Multicolor Variability of Young Stars in the Lagoon Nebula: Physical Drivers and Intrinsic Timescales

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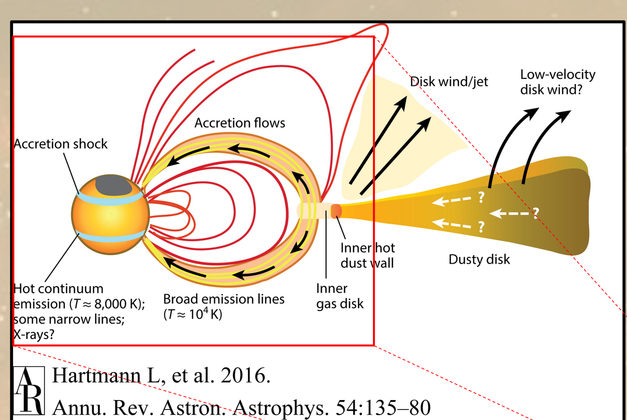
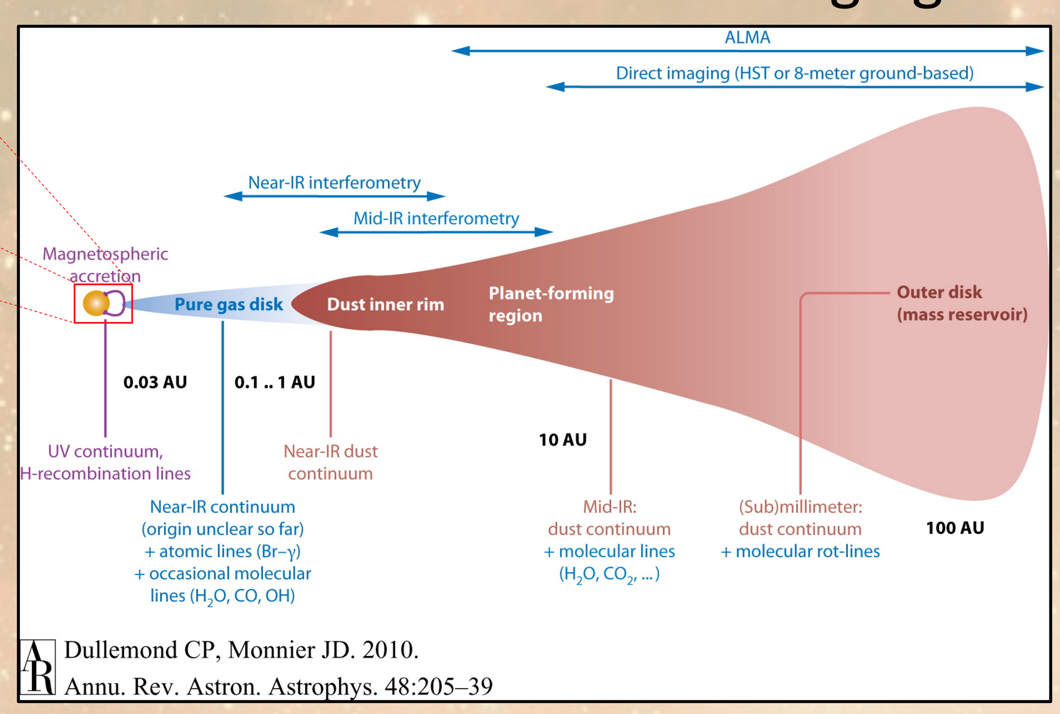
Young star variability: key to the inner disk dynamics

• ***Magnetospheric star-disk interaction***:

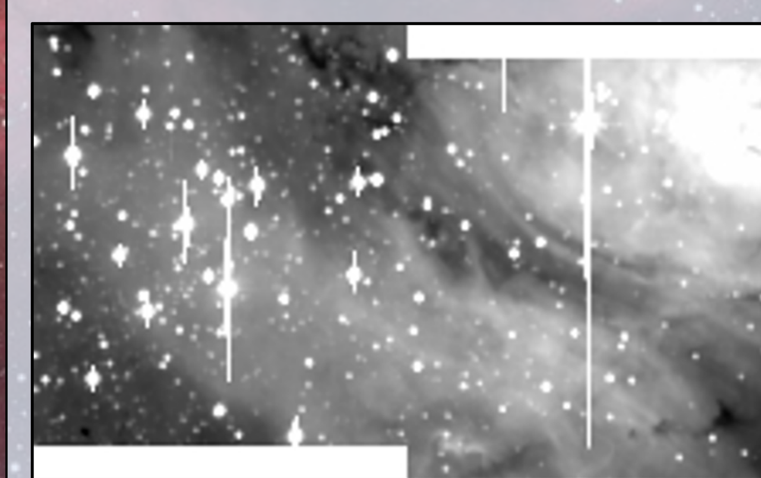


- governs exchange of mass and angular momentum in inner disk environment
- hard to access with direct imaging

• ***Three-pronged strategy*** to study the inner disk:
- reconstruct *star-disk emission spectrum*;
- monitor the *variability* of star-disk luminosity;
- observe *large samples of coeval stars* in young clusters.



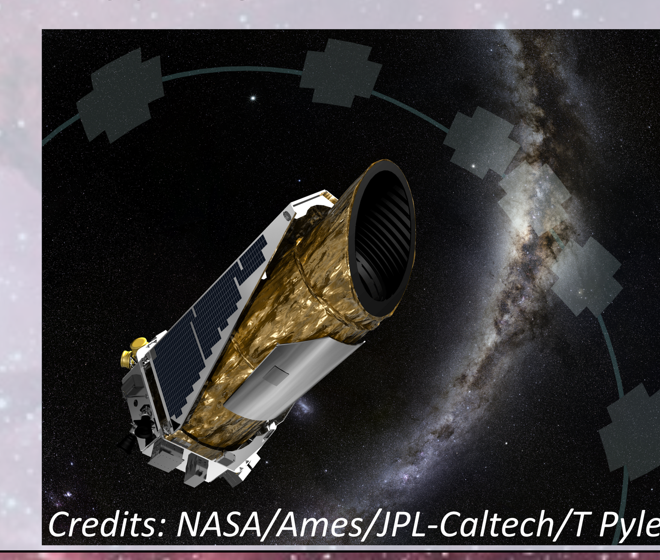
Lagoon Nebula: a young, massive star-forming region



Kepler/*K2* mosaic of Lagoon field

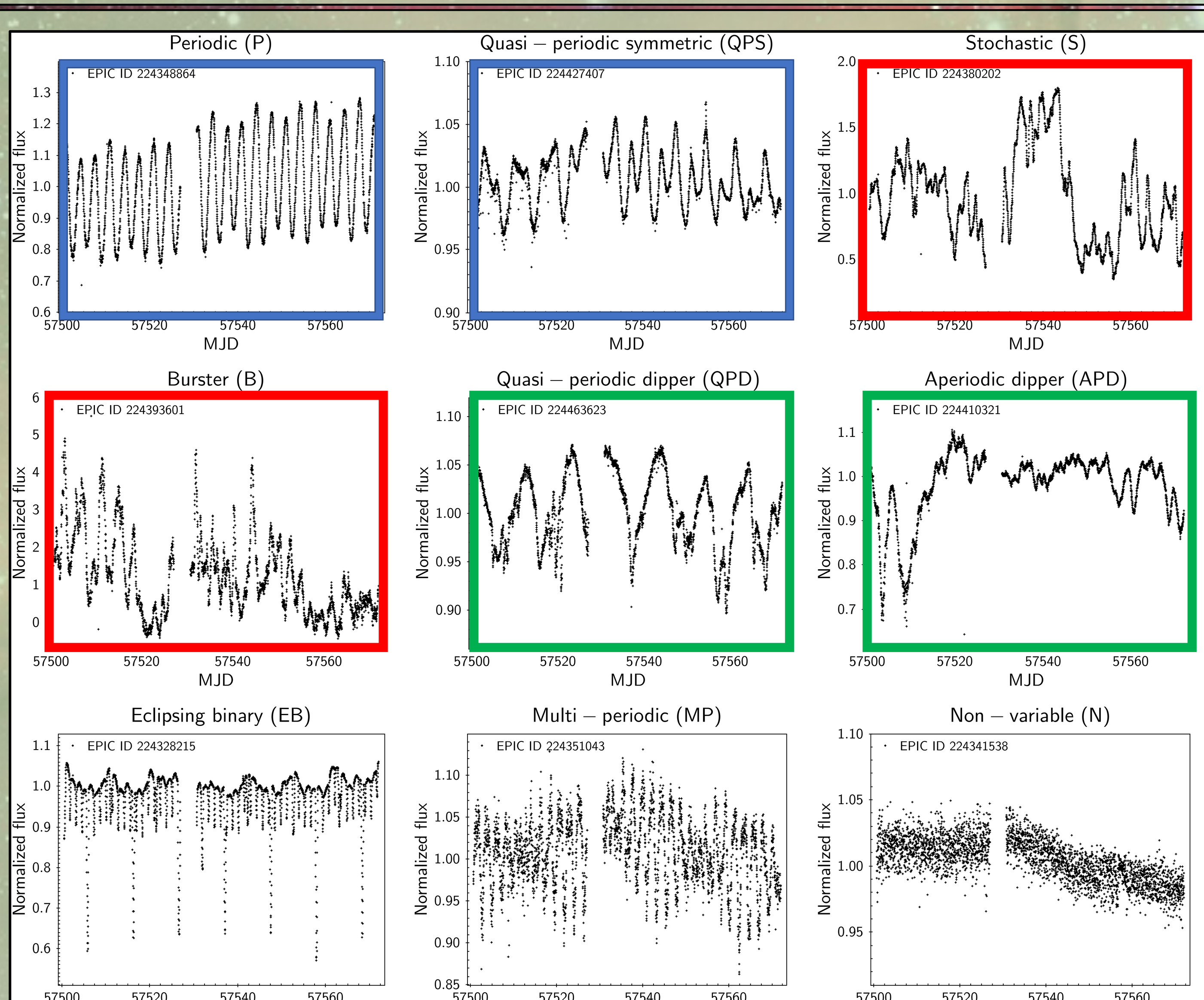
• ***Lagoon Nebula characteristics***:
- contains the ~1-2 Myr-old open cluster NGC 6530 (d = 1325 pc)
  - 2500–3000 stars (Damiani+2019), estimated disk fraction ~50%
  - stellar mass range ~0.1–5 $M_\odot$ *(spectral types from B to late-K)*

• ***Kepler/K2 survey of the Lagoon:***
- ~72 day-long monitoring, Cycle 9
- ~300 embedded, young stars with sufficient S/N in *K2* mosaic
- auxiliary multi-band monitoring (u,g,r,i,Hα) from VST/OmegaCAM



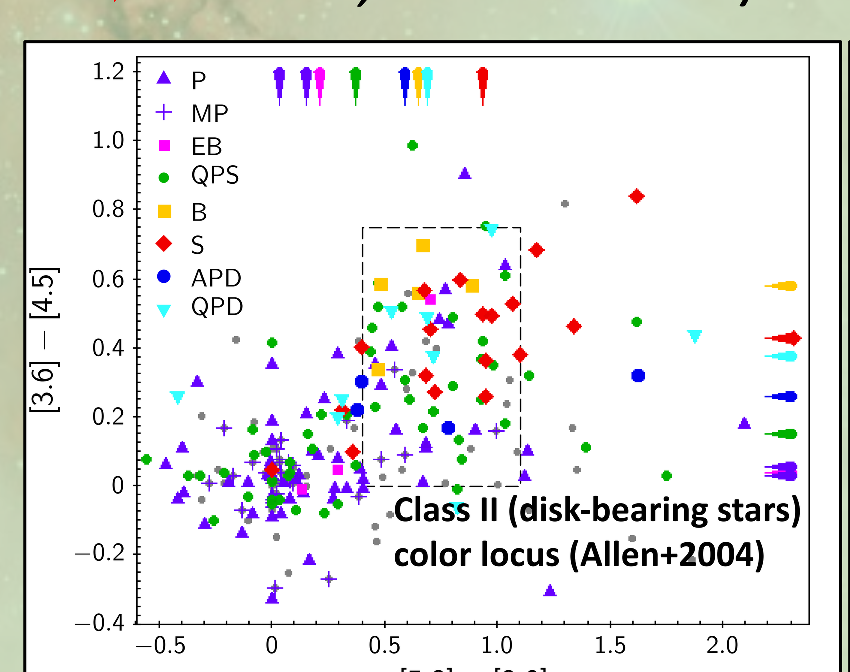
Credits: NASA/Ames/JPL-Caltech/T Pyle

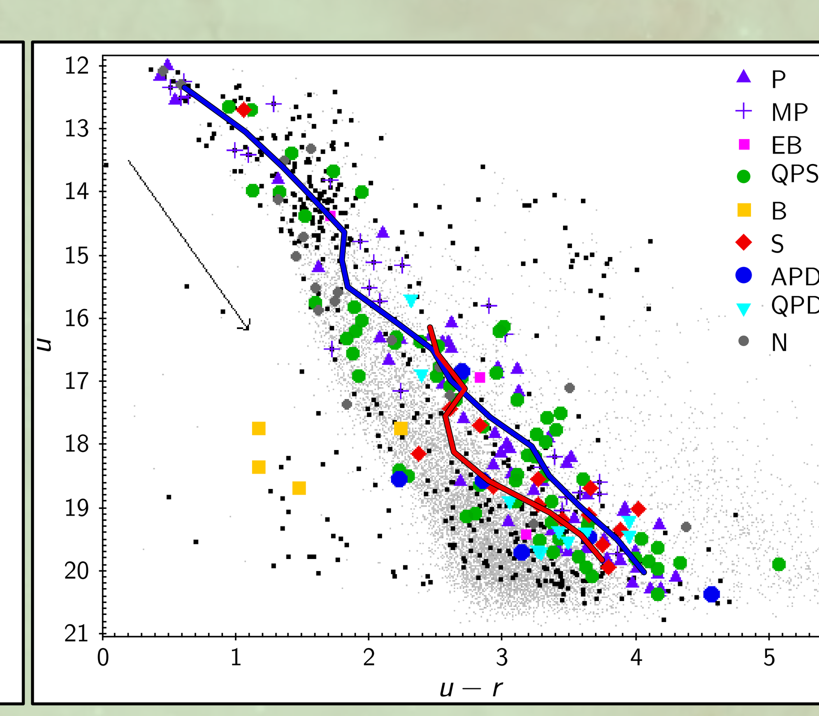
Multi-faceted time behaviors of young stars in the Lagoon Nebula



Venuti et al., to be submitted: *Examples of different variability types identified among the K2 light curves of Lagoon Nebula members.*

- <u>Cody+2014, 2018</u>: *At least 8 distinct variability patterns* identified among the light curves of ***disk-bearing young stars***, based on *periodicity/stochasticity* and on the *balance between brightening events and fading events*
- **<u>Lagoon Nebula</u>**: ~50% disk-bearing stars exhibit **regular modulated behaviors**, ~25% **erratic behaviors**, ~15% **dipping behaviors**
- ***Color properties*** associated to each light curve class *qualify the physical origin*:
  - ➡ *rotational modulation by starspots* for periodic or quasi-periodic variables
  - ➡ *intense, unstable and/or time variable accretion* for erratic variables

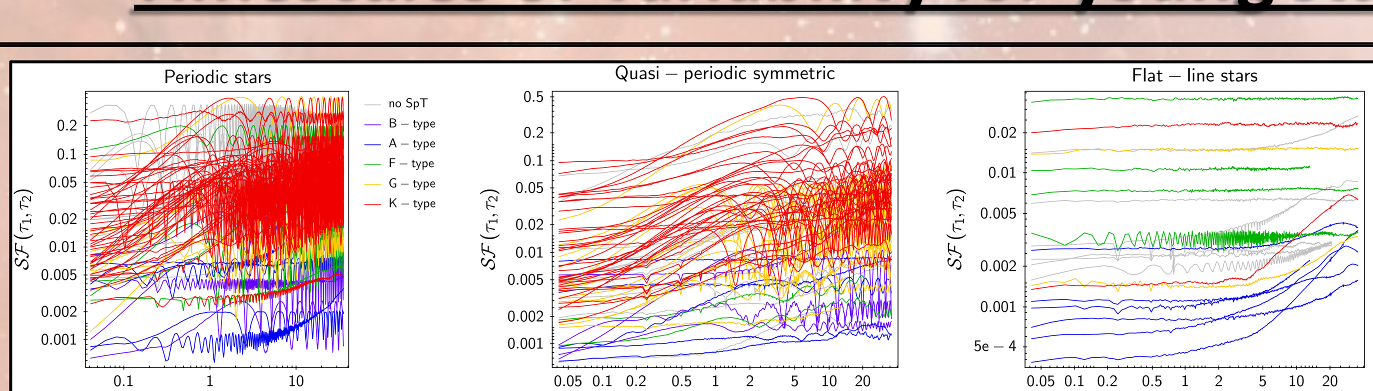




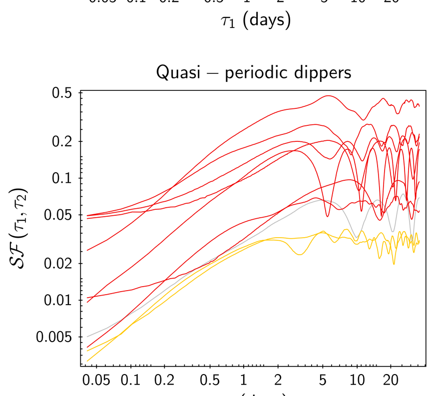
Venuti et al., to be submitted: *Colors of different K2 variables in Spitzer/IRAC filters (left) and VST u,r filters (right). Objects to the left of the blue curve on the (u-r, r) diagram exhibit UV excess above the photospheric level.*

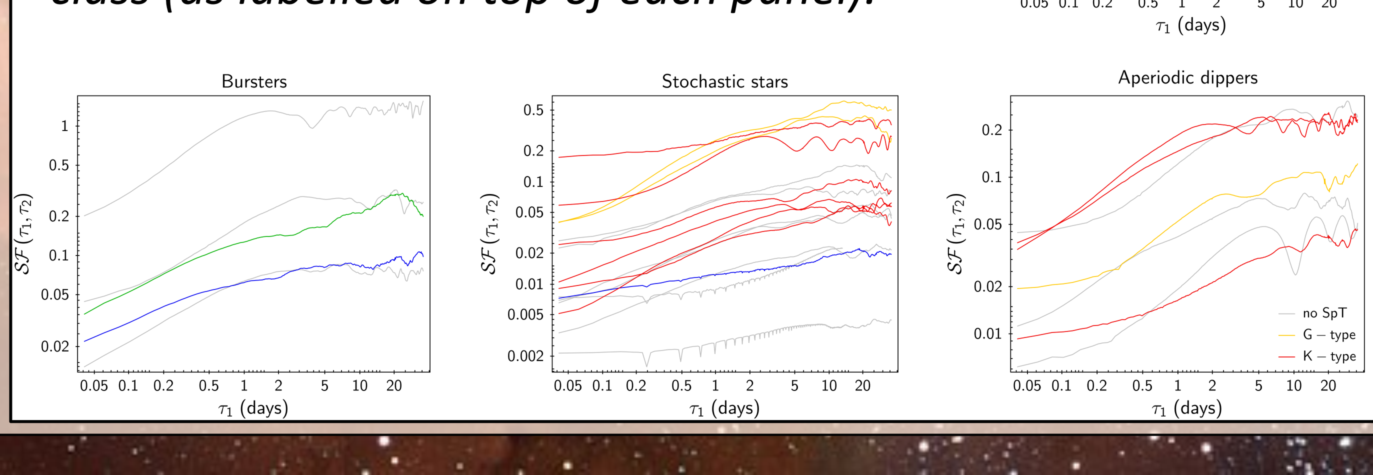
Erratic flux variations can be triggered in different parts of the disk: *inner disk rim* (bursters) vs. *outer magnetosphere* (stochastic).

Timescales of variability for young stars in the Lagoon Nebula



Venuti et al., to be submitted: *Examples of SF behaviors among Lagoon Nebula stars, as a function of spectral type (B to K, purple to red) and of K2 variability class (as labelled on top of each panel).*





• ***Structure function (SF)***: average amplitude of variability across the light curve for any given timescale τ encompassed by the time series

$$\mathcal{SF}(\tau_1,\tau_2)=\sqrt{\frac{1}{N(\tau_1,\tau_2)}\sum_{j>i}(f_i-f_j)^2}\,,\quad \tau_1<t_j-t_i<\tau_2$$

- SF increases with τ until the largest timescale of intrinsic variability is reached (Sergison+2020)

•***Takeaways from SF analysis in the Lagoon***:
- ➢*Higher-mass stars less variable* than lower-mass stars --> ***<u>different magnetic structures</u>***
- ➢*Leading variability timescales* always about *≤1-2 weeks* --> ***<u>no large-scale variations for inner disk processes over 10s-100s of cycles</u>***

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Ames Research Center NASA NASA POSTDOCTORAL PROGRAM Administered by USRA

<u>**References**</u>: Allen et al. 2004, ApJS, 154, 363 • Cody et al. 2014, AJ, 147, 82 • Cody et al. 2018, AJ, 156, 71 • Damiani et al. 2019, A&A, 623, A25 • Sergison et al. 2020, MNRAS, 491