Observational Evidence for the Evolution of Dwarf Irregular Galaxy Disks

Deidre Hunter
Lowell Observatory

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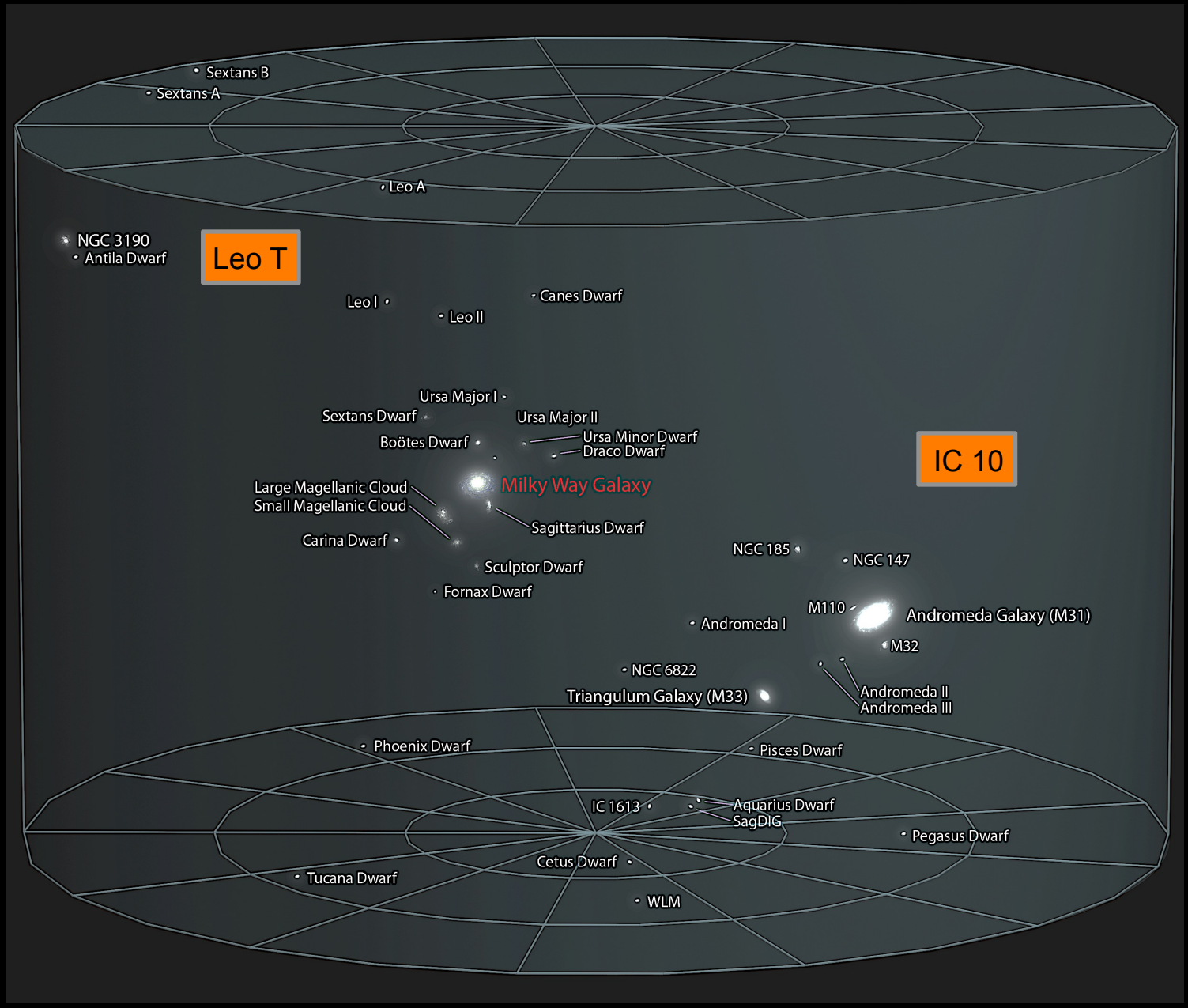
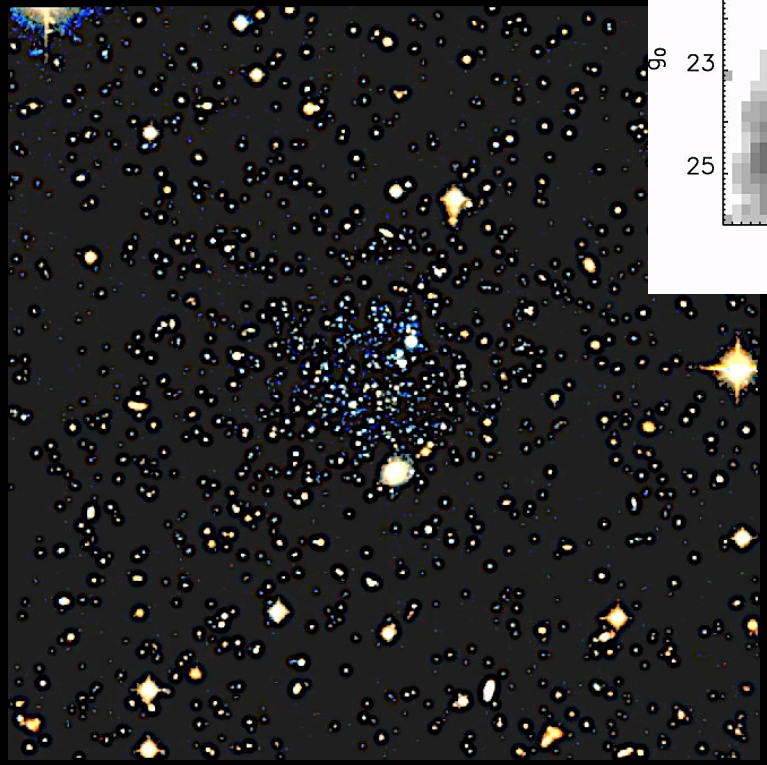
Dwarf Irregulars: Lumpy little galaxies with gas

Hunter, CTIO 0.9 m;
color rendition H. Bond,
STScI


Sextans B
Sextans A
Leo A
NGC 3190
Antila Dwarf
Leo T
Leo I
Canes Dwarf
Leo II
Ursa Major I
Sextans Dwarf
Ursa Major II
Boötes Dwarf
Ursa Minor Dwarf
Draco Dwarf
IC 10
Large Magellanic Cloud
Small Magellanic Cloud
Milky Way Galaxy
Sagittarius Dwarf
Carina Dwarf
NGC 185
NGC 147
Sculptor Dwarf
Fornax Dwarf
M110
Andromeda Galaxy (M31)
Andromeda I
M32
NGC 6822
Triangulum Galaxy (M33)
Andromeda II
Andromeda III
Phoenix Dwarf
Pisces Dwarf
IC 1613
Aquarius Dwarf
SagDIG
Pegasus Dwarf
Cetus Dwarf
Tucana Dwarf
WLM

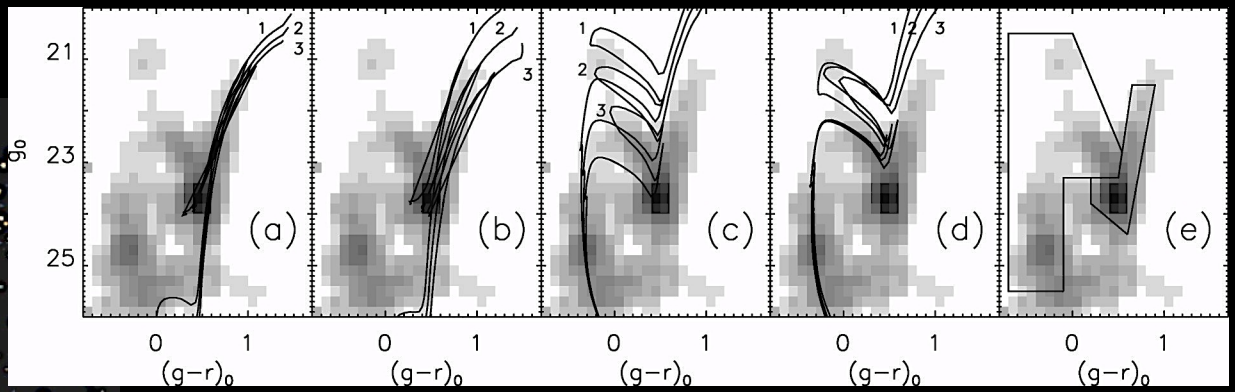
A. Colvin

Leo T



Irwin et al. 2007

de Jong et al. 2008



8 Gyr
3 metallicities

400 Myr
3 metallicities

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

(Ryan-Weber et al. 2008)

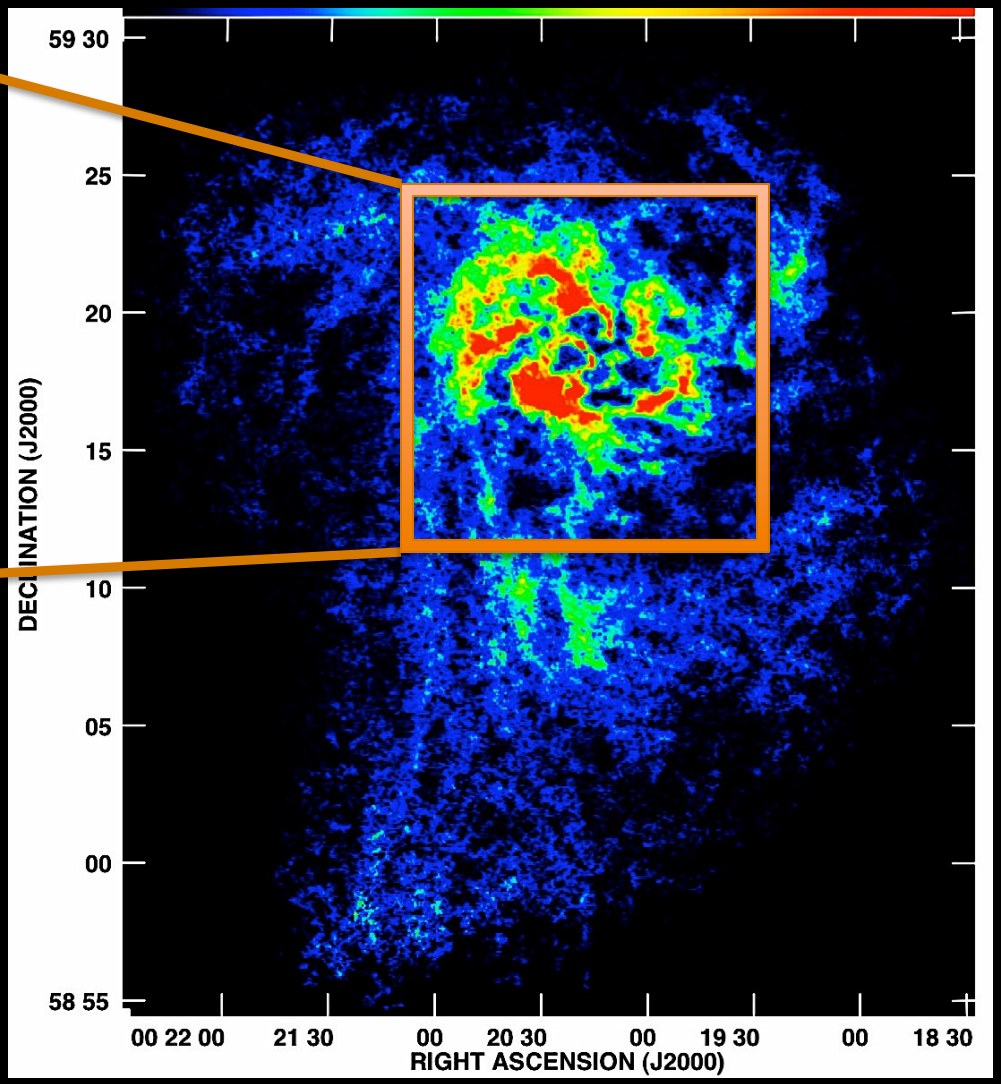
- $\Sigma_{HI}(max)=7\times10^{20}\ cm^{-2}$
- Old stars + young (200 Myr-1 Gyr) stars

IC 10

Optical

Survey of the Resolved Stellar Content of Nearby Galaxies Currently Forming Stars, Massey et al. 2007

HI



Hunter et al. 2012

- M_V~-16, $M_{HI}=3\times10^7\ M_o$, $\Sigma_{HI}(max)=10^{22}\ cm^{-2}$
- Extraordinary number of WR stars/area (Massey & Holmes 2002)
- Merger or interaction (Nidever et al. 2013)

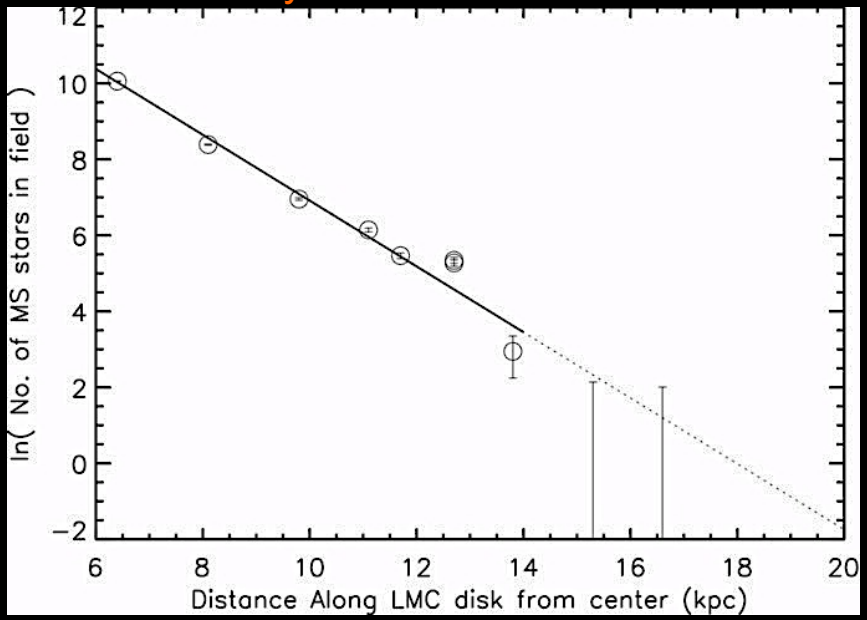
Surprises about dwarf *irregular* galaxy stellar disks …

Stellar disks can extend a very long ways in tiny galaxies.

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

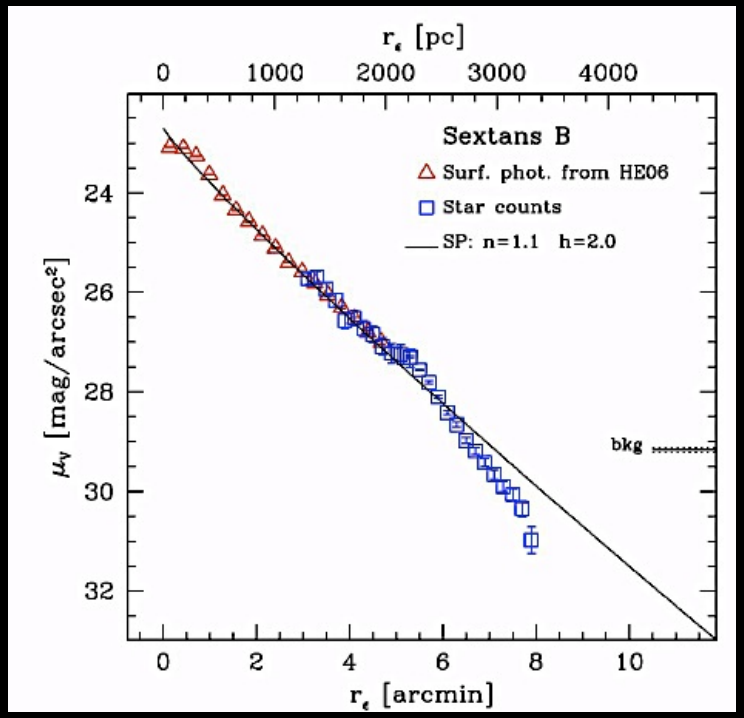
- **Sextans B** Bellazzini et al. 2014
  To 6 disk scale lengths;
  μ_V ~ 31 mag arcsec^{-2}

Surface density of MS stars



5.2 8.7 12.2 15.7 disk scale lengths

μ_V

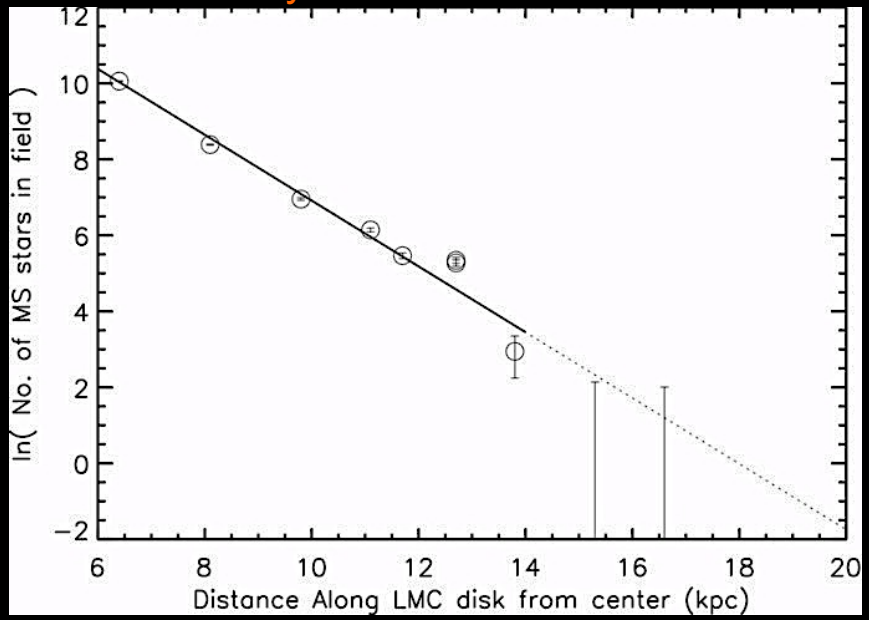


R (arcmin)

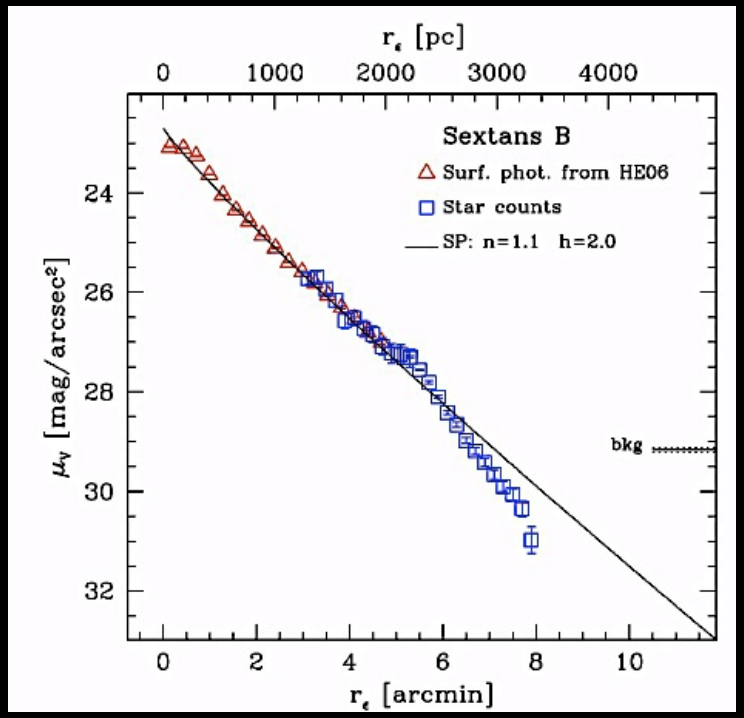
Extended disks are often well-behaved exponentials.

- LMC (Saha et al. 2010)
- Sextans B Bellazzini et al. 2014

Surface density of MS stars



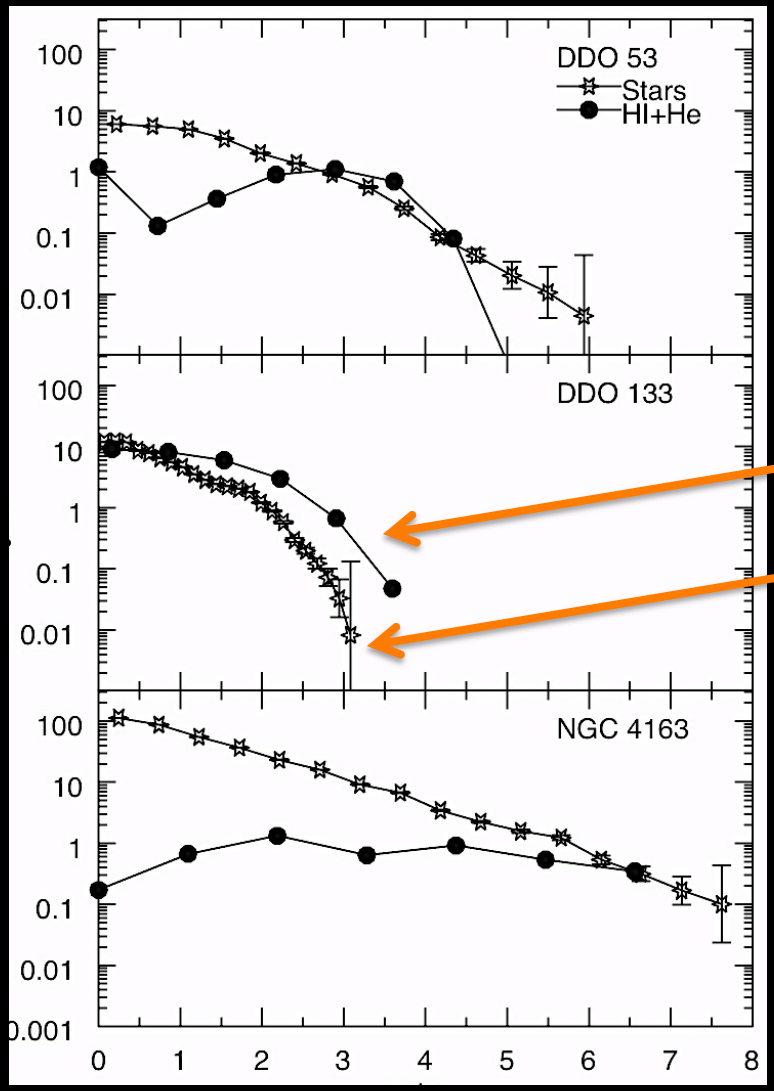
μ_V



R (arcmin)

5.2 8.7 12.2 15.7 disk scale lengths

Mass column densities from deep imaging



Σ (M_O/pc^2)

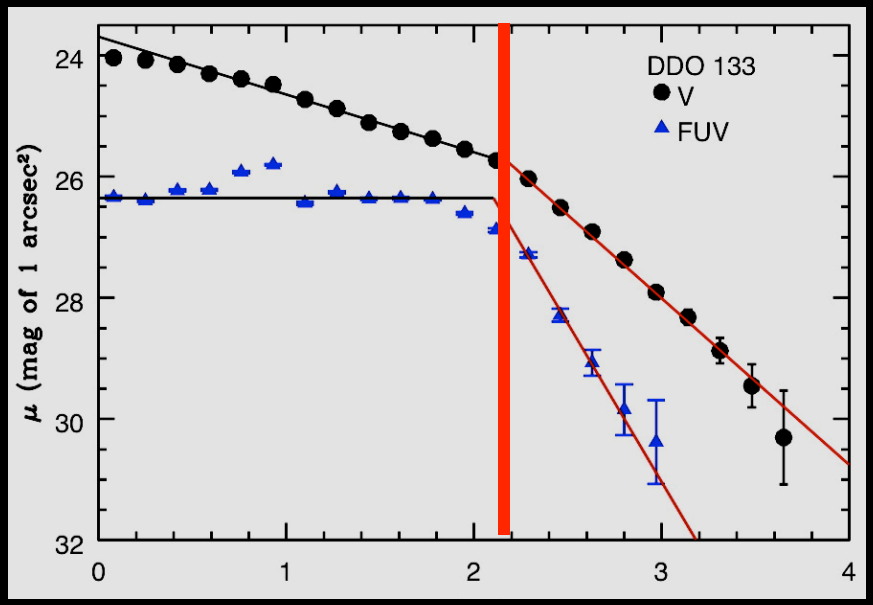
Gas

Stars

Radius in disk scale lengths

Hunter et al. 2011

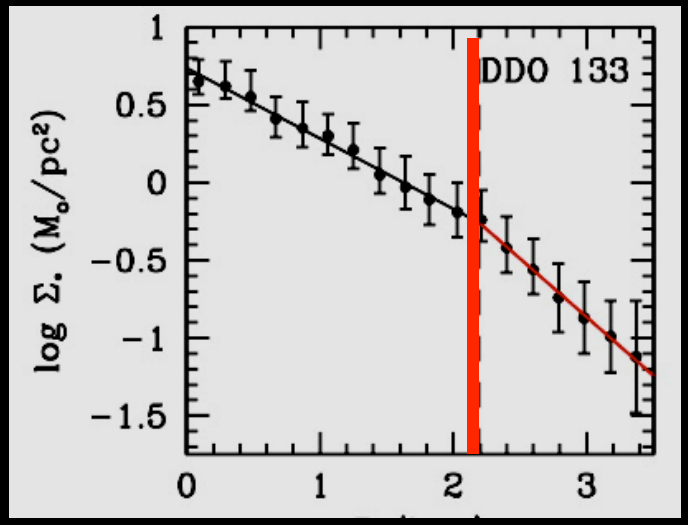
Outer disks: stellar surface brightness/mass profiles with breaks



Hunter et al. 2011

Early studies of spirals: van der Kruit and collaborators 1979, 1982, 1984, 1987, 2002, 2004, de Grijs et al. 2001

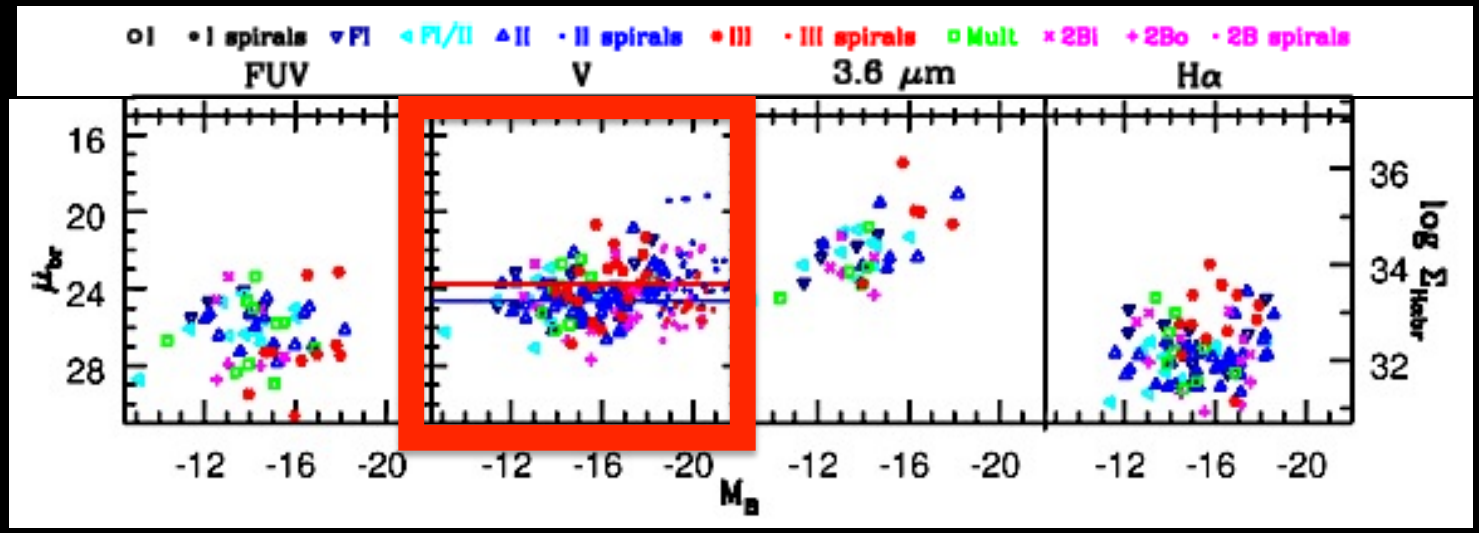
Σ_{stars} (M_O/pc^2)



Zhang et al. 2012;
Herrmann et al., in prep

Spiral and dwarf stellar light profiles break at ~same *V*-band surface brightness

Surface brightness at break



M_B

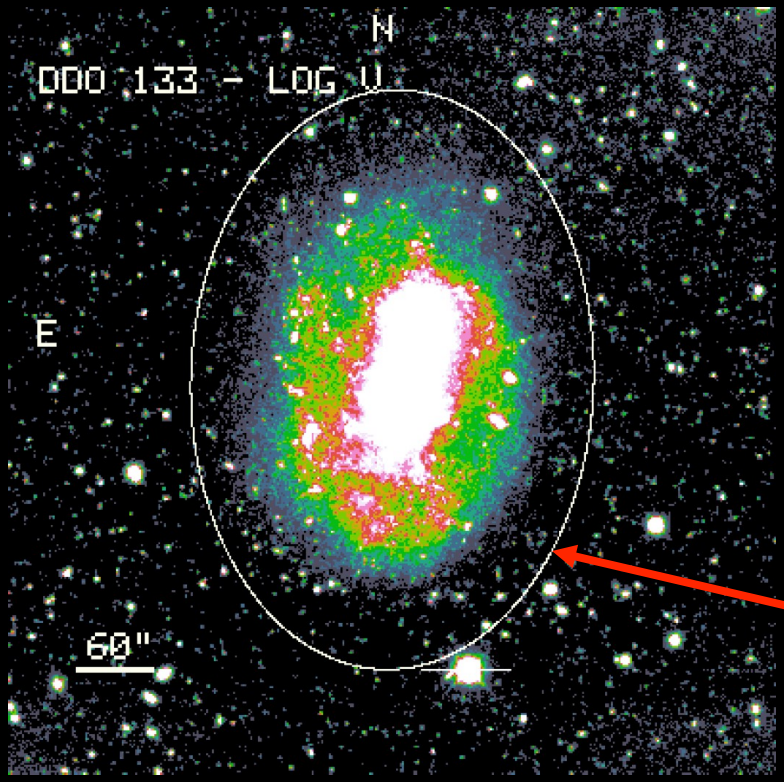
Herrmann et al 2013;
Spirals: Erwin et al. 2005, Pohlen & Trujillo 2006, Erwin et al. 2008, Gutiérrez et al. 2011

See poster by J. Herpich

➔ Something fundamental happens at the break in *both* spirals and dwarfs.

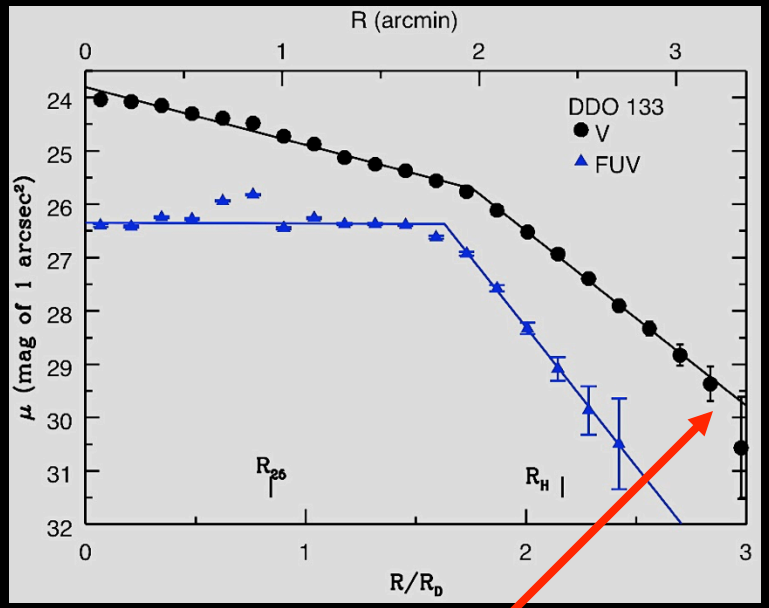
Star formation at the extremes

Stars have formed at extremely low average gas densities.



Hunter et al. 2011

μ_V

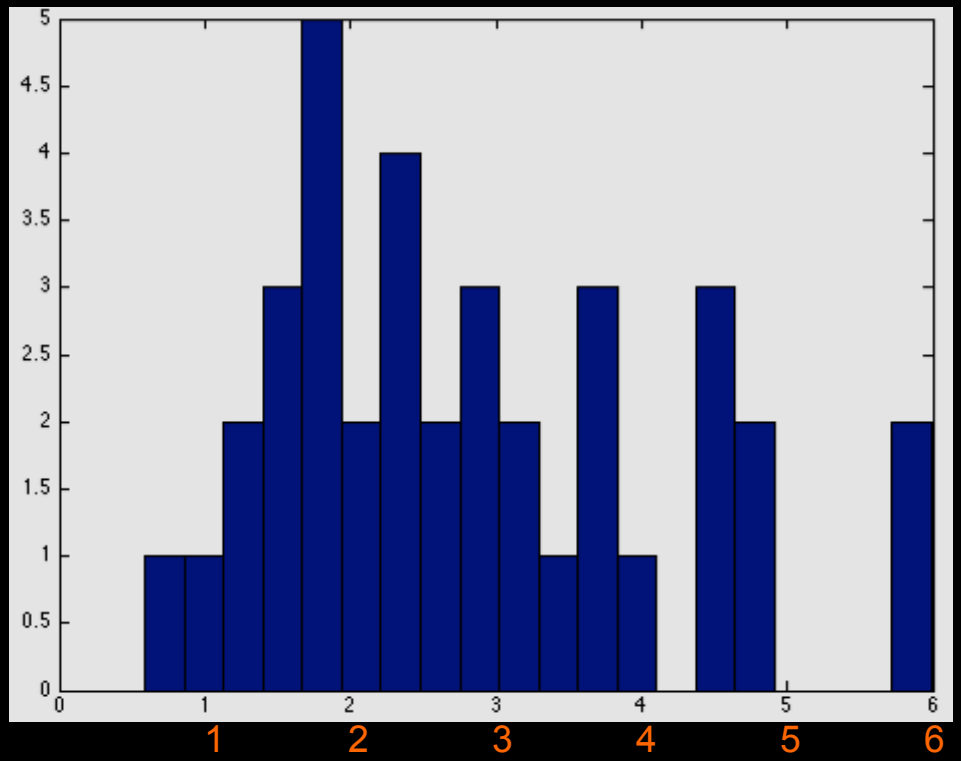


μ_V ~ 30 mag/arcsec^2

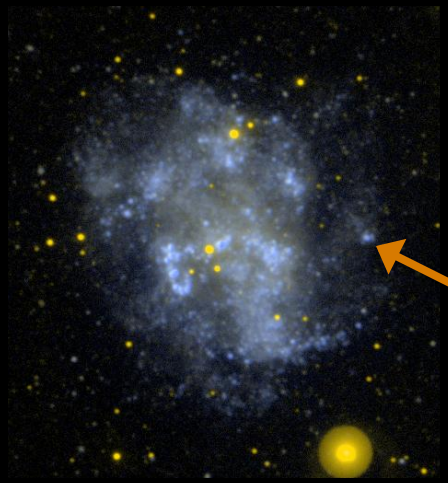
UV extends into the outer disk too implying star formation out there. But Σ_{HI} ~1/20 Toomre Σ_{crit}

FUV knots extend into far outer disks

Gehret, 2014

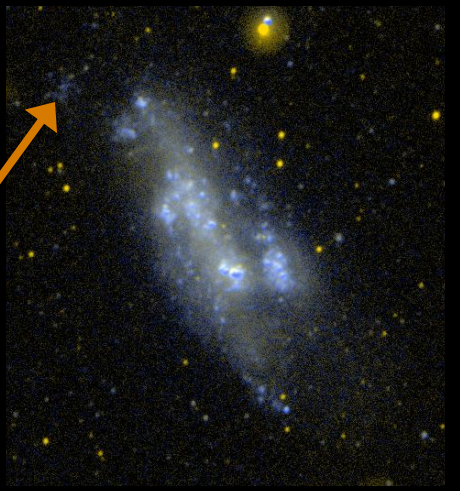


DDO 50



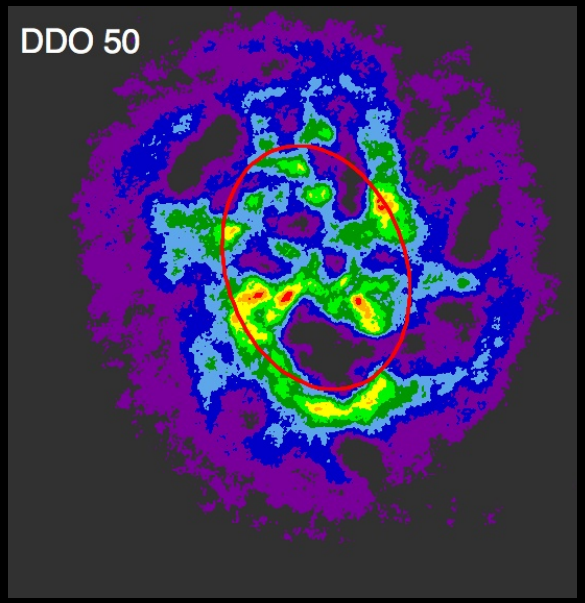
4.8 disk scale lengths

NGC 2366

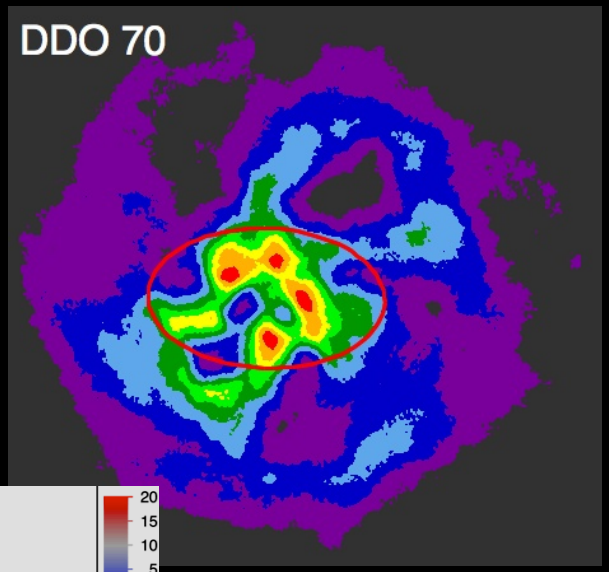


4.5 disk scale lengths

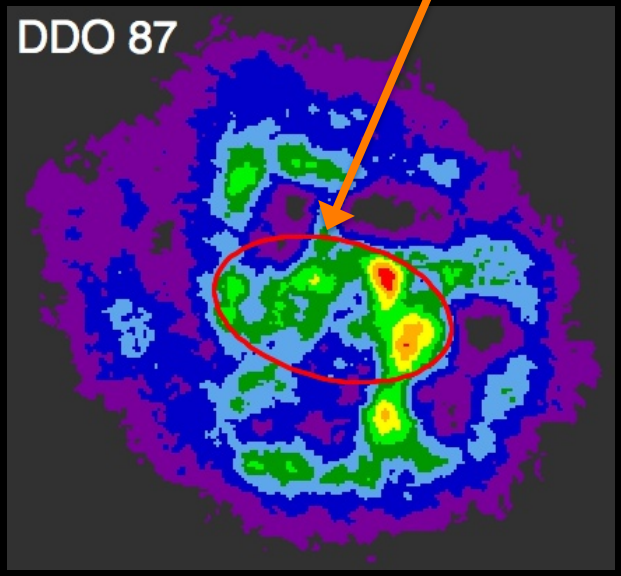
Large HI holes are sometimes found in outer disks



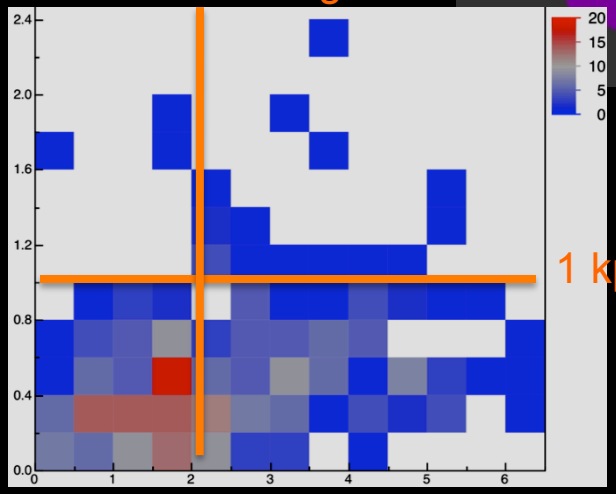
Integrated HI maps



2 optical disk scale lengths in V-band image



2 disk scale lengths



Hole diameter (kpc)

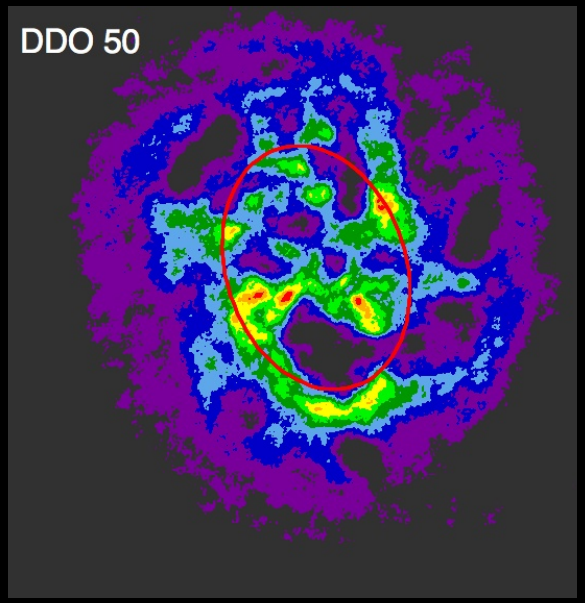
1 kpc diameter

Distance from center of galaxy/disk scale length

Catalogues of holes and analysis of relationship to stellar populations: Pokhrel, PhD in prep

Large HI holes and stars?

Integrated HI map

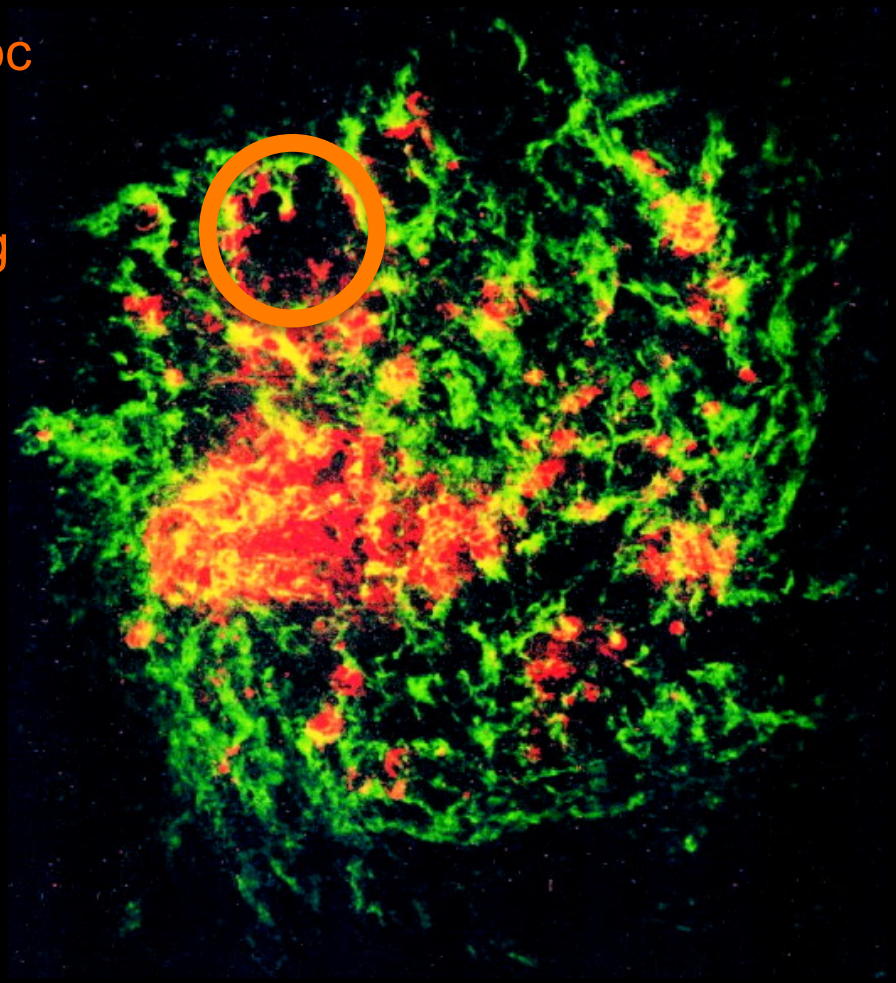


HI, FUV, V

Not stars: Rhode et al 1999, Bureau & Carignan 2002, Dib & Burkert 2005, Wada et al. 2000
Yes stars: Kerp et al 2002, Weisz et al. 2009 (CMDs, but multiple generations)

Constellation III in the LMC

--Diameter ~ 1.8 kpc
--Roughly 2.7 disk scale lengths
--Huge star-forming event 15 Myrs ago



Green = HI

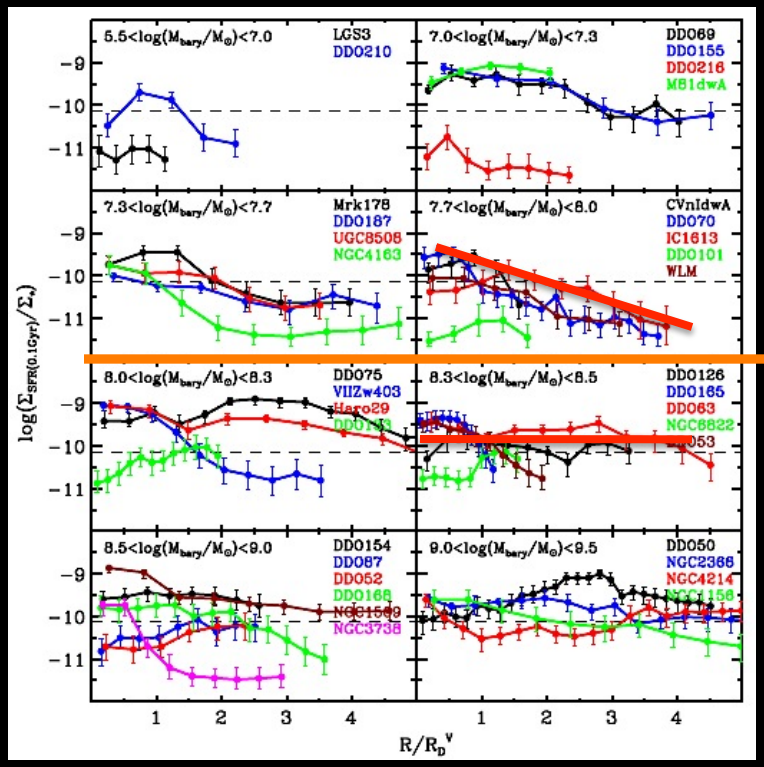
Red = HII

Kim et al. 1999

dIrr disks change with time

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

Zhang et al. 2012;
See also Pan et al. 2015

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

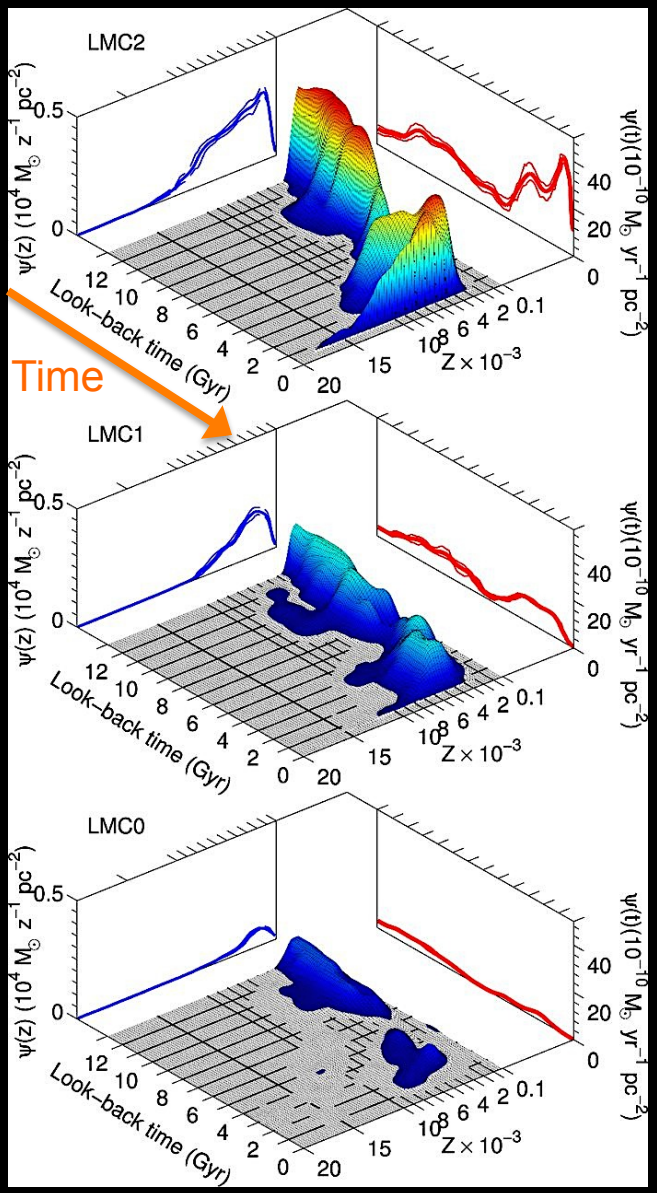
Outside-In: LMC (Meschin et al. 2013)

3.5 – 6 kpc –

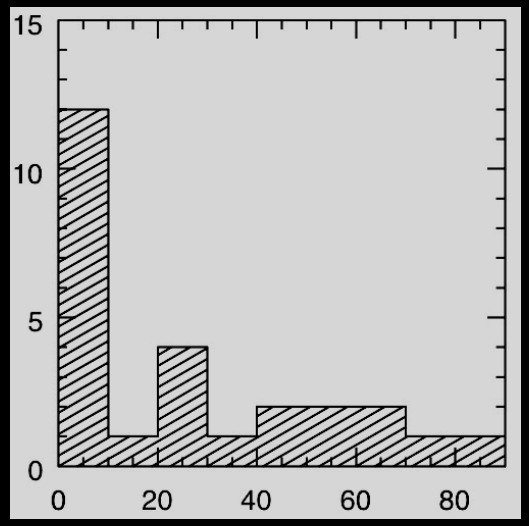
Inner – 4 Gyr and 7 Gyr ago formed equal amounts of stars; continuing to form stars into present epoch

Outer – 40% of stars formed at 4 Gyr as at 7 Gyr ago; continued only to 1 Gyr ago

SFH



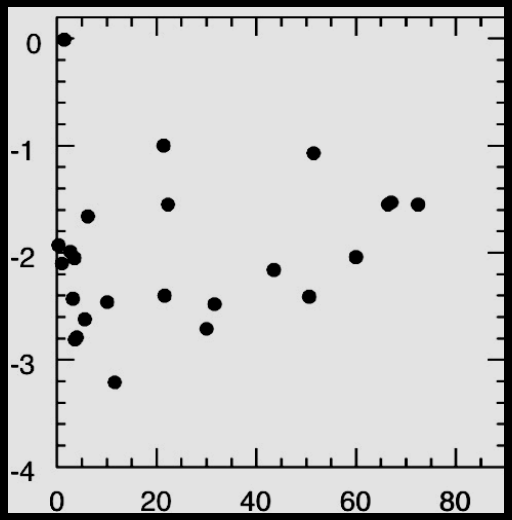
Mismatch of stellar and HI disks



$PA_{HI\ kinematics}$-$PA_{optical\ morphology}$

Δ position angle –
Over half of the LITTLE THINGS galaxies have differences >20°

Indications of an oval disk or warp? But not all of the criteria are met. Kormendy 1982

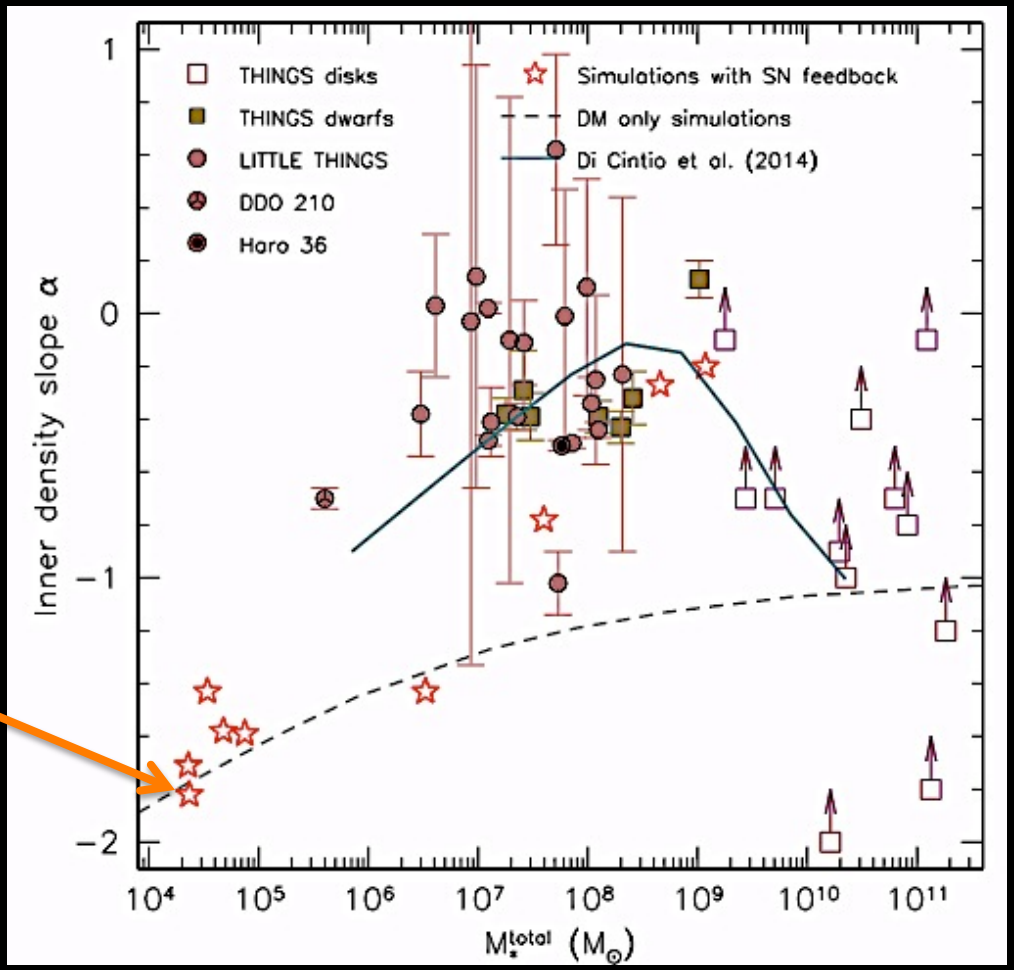


Data from Oh et al. 2015, Hunter & Elmegreen 2006

Core-like Dark Matter distributions indicate DM in dIrrs have been modified by stellar feedback

(Recall talk by C. Brooks)

Prediction from ΛCDM



Oh et al. 2015

Take away points

- dIrrs cover a wide range in star formation rates
- dIrrs often have highly extended, well-behaved stellar exponential disks
- Breaks in stellar profiles in outer disks are common in dIrrs and spirals and reveal some common phenomenon
- Young stellar populations are found in far outer disks
- But over a Hubble time dIrr disks are growing from the outside-in and perhaps changing in fundamental ways