

# Multi-spin gas in Andromeda's bulge

Anne-Laure Melchior, Françoise Combes

LERMA, UMR8112, Paris, France

Observatoire de Paris , Univ. Pierre & Marie Curie

Galaxy in the  
green valley

Quenched SFR  
0.25 Msol/year

LIER no AGN  
(e.g. Belfiore+)

**1 arcsec = 3.8pc**

( 38pc if at 7.8 Mpc)

(380pc if at 78 Mpc)





# Multi-spin gas in Andromeda's bulge

Anne-Laure Melchior, Françoise Combes

LERMA, UMR8112, Paris, France

Observatoire de Paris, Univ. Pierre & Marie Curie

Galaxy in the  
green valley

Quenched SFR  
0.25 Msol/year

LIER no AGN  
(e.g. Belfiore+)

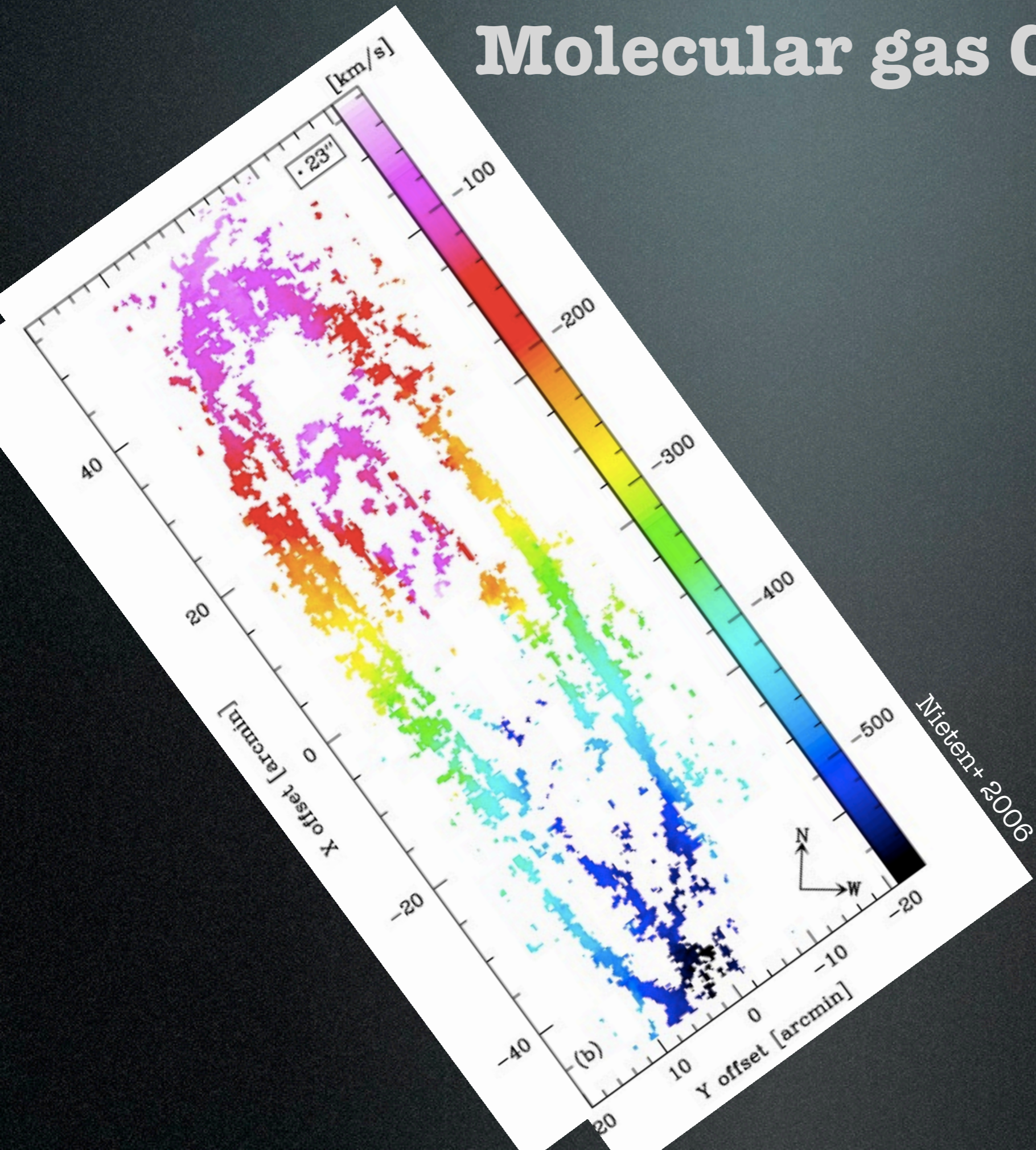
**1 arcsec = 3.8pc**  
( 38pc if at 7.8 Mpc)  
(380pc if at 78 Mpc)



- Large scale view
- Gas in the bulge
- Analysis of molecular gas
- Perspective with 3D  
**SITELLE data cube @CFHT**

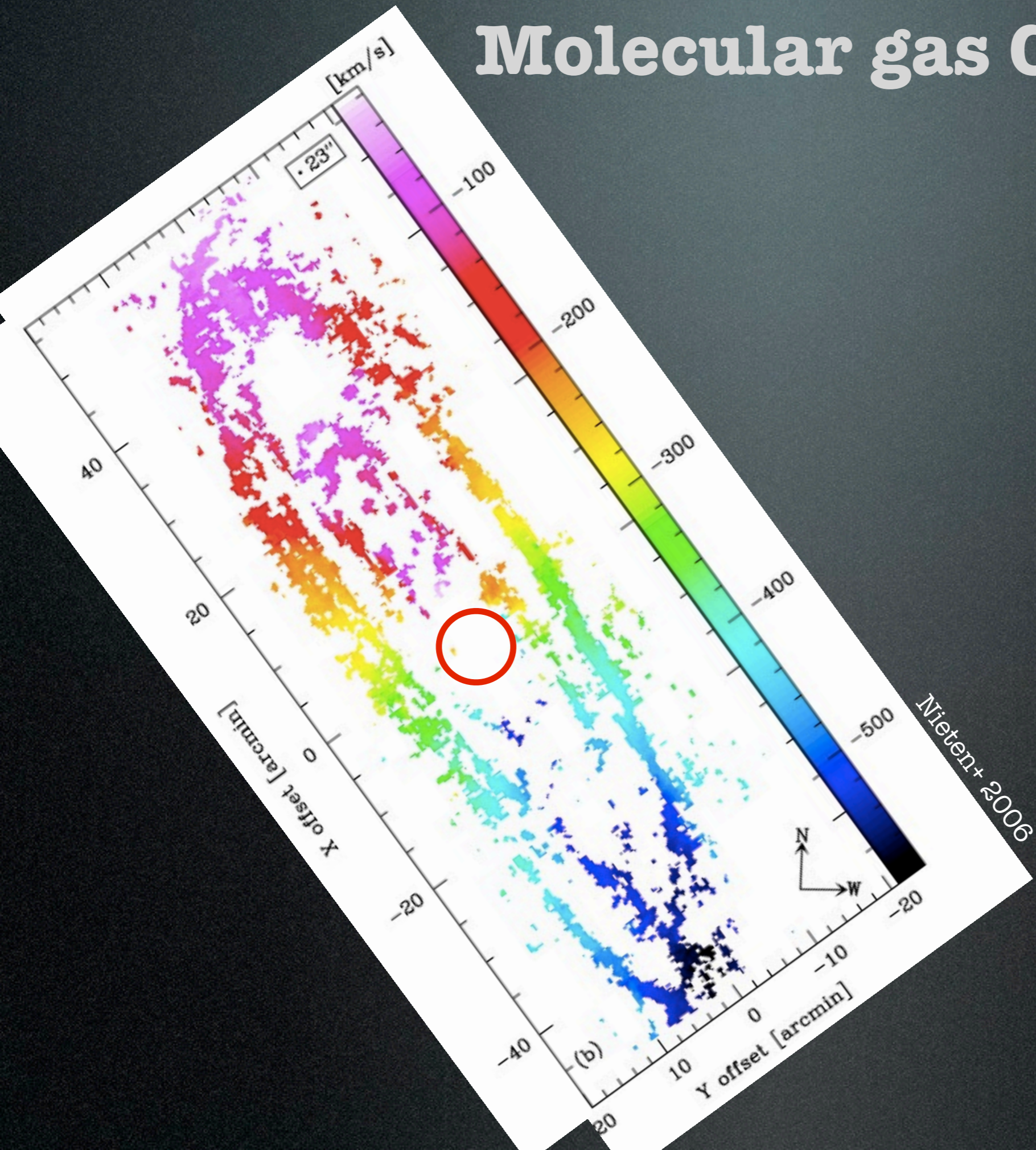


# Molecular gas CO



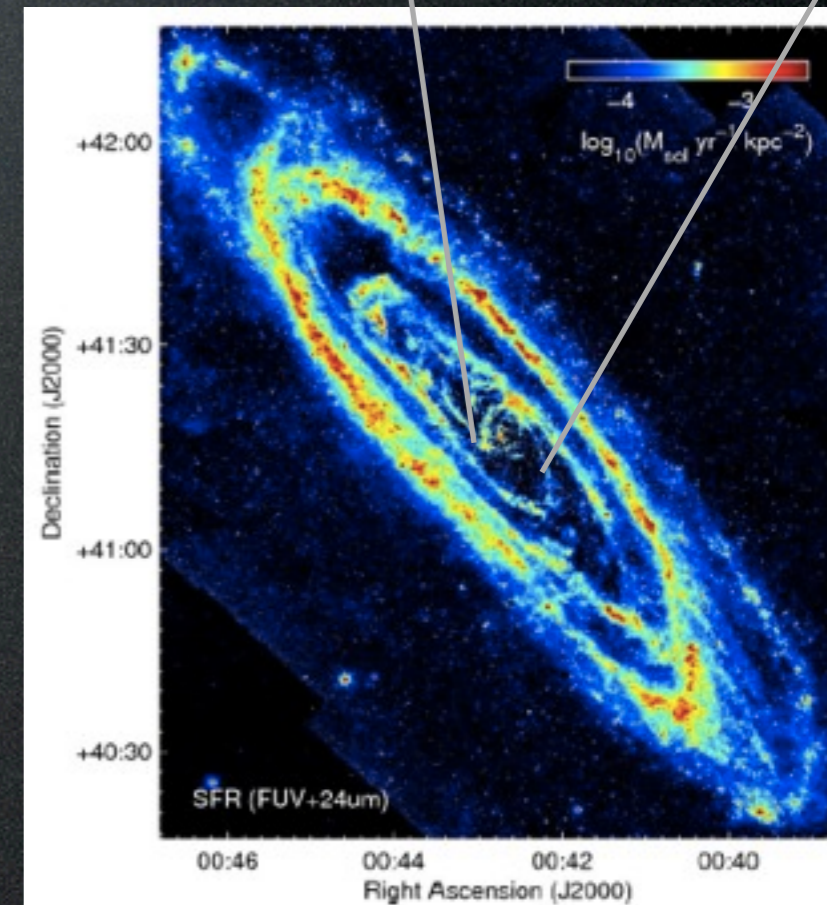
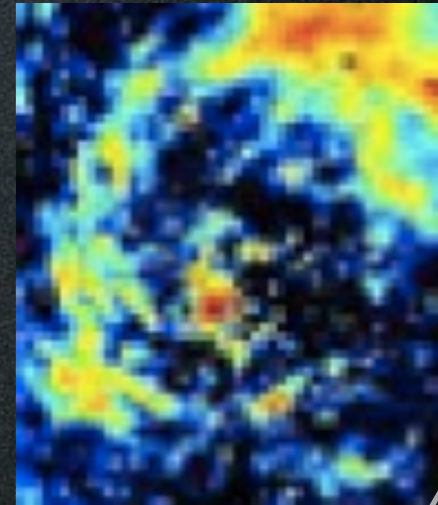
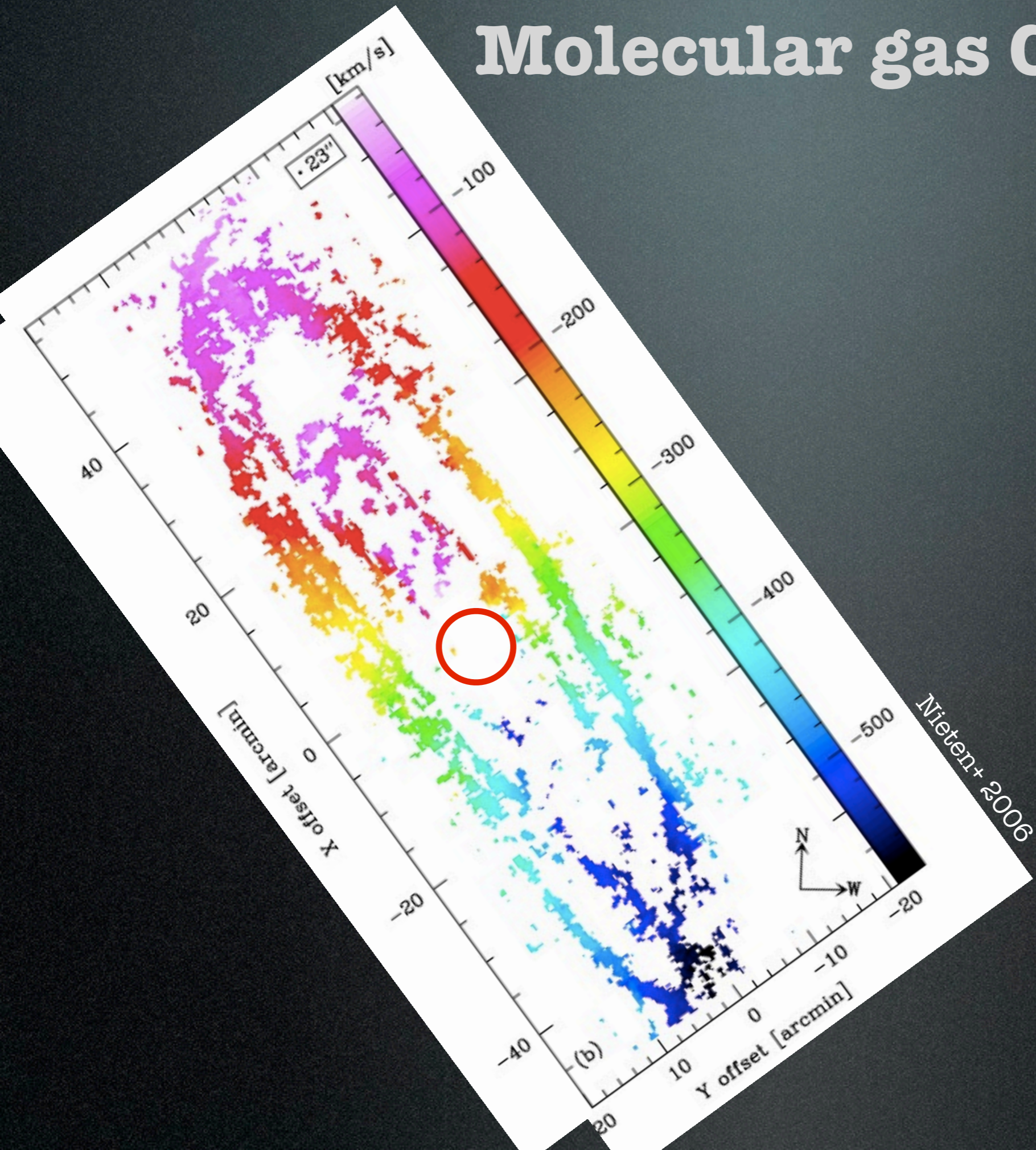


# Molecular gas CO





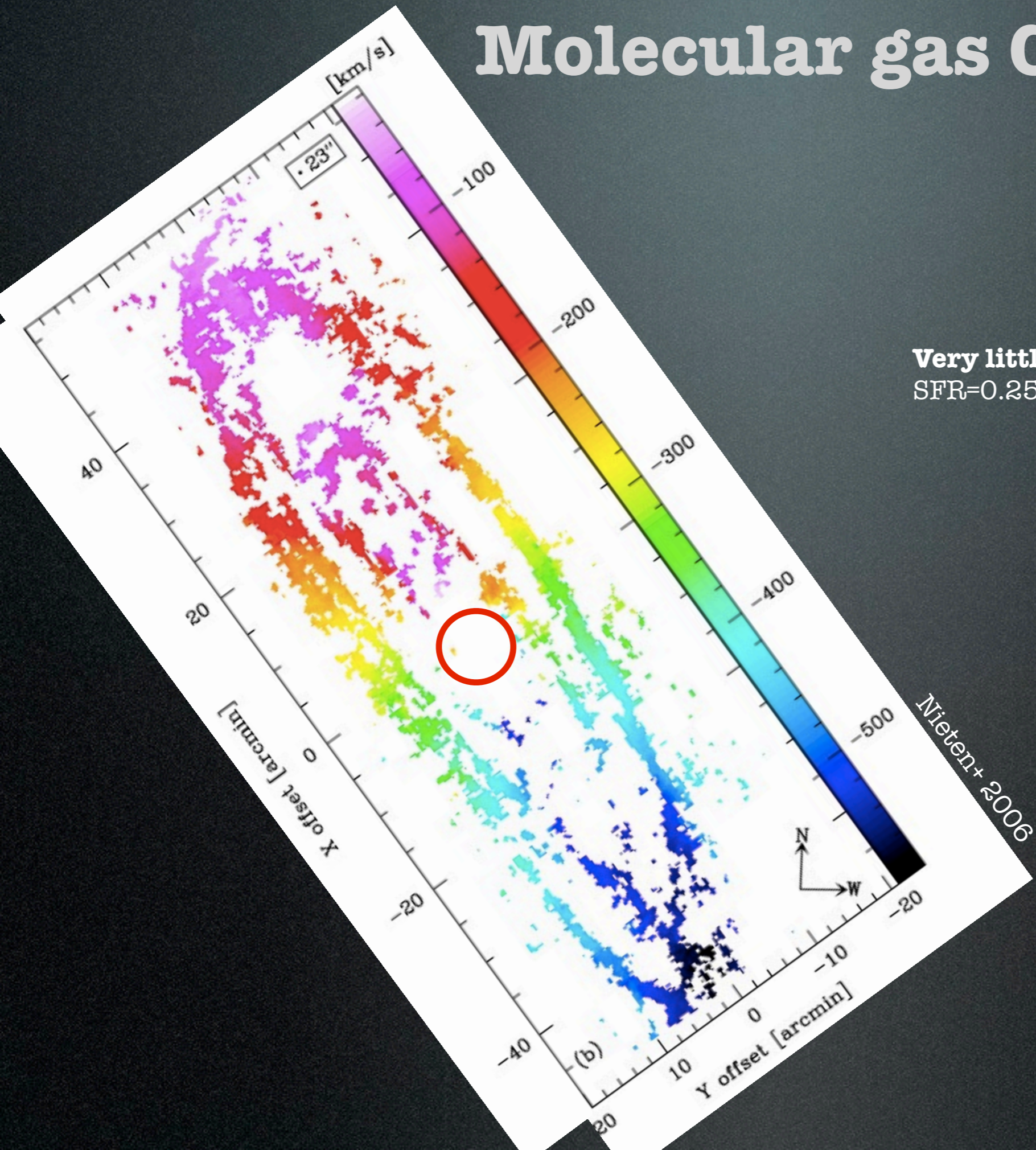
# Molecular gas CO



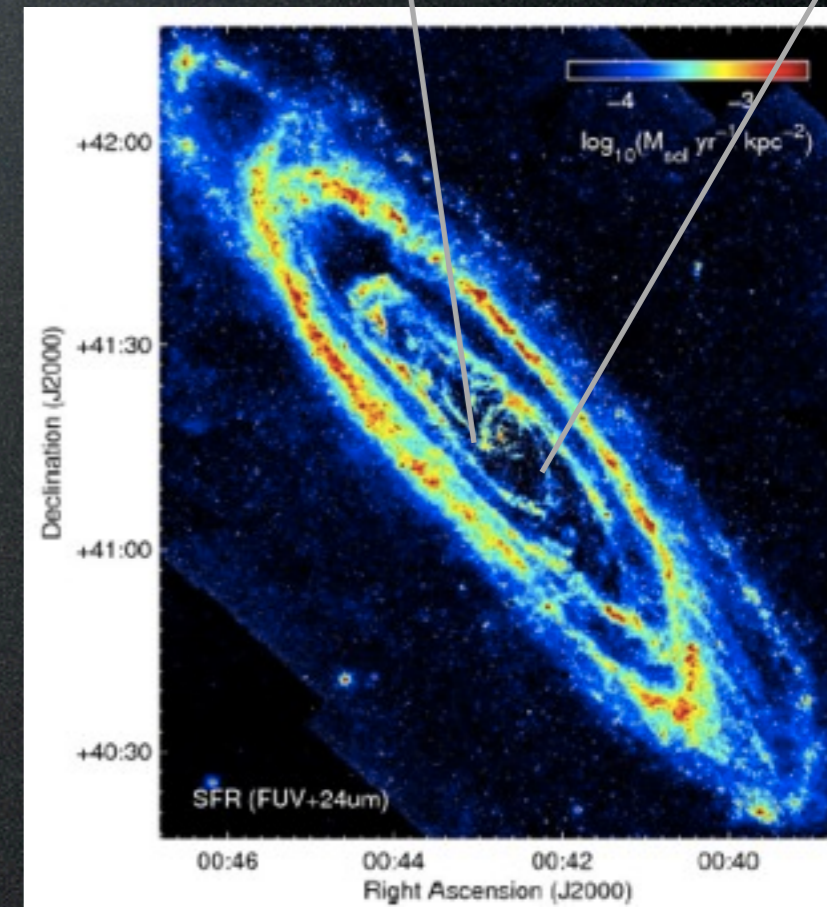
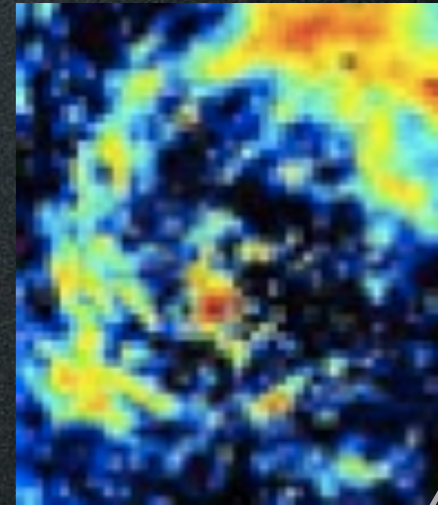
Ford+ 2013



# Molecular gas CO



**Very little star formation**  
 $SFR=0.25^{+0.06} M_{\odot}/\text{year}$



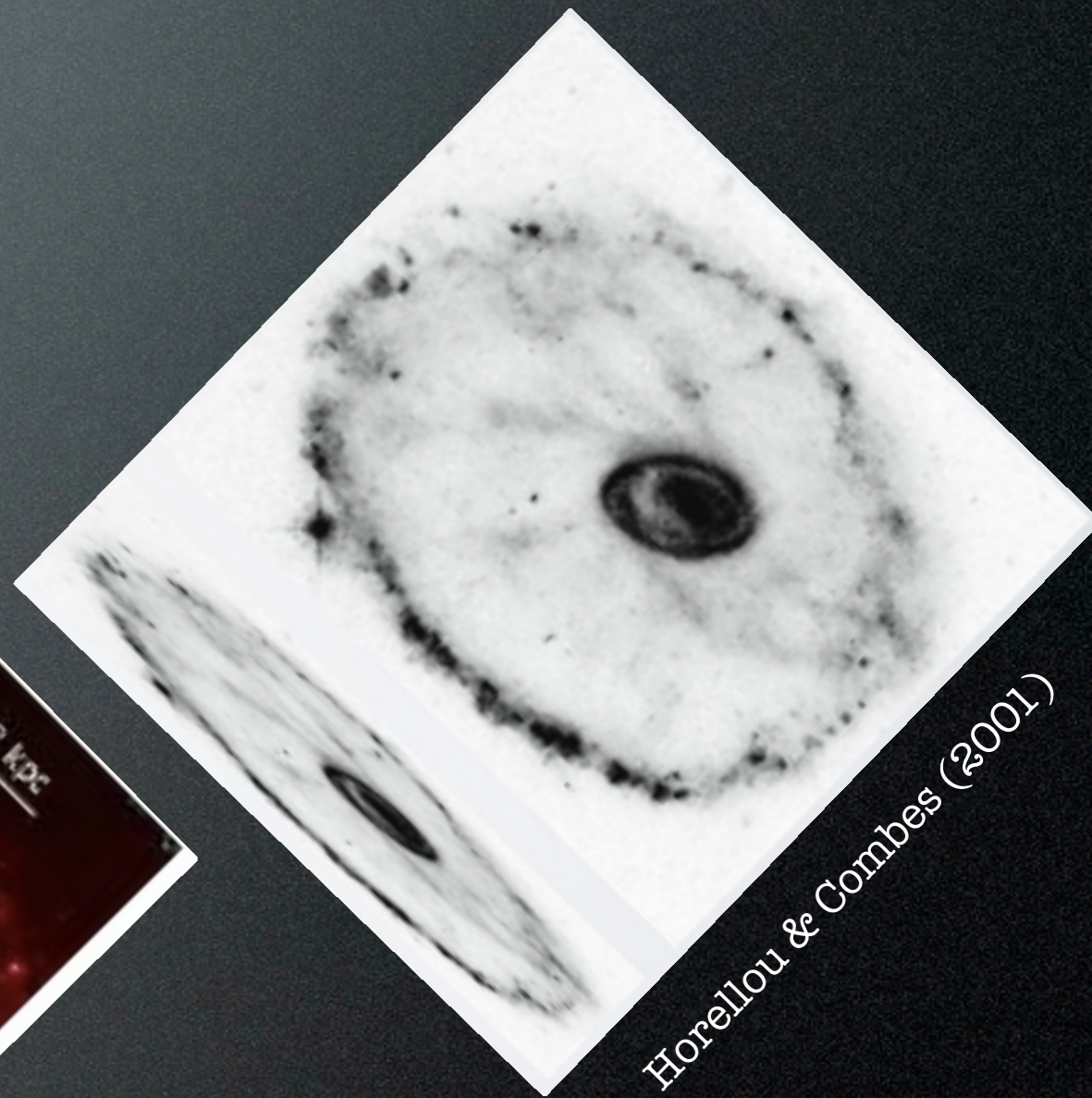
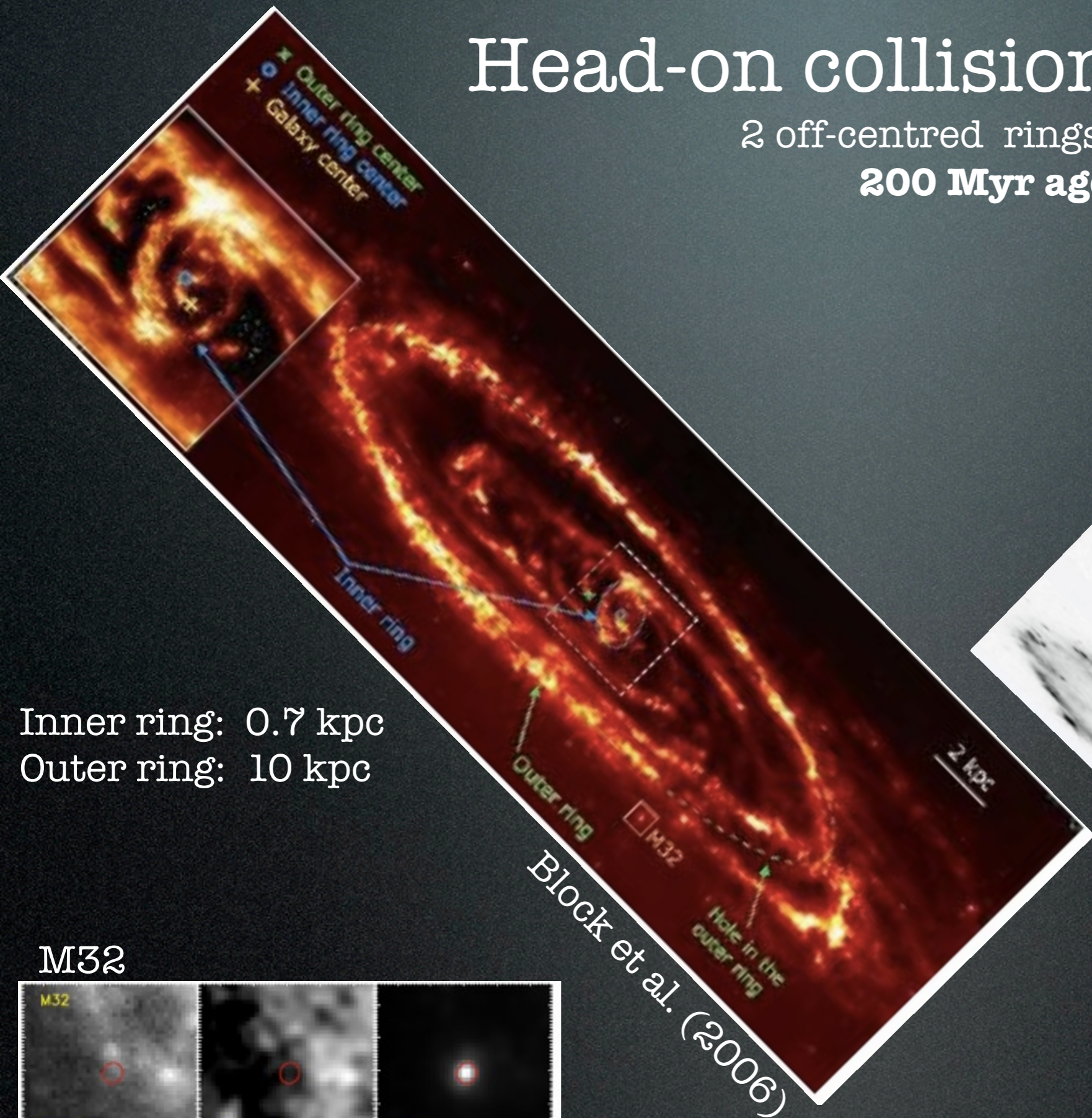
Ford+ 2013



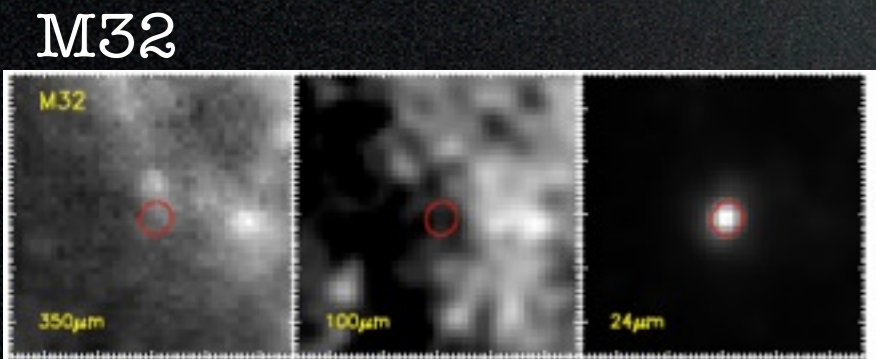
# Head-on collision with M32

2 off-centred rings @ 8 $\mu$ m

200 Myr ago



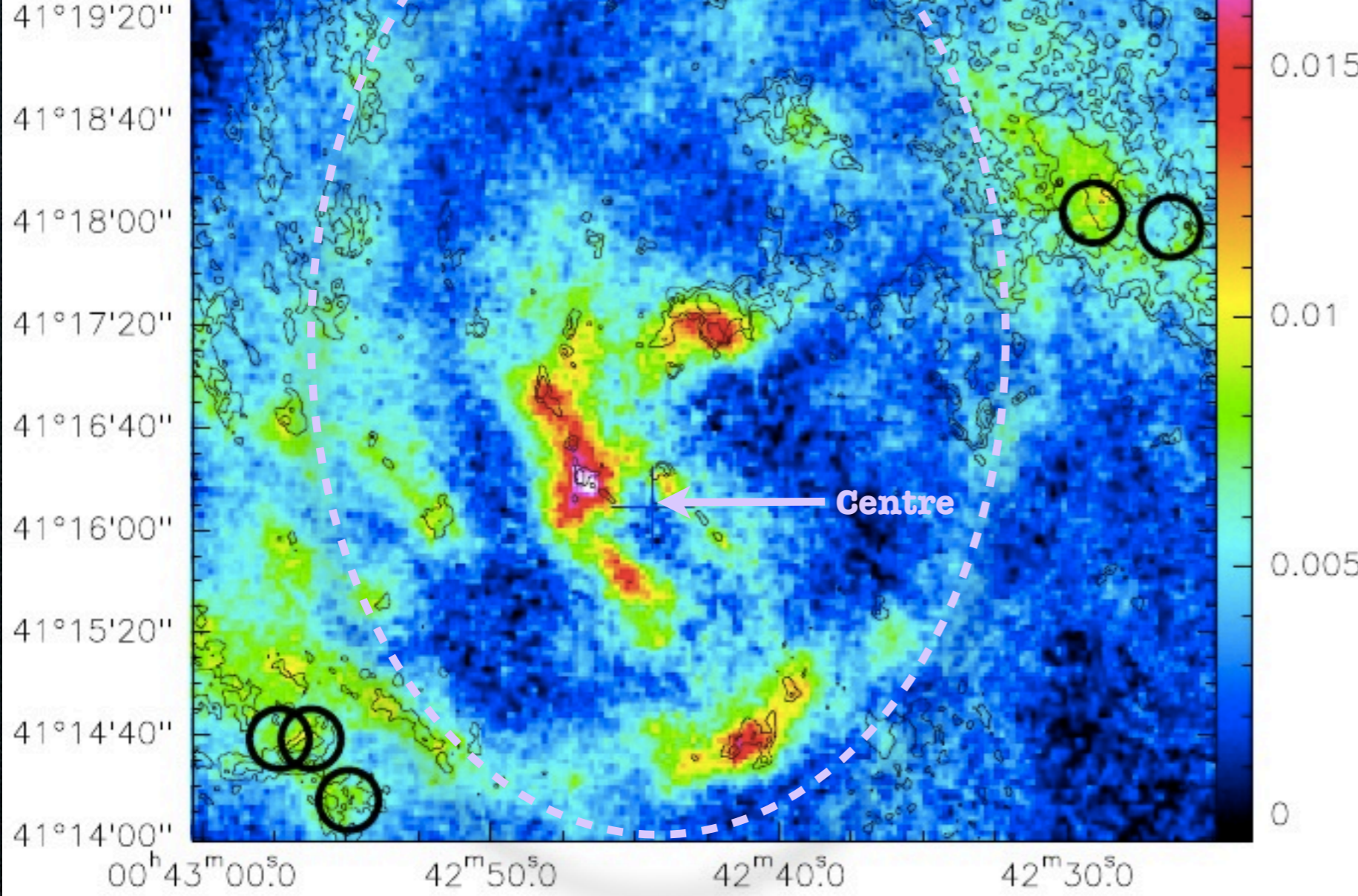
Inner ring: 0.7 kpc  
Outer ring: 10 kpc



→ Off-centered inner ring



# Detection of dense gas at IRAM 30m

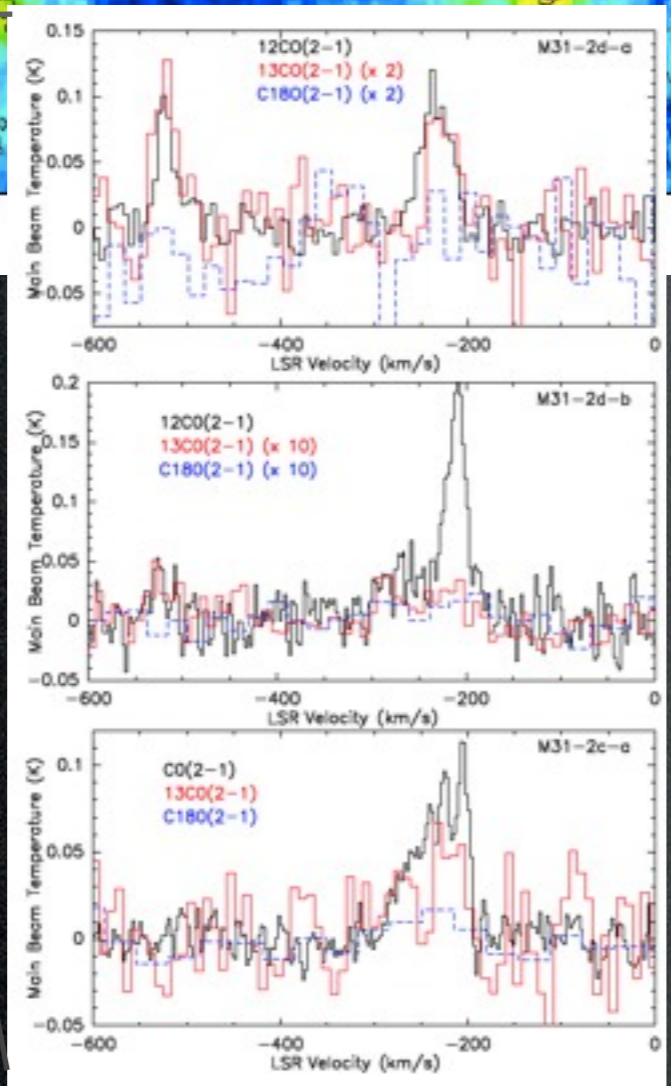
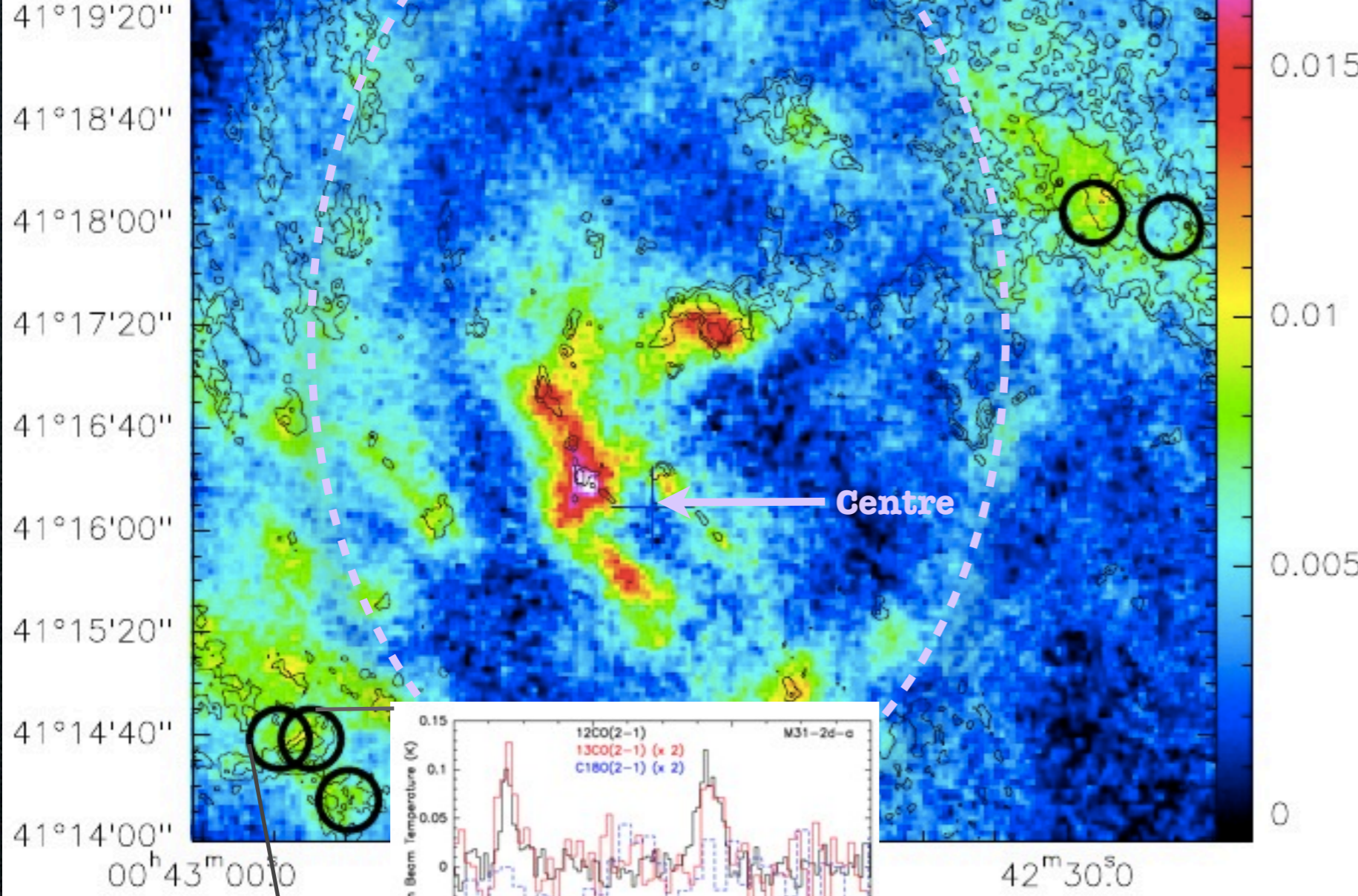


PACS 100um  
Courtesy : S. Viaene

**beam = 11arcsec FWHM**  
**= 40 pc**



# Detection of dense gas at IRAM 30m



PACS 100um  
Courtesy : S. Viaene

beam = 11arcsec FWHM  
= 40 pc

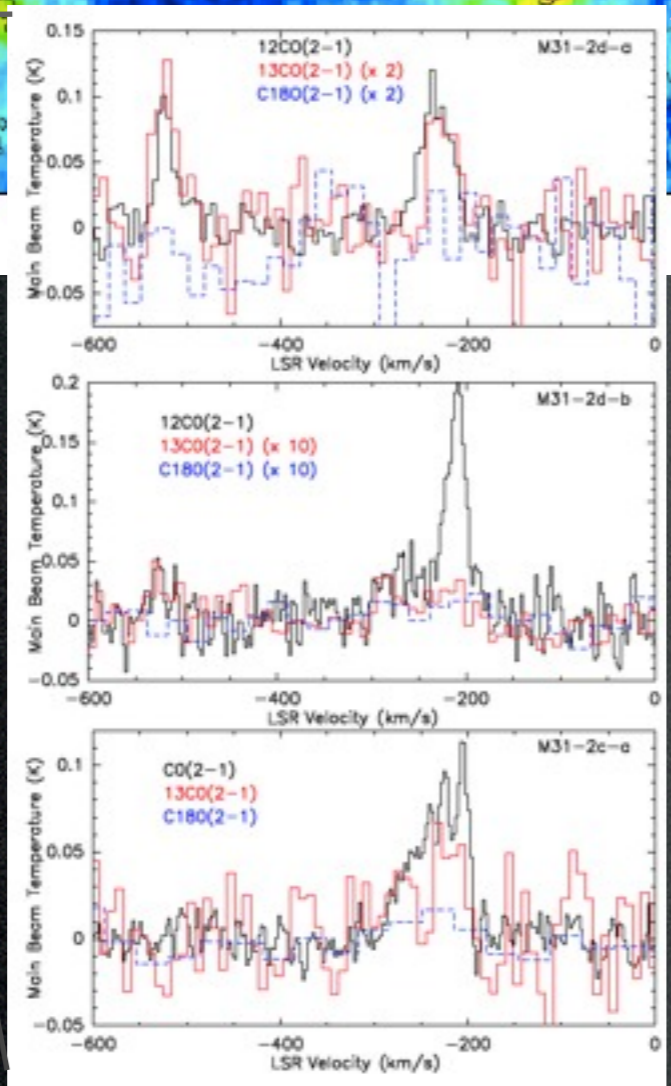
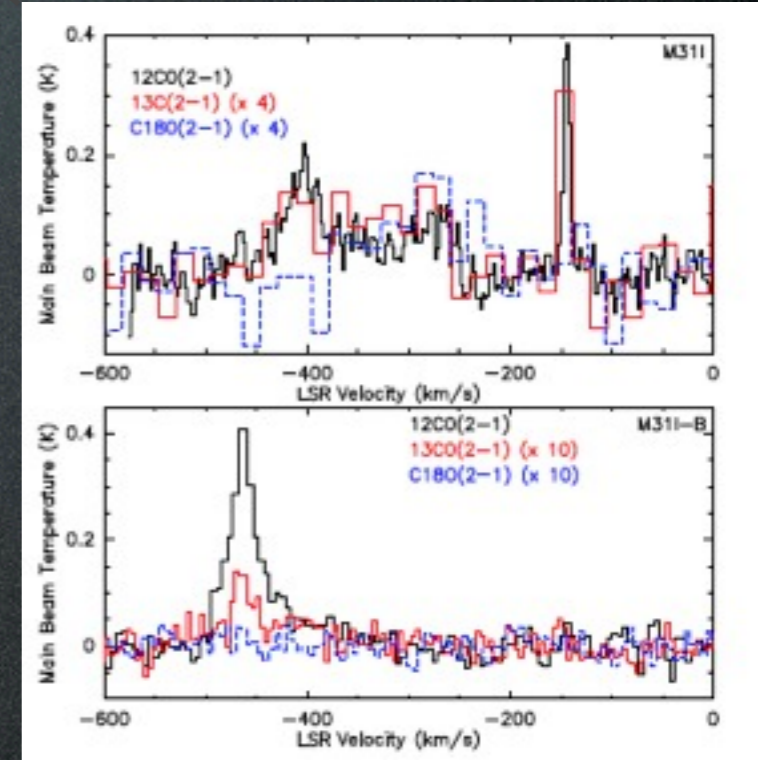
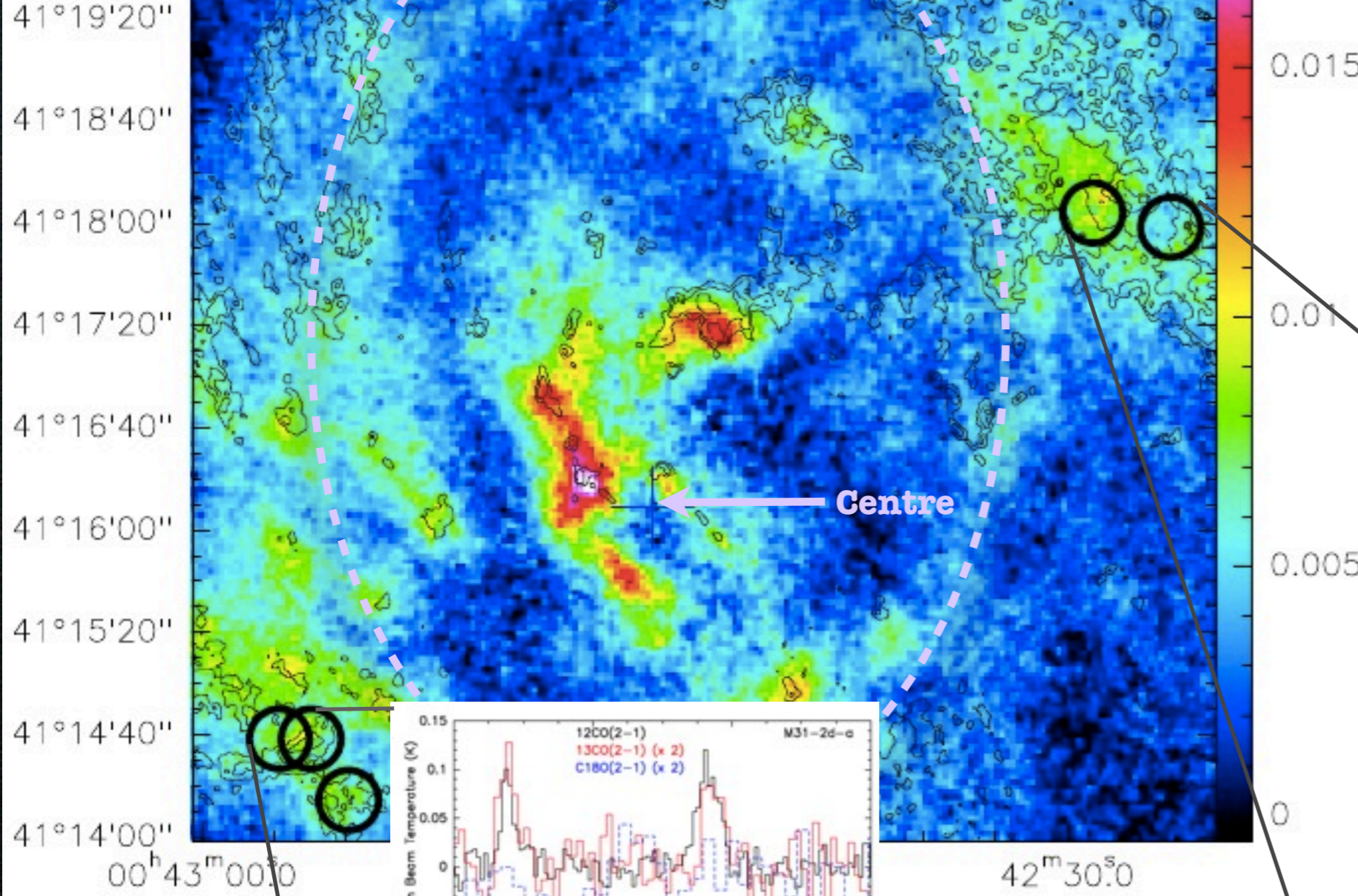
$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

Melchior & Combes 2016



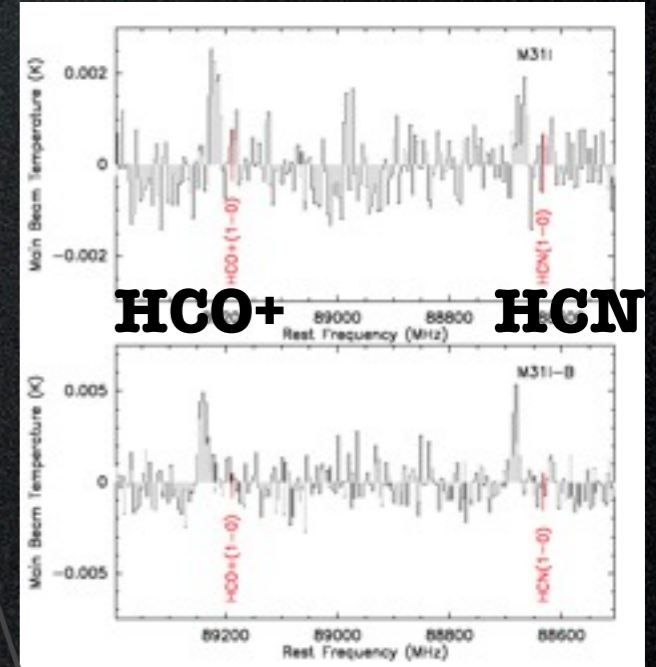
# Detection of dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$ ,  $^{13}\text{CO}(2-1)$ ,  $\text{C}^{18}\text{O}(2-1)$



PACS 100um  
Courtesy : S. Viaene

beam = 11arcsec FWHM  
= 40 pc



**HCO+** **HCN**

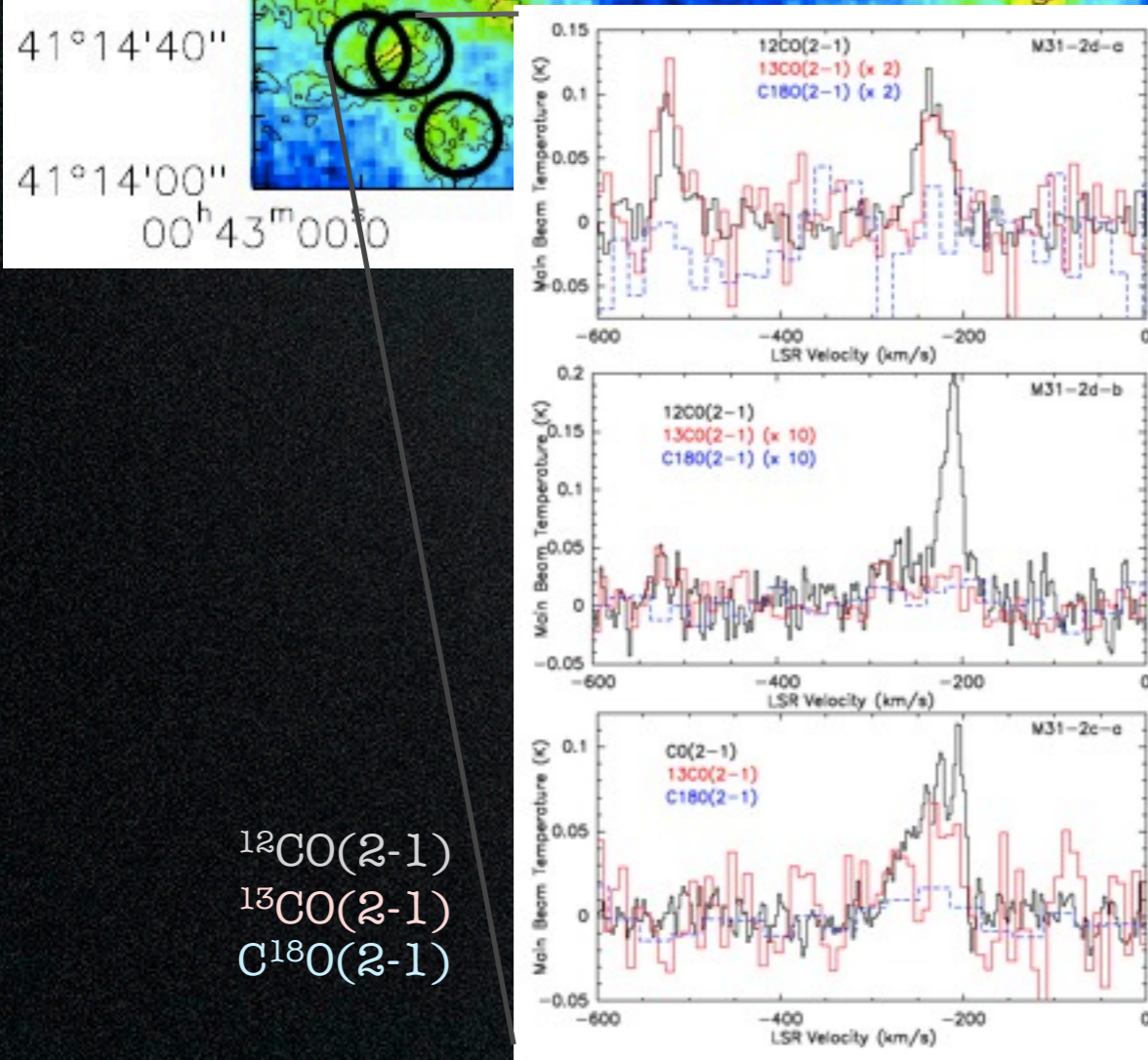
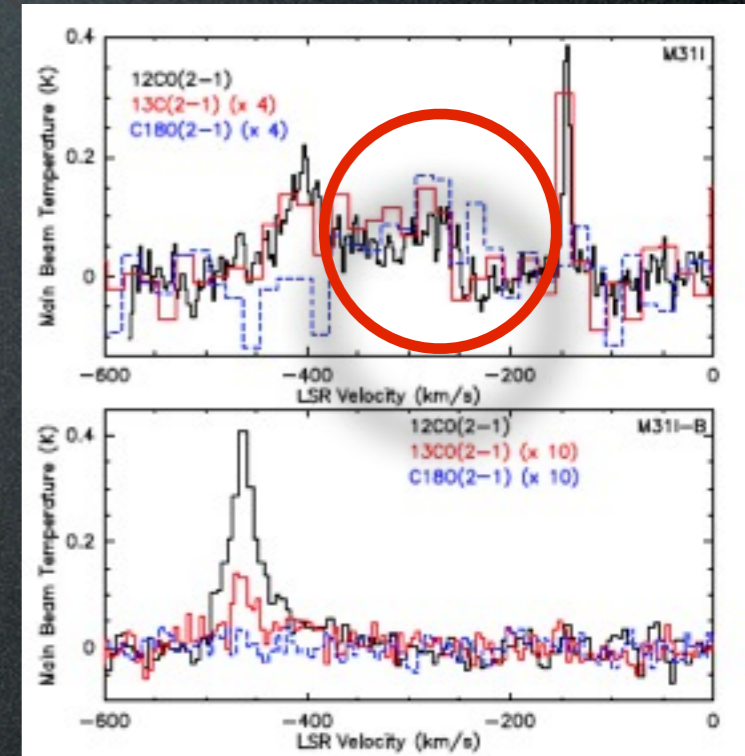
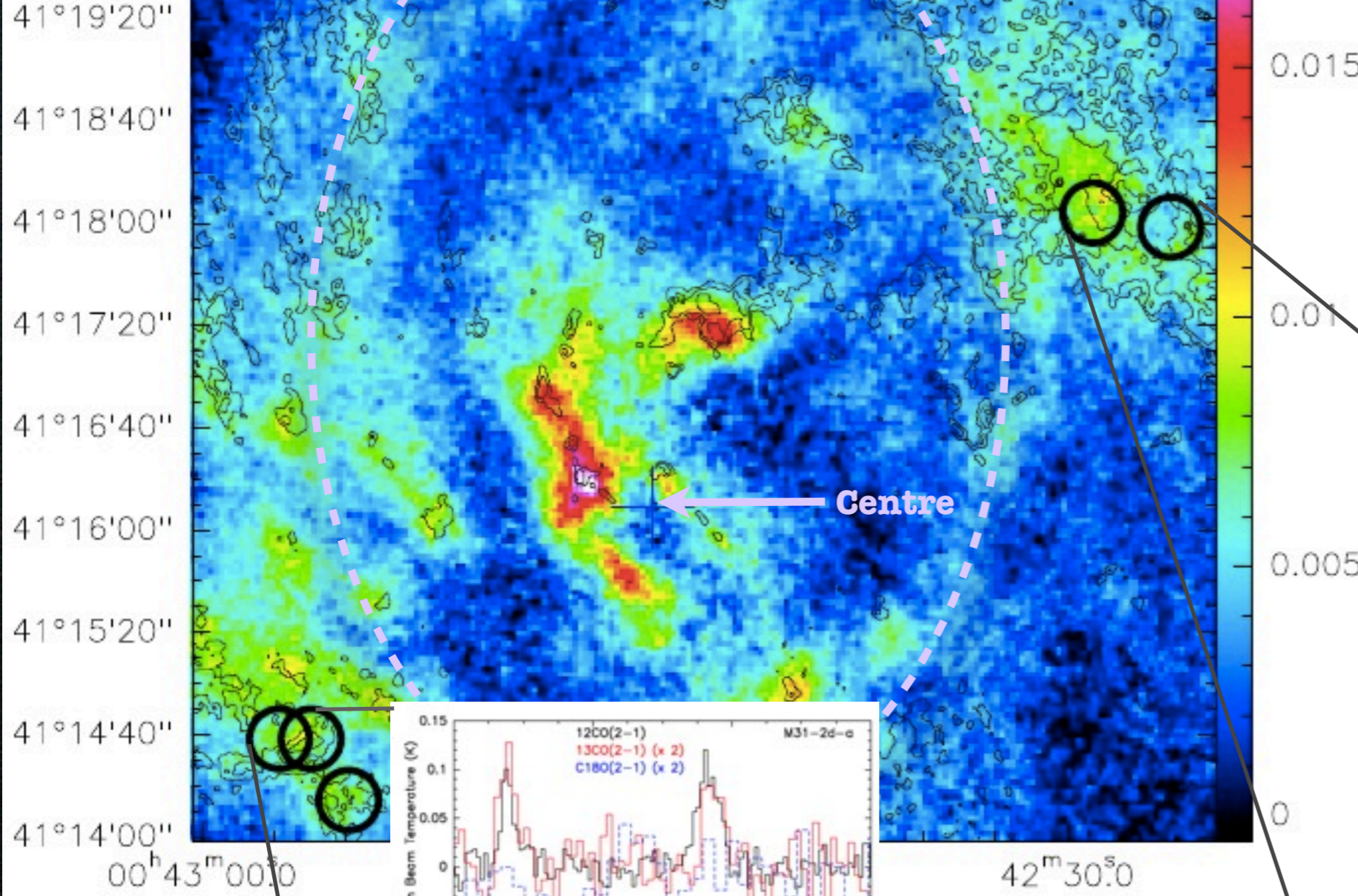
$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

Melchior & Combes 2016



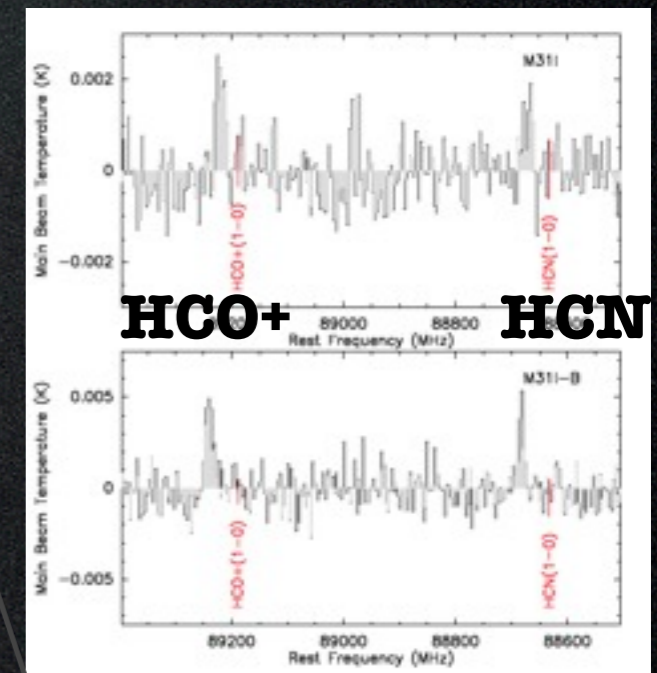
# Detection of dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$ ,  $^{13}\text{CO}(2-1)$ ,  $\text{C}^{18}\text{O}(2-1)$



PACS 100um  
Courtesy : S. Viaene

beam = 11arcsec FWHM  
= 40 pc

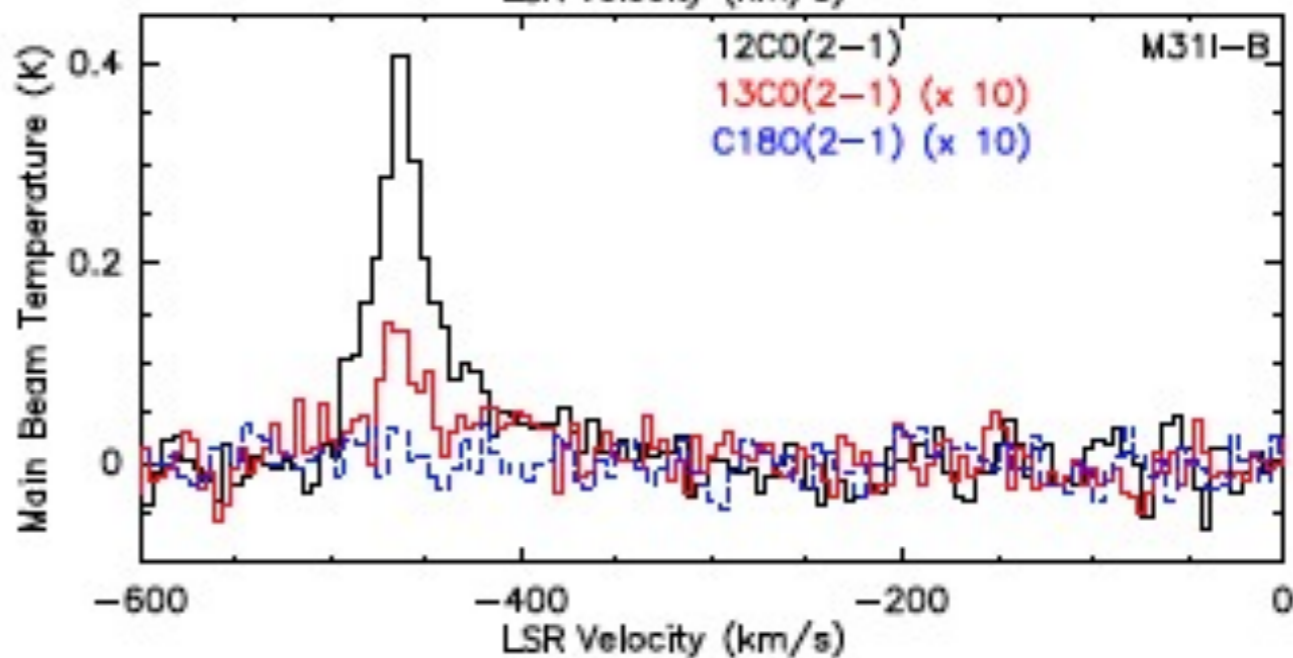
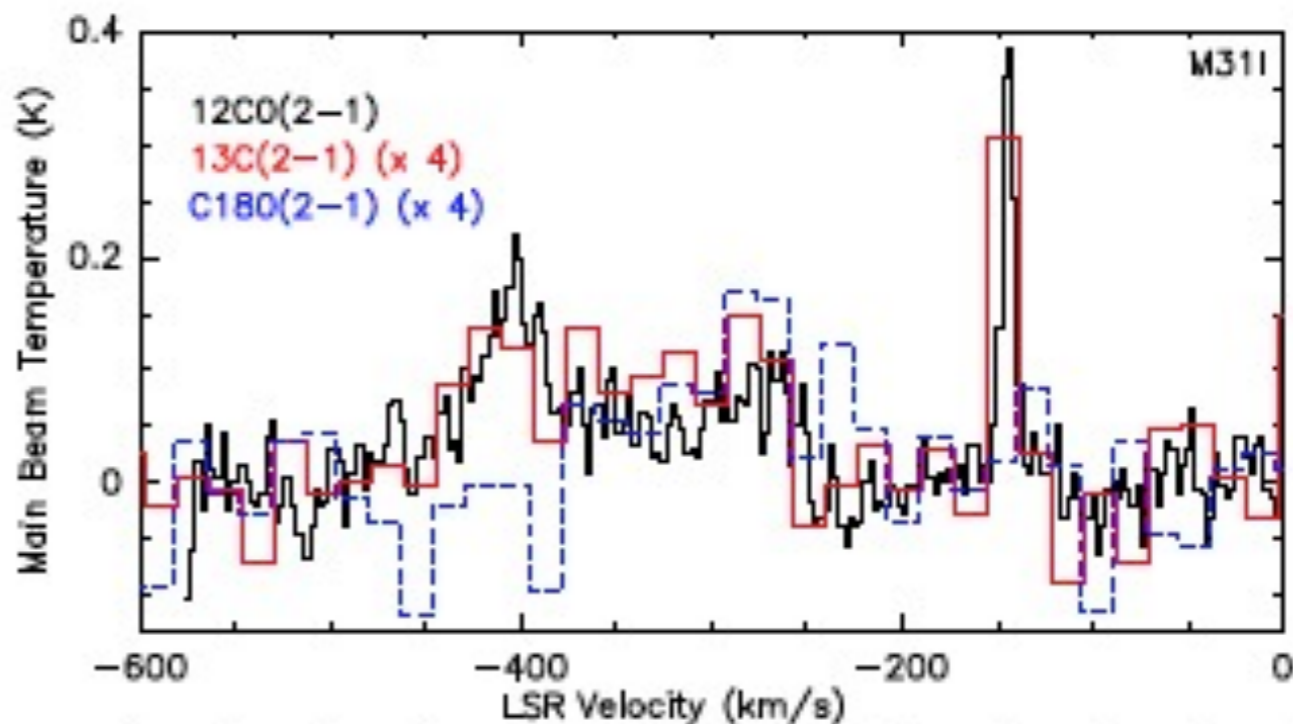
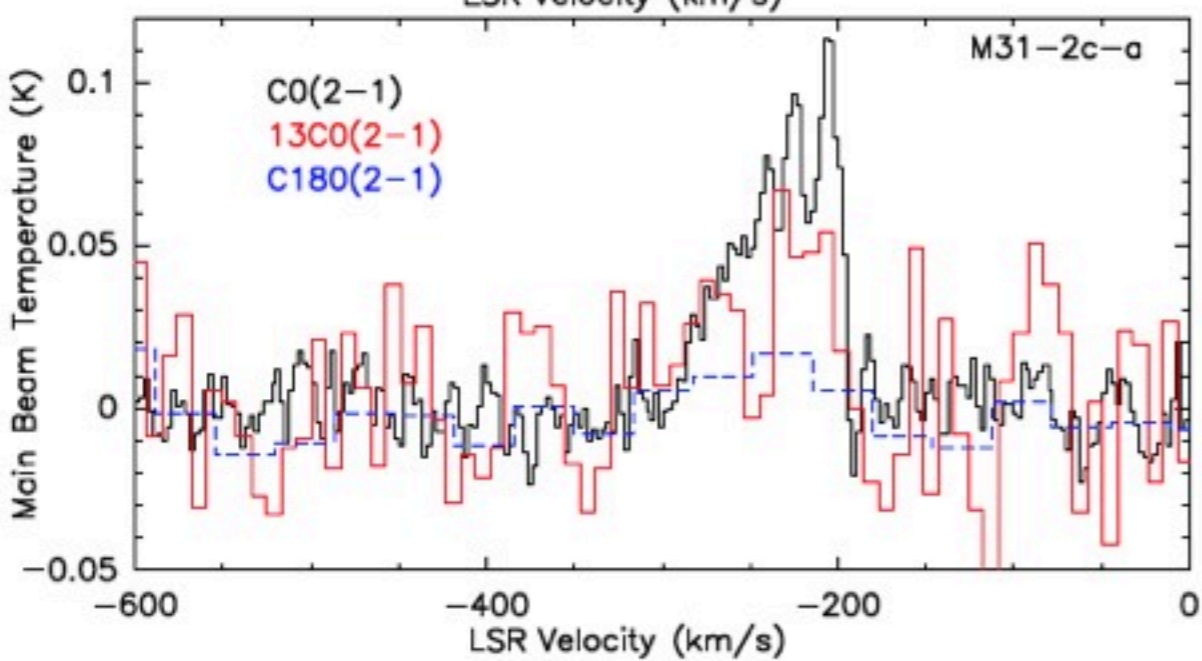
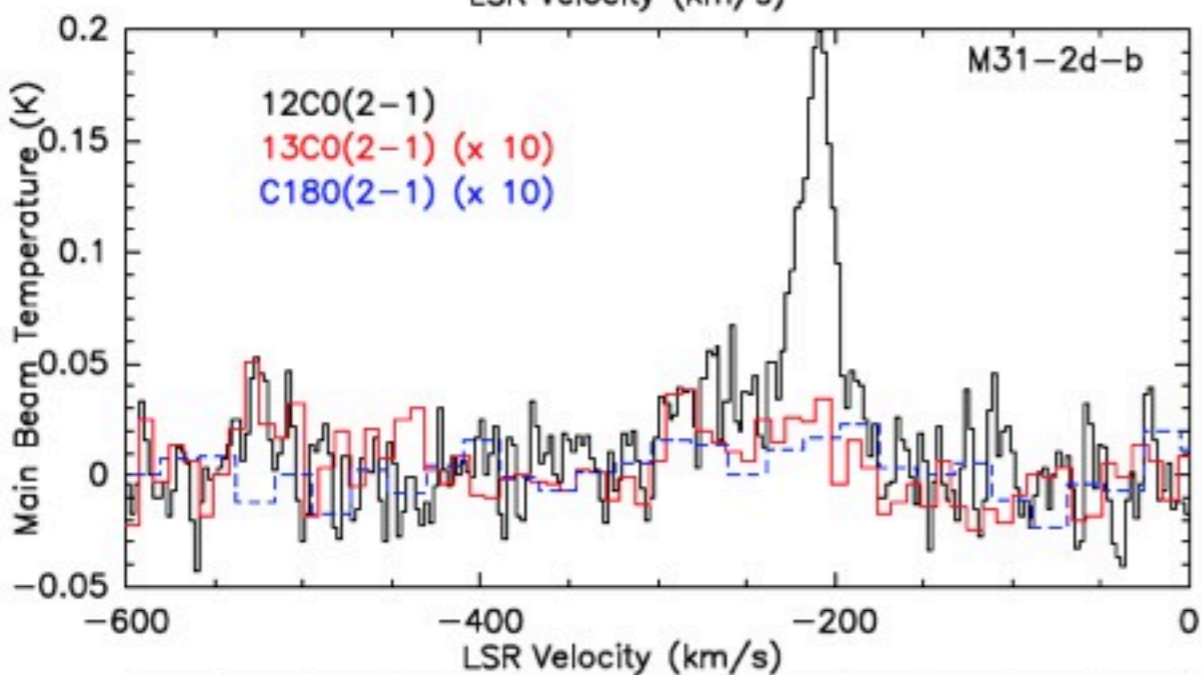
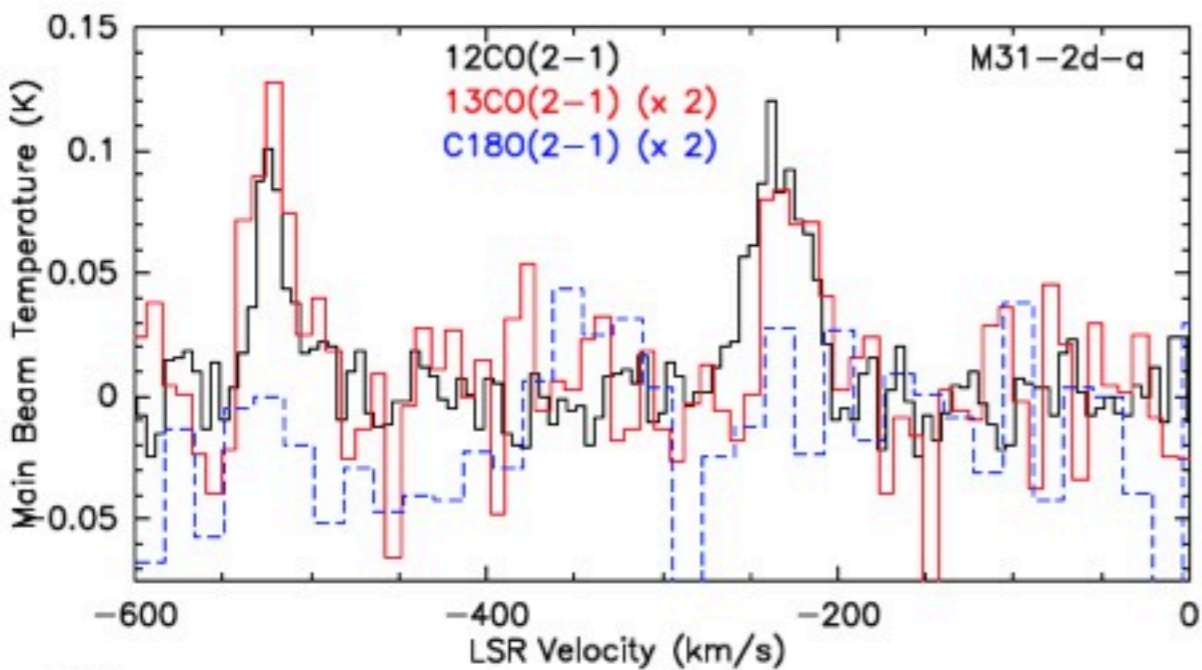


**HCO+** **HCN**

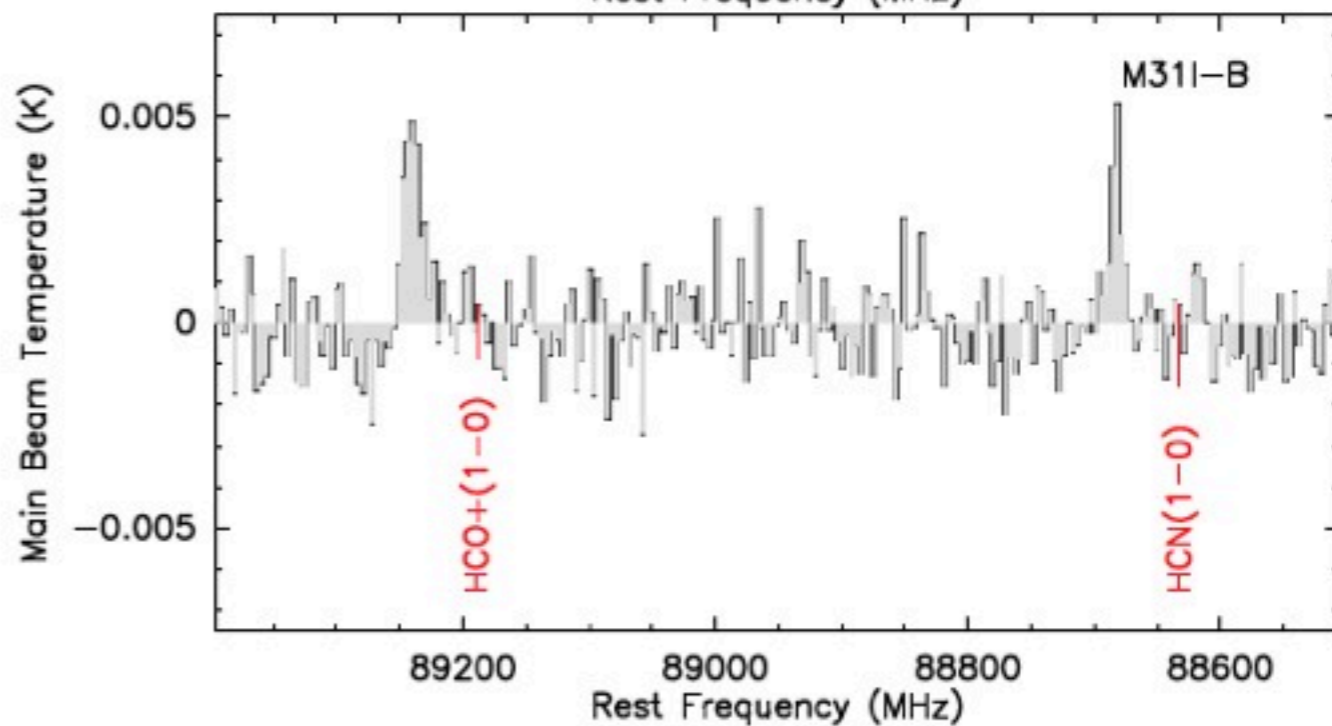
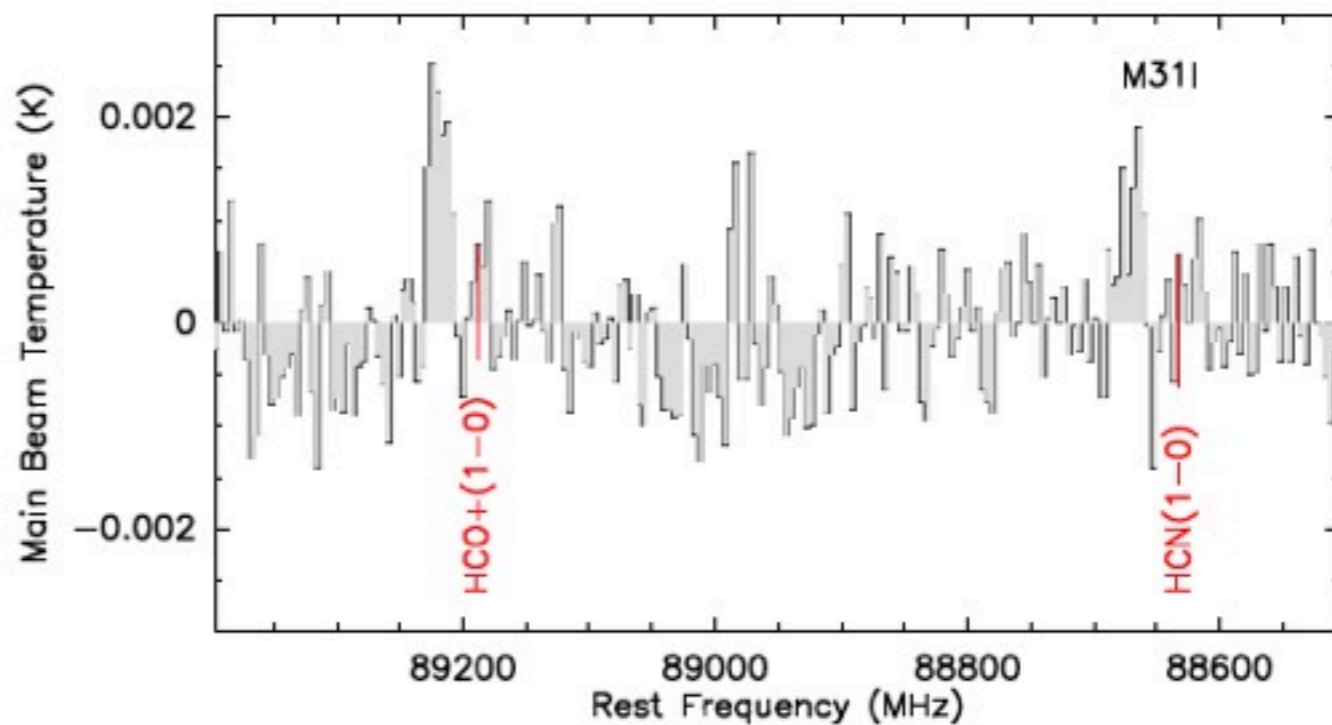
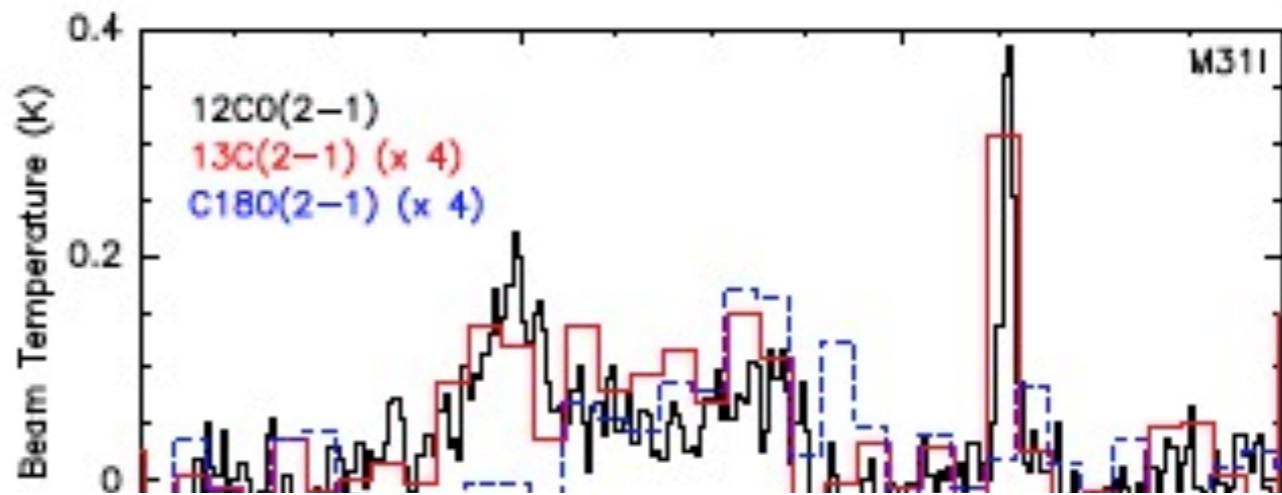
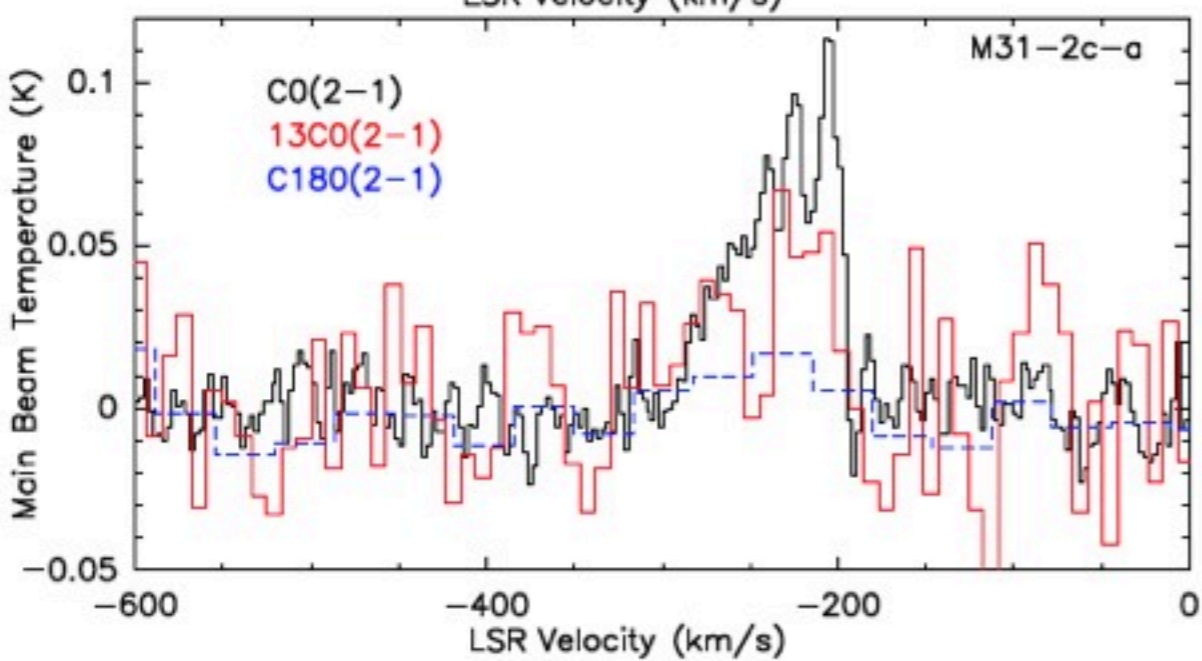
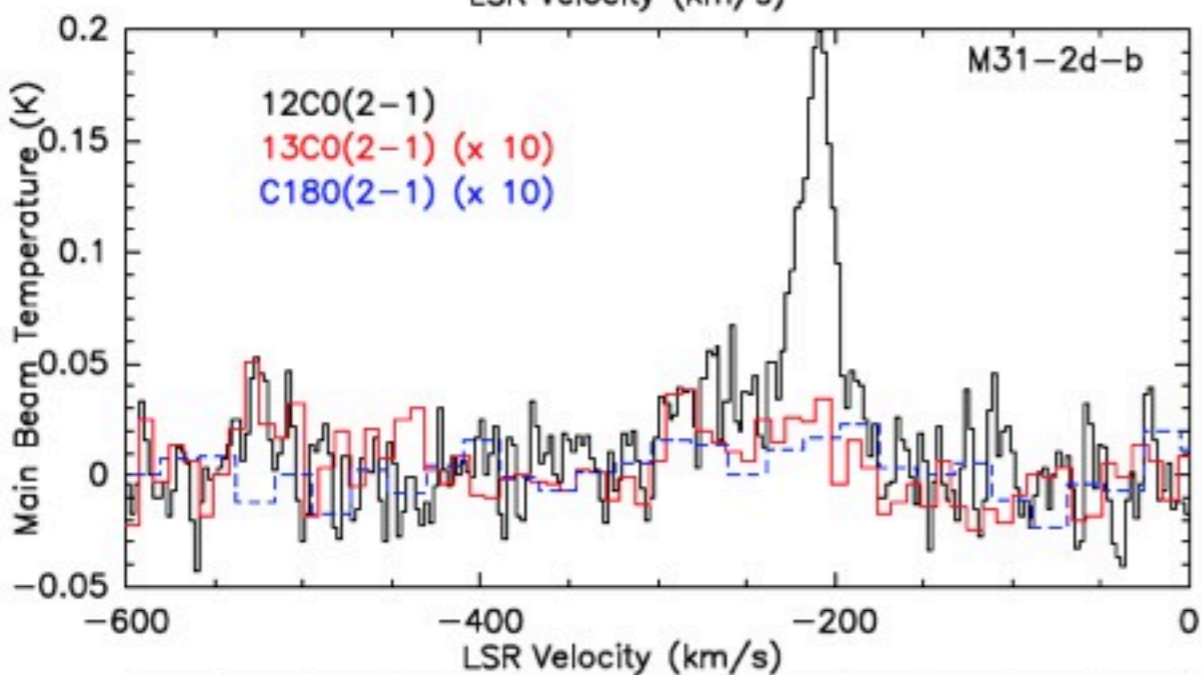
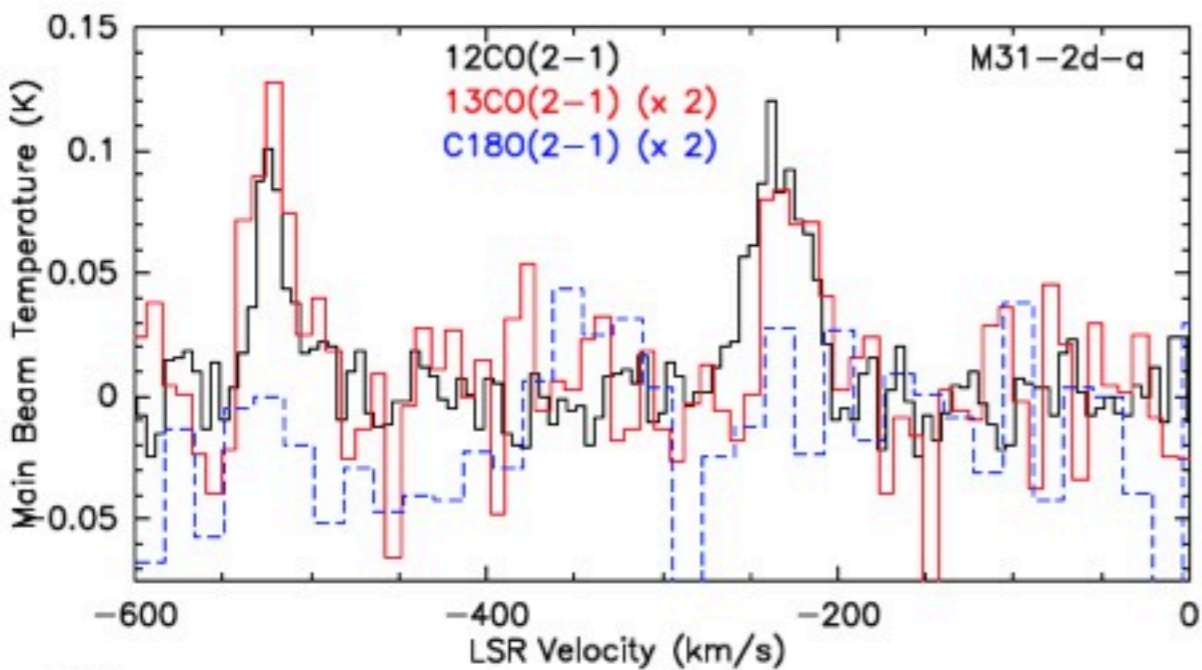
$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

Melchior & Combes 2016











# Analysis: $^{13}\text{CO}$ is depleted

Melchior & Combes 2016

**HCN and HCO<sup>+</sup> subthermally excited, under-abundant**  
 **$^{13}\text{CO}$  and C<sup>18</sup>O close to LTE and  $^{13}\text{CO}$  depleted**

$^{13}\text{CO}$  and C<sup>18</sup>O: optically thin (Column densities..)

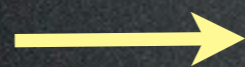
**$^{13}\text{CO} / \text{C}^{18}\text{O} = 1$**  Expected isotope & abundance values : **6-13** (Bergin+ 1995,  
Wilson & Rood 1994)

C<sup>18</sup>O abundance compatible with Galactic value

**$^{13}\text{CO}$  is deficient**

$^{13}\text{CO}$  deficit observed in post-starbursts (Casoli+ 1991,  
Davis 2014)

In 30-40 Myr stars  
decouple from their birth  
clouds  
Bash+ (1977), Bash  
(1979)



**200 Myr starburst** detected next to the centre  
(possibly in projection) Lauer+ (2012)



## 2 “counter-rotating”

## Analysis

Melchior & Combes 2016

Position	V1 km/s	V2 km/s	V3 km/s	SFR Msol/Myr
<u>I</u>	<u>-144</u>	<u>-291</u>	<u>-402</u>	3.2
<u>I-B</u>		<u>-397</u>	<u>-463</u>	2.8
2d-a	<b>-523</b>		<b>-234</b>	1.3
2d-b	<b>-526</b>	<b>-269</b>	<b>-211</b>	1.3
2c-a	<b>-243</b>	<b>-223</b>	<b>-205</b>	1.6

$M_* \sim 3 \cdot 10^7 M_{\text{sol}}$ ;  
 $M_{\text{dust}} \sim 10^3 M_{\text{sol}}$ ;  
 $T_{\text{dust}} = 20\text{K}$

Viaene+ 2014

Average beam filling factor: 0.8%.

The gas is very clumpy.

Average  $N_{\text{H}} = 16 \cdot 10^{22} \text{ cm}^{-2}$

Melchior & Combes 2011



## 2 “counter-rotating”

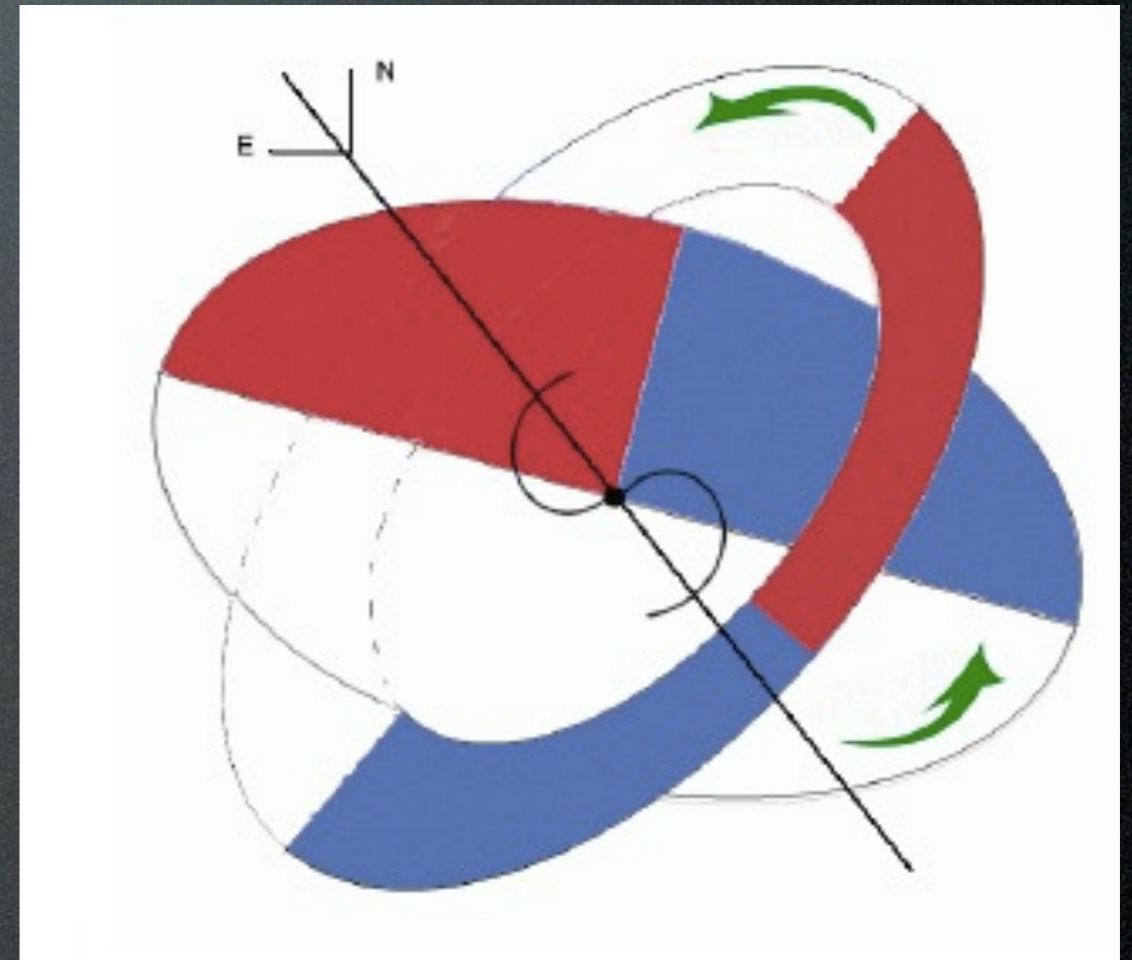
## Analysis

Melchior & Combes 2016

Position	V1 km/s	V2 km/s	V3 km/s	SFR Msol/Myr
I	<b>-144</b>	<b>-291</b>	<b>-402</b>	<b>3.2</b>
I-B		<b>-397</b>	<b>-463</b>	<b>2.8</b>
2d-a	<b>-523</b>		<b>-234</b>	<b>1.3</b>
2d-b	<b>-526</b>	<b>-269</b>	<b>-211</b>	<b>1.3</b>
2c-a	<b>-243</b>	<b>-223</b>	<b>-205</b>	<b>1.6</b>

$M_* \sim 3 \cdot 10^7 M_{\text{sol}}$ ;  
 $M_{\text{dust}} \sim 10^3 M_{\text{sol}}$ ;  
 $T_{\text{dust}} = 20\text{K}$

Viaene+ 2014



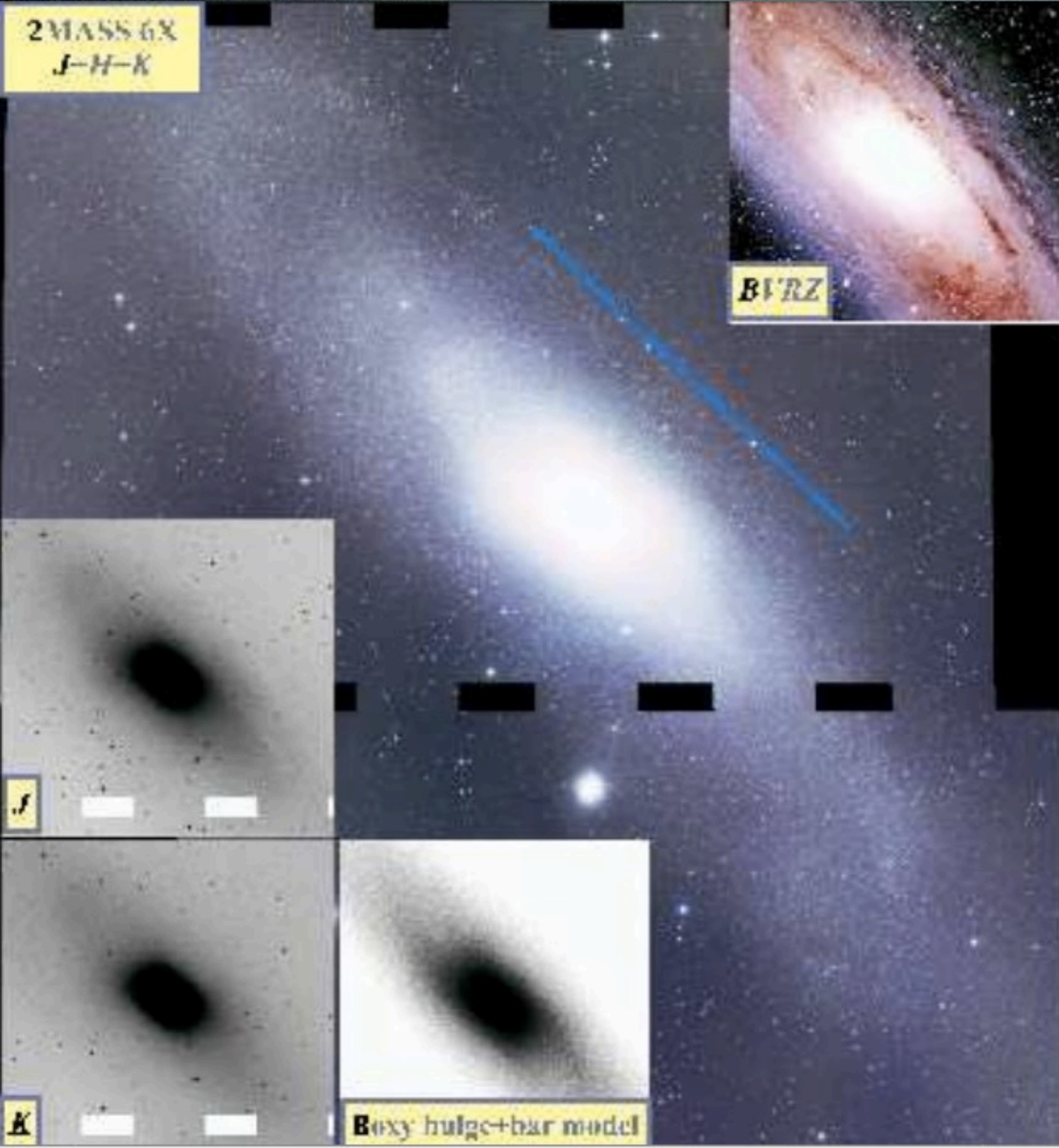
**Average beam filling factor: 0.8%.**

**The gas is very clumpy.**

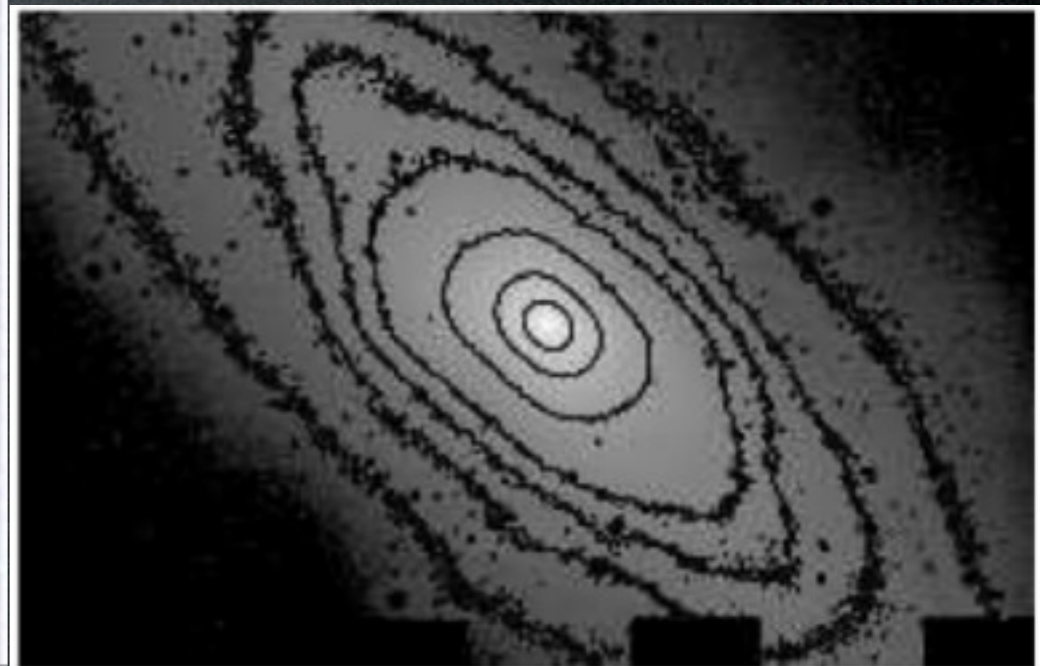
**Average  $N_{\text{H}} = 16 \cdot 10^{22} \text{ cm}^{-2}$**

Melchior & Combes 2011





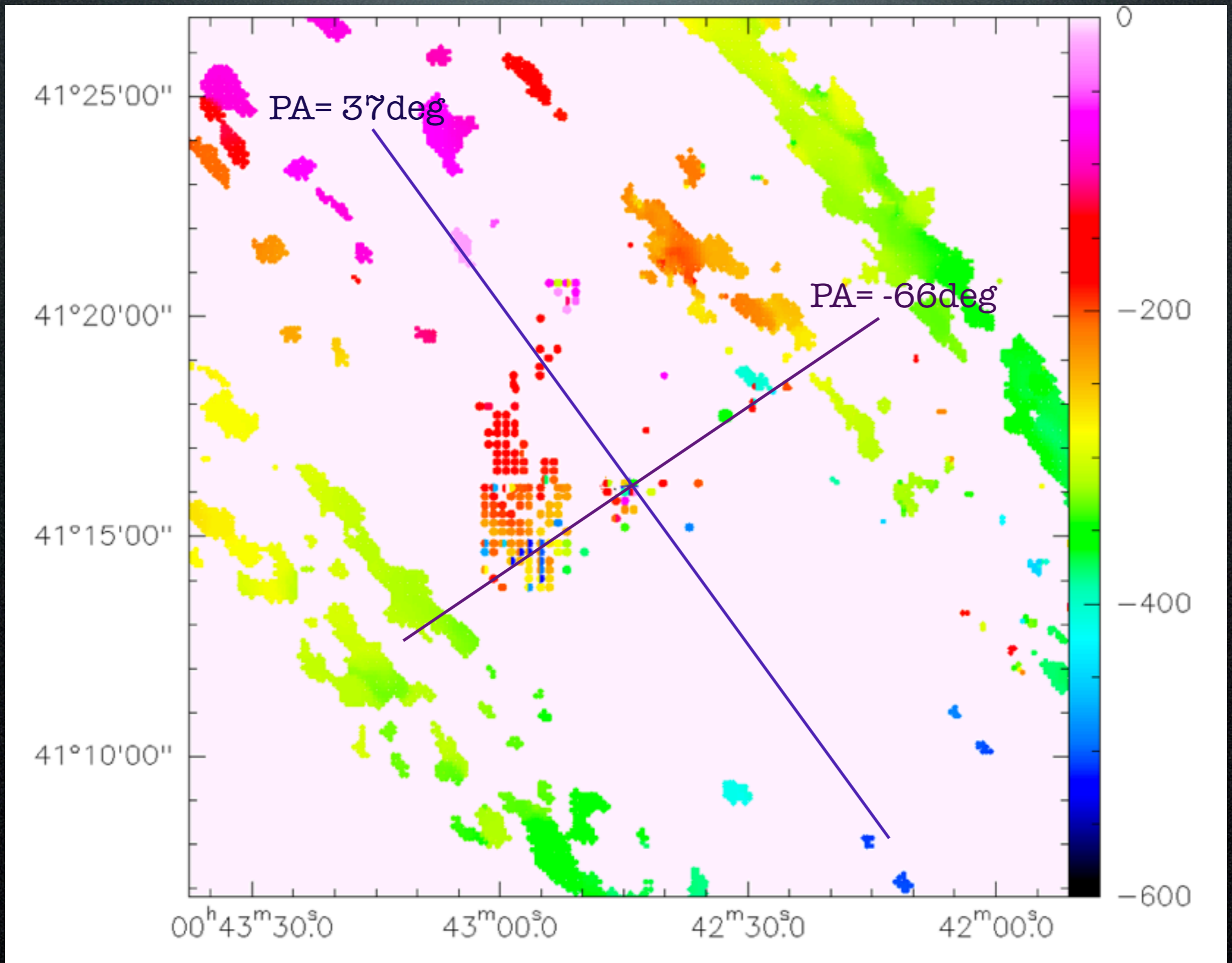
**It is not due to a bar...**



Beaton+ (2006)

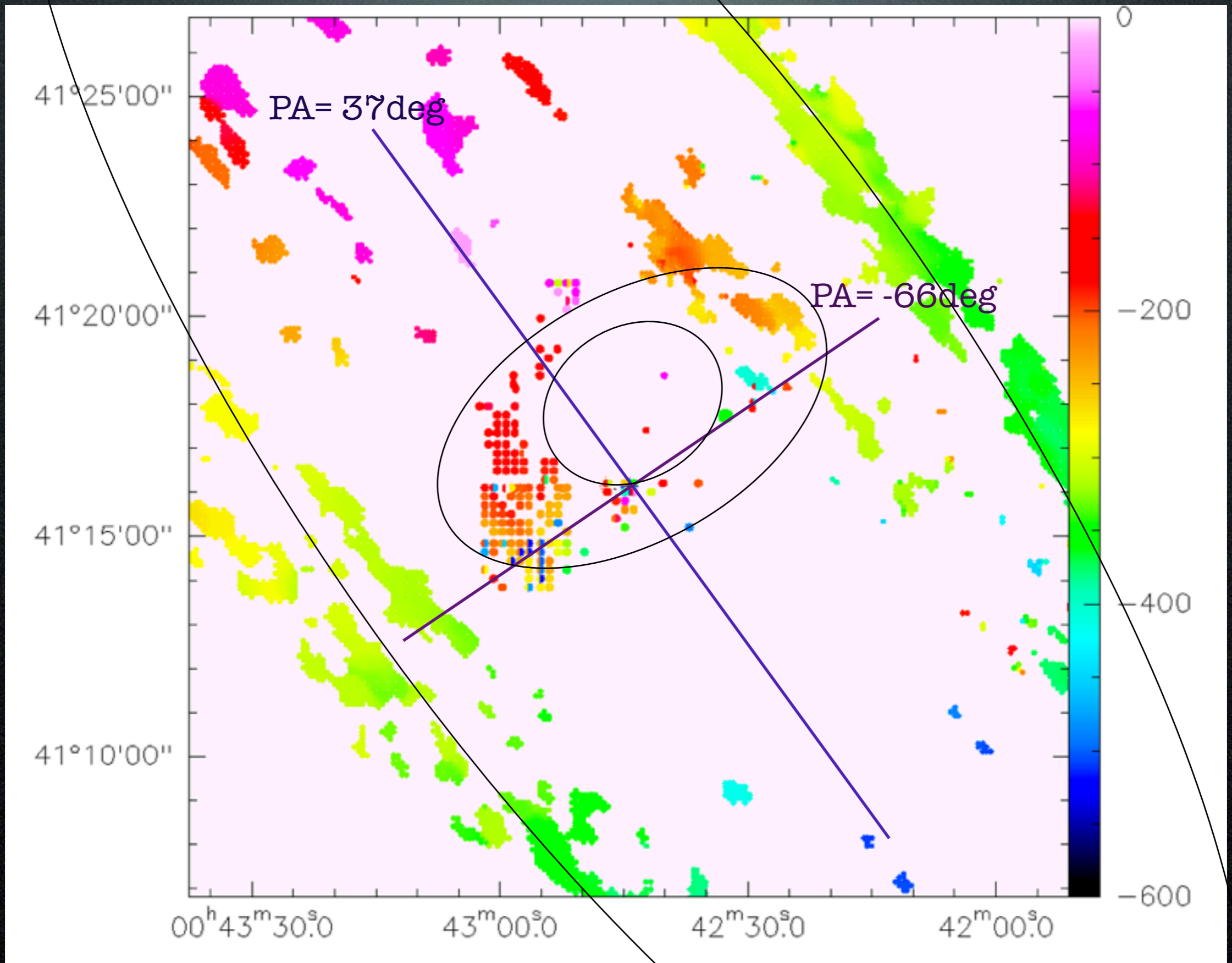
Athanassoula & Beaton (2006)





20' x 20'





20' x 20'



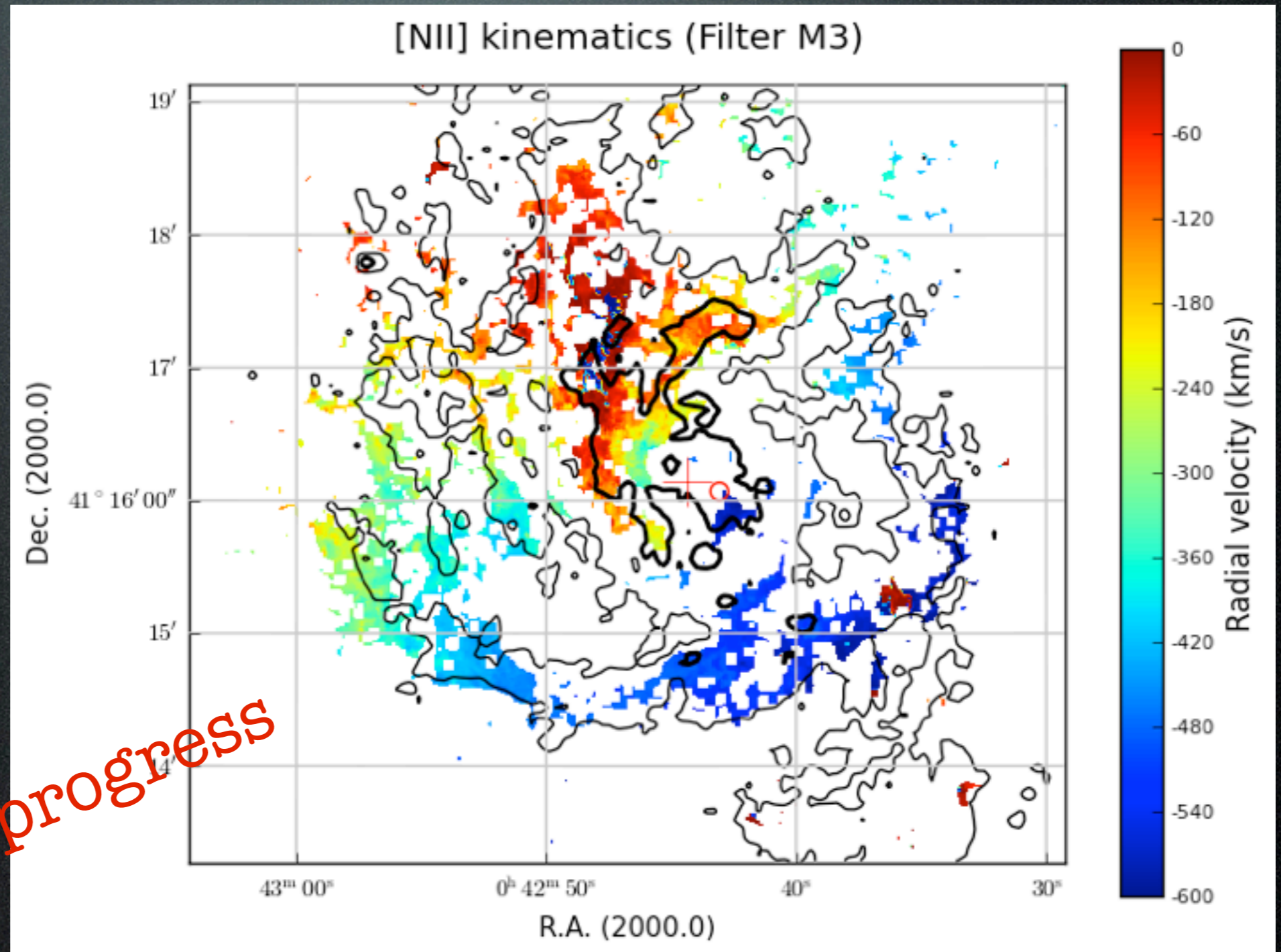
# Observations at Mont Mégatic (Québec)

**Fabry-Perot  
instrument:**

Modulo: 400km/s  
R=10000 (30km/s)

in collaboration with  
Zacharie Sie Kam  
Philippe Amram  
Michel Marcelin  
Claude Carrignan

*Work in progress*





# SITELLE data on CFHT: preliminary velocity [NII]

R=5000  
60km/s

## **International collaboration:**

**Obs-Paris LERMA:** A.-L. Melchior, F. Combes

**Laboratoire d'Astrophysique de Marseille:** Philippe Amram,  
Michel Marcelin, Benoit Epinat

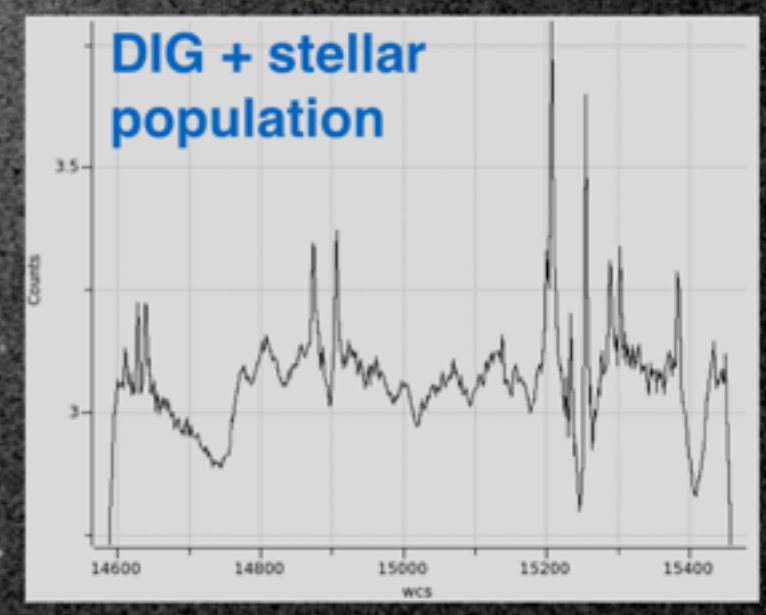
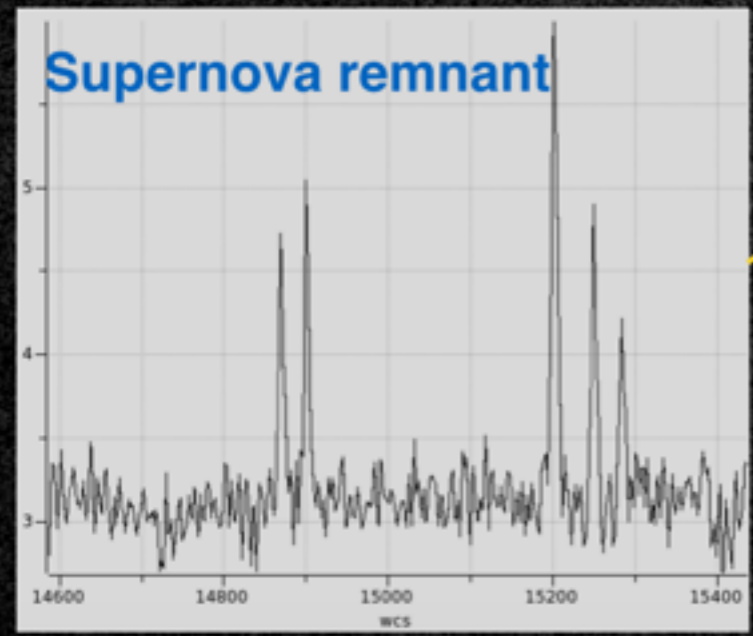
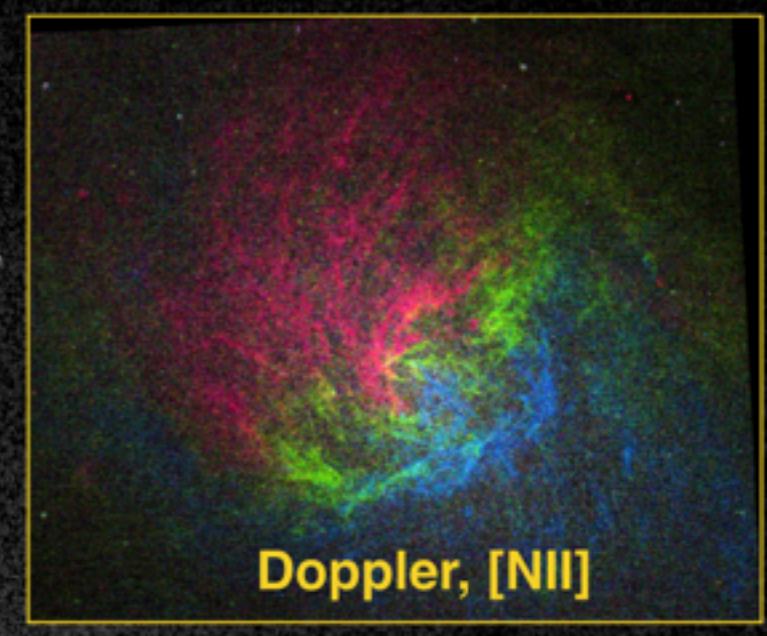
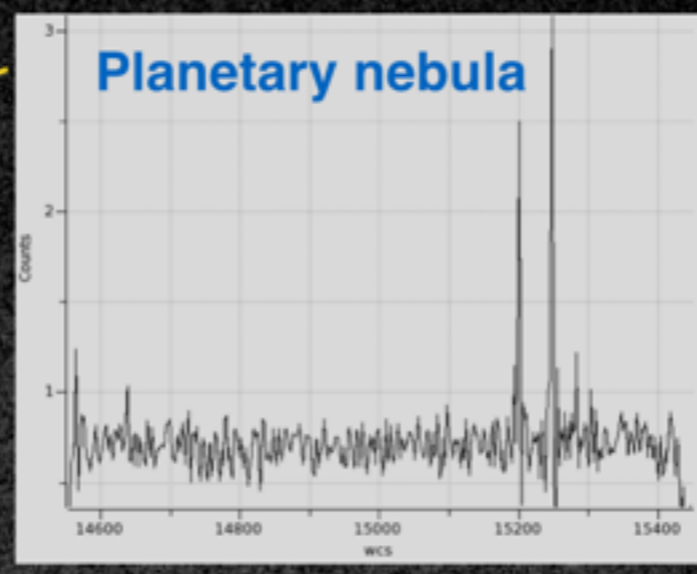
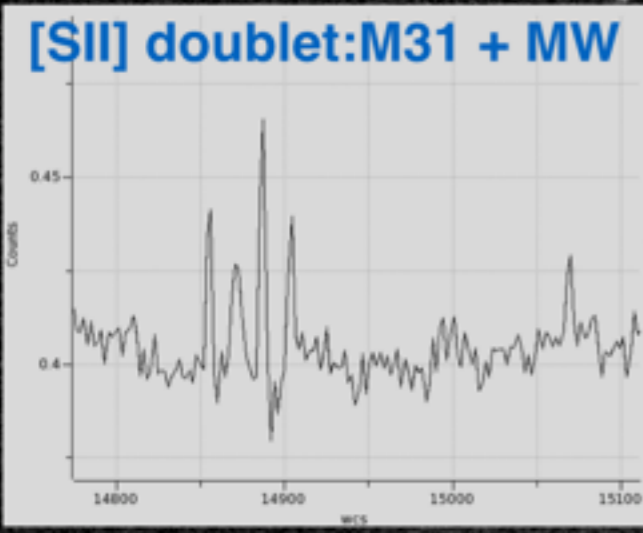
**Université Laval, Canada:** Laurent Drissen, Carmelle Robert,  
Laurie, Rousseau-Nepton

**Instituto de astronomia, UNAM, Mexique:** Christophe Morisset

**Université d'Hawaii à Hilo, USA:** René Pierre Martin

**Université de Ouagadougou, Burkina Faso:** S. Zacharie Kam



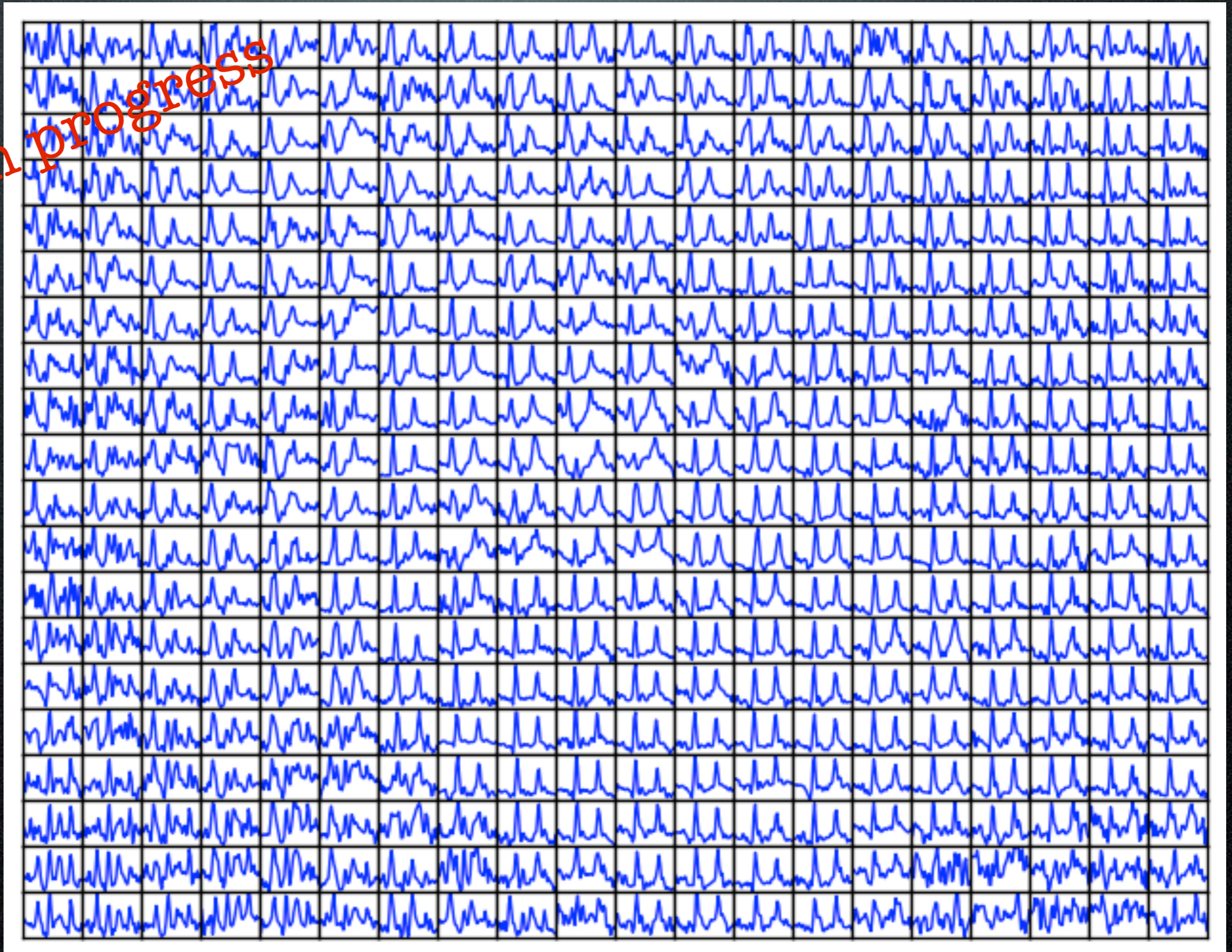




Total: 6 arcmin x 6 arcmin  
pixel: 20"x20"

[SII] doublet

Work in progress





# What we know

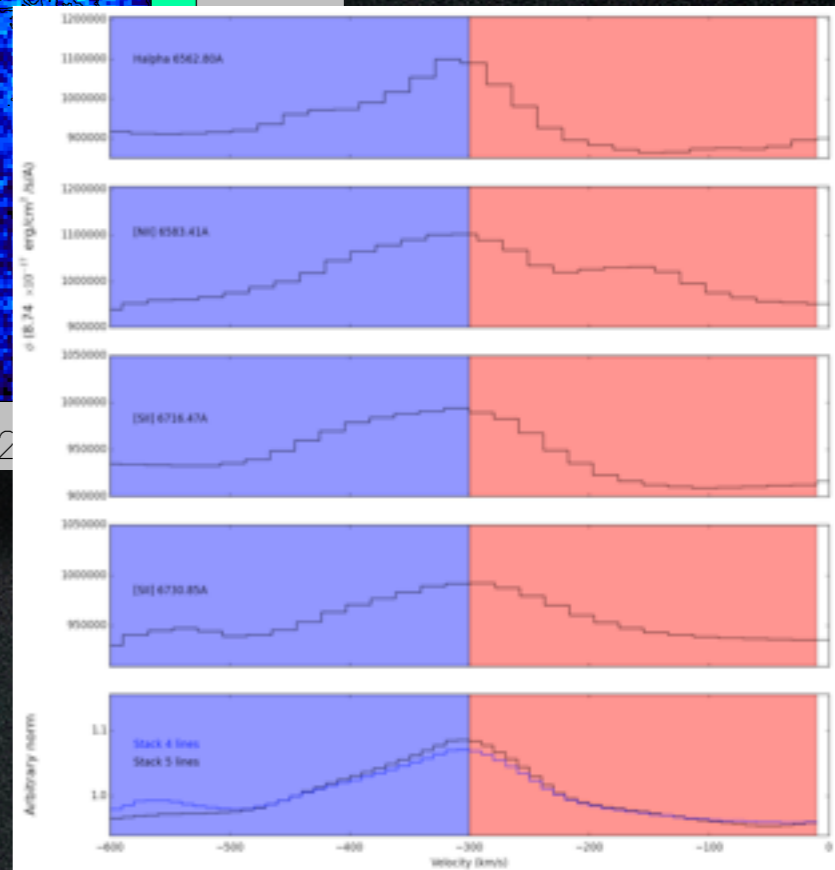
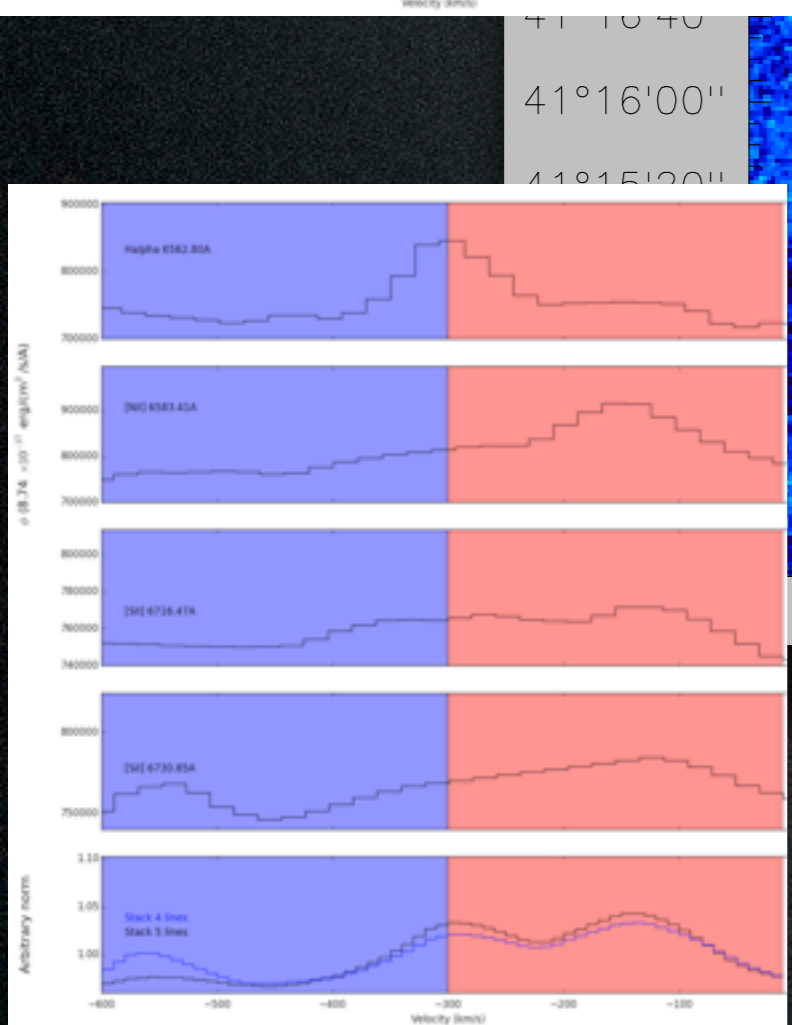
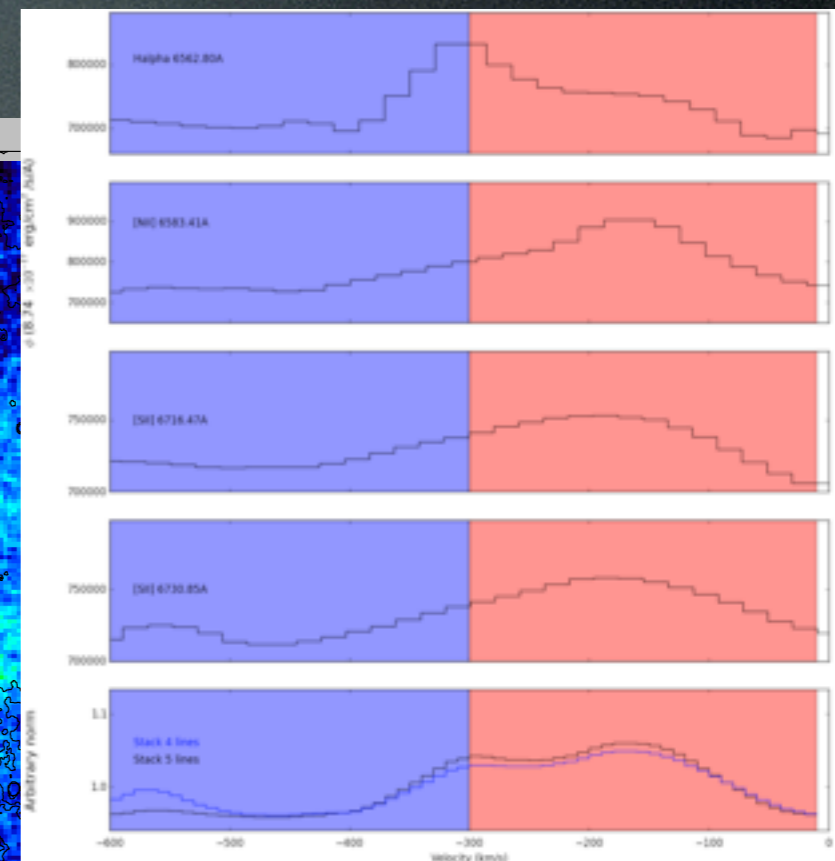
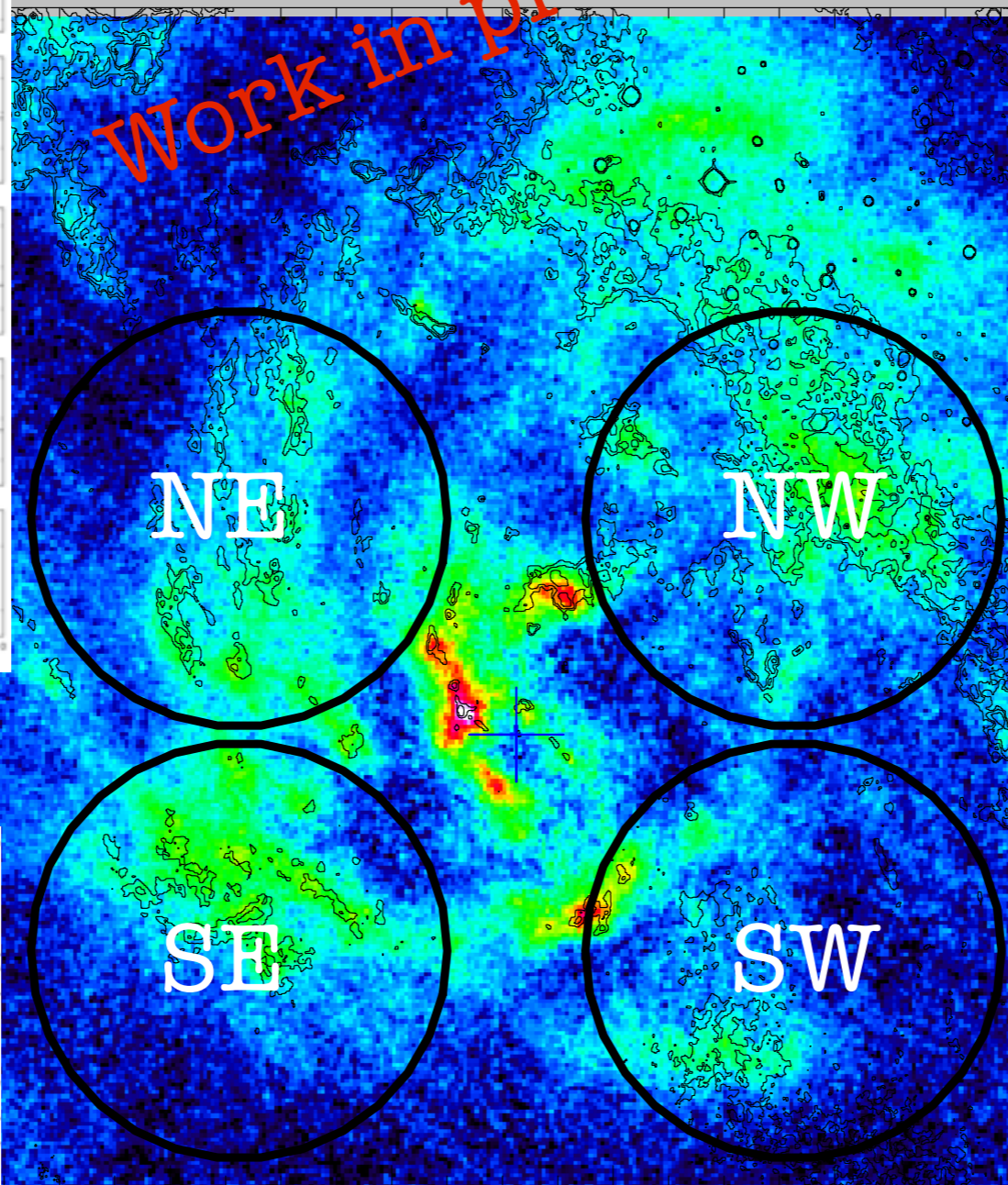
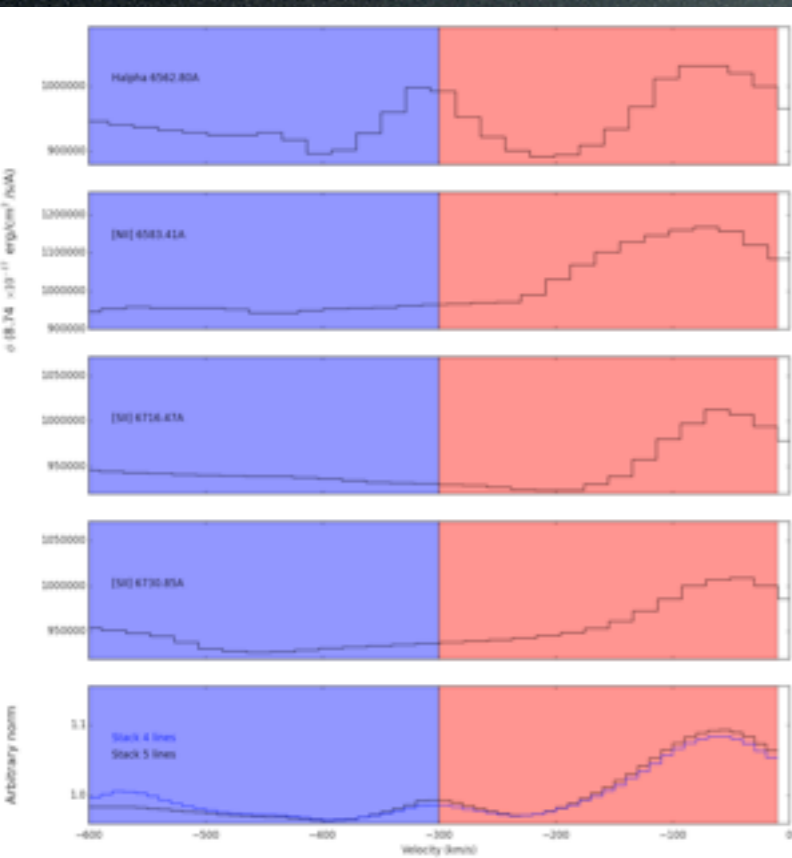
- 10kpc- Main disc: CO gas rotates in a disc (nobody checked for counter-rotation)
- 1kpc-in the bulge, molecular gas does not rotate as main disc
  - components on both sides of the systemic velocity
  - Optical ionised gas is perturbed, does not exactly follow the CO



Thank you



Work in Progress



41° 16' 00"  
41 15 20

00<sup>h</sup> 43<sup>m</sup> 00<sup>s</sup> 42<sup>m</sup> 50<sup>s</sup> 42<sup>m</sup> 40<sup>s</sup> 42<sup>m</sup> 30<sup>s</sup> 42



# Comparison ionised gas with CO(2-1) kinematics

## Minor axis NW

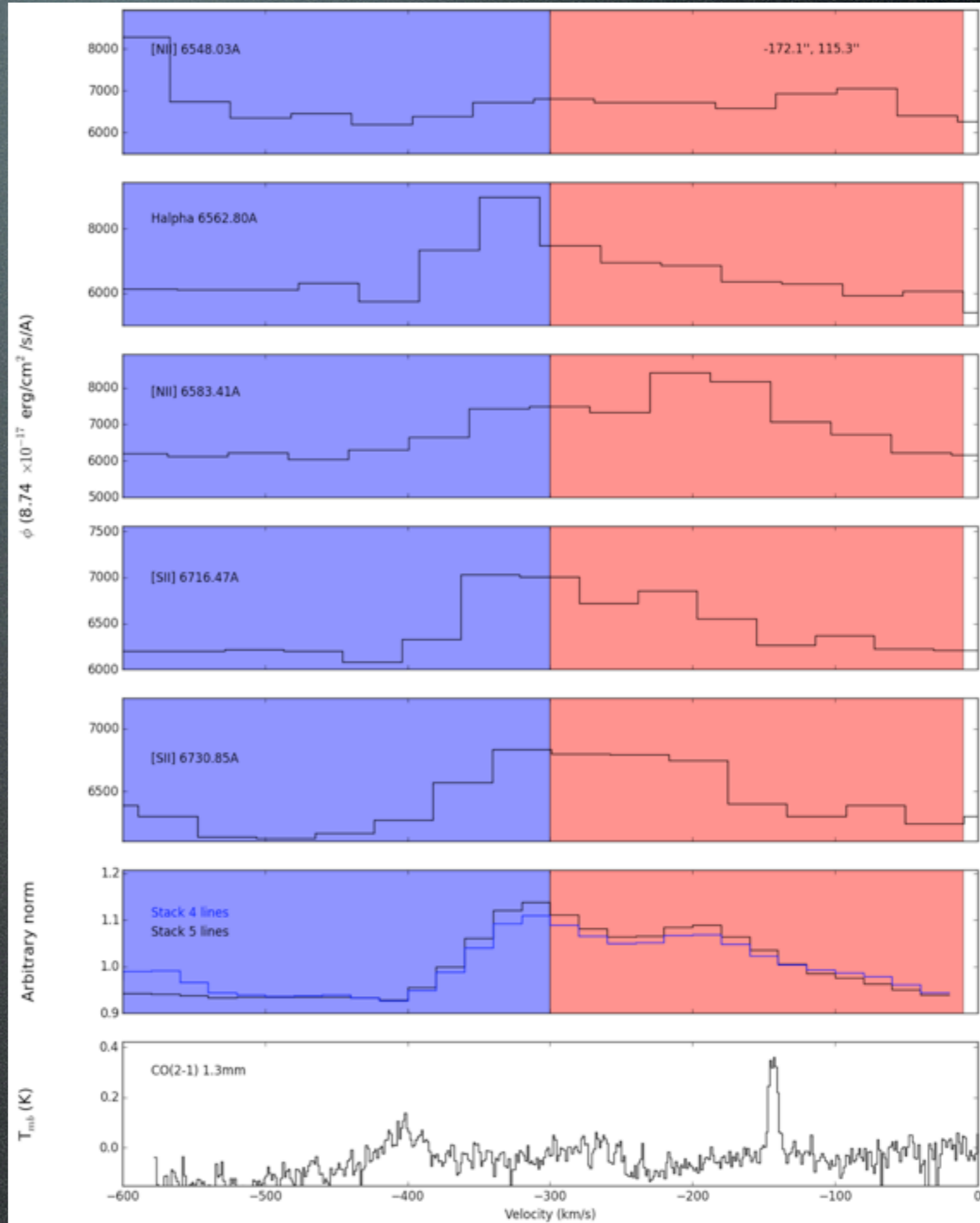
### Halpna:

a component at systemic velocity

### [NII], [SII]:

a red component, marginally compatible with CO(2-1)

**CO blue** component: not detected.





# Comparison ionised gas with CO(2-1) kinematics

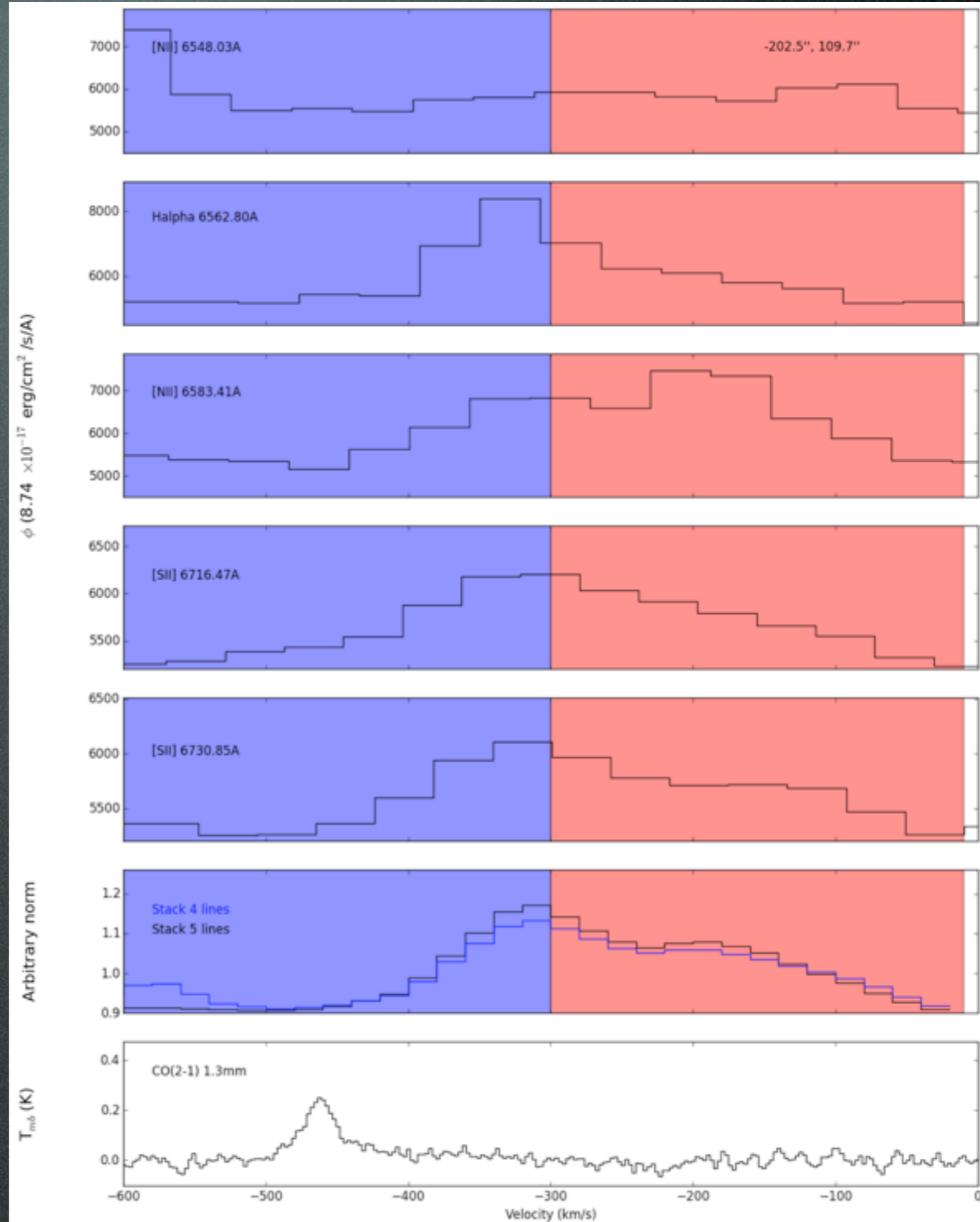
## Minor axis NW

### Halpna:

a component close to systemic velocity

### [NII], [SII]:

a red component, not in CO(2-1)  
CO blue component: not detected.





# Comparison ionised gas with CO(2-1) kinematics Minor axis SE

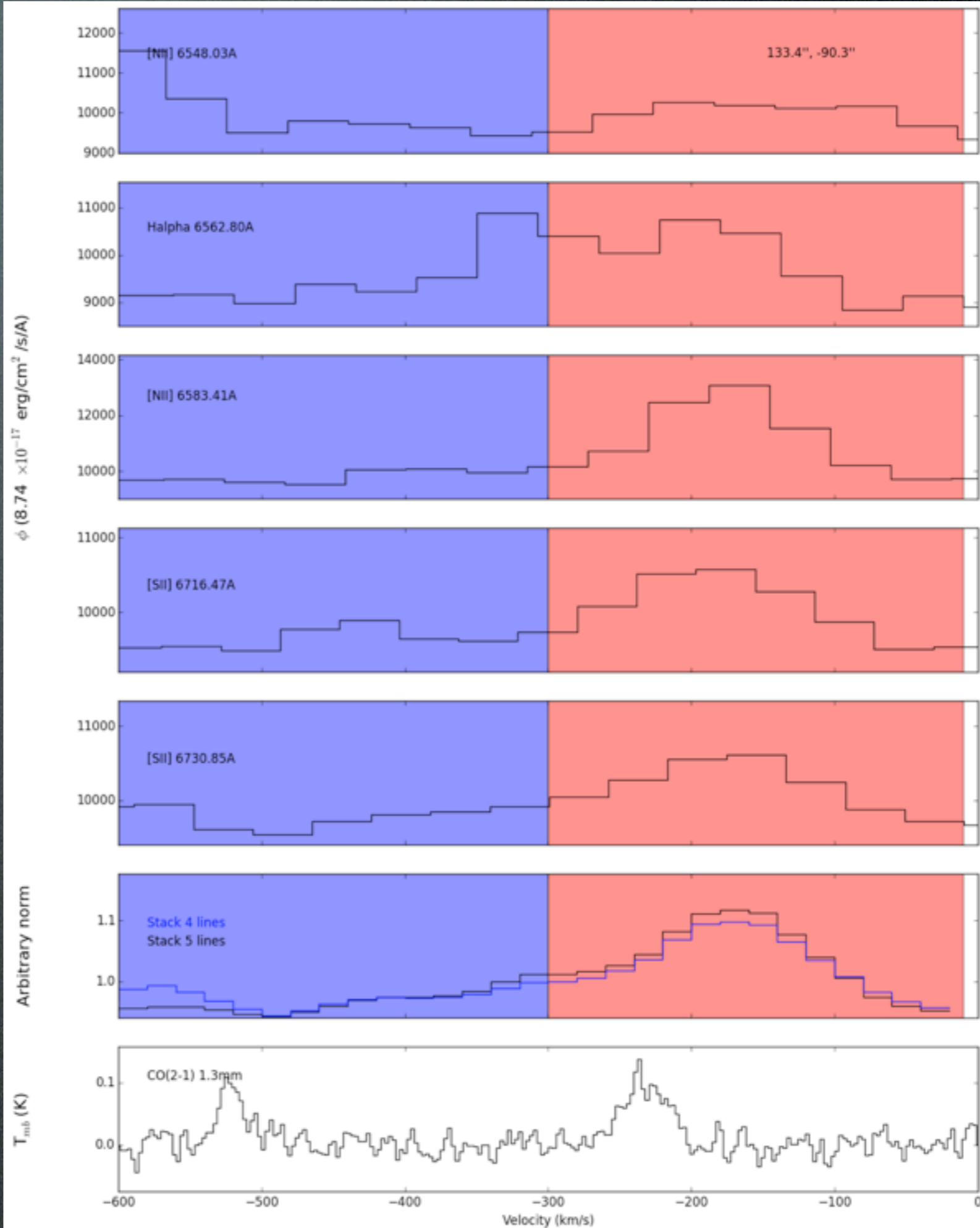
## Halpna:

a component close to systemic velocity

## Halpna, [NII], [SII]:

a red component, marginally compatible with CO(2-1)

CO blue component: not detected.





# Comparison ionised gas with CO(2-1) kinematics

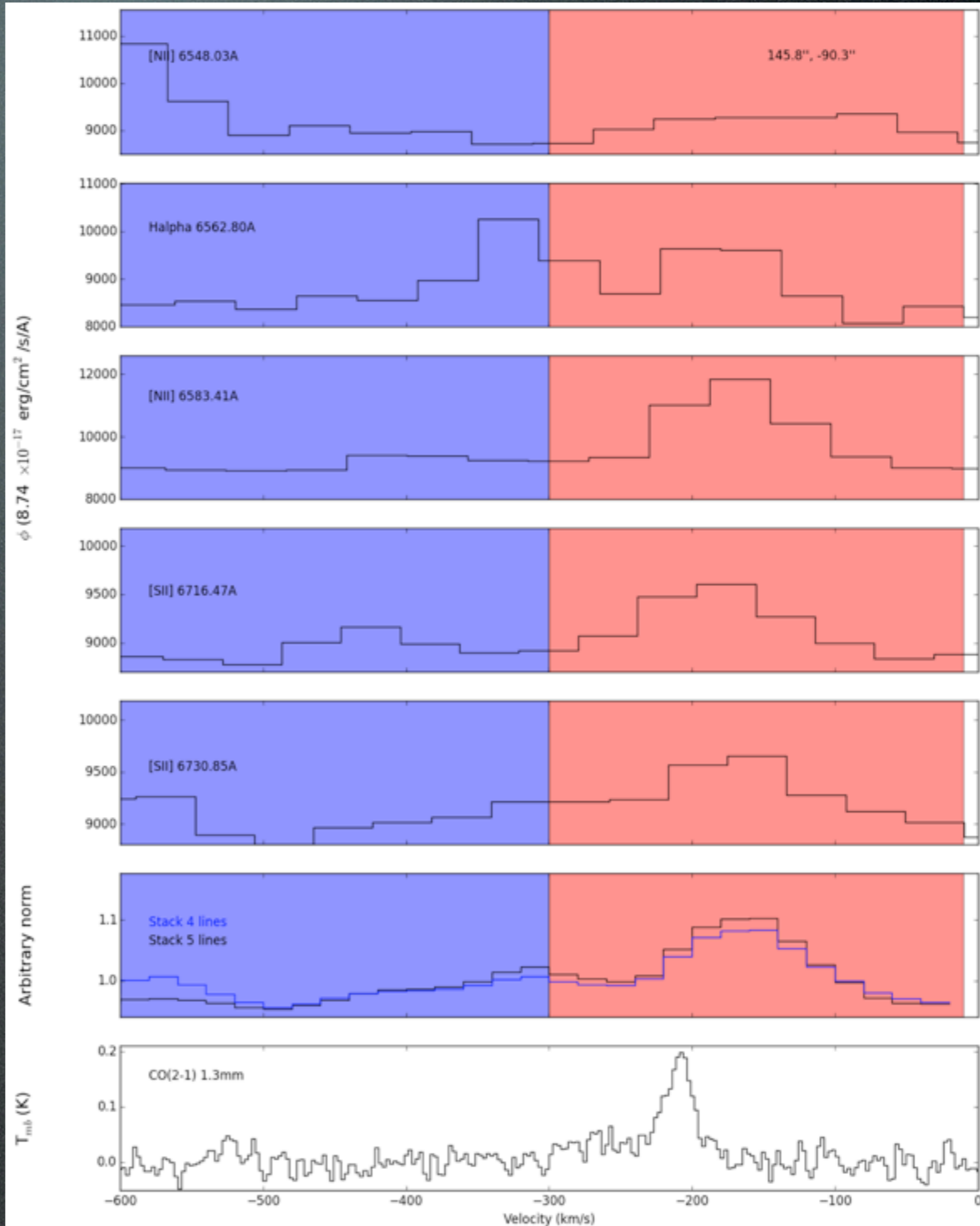
## Minor axis SE

### **Halpha:**

a component close to systemic velocity

### **Halpha, [NII], [SII]:**

a red component, marginally compatible with CO(2-1)





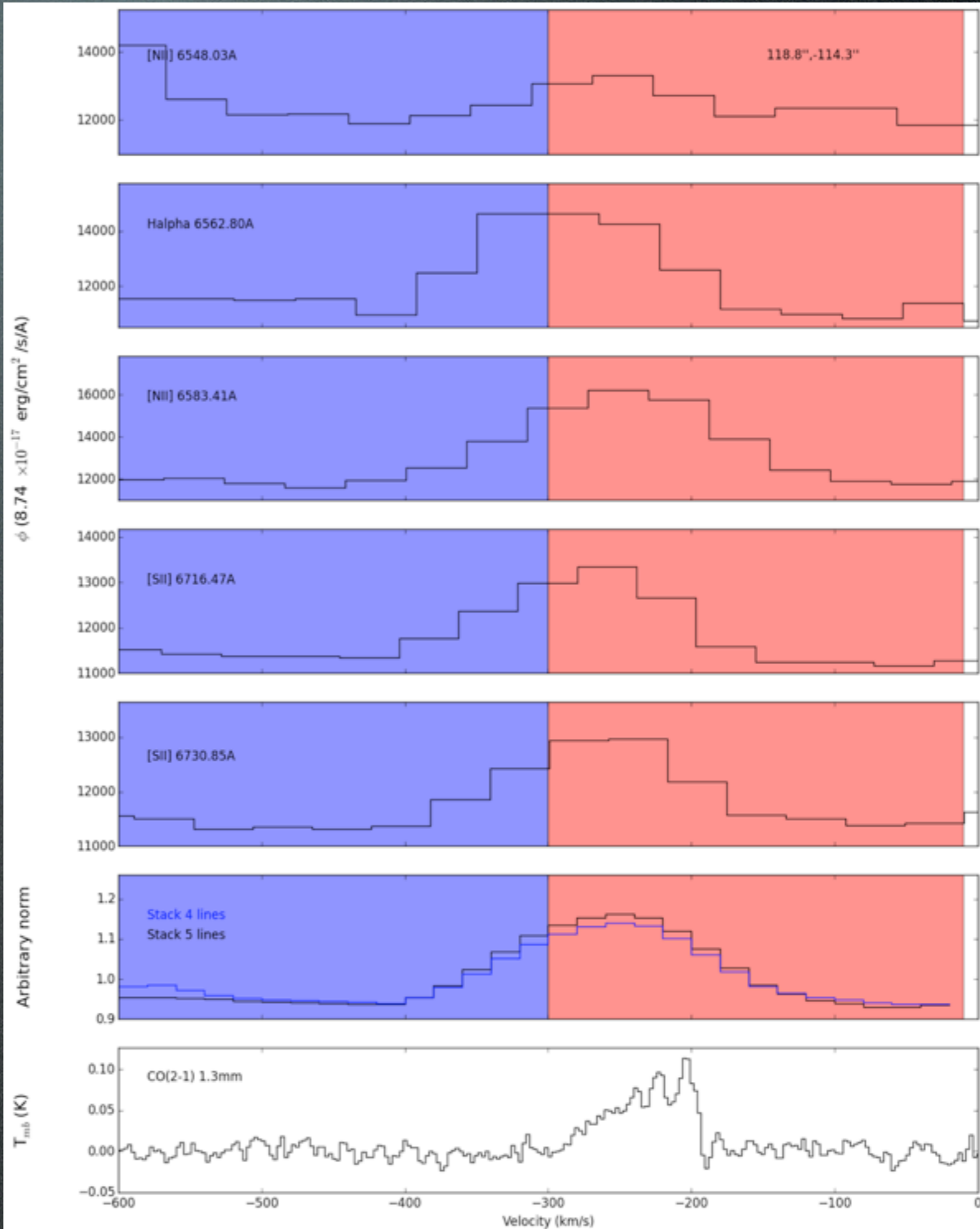
# Comparison ionised gas with CO(2-1) kinematics Minor axis SE

## **Halpha:**

a component close to systemic velocity

## **Halpha, [NII], [SII]:**

a red component, compatible with CO(2-1)





# LINER physics in nearby galaxies

Anne-Laure Melchior

LERMA, UMR8112  
Observatoire de Paris  
Univ. Pierre & Marie Curie

1. LINER classification

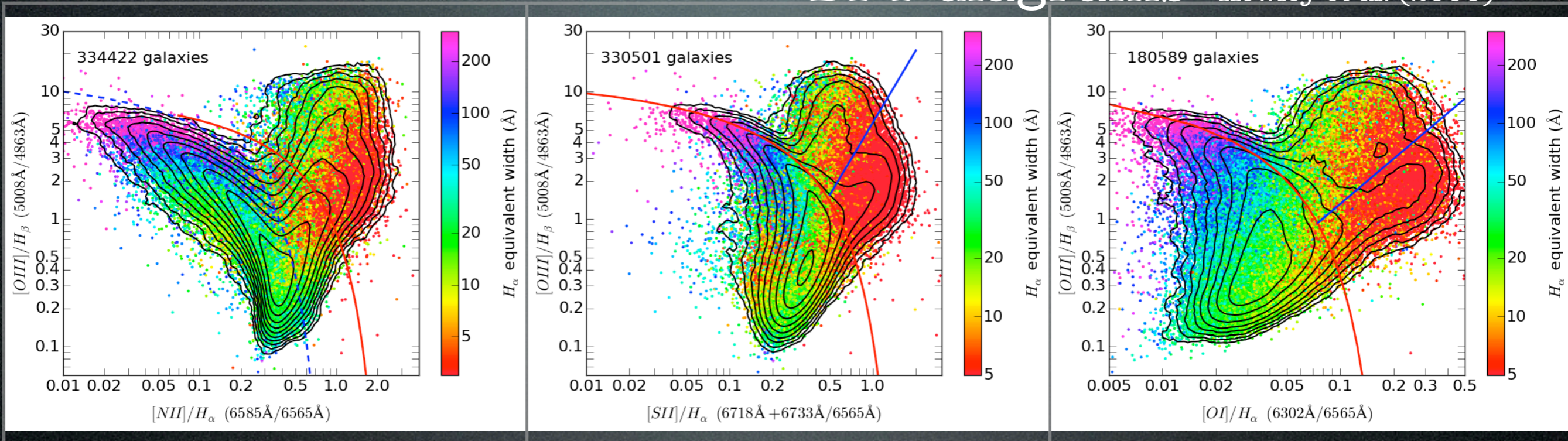
2. Andromeda (CO observations, dense gas, ionised gas)

3. Other cases, NGC 7083



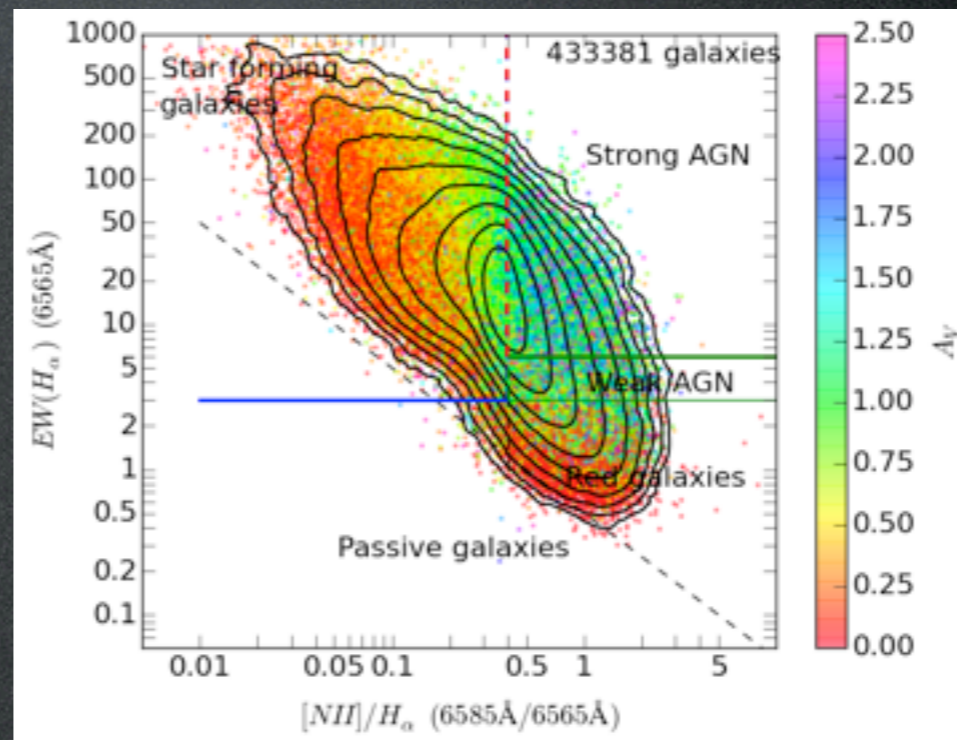
# LINER classification...

## BPT diagrams Kewley et al. (2006)



RCSED A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

## WHAN diagram

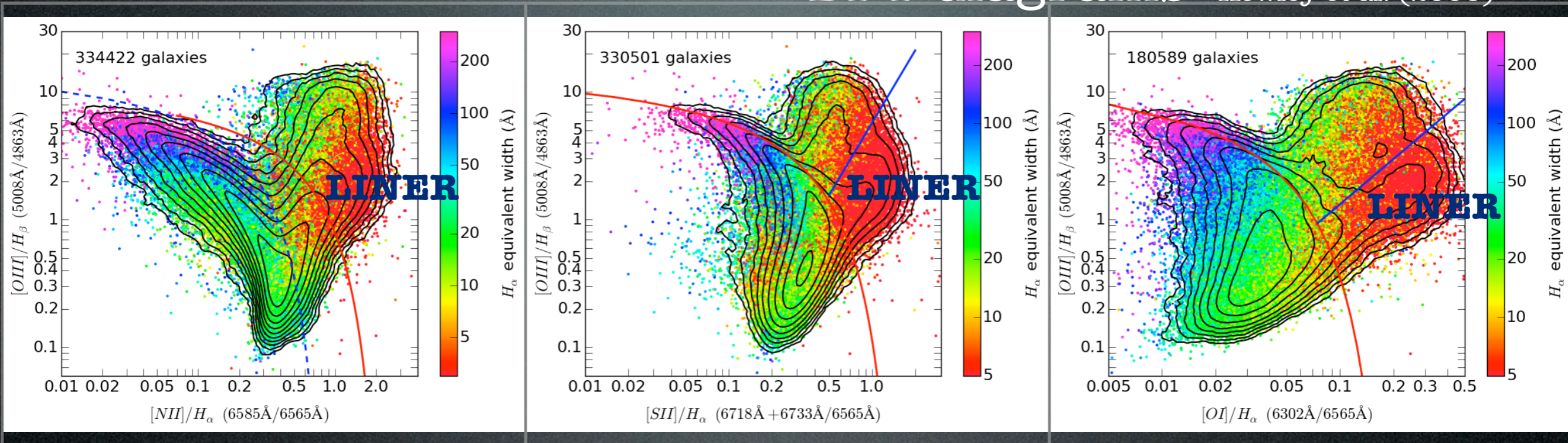


Cid-Fernandes et al. (2011)



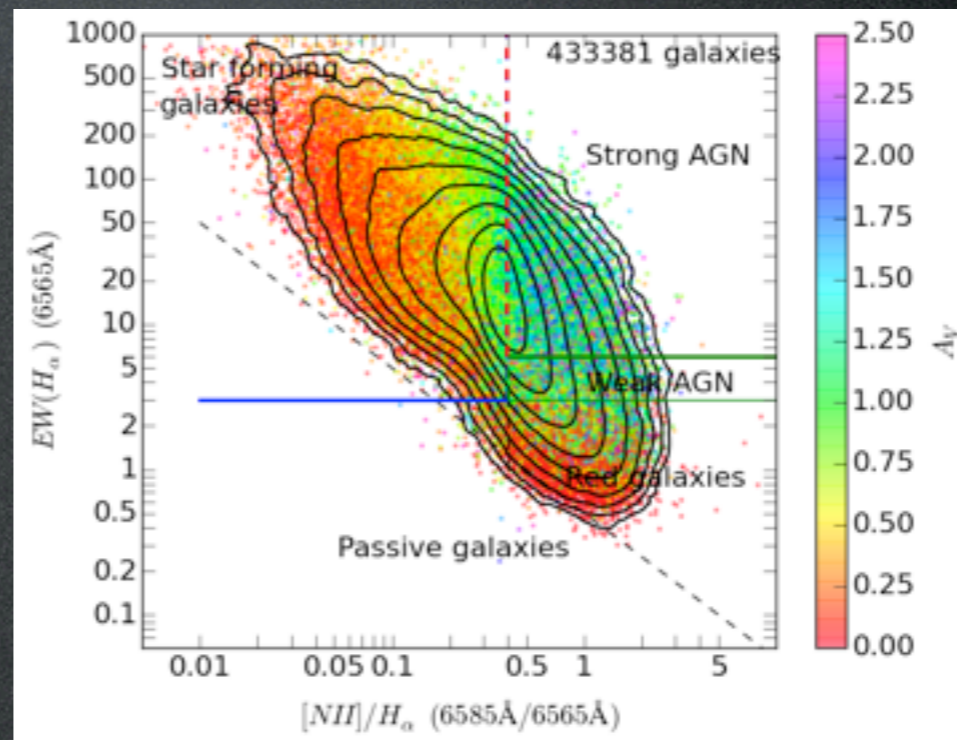
# LINER classification...

## BPT diagrams Kewley et al. (2006)



RCSFD A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

## WHAN diagram

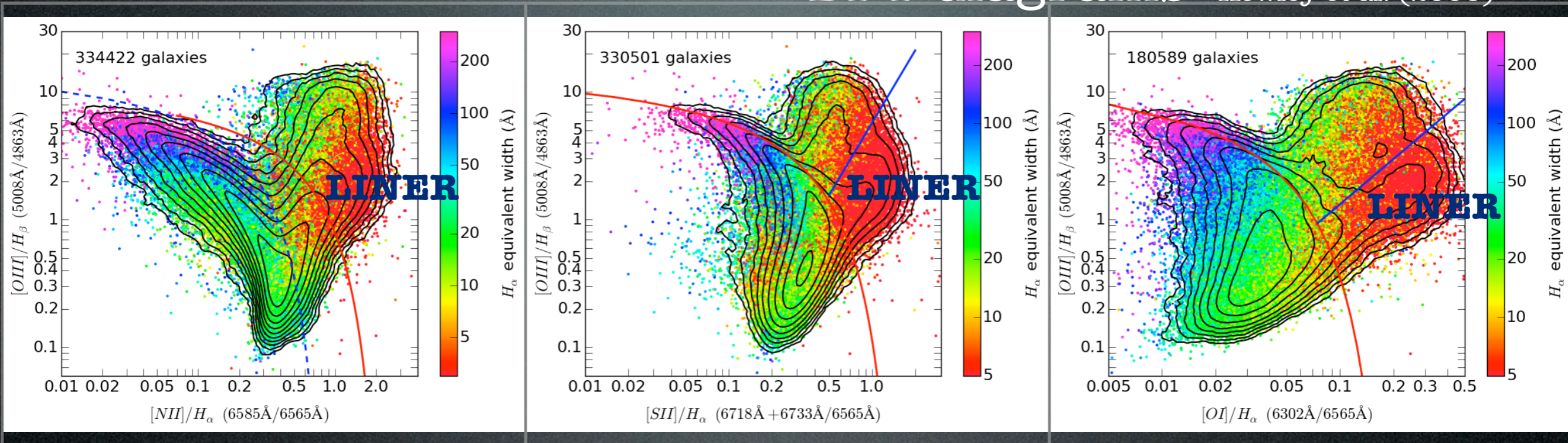


Cid-Fernandes et al. (2011)



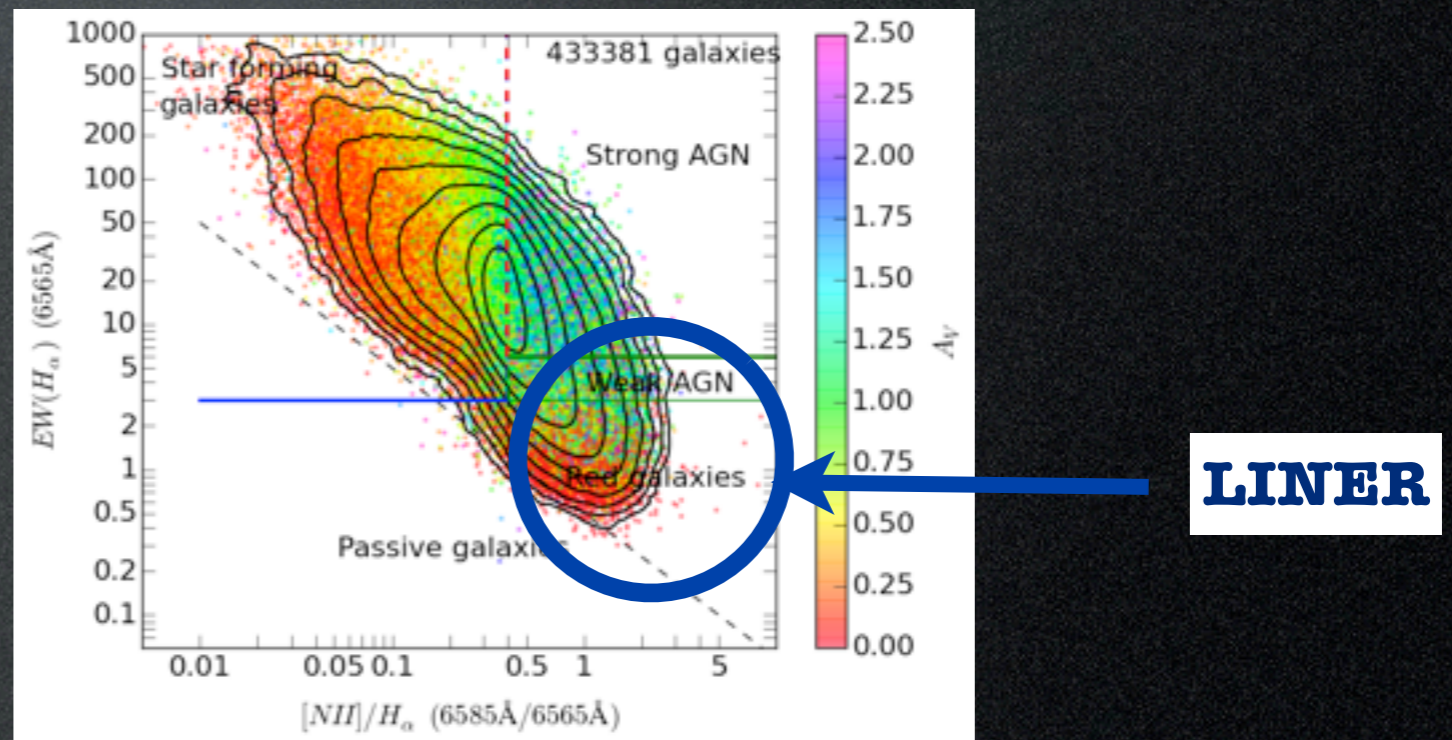
# LINER classification...

## BPT diagrams Kewley et al. (2006)



RCSFD A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

## WHAN diagram

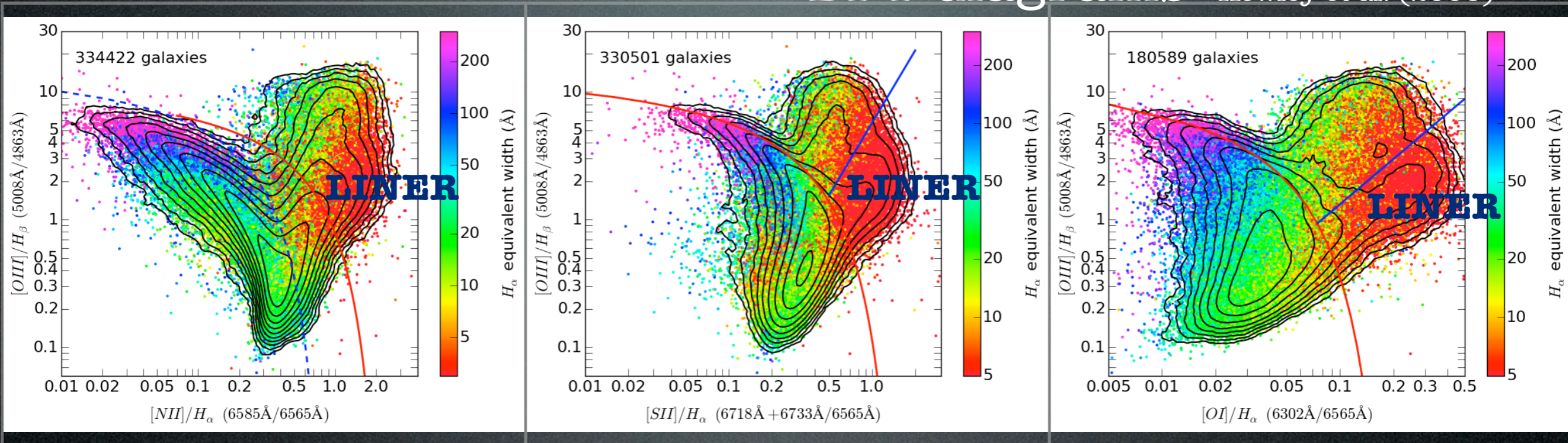


Cid-Fernandes et al. (2011)



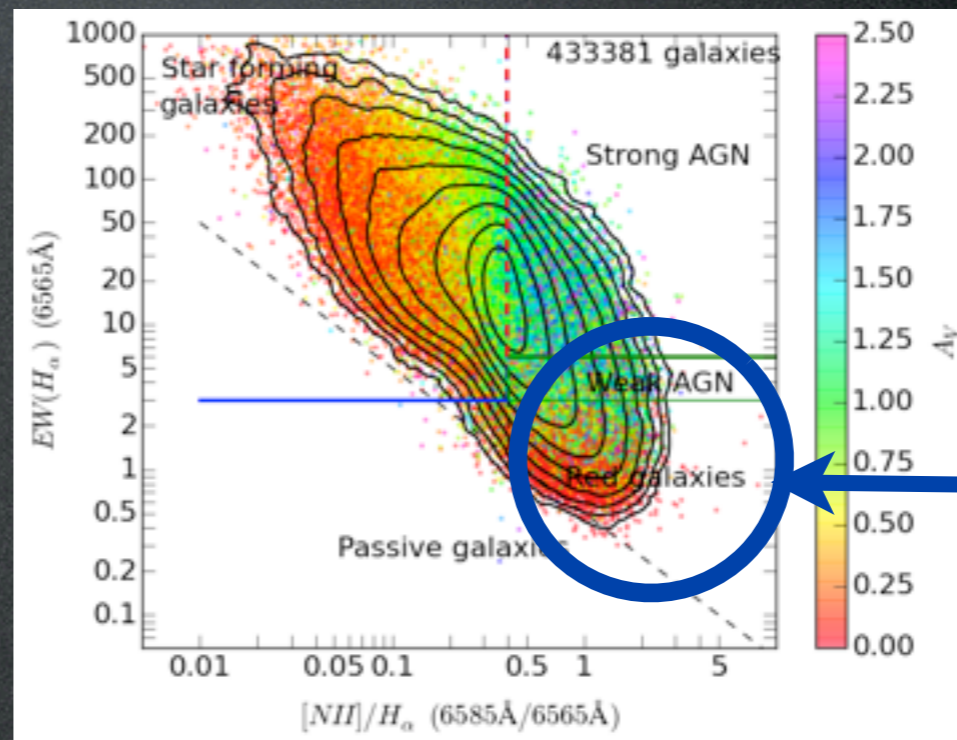
# LINER classification...

BPT diagrams Kewley et al. (2006)



RCSFD A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

WHAN diagram



**LINER**

**HOLMES**

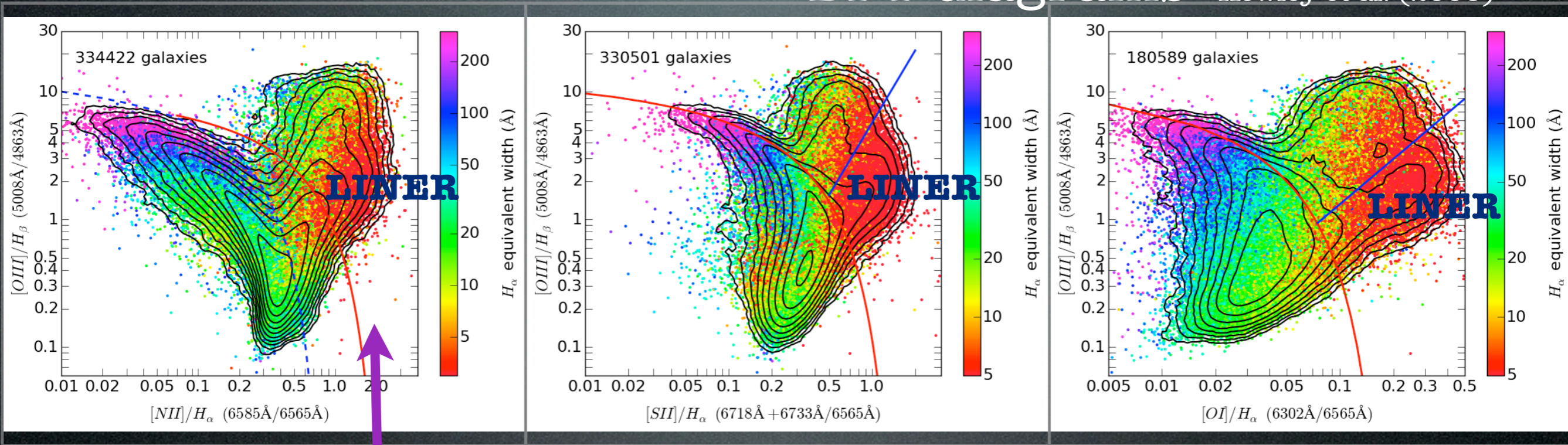
Hot Low-Mass Evolved Stars

Cid-Fernandes et al. (2011)



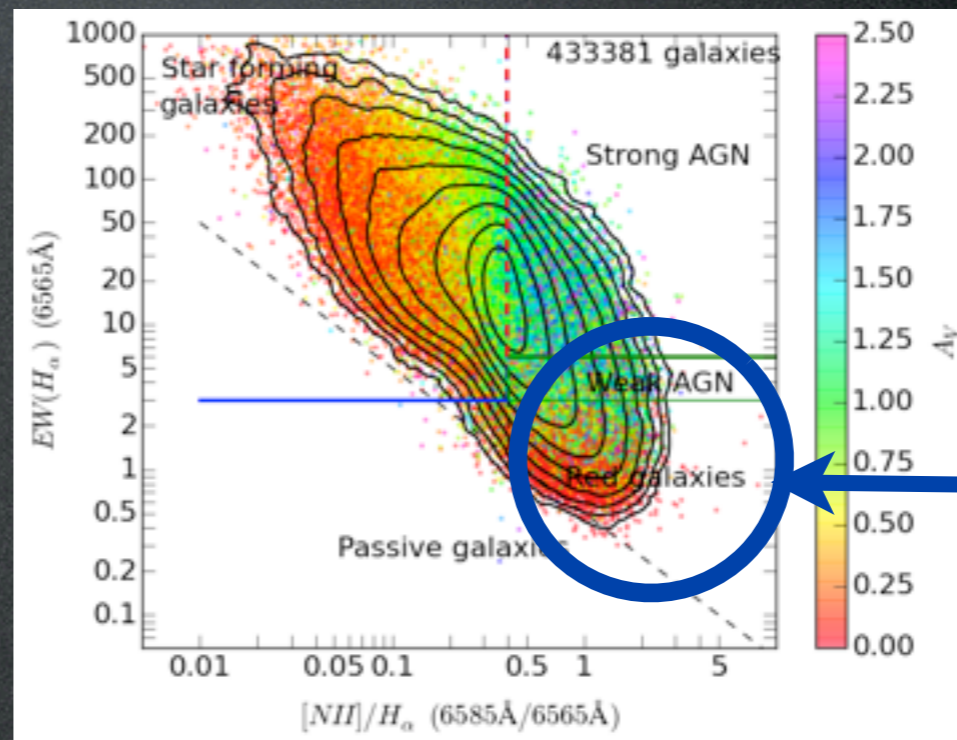
# LINER classification...

## BPT diagrams Kewley et al. (2006)



RCSFD A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

## WHAN diagram



**LINER**

**HOLMES**

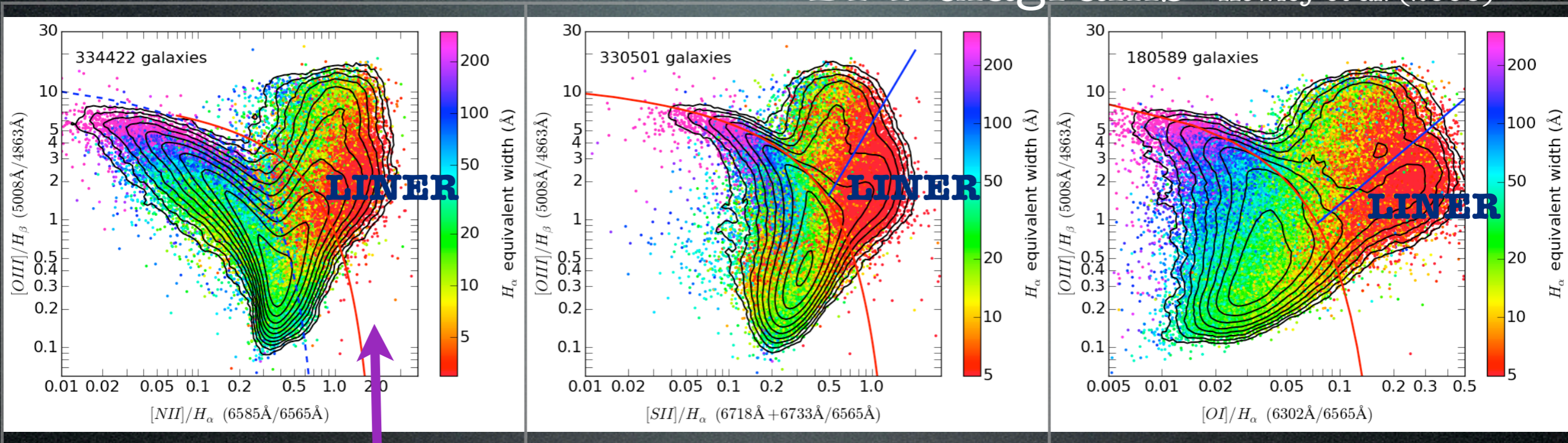
Hot Low-Mass Evolved Stars

Cid-Fernandes et al. (2011)



# LINER classification...

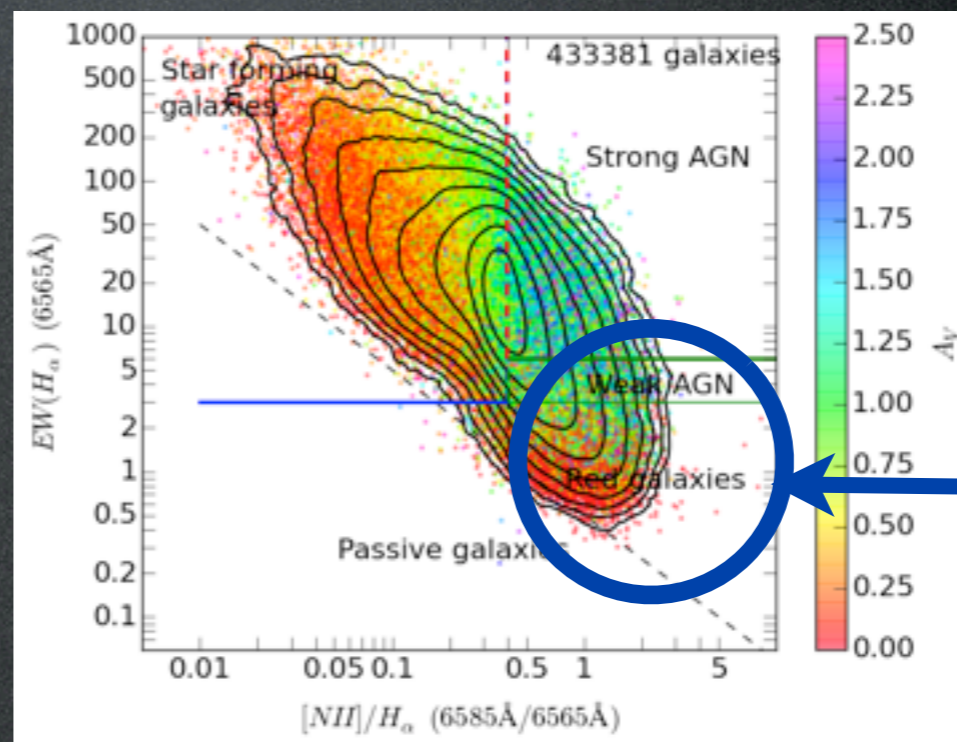
## BPT diagrams Kewley et al. (2006)



M31 bulge  
Rubin & Ford 1971

RCSED A Reference Value-Added Catalogue of Spectral Energy Distributions  
Chilingarian, Zolotukhin, Katkov, Melchior, to be submitted

## WHAN diagram



**LINER**

**HOLMES**

Hot Low-Mass Evolved Stars

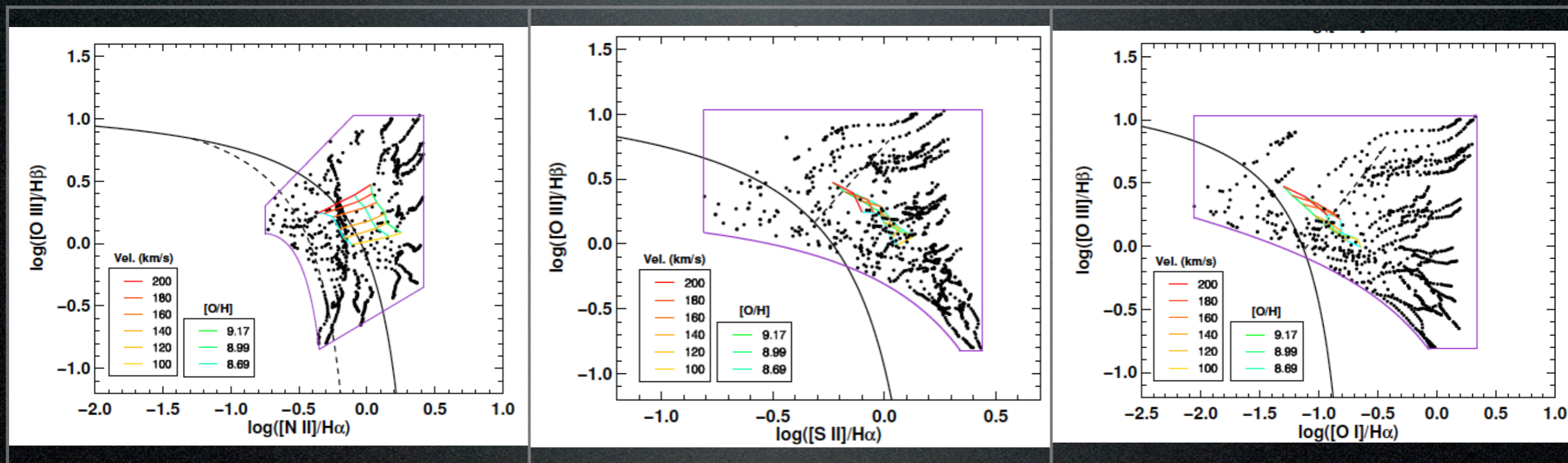
Cid-Fernandes et al. (2011)



# LINER

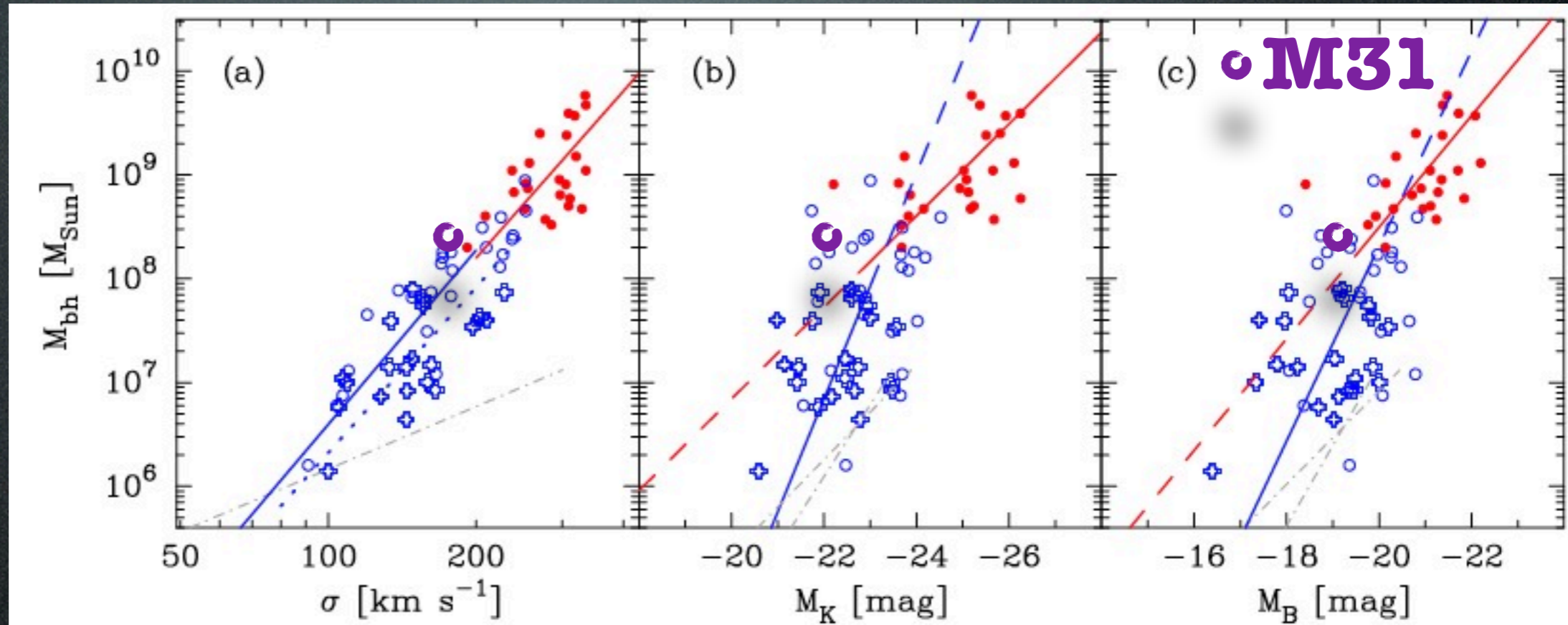
## Low-Ionization Nuclear Emission Region

- Weak AGN
- HOLMES : Hot Low-Mass Evolved Stars
- Also: shocks (e.g. Allen 2008)





# M31: closest low-power end LINER (Heckman 1996)



Graham & Scott 2013

M31\*: Retired AGN

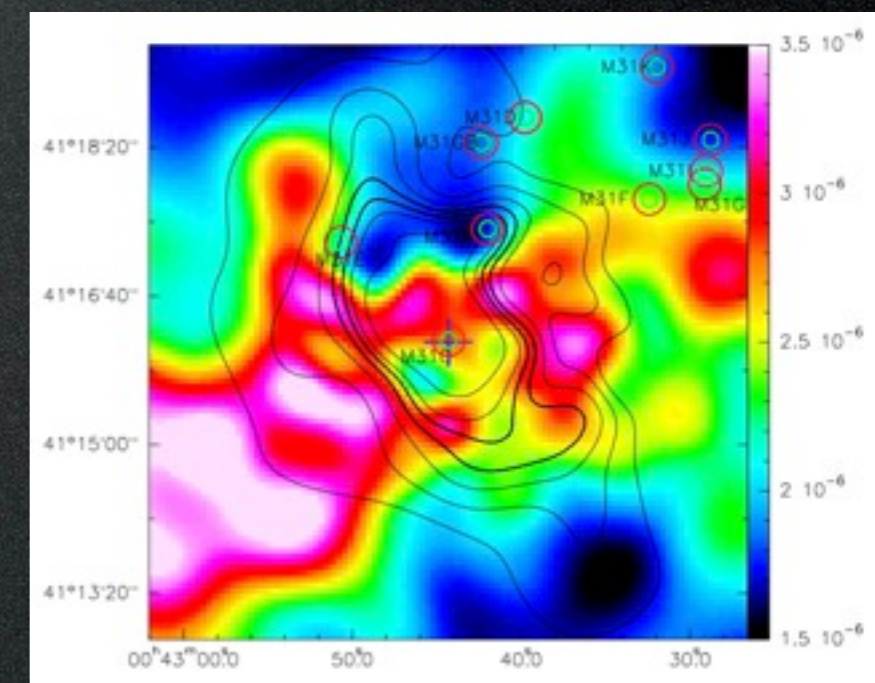
Very massive black hole (Bender et al. 2005)

X-ray source:  $10^{-10} L_{edd}$  with an outburst (x50) in 2006 (Li et al 2011)

+ Diffuse X-ray gas Bogdán & Gilfanov (2008)

+ Diffuse non-thermal radio source Giessübel & Beck (2014)

On the radio-FIR correlation (Walterbos & Graeve 1985)



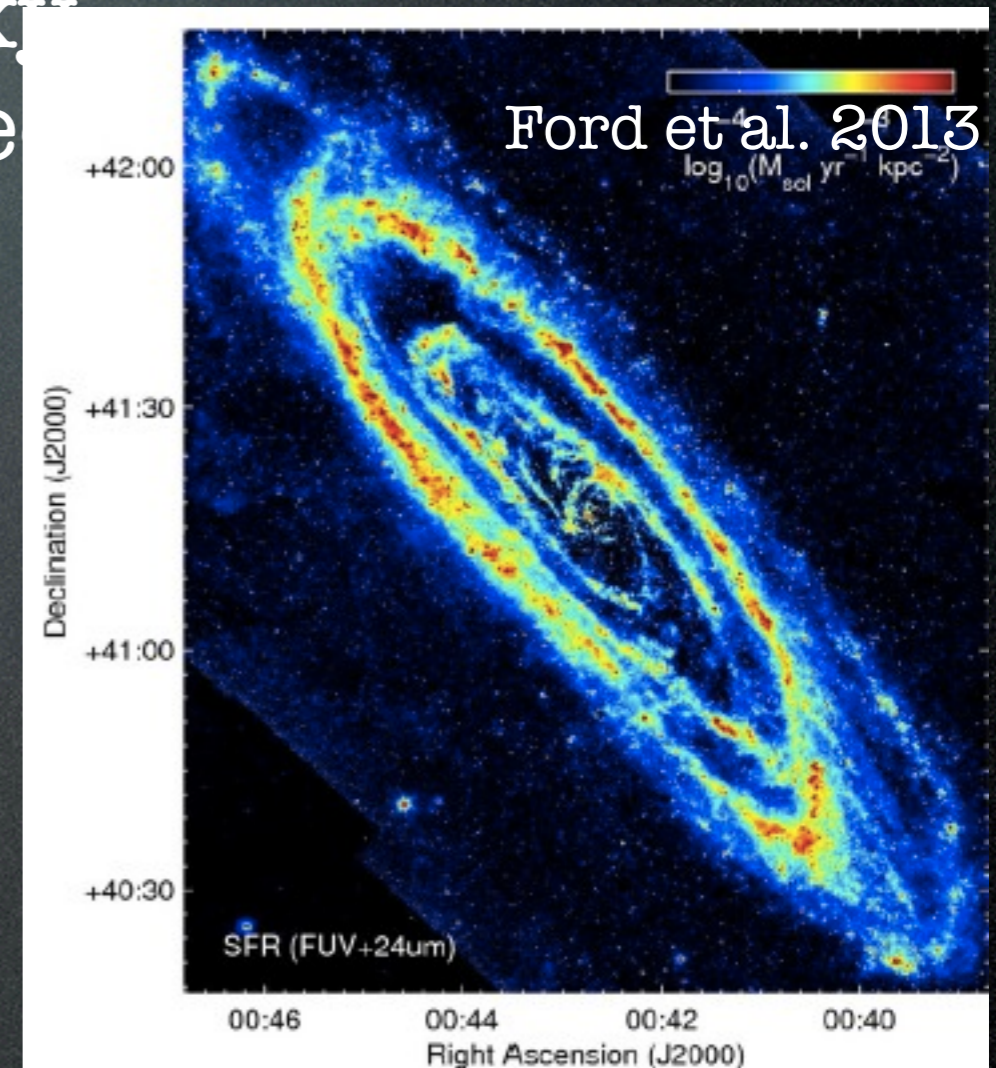
Bogdán & Gilfanov (2008)



# Very little star formation in this large disc galaxy

$0.25^{+0.06}_{-0.04}$  Msol/year in the galaxy,  
as a whole mainly concentrated  
in the main disc

**Next to the black hole: A-star cluster,**  
tracer of «recent star formation»  
(**200 Myr old,  $10^{4-6}$  Msol**); Lauer+ 1993,  
Kormendy+ 1999, Bender 2005



**Mummr of the black hole:** gas infall? (Li+ 2011)

**Could be closed to a post-starburst....**



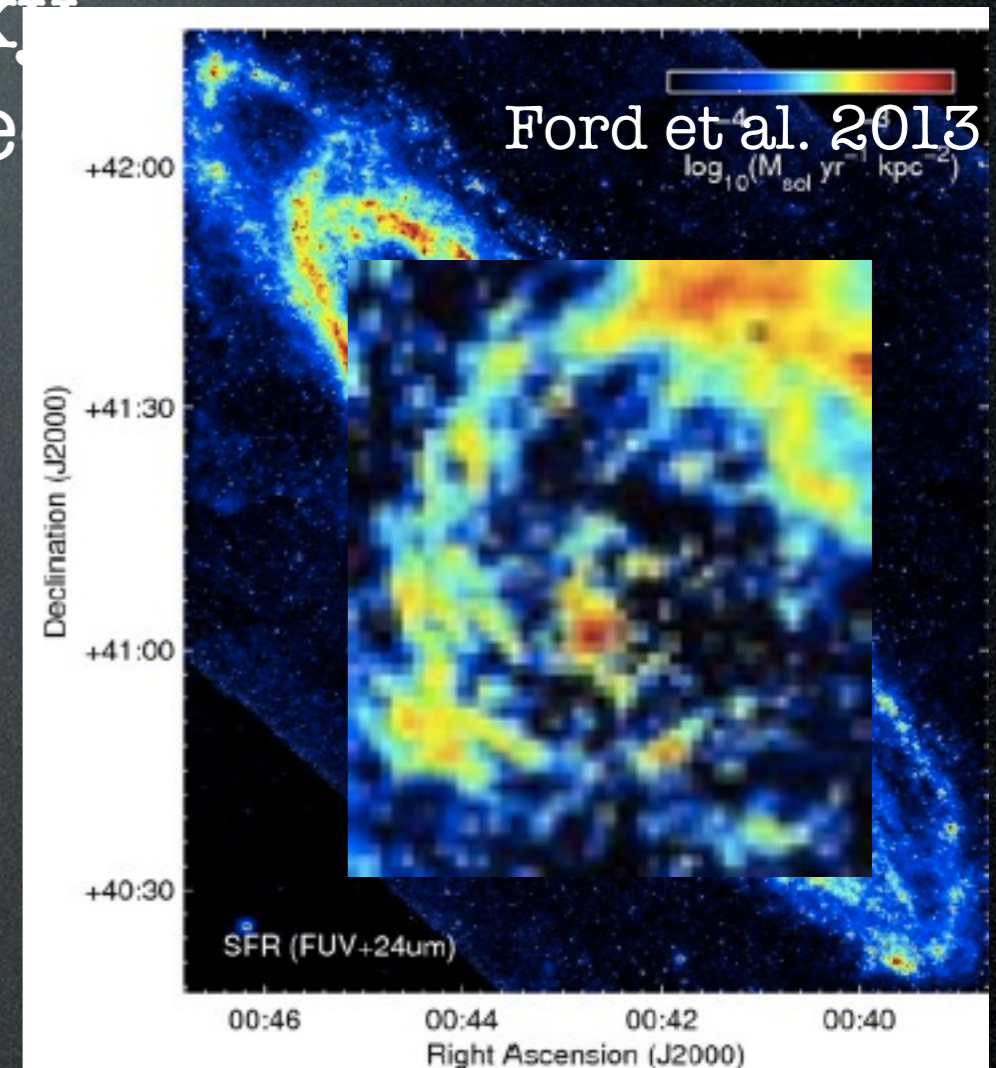
# Very little star formation in this large disc galaxy

$0.25^{+0.06}_{-0.04}$  Msol/year in the galaxy,  
as a whole mainly concentrated  
in the main disc

**Next to the black hole: A-star cluster,**  
tracer of «recent star formation»  
(**200 Myr old,  $10^{4-6}$  Msol**); Lauer+ 1993,  
Kormendy+ 1999, Bender 2005

**Mummr of the black hole:** gas infall? (Li+ 2011)

**Could be closed to a post-starburst....**



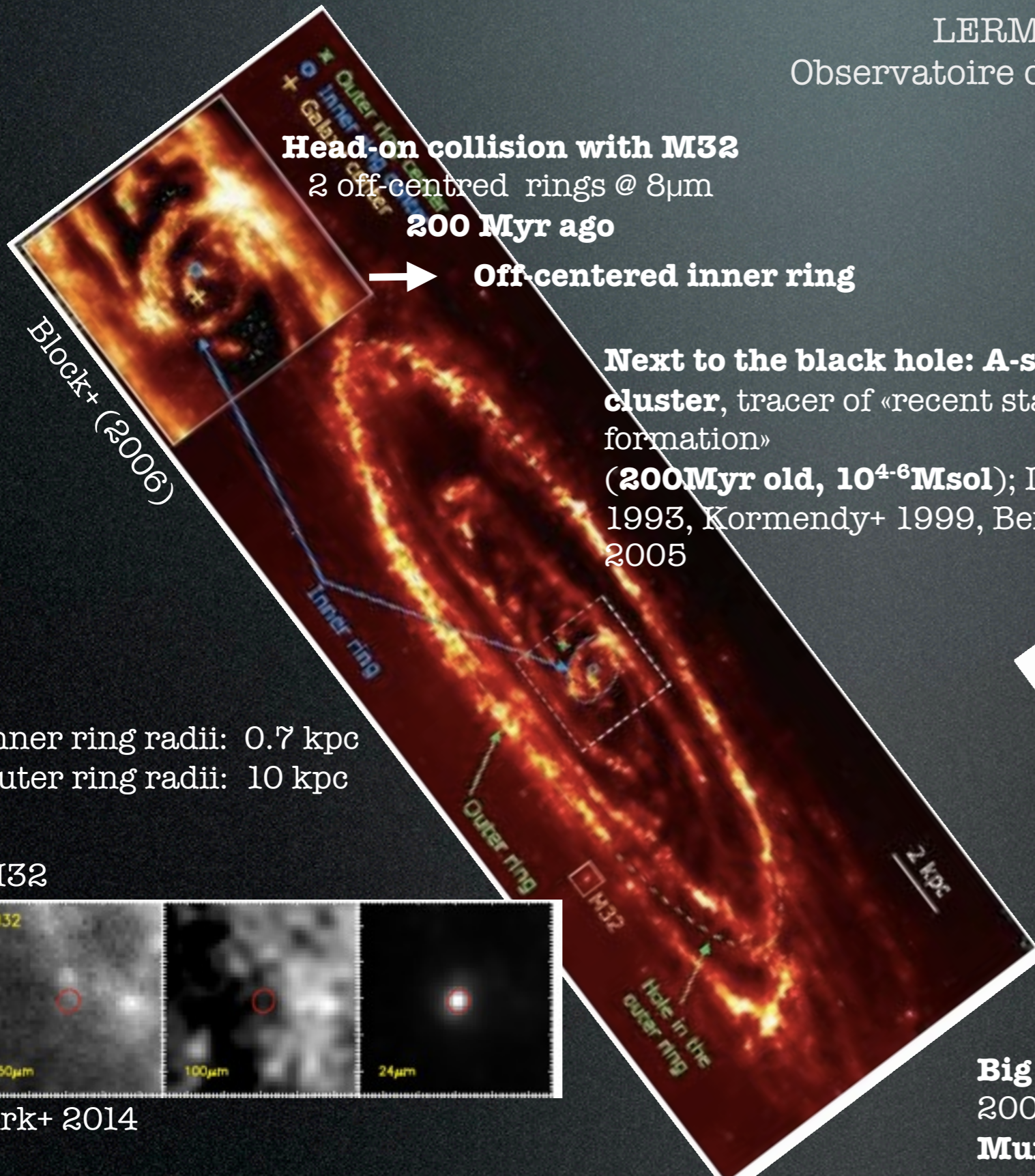


# Multi-spin gas in Andromeda's bulge

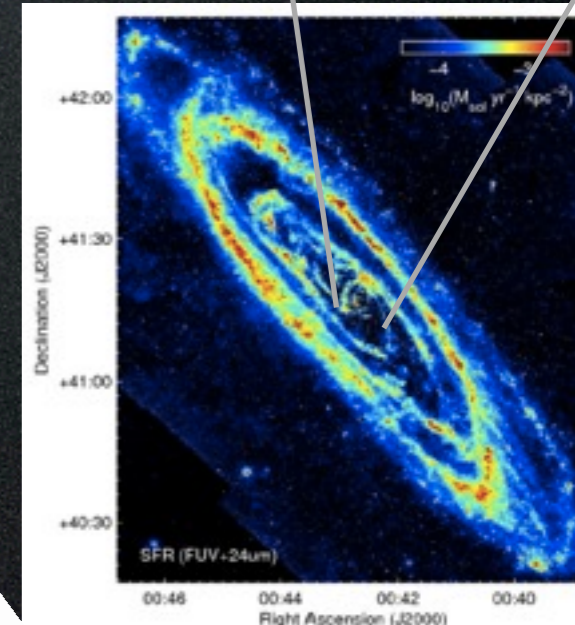
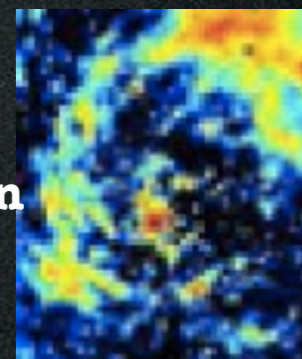
**Anne-Laure Melchior, Françoise Combes**

LERMA, UMR8112, Paris, France

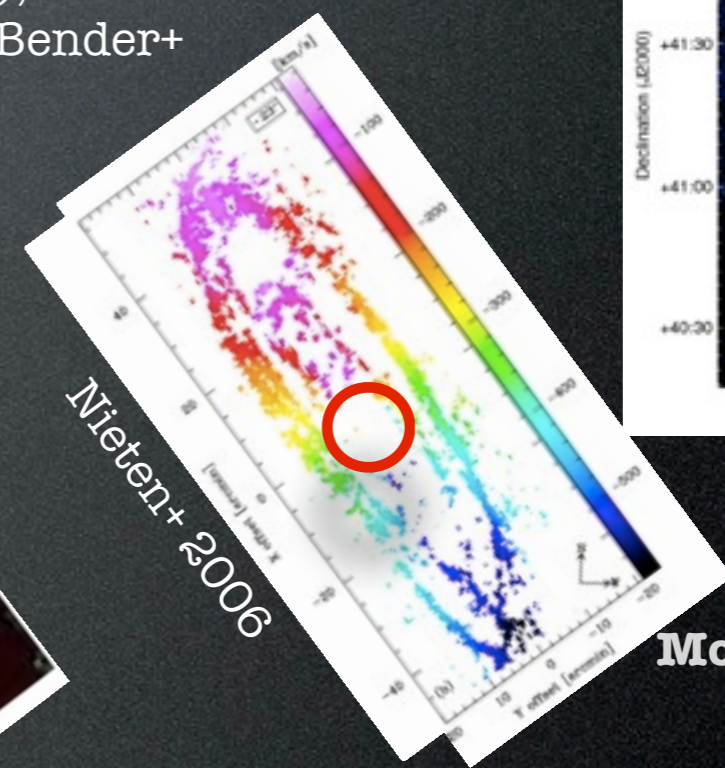
Observatoire de Paris, Univ. Pierre & Marie Curie



**Very little star formation**  
SFR=0.25<sup>+0.06</sup> Msol/year



Ford+ 2013



**Molecular gas CO**

**Big quiet black hole: 0.7-1.4 10<sup>8</sup> M<sub>sol</sub>!** (Bacon+ 2001, Bender+ 2005)

**Mummr of the black hole: gas infall?** (Li+ 2011)

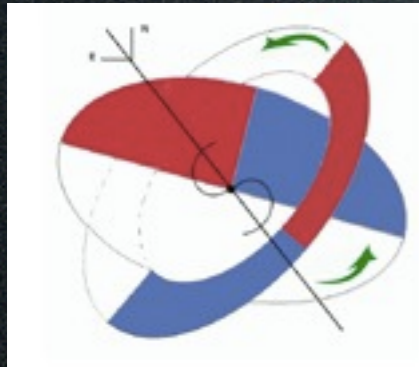


# Multi-spin gas in Andromeda's bulge

Anne-Laure Melchior, Françoise Combes

LERMA, UMR8112, Paris, France

Observatoire de Paris, Univ. Pierre & Marie Curie



Head-on collision with M32

2 off-centred rings @ 8μm

200 Myr ago

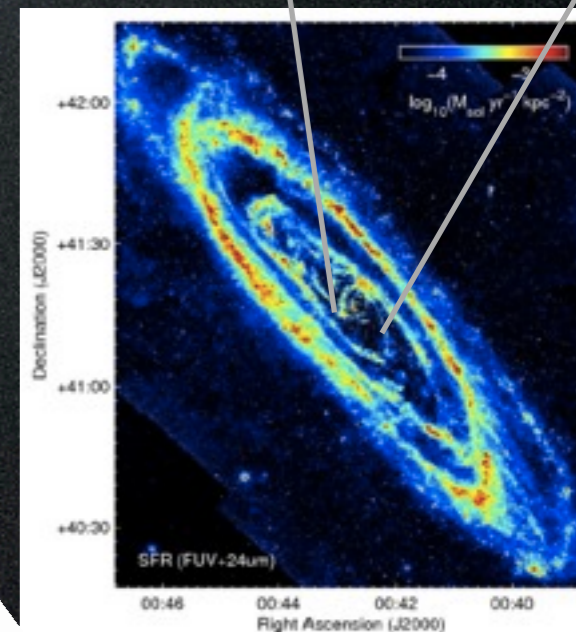
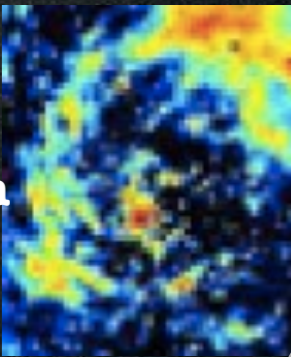
Off-centered inner ring

Next to the black hole: A-star cluster, tracer of «recent star formation»

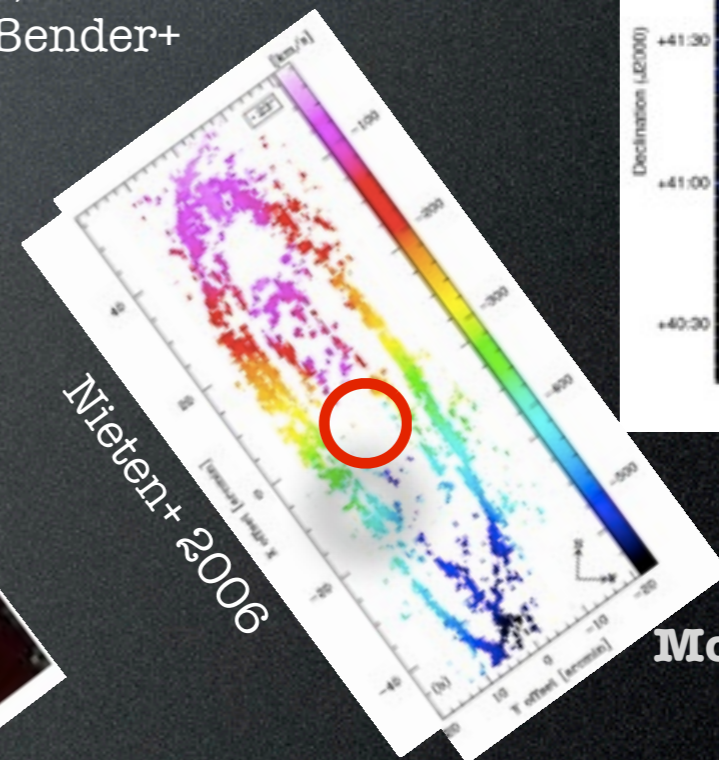
(200 Myr old,  $10^{4-6} M_{\text{sol}}$ ); Lauer+ 1993, Kormendy+ 1999, Bender+ 2005

Very little star formation

SFR =  $0.25^{+0.06} M_{\text{sol}}/\text{year}$



Ford+ 2013



Molecular gas CO

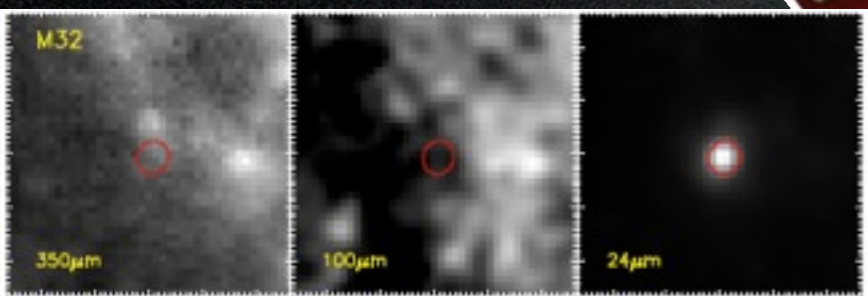
Big quiet black hole:  $0.7-1.4 \cdot 10^8 M_{\text{sol}}$ ! (Bacon+ 2001, Bender+ 2005)

Mummr of the black hole: gas infall? (Li+ 2011)

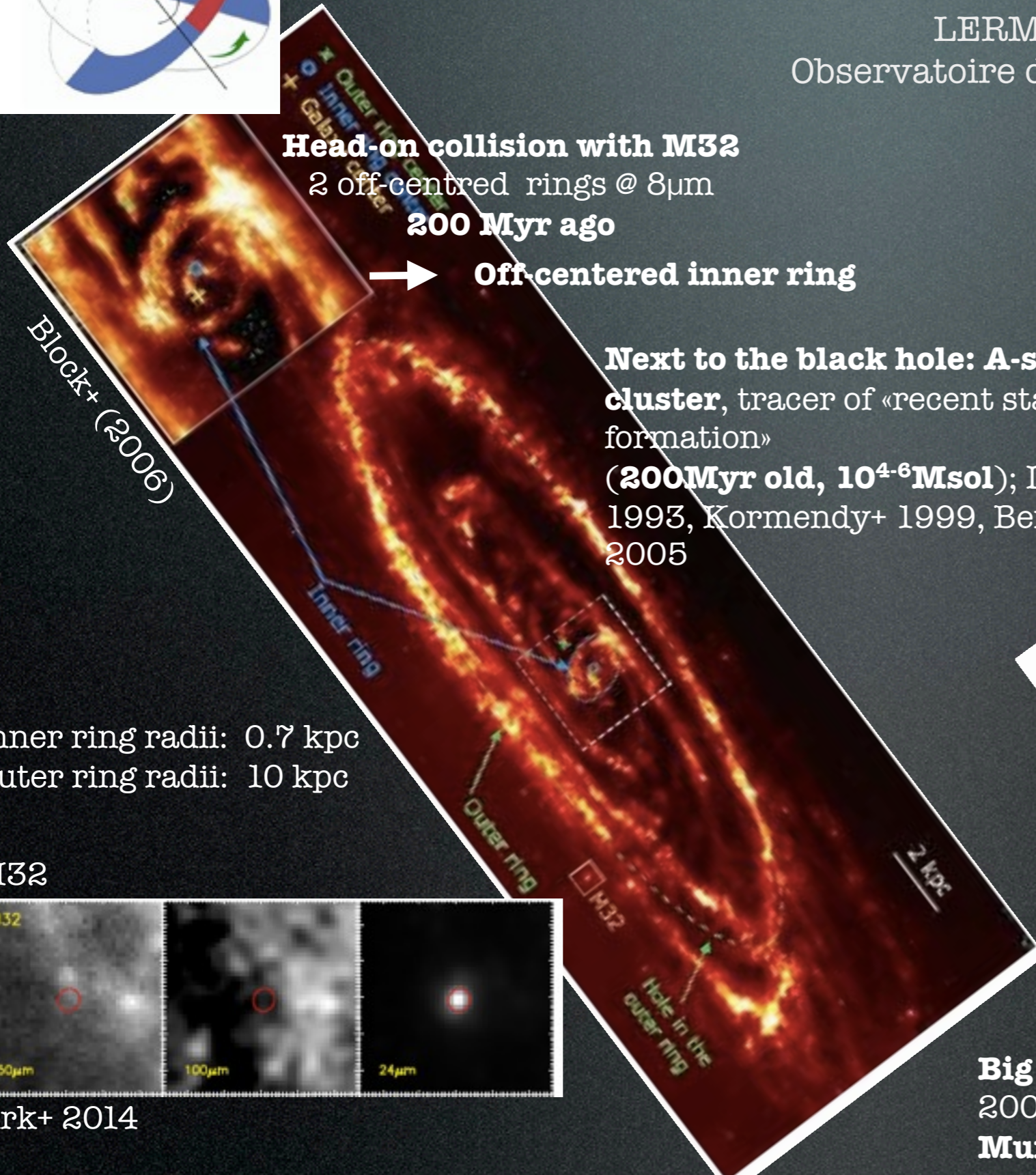
Inner ring radii: 0.7 kpc

Outer ring radii: 10 kpc

M32



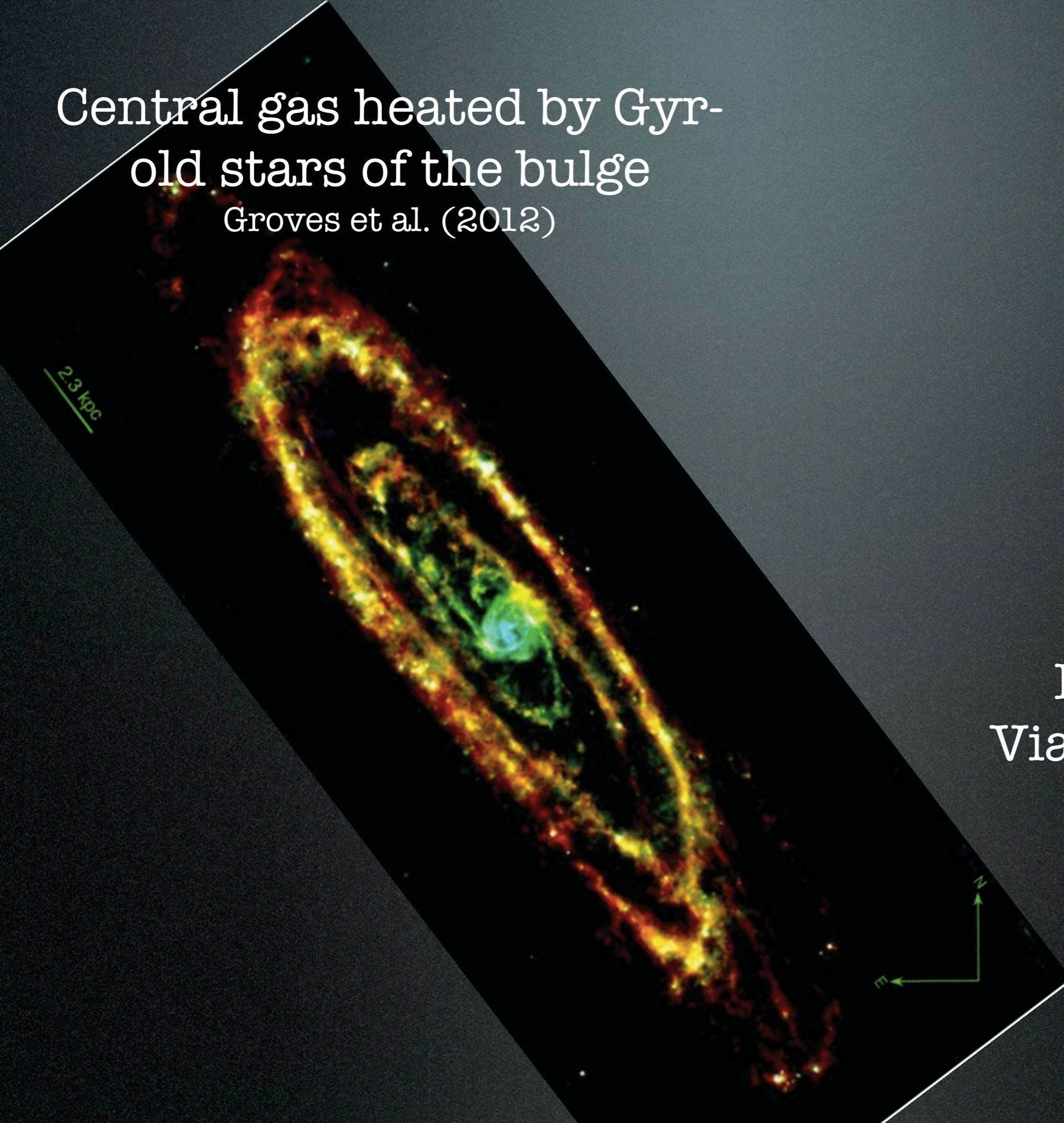
Kirk+ 2014





Central gas heated by Gyr-  
old stars of the bulge

Groves et al. (2012)

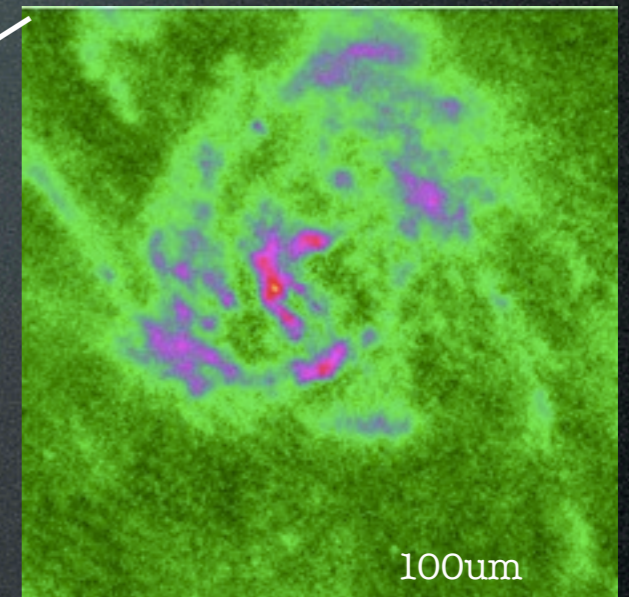
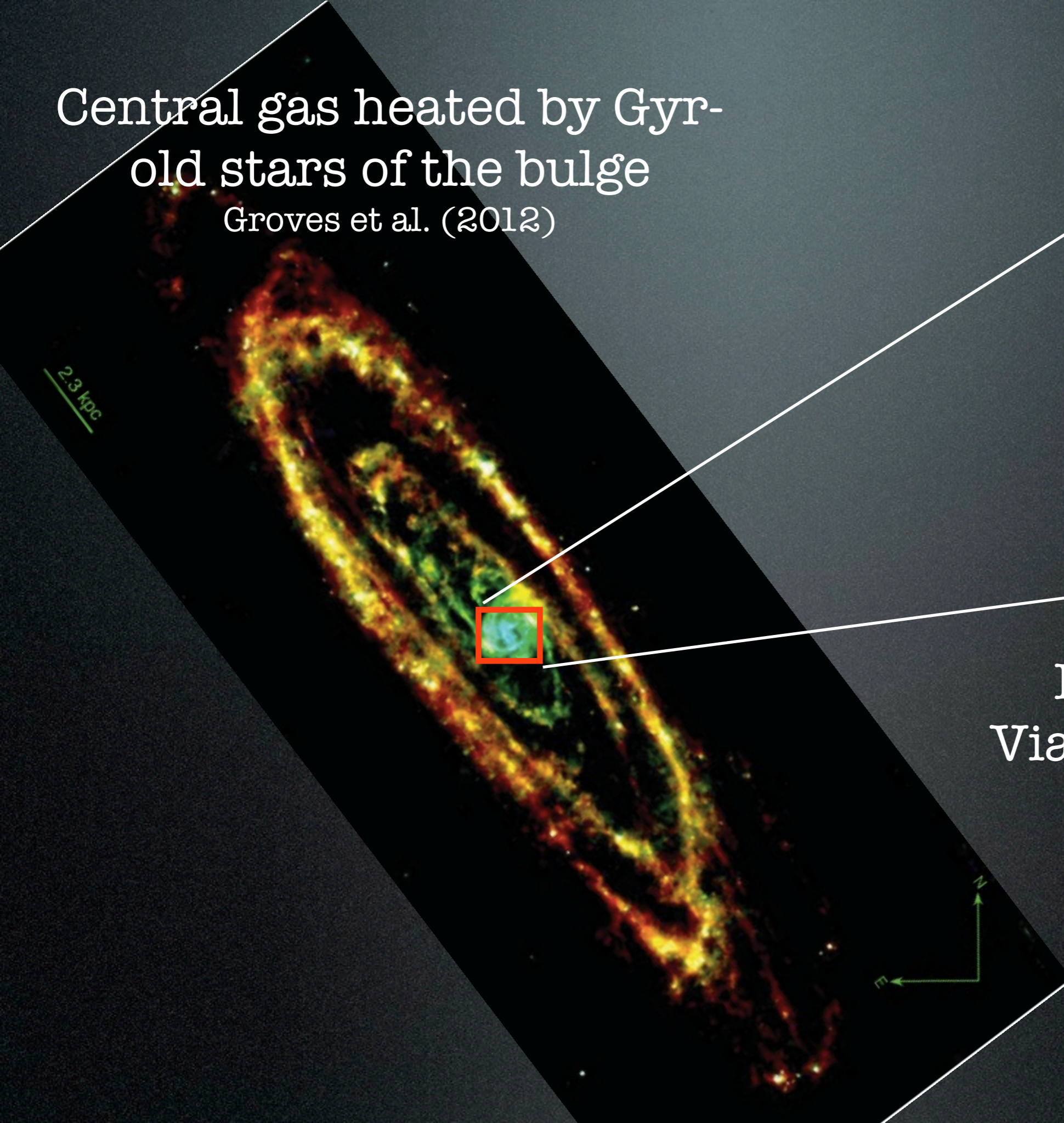


Herschel data  
Viaeney et al. 2014



# Central gas heated by Gyr-old stars of the bulge

Groves et al. (2012)

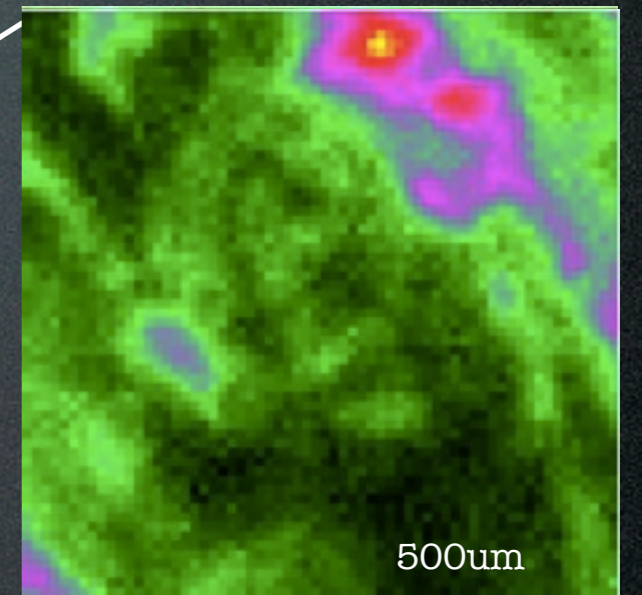
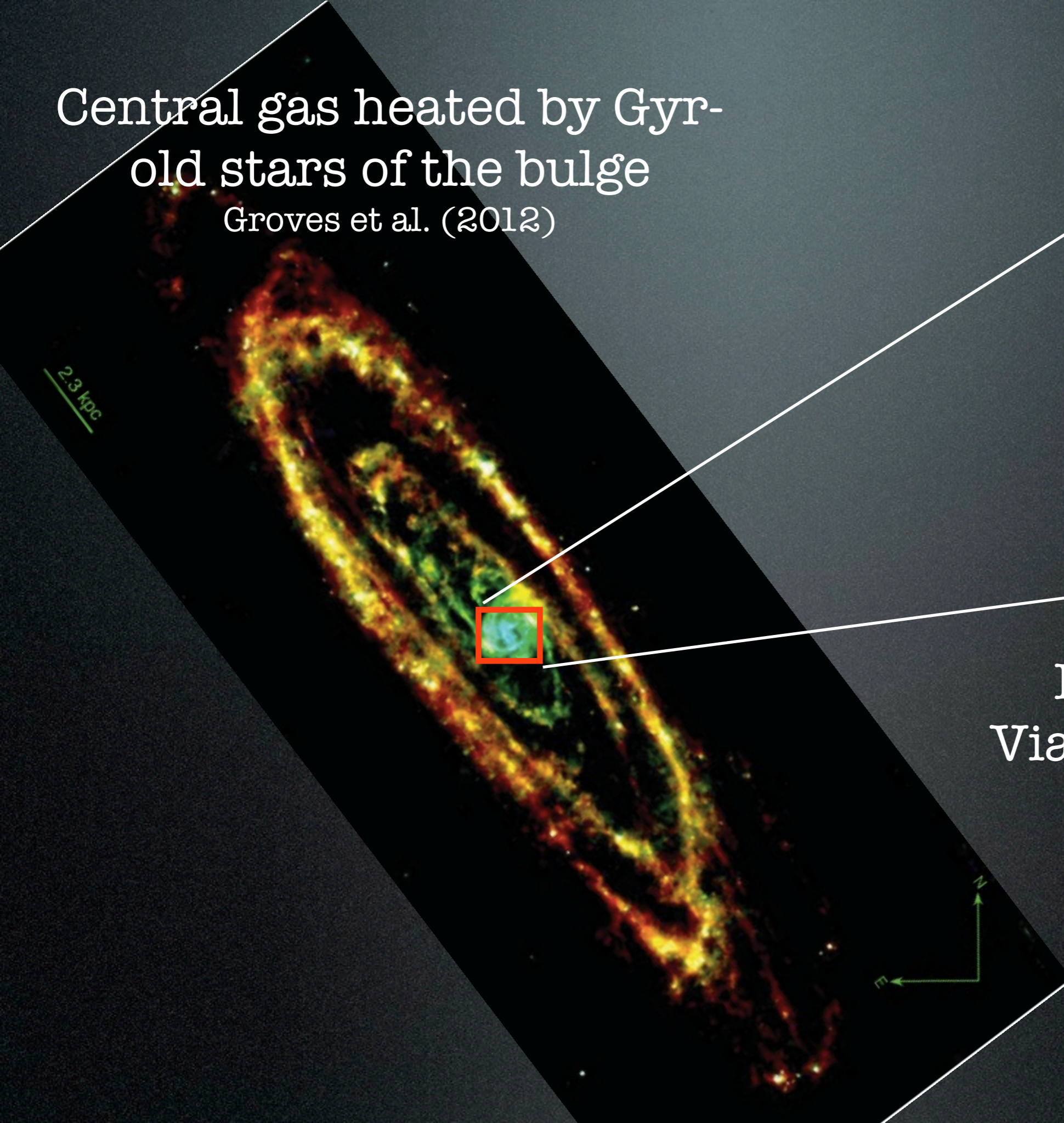


Herschel data  
Viaeney et al. 2014



# Central gas heated by Gyr-old stars of the bulge

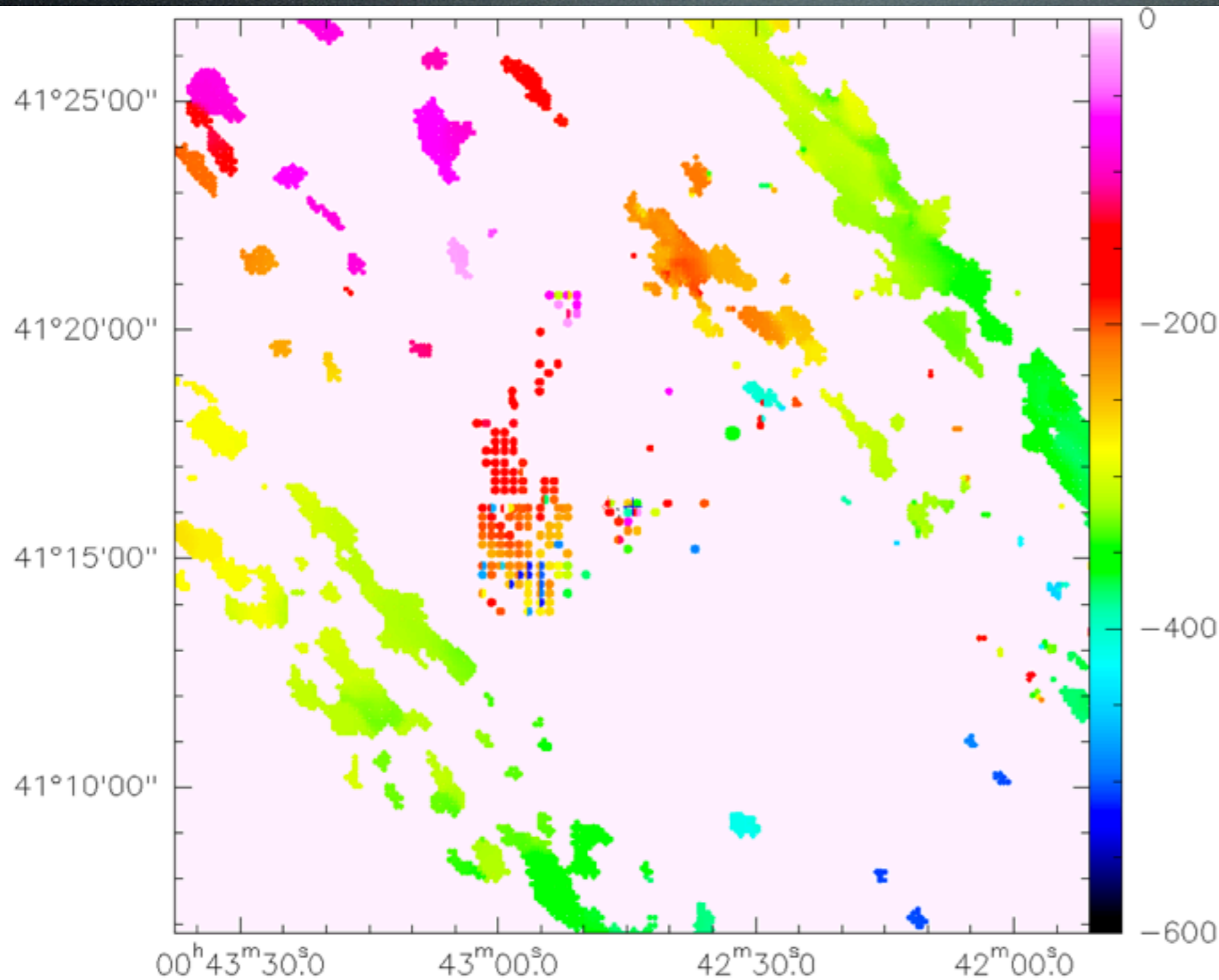
Groves et al. (2012)



Herschel data  
Viaeney et al. 2014



# CO velocity field in the central field IRAM surveys



Nieten et al. (2006)  
M. Guélin's courtesy

Melchior & Combes, in prep.

20' x 20'

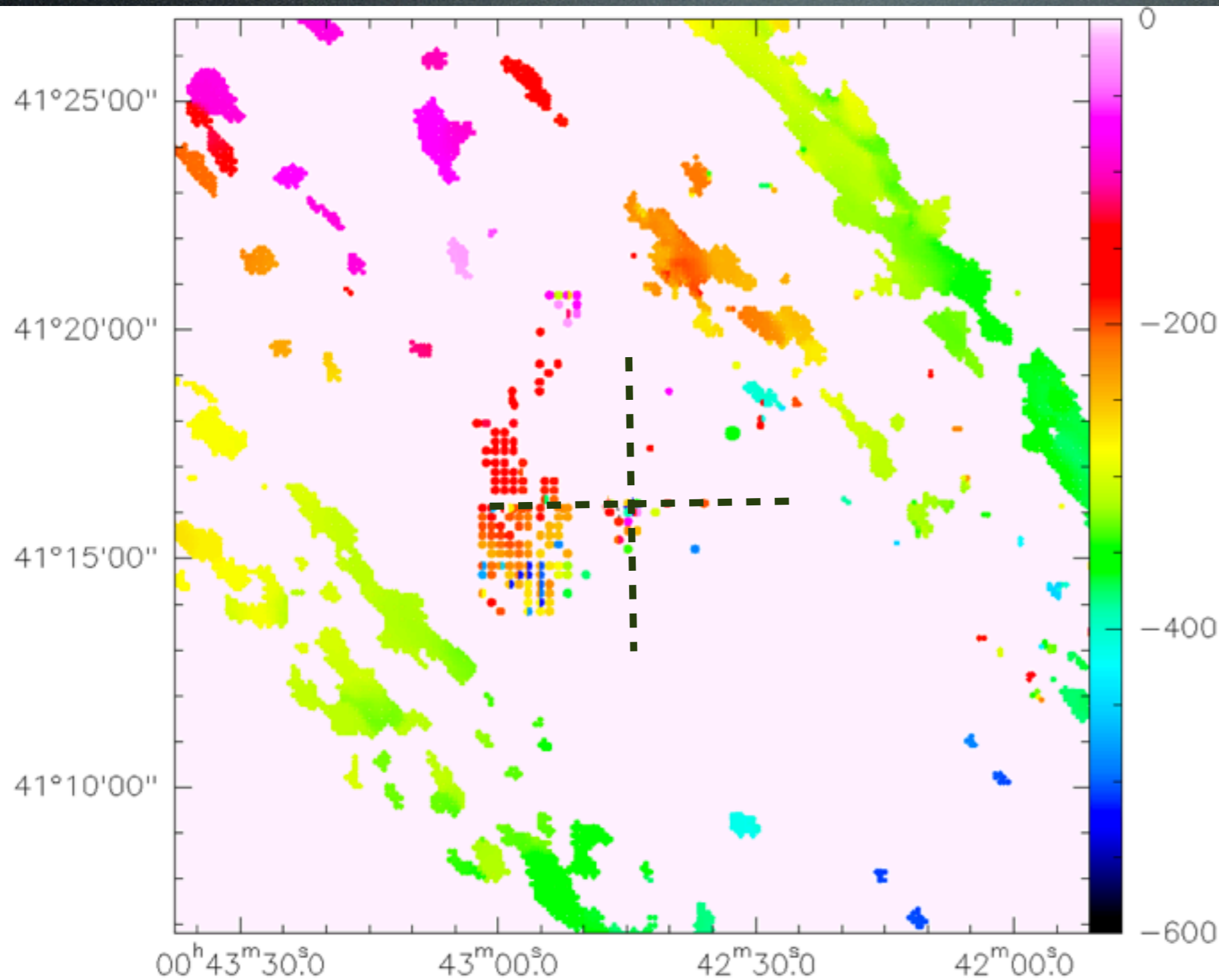
--

4.5 kpc x 4.5 kpc

*Work in progress*



# CO velocity field in the central field IRAM surveys



Nieten et al. (2006)  
M. Guélin's courtesy

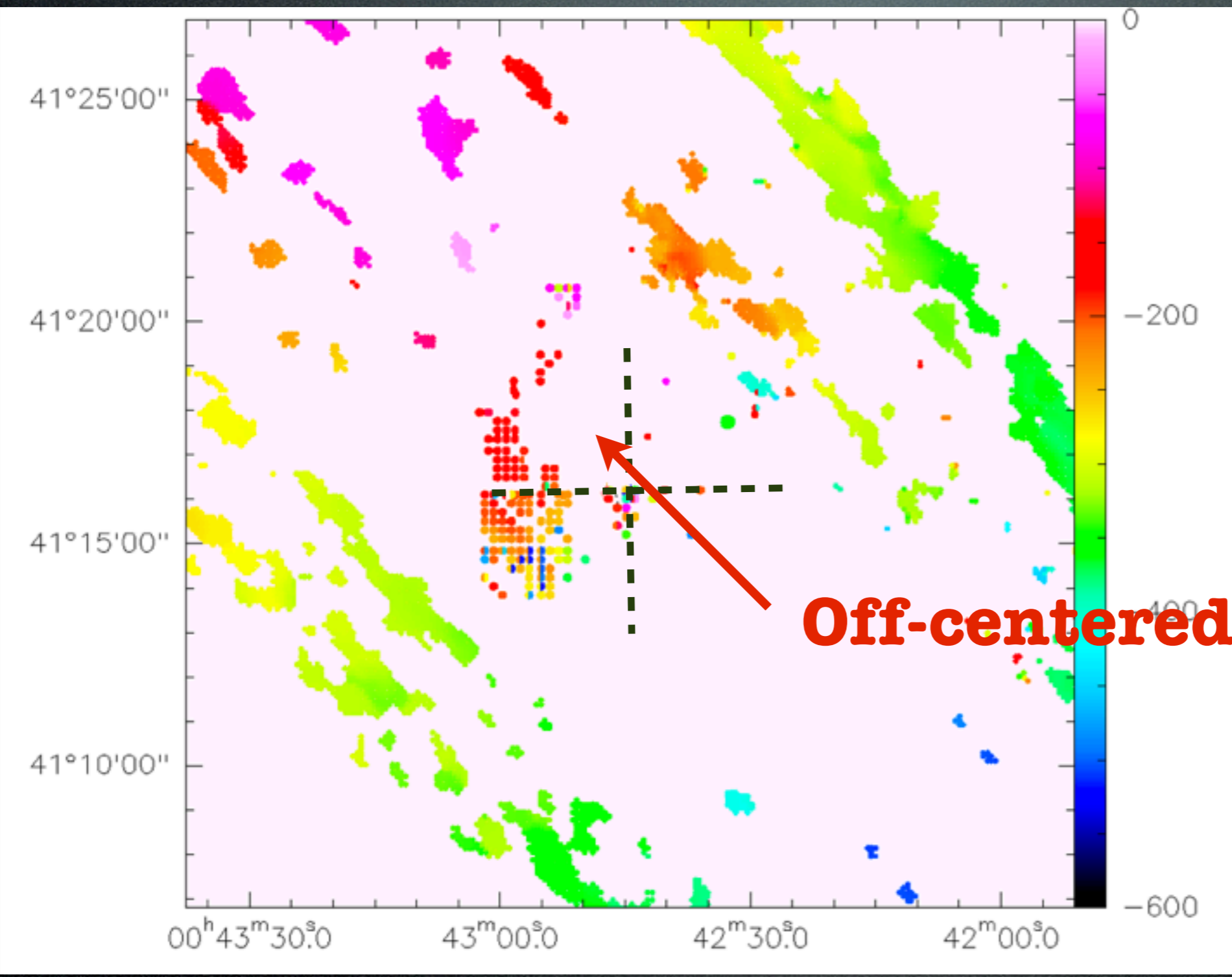
Melchior & Combes, in prep.

20' x 20' -- 4.5 kpc x 4.5 kpc

*Work in progress*



# CO velocity field in the central field IRAM surveys



Nieten et al. (2006)  
M. Guélin's courtesy

Melchior & Combes, in prep.

**Off-centered inner ring**

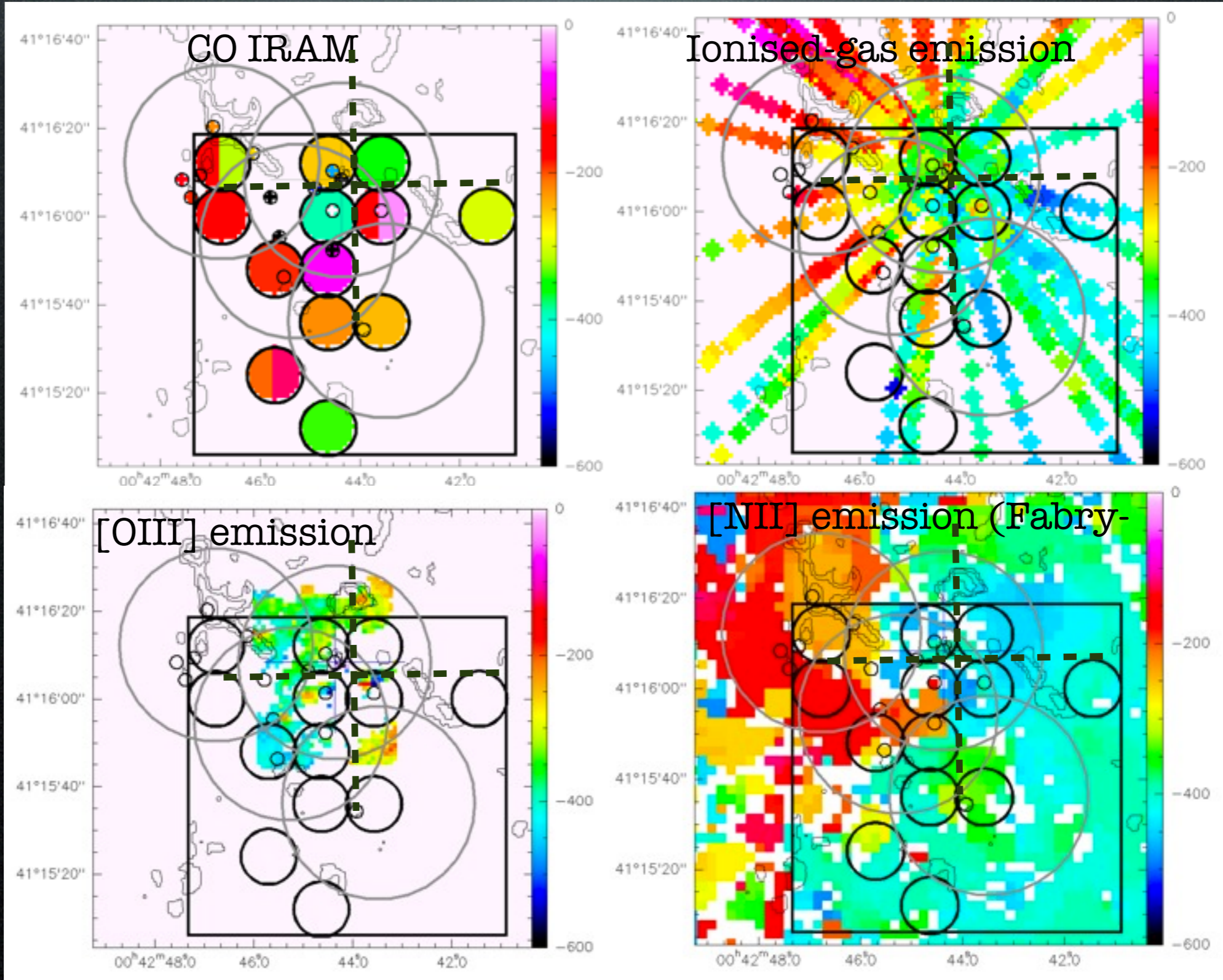
20' x 20' -- 4.5 kpc x 4.5 kpc

*Work in progress*



# M31: the gas does not rotate around the centre

Melchior et al. (2001, 2013, in prep.)



Pastorello, Sarzi et al. (2013)

Rubin & Ford (1971), Ciardullo et al. (1988),  
Saglia et al (2010)

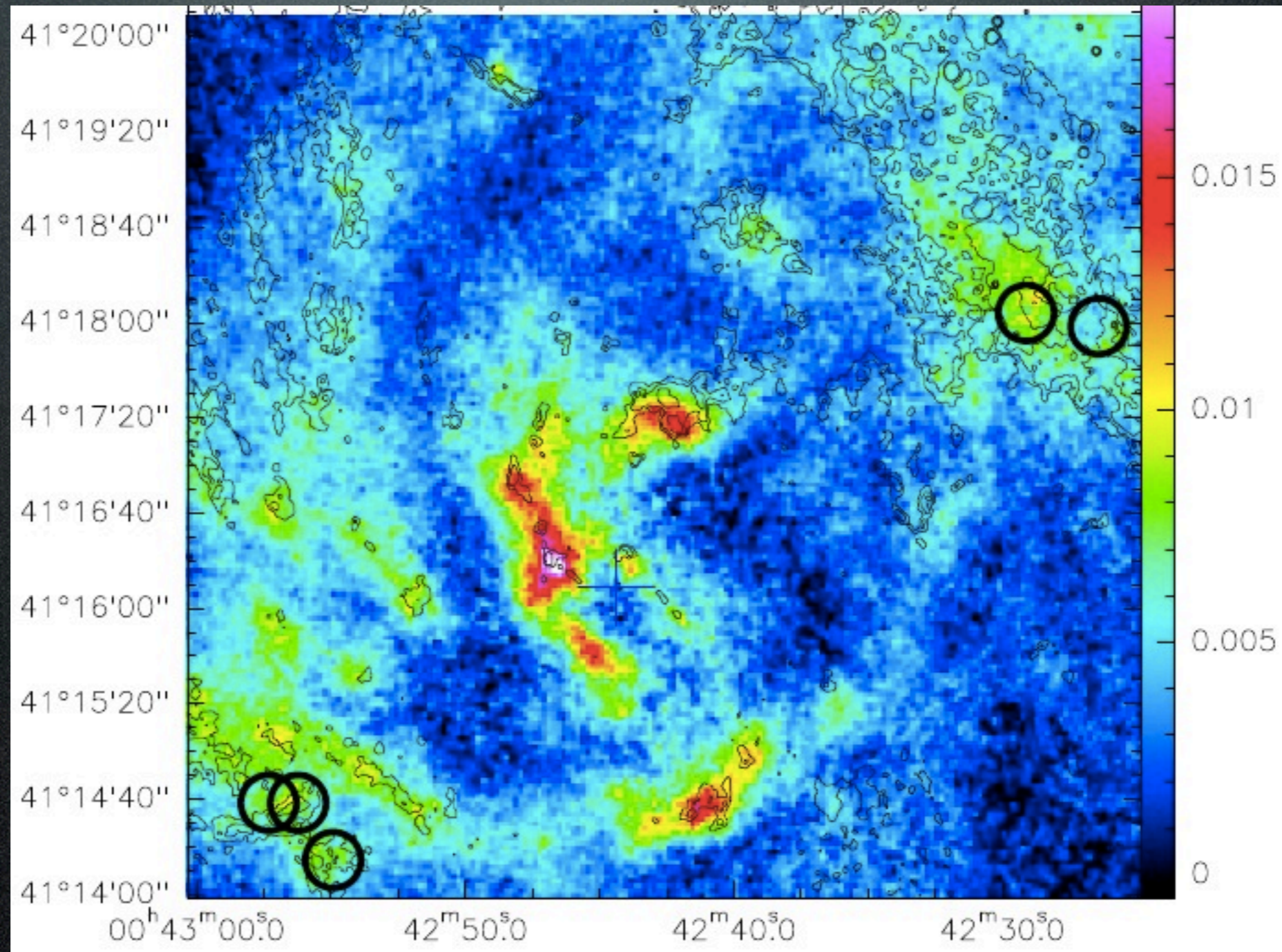
Bouletstex et al. (1987)

Velocity fields

100'' x 100'' (1,7' x 1,7') 380pc x 380pc



# Search for dense gas at IRAM 30m



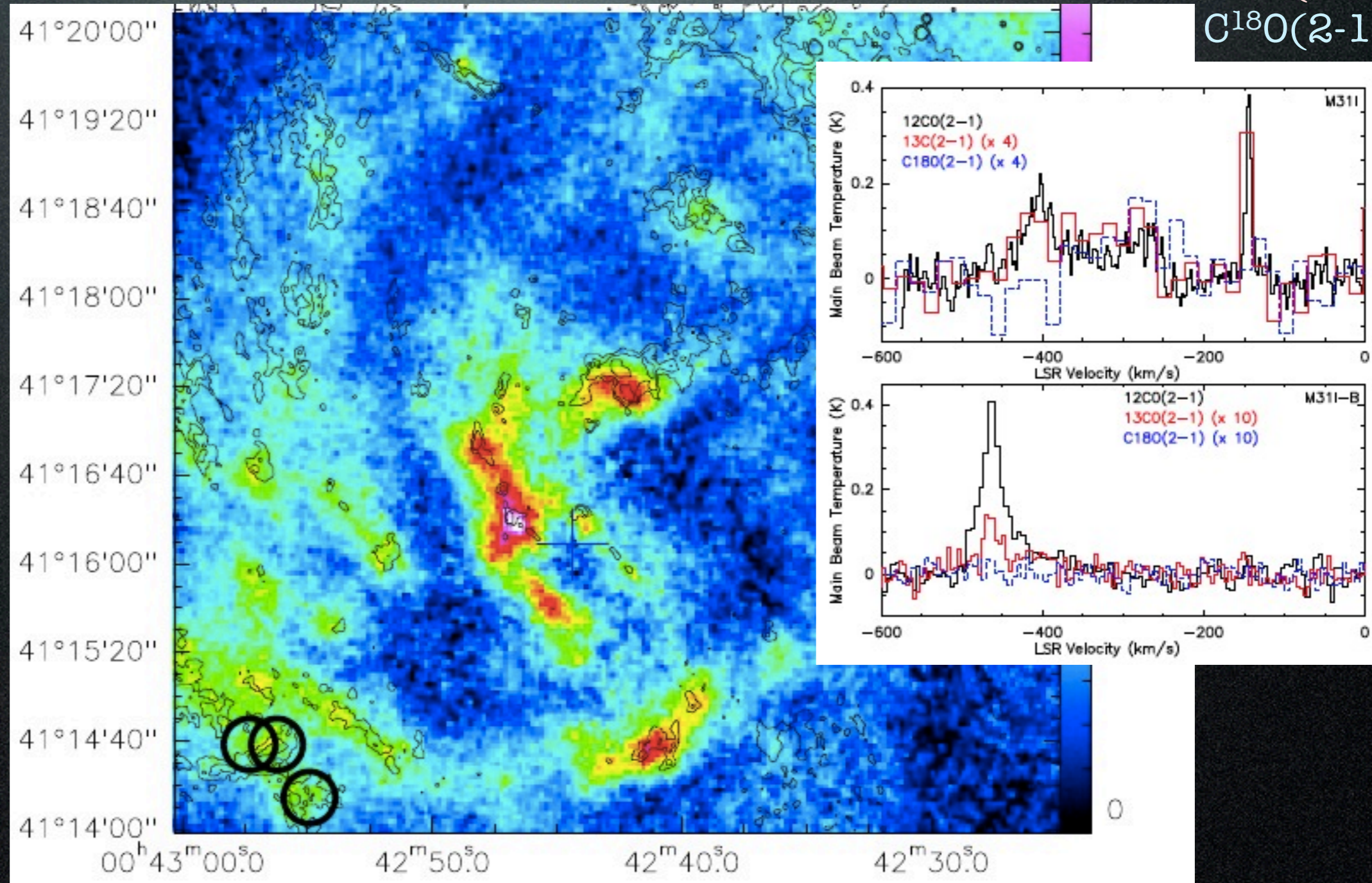
PACS 100um

Courtesy : S. Viaene



# Search for dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$



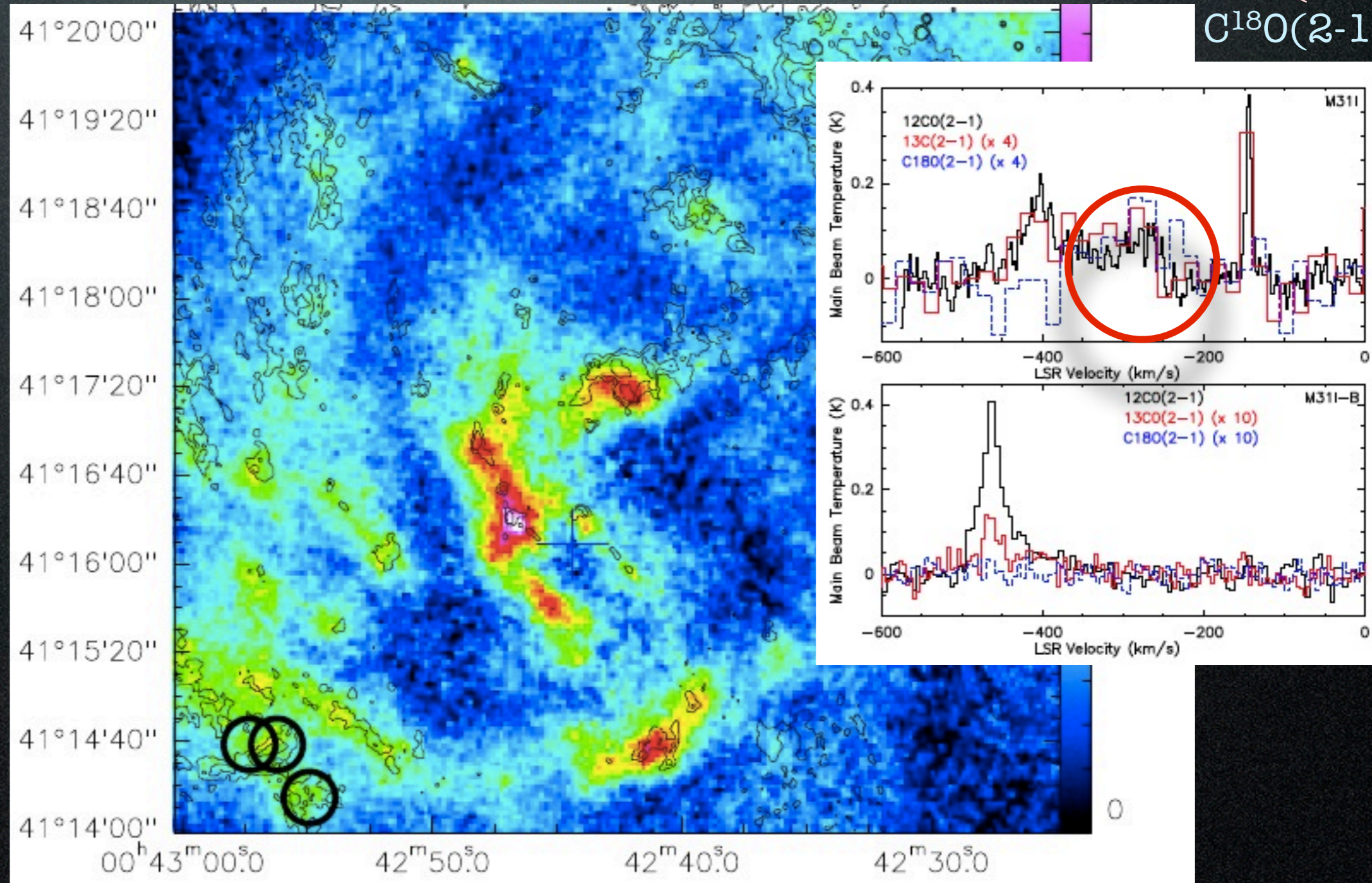
PACS 100 $\mu\text{m}$

Courtesy : S. Viaene



# Search for dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$



PACS 100um

Courtesy : S. Viaene

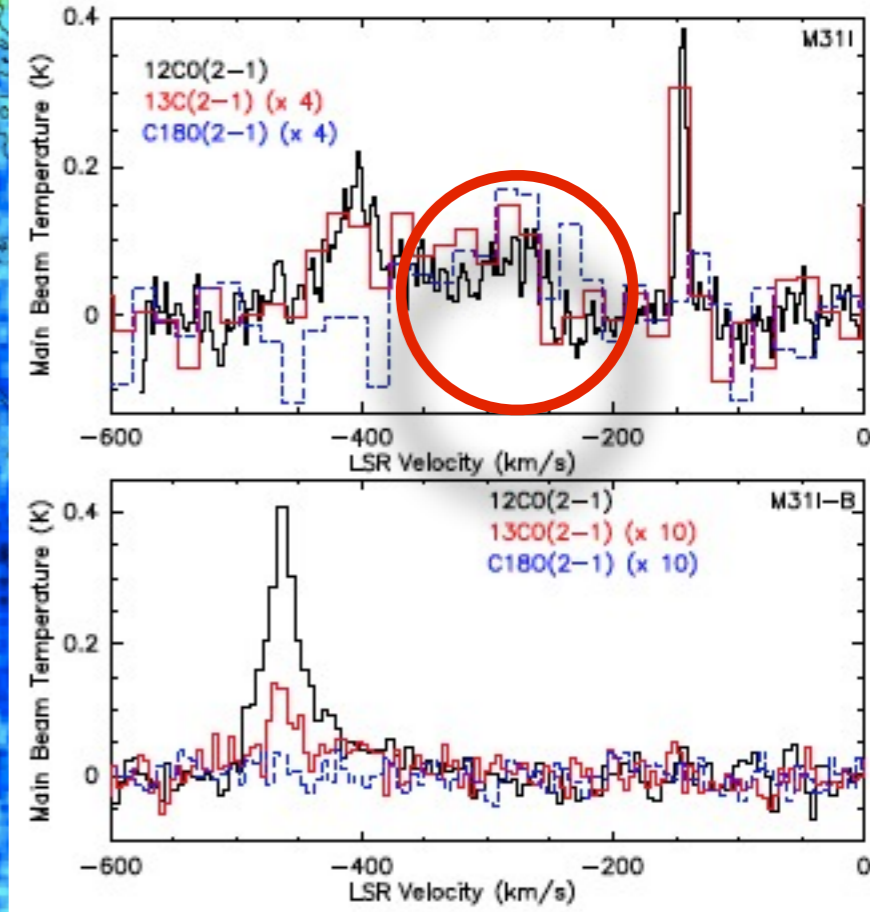
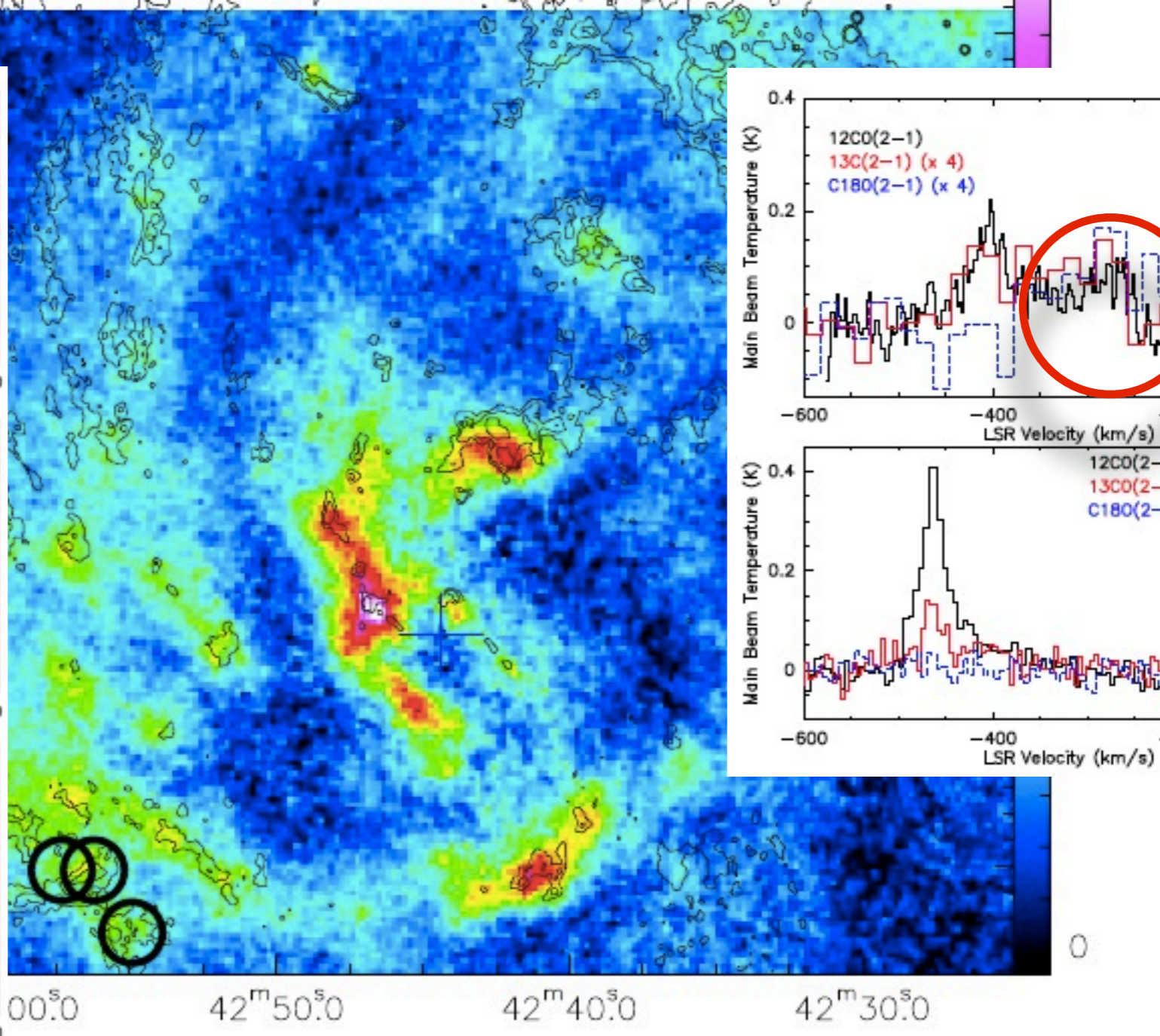
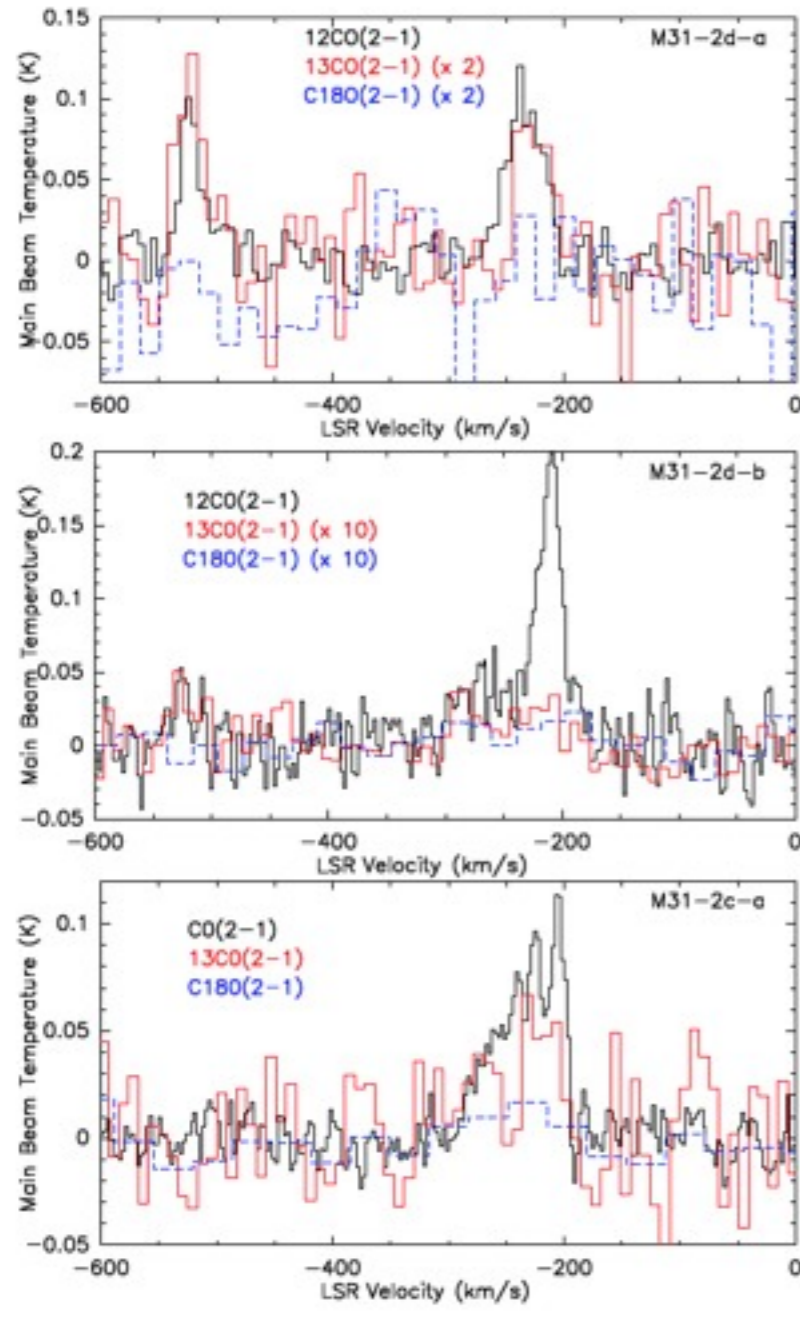


# Search for dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

41°20'00"



PACS 100um

Courtesy : S. Viaene

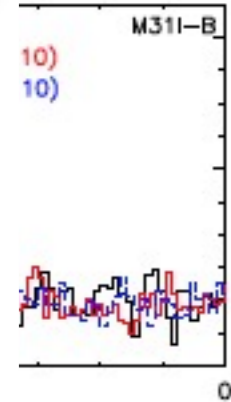
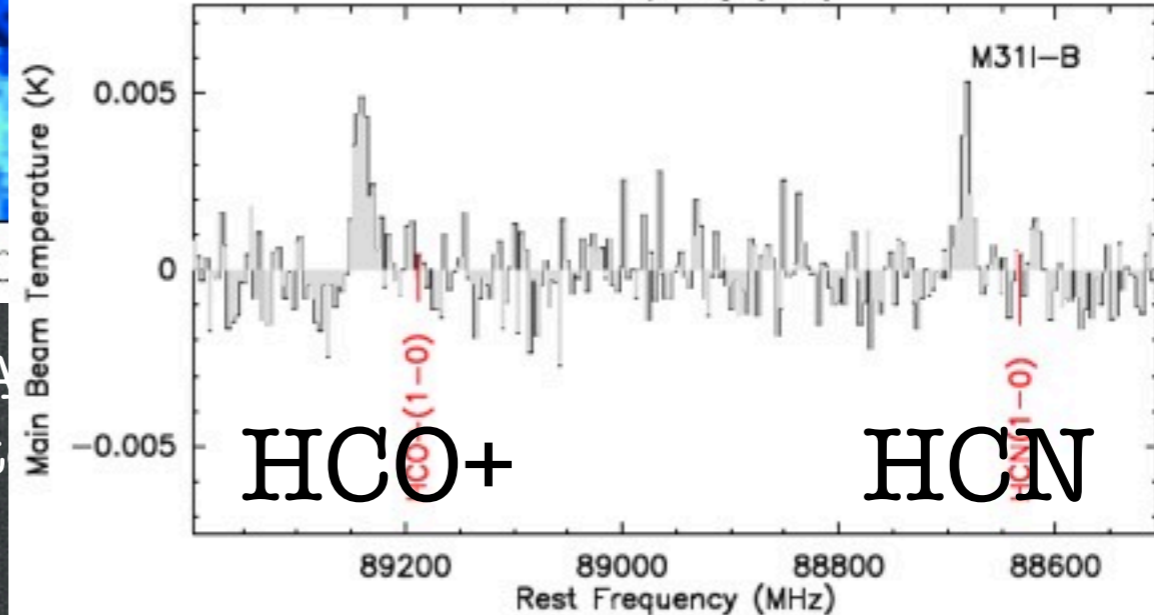
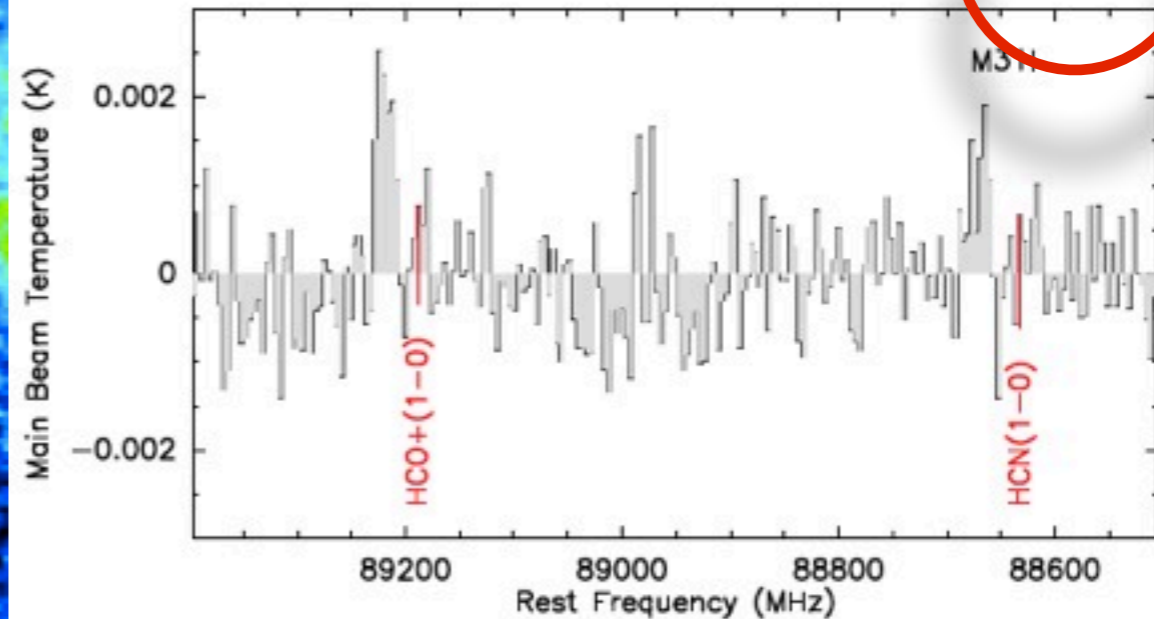
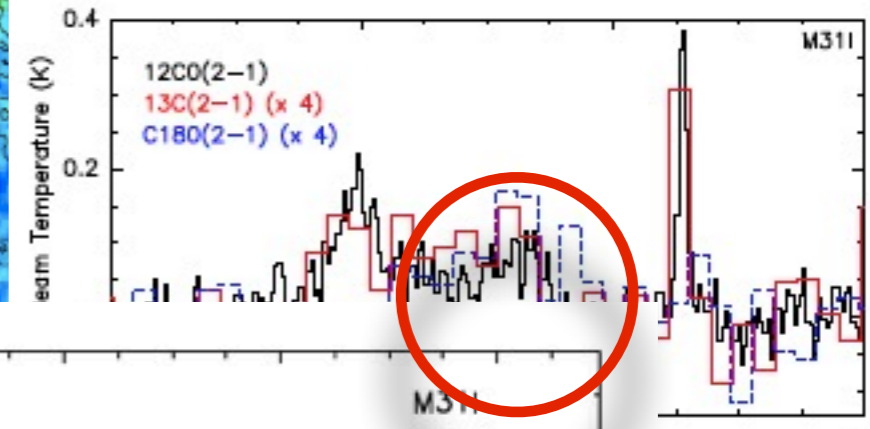
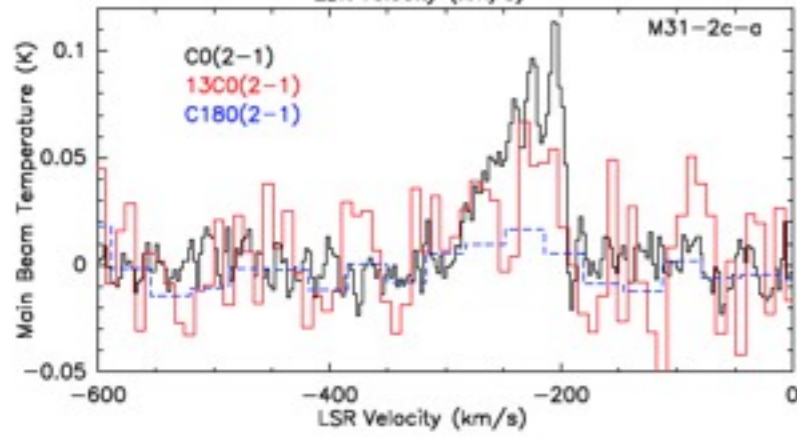
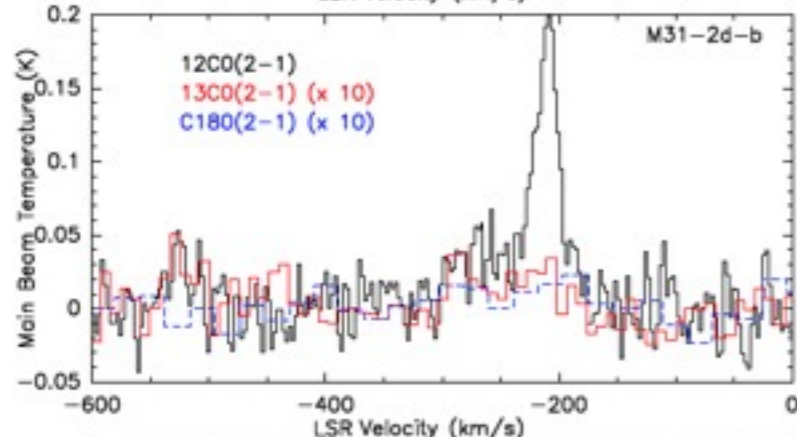
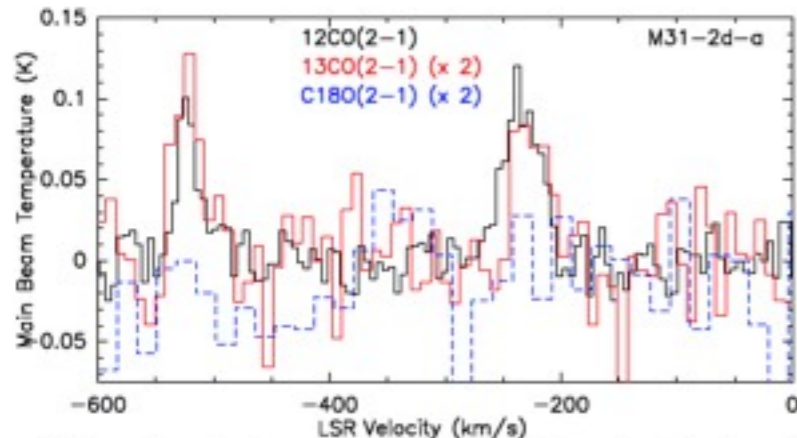
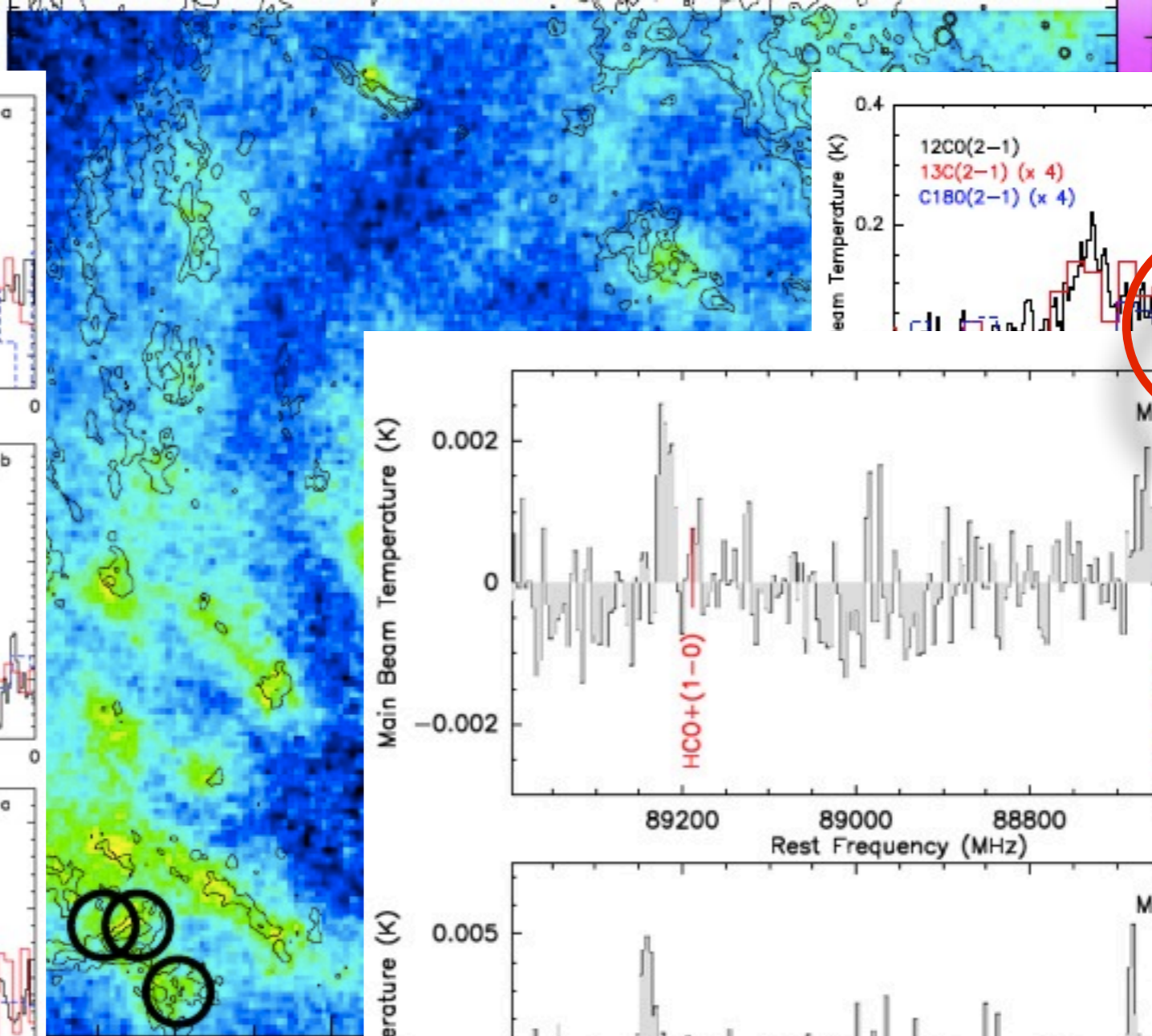


# Search for dense gas at IRAM 30m

$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

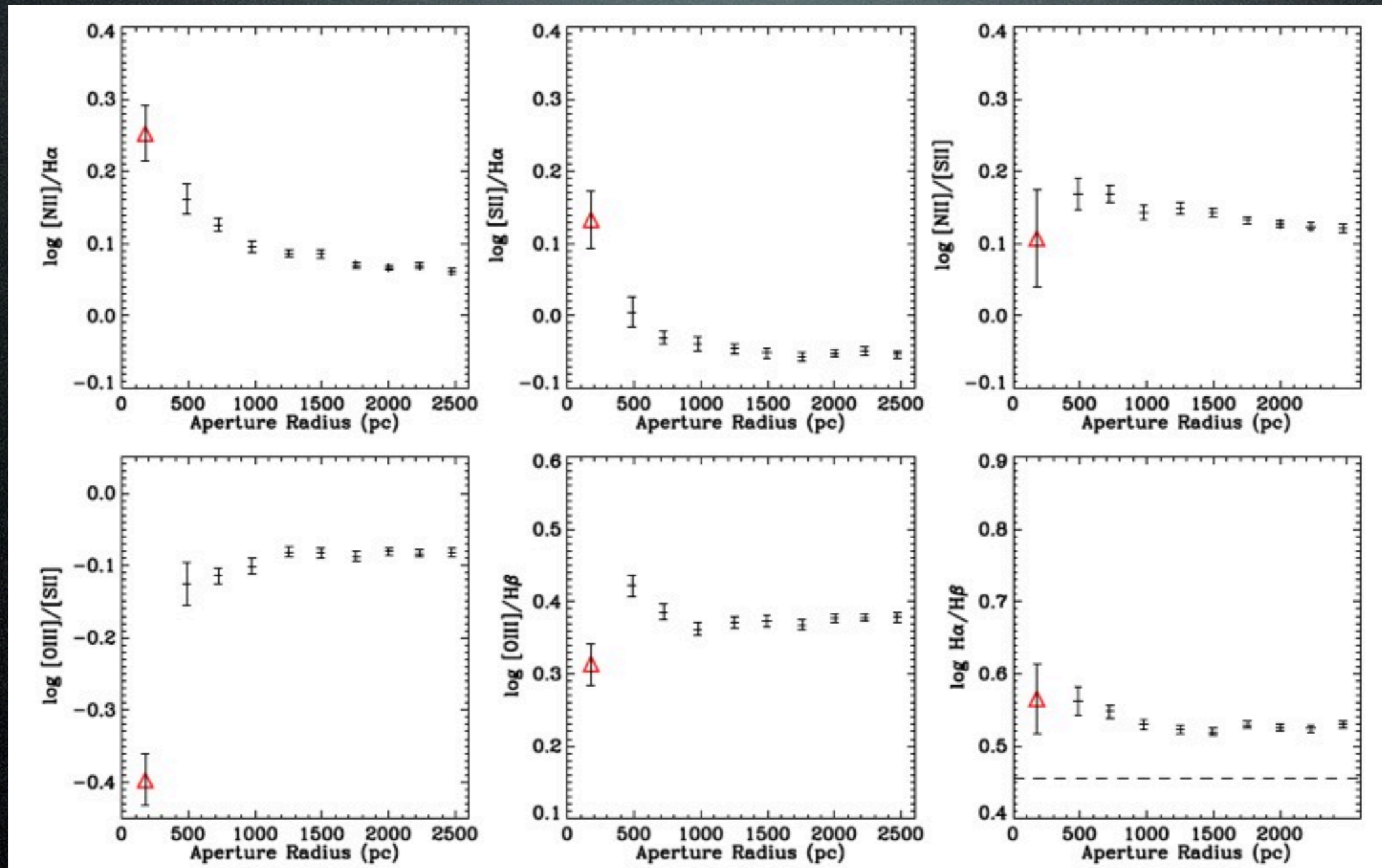
$^{12}\text{CO}(2-1)$   
 $^{13}\text{CO}(2-1)$   
 $\text{C}^{18}\text{O}(2-1)$

41°20'00"





# In other galaxies



Yan & Blanton  
2012

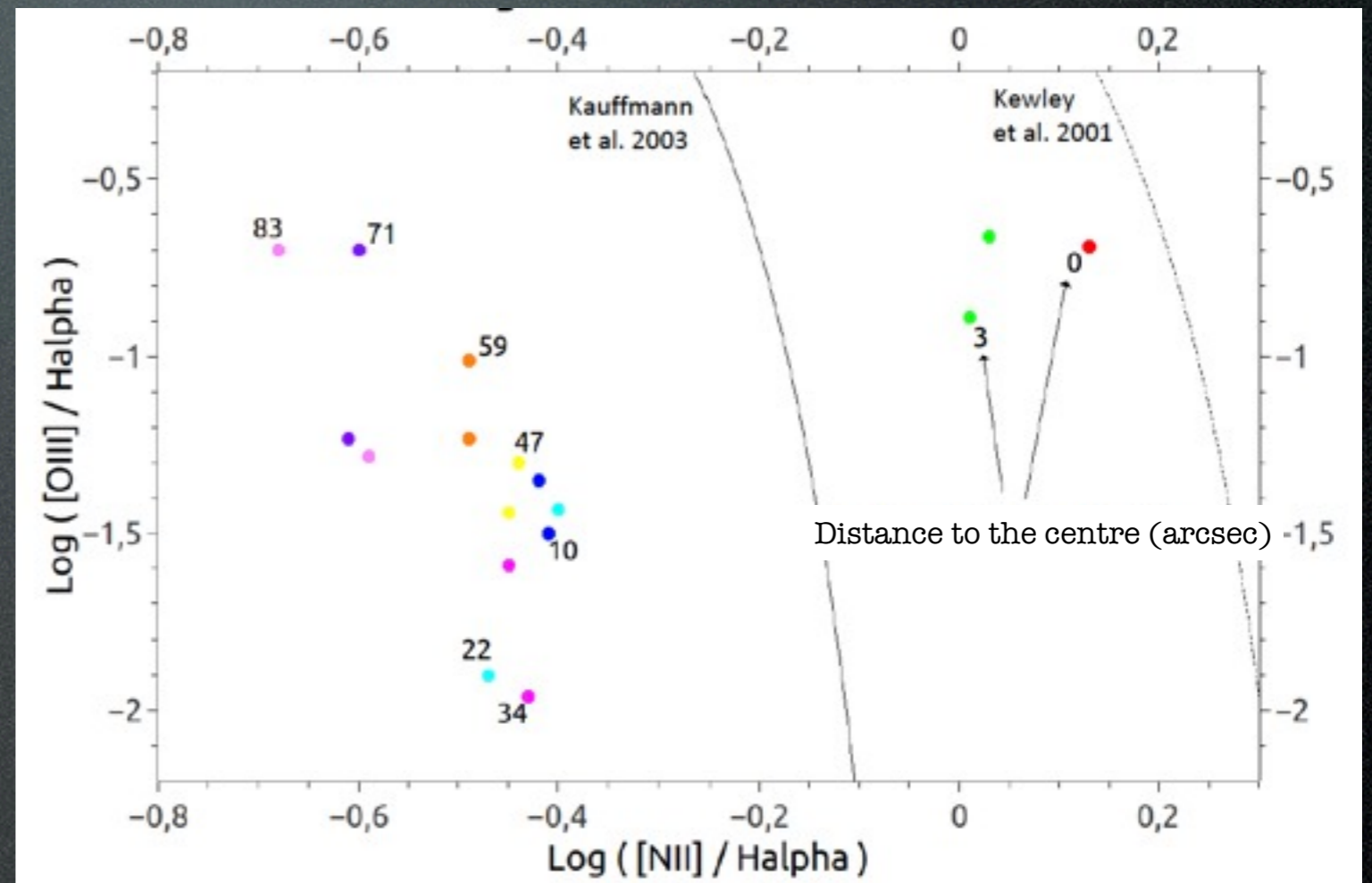
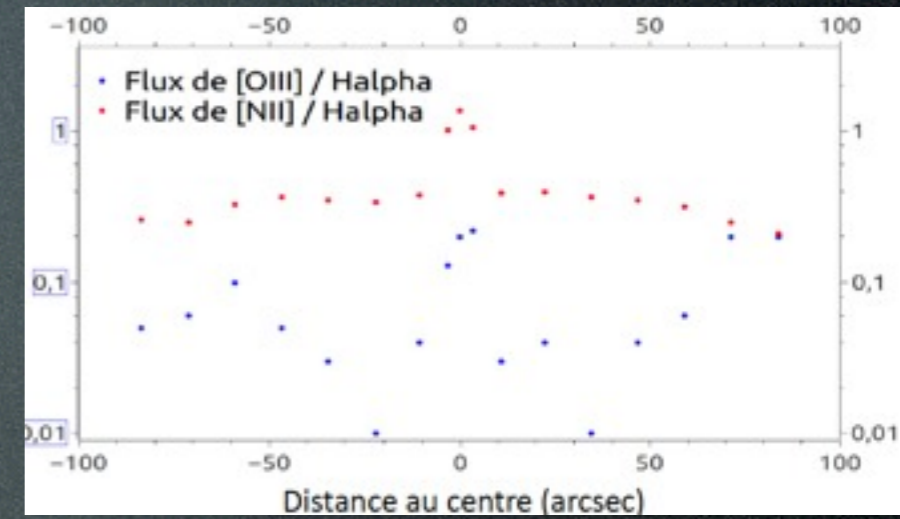
**Lack of resolution...**



# NGC 7083 - M31's sosie?



$z=0.01$



Slit spectroscopy from  
Pizzella et al. (2004)

Master work from M. Veyrat



# Summary : Andromeda's bulge good case to study quenching, post-starburst activity into details

- LINER with no AGN
- Detection of molecular gas close to the black hole ( $>4 \times 10^4 M_{\text{sol}}$ ), not in rotation
- Velocity pattern compatible with main disc with non-circular orbits & **inner disc/ring**
- **Detection of dense gas** - «anomaly» in  $^{13}\text{CO}$  - possible depletion ?  
- **post-(small) starburst triggered by frontal collision with M32, 200Myr ago**
- **Evidence of shocks** in ionised gas --> future prospect : SITELLE/CFHT

**Other nearby galaxies accessible with actual instruments**



Thank you