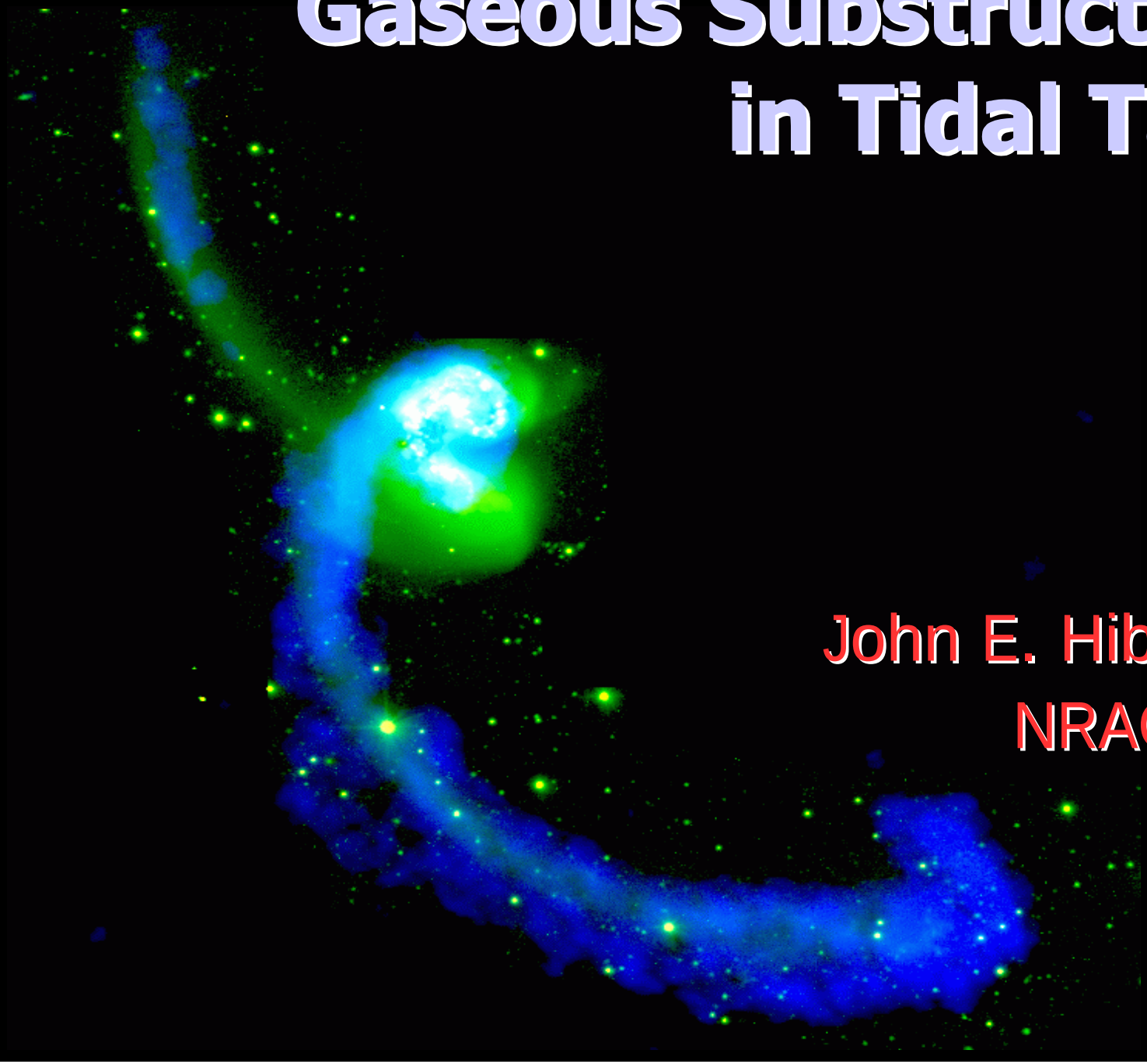
Gaseous Substructure in Tidal Tails



John E. Hibbard
NRAO-CV

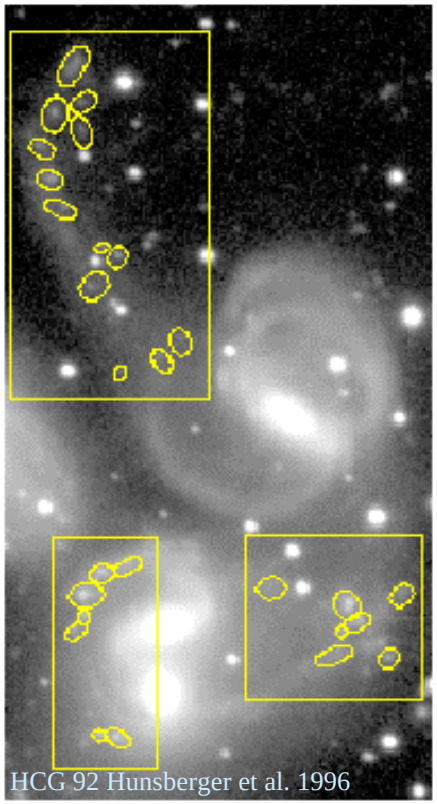
A Range of Substructures are found in Tidal Tails

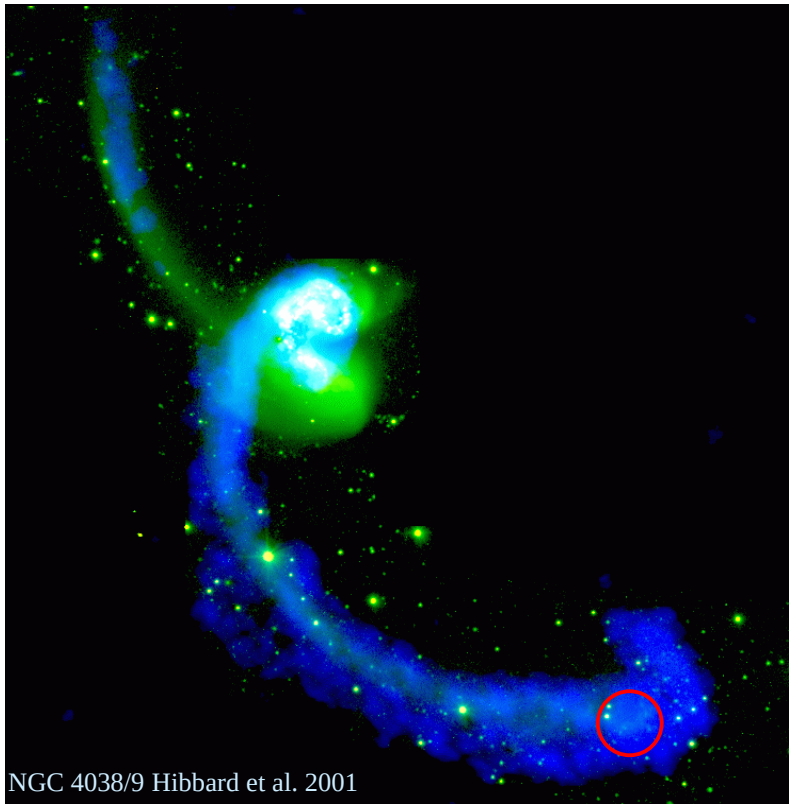
Outstanding Questions:

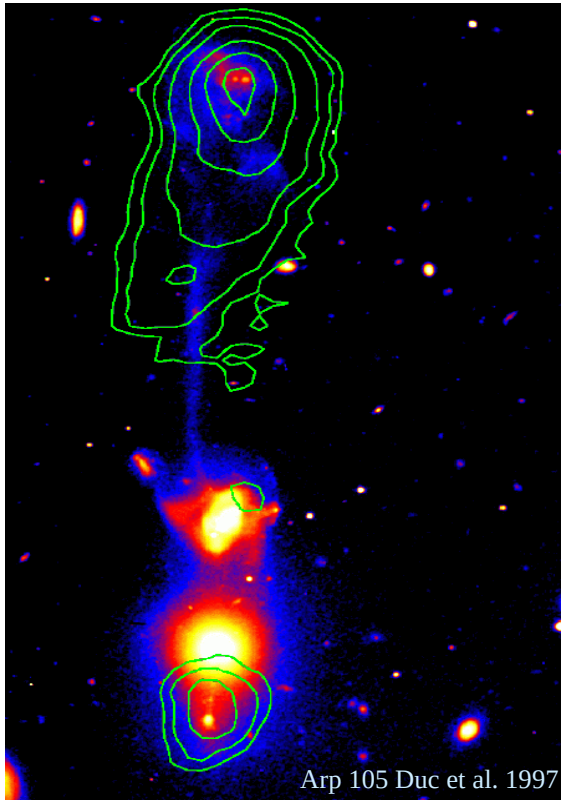
On what scales (if any) are these structures bound?

Is this an evolutionary sequence?

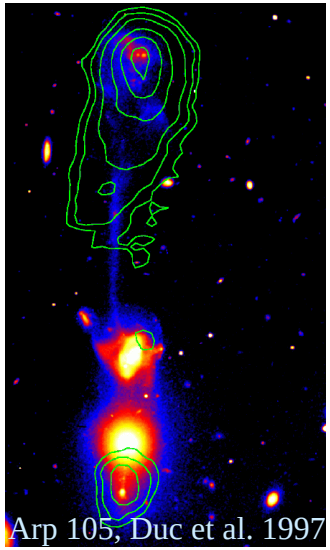
Are these “Tidal Dwarf Galaxies” (TDGs) robust entities?

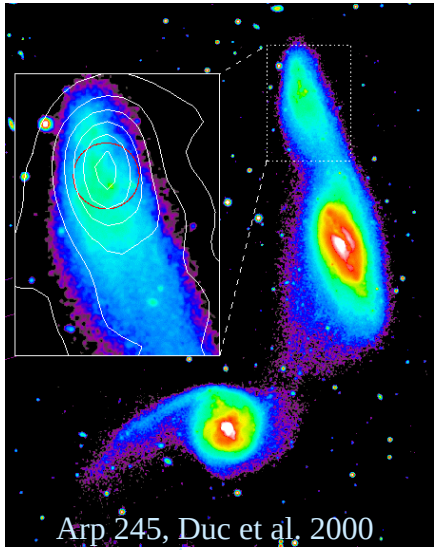

HCG 92 Hunsberger et al. 1996

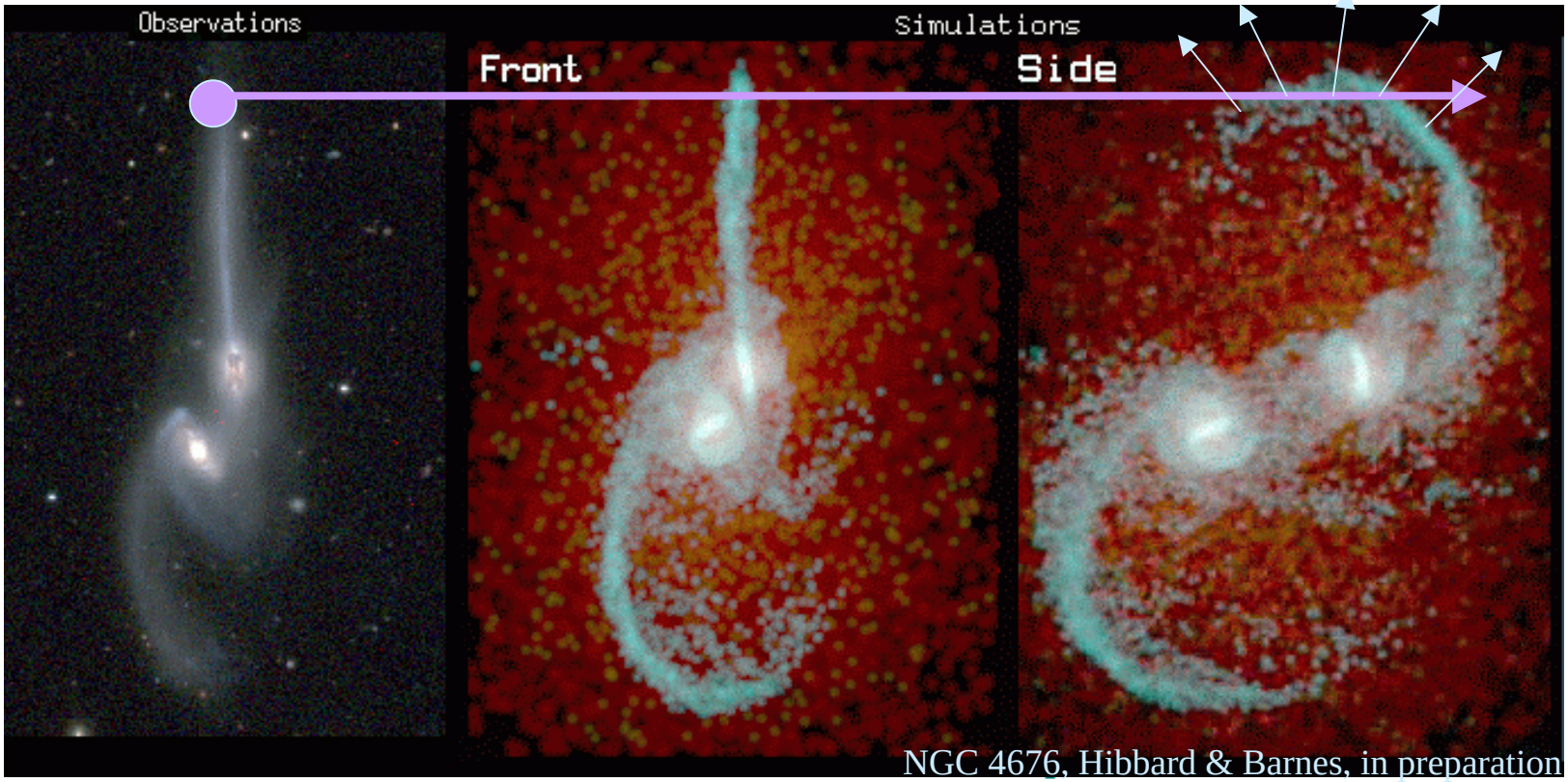

NGC 4038/9 Hibbard et al. 2001


Arp 105 Duc et al. 1997

Many candidate TDGs appear just where you expect line-of-sight integration effects to be the most extreme

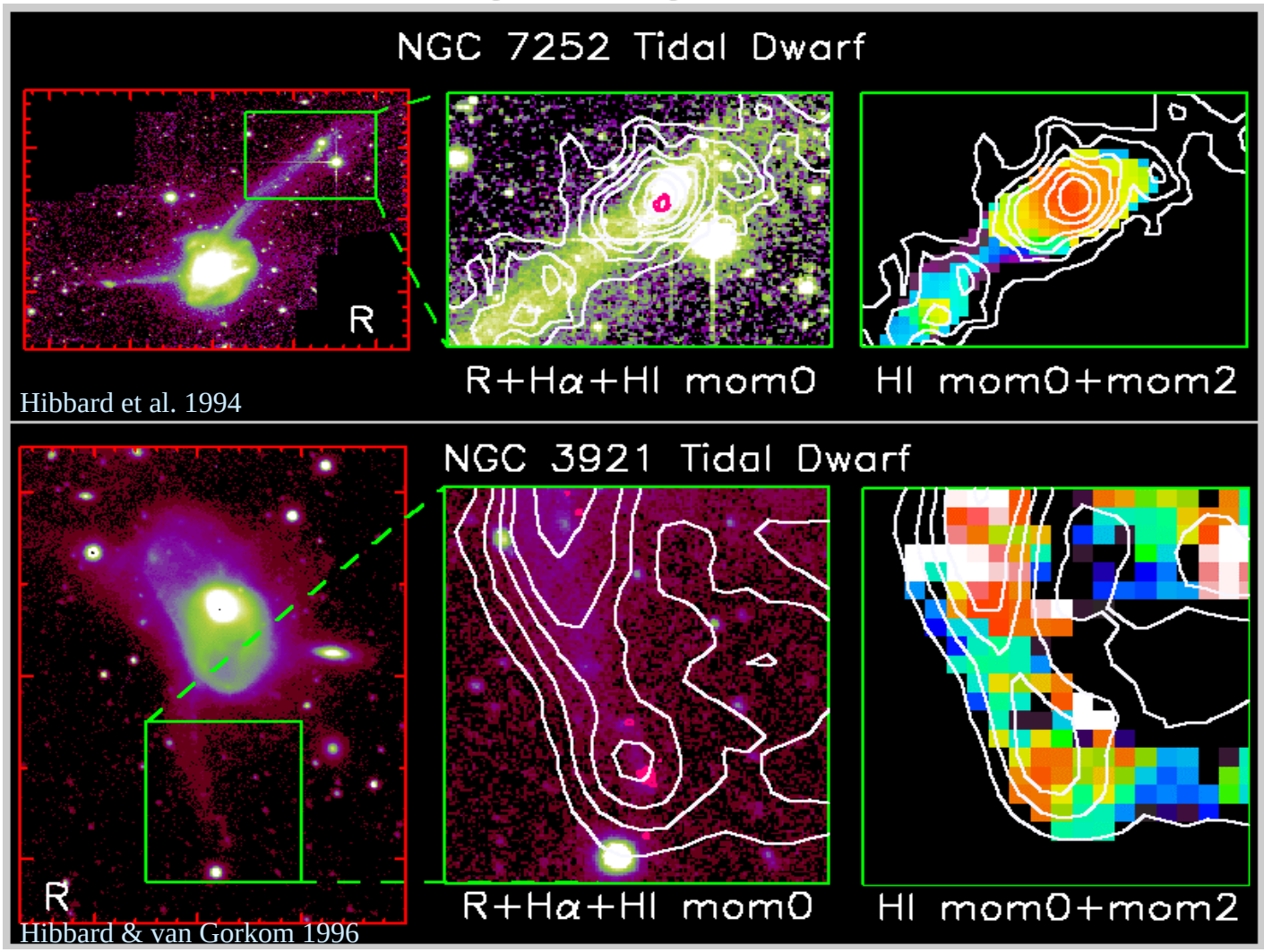

Arp 105, Duc et al. 1997


Arp 245, Duc et al. 2000



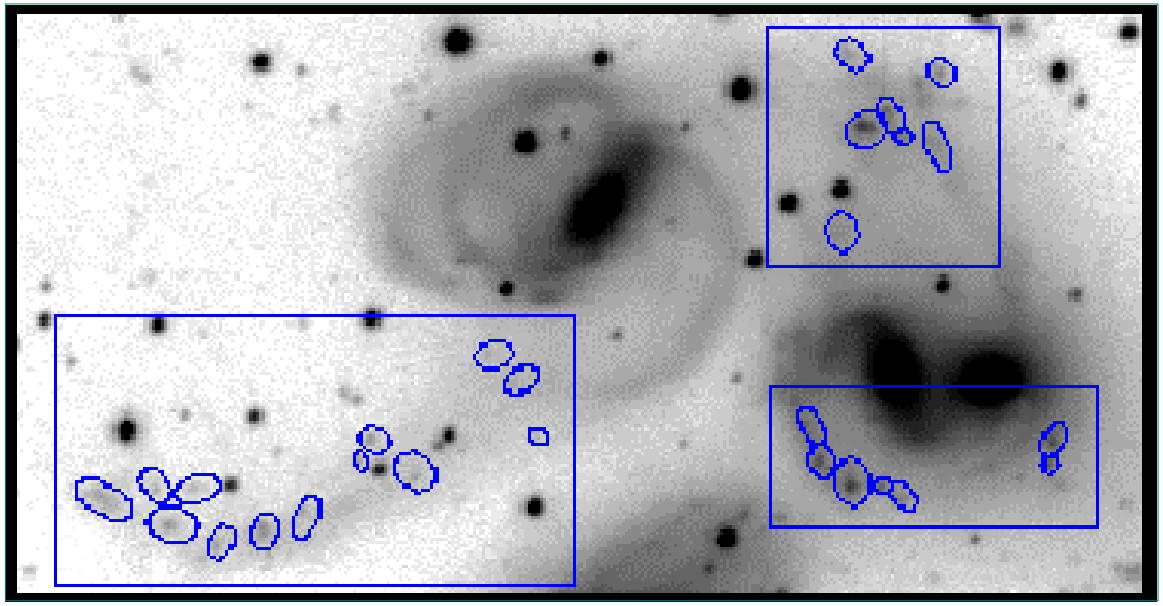
NGC 4676, Hibbard & Barnes, in preparation

Other TDG candidates show an increased gas velocity dispersion coincident with light and gas concentrations



However, these locations also coincide with HII regions, and the increased dispersion could instead be due to energy input from massive star formation

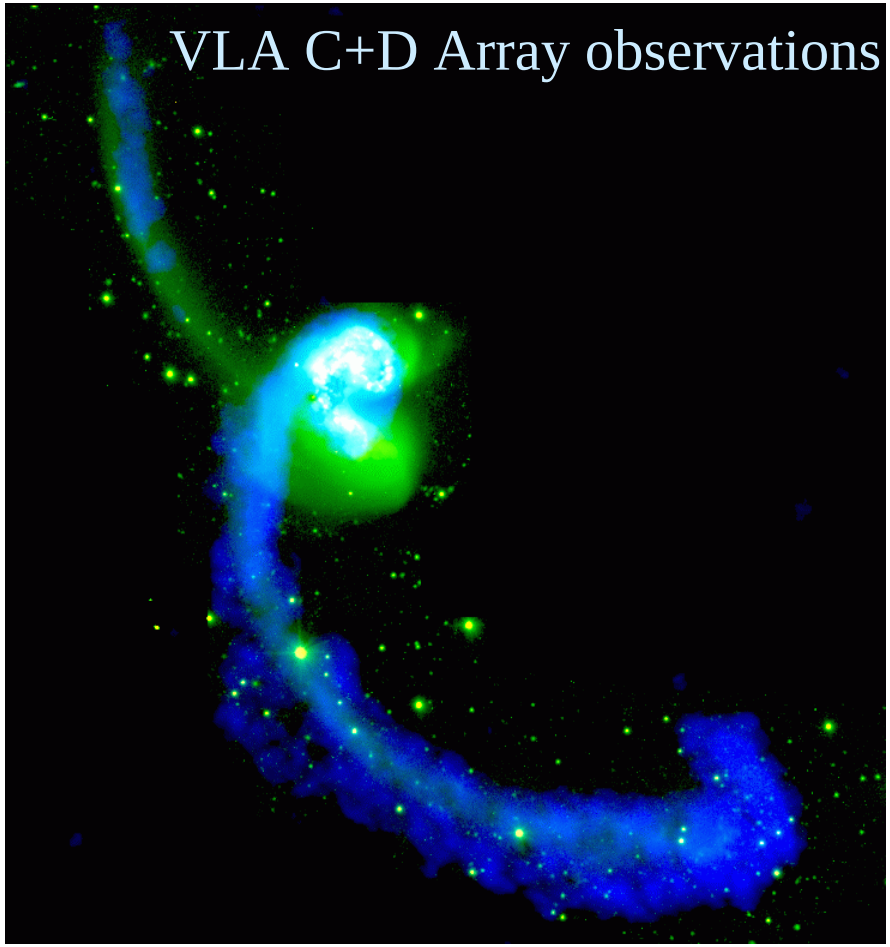
It has become increasingly common to treat every luminosity enhancement as an entity.



Stephans Quintet:
Hunsberger et al., 1996, 1998
also: Hutchings 1996, Deeg et al. 1998, Weilbacher et al. 2000, Iglesias-Paramo & Vilchez 2001

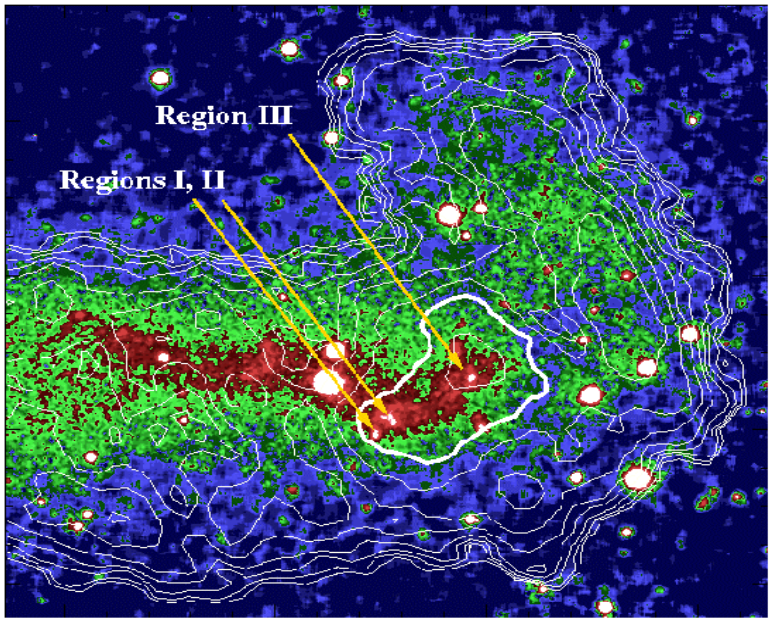
- How Valid is this?
  - Use high-resolution HI datacube to investigate kinematic nature of tidal substructures

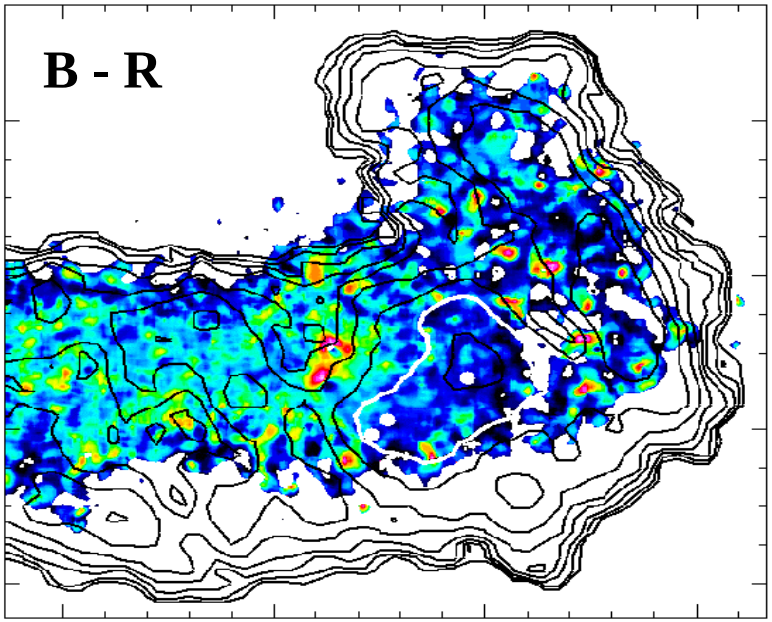
I'll address this with high resolution HI mapping observations of NGC 4038/9 "The Antennae"

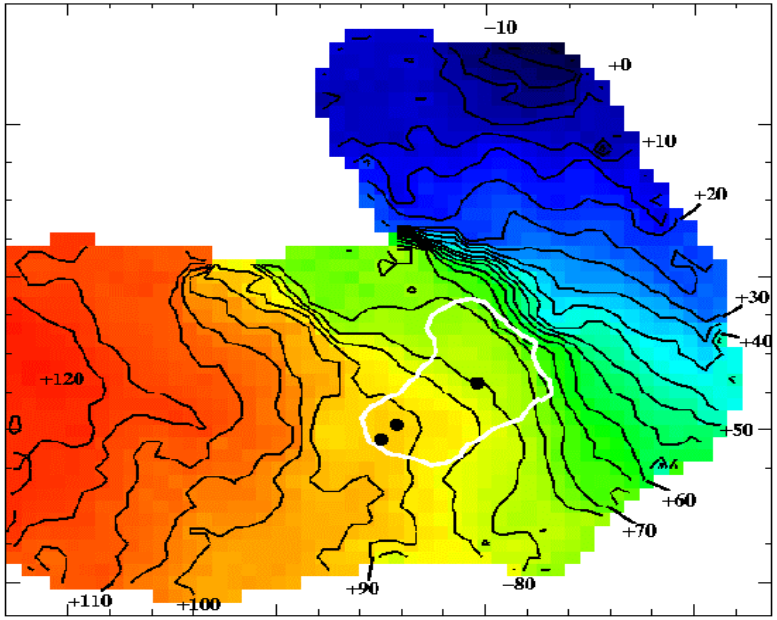


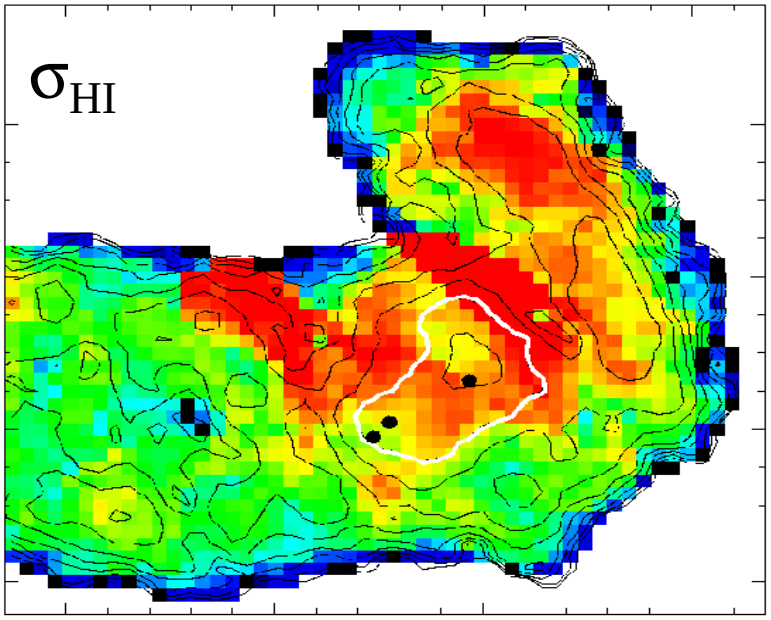
Hibbard, van der Hulst, Barnes & Rich, 2001, AJ, submitted

No clear kinematic signature at TDG.



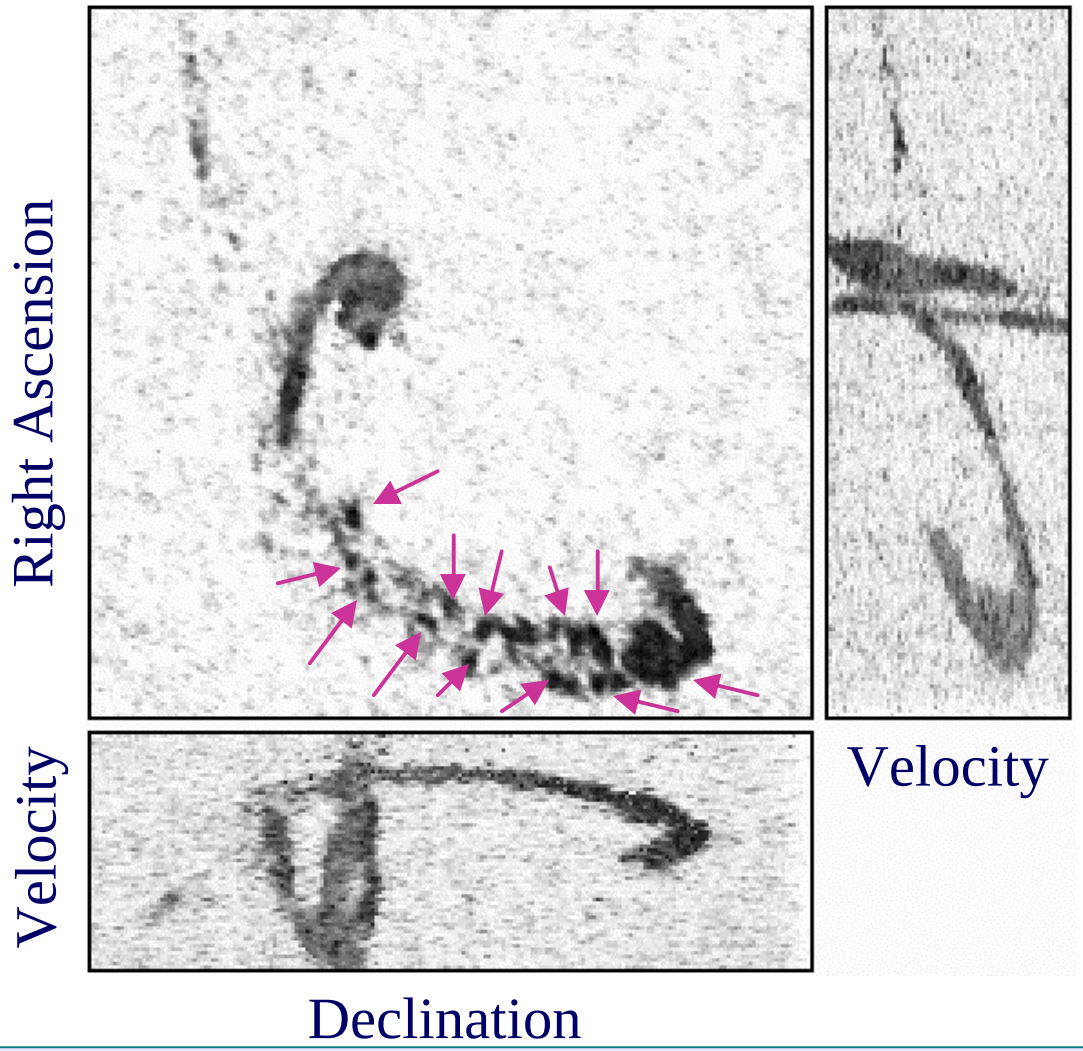




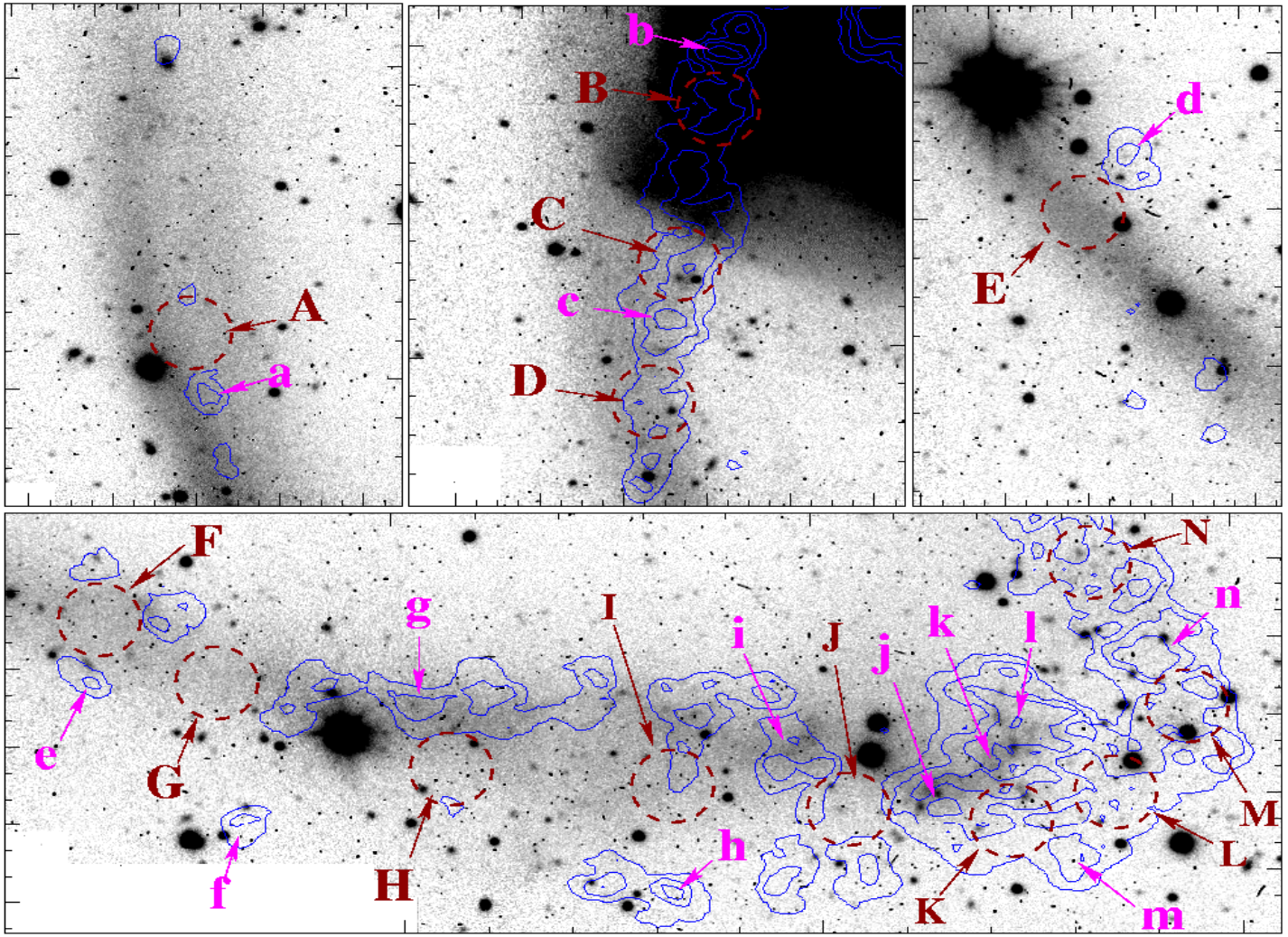


Increase in σ_{HI} may be due to energy input from young stars

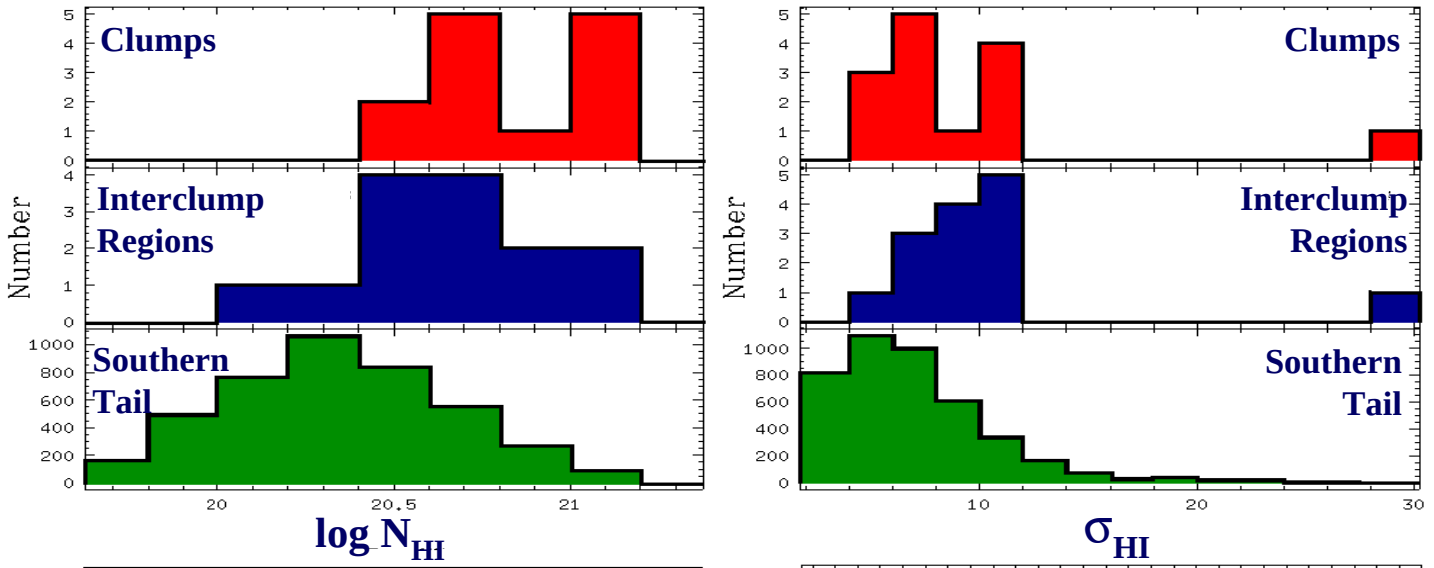
HI observations reveal a wealth of structure within the tails. (resolution ~10"-20", Δv=5.2 km/s)



Identified clumps in tails with contrast of 2 from surrounding material, and with S/N>6
Also Identified an equal number of "interclump" regions



Clumps do not distinquish themselves from interclump region in terms of optical or HI properties



Dynamical Analysis: Is there enough mass in gas and stars to make clumps bound?

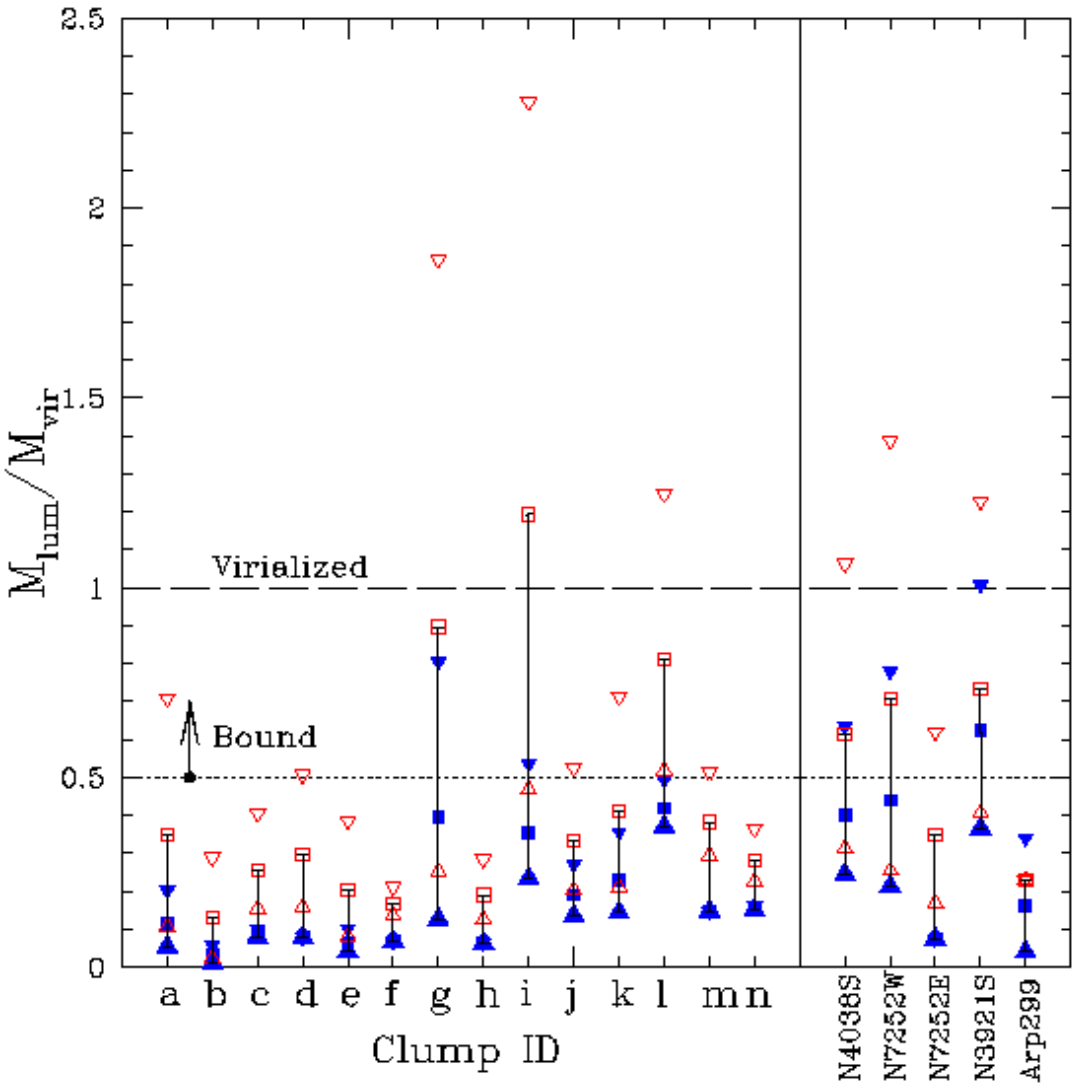
- $2T = -U$
  - $3\sigma_{HI}^2 = G M_{vir}/(aR_{1/2})$
  - $M_{vir} = 1.91 \times 10^6 \sigma_{HI}^2 R_{1/2}$
- $M_{gas} = 1.36 M_{HI}$
- $M_{stars} = (M_*/L_B) * L_B$

△ ▲ $M_*/L_B = 0$

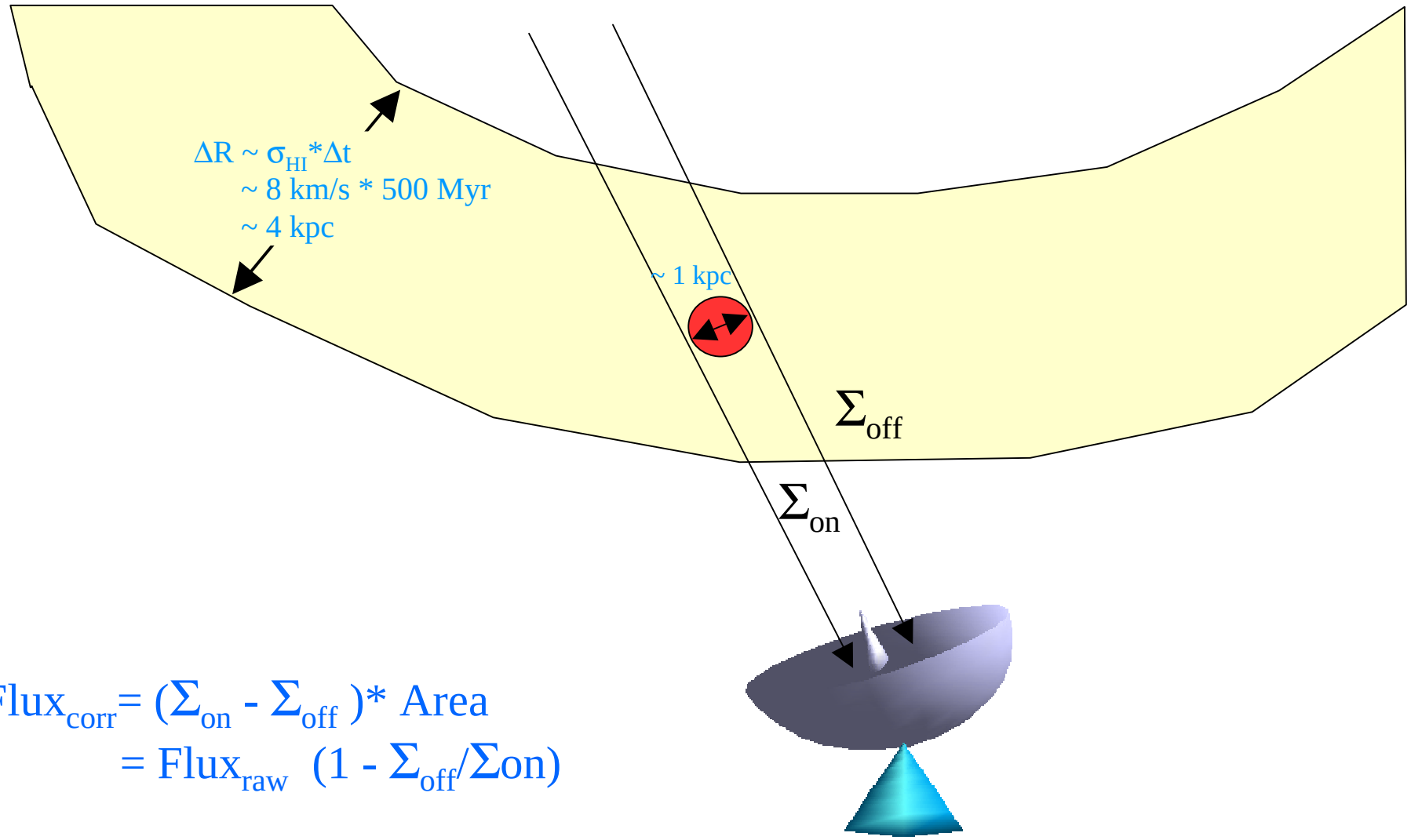
□ ■ $M_*/L_B = 2$ const SFH, 10 Gyr

▽ ▼ $M_*/L_B = 5$ exp SFH, 10 Gyr

- filled symbols = foreground & background subtraction
- open symbols = no foreground or background subtraction



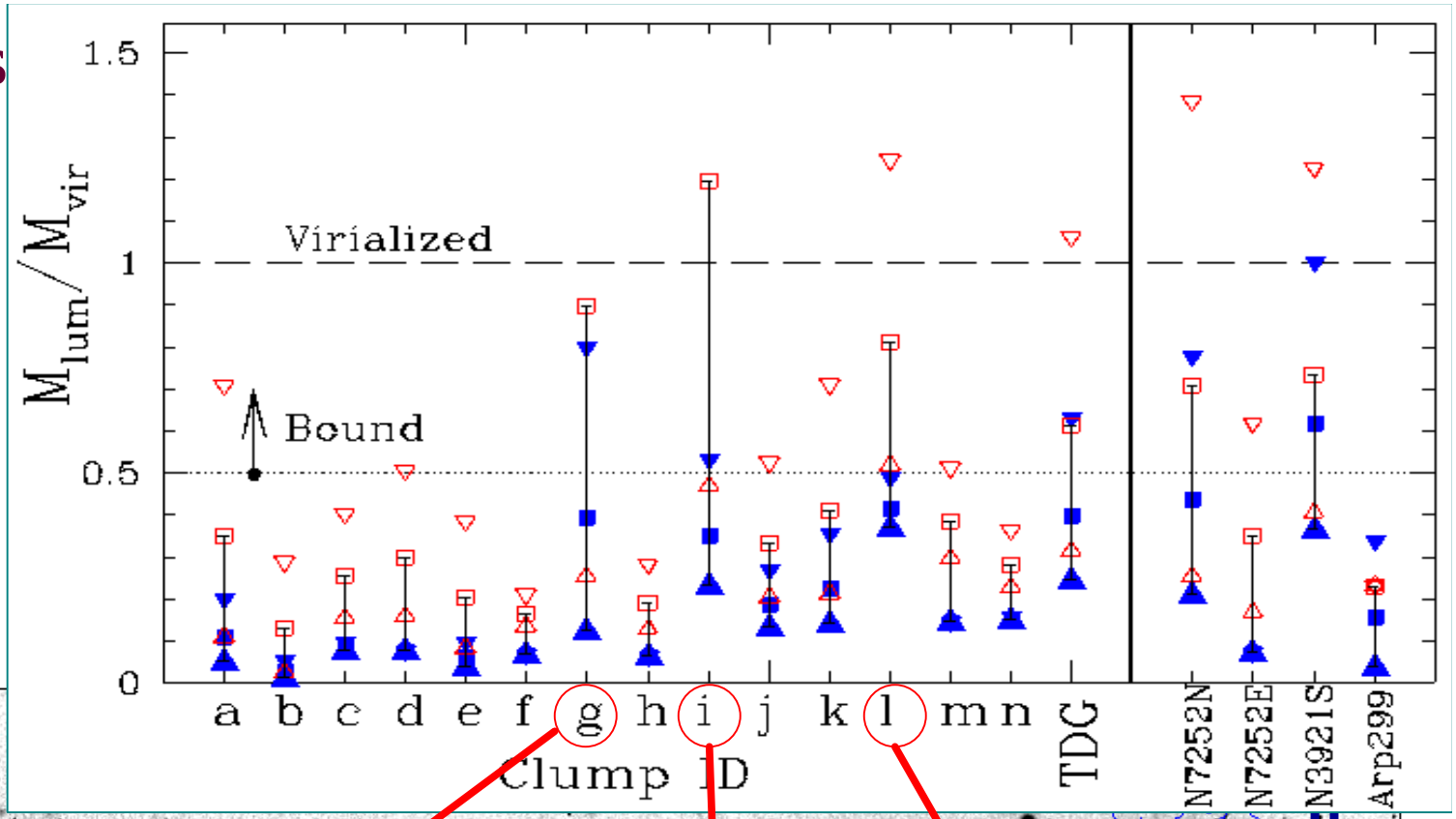
Correction for material falling within beam not associated with clump

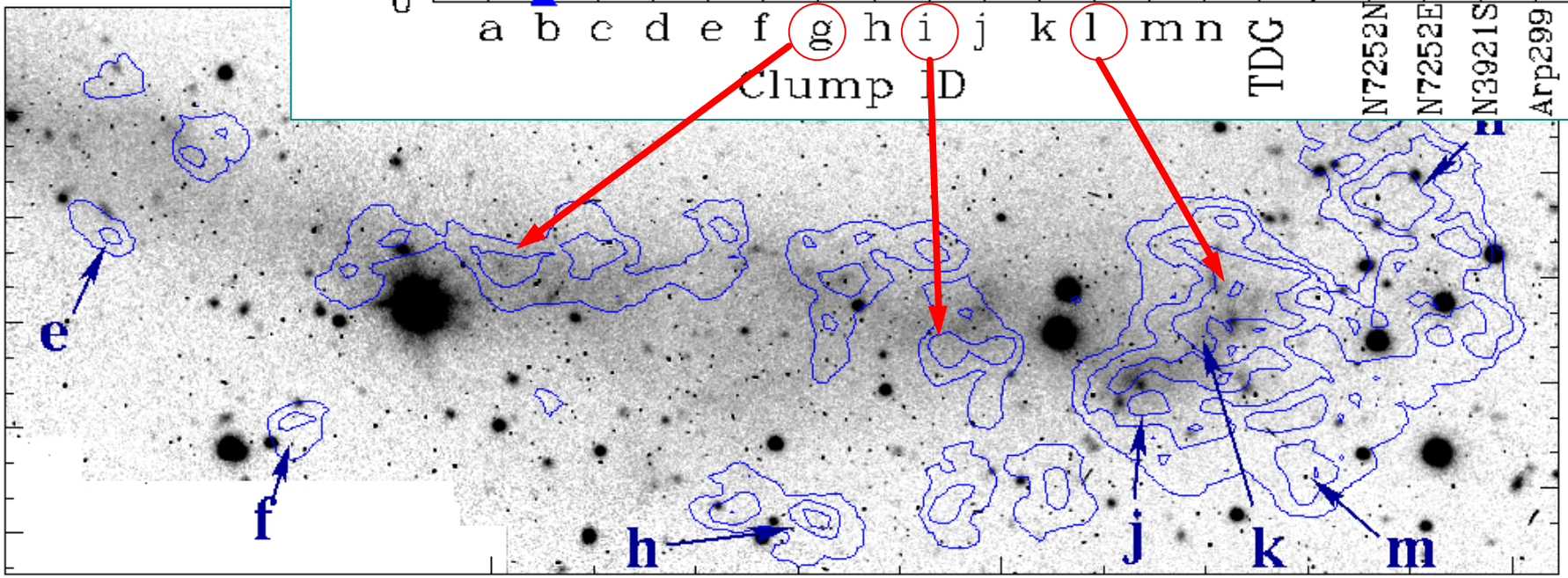


$Flux_{corr} = (\Sigma_{on} - \Sigma_{off}) * Area$

$= Flux_{raw} (1 - \Sigma_{off}/\Sigma on)$

Some regions may be marginally bound, but none by gas alone



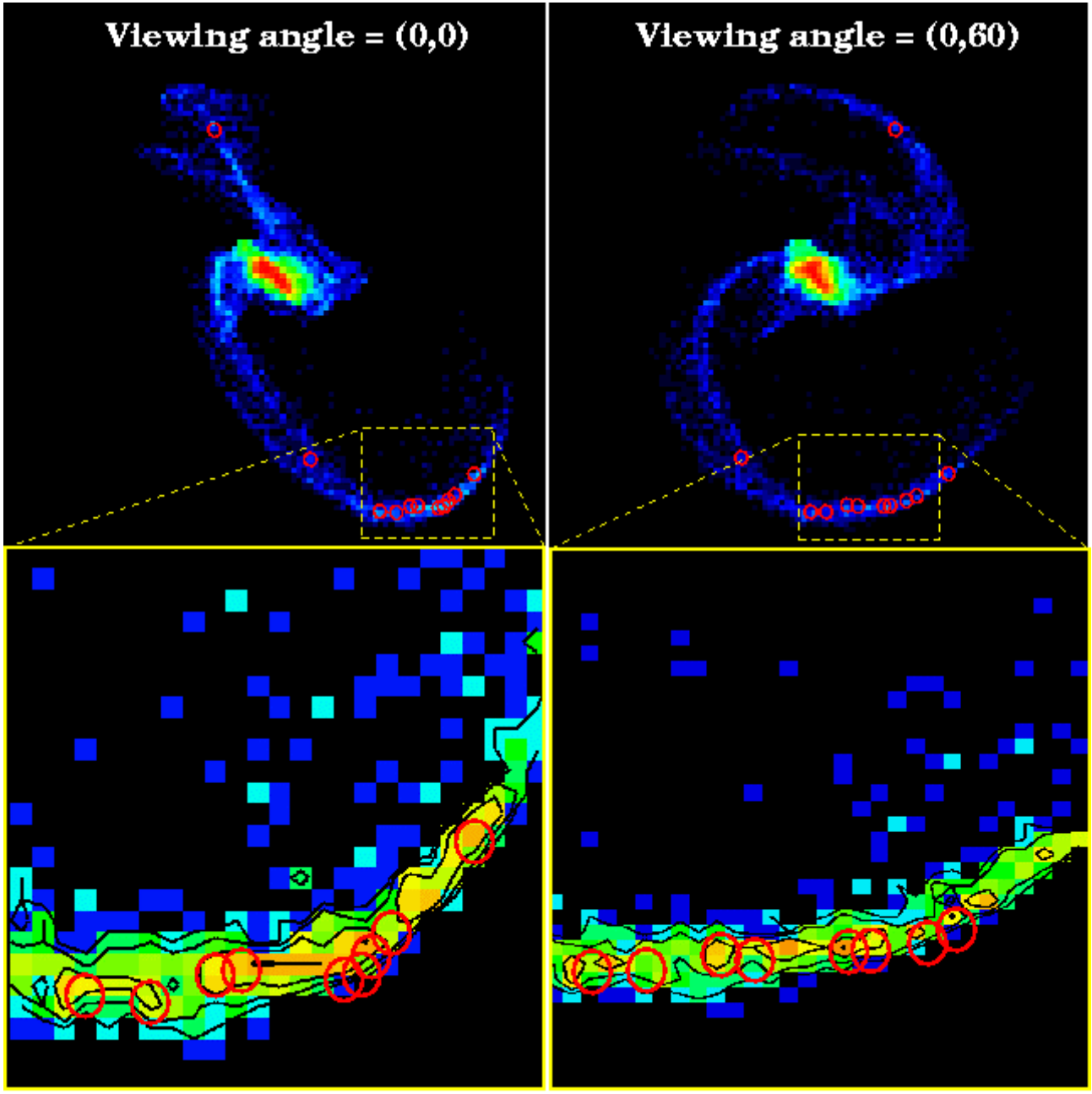


Some pitfalls for calculation of M_{lum} /M_{vir}

$M_{lum} = M_{gas} + M_{stars}$ $\quad\quad$ $G\,M_{vir} = 3\,\sigma_{HI}^{2}\,a\,R_{1/2}$

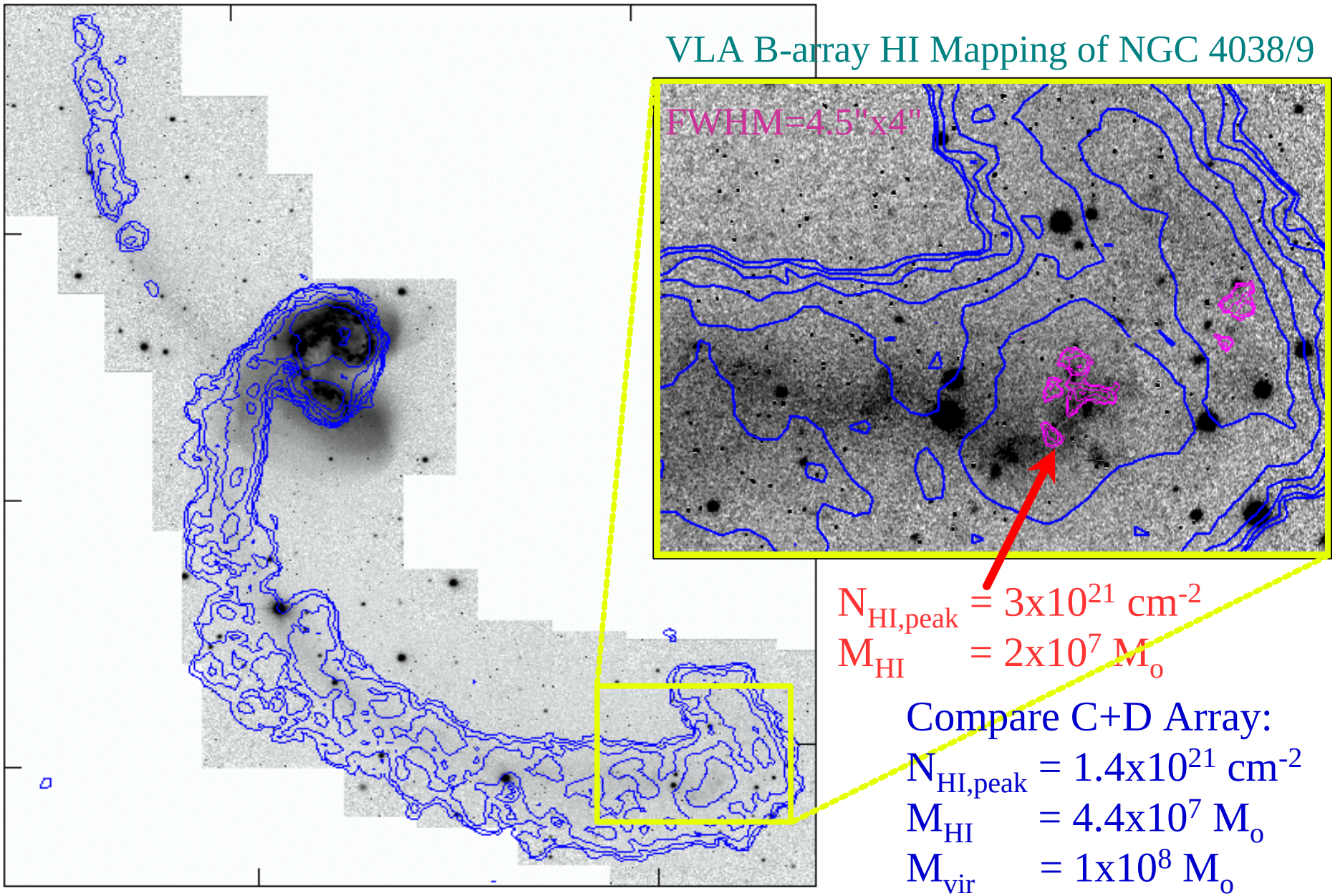
- If stars contribute significantly to M_{lum}, should use stellar velocity dispersion
  - Will be higher than σ_{HI} for evolved populations
- Need to have a well-defined length scale
  - If σ_{HI} → constant and N_{HI} → constant, then M_{lum} grows like R^2. M_{vir} only grows like R, so M_{lum}/M_{vir} grows linearly with length scale

- Simulations show bound objects lying within tidal tails
- However - location of truly bound clumps does not always coincide with projected density peaks
- Even when true clumps coincide with density enhancements, simulated observations fail to recover true mass of bound objects by orders of magnitude
  - $M_{true} \sim 10^7 M_o$
  - $M_{obs} \sim 10^9 M_o$



Kohring, Hibbard & Barnes, poster

Some regions may be bound, but on smaller scales



HST Proposals to study Substruture in Tidal Tails

Cycle 6

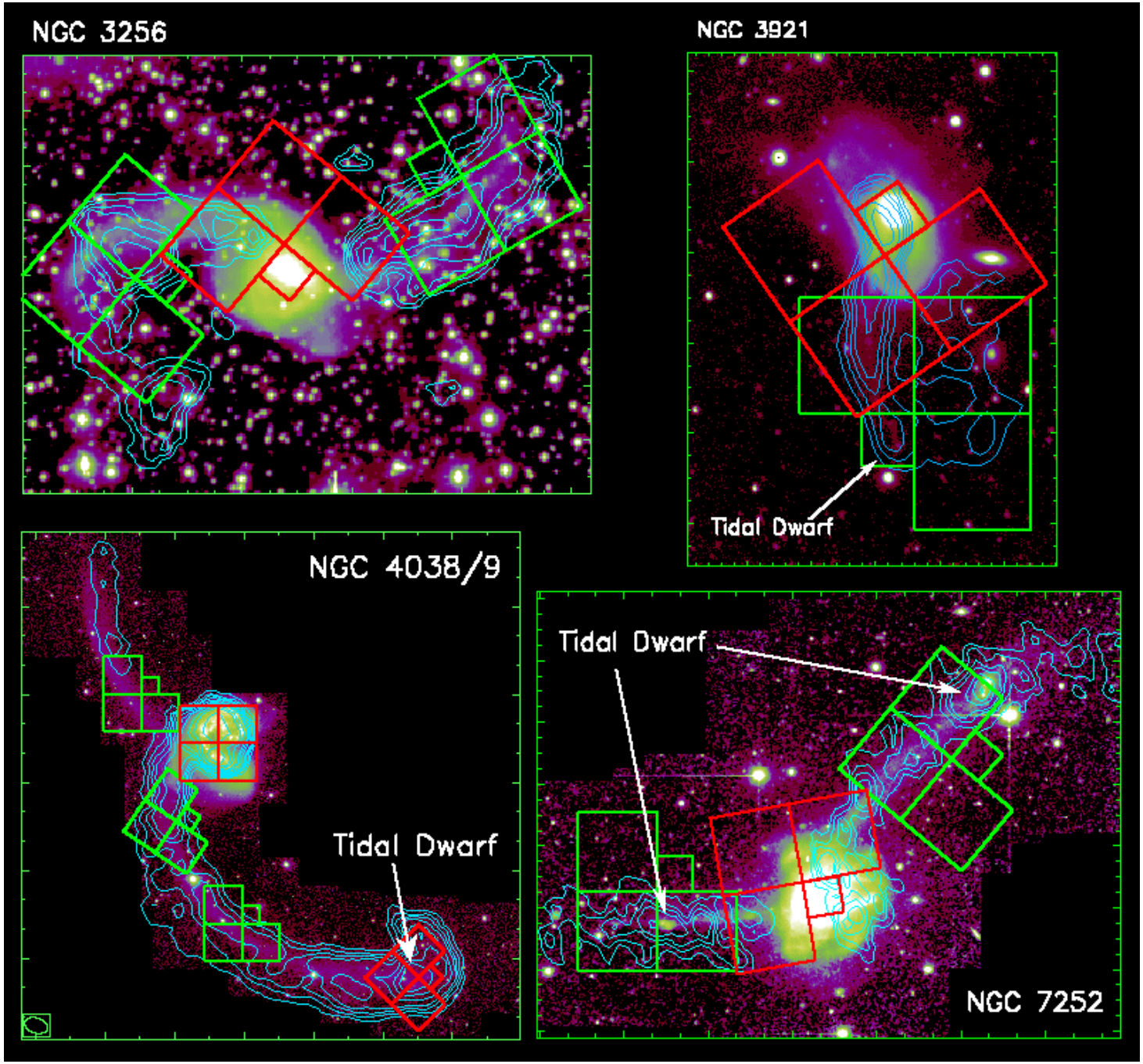
N4038/9 TDG
WFC UBVI
13 orbits
P.I. Hibbard

Saviane, Rich & Hibbard in prep

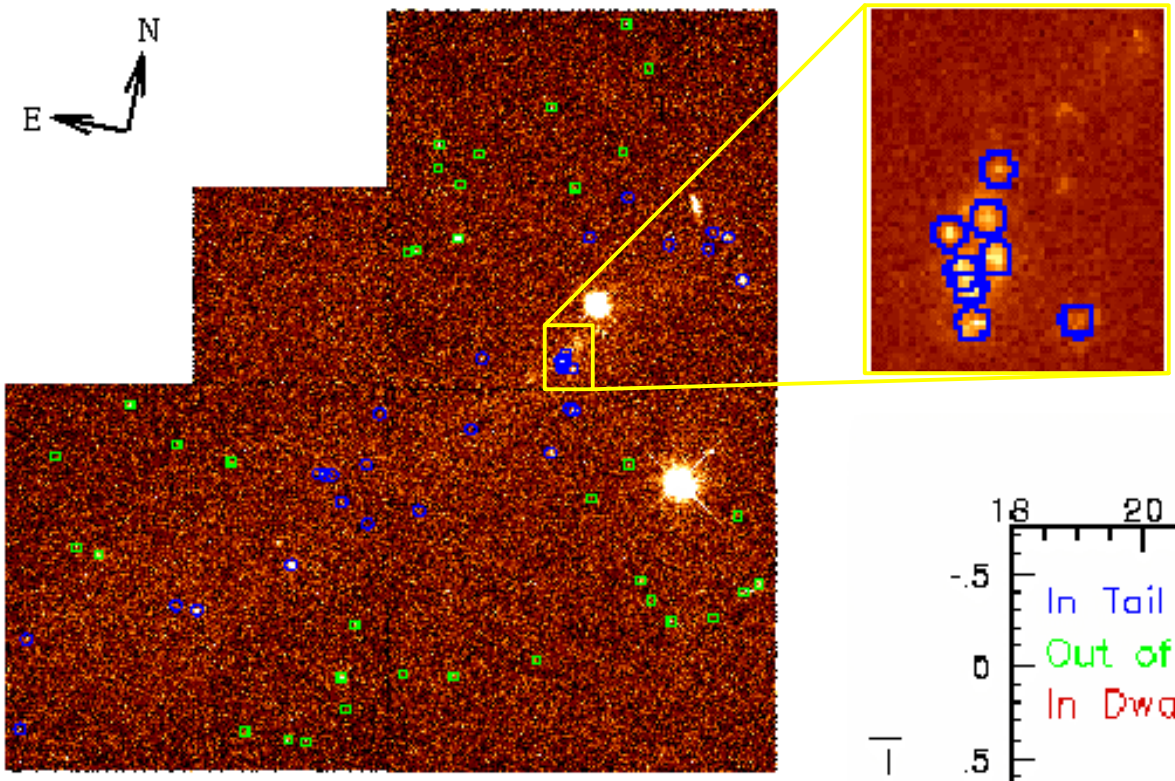
Cycle 7

N4038/9, N3256
N3921, N7252
WFC BI
13 orbits
P.I. Charlton

Kniermann et al. AJ, submitted

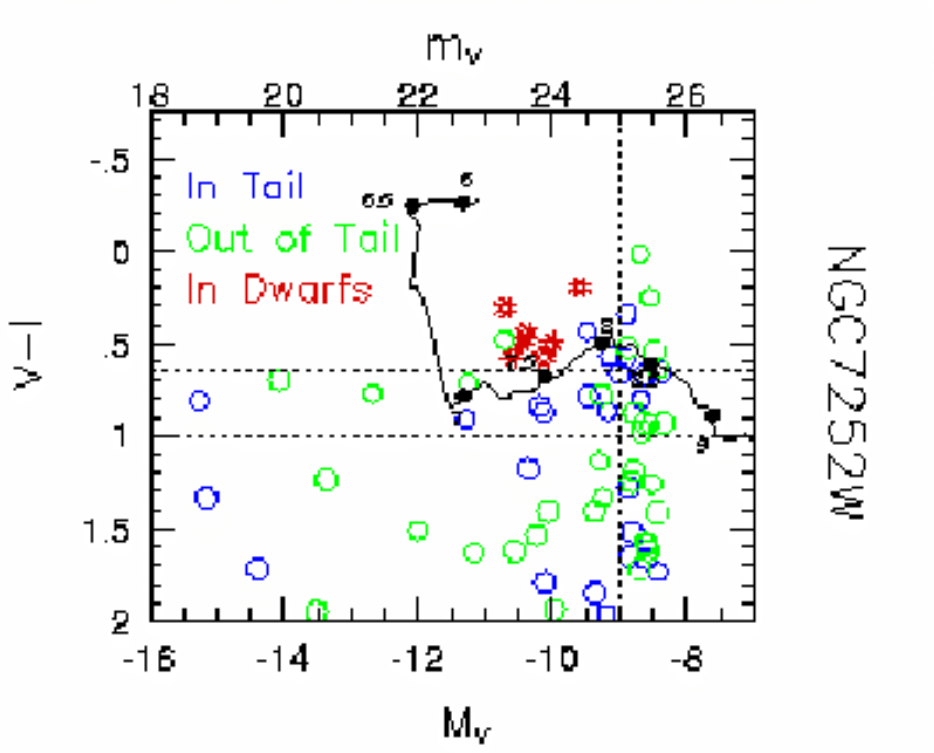


NGC 7252 Western Tail



WFPC2/HST image in F555W filter

Tidal dwarf galaxy at the tip of the western tail of NGC 7252



Knierman, et al. 2001, submitted to AJ

Tidal Substructure Conclusions:

- Most clumps are simply gas density enhancements. Not enough luminous matter to be self-gravitating.
- If they ARE self-gravitating, must be dark matter dominated
- Mass scale may be more appropriate to dSph than to dIrr

- Whether or not TDG in NGC 4038/9 is self-gravitating requires better measures of the stellar M_*/L and kinematics
- HST has discovered super star clusters associated with at least one TDG candidate