Star Formation in dwarfs and outer regions

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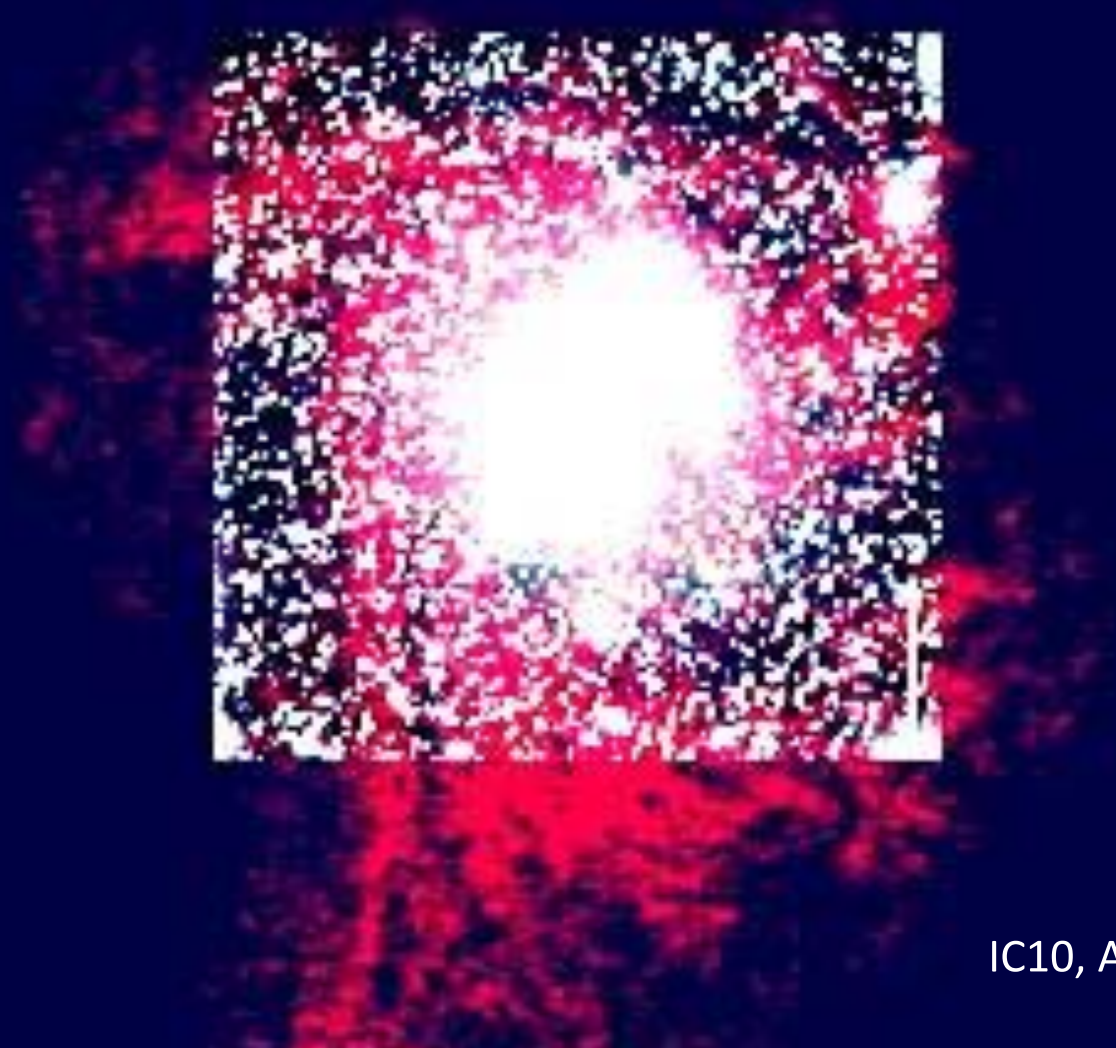
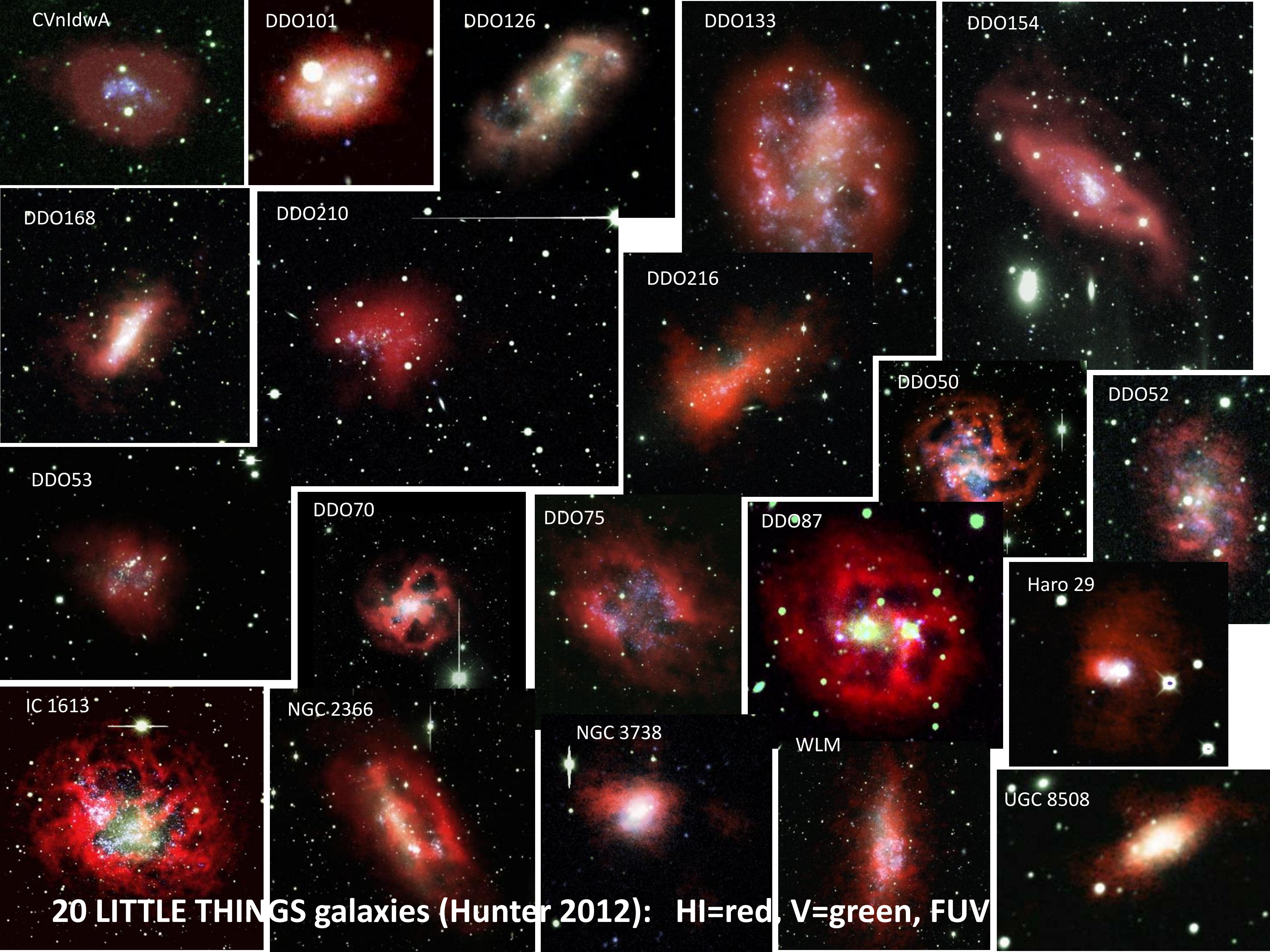


IC10, Ashley +14

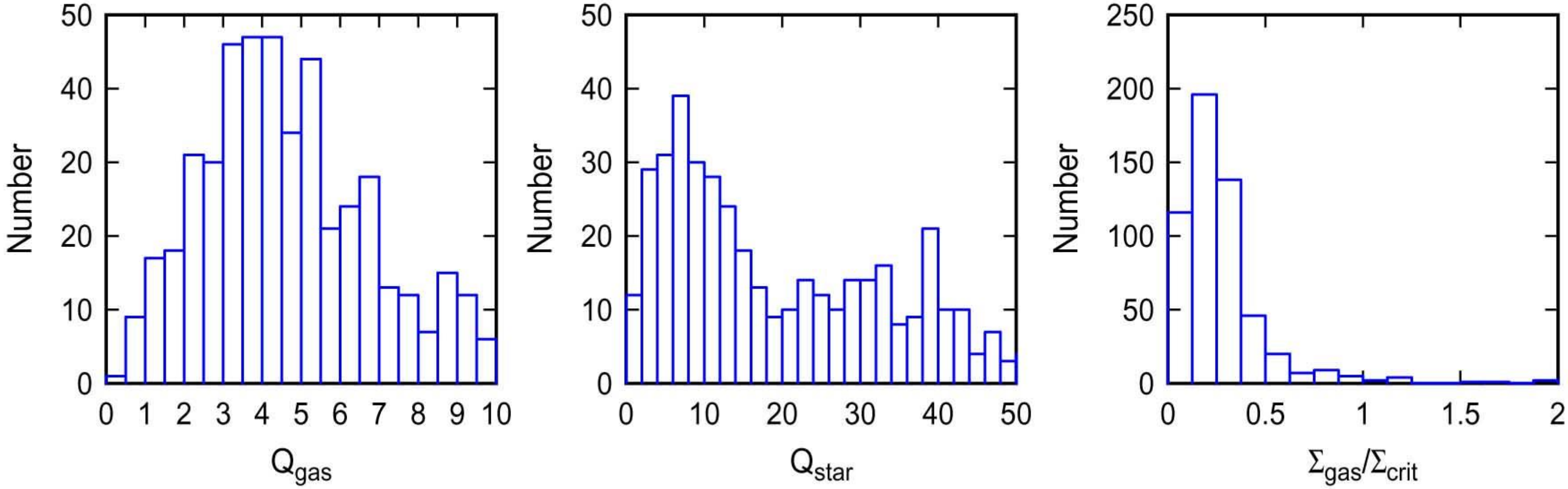
Overview

- SF in local dwarf irregulars (Elmegreen & Hunter 2015)
  - 3D SF without Q regulation
  - outer disk SFR too slow to need accretion
- CO at low metallicity (Rubio, Elmegreen, Hunter, Brinks, et al. 2015)
  - TBD
- Observed accretion in local dwarfs: starbursts & GCs

  (LITTLE THINGS: Ashley +14, Johnson +12)


CVnIdwA
DDO101
DDO126
DDO133
DDO154
DDO168
DDO210
DDO216
DDO50
DDO52
DDO53
DDO70
DDO75
DDO87
Haro 29
IC 1613
NGC 2366
NGC 3738
WLM
UGC 8508
20 LITTLE THINGS galaxies (Hunter 2012): HI=red, V=green, FUV

EH12



Using V_{rot} for κ, Σ_{gas}, σ_{gas}, Σ_{star}, σ_{star} for radial annuli in 20 galaxies:

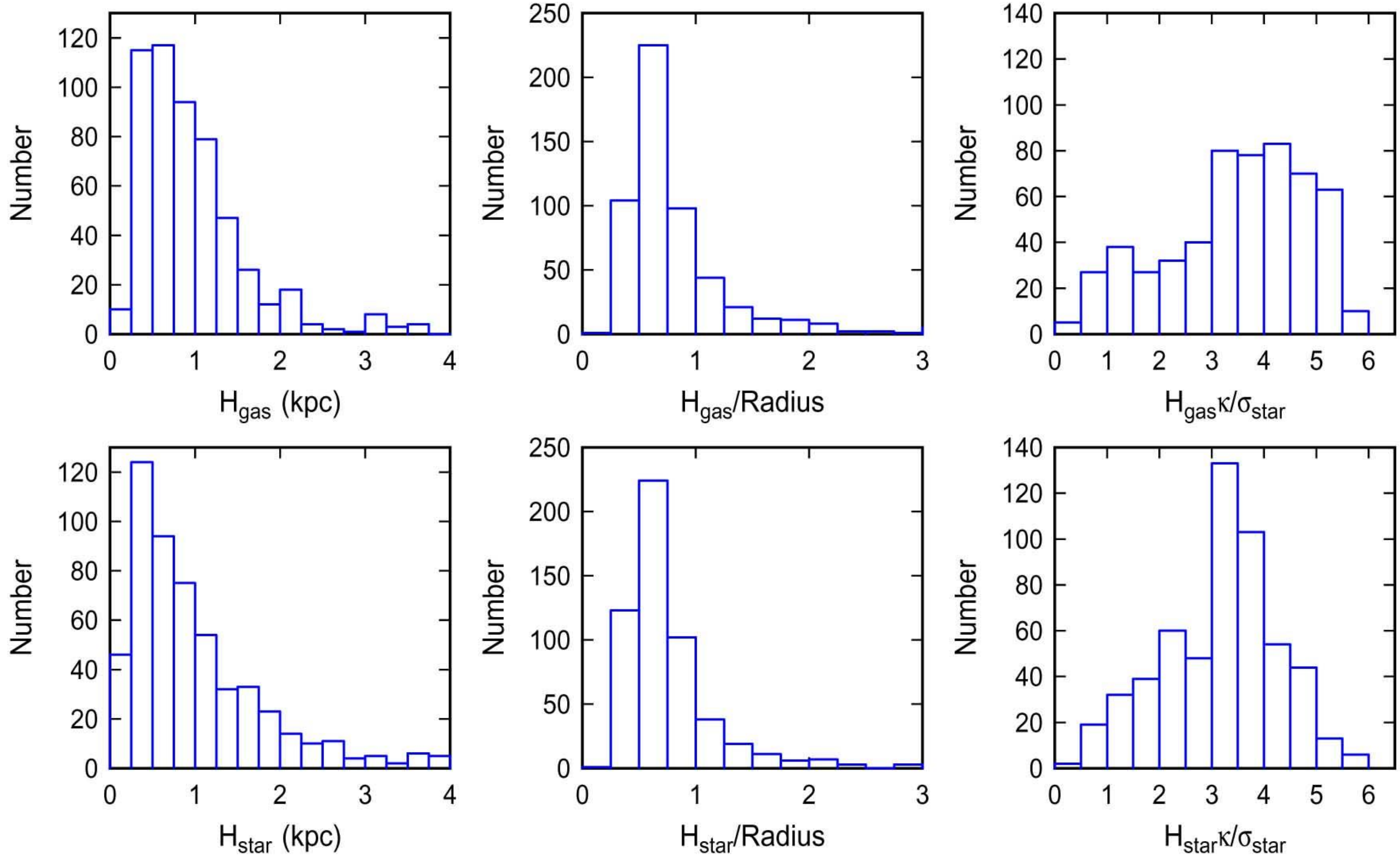
Q_{gas} and Q_{star} >>1

Two fluid effective $Q = 1/ (1/Q_{gas} + 1/Q_{star}) >>1$

$\Sigma_{gas} / \Sigma_{crit} << 1$

→ SF pervasive and normal-looking without Q ~ 1-2 as in spirals.
→ SF & Q do not self-regulate to make Q ~ 1-2 everywhere

EH12

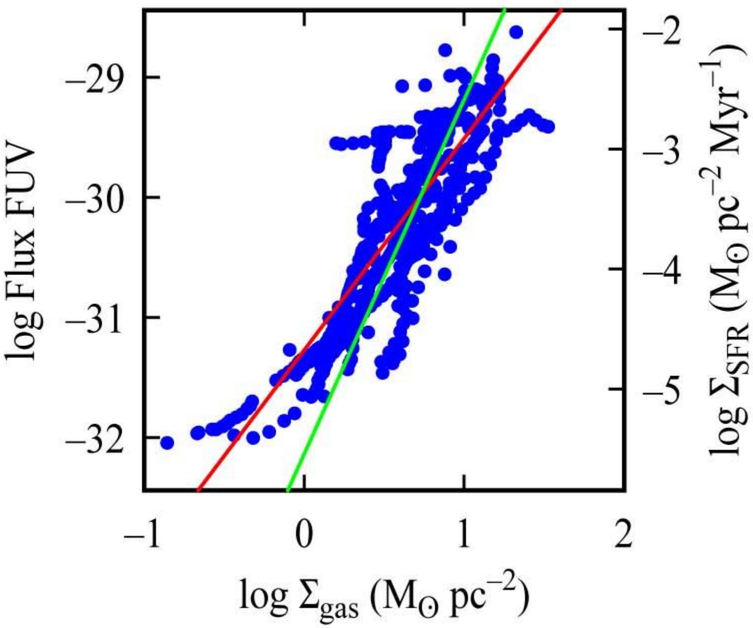


Scale height H: vertical equilibrium with gas, stars & disk DM (Narayan & Jog 02)

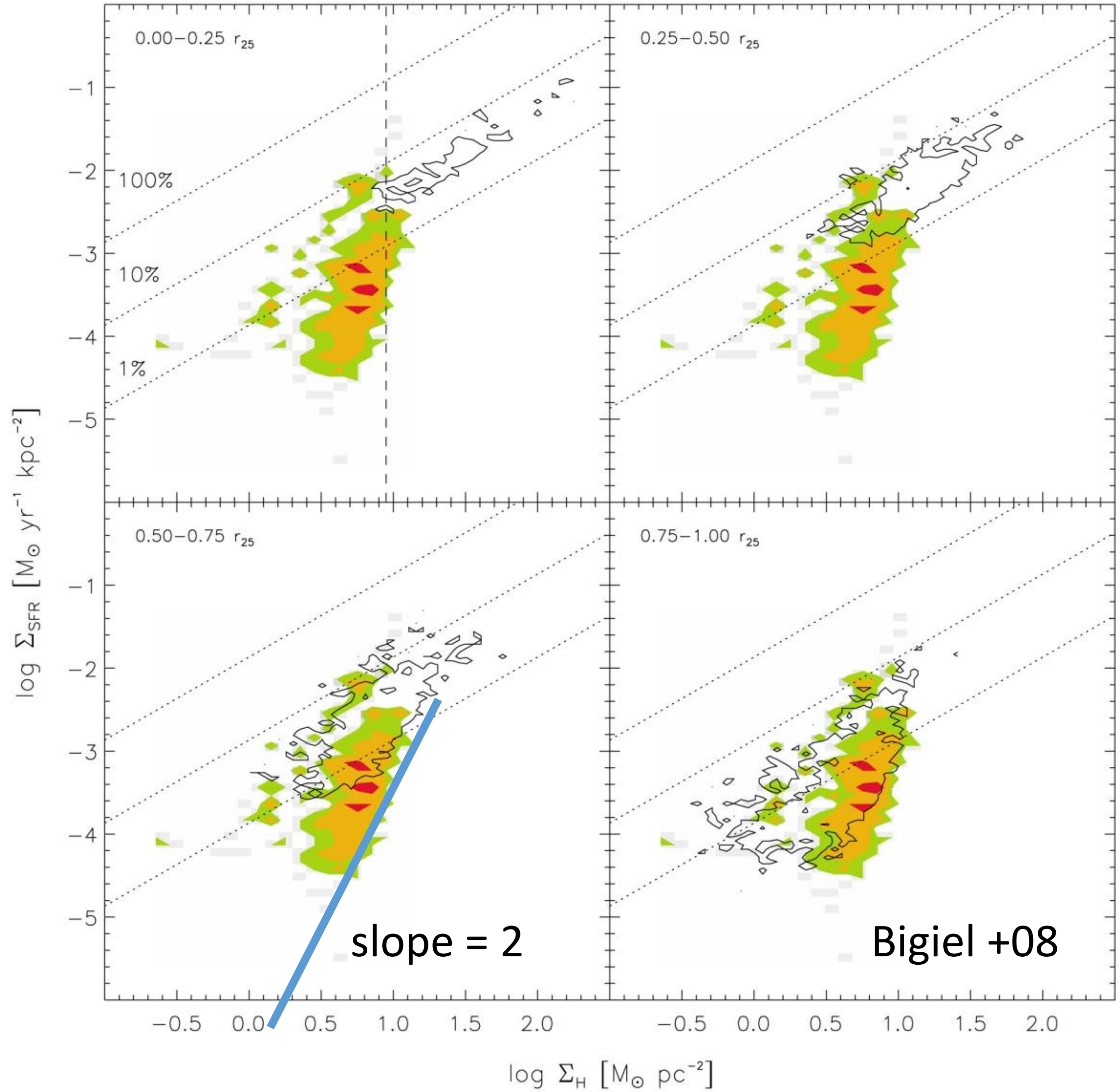
Thick disks: H/Radius ~ 0.6; $H/R_{epicycle}$ ~ 4, make dIrrs even more stable.

→ dIrrs have thick disks

Red slope (all pt avg.) = 1.76pm0.08
Green slope (avg. of gal. slopes)
= 2.95pm2.09



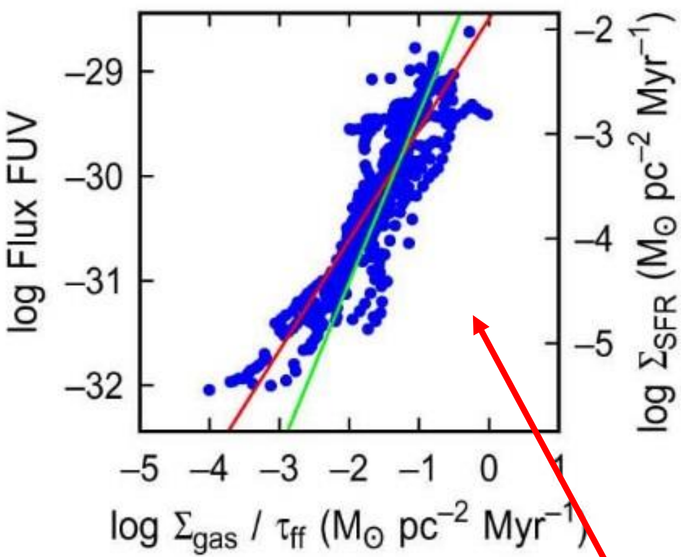
The KS relation has slope ~2

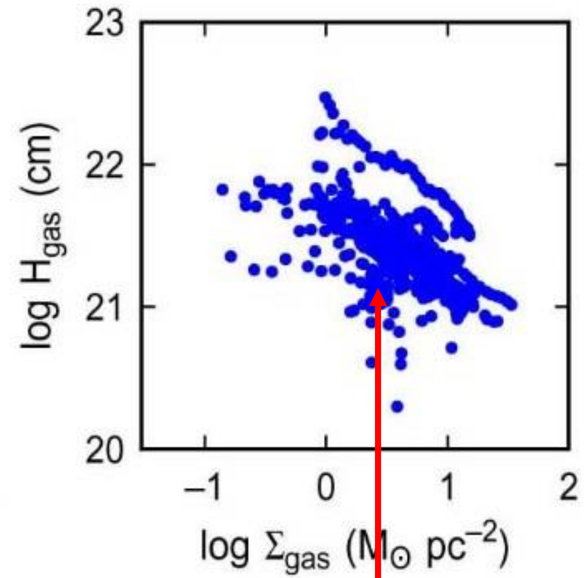


KS in dwarfs like outer parts of spirals.
This the H_2 to HI transition, but more...

Red slope 1.06pm0.04
Green slope 1.61pm0.58

EH12



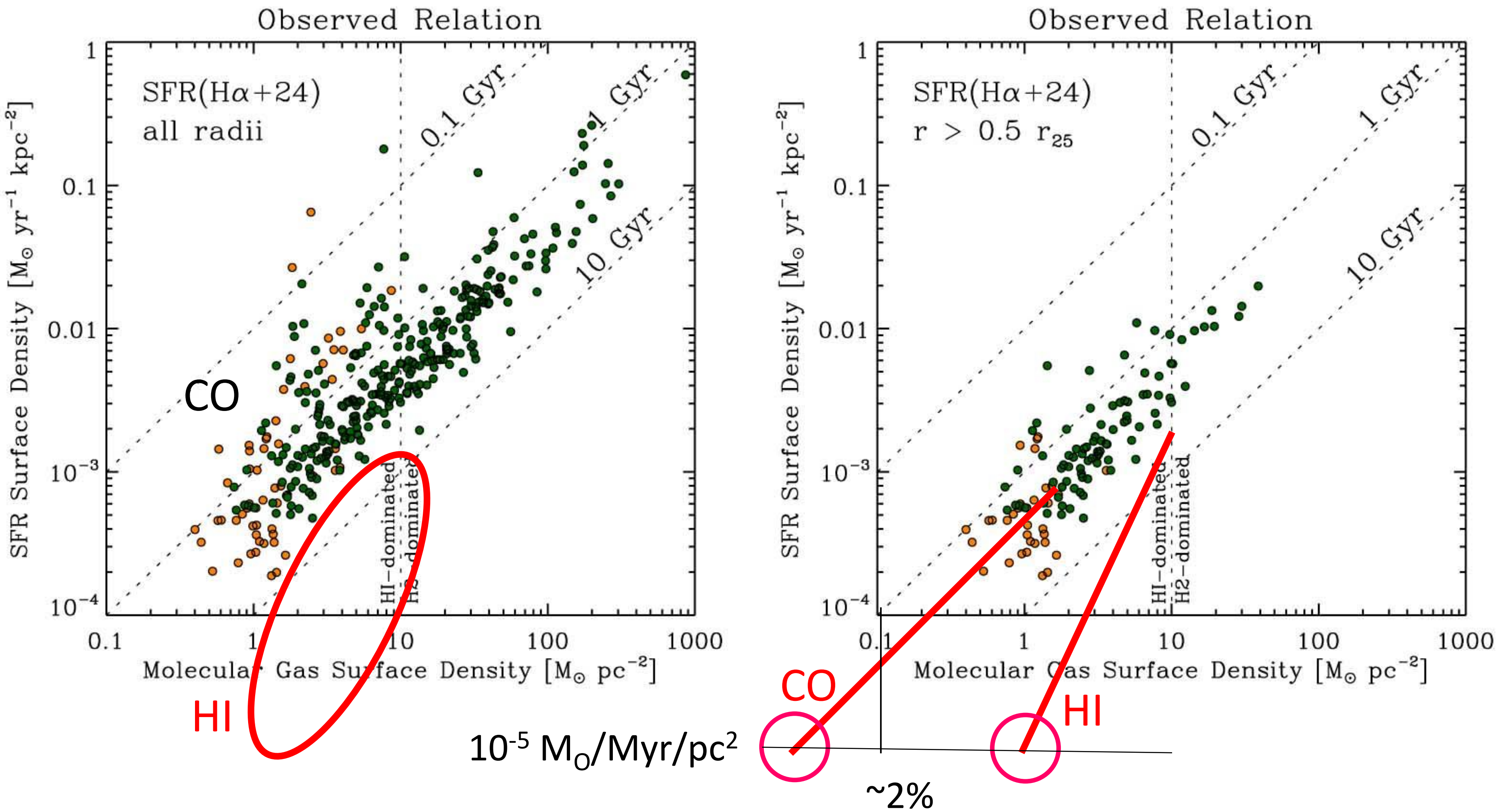


Replot Σ_{SFR} versus Σ_{gas}/τ_{ff} : slope ~ 1, coefficient, ε_{ff} , is 1%

Σ_{SFR} is proportional to $\Sigma_{gas}{}^2$ because H ~ $1/\Sigma_{gas}$

$1/\tau_{ff} \sim \rho^{1/2} \sim (\Sigma_{gas}/H)^{1/2} \sim \Sigma_{gas}$

→ the quadratic KS region is also where $\Sigma_{gas} > \Sigma_{stars}$, HI>>H_2, and also where the disk flares

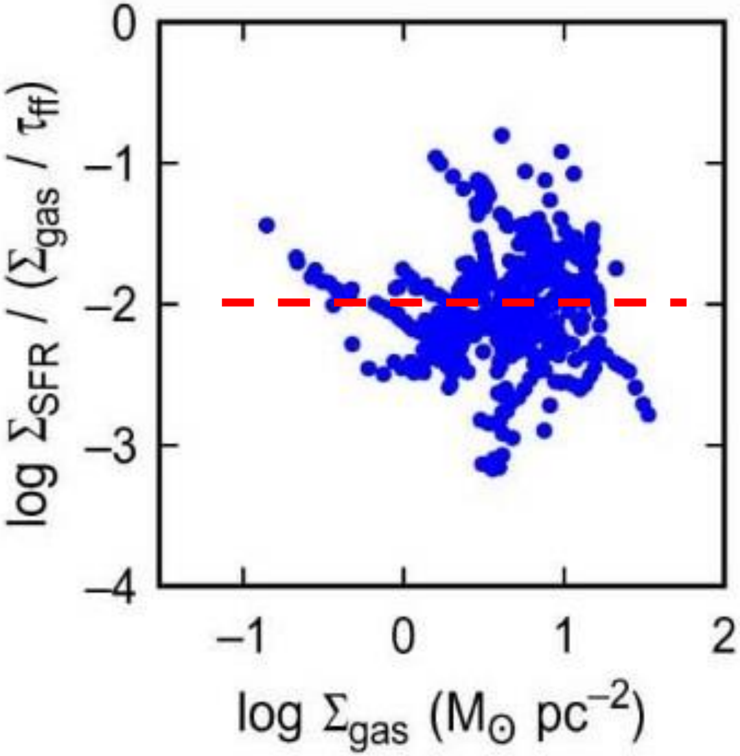


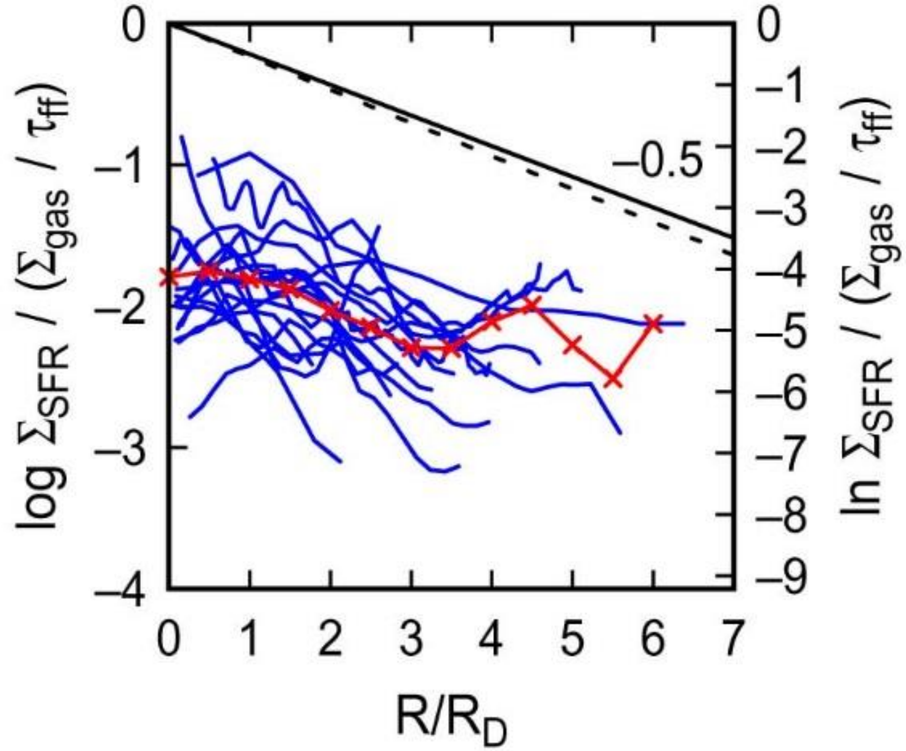
Schruba +11: CO observed in the far-outer regions by stacking.

$\Sigma_{SFR} \sim \Sigma_{CO}^{1}$; $\Sigma_{SFR} \sim \Sigma_{HI}^{2}$

→ Molecular fraction, CO/HI ~ $\Sigma_{SFR}^{1/2} \sim \Sigma_{HI}$

(same for LMC – see Bolatto et al. 2011)



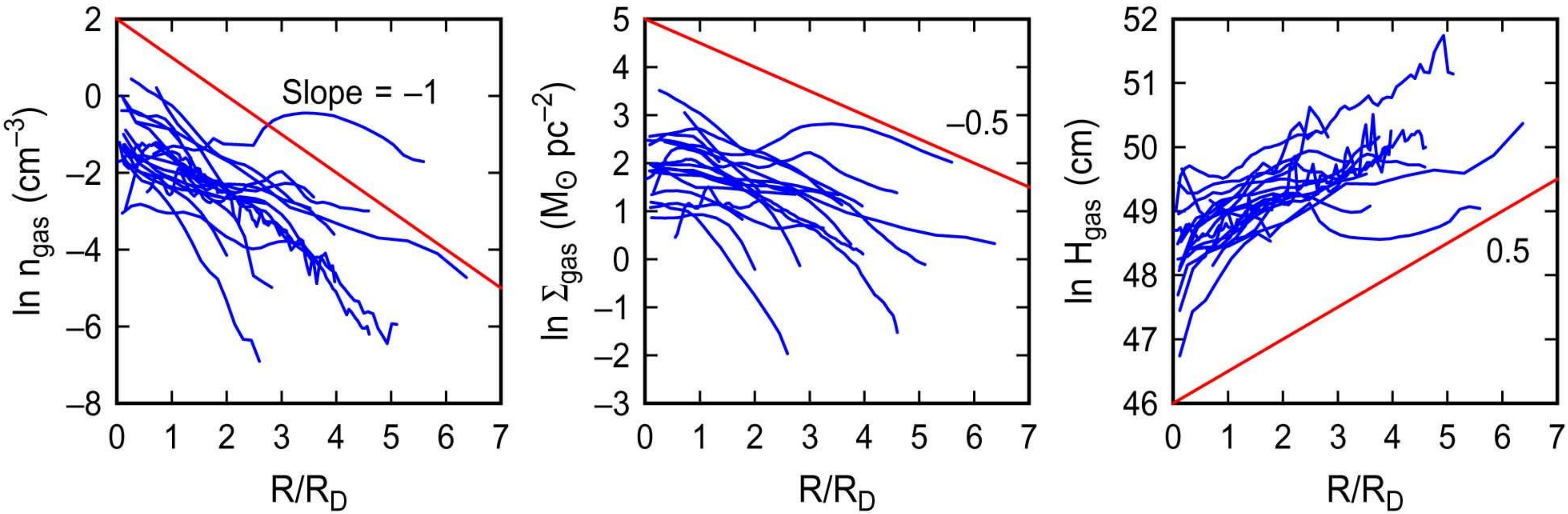


$\Sigma_{SFR}/(\Sigma_{gas}/\tau_{ff}) = \varepsilon_{ff}$ ~1% on average for all regions

In detail, ε_{ff} (R) follows an exponential:

$\varepsilon_{ff}(R)$ ~ $\exp(-0.5R/R_D)$

EH12

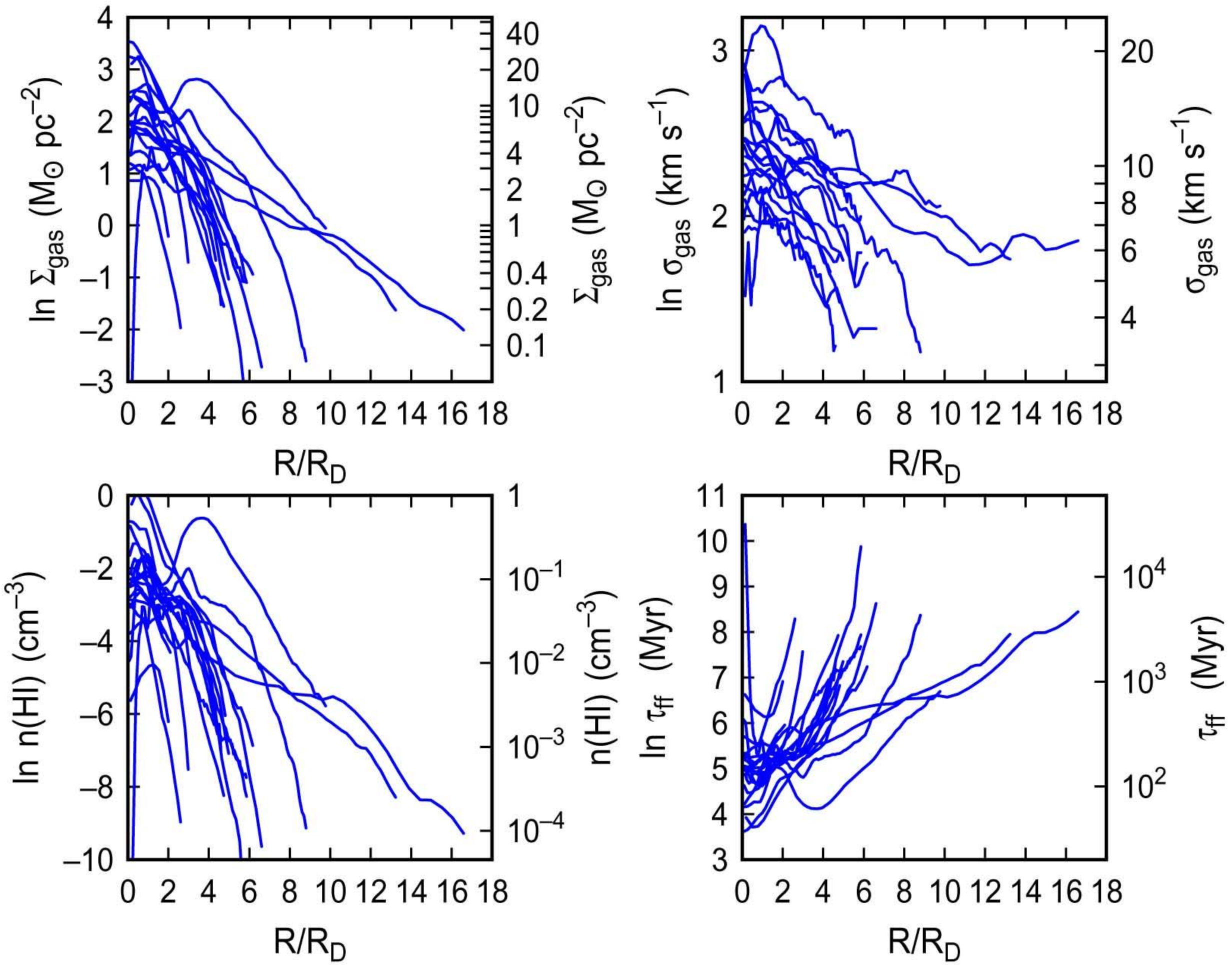


$n_{gas} \sim \exp(-R/R_D)$ $\Sigma_{gas} \sim \exp(-0.5R/R_D)$ $H_{gas} \sim \exp(0.5R/R_D)$

$\varepsilon_{ff}(R)$ and Σ_{gas} both follow $\exp(-0.5R/R_D)$ for the 20 dIrr

So ε_{ff} (R) follows Σ_{gas} (R) like the CO/HI in Schruba +11, Bolatto +11

→ ε_{ff} may be related to the molecular fraction



The far-outer parts of our 20 dIrr galaxies:

– Σ(HI) ~ 0.1 M_O/pc^2 (=0.1Σ_{DLA}) ; n(HI)~10^{-3} cm^{-3} (R_{HII} ~30 kpc for O5 *)

τ_{ff} ~ 1 Gyr so τ_{ff}/ε ~ 100 Gyr

→ no need for accretion to feed outer disk SF

→ no evidence for gas/star accumulation in outer exponential

Summary for the 20 dIrr:

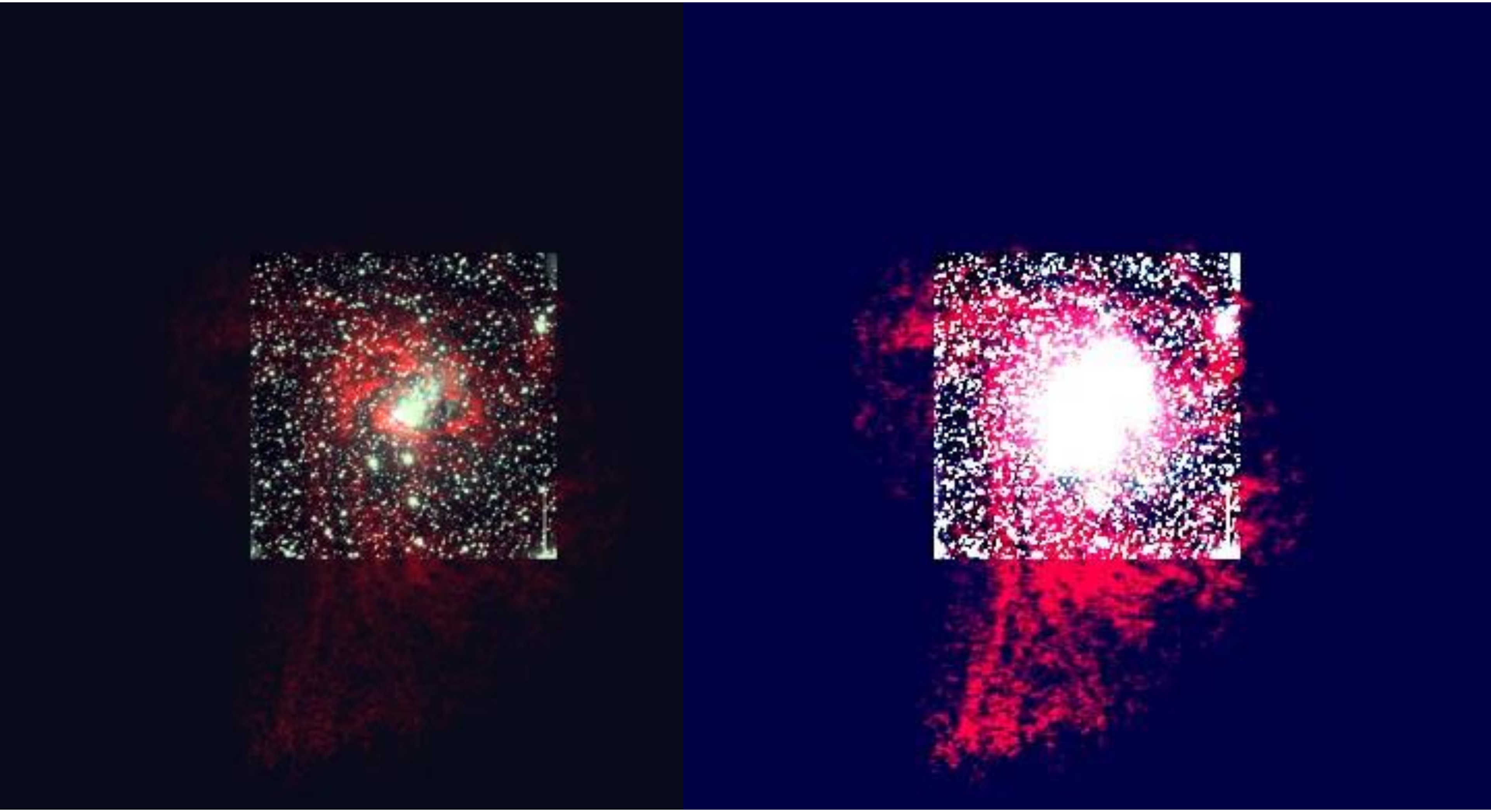
1. Q not regulated by SF feedback; high Q does not stop SF.

2. $\Sigma_{SFR} \sim \Sigma_{gas}^2$ because gas (HI) dominates mass and the disk flares

3. $\Sigma_{SFR} = \varepsilon_0(R)\Sigma_{gas}/\tau_{ff}$ where ε_0 may scale with the CO/HI fraction

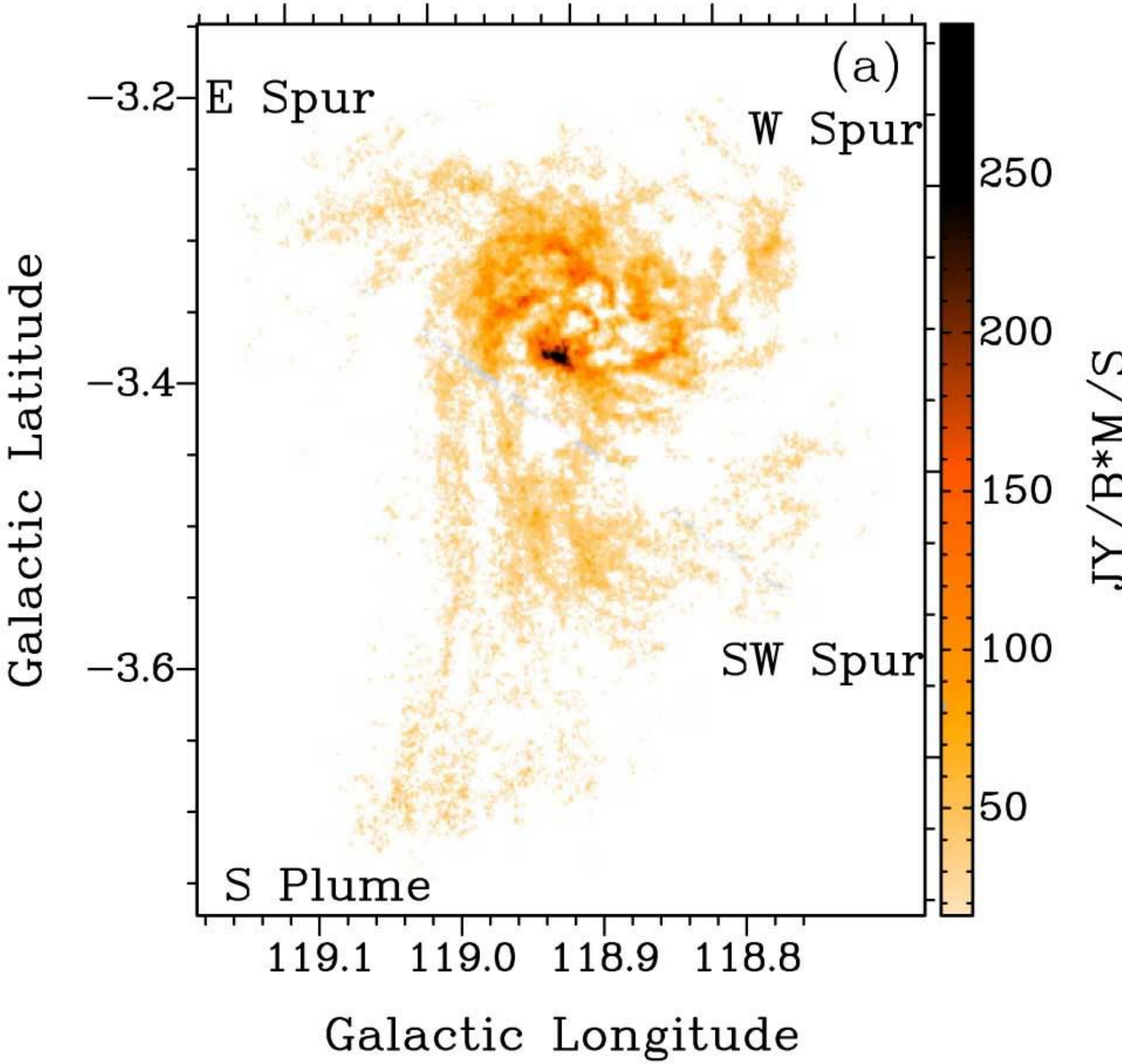
4. Outer parts have τ_{depl} ~100 Gyr and don't need accretion

Accretion in Local Dwarfs

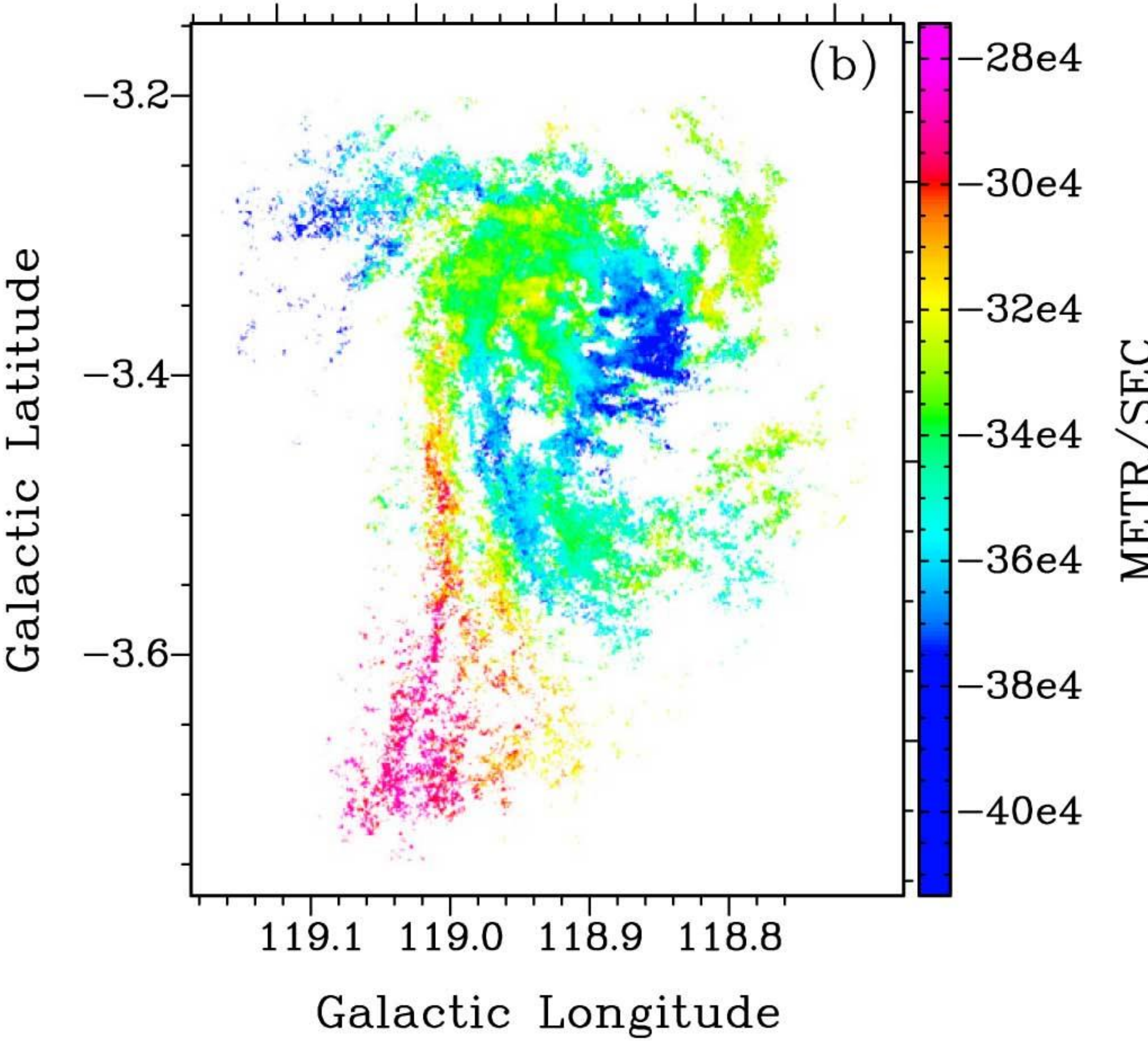


Accretion onto the local (0.7 Mpc) dwarf starburst, IC 10

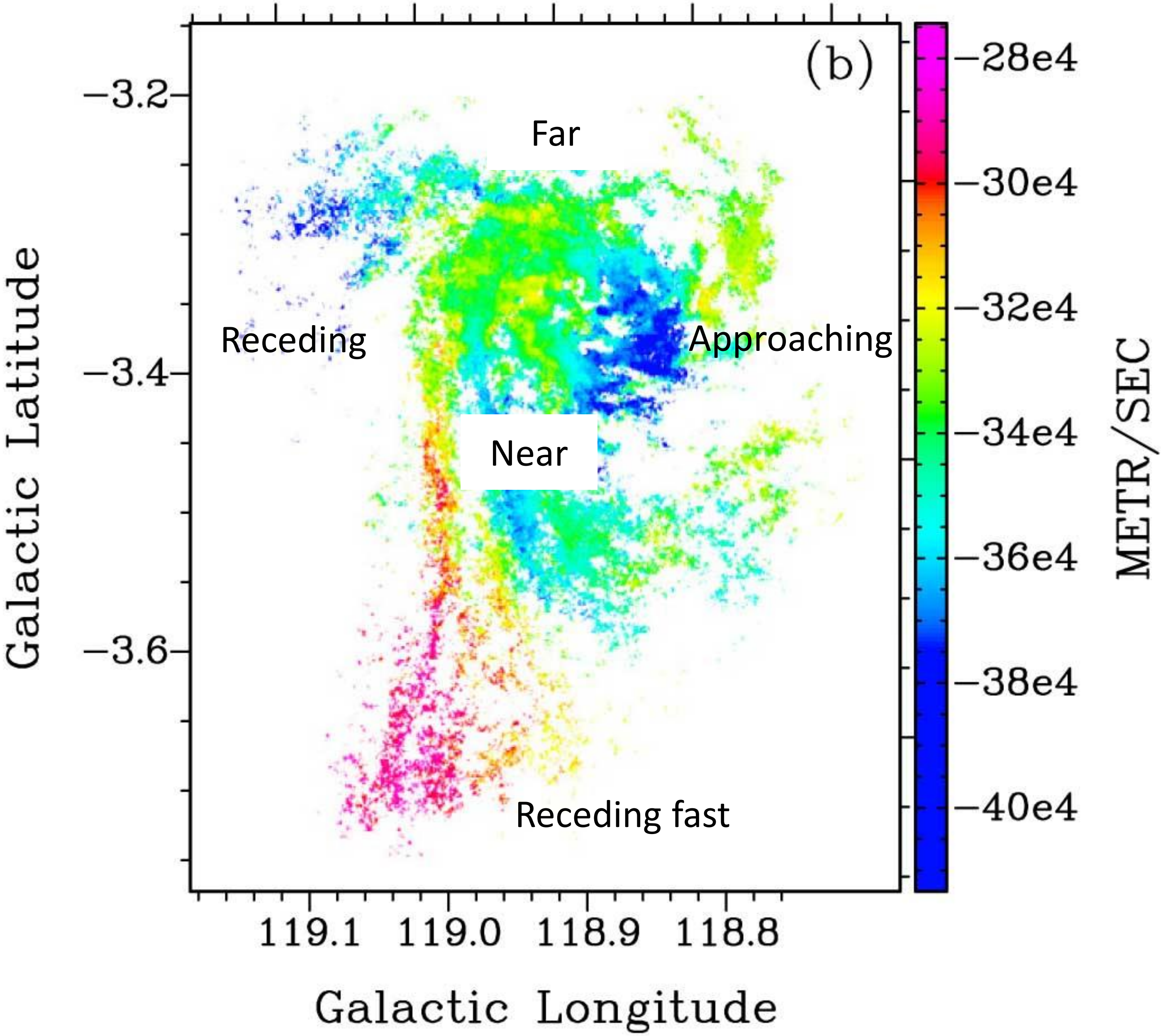
Ashley, Elmegreen, Johnson, Nidever, Simpson, Pokhrel 2014



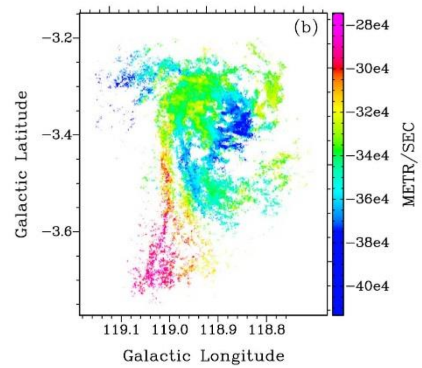
VLA, Ashley +14



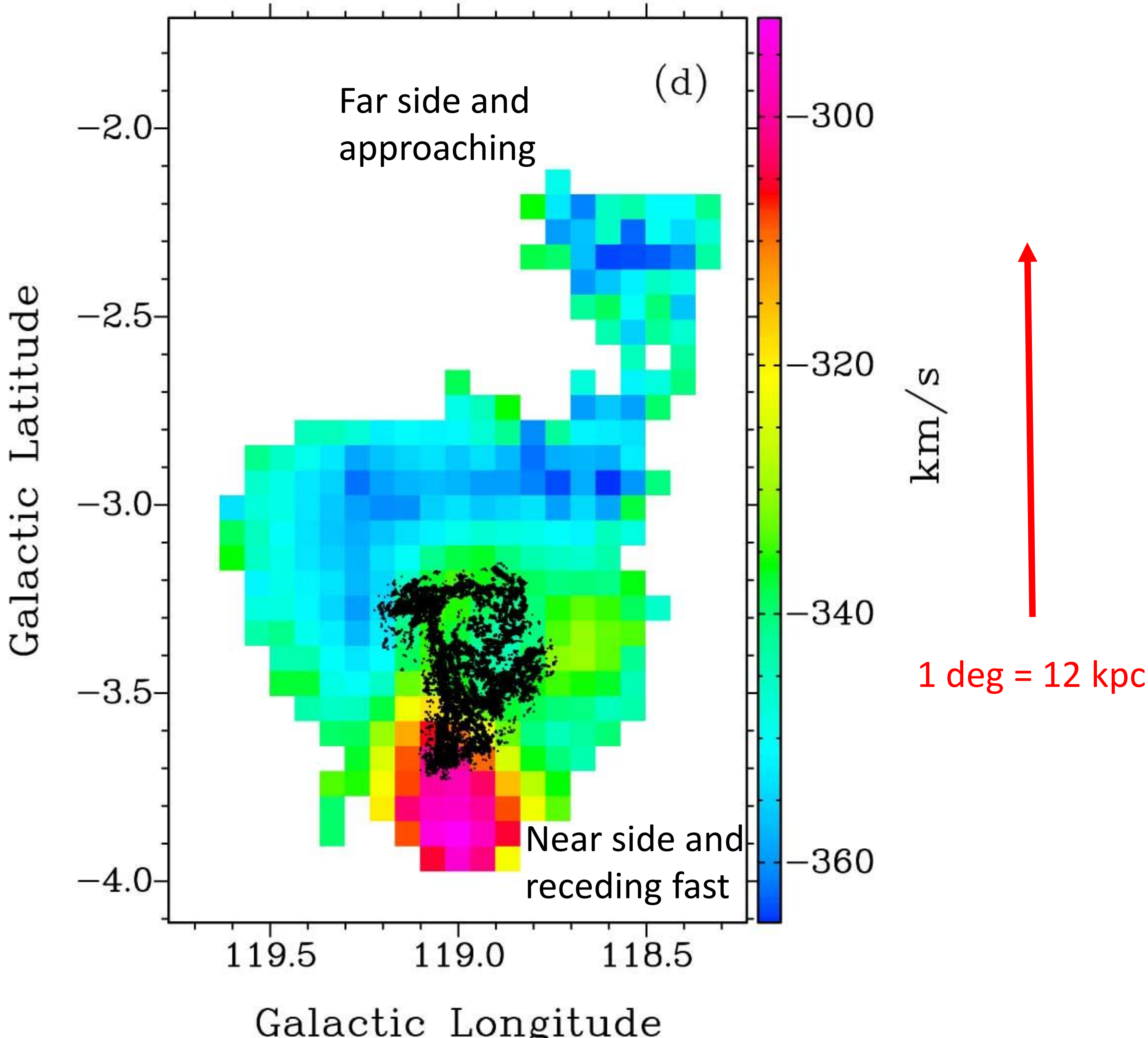
VLA, Ashley +14



VLA, Ashley +14

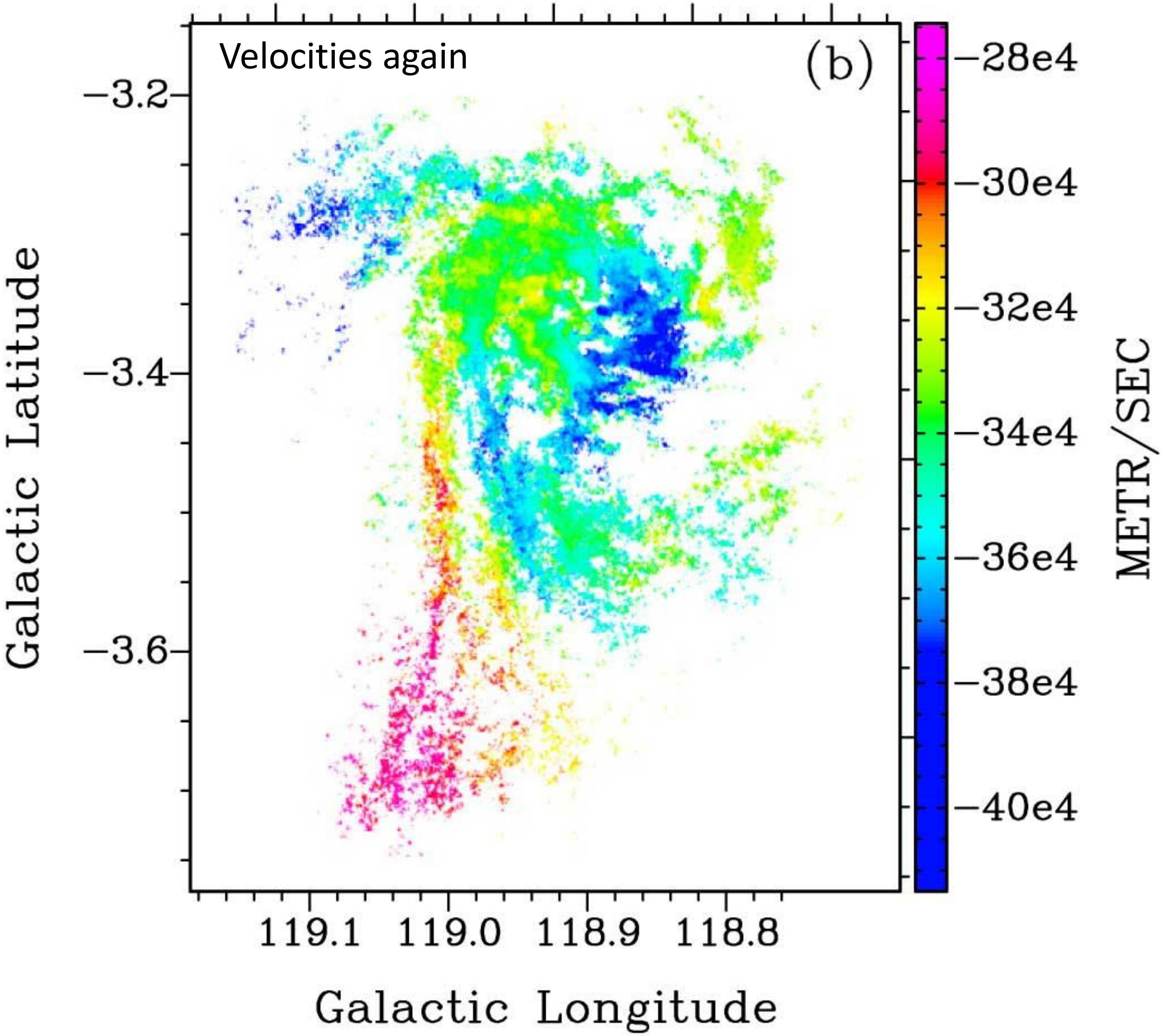

(b)
−3.2
−3.4
−3.6
Galactic Latitude
119.1
119.0
118.9
118.8
Galactic Longitude
−28e4
−30e4
−32e4
−34e4
−36e4
−38e4
−40e4
METR/SEC

GBT

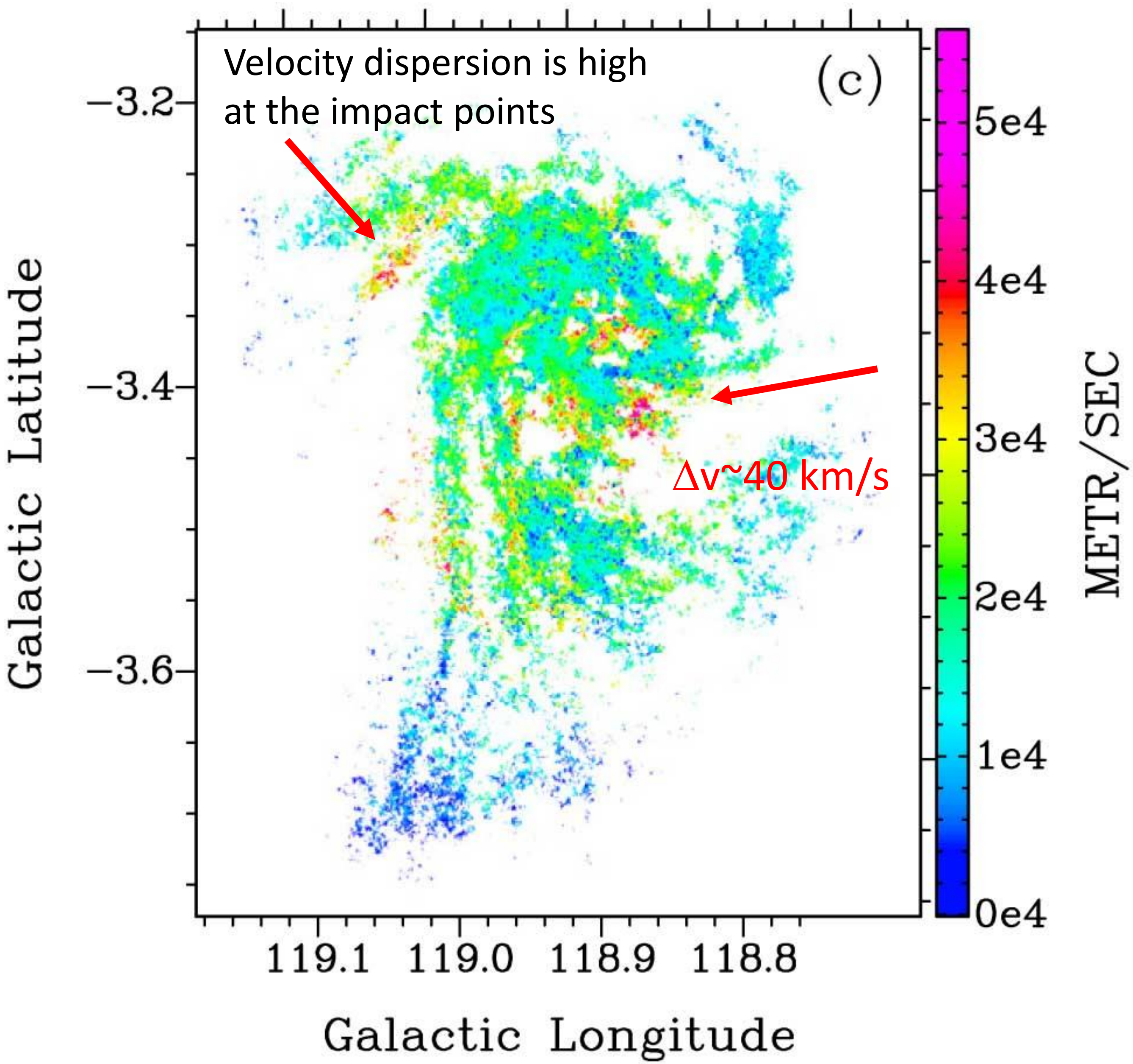


Ashley +14

VLA



Ashley +14



Velocity dispersion is high
at the impact points
(c)
Δv~40 km/s
−3.2
−3.4
−3.6
Galactic Latitude
119.1
119.0
118.9
118.8
Galactic Longitude
5e4
4e4
3e4
2e4
1e4
0e4
METR/SEC

Summary for IC 10:

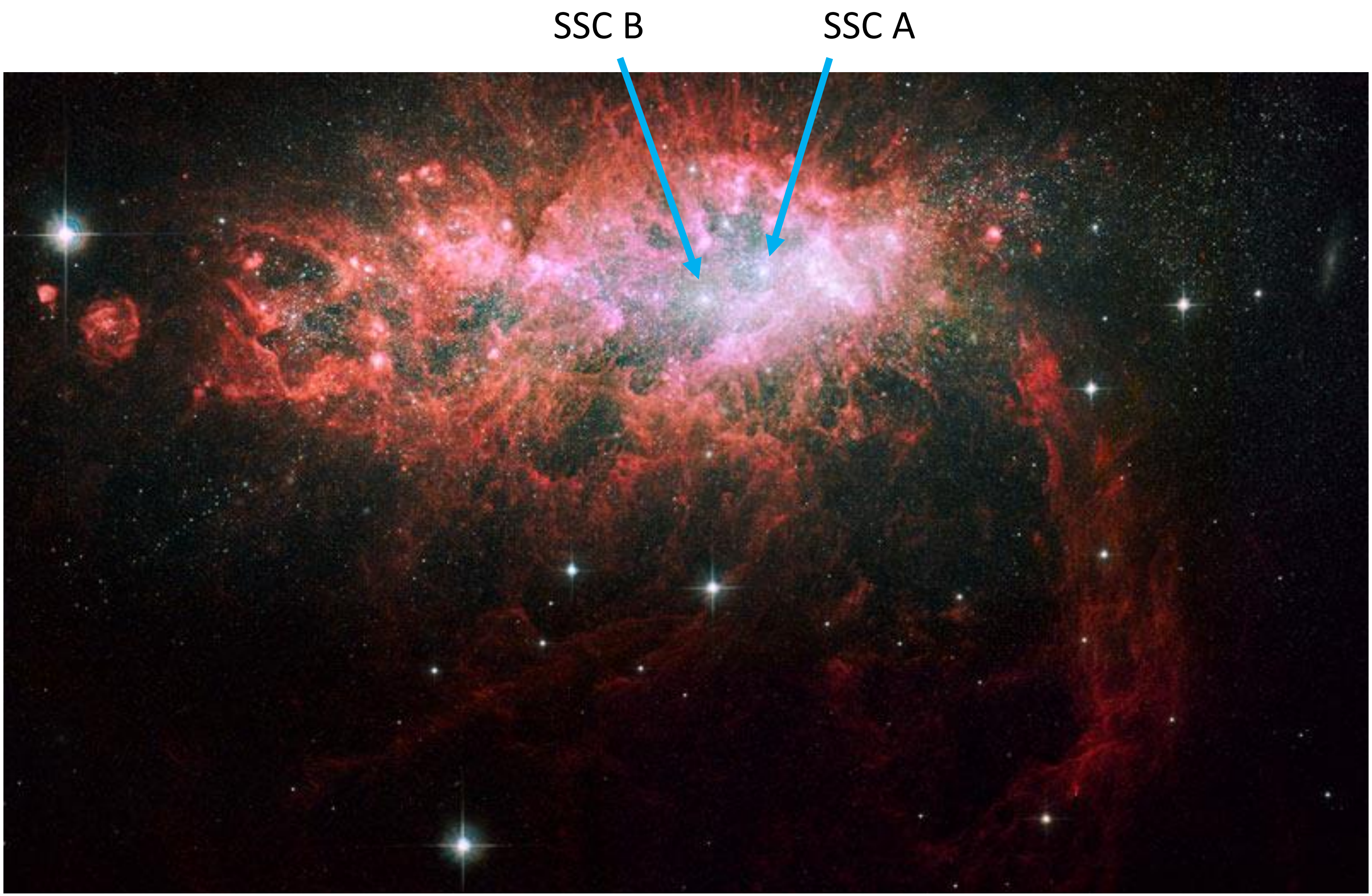
M_{dyn} = 2.6x10^8 M_O (Oh, et al. 2015)

Northern filament: M(HI)=6x10^5 M_O, Δv=15 km/s, L=7 kpc
- dM/dt = MV/L = 0.001 M_O/yr
- time to finish, 0.6 Gyr

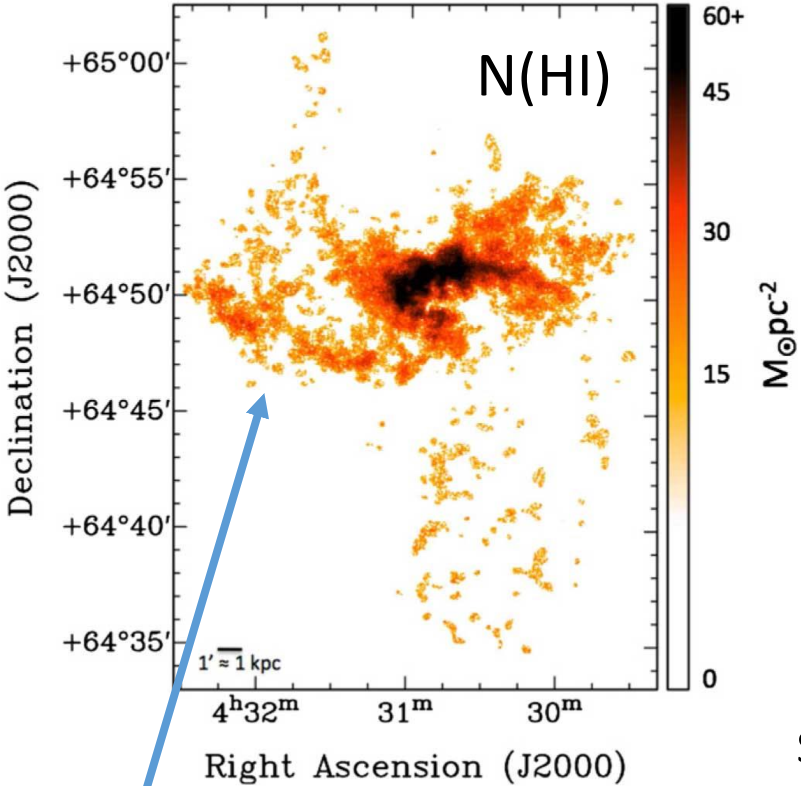
Southern plume 10^7 M_O, Δv ~ 30 km/s, L~7 kpc (assume like N.)
- dM/dt=0.05 M_O/yr
- time to finish 0.2 Gyr

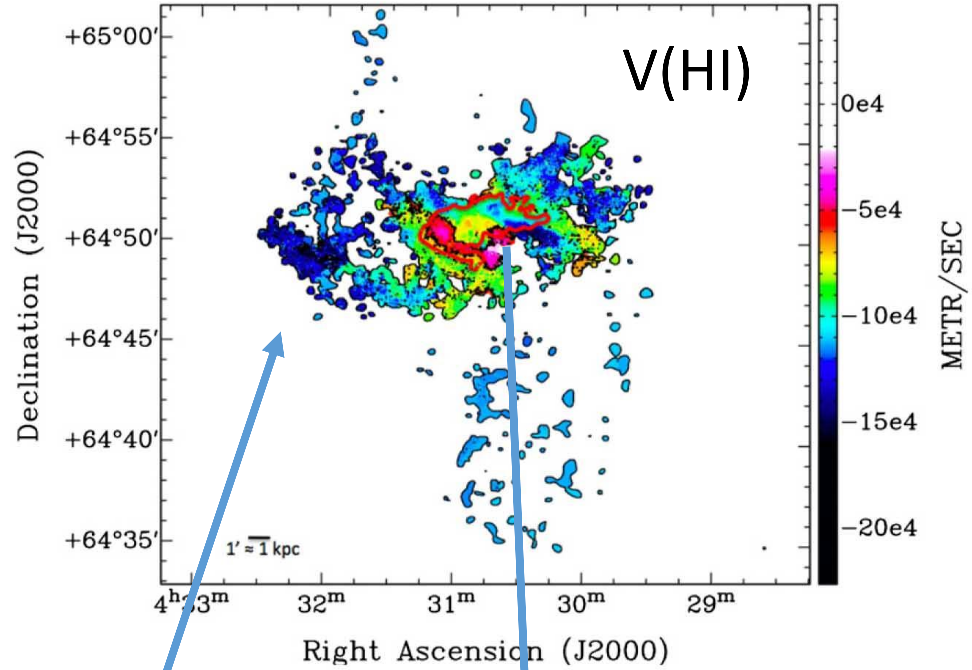
Whereas SFR = 0.08 M_O/yr

→ <u>accretion-fed star formation with local turbulent enhancement, lasting for the next 1/2 Gyr</u>



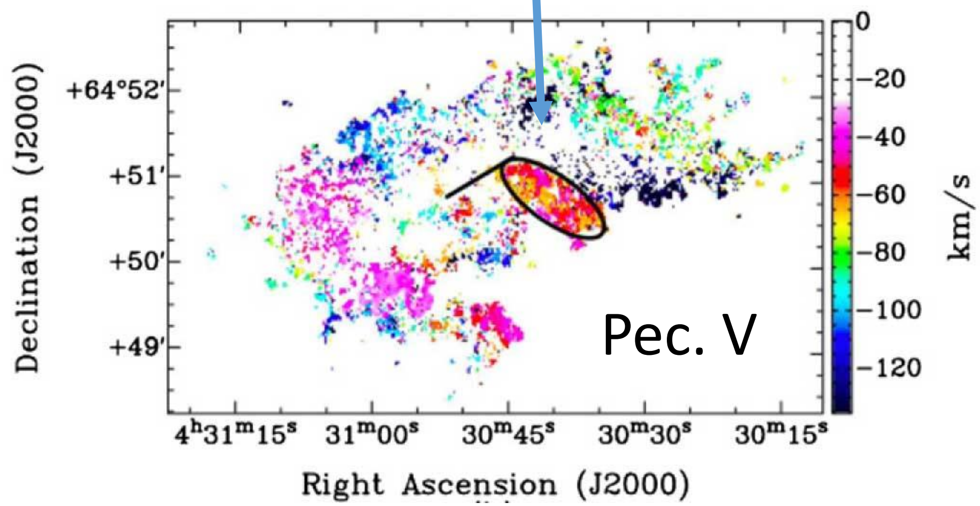
NGC 1569, HST





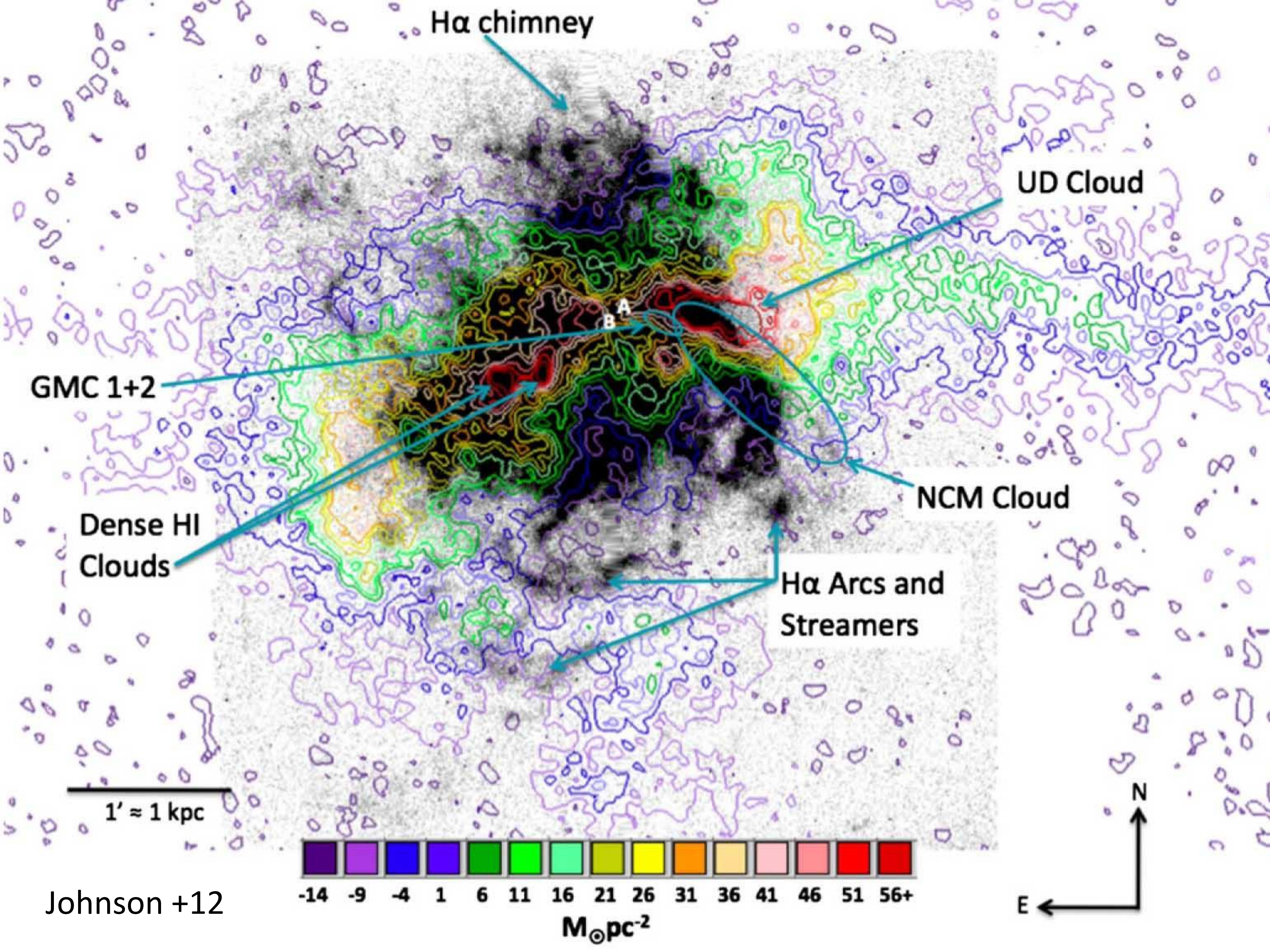
Streamer likely on the backside and approaching

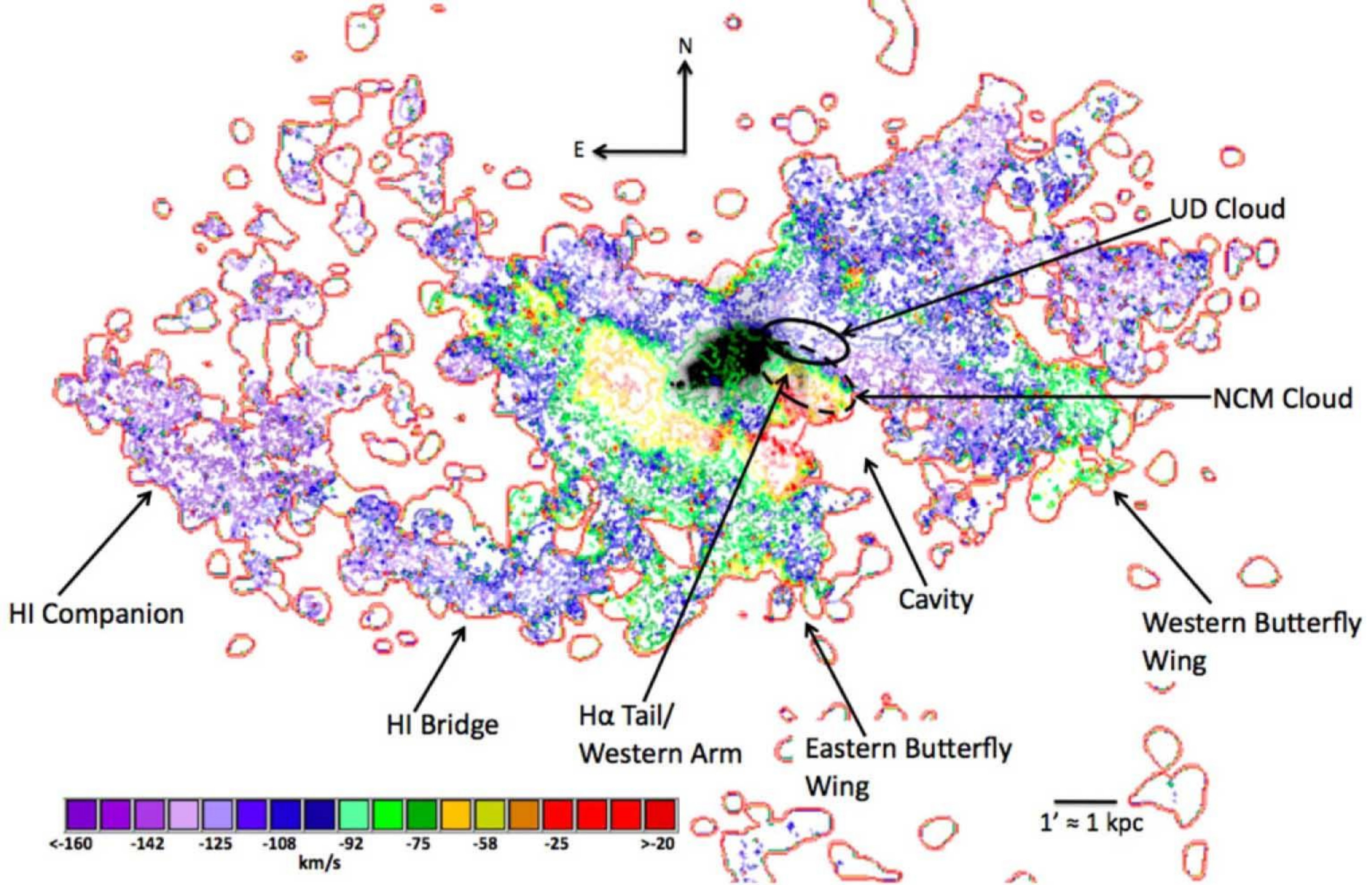
Stil & Israel '98 streamers



NGC 1569, VLA

Johnson, Hunter, Brinks, BGE, et al. '12


Hα chimney
UD Cloud
GMC 1+2
A
B
NCM Cloud
Dense HI
Clouds
Hα Arcs and
Streamers
1′ ≈ 1 kpc
-14 -9 -4 1 6 11 16 21 26 31 36 41 46 51 56+
M⊙pc⁻²
N
E
Johnson +12


N
E
UD Cloud
NCM Cloud
HI Companion
HI Bridge
Hα Tail/
Western Arm
Eastern Butterfly
Wing
Cavity
Western Butterfly
Wing
1′ ≈ 1 kpc
<-160
-142
-125
-108
-92
-75
-58
-25
>-20
km/s

Johnson +12

Summary:

In local dIrrs, Q is not important for SF, even though SF is still a gravitational process, operating as $\varepsilon(R)\Sigma_{gas}(R)/\tau_{ff}(R)$ in three dimensions

- Q is for thin disks and relevant to spirals

All quantities, ε, Σ_{gas}, τ_{ff}, and Σ_{SFR}, in dIrr vary smoothly with R

- no sharp threshold where the ISM converts from H_2 to HI
- gas dominates stars, and the disk flares continuously

The outer regions of dIrrs do not need accretion to feed SF ($\tau_{dep} = \tau_{ff}/\varepsilon$ ~100 Gyr) and there is no evidence for accretion as excess gas above the exponential

WLM : TBD

Accretion in IC10 feeds the starburst; in NGC 1569 it triggered two SSCs

- young metal-poor dwarfs may have formed metal-poor GCs by accretion-induced SF