Confirmation of Candidature:

Cold Gas in Outflows

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Advisors: **Deanne Fisher**
Rebecca Davies

Panel: Glenn Kacprzak **(Chair)**
Jean Brodie
Ryan Shannon
Andrei Ristea

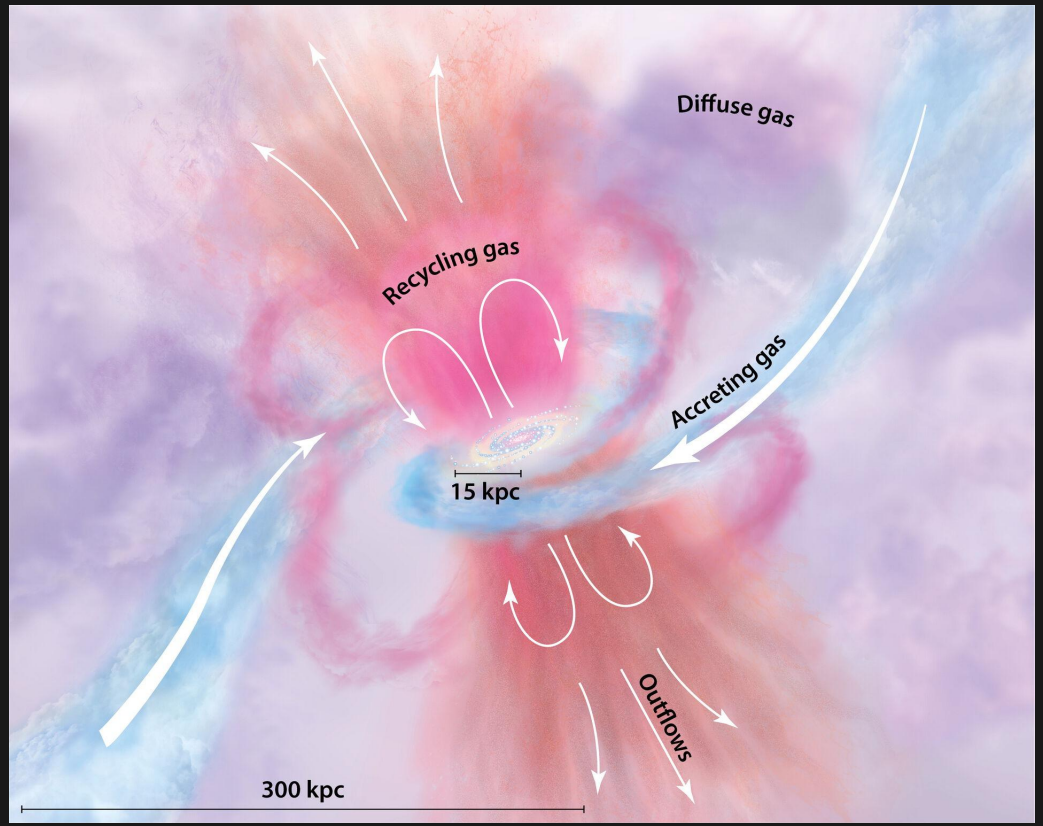


- ~400 billion stars!
- 10% of baryons in the form of stars.
- ~90% of all baryons are **not in galaxies.**
- >40% of metal are **in the CGM/IGM.**

Milky Way over Uluru, NT

Baryonic Cycle: Why are outflows important?

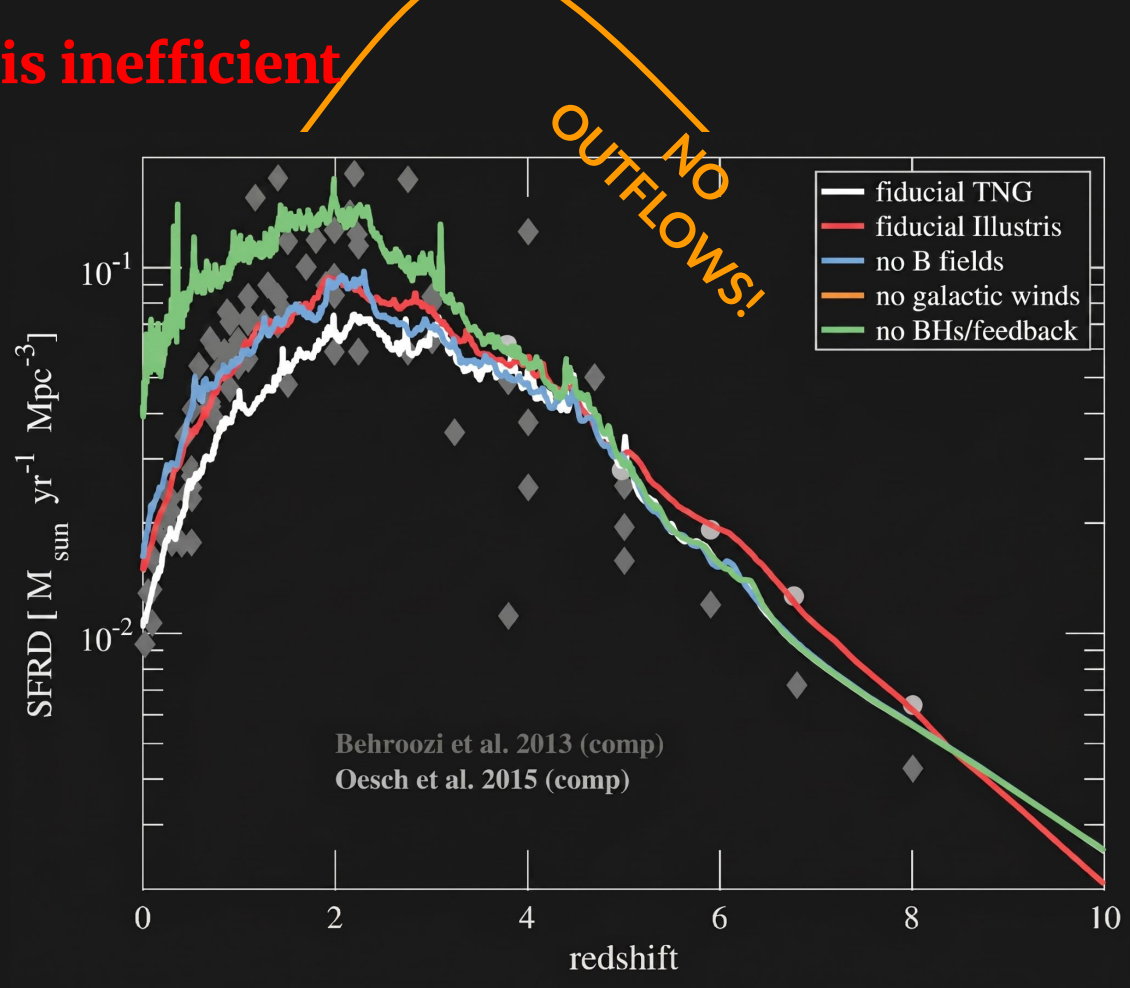
- Galaxies interact with their medium.
- Outflows are an example of **'negative feedback'.**



Tumlinson+(2017)

Star-formation in galaxies is inefficient

- Without feedback, simulations **overpredict** stellar masses.
- Outflows **reconcile** simulations with observations.



Pillepich+(2018)

M82, the "Rosetta Stone" Outflow



M82, the "Rosetta Stone" Outflow



Outflow

Outflow

Hot Phase
($T > 10^7$ K)

Warm Phase
($T \sim 10^4$-10^5 K)

Cold Phase
($T < 10^4$ K)

M82, the "Rosetta Stone" Outflow

CHOOSE YOUR CHARACTER

Starburst/AGN



Outflow

Outflow

Hot Phase
($T>10^7$ K)

Warm Phase
($T\sim10^4$-10^5 K)

Cold Phase
($T<10^4$ K)

M82, the "Rosetta Stone" Outflow



Outflow

Outflow

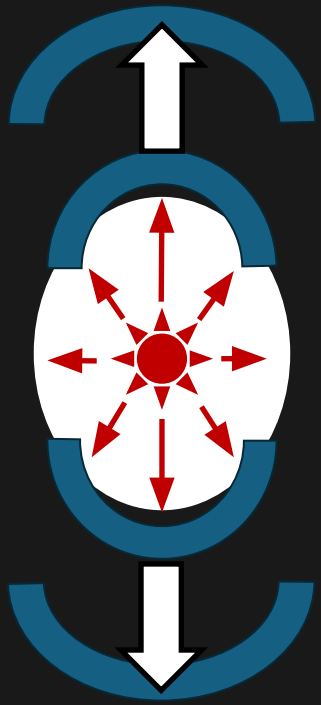
Hot Phase
($T>10^7$ K)

Warm Phase
($T\sim10^4$-10^5 K)

Cold Phase
($T<10^4$ K)

How starburst-driven outflows works?

$$\dot{E}\ \dot{p}\ \dot{M}$$

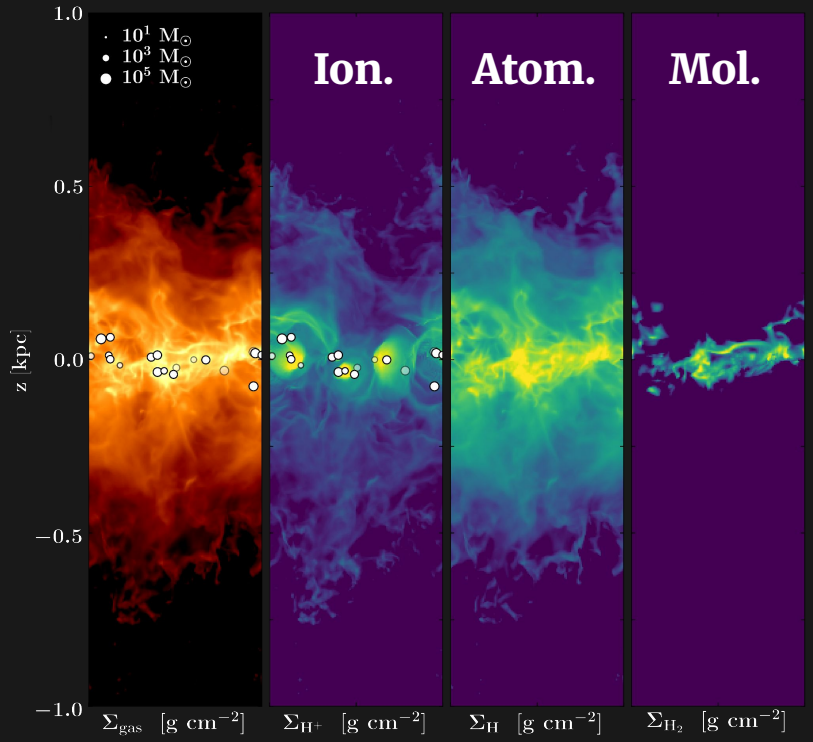


many of them...



The cold gas challenge...

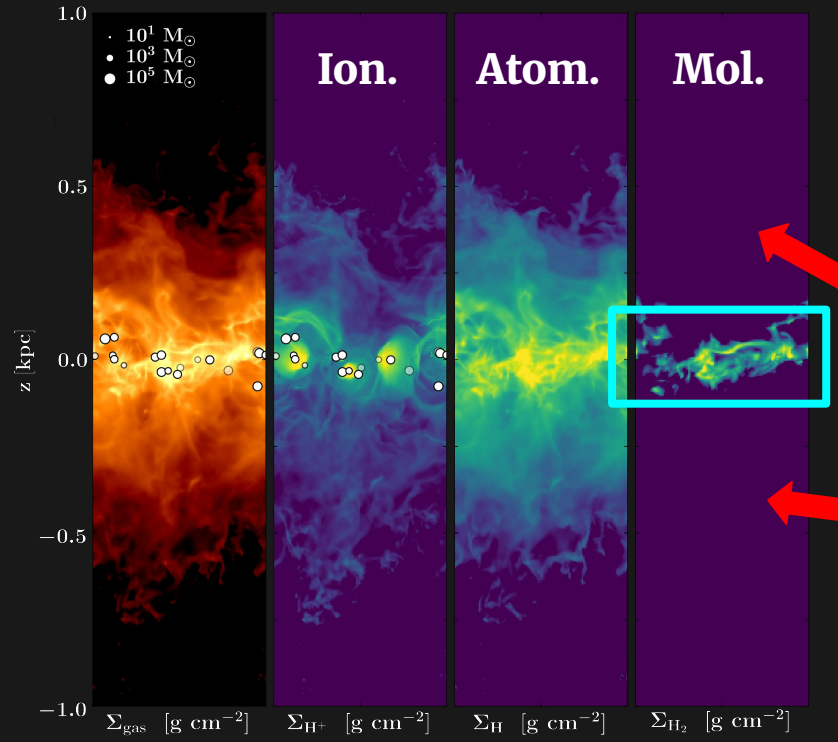
Simulations



Rathjen+(2021)

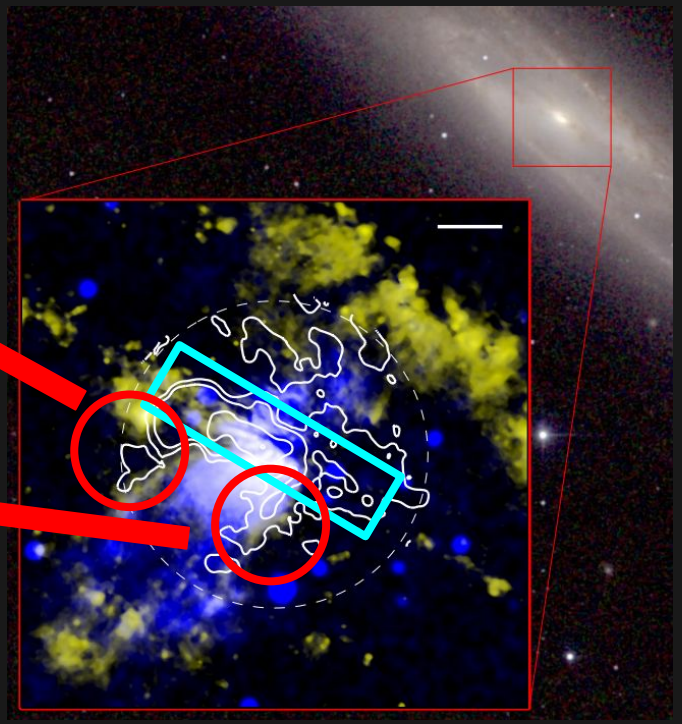
The cold gas challenge... **there is no agreement!**

Simulations



Rathjen+(2021)

Observations



NGC 253 (Bolatto+2013)

Project 1 : Molecular/Ionised outflow in ESO 484-036

The GECKOS survey: Resolving the molecular and ionised gas in the galactic outflow of ESO 484-036

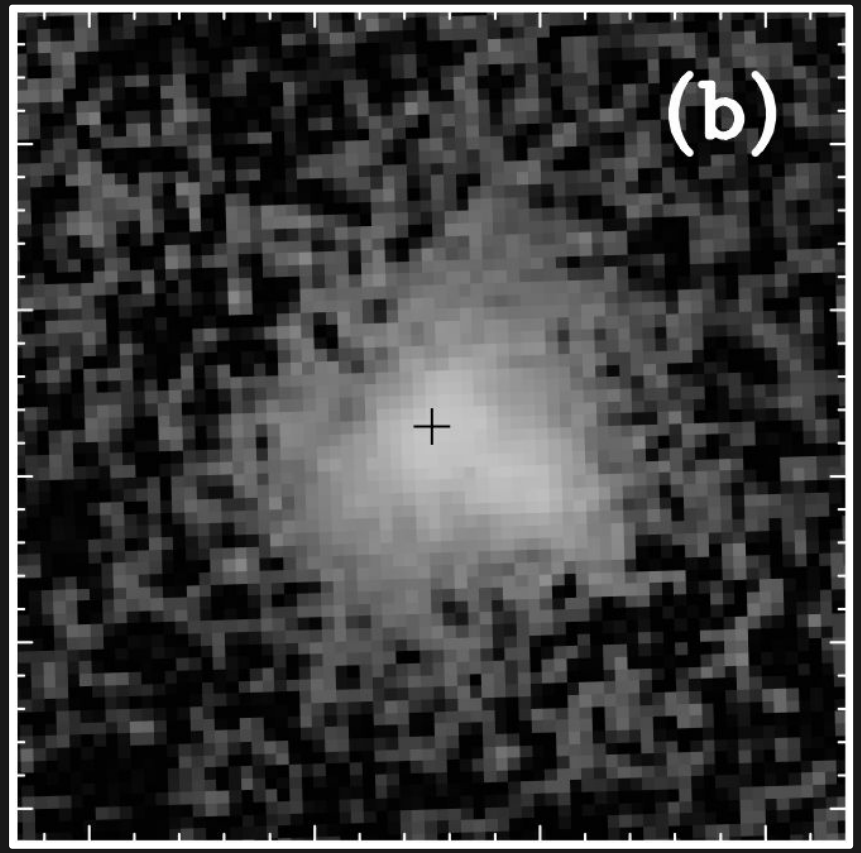
J. Hernández-Yévenes [1,⋆], D. B. Fisher [1,2], B. Mazzilli Ciraulo [1,2], R. L. Davies [1,2], M. Martig [3], A. Fraser-McKelvie [4,2], J. van de Sande [5,2], M. R. Hayden [6], R. Elliott [1,2], E. Emsellem [6], F. Combes [7], A. D. Bolatto [8], J. Bland-Hawthorn [9,2], L. Cortese [10,2], T. A. Davis [11], B. Catinella [10,2], L. M. Valenzuela [12], S. M. Croom [10], S. A. Fortuné [12], L. A. Silva-Lima [13], C. López-Cobá [6], A. Mailvaganam [14,15,2] and G. van de Ven [16]

SUBMITTED

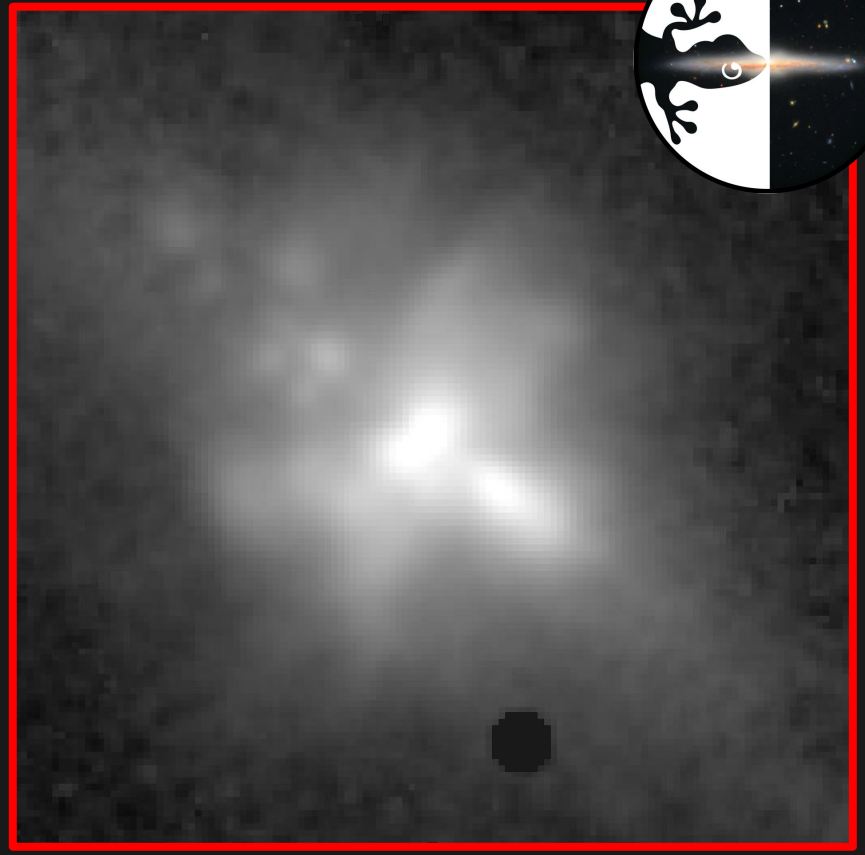
Ideal Laboratory:
ESO 484-036

Type	Starburst, Edge-on
Distance	68.7 Mpc
Inclination (i)	~87.5°
Stellar mass (M_*)	$\log(M_*/M_\odot) = 10.64$
SFR	8.7 $M_\odot$ yr^{-1}

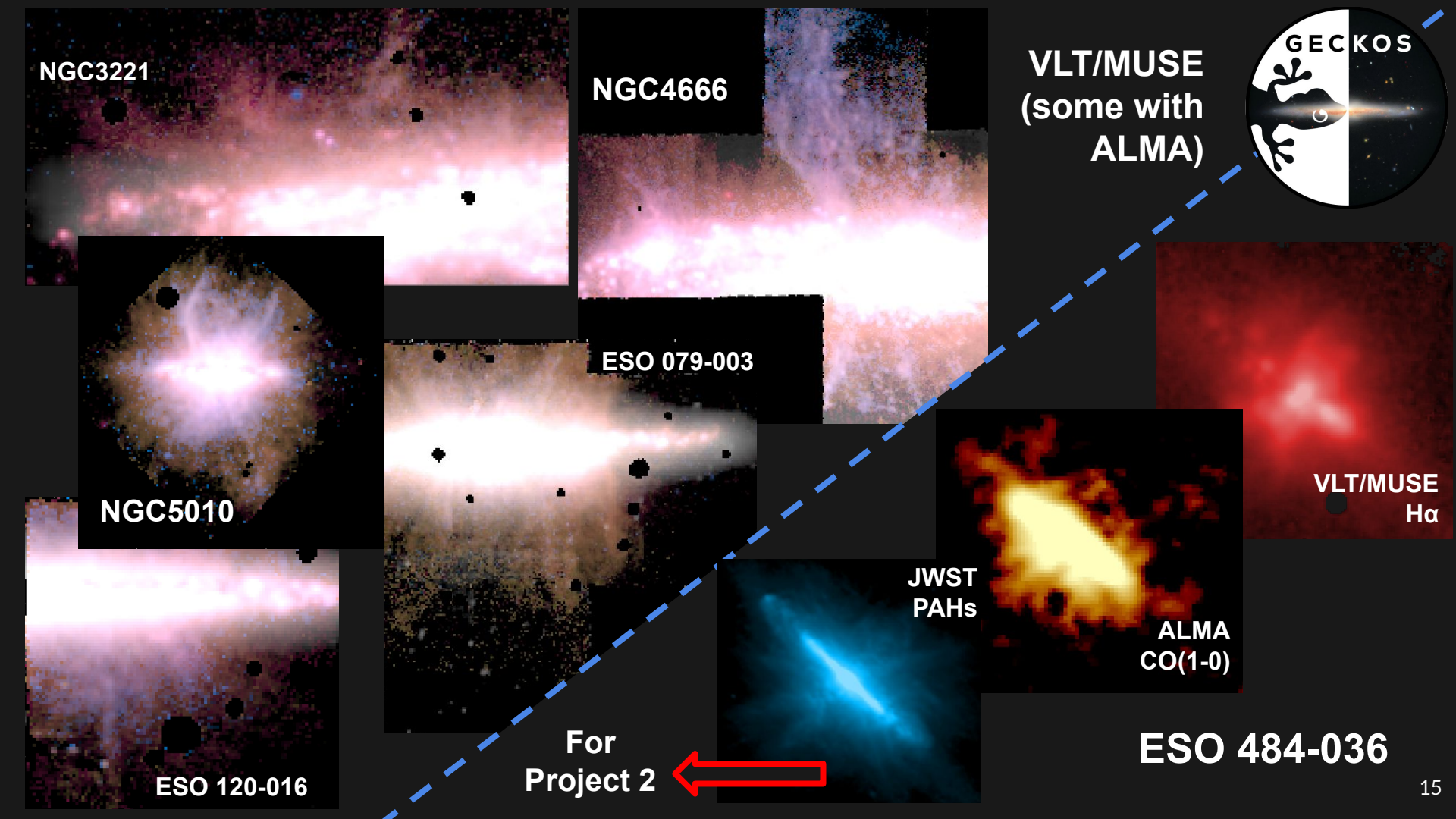




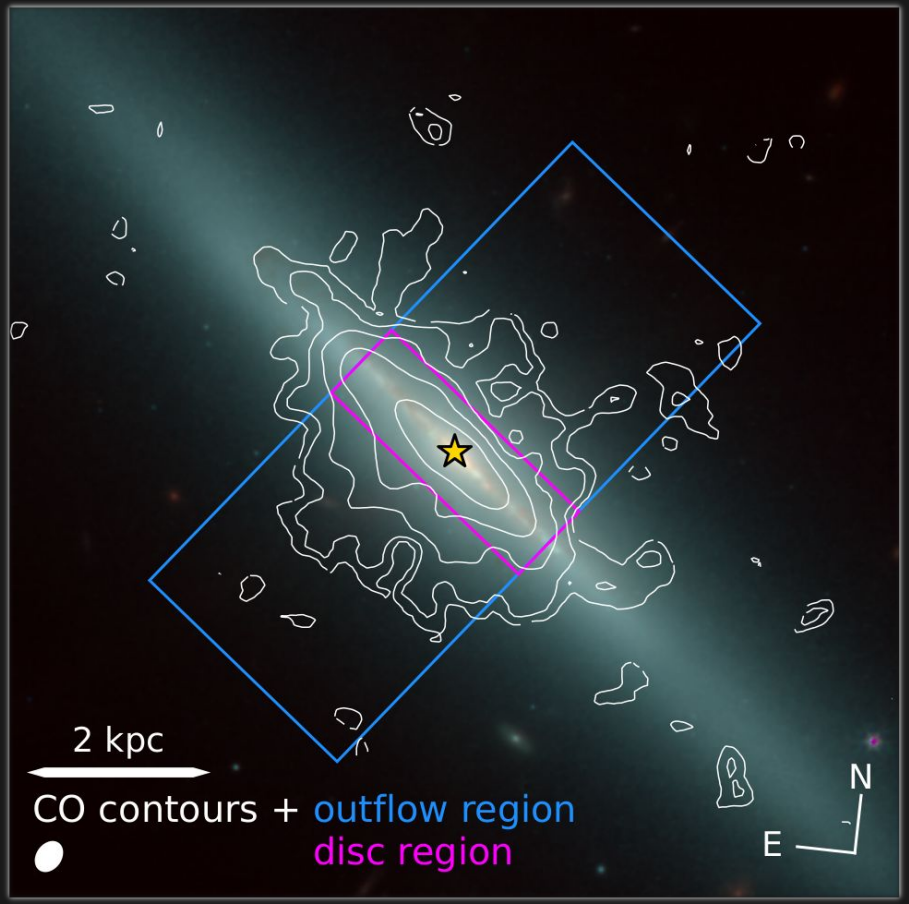
Veilleux+(2003)

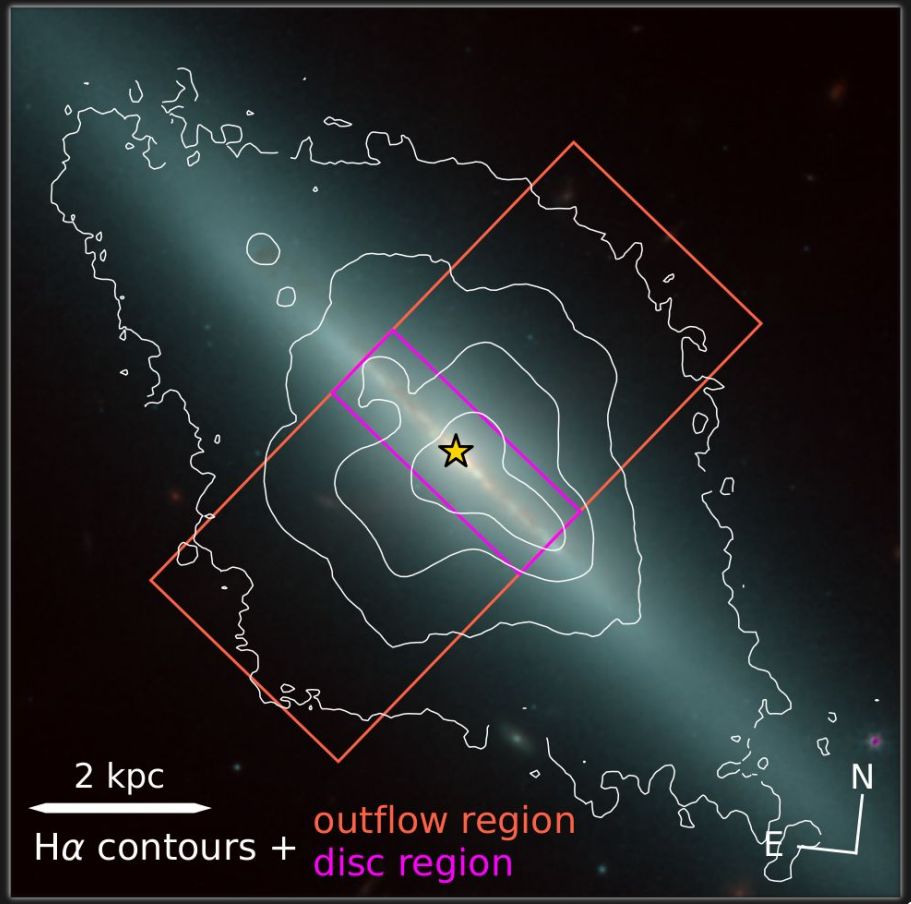


Hernández-Yévenes+(submitted)

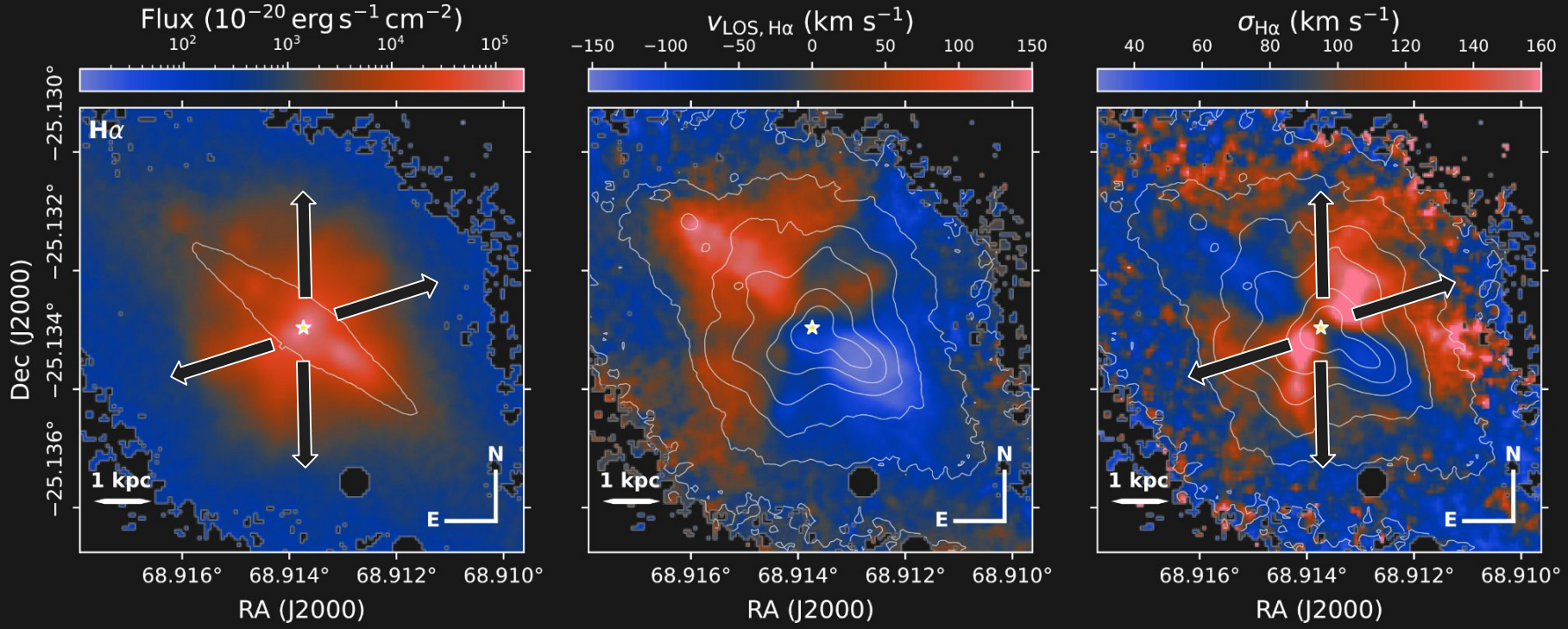

NGC3221
NGC4666
VLT/MUSE
(some with
ALMA)
GECKOS
NGC5010
ESO 079-003
VLT/MUSE
Hα
JWST
PAHs
ALMA
CO(1-0)
ESO 120-016
For
Project 2
ESO 484-036

Extraplanar emission detected with CO and Hα





Hα flux and kinematic maps

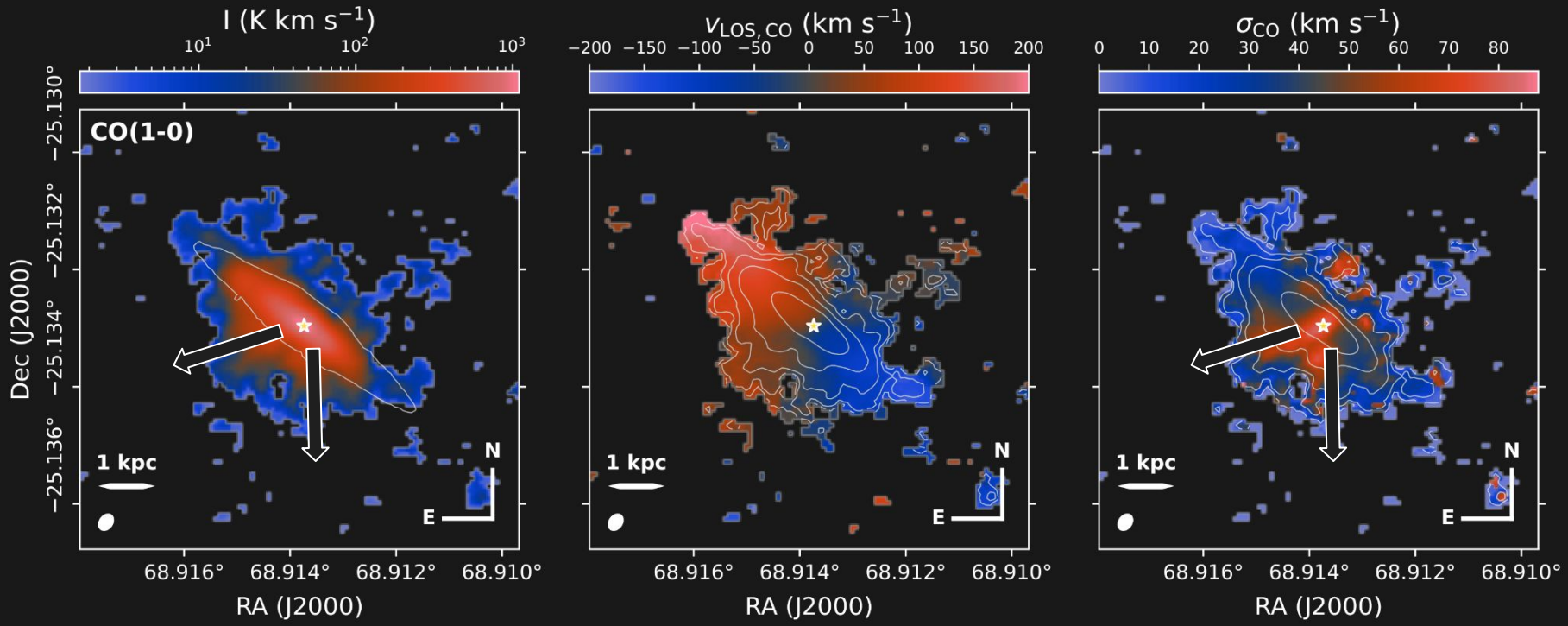


Clear extraplanar emission at both sides of the midplane

Clear orientation of the galaxy inclination

Biconical kinematic structure

CO(1-0) moment maps

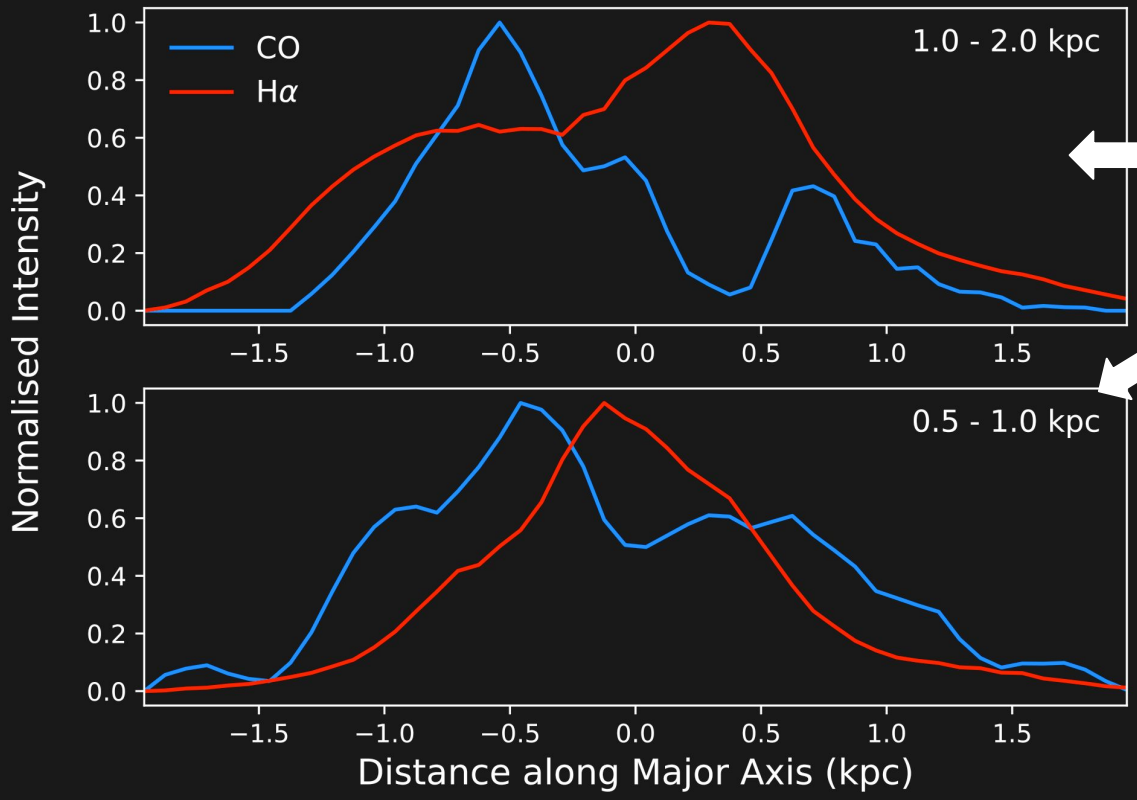


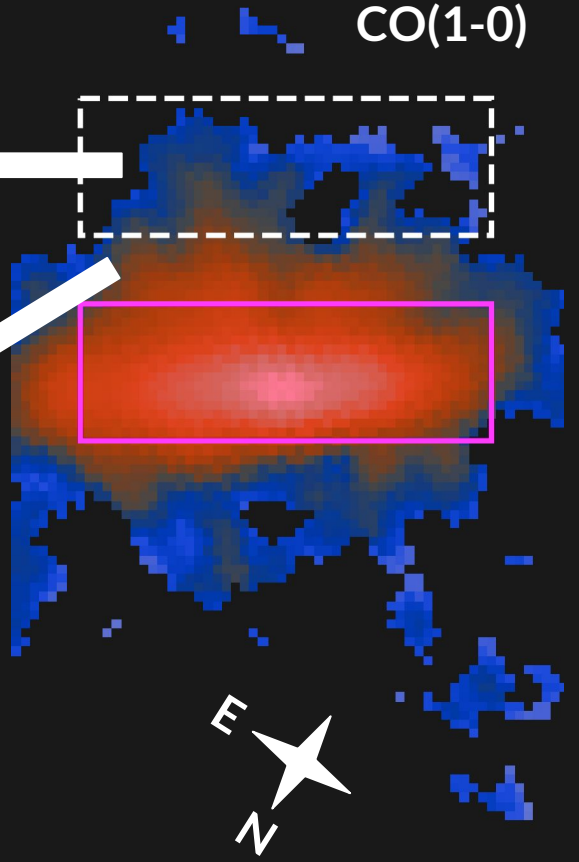
Clear extraplanar emission south of the disc

Rotation in the extraplanar emission

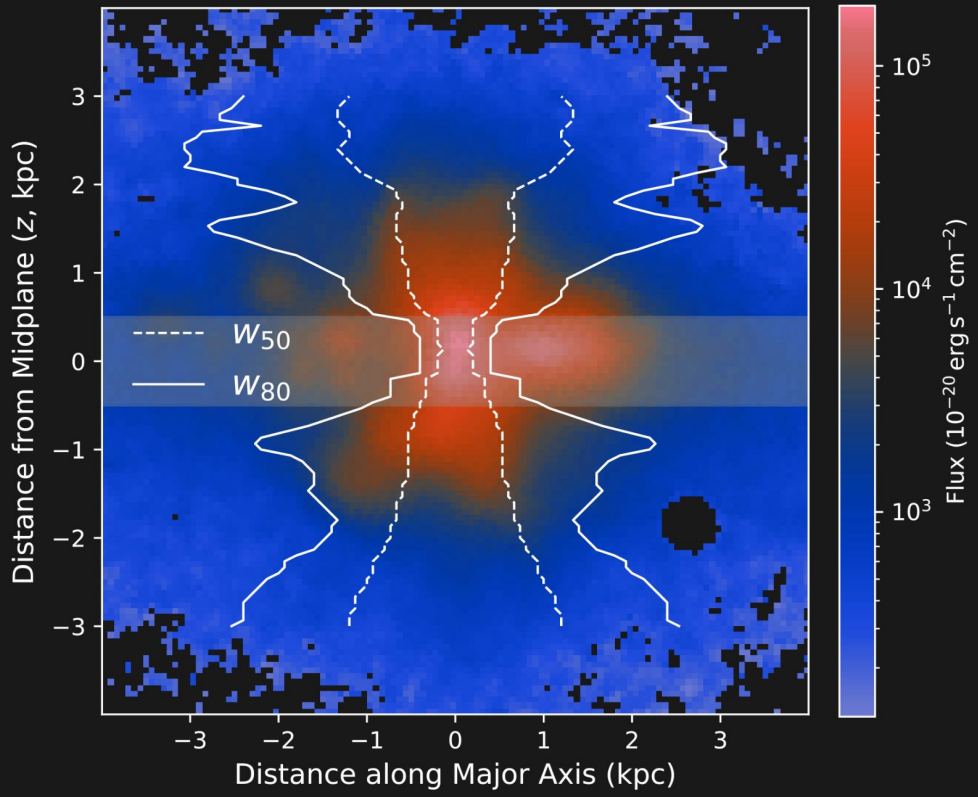
V-shape kinematic structure at south of the disc

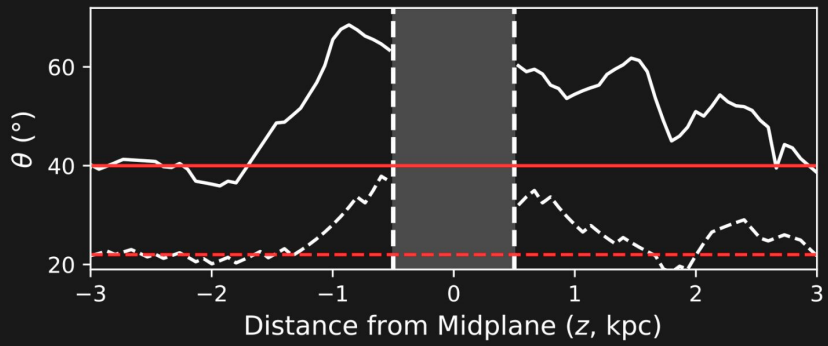
Spatial anti-correlation between CO and Hα

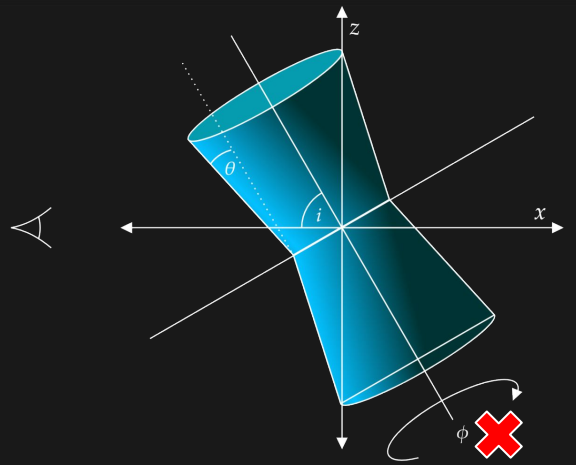




Constraining geometry of the outflow



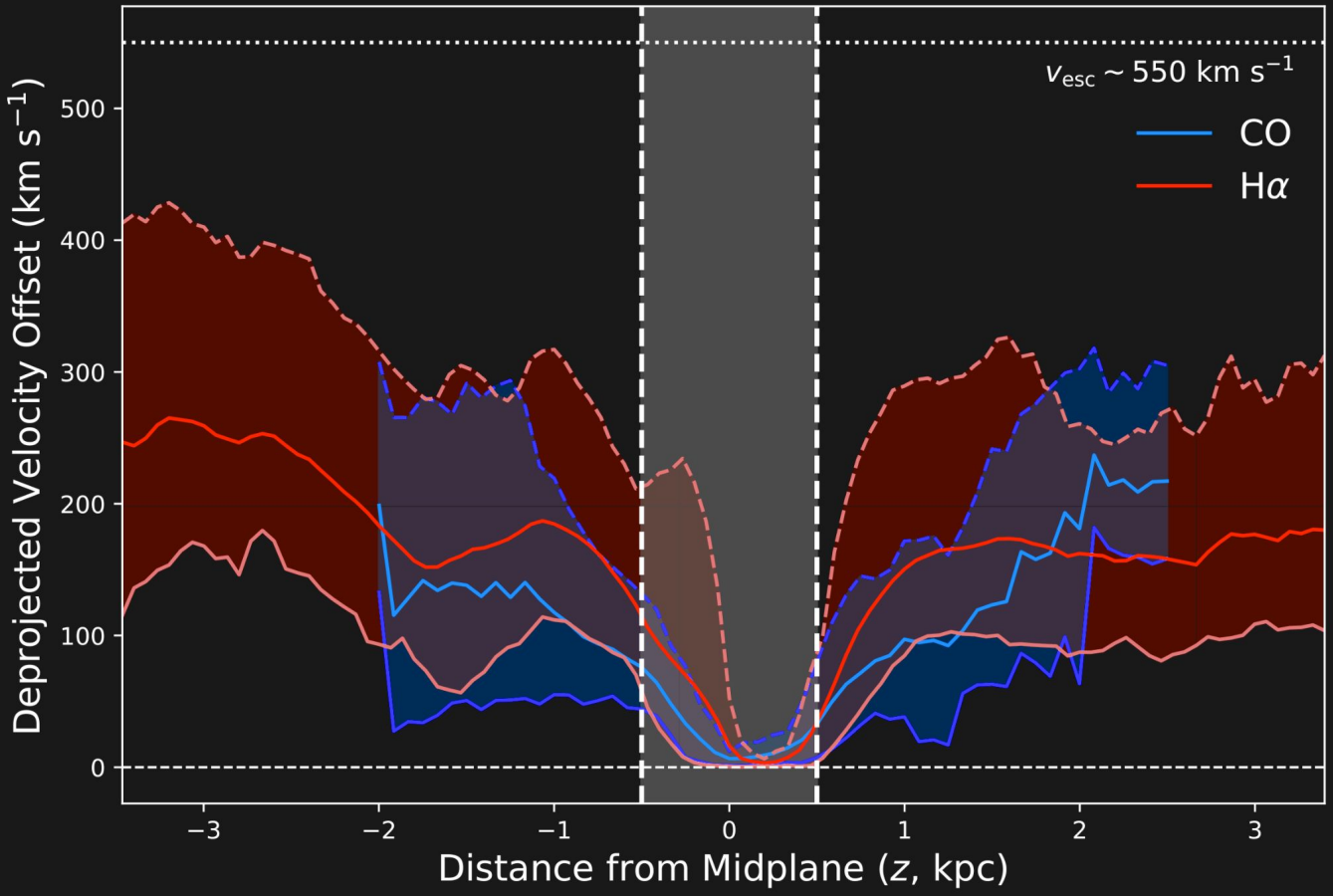




i = 87.5°

θ = 22° – 40°

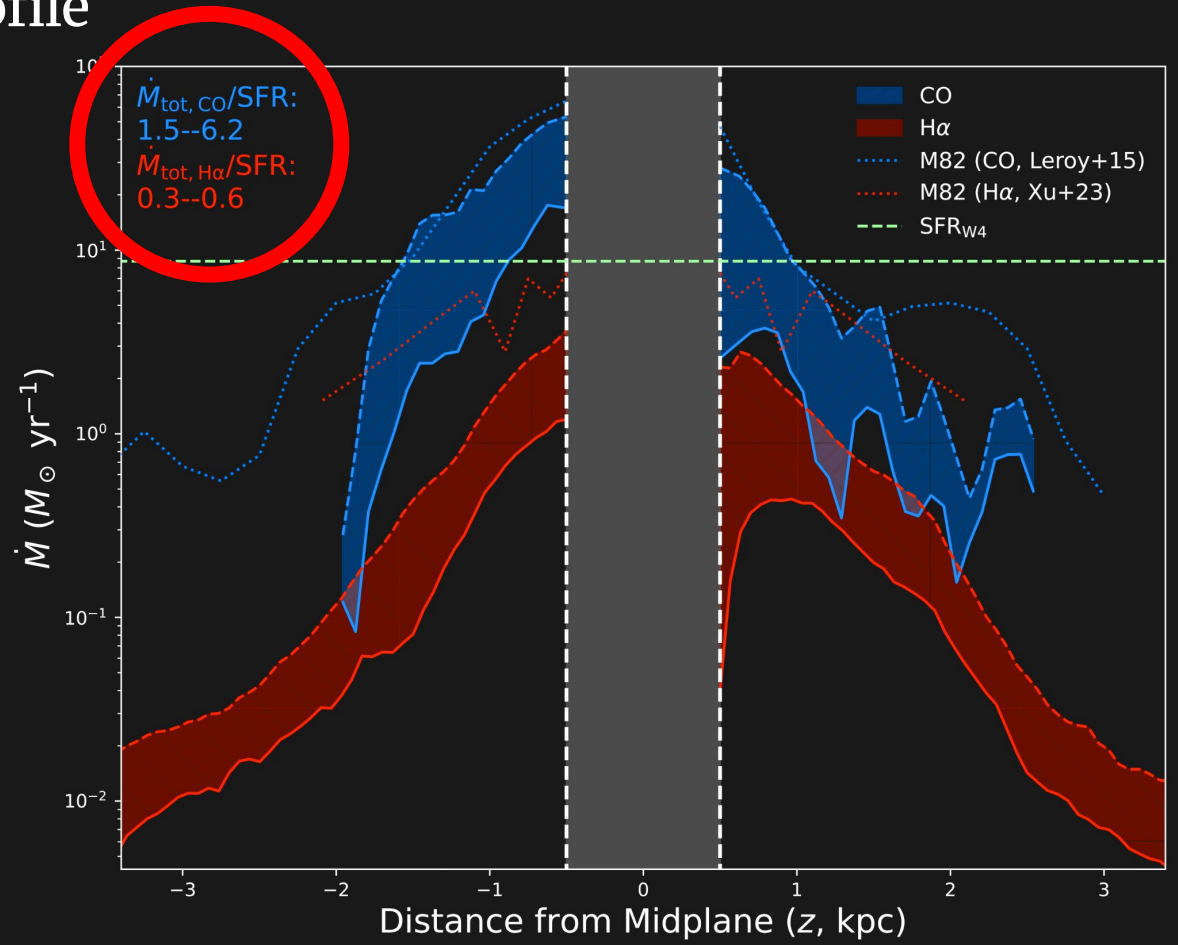
Velocity profiles of the outflow



Outflow mass rate ($\dot{M}$) profile

$$\dot{M} = \frac{M_{\rm gas} \cdot v_{\rm out}}{z} \; [\mathrm{M}_\odot \; \mathrm{yr}^{-1}]$$

$$\eta_M \sim 7$$



Energy and momentum flux ($\dot{E}$ and $\dot{p}$)

$$\dot{E} = \frac{M_{\rm gas} \cdot v_{\rm out}^3}{z} \ [\rm erg\ s^{-1}]$$

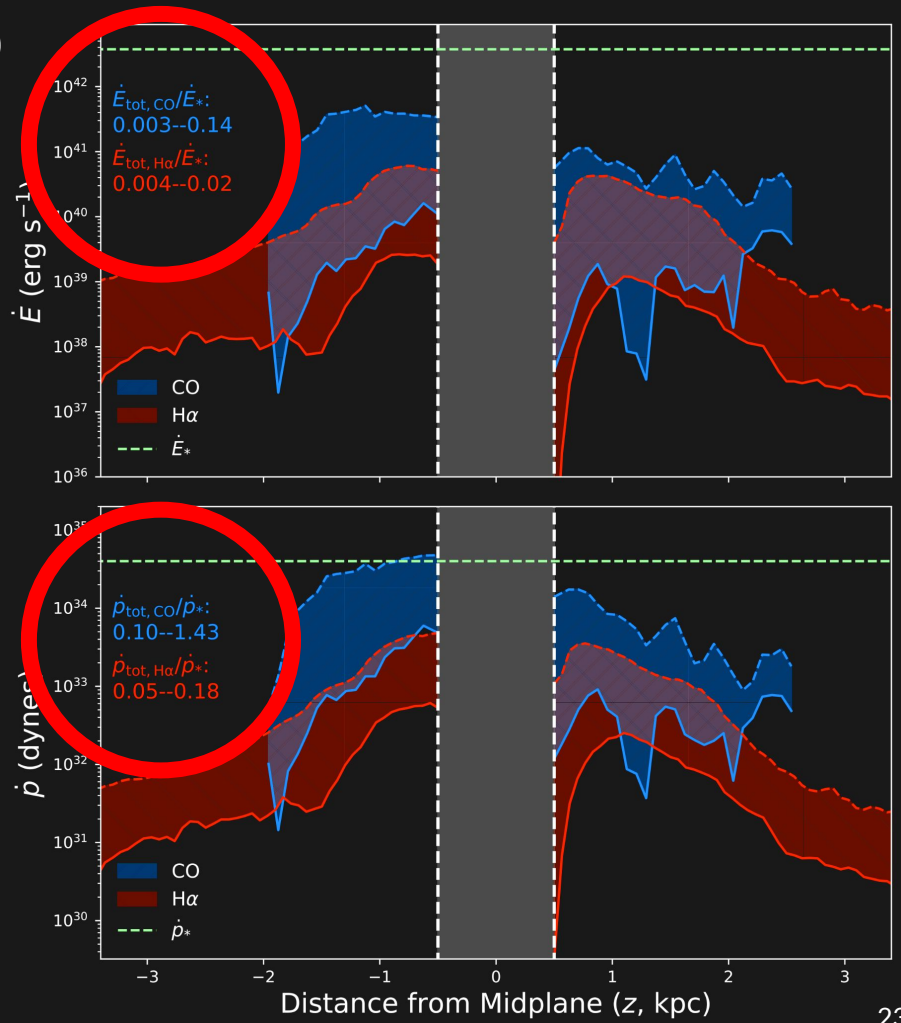
$$\dot{p} = \frac{M_{\rm gas} \cdot v_{\rm out}^2}{2 \cdot z} \ [\rm dynes]$$

$$\eta_E \lesssim 0.4 \Rightarrow \text{Starburst!}$$

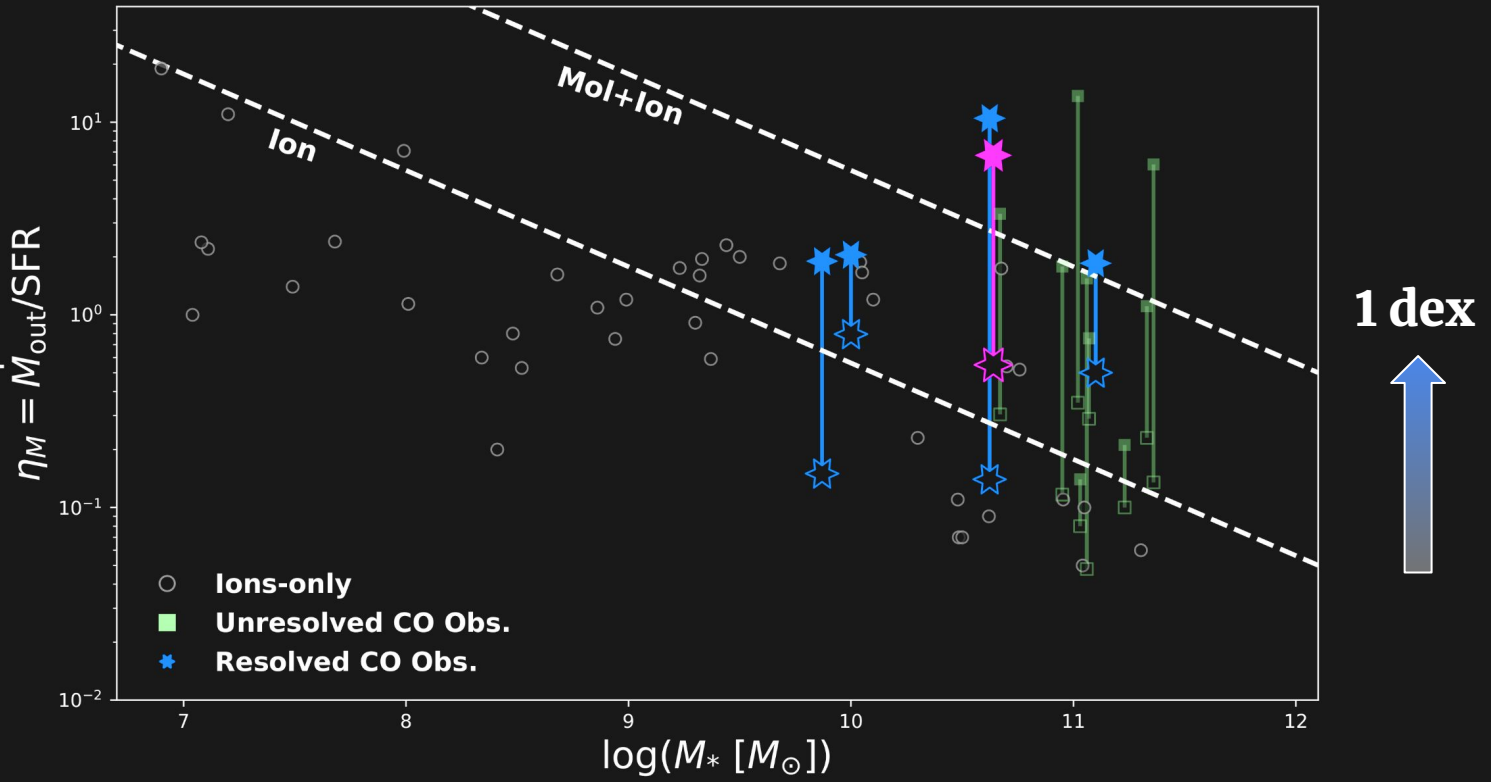
(Chisholm+2017, Cronin+2025)

$$\eta_p \lesssim 1 \Rightarrow \text{Starburst!}$$

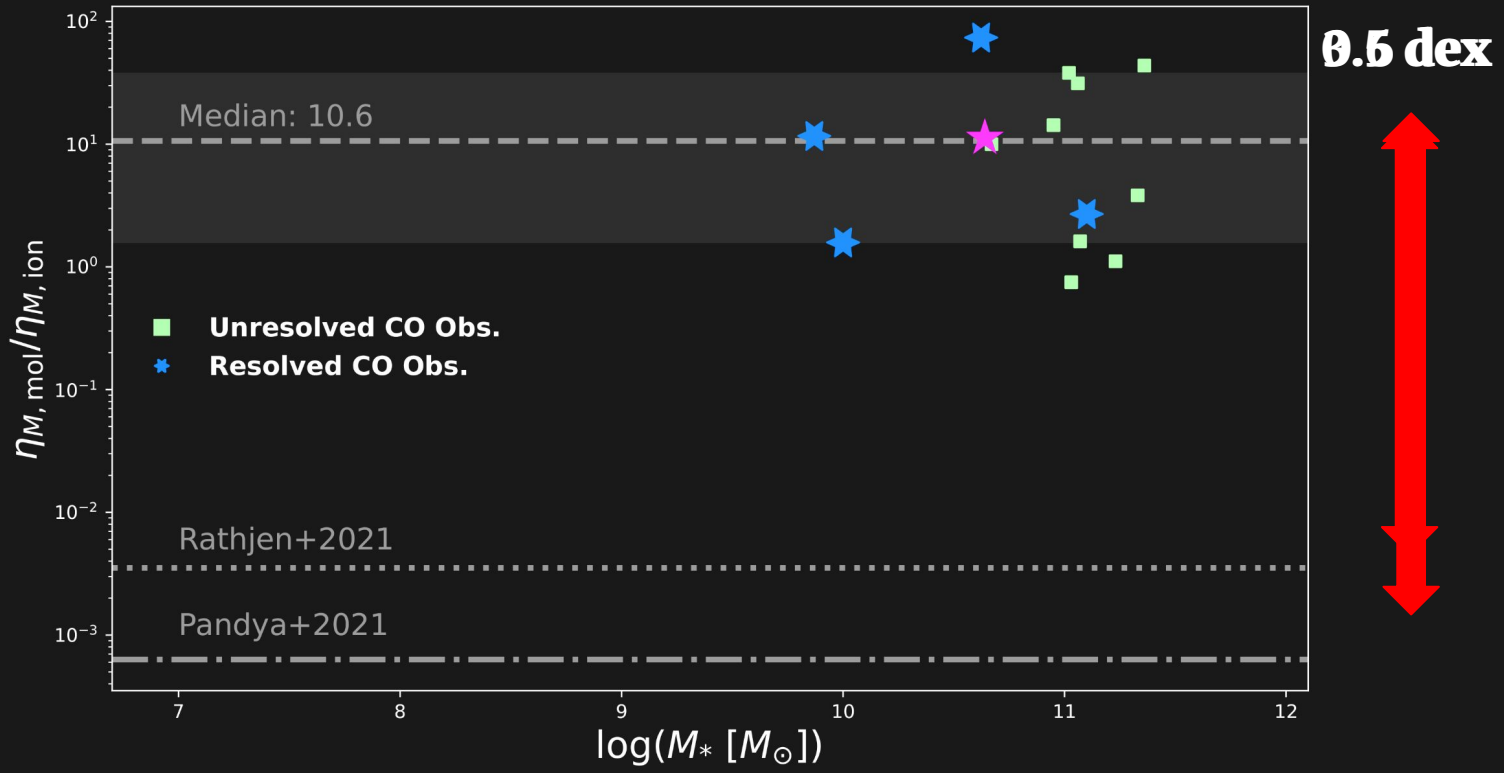
(Hopkins+2012, Chisholm+2017)



Comparison with theoretical expectations

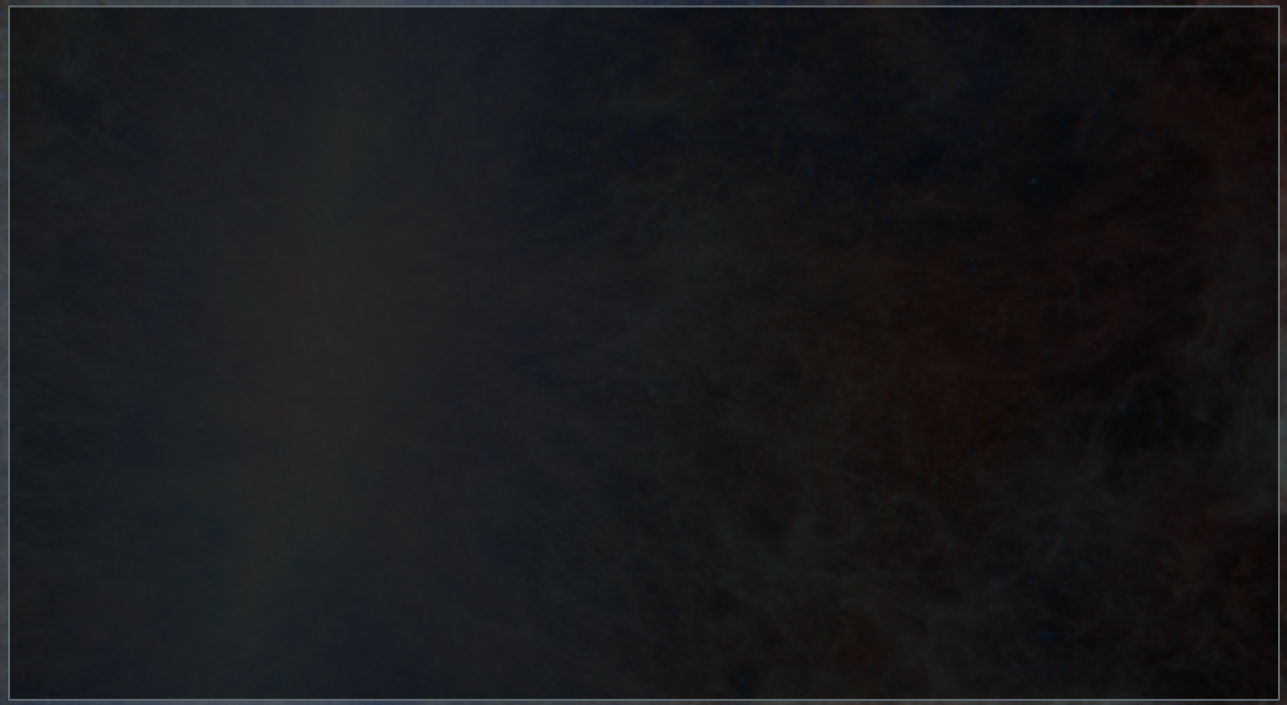


Comparison with theoretical expectations



Confirmation of Candidature:

Cold Gas in Outflows



Thanks for your attention!