Cold molecular CO(1-0) gas in the halos of high-z radio galaxies

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MARIE CU

SEVENTH FRAMEWORK PROGRAMME

GOBIERNO DE ESPAÑA

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CENTRO DE ASTROBIOLOGÍA

Asociado al NASA Astrobiology Institute

High-redshift radio galaxies

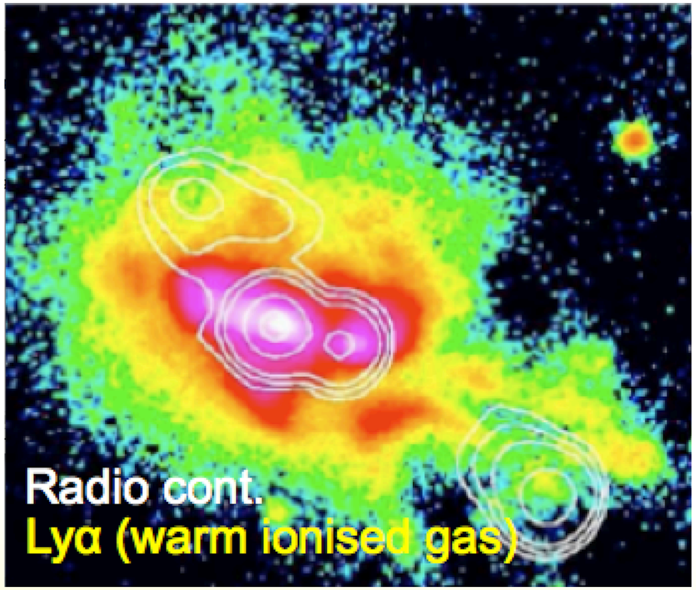
- The edge of the Universe in mid-1990's:

  - HzRGs among the most distant objects known
    Strong radio continuum beacon for faint host galaxy *(e.g. Röttgering+ '97)*

  - HzRGs have quasar-core shielded by torus
    Relatively easy to study the host galaxy

  - HzRGs most massive galaxies in Universe *(Seymour+ '07, De Breuck+ '10)*
    ancestors of giant central-cluster ellipticals
    (e.g. Venemans+ '07, Hatch+ '14)

- The edge of the Universe now:
  HzRGs not the highest-z objects,
  but among *best studied* high-objects



4C41.17 (*z* = 3.8)
(Reuland et al. 2003)

High-redshift radio galaxies

Cold molecular gas → raw ingredient SF & galaxy evolution

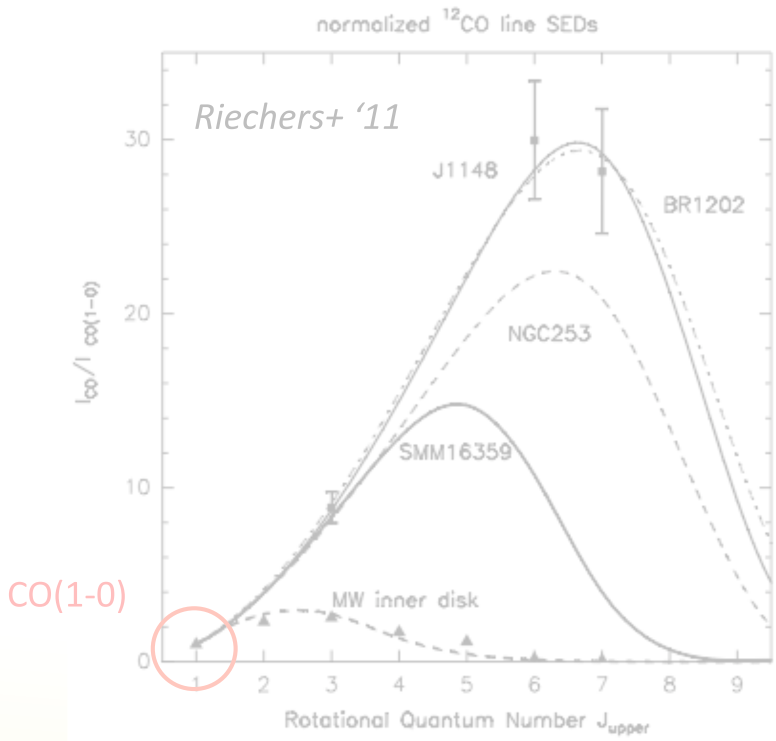
CO detected in individual in HzRGs *(Miley & De Breuck 2008)*

- *found on scales of tens of kpc (e.g. Papadopoulos+ '00)*
- *associated with mergers/companions (Ivison+ '12)*
- *detected in giant Lyα halos (Nesvadba+ '09)*
- *aligned with radio jets (Klamer+ '04, Emonts+ '14)*

Limitations:

- *Single objects, pre-selected on IR-luminosity*
- *Higher-order CO(J,J-1) transitions (>80GHz)*
  → denser gas in SF/AGN regions

CO(1-0) most robust tracer molecular gas
(incl widespread, low-density, subthermally–excited)



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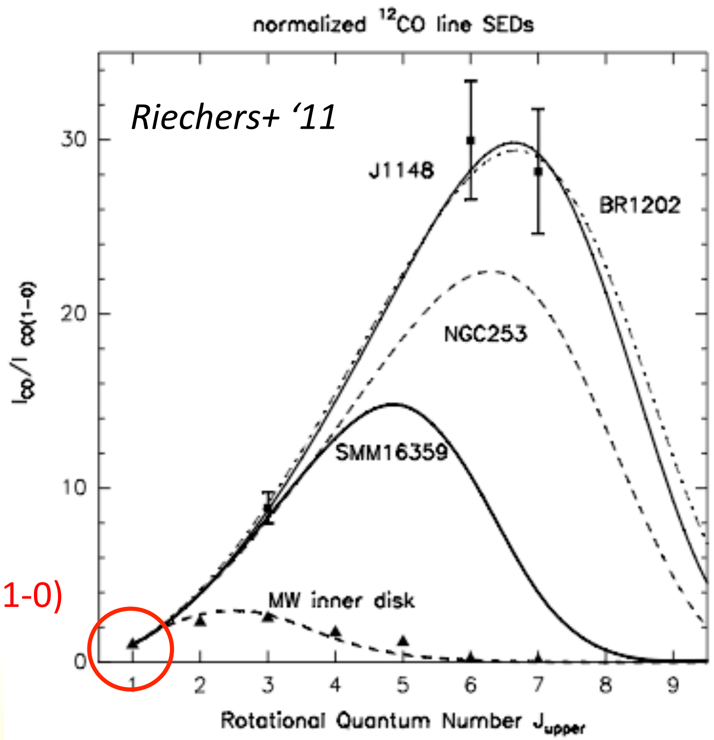
CO(1-0)

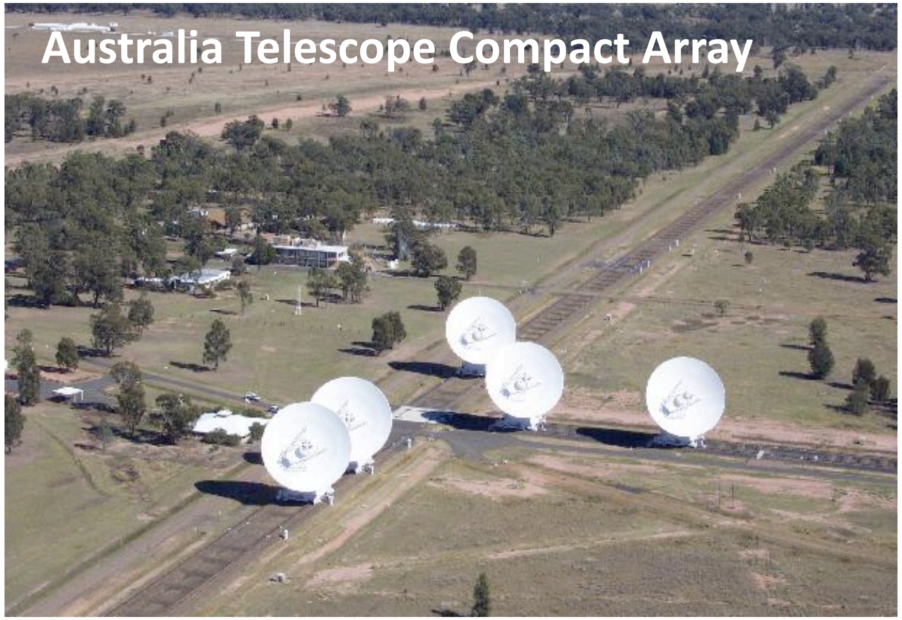


CO(1-0) survey HzRGs

Sample:

All 13 HzRGs from MRC catalogue (*unbiased in IR, submm*):

- in ATCA 30-50 GHz band *(1.3 < z < 2.8)*
- dec < -10
- HST & Spitzer/Herschel data available
  (Pentericci+ '01, De Breuck+ '10, Drouart+ '14)



Results:

- Detection rate 38% (5 out of 13)
- $M_{H2} = 4 - 6 \times 10^{10}\ M_{\odot}$ [α_x=0.8]
- FWZI = 400 - 2000 km/s

Emonts+ 2014 (MNRAS, 438, 2898)

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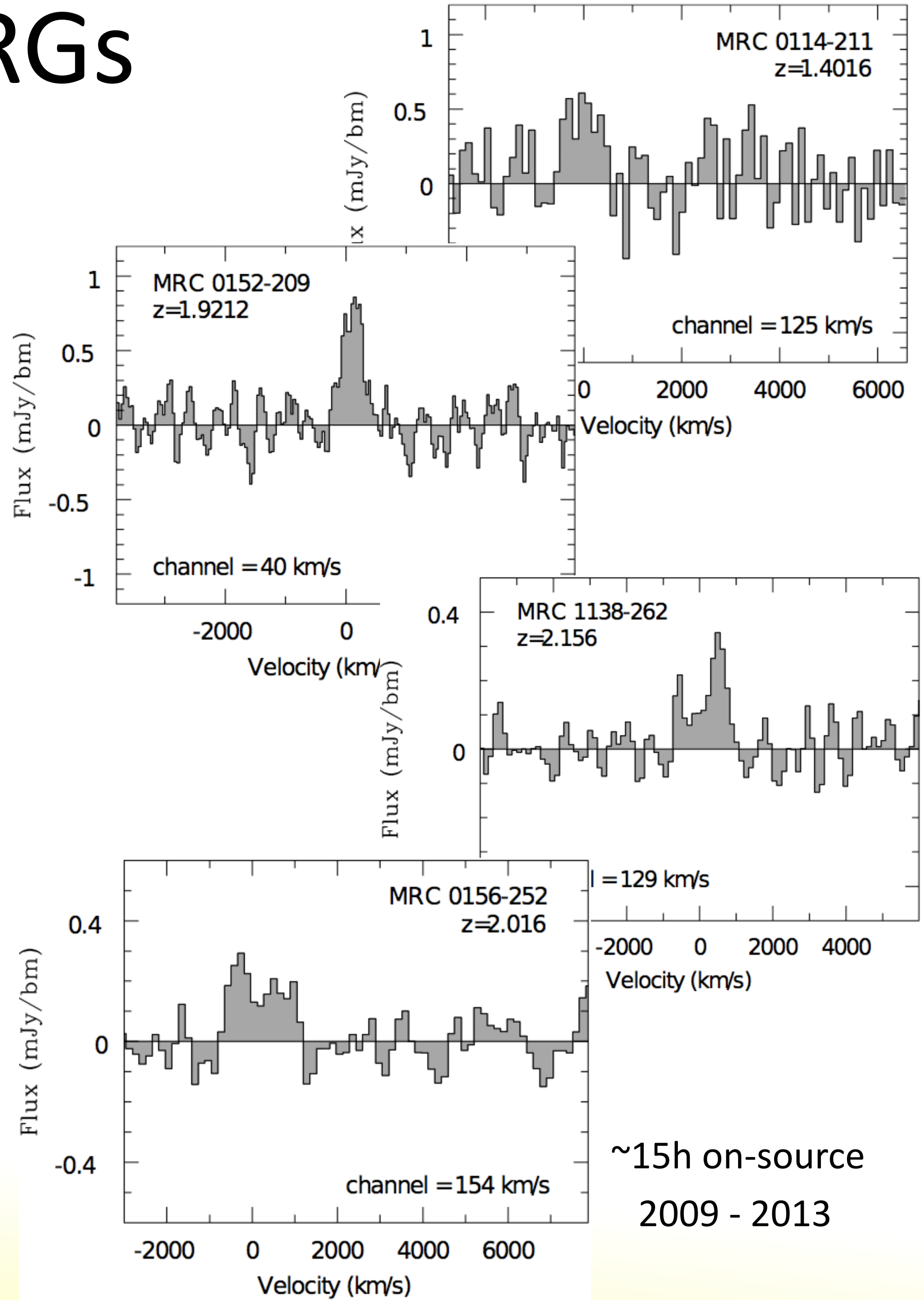


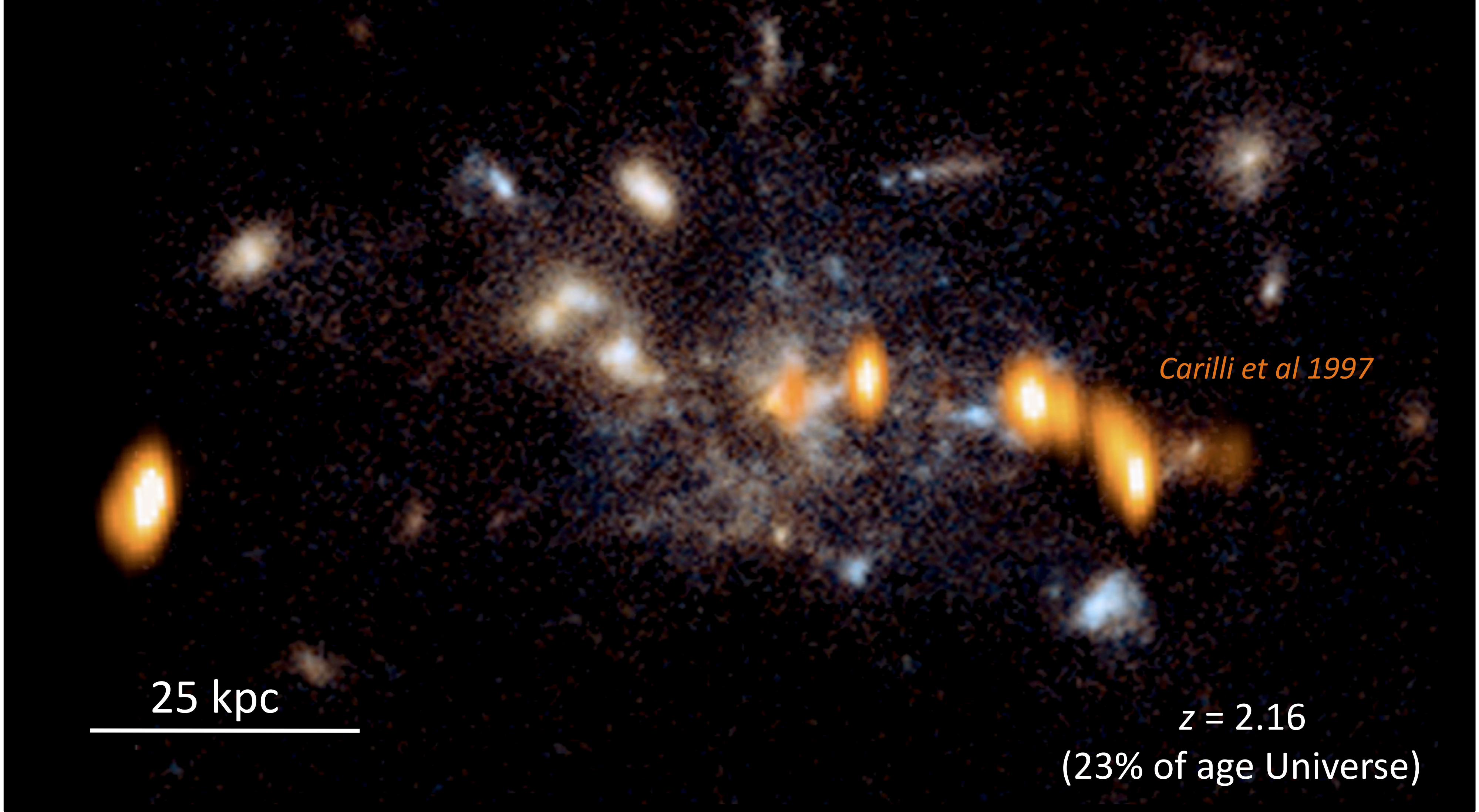
~15h on-source

2009 - 2013

Emonts+ 2014 (MNRAS, 438, 2898)

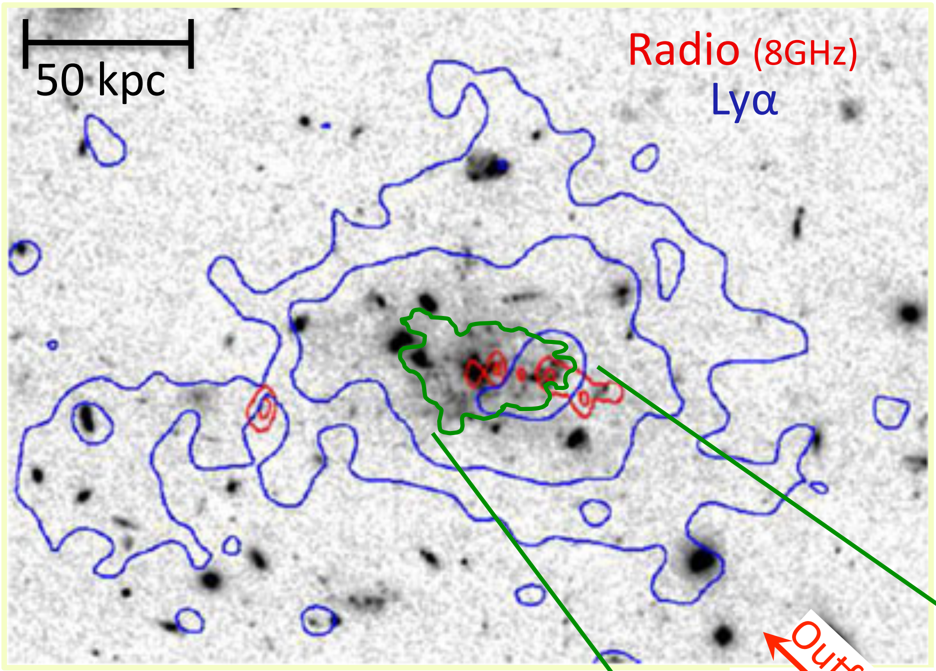
“Spiderweb Galaxy”

(MRC 1138-262)



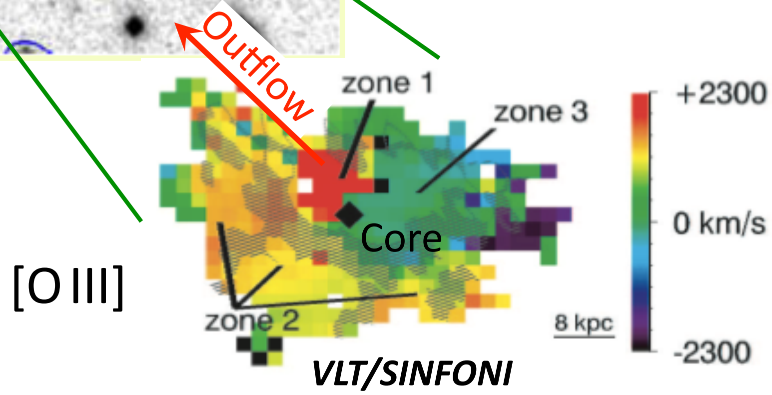
Miley et al. 2006 (Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)

Spiderweb Galaxy



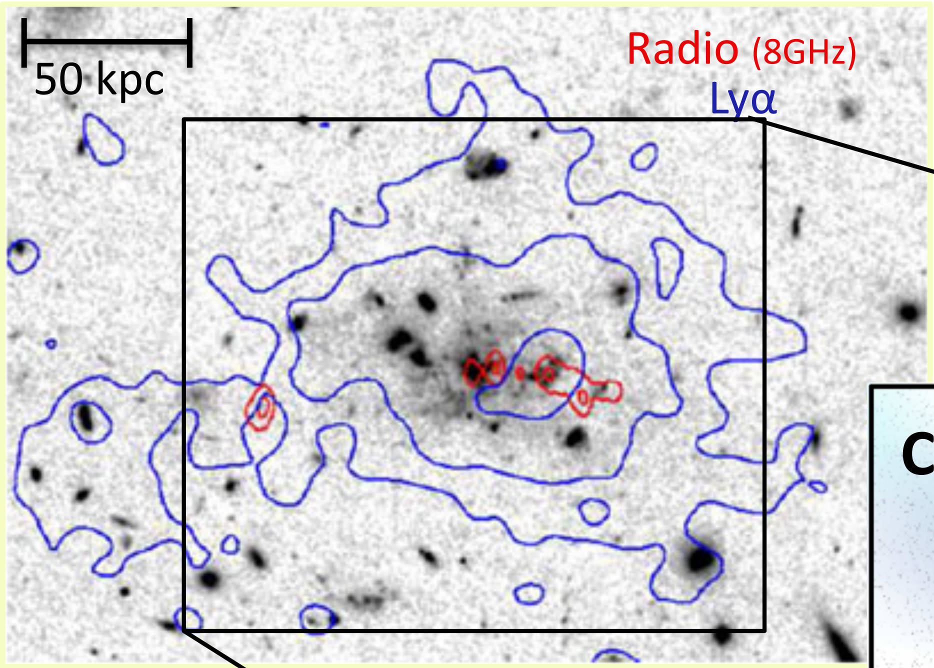
Miley+ (2006)

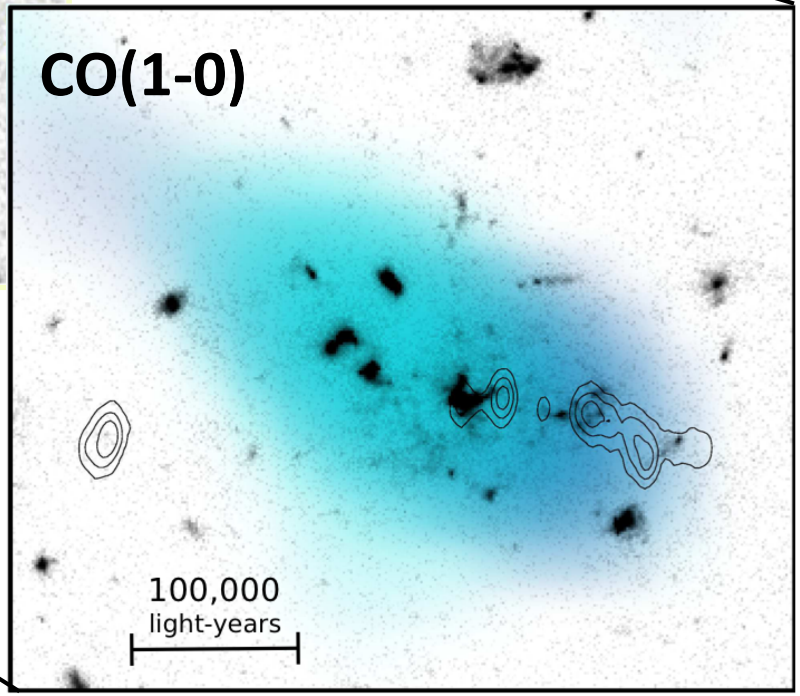
- Giant Lyα halo *(Pentericci+ '97, Miley+ '06)*
- SFR 1400 $M_\odot$/yr *(Seymour+ '12, Ogle+ '12)*
- SF widespread *(Stevens+ '03, Hatch+ '09)*
- SF quenched in nuclear region?
  - *Jet-induced outflows* (Nesvadba+ '06)
  - *Jet-induced H_2 heating* (Ogle+ '12)



Nesvadba+ (2006)

Spiderweb Galaxy





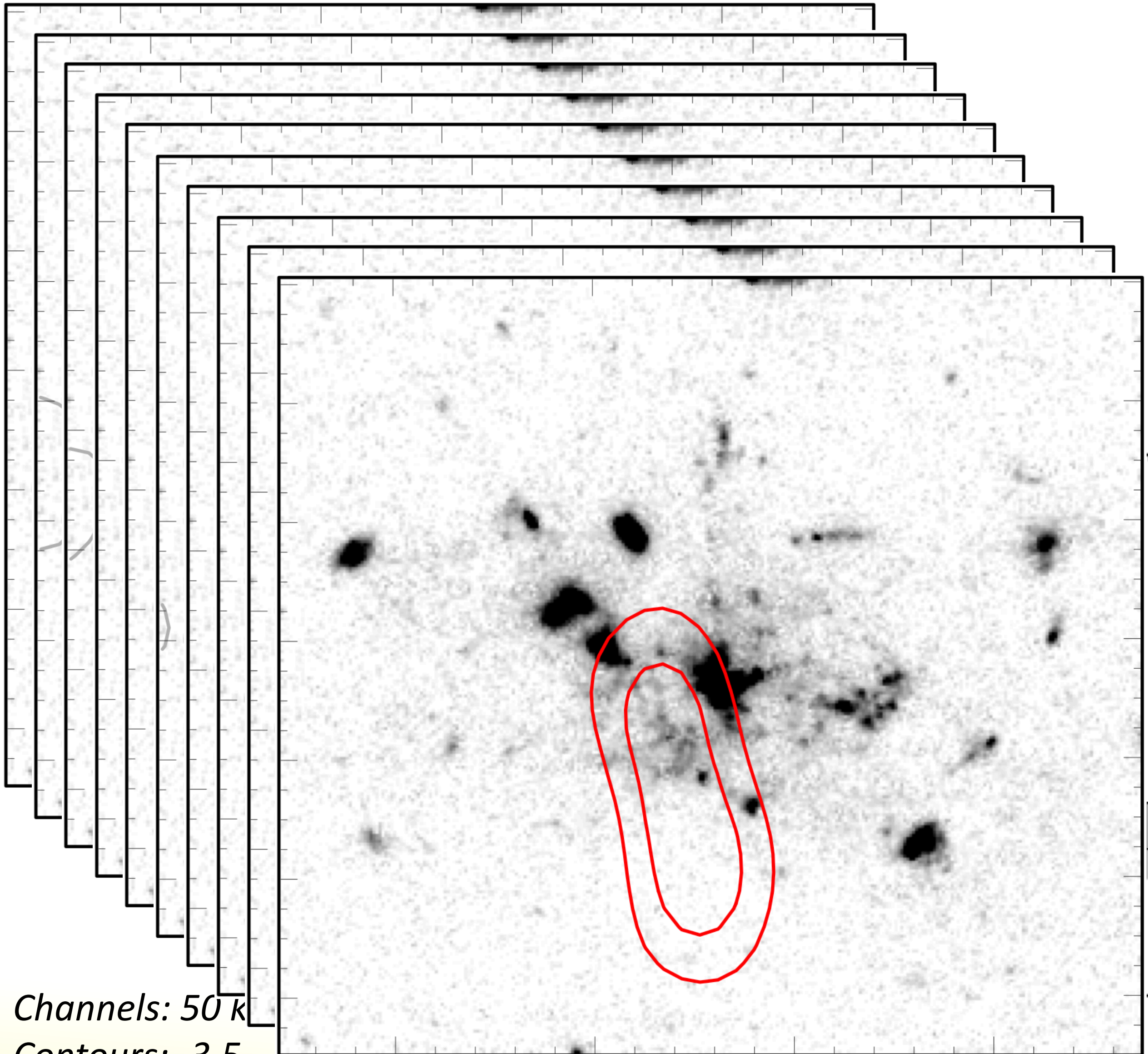
ATCA

(shortest baselines 31-190m)

$M_{H2} = 6 \times 10^{10}\ M_{\odot}$ [α_x=0.8]

Emonts+ 2013 (MNRAS, 430, 3465)

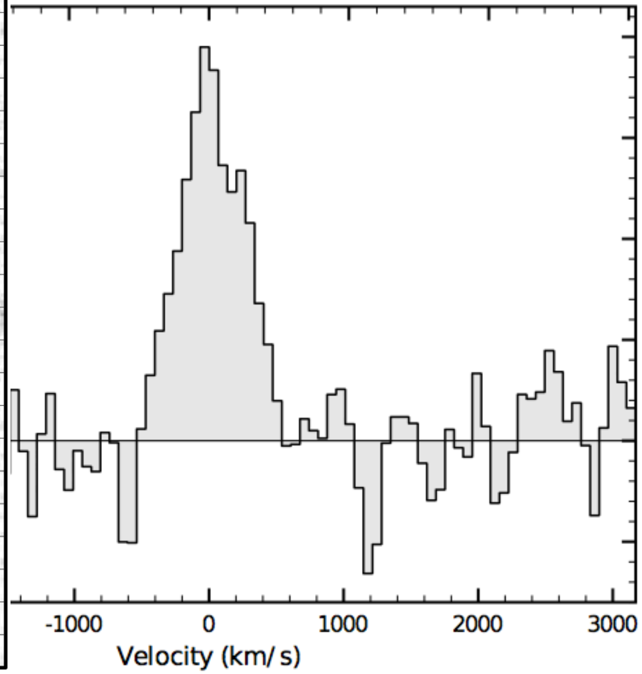
CO(1-0) in the Spiderweb



Preliminary!

~100h ATCA time

+ 24h VLA time
  under analysis



Channels: 50 k

Contours: -3.5, -2.8, 2.8, 3.5, 4.2σ

ATCA: incl. extended EW array (baselines up to 1.5 km)

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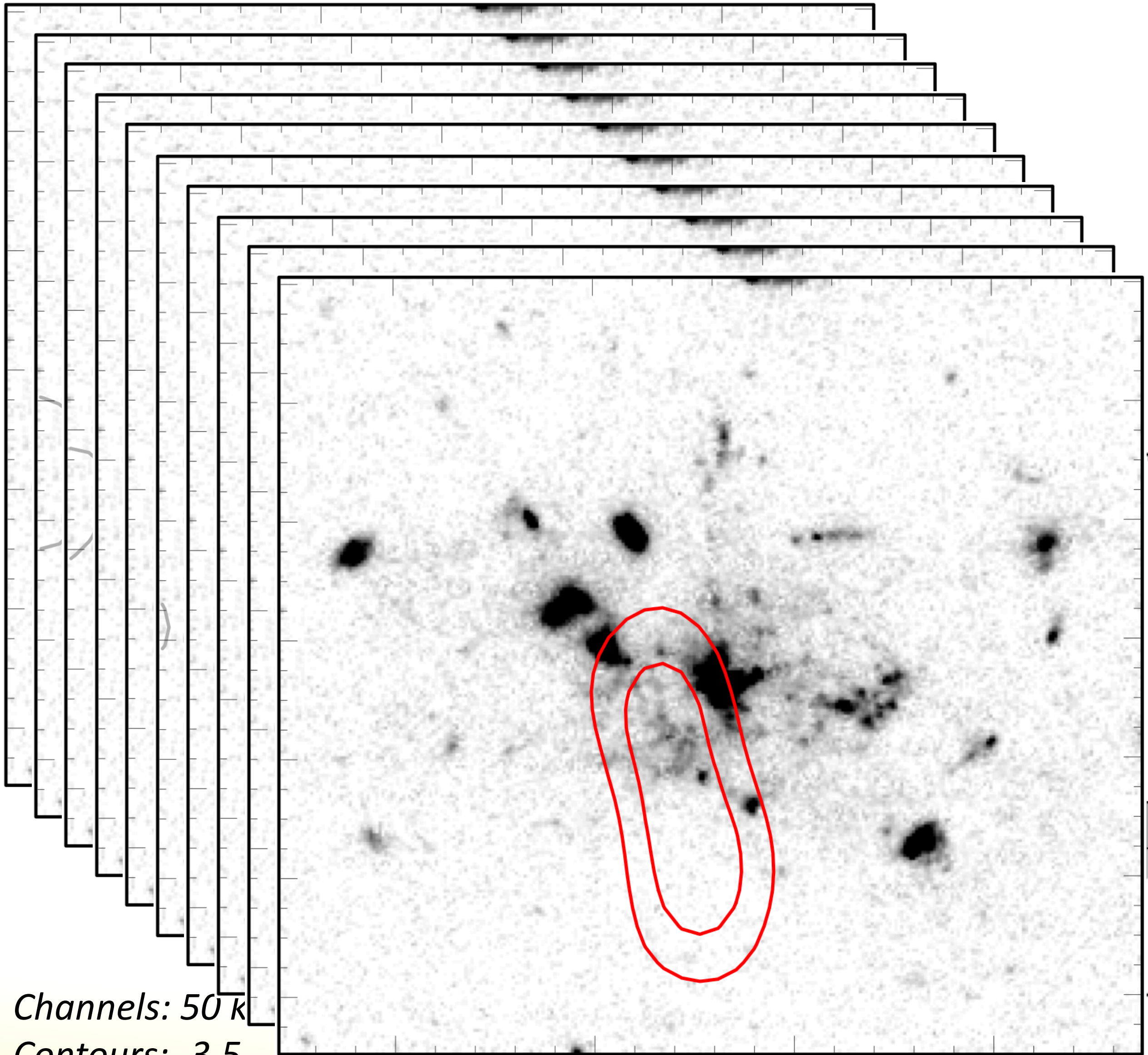

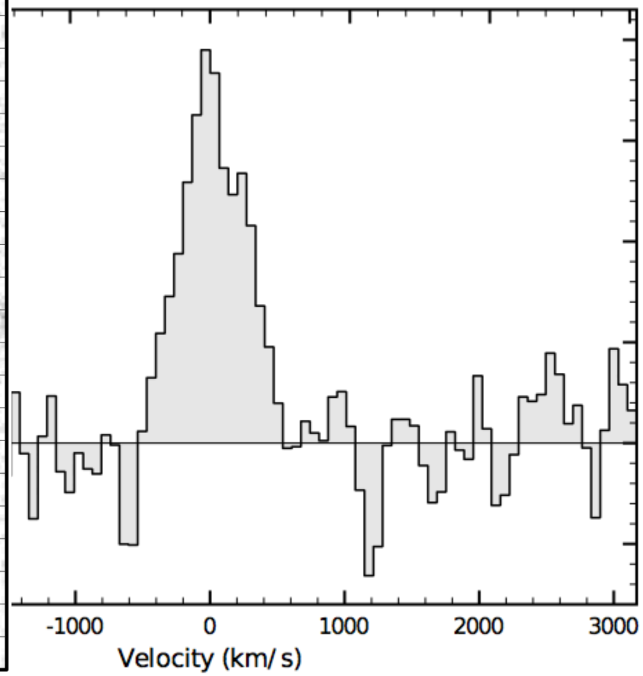

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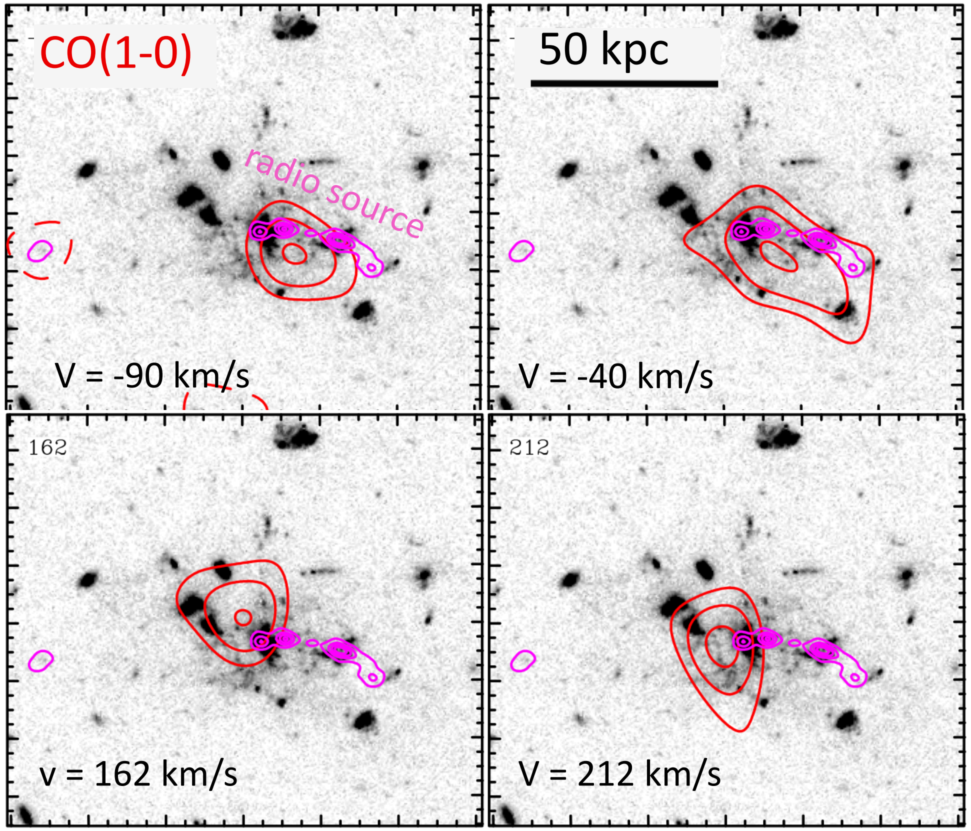
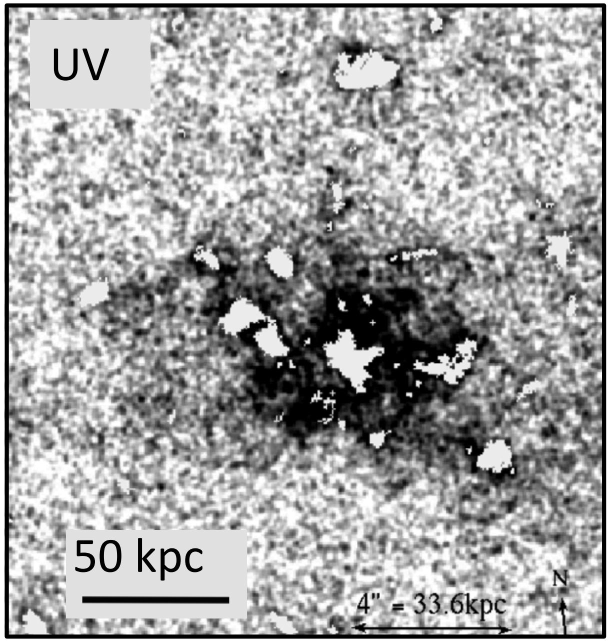


↔

Hatch+ '08



SFR ~ 140 $M_\odot$/yr
in IGM alone!

t_{depl} ~ $4x10^8$ yr
(depleted by z~1)

Results

1. Widespread CO(1-0) in halo: Spiderweb Galaxy

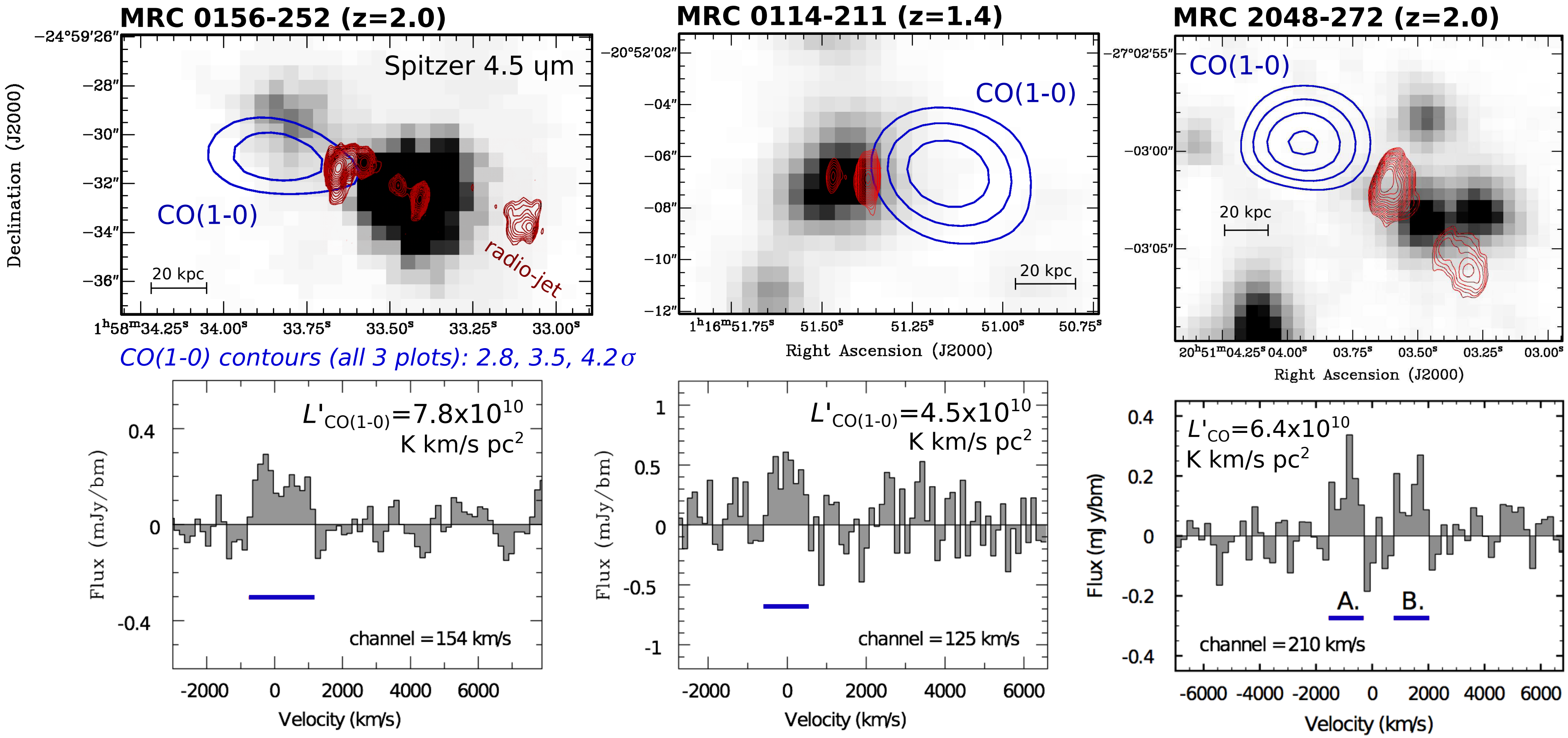
   cold molecular IGM in center of proto-cluster

   - "in-situ" build-up of Giant Elliptical's stellar halo?

   - "cold accretion" in action?

   (formation of molecules induced by shocks from galaxy interactions)

CO(1-0) – radio-jet alignments



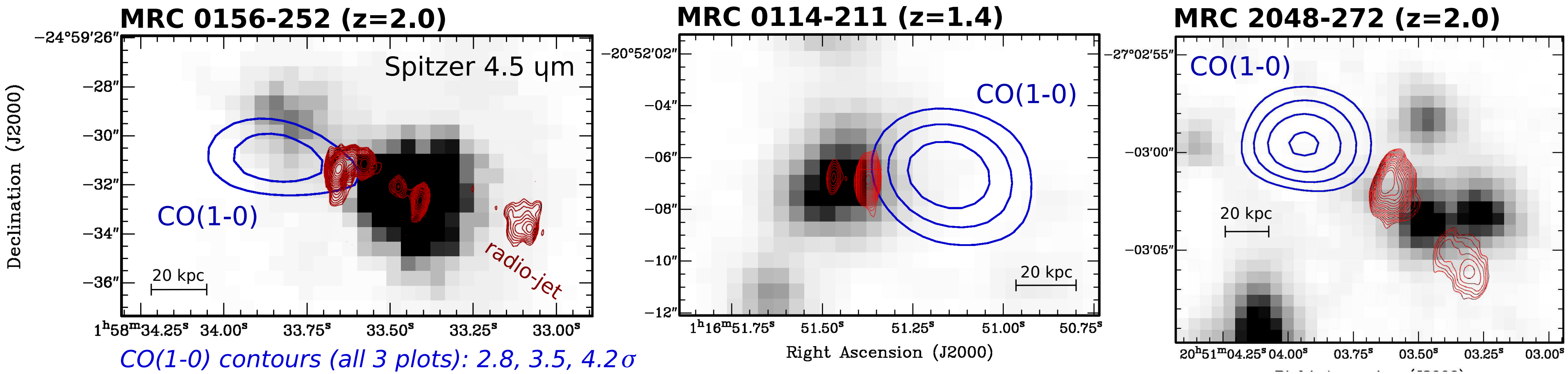
Emonts et al 2014 (MNRAS, 438, 2898)

(Spitzer data from Galametz+'12; Wylezalek+ '13)

$M_{H2} \approx 5\times10^{10}\ M_{\odot}$ [*if* α_x=0.8]

Similar to SMG, but no IR-counterpart (1 mag below L) !*

CO(1-0) – radio-jet alignments



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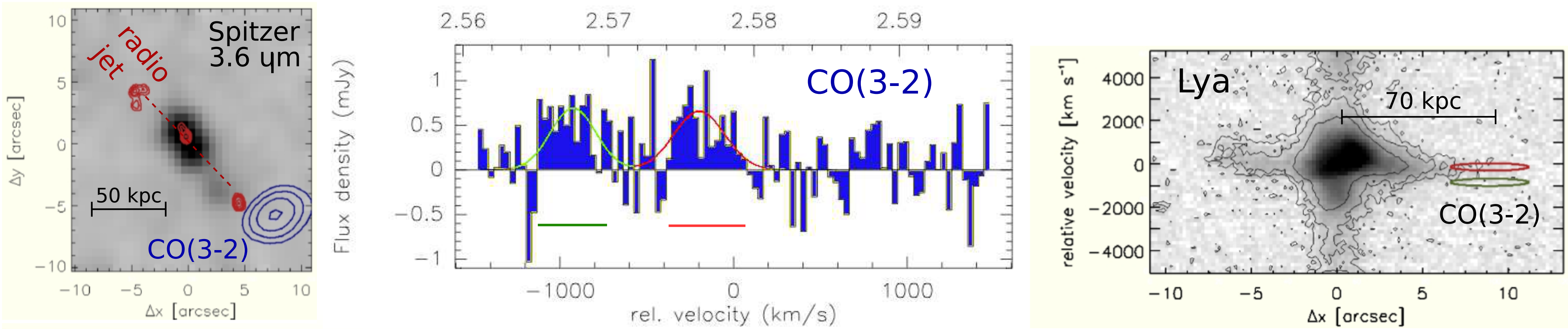
Nesvadba+ '09: CO(3-2) with PdbI



see also: Klamer+ '04

Results

2. Widespread CO(1-0) in halo:
   MRC 0156-252, 0114-211 & 2048-272

   Radio-jet alignments:

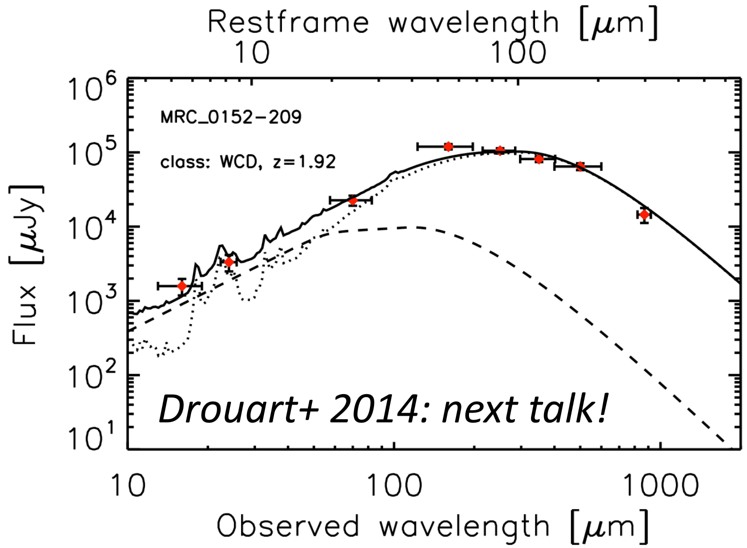
   - Large-scale AGN feedback

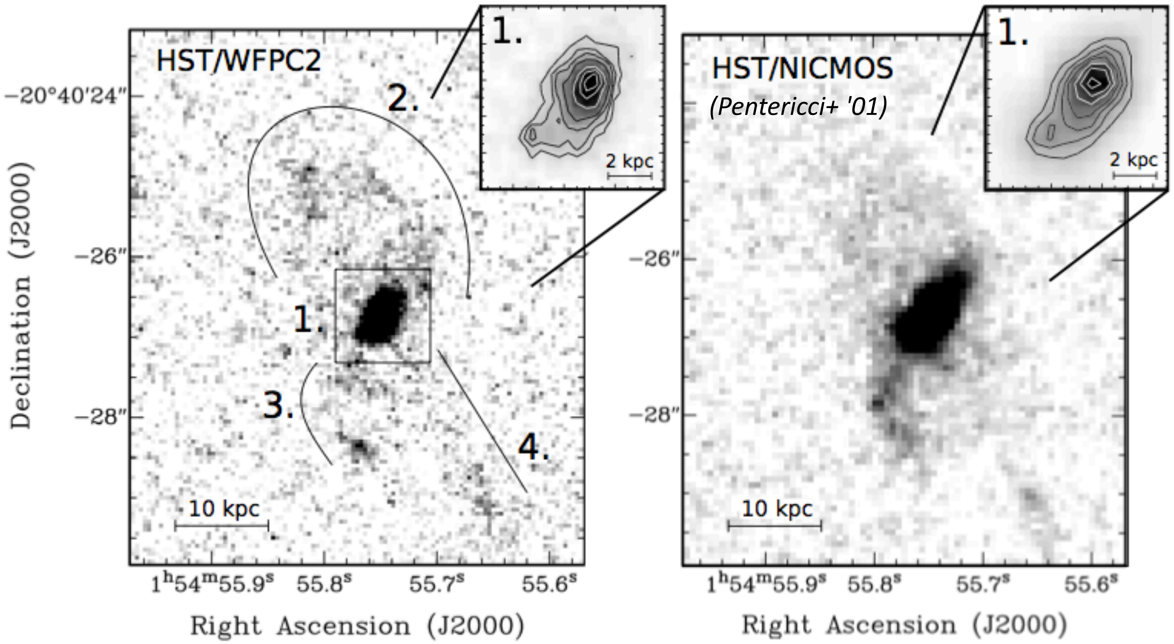
   - Shock-induced formation of cold H_2?

   → jet-induced star formation??

Dragonfly Galaxy (MRC 0152-209)

Major merger at z=1.92





HyLIRG

$L_{IR}(SB) \sim 2 \times 10^{13}\ L_{\odot}$

SFR = 3000 $M_{\odot}$/yr !

Emonts et al 2011, ApJL

Emonts, Mao, et al 2015a, MNRAS, submitted

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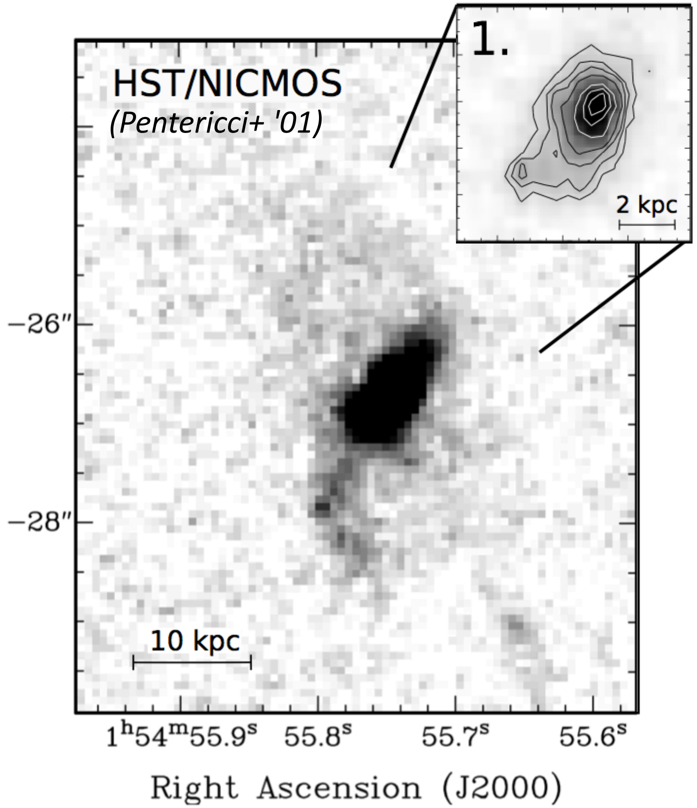

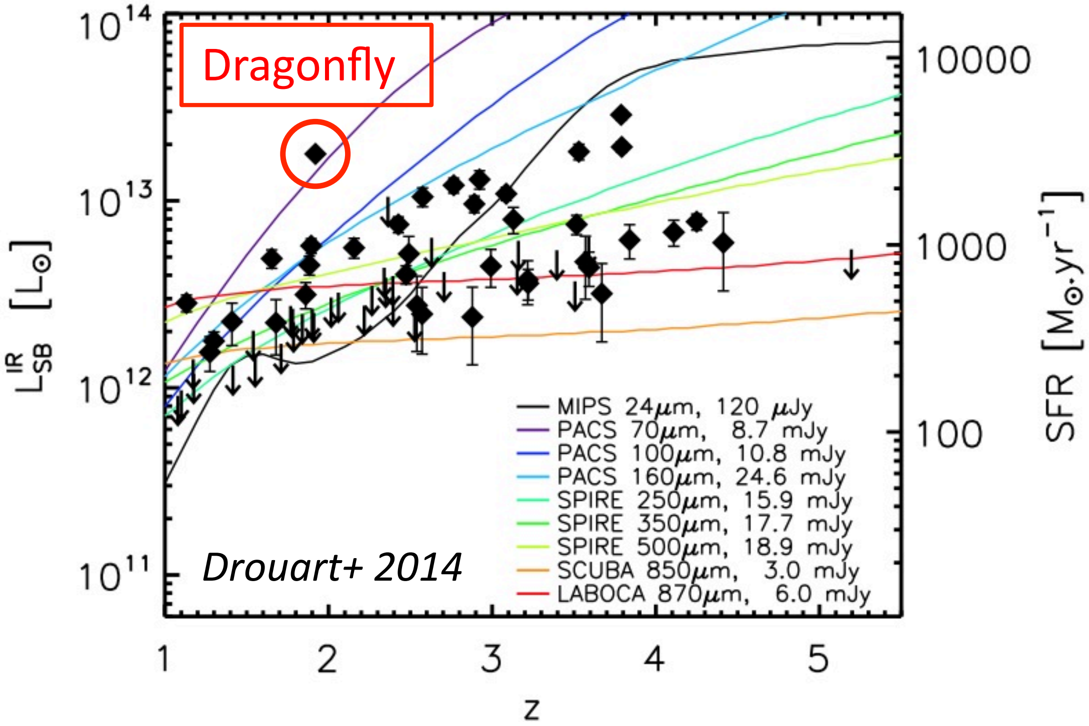

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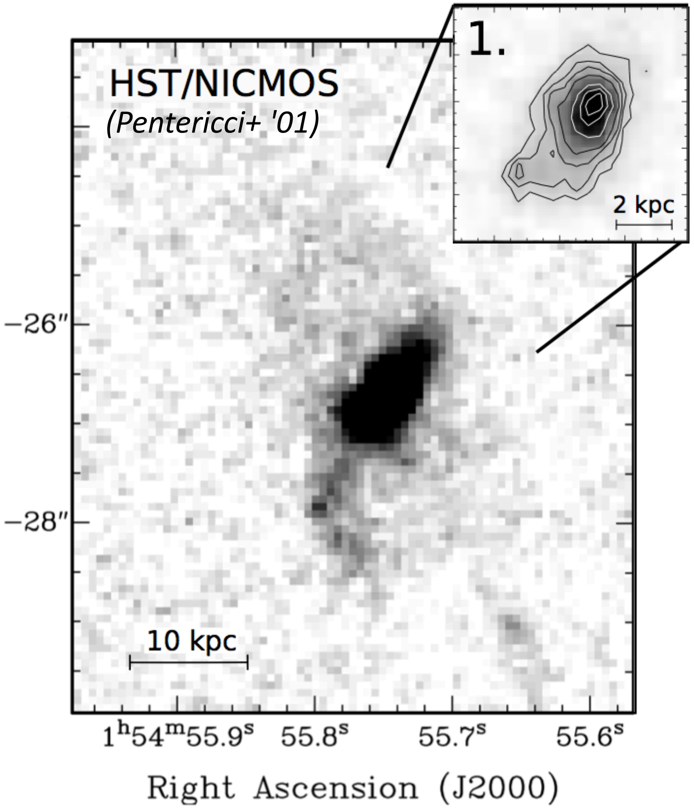

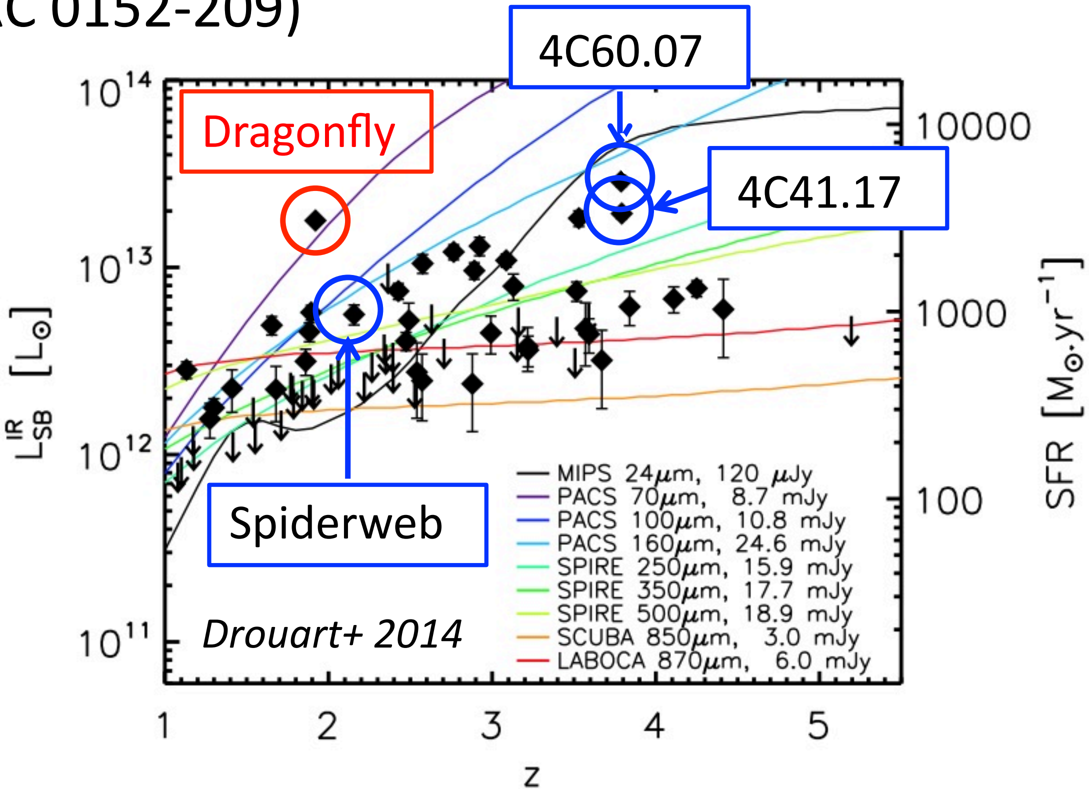

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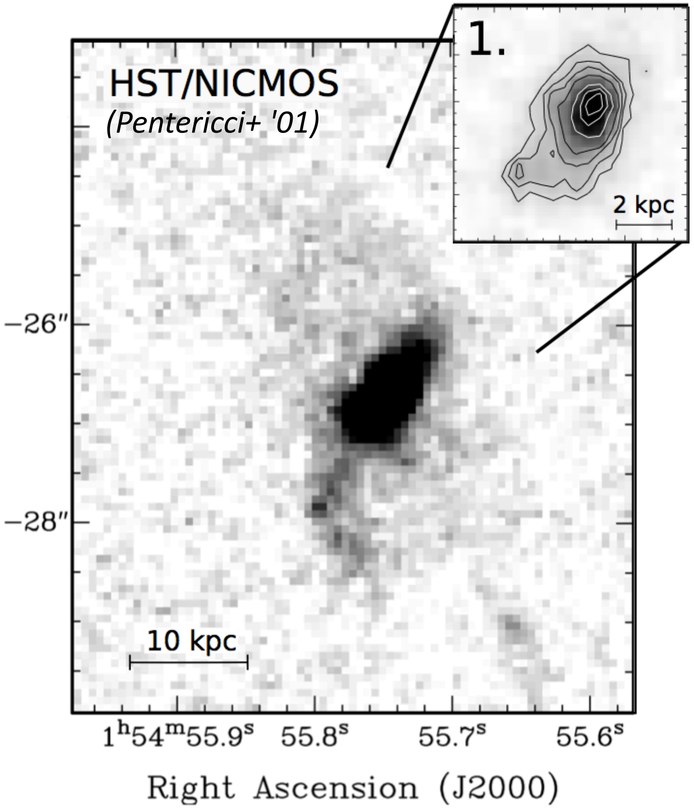

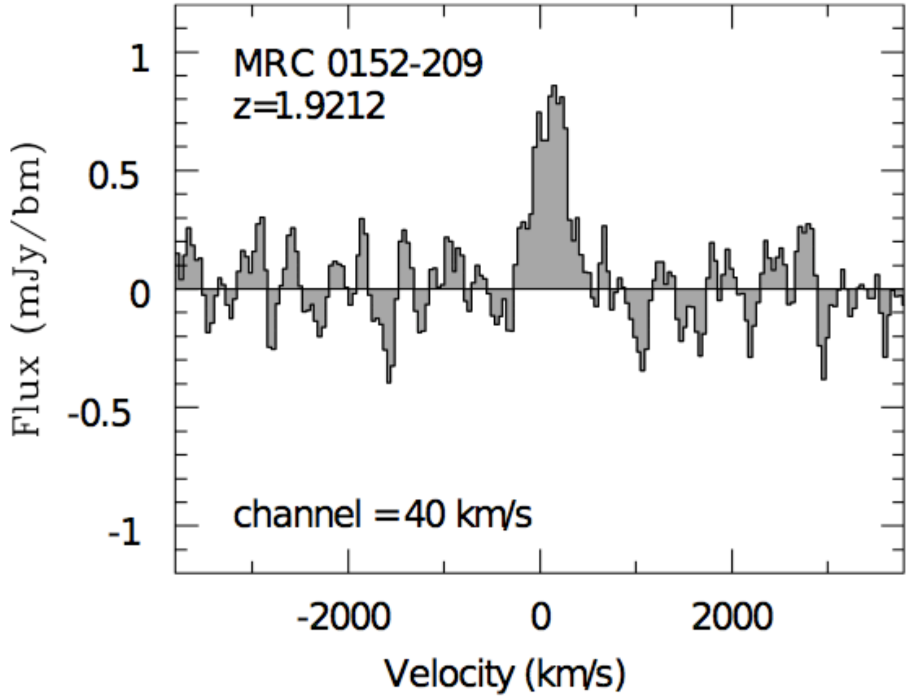

- $M_{H2} = 5 \times 10^{10}\ M_{\odot}$ ($\alpha[M_{H2}/L_{CO}]$= 0.8)
- t_{depl} ~ 15 Myr

HyLIRG

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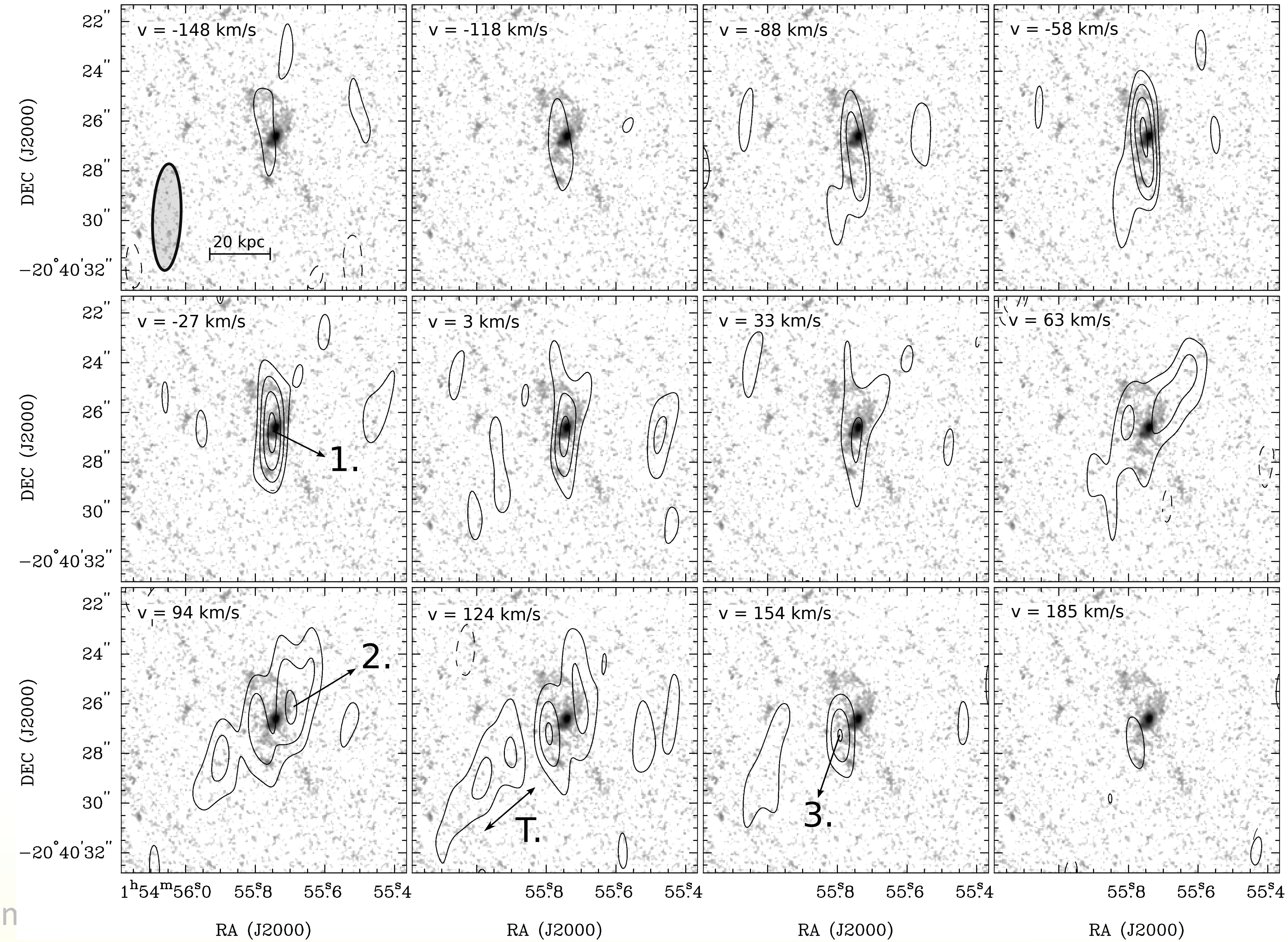
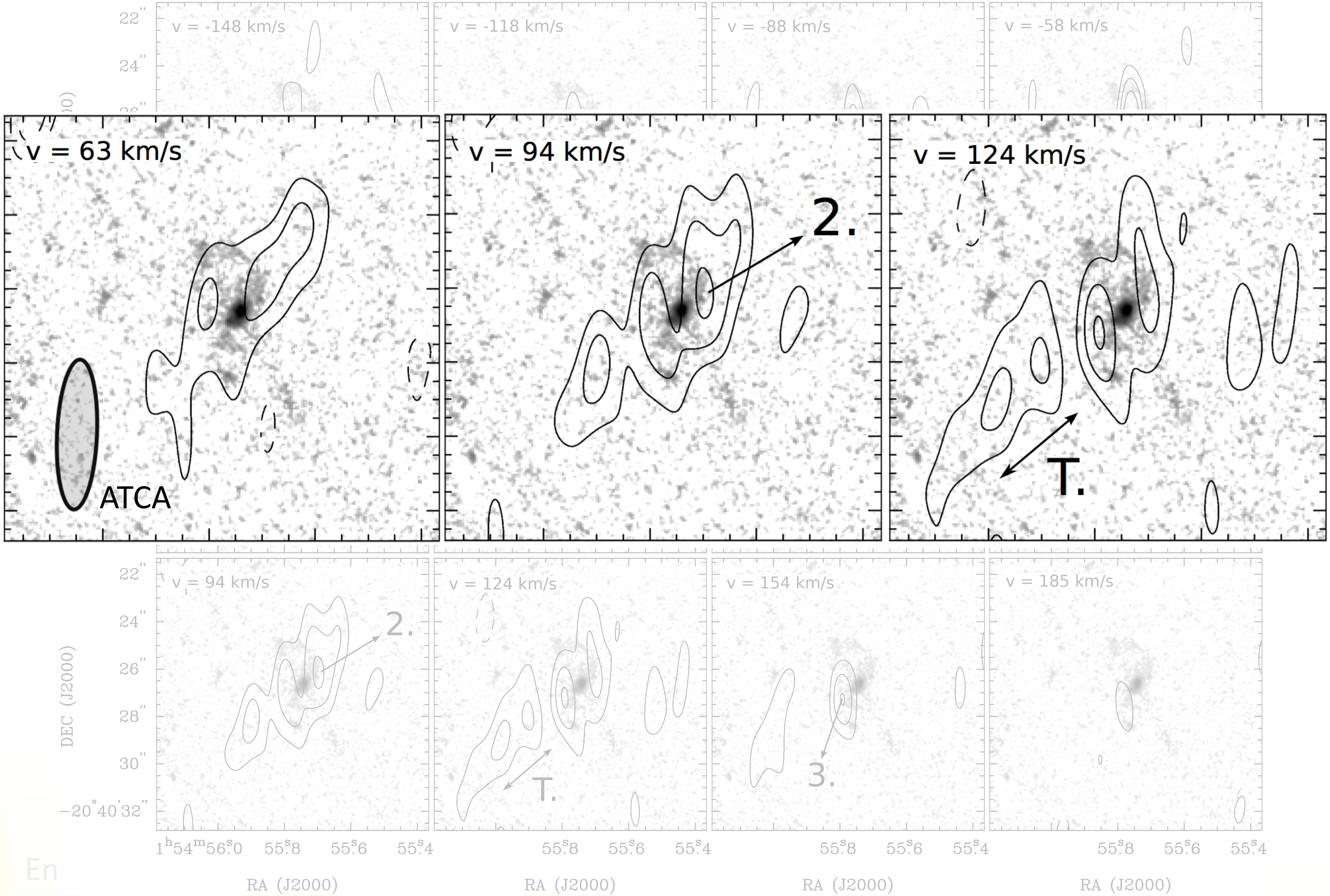
Emonts et al 2011, ApJL
Emonts, Mao, et al 2015a, MNRAS, submitted

CO(1-0) in the Dragonfly Galaxy



En

CO(1-0) in the Dragonfly Galaxy



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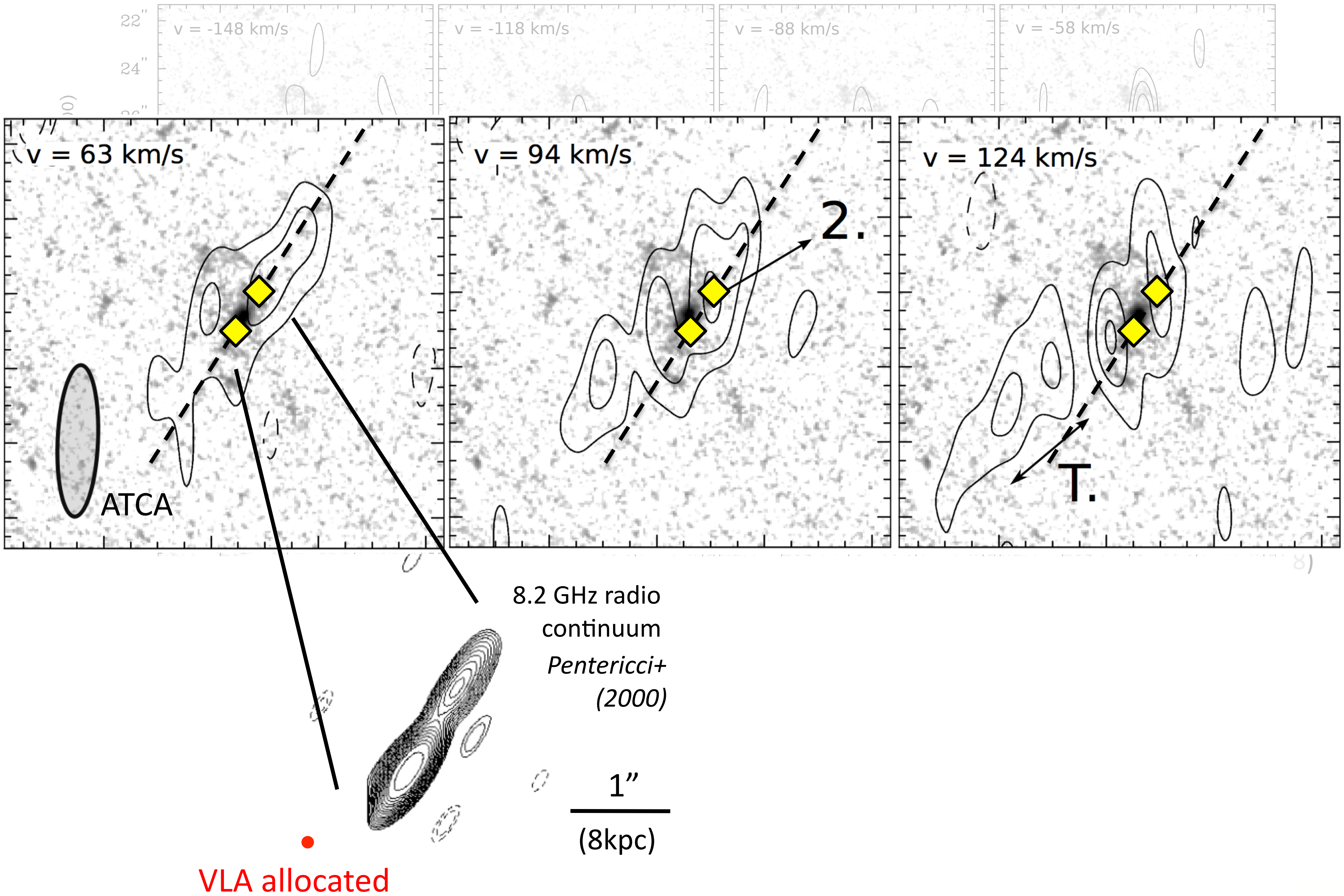
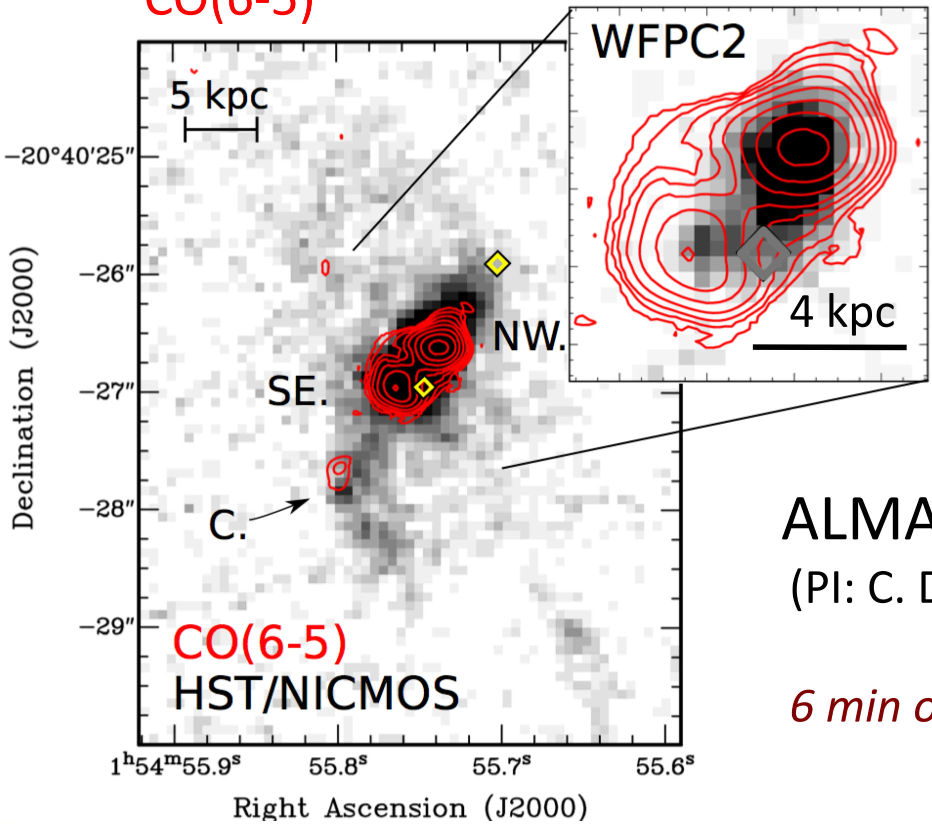


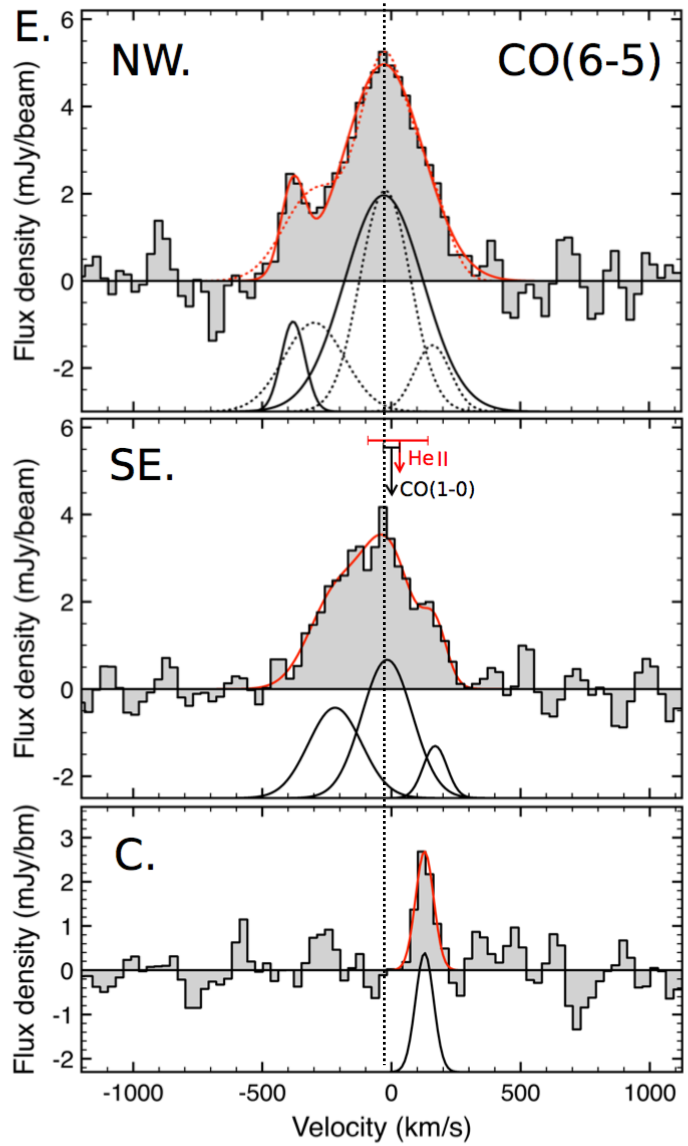
ALMA's view of the Dragonfly Galaxy

Major merger at z=1.92



ALMA cycle-2
(PI: C. De Breuck)

6 min on-source!



Emonts, De Breuck et al 2015b, A&A, submitted

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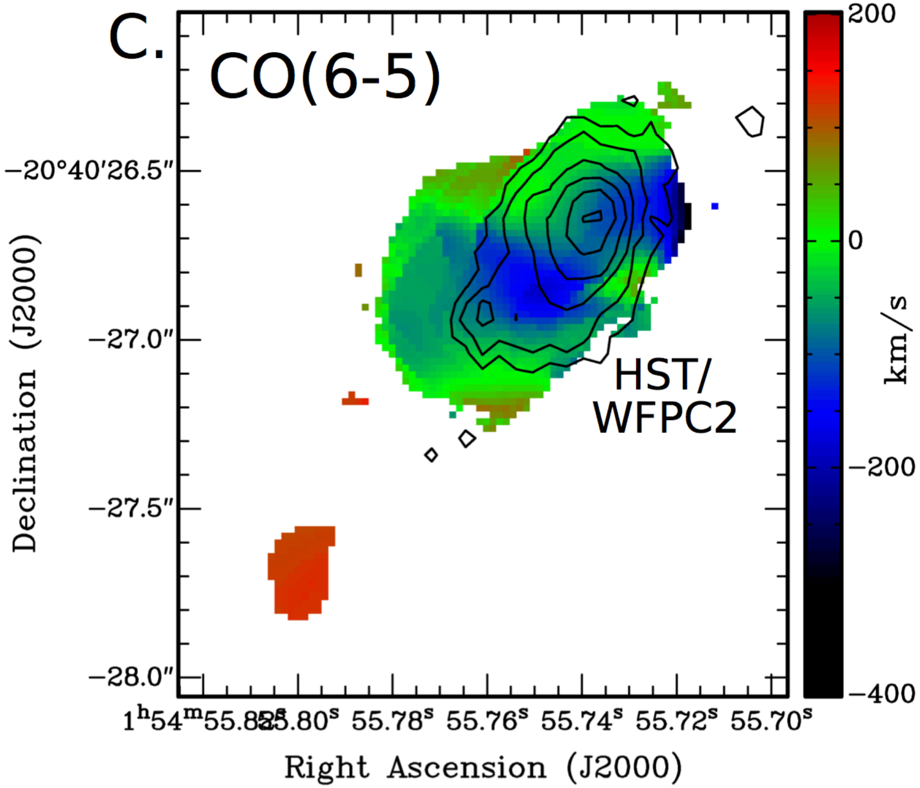

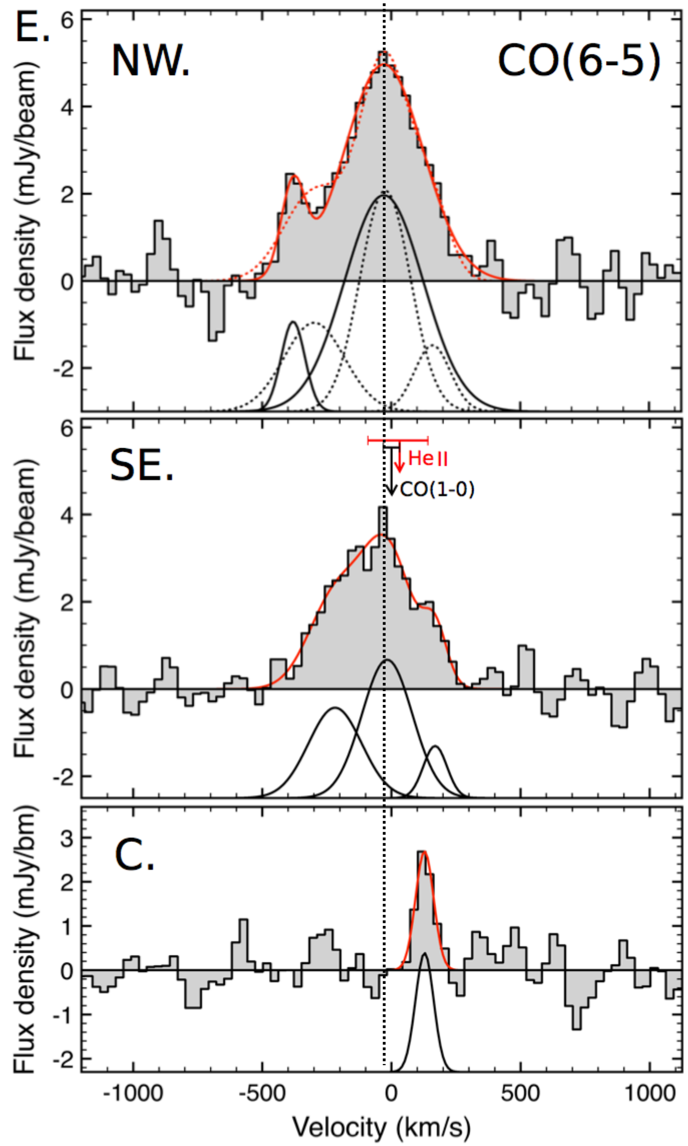

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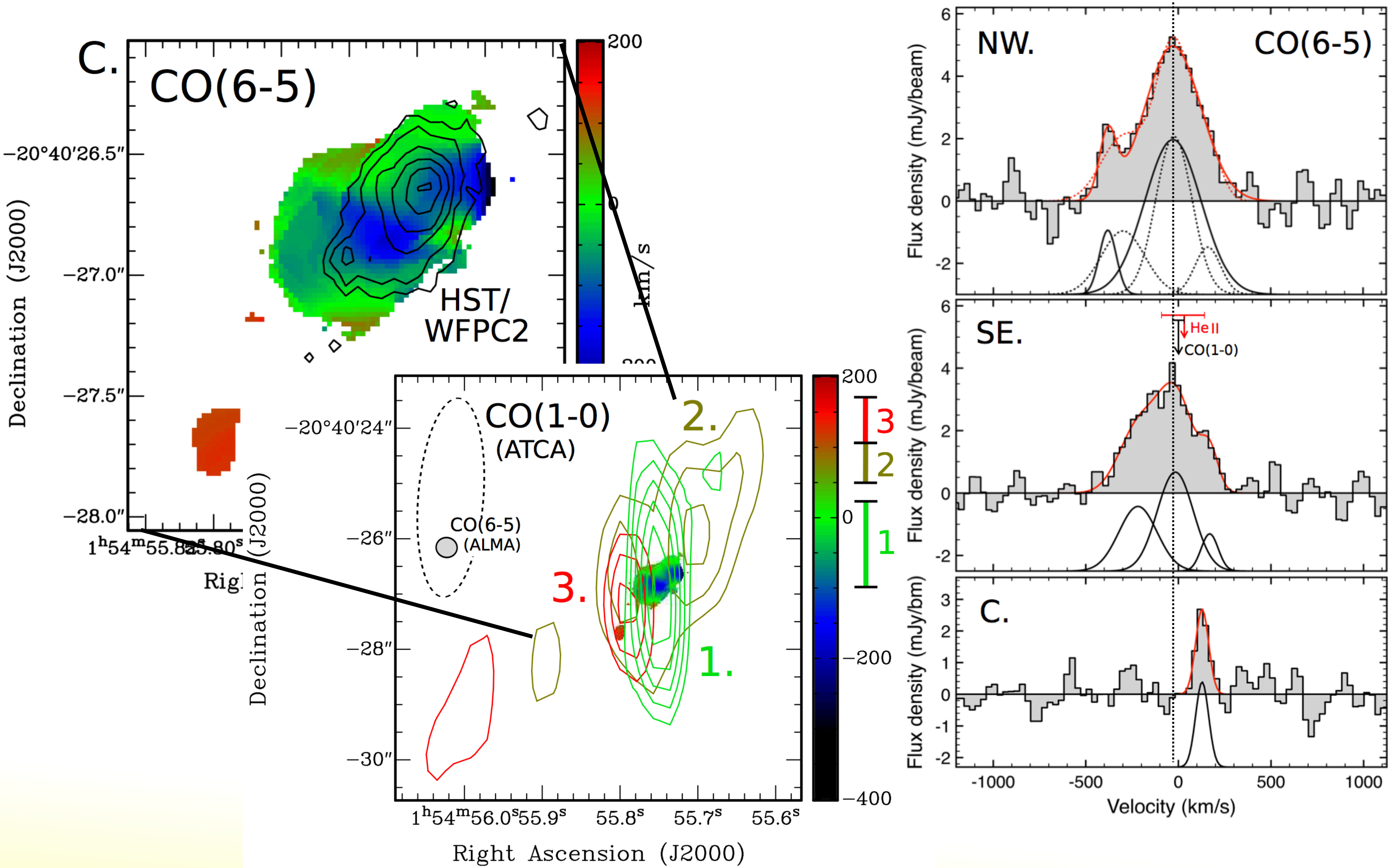

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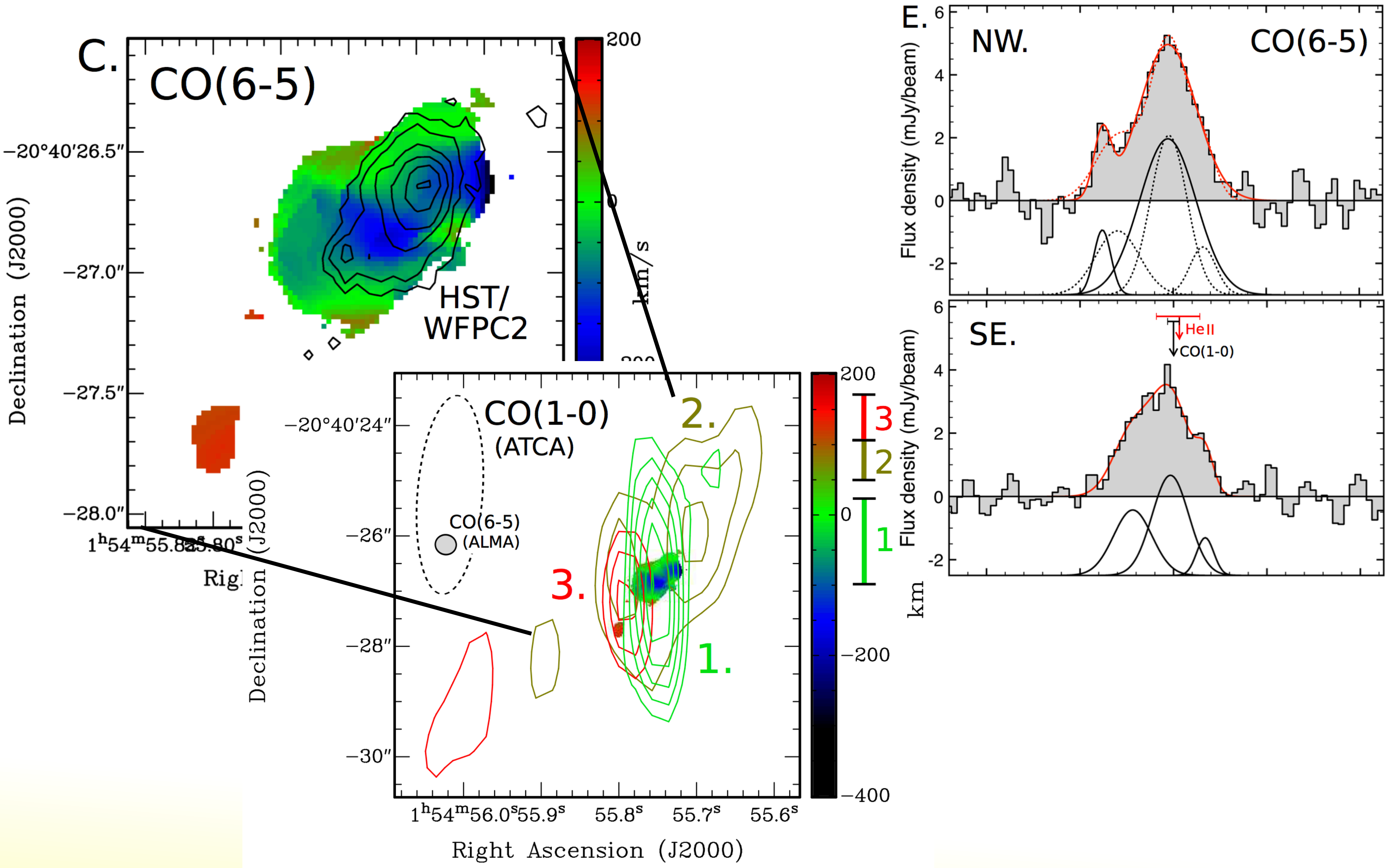

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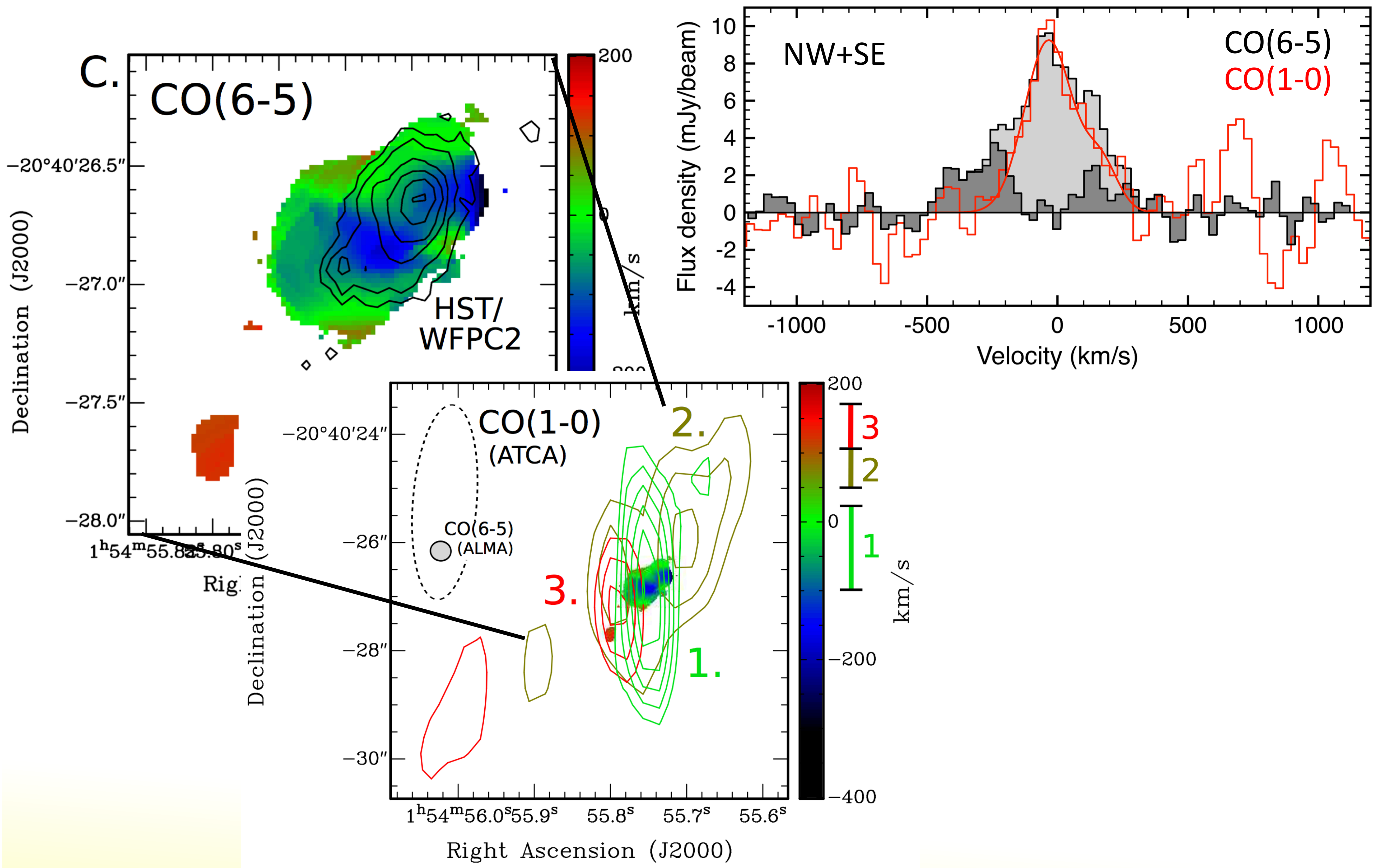

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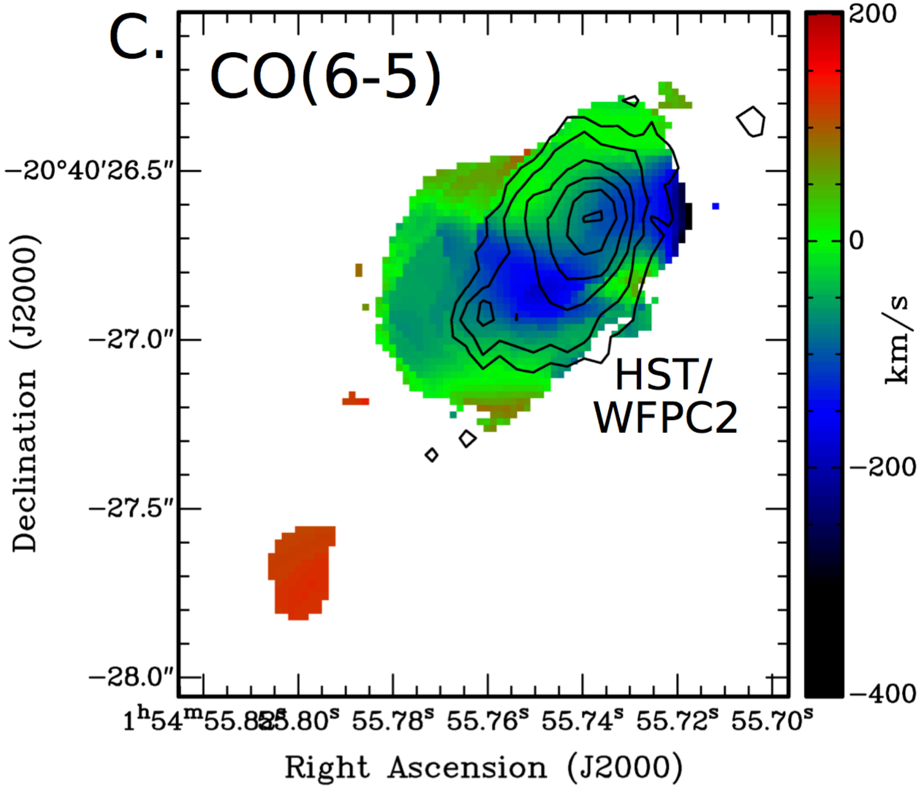
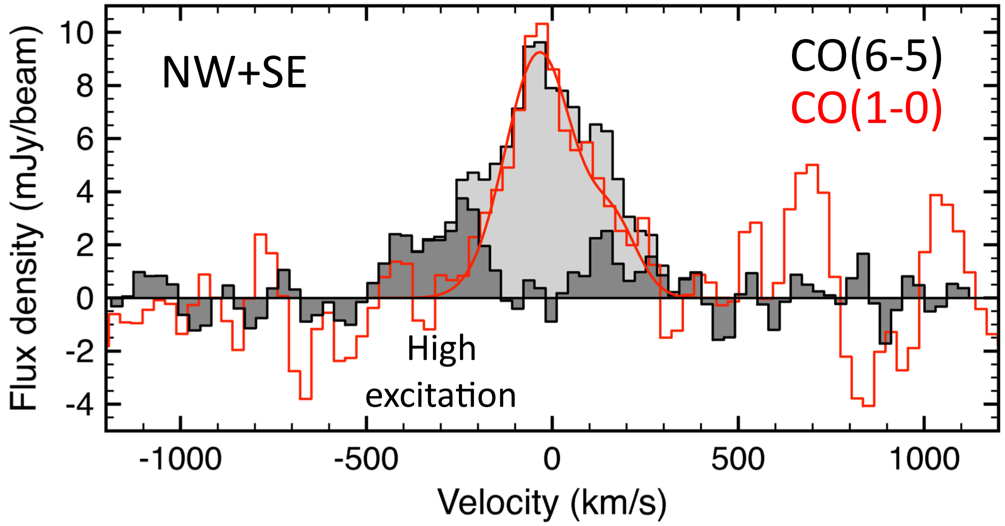




Massive ejecta from double nucleus

- High bulk velocities
- Highly excitated
- $M_{H2} \sim 10^{10}\ M_\odot$
- Tidal features or SB/AGN outflows
- Not reach v_{escape} → redistributed

$\dot{M}\sim 3000\ M_\odot/yr \longleftrightarrow SFR\sim 3000\ M_\odot/yr$

→ *Dynamical effects as important as SF in the evolution of this massive galaxy*

Emonts, De Breuck et al 2015b, A&A, submitted

Results

3. Widespread CO(1-0) in halo *(ATCA)*
   + CO(6-5) in SB/AGN regions *(ALMA cycle-2)* :
   Dragonfly Galaxy

   - triple merger, debris in CO(1-0)

   - AGN/SB triggered in pre-coalescence stage

   - nuclear ejecta in CO(6-5) at 3000 $M_{\odot}$/yr !

Results

1. Widespread CO(1-0) in halo: Spiderweb

   Cold molecular gas in IGM

2. Widespread CO(1-0) in halo: CO-jet alignments

   Large-scale radio-jet feedback

3. Widespread CO(1-0) in halo: Dragonfly Galaxy

   Tidal debris from merger

   Complementary to high-J CO observations with ALMA

Conclusions

Need to search for widespread molecular halo-gas in Early Universe!

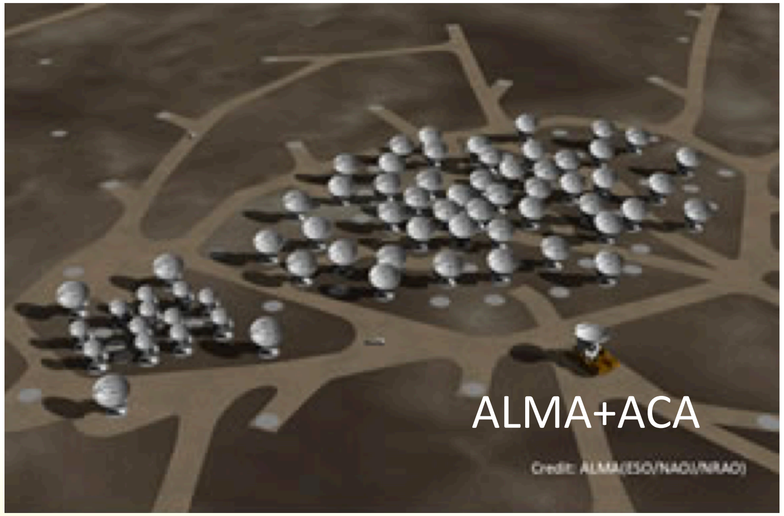
- Cold accretion
- Hierarchical merging
- Large-scale AGN feedback

How?

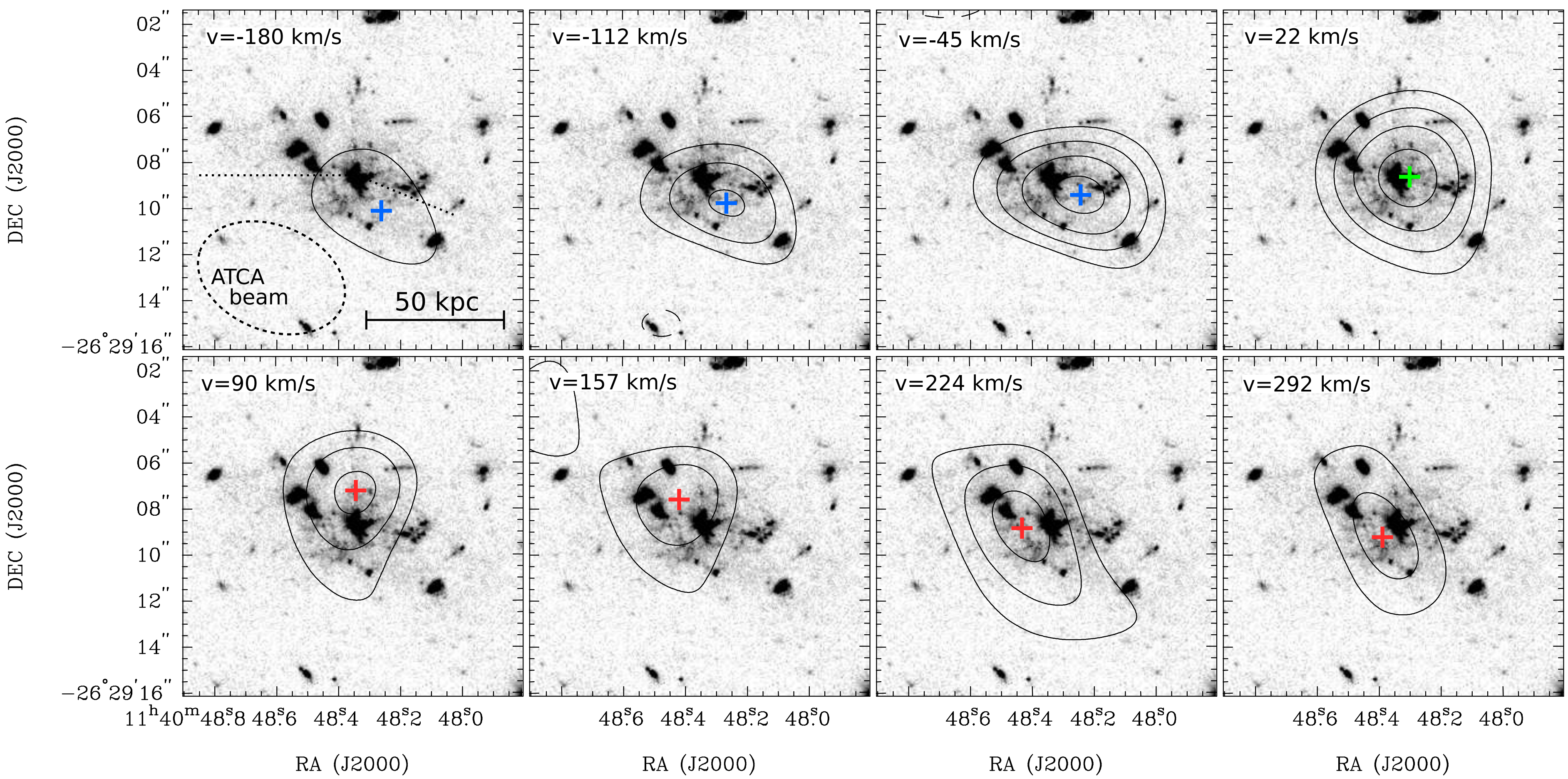
- Low-order CO transitions
  (or other molecular species, e.g. CI, CII)

  Science for receivers <50 GHz
  (ALMA band 1, VLA, ATCA,...)

- Short baselines!!



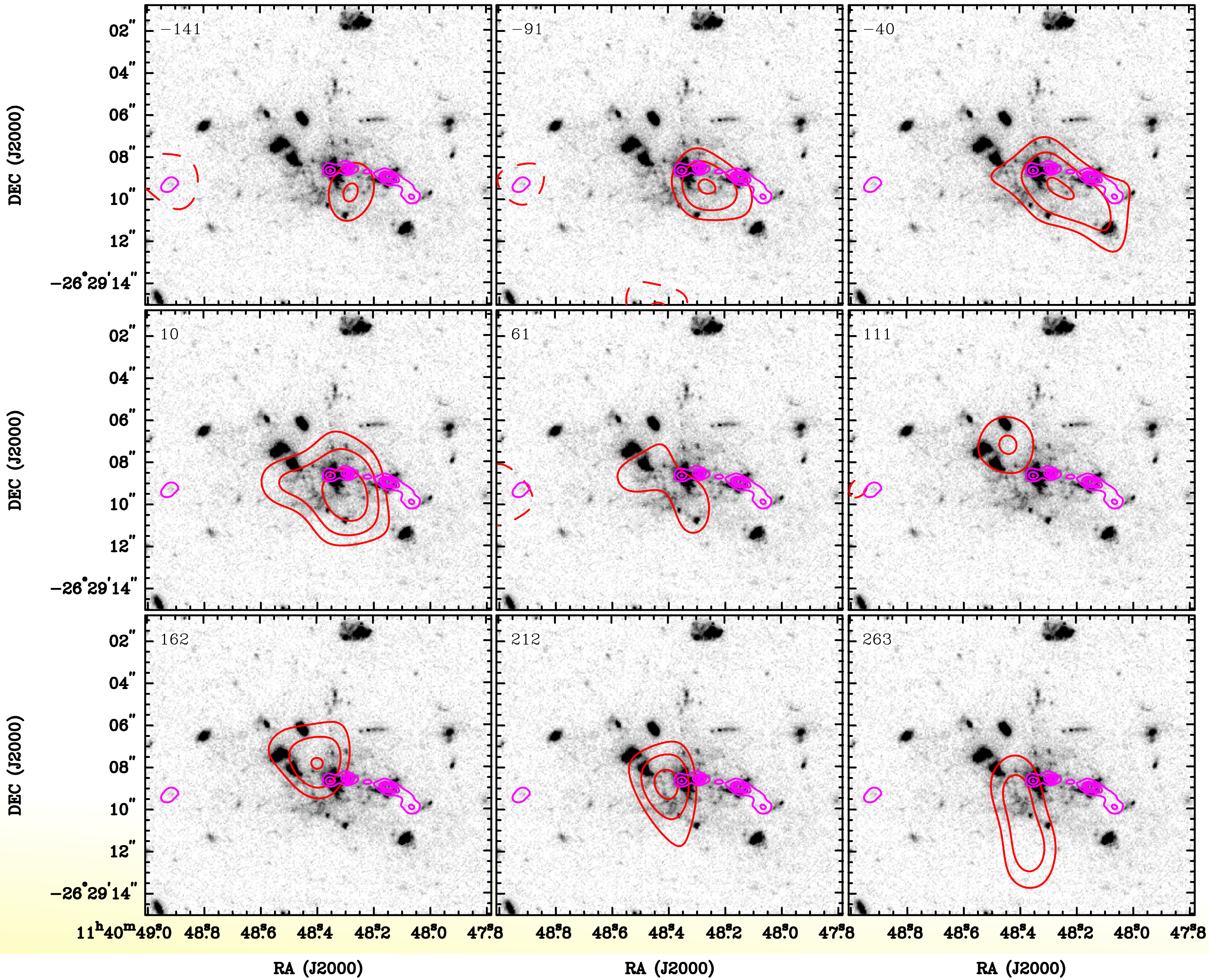
CO(1-0) in the Spiderweb



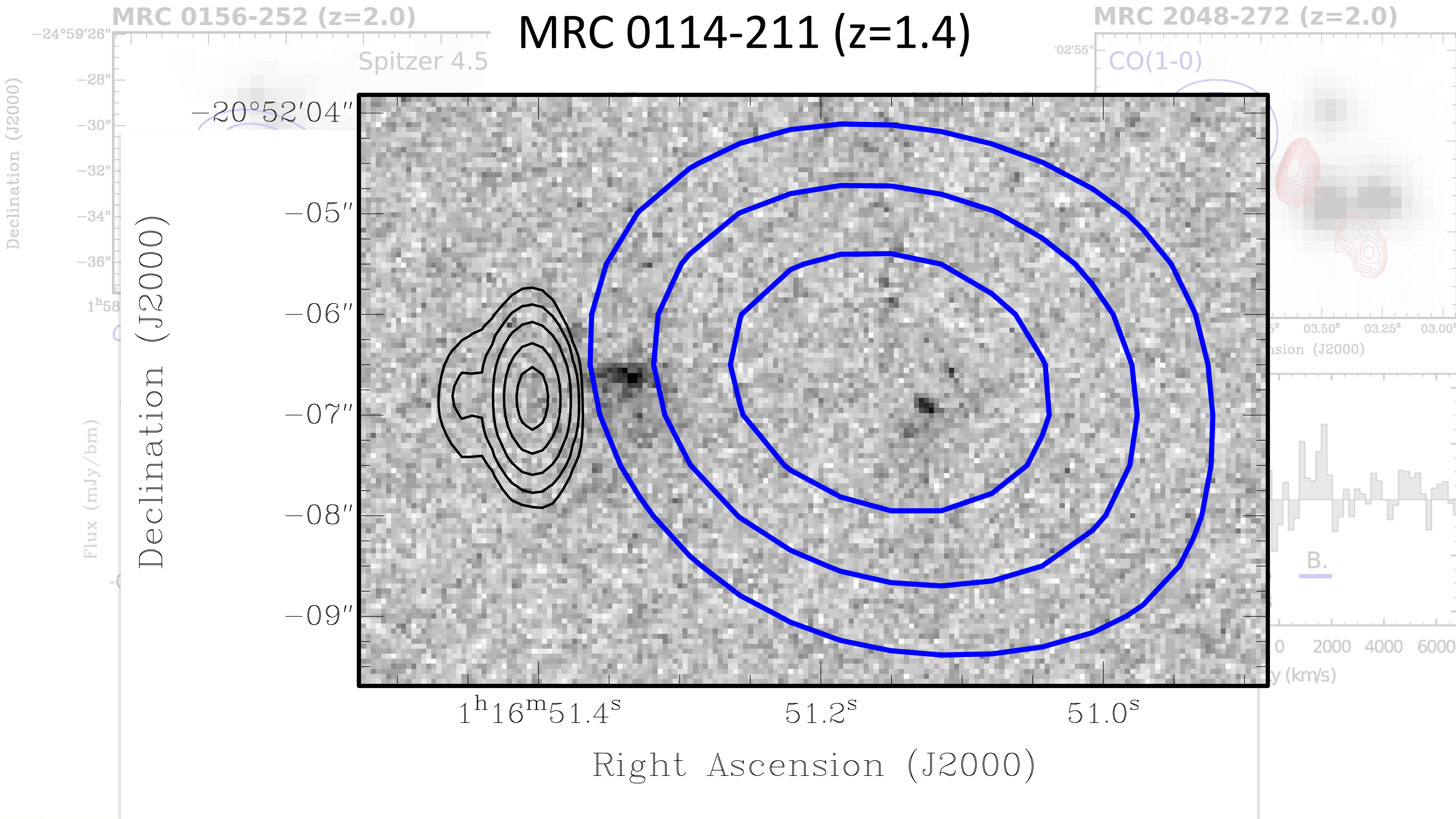
Contours: 2.5, 3.5, 4.5, 5.5 x sigma

ATCA: compact hybrid H214 array (baselines <250m)

CO(1-0) in the Spiderweb



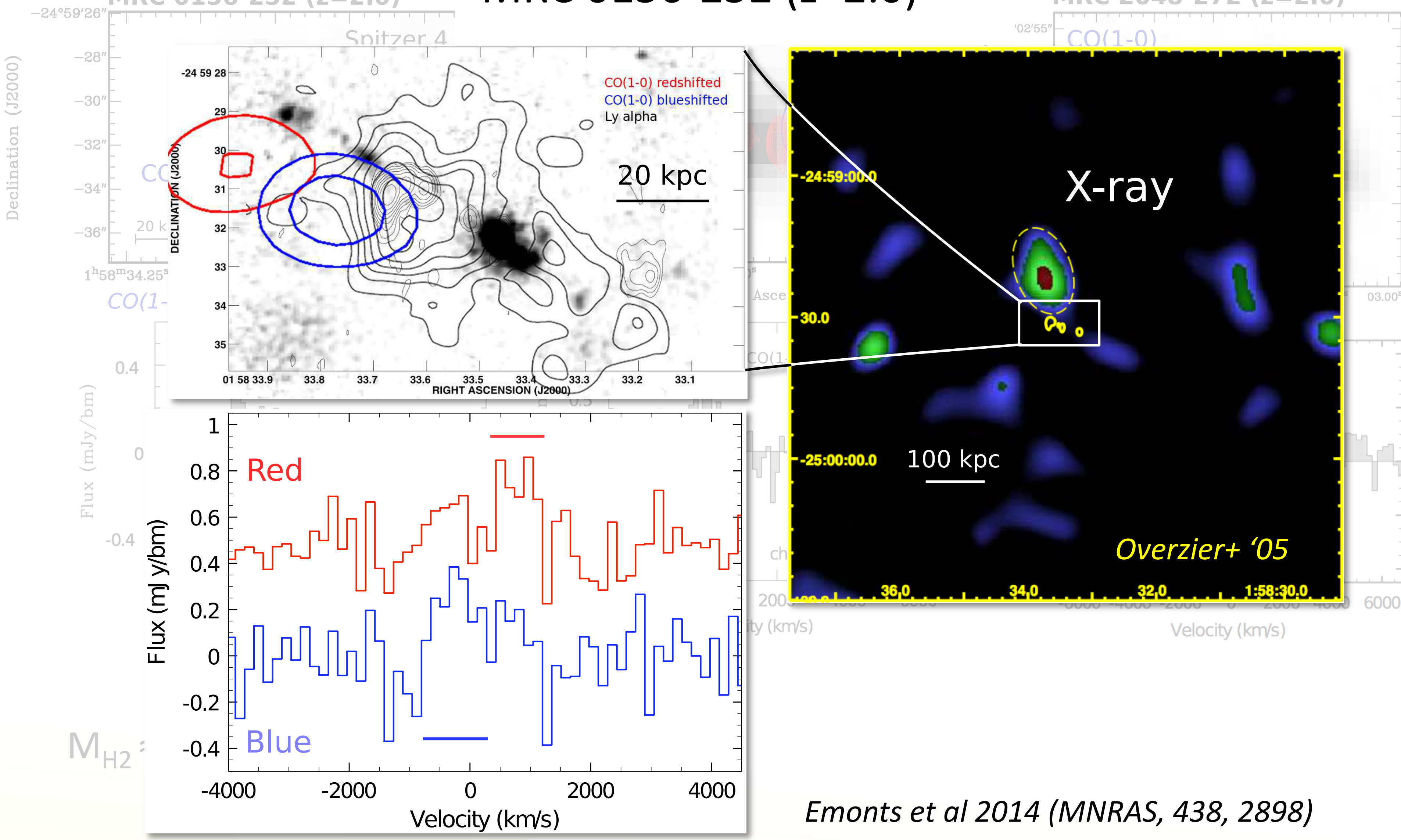
CO(1-0) in halo → radio – CO alignment



Emonts et al 2014 (MNRAS, 438, 2898)

CO(1-0) in halo → radio – CO alignment

MRC 0156-252 (z=2.0)



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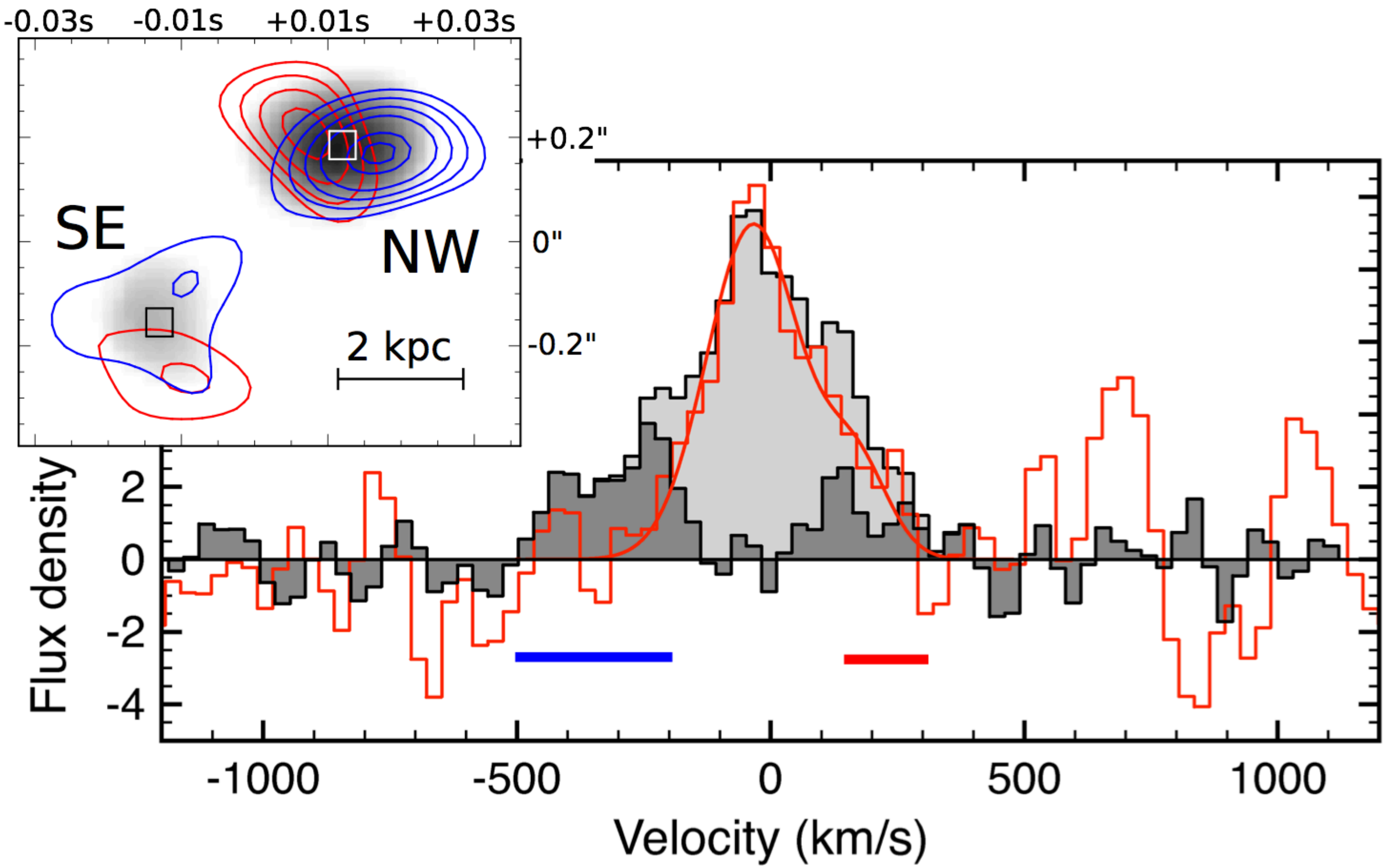

-0.03s
-0.01s
+0.01s
+0.03s
+0.2"
0"
-0.2"
SE
NW
2 kpc
Flux density
2
0
-2
-4
-1000
-500
0
500
1000
Velocity (km/s)