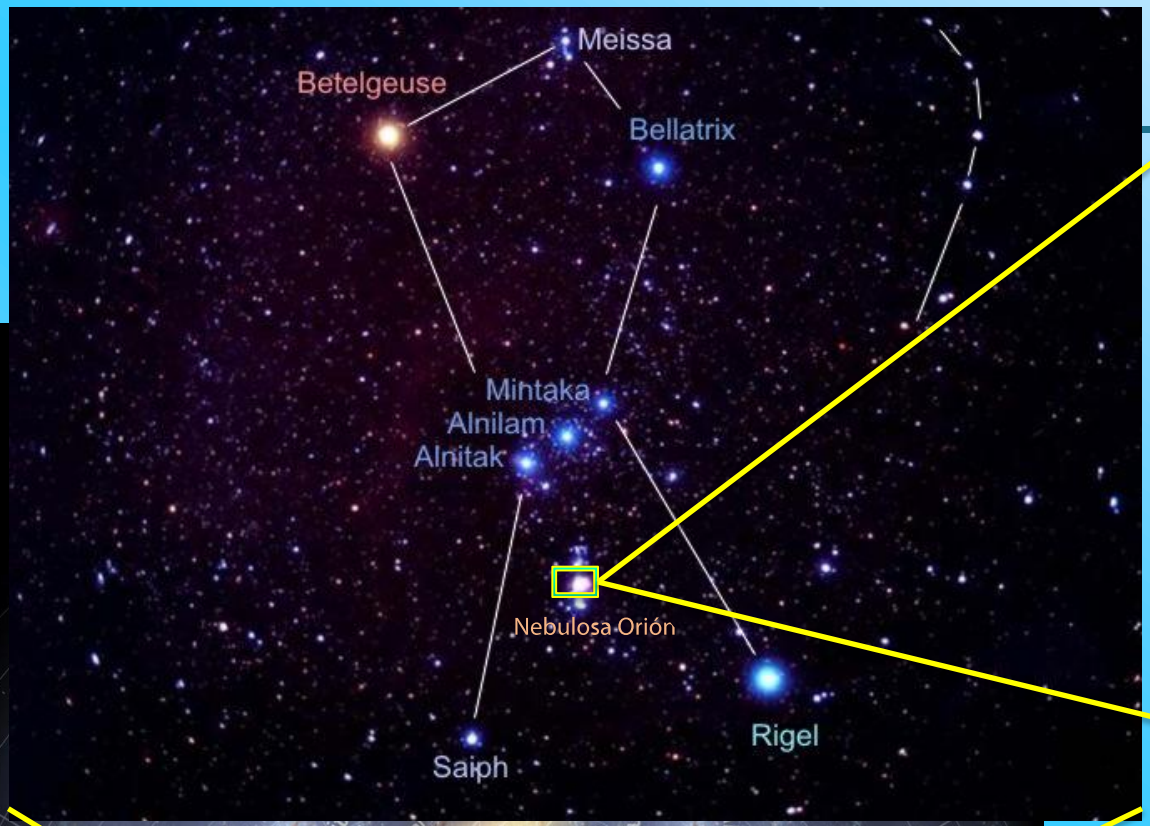
COMBINED IRAM, Herschel/HIFI and ALMA STUDIES of abundant molecules in ORION KL

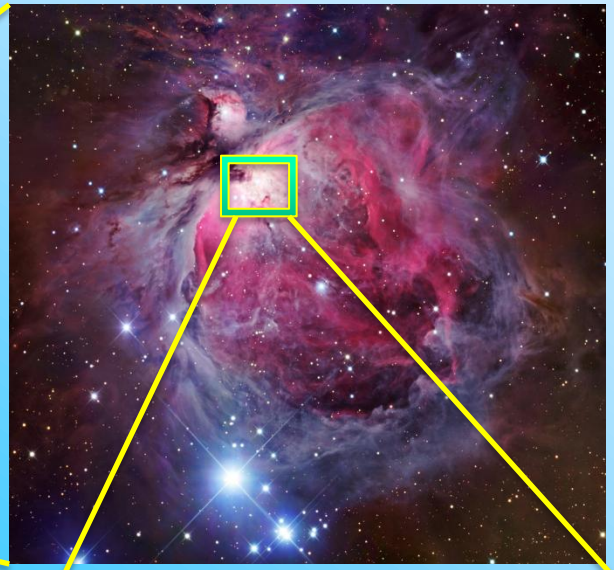
Belén Tercero
ICMM-CSIC, Madrid, Spain

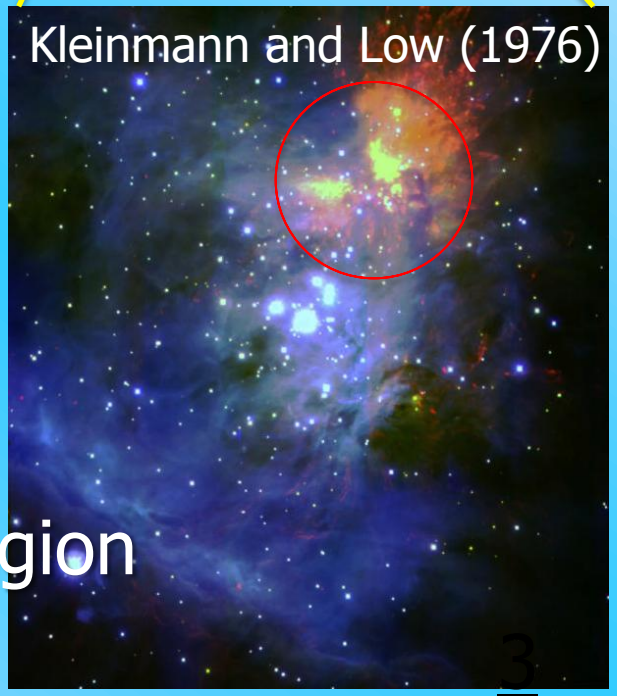
nanoCOSMOS

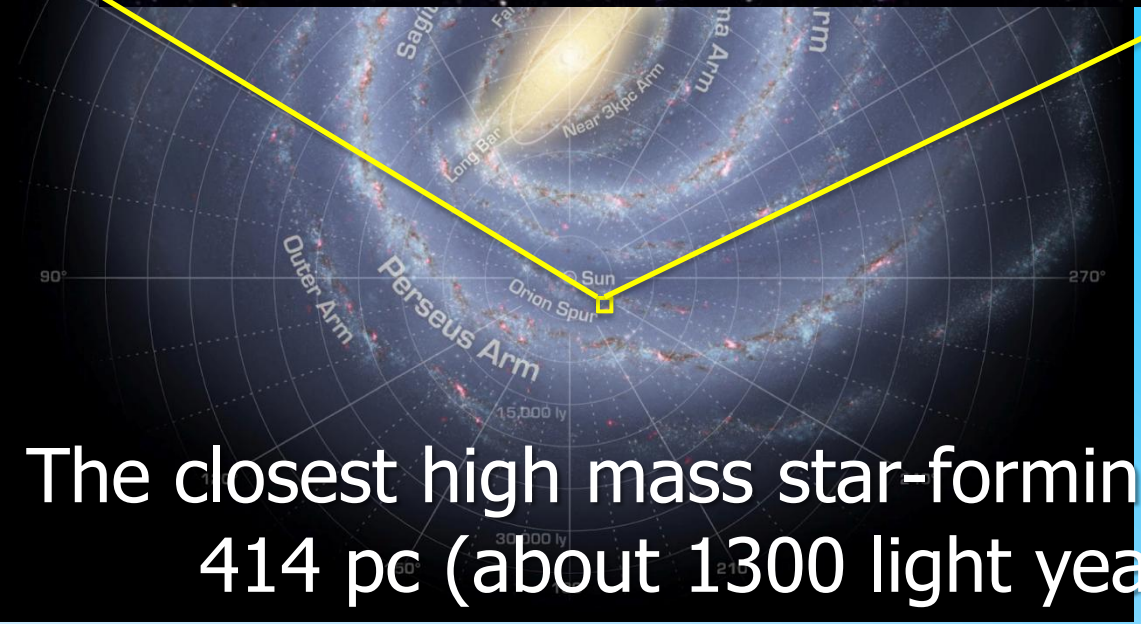
CONTENTS

1. ORION



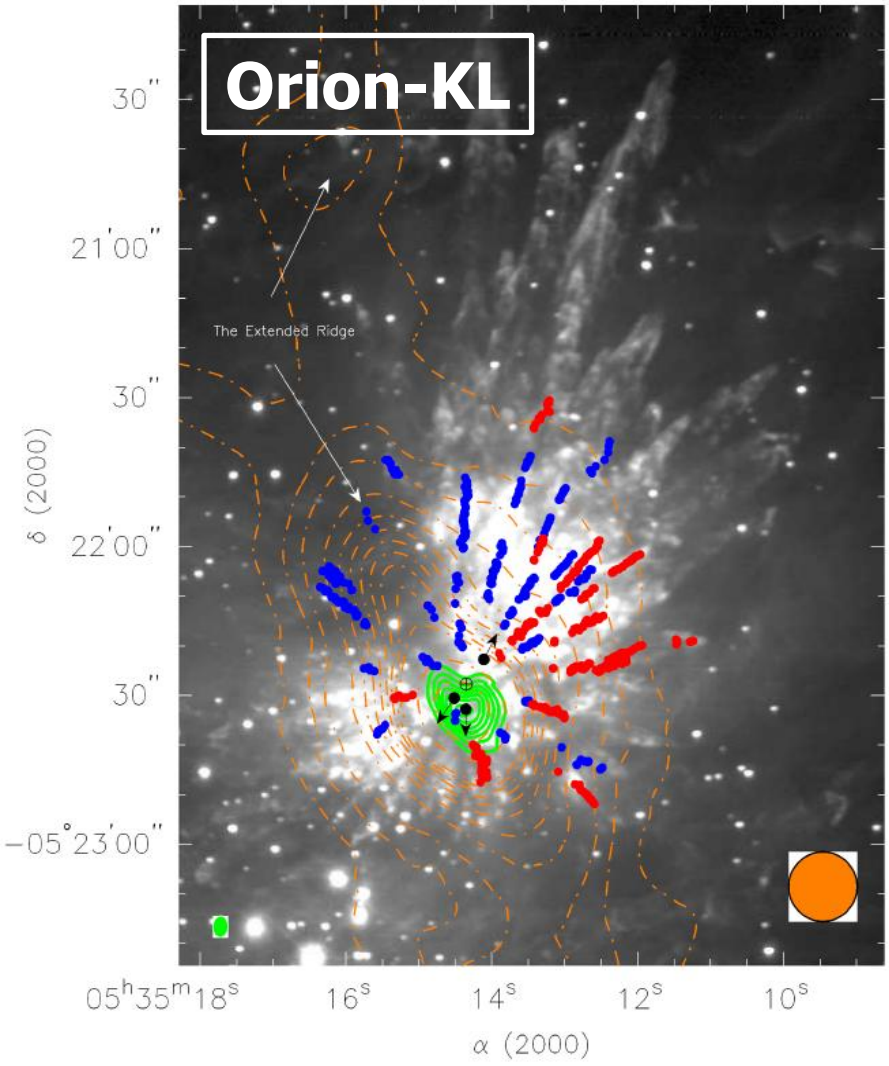






The closest high mass star-forming region
414 pc (about 1300 light years)

1. ORION KL



30" HPBW at 80 GHz IRAM 30-m → 12500 AU

9" HPBW at 280 GHz IRAM 30-m → 3750 AU

2"X1".5 ALMA SV synthetic beam → 830 AU

44" HPBW at 480 GHz HIFI → 18333 AU

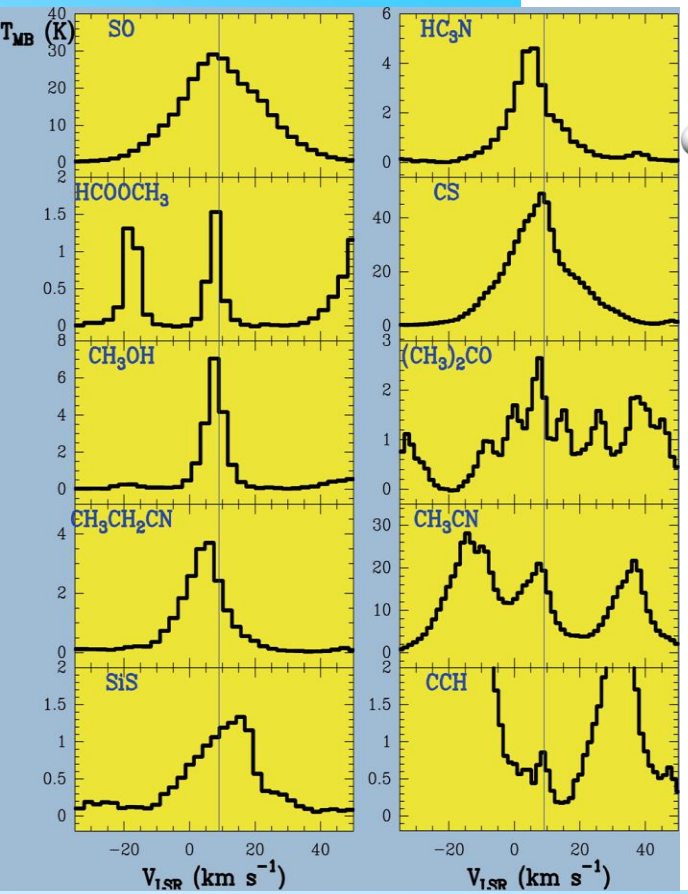
16.5" HPBW at 1280 GHz HIFI → 6827 AU

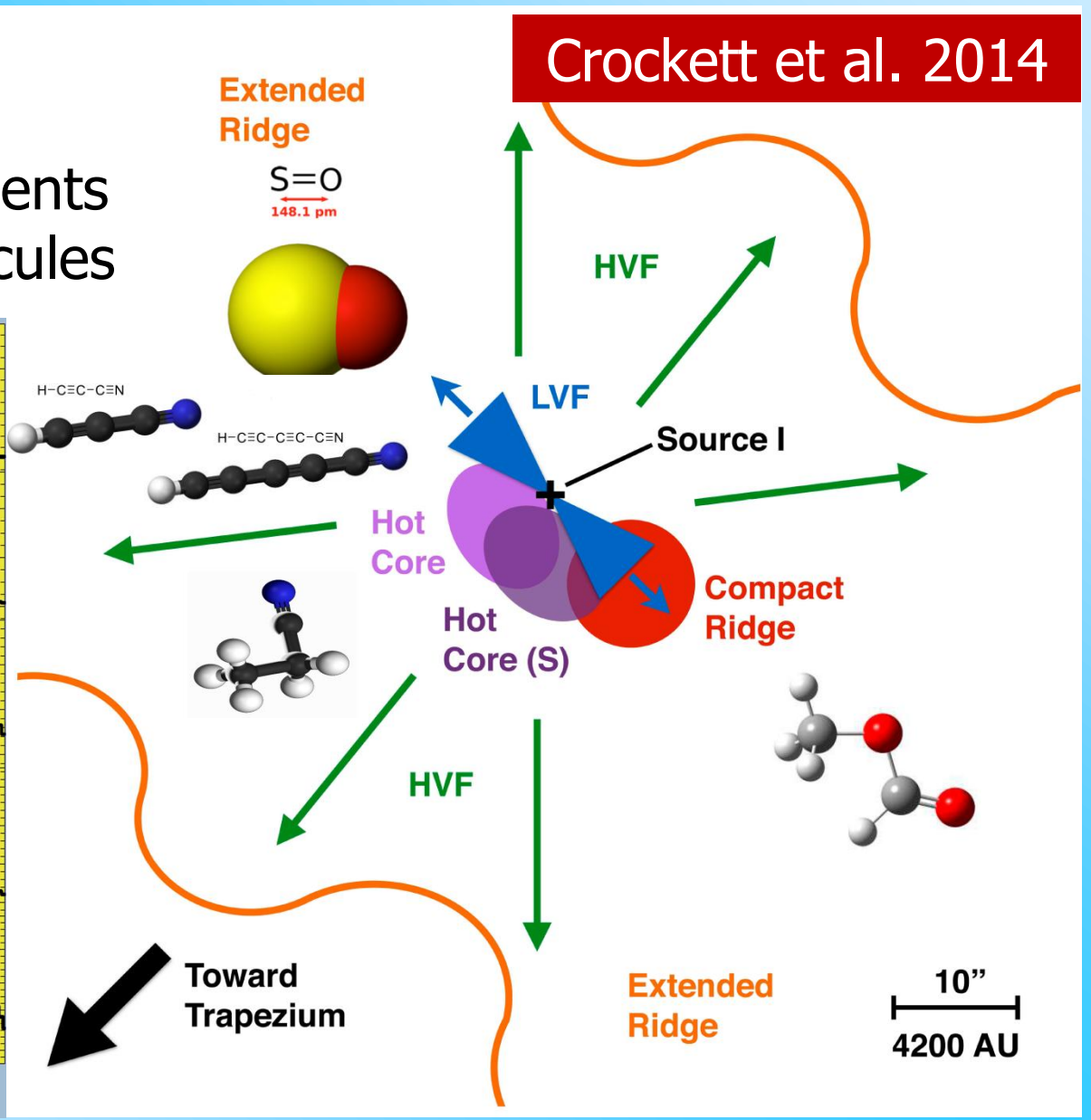
11" HPBW at 1900 GHz HIFI → 4583 AU

White: H_2; **blue/red (SMA)**: CO; **green (SMA)**: CH_3CN; **orange (SCUBA)**: 850 μm; **black**: runaway stars; Zapata et al. 2011.

1. ORION KL

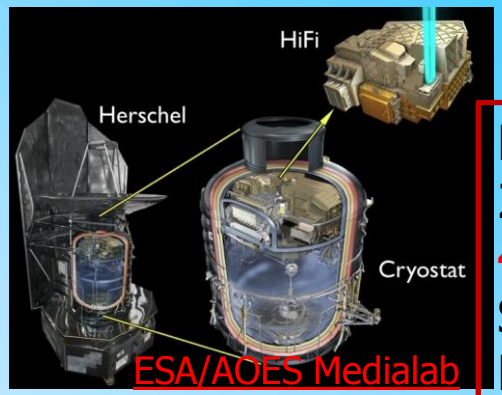
Different gas components
Large variety of molecules





2. THREE SETS OF DATA

IRAM 30-m 1D: 2004-2014 (Tercero et al. 2010; 2015)
80–116, 122.7–178, and 197.5–307 GHz (A,B,C,D; EMIR)
Spectral resolution: 0.8 to 0.2 km/s (0.2 MHz, FFTS)
1.3 mm: Emission peak of most COMs
Line confusion limited
More than 100 lines/GHz; more than 16000 lines
IRAM 30-m 2D: Marcelino et al.



HIFI survey:
2010-2011 (Bergin et al. 2010; Crocket et al. 2014)
480–1280, 1426–1535, and 1573–1906 GHz
Spectral resolution: 0.7 to 0.2 km/s (1 MHz)
FarIR wavelengths; Light hydrides; 13000 lines (11/GHz)

ALMA SV: January 2012; 16 antennas.
213.7–246.7 GHz
Spectral resolution: 0.7 km/s (0.5 MHz)
Synthetic beam: 1".90 X 1".40
Cycle 0,1,2 → expanding the freq. coverage

3. STUDIES OF ORION-KL

FAMILIES OF MOLECULES

Analysis based on all isotopologues and vib. exc. states of related species

GOAL 1: To determine the physical/chemical properties of Orion KL

GOAL 2: To provide new insights related to the chemistry of the ISM

1D/2D IRAM

CS bearing molecules:
Tercero et al. A&A, 517, A96 (2010)

CH_3CN:
Bell et al. A&A, 564, 114 (2014)

Si bearing molecules:
Tercero et al. A&A 528, A26 (2011)

SO and SO_2 species:
Esplugues et al. A&A, 556, 143 (2013)

CH_3CH_2CN species:
Daly et al. ApJ, 768, 81 (2013)

CH_2CHCN species:
López et al. A&A, 572, 44

1D/2D IRAM+1D HIFI

HC_3N, HC_5N species:
Esplugues et al. A&A, 559, 51 (2013)

HIFI + IRAM +ALMA

All detected species (HIFI):
Crockett et al. ApJ, 787, 112 (2014)

DCN and related species:
Marcelino et al. In preparation

1D IRAM + ALMA

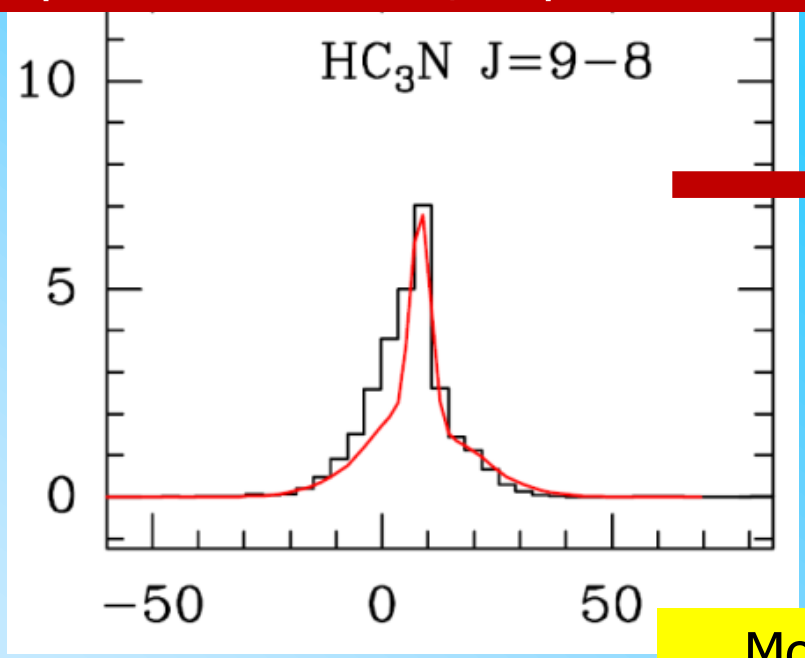
$C_2H_4O_2$ isomers:
López et al. In preparation

3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

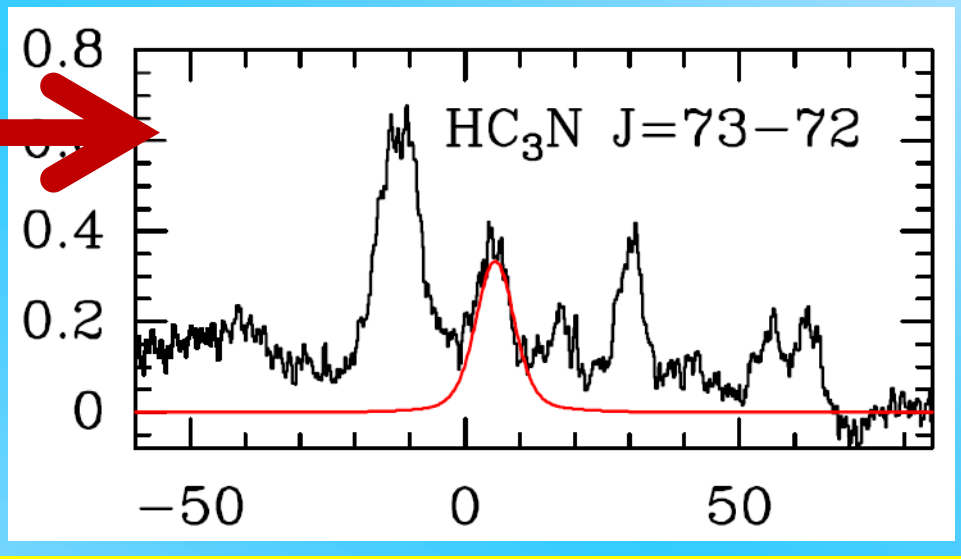
A combined IRAM and Herschel/HIFI study of cyano(di)acetylene in Orion KL: tentative detection of DC_3N★

G. B. Esplugues[1], J. Cernicharo[1], S. Viti[2], J. R. Goicoechea[1], B. Tercero[1], N. Marcelino[3], Aina Palau[4], T. A. Bell[1], E.A. Bergin[5], N. R. Crockett[5], and S. Wang[5].

Freq. = 81881.4 MHz; Eup = 19.6 K



Freq. = 663316.3 MHz; Eup = 1178.7 K



More than 50 lines of HC_3N g.s. were fitted simultaneously using MADEX (Cernicharo 2012) LVG (Large Velocity Gradient)

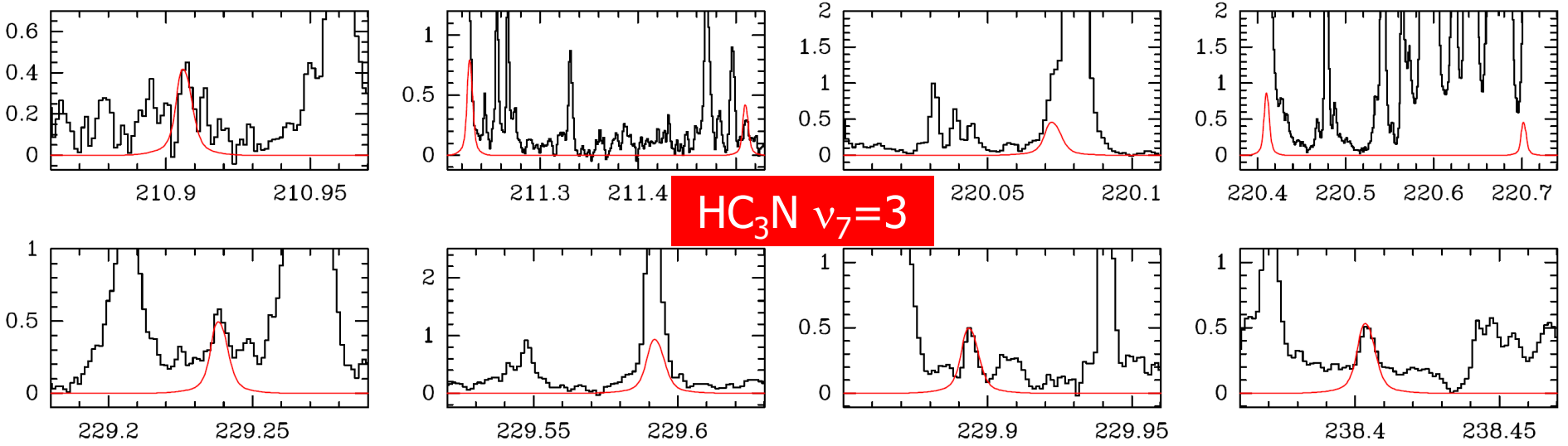
3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

IRAM+HIFI

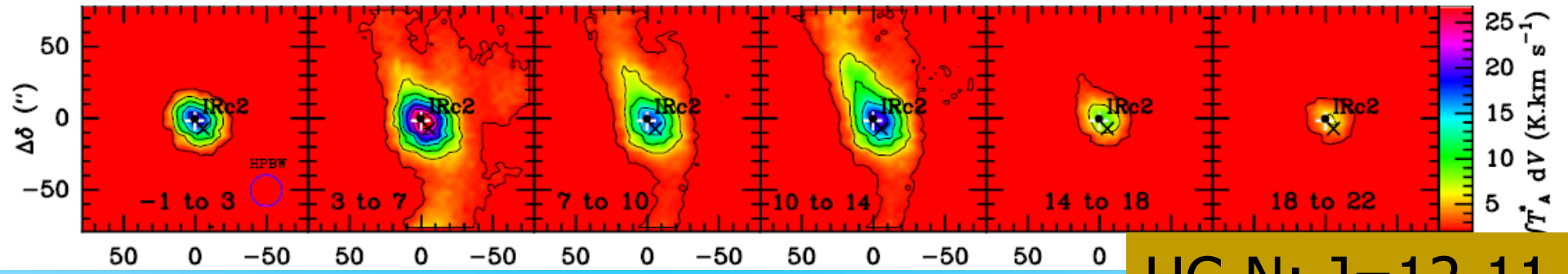
HC_3N g. s.
$H^{13}CCCN$
$HC^{13}CCN$
$HCC^{13}CN$
HC_3N ν_7=1
HC_3N ν_7=2
HC_3N ν_6=1
HC_3N ν_5=1

IRAM

$H^{13}CCCN$ ν_7=1
$HC^{13}CCN$ ν_7=1
$HCC^{13}CN$ ν_7=1
HC_3N ν_7=3
HC_3N ν_7=1 / ν_6=1
DC_3N
HC_5N

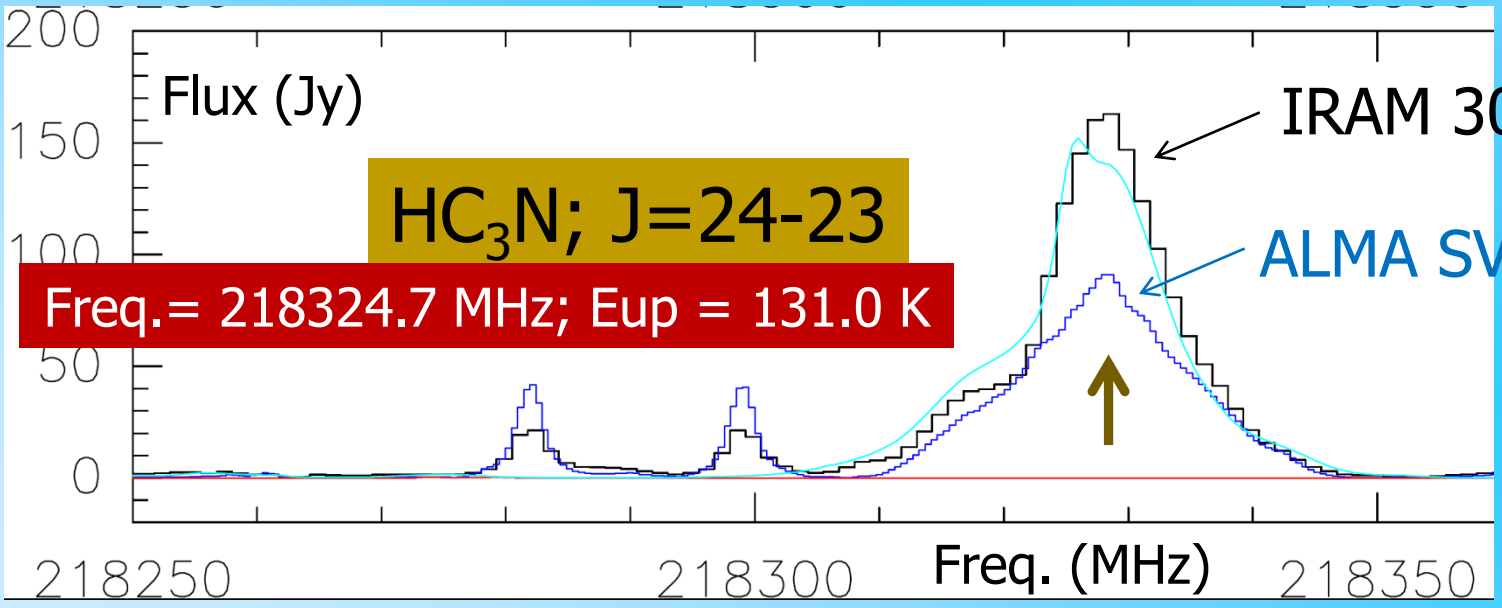


3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES



HC_3N; J=12-11

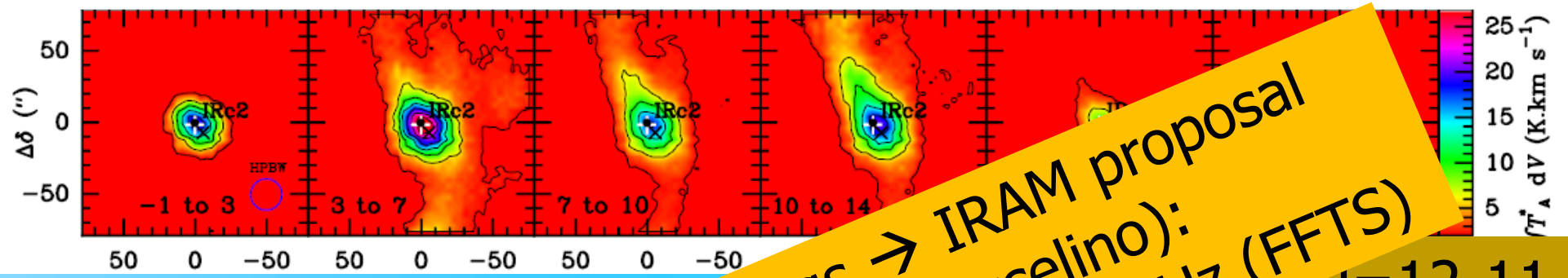
Freq.= 109173.6 MHz; Eup = 34.1 K



HC_3N; J=24-23

Freq.= 218324.7 MHz; Eup = 131.0 K

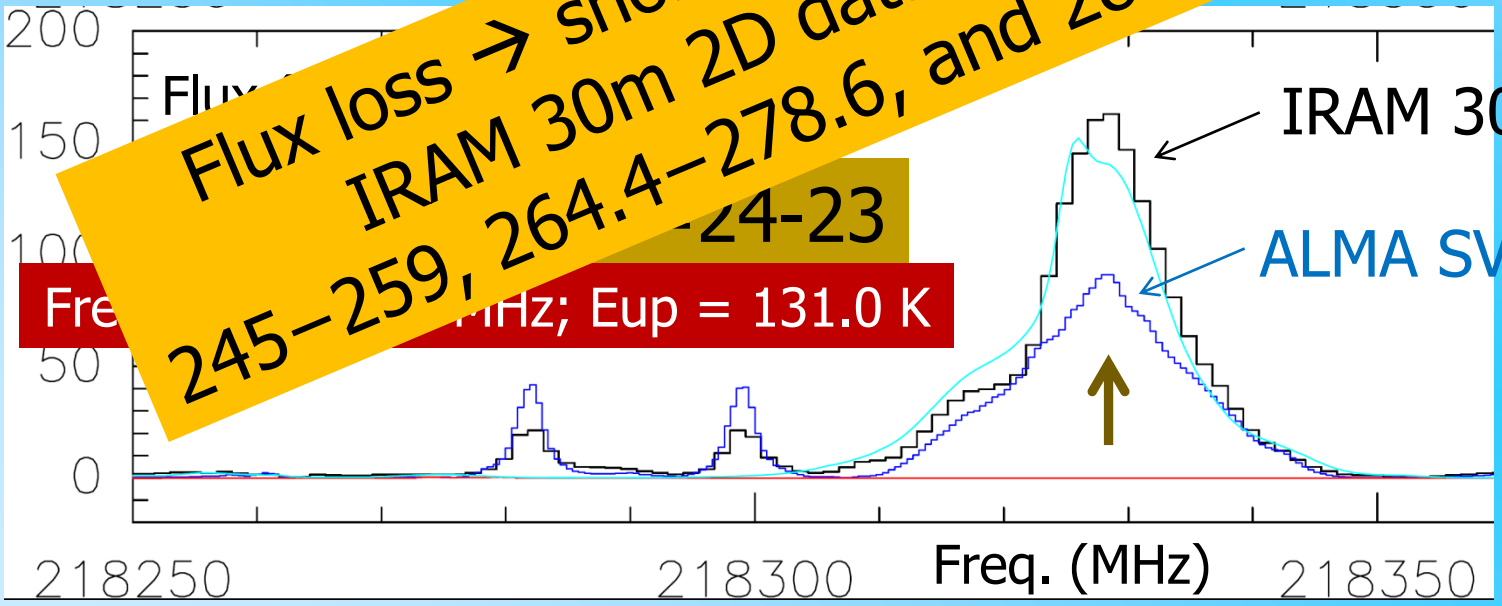
3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES



Flux loss → short spacings → IRAM proposal
IRAM 30m 2D data (N. Marcelino):
245–259, 264.4–278.6, and 289-298 GHz (FFTS)

J=12-11

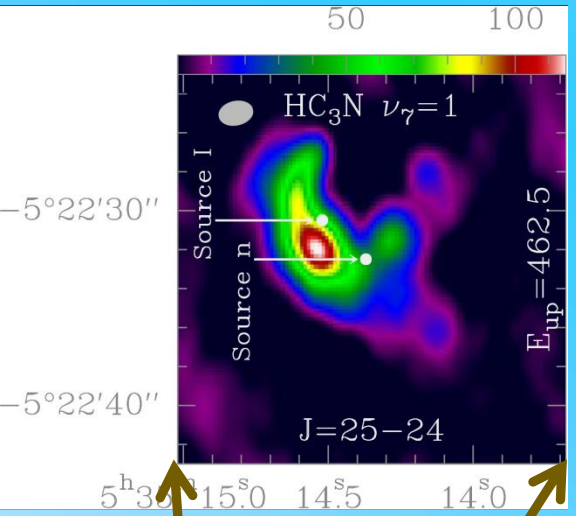
3.6 MHz; Eup = 34.1 K

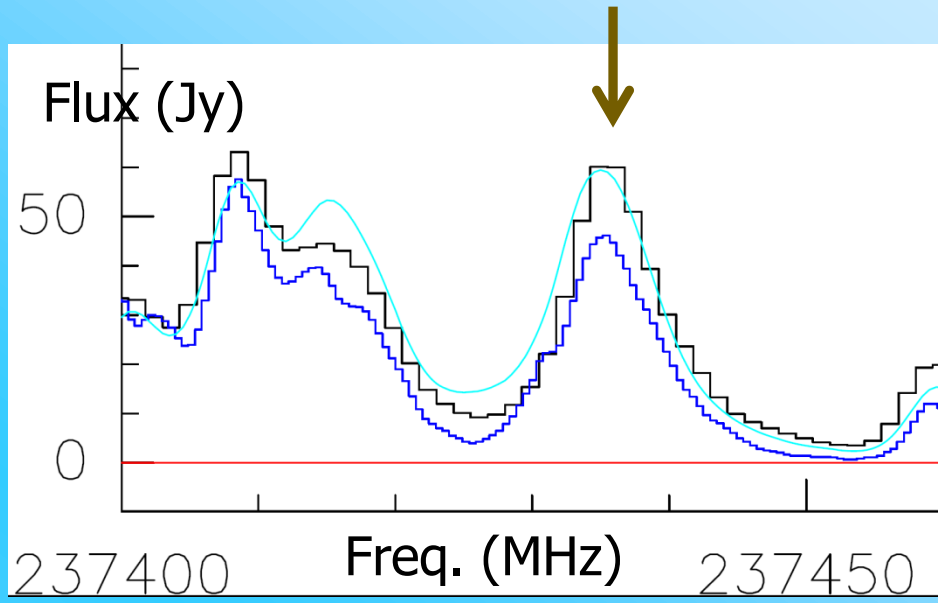


24-23

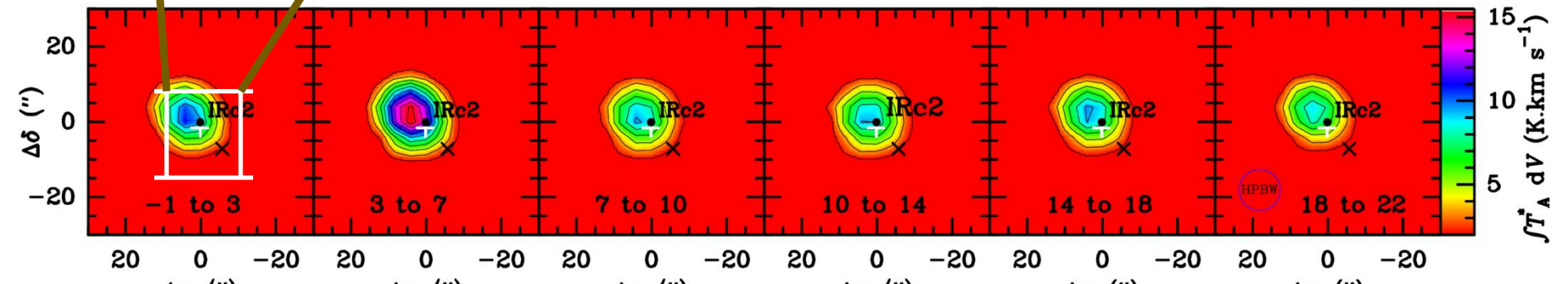
Fre Hz; Eup = 131.0 K

3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES





HC_3N ν_7=1; J=25-24 Eup = 462.3 K



3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

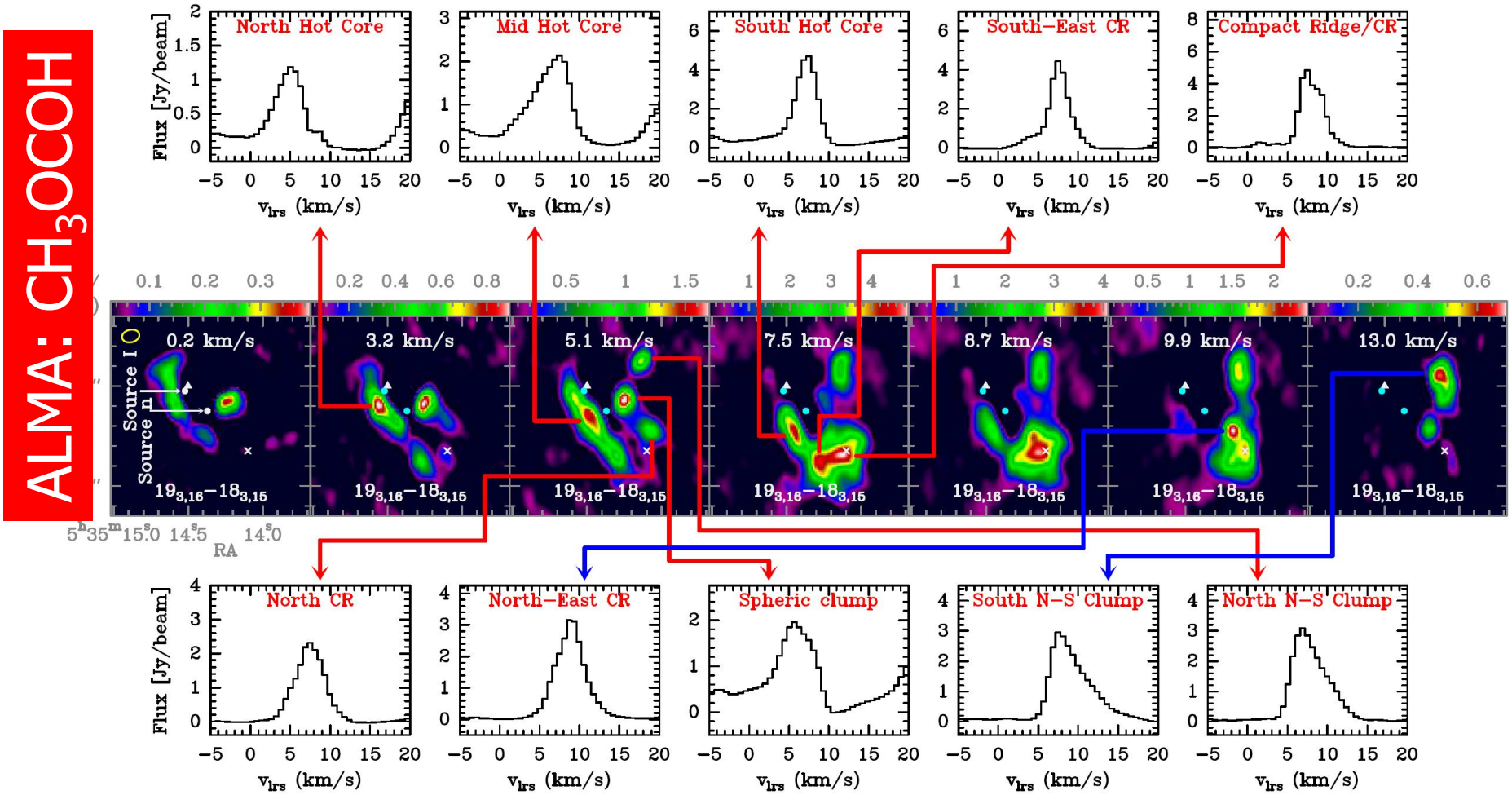
Component	Source diameter (″)	Offset$_{(IRc2)}$ IRAM (″)	HIFI (″)	$n(H_2)$ (cm^{-3})	T_K (K)	$\triangle V_{FWHM}$ (km s^{-1})	V_{LSR} (km s^{-1})
Extended ridge (ER)	120	0	0	10^5	60	4	8.5
Compact ridge (CR)	15	7	3	10^6	110	3	8
High velocity plateau (HP)	30	4	4	10^6	100	30	11
Plateau (PL)	20	0	0	5×10^6	150	25	6
Outer hot core (HC1)	10	2	2	1.5×10^7	220	10	5.5
Inner hot core (HC2)	7	4	4	5×10^6	310	7	5.5
20.5 km s^{-1} component	5	3	3	5×10^6	90	7.5	20.5

IRAM+ALMA+Herschel:
Detection of less abundant species
New insights in the spatial structure
Highly constrained physical parameters

3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

López et al. In preparation; $C_2H_4O_2$ isomers:
Methyl formate (CH_3OCOH), acetic acid (CH_3COOH), glycolaldehyde (CH_2OHCHO)

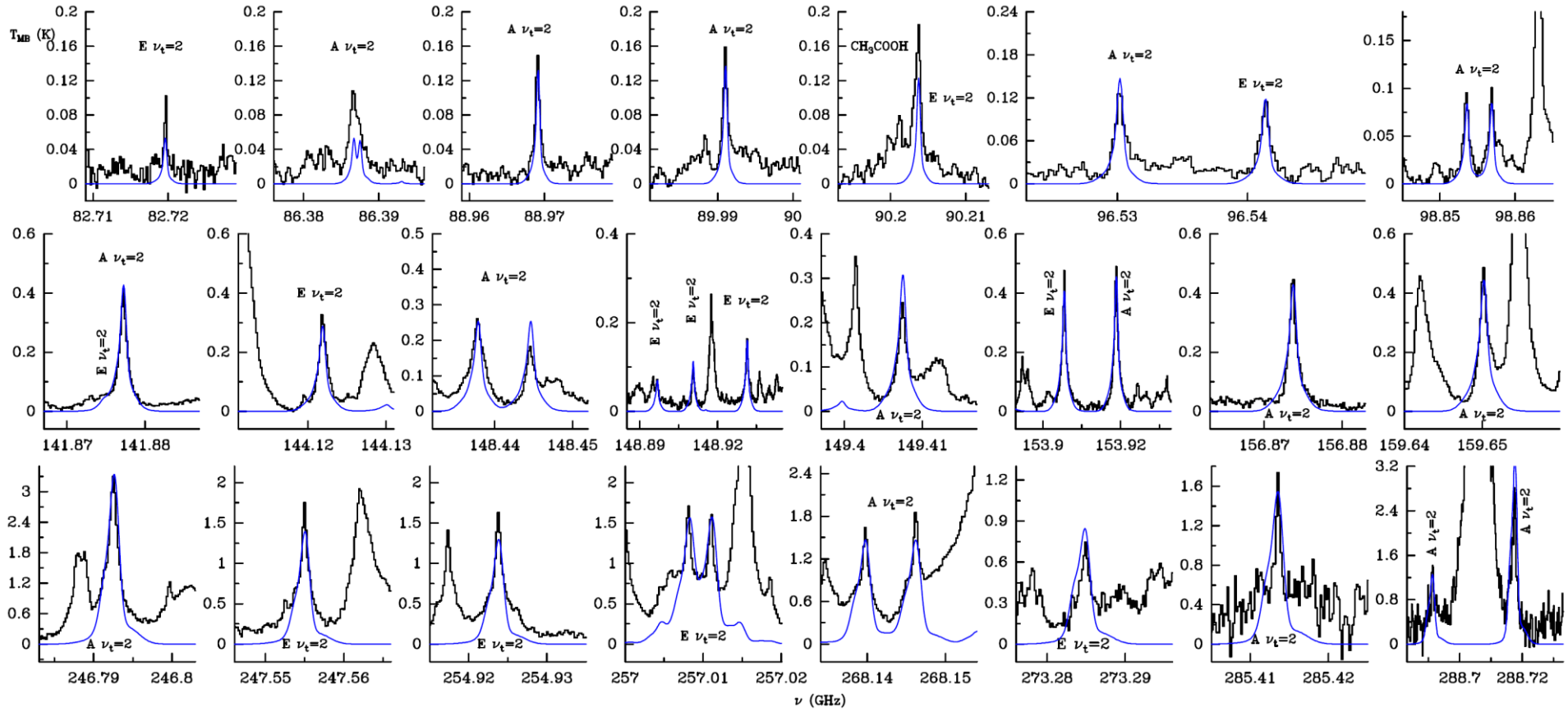
ALMA: CH_3OCOH



3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

López et al. In preparation; $C_2H_4O_2$ isomers:
Methyl formate (CH_3OCOH), acetic acid (CH_3COOH), glycolaldehyde (CH_2OHCHO)

IRAM: CH_3OCOH vt=2



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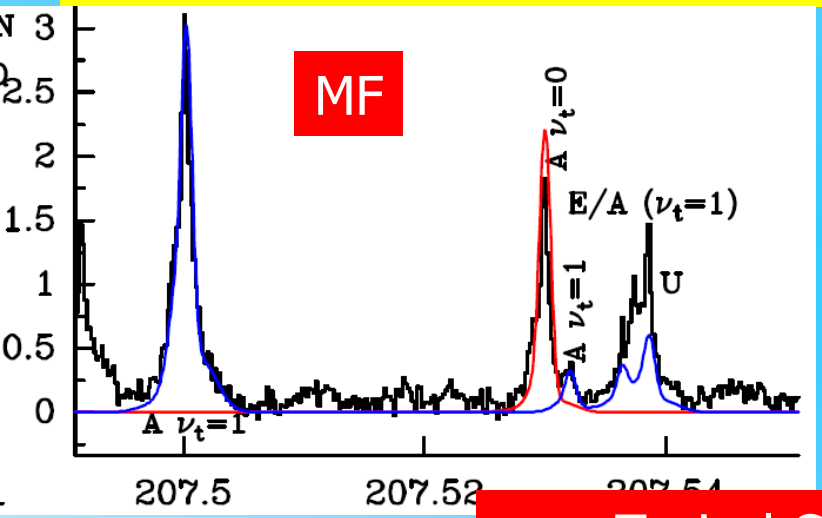
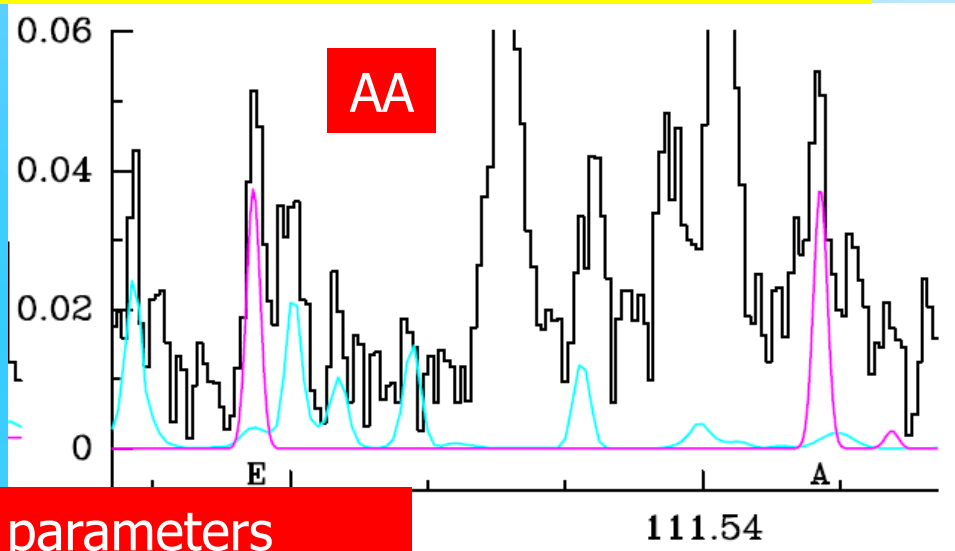
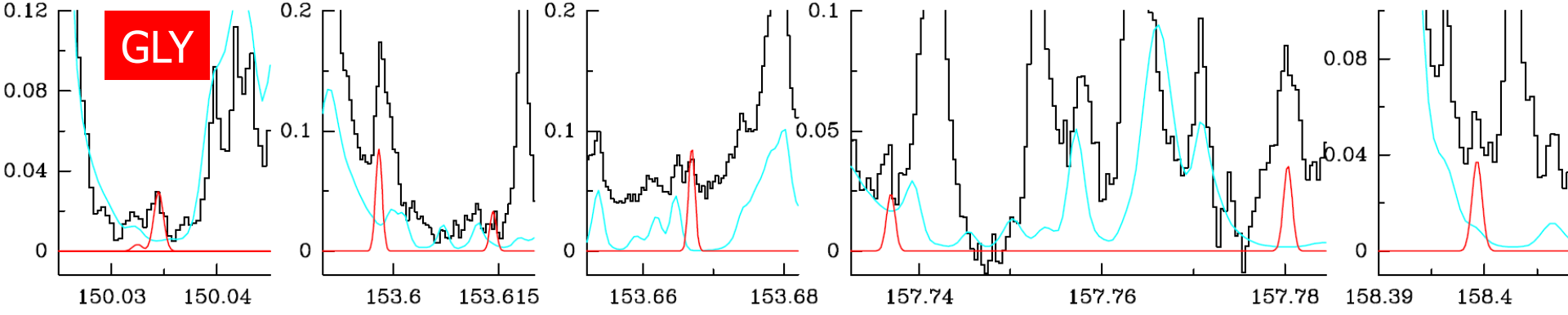
López et al. In preparation; $C_2H_4O_2$ isomers:
Methyl formate (CH_3OCOH), acetic acid (CH_3COOH), glycolaldehyde (CH_2OHCHO)



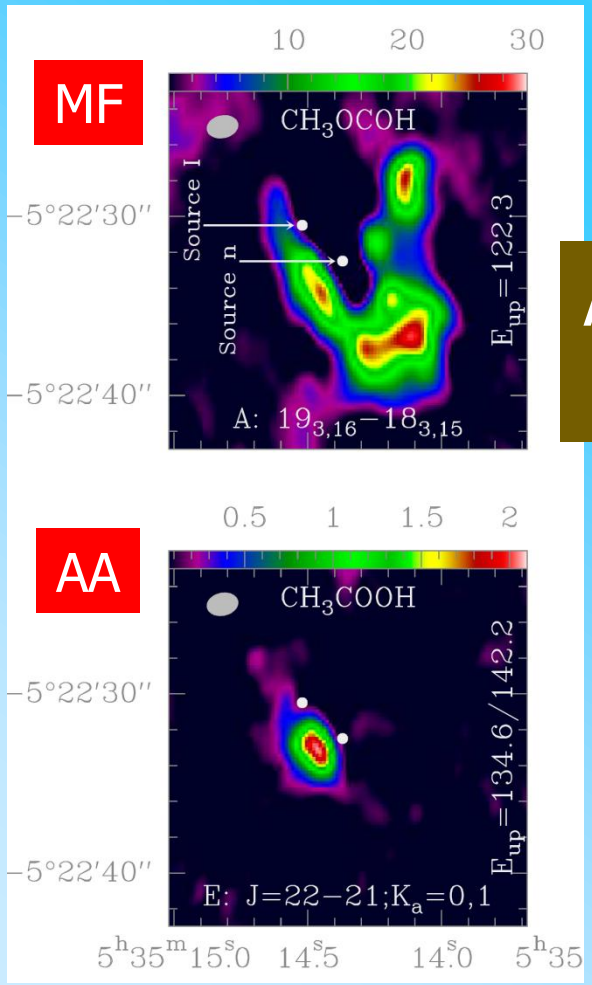


Typical CR line parameters
v_{LSR}=7.5-8.0 km/s; Δv=1.5-2.5 km/s

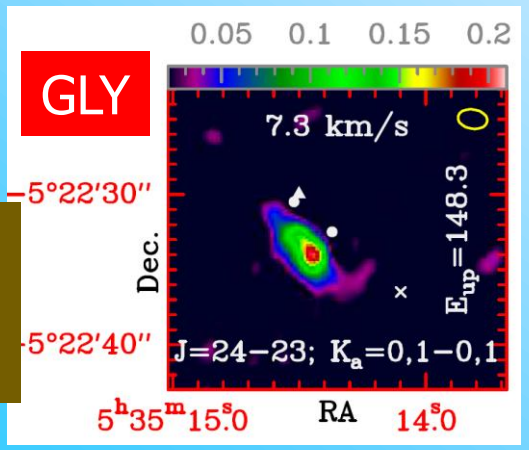


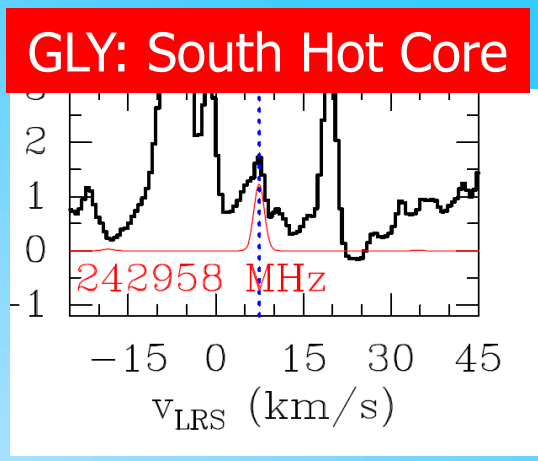
3. STUDIES OF ORION-KL: FAMILIES OF MOLECULES

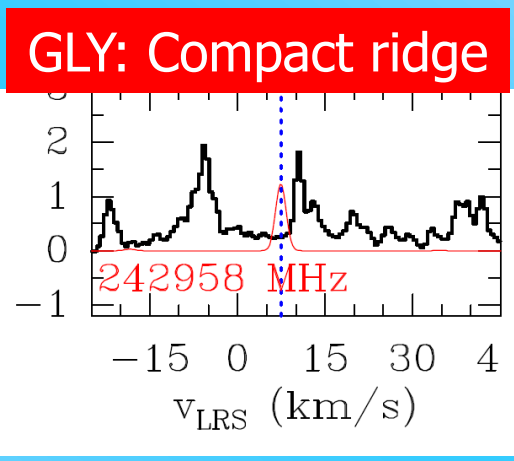
López et al. In preparation; $C_2H_4O_2$ isomers:
Methyl formate (CH_3OCOH), acetic acid (CH_3COOH), glycolaldehyde (CH_2OHCHO)



AA and GLY far away the compact ridge







3. STUDIES OF ORION-KL

SPECTROSCOPY PAPERS BASED ON IRAM DATA

Goal 1: To reduce the number of U lines (3000) and mitigate line confusion

Goal 2: To search for new molecular species

Goal 3: To provide a full molecular census

NEW MOLECULES

METHYL ACETATE, CH_3COOCH_3:
Tercero et al. ApJ, 770, L13 (2013)

AMMONIUM ION, NH_3D^+:
Cernicharo et al. ApJ, 771, L10 (2013)

ETHYL MERCAPTAN, CH_3CH_2SH:
Kolesniková et al. ApJ, 784, L7 (2014)

TENTATIVE / UPPER LIMITS

PHENOL, c-C_6H_5OH:
Kolesniková et al. JMoSp, 289, 13 (2013)

ALLYL ISOCYANIDE, CH_2CHCH_2NC:
Haykal et al. ApJ, 777, 120 (2013)

NEW ISOTOPOLOGUES AND VIBRATIONAL MODES

VYNIL CYANIDE, CH_2CHCN:
López et al. A&A, 572, 44

ETHYL CYANIDE, CH_3CH_2CN:
Demyk et al. A&A 466, 255 (2007)
Margulès et al. A&A 493, 565 (2009)
Daly et al. ApJ, 768, 81 (2013)

METHYL FORMATE, $HCOOCH_3$:
Carvajal et al. A&A 500, 1109 (2009)
Margulès et al. ApJ, 714, 1120 (2010)
Tercero et al. A&A 538, A119 (2012)
Coudert et al. ApJ, 779, 119 (2013)
Haykal et al. A&A, 568, 58 (2014)

FORMAMIDE, NH_2CHO:
Motiyenko et al. A&A 548, A71 (2012)

3. STUDIES OF ORION-KL

SPECTROSCOPY PAPERS BASED ON IRAM DATA + Herschel +ALMA

Goal 1: To reduce the number of U lines (3000) and mitigate line confusion

Goal 2: To search for new molecular species

Goal 3: To provide a full molecular census

NEW MOLECULES

METHYL ACETATE, CH_3COOCH_3:

Tercero et al. ApJ, 770, L13 (201

AMMONI

Cernicharo et

ETHYL MER

Kolesniková et al. ApJ, 784, L7 (2014)

Herschel/HIFI
Light Hydrides
Crockett et al. 2014, ApJ ApJ, 787, 112

TENTATIVE / UPPER LIMITS

IRAM + ALMA
Vinyl acetate, $CH_3COOCHCH_2$
Kolesniková et al. 2015, A&A accepted

CH_2CHCH_2NC:

et al. ApJ, 777, 120 (2013)

NEW ISOTOPOLOGUES AND VIBRATIONAL MODES

VYNIL CYANIDE, CH_2CHCN:

al. A&A, 572, 44

NIDE, CH_3CH_2CN:

A&A 466, 255 (2007)

Margulès et al. A&A 493, 565 (2009)

Daly et al. ApJ, 768, 81 (2013)

METHYL FORMATE, $HCOOCH_3$:

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Margulès et al. ApJ, 714, 1120 (2010)

Tercero et al. A&A 538, A119 (2012)

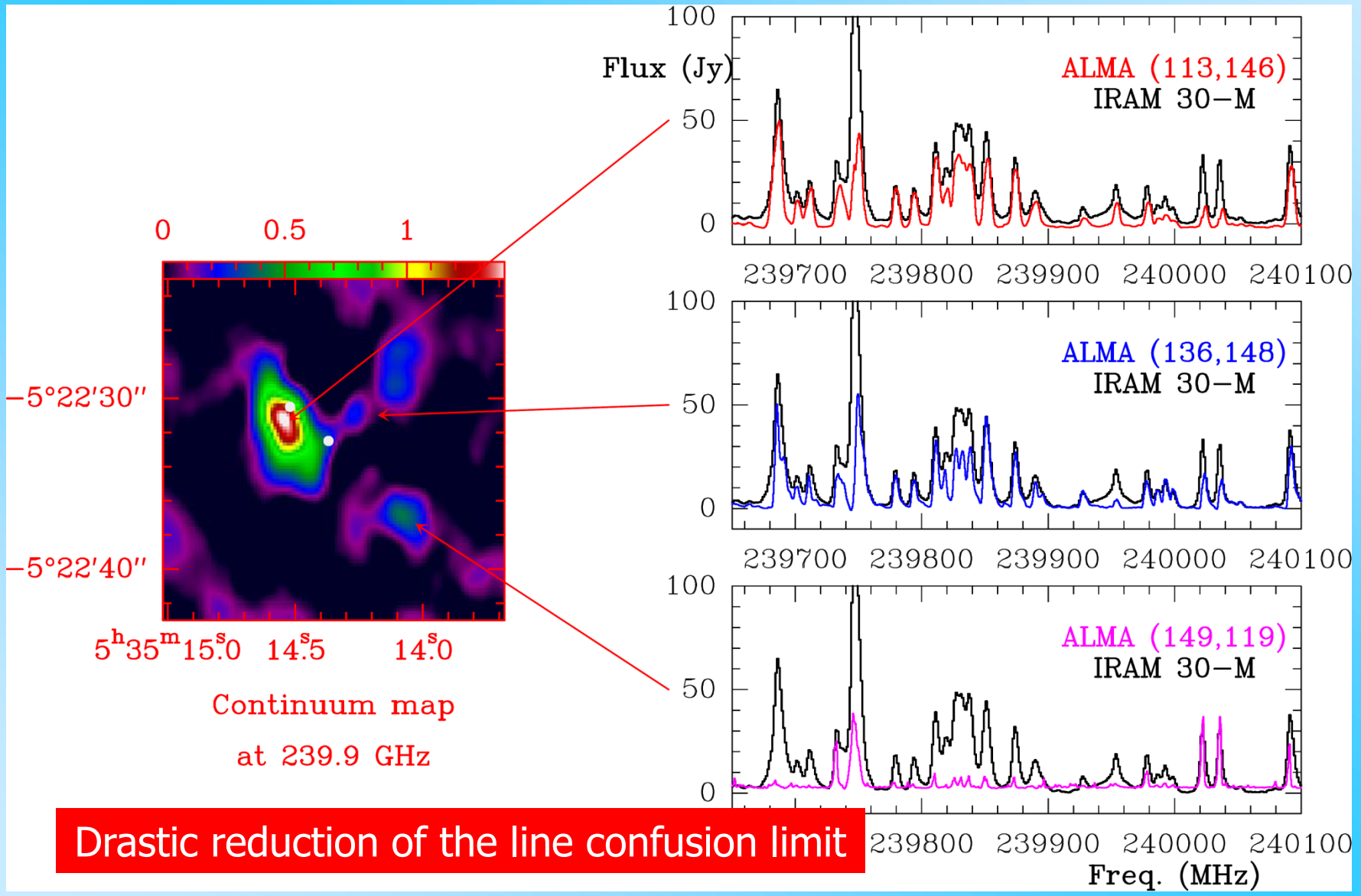
Coudert et al. ApJ, 779, 119 (2013)

Haykal et al. A&A, 568, 58 (2014)

FORMAMIDE, NH_2CHO:

Motiyenko et al. A&A 548, A71 (2012)

3. STUDIES OF ORION-KL

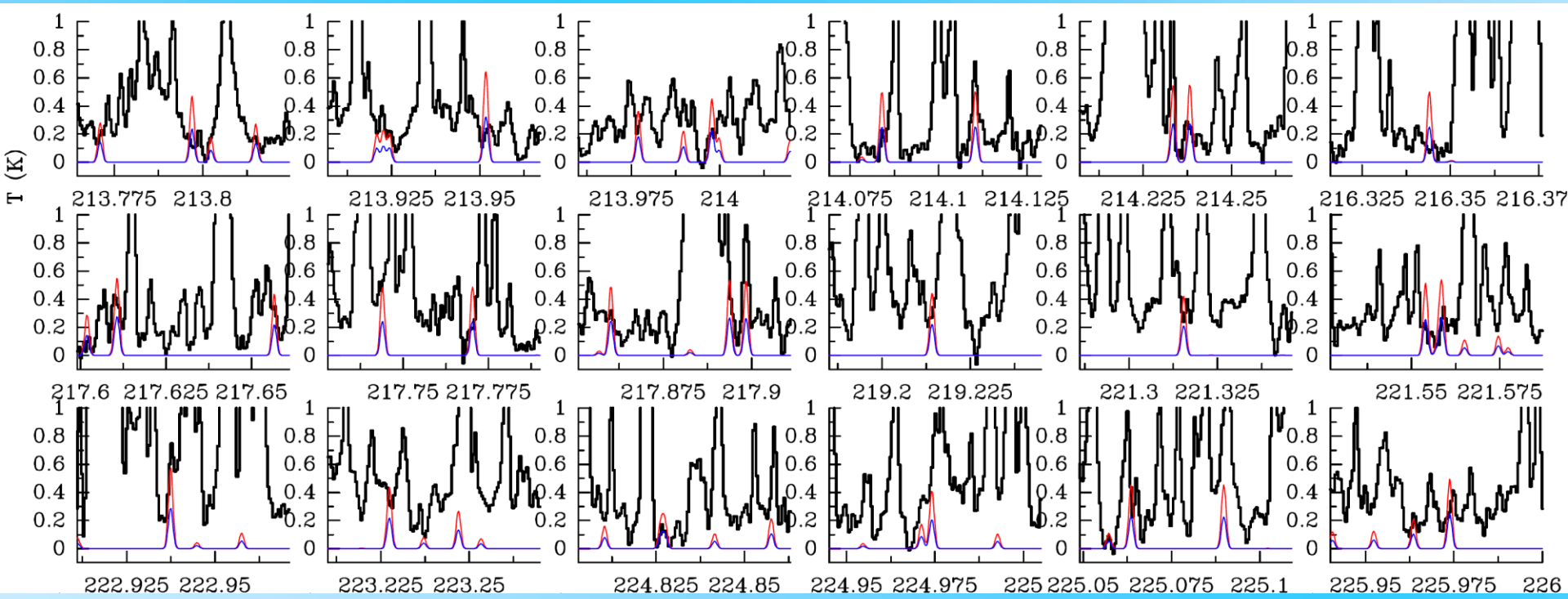


Drastic reduction of the line confusion limit

3. STUDIES OF ORION-KL

The laboratory millimeter wave spectrum and astronomical search of vinyl acetate

L. Kolesniková[1], I. Peña[1], J. L. Alonso[1], J. Cernicharo[2], B. Tercero[2], and I. Kleiner[3]



5x5 pixels spectra over the CR

3. STUDIES OF ORION-KL

***Herschel* observations of EXtra-Ordinary Sources: ANALYSIS OF THE HIFI 1.2 THz WIDE SPECTRAL SURVEY TOWARD ORION KL I. METHODS**[1]

Nathan R. Crockett[1,a], Edwin A. Bergin[1], Justin L. Neill[1], Cécile Favre[1], Peter Schilke[2], Dariusz C. Lis[3], Tom A. Bell[4], Geoffrey Blake[5,11], José Cernicharo[4], Martin Emprechtinger[3], Gisela B. Esplugues[4], Harshal Gupta[6], Maria Kleshcheva[5], Steven Lord[7], Nuria Marcelino[8], Brett A. McGuire[11], John Pearson[6], Thomas G. Phillips[3], Rene Plume[9], Floris van der Tak[10,12], Belén Tercero[4], and Shanshan Yu[6]

Detection of:

HCl H_2O HF NH_2 OH

OH^+ CH^+ H_2O^+

4. CONCLUSIONS

1. Each survey has its advantages:

IRAM: emission peak COMs / detection of less abundant species

Herschel: light hydrides and a very wide spectral band

ALMA: detailed spatial structure and line confusion reduced at a given position

2. A combined study is crucial for:

a. highly constraining the physical parameters of the gas components.

b. providing new insights related to the gas-phase and dust chemistry of the ISM, specially for COM's

c. full molecular census of the cloud

d. reducing the line confusion in spectral observations

3. The collaborations with groups of spectroscopy are essential to fully conclude the analysis of these surveys.

Spectroscopists

Laurent MARGULÈS
Roman MOTIYENKO
Therese R. HUET
Adam DALY
Lucie KOLESNIKOVÁ
José Luis ALONSO
Celina BERMÚDEZ
Carlos CABEZAS
Isabelle KLEINER
Miguel CARVAJAL
Jean-Claude GUILLEMIN
John PEARSON
Zbigniew KISIEL
Laurent H. COUDERT
José Luis DOMÉNECH
Isabel TANARRO
Imane HAYKAL

MORE...

Astronomers

José CERNICHARO
Alicia LÓPEZ
Gisela B. ESPLUGUES
Javier R. GOICOECHEA
Núria MARCELINO
Juan R. PARDO
Tom A. BELL
Ania PALAU
Ted A. BERGIN
Nathan R. CROCKETT
Nathalie BROUILLET
Didier DESPOIS
Alain BRAUDY
Diego MARDONES
Arancha CASTRO-CARRIZO

ISM Chemistries

Serena VITI
Hannah CALCUTT
Evelyn ROUEFF

THANK YOU!