HI and Star Formation in Dwarf Irregular Galaxies

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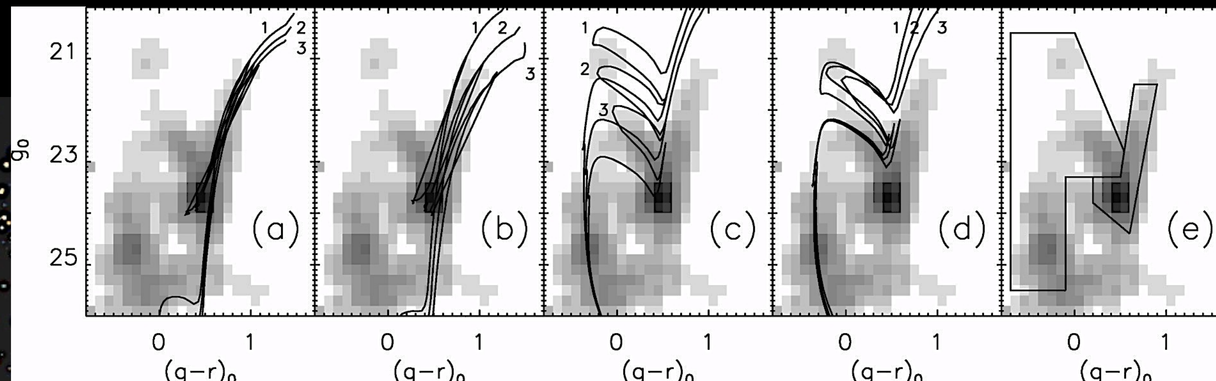
ASTRON, September 2015

Star formation at the extremes

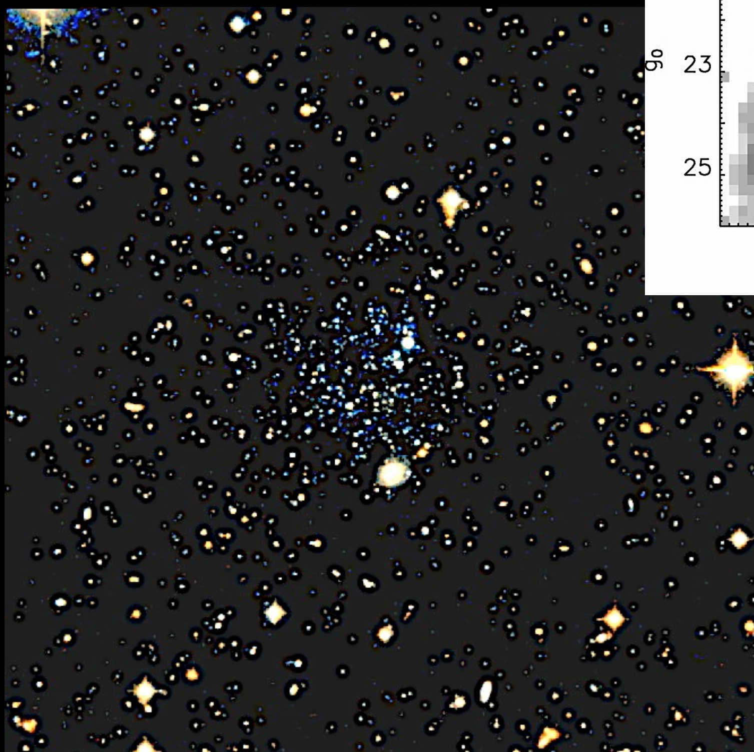
Leo T

de Jong et al. 2008



8 Gyr
3 metallicities

400 Myr
3 metallicities



Irwin et al. 2007

- M_V=-8
- M_*=10^5 M_o, M_{HI}=3xM_*

(Ryan-Weber et al. 2008)

- Σ_{HI}(max)=7×10^{20} cm^{-2}
- Old stars + young (200 Myr-1 Gyr) stars

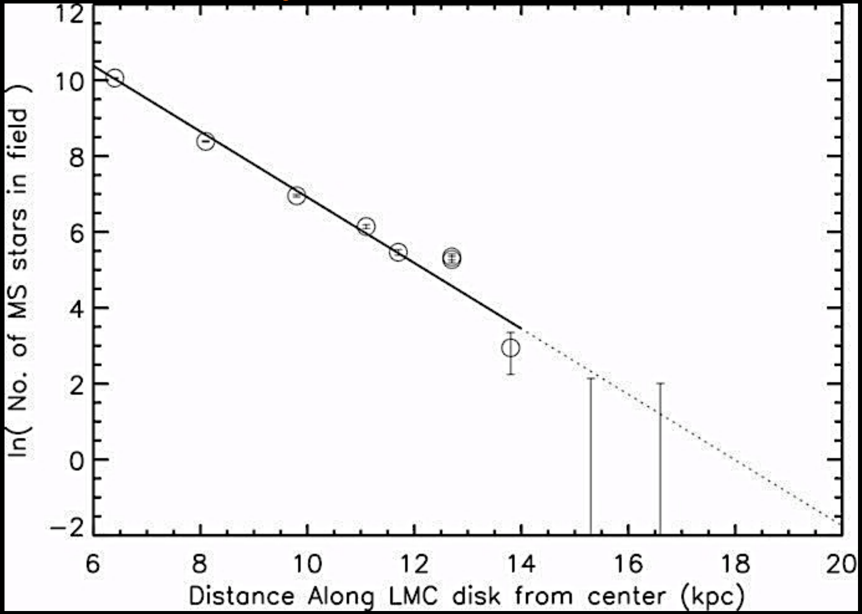
Stellar disks can be very extended and well-behaved exponentials

- LMC (Saha et al. 2010)
  To 12 disk scale lengths;
  μ_I ~ 34 mag arcsec^{-2}

Bellazzini et al. 2014

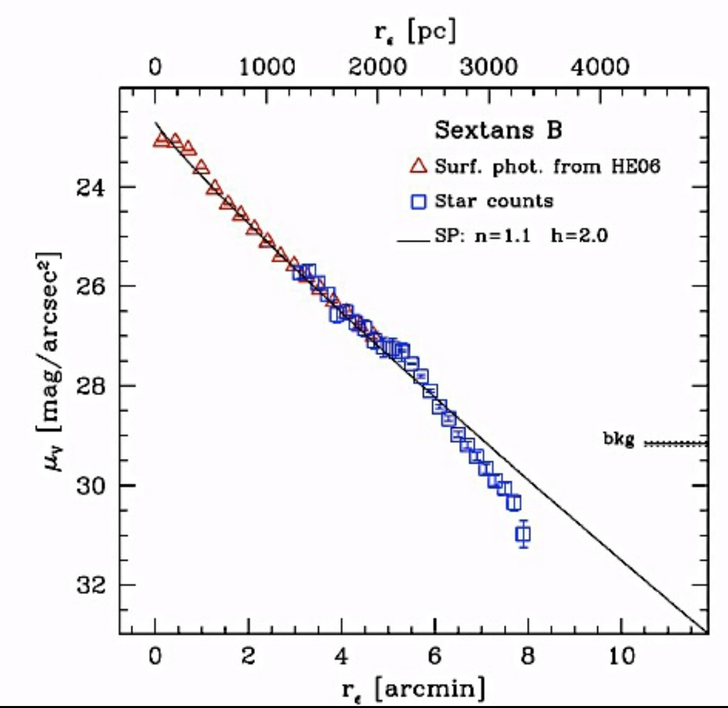
To μ_V ~ 31 mag arcsec^{-2} ~ 6 disk scale lengths

Surface density of MS stars



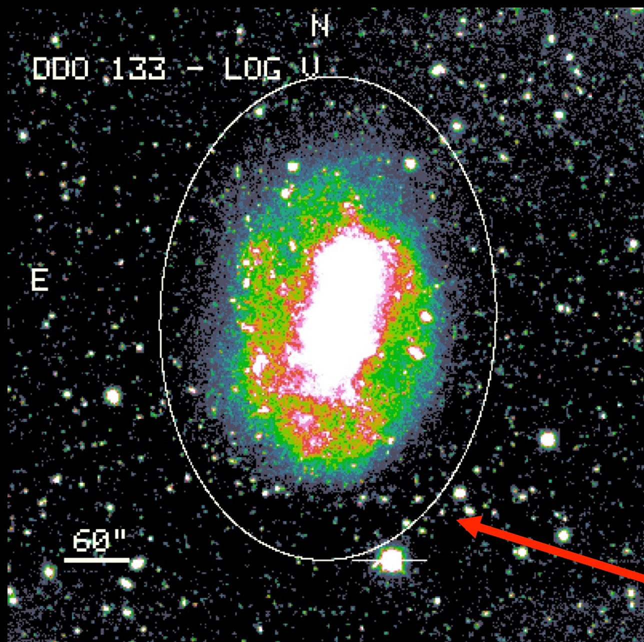
5.2 8.7 12.2 15.7 disk scale lengths

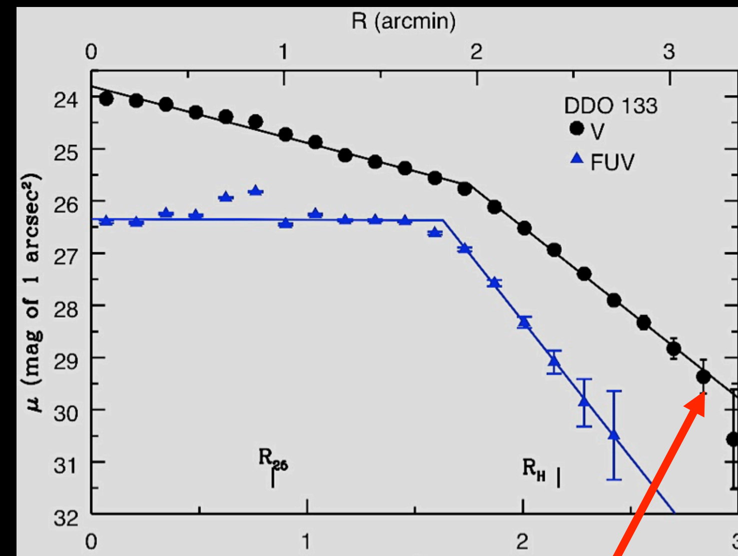
μ_V



R (arcmin)

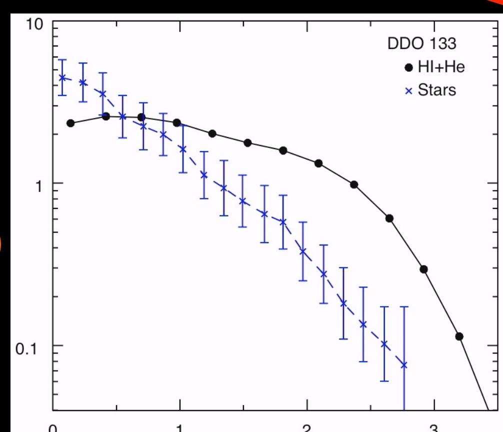
Stars have formed at extremely low average gas densities.





μ_V

R/disk scale length



Σ (M_o/pc^2)

R/disk scale length

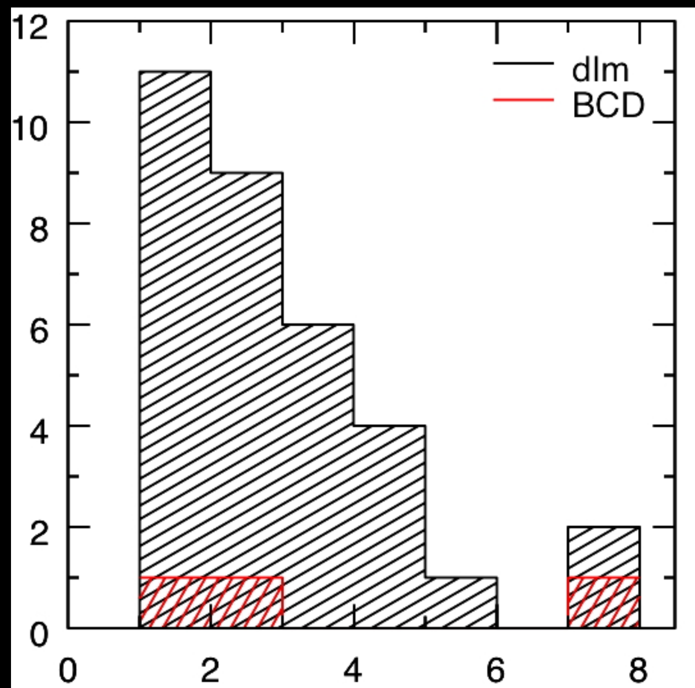
μ_V ~ 30 mag/arcsec^2

UV extends into the outer disk too implying star formation out there. But Σ_{HI} ~1/20 Toomre Σ_{crit}

Hunter et al. 2011

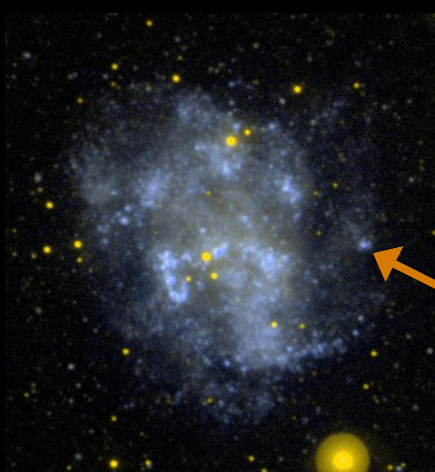
FUV knots extend into far outer disks

Number of LITTLE THINGS galaxies



Radius of furthest FUV knot /disk scale length

DDO 50



3.3 disk scale lengths

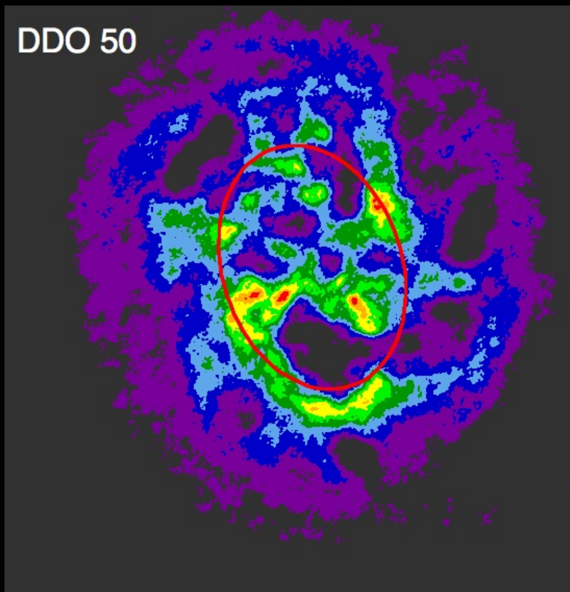
DDO 63

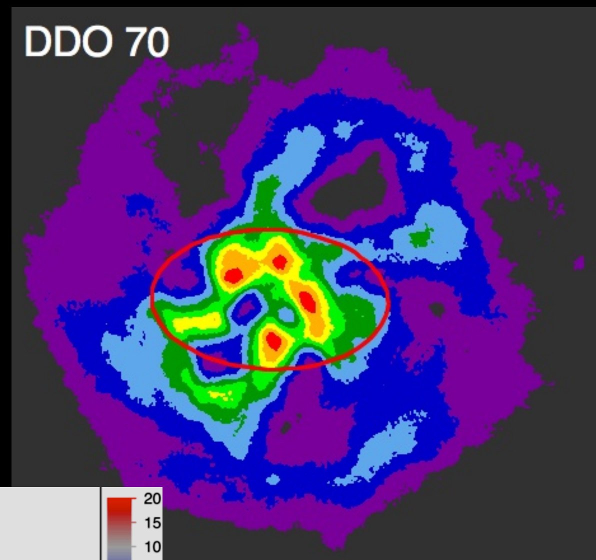
4.2 disk scale lengths

Hunter & Gehret, 2015

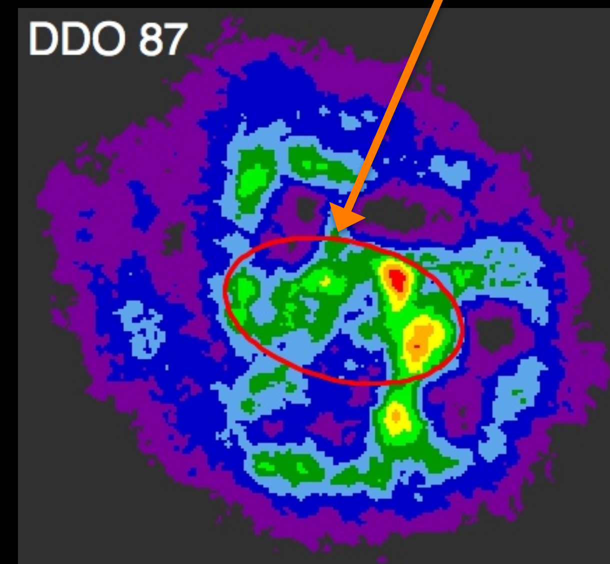
Large HI holes are sometimes found in outer disks

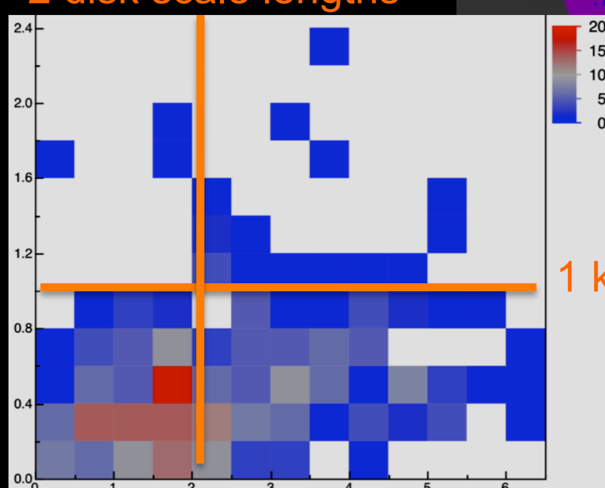
Integrated HI maps





2 optical disk scale lengths in V-band image

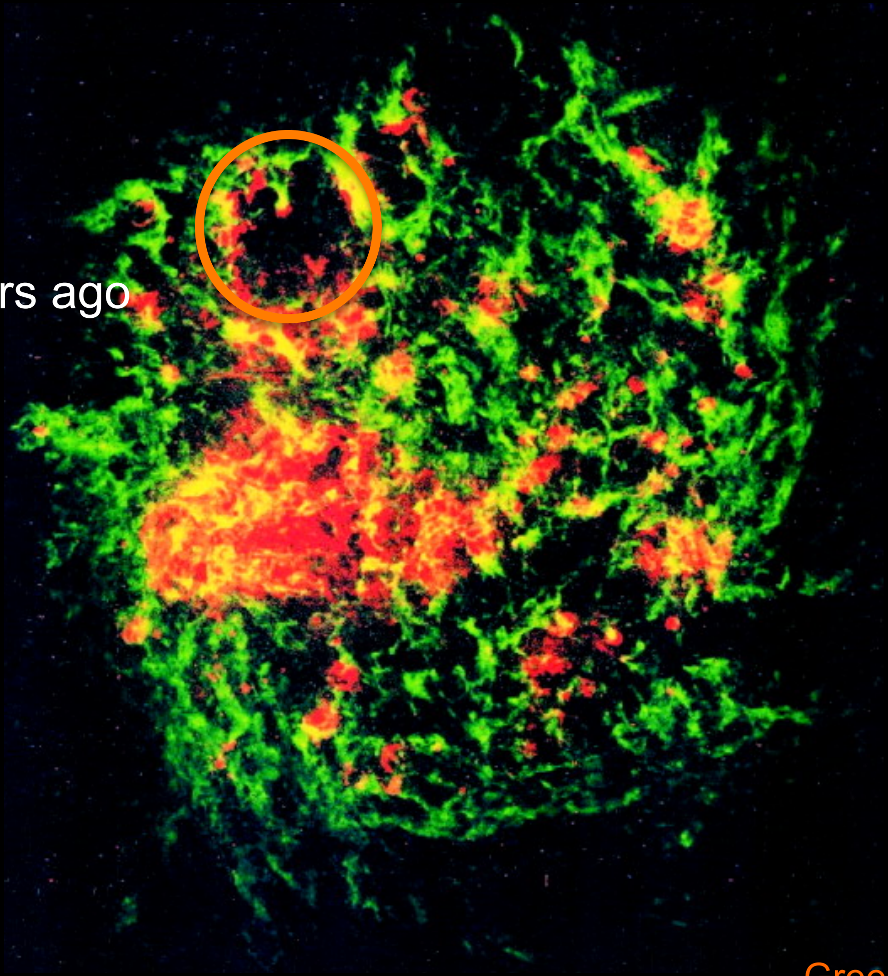




Pokhrel, PhD in prep

Constellation III in the LMC

- HI hole diameter ~ 1.8 kpc
- Large star-forming event(s) 15-30 Myrs ago
- At roughly 2.7 disk scale lengths



Dopita et al. 1985;
Efremov & Elmegreen 1998;
Dolphin & Hunter 1998

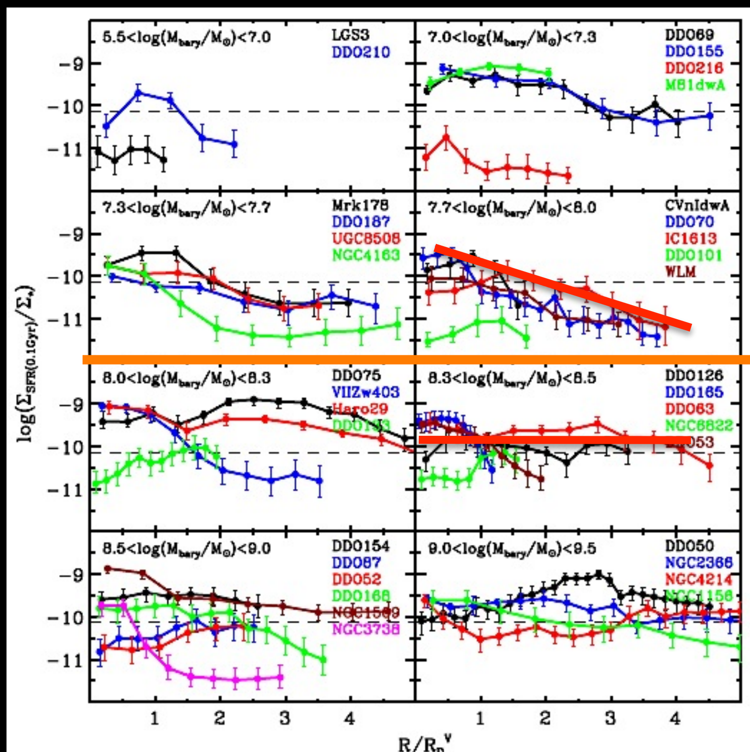
Kim et al. 1999

Green = HI

Red = HII

Stellar disks change with time: *outside-in*

$SFR_{0.1Gyr}$/Stellar mass



Radius in units of disk scale length →

Similar for SFR_{1Gyr}/Stellar mass

log M_{bary} < 8.0

log M_{bary} > 8.0

Also seen in the LMC (Meschin et al. 2013) and other dwarfs (Pan et al. 2015)

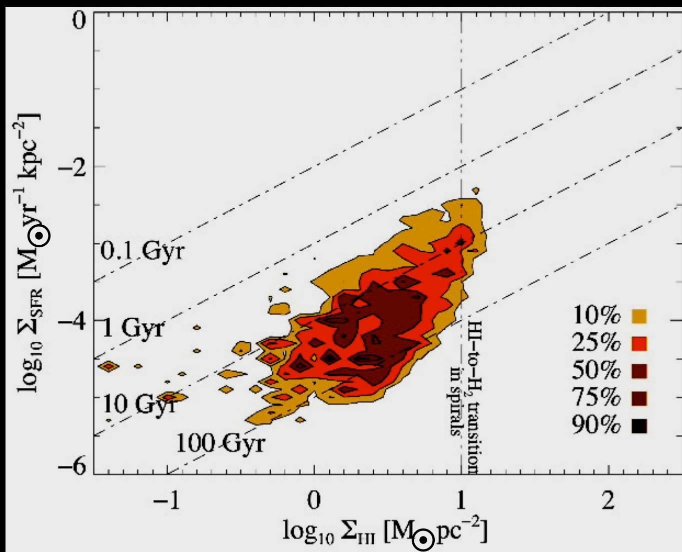
Zhang et al. 2012

➔ Star formation is shrinking with time in dwarfs.
But *inside-out* in spiral disks.

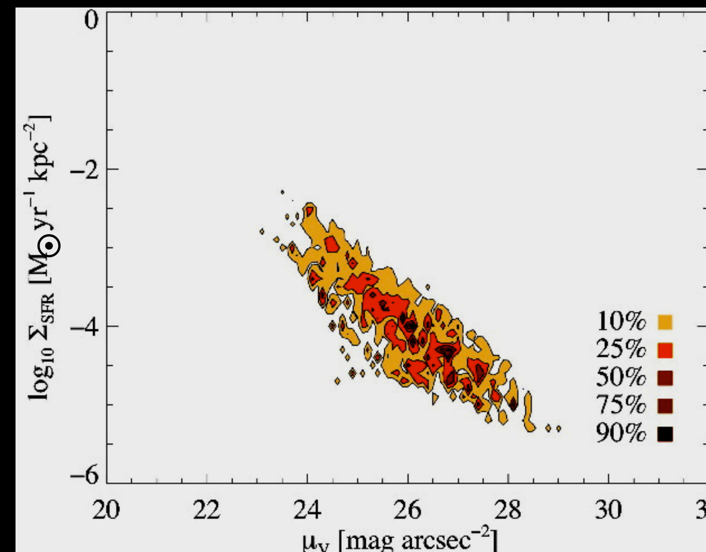
Turning HI into star-forming clouds

Gas density is not a good predictor of star formation, but older stars are.

20 LITTLE THINGS galaxies combined

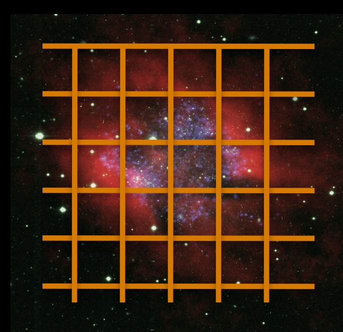


Log Σ_{SFR}

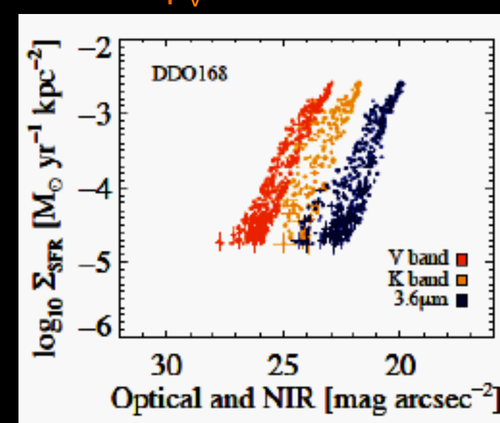


Log Σ_{HI}

μ_V



One galaxy; multiple passbands

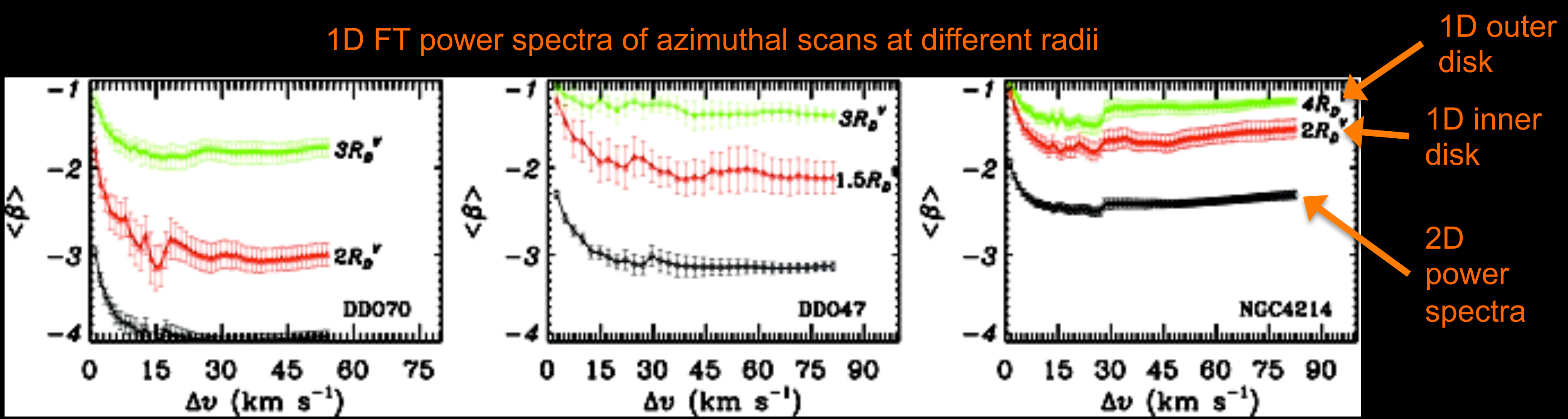


Ficut-Vicas, 2015 PhD thesis; see also Bigiel et al. 2008, Roychowdhury et al. 2015

Inner disks have proportionally more cooler HI than outer disks

Radial variations of the β–Δv relation reflects the relative spatial distributions of HI gas with different temperatures

1D FT power spectra of azimuthal scans at different radii



Zhang et al. 2012b

Nearby dwarfs: No correlation of cool phase with SF. Young & Lo 1997, Young et al. 2003

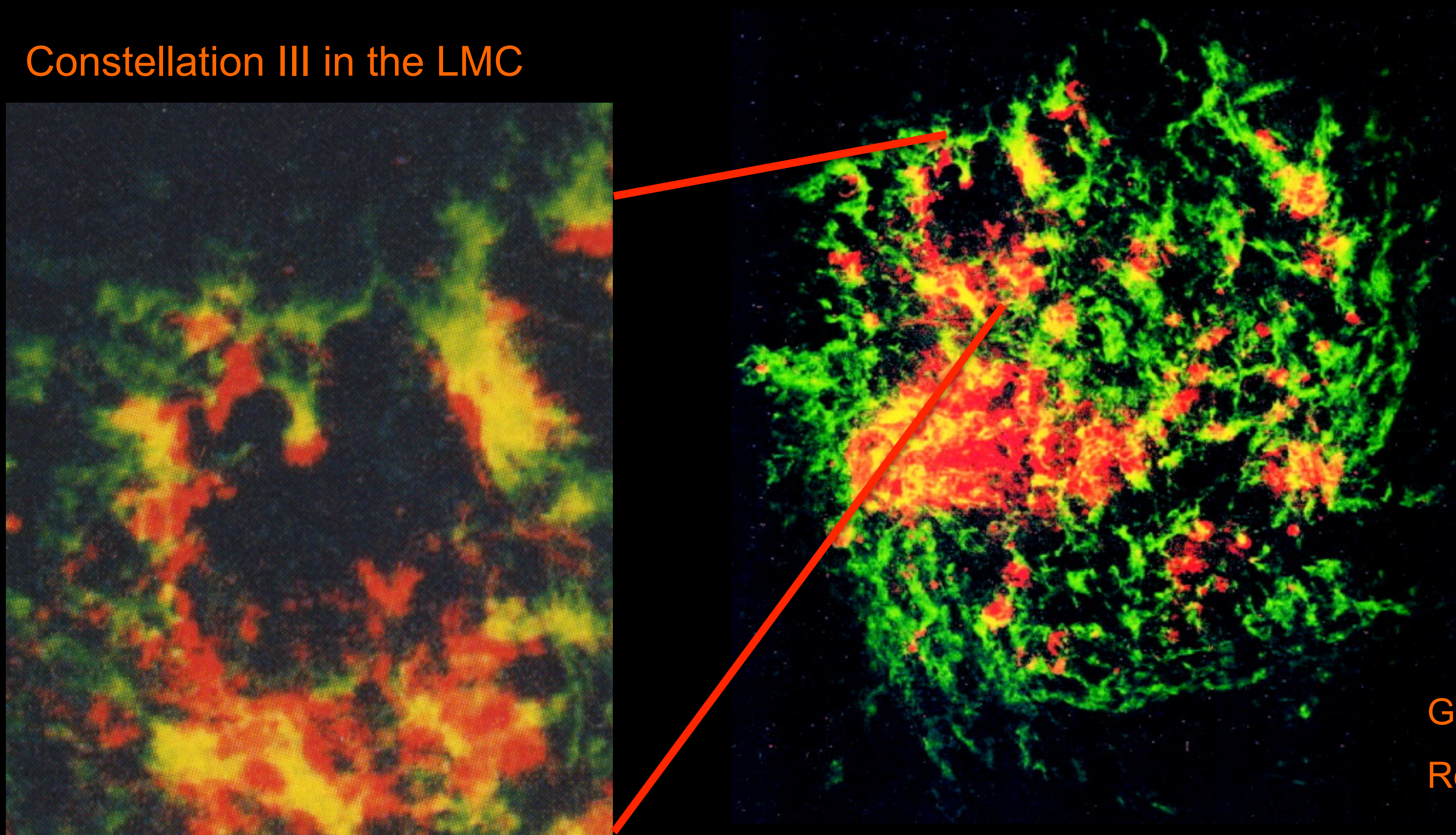
NGC 6822: SF driven by cool phase? de Blok & Walter 2006

LMC: Cool HI decreases away from 30 Doradus. Dickey et al. 1994

SMC: Cool HI is only 15% of total. Dickey et al. 2000

What drives cloud formation? - Stellar feedback

Constellation III in the LMC



Green = HI

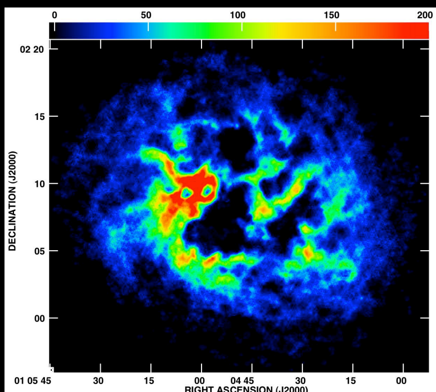
Red = HII

Kim et al. 1999

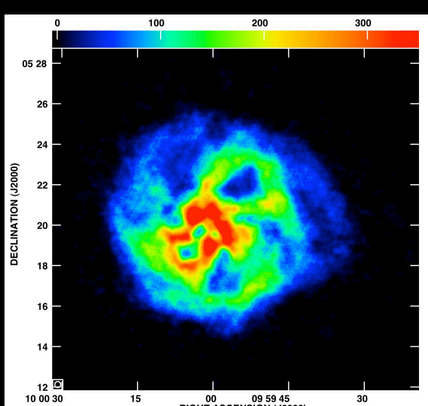
What percentage of star formation is due to stellar feedback?
What is the effect of porosity (the filling factor of the holes) on star formation?

Pohkrel, PhD thesis, in progress

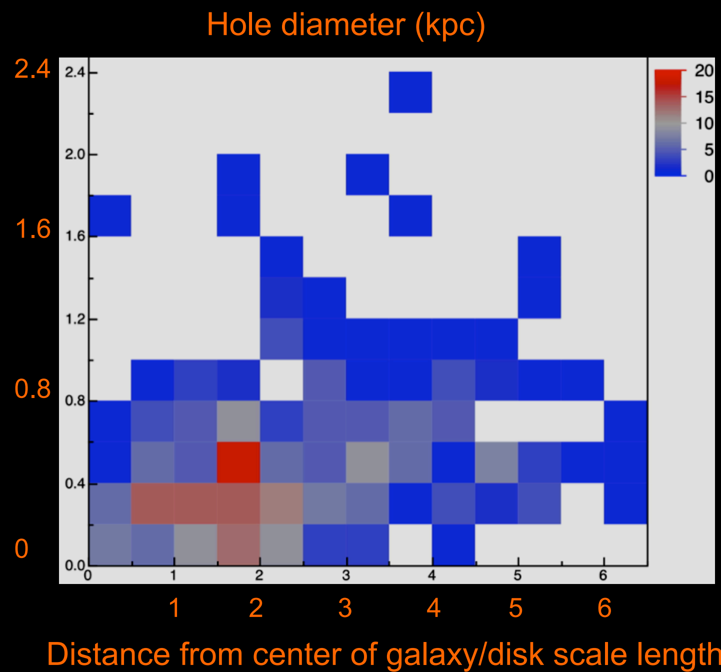
LITTLE THINGS integrated HI maps

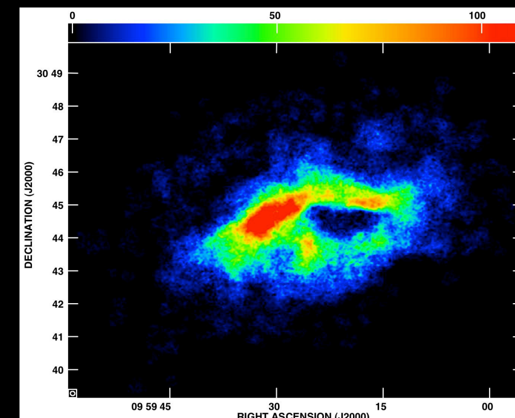


IC 1613

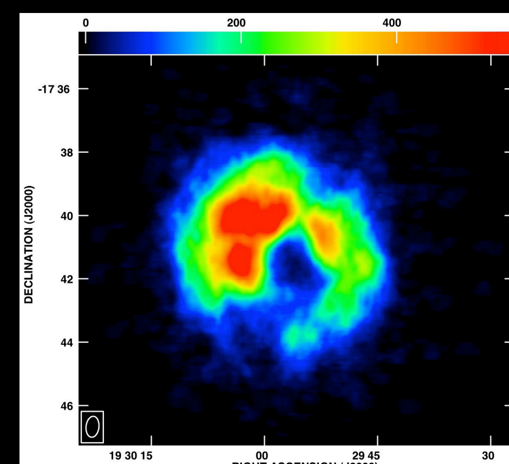


DDO 70





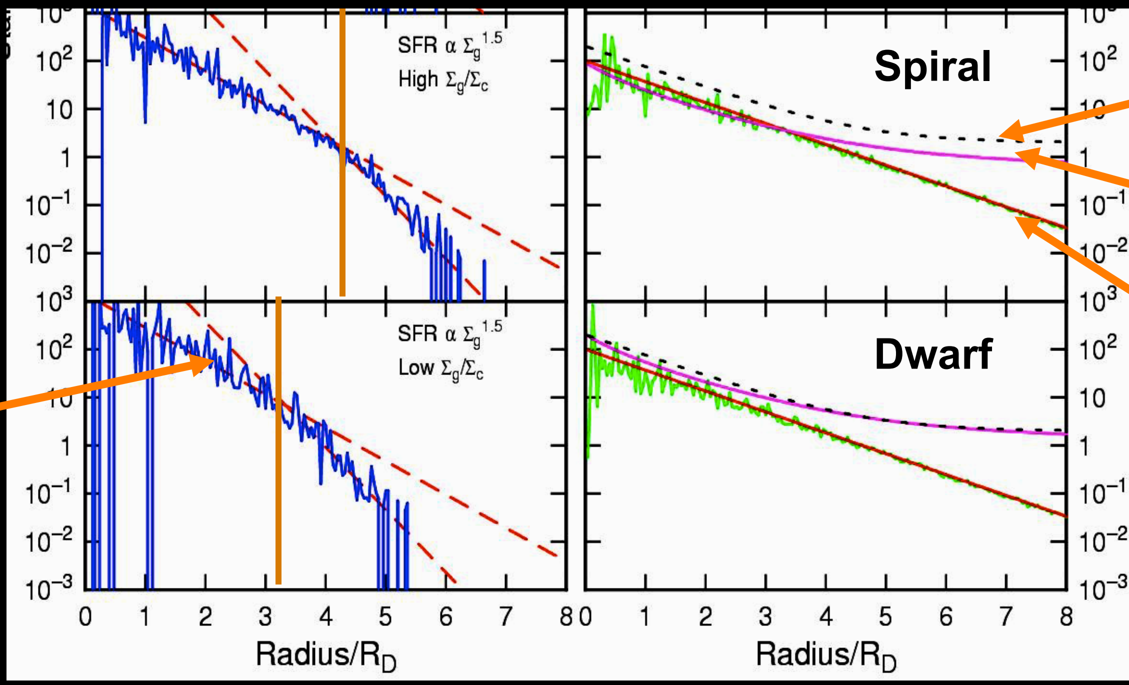
DDO 69

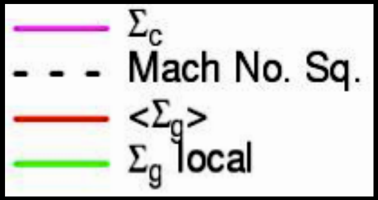


SagDIG

- LMC supershells: ≥4-11% (Dawson et al. 2013)
- DDO 50 and IC 2574: “most” (Stewart et al. 2000, Stewart & Walter 2000)

What drives cloud formation? – Turbulence



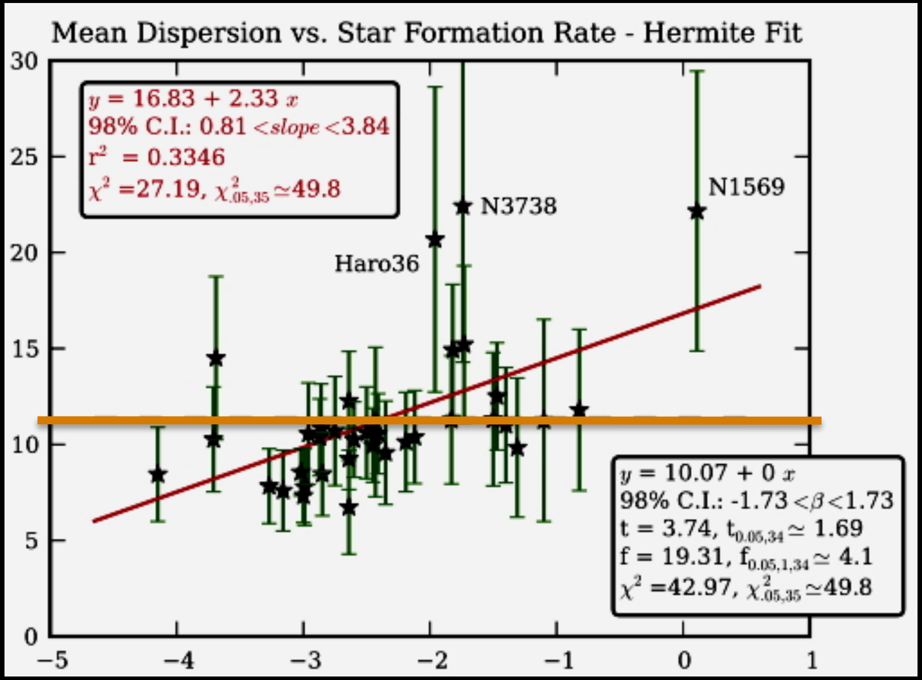


Elmegreen & Hunter 2006

The role of turbulence is complicated: no correlation with global star formation rates

LITTLE THINGS dwarfs

Galaxy-wide average velocity dispersion of HI; error bars: range of σ_{HI}

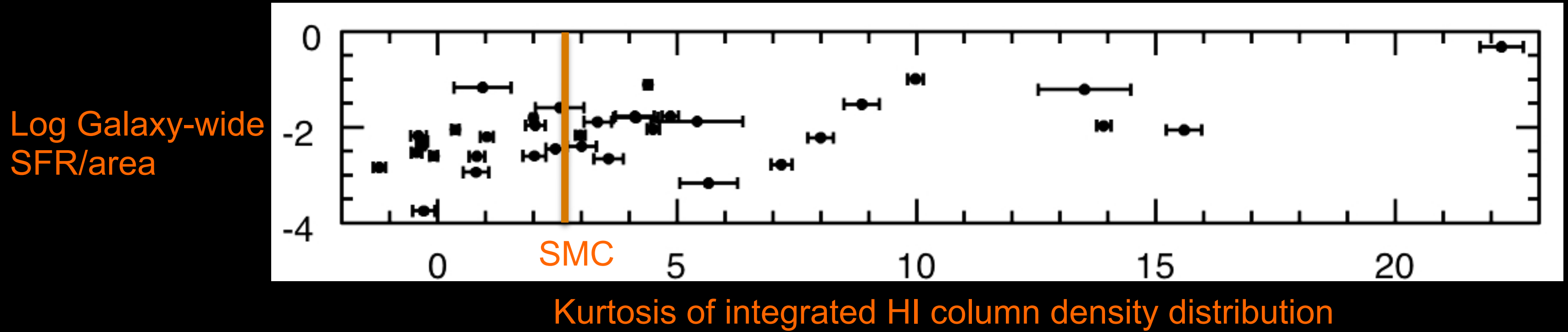


Log Galaxy-wide SFR/area

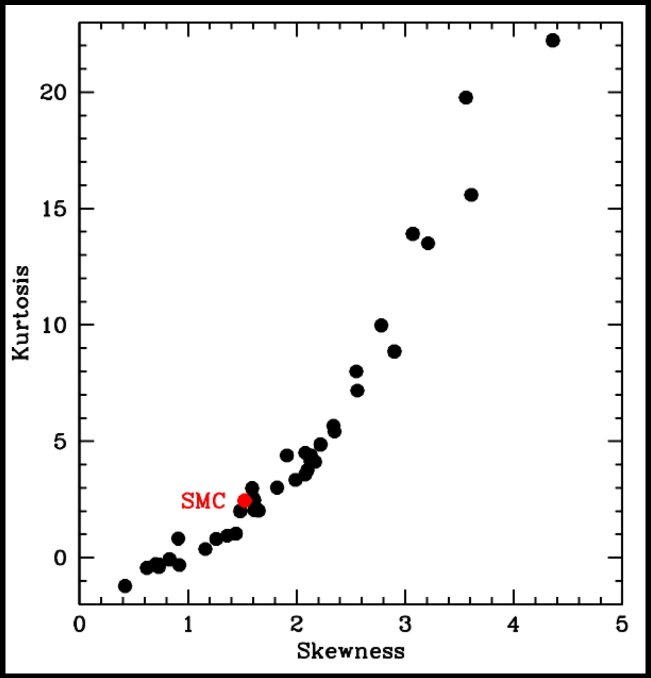
Cigan, 2012

The role of turbulence is complicated: most dwarfs have turbulence like that in the SMC

Hollyday, 2014

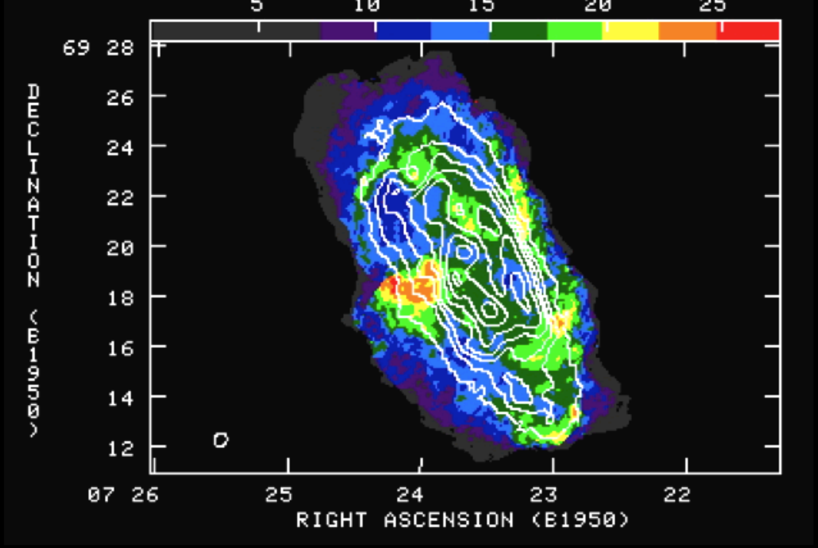


SMC: Burkhart et al. 2010
- Mach number ~ 0-2 implying subsonic or transonic turbulence
- Most turbulent regions not associated with star formation



The role of turbulence is complicated: anti-correlates with Σ_{HI}

NGC 2366

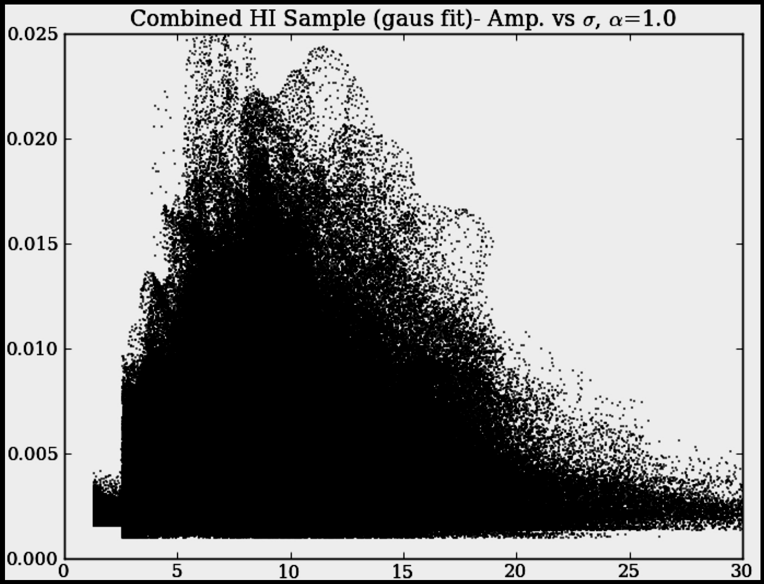


Color image: HI velocity dispersion
Contours: integrated HI

Hunter et al. 2001, 2011

LITTLE THINGS dwarfs:
fit Gaussians to Amp vs velocity profiles

Amplitude (Jy/beam)



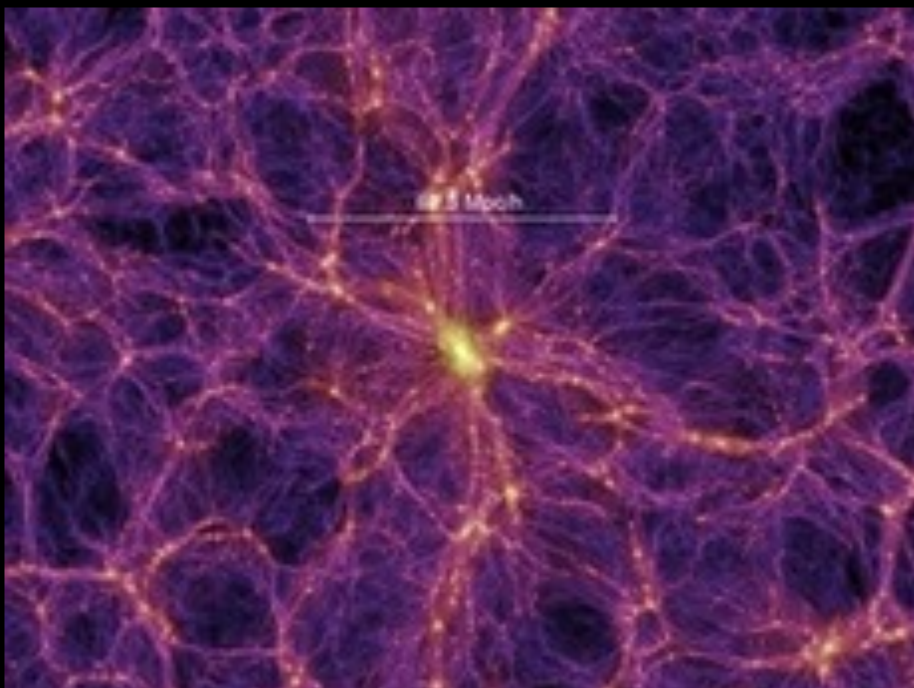
σ_{HI} (km/s)

Cigan, 2012

Consistent with MRI? (see also THINGS, Tamburro et al. 2009)
But… ANGST: σ_{HI} correlates with Σ_{HI}, turbulence gravitational?
Stilp et al. 2013

What drives cloud formation? - Cosmic accretion

The Cosmic Web



The Millennium Simulation

Gas raining down on a galaxy

Artist's impression: ESO/L. Calçada

But dwarfs have plenty of gas; the problem is how to turn what they have into clouds.

Dwarf irregular galaxies

- Dwarfs are forming stars and producing exponential disks under extreme conditions.
- What process turns HI into star-forming clouds isn't clear.
- Dwarfs present us with many challenges and, better yet, opportunities.