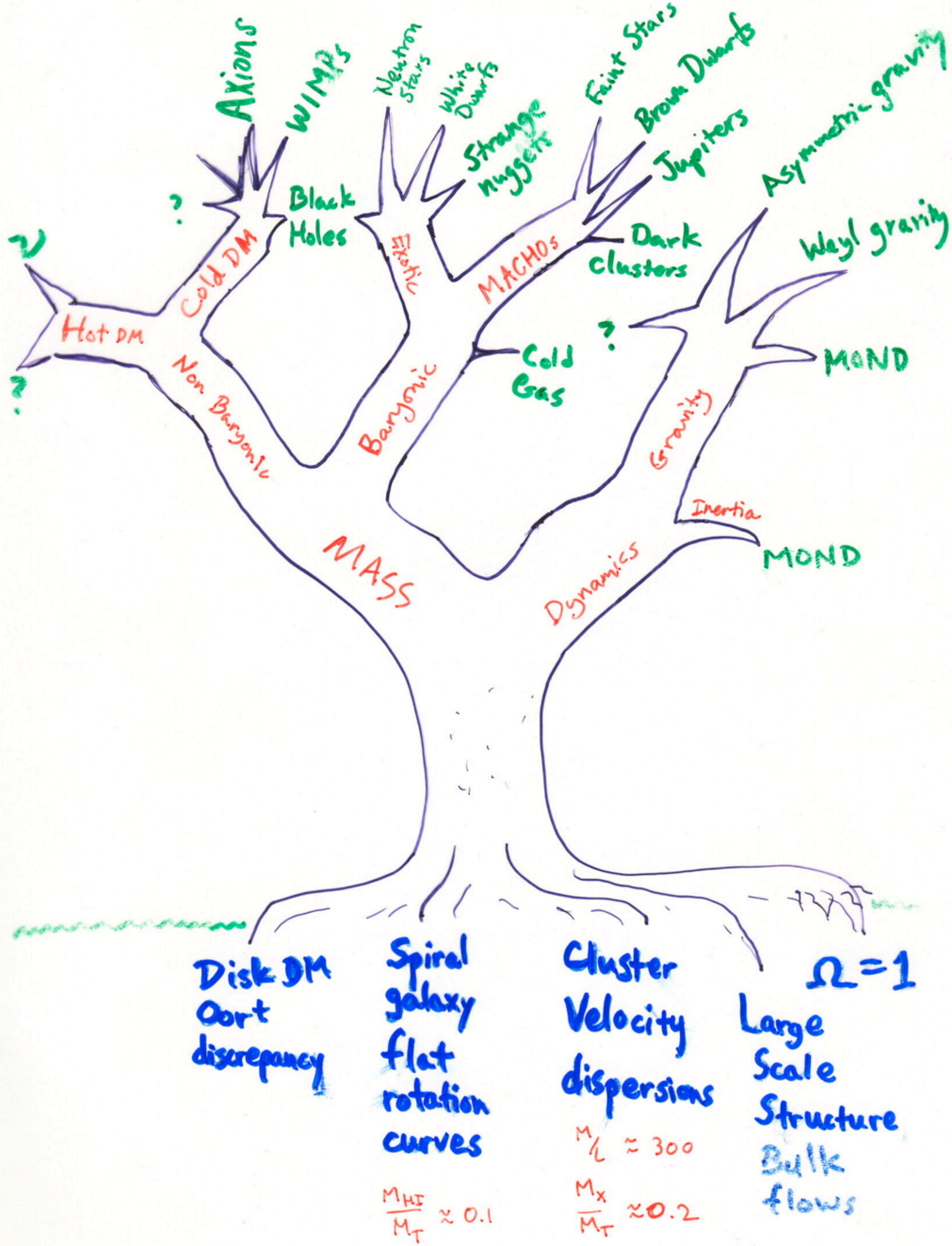
Dark Matter

ASTR 333/433

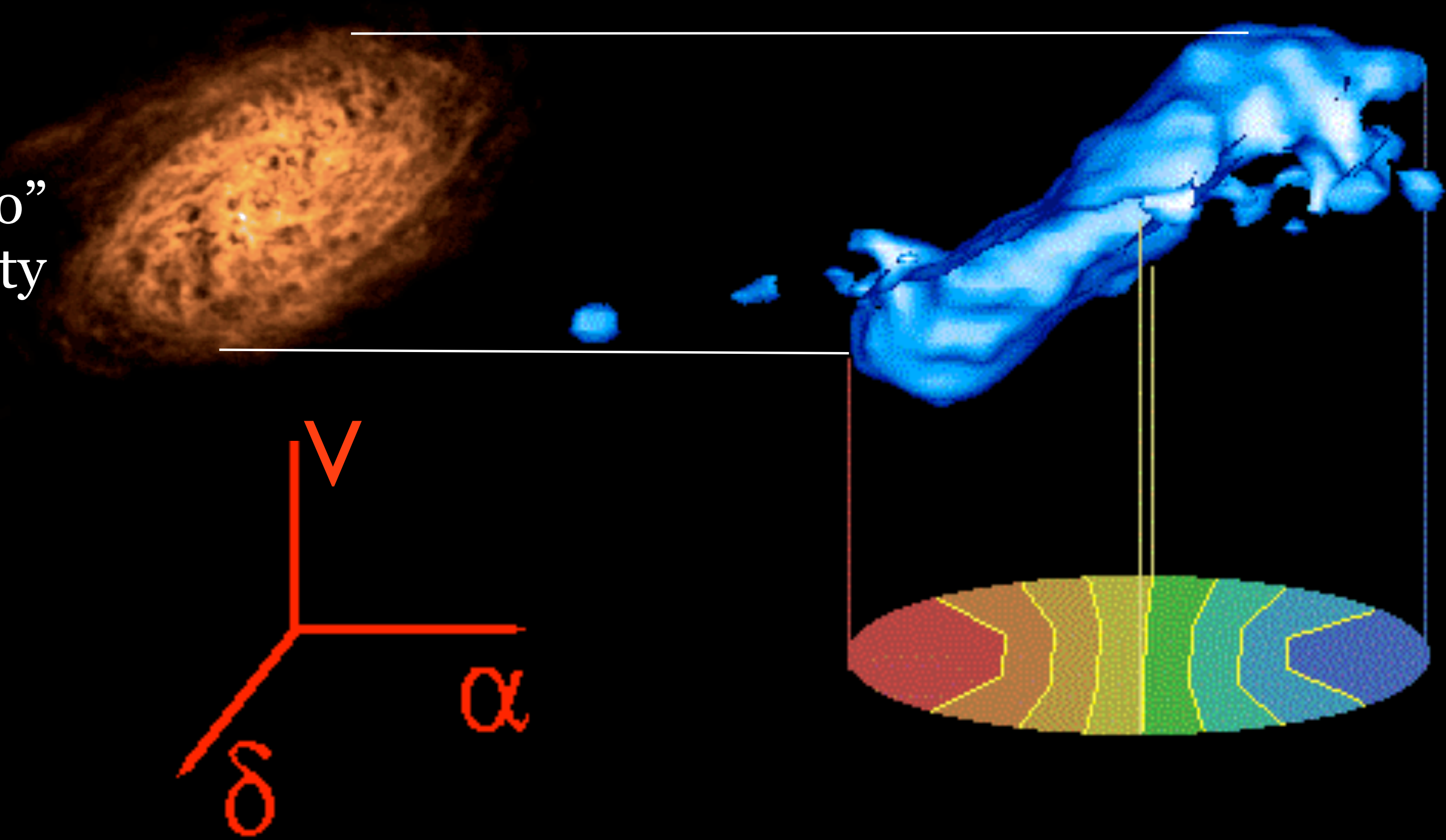
TODAY

Velocity Fields
Stellar Populations



Multi-dish radio synthesis telescope arrays give brightness temperature (HI surface density) & velocity

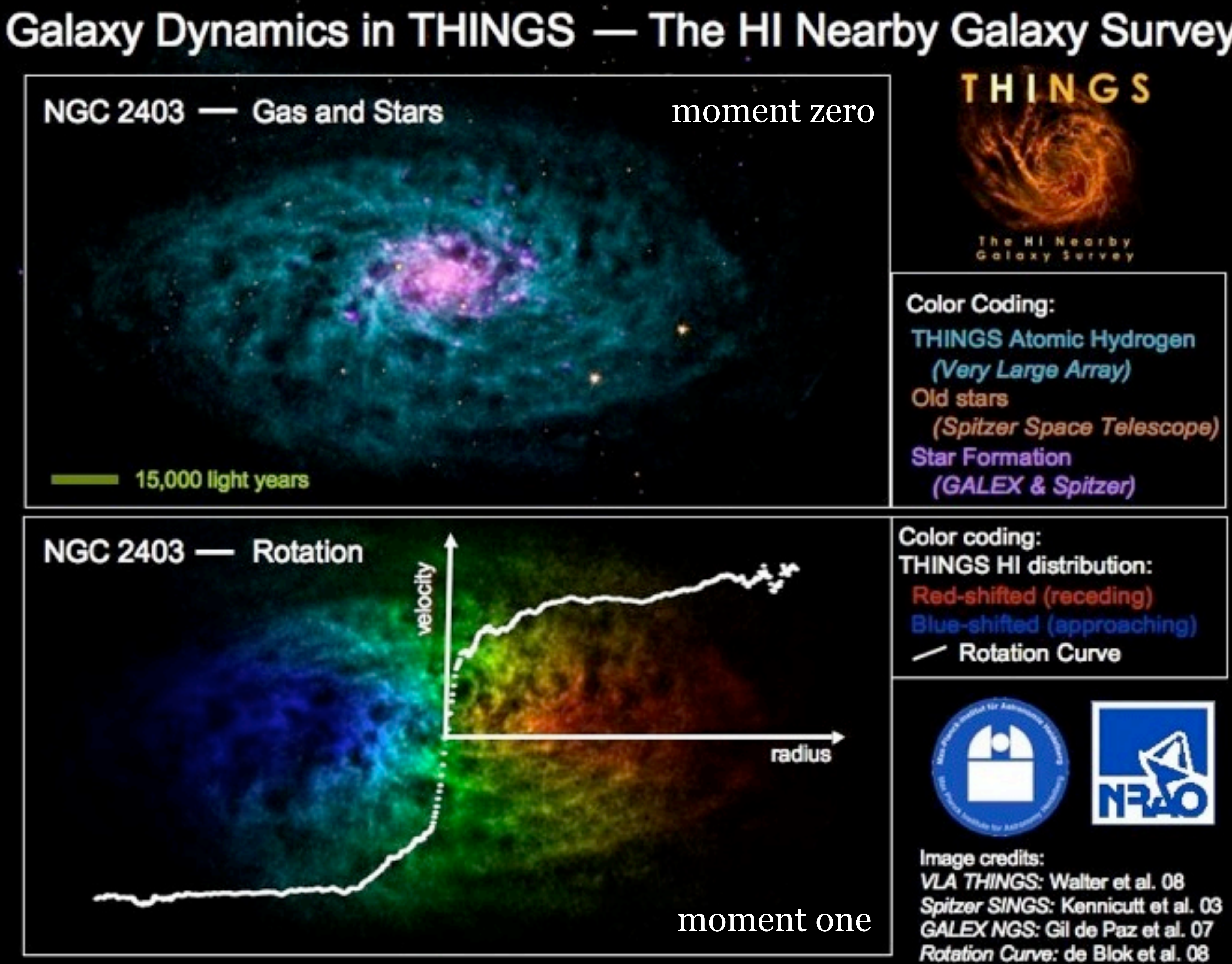
HI map
“moment zero”
surface density
of atomic gas

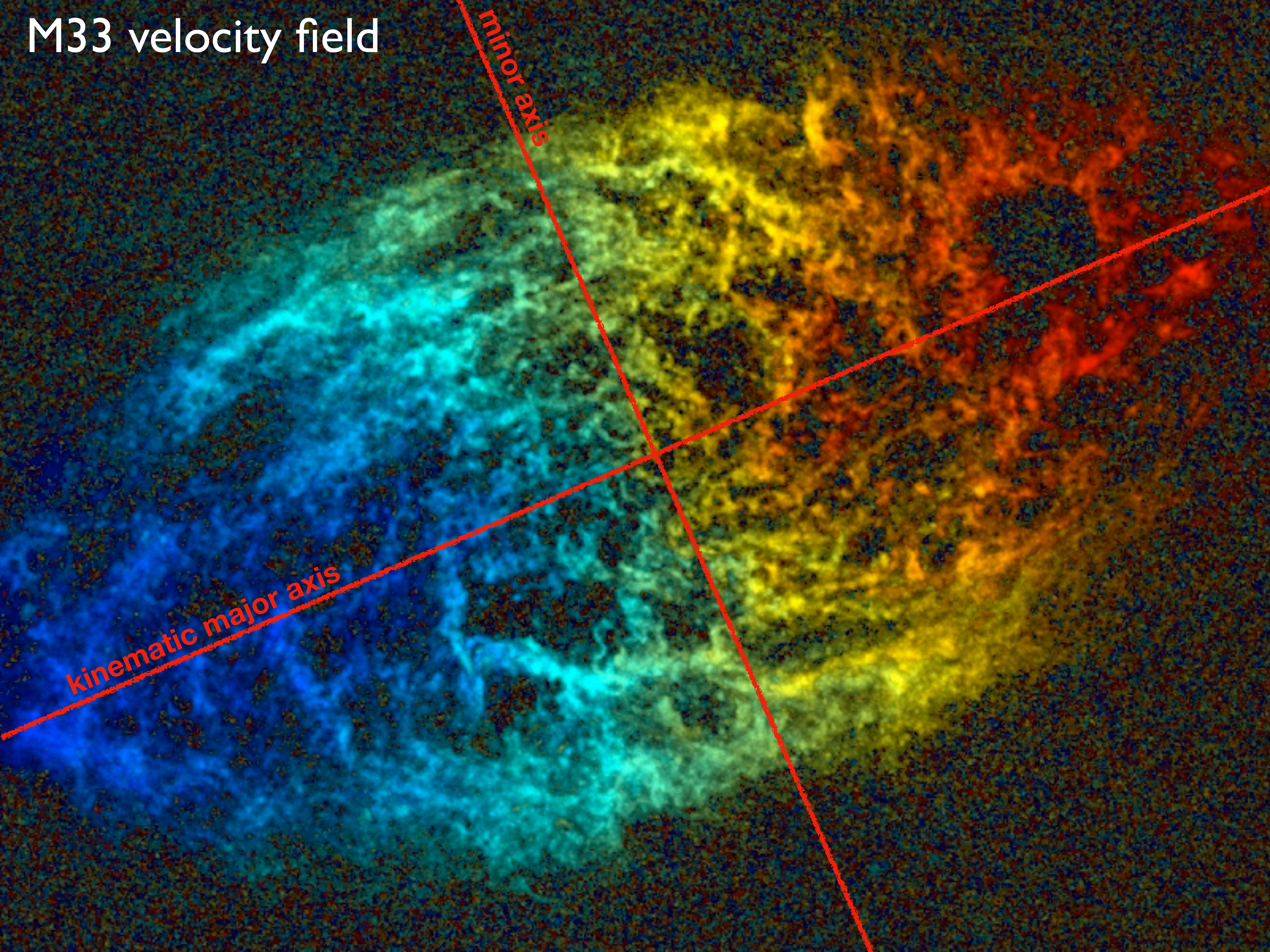


Velocity field
“moment one”
doppler shifts
of atomic gas

from 3D data cube of 21 cm position and redshift

Multi-dish radio telescope arrays give surface density and velocity

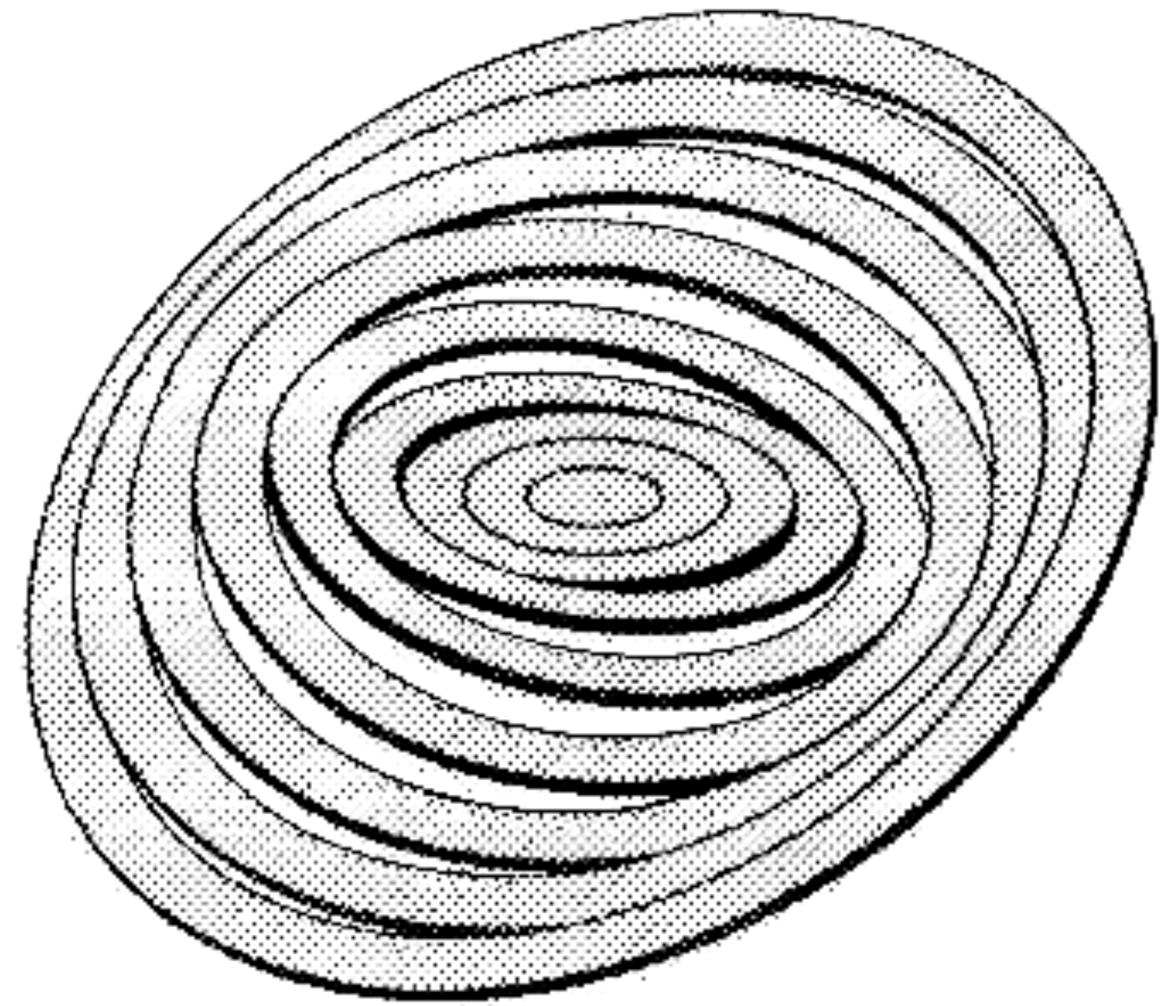


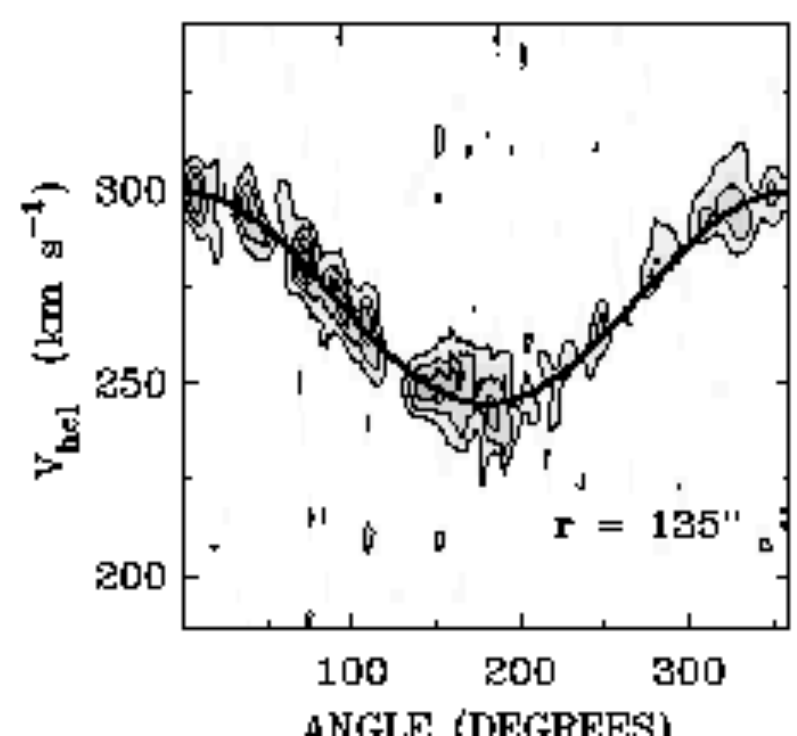

M33 velocity field
minor axis
kinematic major axis

Rotation curves extracted using "tilted ring" fits

Fit ellipses that most closely match the circular velocity at a given radius. In principle, get ellipse center, position angle, axis ratio, inclination, and rotation velocity. In practice, usually have to fix some of these parameters.

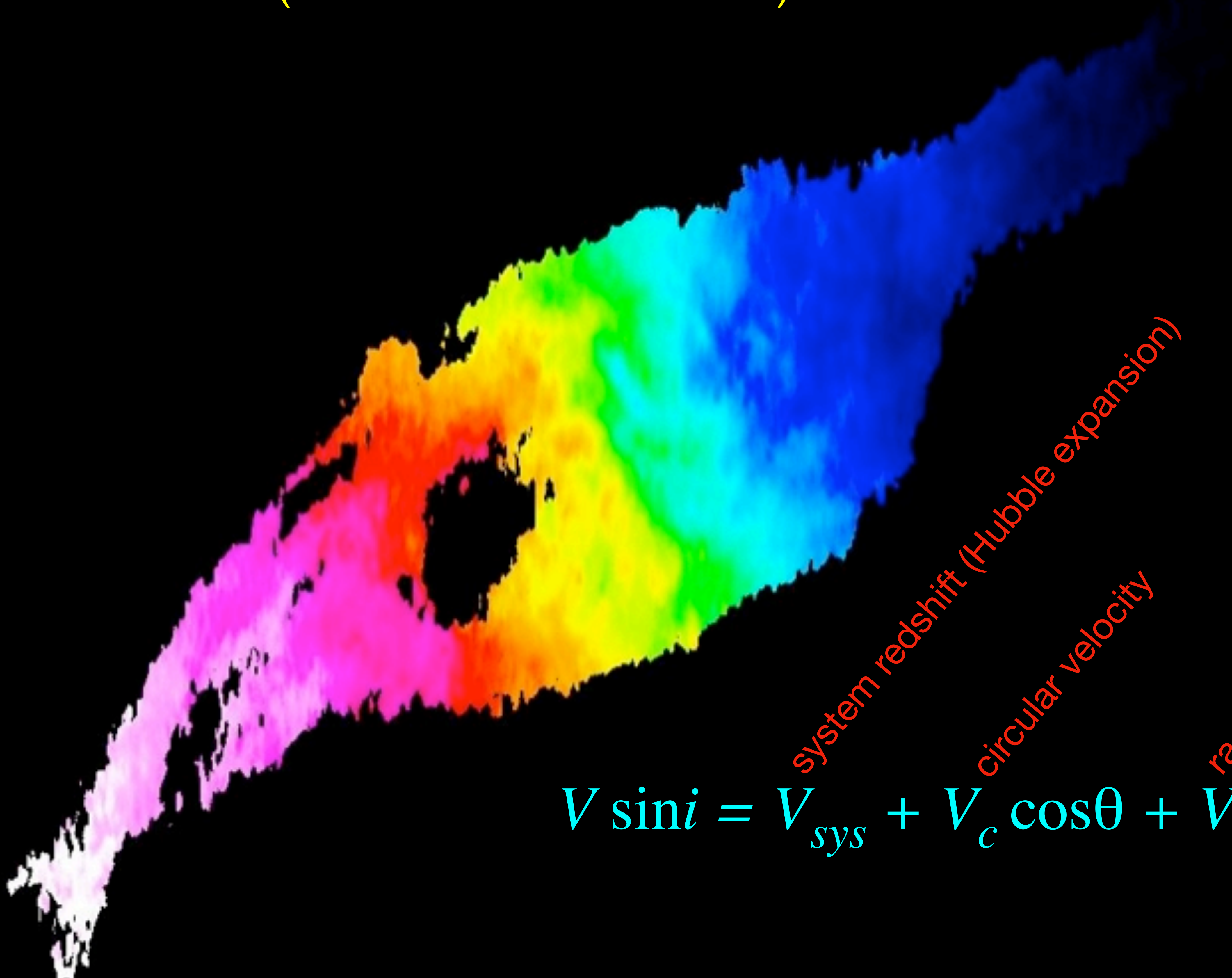
titled ring model





velocity variation along ring

NGC 6822 (Weldrake & de Blok 2003)



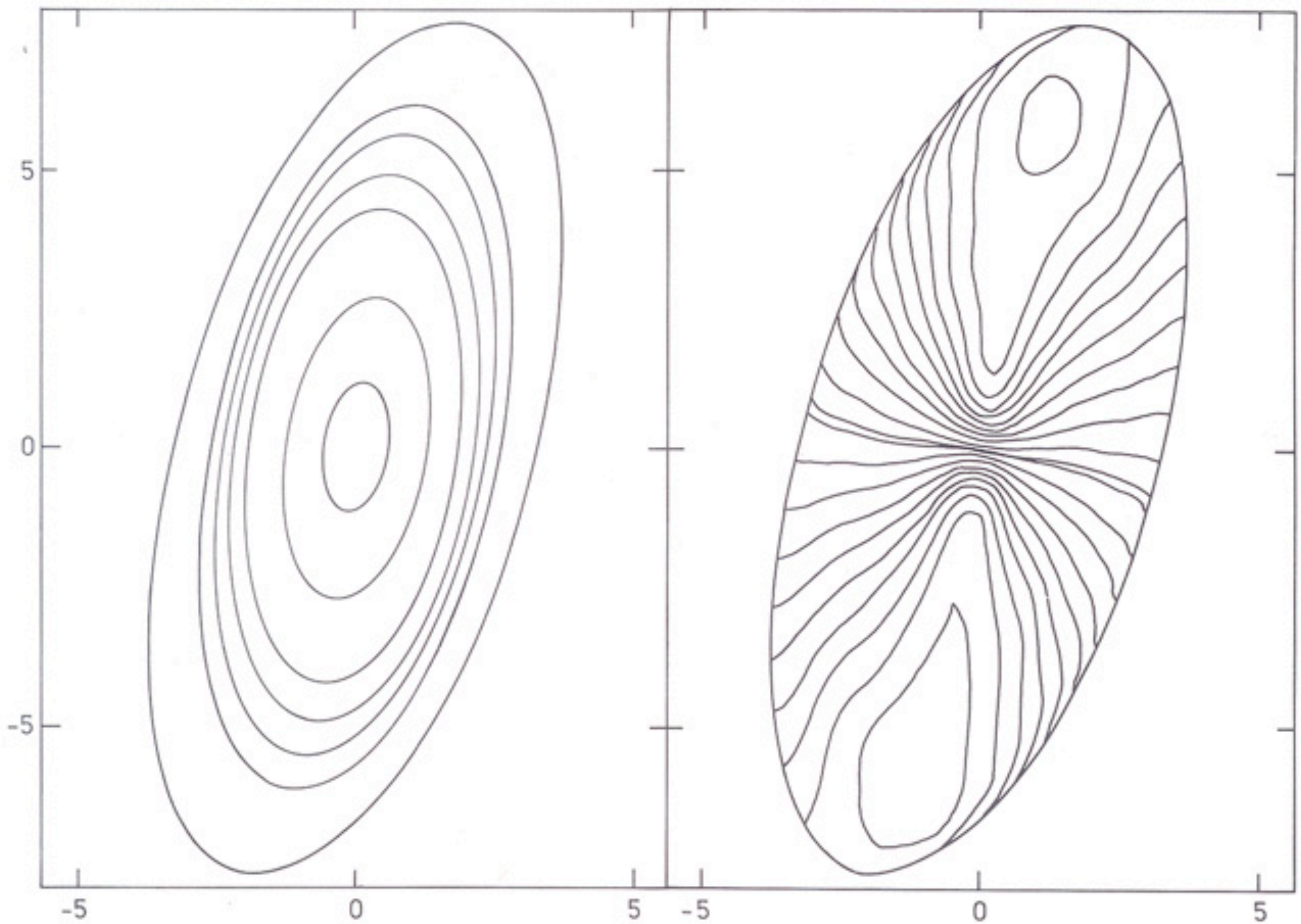
system redshift (Hubble expansion)

circular velocity

radial velocity

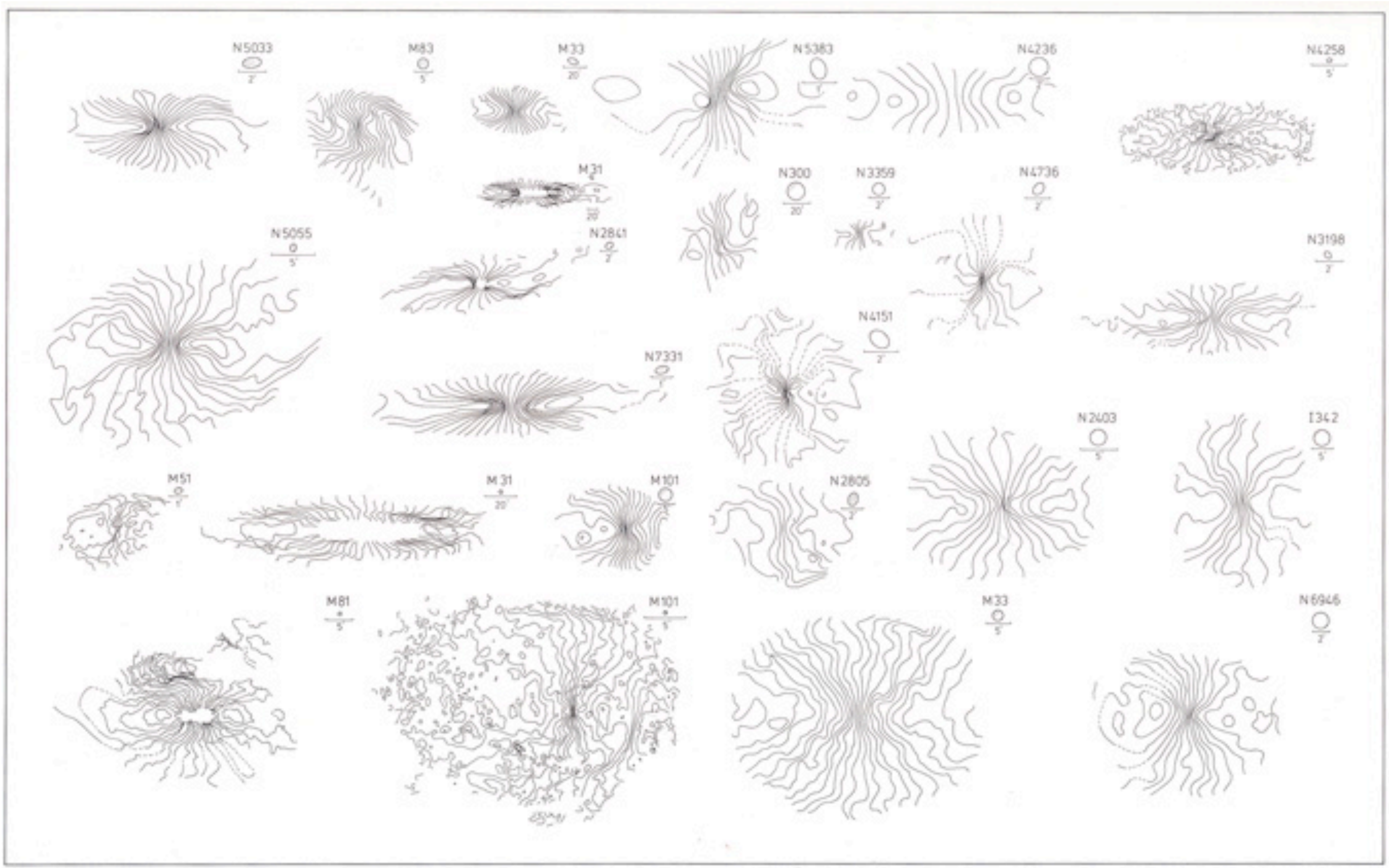
$$V \sin i = V_{sys} + V_c \cos\theta + V_r \sin\theta$$

titled ring model



isovelocity contours

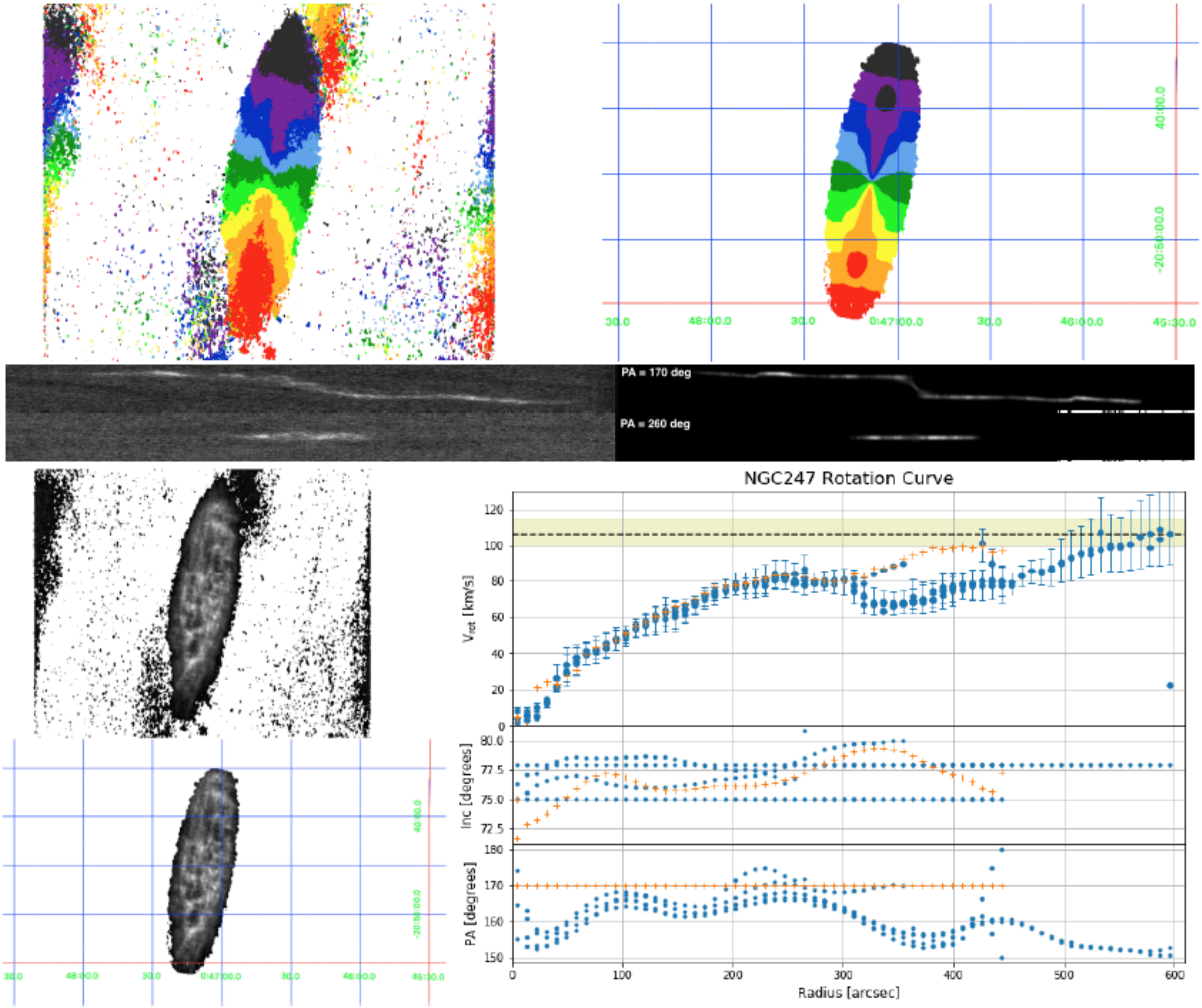
observed velocity fields



Bosma (1981)

NGC 247

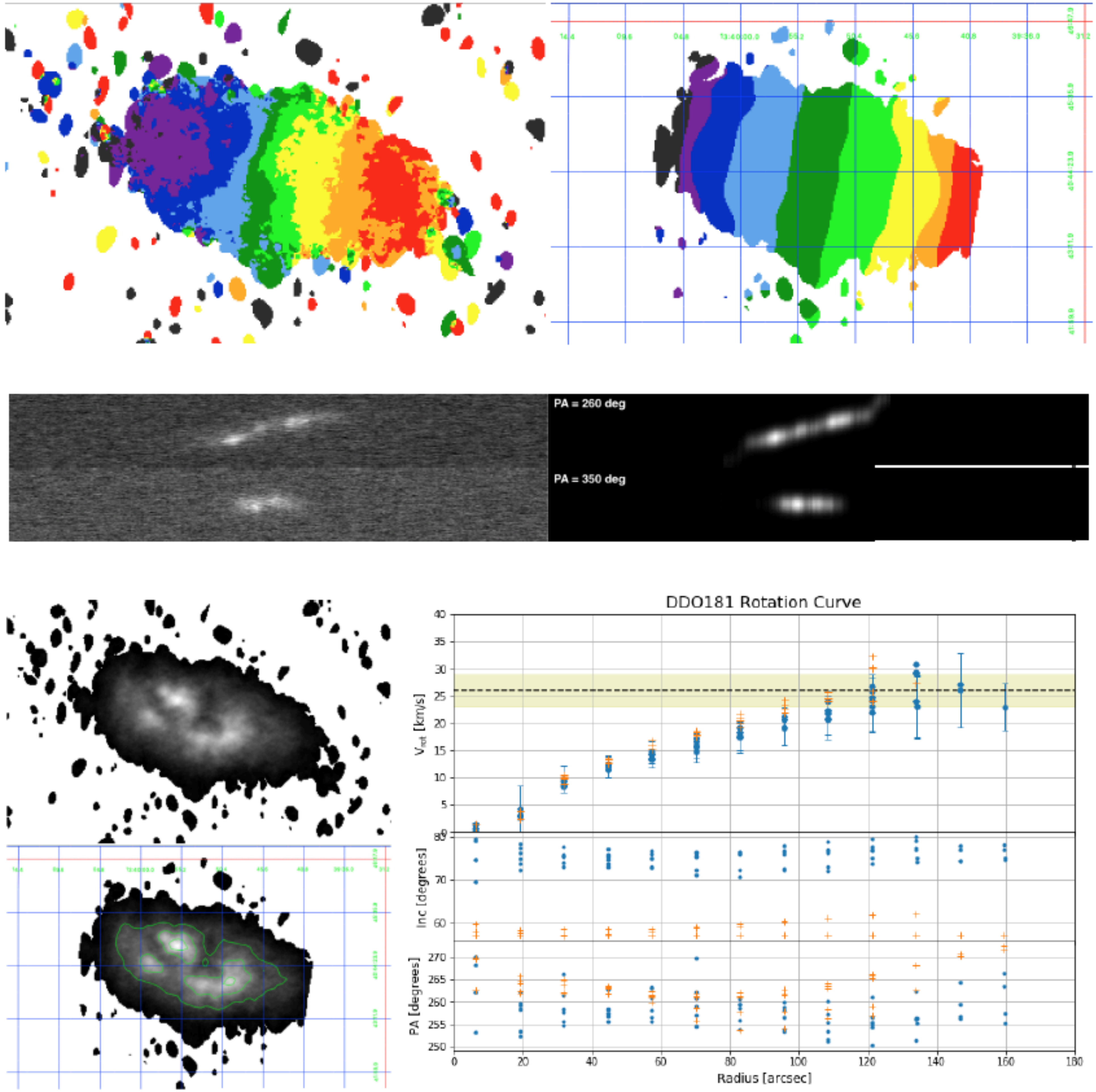
data **model**



Fit made with 3DBarolo by K. Parker

DDO 181

data **model**



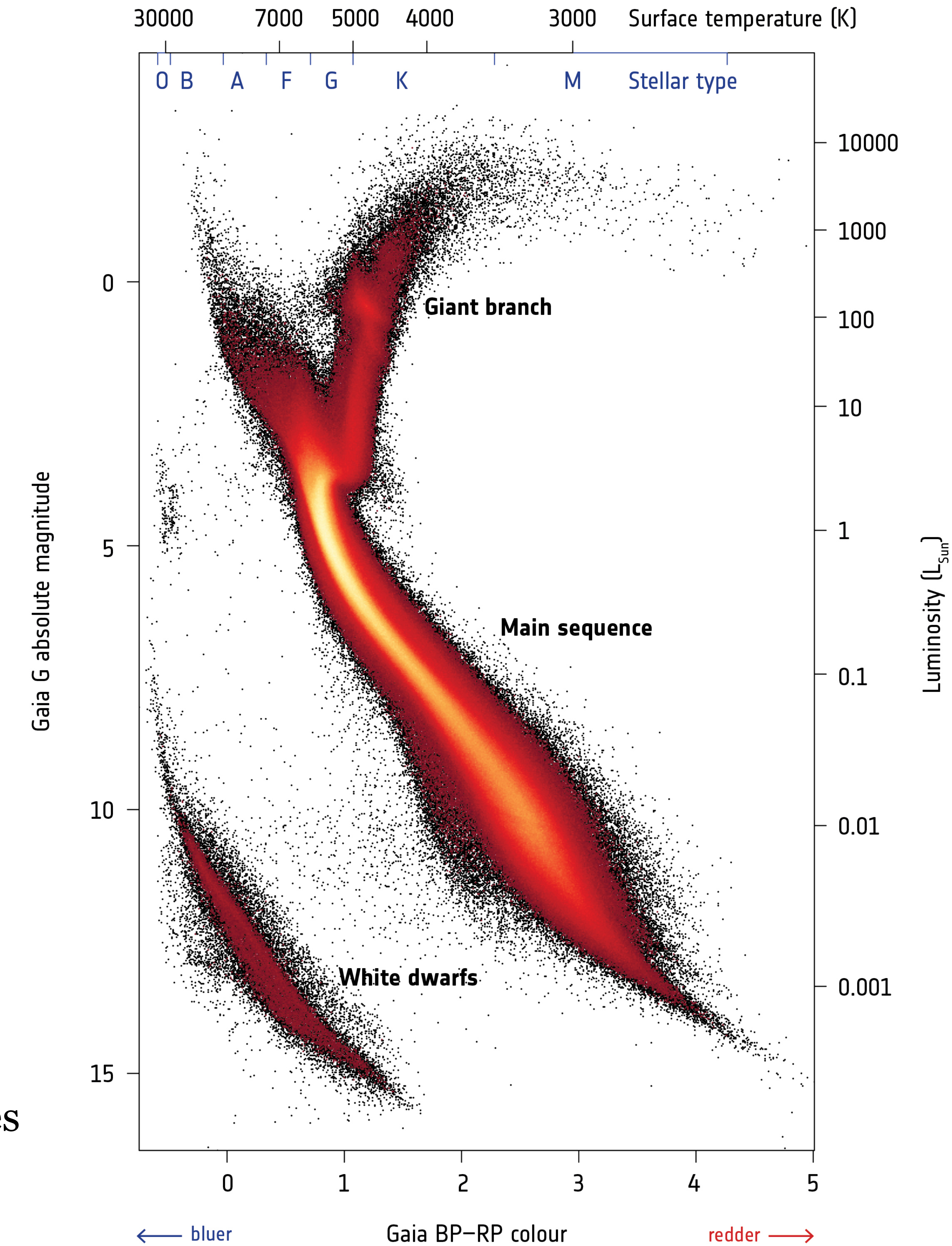
Fit made with 3DBarolo by K. Parker

Stars & Stellar populations

To separate the dark from the lights, gotta understand stars

The Milky Way has a complex stellar population composed of many generations of stars

- Stellar Evolution
  - lives of individual stars
- IMF (Initial Mass Function)
  - mass spectrum of stars formed
- Star Formation History
  - rate at which stars form
- Metallicity
  - distribution of chemical abundances



Typical Stellar composition

- Hydrogen mass fraction $X = 0.74$
- Helium mass fraction $Y = 0.25$
- Heavier elements (“metals”): $Z \approx 0.01$

Abundances of H & He set during Big Bang.
Heavier elements made in previous generations of stars.
Z often called “metallicity” and sometimes referenced to the iron abundance, [Fe/H].

open cluster

Stellar populations

- Simple Single Population (SSP)
  - stars of all masses born at the same time
  - e.g., a star cluster

- Complex stellar population
  - Convolution of many star forming events
  - need to know
    - IMF (initial mass function)
    - Birthrate (star formation rate history)

globular cluster

Galaxy spectra composed of complex stellar populations

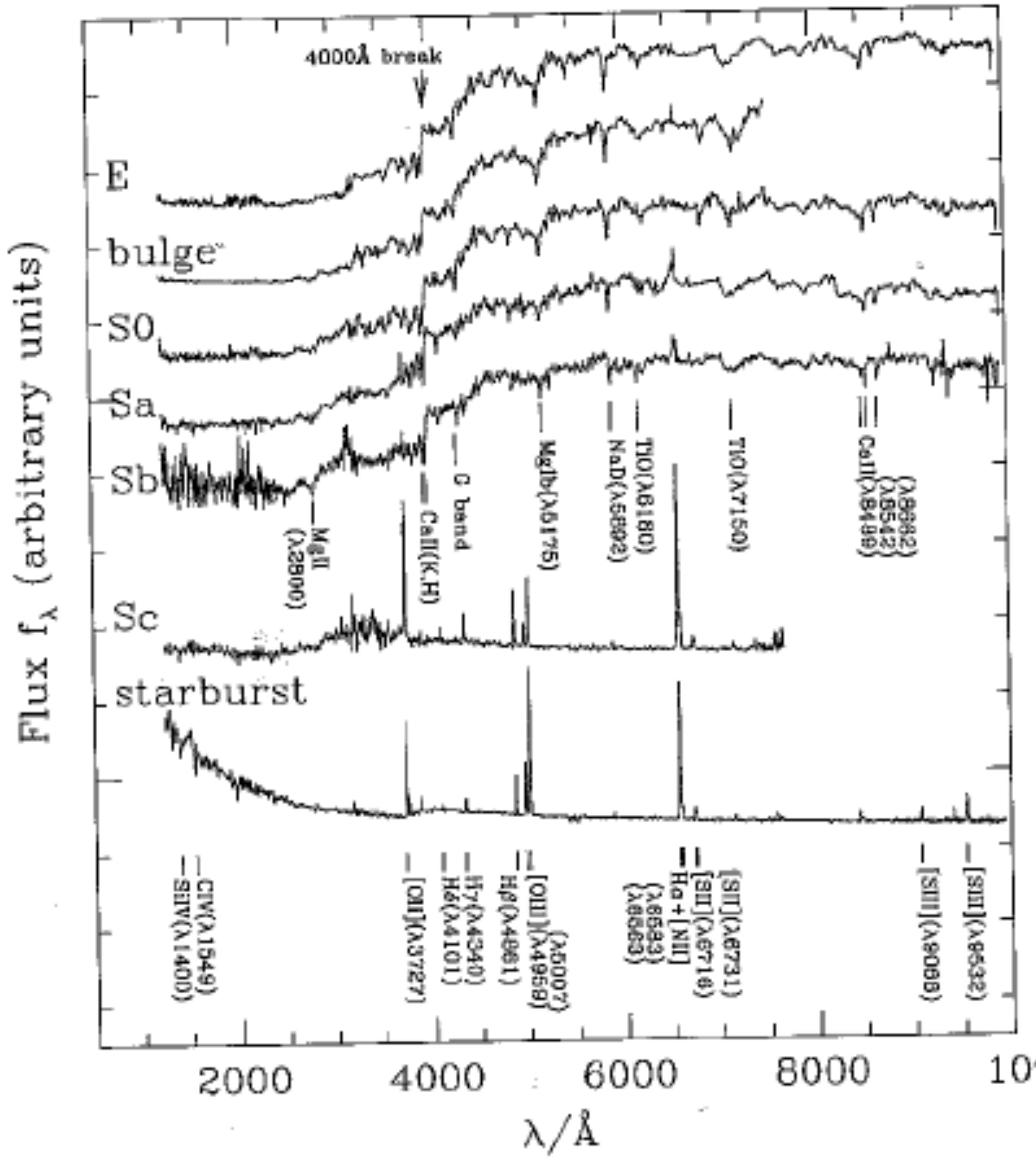
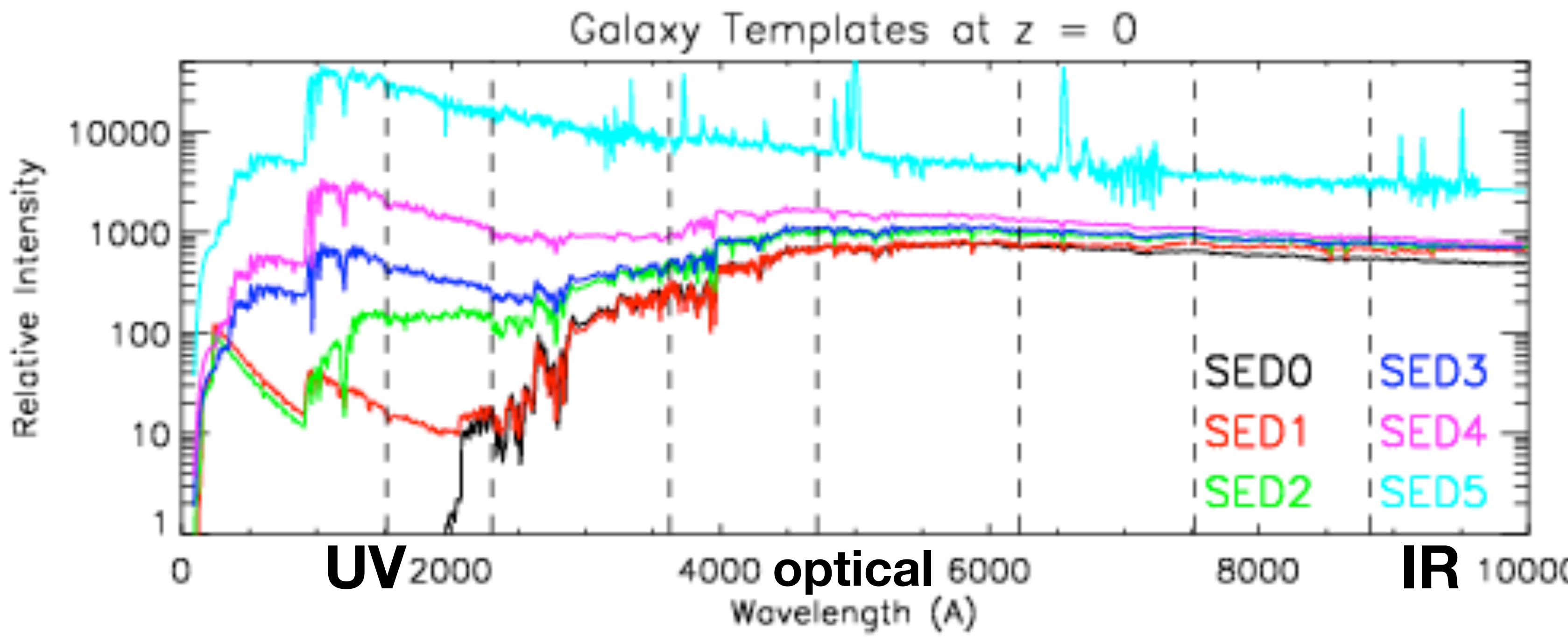
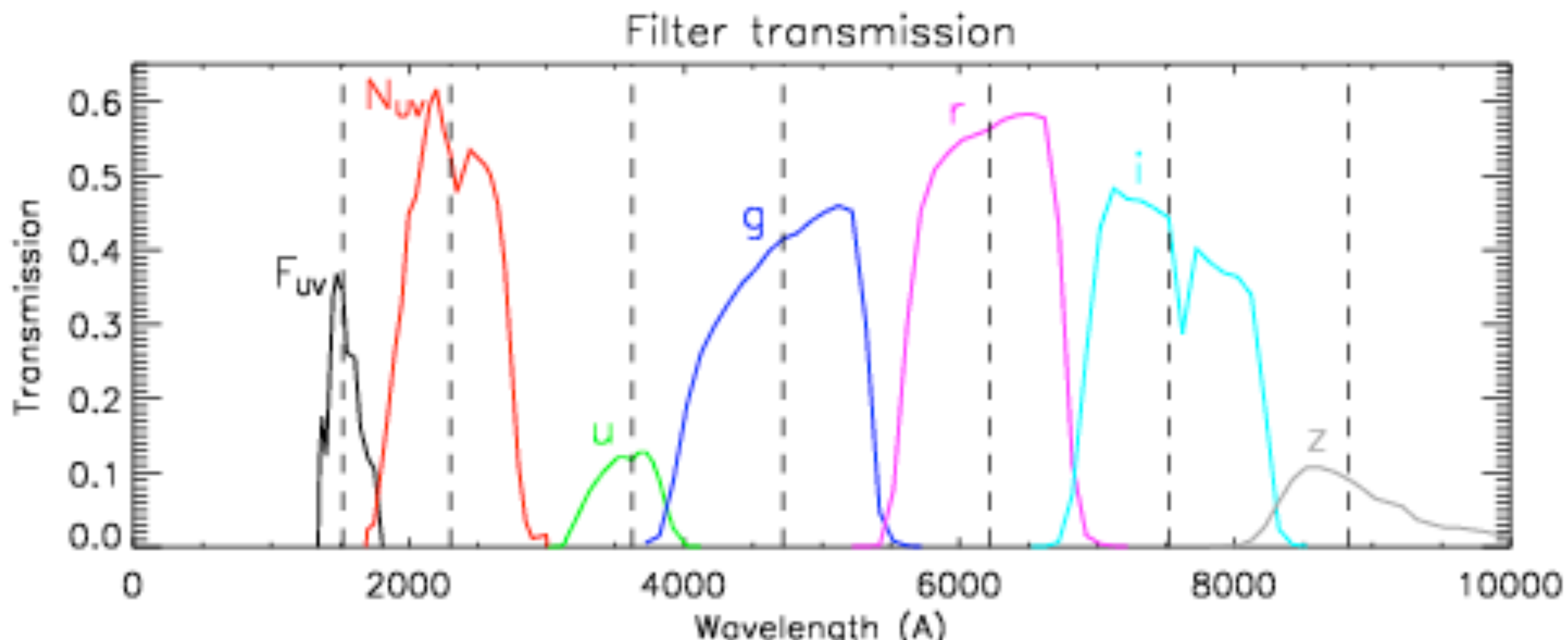


Fig. 2.12. Spectra of different types of galaxies from the ultraviolet to the near-infrared. From ellipticals to late-type spirals, the blue continuum and emission lines become systematically stronger. For early-type galaxies, which lack hot, young stars, most of the light emerges at the longest wavelengths, where one sees absorption lines characteristic of cool K stars. In the blue, the spectrum of early-type galaxies show strong H and K absorption lines of calcium and the G band, characteristic of solar type stars. Such galaxies emit little light at wavelengths shorter than 4000 Å and have no emission lines. In contrast, late-type galaxies and starbursts emit most of their light in the blue and near-ultraviolet. This light is produced by hot young stars, which also heat and ionize the interstellar medium giving rise to strong emission lines. [Based on data kindly provided by S. Charlot]

The effect of age variations

Galaxy Spectra

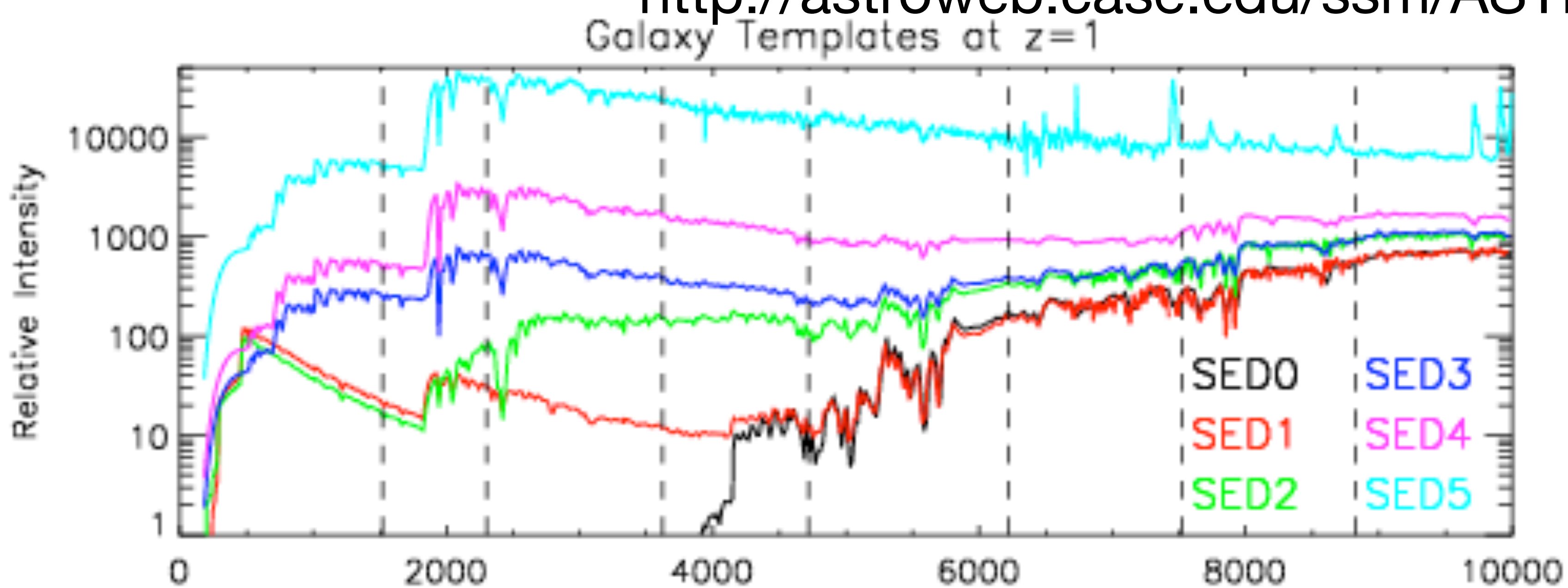




ugriz -
Gunn filters
Sloan (SDSS)

http://astroweb.case.edu/ssm/ASTR620/mags.html

The effect of redshift



Stars by mass, light, and number

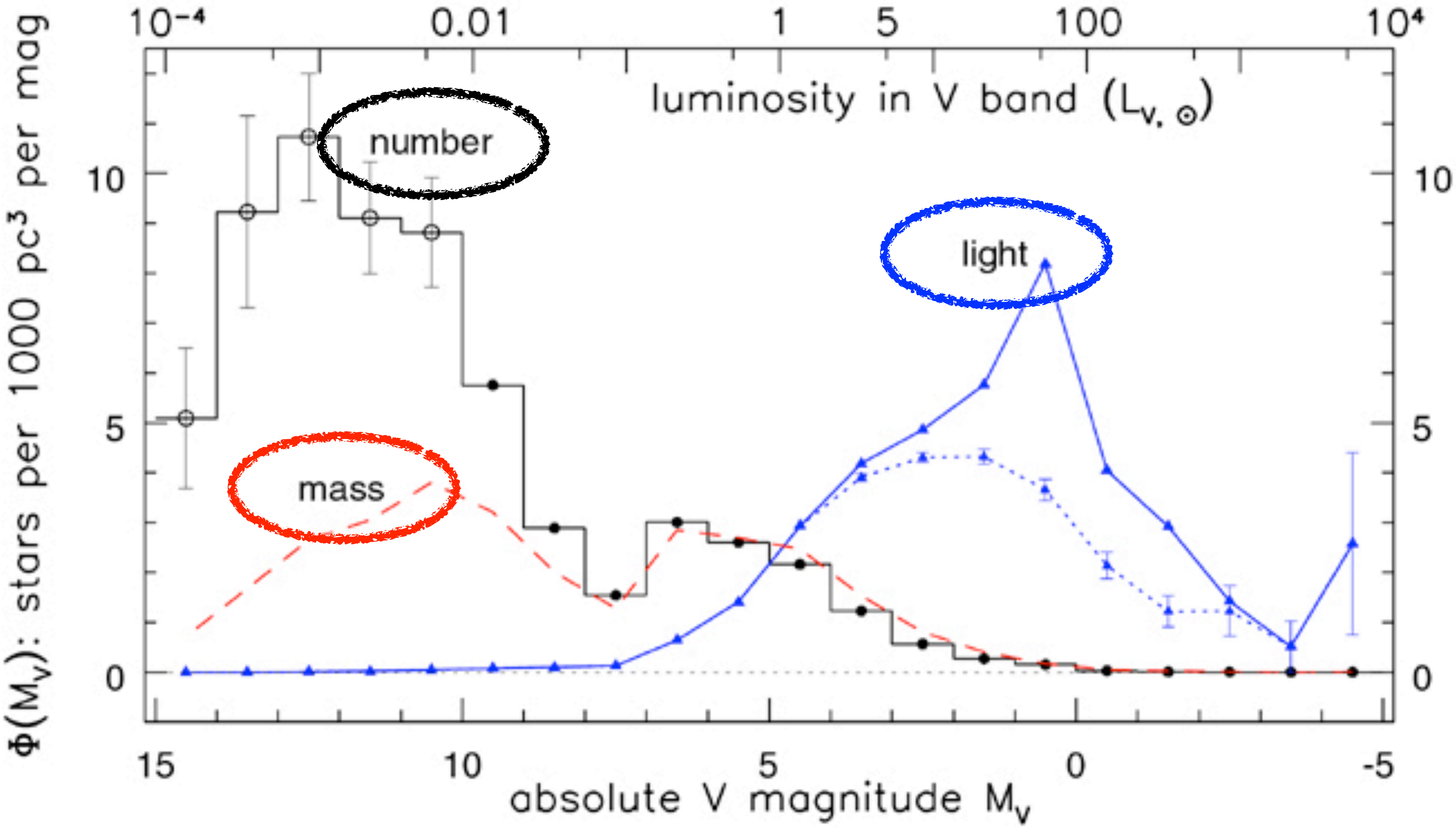


Fig 2.3 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Low mass stars exist in the greatest numbers
and contain most of the mass.
High mass stars produce most of the light.

IMF vs PDF

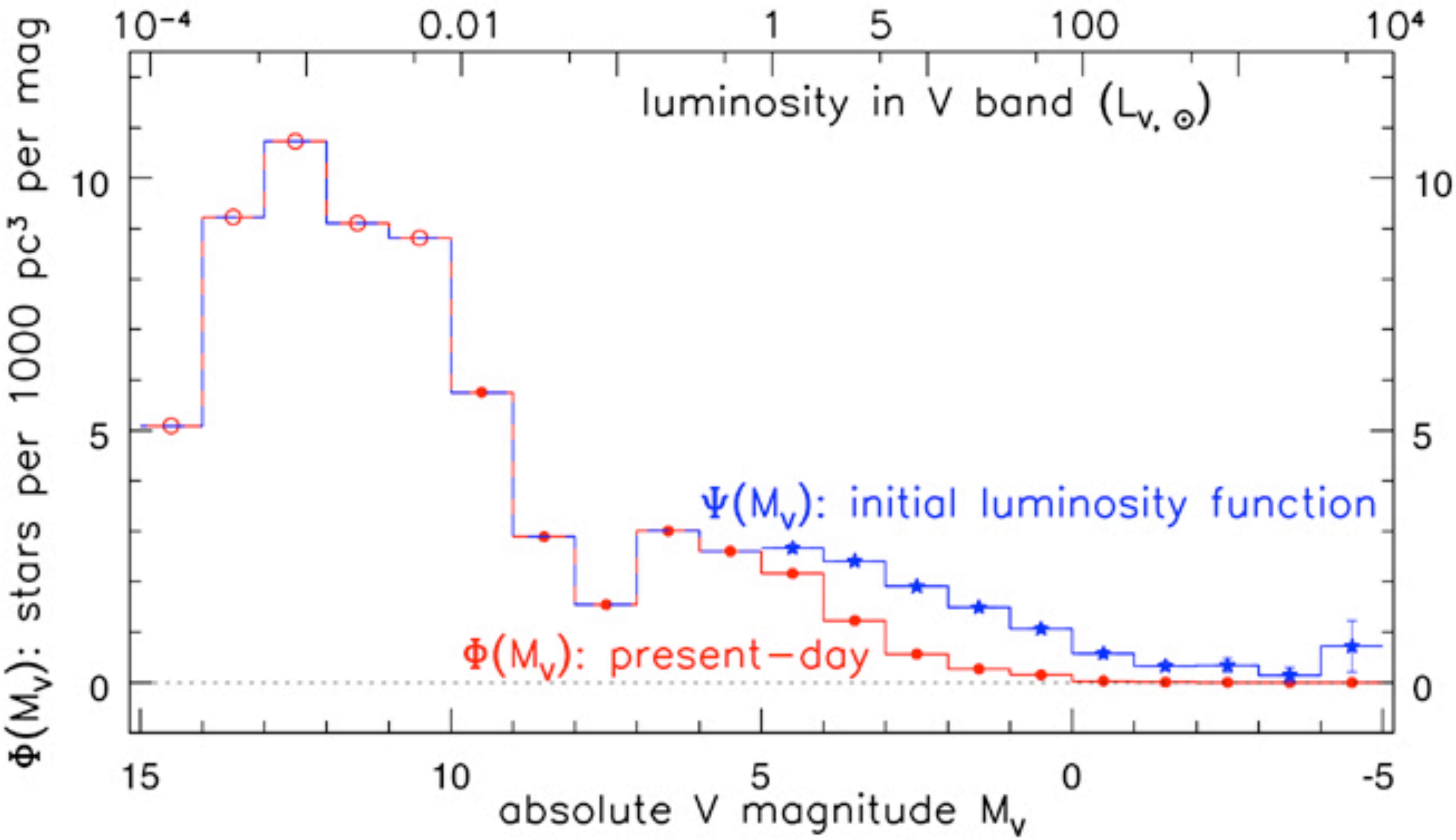


Fig 2.4 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Pleiades:

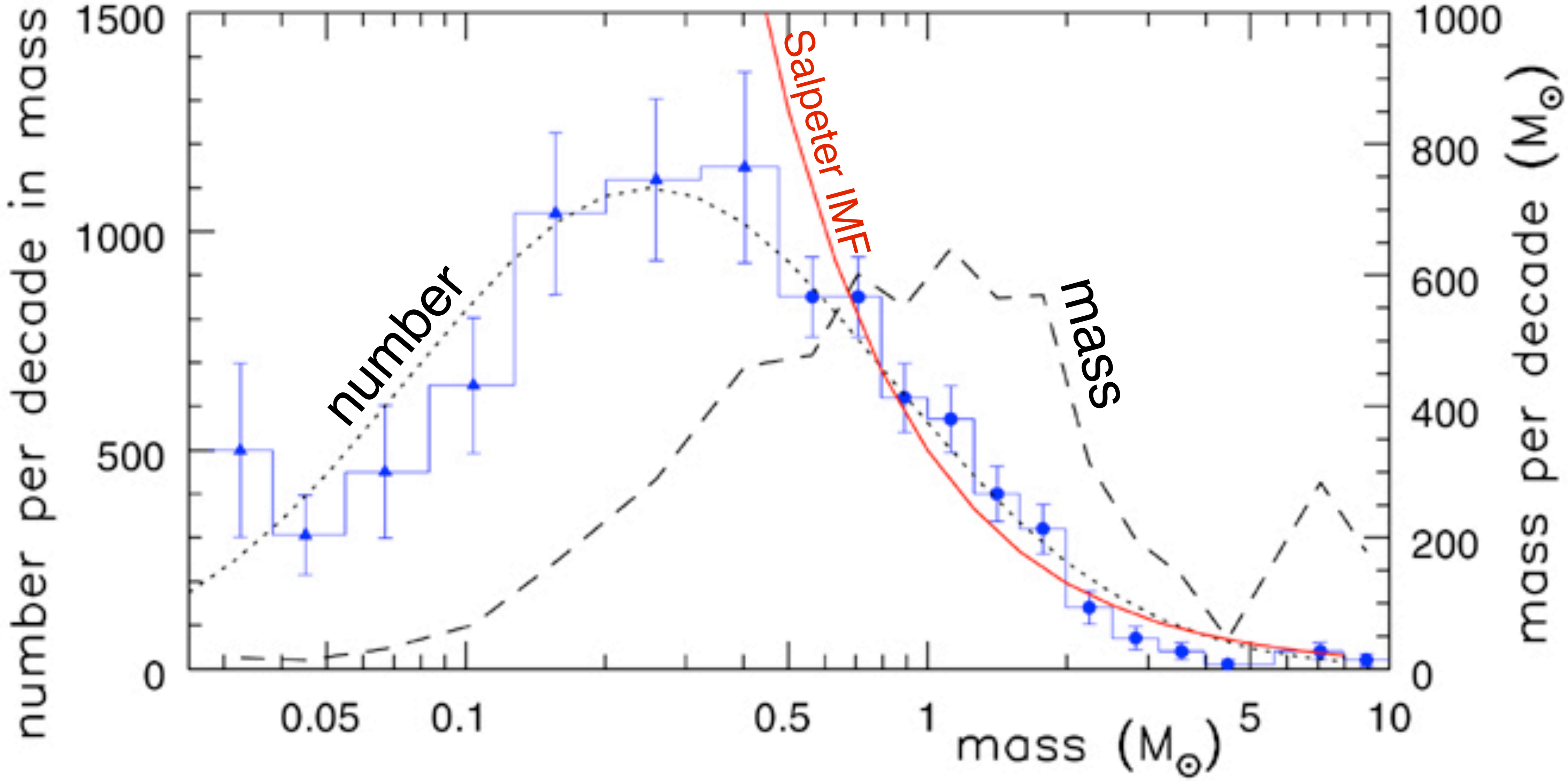
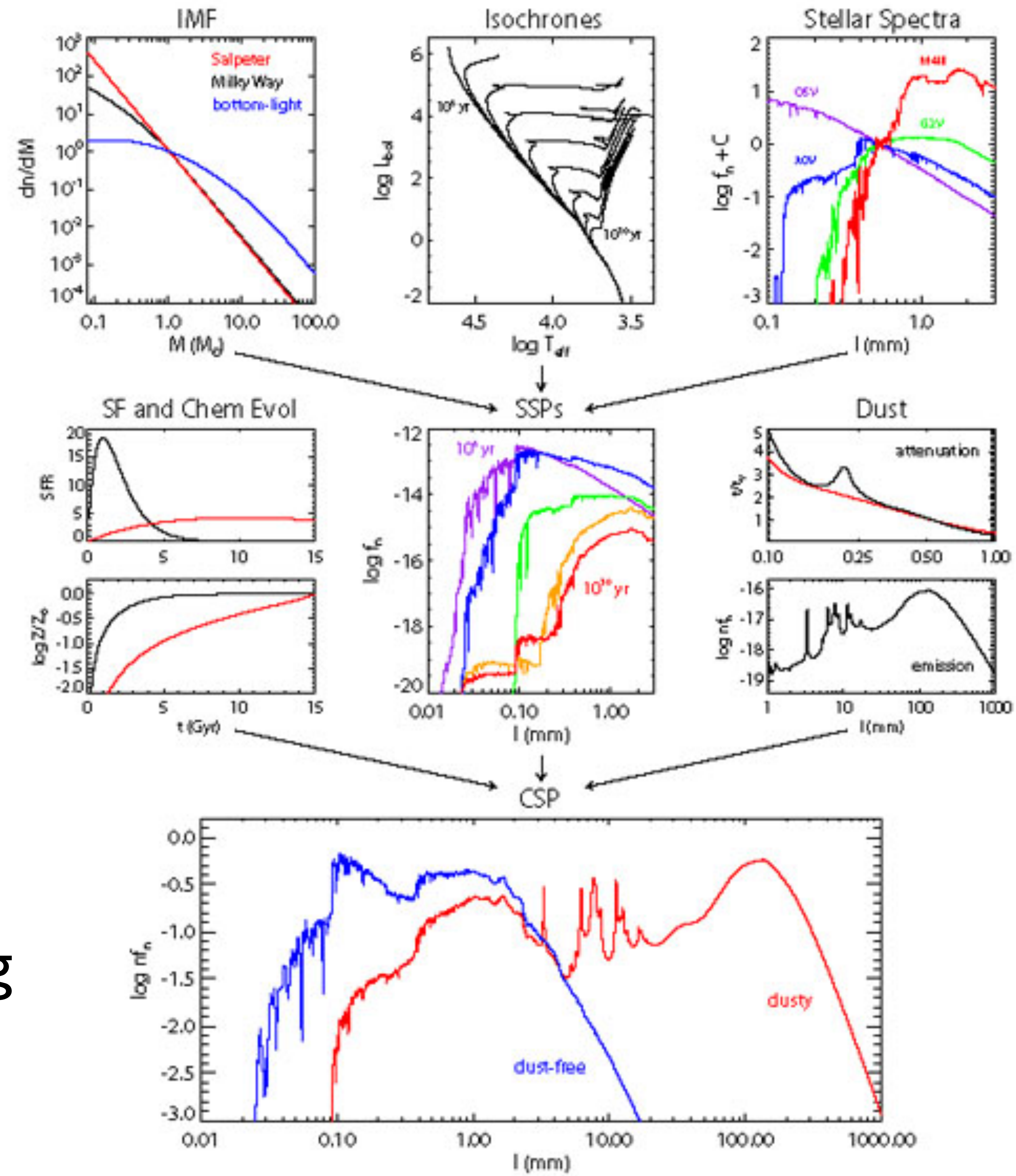


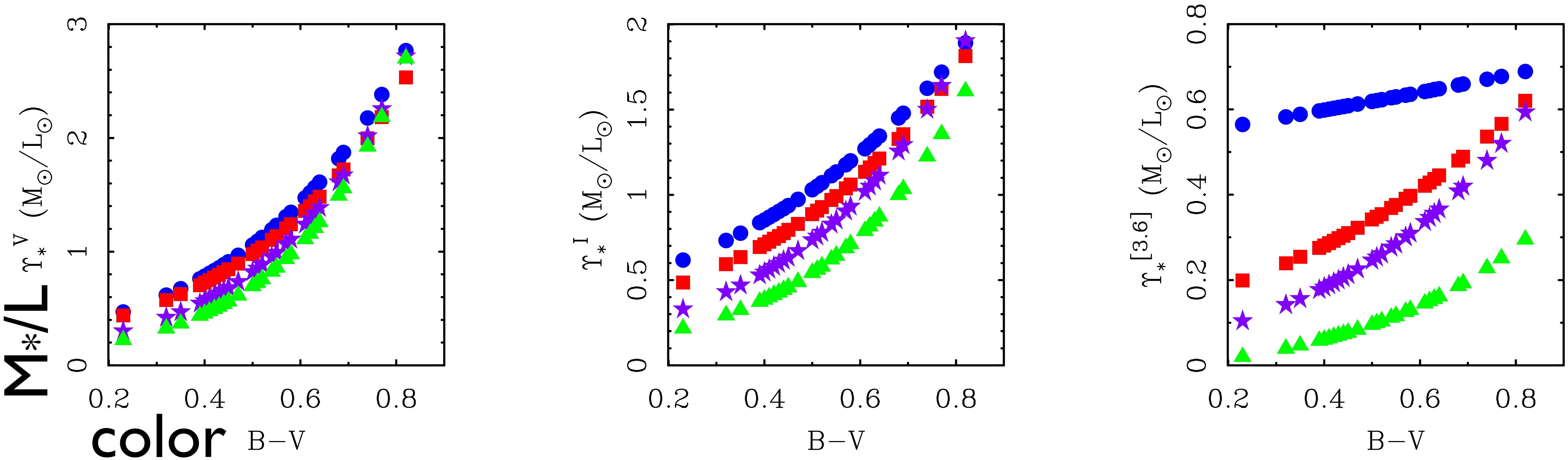
Fig 2.5 (E. Moreau) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



Stellar population synthesis modeling technique

stellar population models

Typically, redder colors mean higher mass-to-light ratios



$$\log\left(\frac{M_*}{L_i}\right) = a_i + b_i(B - V)$$

Table 5
Self-Consistent Population Synthesis Mass-to-Light Ratios

Model	a_V	b_V	α_I	β_I	$\alpha_{[3.6]}$	$\beta_{[3.6]}$	$\Upsilon^V_{0.6}$	$\Upsilon^I_{0.6}$	$\Upsilon^{[3.6]}_{0.6}$
Bell et al. (2003)	−0.628	1.305	−0.259	0.565	−0.313	−0.043	1.43	1.20	0.46
Portinari et al. (2004)	−0.654	1.290	−0.302	0.644	−0.575	0.394	1.32	1.22	0.46
Zibetti et al. (2009)	−1.075	1.837	−0.446	0.915	−1.115	1.172	1.07	1.27	0.39
Into & Portinari (2013)	−0.900	1.627	−0.394	0.820	−0.841	0.771	1.19	1.25	0.42