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Sub-Neptune Formation: The View from Resonant Planets

Nick Choksi, Eugene Chiang

(Submitted on 6 Mar 2020)

The orbital period ratios of neighbouring sub-Neptunes are distributed asymmetrically near first-order resonances. There are deficits of systems---"troughs" in the period ratio histogram---just short of commensurability, and excesses---"peaks"---just wide of it. We reproduce quantitatively the strongest peak-trough asymmetries, near the 3:2 and 2:1 resonances, using dissipative interactions between planets and their natal disks. Disk eccentricity damping captures bodies into resonance and clears the trough, and when combined with disk-driven convergent migration, draws planets initially wide of commensurability into the peak. The migration implied by the magnitude of the peak is modest; reductions in orbital period are $\sim$10\%, supporting the view that sub-Neptunes complete their formation more-or-less in situ. Once captured into resonance, sub-Neptunes of typical mass $\sim$5--$15 M_\oplus$ stay captured (contrary to an earlier claim), as they are immune to the overstability that afflicts lower mass planets. Driving the limited, short-scale migration is a gas disk whose surface density is fairly constant inside 1 AU and depleted relative to a solar-composition disk by 3--5 orders of magnitude. Such gas-poor but not gas-empty environments are quantitatively consistent with sub-Neptune core formation by giant impacts (and not, e.g., pebble accretion). While disk-planet interactions at the close of the planet formation era adequately explain the 3:2 and 2:1 asymmetries at periods $\gtrsim$ 5--15 days, subsequent modification by stellar tides appears necessary at shorter periods, particularly for the 2:1.

Comments: Submitted to MNRAS
Subjects: **Earth and Planetary Astrophysics (astro-ph.EP)**
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Effects of scattering, temperature gradients, and settling on the derived dust properties of observed protoplanetary disks

Anibal Sierra, Susana Lizano

(Submitted on 6 Mar 2020)

It is known that the millimeter dust thermal emission of protoplanetary disks is affected by scattering, such that for optically thick disks the emission decreases with respect to the pure absorption case and the spectral indices can reach values below 2. The latter can also be obtained with temperature gradients. Using simple analytical models of radiative transfer in thin slabs, we quantify the effect of scattering, vertical temperature gradients, and dust settling on the emission and spectral indices of geometrically thin face-on accretion disks around young stars. We find that in vertically isothermal disks with large albedo ($\omega_\nu \gtrsim 0.6$), the emergent intensity can increase at optical depths between 10^{-2} and 10^{-1}. We show that dust settling has important effects on the spectral indices in the optically thick regime, since the disk emission mainly traces small dust grains in the upper layers of the disk. The $\lambda = 870\ \mu$m emission of these small grains can hide large grains at the disk mid plane when the dust surface density is larger than $\sim$ 3.21 g cm^{-2}. Finally, because of the change of the shape of the spectral energy distribution, optically thick disks at 1.3 mm and grains with sizes between 300 μm $< a_{\rm max} <$ 1 mm have a 7 mm flux $\sim$ 60\% higher than the extrapolation from higher millimeter frequencies, assumed when scattering is neglected. This effect could provide an explanation to the excess emission at $\lambda = 7$ mm reported in several disks.

Subjects: **Earth and Planetary Astrophysics (astro-ph.EP)**; Solar and Stellar Astrophysics (astro-ph.SR)
Cite as: arXiv:2003.02982 [astro-ph.EP]
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Most Stars (and Planets?) Are Born in Intense Radiation Fields

Eve J. Lee, Philip F. Hopkins

(Submitted on 6 Mar 2020)

Protostars and young stars are strongly spatially "clustered" or "correlated" within their natal giant molecular clouds (GMCs). We demonstrate that such clustering leads to the conclusion that the incident bolometric radiative flux upon a random young star/disc is enhanced (relative to volume-averaged fluxes) by a factor which increases with the total stellar mass of the complex. Because the Galactic cloud mass function is top-heavy, the typical star in our Galaxy experienced a much stronger radiative environment than those forming in well-observed nearby (but relatively small) clouds, exceeding fluxes in the Orion Nebular Cluster by factors of $\gtrsim$30. Heating of the circumstellar disc around a median young star is dominated by this external radiation beyond $\sim$ 50 AU. And if discs are not well-shielded by ambient dust, external UV irradiation can dominate over the host star down to sub-AU scales. Another consequence of stellar clustering is an extremely broad Galaxy-wide distribution of incident flux (spanning > 10 decades), with half the Galactic star formation in a substantial "tail" towards even more intense background radiation. We also show that the strength of external irradiation is amplified super-linearly in high-density environments such as the Galactic centre, starbursts, or high-redshift galaxies.

Comments: MNRAS Letters in press
Subjects: **Solar and Stellar Astrophysics (astro-ph.SR)**; Earth and Planetary Astrophysics (astro-ph.EP); Astrophysics of Galaxies (astro-ph.GA)
Cite as: arXiv:2003.03390 [astro-ph.SR]
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Global 3-D Radiation Magnetohydrodynamic Simulations for FU Ori's Accretion Disk and Observational Signatures of Magnetic Fields

Zhaohuan Zhu, Yan-Fei Jiang, James M. Stone

(Submitted on 3 Dec 2019 (v1), last revised 6 Mar 2020 (this version, v2))

FU Ori is the prototype of FU Orionis systems which are outbursting protoplanetary disks. Magnetic fields in FU Ori's accretion disks have previously been detected using spectropolarimetry observations for Zeeman effects. We carry out global radiation ideal MHD simulations to study FU Ori's inner accretion disk. We find that (1) when the disk is threaded by vertical magnetic fields, most accretion occurs in the magnetically dominated atmosphere at z~R, similar to the "surface accretion" mechanism in previous locally-isothermal MHD simulations. (2) A moderate disk wind is launched in the vertical field simulations with a terminal speed of ~300-500 km/s and a mass loss rate of 1-10\% the disk accretion rate, which is consistent with observations. Disk wind fails to be launched in simulations with net toroidal magnetic fields. (3) The disk photosphere at the unit optical depth can be either in the wind launching region or the accreting surface region. Magnetic fields have drastically different directions and magnitudes between these two regions. Our fiducial model agrees with previous optical Zeeman observations regarding both the field directions and magnitudes. On the other hand, simulations indicate that future Zeeman observations at near-IR wavelengths or towards other FU Orionis systems may reveal very different magnetic field structures. (4) Due to energy loss by the disk wind, the disk photosphere temperature is lower than that predicted by the thin disk theory, and the previously inferred disk accretion rate may be lower than the real accretion rate by a factor of ~2-3.

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The HOSTS survey for exozodiacal dust: Observational results from the complete survey

Steve Ertel, Denis Defrère, Philip M. Hinz, Bertrand Mennesson, Grant M. Kennedy, William C. Danchi, Christopher Gelino, John M. Hill, William F. Hoffmann, Johan Mazoyer, George Rieke, Andrew Shannon, Karl Stapelfeldt, Eckhart Spalding, Jordan M. Stone, Amali Vaz, Alycia J. Weinberger, Phil Willems, Olivier Absil, Paul Arbo, Vanessa P. Bailey, Charles Beichman, Geoffrey Bryden, Elwood C. Downey, Olivier Durney, Simone Esposito, Andras Gaspar, Paul Grenz, Chris A. Haniff, Jarron M. Leisenring, Lindsay Marion, Tom J. McMahon, Rafael Millan-Gabet, Oscar M. Montoya, Katie M. Morzinski, Saavidra Perera, Enrico Pinna, Jörg-Uwe Pott, Jennifer Power, Alfio Puglisi, Aki Roberge, Eugene Serabyn, Andrew J. Skemer, Kate Y. L. Su, Vidhya Vaitheeswaran, Mark C. Wyatt

(Submitted on 7 Mar 2020)

The Large Binocular Telescope Interferometer (LBTI) enables nulling interferometric observations across the N band (8 to 13 um) to suppress a star's bright light and probe for faint circumstellar emission. We present and statistically analyze the results from the LBTI/HOSTS (Hunt for Observable Signatures of Terrestrial Systems) survey for exozodiacal dust. By comparing our measurements to model predictions based on the Solar zodiacal dust in the N band, we estimate a 1 sigma median sensitivity of 23 zodis for early type stars and 48 zodis for Sun-like stars, where 1 zodi is the surface density of habitable zone (HZ) dust in the Solar system. Of the 38 stars observed, 10 show significant excess. A clear correlation of our detections with the presence of cold dust in the systems was found, but none with the stellar spectral type or age. The majority of Sun-like stars have relatively low HZ dust levels (best-fit median: 3 zodis, 1 sigma upper limit: 9 zodis, 95% confidence: 27 zodis based on our N band measurements), while ~20% are significantly more dusty. The Solar system's HZ dust content is consistent with being typical. Our median HZ dust level would not be a major limitation to the direct imaging search for Earth-like exoplanets, but more precise constraints are still required, in particular to evaluate the impact of exozodiacal dust for the spectroscopic characterization of imaged exo-Earth candidates.

Comments: accepted for publication in AJ
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Peas in a Pod? Radius correlations in Kepler multi-planet systems

Lena Murchikova, Scott Tremaine

(Submitted on 4 Mar 2020)

We address the claim of Weiss et al. (2018) that the radii of adjacent planets in Kepler multi-planet systems are correlated. We explore two simple toy models---in the first the radii of the planets are chosen at random from a single universal distribution, and in the second we postulate several types of system with distinct radius distributions. We show that an apparent correlation between the radii of adjacent planets similar to the one reported by Weiss et al. (2018) can arise in both models. In addition the second model fits all other aspects of the radius distribution, including the signal-to-noise distribution of the observed planets. We also comment on the validity of a commonly used correction that is used to estimate intrinsic planet occurrence rates, based on weighting planets by the inverse of their detectability.

Comments: 13 pages, 8 figures, 1 appendix
Subjects: **Earth and Planetary Astrophysics (astro-ph.EP)**
Cite as: arXiv:2003.02290 [astro-ph.EP]
(or arXiv:2003.02290v1 [astro-ph.EP] for this version)

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Importance of radiative effects in gap opening by planets in protoplanetary disks

Alexandros Ziampras, Wilhelm Kley, Cornelis P. Dullemond

(Submitted on 4 Mar 2020)

Recent ALMA observations revealed concentric annular structures in several young class-II objects. In an attempt to produce the rings and gaps in some of these systems, they have been modeled numerically with a single embedded planet assuming a locally isothermal equation of state. This is often justified by observations targeting the irradiation-dominated outer regions of disks (approximately 100 au). We test this assumption by conducting hydrodynamics simulations of embedded planets in thin locally isothermal and radiative disks that mimic the systems HD 163296 and AS 209 in order to examine the effect of including the energy equation in a seemingly locally isothermal environment as far as planet-disk interaction is concerned. We find that modeling such disks with an ideal equation of state makes a difference in terms of the number of produced rings and the spiral arm contrast in the disk. Locally isothermal disks produce sharper annular or azimuthal features and overestimate a single planet's gap-opening capabilities by producing multiple gaps. In contrast, planets in radiative disks carve a single gap for typical disk parameters. Consequently, for accurate modeling of planets with semimajor axes up to about 100 au, radiative effects should be taken into account even in seemingly locally isothermal disks. In addition, for the case of AS 209, we find that the primary gap is significantly different between locally isothermal and radiative models. Our results suggest that multiple planets are required to explain the ring-rich structures in such systems.

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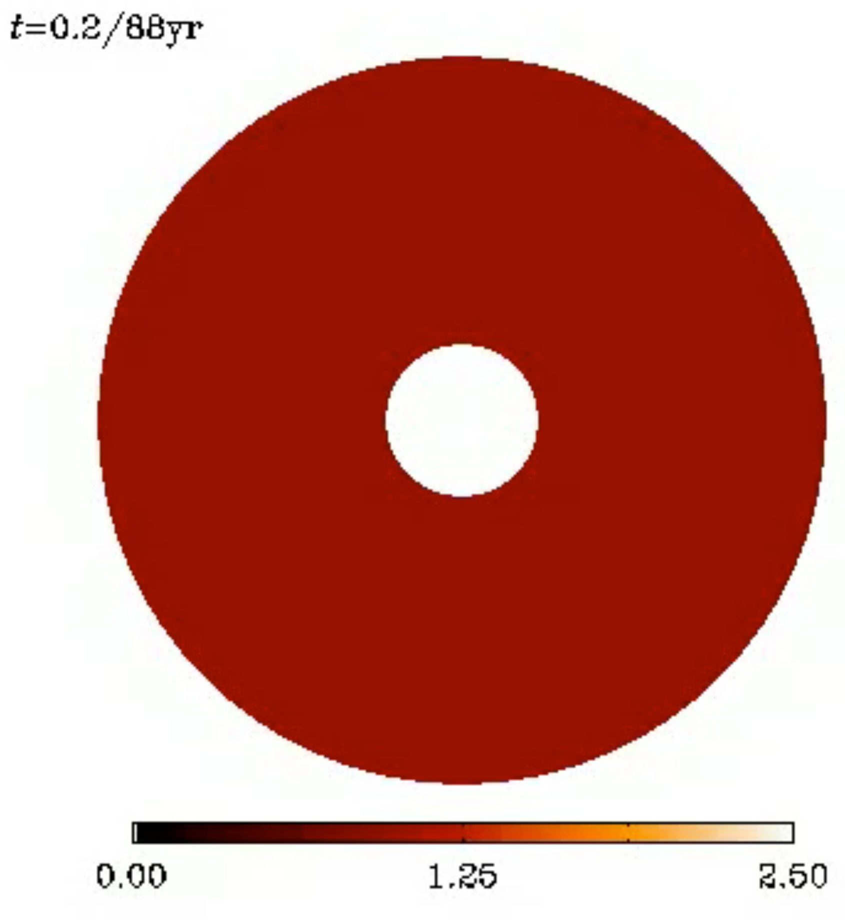
Linking studies of tiny meteoroids, zodiacal dust, cometary dust and circumstellar disks

Anny-Chantal Levasseur-Regourd, Clément Baruteau, Jérémie Lasue, Julien Milli, Jean-Baptiste Renard

(Submitted on 6 Mar 2020)

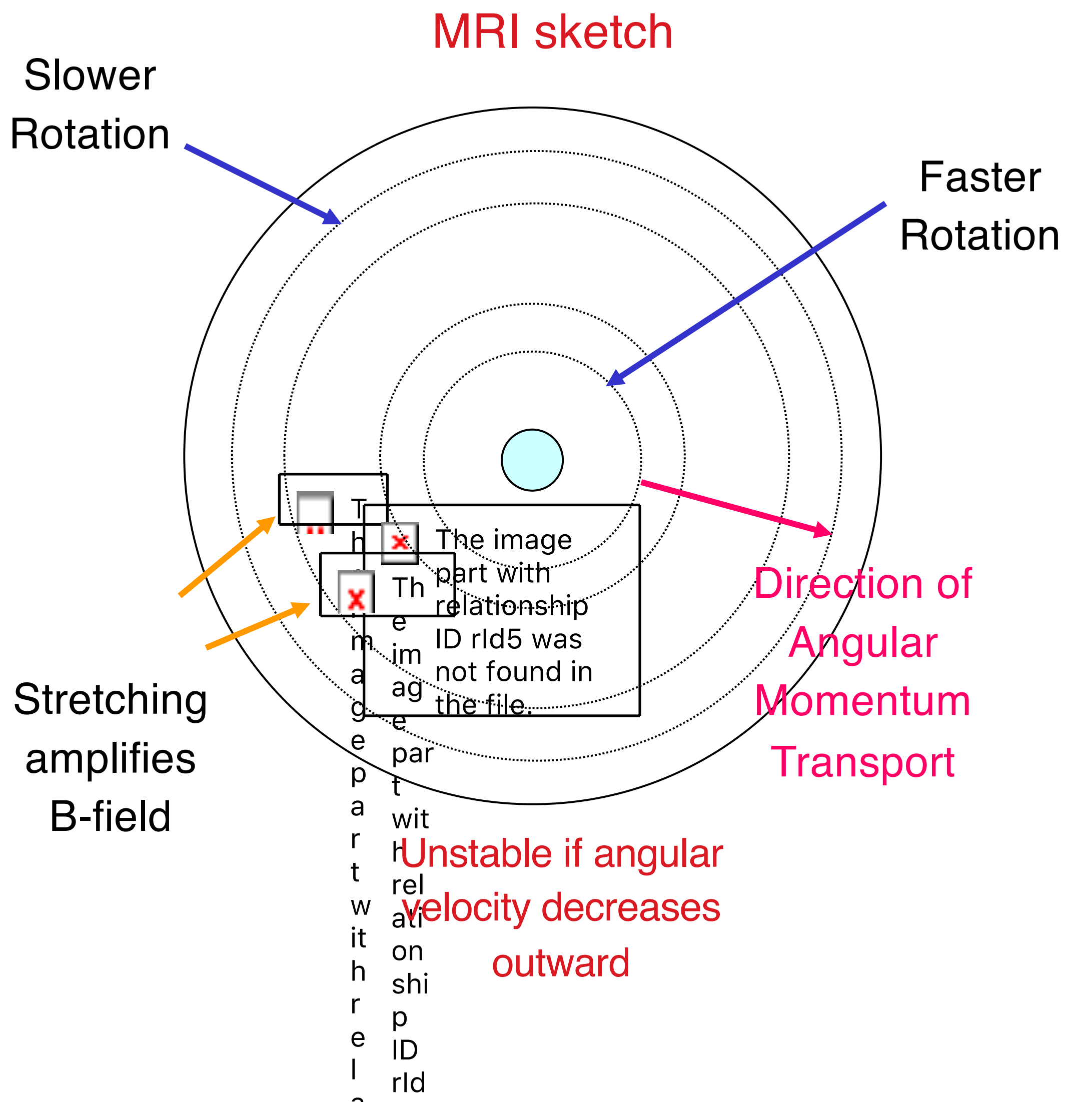
Tiny meteoroids entering the Earth's atmosphere and inducing meteor showers have long been thought to originate partly from cometary dust. Together with other dust particles, they form a huge cloud around the Sun, the zodiacal cloud. From our previous studies of the zodiacal light, as well as other independent methods (dynamical studies, infrared observations, data related to Earth's environment), it is now established that a significant fraction of dust particles entering the Earth's atmosphere comes from Jupiter-family comets (JFCs). This paper relies on our understanding of key properties of the zodiacal cloud and of comet 67P/Churyumov-Gerasimenko, extensively studied by the Rosetta mission to a JFC. The interpretation, through numerical and experimental simulations of zodiacal light local polarimetric phase curves, has recently allowed us to establish that interplanetary dust is rich in absorbing organics and consists of fluffy particles. The ground-truth provided by Rosetta presently establishes that the cometary dust particles are rich in organic compounds and consist of quite fluffy and irregular aggregates. Our aims are as follows: (1) to make links, back in time, between peculiar micrometeorites, tiny meteoroids, interplanetary dust particles, cometary dust particles, and the early evolution of the Solar System, and (2) to show how detailed studies of such meteoroids and of cometary dust particles can improve the interpretation of observations of dust in protoplanetary and debris disks. Future modeling of dust in such disks should favor irregular porous particles instead of more conventional compact spherical particles.

Balbus & Hawley (1991) – Magnetorotational Instability as source of turbulence



Magnetized disk

Lyra et al. (2008a)



Saturated State of MRI

Energy budget

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Dynamo-generated Turbulence and Large-Scale Magnetic Fields in a Keplerian Shear Flow

Show affiliations

Brandenburg, Axel; Nordlund, Ake; Stein, Robert F.; Torkelsson, Ulf

The nonlinear evolution of magnetized Keplerian shear flows is simulated in a local, three-dimensional model, including the effects of compressibility and stratification. Supersonic flows are initially generated by the Balbus-Hawley magnetic shear instability. The resulting flows regenerate a turbulent magnetic field which, in turn, reinforces the turbulence. Thus, the system acts like a dynamo that generates its own turbulence. However, unlike usual dynamos, the magnetic energy exceeds the kinetic energy of the turbulence by a factor of 3-10. By assuming the field to be vertical on the outer (upper and lower) surfaces we do not constrain the horizontal magnetic flux. Indeed, a large-scale toroidal magnetic field is generated, mostly in the form of toroidal flux tubes with lengths comparable to the toroidal extent of the box. This large-scale field is mainly of even (i.e., quadrupolar) parity with respect to the midplane and changes direction on a timescale of ~30 orbits, in a possibly cyclic manner. The effective Shakura-Sunyaev alpha viscosity parameter is between 0.001 and 0.005, and the contribution from the Maxwell stress is ~3-7 times larger than the contribution from the Reynolds stress.

FIG. 6.—Sketch of the energy budget. Energy is tapped from the Keplerian motion and goes into magnetic and kinetic energy, and is finally converted into heat. The numbers give the approximate energy fluxes in units of $\langle \frac{1}{2} B^2 \Omega \rangle$.

$$\frac{d}{dt}\left(\frac{1}{2\mu_0}B^2\right) = -\frac{3}{2}\Omega_0 \frac{1}{\mu_0} B_x B_y - \boldsymbol{u}\cdot(\boldsymbol{J}\times\boldsymbol{B}) - \eta\mu_0 J^2$$

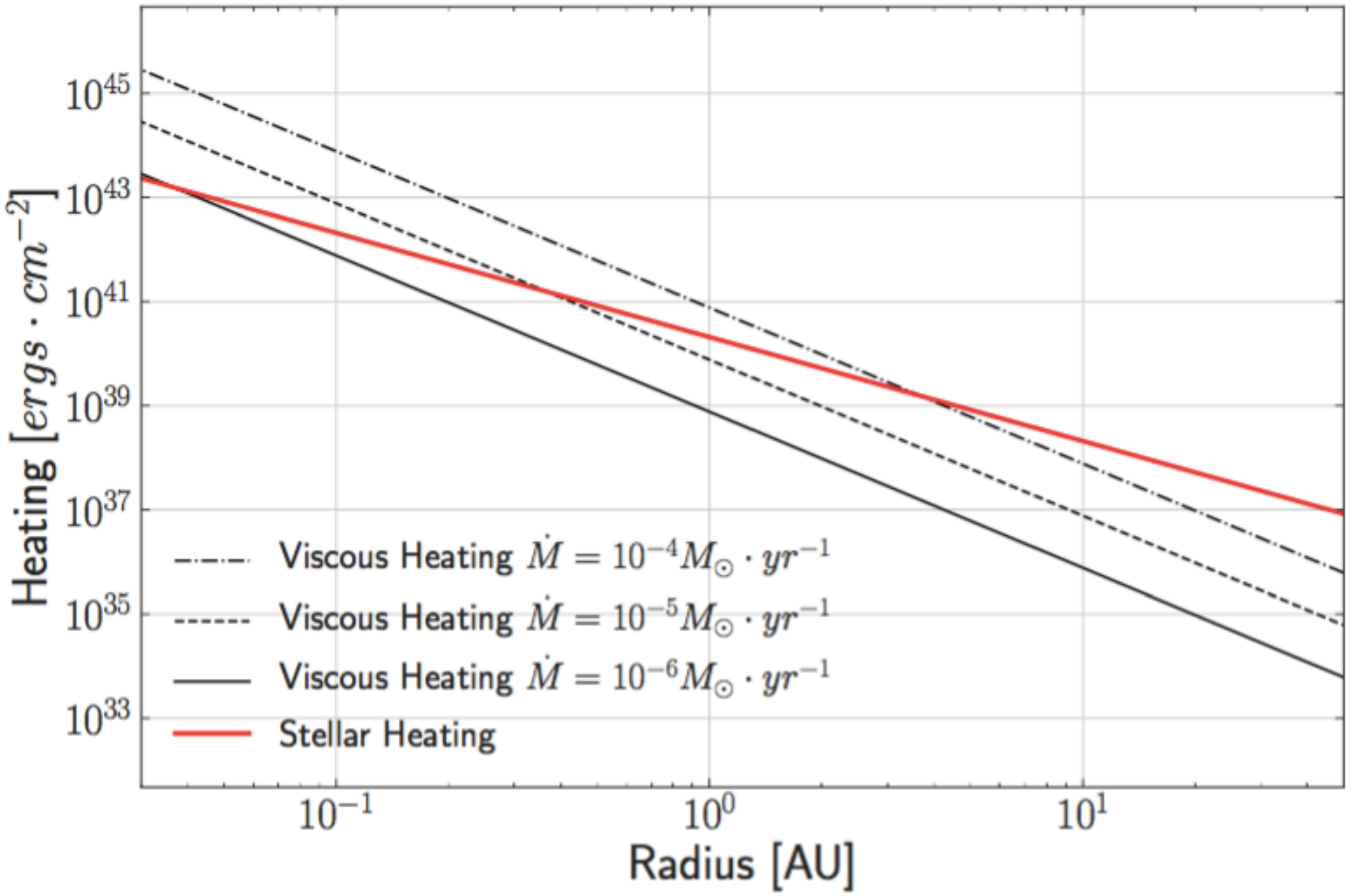
$$\frac{d}{dt}\left(\frac{1}{2}\rho u^2\right) = \frac{3}{2}\Omega_0 \rho u_x u_y + \rho\boldsymbol{u}\cdot\boldsymbol{g} - \boldsymbol{u}\cdot\nabla p + \boldsymbol{u}\cdot(\boldsymbol{J}\times\boldsymbol{B}) - 2\nu\rho S^2$$

$$\frac{d}{dt}\rho e = -p\nabla\cdot\boldsymbol{u} + 2\nu\rho S^2 + \eta\mu_0 J^2 + \rho Q$$

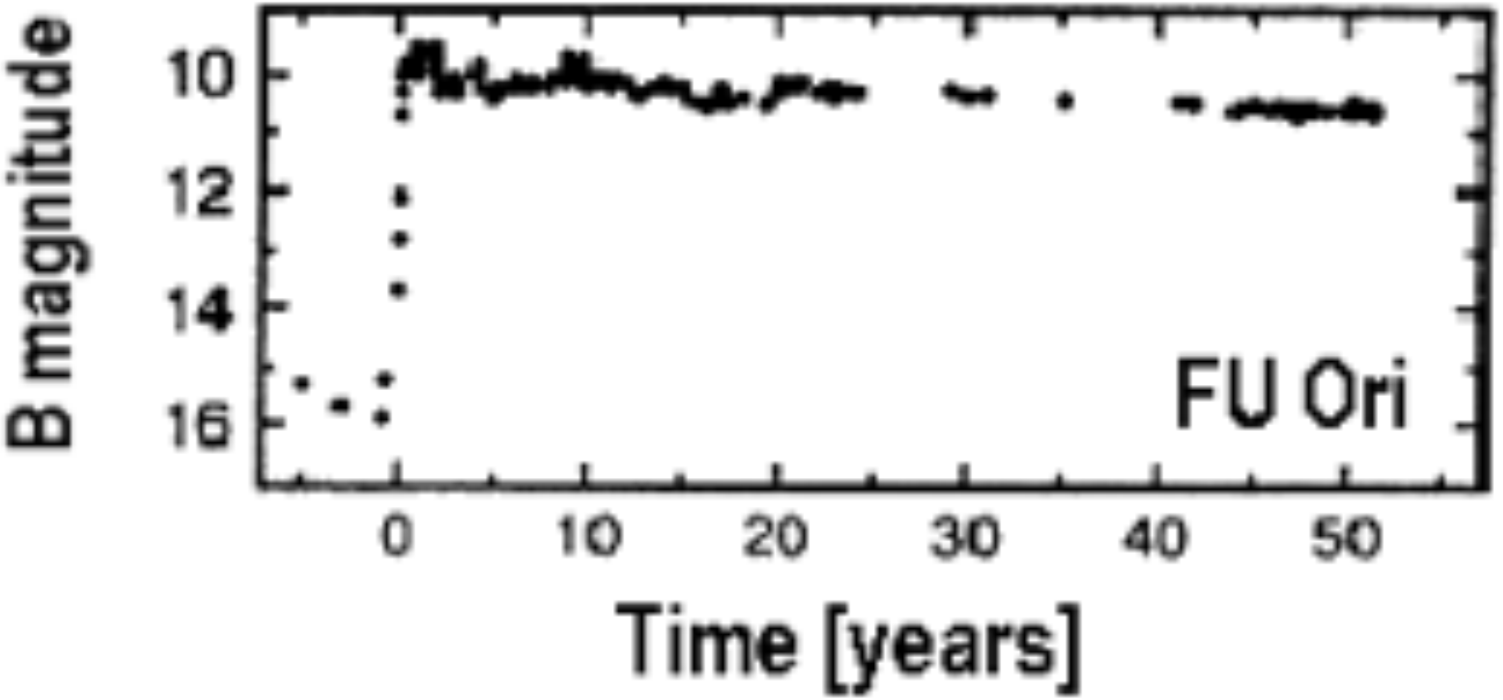
$$\frac{d}{dt}E_{tot} = \frac{3}{2}\Omega_0\left(\rho u_x u_y - \frac{1}{\mu_0}B_x B_y\right) + \rho Q$$

Viscous heating

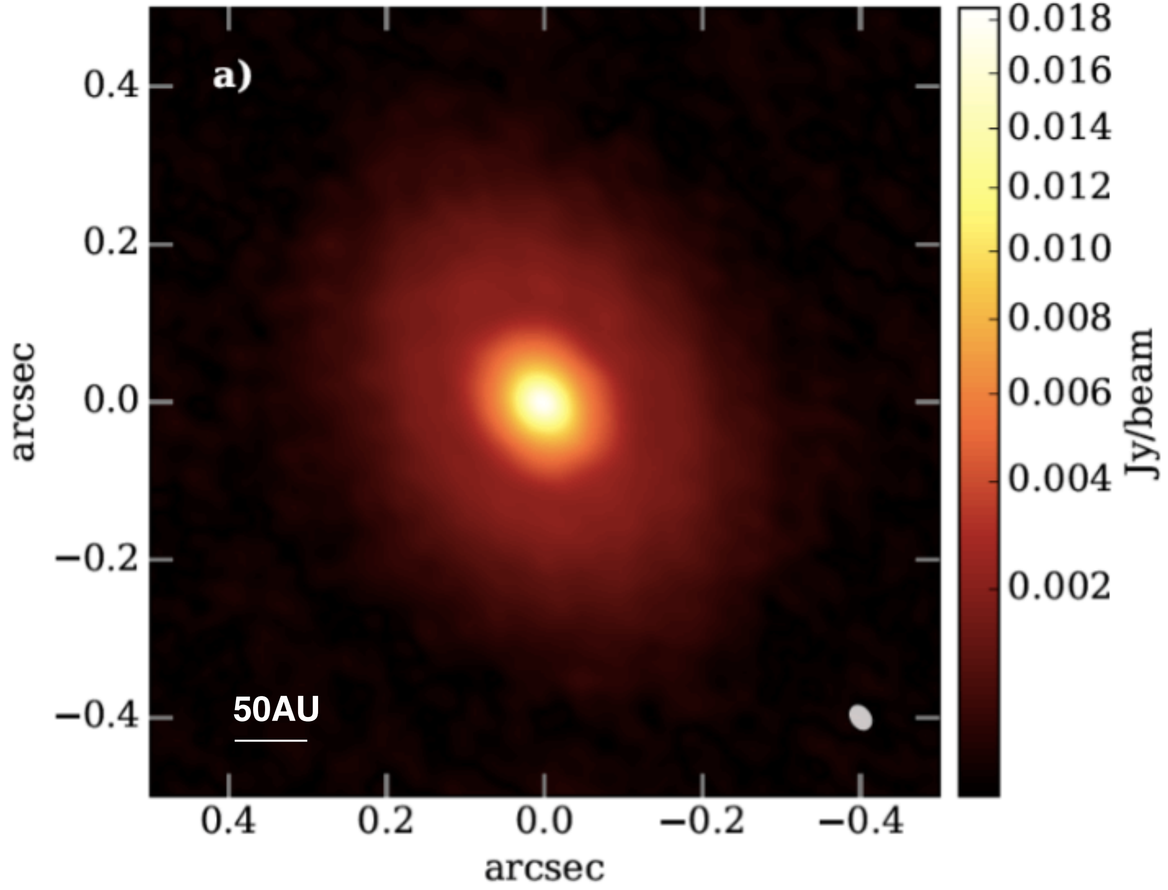
$$q^{+} = \frac{3}{8\pi}\dot{M}\Omega_K^2$$



FU Orionis



V883Ori

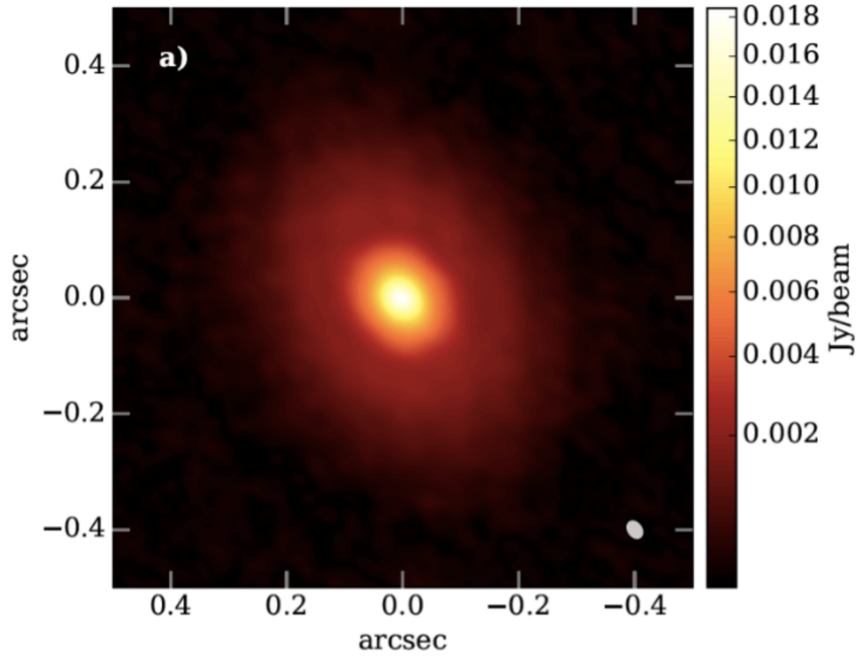


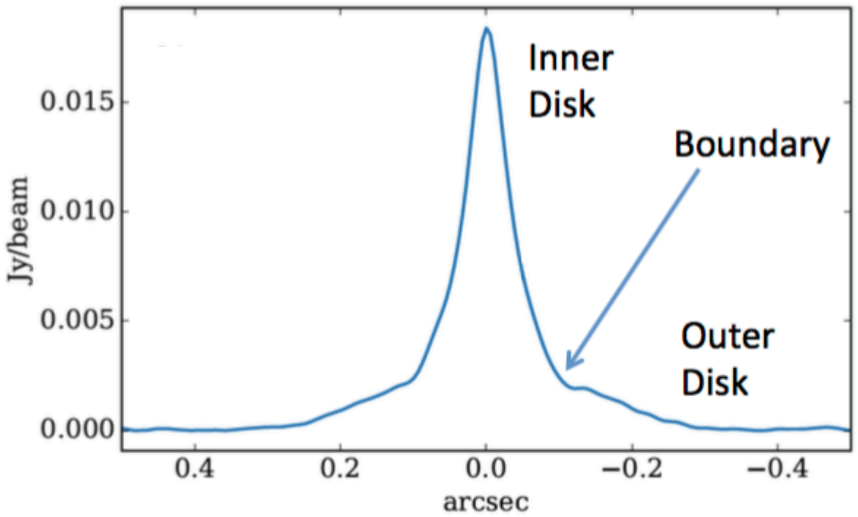
Class I protostar
(Age ~0.5 Myr)
(L_* ~ 6 L_{sun})

M_* = 1.3 +/- 0.1 M_{sun}
M_{disk} ~ 0.3 M_{sun}
d = 414 +/-7 pc
$Ldisk$ = 400 L_{sun}

Cieza et al. (2016)

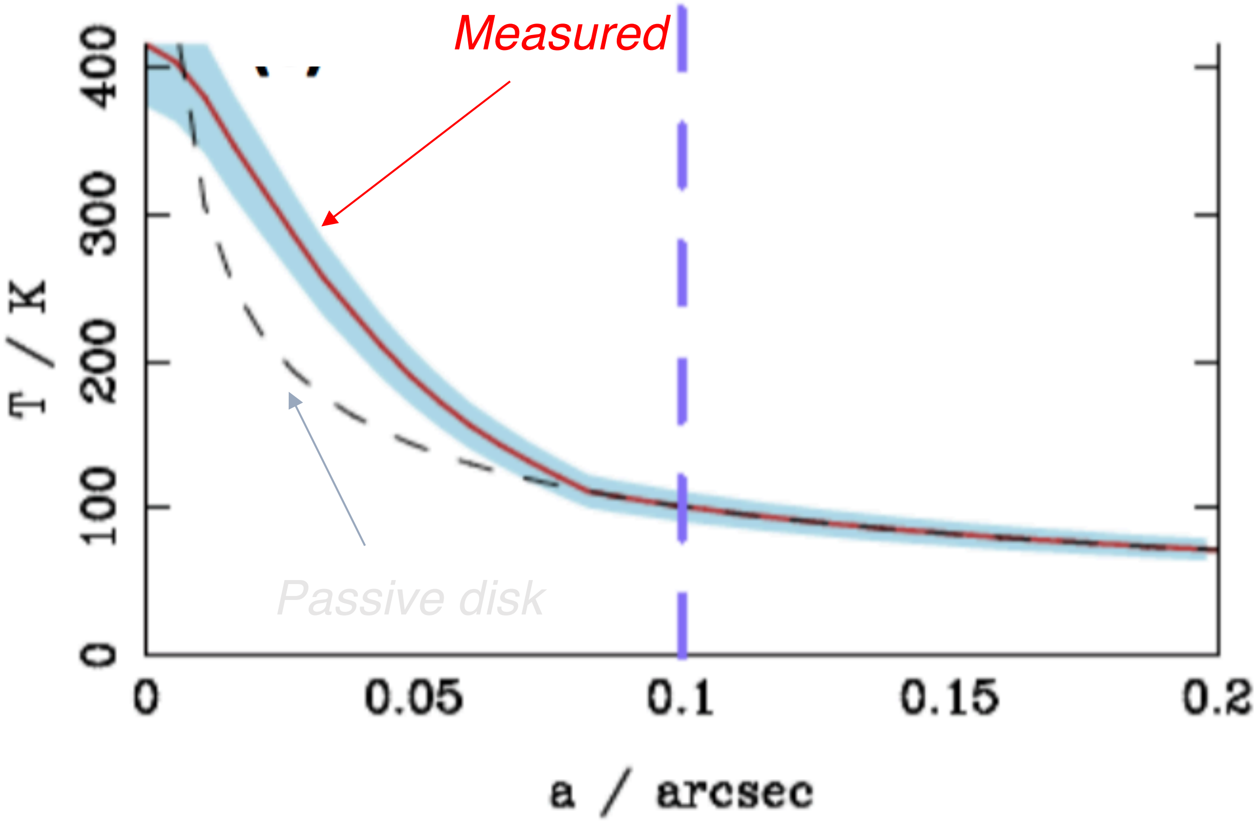
V883Ori





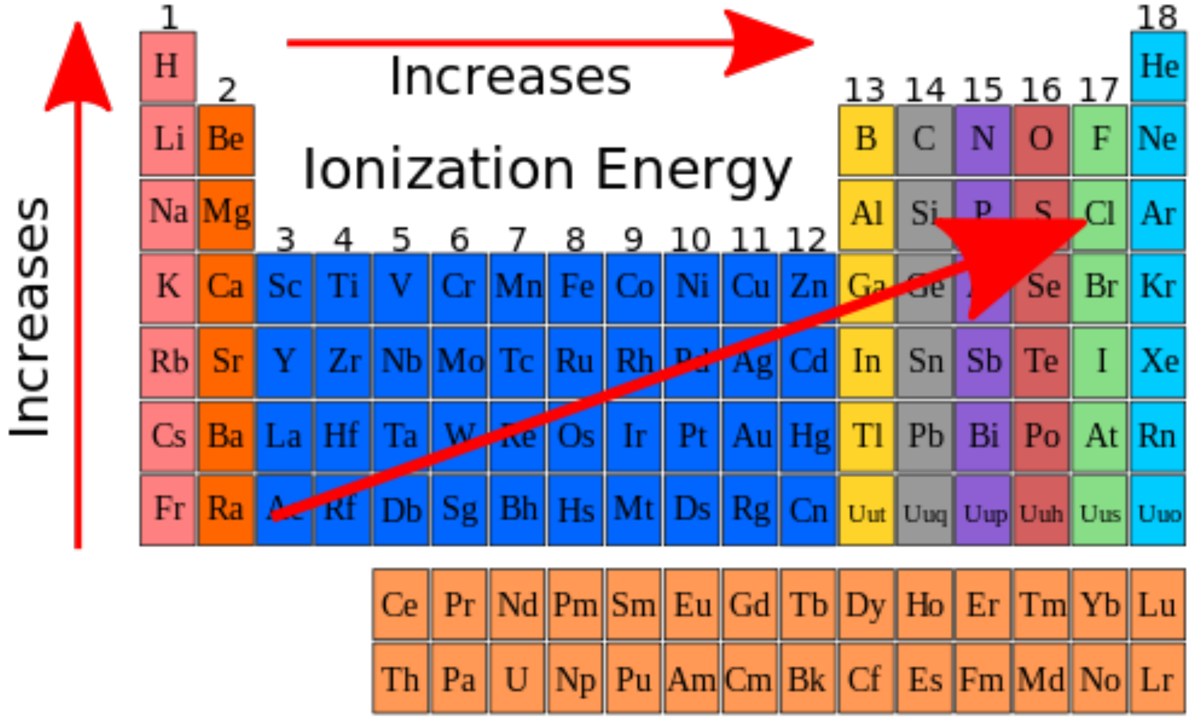
Cieza et al. (2016)

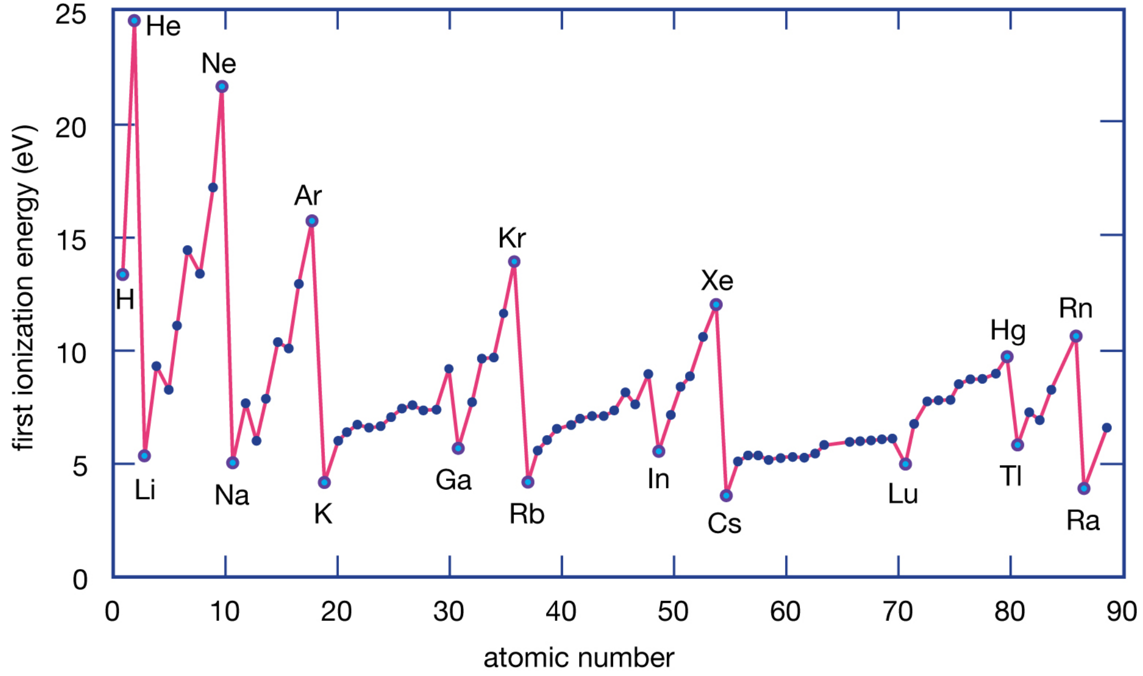
Extra source of heating needed



Cieza et al. (2016)

Ionization energy





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Thermal ionization

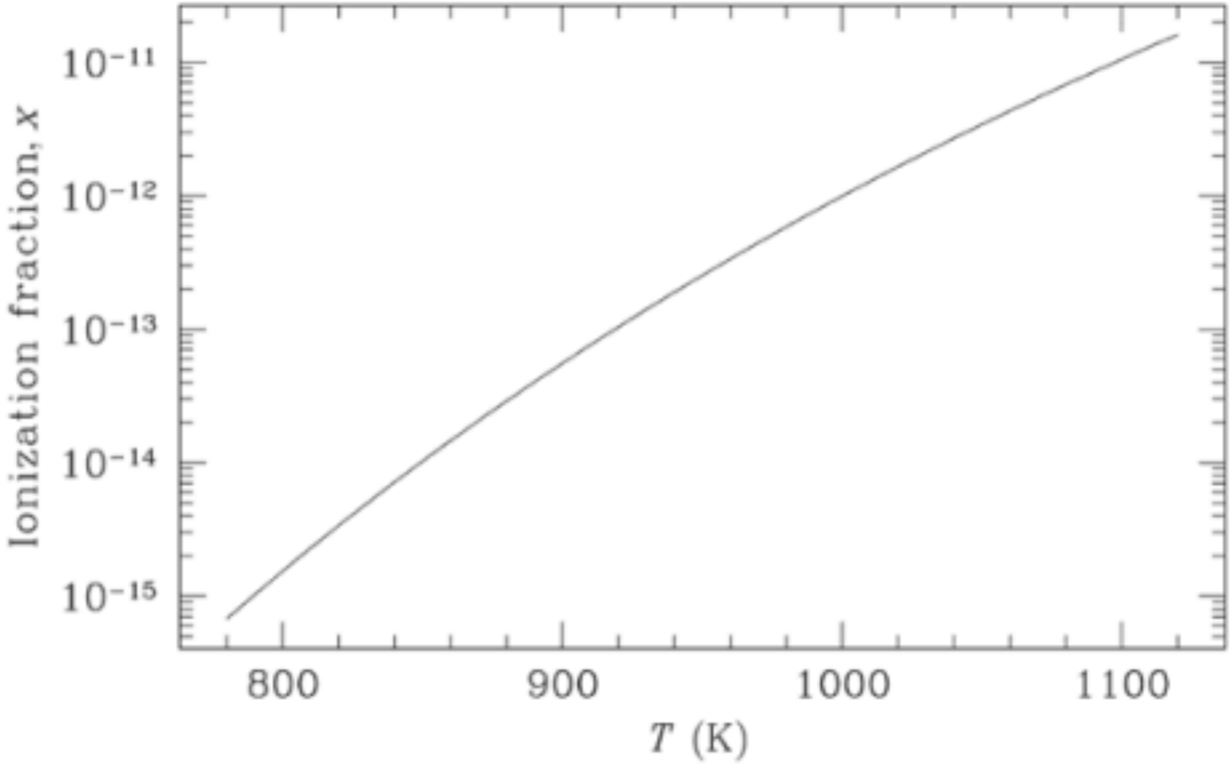
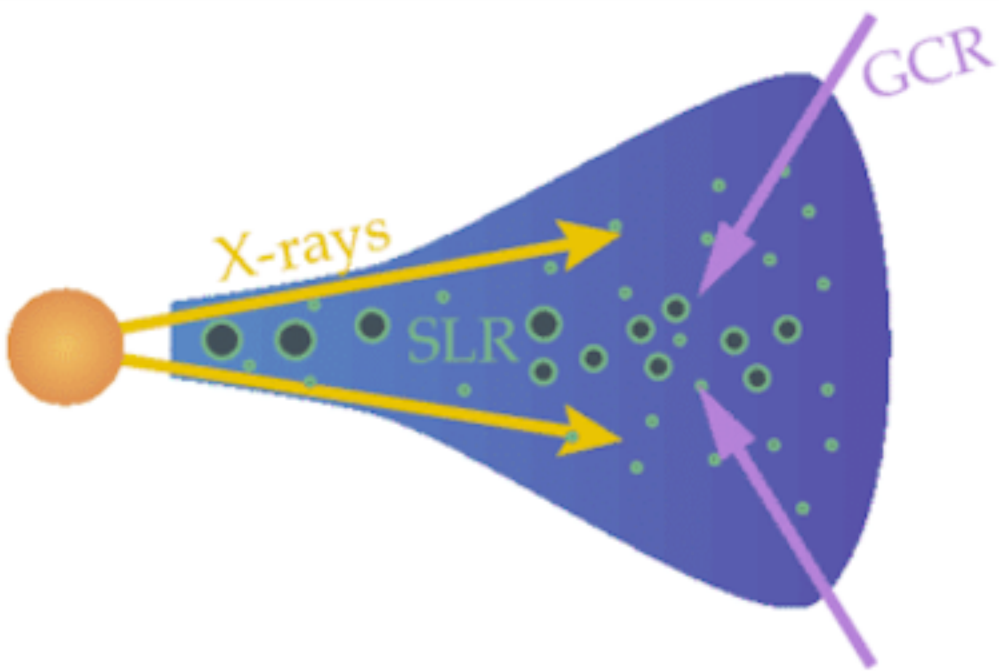
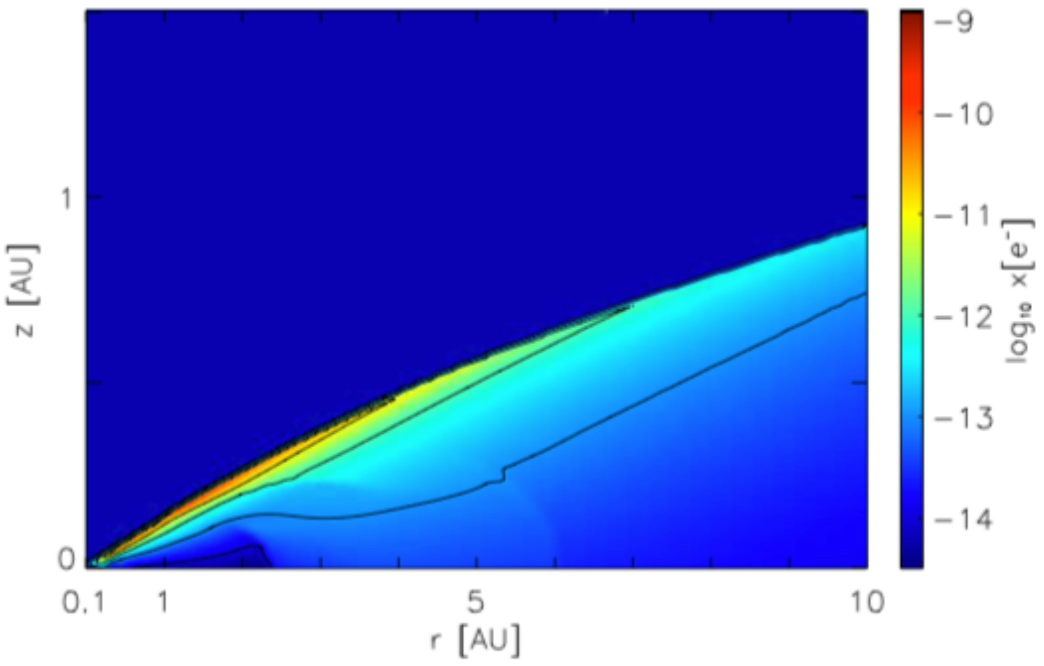


Figure 2.8 The Saha equation prediction for the ionization state of the disk due to the thermal ionization of potassium (ionization potential $\chi = 4.34\,\mathrm{eV}$). The fractional abundance of potassium has been taken to be $f = 10^{-7}$, and the total number density of neutrals $n_n = 10^{15}\,\mathrm{cm}^{-3}$.

Non-thermal ionization





Dead zones and “Layered” accretion

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LAYERED ACCRETION IN T TAURI DISKS

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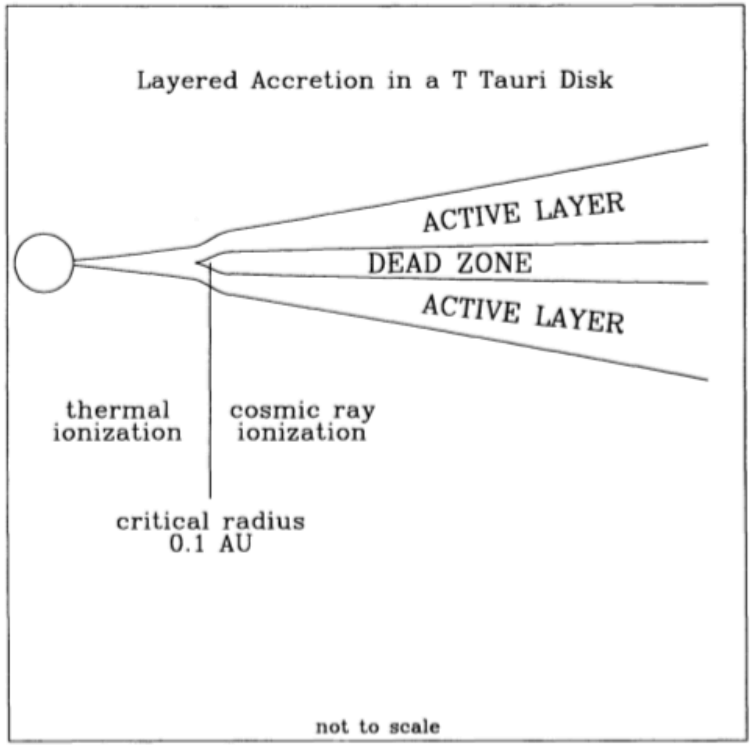
Received 1995 May 8; accepted 1995 July 28

ABSTRACT

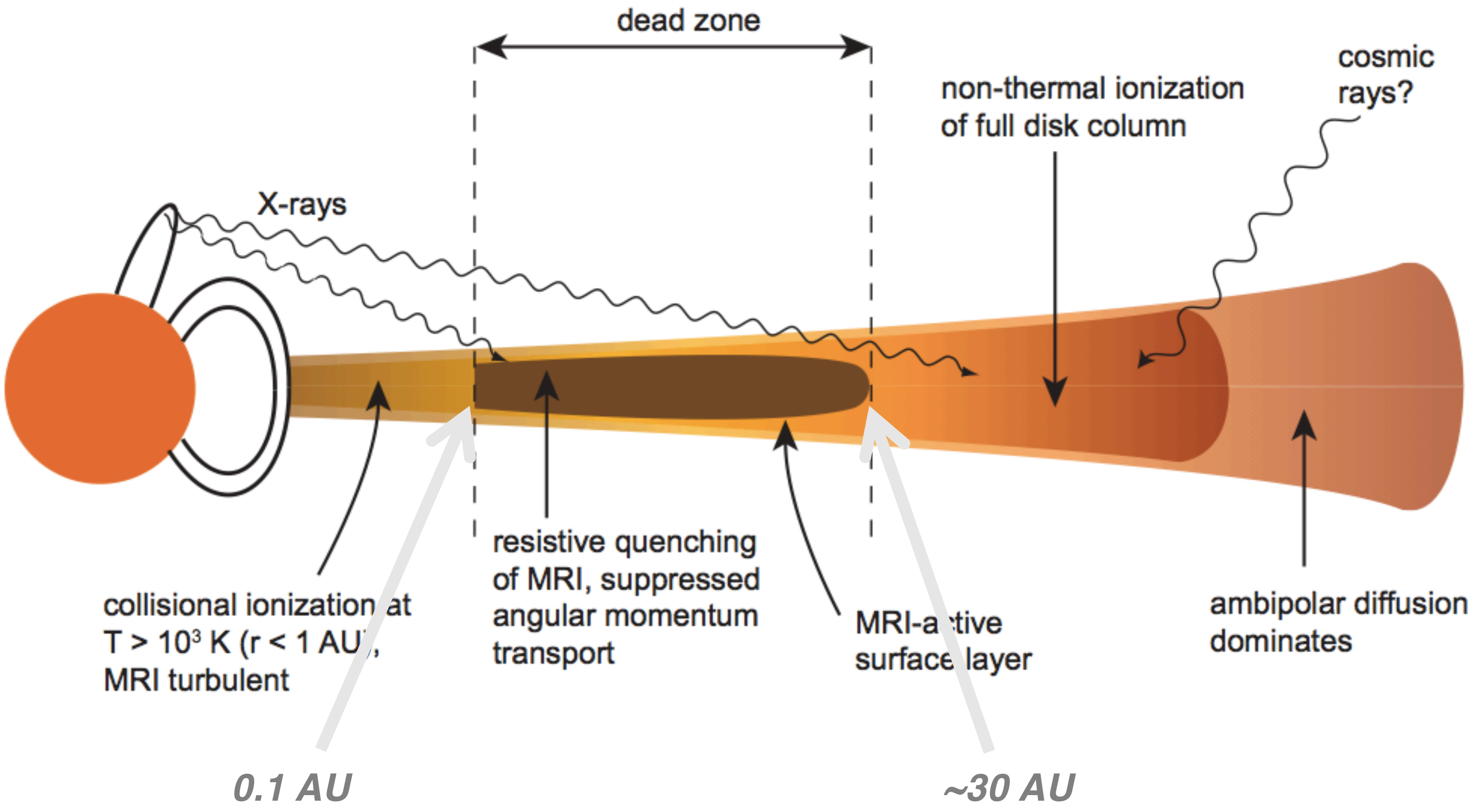
We put forward a model for accretion disks around T Tauri stars. The model assumes that angular momentum transport is driven by magnetic fields and can occur only in those parts of the disk that are sufficiently ionized that the gas can couple to the magnetic field. These regions lie at $R \lesssim 0.1$ AU, where collisional ionization is effective, and at $R \gtrsim 0.1$ AU in a layer of thickness ≈ 100 g cm^{-2} at the surface of the disk where cosmic-ray ionization is effective.

The model predicts that the stellar accretion rate is about $10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$, independent of the rate of infall onto the disk. Matter that is not accreted onto the star accumulates in the inner few AU of the disk at a rate of about $10^{-3}\ M_\odot$ in 10^4 yr. Given this buildup it is unlikely that accretion is steady. The effective temperature profile is $T_e \sim r^{-1/2}$ outside of 0.1 AU, which differs from the canonical $T_e \sim r^{-3/4}$. We calculate the expected spectral energy distribution for the disk and show that this temperature profile produces an infrared excess. Finally, we discuss some of the leading uncertainties in the theory.

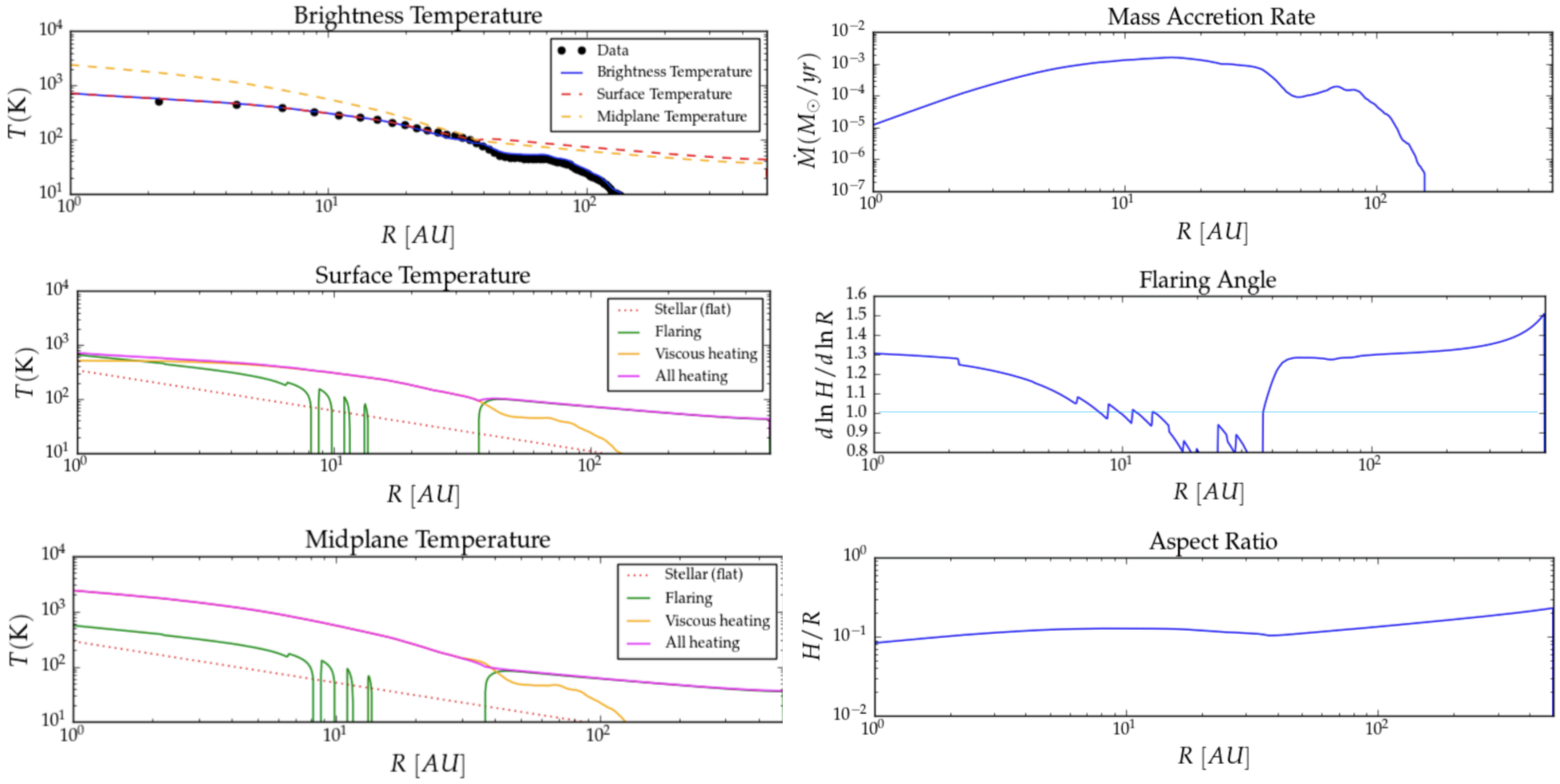
Subject headings: accretion, accretion disks — stars: magnetic fields — stars: pre–main-sequence



Dead zones

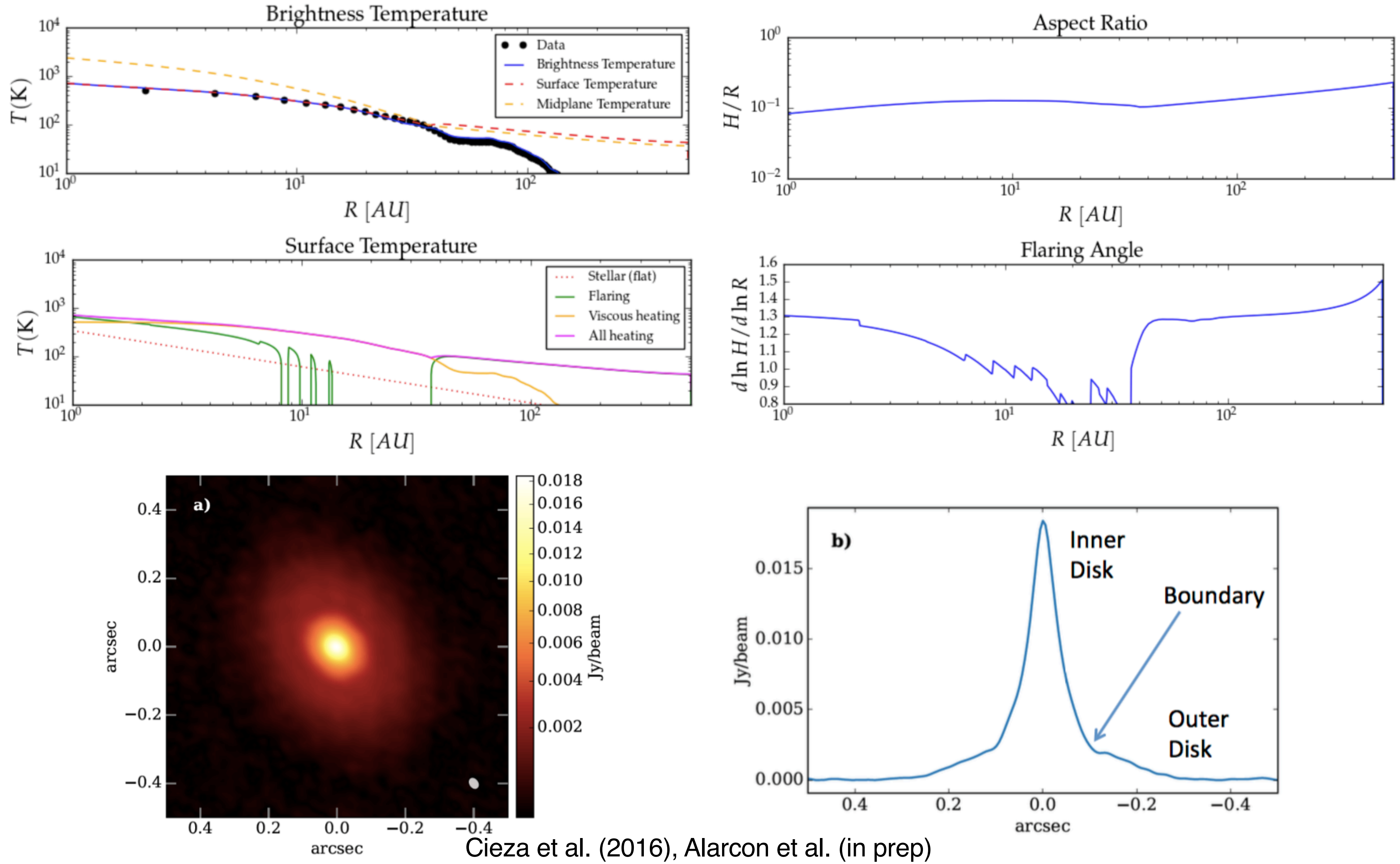

dead zone
non-thermal ionization
of full disk column
cosmic
rays?
X-rays
resistive quenching
of MRI, suppressed
angular momentum
transport
collisional ionization at
T > 10³ K (r < 1 AU),
MRI turbulent
MRI-active
surface layer
ambipolar diffusion
dominates
0.1 AU
~30 AU

Best fit



Alarcon et al. (in prep)

Self-shadowing



Cieza et al. (2016), Alarcon et al. (in prep)