

SOLAR SYSTEM DARK MATTER

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DARK MATTER CAN BE BOUND IN GRAVITATIONAL
POTENTIAL WELLS ON DIFFERENT SCALES:

- GALACTIC
- SOLAR SYSTEM: SUN-BOUND
- EARTH / PLANET - BOUND

• GALACTIC HALO DARK MATTER

MASS DENSITY $\rho \sim 0.3 \text{ GeV}/c^2 \text{ cm}^{-3}$

MAXWELLIAN VELOCITY DISTRIBUTION

$$f \propto v^2 e^{-3v^2/2\bar{v}^2} \quad \bar{v} \sim 270 \text{ km/s}$$

$$v = v_{\text{DARK MATTER}} + v_{\oplus}$$

↑ EARTH MOTION VELOCITY

DRUIKER, FREESE + SPELDEL } ANNUAL MODULATION EFFECT
FREESE, FRIEMAN + GOULD } DAMA/LIBRA SIGNAL

• SOLAR SYSTEM- BOUND DARK MATTER?

FROM STUDY OF PLANETARY ORBITS -

FRÈRE, LING & VERTONGEN

SERENO & JETZER

IORIO

KHRIPOVICH & PITJEVA

PERIHELION PRECESSION

KEPLER THIRD LAW

ASSUME SPHERICAL SYMMETRY

$$\rho < 10^5 \text{ GeV}/c^2 \text{ cm}^{-3}$$

COULD PRODUCE A DAILY (SIDEREAL TIME)

MODULATION IN DAMA/LIBRA \rightarrow 24 HOUR PERIOD

DISTINGUISHABLE FROM CHANNELING EFFECT OF

GALACTIC HALO - AVIGNONE, CRESWICK & NUGSINOV

\rightarrow 12 HOUR PERIOD

QUANTITATIVE:

$V_{\oplus} \sim 30 \text{ km/s}$ EARTH ORBITAL VELOCITY

$V_{\text{SURFACE ROTATION}} \sim 0.5 \text{ km/s}$ EQUATOR
 $0.3 \text{ km/s} \sim \frac{1}{100} V_{\oplus}$ 45° LATITUDE

$V_{\text{LOW ORBIT SATELLITE}} \sim 5-10 \text{ km/s} \sim \frac{1}{6} - \frac{1}{3} V_{\oplus}$

DARK MATTER DIRECT DETECTION EXPERIMENTS THAT
LOOK FOR ρ_{GALACTIC} WILL ALSO PLACE A BOUND

ON $\rho_{\text{SUN-BOUND}}(\theta)$ $\theta =$ ANGLE BETWEEN DARK MATTER
AND EARTH ORBITS

AND $\rho_{\text{SUN-BOUND}}$ INTEGRATED ON SPHERICAL SYMMETRY MODEL

EARTH (PLANET-BOUND) DARK MATTER ?

CAN PLACE DIRECT BOUND AS FOLLOWS

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FOR A SATELLITE OF NEGLIGIBLE MASS IN CIRCULAR ORBIT AROUND BODY OF MASS M, ORBIT RADIUS R AND PERIOD T GIVE GM :

$$GM = \frac{4\pi^2 R^3}{T^2}$$

• LAGEOS TRACKING R ~ 12,300 km
GIVES GM_{\oplus}

• LUNAR ORBITERS GIVE GM_m

MORE ACCURATE: EROS ASTEROID FLYBY

GIVES $R_{\oplus/m} = \frac{GM_{\oplus}}{GM_m}$

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- LUNAR LASER RANGING GIVES GM FOR EARTH-MOON SYSTEM, INCLUDING MASS OF DARK MATTER WITHIN MOON'S ORBIT

$$GM_{\text{COMBINED}} = GM_{\oplus} + GM_m + GM_{\text{DM}}$$

$$\text{SO } GM_{\text{DM}} \approx GM_{\text{COMBINED}} - GM_{\oplus} - \frac{GM_{\oplus}}{R_{\oplus/m}}$$

$$\approx (0.3 \pm 4) \times 10^{-9} GM_{\oplus}$$

↑
DOMINANT ERROR FROM LUNAR RANGING;
WILL GET BETTER

IF BOUND WERE ATTAINED, AND IF MASS WERE UNIFORMLY DISTRIBUTED BELOW THE MOON'S ORBIT, DENSITY WOULD BE

$$\rho \sim 6 \times 10^{10} \text{ g} \cdot \text{v} / \text{c}^2 \text{ cm}^{-3} \gg \begin{matrix} \rho_{\text{NANO}} \\ \rho_{\text{SUN-BOUND}} \\ \text{LIMIT} \end{matrix}$$

SUMMARY

$$\rho_{\text{GALACTIC}} \sim 0.3 \text{ GeV}/c^2 \text{ cm}^{-3}$$

$$\rho_{\text{SUN-BOUND}} < 10^5 \text{ GeV}/c^2 \text{ cm}^{-3}$$

$$\rho_{\text{EARTH-BOUND}} < 6 \times 10^{10} \text{ GeV}/c^2 \text{ cm}^{-3}$$

LARGE NUMBERS - COULD PROVIDE
A TEMPTING TARGET FOR EXPERIMENT



POSSIBLE APPLICATIONS OF EARTH AND PLANET-BOUND
DARK MATTER (SPECULATIVE!)

• JOVIAN PLANET ANOMALIES

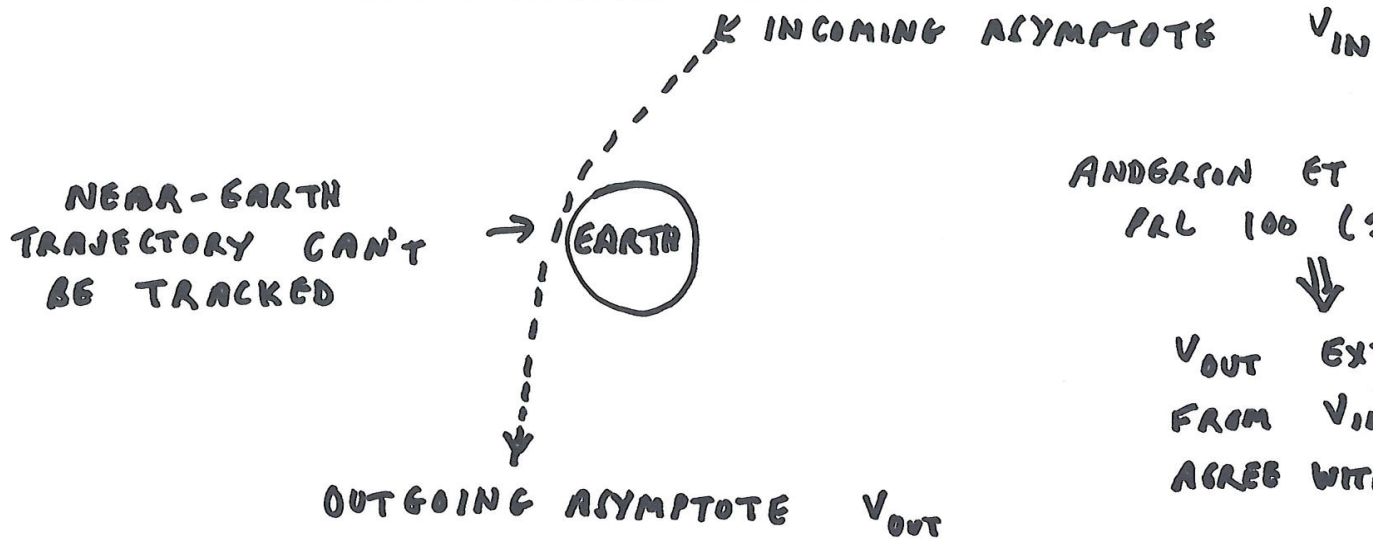
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<u>SURFACE HEAT FLUX</u>	H	$\frac{evs}{cm^2s}$	<u>PLANET</u>	(de Pater → Lissauer)
5990			JUPITER	
2010			SATURN	
<42			URANUS	
433			NEPTUNE	

① ACCRETION OF PLANET-BOUND DARK MATTER COULD ACCOUNT FOR UNEXPLAINED INTERNAL HEAT PRODUCTION (REQUIRES LOW ENERGY RELEASE EFFICIENCY)

② URANUS AXIS ON ITS SIDE RELATIVE TO ECLIPTIC - COLLISION CAUSING THIS COULD HAVE KNOCKED URANUS OUT OF ITS DARK MATTER CLOUD

• FLYBY ANOMALY



ANDERSON ET AL
PRL 100 (2008) 091102



V_{OUT} EXTRAPOLATED
FROM V_{IN} DOES NOT
AGREE WITH OBSERVATION

	GALILEO II	NEAR
DATE	12/8/92	1/23/98
$\Delta V_{\infty} \frac{mm}{s}$	-4.6	13.46
$\sigma V_{\infty} \frac{mm}{s}$	1.0	0.01

EFFECT IS $\sim 10^{-6} V_{\infty}$
EITHER SIGN

POSSIBILITIES:

- EFFECT IS AN ARTIFACT - OMITTED KNOWN PHYSICS
- NEW ELECTROMAGNETIC PHYSICS
- NEW GRAVITATIONAL PHYSICS (NON-MOND)
- EFFECT COMES FROM COLLISIONS WITH EARTH-BOUND DARK MATTER

VELOCITY INCREASE:

EXOTHERMIC



$$m_0 > m'_0$$

VELOCITY DECREASE:
(CONVENTIONAL DRAG)

ELASTIC SCATTERING



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CONSTRAINTS \Rightarrow

- DARK MATTER LOCALIZED WELL WITHIN MOON ORBIT AND NOT TOO NEAR EARTH
- DARK MATTER MASS \ll GeV
- σ_{DM-N} HIGH: 10^{-33} cm² TO 10^{-27} cm²
- DARK MATTER NON - SELF - ANNIHILATING AND STABLE IN ABSENCE OF NUCLEONS

CURRENT WORK - MODELING DARK MATTER

ORBITING EARTH (TWO SPECIES - INELASTIC AND ELASTIC SCATTER WITH NUCLEON) TO TRY TO FIT ANDERSON GROUP DATA