Phases and Processes in the ISM

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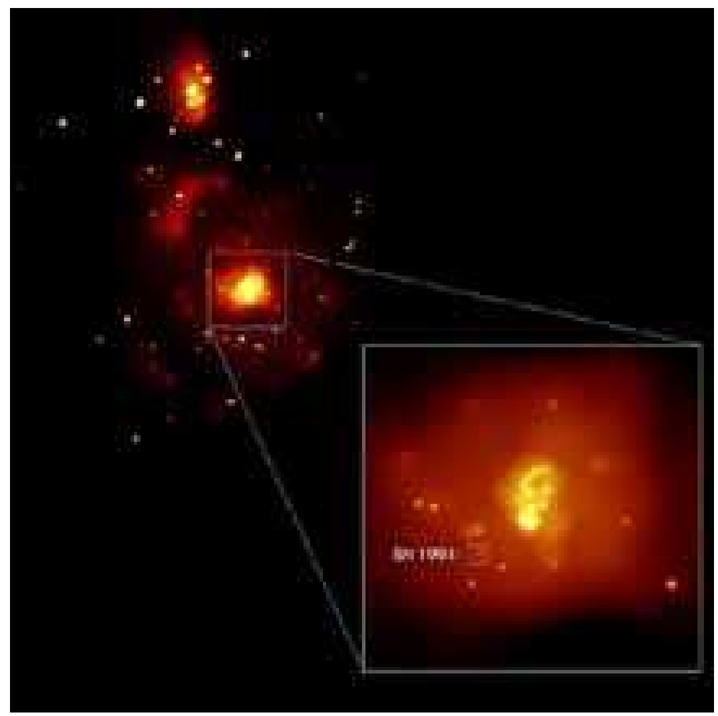
M51

HST

Spitzer

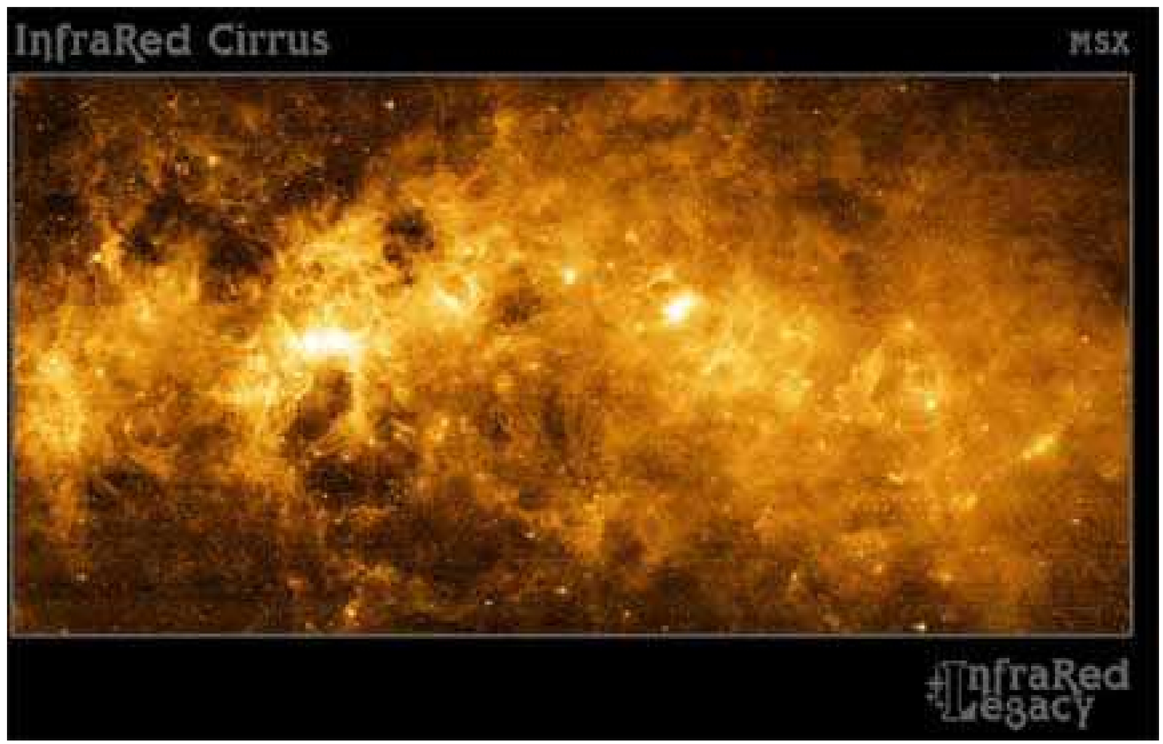
Chandra



Overview

- Phases: temperatures, densities, pressures
- Structures: clouds, shells, filaments, fractals
- Origins: instabilities, explosions, density waves, turbulence
- Star formation follows dense cloud formation
- Great Observatories: close-up views

IC 1396 Spitzer



In the thermal 60's, our understanding of heating and cooling processes for the atomic ISM led to the concept of ISM "phases."

&

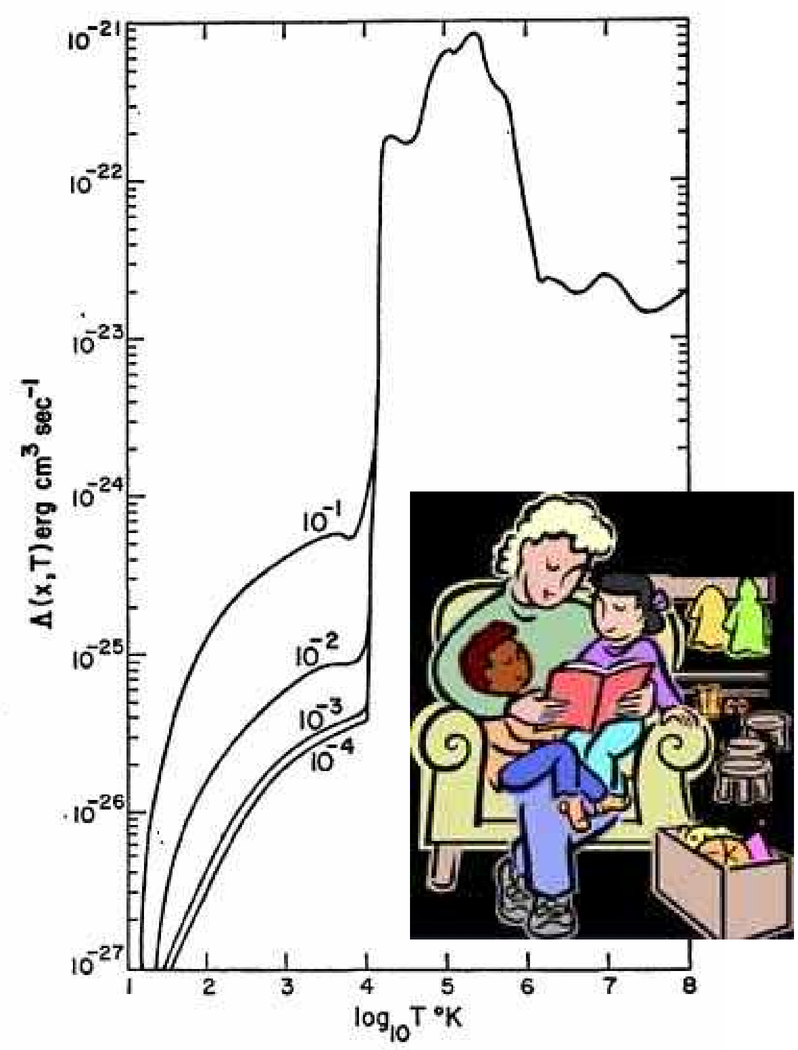
Optical and HI observations of absorption and emission led to the concept of "clouds."

THEN,

In the explosive 70's, a hot phase was added after the prevalence of supernova was appreciated.

&

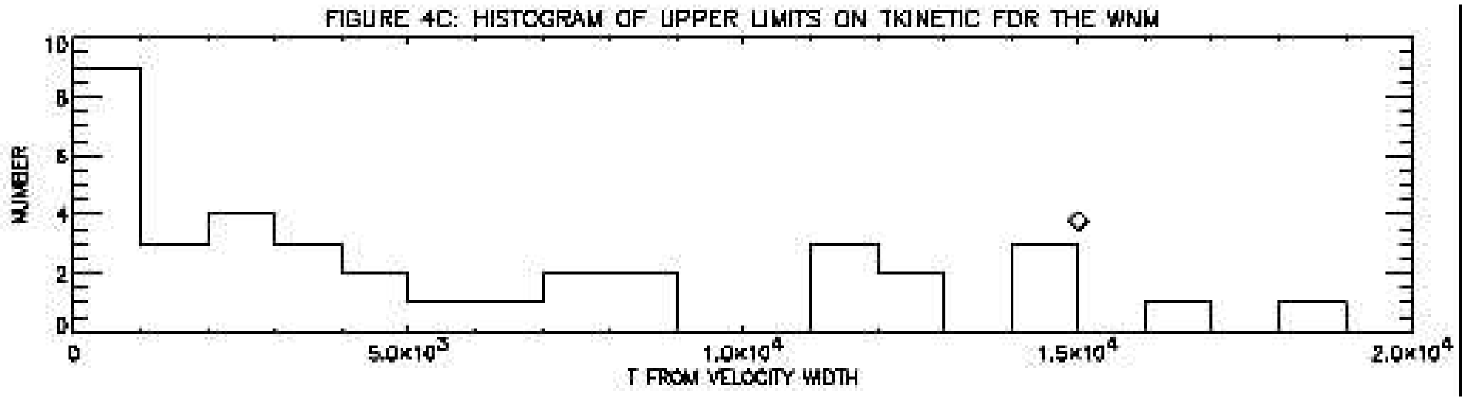
A molecular phase was also added in the 70's after Penzias & Wilson's discovery of mm-wave line emission.



Dalgarno & McCray '72

Heiles' 5 phases (2000, 4th Tetons conference)

- Hot ionized medium: T~10^7K, P/k>20000, n~0.003, f~0.5, shock-heated
- Reynolds' warm ionized medium: T~8000K, P/k>3400, n~0.08, f~0.1, from OB stars
- Warm neutral med.: T~500-8000K, P/k~200-4000, n~0.1-0.4, f~0.5; multiple sources
- McKee-Ostriker warm ionized medium: T,P,n,f same; multiple heat sources
- Cold neutral medium: T~10-75K, P/k~1500-10000, n~20-250, f~0.01, C ionization
- (plus cold, molecular & self-gravitating: T~10-25K, P/k~10^5-10^6, n>10^3, f~0.01)



A high fraction of the WNM is at a temperature that should be thermally unstable.

Phases and Pressure Variations in a Turbulent ISM

- P variations: high in some regions – (Oey & Garcia-Segura 04 from superbubble growth; Jenkins & Tripp 01 from CI fine-structure)
- Halo flows regulate midplane P, so filling factor$_{hot}$~SNR$^{0.363}$ and is generally small (17% for galactic SNR) – deAvillez & Breitschwerdt '04

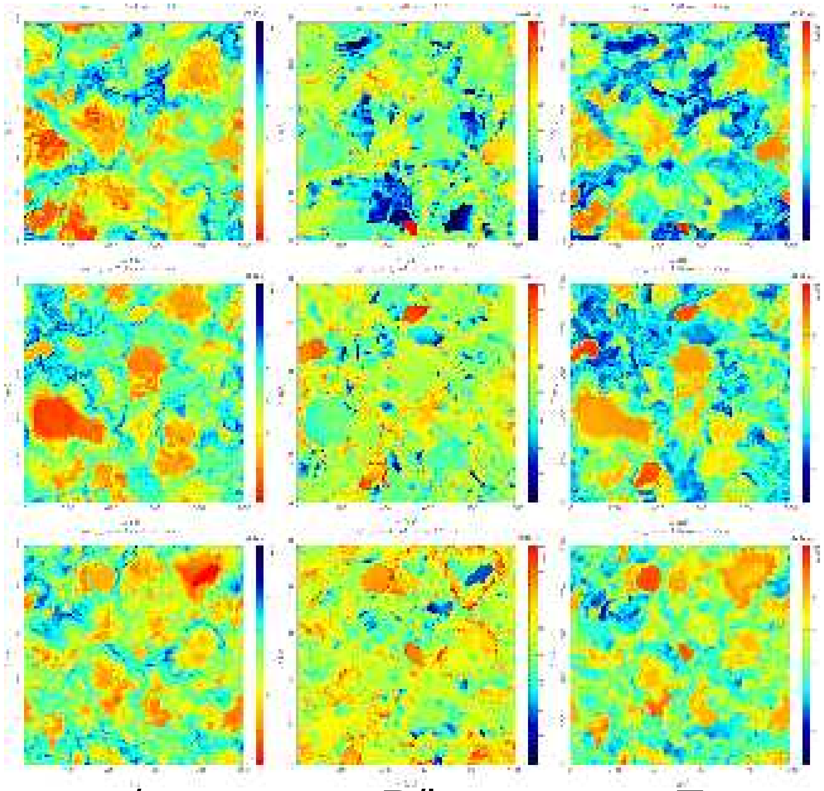
1 kpc^2 in galactic plane

includes starlight heating
which makes T~3000K bistable,
but not magnetic field

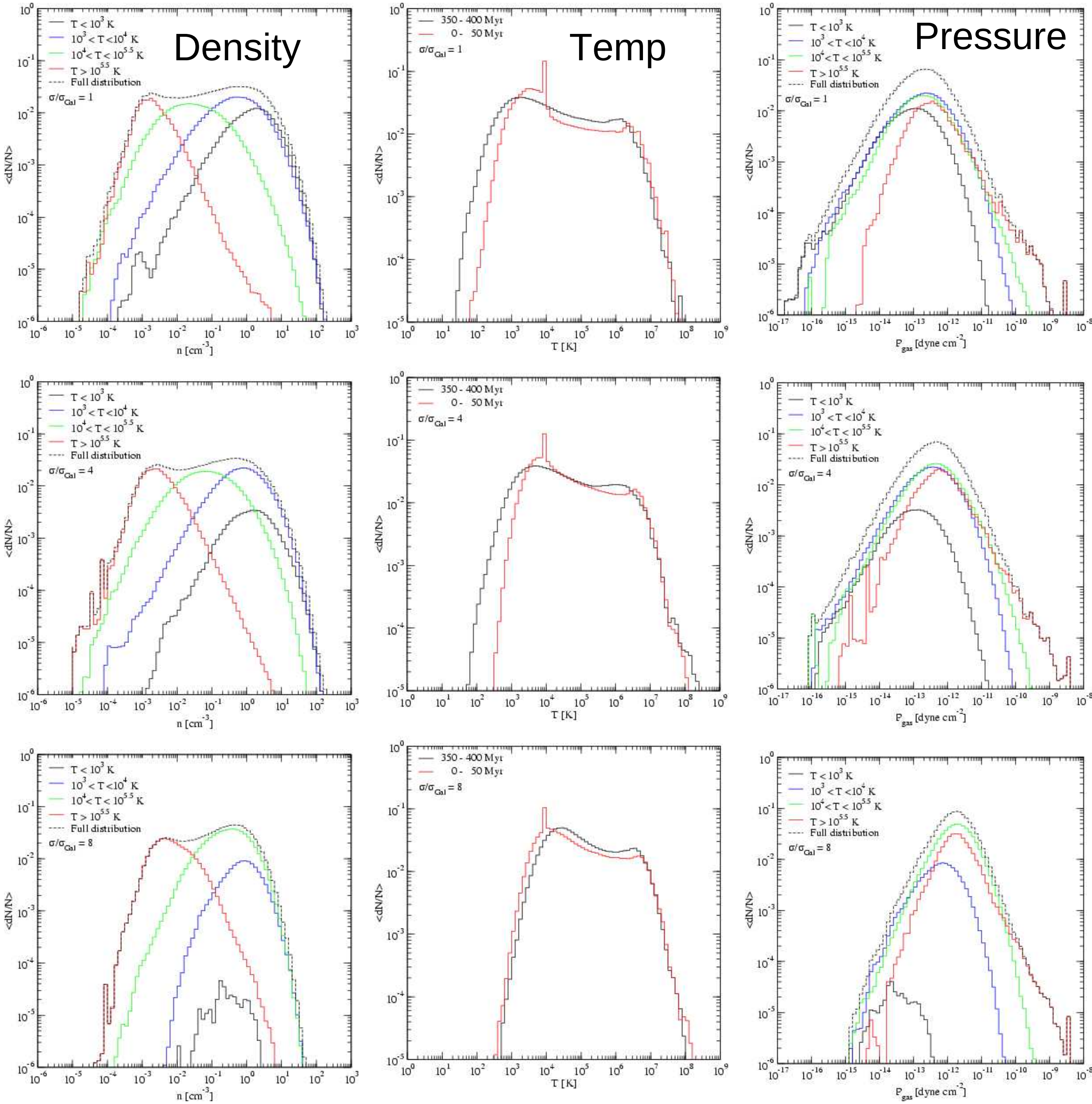
SNR~MW

SNR~2MW

SNR~4MW



ρ/ρ_0 P/k T



SNR~MW

deAvillez & Breitschwerdt ‘04

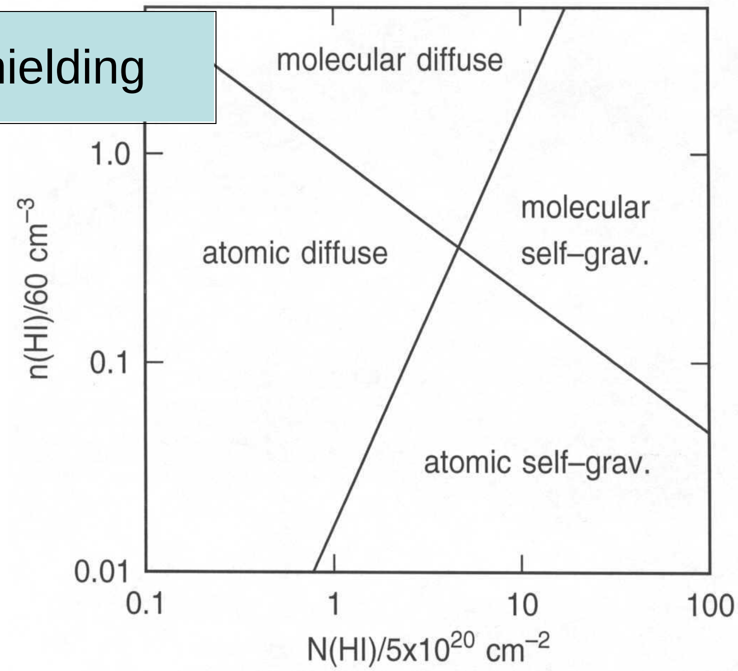
SNR~2MW

SNR~4MW

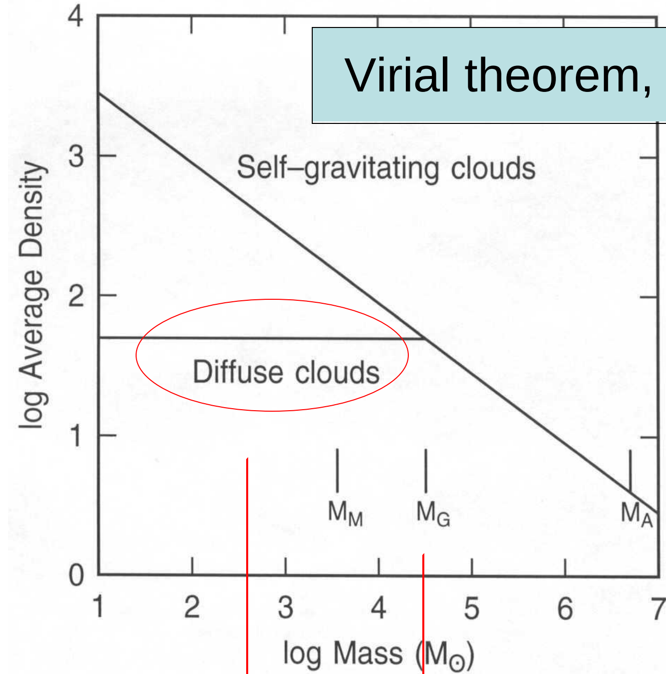
No bistable T – see also Gazol et al 01

Molecular phases: Shielding, Self-gravity

Shielding

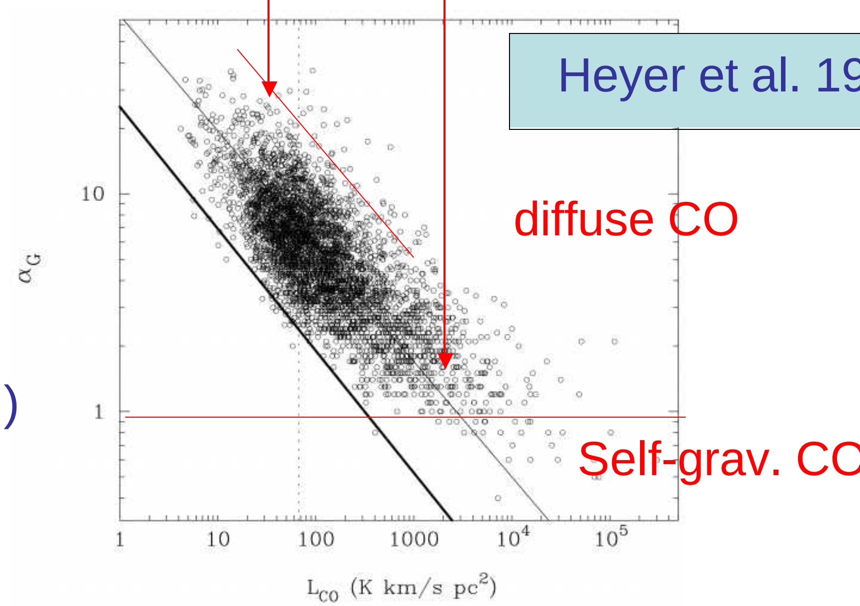


Virial theorem, const. P



Elmegreen 1995 7th
Guo Shoujing School

Heyer et al. 1998



atomic diffuse (low n, low N)
molecular diffuse (nigh n, low N)
atomic self-gravitating (high N, high M)
molecular self-gravitating (high N)

Radial profiles in galaxies

- CO/HI decreases with distance (e.g. Heyer et al. ‘04, Blitz et al. ’04 for M33; … Sofue et al ‘95)
    - lower P and Z make proportionally less diffuse molecular gas
- Thermal temp of cool diffuse HI gas increases slightly with distance (Braun ‘95, ‘97).
    - lower Z decreases coolants
- Fraction of HI in cool diffuse phase decreases with distance (Dickey et al. 1990; Braun ‘97)
    - low P, coolants favors warm equilibrium phase of HI
- Extragalactic ionization cuts off outer HI disk at $N \sim 10^{19.5}$ cm^{-2} (Maloney 93, Corbelli & Slapeter 94, Dove & Shull 94)
- Filling factor of hot gas increases with z
    - fountains, superwinds, greater scale height of hot gas
- Turbulent velocity dispersion decreases with distance (Boulanger \& Viallefond 1992).

How do these generalities hold up under detailed inspection using HST, Spitzer, and Chandra?

M51, Spitzer
3.6, 4.5, 5.8, 8.0 mu

M51, HST

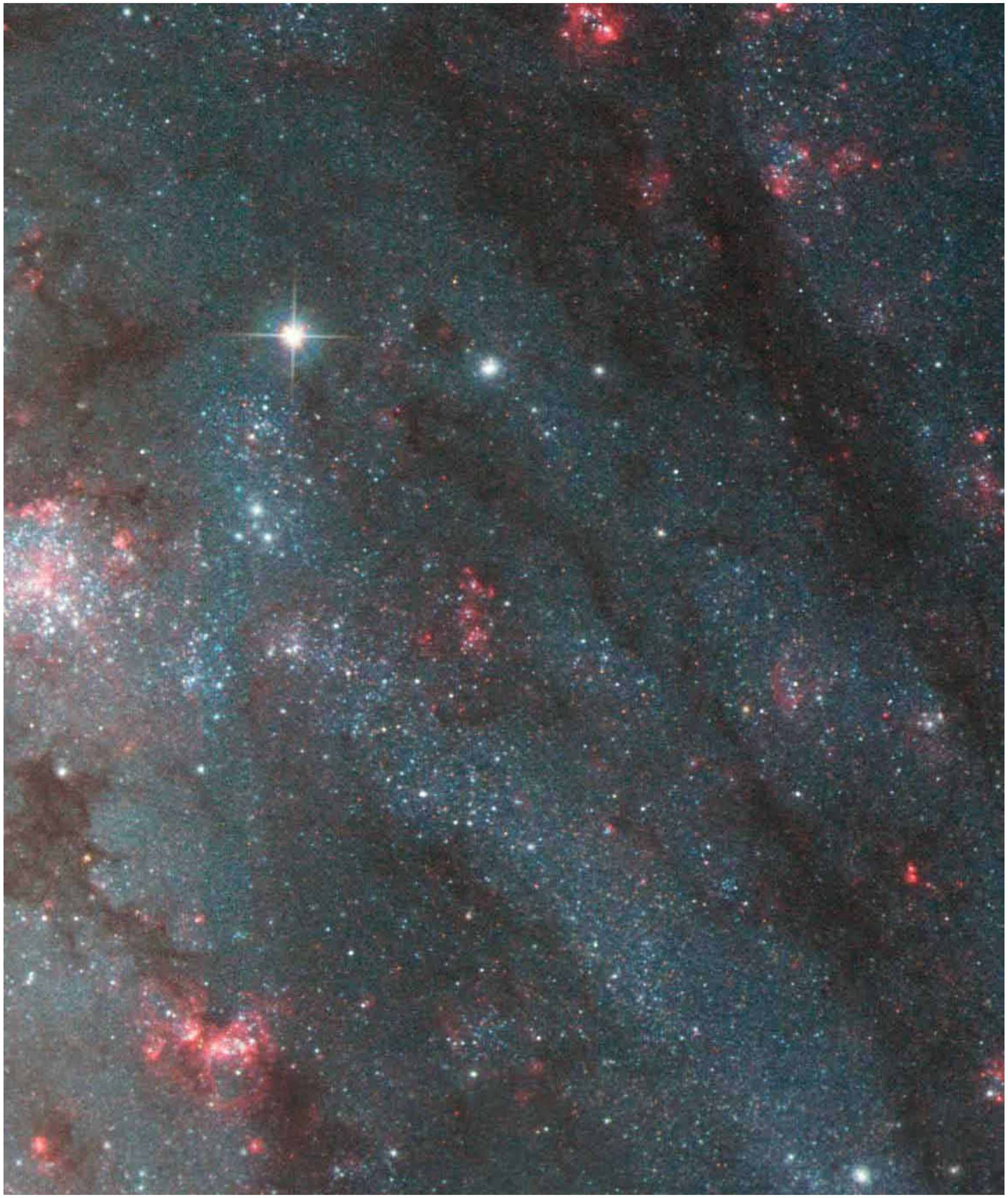
M51, HST: central disk

high shear, tidal forces,
sub-threshold N,
strong radiation field,
what makes holes?

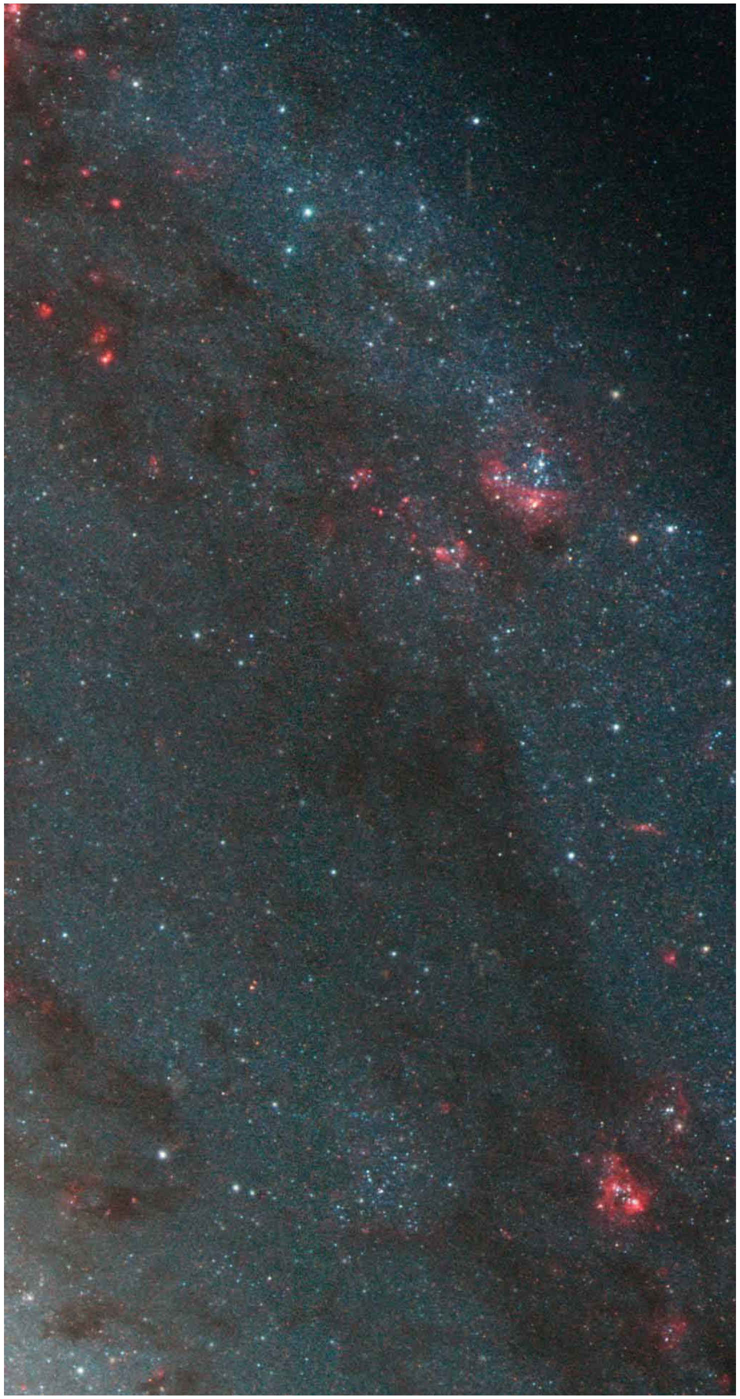
ambient radiation pressure?

stellar winds? turbulence?

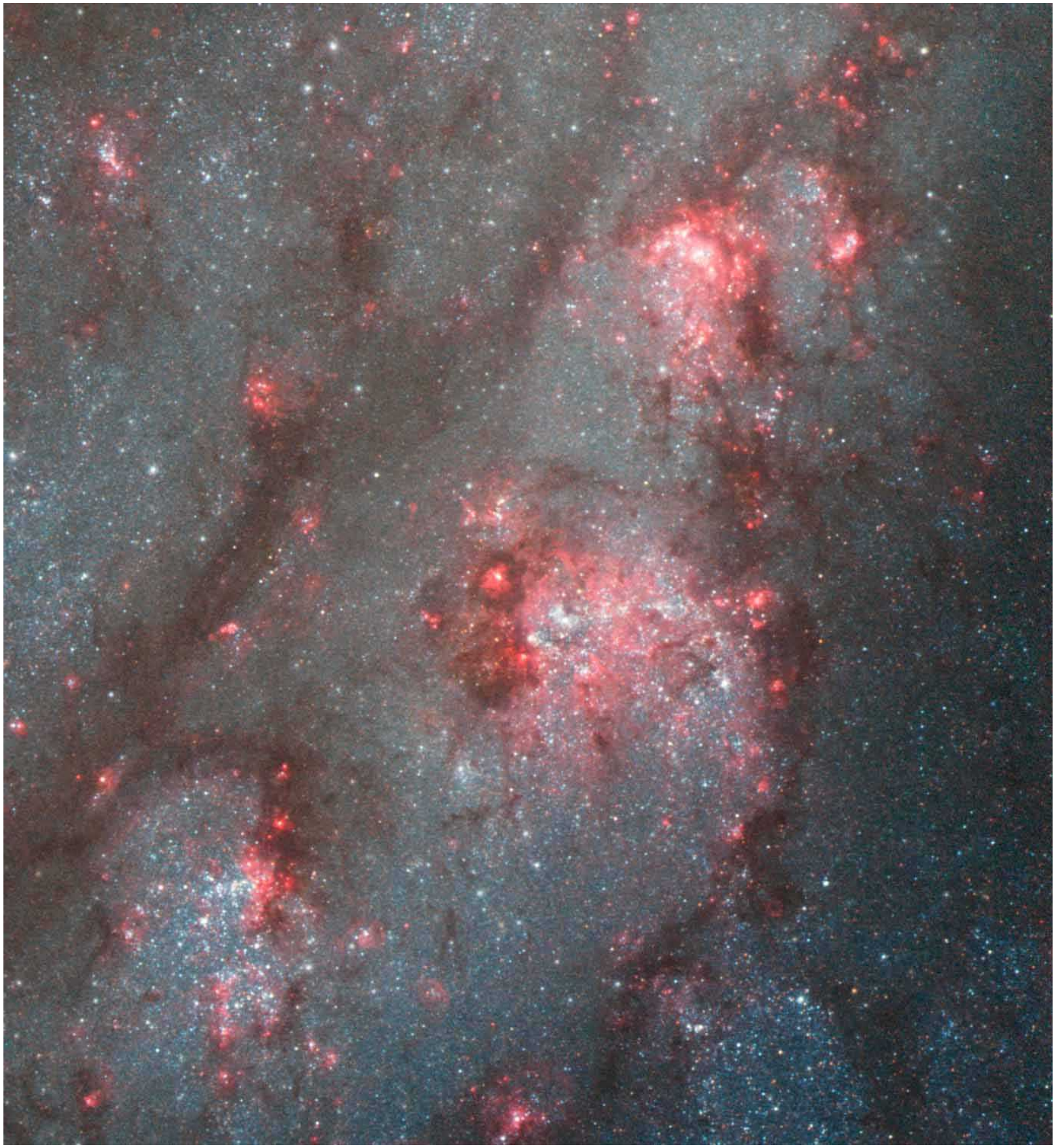
M51, HST western spur



M51, HST
western
outer arm



M51, HST
southern
middle arm

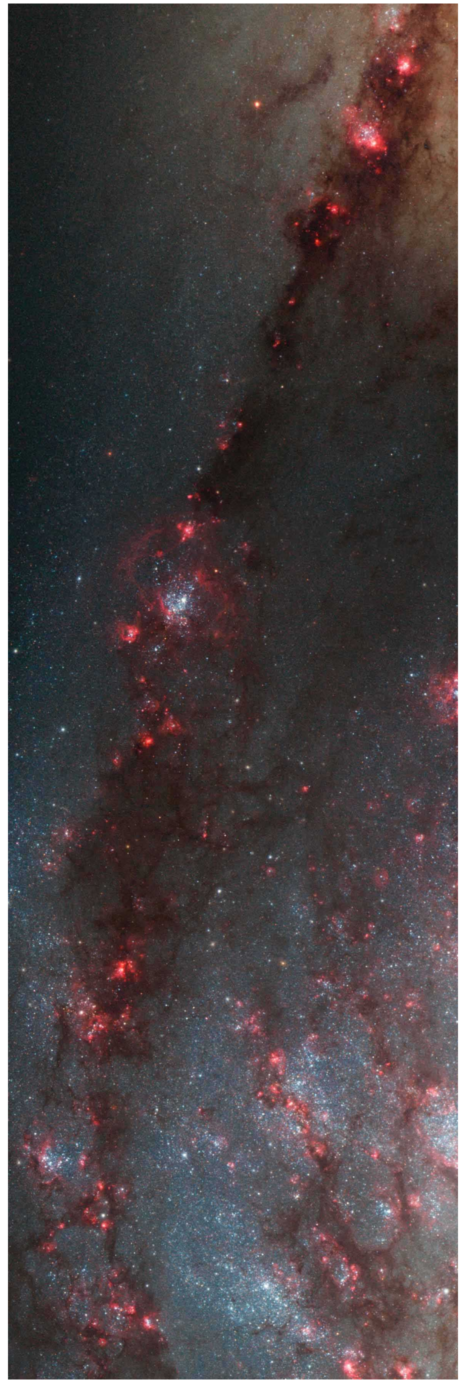


M51, HST
eastern
spur

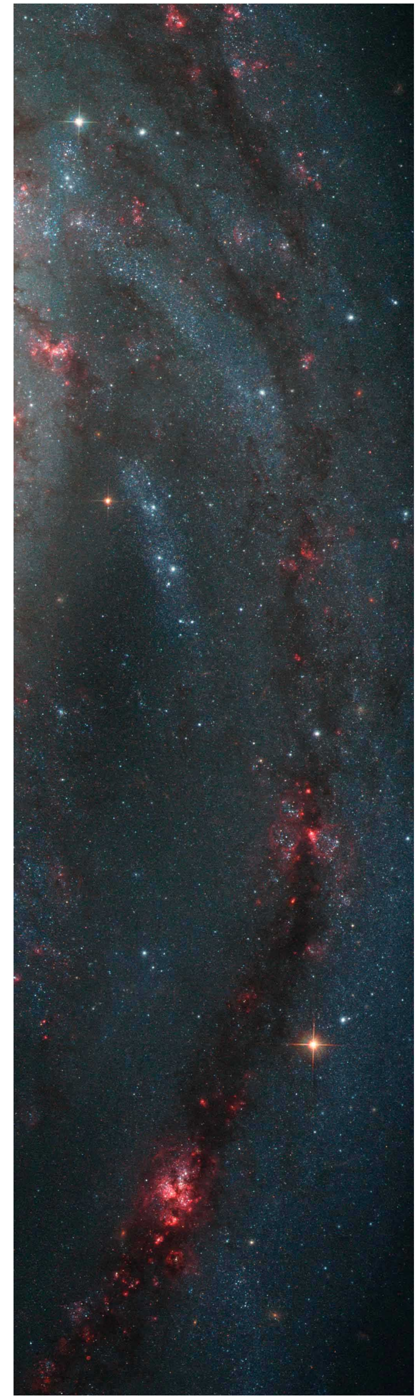
M51, HST
northern
middle arm

M51, HST
tidal arms

N



S



Arm to arm sequence:

1. dust lane formation

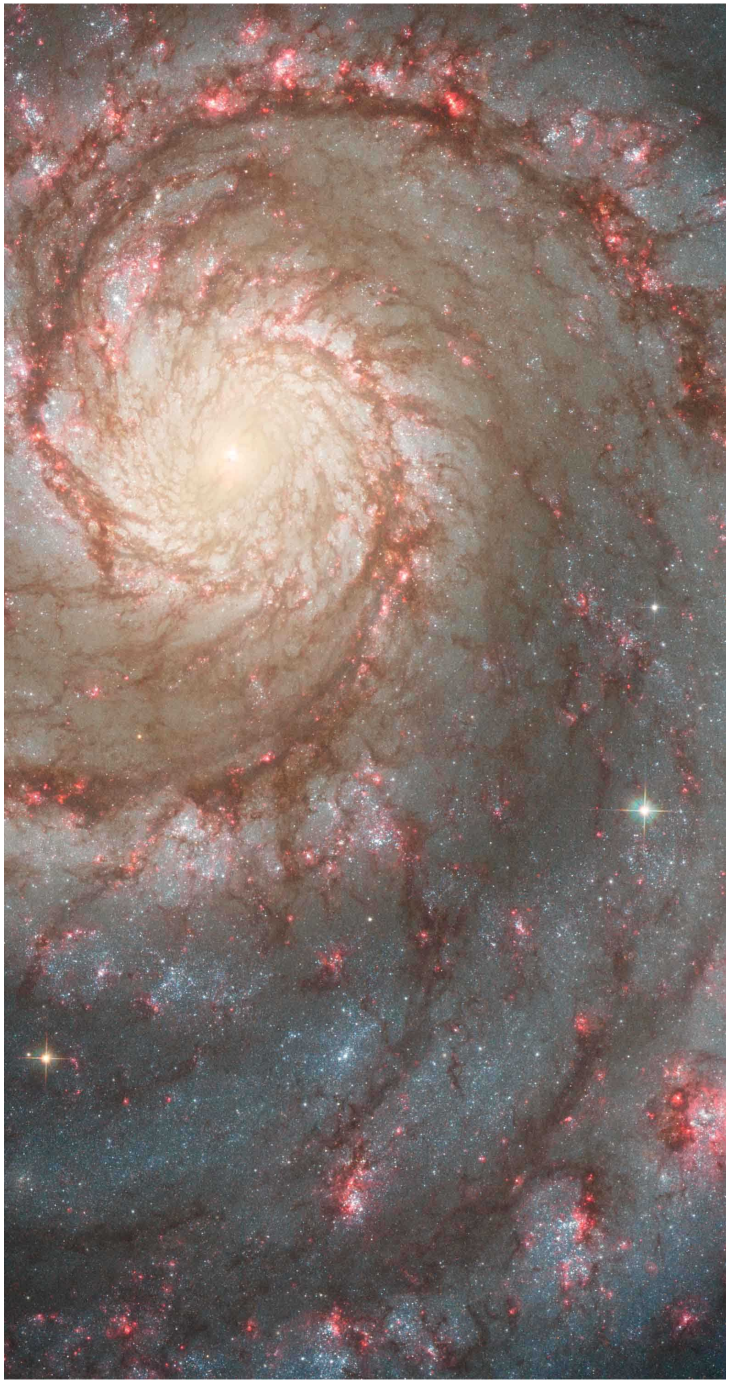
2. dust lane collapse

3. downstream feathering

4. cloudy debris

5. shell formation

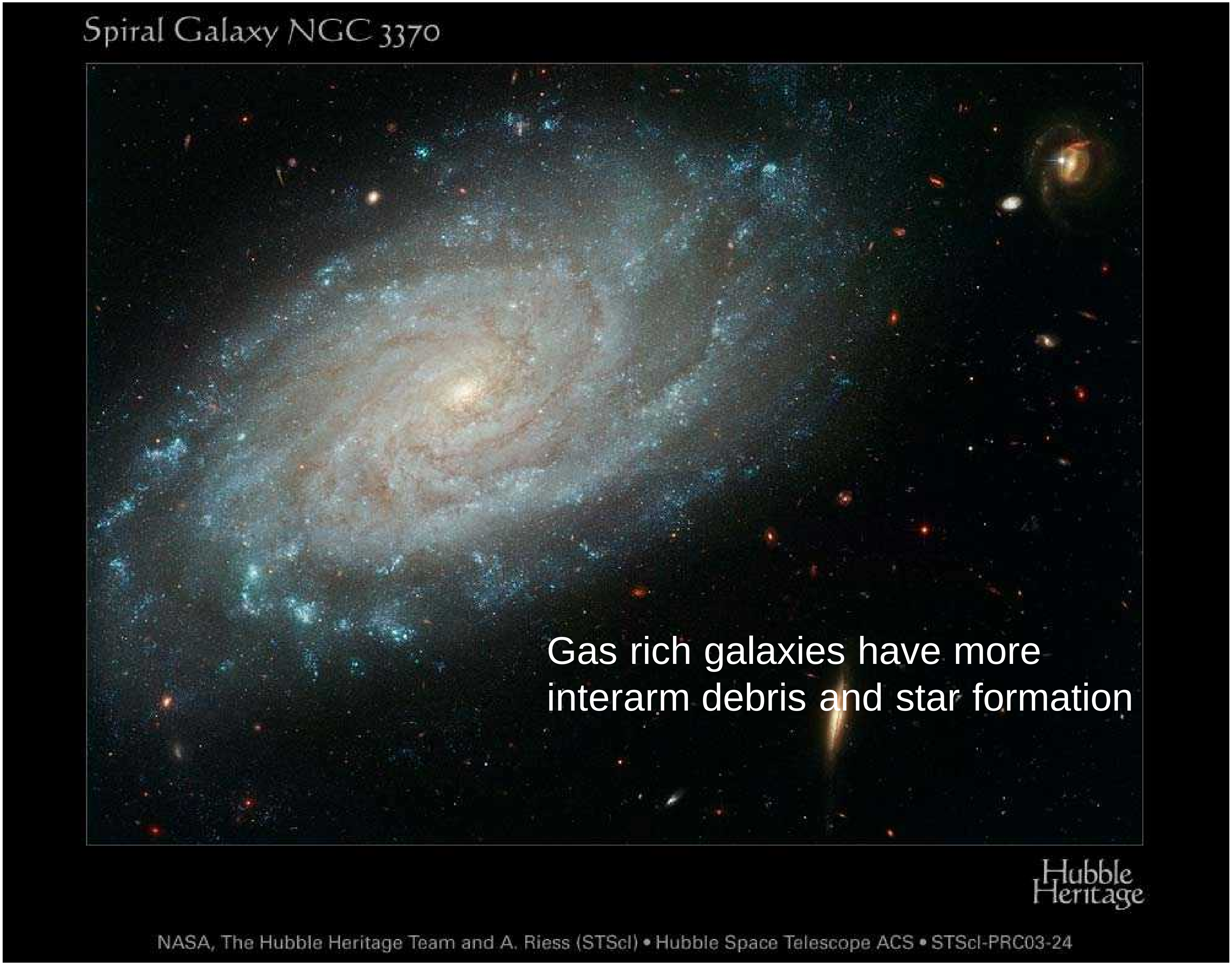
6. diffuse clouds

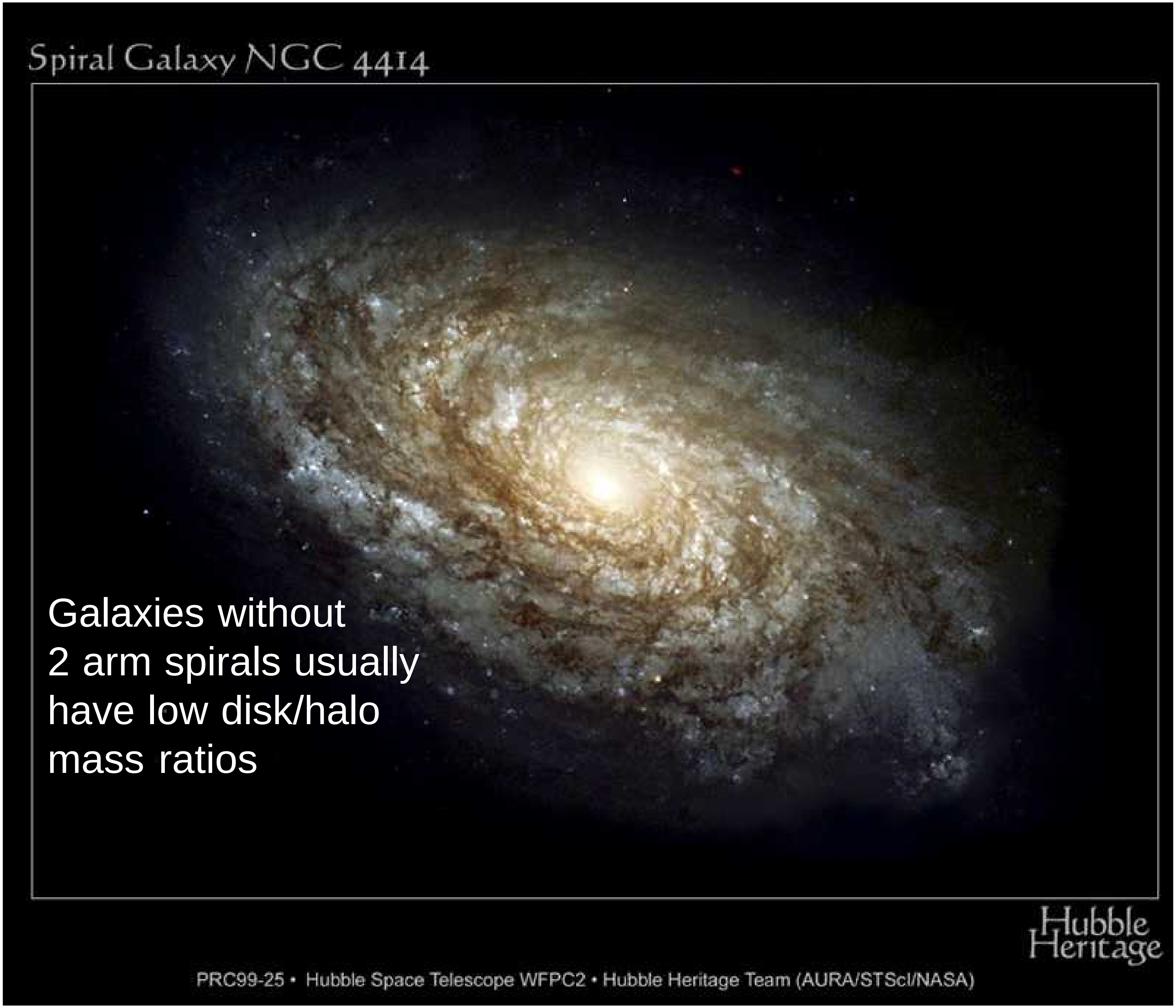


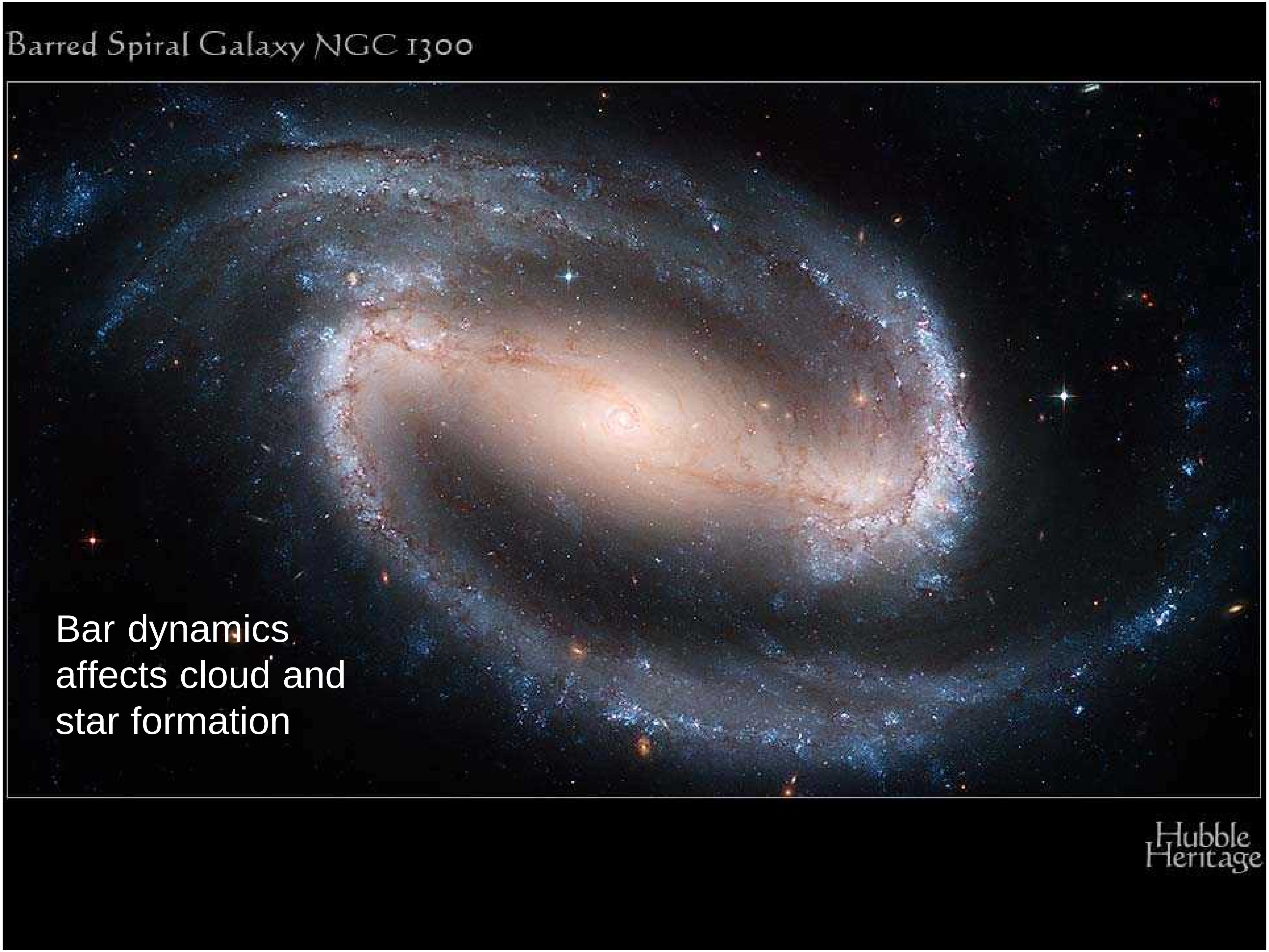
Dark clouds in HST are emission regions at IR

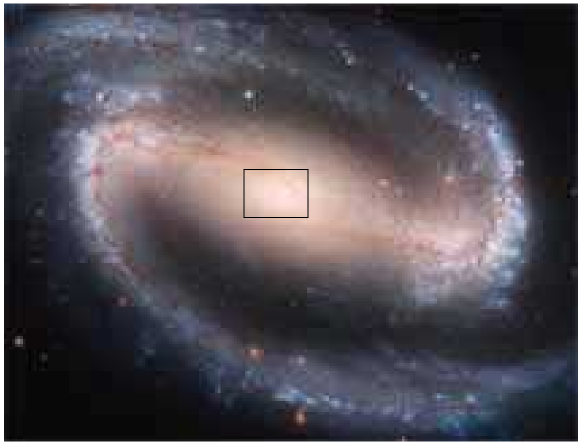
M51, Spitzer
Legacy
3.6, 4.5, 5.8, 8.0 microns

Lingering SF or triggering in debris fields

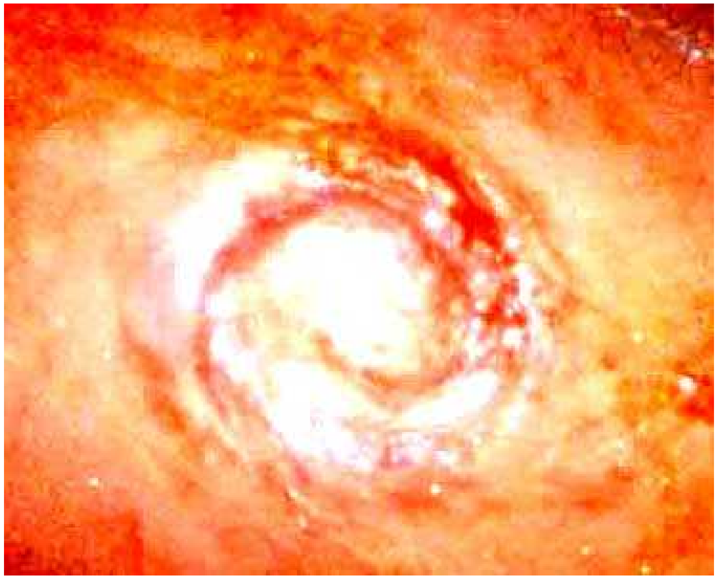

Spiral Galaxy NGC 3370
Gas rich galaxies have more
interarm debris and star formation
Hubble Heritage
NASA, The Hubble Heritage Team and A. Riess (STScI) • Hubble Space Telescope ACS • STScI-PRC03-24

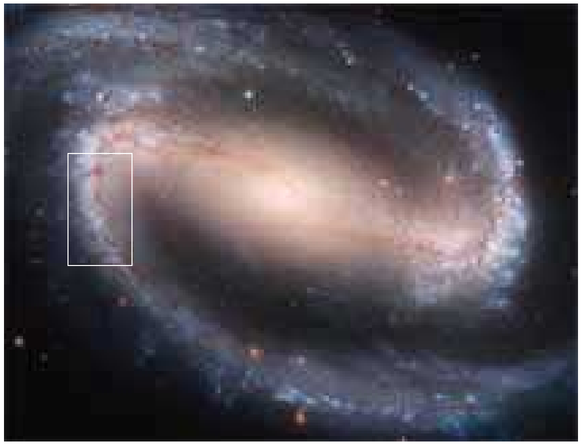

Spiral Galaxy NGC 4414
Galaxies without
2 arm spirals usually
have low disk/halo
mass ratios
Hubble Heritage
PRC99-25 • Hubble Space Telescope WFPC2 • Hubble Heritage Team (AURA/STScI/NASA)


Barred Spiral Galaxy NGC 1300
Bar dynamics affects cloud and star formation
Hubble Heritage



NGC 1300
center ring at bar resonance

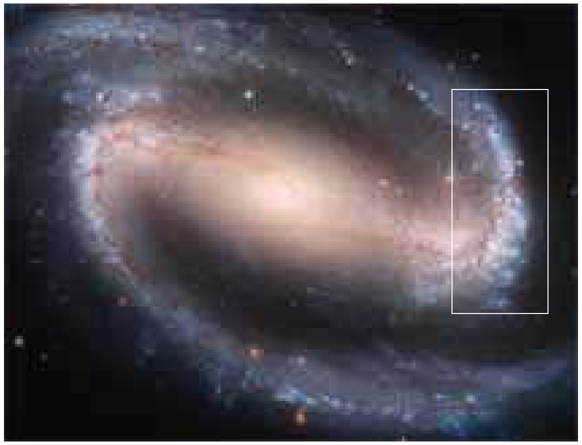




Dust lane much more open.
Gas density lower.
Little feathering.

N1300 outside corotation.

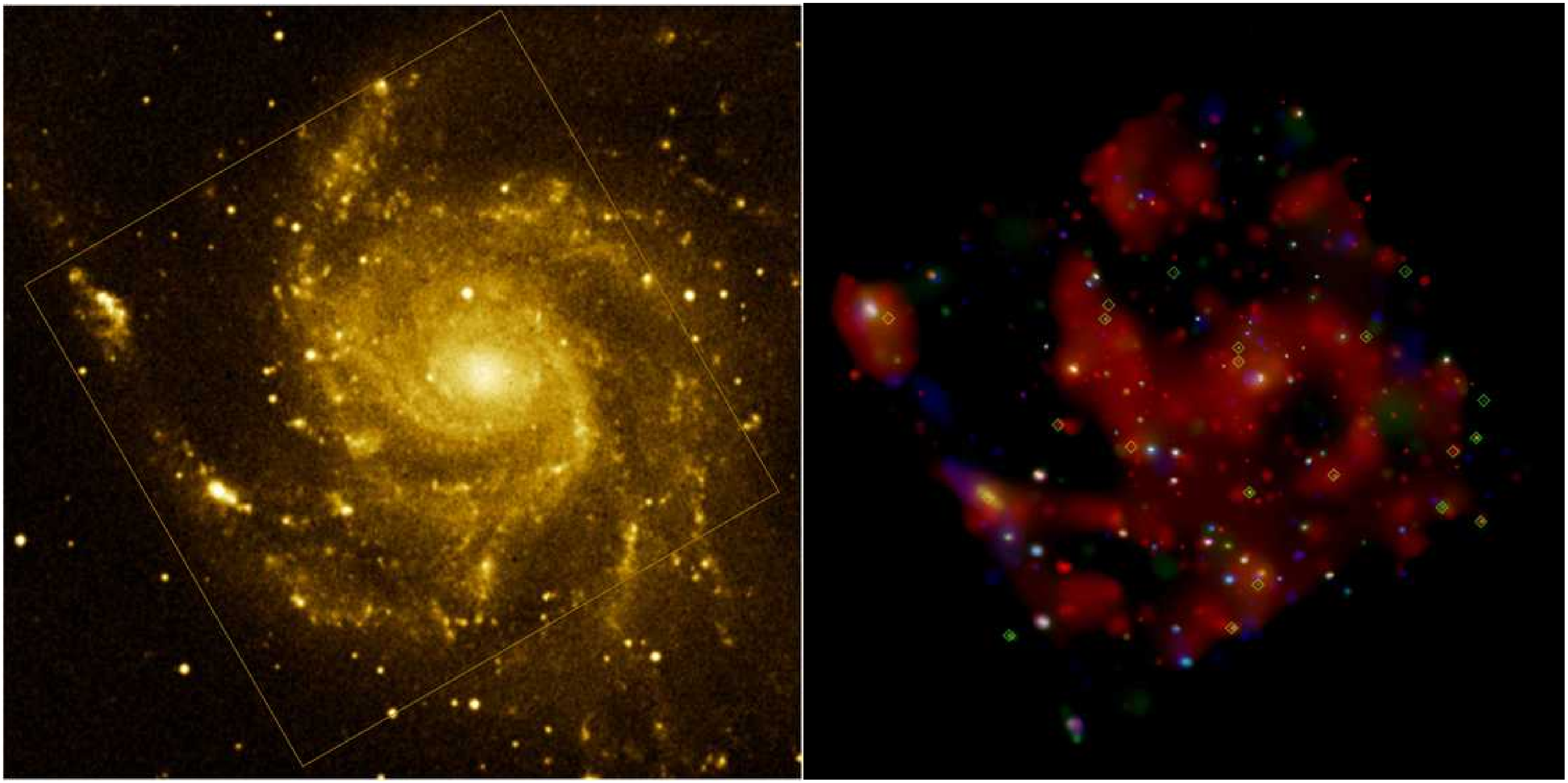
NGC 1300 inner dust lanes diffuse because of shear and tidal forces



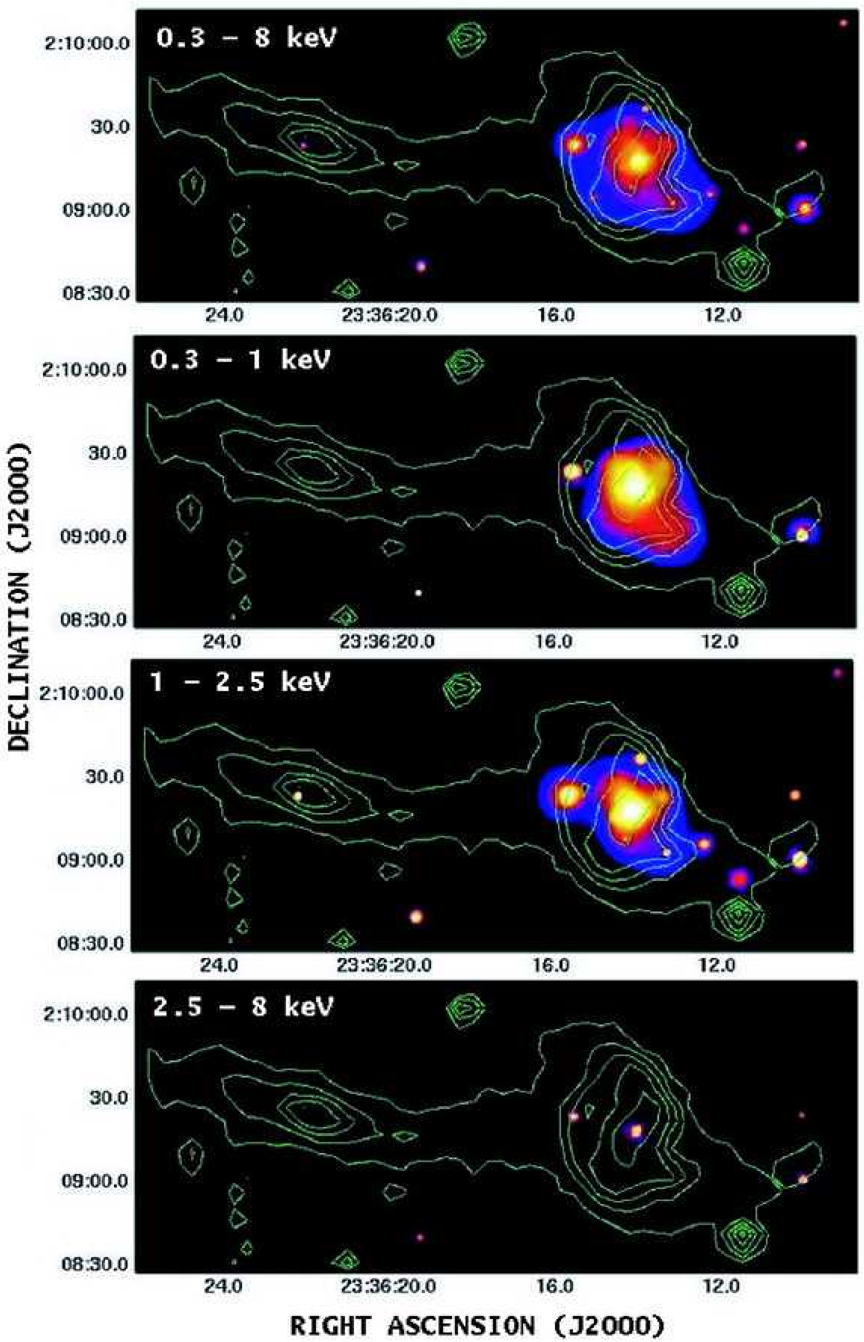
Enhanced SF at end of bar.

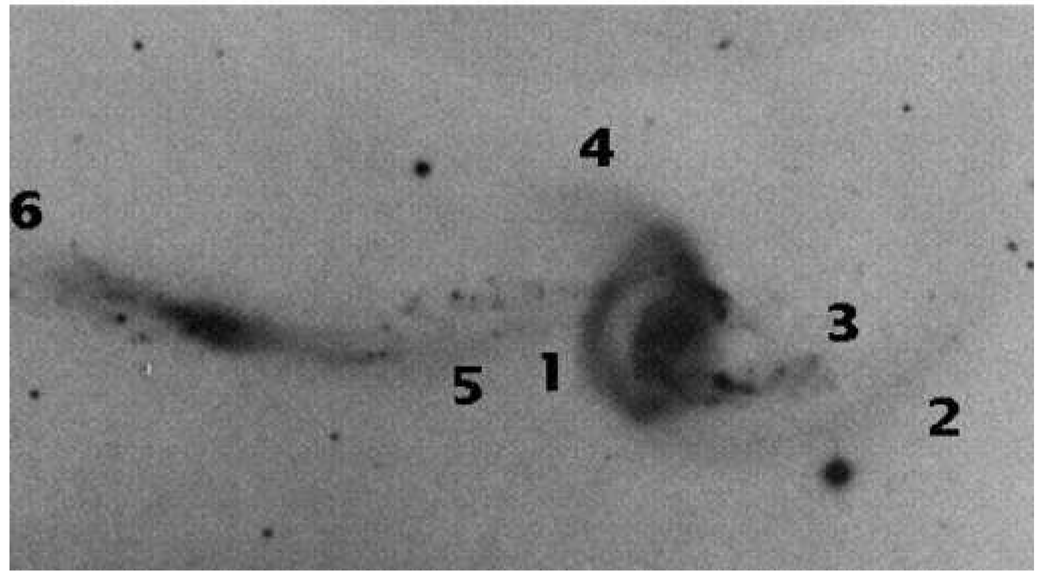
crowding effect?

co-rotation effect?



M101: optical and Chandra
x-ray is patchy, follows star formation



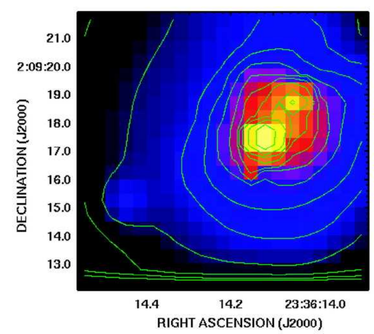


X-ray emission from nuclear region of interacting galaxy NGC 7714

-SNR possible energy source
-superwind evident
-2nd pt source in nucleus ~ SSC

(Smith, Struck & Nowak 05)

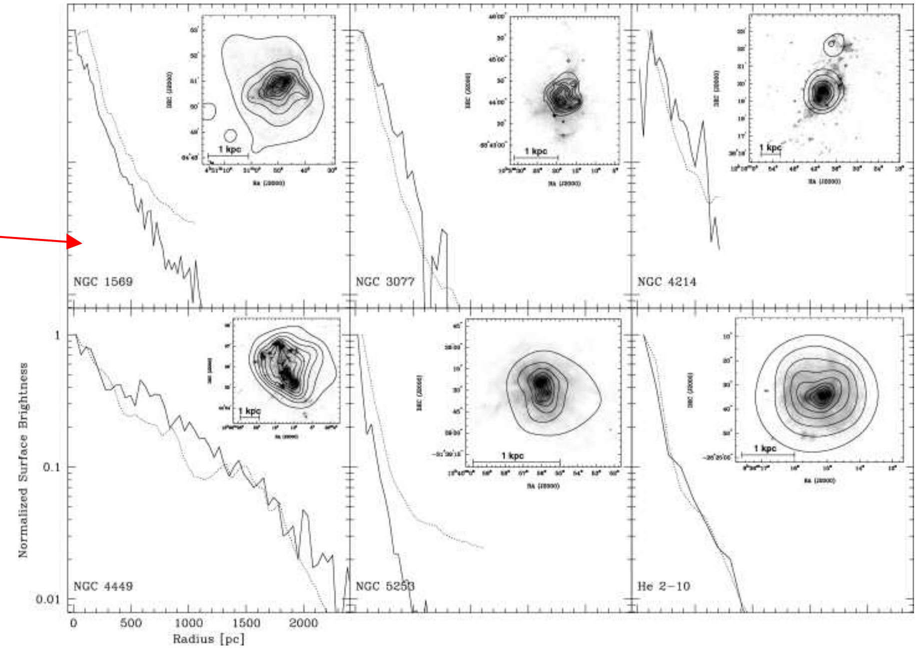
CHANDRA images

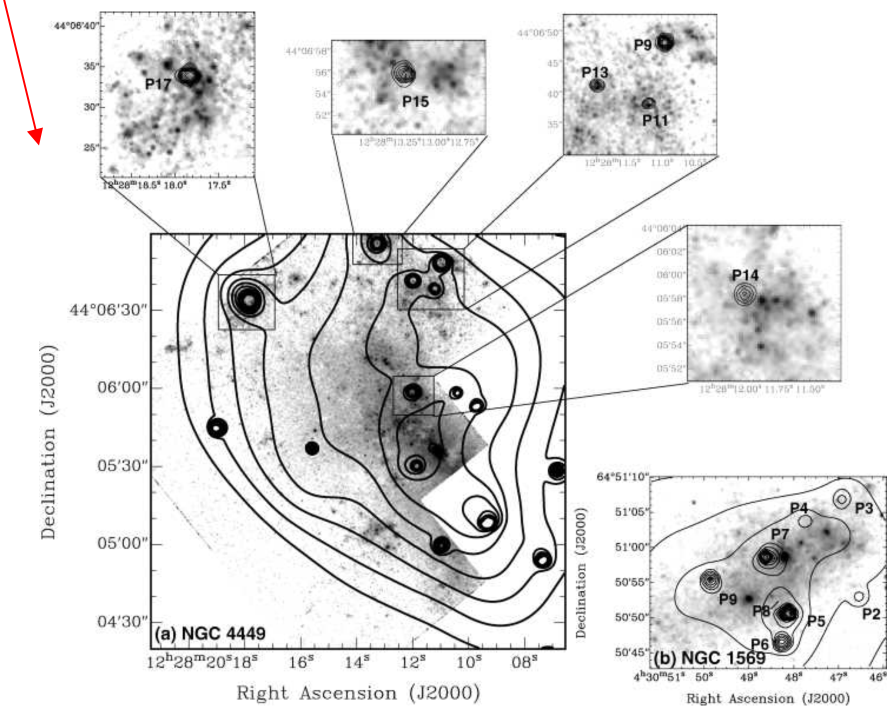


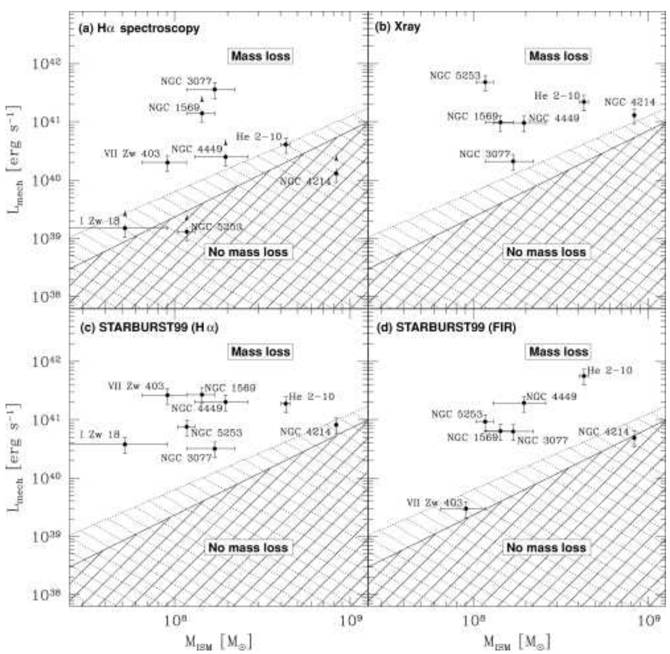
A study of XR and SF in 6 dwarf galaxies (Ott, Walter, Brinks 05) shows a correlation between them

SF regions also contain XR point sources in proportion to the SFR

The XR emission suggests a superwind







Conclusions

- ISM “phase” depends on thermal heating and cooling
  - starlight, atomic/molecular processes, grains, shocks, cosmic rays, …
- ISM “structure” depends on its motion, which is generated by different energy sources than its “phase”
  - supernovae, self-gravity, ionization, turbulence, spiral arms, …
- ISM structure varies within a galaxy and from galaxy to galaxy
  - SDW-dominated galaxies produce lots of spiral filaments and timed evolution of young stars (SDW triggering, dispersal, debris triggering…)
  - Barred galaxies produce end-of-bar enhancements, inner rings, corotation stagnation zones, stable bar dust lanes etc.
  - P,n,N,Z,G_{uv},B, …, κ … variations determine ease of conversion of ISM gas from diffuse to self-gravitating to stars.
  - above the Toomre/Kennicutt threshold, SF is easy, unavoidable, and as fast as possible, i.e., always at the dynamical rate → Schmidt $n^{1.5}$ law.
- Great Observatories see structure (HST), thermal states and embedded stars (*Spitzer*), hot gas and hot energy sources (*Chandra*)