NESSI:
New Mexico Exoplanet Spectroscopic Survey Instrument

National Aeronautics and Space Administration

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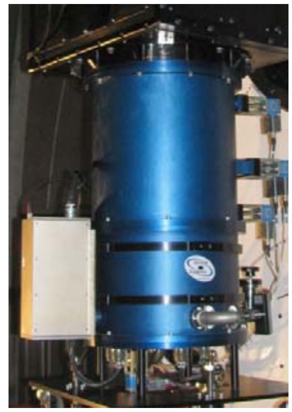
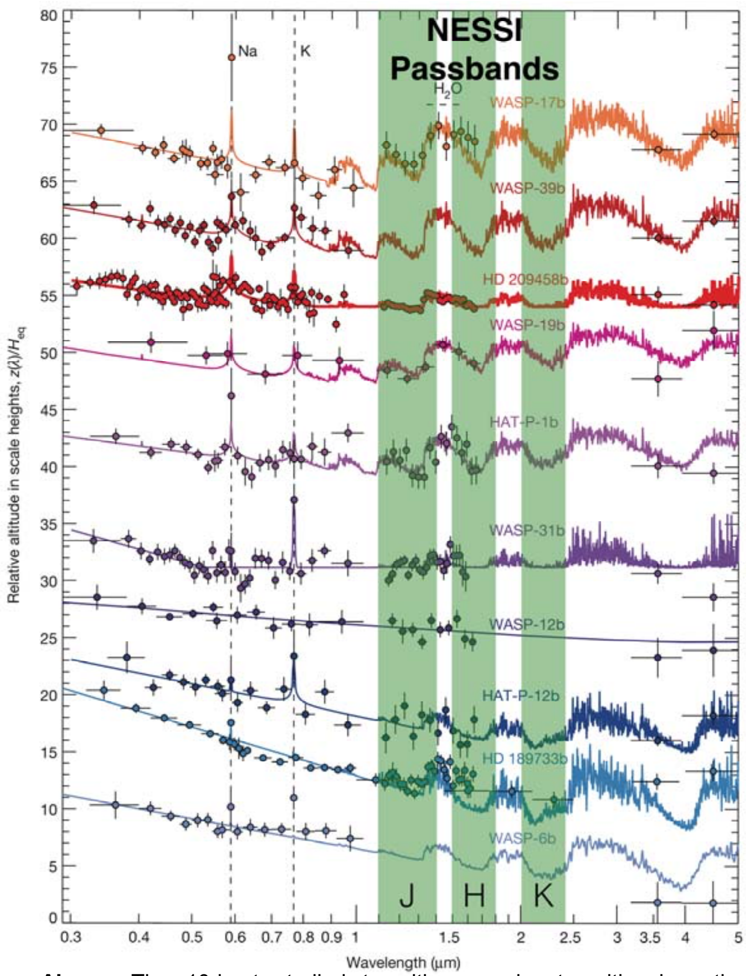
NESSI is a wide-field, multi-object J-H-K band spectrograph (using non-deviating grisms), which can also be used as a J, H, K or narrow-waveband, wide-field camera (0.5" pixel imaging). NESSI is currently being commissioned on the Hale 200 inch at Palomar Observatory. The spectral capability is R=250 in J-H-K, or R=1100 in J, or H, or K. Multi-object capability over a 6.5 arcmin field of view is provided through custom slit masks or the spectrograph can be deployed in slit-less or long-slit mode. NESSI was specifically built for high-precision transiting exoplanent spectroscopy via its high stability and large ~6' field-of-view.

The NESSI instrument

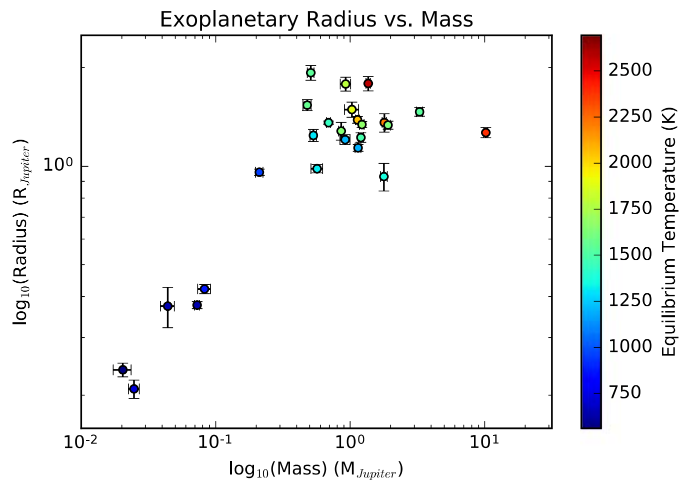
Left: CAD model of NESSI (green) on its new handling fixture, which we can use to rotate, test, and assemble it.

Right: Photograph of NESSI during testing at New Mexico Tech.

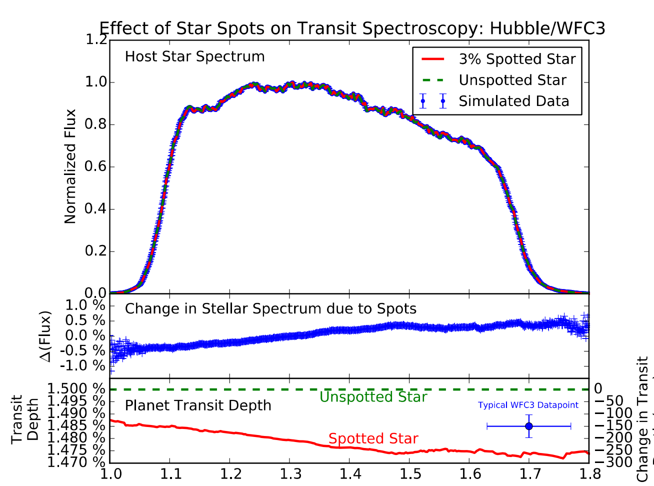




Above: The 10-best studied transiting exoplanets with absorption spectroscopy. Observations span the visible (Hubble/STIS), infrared (Hubble/WFC3), and mid-infrared (Spitzer/IRAC) and indicate a continuum of cloudy (bottom) to clear (top) planets. NESSI will observe spectroscopically in the J-, H-, and K-bands (shaded green), providing improved estimation of the mixing ratios of molecules such as H_2O, CH_4, CO, & HCN. Commissioning NESSI spectra will be confirmed with existing Hubble/WFC3 data and extend the wavelength coverage of these planets to longer wavelengths. Adapted from Sing et al. (2016).



Above: Sample of transiting exoplanets with existing Hubble/WFC3 spectra (1.1-1.6 μm), which are ideal targets for follow up NESSI observations to extend their spectral coverage to 2.4 μm at higher spectral resolution (R=1100) than is possible with Hubble.



Left: Our observations with NESSI will also allow us to characterize the host stars' activity due to unocculted star spots, which can drastically alter the observed exoplanetary signal, biasing the interpretation of its spectrum. NESSI spectroscopy will characterize and correct for stellar variability not only in NESSI near-IR measurements, but also for other instruments that overlap its bandpass, such as Hubble/WFC3 and JWST.

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Poster No. A-01

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ExoPlanetary Systems in Polarized Light

Author: Maxwell A. Millar-Blanchaer (3262)

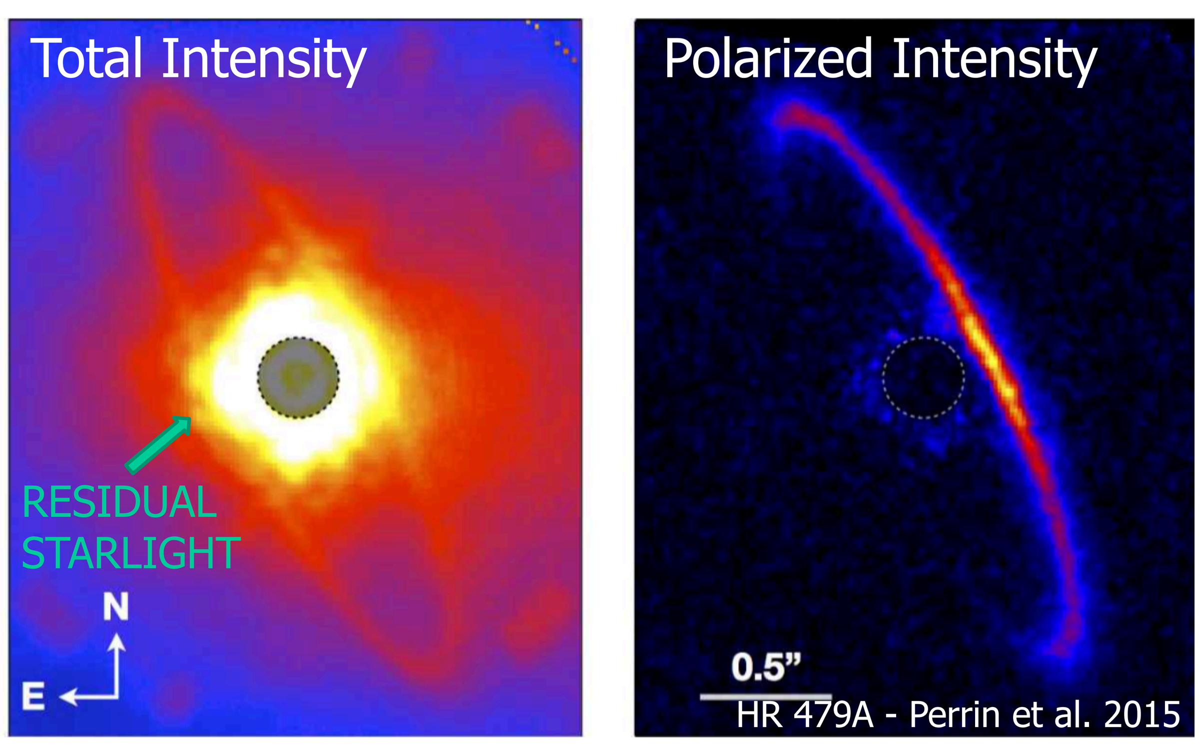
The GPIES Collaboration, Gautam Vasisht (3262), Eugene Serabyn (3262), Dimitri Mawet (Caltech), Ricky Nilsson (Caltech), Kaew Tinyanont (Caltech)

Debris Disk Morphology and Composition

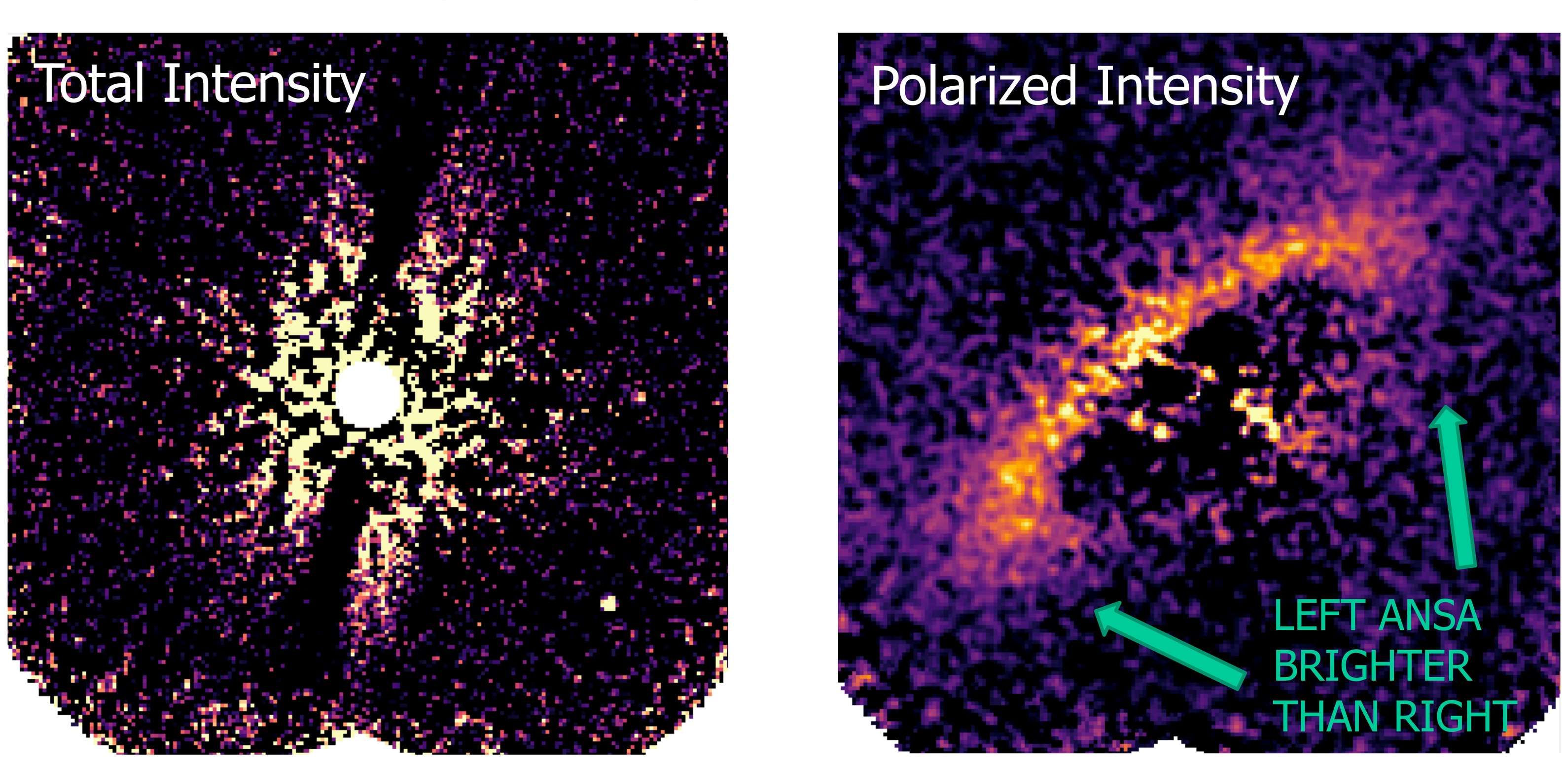
Debris disks, extrasolar analogs to the Kuiper and Asteroid belts, can expose the grain growth histories of their systems through studies of their dust composition and can reveal the presence of unseen exoplanets through tell-tale morphological signatures. The GPIES Survey is searching for new debris disks in polarized using the Gemini Planet Imager's polarimetry mode.

Higher Contrasts in Polarized light

Observations of debris disks in scattered light are challenging due to the high contrast ratios between their emission and that of their host star. Polarimetry can reject unpolarized star-light, improving disk detection limits.



Morphological Signs of Unseen Planets



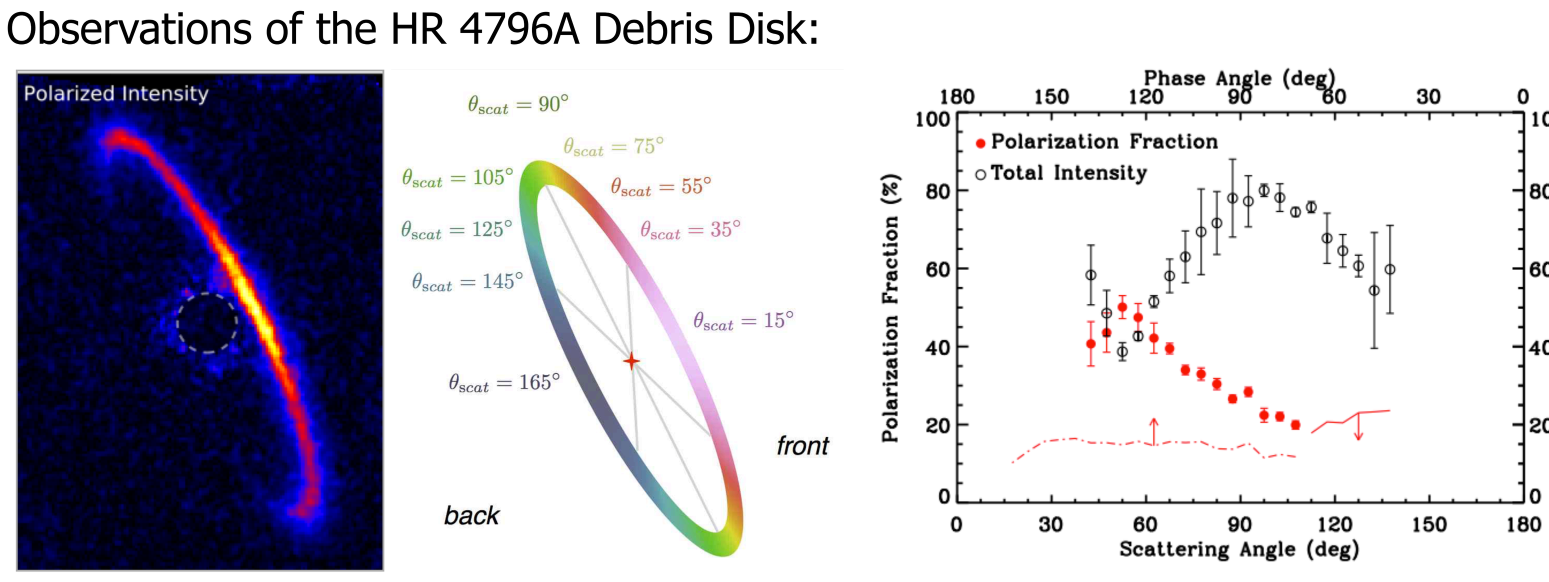
HD 157587 - Millar-Blanchaer et al. 2016

Total intensity dominated by residual starlight – No disk detection!

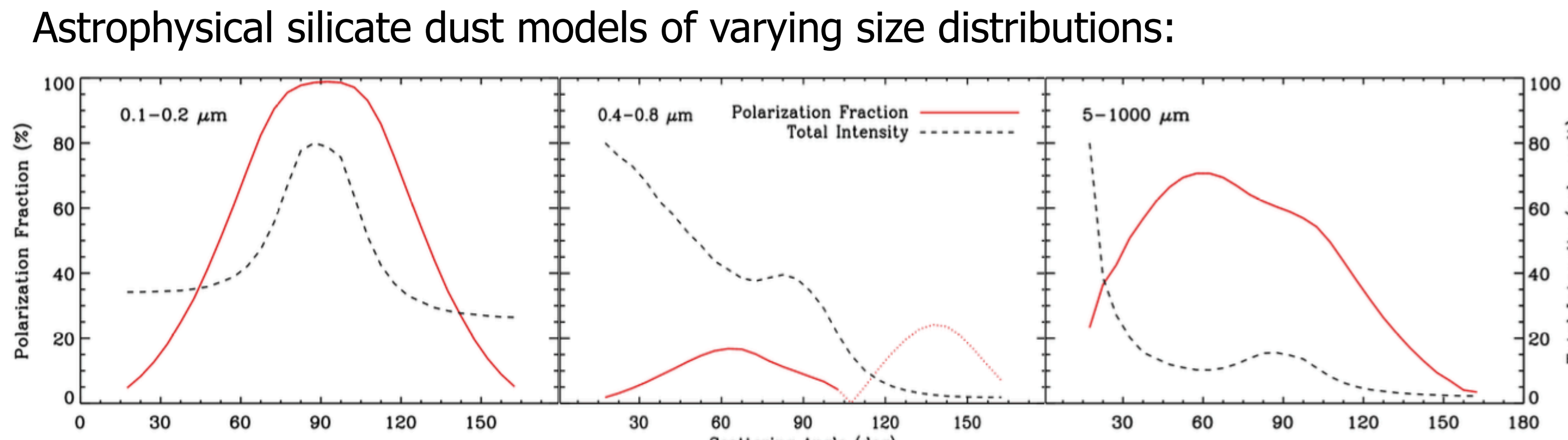
Strong disk detection. Brightness asymmetry likely caused by a planet-induced stellocentric offset.

Dust Scattering Phase Functions

Observations of the HR 4796A Debris Disk:



Astrophysical silicate dust models of varying size distributions:



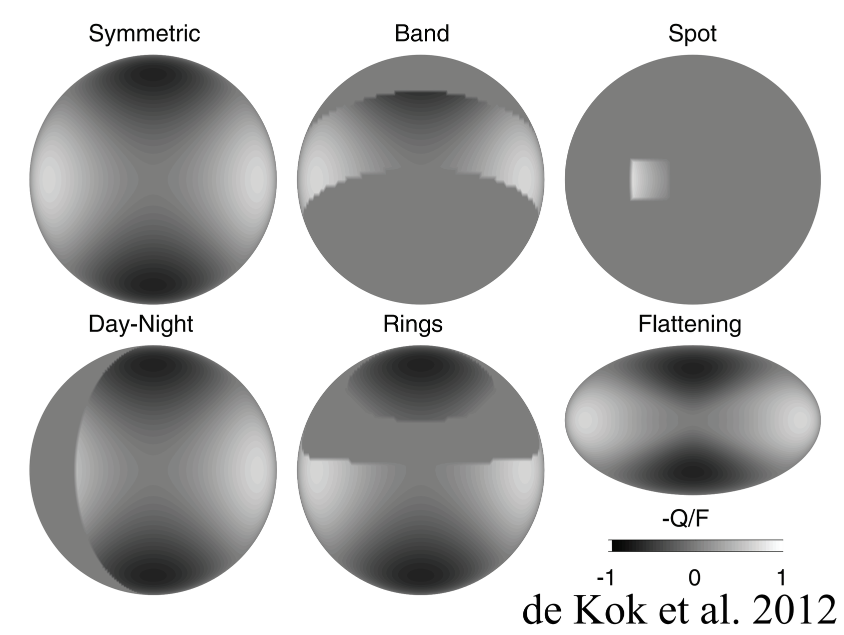
Perrin et al. 2015

Exoplanet and Brown Dwarf Atmospheres

Spectra of exoplanets and brown dwarfs have revealed signs of patchy clouds. However, very little is known about the true nature of these clouds, such as their height and their composition.

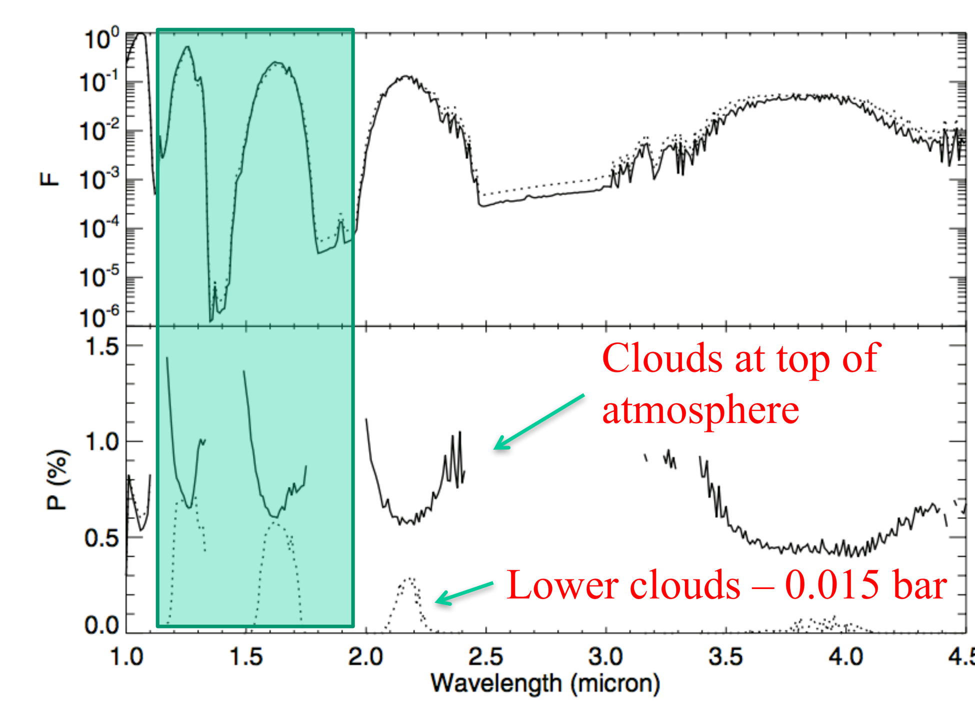
Polarized Atmospheres

Exoplanet and brown dwarf atmospheres can be polarized if there is an asymmetry in the atmosphere:



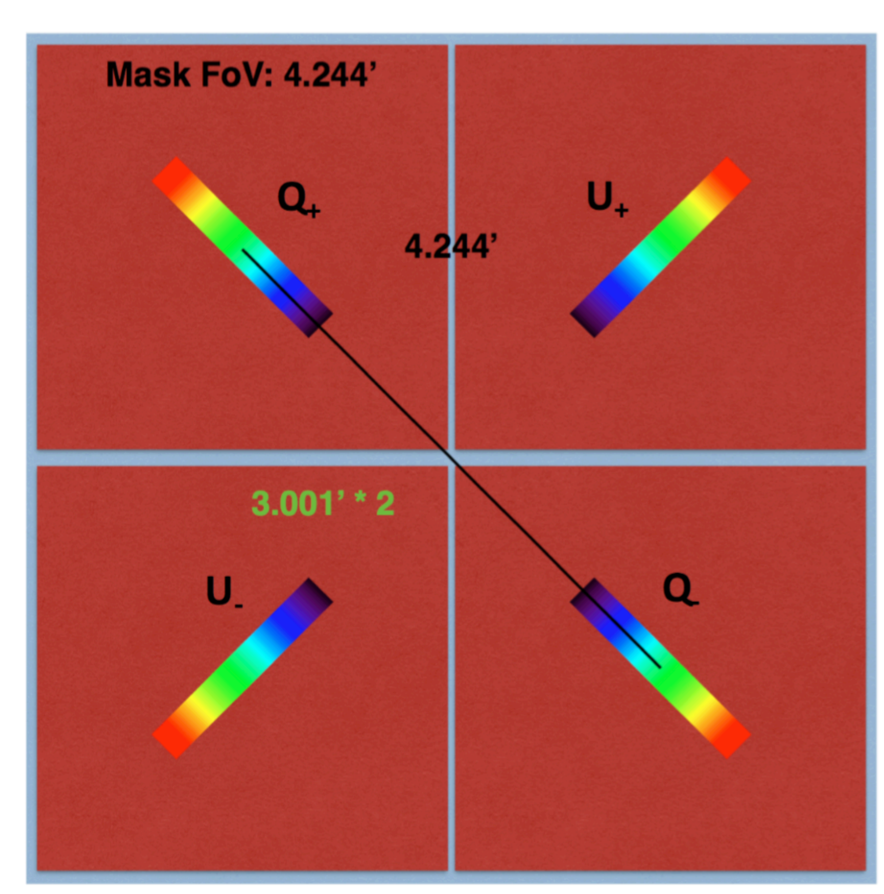
de Kok et al. 2012

Spectropolarimetry can provide a unique handle on cloud heights in these objects:

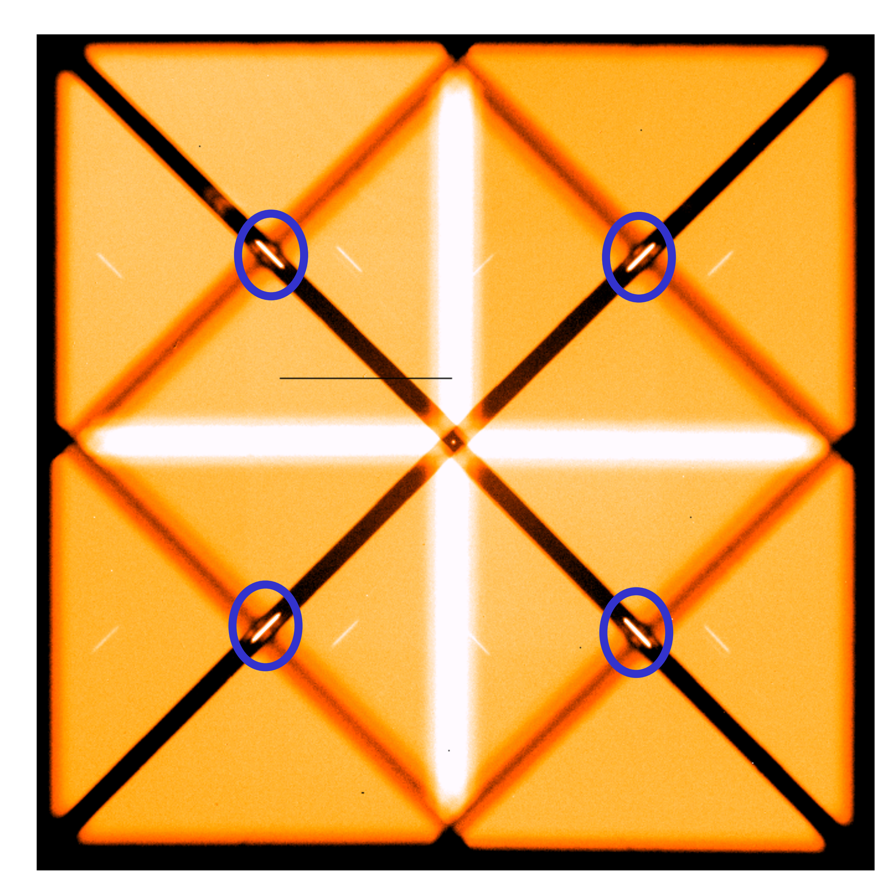


Spectropolarimetry with WIRC+POL

WIRC+POL is a new J- and H-band spectropolarimetry upgrade for the Palomar 200-inch telescope.



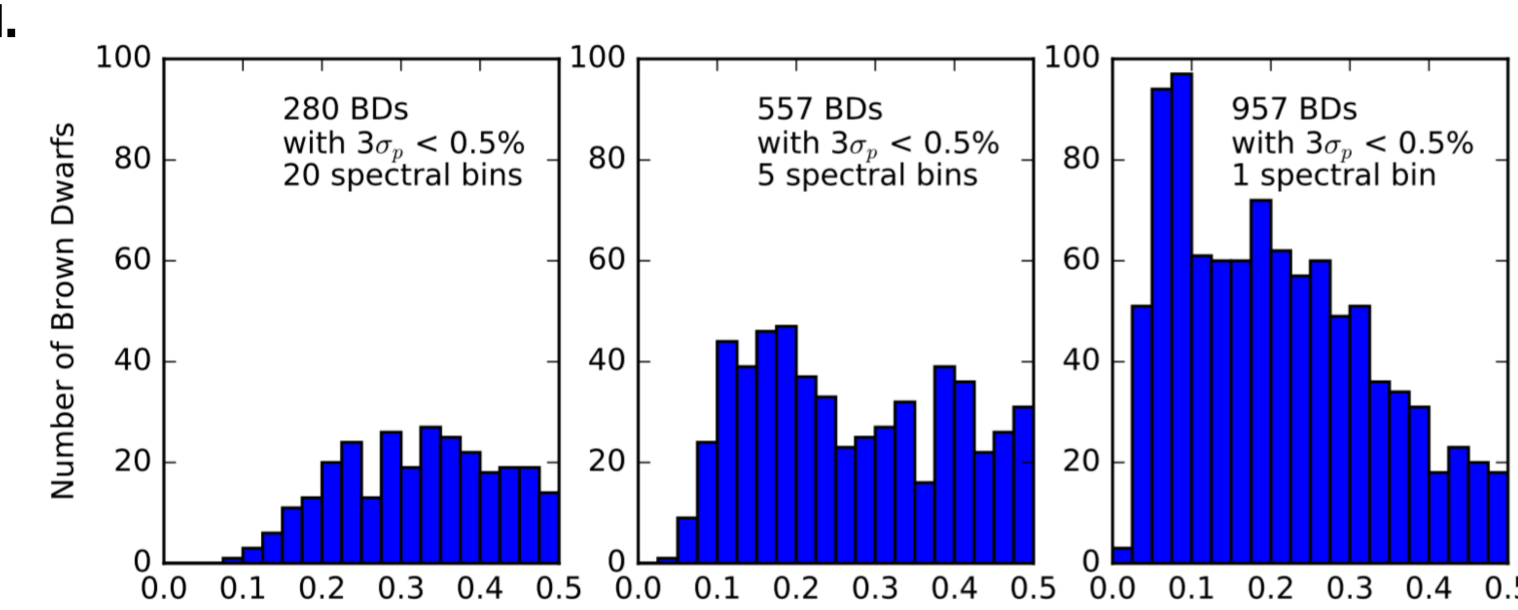
Cartoon image of the focal plane. A custom polarization grating creates four spectra, allowing us to measure Stokes Q and U in a single snapshot measurement.



On-sky data: a focal plane mask creates a unique background image on the detector. The four spectra for the central source (blue circles) and two other sources are all visible.

The WIRC+POL Brown Dwarf Survey

A multi-year survey starting in the fall of 2017 to observe several 100s of brown dwarfs and systematically catalogue cloud properties across brown dwarf spectral types -> Implications for polarized exoplanets observations as well.



Simulated survey sensitivities for different spectral resolutions.

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Poster No. A-02

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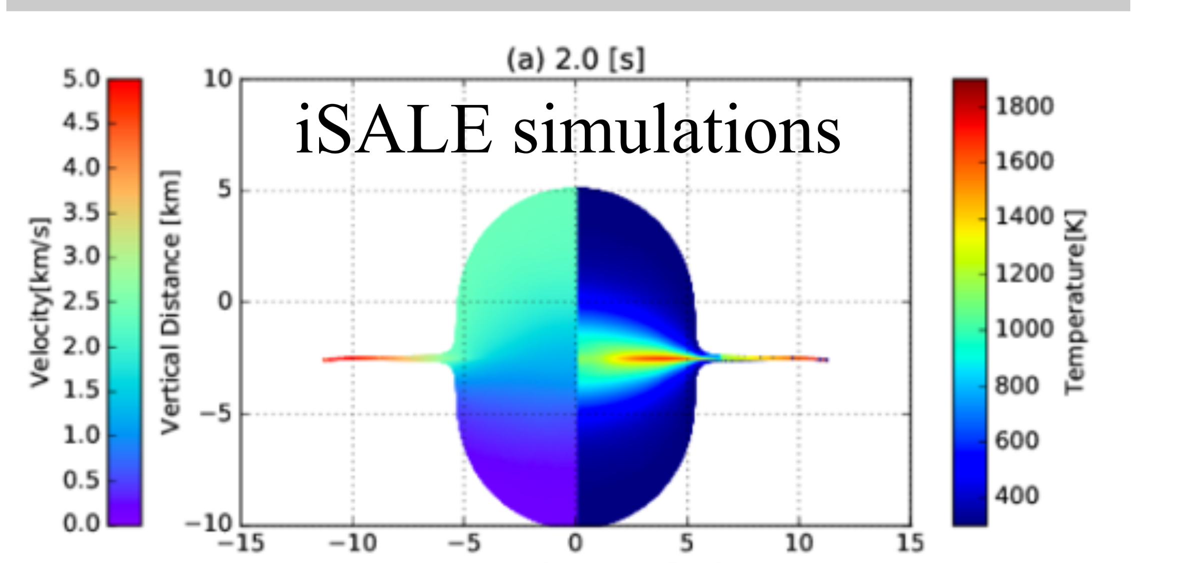
Impact Jetting and the Origin of Ordinary Chondrites

Author: Yasuhiro Hasegawa (JPL/Caltech: 3263)
Neal Turner (JPL/Caltech: 3263), Joseph Masiero (JPL/Caltech:3224)
Shigeru Wakita (CfCA), Yuji Matsumoto (CfCA), Shoichi Oshino (CfCA)

Introduction: Chondrules as the Fossil Record of the Solar System

- Chondrules are abundant (< 80% by volume) in the most common meteorites, chondrites
- Chondrules are ~ 1 mm-sized spherical particles formed as molten droplets of silicate
- The thermal history of chondrules such as flash hearing and relatively slow cooling provides invaluable clues about how chondrules formed in the solar nebula
- Chondrules kept forming for 3-5 Myr after Calcium-Aluminum-rich Inclusion (CAI) formation began, which is 4.567 Gyr ago from now
- Understanding of chondrule formation and accretion sheds light on the properties of the solar nebula, and hence the origin of the solar system

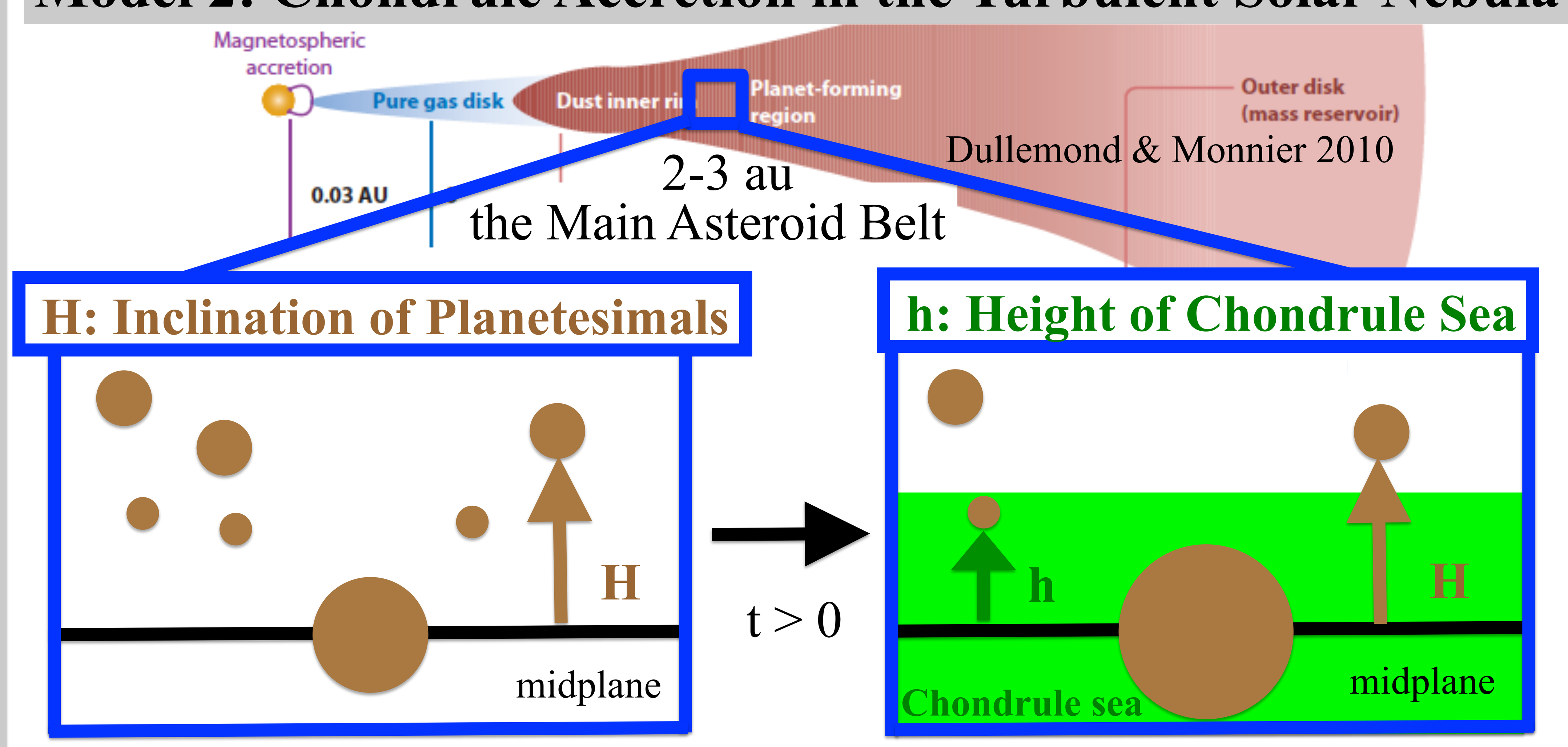
Model 1: Chondrule Formation



Wakita et al 2017

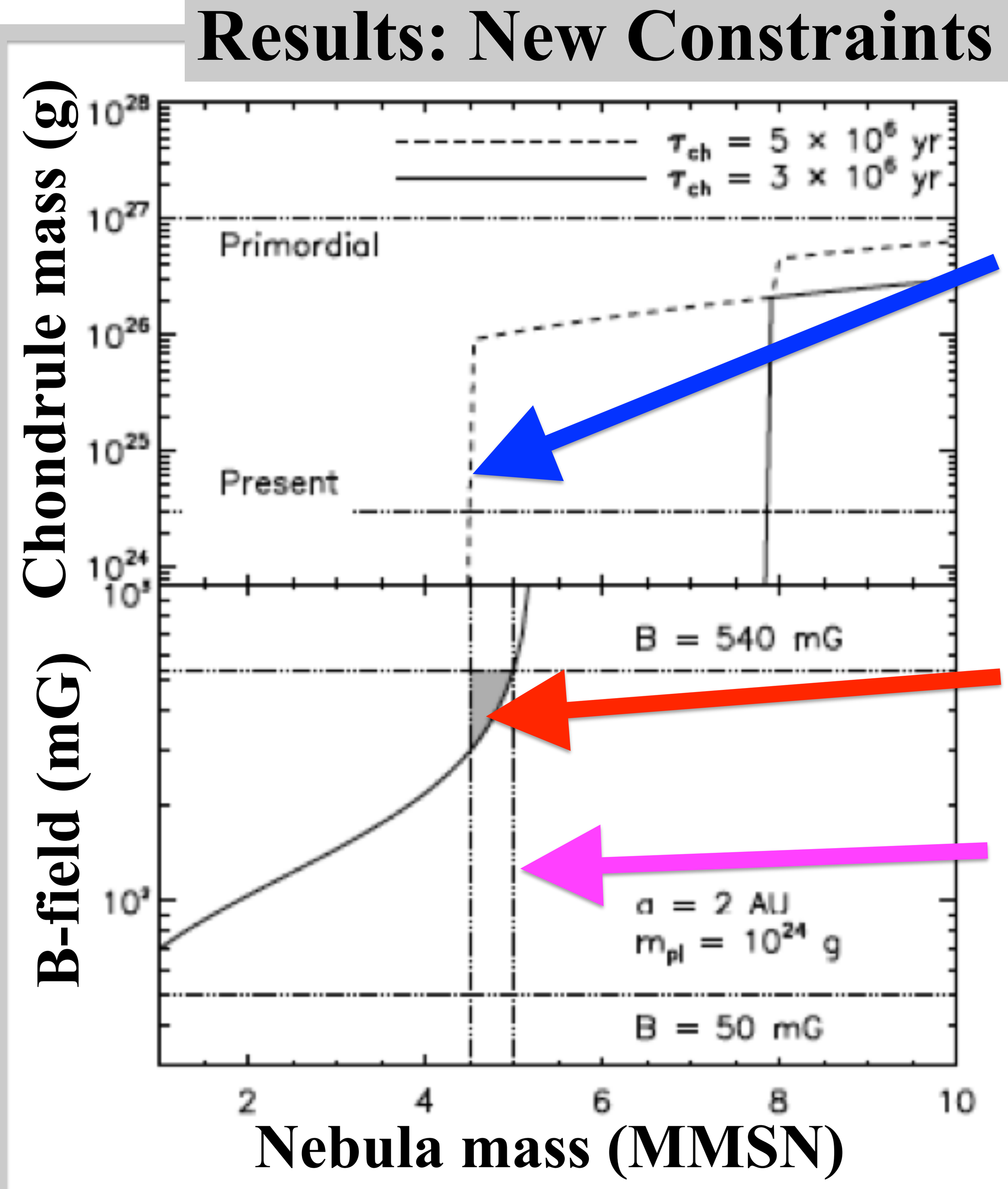
- Planetesimal collisions can serve as chondrule-forming events
- Some materials melt, and are ejected from the system
- about 1 % of impactors' mass can be the progenitor of chondrules when the impact velocity is > 2.5 km/s

Model 2: Chondrule Accretion in the Turbulent Solar Nebula



- Chondrules form as planetesimal collisions generate protoplanets
- Chondrules are accreted onto planetesimals only when H < h
- The value of h is controlled by magnetized turbulence in the nebula

Results: New Constraints on the Nebula



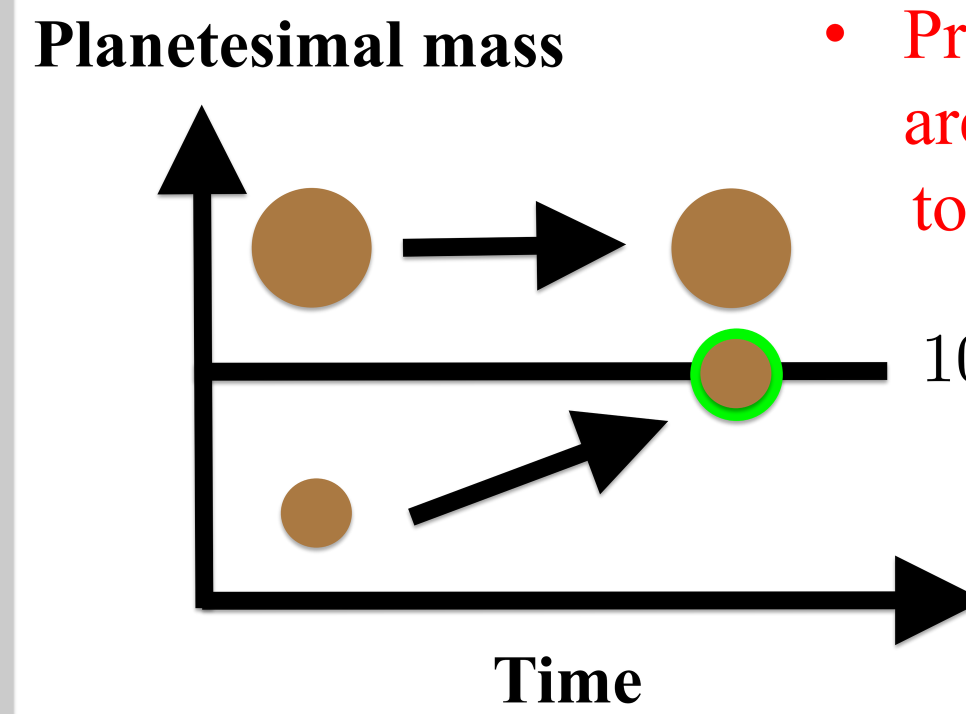
Minimum nebula mass to form many chondrules

Chondrule formation and accretion can occur when the nebula mass is < 5 MMSN, and the planetesimal mass is $< 10^{24}$g

Maximum nebula mass to achieve chondrule accretion onto existing planetesimals

Top: the primordial and the present Asteroid belt masses are shown by the horizontal lines, and two timescales are adopted for chondrule formation (τ_{ch})
Bottom: B-field strengths inferred from magnetized chondrules are by the horizontal lines

Implications & Impacts on NASA's Missions



- Pre-existing planetesimals are needed for our model to be effective
- Chondrule-rich surface layers are ~ 0.3 km for 200km-sized planetesimals

The details can be found at Hasegawa et al 2016a,b, Wakita et al 2017, Matsumoto et al 2017

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Poster No. A-04

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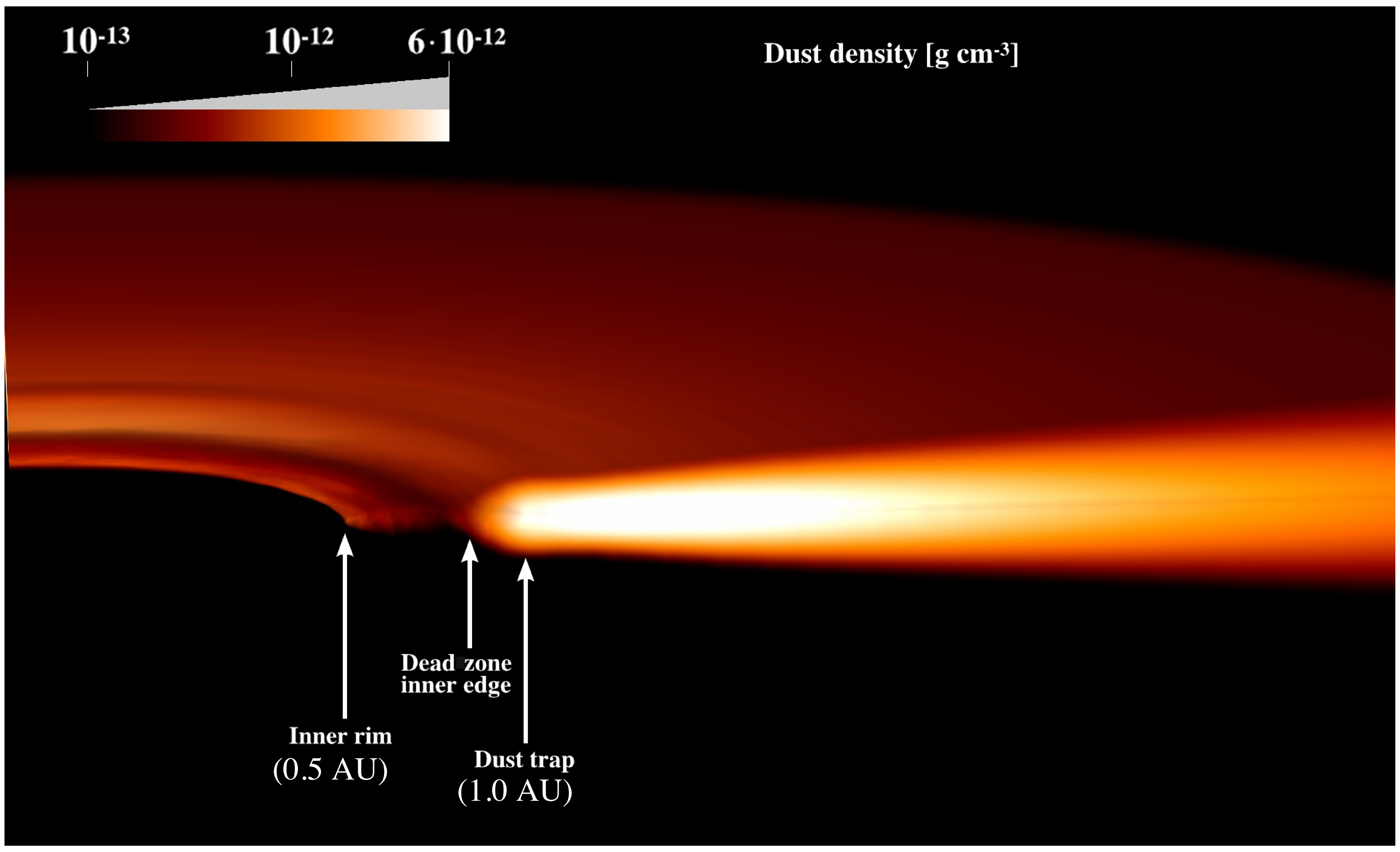
The Inner Rim in Protoplanetary Disks

Authors: **Mario Flock** (3263) and **Neal Turner** (3263)

Determining the structure of gas and dust around the silicate sublimation front is key for understanding the origins of planets, especially the thousands of exoplanets that orbit within 1 AU of their stars.

Overview

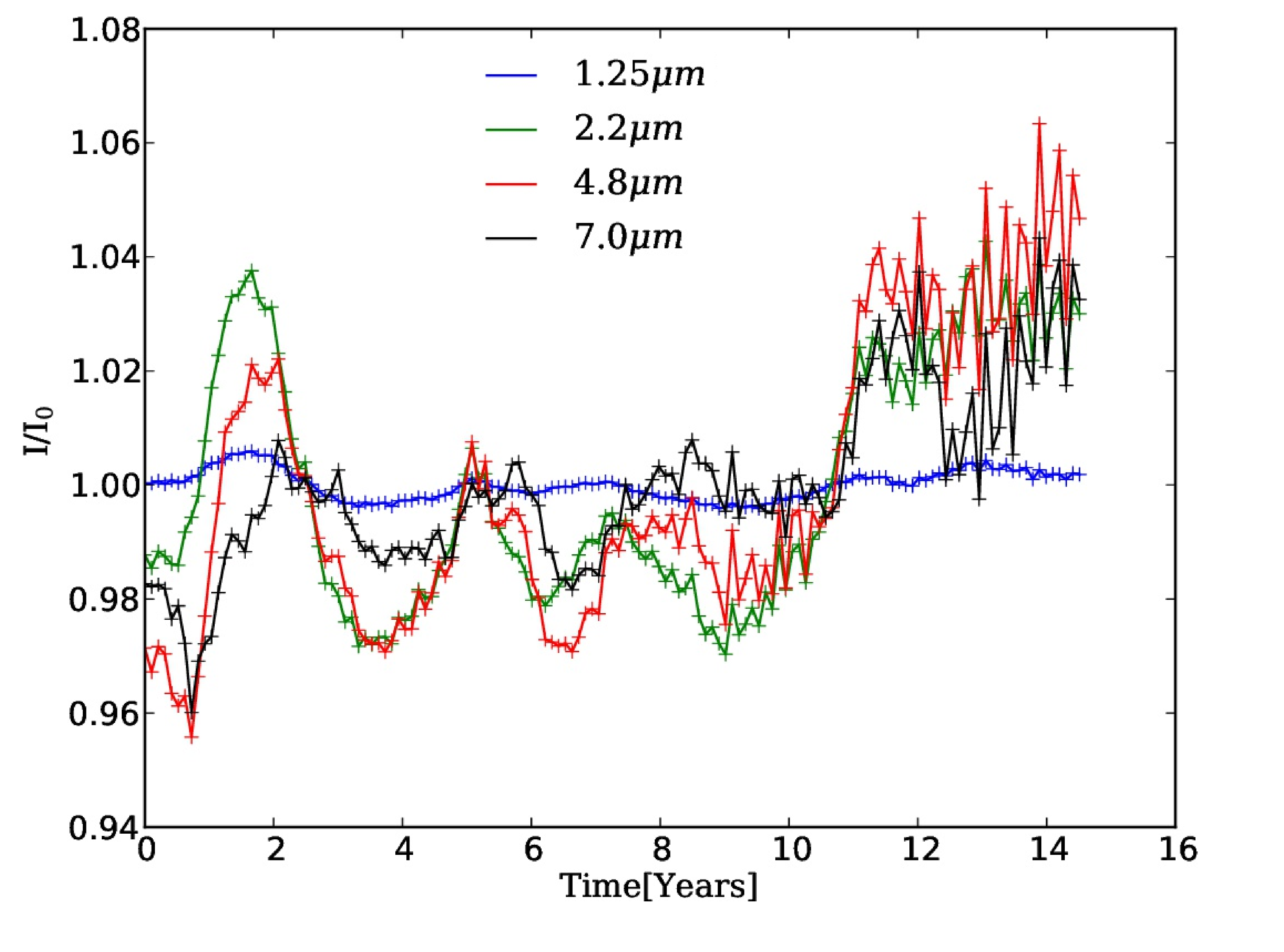
- We investigate the inner rim of the disk round a young 2-Solar-mass star
- We present the first global 3D radiation non-ideal MHD calculations
- Volume rendering at right shows tenuous dust at sublimation front (0.5 AU) and abundant dust where temperatures fall below the thermal ionization threshold, weakening magnetic forces so inflow piles up (0.8 AU).
(*Star is not shown at image's left edge*)



Near-infrared Variability

Magnetic dynamo in disk makes time-varying atmosphere near sublimation front, causing quasi periodic thermal-infrared variability

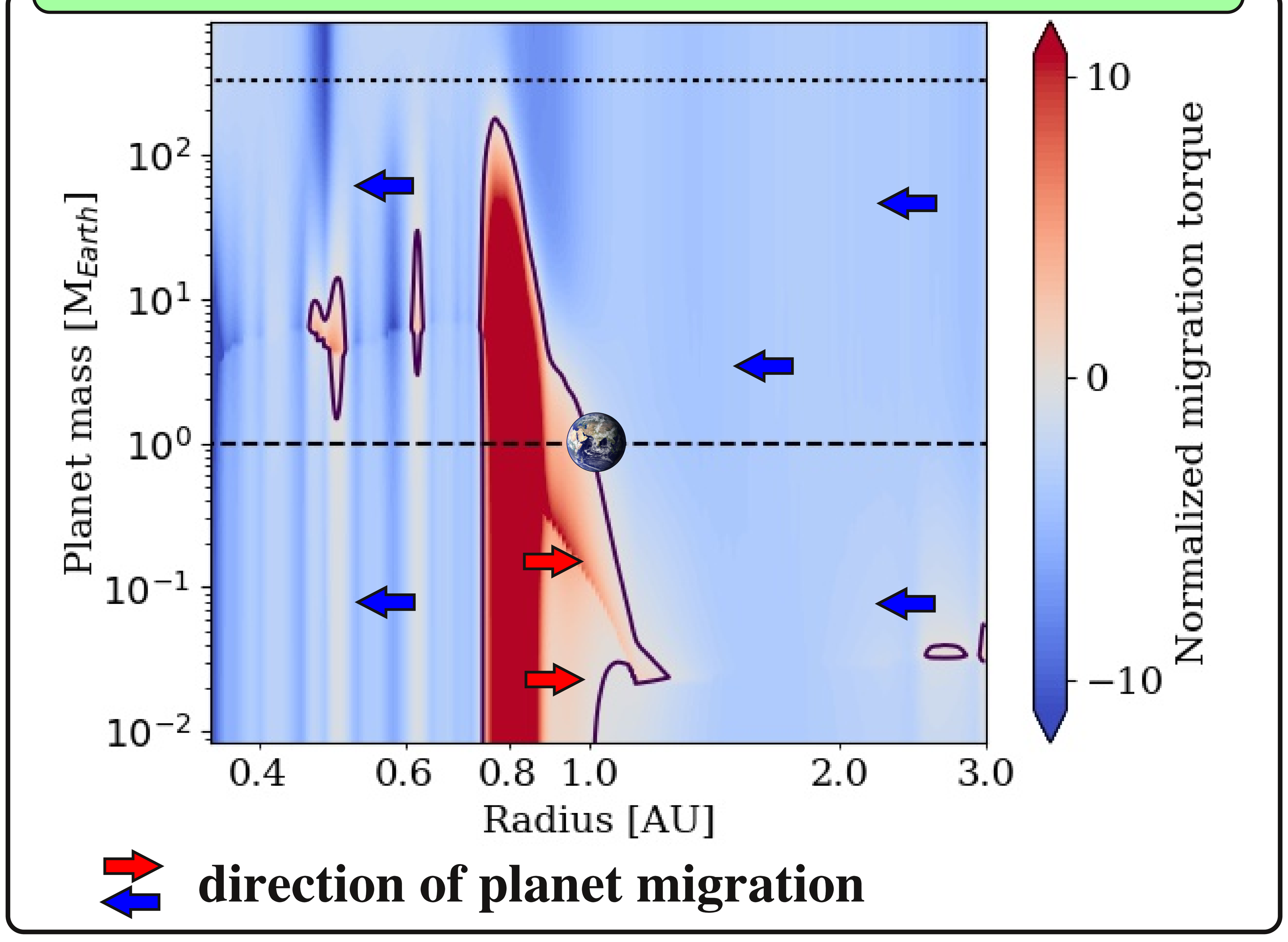
Intensity over time



Planet trap

Simulation results show an efficient trap for low mass planets (< 10 M_{Earth}) close to the dead zone inner edge

Planets migrate to red area's outer edge (Torque=0)



Conclusions

The first 3D radiation non-ideal-MHD models show:

- **gas, dust and temperature structure**
- **dynamical stability**
- **near-infrared variability of the disk at and around the sublimation front**
- **dust trap concentrates pebbles to grow planets**
- **any super-Earths will migrate to a nearby stopping point (type I migration trap)**

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Reference: ApJ 2017, 835, 230

Poster No. A-05

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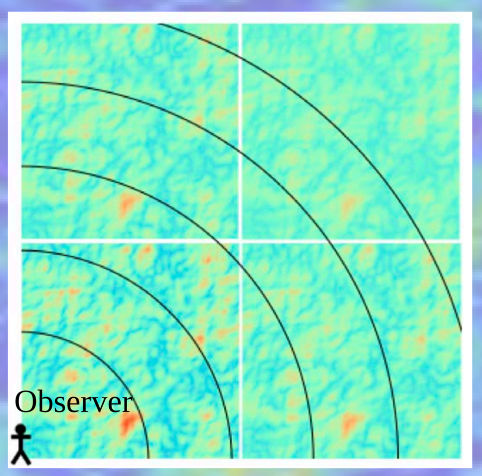
Fast generation of mock galaxy catalogues

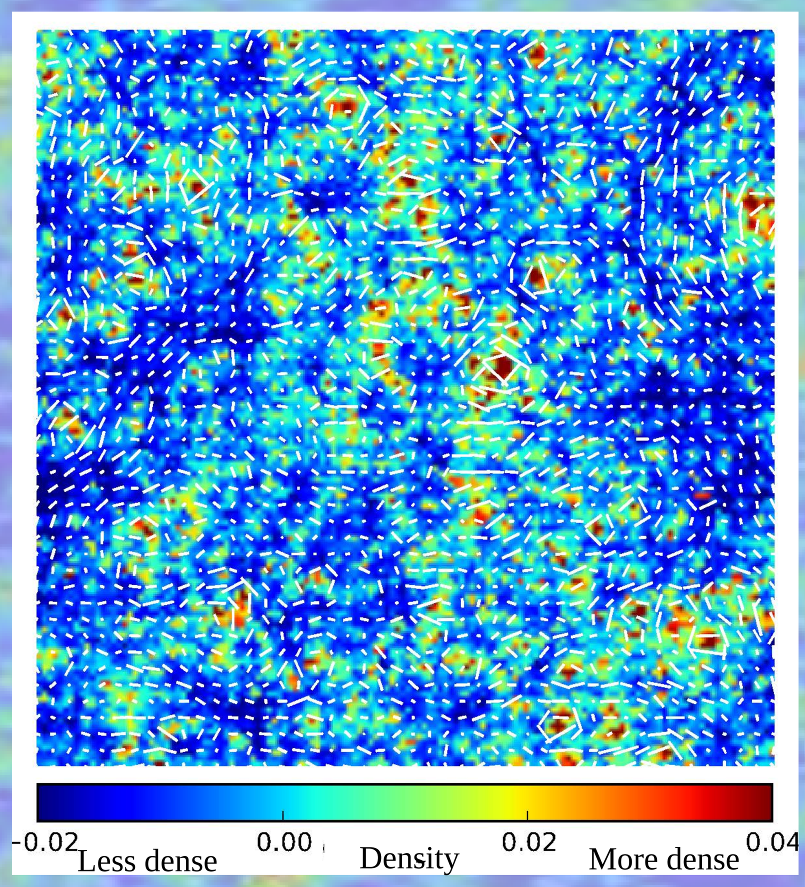
Author: Albert Izard (3266)
Co-Authors: Alina Kiessling (3266), Eric Huff (3268), Philip Bull (3268)

- NASA's Wide-Field Infrared Survey Telescope (WFIRST) and the ESA/NASA Euclid telescope are future space-based dark energy missions with the Jet Propulsion Laboratory (JPL) providing key scientific leadership in both surveys.
- Both will use weak lensing and galaxy clustering as primary probes of cosmology.
- A good understanding and mitigation of systematic effects is imperative to optimally exploit the data from these upcoming surveys.
- We present an efficient pipeline to produce mock galaxy catalogs, which we use to study the contribution of systematic effects to the overall error budget for the surveys.

Cosmological simulations

- Standard **numerical methods** for producing dark matter simulations are **computationally very expensive**. Running a typical simulation requires thousands of CPUs over many days or weeks. Many thousands of simulations are required both in the preparation for surveys and in the eventual analysis of the data.
- The COmoving Lagrangian Acceleration (COLA) method generates **fast dark matter only simulations**. The speed-up is between 2-3 orders of magnitude with respect to standard simulations.
- Our COLA fast simulations (Izard et al. 2017) provide mock **observational light cones** with dark matter halos and weak gravitational lensing included.





Top: Light cone geometry. **Right**: Map of weak lensing in 2D cross section through the light cone. The size of the matter density peaks are the colors and the weak lensing "light blending" magnitudes are the white ticks. Higher density peaks induce larger weak lensing signal.

SIMULATIONS

Detect collapsed regions

HALOS

Populate halos with galaxies

IDEAL GALAXIES

Add systematic effects

~ OBSERVED GALAXIES

Survey mask

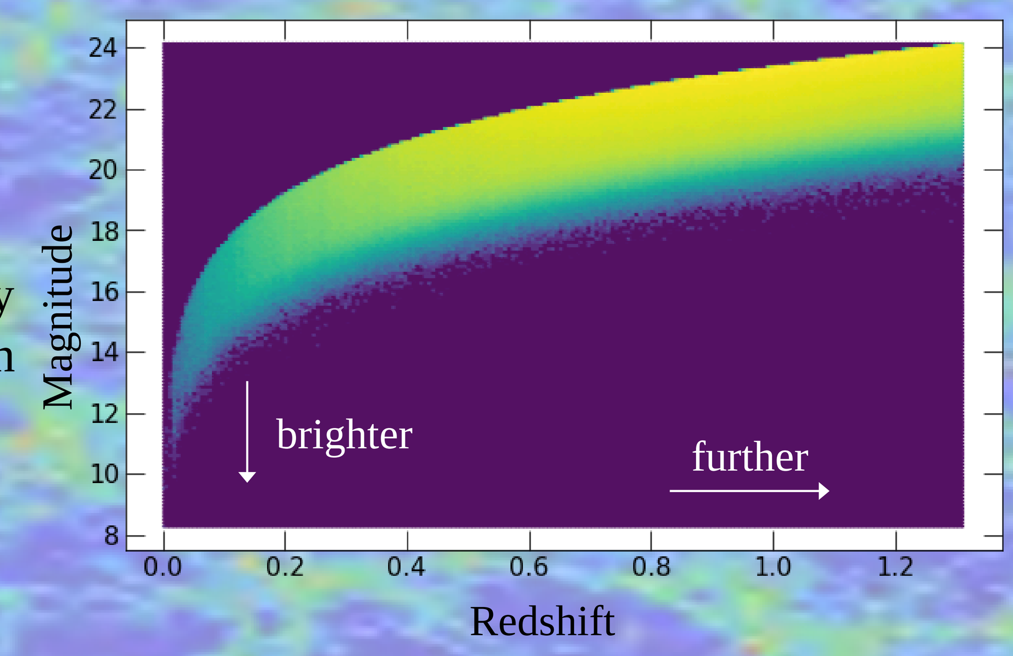
SAMPLES

Define observables

MEASUREMENTS

Mock catalog galaxy magnitude as a function of redshift

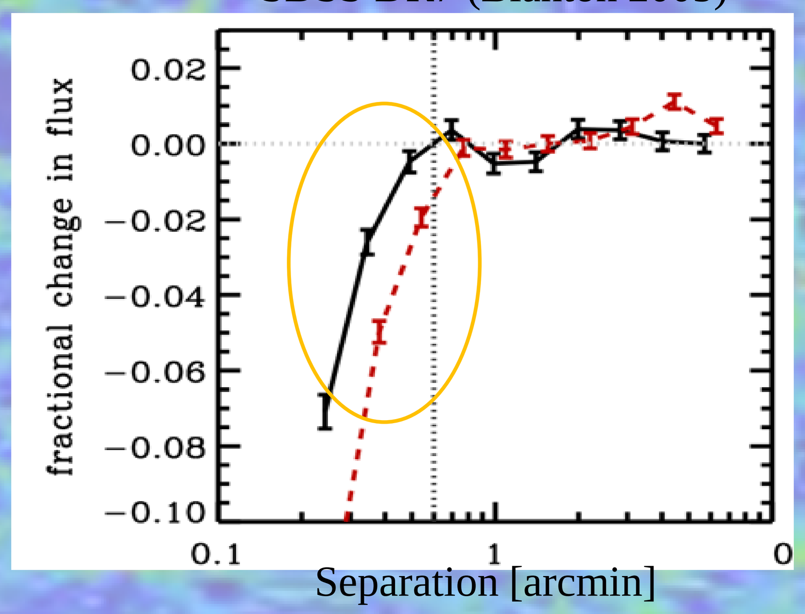
The mass resolution of the simulations imposes a limit on the luminosity range that we can model. More distant galaxies are fainter.



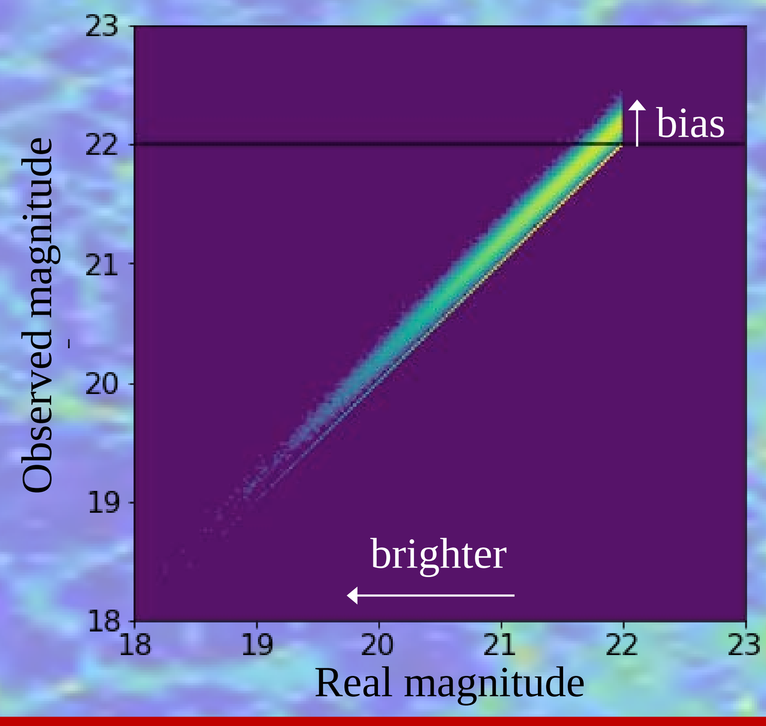
We introduce systematic effects by modelling the probability of detecting a galaxy and measuring its photometry and shape given its position on the sky and its true (or ideal) properties.

Proximity effect:
The measured flux of galaxies is affected by the presence of close neighbors. The flux is underestimated when the angular separation between two galaxies is small.

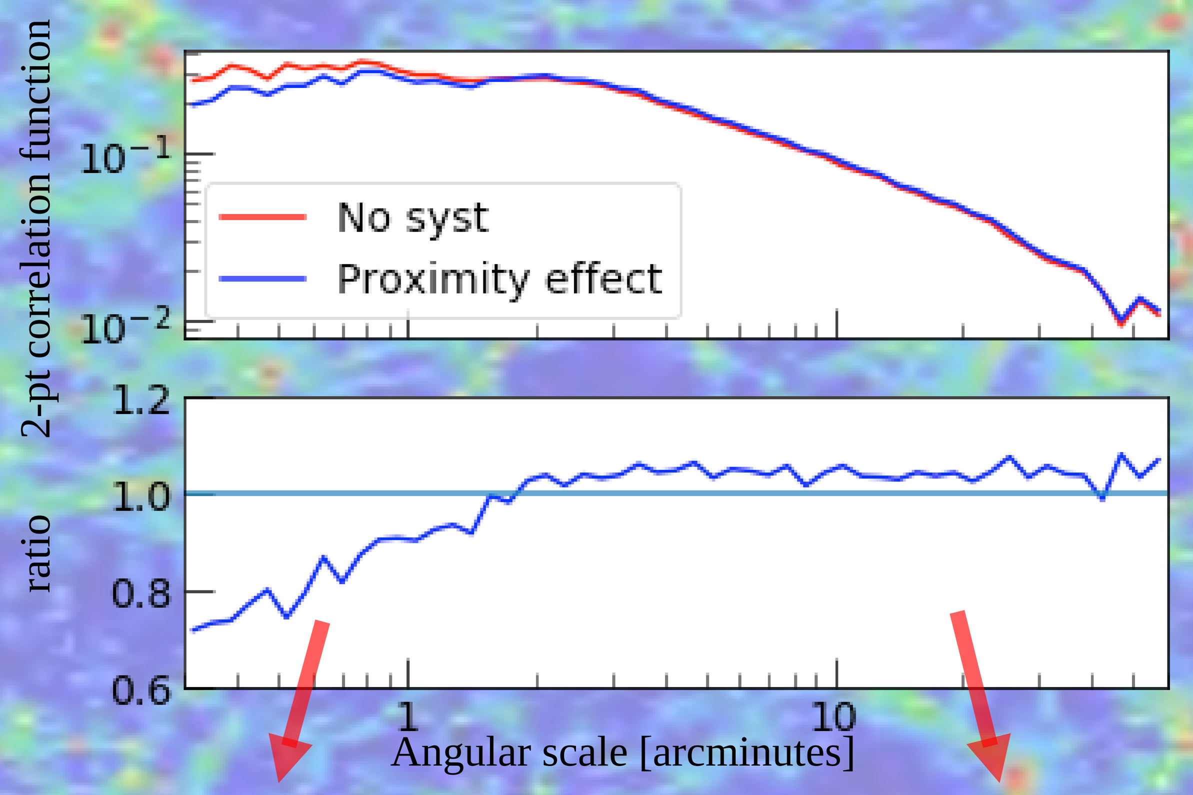
Huff & Graves (2014)
SDSS DR7 (Blanton 2005)



We model the proximity effect by introducing a **bias** into the **observed galaxy magnitude**. This bias depends on the total luminosity (of all neighbor galaxies) at the galaxy's sky position.



We analyze the **clustering properties** of the galaxy distributions by measuring the two-point correlation function, which describes the excess of probability of having two objects separated by a given distance compared to a random distribution. We show below the correlation function of a catalog with and without the proximity effect:



Small scales: the proximity effect reduces the number of galaxies close to each other in the sample, thus lowering the clustering strength at these scales.

Large scales: the proximity effect excludes faint galaxies from the sample. And since luminous galaxies have a higher clustering amplitude, the signal increases.

Summary
-Generating mock galaxy catalogs from numerical simulations is computationally very expensive. We developed an efficient pipeline based on fast N-body simulations.
-The mock galaxy catalogs include the weak lensing effect and have a broad range of applications (e.g. to study the physics of gravitational collapse, validate analysis pipelines, and test halo-galaxy models).
-We are currently using the galaxy mocks to study the impact of observational systematics on cosmological parameter estimates in the preparation for WFIRST and Euclid .
-This work puts JPL in the forefront of mitigating the key observational systematics affecting cosmological parameter estimates from WFIRST and Euclid.

Next steps
-We are implementing other systematic effects such as shape measurement errors, photometric redshift errors, and the selection function.

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Poster No. A-06

Survey of the Ionized ISM in our Galaxy using the Stratospheric Terahertz Observatory2

National Aeronautics and Space Administration

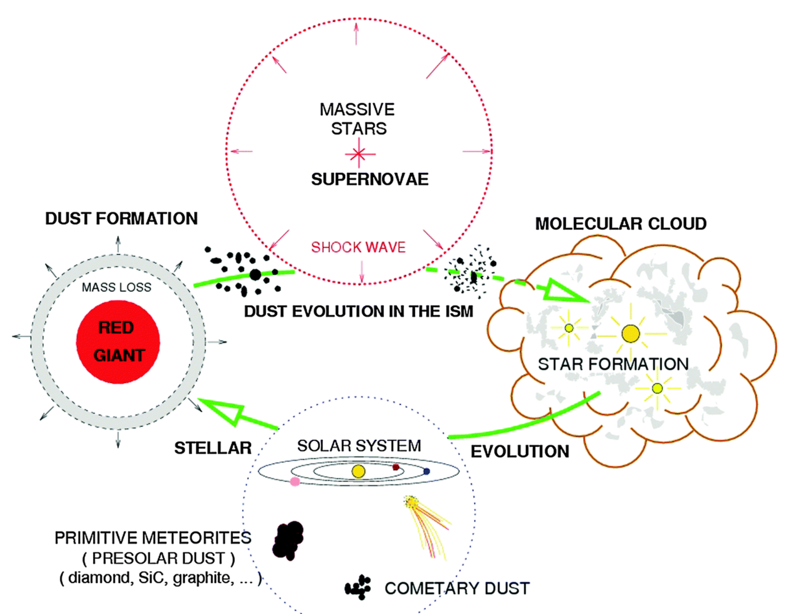
Author: Youngmin Seo (JPL, 3266)

Paul Goldsmith (JPL, 3266), Chris Walker (U. Arizona), & STO2 Team

INTRODUCTION

Life cycle of the interstellar medium

- Importance:
  a. Drives the evolution of galaxies in the universe
  b. Closely related to planet formation
- Understanding the evolution and the life cycle of the interstellar medium is a central part of NASA's strategic objective in astrophysics.



[Bromley et al. 2014]

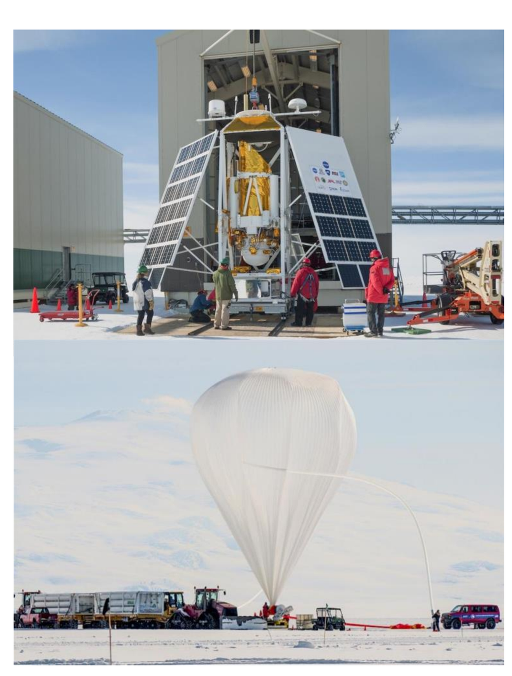
- [CII] and [NII] are important lines in investigating the life cycle of ISM because [CII] is related to star formation activity and cooling and [NII] is related to the star formation rate.
- Ionized [CII] and [NII] are not well probed due to difficulties in observation from any ground-based observatory

OBJECTIVES

- Survey [CII] and [NII]
- Study formation and destruction of molecular clouds
- Map the star formation rate

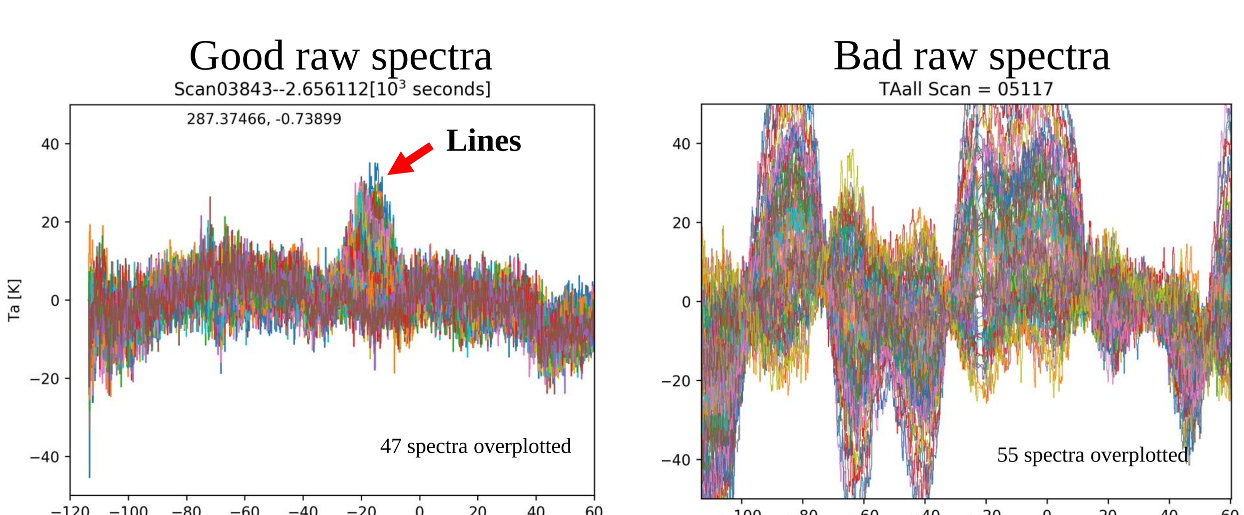
OBSERVATION

- Using Stratospheric Terahertz Observatory-2
- STO2 is the first terahertz balloon mission in astronomy
- 0.8-meter telescope, 1' resolution @ 158 µm
- Heterodyne receiver array for [CII] and [NII]
- Flight from Dec. 9, 2016 to Dec. 28, 2016
- Observed Trumpler14, Eta Carinae, NGC3576, Galactic plane at G310, G328, & G330
- Complementary to Herschel and SOFIA



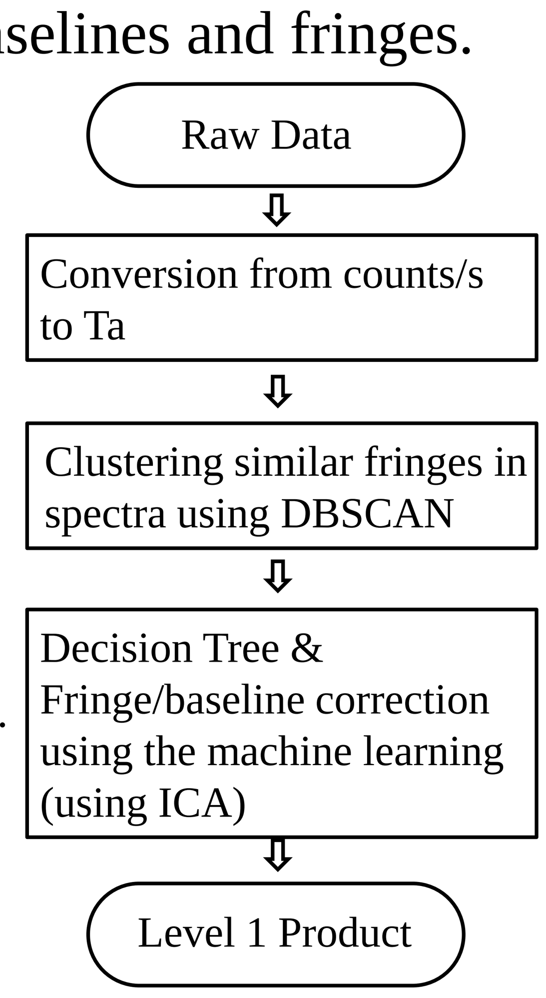
DATA QUALITY & REDUCTION

- Data are obtained from one feed of [CII] and two feeds of [NII]
- Native velocity resolutions are 0.17 km/s for [CII] and 0.23 km/s for [NII]
- 50% of data are in a relatively good shape but the other 50% of data have complex baselines due to technical problems of telescope system during observation.
- Total number of spectra: ~300,000
- Machine learning is used to process complex baselines and fringes.



Initial reduction of good spectra is under progress.

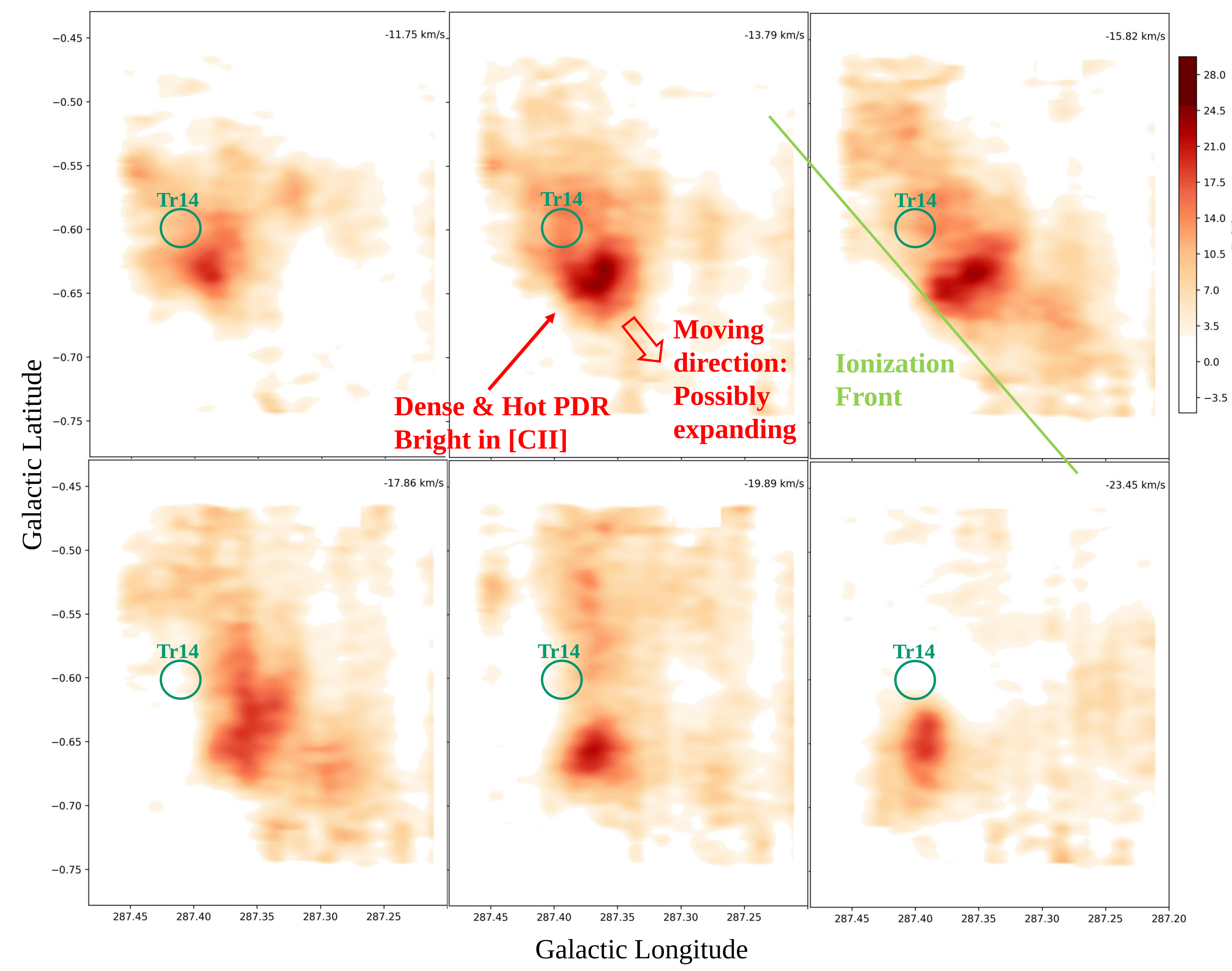
Bad spectra have been identified. Requires extensive effort to reduce.

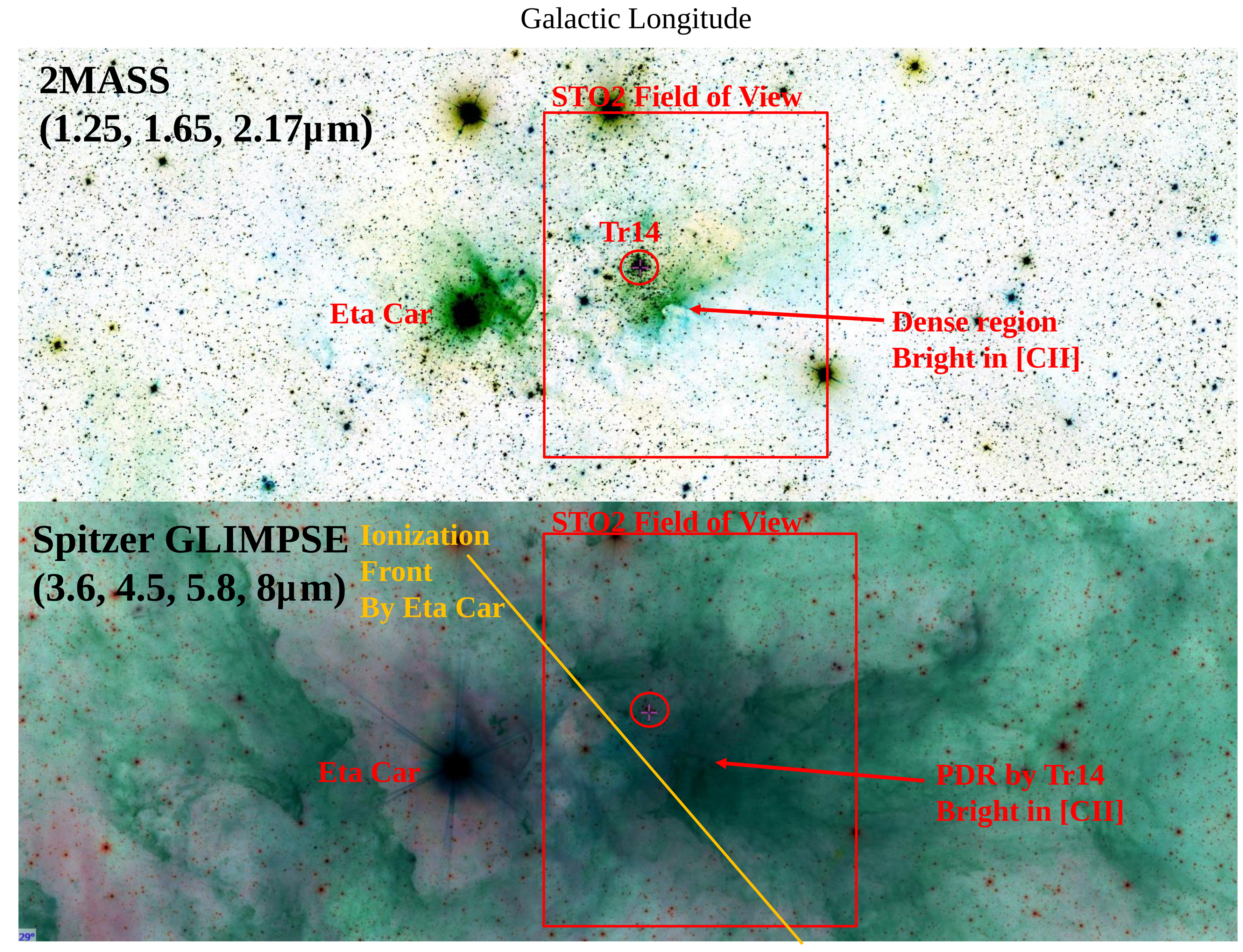


RESULTS

Trumpler 14

- [CII] channel maps of Trumpler 14 (level 1 product, baseline corrected)
- Spatial resolution of 72 arcseconds and velocity resolution of 0.34 km/s





- [CII] emission is the brightest where the hot dust exists (GLIMPSE) Consistent picture with Spitzer GLIMPSE
- [CII] at -18 km/s may show ionization front created by Eta Carina
- No [NII] detected in Trumpler14.

CONCLUSIONS & FUTURE WORKS

- STO2 successfully detected [CII] line emission and the level 1 product (baseline corrected data) will be delivered by the end of August 2017.
- Level 3 data (publishable data) will be prepared by the end of year.
- The STO2 pipeline will be transferred to GUSTO (Galactic/ Extragalactic ULDB Spectroscopic Terahertz Observatory) Explorer MoO to be launched in Dec. 2021

Poster No. A-07

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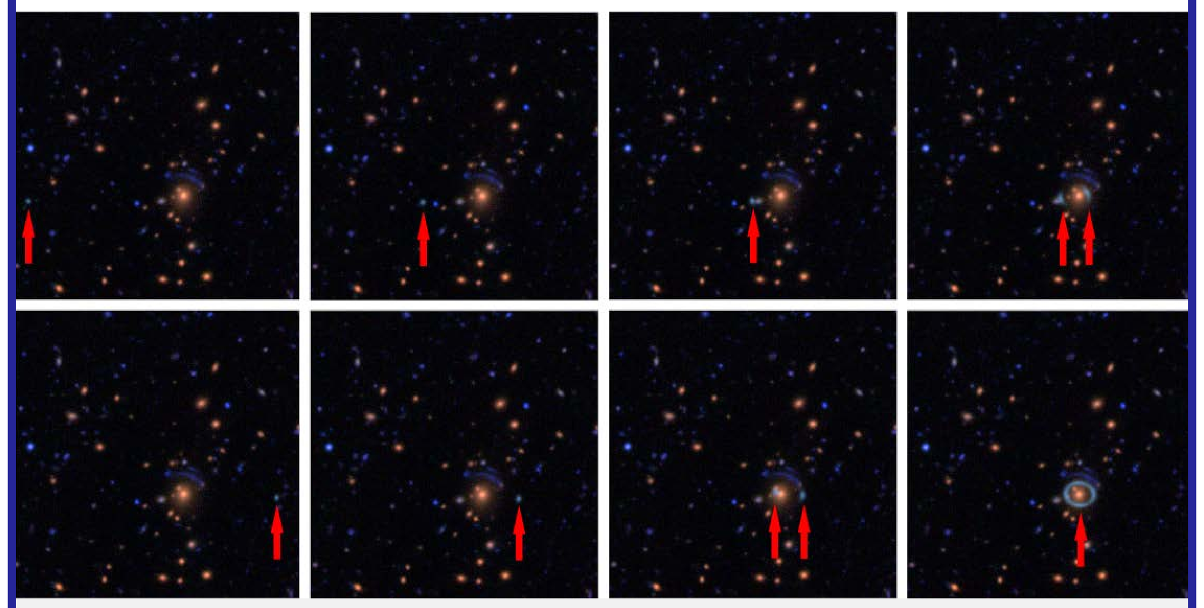
Measuring and Mitigating Systematic Biases in Weak Lensing Surveys

Melanie Simet (3266)
Rachel Mandelbaum, Hironao Miyatake (3268), and the HSC collaboration

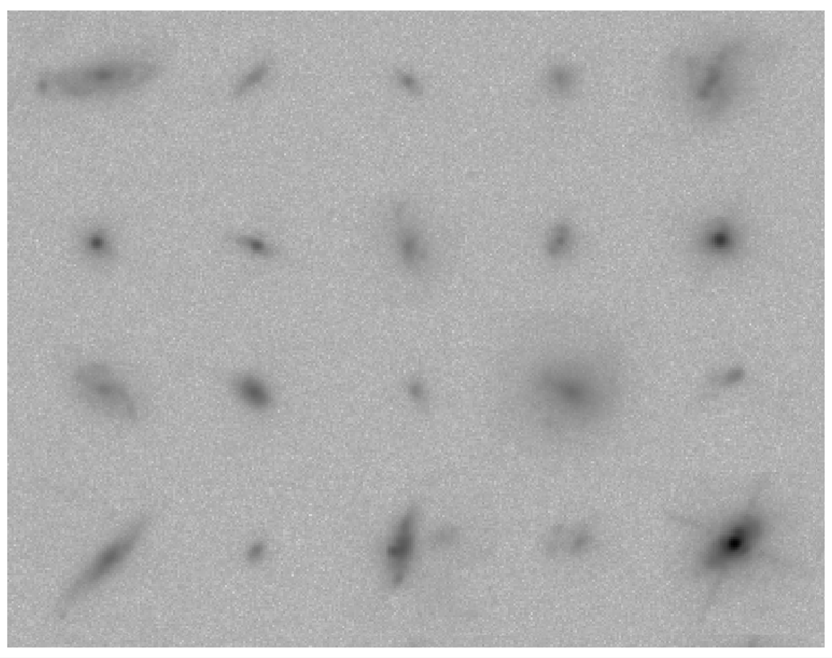
INTRODUCTION TO WEAK LENSING

Weak gravitational lensing is the study of the distortions in distant galaxy images caused by gravitational fields in the universe. Measuring this effect is one of the primary goals of NASA's upcoming Wide-Field Infrared Survey Telescope (WFIRST), plus NASA-involved missions such as the ESA Euclid survey and the DOE/NSF Large Synoptic Survey Telescope.



The small blue galaxy indicated by the red arrow is being lensed by the galaxy cluster in the lower right. In the left two panels, the lensing is *weak*: it is difficult to tell that the image is distorted. In the right four panels, the lensing is *strong:* the image is very distorted and much brighter.
(Simulation made with Lens Toy: http://slowe.github.io/LensToy/)

Because gravity is causing the distortions, weak lensing is equally sensitive to dark matter and ordinary matter—making it a powerful probe of cosmology. But the distortions are small (typically 0.1% of the intrinsic dispersion of galaxy shapes), so the measurements have high required accuracy. Yet most galaxies are faint and small.



Simulated galaxy images from the GREAT3 simulations (Mandelbaum et al 2014), typical of—or even better resolved than—galaxies we use in weak lensing measurements. The required accuracy for upcoming surveys is biases $<10^{-3}$.

THE HYPER SUPRIMECAM SURVEY

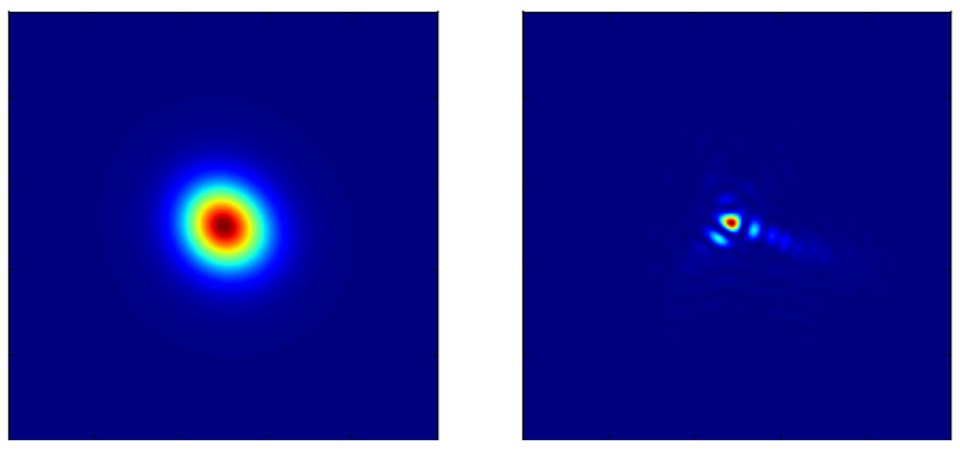
Large-scale cosmological surveys take images of large fractions of the sky. The ongoing Hyper SuprimeCam Strategie Survey Project recently released its first-year data, comprising 12 million galaxies with measured shapes over 140 deg^2 (Aihara et al 2017). We can compare images from HSC to the Sloan Digital Sky Survey, a ground-based survey that began taking data in the 1990s, to see the improvement in detectors and telescopes for cosmological surveys.

Image credit: Top: SDSS SkyServer; bottom: NAOJ

HSC can detect about 20 times as many useful objects for weak lensing as SDSS, and NASA'S WFIRST mission will detect twice as many again. HSC is an important test bed for upcoming surveys, as well as producing its own interesting science.

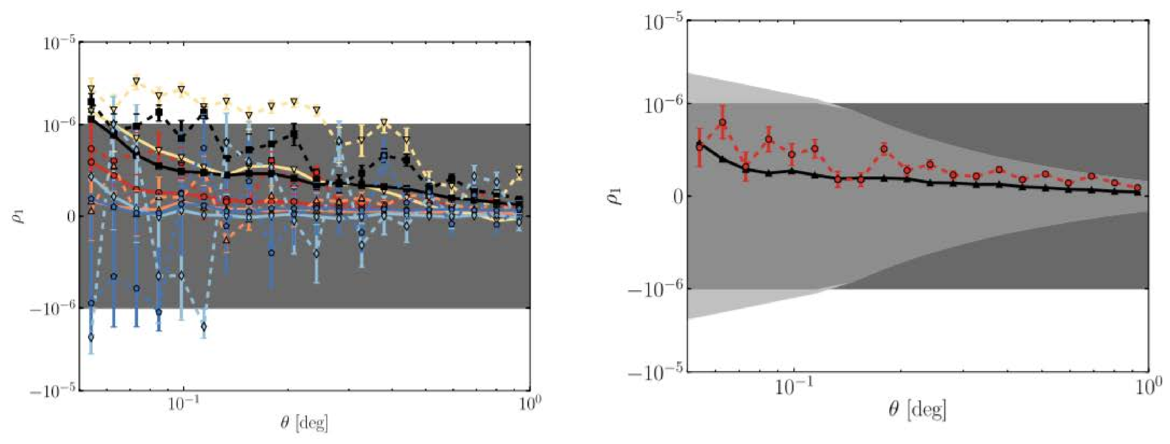
MEASURING SYSTEMATIC ERRORS

An important source of systematic error in lensing measurements is the point-spread function (PSF) that blurs the galaxy images.



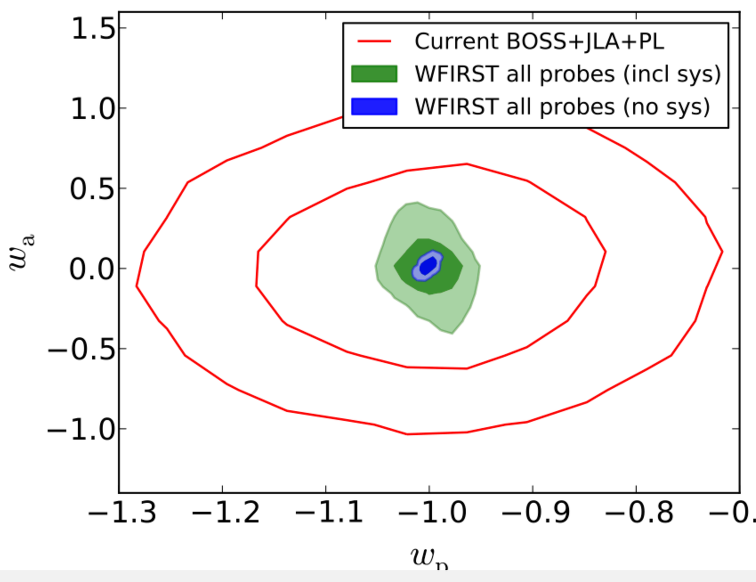
Example ground-based (left) and space-based (right) PSFs. Ground is dominated by the atmosphere, space by optical aberrations and diffraction.

One way to measure the success of this correction is to examine correlations of the residuals between the PSF model shape and the measured star shapes, which trace the PSF. We set requirements on these values based on our statistical uncertainties. For our first year of HSC data, we meet the requirements (right), although there are significant differences between the six HSC first-year fields (left):



Black points were used in PSF determination; red points are the reserved sample. Mandelbaum et al 2017.

These measurements are important to meet our cosmological precision goals. For WFIRST, shape measurement (including PSFs) is a critical contributor to systematic uncertainties.



Plot courtesy Tim Eifler

WHAT'S NEXT: ROAD TO WFIRST

As we continue to analyze data from HSC and prepare for upcoming missions like WFIRST, we will extend the kinds of measurements made above. Simulations like the GREAT3 simulations, with added realistic complexities, enable tests of the measurement algorithms with known truth values. HSC data provides novel science, and the increased area of upcoming data releases will require higher accuracy for PSF determination and other systematics. And ongoing work at JPL investigates the new detectors that will be used for upcoming surveys.

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Poster No. A-08

A Galaxy-Halo Model for Multiple Cosmological Tracers

Author: Philip Bull (326)

National Aeronautics and Space Administration

Motivation: Joint analysis of galaxy surveys

Future galaxy surveys like Euclid, LSST, and SKA will map out a huge fraction of the observable Universe. These data will enable several exciting new tests of fundamental physics at the **cosmic horizon**.

To get the precision needed to carry out these tests, we must combine the data from multiple surveys through a consistent **joint analysis**, i.e. using the galaxy auto- and cross-spectra together.

An important ingredient of this process is a **multi-tracer halo model**, which describes how the galaxies seen by each survey *jointly* populate dark matter halos.

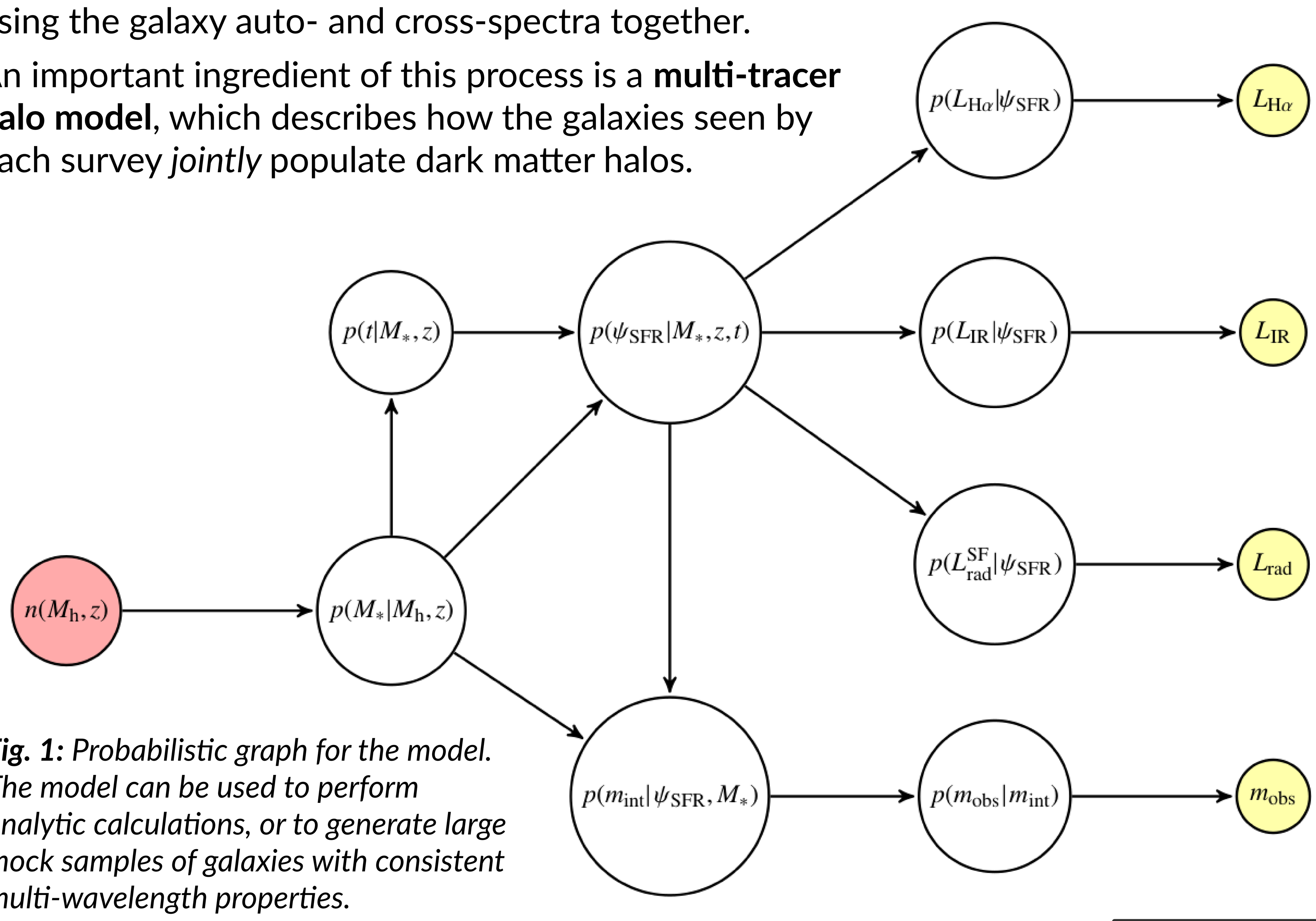

***Fig. 1:** Probabilistic graph for the model. The model can be used to perform analytic calculations, or to generate large mock samples of galaxies with consistent multi-wavelength properties.*

Statistical model

The model is built on the principle of decomposing the **joint pdf for all relevant galaxy parameters** into a chain of simpler analytic conditional distributions.

Broadly speaking, the model has two steps:

(1) DM → galaxy properties: Model how basic physical properties of the galaxy (e.g. stellar mass) depend on properties of the host dark matter halo.

(2) Galaxy properties → observables: Model how observable properties (e.g. luminosities, sizes) depend on basic galaxy properties.

Conditional distributions: The literature is teeming with useful scaling relations for steps (1) and (2). The model promotes these scaling relations to *conditional probability distributions* (see *Fig. 1*).

Both the relations and the probability distributions are **parametrized**. The game is then to find values for the parameters that allow the model to reproduce as many properties of real galaxy populations as possible.

Fits to multi-band luminosity functions

In its current form, the model has 17 free parameters. They were calibrated using an MCMC fit to the following **optical and radio luminosity function data**, all at z ~ 0:

- GAMA *g,z*-band LFs (*Loveday+ 2012*)
- NVSS/6dfGS radio continuum LF (*Mauch & Sadler 2007*)

Successes: Fits the radio and *g,z* LFs well, and accurately predicts the *u,r,i* LFs (*Fig. 3*). Also predicts the stellar mass function of SDSS star-forming galaxies quite well.

Failures: Does not reproduce stellar mass function of passive galaxies, or optical colors (e.g. red sequence).

Future work will focus on improving reproduction of colors and adding additional radio properties.

Analytic model for optical magnitudes

Galaxies have complex optical spectra, with many emission and absorption features, and a non-trivial continuum shape. They are typically modeled using Stellar Population Synthesis (SPS) models.

SPS models are highly complex – they need to track the evolution of multiple stellar populations, and model radiative transfer in varied physical conditions. They are slow "black boxes".

Many large galaxy surveys only provide *broadband photometry*, so we can avoid having to model the spectra in detail. I was able to find a **simple, accurate fitting function** for *ugriz* magnitudes that depends only on stellar mass + SFR:

$$\overline{m}_\nu(\psi_{SFR}, M_\star) = -c_0^{(\nu)} + A_\star^{opt}\left(c_\star^{opt} + \left(\frac{M_\star}{10^9 M_\odot}\right)^{\beta_\star^{opt}}\right) + A_\times^{(\nu)}\left(\frac{M_\star}{10^9 M_\odot}\right)^{\beta_\times^{opt}} (\psi_{SFR})^{\gamma_\times^{opt}}.$$

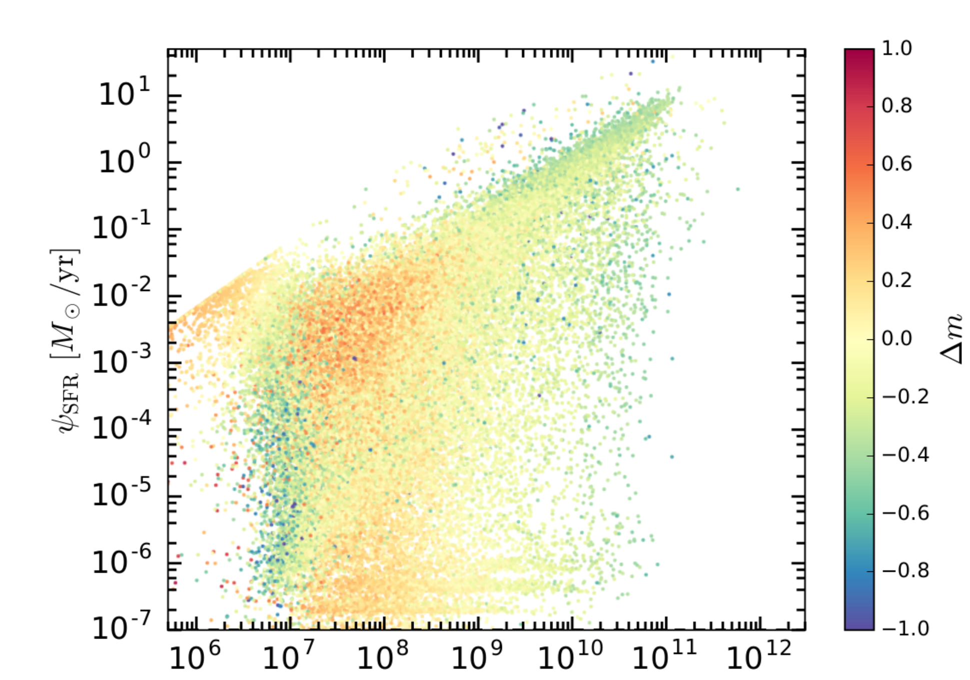

***Fig. 2:** Difference between the i-band magnitudes predicted by the Guo+ (2011) semi-analytics and my model, for a set of galaxies in the Millennium simulation. The residuals are small and have little structure.*

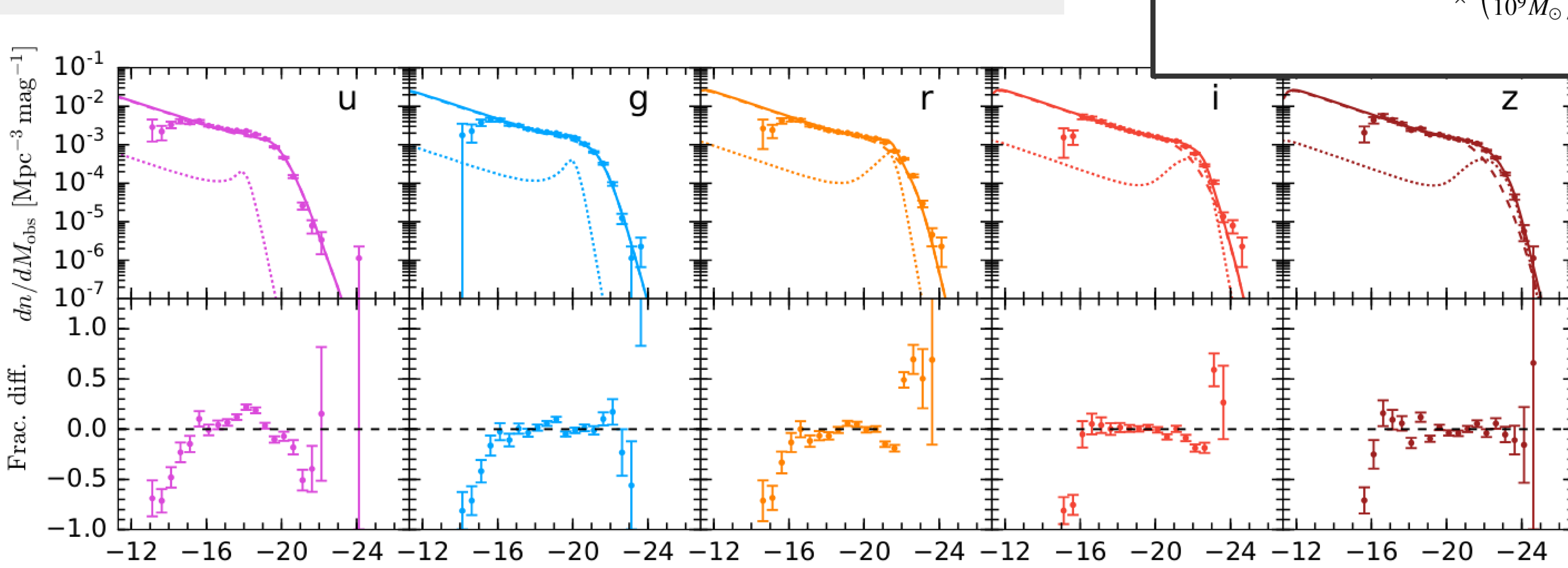

***Fig. 3:** Luminosity functions predicted by the best-fit model (solid lines) compared with the GAMA optical LFs at z ~ 0. Only the g,z bands (and radio data) were used in the fits; the u,r,i-band LFs are predictions.*

P. Bull (MNRAS accepted)
arXiv:1610.08948

Poster No. A-09

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Space Administration

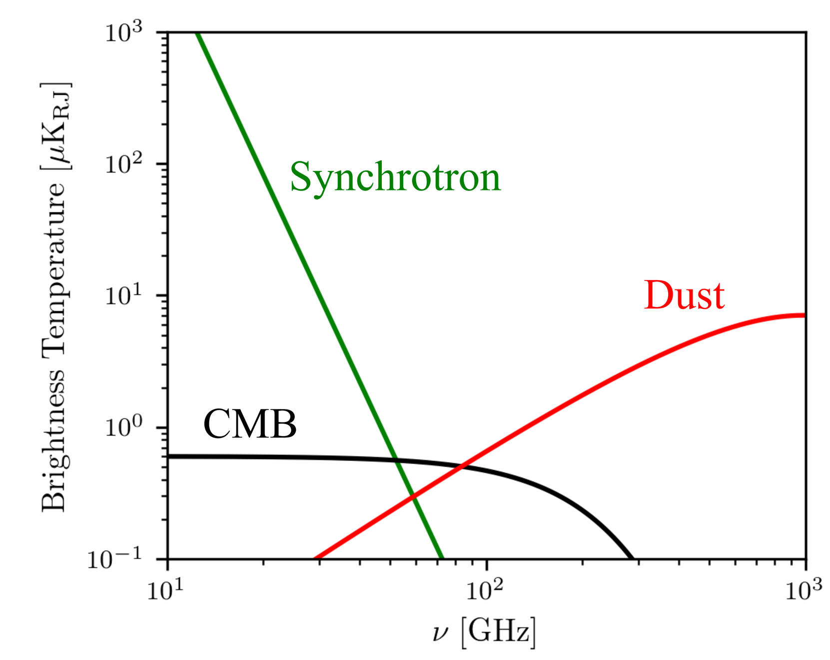
Mitigating Complex Dust Foregrounds in Future CMB Polarization Experiments

Brandon Hensley (3268) and Phil Bull (3268)
with Curt Cutler (3268), Sergi Hildebrandt (3268), Jeff Jewell (398L), and Graca Rocha (3268)

Introduction

- The polarization of the Cosmic Microwave Background directly probes physics of the early Universe, and may contain a signal imprinted by Gravitational Waves during the Inflationary Epoch
- Measuring the polarized CMB is difficult because our Galaxy produces polarized emission at the same frequencies via dust and synchrotron emission– need to *precisely* subtract out the Galaxy to get to the cosmological signal
- **Key Question**: What frequencies does a CMB experiment need to measure to best subtract the Galactic signal and make a high-fidelity measurement of the CMB?

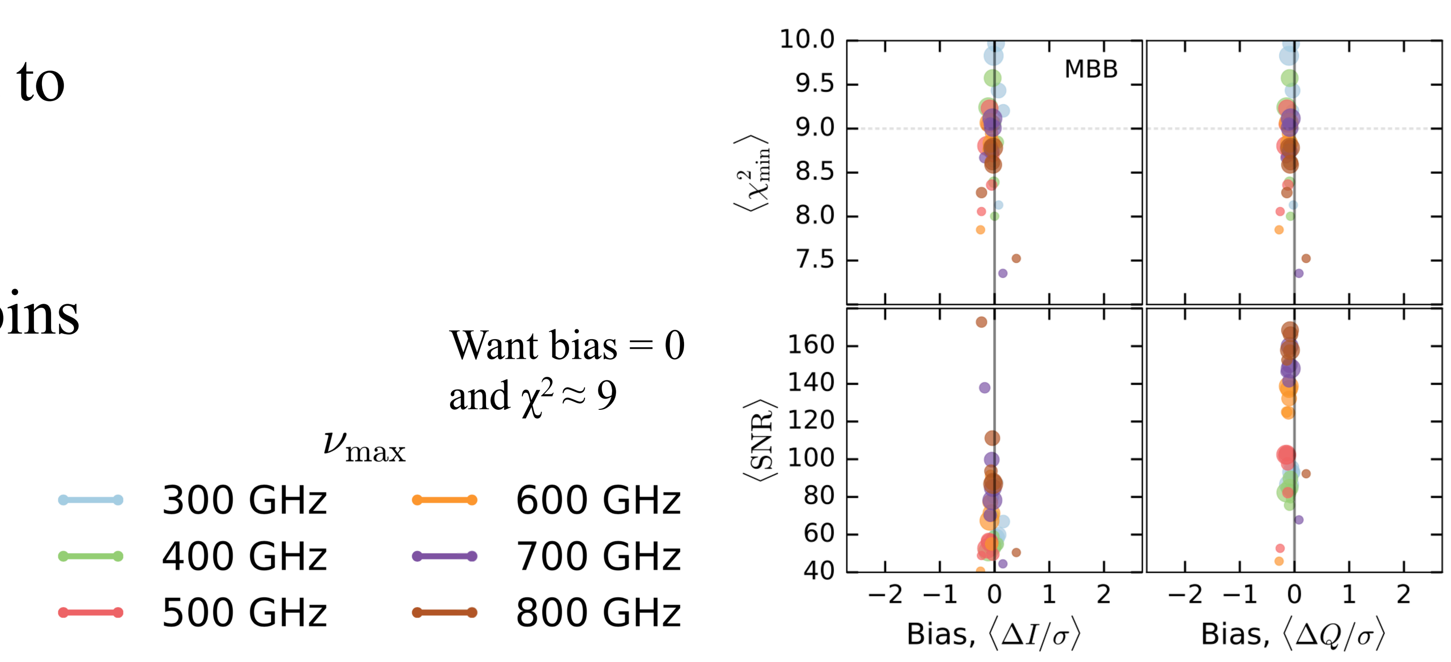
The Polarized Microwave Sky



Method

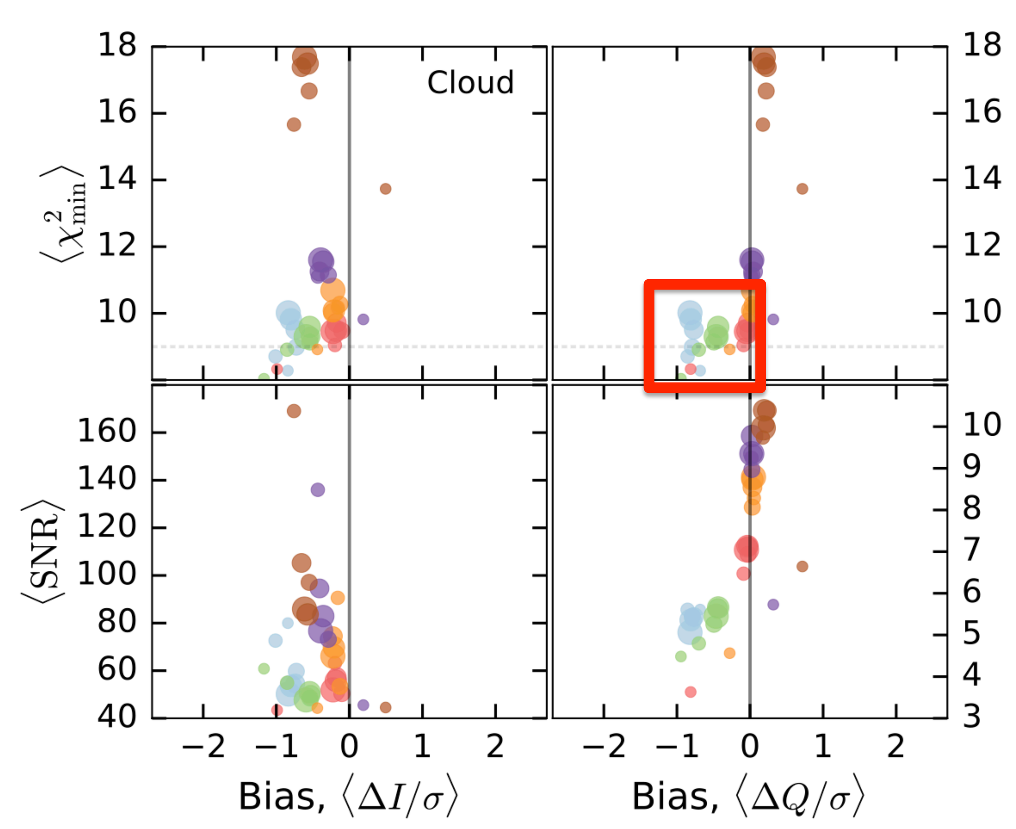
1. Work with one realization of all non-dust components in the microwave sky, set to representative spectra
2. Employ a suite of dust models encompassing a range of dust physics
3. Employ a suite of mock instruments measuring in seven log-spaced frequency bins
4. Add noise based on forecasts for next-generation CMB experiments (100 realizations)
5. Perform parametric component separation with standard dust models
6. Compute bias on fit CMB

Test Case: Model In = Model Out



Depolarization

Dust polarization changes along the line of sight, causing the **polarization angle** to rotate with frequency



Dust Complexities

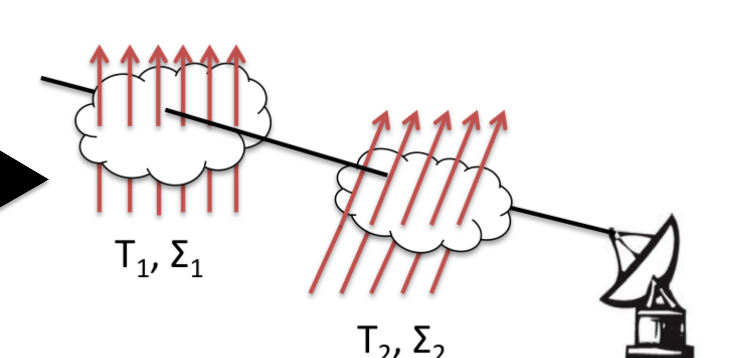
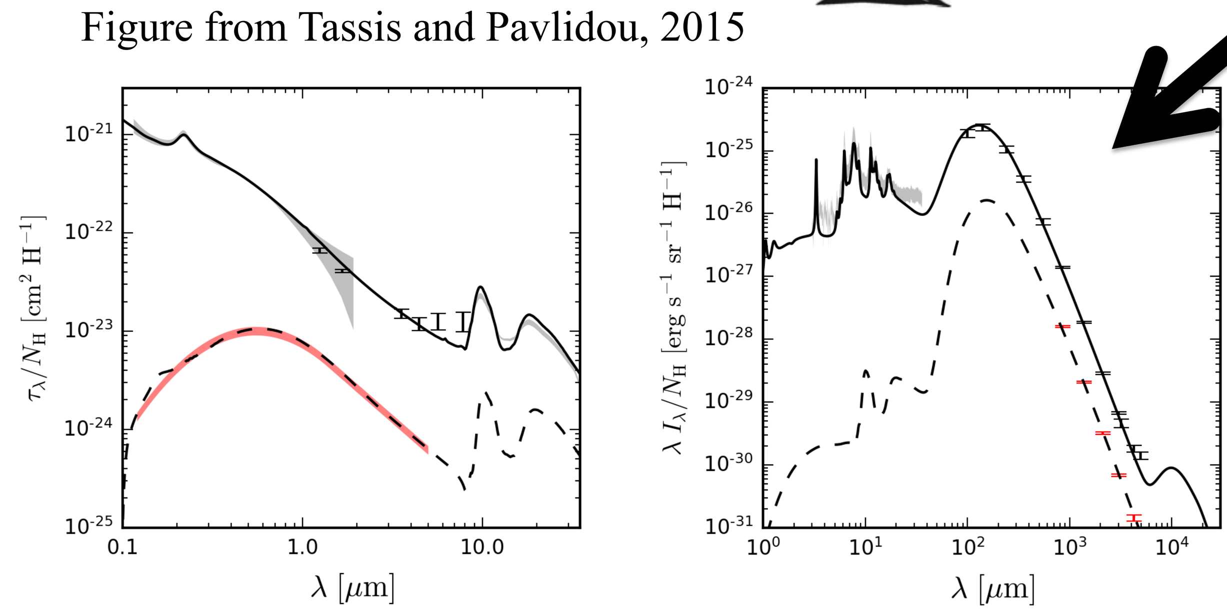


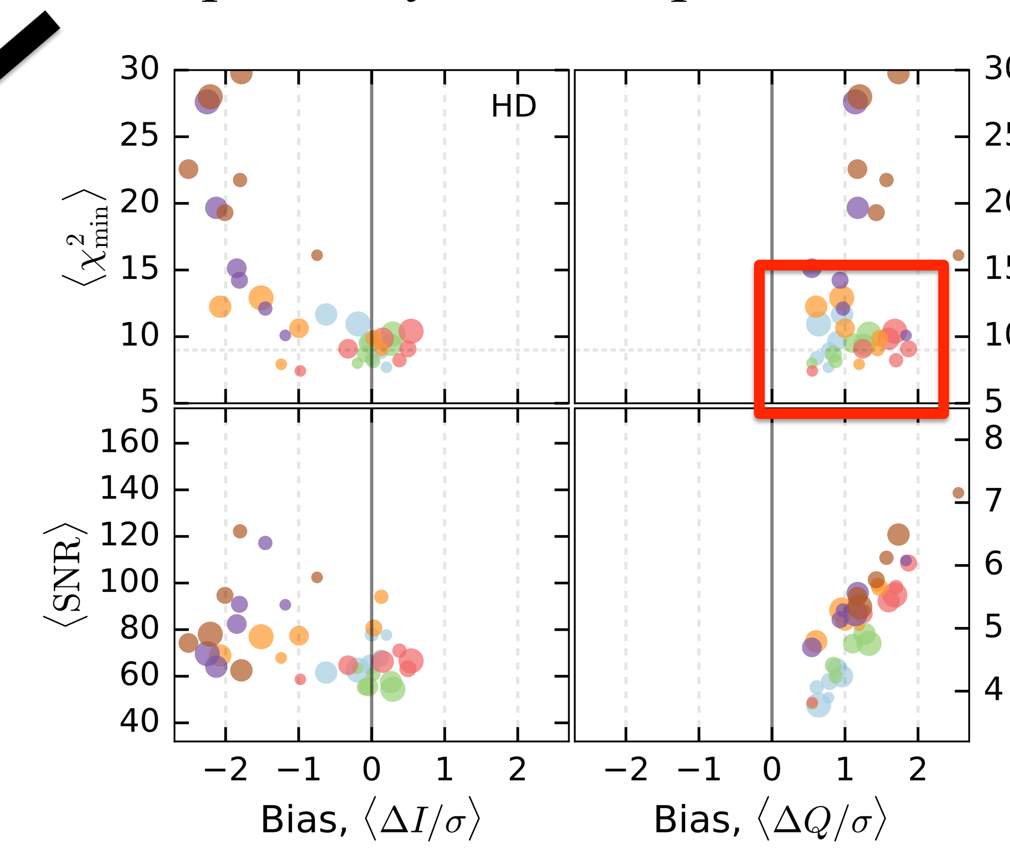
Figure from Tassis and Pavlidou, 2015



Dust model of Hensley and Draine, 2017, shown reproducing the observational constraints on dust extinction (left) and emission (right)

Physical Models

Physical models of dust grains based on **realistic** material properties that do not have simple analytic descriptions



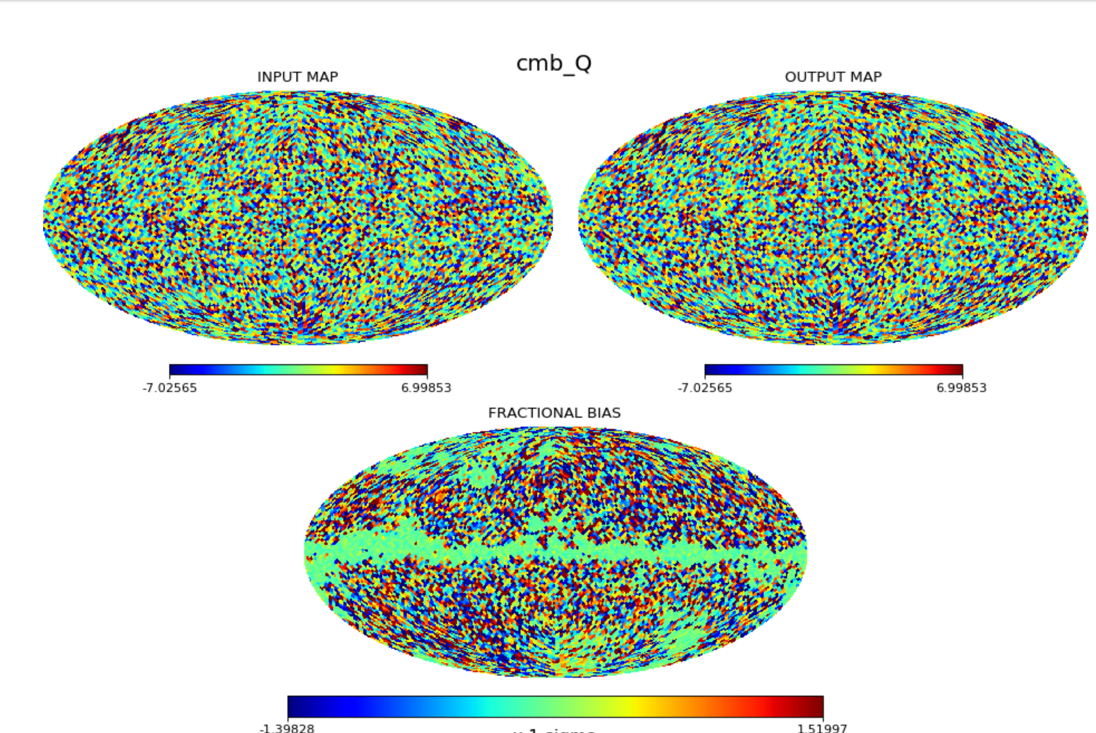
In both cases, experiment designs without high frequency bands can be **biased** but still have an acceptable model fit!

Conclusions

- High frequency data points (at least up to ~500 GHz) are critical for identifying bad model fits and biased results
- Depolarization effects and non-ideal dust spectra are both problematic at the noise levels of next generation experiments
- More work must be done on developing analysis techniques to deal with these complexities

Future Work

- Instead of employing a single realization of the microwave sky, work with maps and perform this analysis in each pixel independently
- Introduce instrument systematics



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Poster No. A-10

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Learning about the early universe from future cosmological surveys

Jérôme Gleyzes (3268)

With Roland de Putter (Caltech) and Olivier Doré (3268)

What do we know about the early universe?

Initial distribution of matter fluctuations δ is:

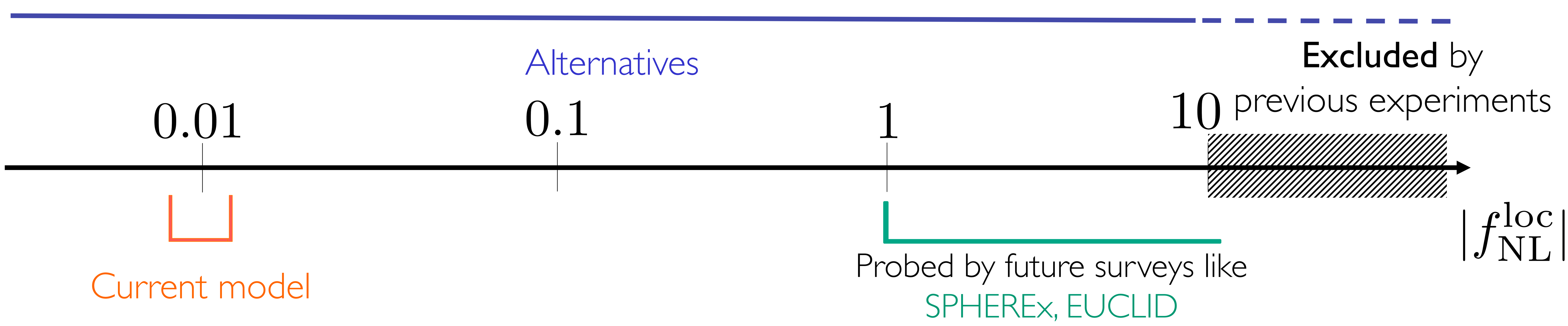
- **Scale independent**
- **Close to Gaussian**

Non Gaussianity parameter $f_{\rm NL} \sim \frac{\langle \delta^3 \rangle}{\langle \delta^2 \rangle^2}$

The simplest picture: Inflation

Period of accelerated expansion, cannot be caused by ordinary matter.
Many models can explain it.

Non Gaussianity can distinguish between models



A detection with $|f_{\rm NL}| \gtrsim 1$ would rule out our current model. What do we learn if $|f_{\rm NL}| \lesssim 1$?

Goal:

Quantify where the predictions from alternatives lie on the $|f_{\rm NL}|$ scale.

Results:

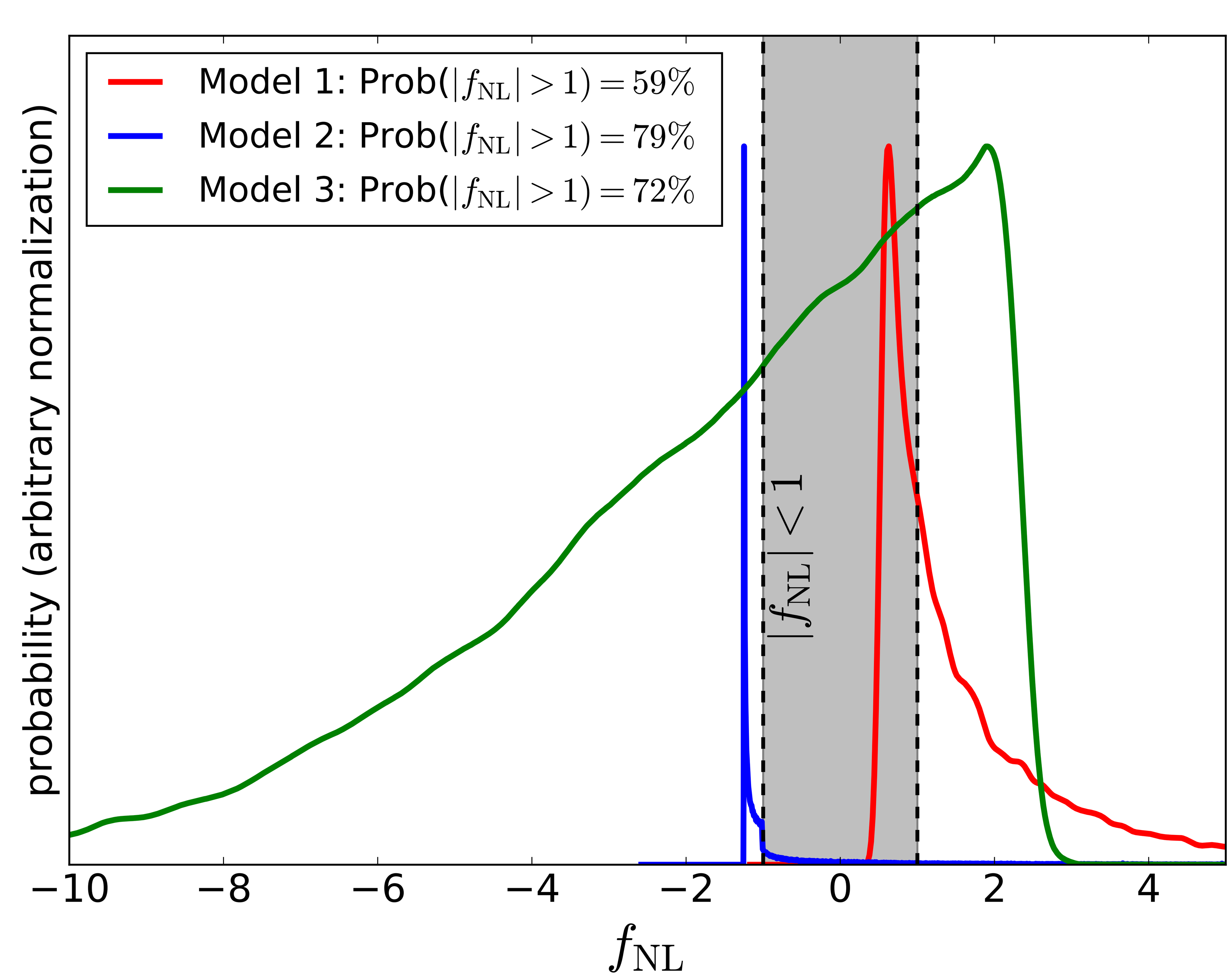
We considered 3 representative alternative models. For all of them, we found that more than 50% of the parameter space produced $|f_{\rm NL} > 1|$.

Conclusion:

The target $|f_{\rm NL}| = 1$ which should be reached by future experiments is well motivated form a theoretical point of view: broad classes of early universe models typically predict a non Gaussianity parameter of that order. It is thus a decisive tool for understanding the how our universe began.

Method:

Explore the parameter space of alternative models using Monte Carlo Markov Chains.



See Phys.Rev. D95 (2017) no.12, 123507 for more details.

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Poster No. A-11

National Aeronautics and Space Administration

A new map of dust reddening in the Milky Way

Author: Daniel Lenz (3268)
with: Brandon Hensley, Olivier Doré (3268)

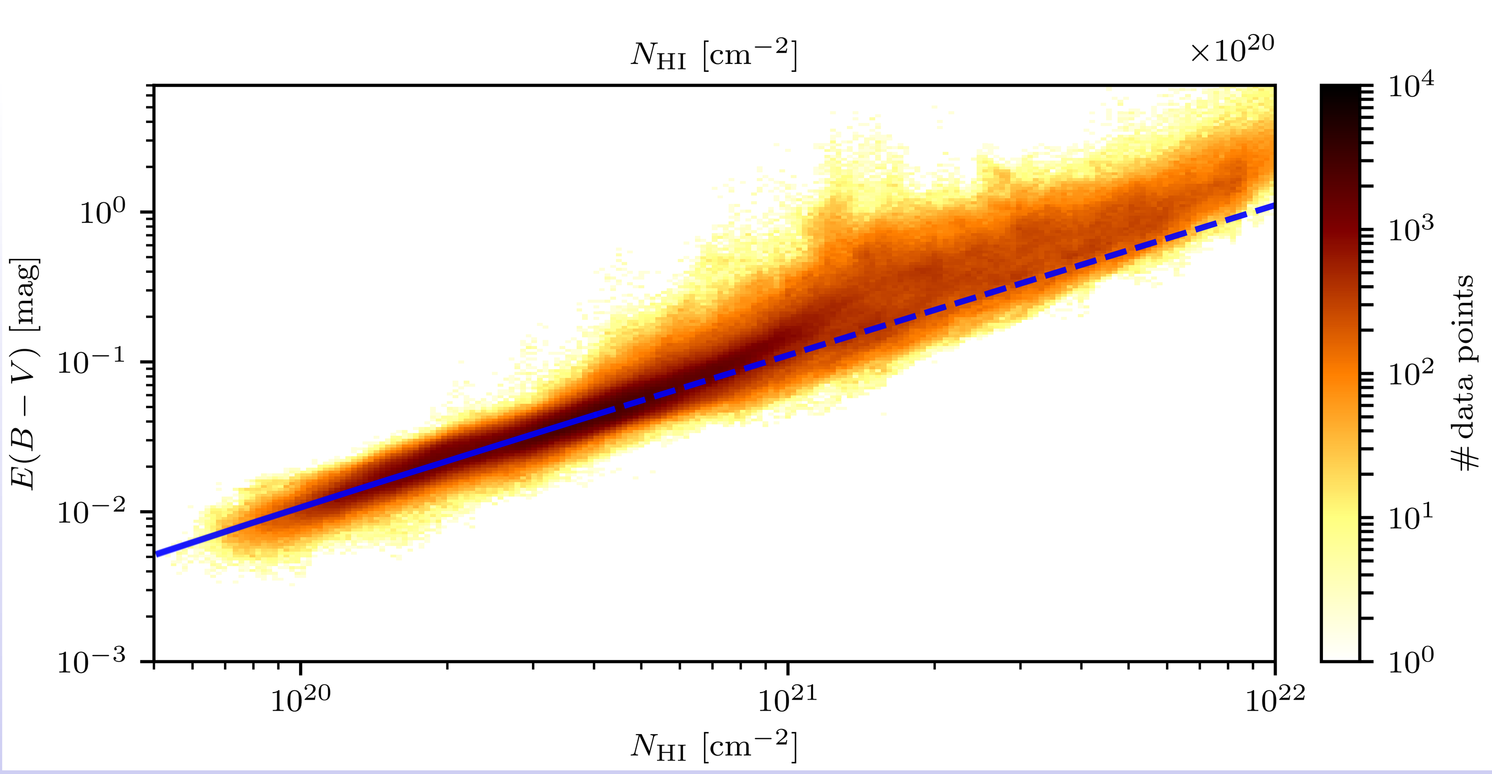
Context

- Photons scatter off of dust particles in the interstellar medium, leading to a net reddening
- Needs to be corrected for in extragalactic observations, future cosmology experiments rely on better maps
- Existing maps suffer from systematics, low sensitivity, or only partial sky coverage

Conclusions

- We use data of atomic neutral hydrogen (HI) to correct existing reddening estimates
- HI-based, large-scale reddening map, overcomes many of the systematics
- In agreement with completely independent corrections

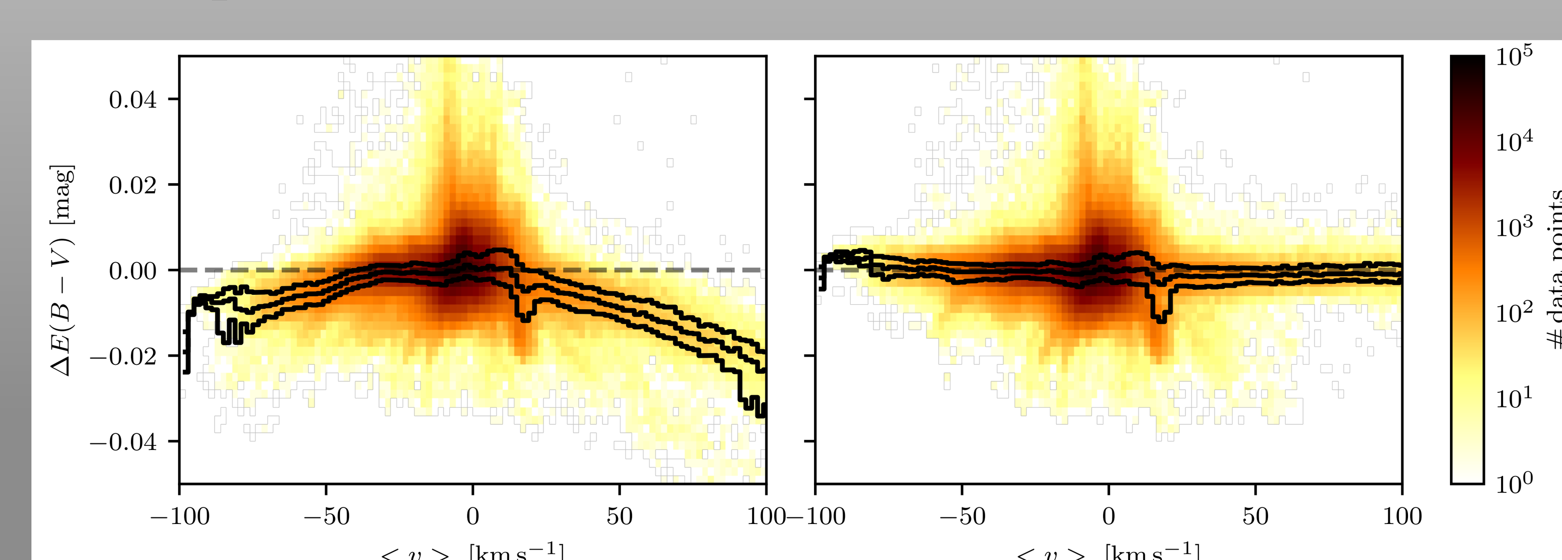
Motivation



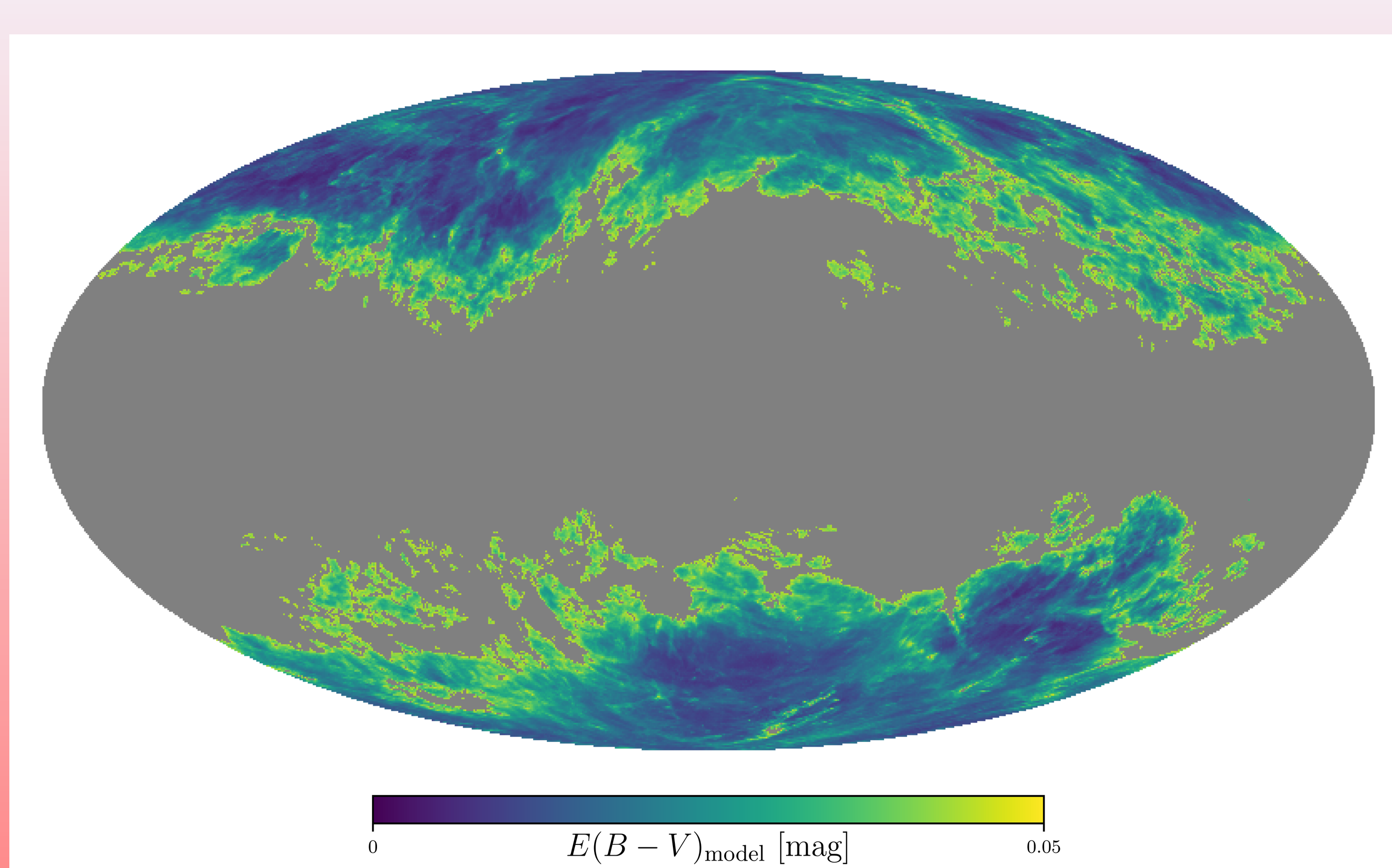
- Dust-based reddening estimates are biased by
  - Dust in the solar system
  - Dust from other galaxies
- HI is an excellent tracer of dust reddening E(B-V), does not suffer from these caveats

Methods

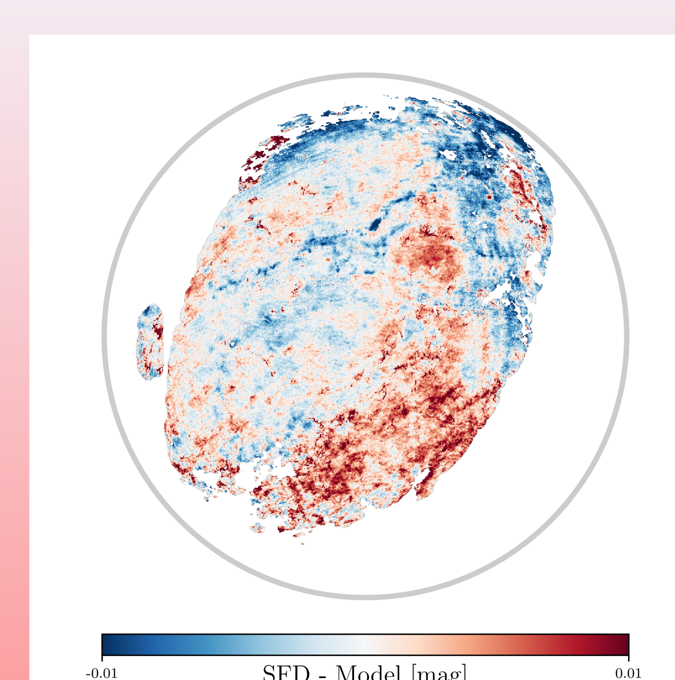
- HI data do not only cover the full sky, but also give us velocity information of the gas
- Our innovative model utilizes this additional dimension:
  - Left: Simple model using the full HI data
  - Right: Velocity filtering, overcomes issues from previous studies



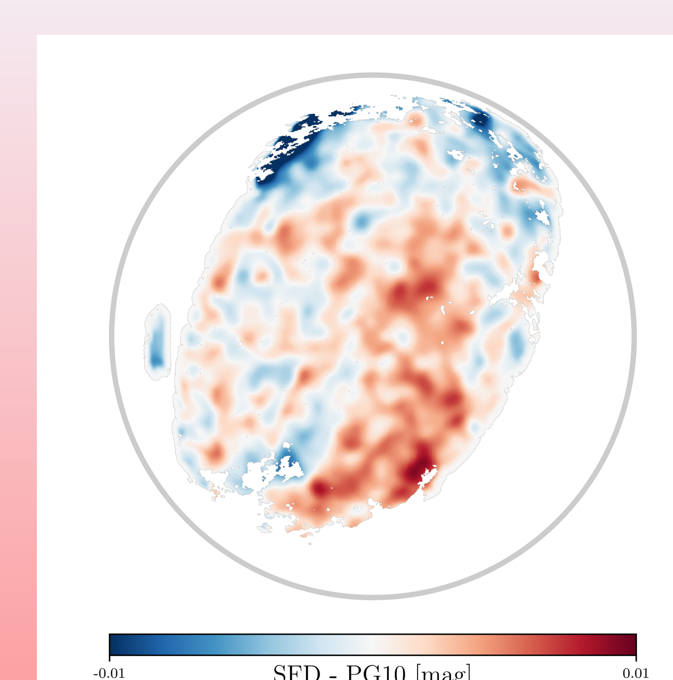
Results



New large-scale, HI-based reddening map



Our corrections, based on Galactic HI



Independent corrections, based on other galaxies

Our map agrees very well with completely orthogonal maps and is better in terms of sky coverage and resolution.

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Poster No. A-12

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Weak-Lensing Mass Measurement of ACTPol Sunyaev-Zel'dovich Galaxy Clusters with the Subaru Hyper Suprime-Cam Survey

Hironao Miyatake (3268)

Hyper Suprime-Cam Collaboration & Atacama Cosmology Telescope Collaboration

1. Introduction

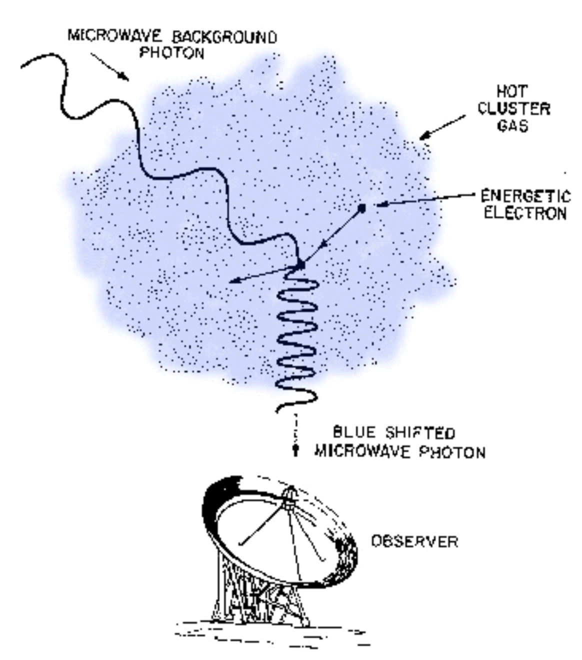
•The number density of galaxy clusters is sensitive to cosmological information, such as the nature of dark energy.

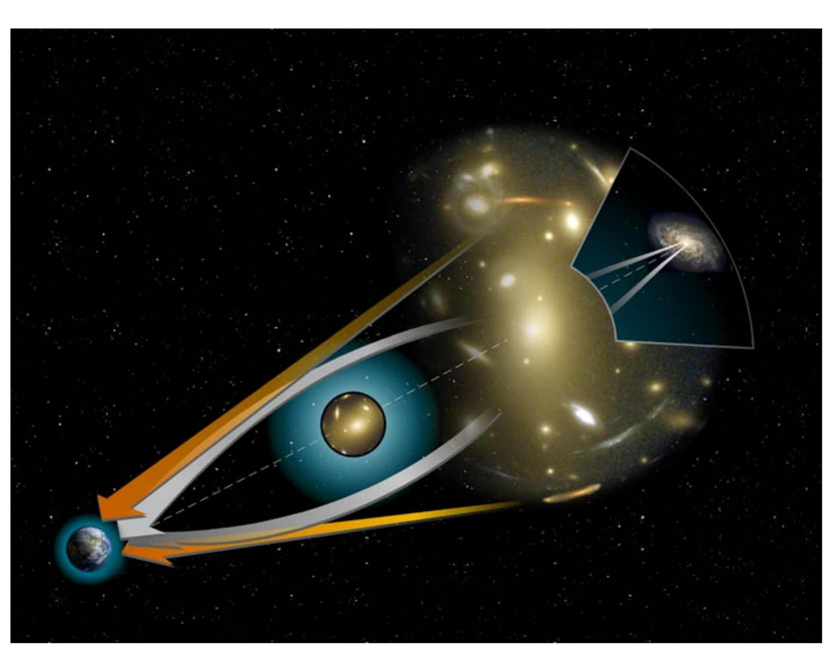
•The ***Sunyaev-Zel'dovich (SZ) effect***, a spectral distortion of cosmic microwave background (CMB) due to inverse Compton scattering between CMB photons and hot gas in galaxy clusters, is a powerful tool to detect galaxy clusters, since the SZ signal is independent of redshift.

•A cluster mass estimated from SZ signal is biased since the SZ signal is not sensitive to dark matter, which makes up about 80% of matter in the Universe, and one needs an assumption in cluster physics such as hydrostatic equilibrium. For example, Planck Collaboration reported a 2-sigma tension between CMB and SZ cluster constraints.

•***Weak gravitational lensing (WL)***, a coherent distortion of distant galaxy images due to foreground structures such as a galaxy cluster, enables to measure matter distribution around clusters including ordinary matter and dark matter, and thus provides unbiased cluster mass estimates.

•In the era of precision cosmology, it is of great importance to calibrate cluster mass by WL.





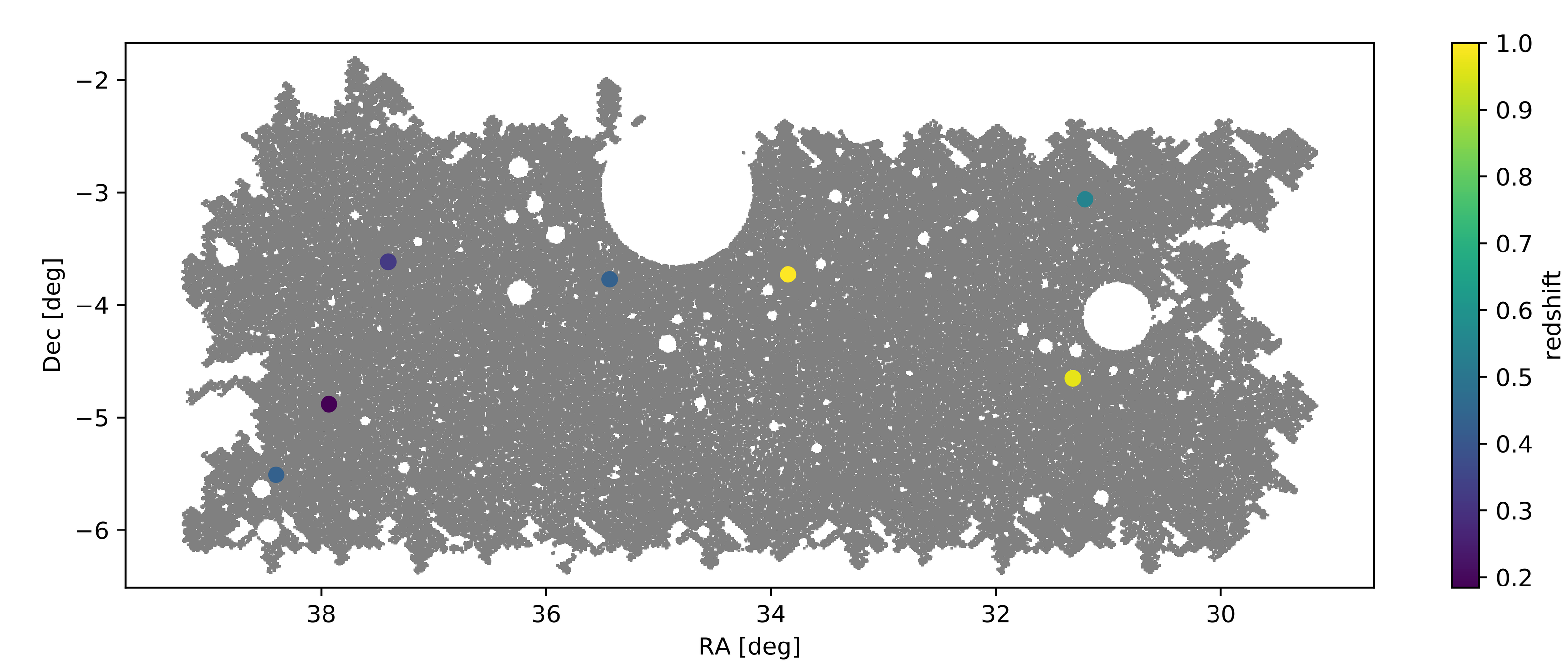
Schematics of the SZ effect (left) and weak gravitational lensing (right).

2. Data

•We use a proprietary SZ cluster catalog based on the season 2 data collected by the ***Atacama Cosmology Telescope Polarimeter (ACTPol) Survey.*** ACTPol is a high angular resolution, high sensitivity CMB telescope which enables to detect galaxy clusters down to M_{500c}~$2x10^{14}$ M_{*}. We use galaxy clusters whose signal-to-noise ratio is greater than 5.

•We use a proprietary galaxy shape catalog based on the first year data collected by the ***Subaru Hyper Suprime-Cam (HSC) Survey*** to measure WL signal around galaxy clusters. HSC is a newly-developed wide-field prime focus camera at Subaru Telescope. The tremendous light-gathering power and superb image quality (0.6" seeing) of Subaru HSC enable precise shape measurements of distant, faint galaxies.

•Within the overlapping region between ACTPol and HSC (30 deg^2), we find 8 galaxy clusters whose redshift range spans from z~0.2 to z~1.0.



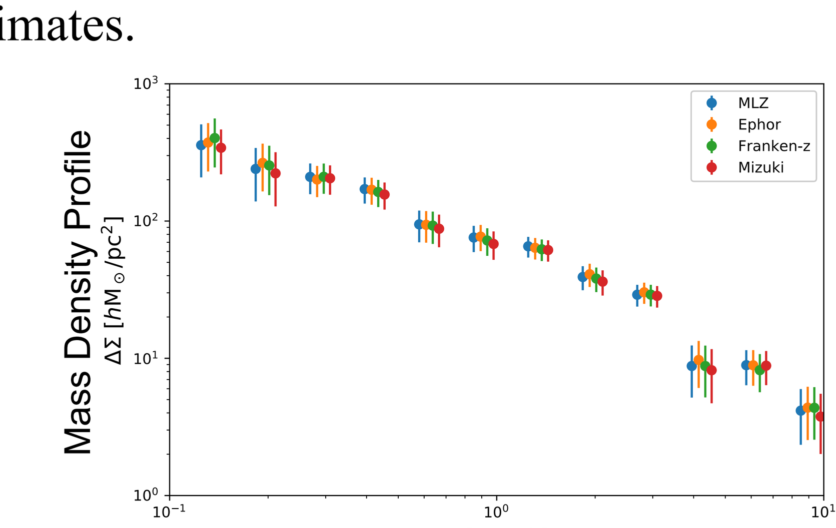
Colored points denote galaxy clusters detected through the SZ effect in the ACTPol data. Grey regions denote the area where galaxies used for WL measurements are observed by HSC.

3. Measurements

We investigate various systematic uncertainties in the stacked lensing signal, which includes the following tests.

1. Impact of photometric redshift estimates.

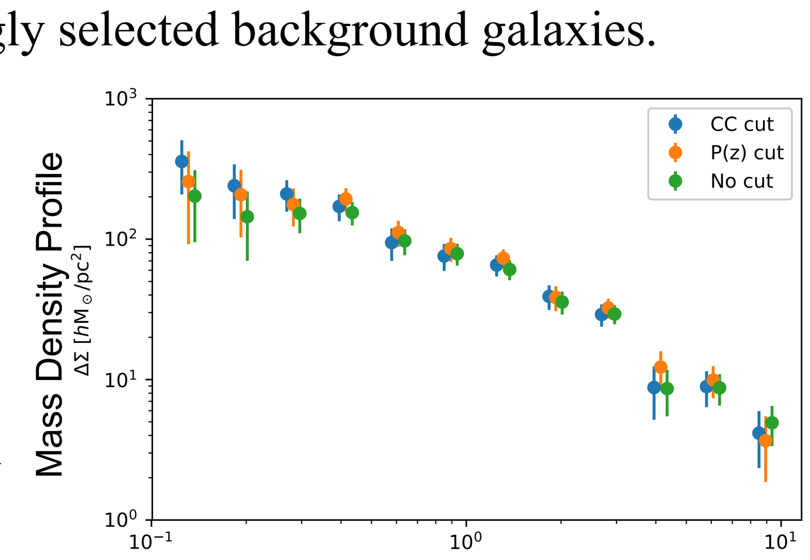
We compare WL signals computed with different photometric redshift estimates which are based on completely different approaches, such as template fitting and machine learning. The lensing signals are consistent within statistical uncertainties.



Projected Separation from Cluster Center

2. Dilution of WL signal due to wrongly selected background galaxies.

Selecting cluster member galaxies as lensed background galaxies causes dilution of WL signals at small scales. We test different selection methods; the one is based on galaxy colors (CC cut) and the other is based on probability density function (PDF) of photometric redshifts. The CC cut shows the smallest dilution.



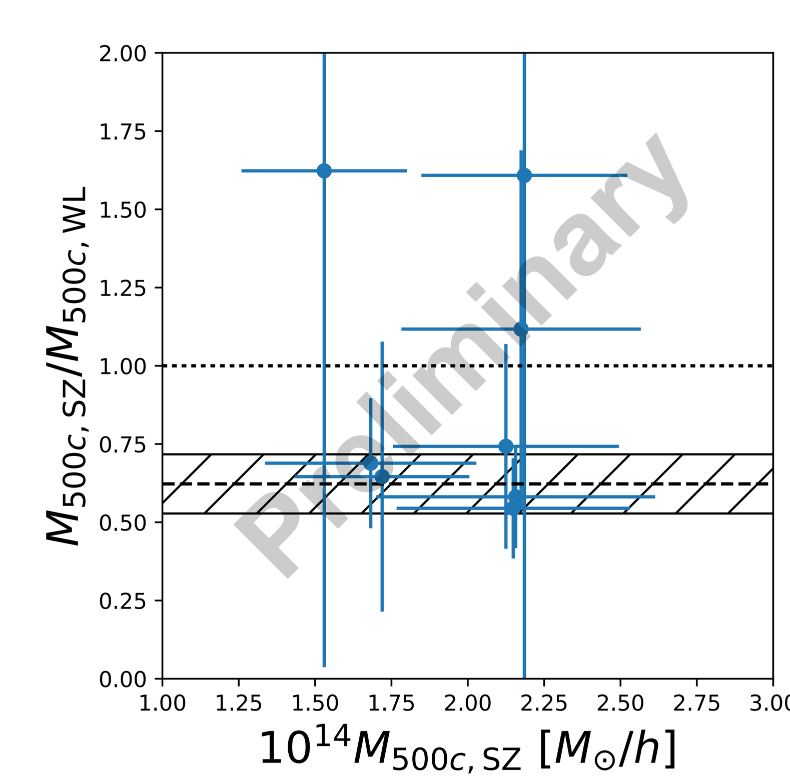
Projected Separation from Cluster Center

4. Results

We derive cluster masses by fitting a theoretically standard profile (NFW profile) to individual cluster lensing signals. The average ratio between WL mass and SZ mass is

$$1 - b = 0.62 \pm 0.09$$

. This calibration could reconcile the cosmological constraints from the number density of clusters with that from the Planck CMB measurement.



5. Summary

- Having accurate cluster masses by WL measurement is essential to place precise cosmological constraints based on the number density of galaxy clusters
- Using the galaxy shape catalog of the Subaru HSC Survey, we have measured the WL signal around galaxy clusters detected through the SZ effect observed by the ACTPol Survey.
- We have constrained difference between WL mass and SZ mass.

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Poster No. A-13

National Aeronautics and Space Administration

Predicting the number density of Hα-emitting galaxies

Author: Alexander Merson (3268)

Yun Wang (Caltech/IPAC), Andrew Benson (Carnegie), Andreas Faisst (Caltech/IPAC), Daniel Masters (Caltech/IPAC), Alina Kiessling (3266), Jason Rhodes (3200)

Hα is a spectral line, with wavelength 656.3nm, emitted when a hydrogen electron falls from the n=3 to n=2 energy level. Star-forming galaxies typically have strong Hα emission.

Context

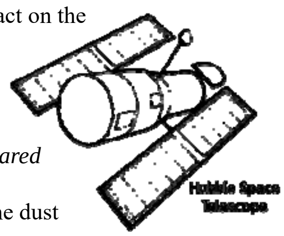
- The ESA/NASA Euclid and NASA Wide Field Infrared Survey Telescope (WFIRST) missions aim to understand what is driving the accelerated expansion of the Universe.
- They will do this by making precise measurements of various *cosmological probes*, including measuring the clustering of Hα-emitting galaxies embedded in the cosmic large-scale structure (see Figure 1).
- The clustering of galaxies and growth of cosmic structure is sensitive to the expansion history of the Universe, which itself depends on fundamental cosmological physics.
- Existing estimates of the number density of Hα-emitting galaxies have a large scatter (between 20%-50%).
- **Knowledge of the number density of Hα-emitting galaxies is crucial for optimizing the observing strategies of these missions.**

Objective

We apply the galaxy formation model '*Galacticus*' (Benson 2012) to a cosmological simulation of the Universe in order to make predictions for how many Hα-emitting galaxies we expect to see with Euclid and WFIRST.

Methodology

- Galacticus is a galaxy formation model that describes the astrophysical processes that govern galaxy formation.
- Dimming of light by interstellar dust has a big impact on the observed galaxy counts. We implemented three different methods for modelling dust attenuation within Galacticus.
- To calibrate the Galacticus model we compare the predictions to observed counts from the *WFC3 Infrared Spectroscopic Parallels* (WISP) survey using χ^2 minimization to identify optimum parameters for the dust attenuation methods.
- WISP is an existing small area survey of Hα-emitting galaxies carried out with the Wide Field Camera 3 on the Hubble Space Telescope.



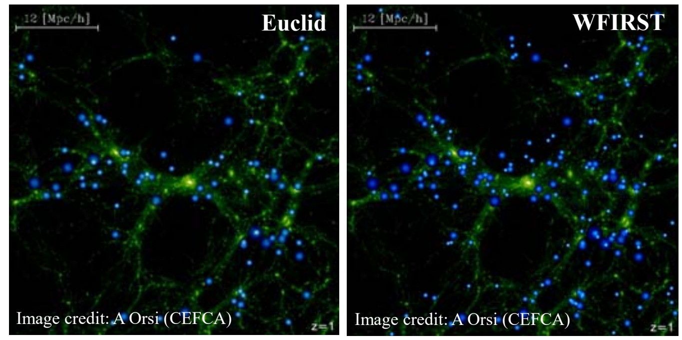


Figure 1: Simulated Hα-emitting galaxies (blue) embedded in the cosmic large-scale structure (green). Thanks to a fainter flux limit, WFIRST is expected to see more galaxies, but over a smaller area of the sky, compared to Euclid.

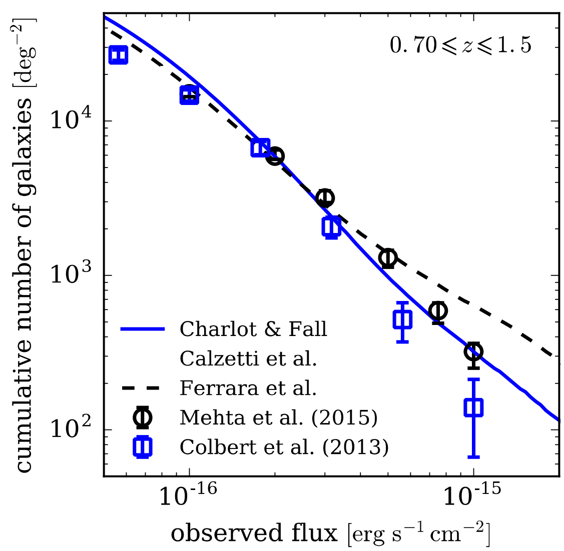


Figure 2: Number counts of Hα-emitting galaxies as observed by WISP (data points) and as predicted by Galacticus model when using three models for attenuation by interstellar dust (Ferarra et al. 1999; Calzetti et al. 2000; Charlot & Fall 2000).

Table 1: Predicted number densities (in $\deg^{-2}$) from Galacticus for a simulated Euclid-like and a simulated WFIRST-like mission. Number densities are shown for the three different dust methods used in Galacticus.

Flux limit (erg s^{-1} cm^{-2})	Ferrara et al.	Calzetti et al.	Charlot & Fall
Euclid			
2 x 10^{-16}	4036 ± 62	4849 ± 192	3884 ± 252
WFIRST			
1 x 10^{-16}	10403 ± 141	15176 ± 528	12195 ± 987

Summary & Conclusions

- With Galacticus, including our dust models, we are able to reproduce, for the first time, the number counts of Hα-emitting galaxies from WISP (see Figure 2).
- We can also predict the number density of Hα-emitting galaxies that we expect to observe with Euclid or WFIRST (see Table 1).

Benefit To JPL

- State-of-the-art models such as Galacticus are highly valuable tools that allow JPL to provide crucial predictions that are highly desirable and key requirements for the Euclid and WFIRST collaborations.
- With such predictions JPL is making a vital contribution to future cosmology missions, enabling us to have an enormous influence on the observational strategy and implementation of such missions.

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Poster No. A-14

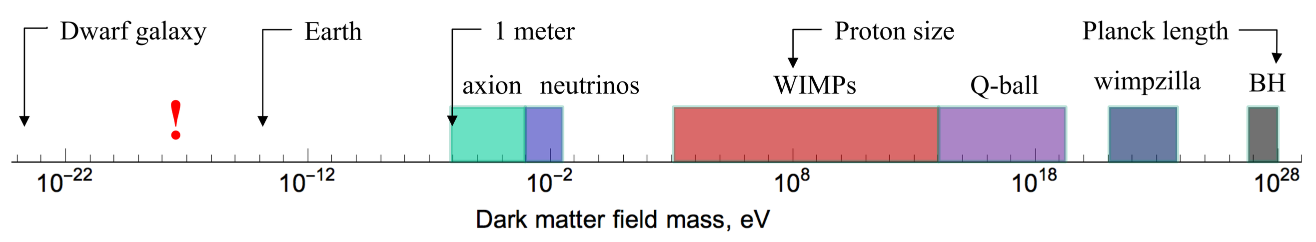
National Aeronautics and Space Administration

Searching for dark matter with atomic clocks in space

Author: Tigran Kalaydzhyan (332J)
Supervisor: Nan Yu (332J)

Introduction

- No direct detection of the dark matter to date, while having an overwhelming amount of indirect observations. Importance: 27% of energy content of the Universe, 85% of the mass content.
- Vast range of unexplored masses (about 80%) of the total span 10^{-24} eV - 10^{28} eV. WIMPs are typically tested above GeV and axions above μeV scale.
- Light bosons predicted by nearly every new theory beyond the Standard Model.
- Specifically for the clock stability studies: able to show high-frequency signals and make easier to identify different types of noise.



Theory

We consider an ultralight scalar field with the interaction Lagrangian:

$$\mathcal{L}_{int}^{(n)} = \phi^n \left[\frac{1}{4e^2\Lambda^n_{\gamma,n}} F_{\mu\nu}F^{\mu\nu} - \frac{\beta_{YM}}{2g_{YM}\Lambda^n_{g,n}} G_{\mu\nu}G^{\mu\nu} - \sum_{f=e,u,d} \left(\frac{1}{\Lambda^n_{f,n}} + \frac{\gamma_{m_f}}{\Lambda^n_{g,n}} \right) m_f \bar{\psi}_f \psi_f \right]$$

Presence of dark matter can induce a change in the fundamental constants:

$$\frac{\delta\alpha}{\alpha} = \left(\frac{\phi}{\Lambda_{\gamma,n}}\right)^n, \quad \frac{\delta m_f}{m_f} = \left(\frac{\phi}{\Lambda_{f,n}}\right)^n, \quad \frac{\delta\Lambda_{QCD}}{\Lambda_{QCD}} = \left(\frac{\phi}{\Lambda_{g,n}}\right)^n,$$

Clock response is due to the change in the atomic transition frequency:

$$\nu = \text{const} \cdot R_\infty \cdot \alpha^{K_\alpha} \left(\frac{m_q}{\Lambda_{QCD}}\right)^{K_{q\Lambda}} \left(\frac{m_e}{\Lambda_{QCD}}\right)^{K_{e\Lambda}}$$

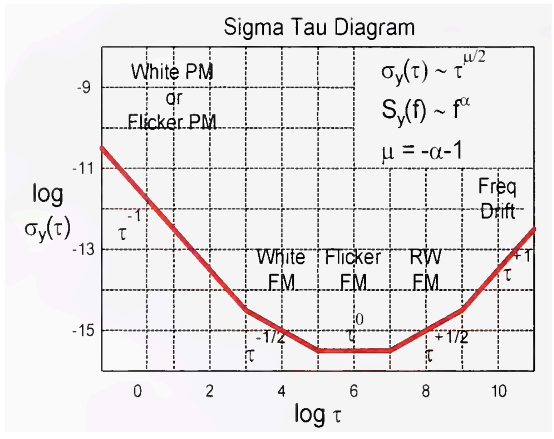
Average fractional frequency deviation:

$$\bar{y}(t) = \frac{1}{\tau} \int_{t-\tau}^{t} y(t')\, dt'$$

Allan variance (continuous version):

$$\sigma^2_y(\tau) = \frac{1}{2} \lim_{T\to\infty} \frac{1}{T} \int_0^T [\bar{y}(t+\tau) - \bar{y}(t)]^2\, dt$$

Regime of our interest: $\sigma_y(\tau) = \sigma_0/\sqrt{\tau}$



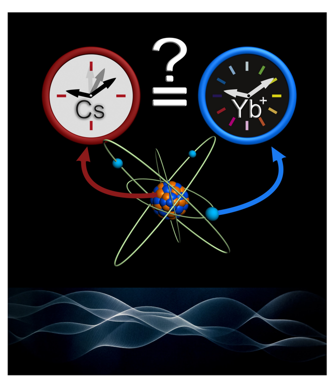
W.J. Riley's Handbook

Species	^{133}Cs	^{199}Hg$^+$	^{199}Hg	^{27}Al$^+$	^{87}Sr	^{162}Dy	^{164}Dy	^{229}Th
States	hyperfine	$5d^9 6s^2\,^2D_{5/2}$	$6s6p\,^3P_0$	$3s3p\,^3P_0$	$5s5p\,^3P_0$	$4f^9 5d^2 6s$	$4f^{10} 5d6s$	nuclear
	hyperfine	$5d^{10} 6s\,^2S_{1/2}$	$6s^2\,^1S_0$	$3s^2\,^1S_0$	$5s^2\,^1S_0$	$4f^{10} 5d6s$	$4f^9 5d^2 6s$	nuclear
K_α	2.83	-3.19	0.81	0.008	0.06	8.5×10^6	-2.6×10^6	10^4(?)
$\sigma_0(10^{-16}\text{Hz}^{-1/2})$	10^3	28	1.8	28	3.1	4×10^7	1×10^8	10(?)

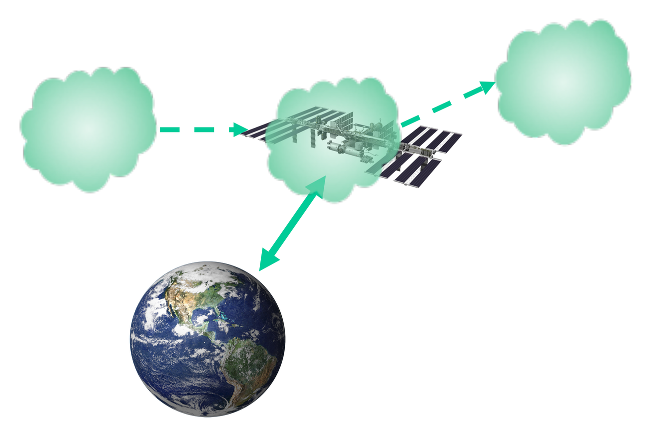
Method

Compare two clocks of different type or spatially separated. Investigate the two dark matter configurations: dark matter waves or clumps (e.g., topological defects: monopoles and strings).

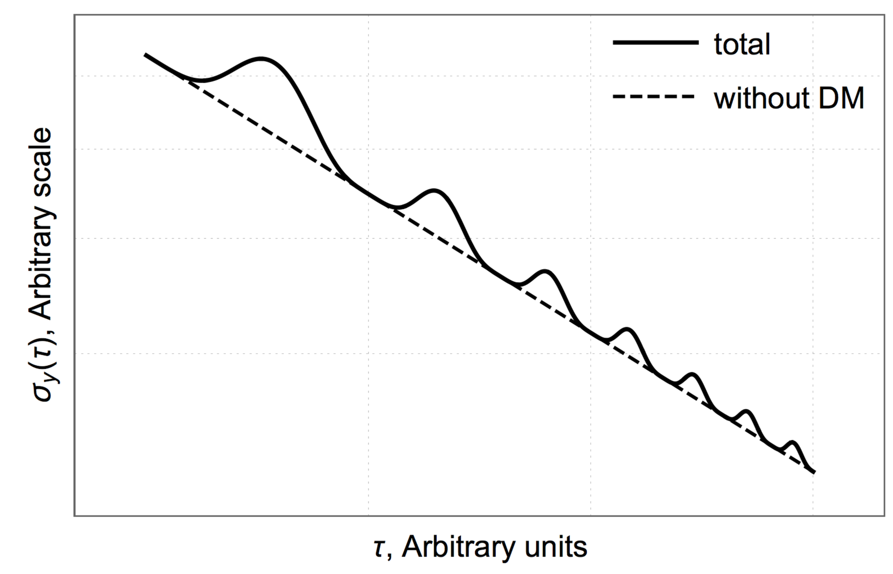
1. Waves with frequency $f = m_\phi/(2\pi)$

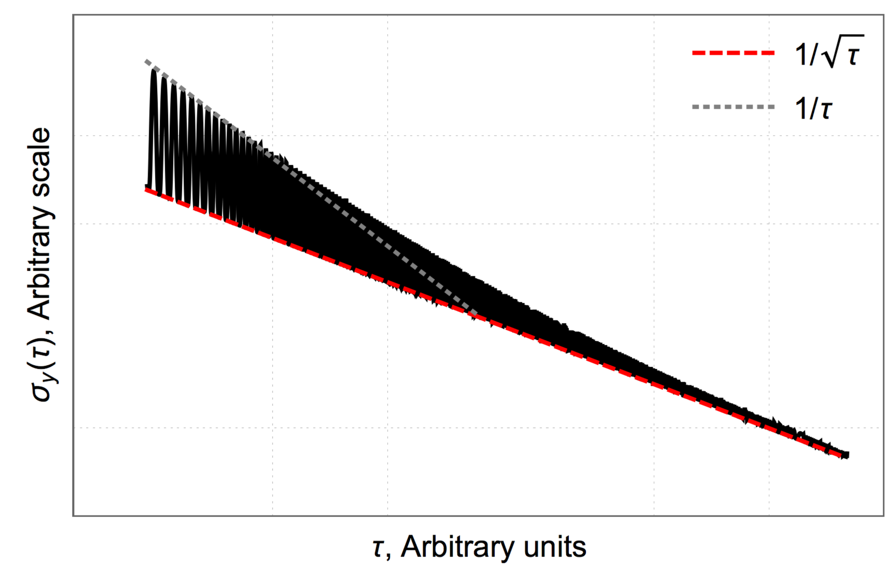


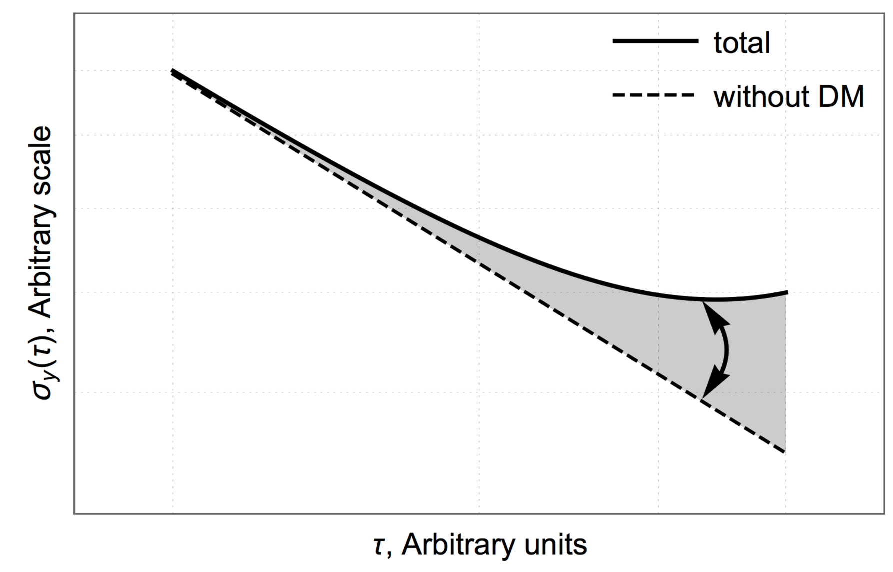
2. Clumps of dark matter of size $d \sim \hbar/(m_\phi c)$

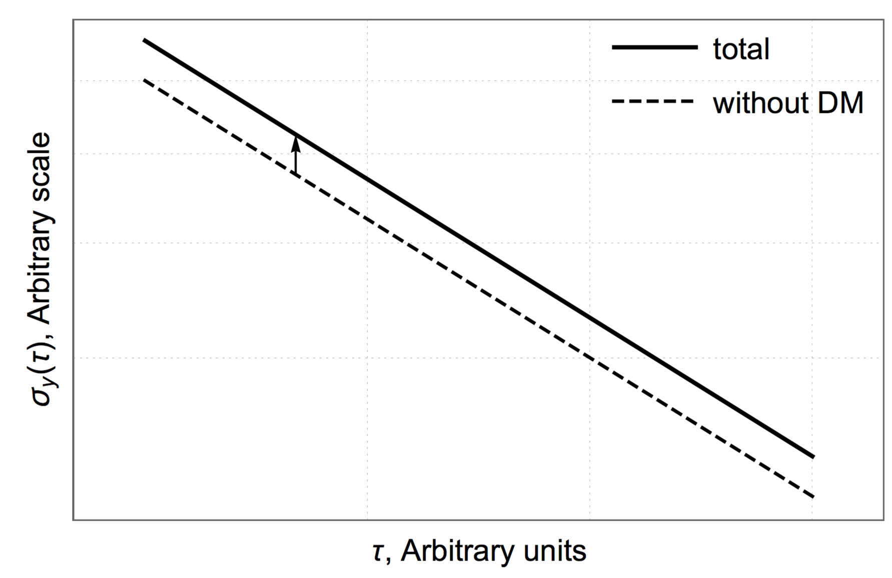


Anomalies in the clock stability diagrams



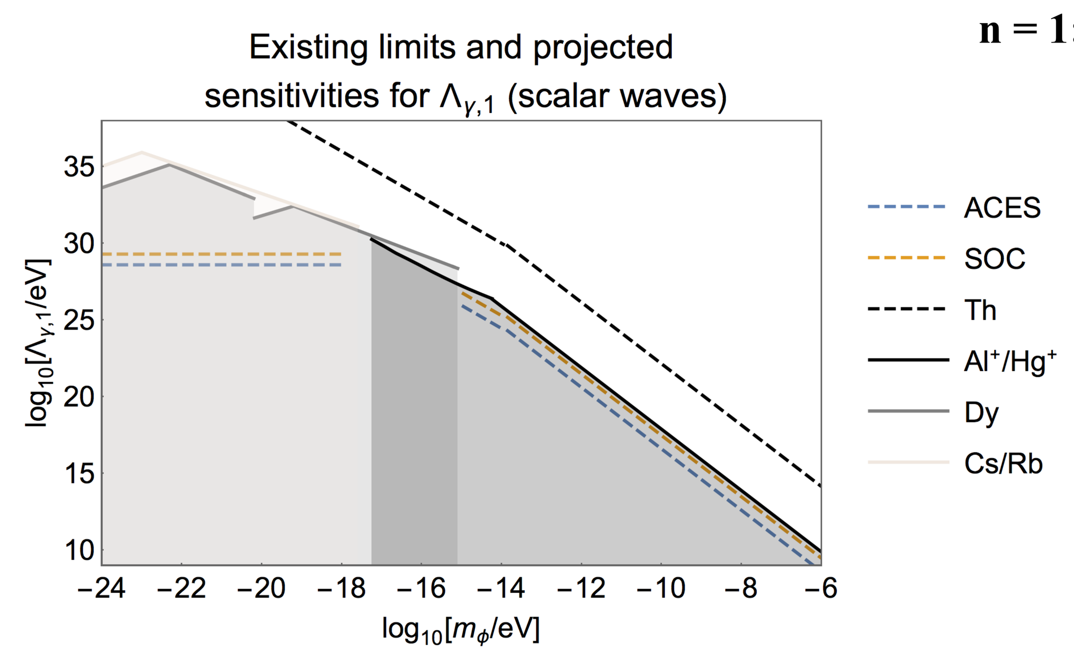


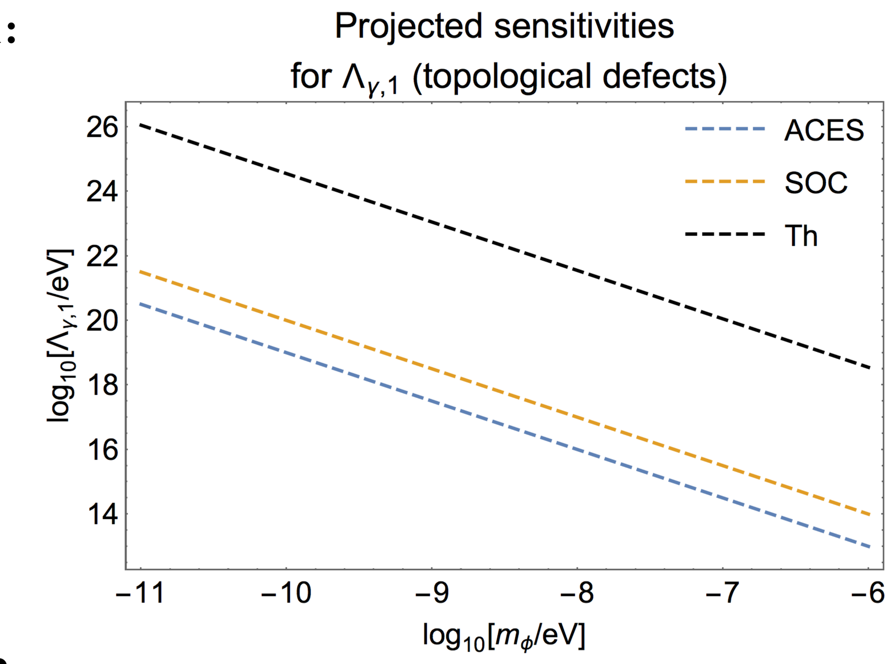




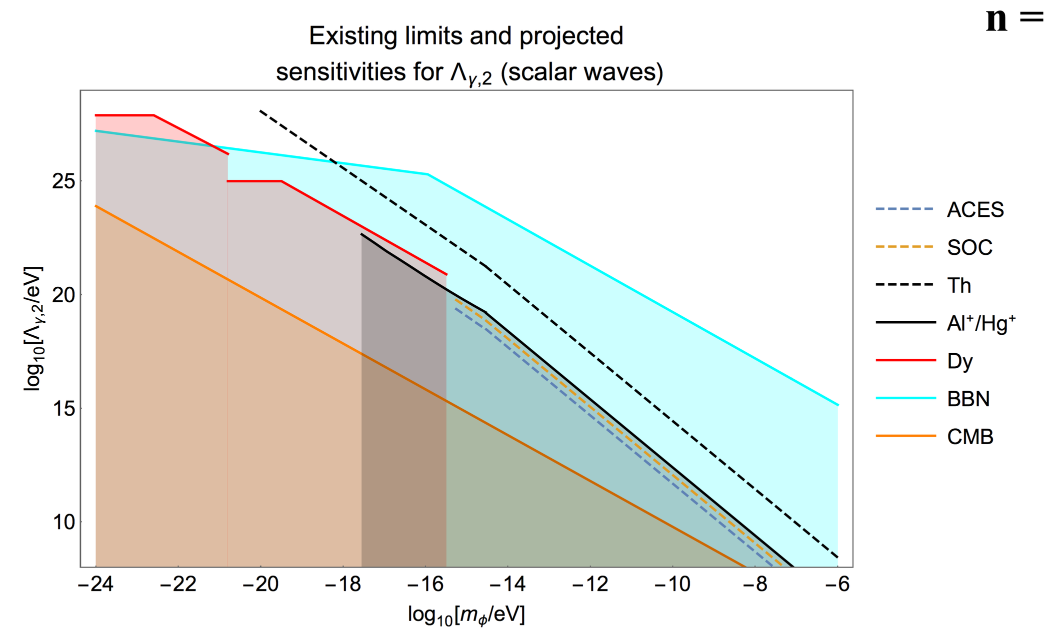
Results

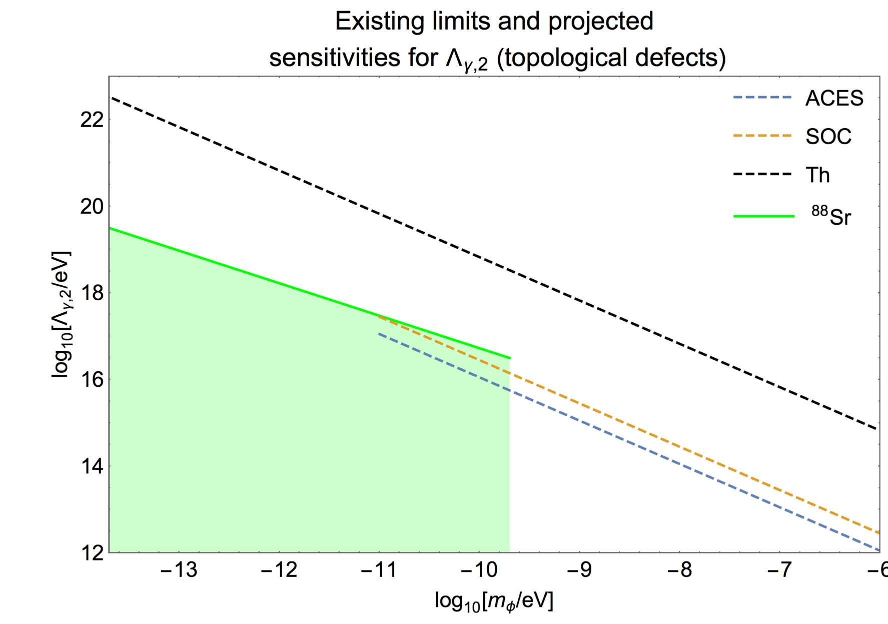
n = 1:





n = 2:





Conclusions

- Comparison of ultra-stable atomic clocks provides an opportunity for direct tests of light dark matter. Such comparison can be done in the nearest future, involving JPL.
- Clock stability analysis can be used as a tool and opens access to a new region of parameter space for the DM masses and couplings.
- We demonstrate the feasibility of our method by using existing data for Hg$^+$/Al$^+$ comparison to put new limits on the DM coupling in the DM wave background.
- As the next step, networks of atomic sensors can be used for the search of the stochastic backgrounds of new fields, including the dark matter.

For more information, see the preprint: arXiv:1705.05833

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Poster No. A-15

Poster No: A-16

Next Generation Methodologies to Advance Space Weather Monitoring and Predictability: A New Perspective through Network Analysis

McGranaghan et al. [2017]

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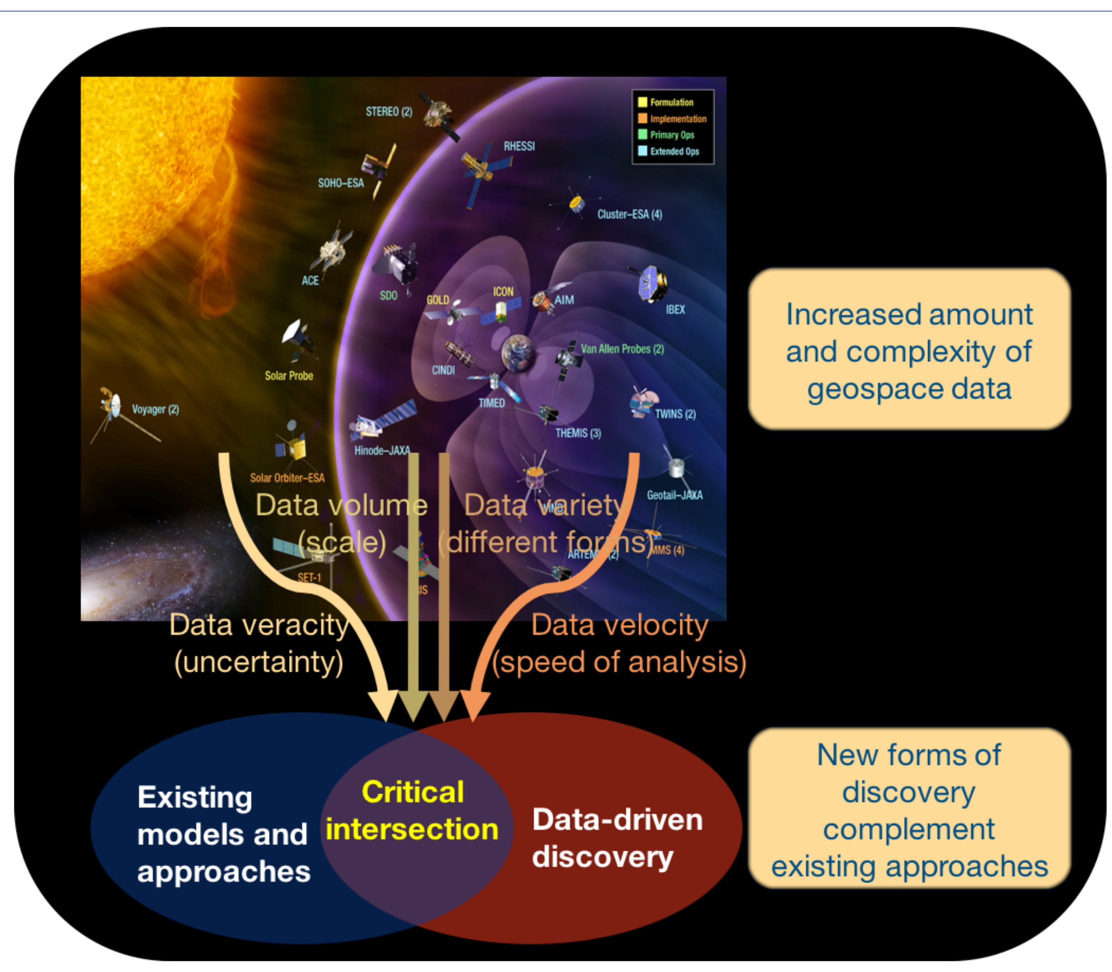
Key Findings

Hypothesis: Network analysis is an **innovative** and promising approach to navigate the new landscape in space sciences at intersection of Heliophysics and data science

- **First ever** complex network theory based analysis of high-latitude total electron content (TEC) obtained from Global Navigation Satellite System (GNSS) signals
- Network analysis reveals significant structure in TEC correlation patterns and we **discover** that important characteristic scale sizes in TEC data vary across season and hemisphere
- New knowledge illustrates importance of **innovation at the intersection of disciplines** to the future of space science research

Motivation: A New Heliophysics Landscape



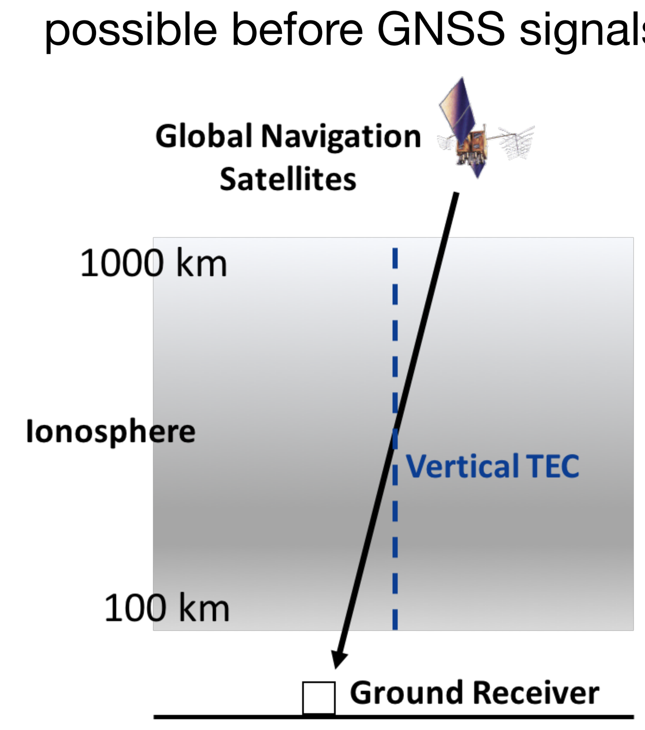
Data-driven discovery is critical to the '**New landscape**' in Heliophysics:

- Complements existing approaches
- Reveals relationships among diverse data sets
- Increases utility of observational system

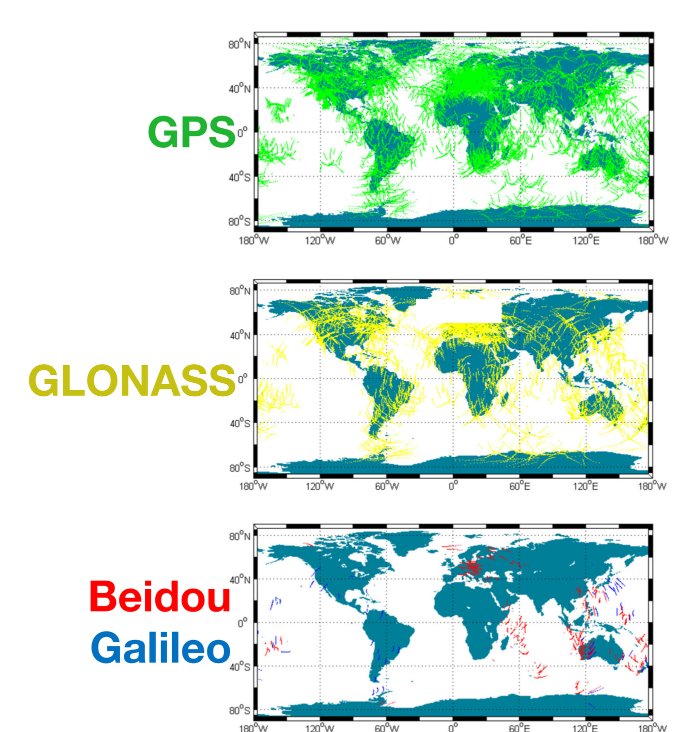
Societal Relevance and Significance to JPL

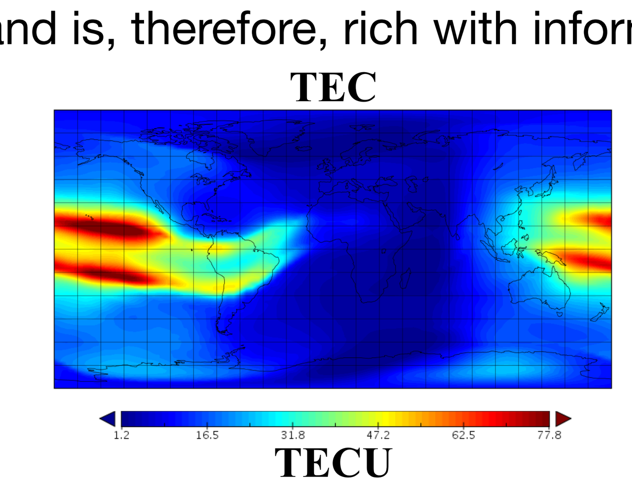
1. Innovation leads to new discovery in solar-terrestrial connection, and **improved space weather prediction**
2. Represents an **exciting new domain to extend the JPL strategic plan for applying data science** across the institution
   - We **introduce a new use case** for a critical Heliophysics data set: Total electron content (TEC)
3. Opportunity to **connect JPL groups** based on common need to better utilize and manage data and transfer methodologies

Global monitoring of near-Earth space environment (geospace) not possible before GNSS signals



Global, high-latitude response of TEC data is the result of numerous complex geospatial processes, and is, therefore, rich with information





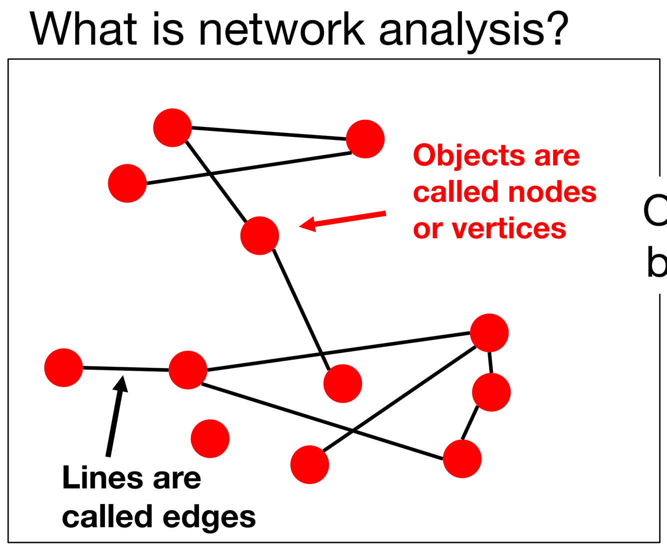
However, characteristics of TEC data at high-latitudes are not well understood and novel, sophisticated approaches are needed to:

- Understand the information content of these data and
- Gain the most scientific utility from them

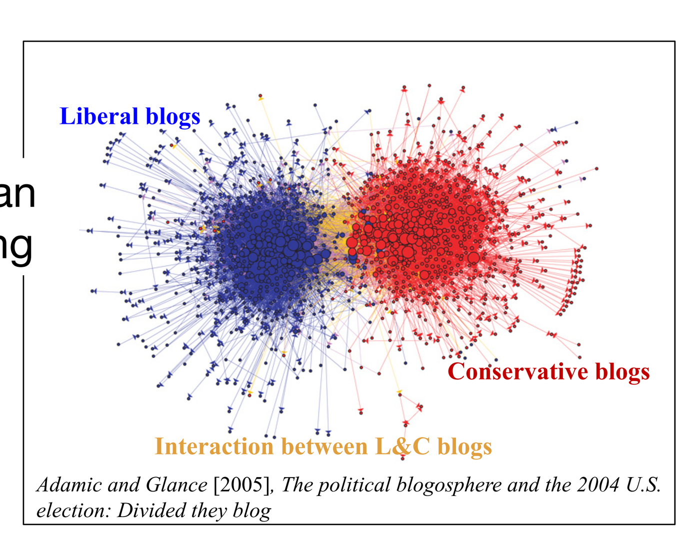
Novel Method: Network Analysis (NA)

We introduce a **new data-driven approach** to the analysis of high-latitude, hemispheric-specific, TEC data known as **network analysis**

What is network analysis?

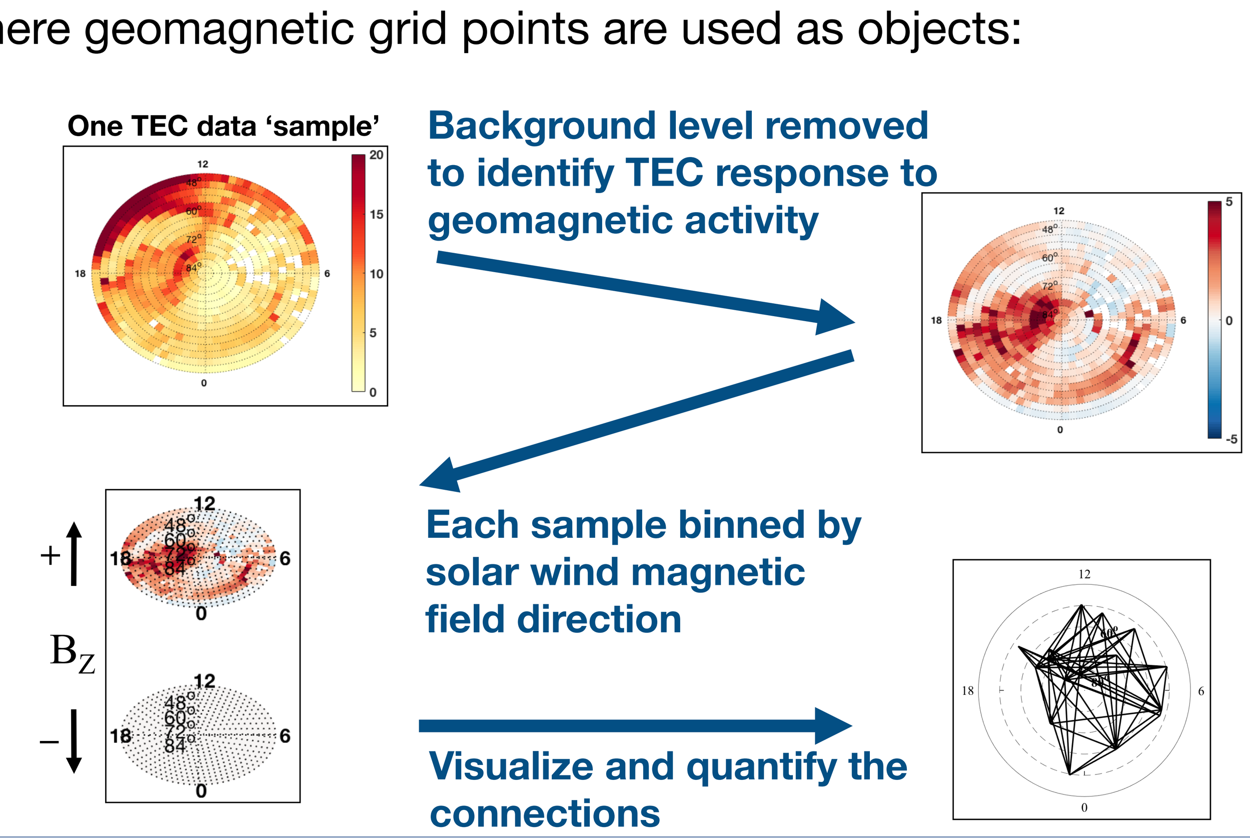


Objects can be anything

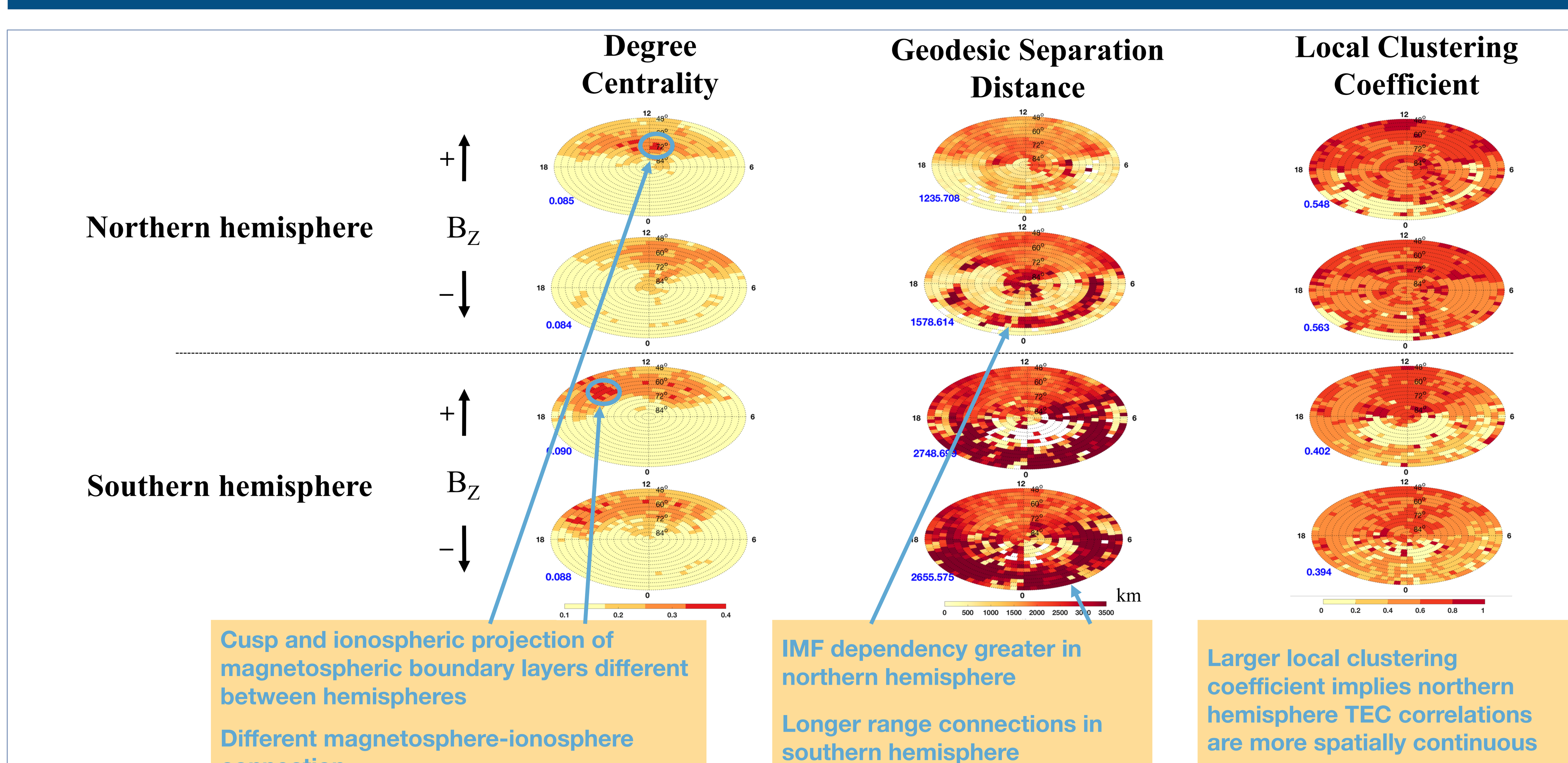


Adamic and Glance [2005]. The political blogosphere and the 2004 U.S. election: Divided they blog

We apply these techniques to high-latitude TEC **for the first time**, where geomagnetic grid points are used as objects:



Results



All figures: Local winter distributions for northern (top) and southern (bottom) hemispheres. Data are in AACGM MLAT-MLT coordinates with 3° MLAT resolution and variable MLT resolution to yield equal area bins. Results for northward (top) and southward (bottom) Interplanetary magnetic field (IMF) are illustrated.

Network measures used to study ionosphere network behavior

Measure	Significance (Interpretation)
Degree Centrality	Influence of grid points on network function (larger = greater influence)
Median geodesic separation distance	Scale sizes of connectivity (larger = longer range connections)
Local clustering coefficient	Spatial continuity of TEC (larger = more spatially continuous)

New Actionable Knowledge and Future Work

Conclusions: Network analysis of TEC data: 1)Enhances the utility of the data; 2)Reveals new information about magnetosphere-ionosphere connections and space weather-related phenomena; and 3)Illustrates broader importance of novel data-driven discovery

1. **Can TEC data be used as an auxiliary variable for complex space weather phenomena?**
2. **To what extent can machine learning techniques play a critical role in Heliophysics and space weather forecasting?**

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