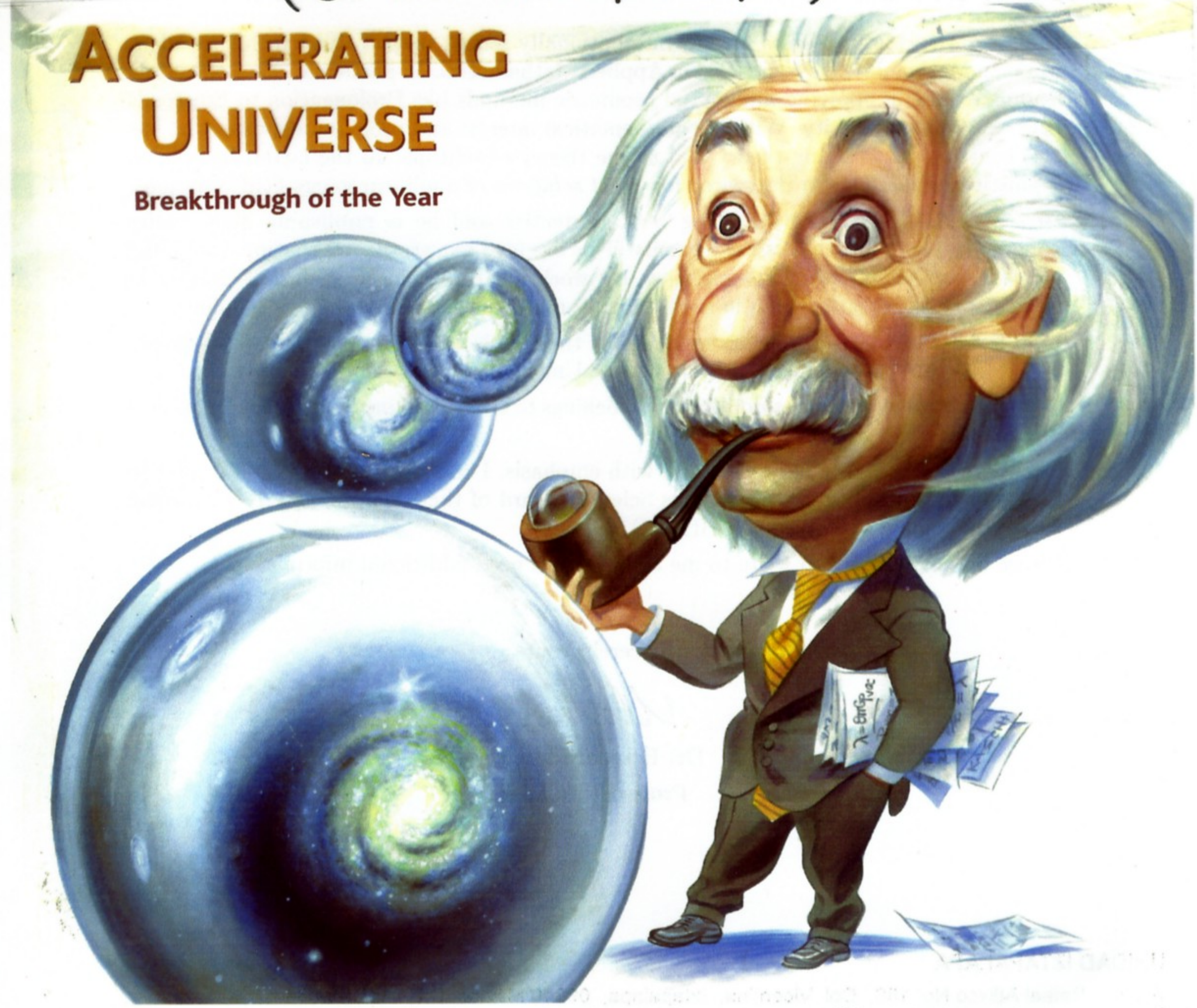
TOROIDAL HALOS IN A BEC TYPE SCALAR MODEL OF DARK MATTER

Eckehard W. Mielke

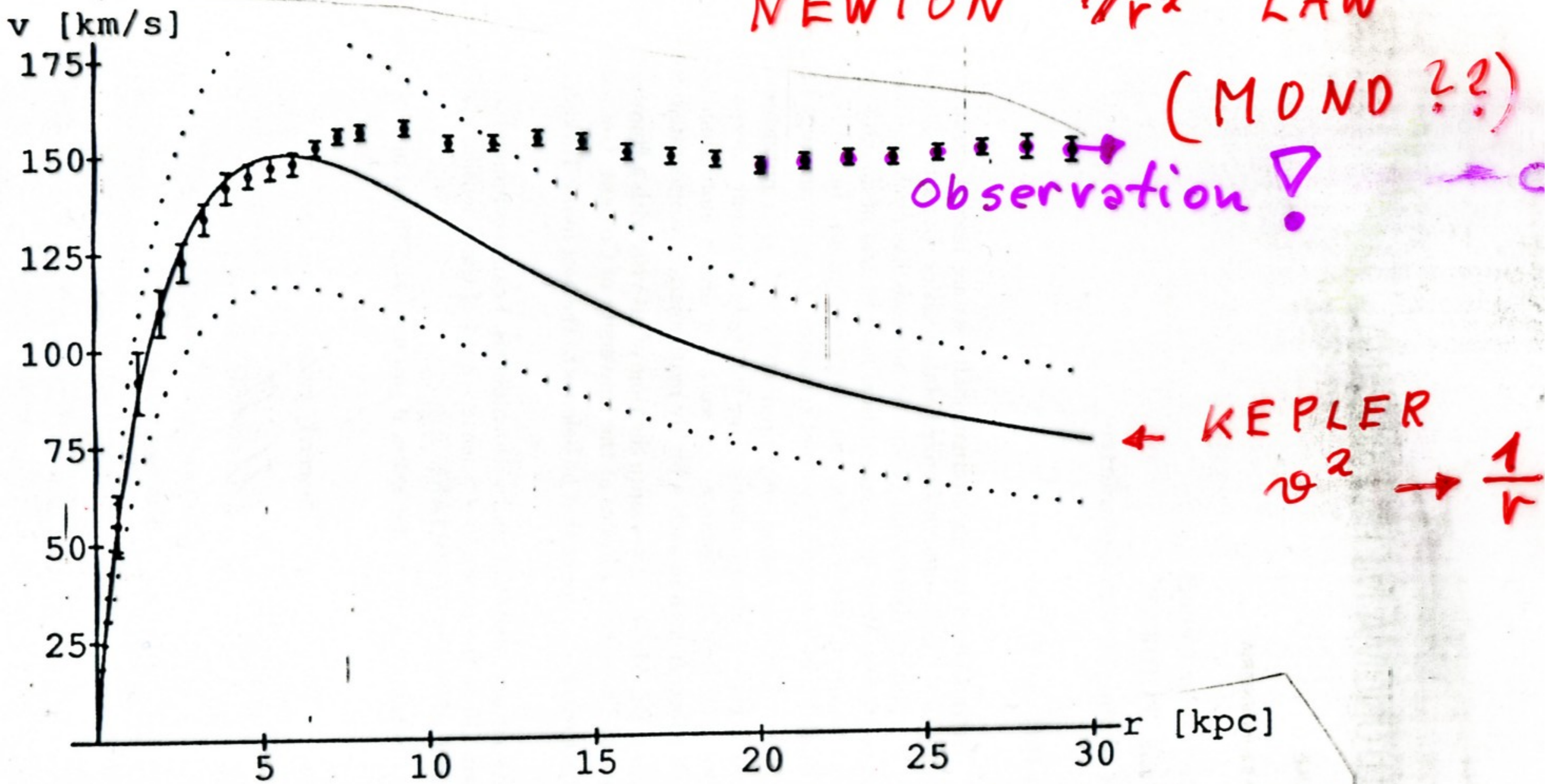
(UAM–Iztapalapa)



rotation curves

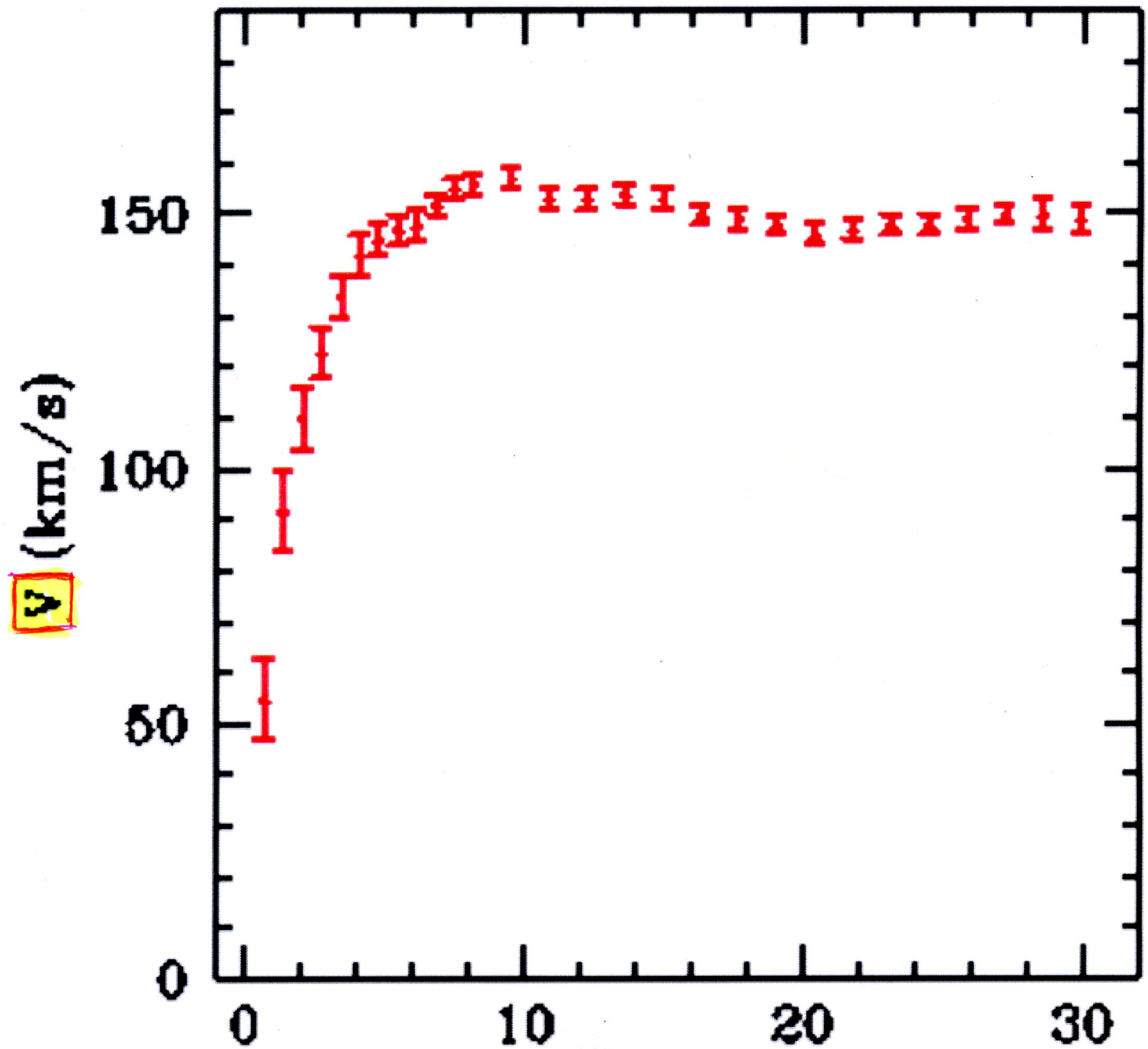
PROBLEM WITH THE HOOKE-NEWTON $1/r^2$ LAW

(MOND ??)



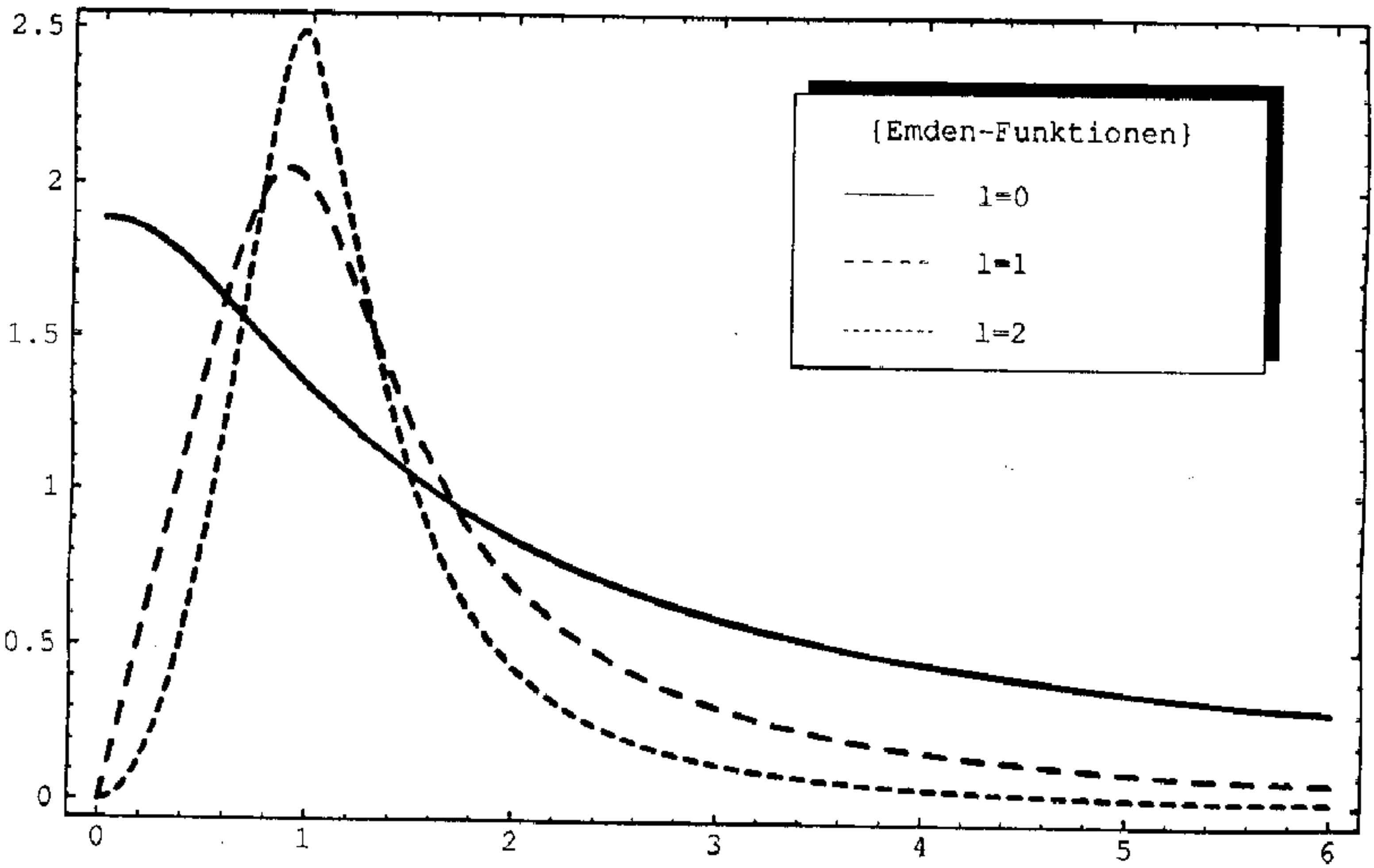
Rotationskurve der Galaxie NGC 3198. Gezeigt werden die gemessenen Geschwindigkeiten, sowie die aus dem Luminositätsprofil mit Newton'scher Gravitation berechneten Rotationsgeschwindigkeiten. (für $M/L = 2.8\, M_\odot/L_\odot$, $M/L = 4.7\, M_\odot/L_\odot$ *und* $M/L = 7.0\, M_\odot/L_\odot$ *)*

rotation curves



Emden type nonlinear scalar model

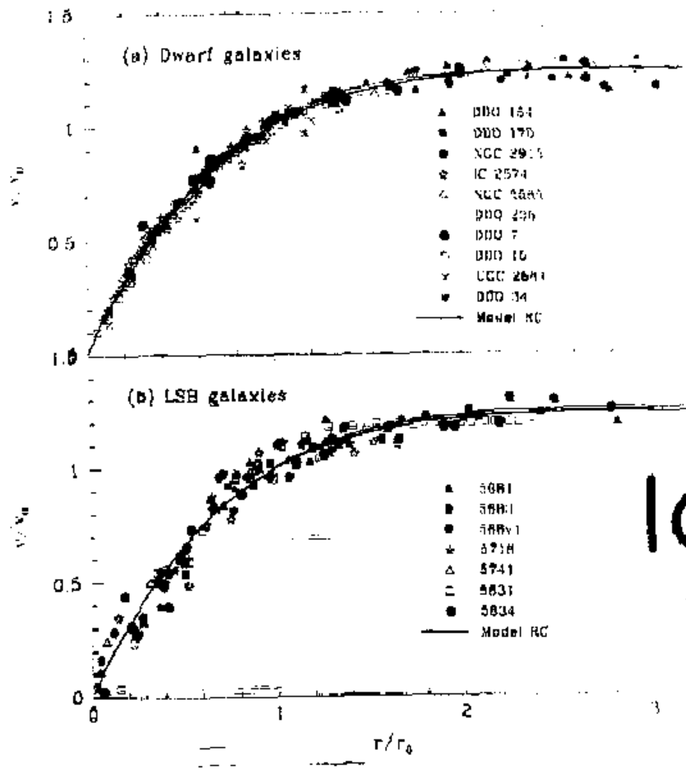
with a $U(|\Phi|^2) \sim |\Phi|^6$ in flat spacetime



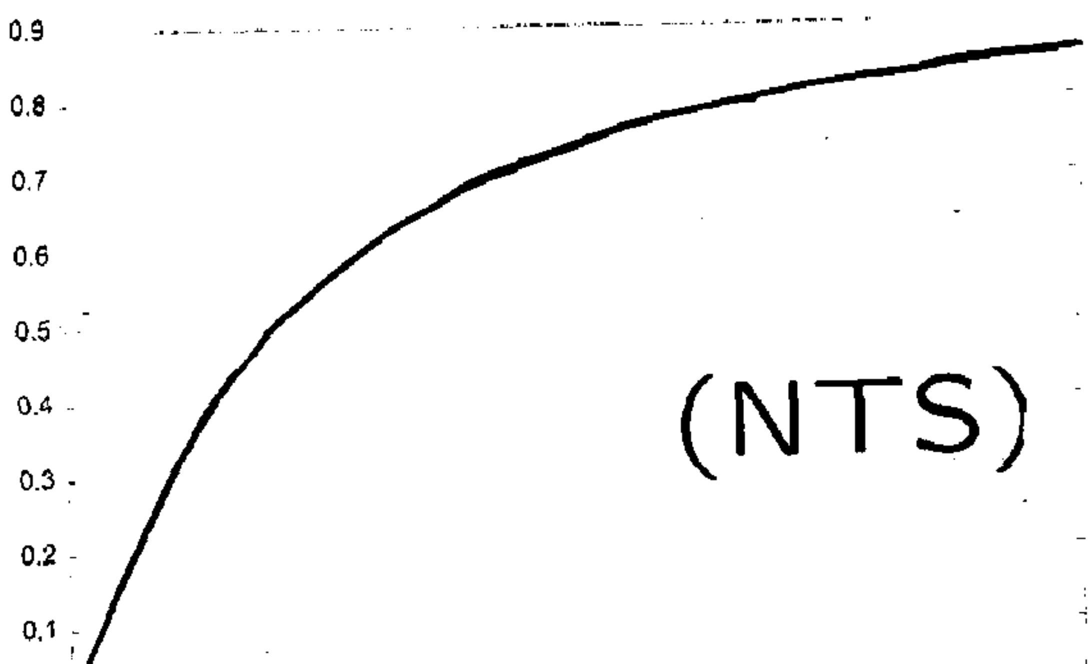
solutions $\Phi \sim x^l \sqrt{(2l+1)/(x^{2(2l+1)}+1)}$

l: angular momentum quantum number

Observational rotation curves



(dwarf – low surfaces brightness galaxies)



(NTS) (soliton) $l = 1$

Newtonian rotation

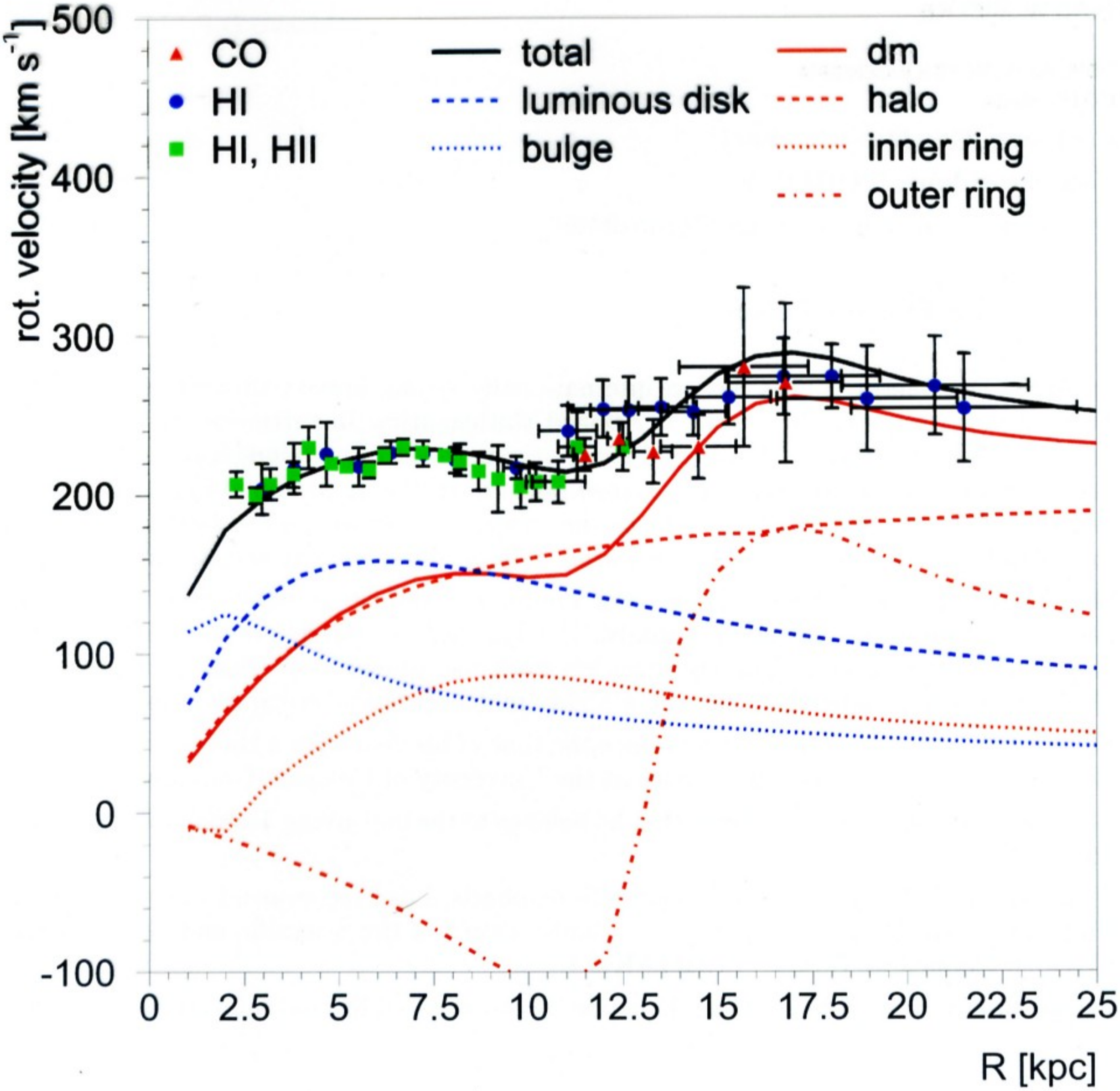


Fig. 8. The rotation curve of the galaxy for the DM haloprofile of Fig. 5. The data are from Refs. [38,39,40]. The contributions from the individual masses have been indicated. Note the negative contribution of the massive gaussian ring of DM at 14 kpc, which exerts an outward and hence negative force on a tracer well inside that ring.

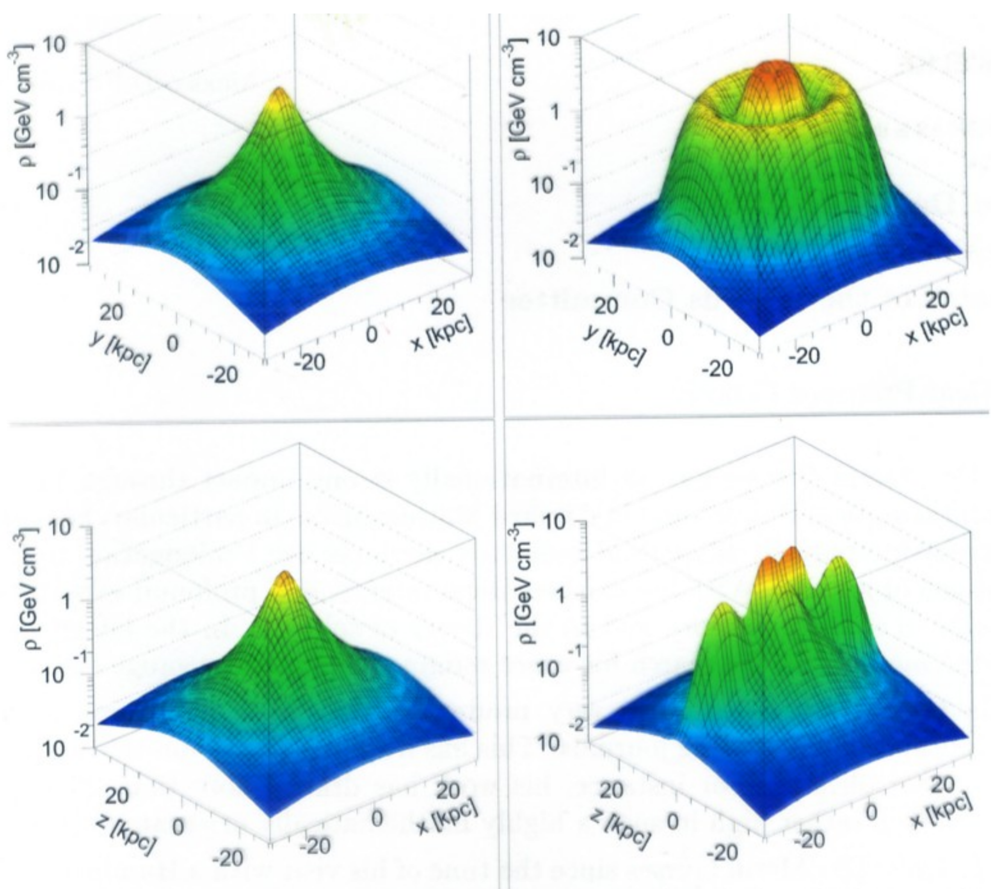
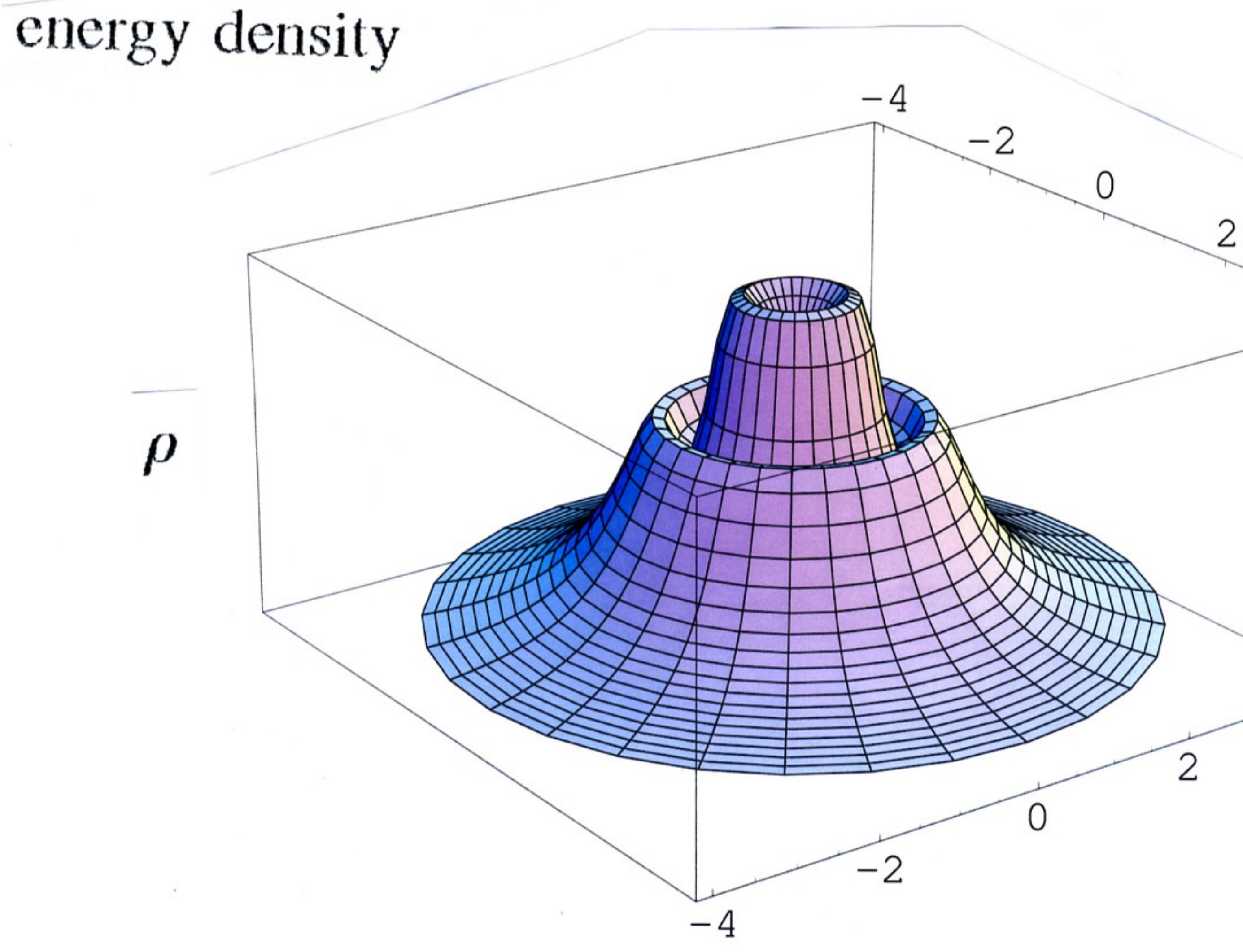


Fig. 5. 3D-distributions of the isothermal haloprofile in the xy- (top row) and xz-plane (bottom row) without (left) and with (right) rings. The elliptical shape (b/a=0.8,c/a=0.9) and ring structures in the disc (z=0 plane) are clearly seen.

TOROIDAL HALOS in a BEC type SCALAR MODEL of DARK MATTER



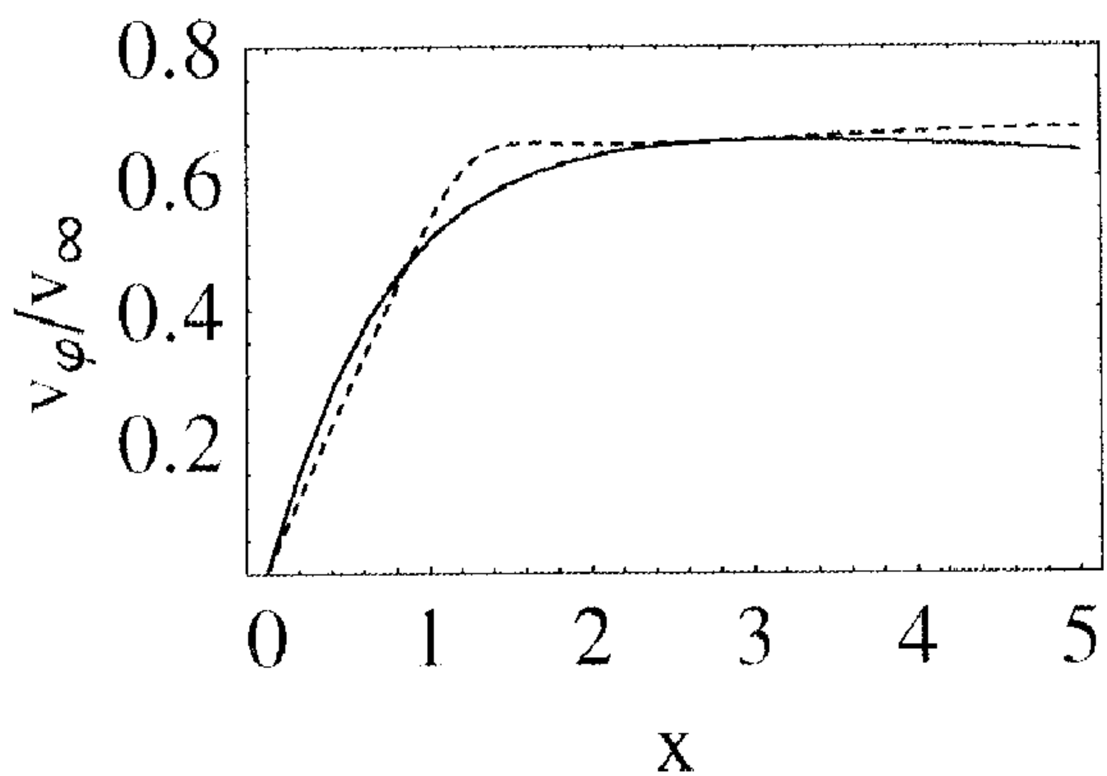
super position of a spherical ($l = 0$) and a rotating ($l = 1$) NTS halo

rotation curves

circular velocities of stars or HI gas in galaxies are bounded by $v_\varphi/c \leq 10^{-3}$. Although they are *nonrelativistic*, we nevertheless depart from the general relativistic formula

$$v_\varphi^2 := \frac{r}{2}\frac{d\nu}{dr} = \frac{\kappa}{2}\left[\frac{M(r) + 4\pi p_{\text{sup}} r^3}{4\pi r - \kappa M(r)}\right]$$

$$\simeq \frac{\kappa}{2}\left[\frac{M(r)}{4\pi r} + p_{\text{sup}} r^2\right]$$



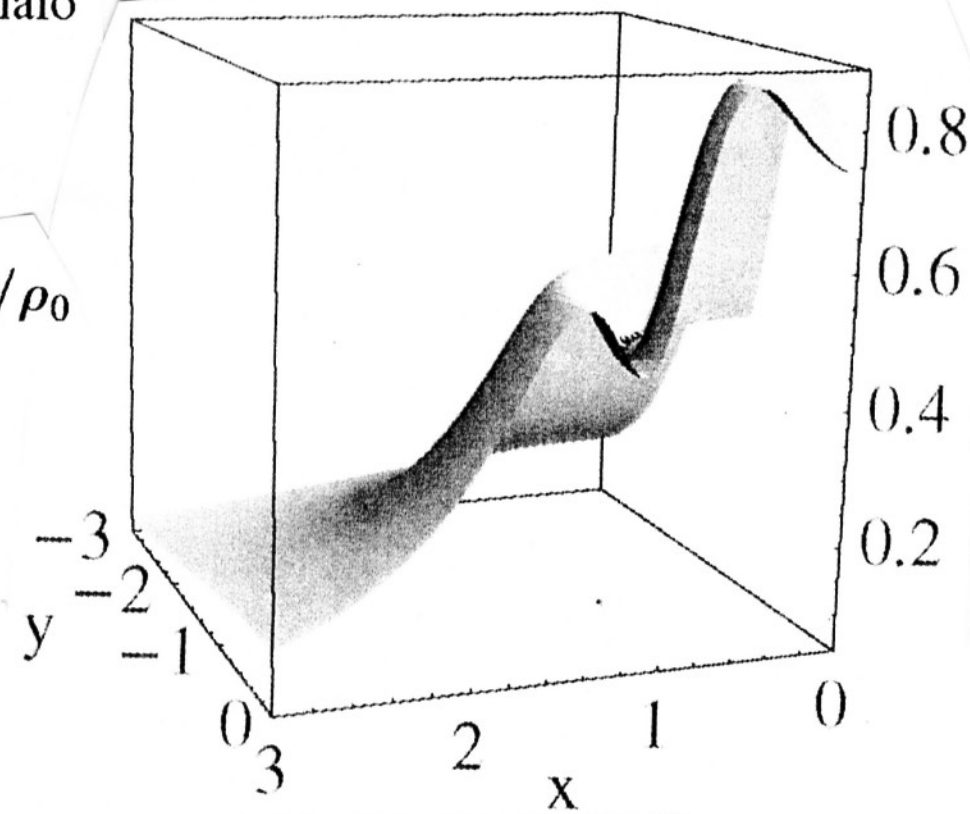
Rotation curve of the superposed NTS halo (dashed line) normalized by $v_\infty := \sqrt{\kappa/2A\sqrt{\chi}}$ including angular momentum up to $l = 1$ for $A = 0.805$, in comparison to the empirical Burkert fit (solid line).

Toroidal halos in a nontopological soliton model

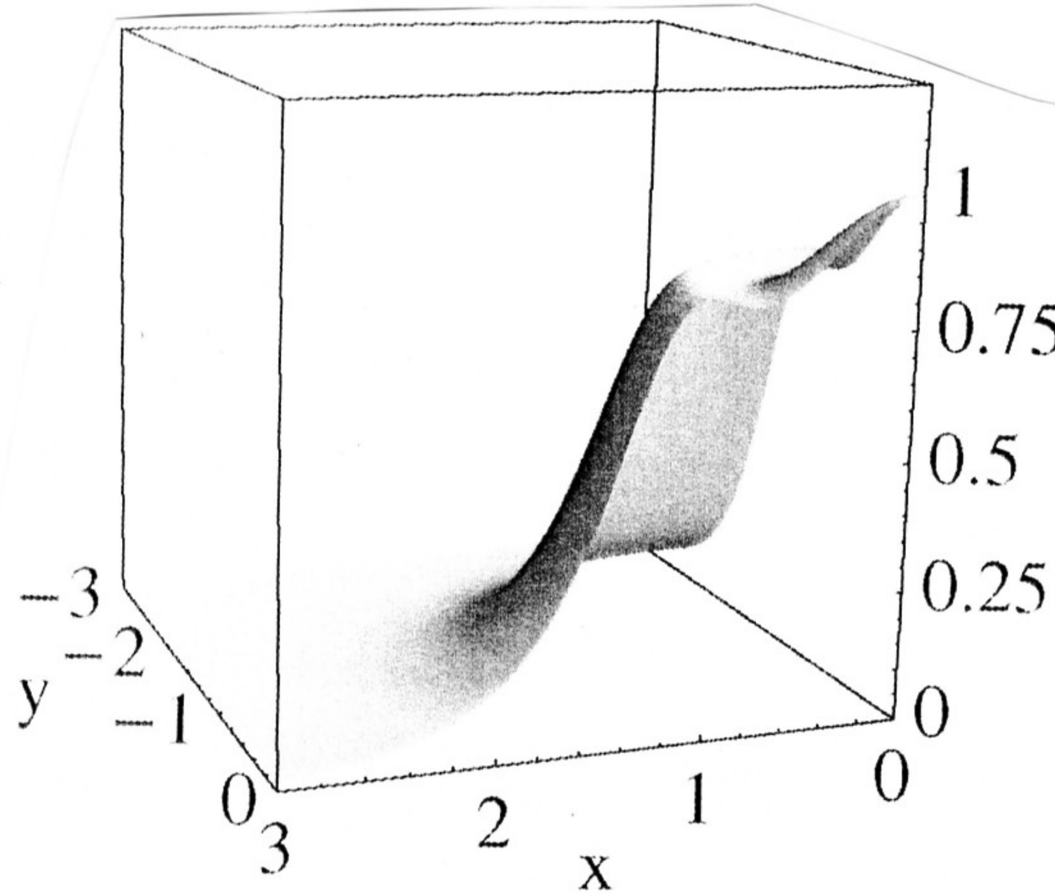
PHYSICAL REVIEW D **75** (2007)

super position of a spherical ($l = 0$) and a rotating ($l = 1$) NTS halo

energy density $\rho := \rho_{\text{sup}}/\rho_0$



pressure distribution



Dark halo as a self-gravitating Bose-Einstein condensate?

Einstein and Bose: identical integer spin particles can occupy the same ground state.
Bose-Einstein condensate (BEC)
experimentally realized in 1995

In the mean-field ansatz, the interaction is approximated by the effective potential

$$U(|\Psi|)_{\text{eff}} = \frac{\lambda}{4}|\Psi|^4$$

Nonlinear Schrödinger equation (Gross-Pitaevskii equation)

Bosonic particles such as fundamental scalars allow a selfgravitating BEC on an astrophysical scale

Mielke and Scherzer and Colpi *et al.*: boson stars (BSs)

with *repulsive* self-interaction $U(|\Phi|)$

BEC condensate on a galactic scale: tiny 'bare' mass of

$m_\Phi \simeq 10^{-22}$ eV/c²

cold BS below the critical temperature

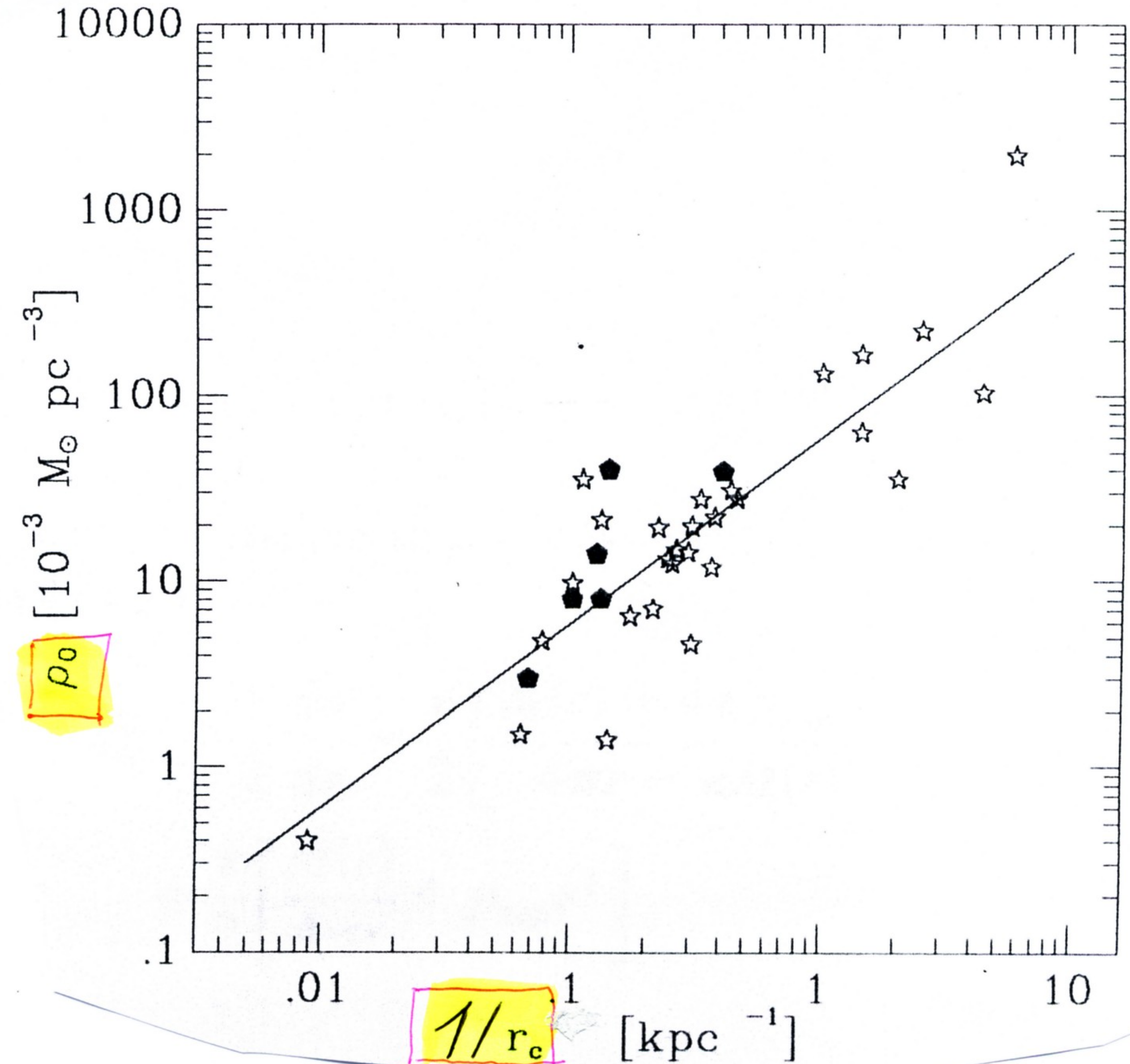
$$T_c = \frac{2\pi\hbar^2}{mk}\left[\frac{N}{\xi(3/2)V}\right]$$

(heat bath of the cosmic background radiation of nowadays 2.726 K)

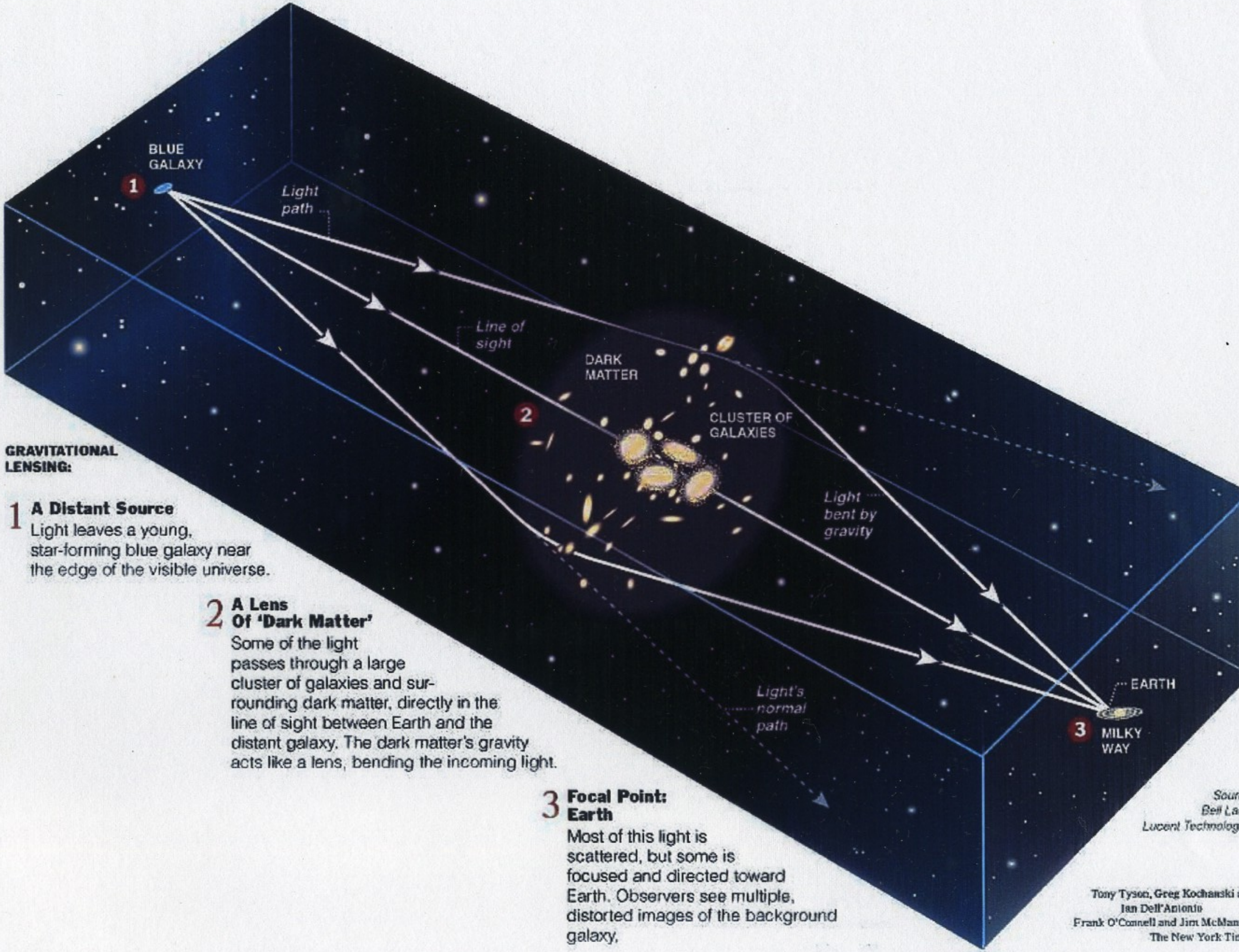
Scaling behaviour of a scalar field model

Mon. Not. R. Astron. Soc. **350,** 707–709 (2004)

central density
∝ 1/ scale radius



halo models are constructed assuming ‘maximum discs’. Open symbols: low-surface-brightness galaxies; filled symbols: nearby bright galaxies.



GRAVITATIONAL LENSING:

1 A Distant Source
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

2 A Lens Of 'Dark Matter'
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

3 Focal Point: Earth
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy,

Source: Bell Labs, Lucent Technologies

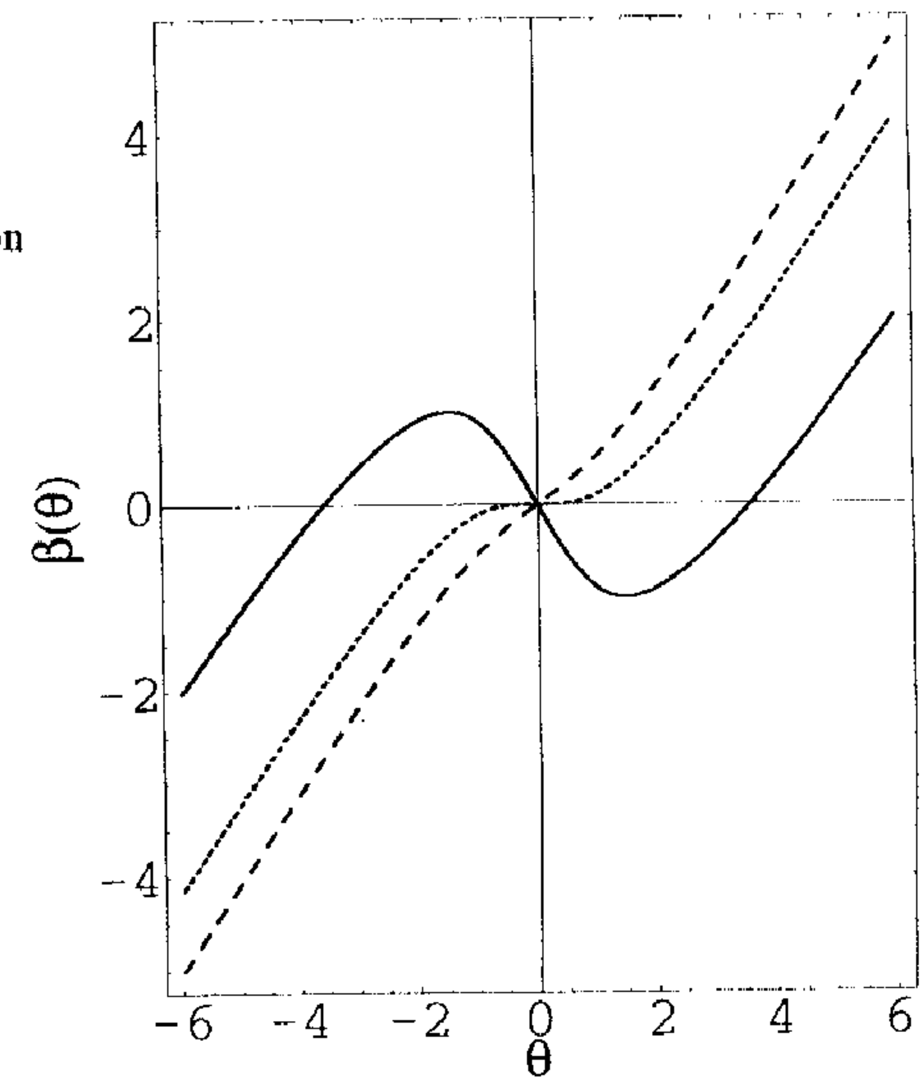
Tony Tyson, Greg Kochanski and Ian Dell'Antonio
Frank O'Connell and Jim McManus/ The New York Times

Scalar field haloes as gravitational lenses

Mon. Not. R. Astron. Soc. **369**, 485–491 (2006)

Dimensionless lens equation

NTS halo with pressure



The solid, dotted, and dashed lines are, respectively, for $\lambda = 2$, λ_{cr} and 0.3. Multiple images occur for $\lambda > \lambda_{cr} = 0.692\,428$.

BIFURCATIONS OF NONLINEAR

CURVATURE LAGRANGIANS

AND DARK MATTER

E.W. Mielke, F. Kusmartsev and F.E. Schunck GRG Aug. 2005

Gravitationally coupled scalar field

$$\mathcal{L}_{\mathrm{DM}} = \frac{\sqrt{|\,g\,|}}{2\kappa}\{R + \kappa[g^{\mu\nu}(\partial_\mu\phi^*)(\partial_\nu\phi) - 2U(|\phi|^2)]\}$$

(gravity + scalar field + potential)

Nonlinear Lagrangian

$$\mathcal{L}_{\text{eff}} = L\,(R)\,\sqrt{|\,g\,|}$$

field momentum

$$\mathcal{P} = \frac{\delta L}{\delta R} = L'(R)$$

Legendre transformation

$$\begin{aligned}\mathcal{L}_{\text{eff}} \to \mathcal{H} \;&=\; \left(R\frac{\delta L}{\delta R} - L\right)\sqrt{|\,g\,|}\\ &=\; (R\mathcal{P} - L)\,\sqrt{|\,g\,|}\end{aligned}$$

Conformal mapping to an Einstein frame *effective potential*

$$u\,(\mathcal{P}) = \mathcal{P}^{n/(2-n)}(R\mathcal{P} - L)$$

Method of Helmholtz:

Exact parametric solution

$$R = \frac{d}{d\mathcal{P}} H(\mathcal{P})$$

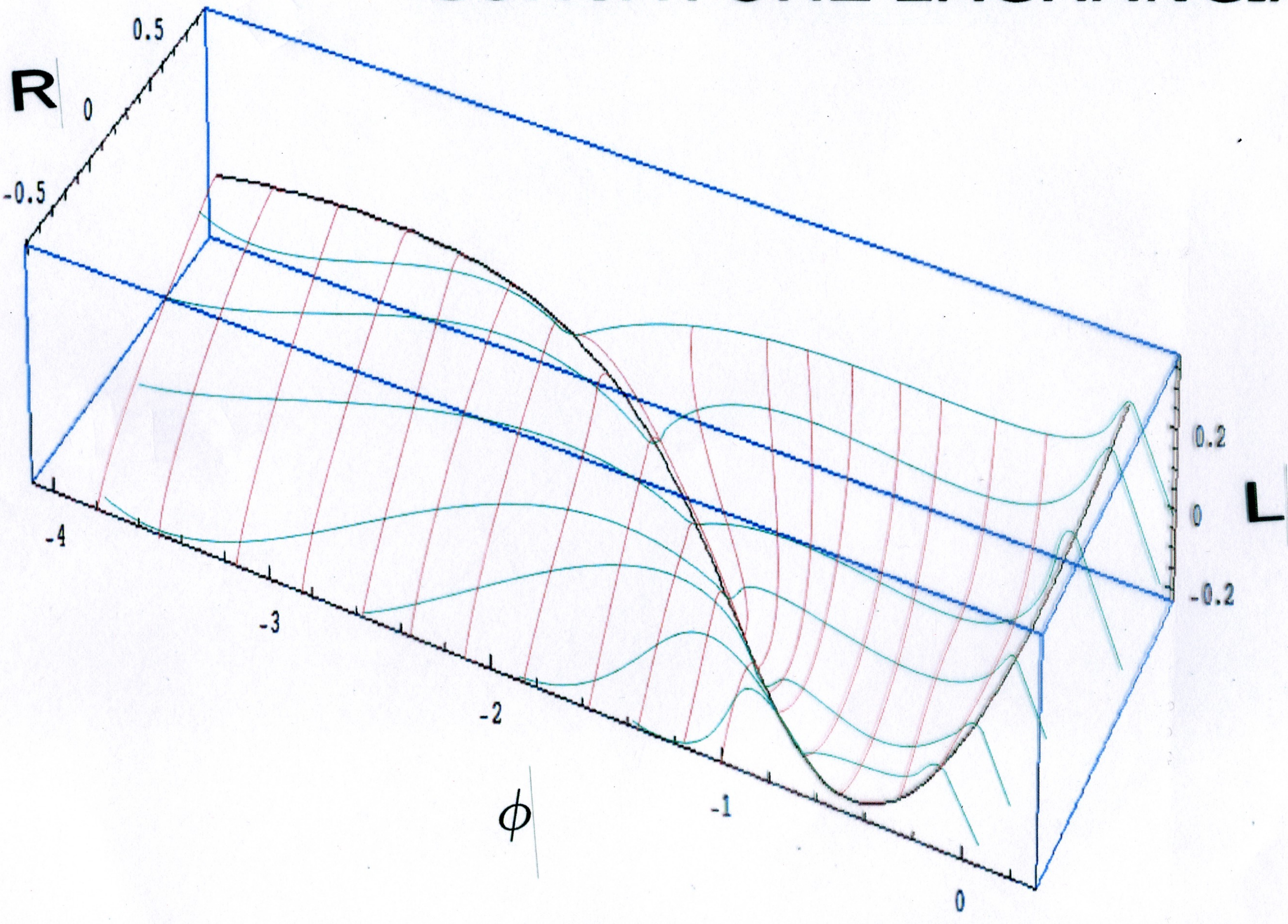
$$L = \mathcal{P}R - H = \mathcal{P}^2 \frac{d}{d\mathcal{P}} [H(\mathcal{P})/\mathcal{P}]$$

Bifurcations with effective 'dark energy'

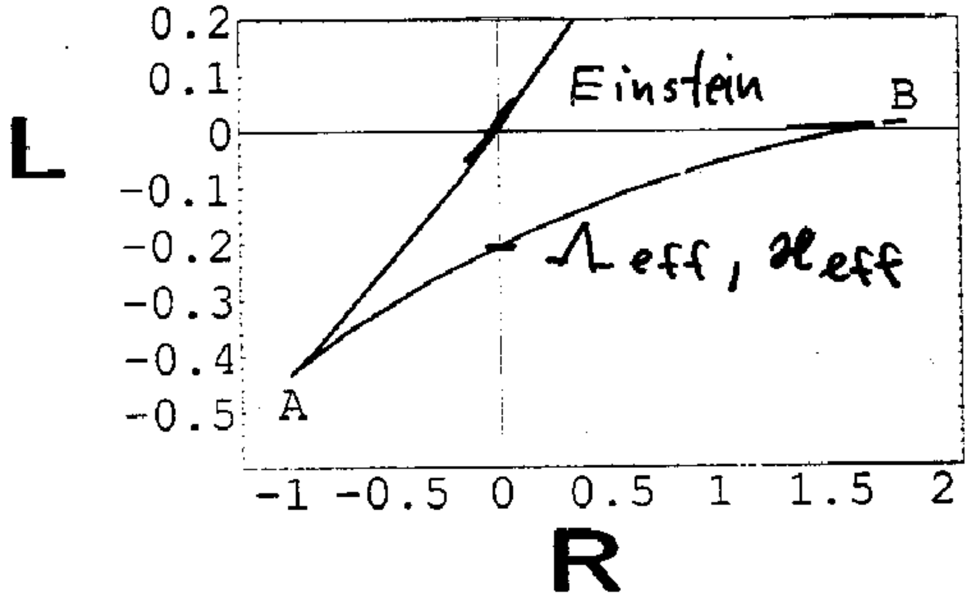
$$L \simeq \frac{1}{2\kappa_{\mathrm{eff}}} (R - 2\Lambda_{\mathrm{eff}})$$

(Einstein Lagrangian with *effective* gravitational and cosmological constants)

WHITNEY 'SURFACE' OF NONLINEAR CURVATURE LAGRANGIANS

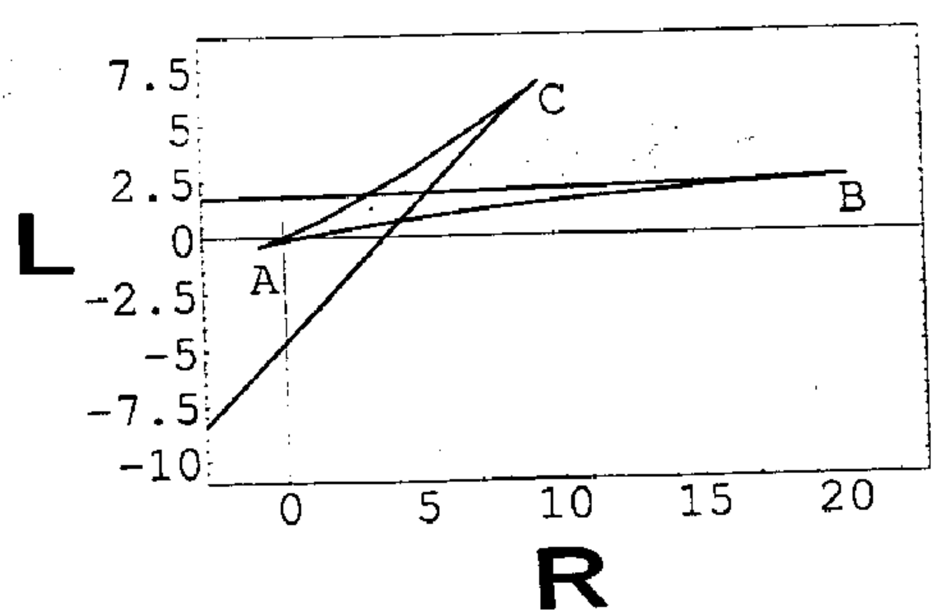


Swallow tail for a 'free' field



Einstein's GR: $L \propto R$

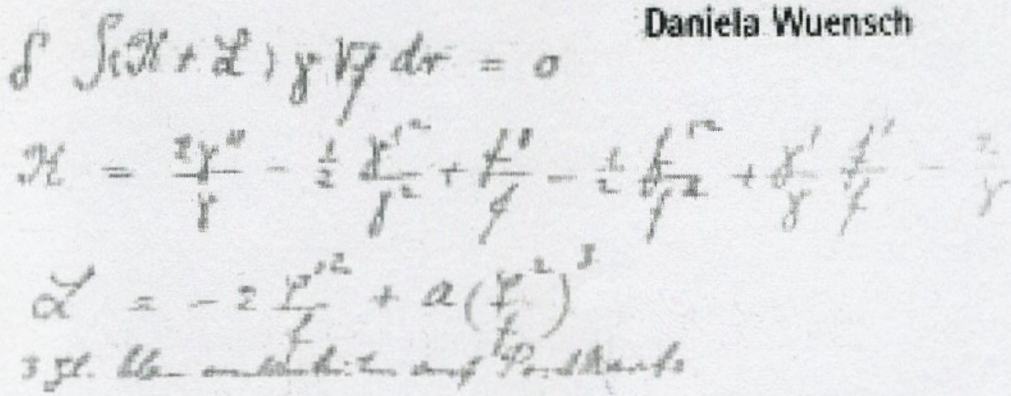
Butterfly catastrophe



„zwei wirkliche Kerle"

Neues zur Entdeckung der Gravitationsgleichungen der Allgemeinen Relativitätstheorie durch Albert Einstein und David Hilbert

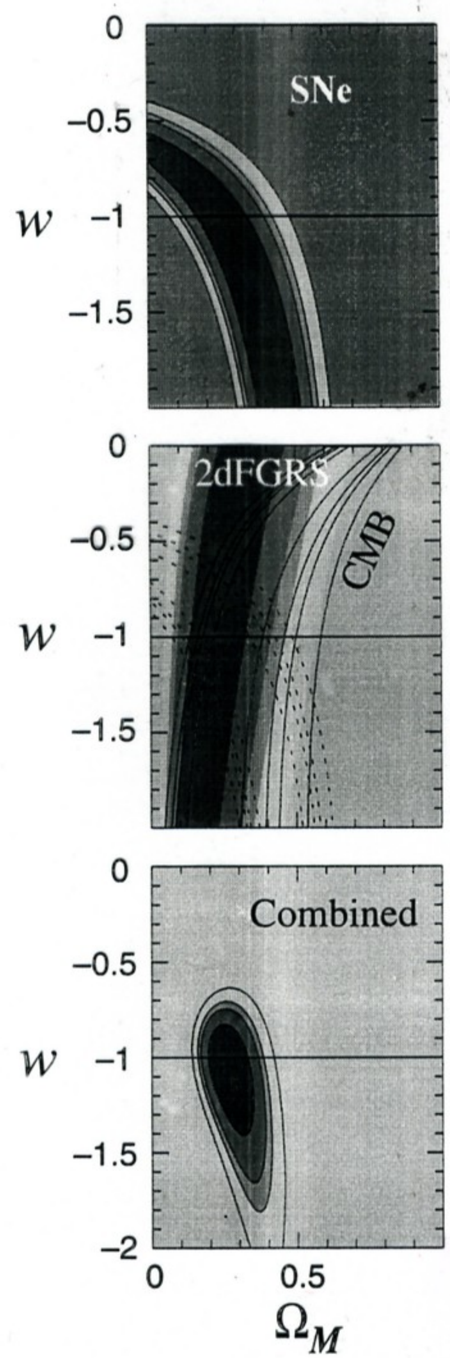
Daniela Wuensch



Termessos

2005

$R_{ij} = 0$ Einstein + Grossman 1913 ?
Vacuum Field Equations



Supernova Cosmology Project
Knop *et al.* (2003)

Assuming constant w $= \frac{p}{\rho}$

With limits from;
2dFGRS (Hawkins et al. 2002)
and CMB (Bennet et al. 2003,
Spergel et al. 2003)

oscillating DE ?

$w = -1.05 \ ^{+0.15}_{-0.20}$ (statistical)

± 0.09 (systematic)

phantom DE $w < -1$

Einstein's "biggest blunder"

Cosmological constant → $w = -1$?!