Molecular gas and dust in galaxy collisions

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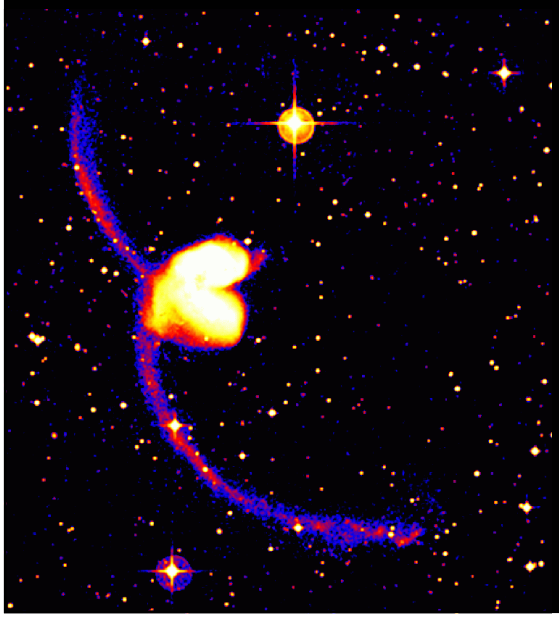

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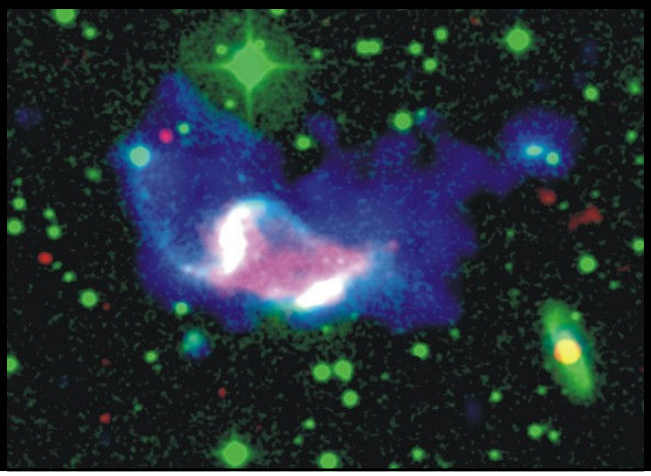
Different types of Galaxy collisions



Molecular gas observations

In my talk I will adress **molecular gas** and dust outside main galaxies in different types of object:

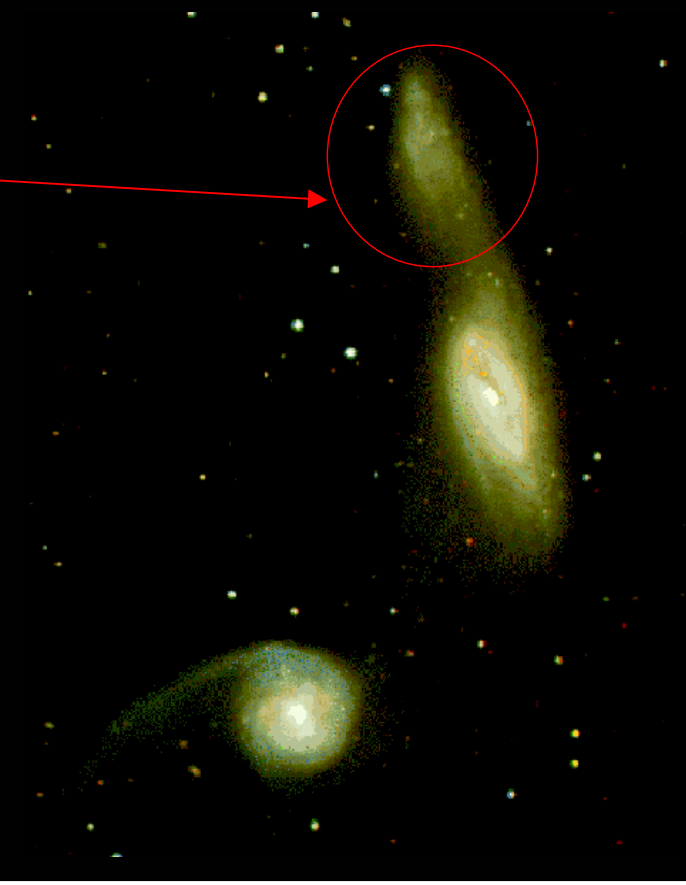
1. Tidal Dwarf Galaxies
2. Intragroup molecular gas in Stephan's Quintet
3. Bridge of head-on (direct) collision system (Taffy Galaxies)
4. Infalling and disrupted dwarf (?) close to NGC 3226/7

Main conclusions about the molecular gas:

1. Molecular gas , observed by single dish telescopes if found (almost) is everwhere where HI is
2. Molecular gas, observed with interferometers, is found coincident with SF regions

What are TDG?

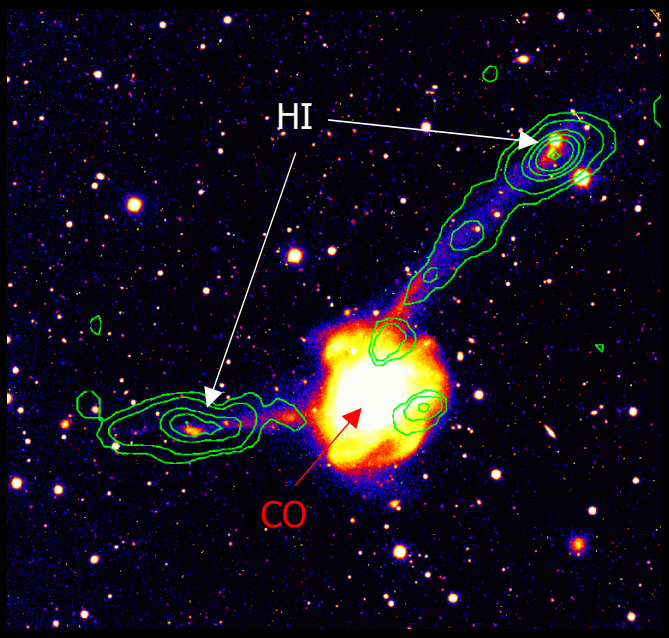
A self-gravitating entity formed out of the debris in tidal interactions



- Self-gravitating, i.e not just a agglomerations of stars and gas (hard to decide observationally)
- Can contain both stars and gas from debris
- Future development unclear, but potential to become a dwarf galaxy

What do we know about TDGs?

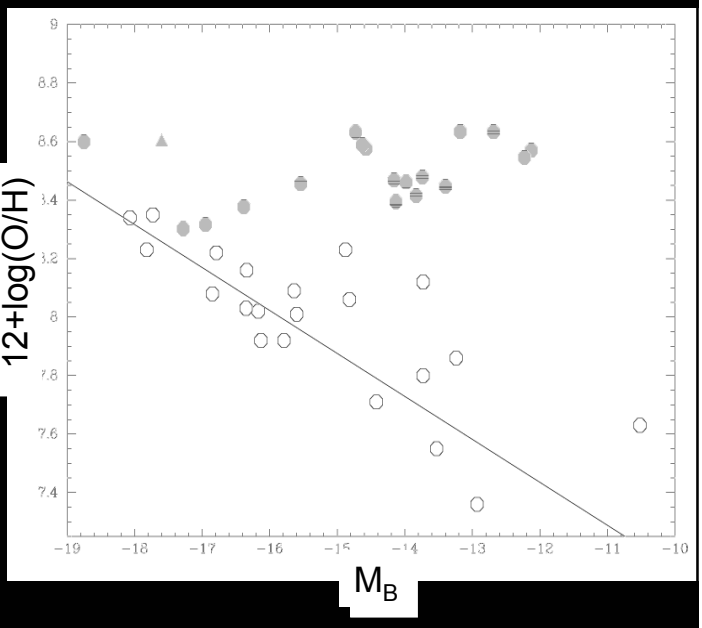
- Produced in galaxy interactions in tidal tails
- Gas segregation: HI at end of tails, most CO in parent galaxies
- Most TDGs have two main stellar components:
  - young stars recently formed
  - older stars (~1 Gyr) from parent galaxies



NGC 7252

What do we know about TDGs?

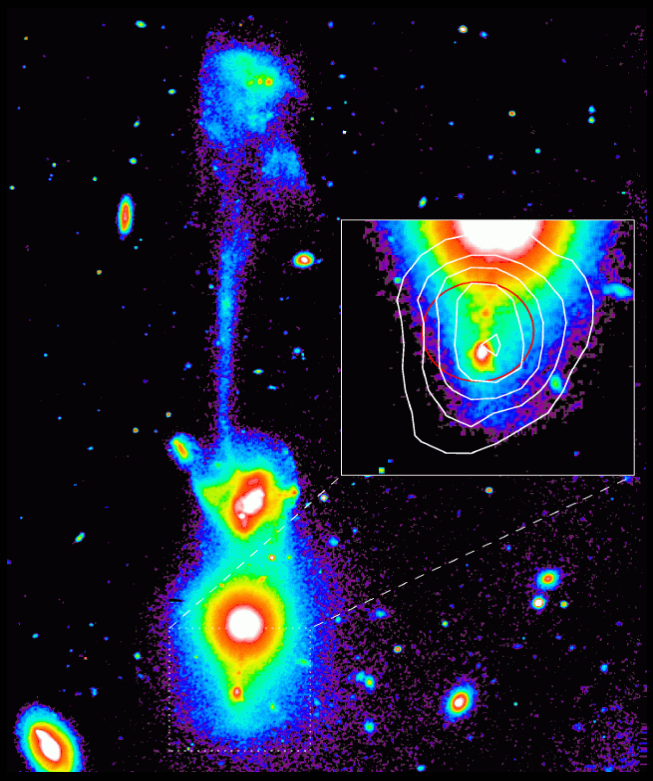
- Gaseous and stellar properties: similar to classical dwarf irregular and blue compact dwarfs …..
- ….except their high metallicity
  - ➔typical of outer regions of spiral galaxies
  - ➔higher than in classical dwarf systems of comparable size
  - ➔do not follow luminosity-metallicity relation



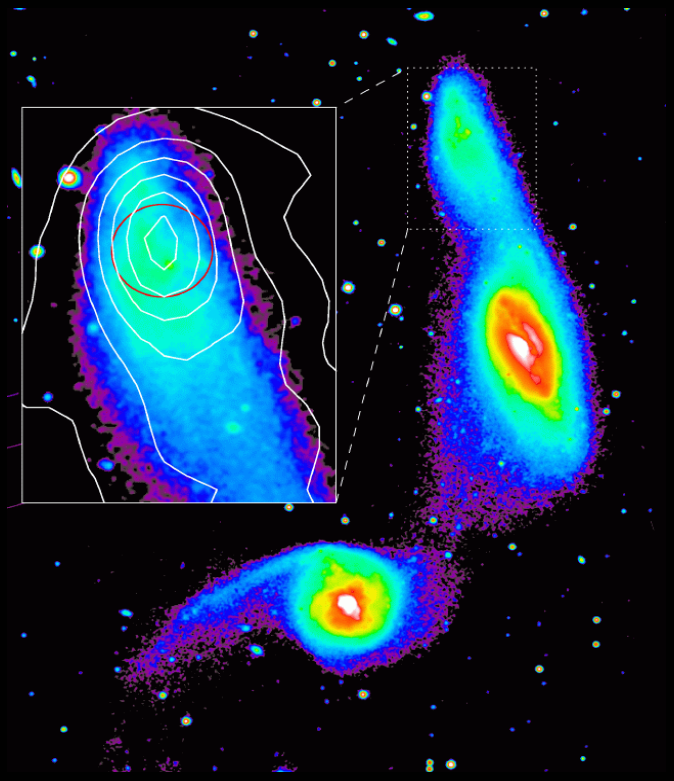
(Duc et al. 2000)

Single-dish CO observations in a sample of TDGs

12 galaxies observed,
9 detected



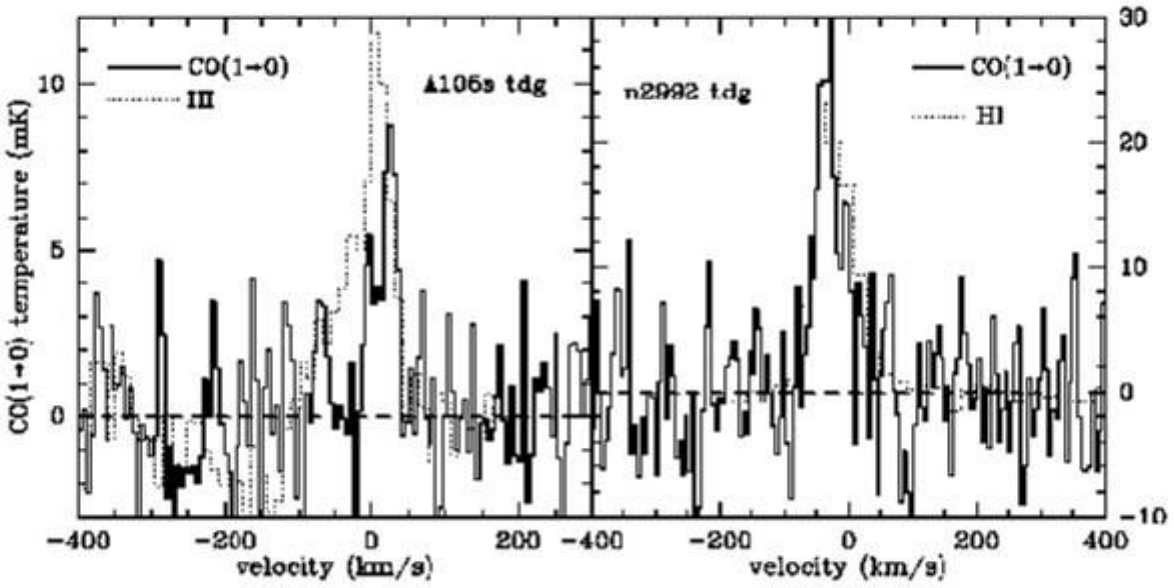
Arp 105



NGC 2992/93

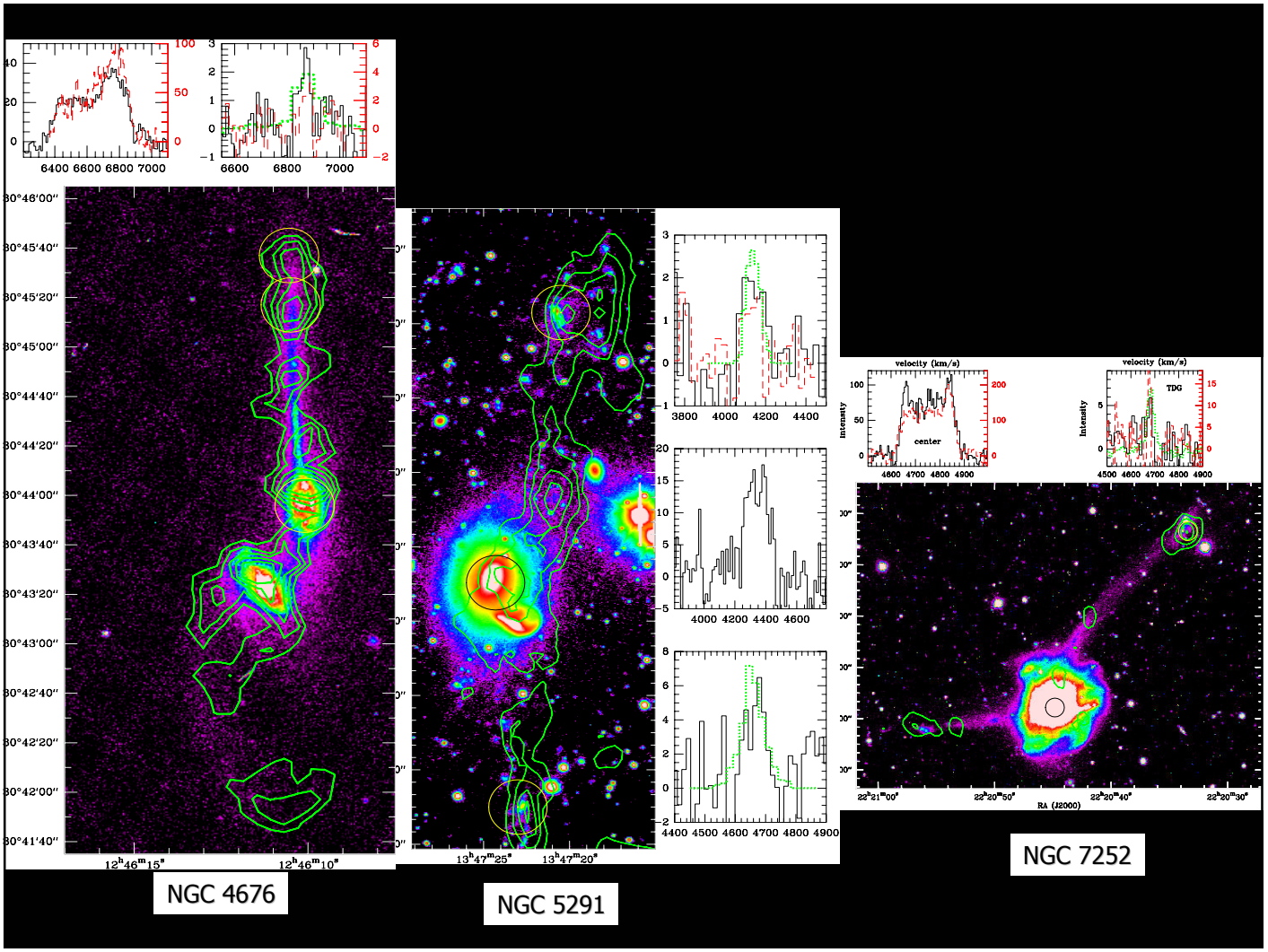
Braine et al. 2000
Braine et al. 2001

CO spectra



- CO lines coincides spatially and kinematically with HI
- spatial coincidence with Ha

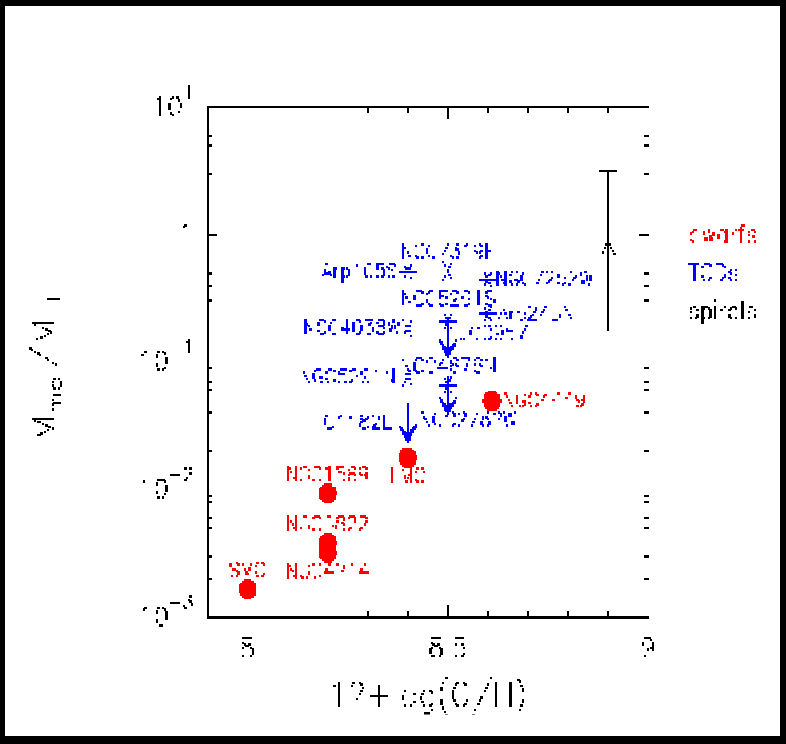
We see: HI → H2 → star formation


NGC 4676
NGC 5291
NGC 7252
velocity (km/s)
intensity
center
TDG
RA (J2000)

Comparison to spiral and classical dwarf galaxies

1) Molecular gas fraction:

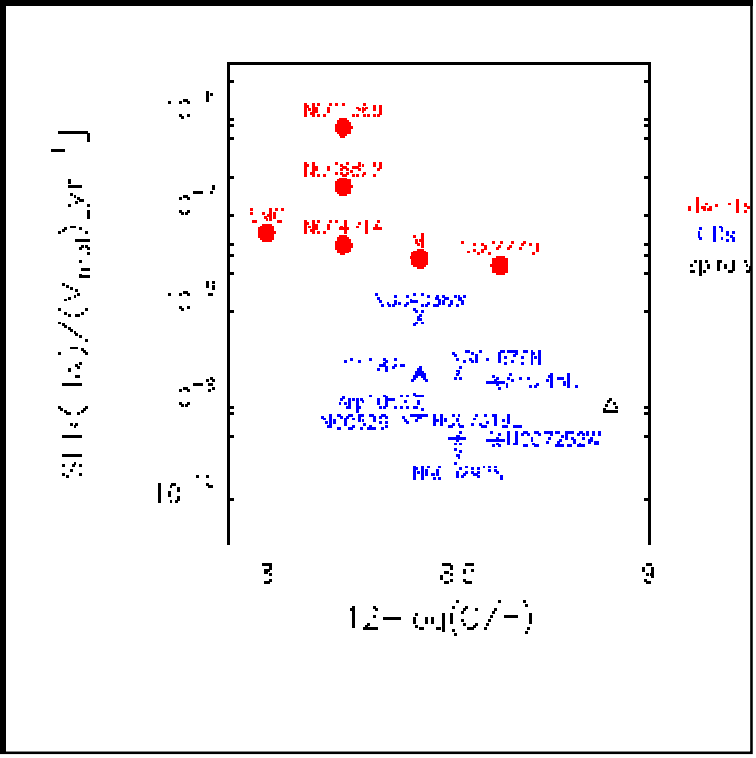
- TGDs similar to spirals
- Classical dwarfs have low molecular gas fraction due to low metallicity



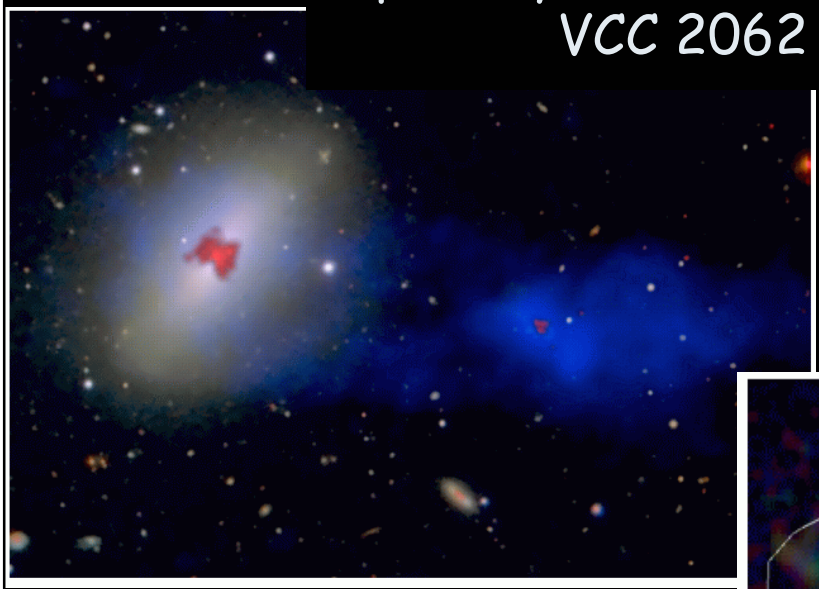
Comparison to spiral and classical dwarf galaxies

2) Star formation efficiency (with respect to molecular gas):

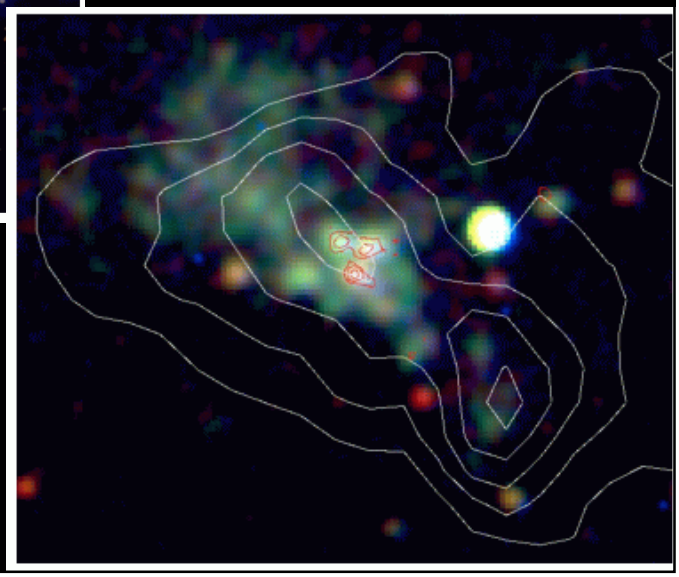
- Normal in TDGs
- Low in classical dwarfs



Spatially resolved observations of TDGs: VCC 2062 (Duc et al., in prep)

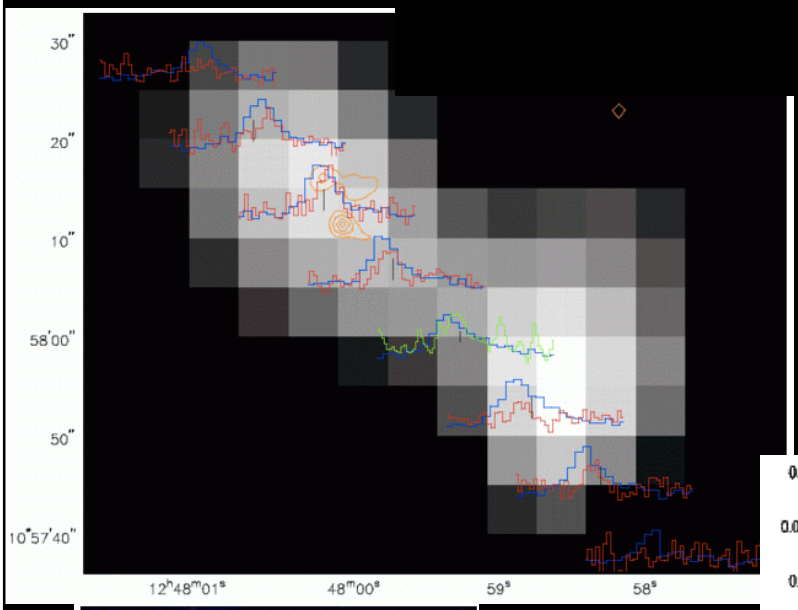


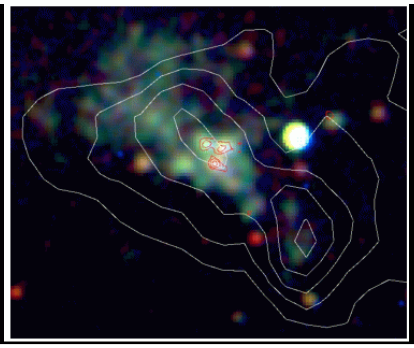
True color image (BVR) pf VCC 2062.
Superimposed: HI (white contours), Ha (red contours)



True color image (BVR) of NGC 4694 and VCC 2062
Superposed: HI (blue) and Ha (red)

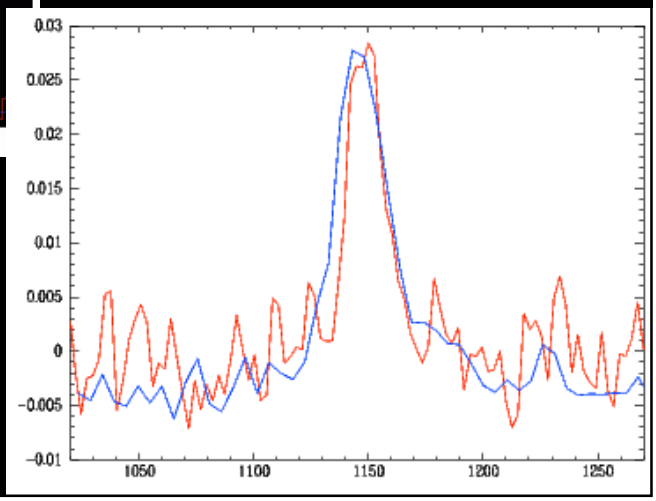
Interferometric observations of TDGs: VCC 2062





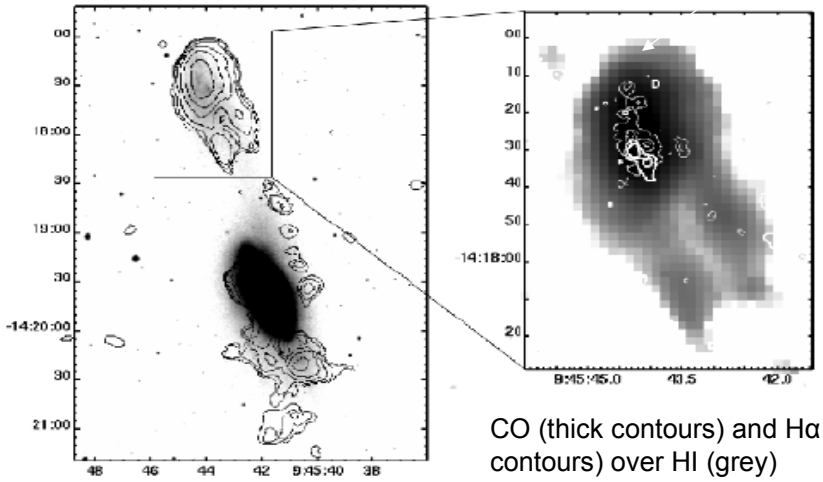
CO follows HI very well in distribution and kinematics

Integrated CO (red) and CO (blue) line



Interferometric observations of TDGs: NGC 2992/3

Brinks, Duc & Walter (2004)

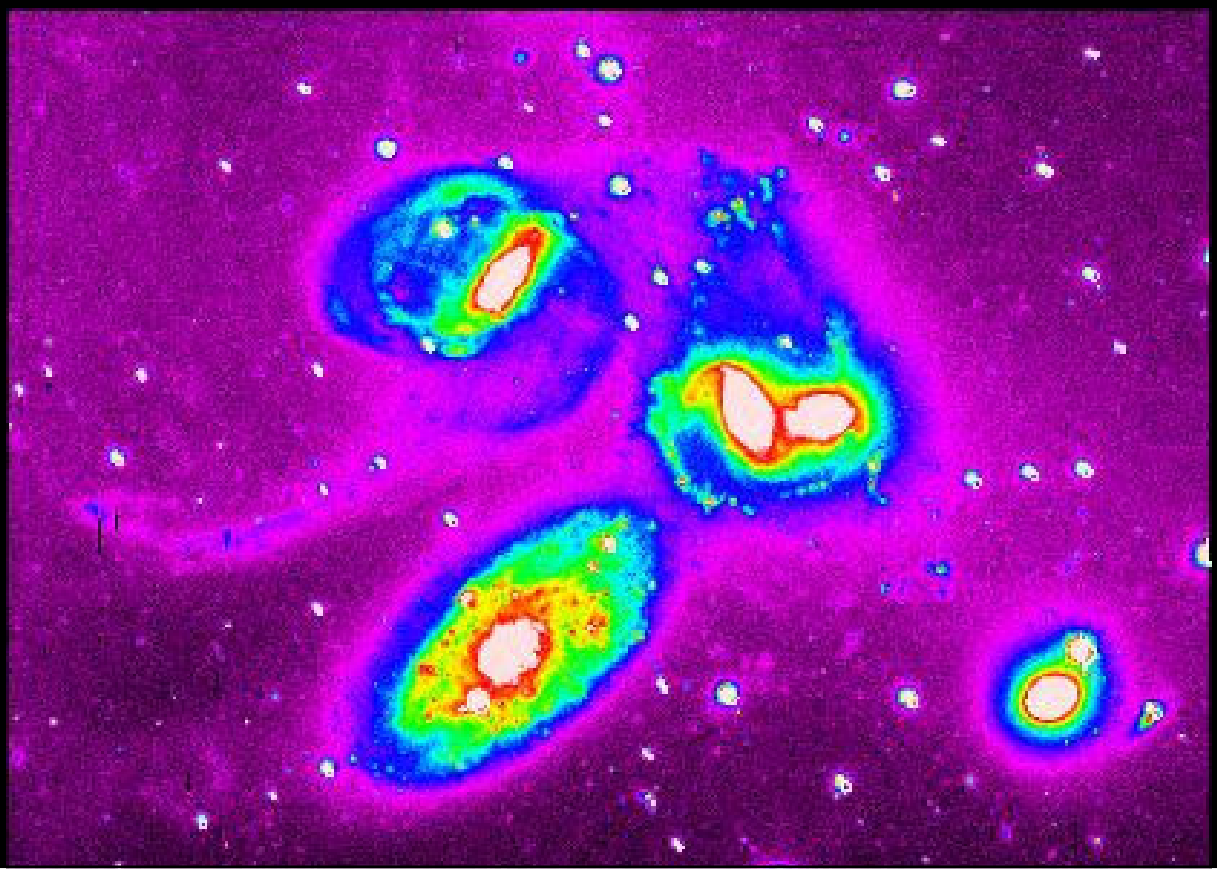


HI (contours) over Rband

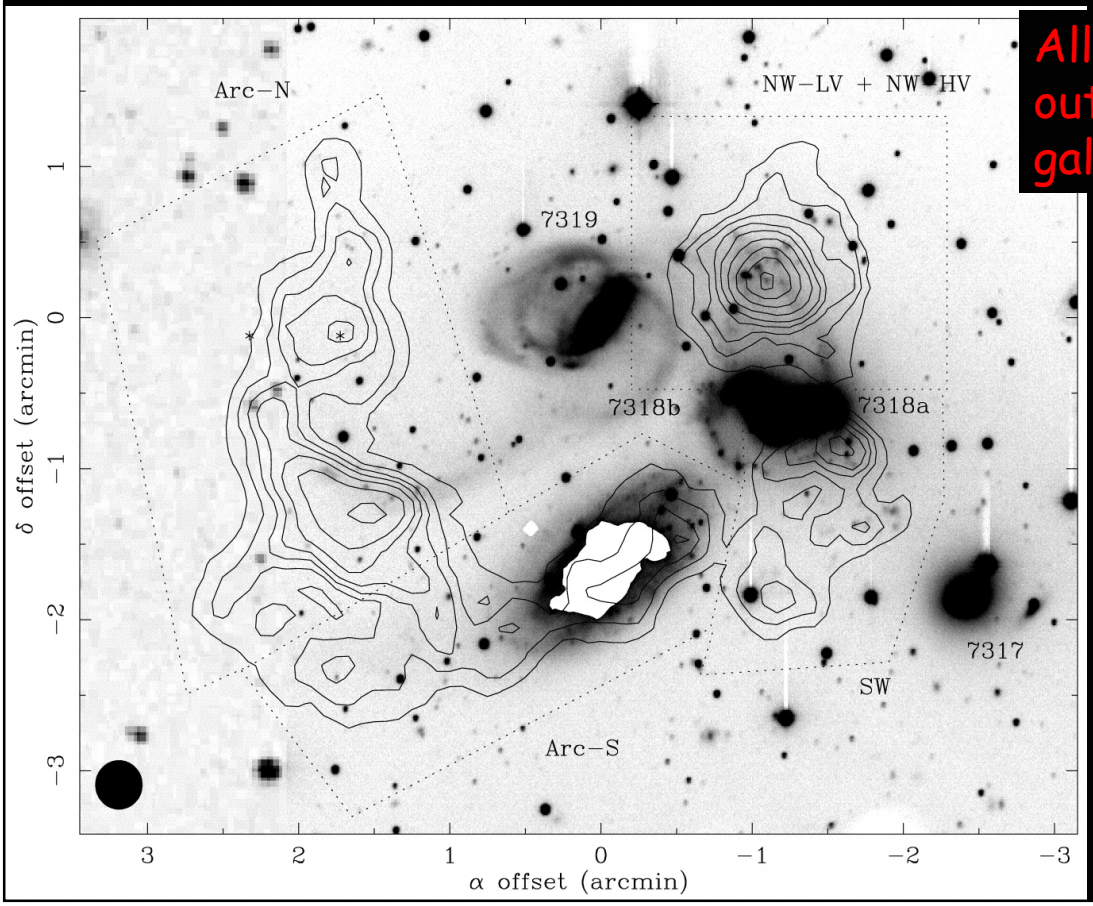
CO (thick contours) and Hα (thin contours) over HI (grey)

- CO is found where SF takes place (→ Hα)
- Interferometric observations yield only 25% of flux from single-dish measurements → smoothly distributed component present

A special case: The Hickson Compact Group Stephan´s Quintet

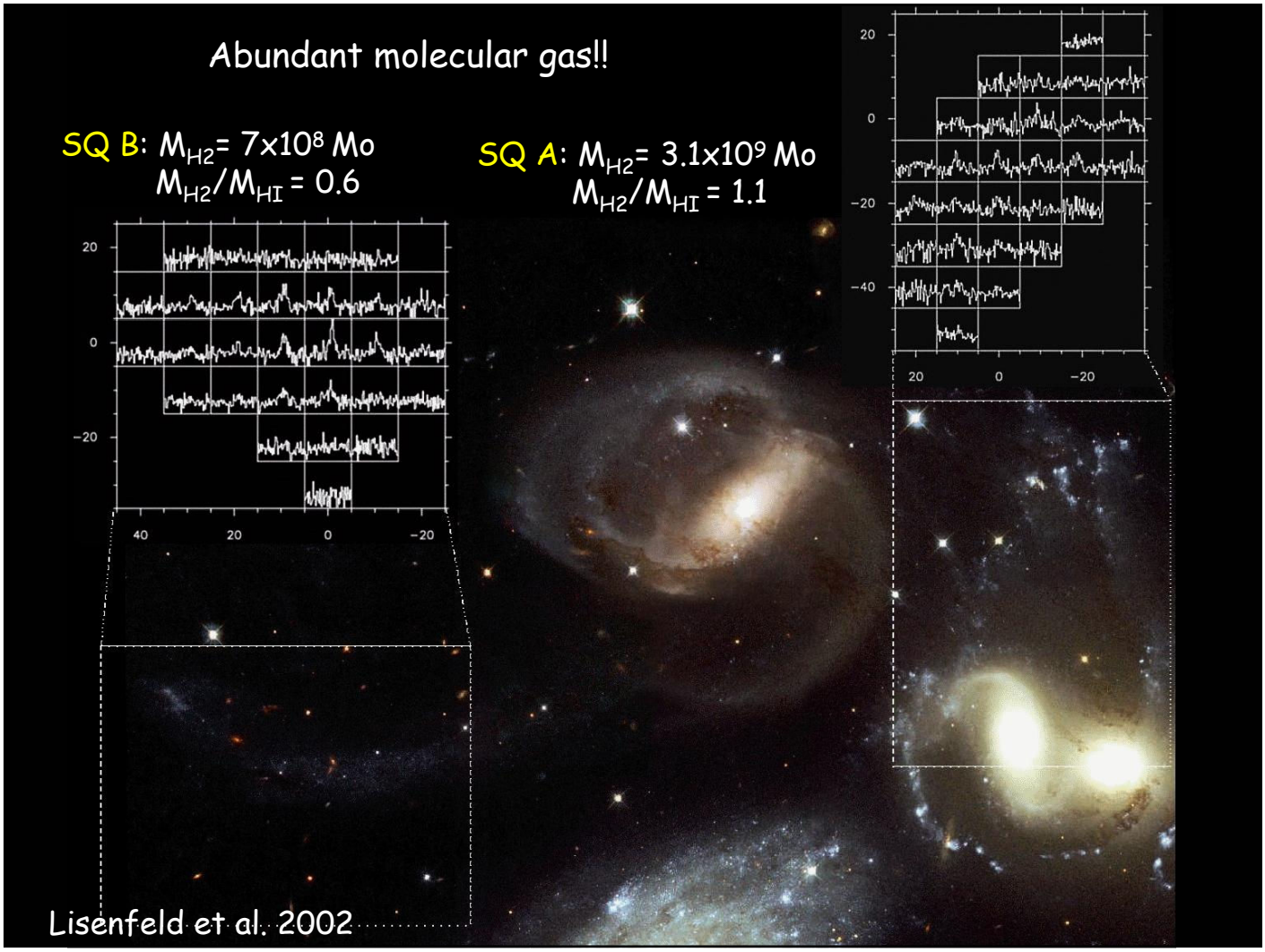


Atomic hydrogen



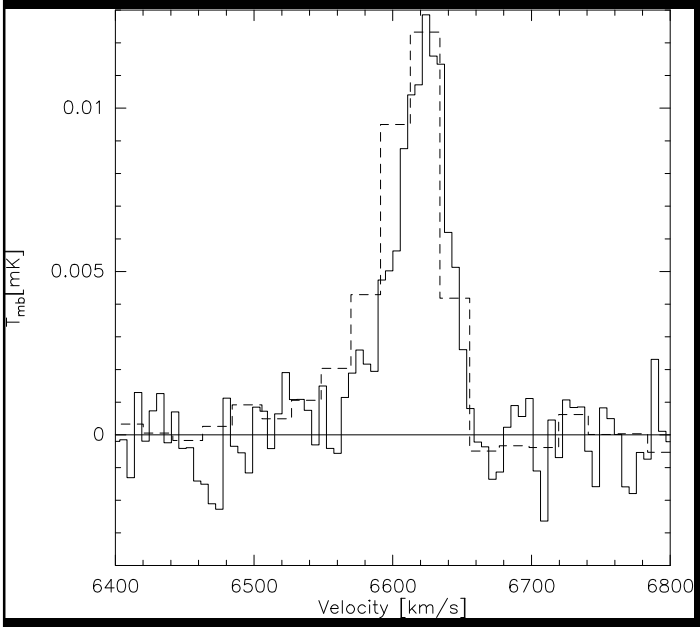
All the HI outside of galaxies!

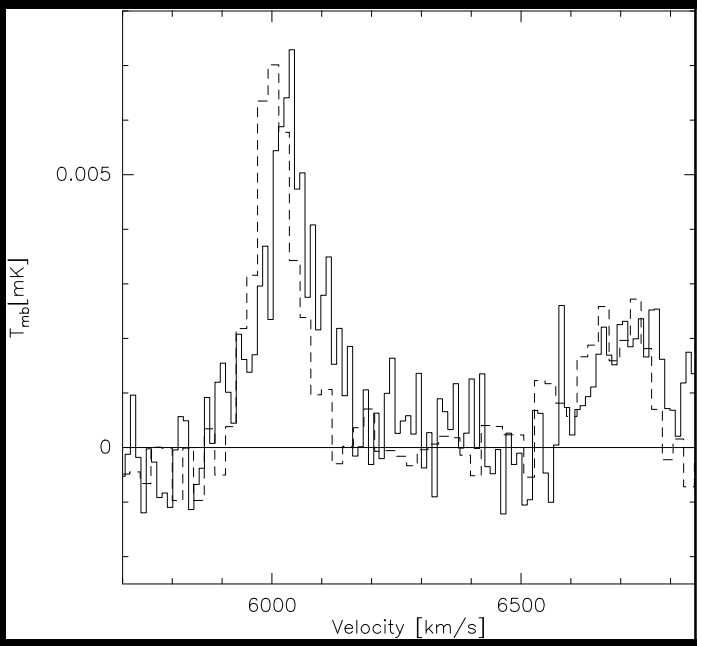
From Williams et al. (2002)


Abundant molecular gas!!
SQ B: M_{H2}= 7x10^8 Mo
M_{H2}/M_{HI} = 0.6
SQ A: M_{H2}= 3.1x10^9 Mo
M_{H2}/M_{HI} = 1.1
20
0
−20
40
20
0
−20
20
0
−20
−40
20
0
−20
Lisenfeld et al. 2002

•Different line shapes in both regions

Good kinematical agreement with HI



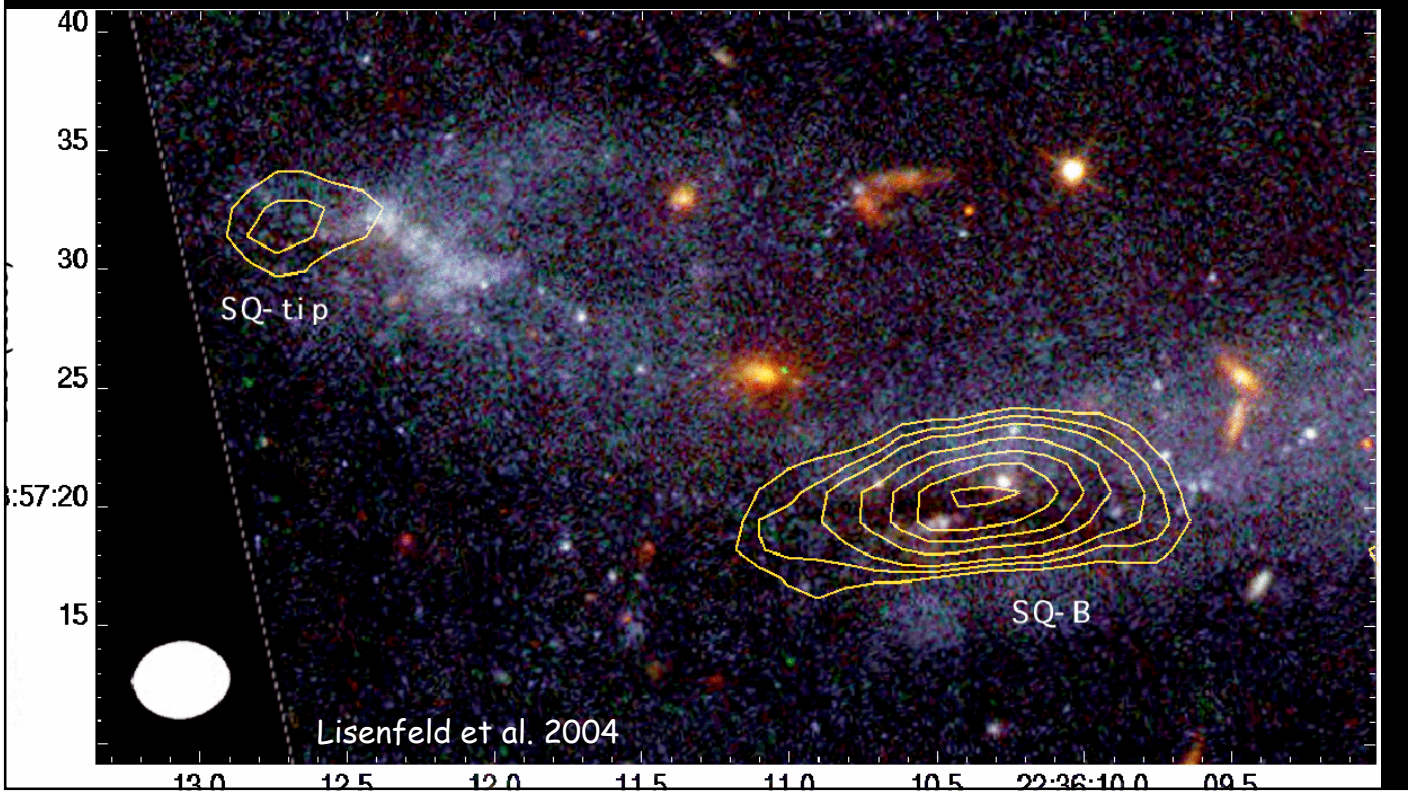


SQ B: narrower
(FWHM ≈ 50km/s)
Maximum of CO coincides with Ha

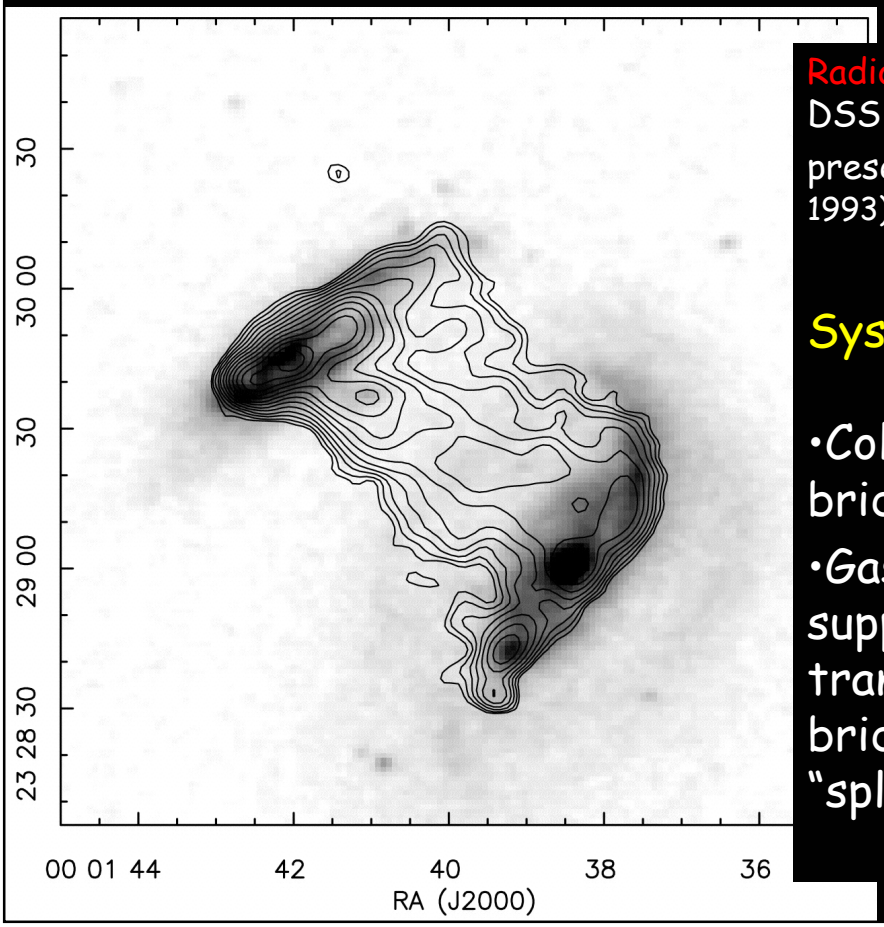
SQ A: wide, two velocities
(FWHM ≈ 140 km/s)

Observations of SQ B with Plateau de Bure Interferometer

- Two concentrations of CO, coinciding with SF regions
- Comparison with IRAM 30m observations: 50% of molecular gas in diffuse component



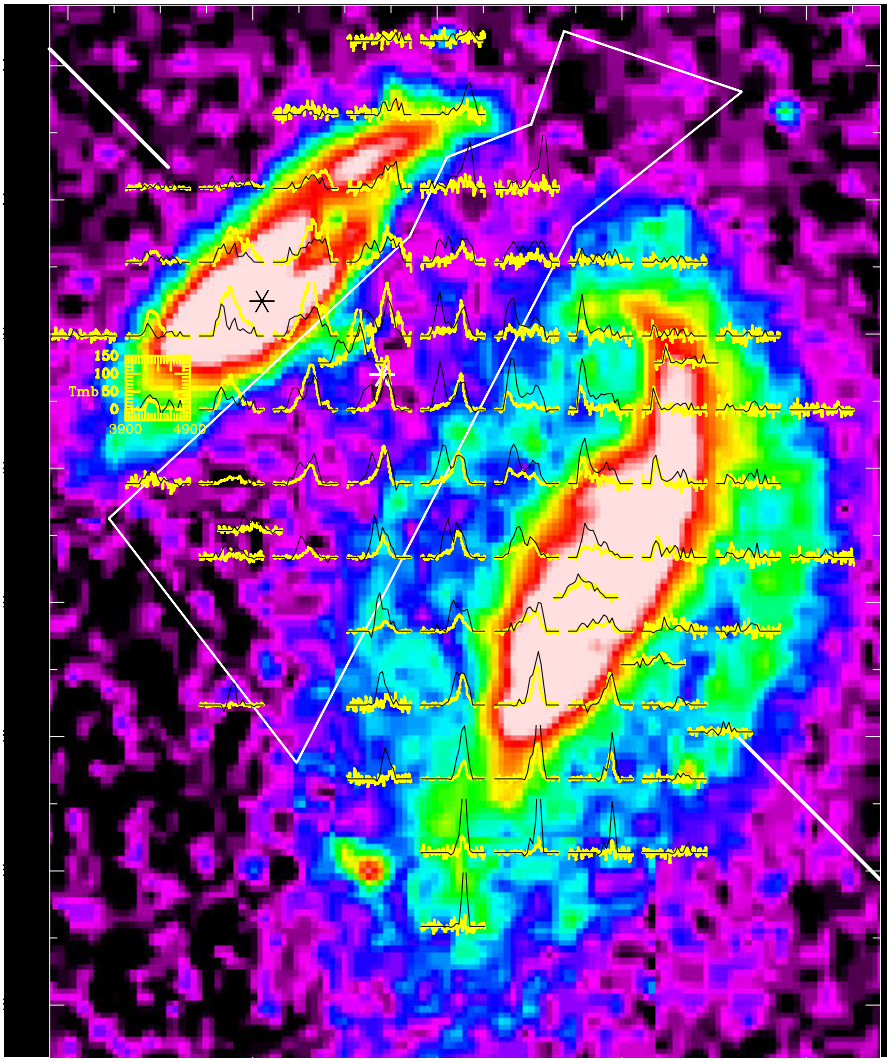
Head-on collision: The Taffy Galaxy



Radio continuum (contours) over DSS image. Also abundant HI present in bridge. (Condon et al. 1993)

System is special because:

- Collisional (not tidal) bridge
- Gas clouds collide. Gas is supposed to be transported into the bridge in a dissipative "splash" (Struck 1997)



-Abundant molecular gas in bridge!!

- $M_{H2\text{-bridge}} \approx 10^9 M_o$

- $M_{H2}/M_{HI} \approx 1$

(Braine et al. 2003)

Molecular line ratios and star formation in bridge

- $^{13}CO/^{12}CO$ low (in comparions to spiral galaxies
- $HCN/^{12}CO$ low (HCN -> dense gas tracer)

→ indicate gas of low opacity

- No indications of important SF in bridge

How does the molecular gas get into the bridge?

Either:

- H_2 could be newly formed from HI → unlikely due to short timescales and low densities

Or:

- Must come from parent galaxies → molecular gas clouds must have collided.
- Filling factor high enough for this to happen
- Problem: Molecular gas are expected be destroyed in high-energy collision between gas clouds → gas clouds get ionized inmediatedly

But:

- Cooling time is very short (Struck 1997)
- Molecular gas could form again quickly after ionization before cloud dissipates (Harwit et al. 1987)

In any case:

- Dense molecular cores necessary for SF seem to have been destroyed, or density lowered → no SF

The interacting system Arp 94

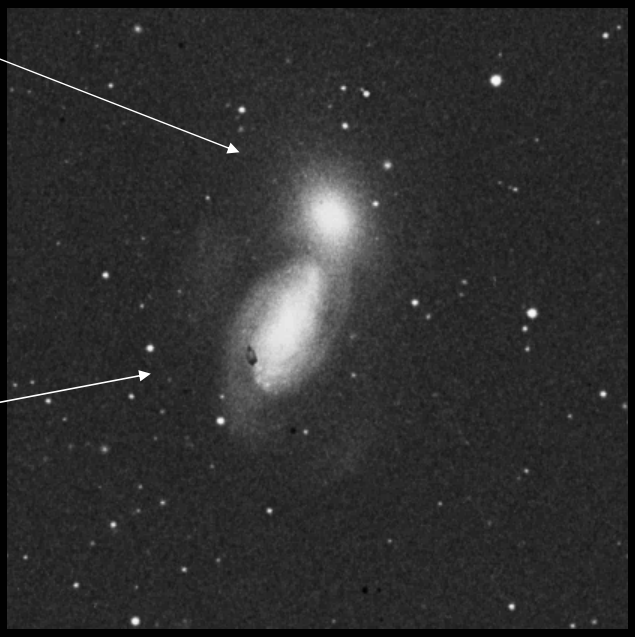
It consists of:

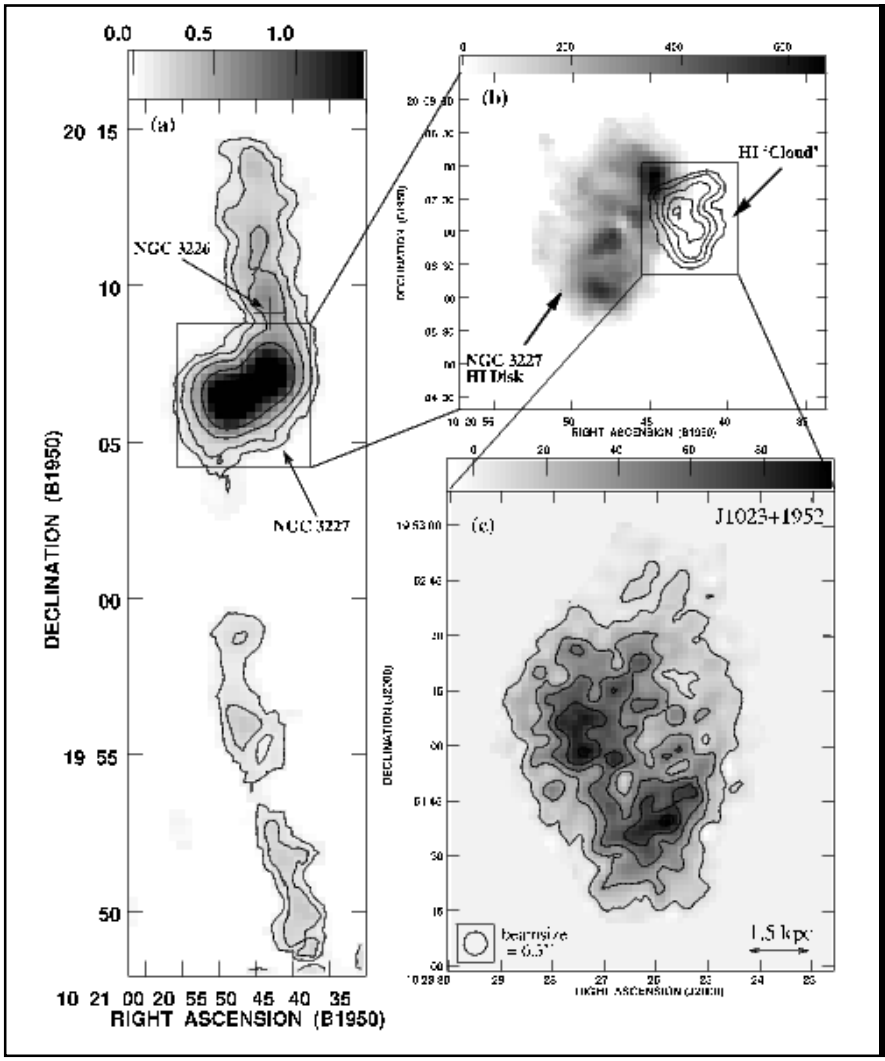
NGC 3226:

- Hubble type E2 pec

NGC 3227:

- Hubble type SAB pec
- Seyfert nucleus (one of the original Seyfert galaxies of Seyfert)



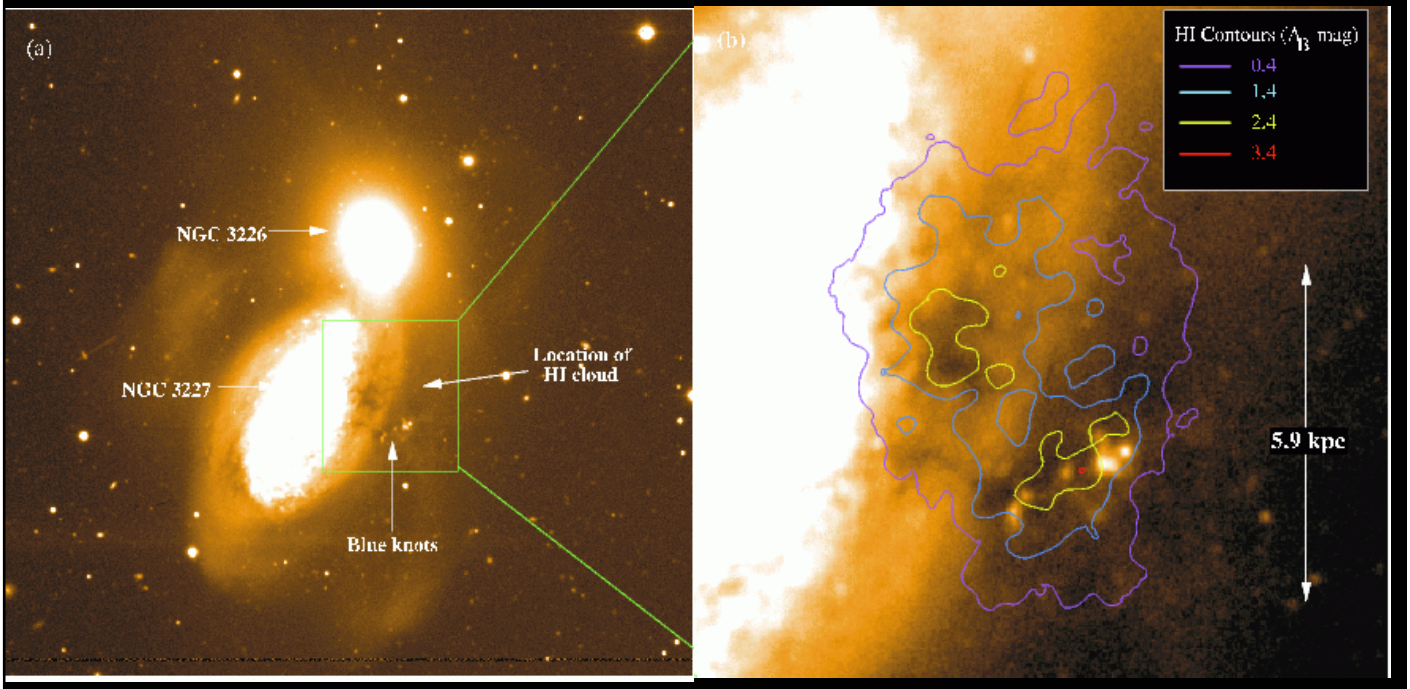


HI observations
with the VLA revealed
(Mundell et al. 1995)

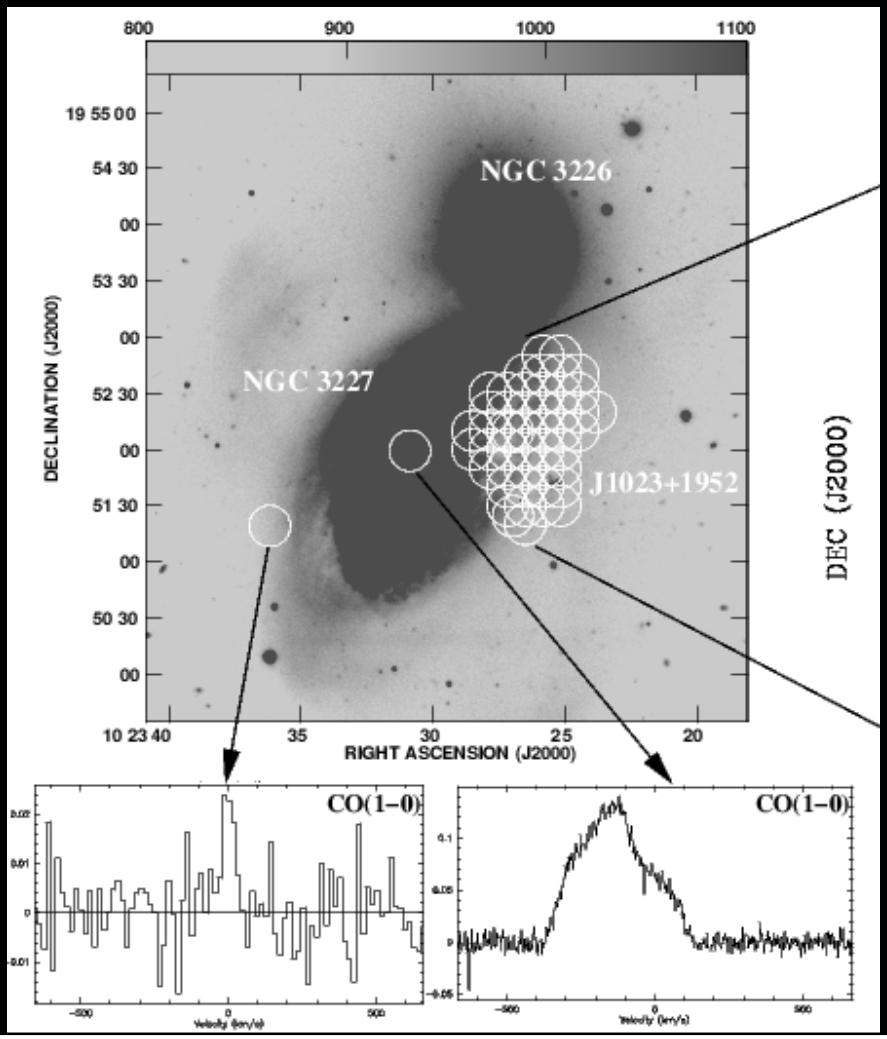
- northern and southern tidal tail
- dwarf companion close to NGC 3227:
J1023+1952

HI diameter: 8.9 kpc
HI mass: 3.8×10^8 Mo

Deep images show star formation in J1023+1953



Blue image (Mundell et al. 2004) from the Isaac Newton Telescope



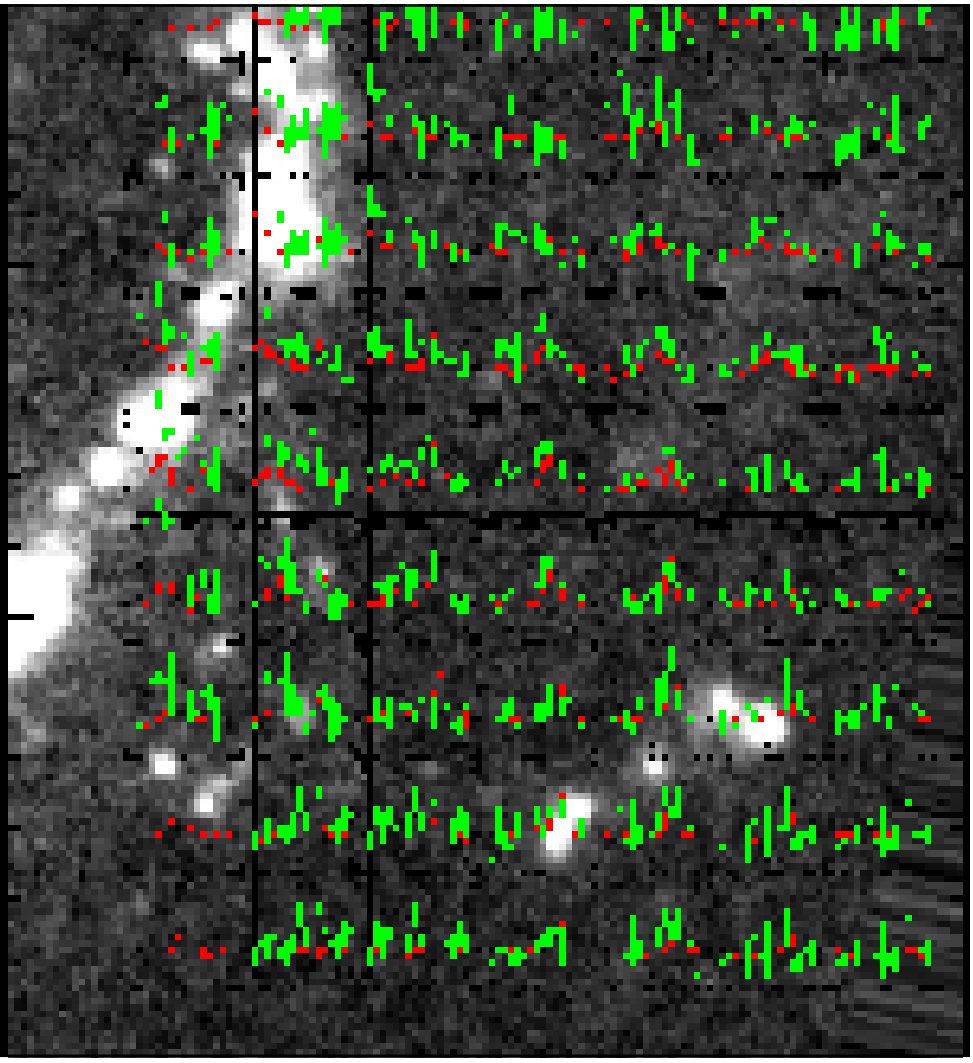
- IRAM 30m observations of CO of J1023.
- Expected: detect molecular gas in the SF region
- But…

Molecular gas extended over whole galaxy!

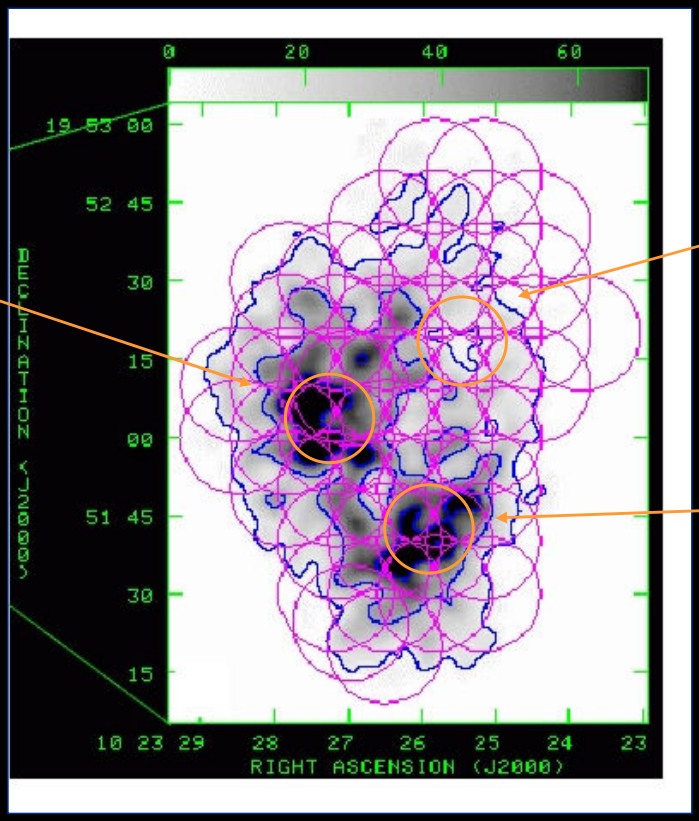
In general good kinematical agreement with HI.

Towards west: Line blending with CO from NGC 3227→ do a fitting of 2 Gaussian lines to disentangle.

CO green
HI red



Look at SF properties of 3 regions:



2. High HI surface density

3. Low HI surface density

1. SF region

Lines at region 1:

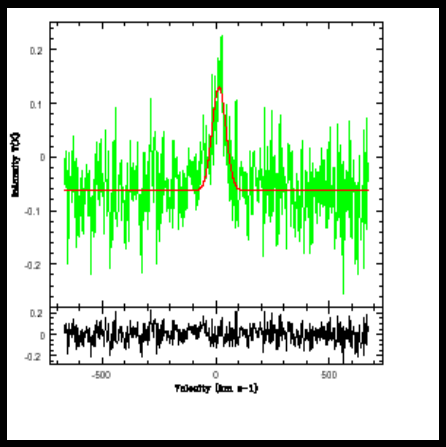
- Thin lines (total widths of ~ 40 km/s)
- Fit by a single gaussian
- $2N(H_2)/N(H) = 0.5$
- $2N(H_2)+N(H) = 1.8\ 10^{21}\ cm^{-2}$

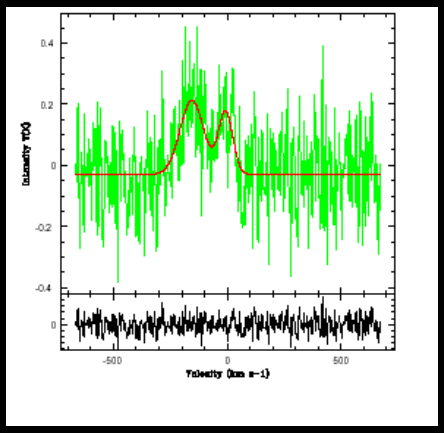
Lines at region 2:

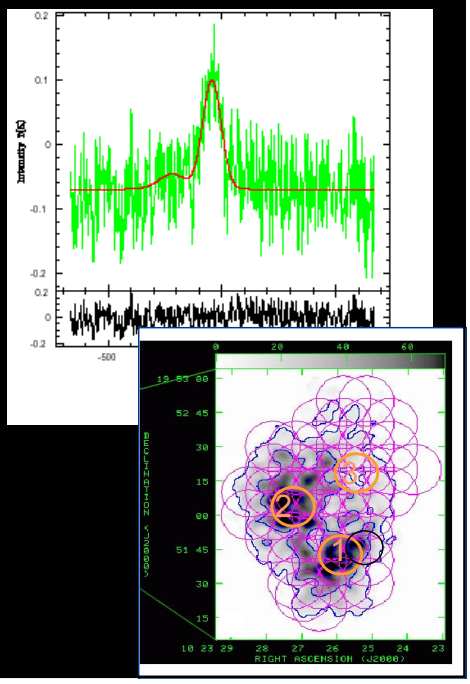
- Wider lines (total widths of ~ 100 km/s)
- Fit by two gaussian
- $2N(H_2)/N(H) = 1.1$
- $2N(H_2)+N(H) = 3.1\ 10^{21}\ cm^{-2}$

Lines at region 3:

- Wider lines (total widths of ~ 100 km/s)
- Fit by a single gaussian
- $2N(H_2)/N(H) = 0.7\text{-}1.2$
- $2N(H_2)+N(H) = 1.2\text{-}1.6\ 10^{21}\ cm^{-2}$







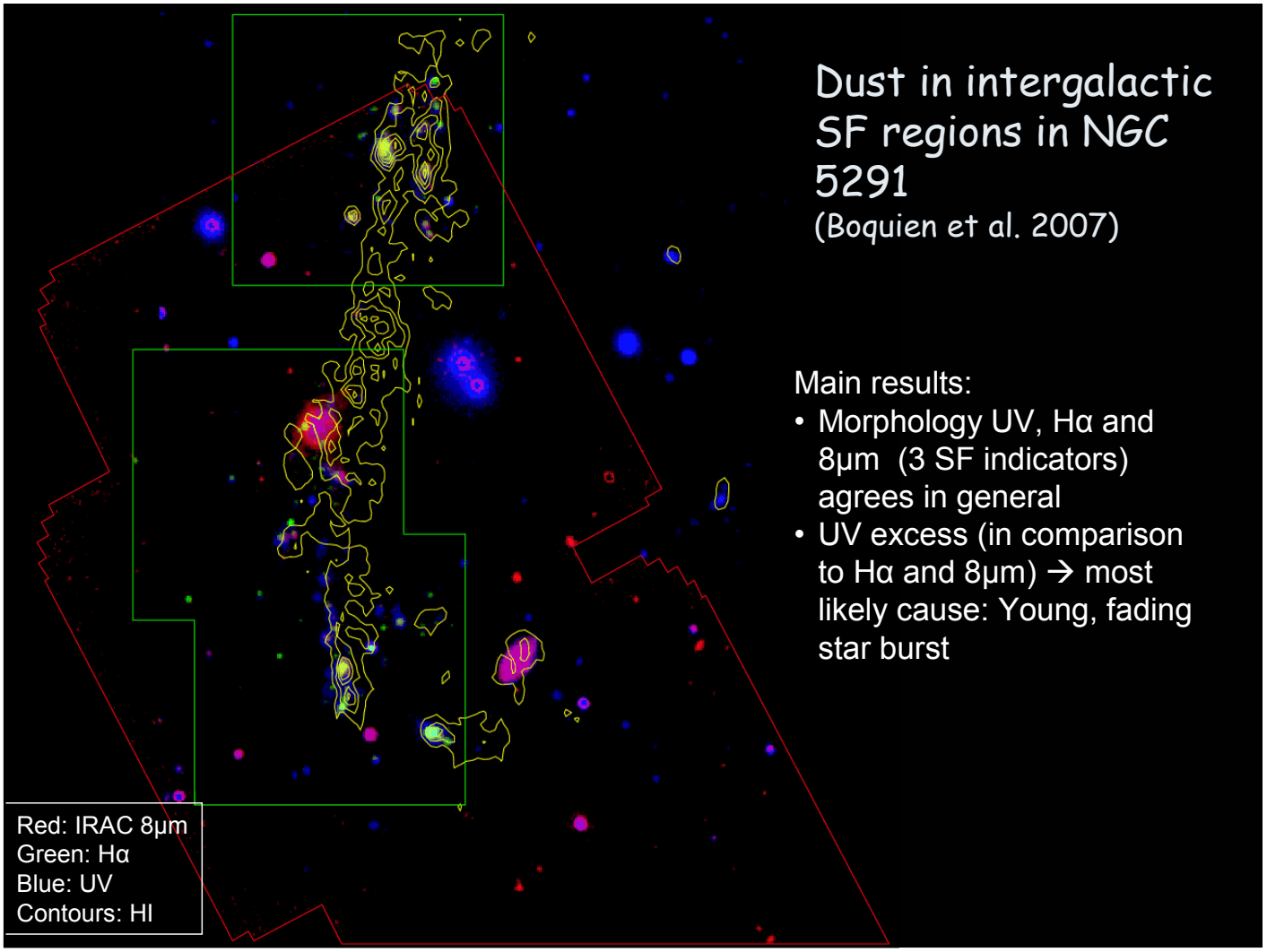
Green: Data
Red: Gaussian Fit
Black: Residual

Possible origin of J1023: tidally disrupted infalling body (??)

Image from SDSS

Dust emission in these objects

- JCMT detection at 450 μm (25+-6mJy) and 850 μm (7+-1mJy) of NGC 2992N: consistent with warm (T ≈ 20K) dust with Galactic gas-to-dust ratio
- Spitzer:
  - IRAC data for various objects in archive
  - Published/in progress so far:
    - NGC 5291: PAH spectra detected (Higdon et al. 2006)
    - NGC 5291: Comparison of 8 μm, UV and Hα (Boquien et al. 2007)
    - J1023: IRAC and MIPS data (Lisenfeld et al., in prep.)

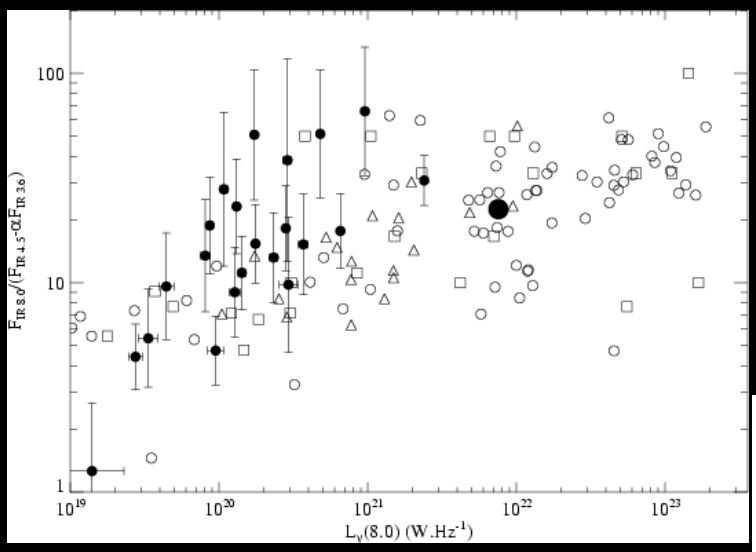


Dust in intergalactic SF regions in NGC 5291

(Boquien et al. 2007)

Main results:

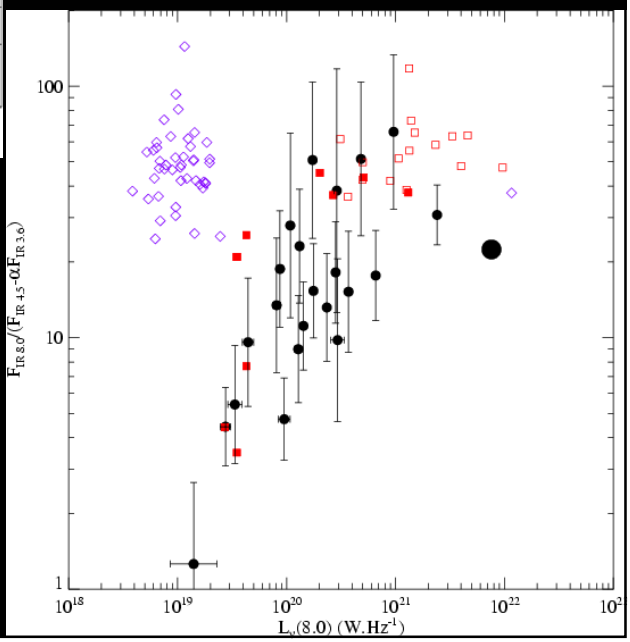
- Morphology UV, Hα and 8μm (3 SF indicators) agrees in general
- UV excess (in comparison to Hα and 8μm) → most likely cause: Young, fading star burst

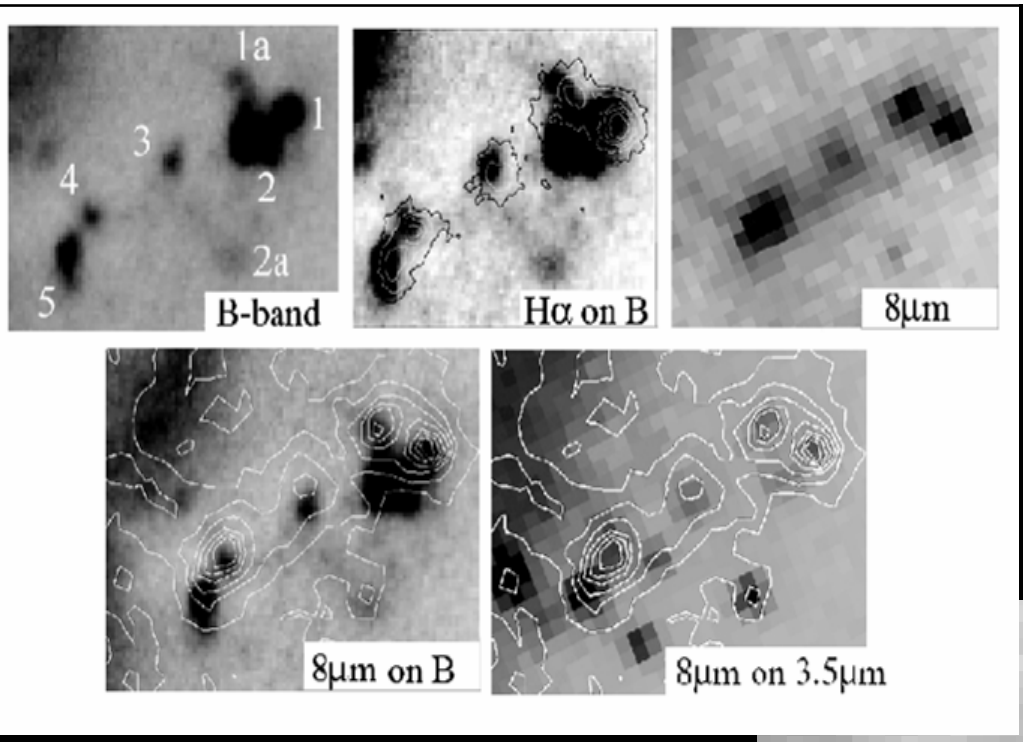


Filled circles: NGC 5291
Open circles: Galaxies from Sings (Dale et al. 2006)
Squares: Dwarfes from Engelbracht (2005)
Triangles: Dwarfes from Rosenberg (2006)

8 μm emission is comparable to integrated emission of dwarf and spiral galaxies and of HII region in M81 and Arp 82.

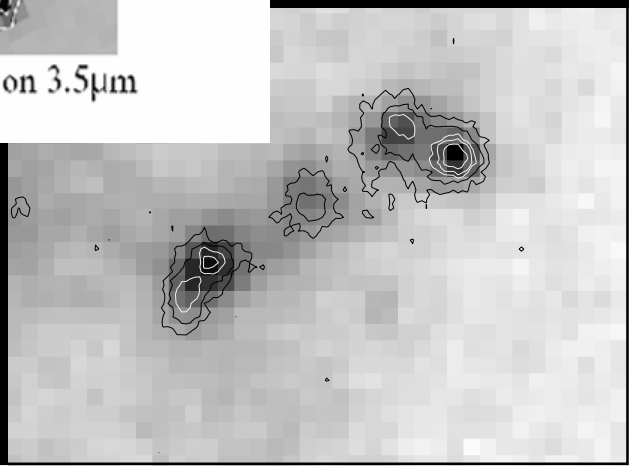
Filled circles: NGC 5291
Diamonds: HII regions in M81 (Pérez-Gonzalez et al. 2006)
Squares: HII regions in Arp 82 Hancock et al. (2006)





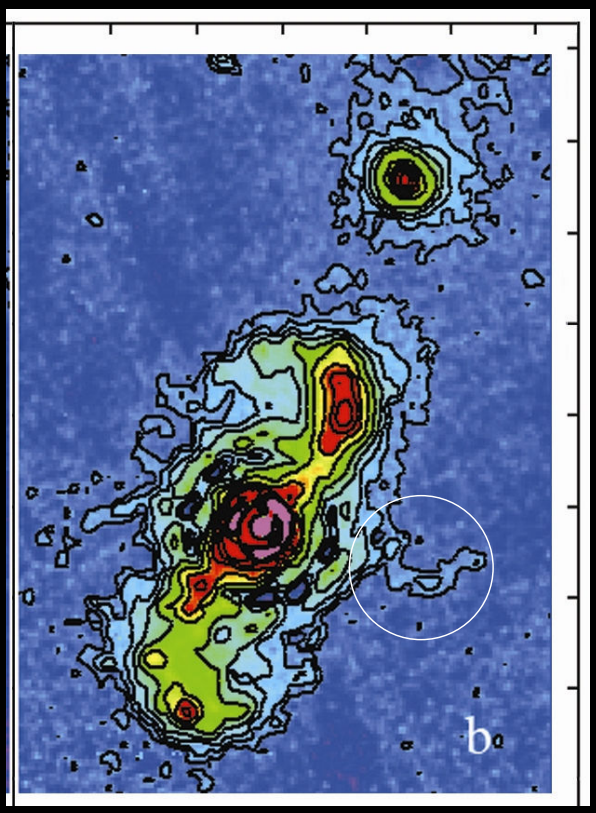
Spitzer data for J1023

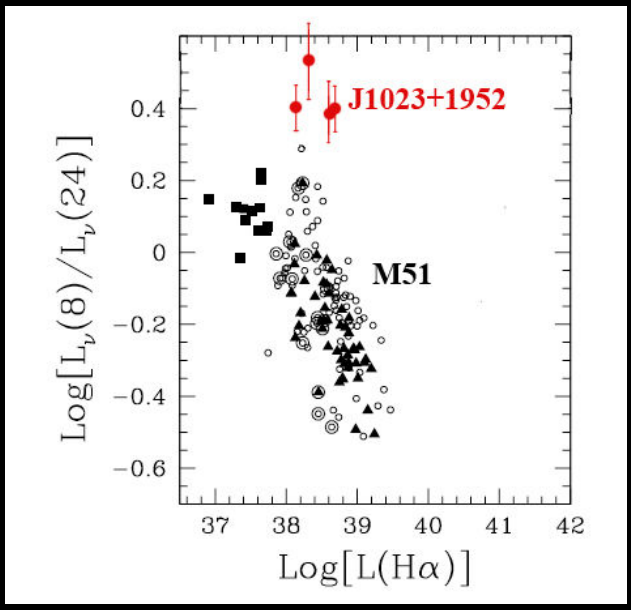
8mu on Hα



- Perfect agreement between 8μm and Ha
- Difference between 8 μm/Ha and blue: age effect
- Little emission at 3.5 mu → no old stellar population

24 μm emission





Preliminary result: Excess of 8 μm emission

Conclusions

Abundant molecular gas outside galaxies in all systems!!

- Tidal Dwarf Galaxies:
  - Interferometric observations show localized CO at SF regions
  - Part (50-75%) of the molecular gas is in a smooth phase following the HI distribution and kinematics
  - Star formation proceeds normally (normal molecular gas fraction, normal star formation efficiency)
- Stephan's Quintet: Two "phases" molecular gas:
  - Abundant diffuse H_2
  - And compact H_2 coinciding with Ha
- Head-on brigdes: Molecular gas cloud collisions?
- J1023+1953:
  - Abundant molecular gas following HI cloud
  - In SF region: narrow lines

First data on dust in these systems becoming available with Spitzer