Inner dynamics of massive galaxies (ETG)

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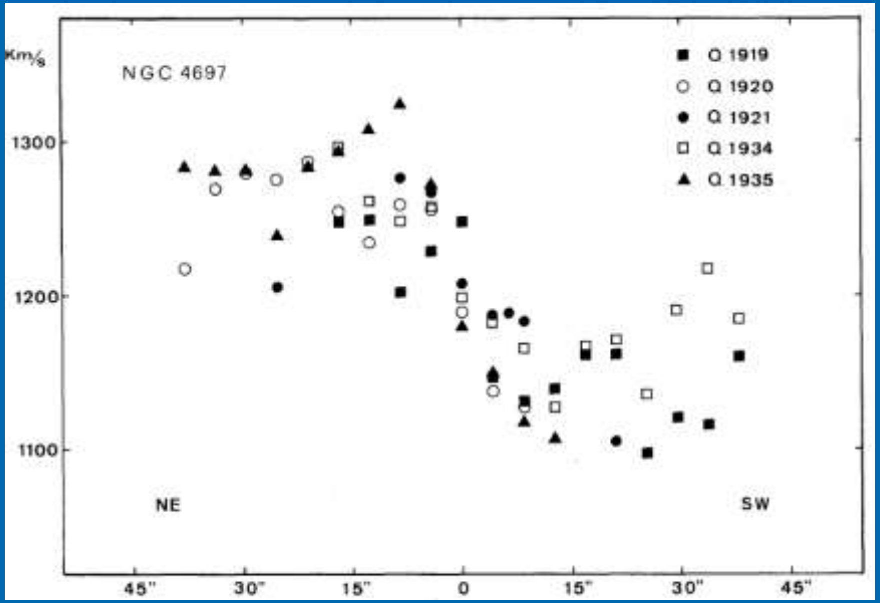
First rotation curve of an elliptical

V

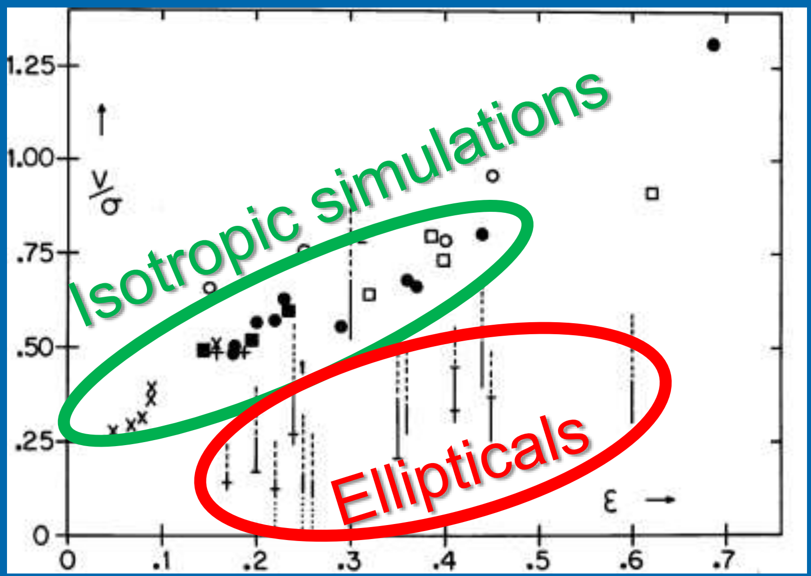


(Bertola+Capaccioli75)

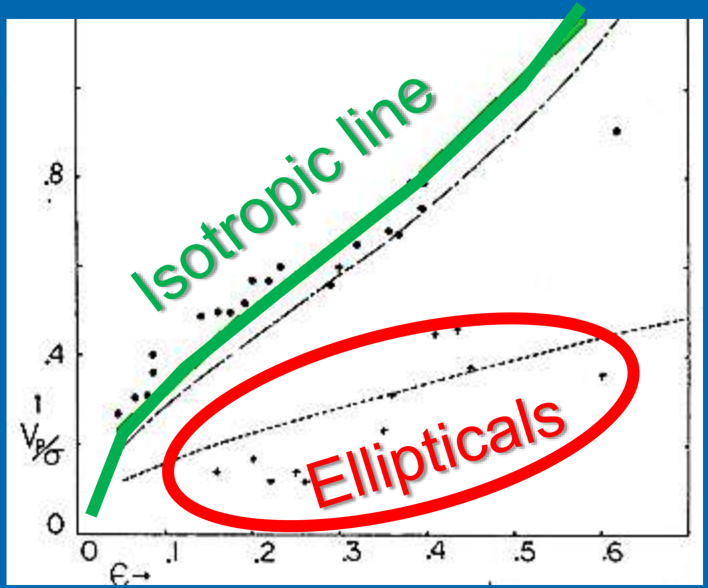
- Elliptical galaxy NGC4697
- 2 hr of observations at 5-m Palomar
- Angular momentum much lower than spirals

Introducing the (V/σ,ε) diagram

$\frac{V}{\sigma}$



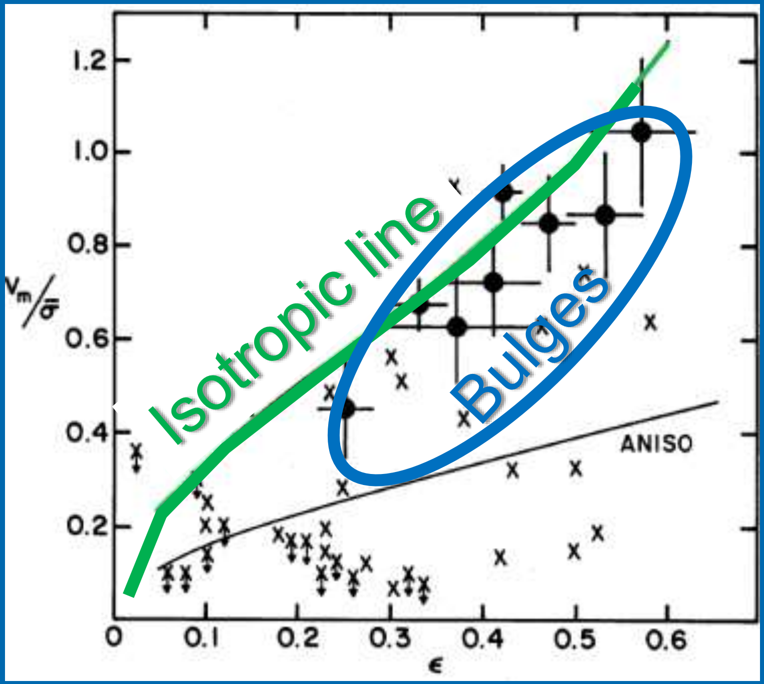
(Illingworth77)



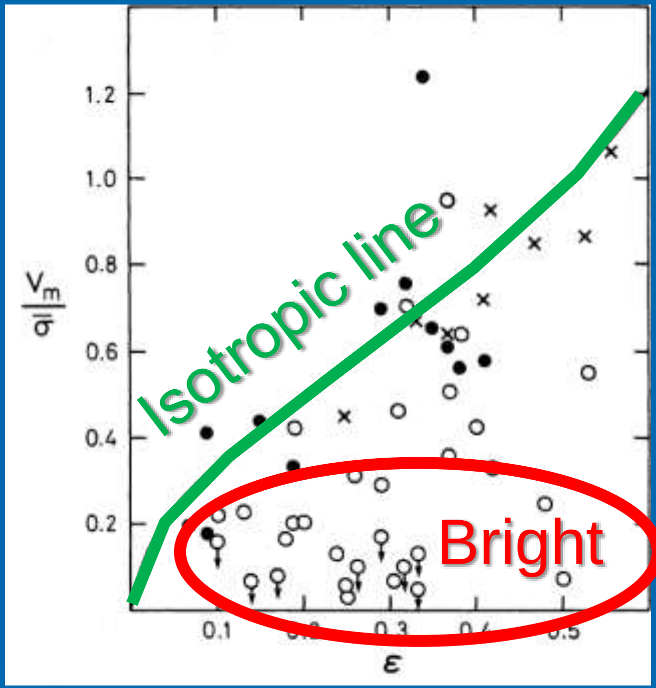
(Binney78)

- Sample of 13 ellipticals (Illingworth77)
- Less rotation than isotropic simulations
- Isotropic line from tensor virial theorem (Binney78)

Kinematics depends on luminosity



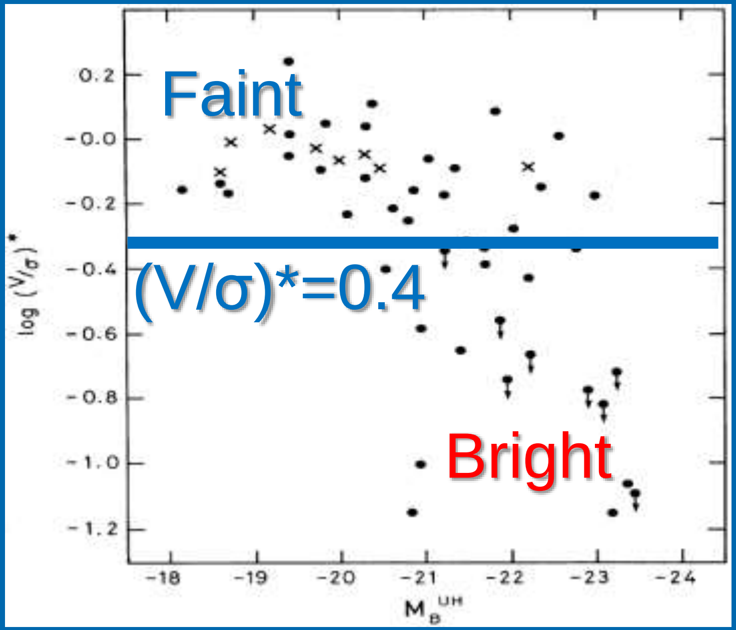
(Kormendy+Illingworth82; K82)



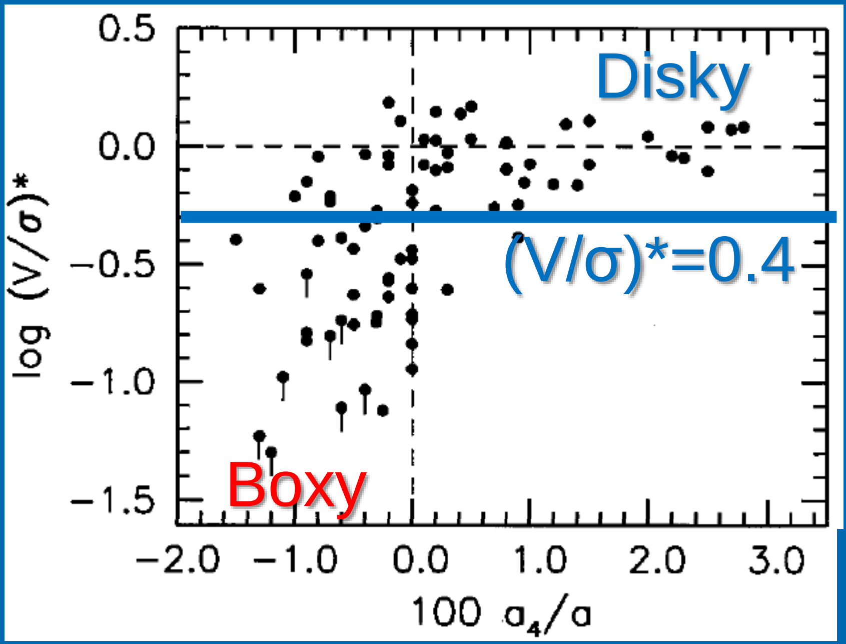
(Davies+83)

- Bulges close to isotropic (Kormendy+Illingworth82)
- Bulges similar to faint ellipticals (Davies+83)
- But bright ellipticals rotate slowly

(V/σ)* and galaxy photometry



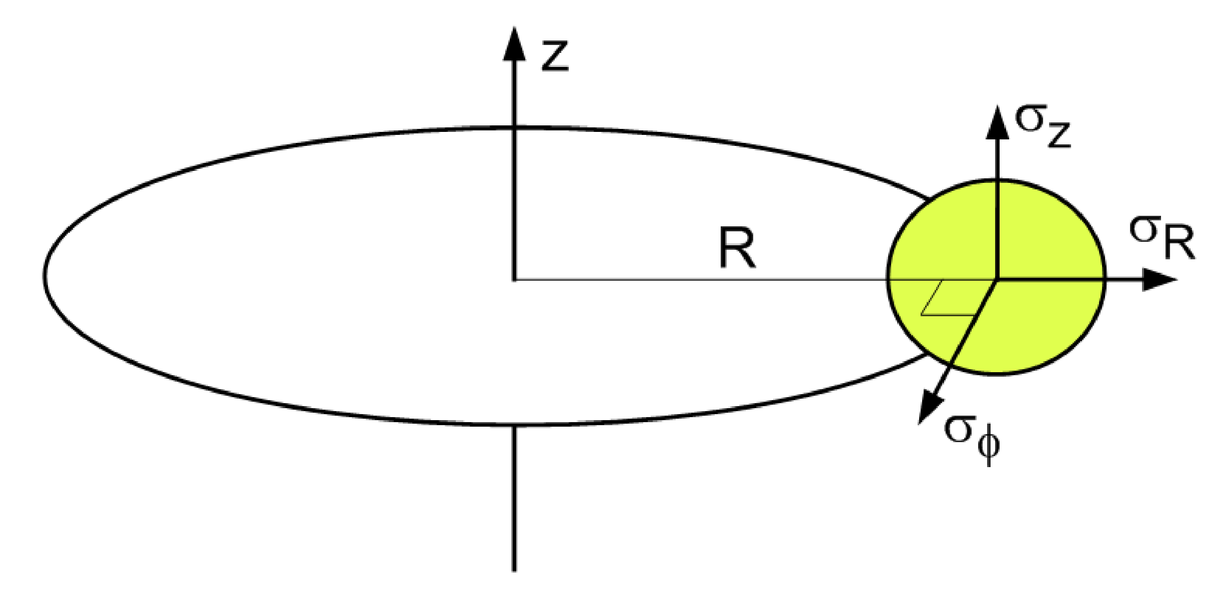
(Davies+83)



(Bender88; Kormendy+Bender96)

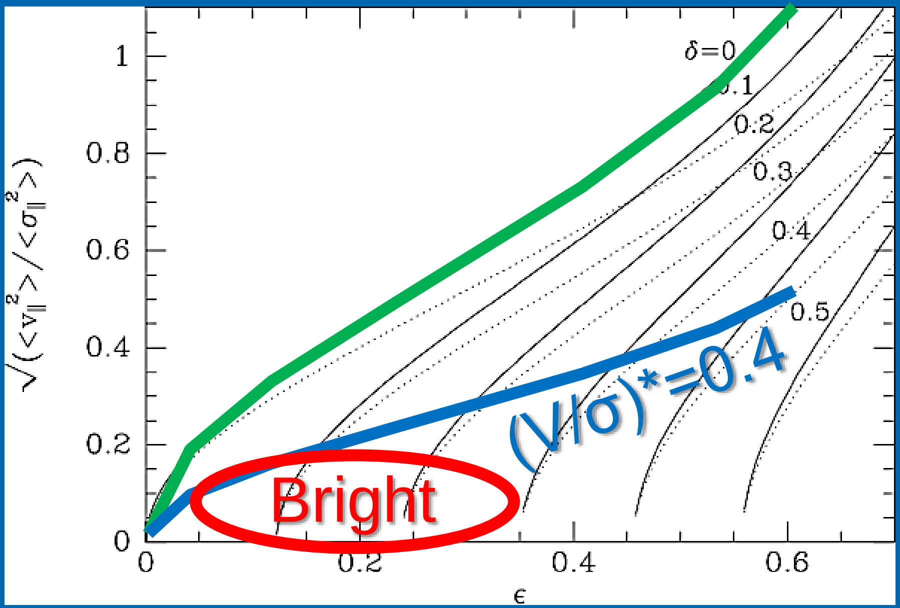
- $(V/\sigma)^* \equiv (V/\sigma) / (V/\sigma)_{ISO}$ (Kormendy+Illingworth82; Davies+83)
- Faint ellipticals only for (V/σ)*>0.4 (Davies+83)
- Disky galaxies only for (V/σ)*>0.4 (Bender88)

Anisotropy and velocity ellipsoid

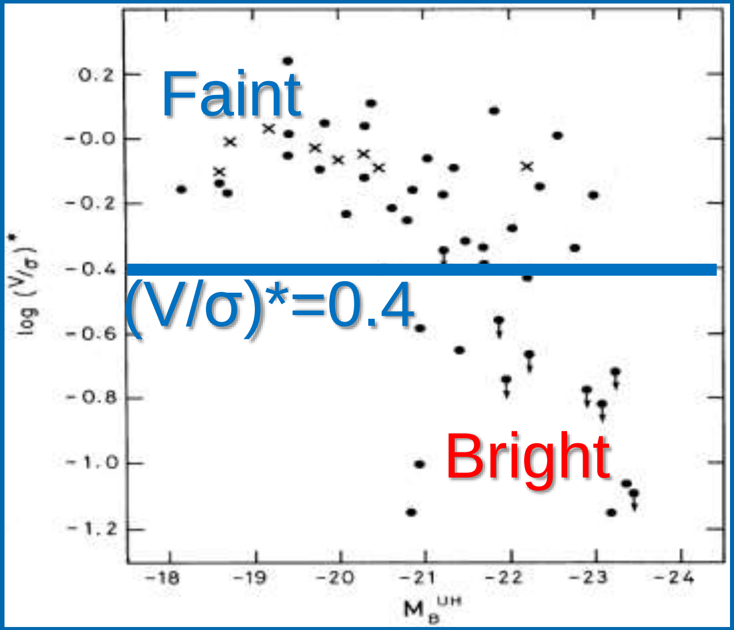


- $\beta = 1 - \frac{\sigma_z^2}{\sigma_R^2}; \gamma = 1 - \frac{\sigma_\phi^2}{\sigma_R^2}; \delta = 1 - \frac{2\sigma_z^2}{\sigma_R^2 + \sigma_\phi^2}$ (Cappellari+07)
- δ is measured by the (V/σ,ε) diagram (Binney78,05)
- β, γ require dynamical models
- $\sigma_R = \sigma_\phi \rightarrow (\delta = \beta;\ \gamma = 0)$: Oblate velocity ellipsoid

(V/σ)* not a measure of anisotropy



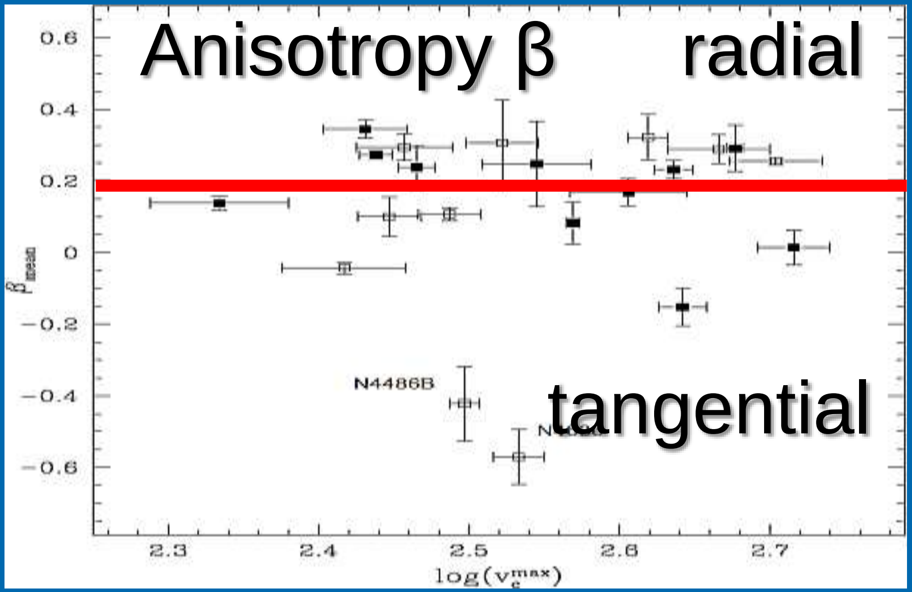
(Binney+Tremaine87,08)



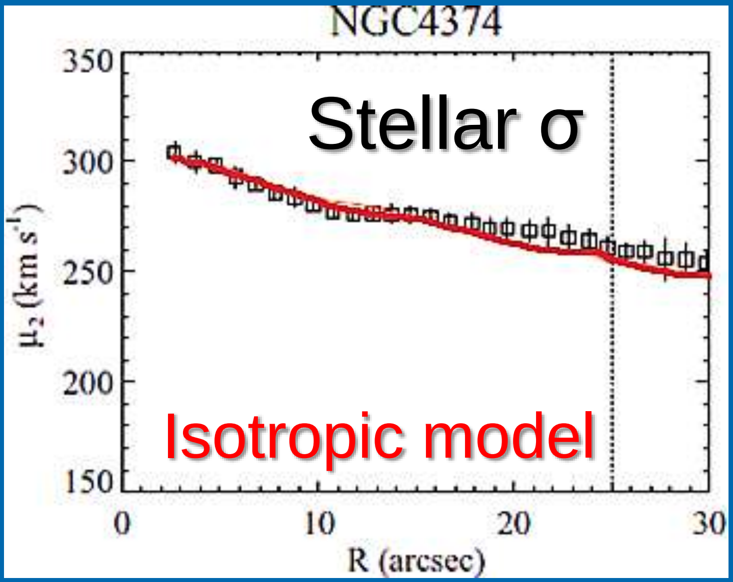
(Davies+83)

- $(V/\sigma)^* \equiv (V/\sigma) / (V/\sigma)_{ISO}$
- (V/σ)* does not measure anisotropy (δ)
- Only bright galaxies are below (V/σ)*=0.4

Modeling round bright ellipticals



(Gerhard+01)



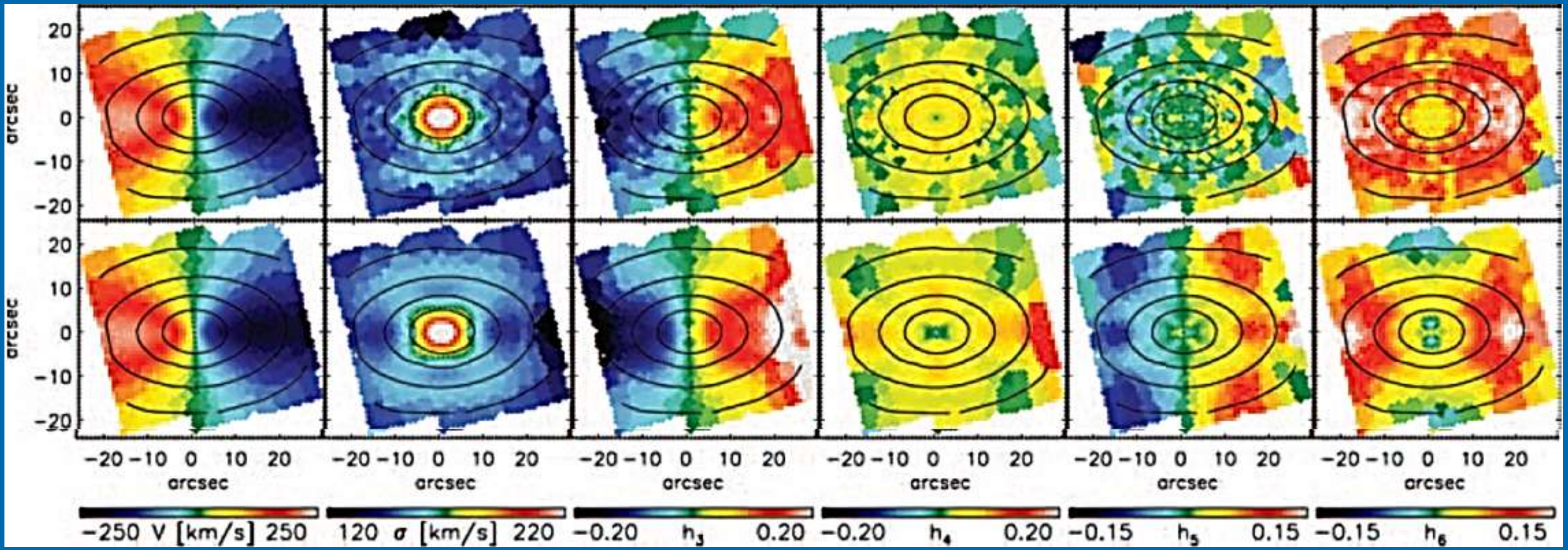
(Cappellari+07)

- Spherical dynamical models (Kronawitter+00)
- $\beta \approx 0.2$ within 1Re (just 10% from isotropic)
- Consistent with (V/σ,ε) → OK
- Consistent with Jeans models → OK

Modeling flattened ETGs

SAURON Data

Model



(Krajnović+05; see also van der Marel+98; Gebhardt+00; Cappellari+02; Verolme+02; Thomas+04; Valluri+04;…)

- Orbits have 3 integrals of motion
- Need 3-dimensional observable
- Integral-field data (or multiple slits) essential

→ SAURON survey: 48 ETGs (de Zeeuw+02)

Anisotropy of flattened ETGs

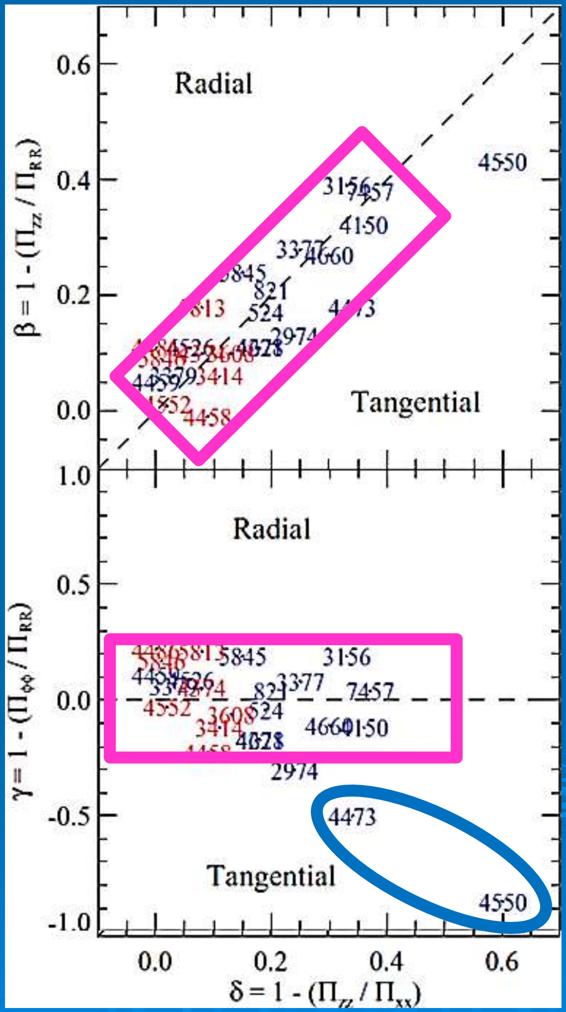
- SAURON integral-field data
- Schwarzschild's axisymmetric models
- 24 galaxies (Cappellari+07)

→ $\delta \approx \beta \ and \ \gamma \approx 0$

(2 important exceptions)

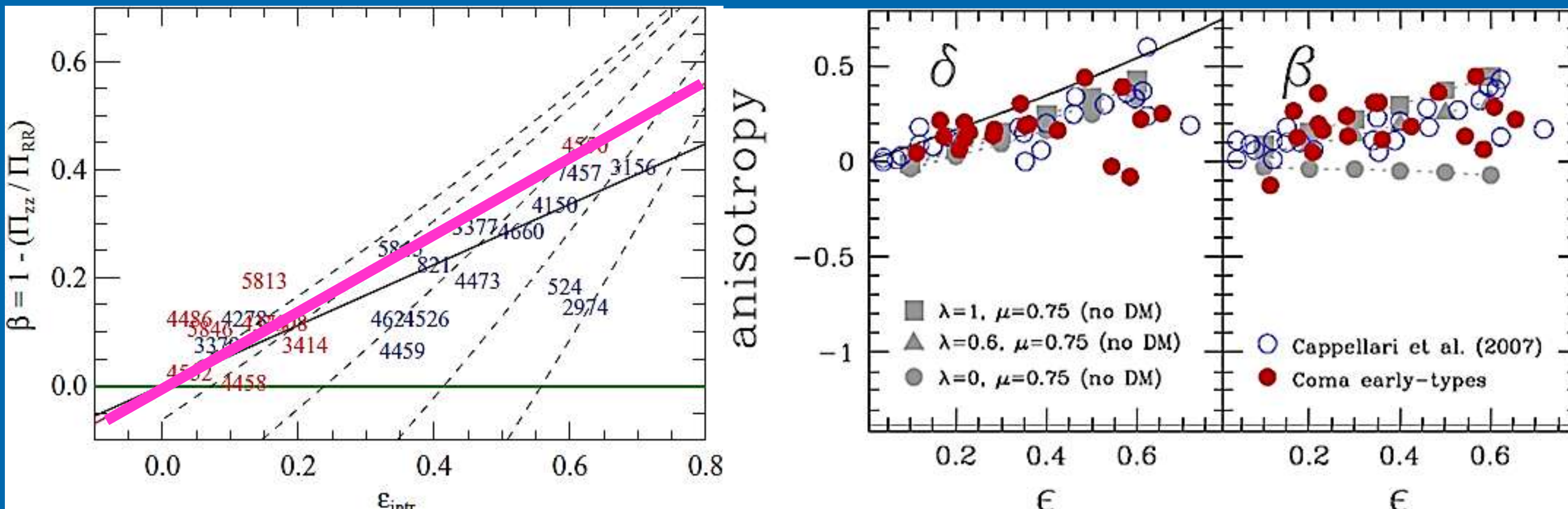
→ Oblate velocity ellipsoid!

- Independently confirmed in Coma (Thomas+09)



(Cappellari+07)

Anisotropy versus flattening



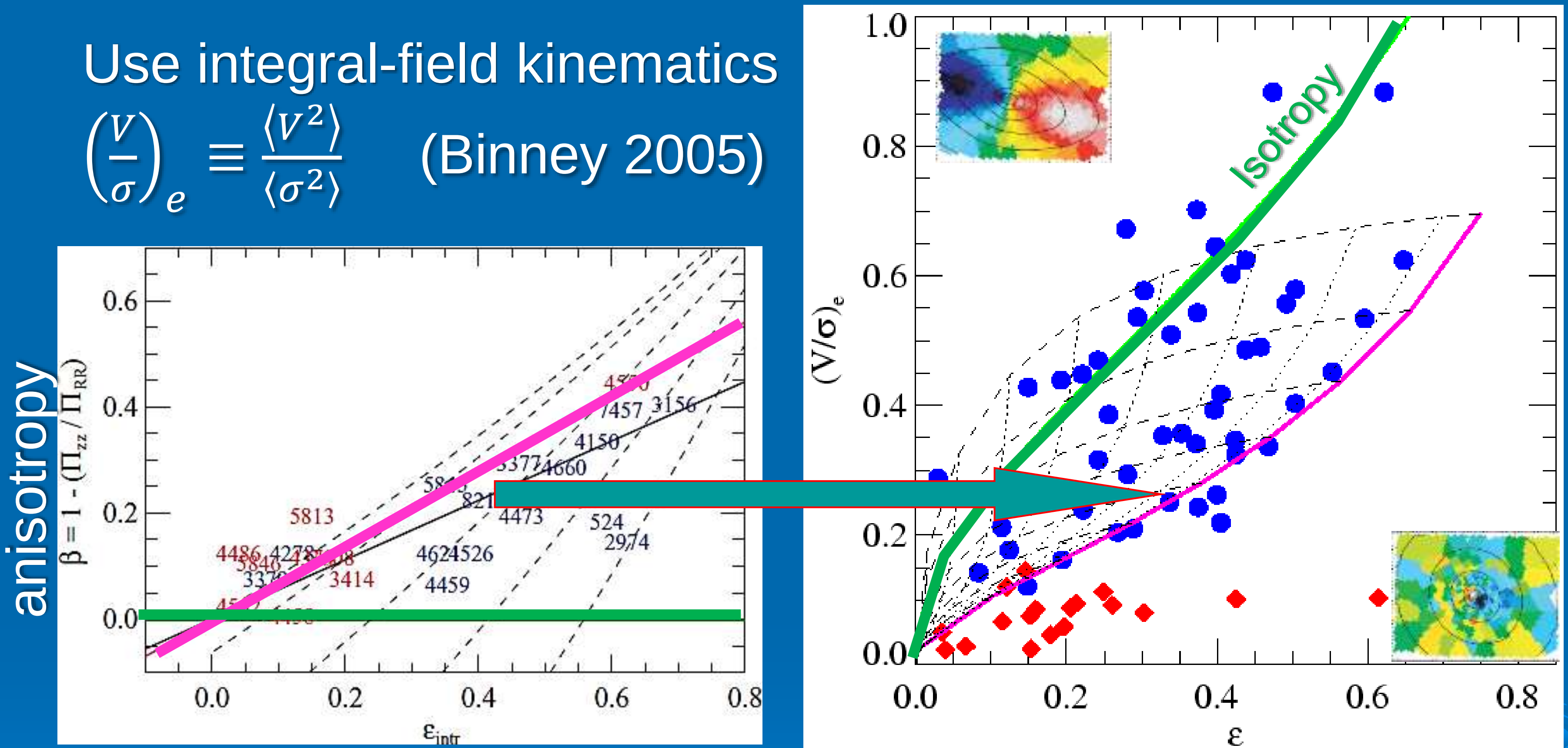
(Cappellari+07) (Thomas+09)

- Trend of anisotropy versus flattening
- Exclusion zone at high anisotropy (magenta line)

Understanding the (V/σ,ε) diagram

Use integral-field kinematics

$$\left(\frac{V}{\sigma}\right)_e \equiv \frac{\langle V^2 \rangle}{\langle \sigma^2 \rangle}$$ (Binney 2005)

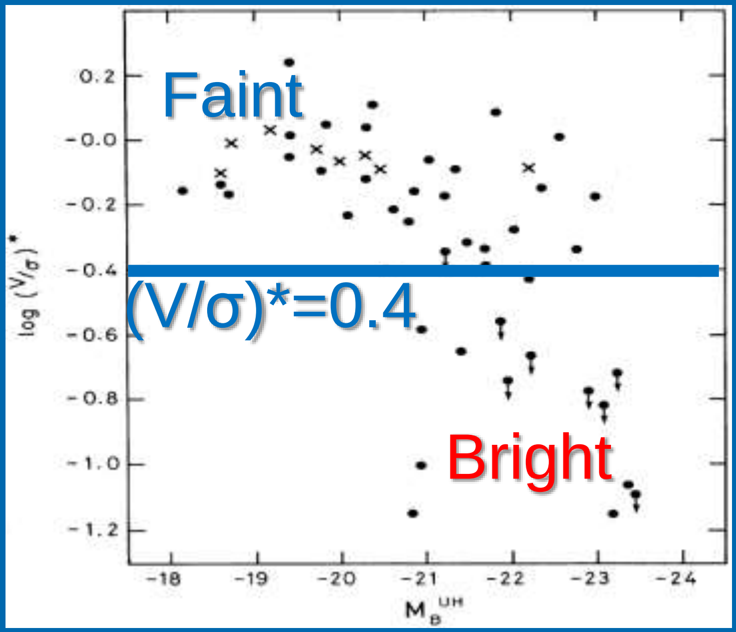


24 models

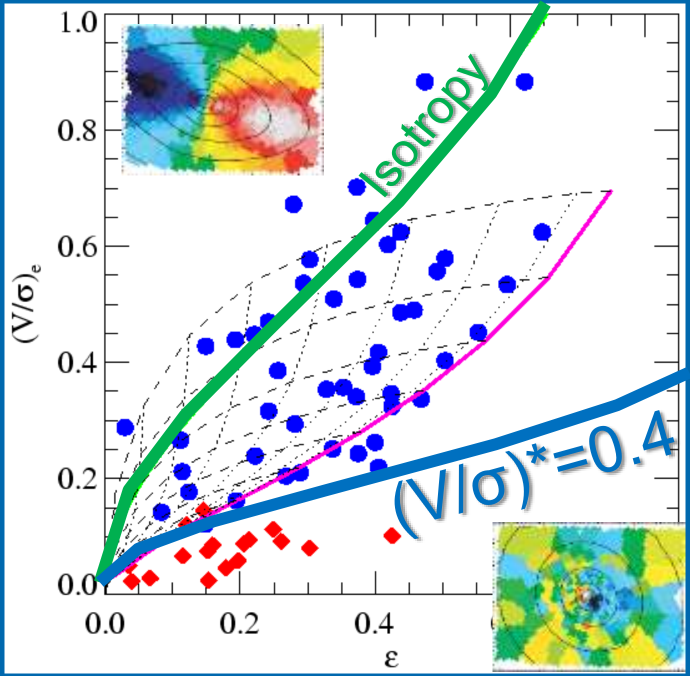
Entire sample (Cappellari+07)

- (V/σ,ε) consistent with dynamical models
- Fast and slow rotators distinct on (V/σ,ε)

Revisiting (V/σ)*



(Davies+83)

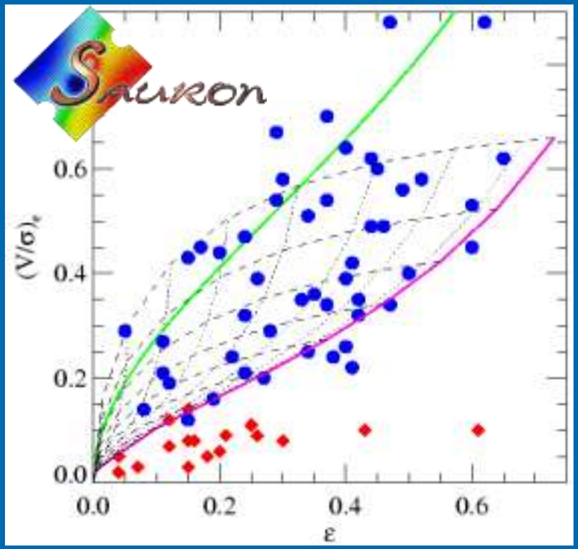


(Cappellari+07)

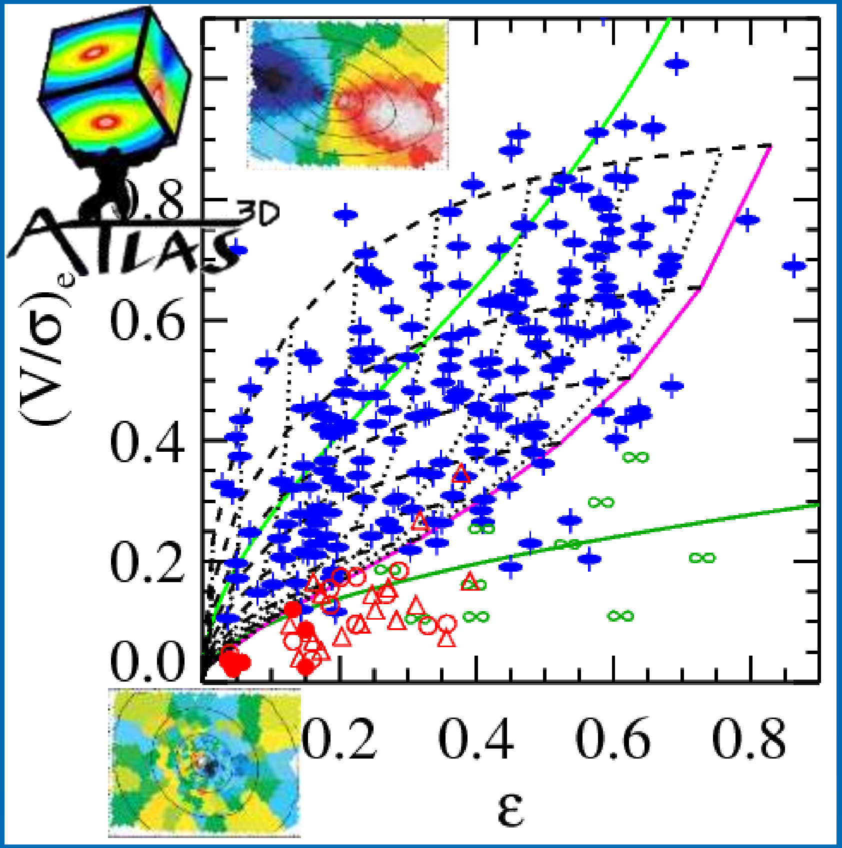
- Fast rotators: anisotropic oblate family
- Slow rotators: weakly triaxial and brighter

(Emsellem+07; Cappellari+07)

From SAURON to ATLAS^{3D}



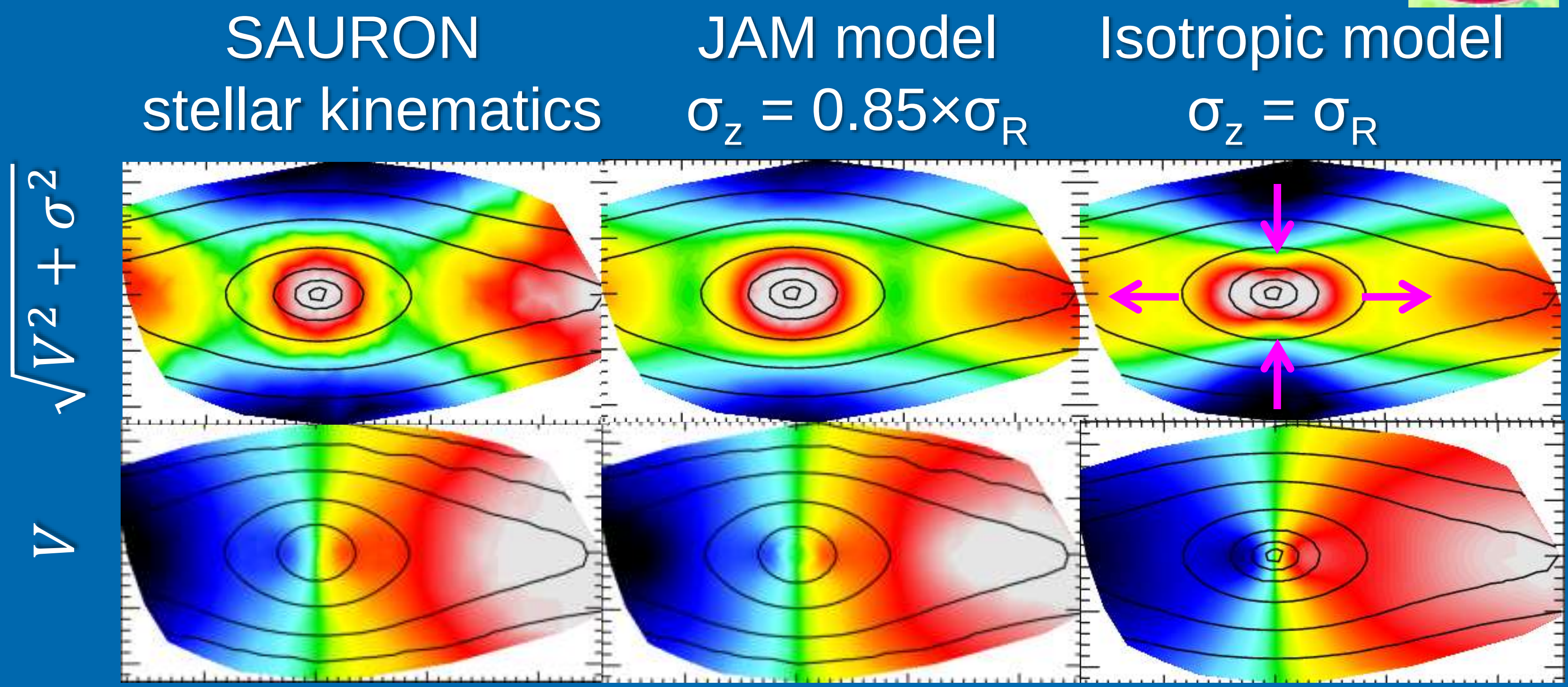
(Cappellari+07)



(Emsellem+11)

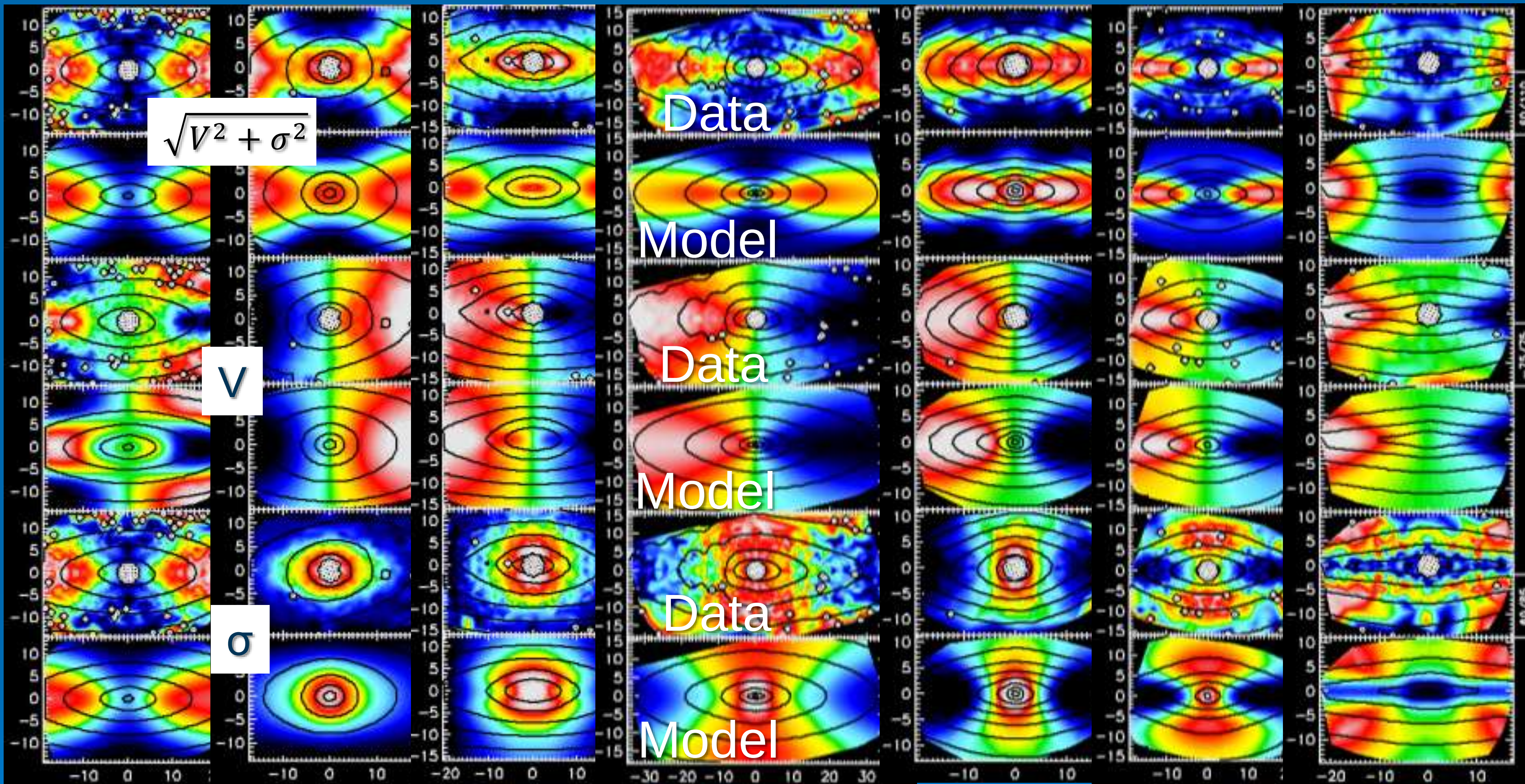
- ATLAS^{3D} volume-limited sample (Cappellari+11)
- SAURON result strongly confirmed
- But ATLAS^{3D} gives proper statistics → Krajnović talk

Jeans Anisotropic Models (JAM)



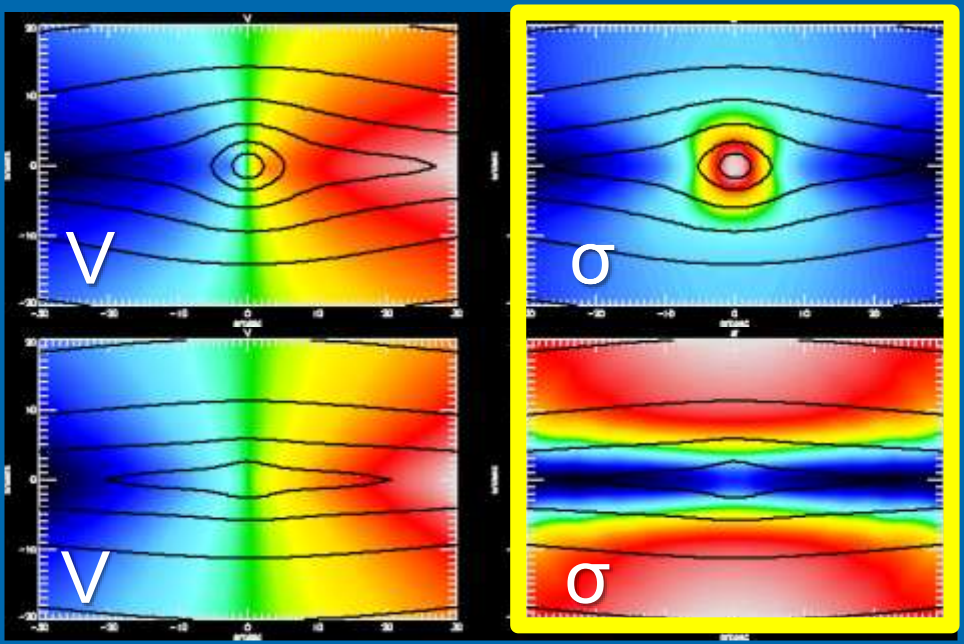
- Fast rotators ETGs have $\sigma_z < \sigma_R \approx \sigma_\phi$ (Cappellari+07, Thomas+09)
- Use Multi-Gaussian Expansion to fit images (Emsellem+94)
- Efficient anisotropic Jeans solution with $\sigma_z \neq \sigma_R$ (Cappellari 08)
- Just two parameters (i, σ_z/σ_R) fit shape of both V_{rms} and V! (http://purl.org/cappellari/idl)

JAM with oblate velocity ellipsoid



- Large variations in observed kinematics
- Still captured by just two parameter (i, β_z) !

σ measures mass not anisotropy

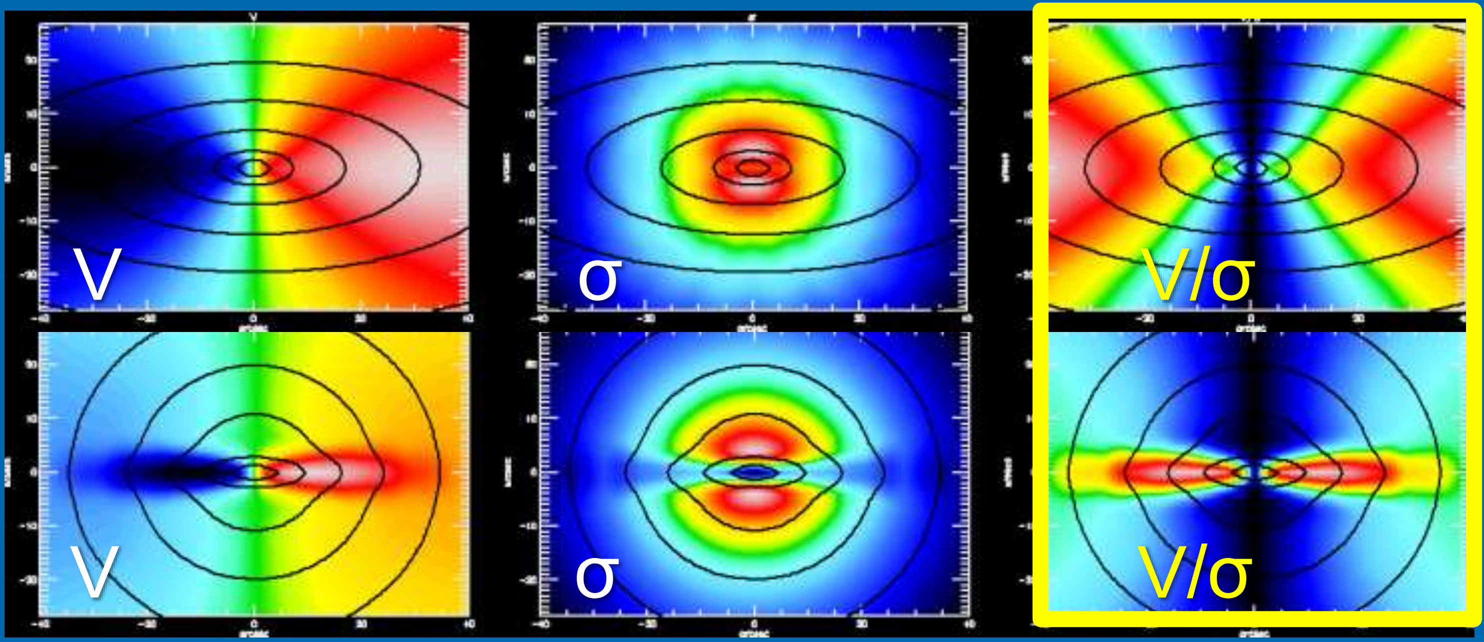


Isotropic model
Bulge mass=10

Isotropic model
Bulge mass=1

- Anisotropy variations small in real fast rotator
- σ <u>mainly</u> a tracer of mass distribution
- σ-peak no indication of “hot component”
- Kinematics encoded in photometry!

Local-V/σ not meaningful

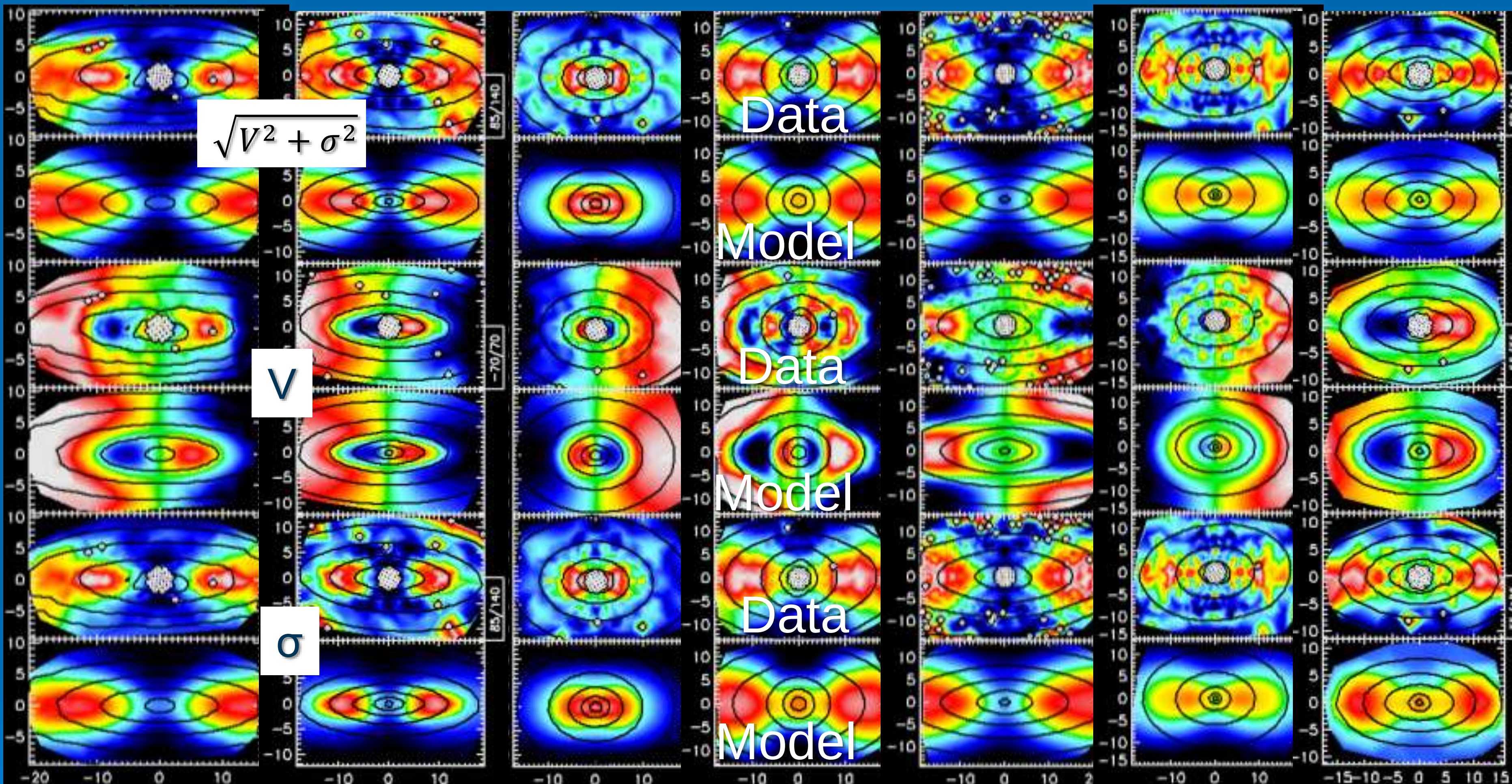


Isotropic model Constant ε

Isotropic model Variable ε

- Global (V/σ,ε) well defined with constant ε
- But varies locally with constant ε and anisotropy
- V/σ variations not related to “pressure support”

Exception 1: counter-rotating disks

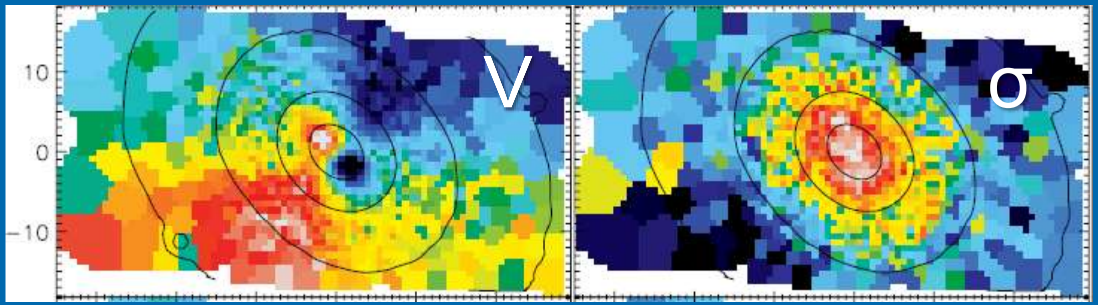


28% 27% 13% 43% 49% 15% 42%

Masses KDC

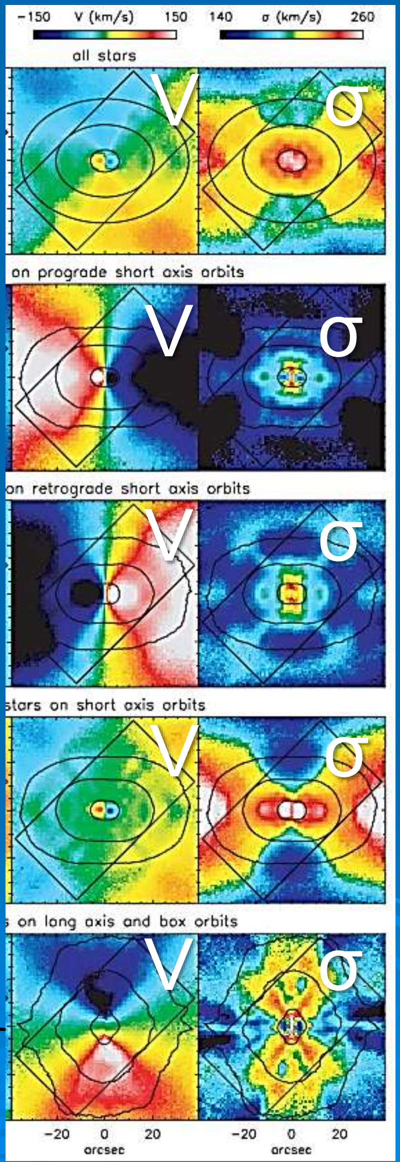
Cappellari + ATLAS^{3D} in prep.

Exception 2: KDCs in slow rotators



NGC4365 (Davies+01; vdB+08)

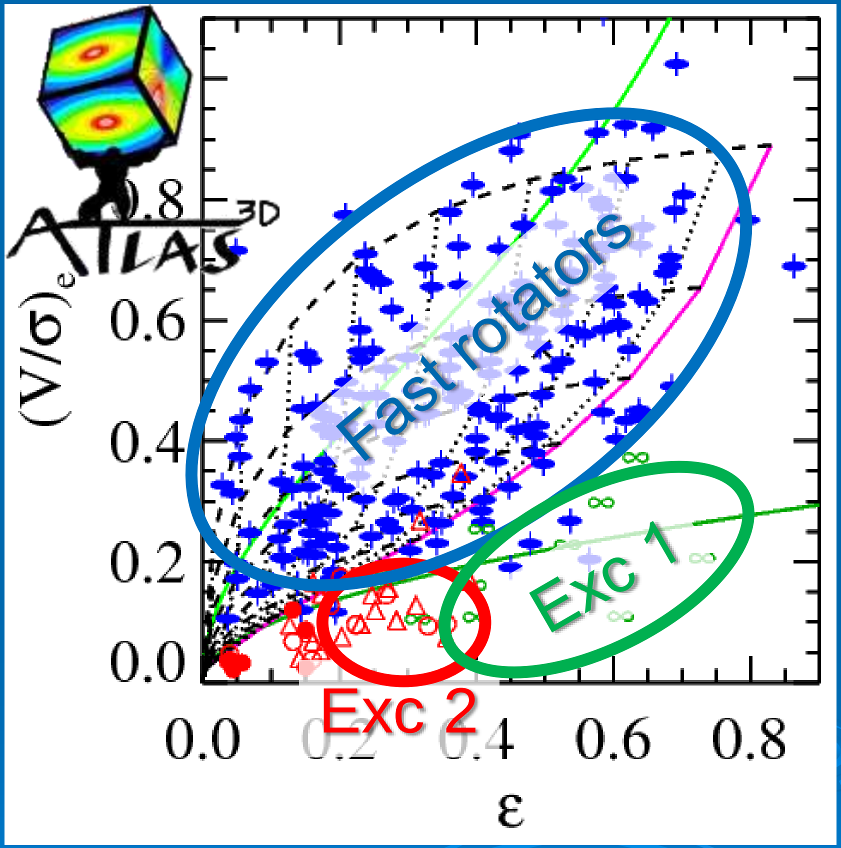
- Prototypical triaxial galaxy
- Orthogonal KDC (Wagner+88)
- KDC only "apparent"
- Cancellation of counter-rotating tube orbits (van den Bosch+08)



(Van den Bosch+08)

Summary inner dynamics of ETGs

- Classic results revisited
- Most ETGs within 1Re: axisymmetric, randomly inclined, anisotropic, very homogeneous!
- Exceptions:
  1. counter-rotating disks
  2. "Apparent" KDCs in triaxial slow rotator



(Emsellem+11)