## Fifth Force Searches in Galaxies

### Harry Desmond



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#### Introduction I. Fifth forces

- Generic extensions to the standard model couple new dynamical fields to matter
- $\rightarrow$  New (*fifth*) forces, described by strength and range

$$\Phi_{\rm tot} = -\frac{G_N M}{r} \left( 1 + \frac{\Delta G}{G_N} e^{-mr} \right) = \Phi_N - \frac{\Delta G M}{r} e^{-mr}$$

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- Chameleon:  $m_{eff} \rightarrow \infty$  (e.g. f(R))
- *Kinetic*:  $\partial \phi \rightarrow \infty$  (e.g. K-mouflage)
- Symmetron & Vainshtein:  $\Delta G \rightarrow 0$  (e.g. Galileons, DGP)



Chameleon

# Searching for screening in astrophysics

Logic of screening points us to low mass galaxies in voids Need observational proxies for degree of screening



Mechanism	Dominant term at high $\rho$	Observational proxy
Chameleon	Mass	Newtonian potential $\Phi$
Kinetic/K-mouflage	Kinetic	Acceleration $a$
Vainshtein	Higher-order	Curvature $K$

#### Gravitational Mapmaking I. Method

$$\Phi_{j} \sim \sum_{i} GM_{i}/r_{ij} \qquad \vec{a}_{j} \sim \sum_{i} GM_{i}\hat{\vec{r}_{ij}}/r_{ij}^{2} \qquad K_{j} \sim \sum_{i} GM_{i}/r_{ij}^{3}$$

Three contributions to each:

1) Halo mass associated with 2M++ galaxies

- 2) Halos hosting galaxies too faint to see
- 3) Mass in long-wavelength modes (Lavaux & Jasche 2016)

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Desmond et al, MNRAS 474:3152 (2018)

#### Gravitational Mapmaking II. Results



potential

#### acceleration



#### curvature



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#### Signals of Screened Fifth Forces A. Separation of stars and gas

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• Equilibrium offset  $\vec{r}_*$  given by:

$$\frac{G_N M(< r_*)}{r_*^2} \, \hat{r}_* = \vec{a}_5 \, \frac{\Delta G}{G_N}, \qquad |\Phi| < |\Phi_c|$$
  
$$\vec{r}_* = 0, \qquad |\Phi| > |\Phi_c|$$



- Measure stars with optical emission (SDSS) and gas with HI (ALFALFA), then constrain  $\Delta G$  and  $\lambda_c$  with Bayesian likelihood formalism

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Desmond et al, Phys. Rev. D 98, 064015 (2018)

# Magnitude of signal



 $F_5$  model:  $\Delta G = G_N$ ,  $\lambda_c = 5$  Mpc

ALFALFA data

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Desmond et al, Phys. Rev. D 98, 064015 (2018)

# Investigating the noise

- Derives from measurement uncertainty and baryonic physics
- Convolve fifth-force likelihood with Gaussian of width  $\sigma,$  and marginalise over  $\sigma$



#### Constraints



Desmond et al, Phys. Rev. D 98, 064015 (2018)

### Constraints



At maximum likelihood:

- λ<sub>c</sub> = 1.8 Mpc
- $\Delta G/G_{N} = 0.025$
- Δ(logL) = 16
- 6.6  $\sigma$  discrepancy of  $\Delta G/G_N$  posterior from 0

Desmond et al, Phys. Rev. D 98, 064015 (2018)

### **Systematics**

1 "Galaxy formation" physics (ram pressure, feedback etc) affects stars & gas differently, so may lead to similar signal

– Unlikely to correlate  $\vec{r}_{*}$  with gravitational environment and halo properties in same way as screened fifth force (?)

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- 2 Assumed ACDM for calculating density profiles and screening/fifth-force fields
  - Difference should be small for { $\Delta G$ ,  $\lambda_{c}$ } as low as here
- 3 Calculation of DM density within ~100pc of halo centre
  - Affects inference of  $\Delta G$  but not  $\Delta \log(L) \lambda_{c}$

#### Probing Screened Fifth Forces B. Warps in galactic disks

- Potential gradient across disk bends it into U-shape
- At equilibrium:

$$z(x) = -a_{5,z} \frac{\Delta G}{G_N^2} \frac{|x|^3}{M_{\text{halo}}($$



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Desmond et al, Phys. Rev. D 98, 083010 (2018)

#### Probing Screened Fifth Forces B. Warps in galactic disks

#### Model using power-law halo profile with exponent n



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J003938.31+143951.2  $W_1 = -1.1 \times 10^{-4}$ 

J115012.10+065956.9  $w_1 = 1.7 \times 10^{-3}$ 





### Constraints

#### Gas-star offsets



### Constraints

#### Gas-star offsets

#### Stellar disk warps



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### Validation Mock data with maximum-likelihood ΔG



• Refit many mock data sets generated at max-likelihood { $\Delta G$ ,  $\lambda_{c}$ }

• Near-perfect agreement in reconstructed  $\Delta G/G_N$  and  $\Delta \log(L) \rightarrow$  mock data behaves exactly like real data

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# Conclusions

- Galaxy structure probes fundamental physics in new regions of parameter space with potentially great sensitivity
- Environment dependence → require gravitational maps of local universe
- Two probes of chameleon & symmetron screening:
  - Separation of stars and gas
  - Warping of stellar disks
- Apparent signal at  $\lambda_{c} \approx 2$  Mpc,  $\Delta G/G_{N} \approx 0.02...$
- The future is bright:
  - Several signals still to explore (e.g. Jain & Vanderplas 2011)
  - ++ quantity and quality of data with upcoming surveys