Recent Extragalactic Results from the SMA

Glen Petitpas
Submillimeter Array

SMA CO Nearby Extragalactic Survey (SCONES)

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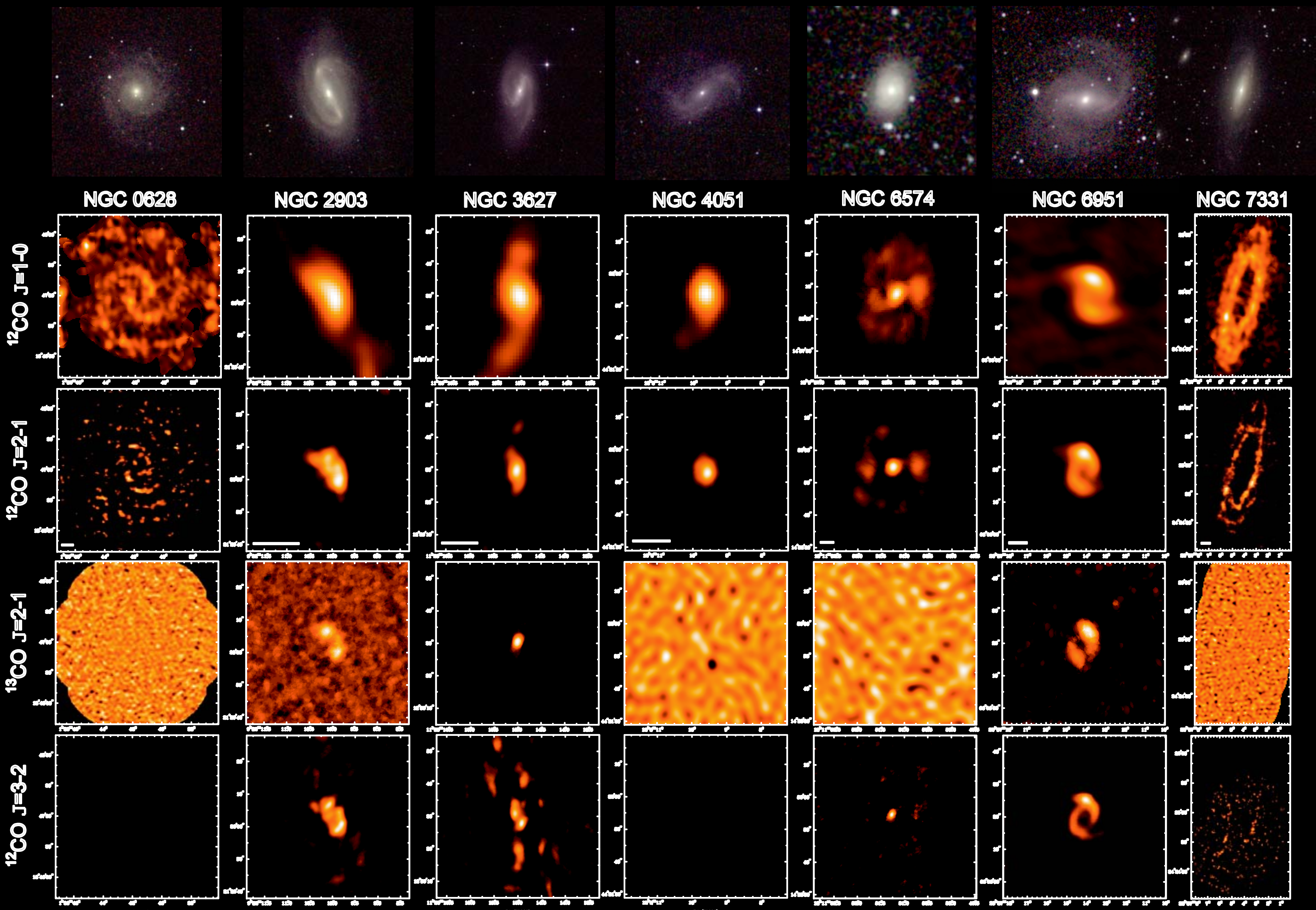
Goals of the Survey

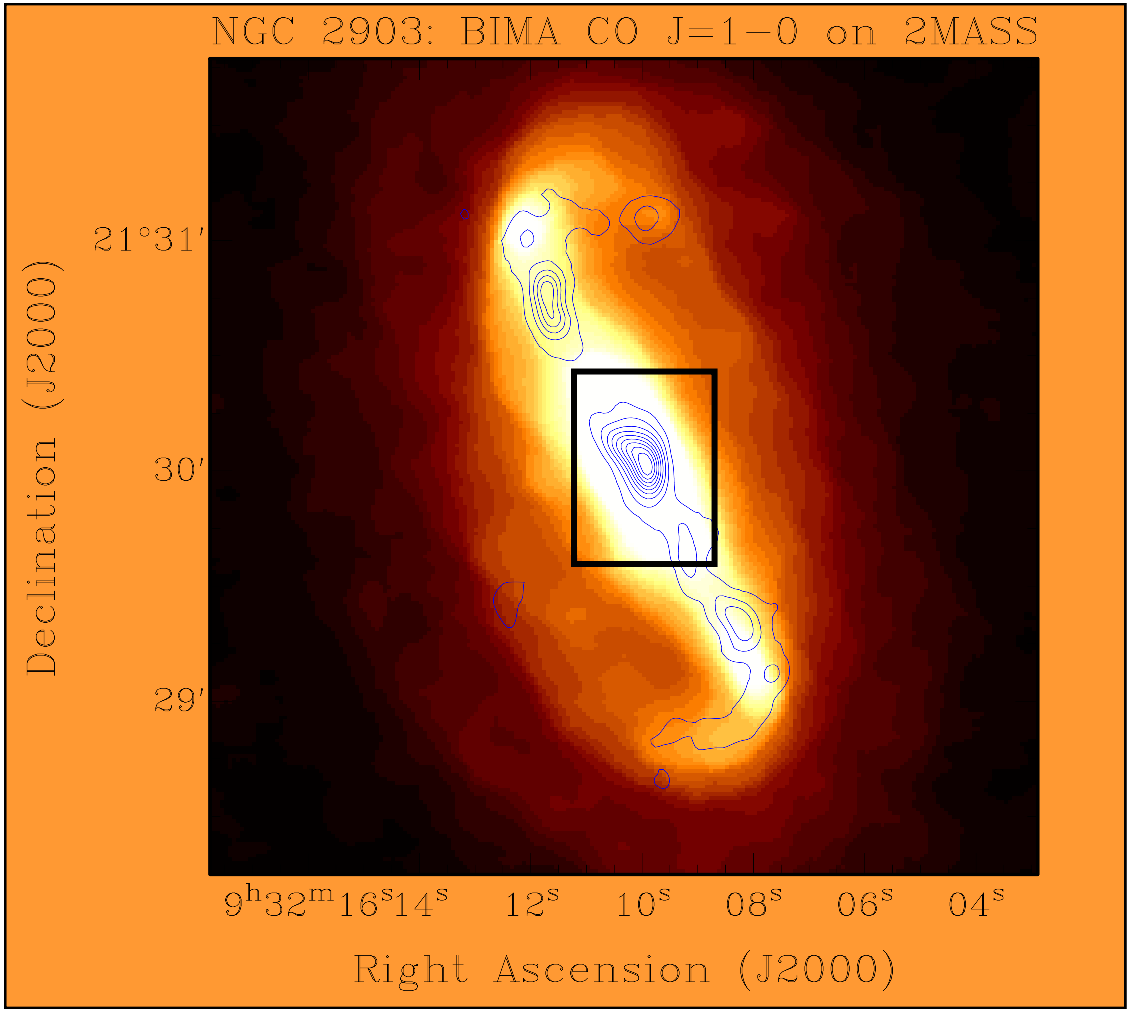
1) Do the temperature and density of molecular gas correlate with the CO morphology?

2) Do the morphologies and dynamics of the warm gas match those of the cool gas?

3) How does the CO-to-H_2 conversion factor vary with galaxy type?

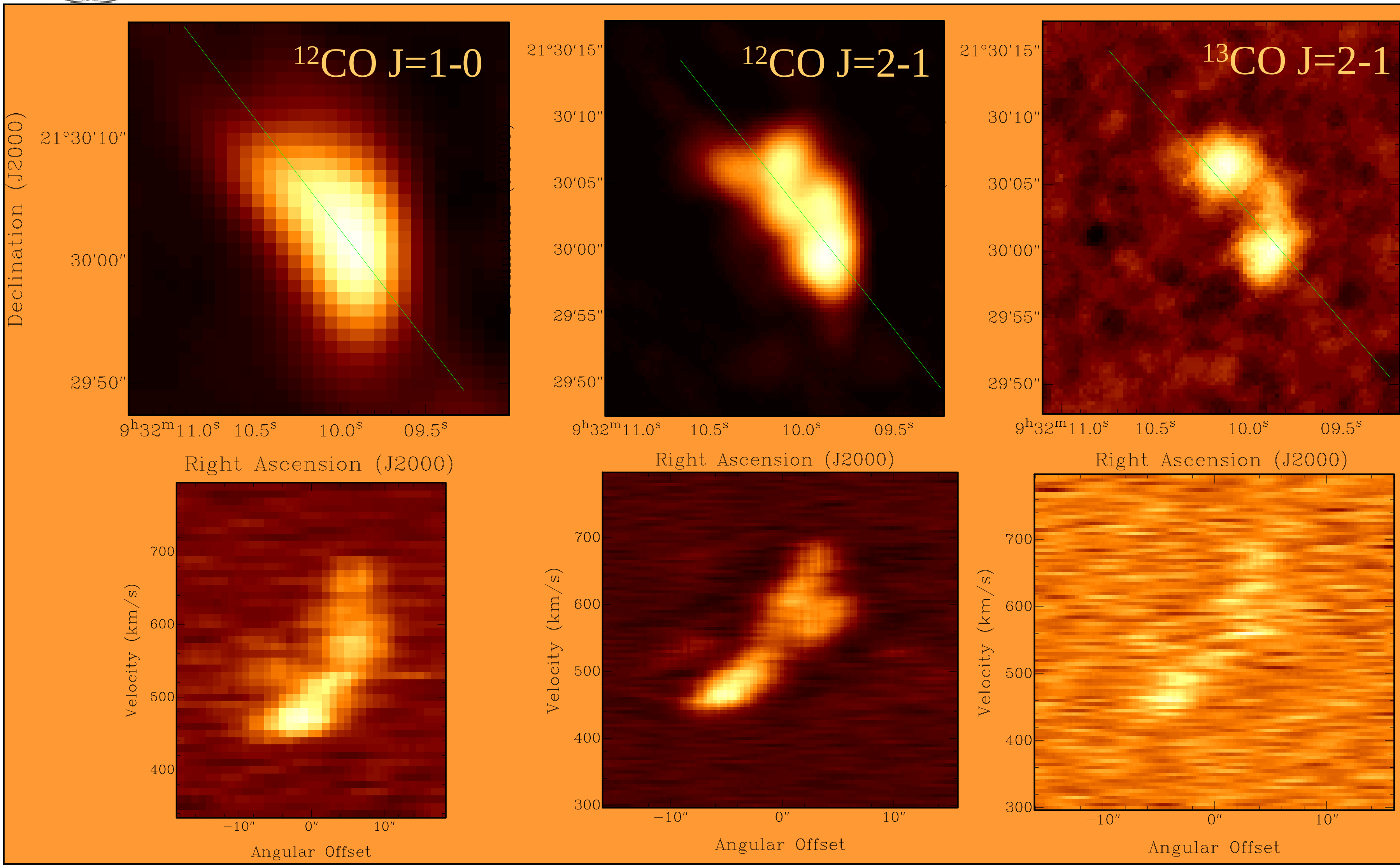

NGC 0628
NGC 2903
NGC 3627
NGC 4051
NGC 6574
NGC 6951
NGC 7331
^{12}CO J=1-0
^{12}CO J=2-1
^{13}CO J=2-1
^{12}CO J=3-2

Dynamics (NGC 2903)



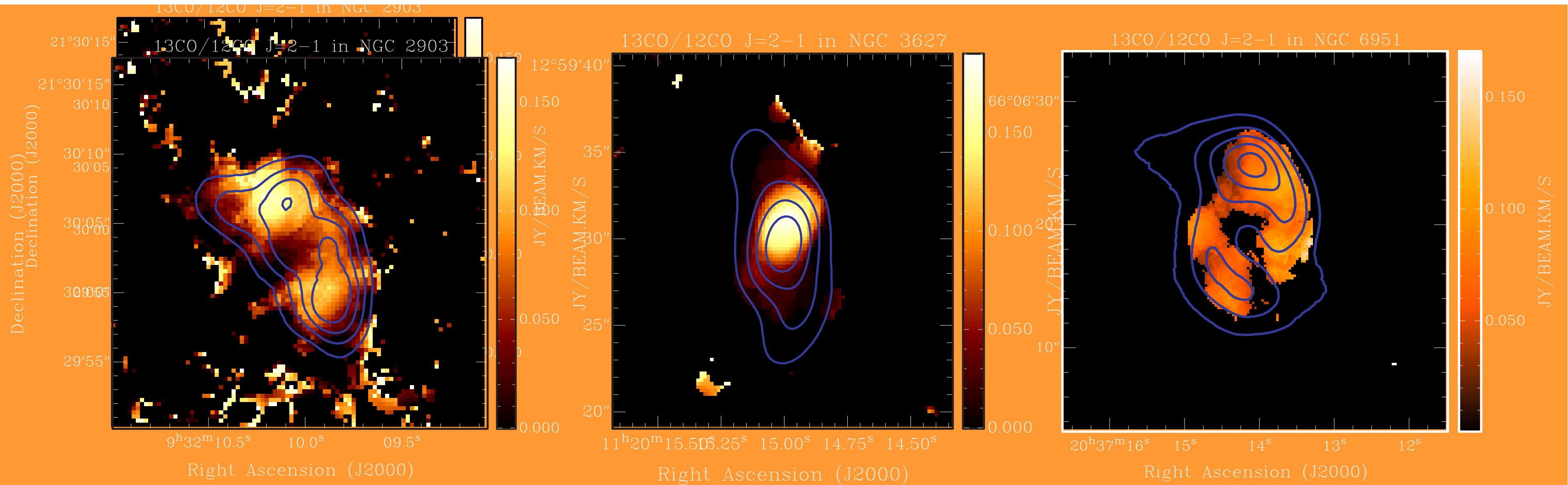
2MASS IR with ^{12}CO J=1-0 from the BIMA SONG (Helfer *et al.* 2003, ApJS, 145, 259)

Dynamics (NGC 2903)



Isotopic ratios and optical depth

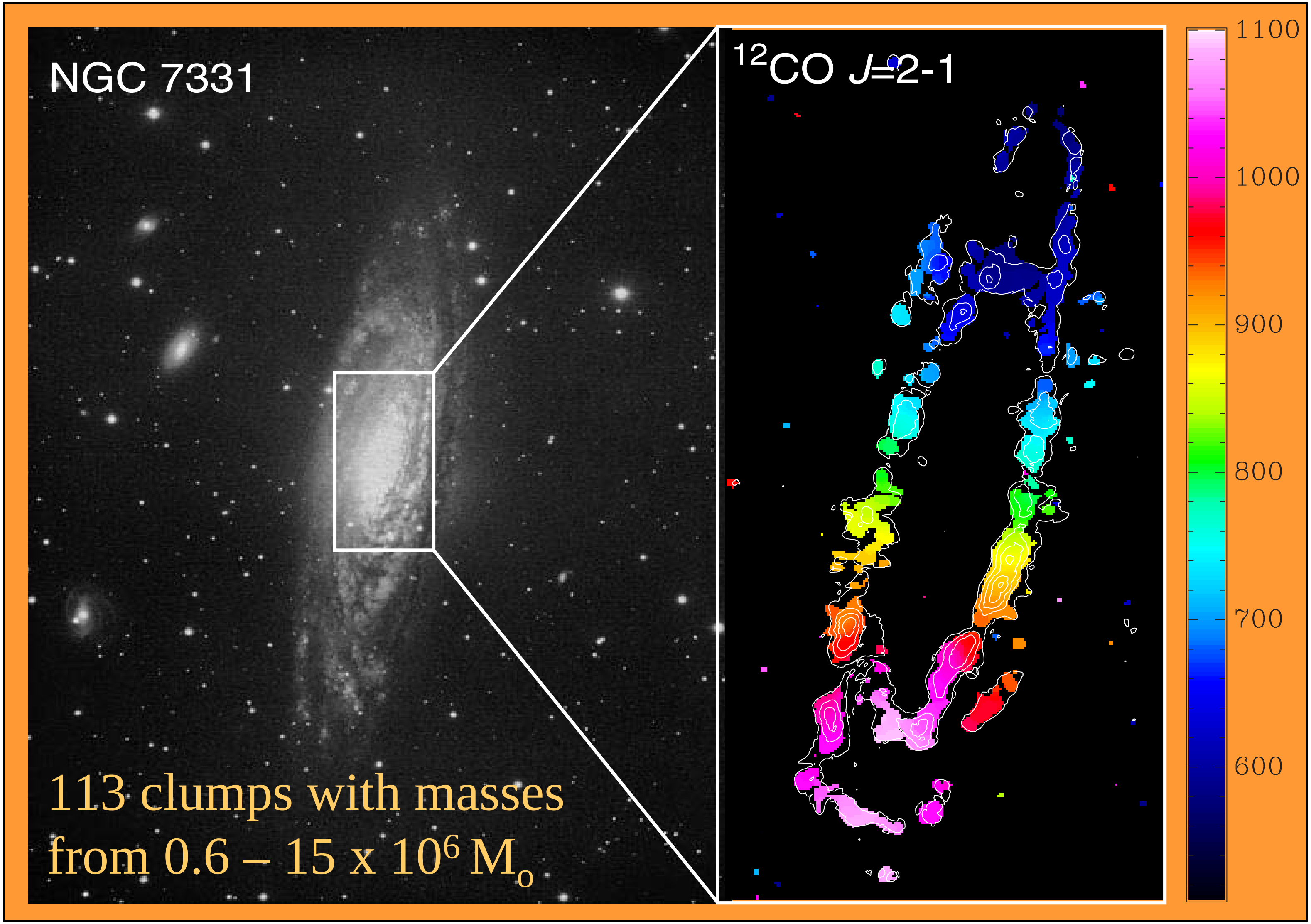
$^{13}CO/^{12}CO$ J=2-1



NGC 2903 NGC 3627 NGC 6951

Of note is that the peak value for the centrally concentrated NGC 3627 (0.19) is higher than the peak value for twin peaked emission in NGC 2903 and NGC 6951 (0.17). Since $^{13}CO/^{12}CO \sim \tau(^{12}CO)/X$ (where X is the $^{12}CO/^{13}CO$ abundance ratio = 43-62 in the Galaxy: Langer & Penzias, 1993 ApJ, 408, 539) we estimate the peak optical depth of the molecular gas to be around 10 in NGC 3627 and 8.5 in NGC 2903 and NGC 6951, i.e. the molecular ***gas is very optically thick in all of these galaxies***.

Dynamics and Mass Spectrum



Mass spectrum similar to M31 and M33

Gas Properties of Cen A: CO(2-1) SMA and HI VLBA Imaging Towards Its Nucleus

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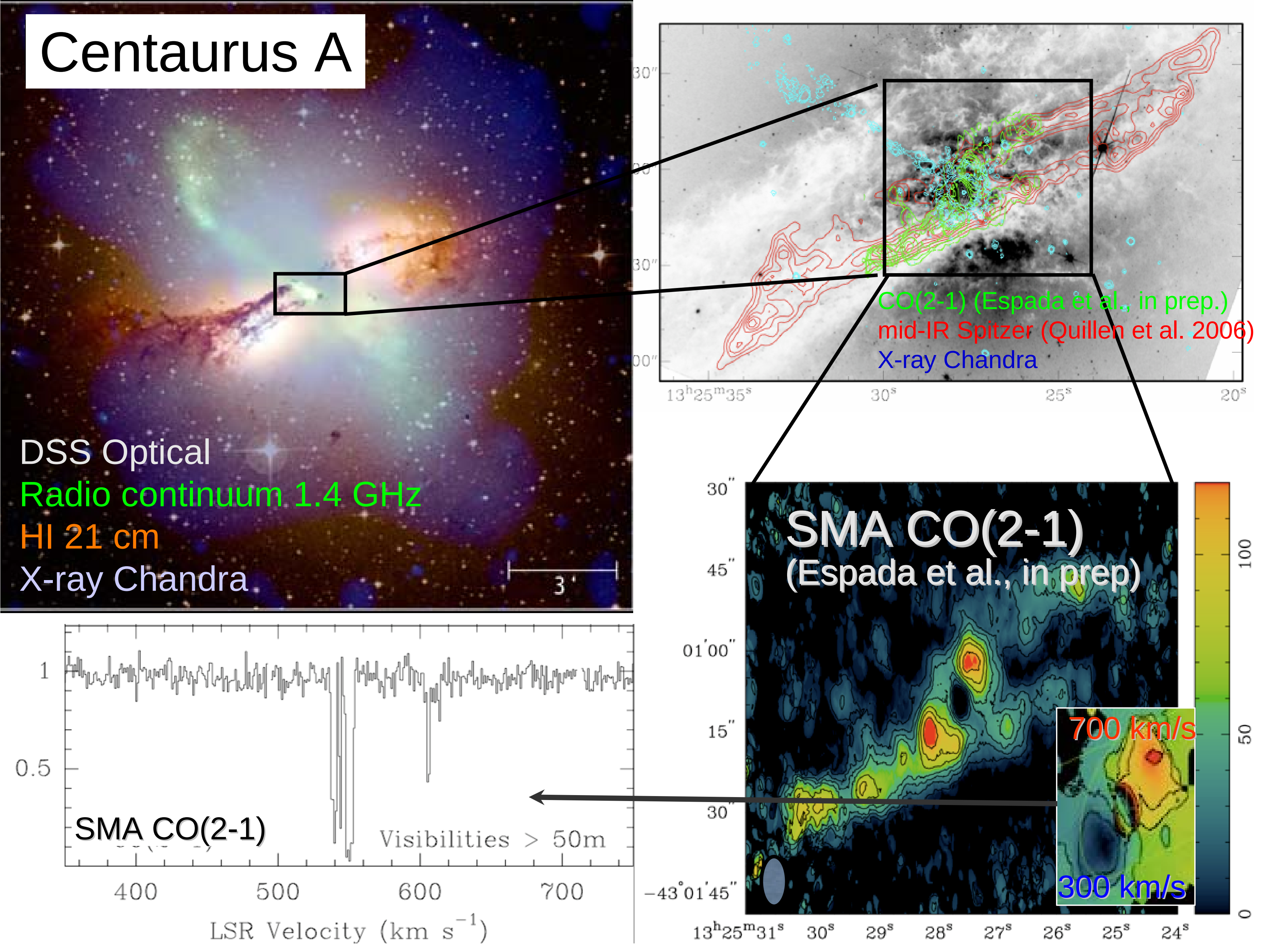
Y. Pihlstroem, G. Taylor (UNM),
S. Muller, D.-V.-Trung (ASIAA)

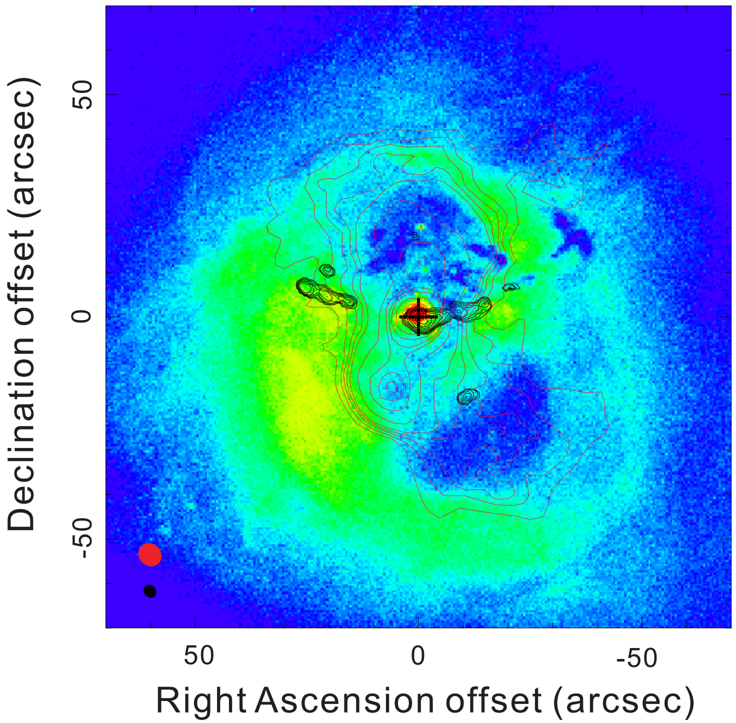


Centaurus A
DSS Optical
Radio continuum 1.4 GHz
HI 21 cm
X-ray Chandra
3'
CO(2-1) (Espada et al., in prep.)
mid-IR Spitzer (Quillen et al. 2006)
X-ray Chandra
30"
30"
00"
13h25m35s
30s
25s
20s
SMA CO(2-1)
(Espada et al., in prep)
30"
45"
01'00"
15"
30"
−43°01'45"
13h25m31s
30s
29s
28s
27s
26s
25s
24s
700 km/s
300 km/s
0
50
100
1
0.5
SMA CO(2-1)
Visibilities > 50m
400
500
600
700
LSR Velocity (km s−1)

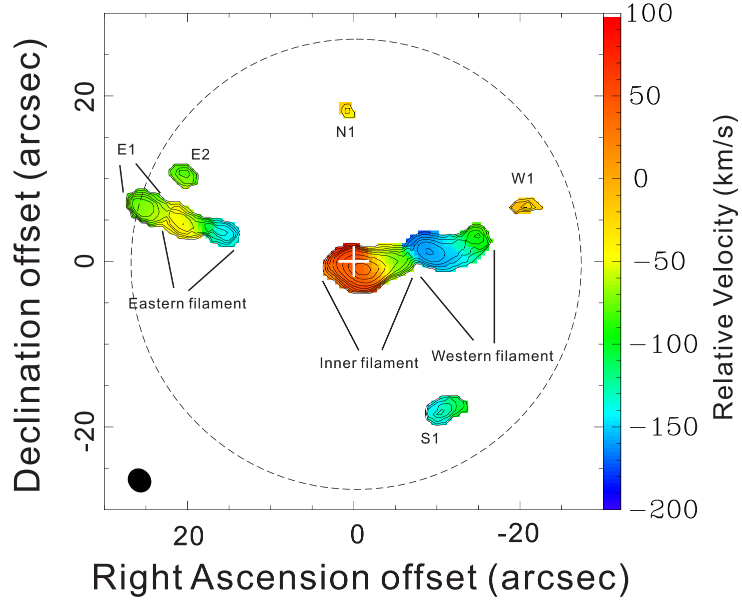
Radially-Inflowing Molecular Gas in NGC 1275 from a X-ray Cooling Flow in the Perseus Cluster

J. Lim, Y.-P. Ao, and Dinh-V.-Trung

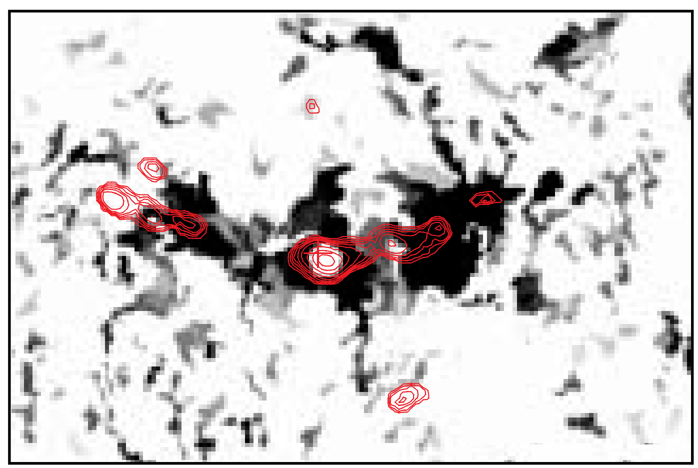
Lim, Ao, & Dinh 2007, ApJ, accepted



CO(2-1) emission (black contours) in Perseus A, central giant elliptical galaxy in Perseus cluster, overlaid on radio jets (red contours) and X-rays (color).

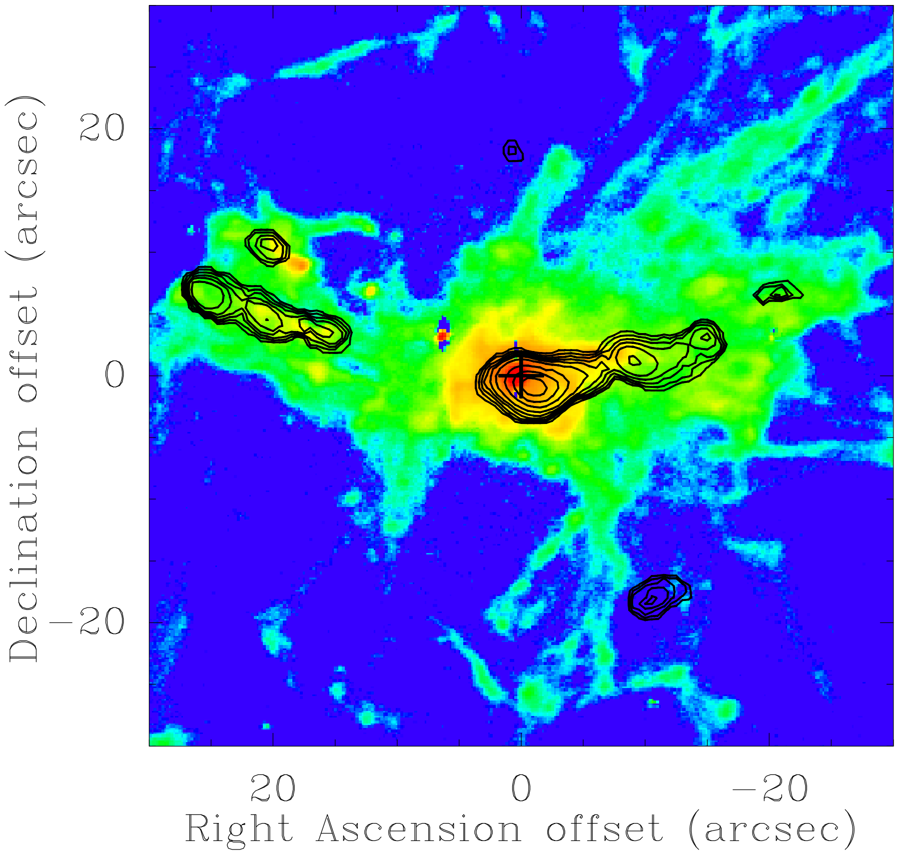


Velocity map of the CO(2-1) emission. Note the increasing blueshifted velocities with decreasing radii for eastern and western filaments

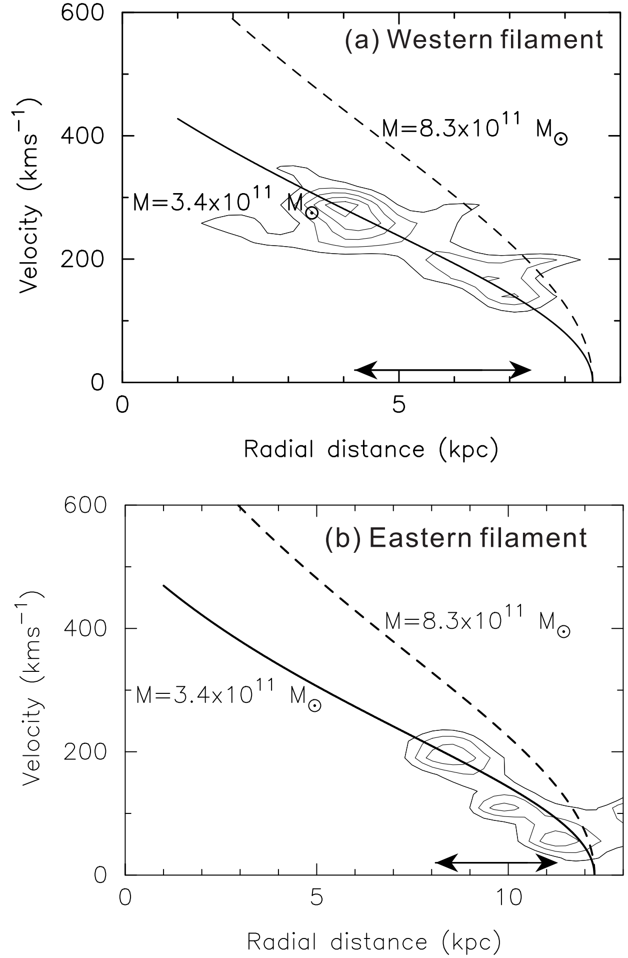


CO(2-1) emission (red contours) overlaid on coolest X-ray gas in cluster core at ~5x10^{6} K (grey).

Lim, Ao, & Dinh 2007, ApJ, accepted



CO(2-1) emission (black contours) overlaid on Hα emission (color).



PV diagrams of eastern and western filaments, reproduced as free-fall in gravitational potential of Per A, indicating that molecular gas originates from X-ray cooling flow

Warm Molecular Gas in Merging Systems: The Prototypical Antennae

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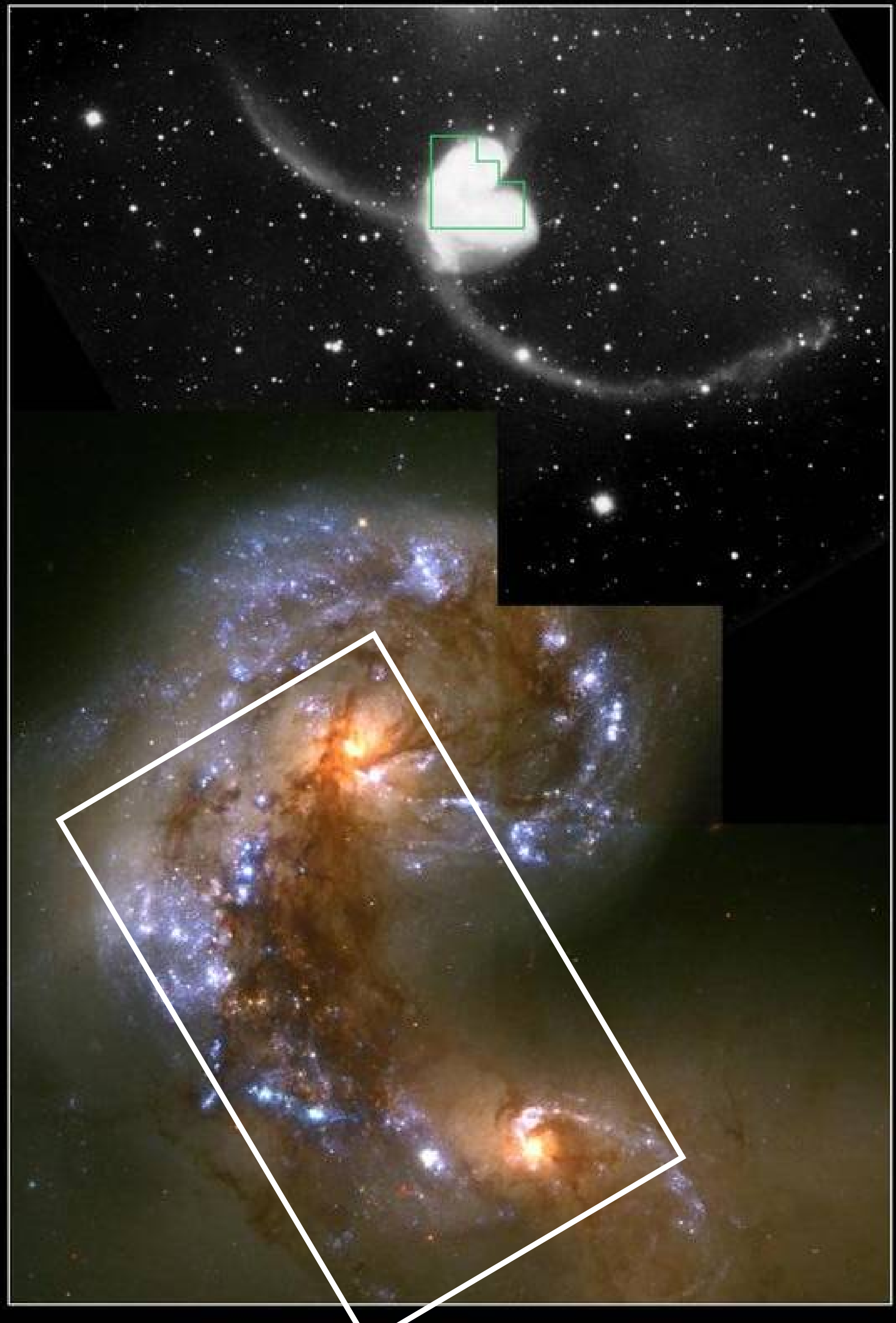
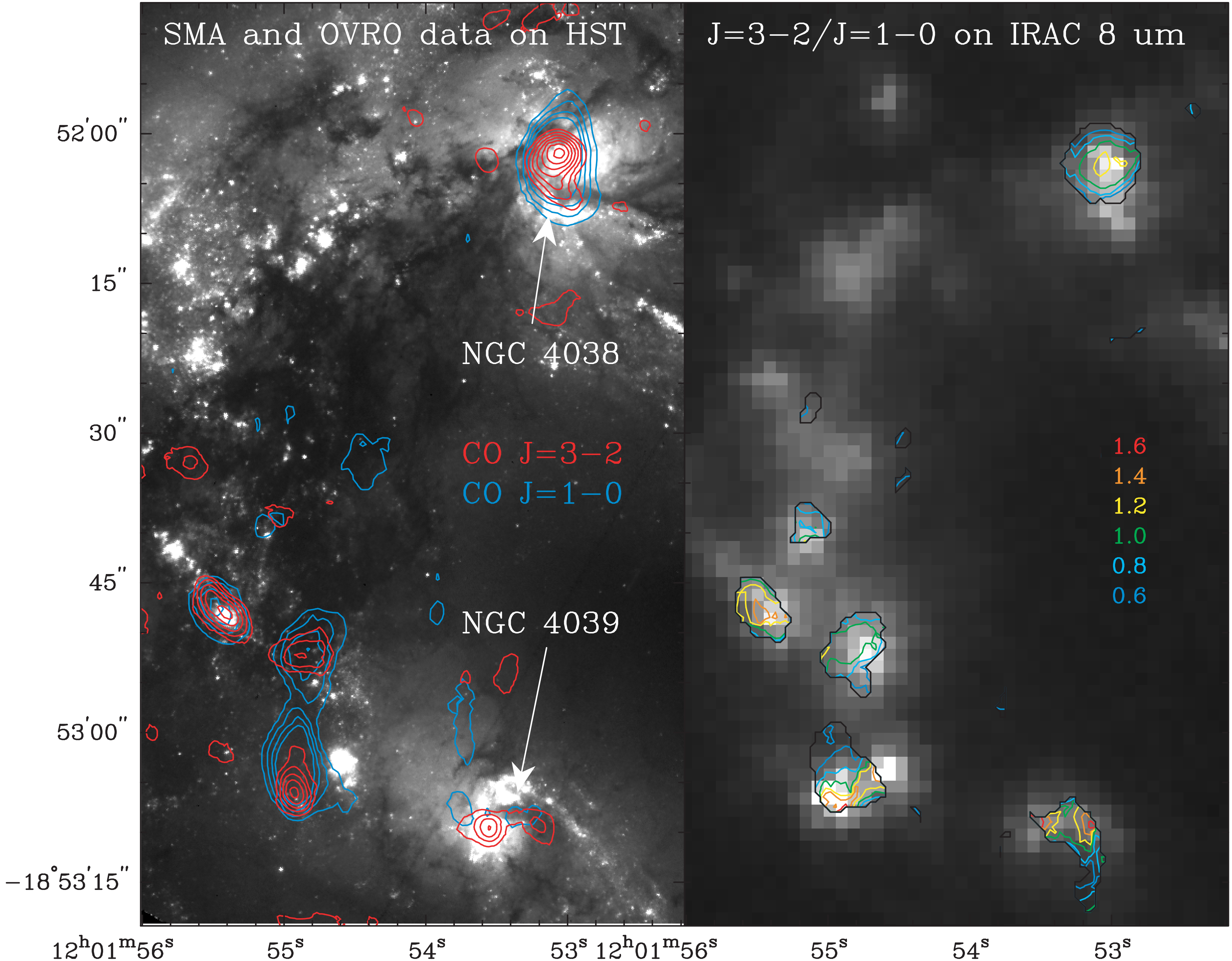
K. Sakamoto (NAOJ), J. Wang, Q. Zhang,
A. Rots,Z. Wang (CfA), M. Yun (UMass),
J. Surace (SSC), R.-Q. Mao (PMO)





SMA and OVRO data on HST
J=3−2/J=1−0 on IRAC 8 um
NGC 4038
NGC 4039
CO J=3−2
CO J=1−0
1.6
1.4
1.2
1.0
0.8
0.6
52′00″
15″
30″
45″
53′00″
−18°53′15″
12h01m56s
55s
54s
53s
12h01m56s
55s
54s
53s

Luminous Infrared Galaxies with the Submillimeter Array: Probing the Extremes of Star Formation

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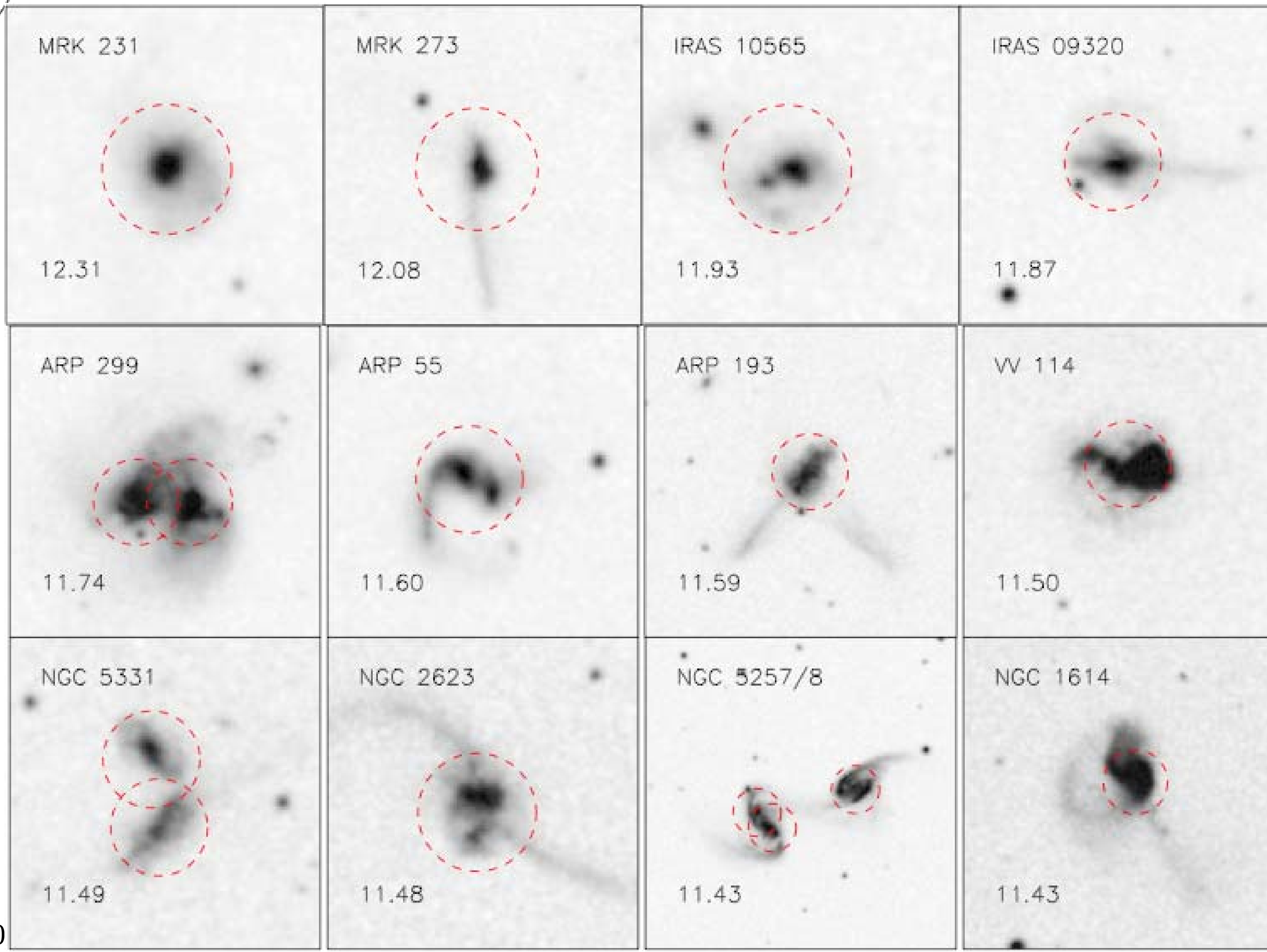
Paul Ho, Satoki Matsushita (ASIAA),
L. Armus (IPAC), A. Baker (Maryland),
Daisuke Iono (NAOJ), M. Juvela (Helsinki),
C. Mihos (Case Western), Y. Pihlstrom (UNM),
M. Yun (U.Mass)

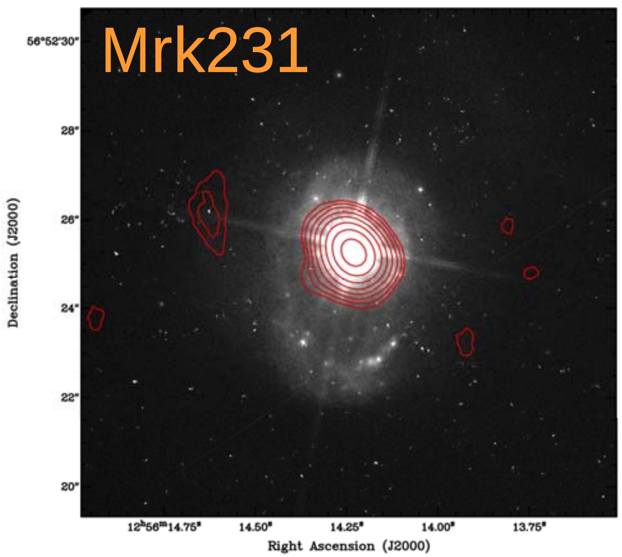
Science Goals of the Survey

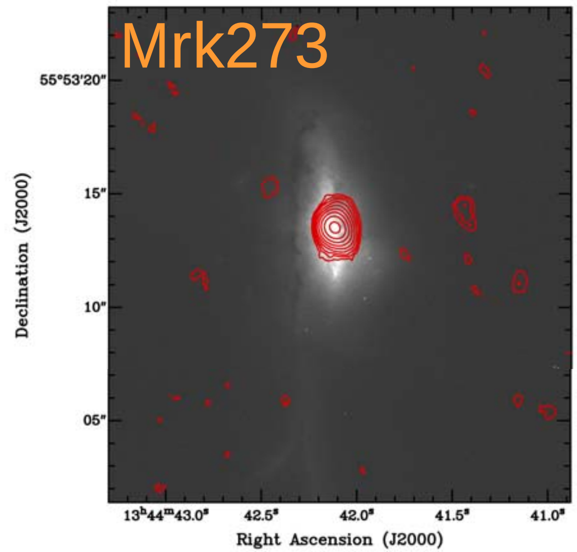
- Determine the distributions, kinematics, and physical conditions of dense molecular gas in U/LIRGs
- Determine the spatial distribution of dust in U/LIRGs
- Constrain the origin of nuclear OH megamasers
- Determine how the gas properties change as the interaction progresses
- Compare the properties of the dense gas in local ULIRGs with the high-redshift submillimeter sources

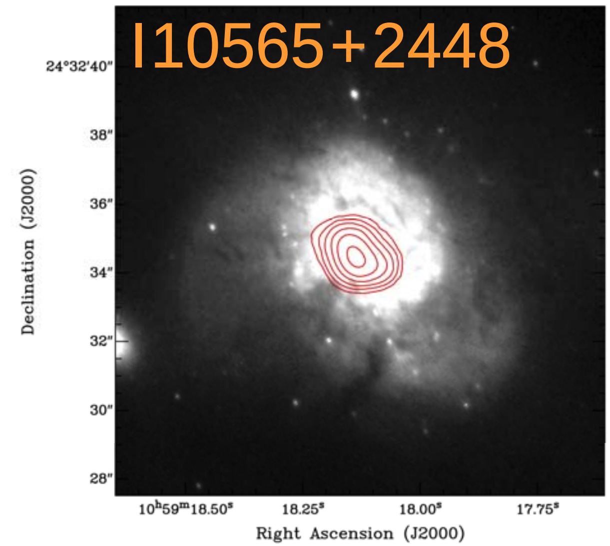
The Nearby Luminous Infrared Galaxy Sample

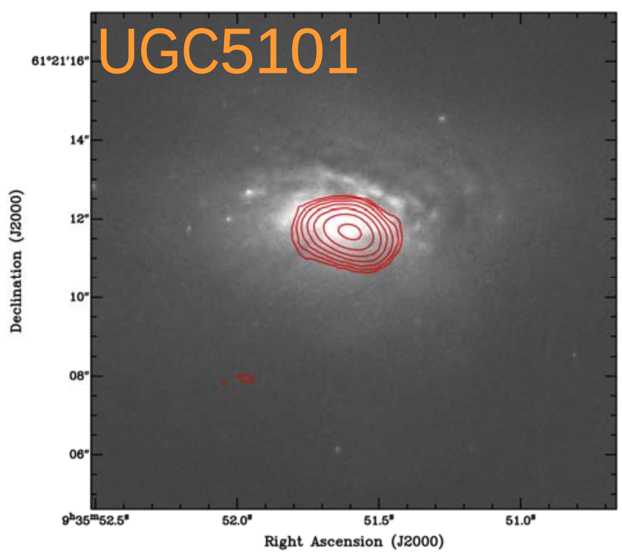


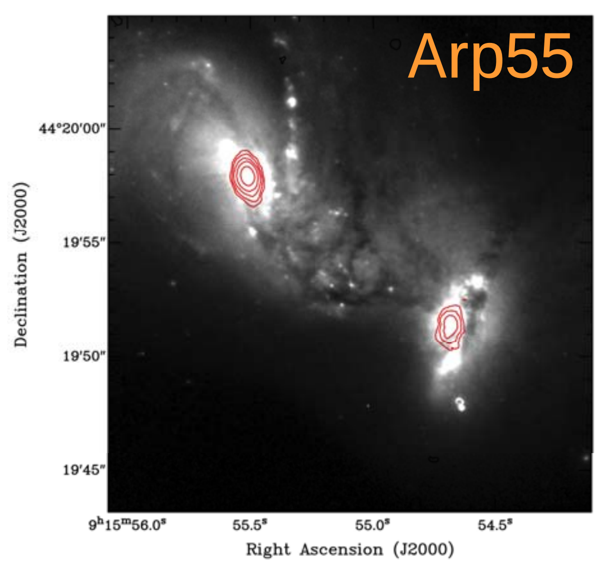
Centrally compact CO 3-2 emission





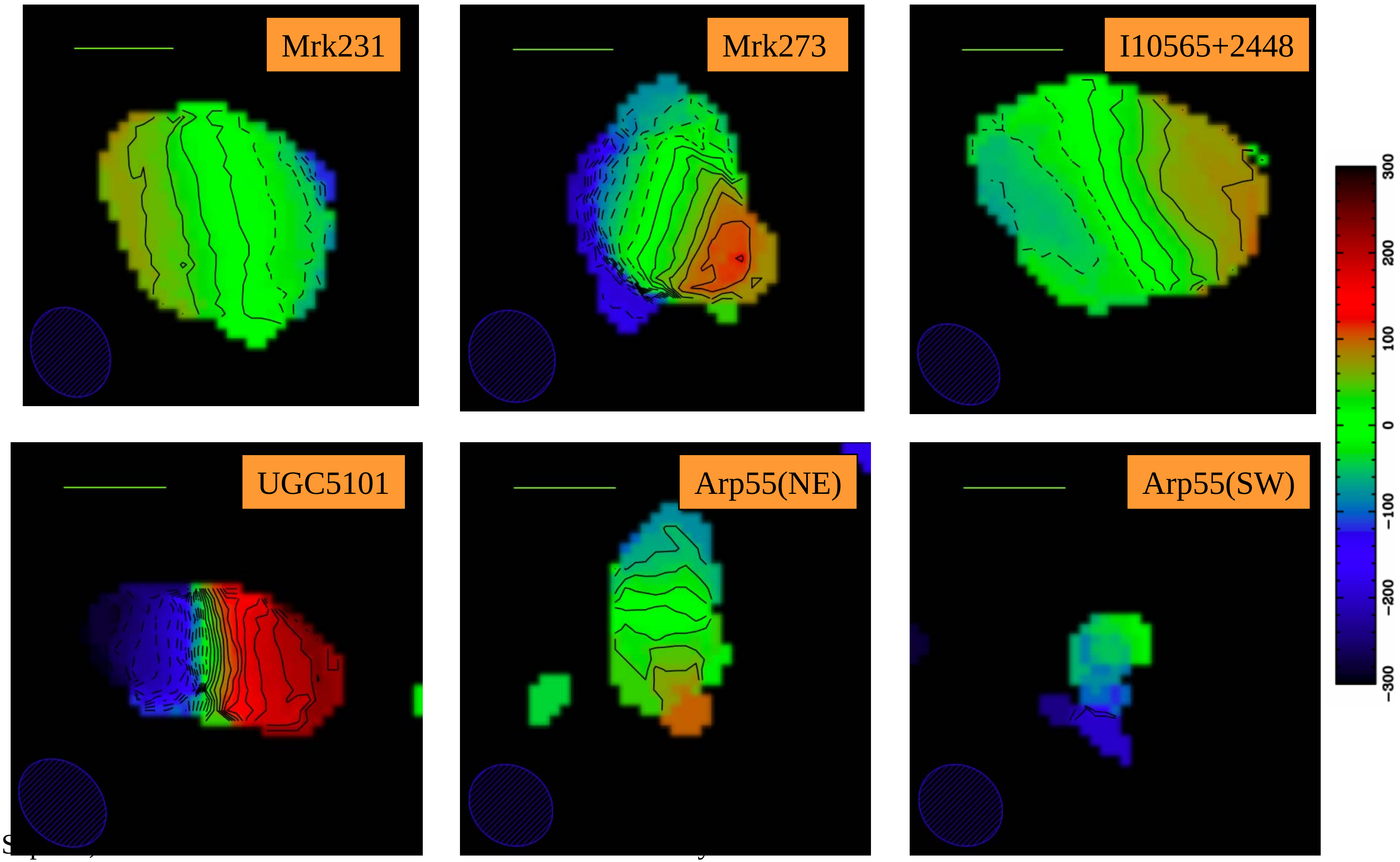






(HST images of Arp55 and I10565+2448 from Evans, Vavilkin, et al., 2006, in prep.)

Velocity Fields within R<1 kpc



Dynamical Mass and Gas Mass Fraction

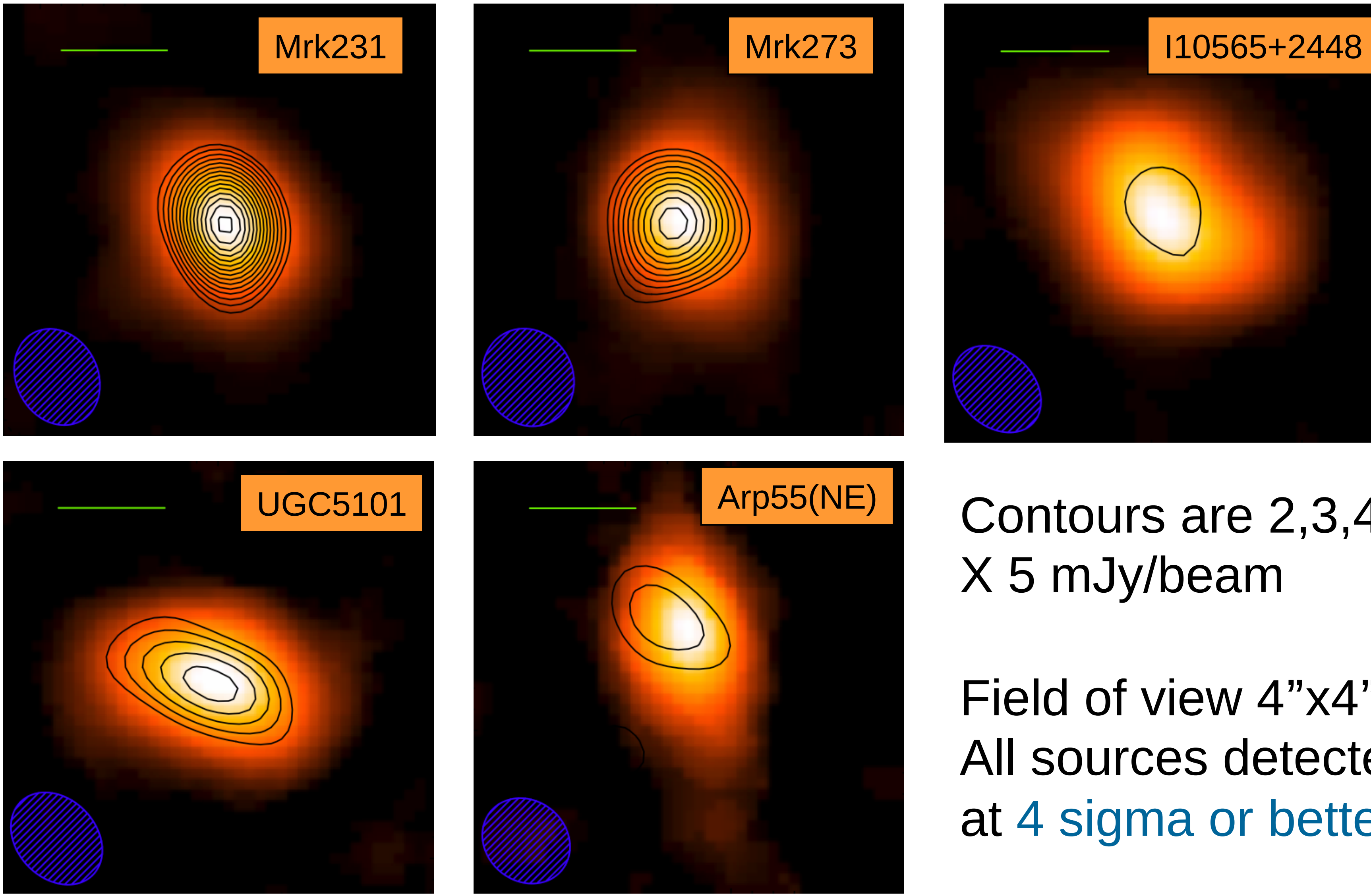
Galaxy	D_{FWHM} (pc)	V_{FWHM} (km/s)	$M_{dyn} \sin^2 i$ (10^9 $M_\odot$)	i (deg)	M_{H_2} (10^9 $M_\odot$)	M_{H_2}/M_{dyn}
Mrk231	~400	180	0.39	10	4.1	0.3
Mrk273	~300	480	2.5	45	5.1	1.0
10565+2448	900	190	0.98	20	3.1	0.4
UGC5101	900 × <400	640	10.2	60	2.7	0.2
Arp55(NE)	600 × <400	200	0.72	45?	1.2	(0.8)
Arp55(SW)	800 × <400	320	2.3	...	0.65	...

- $M(H_2) = 0.8\ L(CO1\text{-}0)$ (Downes & Solomon 1998); with CO3-2/1-0=0.5
- $M_{dyn} \sin^2 i = RV^2/G$, assuming $V=V_{FWHM}/2$ and $R=D_{FWHM}/2$

Estimate gas mass fractions of 0.2-1

- Inclinations are critical; from Downes & Solomon 1998, Genzel et al. 1998 (U5101), our fit (Arp55NE)

850 μm continuum overlaid on CO3-2



Contours are 2,3,4 ... X 5 mJy/beam

Field of view 4”x4”.
All sources detected at 4 sigma or better.

The Gas to Dust Mass Ratio

Galaxy	M_{dust} (10^7 $M_\odot$)	M_{H_2} (10^9 $M_\odot$)	Gas/Dust Ratio
Mrk231	4.43	4.13	93
Mrk273	3.26	5.10	156
10565+2448	1.27	3.10	244
UGC5101	3.45	2.66	77
Arp55(NE)	1.79	1.18	66
Arp55(SW)	<0.75	0.65	>87

Average gas/dust ratio = 120 +/- 30

(good agreement with typical Galactic value)

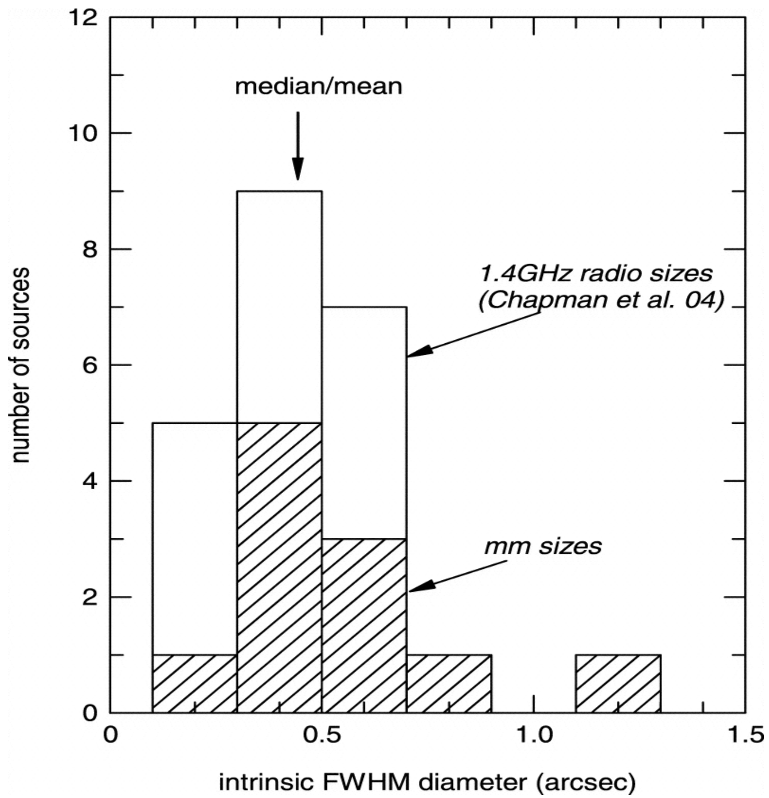
- M_{dust} assumes κ = 1 cm^2/g and T_{dust} from blackbody fit to IRAS 60 and 100 μm (Solomon et al. 1997)

ULIRGs at Low and High Redshift

Compare results for our four brightest galaxies with eight high-redshift galaxies with high resolution CO 3-2 imaging *(Tacconi et al. 2006, Downes & Solomon 2003, Genzel et al. 2003, Weiss et al. 2003)*

- High-redshift galaxies are at least an order of magnitude more luminous in CO 3-2
  - L_{CO} = 3.5x10^{10} versus 2.5x10^{9} K km/s pc^2
- High-redshift galaxies have somewhat broader lines than the local sample
  - 560+/-90 versus 370 +/-90 km/s

CO Size Distribution of High-Redshift Submillimeter Galaxies



Tacconi et al. 2006

- Average D_{FWHM} measured in CO for four high redshift galaxies is 5000 pc
- Compare to average D_{FWHM} of 600 pc for local sample
- Our 5th galaxy, Arp55, has two components spaced by 8000 pc ...

The end