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A Unified Electro-Gravity Theory to Model Gravitational Mass in Galaxy Clusters without Dark Matter

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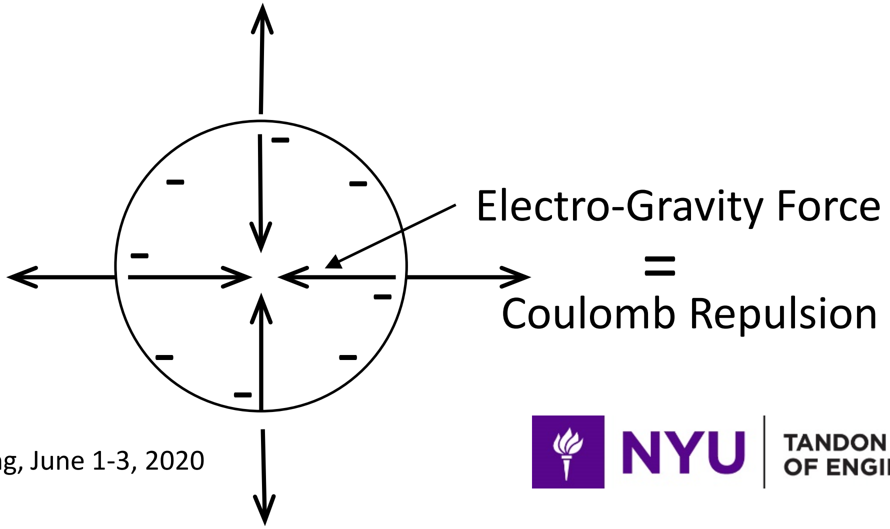
Introduction: Unified Electro-Gravity (UEG) Theory

- Newtonian gravitation is strictly valid only in the external region of a neutral, non-radiating, massive body.
- Gravitation is much stronger in the presence of any electromagnetic field or light radiation, constituting a new modified gravity theory, referred to as Unified Electro-Gravity (UEG) theory.
- The UEG field of a charged elementary particle, such as the electron, would counter the self-repulsive force of the charge, resulting in a self-consistently stable charge structure.



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Unified Electro-Gravity Theory (Continued)

- In the simplest form, for a spherically symmetric structure, the gravitational acceleration $\bar{E}_g$ at a given location due to the UEG field is defined proportional to the electromagnetic energy density W_τ at the location, with the constant of proportionality γ called the UEG constant, and the $\bar{E}_g$ is directed towards the gravitational center.
- The UEG constant is estimated from flat rotation in spiral galaxies, consistent with elementary charged-particle modeling, to be approximately equal to $\gamma \approx 600\ (\frac{ms^{-2}}{Jm^{-3}})$, and is directly related to the dimensionless Fine-Structure Constant ∝ of electro-dynamics, in terms of the mass m_e and classical radius r_e of the electron: $(\gamma m_e/r_e^2)$=(2/ ∝).

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Unified Electro-Gravity (UEG) Theory for Spiral Galaxies and Galaxy Clusters

- The UEG theory is applied to support central acceleration in spiral galaxies, with the UEG field produced due to the energy density associated with stellar light radiation. (Recently presented in AAS 235 meeting, Honolulu; also available in N. Das, preprints.org: 2019)
- The UEG theory must also be similarly applied to model excess gravitational mass in galaxy clusters, with the UEG field produced due to the energy density associated with the cosmic microwave background (CMB) radiation.
- The UEG theory is applied to model gravitational mass distribution, by properly accounting for any spherical asymmetry in a galaxy cluster (Bullet Cluster), consistent with similar modeling in spiral galaxies.

UEG Theory for Galaxy Clusters, General Analysis

- Basic Properties of Galaxy Clusters:

  - Gravitational mass M = 10^{14} to 10^{15} M_0

    M $\approx$ $5 \times 10^{14} \times 2 \times 10^{30} = 10^{45}$ kg

  - Diameter d = 2 to 10 Mpc

    d $\approx 6 \times 3.086 \times 10^{22} = 18.5 \times 10^{22}$ m

-Maximum acceleration $\mathbf{a = \frac{4GM}{d^2} = 0.78 \times 10^{-11} m/s^2}$

- This acceleration is comparable to the UEG acceleration a_{UEG} due to CMB radiation, considering the spread of the values of M and d:

$$- \boldsymbol{a_{UEG} = \gamma W_{\tau(CMB)} = \gamma \left(\frac{4\sigma}{c}\right) T^4 = 2.5 \times 10^{-11} m/s^2 \gtrsim a}$$

$\boldsymbol{\gamma(UEG) = 6 \times 10^2 (ms^{-2})/(Jm^{-3})}$, $T(CMB) = 2.725^0 K$

σ (Stefan-Boltzman Constant) = $5.670 \times 10^{-8} \frac{W}{m^2 K^4}$

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UEG Theory for Specific Galaxy Clusters: Virgo Cluster

- Basic Parameters of Virgo Cluster:
  - Gravitational mass M = $1.2 \times 10^{15}\ M_0$

    $\mathrm{M} = 1.2 \times 10^{15} \times 2 \times 10^{30} = 2.4 \times 10^{45}$ kg
  - Diameter d = 2 X 2.3 Mpc (+/-8 degrees at distance R=16.5MPc)

    $\mathrm{d} = 4.6 \times 3.086 \times 10^{22} = 1.42 \times 10^{22}$ m
  - Red shift z=0.00385 (~ 70 (km/s)/Mpc x R/c)
  - Maximum acceleration reuired $\mathrm{a} = \frac{4GM}{d^2}$ = $3.18 \times\ 10^{-11} m/s^2$
  - Maximum required acceleration (non-Newtonian) $\boldsymbol{\mathrm{a}' = 0.9a}$ **= 2.86** $\boldsymbol{\times\ 10^{-11} m/s^2}$

- This acceleration a' is comparable to the UEG acceleration a_{UEG} due to CMB radiation:

$$\boldsymbol{- a_{UEG} = \gamma W_{\tau(CMB)} = \gamma \left(\frac{4\sigma}{c}\right) T^4 \times (1+z)^4 = 2.54 \times 10^{-11} m/s^2} \text{ = 0.88a'}$$

$$\boldsymbol{\gamma(UEG) = 6 \times 10^2 (ms^{-2})/(Jm^{-3})}, \; T(CMB) = 2.725^0 K$$

σ (Stefan-Boltzman Constant) = $5.670 \times 10^{-8} \frac{W}{m^2K^4}$

- The small difference (~12%) in the required acceleration a' and a_{UEG} can be accommodated by having the measured distance R (hence cluster diameter d) **larger about 6% (R ~ 17.6kpc).** This is very likely, considering that the measurement of distance R for the Virgo cluster based on individual galaxy distance measurement has significant spread (**P. Foque, et al., A&A (375),770 (2001).**

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UEG Theory for Specific Galaxy Clusters: Bullet Cluster

- Basic Parameters of Bullet Cluster:
  - Gravitational mass M = $5.1 \times 10^{14}\ M_0$

    $M = 5.1 \times 10^{14} \times 2 \times 10^{30} = 1.02 \times 10^{45}$ kg
  - Diameter d = 1.9 Mpc (selected)

    $d = 1.9 \times 3.086 \times 10^{22} = 5.86 \times 10^{22}$ m
  - Red shift z=0.3
  - Maximum acceleration required $a = \frac{4GM}{d^2} = 7.93 \times 10^{-11} m/s^2$
  - Maximum required acceleration (non-Newtonian) $\mathbf{a' = 0.9a = 7.14 \times 10^{-11} m/s^2}$

- This acceleration a' is close to the UEG acceleration a_{UEG} due to CMB radiation:

$$\boldsymbol{a_{UEG} = \gamma W_{\tau(CMB)} = \gamma \left(\frac{4\sigma}{c}\right) T^4 \times (1+z)^4 = 7.14 \times 10^{-11} m/s^2 \approx a'}$$

$\boldsymbol{\gamma(UEG) = 6 \times 10^2 (ms^{-2})/(Jm^{-3})}$, $T(CMB) = 2.725^0 K$

σ (Stefan-Boltzman Constant) = $5.670 \times 10^{-8} \frac{W}{m^2K^4}$

- Dark Matter distribution in Bullet Cluster is consistent with the UEG model of having the UEG acceleration proportional to an effective energy density, determined based on the cluster's Newtonian potential distribution.

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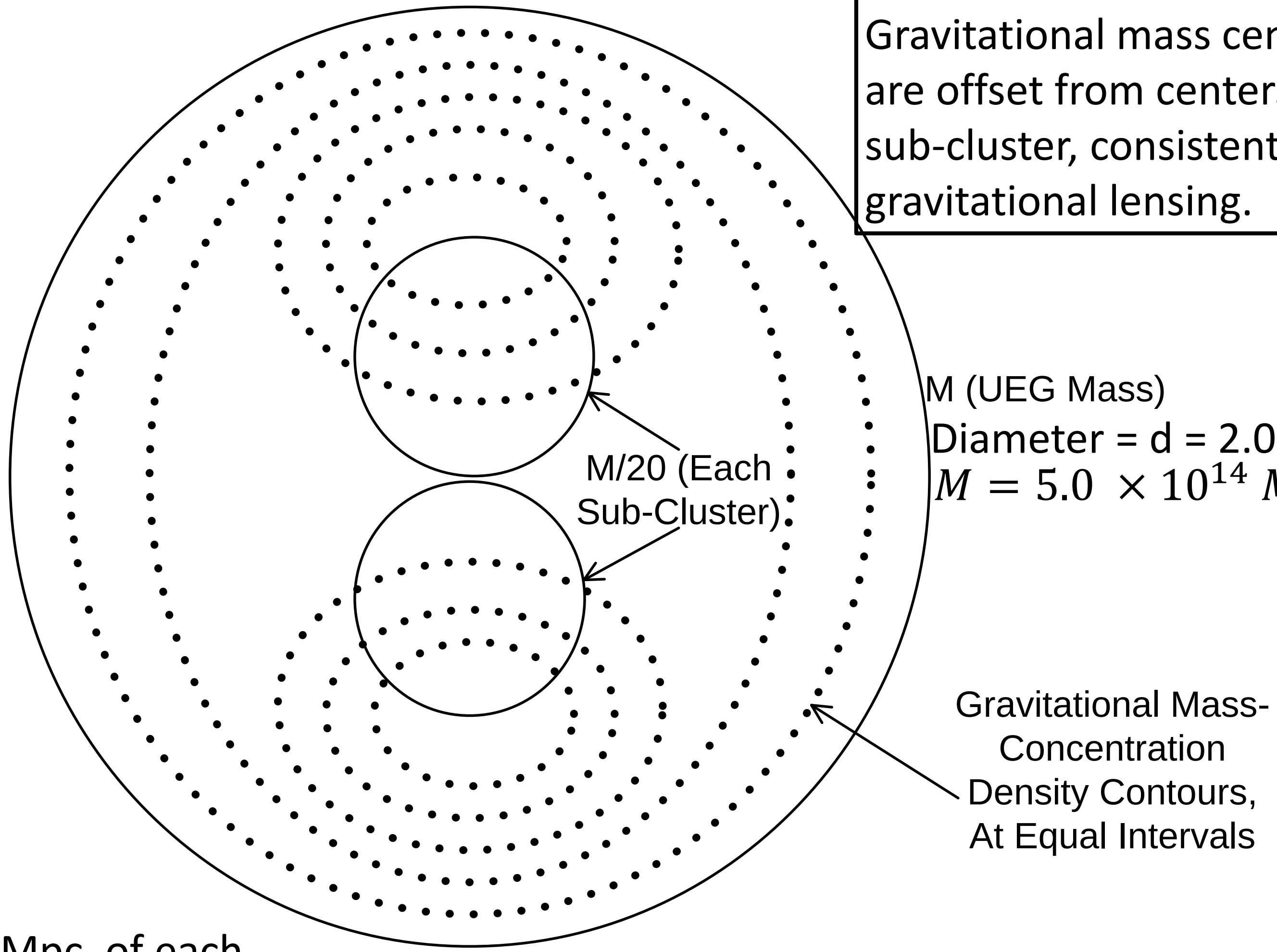
Simplified (Symmetric Sub-Clusters) UEG Model for Gravitational Mass Distribution of the Bullet Cluster

Note:
Gravitational mass centers are offset from centers of each sub-cluster, consistent with gravitational lensing.



Diameter = d = 2.0 Mpc

$M = 5.0 \times 10^{14} M_0$

Diameter =0.5 Mpc, of each
Newtonian body (Sub-Cluster) of mass M/20

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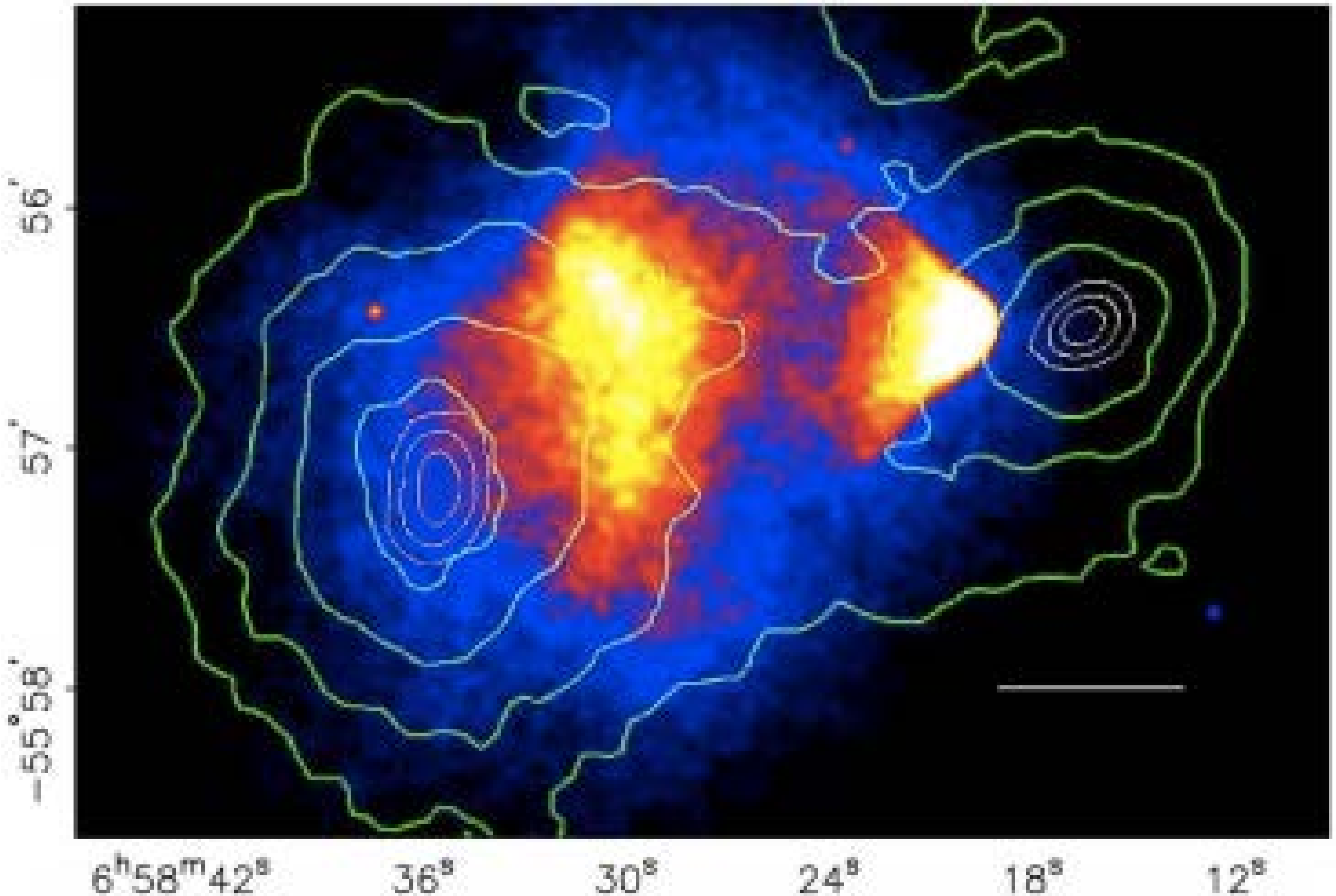
Gravitational Lensing Measurement of Gravitational Mass-Concentration Density Contours of Bullet Cluster



Ref: D. Clowe, et al., ApJ (Aug. 2006)

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Unified Electro-Gravity (UEG) Theory for Galaxy Clusters: Conclusion

- The UEG theory for galaxy clusters successfully predicts/models the observed gravitational mass in galaxy clusters, in general, as well as specifically in Virgo and Bullet clusters.
- The UEG constant γ used in the galaxy cluster modeling is close to the $\gamma = 600\ (\frac{m}{s^2})/(\frac{J}{m^3})$ extracted from spiral galaxy model as well as from a charge-particle model.
- The UEG theory properly models mass distribution in Bullet Cluster, consistent with gravitational lensing measurements.
- The UEG theory can also be similarly extended as a substitute for dark matter and dark energy in cosmology (due to CMB radiation, and any current or future star lights)

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Supplemental Slides

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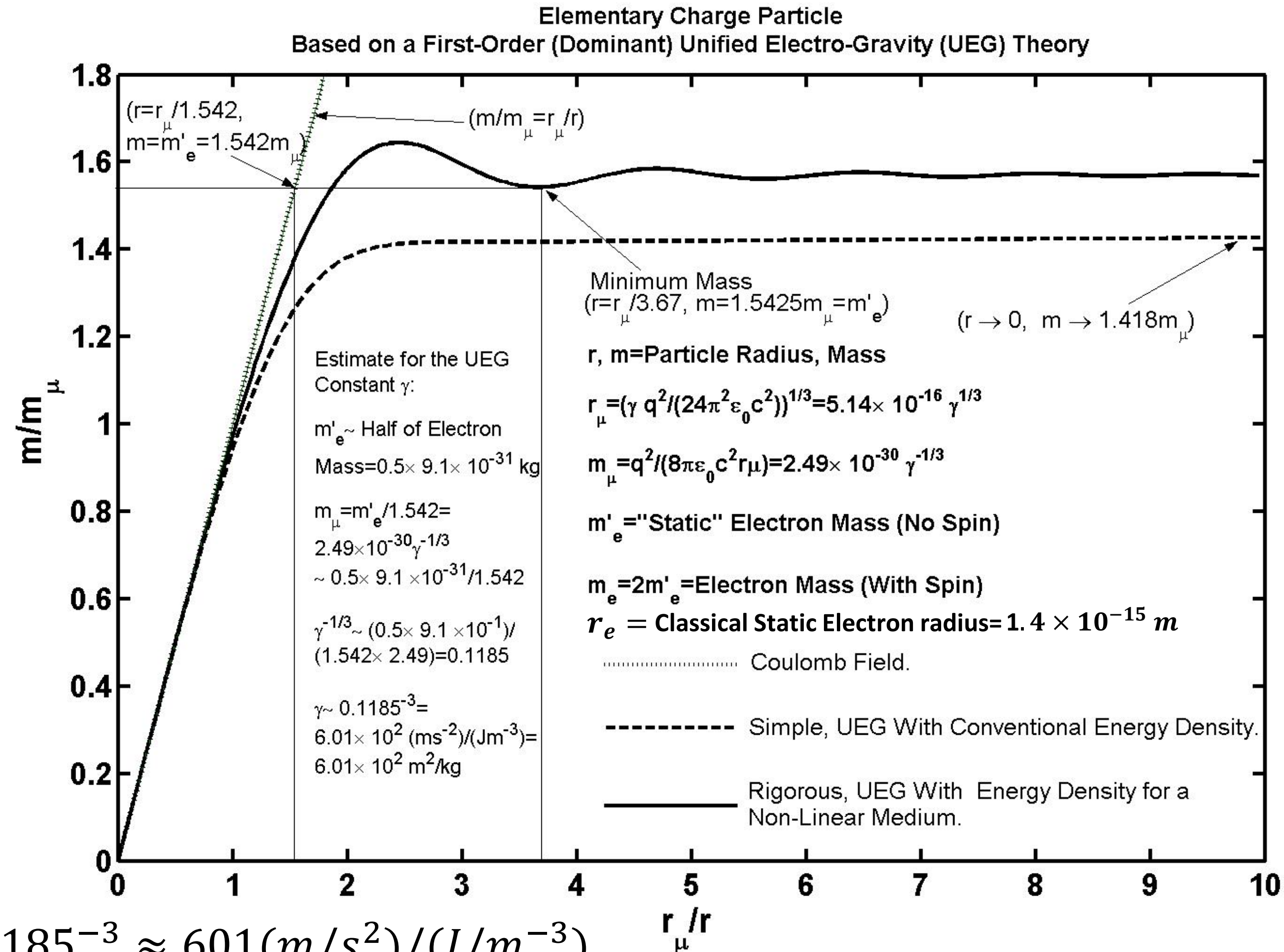
The UEG Constant Estimate from a Charge-Particle Model



$$\gamma = 0.1185^{-3} \approx 601(m/s^2)/(J/m^{-3})$$

$\gamma m_e/r_e^2 \approx 2/\alpha(Fine\ Structure\ Constant)$ ≈274 (Dimensionless)

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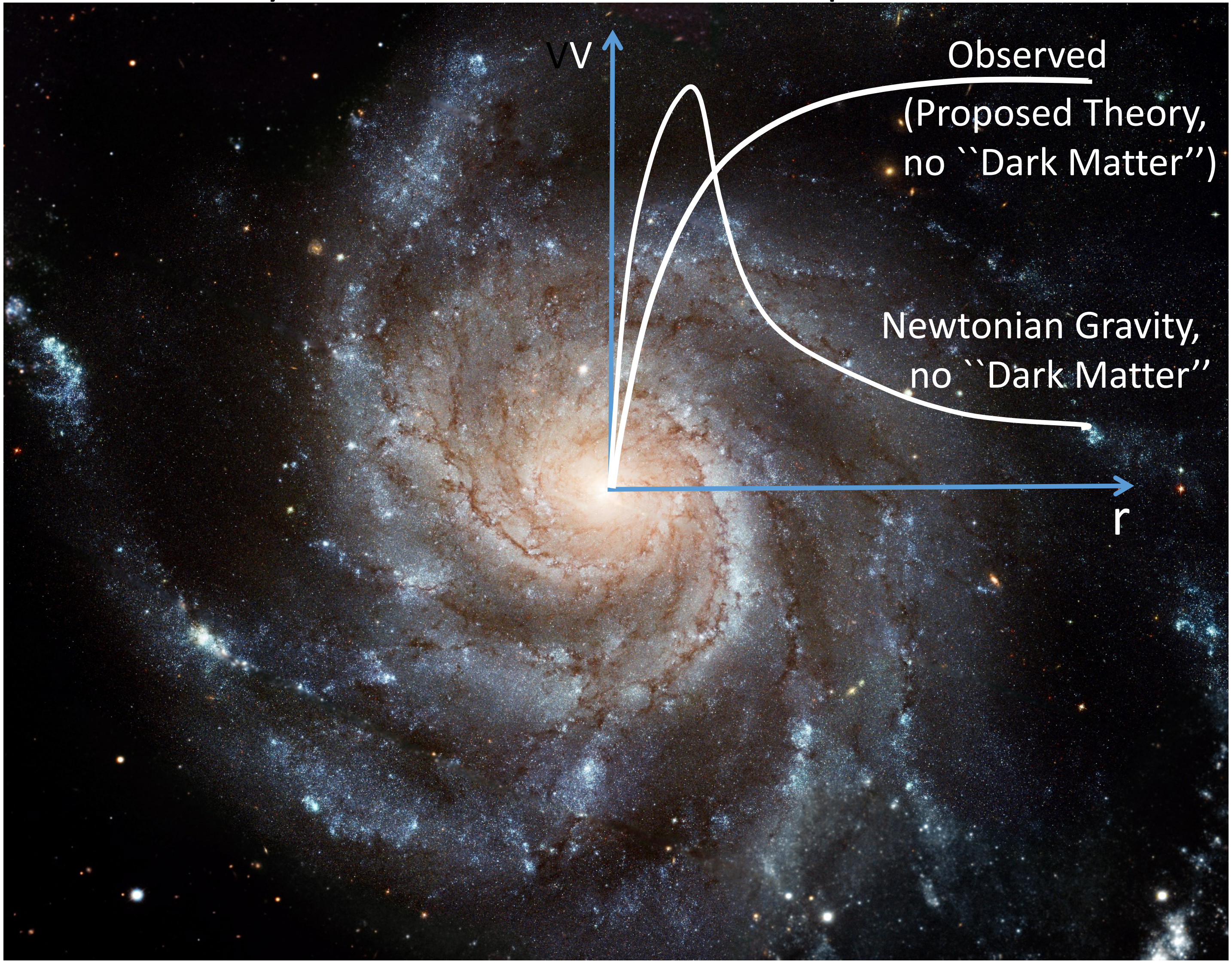
UEG Theory for Flat Rotation in Spiral Galaxies



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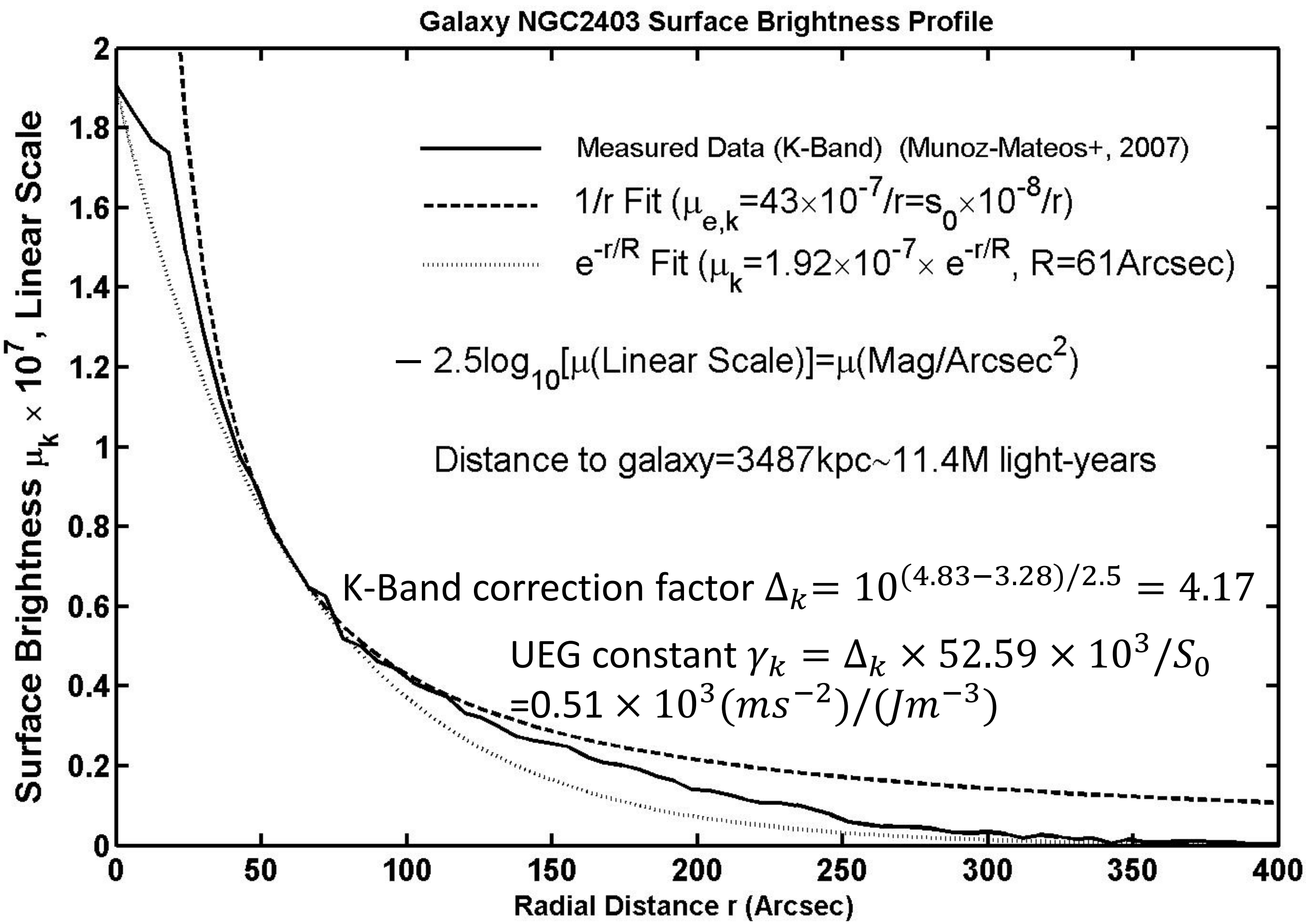
The UEG Constant from Specific Galaxy Data



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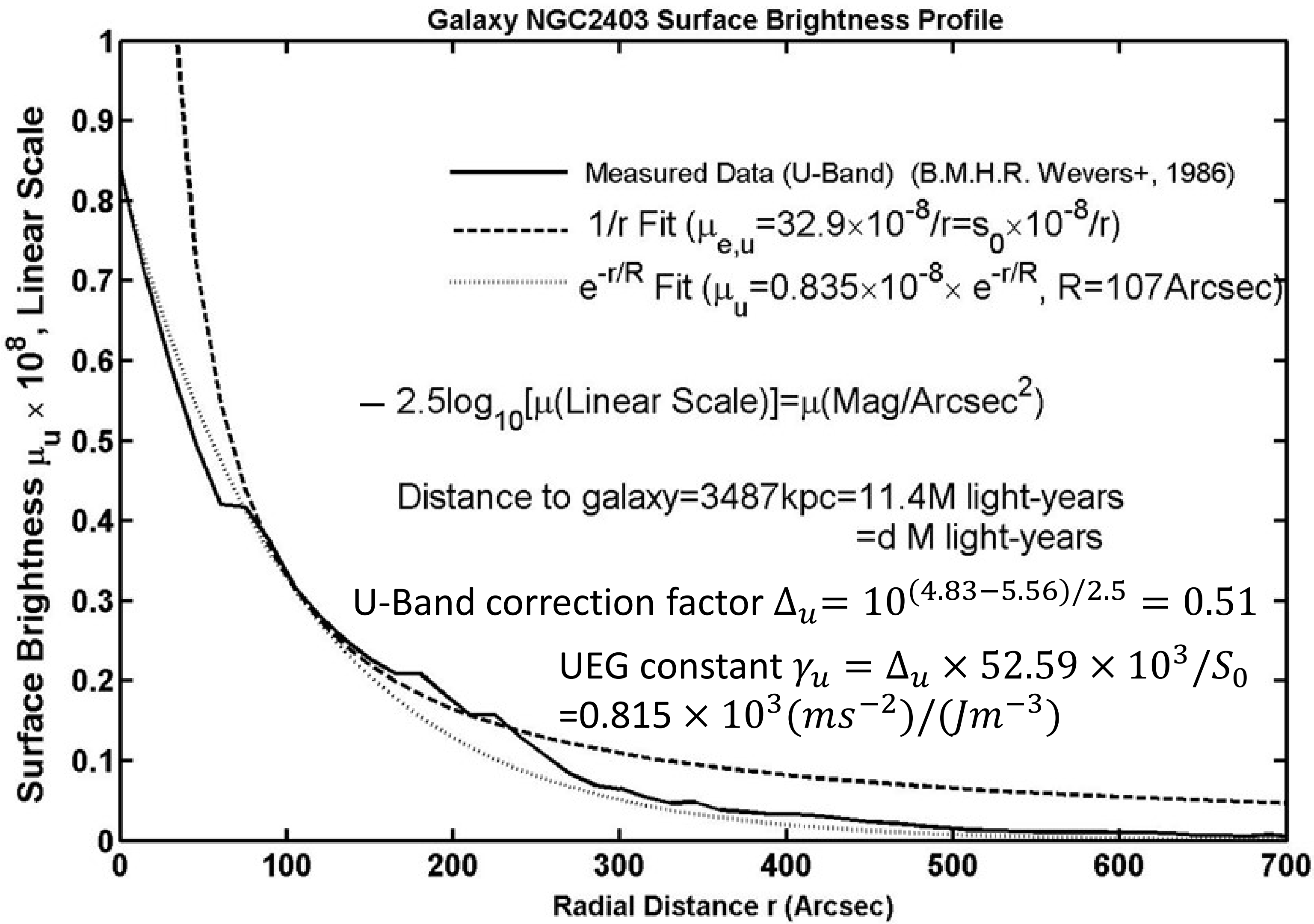
The UEG Constant from Specific Galaxy Data



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UEG Constant Estimation from Spiral Galaxy NGC2403 Data

- NGC 2403 U-Band Galaxy data from B. M. H. R. Weavers, et al., Astronomy and Astrophysics Supplement Series, 66, 505 (1986); K-Band data from J. Munoz-Mateos, et al., Astrophysical Journal 658, 1005 (2007

Surface brightness $\mu = \mu_0 e^{-r/R}$

Effective surface brightness $\mu_e = a/r = S_0 \times 10^{-8}/r$ (in Linear Mag/Arcsec^2 , r in Arcsec)

= $S_0 \times 10^{-8} \times (1.46 \times 10^4)/r$ (in W/m^2 ; r in Arcsec)

= $S_0 \times 10^{-8} \times (1.46 \times 10^4) \times (d \times 4.6 \times 10^{16})/r$ (in W/m^2 , r in m, distance to galaxy d in MLY)

Energy density $W_{\tau e} = (e/2)\mu_e/c = 3.04 \times S_0 \times d \times 10^4$/r (J/m^3), d in MLY

UEG acceleration $\gamma W_{\tau e} = v^2$/r

UEG constant estimate $\gamma = \frac{v^2 \times 10^2}{S_0 \times d \times 3.04}$ $(ms^{-2})/(Jm^{-3})$, d in MLY, v in km/s

$= \frac{52.59 \times 10^3}{S_0}$ $(ms^{-2})/(Jm^{-3})$ for NGC 2403;

d =11.4 MLY (Cepheid measurement), v =135 km/s

- K-Band: Surface brightness data $S_0 = 430$, K-Band correction factor $\Delta_k = 10^{(4.83-3.28)/2.5} = 4.17$

UEG constant estimate $\boldsymbol{\gamma_k = \frac{\Delta_k \times 52.59 \times 10^3}{S_0}}$ **=0.51**$\boldsymbol{\times 10^3 \ (ms^{-2})/(Jm^{-3})}$

- U-Band: Surface brightness data $S_0 = 32.9$, U-Band correction factor $\Delta_u = 10^{(4.83-5.56)/2.5} = 0.51$

UEG constant estimate $\boldsymbol{\gamma_u = \frac{\Delta_u \times 52.59 \times 10^3}{S_0}}$ **=0.815**$\boldsymbol{\times 10^3 \ (ms^{-2})/(Jm^{-3})}$

- **UEG constant estimate** $\boldsymbol{\gamma \approx (\gamma_K + \gamma_u)/2}$**=0.66**$\boldsymbol{\times 10^3 \ (ms^{-2})/(Jm^{-3})}$

UEG constant estimate from particle model /electrodynamics $\boldsymbol{\gamma}$**=0.6** $\boldsymbol{\times 10^3 \ (ms^{-2})/(Jm^{-3})}$

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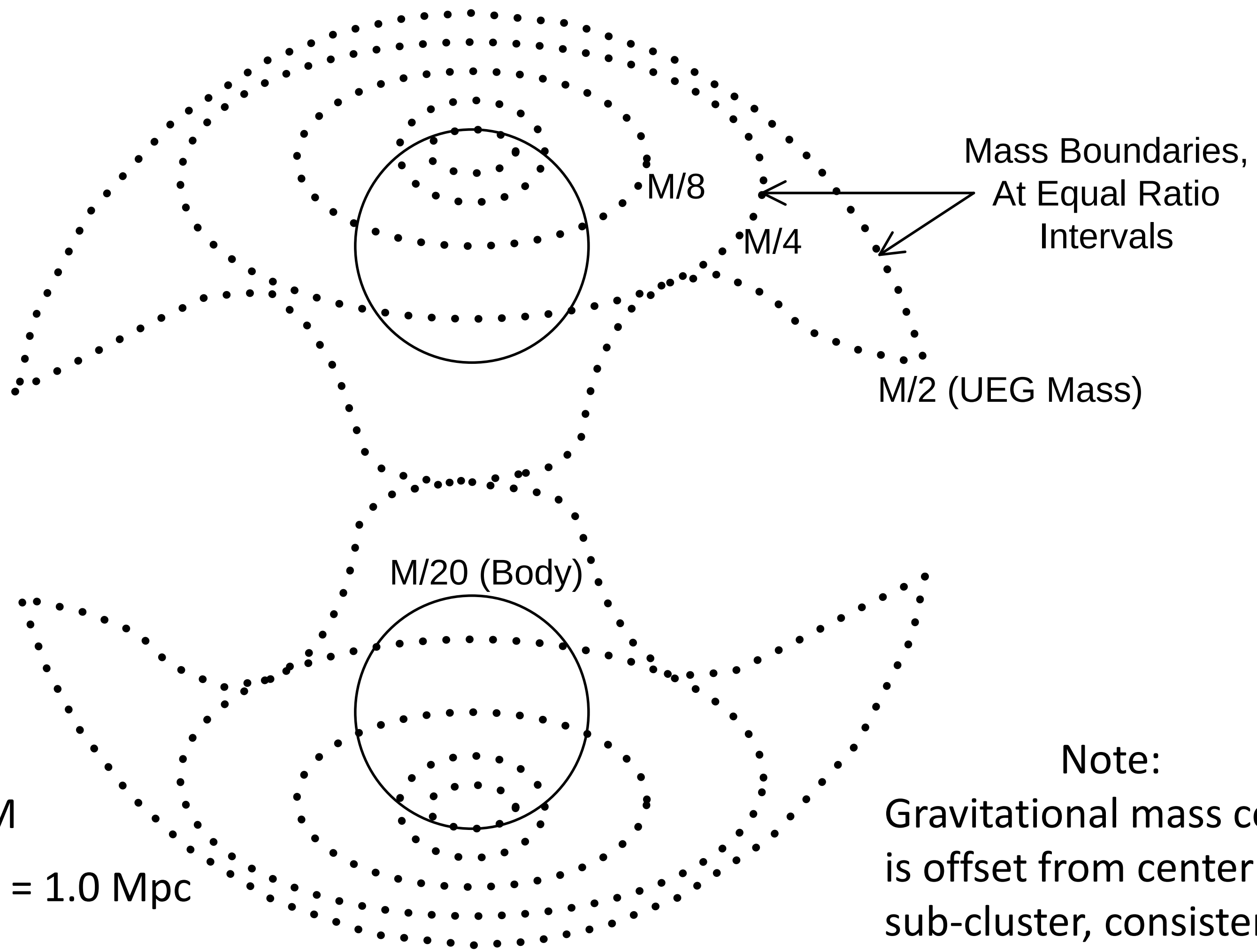
Simplified, Symmetric UEG Model for Mass Distribution of the Bullet Cluster



Total Mass=M

Diameter = d = 1.0 Mpc

Diameter =0.25 Mpc (core diameter), of each Newtonian body of mass M/20

Note:
Gravitational mass center is offset from center of each sub-cluster, consistent with Gravitational lensing.

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