Understanding the state of the gas surrounding Andromeda's black hole

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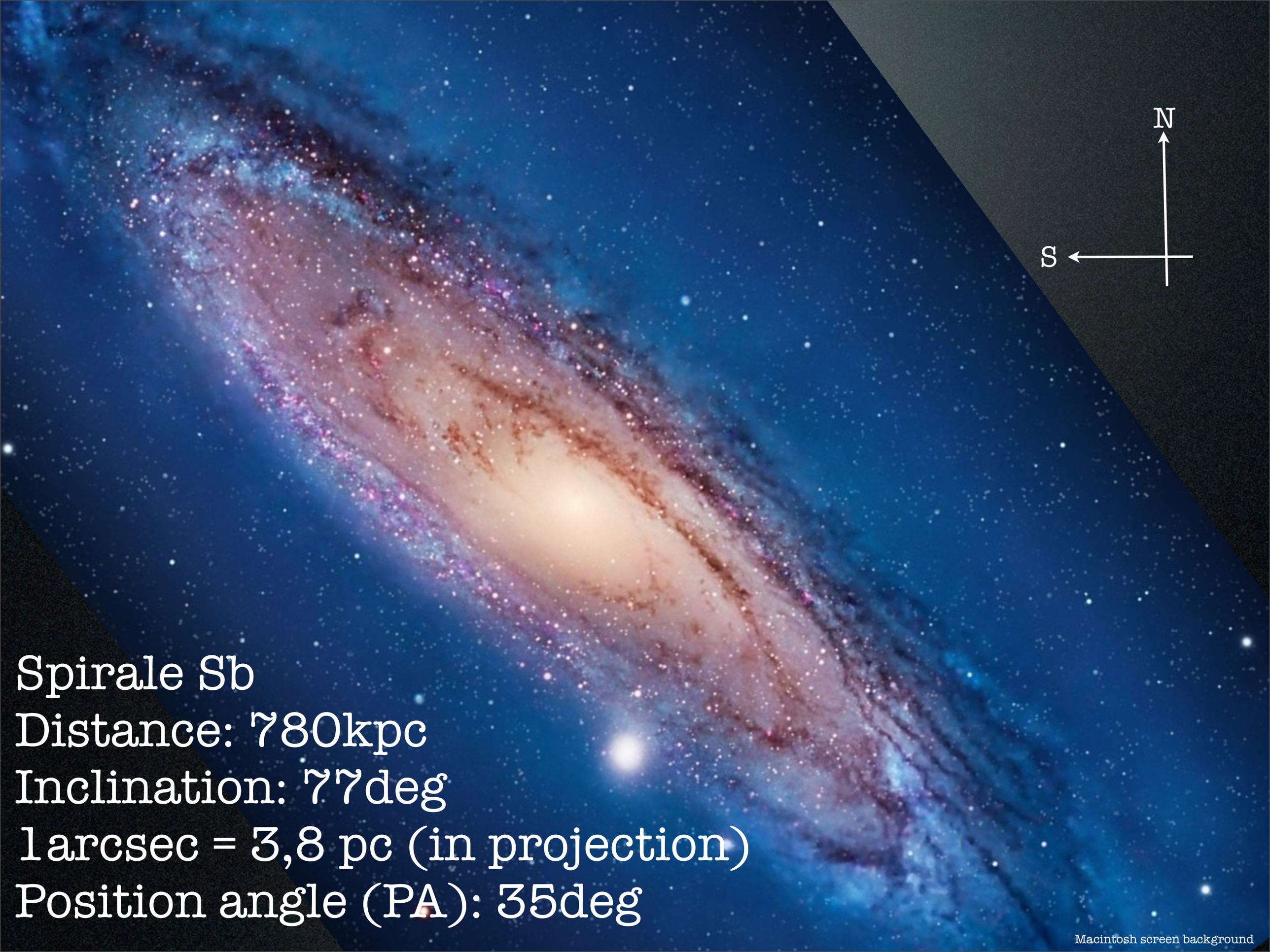
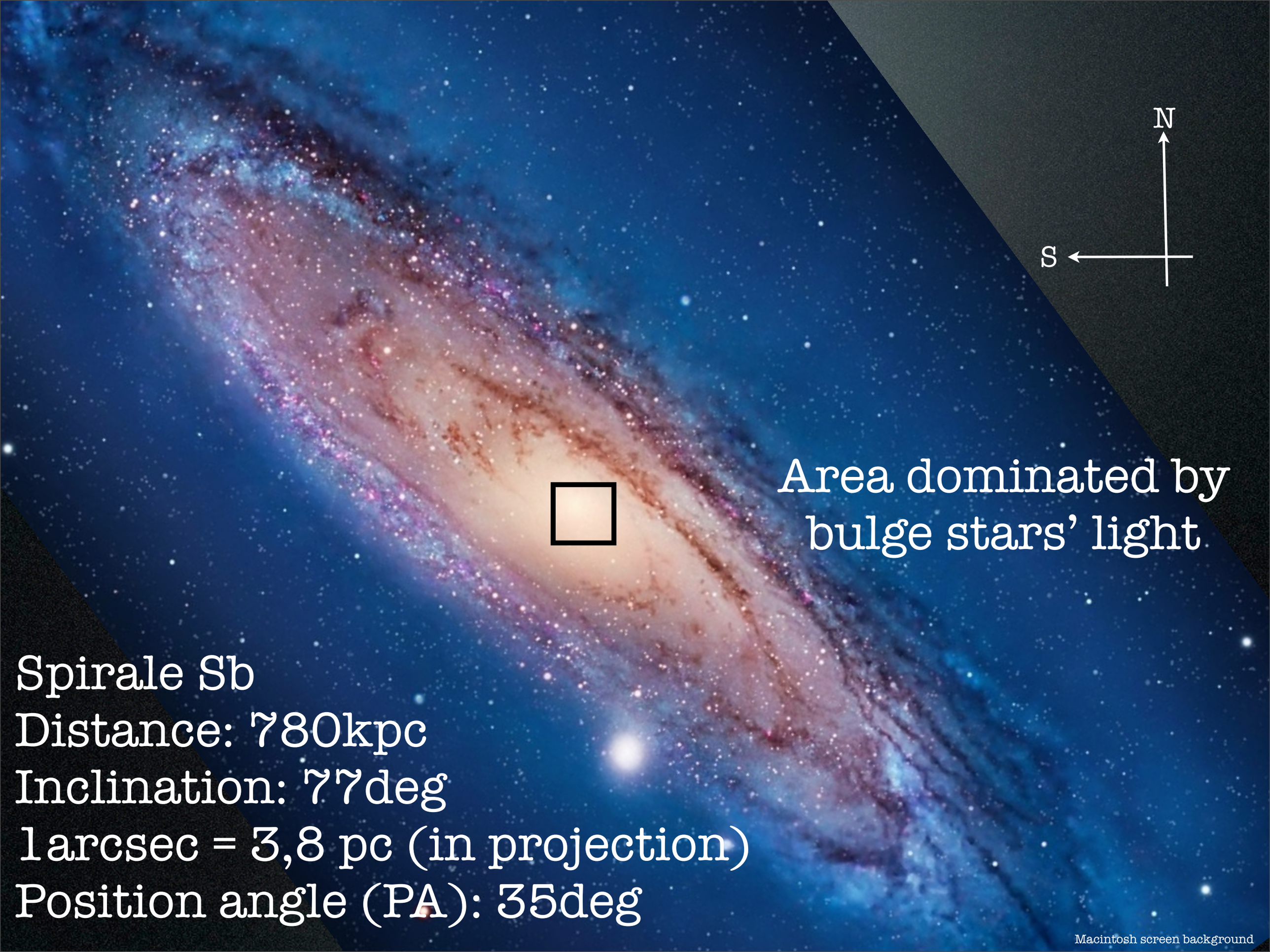
with Françoise Combes

1. Detection of gas in the 120pc x 120pc central field

2. Velocity pattern and the inner ring (0.7kpc x 0.7kpc)

3. Physical conditions of the gas


N
S
Spirale Sb
Distance: 780kpc
Inclination: 77deg
1arcsec = 3,8 pc (in projection)
Position angle (PA): 35deg
Macintosh screen background


N
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Area dominated by
bulge stars' light
Spirale Sb
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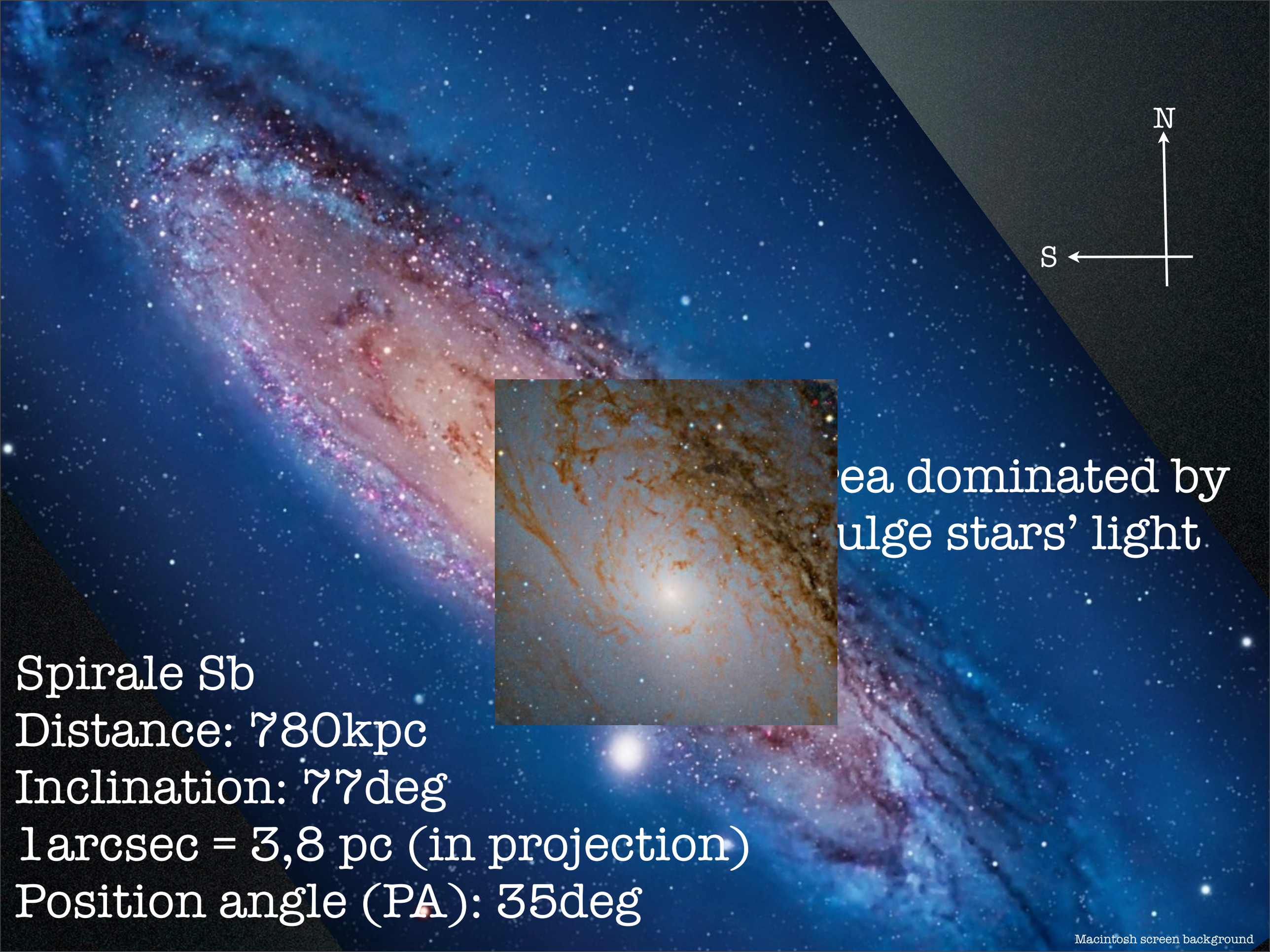
1arcsec = 3,8 pc (in projection)
Position angle (PA): 35deg
Macintosh screen background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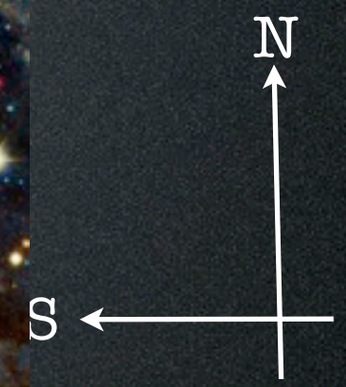
Macintosh screen background

Calar Alto Observatory (CAHA) CAHA, Fundación Descubre, DSA, OAUV, Vicent Peris (OAUV), Jack Harvey (SSRO), Steven Mazlin (SSRO), Gilles Bergond (CAHA)

nated by
s' light

Spirale S
Distance:
Inclinatio
1arcsec =
Position angle (PA): 30deg



nated by
s' light

Spirale S
Distance:
Inclinatio
1arcsec =
Position angle (PA): 0deg

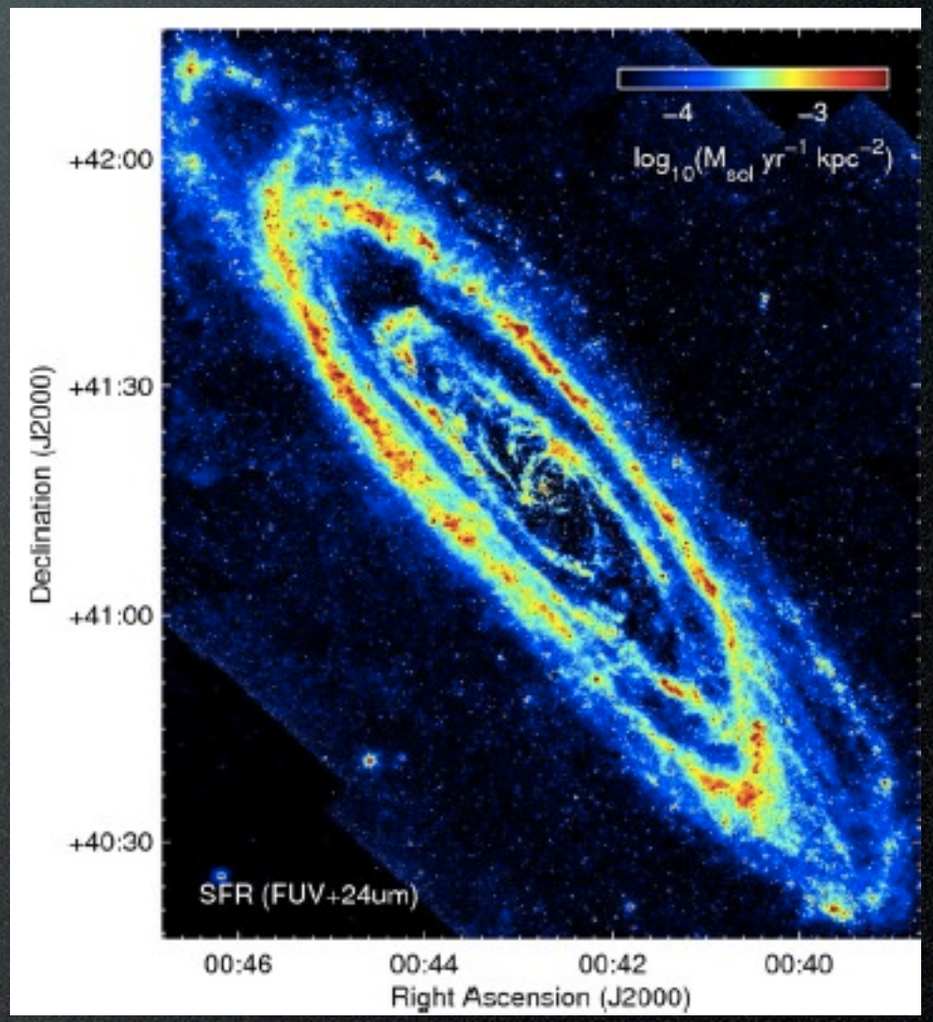
Macintosh screen background

But very little star formation

$0.25^{+0.06}_{-0.04}$ Msol/year in the galaxy as a whole

mainly concentrated in the main disc

Ford et al. 2013



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

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

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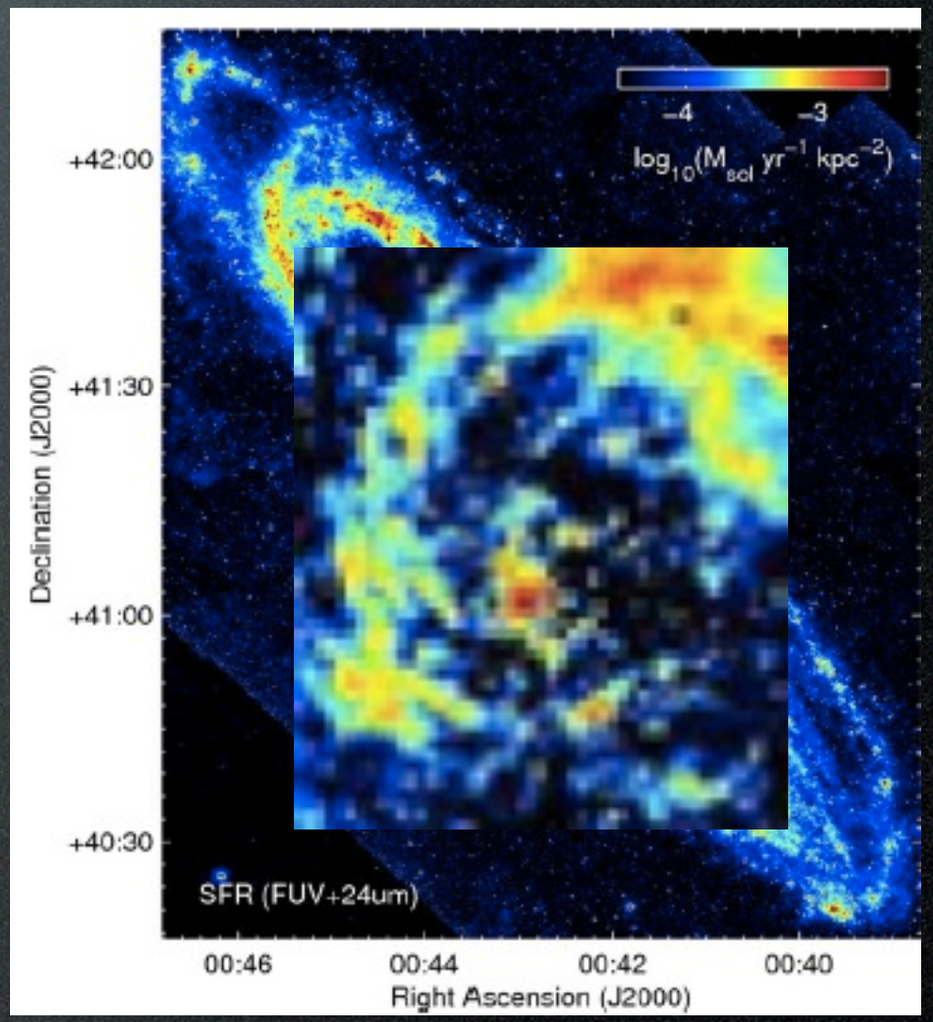

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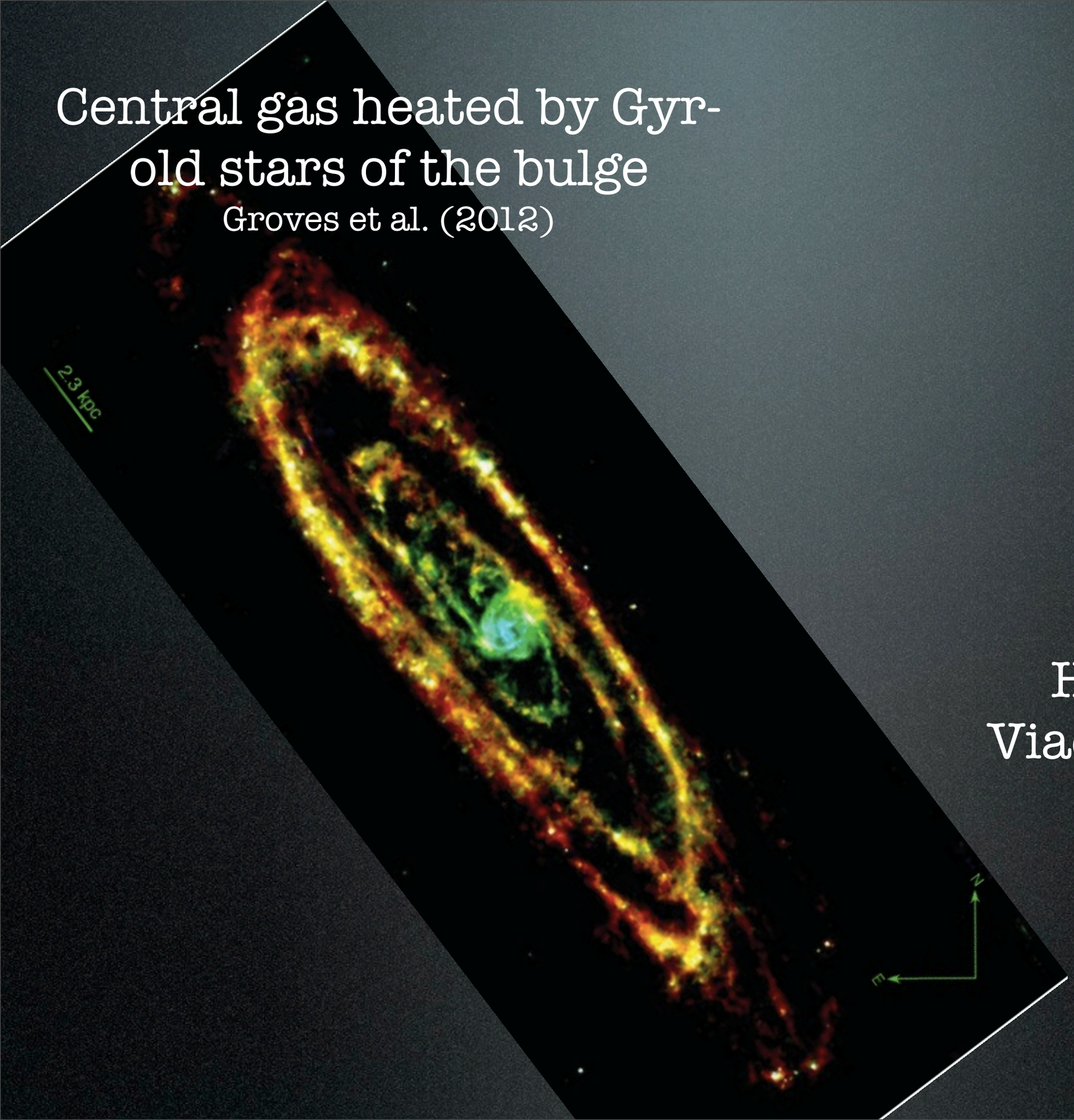
Central gas heated by Gyr-old stars of the bulge

Groves et al. (2012)



Herschel data
Viaeney et al. 2014

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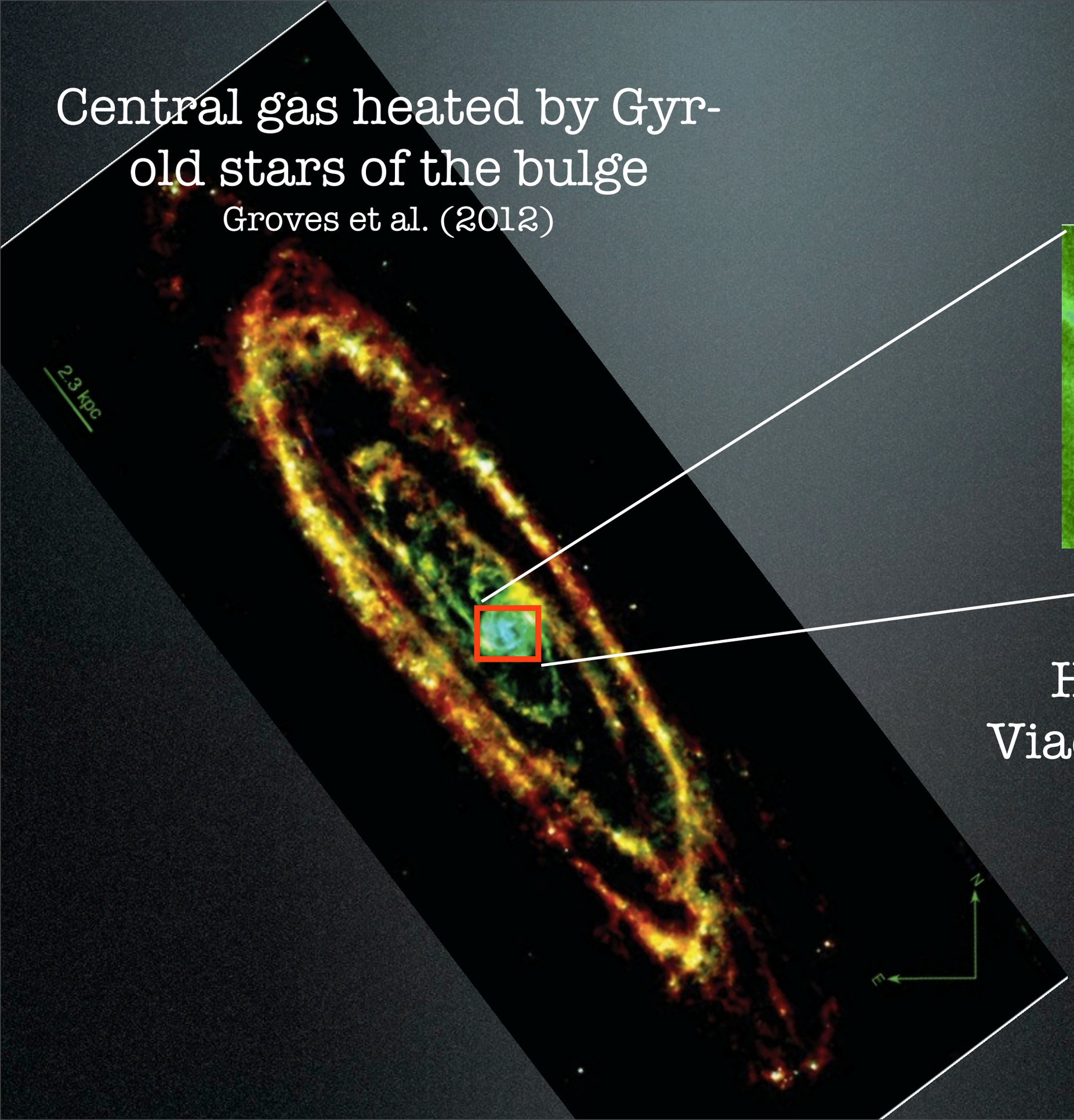
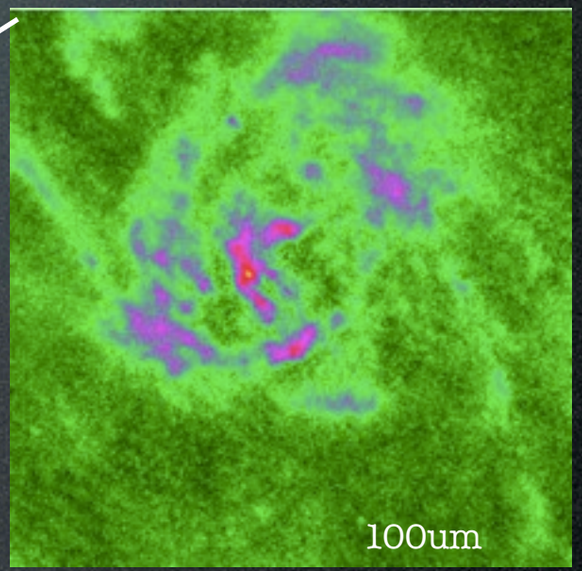
Groves et al. (2012)





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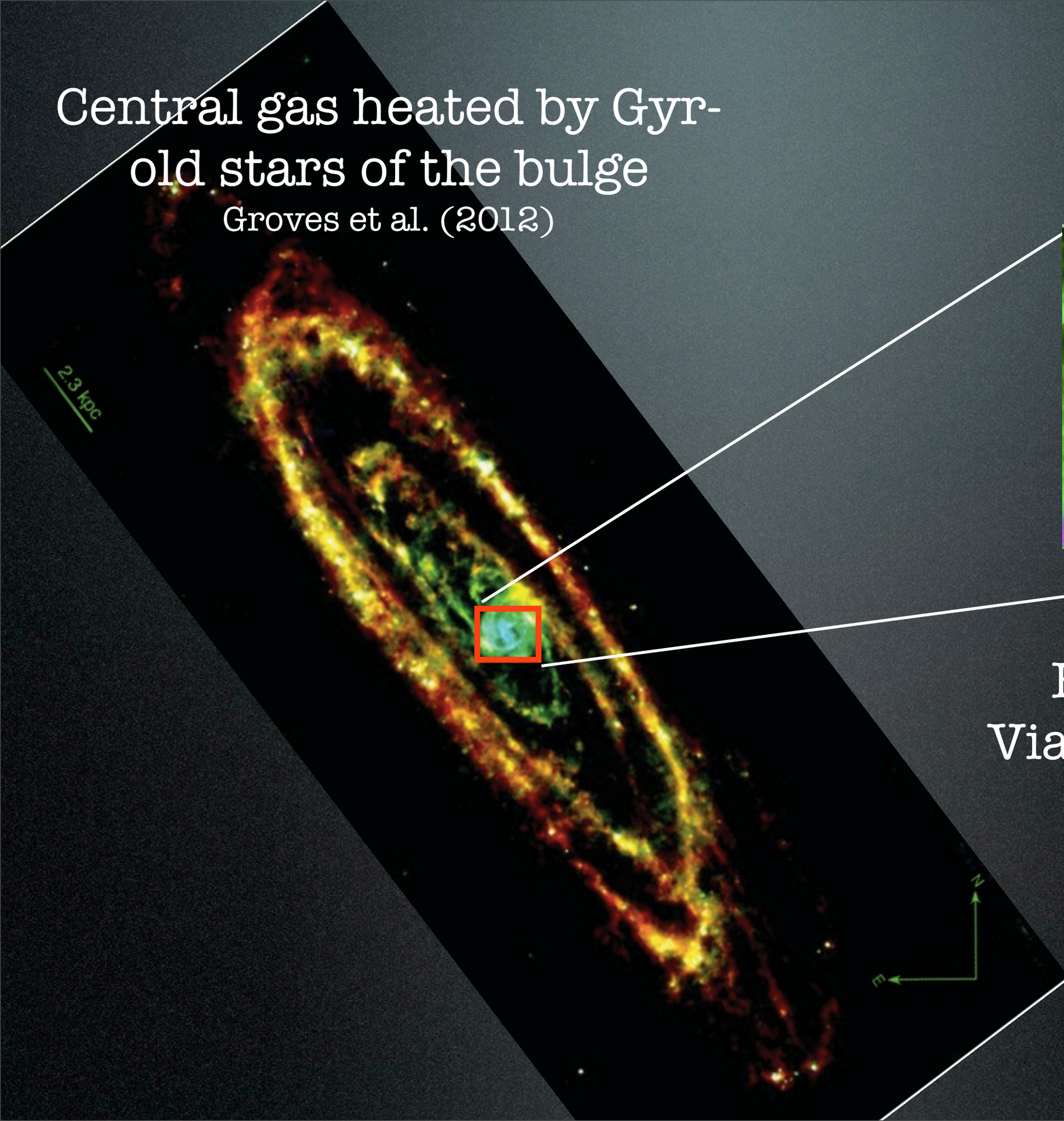
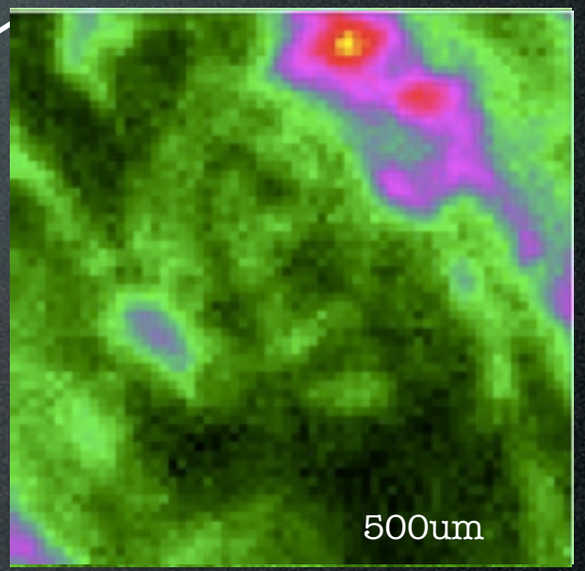
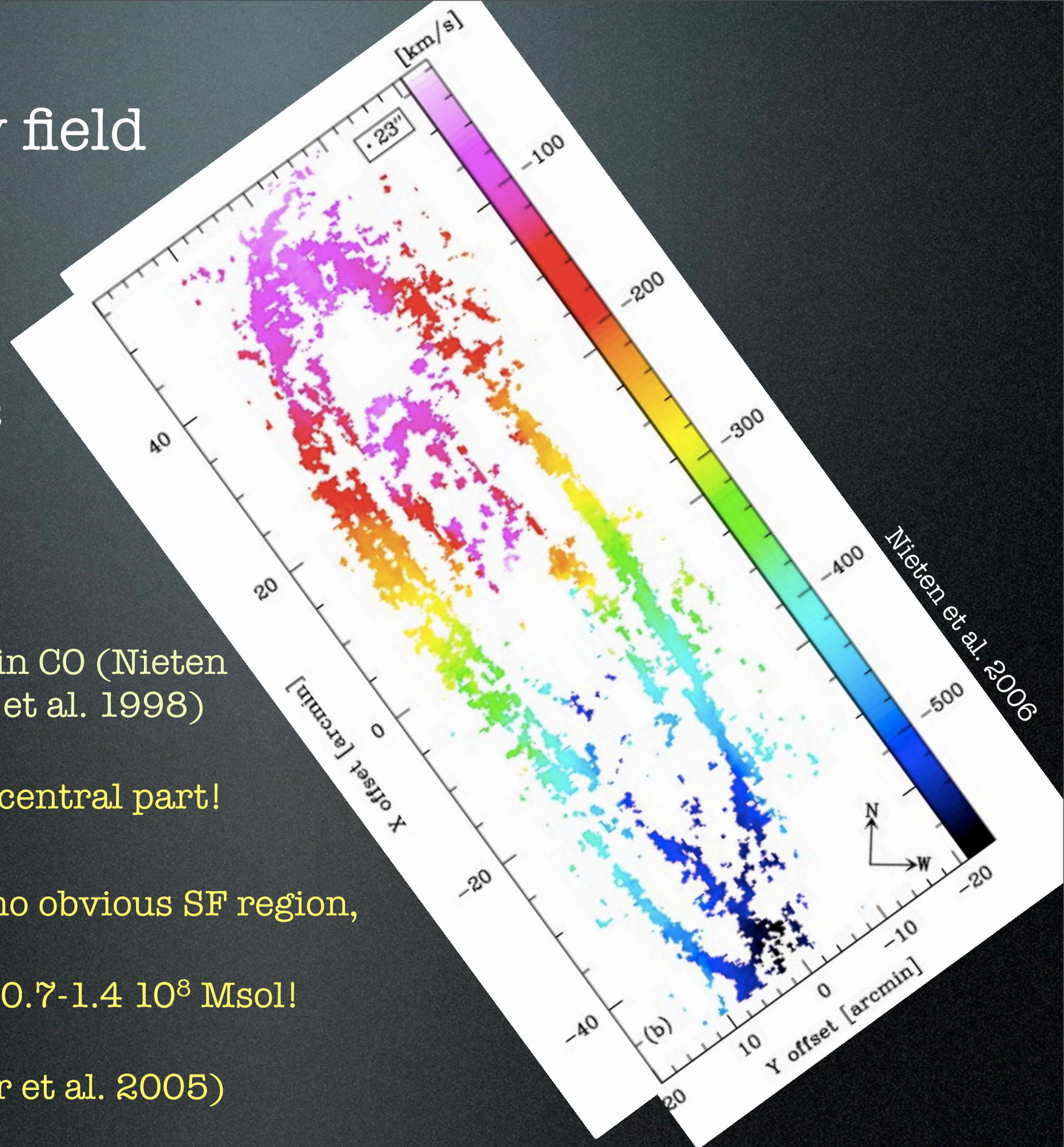




Herschel data
Viaeney et al. 2014

CO(1-0) velocity field
@IRAM
R= 115000
Dv=2.6km/s
«pixels»=9arcsec



Nieten et al. 2006

- Regular rotating disc in CO (Nieten et al. 2006, Neininger et al. 1998)
- Nothing strong in the central part!

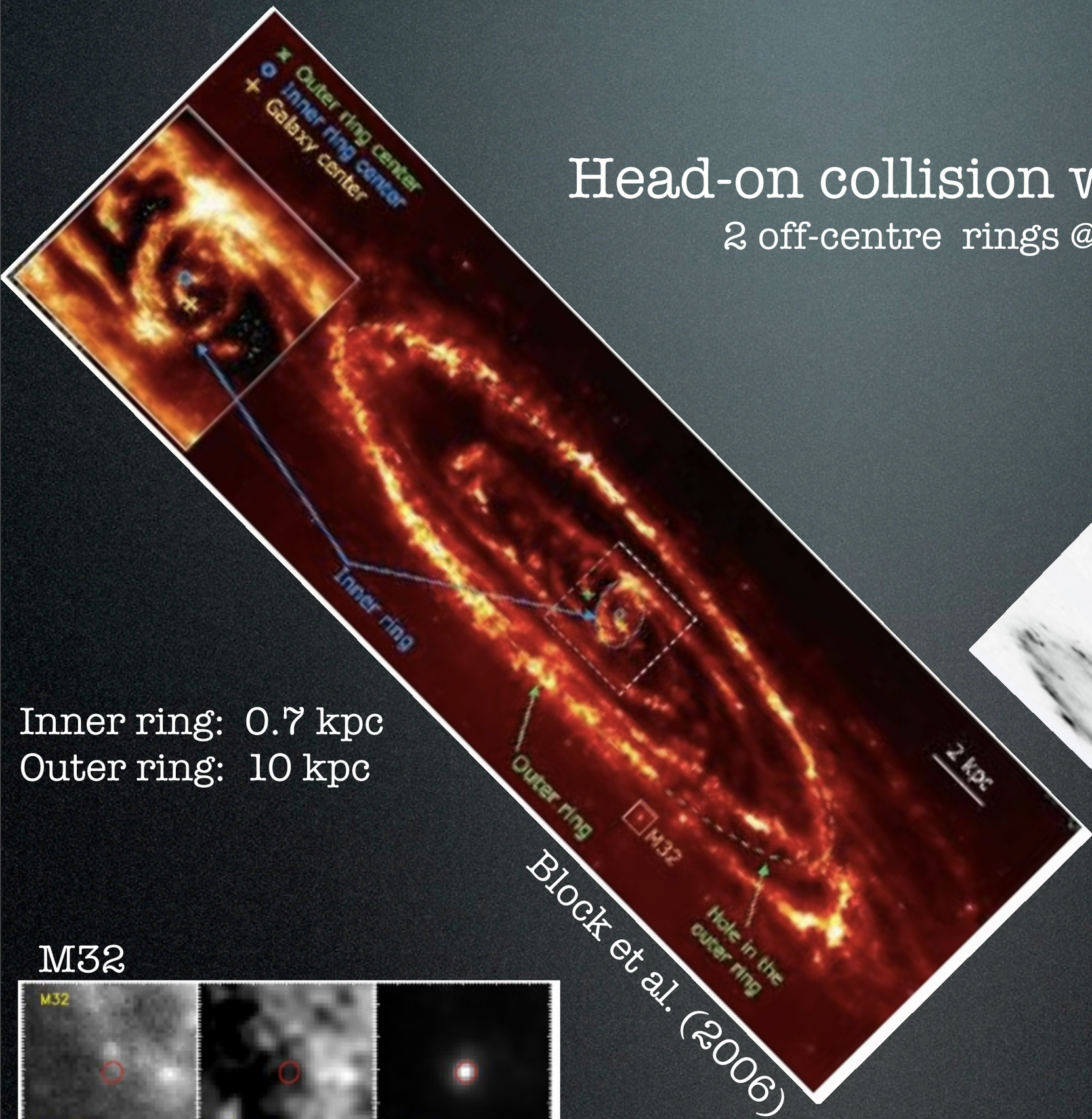
--> No spiral arm, no bar, no obvious SF region,

but a big quiet black hole: 0.7-1.4 10^8 Msol!

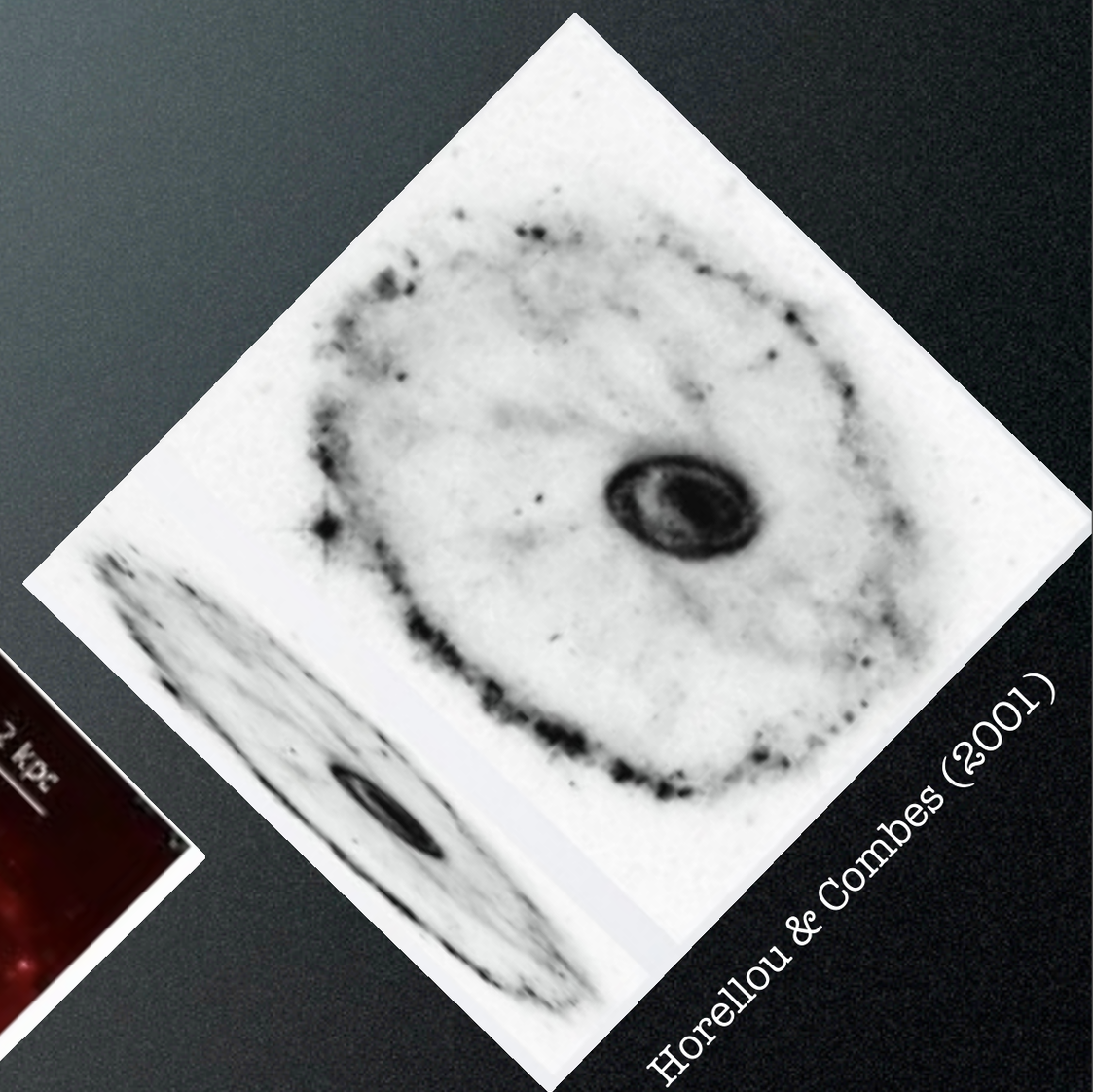
(Bacon et al. 2001, Bender et al. 2005)

Head-on collision with M32

2 off-centre rings @ 8μm



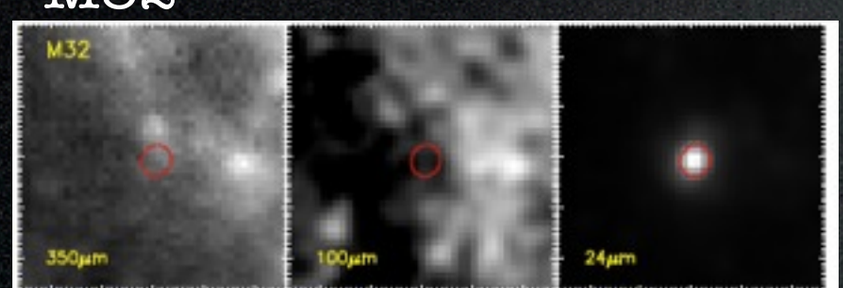
Block et al. (2006)



Horellou & Combes (2001)

Inner ring: 0.7 kpc
Outer ring: 10 kpc

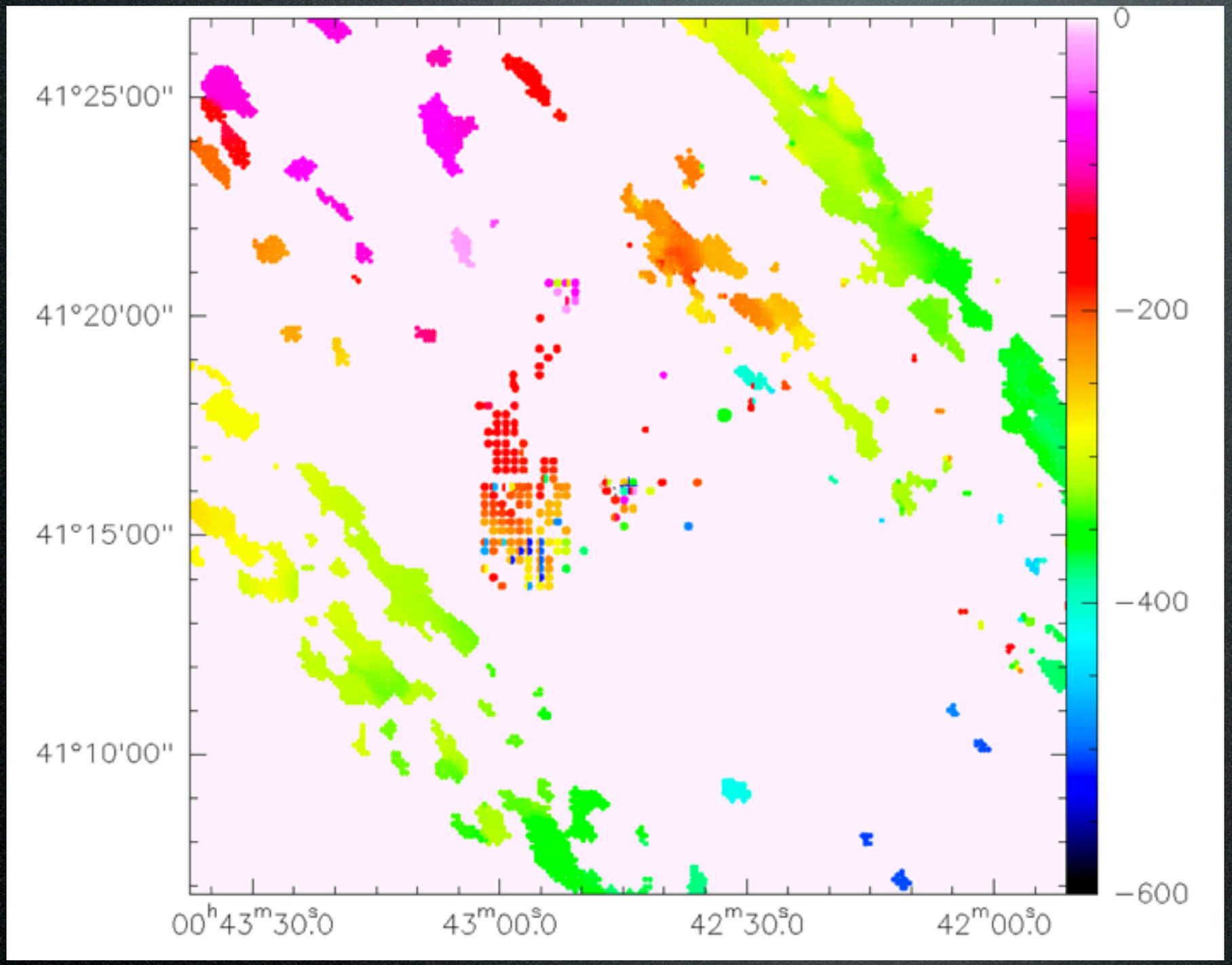
M32



Kirk et al. 2014

→ Off-centered inner ring

CO velocity field in the central field IRAM surveys



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

Melchior & Combes 2013,
in prep.

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

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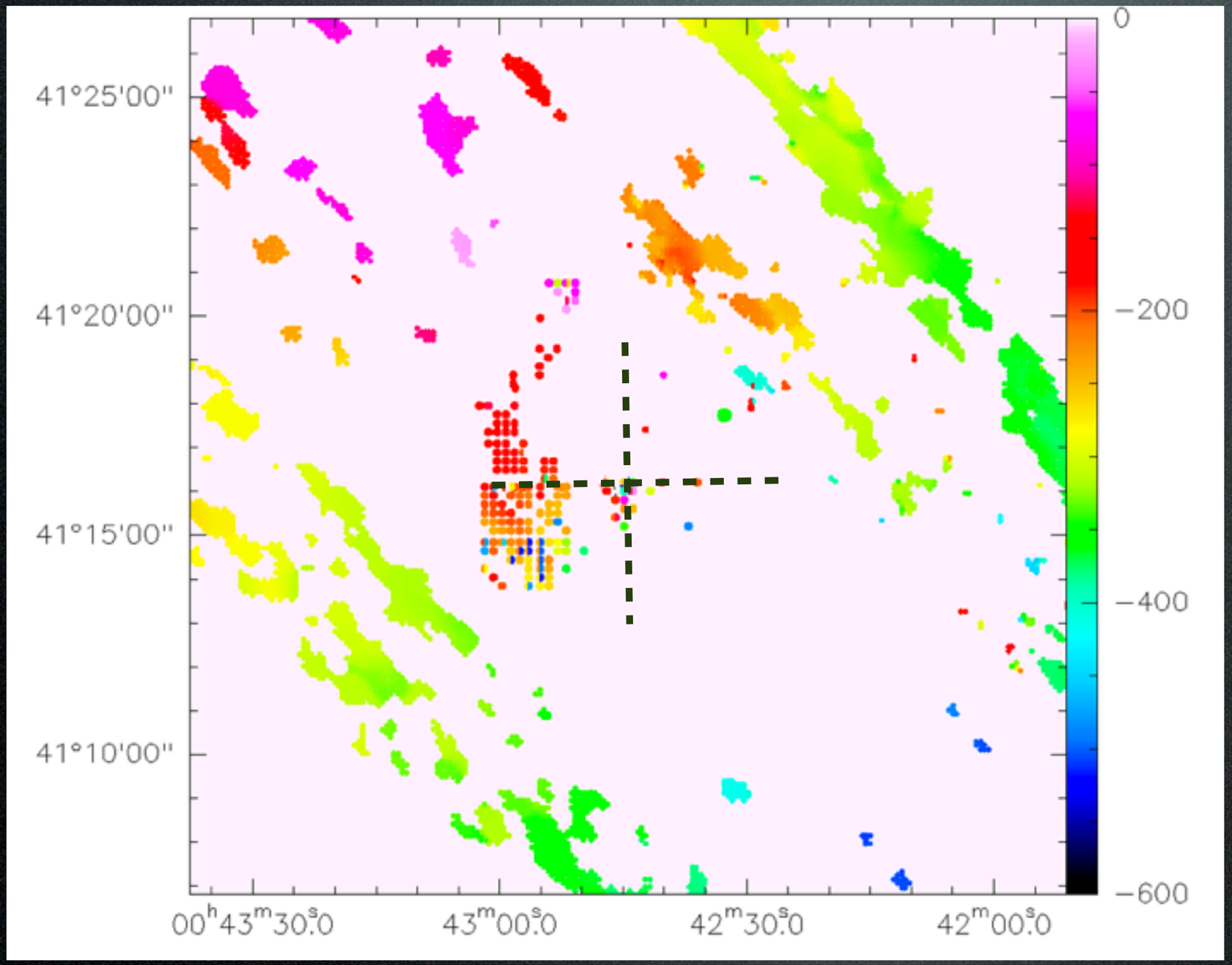

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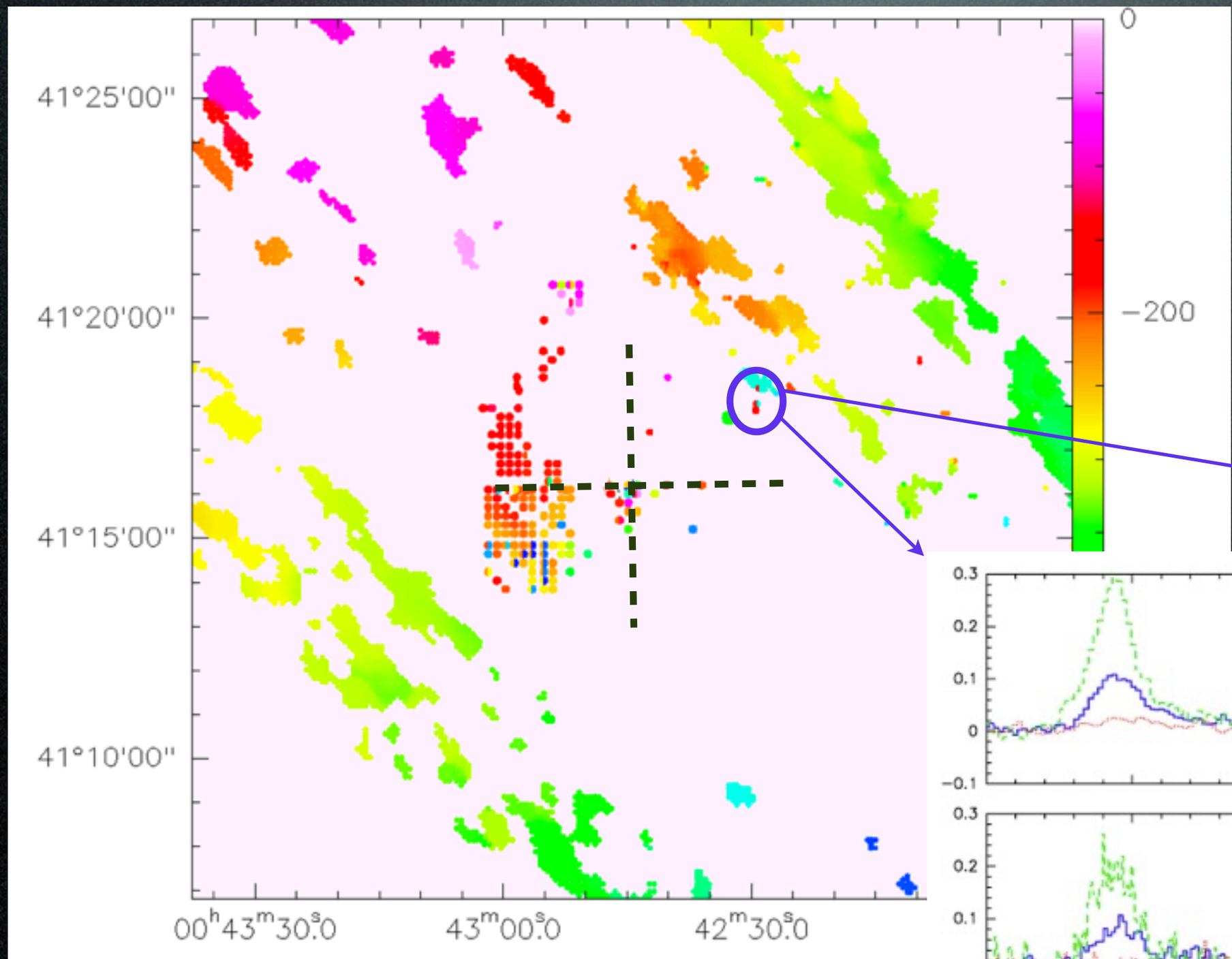

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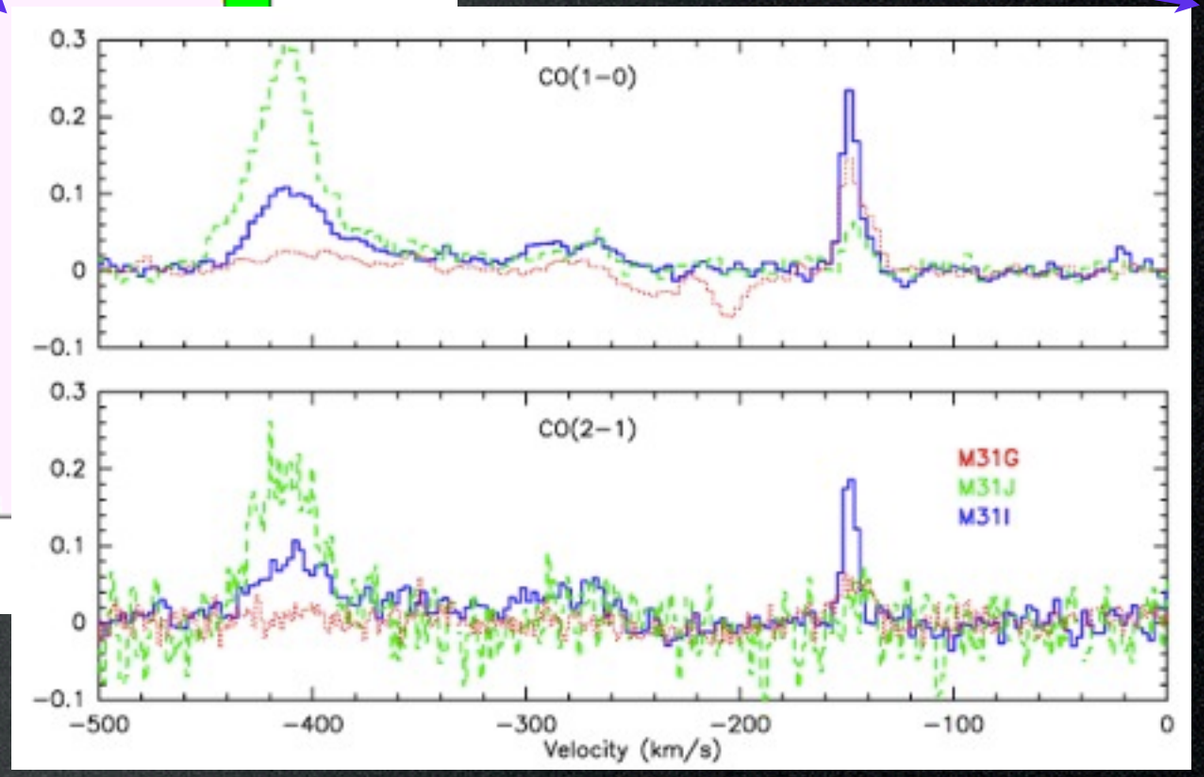

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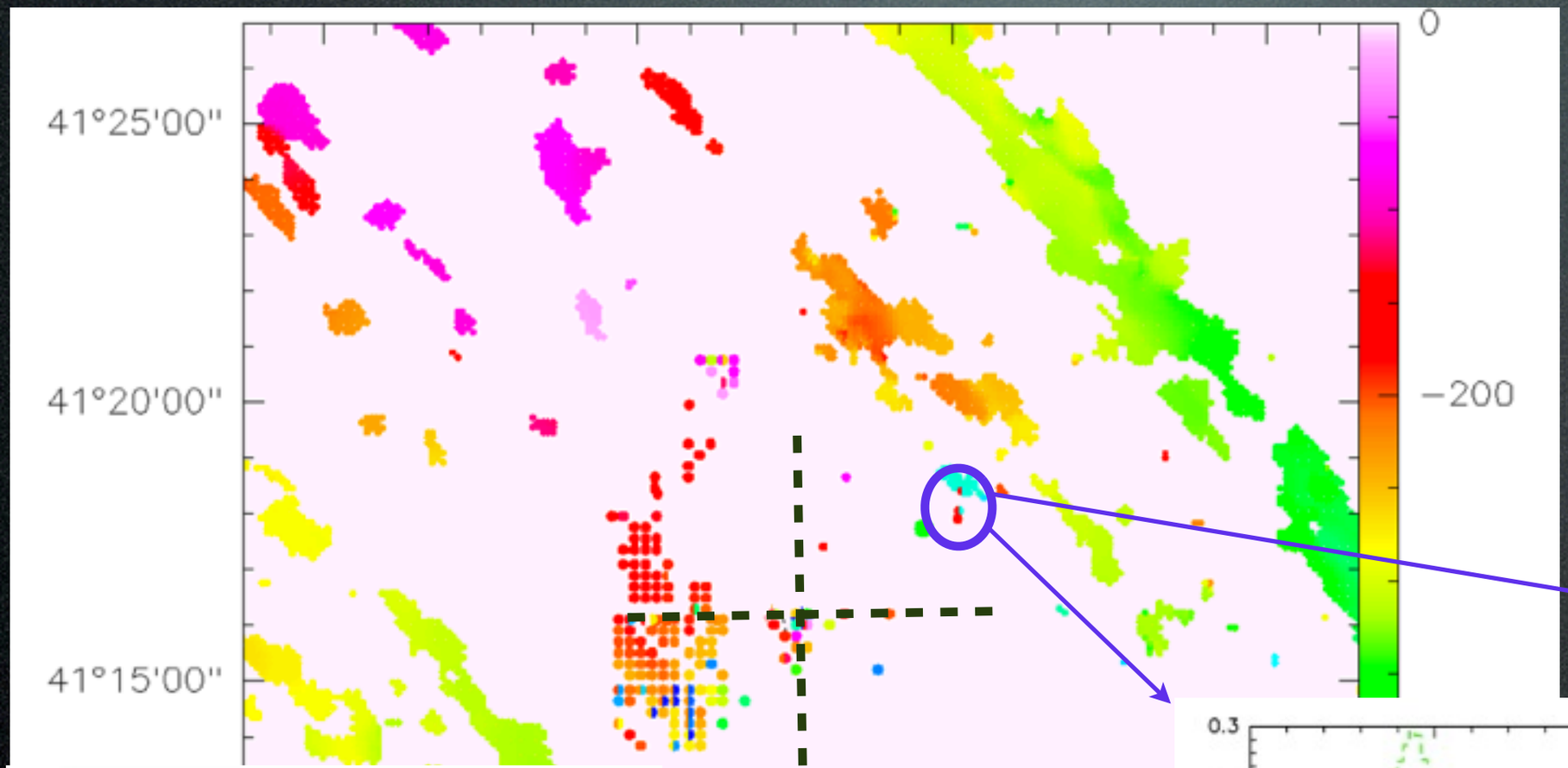
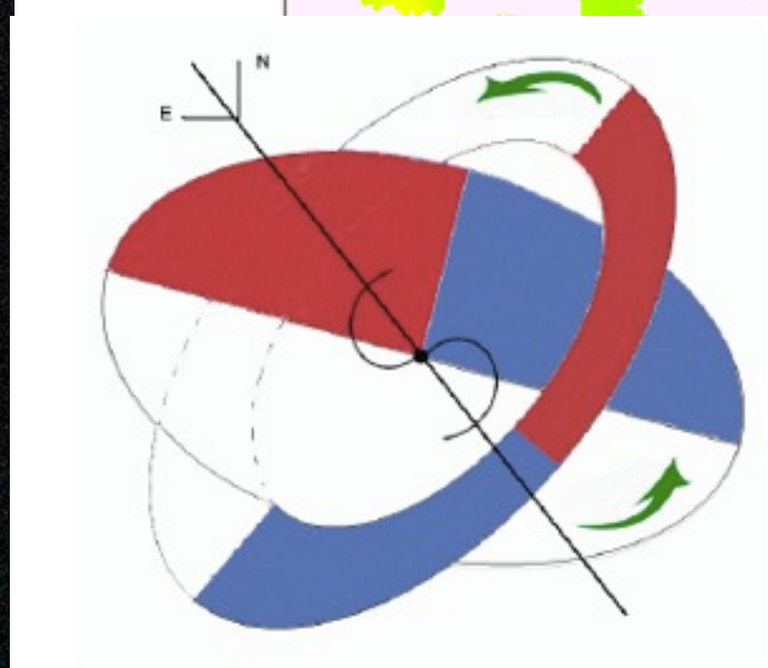
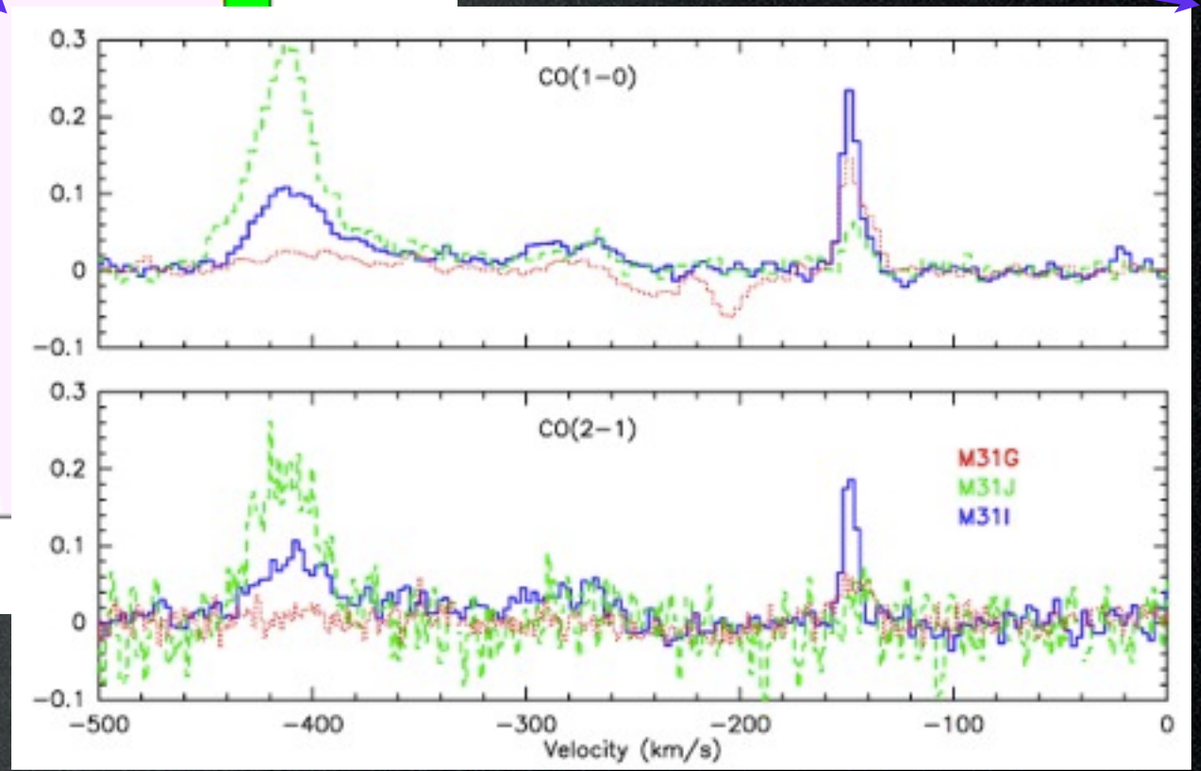
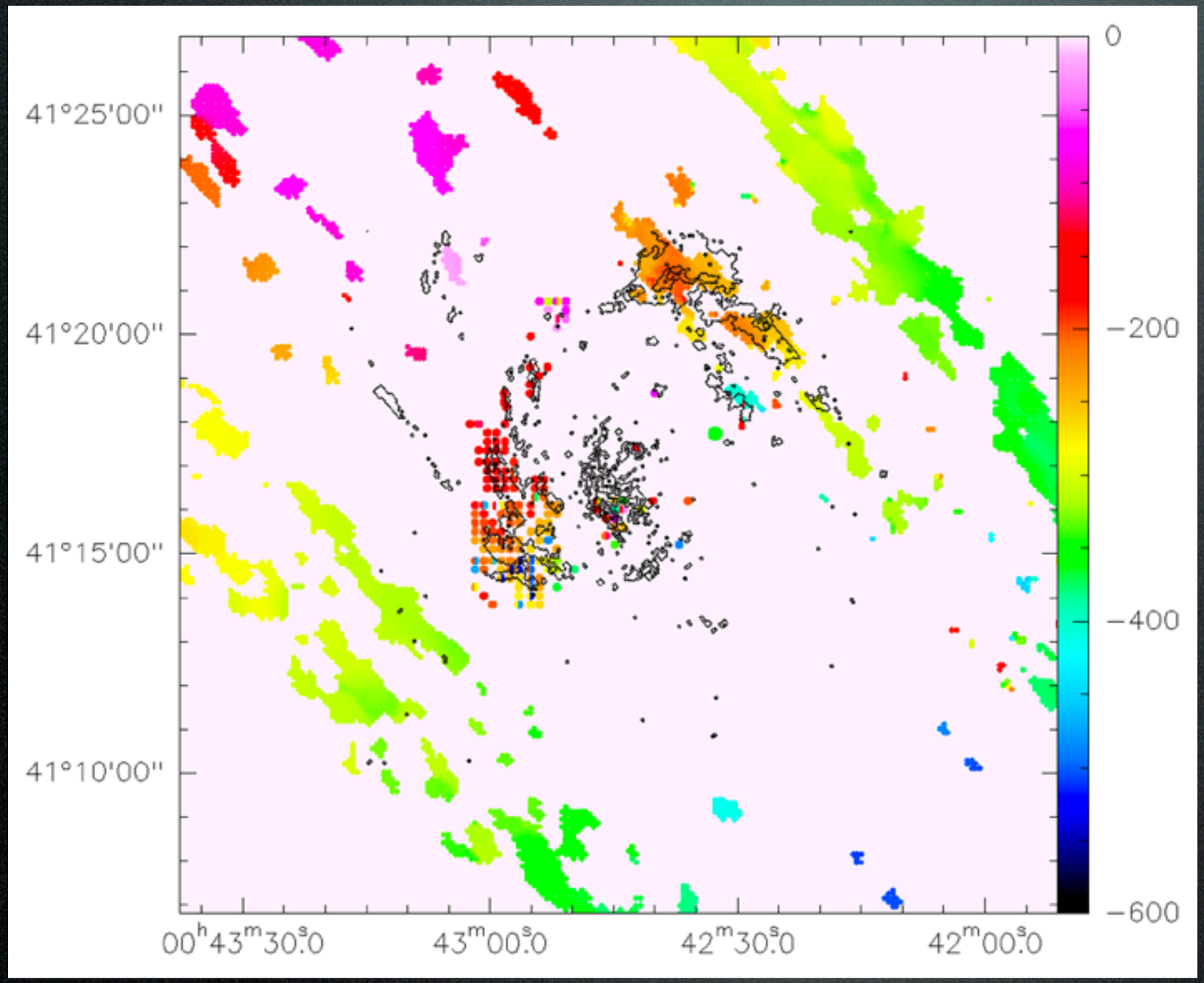




4.5 kpc x 4.5 kpc



Superimposition of 8um Spitzer data from Block et al. (2006)



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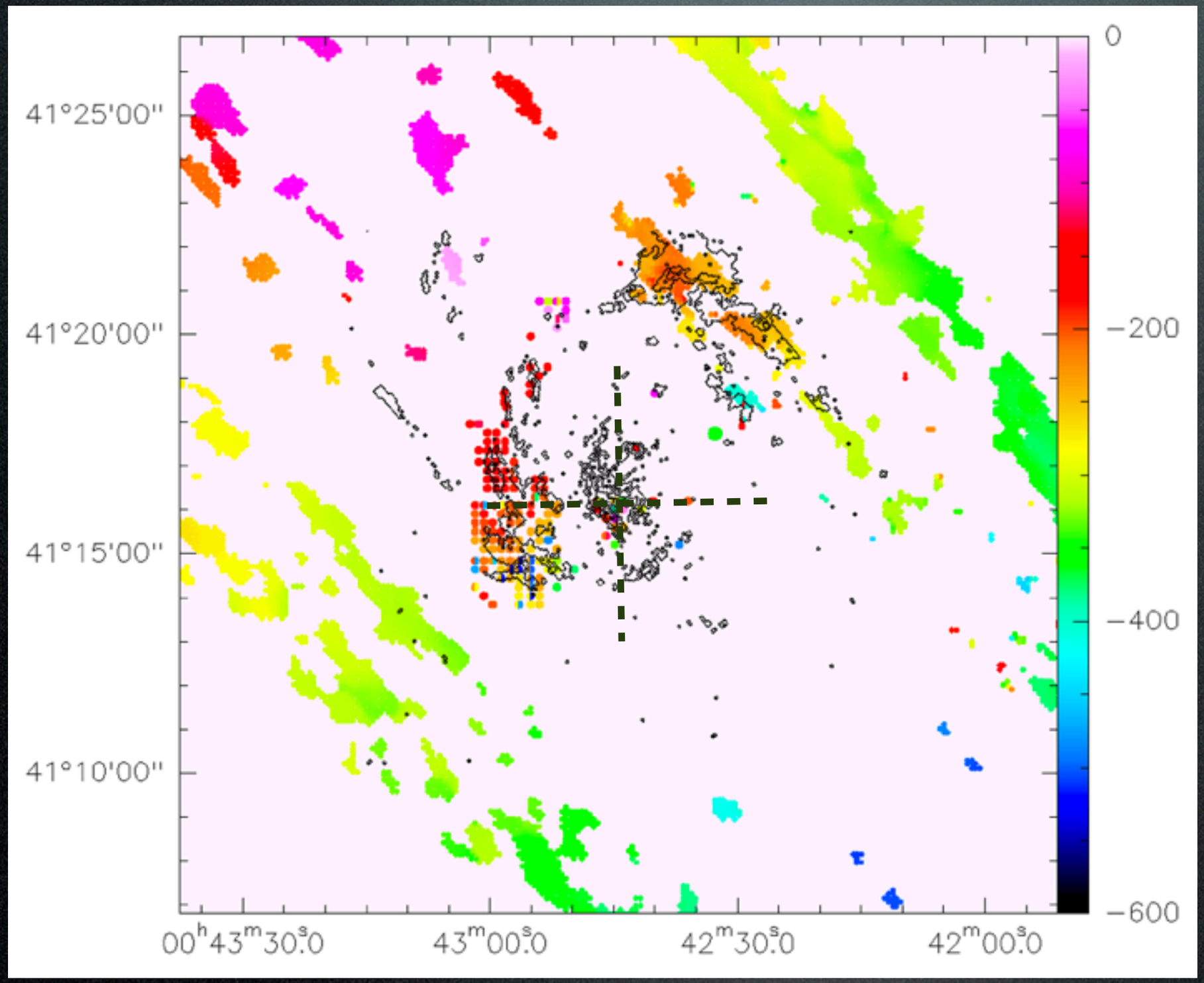

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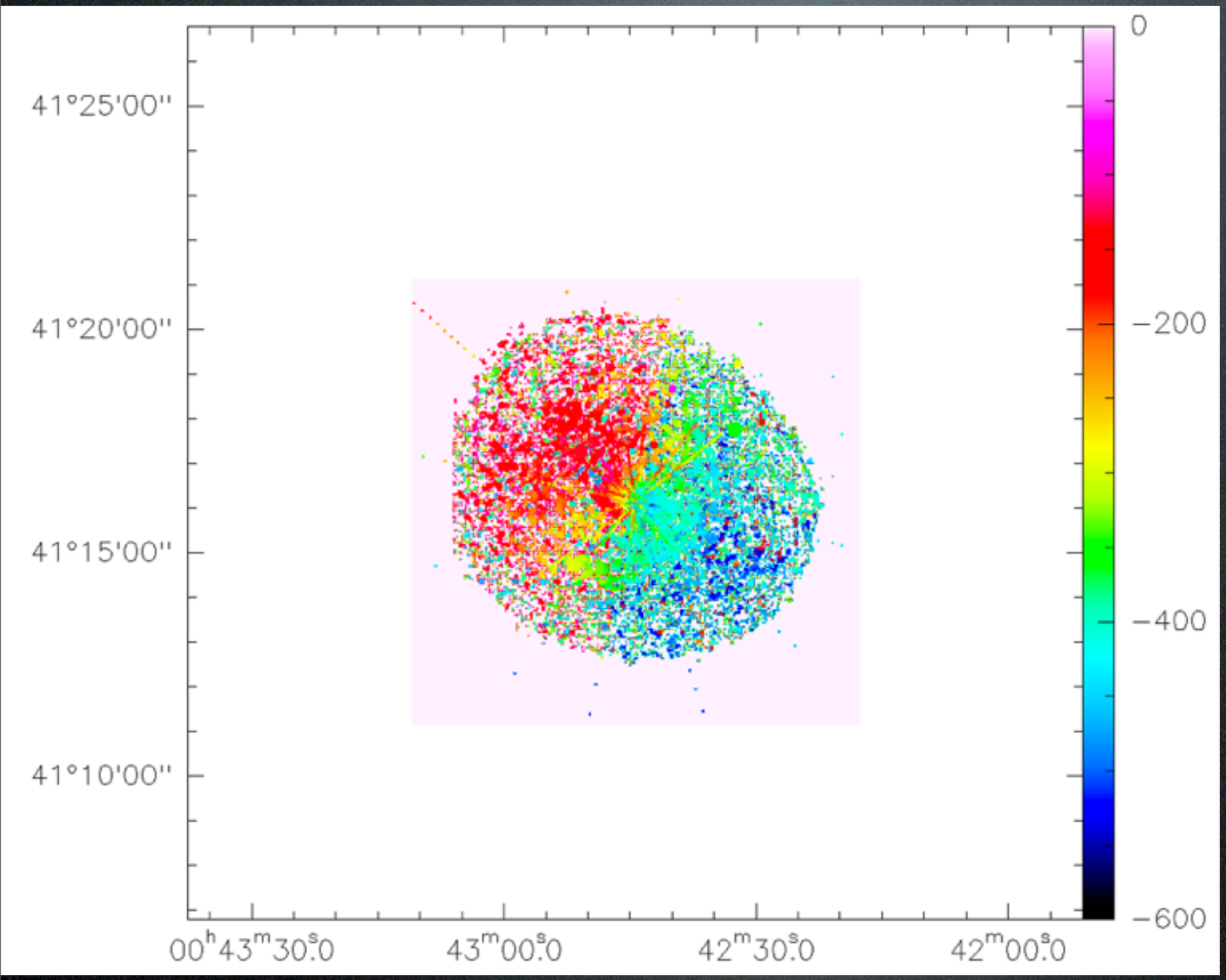
Ionised gas velocity field: current state of the art



Boulesteix et al. 1987
(Fabry-Pérot, [NII])

Slits measurements:
Rubin & Ford 1971
Ciardullo et al. 1988
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20' x 20'

New Halpha observations at Mont Megantic , Canada (Fabry-Perot)..... work in progress

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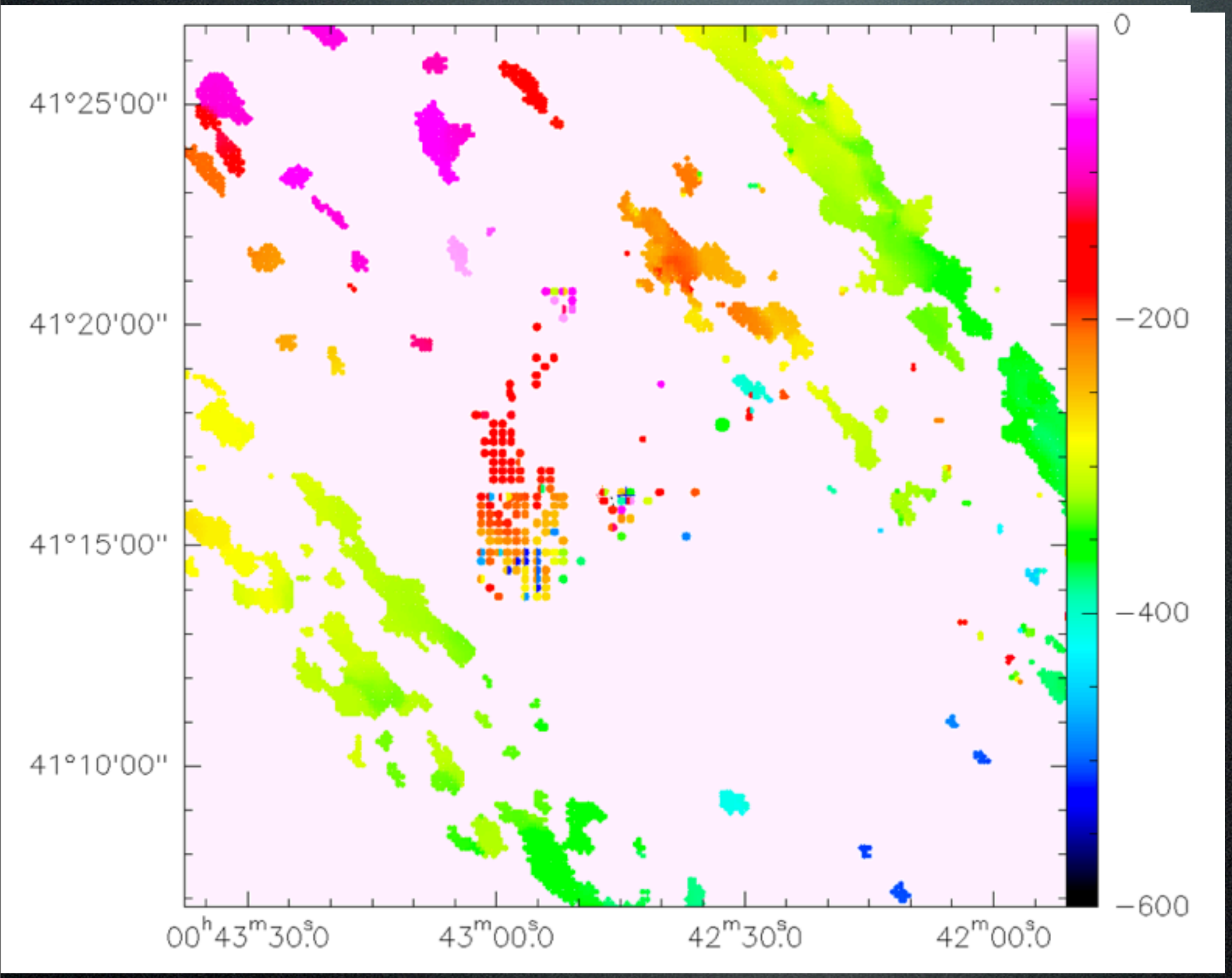

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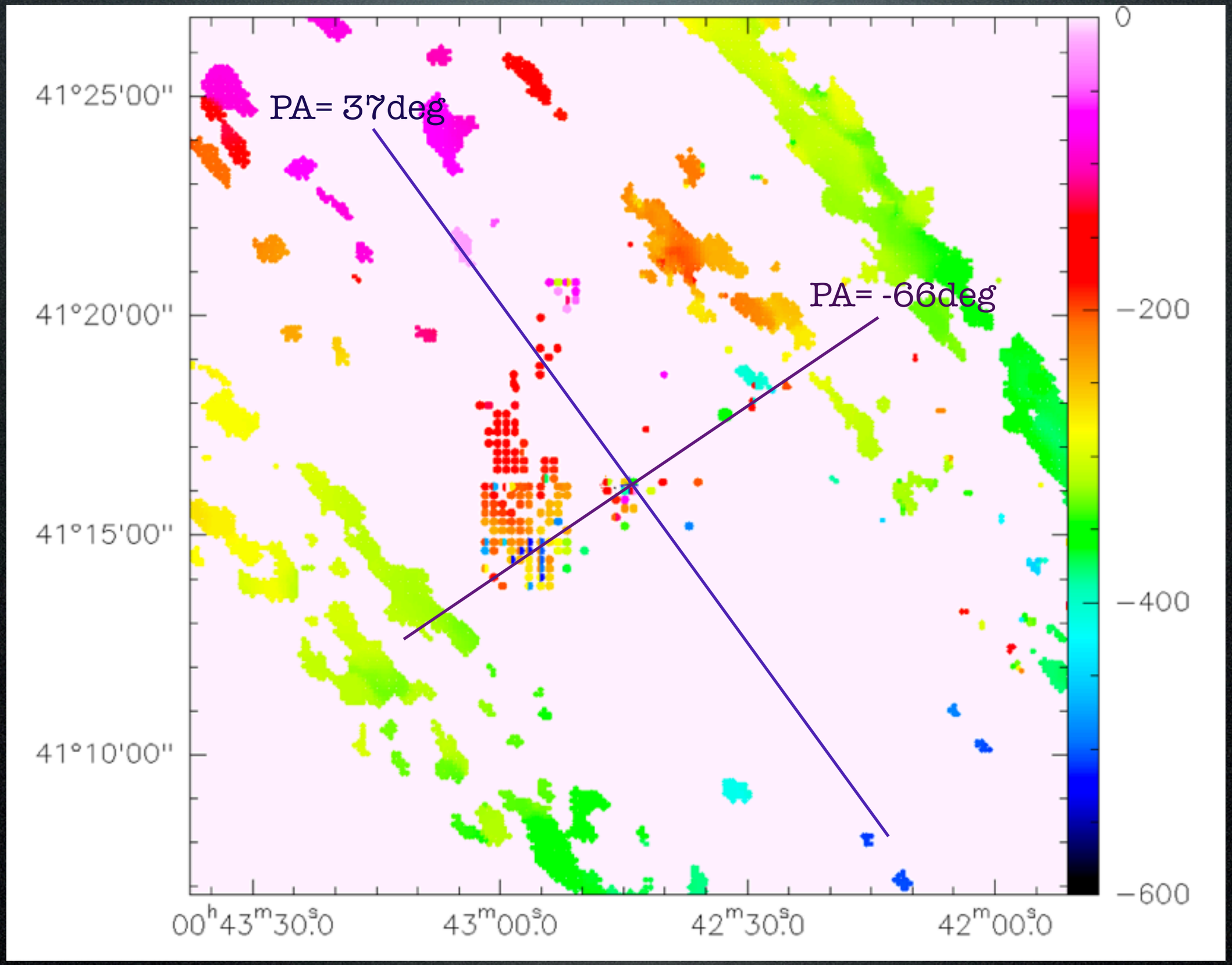
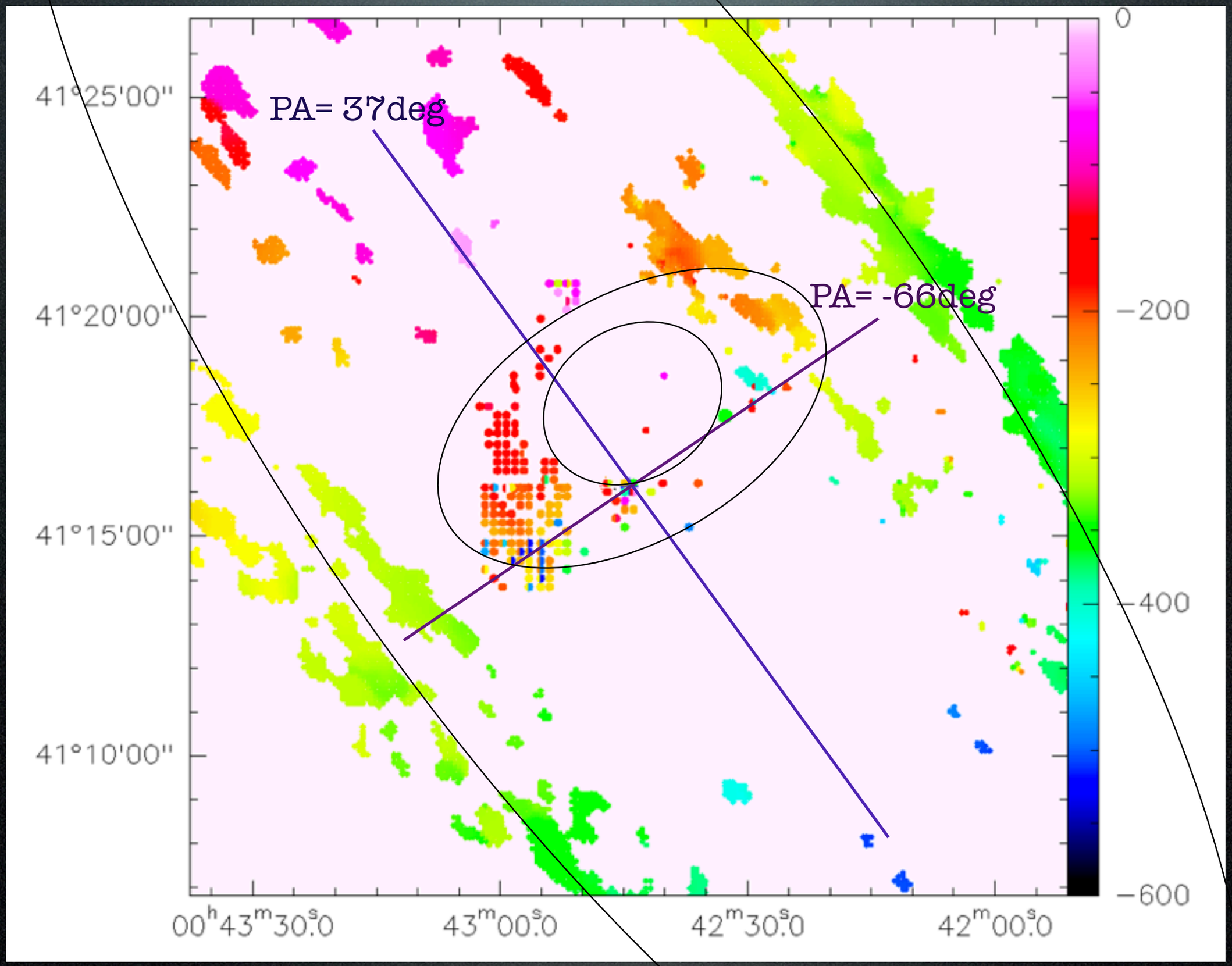

PA= 37deg
PA= -66deg
41°25'00"
41°20'00"
41°15'00"
41°10'00"
00h43m30s.0
43m00s.0
42m30s.0
42m00s.0
0
−200
−400
−600

20' x 20'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42m30.0s
42m00.0s
0
−200
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20' x 20'

Detection of CO close to the centre

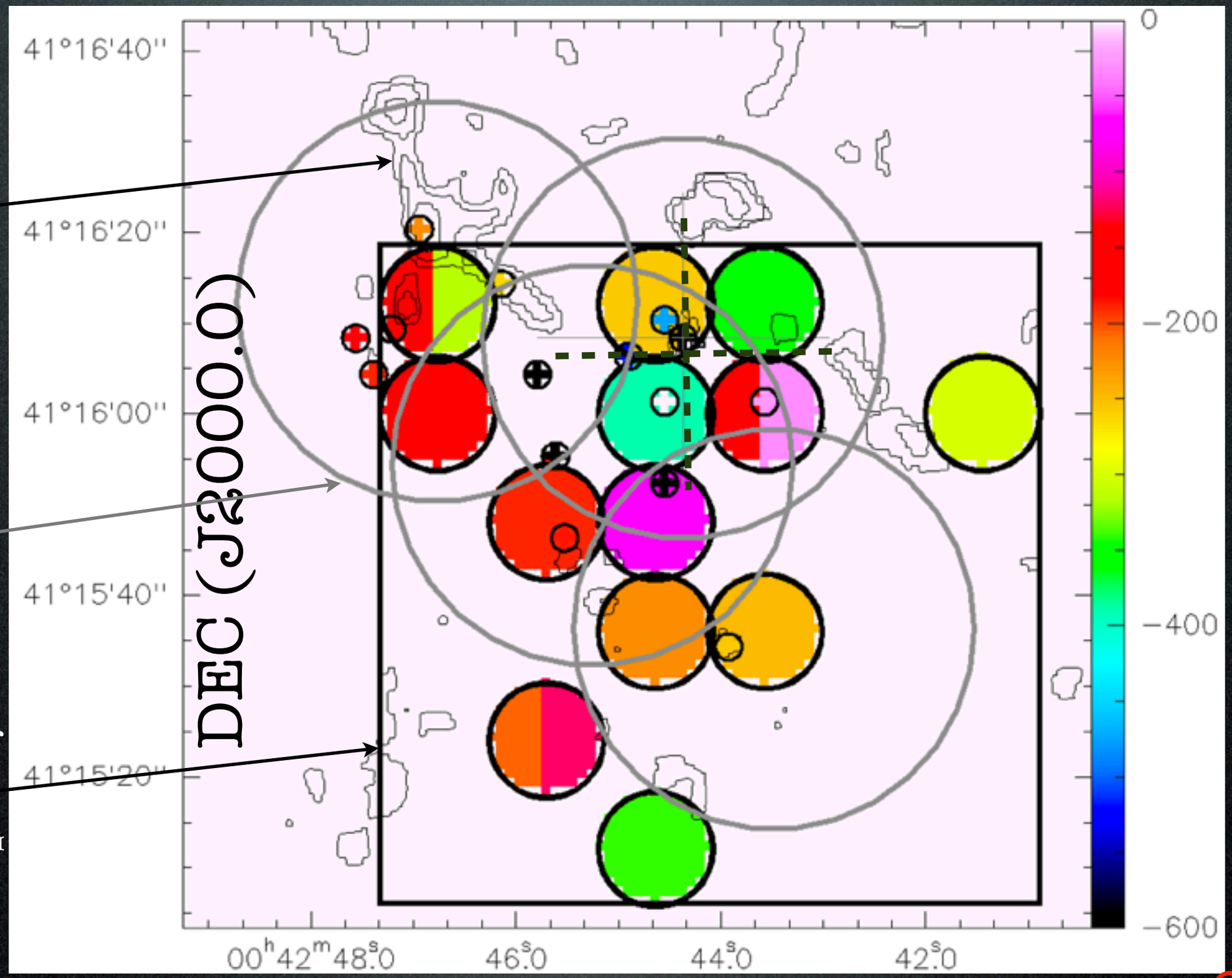
A_B

extinction

Melchior et al 2001

IRAM-PdB interferometer field of view Beam: 2''FWHM

IRAM-30m HERA field of view Beam: 12''FWHM



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

Work in progress

Detection of CO close to the centre

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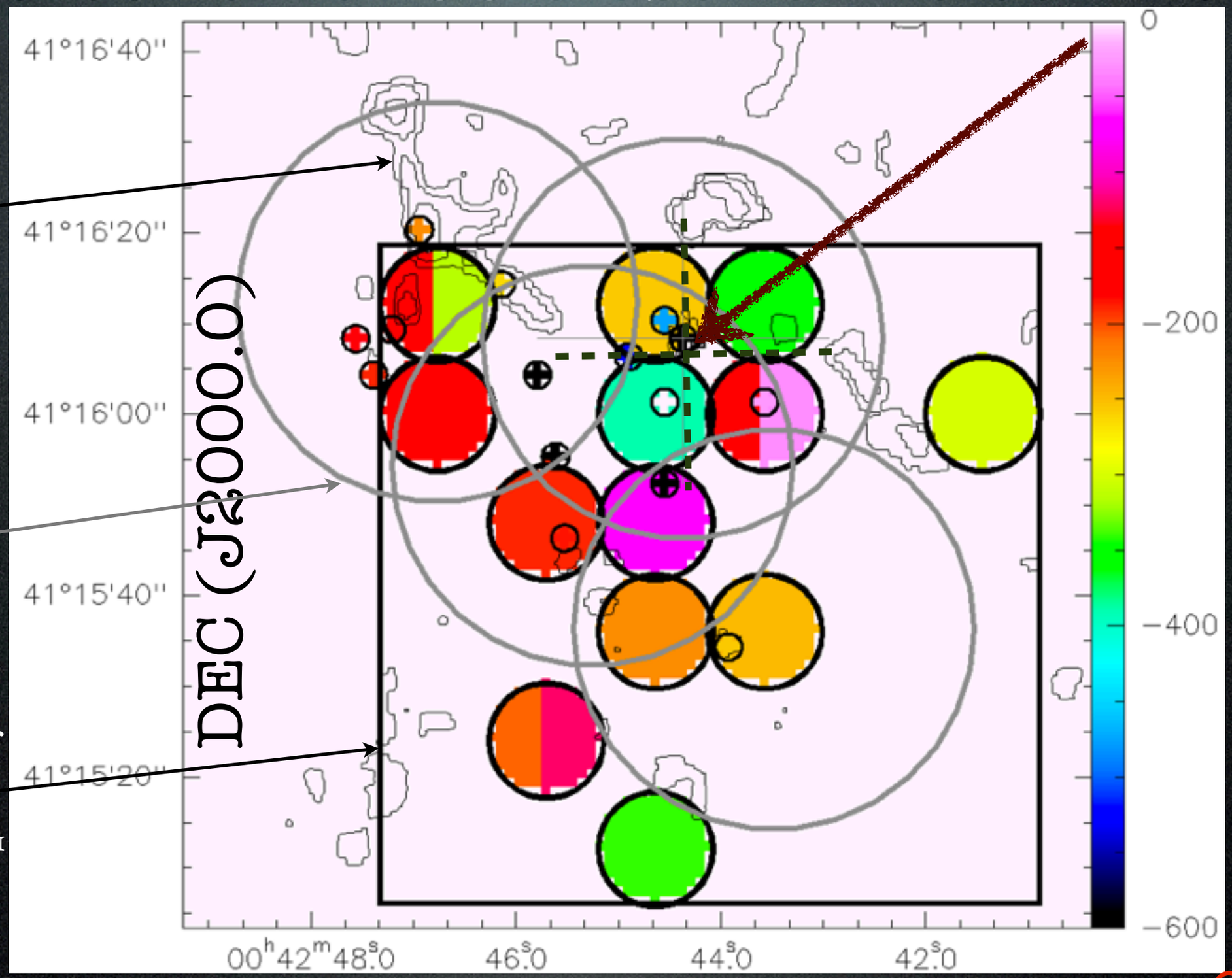

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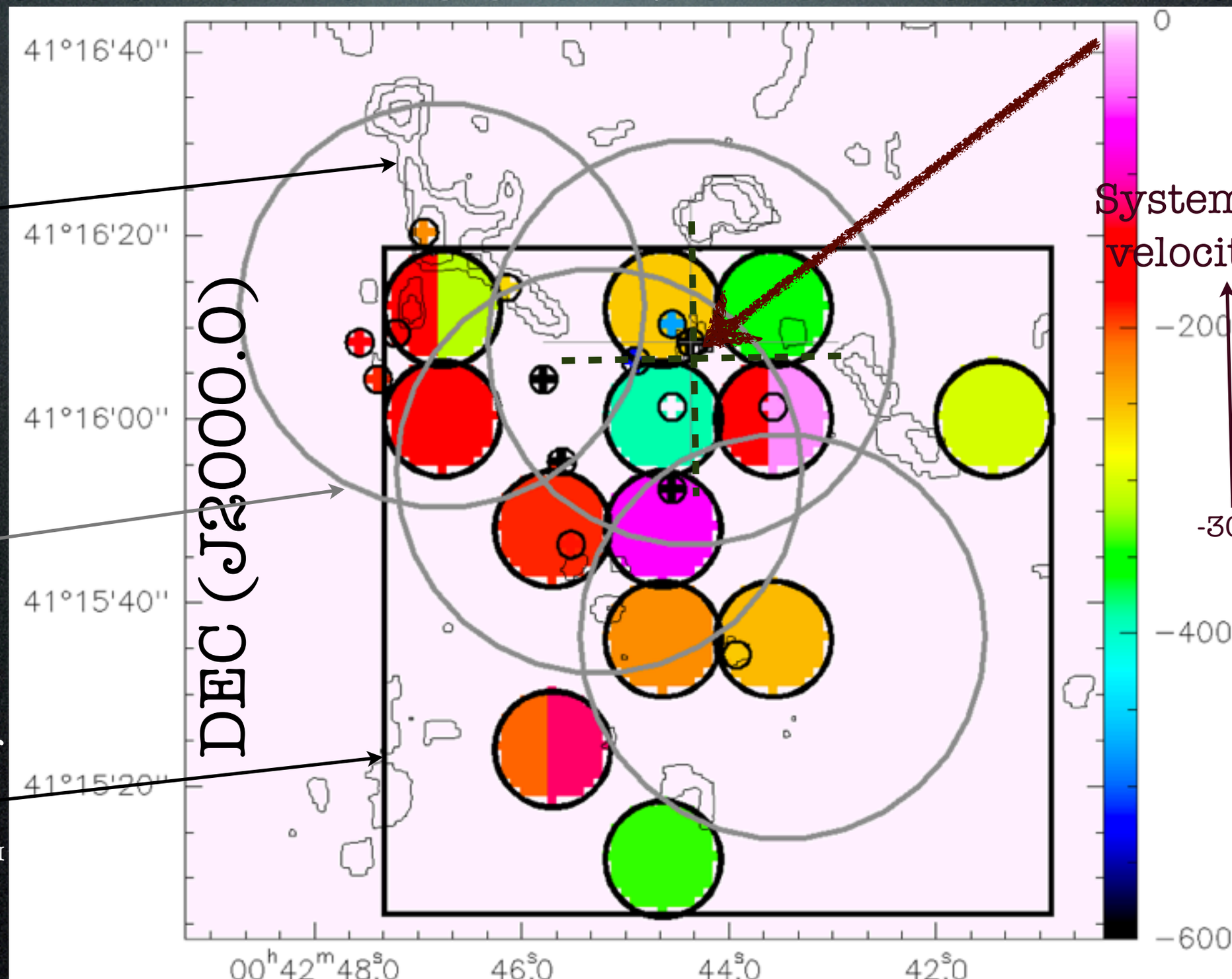

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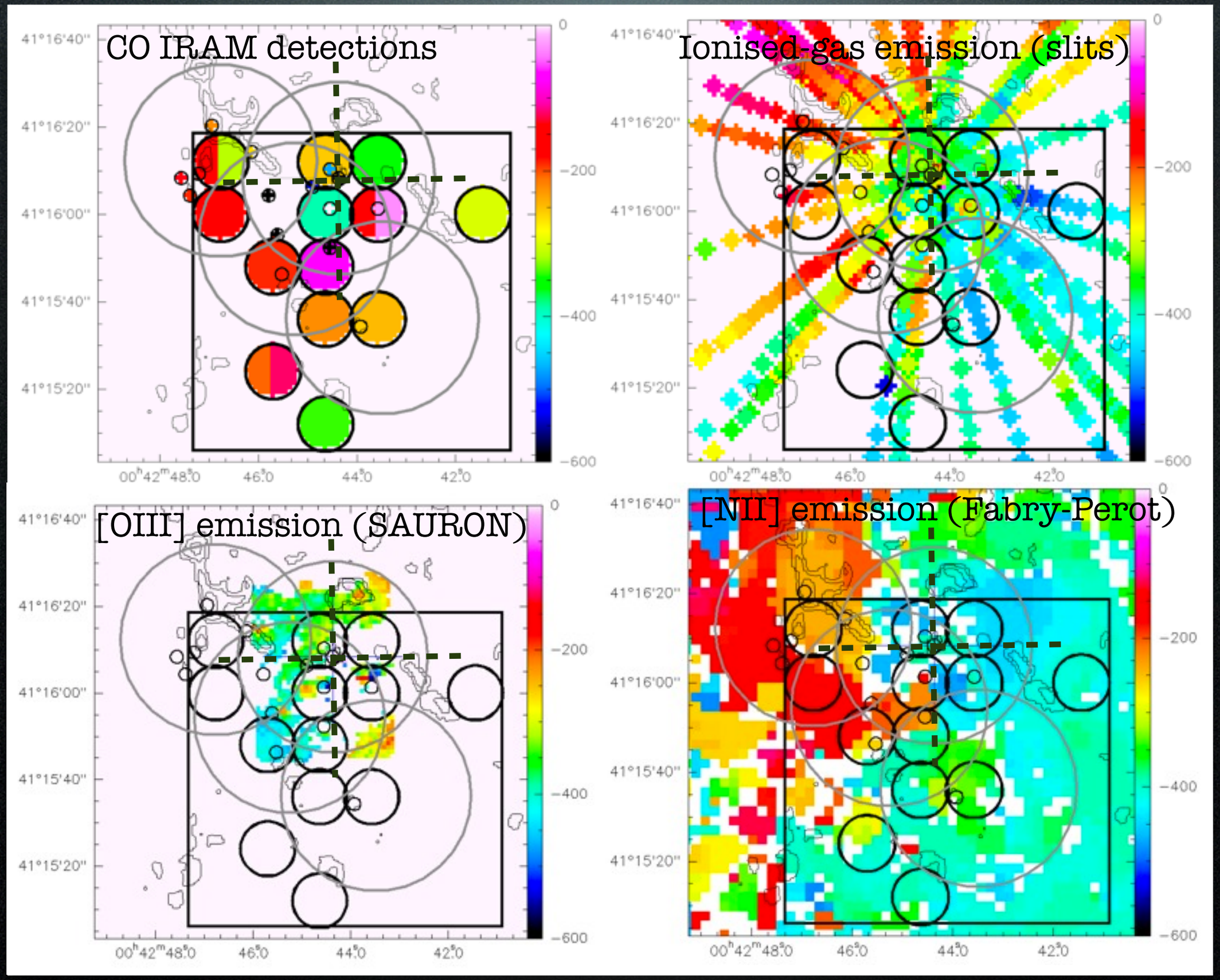
Work in progress

Velocity fields



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

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

Pastorello, Sarzi et al. (2013)

Boulesteix et al. (1987)

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

Mass budget

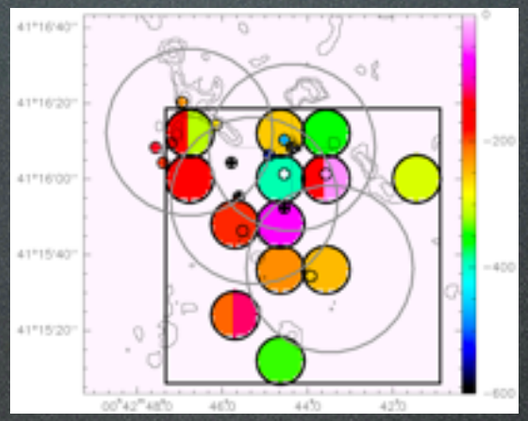
HI data (Braun et al. 2009)

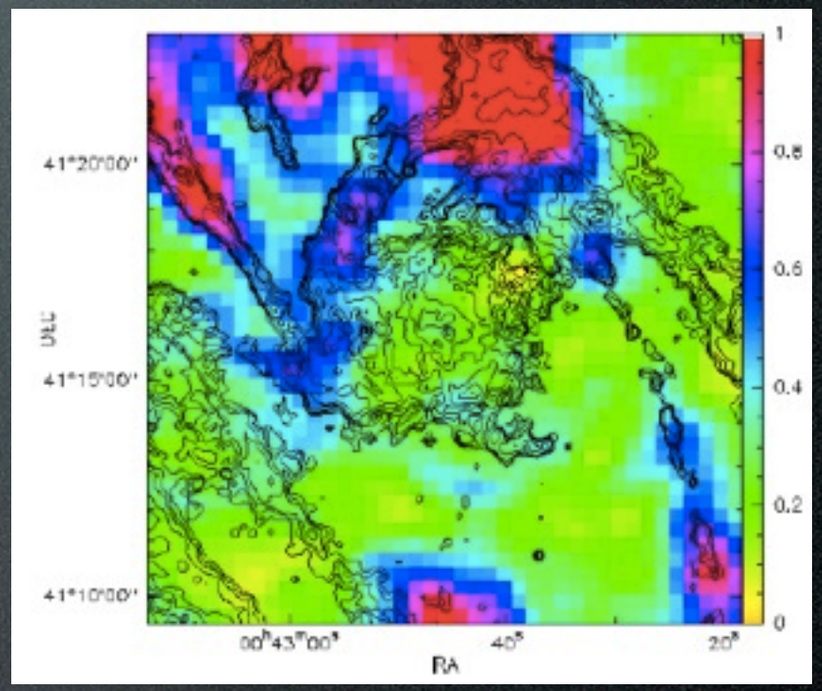
Total measured mass:

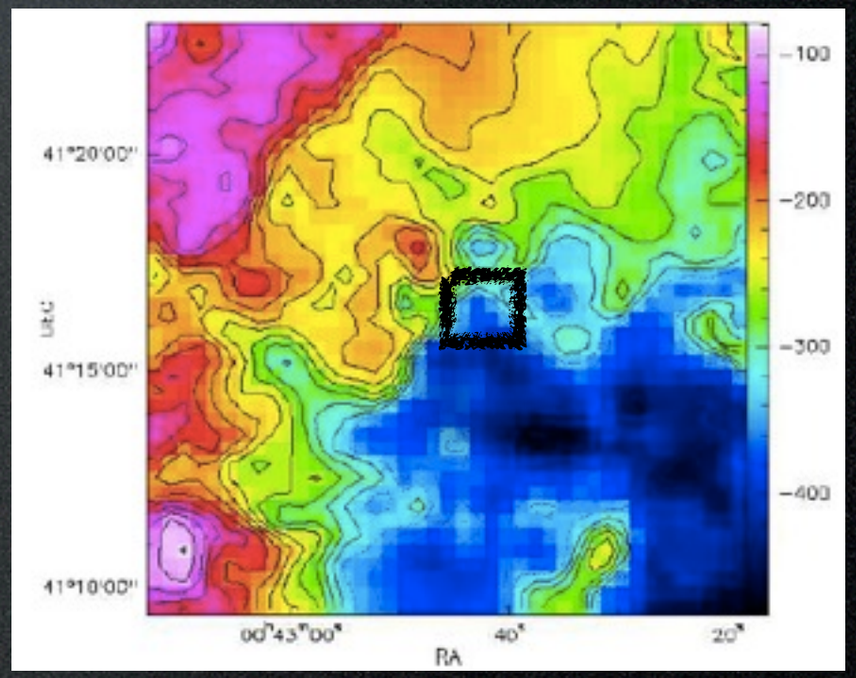
> **4 x 10^4 Msol**

87% with v>-300km/s

13% with v<-300km/s

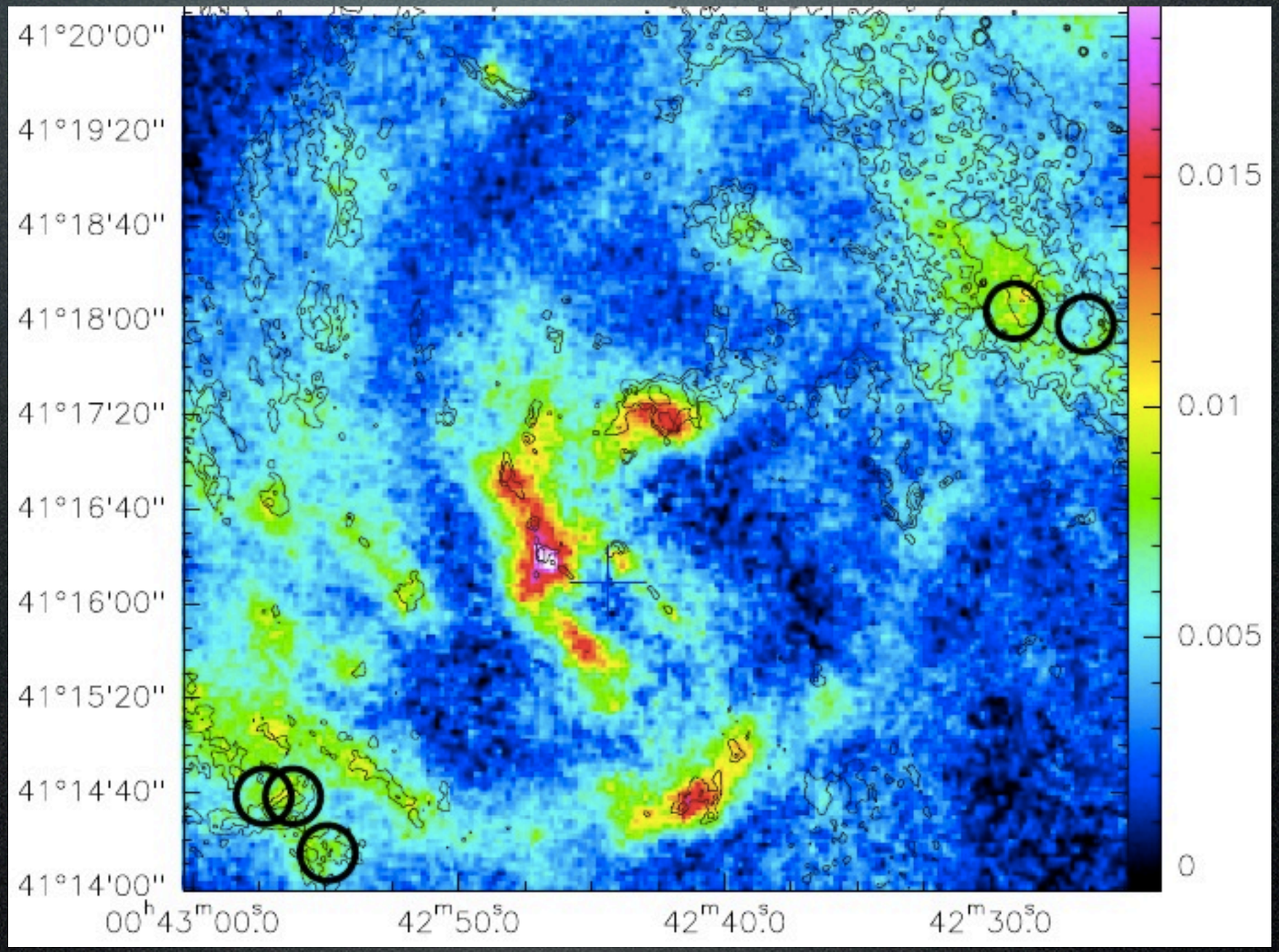






There is some molecular gas next to the black hole but it does not rotate.

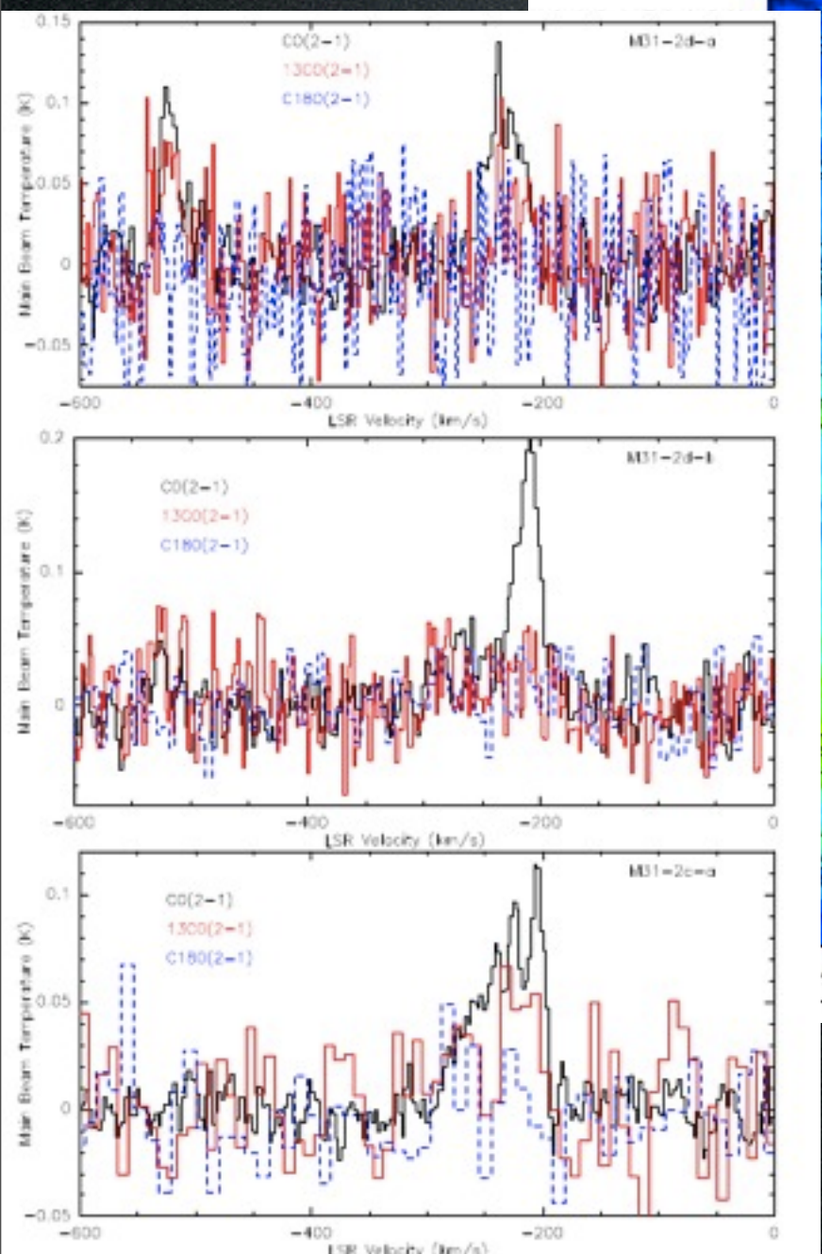
Search for dense gas at IRAM 30m

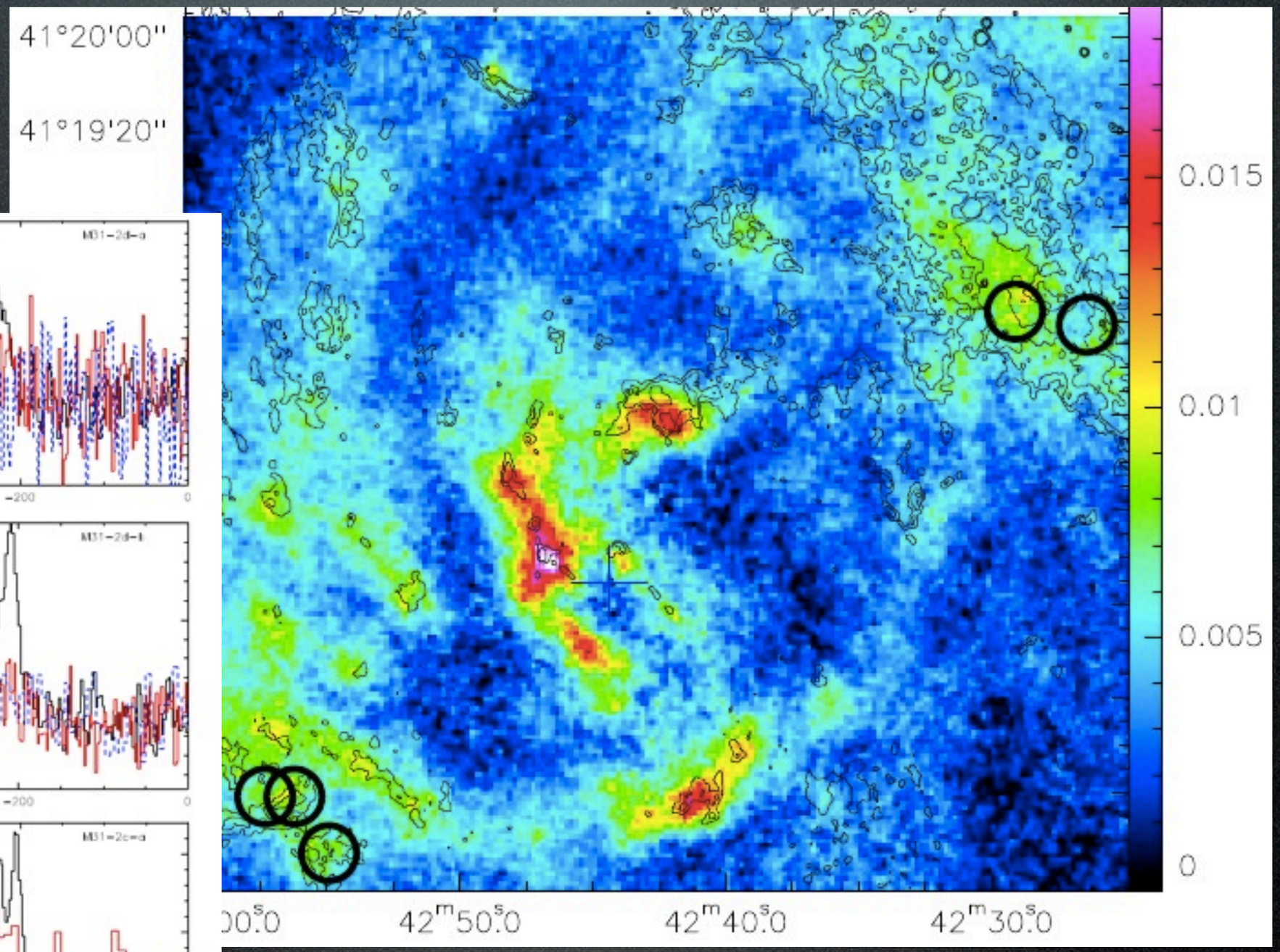


PACS 100um
Courtesy : S. Viaene

Search for dense gas at IRAM 30m

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





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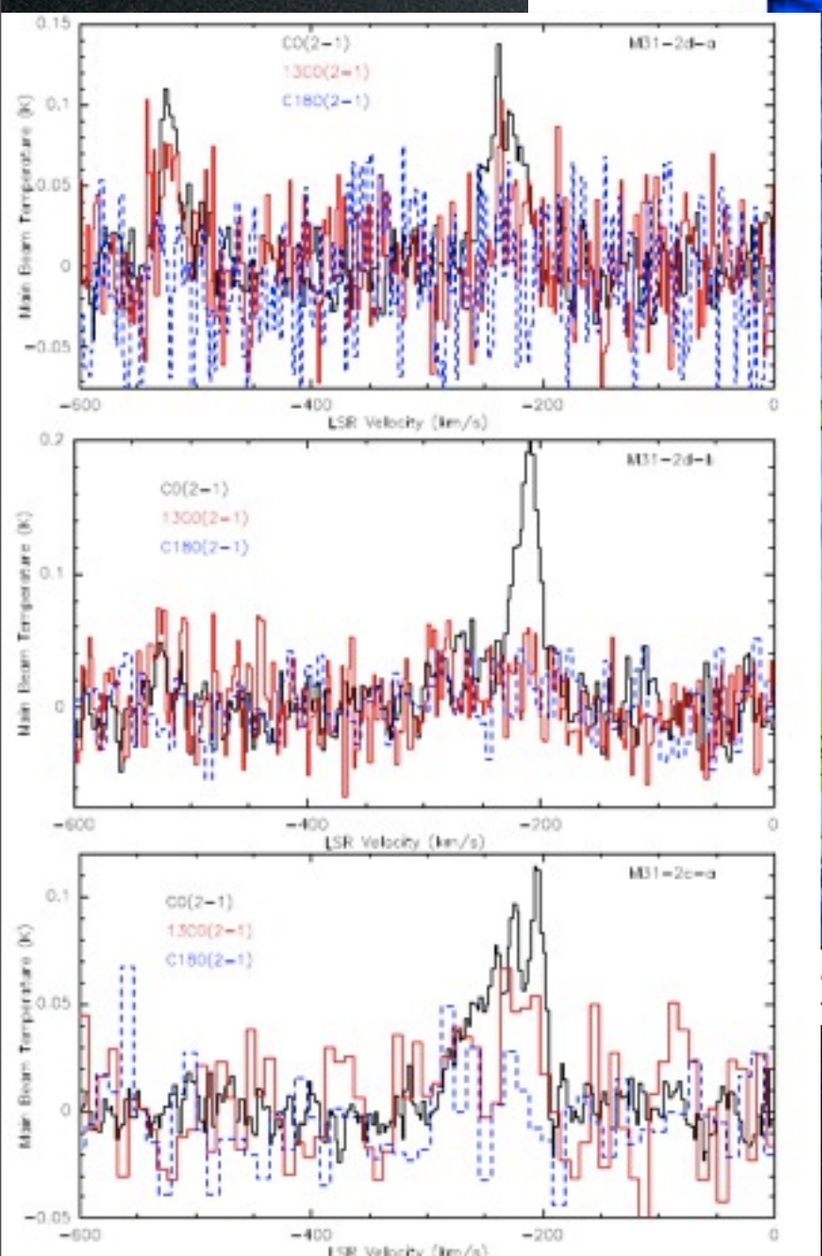

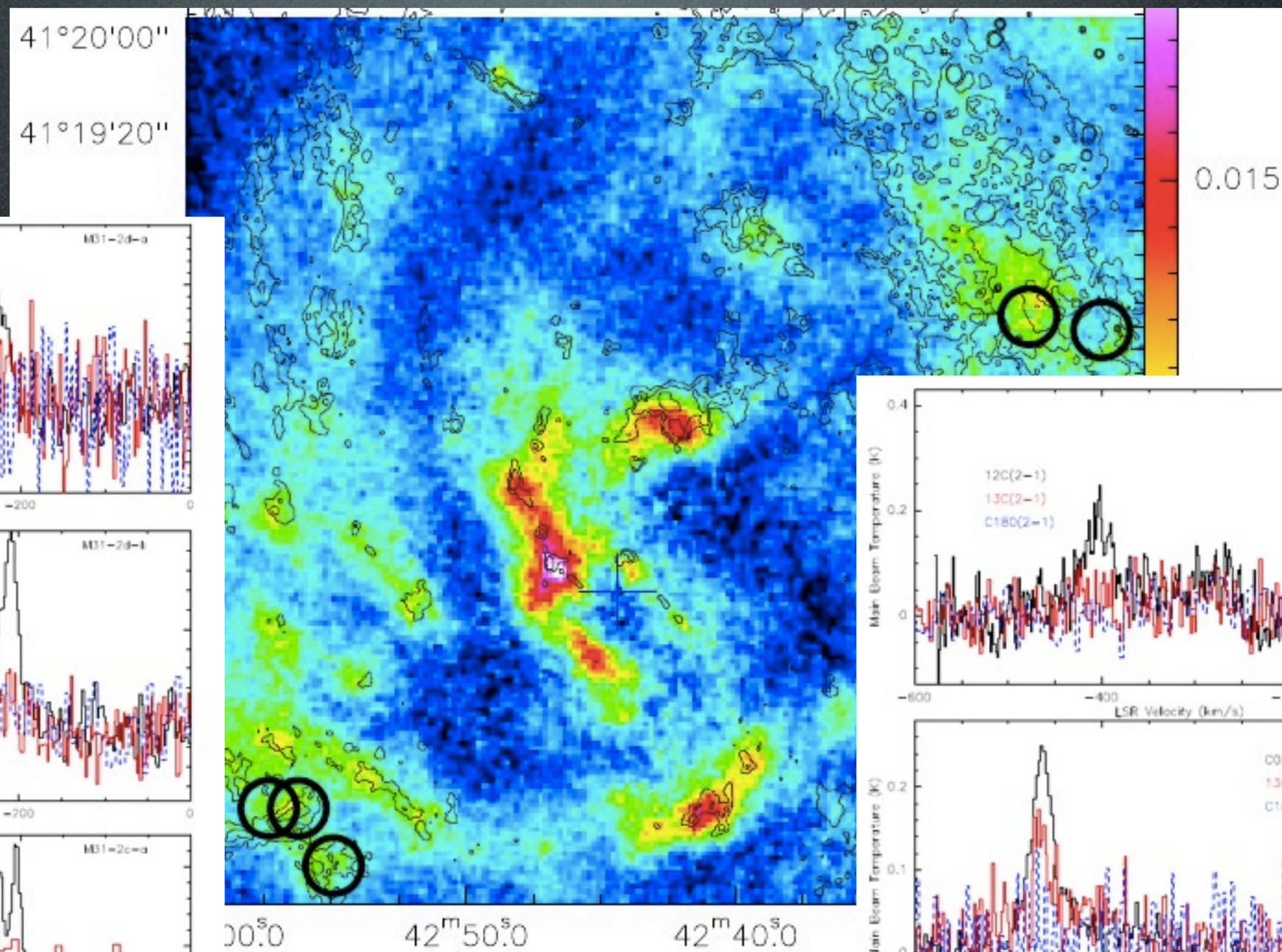

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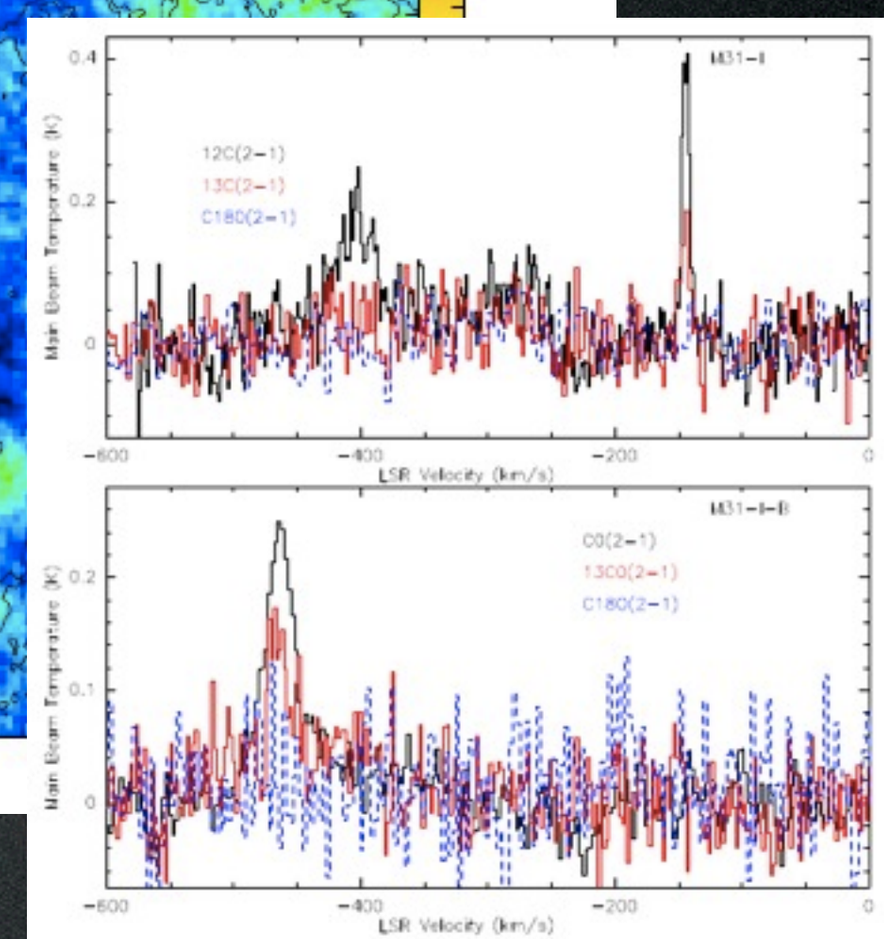

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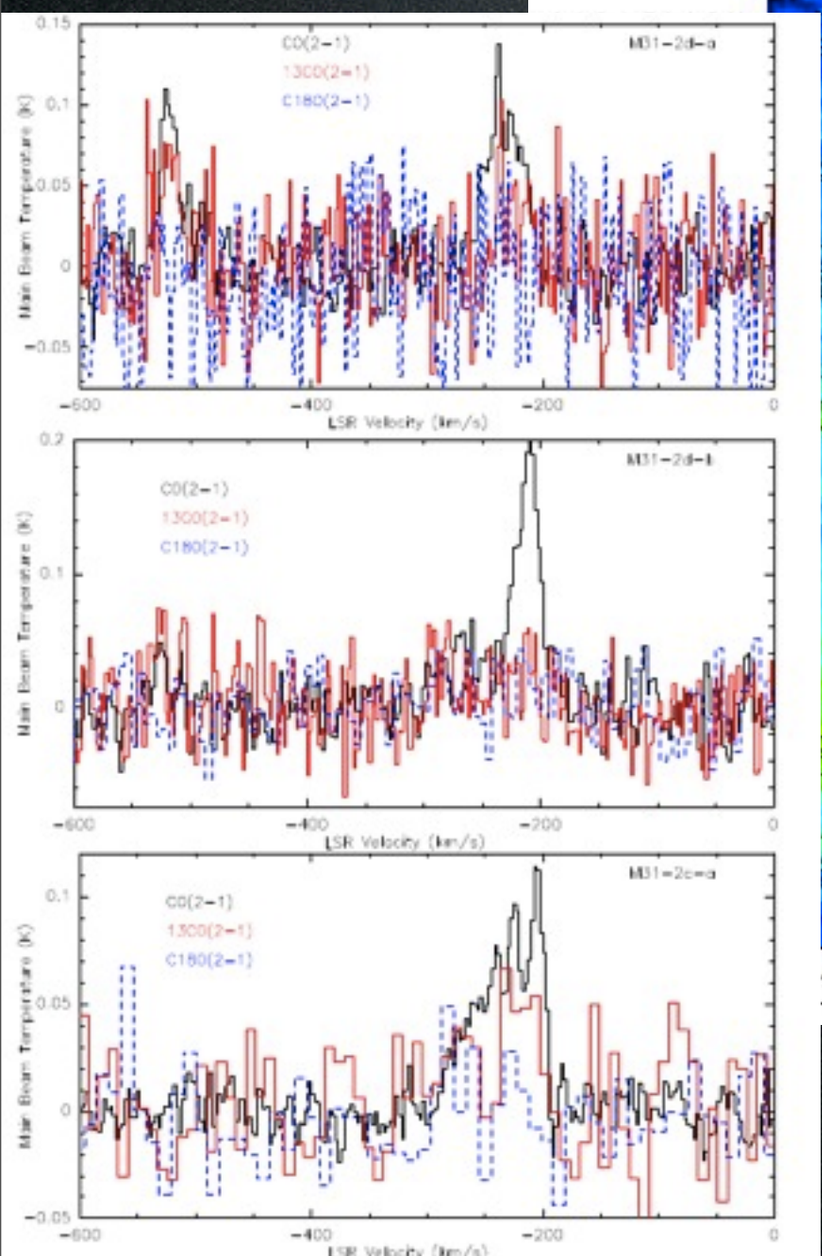
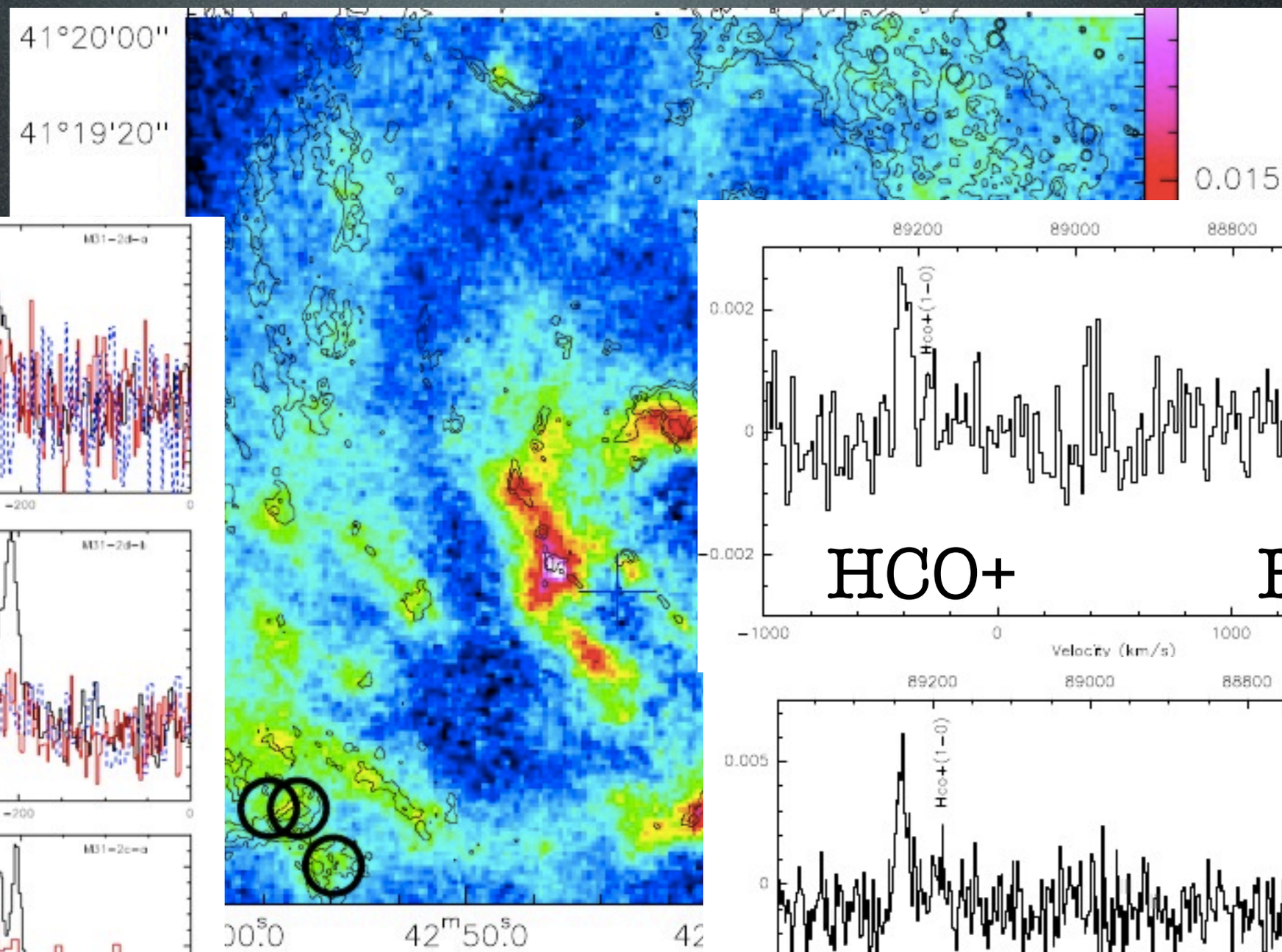
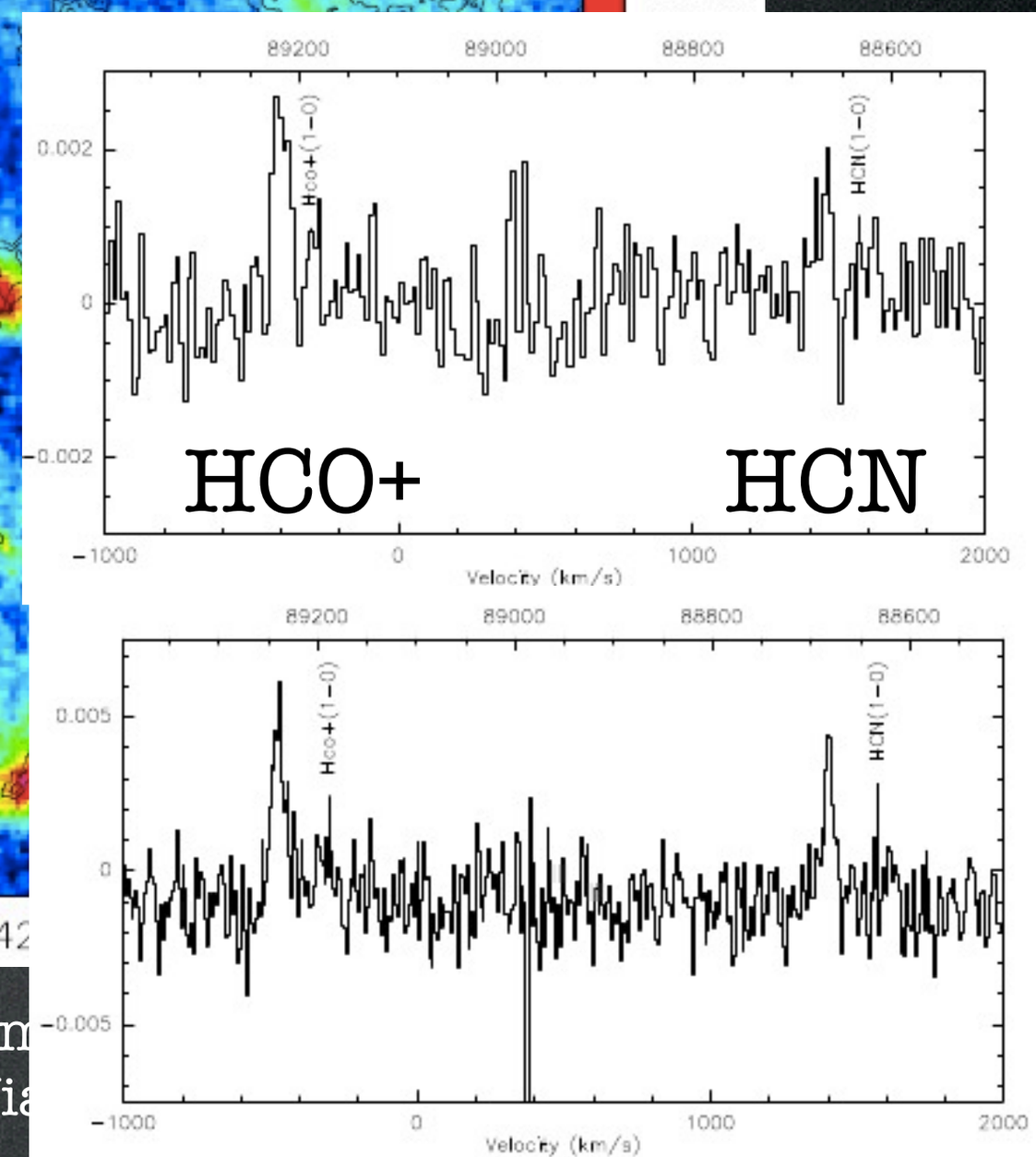






PACS 100um
Courtesy : S. Via

What do we know from other data...

	tau_V	M_*	M_{dust}	SFR Msol/Myr
I	0.52	3.2 10^7	2.9 10^3	3.2
I-B		2.4 10^7	2.9 10^3	2.8
2d-a		3.2 10^7	0.9 10^3	1.3
2d-b		3.2 10^7	0.9 10^3	1.3
2c-a	1.9	3.5 10^7	1.5 10^3	1.6

One difficulty: **the filling factor**!

T_{dust}=20K

beam = 11arcsec FWHM
= 40 pc

Viaene et al. 2014

One «clump» in M31 - I

	^{12}CO	^{13}CO	$C^{18}O$
Tpeak (mK)	77	4.9	4.5
Delta v (km/s)	69 (18)	69	69
ICO (K km/s)	6(1)	0.36(0.06)	0.29(0.07)

v=-291(9) km/s

N_{H2}=1.2 10^{21}cm^{-2}

Melchior & Combes 2011:
CO(2-1)/CO(1-0)=0.8
--> subthermal
$T_{ex}<T_K=T_{dust}$=20K

Expected abundance ratios (ISM) (**4kpc** -- GC)
Wilson & Wood 1994
$^{12}CO/^{13}CO$ = 53 -- 20
$^{12}CO/C^{18}O$ = 327 -- 250
$^{13}CO/C^{18}O$ = 6.2 -- 12.5

$^{12}CO/^{13}CO$ = 16.7(0.3)
$^{12}CO/C^{18}O$ = 20.7(0.4)
$^{13}CO/C^{18}O$ = 1.24(0.4)

--> Optically thick

What is the state of the gas?

$T_B = eta_{bf} (f(T_{ex})-f(T_{bg})) (1-exp(-tau))$ with tau>>1

$T_B = eta_{bf} (f(T_{ex})-f(T_{bg}))$

eta_{bf} : **beam filling factor**

T_{ex} : **excitation temperature** ; T_{bg}: background temperature

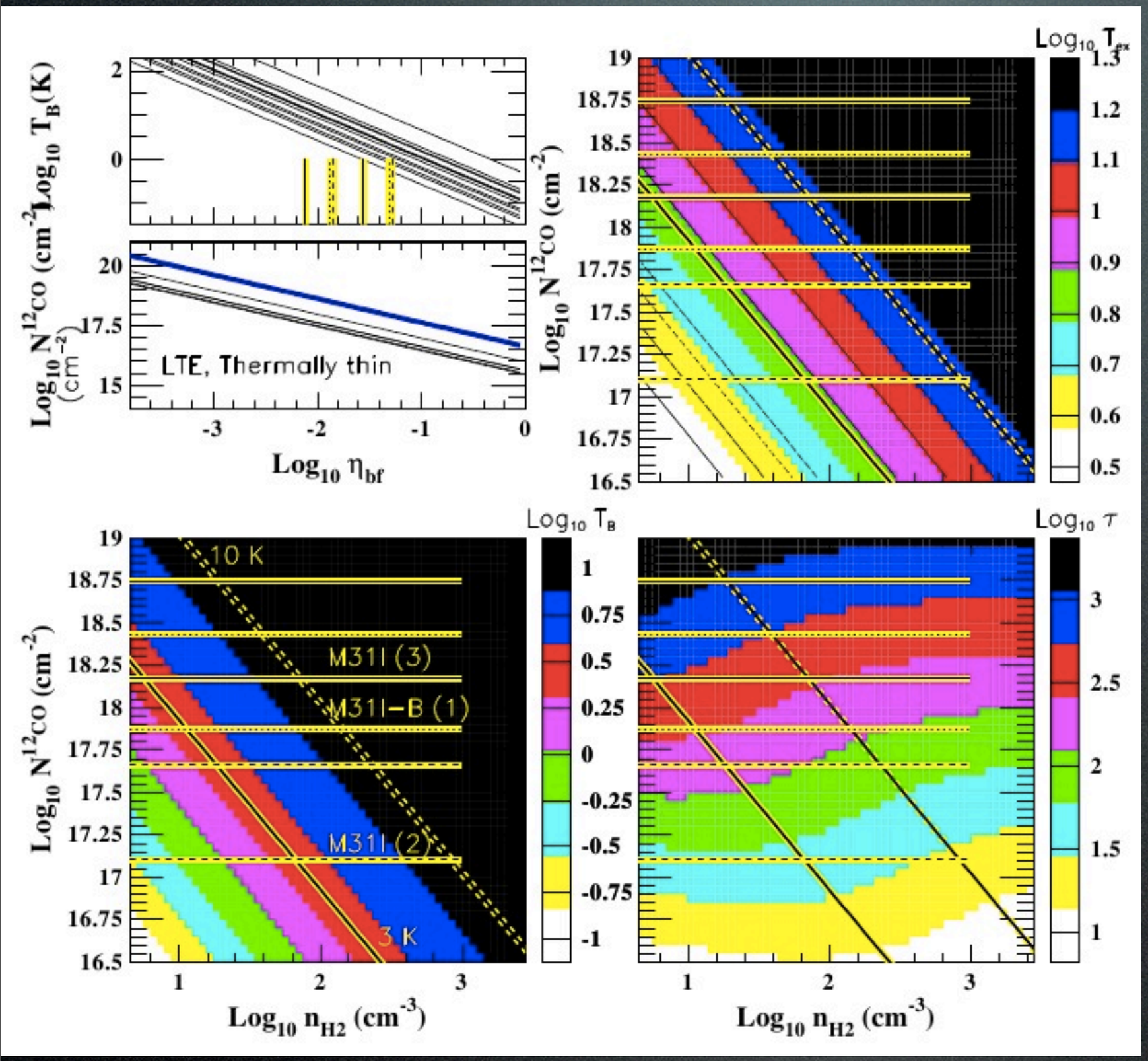
Larson's relations not conclusive...

Assumptions:

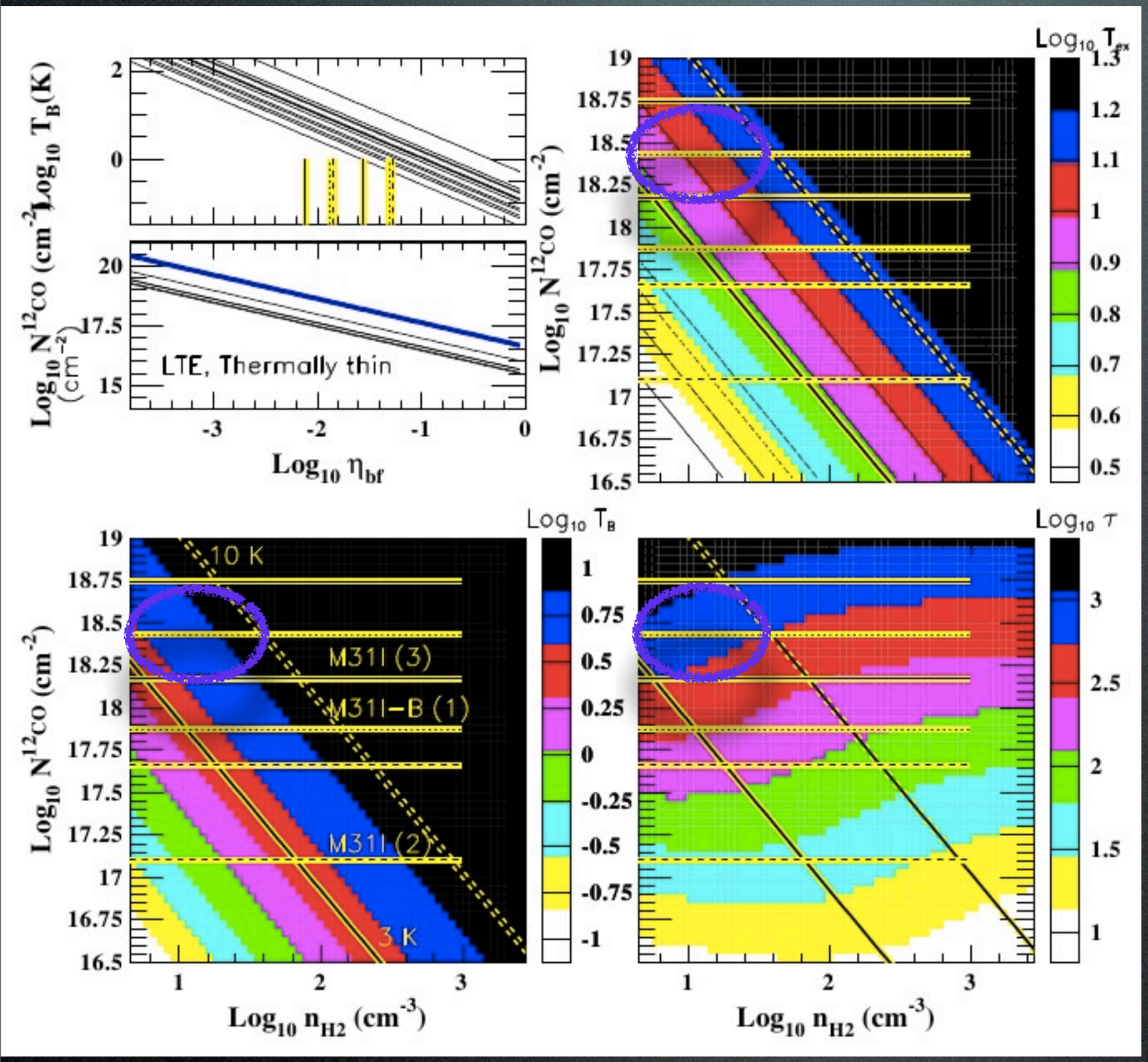
1. Standard abundances of the ISM : $X_{CO}=2.8\ 10^{-5}$ (Bergin et al. 1995)

2. T_B/eta_{bf} = 3-**10K** (--> filling factor)

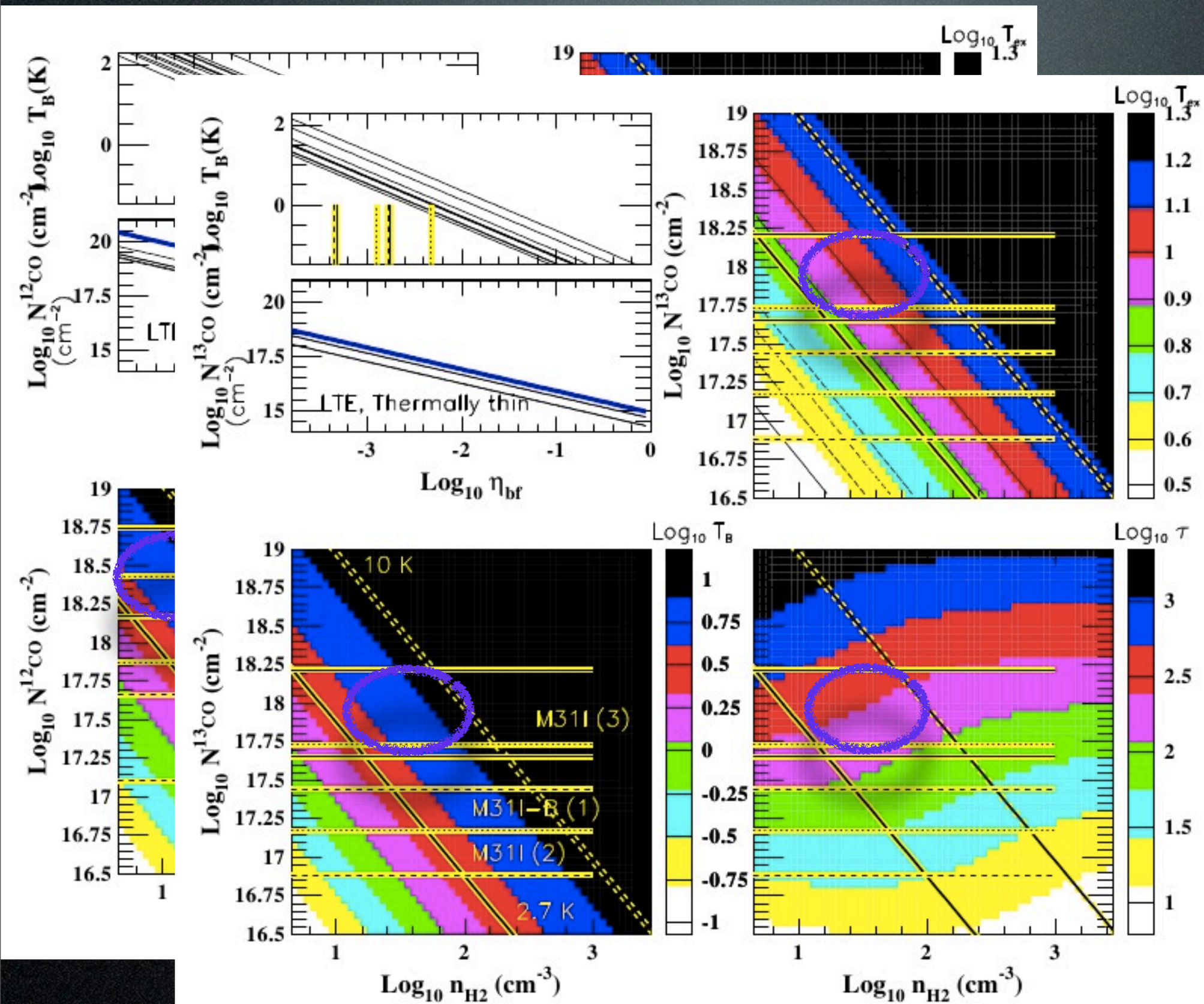
Comparison with (non-LTE) **RADEX** simulations (van der Tak et al. 2009)



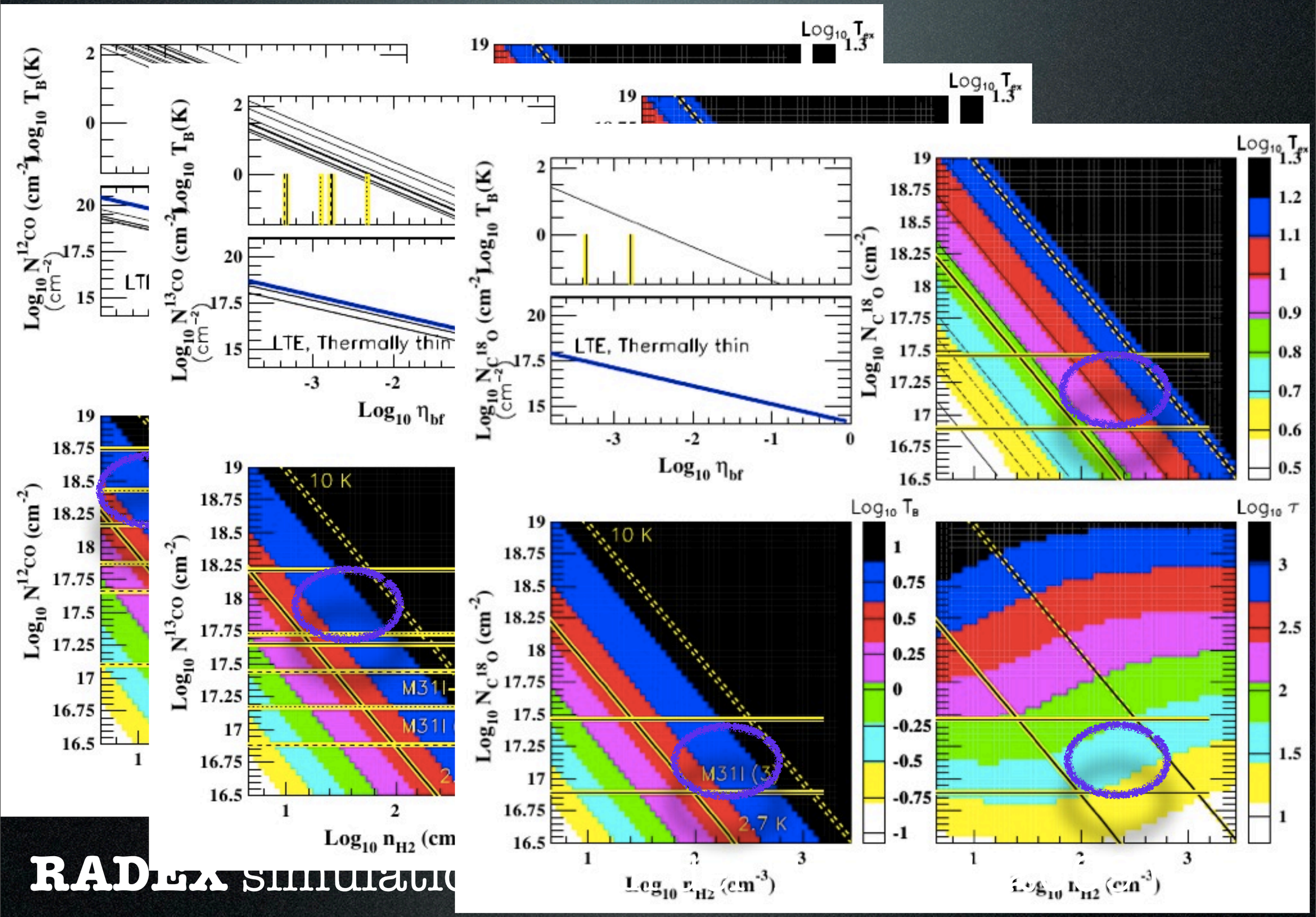
RADEX simulations (van der Tak et al. 2009)



RADEX simulations (van der Tak et al. 2009)



RADEX simulations (van der Tak et al. 2009)



RADEX simulatio

Results

M31I(3)	$^{12}CO(2-1)$	$^{13}CO(2-1)$	$C^{18}O(2-1)$
eta_{bf}	**[0.7**-3] $\mathbf{10^{-2}}$	**[0.5**-1.8] $\mathbf{10^{-3}}$	**[0.5**-1.7] $\mathbf{10^{-3}}$
N_{CO} (cm^{-2})	[1.5-**5.5]** $\mathbf{10^{18}}$	[0.4-**1.6]** $\mathbf{10^{18}}$	[0.8-**2.9]** $\mathbf{10^{17}}$
n_{H2} (cm^{-3})	[0.1-**7.1]** $\mathbf{10^{1}}$	[0.06-**2.2]** $\mathbf{10^{2}}$	[0.03-**1.3]** $\mathbf{10^{3}}$
tau	[**290**-1600]	[**88**-550]	[**31**-1100]
r_{clump} (pc)	[**120**-23 10^3]	[**600**-79 10^3]	[**117**-21 10^3]

Same feeling factor for ^{13}CO and $C^{18}O$?

^{13}CO depletion?? (e.g. Casoli et al. 1992)

Henkel et al. 2014 : $^{12}CO/^{13}CO = ^{12}CO/C^{18}O = 100$?

Davis 2014 : excitation conditions?

Two other dense clumps

M31I(2)	^{12}CO	^{13}CO	HCN	HCO+
Tpeak (mK)	146	4.6	3	3.6
Delta v (km/s)	62 (12)	62	25(7)	60(10)
ICO (K km/s)	9.6(0.5)	0.30(0.06)	0.08(0.02)	0.23(0.04)

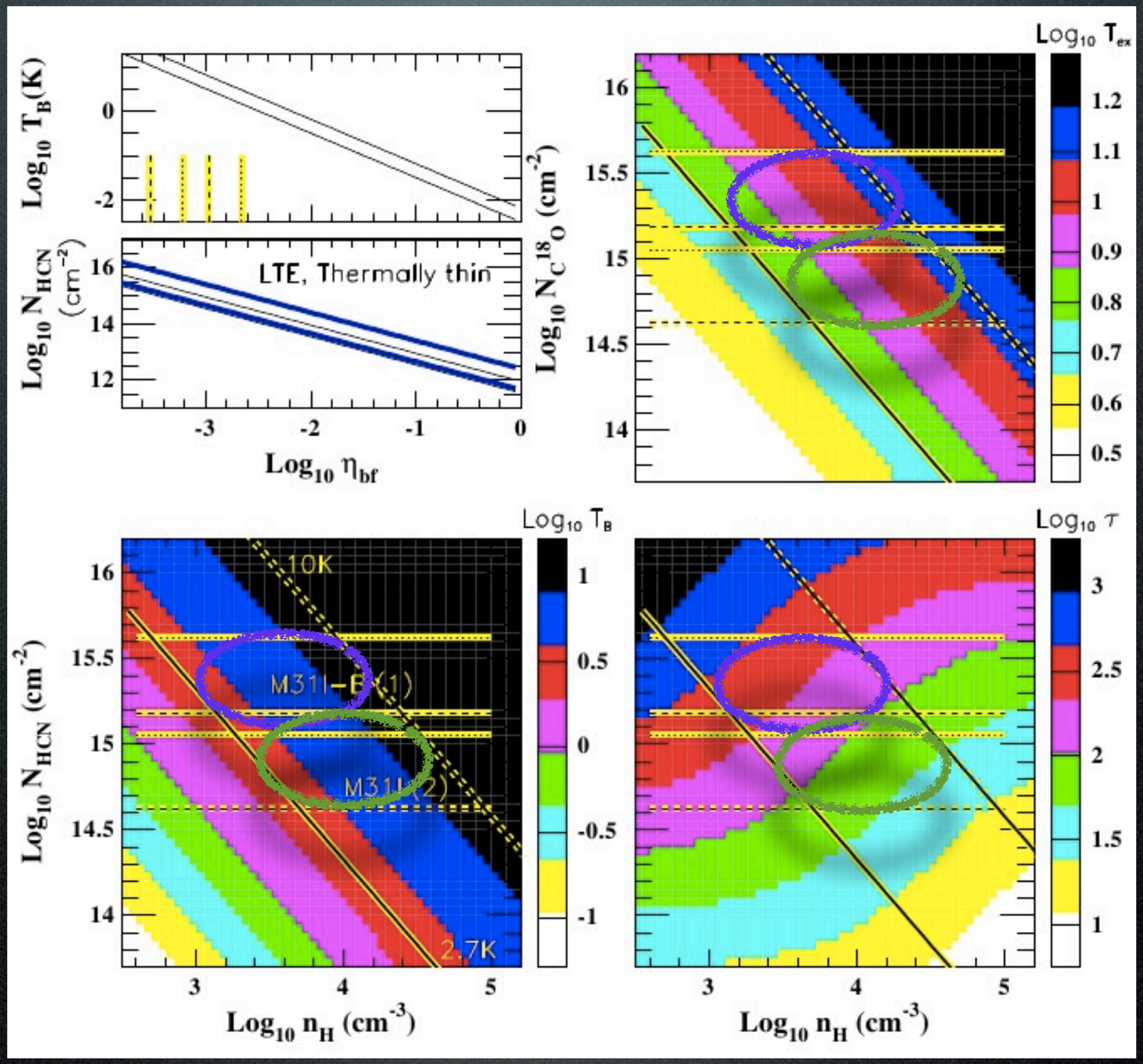
v=-402(3) km/s
N_{H2}=1.9 $10^{21}cm^{-2}$

Expected isotope & abundance ratios (ISM)
Wilson & Wood 1994
Bergin et al. 1995

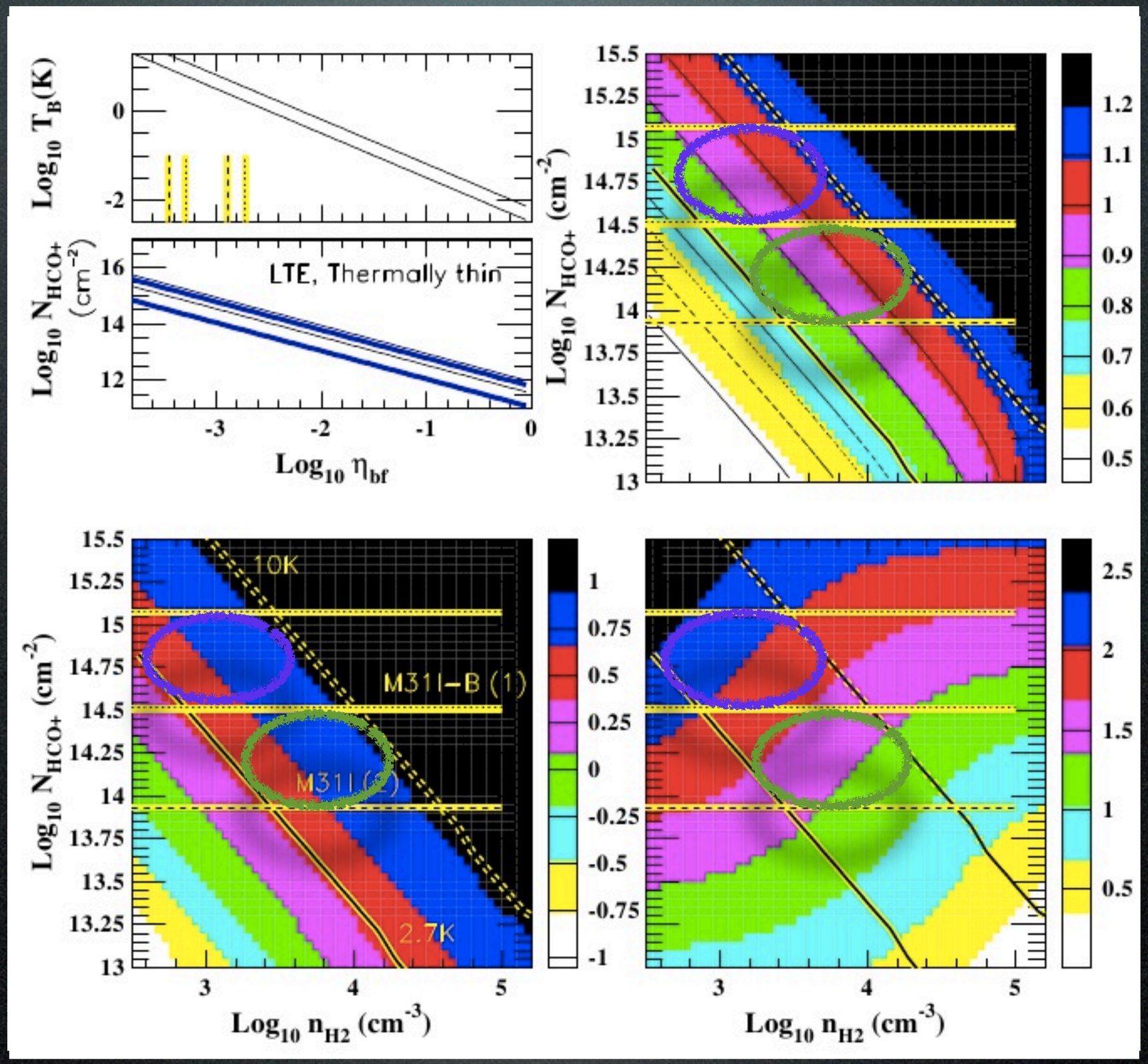
M31I-B(1)	^{12}CO	^{13}CO	HCN	HCO+
Tpeak (mK)	138	13	6.1	3.6
Delta v (km/s)	36(2)	36	32(8)	65(10)
ICO (K km/s)	5.3(0.2)	0.48(0.04)	0.21(0.04)	0.36(0.04)

v=-473(4) km/s
N_{H2}=1.1 $10^{21}cm^{-2}$

--> Optically thick



RADEX simulations (van der Tak et al. 2009)



RADEX simulations (van der Tak et al. 2009)

Results

M31I(2)	^{12}CO(2-1)	^{13}CO(2-1)	HCN(1-0)	HCO+(1-0)
eta_{bf}	[**1.5**-5.4] $\mathbf{10^{-2}}$	[**0.5**-1.7] $\mathbf{10^{-3}}$	[**0.3**-1.1] $\mathbf{10^{-3}}$	[**0.4**-1.4] $\mathbf{10^{-3}}$
N_{CO} (cm^{-2})	[1.3-**4.6**] $\mathbf{10^{17}}$	[0.5-**1.7**] $\mathbf{10^{17}}$	[0.4-**1.5**] $\mathbf{10^{15}}$	[0.9-**3.1**] $\mathbf{10^{14}}$
n_{H2} (cm^{-3})	[0.2-**8.9**] $\mathbf{10^{2}}$	[0.06-**1.1**] $\mathbf{10^{3}}$	[0.02-**1.0**] $\mathbf{10^{5}}$	[0.07-**4**] $\mathbf{10^{4}}$
tau	[**25-160**]	[**15**-100]	[**20**-260]	[**9**-95]
r_{clump} (pc)	[**0.8**-120]	[**20**-3 10^3]	[**0.35**-80]	[**0.7**-150]

M31I-B(1)	^{12}CO(2-1)	^{13}CO(2-1)	HCN(1-0)	HCO+(1-0)
eta_{bf}	[**1.4**-5.0] $\mathbf{10^{-2}}$	[**1.3**-4.8] $\mathbf{10^{-3}}$	[**0.6**-2.2] $\mathbf{10^{-3}}$	[**0.5**-1.9] $\mathbf{10^{-3}}$
N_{CO} (cm^{-2})	[0.7-**2.7**] $\mathbf{10^{18}}$	[1.5-**5.4**] $\mathbf{10^{17}}$	[1.1-**4.1**] $\mathbf{10^{15}}$	[0.3-**1.2**] $\mathbf{10^{14}}$
n_{H2} (cm^{-3})	[0.03-**1.6**] $\mathbf{10^{2}}$	[0.2-**6.3**] $\mathbf{10^{2}}$	[0.05-**3.6**] $\mathbf{10^{4}}$	[0.02-**1**] $\mathbf{10^{4}}$
tau	[**90**-550]	[**25**-190]	[**60**-680]	[**30**-300]
r_{clump} (pc)	[**27**-4.9 10^3]	[**70**-10 10^3]	[**3**-700]	[**11**-2.6 10^3]

Summary

- Detection of molecular gas close to the black hole (>4 10^4 Msol), not in rotation
- Velocity pattern compatible with multiple components & **inner ring**
- **Detection of dense gas** - «anomaly» in ^{13}CO
  - possible depletion ?
  - post-(small) starburst triggered by frontal collision with M32?

Thank you