review & update of dipper systems

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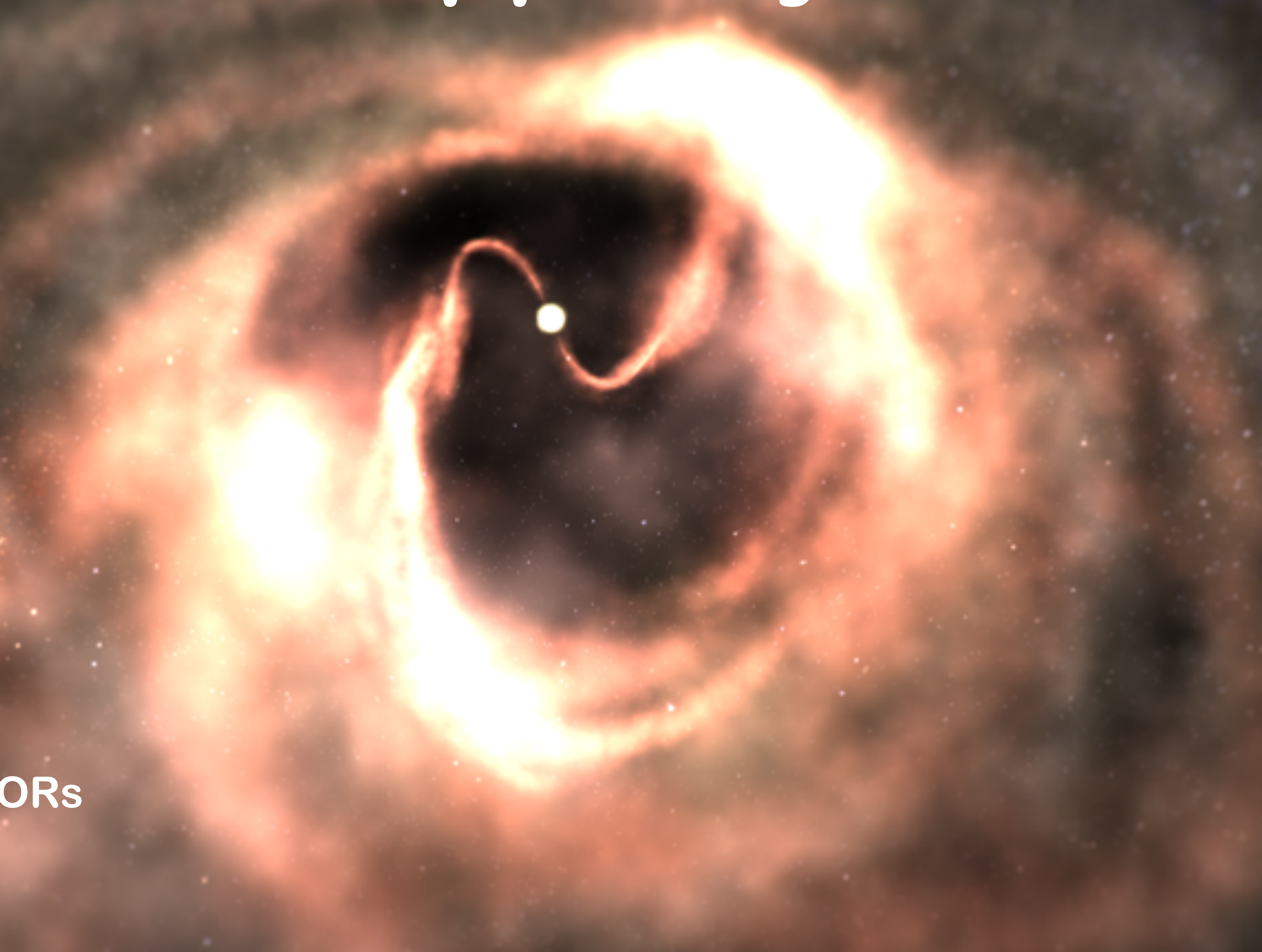


2nd International Workshop on UXORs
St. Petersburg, 3 Oct. 2019

what are “dippers” systems?

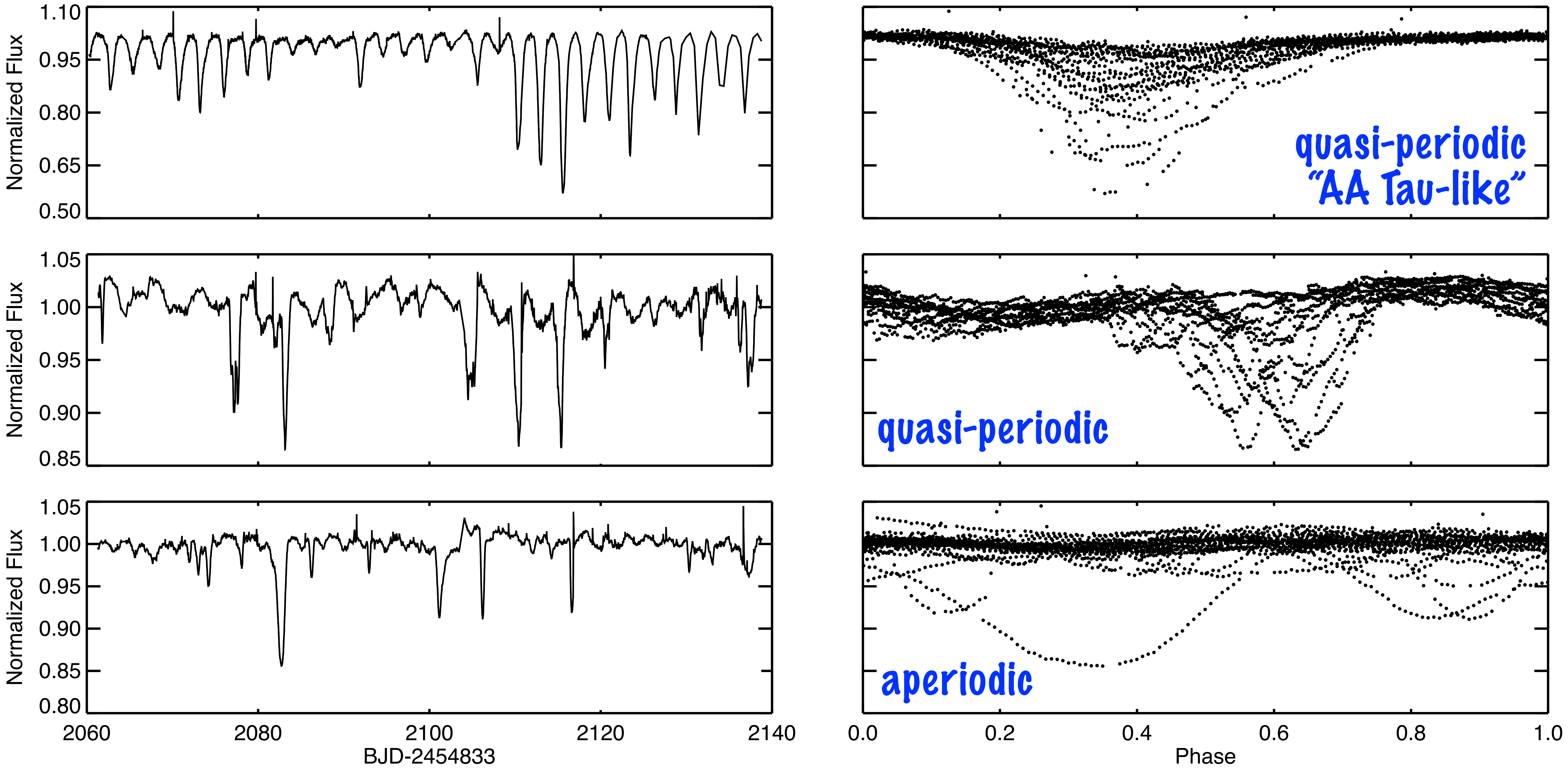


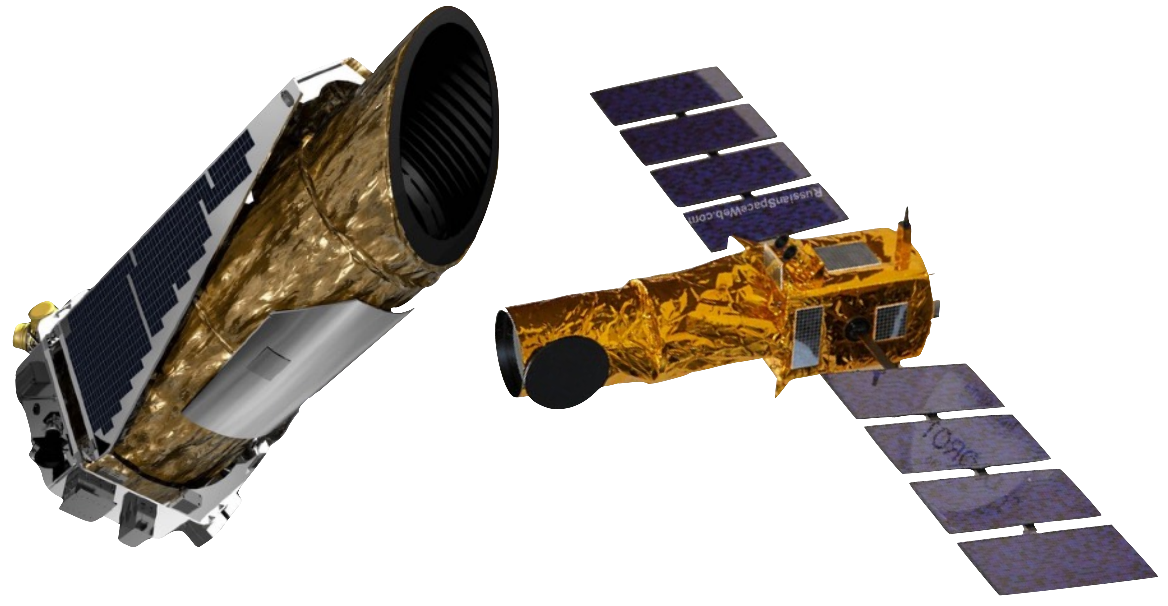
exhibit dimming events

- deep (> 10 % in flux)
- moderate-duration (1 day)
- quasi-periodic or aperiodic (QP ~ stellar rotation period)

young stars + disks

- 1-10 Myr (normal) TTauri stars
- common (30% of YSOs)
- host protoplanetary disks

CoRoT + K2



Ansdell et al. 2016a

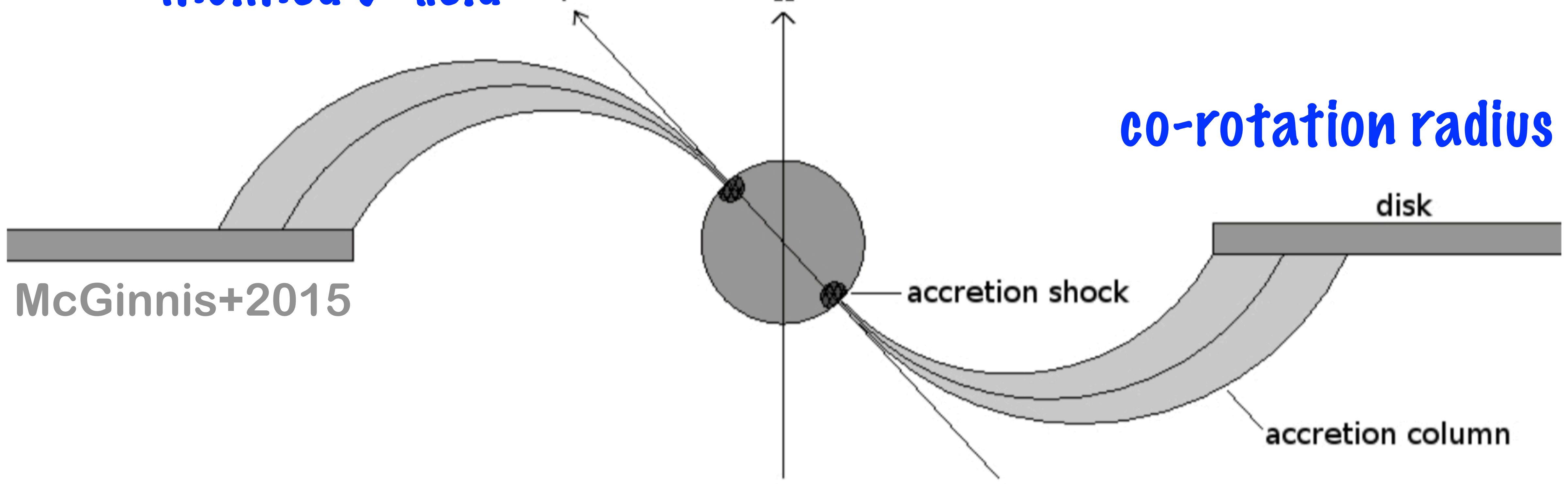
how are “dippers” different from UXORs?

	UXORs	Dippers	
PERIODICITY	aperiodic	aperiodic or quasi-periodic	→ harder to explain with single/unified mechanism?
DIP DURATION	weeks - months	0.5 - 2 days	→ difficult to schedule simultaneous observations
DIP DEPTH	1 - 3 mags	0.1 - 1 mags	→ need space-based telescopes to detect variability
STELLAR HOSTS	Herbigs	T Tauri stars	→ more common, but fainter; harder follow up observing

what causes dippers?

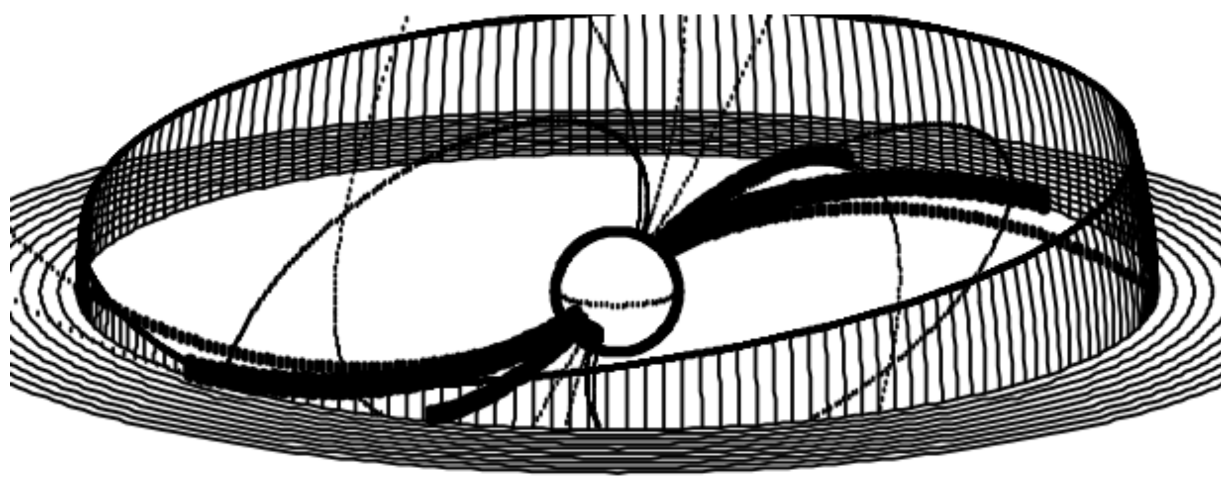
inclined B-field

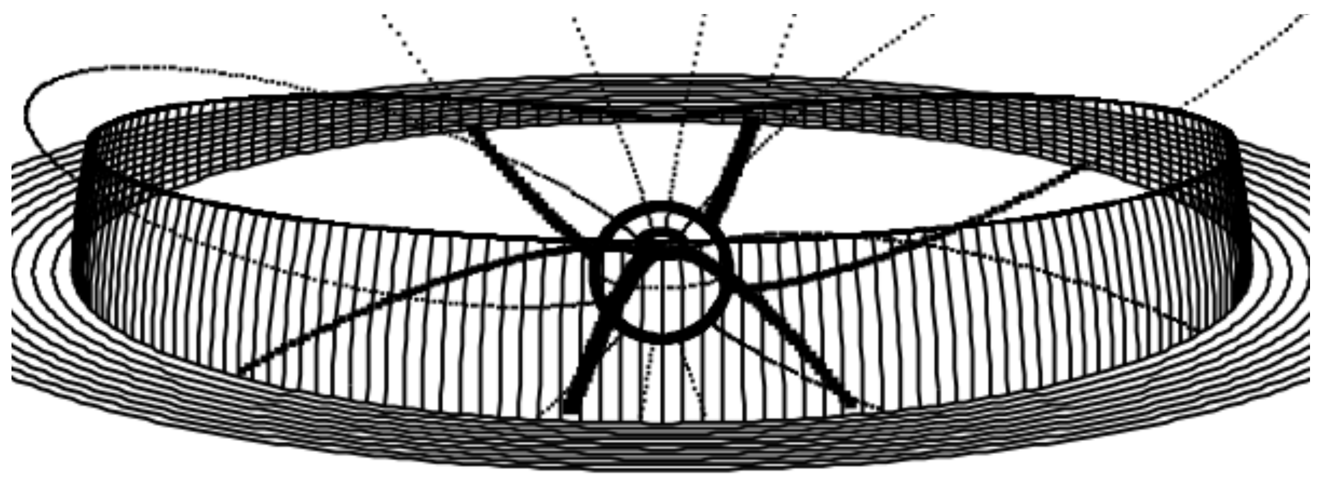
co-rotation radius



McGinnis+2015

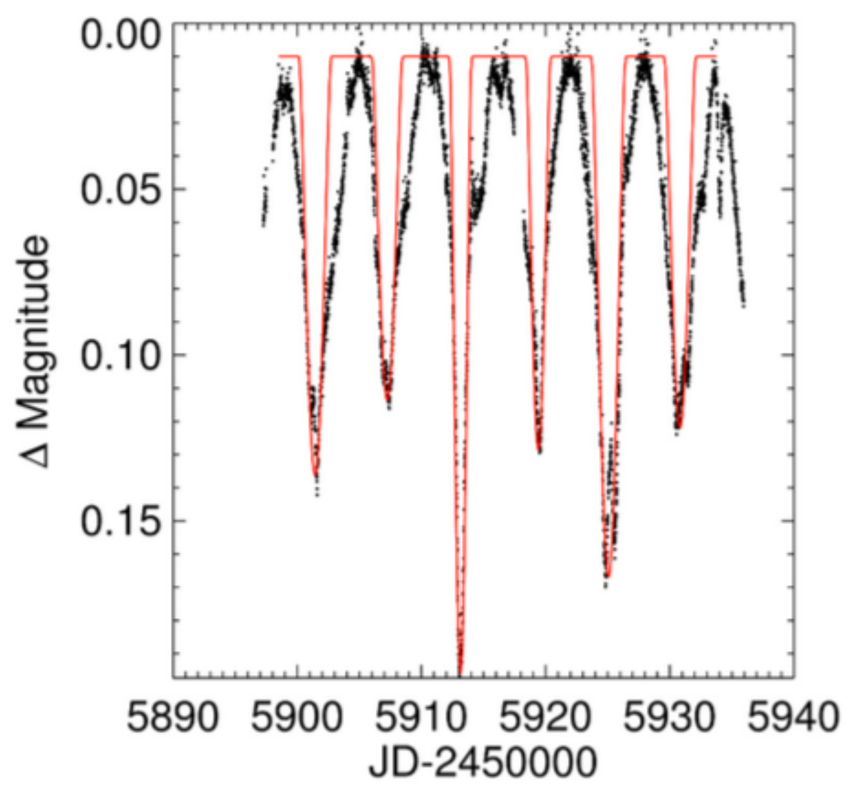
inner warp in edge-on accretion disk

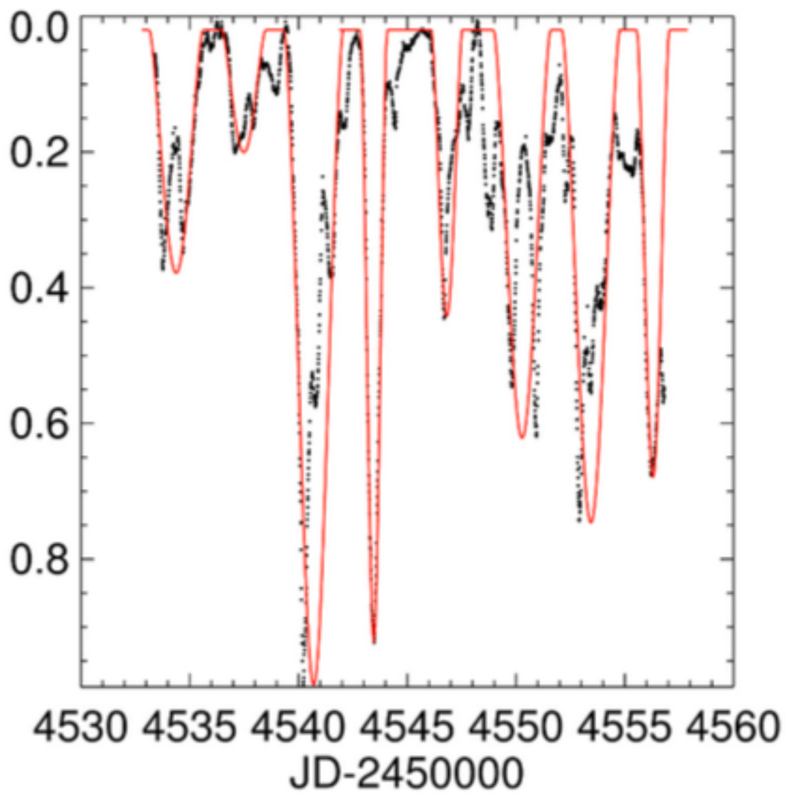




Bouvier+1999

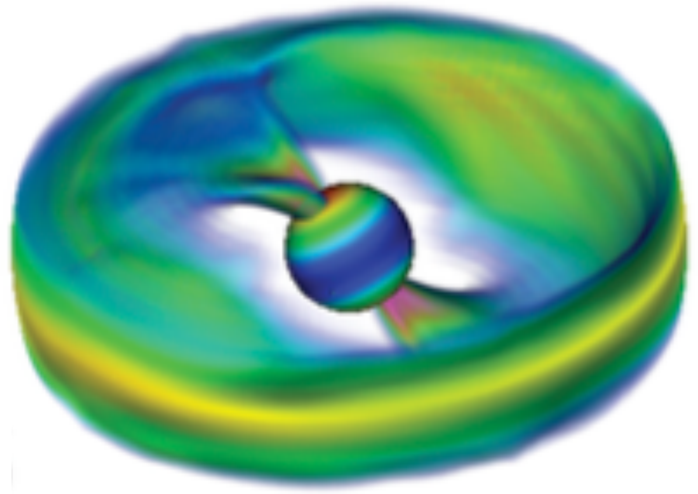
nearly edge-on (70 deg) disk

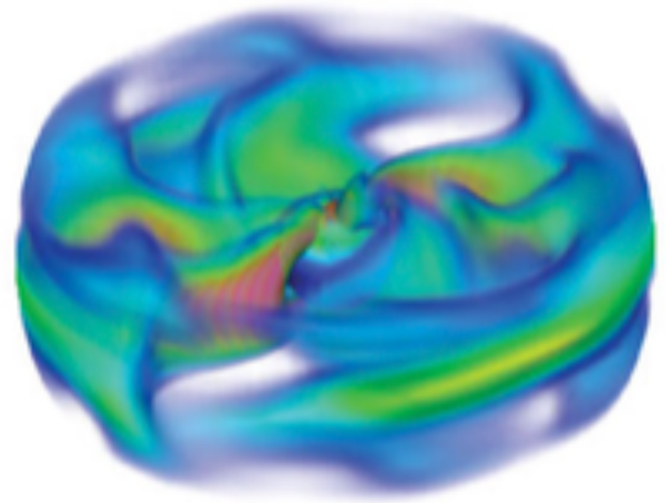




quasi-periodic → stable accretion

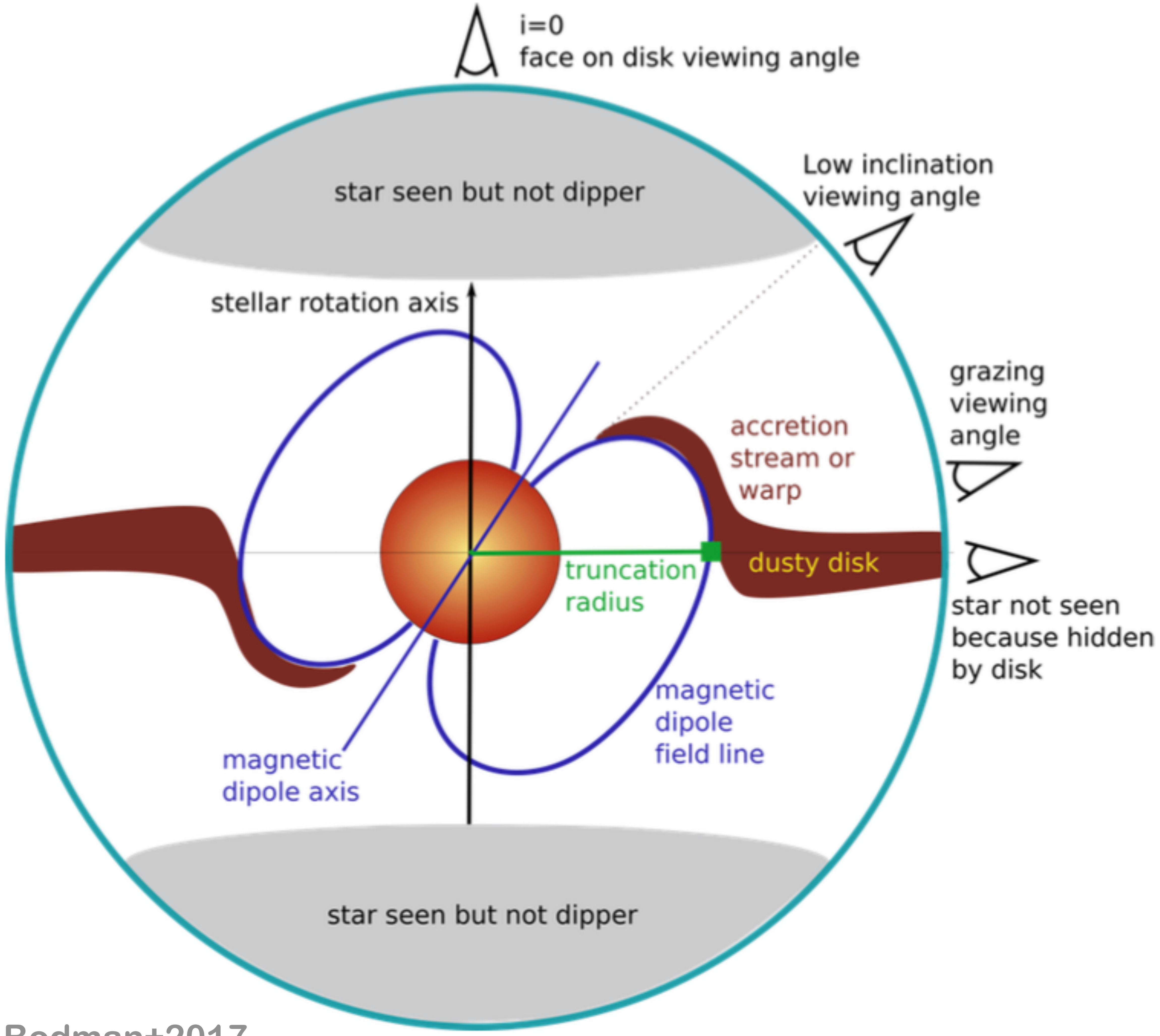
aperiodic → unstable accretion





Kurosawa & Romanova 2013

what causes dippers?

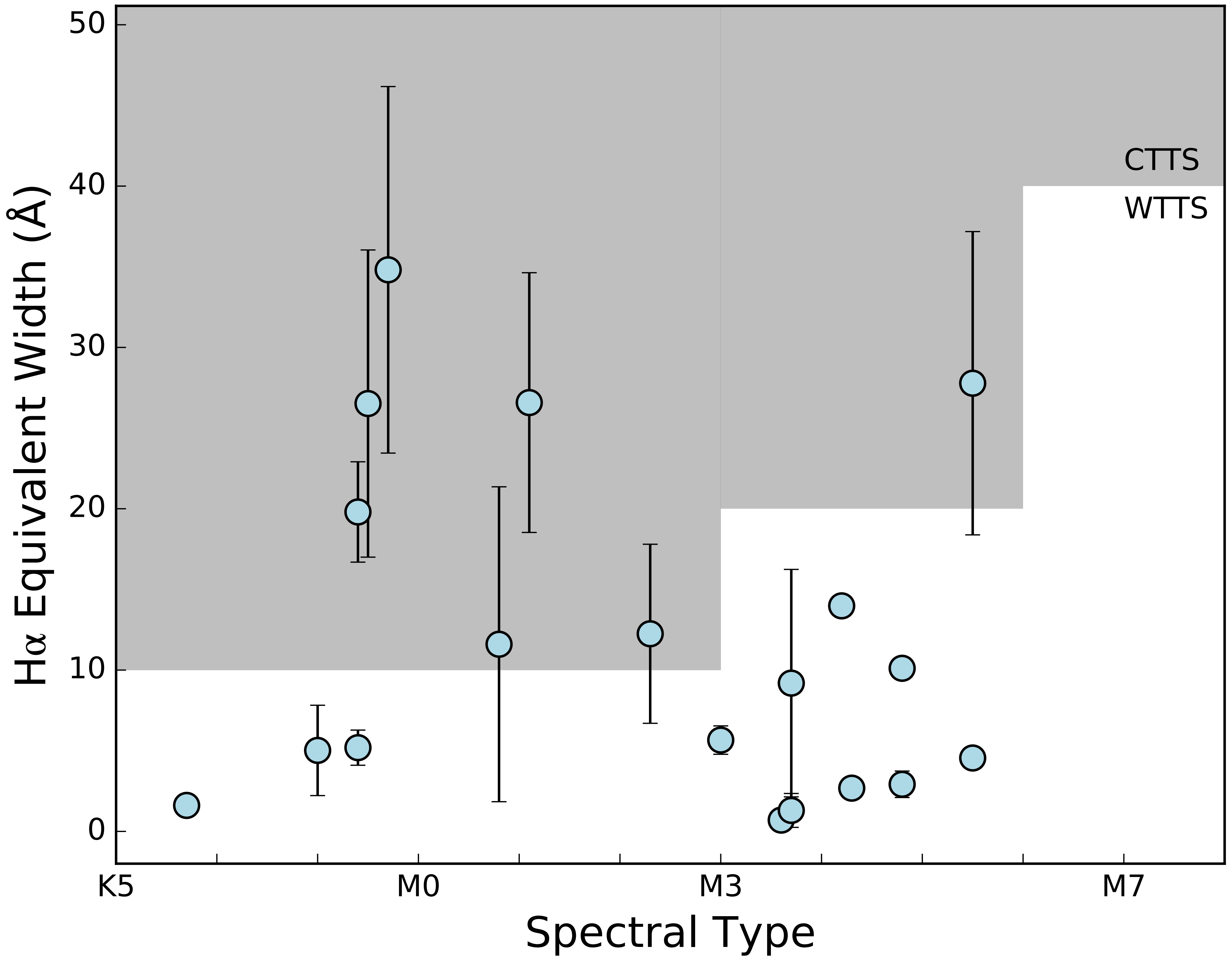


Bodman+2017

- co-rotation radius > sublimation radius for low-mass (K/M-type) stars
- co-rotation radius ~ B-field truncation radius allows material to flow up B-field lines
- inclined B-field axis enables <u>moderate</u> disk inclinations to exhibit dipper behavior

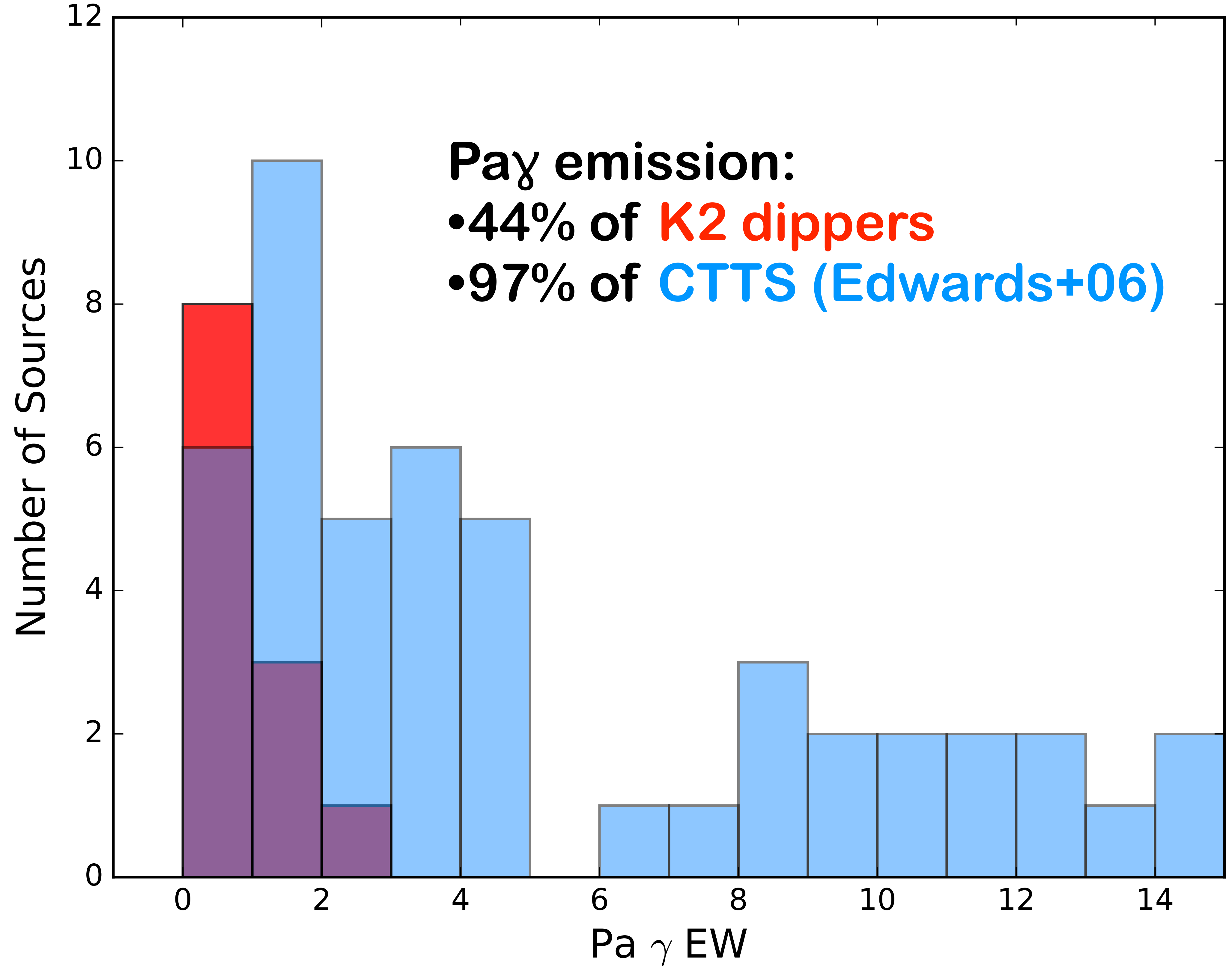
need measurements of B, μ, Ω, $\dot{M}_{acc}$ to confirm

most dippers are not significantly accreting



most are WTTS based on Hα emission

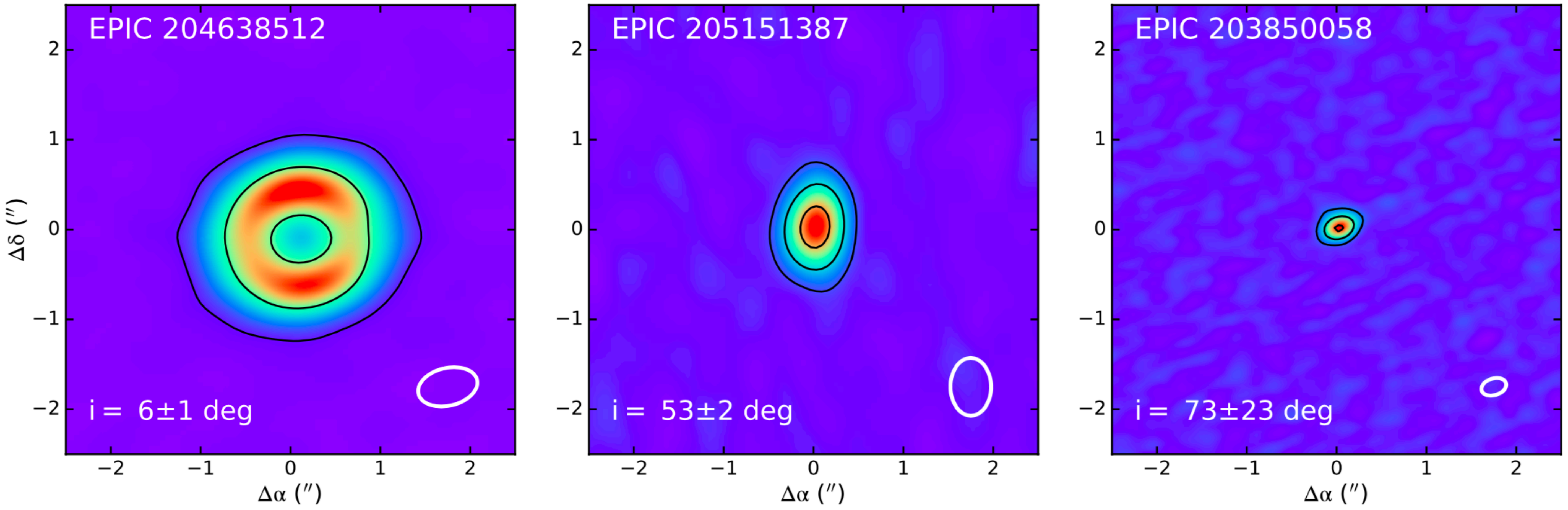
White & Basri 2003



weak or no accretion based on Paγ emission

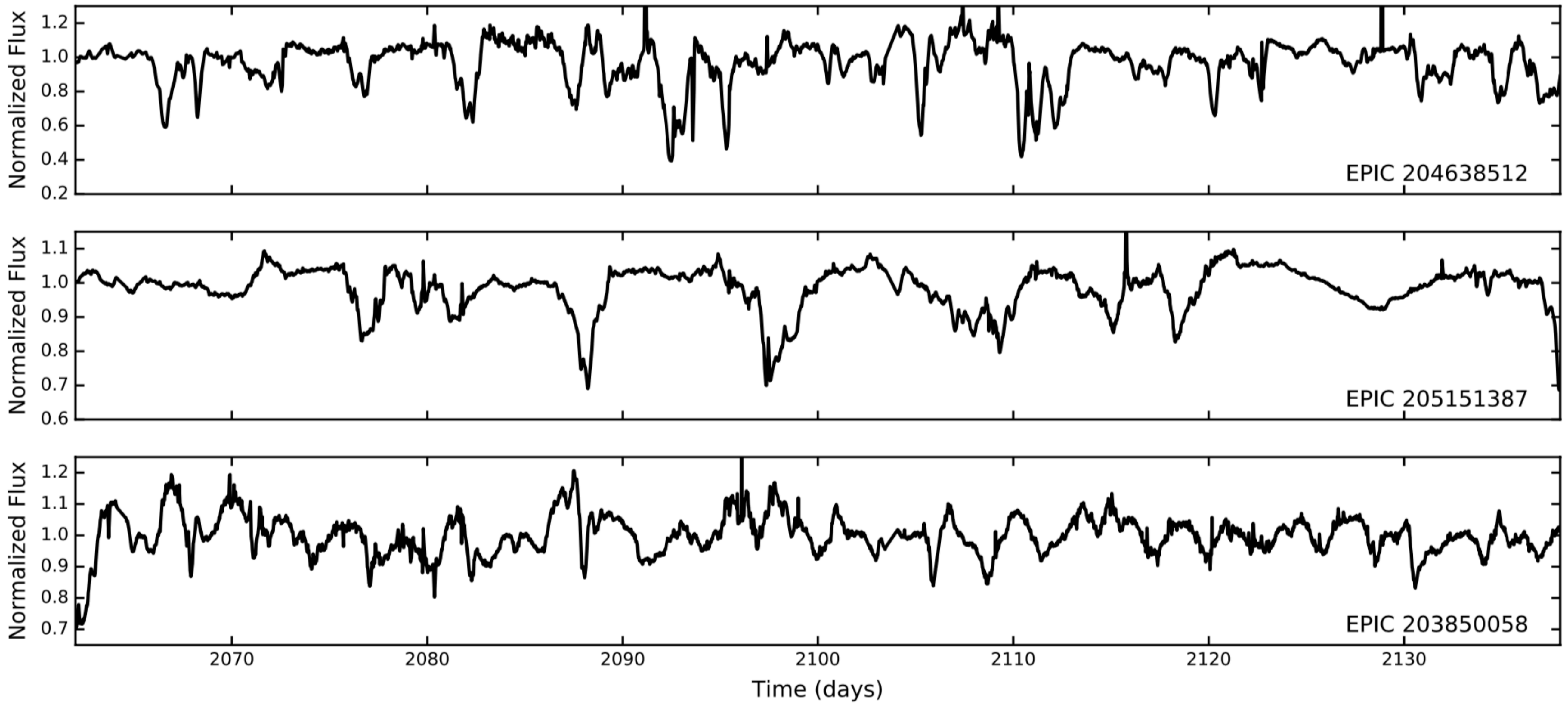
Edwards+2006

are dipper disks really edge-on?

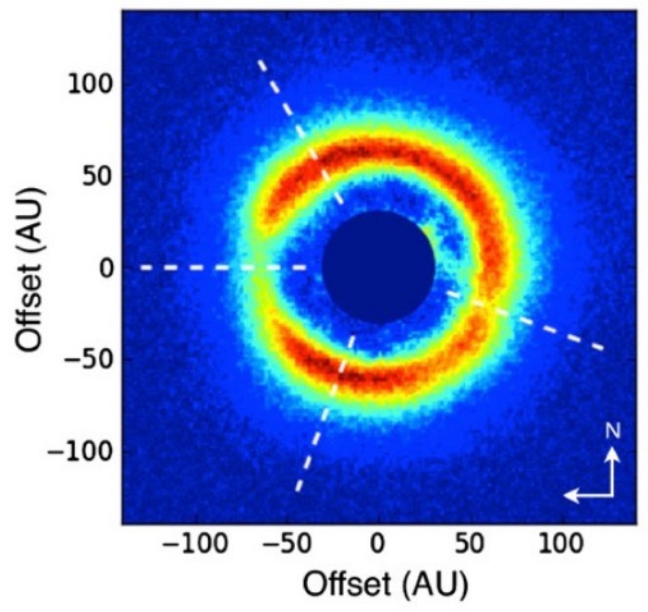


Early search of ALMA archive suggested not by turning up face-on, edge-on, and intermediate inclination dipper disks

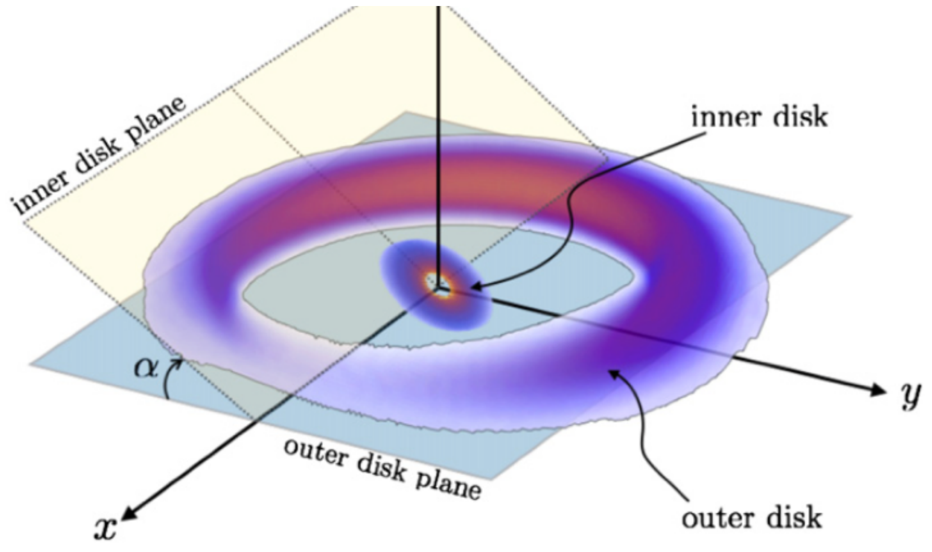
Ansdell et al. 2016b



J1604: misaligned inner disk from inclined companion



Takami+2014, Pinilla+2018



Marino+2015 (HD152527)

measuring outer disk inclinations with ALMA

GALARIO

Tazarri+2018

GPU-accelerated Python library for fitting radio interferometry visibilities

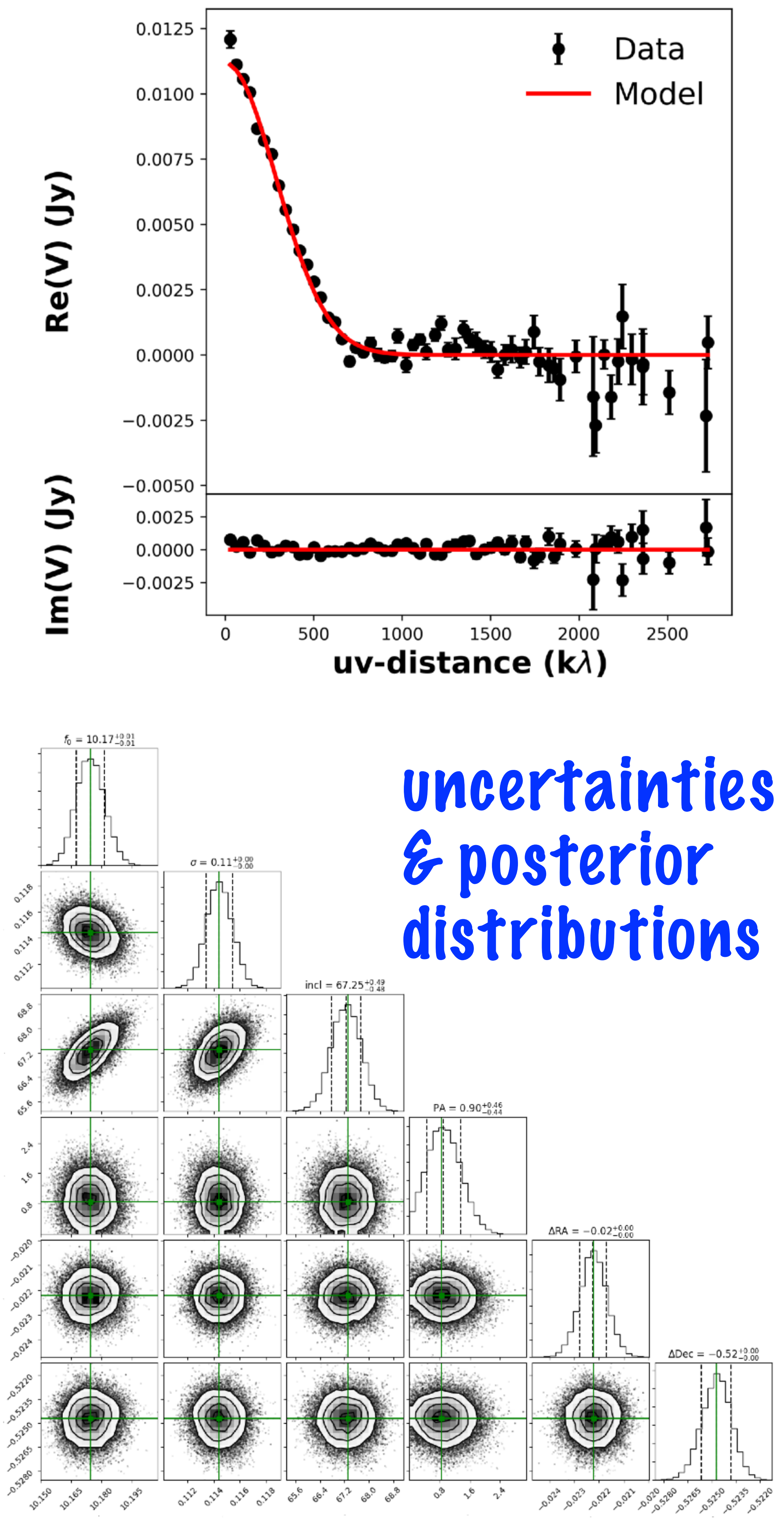
+

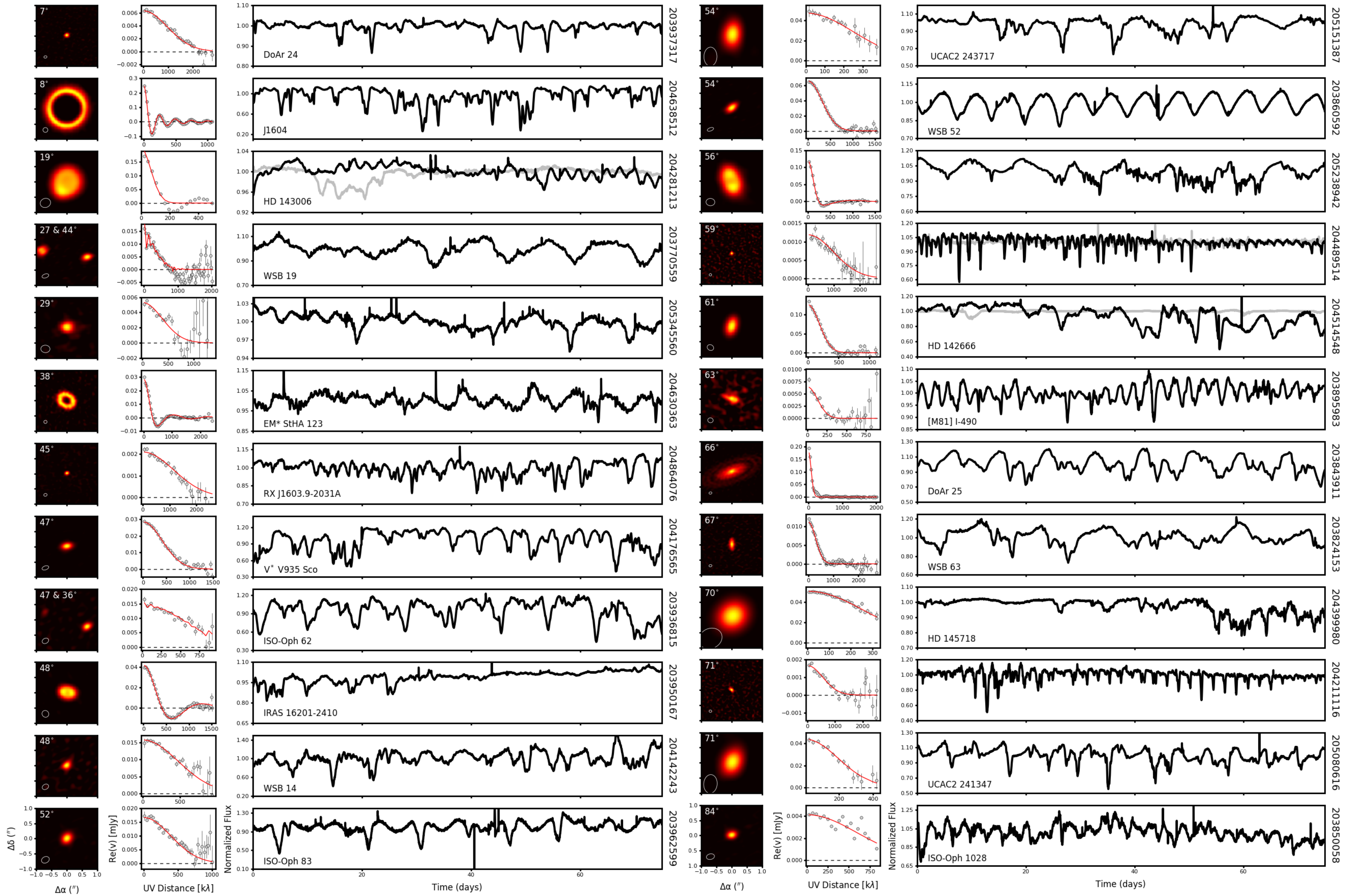
emcee

Forman-Mackey+2013

MCMC sampler in Python for Bayesian parameter estimation

→





24 dippers in USco & ρ Oph

Ansdelll (subm.)

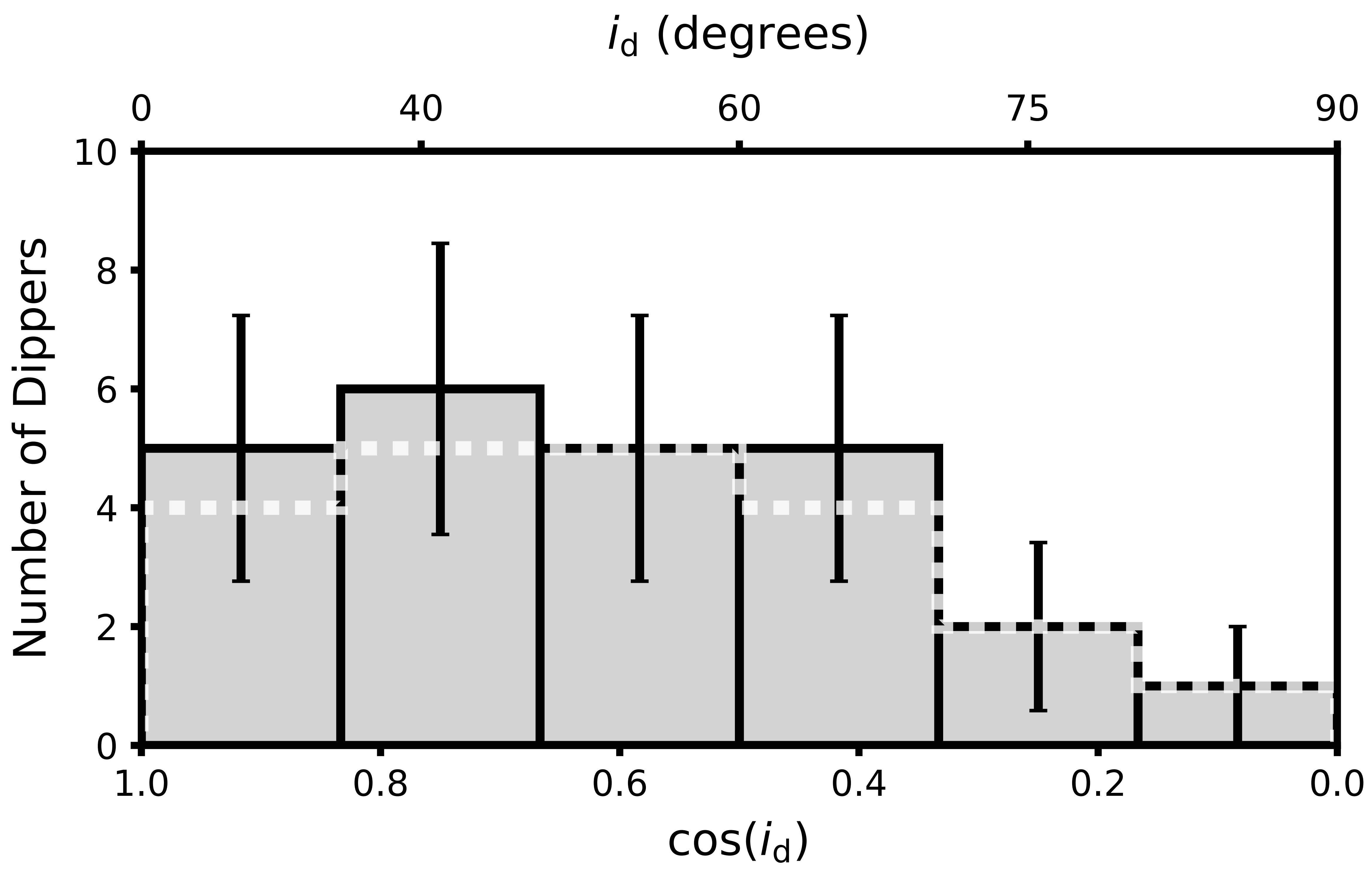
dippers found in K2 light curves

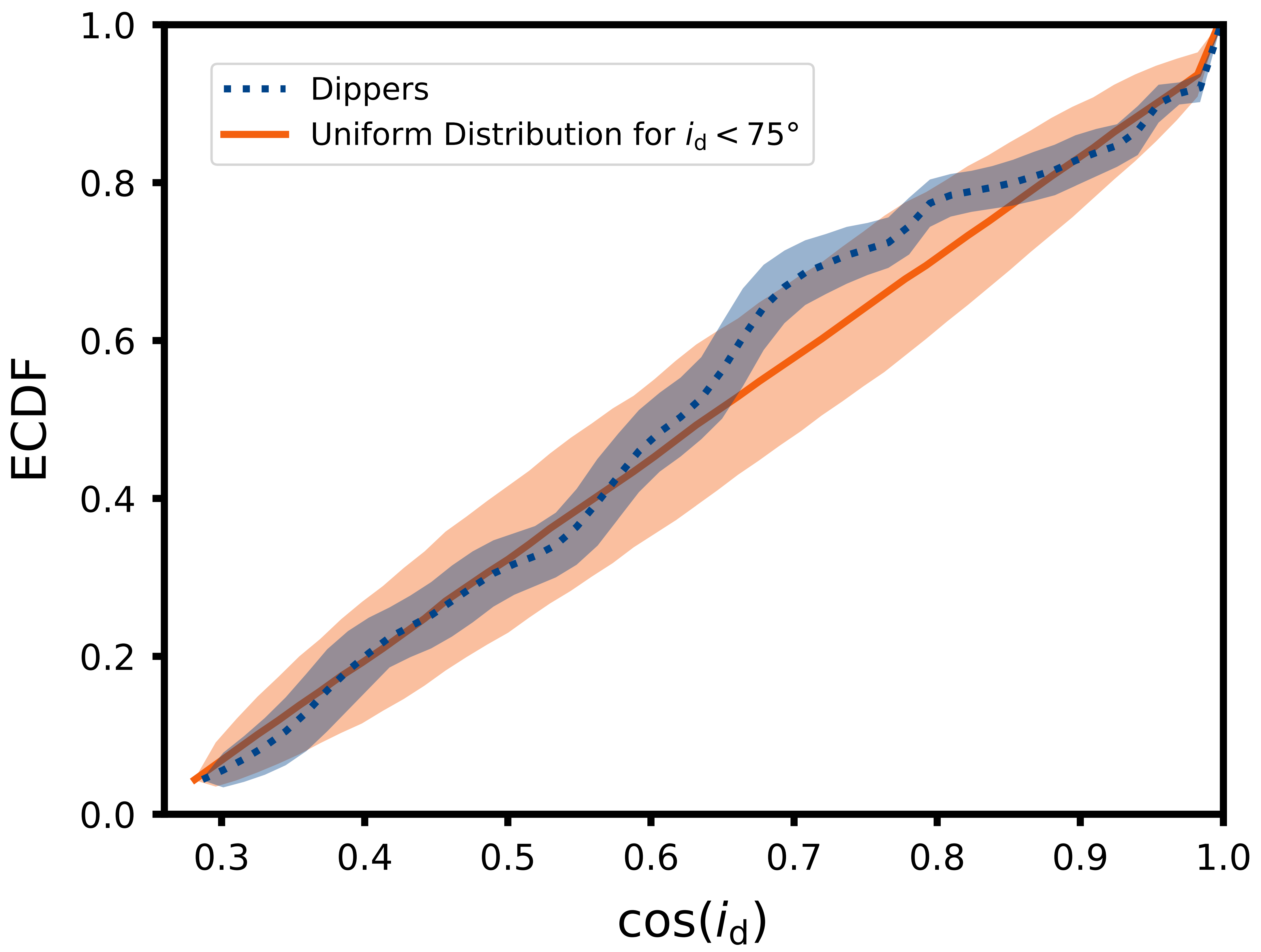
Ansdell+2016a
Hedges+2018
Cody & Hillenbrand 2018

outer disks resolved by ALMA

ALMA archive

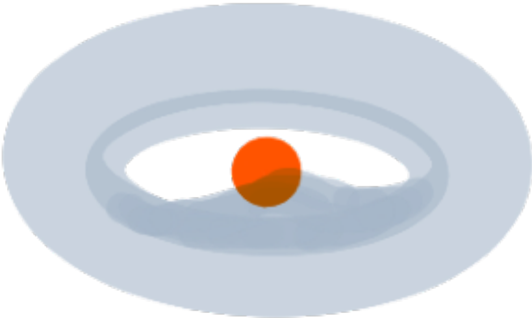
dippers exhibit an isotropic i_{disk} distribution





Ansdell et al. (subm.)

MC sampling of posterior distributions

<table>
<tr><th>EPIC</th><th>i_d</th><th>accretion-driven disc warp
</th><th>vertical disc instability
</th><th>broken inner disc
</th><th>dusty disc winds
</th></tr>
<tr><td>203937317</td><td>7</td><td rowspan="11">disc inclination too low</td><td rowspan="20">disc inclination too low</td><td>no resolved cavity</td><td rowspan="16">disc inclination too low</td></tr>
<tr><td>204638512</td><td>8</td><td></td></tr>
<tr><td>204281213</td><td>19</td><td></td></tr>
<tr><td>203770559</td><td>27</td><td rowspan="2">no resolved cavity</td></tr>
<tr><td>205345560</td><td>29</td></tr>
<tr><td>204630363</td><td>38</td><td></td></tr>
<tr><td>204864076</td><td>45</td><td rowspan="3">no resolved cavity</td></tr>
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<tr><td>204489514</td><td>59</td><td></td><td rowspan="9">no resolved cavity</td></tr>
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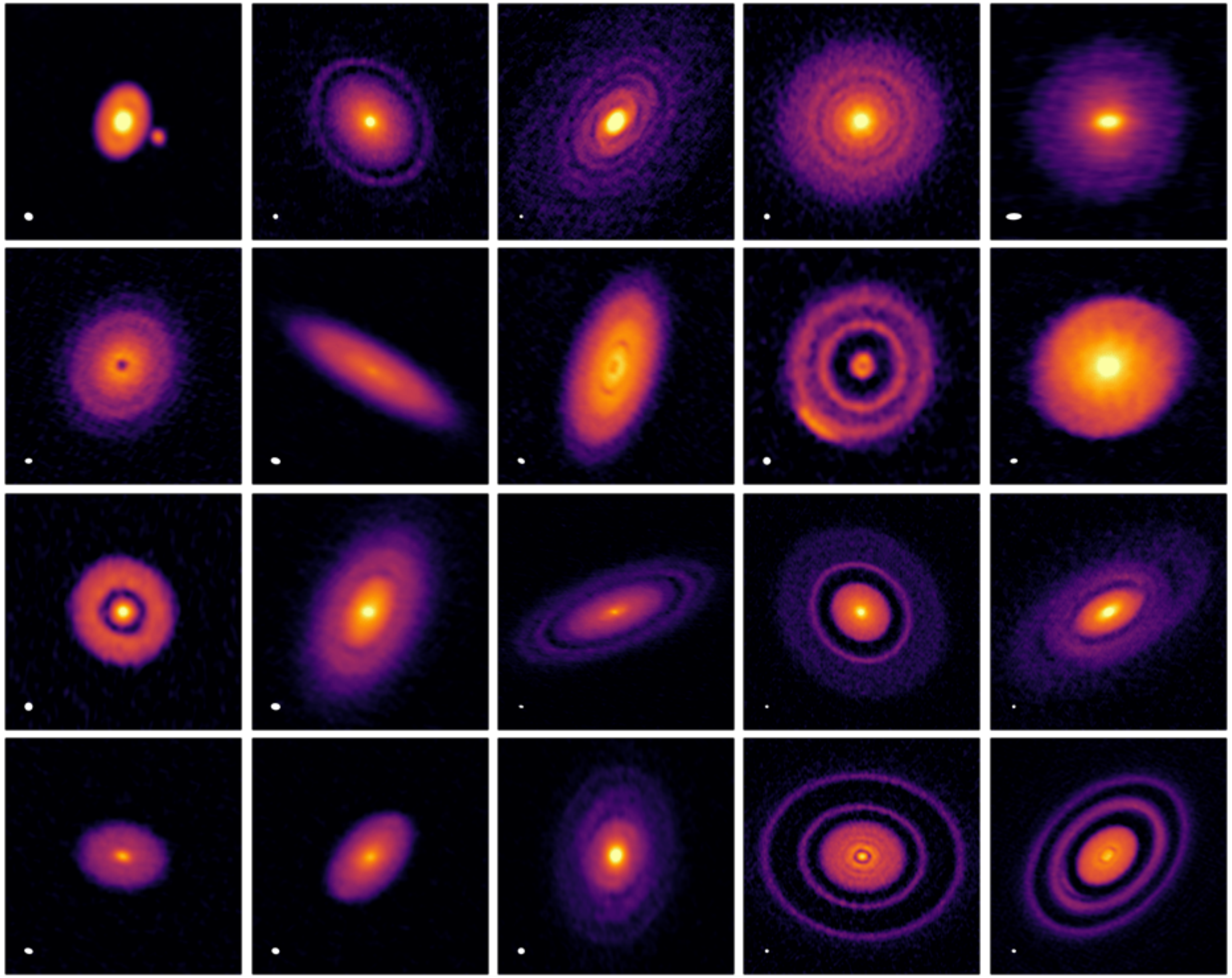
multiple (+new) mechanisms needed to explain dippers?

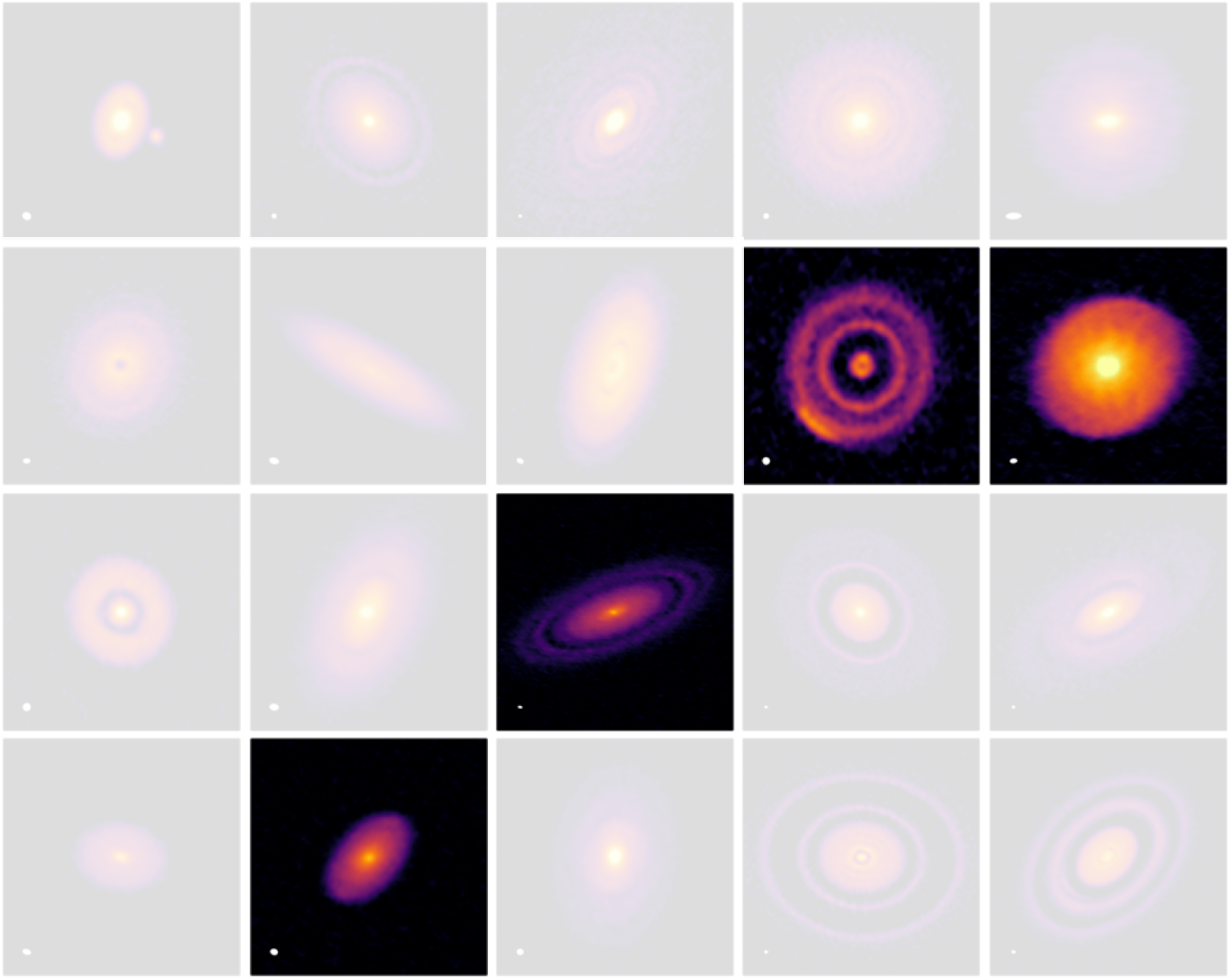
Ansdell et al. (subm.)

DSHARP observations of dipper disks



Andrews et al. 2018, Huang et al. 2018

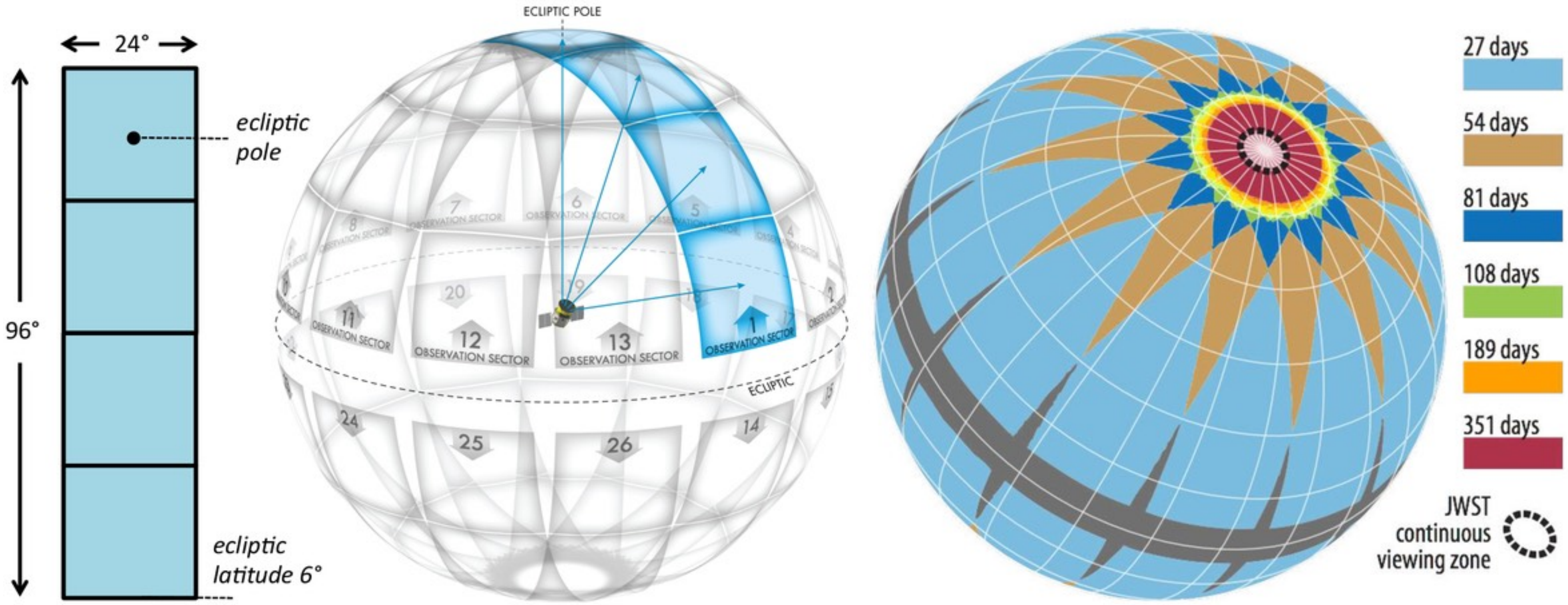
DSHARP observations of dipper disks



Andrews et al. 2018, Huang et al. 2018

- diverse disk morphologies down to ~ 5au scales
- diversity reflects larger DSHARP sample
- other DSHARP disks with K2 light curves are not dippers

finding intermediate-aged dippers with TESS

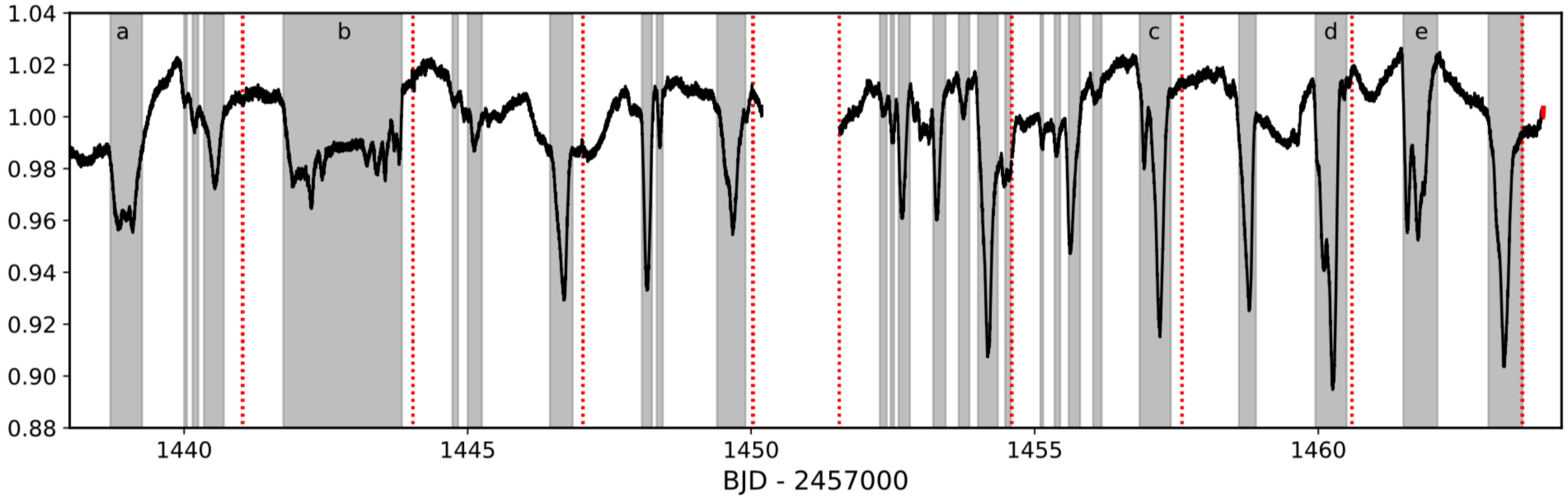


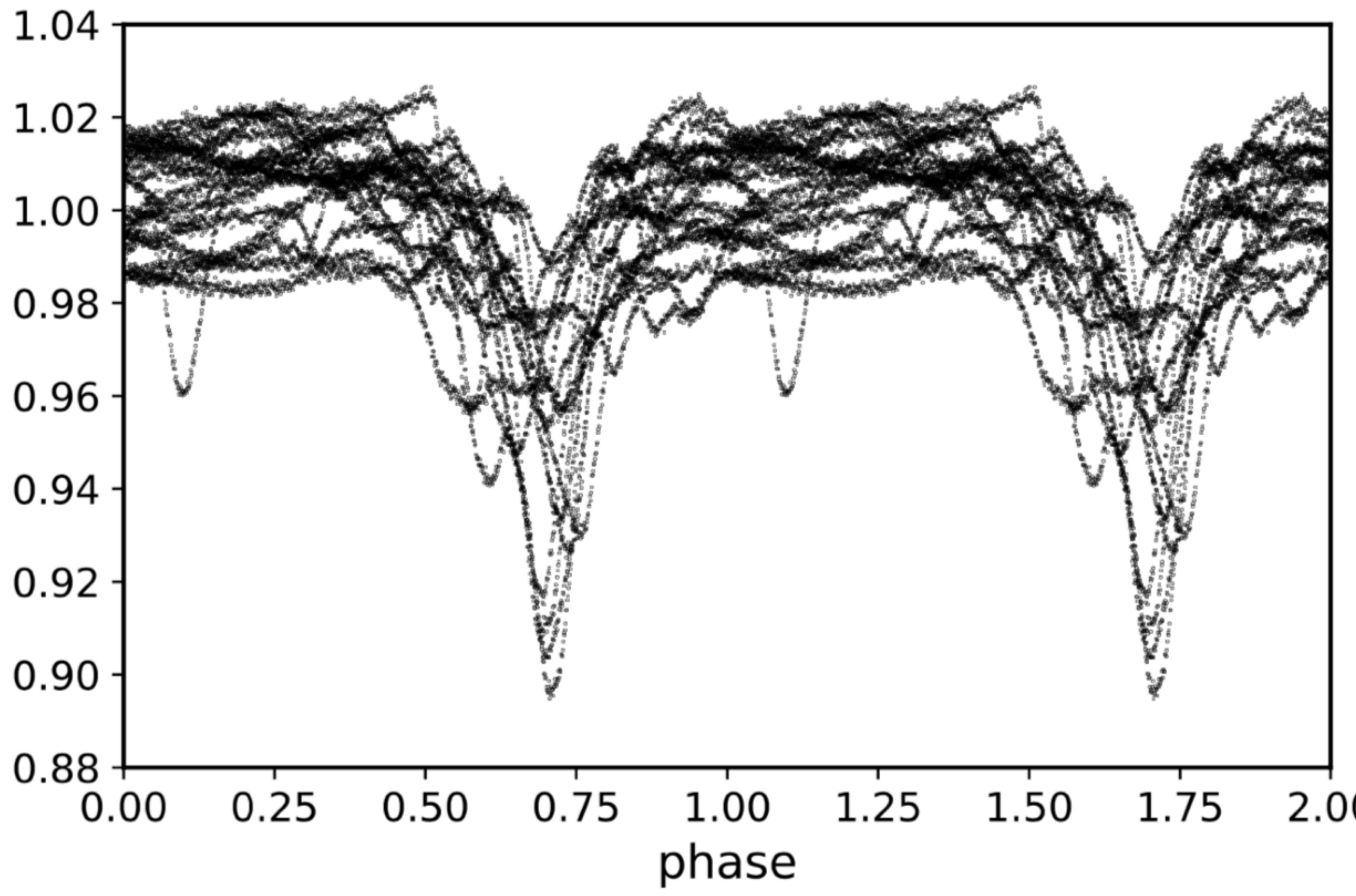
TESS covers the entire sky, including nearby YMGs (10-150 Myr)

finding intermediate-aged dippers with TESS

HD 240779 [1M$_\odot$, 125 Myr]

Gaidos et al. 2019





- many of the dipper mechanisms (e.g, accretion-driven inner disk warps) ruled out
- can be explained by disrupted ~100 km planetesimal due to tides or stellar irradiation?
- will give insight into final phase of rocky planet formation (30 TESS dippers already identified)

Summary

- Dipper disks are not biased toward nearly edge-on inclinations
- Dippers have an isotropic outer disk inclination distribution and exhibit a range of morphologies echoing the general disk population

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- This suggests that multiple mechanisms may be required to explain the dipper phenomenon (inner warps, disk winds, inclined planets)
- More broady, this also suggests that the geometry and morpholoy outer disk is completely unrelated to the dynamic inner disk