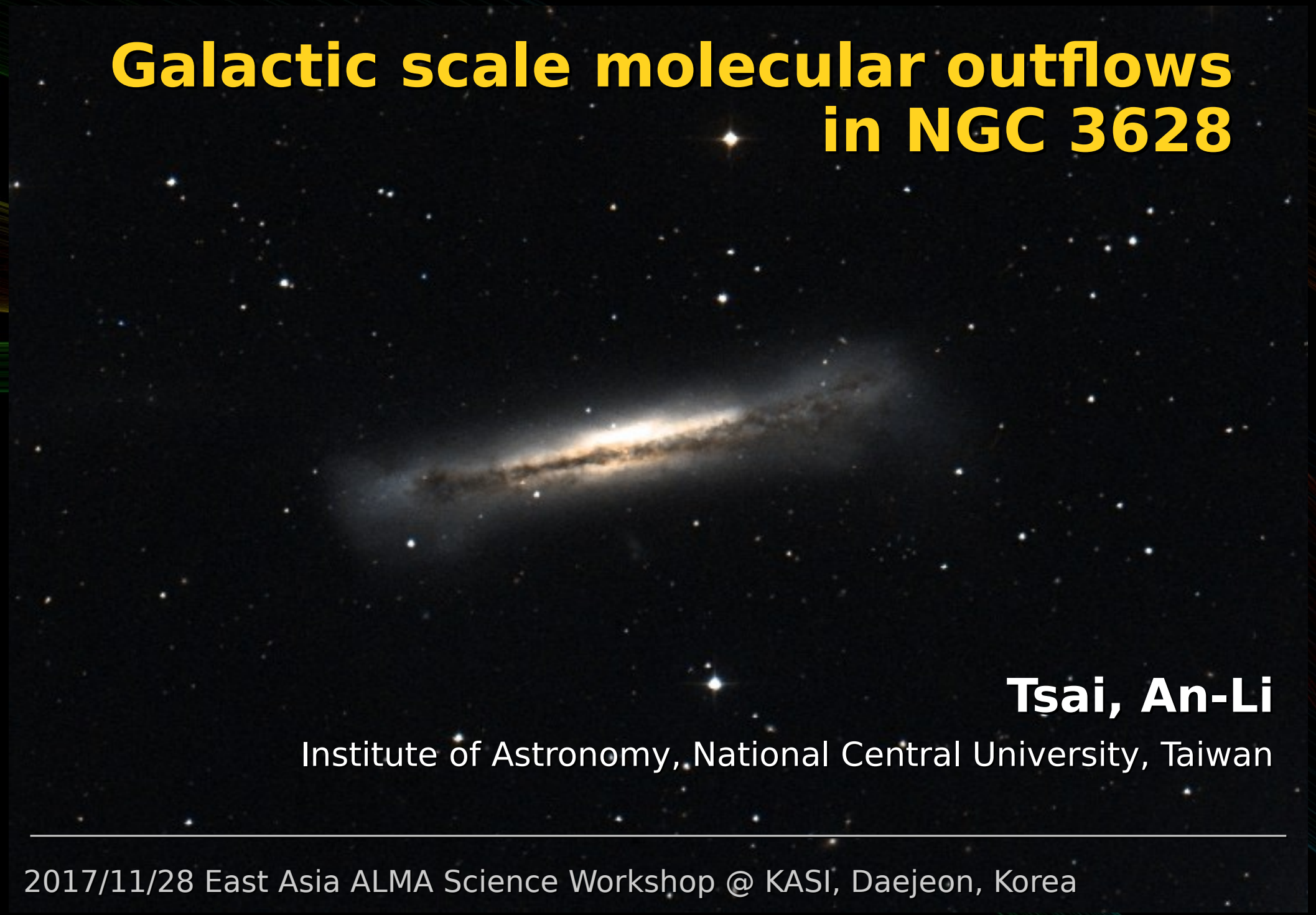
Galactic scale molecular outflows in NGC 3628



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2017/11/28 East Asia ALMA Science Workshop @ KASI, Daejeon, Korea

Gas/Dust studies on extra-galactic sources

- Many extra-galactic sources
- Individual extra-galactic source
  - Distant extra-galactic source
    - LAE @ z=7.15 – [OIII] [CII] - Takuya Hashimoto
    - LAB18 @ z=3.1 – CO(4-3) 860μm 3mm - Yuta Kato
    - SDP.9 @ z=1.6 – ? - Ishida Tsuyoshi
  - Nearby galaxies
    - NGC 1614 (65 Mpc) – 12/13CO(3-2) - Misaki Ando
    - NGC 1097 (20 Mpc) – CO(3-2) 860μm - Takuma Izumi
    - NGC 1052 (20 Mpc) – ? - Seiji Kameno
    - NGC 3628 (7.7 Mpc) – CO(1-0) CO(2-1)
    - NGC 253 (3.5 Mpc)
    - M82 (3.5 Mpc)

Molecular gas vs. Galaxies evolution

Star forming galaxies

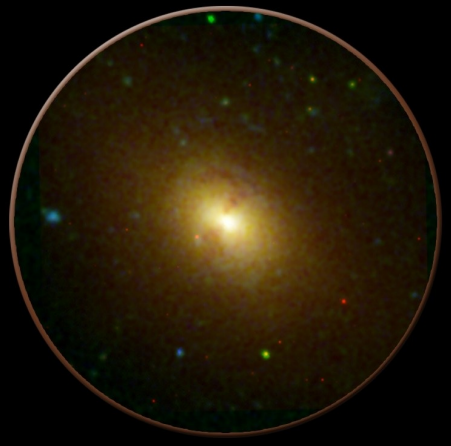
passive galaxies

NGC 300

GALEX Galaxy Evolution Explorer NUV FUV

Forming too many stars?

Gas loss through outflow?



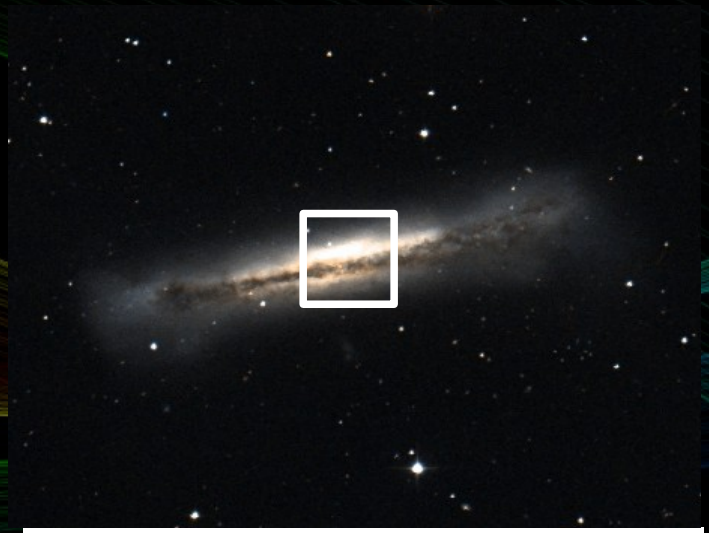
NGC 1316

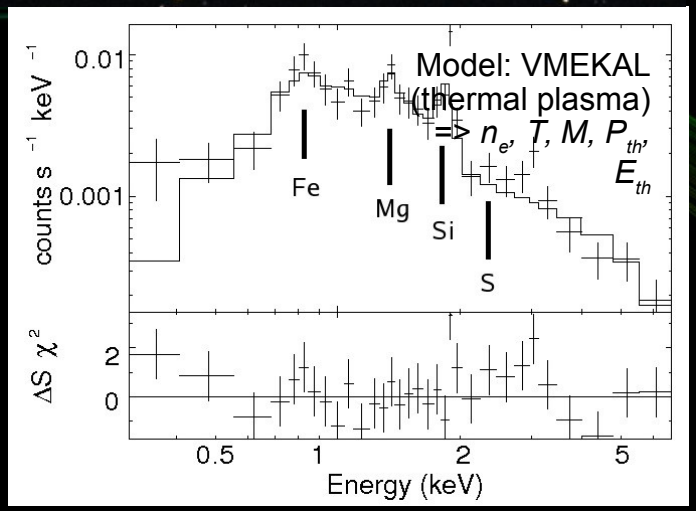
GALEX Galaxy Evolution Explorer NUV FUV

Mass loss, such as outflows, are commonly detected in local starburst galaxies.

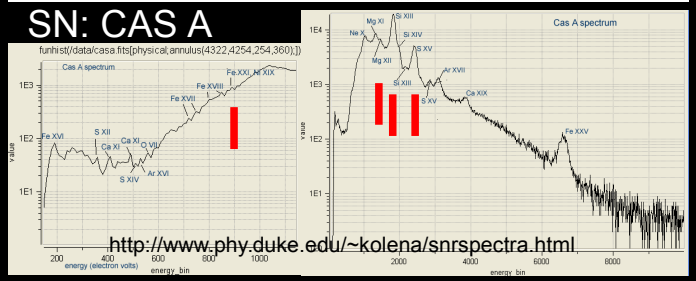
Starburst galaxies are good candidates to study galaxies evolution.

Case study: Starburst galaxy NGC 3628



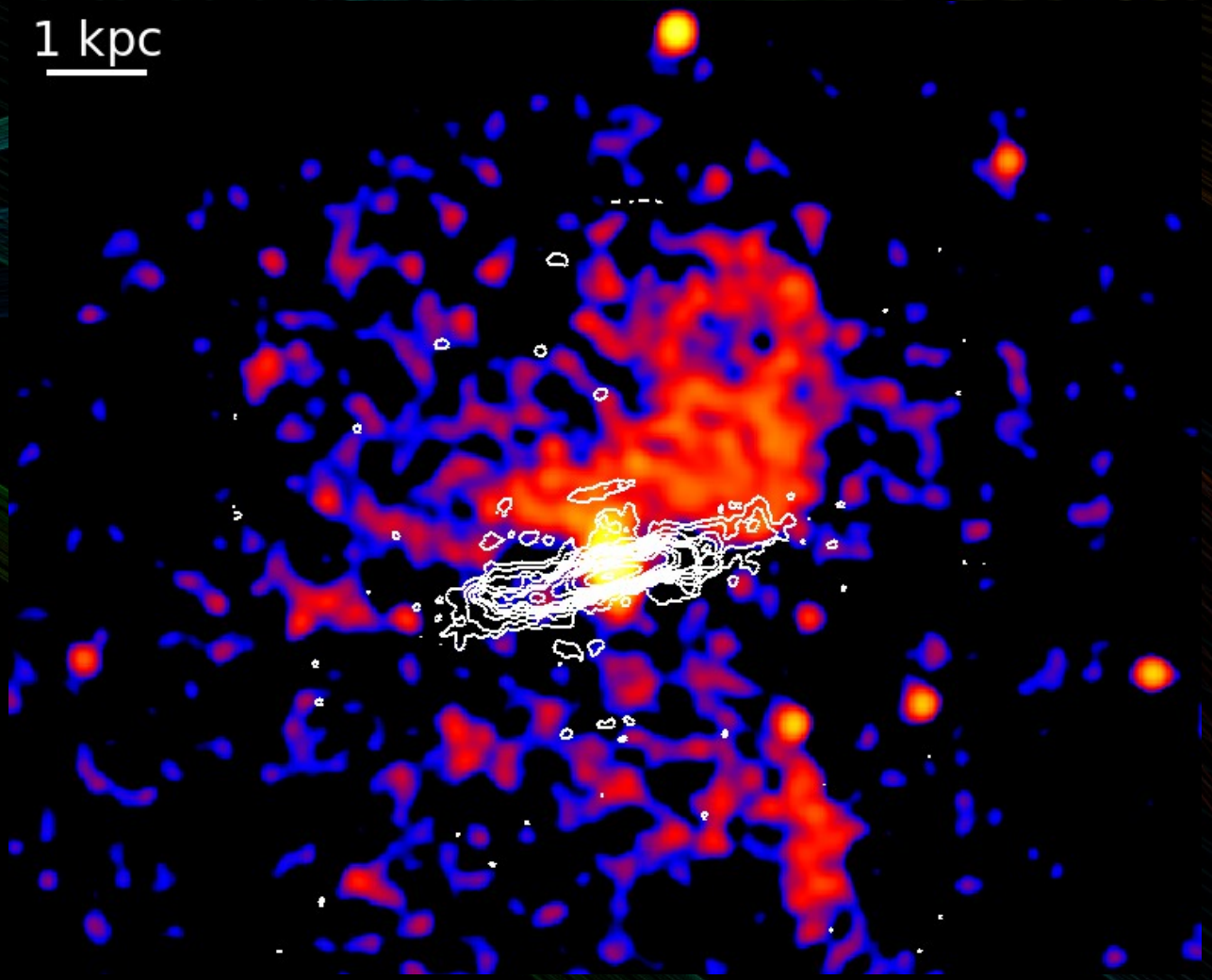


SN: CAS A



D=7.7 Mpc (1" ~37pc) ; $L_{IR}=10^{10.25}$ L_{sun}

1 kpc

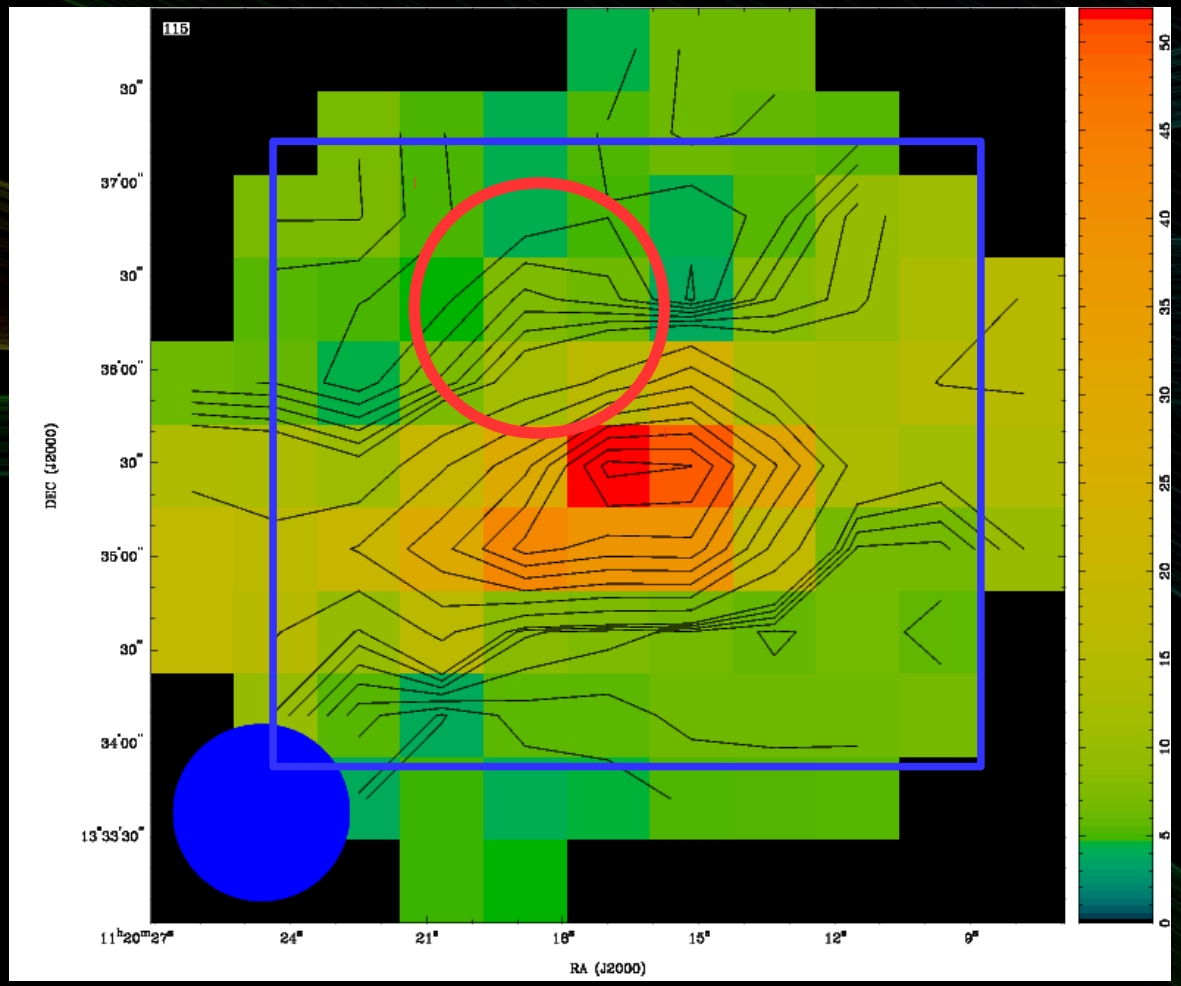


White contour: Our NMA CO(1-0) (Tsai, et al. 2012)
Color: CXO soft X-ray (Strickland et al. 2000)

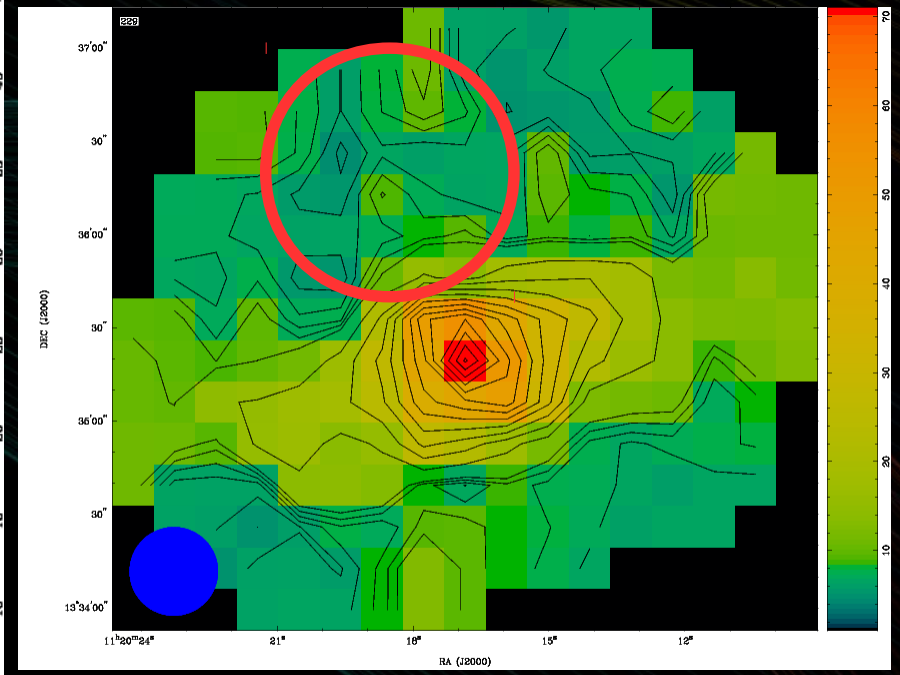
Observations

- ALMA CO(1-0) Band 3 115GHz interferometry
  - Mosaic field: 102''x66'' ; spatial resolution = 3''
  - Observed in 2016, 2017
  - 1.3 hours 12m + 5.2 hours ACA
  - 2 mJy/beam for $\Delta v = 20$km/s
- ARO 12m CO(1-0) 115GHz single dish
  - Mapping field: ~150”x120” ; beam size = 53''
  - Observed in 2016, 2017
  - 25 hours
  - ~3mK for Δv = 20km/s
- ARO SMT CO(2-1) 230GHz single dish
  - Mapping field: ~120”x90” ; beam size = 26''
  - Observed in 2016, 2017
  - 35 hours
  - ~3mK for Δv = 20km/s

Single Dish Mapping

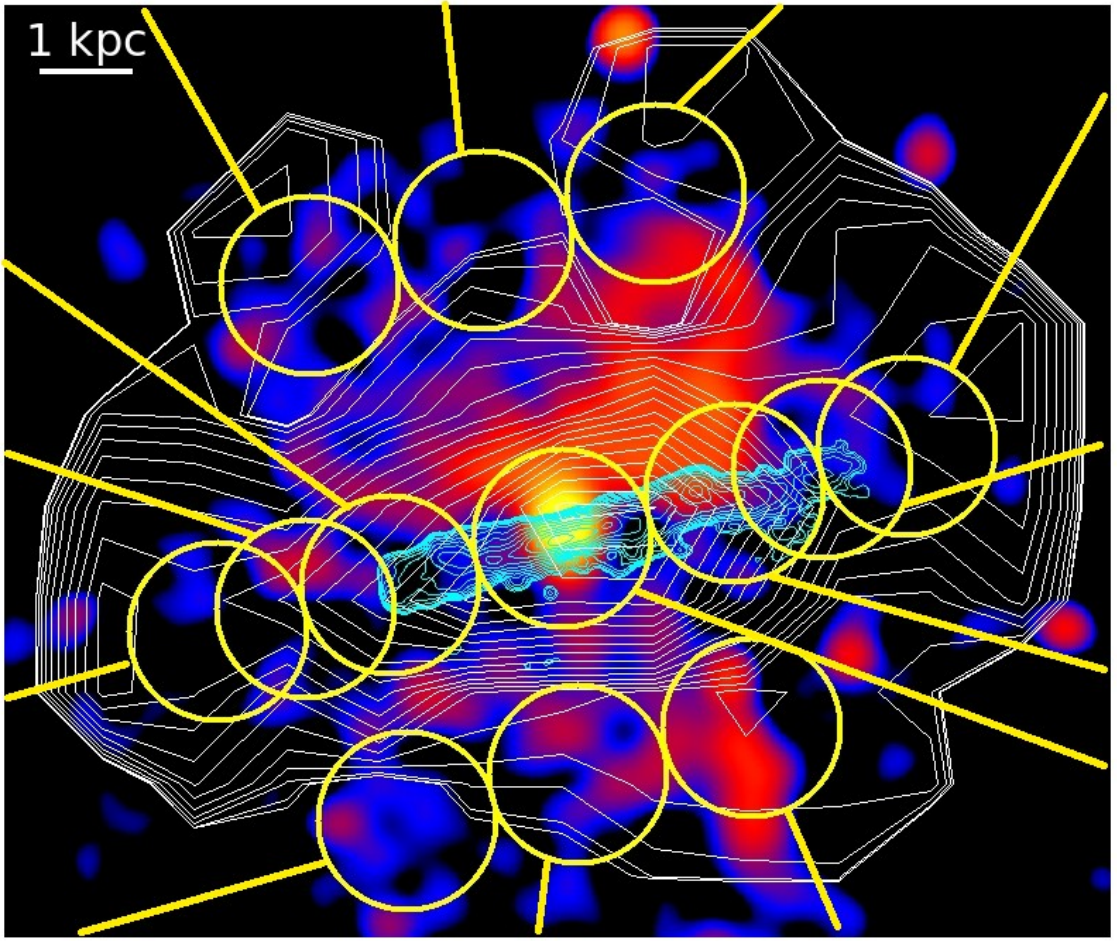


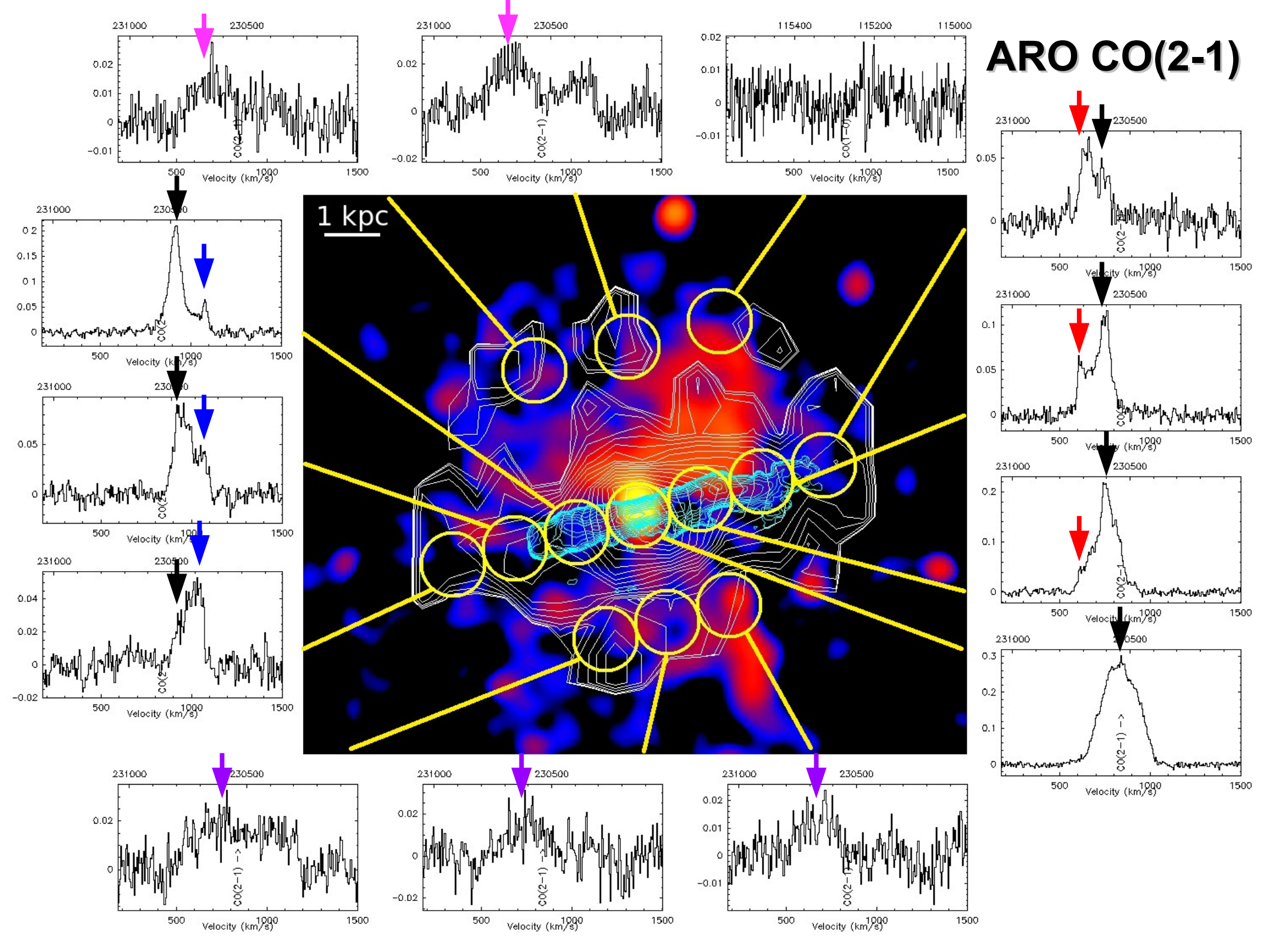
ARO 12m CO(1-0)

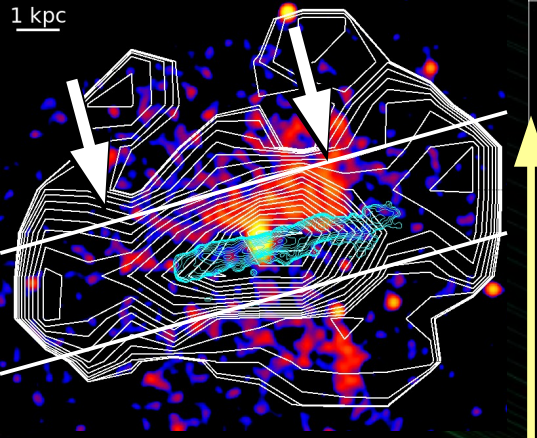


ARO SMT CO(2-1)

ARO CO(1-0)

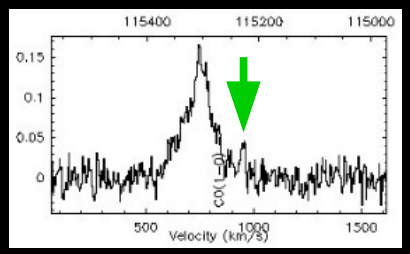


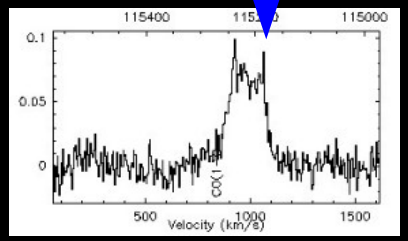

ARO CO(2-1)
1 kpc
231000
230500
115400
115200
115000
Velocity (km/s)
500
1000
1500
CO(2-1)
CO(1-0)



ARO CO(1-0) Disk

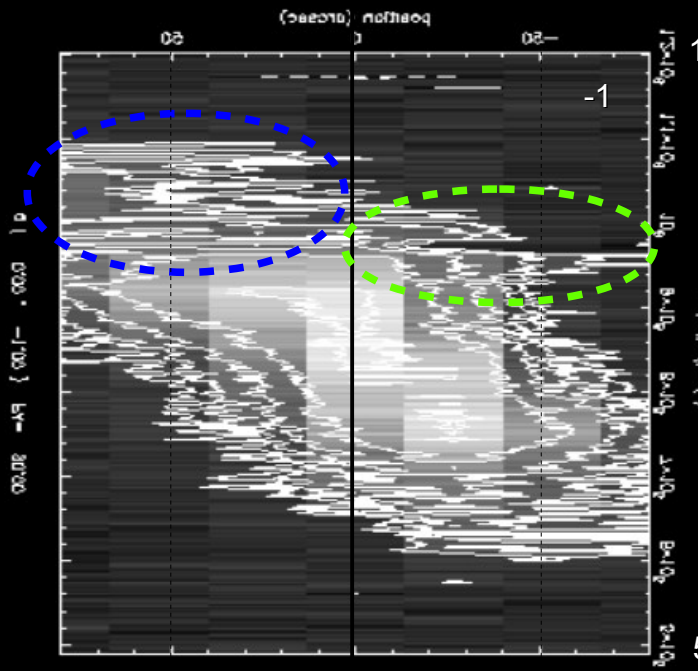
Δv=+200 km/s

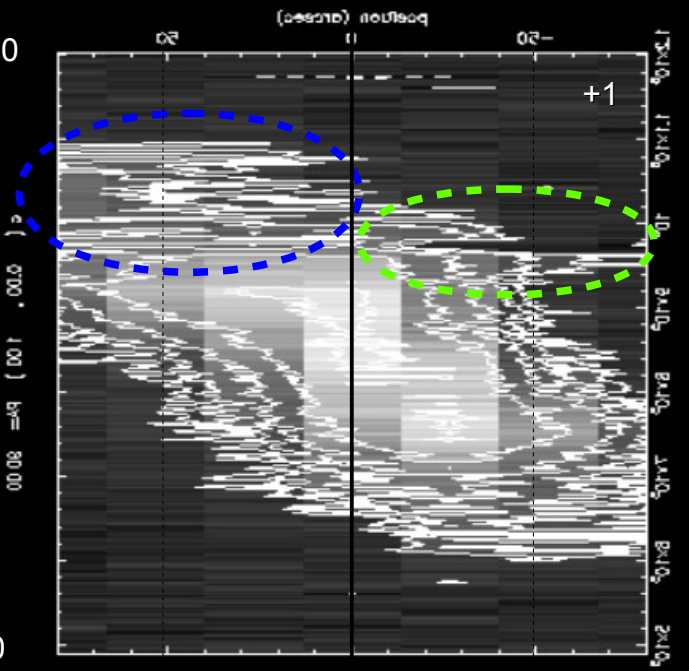


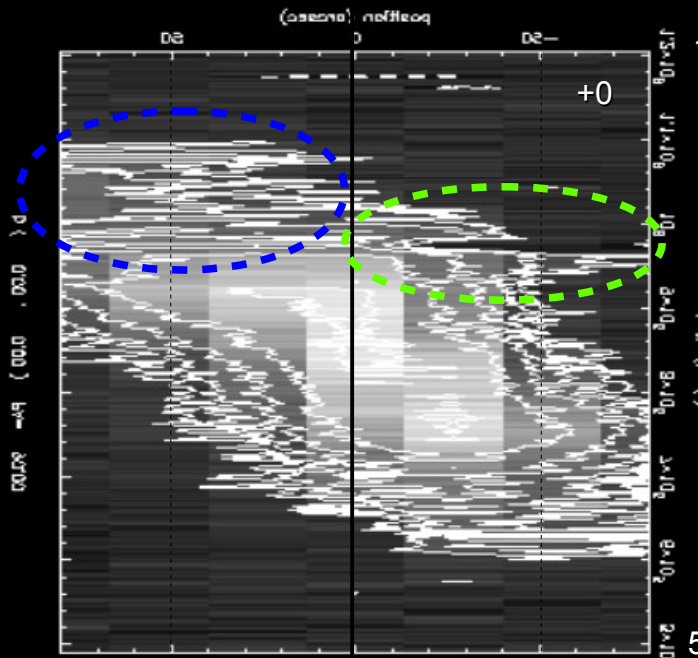


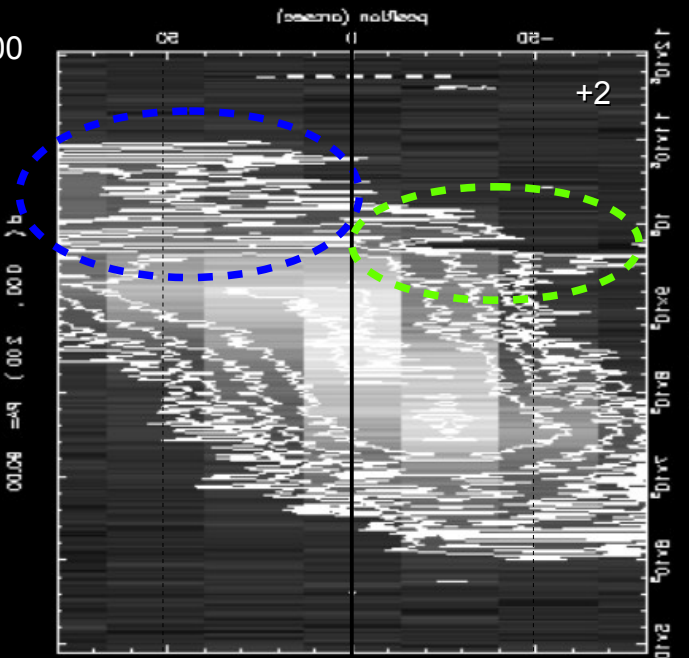
Δv=+150 km/s

Velocity

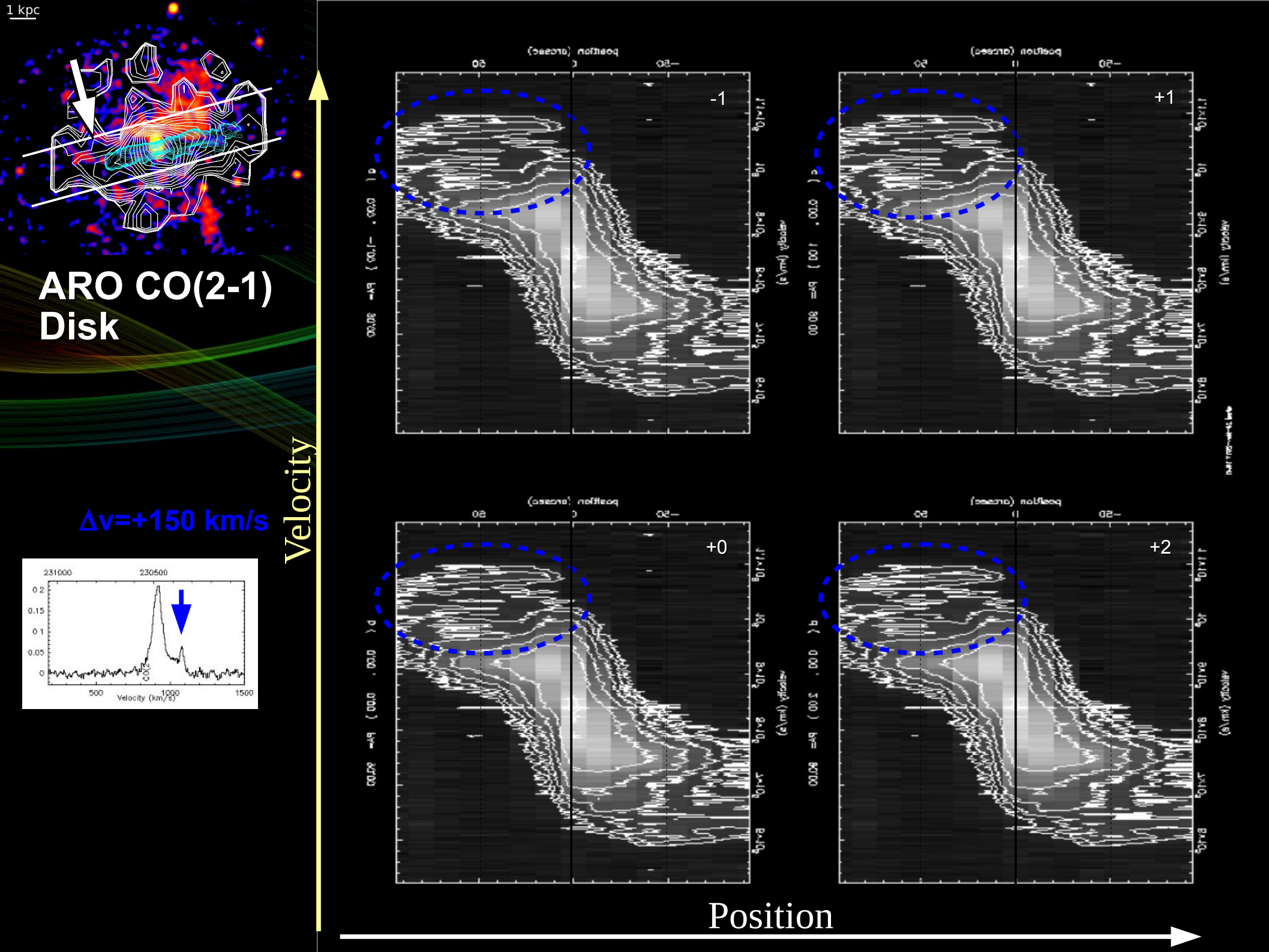




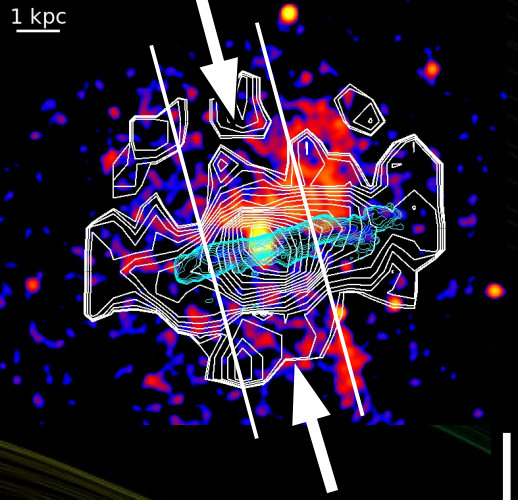




Position

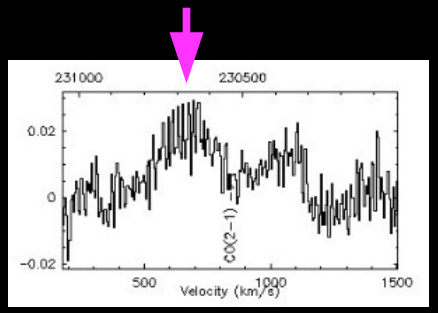

1 kpc
ARO CO(2-1)
Disk
Δv=+150 km/s
231000
230500
Velocity (km/s)
Velocity
-1
+1
+0
+2
Position

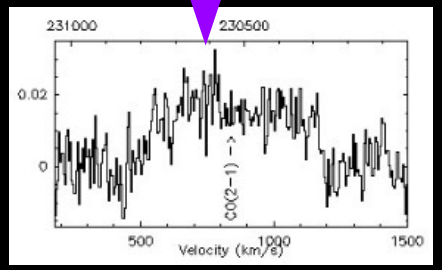
ARO CO(2-1) Outflows

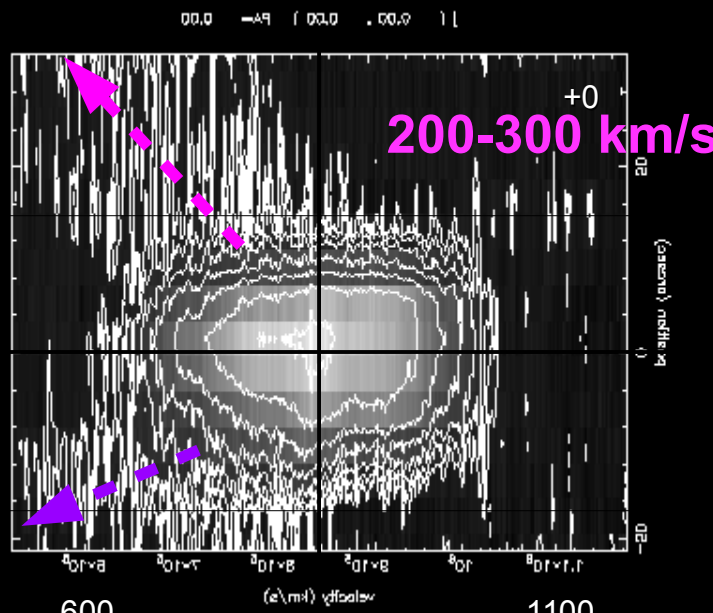


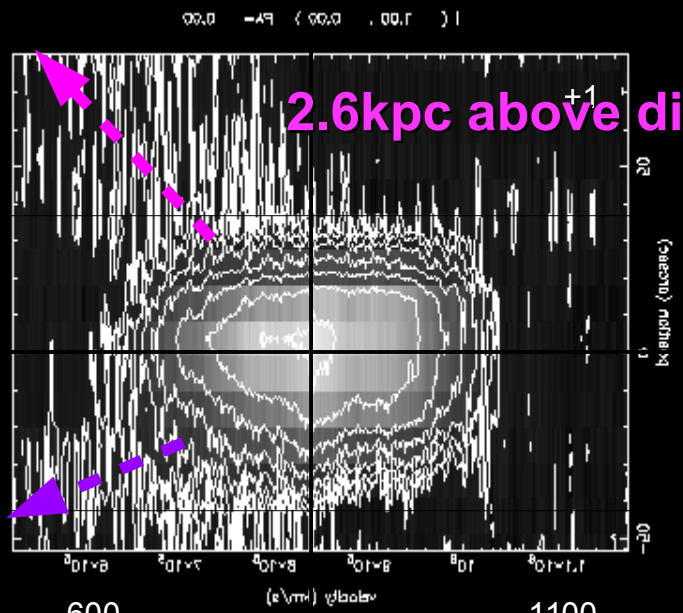
Velocity

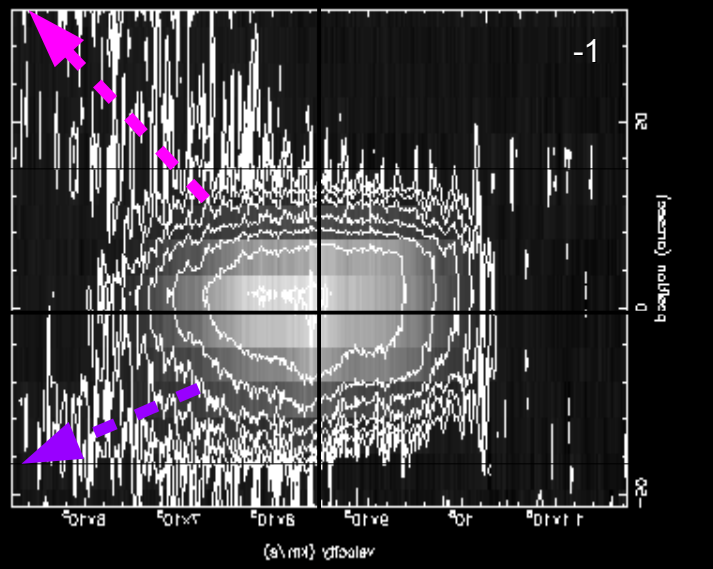
Position

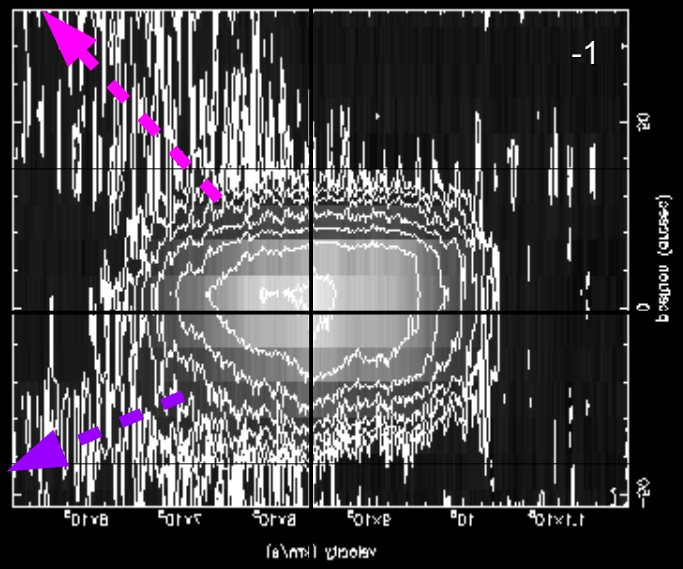


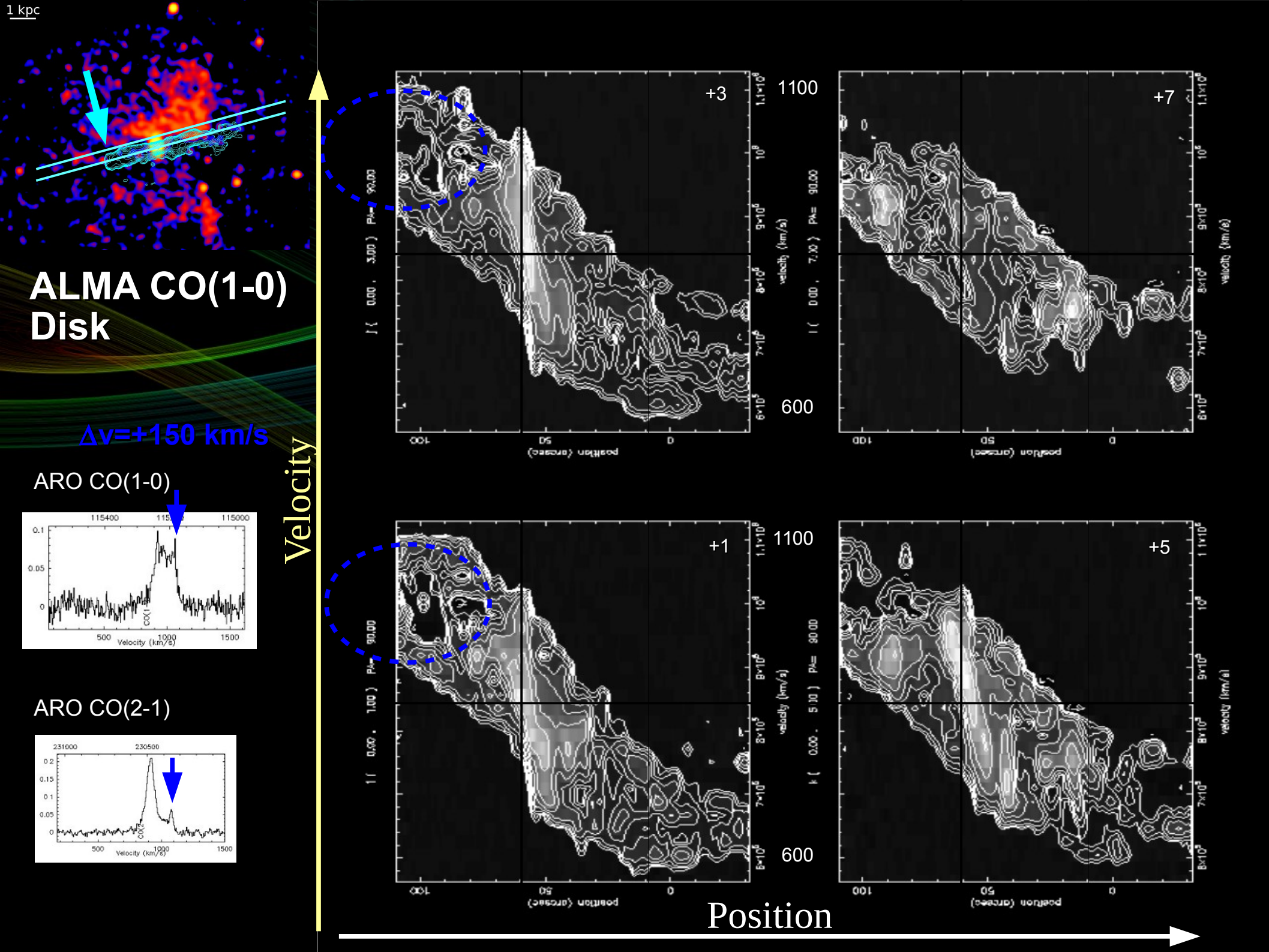


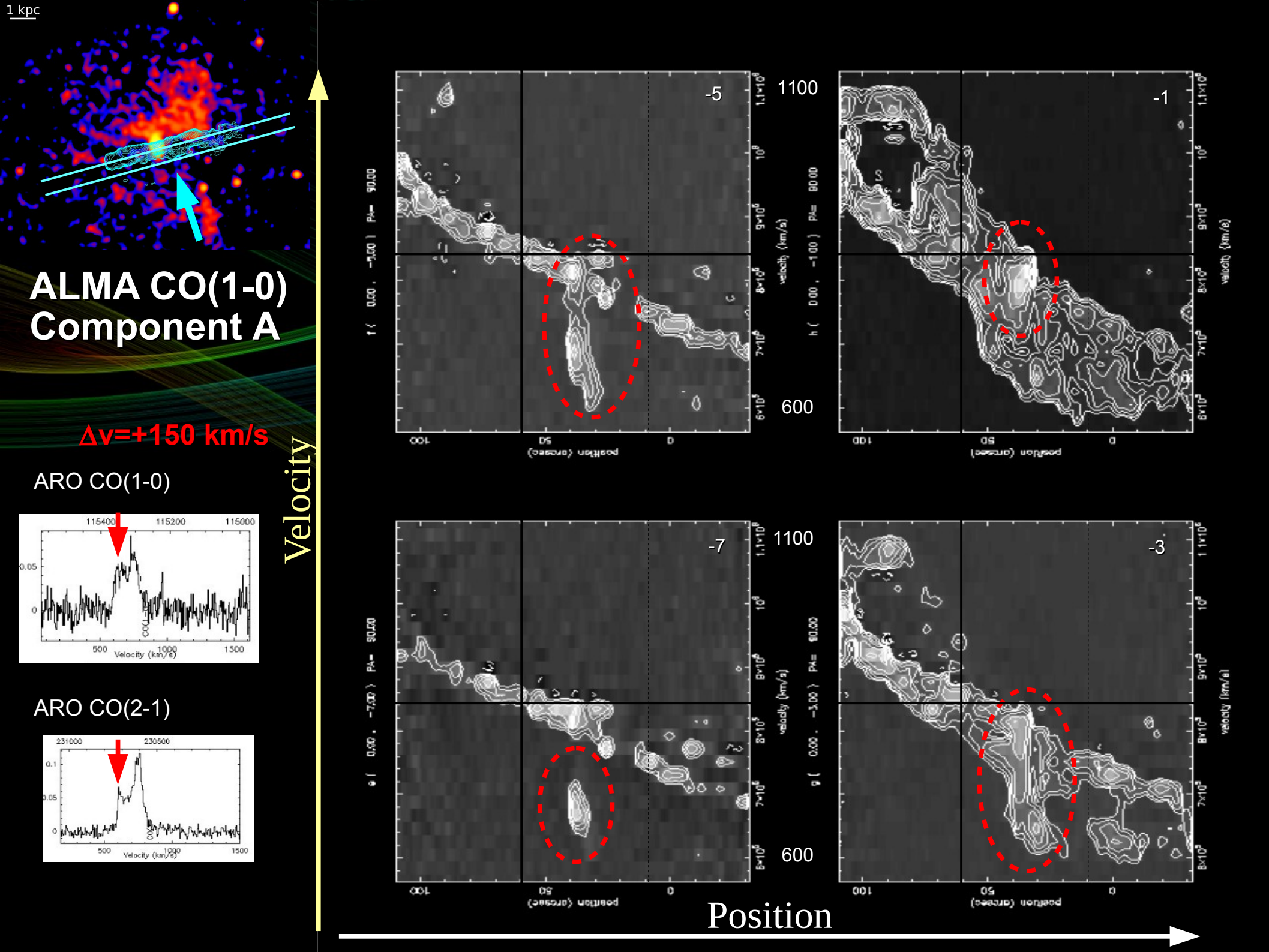


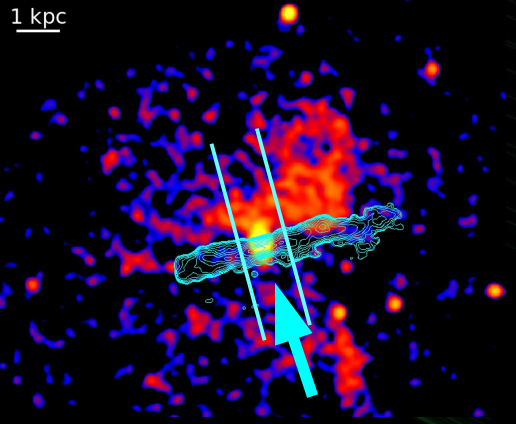







1 kpc
ALMA CO(1-0)
Disk
Δv=+150 km/s
ARO CO(1-0)
ARO CO(2-1)
Velocity
Position
+3
+7
+1
+5
1100
600
1100
600


1 kpc
ALMA CO(1-0)
Component A
Δv=+150 km/s
ARO CO(1-0)
ARO CO(2-1)
Velocity
Position
-5
-1
-7
-3
1100
600



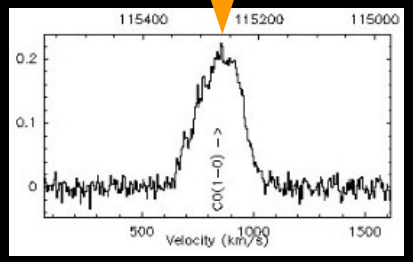
ALMR CO(1-0) Component B

Velocity

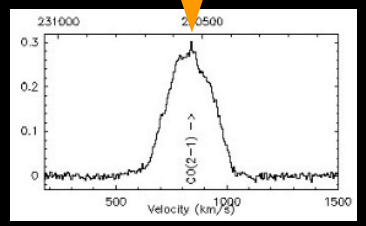
Position

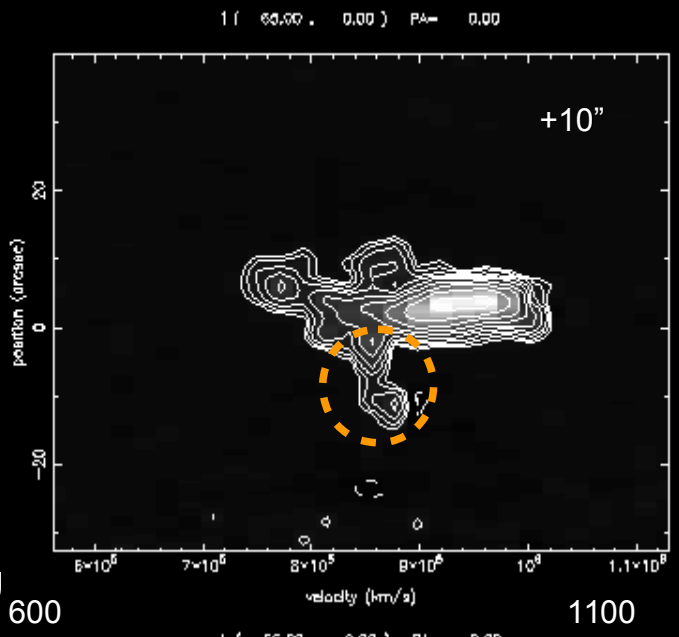
Δv=+0 km/s

ARO CO(1-0)

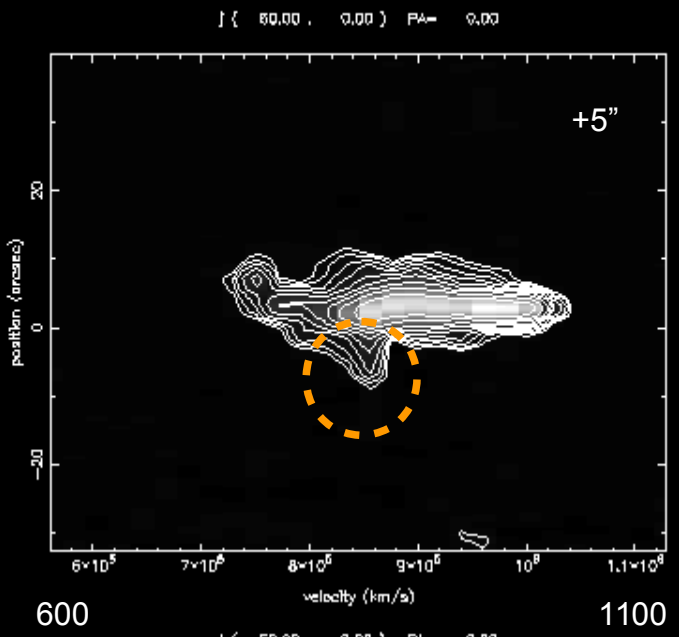


ARO CO(2-1)

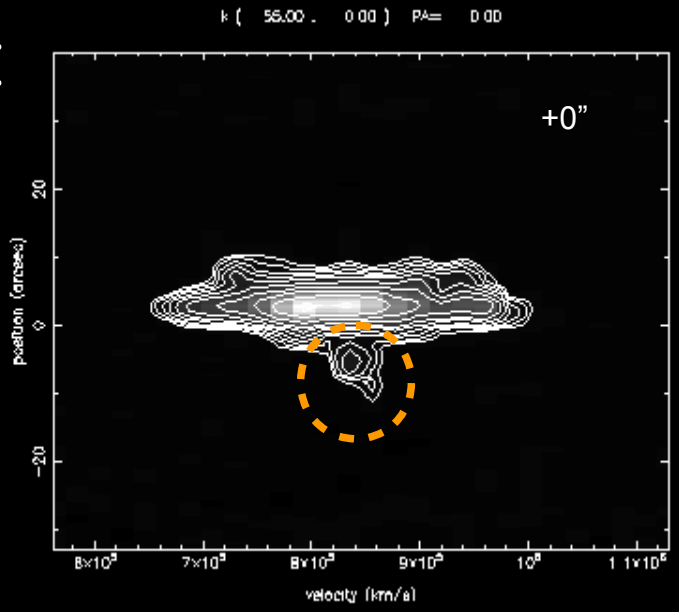


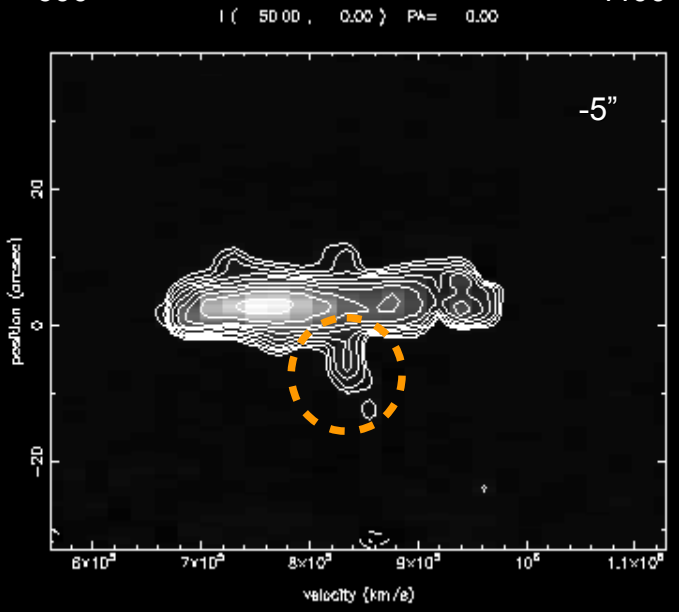


600 1100



600 1100





NGC 3628 is a……

- Nearby starburst galaxy : D=7.7Mpc
- Large scale bipolar outflows (detected by ARO)
  - >2.6 kpc above molecular disk
  - Outflow velocity : 0 – 300 km/s
- Multiple components in disk (detected by ARO and ALMA)
  - Velocity difference to the disk : 0 – 200 km/s
  - Remnants from merging?
- The advantage of using ALMA
  - A nearby starburst sample to study merging system?