AGN-driven turbulence revealed by extreme [CII]158µm line cooling in radio-galaxies

Pierre Guillard
CNES Fellow
Intitut d'Astrophysique Spatiale, Orsay, France

"The Universe Explored by Herschel", ESTEC, Noordwijk, October 15th 2013

with: Nicole Nesvadba (IAS), Patrick Ogle (IPAC), François Boulanger (IAS), Matt Lehnert (IAP), Phil Appleton (NHSC), Bjorn Emonts (CSIRO), Pierre Lesaffre (ENS/LERMA), Michelle Cluver (SSC), Guillaume Pineau des Forêts (IAS, LERMA), Edith Falgarone (ENS/LERMA), Raphaella Morganti (SRON)

Outline

- AGN feedback…sure, but with which efficiency ???

- Physical state of the molecular gas in radio-galaxies: lessons from *Herschel* and insights into the physics of feedback

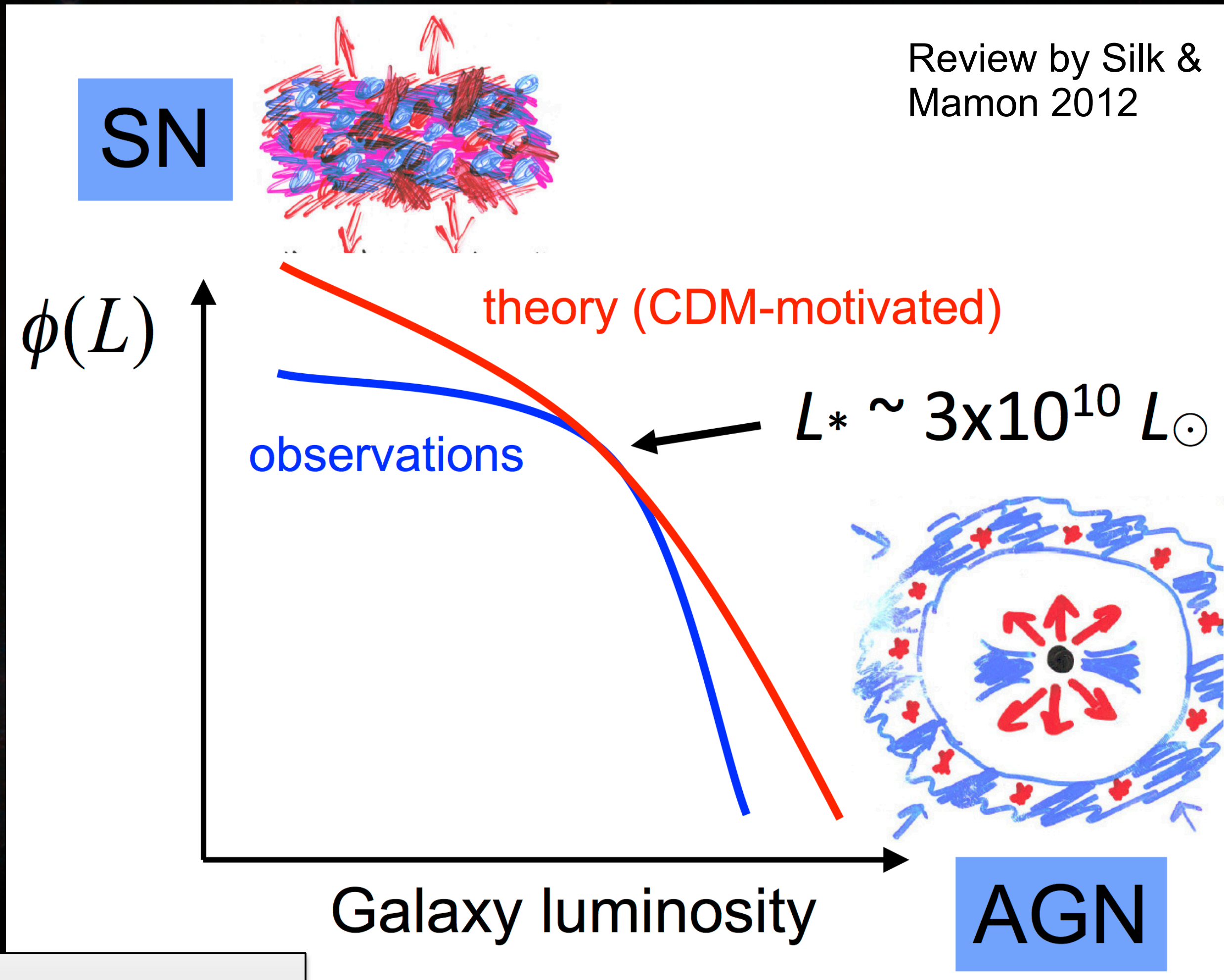
- [CII] as a tracer of low pressure, warm, non star-forming H_2 gas (too diffuse to be bright in CO)

Feedback is needed to make galaxy growth inefficient…

Dual role of AGN feedback:

- High redshifts: quenches the initial starburst associated with early phases of galaxy formation

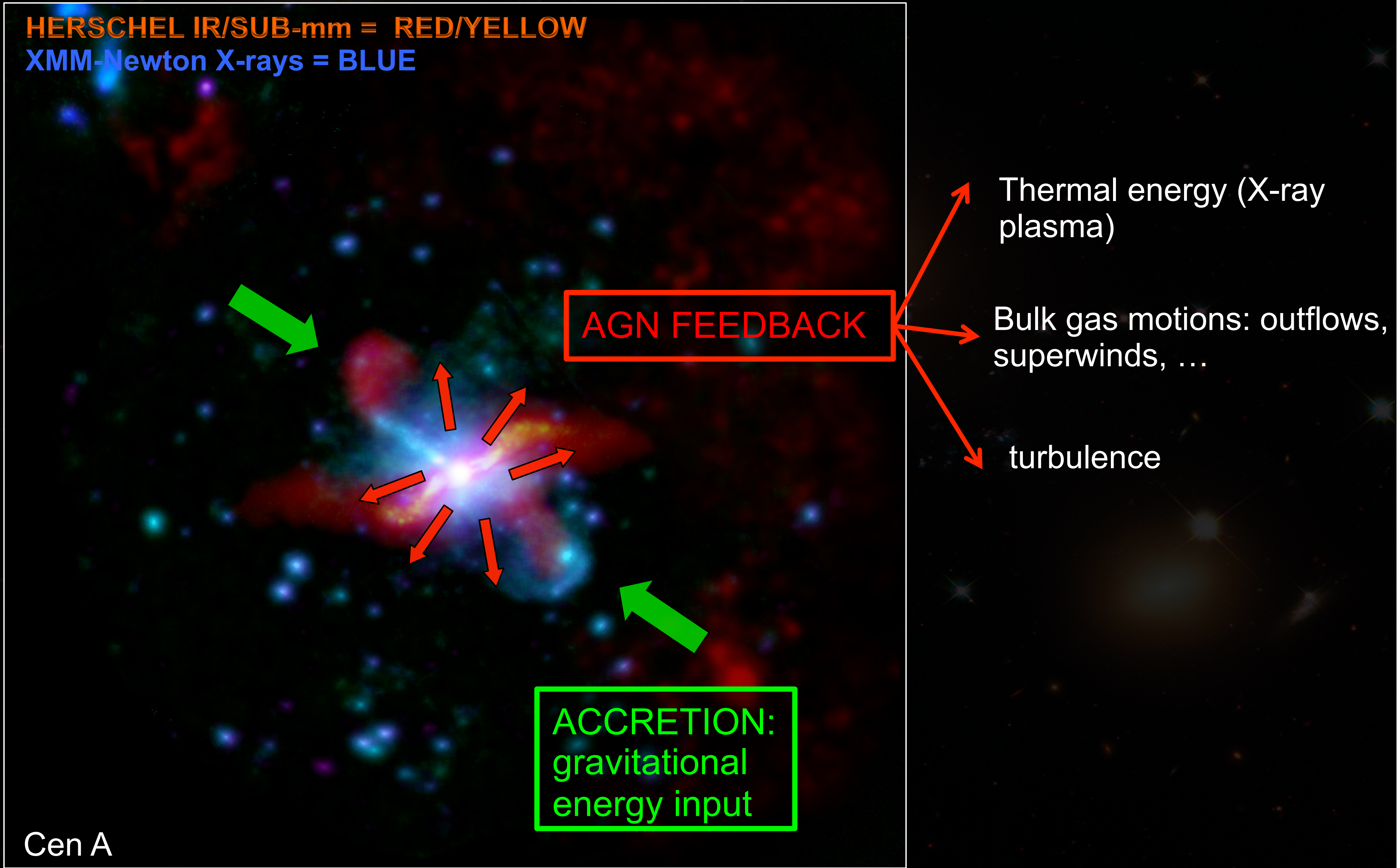
- Low redshifts: complements SN feedback to suppress gas cooling and prevent gas accretion



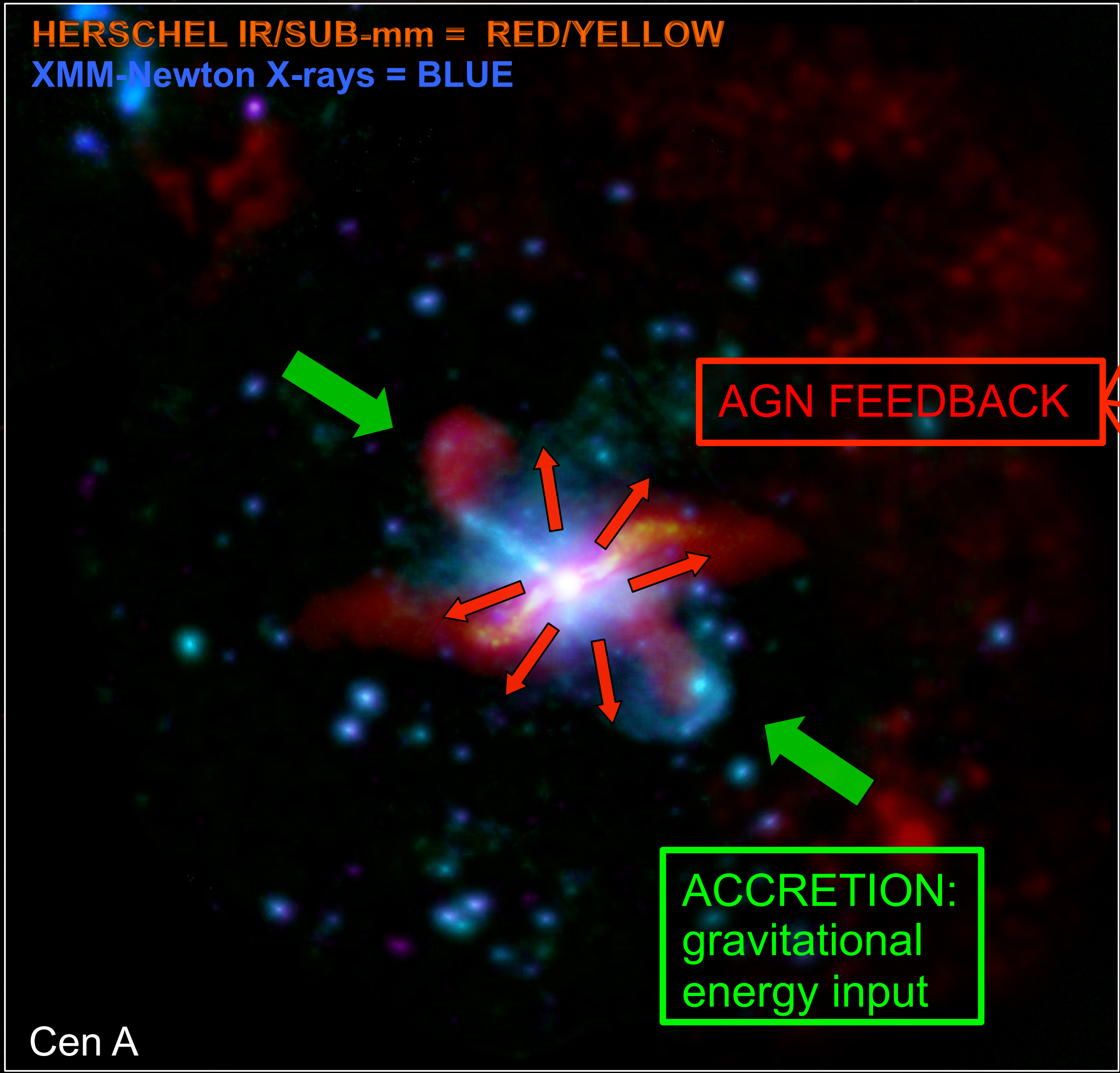
"Too many small galaxies,
too many big galaxies in the nearby universe,
too few massive galaxies at high redshift,
too many baryons within the galaxy halos."

AGN feedback seems an appealing solution…

AGN feedback is needed to make galaxy growth inefficient…
But why what efficiency??



AGN feedback is needed to make galaxy growth inefficient…
But why what efficiency??



Thermal energy (X-ray plasma)

Bulk gas motions: outflows, superwinds, …

Turbulence in H_2 gas

→ Role of Turbulence in galaxy formation?

→ Impact on the molecular gas? On the SFE?

Why observing [CII] in radio-galaxies with Herschel?

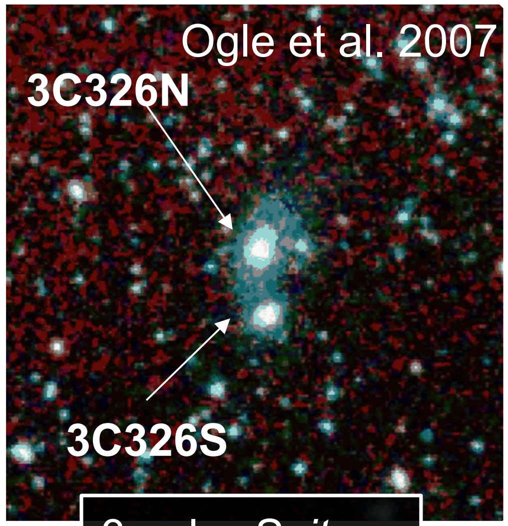
Advantages of radio-galaxies: we can estimate
- Their jet mechanical power
- The spatial scales of energy dissipation: up to Mpc !

Multi-wavelength observations of powerful radio-galaxies:
- X-rays
- HI, NaD: outflow signatures, mass outflow rates
- CO(1-0)
- *Spitzer* mid-IR spectroscopy (H_2/PAH: kinetic vs UV heating)
- *Herschel* far-IR spectroscopy:

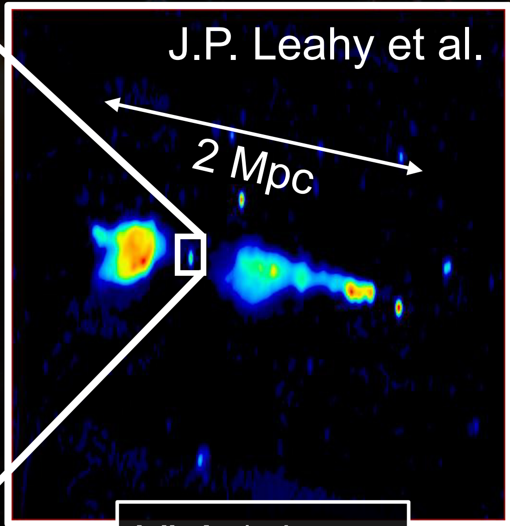
[CII]158 μm, $\Delta E/k = 91K$. Probes WNM > CNM transition (30 – 10^4 K)

→ Observations provide access to the physical conditions of the gas and the way kinetic energy dissipates in the different ISM phases, including the molecular gas

The 3C 326 radio galaxy: one of the best example of negative jet-driven feedback



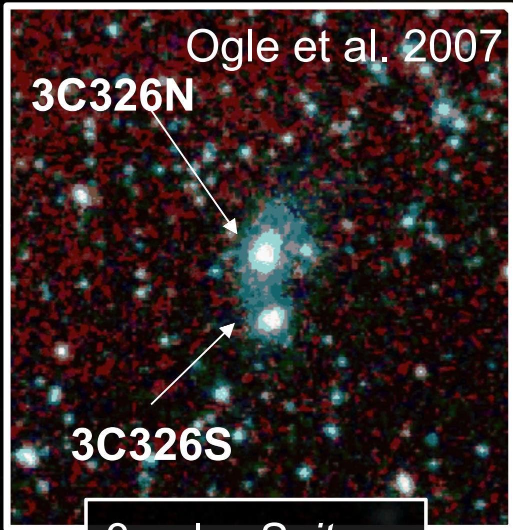
3-color *Spitzer* IRAC image



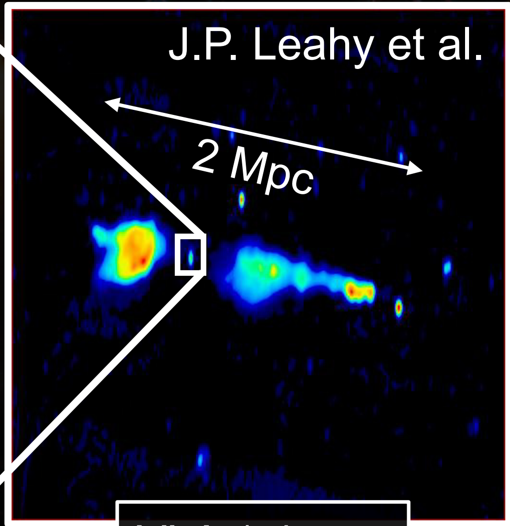
VLA 1.4 GHz image

- Pair of galaxies 3C326N & S at z=0.089
- Both contain nuclear radio sources. Which creates the jets? (Rawlings+90)

Warm H_2 gas in the 3C 326N radio galaxy

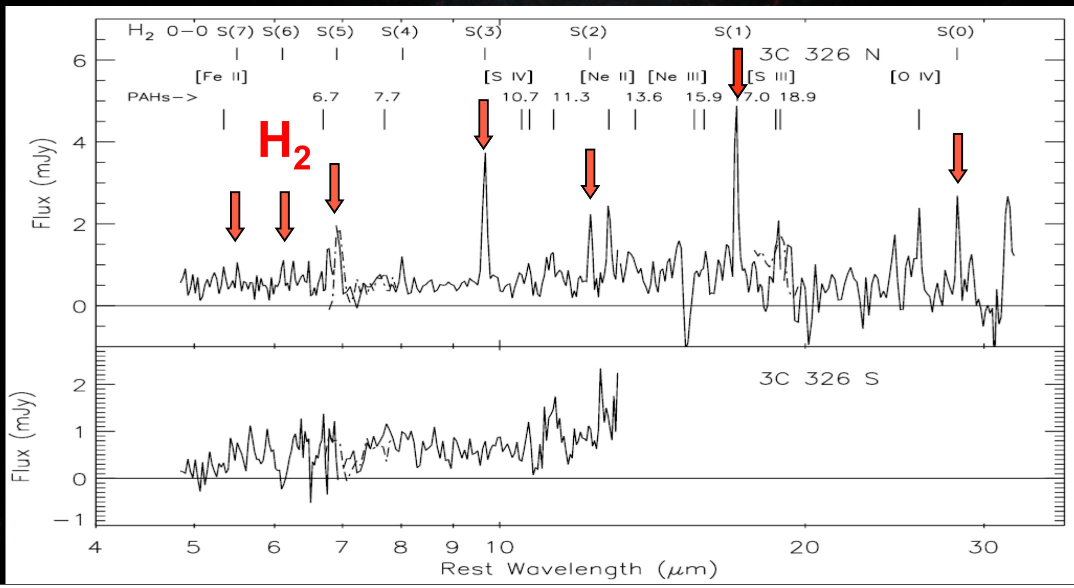


3-color *Spitzer* IRAC image



VLA 1.4 GHz image

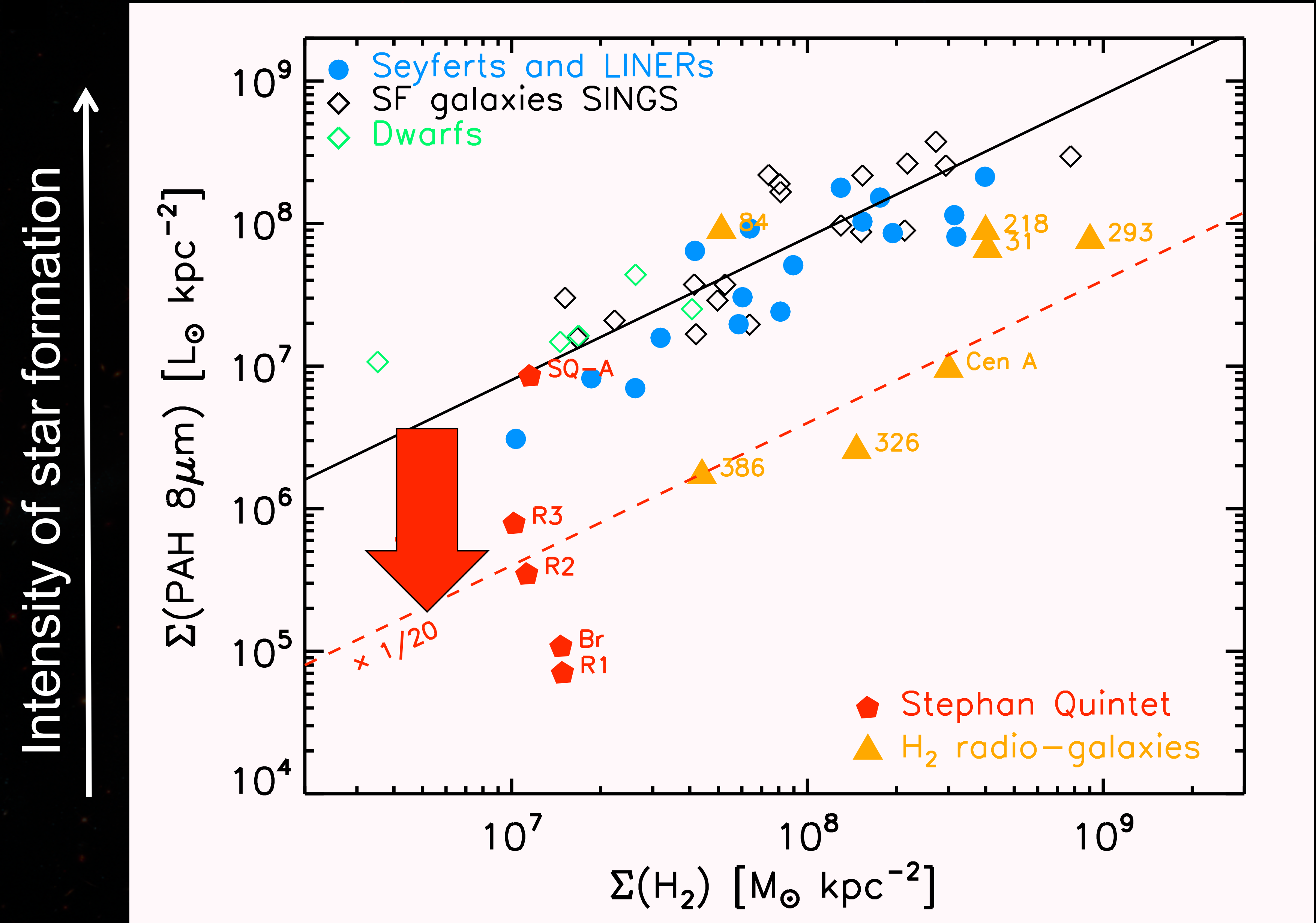
- Pair of galaxies 3C326N & S at z=0.09
- Both contain nuclear radio sources. Which creates the jets? (Rawlings+90)



Ogle et al. 2007

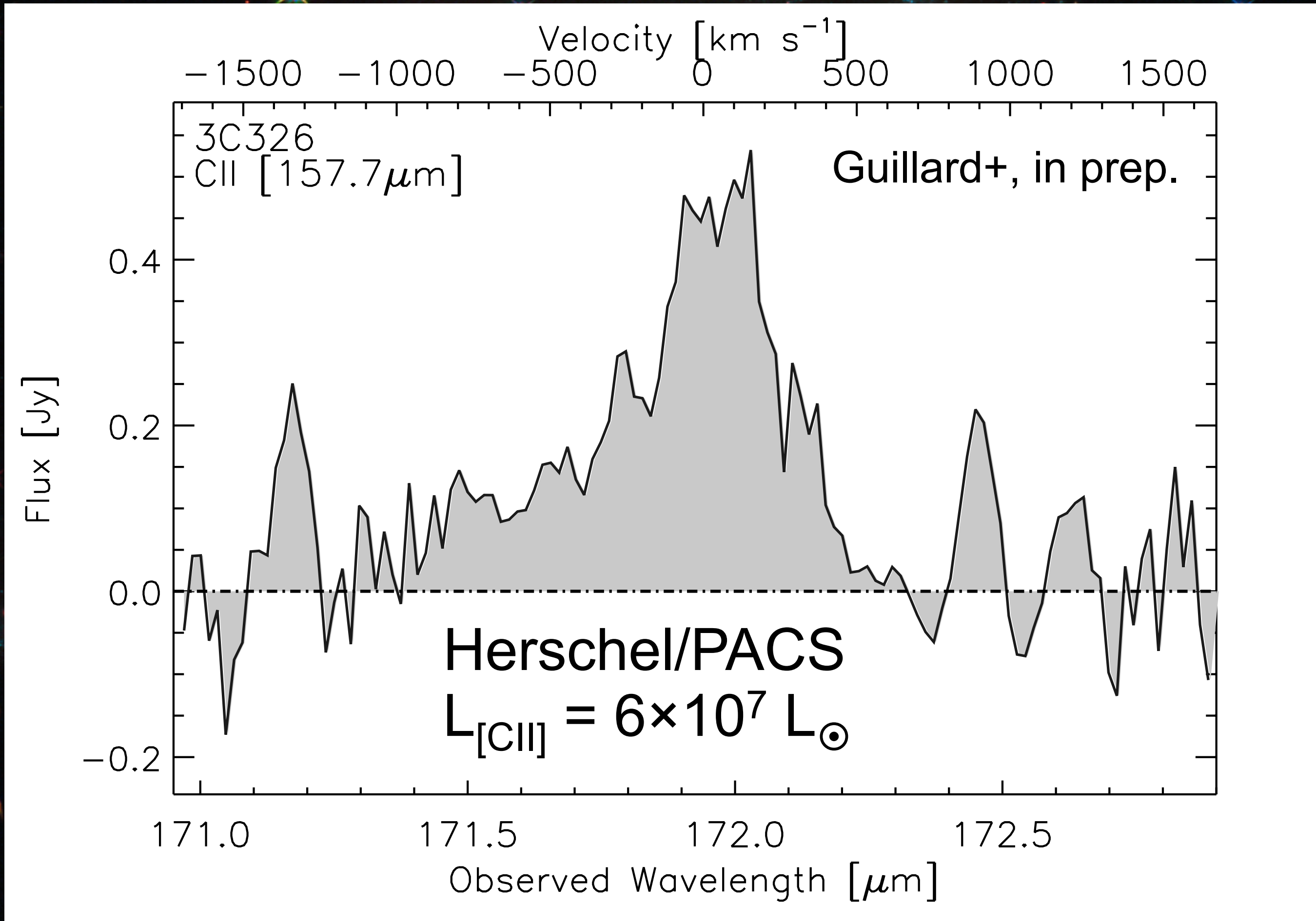
- $L(H_2)=8 \times 10^{41}$ erg/s
  $2 \times 10^9\ M_\odot$ of warm H_2
- 3kpc turbulent H_2 disk (Nesvadba+11)
- SFR $< 0.07\ M_\odot\ yr^{-1}$
- $L(H_2)/L(IR) \sim 0.2$!!

Evidence for suppression of star formation



Nesvadba et al. 2010, Guillard et al. 2012b

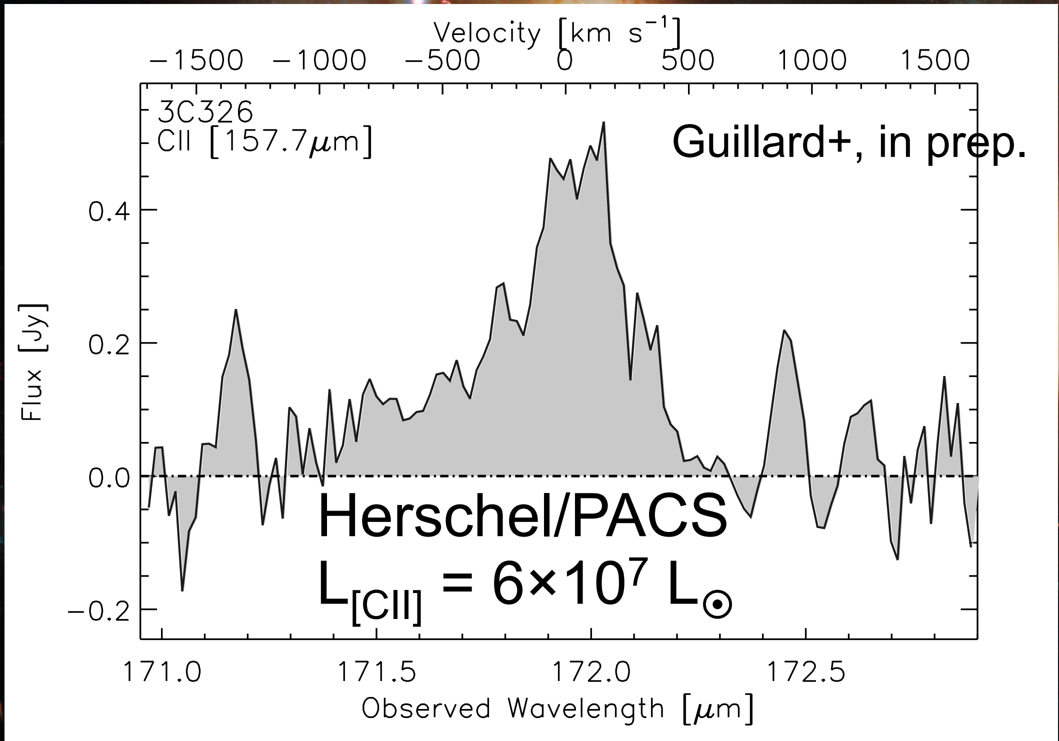
Powerful [CII] line but weak UV and star formation!

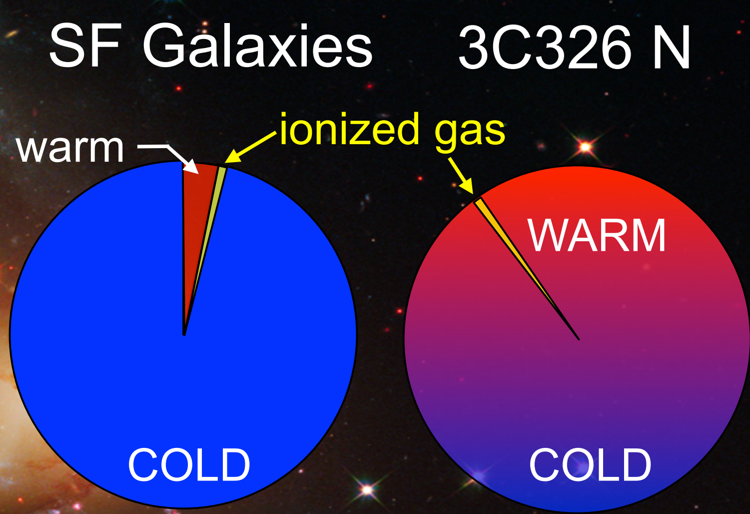


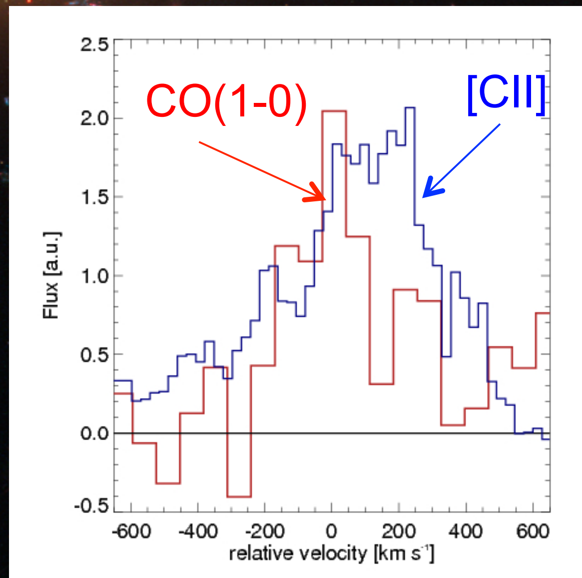
Mass of [CII]-emitting gas: $1.5\times10^{9}\ M_{\odot}$
at n_H = 100 cm^{-3} and T=100 K

The warm molecular gas is the only gas reservoir that can account for the [CII] emission

Powerful [CII] line but weak UV, CO and star formation!





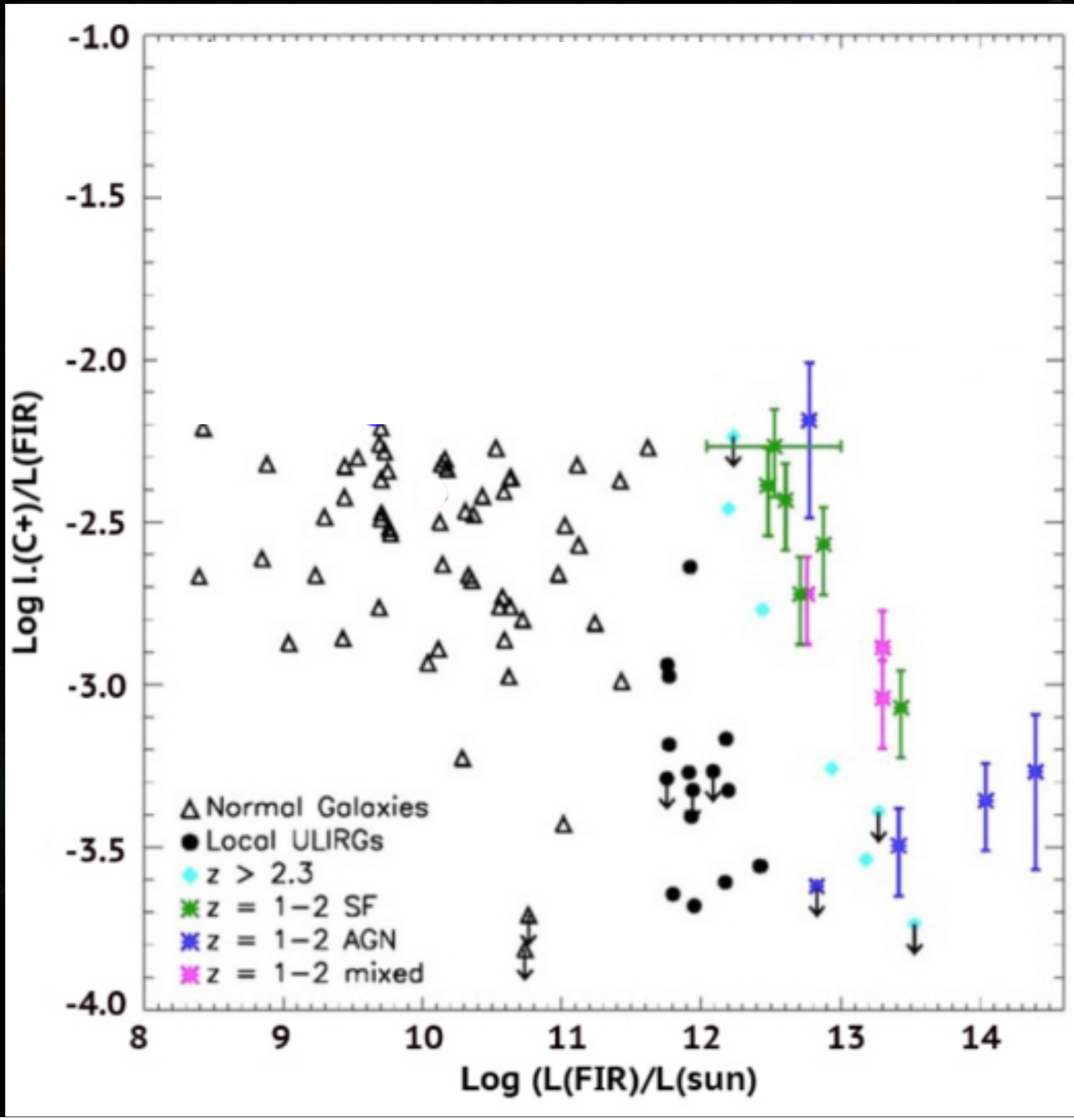


Weak CO emission. [CII] / CO(1-0) = 4000

Mass of [CII]-emitting gas: $1.5\times10^9\ M_\odot$
at n_H = 100 cm^{-3} and T=100 K

The warm molecular gas is the only gas reservoir that can account for the [CII] emission

[CII] emission in star-forming galaxies

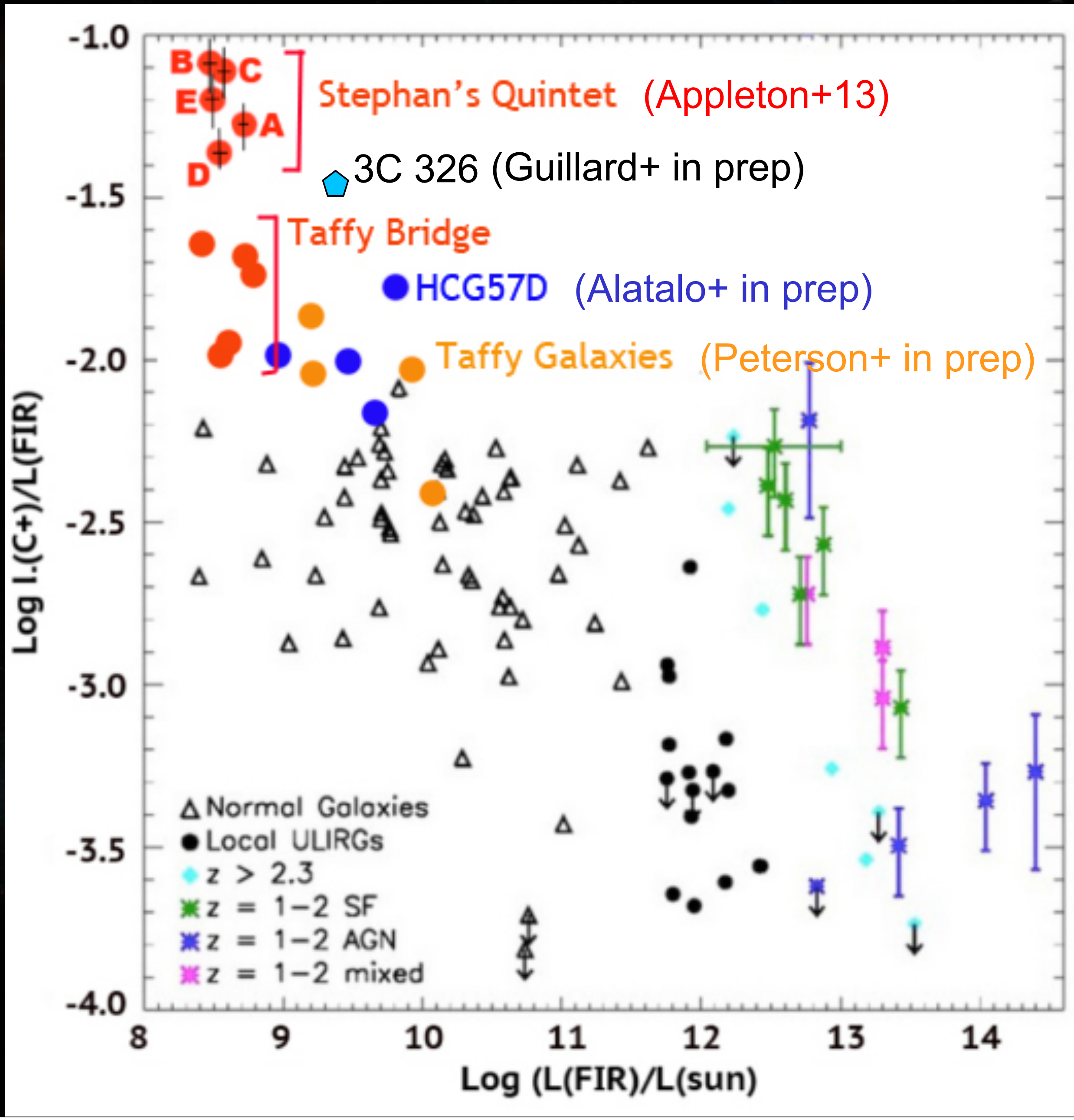


Stacey+10

Enhanced [CII] emission

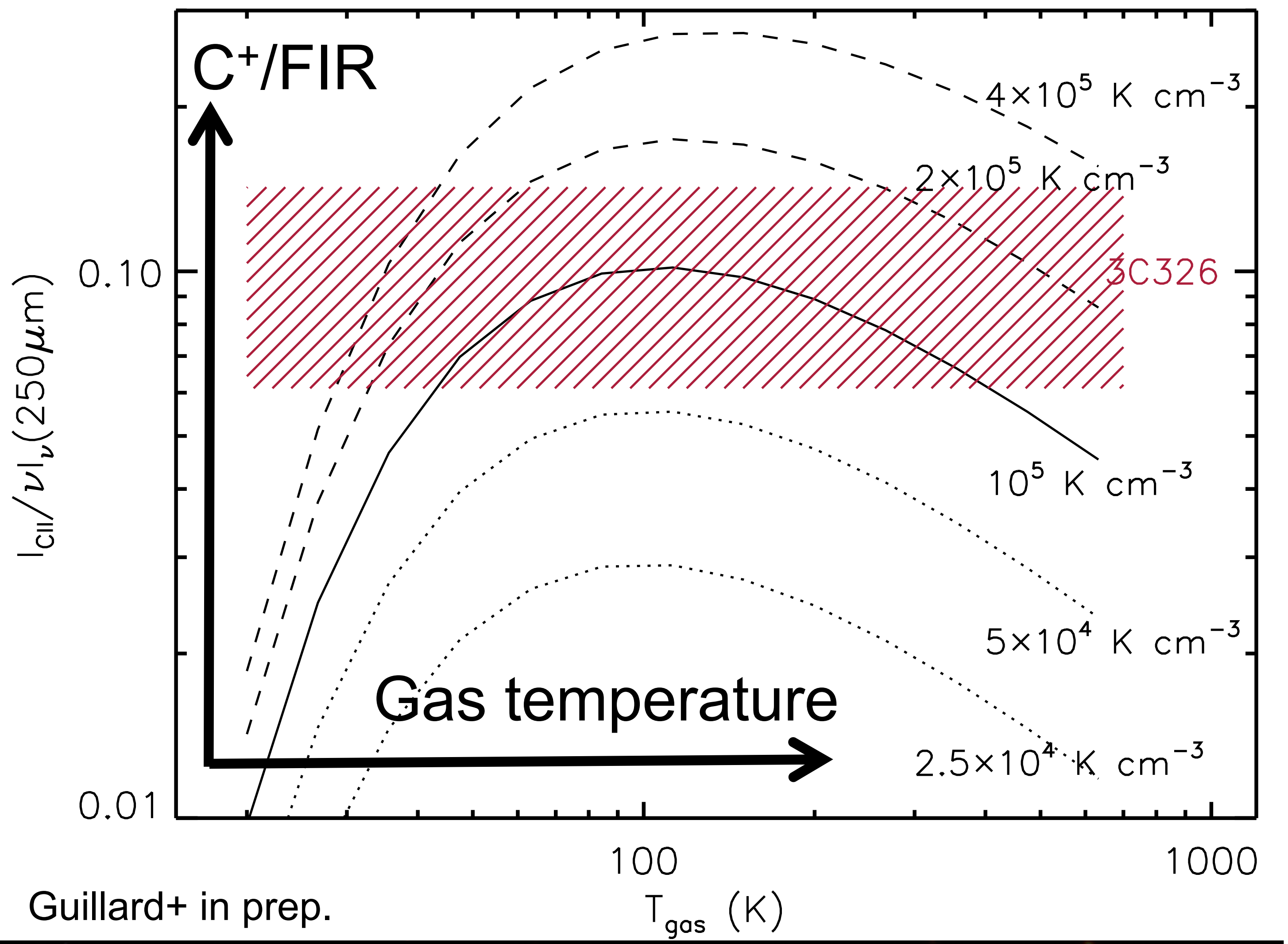
Turbulent Heating ?

Star formation heating



[CII] emission as a probe of warm diffuse H_2 gas in AGN hosts

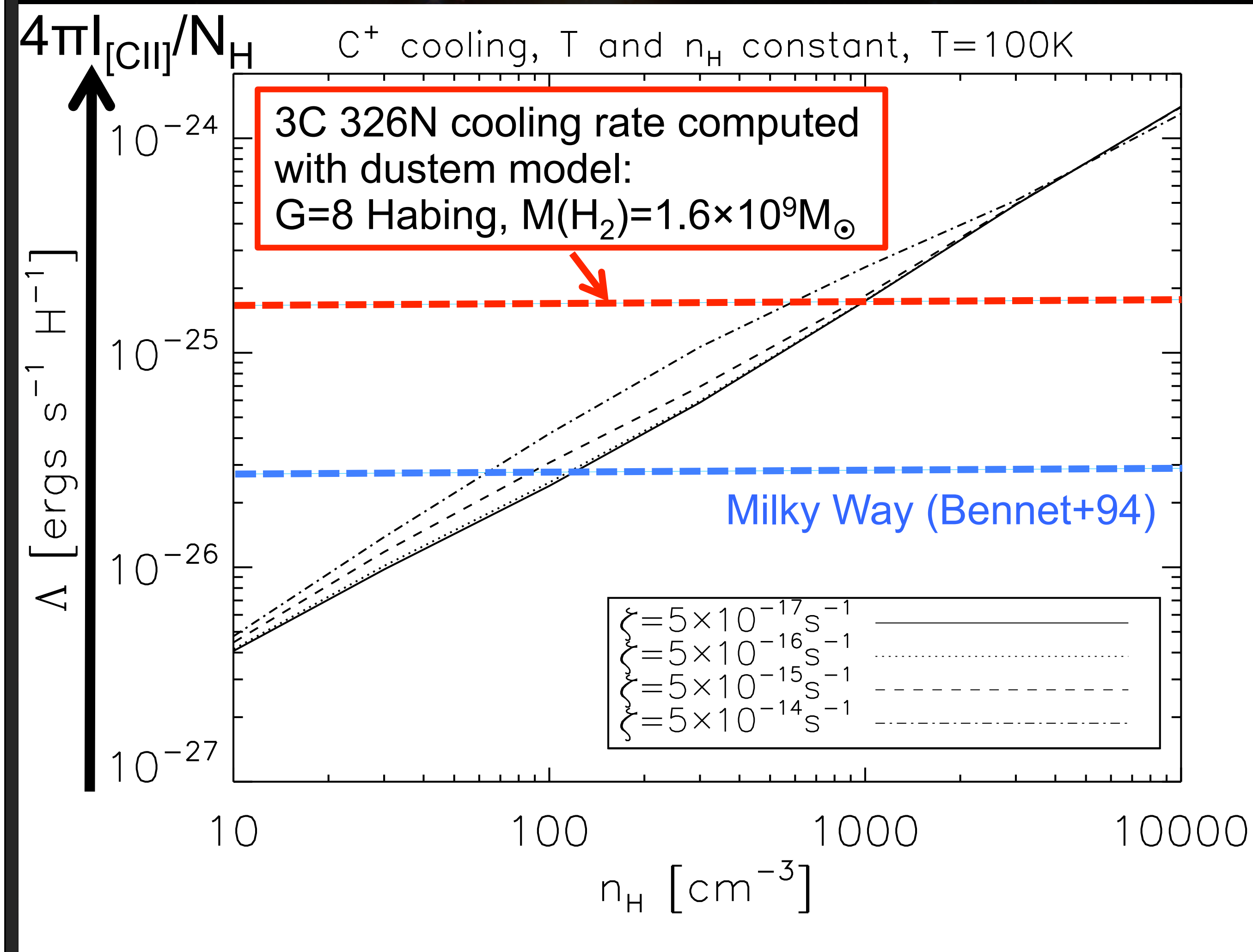
- C^+ cooling rate for a molecular fraction of 90%, and solar abundance (40% in gas phase)
- Dust model (Compiègne+10) for $I_{250\mu m}$
- Pressure ~ 10^5 K cm^{-3} for 3C 326
- Weak [OI] emission implies T<300K and $n_H \leq 5\times10^3$ cm^{-3} (Guillard +13a)
- No detection of high-J CO lines.



Guillard+ in prep.

What is the gas heating source?

Cosmic Rays?



- $\zeta = 2\times10^{-14}s^{-1}$ required to balance the observed [CII]+H_2 cooling rate (line luminosity to mass ratio).
  → energetically possible
- The gas has to be denser than $n_H \approx 10^4$ cm^{-3} to remain molecular
- [CII]/[OI] > 2.2 and weak CO lines do not favor this solution
- But…CRs could be responsible for high C^+/ CO abundance in H_2 gas (Mashian+13)

What is the gas heating source?

Turbulent heating?

- 10% of the jet mechanical power (a few 10^{44} erg s^{-1}) is enough to drive the outflow and power the observed H_2 luminosities (Nesvadba+10)

- turbulent heating is energetically possible if:

$$\Gamma_{turb} = \frac{3}{2} M_{\mathrm{H}_2} \frac{\sigma^3_{turb}}{H} > L_{[\mathrm{CII}]} + L_{\mathrm{H}_2}$$

$L(C^+ + H_2)/M(H_2) = 0.50\ L_\odot/M_\odot$

$\sigma > 180$ km/s for H = 3 kpc.

Observations: σ = 200-250 km/s

from [CII] and near-IR H_2 (Nesvadba+11)

What is the gas heating source?

Turbulent heating?

- 10% of the jet mechanical power (a few 10^{44} erg s^{-1}) is enough to drive the outflow and power the observed H_2 luminosities (Nesvadba+10)

- turbulent heating is energetically possible if:

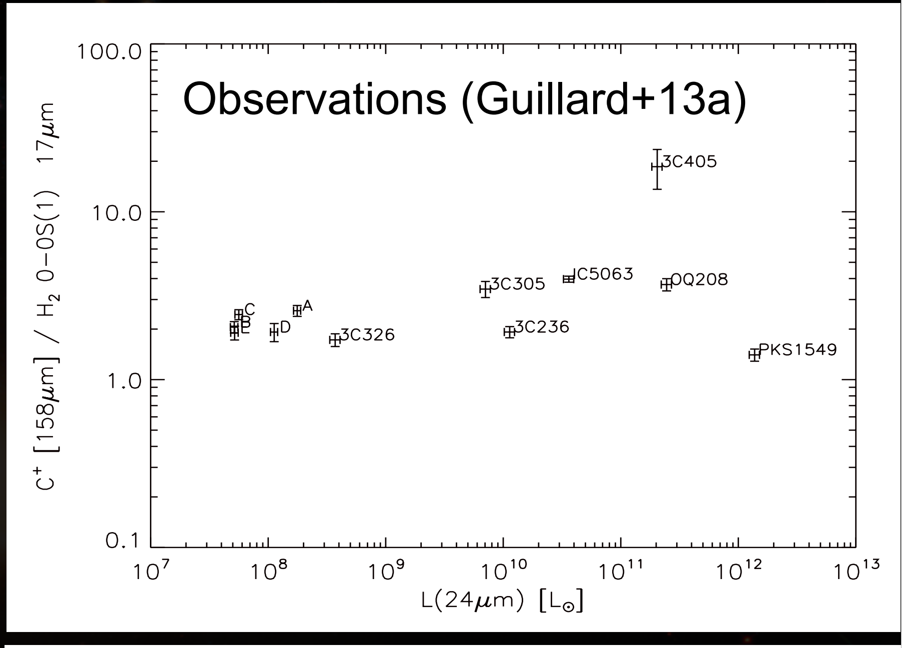
$$\Gamma_{turb} = \frac{3}{2} M_{\mathrm{H_2}} \frac{\sigma^3_{turb}}{H} > L_{\mathrm{[CII]}} + L_{\mathrm{H_2}}$$

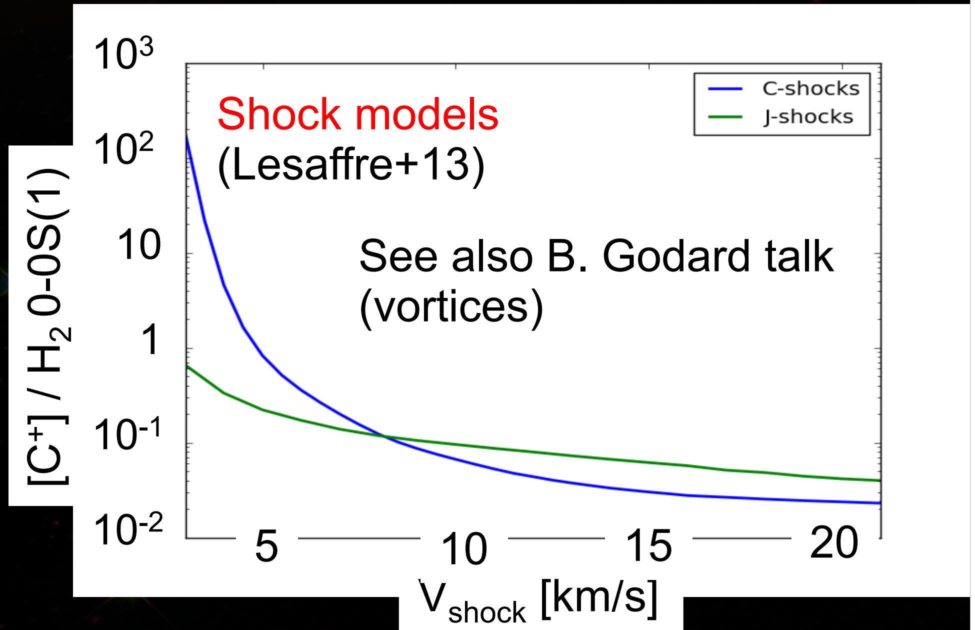
$L(C^+ + H_2)/M(H_2) = 0.50\ L_\odot/M_\odot$

$\sigma > 180$ km/s for H = 3 kpc.

Observations: σ = 200-250 km/s

from [CII] and near-IR H_2 (Nesvadba+11)





Low-velocity shocks in diffuse UV-irradiated gas

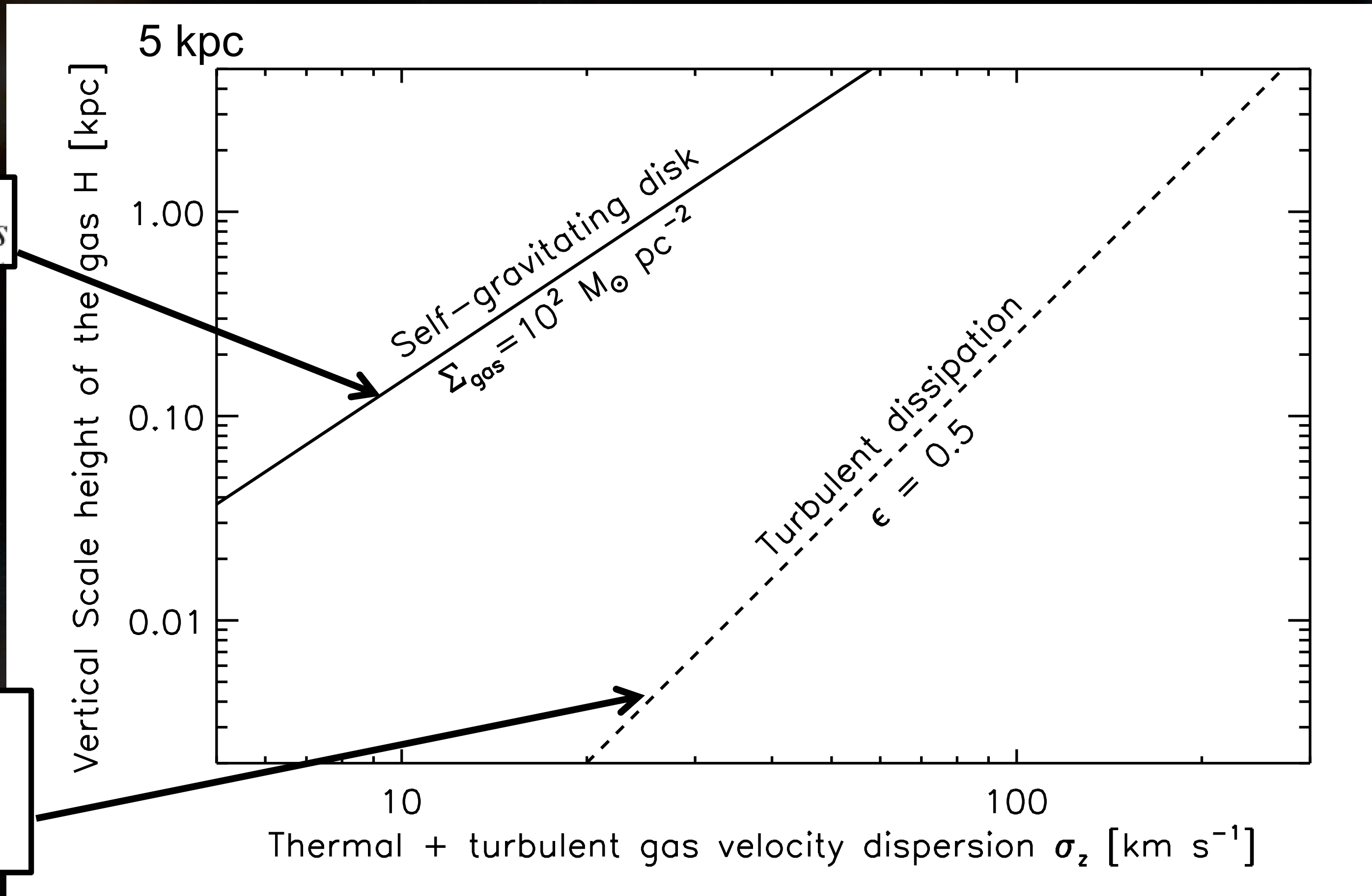
Turbulence as a feedback mechanism?
A non self gravitating disk in 3C 326N

Pressure equilibrium
(self-gravitating disk,
stellar spheroid)

$$H \approx (2/\pi G)\sigma_{gas}^2/\Sigma_{gas}$$

Turbulent heating rate
> Cooling rate

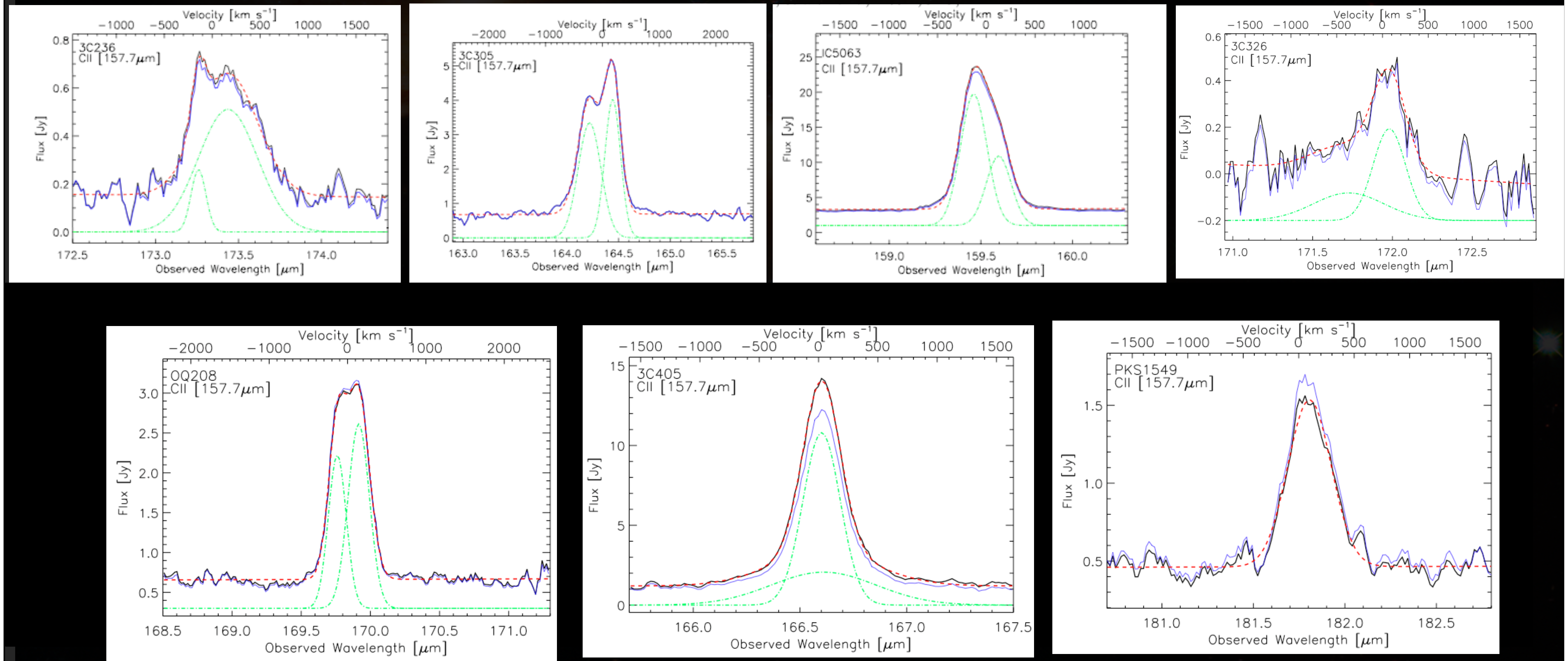
$$\frac{3}{2}\frac{\sigma_z^3}{H} = \epsilon^{-1}\frac{L_{[CII]+H_2}}{M_{H_2}}$$



The H_2 gas is not gravitationnally bound on the physical scale of the disk ⟶ Low SFE

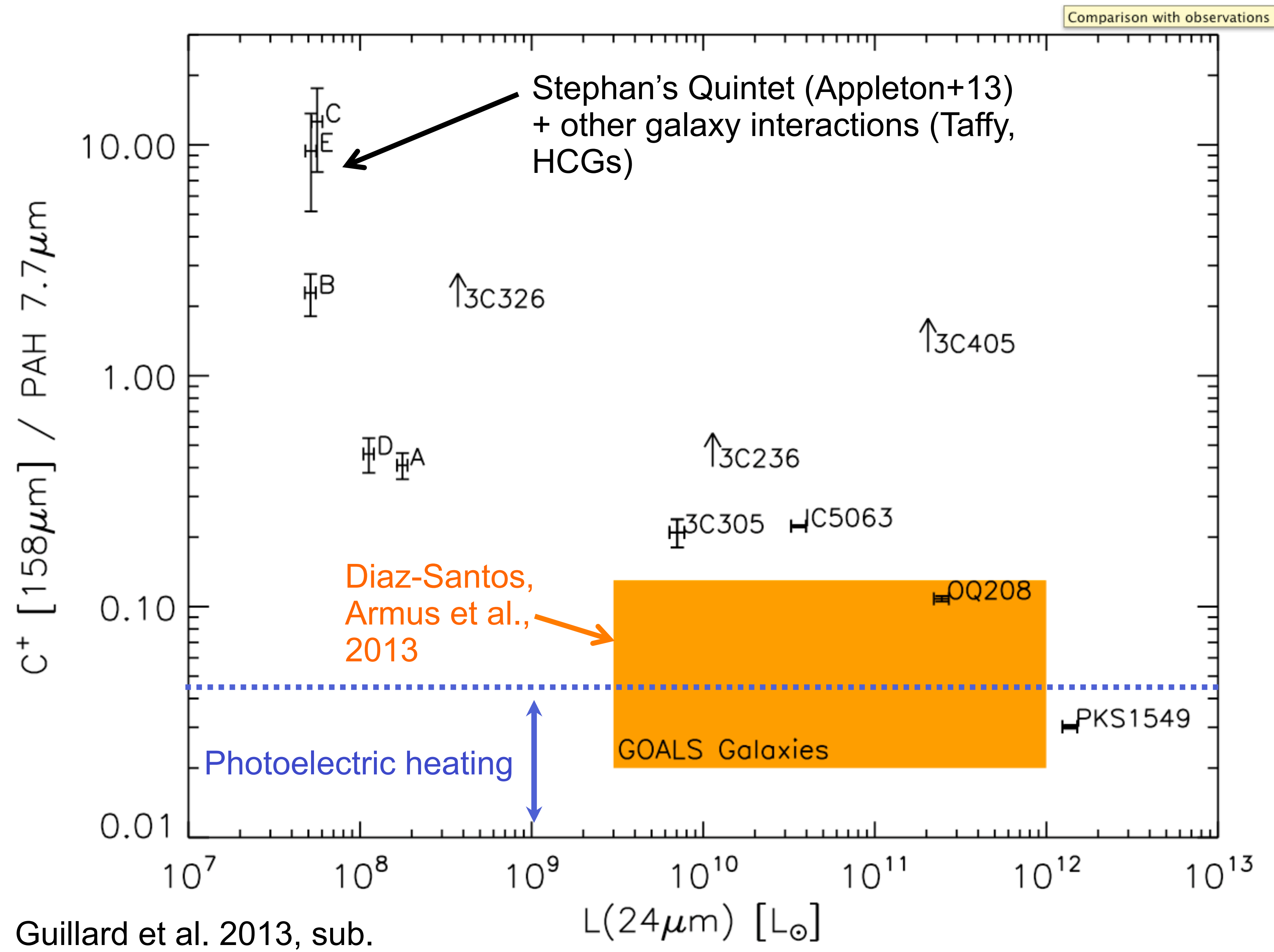
3C 326N is not a « one-off »

Bright (2 – 18 × 10^{-17} W/m^{-2}) and very broad (400 – 1200 km/s) C^+ line with complex, asymetric profiles (Guillard et al. in prep.).



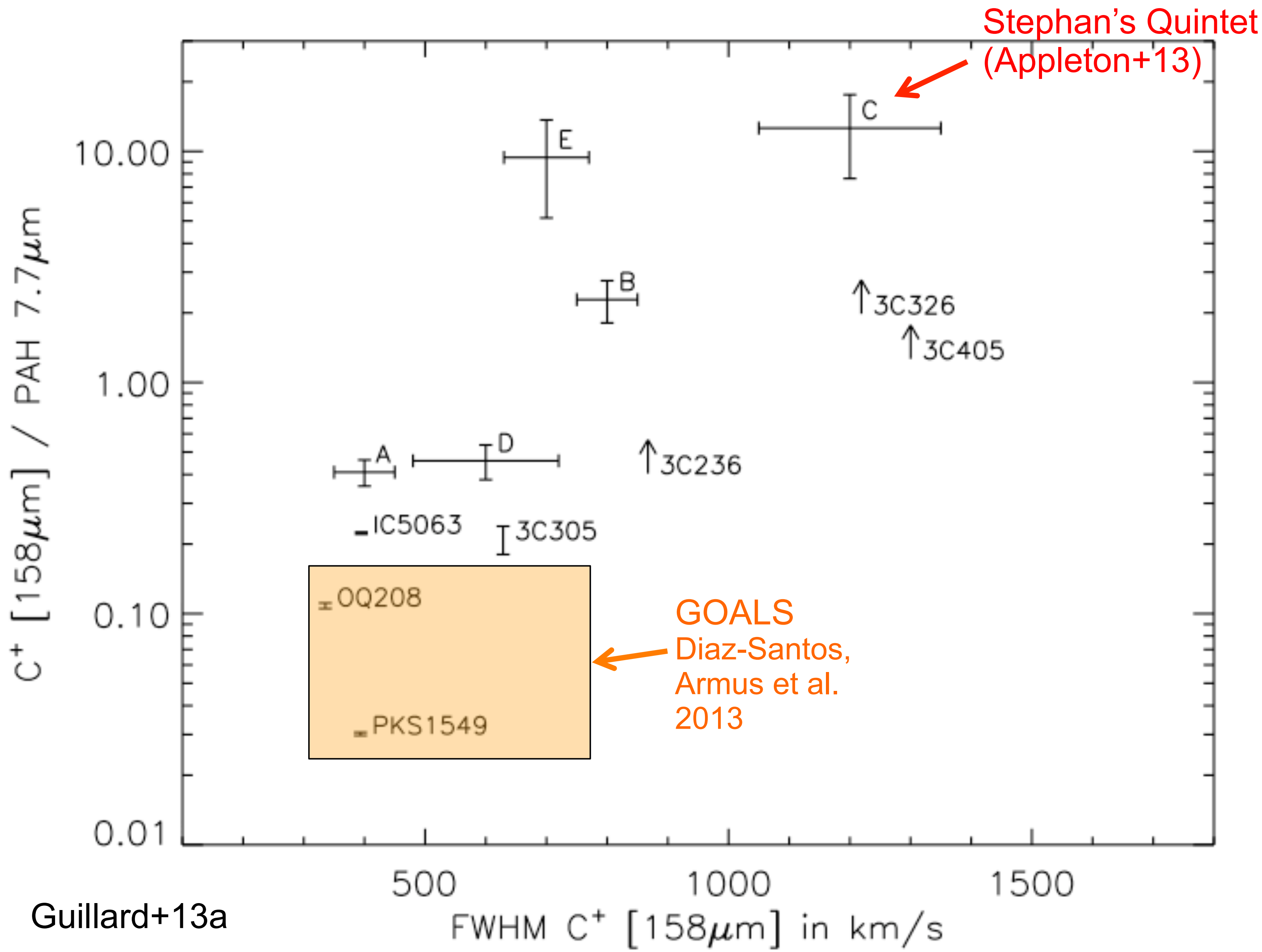
All these galaxies also show shock-excited rotational lines of H_2 in the mid-IR (Guillard+12)

Extreme C^+/PAH ratios: [CII] as a tracer of non star-forming gas



Guillard et al. 2013, sub.

Enhancement of C⁺ emission by turbulence?



Guillard+13a

Conclusions

- Discovery of kinematically-broad C^+ line emission in powerful radio-galaxies, too bright to be excited by star-formation alone.

- [CII] traces non star-forming warm H_2 gas, too diffuse to be bright in CO.

- The dissipation of mechanical energy (jet) is the most likely heating source. Cosmic rays play an important chemical role (high C^+/CO abundance in low A_V gas).

- Turbulent heating has a very important impact on the physical state of the molecular gas and can prevent the H_2 gas to be bound on disk scales.

- Towards an understanding of how the mechanical energy is dissipated and re-distributed among thermal/bulk/turbulent components... Crucial to understand the suppression of star formation (negative feedback) in early galaxy formation. Input for galaxy formation models!