dense ISM in ULIRG mergers : NGC 6240 and Arp 220
Cycle 0 ALMA --

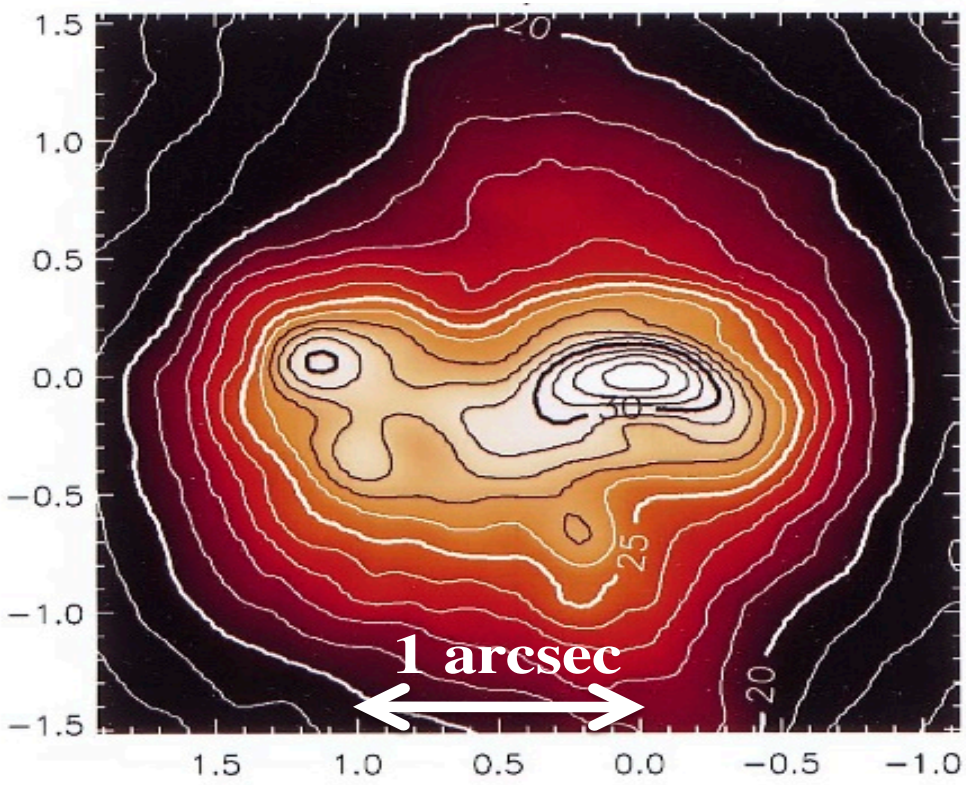
Band 7 (0.5") : HCN (4-3) , CS (7-6) , H26α
Band 9 (0.3") : HCN (8-7)

Cycle 1 → Band 7 w/ 0.2"

w/ Sheth, Manohar, Zschaechner, Walter, Koda, Tacconi, Davies, Narayanan, Brown, van der Werf, Hayward, Robertson, Thompson, Barnes, Hernquist, Genzel, Fomalont, Sanders

submm recomb lines
modeling of disks

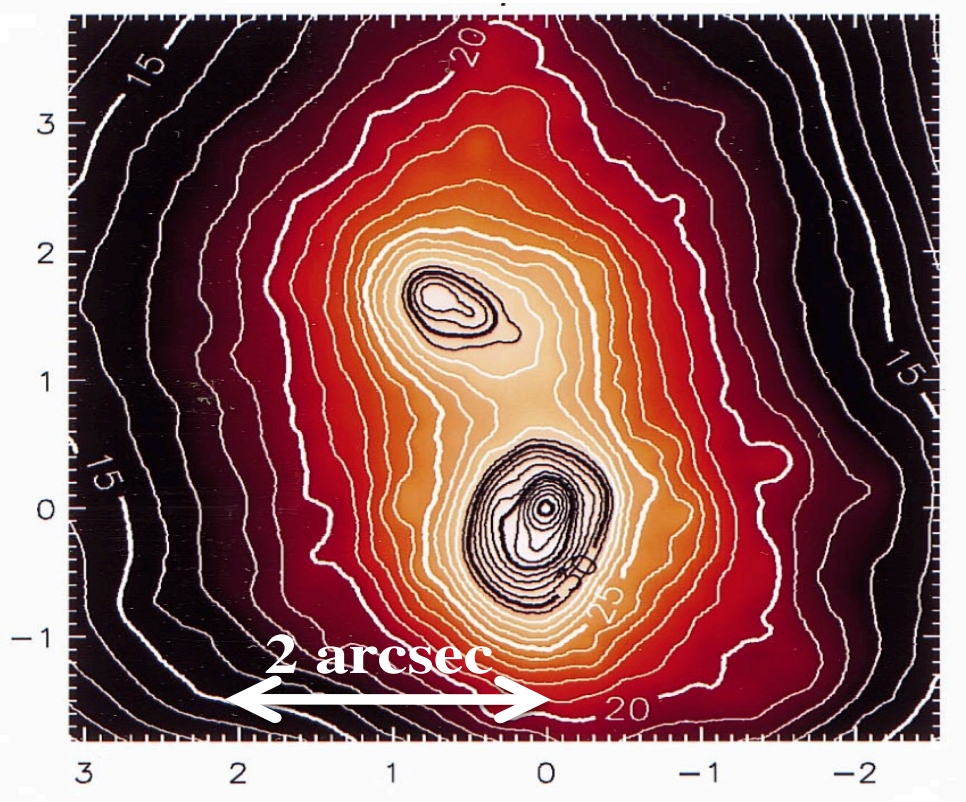
Arp 220 - 2μm



$2.5 \times 10^{12}\ L_{\odot}$

1 arcsec ➔ 361 pc

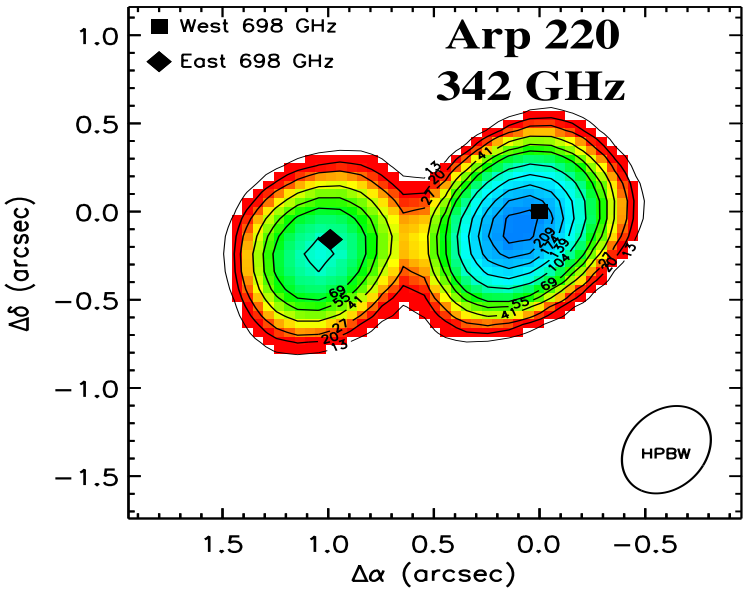
NGC 6240 - 2μm

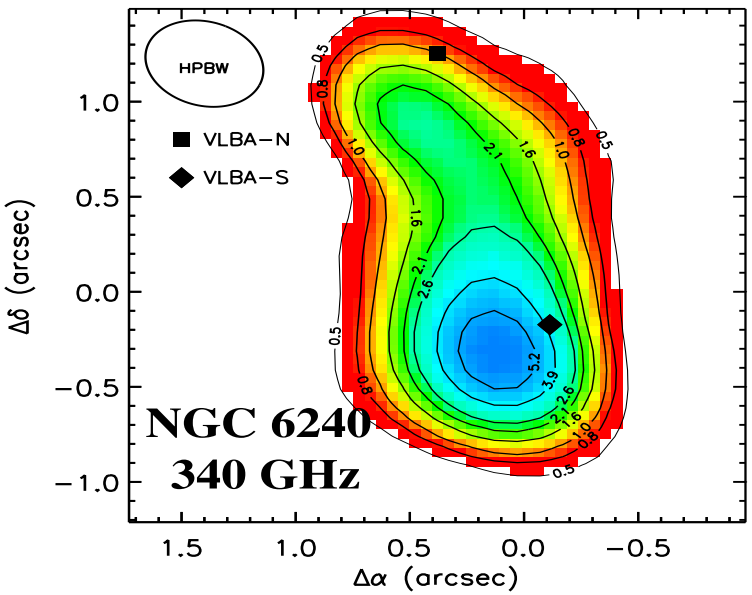


$9 \times 10^{11}\ L_{\odot}$

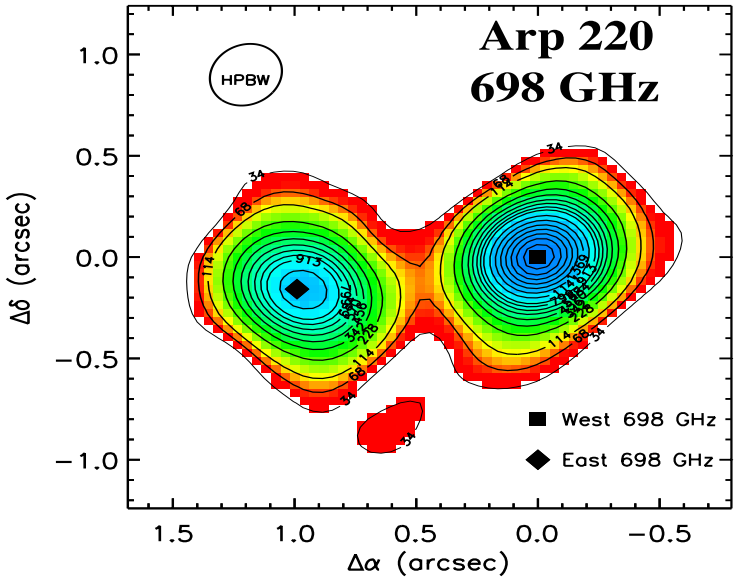
1 arcsec ➔ 475 pc

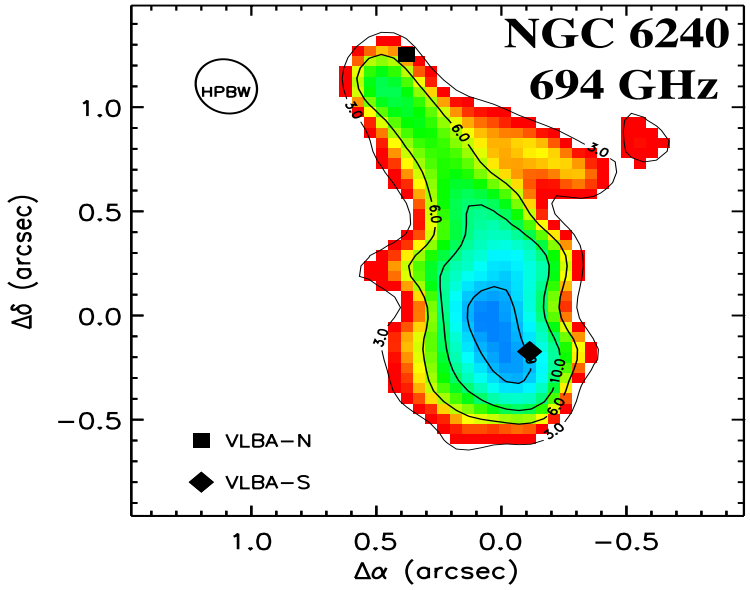
continuum





Band 7





Band 9

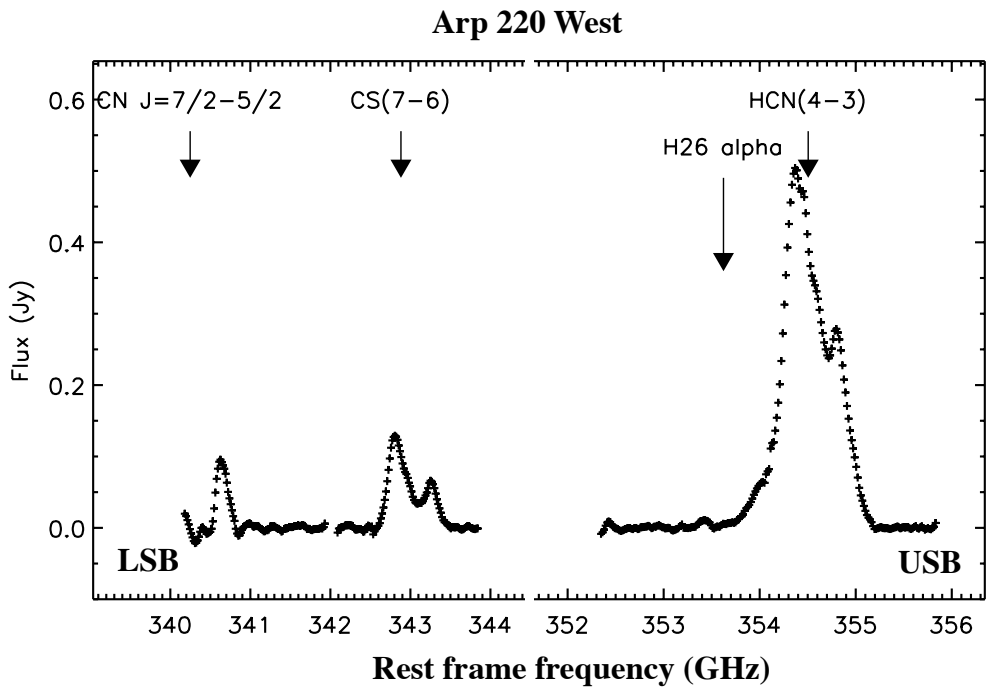
dust continuum
➔ISM mass

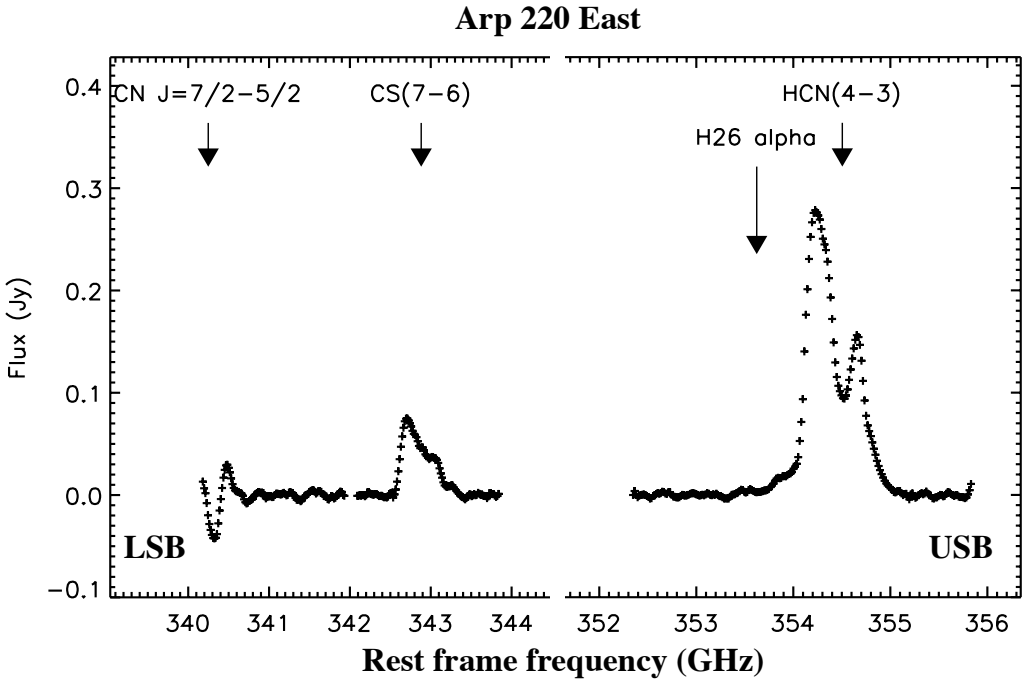
Masses from RJ dust continuum :

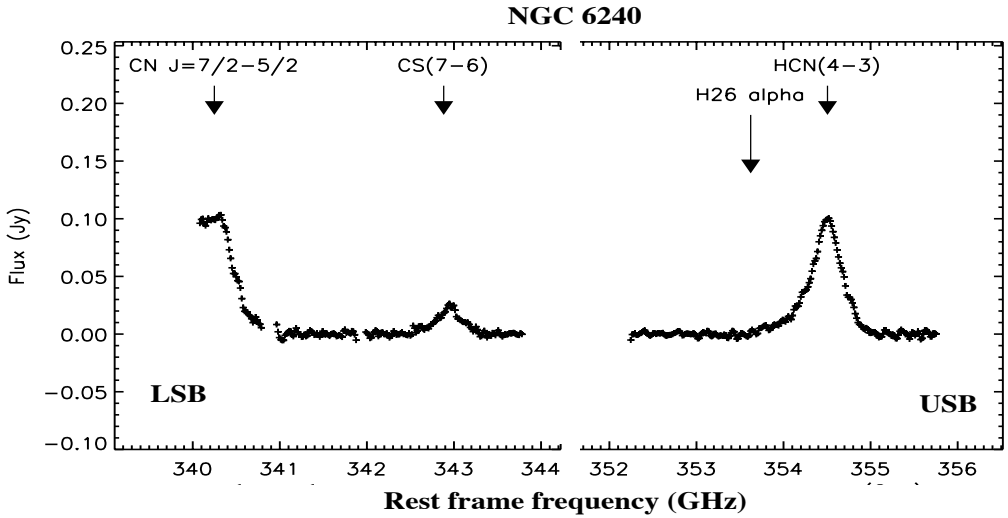
$$M_{ISM} = \frac{0.87\ S_\nu(mJy) d^2_{Gpc}}{(1+z)^{4.8} T_{25} \nu^{3.8}_{350} \Gamma_{RJ}} 10^{10} M_{sun}$$

ISM Masses from Dust Continuum

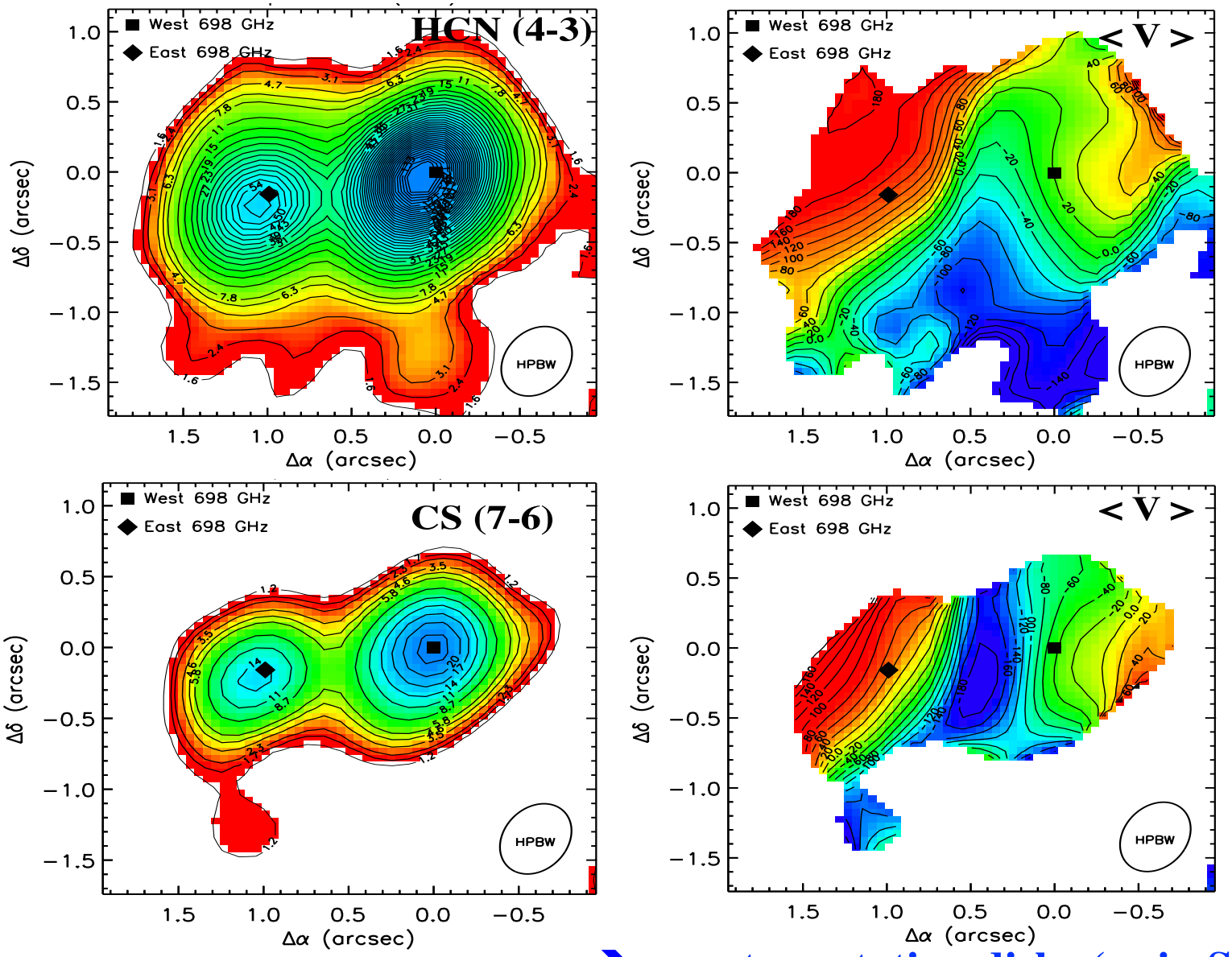
Source	ν_{obs}	Flux	T_d [a]	Γ_{RJ}	Mass	diameter[b]	Radius	$< \Sigma_{gas} >$[c]
	GHz	mJy	K		10^9 $M_\odot$	$''$	pc	$M_\odot$ pc^{-2}
Arp 220 East	347.6	161	100	0.917	1.96	$\lesssim$ 0.38	$\lesssim$ 69	$\gtrsim$ 1.3×10^5
Arp 220 West	347.6	342	100	0.917	4.16	$\lesssim$ 0.36	$\lesssim$ 65	$\gtrsim$ 3.1×10^5
NGC 6240	693.5	126	25	0.468	1.64	0.8	190	$\gtrsim$ 1.4×10^4


Arp 220 West
CN J=7/2-5/2
CS(7-6)
HCN(4-3)
H26 alpha
LSB
USB
Flux (Jy)
Rest frame frequency (GHz)

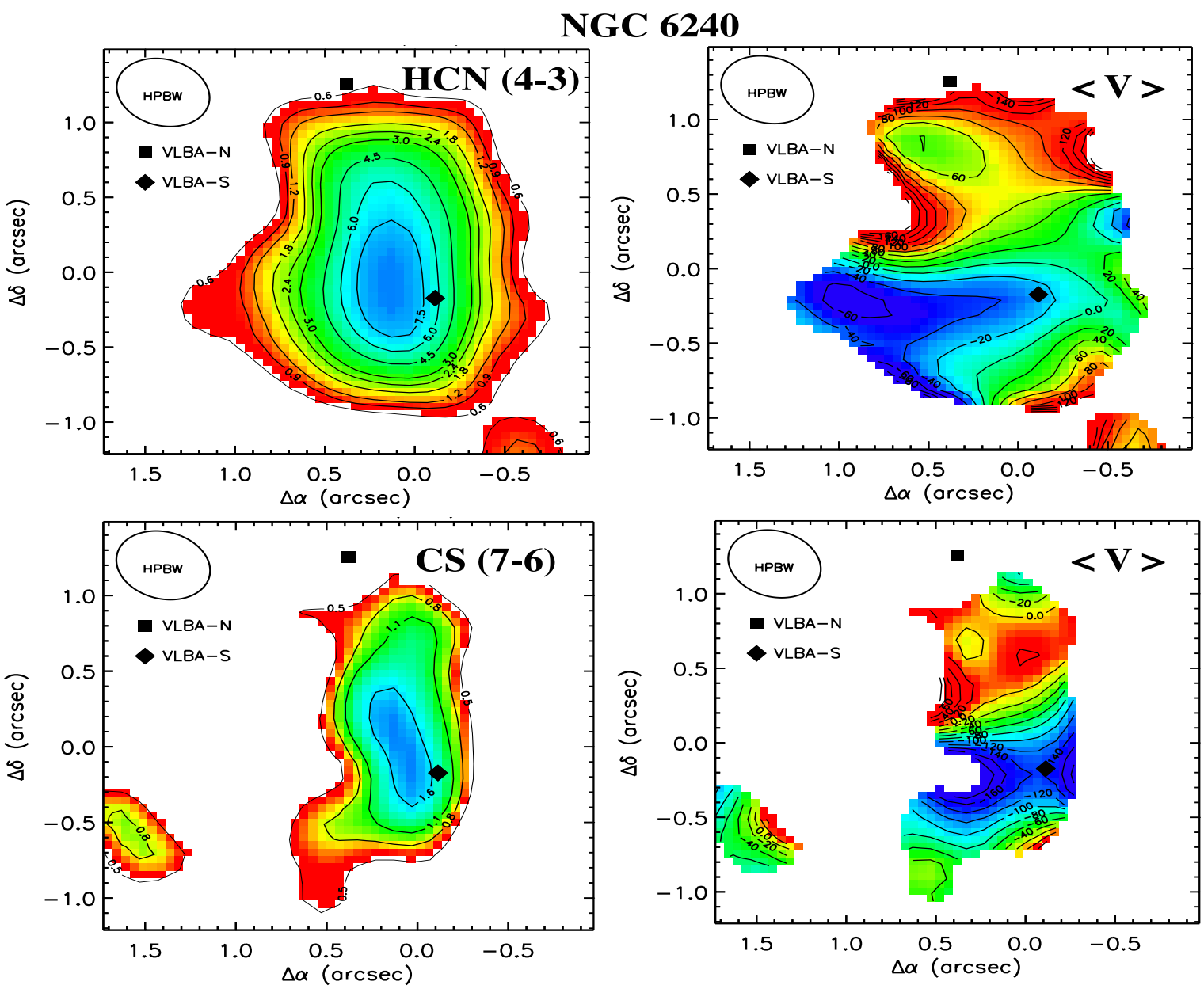

Arp 220 East
CN J=7/2-5/2
CS(7-6)
HCN(4-3)
H26 alpha
LSB
USB
Flux (Jy)
Rest frame frequency (GHz)


NGC 6240
CN J=7/2-5/2
CS(7-6)
HCN(4-3)
H26 alpha
LSB
USB
Flux (Jy)
Rest frame frequency (GHz)

Arp 220



➔ counter-rotating disks (as in Sakamoto etal '98)


NGC 6240
HCN (4-3)
< V >
CS (7-6)
< V >
HPBW
VLBA−N
VLBA−S
Δδ (arcsec)
Δα (arcsec)

double Gaussian fits

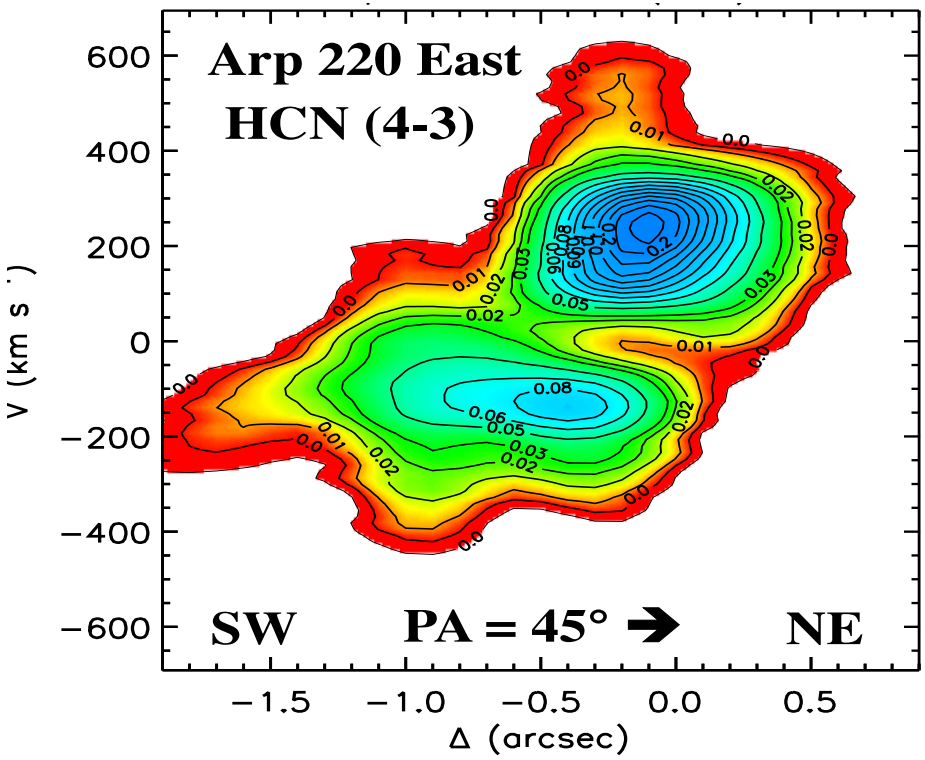
Source		Beam major ″	Beam minor ″	Beam PA °	Deconvolved major ″	Deconvolved minor ″	T_B K
band 7							
Arp 220	continuum	0.60	0.42	-32.0	0.28	0.27	33.9
Arp 220	continuum	0.60	0.42	-32.0	0.37	0.27	11.1
Arp 220	continuum	0.52	0.39	-27.2	0.36	0.24	34.9
Arp 220	continuum	0.52	0.39	-27.2	0.38	0.32	9.6
NGC 6240	continuum	0.55	0.46	65.6	0.50	0.39	0.4
NGC 6240	continuum	0.55	0.46	65.6	1.09	0.53	0.1
NGC 6240	continuum	0.53	0.44	64.7	0.49	0.40	0.3
NGC 6240	continuum	0.53	0.44	64.7	1.07	0.57	0.0
band 9							
Arp 220	continuum	0.32	0.28	-38.6	0.23	0.19	148.9
Arp 220	continuum	0.32	0.28	-38.6	0.30	0.24	47.2
NGC 6240	continuum	0.27	0.24	29.7	0.82	0.30	0.2
band 7							
Arp220	CS (7-6)	0.60	0.42	-32.0	0.49	0.43	10.1
Arp220	CS (7-6)	0.60	0.42	-32.0	0.40	0.35	7.5
Arp220	HCN (4-3)	0.52	0.39	-27.2	0.57	0.41	39.3
Arp220	HCN (4-3)	0.52	0.39	-27.2	0.58	0.45	21.5
NGC 6240	CS (7-6)	0.55	0.46	65.6	....[a]	....[a]	....[a]
NGC 6240	HCN (4-3)	0.53	0.44	64.7	1.14	0.60	1.5

major axis radii ~ 0.25'' ➔ r ~ 90 pc

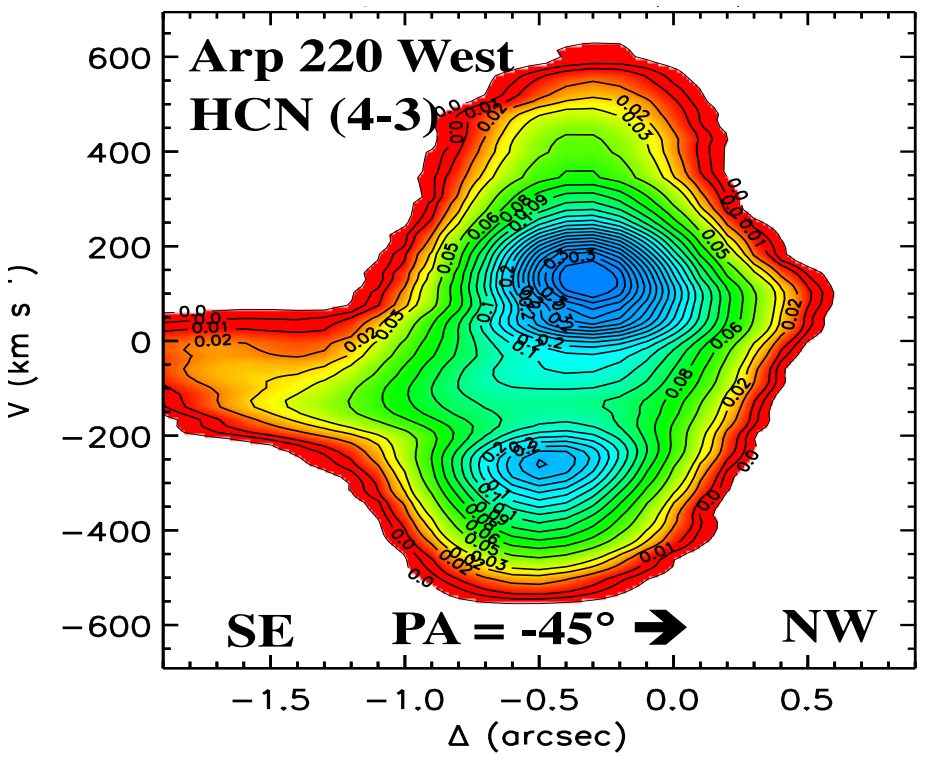
kinematics ➔

spatial – velocity strip maps along major axes

East



West



kinematic modeling

use kinematic deconvolution

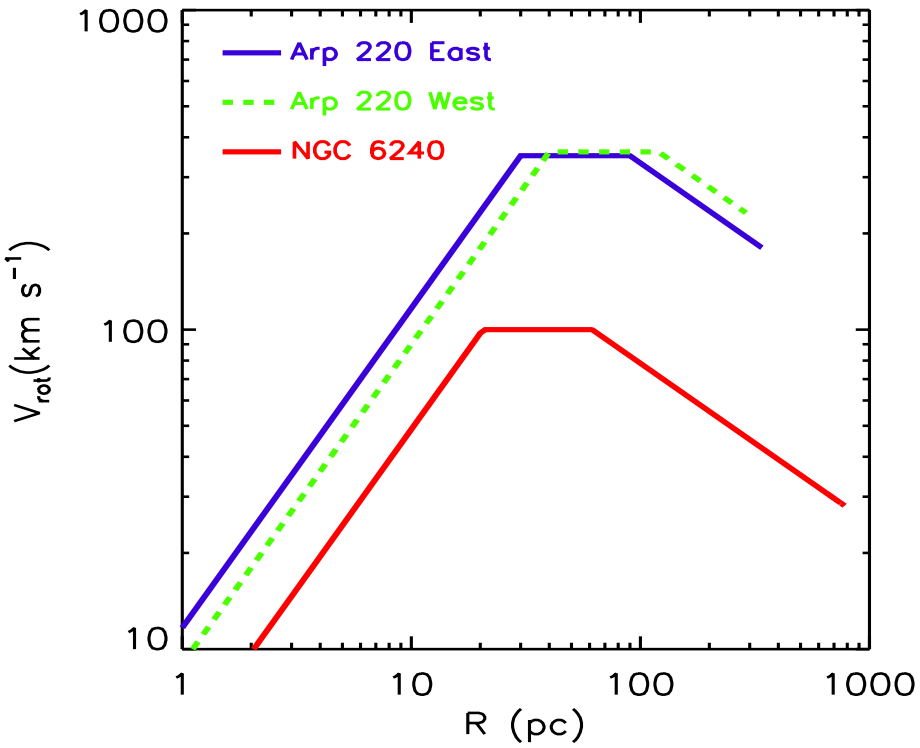
Scoville, Young & Lucy ‘83

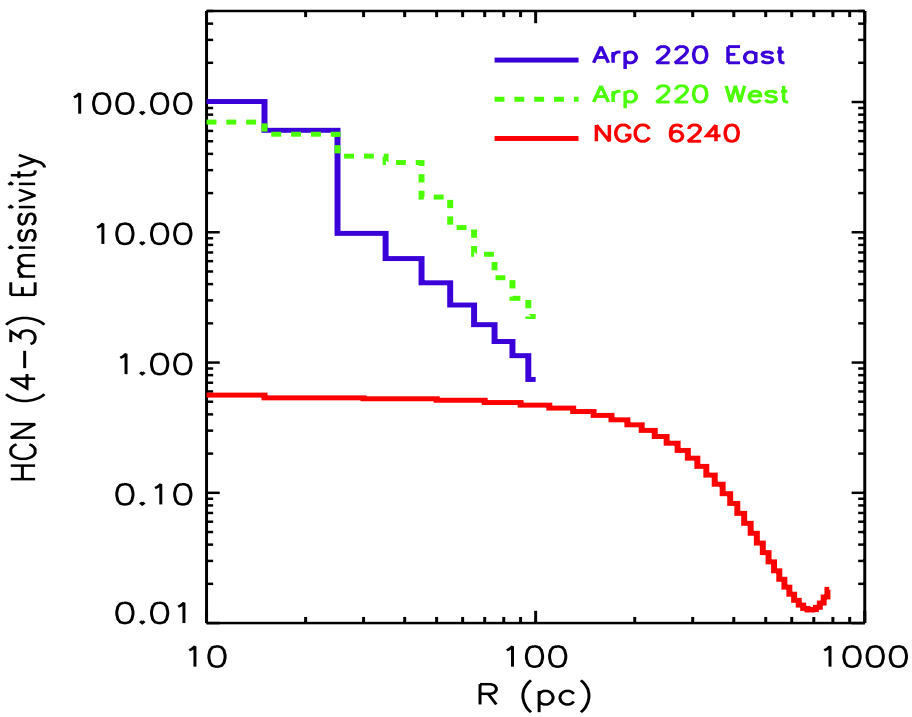
if vel. field known,

use observed line profiles

➔ super resolution much better than beam width

solve for rot. curve and emissivity (r)
which give best fit between obs. and model line profiles

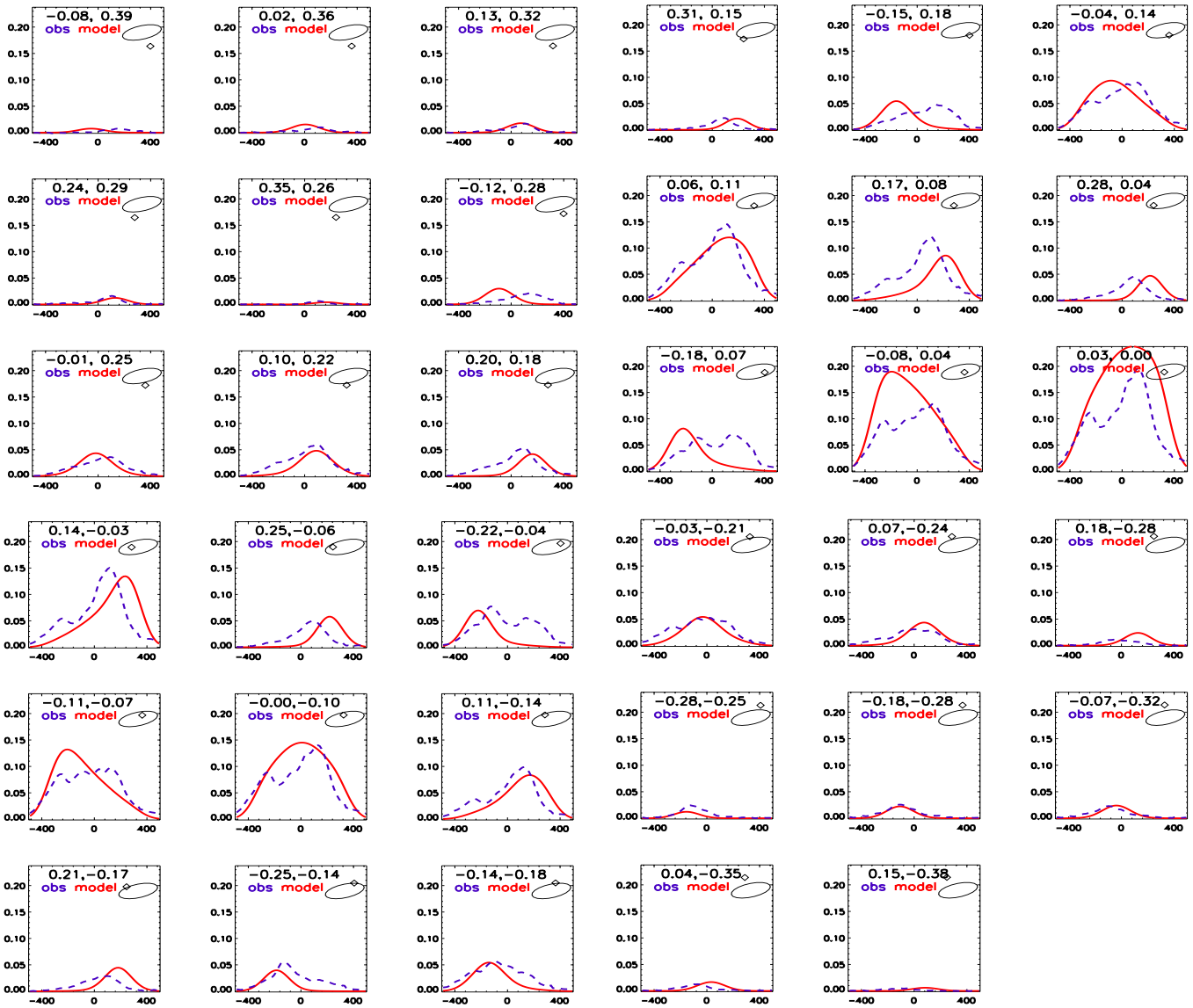




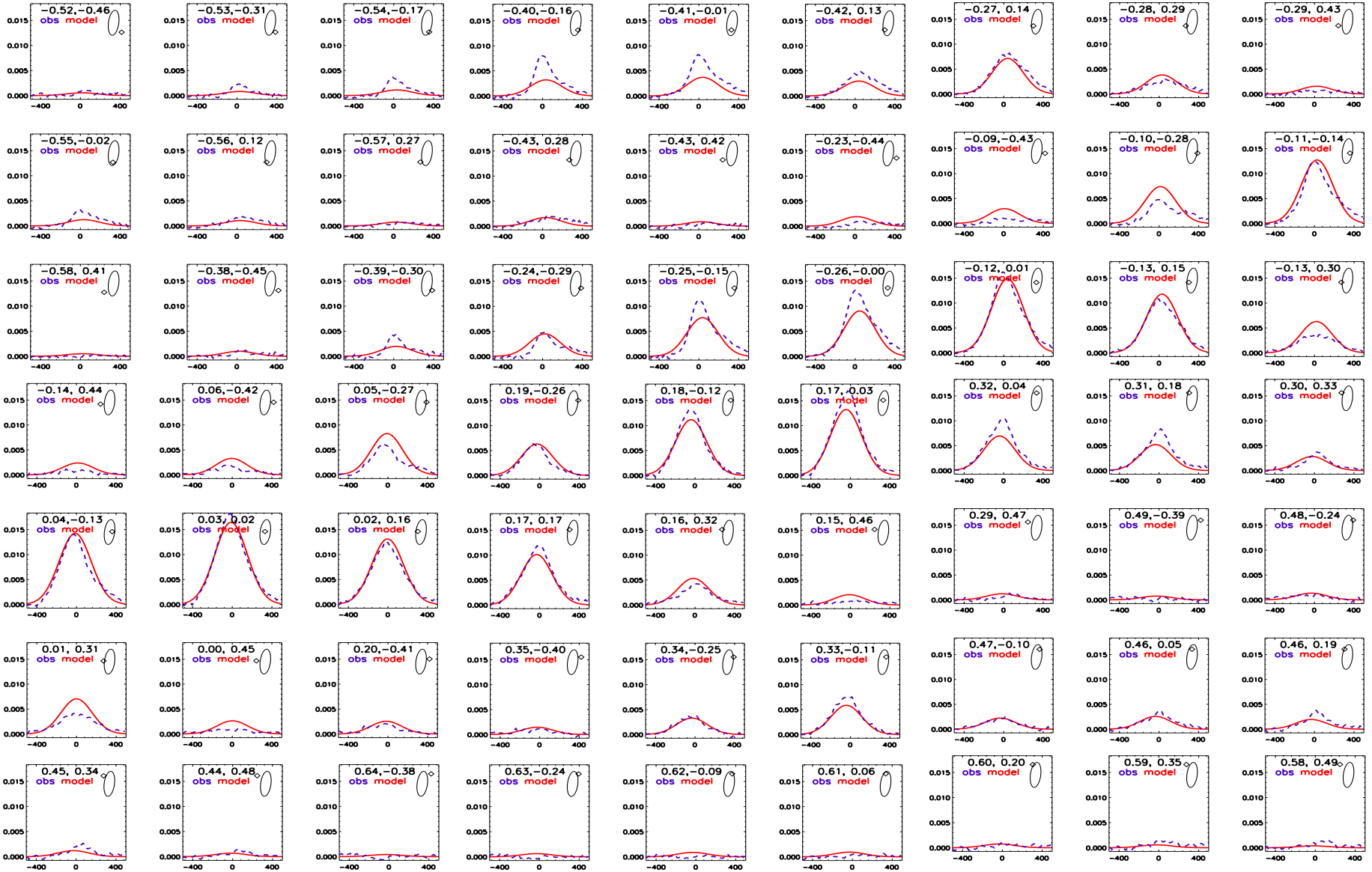
Disk Models

Source	V_0	R_0	incl.	PA	σ_v
	km s^{-1}	pc	°	°	km s^{-1}
Arp 220 East	350	30	71	47	90
Arp 220 West	360	40	64	-15	90
NGC 6240	100	20	70	-6	160

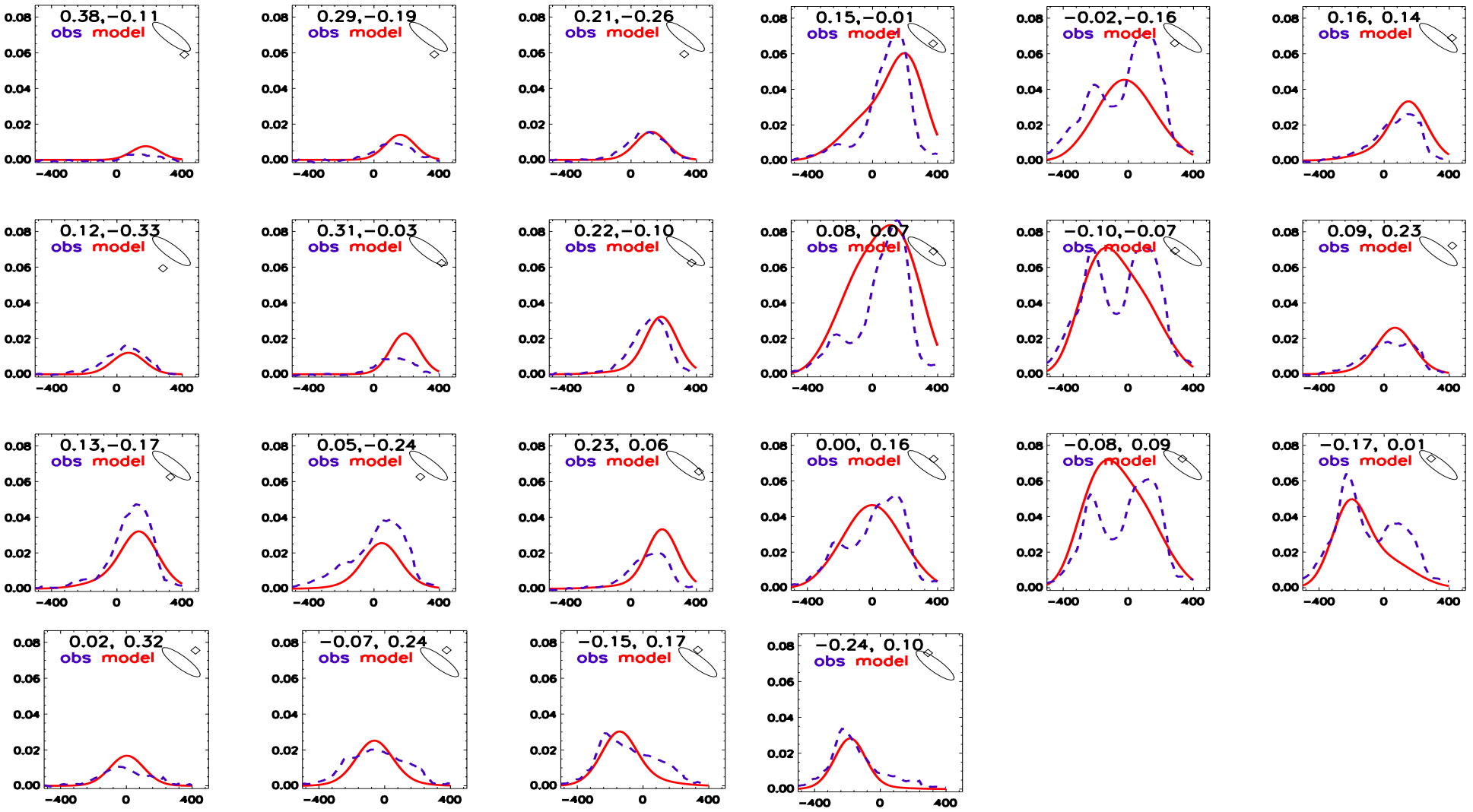
Arp 220 West – observed and model spectra

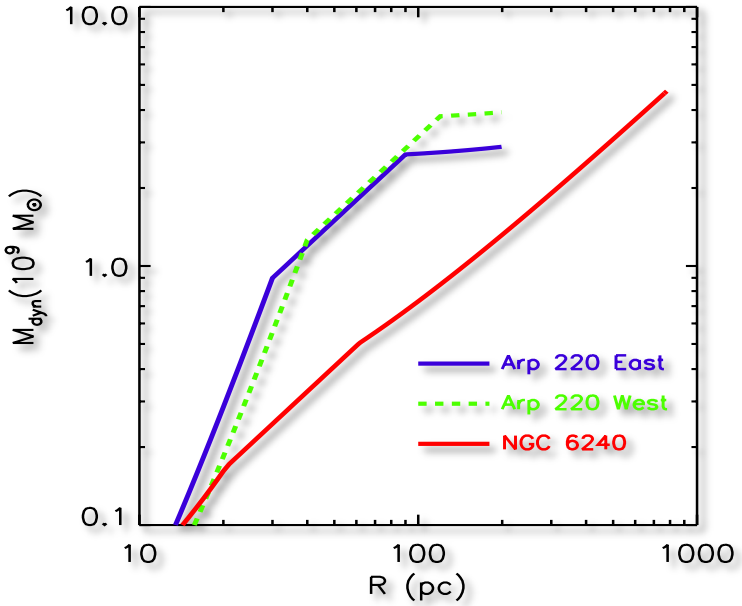


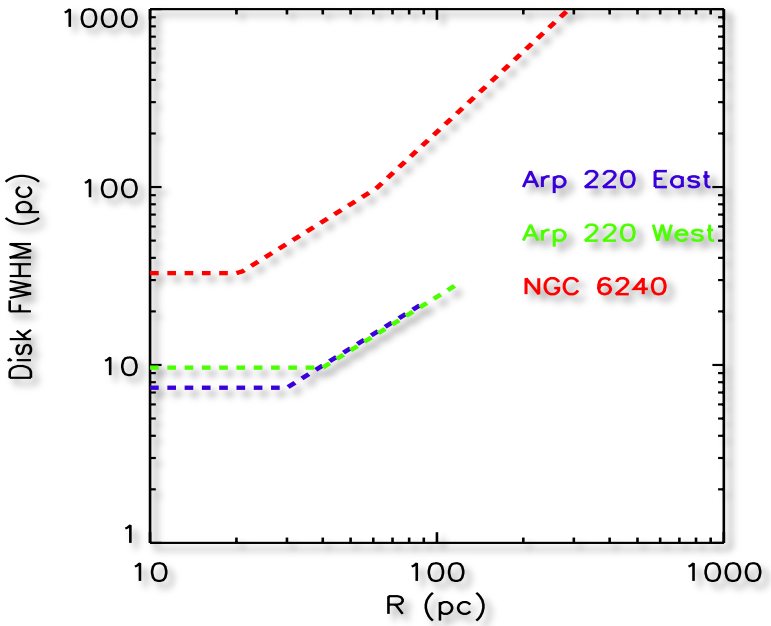
NGC 6240 – observed and model spectra



Arp 220 East – observed and model spectra







ISM Masses from Dust Continuum

Source	ν_{obs}	Flux	T_d [a]	Γ_{RJ}	Mass	diameter[b]	Radius	$<\Sigma_{gas}>$[c]
	GHz	mJy	K		$10^9\ M_\odot$	$''$	pc	$M_\odot\ pc^{-2}$
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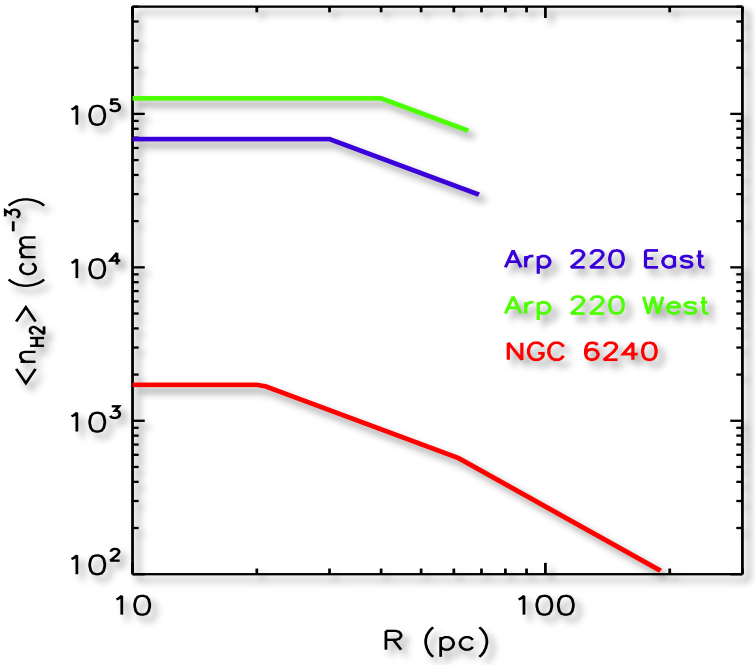
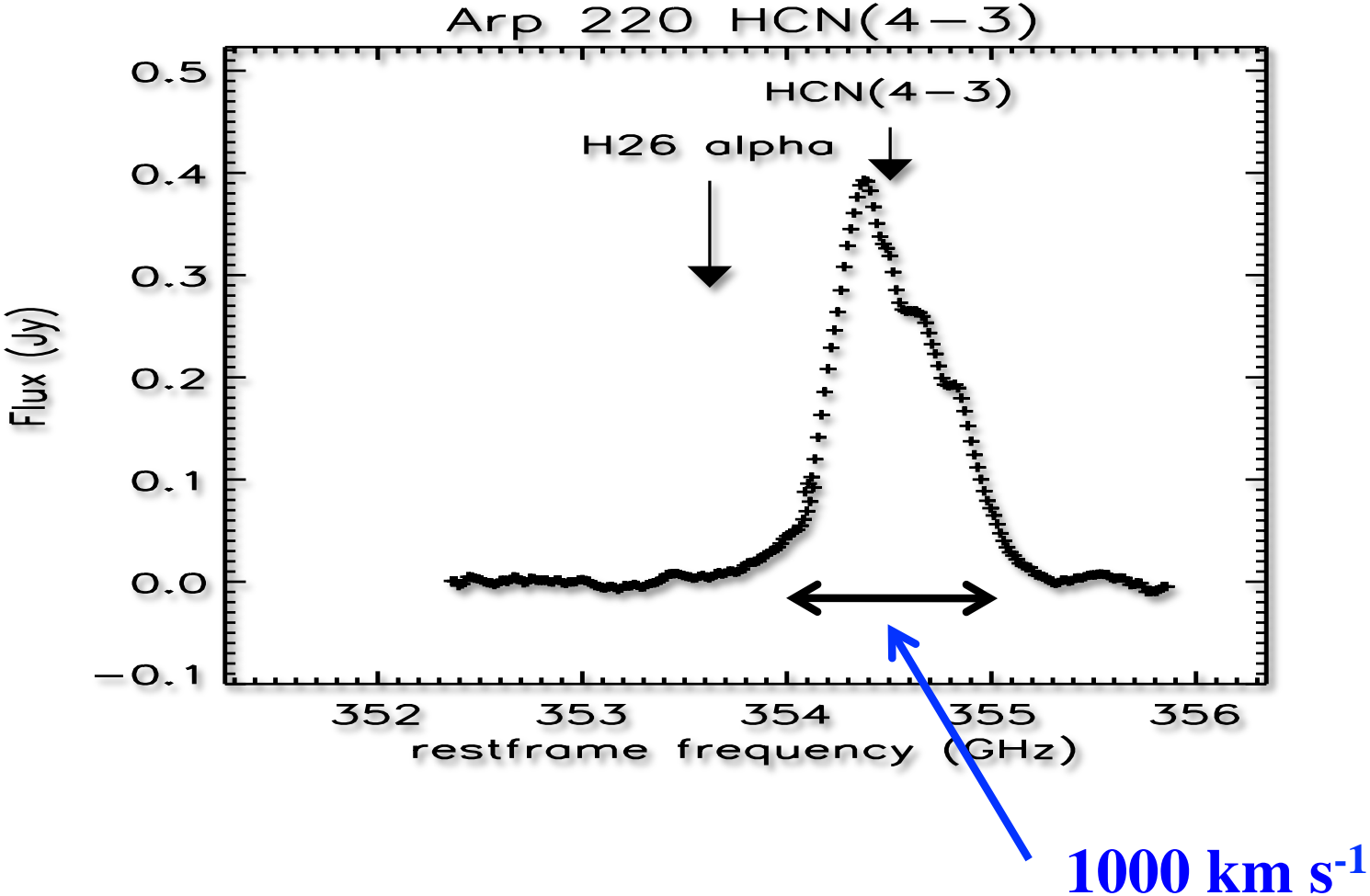


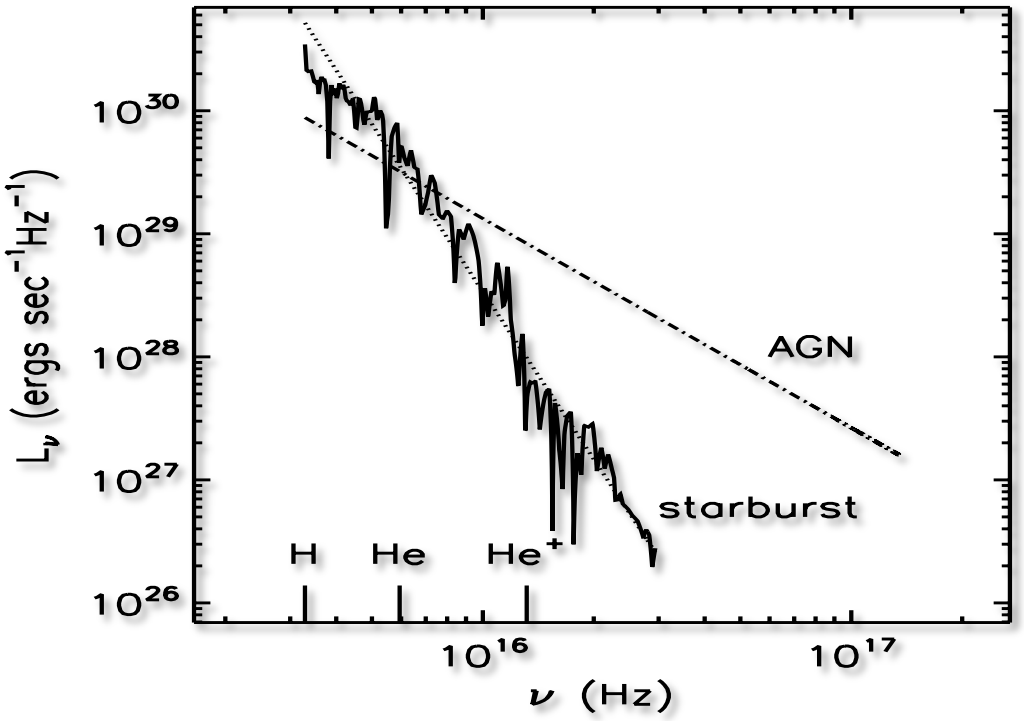
diagnosing AGN vs Starburst Power

ALMA Band 7 -- 350 GHz integrated spectra



diagnosing AGN vs Starburst Power

long standing issue with ULIRGs – AGN vs SB ??
ALMA can discriminate !!

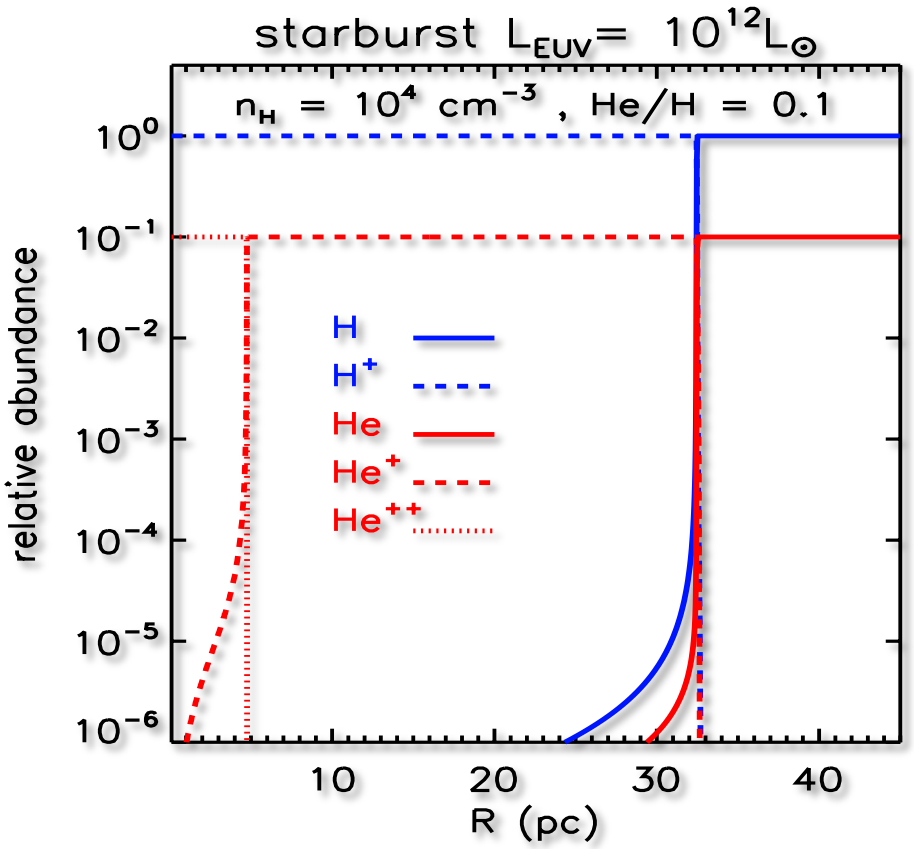


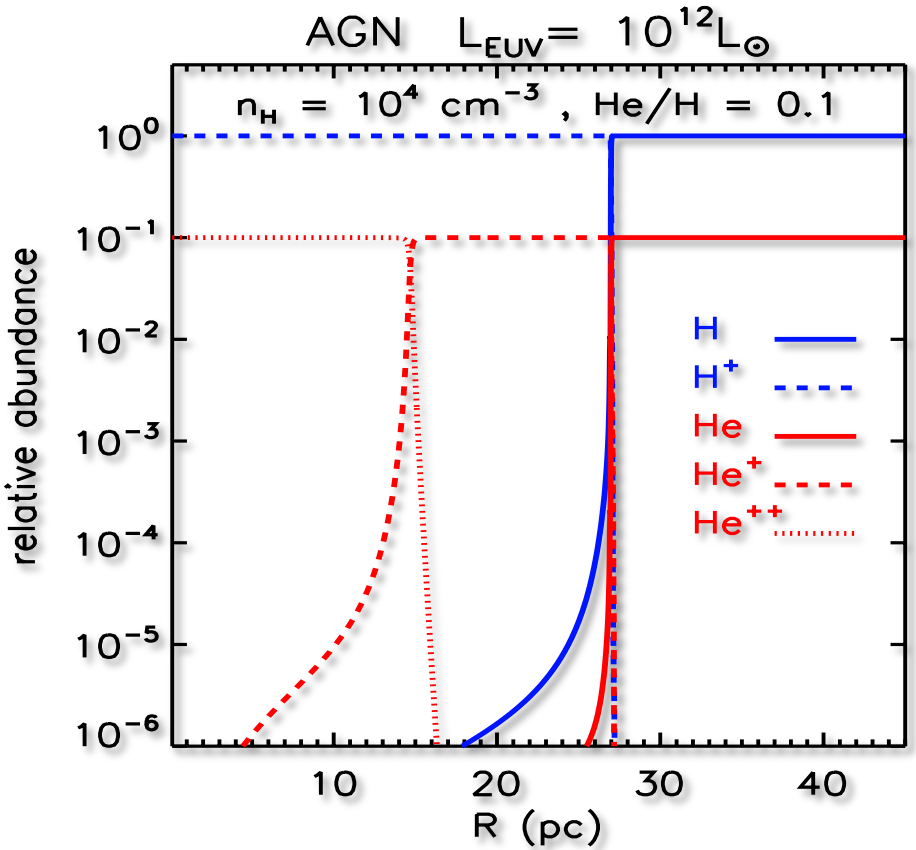
EUV spectra are very different !!

H vs He$^+$ submm recomb. lines

Scoville & Murchikova '13 (ApJ)

ionization equilibrium :

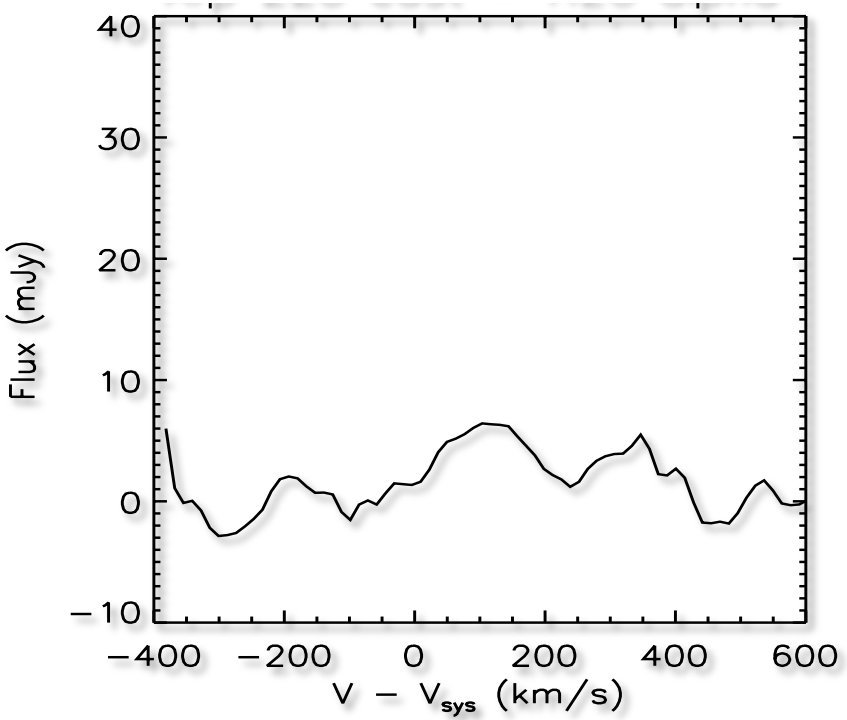




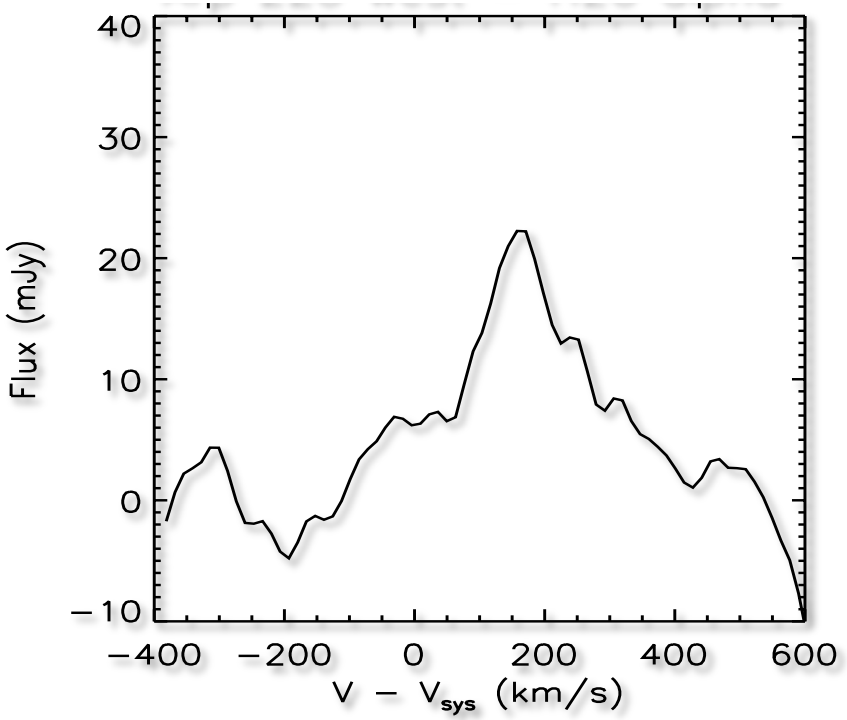
➔ **He^{++} / H^+ changes by 20x**

H 26α – a new probe of dust obscured SF !!

Arp 220 East



West



H 26α : 4 Jy km/s

low-n recomb. line flux ➔HII emission measure (n^2 x volume)

➔Lyc ν

4 Jy km/s ➔ 100 $M_\odot$ / yr