Impact of ionized gas outflows on the evolution of Seyfert galaxies

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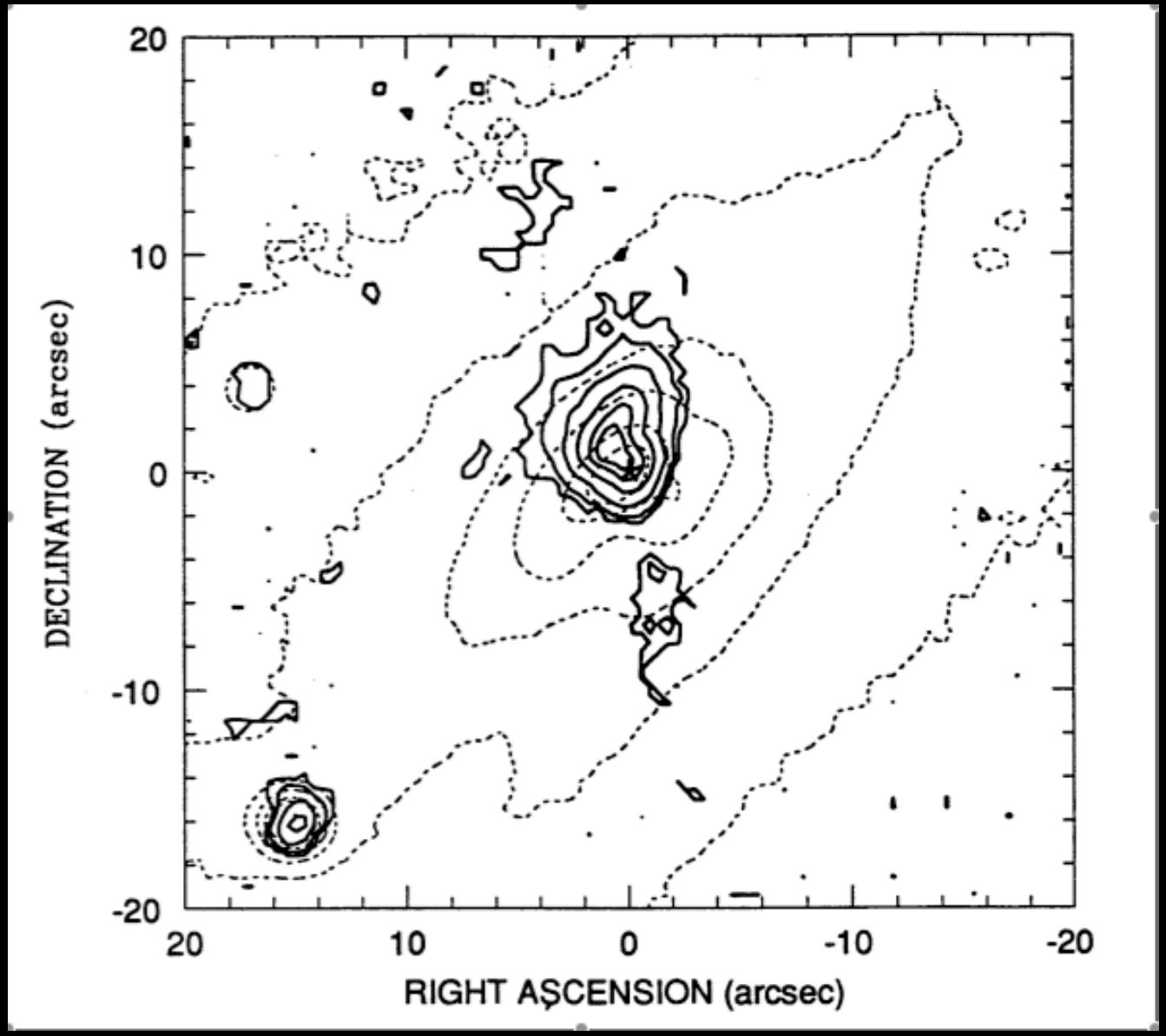
Ionization cone in NGC3281



Storchi-Bergmann et al. 96

Science Objectives

Using adaptive optics on Keck and the VLT to reach scales down to 0.075” in the K- band, we can for the first time directly resolve the NL- and CLRs of nearby active galaxies and investigate:

- Size and kinematics of the NLR and the CLR: prevalence of non-circular motions in their velocity fields and their nature as AGN-induced outflows

- Orientation effects invoked by the torus model of AGN and correlations

- Do AGN outflows actually deliver enough energy to their environments to alter the evolution of the host galaxy in a meaningful way?

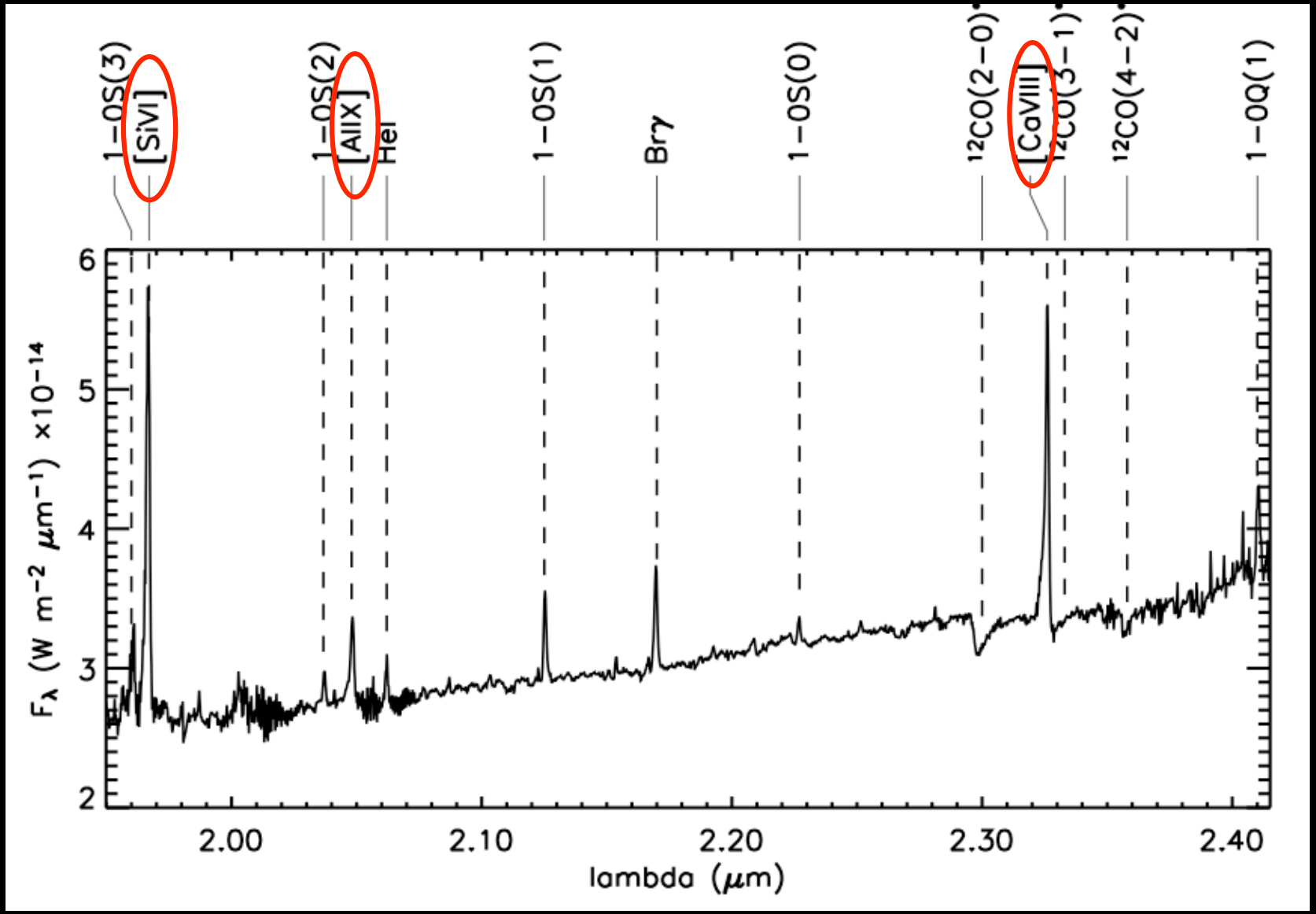
The Nearby AGN Sample

Object	*Classification*	*D (Mpc)*	*Resolution*	
NGC 1097**	LINER, Sy1	18	0.245”	21pc
NGC 2992	Sy1	33	0.30”	48pc
NGC 3227	Sy1	17	0.085”	7pc
NGC 3783	Sy1	42	0.18”	37pc
NGC 4945*	Starburst, Sy2	5	0.09”	2.5pc
NGC 7469	Sy1	66	0.085”	27pc
NGC 1068	Sy2	14	0.085”	6pc
Circinus	Sy2	4	0.22”	4pc
NGC 4051	Sy1	10	0.12”	5.8pc
NGC 4151	Sy1	14	0.11”	7.5pc
NGC 6814	Sy1	22	0.17”	18.2pc
NGC 7469	Sy1	66	0.11”	35.2pc

*No coronal lines

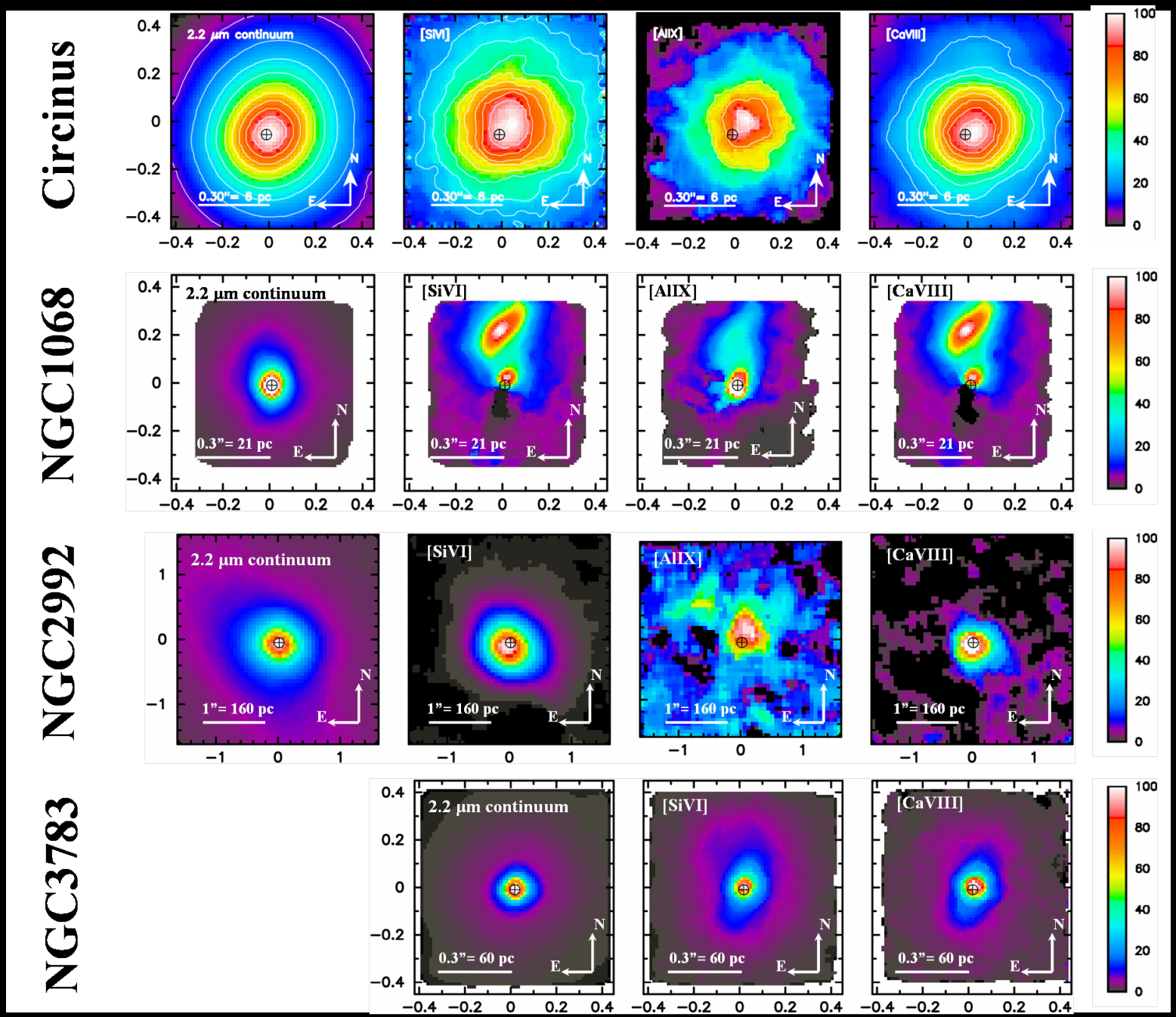
**No coronal lines, no Brg emission

Integrated spectrum of Circinus



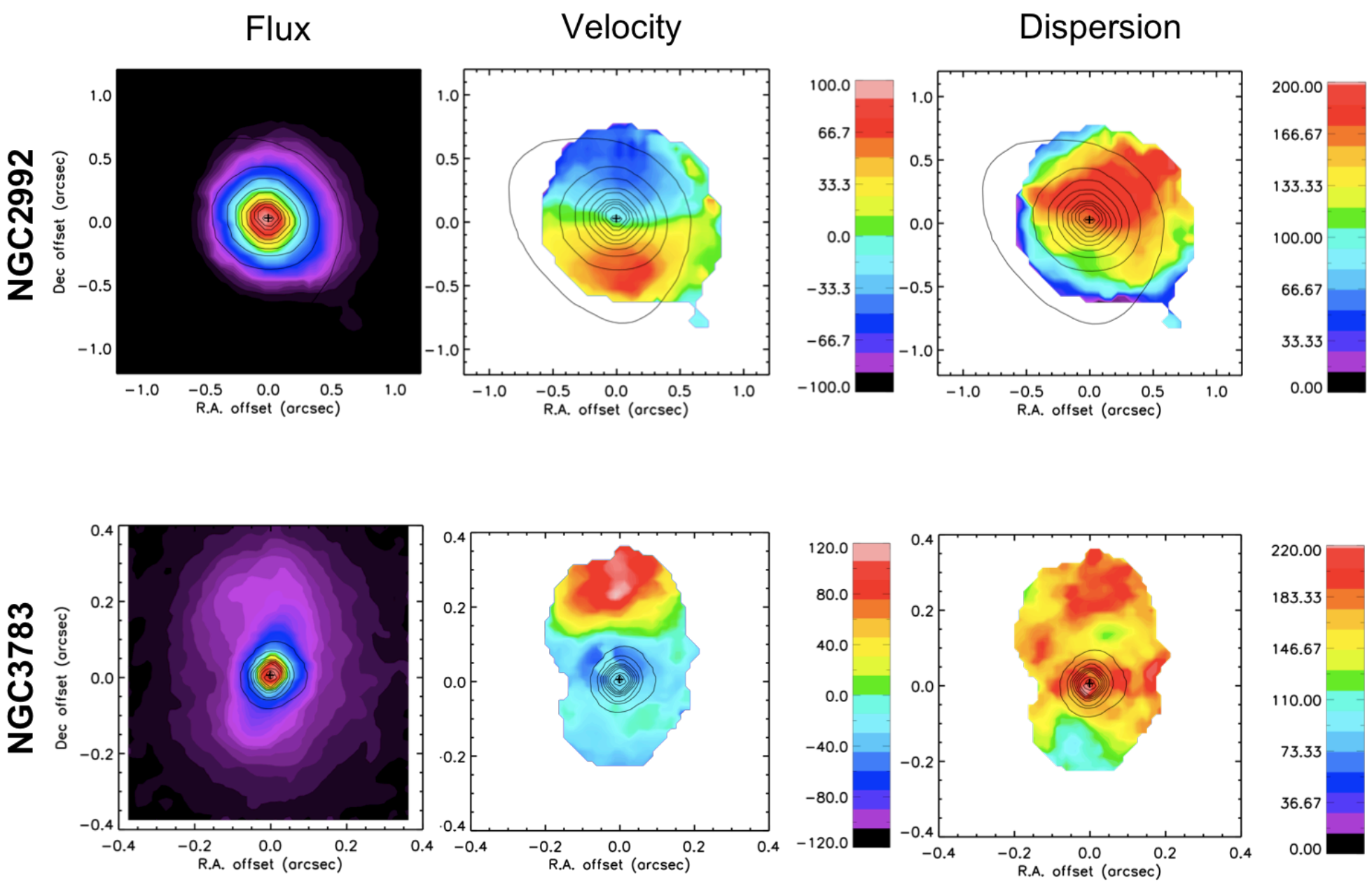
Müller-Sanchez et al. 06

Coronal lines

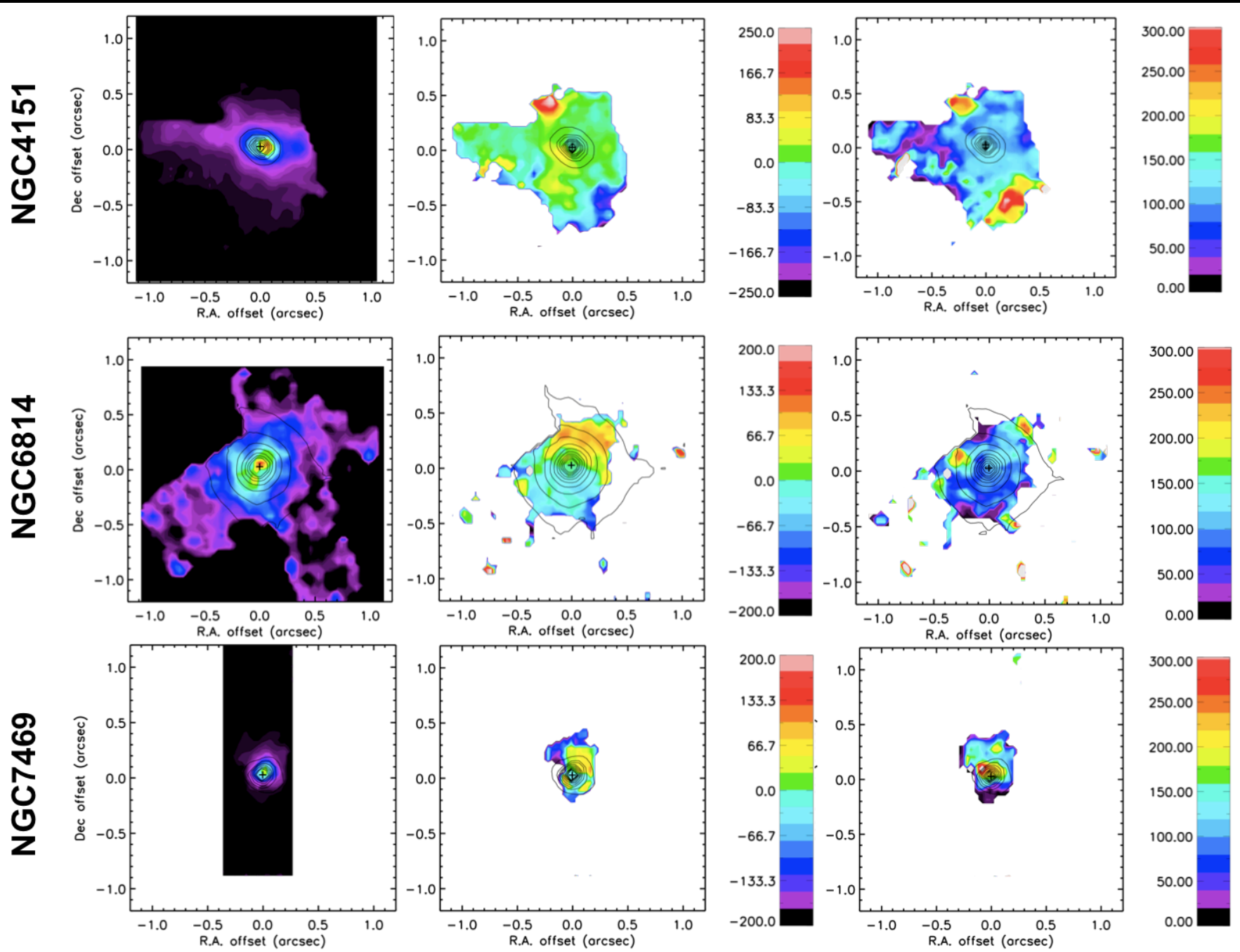


Müller-Sanchez et al. 10

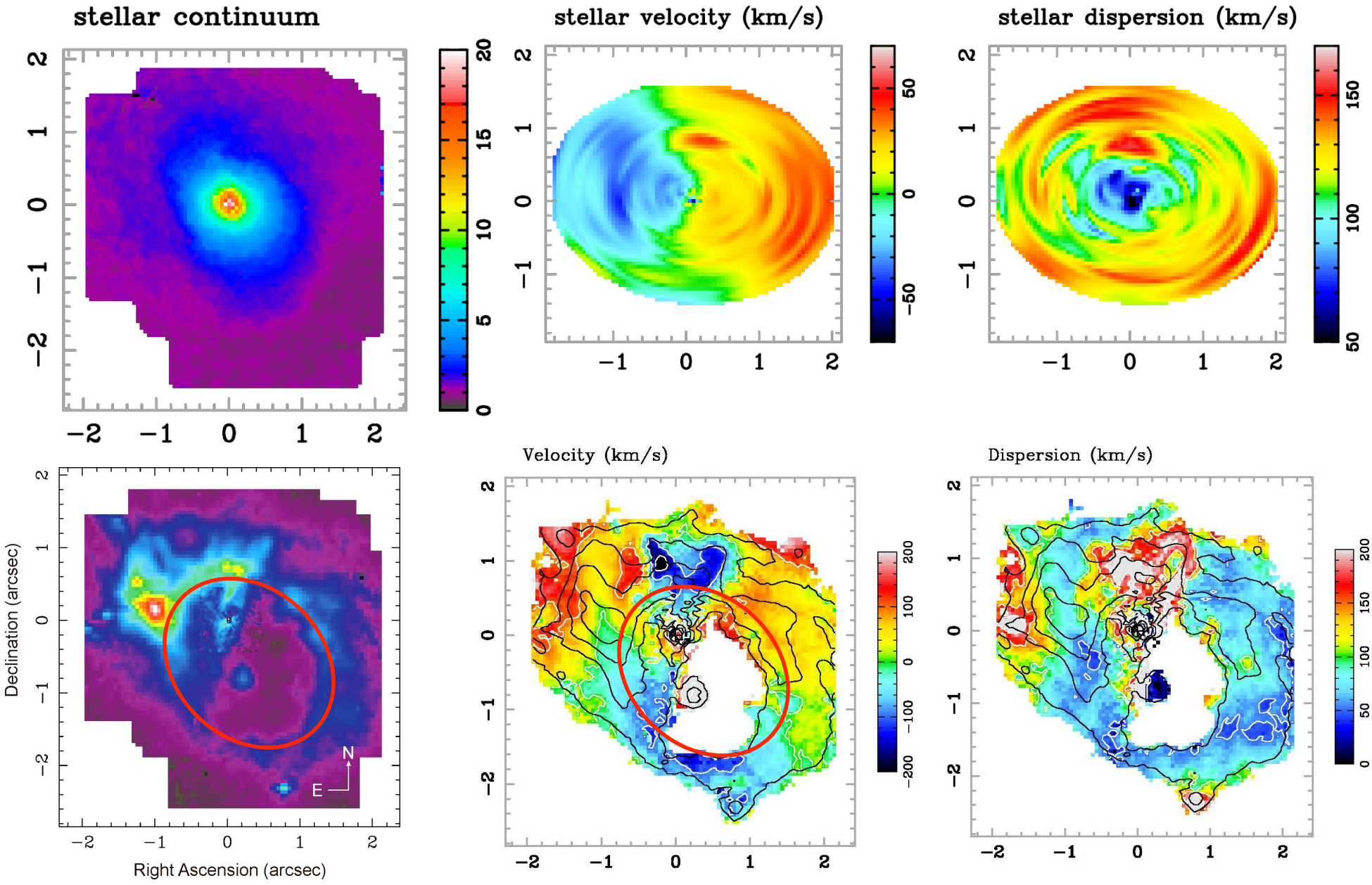
[SiVI]


Flux
Velocity
Dispersion
NGC2992
NGC3783
Dec offset (arcsec)
R.A. offset (arcsec)
1.0
0.5
0.0
−0.5
−1.0
100.0
66.7
33.3
0.0
−33.3
−66.7
−100.0
200.00
166.67
133.33
100.00
66.67
33.33
0.00
0.4
0.2
0.0
−0.2
−0.4
120.0
80.0
40.0
0.0
−40.0
−80.0
−120.0
220.00
183.33
146.67
110.00
73.33
36.67
0.00

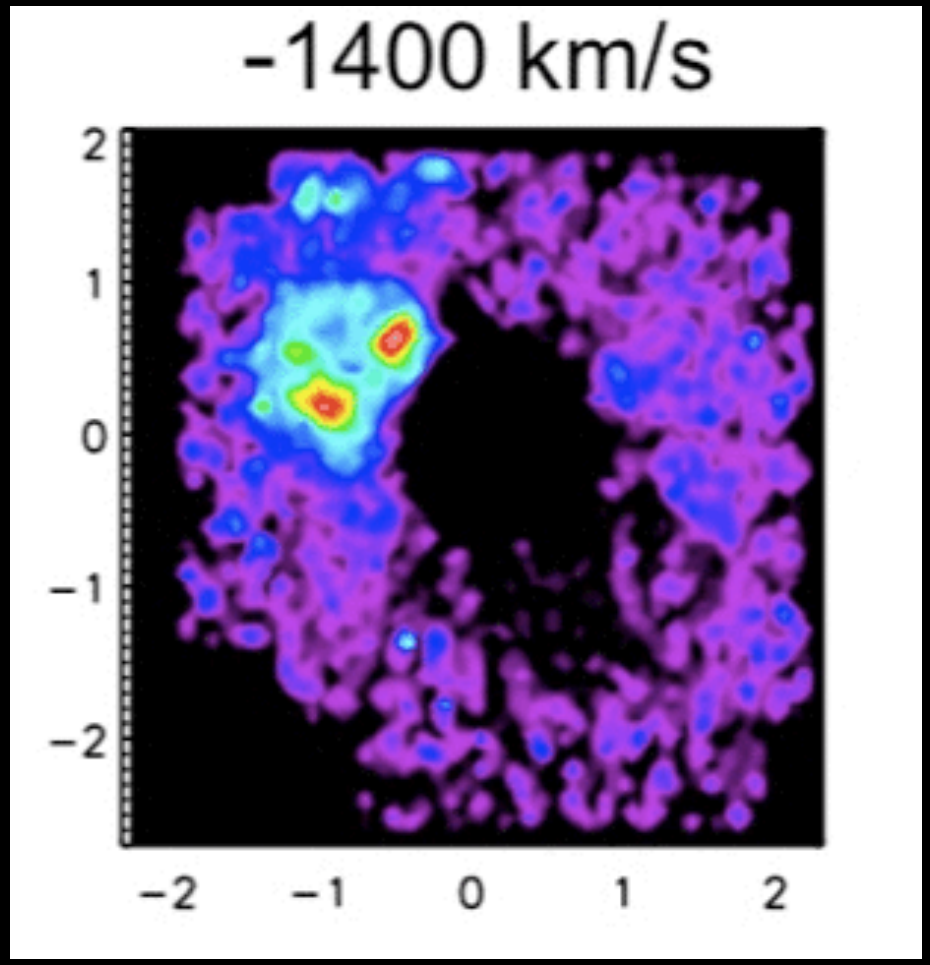
[SiVI]

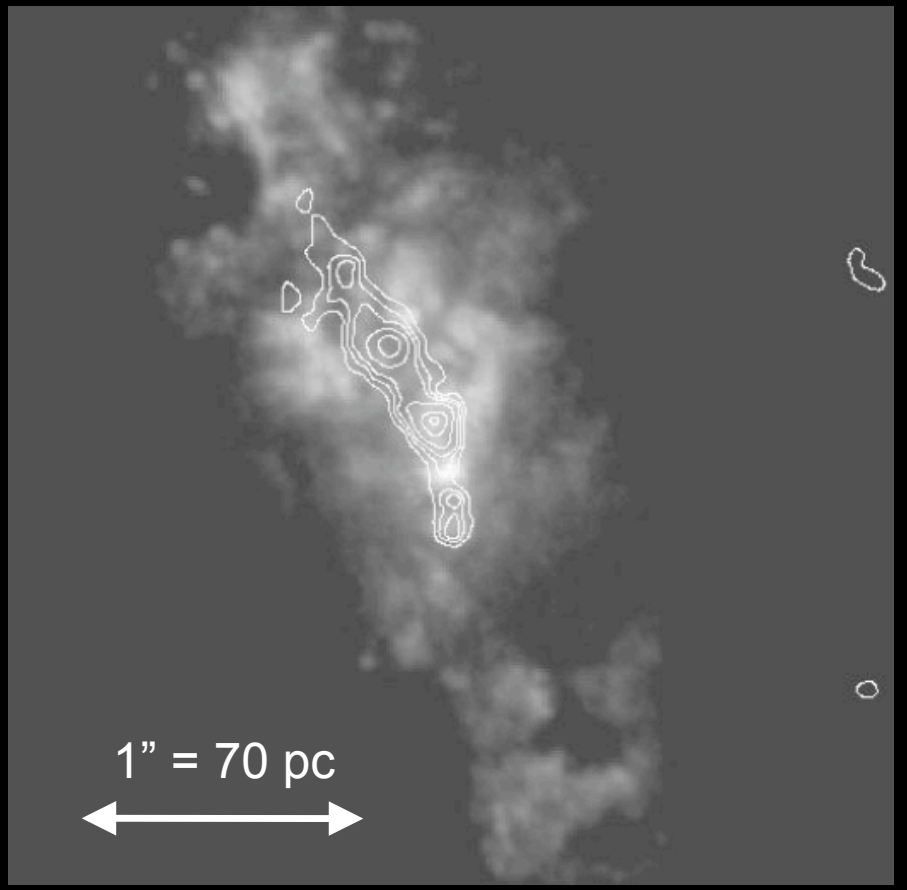

NGC4151
NGC6814
NGC7469
Dec offset (arcsec)
R.A. offset (arcsec)
1.0
0.5
0.0
−0.5
−1.0
250.0
166.7
83.3
0.0
−83.3
−166.7
−250.0
200.0
133.3
66.7
0.0
−66.7
−133.3
−200.0
300.00
250.00
200.00
150.00
100.00
50.00
0.00

Stars vs Molecular Gas in NGC1068



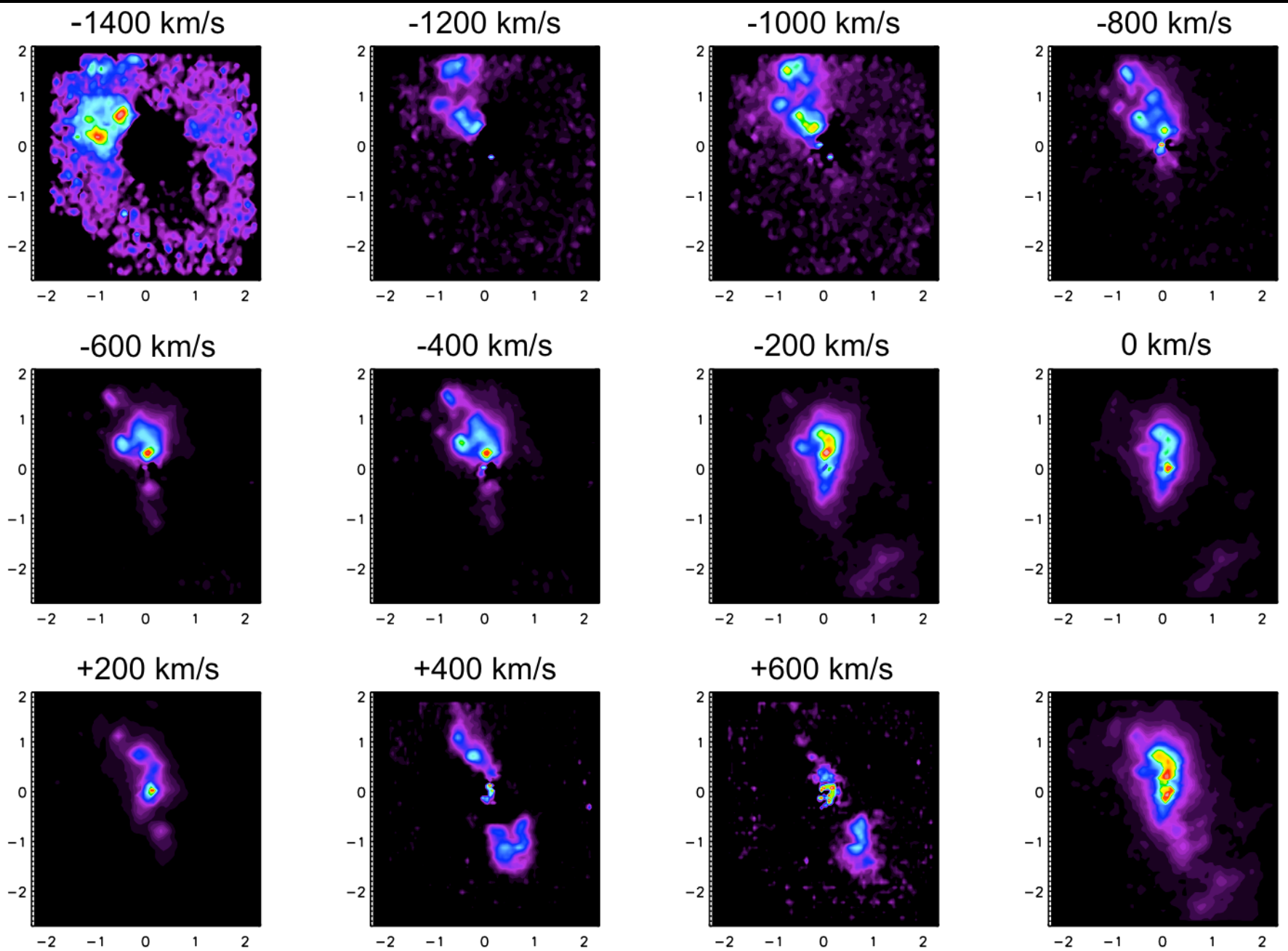
Outflow in NGC1068



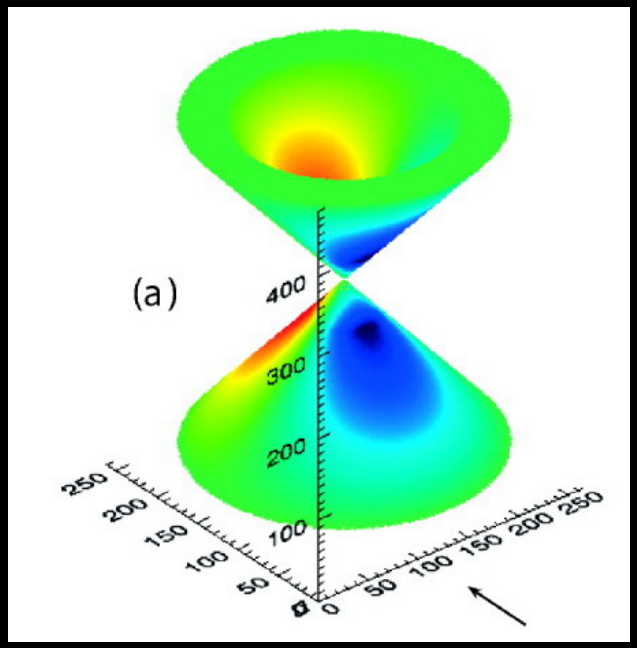


Spatial correlation between radio jet and ionized gas

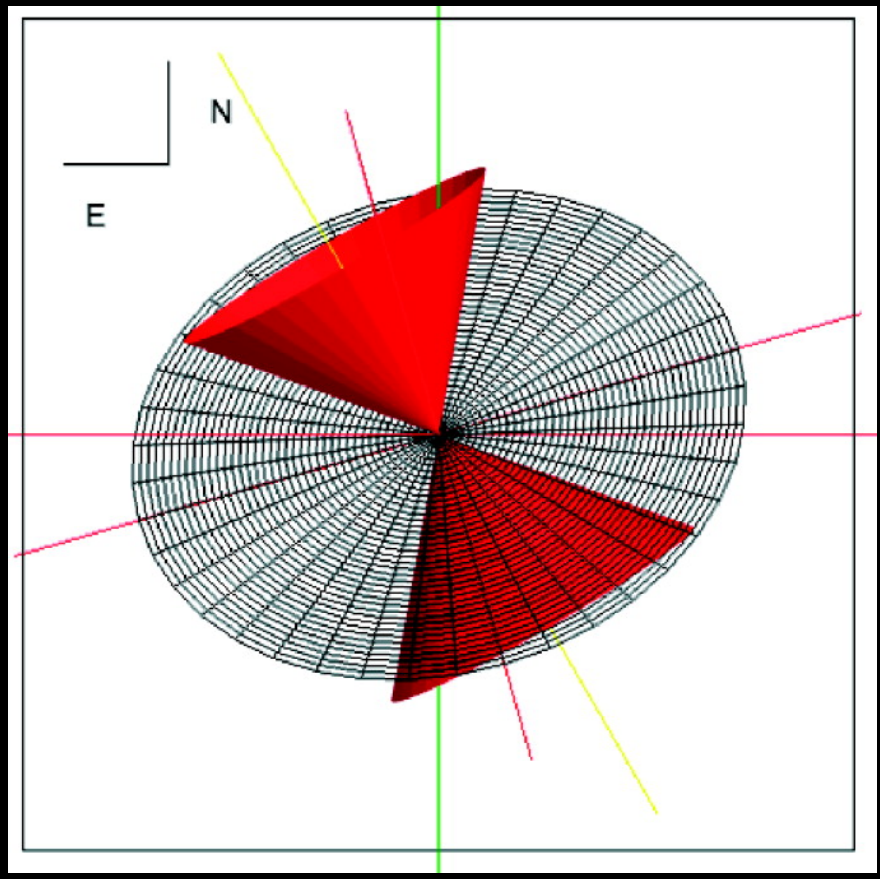
Outflow in NGC1068



Comparison to Ionisation cones



position in 3D,
colours indicate velocity,
arrow is l.o.s.

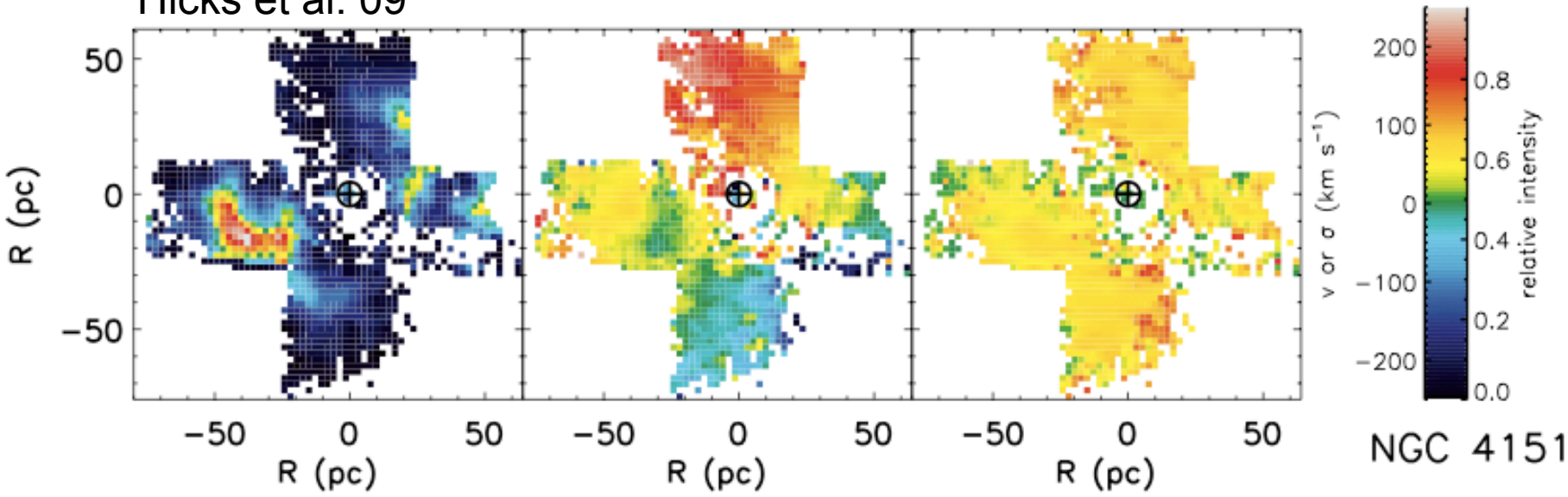


Northern cone is in front of galaxy plane,
southern cone behind;
Blueshifted and redshifted velocities in
both parts of the plane

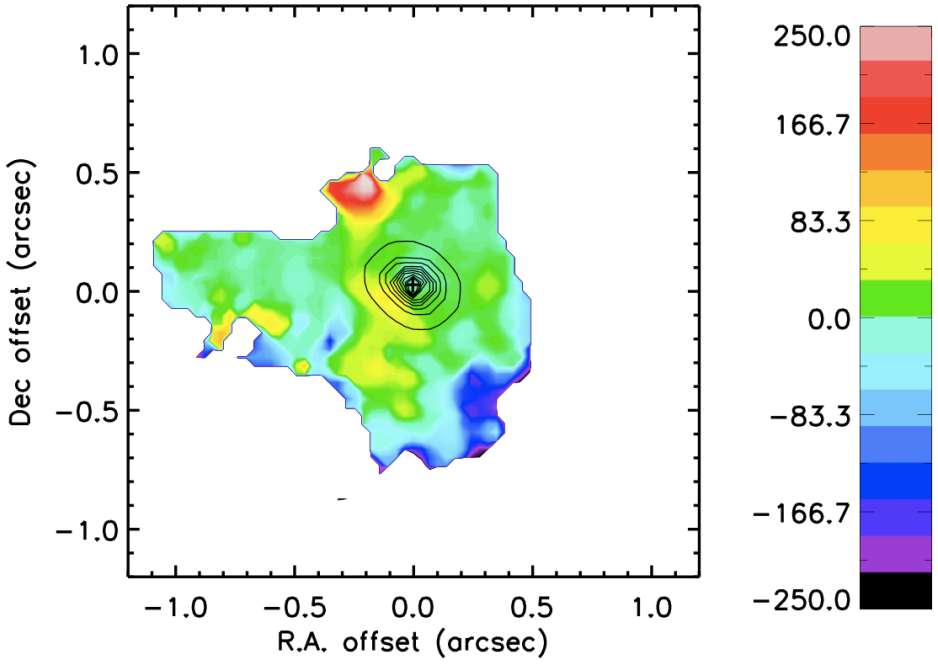
Das et al. 06

NGC4151

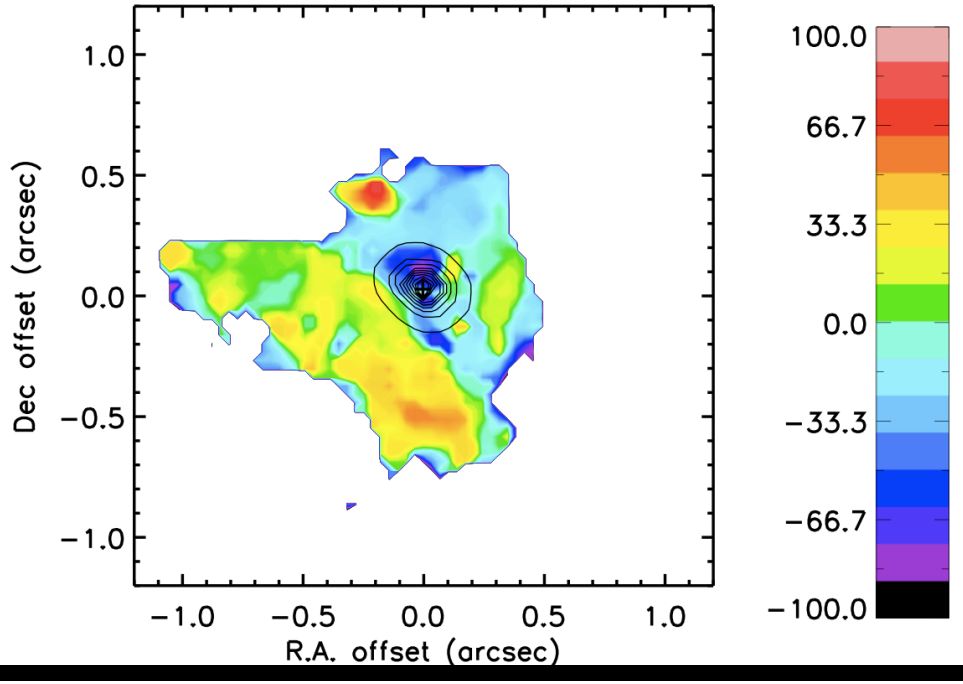
Hicks et al. 09



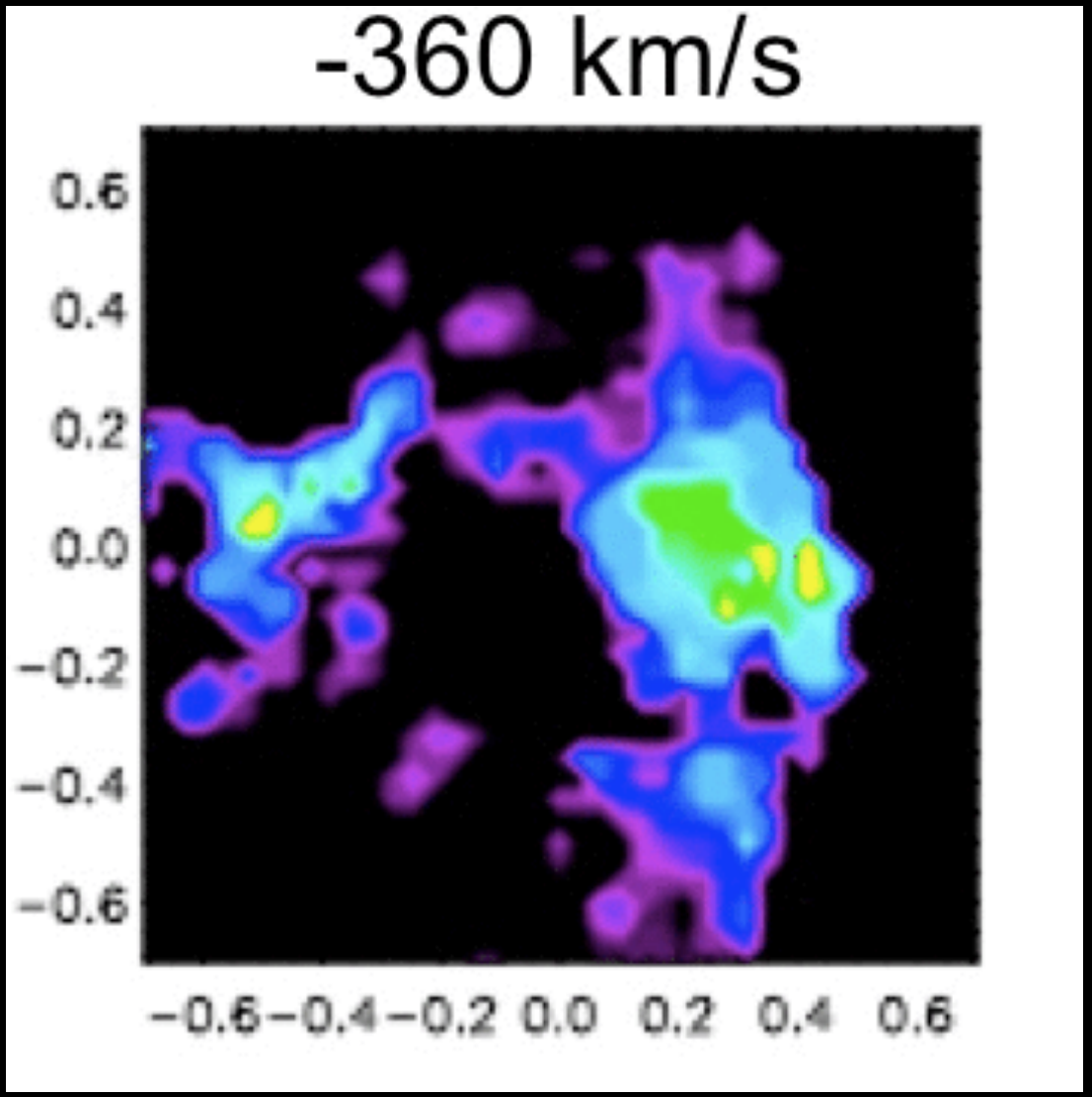
Velocity map [SiVI] (km/s)



Residual map (km/s)

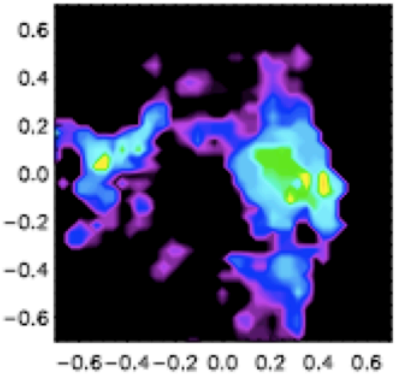


Velocity tomography of [SiVI] in NGC4151

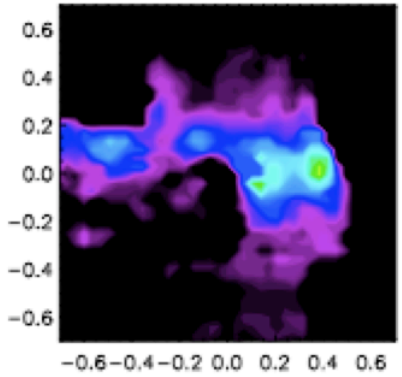


Outflow in NGC4151

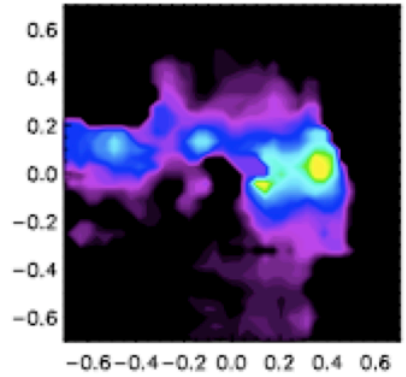
-360 km/s



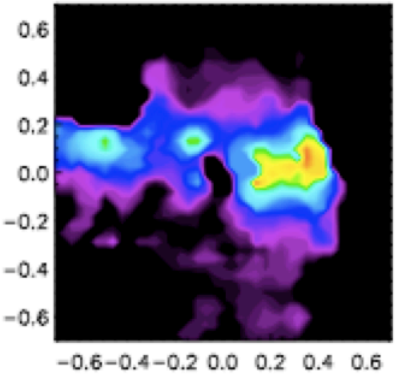
-240 km/s



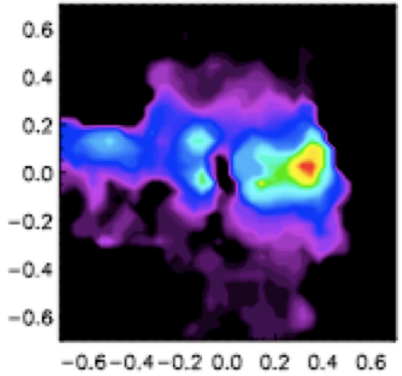
-120 km/s



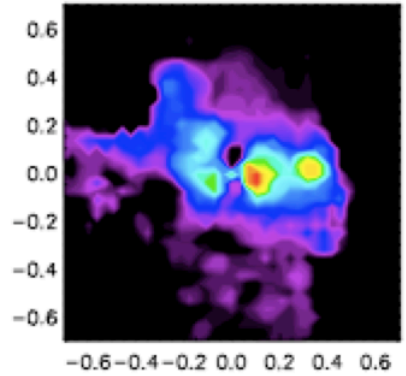
0 km/s



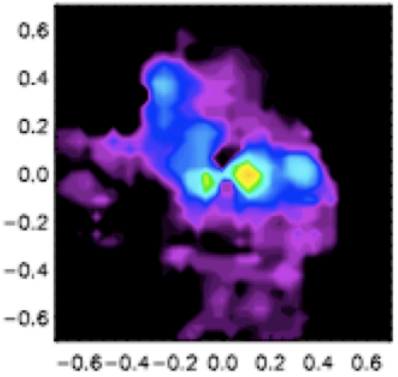
120 km/s



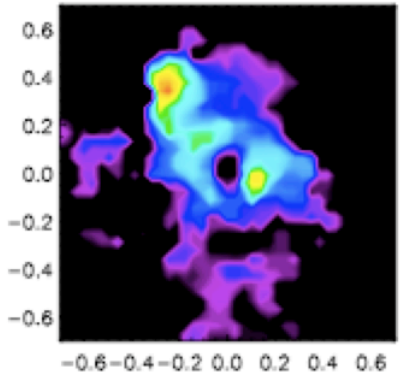
240 km/s

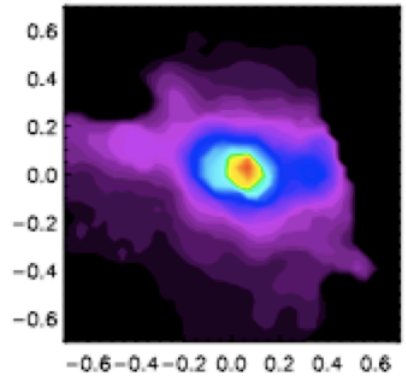


360 km/s

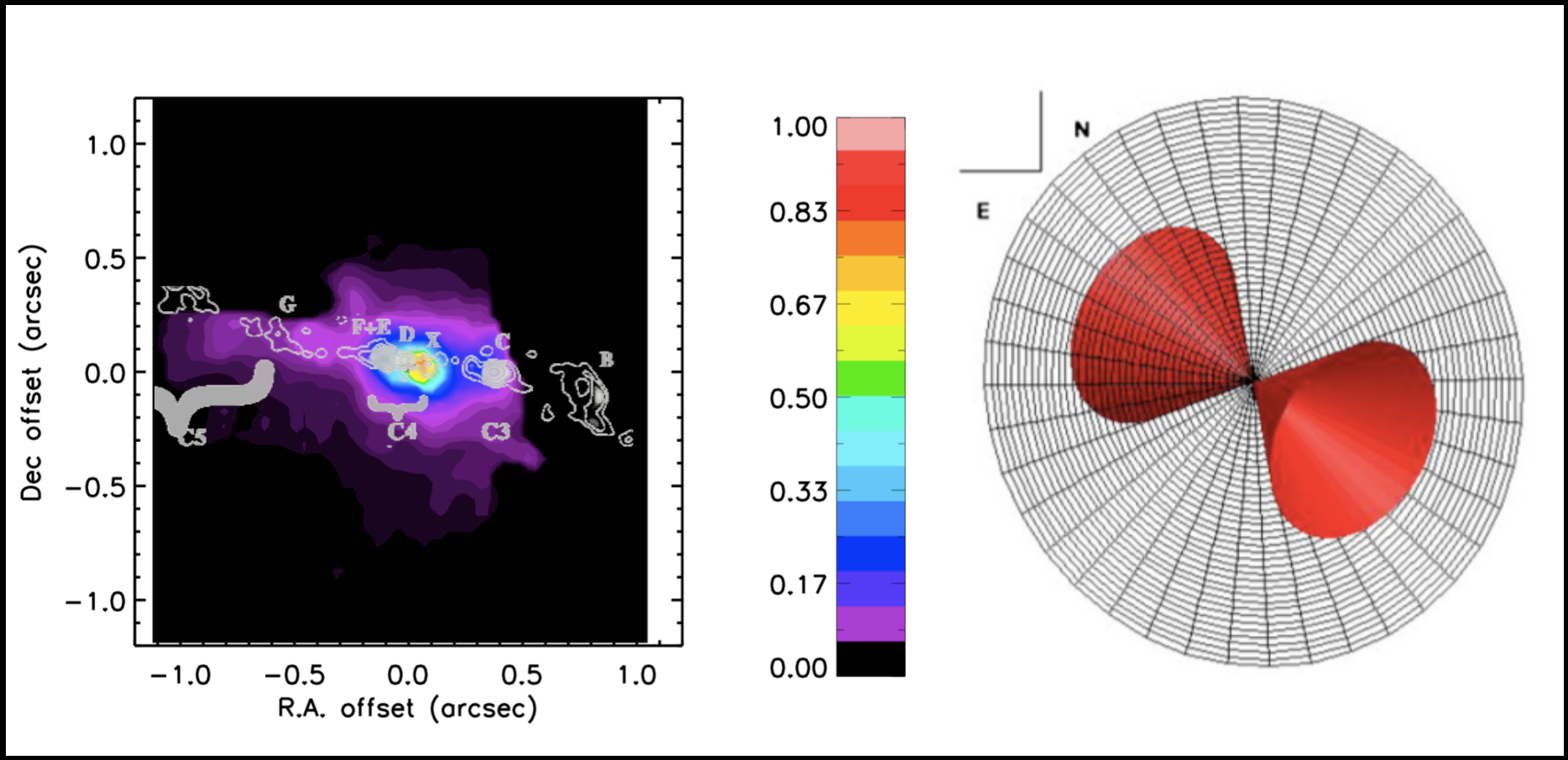


480 km/s





Comparison to Ionisation cones

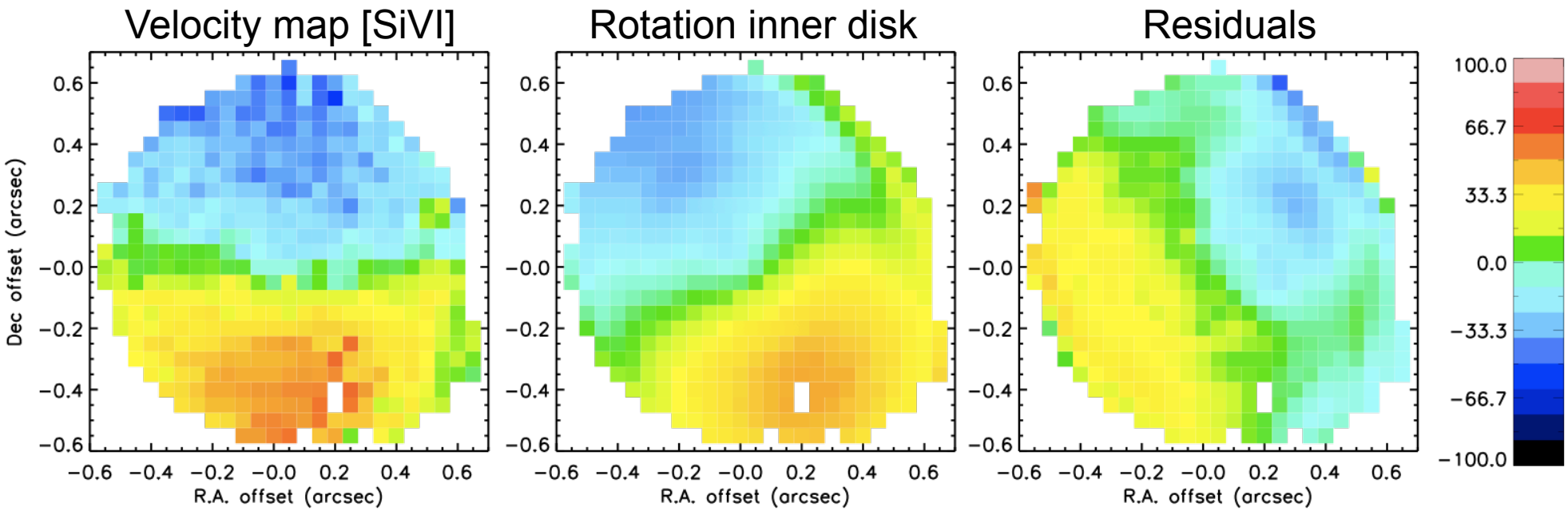


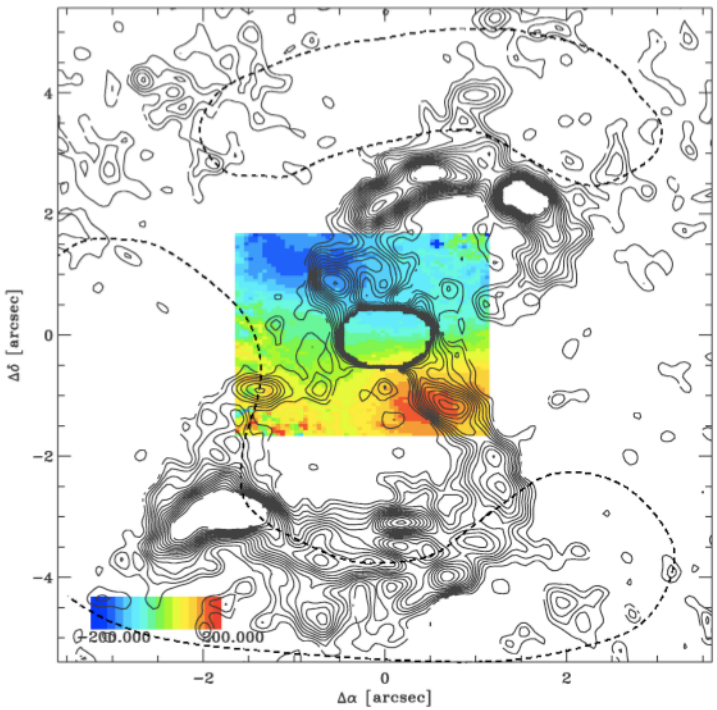
Mundell et al. 03

Northestern cone is behind the galaxy plane,
Southwestern cone infront;
Blueshifts and redshifts observed only in one side

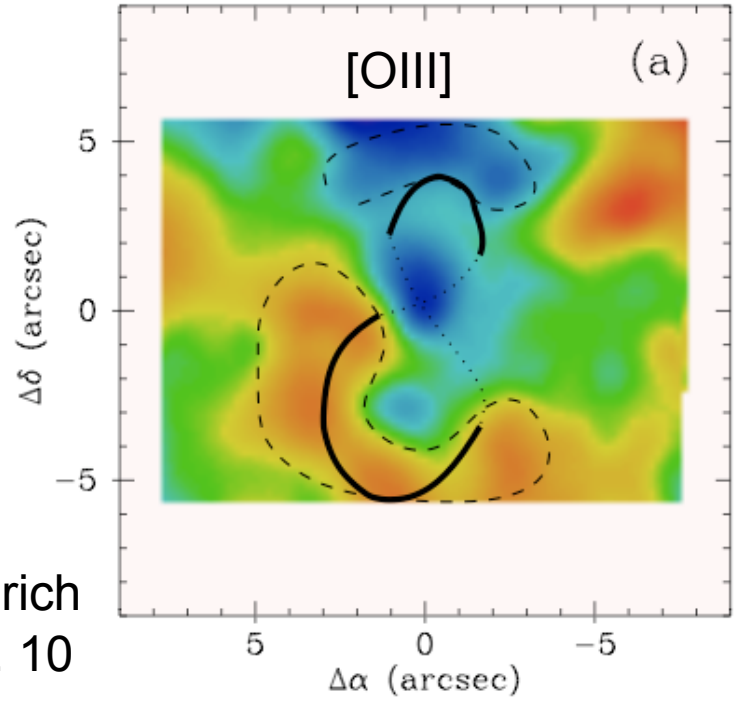
Crenshaw et al. 10

NGC2992



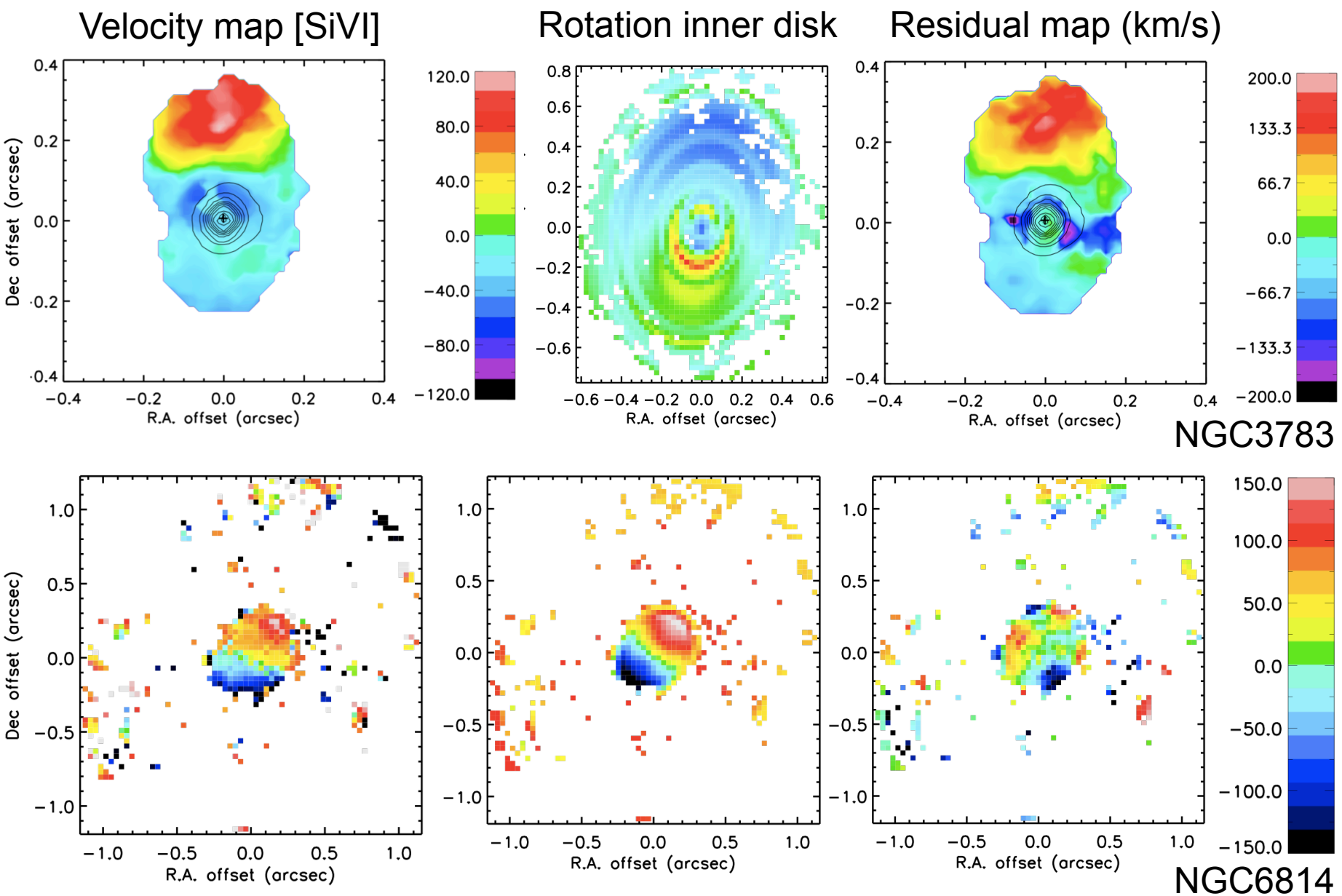


Friedrich et al. 10



Garcia-Lorenzo et al. 10

NGC3783 and NGC6814



Mass outflow rates and Kinetic energy

$$M_{out} = 2 n_e m_p A V(r) f \quad [M_{sun}\ yr^{-1}]$$

$$M_{accr} = L_{bol}/\eta c^2 \quad [M_{sun}\ yr^{-1}]$$

$$E_{kin} = M_{out}(v^2 + \sigma^2)/2 \quad [erg\ s^{-1}]$$

Object	*D (pc)*	*V(r)*	*Mout*	*Maccr*	*Ekin*	*Lbol*
NGC 1068	70	1400	1	0.09	7×10^{41}	8×10^{44}
NGC 2992*	40	200	0.07	0.02	0.2×10^{41}	1×10^{44}
NGC 3783	---	---	---	---	---	---
NGC 4151	100	600	2.4	0.01	2×10^{41}	7×10^{43}
NGC 6814	---	---	---	---	---	---

E_{kin} = [0.007 – 0.003] L_{bol} which is a fraction of the order of the AGN feedback derived in simulations for co-evolution of BHs and galaxies (0.5% of L_{bol})

Di Matteo et al. 05

Conclusions

• For the AGN exhibiting coronal lines, the Brγ morphology is similar to the coronal lines

• The coronal line region is spatially coincident with the inner NLR. At larger scales the situation is different

• Radial motions dominate the velocity fields of coronal lines and in all cases they are well reproduced as an ouflow

• There exist signatures of orientation effects favouring the torus model

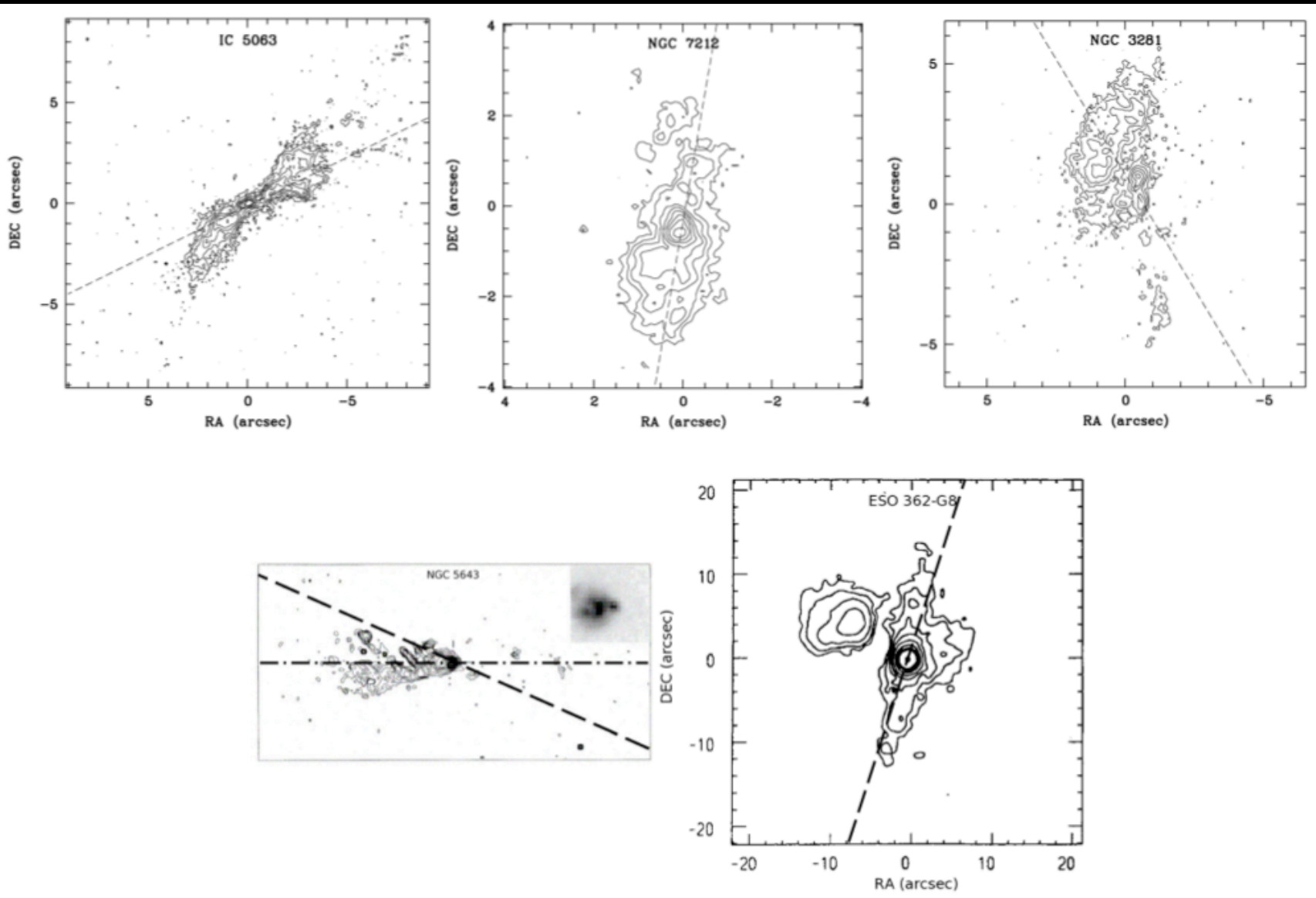
• E_{kin} = [0.007 – 0.003] L_{bol} which is a fraction of the order of the AGN feedback derived in simulations for co-evolution of BHs and galaxies (0.5% of L_{bol})

Preliminary results and current work

✓ For the AGN exhibiting coronal lines, the Brg morphology is similar to the coronal lines
✓ Three cases are identified in Brg kinematics: rotation, perturbed rotation and radial motions
✓ Two AGN with coronal lines exhibit only radial motions in Brg (n1068 and n3783), one perturbed rotation (n2992) and one pure rotation (Circinus)
✓ There is clear structure in Brg dispersion (evidence for outflow?)
✓ Radial motions dominate the velocity fields of coronal lines (outflow for NGC1068 confirmed through velocity slices)

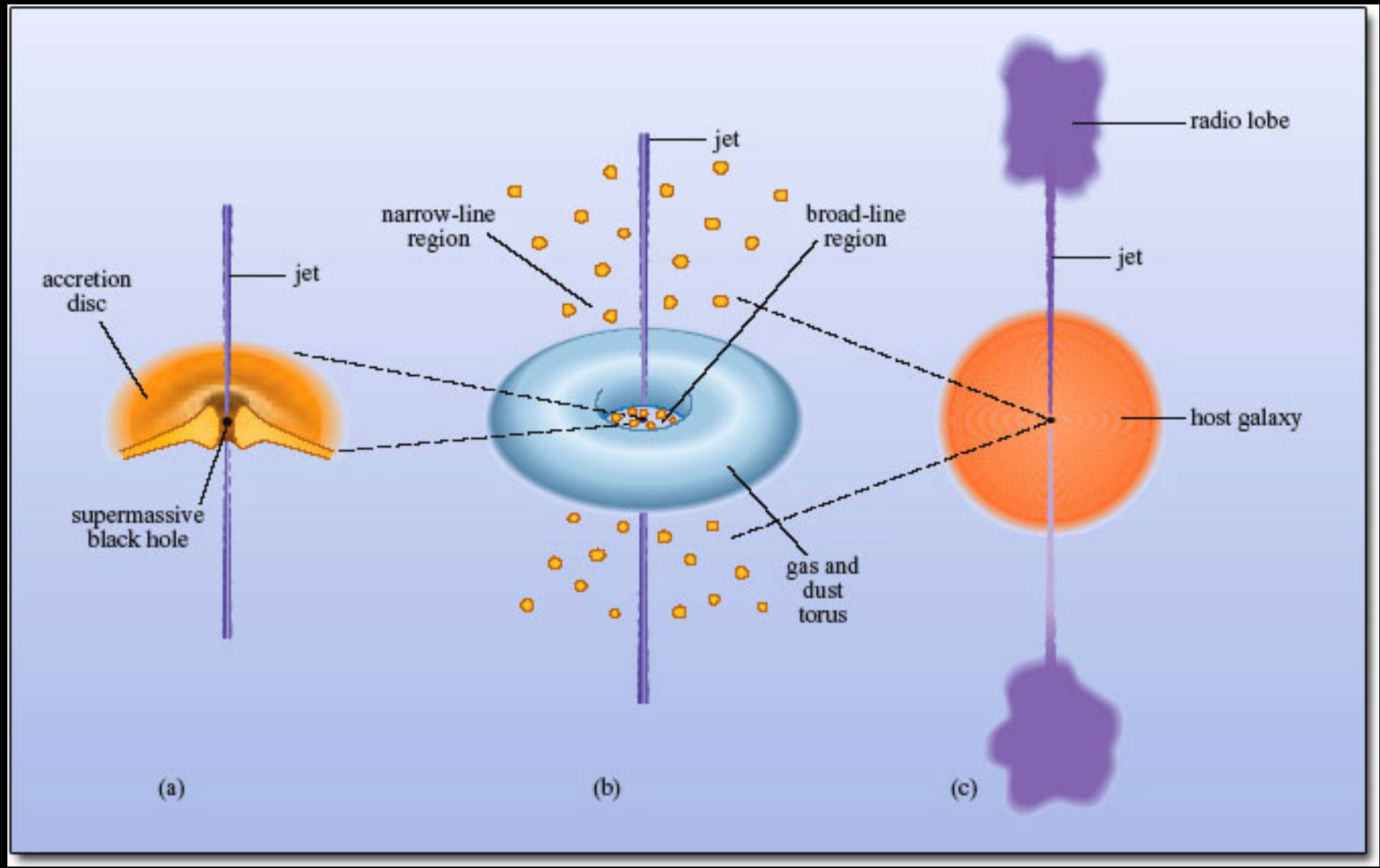
➢ Measure sizes of narrow Brg and coronal line emitting regions
➢ Modeling of the Brg kinematics with a simple rotating disc and study residuals
➢ Compare flux and dispersion maps with radio, [OIII] and X-ray data
➢ Find clear transition between the AGN-excited NLR and the surrounding star-forming areas (line ratios)
➢ Map the two components of Circinus and NGC2992
➢ Biconical modeling of NGC1068 and NGC3783
➢ Look for any type of correlation
➢ Analyze new data
➢ What about BLR?

Examples of NLRs



Bennert et al. 06

AGN Paradigm



Open questions

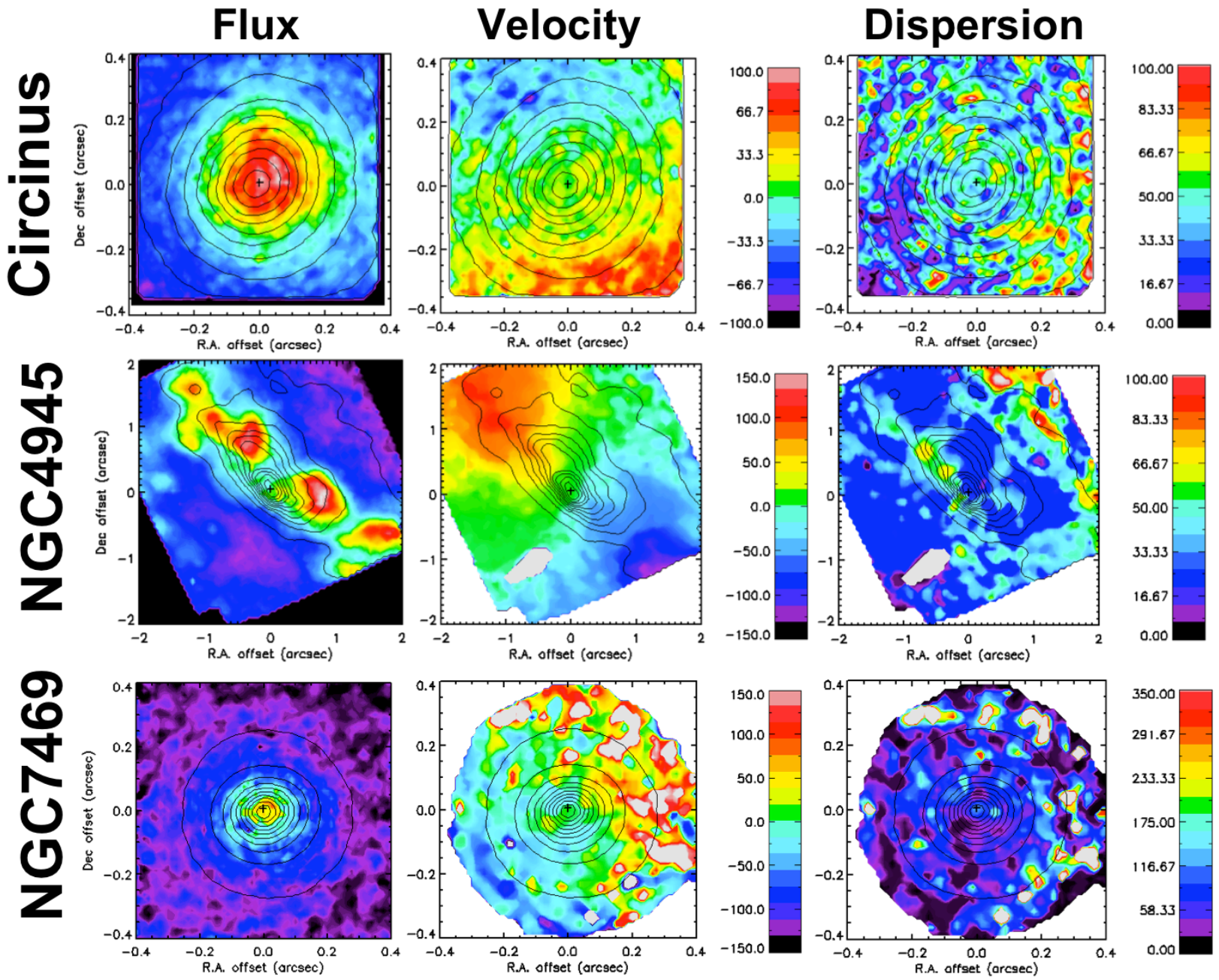
- Ionization mechanisms in Seyfert galaxies: collisionally ionized, gas is ionized in situ by photons generated in the hot shocked gas "photoionizing shock", or AGN photoionization? Contribution of stars?

- Kinematics of the NLR, is the material in the ionization cone outflowing? Origin of the outflow: starburst-driven wind, collimated radio jet, thermal wind from the AGN?

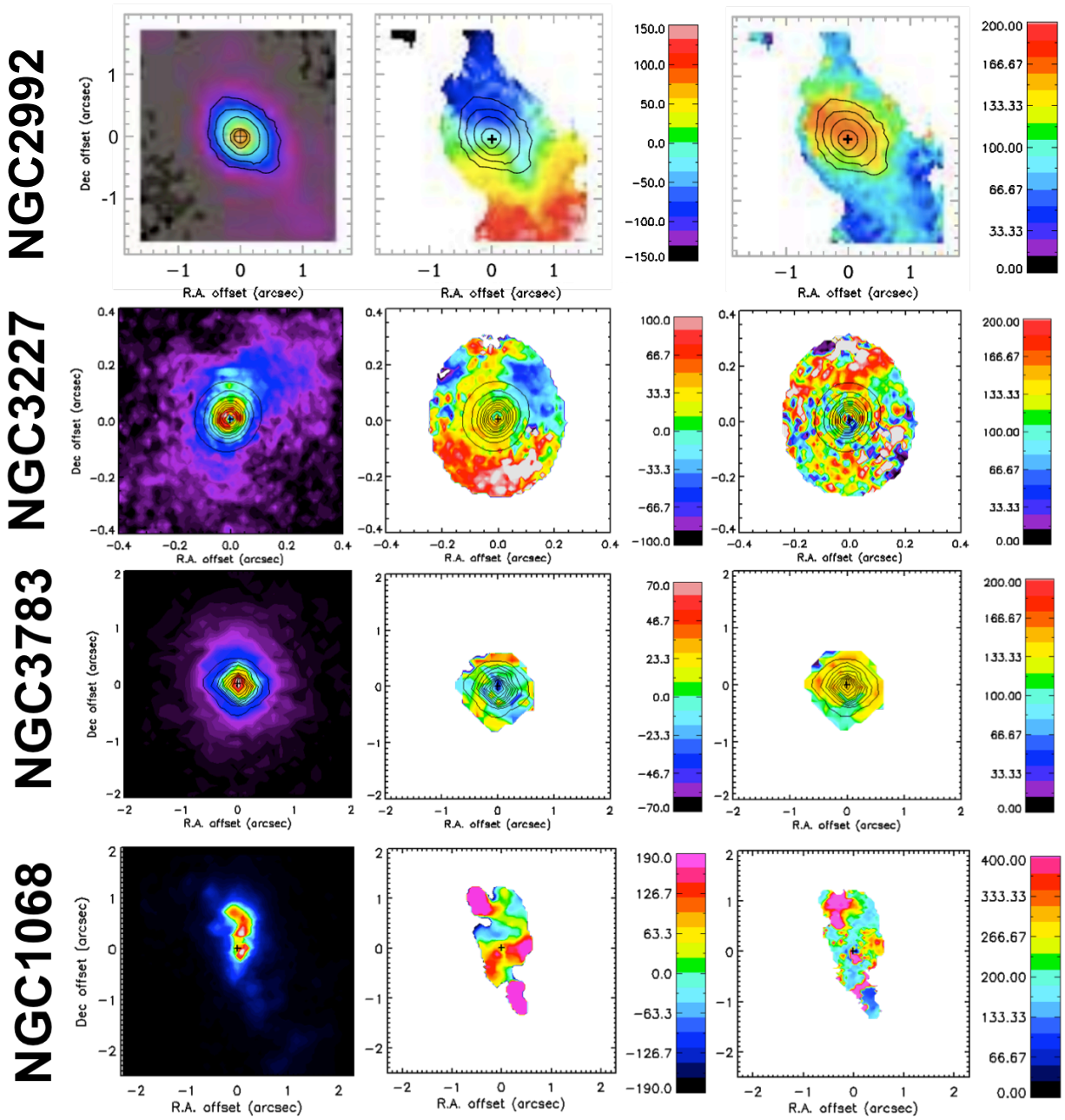
- Morphology and kinematics of the coronal lines, are they part of the NLR (ionization cone)? do they show signs of rotation? are there any correlations with other AGN-based phenomena?

- Do AGN outflows actually deliver enough energy to their environments to alter the evolution of the host galaxy in a meaningful way? e.g. controlling star formation and accretion processes, thus regulating BH growth.

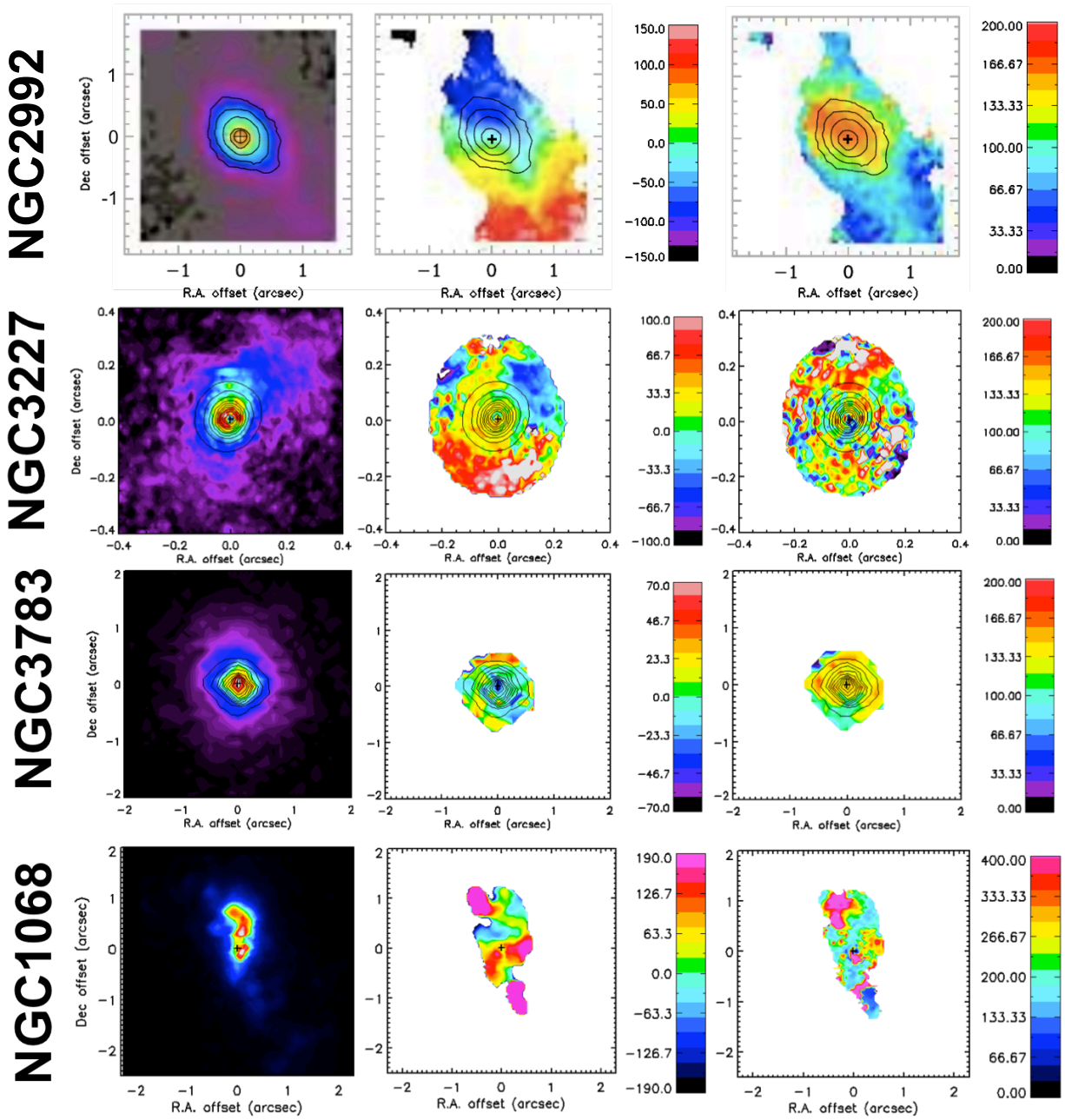
Brγ


Flux
Velocity
Dispersion
Circinus
NGC4945
NGC7469
Dec offset (arcsec)
R.A. offset (arcsec)

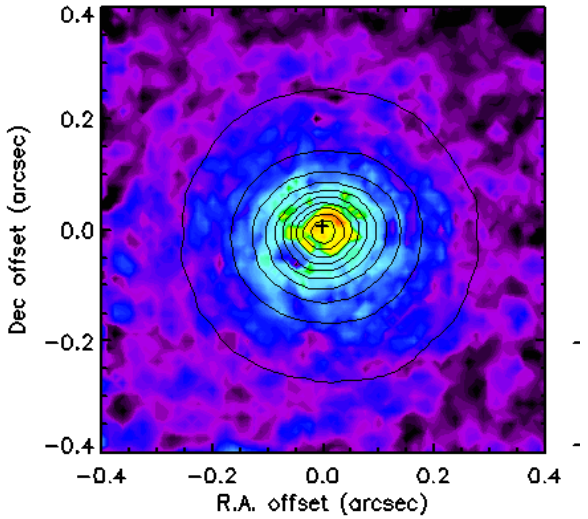
Brγ

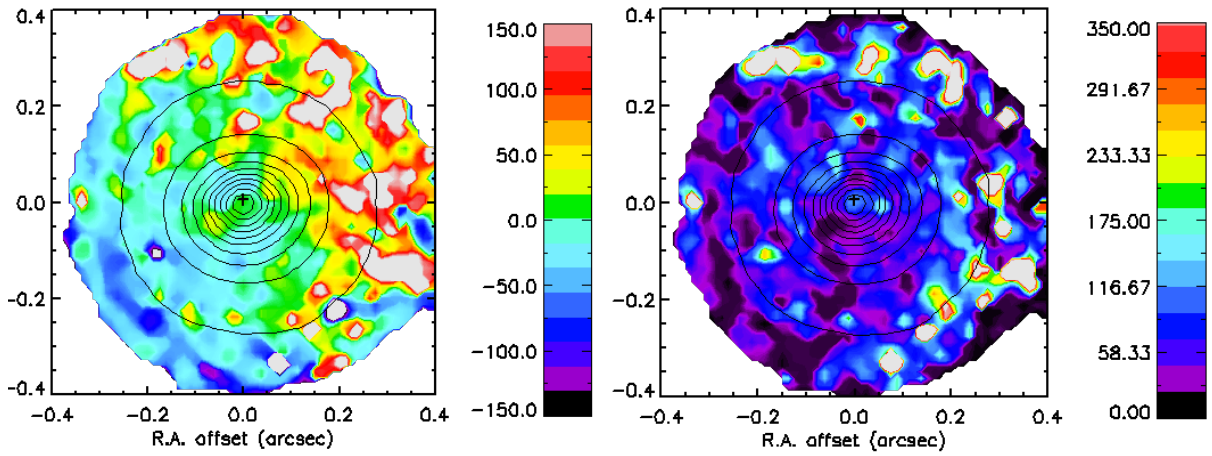

NGC2992
NGC3227
NGC3783
NGC1068
Dec offset (arcsec)
R.A. offset (arcsec)

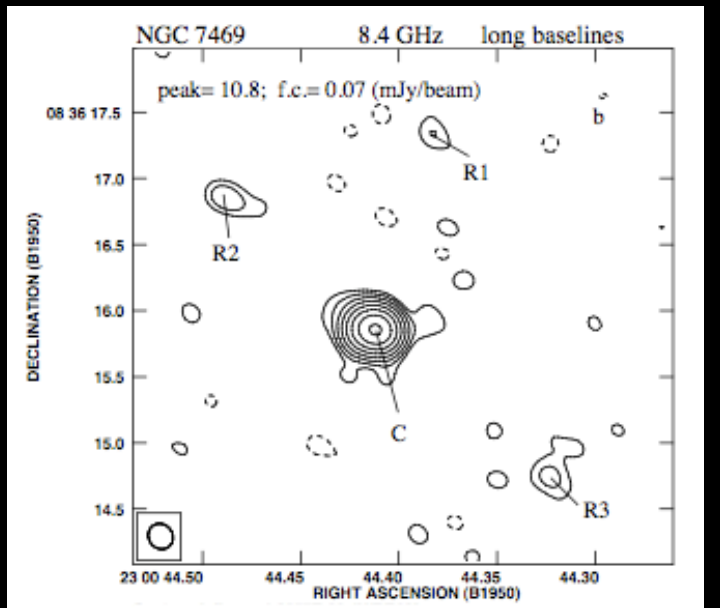
Brγ

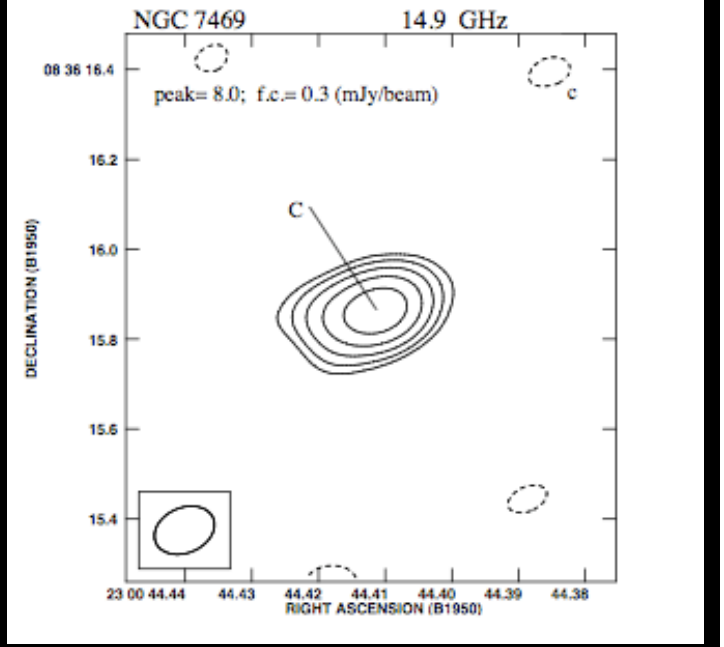

NGC2992
NGC3227
NGC3783
NGC1068
Dec offset (arcsec)
R.A. offset (arcsec)

NGC7469

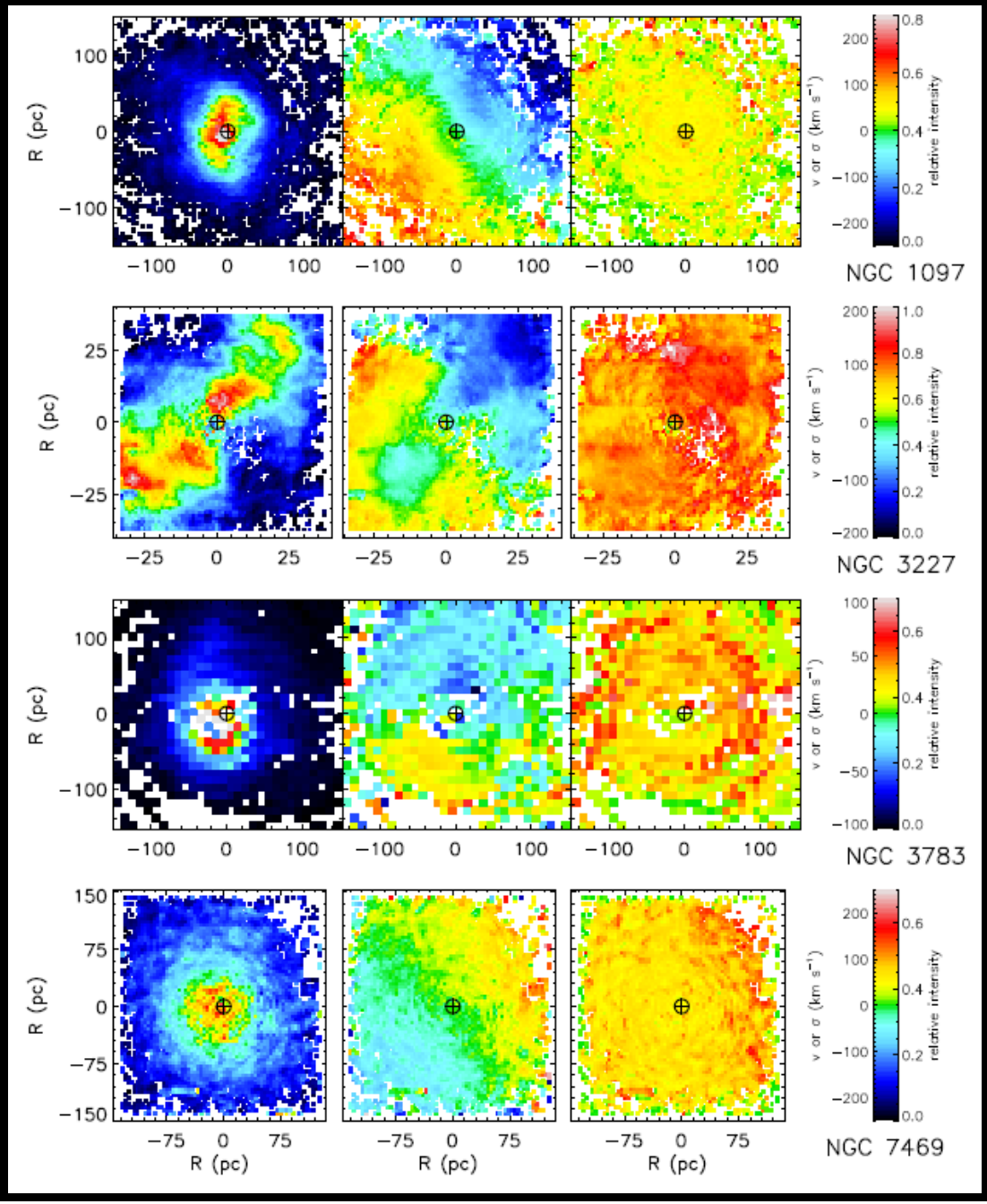

Dec offset (arcsec)
R.A. offset (arcsec)


R.A. offset (arcsec)
R.A. offset (arcsec)


NGC 7469
8.4 GHz
long baselines
peak= 10.8; f.c.= 0.07 (mJy/beam)
R1
R2
C
R3
b
DECLINATION (B1950)
RIGHT ASCENSION (B1950)


NGC 7469
14.9 GHz
peak= 8.0; f.c.= 0.3 (mJy/beam)
C
c
DECLINATION (B1950)
RIGHT ASCENSION (B1950)

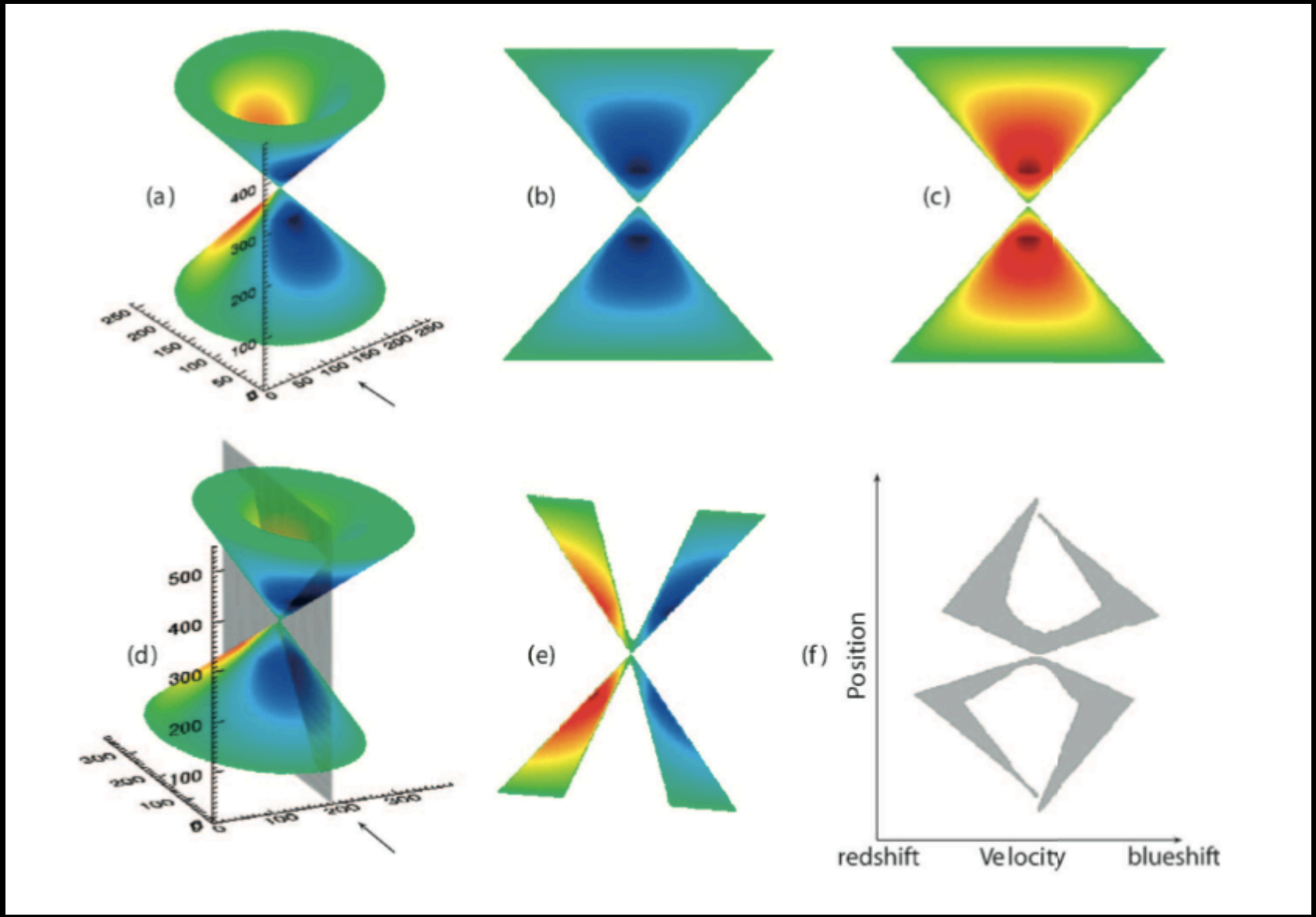
Molecular gas in AGN I



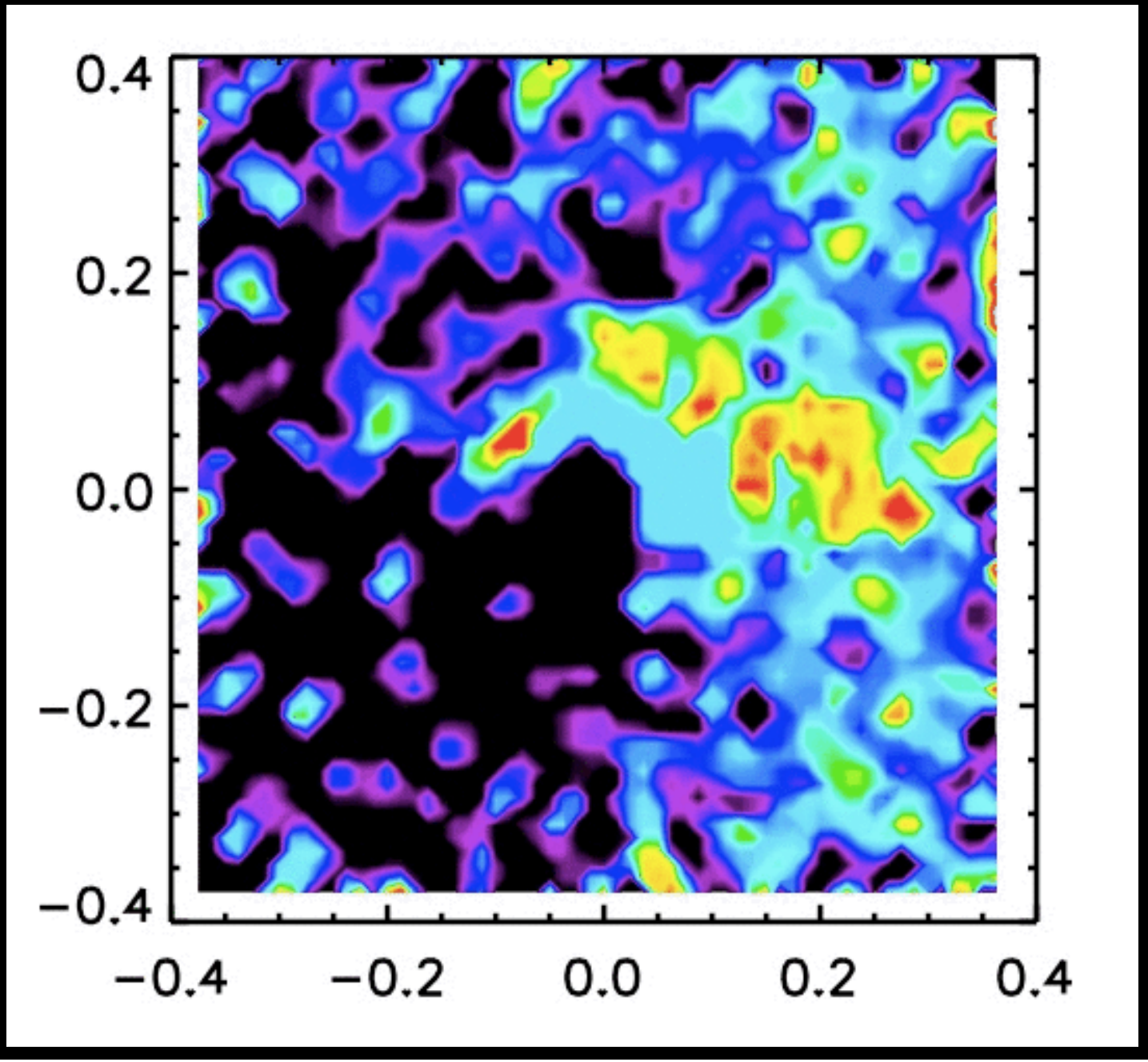
Conclusions

- The molecular hydrogen traced by the 1-0 S(1) line at 2.1 μm forms an optically and geometrically thick rotating disk.
- The size scale of the typical gas disk is found to have a radius less than 35 pc with a comparable vertical height
- The molecular gas observed is likely to be the outer extent of the nuclear obscuring structure
- The velocity dispersion is correlated with the SFR per unit area suggesting that the molecular/dusty structure on these scales may be dynamic. In such a case the fraction of viewing angles that pass through the obscuring region will depend not only on orientation, but also on the state of the nuclear starburst, with Sy2-AGN more likely to be observed during a phase of intense star formation
- NGC1068: massive inflow directly inwards to central few parsecs

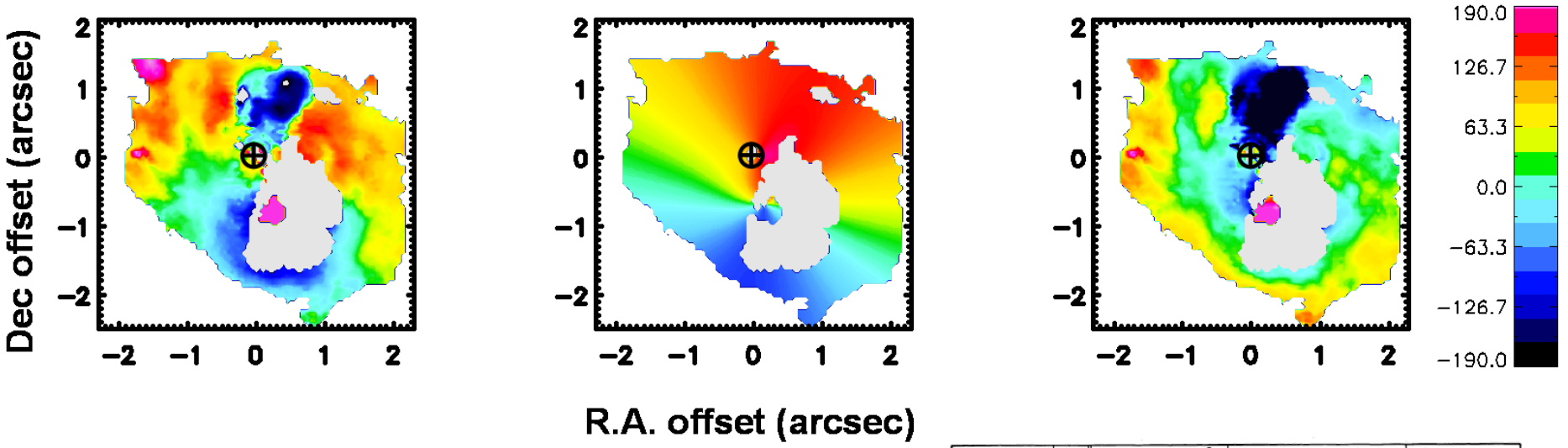
Outflow biconical model

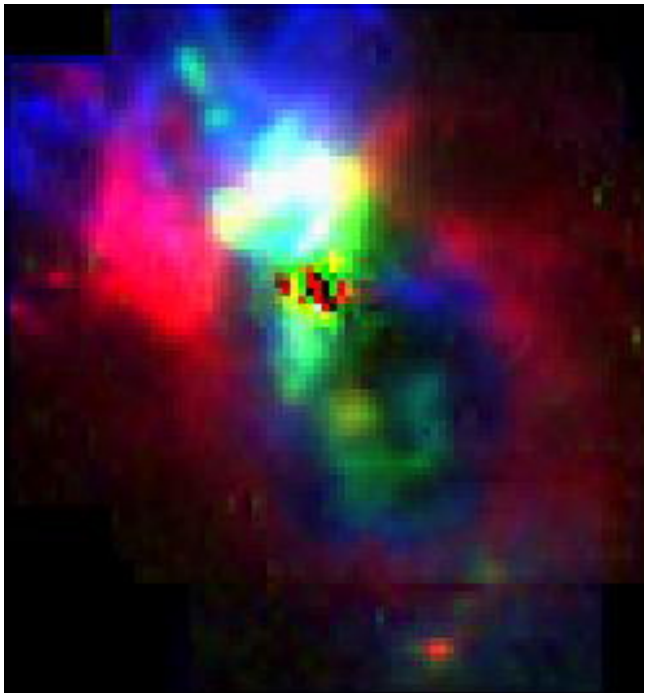


NGC3783



Kinematic model

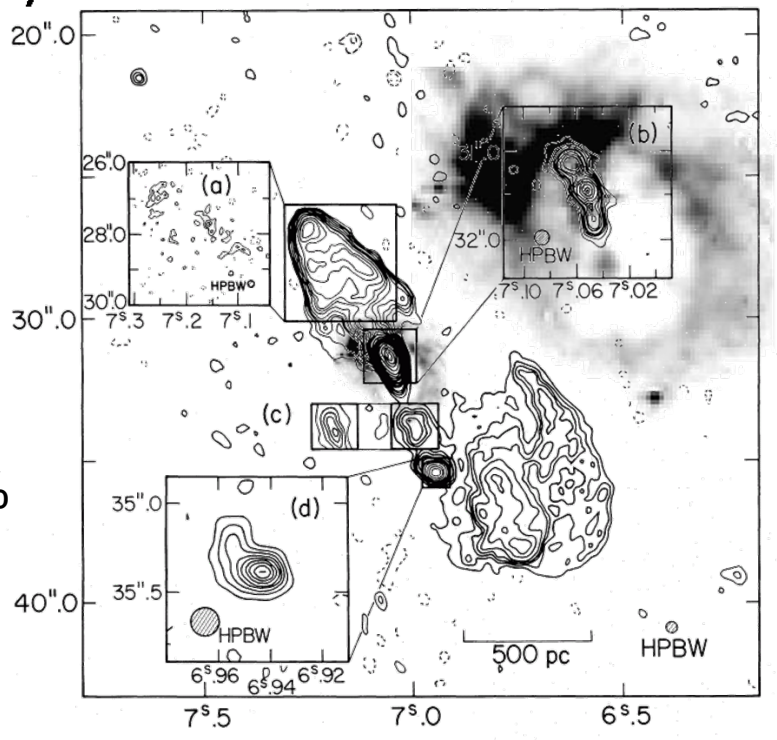




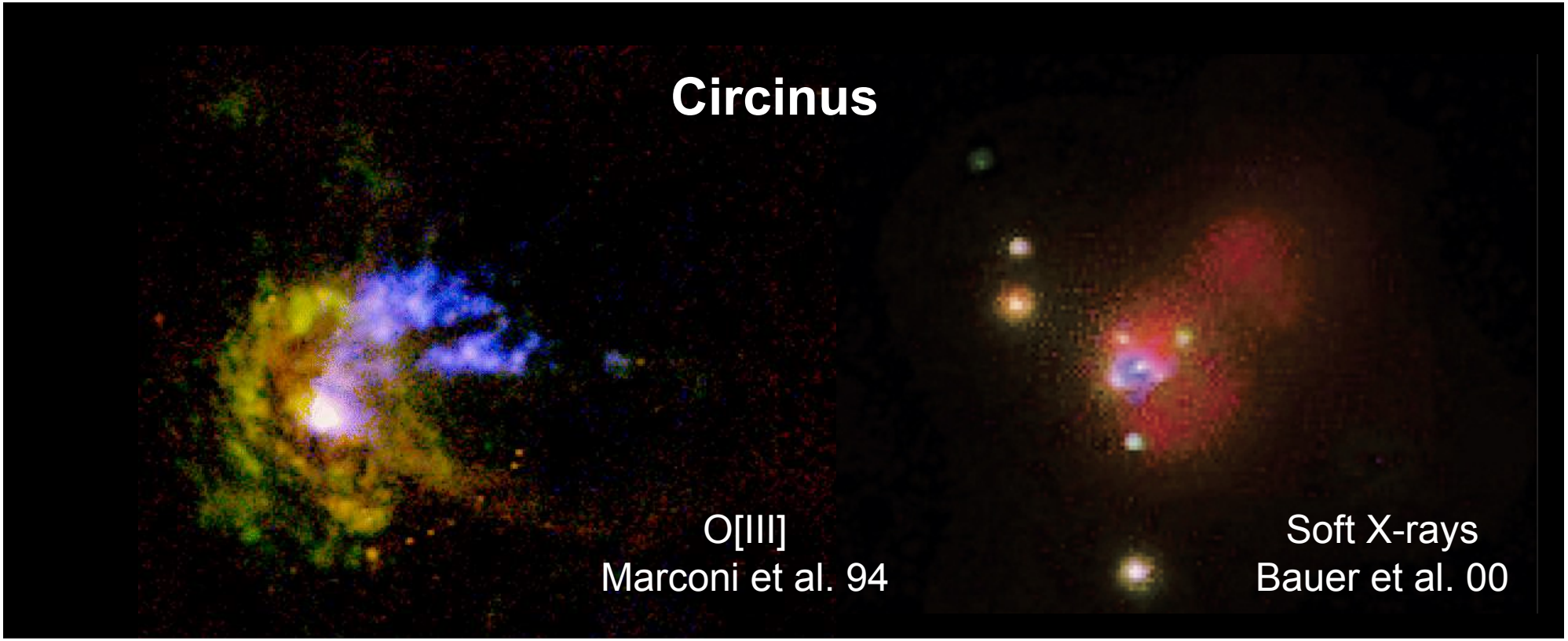
Interaction between expansion and rotating material

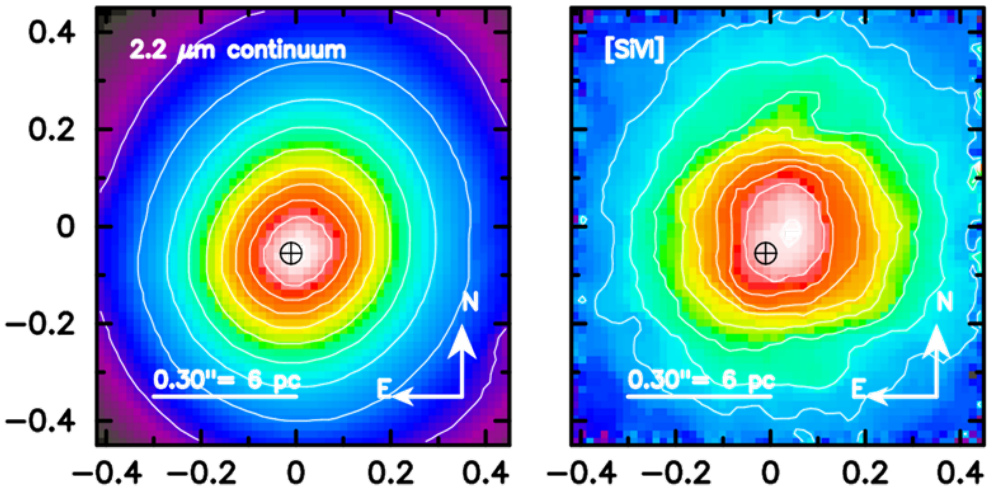
Angular momentum loss ~70-80%

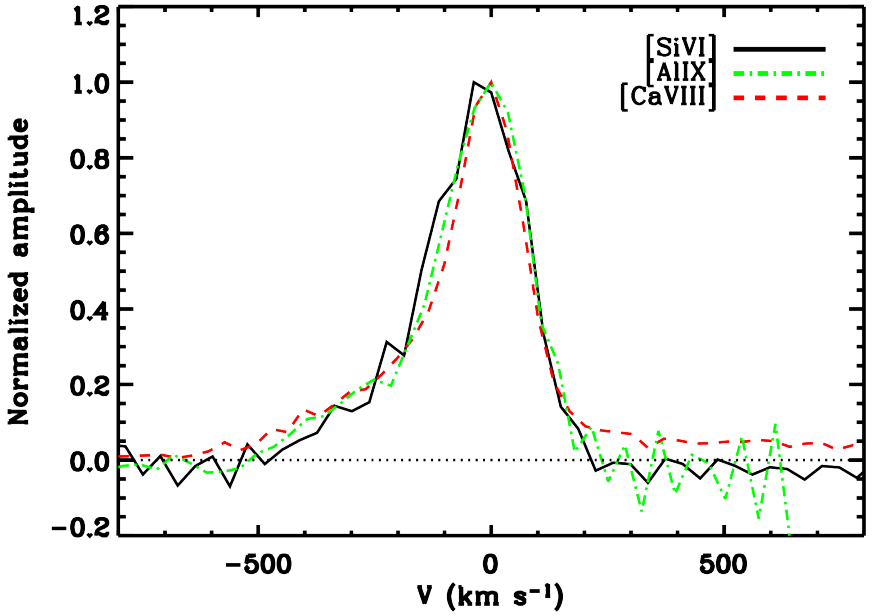
red=1-0S(1), blue=[FeII], green=Brg



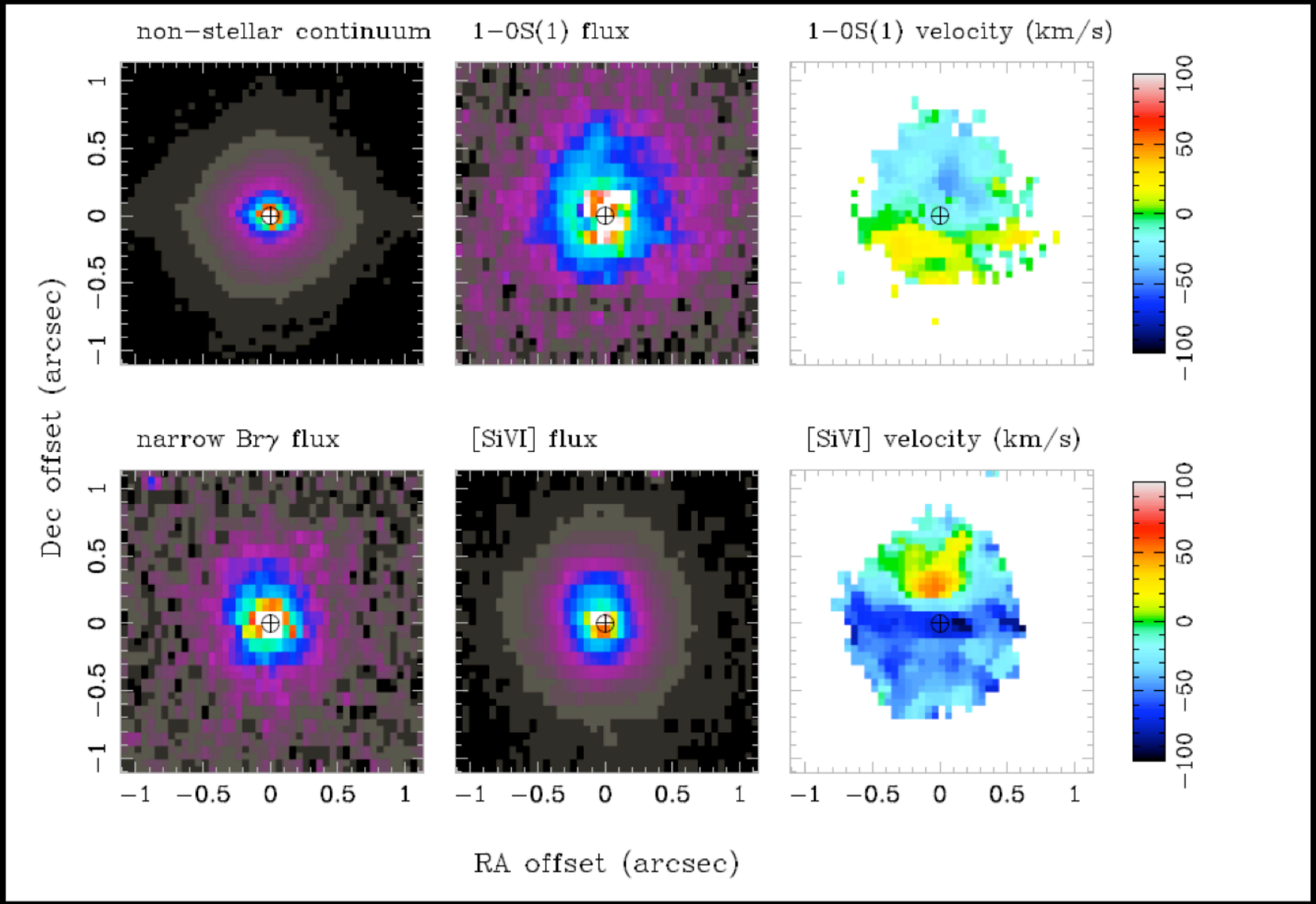
Circinus

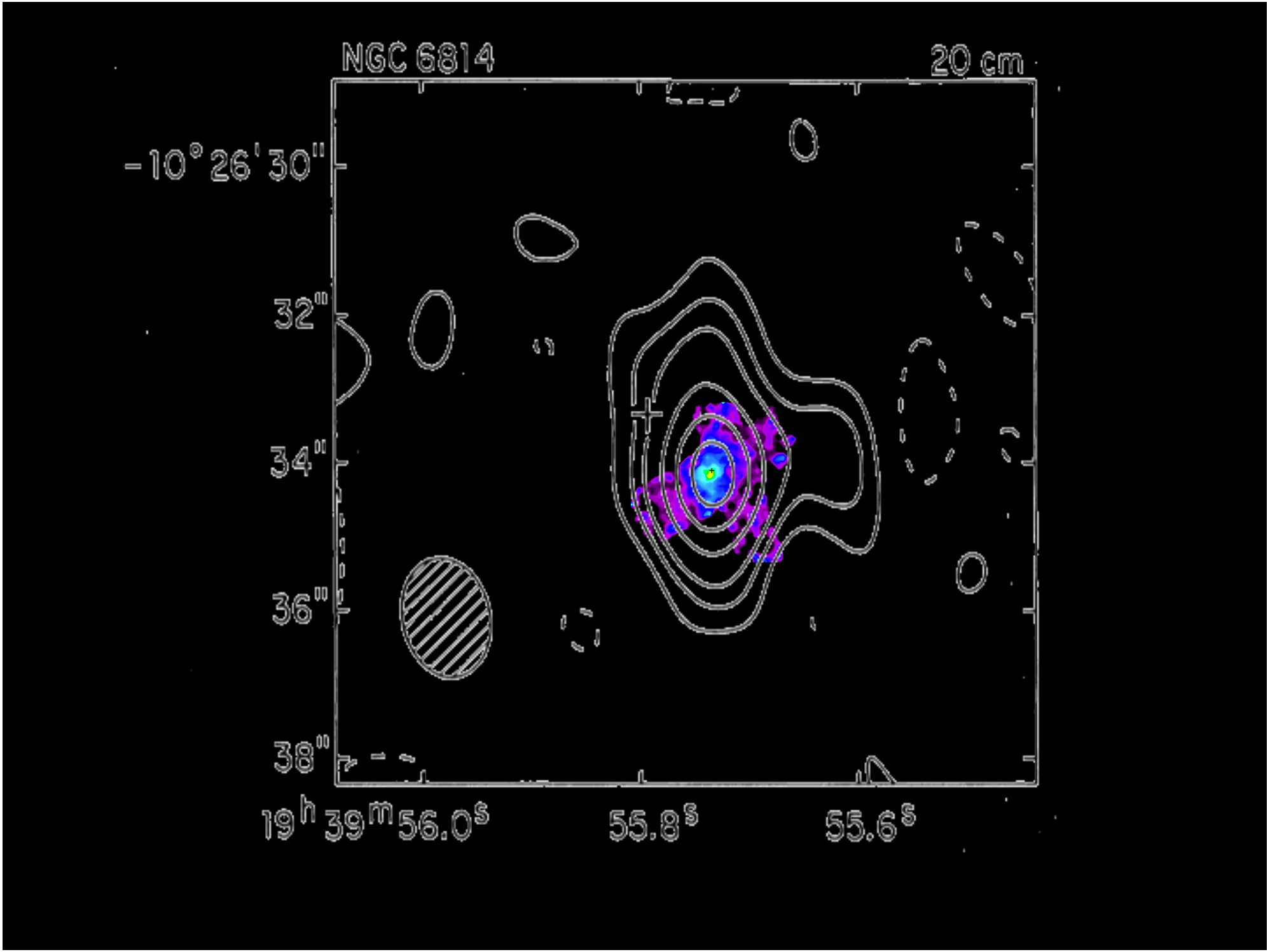

O[III]
Marconi et al. 94
Soft X-rays
Bauer et al. 00


2.2 μm continuum
[SiVI]
0.30" = 6 pc
N
E
0.4
0.2
0
−0.2
−0.4


[SiVI]
AlIX
[CaVIII]
Normalized amplitude
V (km s⁻¹)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−500
0
500

NGC3783


non−stellar continuum
1−0S(1) flux
1−0S(1) velocity (km/s)
narrow Brγ flux
[SiVI] flux
[SiVI] velocity (km/s)
Dec offset (arcsec)
RA offset (arcsec)
−1
−0.5
0
0.5
1
−100
−50
0
50
100


NGC 6814
20 cm
-10° 26' 30"
32"
34"
36"
38"
19h 39m 56.0s
55.8s
55.6s