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Gyrochronology Relating Star Age to Rotation Period is Derived From First Principles Through a Novel Time Dual for Thermodynamics, Named 'Lingerdynamics'

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Abstract—*Gyrochronology estimates the age of a low-mass star from its rotation period, which is found from changes in brightness caused by dark star spots. First revealed in 1972 as an insight by Skumanich it allows astronomers to find true sun-like stars that may harbor life in its planets. Here a simple expression for the age of a star in the past Age(t-Δt) is derived in terms of the ratio of its present P(t) to past P(t-Δt) rotation periods. The derivation is achieved through a novel Linger Thermo Theory (LTT) integrating Thermodynamics with its discovered time-dual, named Lingerdynamics that relates the lifespan of the star τ to its LTT perpetual rotation period $\hat{A}$ and is a child of the Universal Cybernetics Duality Principle treated at the end of the poster. The LTT lifespan/period relationship is given by the equation $\tau = (2\Pi/3\hat{v}^3) \times G^2M^2\hat{A}$ where G is the gravitational constant, Π is the retention pace in s/m³ units of the star's operation lifespan per retention volume (e.g., the sun's current retention pace is five billion 'future' years over its volume), and $\hat{v}$ is the perpetual radial speed about the star's point-mass M. Since in LTT the star medium is modeled as a point-mass M that resides at the center of a sphere of radius r whose volume matches that of the medium, one finds that it's perpetual rotation period $\hat{A}$ does not match the true rotation period of the star P (e.g., the sun's current P(t) is 25.34 days while the current $\hat{A}(t)$ is 0.116 days that is derived according to: $\hat{A}=2\pi r_{Sun}/\hat{v} = 2\pi r_{Sun}/(GM_{Sun}/r_{Sun})^{1/2}$. However, using conservation of angular momentum arguments it is assumed here that the observed past to present rotation period ratio P(t)/P(t-Δt) approximates the theoretical LTT ratio $\hat{A}(t)/\hat{A}(t-\Delta t)$. Using this key enabling theoretical assumption one then sensibly arrives at gyrochronology from our first principles LTT perspective.*

The LTT Gyrochronology Past Age Equation

$$Age(t-\Delta t) = \tau(0) - (\tau(0) - Age(t))\, k_G\, P(t)/P(t-\Delta t)$$

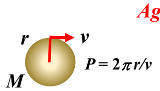


Illustration: Sun Δt = 2 billion years ago (k_G = 1)

Lifespan of Sun at Birth: $\tau(0)$ = 9.5 billion years

Past Sun Age: $Age(t-\Delta t)$ = 2.5 billion years (Gyr)

Current Period $P(t)$ = 25.34 days (d)

Past Period $P(t-\Delta t)$ = 18.21 days

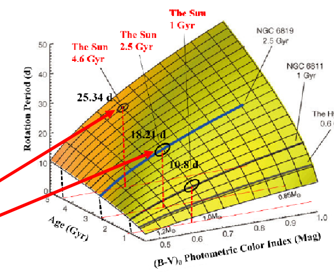
Current Sun Lifespan $\tau(t)$ = 5 billion years, *Current Sun Mass* $M(t) = 1.98855 \times 10^{30}$ kg, *Current Sun Radius* $r(t) = 6.957 \times 10^{8}$ m, *Current Sun Speed* $v(t)$ = 1996.6 m/sec, *Current Sun Age* $Age(t)$ = 4.5 billion years

Three Gyrochronology Historical Highlights

1. *Observation that star age was related to the stellar rotation measure, v sin i, was first reported in:* 1972: Skumanich, A., Astrophysical Journal, 171:565

2. *The name Gyrochronology was coined by Barnes in:* 2003: Barnes, S. A. Astrophysical Journal, 586 (3): pp. 464-479

3. *General relationship (see picture below) among age, rotation period and mass (or color) was 'hypothesized' in:* 2015: Meibom, S., Barnes, S. A., Platais, I., Gilliland, R. L., Latham, D. W., Mathieu, R. D., Nature, 517: 589-591



B. Sun 2 Billion Years Ago (k_G = 1)

Assuming k_v =1.0065 and the value of the past sun mass M(t-Δt) to be given by:

$$M(t-\Delta t) = M(t) + M_{Fusion}(\Delta t) + M_{SolarWind}(\Delta t) = 1.9889 \times 10^{30}\ kg$$

where it is assumed that the lost sun fusion mass is given by $M_{Fusion}(\Delta t) = 2/4.5 \times 0.0003M(t) = 2.6514 \times 10^{26}$ kg, and the lost sun solar-wind mass by $M_{SolarWind}(\Delta t) = 2/4.5 \times 0.0001M(t) = 0.8838 \times 10^{26}$ kg (see Sun and Solar Wind Wikipedia).

One then finds the sun's remaining gains, radius and radial speed values to be:

$$k_{\hat{v}} = 0.92094, \quad k_\tau = 1.0929$$

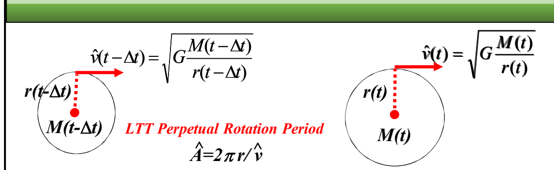
Past Radius $r(t-\Delta t) = 0.8477\, r(t)$

Past Radial Speed $v(t-\Delta t) = 1.1794\, v(t)$

C. Conclusions

In this paper Linger Thermo Theory or LTT has not only arrived at Gyrochronology from first principles but also allowed us to estimate the past radius and radial speed of a star under the assumption that the past mass is known. The mass of the sun two billion years ago is assumed given by the sum of its present mass and estimated mass losses due to fusion and solar wind. Other kinds of mass losses will be studied in the future, including dark-matter candidates like the axion and the thermote (Feria, E.H., 2017, AAS 230th Meeting, Austin, Texas, 7 June)

A. Derivation of 5 LTT Gyrochronology Equations



The derivation starts by noticing that the lifespan from birth of a star $\tau(0)$, current lifespan $\tau(t)$ and present age Age(t) are related by $\tau(t) = \tau(0) - Age(t)$. A similar relationship applies at time t-Δt, thus our proof begins with the expression:

$$Age(t-\Delta t) = \tau(0) - (\tau(0) - Age(t))\ \tau(t-\Delta t)/\tau(t)$$

This equation is then followed by finding a relationship between the lifespan ratio $\tau(t-\Delta t)/\tau(t)$ and the LTT perpetual rotation period ratio $\hat{A}(t)/\hat{A}(t-\Delta t)$ according to:

→ *Pace $\Pi = \tau/V$ = Lifespan/Volume = Time-Dislocation/Space-Penalty*

$$\rightarrow \tau(t-\Delta t) = \Pi(t-\Delta t)V(t-\Delta t) = \Pi(t-\Delta t)\,4\pi r^3(t-\Delta t)/3$$

$$\rightarrow \tau(t-\Delta t) = (2\Pi(t-\Delta t)/3\hat{v}^3(t-\Delta t))G^2M^2(t-\Delta t)\hat{A}(t-\Delta t)$$

$$\rightarrow \tau(t) = (2\Pi(t)/3\hat{v}^3(t))G^2M^2(t)\hat{A}(t)$$

$$\rightarrow \Pi(t-\Delta t) = \tau(t-\Delta t)/V(t-\Delta t) = \tau(t-\Delta t)/4\pi r^3(t-\Delta t)/3$$

$$\rightarrow \Pi(t) = \tau(t)/V(t) = \tau(t)/4\pi r^3(t)/3$$

$$\rightarrow \frac{\tau(t-\Delta t)}{\tau(t)} = \frac{\tau(t-\Delta t)r^3(t)M^3(t)\hat{v}^3(t)M^5(t-\Delta t)\hat{A}(t-\Delta t)}{\tau(t)r^3(t-\Delta t)M^3(t-\Delta t)\hat{v}^3(t-\Delta t)M^5(t)\hat{A}(t)}$$

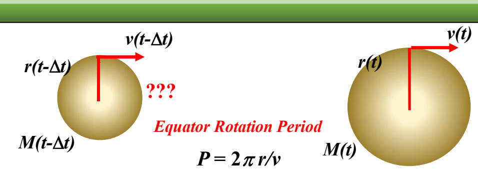
$$\rightarrow I\hat{\omega}: \text{Angular Momentum} = \text{Moment of Inertia} \times \text{Angular Velocity}$$

$$\rightarrow k_{\hat{v}} = \frac{I(t-\Delta t)\hat{\omega}(t-\Delta t)}{I(t)\hat{\omega}(t)} = \frac{r(t-\Delta t)M(t-\Delta t)\hat{v}(t-\Delta t)}{r(t)M(t)\hat{v}(t)}$$

$$\rightarrow \frac{\tau(t-\Delta t)}{\tau(t)} = \frac{\tau(t-\Delta t)M^5(t-\Delta t)\hat{A}(t-\Delta t)}{\tau(t)k_{\hat{v}}^3M^5(t)\hat{A}(t)}$$

$$\rightarrow \frac{\tau(t-\Delta t)}{\tau(t)}\frac{k_{\hat{v}}^3M^5(t)}{M^5(t-\Delta t)} = \frac{\tau(t-\Delta t)}{\tau(t)}\frac{\hat{A}(t-\Delta t)}{\hat{A}(t)}$$

$$\rightarrow \frac{\tau(t-\Delta t)}{\tau(t)} = k_\tau\frac{M^5(t-\Delta t)}{k_{\hat{v}}^3M^5(t)} = k_\tau\frac{\hat{A}(t)}{\hat{A}(t-\Delta t)}, \quad k_\tau \text{ is an arbitrary constant}$$



Finally the LTT gyrochronology equations result from finding the relationship between the rotation period ratio P(t)/P(t-Δt) and the LTT perpetual rotation period ratio $\hat{A}(t)/\hat{A}(t-\Delta t)$ via the use of gain-mediated, or approximate, conservation of angular momentum arguments:

$$\rightarrow k_v = \frac{I(t-\Delta t)\omega(t-\Delta t)}{I(t)\omega(t)} = \frac{r(t-\Delta t)M(t-\Delta t)v(t-\Delta t)}{r(t)M(t)v(t)}$$

$$\rightarrow \frac{\hat{A}(t)}{\hat{A}(t-\Delta t)} = \frac{k_{\hat{v}}}{k_v}\frac{P(t)}{P(t-\Delta t)}$$

1. ***LTT Gyrochronology Past Age Equation***

$$Age(t-\Delta t) = \tau(0) - (\tau(0) - Age(t))k_G\frac{P(t)}{P(t-\Delta t)}$$

2. ***LTT Gyrochronology Past Gain Equation***

$$k_G = k_\tau k_{\hat{v}}/k_v$$

3. ***LTT Gyrochronology Past Mass Equation***

$$M(t-\Delta t) = (k_{\hat{v}}^4/k_v)^{1/5}\left(\frac{P(t)}{P(t-\Delta t)}\right)^{1/5}M(t)$$

4. ***LTT Gyrochronology Past Radius Equation***

$$r(t-\Delta t) = (k_{\hat{v}}^3/k_v^2)^{1/5}\left(\frac{P(t-\Delta t)}{P(t)}\right)^{3/5}r(t)$$

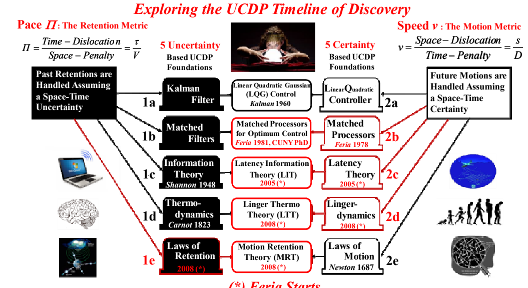
5. ***LTT Gyrochronology Past Speed Equation***

$$v(t-\Delta t) = 2\pi r(t-\Delta t)/P(t-\Delta t)$$

The Universal Cybernetics Duality Principle (UCDP)

The UCDP is the integrated physics and mathematics duality revelation "Synergistic Physical and Mathematical Dualities Arise in Efficient System Designs." Identified in 1978 in optimum control theory as part of graduate studies in Cybernetics (see UCDP timeline of discovery below), the UCDP first led us to the space-time certainty-based Matched Processors for Quantized Control, with applications in CNS modeling for use in biofeedback. This method was the time-dual of the space-time uncertainty-based Matched Filters for quantized-state detections. Later in the mid 2000's motivated by a grant from the 2001-2005 DARPA High-Performance Radar KASSPER Program, the UCDP led to the discovery of the time-dual of Information Theory, named Latency Theory in 2005, and also to the discovery of the time-dual of Thermodynamics later on, named Lingerdynamics. In addition, the space-dual of the laws of motion in physics, named 'the laws of retention in physics,' was also revealed such as the space-dual of the speed of light in a vacuum, named 'the pace of dark in a black hole.' Some of these dualities appeared in the International Society of Optics and Photonics SPIE Newsroom Article, Feria, E. H., 2014, Maximizing the Efficiency and Affordability of High-Performance Radar (this article was invited and edited by the SPIE Newsroom http://dx.doi.org/10.1117/2.1201407.0005429). Since then LTT has led us to the discovery of the thermote that enables the simple finding of a medium's entropy (Feria, E. H., 2016, Linger Thermo Theory, Proc. IEEE Int'l Conf. on Smart Cloud, DOI 10.1109/SmartCloud.2016.57, 18 pages, Columbia Univ., N. Y., USA), and also offers a sensible candidacy for dark-matter (Feria, E.H., 2017, AAS 230th Meeting, Austin, Texas, 7 June) as well as dark-energy due to the temperature dependency of the thermote energy.

Exploring the UCDP Timeline of Discovery



Black Hole (BH) Thermote Energy $e_{Th}^{BH} = N_{DoF}k_BT/2 = k_BT$

Thermote Energy e_{Th} and its Gyrador Mass m_G $e_{Th} = N_{DoF}k_BT/2 = m_G\hat{v}^2/2$

Photon Gas (PG) Thermote Energy $e_{Th}^{PG} = N_{DoF}k_BT/2 = 3k_BT/2$

Pace of Dark in a Black Hole $\chi = 480\,c^2/Gh = 6.1294 \times 10^{63}\ sec/m^3$

Gyrador Thermo Source Entropy (TSE) $\hat{H}^G = J/2\ln 2, \quad J = Mc^2/e_{Th}$

Speed of Light in a Vacuum $c = \sqrt{Gh\chi/480} = 2.9979 \times 10^8\ m/sec$