extragalactic star formation

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nearby extragalactic star formation — themes

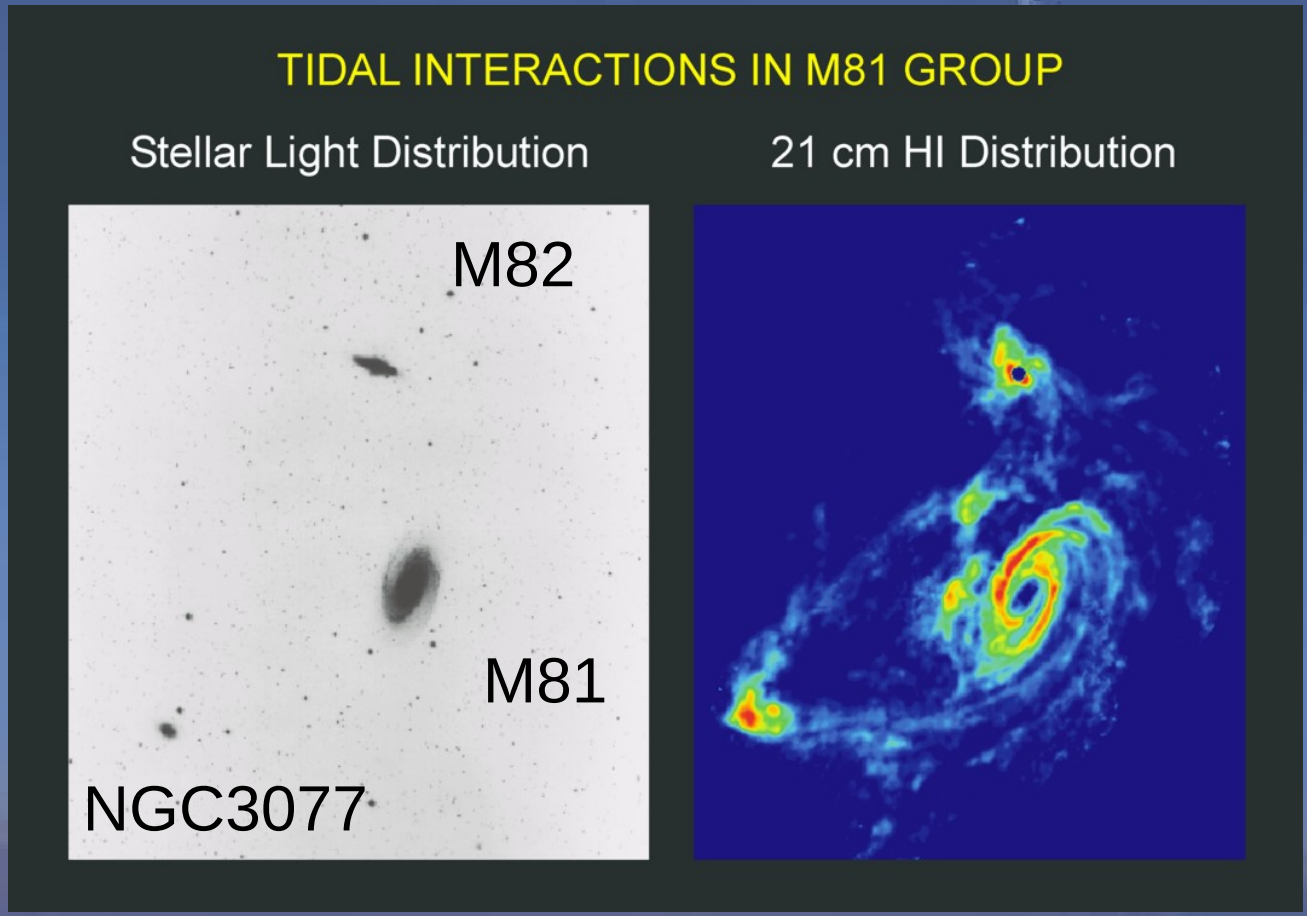
normal galaxies: gas and star formation, much to be “resolved”

extreme star formation: formation and evolution of super star clusters

starburst feedback and molecular gas

high z galaxies: related to ULIRGs (Aaron Evans)

gas and extreme star formation



VLA 21 cm Yun, Ho, Lo 1994

star formation in normal galaxies

observed: stellar populations, “strings of pearls”, Schmidt law, Toomre Q

what is the relation of gas and spiral structure?

molecular clouds turbulently supported (Krumholz et al. 2005, Padoan et al. 2002, 2007) trigger for the collapse?

direct imaging of extragalactic star formation with ALMA

Continuum sensitivities ~10 μJy in an hour

Massive HII regions via their free-free emission

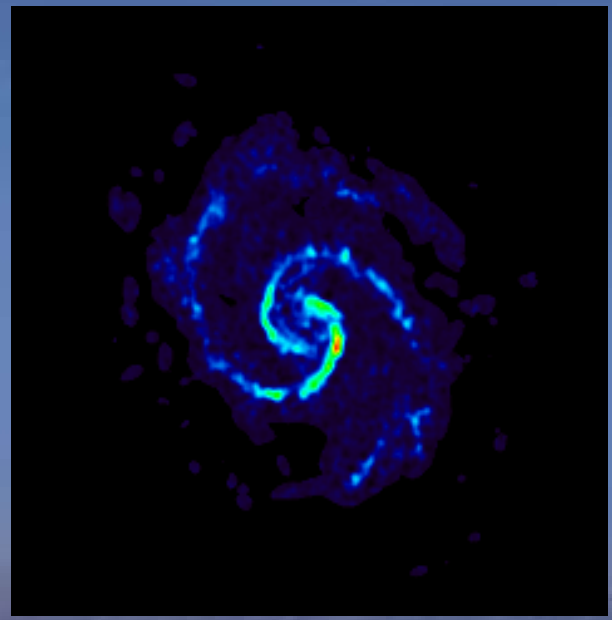
Super star clusters: imaging to 50 Mpc
Orions: image to ~10Mpc, detect to Virgo

Dust emission from low and high mass stars

More sensitive than free-free
Local Group, 10 mas = .04 pc = 10,000 AU

star formation and galactic structure: M51

CO BIMA-SONG

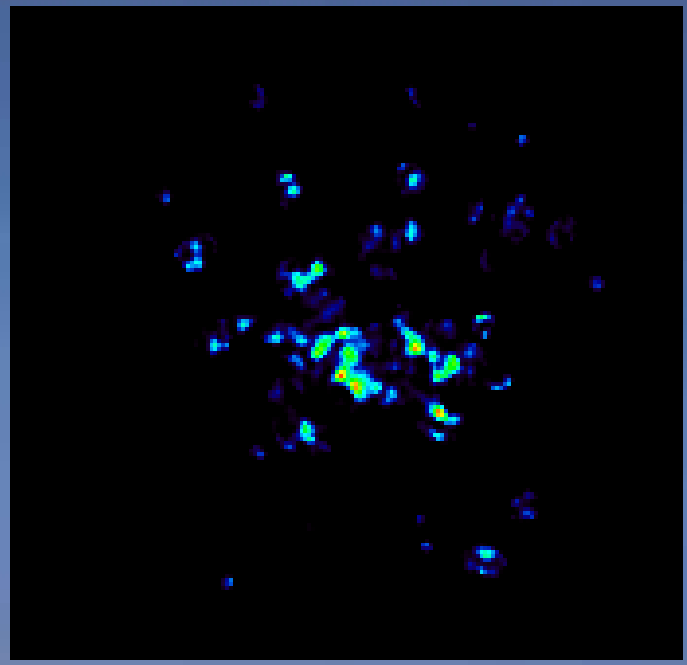


Helfer et al. 2003

star formation and galactic structure: NGC 2403

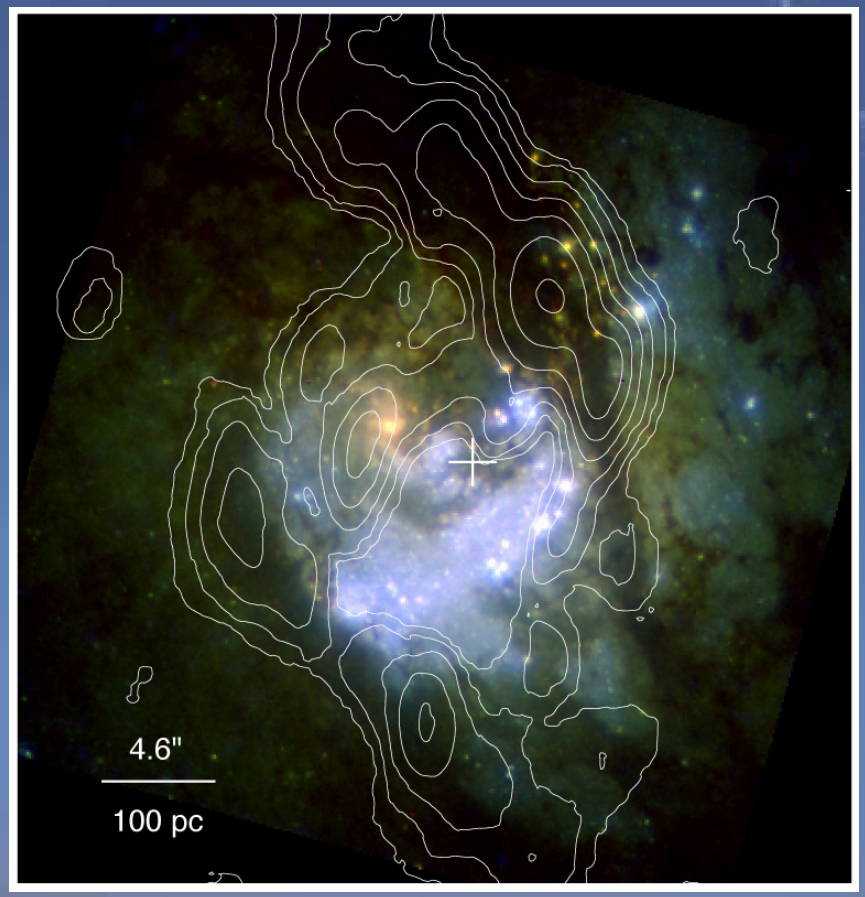
F. Calvert, A. Block, NOAO/AURA/NSF

CO BIMA-SONG



Helfer et al. 2003

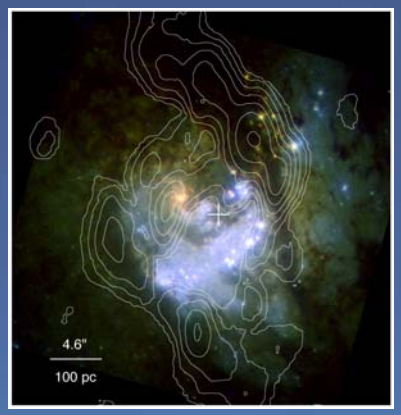
spiral galaxies: nuclear bars and star formation



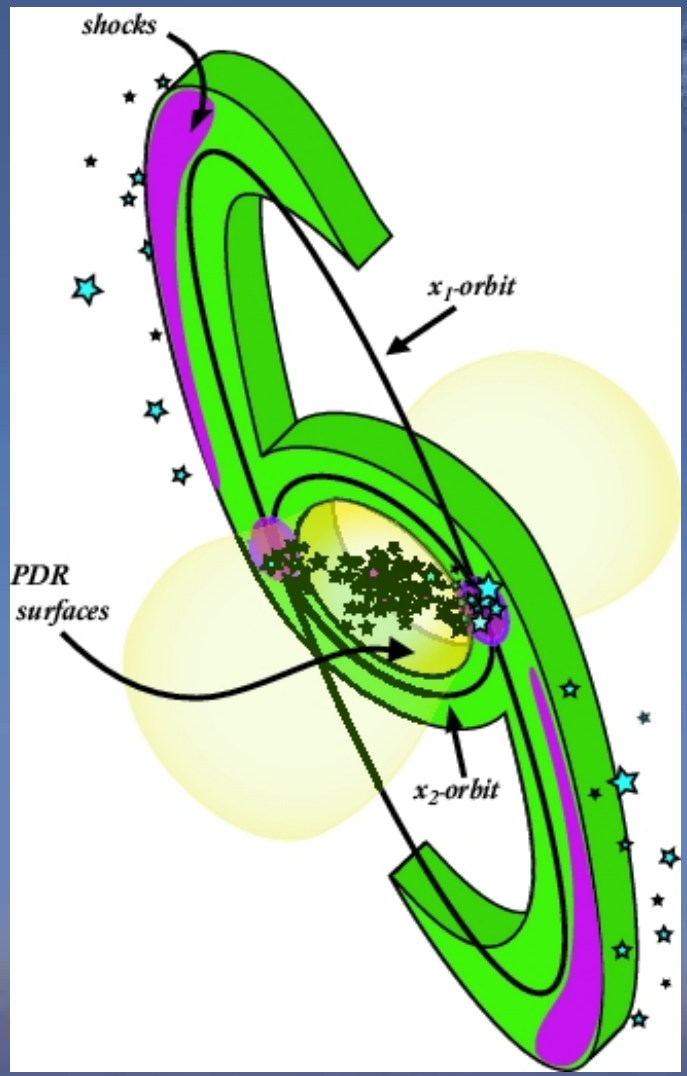
CO J=3-2 line M83

SMA Sakamoto et al. 2004

spiral galaxies: nuclear bars and star formation



M83 CO 3-2 SMA
Sakamoto et al. 2004



Meier & Turner 2005

tidal stretching/ shear of bar clouds: SF suppressed?

dynamical triggering at x_1-x_2 orbit intersections

extreme star formation

super star clusters

how do you form a globular cluster?

are SSCs protoglobular clusters?
massive enough? live long enough (10 Gyr)?

the youngest clusters will be embedded => fIR and submm targets

what favors “extreme” star formation

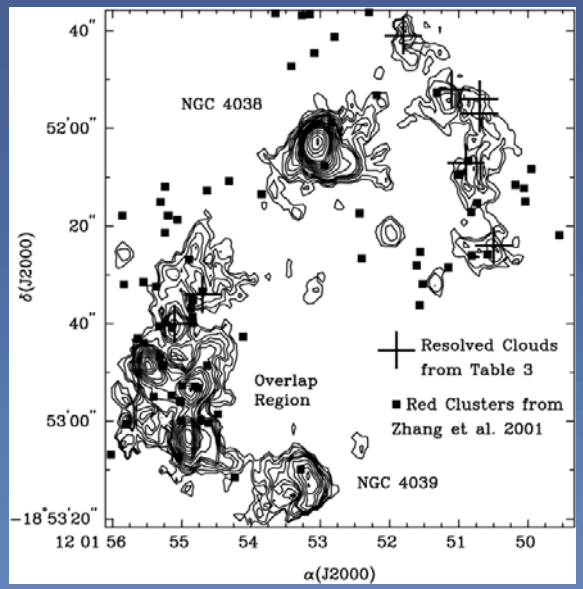
HST

NGC 1569
O’Connell et al. 1994

M82 O’Connell et al. 1995

Antennae
Whitmore & Schweizer 1995

link: GMCs and large scale forces and stars?



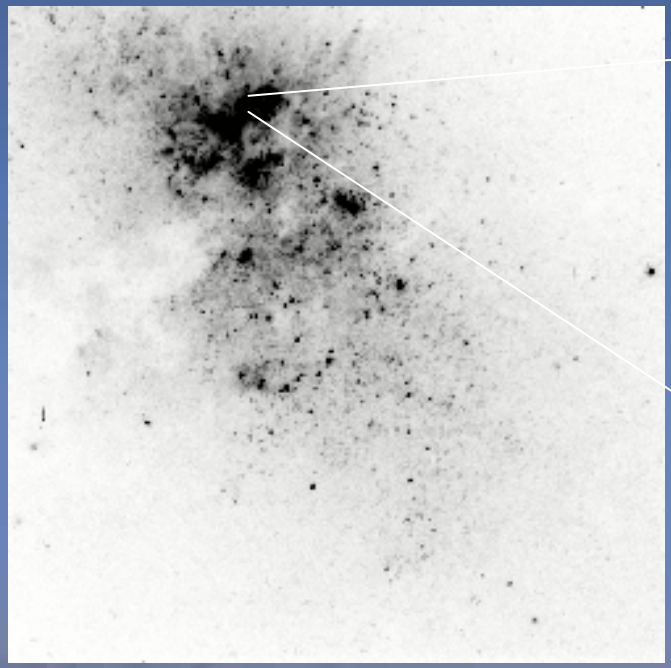
CO OVRO Wilson et al. 2004

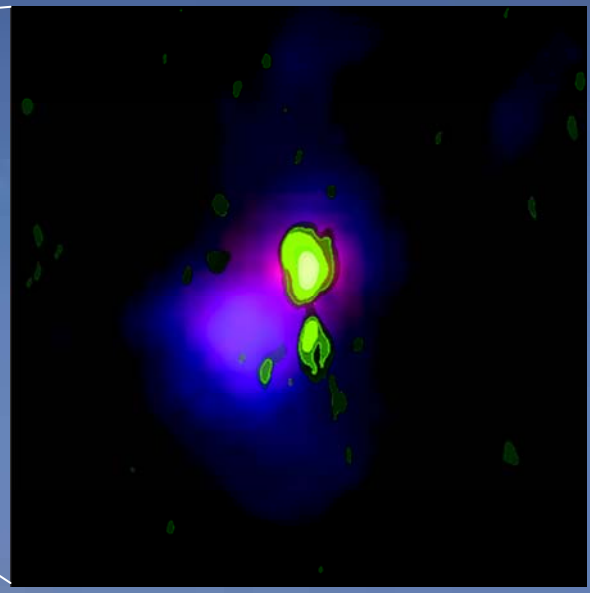
lotsa gas, lotsa stars "SGMCs" Harris & Pudritz 1994

but turbulence defines the star formation, taking place in only 1% of the gas? Padoan et al. 2002, Krumholtz & McKee (2005)

dwarf galaxy: NGC 5253

VLA + Pietown 50x110mas



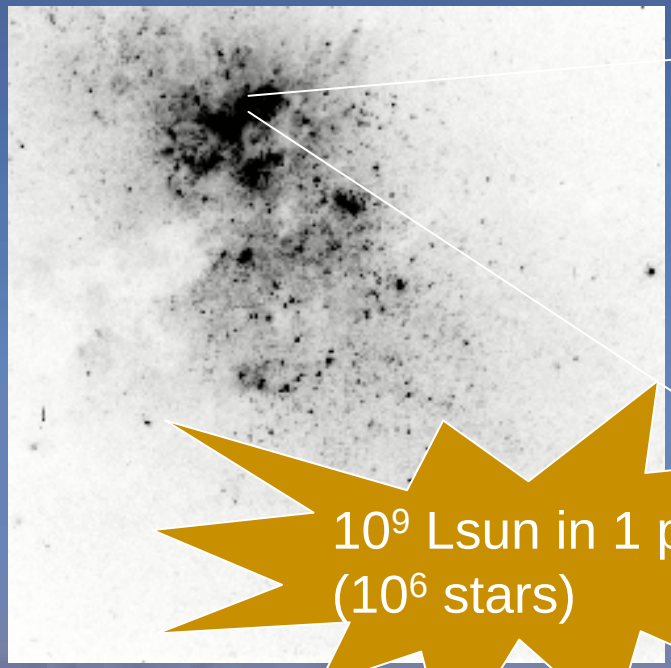


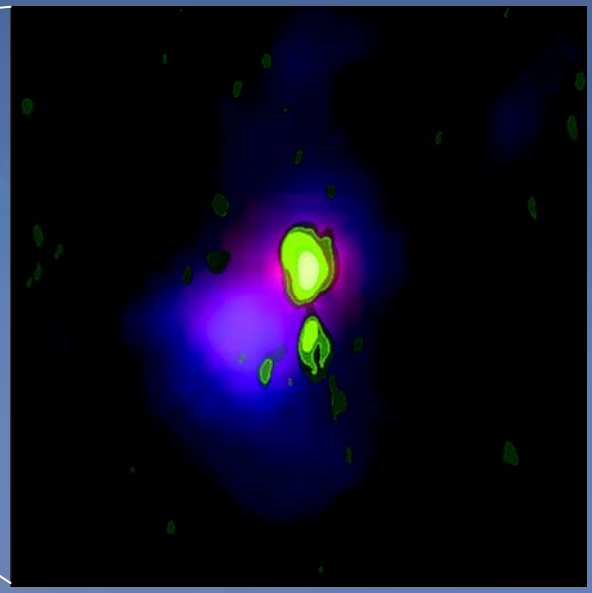
2”

Turner & Beck 2004
blue = 1.1m HST/NICMOS
red = 1.9m

dwarf galaxy: NGC 5253

VLA + Pietown 50x110mas





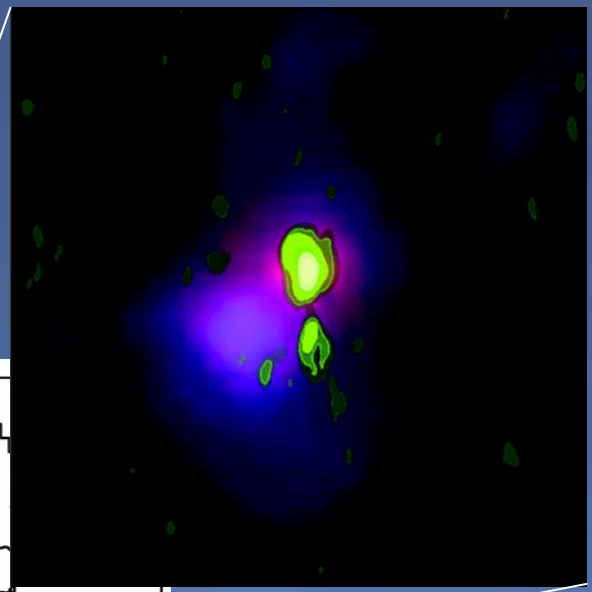
2”

10^9 Lsun in 1 pc
(10^6 stars)

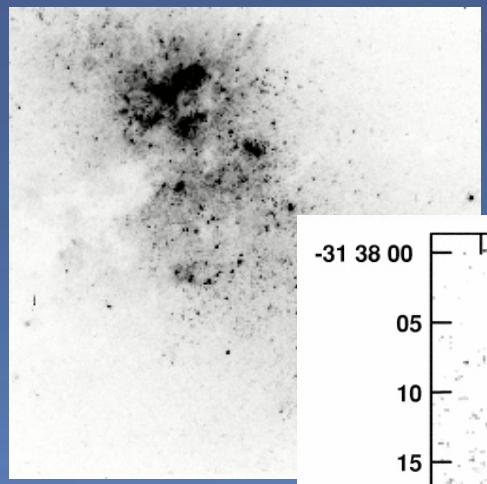
Turner & Beck 2004
blue = 1.1m HST/NICMOS
red = 1.9m

dwarf galaxy: NGC 5253

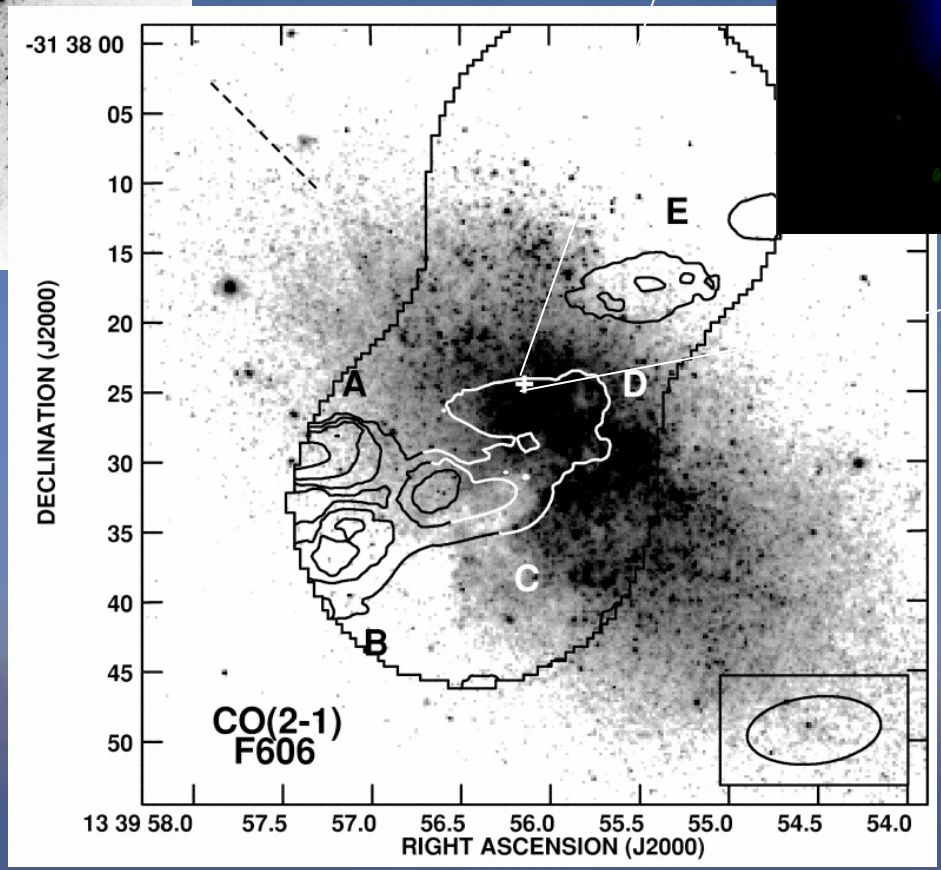
Turner & Beck 2004



2”



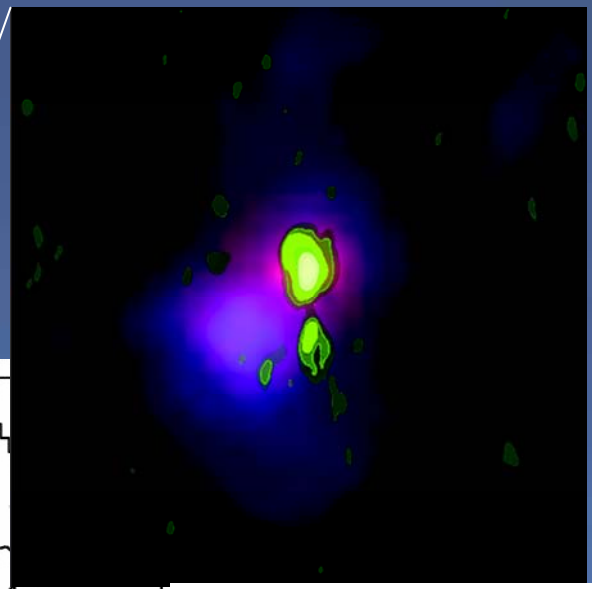
OVRO CO(2-1)



Meier et al. 2002

dwarf galaxy: NGC 5253

Turner & Beck 2004



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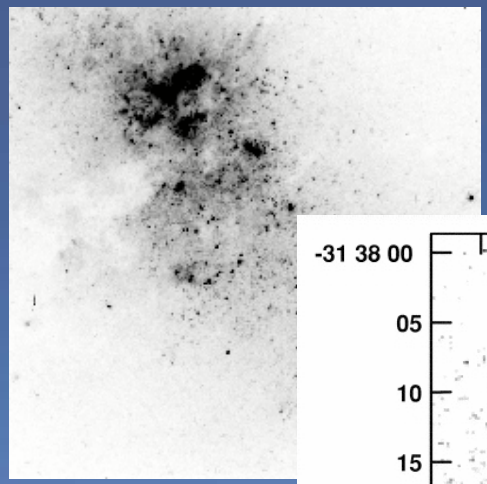

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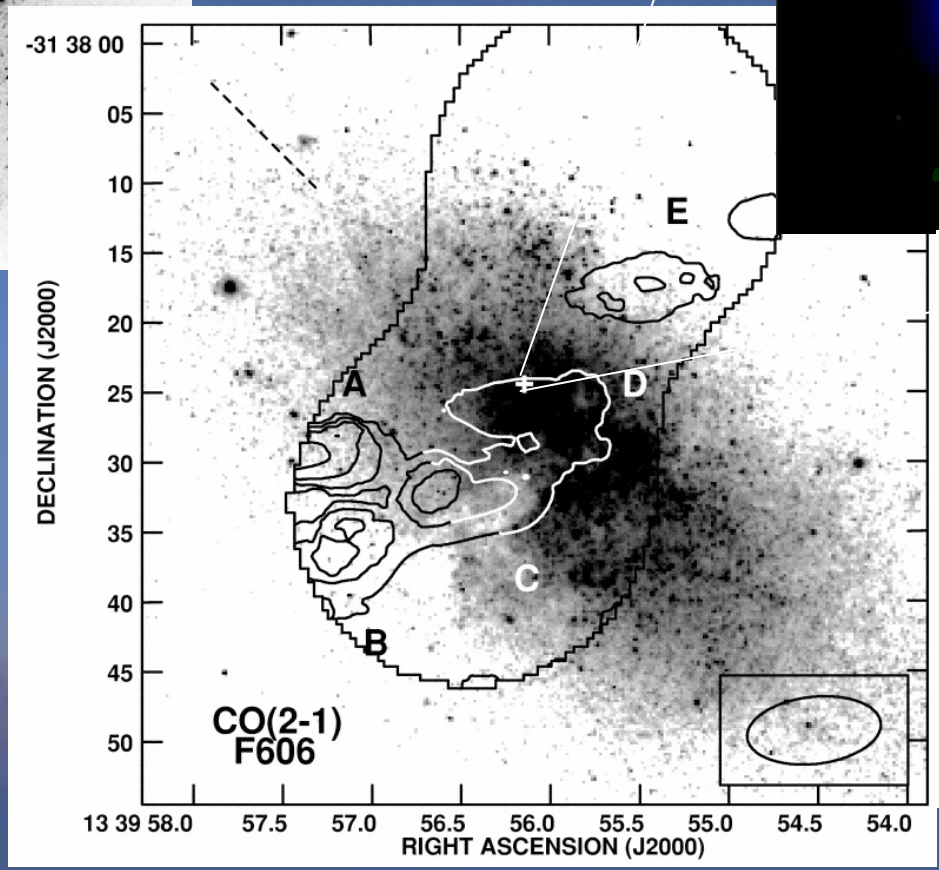
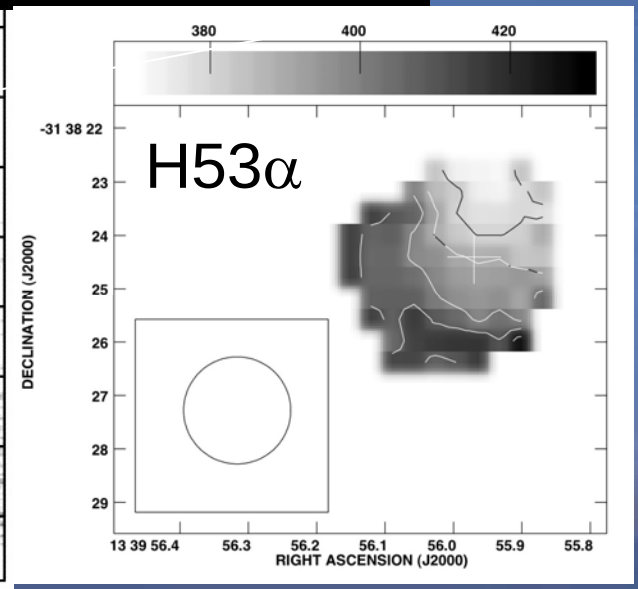


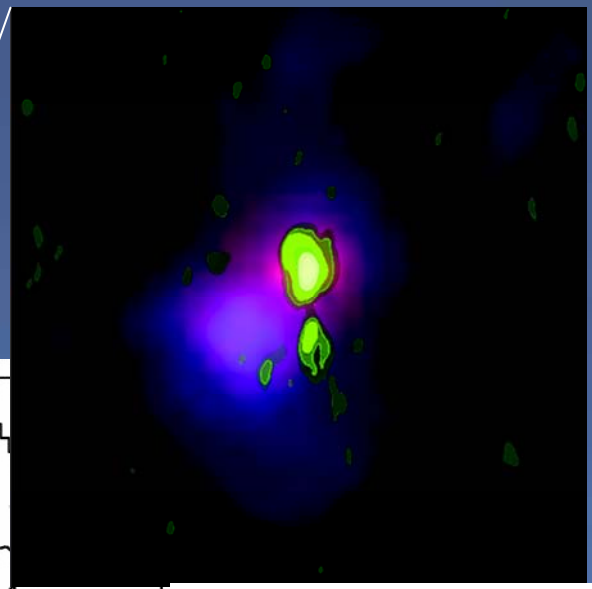
Meier et al. 2002



Rodriguez-Rico et al. 2007

dwarf galaxy: NGC 5253

Turner & Beck 2004



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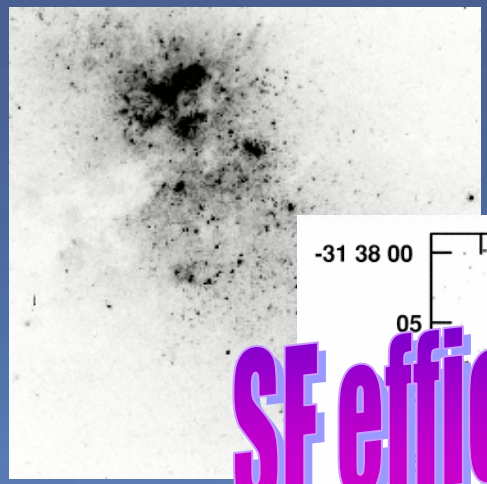
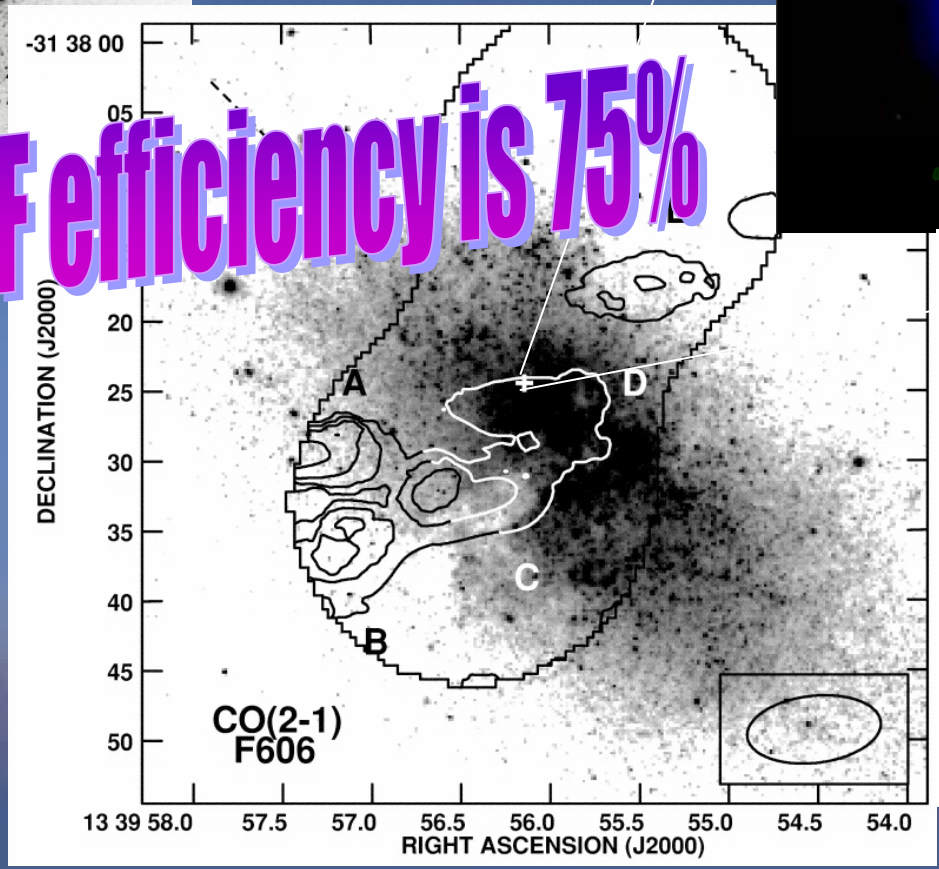
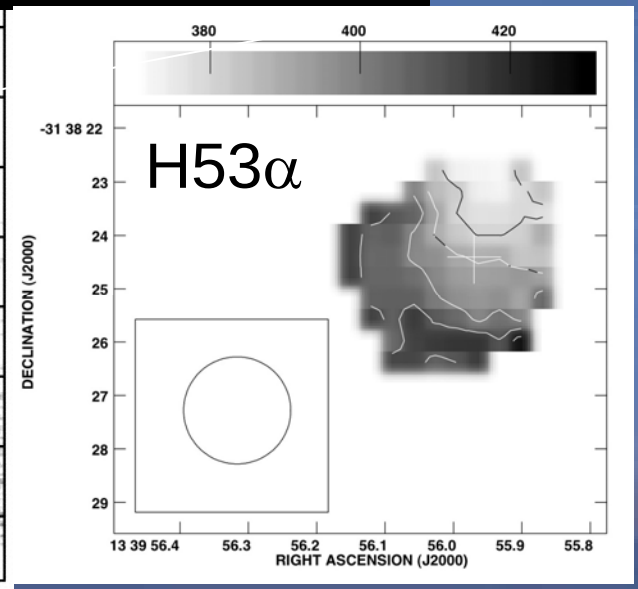


SF efficiency is 75%



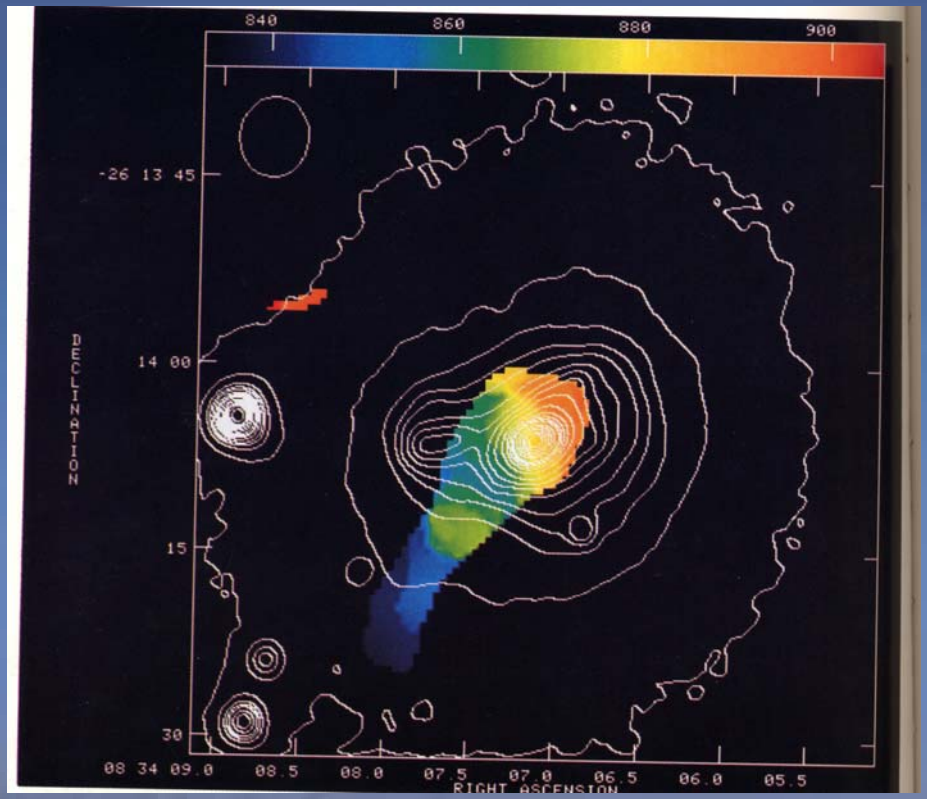
Meier et al. 2002



Rodriguez-Rico et al. 2007

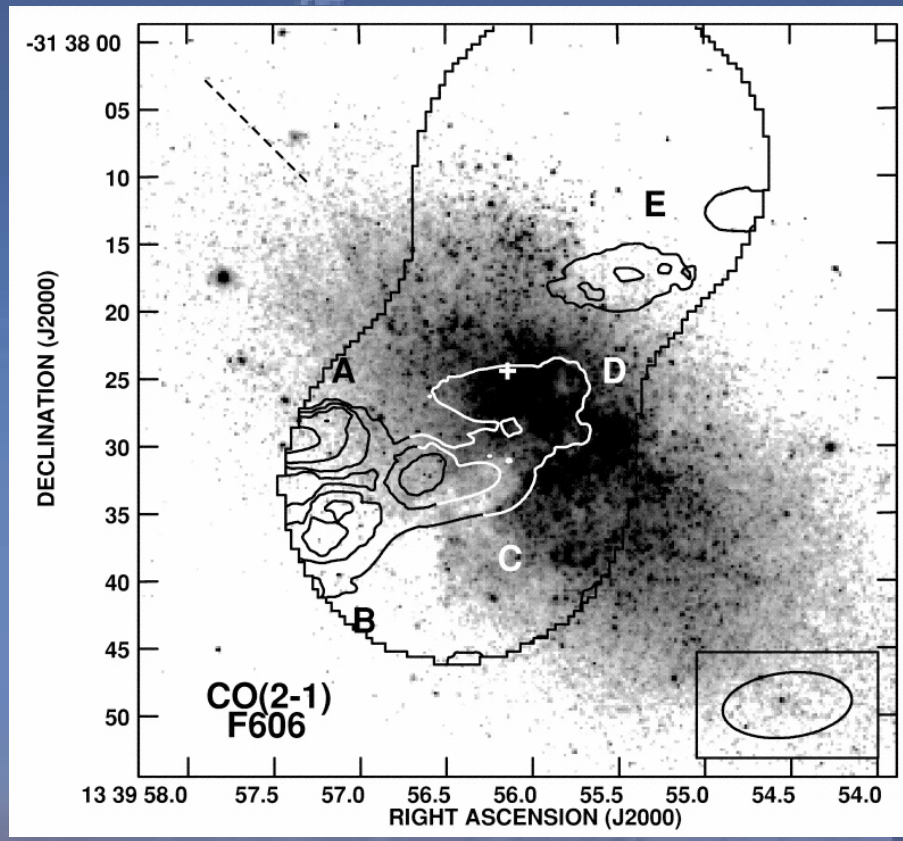
dwarf galaxies

He 2-10

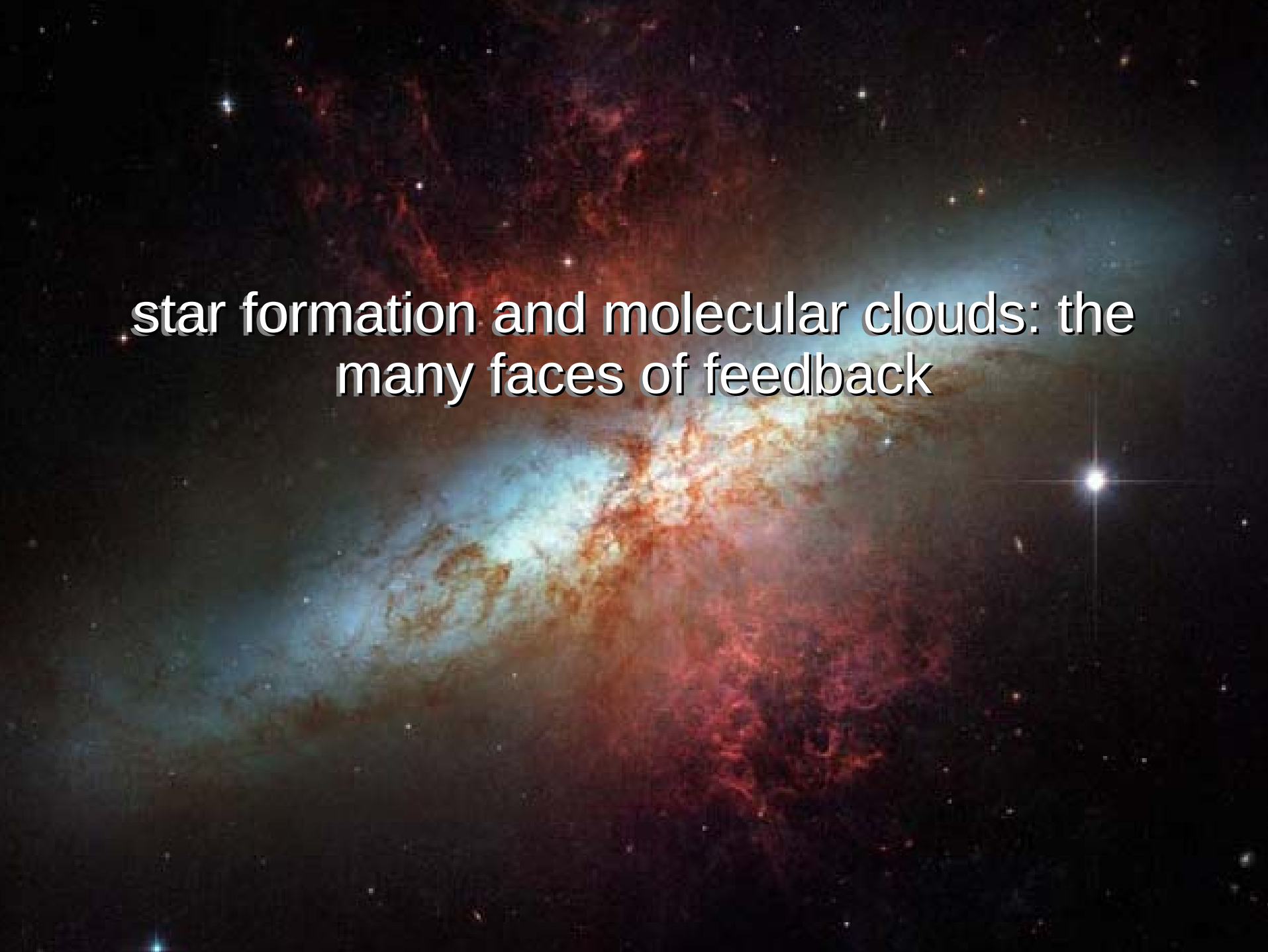


Kobulnicky et al. 1995

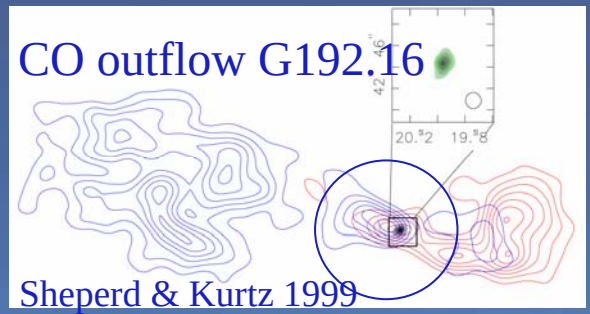
NGC 5253



Meier et al. 2002

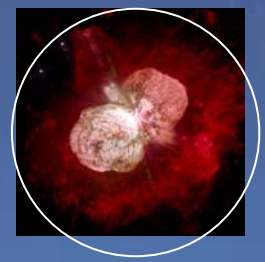

star formation and molecular clouds: the many faces of feedback

feedback: what a single O star can do to 1 pc (much less several thousand)



0.5 Myr

10^{-3} $M_\odot$/yr



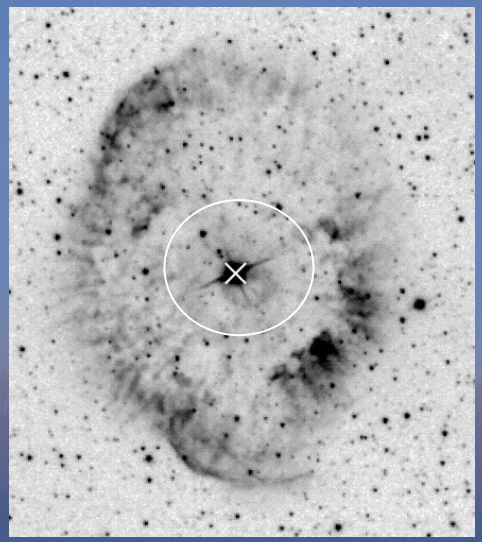
LBV
10^{-5} $M_\odot$ /yr
400 km/s

Morse et al. 1996

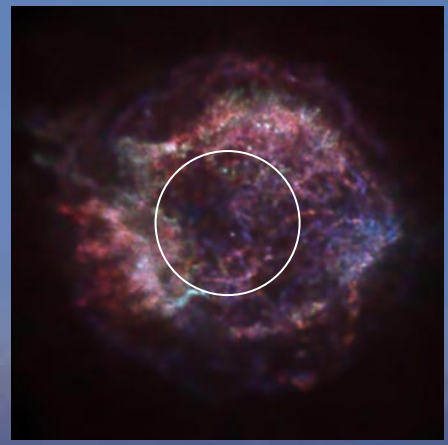
1 Myr

WR Ring Nebula
10^{-5} $M_\odot$/yr
100 km/s

2-3 Myr



Gruendl, Chu et al. 2000



SNR
10,000 km/s

Hughes et al. 1999

3-10 Myr

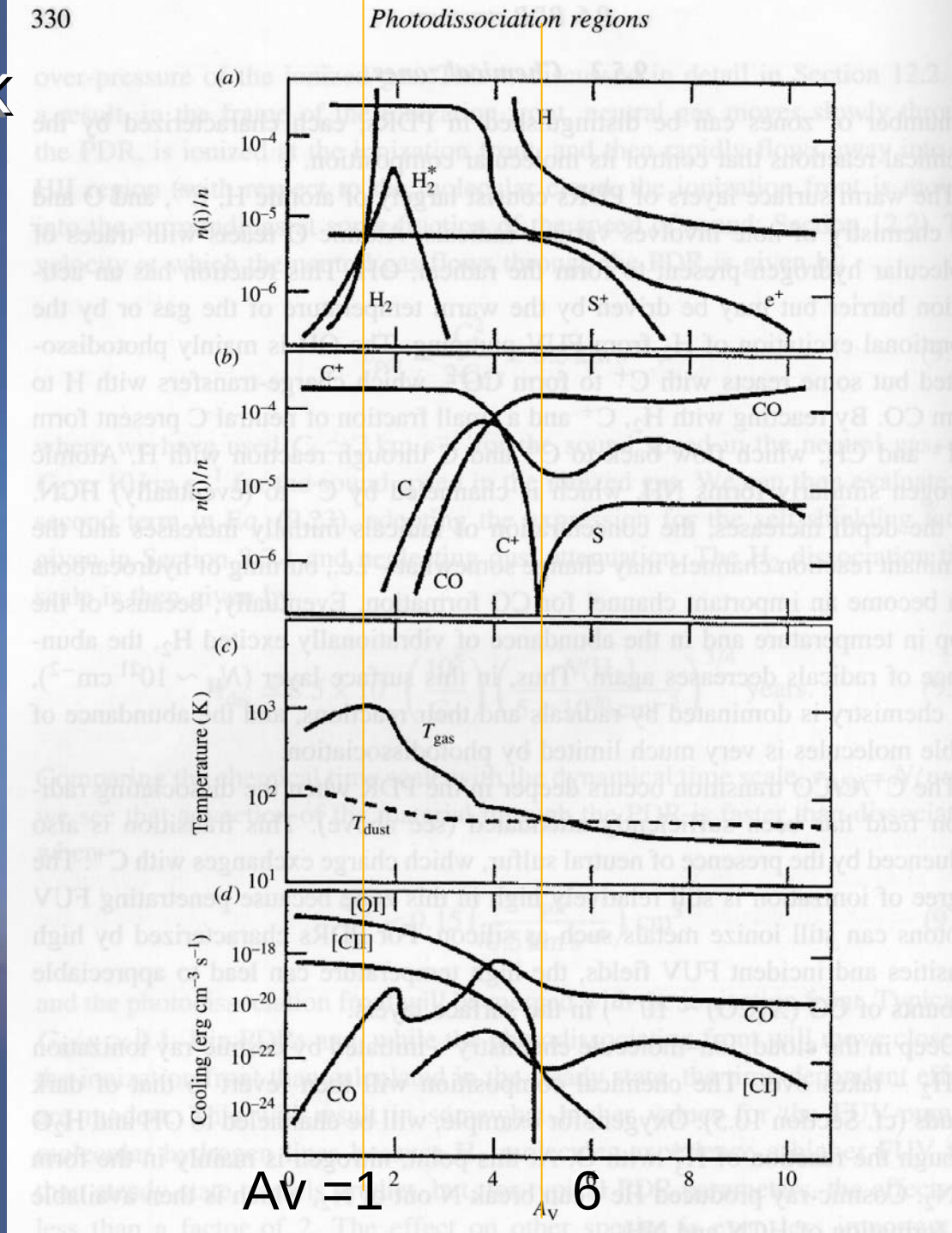
chemical feedback

Photodissociation Regions
PDRs

Tielens & Hollenbach 1985

Wolfire et al. 1995

Tielens textbook 2006



chemical feedback : Orion PDR

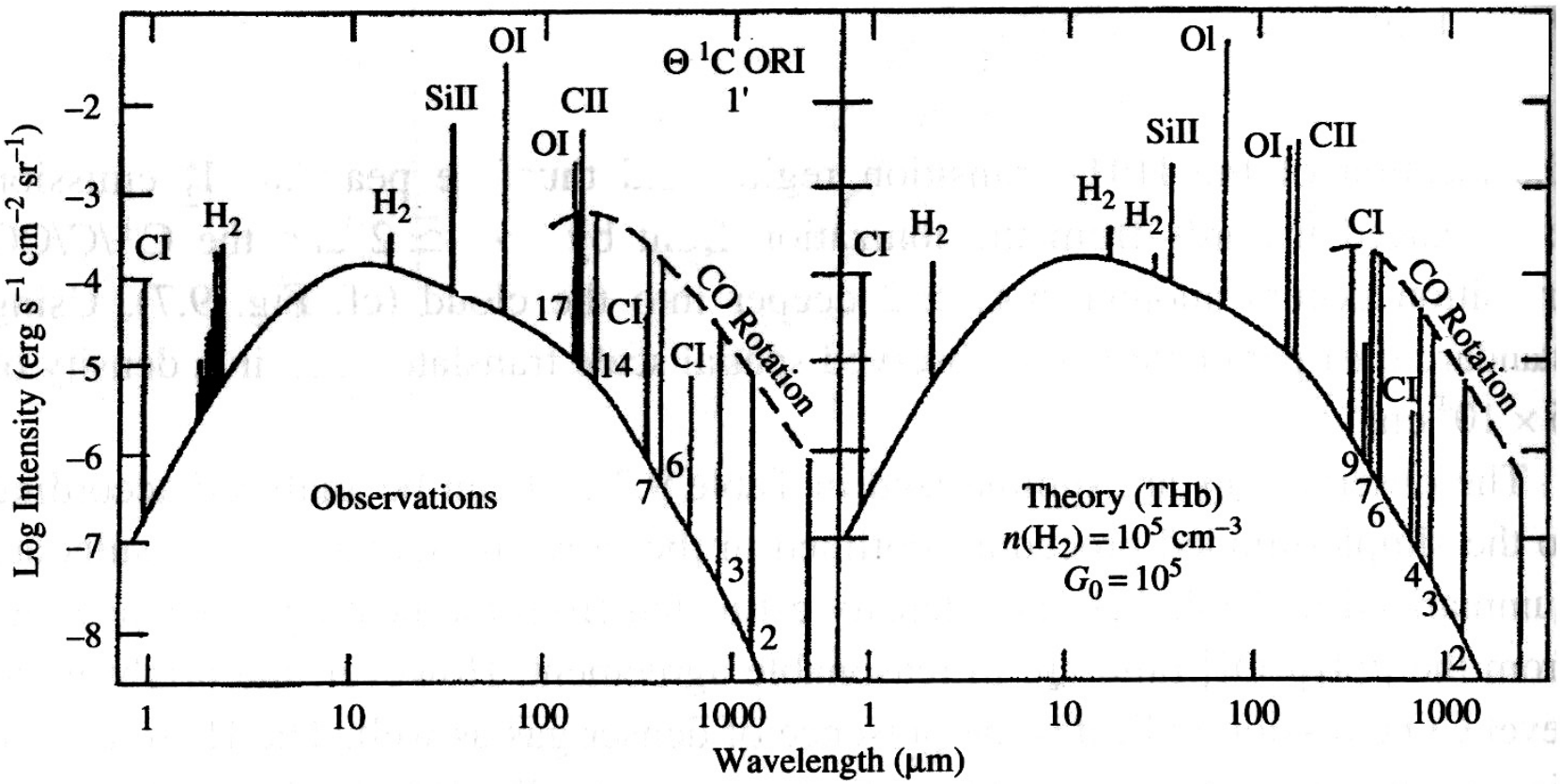
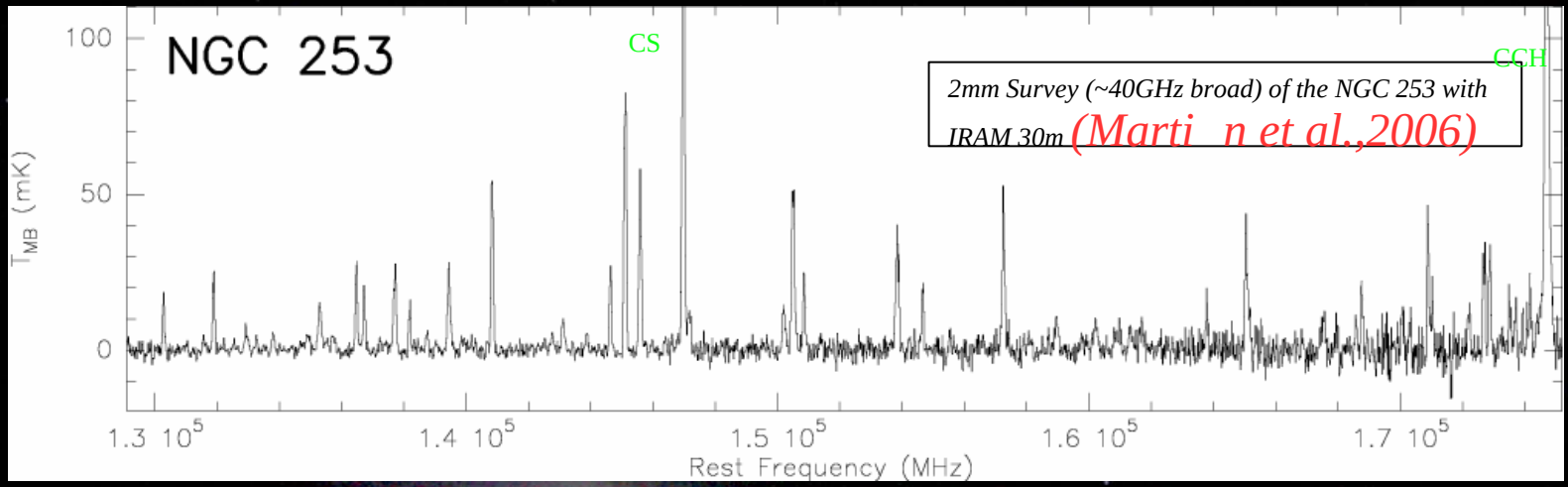


Figure 9.12 The emission spectrum calculated for conditions appropriate to Orion (cf. Fig. 9.7) is compared to the observed spectrum. Emission lines originating in the ionized gas are not shown. Figure reproduced with permission from D. Hollenbach and A. G. G. M. Tielens, 1999, *Rev. Mod. Phys.*, **71**, p. 173.

Tielens 2006

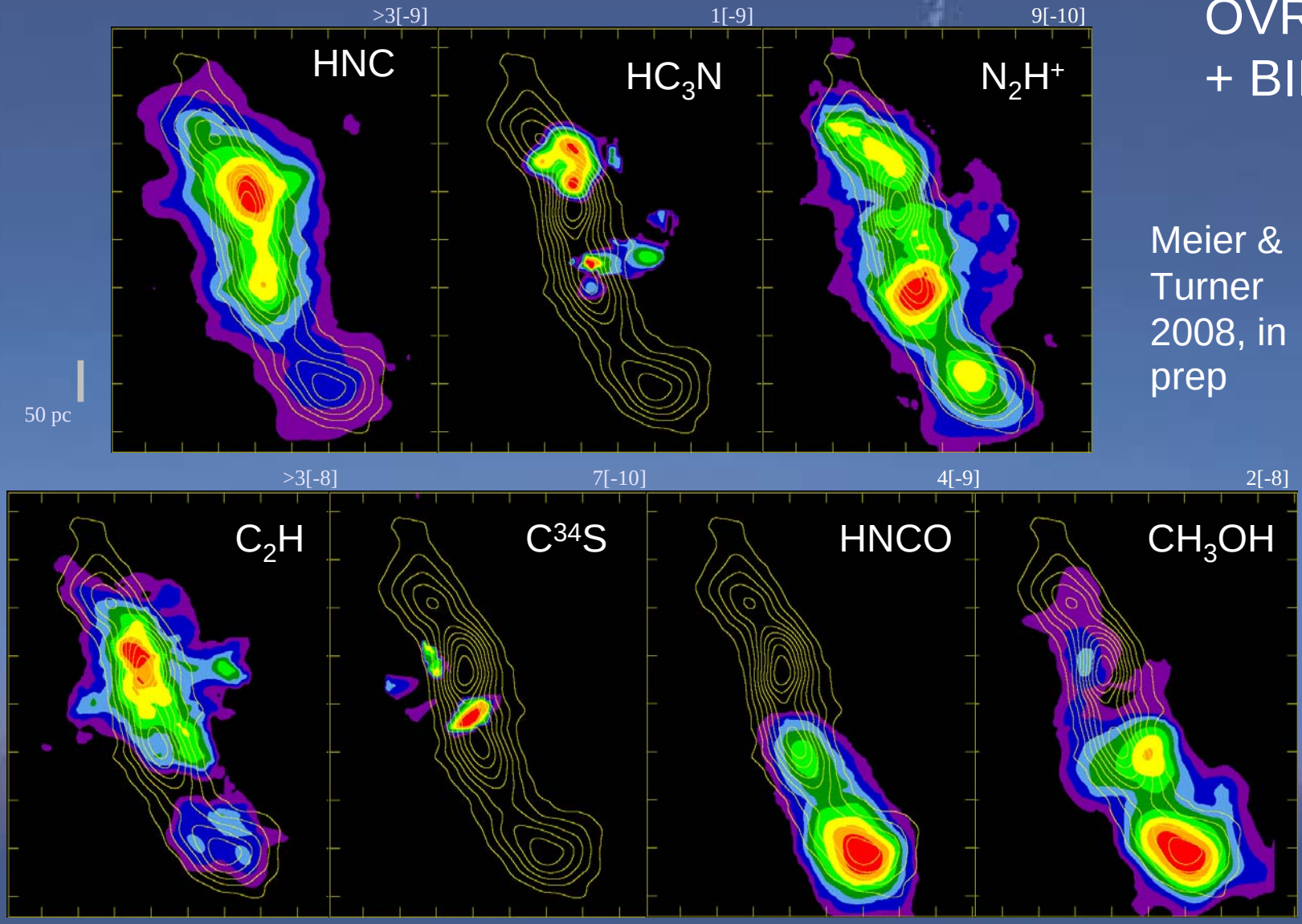


First unbiased line survey in a galaxy IRAM: 129.1 - 175.2 GHz @ dv ~ 9 km/s

IRAM

2MASS - Jarrett

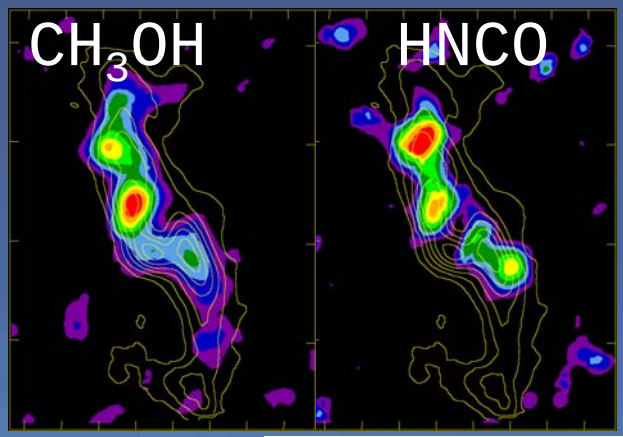
Maffei 2 3mm chemistry

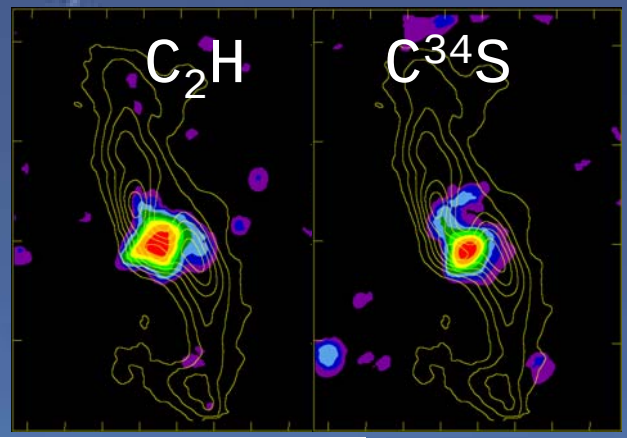


OVRO + BIMA

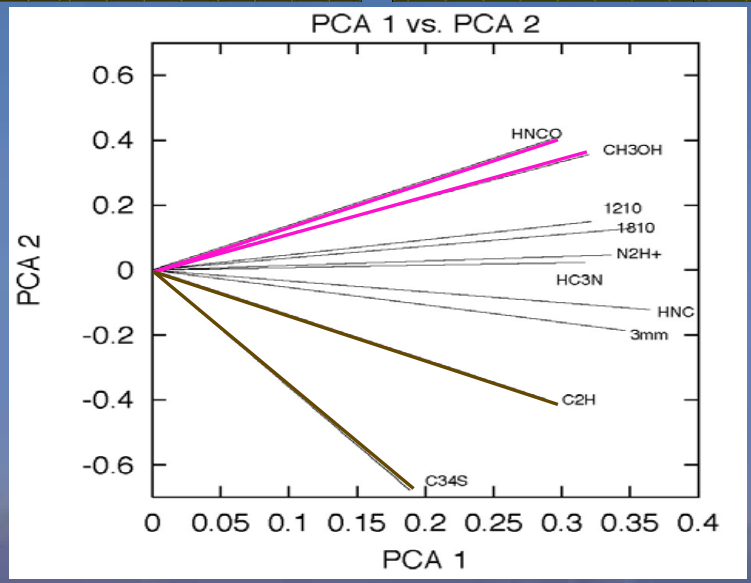
Meier & Turner 2008, in prep

IC 342 principal component analysis





pc axis 2



HNCO
CH_3OH

C_2H
$C^{34}S$

Meier & Turner 2005

IC 342

IC 342 principal component analysis: correlation matrix

Table 6. PCA Correlation Matrix

Maps	^{12}CO	$C^{18}O$	3MM	C_2H	$C^{34}S$	CH_3OH	HC_3N	HCN	HNC	HNCO	N_2H
^{12}CO	1.0										
$C^{18}O$	0.82	1.0									
3MM	0.65	0.76	1.0								
C_2H	0.53	0.62	0.76	1.0							
$C^{34}S$	0.38	0.39	0.48	0.50	1.0						
CH_3OH	0.75	0.80	0.67	0.49	0.21	1.0					
HC_3N	0.60	0.71	0.85	0.57	0.30	0.68	1.0				
HCN[a]	0.65	0.75	0.90	0.74	0.49	0.64	0.77	1.0			
HNC	0.76	0.85	0.94	0.79	0.49	0.72	0.81	0.91	1.0		
HNCO	0.67	0.75	0.58	0.42	0.19	0.78	0.57	0.57	0.66	1.0	
N_2H^+	0.73	0.81	0.75	0.59	0.42	0.71	0.68	0.74	0.82	0.69	1.0

[a]Data from (Downes et al. 1992). The data was taken at the Plateau de Bure Interferometer and he
has a slightly smaller primary beam.

Meier & Turner 2005

IC 342 principal component analysis: correlation matrix

Table 6. PCA Correlation Matrix

Maps	^{12}CO	$C^{18}O$	3MM	C_2H	$C^{34}S$	CH_3OH	HC_3N	HCN	HNC	NCO	N_2H
^{12}CO	1.0										
$C^{18}O$	0.82	1.0									
3MM	0.65	0.76	1.0								
C_2H	0.53	0.62	0.76	1.0							
$C^{34}S$	0.38	0.39	0.48	0.50	1.0						
CH_3OH	0.75	0.80	0.67	0.49	0.21	1.0					
HC_3N	0.60	0.71	0.85	0.57	0.30	0.68	1.0				
HCN[a]	0.65	0.75	0.90	0.74	0.49	0.64	0.77	0			
HNC	0.76	0.85	0.94	0.79	0.49	0.72	0.81	0.91	1.0		
HNCO	0.67	0.75	0.58	0.42	0.19	0.78	0.57	0.57	0.66	1.0	
N_2H^+	0.73	0.81	0.75	0.59	0.42	0.71	0.68	0.74	0.82	0.69	1.0

[a]Data from (Downes et al. 1992). The data was taken at the Plateau de Bure Interferometer and he
has a slightly smaller primary beam.

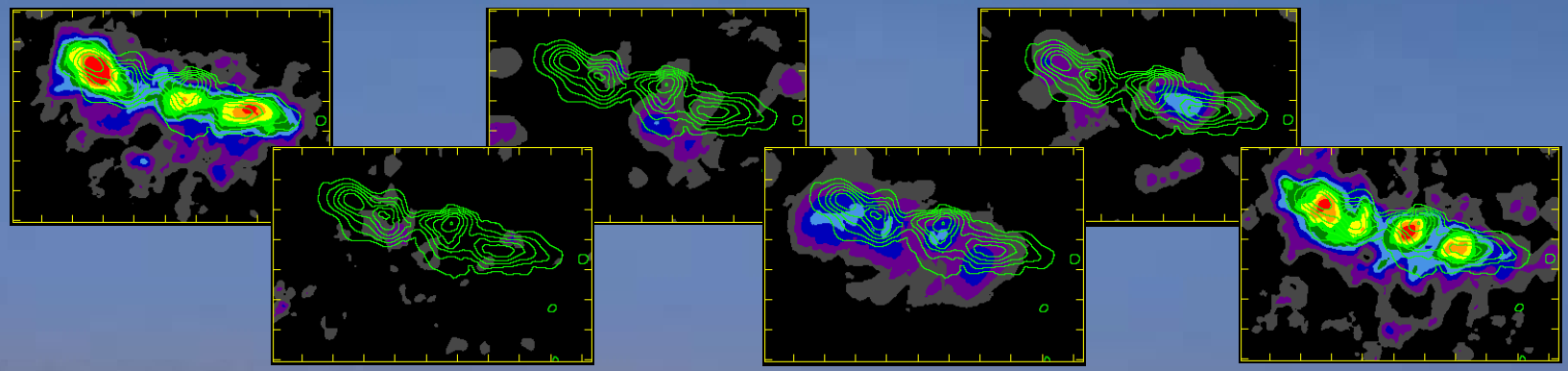
Gao & Solomon result holds at 10s of pc scale

Meier & Turner 2005

imaging chemistry in M82: a “giant PDR”

CH_3OH and HNCO undetected in these maps

CN, C_2H and HNC bright & more extended than CO



CCH HNCO $C^{34}S$ N_2H^+ HC_3N HNC

BIMA images

Meier & Turner 2008

extragalactic star formation in the ALMA age

ALMA will be a powerful imaging device for study of the process of star formation in galaxies

HII regions (free-free), dust emission, molecular clouds

on sizescales of clusters —1pc (SF regions, AGN)

to galaxy-wide studies of star formation efficiency and feedback, out to galaxies hundreds of Mpc distant

spiral galaxies, dwarf galaxies, mergers, any type of galaxy

LMC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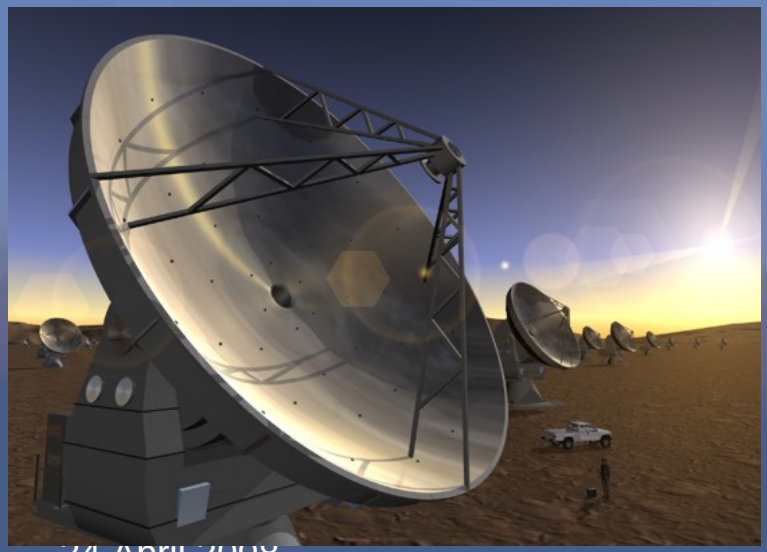
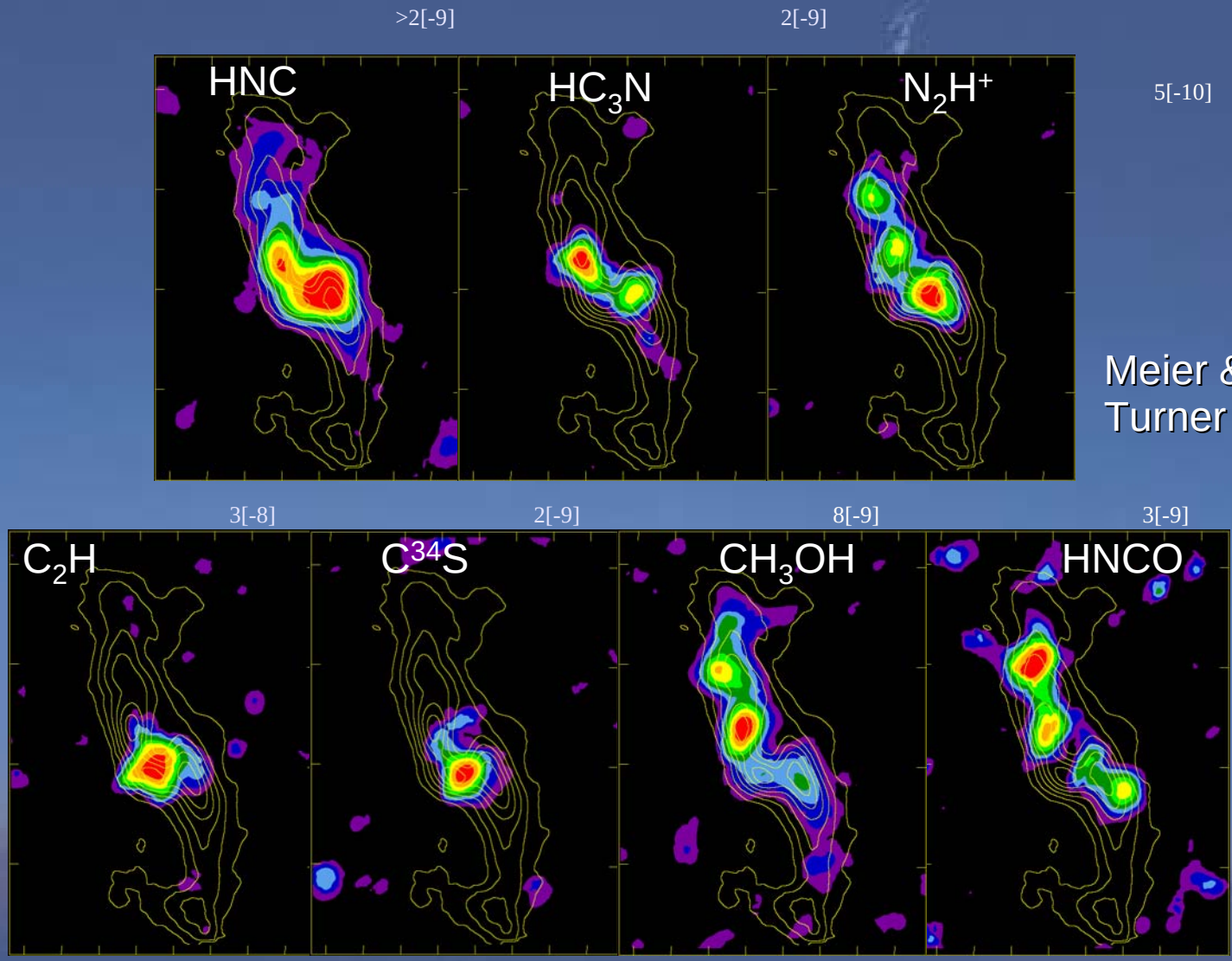
ALMA



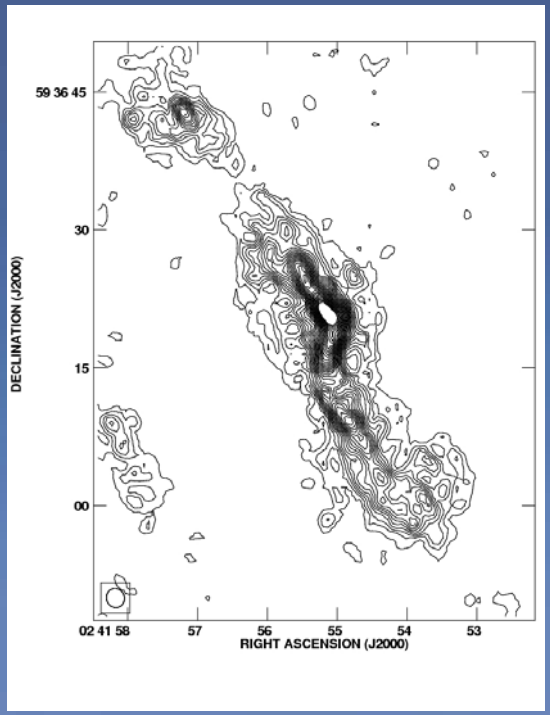
chemical feedback: nuclear bar in IC342



Meier & Turner 2005

OVRO 3mm maps at 4” resolution (60 pc)

chemical feedback in Maffei 2



C_2H prefers the starburst region, but is more extended (outflow?)

CH_3OH follows the molecular bar arms, especially the bar ends

HNCO emission is tightly correlated with CH_3OH

MAFFEI 2