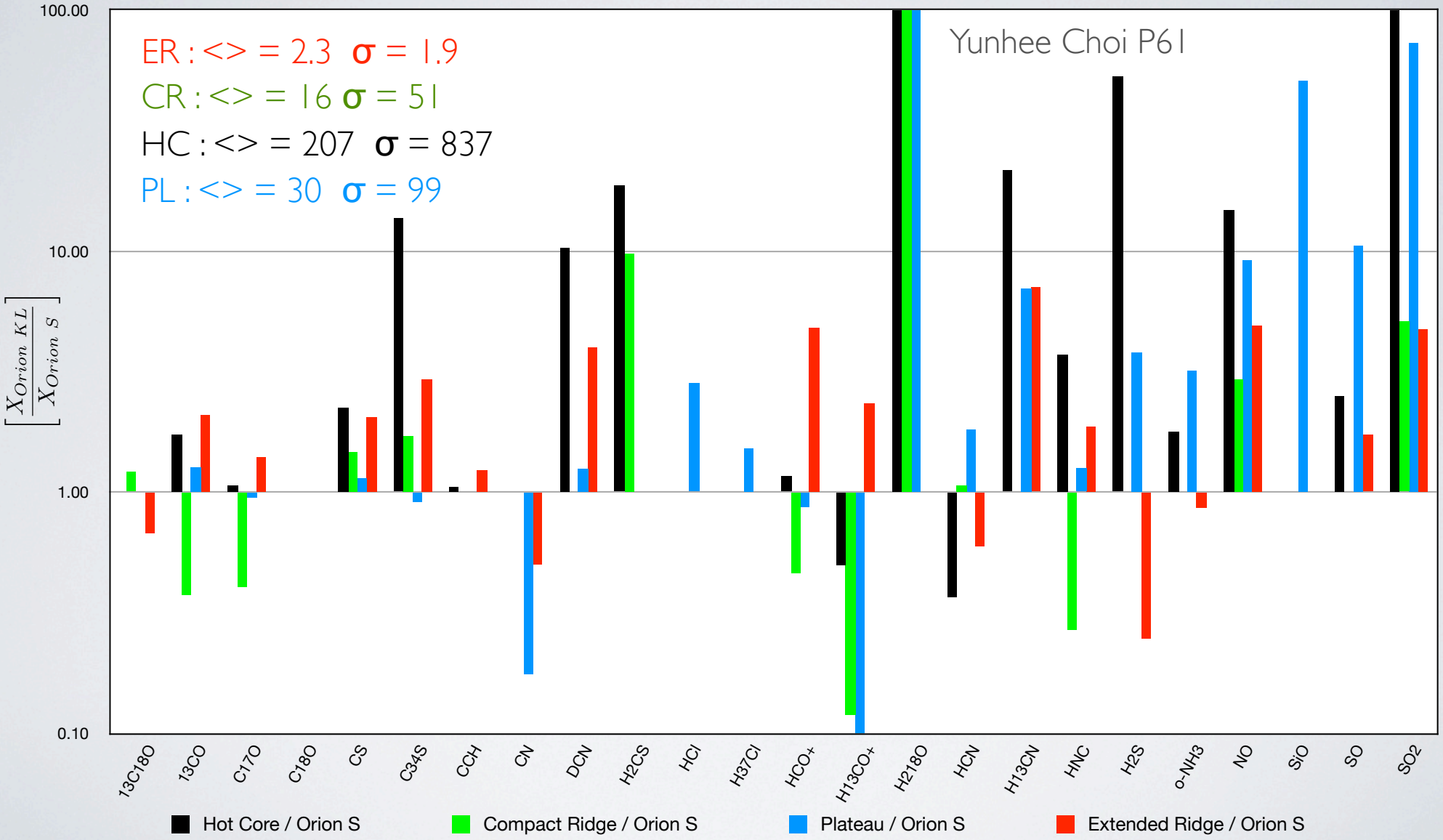
Comparison with Orion KL (N. Crockett et al. 2013)



Abundance Variations

Comparison with Orion KL (N. Crockett et al. 2013)

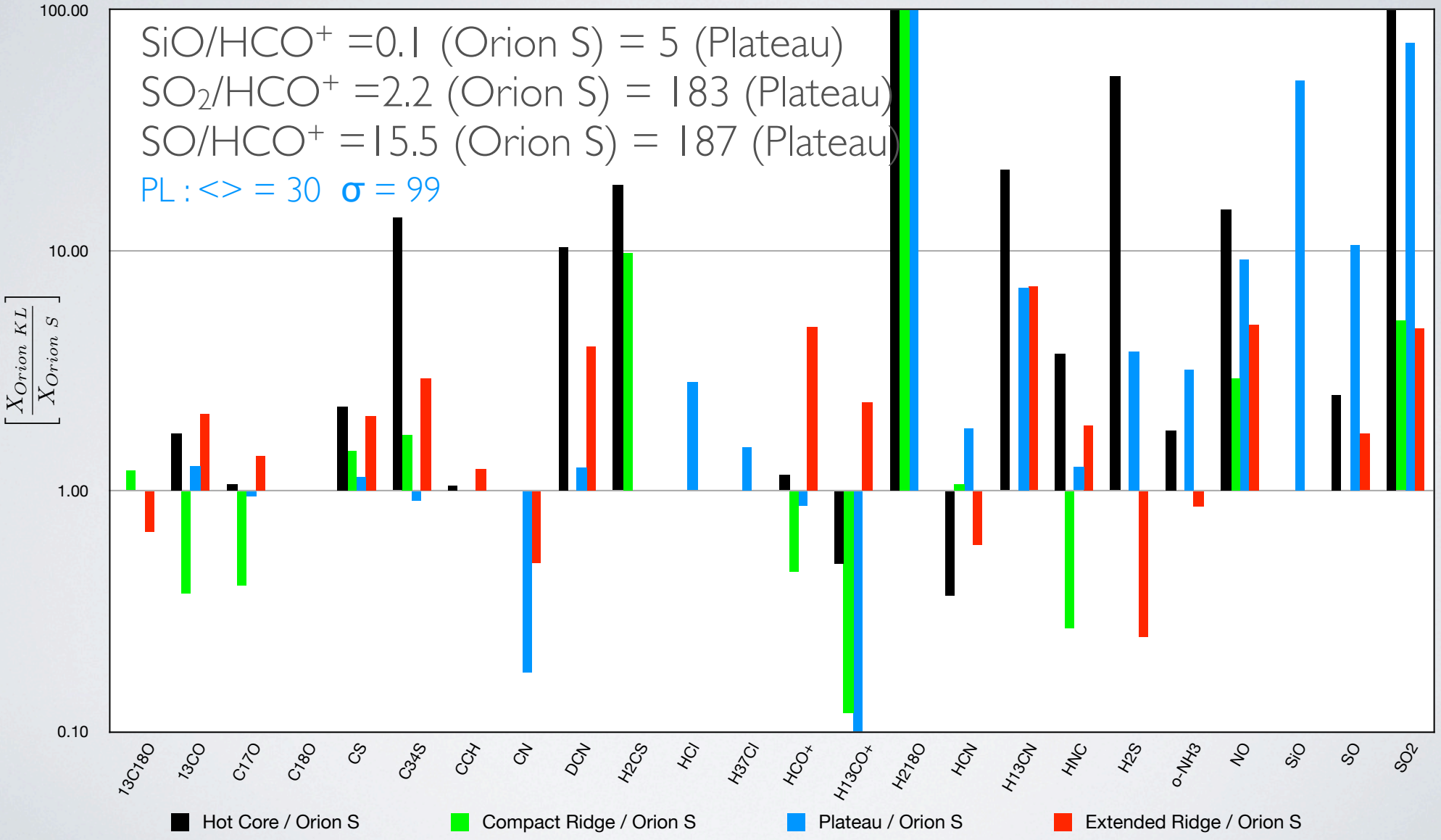
$N(H_2) = 500 \times 10^4 \times N(C^{18}O)$



Abundance Variations

Weak Shock Chemistry

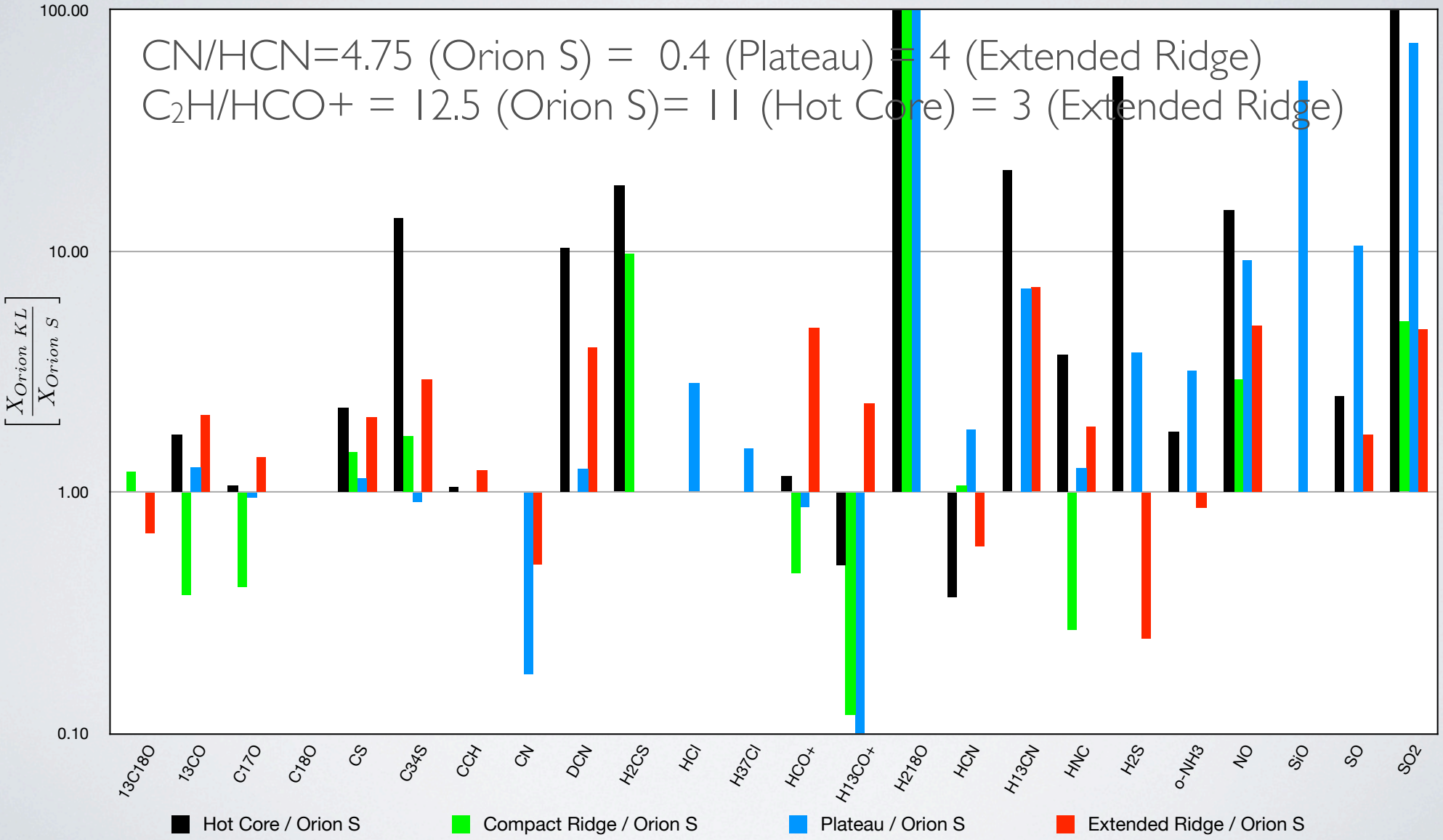
$N(H_2) = 500 \times 10^4 \times N(C^{18}O)$



Abundance Variations

Enhanced UV Chemistry?

$N(H_2) = 500 \times 10^4 \times N(C^{18}O)$



Conclusions

UNIVERSITY OF CALGARY

- Covered 460-1900 GHz with spectral resolution of 1.1 MHz
- Identified & fit Gaussian profiles to over 300 transitions from 45 species
- Using LTE models, determined physical parameters for each of the species (N, T_{ex}, etc.)
  - Single, warm (40 - 60K) physical component works well in most cases
  - 2 components (cool/narrow + warm/broad) needed in some instances
- Warm gas is fairly extended and possibly externally heated
- Orion S has chemical composition most similar to Orion KL Extended & Compact Ridges (except for $H_2{}^{18}O$)
  - no complex organics & poor fit to Hot Core → no Hot Core chem
  - poor fit to Plateau & low SiO, SO, SO_2 abundances → weak shock chem
  - Evidence for UV chemistry
- Need chemical & RADEX modeling