AGN Feedback in Action:

The Molecular Outflow in Circinus Galaxy

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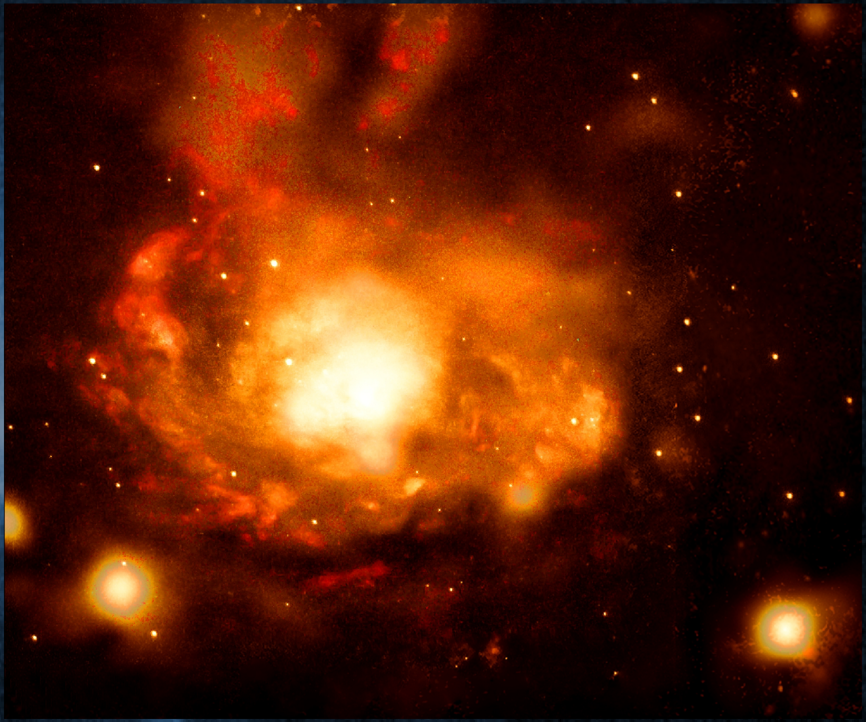

LocalGas2015 – 2 September 2015

Background image NASA/STScI

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**And a little about NGC 253*

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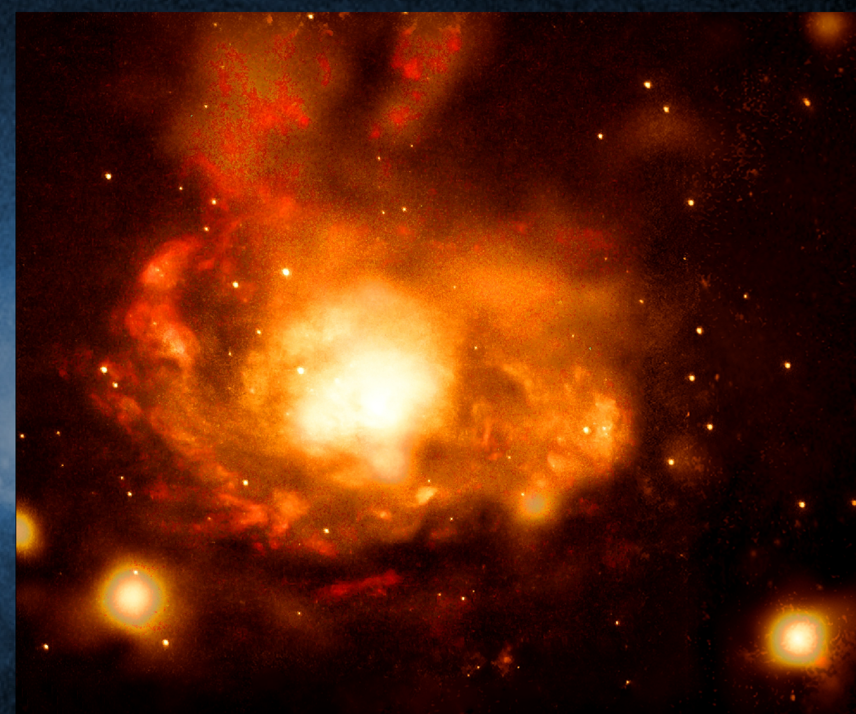

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Galactic winds play key roles in feedback processes

- quench star formation
- limit the total mass of large galaxies
- hinder accretion from IGM

Insufficient understanding of galactic scale feedback, particularly the molecular phase which closely traces star formation and likely dominates the mass budget, is arguably the greatest weakness in our current knowledge of galaxy evolution.

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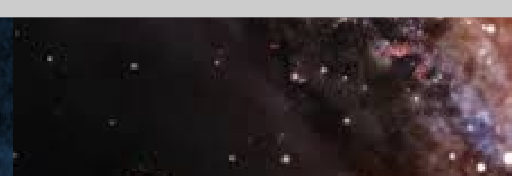
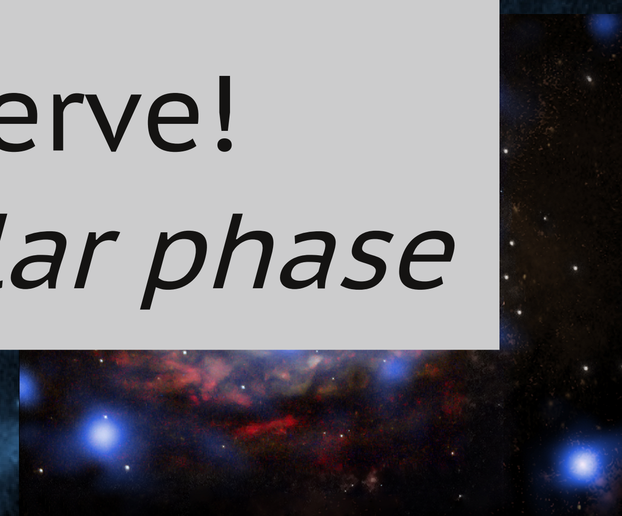
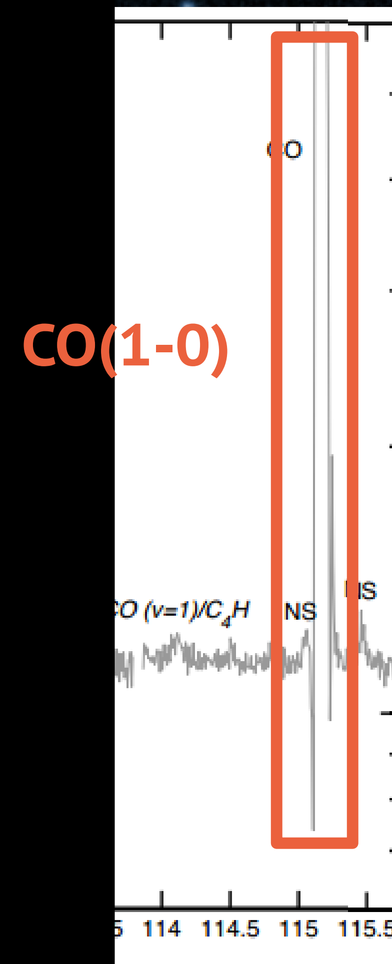
Difficult to observe!

Especially molecular phase





ALMA, NOEMA now make observations of the molecular phase feasible.



Meier et al. (2015)

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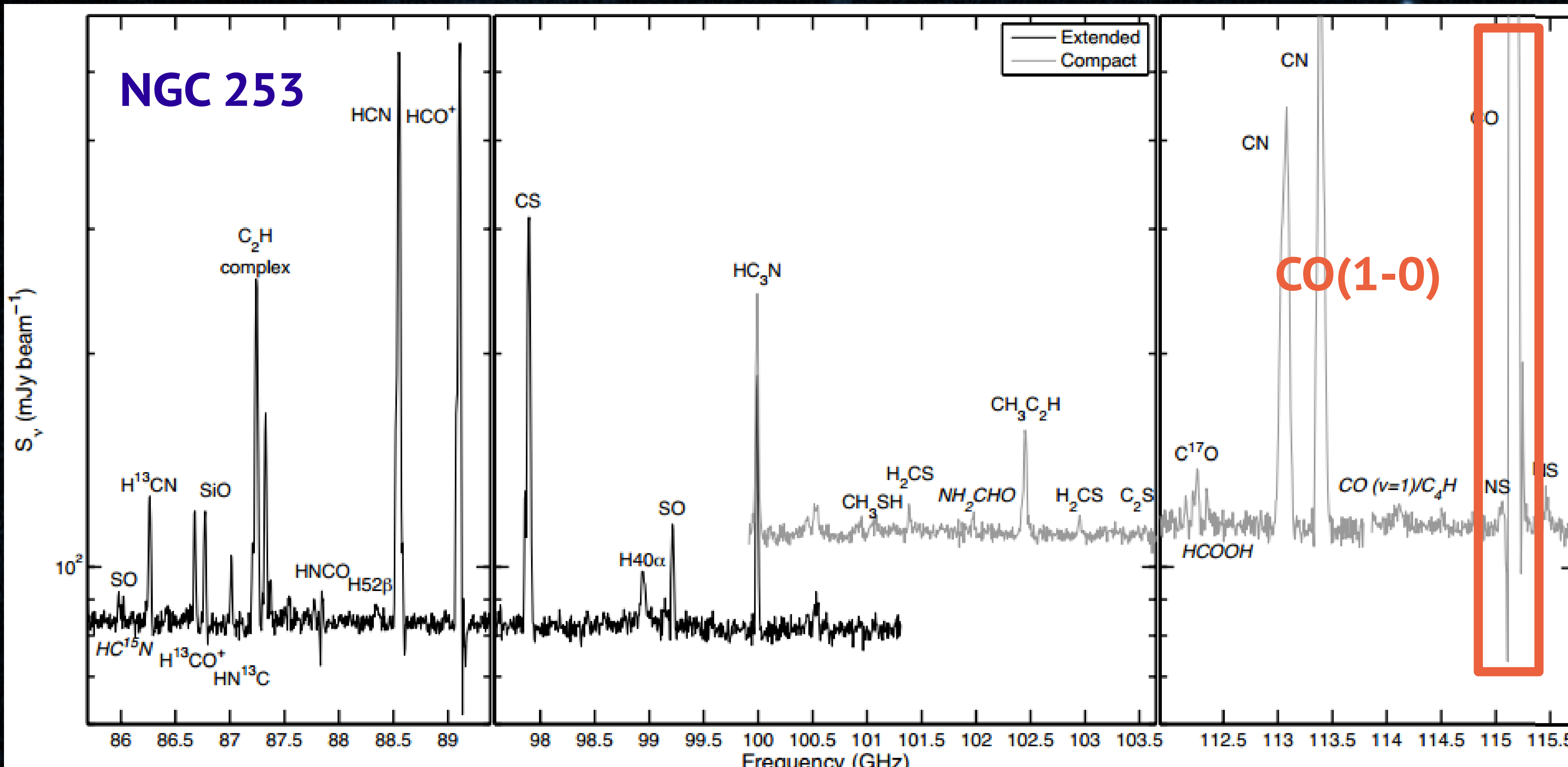

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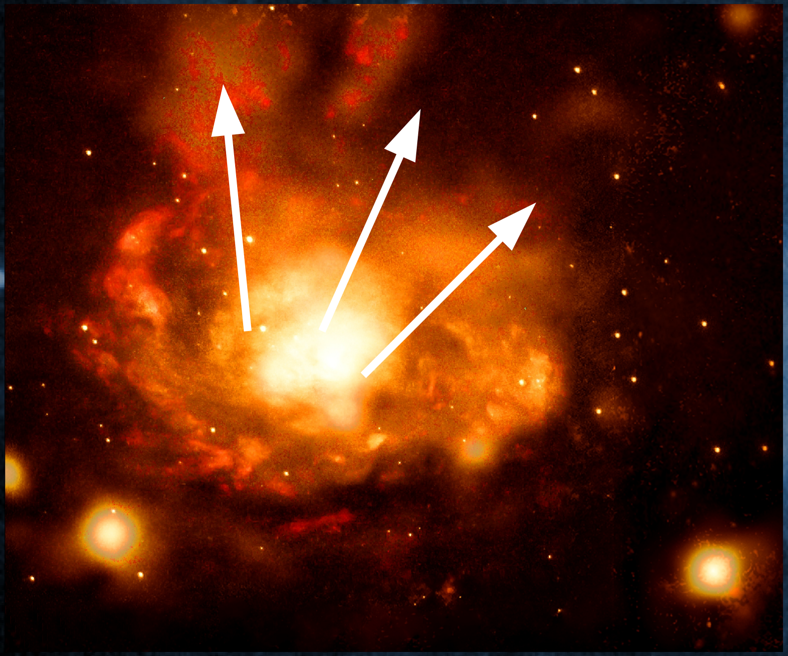
Evidence for entrainment of cool gas by hot wind

- Lower velocities observed in neutral gas (Rupke, Veilleux, & Sanders (2002, 2005)
- Observed rotation in outflow (e.g. Shopbell & Bland-Hawthorn 1998)
- Bolatto et al. (2013) show mass expelled ~3X's SFR in NGC 253 (starburst).



- *How much reaches the IGM?*
- *How much is reaccreted?*

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How do AGN-driven winds compare?

Relative importance of starburst- vs. AGN-driven winds in feedback process unknown

- Simulations and observations indicate AGN-driven winds more energetic (e.g. Sharma & Nath 2012)
  - higher chance of material escaping galaxy
  - a lower likelihood of fueling future star formation
- Both present -> may amplify their respective contributions (Pawlik & Schaye 2009)
  - Can also counteract each other's effects (Booth & Schaye 2013).

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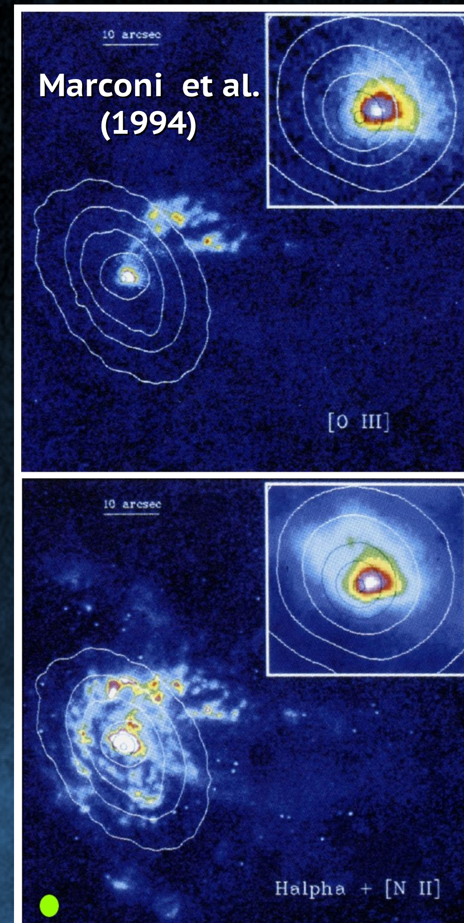
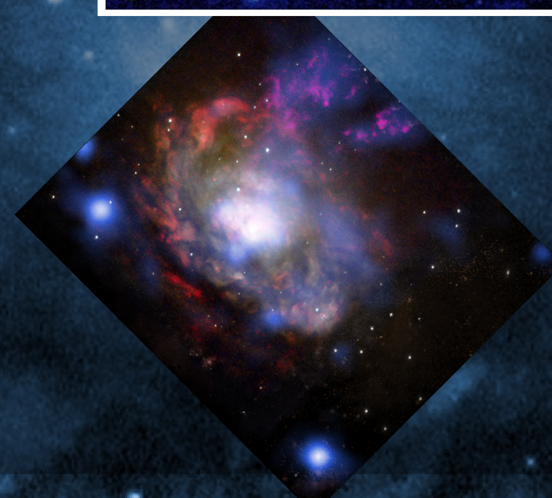
Observations clearly needed!

ALMA Cycle 2 – Circinus Galaxy

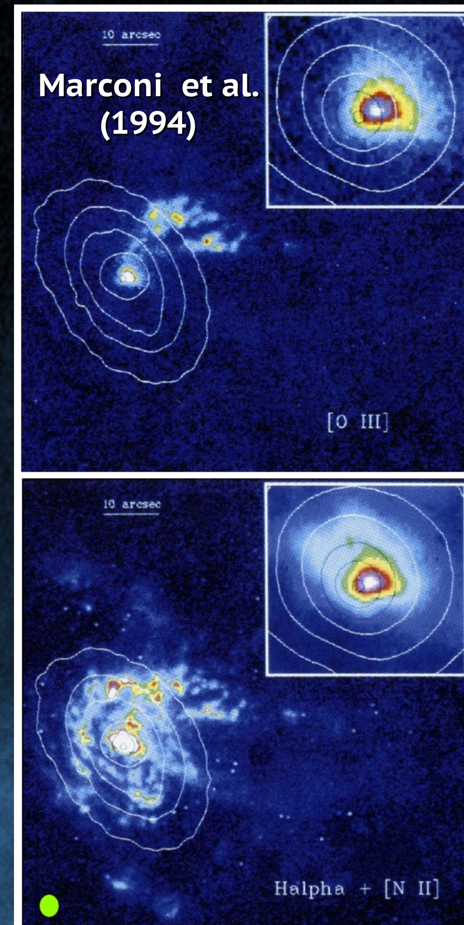
- **AGN-driven wind**
  - Nearest Seyfert
  - Blue-shifted (150 km/s) galactic wind clearly observed in H-alpha (Veilleux & Bland-Hawthorn 1997)

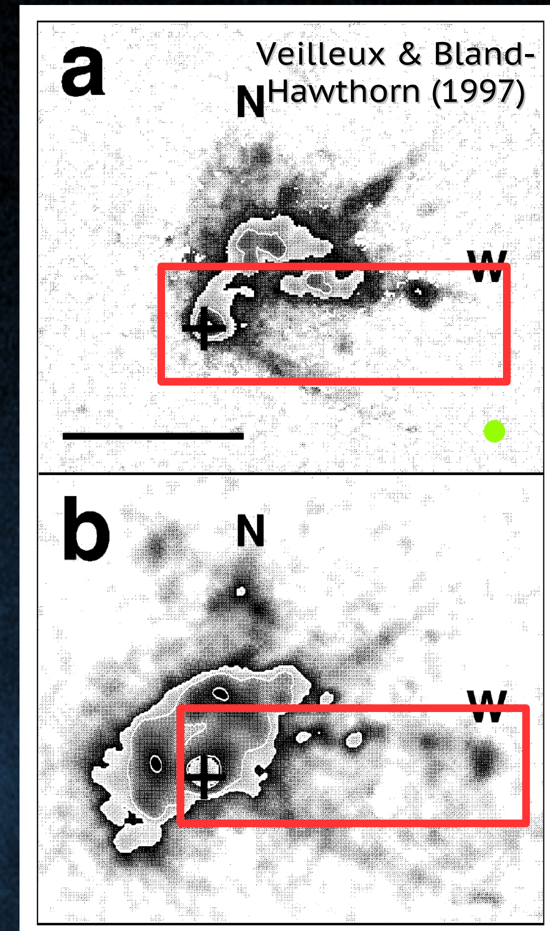


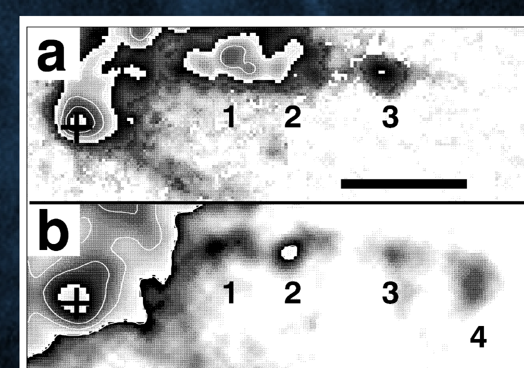


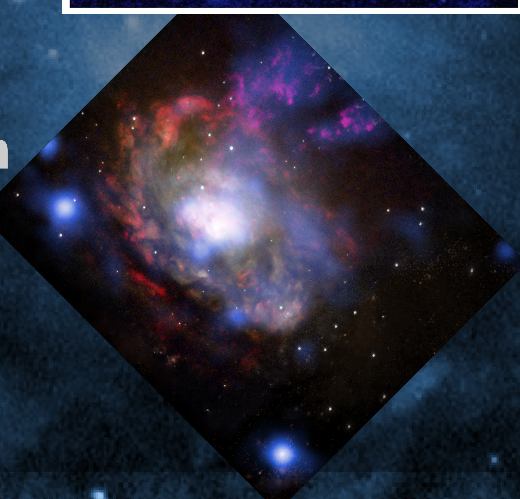
ALMA Cycle 2 – Circinus Galaxy

- AGN-driven wind
  - Nearest Seyfert
  - Blue-shifted (150 km/s) galactic wind clearly observed in H-alpha (Veilleux & Bland-Hawthorn 1997)
    - Filaments entrained in the wind
    - Bow-shocked features resembling Herbig Haro objects at the ends
      - Strong interaction with the surrounding ISM (Bland-Hawthorn 1997)
  - Circinus is unusually HI rich -> likely also rich in molecular gas.



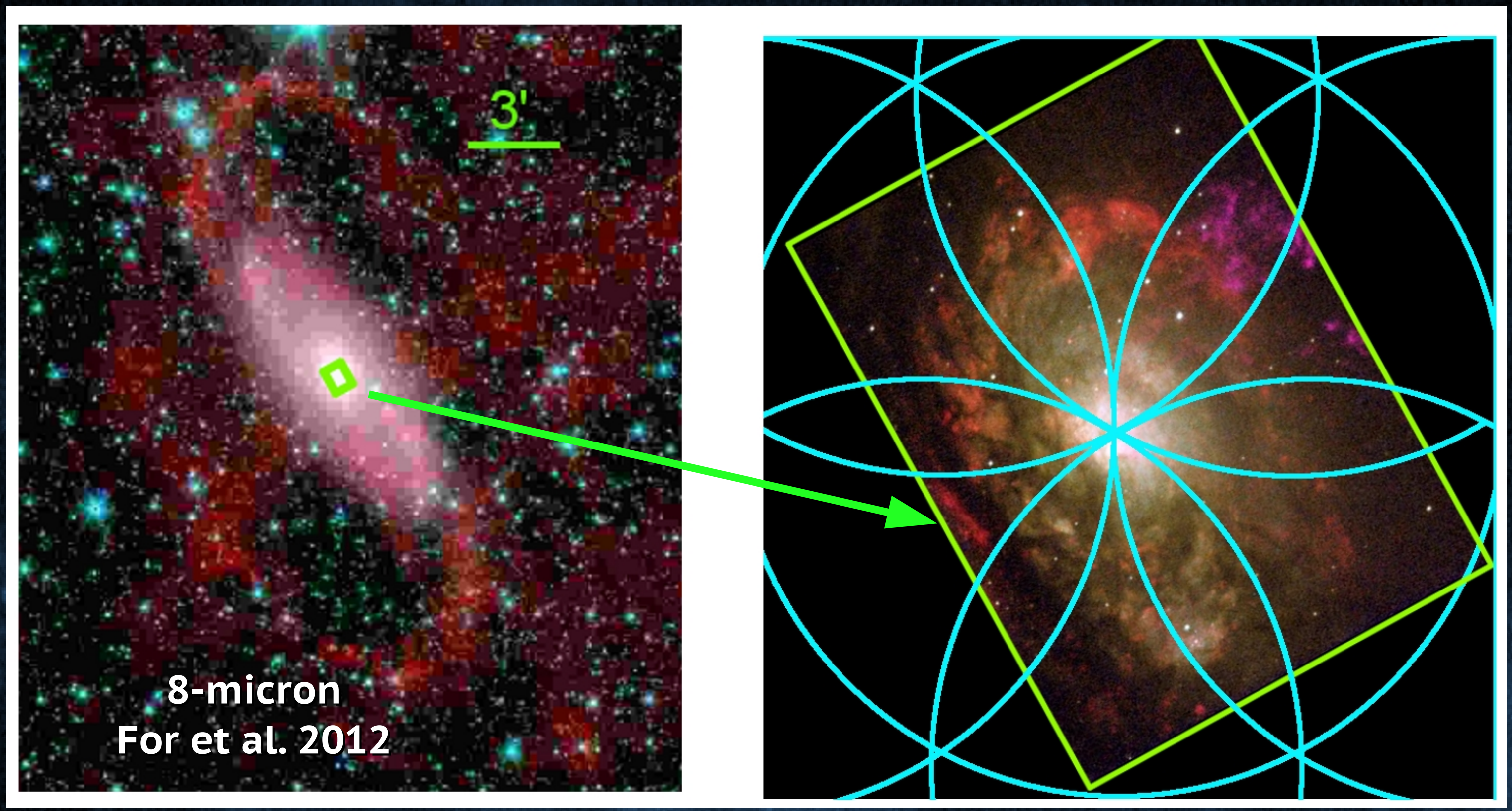




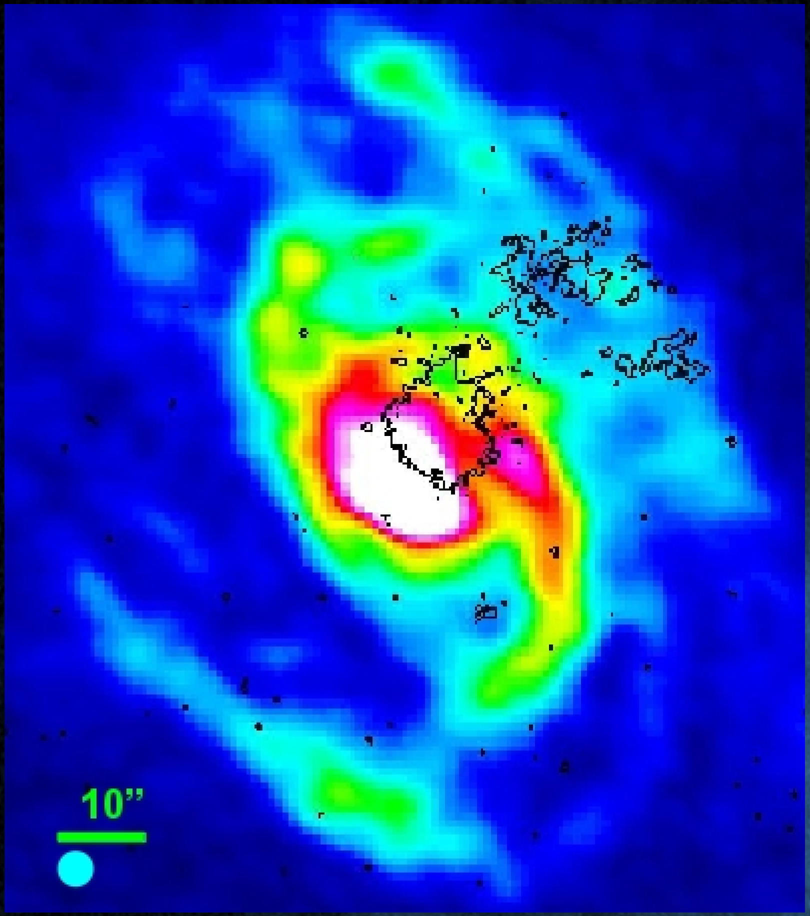


The Observations

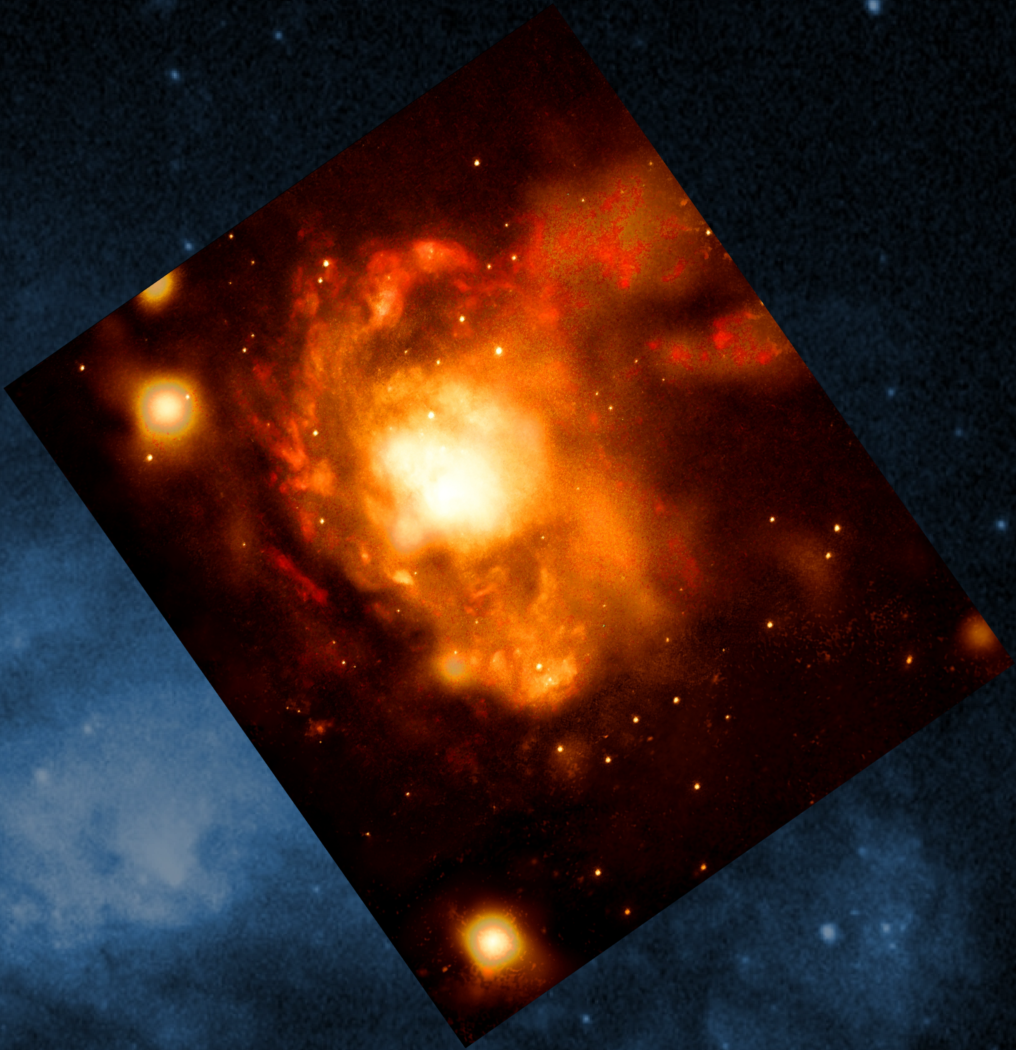
- 12CO(1-0) in central 1′
- 3.5” beam, 4 mJy/bm rms over 2.5 km/s
  - *2 orders of magnitude* improvement in beam area and sensitivity compared to previous observations by Curran et al. (2008).



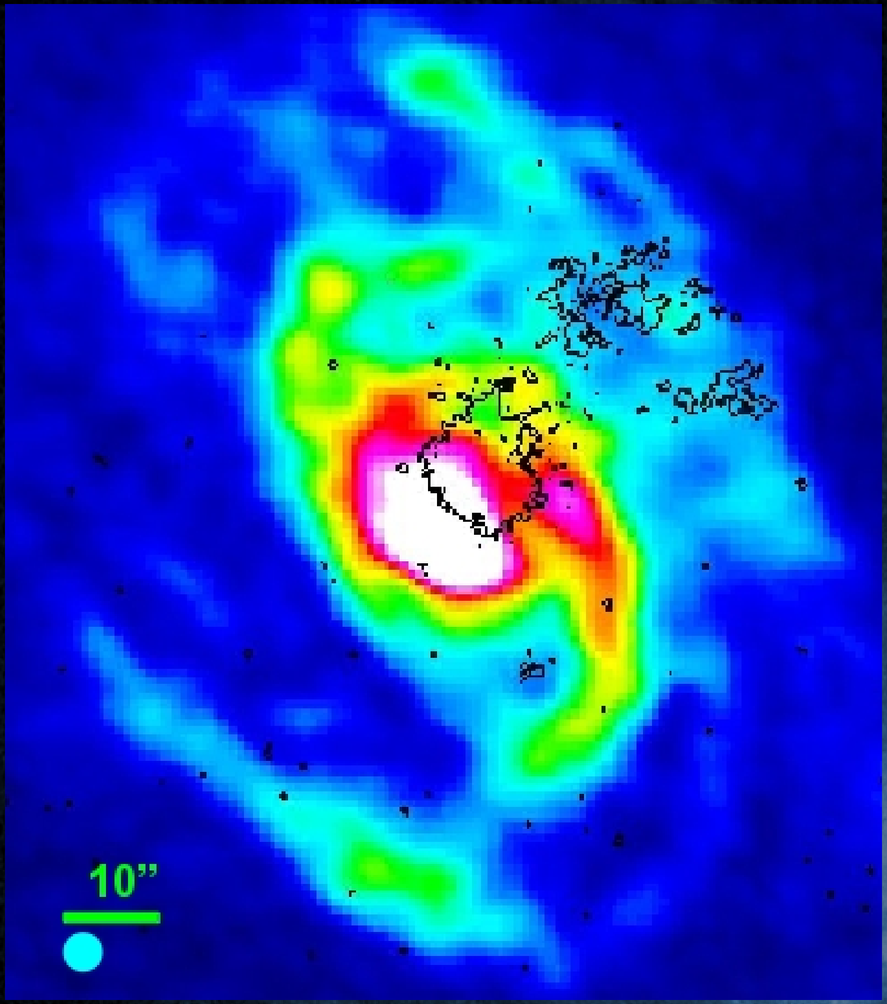
ALMA CO(1-0)

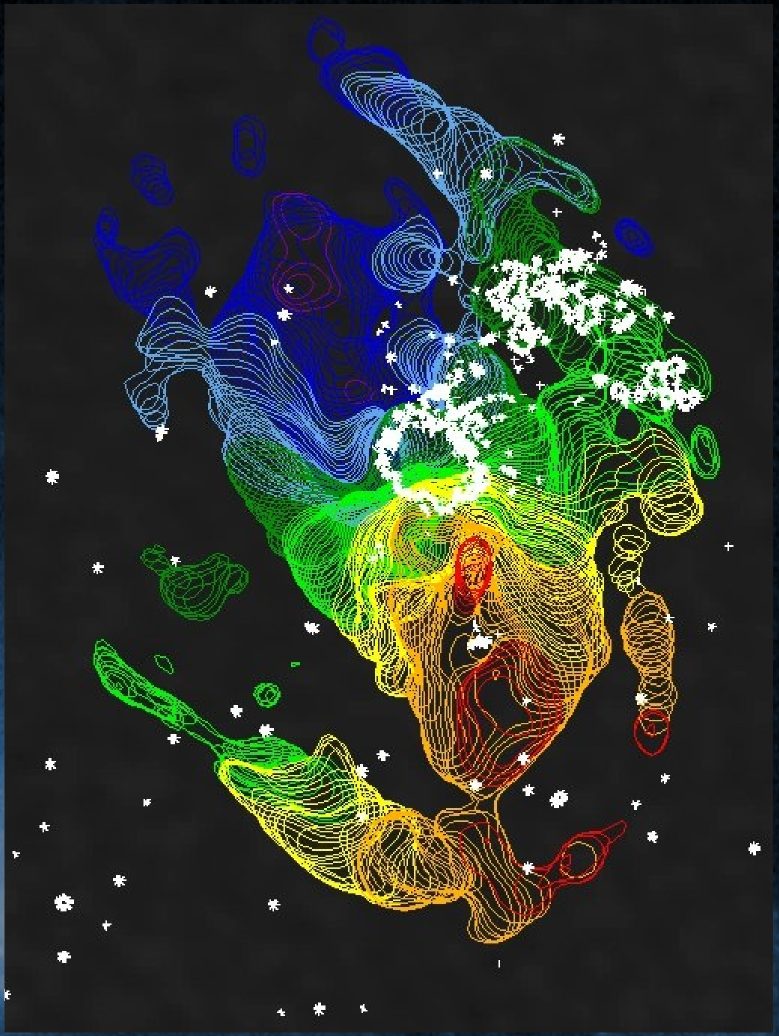


HST



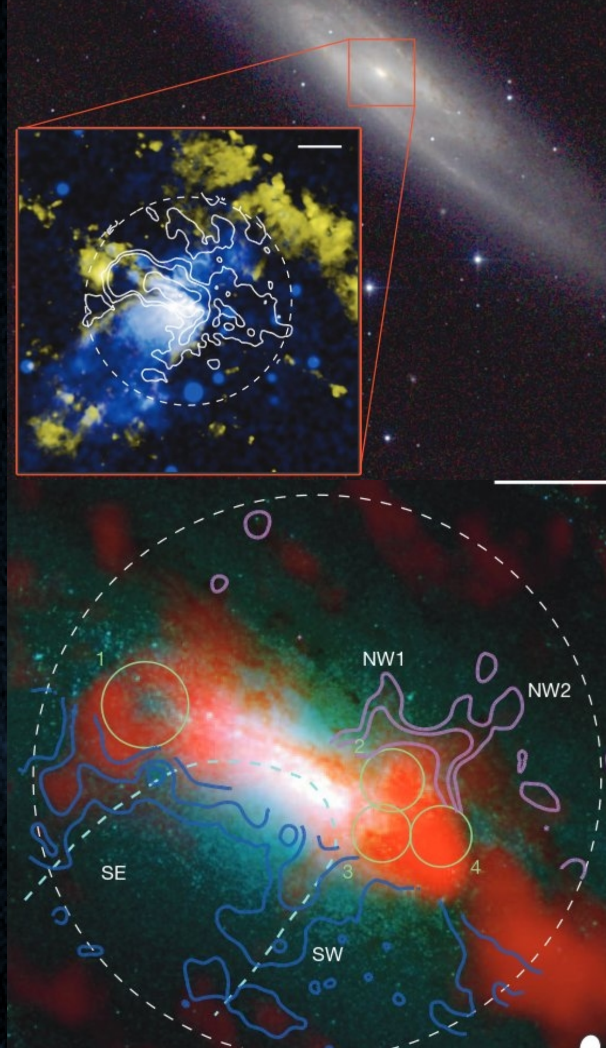
Where's the wind?





No, seriously, where is the wind?

Back to NGC 253...



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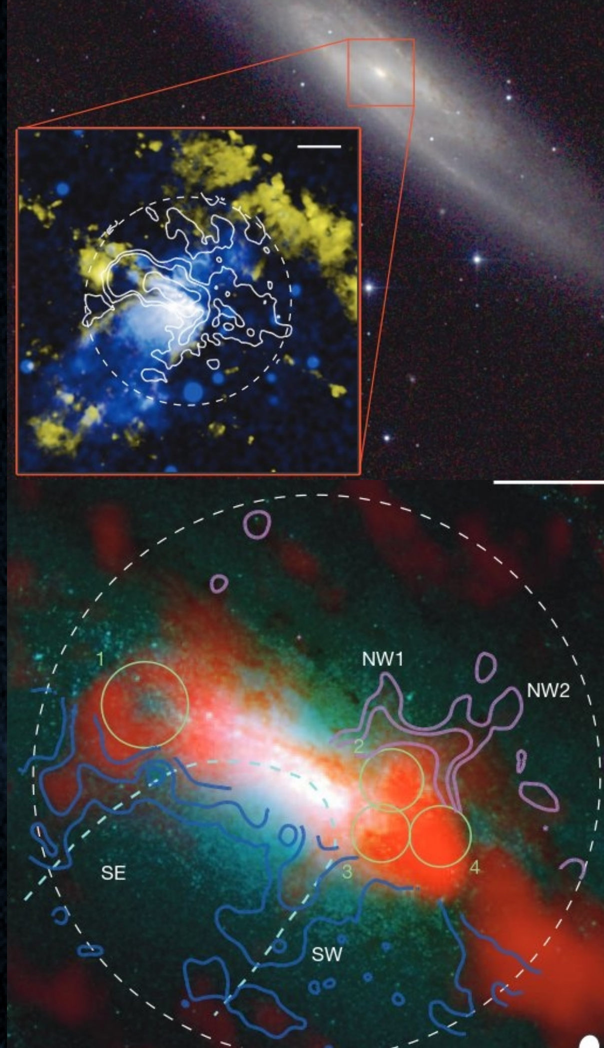

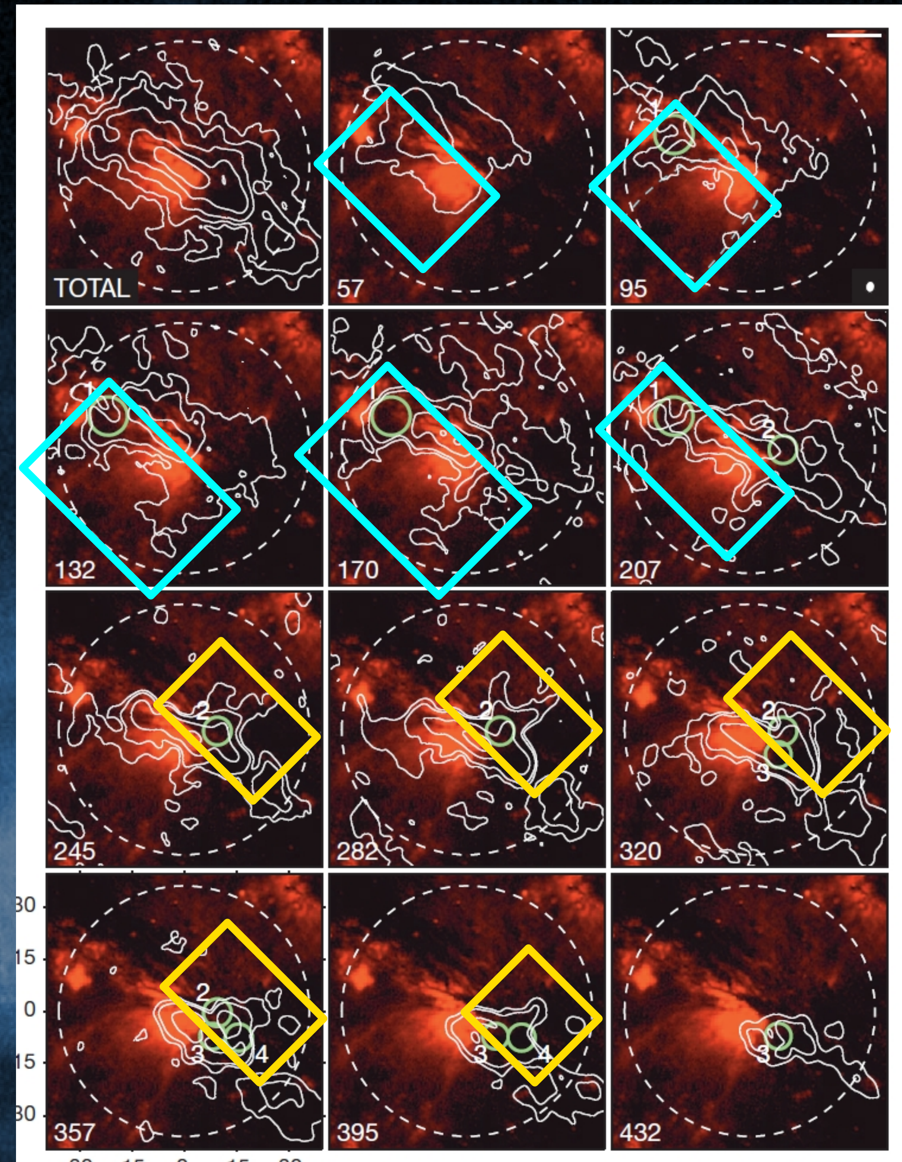

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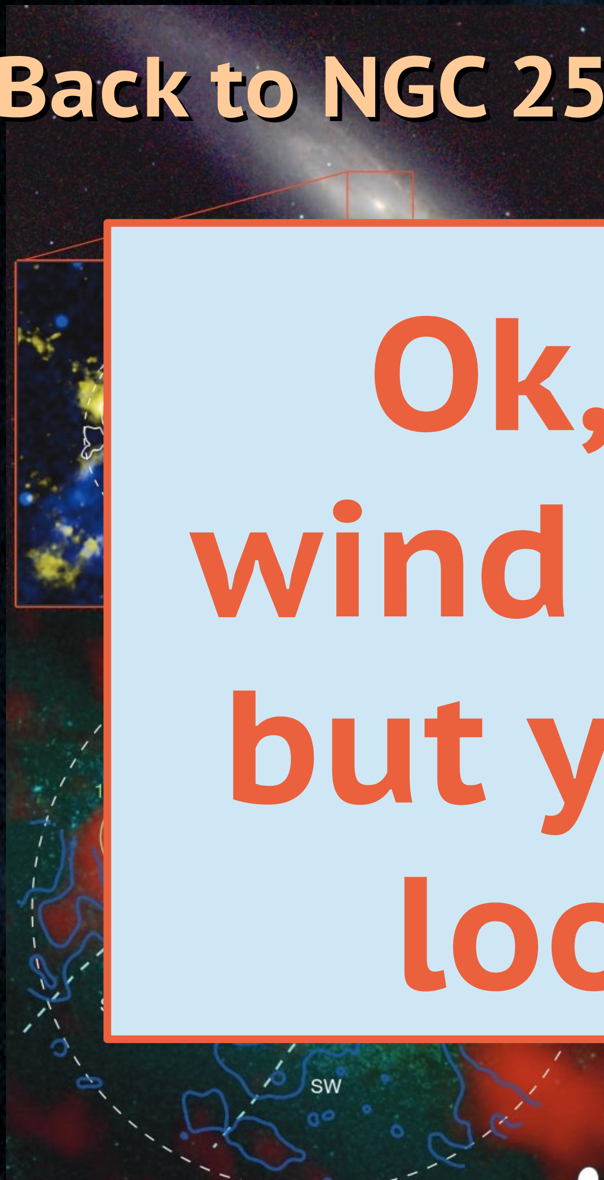


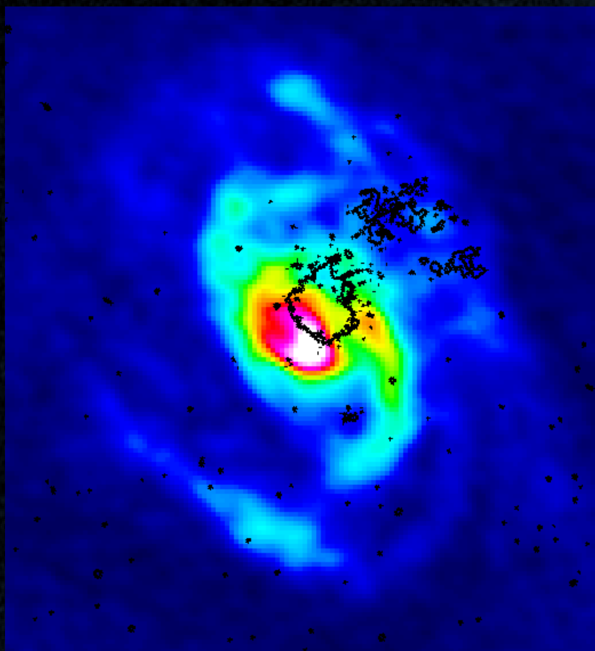
Bolatto et al. (2013)

Ok, there's a wind in NGC 253, but you need to look for it...

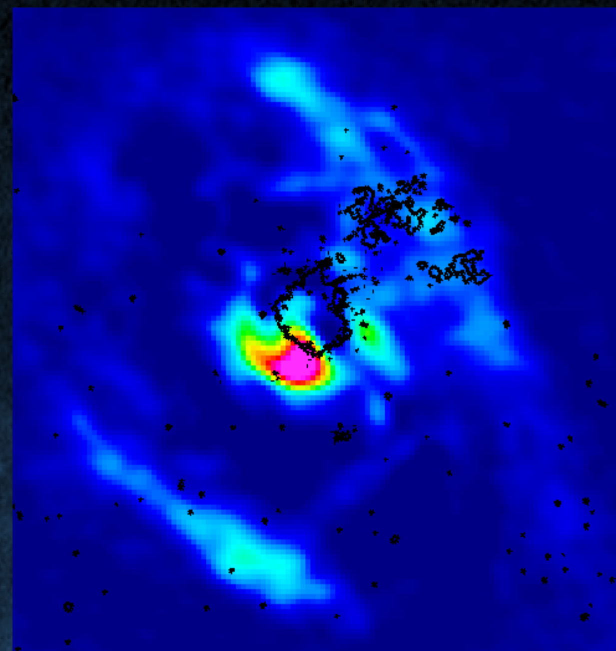
Extracting the Wind

1) **Model the main disk**
   - Tilted-ring modeling (Rogstadt 1978)
   - TiRiFiC (Jozsa et al. 2007)
     - Bars, spiral arms, radial/vertical motions, etc.
     - Model segments and wedges
2) **Subtract the model**
3) **Look for the wind**

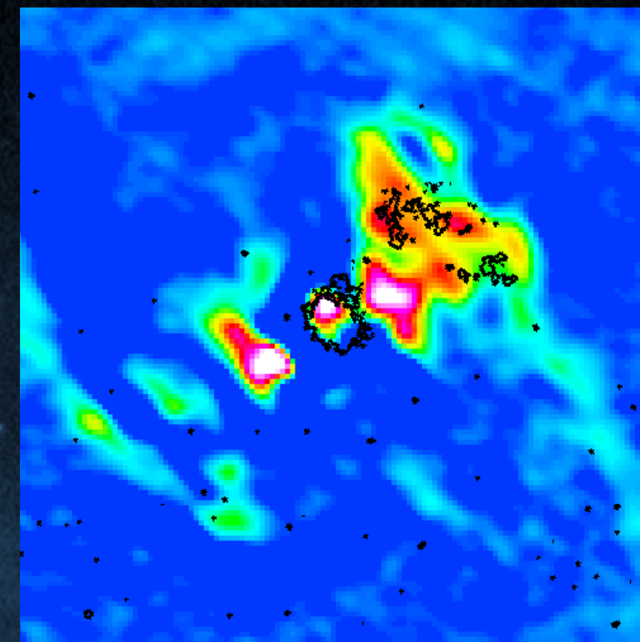
Extracting the Wind



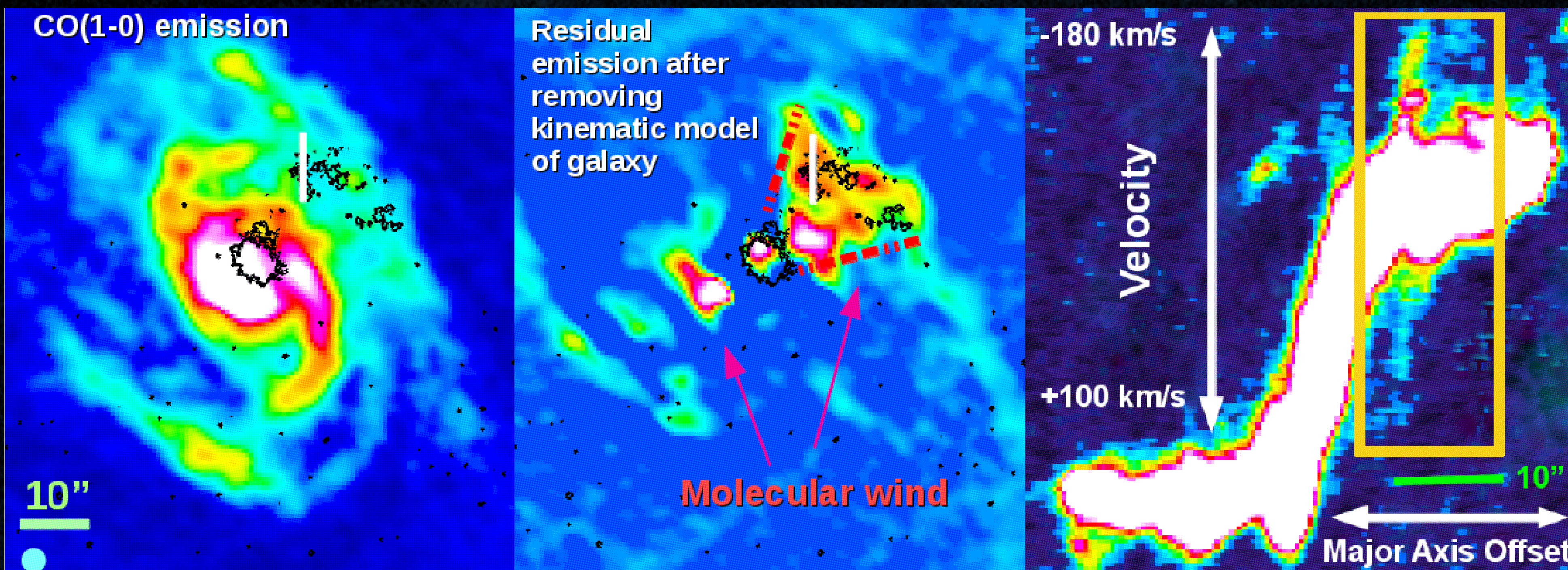
data



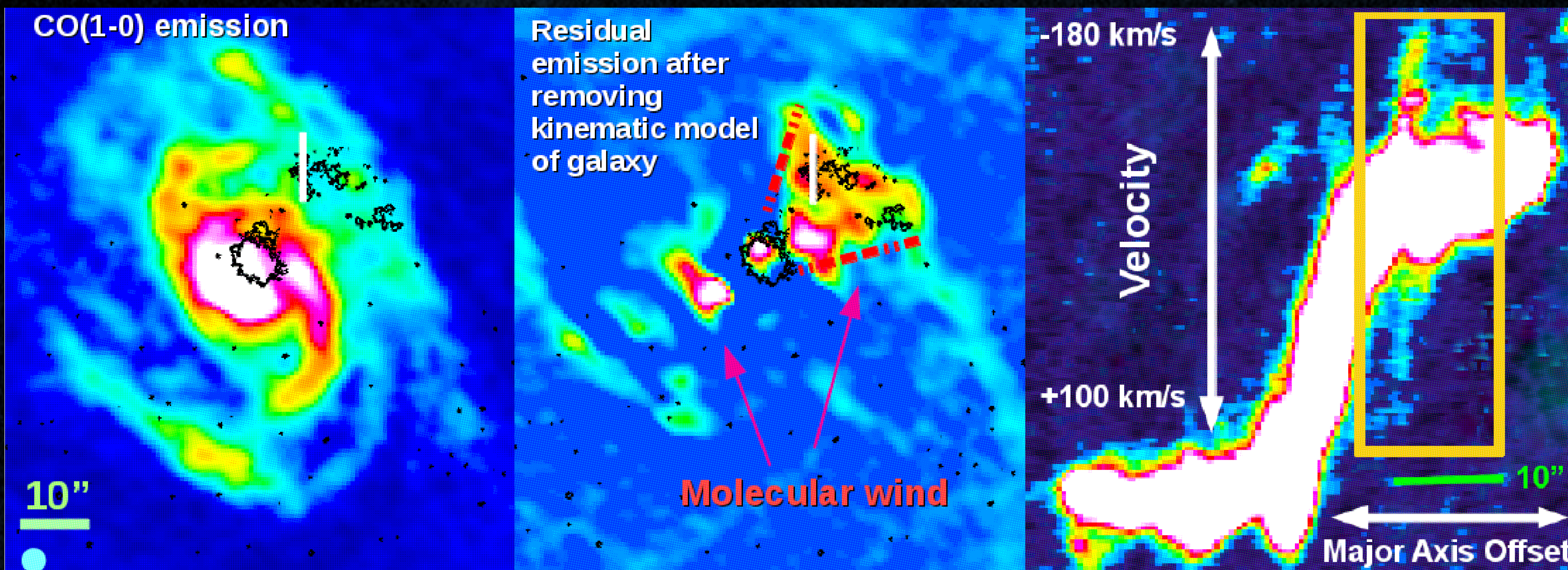
data – model
(intermediate)



data – model
(current best)



CO(1-0) emission
10”
Residual emission after removing kinematic model of galaxy
Molecular wind
-180 km/s
Velocity
+100 km/s
10”
Major Axis Offset



Cycle 3 ALMA time granted

Properties of the wind

Molecular mass: ~ few X's 10^7 M_o

- On the order of a few percent of total
- Total based on Curran et al. (1998), For et al. (2012)
  - TP needed for ALMA data

Velocity: 150-200 km/s

SFR: 3-8 M_o/yr (For et al. 2012)

Mass outflow rate: TBD

Properties of the wind

It is crucial to constrain all of these quantities.

Clear & consistent methods

Increase sample

ALMA Cycle 3 granted for both Circinus and NGC 253.