# ESO in the 2020s: the “bright” mm/sub-mm future

Claudia Cicone
University of Cambridge

# Relevant questions in extragalactic astronomy

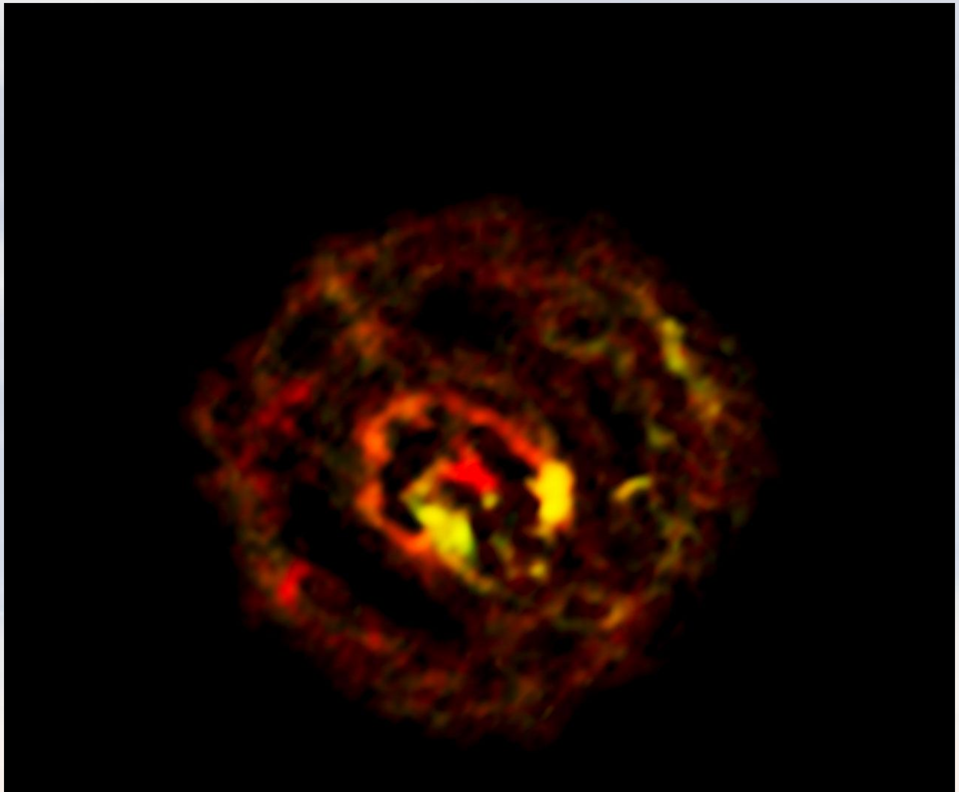
## *1. Feedback*

- What are the feedback mechanisms regulating (or "quenching") star formation in (different types of) galaxies?
- What is the role of AGNs in galaxy evolution?

## *1. Early Universe*

- How do high redshift galaxies look like?
- How does feedback work in the early Universe?

# 1. Feedback: why to use ALMA?



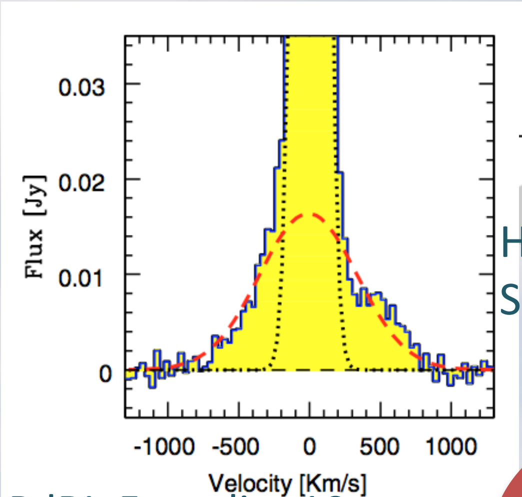
Molecular gas and outflow in NGC 1433
Credit: ALMA / F. Combes

**Molecular gas** is the key!

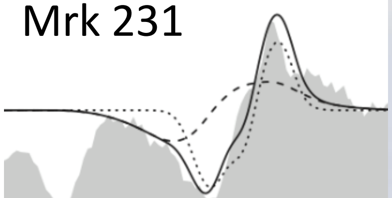
1. Primary ingredient for star formation
2. Dominates ISM mass of massive, star forming galaxies

Any mechanism affecting cold $H_2$ would naturally affect the galaxy's capability of forming new stars

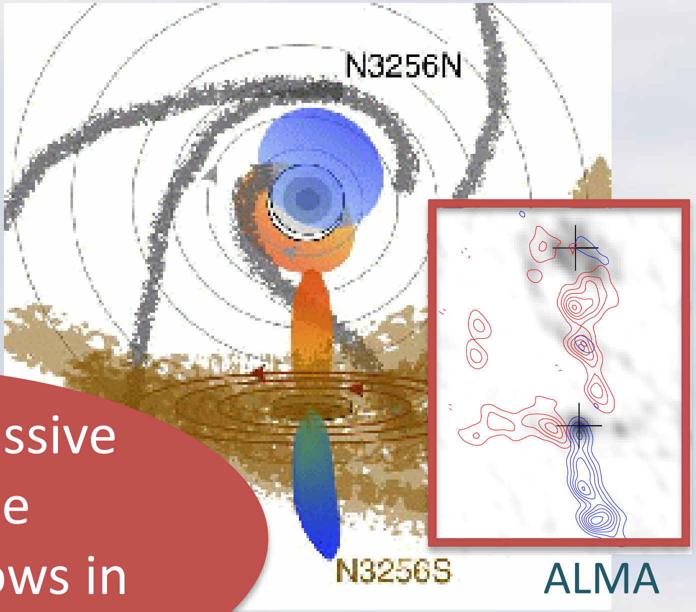
# 1. Feedback revealed by $H_2$ outflows




PdBI, Feruglio+10, Cicone+12

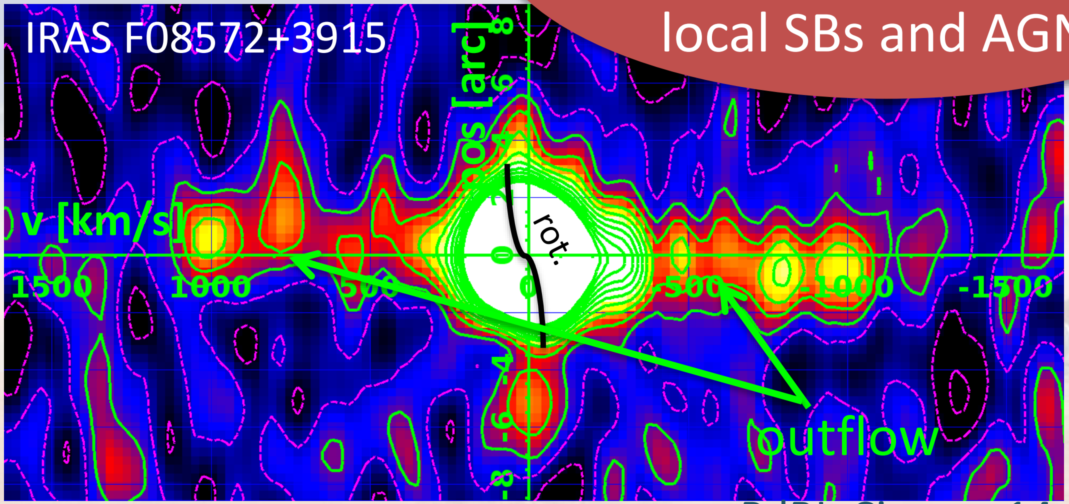



Herschel, Fischer+10
Sturm+11




ALMA
Sakamoto+14

Discovery of massive and kpc-scale molecular outflows in local SBs and AGNs

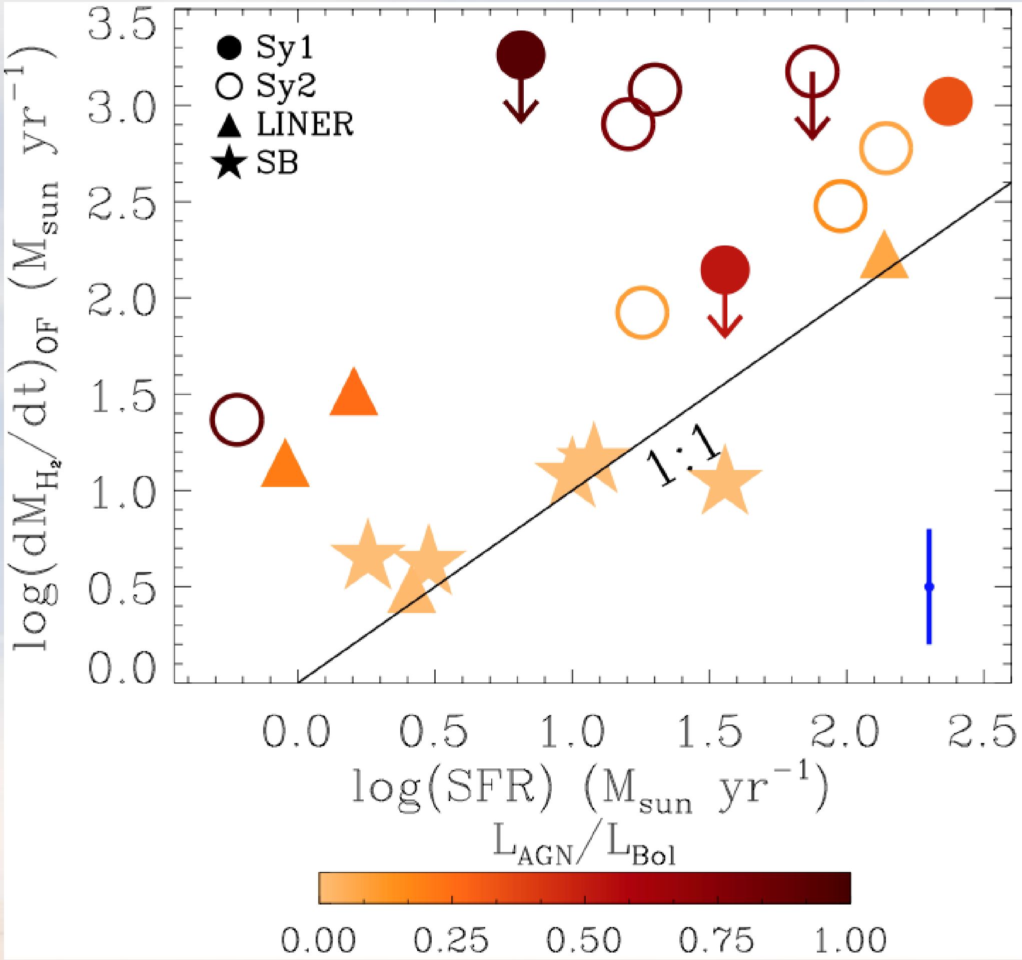



PdBI, Cicone+14

Rapidly expanding field!

See also: Alatalo+11,+15, Aalto+12,+15, Aalto+14, Bolatto+13, Combes+13, Dasyra+12,+14, Veilleux+13, Spoon+13, Feruglio+13, Morganti+13, Sun+14, Gonzalez-Alfonso+14, Tunnard+15

# 1. Feedback revealed by $H_2$ outflows



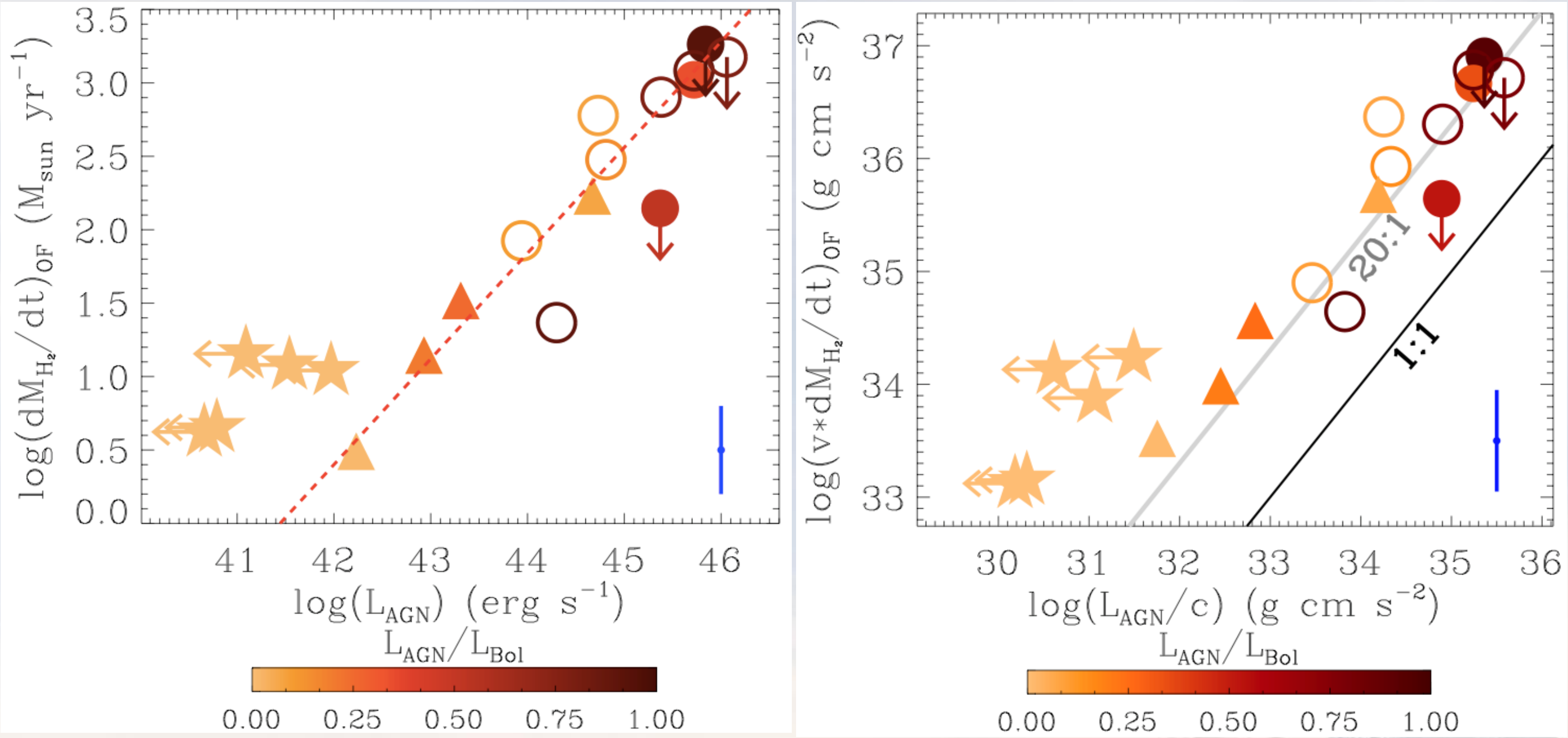

Cicone+14

## Outflow mass-loss rate vs SFR

1. Starburst-dominated galaxies: outflow rate and SFR comparable (wind mass loading factor η~1)

1. Outflow rates strongly **"boosted"** by the presence of an AGN (increases with $L_{AGN}/L_{bol}$)

# 1. Feedback revealed by $H_2$ outflows




Outflow rate correlates with $L_{AGN}$ in AGN hosts
-> AGN-driven outflows?

Outflow momentum rate vs $L_{AGN}/c$

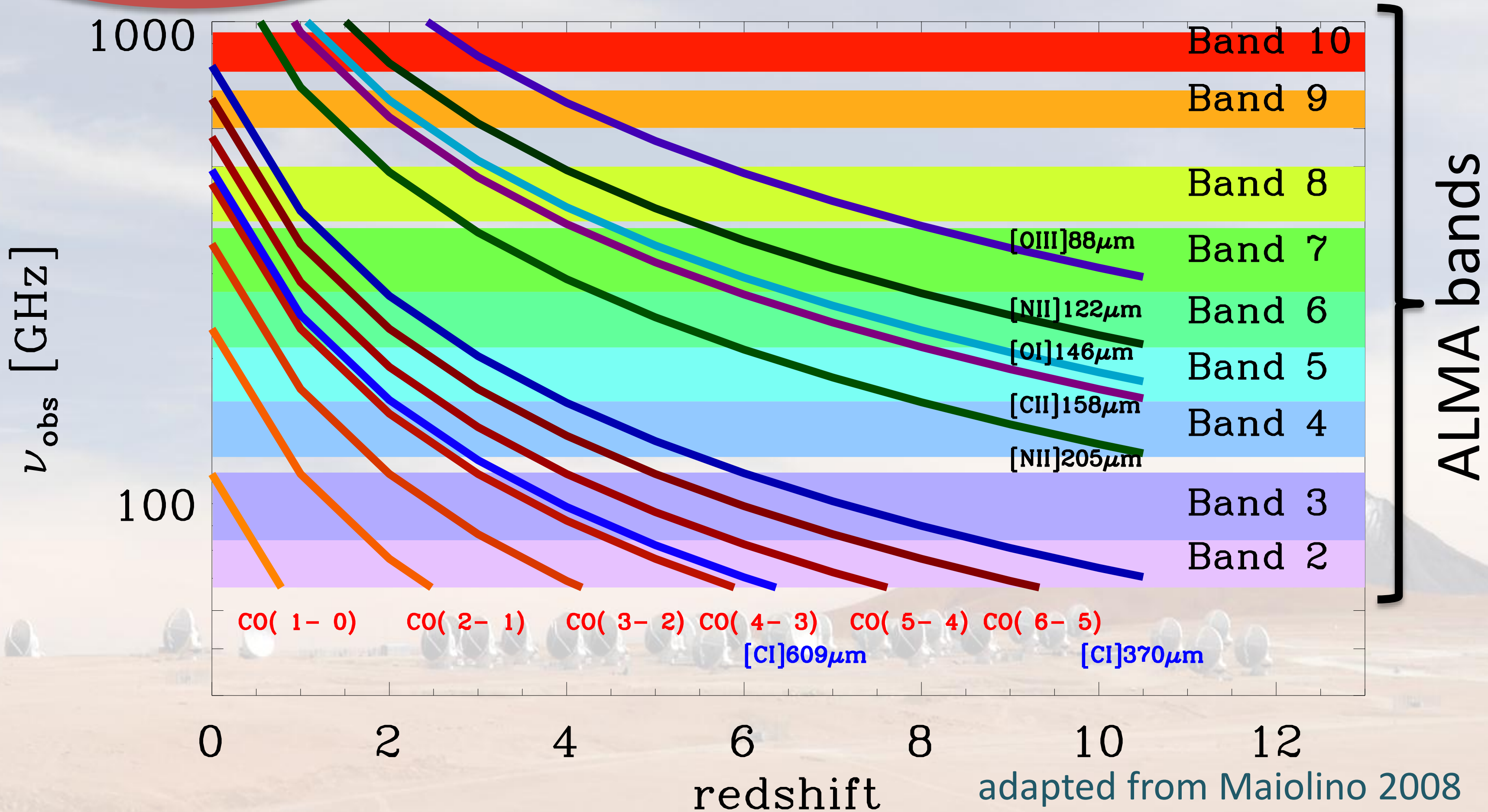
**$M_{OUT}$ v ~ 20 $L_{AGN}/c$**

Cicone+14

# 2. The early Universe: why mm/sub-mm wavelengths?

Synergy with ZEUS-2@APEX

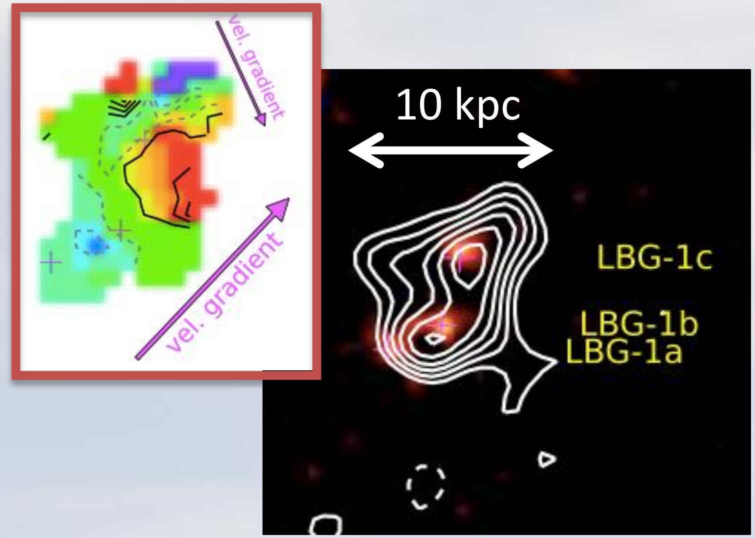
FIR fine structure lines are extremely promising ISM tracers at high redshift



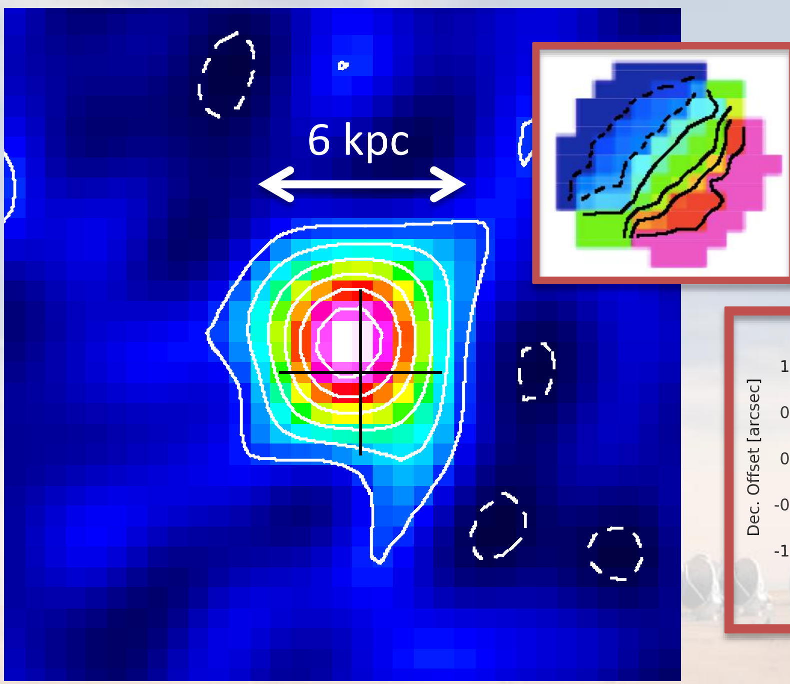

adapted from Maiolino 2008

# 2. The early Universe as seen by ALMA

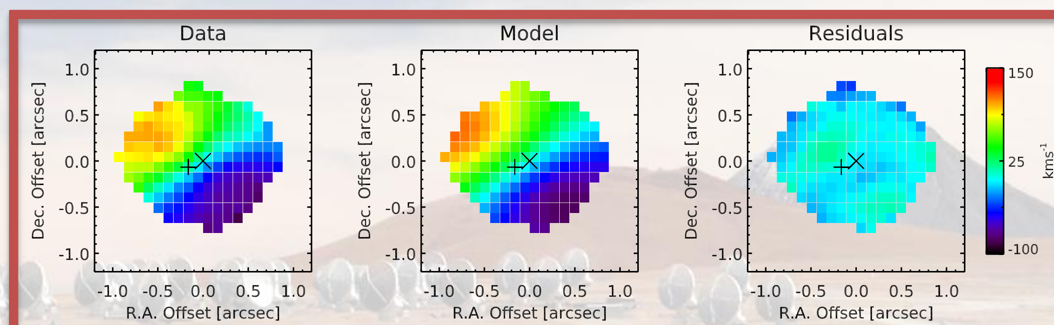
ALMA [CII] observations *resolve* kinematics of primordial galaxies




“typical” star forming galaxy at z=5.3, Riechers+14

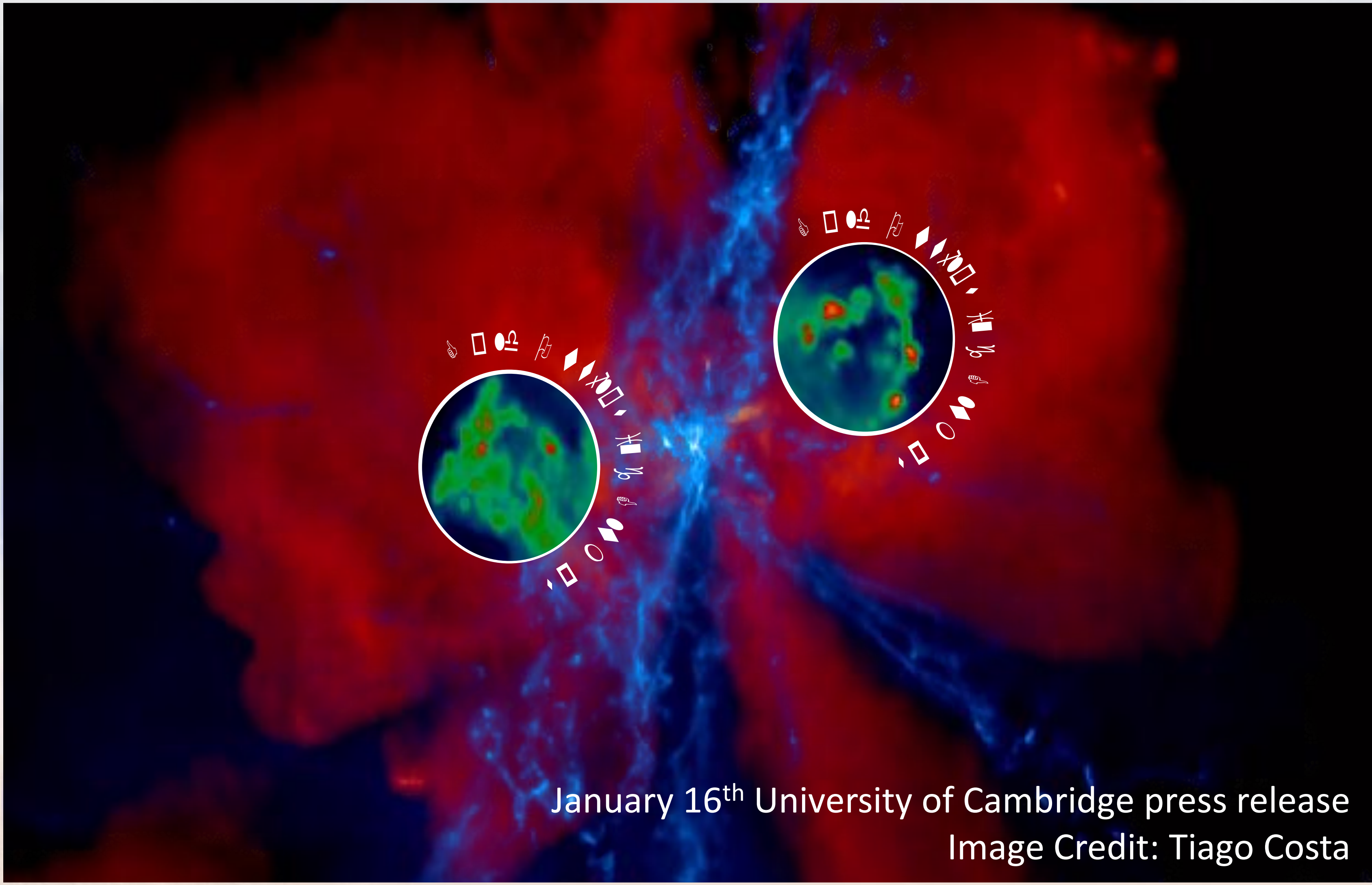



A quasar at z=6.1, Wang+13



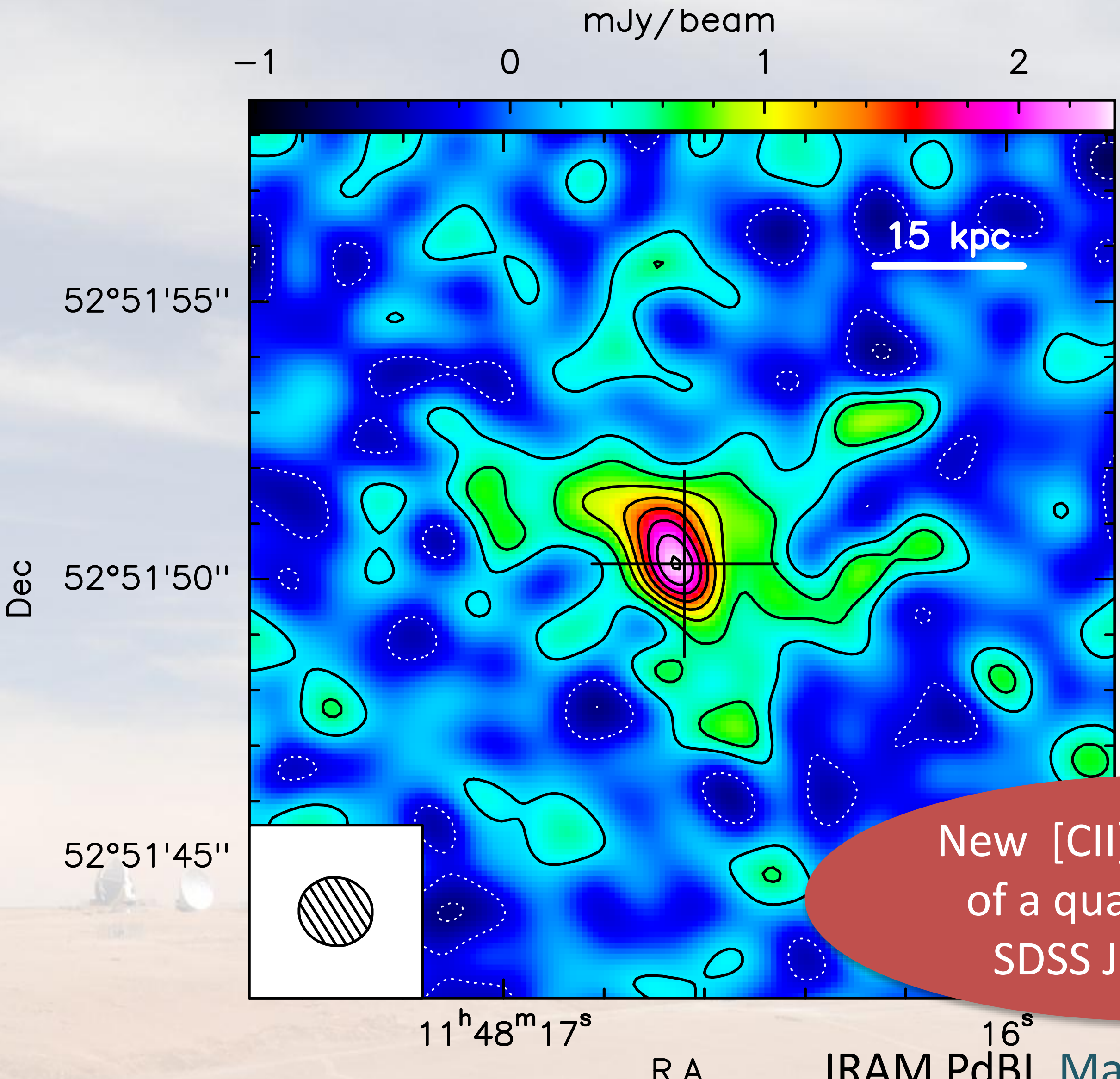

Turbulent rotating disk in a galaxy at z=4.8 De Breuck+14

# Galactic ‘hailstorm’ in the early Universe



January 16th University of Cambridge press release
Image Credit: Tiago Costa

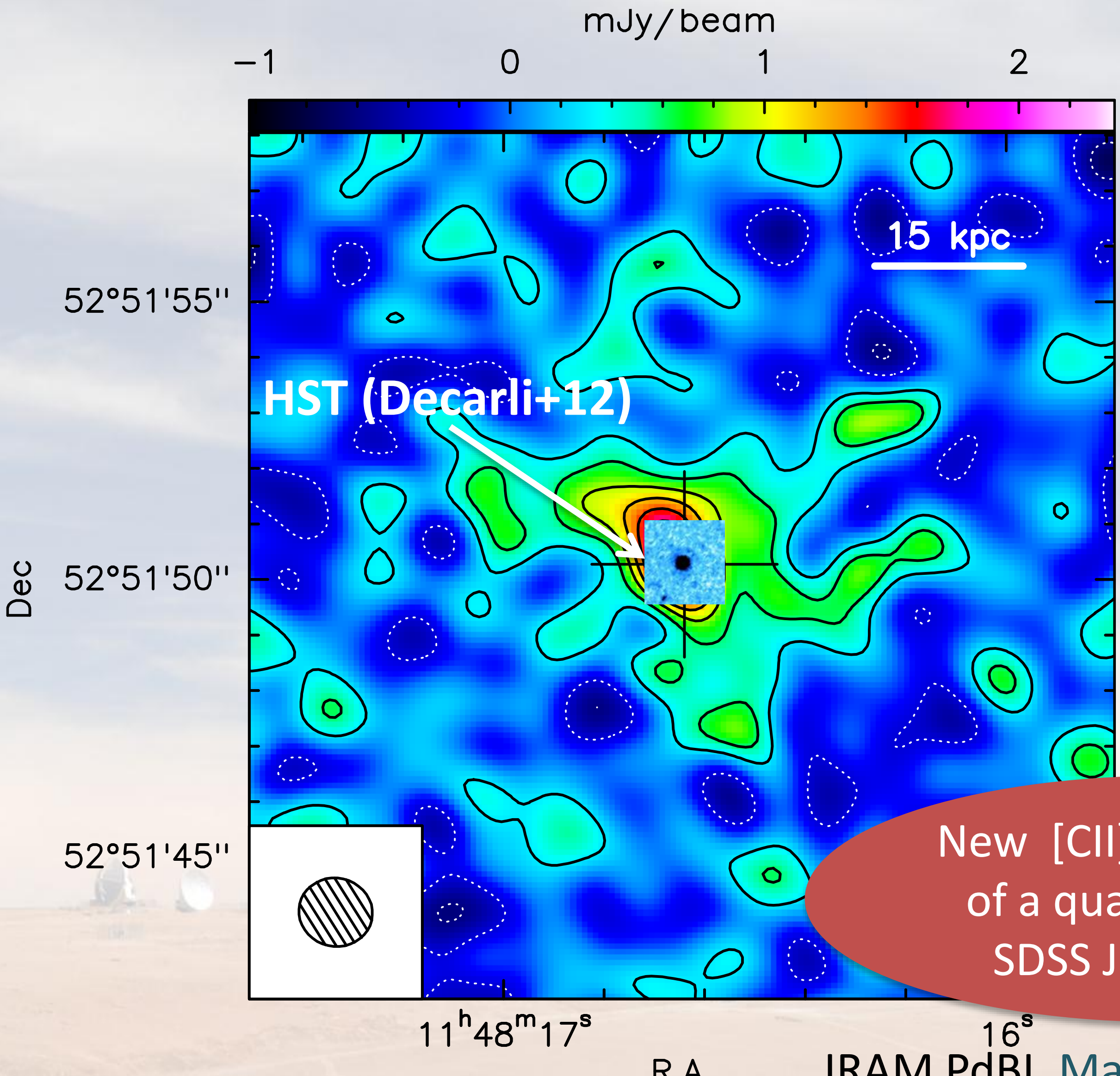
# "Galactic hailstorm in the early Universe"




New [CII] observations of a quasar at z=6.4, SDSS J1148+5251

IRAM PdBI, Maiolino+12 Cicone+15

# "Galactic hailstorm in the early Universe"



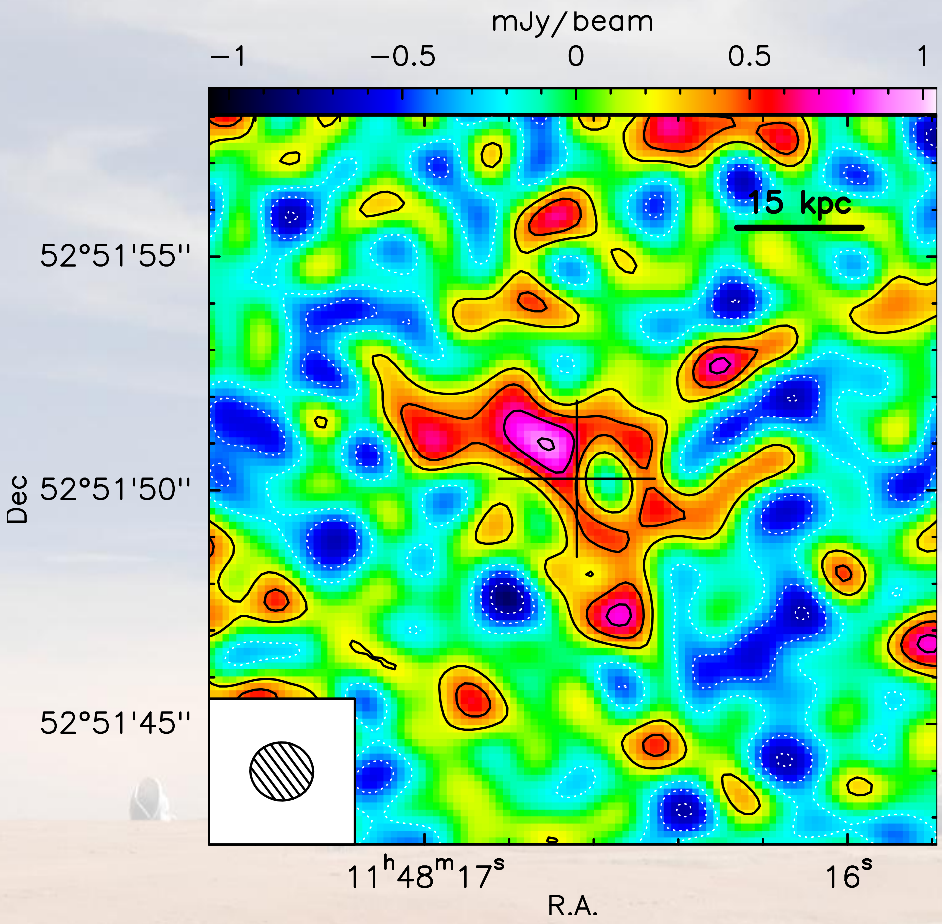

[CII] map reveals incredibly extended structures

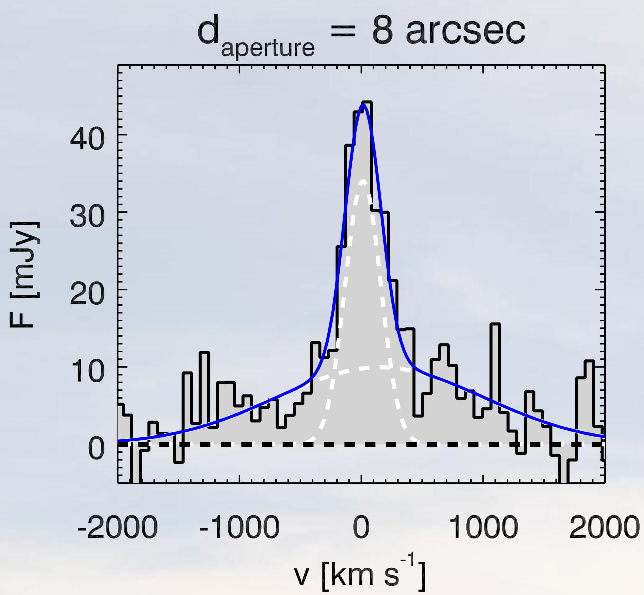
New [CII] observations of a quasar at z=6.4, SDSS J1148+5251

IRAM PdBI, Maiolino+12 Cicone+15

# “Galactic hailstorm in the early Universe”

*Resolved* gigantic [CII] outflow extended up to r ~ 30 kpc !!!

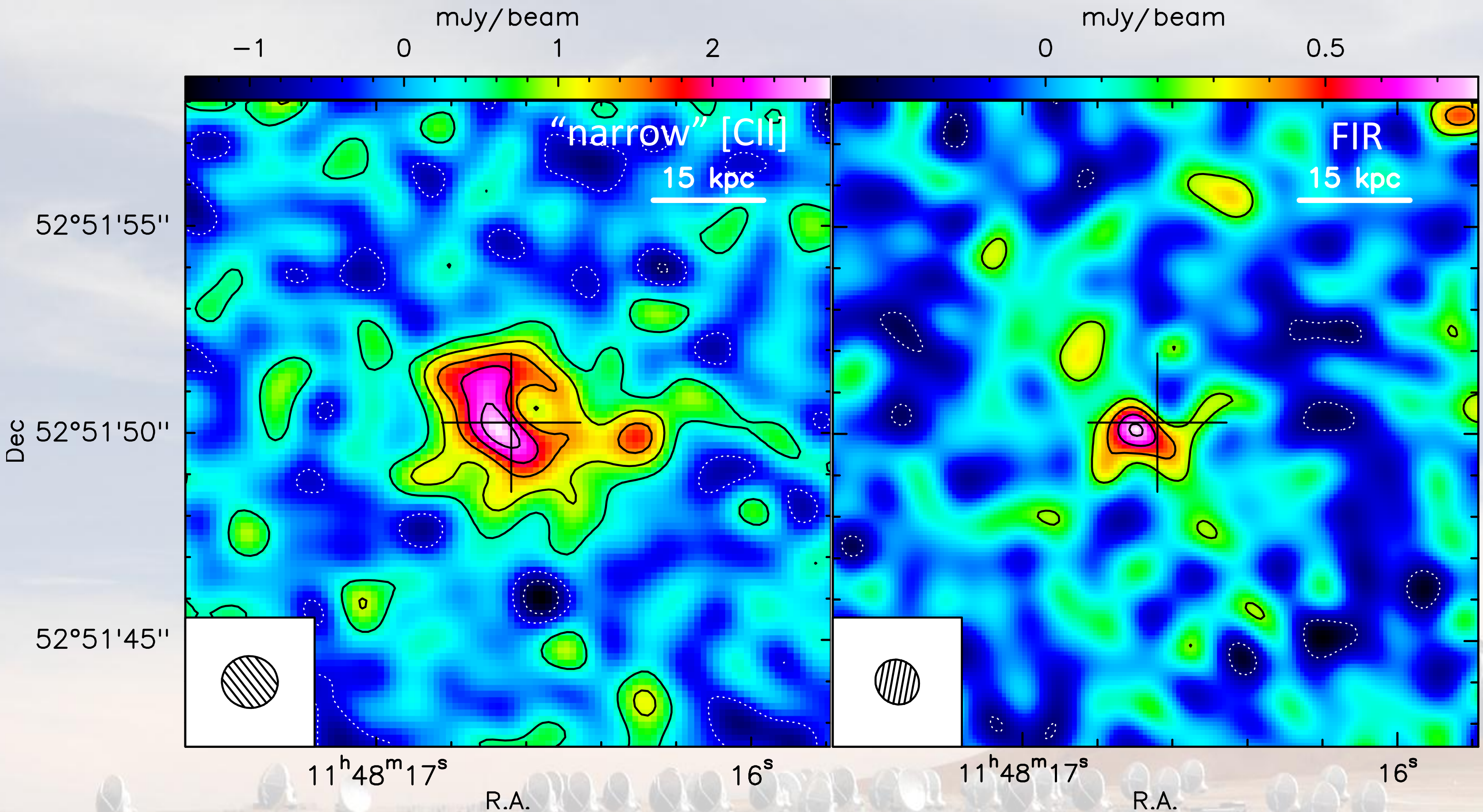



High velocity and spatially extended “cool” outflows likely result from synergy between SNe explosions and powerful quasar-mode feedback

Maiolino+12, Cicone+15, Costa+15

# How does its host galaxy look like?




Surprisingly extended *quiescent* [CII] emission and FIR continuum
-> large masses of cold gas in the halo (+ star formation on large scales)

Cicone+15

# Conclusions

1. Observations at mm/sub-mm wavelengths with ALMA and APEX will play a key role in extragalactic astronomy in the next years

1. ALMA observations of cold molecular gas will provide new constraints on SF/AGN feedback theories

1. ALMA and APEX observations of cool ISM via atomic FIR fine structure lines will considerably advance our understanding of the early Universe