Astrophysical dynamics - Hot topic seminars

STARBUST GALAXIES

Starbust galaxies

1. Overview
   1.1. Definition
   1.2. Observations
   1.3. Facts and statistics
2. Triggering mechanisms
   2.1. Interactions and mergers, a story of love and hate
   2.2. Instabilities, here you are!
   2.3. Influence of bar and bulge
3. Simulations

M82 galaxy

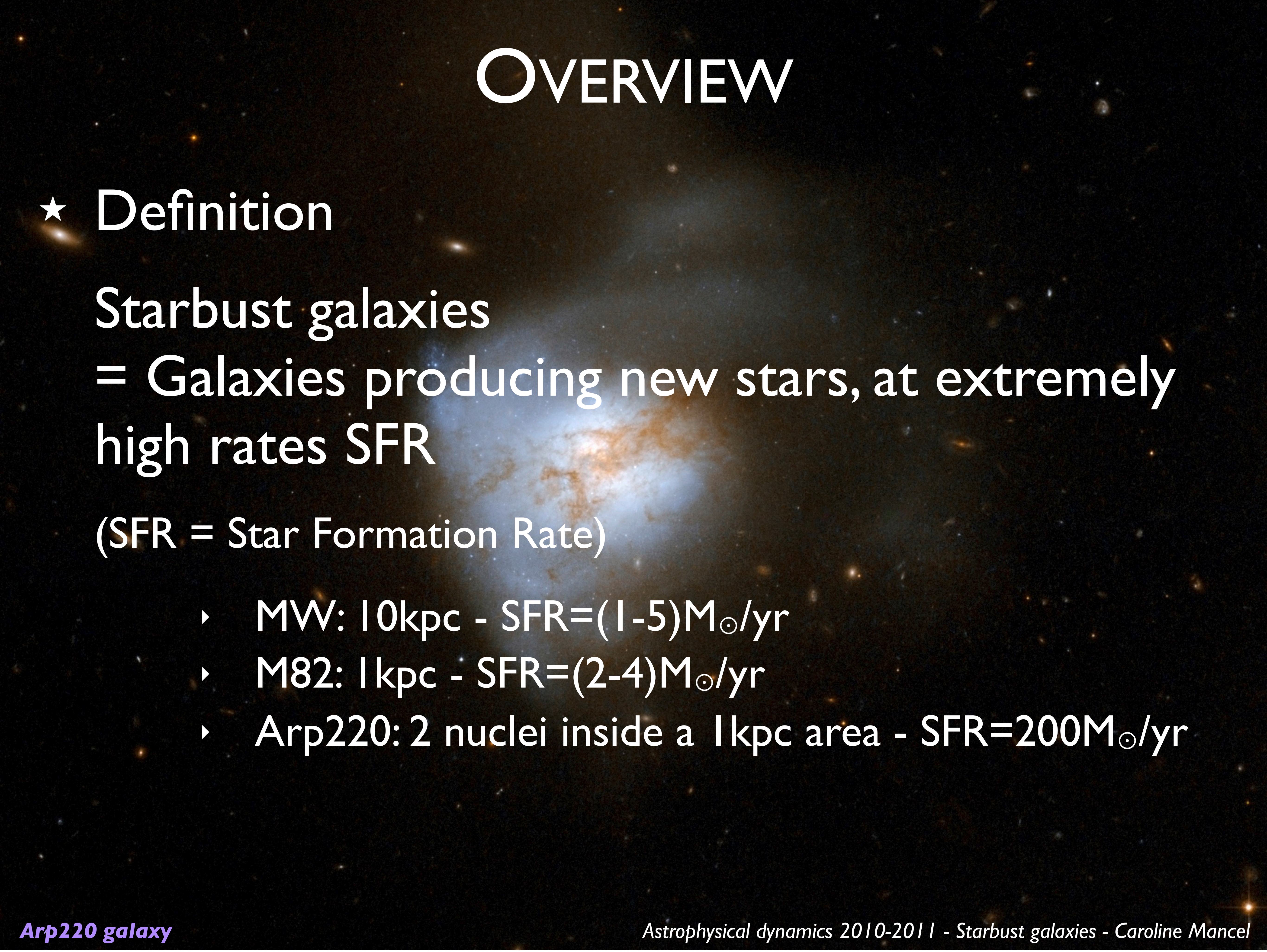
OVERVIEW

- Definition

  Starbust galaxies
  = Galaxies producing new stars, at extremely high rates SFR

  (SFR = Star Formation Rate)

  - MW: 10kpc - SFR=(1-5)$M_{\odot}$/yr
  - M82: 1kpc - SFR=(2-4)$M_{\odot}$/yr
  - Arp220: 2 nuclei inside a 1kpc area - SFR=200$M_{\odot}$/yr



Arp220 galaxy

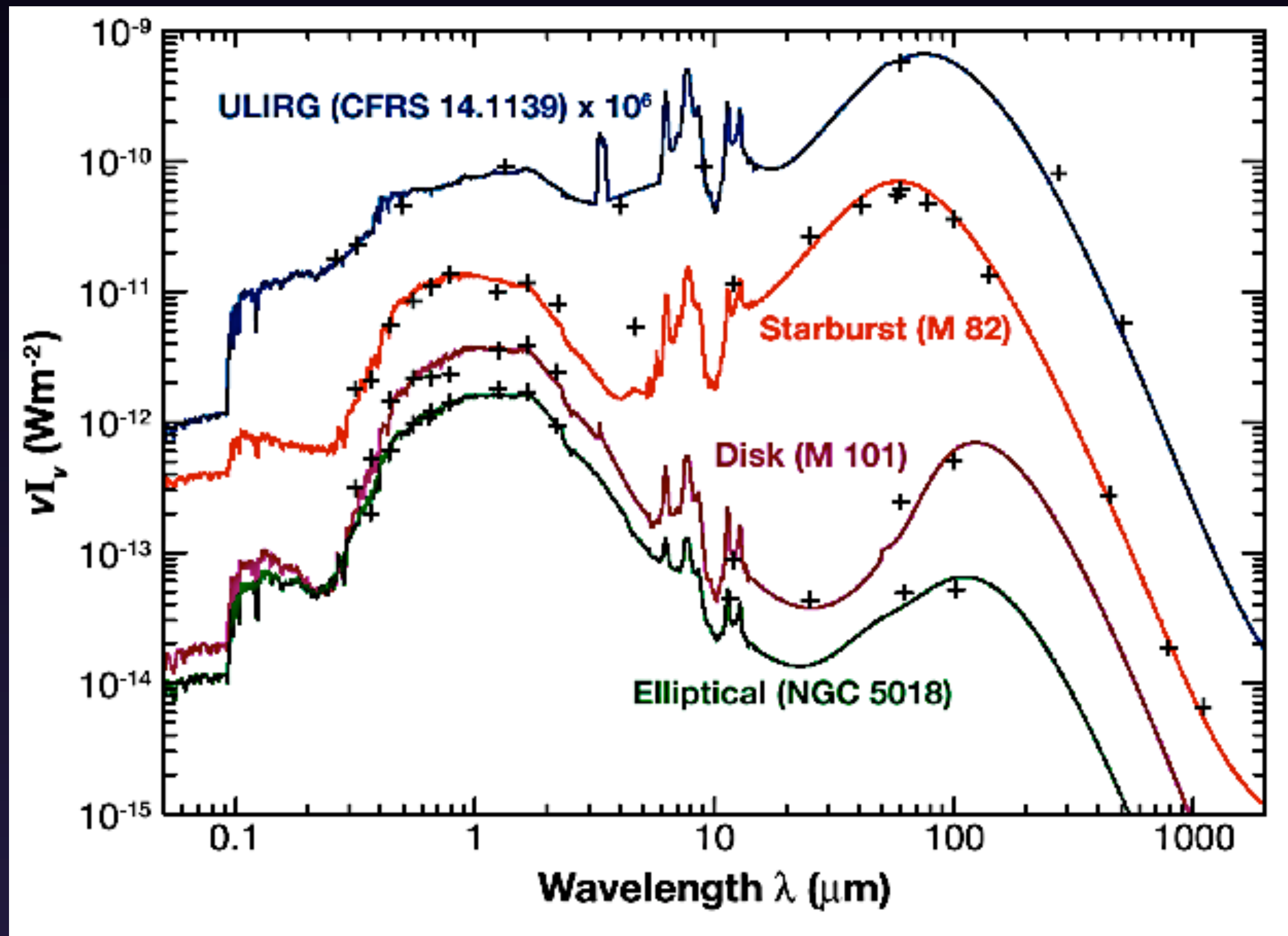
Overview

⋆ Observations - The symptoms

- Optical spectra
  - Strong emission lines of H & other ionized elements
  - Broad line widths
- IR - FarIR spectra
  - Very high luminosities

    MW: $L_{FIR} \sim 10^{10} L_\odot$

    Starburst G: $L_{FIR} \geq 10^{11} L_\odot$
- Radio spectra
  - Strong continuum emission



Overview

- ⋆ Observations - What do they tell us?

  - Strong radio continuum emission
    = Presence of many high-mass blue stars

  - High IR - FarIR luminosities
    = Re-radiation of UV by abundant surrounding dust

Overview

- ⋆ Facts and statistics
  - *When* are starburst triggered?

    - Most of them result from interacting/merging galaxies

    - Ultraluminous activity is not always a feature of strongly interacting galaxies

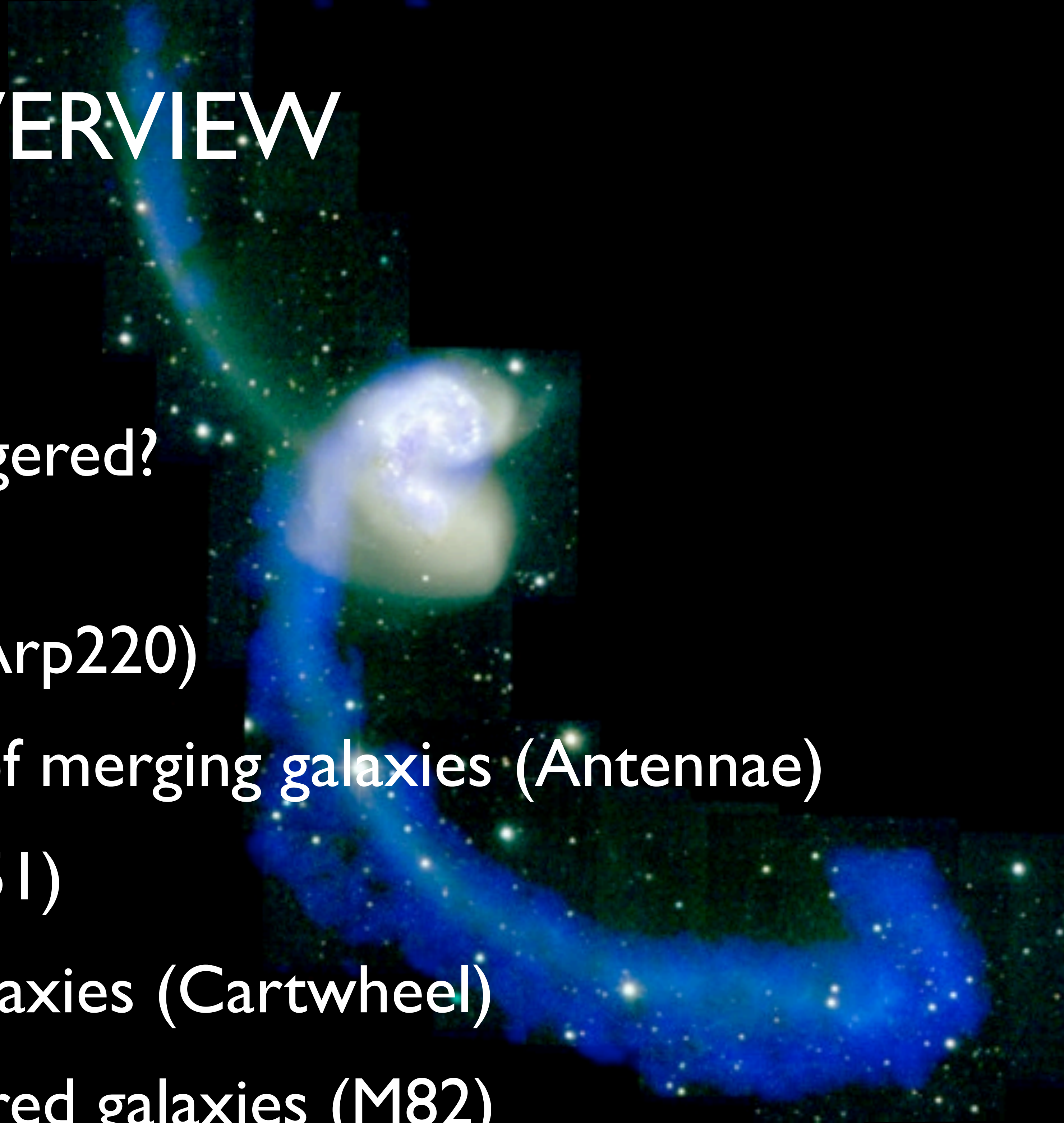
    - Quite rare phenomenon

    - More common in the past (high-redshift galaxies)

    - Short time duration: SFR is so high that the fuel (cold gas) is used up very quickly

Overview

- ★ Facts and statistics
  - *Where* are starburst triggered?
    - In nuclei of galaxies (Arp220)
    - Overlapping regions of merging galaxies (Antennae)
    - Bright spiral arms (M51)
    - Collisional rings of galaxies (Cartwheel)
    - Resonant rings of barred galaxies (M82)



Antennae galaxy

OVERVIEW

- Facts and statistics
  - Global gravitational instabilities of gas disk

Kennicutt law $$\Sigma_{SFR} \propto \begin{cases} \Sigma_{gas}^{1.4} \\ \Sigma_{gas} \cdot \Omega_{gas} \propto \dfrac{\Sigma_{gas}}{t_{dyn}} \end{cases}$$

  - Intuition given by local gravitational instabilities

$$\rho_{SFR} \propto \frac{\rho_{gas}}{t_{free-fall}} \propto \rho_{gas}^{1.5}$$

  - Statistics (observations) = Kennicutt law

So... What happens?

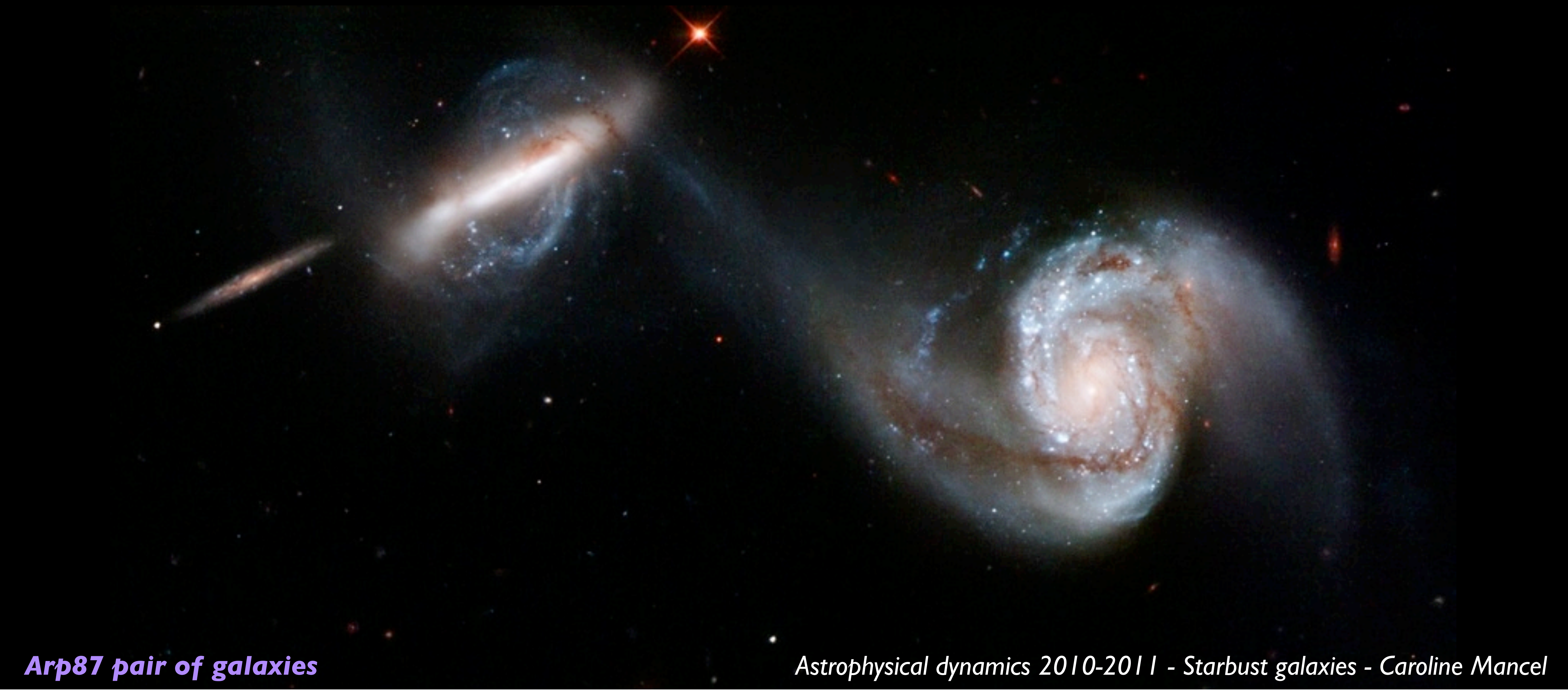
What are the triggering mechanisms?

TRIGGERING MECHANISMS

- ★ The need for fuel, ie molecular gas
  - Interactions between galaxies is an usual feature of galaxies' evolution
    - Distance btw galaxies ≳ Size of galaxies
  - Stars do not collide much...
    - Distance btw stars ≫ Size of stars
  - ... But gas is strongly perturbed
    - Tidal forces
    - Gravity torques
    - Increased gas turbulence
    - Increased number of shocks

TRIGGERING MECHANISMS

- Formation of tidal features
  - Bridges



Arp87 pair of galaxies

TRIGGERING MECHANISMS

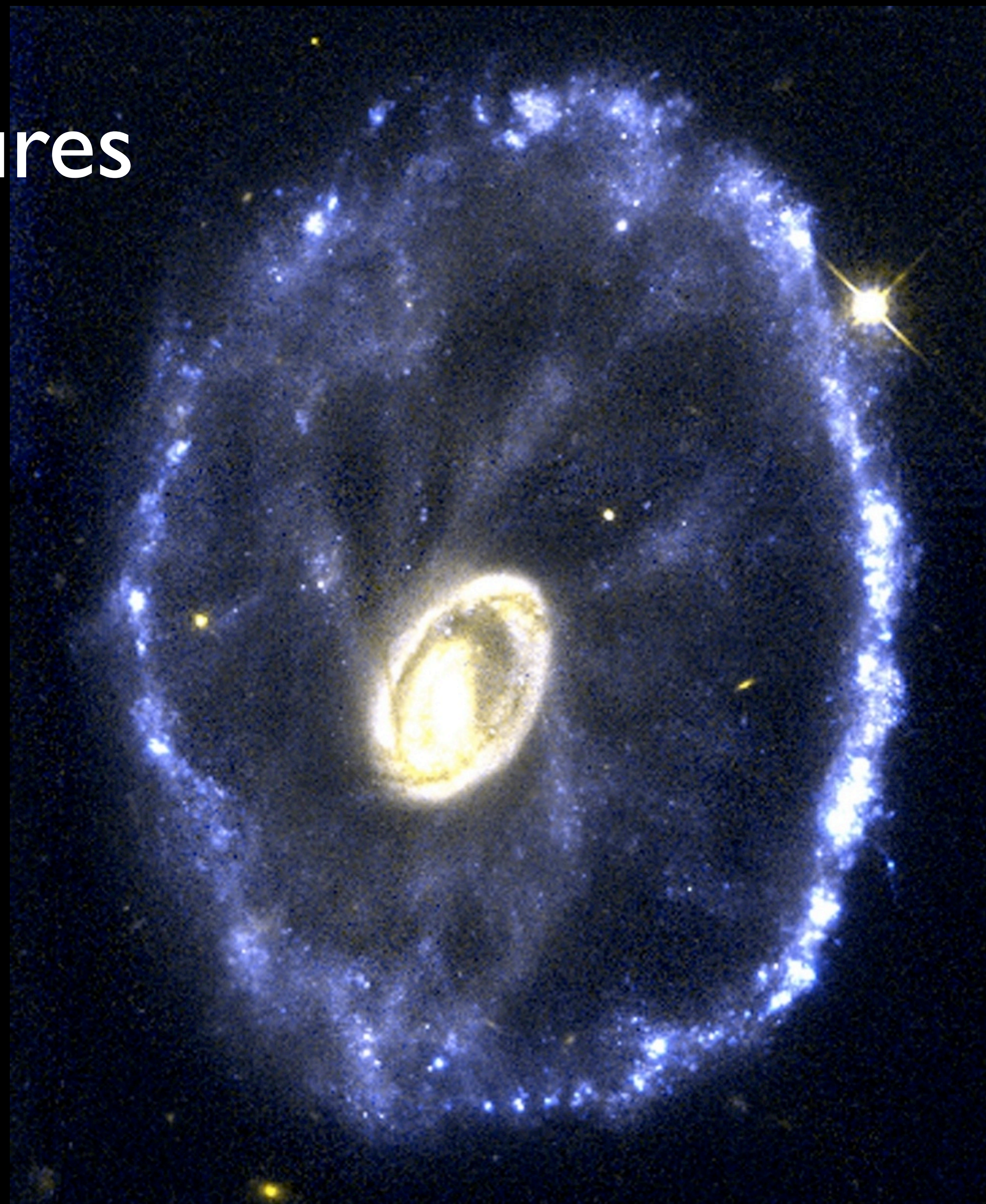
★ Formation of tidal features

- Bridges
- Tails

The Mice

TRIGGERING MECHANISMS

- Formation of tidal features
  - Bridges
  - Tails
  - Collisional rings (head-on collisions)



The Cartwheel galaxy

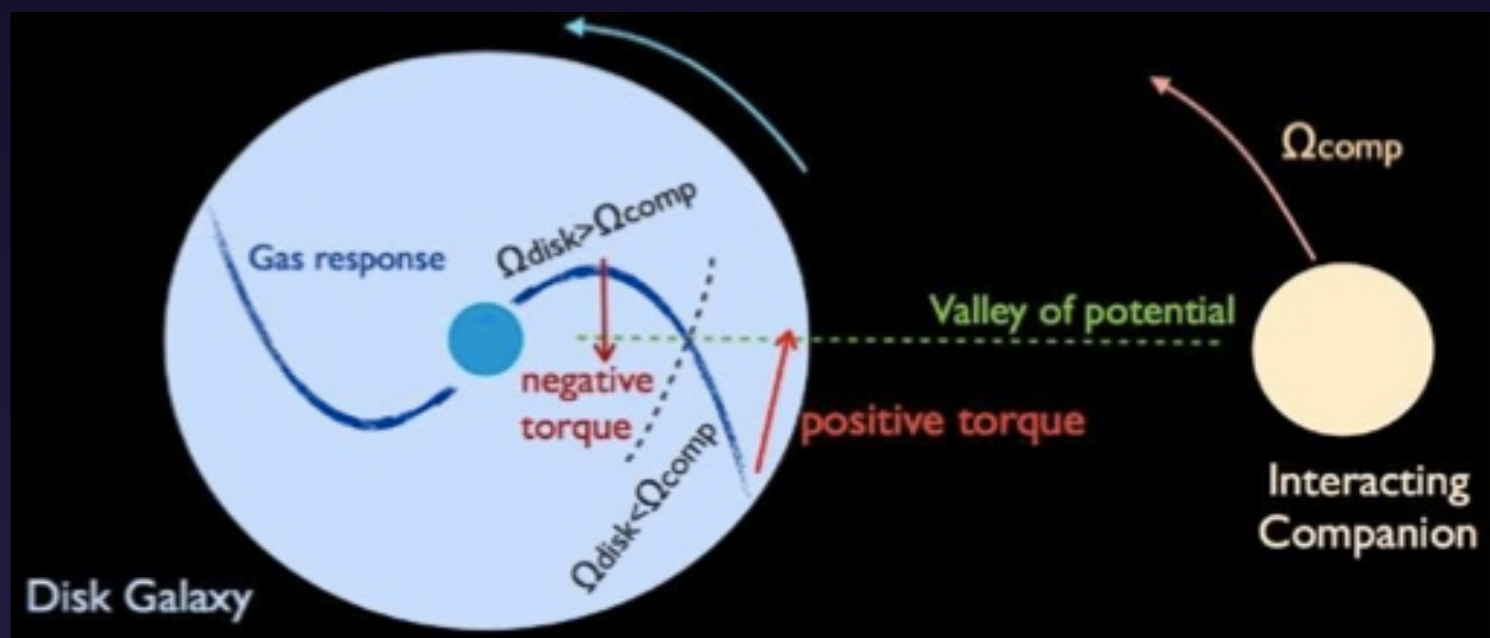
TRIGGERING MECHANISMS

- ⋆ Formation of tidal features
  - Bridges
  - Tails
  - Collisional rings (head-on collisions)
  - Polar rings (accretion process)

4650 galaxy

TRIGGERING MECHANISMS

- ★ Simplified model for gas response to interactions
  - Symmetry of the gravitational potential is broken
    (Tidal field due to companion galaxy)
  - $\Omega_{disk} \sim \Omega_{comp}$ at $R_{corotation} \sim$ few kpc
  - $\Omega_{disk} > \Omega_{comp}$
    - Negative gravity torque on gas
    - Loss of angular momentum
    - Inflow towards the center
  - $\Omega_{disk} > \Omega_{comp}$
    - Positive gravity torque on gas
    - Gain of angular momentum
    - Flow outwards (tidal tails...)



TRIGGERING MECHANISMS

- Increased number of shocks

  Crossing of gas streamlines creates shocks

  - ➡ Energy radiation, i.e. loss of energy for the gas
    - ➡ Spiraling of the gas inward

- Once enough gas has reached the inner kpc
  - Either it fragments, and stars form
  - Or it keeps flowing inwards and fuel an AGN

TRIGGERING MECHANISMS

- The feedback loop

  Star formation

  ➡ Heating by supernovae

  ➡ Increase of pressure in the intercloud material

  ➡ Collapse of more and more clouds (assuming T_{cloud} = ct)

  ➡ Formation of more stars

- Gas supply is necessary, but not sufficient
  - Gas must gather fast enough, ie low enough $t_{free\text{-}fall}$ (Superwind outflows (extremely hot and fast) can blow out the gas)
  - For a cold gas cloud (M_{cloud}, T_{cloud}) to collapse, the pressure on its outer boundary must be high enough

Instabilities

- Stability of molecular gas clouds
  - Kinetic pressure stabilizes small-scale structures

$$\lambda_J = \sigma^2/G\Sigma_{gas}$$

  - Differential rotation stabilizes large-scale structures

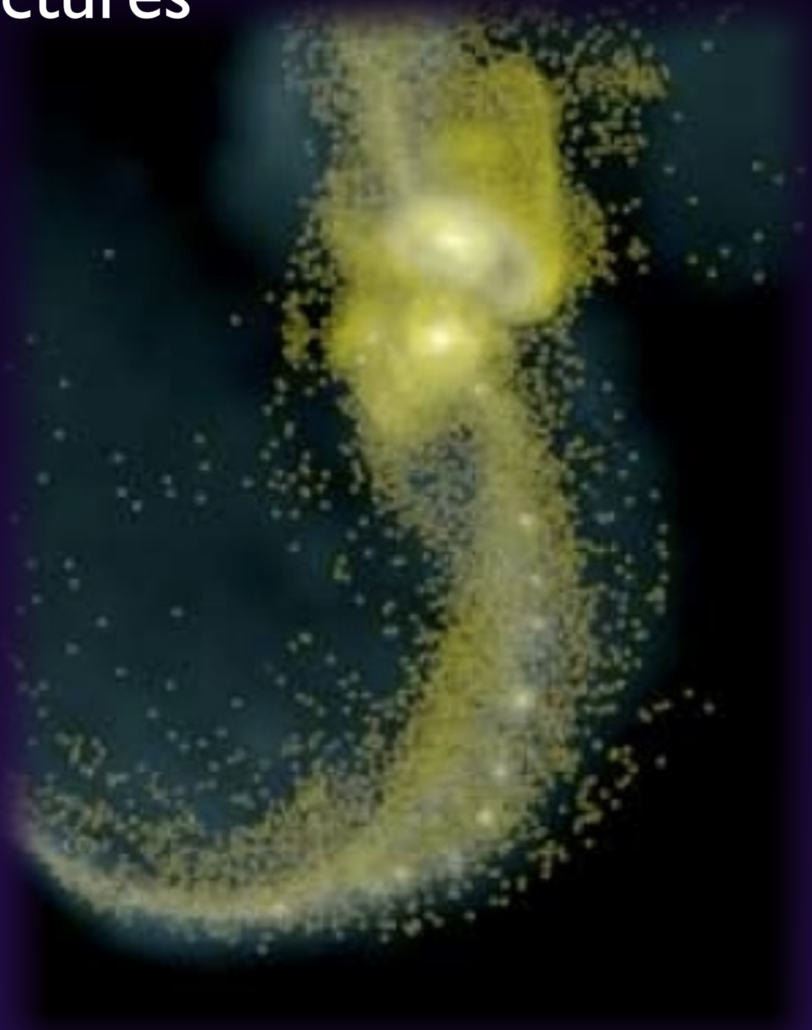
$$\lambda_{crit} = 4\pi^2 G\Sigma_{gas}/\kappa^2$$

  - All scales stabilized if $\lambda_{crit} < \lambda_J$

$$\text{i.e. } \kappa\sigma/2\pi G\Sigma_{gas} > 1$$

- In reality, 2-phase medium (gas & stars)
- ... apart from: tidal tails

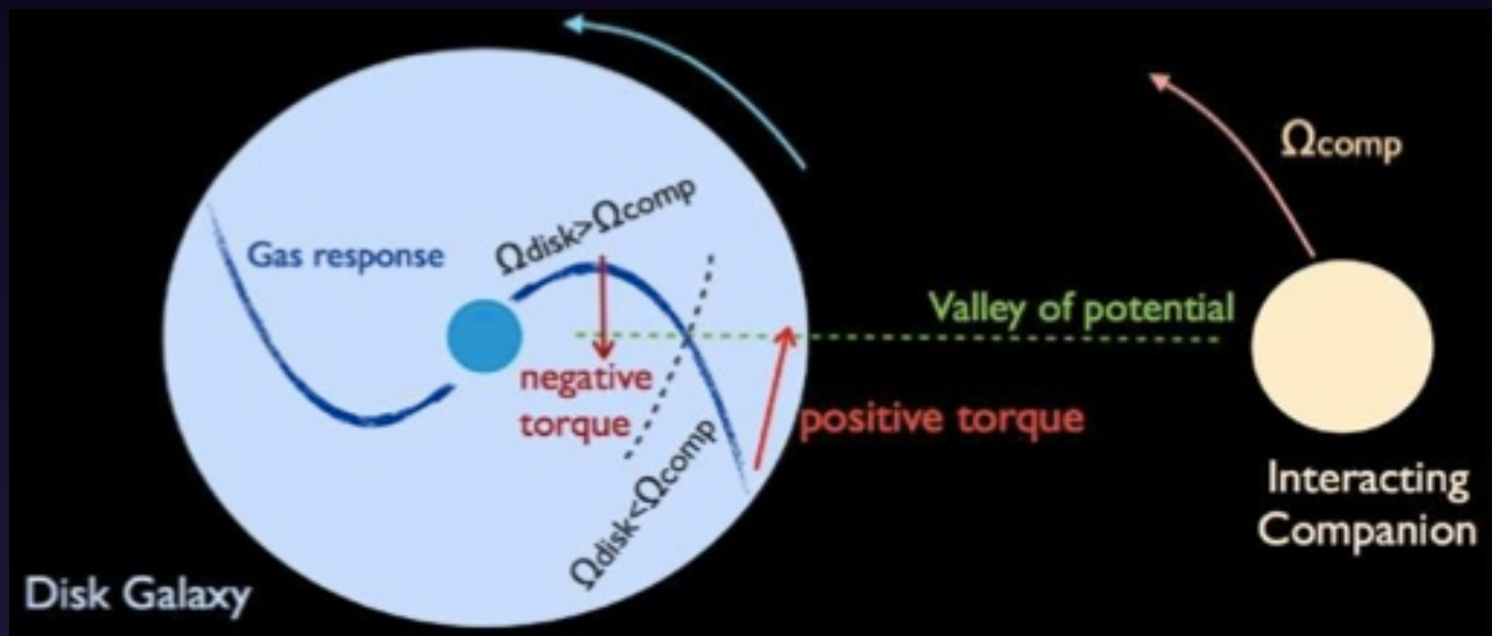
→ «Beads on string» appearance



«Beads on string», simulation, F. Bournaud, astro-ph.18112v2

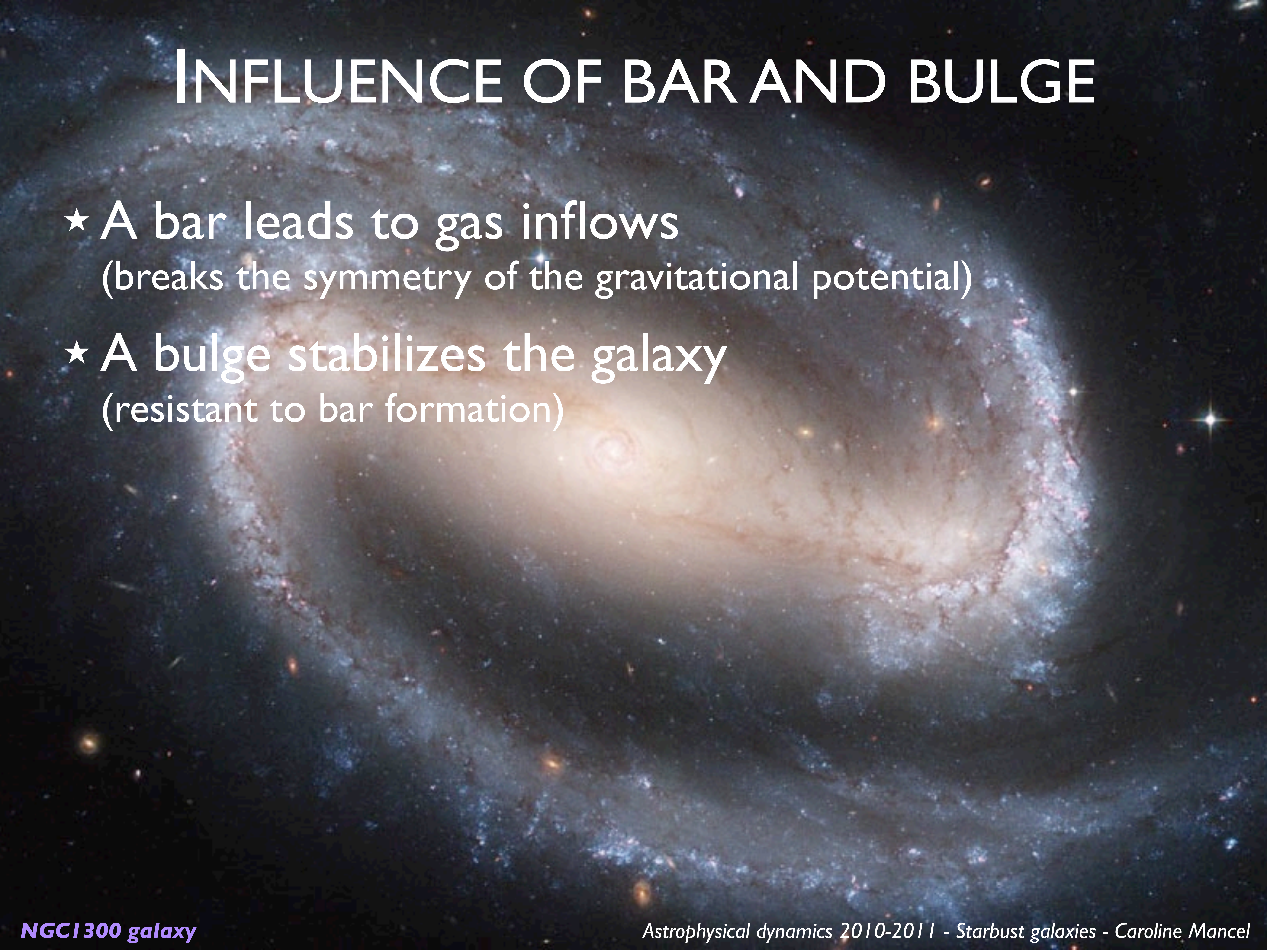
Influence of bar and bulge

- ★ A bar leads to gas inflows
  (breaks the symmetry of the gravitational potential)



INFLUENCE OF BAR AND BULGE

- A bar leads to gas inflows
  (breaks the symmetry of the gravitational potential)
- A bulge stabilizes the galaxy
  (resistant to bar formation)



NGC1300 galaxy

Influence of bar and bulge

- In fact,

  Major mergers = quite rare
  Minor mergers = more common

  ⇒ Satellite accretion

  Coupling btw orbital & rotational motions can induce bar formation...

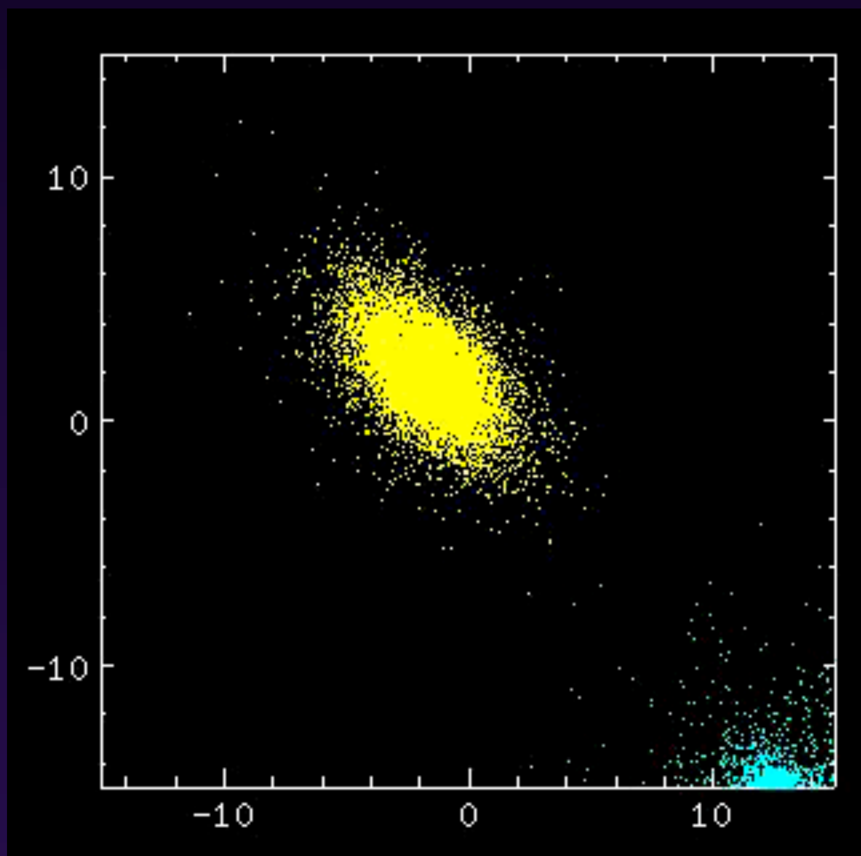
- Also, turbulence effects...

  Recall the lecture about turbulence

  - Bonazzola / Vazquez-Semadeni / Gazal
    Turbulence could inverse Jeans criterion i.e. stars could form in low-mass dense cores of clouds where global collapse is not expected

SIMULATIONS

- Models need to take into account:
  - Gravity
  - Hydrodynamics
  - Star formation
  - Feedback



NGC 2442 galaxy + simulation by Chris Mihos

GalCrash simulation tool

http://burro.cwru.edu/JavaLab/GalCrashWeb/main.html

Conclusion

Time for...
question-burst!