Gas and Star Formation in the Circinus Galaxy

Bi-Qing For

PhD student

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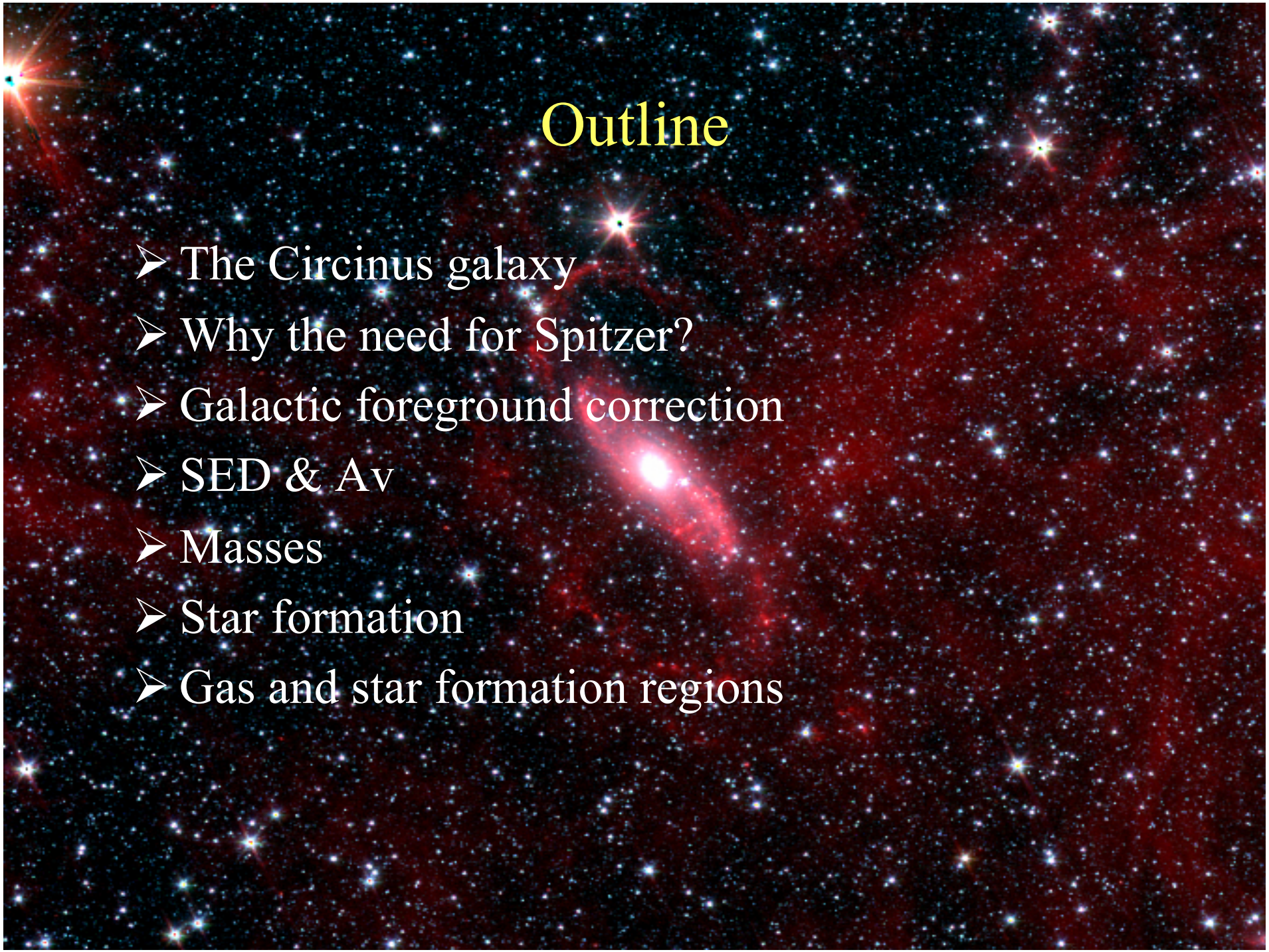

Outline
The Circinus galaxy
Why the need for Spitzer?
Galactic foreground correction
SED & Av
Masses
Star formation
Gas and star formation regions

Circinus

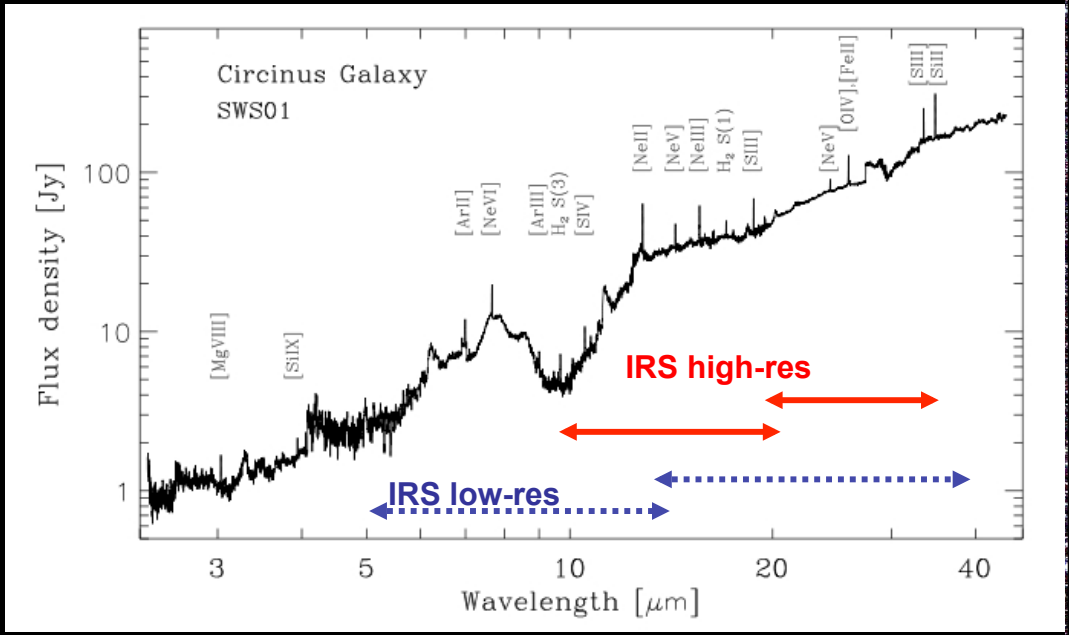
- Nearby Sb-Sd type spiral galaxy, 4.2 Mpc, ~17’ Holmberg diameter of stellar disk (Freeman et al. 1977)
- It lies near to the Galactic plane (b = -4^{o})

2MASS JHK composite image (~24’ x 24’)

(Jarrett et al. 2003)

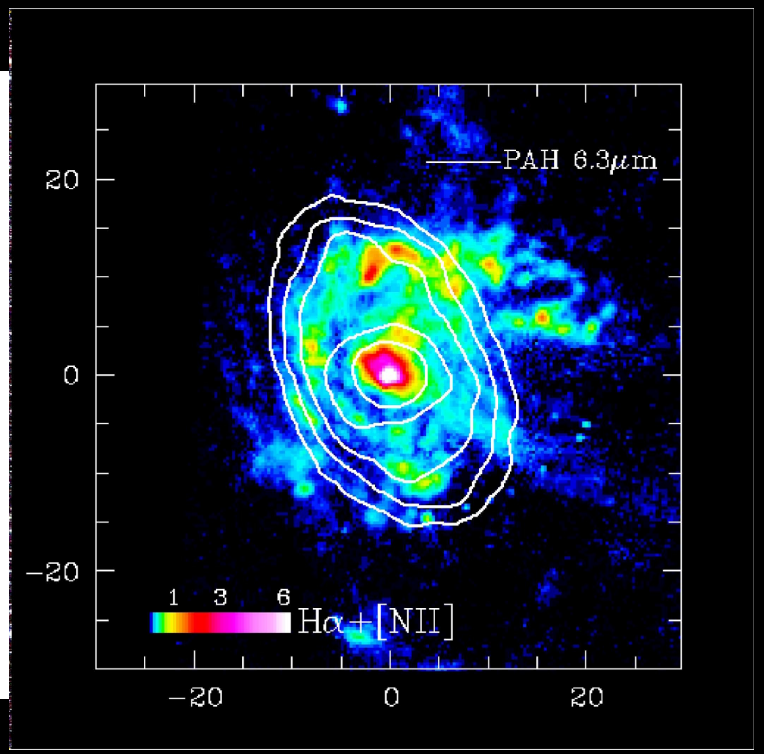
Circinus

- Seyfert nucleus
- Circum-nuclear ring (starburst activity)



Moorwood et al. 1996

High-excitation emission

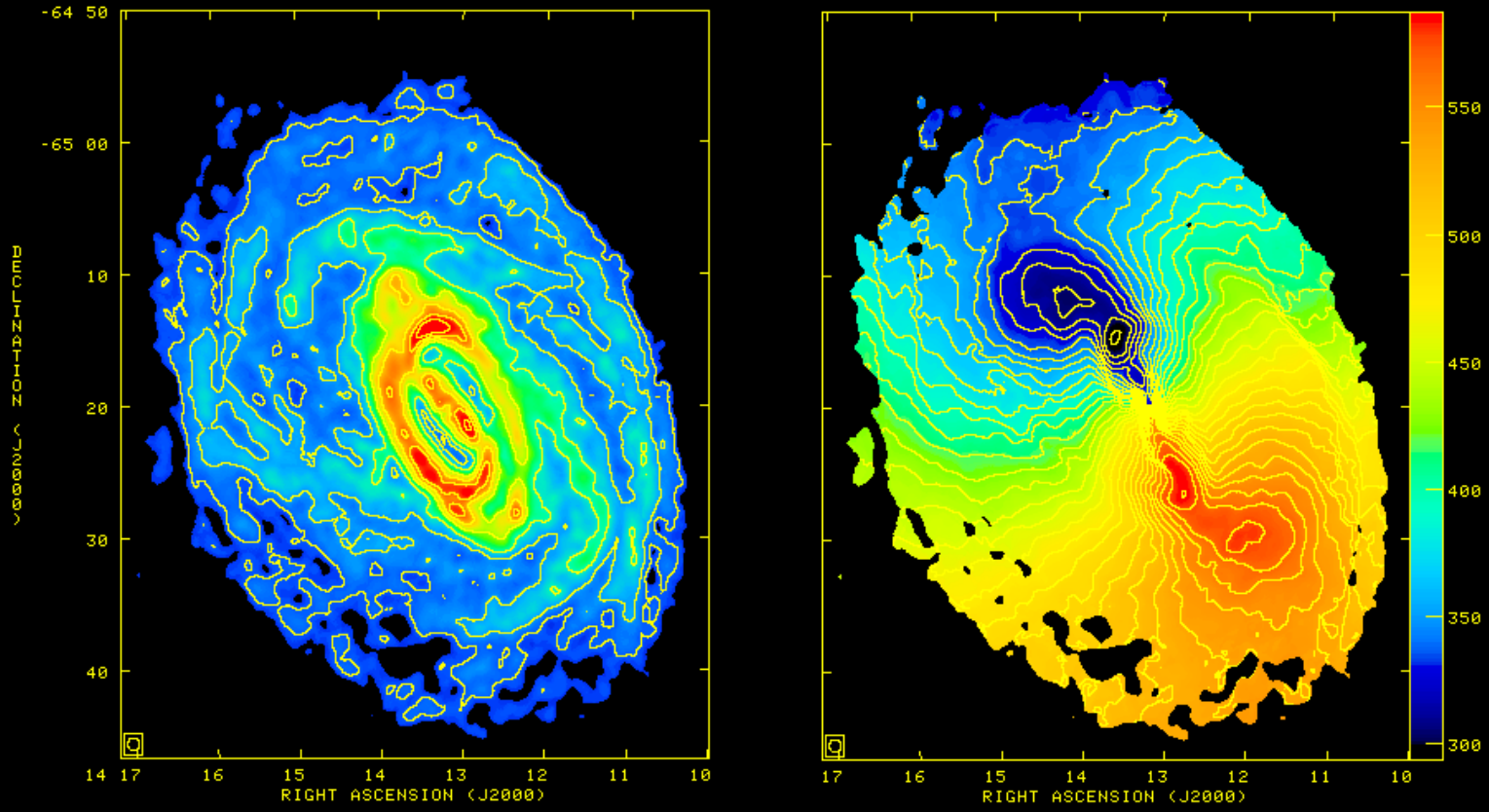


Moorwood 1999

1' central region

Circinus

- Enormous H I envelope (80', ~100 kpc), $M_{HI} = 8 \times 10^9 M_{sun}$
- Warped disk with strong but irregular spiral pattern and inner bar



Large-scale HI distribution and mean velocity field of the Circinus galaxy taken with various arrays of the ATCA (Jones et al. 1999). (80' x 60')

Why Spitzer?

- Optical: obscured by foreground dust
- Limited to nuclear and central regions
  - HST, Chandra, ISO
- IRAS and ISO (lack resolution + sensitivity)
- Spitzer → high resolution + sensitivity MIR imaging
  - IRAC 3.6, 4.5 μm (stellar light)
  - IRAC 5.8, 8.0 μm (PAHs → spiral structure)
  - MIPS 24 μm (warm dust)
  - MIPS 70 μm (cold dust)

~0.3 – 0.5 MJy/sr, ~2", 6" and 18" resolution

50'x50'

Challenges….

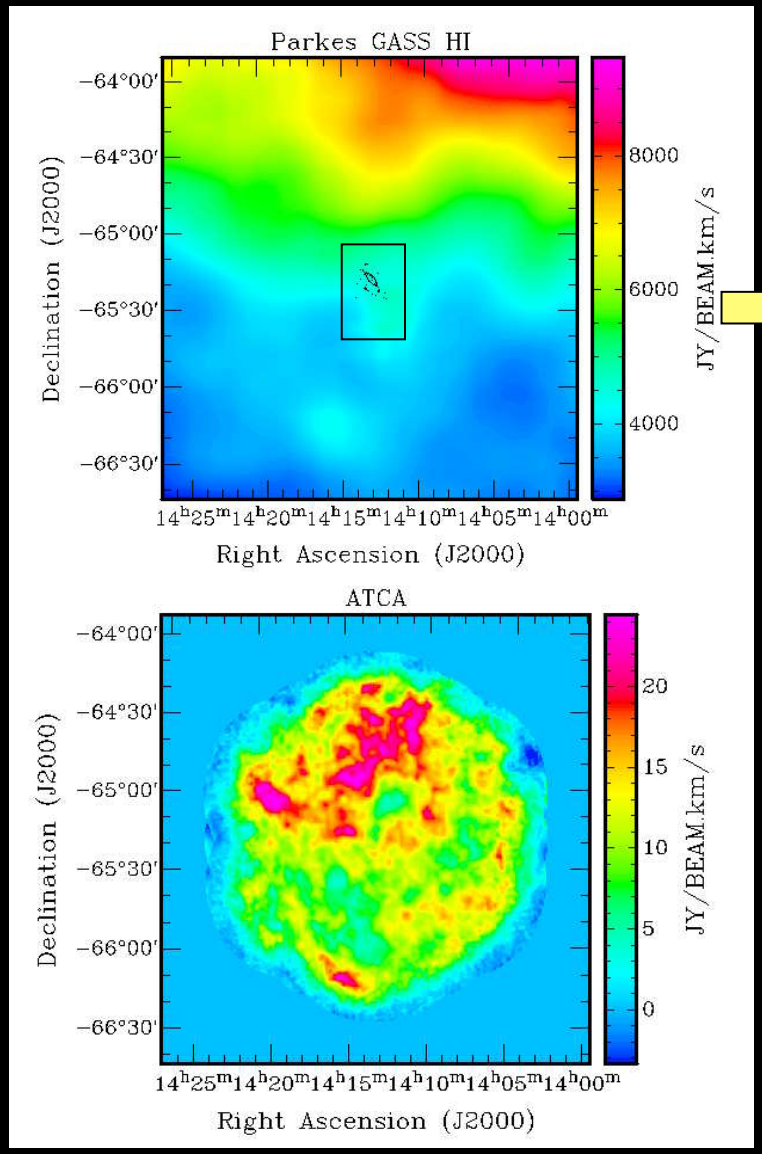
- Removal of foreground stars (pipeline of WISE)
- Removal of Galactic foreground
  - IRAC 5.8 & 8.0 μm ; MIPS 24 μm
  - Correlation analysis (MIR dust emission with 21 cm HI emission)

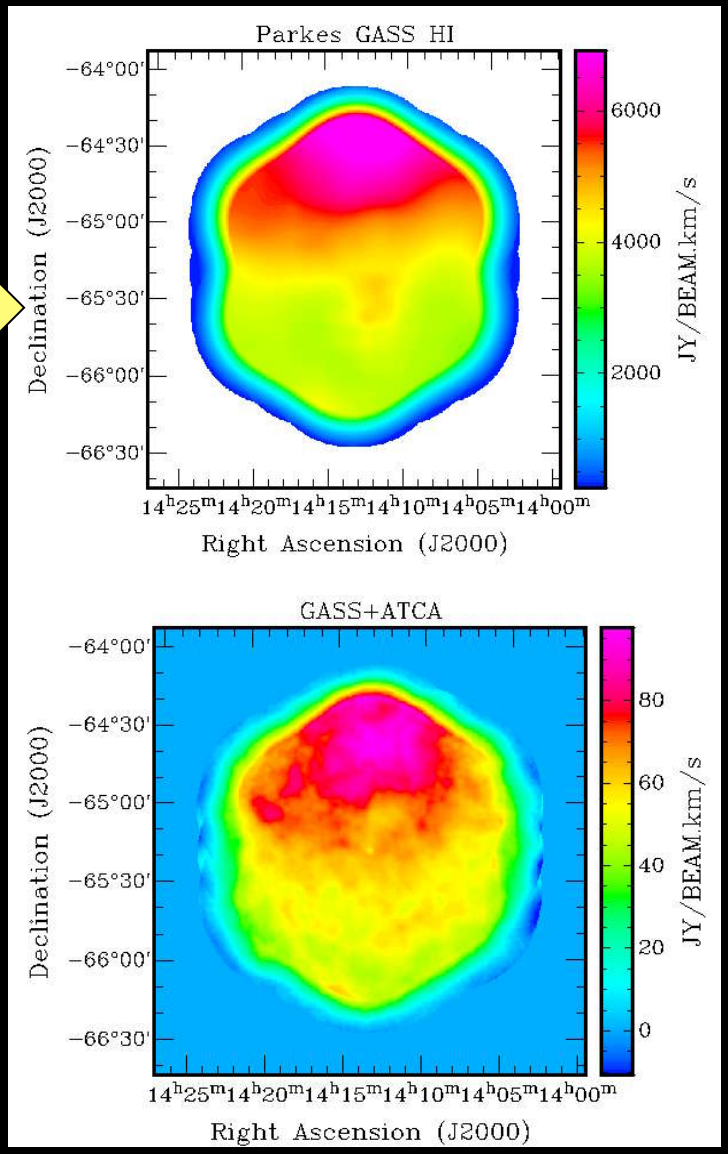
Images credit:
www.atnf.csiro.au

ATCA (interferometer) + Parkes (single dish)

Jones et al. (1999)

Galactic All Sky Survey (GASS)
McClure-Griffiths et al. (2009)





For, Koribalski & Jarrett, in prep

Correlation

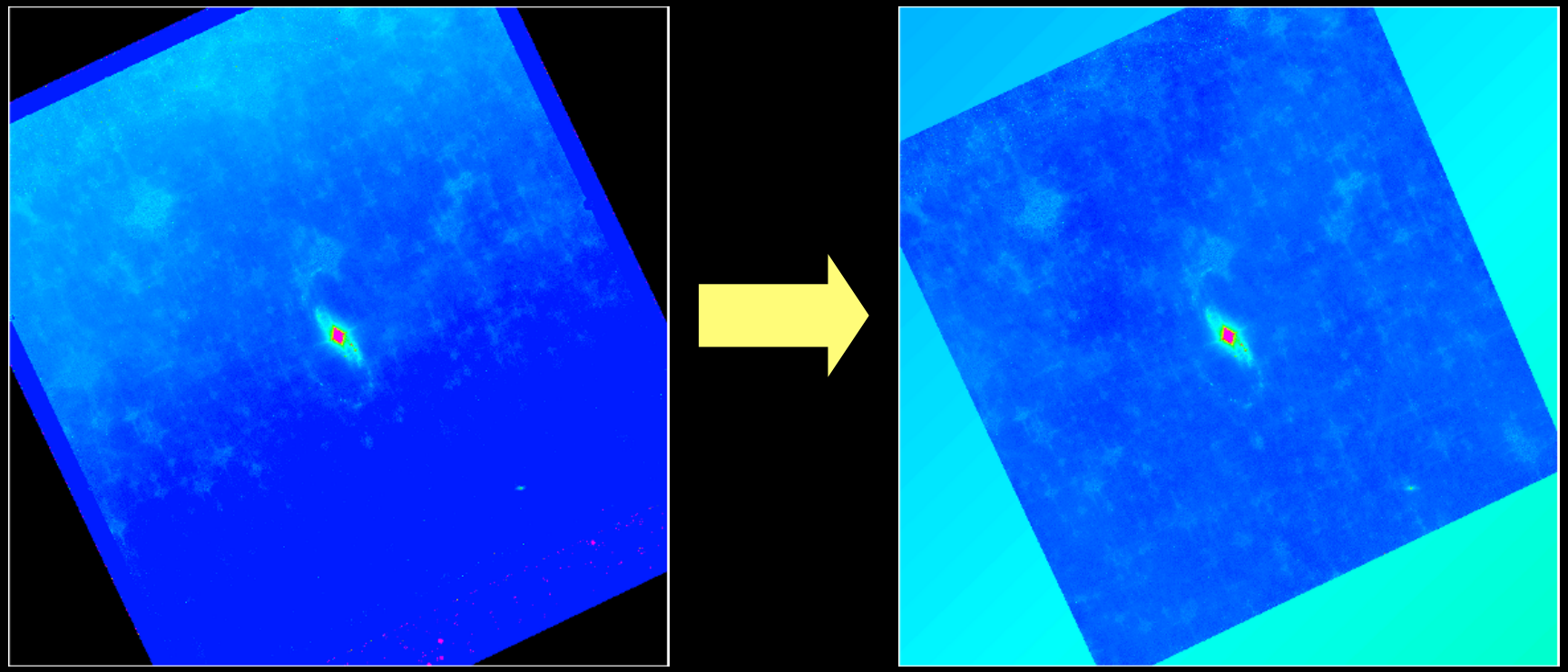
- $I_{spitzer} = a \times I_{HI} \rightarrow a = I_{spitzer} / I_{HI}$

Final image $I_{spitzer} = I_{spitzer} - a \times I_{HI}$

- Residual IR gradient: "first frame effect"
  - Fitting 1st order polynomial to the background

Employed image $I_{spitzer}$ fitted with $g(x,y)$

Significant “first frame effect” : 5.8 μm



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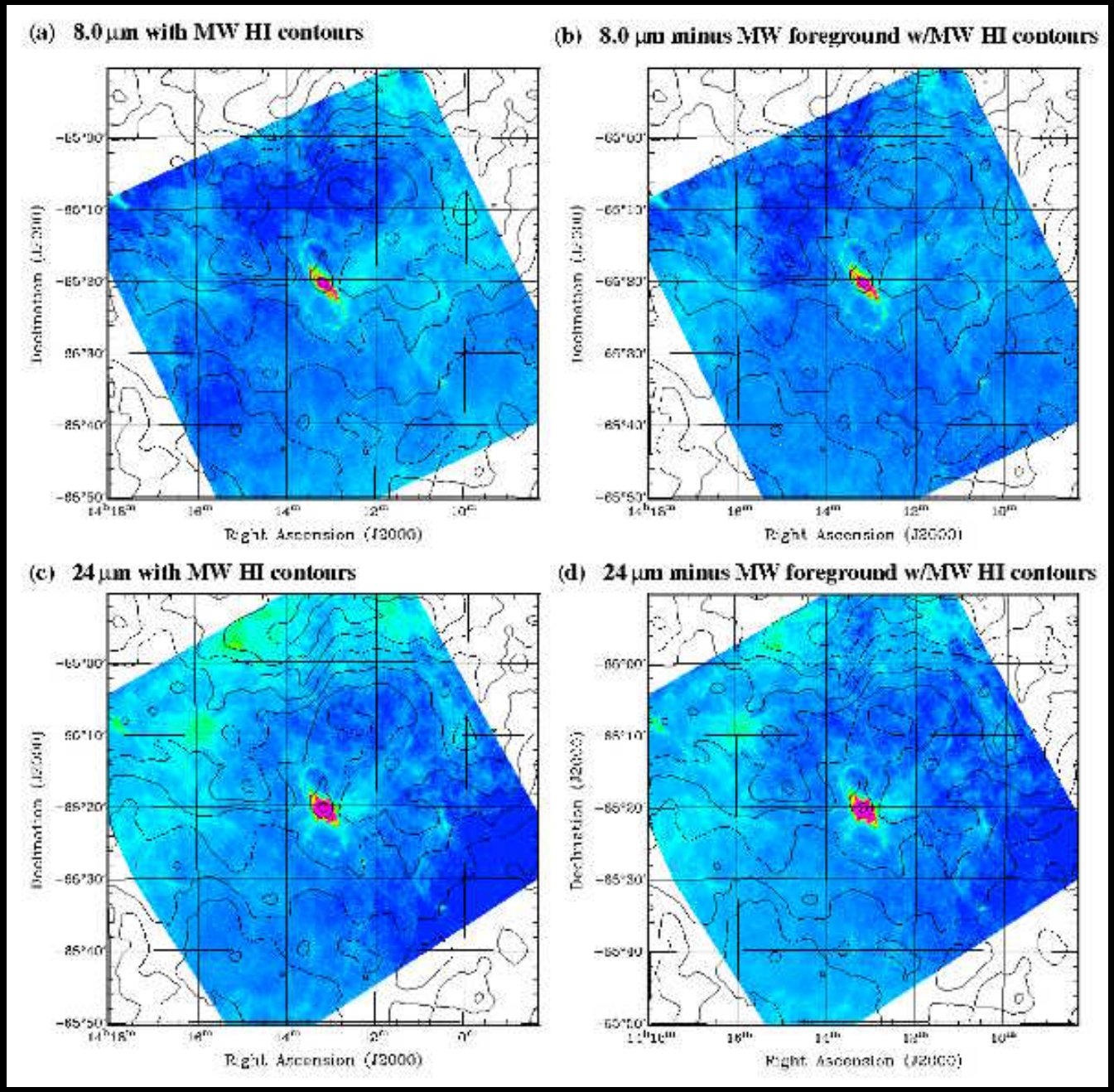

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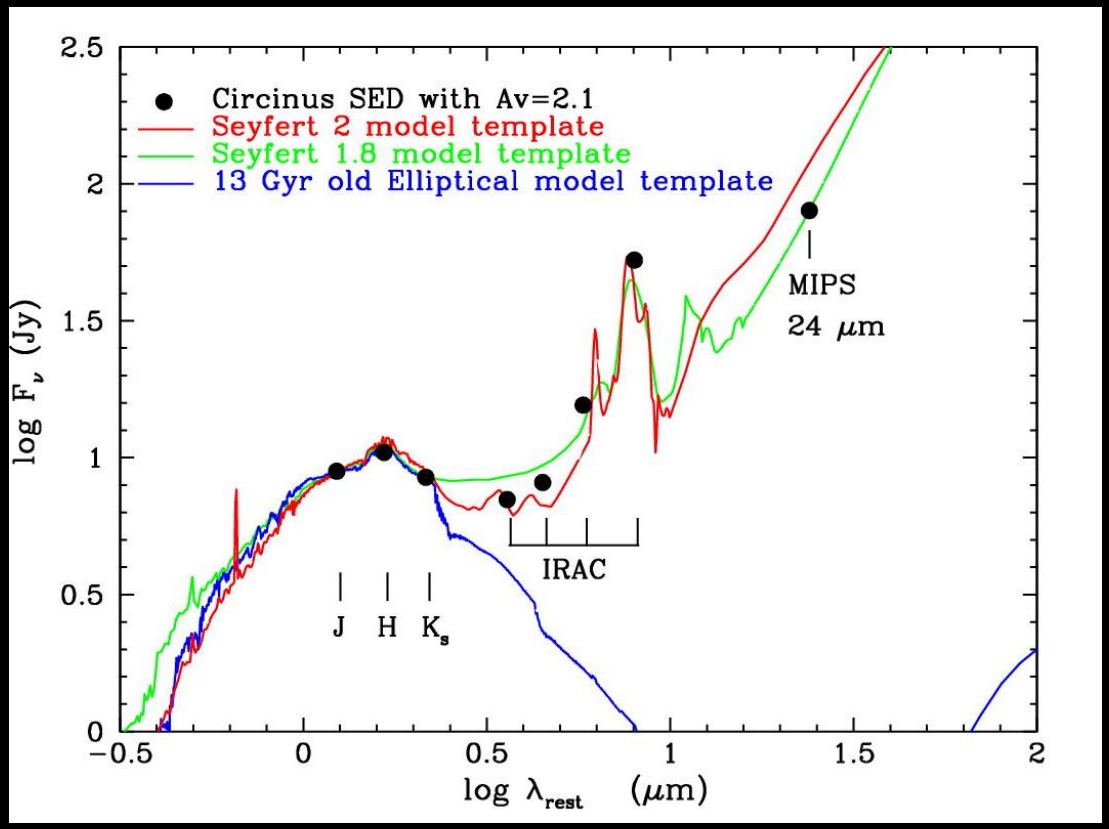
SED & Av

- Common method: all-sky extinction map (Schlegel et al. 1998)
- Uncalibrated for $|b| < 5^{o}$
- Av=4.6 (Schlegel et al. 1998)

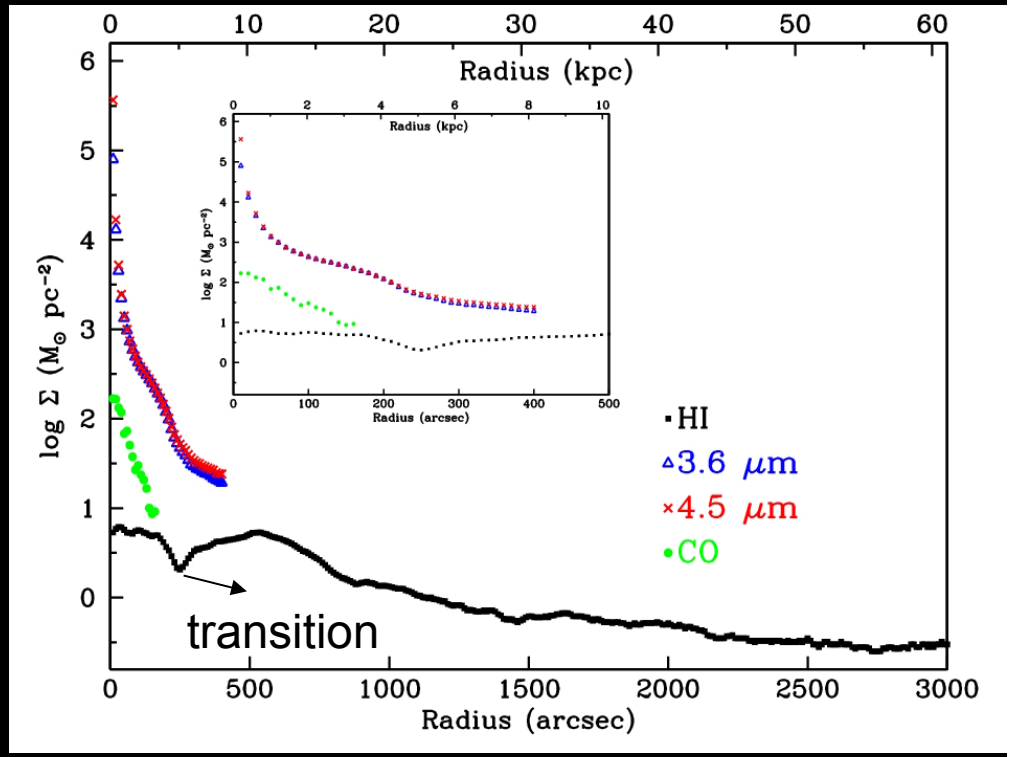


For, Koribalski & Jarrett, in prep

Masses

- Stellar: 3.6 μm & 4.5 μm: 9 x 10^{10} Msun
- Gas:
  - HI (ATCA, single-pointing): 6.6 x 10^{9} Msun
    - Curran et al. (2008): 6 x10^{9} Msun
  - $CO_{1\rightarrow2}$ (Curran et al. 2008) → H_2: 1.1 x 10^{9} Msun
    - Curran et al. (2008): 2 x 10^{9} Msun

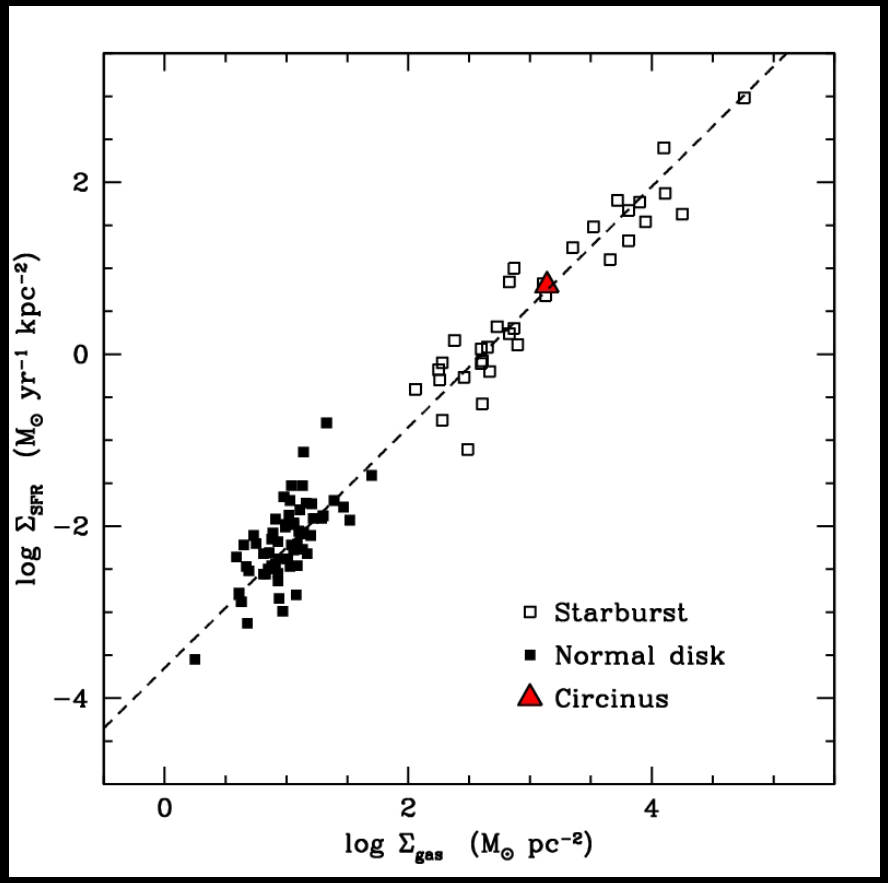
$M_{gas} = M_{HI} + M_{H2} \sim 8 \times 10^{9}$ Msun



For, Koribalski & Jarrett, in prep

Star Formation Rate Surface Density

- Global Kennicutt-Schmidt's Law
  - $\Sigma_{SFR} \alpha \Sigma^{N}_{gas}$, $N = 1.4$



Kennicutt 1998; For, Koribalski & Jarrett, in prep

Global Star Formation Rate

Table 6. Derived global star formation rates for the Circinus galaxy.

SFR ($M_\odot$ yr^{-1})	Wavelength Required	Calibration Method	Reference
8.6	24μm	$L_{24\mu m}$–Hα	Wu et al. (2005)
6.9	8μm	$L_{8\mu m}$–Hα	Wu et al. (2005)
8.3	24μm	$L_{24\mu m}$–1.4 GHz	Wu et al. (2005)
7.8	8μm	$L_{8\mu m}$–1.4 GHz	Wu et al. (2005)
2.8	24μm	$L_{24\mu m}$	Calzetti et al. (2007)
4.3	24μm	$L_{24\mu m}$	Rieke et al. (2009)
< 1	24μm, 70μm, 160μm	L_{FIR}	Kennicutt (1998b)
4.6	24μm	$L_{24\mu m}$	Alonso-Herrero et al. (2006)

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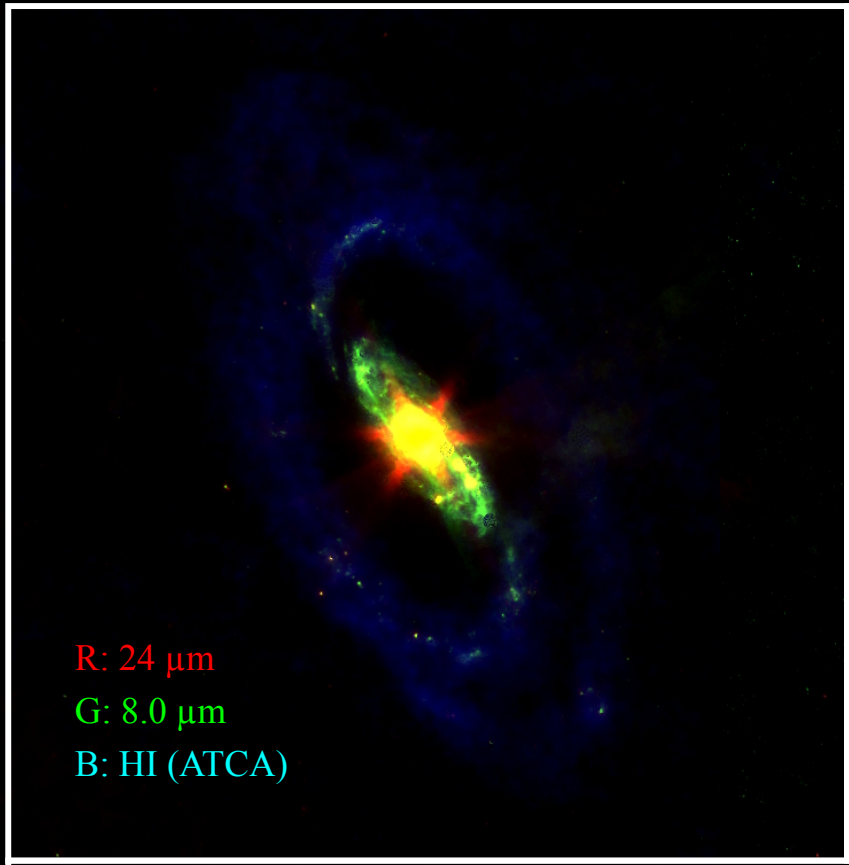
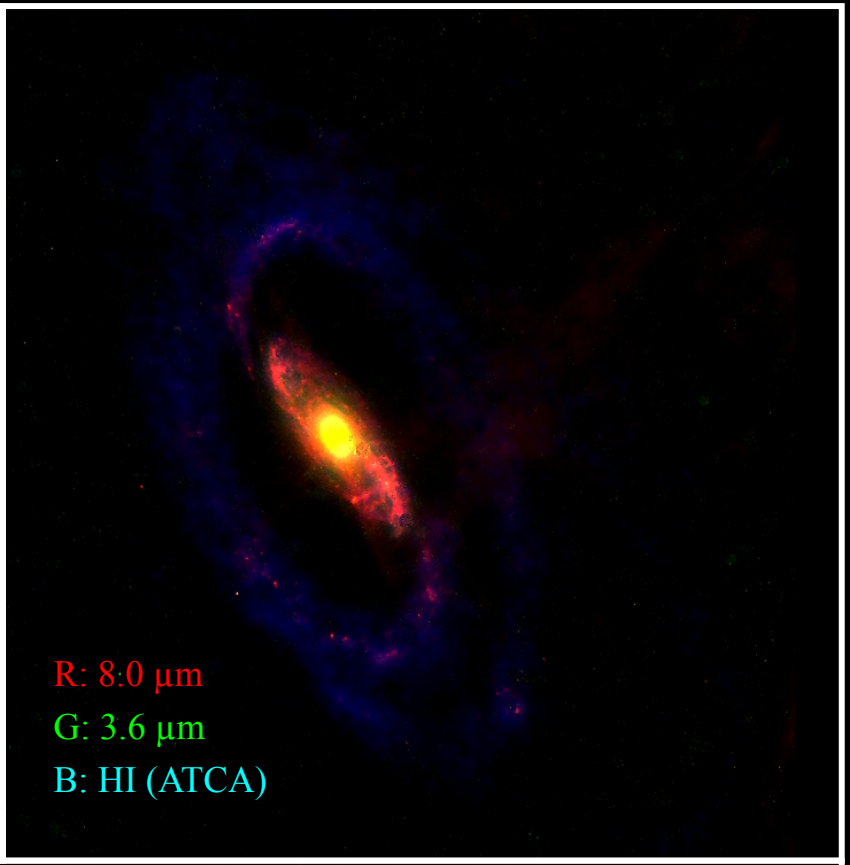
~3 – 8 Msun yr^{-1}

Gas and Star Formation Regions

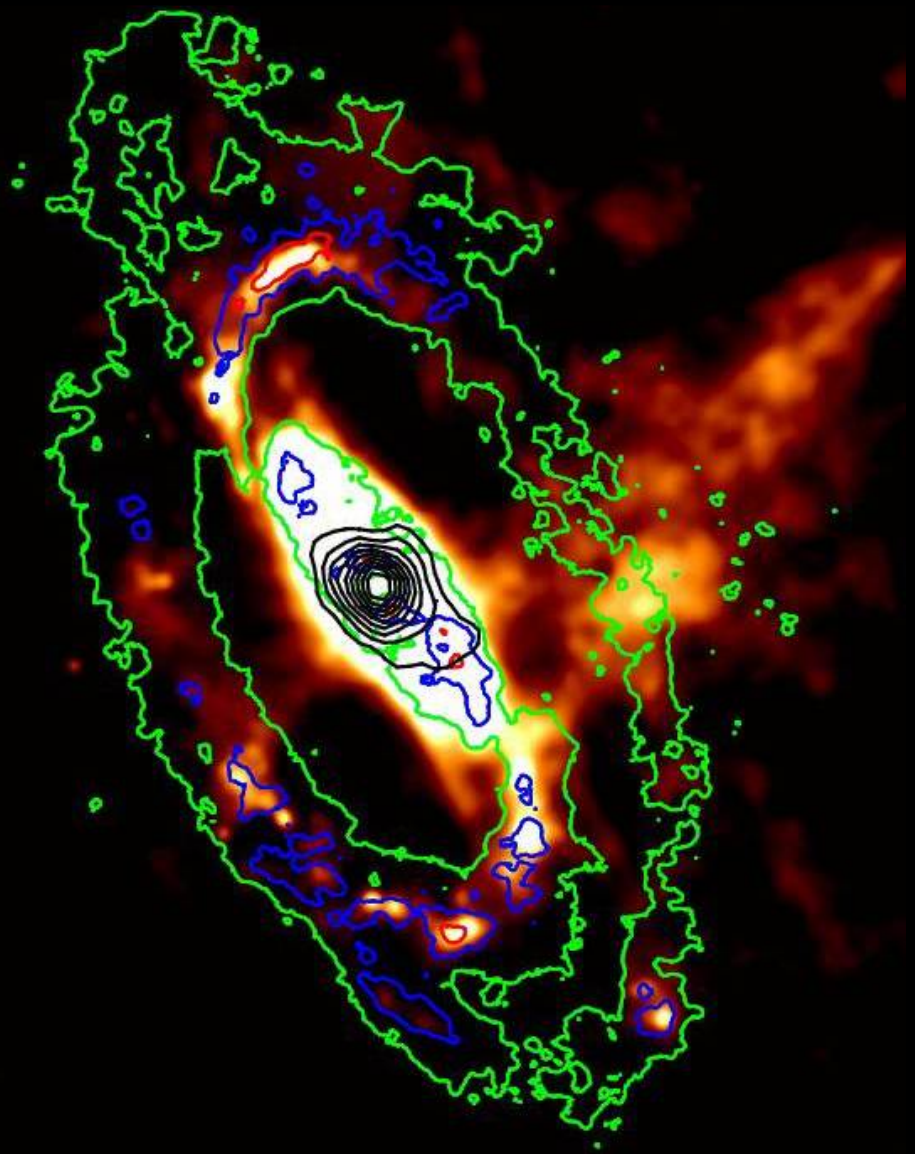




The Circinus Galaxy Spitzer Space Telescope (IRAC, MIPS) + ATCA

For (UTexas), Koribalski (CASS) & Jarrett (SSC)

Gas and Star Formation Regions



N_{HI} (cm^{-2})

Green: 1.23×10^{21}

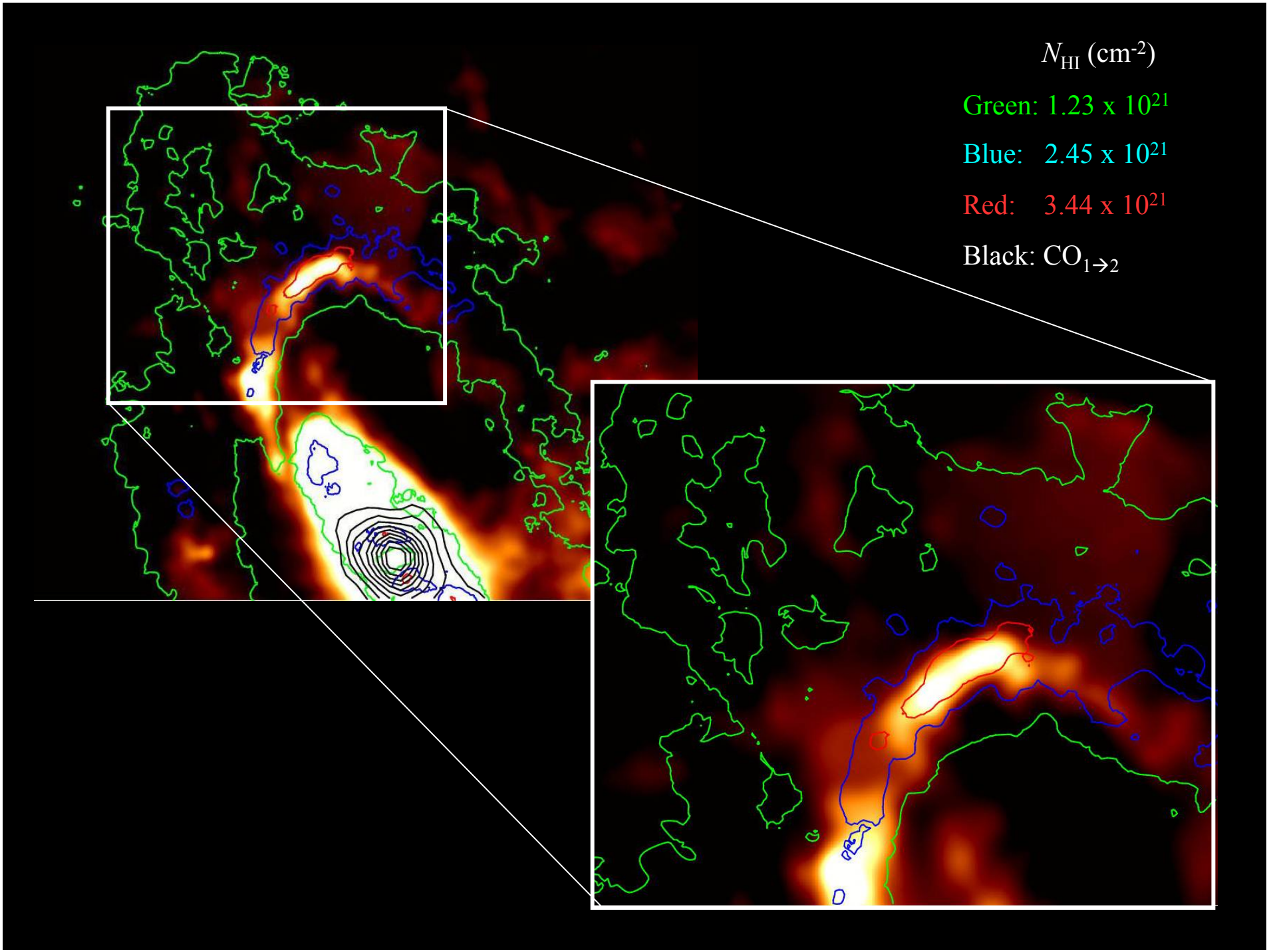
Blue: 2.45×10^{21}

Red: 3.44×10^{21}

Black: $CO_{1\rightarrow2}$

Spitzer 8.0 μm (convolved 15")

ATCA (HI convolved 15")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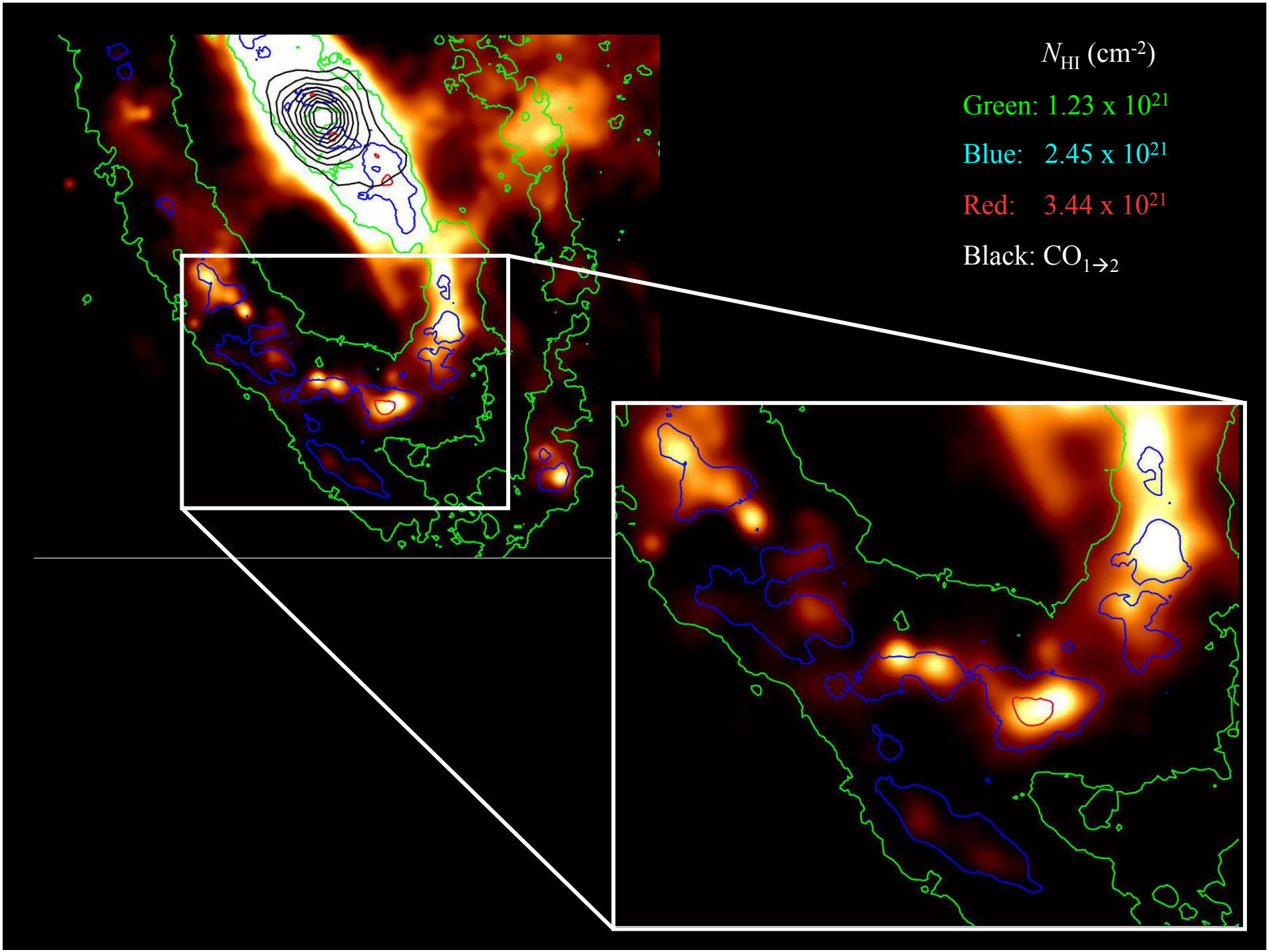
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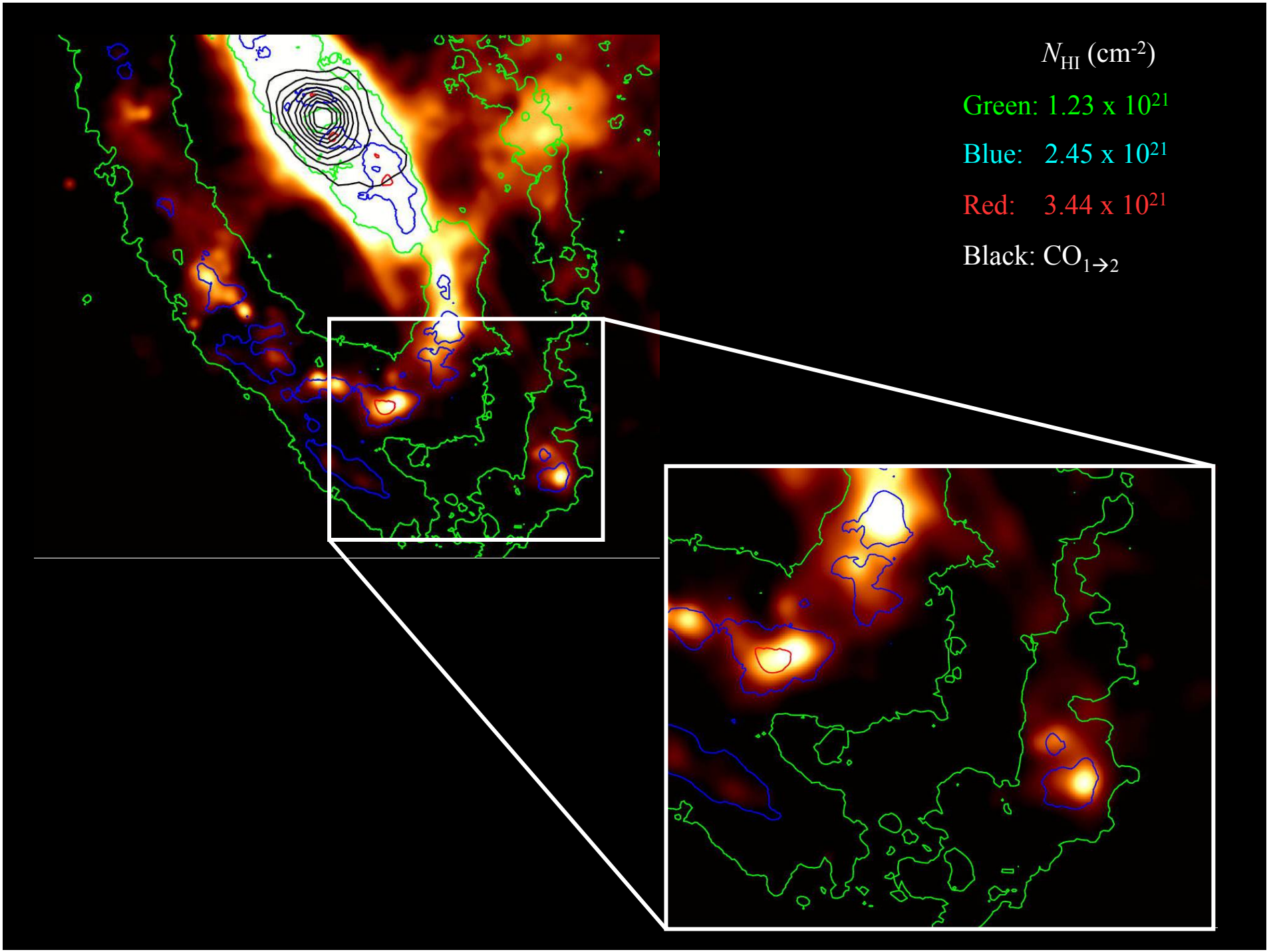
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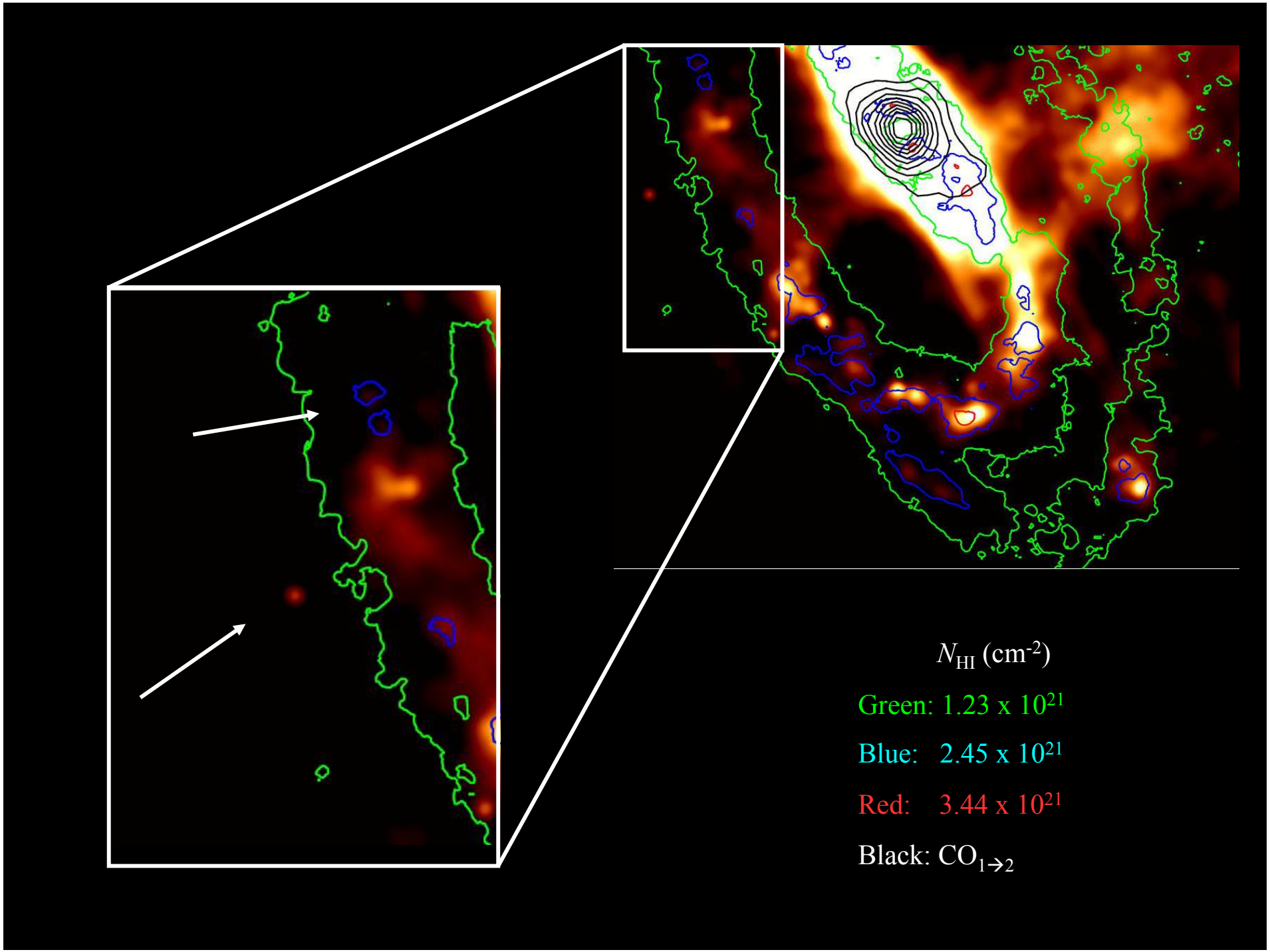
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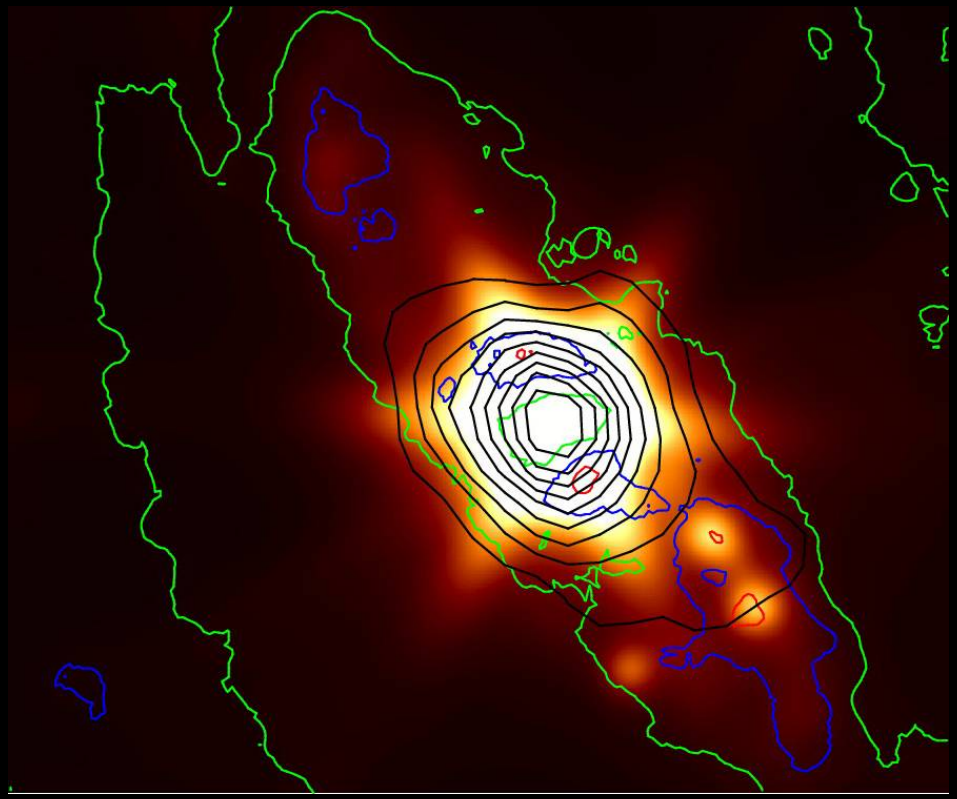


Spitzer 24 μm

ATCA (HI convolved 15")

CO1→2 (convolved 50")

N_{HI} (cm^{-2})

Green: 1.23×10^{21}

Blue: 2.45×10^{21}

Red: 3.44×10^{21}

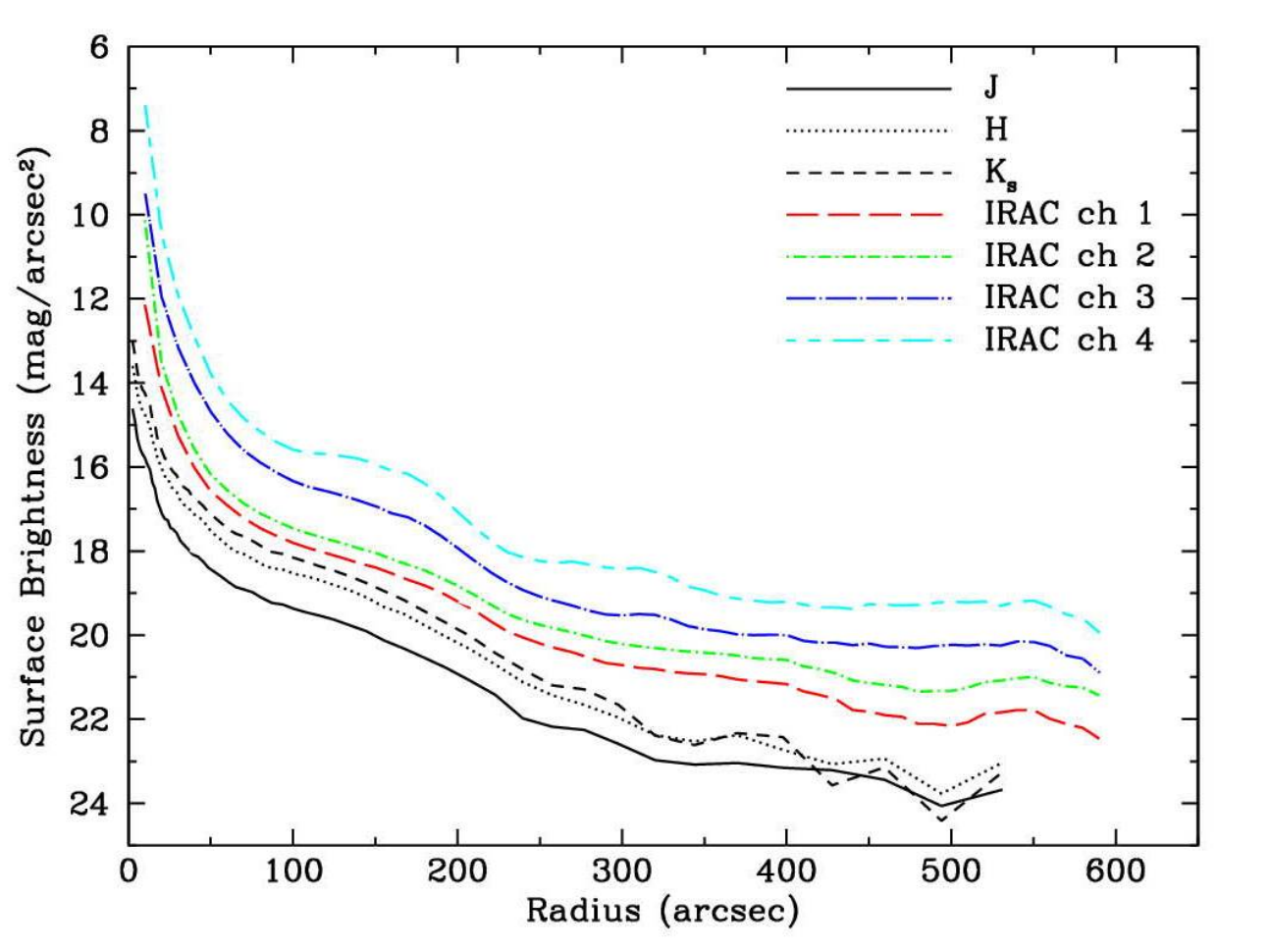
Black: $CO_{1\rightarrow2}$

Conclusions

- Spitzer reveals the Circinus spiral arms for the first time
- Av= 2.1
- Stellar: 9 x 10^{10} Msun
- M*gas* = 8 x 10^{9} Msun
- Star formation rate: ~3 – 8 Msun yr^{-1}
- Star formation caused by the density wave


Thank you!
BQF thanks CASS for the financial support of this work.

Surface brightness profiles



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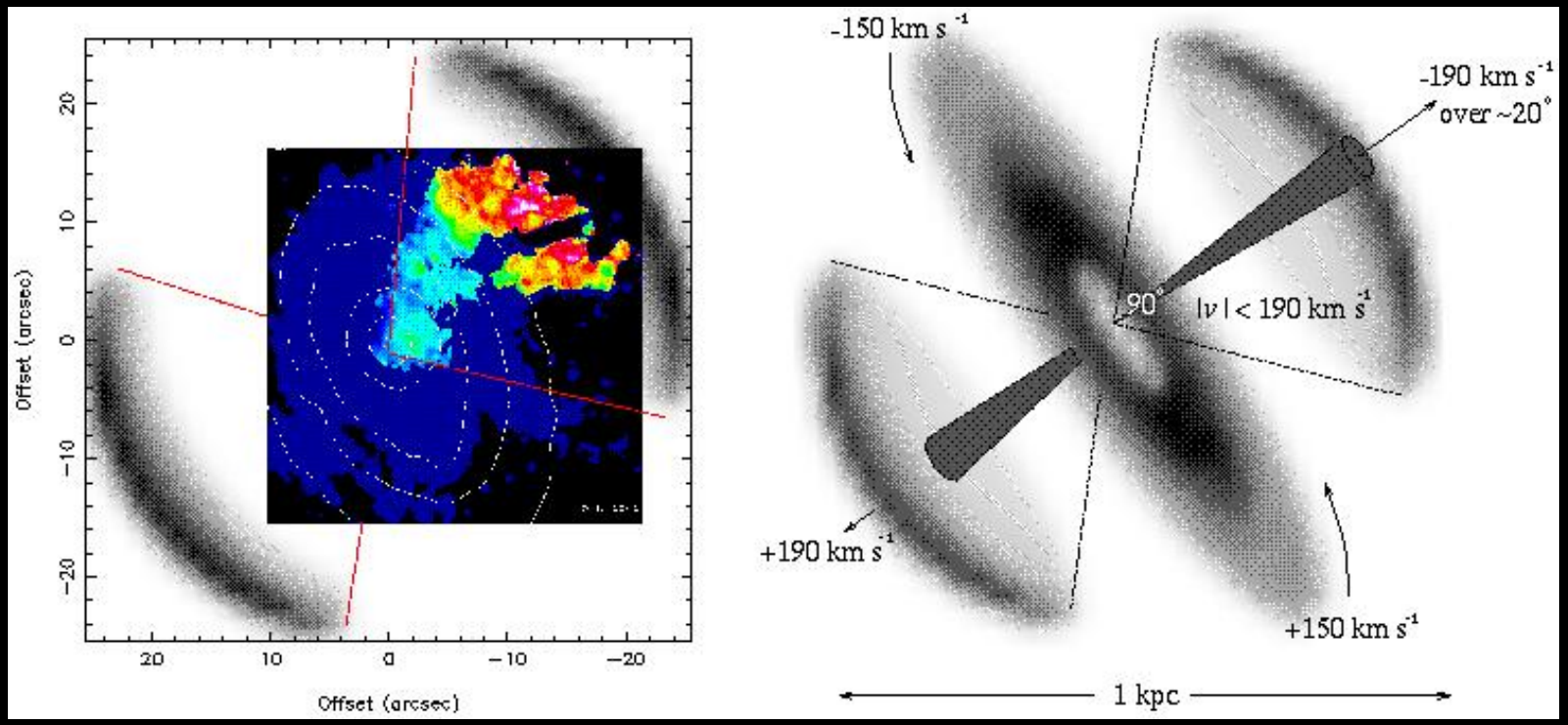
Circinus

- Ionized gas associated with the outflow
  - Molecular outflow (Curran et al. 1999)
- Minor axes radio lobes (Elmouttie et al. 1995)



The ionisation cone in Circinus (Marconi et al. 1994) scaled and superimposed upon the molecular outflow of Curran et al. (1999).