

# Molecular gas outflow in the starburst galaxy NGC 1808 imaged by ALMA

**Dragan Salak**

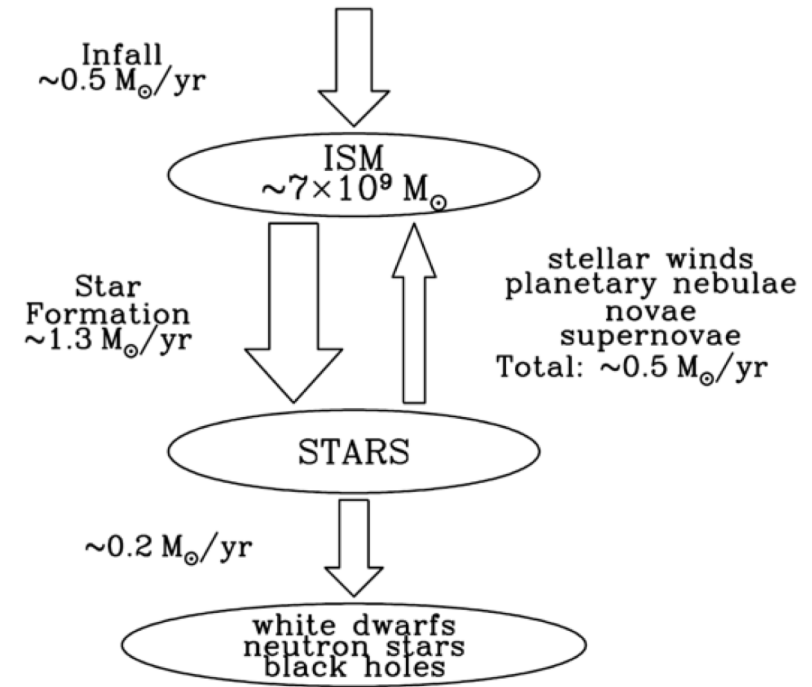
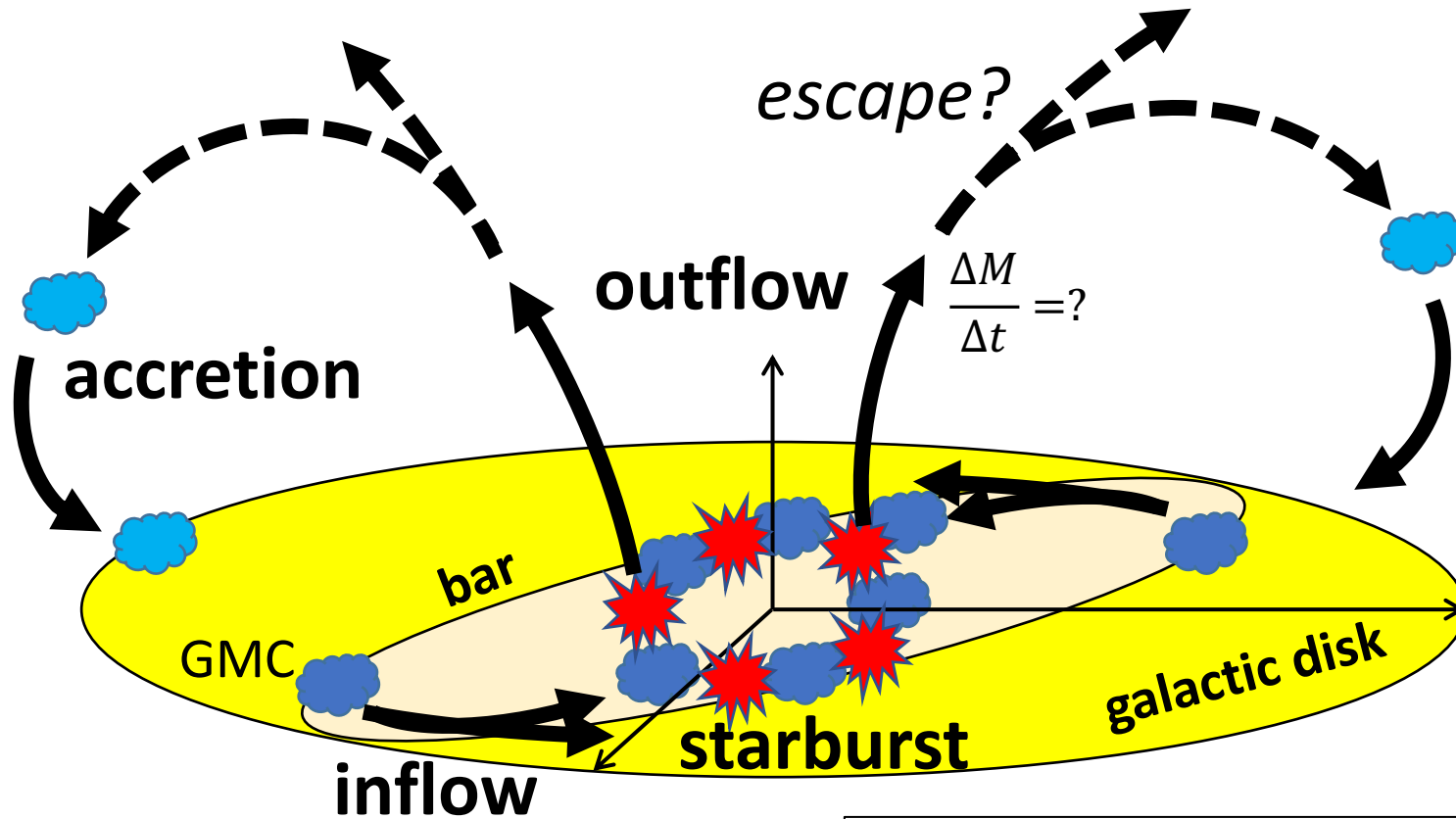
Kwansei Gakuin University

Y. Tomiyasu, N. Nakai, N. Kuno, T. Hatakeyama (Tsukuba University),  
Y. Miyamoto, H. Kaneko (National Astronomical Observatory of Japan)

*Interstellar Medium in the Nearby Universe @ Bamberg*

26 March 2018

# Baryon cycle of galaxies



- Gas accretion: e.g., van Gorkom (2012)
- Bar-induced inflow: Athanassoula (1992)
- Outflows: Veilleux et al. (2005)

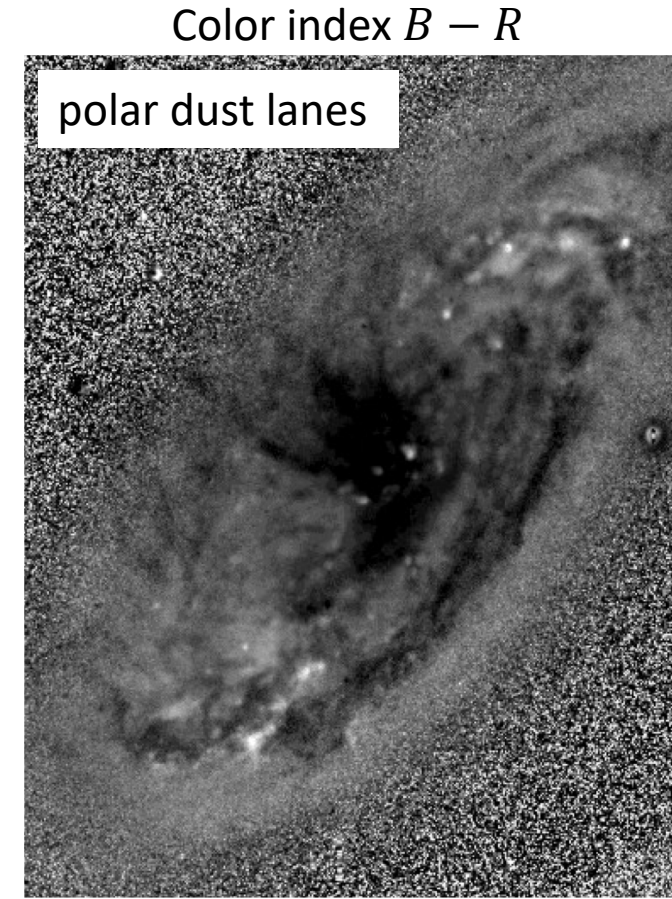
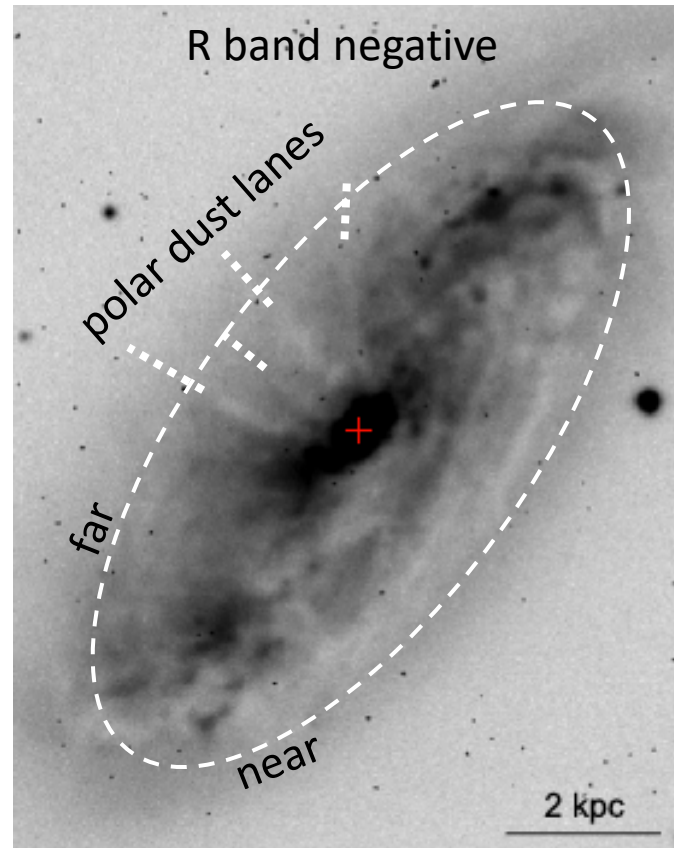
Examples: M82 and NGC 253

**Science with ALMA:**  
 Reveal and study **cold gas inflows** and **starburst-driven outflows** in nearby galaxies

**baryon cycle in the Milky Way**  
*"Physics of the ISM and IGM"* Draine

# Case study: barred galaxy NGC 1808

- Nearby ( $\sim 11$  Mpc;  $1'' \sim 50$  pc)
- Starburst in central 500 pc
- Evidence for neutral gas outflow

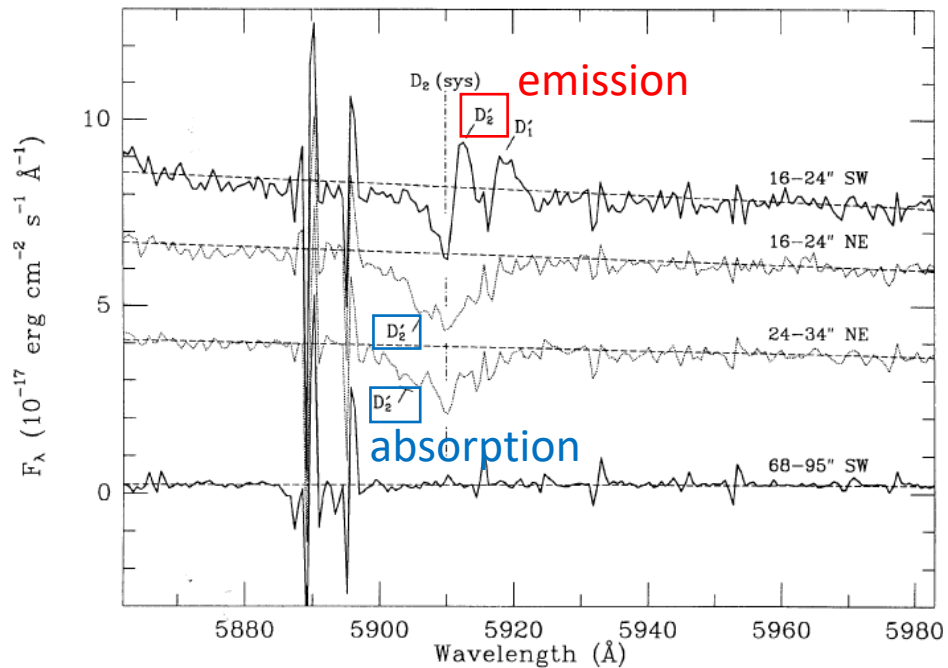


(Carnegie Galaxy Survey)

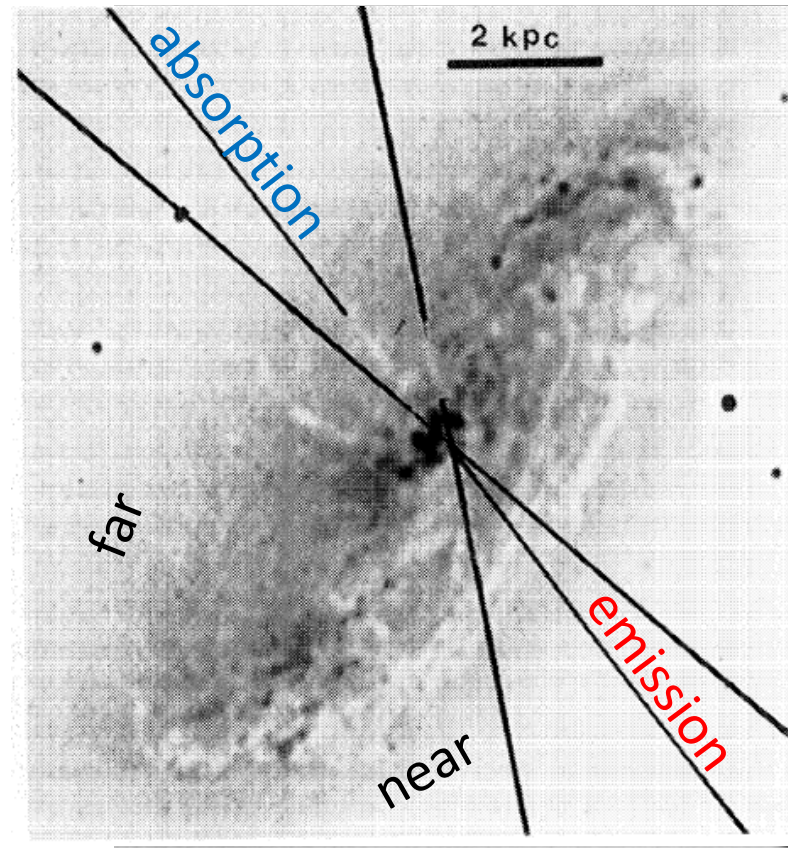


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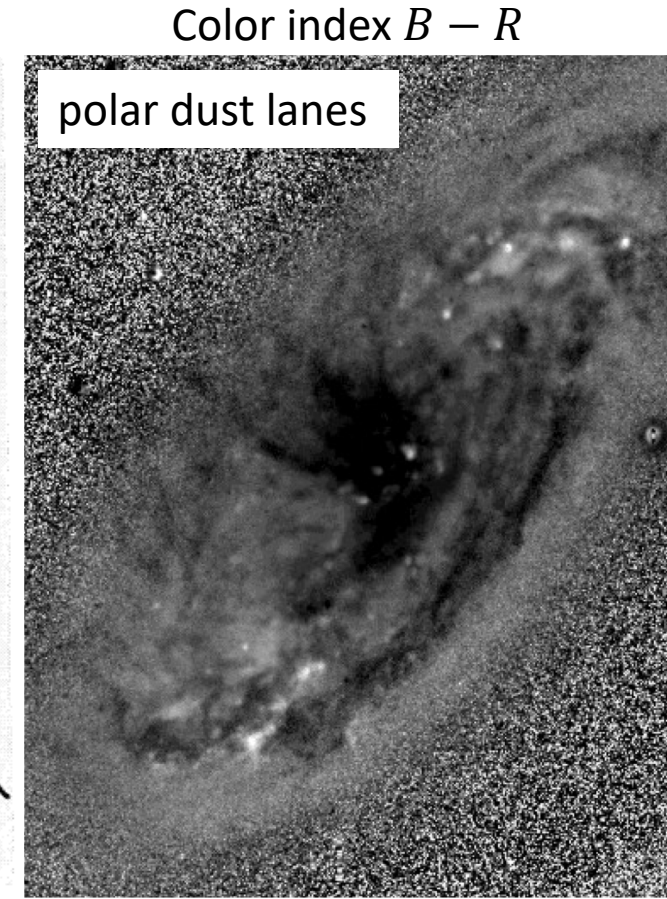
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Na I (Phillips 1993)



B band negative (Phillips 1993)



(Carnegie Galaxy Survey)

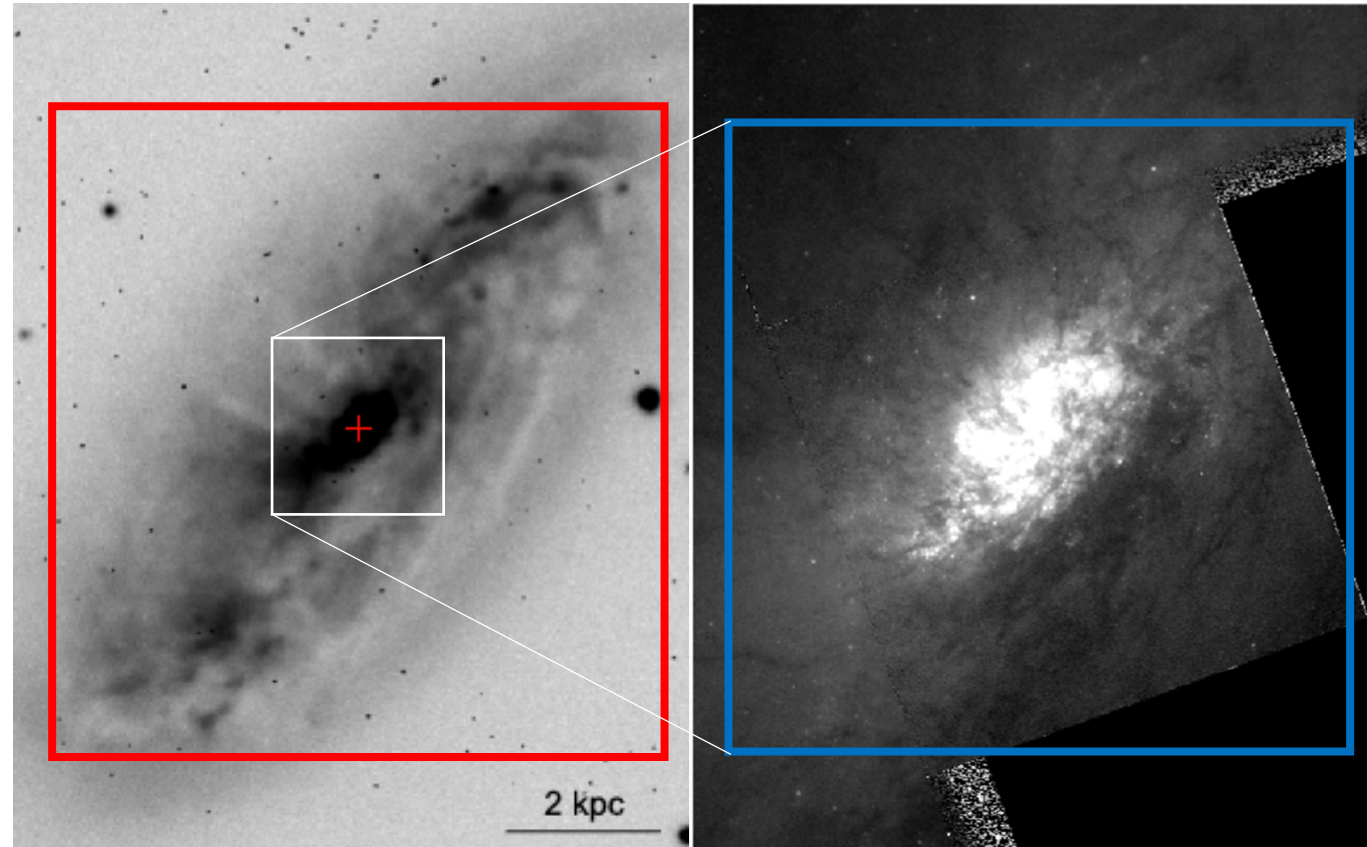


# CO observations of NGC 1808 by ALMA



Cycle	1	2	5
Resolution	2" (100 pc)	0.5"-1" (25-50 pc)	1" (50 pc)
Spectral line	<b>CO (1-0)</b>	<b>CO (3-2)</b> HCN (1-0) HCO <sup>+</sup> (1-0) etc.	CO (2-1) <sup>13</sup> CO (2-1) C <sup>18</sup> O (2-1) [CI]

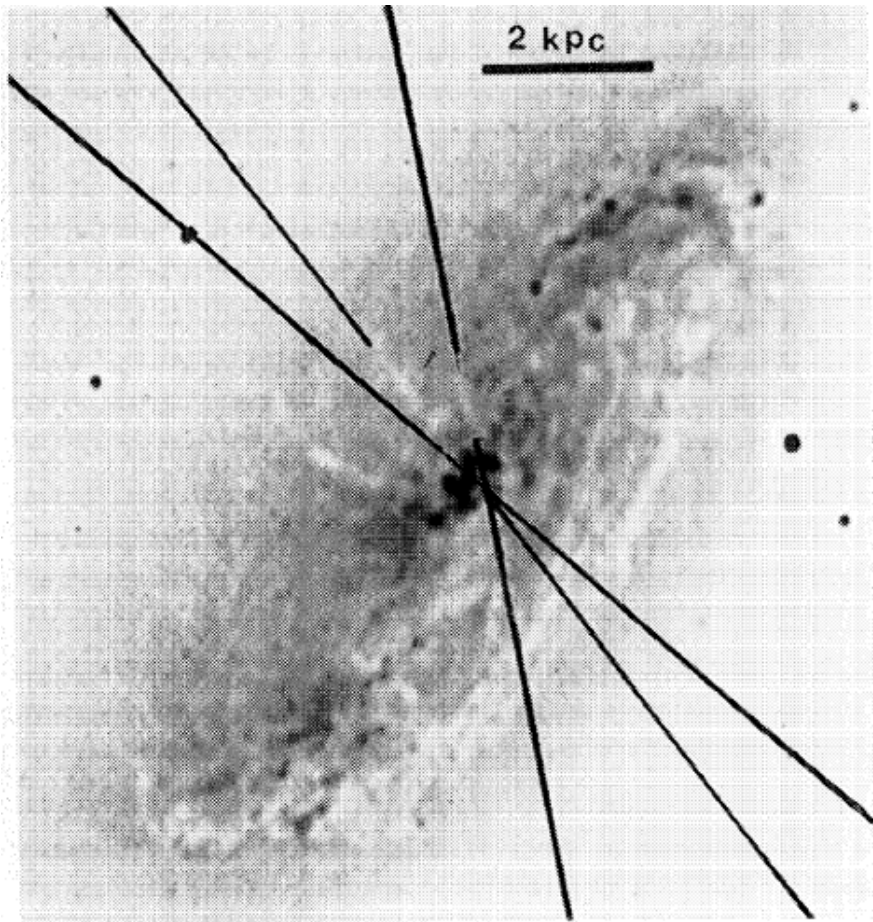
DS+ 2016 ApJ, 823, 68  
 DS+ 2017 ApJ, 849, 90  
 DS+ 2018 ApJ, accepted



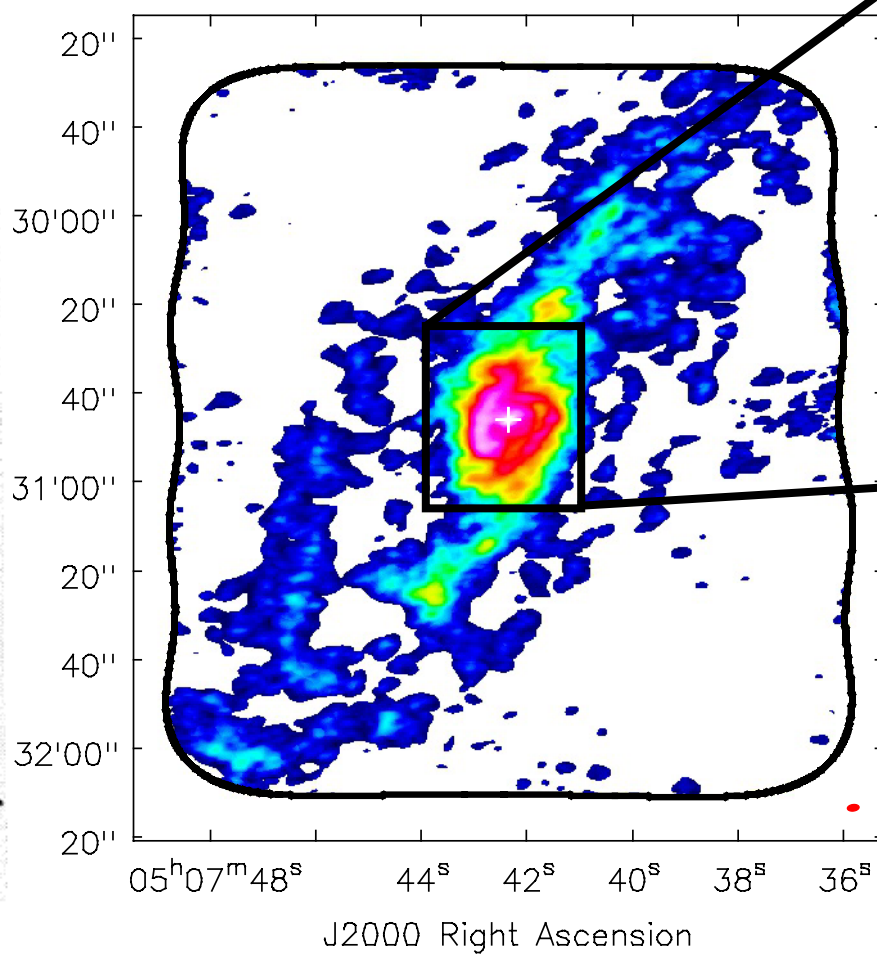
ISM 2018 Bamberg

R band  
 (Hubble Legacy Archive)

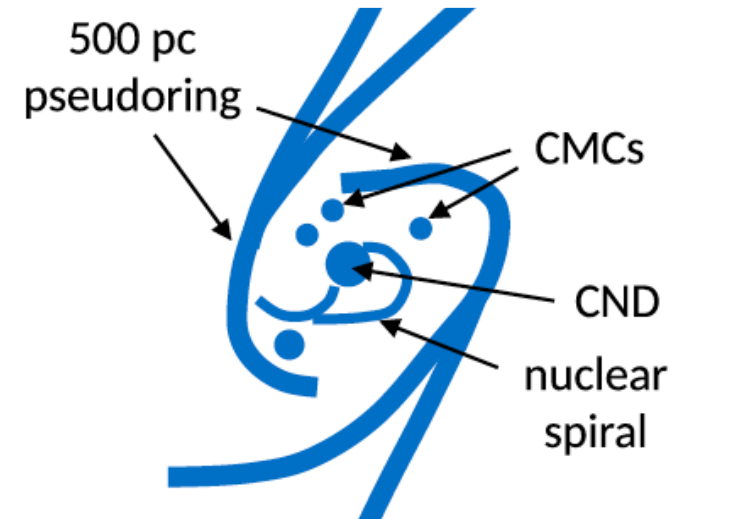
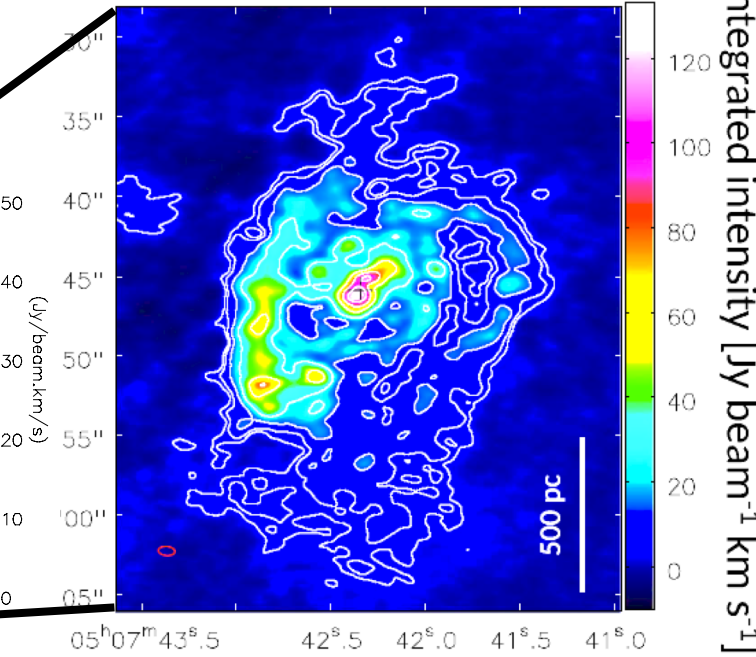
# Molecular gas distribution



CO (J=1-0) integrated intensity



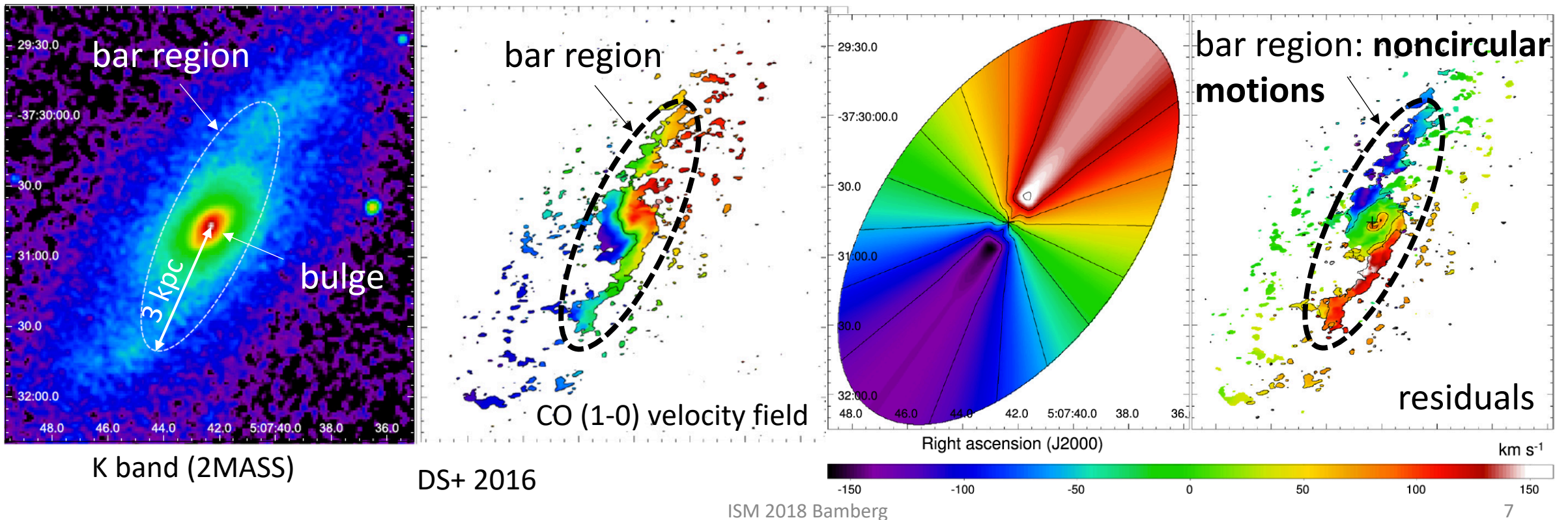
CO (J=3-2)





# Bar-driven molecular gas inflow

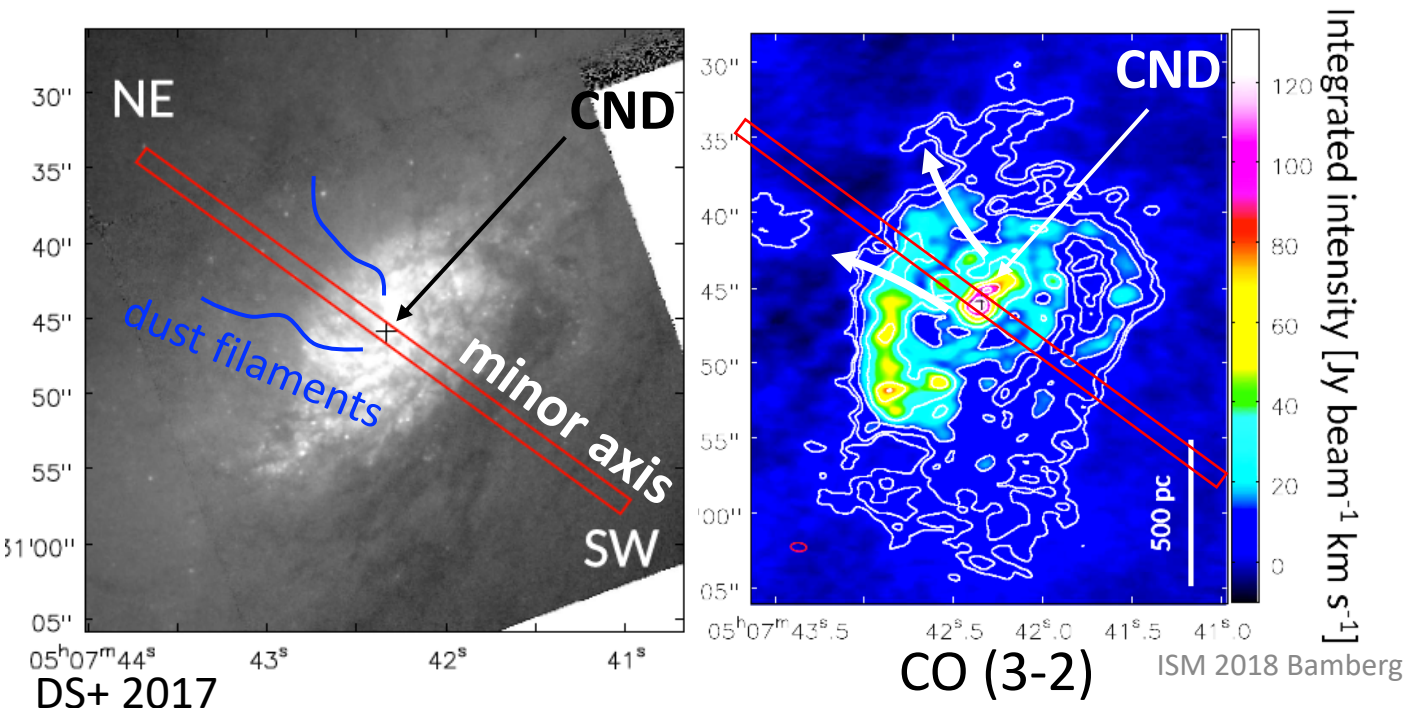
- Large-scale noncircular motions of molecular gas in the bar
- Nuclear starburst consequence of gas supply by the bar





# Molecular gas outflow from the CND

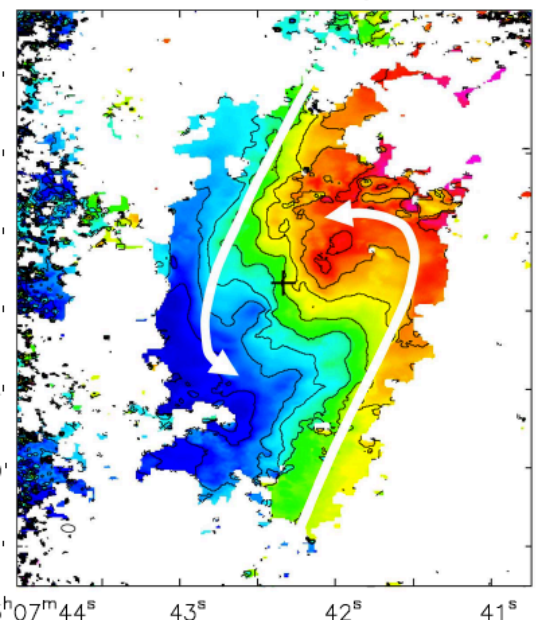
- Position-velocity diagram along the minor galactic axis (polar dust lane) centered at circumnuclear disk (CND)
- Line splitting: disk rotation and outflow gas ( $v \sim 200$  km/s)
- Outflow mass  $\ll$  total molecular gas mass



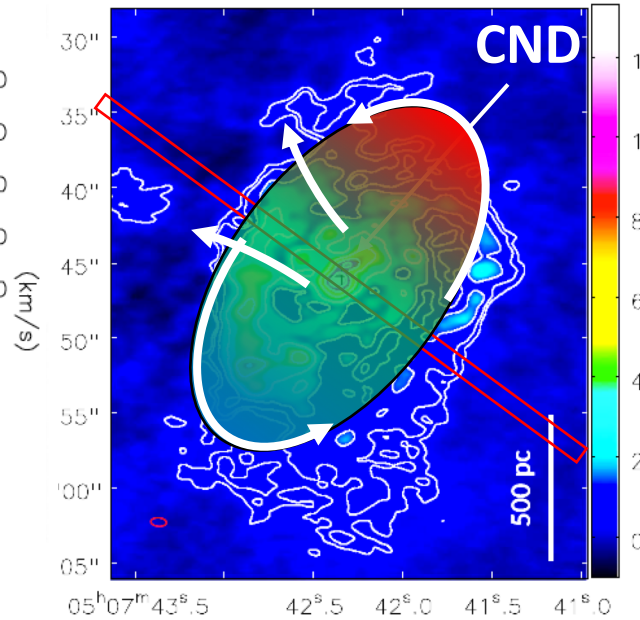
# Molecular gas outflow from the CND

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CO (3-2) velocity field

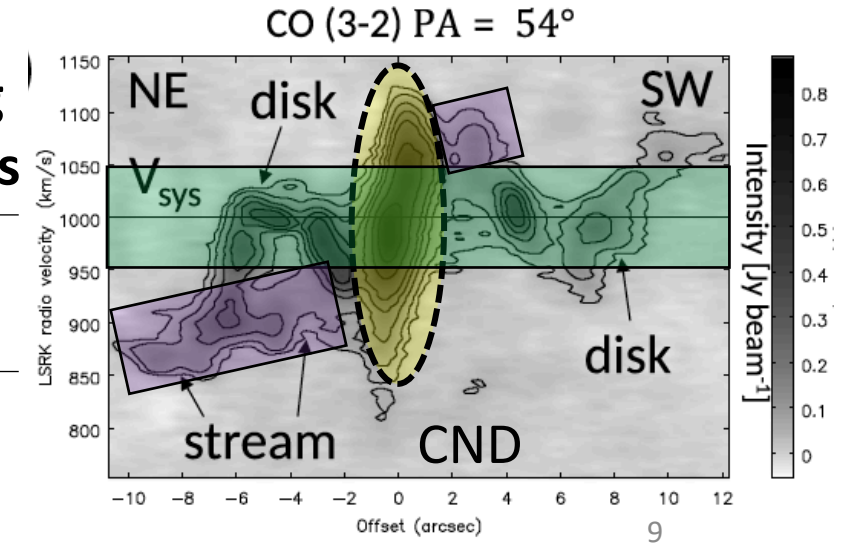
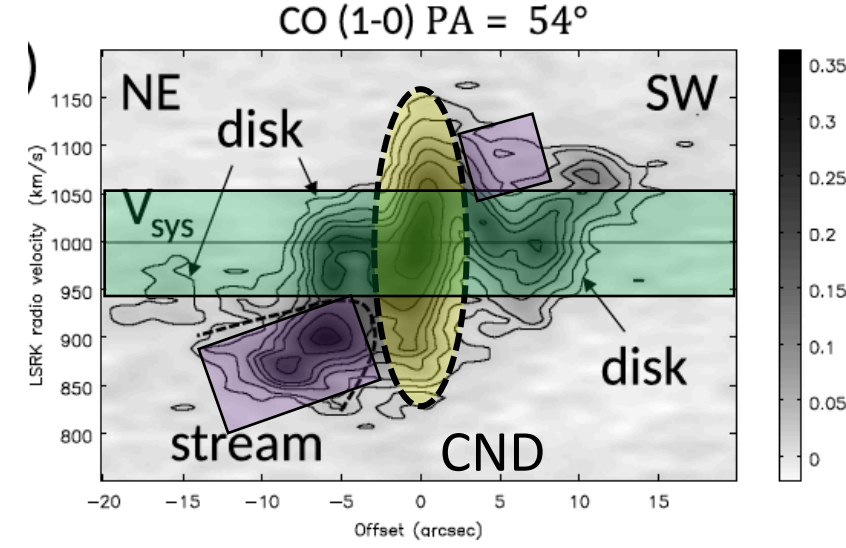
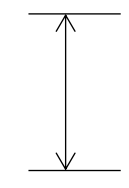


DS+ 2017



CO (3-2) ISM 2018 Bamberg

**line splitting  
100-150 km/s**



# Outflow dynamics

- **Mass outflow rate**  $dM/dt \sim 1-10 M_{\odot}/\text{yr}$   
comparable to the total SFR ( $R < 500 \text{ pc}$ )  $\sim 5 M_{\odot}/\text{yr}$

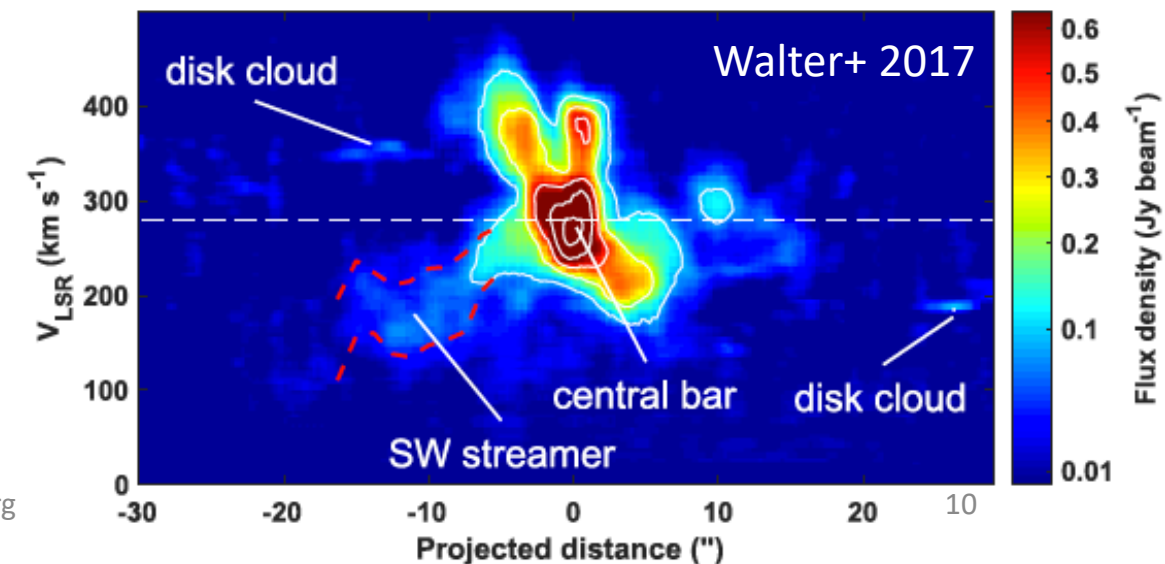
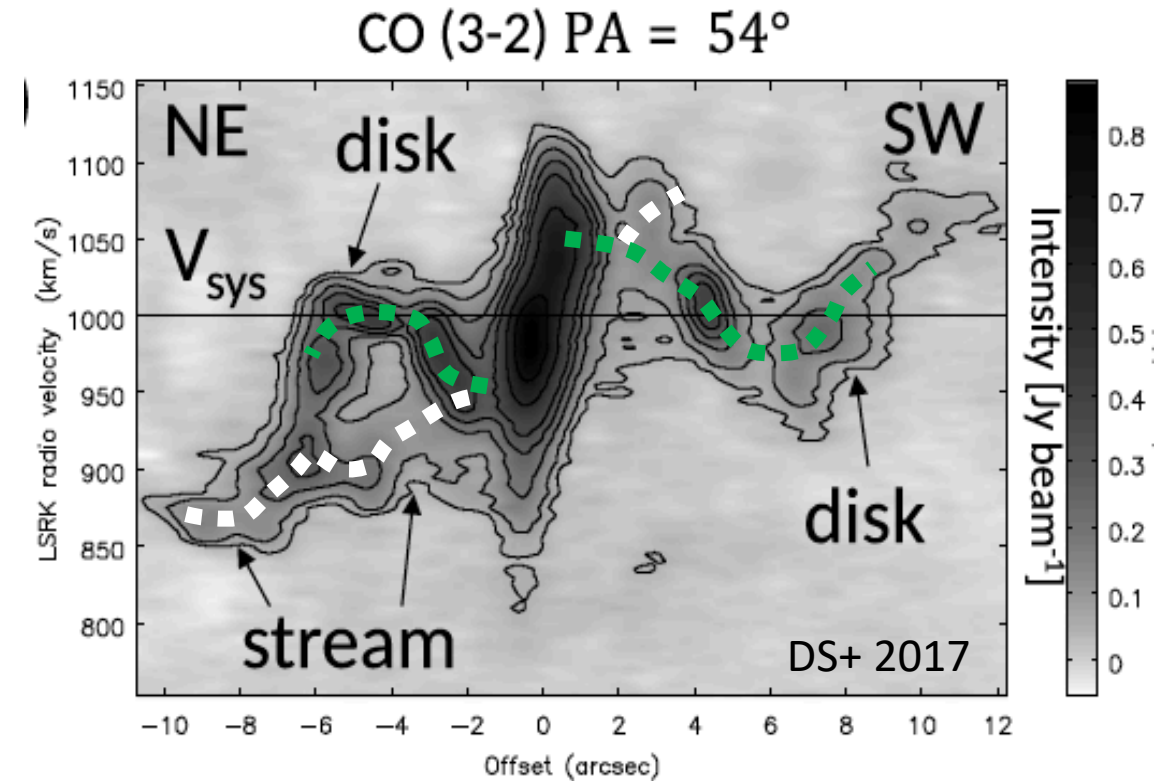
- **Velocity gradient (minor axis)**  $\sim +0.4 \text{ km/s/pc}$

CO velocity: 240 km/s at  $-12''$

Na I velocity: 400 km/s at  $-30''$  (Phillips 1993)

- Outflow velocity  $\sim 200 \text{ km/s}$  at radius 1 kpc  
< escape velocity  $\sim 300 \text{ km/s}$

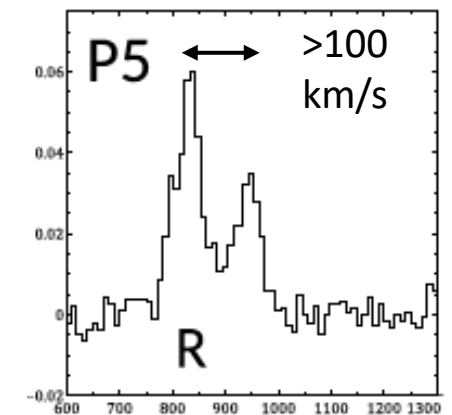
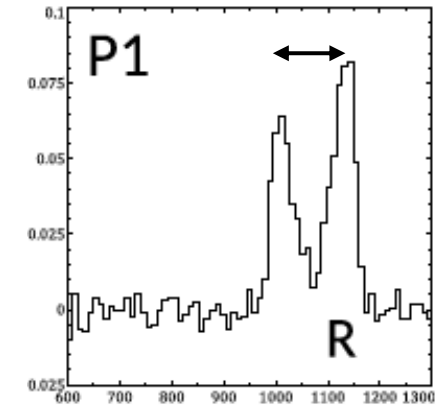
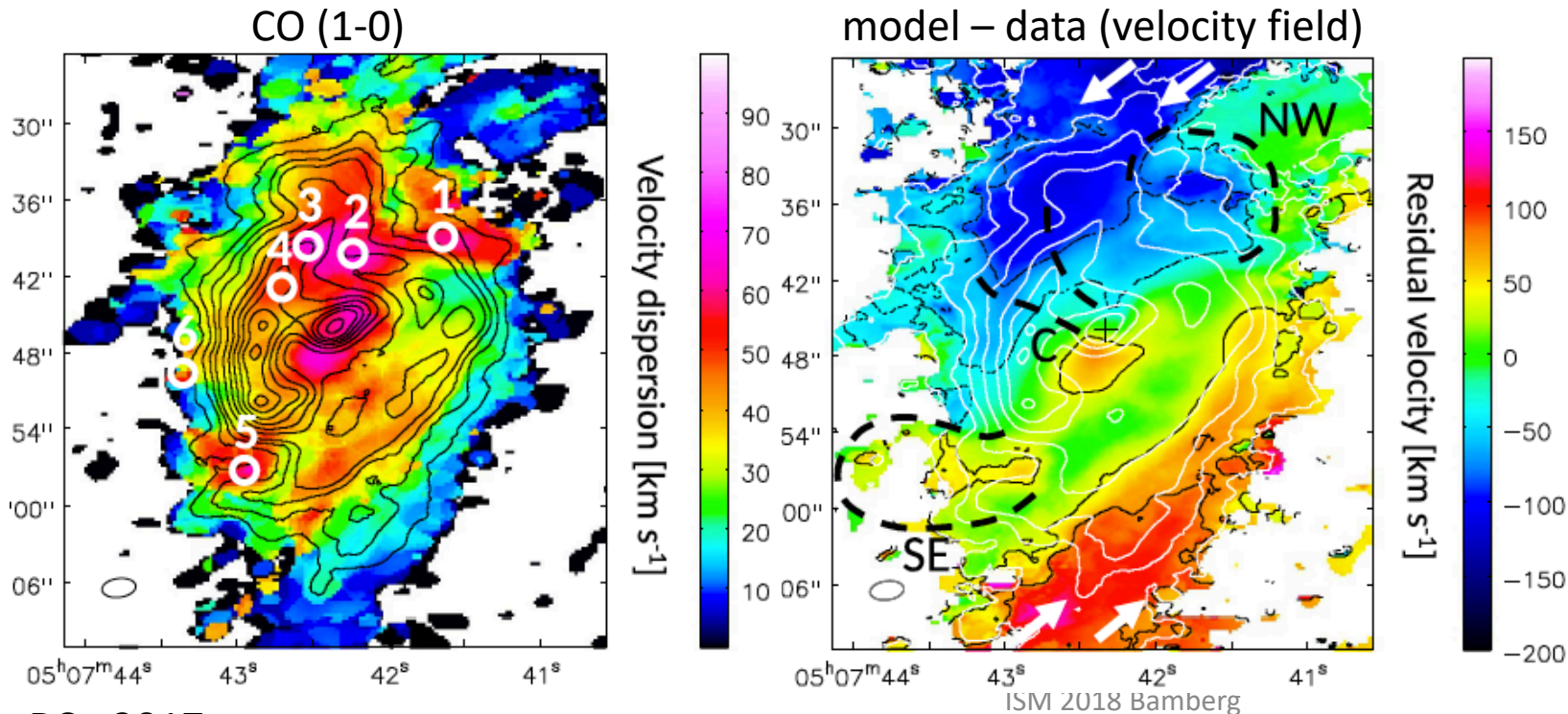
- cf. velocity gradient  $\sim +1 \text{ km/s/pc}$  in NGC 253  
(Walter et al. 2017)





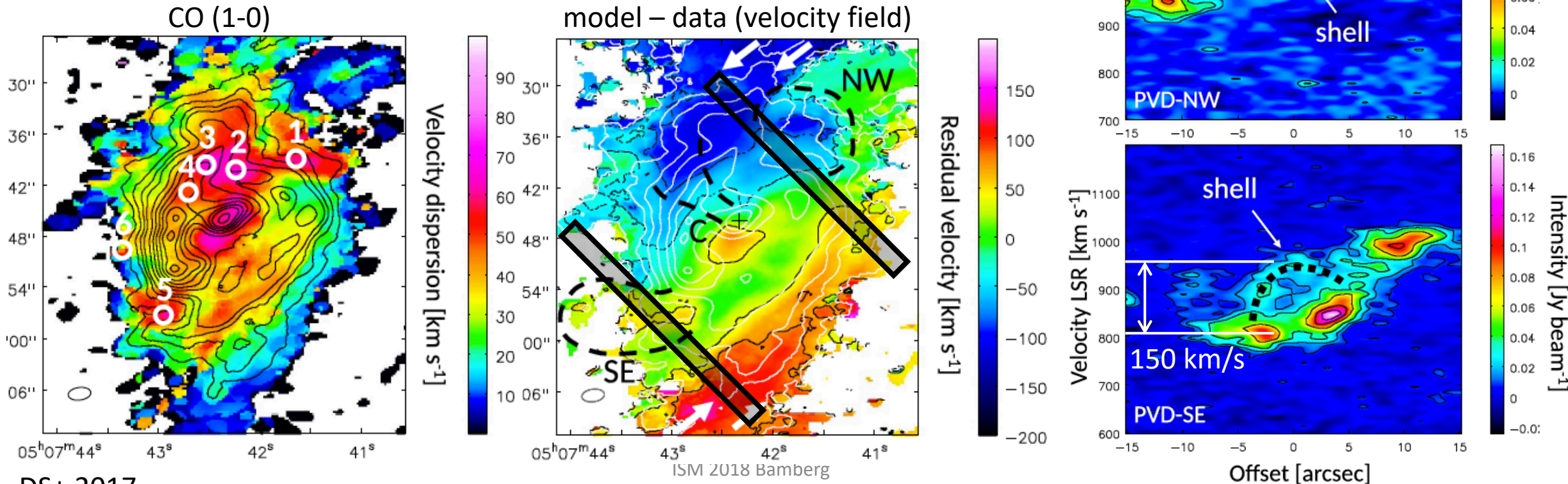
# Molecular outflows from the 500 pc ring

- Major line splitting ( $\sim 100$  km/s) found in the 500 pc ring
- Outflow mass  $\sim 10^{-3}$  of total molecular gas mass in the starburst
- If spherical geometry (shell), maximum velocity  $\sim 75$  km/s



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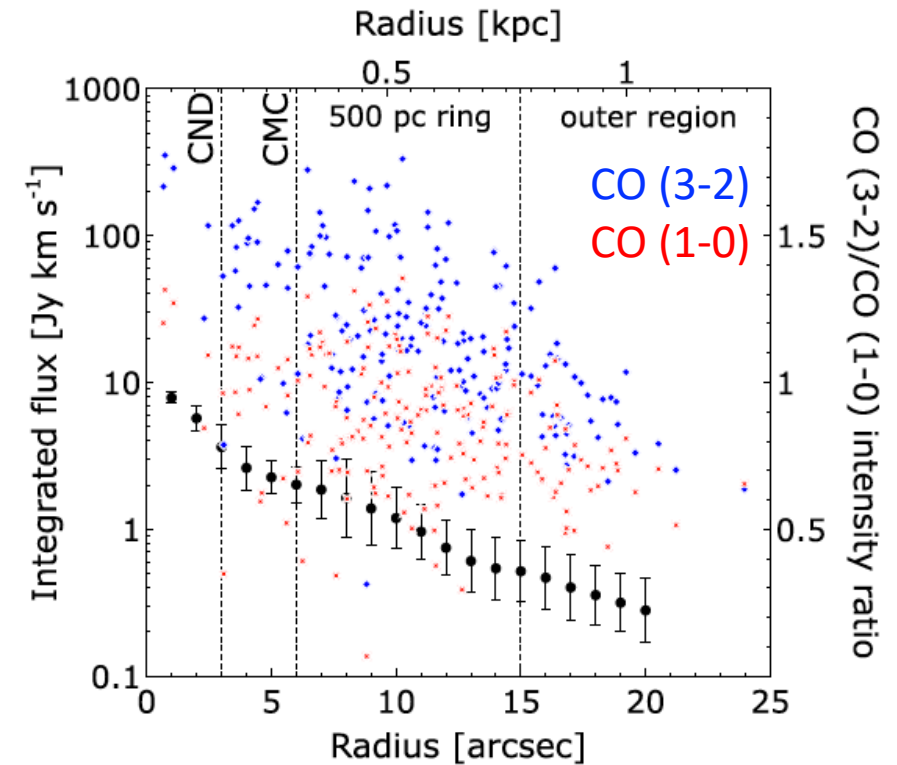
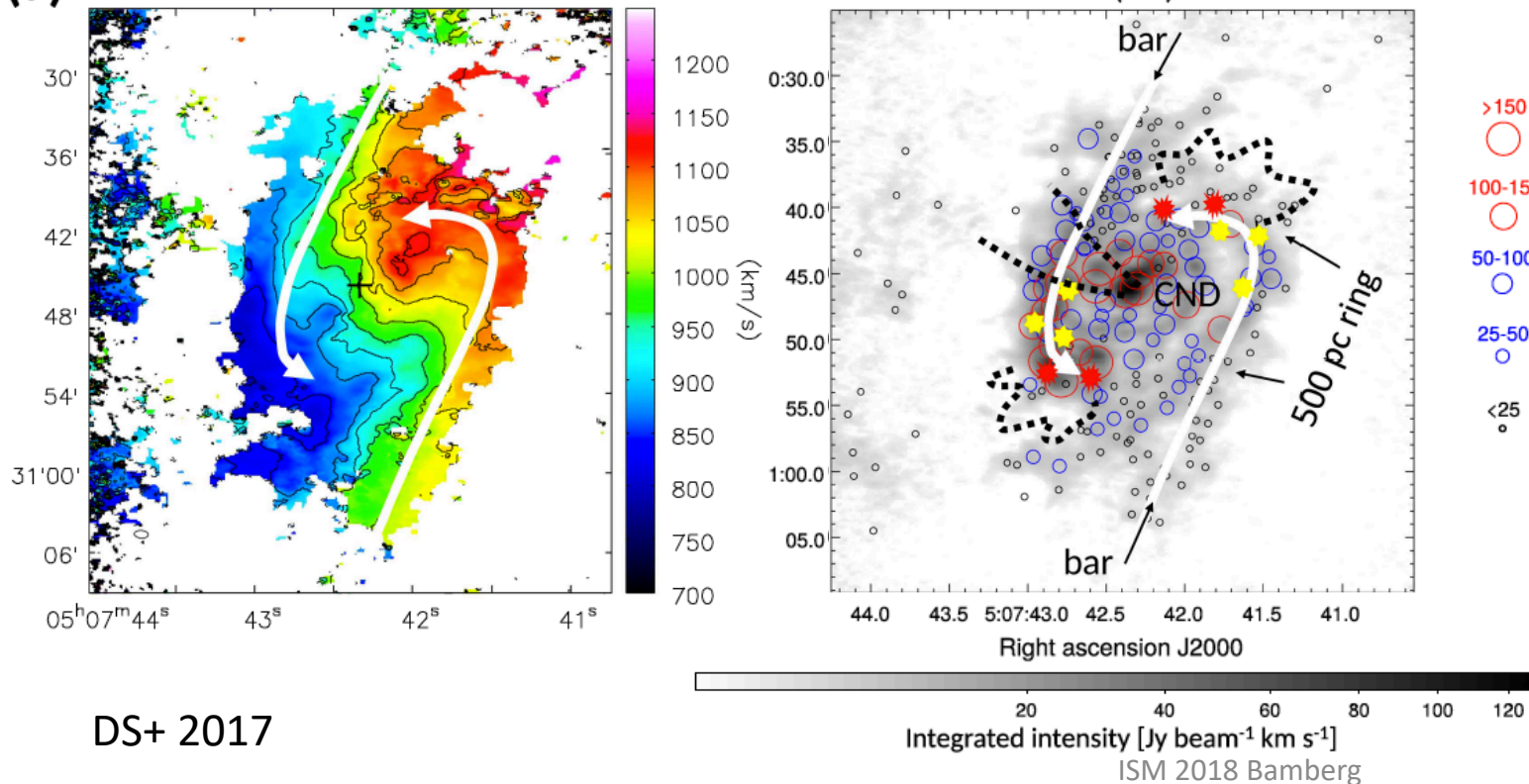


# Molecular medium evolution

- Cloud identification conducted using CLUMPFIND (Williams+ 1994) on CO (3-2) data
- CO (3-2) luminosity of clouds increases with inflow from bar to 500 pc ring

(a)

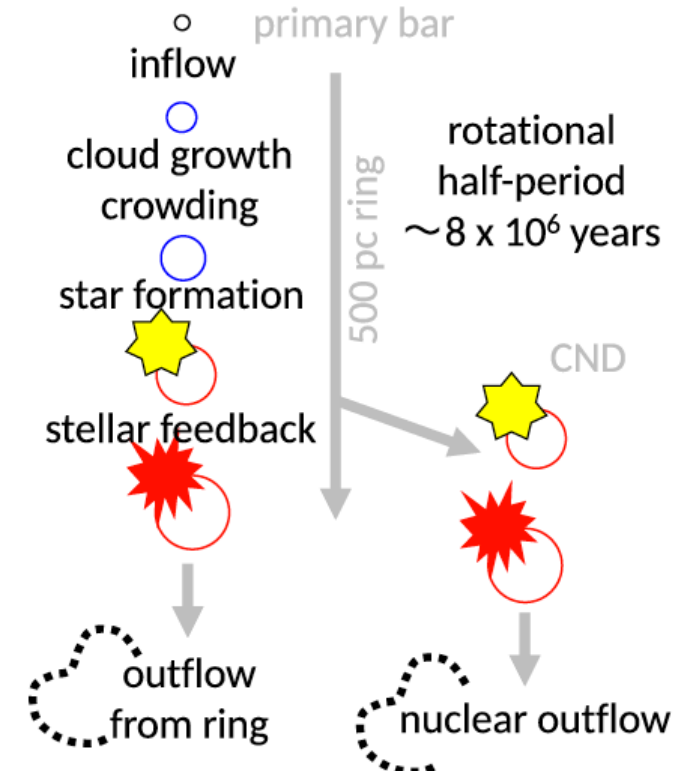
CO (3-2) velocity field





# Conclusions

- First high-resolution CO (J=1-0 and J=3-2) images of the starburst galaxy NGC 1808
- Revealed inflows and outflows of molecular gas: dusty filaments and shells from the nucleus and 500 pc ring
- Mass outflow rate comparable to SFR
- Velocity gradient +0.4 km/s/pc on minor axis: possible outflow acceleration (as in NGC 253)
- Most of the gas unlikely to escape to intergalactic space
- Inflowing gas supplies fuel for star formation, which triggers molecular winds



DS+ 2017