Palomar Gattini-IR

The dawn of wide-field infrared time domain astronomy

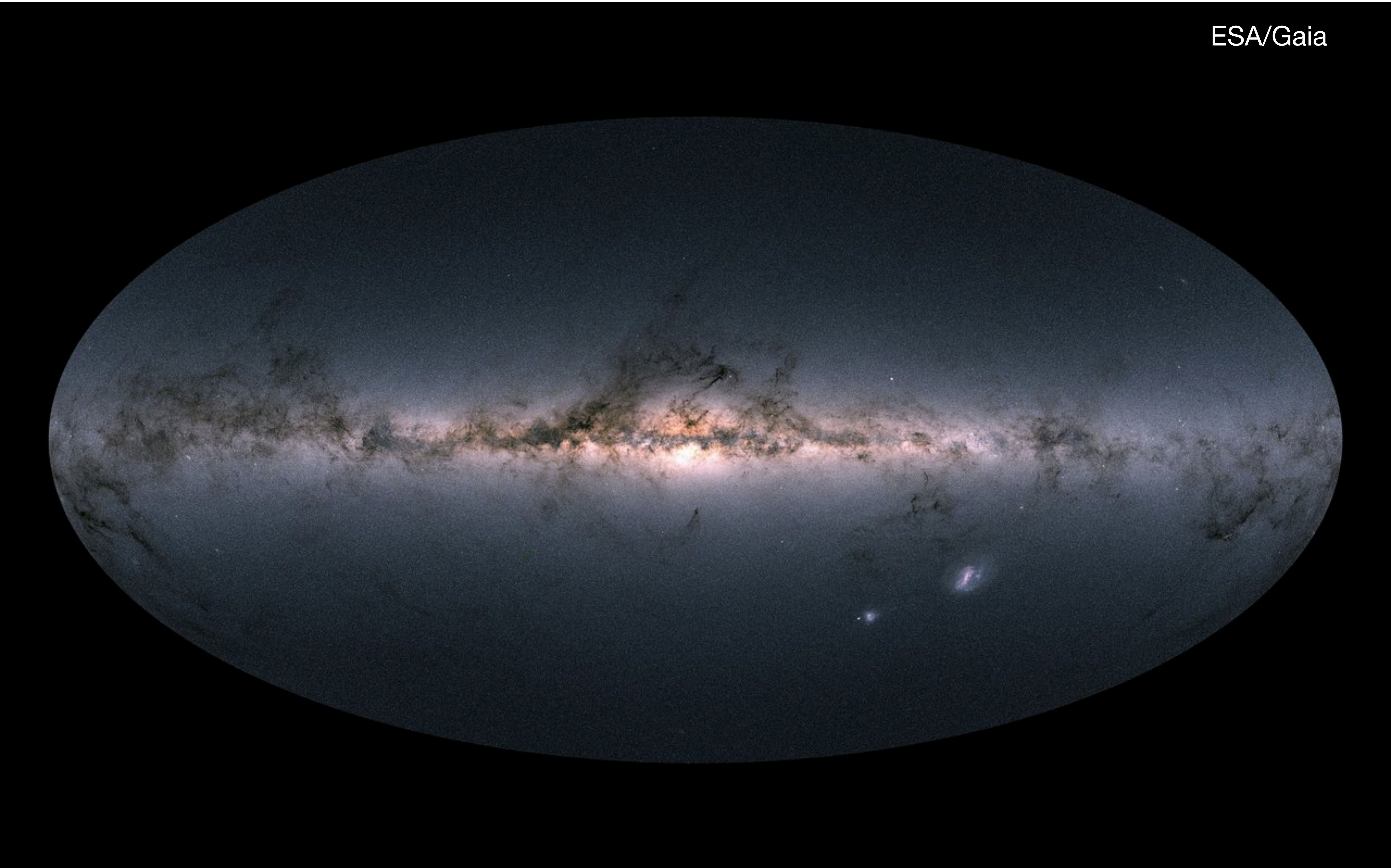
Kishalay De

Caltech → MIT (NASA Hubble Fellow + Kavli Fellow)

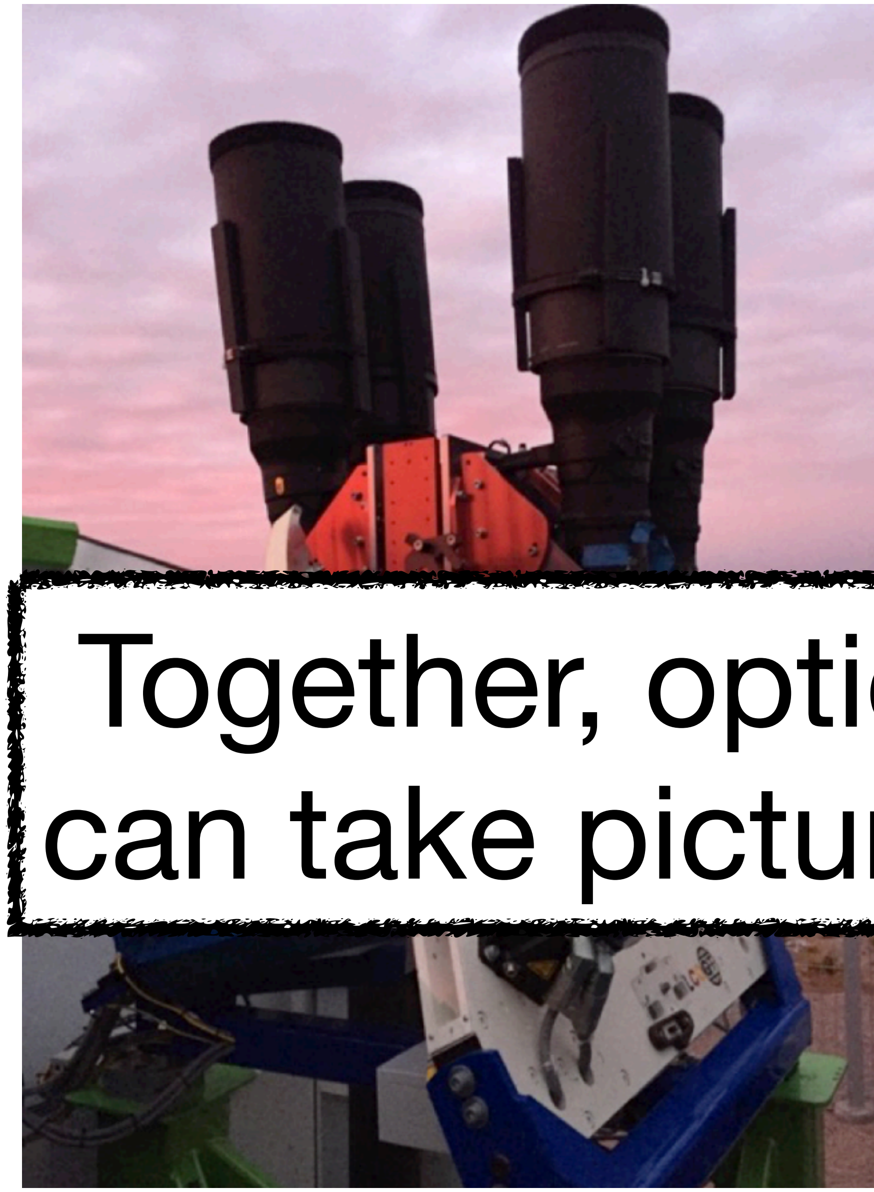
Outline

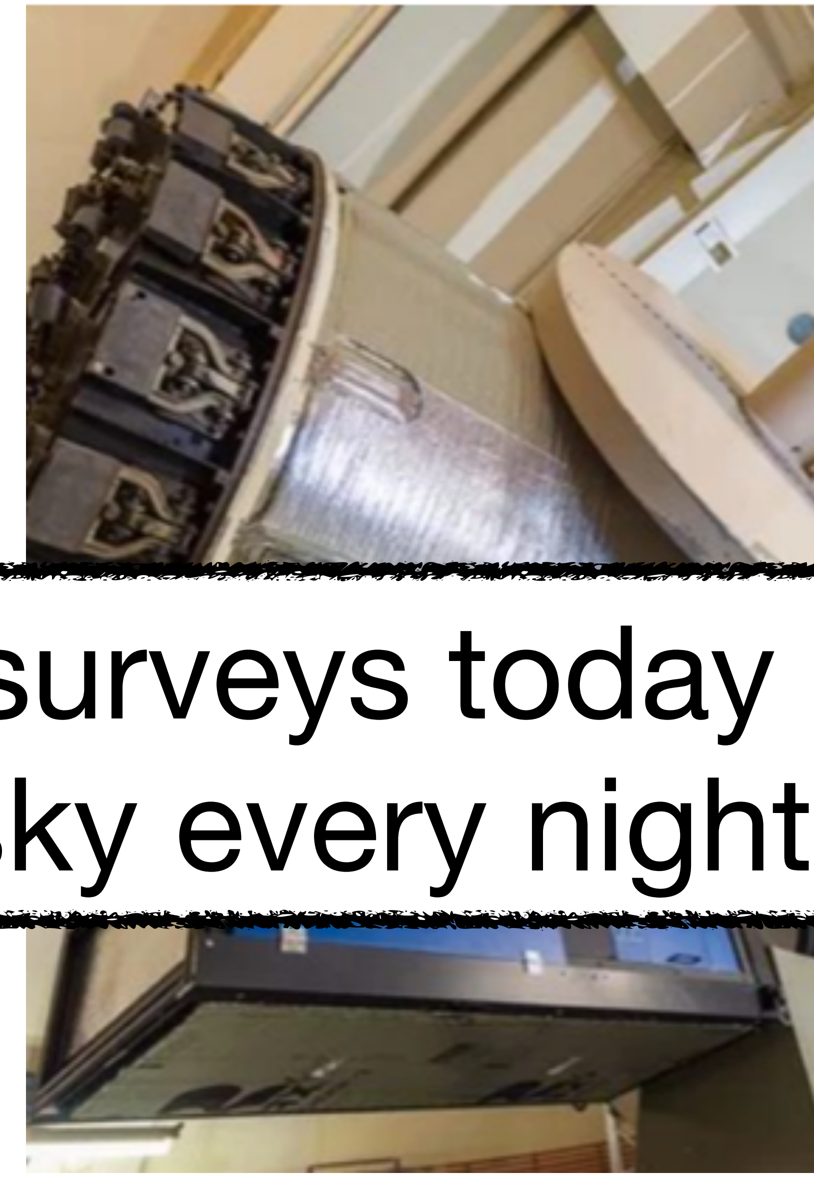
- Why IR time domain astronomy?
- The Challenges
- Novel Techniques: Palomar Gattini-IR
- First Results: The Dynamic Infrared Galaxy
- The Next Frontier
  - Multi-messenger astronomy
  - Multi-wavelength view of the obscured universe

The Era of All-sky Optical Surveys



Finding things that go boom





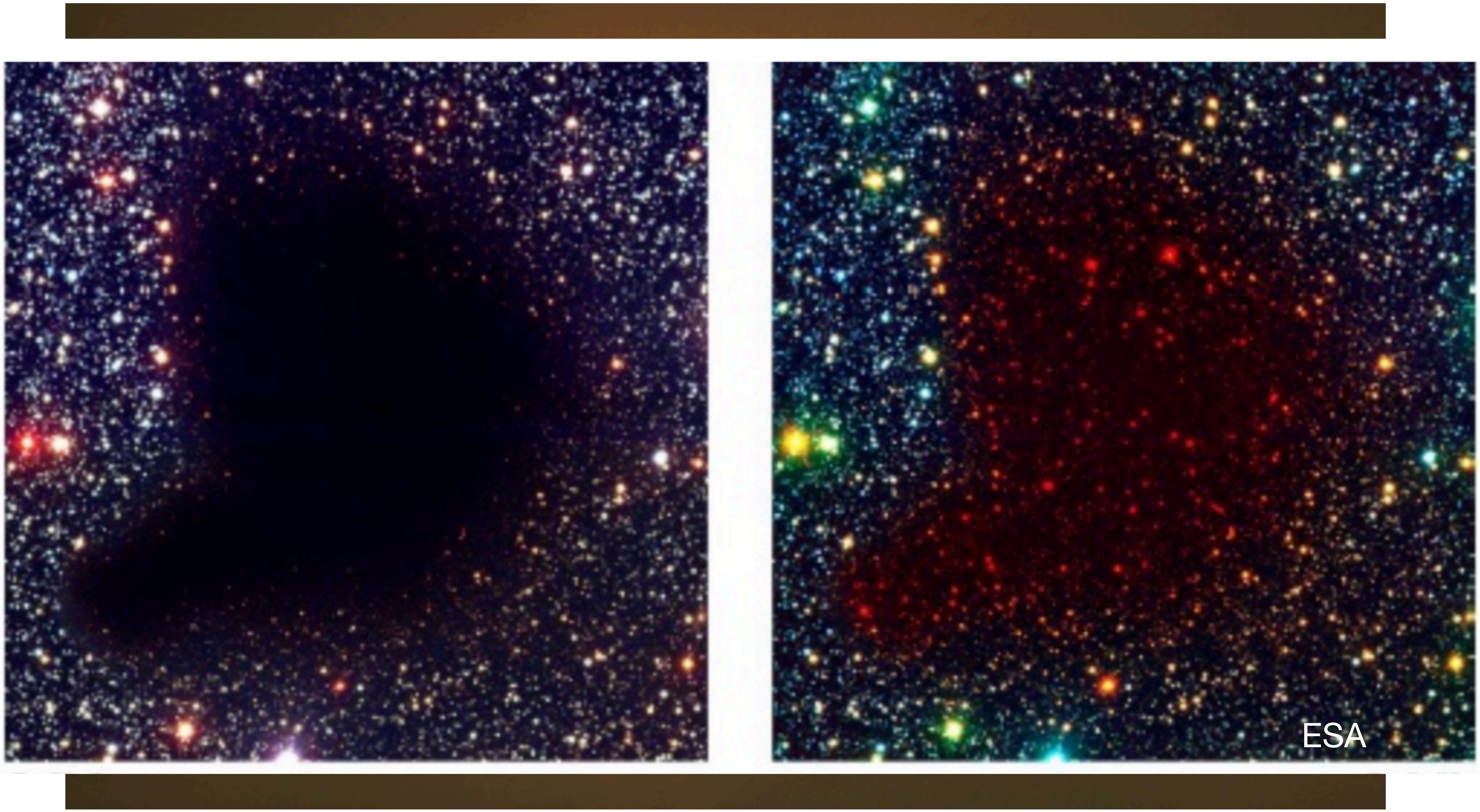
Together, optical time domain surveys today can take pictures of the entire sky every night

ASASSN
20 X 14 cm lens
FOV ~ 80 deg^2
Limit g ~ 18 mag

ATLAS
2 X 0.5 m telescope
FOV ~ 30 sq. deg.
Limit c ~ 19.5 mag

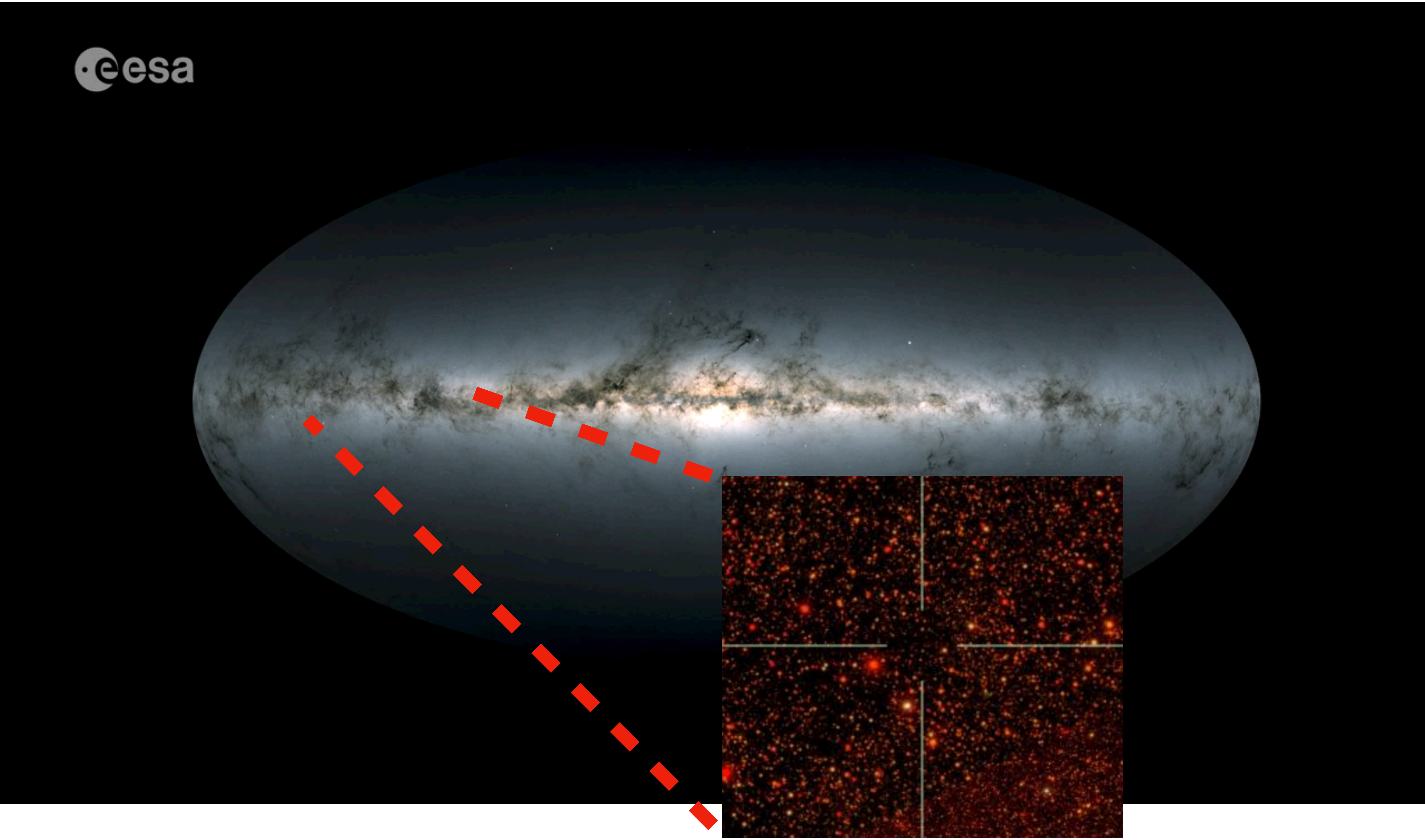
ZTF
1 X 1.2 m telescope
FOV ~ 47 sq. deg.
Limit r ~ 20.5 mag

Why time domain astronomy in the NIR?



The NIR is sensitive to the temporal phenomena obscured by dust or intrinsically red

The Milky Way as viewed by Gaia space mission



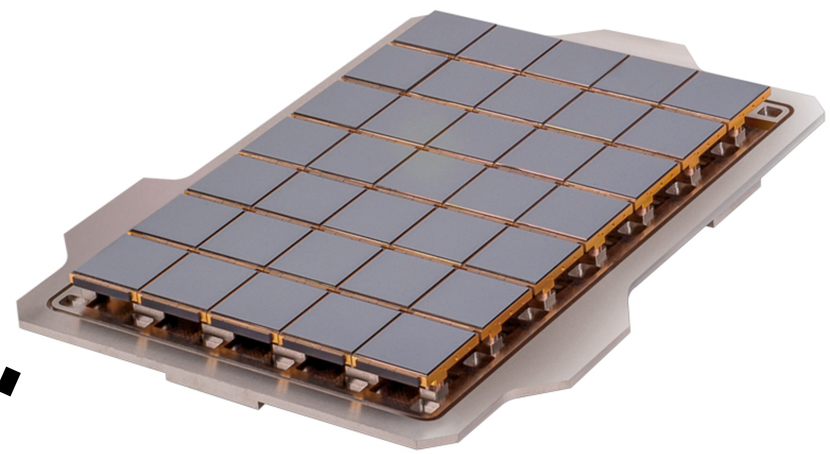
Most stars in our Galaxy are hidden by dust

The Challenges

Caveat #1: The atmosphere

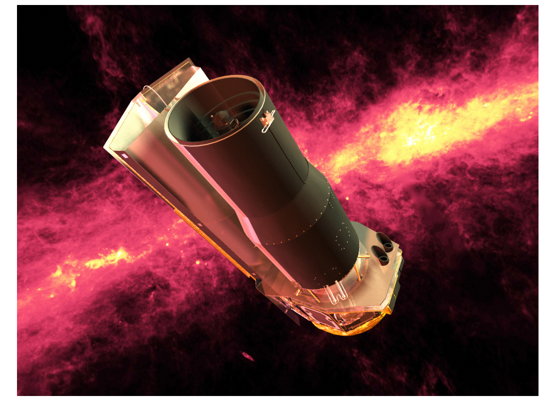
Optical

Near-Infrared:
Special detectors

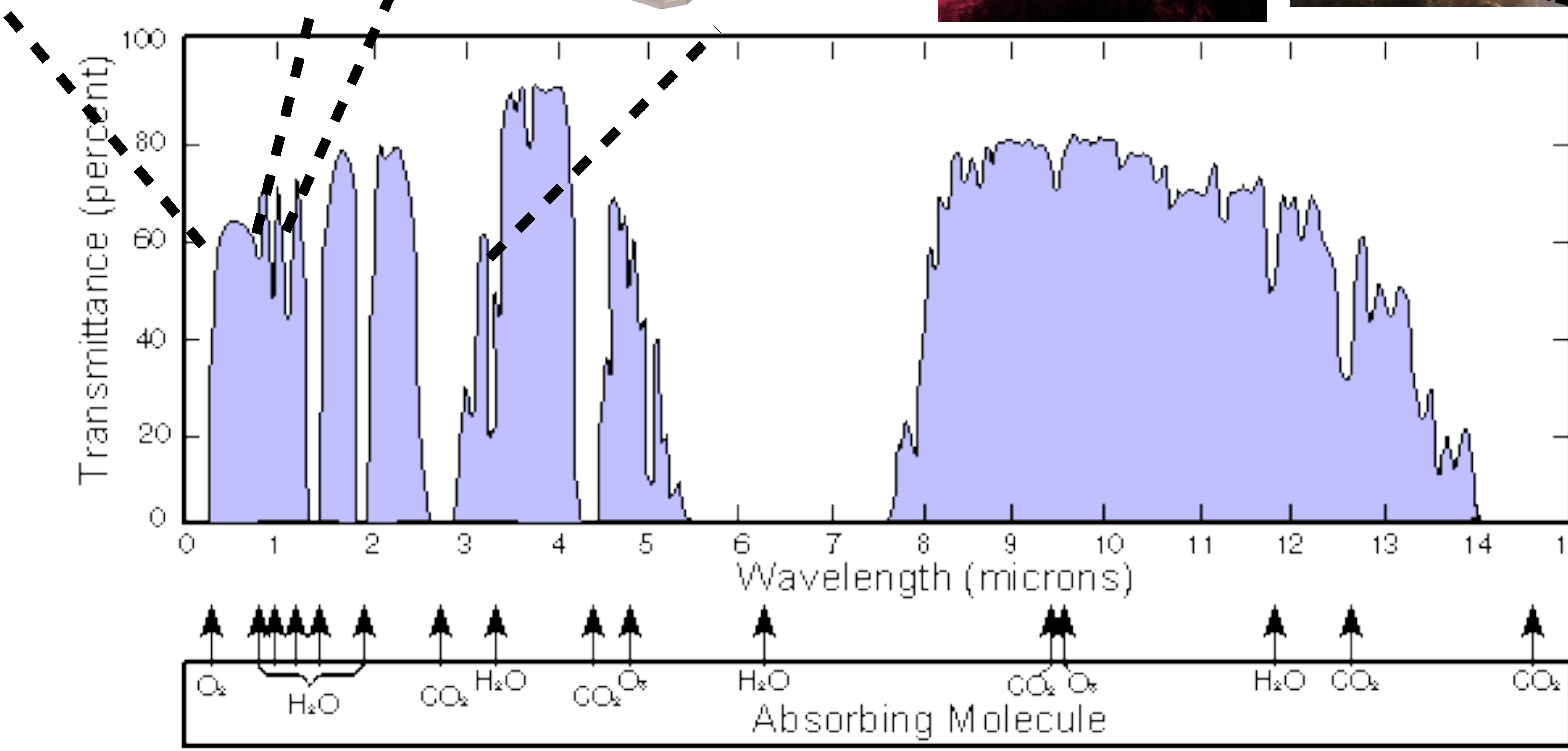


Mid-infrared

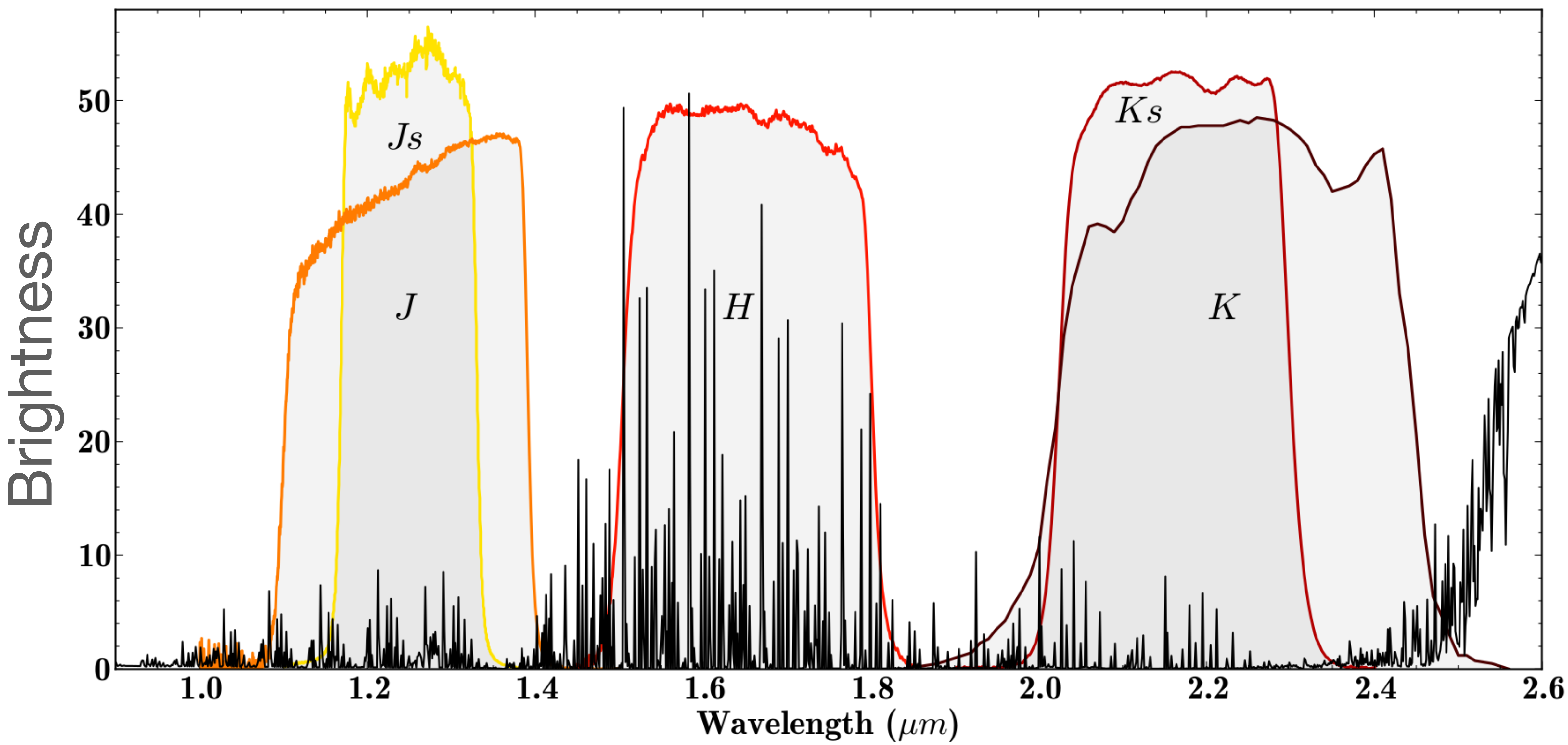
Spitzer Space Telescope



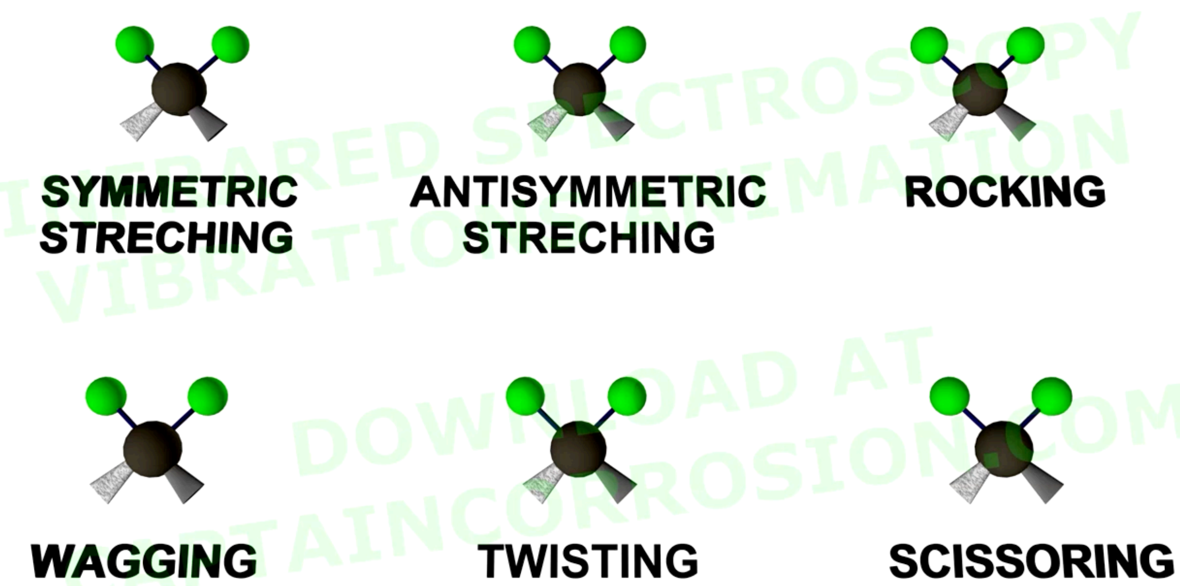
Herschel Space Observatory



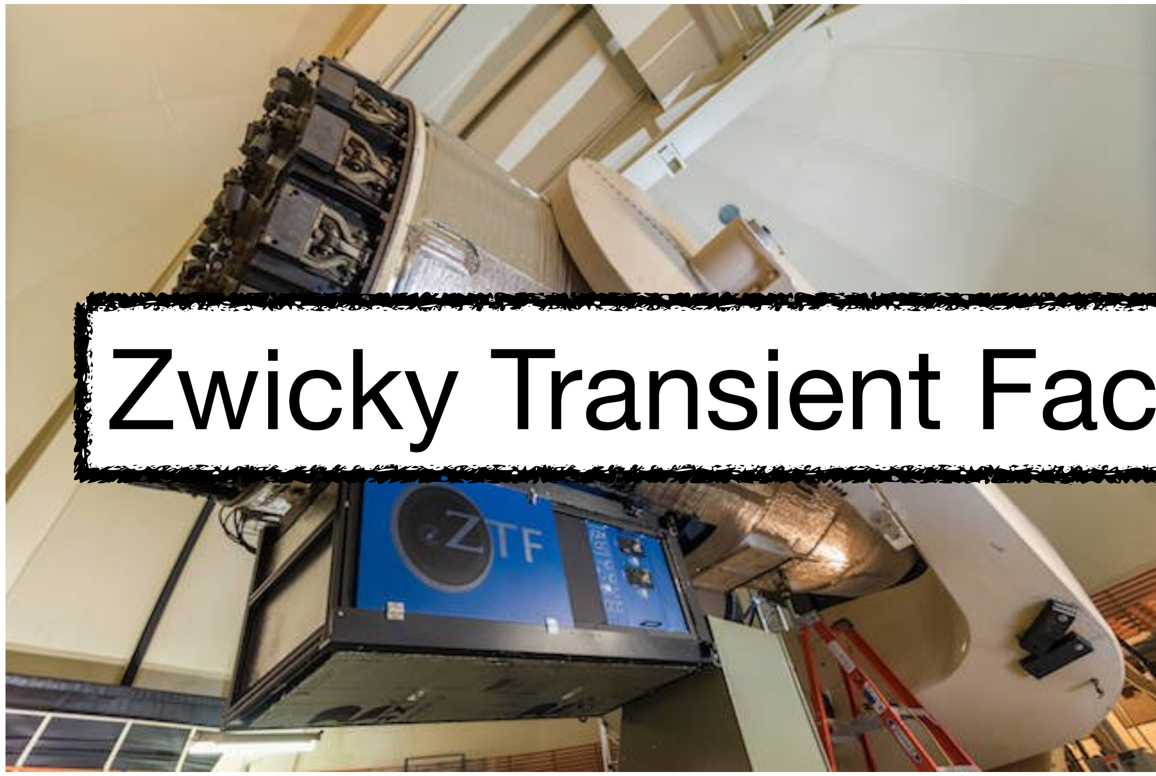
Caveat #2: The atmosphere (again..)

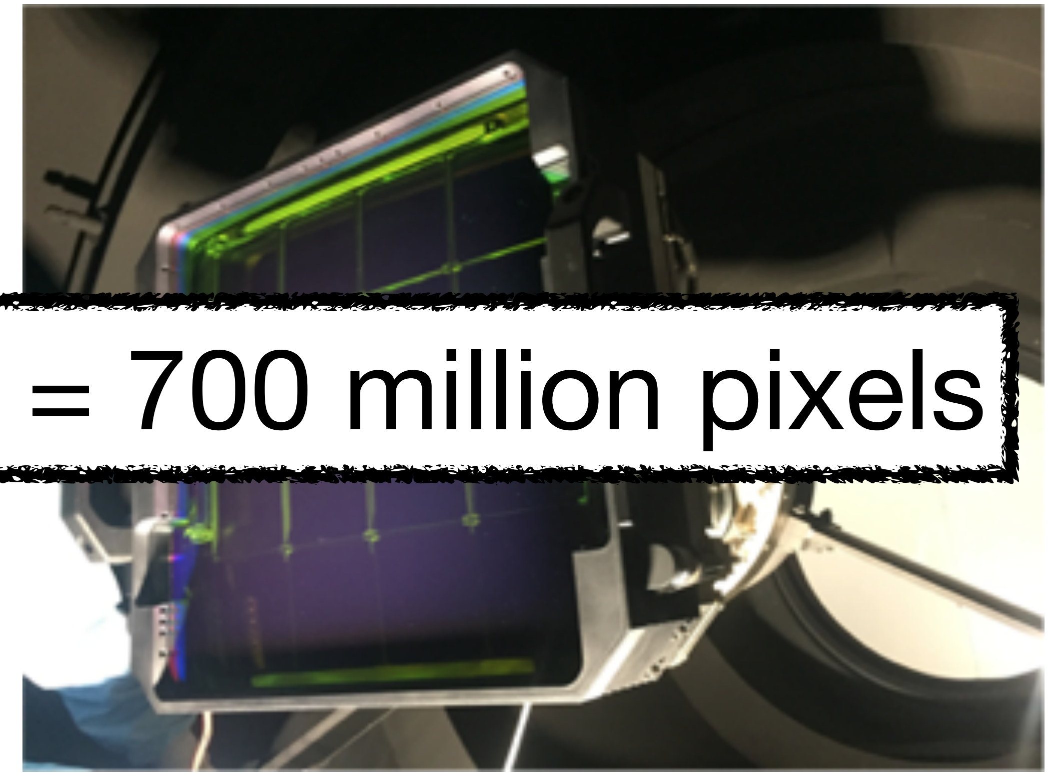


Atmospheric molecules emit light at IR wavelengths:
The night sky is not dark in the infrared!

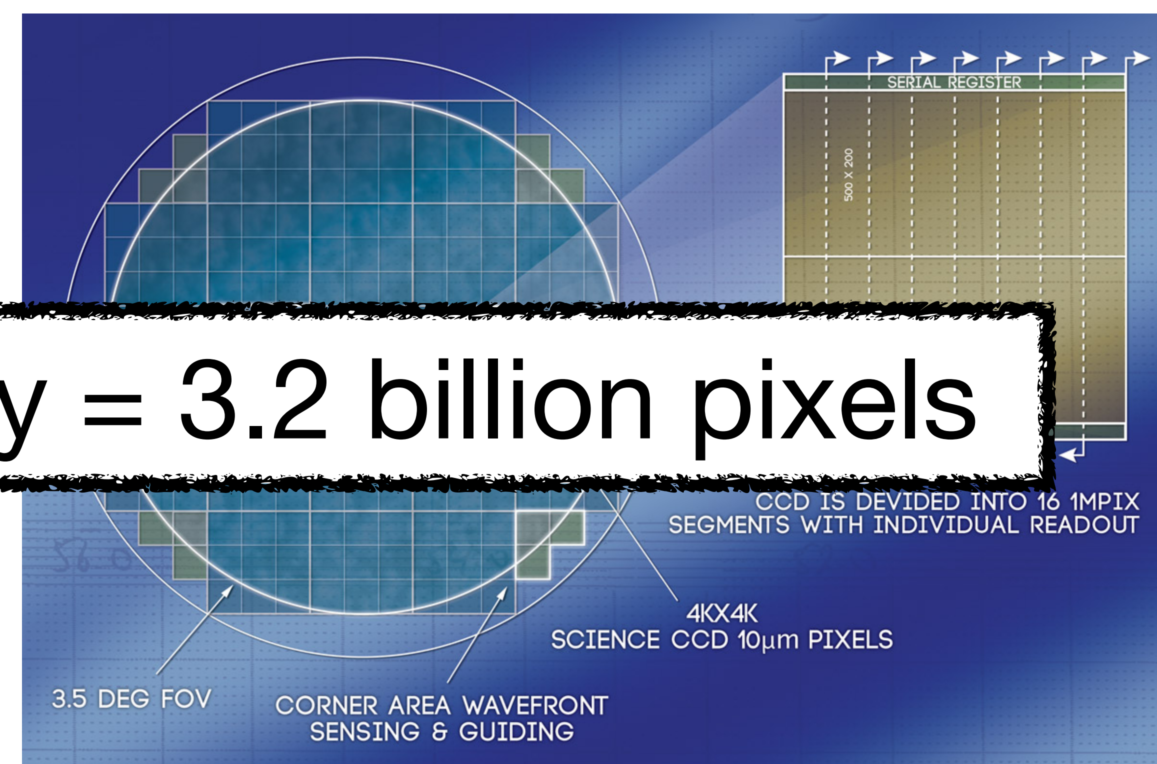


Optical time domain astronomy has exploded thanks to large format cameras





Zwicky Transient Facility = 700 million pixels

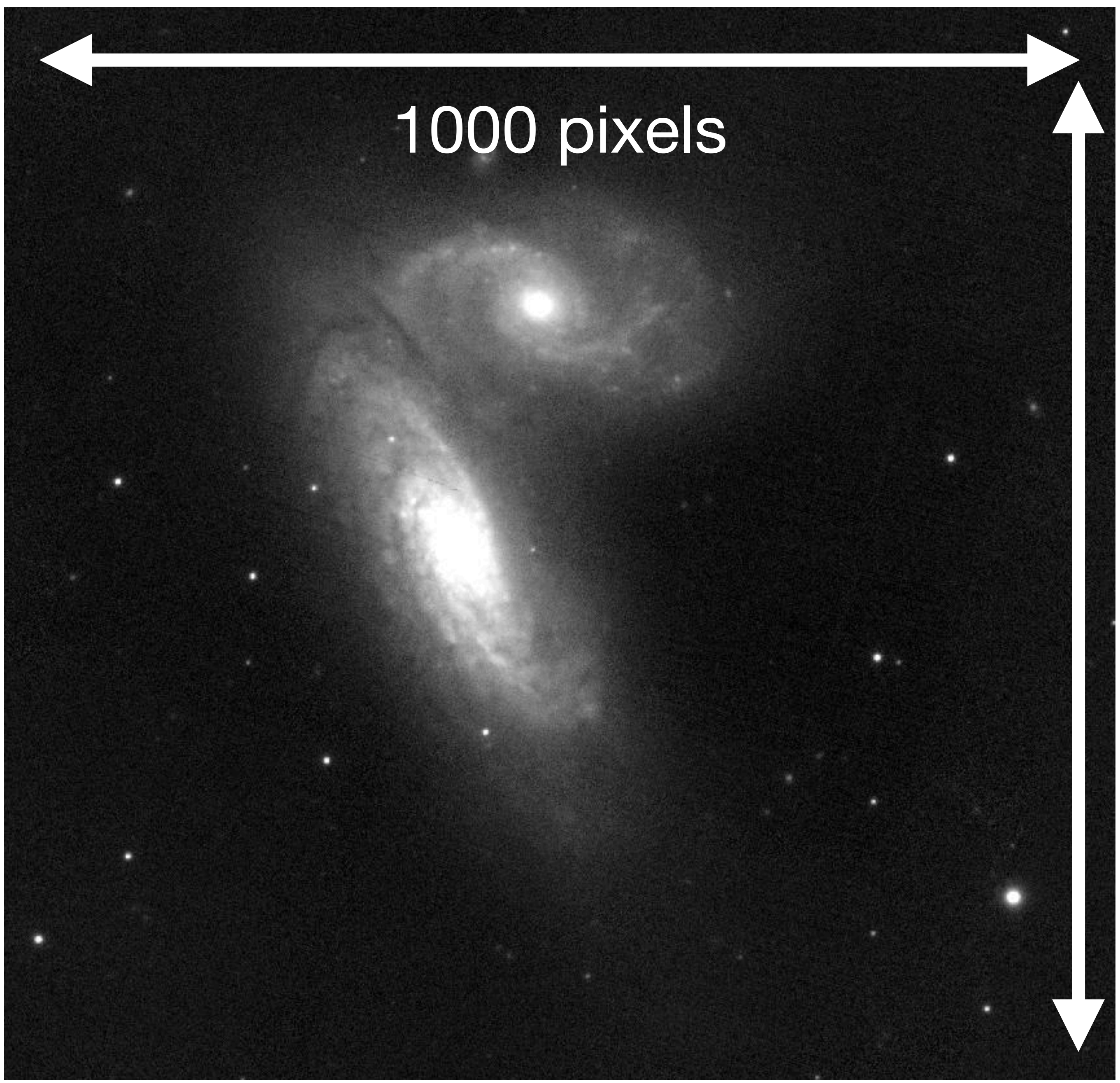


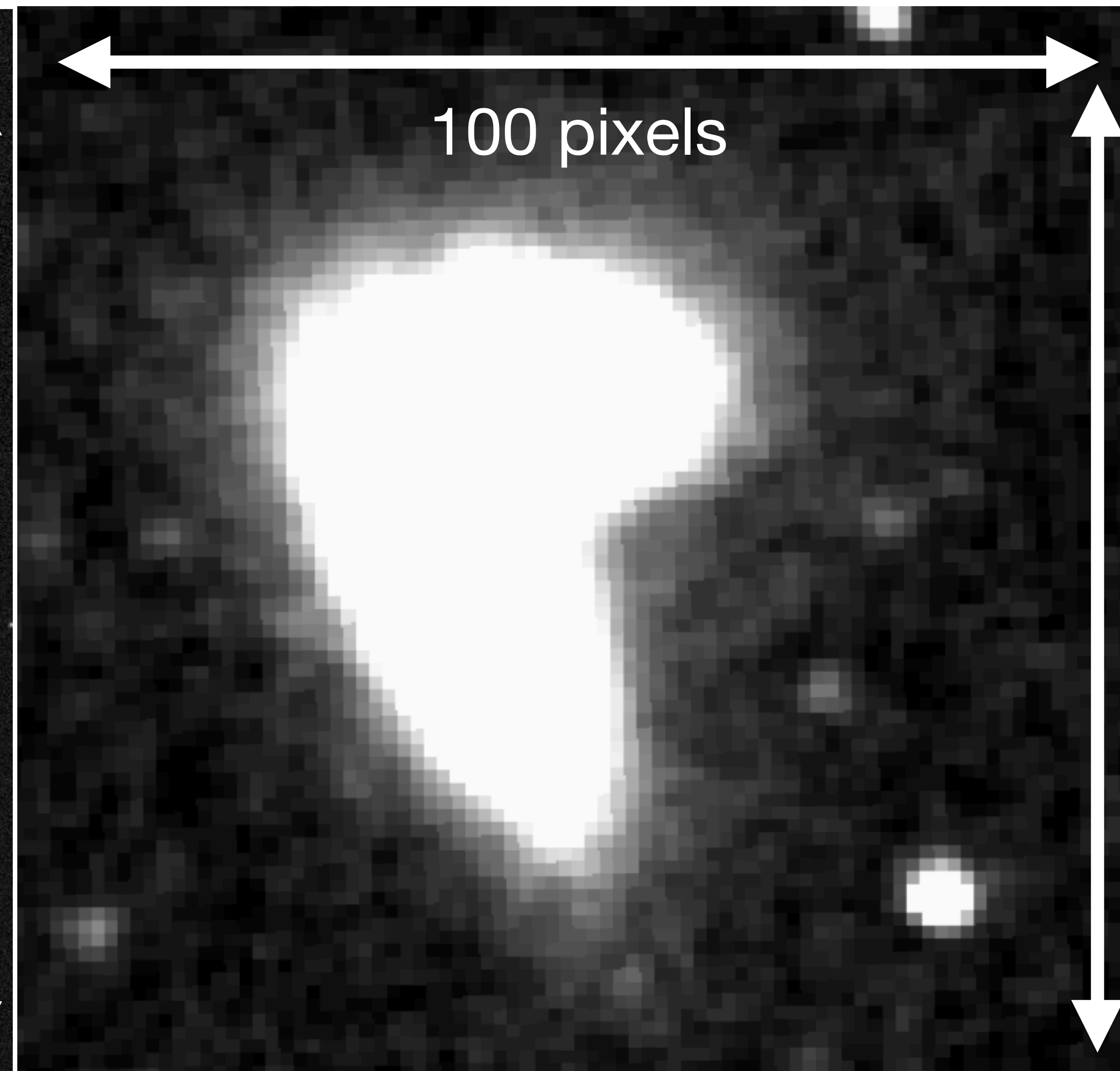
Vera Rubin Observatory = 3.2 billion pixels

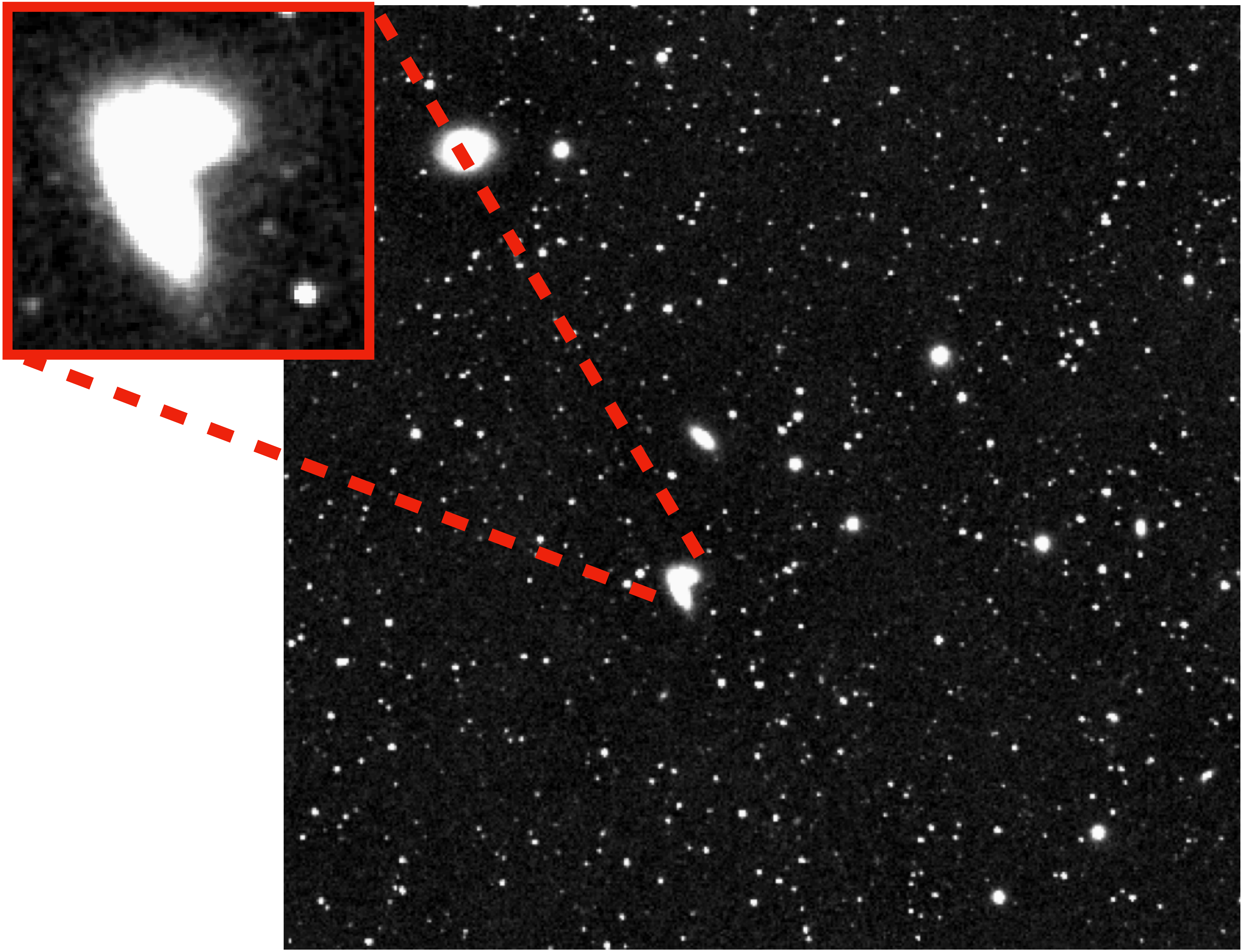
Caveat #3: (Conventional) Infrared cameras are about **ten times** more expensive (per pixel) than optical

How can we take bigger pictures with the same detector?

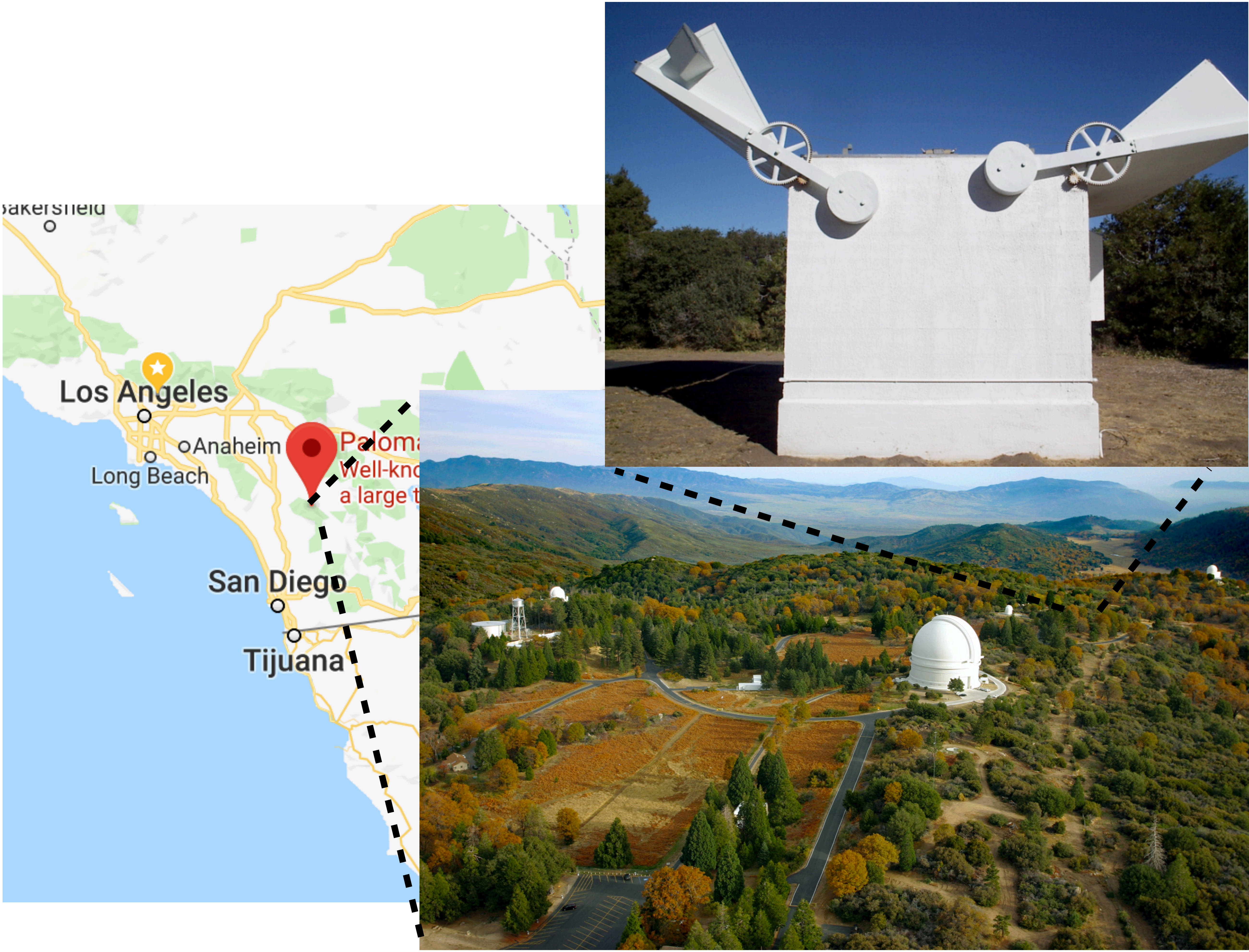
Say I had a camera with 1 million pixels

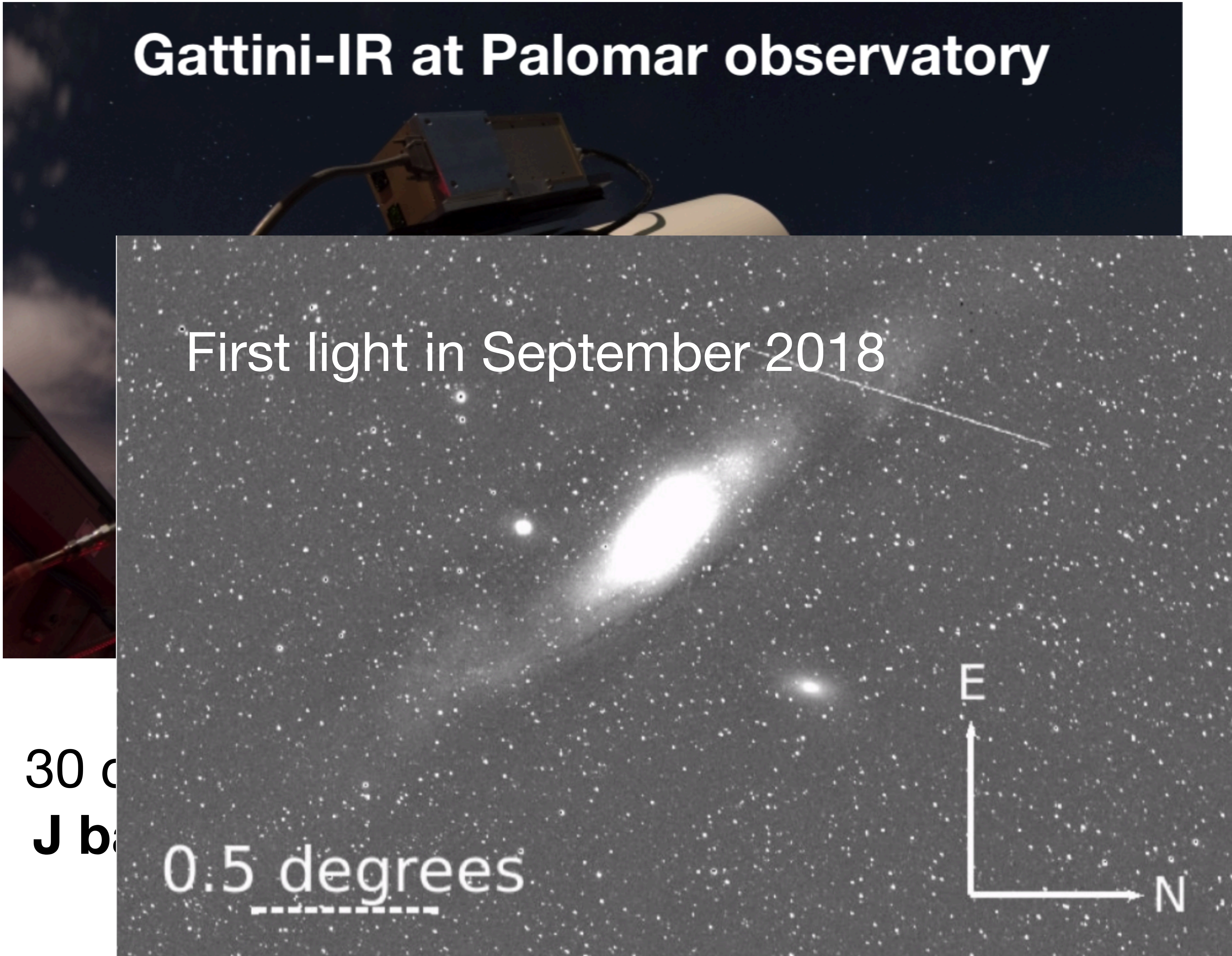






Palomar Gattini-IR

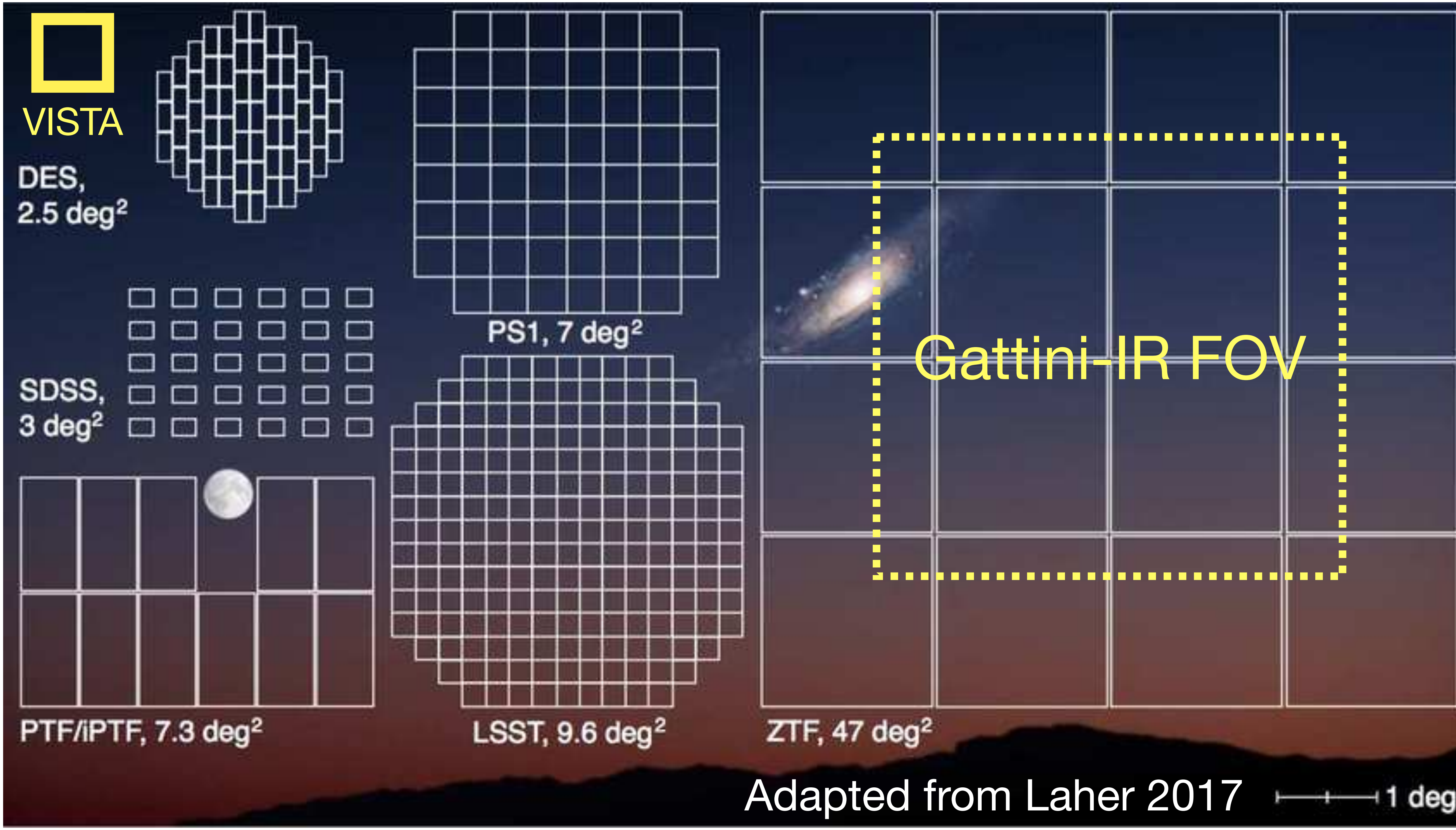

Los Angeles
Anaheim
Long Beach
San Diego
Tijuana



30 c

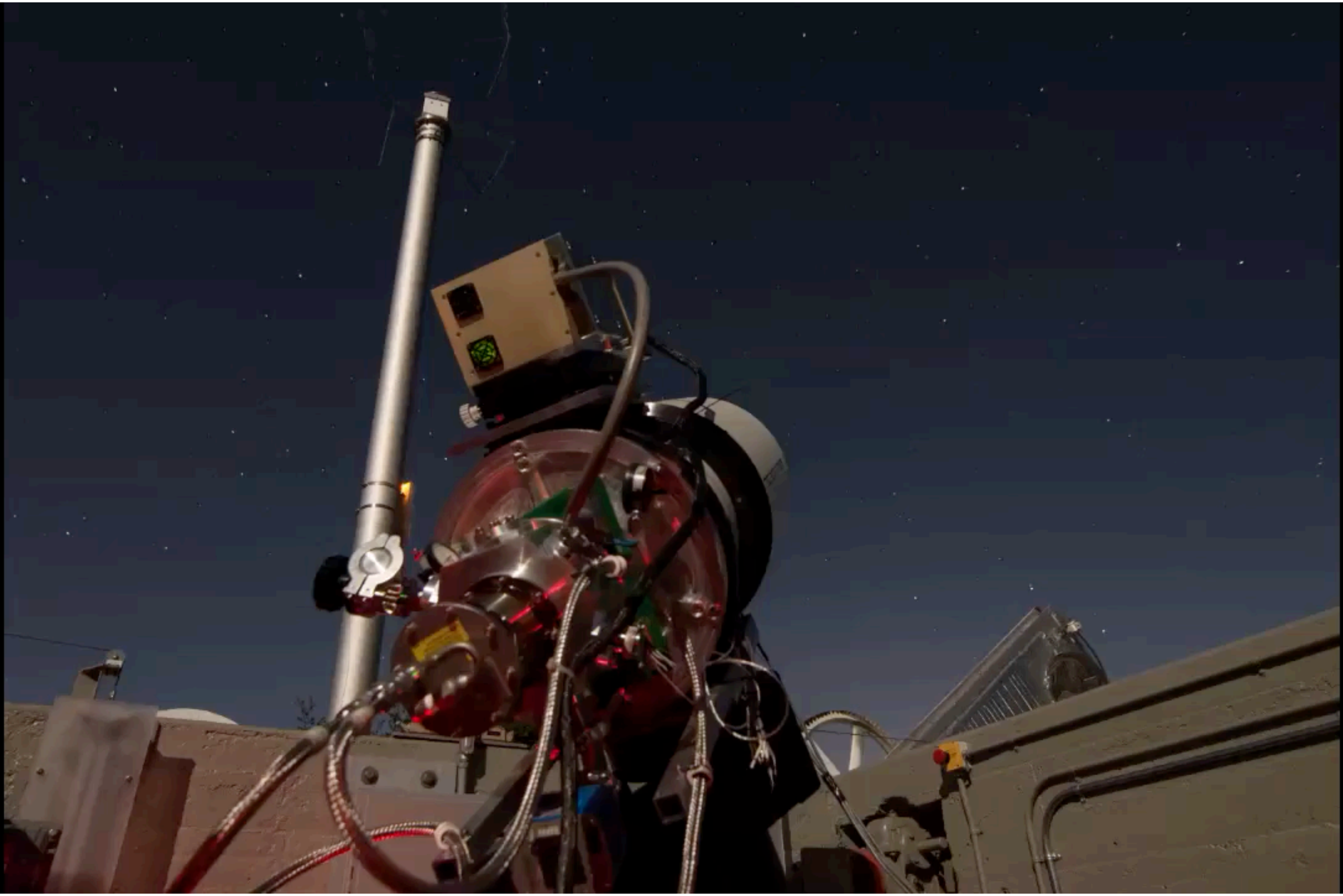
J ba

De+ 2020a, Moore & Kasliwal 2019



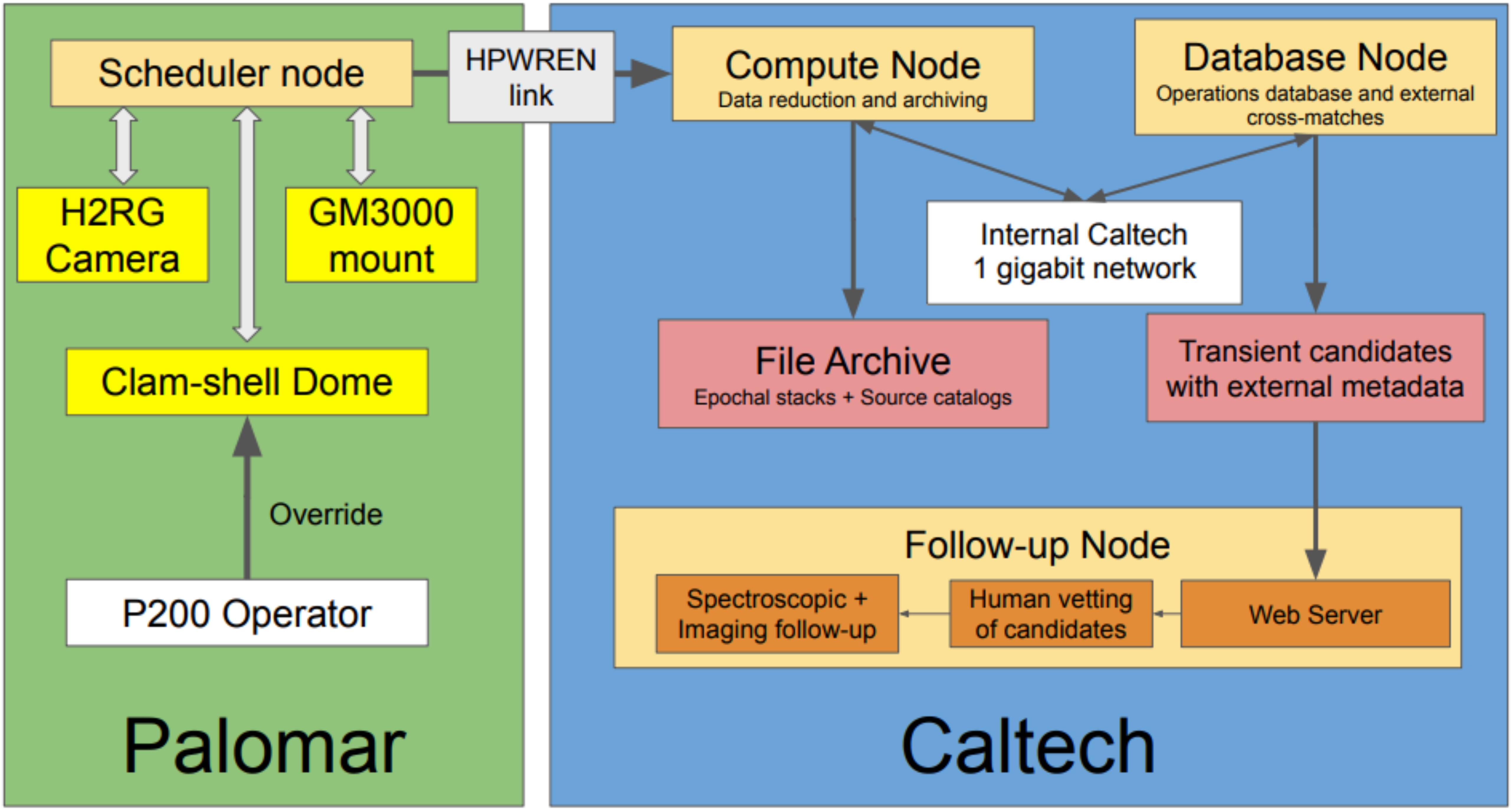
Palomar Gattini-IR (PGIR) field of view is 40 times larger than any other current near-infrared instrument

Robotic eyes on the infrared sky



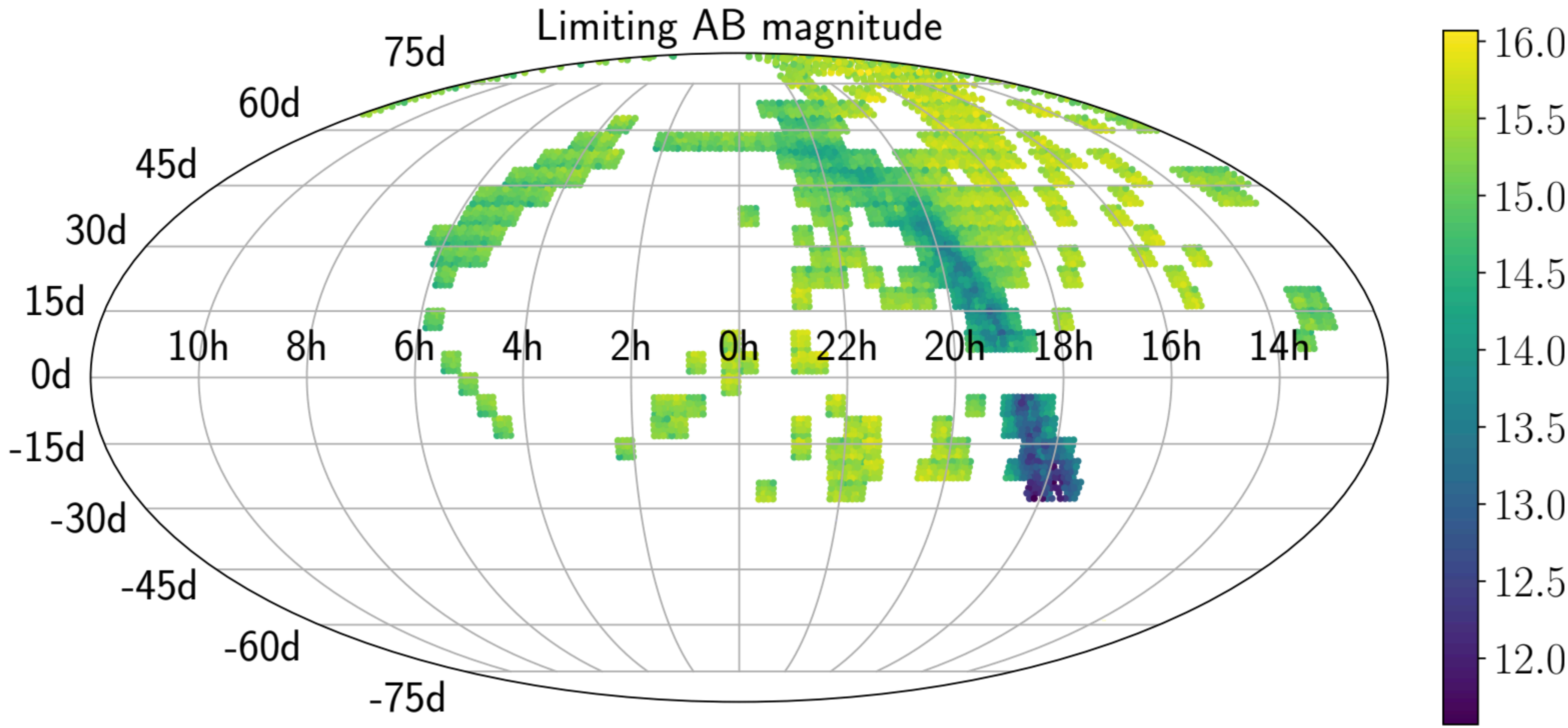
Credit: Scott Adams

Robotic telescope operations and automated real-time data processing + Transient identification



De+ 2020a, PASP, 132

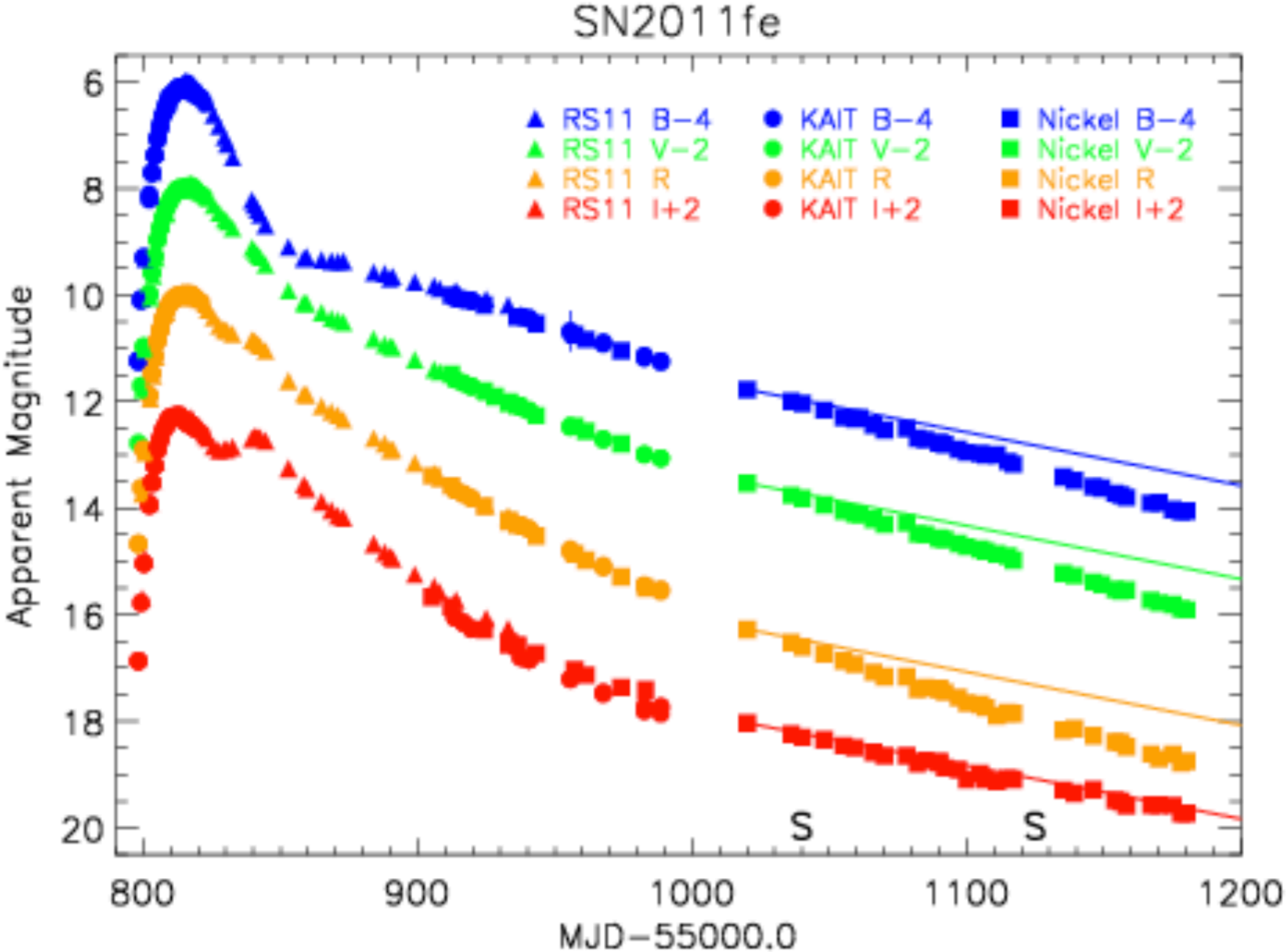
Nightly sky coverage



Areal coverage of ~ **7500 square degrees per night to a depth of J ~ 16 AB mag**

Finding transients

I



transmission, clouds, correlated pixel noise ..

The Dynamic Infrared Galaxy

First results

A NIR census of the dynamic, obscured Galactic plane

- Accreting young star outbursts
  Hillenbrand, De et al. 2021, arXiv: 2101.04203
  Hankins et al. in prep.

- Erupting classical novae
  De et al. 2021, arXiv: 2101.04045

- Flaring magnetars and fast radio bursts
  De et al. 2020c, ApJL, 901, arXiv: 2007.02978

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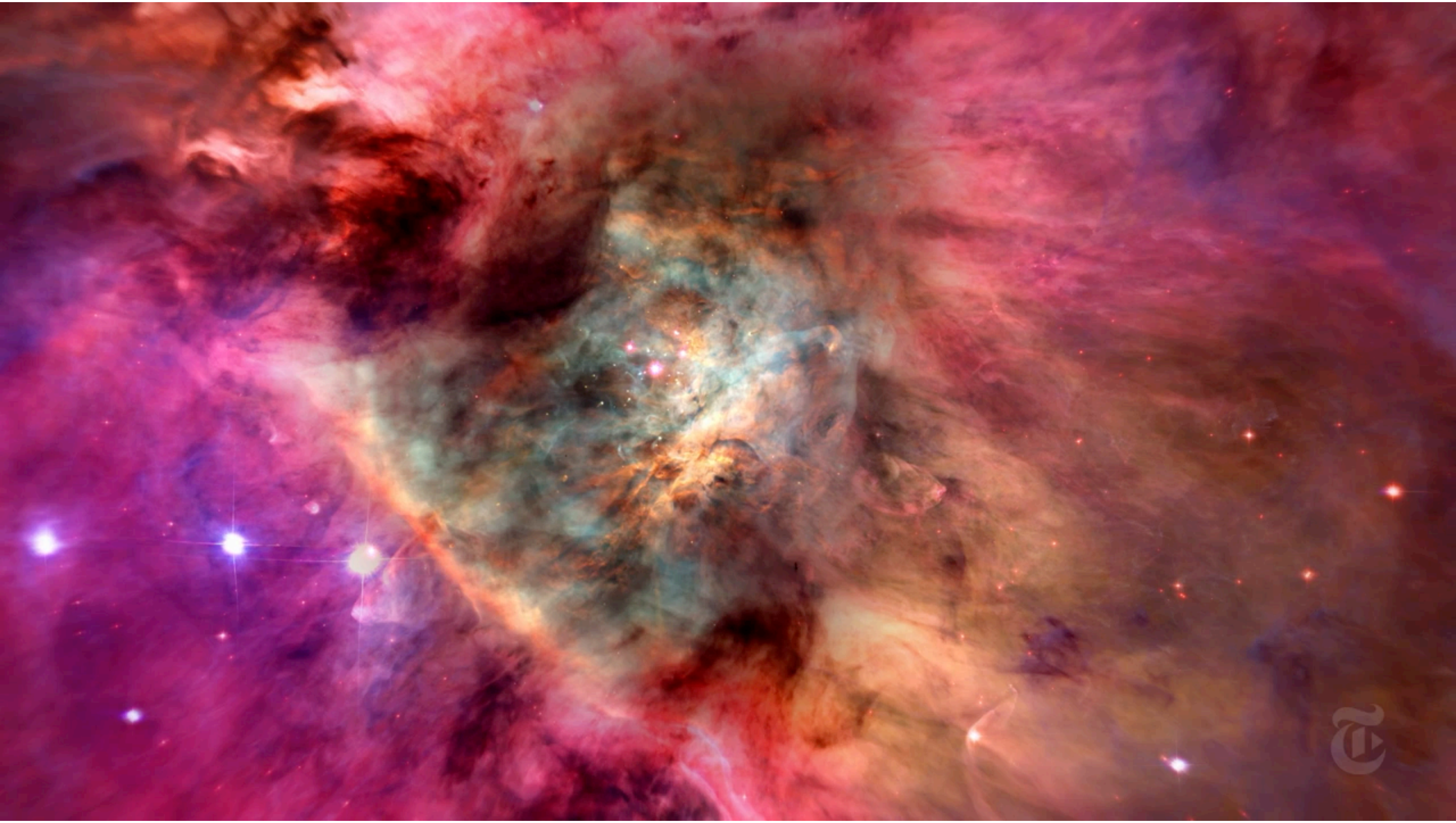
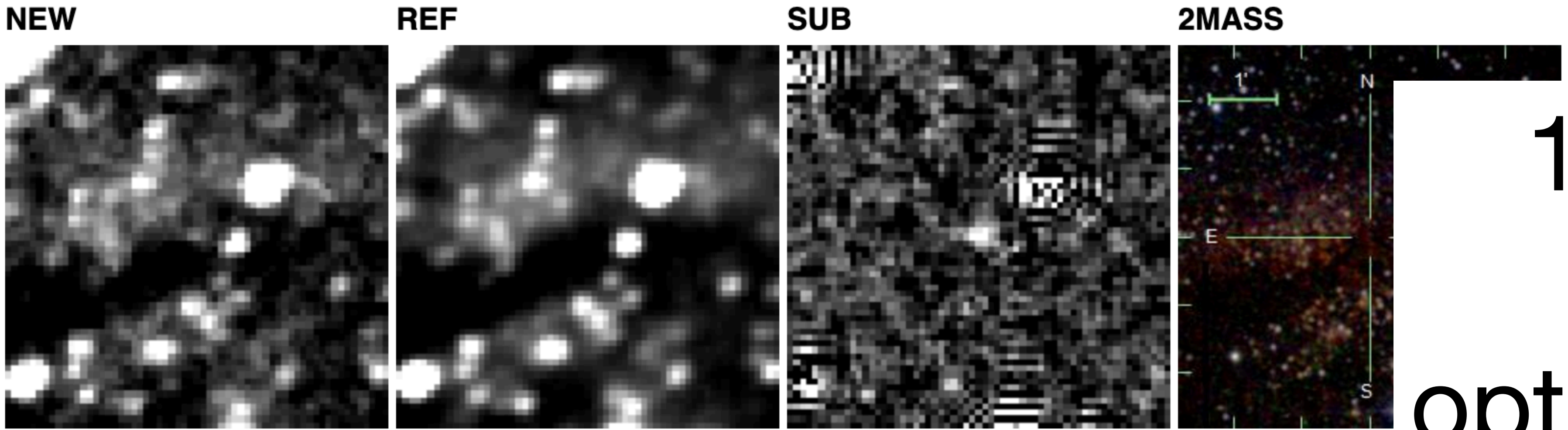
Stars are born in dust

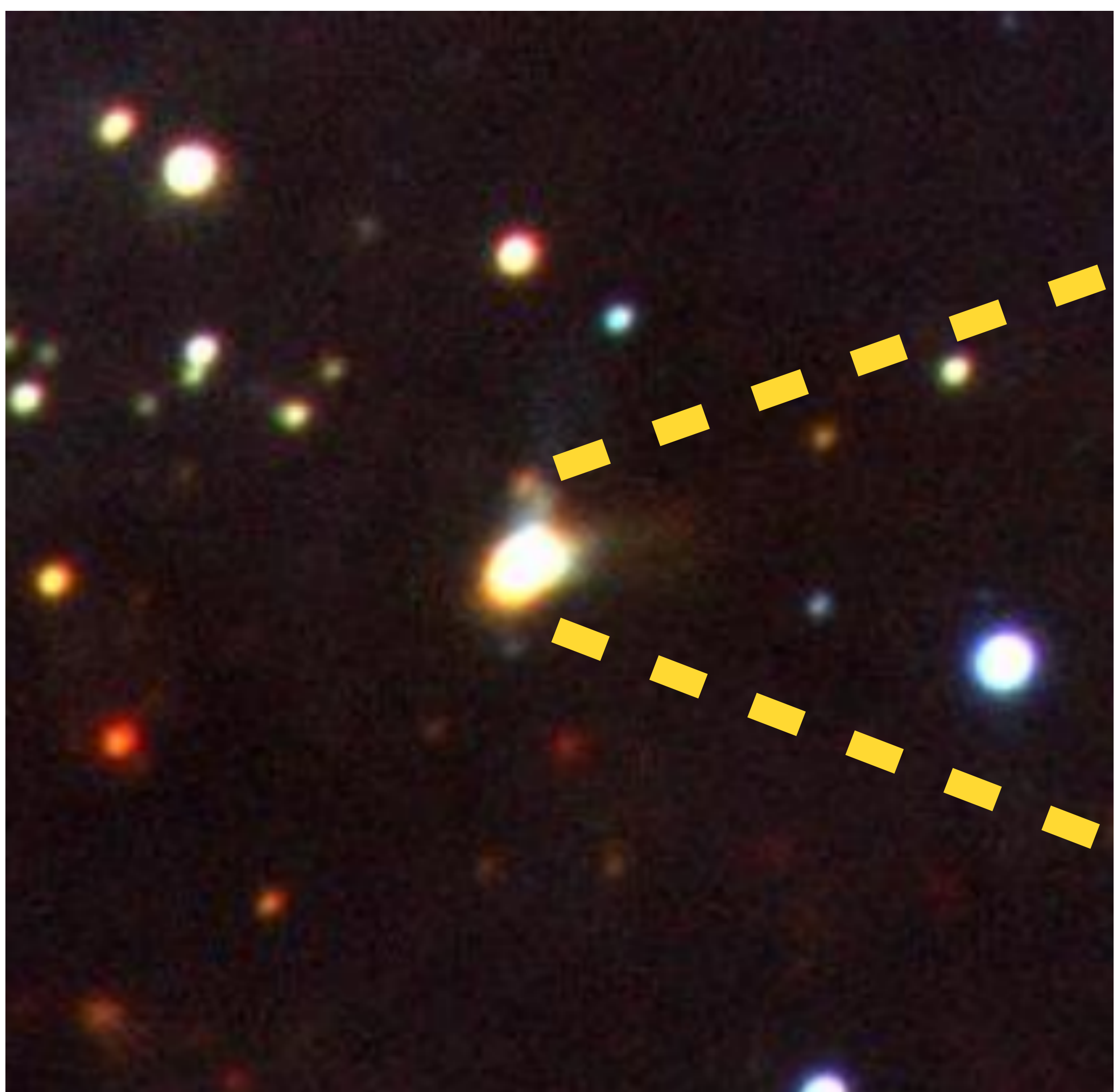


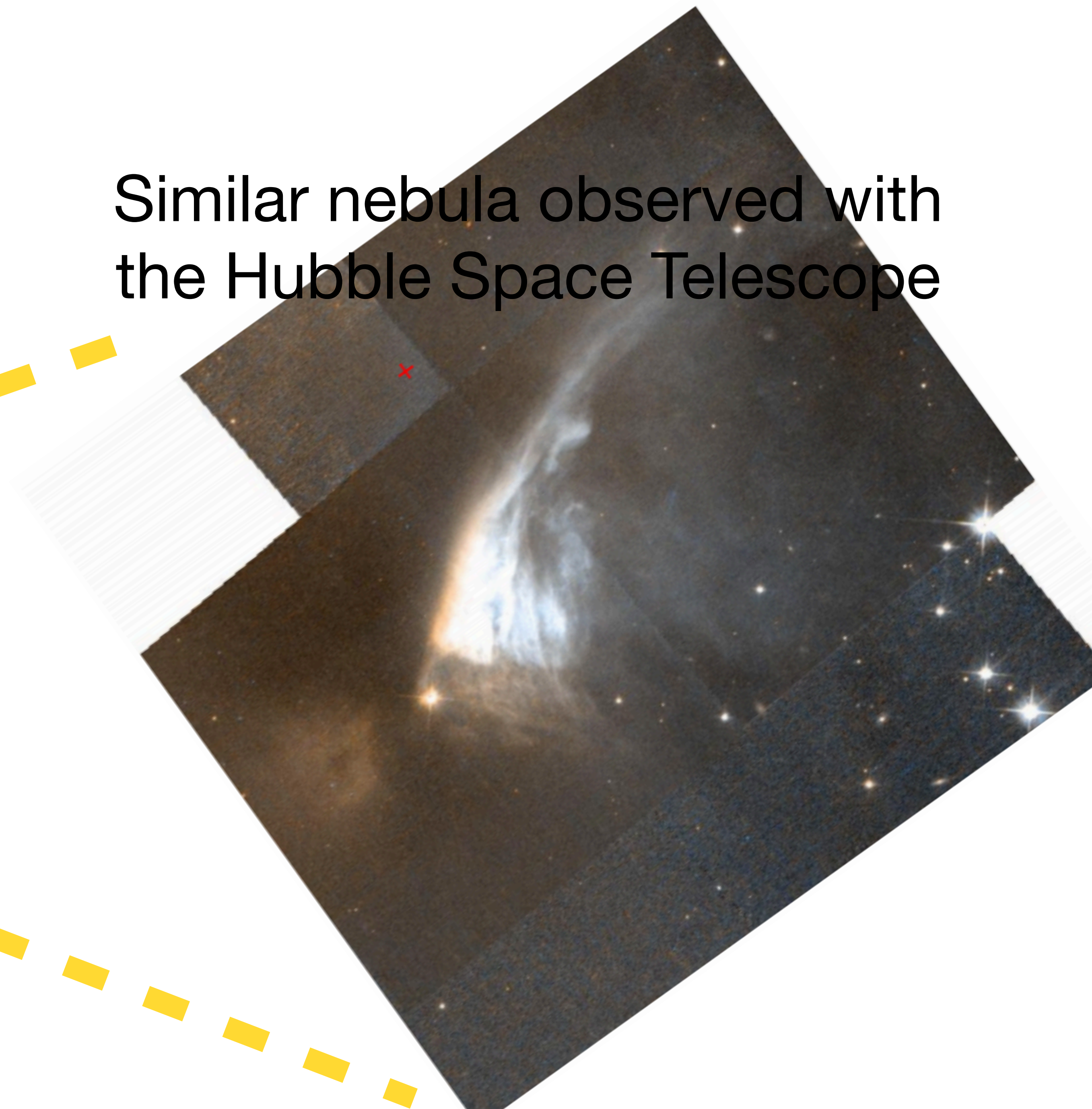
Understanding dust obscured star formation is crucial to understand where we came from



1 Million times fainter in the optical due to dust!

“False-color” Infrared Image from the ground





Similar nebula observed with the Hubble Space Telescope

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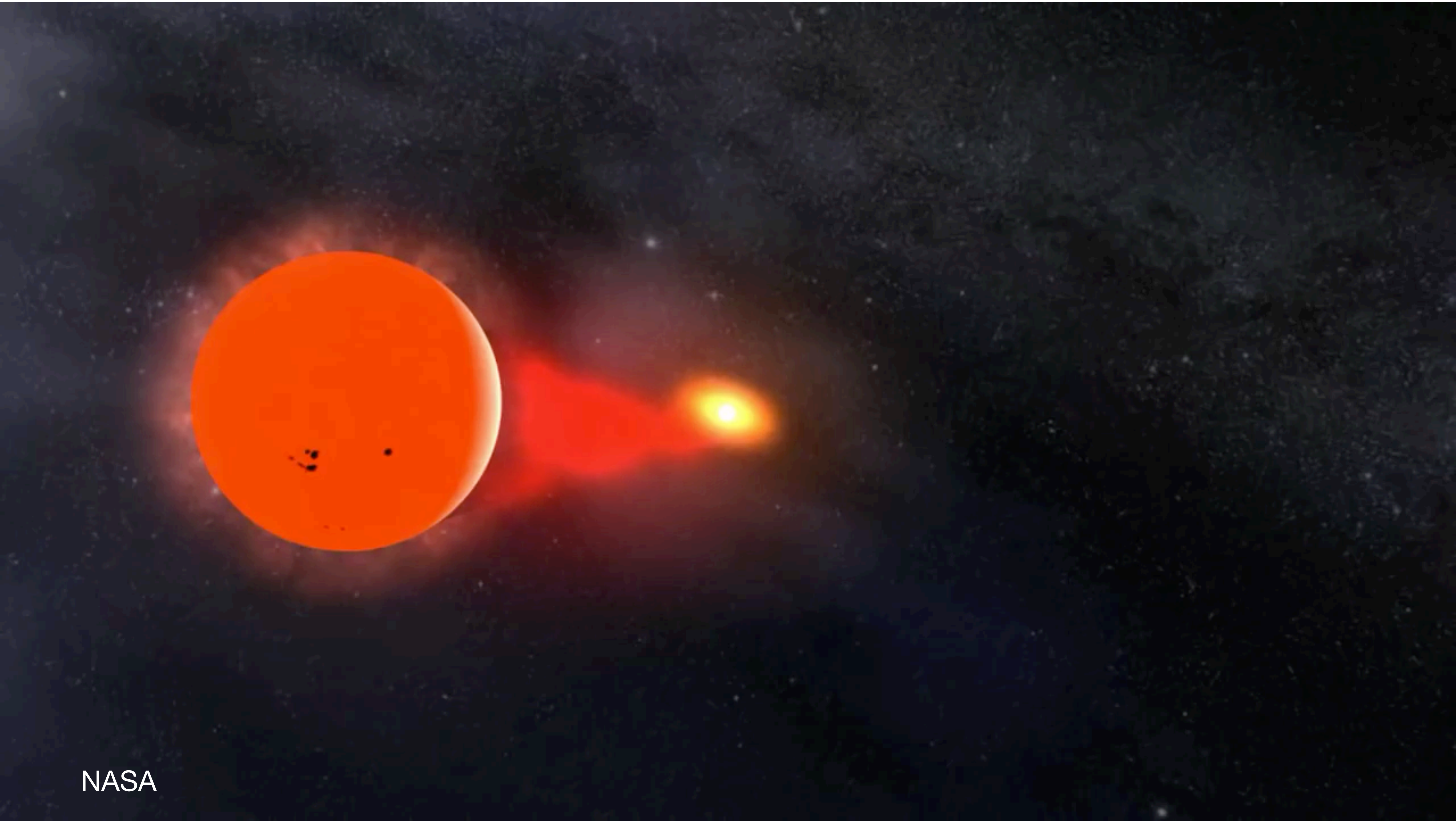
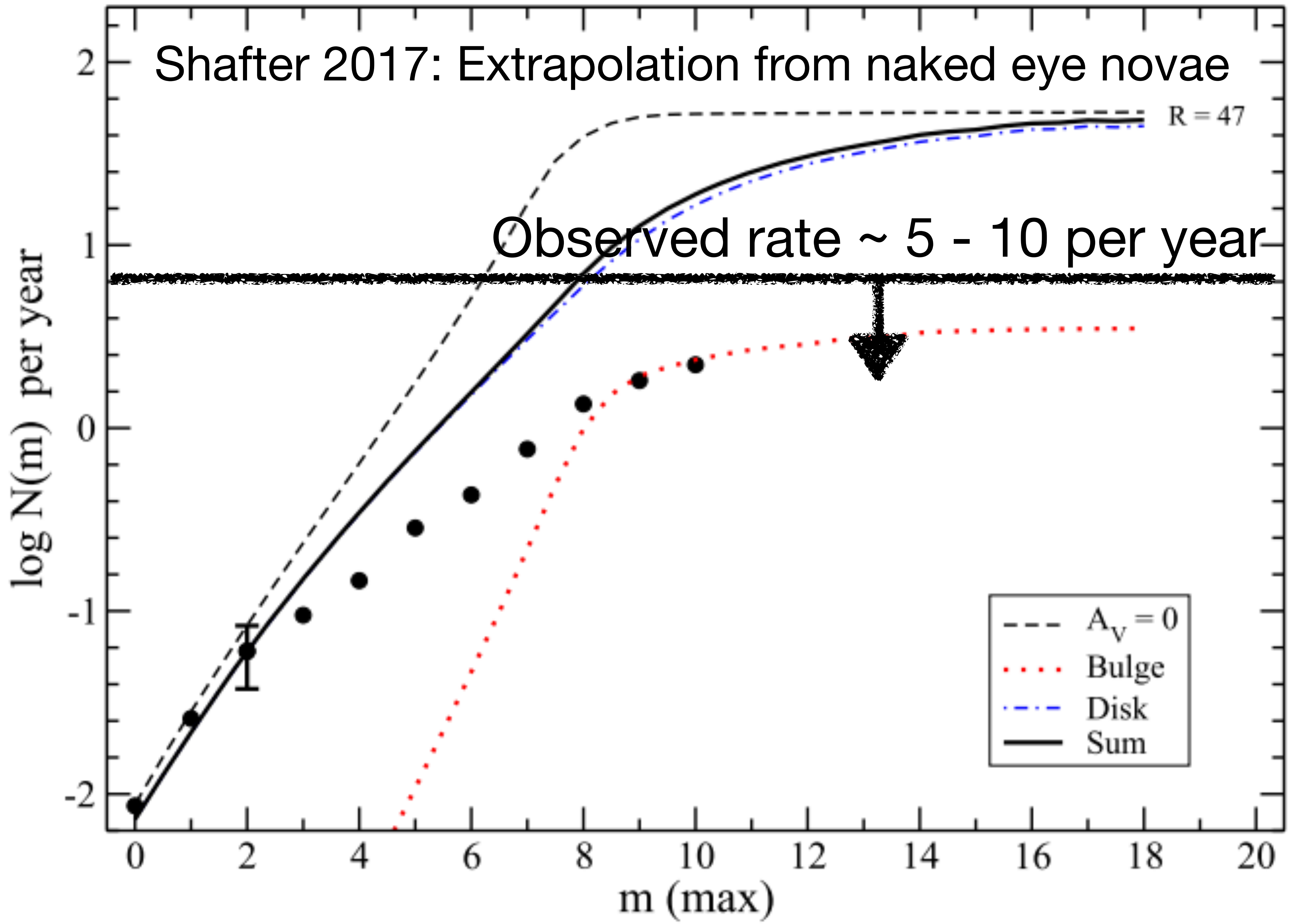
The first infrared census of Galactic novae



Complete census of Galactic novae crucial for understanding Galactic chemical evolution (Na, Li) and constraining progenitors of Type Ia supernovae

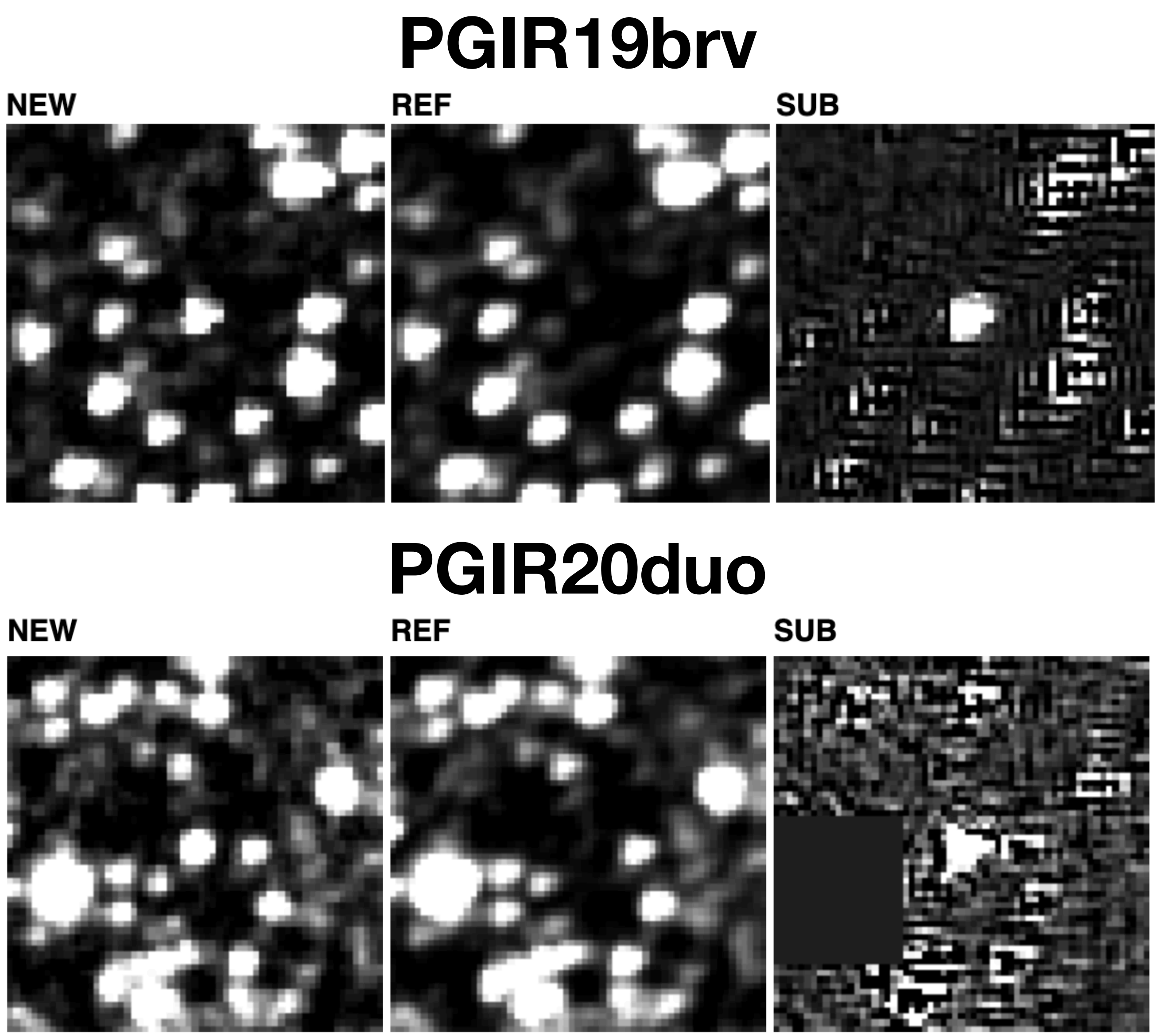
What is the Galactic rate of novae?

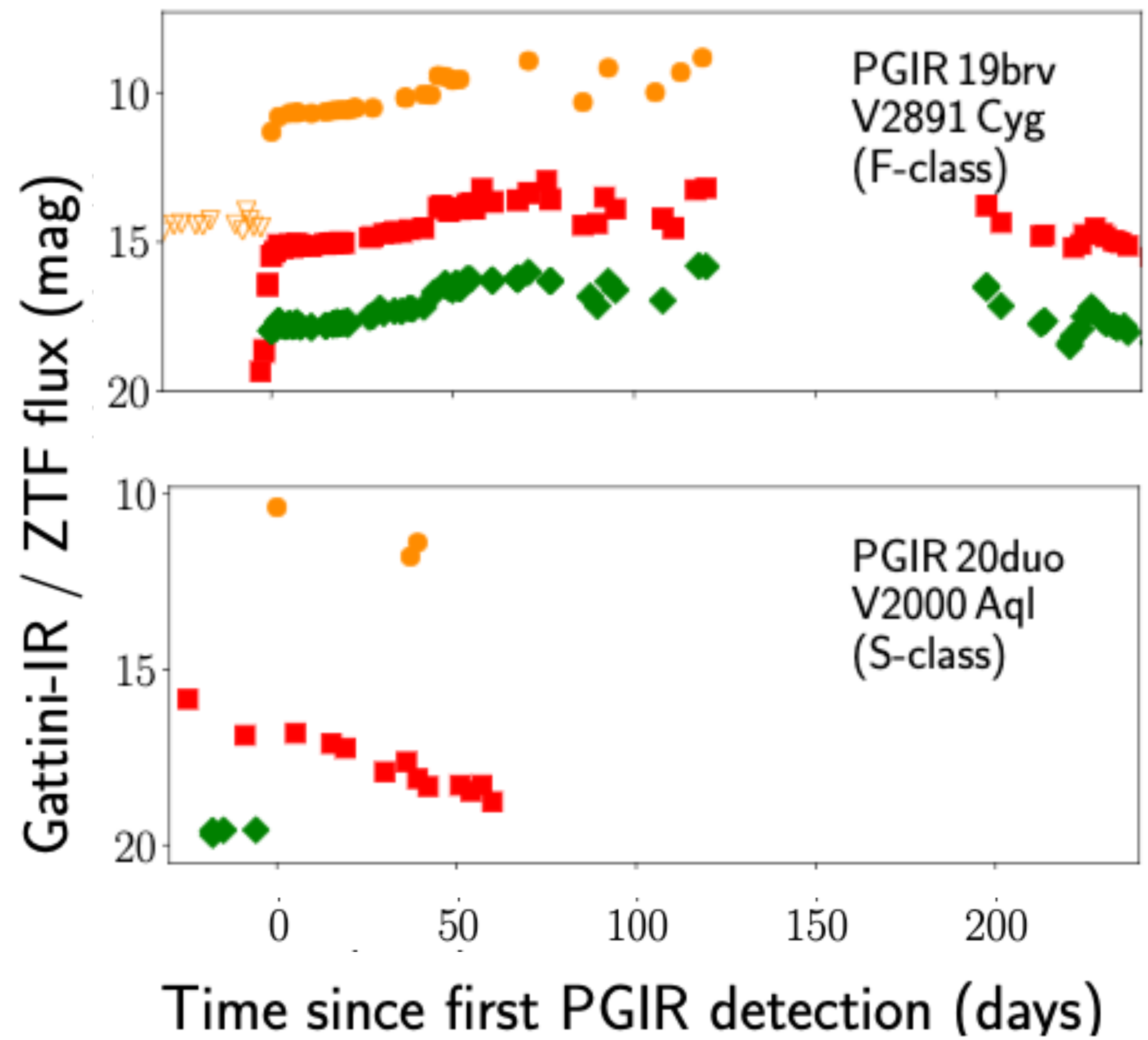
Estimates range from ~10 - 300 per year!



Are optical nova samples complete? Rate overestimated from nearby novae? Could most be dust obscured?

Search for large amplitude transients in PGIR



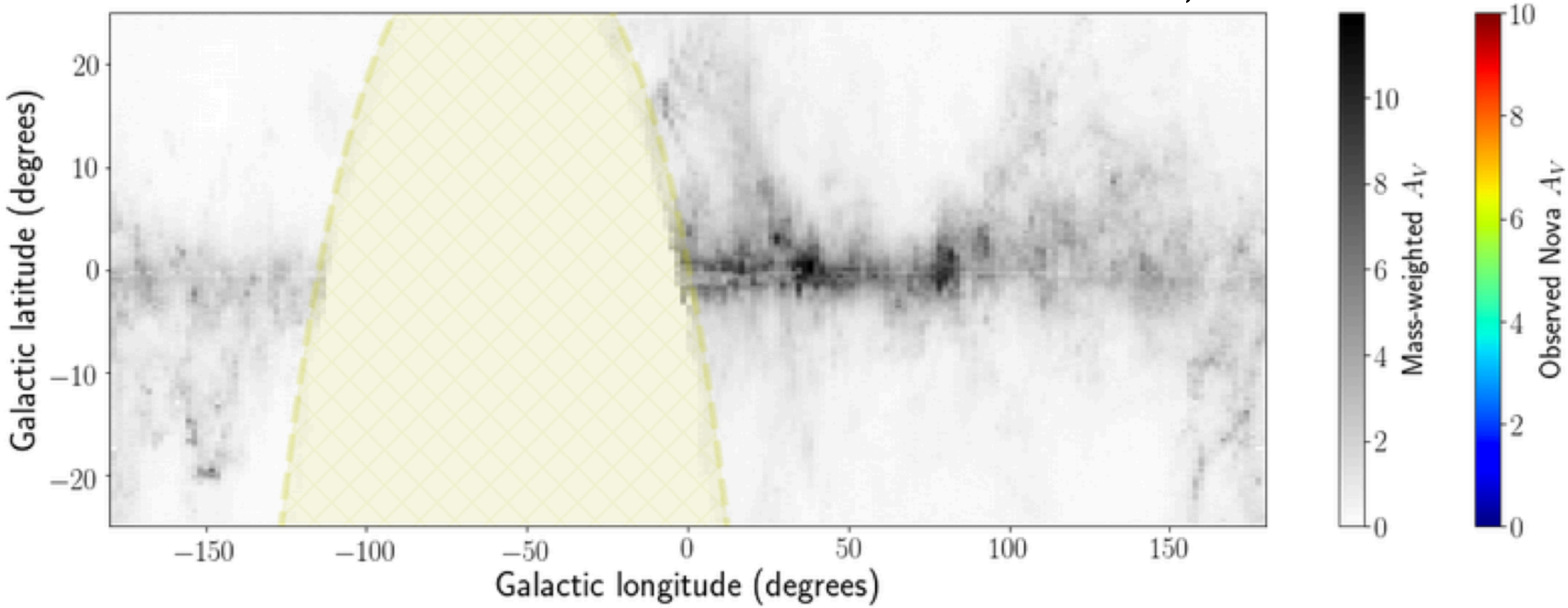


De+ 2021, arXiv: 2101.04045

PGIR has doubled the discovery rate of novae in the PGIR observable footprint

The Galactic distribution of novae

De+ 2021, arXiv: 2101.04045



3-D dust distribution models from Green et al. 2019

The Galactic distribution of novae

Circles = Complete sample of 180 optically discovered novae with extinction estimates until 2018 (Özdönmez+ 2016, 2018)

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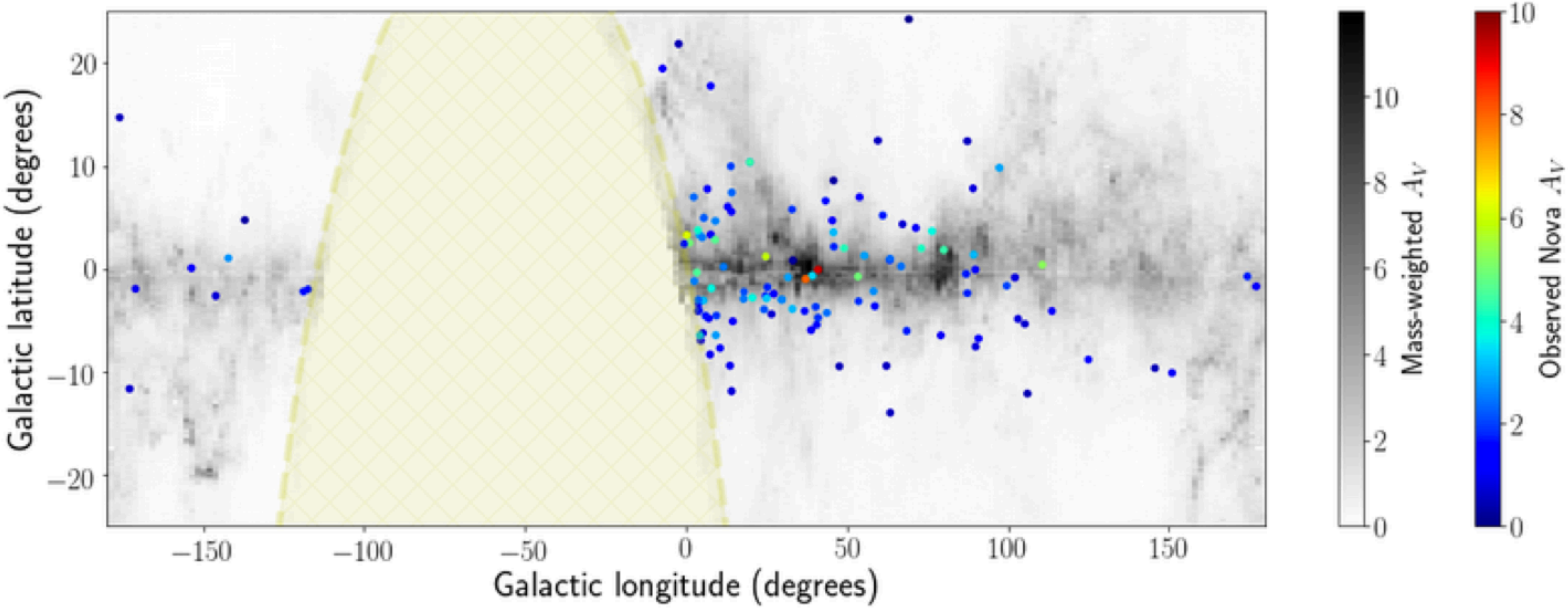

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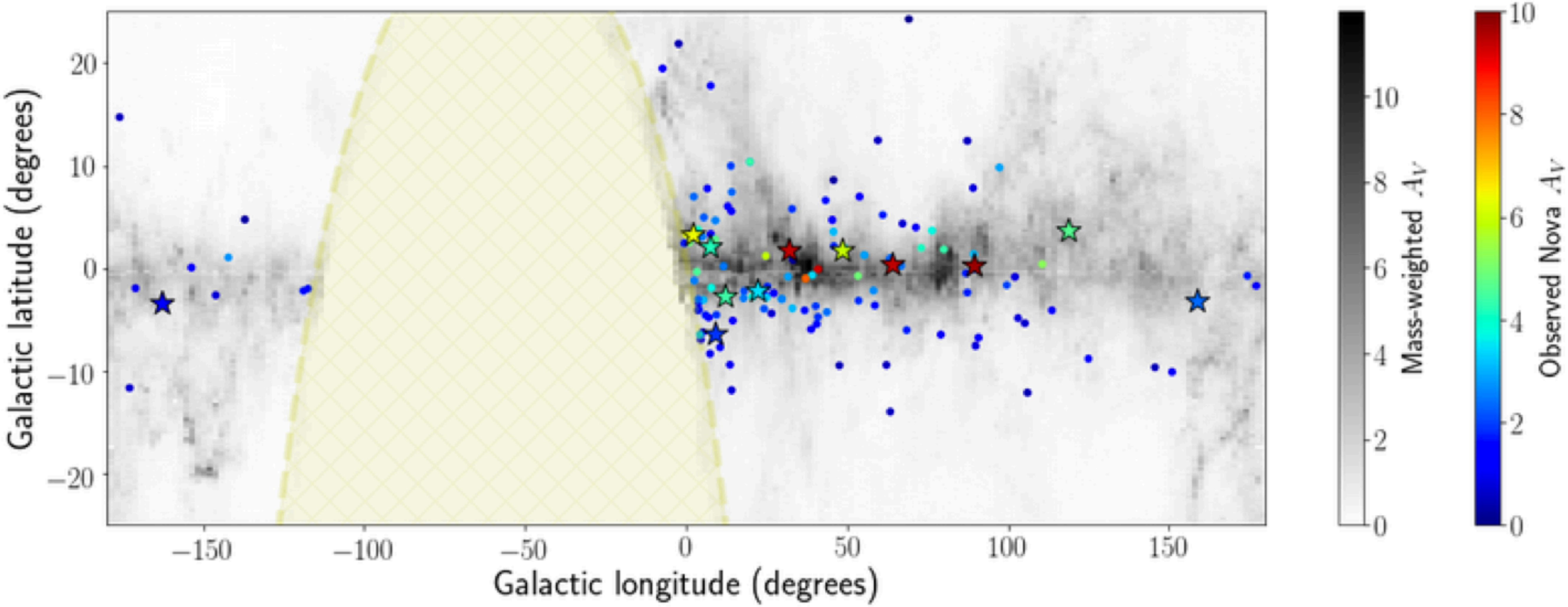
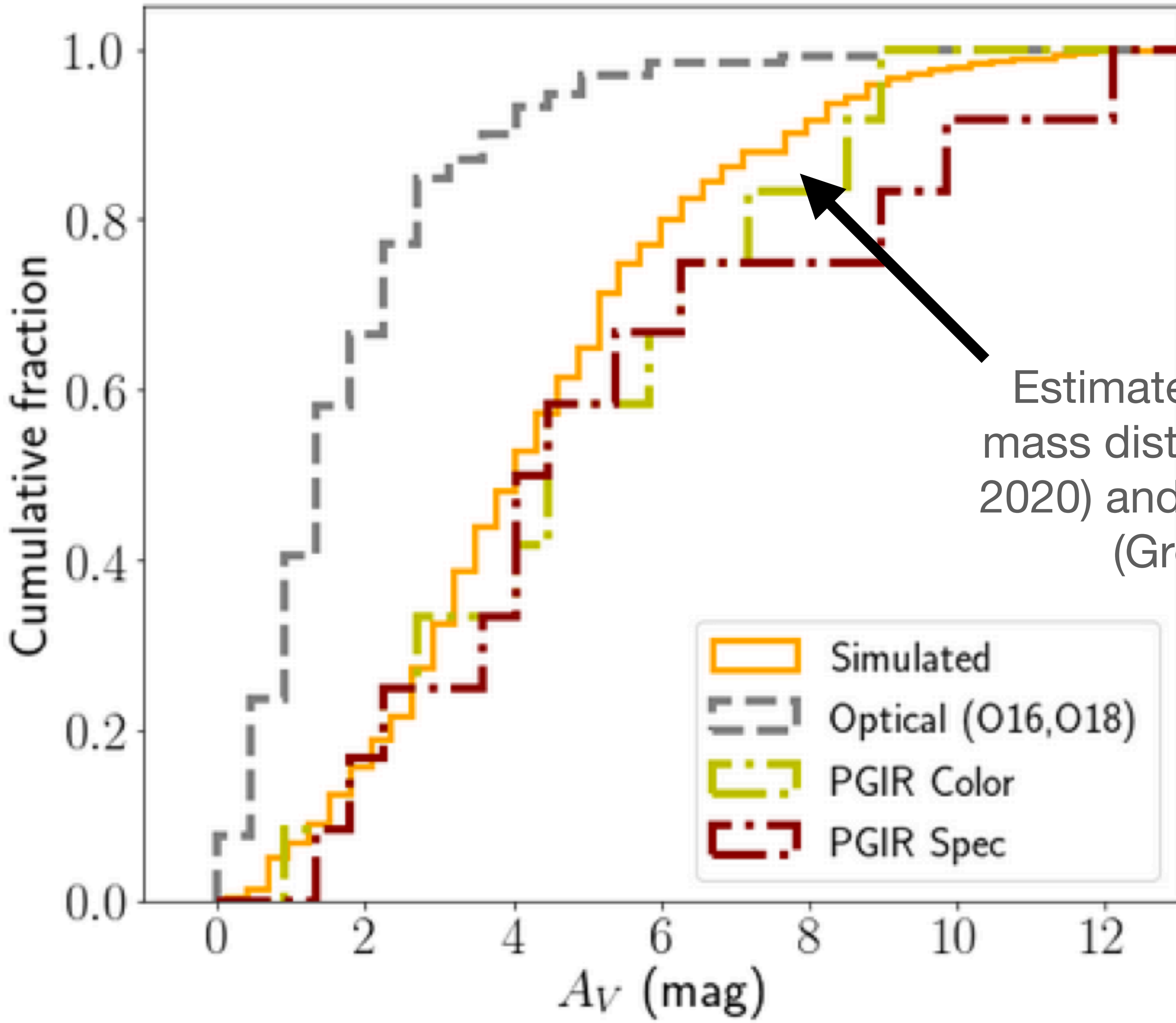


Stars = 17 months of PGIR novae

3-D dust distribution models from Green et al. 2019

The extinction distribution of Galactic novae

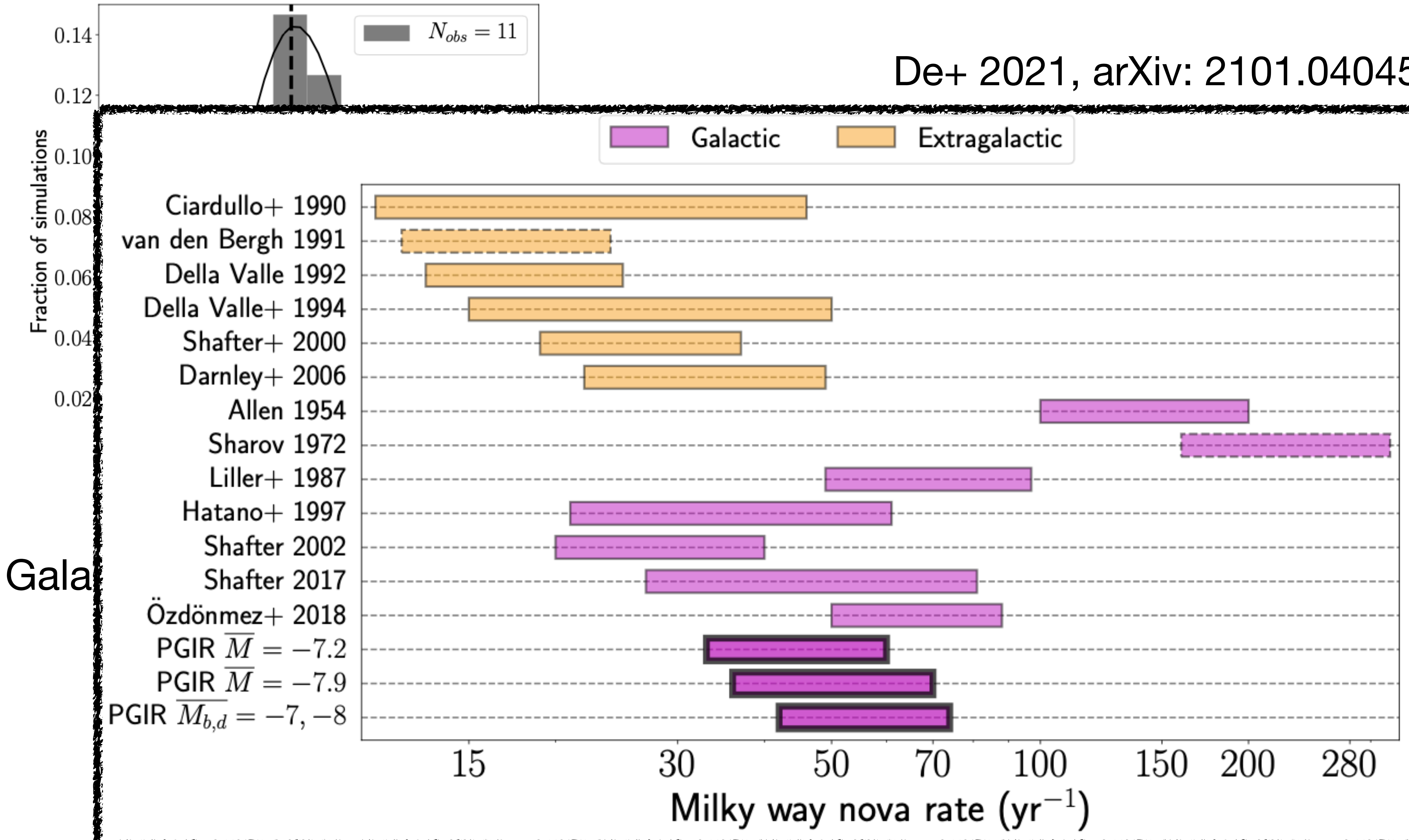


De+ 2021, arXiv: 2101.04045

Null hypothesis probability < 0.01%.
Most obscured novae are likely missed in optical searches

Quantitative simulations of PGIR survey

De+ 2021, arXiv: 2101.04045



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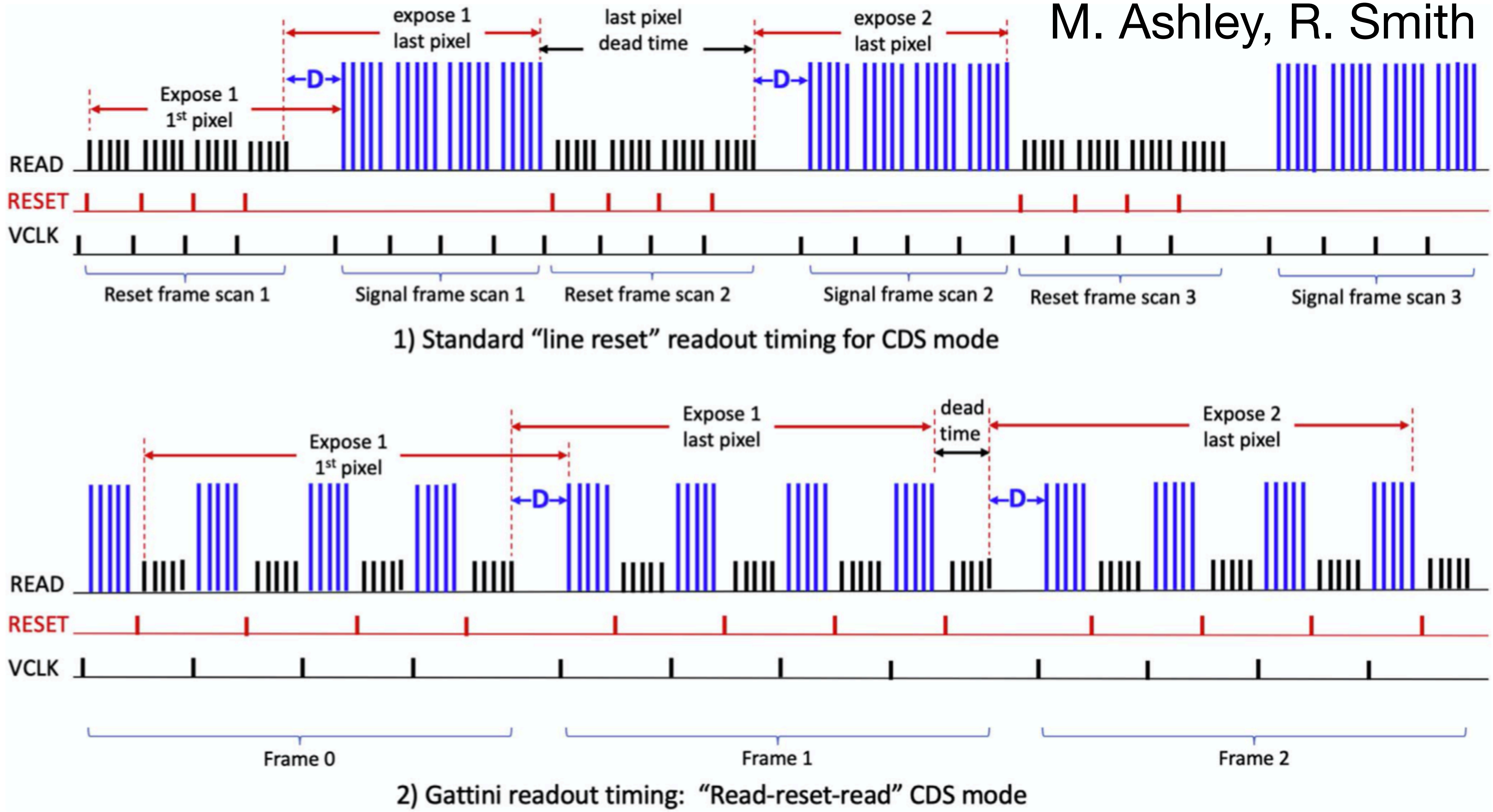
Fast H2RG readout mode

M. Ashley, R. Smith



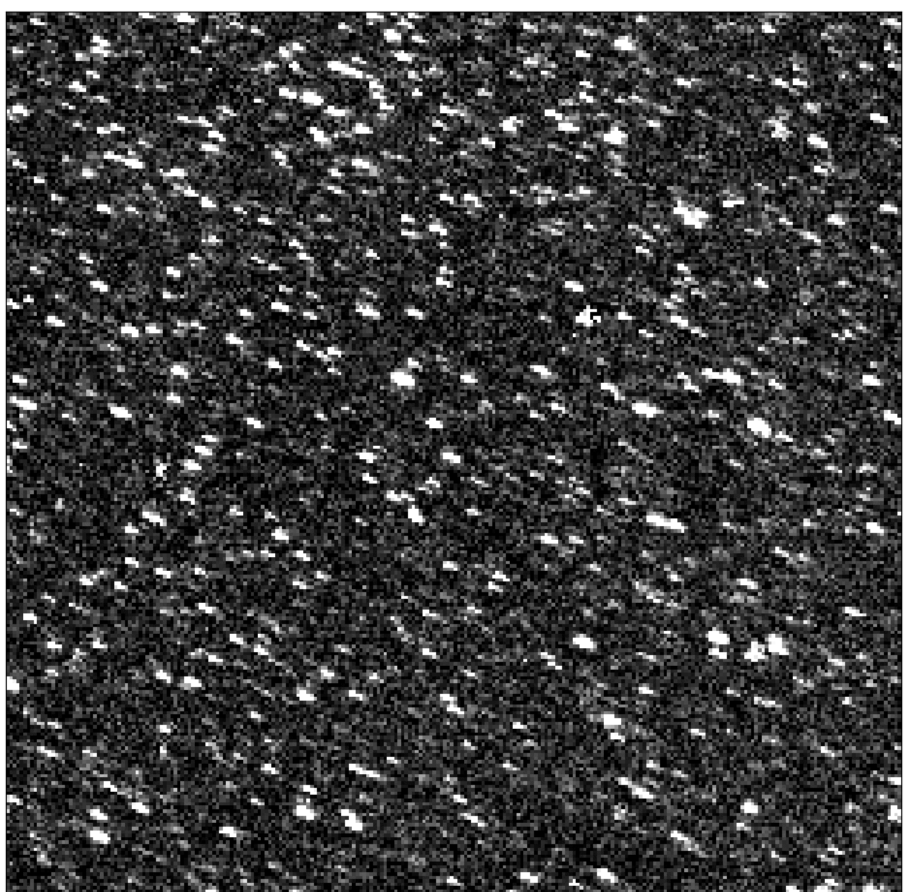
Achieves 99.98% observing efficiency with 0.84 second exposures and enables increased dynamic range

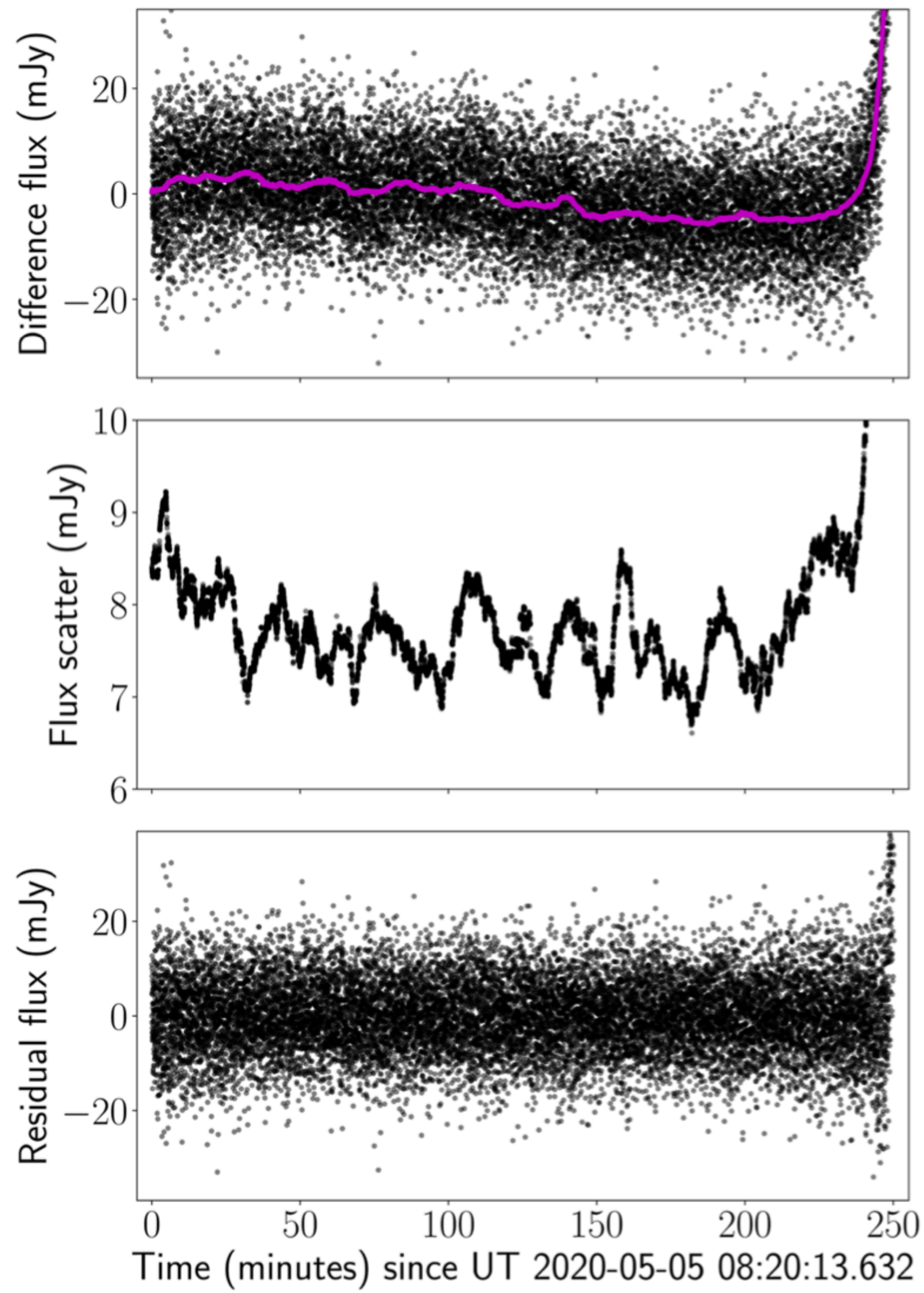
The first Galactic Fast Radio Burst

Targeted follow-up of SGR1935+2154

First reported Galactic FRB
(CHIME+2020, Bochenek+2020)

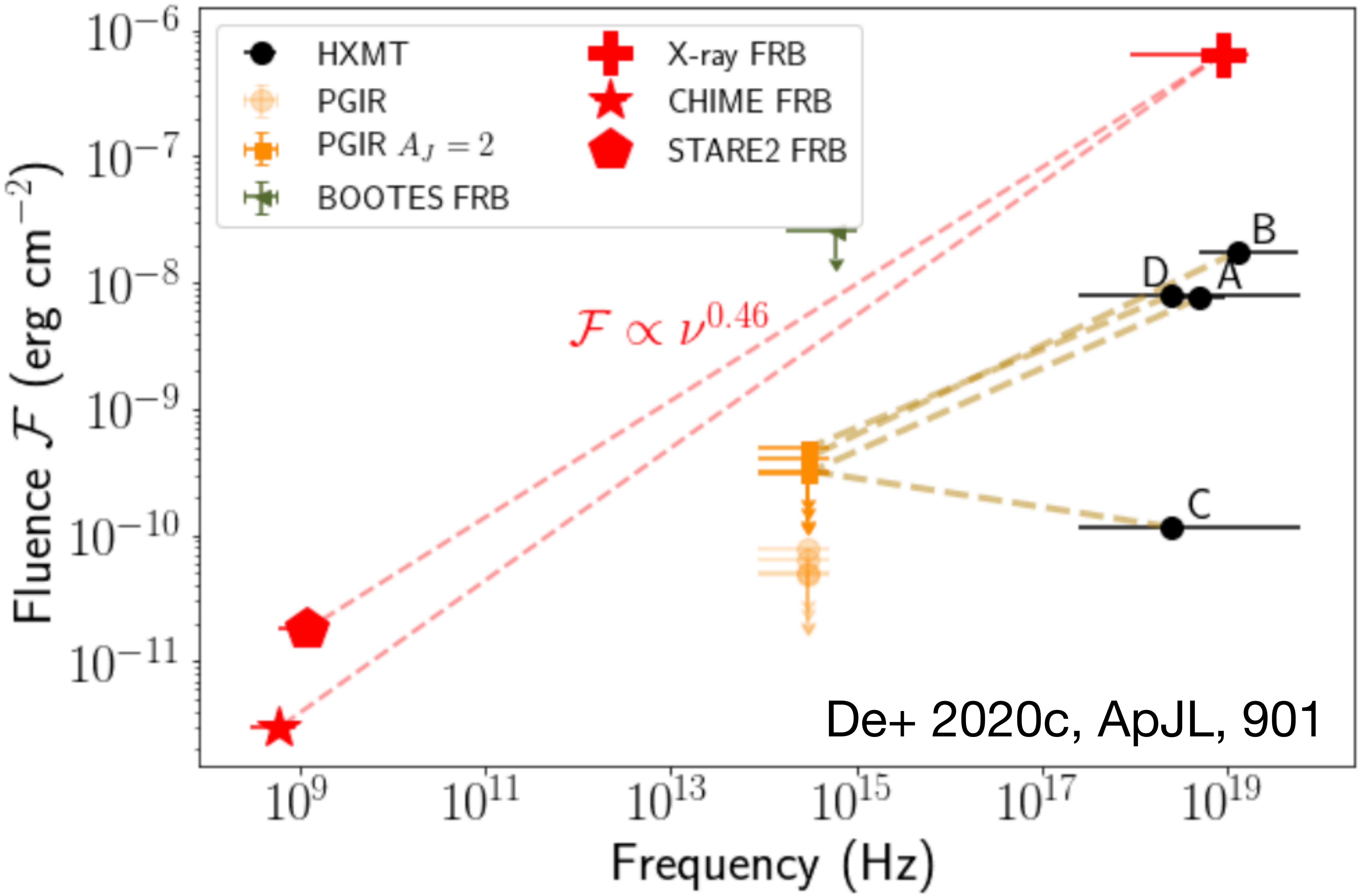
Behind $A_V \approx 7 - 10\,\mathrm{mag}$





De+ 2020c, ApJL, 901

Simultaneous NIR constraints on X-ray bursts detected by HXMT + NuSTAR



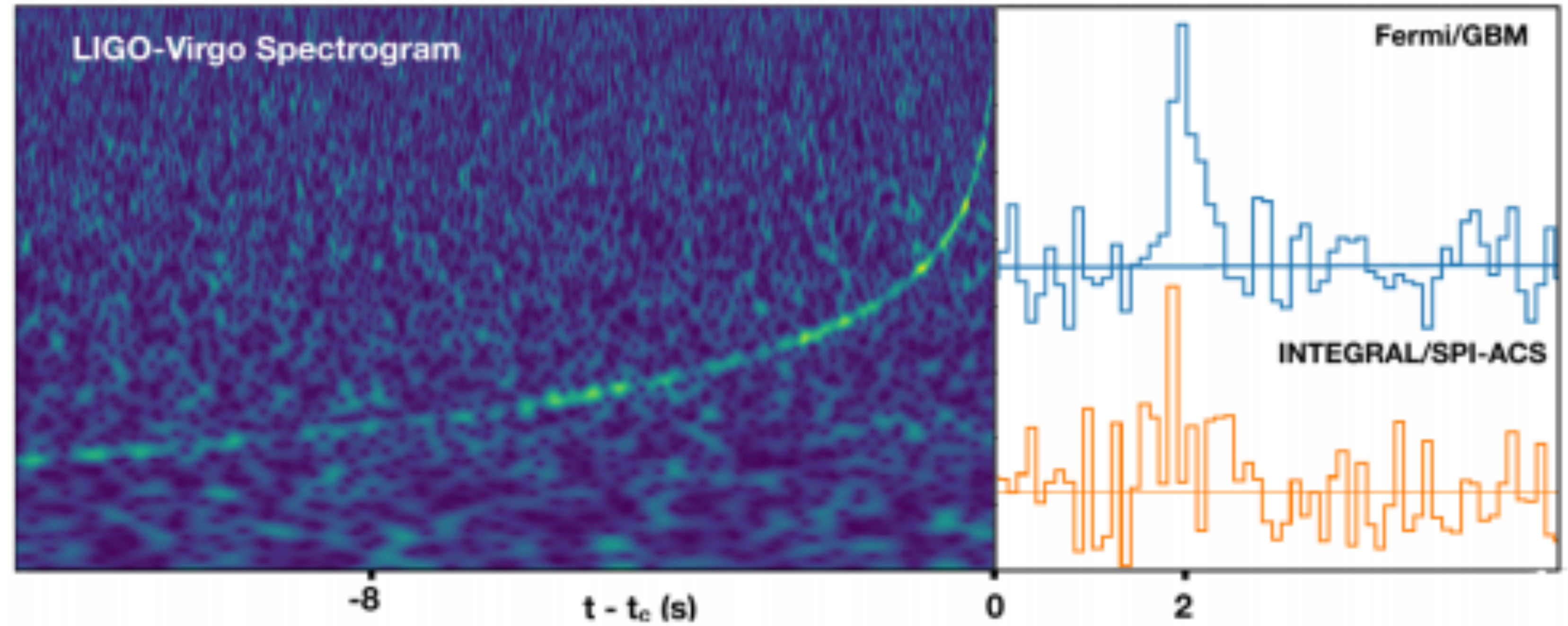
Deep PGIR limits rule out simple power law interpolation between the X-ray and radio bands

The Next Frontier

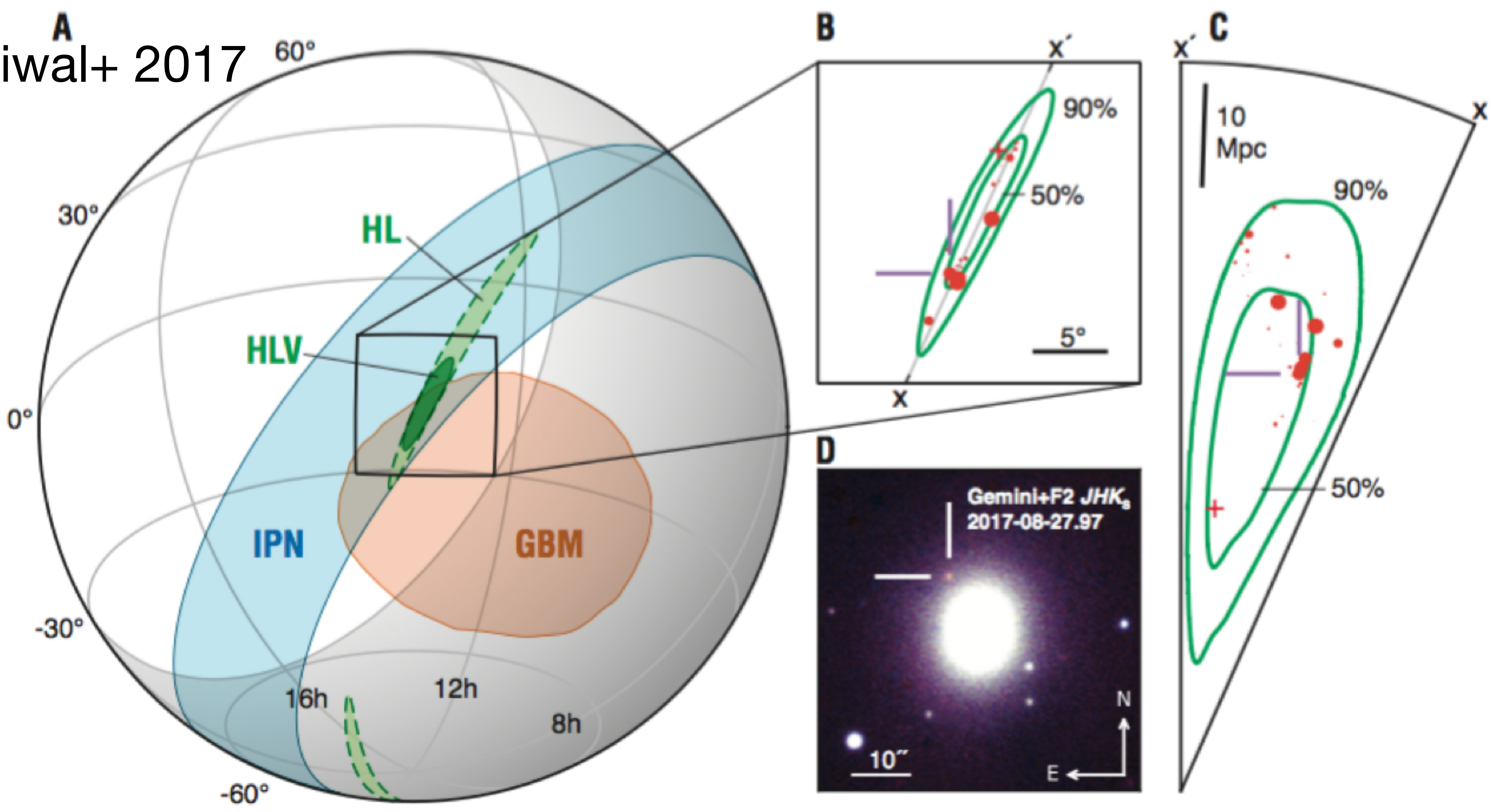
Multi-messenger astronomy

GW170817 coincident with GRB170817A

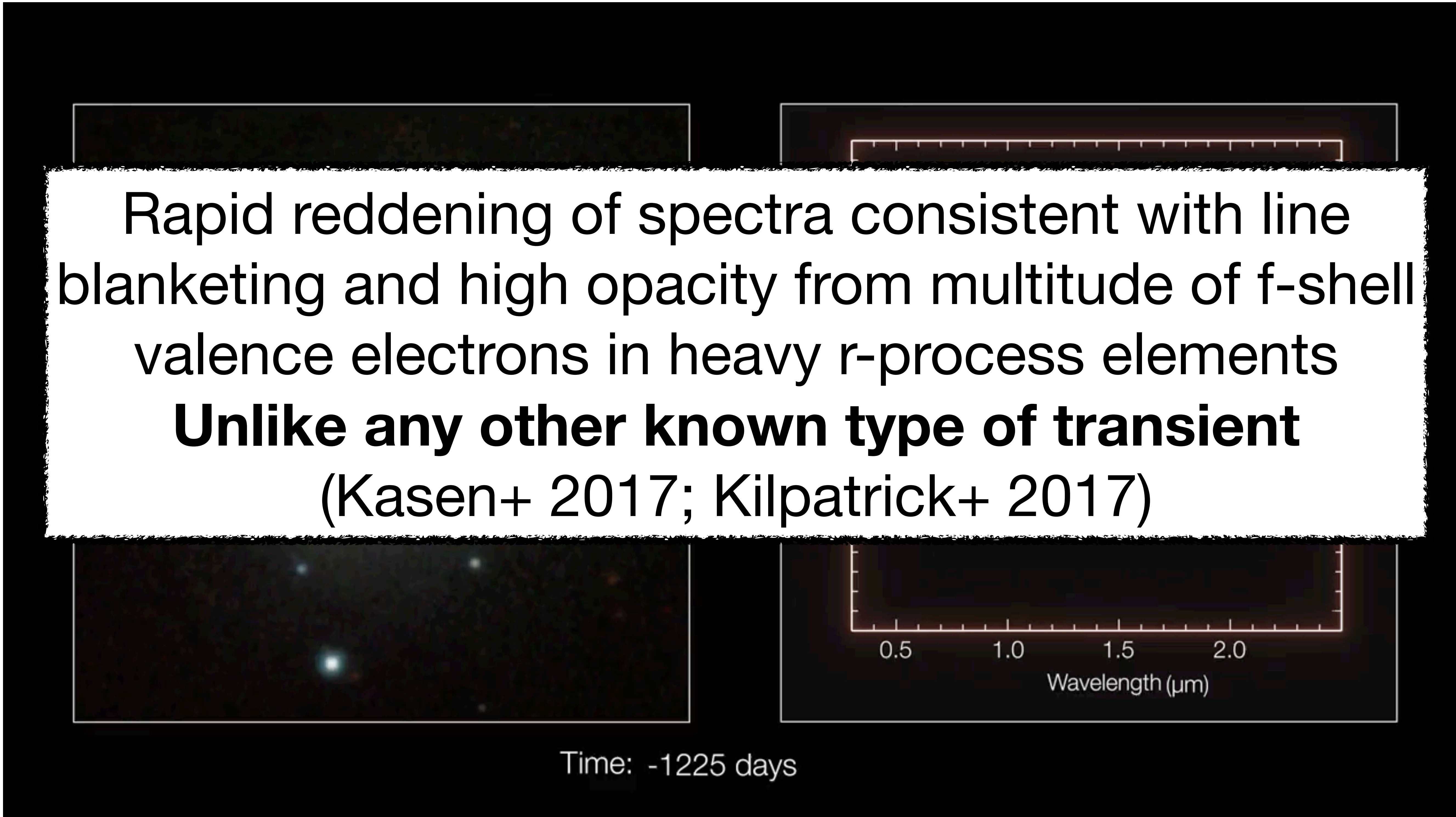
Abbott+ 2017



Kasliwal+ 2017



Spectroscopic signatures of r-process



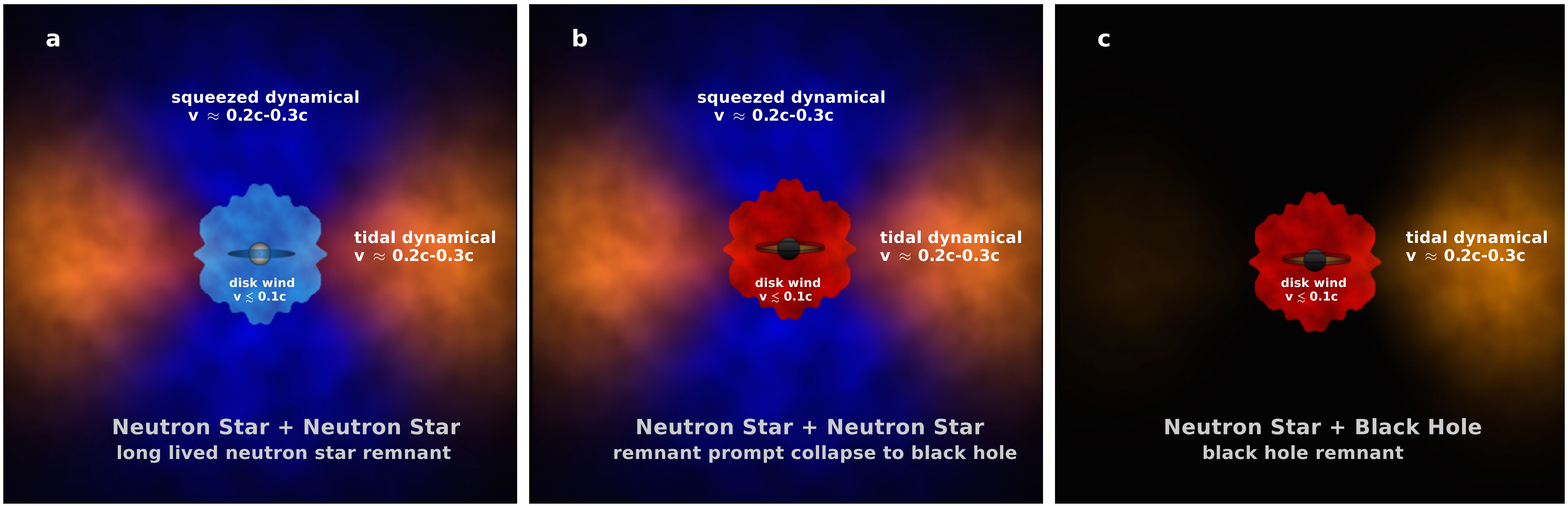
Rapid reddening of spectra consistent with line blanketing and high opacity from multitude of f-shell valence electrons in heavy r-process elements

Unlike any other known type of transient

(Kasen+ 2017; Kilpatrick+ 2017)

Pian+ 2017

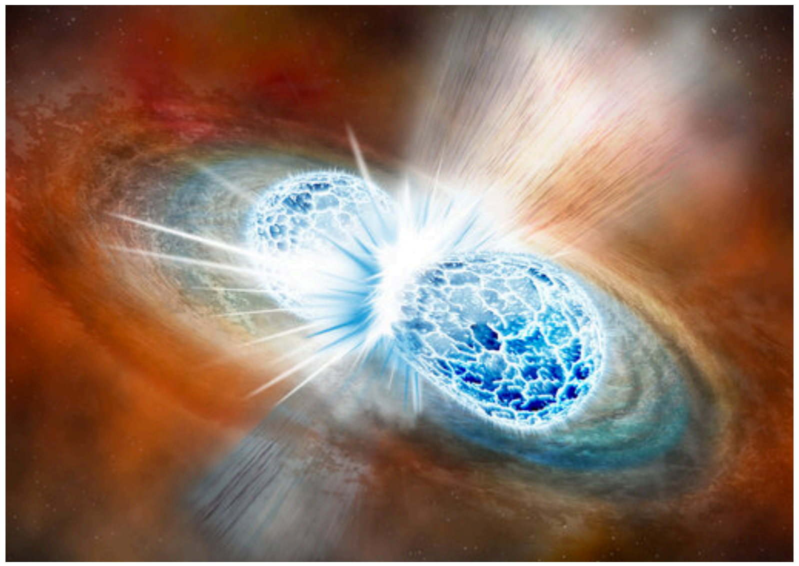
Infrared emission is ubiquitous

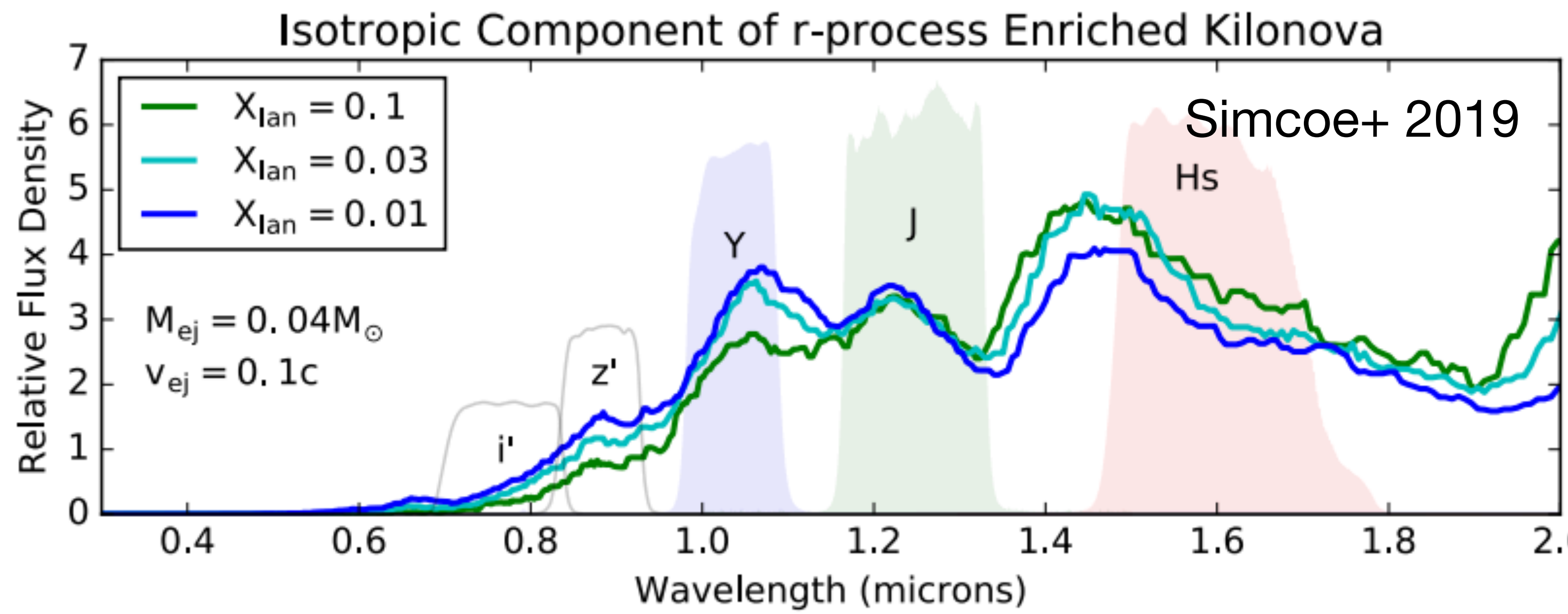


Kasen+ 2017

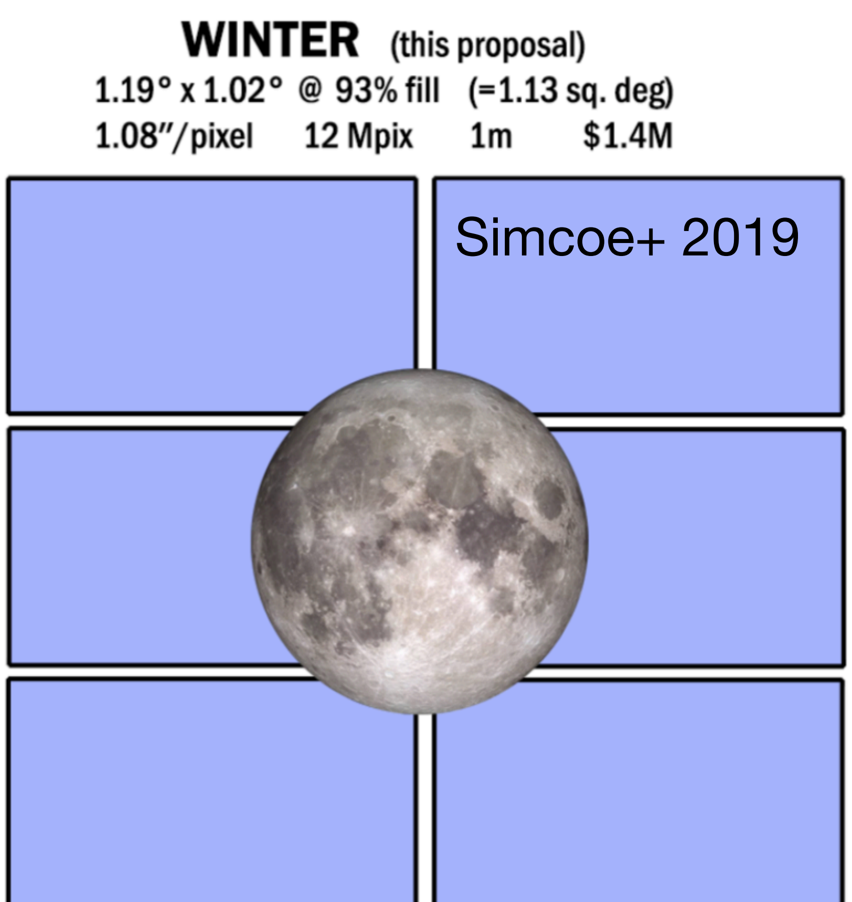
Independent of mass, viewing angle

Pathfinder to GW counterpart search



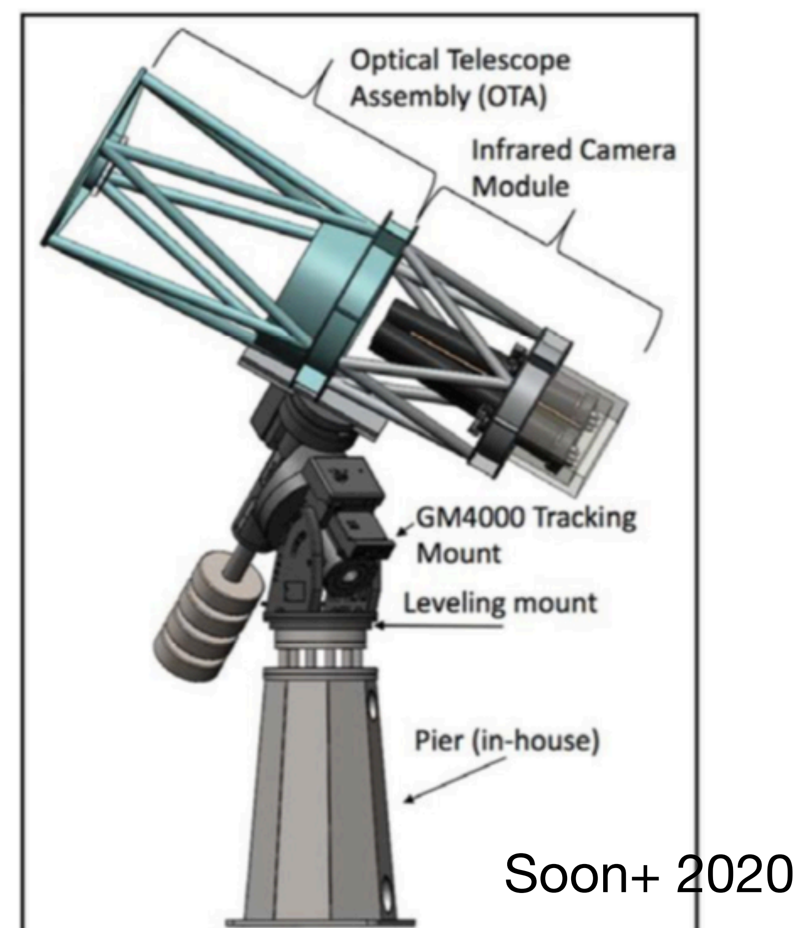


Alternative detector technologies (InGaAs) driving the IR TDA revolution



WINTER and DREAMS

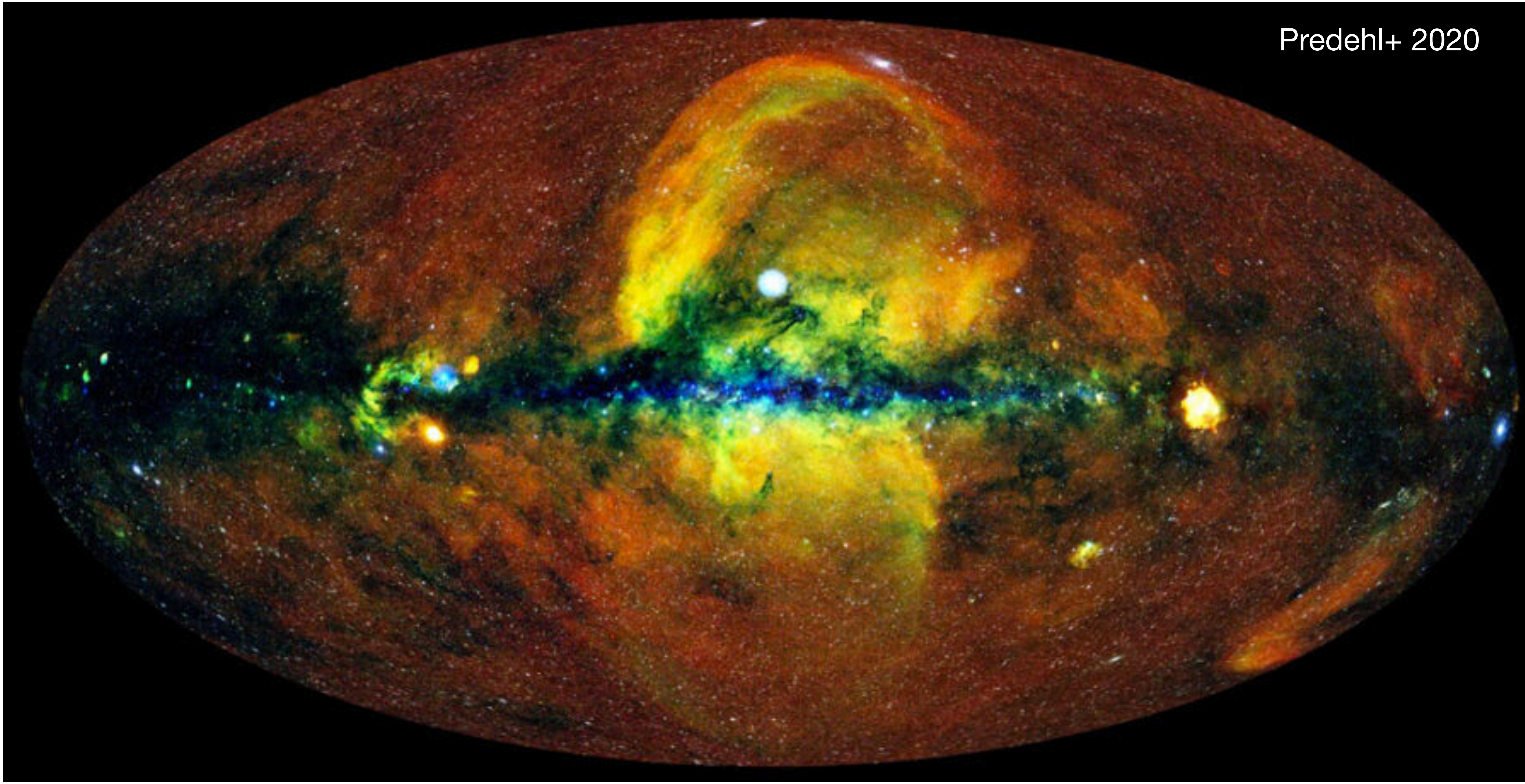
Upcoming projects with smaller fields of view and larger depths, aiming to search for EM-GW counterparts



The Next Frontier

High energy phenomena in the Milky Way

The X-ray sky revolution

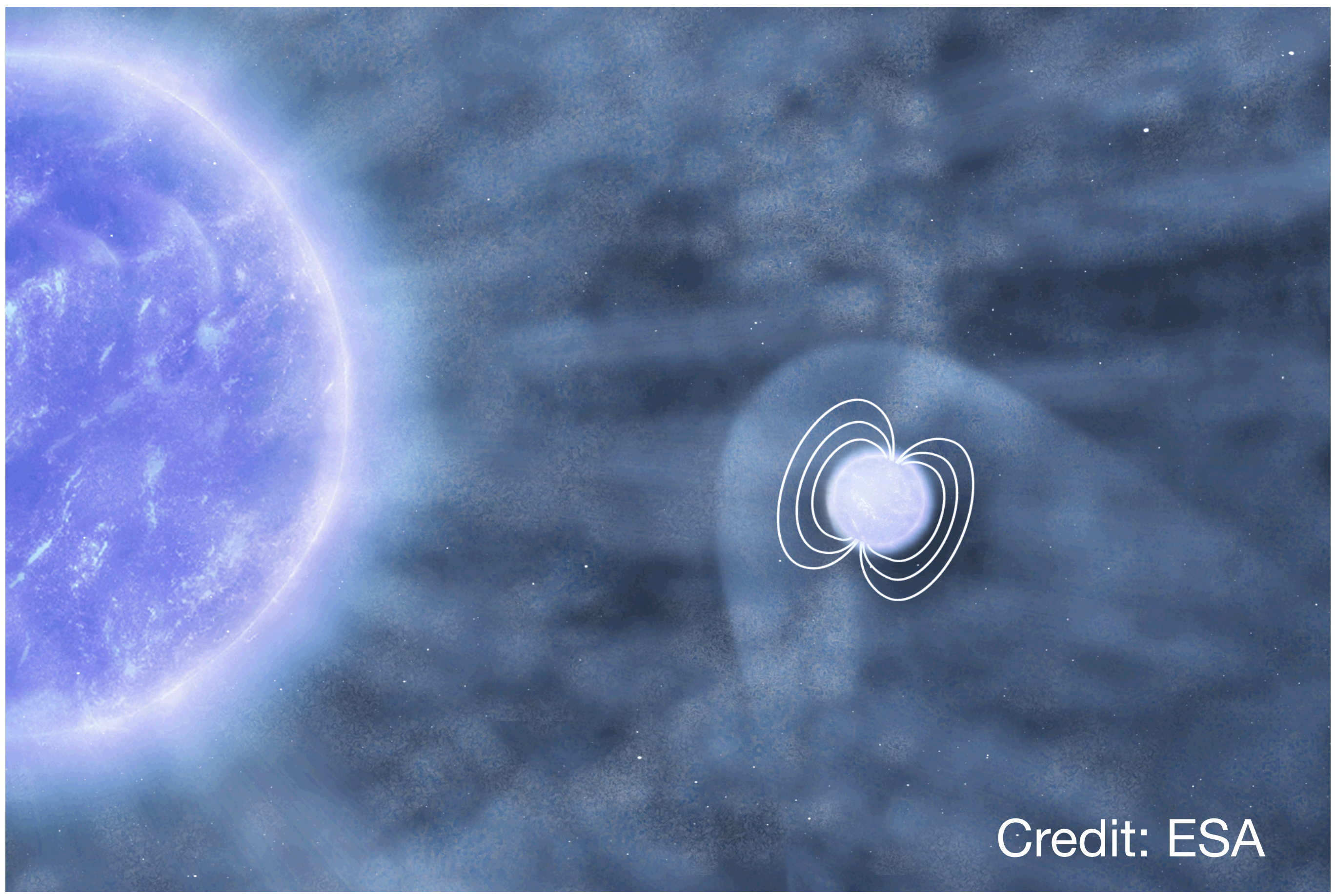


MAXI, BAT, GECAM, SVOM, eROSITA ..

IR time domain surveys will provide unprecedented temporal coverage of optically obscured high energy phenomena

Un-targeted searches for second timescale variability

Extreme accretion phenomena

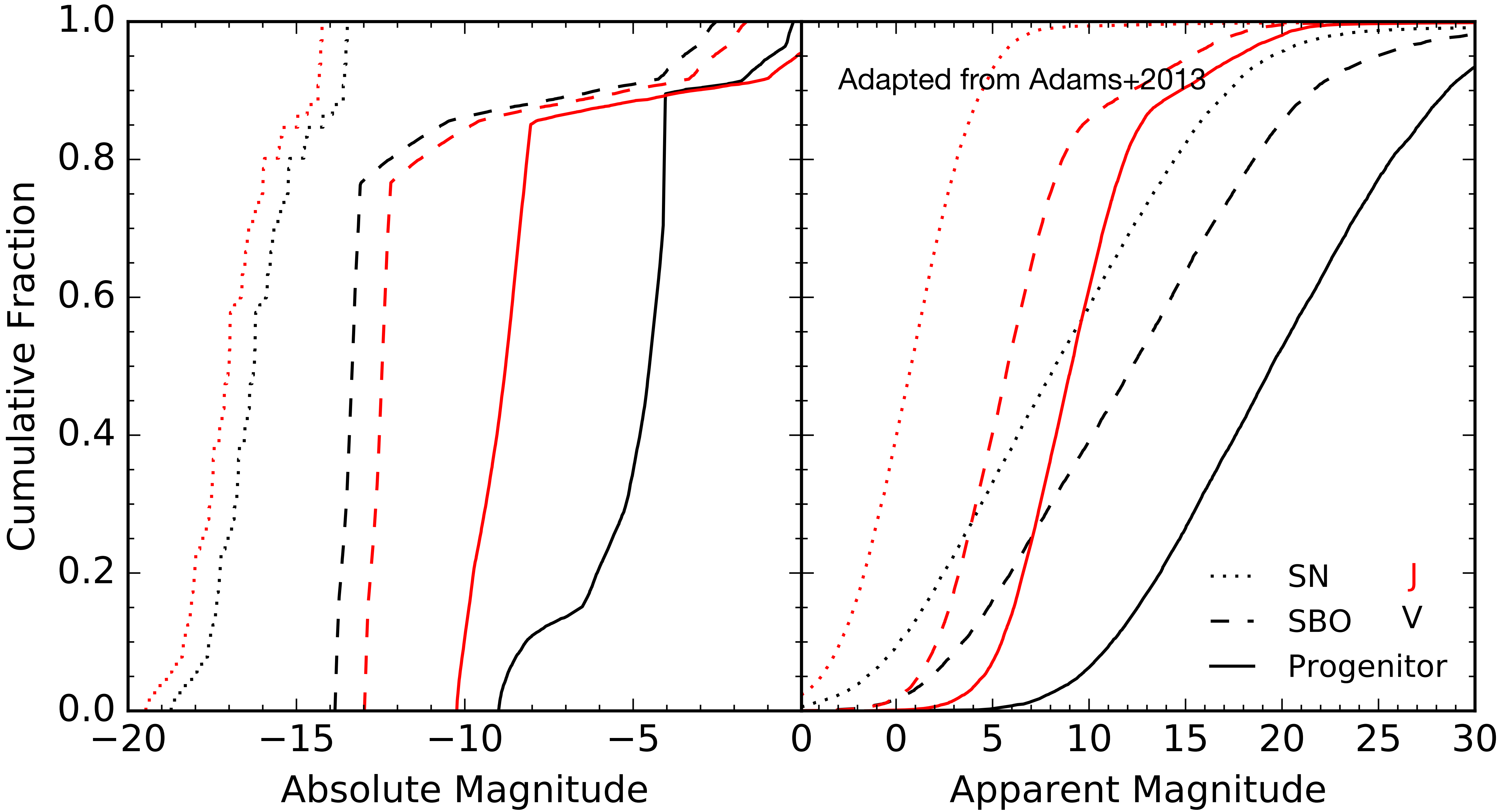


“Supergiant Fast X-ray Transients”

Extreme magnetospheric phenomena

Magnetar Flares

The next supernova in the Milky Way



Ongoing effort to increase PGIR dynamic range
to study stars as bright as ~0th magnitude

- Palomar Gattini-IR is performing the first 3π NIR time domain survey from Fall 2019.

- Gattini-IR is probing the reddest, dustiest time domain phenomena— obscured Galactic novae, microlensing events, dusty variables, young stellar objects, flaring magnetars and IR bright supernovae.

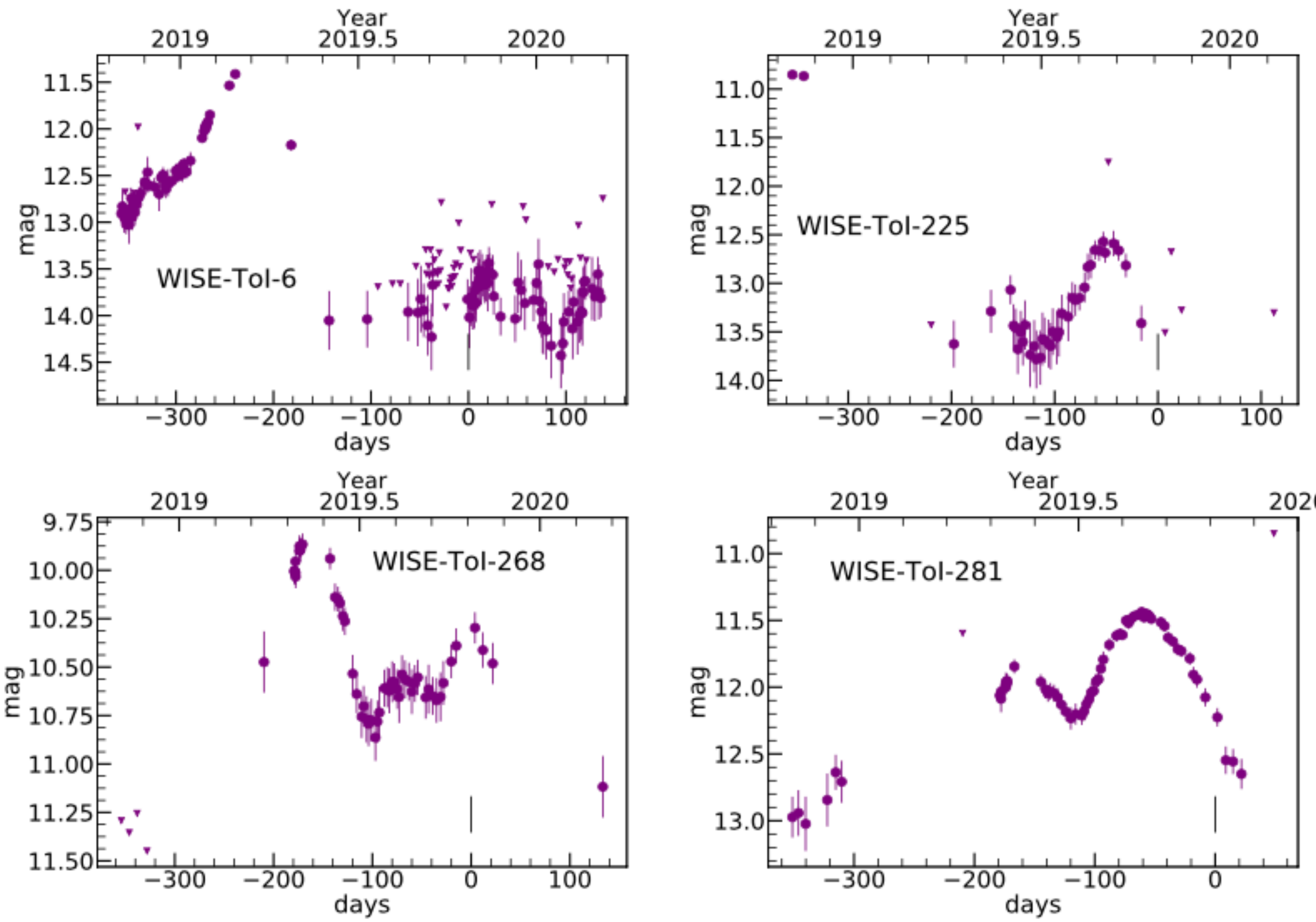
- The dynamic and obscured Galactic plane is ripe for exploration combining upcoming wide-field IR + X-ray/radio follow-up!

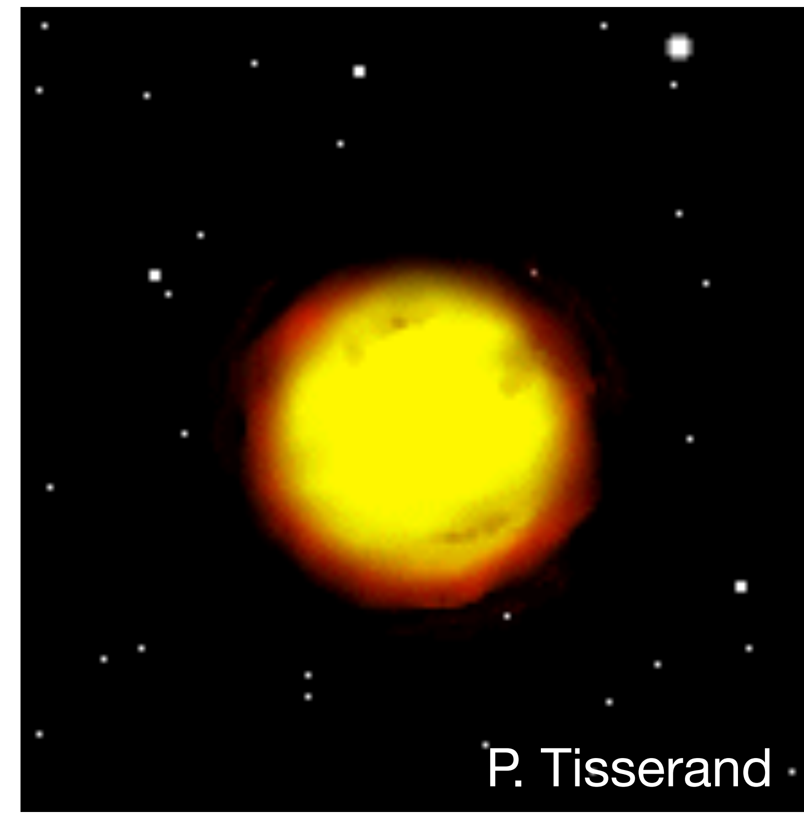
Thanks for listening!

kde@astro.caltech.edu

www.astro.caltech.edu/~kde

The first infrared census of dust forming R Coronae Borealis (RCB) stars



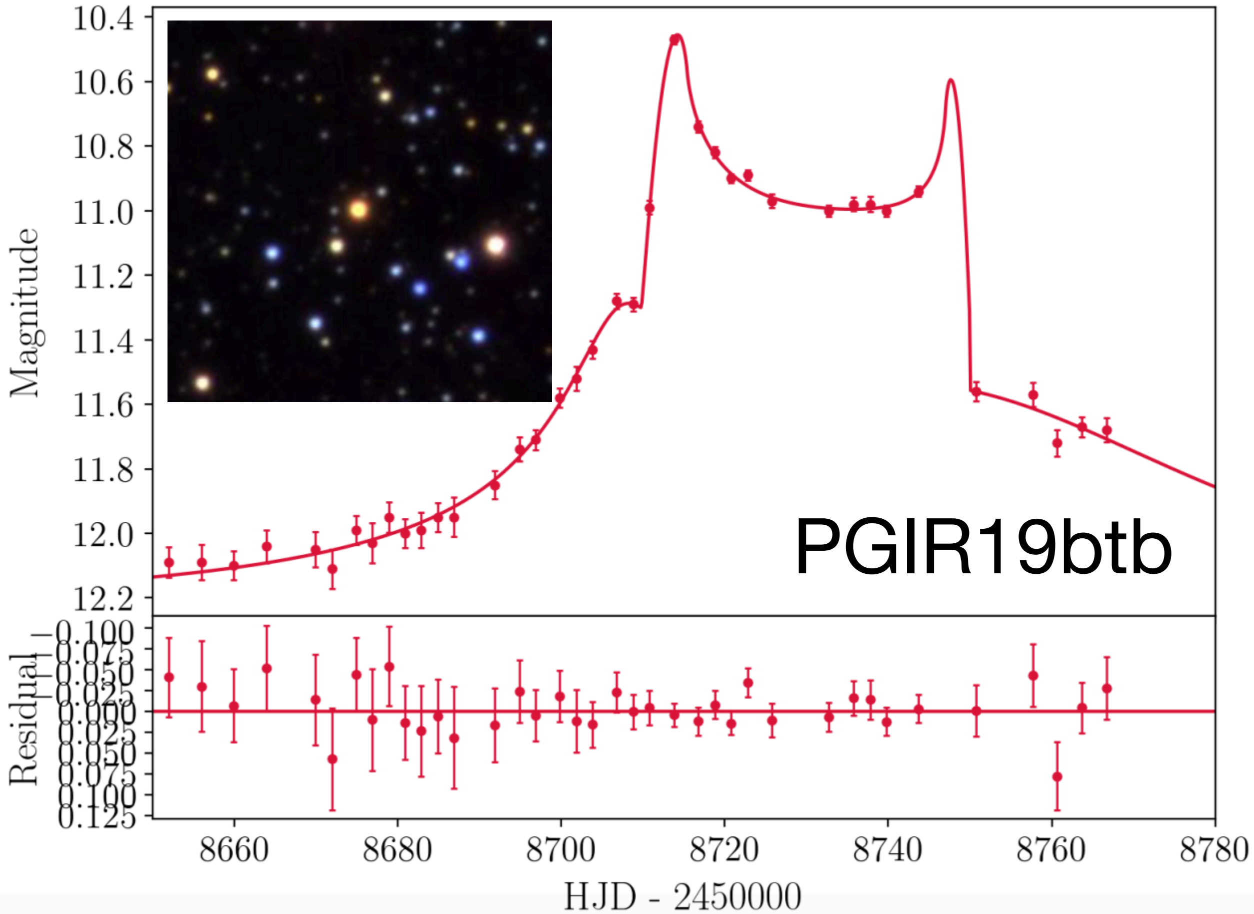


Karambelkar+ 2021
arXiv: 2012.11629

149 RCB candidates selected on PGIR variability, 11 confirmed with pilot spectroscopy

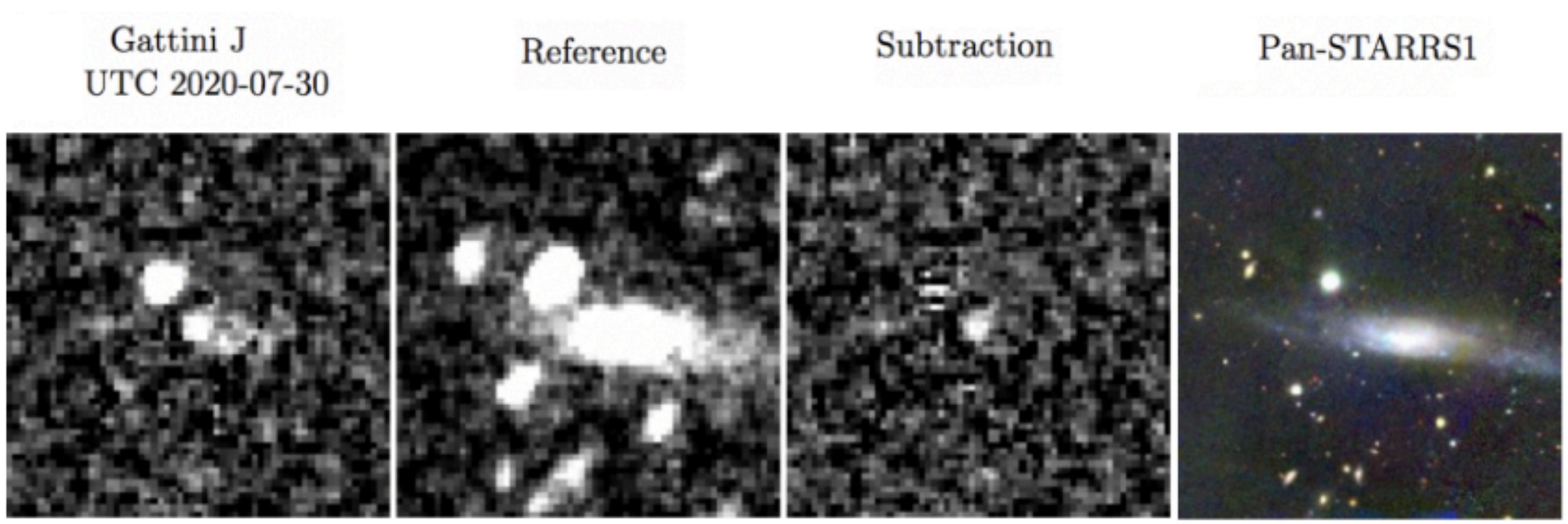
New measurements of O^{16}/O^{18} ratios consistent with white dwarf merger scenarios

Other upcoming results



A population of reddened microlensing events in the Galactic plane

Mroz+ in prep



Infrared-bright supernovae in nearby galaxies

Srinivasaragavan+ in prep