Heliophysics as Applied to Stellar Systems

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+

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I. Sokolov, D. Borovikov, J. Kasper, F. Fraschetti

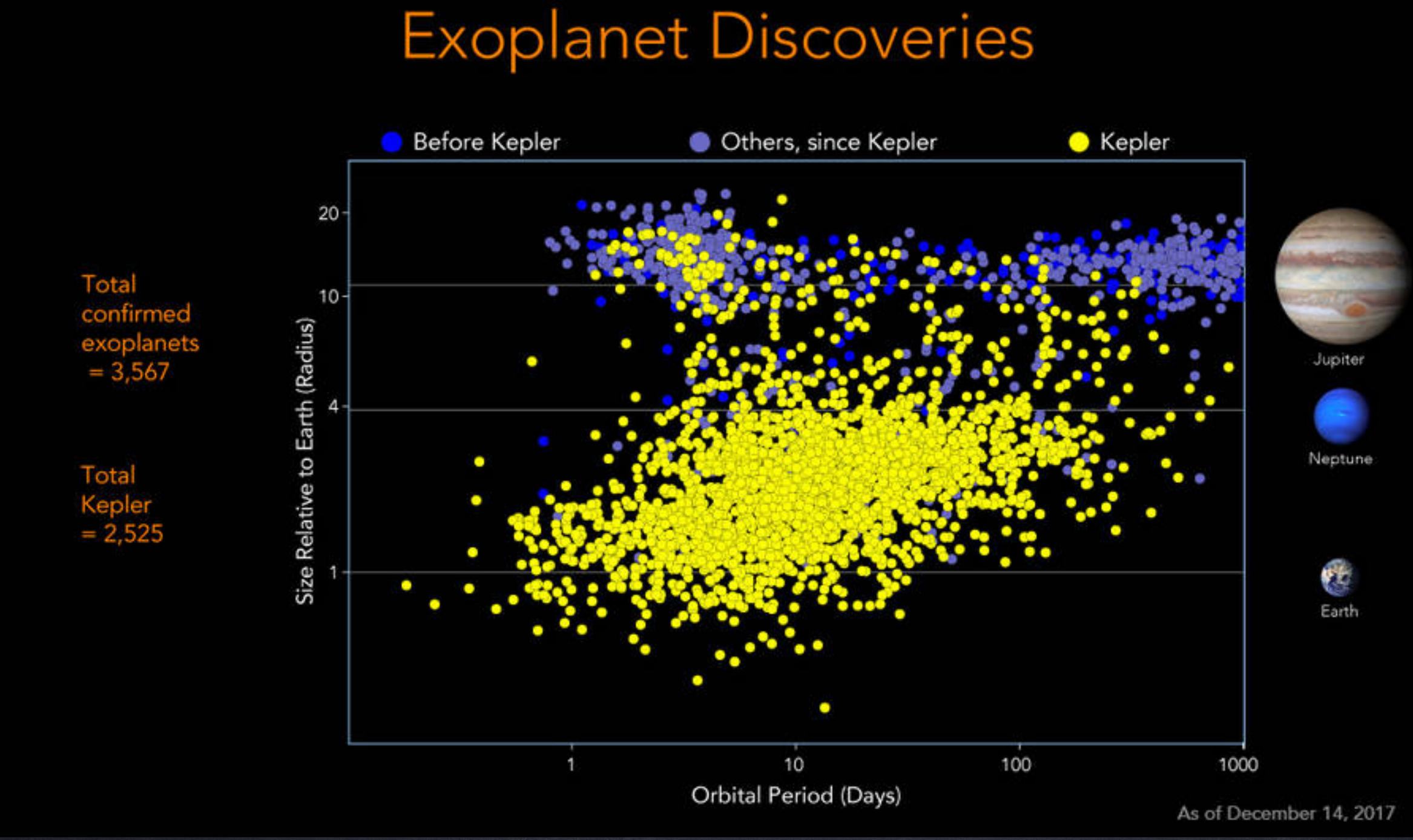
Solar Physics Webinar, 5 September 2018, Boston

Illustration: NASA/JPL-Caltech

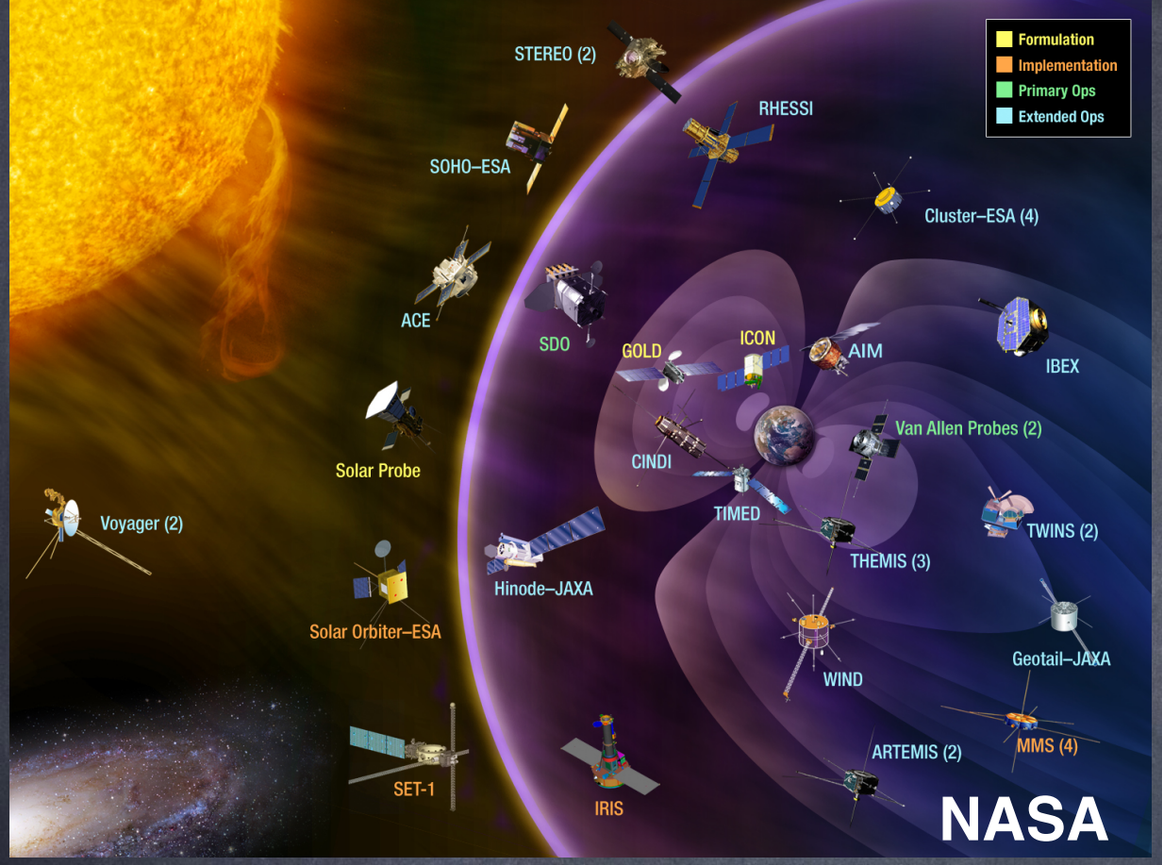
Outline

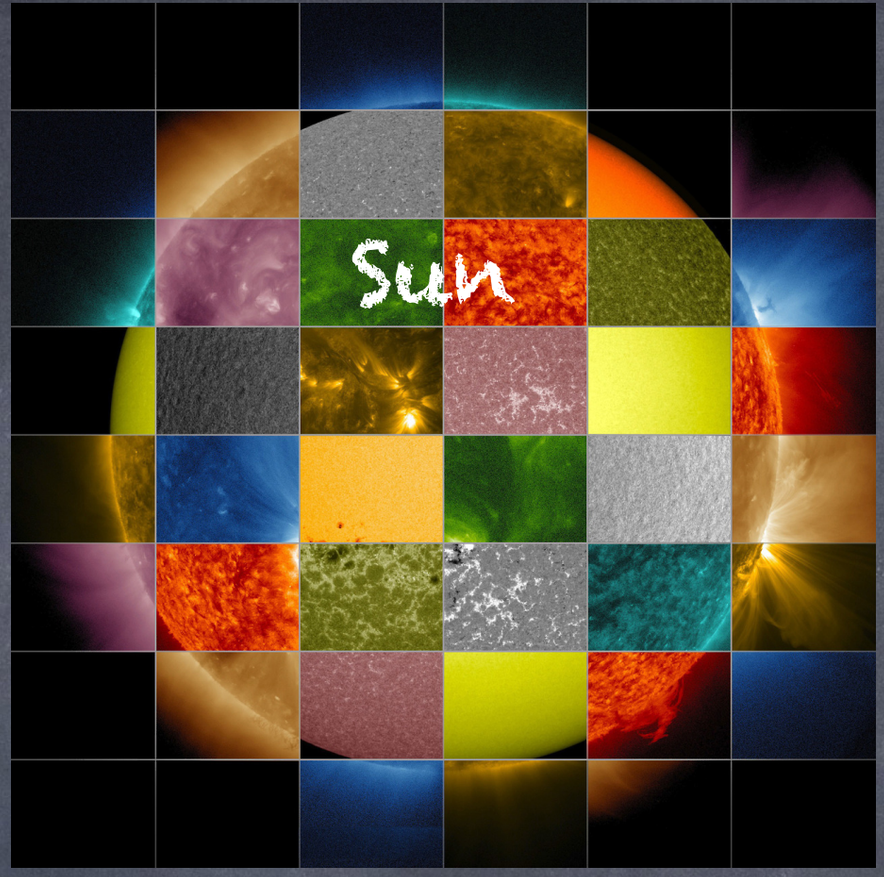
- Motivation: Solar <-> Astrophysics
- Solar/Stellar magnetic fields & activity cycles
- Heliosphere & Astrospheres
- Solar & Extrasolar Space Weather
- Future Observations
- Take away message

Motivation



Credit: NASA/Ames Research Center/Jessie Dotson and Wendy Stenzel

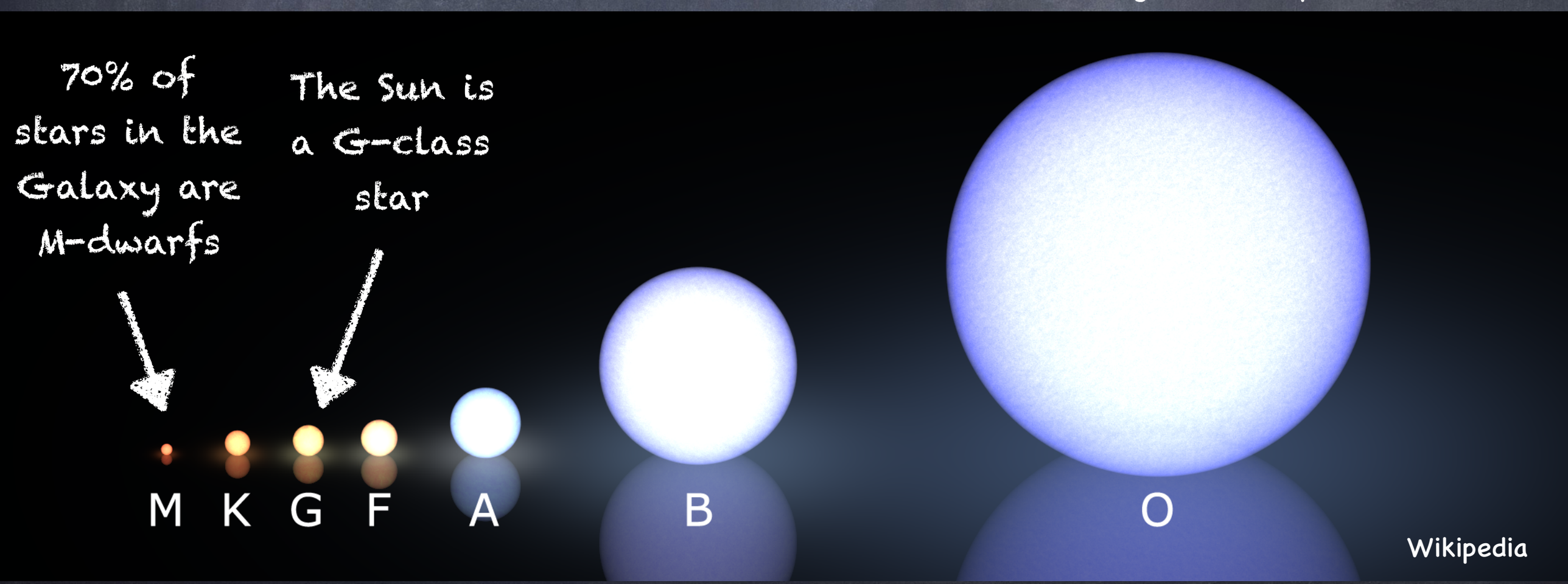




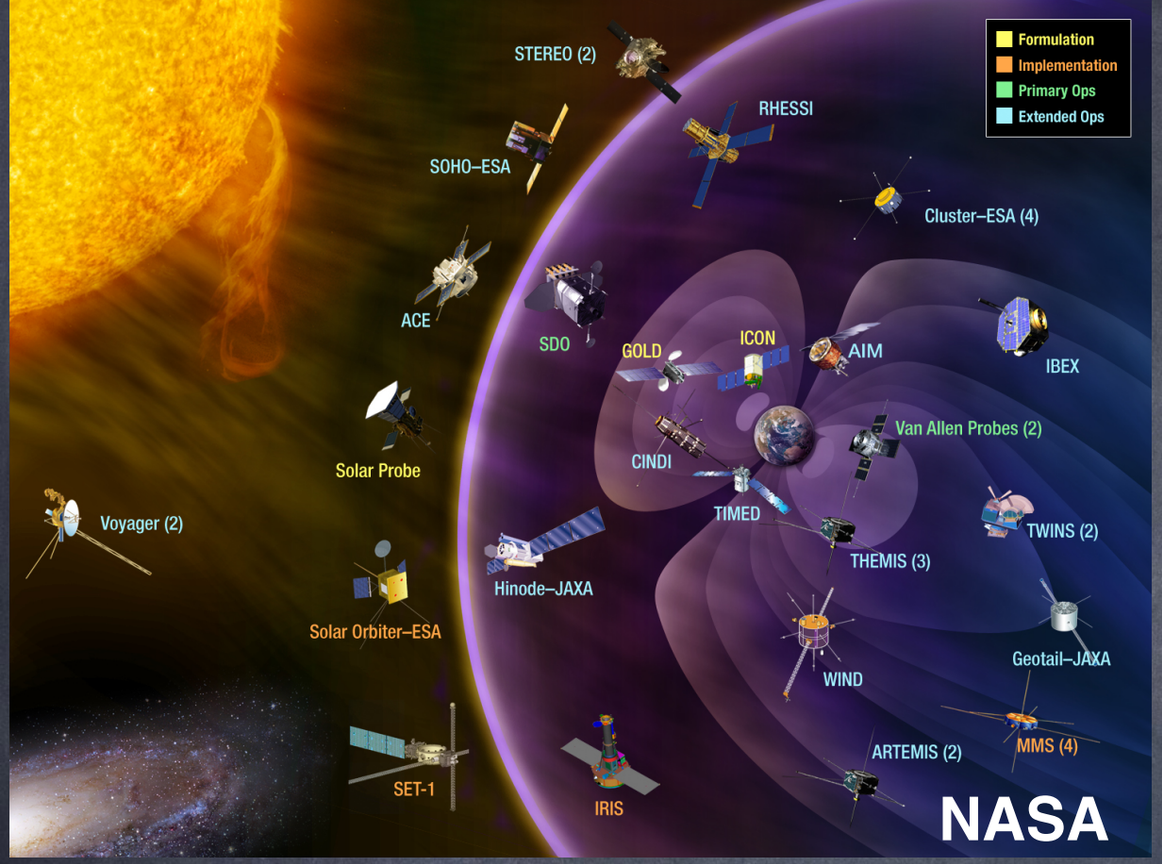
Morgan-Keenan spectral classification

70% of stars in the Galaxy are M-dwarfs

The Sun is a G-class star



Wikipedia



Generalized?

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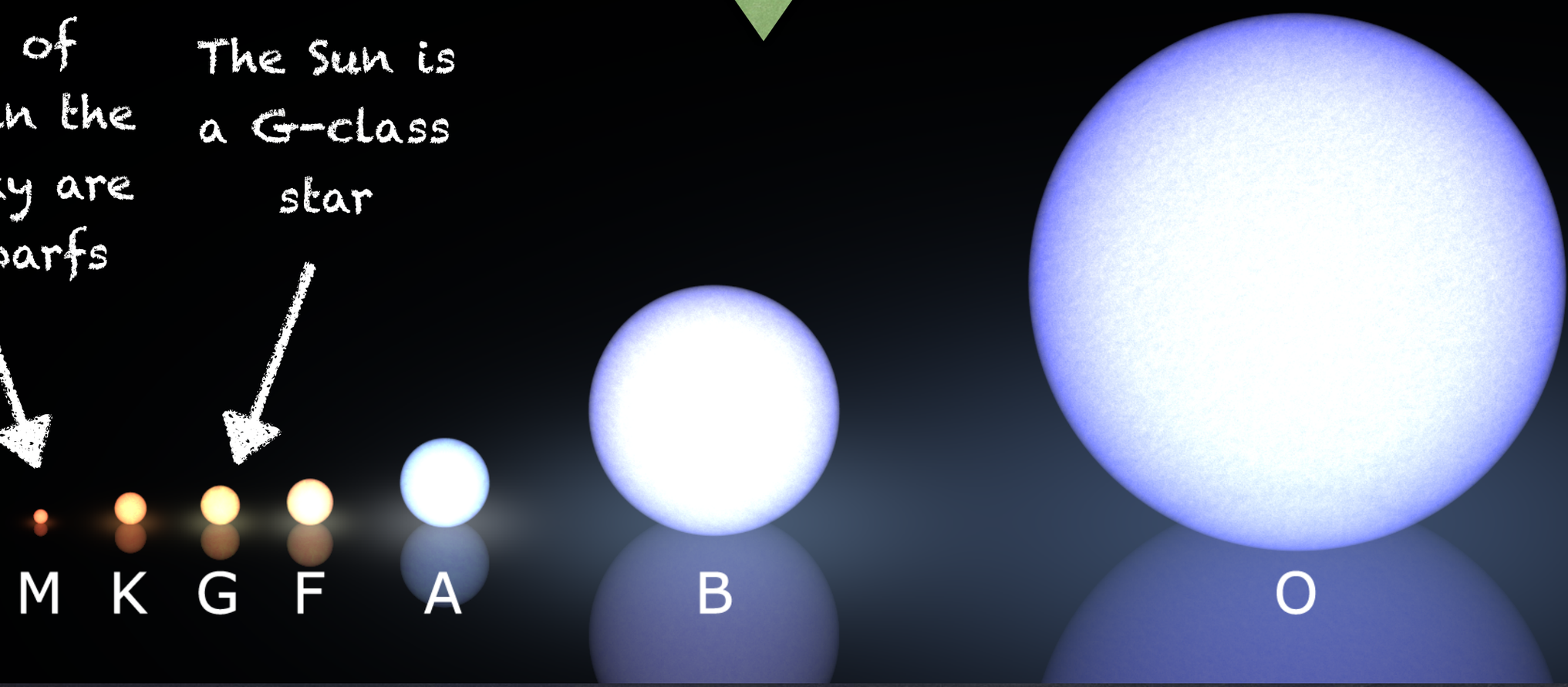

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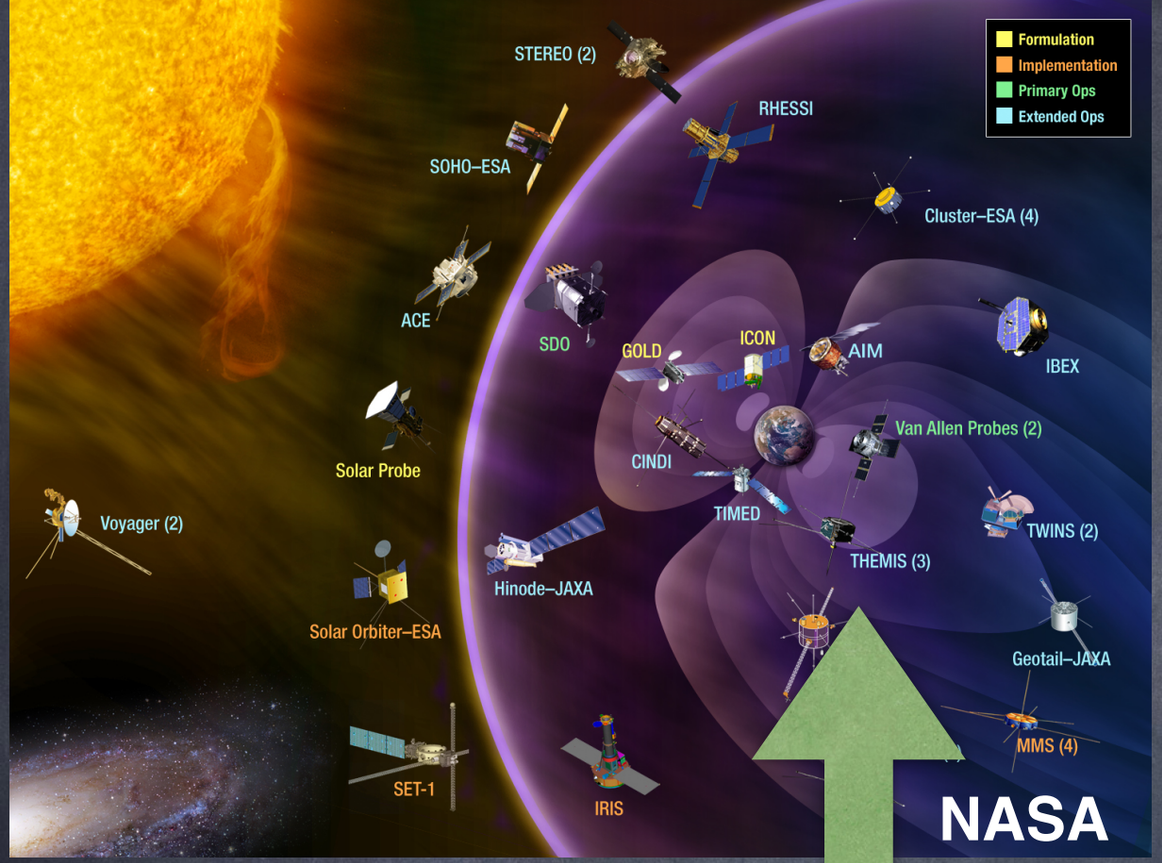

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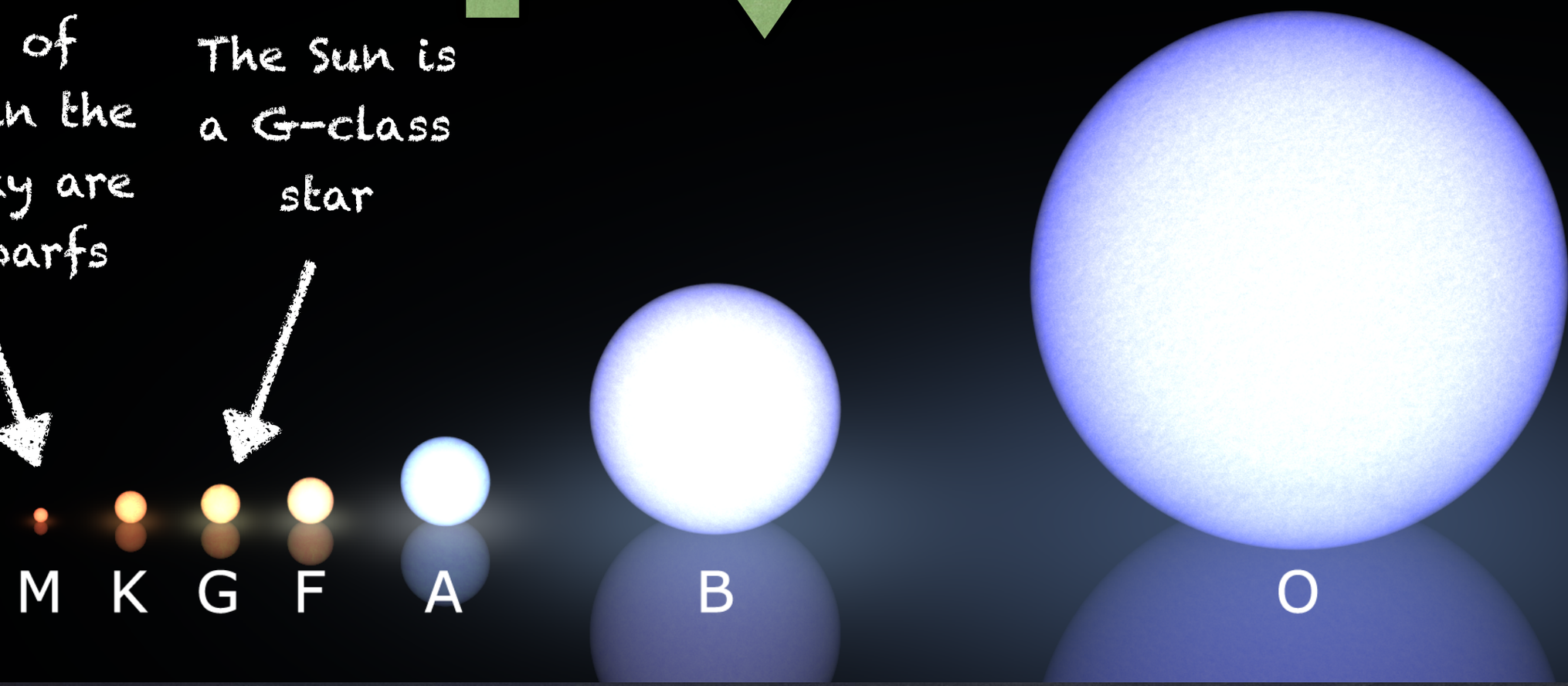


Wikipedia

Solar Physics:

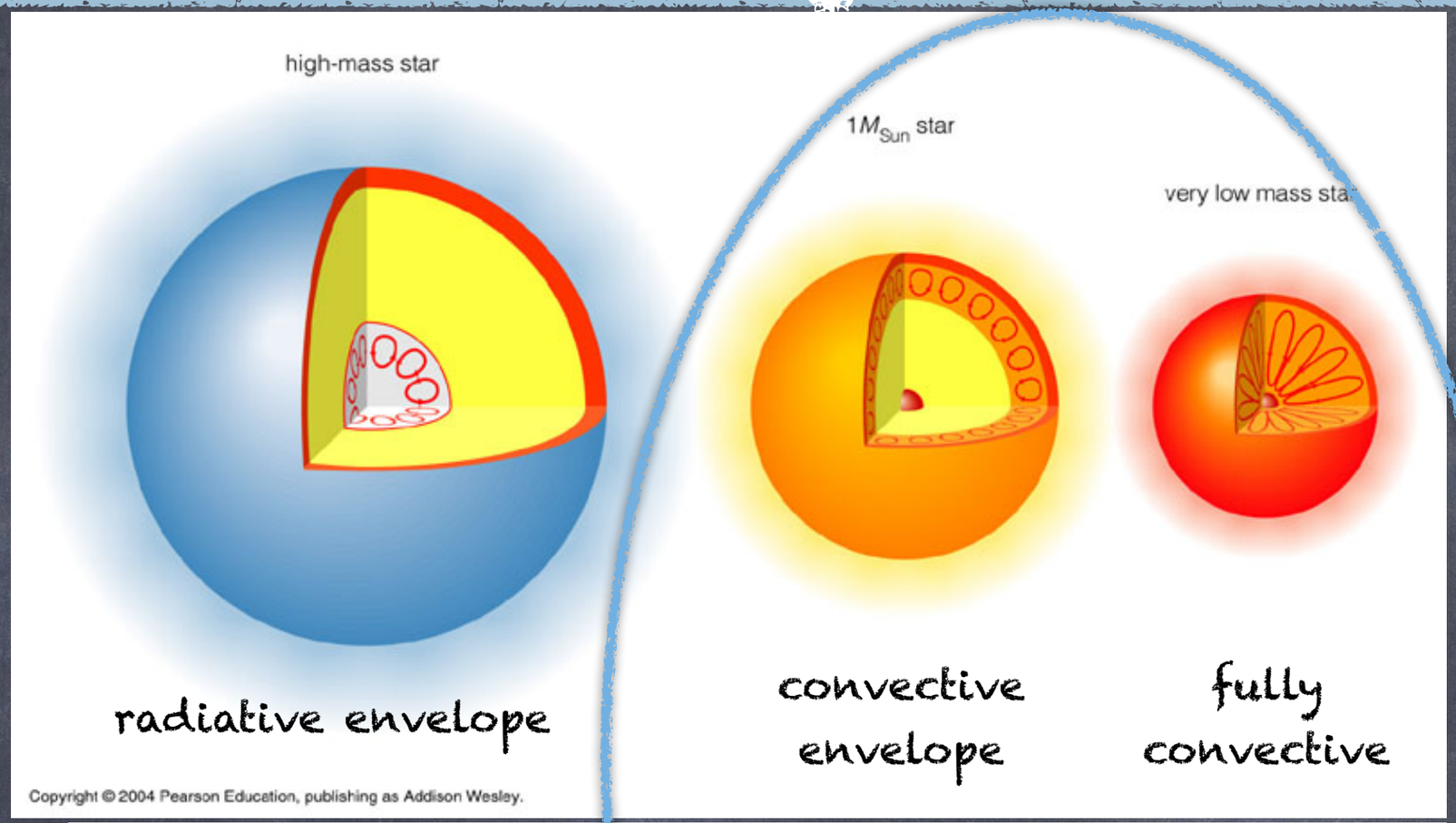
1. Continuous high-resolution high-cadence observations
2. Multi-wavelength observations
3. In-situ observations of the interplanetary environment
4. Constrained models
5. Information only about one star

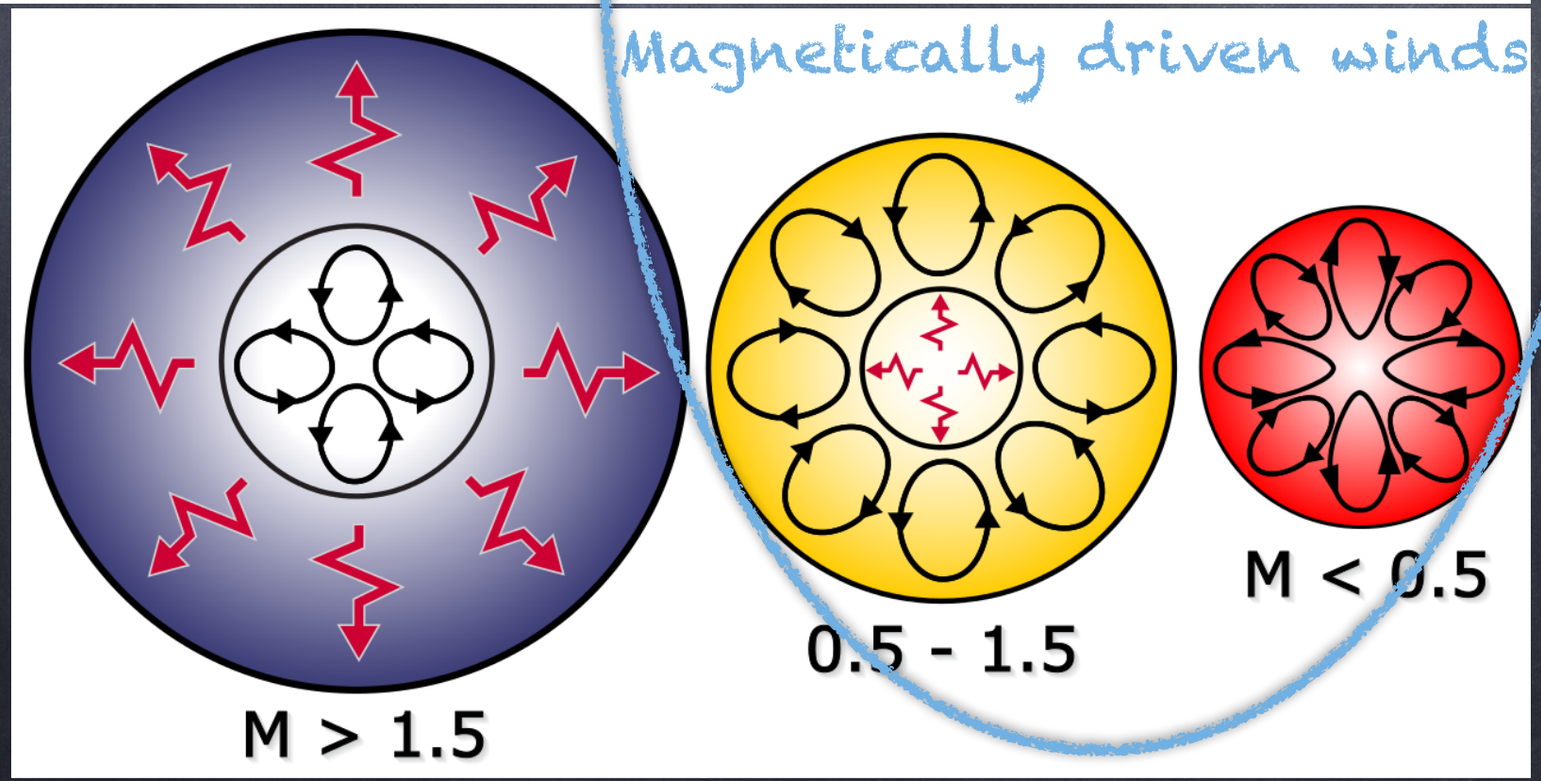
Stellar Astrophysics:

1. Statistical information on many stars
2. Data on different spectral types
3. Data on stellar evolution of each type
4. Recent exoplanetary system discoveries
5. Limited information of specific parameters, e.g. stellar winds and interplanetary environments
6. Unconstrained models

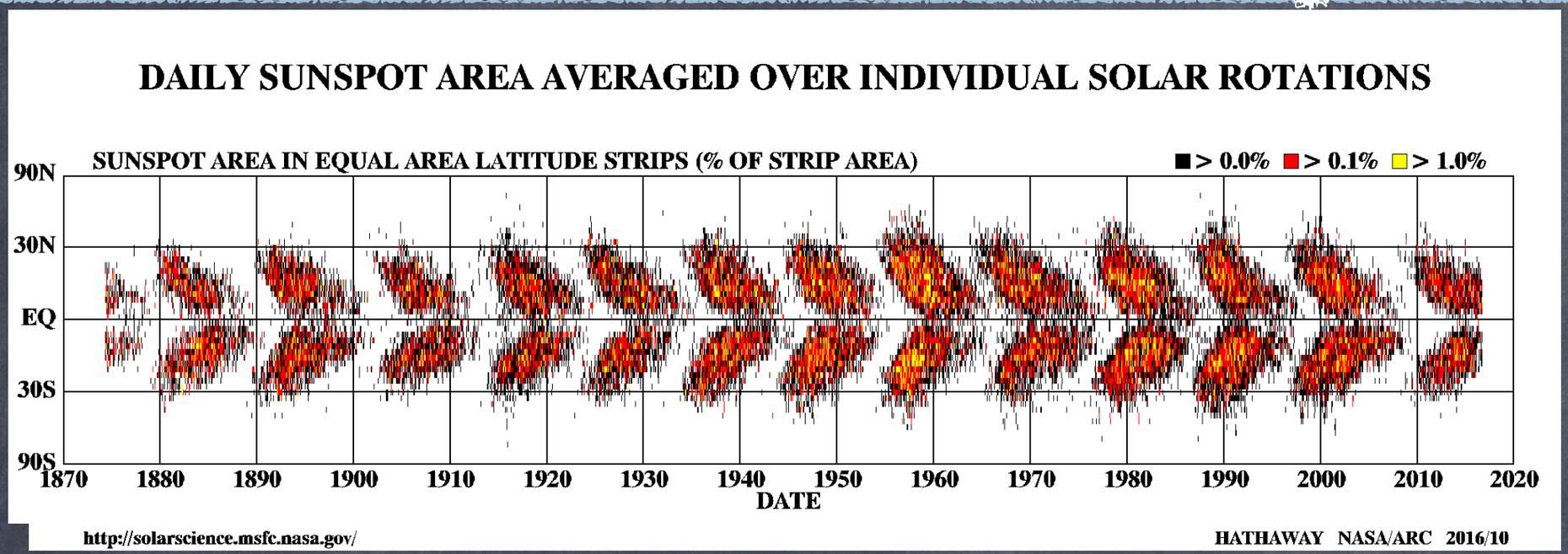
Solar and Stellar Activity

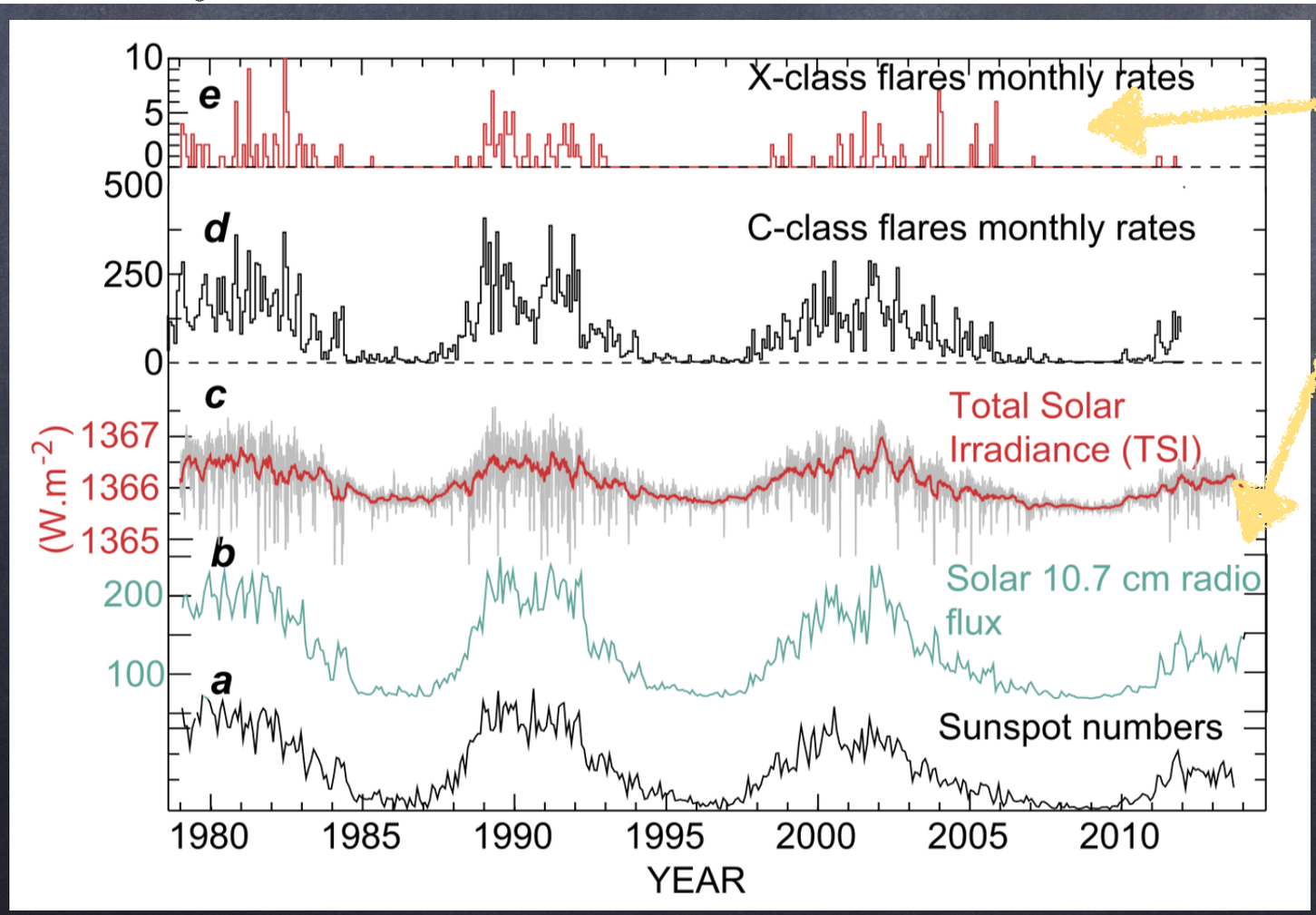
Stellar Dynamos





Solar Activity





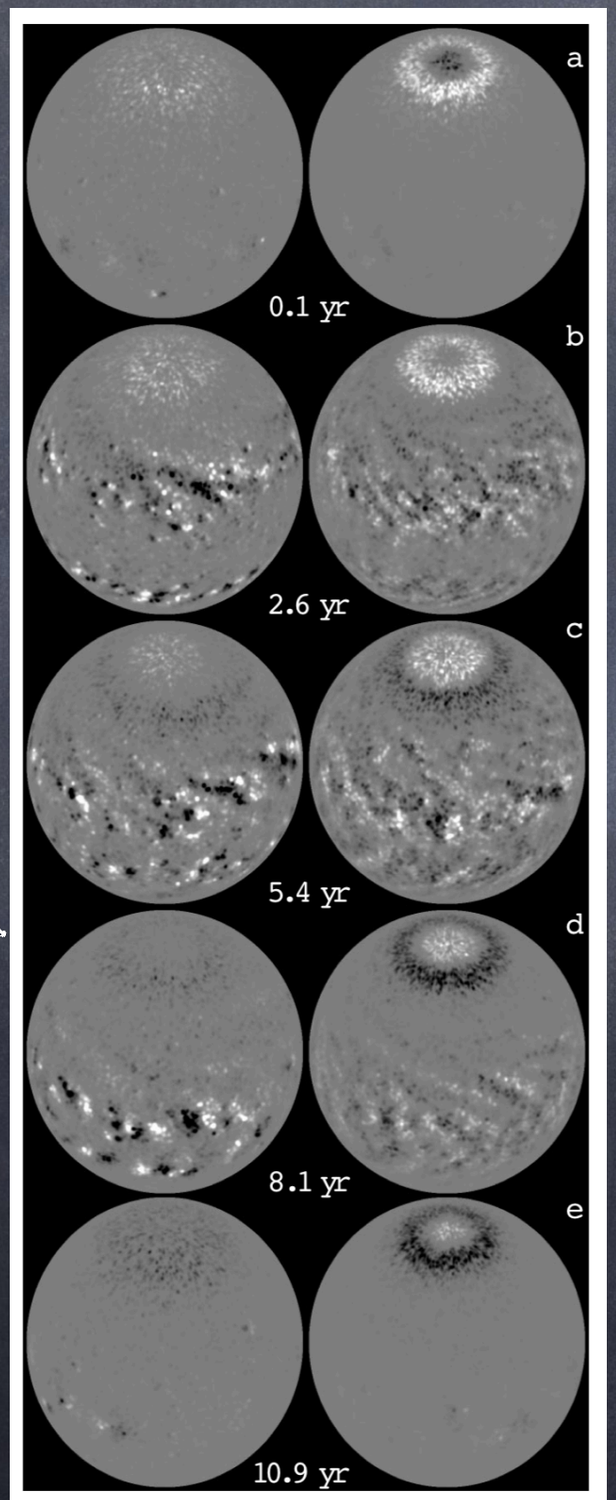
Activity Indicators

Balogh et al, 2014, SSR

Stellar Magnetic Fields

Sun x30

Schrijver & Title, 2001



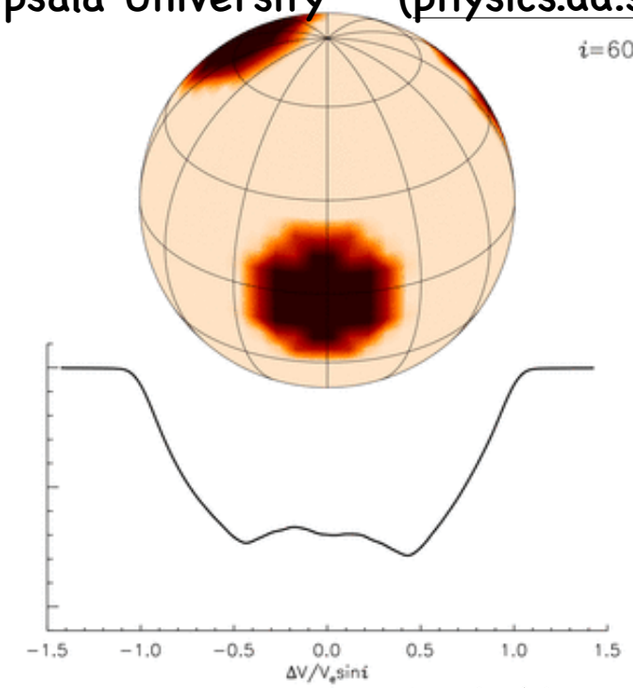
flux transport models

Scaling solar magnetic field

Observations: (ZDI)

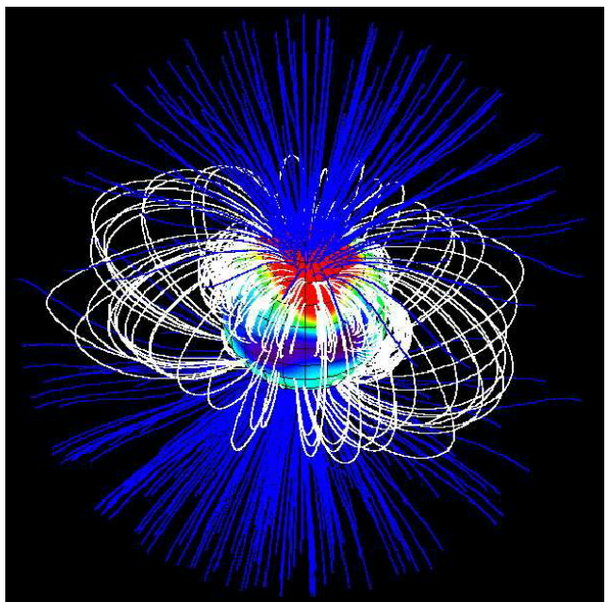
Zeeman-Doppler Imaging

Upsala University (physics.uu.se)



Doppler Imaging + Zeeman Broadening + Polarization

Kochukhov et al.



Donati et al., 2008

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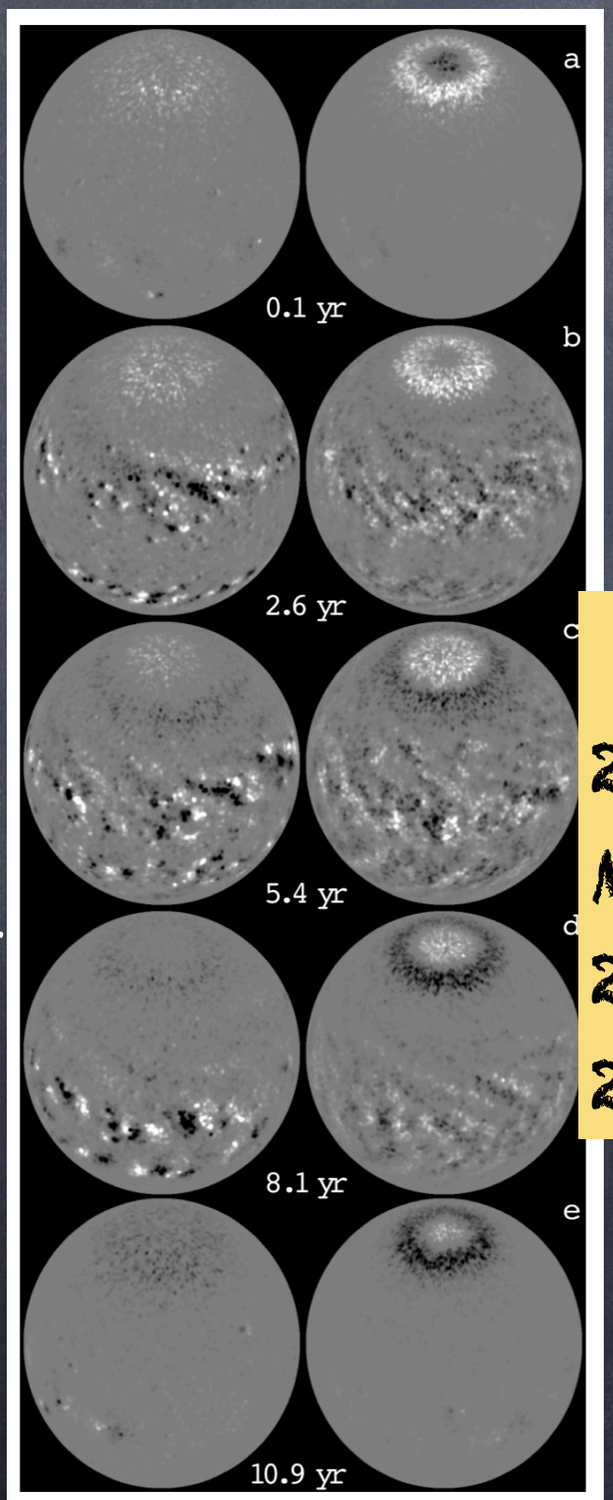

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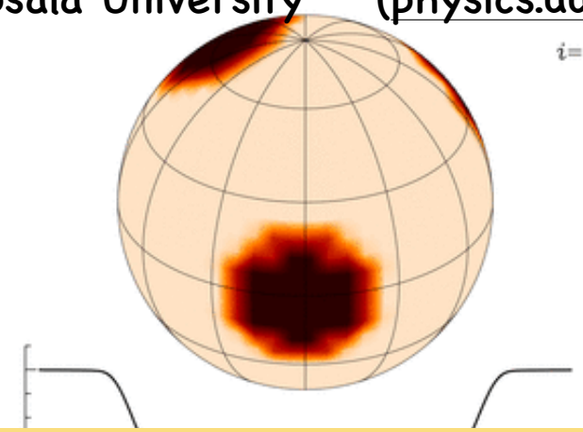
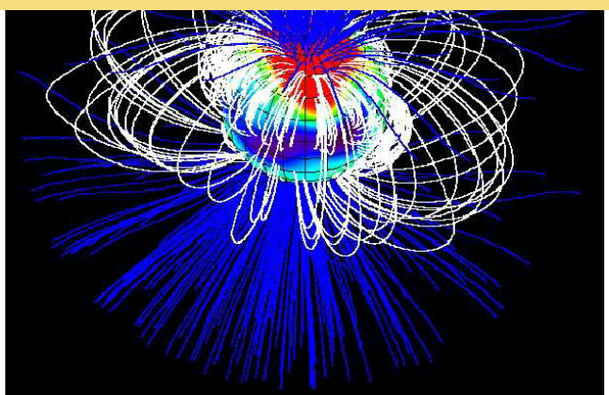


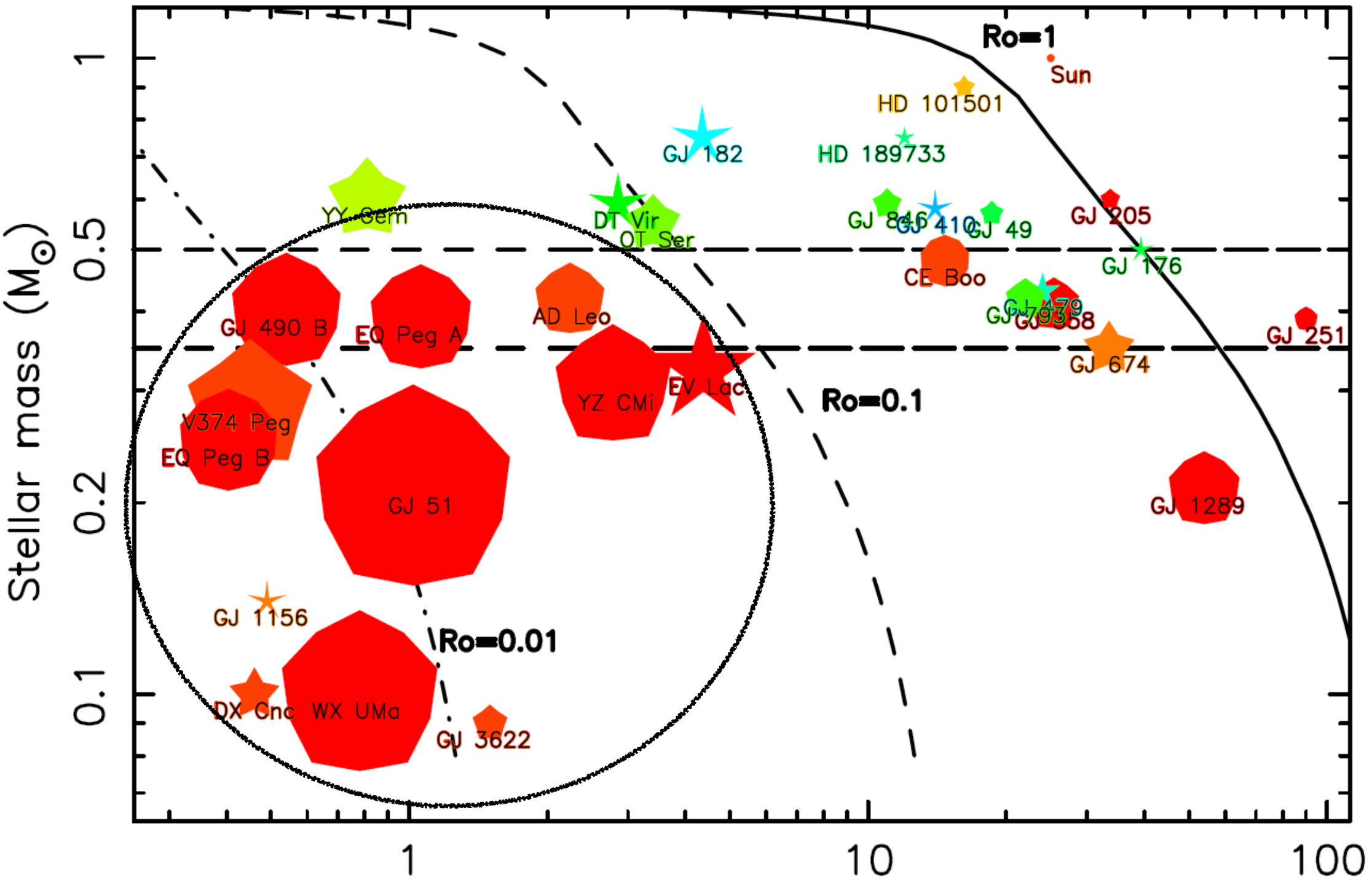
Doppler Imaging + Zeeman Broadening

(e. g. Donati 2003; Hussain et al. 2007, Donati & Landstreet 2009; Marsden et al. 2011; Waite et al. 2015; Alvarado-Gomez et al. 2015).



Donati et al., 2008

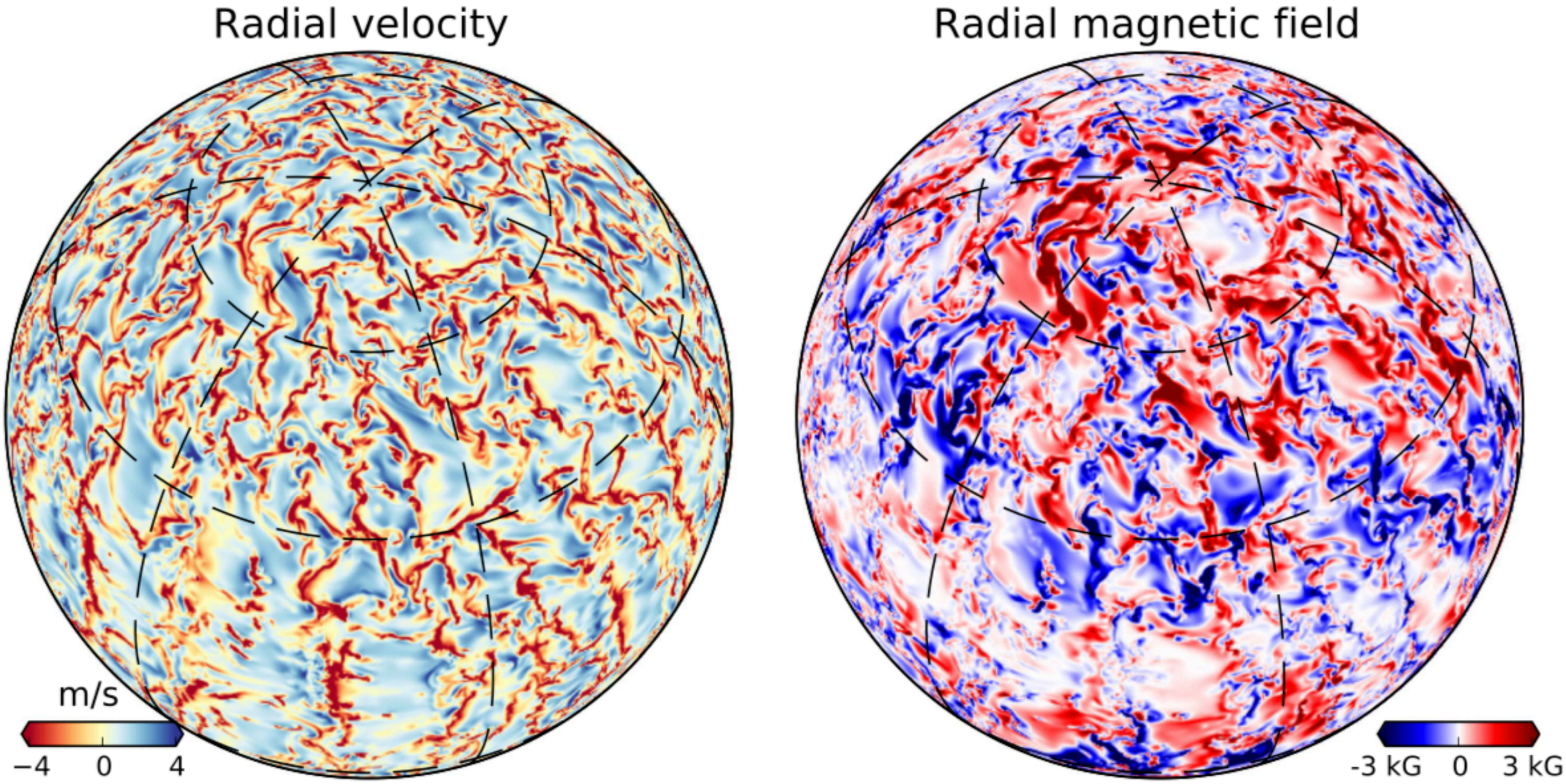
Confusogram



Moutou et al., 2017, MNRAS

Dynamo simulations

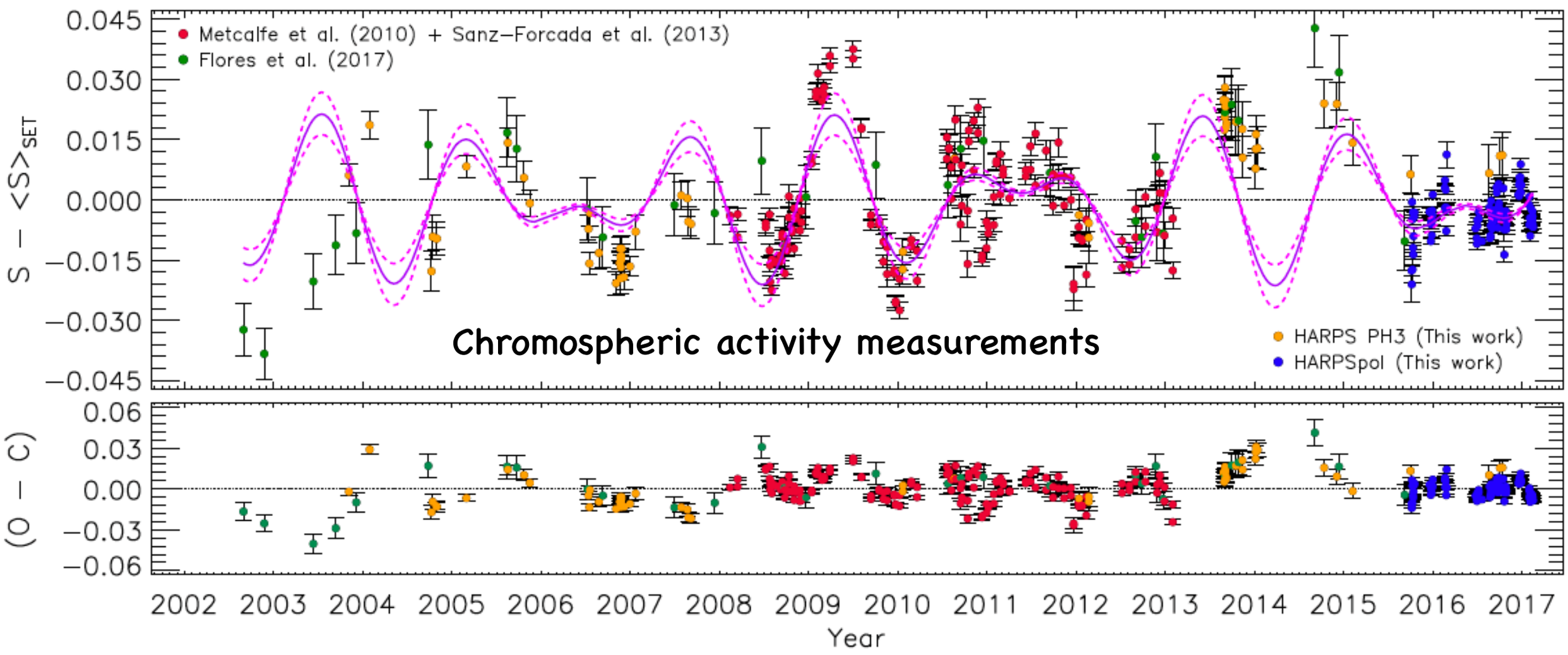
Proxima Centauri (M dwarf)



Yadav et al, 2016, ApJL

Stellar Activity

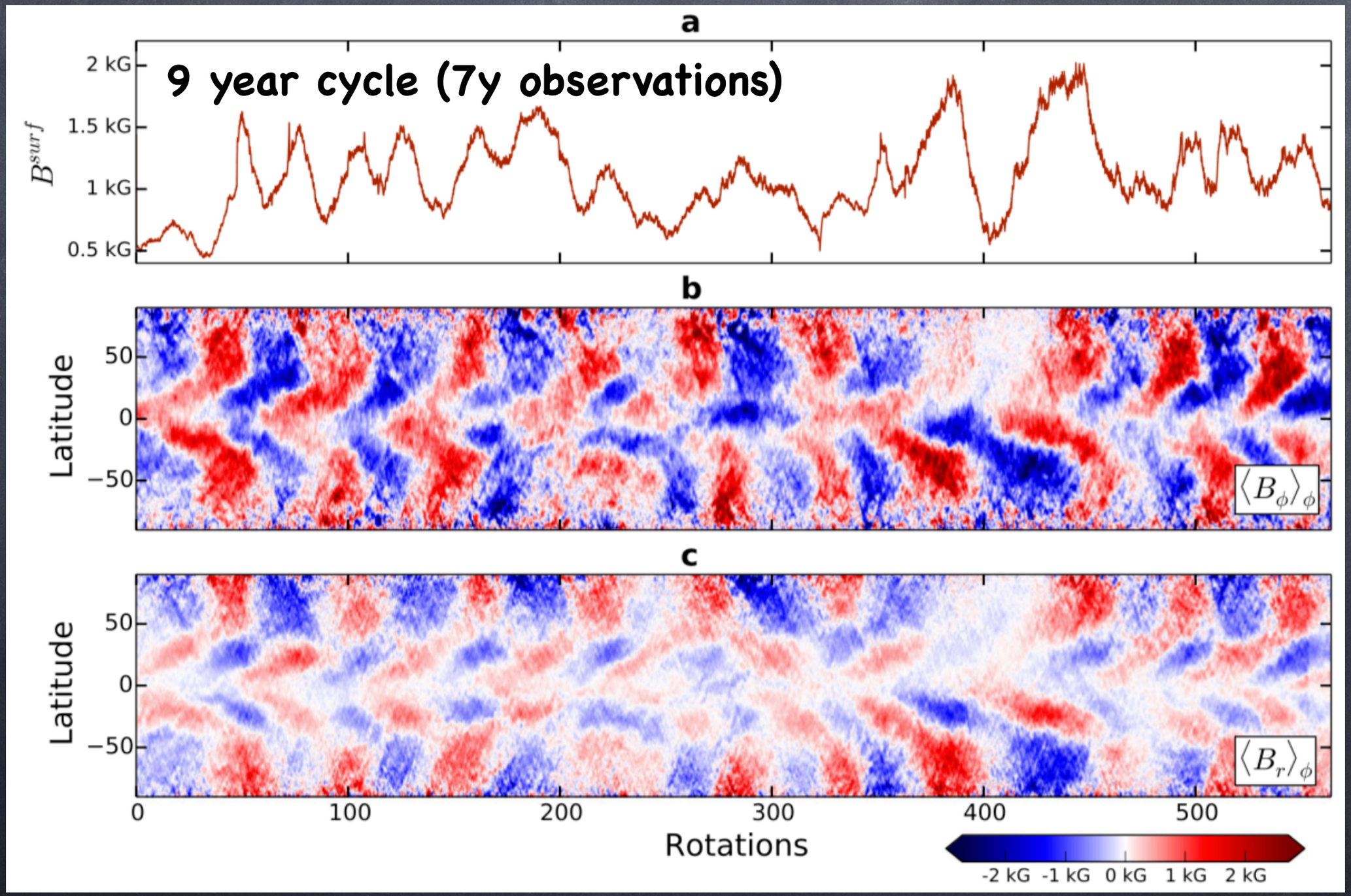
1-Horologium: $P_{cyc} \approx 1.6$ yr



Alvarado-Gomez, et al, MNRAS, 2018

Dynamo models & Activity cycles

Proxima Centauri, P ≈ 80 d



Yadav et al, 2016, ApJL

Heliosphere and Astrospheres

Solar Wind

Solar Wind

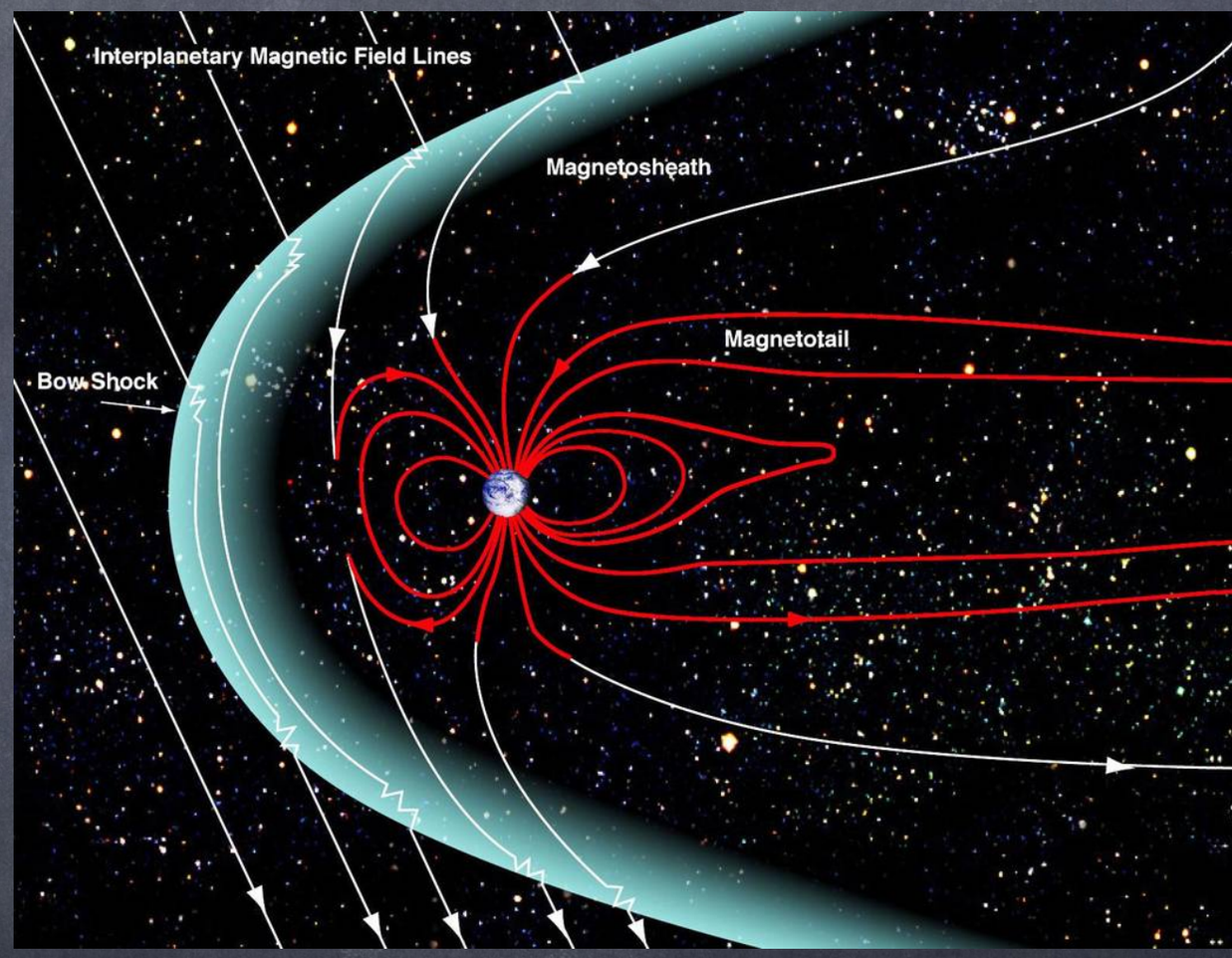
Alfvén surface

V<VA

V>VA

Mercury

Venus

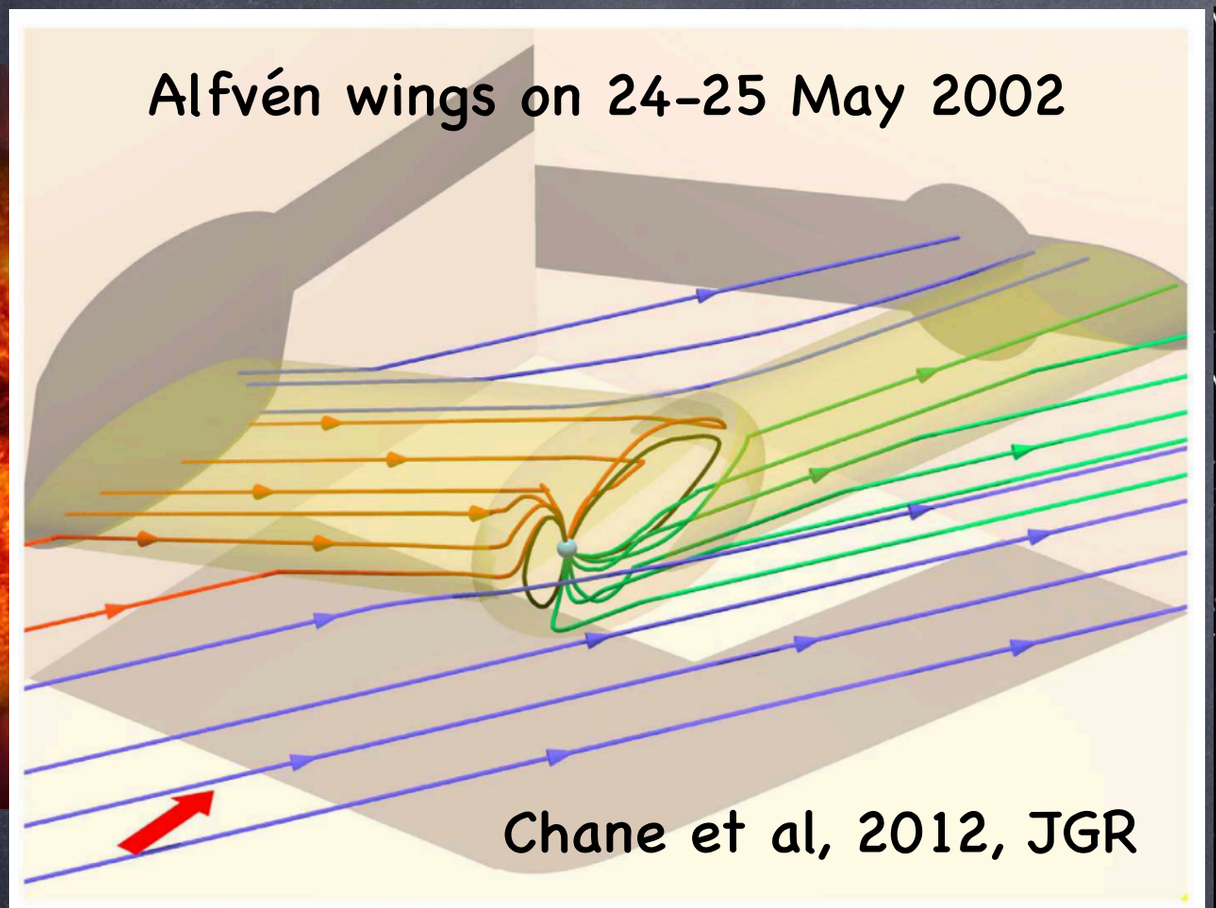


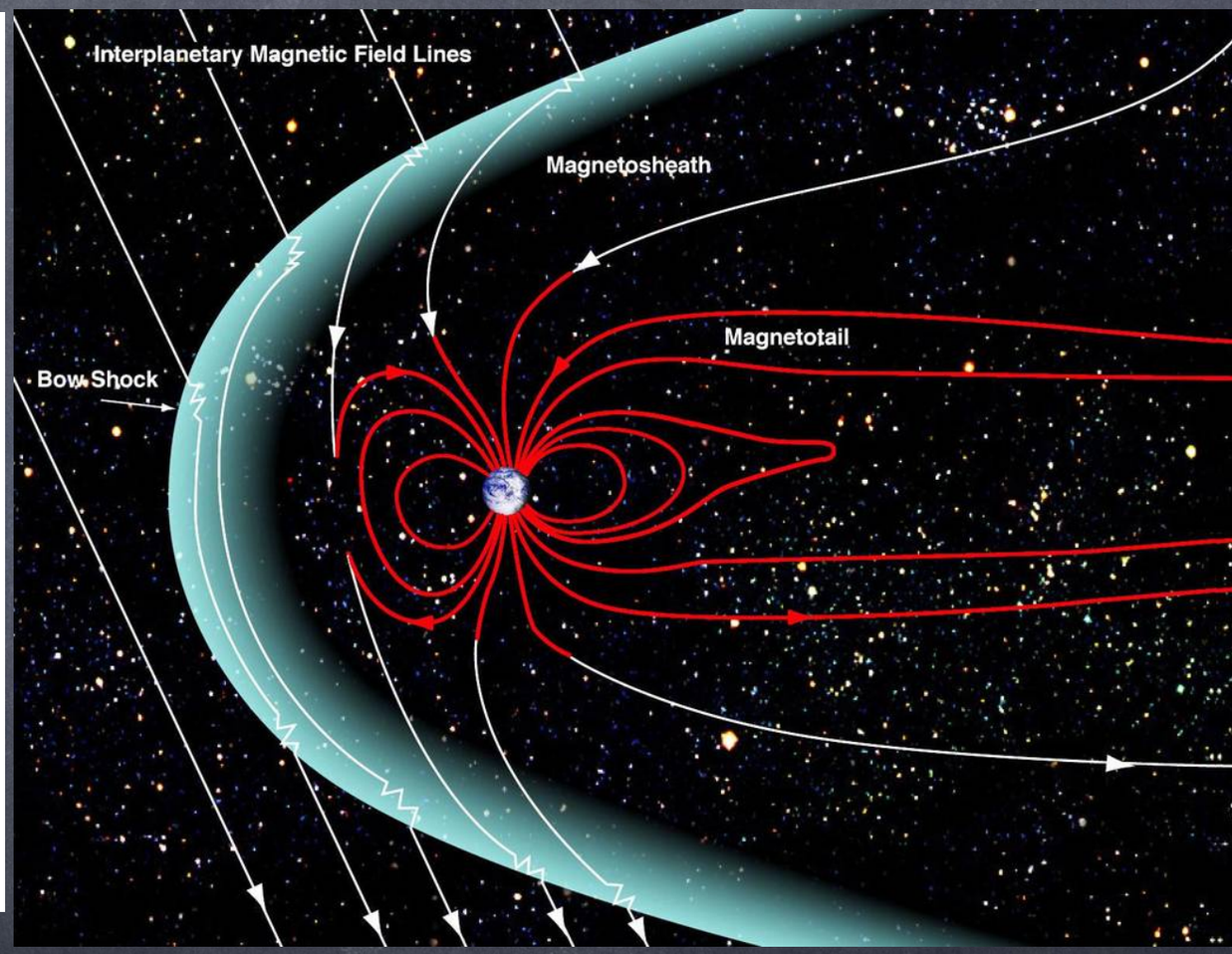
≈0.1AU

1AU

Solar Wind

Solar Wind

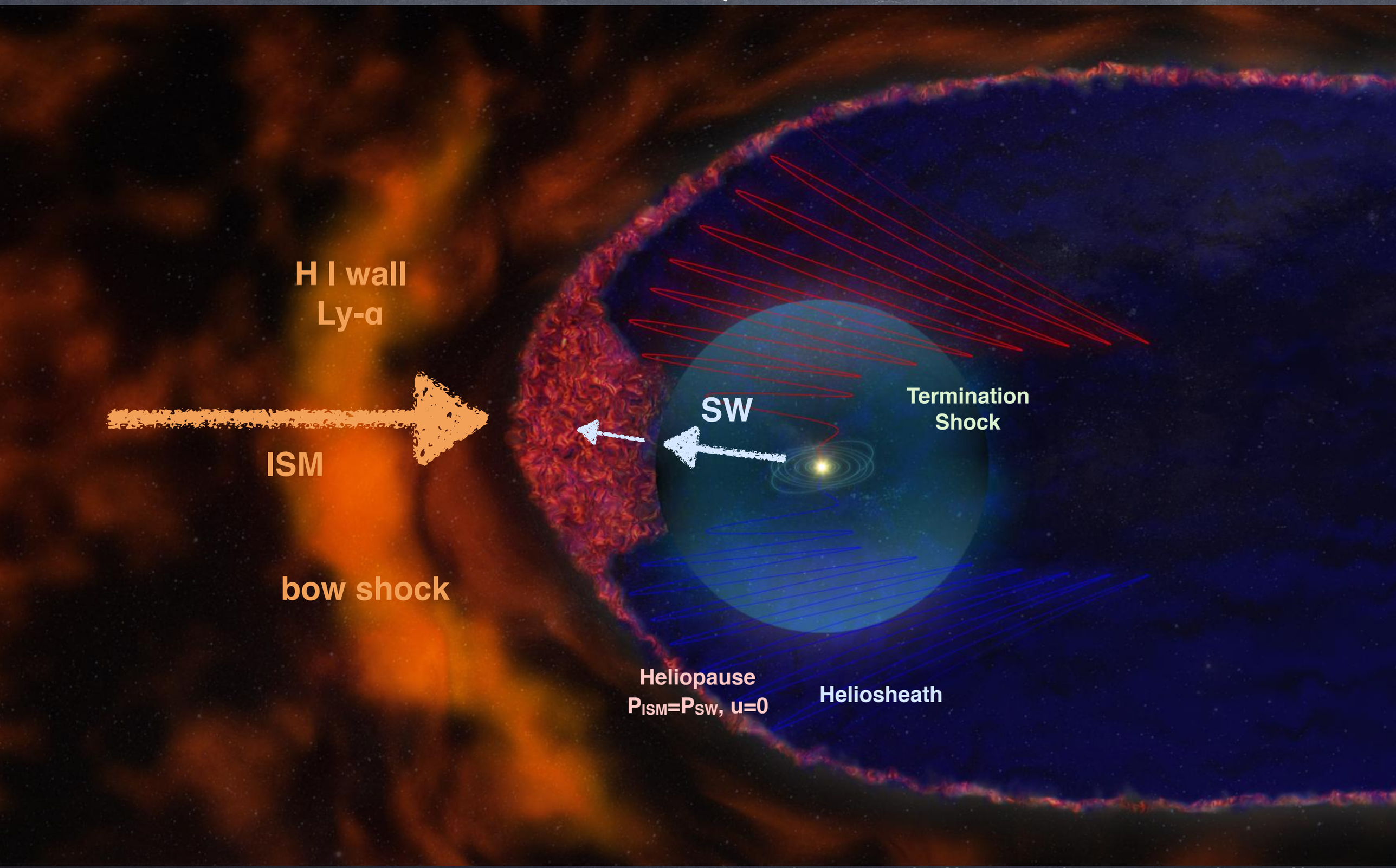




≈0.1AU

1AU

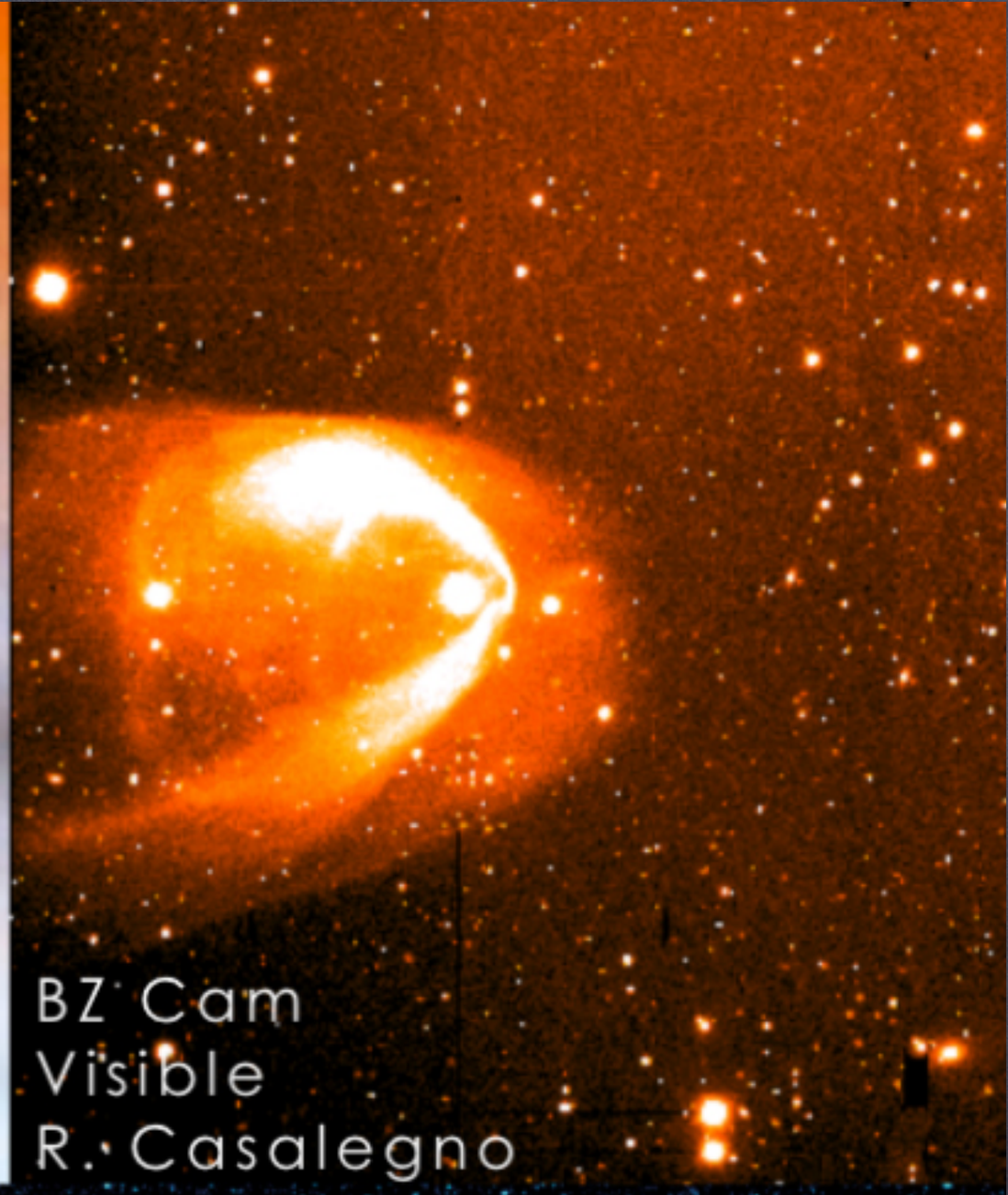
Heliosphere



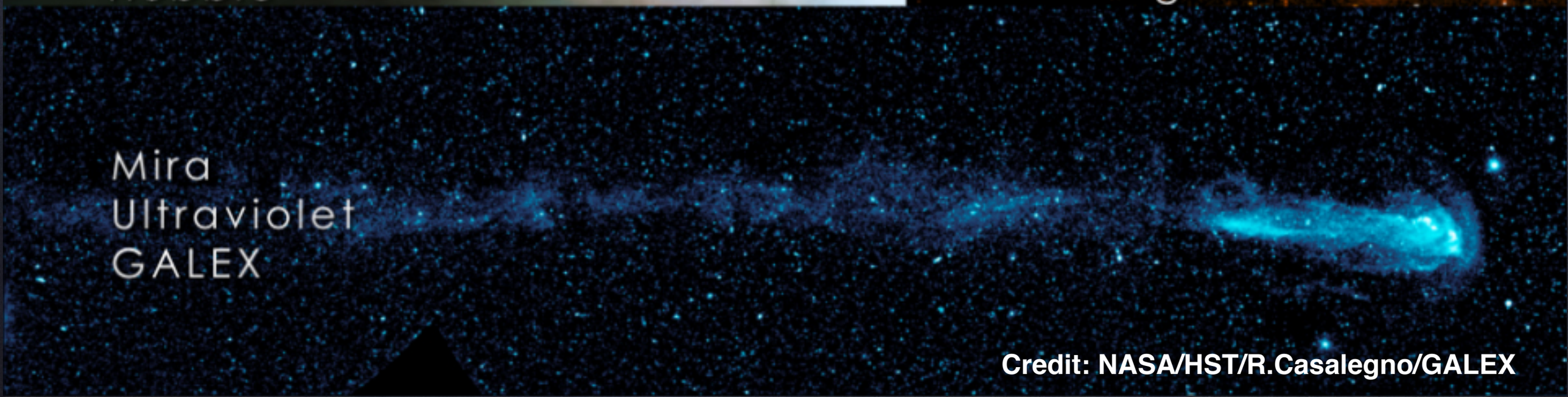
Credit: NASA/Goddard Space Flight Center/CI Lab+

Astrospheres

LL Orionis
Visible
Hubble



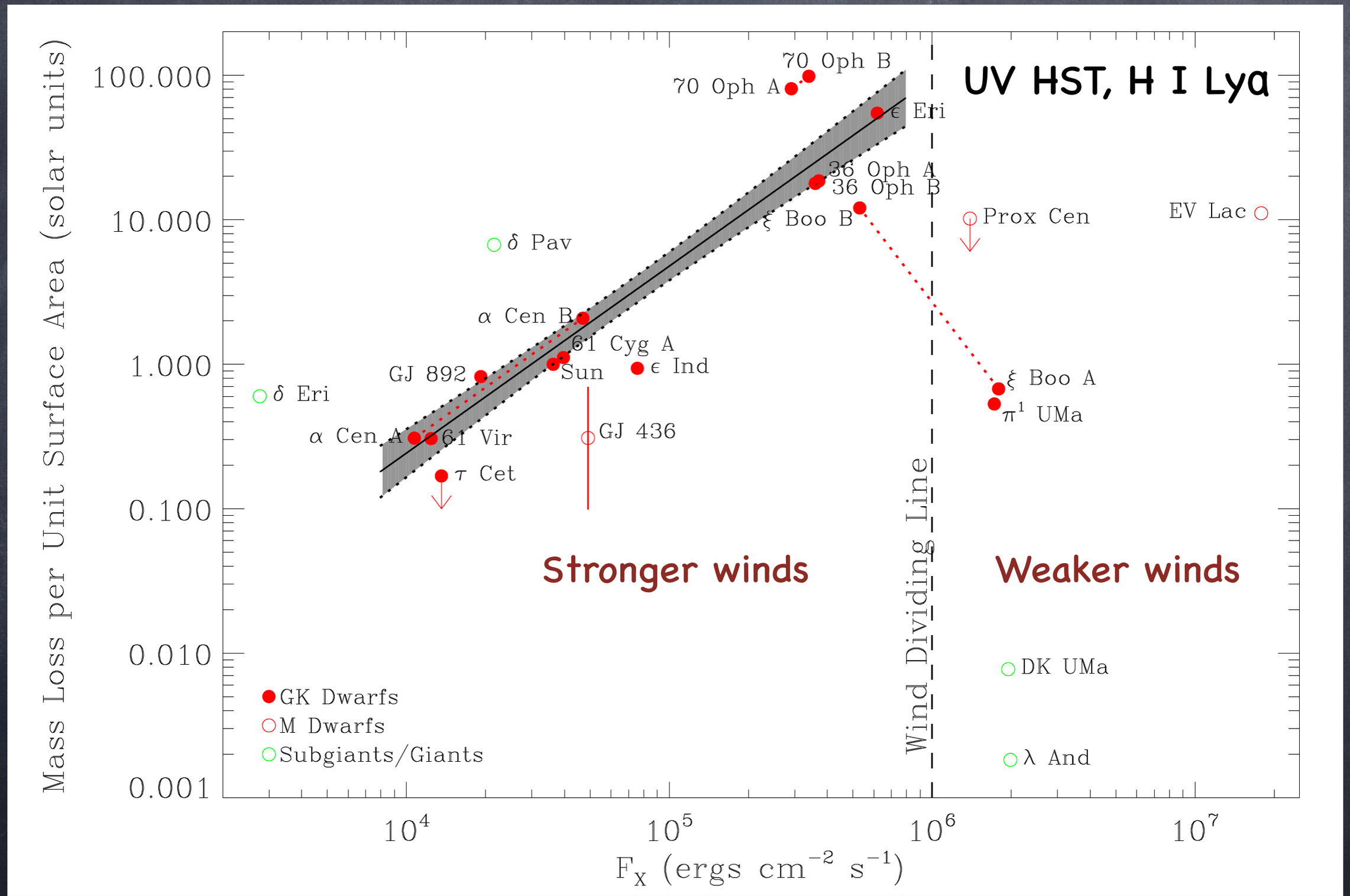
BZ Cam
Visible
R. Casalegno



Mira
Ultraviolet
GALEX

Credit: NASA/HST/R.Casalegno/GALEX

Mass loss-activity diagram

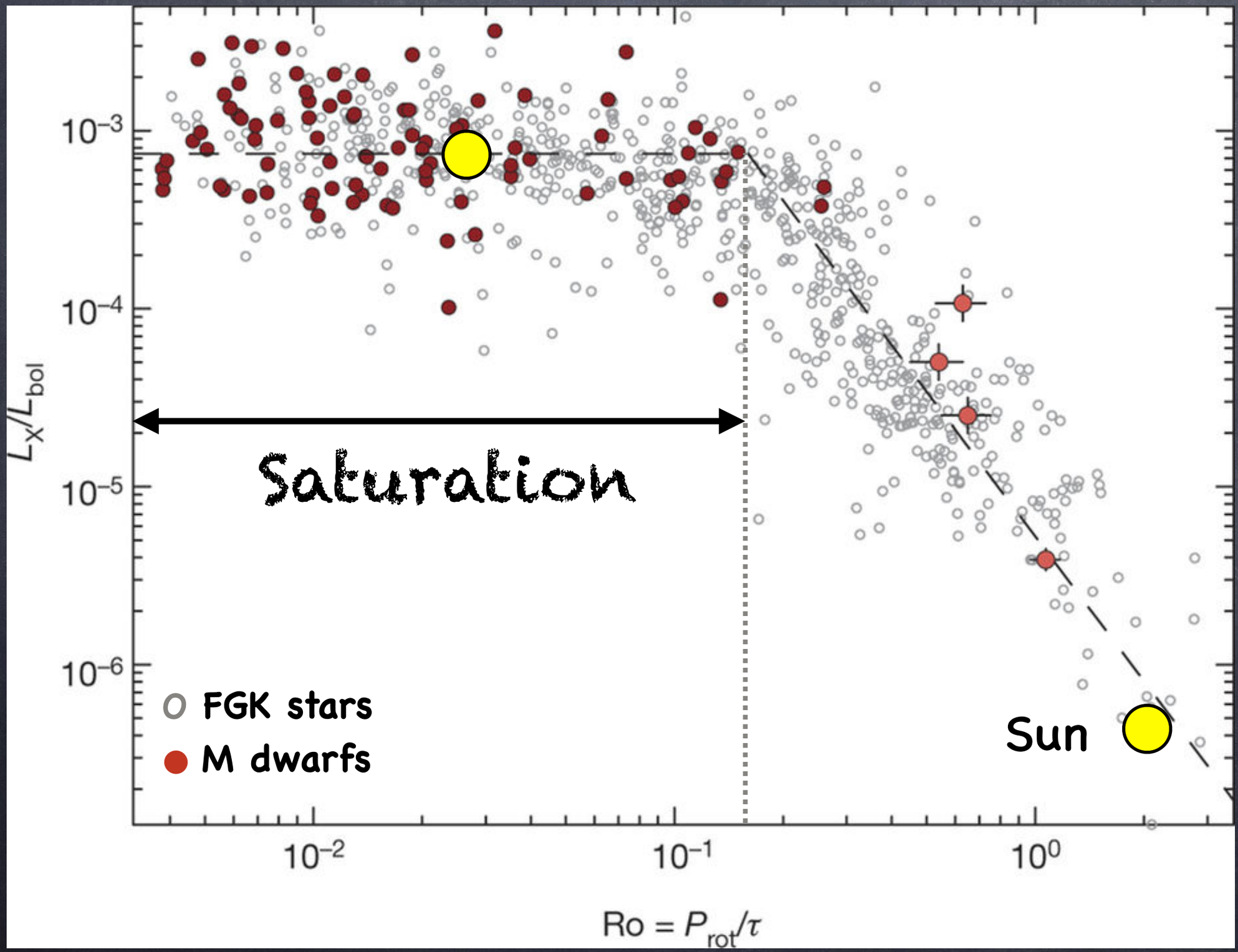


Wood, J. of Phys. Conf. Ser., 2018

Astrospheric dynamics depend on:

- Age
- Rotation
- Stellar activity
- Magnetic field

X-ray activity .vs. rotation: Proxy for stellar dynamo



Wright et al. 2011, 2018

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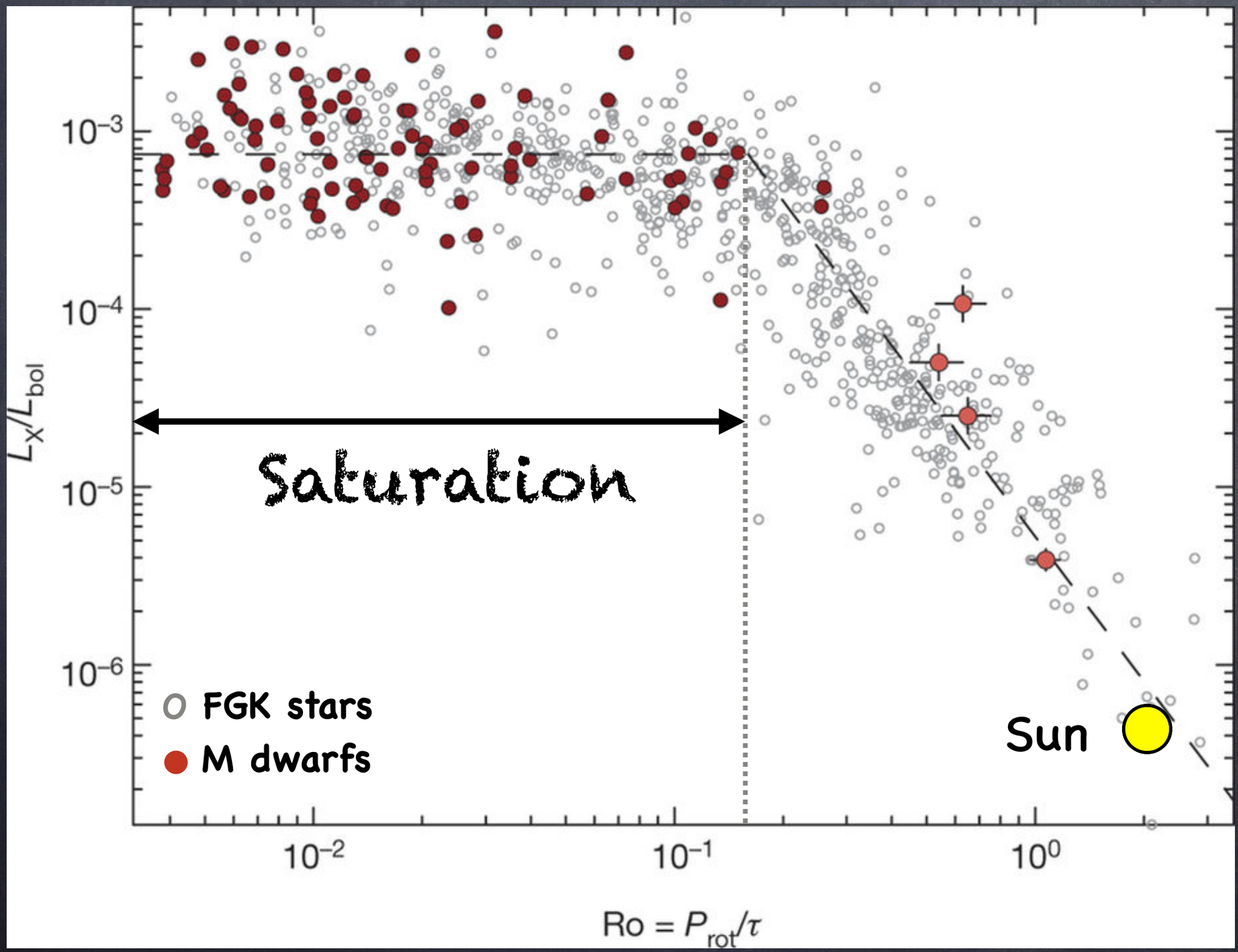

Wright et al. 2011, 2018

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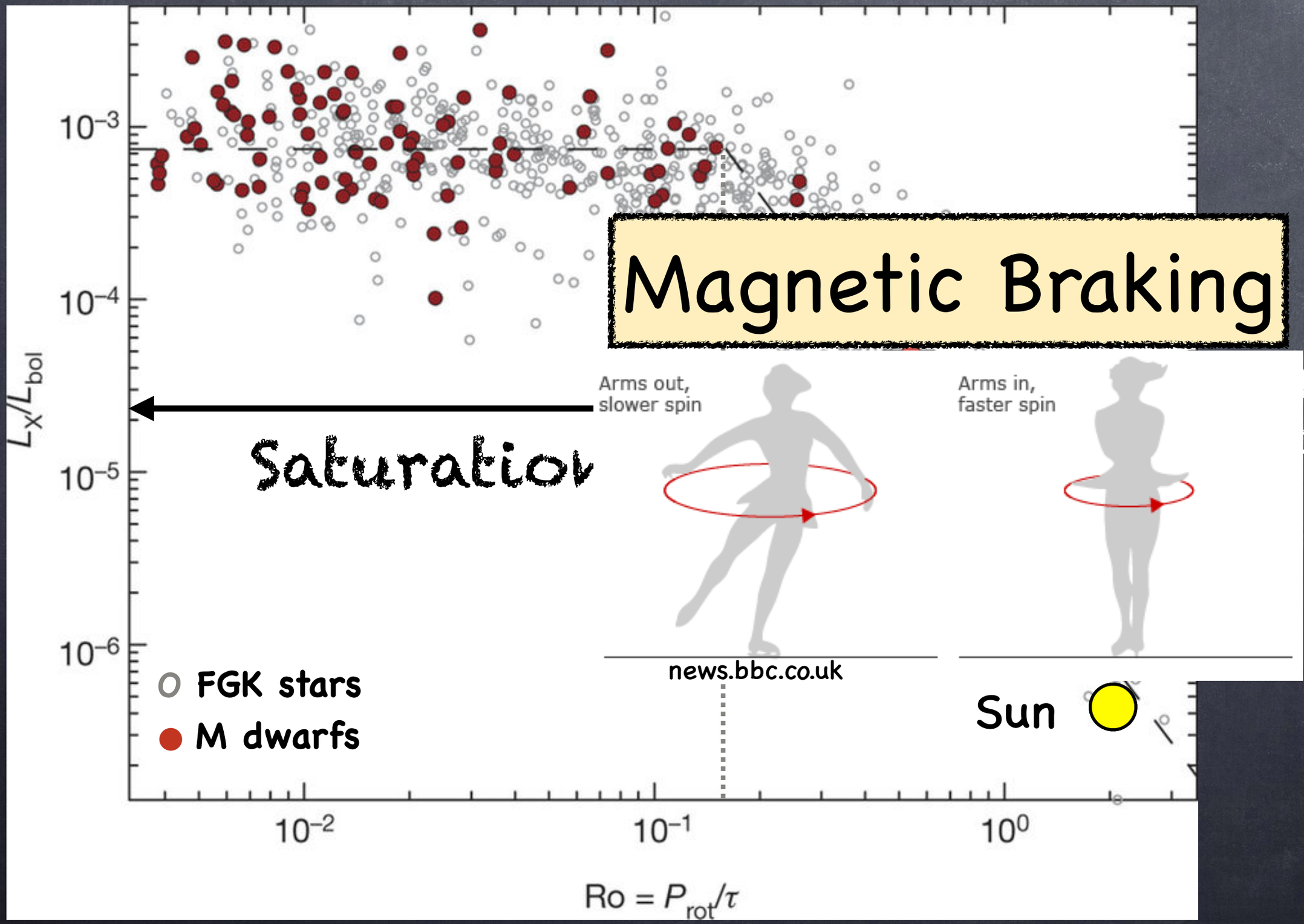
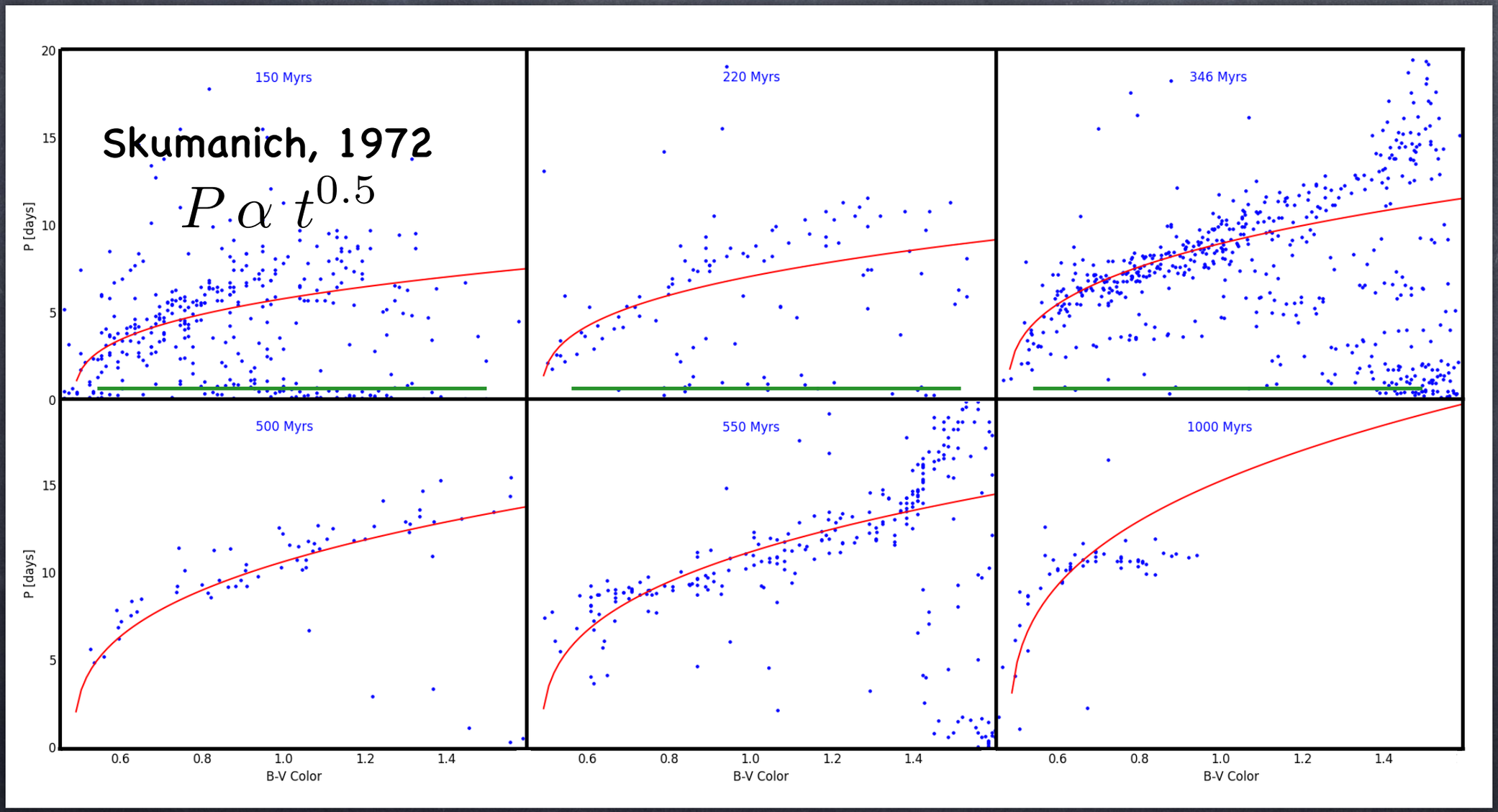


ht et al.
1, 2018

Stellar spindown

Open Cluster Observations



F G K M

Stellar spindown

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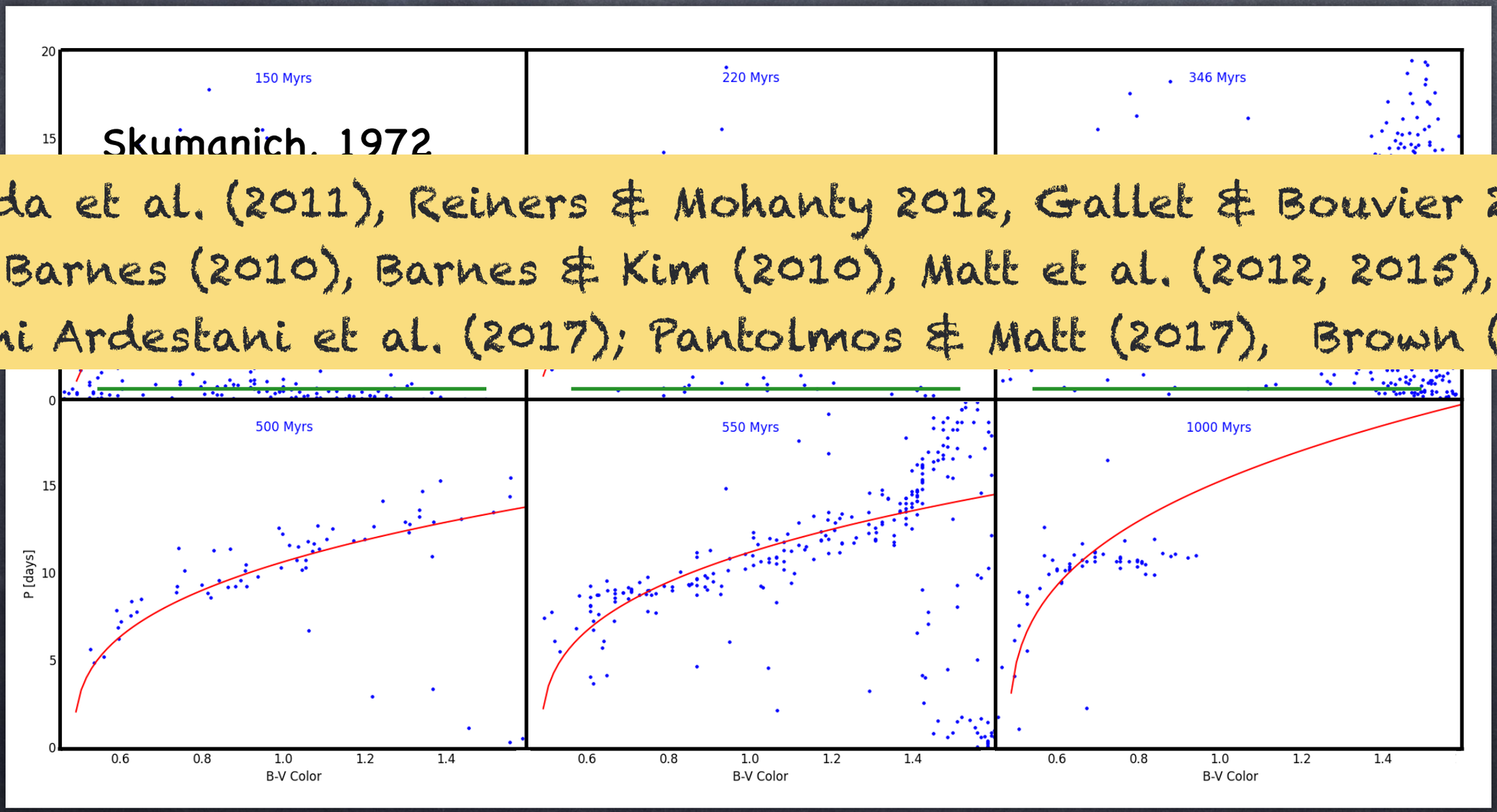

Spada et al. (2011), Reiners & Mohanty 2012, Gallet & Bouvier 2013, Barnes (2010), Barnes & Kim (2010), Matt et al. (2012, 2015), Sadeghi Ardestani et al. (2017); Pantolmos & Matt (2017), Brown (2014)

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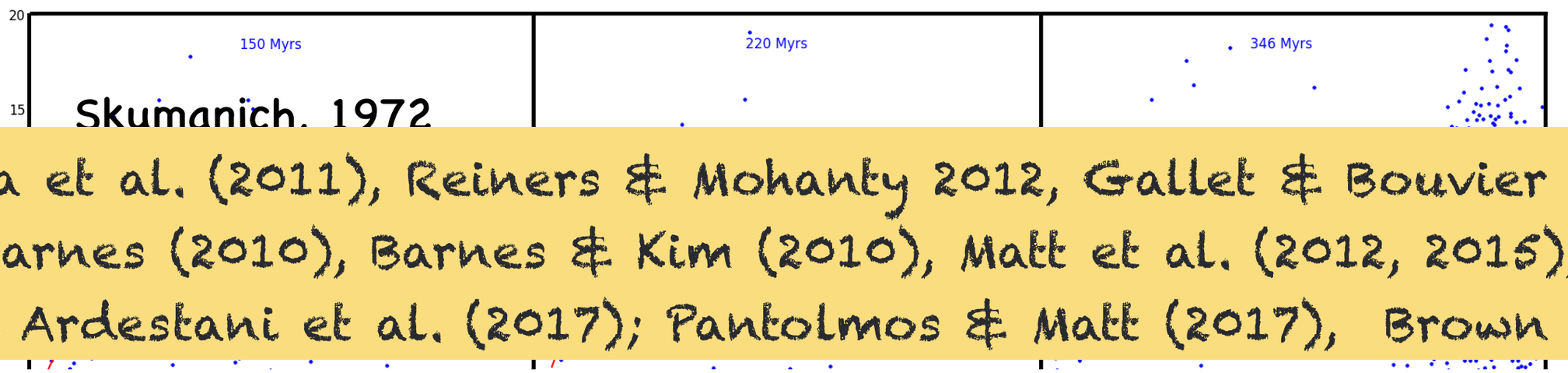

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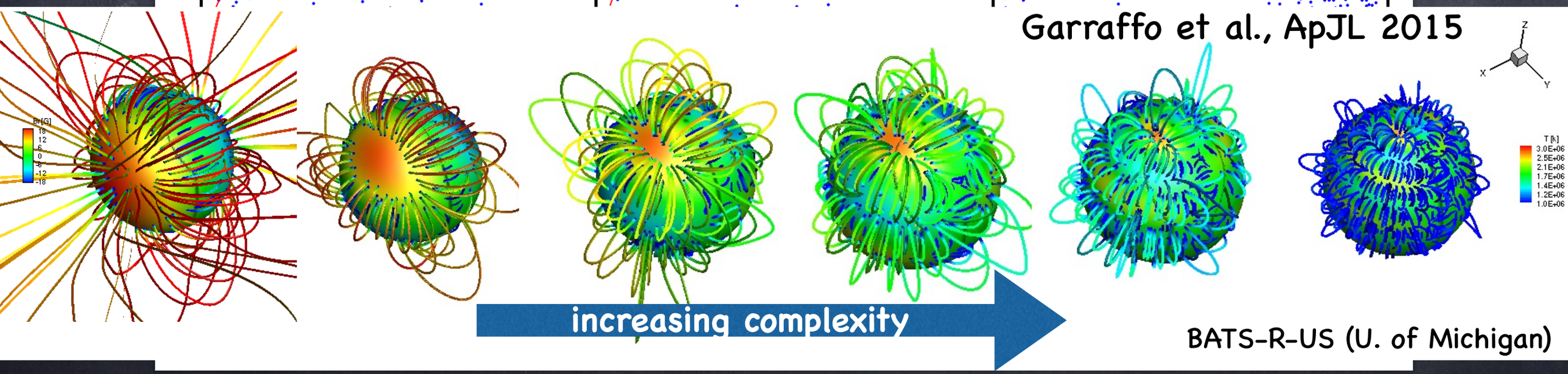
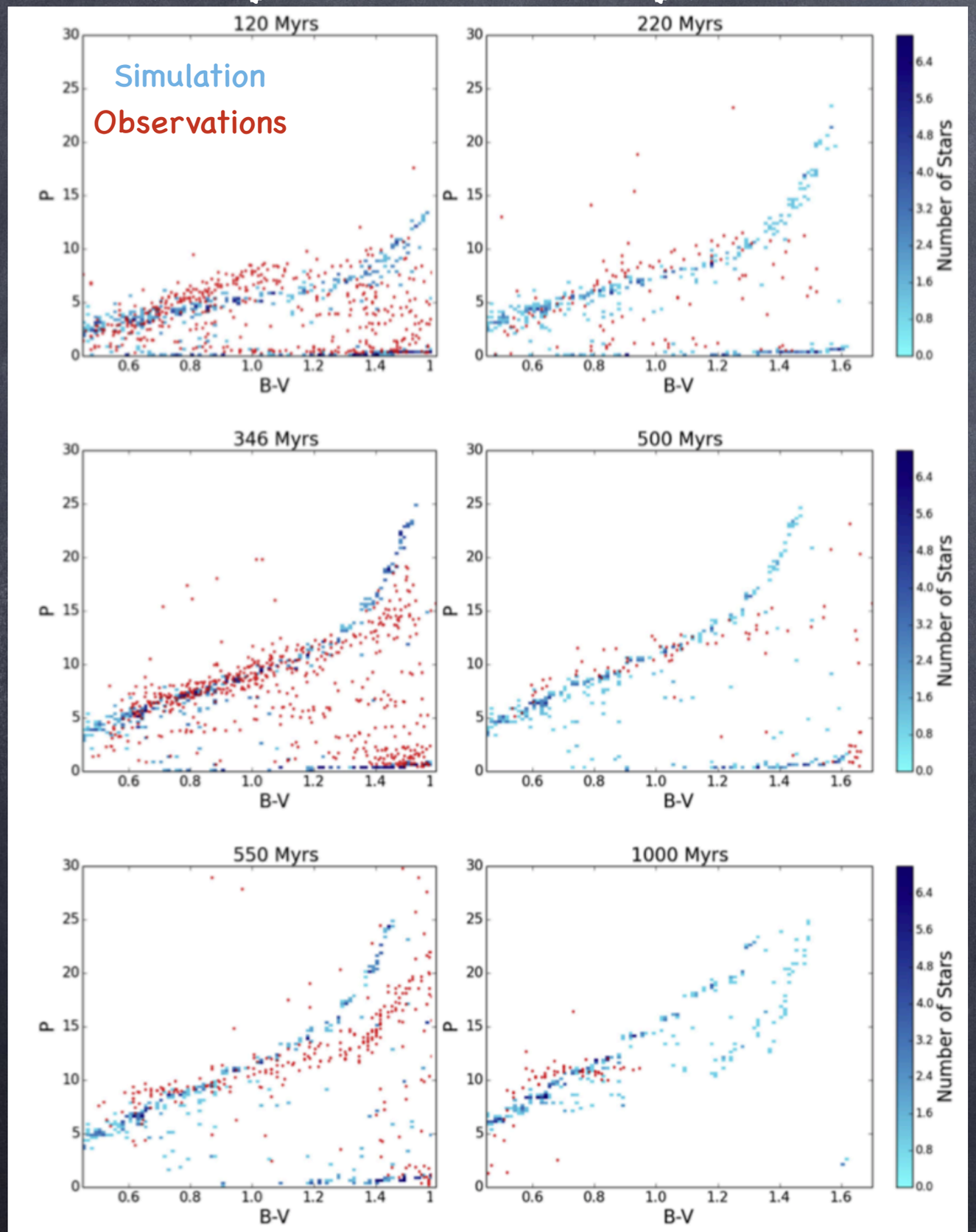
Garraffo et al., ApJL 2015



F G K M

Complete spindown model



Evolving complexity
+ Magnetic braking

Garraffo et al.,
ApJ, 862, 90, 2018

Solar & Stellar Environments

Stellar environments affected by

- Wind
- CMEs
- Flares
- EPs
- High energy radiation

Follow the energy

A.R.

GONG

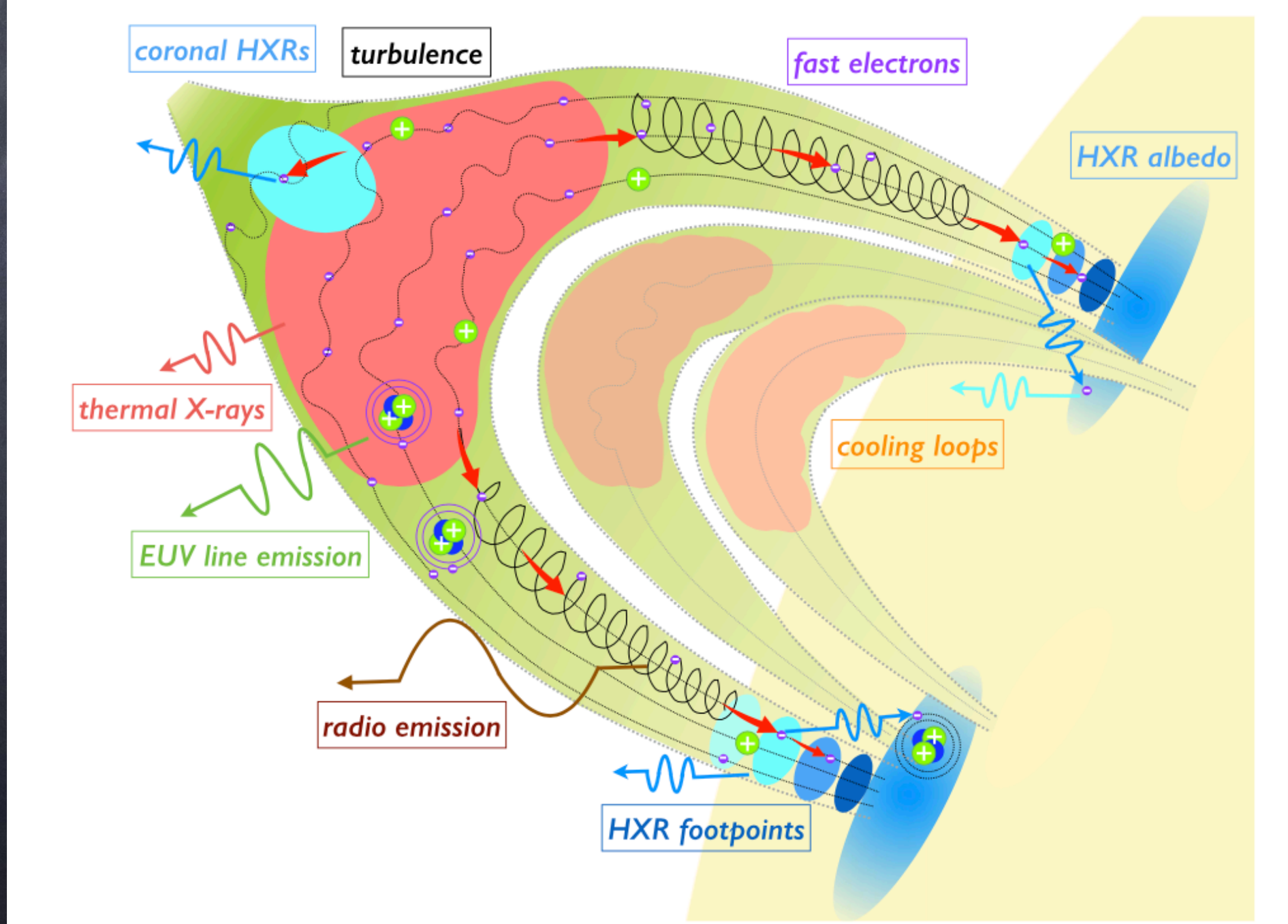
Flares

CMEs

EPs

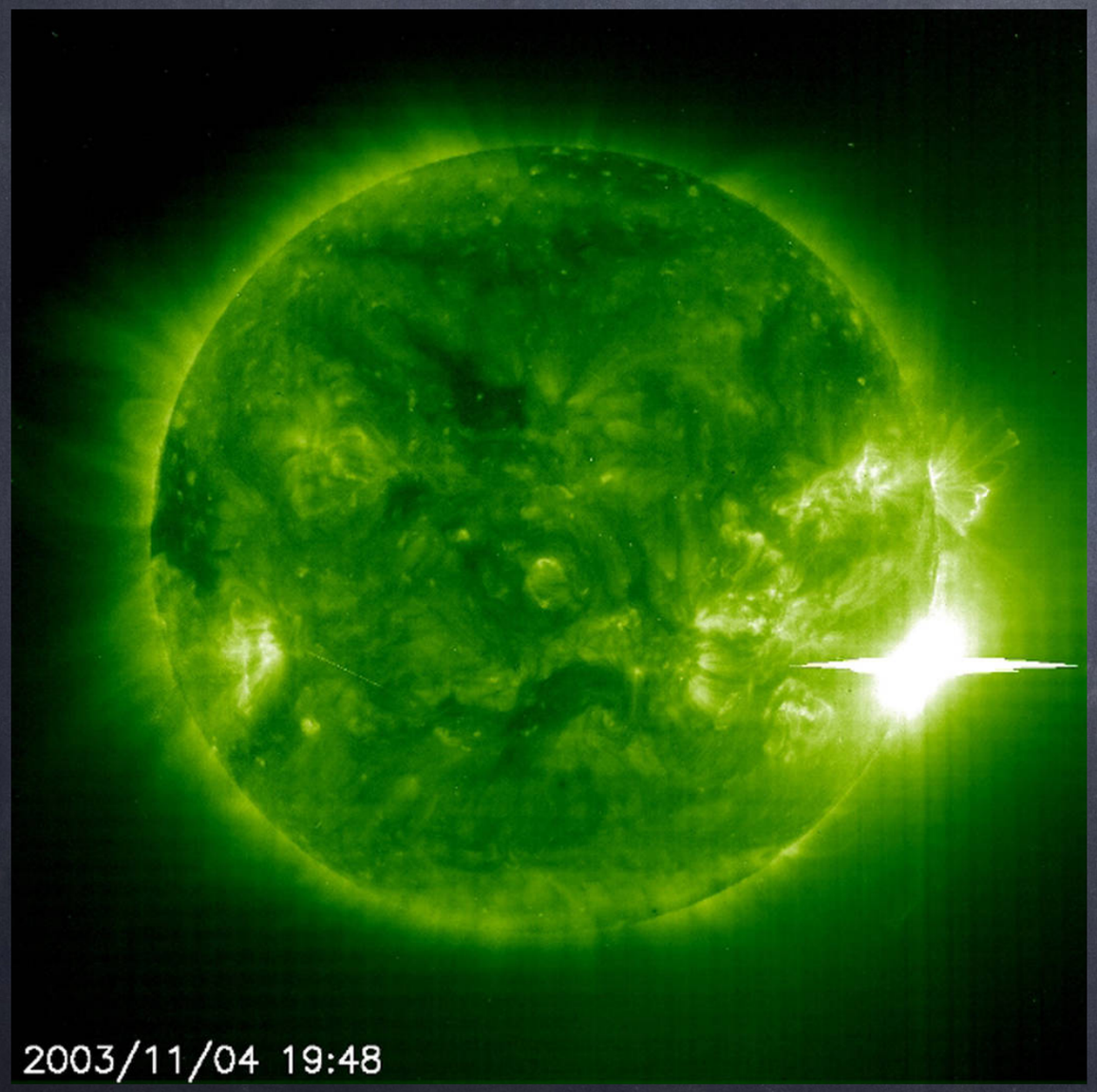
Solar CME-flare scenario

Kontar et al., PRL, 2017

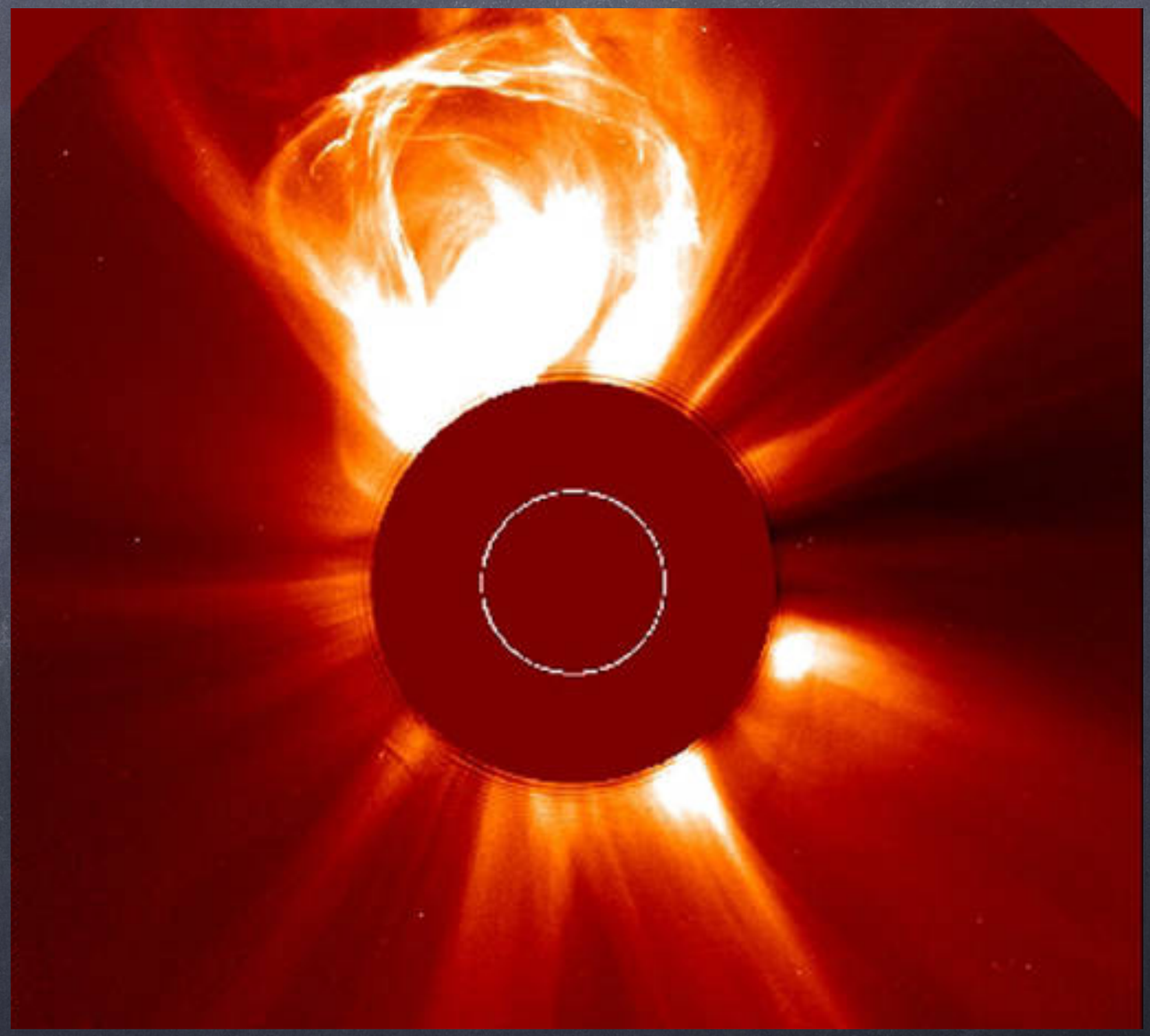


Solar flares & CMEs can be imaged

EIT 195 Å

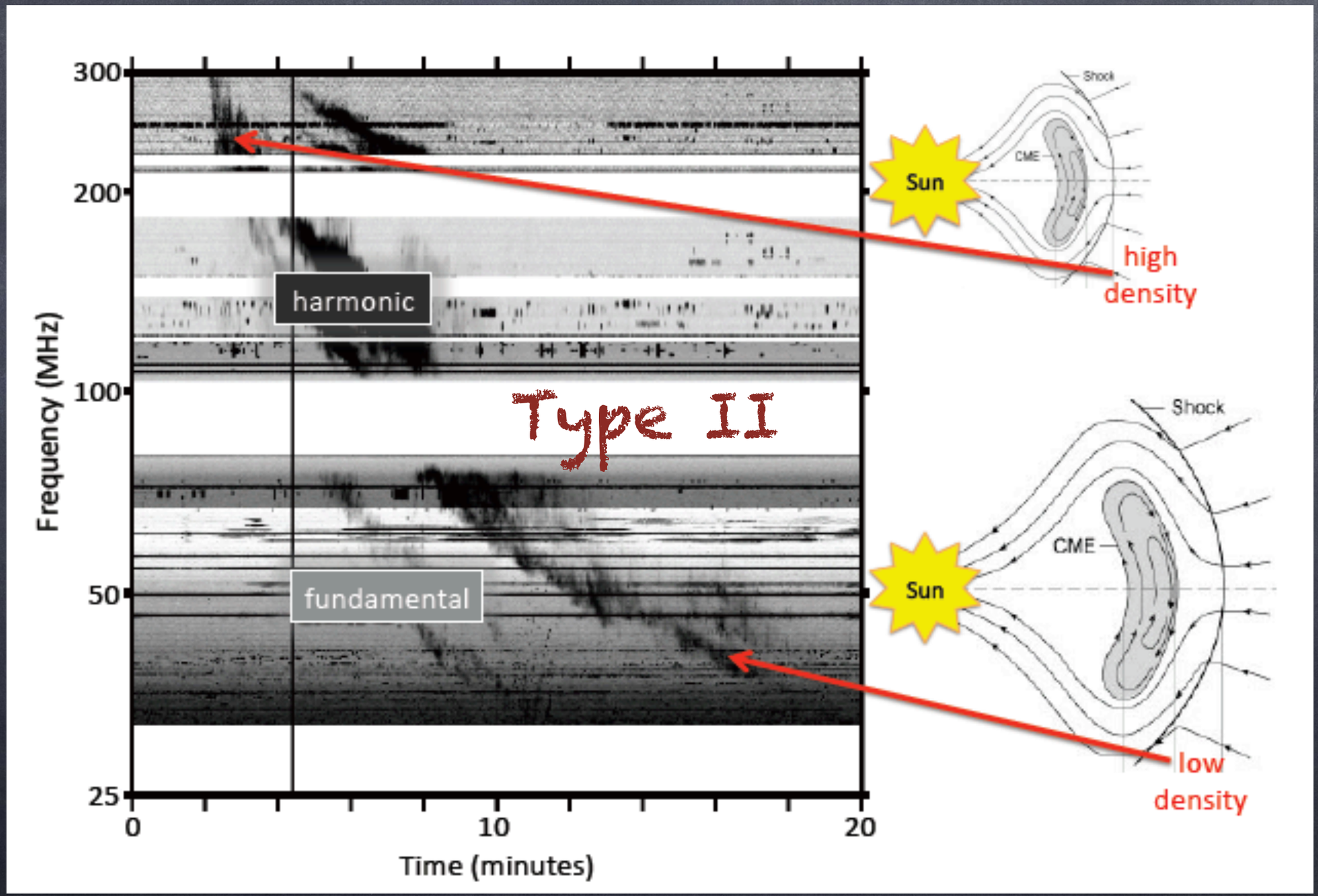


LASCO/C2



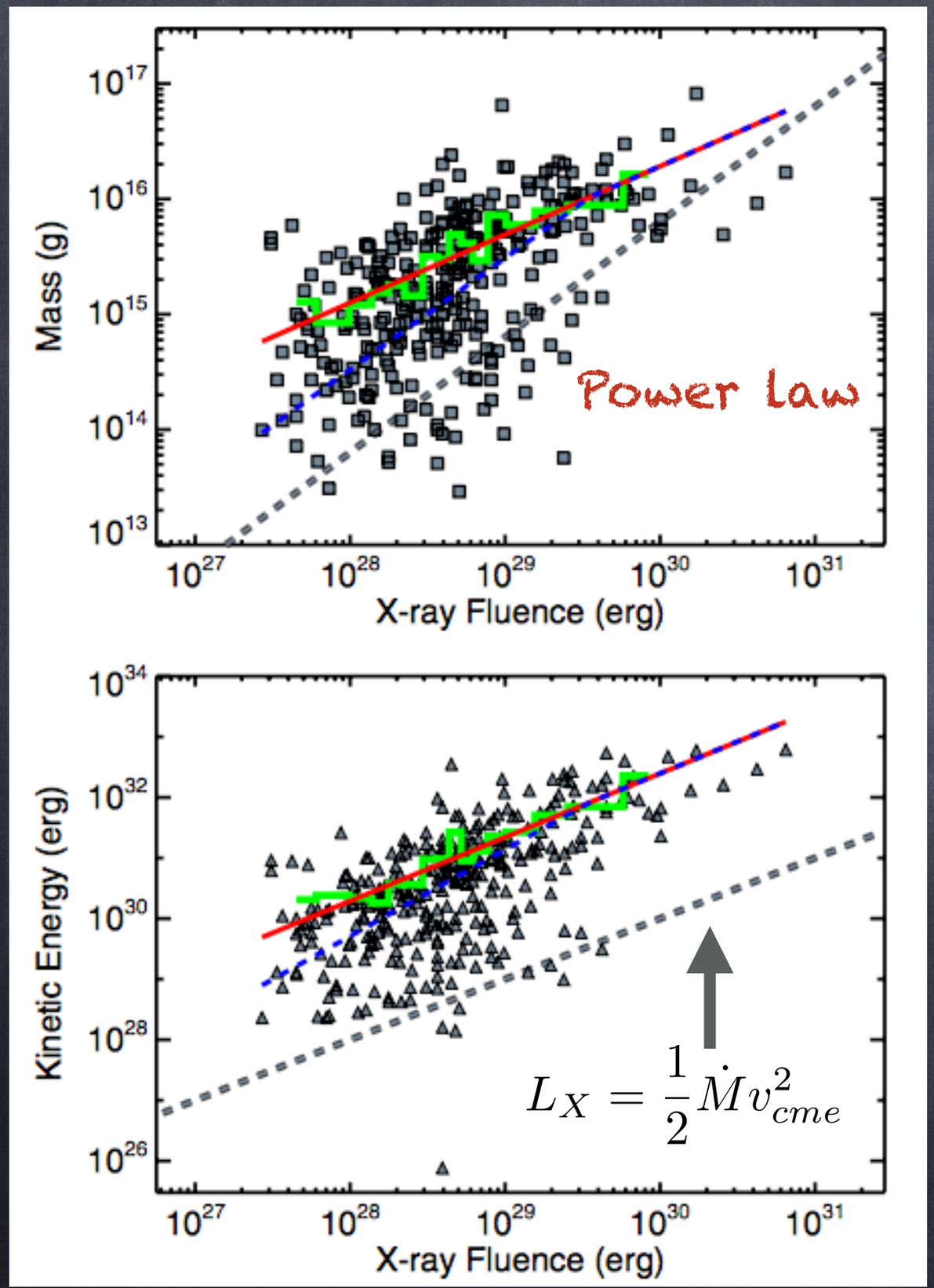
Credit: SOHO ESA & NASA

Radio CME signatures



Kouloumvakos et al., 2014 + Villadsen PhD, 2017

X-ray flares & CMEs



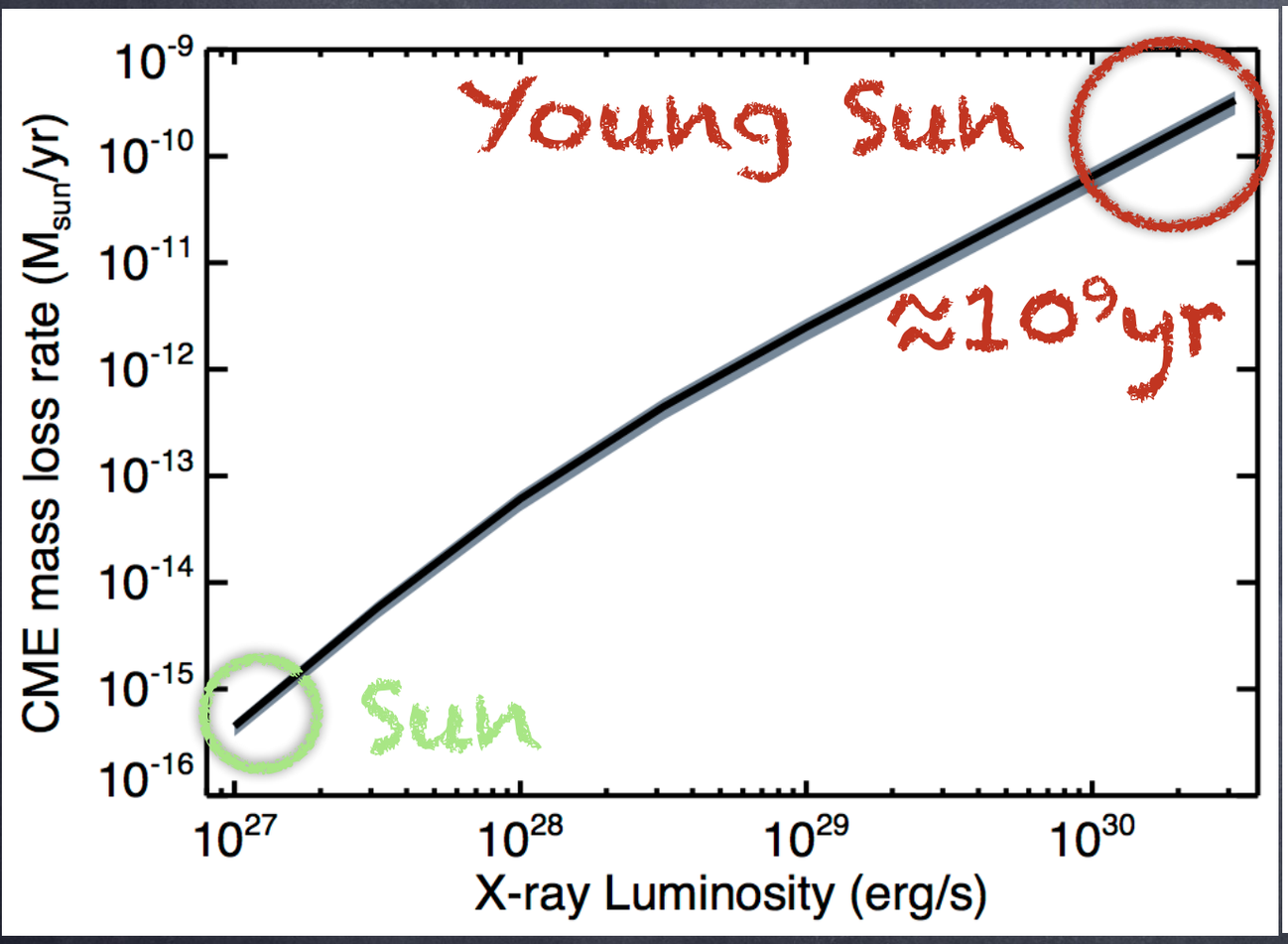
e.g. Yashiro & Gopalswamy (2009), Aarnio et al (2011), Drake et al (2013)

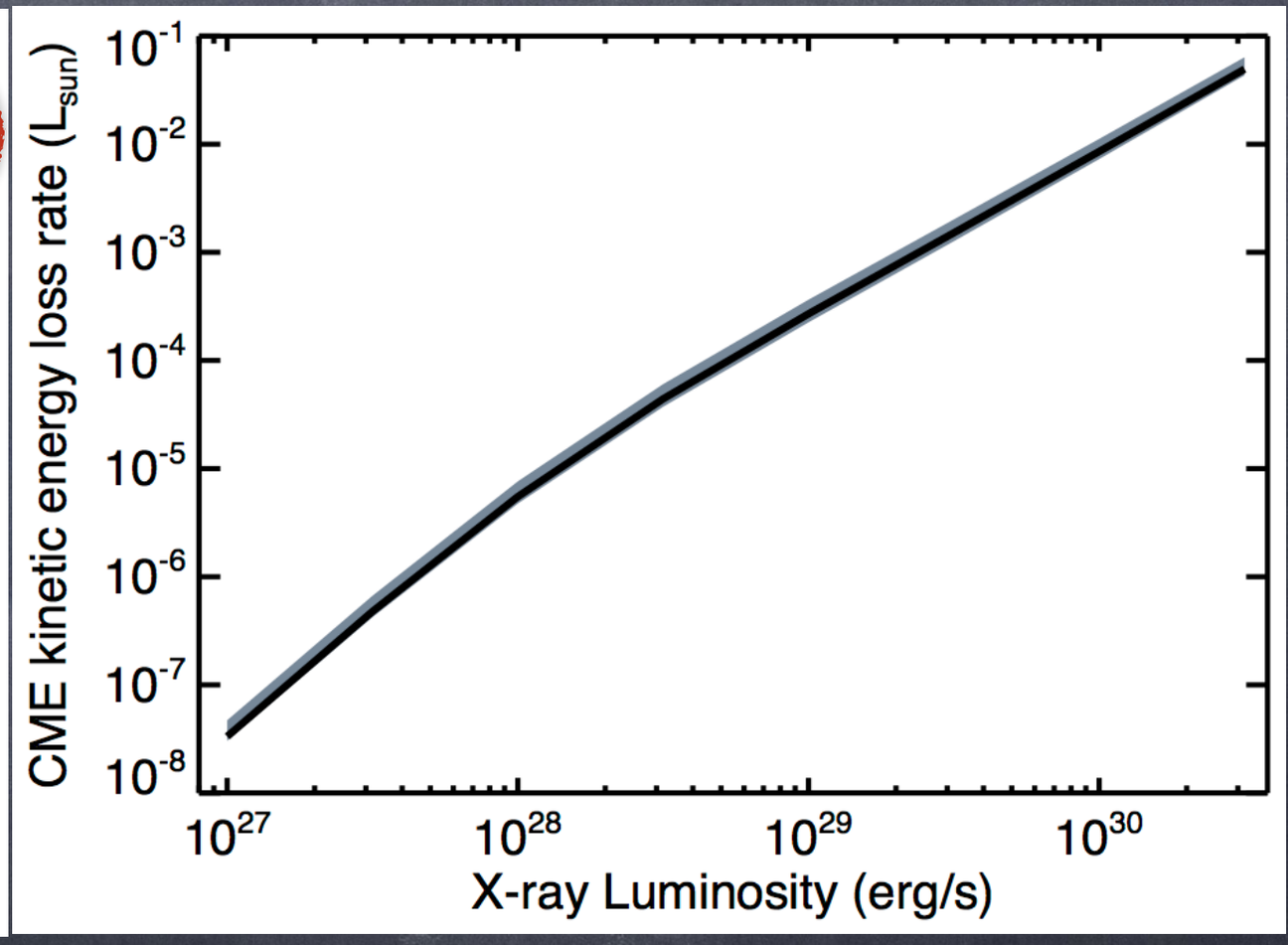
Distribution of flares per unit energy

$$\frac{dn}{dE} = kE^{-\alpha}$$

$\dot{E}_{k,CME}$, $\dot{M} = f(L_X)$

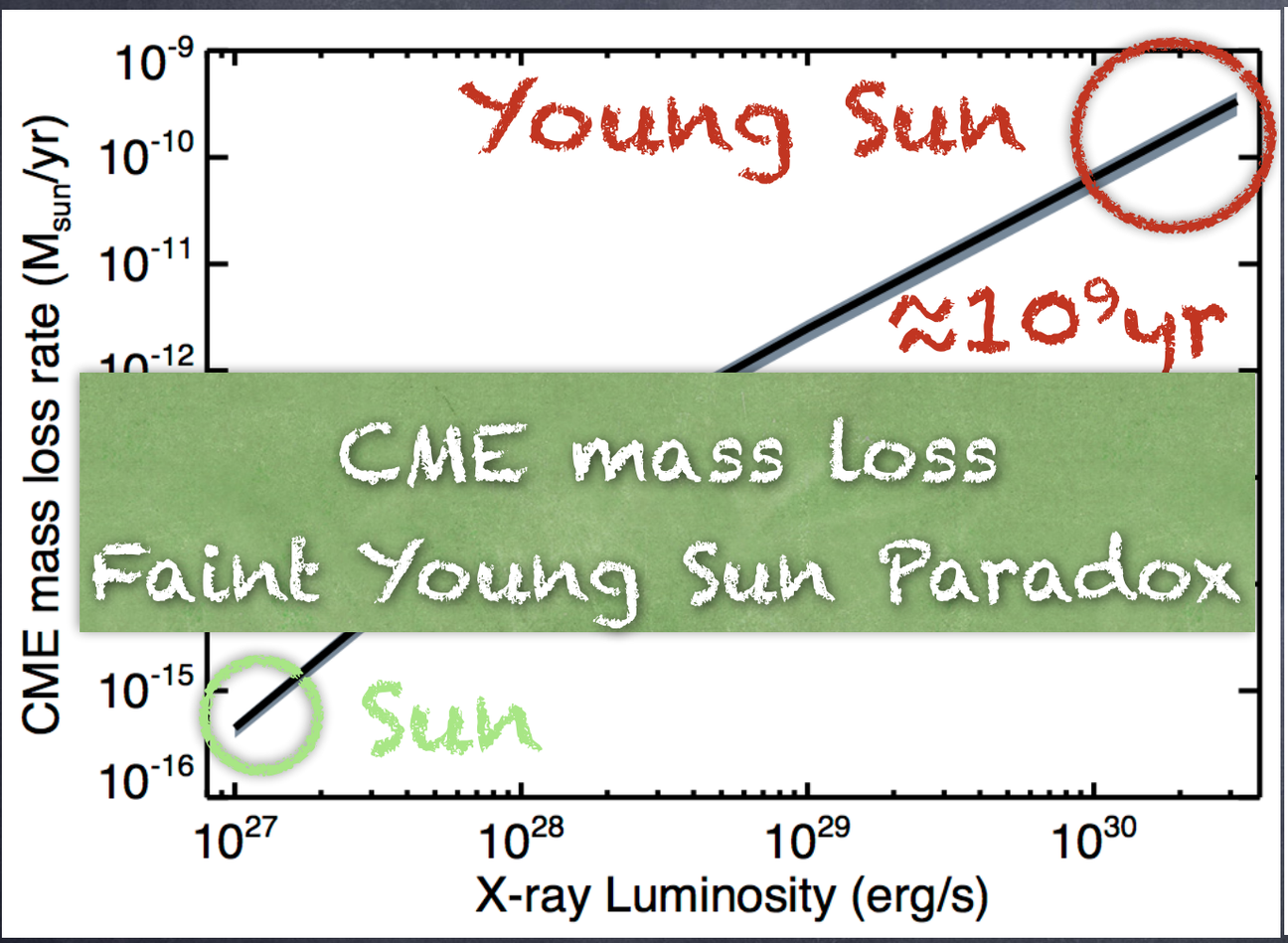
Inferred Mass and Energy loss rates

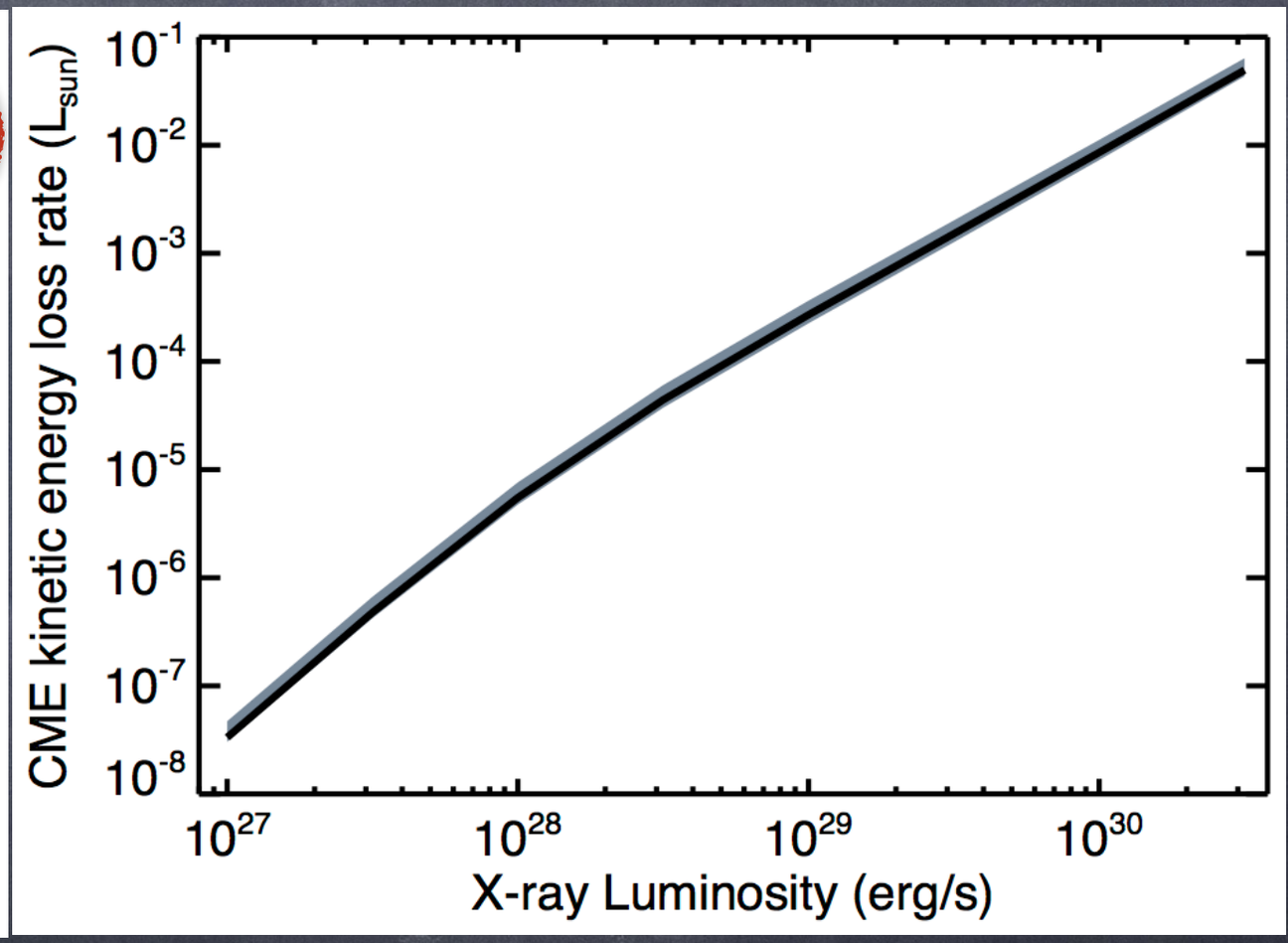




Drake et al, 2013

Inferred Mass and Energy loss rates





Drake et al, 2013

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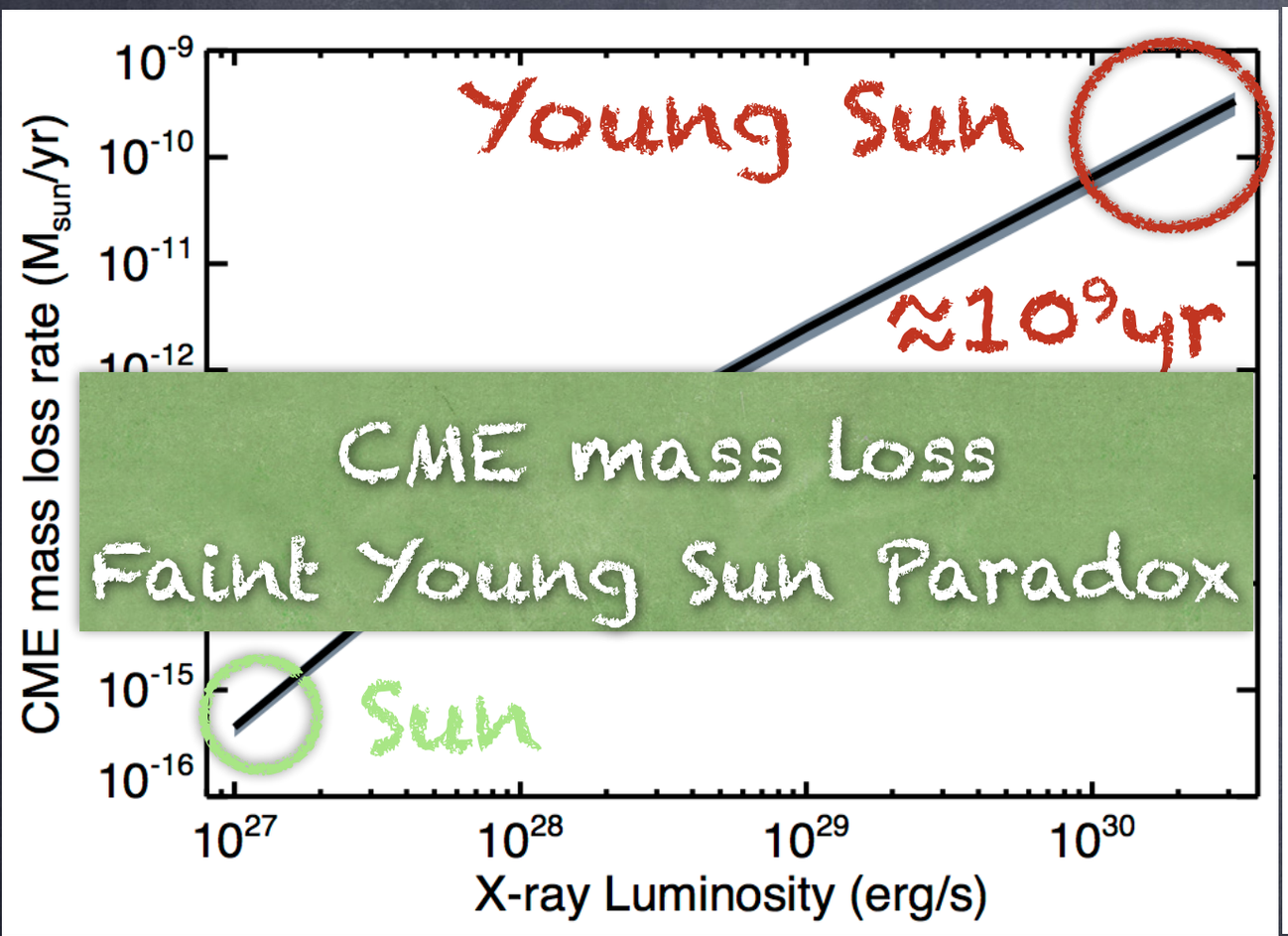
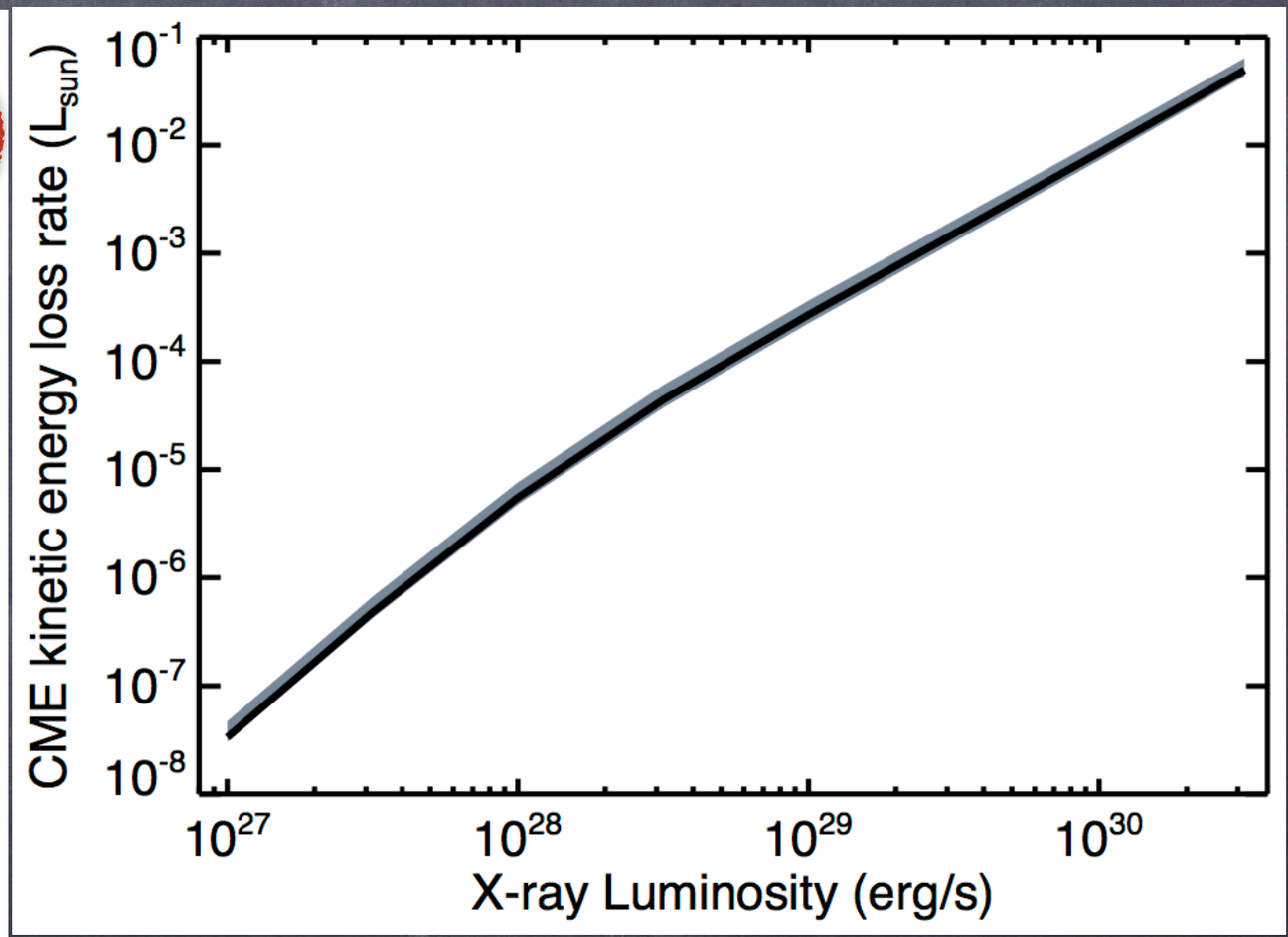
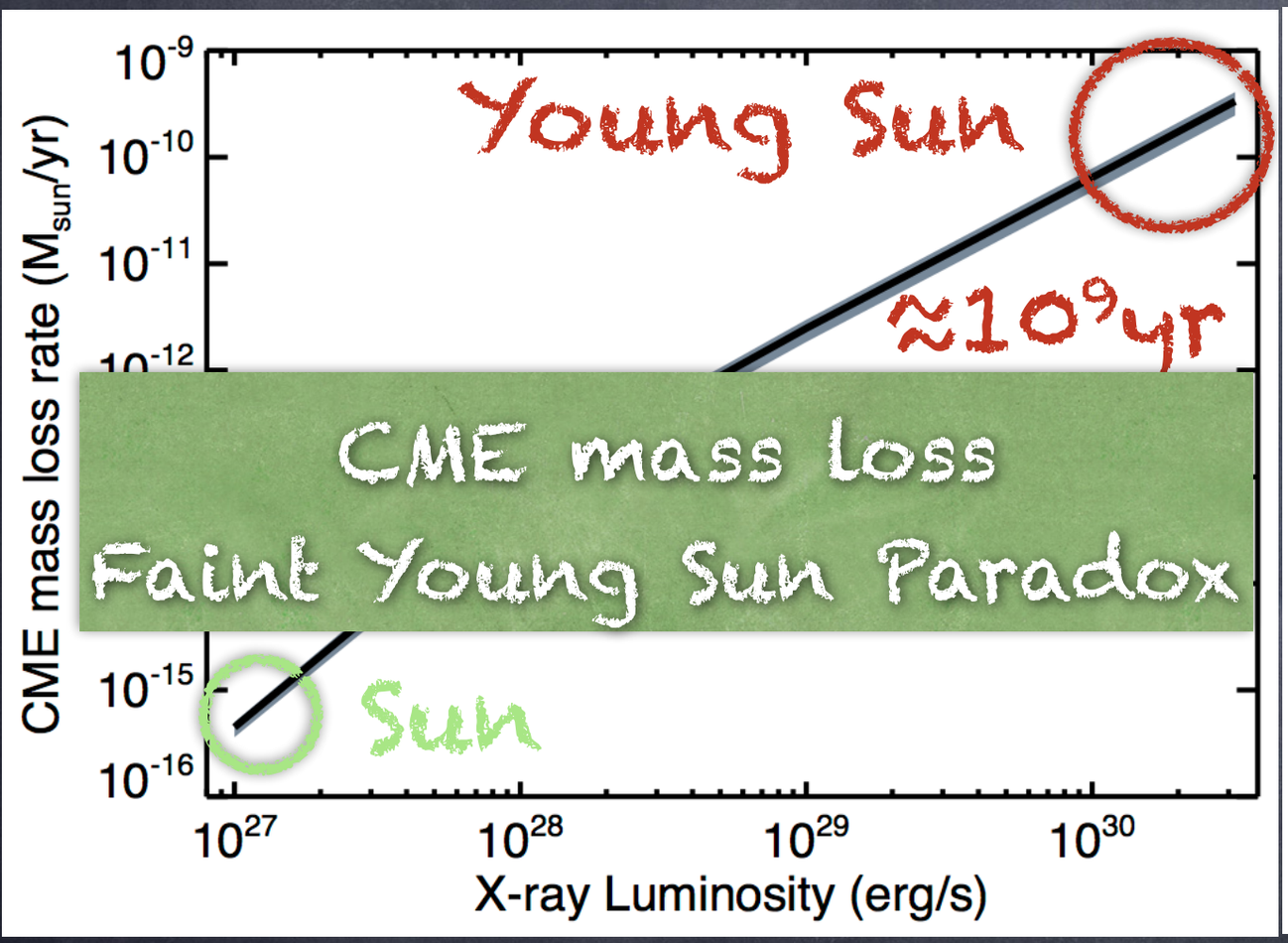


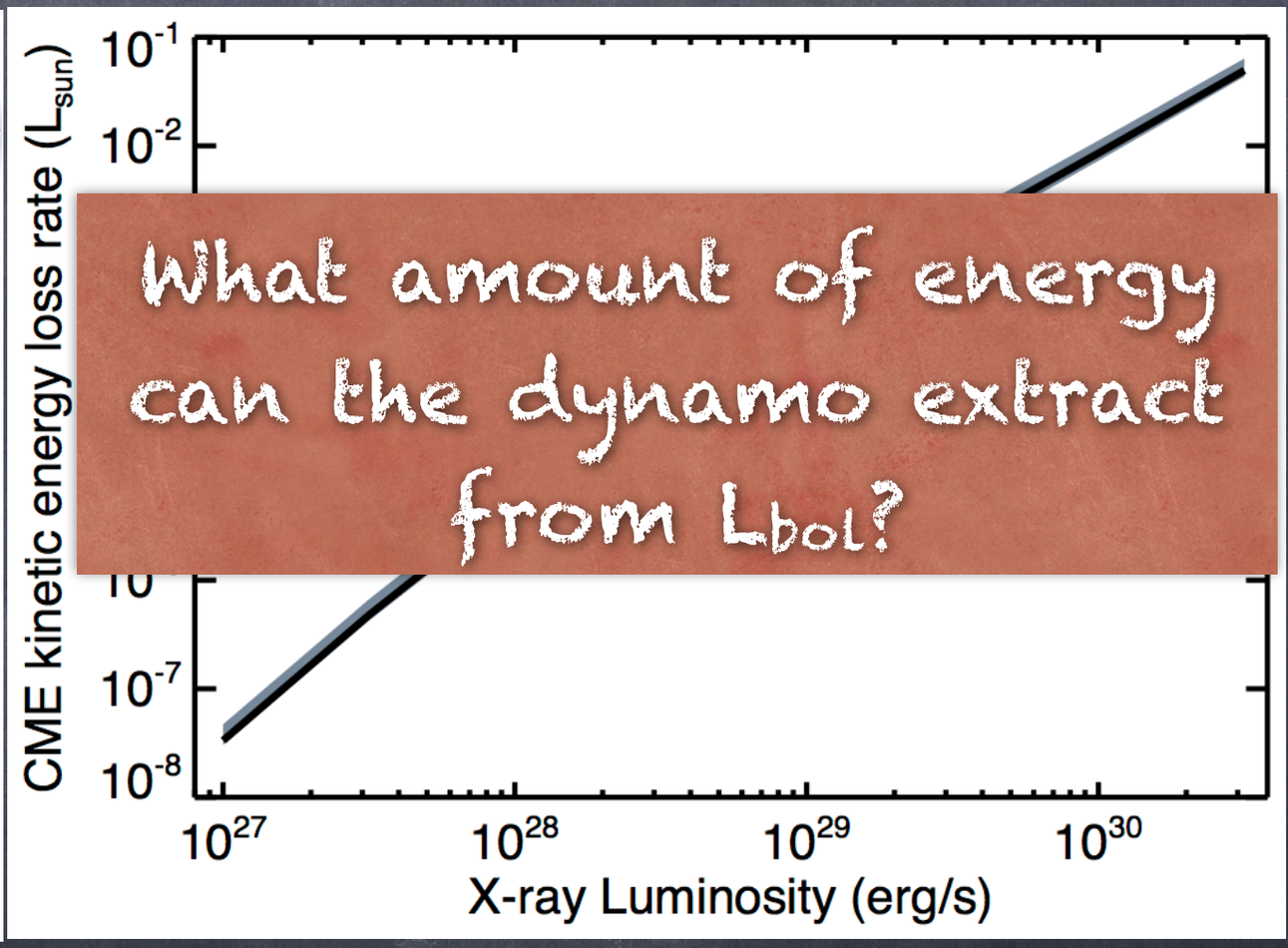


Drake et al, 2013

Aarnio et al, 2012, T-Tauri stars

Inferred Mass and Energy Loss rates



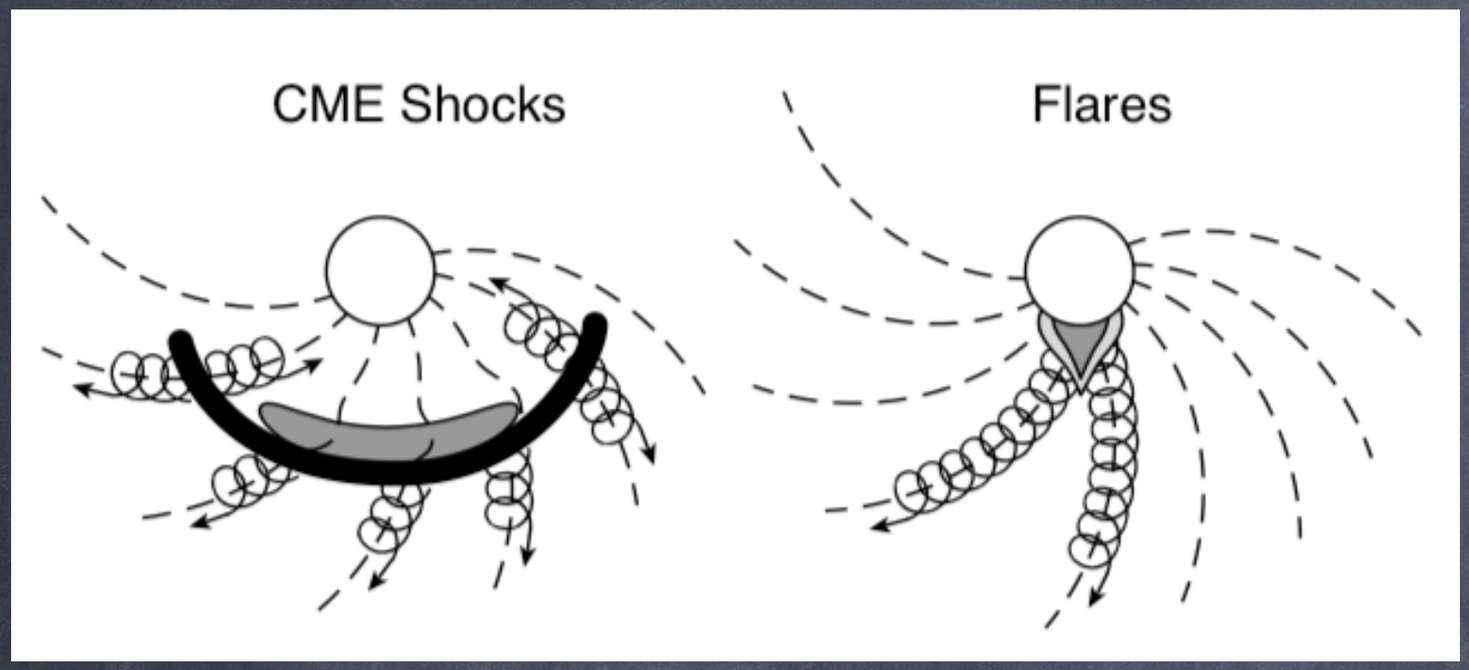


Drake et al, 2013

Aarnio et al, 2012, T-Tauri stars

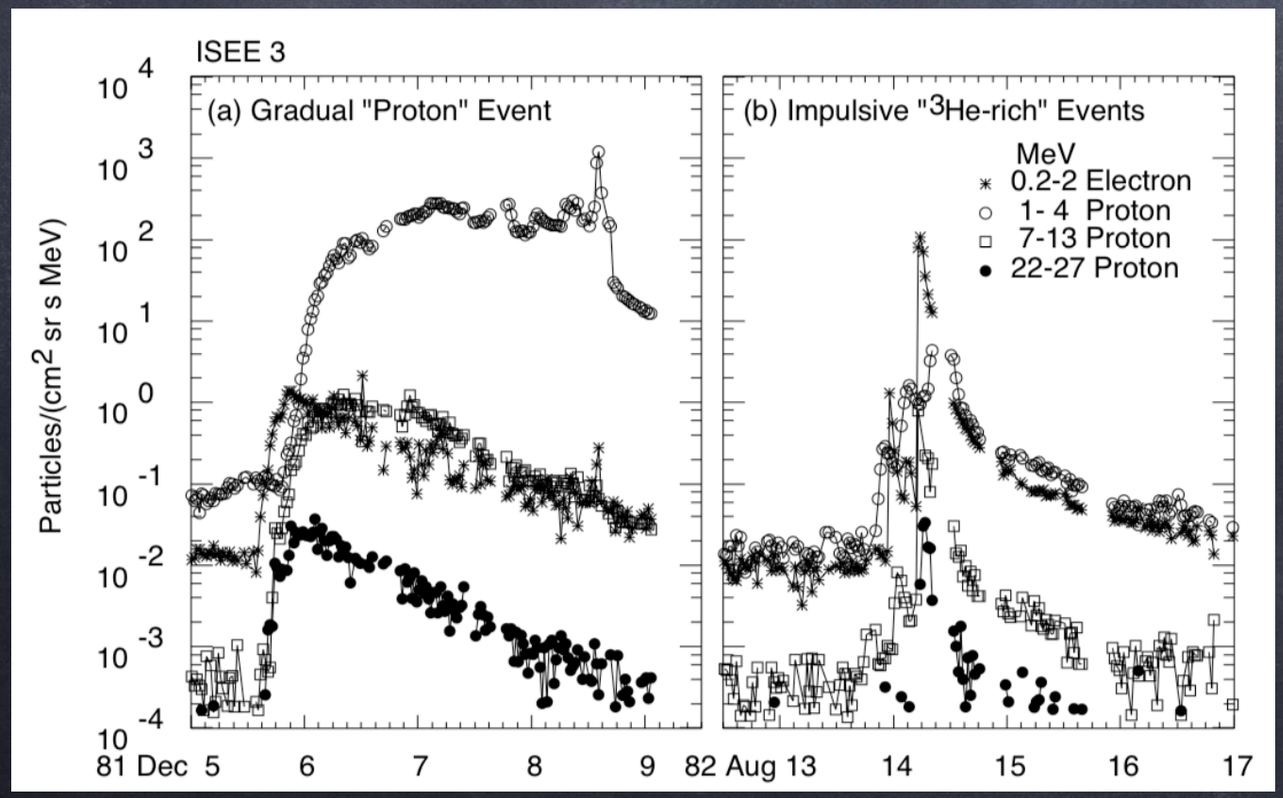
Energetic Particles

Solar EPs



Reames, 1999, SSR

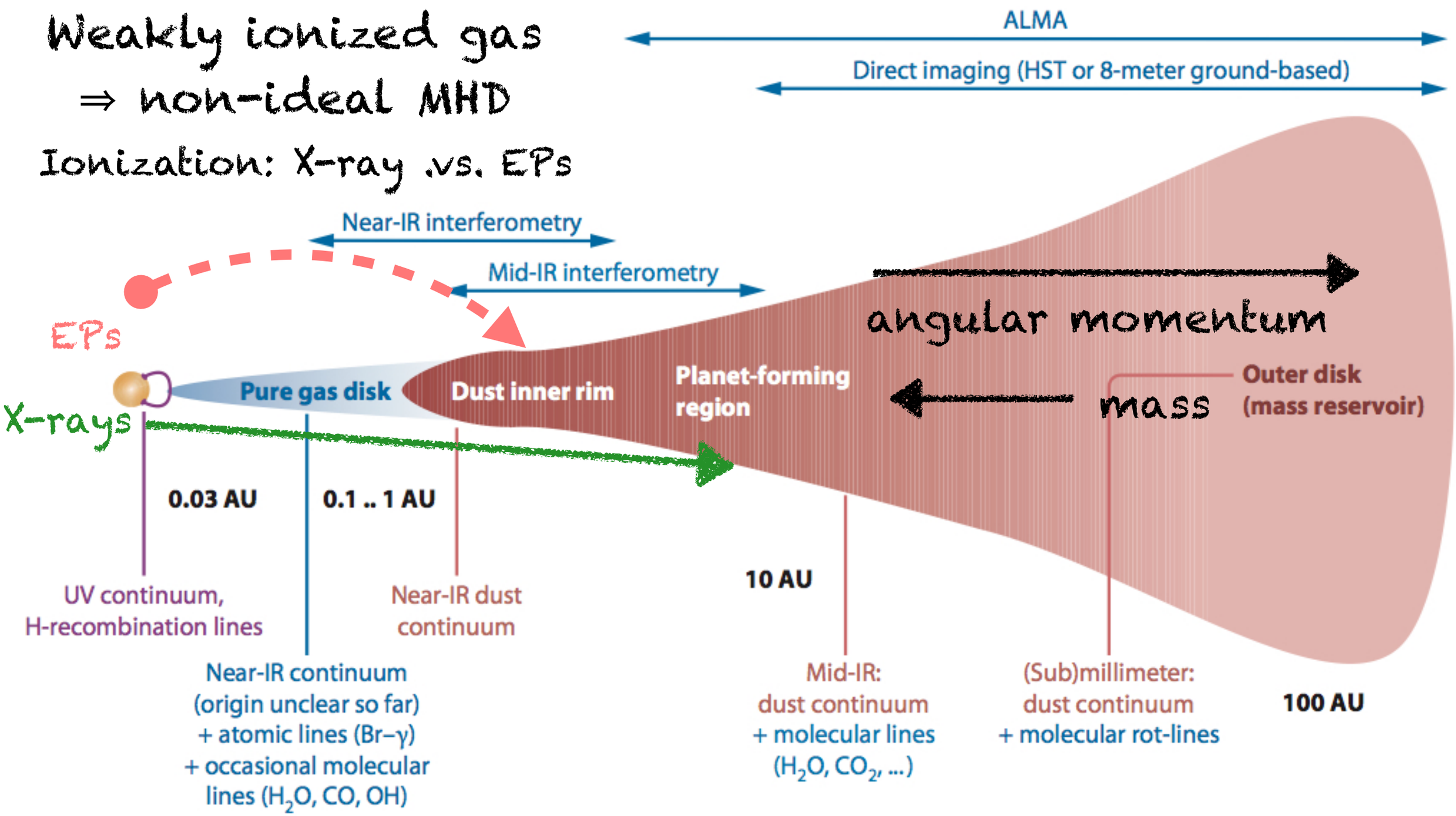
SEP Classes	Gradual (CMEs)	Impulsive (flares)
X-rays	Gradual	Impulsive
Duration	Days	Hours
Radio-bursts	Type II	Type III



Protoplanetary disks

Weakly ionized gas
⇒ non-ideal MHD

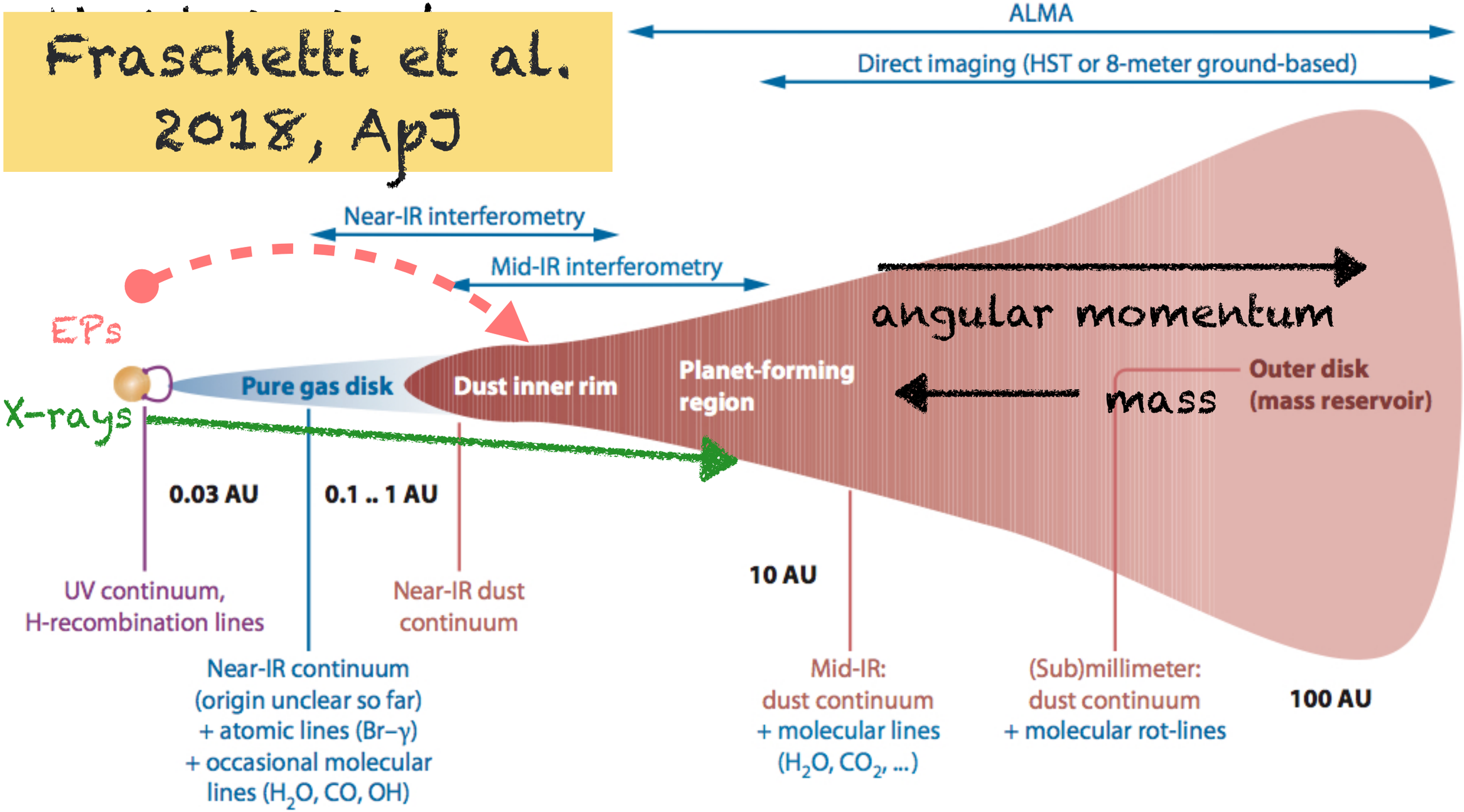
Ionization: X-ray .vs. EPs



Dullemond & Monnier, 2010

Protoplanetary disks

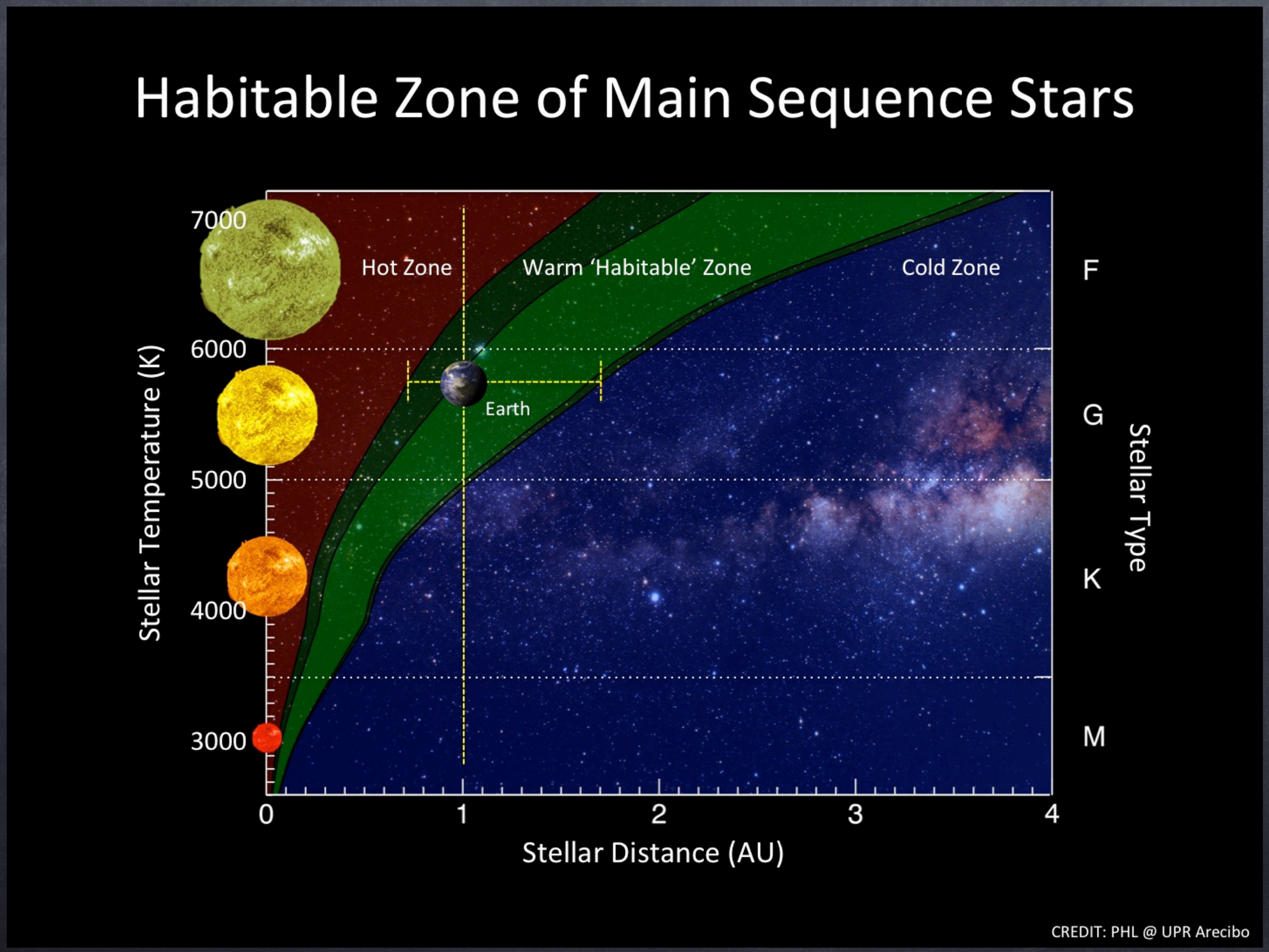
Fraschetti et al. 2018, ApJ



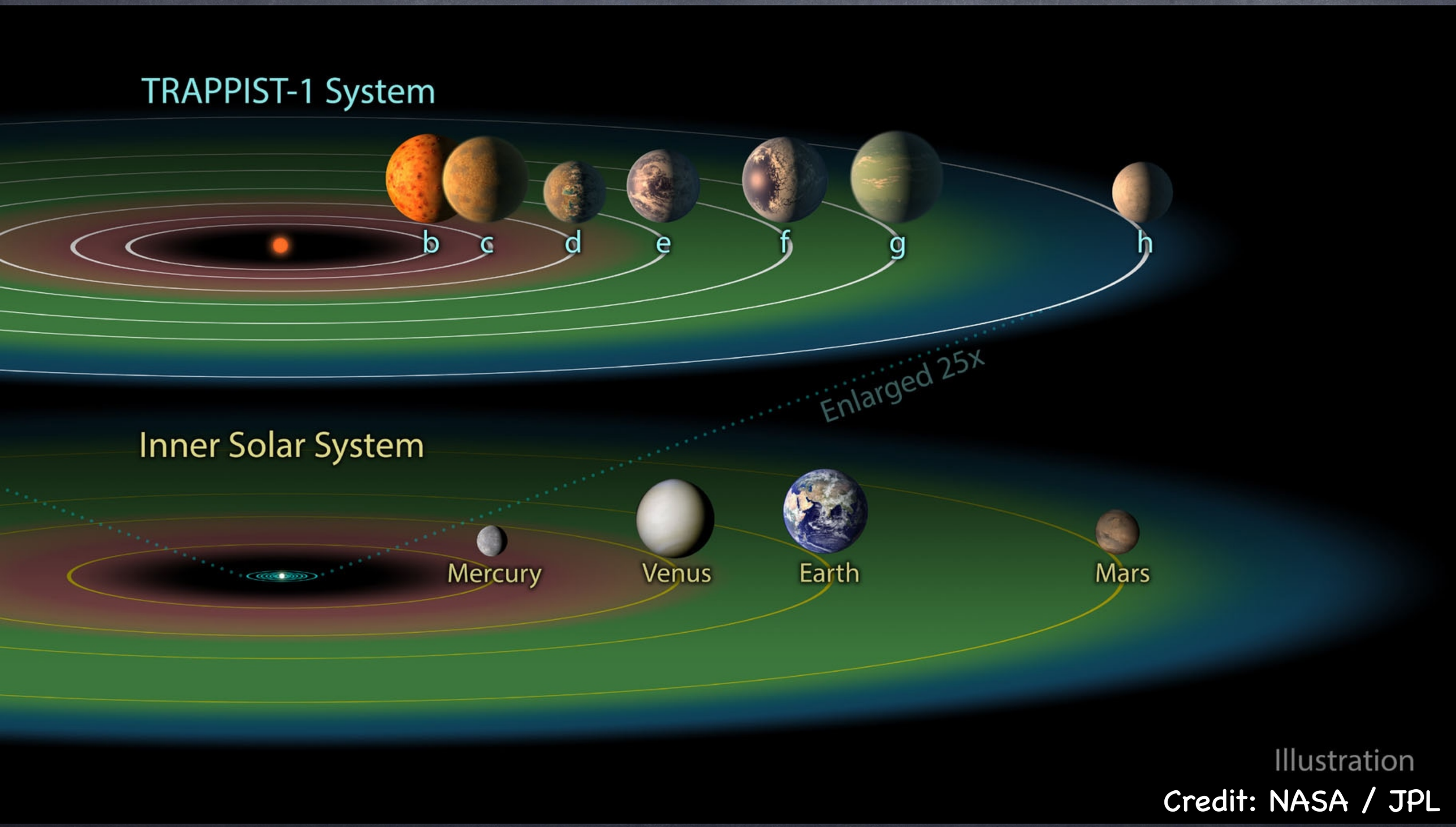
Dullemond & Monnier, 2010

Habitability around active stars

Habitable zone



Habitable zone

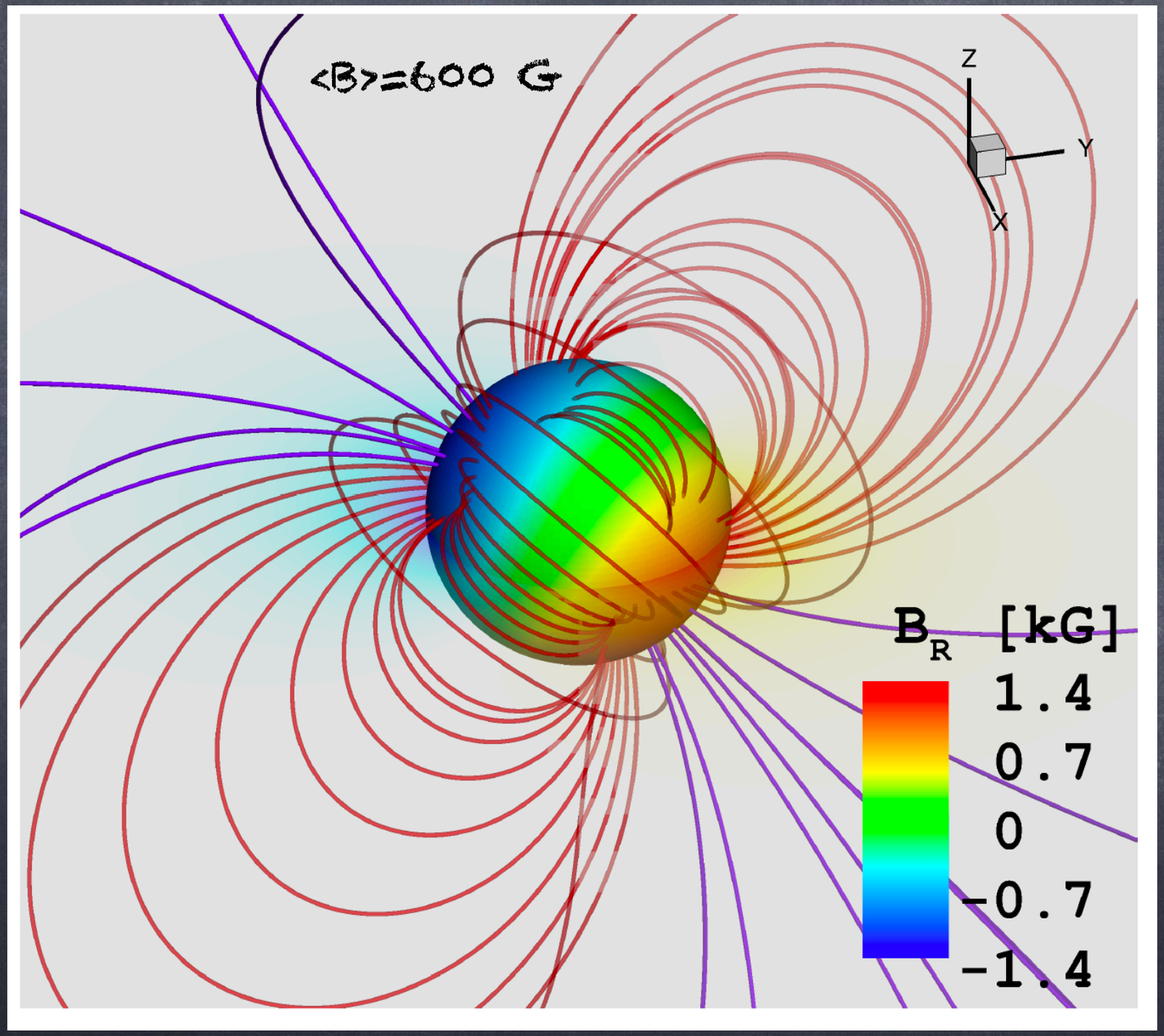


Illustration

Credit: NASA / JPL

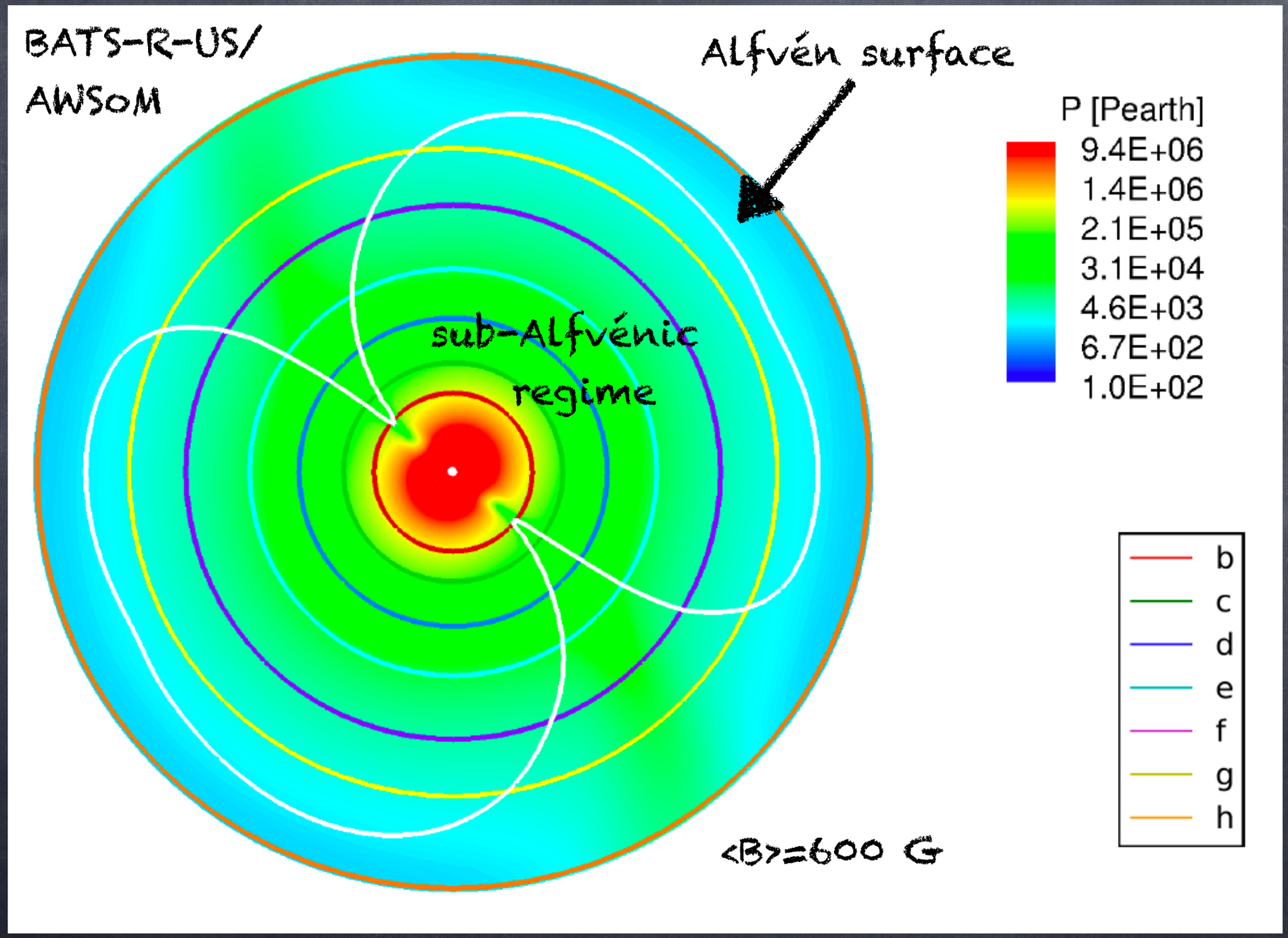
Stellar Winds

Trappist-1



Garraffo et al. 2017, ApJL

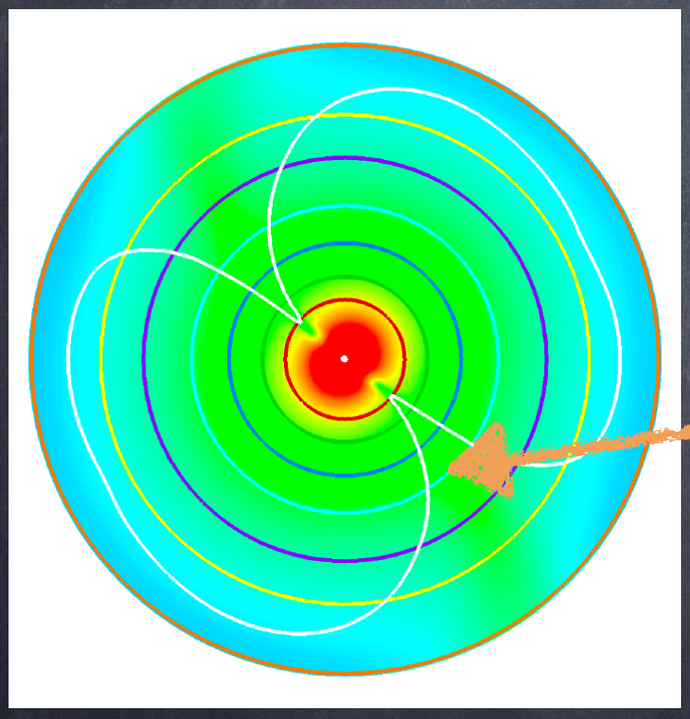
Wind from Trappist-1

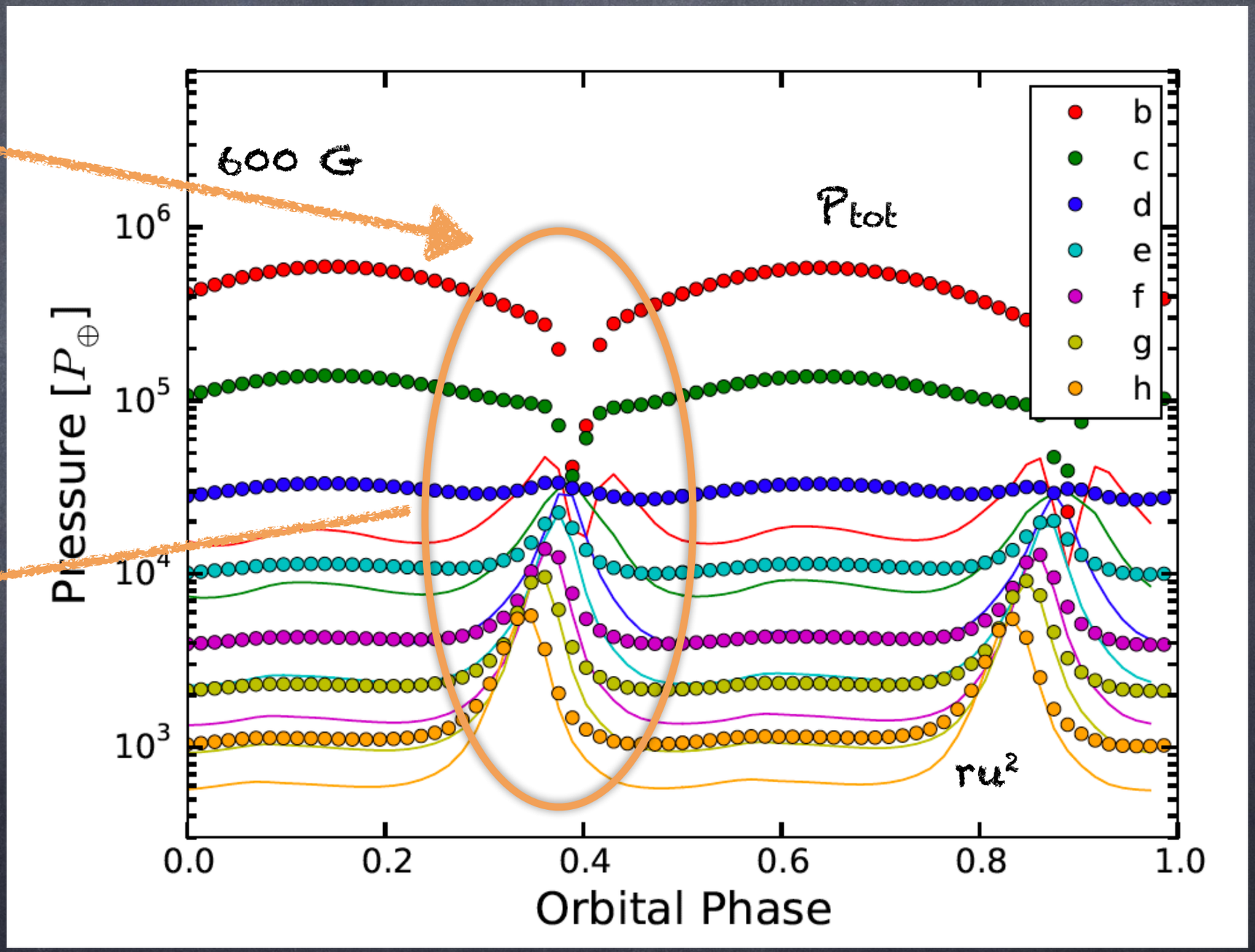


Garraffo et al. 2017, ApJL

Wind conditions at planetary orbits

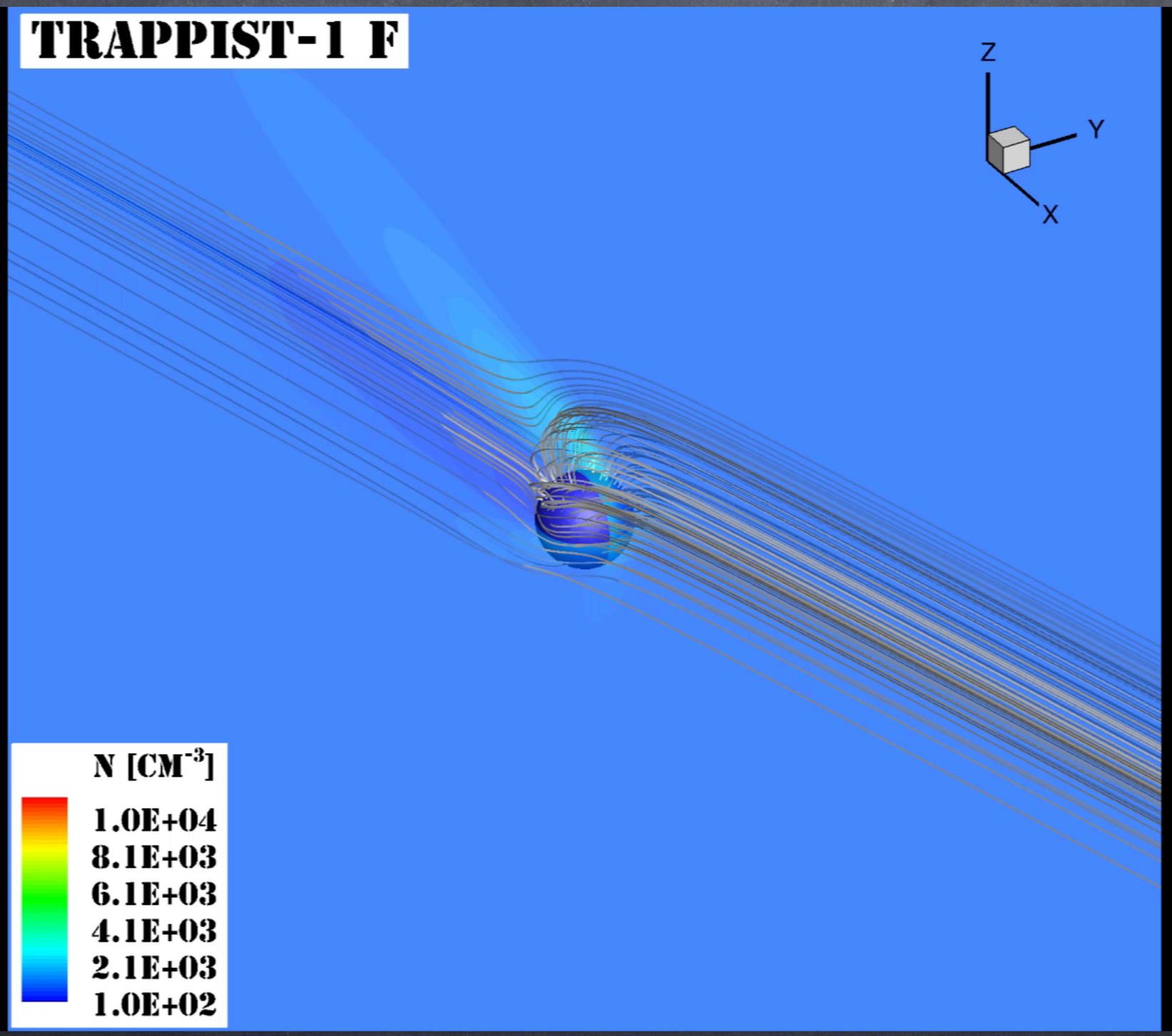
Alfvén surface crossings





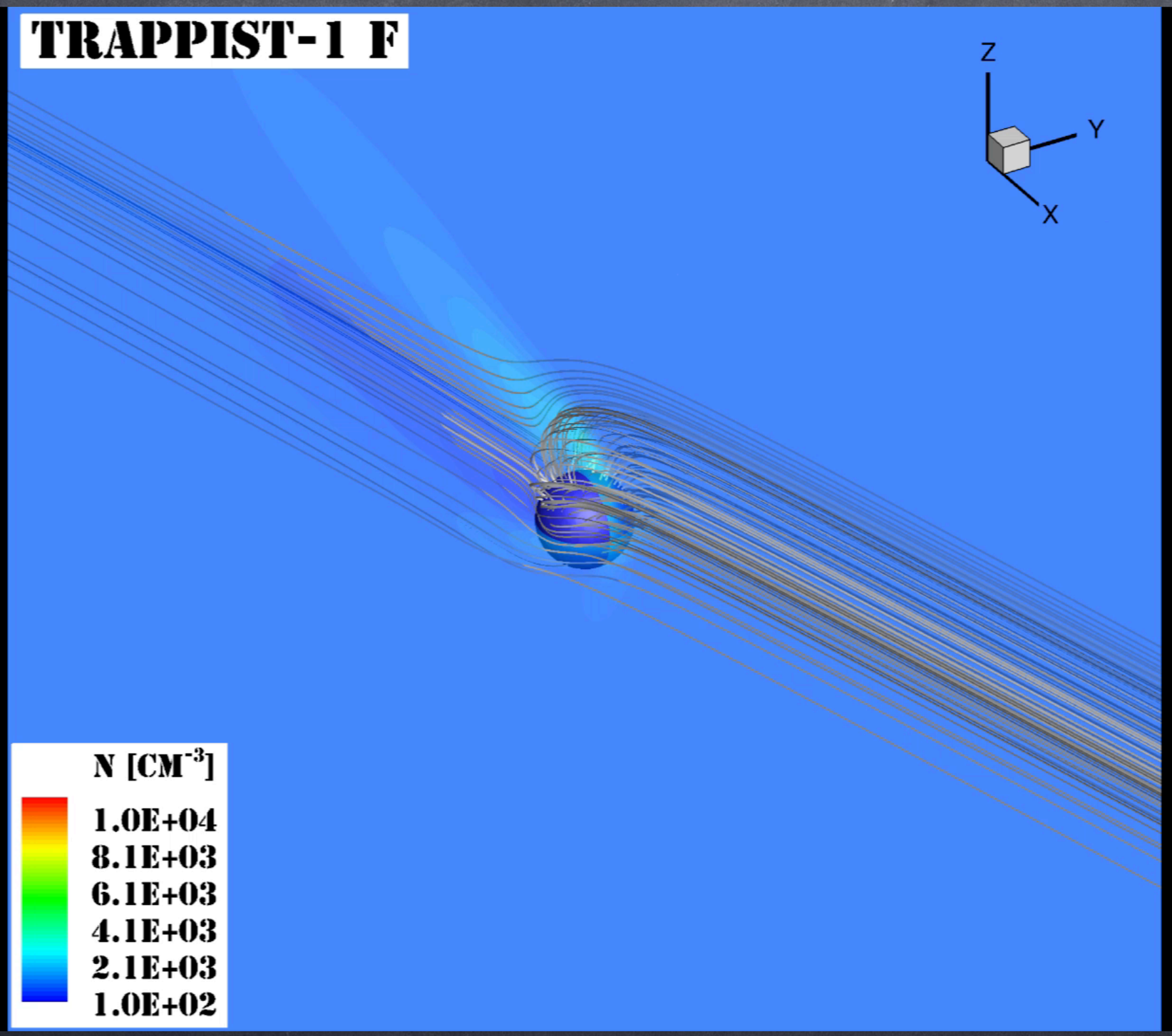
Garraffo et al. 2017, ApJL

Magnetospheric disturbance



Garraffo et al. 2017, ApJL

Magnetospheric disturbance

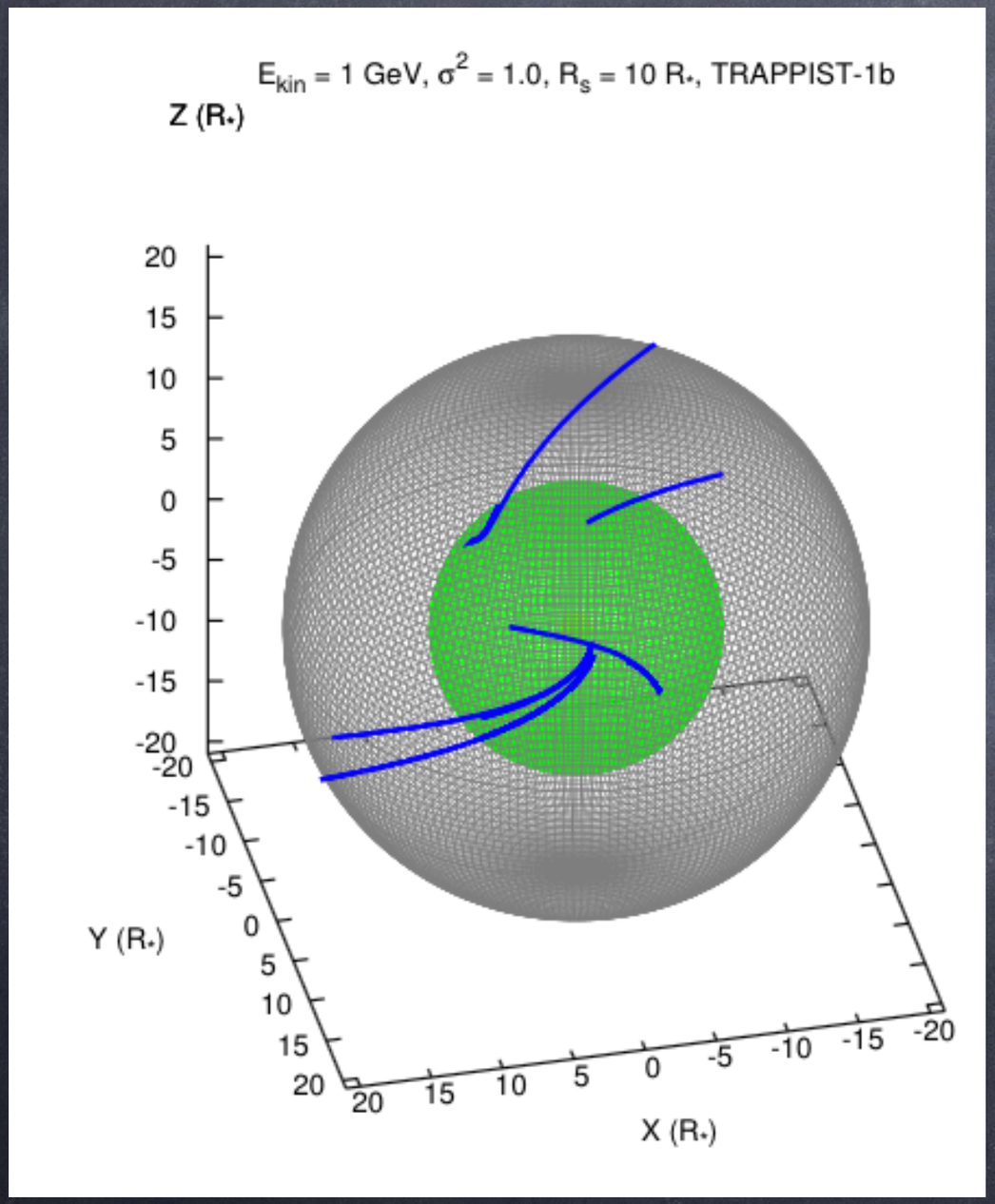


Garraffo et al. 2017, ApJL

What about EPs?

Energetic particles from Trappist-1

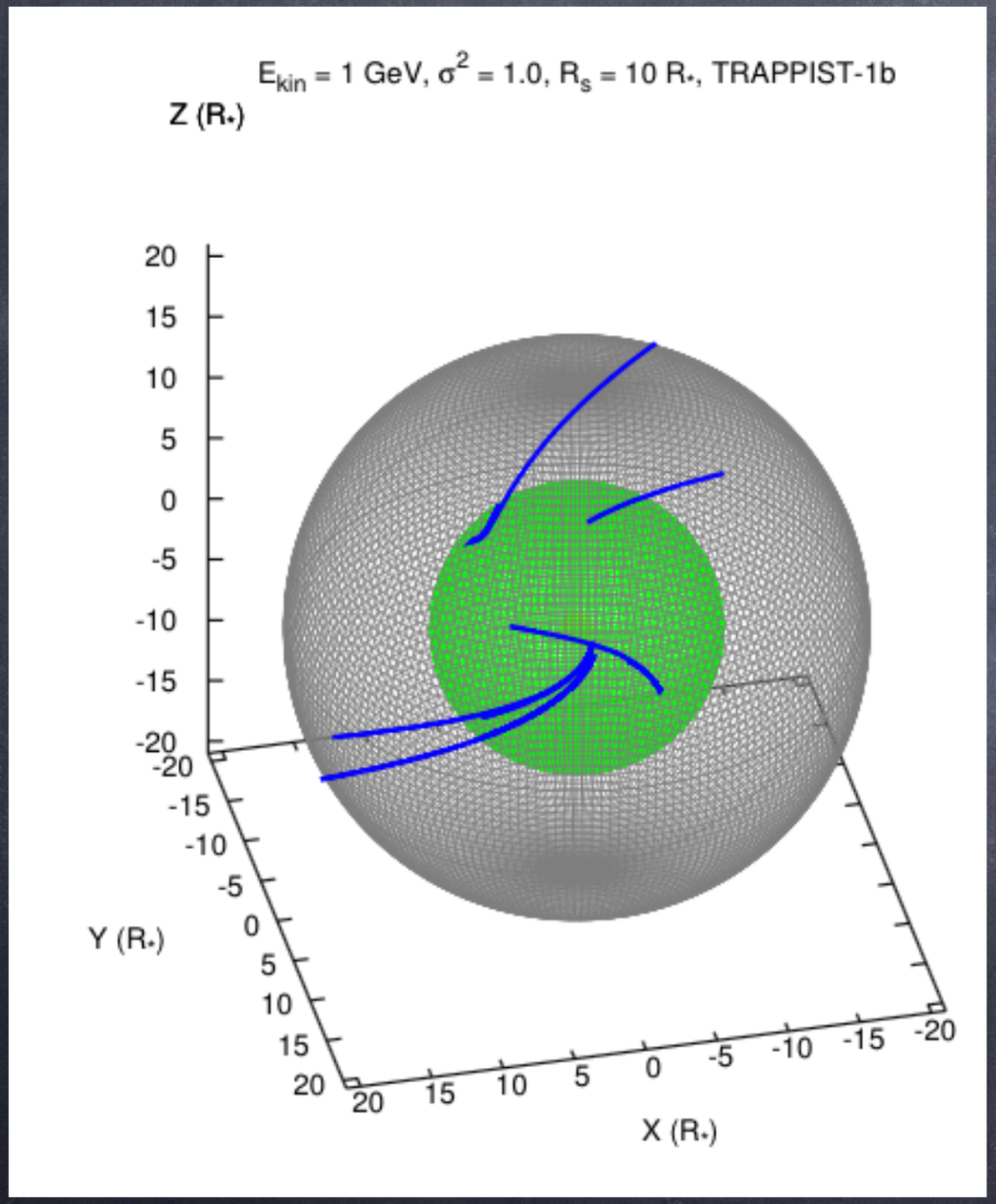
Turbulence: $\sigma^2 = (\delta B/B_o)^2$

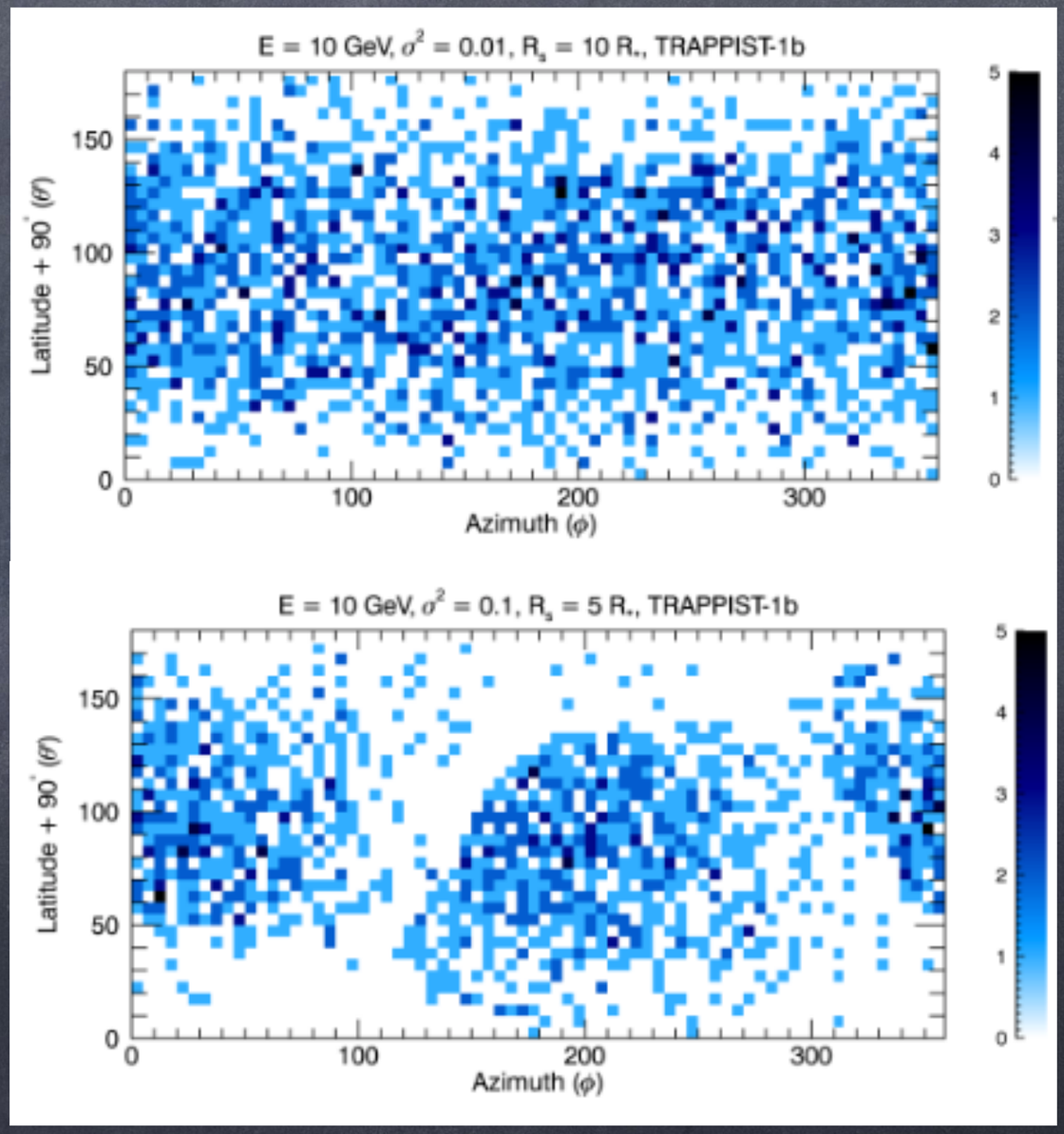


Fraschetti et al. 2018 (in prep)

Energetic particles from Trappist-1

Turbulence: $\sigma^2 = (\delta B/B_o)^2$





Fraschetti et al. 2018 (in prep)

Atmospheric escape

Energization and escape

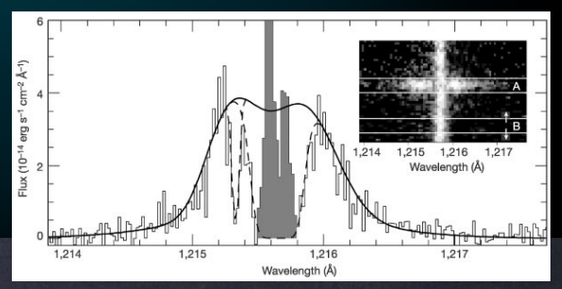
X-ray

Extreme Ultraviolet

Ionization

Wind

Lyman-α



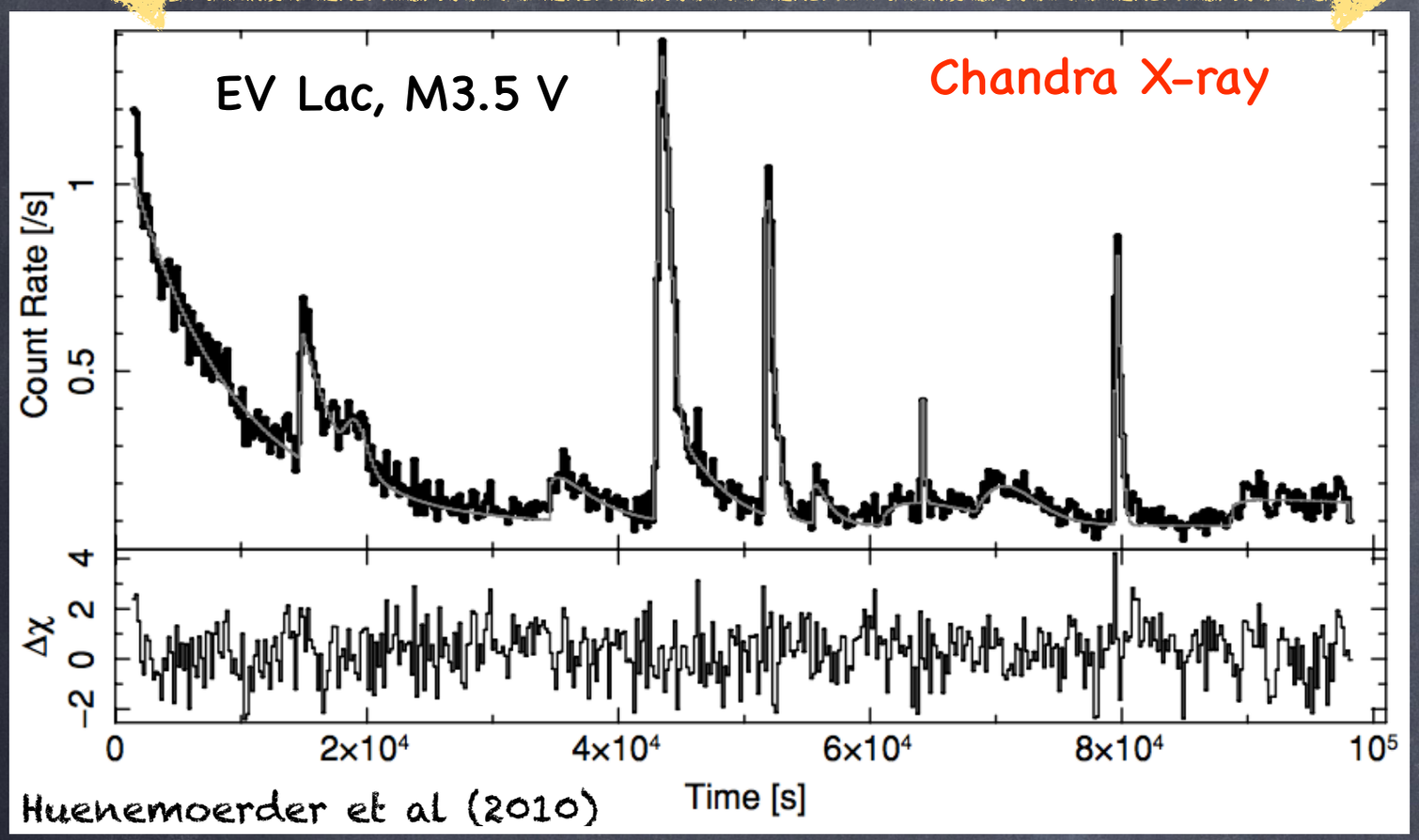
Vidal-Madjar et. al, 2003

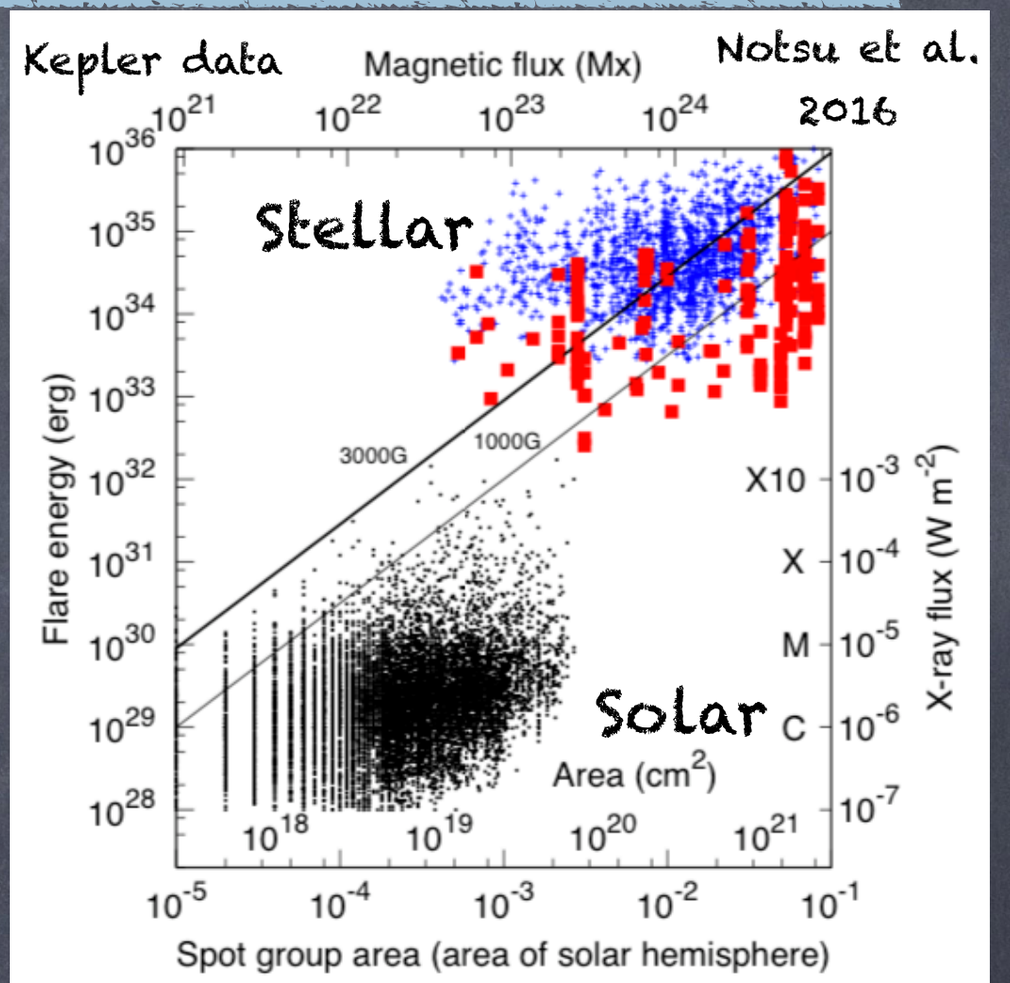
Credit: NASA/Goddard/
University of Colorado/MAVEN

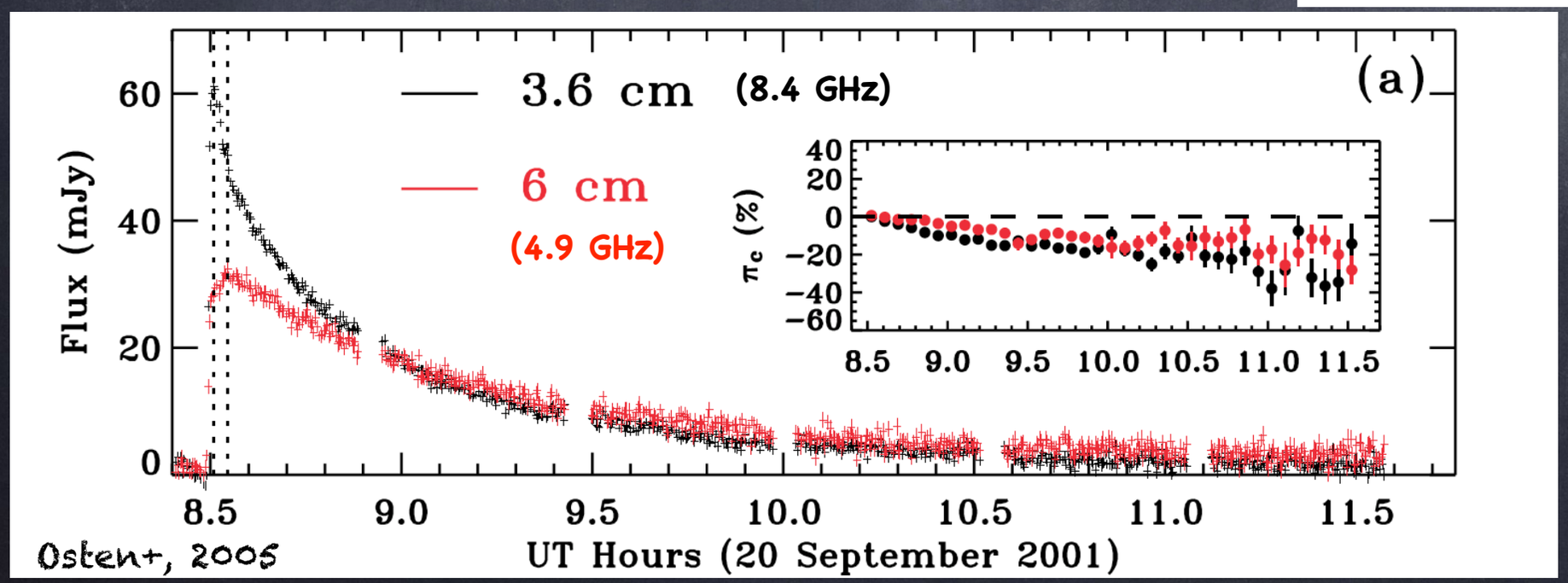
Stellar flares

Stellar flares

≈30 hours



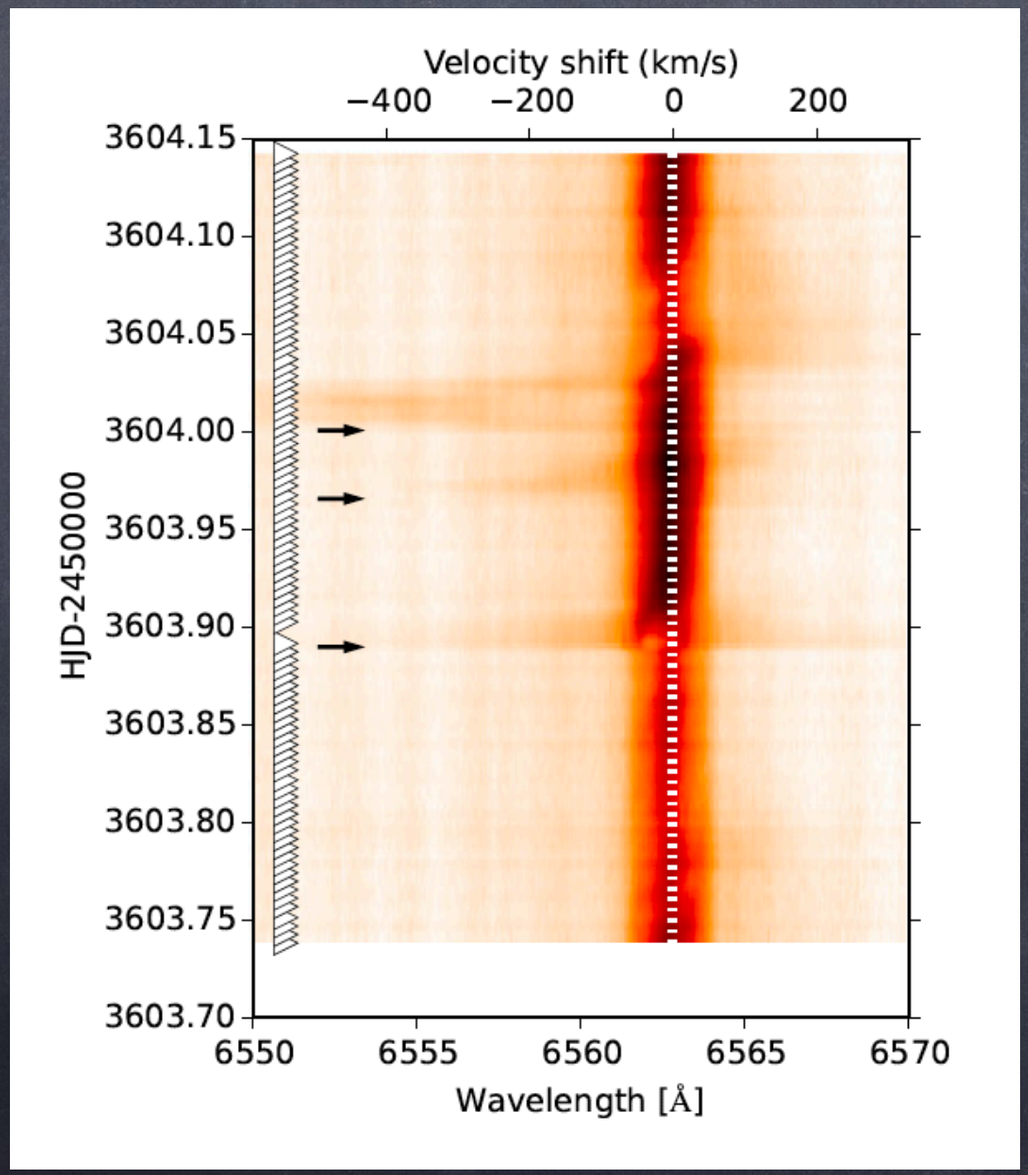




What can we do for stellar CMEs?

Stellar CME Observations

1. Doppler shifts



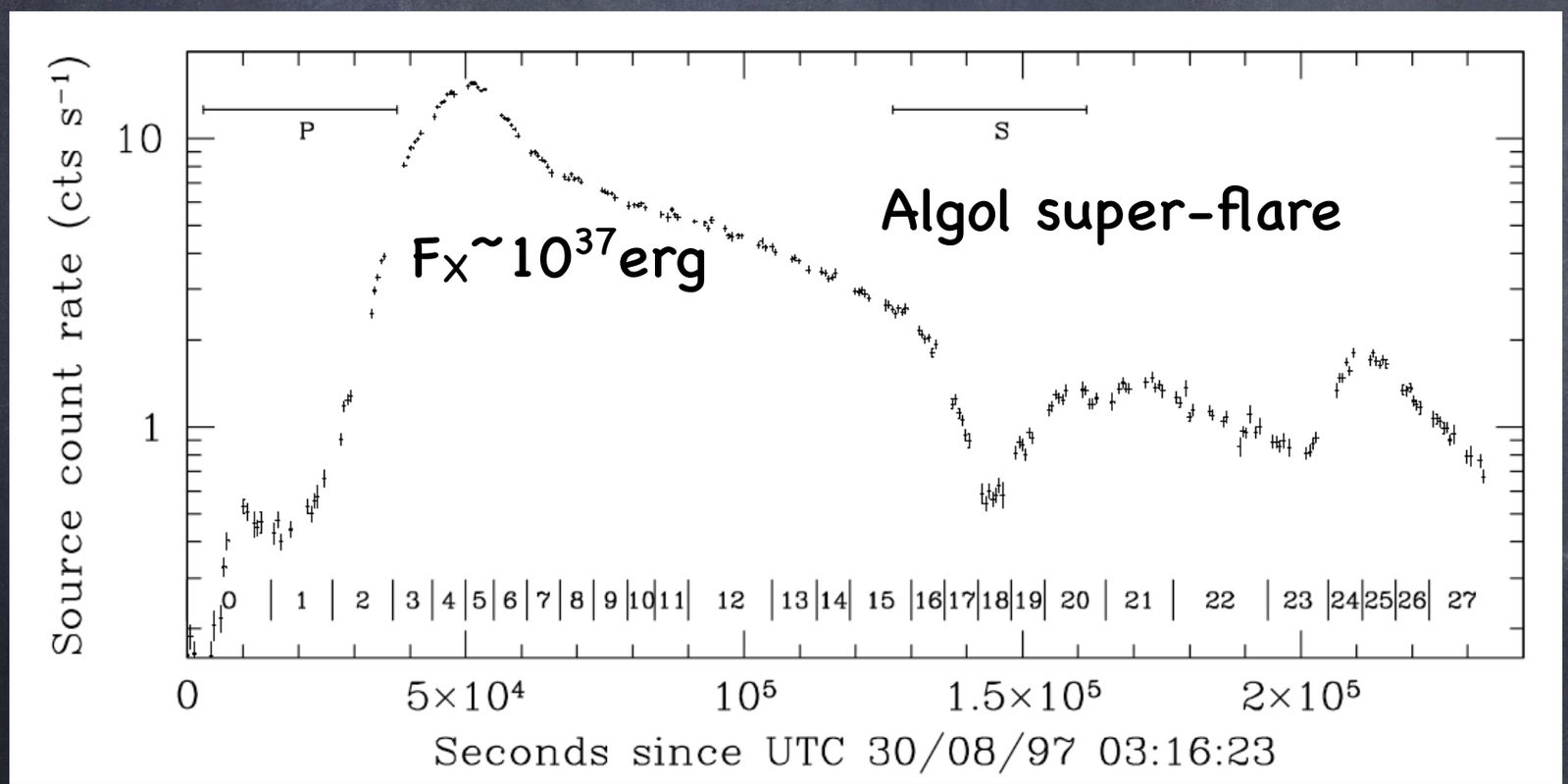
$H\alpha$, $T \propto 10^4 K$

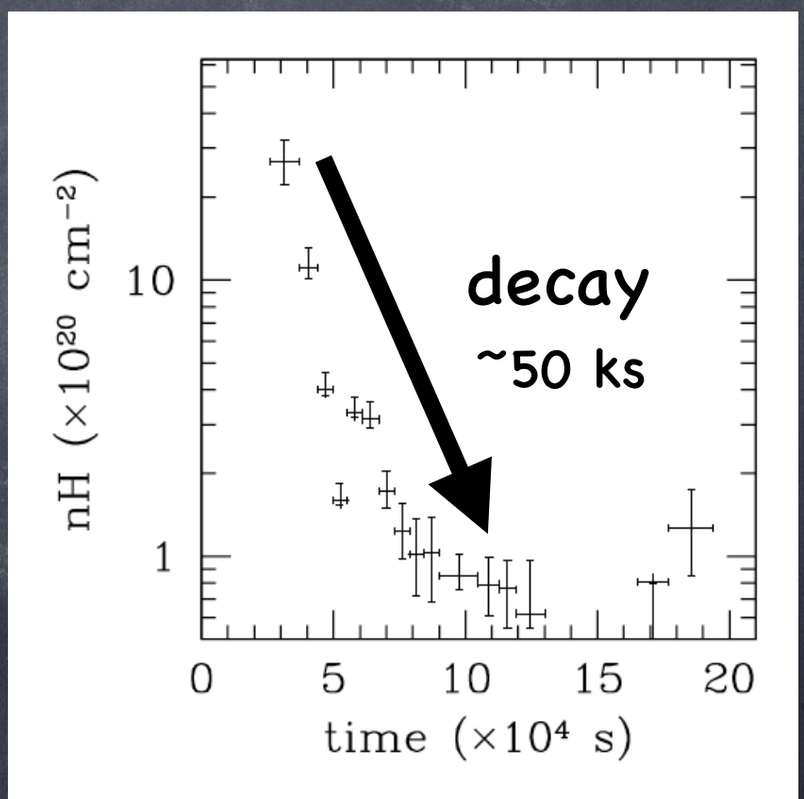
Vida et al. 2016, A&A

Blue-wing: CME signature from V374 Peg

Stellar CME Observations

1. Doppler shifts
2. X-ray absorption

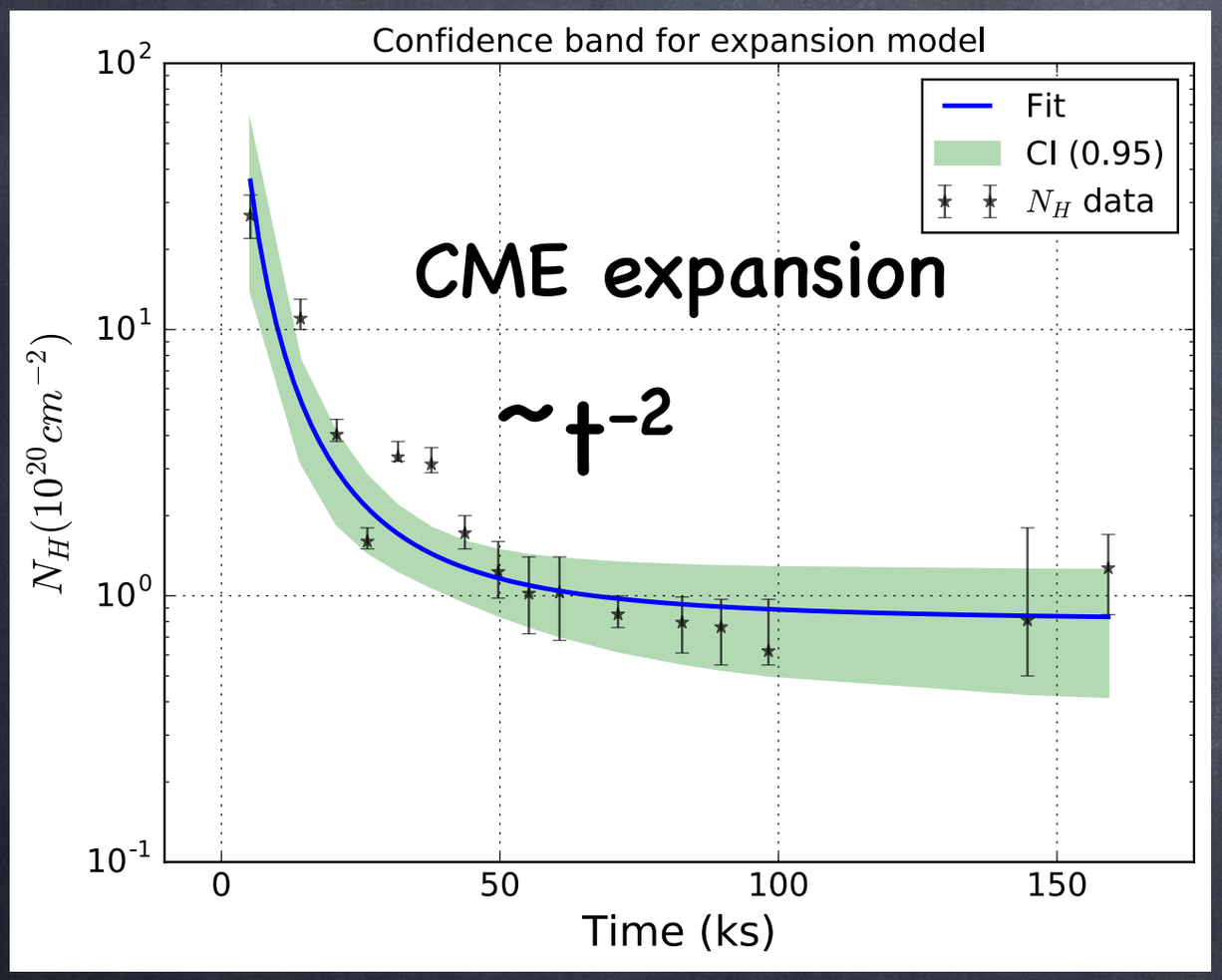


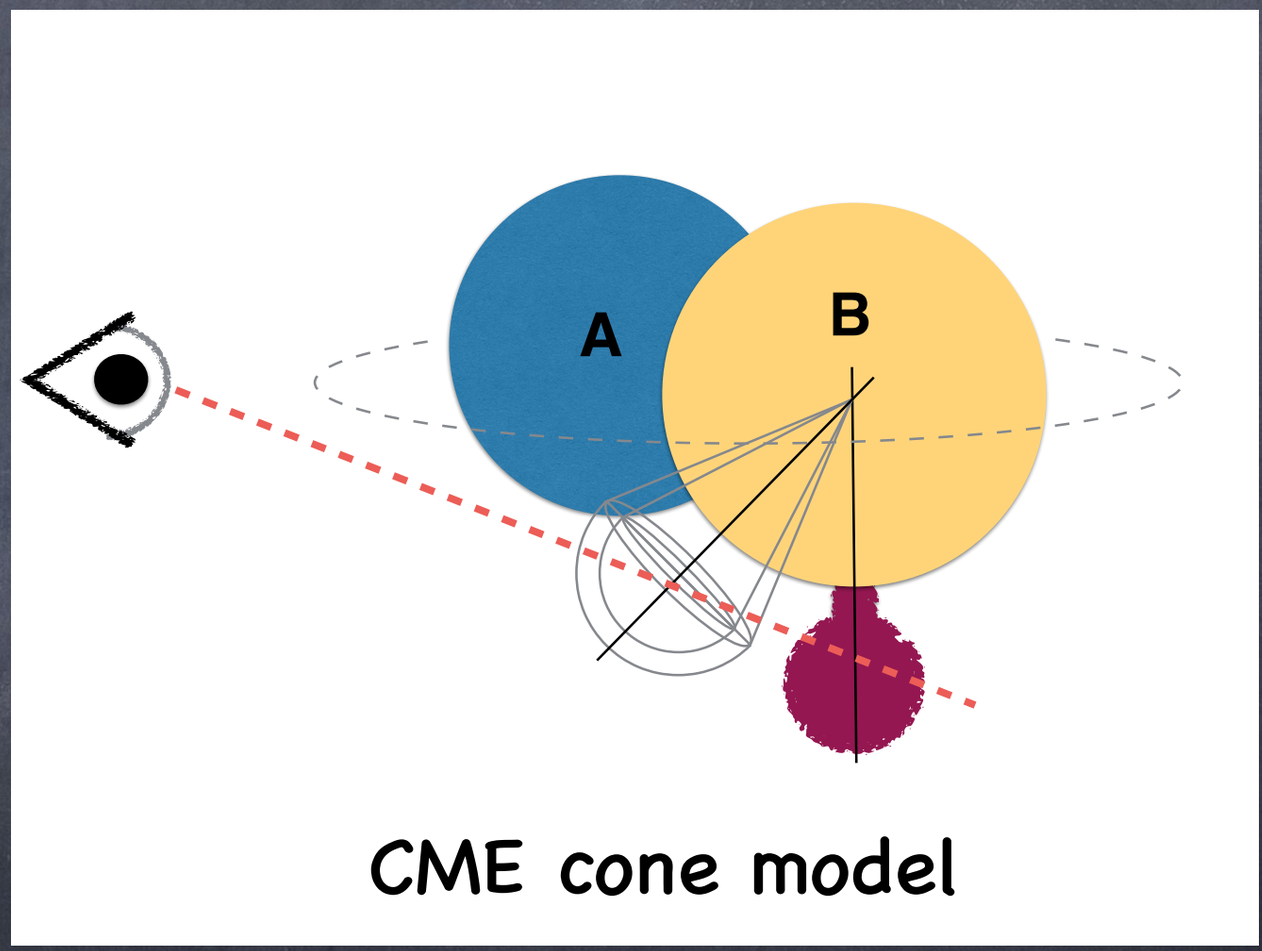


Favata & Schmitt, 1999

Monster CME obscuring Demon Star flare

Algol (aka Demon Star)



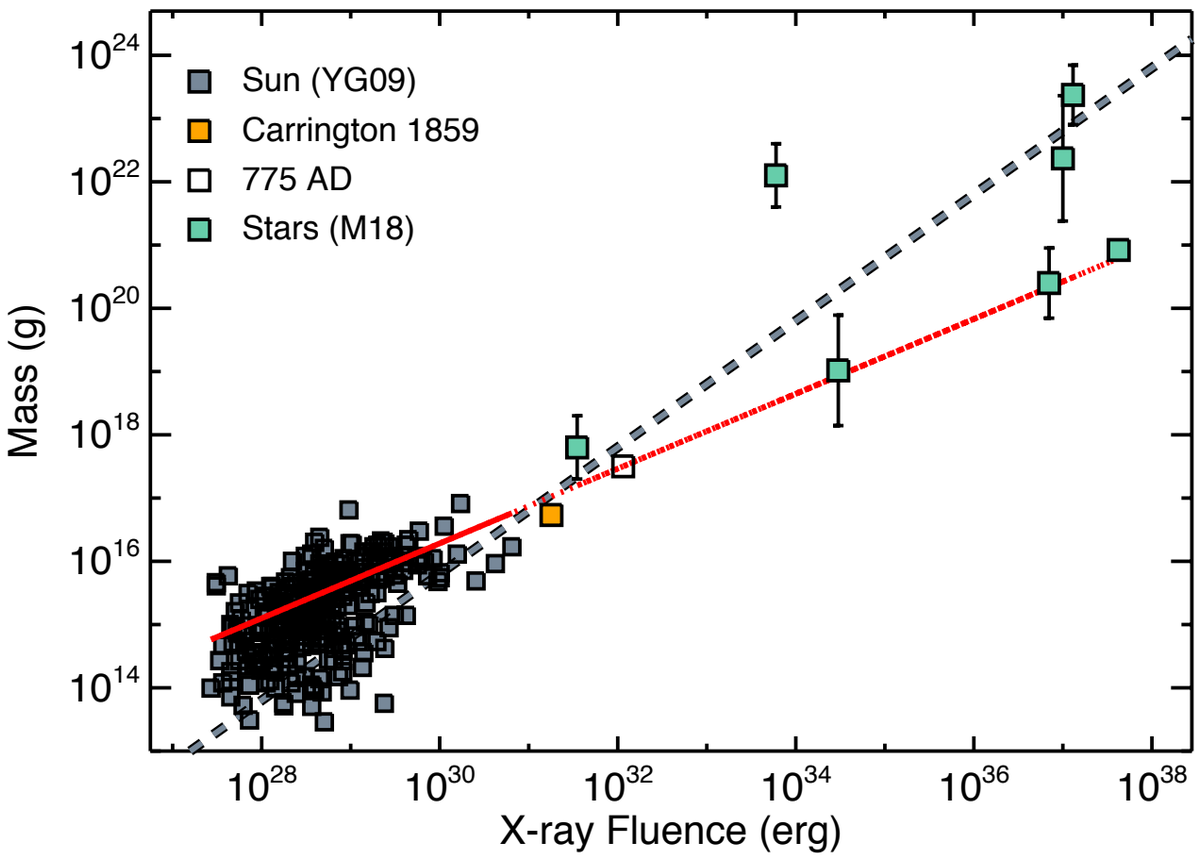


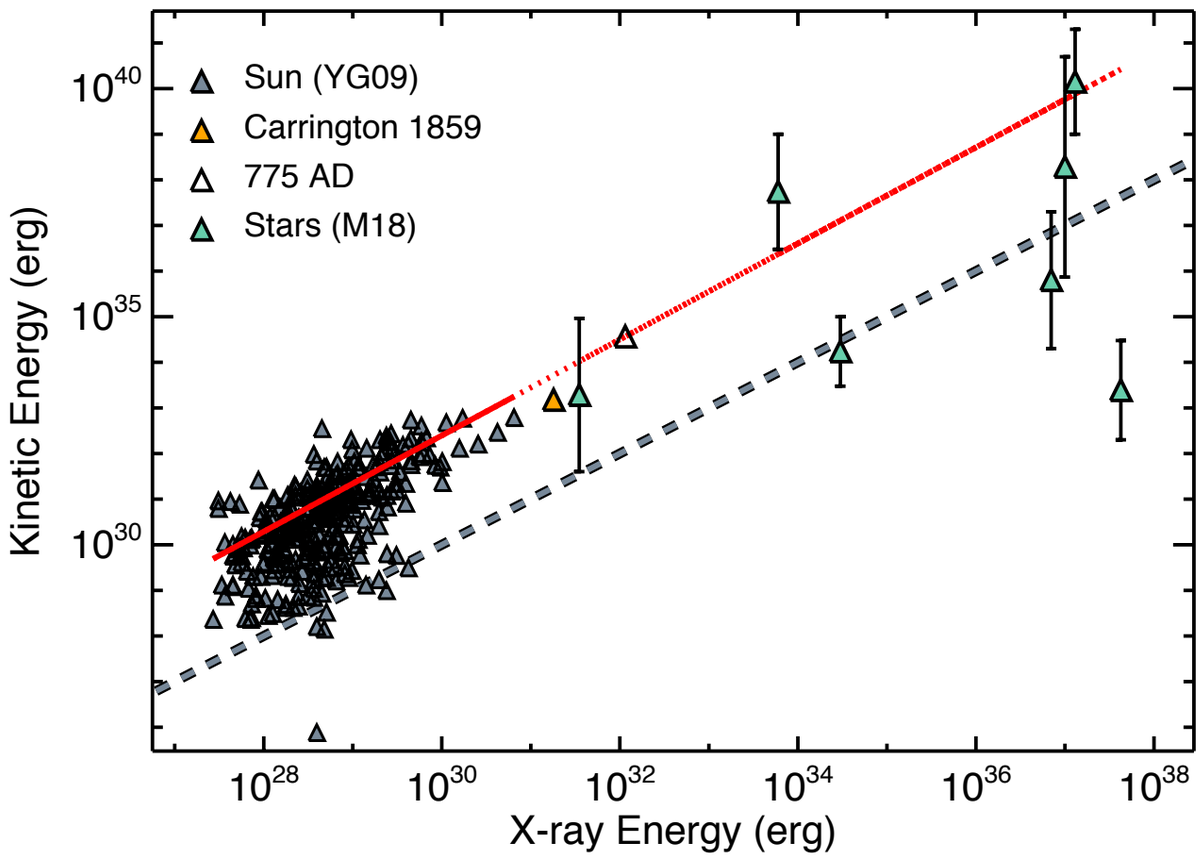
Moschou et al., ApJ, 850, 191, 2017

"A Monster CME Obscuring a Demon Star Flare"

Stellar CME-flare relation

Preliminary

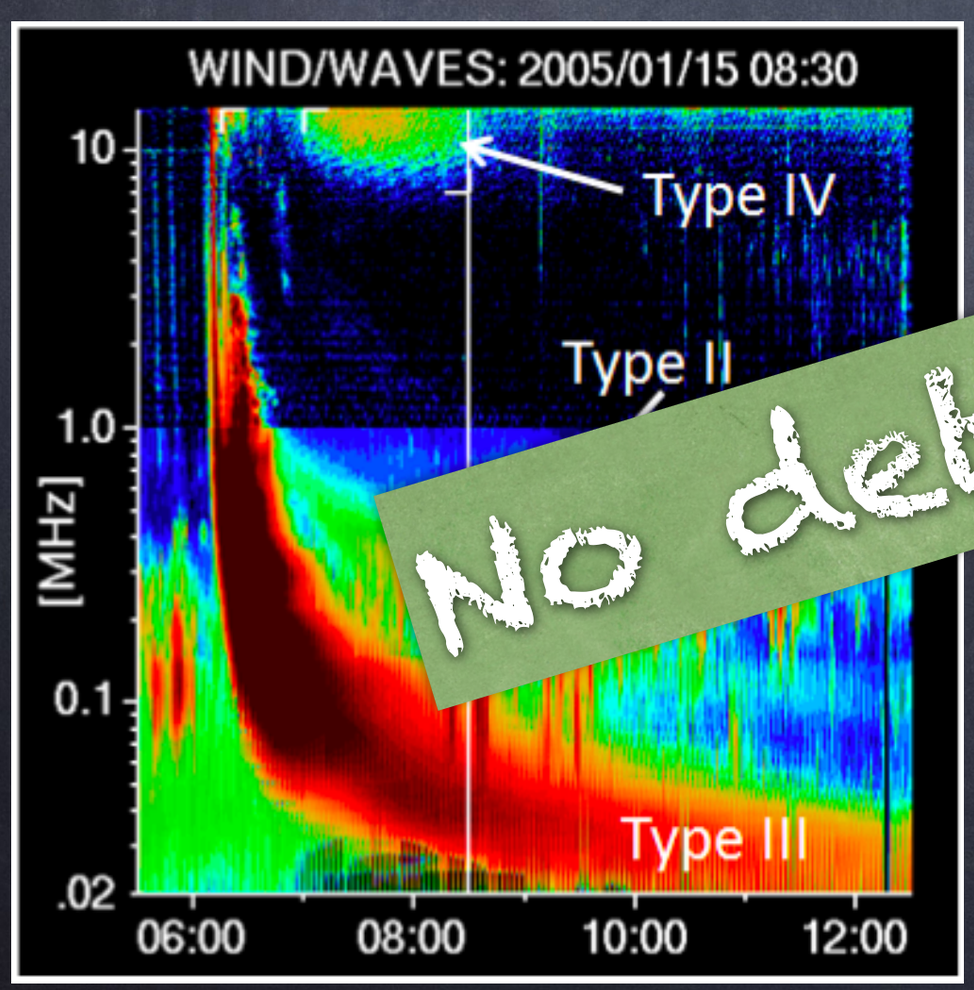




Moschou et al. 2018, in prep

Stellar CME Observations

1. Doppler shifts
2. X-ray absorption
3. Type-II radio bursts



Gopalswamy, ARXIV, 2016

VLA, New Mexico

Credit: NRAO

Crosley et al., ApJ, 2016, 2018a, 2018b

No detection YET

Simulations could save the day!

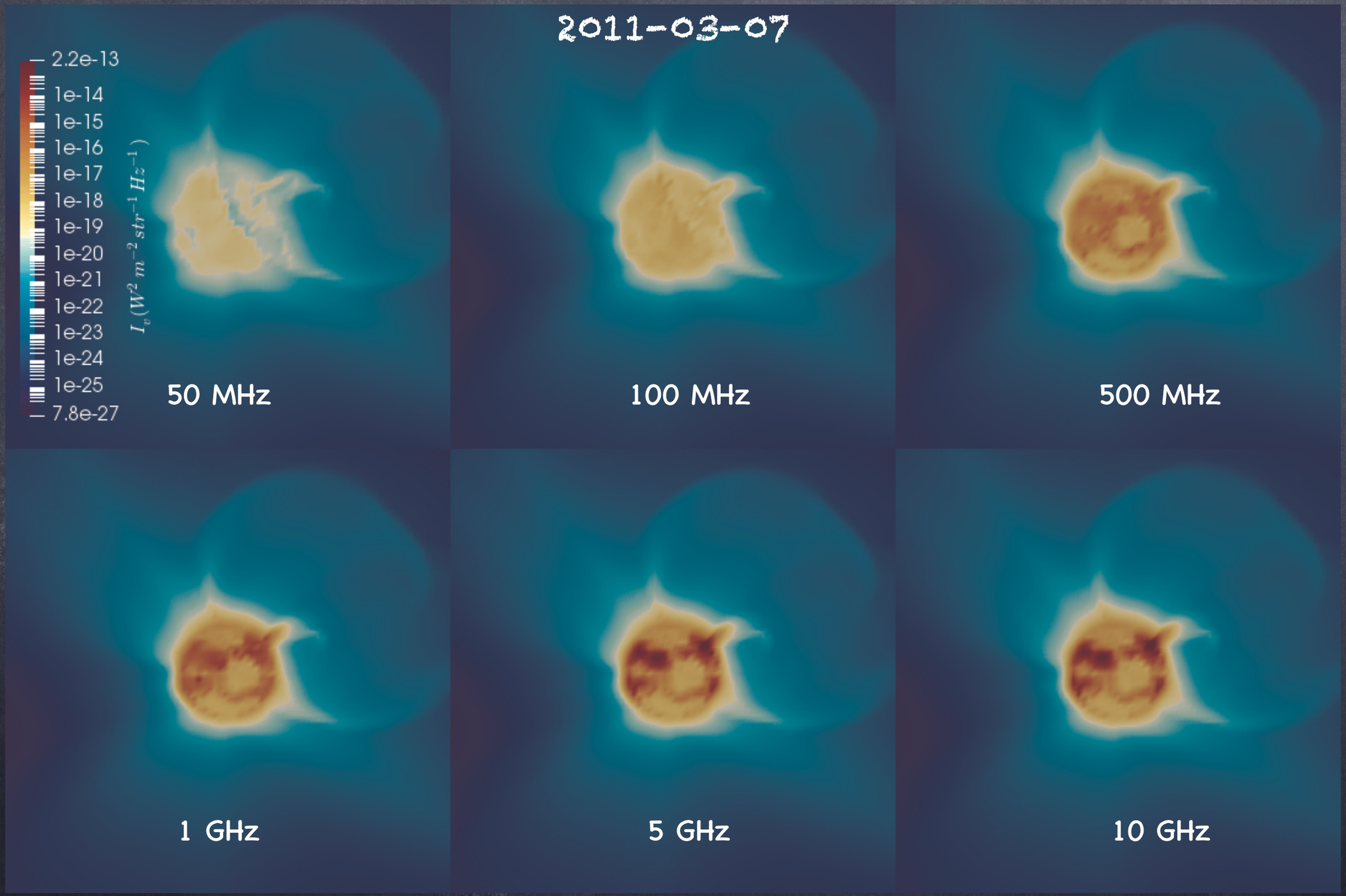
Towards a Realistic Radio Corona

BATS-R-US + AWSoM/R+ Radio Synthetic Imaging: Bremsstrahlung + Refraction

Moschou et al. 2018a (under review)

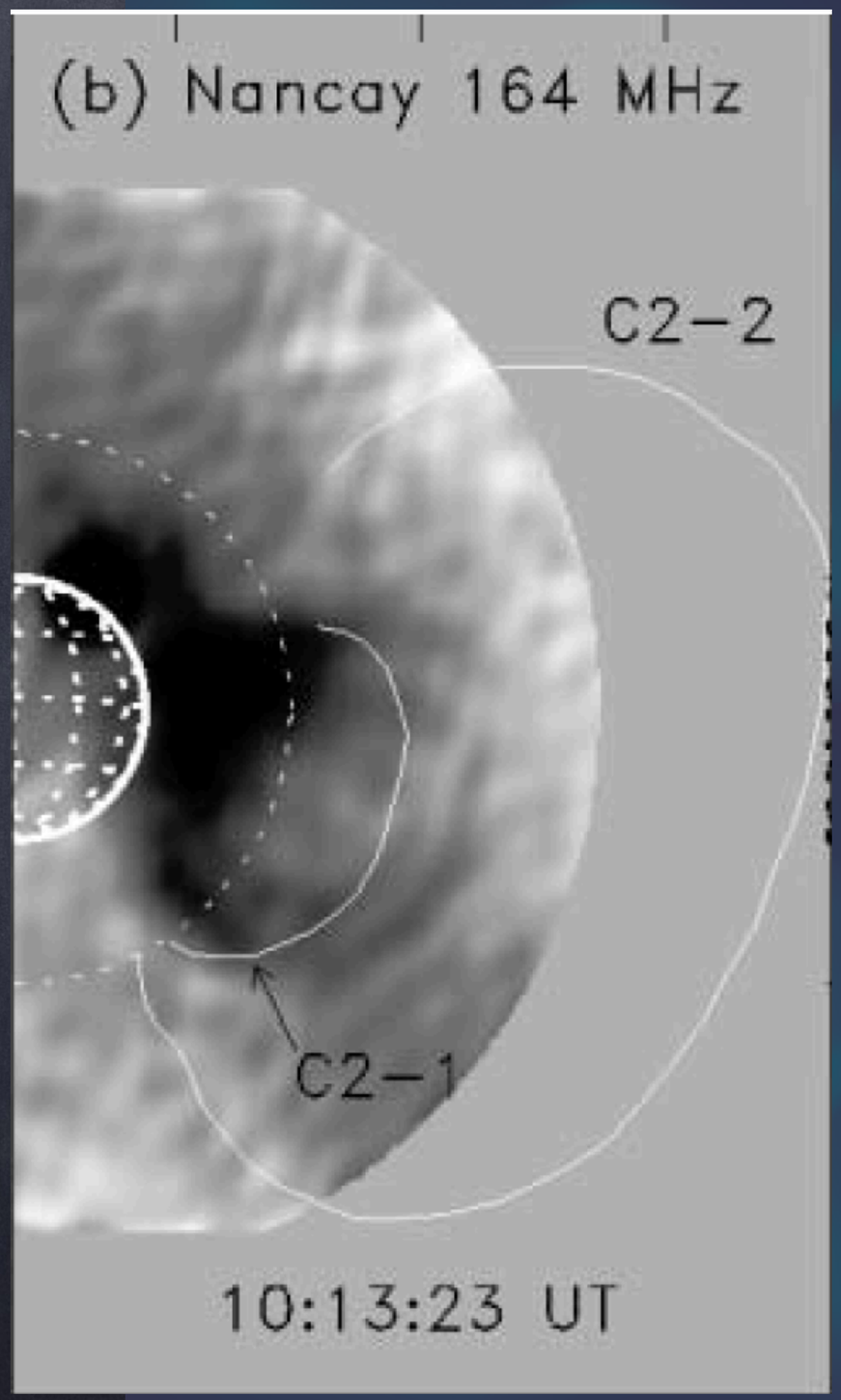
Towards a Realistic Radio Corona

2011-03-07

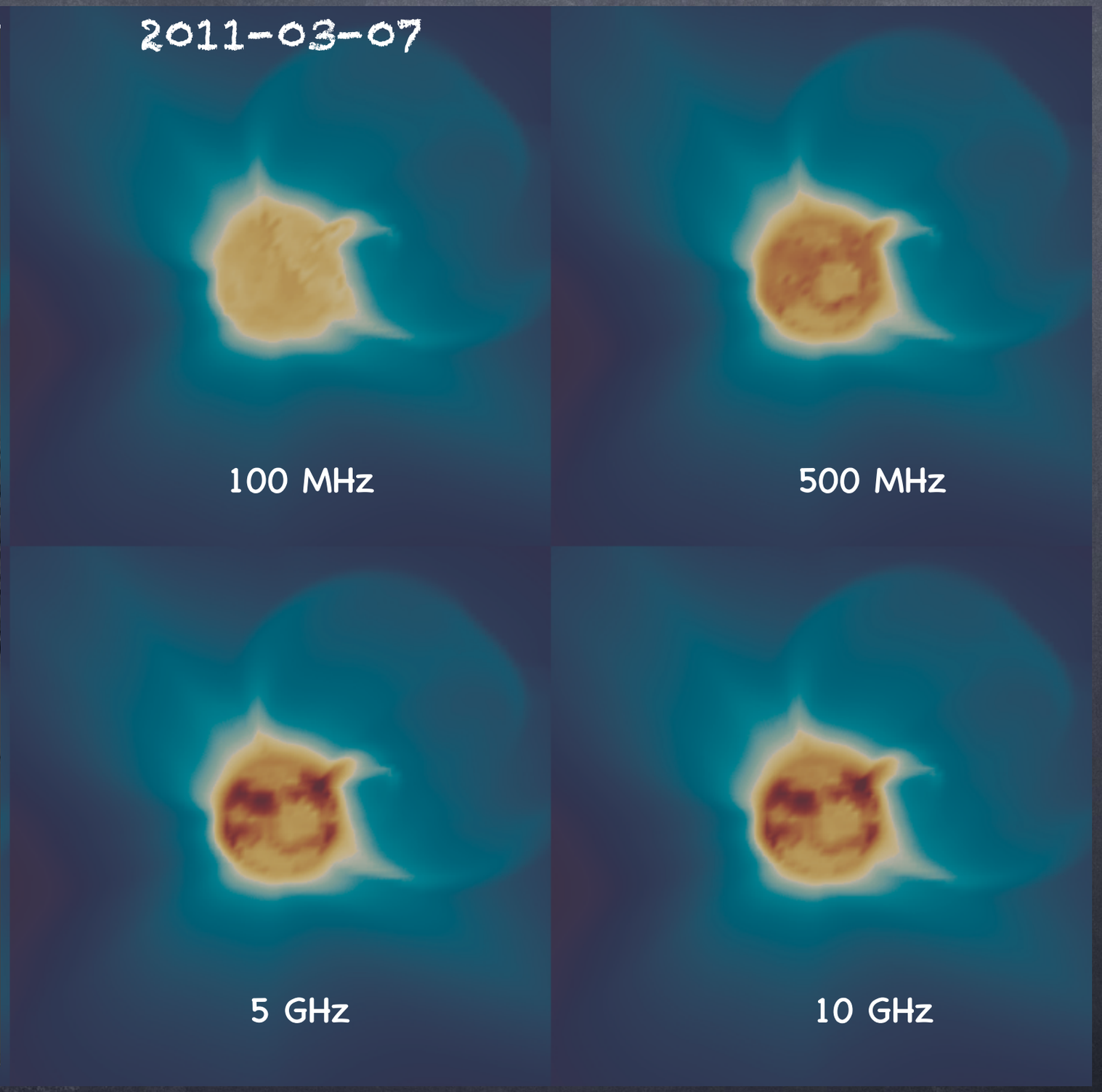


Moschou et al. 2018a (under review)

Towards a Realistic Radio Corona



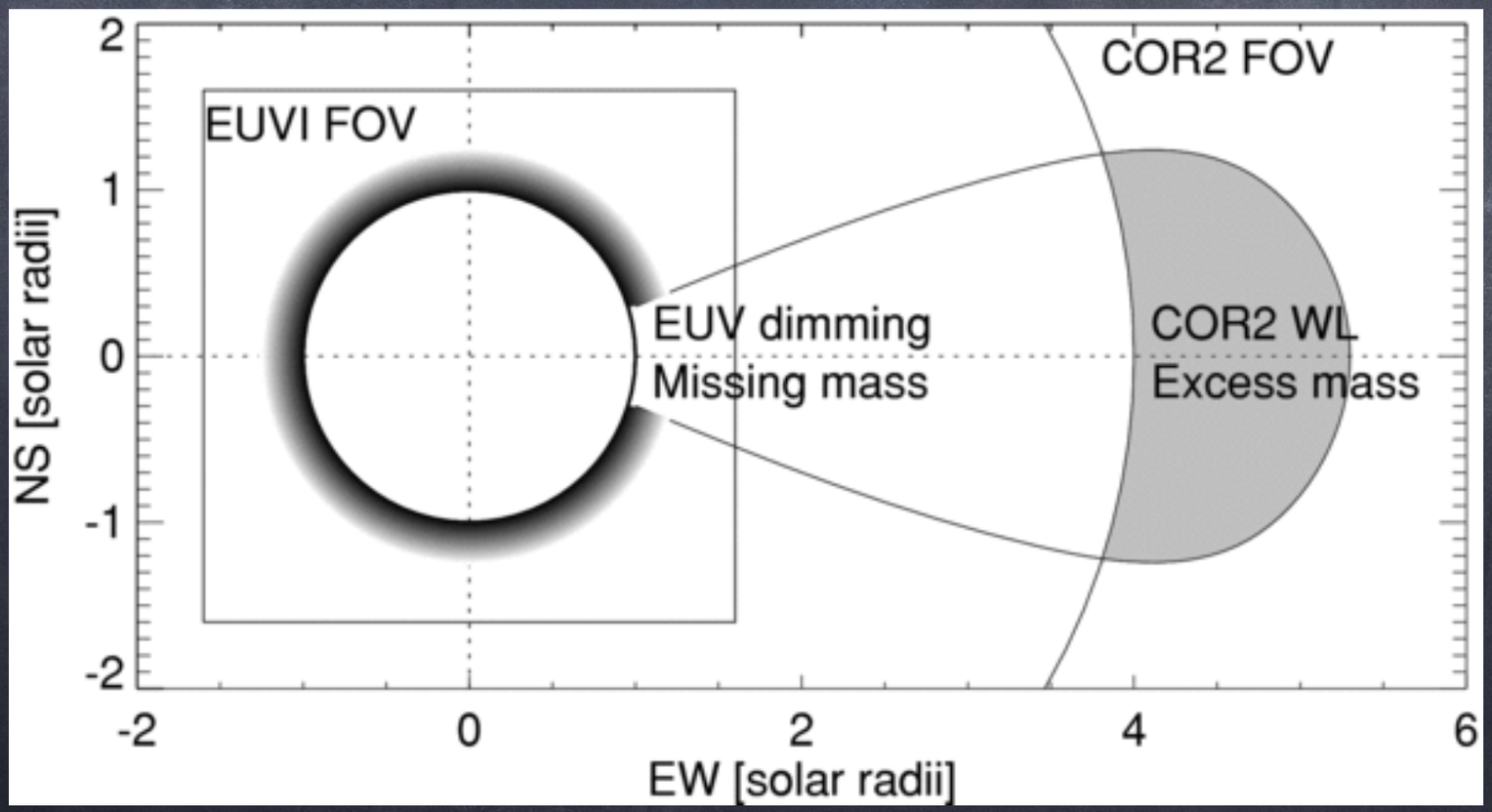
Bastian et al. 2001



Moschou et al. 2018a (under review)

Stellar CME Observations

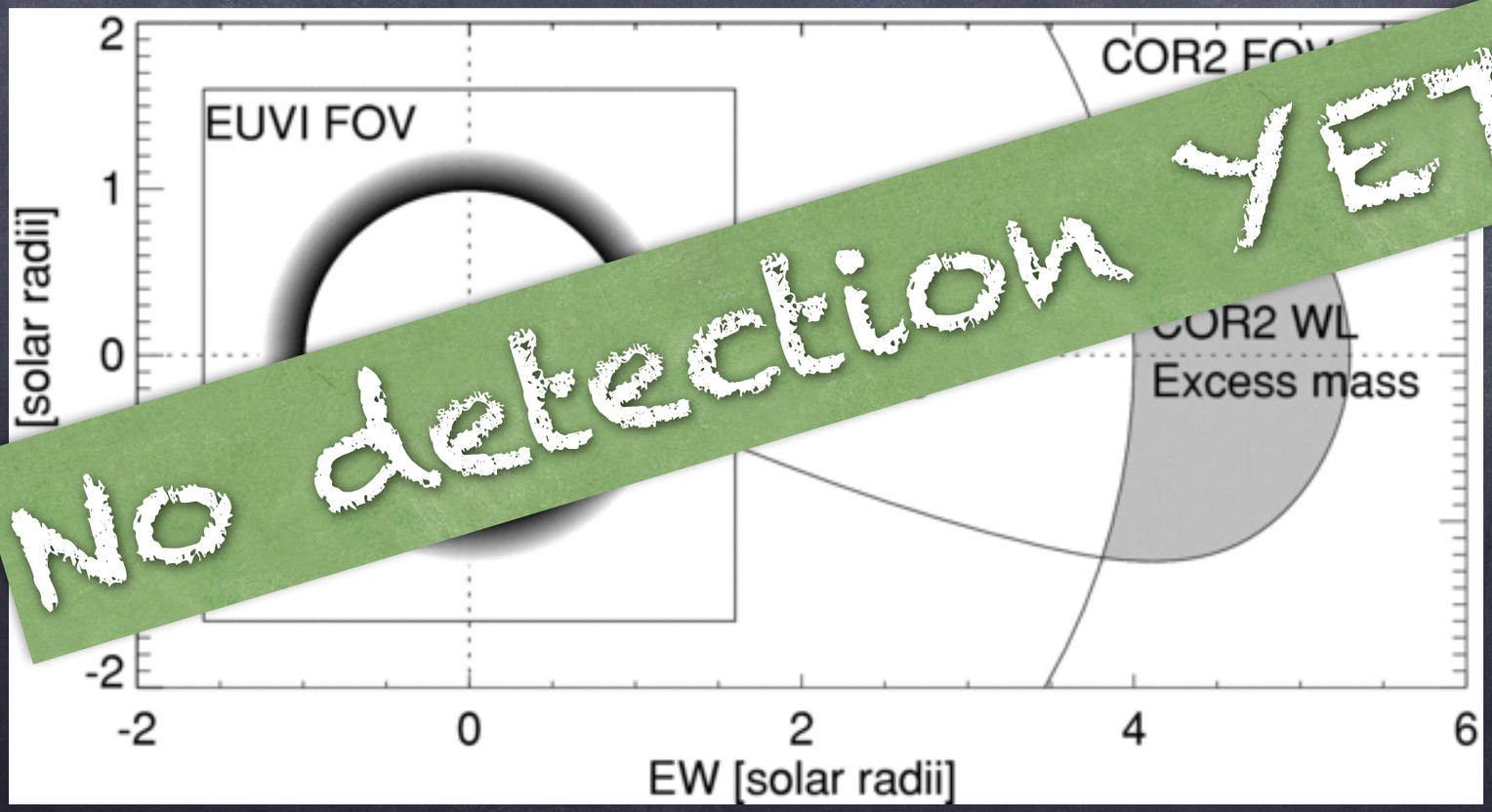
1. Doppler shifts
2. X-ray absorption
3. Type-II radio bursts
4. EUV Dimming



Aschwanden et al., ApJ, 2009; Mason et al., ApJ, 2014

Stellar CME Observations

1. Doppler shifts
2. X-ray absorption
3. Type-II radio bursts
4. EUV Dimming



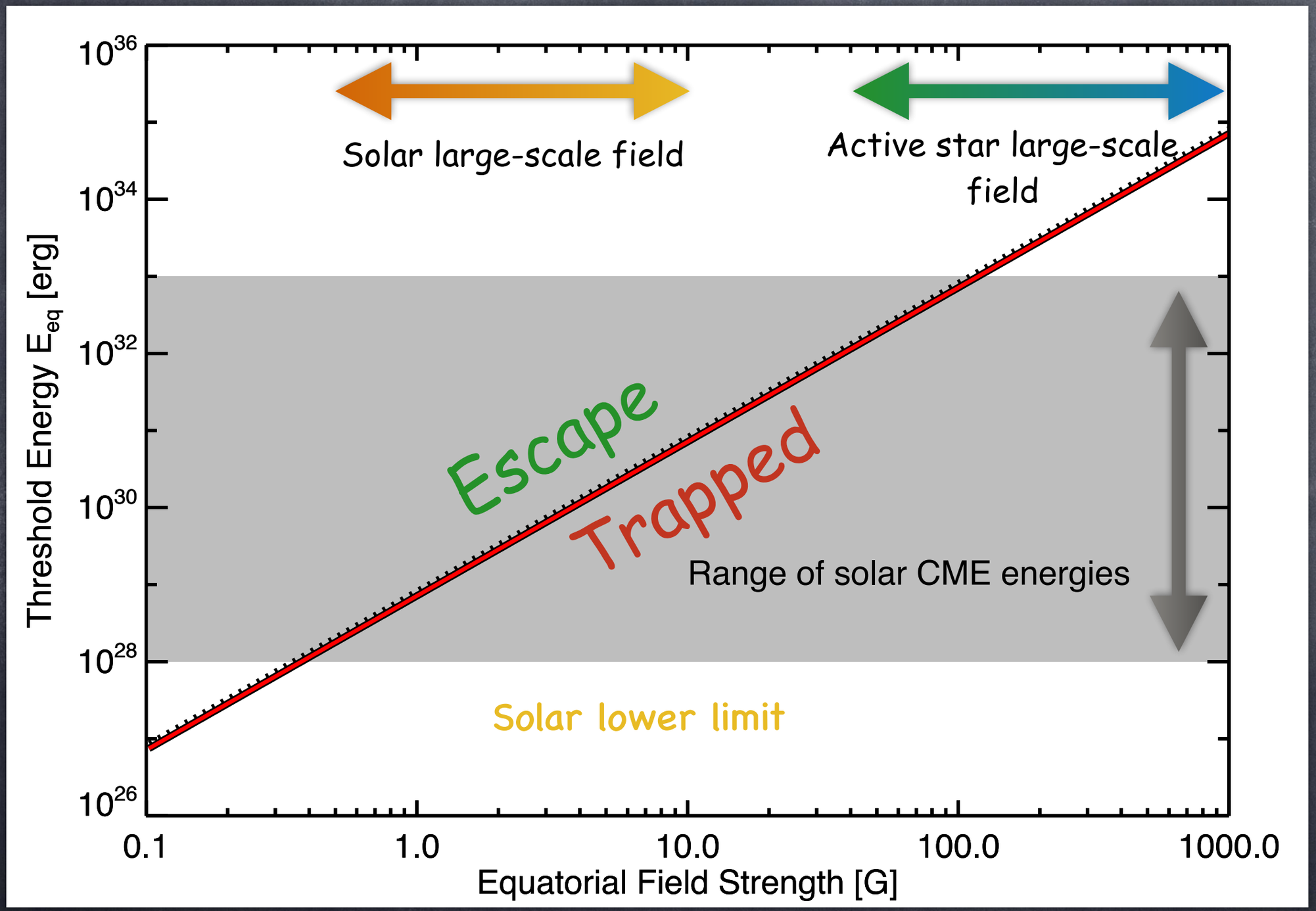
No detection YET

Aschwanden et al., ApJ, 2009; Mason et al., ApJ, 2014

To wrap up

- ✓ Beyond the T-based "habitable zone"
- ✓ Extrasolar space weather (CMEs+flares)
- ✓ Monster stellar CMEs expected from solar extrapolations associated with super-flares.
- ✓ Stellar CME-flare observational discrepancy (Moschou et al. 2018, in prep)
- ✓ Observational bias or fundamental process?
- ✓ More/new observations + modeling needed

CME suppression: theoretical threshold

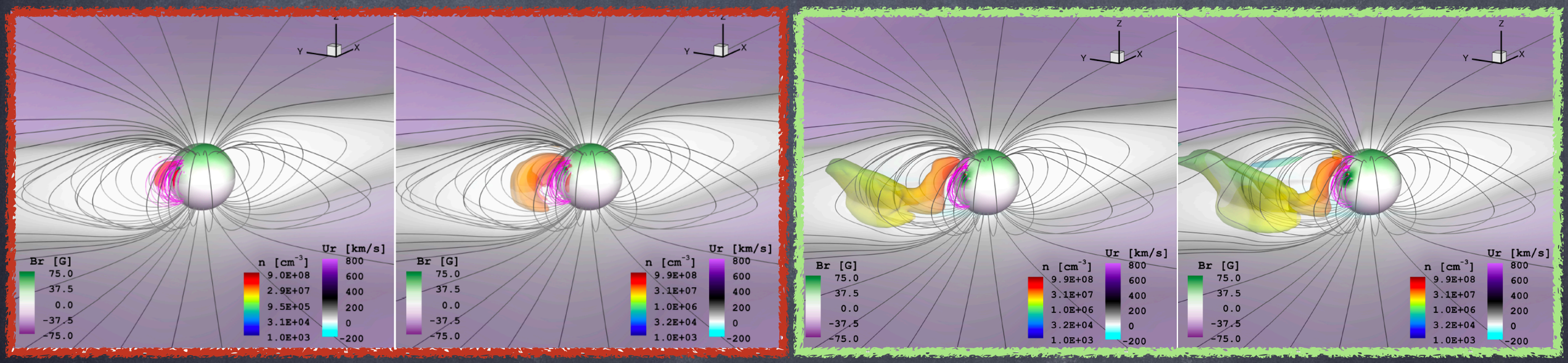


Drake et al. 2018 (in prep.)

Computational experiment

Strong large-scale B≈100G

Increasing Poloidal Flux available →

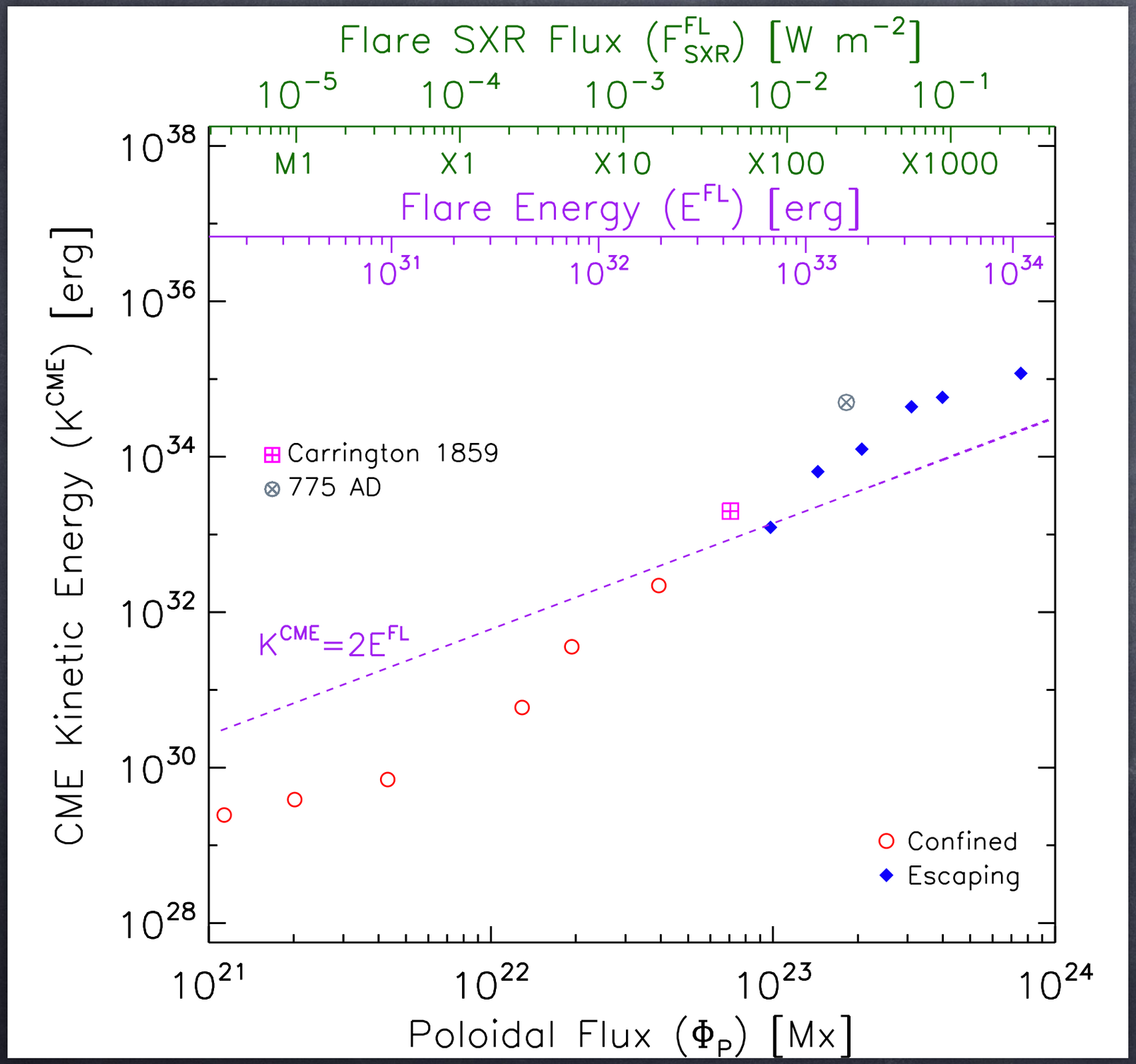


Suppressed

Escaping

Alvarado-Gomez et al., ApJ, 862, 93, 2018

CME suppression: computational threshold



Drake et al. 2013

$K^{CME} \approx 200\ E^{FL}{}_{,X}$

+

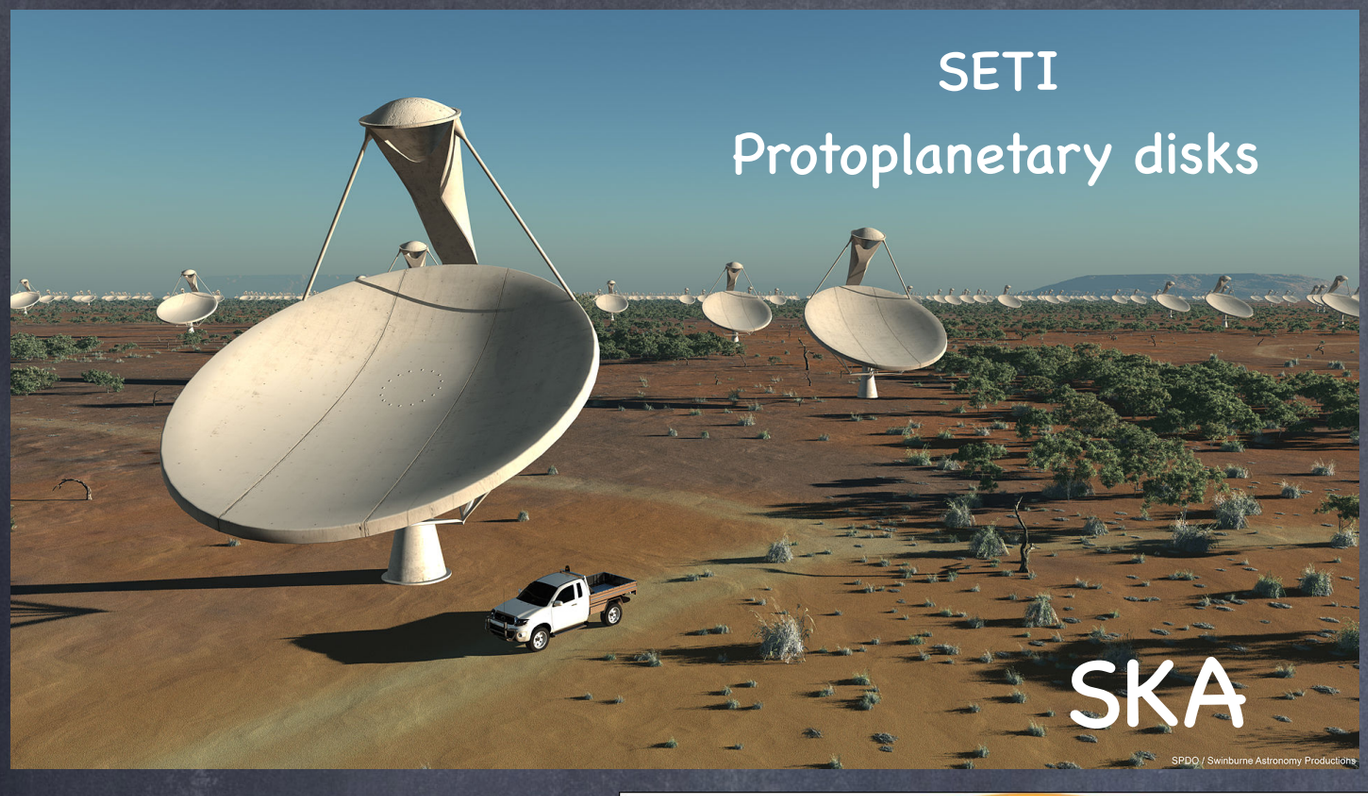
Kretzschmar (2011)

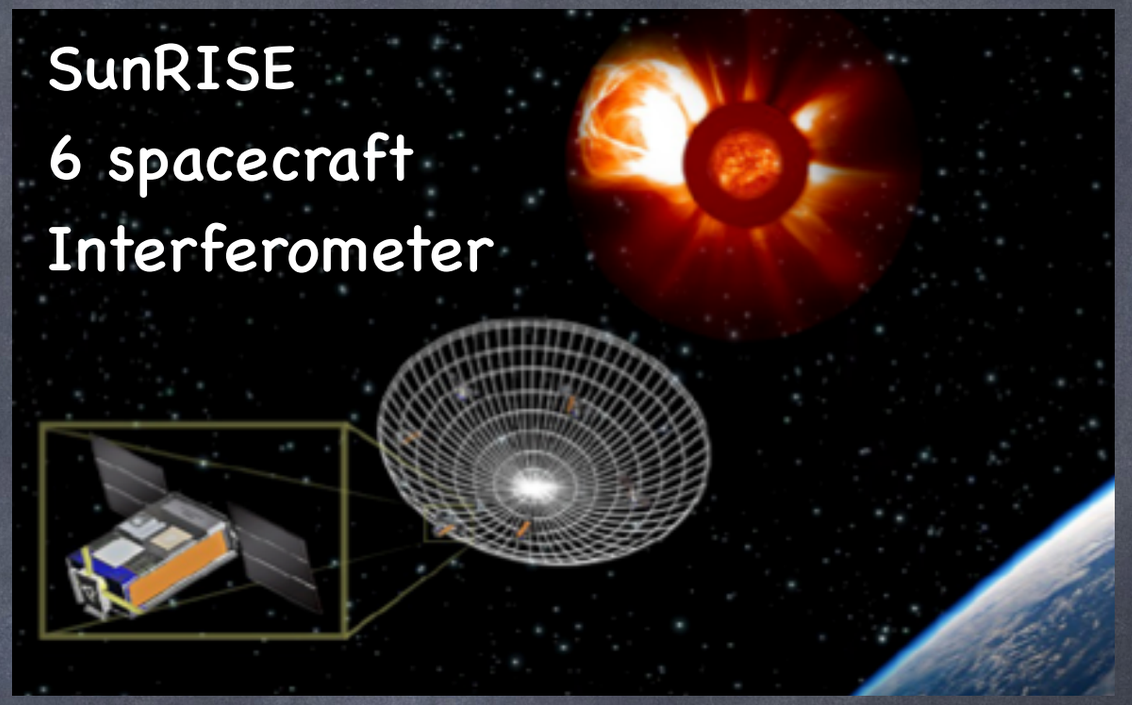
$E^{FL}{}_{,X} \approx 1\%\ E^{FL}$

Alvarado-Gomez et al. ApJ, 862, 93, 2018

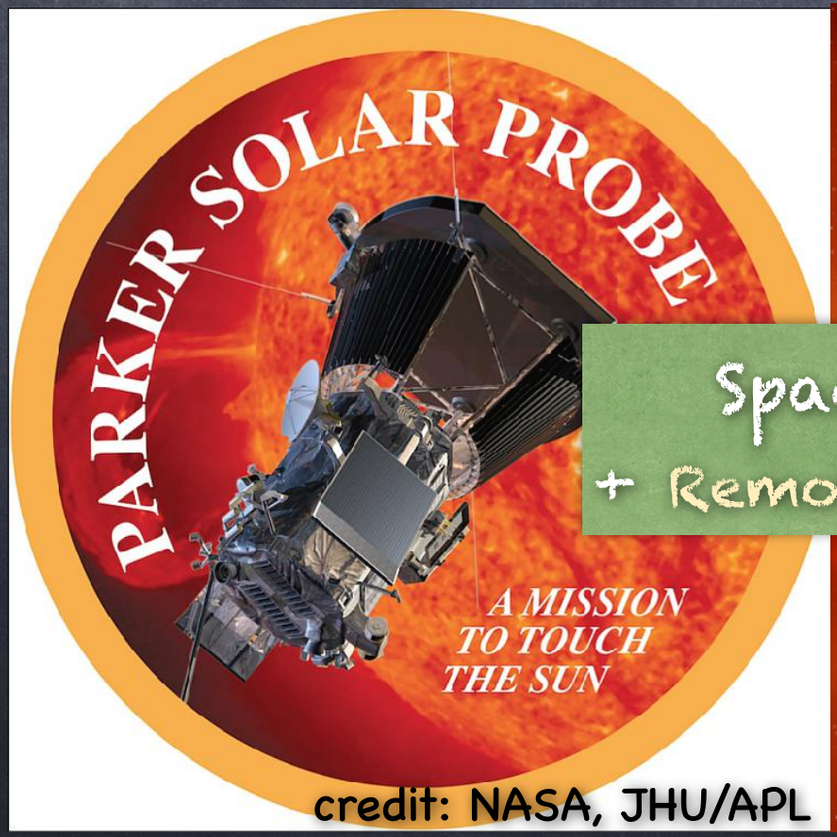
Future Observational Capabilities

Radio observations

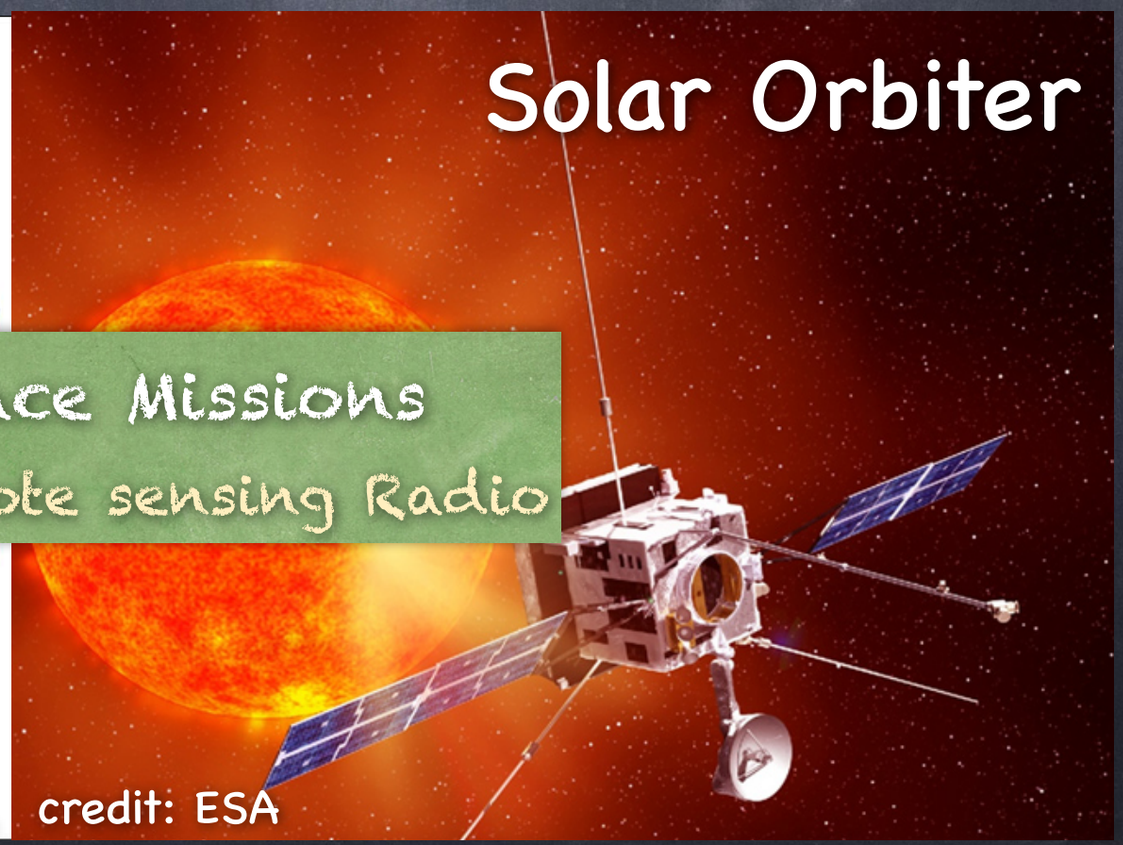




ngvla
Next Generation Very Large Array



credit: NASA, JHU/APL



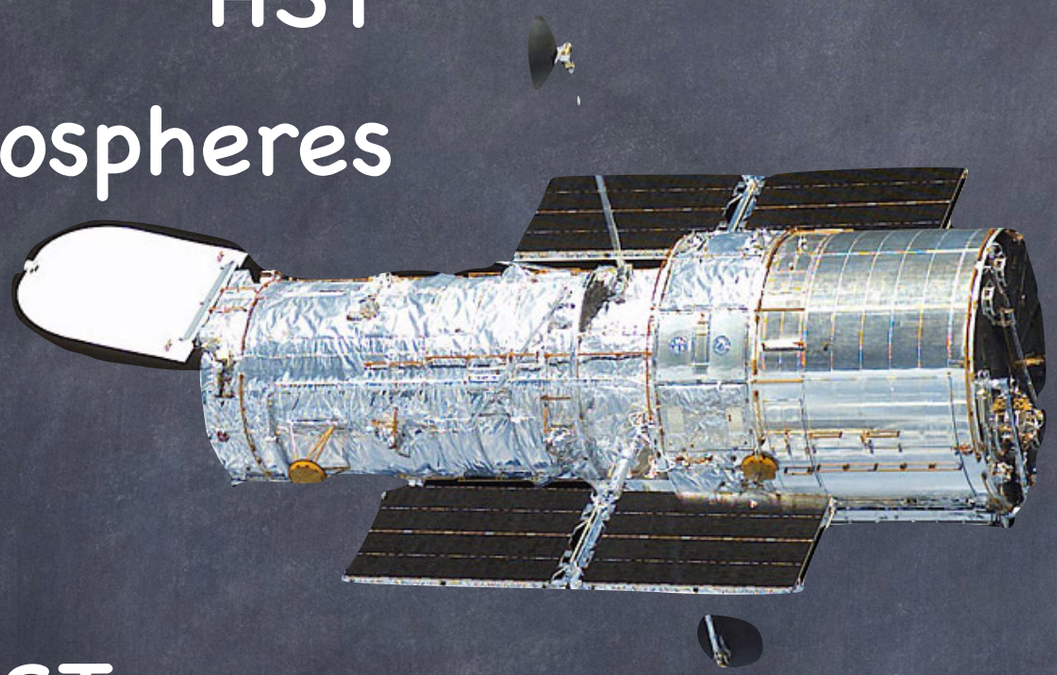
credit: ESA

Space Missions
+ Remote sensing Radio

Star & planet observations

HST

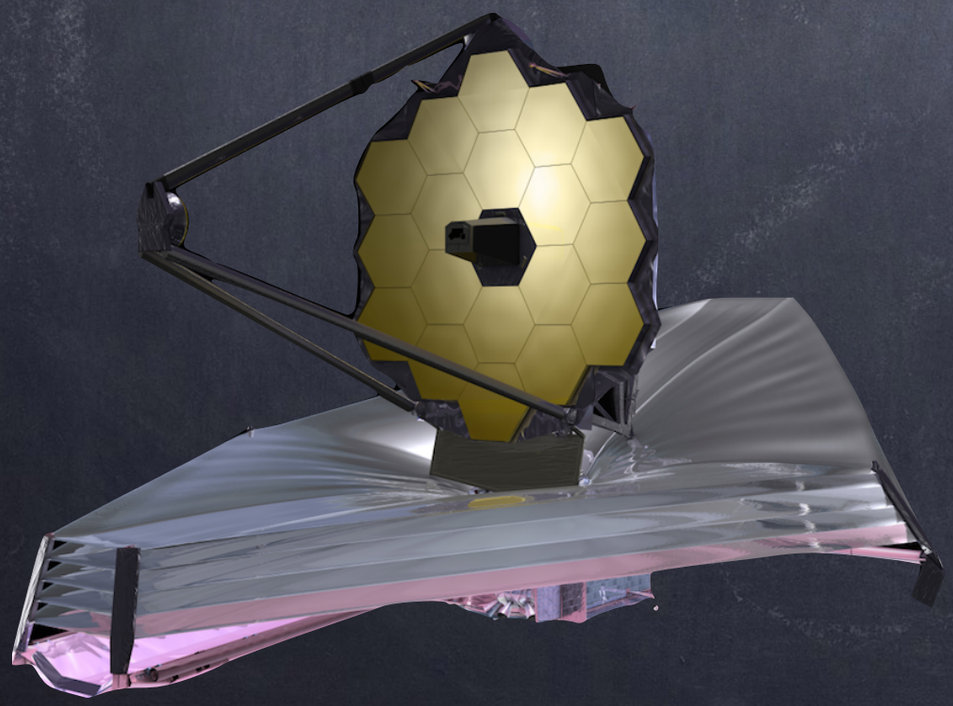
Astrospheres



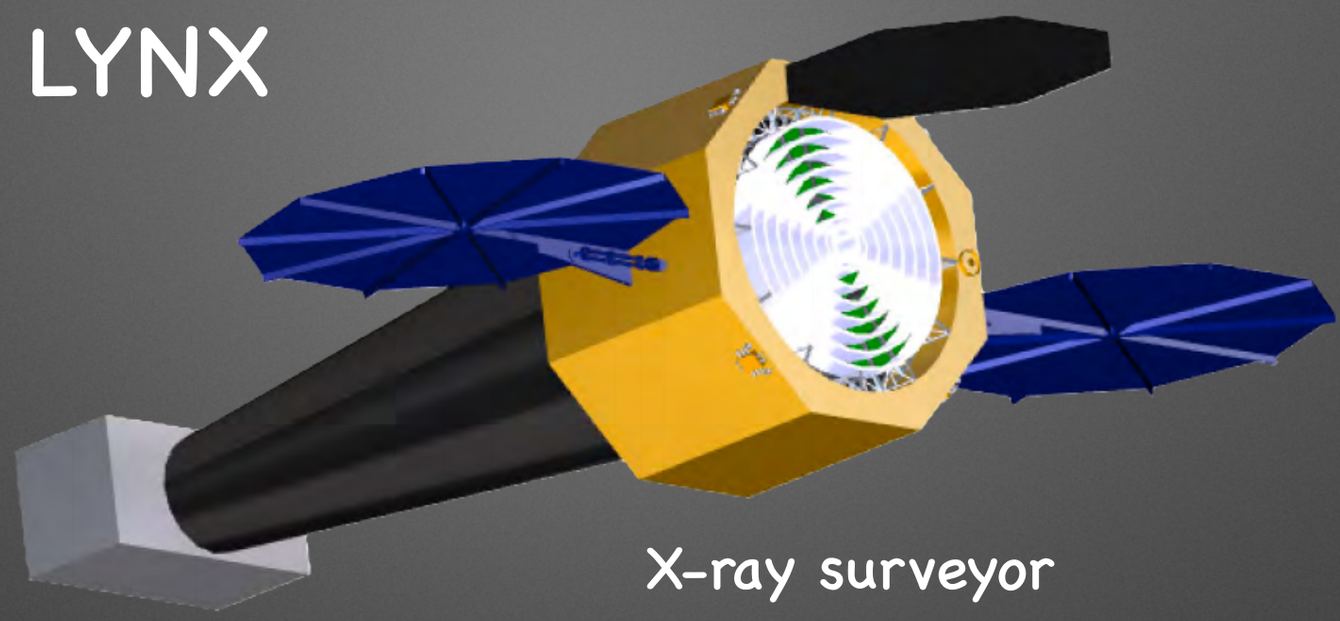
TESS

Transiting Exoplanet Survey Satellite

JWST



LYNX



X-ray surveyor

Conclusions

- Sun & fully convective stars both have magnetically driven winds
- Extrapolations are the 1st step
- Need to consider stellar evolution for different stellar types
- Account for new regimes, e.g. sub-Alfvénic, intense activity ones

Take away

- Increasing interest for exoplanetary environment characterization
- Solar physics is a great tool + detailed fundamental processes
- Exciting times for solar-stellar research: intensify dialogue

Thank you!

futuramaworldsoftomorrow.gamepedia.com

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