Scaling Relations between Gas and Star Formation in Nearby Galaxies
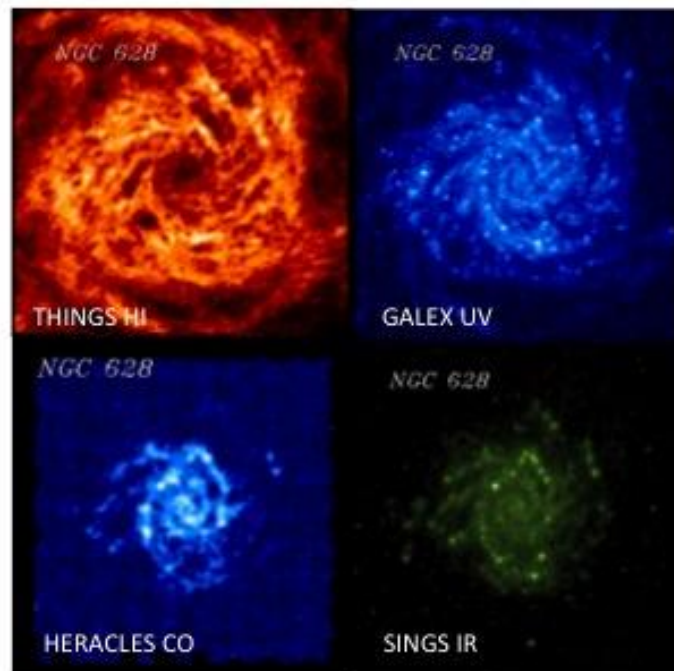
Frank Bigiel
Univ of Heidelberg

Gas and Star Formation in Nearby Galaxies

HI, H$_2$, and the SFR in Galaxies

- Stacking CO using HI priors

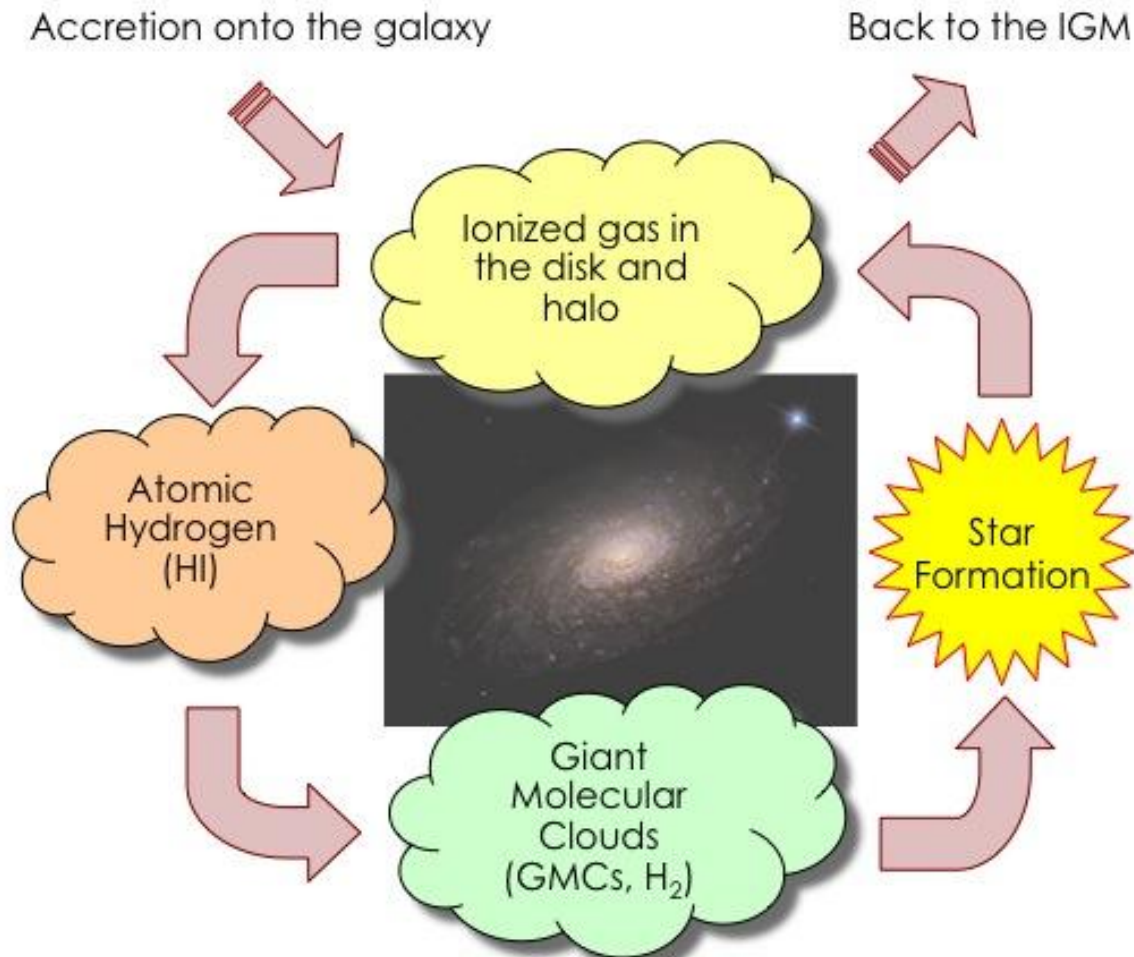- The relative roles of HI, H$_2$, and total gas in star formation

The H$_2$-SFR Relation in Detail

- Comparison to literature, different SFR tracers

- Where it breaks: scale, metallicity, galaxy centers/starbursts

Outer Galaxy Disks

- HI and SF at large radii, comparison to inner disks, composite scaling relations

- HI and SF in the extreme outer disks of M83

Gas and Star Formation in Nearby Galaxies

Accretion onto the galaxy

Back to the IGM

Ionized gas in the disk and halo

Atomic Hydrogen (HI)

Giant Molecular Clouds (GMCs, H_2)

Star Formation

HERACLES & THINGS: Multiwavelength Atlas

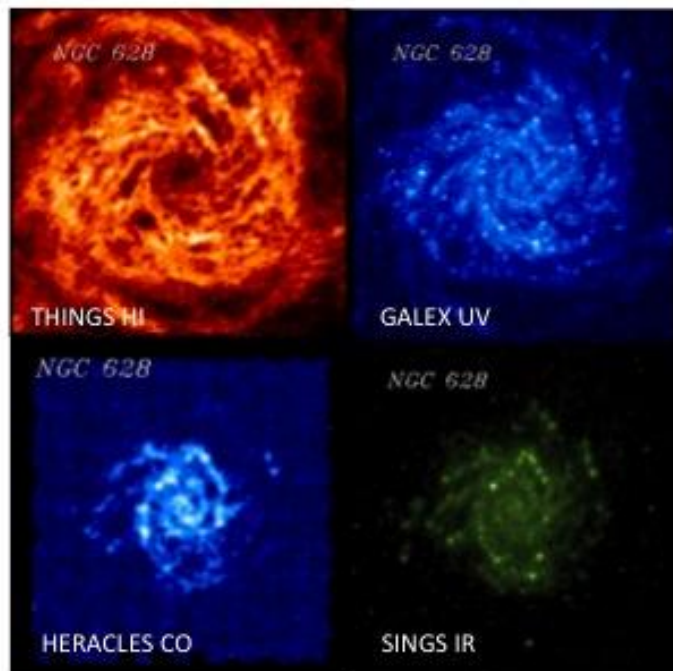- A database to understand star and GMC formation in galaxies:

THINGS
VLA Large Program
WALTER+ '08

+ new/archival VLA
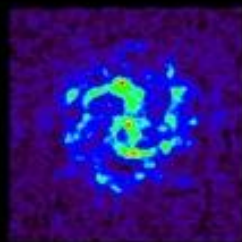
HERACLES
IRAM Large Program
LEROY+ '09

GALEX
Nearby Galaxies Survey
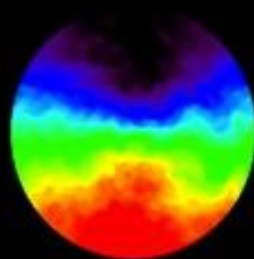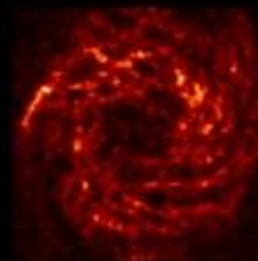GIL DE PAZ+ '07

SINGS + LVL
Spitzer Legacy Surveys
KENNICUTT+ '03, LEE+ '09

NGC 628 — THINGS HI, GALEX UV, HERACLES CO, SINGS IR

Currently: data on HI, H_2, star formation, stars, kinematics, dust for **48** galaxies.

Molecular Gas
Peak CO intensity
From HERACLES

Kinematics
Here from HI line
Also from CO

Recent Star Formation
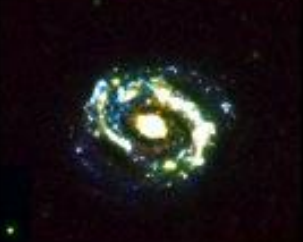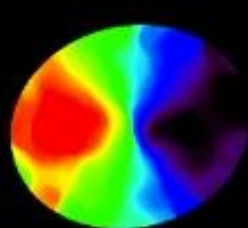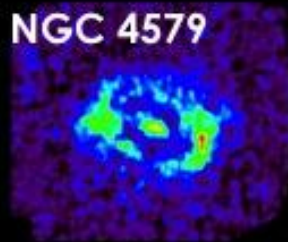Composite of FUV (GALEX),
mid-IR (SINGS/LVL),
and Hα (SINGS/LVL)
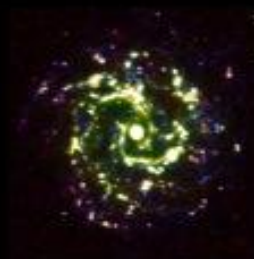
Atomic Gas
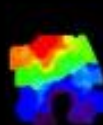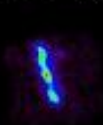VLA 21cm data THINGS +
new & archival

Old Stars
Near infrared intensity
From SINGS and LVL

NGC 4579

NGC 4569

NGC 7331
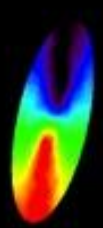
NGC 4254

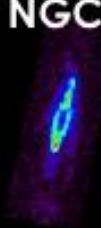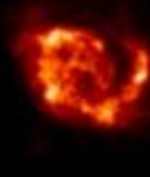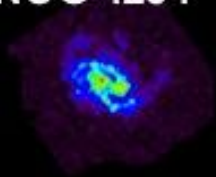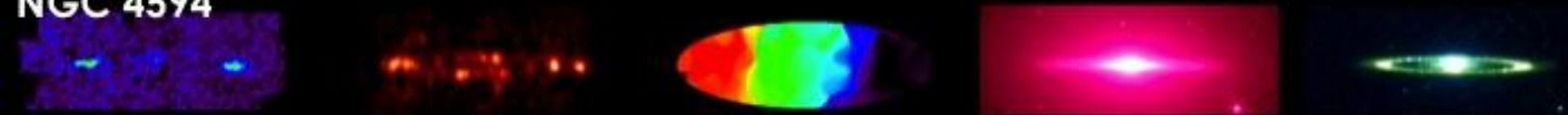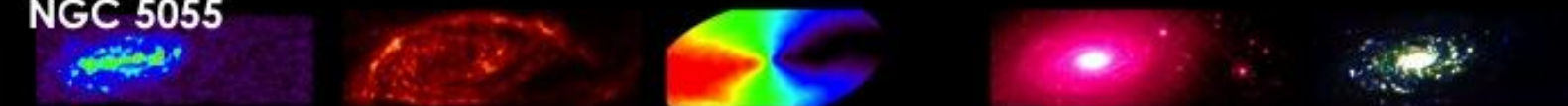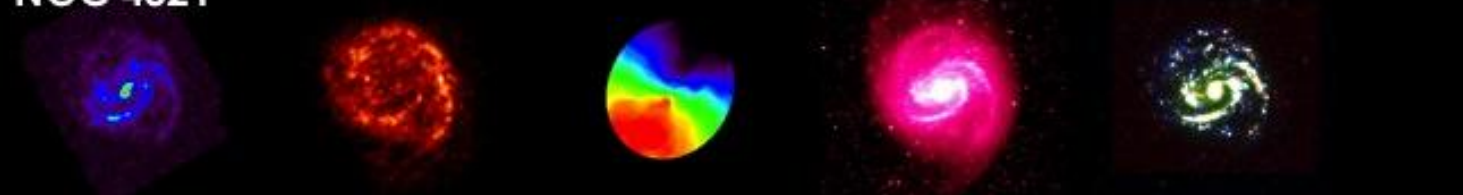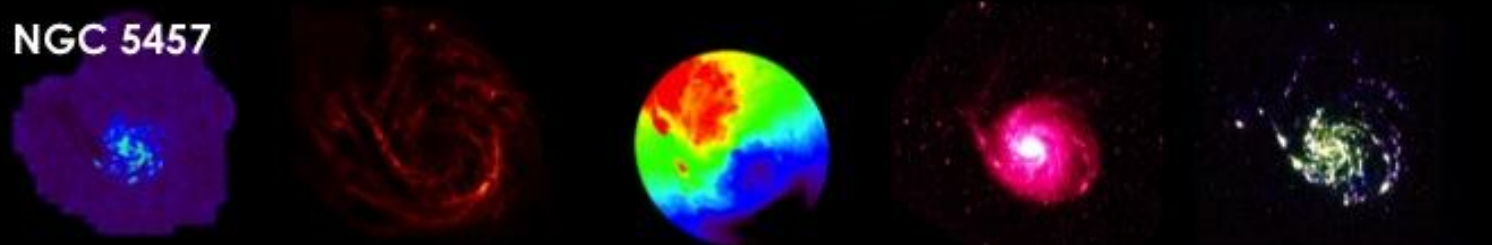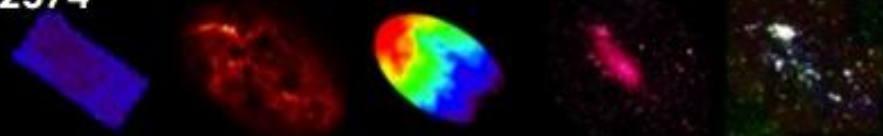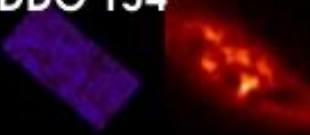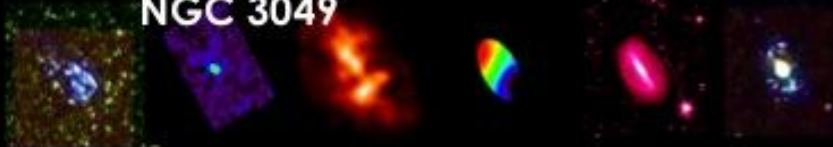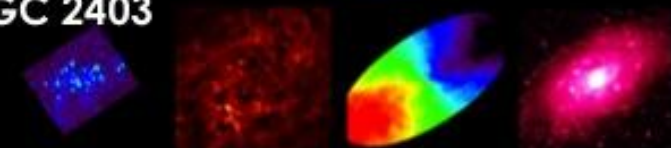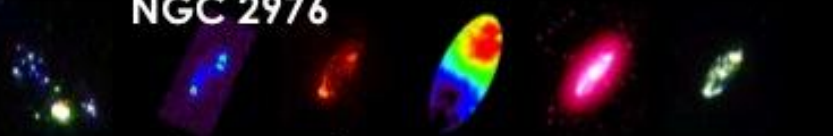NGC 4594

NGC 5055

NGC 5194

NGC 4321

NGC 5457

IC 2574

DDO 154

NGC 3049

NGC 2403

NGC 2366

NGC 2976

Holmberg II
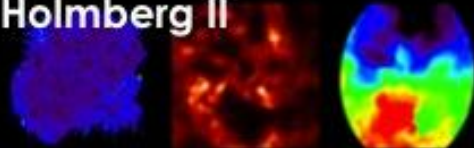
M81 Dwarf A
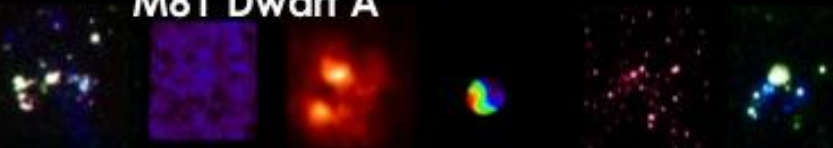
NGC 4625
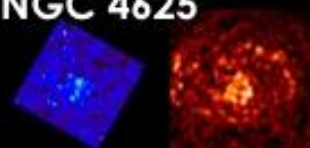
Holmberg I
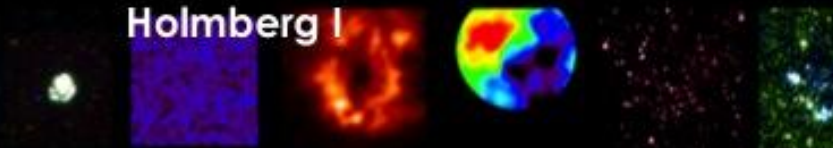
DDO 053
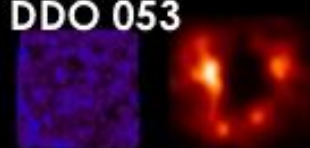
M81 Dwarf B
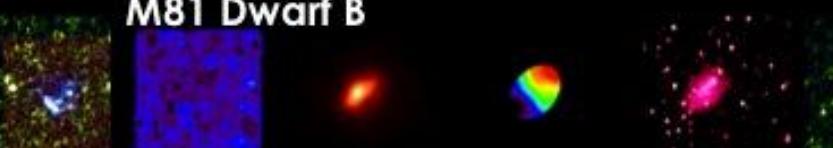
HI, H$_2$, and the SFR

- Whole galaxies: physics, roles of HI and H$_2$ ambiguous
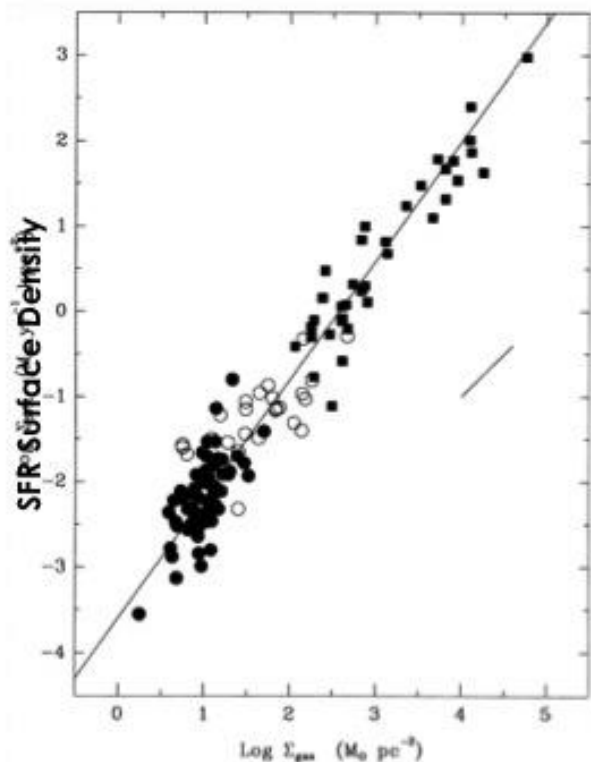
Total (HI + H$_2$) Gas Surface Density
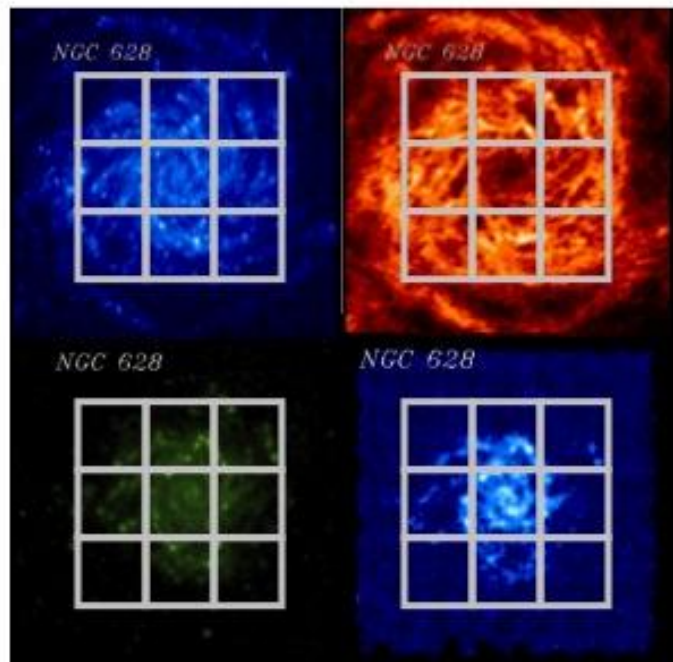
Grid not to scale!

HI, H$_2$, and the SFR

- Inside galaxies: H$_2$ has clearer relationship, but little data where HI > H$_2$
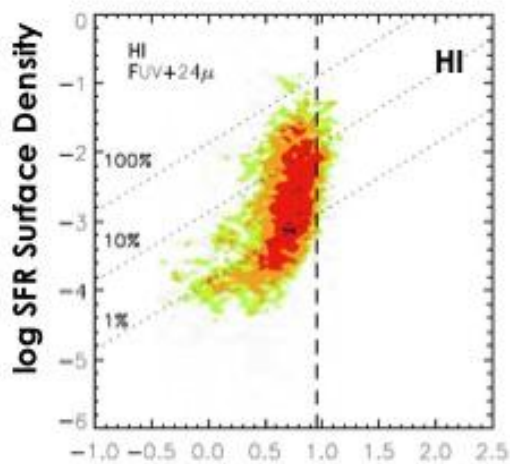
log SFR Surface Density — log Atomic Gas Surface Density
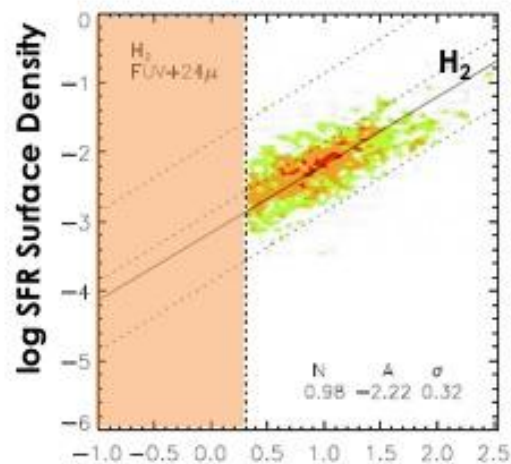
log SFR Surface Density — log Molecular Gas Surface Density

WONG & BLITZ '02, KENNICUTT+ '07, BIGIEL+ '08

Using HI to Stack CO

- CO averaging complicated by galaxy rotation, wide bandpass.

- HI and CO have about the same mean velocity.

- HI detected to larger radii (flatter profiles than CO).
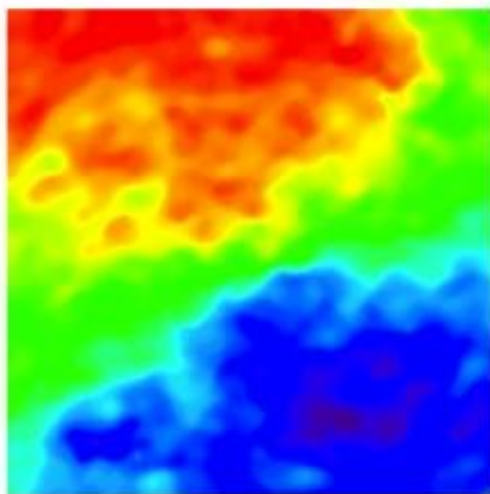
HI Velocity Field
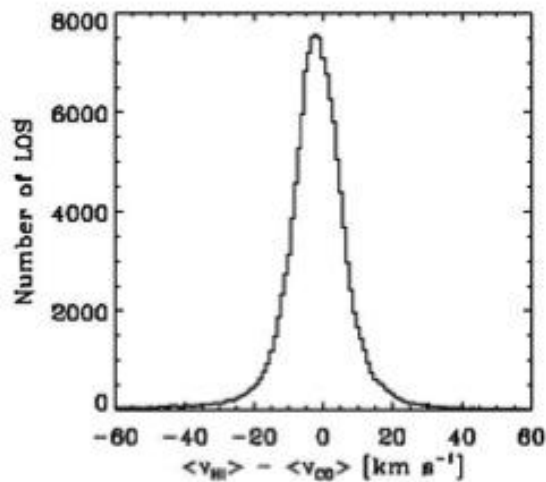
HI – CO velocity

Using HI to Stack CO

- Using HI to define local "zero" velocity.

- Coherent averaging brings out clear signal from averaging.
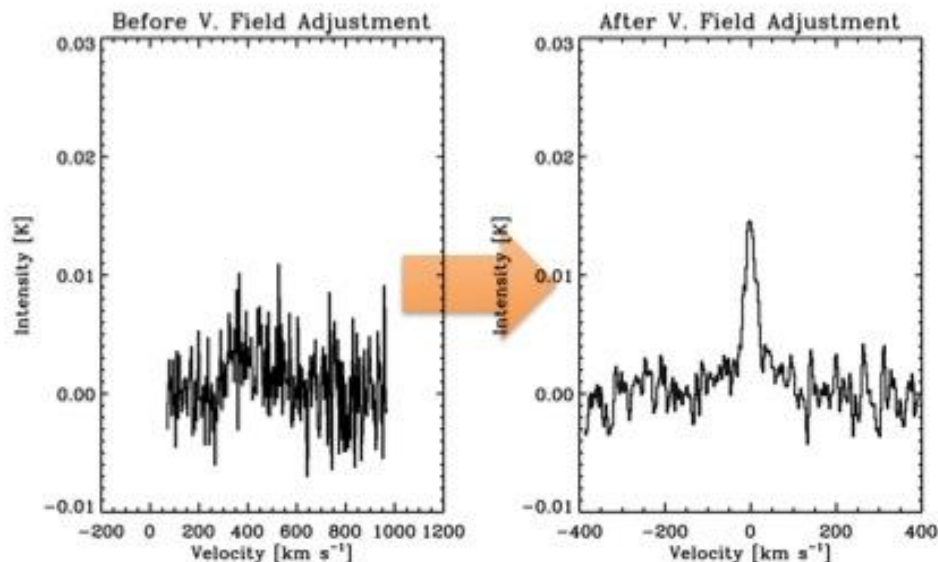
- Stack vs. radius, get sensitive profiles of ~33 galaxies:
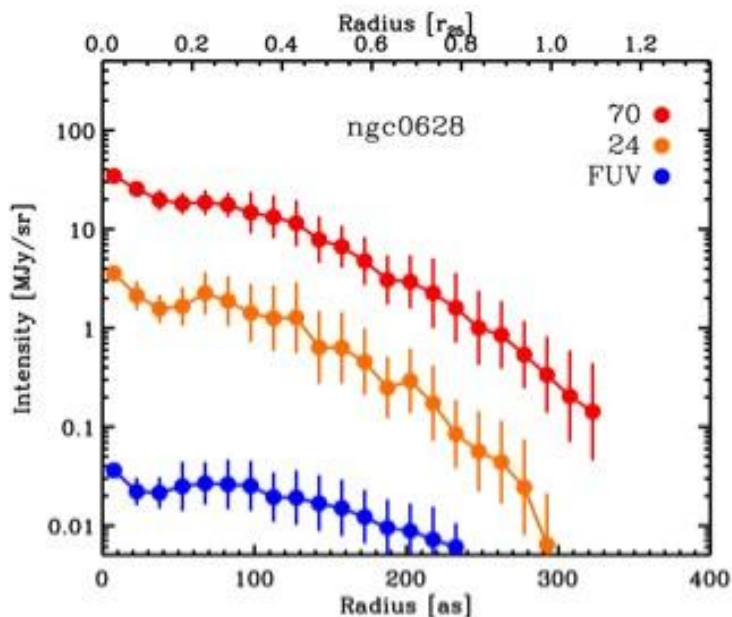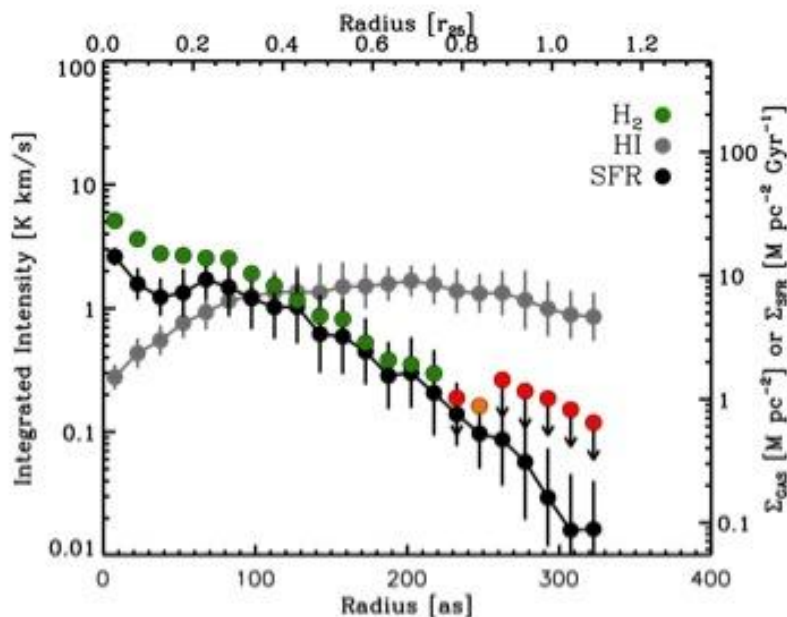
HI, H$_2$, and SFR Scalings
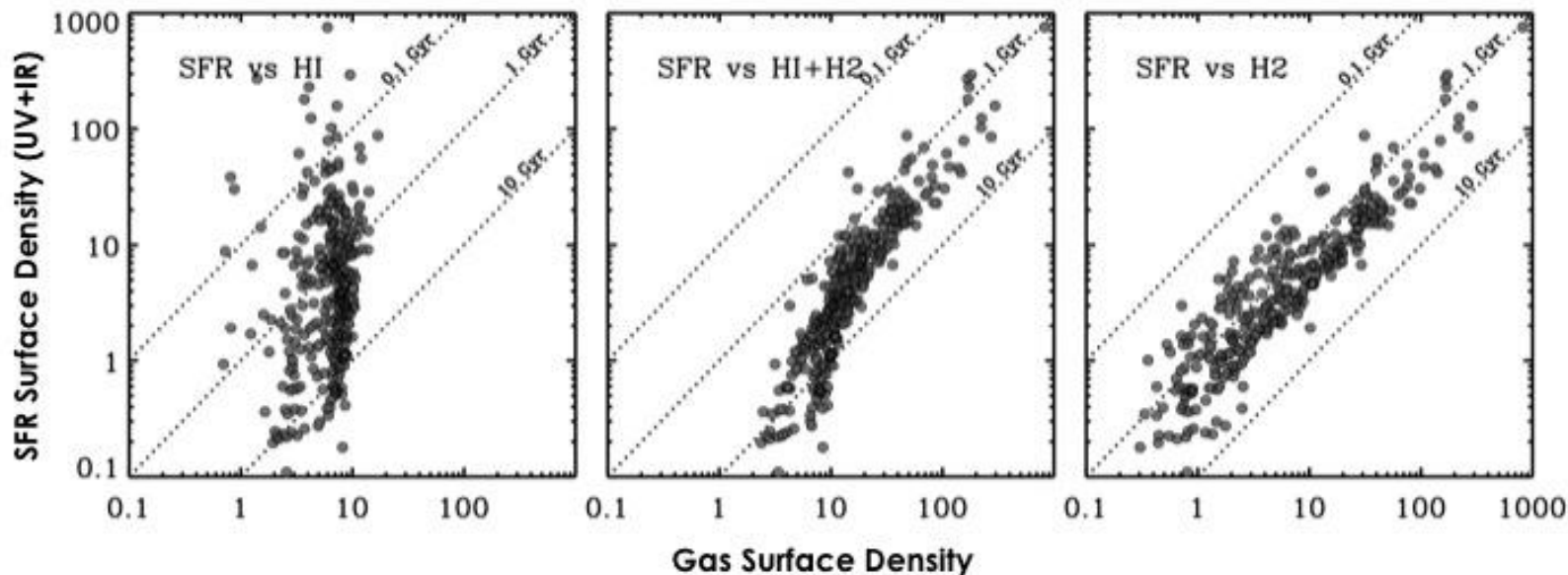
- Star formation and different gas types for stacked profiles:

- SFR-H$_2$ correlation extends to where HI > H$_2$

- Correlation with total gas depends on regime ("threshold").

HI, H$_2$, and SFR Scalings
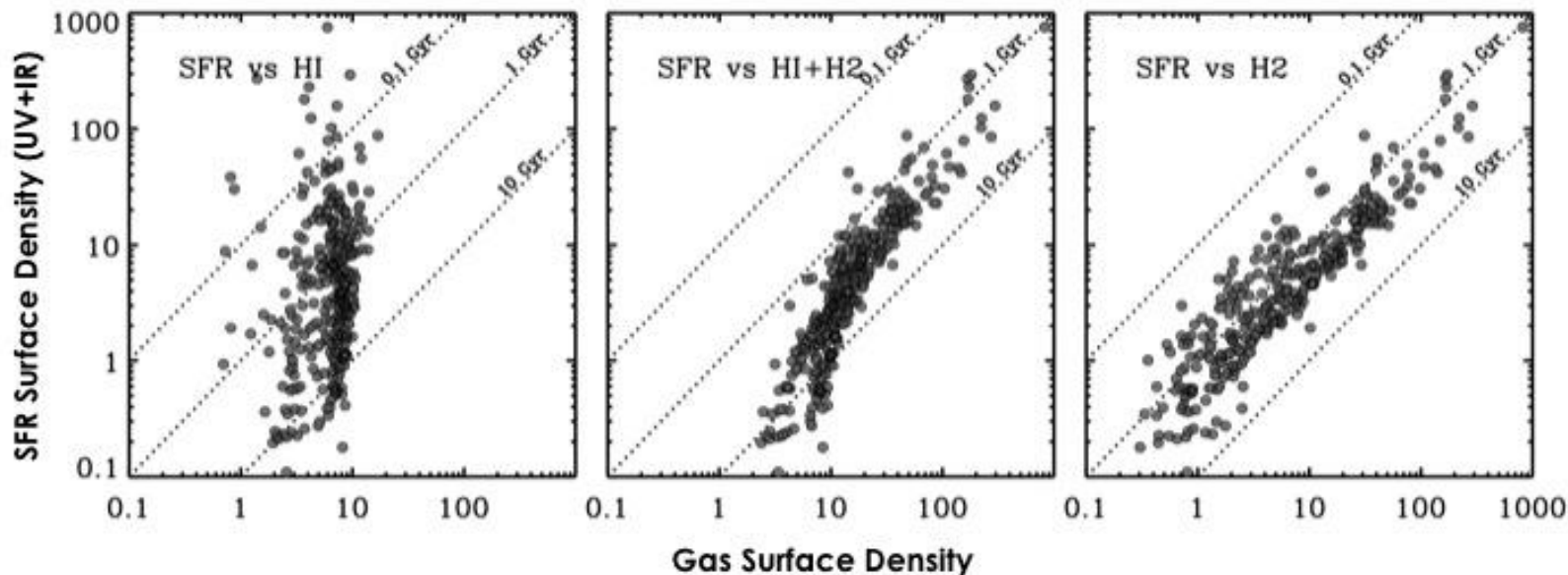
- Star formation and different gas types for stacked profiles:

- SFR-H$_2$ correlation extends to where HI > H$_2$

- Correlation with total gas depends on regime ("threshold").

The H$_2$-to-HI Ratio as a Threshold

- Total gas behavior consistent with previous "thresholds:"
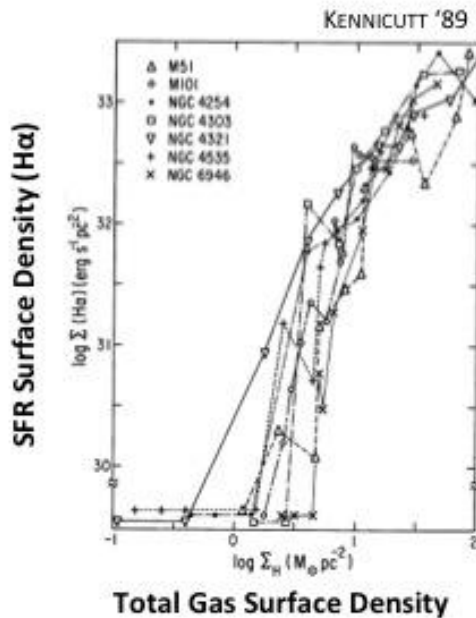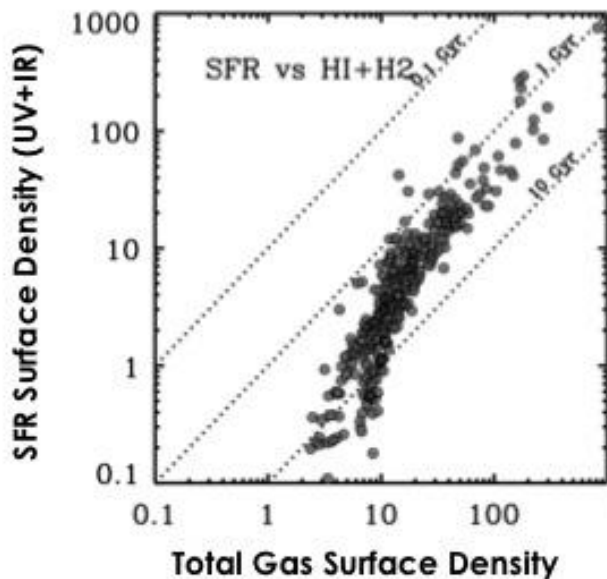
The H_2-to-HI Ratio as a Threshold

- "Threshold" a product of changing molecular gas fraction:
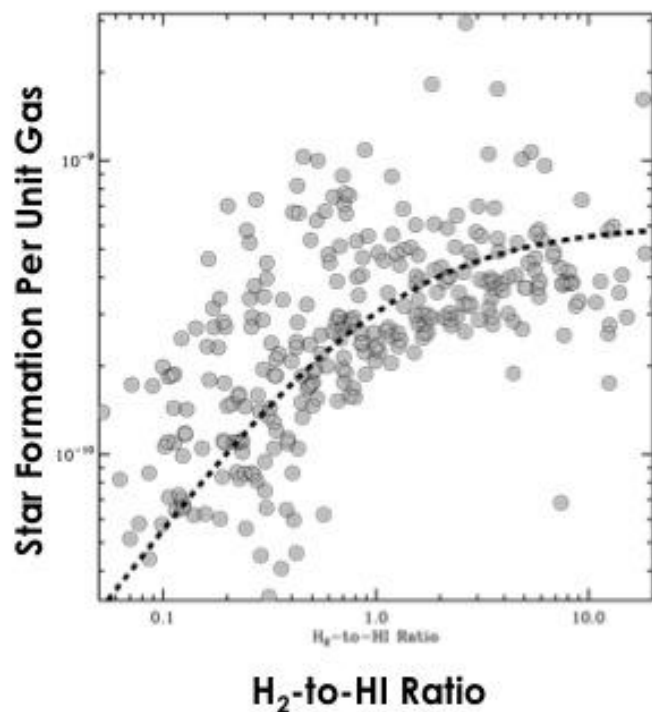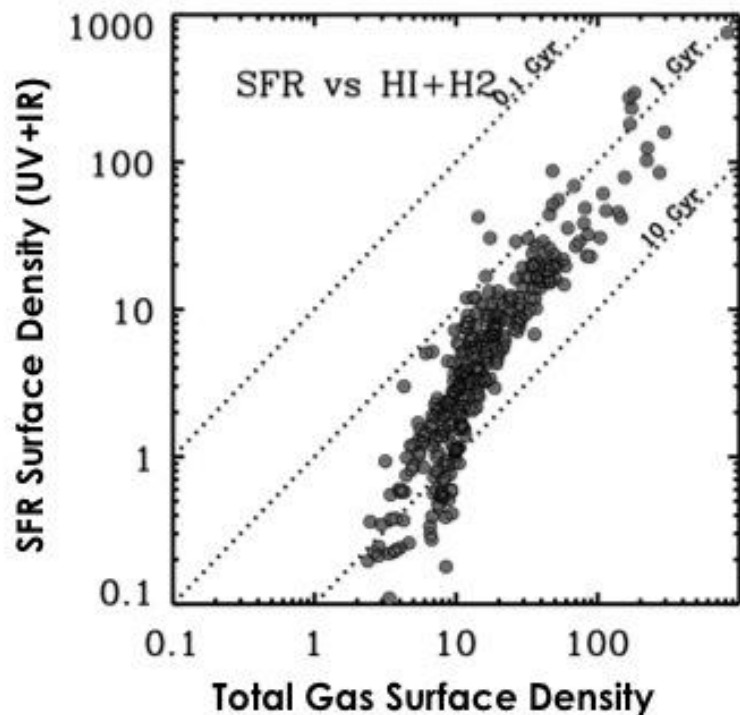
Gas and Star Formation in Nearby Galaxies

HI, H_2, and the SFR in Galaxies

- **HI can be used to stack CO emission to very high sensitivity**

- **H_2 (CO) nearly fixed ratio with SF tracers, HI steeper, HI+H_2 complex**

## The H_2-SFR Relation in Detail

- Comparison to literature, different SFR tracers

- Where it breaks: metallicity, galaxy centers/starbursts, small scales

Details of the H₂-SFR Relation

H₂ Surface Density from CO

BIGIEL+ 2011
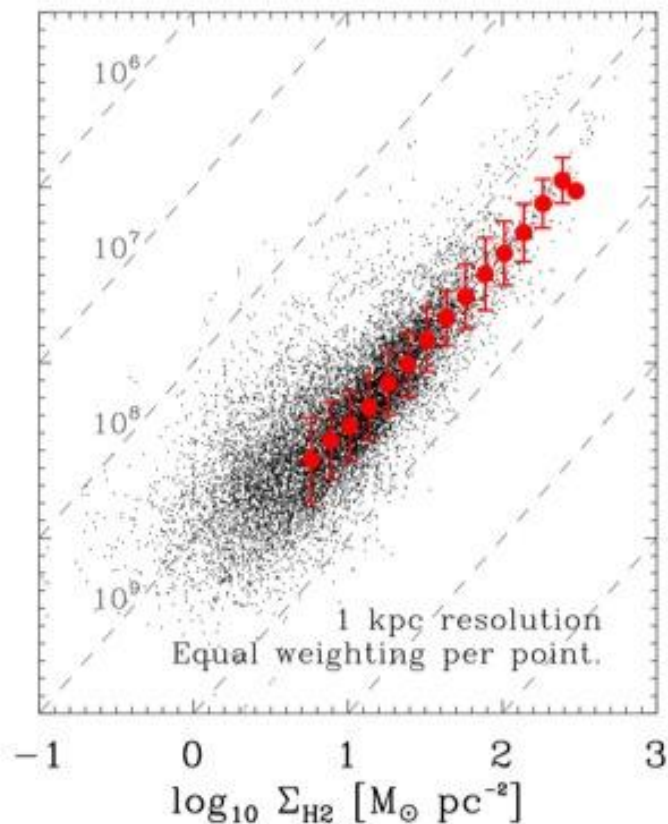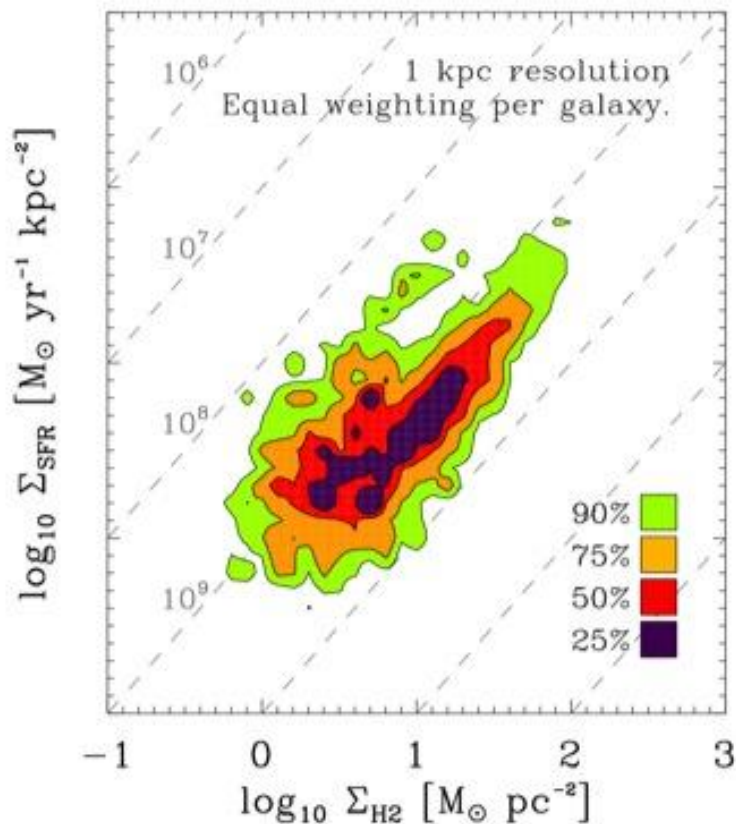
Using Different SF Tracers

SFR Surface Density (vertical axis label)

H₂ Surface Density from CO

Comparison to Literature Measurements
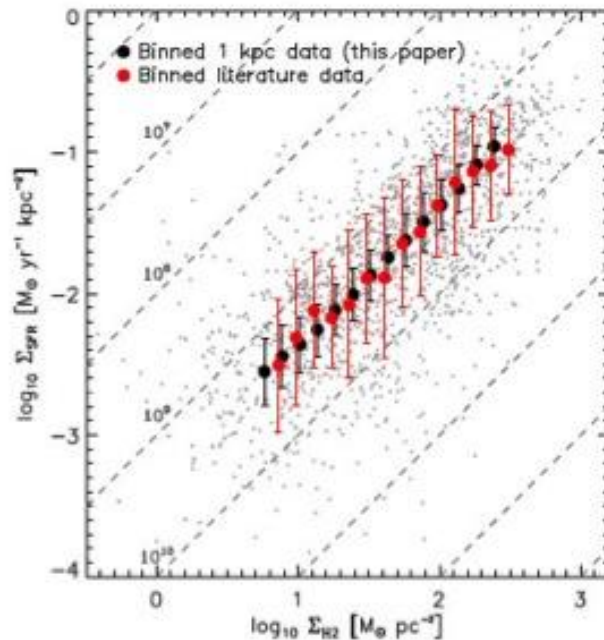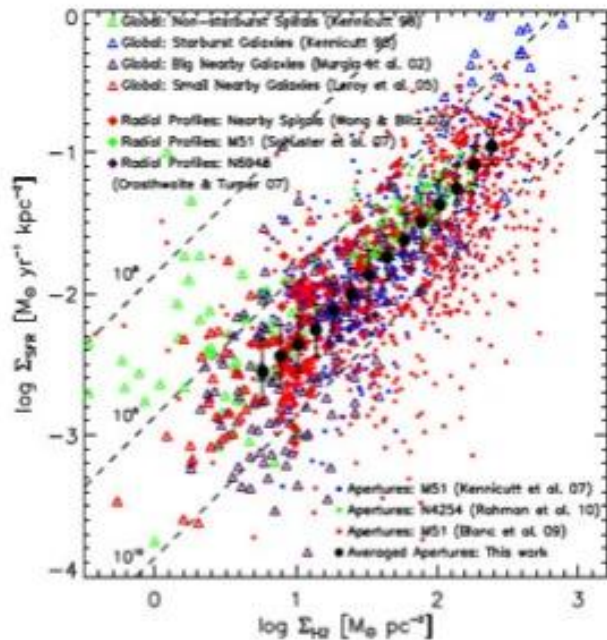
Galaxy-to-Galaxy Scatter

- Galaxy-to-galaxy scatter from CO-SFR relation:
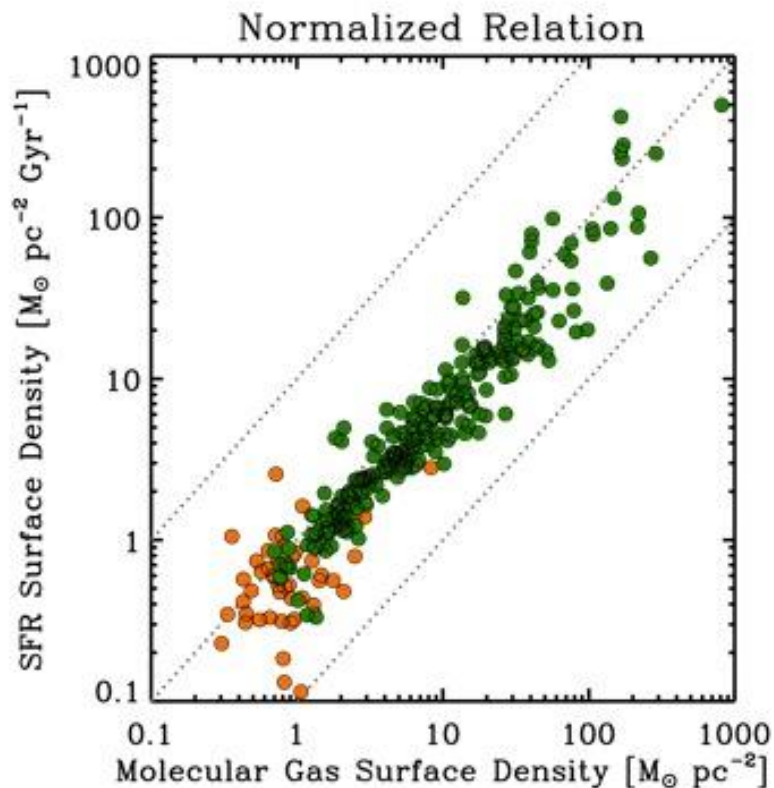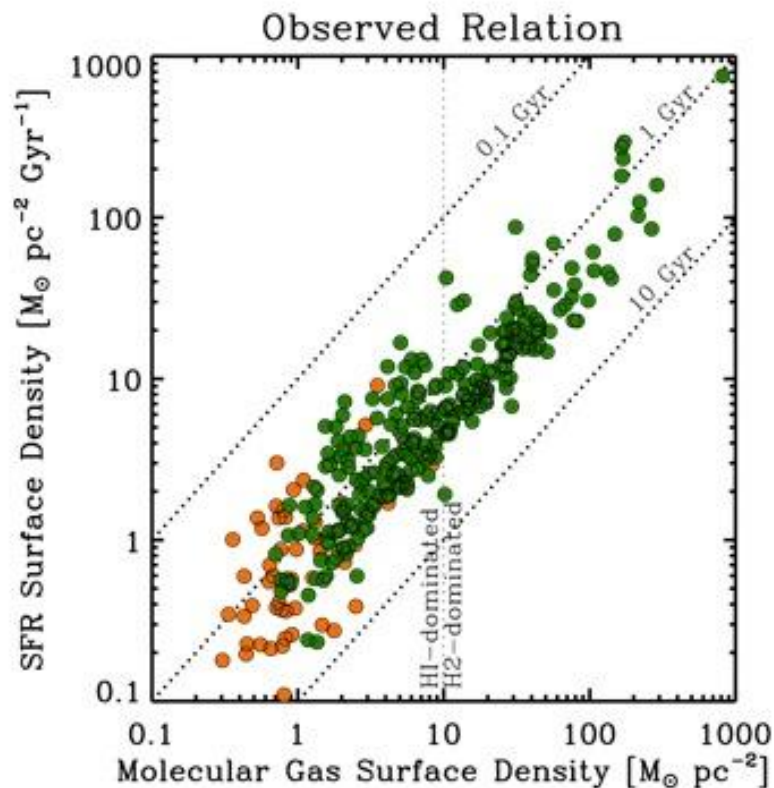
Each point : one ring in one galaxy

SCHRUBA+ '11

Breakdown at Low Mass, Metallicity

LEROY, BIGIEL, WALTER+ IN PREP.
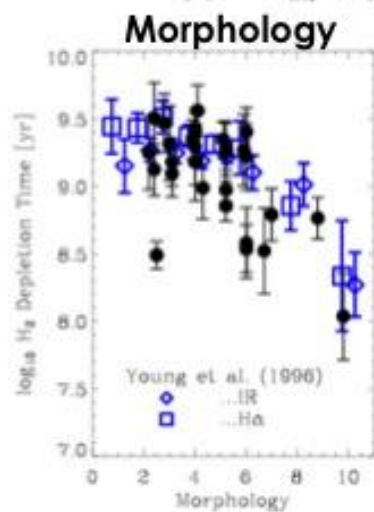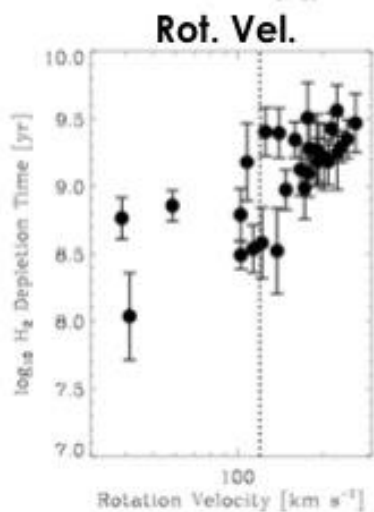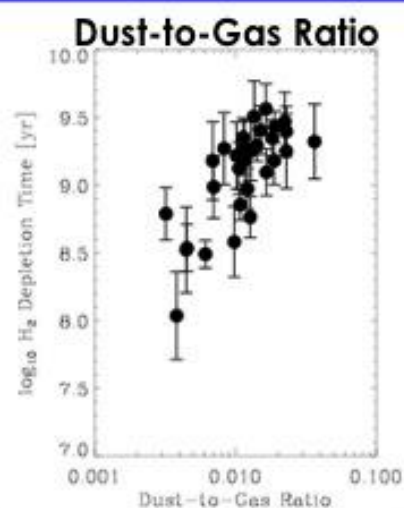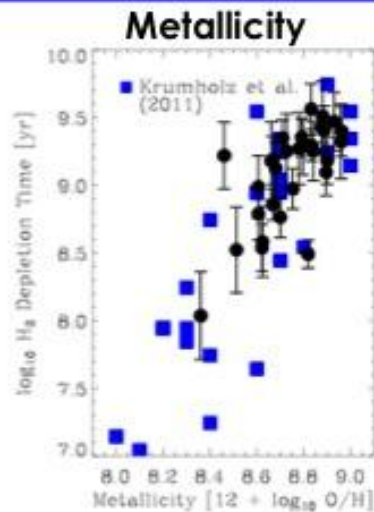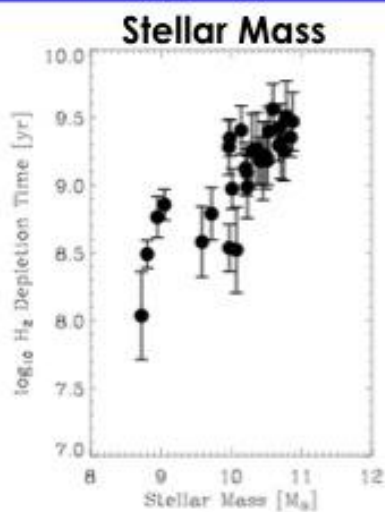
Breakdown in Galaxy Centers
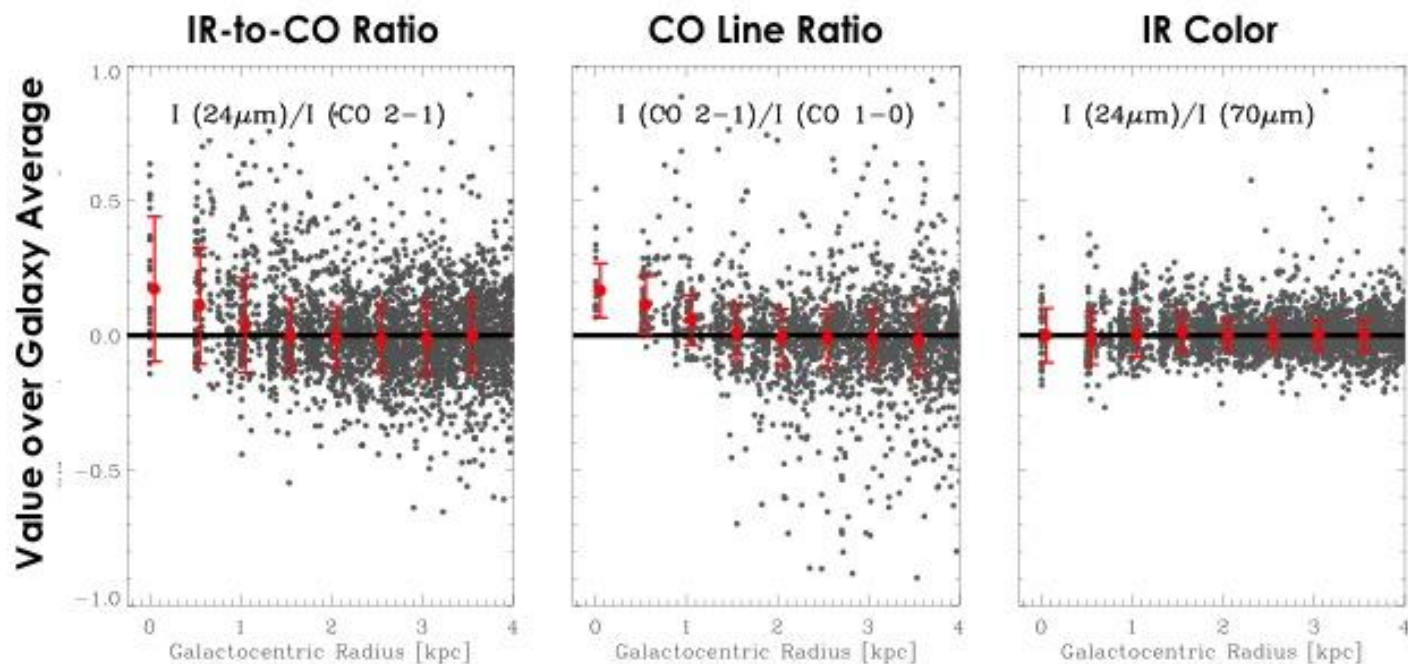
Each point : one one kpc res. Line of sight

Breakdown in Starburst Galaxies
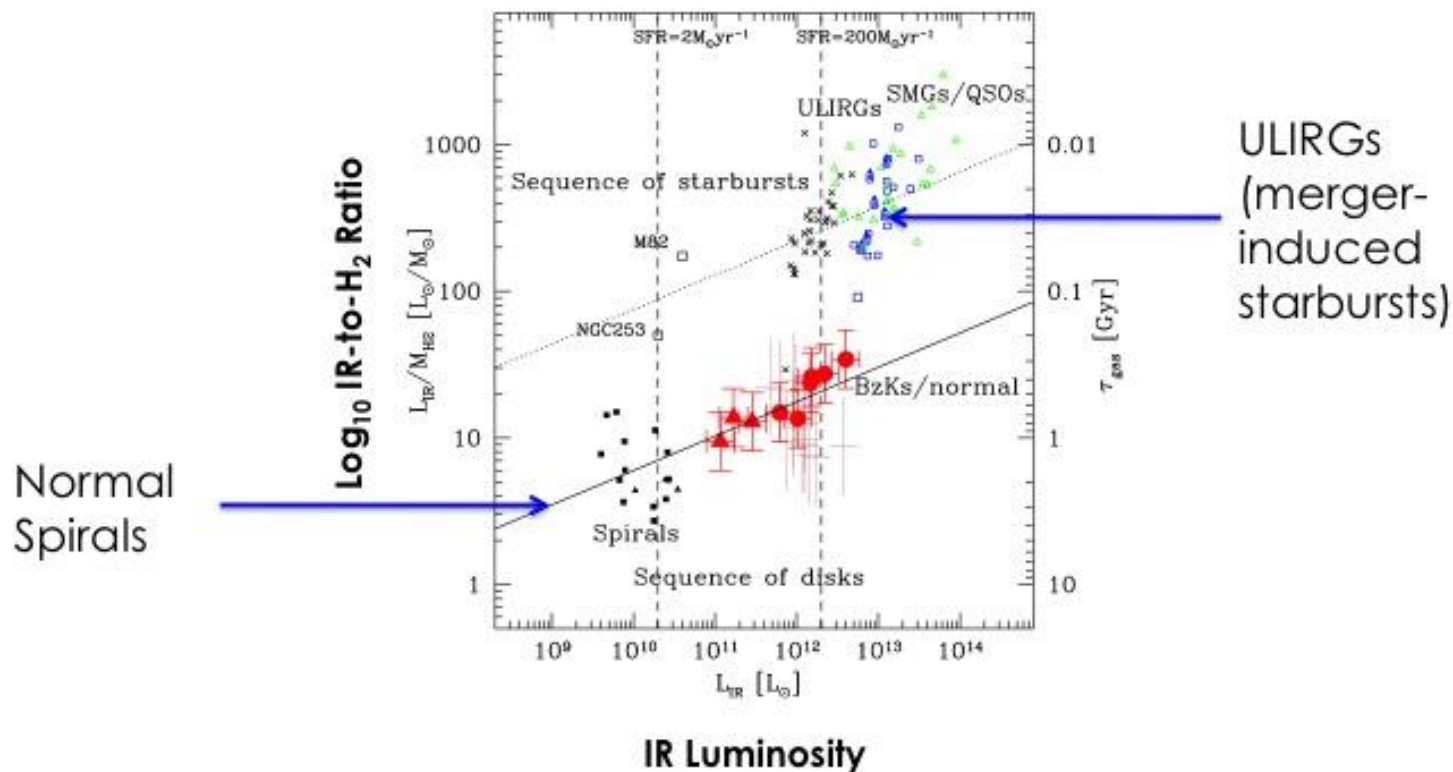
Each point : one galaxy

Breakdown at Small Scales
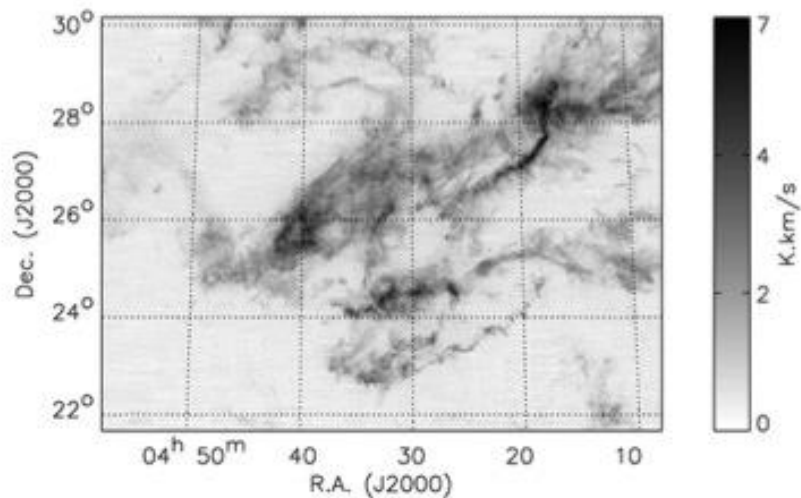
Goldsmith+ '08

Photo credit: R. Gendler

M33: Near Enough, Far Enough

- Distinguish HII regions and GMCs, still see whole galaxy:

SCHRUBA+ '10; HII REGIONS: HODGE+ '02; GMCs: ROSOLOWSKY+ '07
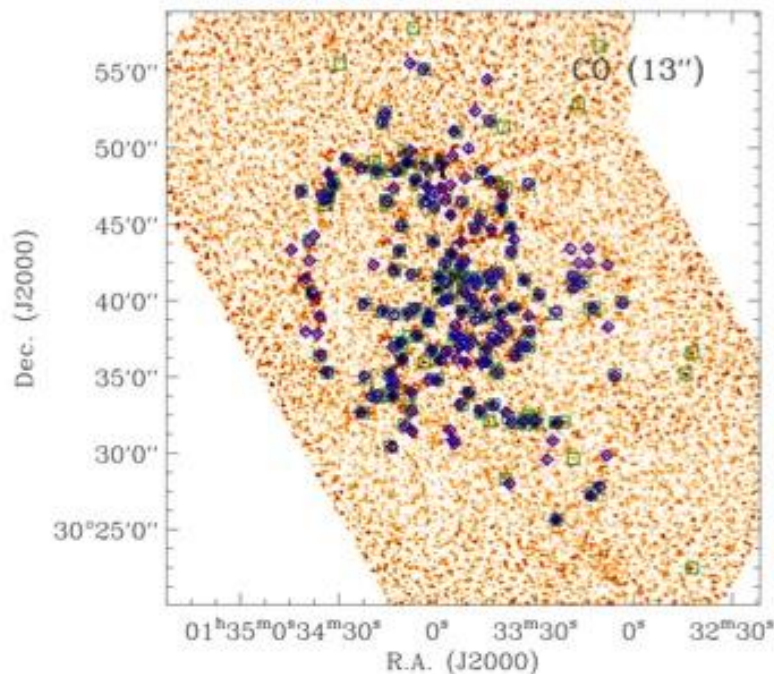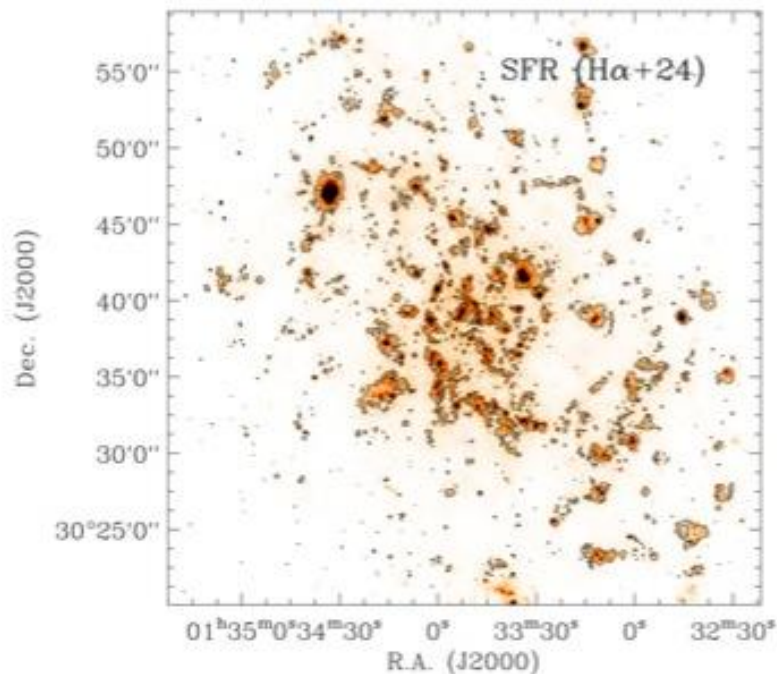
Measuring CO-to-Hα

- Target CO, Hα peaks with varying size apertures, measure CO/Hα

d=75 pc

d=1200 pc
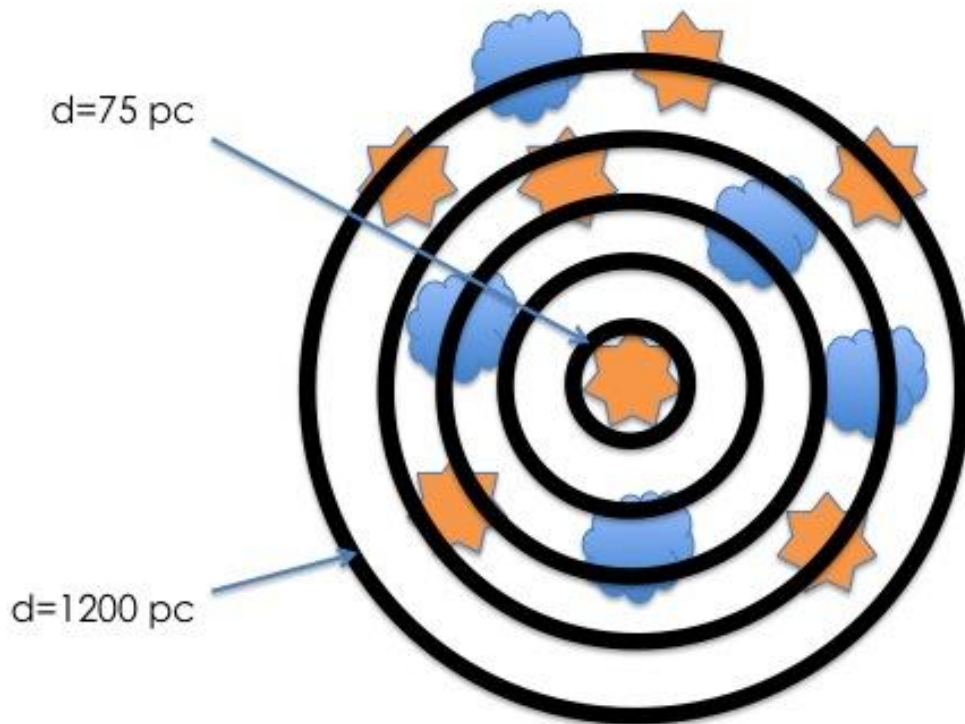
A "Normal" Spiral at ~kpc Scales

- Recover the known result of a molecular Schmidt law at ~1.2 kpc:

HEYER+ '04; VERLEY+' 08; SCHRUBA+ '10
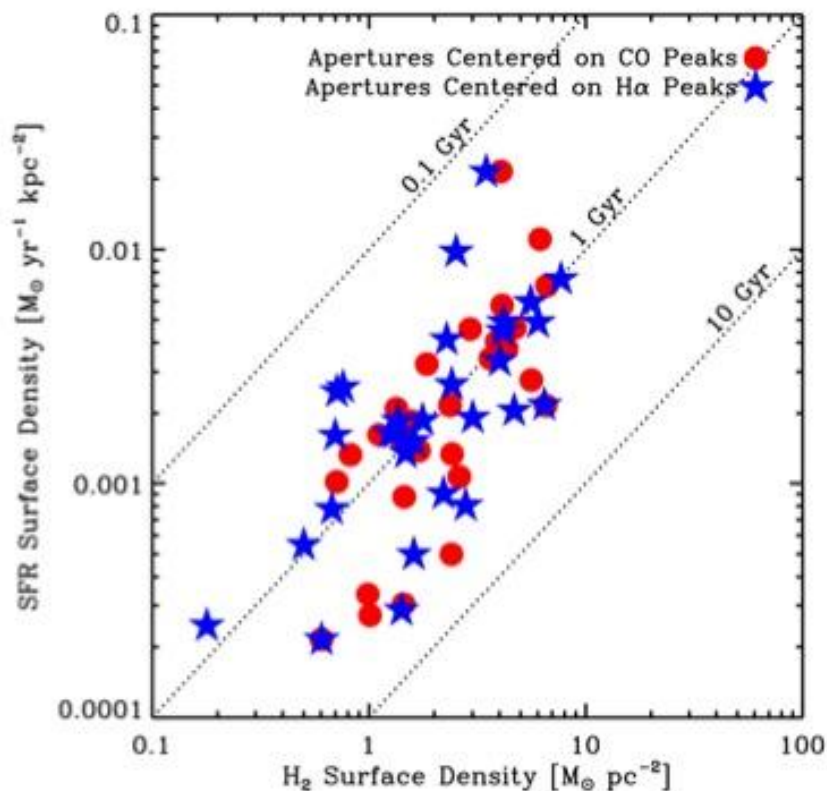
CO-to-Hα vs. Scale, Target

- CO-to-Hα ratio as a function of target and scale:

SCHRUBA+ '10
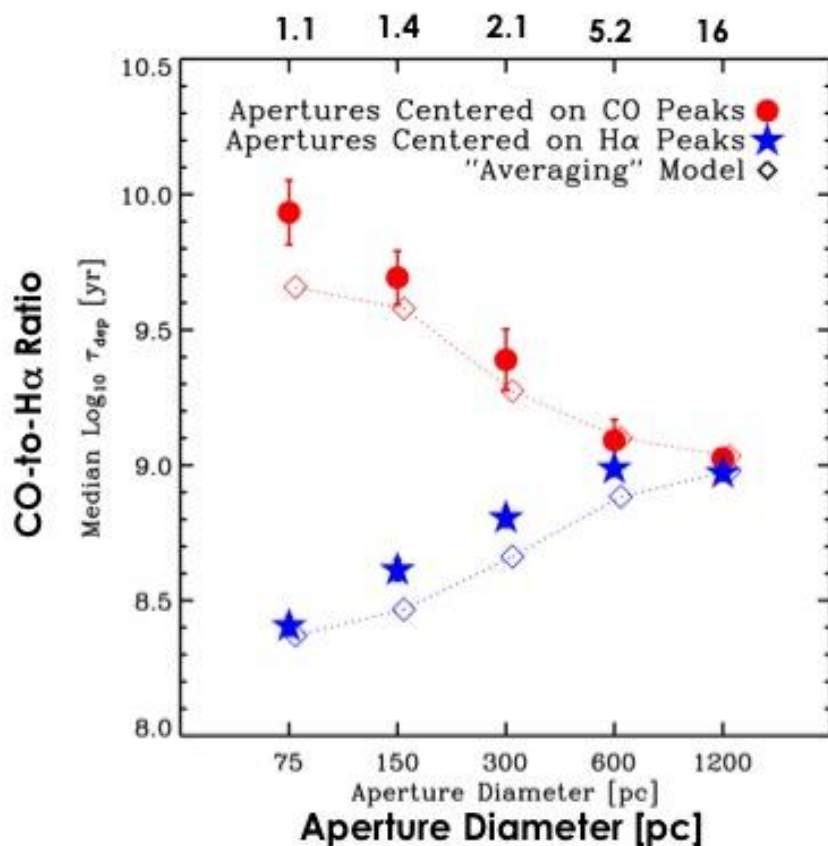
CO-to-Hα vs. Scale, Target

- High resolution introduces "scatter" to SF-CO relation.

- Scatter encodes information on the life-cycle of SF regions.
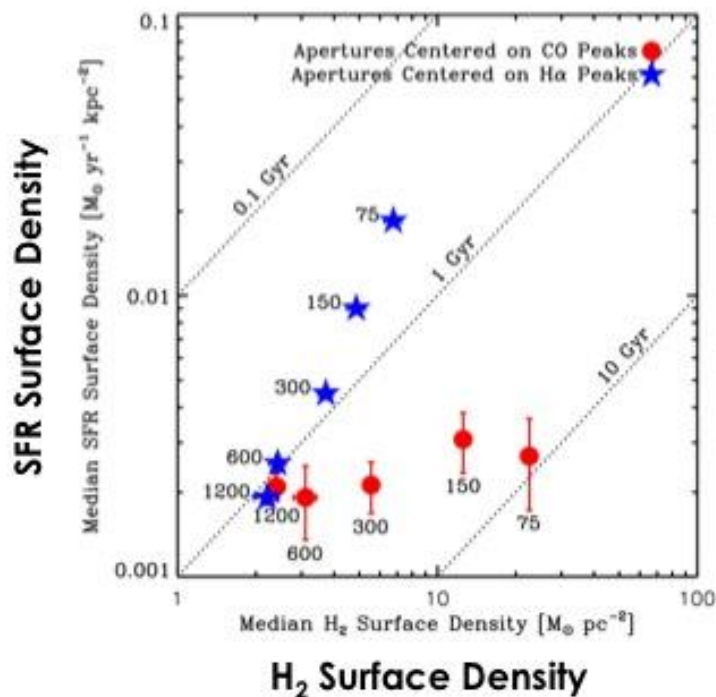
SCHRUBA+ '10; MILKY WAY: MURRAY '10; THEORY: FELDMAN+ '10

Gas and Star Formation in Nearby Galaxies

HI, H_2, and the SFR in Galaxies

- HI can be used to stack CO emission to very high sensitivity

- H_2 (CO) nearly fixed ratio with SF tracers, HI steeper, HI+H_2 complex

The H_2-SFR Relation in Detail

- **Good agreement with the literature, different SF tracers**

- **Breakdown with metallicity (X_{CO}), scale (GMC evolution), and in starbursts**

Outer Galaxy Disks

- HI and SF at large radii, comparison to inner disks, composite scaling relations

- HI and SF in the extreme outer disks of M83

Outer Galaxy Disks
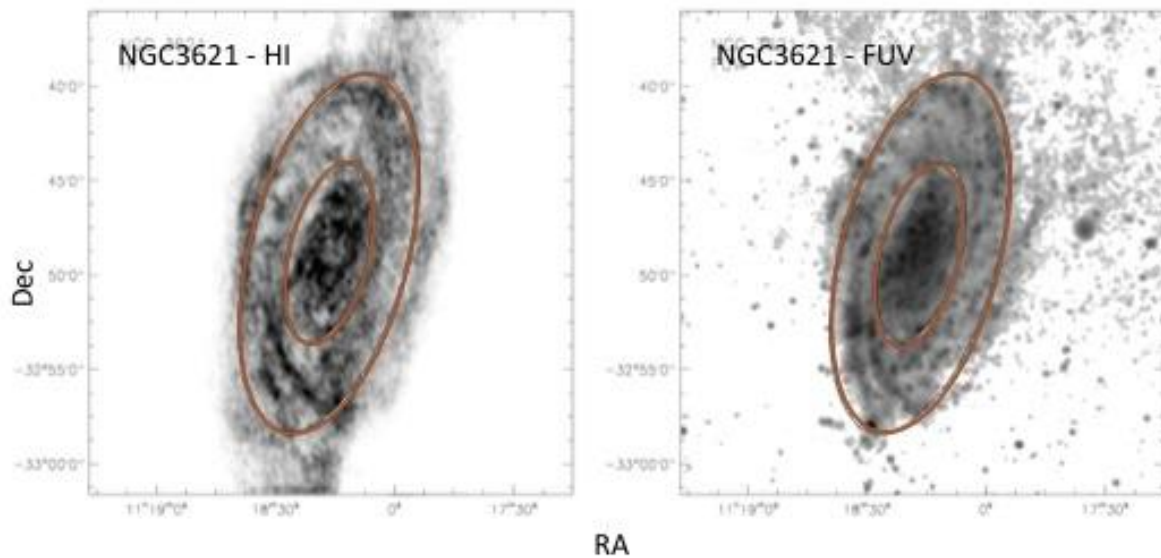
- Extend SFR-gas measurements to regime between 1 and $2*r_{25}$

- Interesting regime: HI dominated, generally lower gas columns and metallicities / dust content, high shear, weak stellar potential → different to inner parts of galaxies!

- Assume $\Sigma_{gas} \sim \Sigma_{HI}$ and $\Sigma_{SFR} \sim \Sigma_{FUV}$ (i.e., ignore H_2 and 24μm emission)

- Overlap of THINGS and the GALEX NGS: 22 galaxies

BIGIEL+ '10A

SFR-HI Scaling
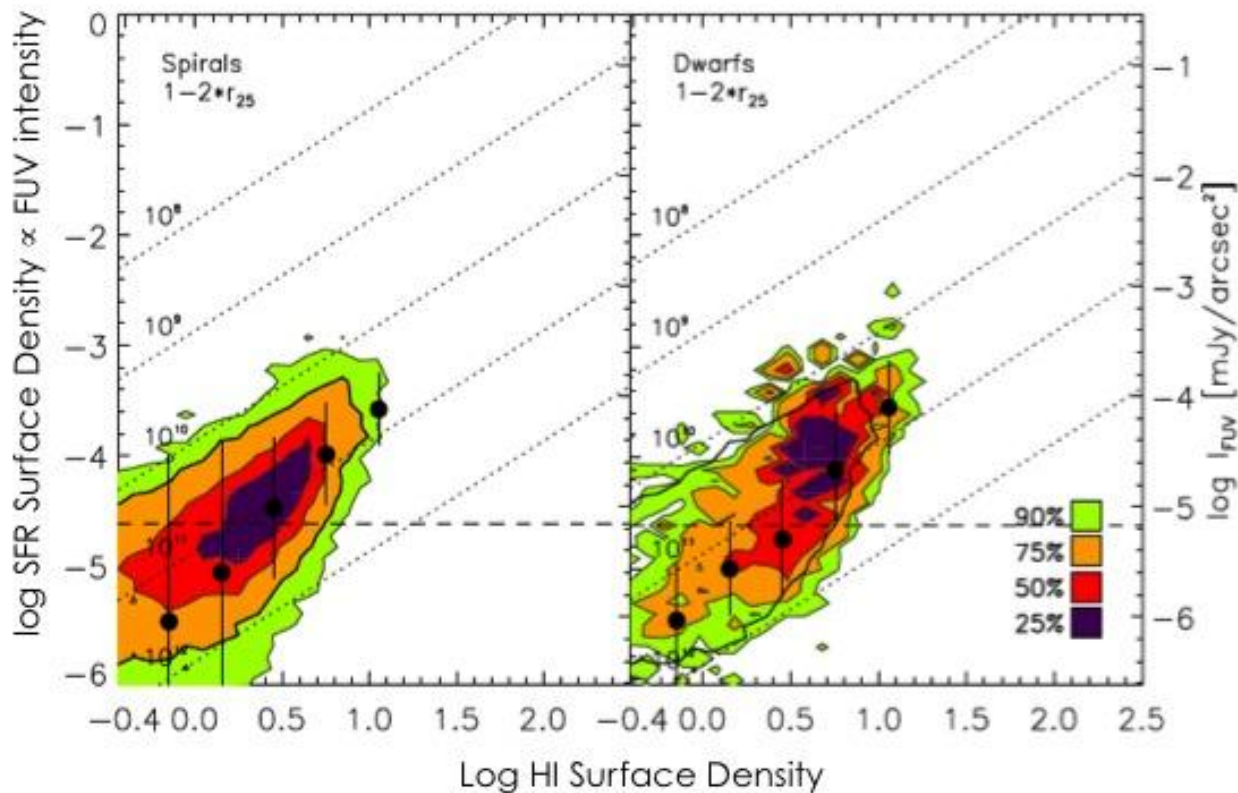
- SFRs are very low

- Σ_{SFR} scales with Σ_{HI} in outer disks (though with large scatter)

BIGIEL+ '10A

SFR – Gas Scaling: Inner vs Outer Disks
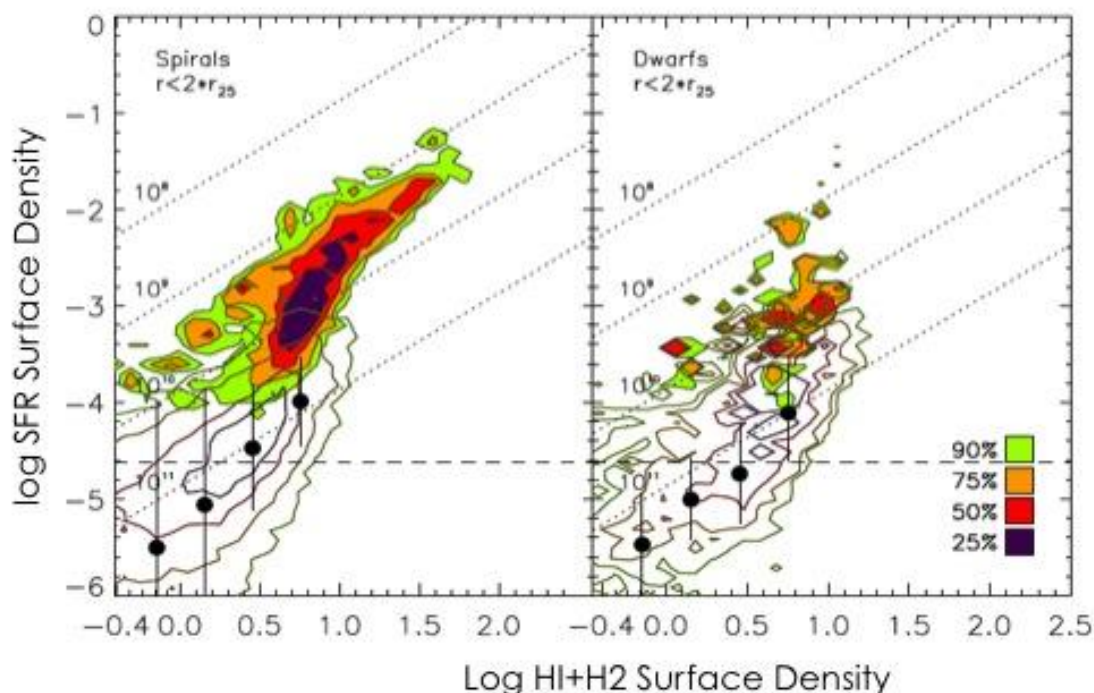
- Smooth transition from optical into outer disks

- Σ_{HI} ("the availability of HI") appears to be key for regulating the SFE at large radii

- Combining multiple environments on one plot yields complex distribution (on <kpc scales)

BIGIEL+ '10A

The Extreme Outer Disk of M83
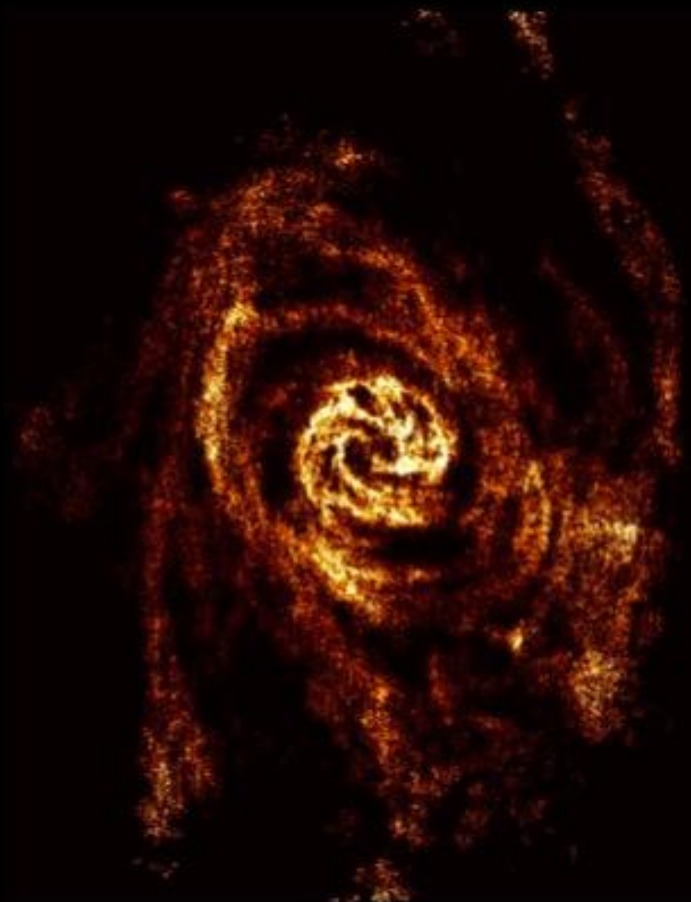

M83 - GALEX FUV

M83 - THINGS HI
THILKER+ '05, BIGIEL+ '10B

The Extreme Outer Disk of M83

- Radial HI distribution ~flat far out in outer disk (~3.5 r_{25})

- FUV profile decreases steeply; levels off in the far outer disk
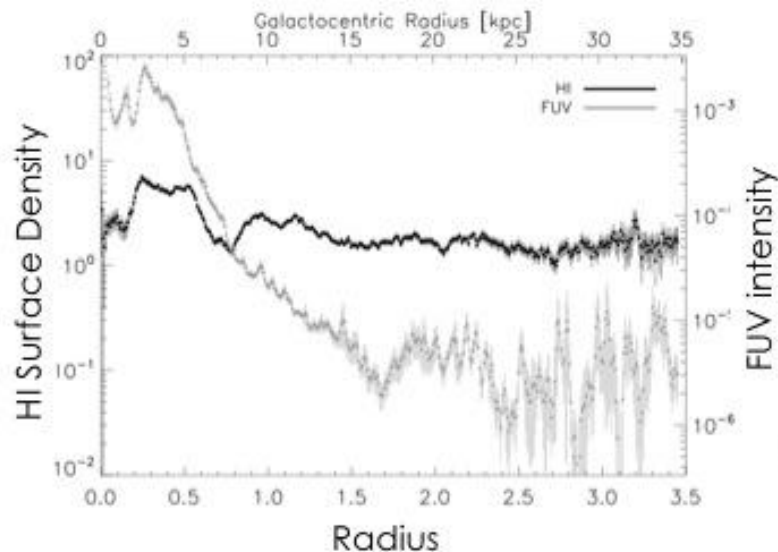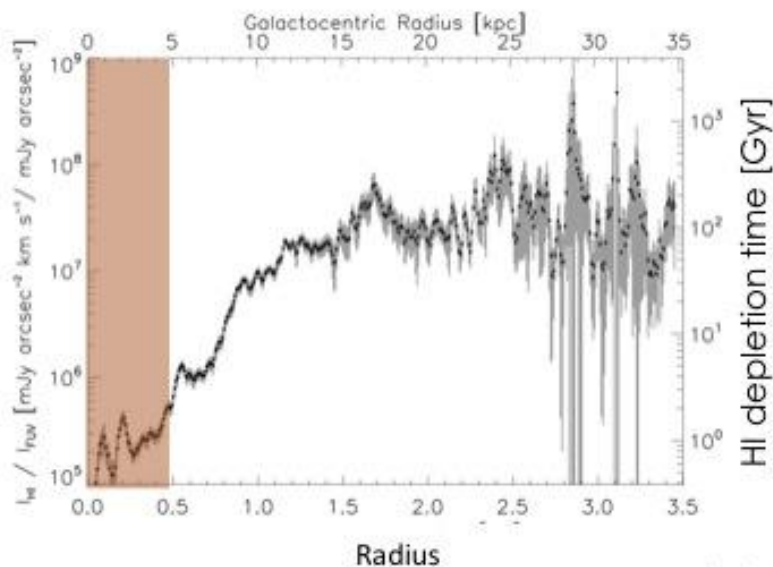
- Leads to ~constant HI depletion time at large radii of ~100 Gyr!

BIGIEL+ '10B

Gas and Star Formation in Nearby Galaxies

HI, H$_2$, and the SFR in Galaxies

- HI can be used to stack CO emission to very high sensitivity

- H$_2$ (CO) nearly fixed ratio with SF tracers, HI steeper, HI+H$_2$ complex

The H$_2$-SFR Relation in Detail

- Good agreement with the literature, different SF tracers

- Breakdown with metallicity (X_{CO}), scale (GMC evolution), and in starbursts

Outer Galaxy Disks

- **Combined inner/outer disk SFR-gas data yields complex distribution (environment!)**

- **Outskirts: HI dep times of order many Hubble times; long-lived massive HI reservoir**