14 LSST Solar Neighborhood Collaboration Roadmap Planning Document

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14.1 Purpose of this Document

- Identify the technical and scientific challenges for LSST in studying low mass stars and the solar neighborhood
- Identify tasks for collaboration members that can overcome these challenges on a timescale of a few years.
- Organize collaboration members to perform assigned tasks before data delivery

14.2 History

- 22 October 2013 (AJB): Version 1 released to working group
- 1 November 2013 (AJB): comments integrated and sent to leads
- 2 January 2013 (AJB): comments from WIllman
- 14 August 2014 (MCL): cleanup of edits

14.3 Introductory Material

14.3.1 Key target populations:

- Solar neighborhood: classically d $<$ 10-25 pc, extend to $\sim$100 pc in LSST era
- Young stars: clusters, moving groups & associations
- Old stars: subdwarfs, thick disk and halo objects, globular clusters (??)
- Brown dwarfs: $<$0.07 Msun, including free-floating planets
- White dwarfs (and other remnants?)
- Binaries and higher order multiples: q $>$ 0.1, resolved and unresolved
- Low mass companions: q $<$ 0.1, resolved and unresolved

14.3.2 Definitions & Acronyms used in the text

Mass scales:

- $>$ 2 Msun = "massive" 0.5-2
- Msun = "solar type"
- 0.1-0.5 Msun = "low mass" (LM)
- $<$ 0.1 = "very low mass" (VLM)
- $<$ 0.07 Msun = "brown dwarf" (BD)
- $<$ 0.013 Msun = "planetary-mass object" (PMO)

CPM = common proper motion DBMM = deuterium burning minimum mass, nominally 0.013 Msun for solar Z GC = globular cluster HBMM = hydrogen burning minimum mass, nominally 0.07 Msun for solar Z LBMM = lithium burning minimum mass, nominally 0.06 Msun for solar Z [M/H] = metallicity MF = mass function MG = moving group MS = main sequence star NIR = near infrared PM = proper motion PMS = pre-main sequence star RPM = reduced proper motion RV = radial velocity SED = spectral energy distribution SpT = spectral type ToO = target of opportunity WD = white dwarf YA = young association YMG = young ($<$100 Myr) moving group

14.4 Roadmap Plan

- Phase 1 (deadline: 1 Nov 2013): Highlight technical/scientific challenges that must be worked on to conduct our science with LSST.
- Phase 2 (deadline: TBD): Develop a strawman path towards overcoming those challenges before LSST data start flowing.
- Phase 3 (deadline: TBD): raise interesting precursor science that can be done by you/can get grant support now.

14.5 Identified inputs required for planning (priorities TBD)

- precise LSST filter definitions
- photometric sensitivity per band for single and deep pointing
- astrometric performance (proper motion & parallax) per band as a function of brightness, spectral type, # of epochs, time baseline and sky location (see preliminary results from DAWG = Differential Astrometry Working Group)
- LSST imaging cadence(s)
- LSST PSF shape model (including saturation)
- galactic model

- spectroscopic followup resources
- theoretical atmospheric models of LMs/VLMs/BDs as a function of Teff, log g, [M/H], clouds, circulation that span LSST bands
- empirical templates of sources (MLTY standards, subdwarfs and young dwarfs)
- evolutionary models and forward modeling samples for BD population
- flare emission model to determine LSST response/sensitivity to LM flares
- cloud spot model to determine LSST response/sensitivity to BD weather patterns
- An (updateable) list of currently nearby LMs/VLMs/BDs (ra, dec, spt, distance, predicted LSST mags, age/cluster, etc)
- Quantification of completeness as a function of SpT and distance

14.6 Primary science investigations: Objectives, issues and tasks

14.6.1 Volume-complete (astrometric) sample of extended solar neighborhood

definition: all sources for which parallax measurements can be made with LSST

interested collaborators: Adam Burgasser, John Gizis, Todd Henry, Michael Liu, Keivan Stassun, Sebastien Lepine.

interface with other collaborations: Galactic Structure and ISM:

objectives:

- distance-limited sample of solar neighborhood (to be defined)
- 6D phase space determination (XYZUVW)
- LM/VLM/BD MF determination
- Full physical, atmospheric, multiplicity characterization of complete sample
- map evolution of ultracool objects through the M/L, L/T, and T/Y transitions.

issues:

- number of epochs and cadence required to distinguish proper motion and parallax
- overlap with GAIA (minimal/non-existent for L/T/Y dwarfs)
- astrometric calibration and astrometric uncertainties
- distance limit for completeness
- brightness limit for completeness (e.g., astrometric accuracy vs. brightness)
- detection of/contamination by astrometric binaries and unresolved binaries

- followup spectroscopy: science goals & data needs (sample size, resolution, etc.)
- RV measurements
- kinematics (statistical) ages?
- handling crowding along Galactic plane (e.g. image differencing, pixel-level modeling)

tasks to do:

- need a current list of stars (perhaps broken down by SpT) w/in XX pc to assess where the big holes in completeness are - both X and SpT regime that we care about will need to be defined (Todd?), will require some "population synthesis" modeling for BDs (Adam?), as well as kinematic considerations (Paul Thorman?)
- summarize existing compliations from Pan-STARRS solar neighborhood work (Mike)
- model astrometric binary contribution/contamination
- comprehensive follow-up of sources - RV, high resolution imaging
- examine model parameter sensitivity through LSST photometry
- Lists of proper motion selected M dwarfs already exist to at least 100 pc. A local kinematics model (velocity space distribution), combined with luminosity function, will determine how many stars are missing from the current census as a function of magnitude, and e.g. what the distance range of GAIA will be for stars of different magnitudes. This will determine the "sweet spot" (in distance/luminosity) for LSST to reap the most results.

tasks completed:

14.6.2 Deep sample of LM/VLM/BD dwarfs

definition: sources inaccessible to parallax

interested collaborators:

interface with other collaborations: Galactic Structure and ISM: The Galactic Bulge: Near Field Cosmology:

objectives:

- extremely large sample (10^6?) for population analysis
- galactic stratigraphy - chemical abundances, kinematic "heating", structural features out to XX kpc
- galactic scaleheight as a function of mass (constraint on potential and formation mechanisms)
- search for thick disk/halo objects

issues:

- spectroscopy won't be viable for whole sample - photometric selection criteria, RPM (limits)
- most sensitive filter likely to be Y(4): will single-band detections(+astrometry) be useful?
- limit to which PM is viable
- metallicity characterization through photometry alone

tasks to do:

- simulate yield along different sitelines, with variations in scale height, MF, etc.
- calibration sample for metallicity effects tasks completed:

14.6.3 Ultracold brown dwarfs (late-T and Y dwarfs)

definition: BDs cooler than $\sim$1000 K =¿ T5 and later, any distance
interested collaborators: Adam Burgasser, Michael Liu
interface with other collaborations: Galactic Structure and ISM:
objectives:

- detect a significant population of T and Y dwarfs for MF determination
- kinematic characterization (6D phase space)
- identify extreme TY populations (halo, young, cloudy, etc.)
- measure how optical SEDs change across K$-$ >KCl, Na$-$ >NaCl/Na2S transitions

issues:

- sensitivity of LSST filters to cool T and Y dwarfs - detection limits, expected numbers assuming an MF
- compare expected performance to WISE. e.g. LSST will not be competitive in this area, at least for discovery of the coolest objects.
- most sensitive filter likely to be Y(4): will single-band detections(+astrometry) be useful?
- possible to spectroscopically follow these up? (necessary for classification, RV)
- minimal information set required to eliminate contaminants (e.g., RPM, color sets, necessary filters)

tasks to do:

- examine photometric classification and contamination

tasks completed:

14.6.4 Halo dwarfs across the substellar limit

definition: dwarfs with halo kinematics and/or $[M/H] \leq -1$

interested collaborators: Pat Boeshaar, Adam Burgasser, John Gizis, Michael Liu, Sebastien Lepine

interface with other collaborations: Galactic Structure and ISM:

objectives:

- Halo mass function across substellar limit
- measurement of H-burning "age gap" (z-dependent HBMM)
- confirmation of BD formation in low metallicity environment
- metallicity effects on low mass spectra/photometry
- multiplicity of halo LM/VLM/BD dwarfs
- map out velocity space distribution
- search for substructure in LM halo
- discovery of extremely metal poor ($[Fe/H] < -3$) VLM dwarfs
- Pop III VLM dwarfs?

issues:

- game selection: target max V (anticenter and vertical ring)
- efficient and robust selection: RPM, metallicity effects, contaminants
- mapping LSST photometry to physical properties - templates? models?
- spectral characterization?

tasks to do:

- model discovery rate using MF forward modeling + atmosphere models (colors)
- identify templates for SED characterization
- estimate the local density of halo subdwarfs and their expected magnitude/color distribution, based on the existing census.
- Calculate the distance range over which LSST will be detecting M subdwarfs of different subtypes, what can be expected of their proper motion distribution, and determine the distance range required to assemble statistically significant samples of various metallicity classes (i.e. halo sub-populations).

tasks completed:

14.6.5 Co-moving populations

definition: members of well-defined clusters, young associations, and moving groups in the Solar Neighborhood

interested collaborators: Michael Liu, Keivan Stassun, Sebastien Lepine
interface with other collaborations: Star Clusters
objectives:

- complete MFs for YAs/MGs in VLM/BD regimes]temsearch for new YAs/MGs, associated with "isolated" stars or as completely new groups.
- identify ultracool dwarf benchmarks over a broad range in age ($\sim$1 Myr to $\sim$1 Gyr)
- build up sample of ultracool dwarf benchmarks (i.e. with well constrained ages, compositions, distances)
- disk/jet/accretion properties of young group members (e.g., TWA)

issues:

- probability of cluster membership: CPM, π/Dest, phot/spec properties, UV/X-ray, variability?; are RVs necessary?
- how to we obtained activity diagnostics to examine youth? (e.g., Halpha)
- Will u photometry be sufficient to characterize UV emission excess?
- disentangling multiple memberships (overlapping nearby groups)
- what is lowest mass we can probe to in a given group?
- mapping observations to physical properties (Teff, logg, masses, ages)
- mass sensitivity limit for nearest GCs, older clusters (including age effects)
- The young local pop will start to merge with ScoCen - how do we interface with the Star Cluster subgroup?

tasks to do:

- determine requirements on RV measurement for cluster association
- confirm and compile properties of nearby YAs/MGs/GCs
- predict mass limits for various groups item characterize impact of disk/jet emission/envelope obscuration on LSST (+2MASS +WISE?) photometry, map color terms to physical measures

tasks completed:

14.6.6 VLM Multiples

definition: all multiples with a VLM/BD primary, including PMOs
interested collaborators: Adam Burgasser, Michael Liu
interface with other collaborations
objectives:

- measure the wide separation binary fraction and separation distribution via CPM
- measure the small separation binary fraction via astrometric binaries
- detect eclipsing binaries; if sufficient number, measure binary fraction at close separations
- use these measurements to constrain separation and mass ratio distributions, binary fraction all as a function of mass/SpT
- use astrometric and transit binaries to determine orbital distributions (eccentricity, mass ratio)
- use transit binaries to test VLM/BD structure models
- robustly determine higher-order fractions for LM/VLM/BDs
- measure planetary companion fraction to VLM/BDs

issues:

- what is the transit detection rate for various cadences? what cadence would optimize?
- what are the astrometric requirements for CPM assessment as a function of binary separation, distance, mass ratio?
- how can color/photometry winnow candidates for wide binaries?
- how reliable is photometric information for constraining mass ratios? separate question for */*, */BD and BD/BD pairs
- what constraints can wide VLM binaries have on DM distribution?

tasks to do:

- ensitivity limits for these three cases
- simulate discovery fraction and efficiency for each class of systems (simulations of population, detectability for eclipsing/astrometric/resolved binaries)
- interface astrometric requirements with halo PM, parallax requirements
- false positive simulation for wide binaries
- RV followup of astrometric, transit binaries

- compile specific predictions of VLM formation models on binary stats (e.g., co-ejection for wide multiples)
- model wide separation limits due to DM substructuring, differential tests with massive, LM, & VLM wide binary distributions

tasks completed:

14.6.7 VLM/BD companions to stars

definition: resolved LM/VLM/BD/PMO companions to stars
interested collaborators: Michael Liu
interface with other collaborations:
objectives:

- measure the companion fraction at low q to various stellar types
- characterize "BD desert" at wide separations
- build up sample of ultracool dwarf benchmarks (i.e. with well constrained ages, compositions, distances)
- test brown dwarf evolutionary models and model atmospheres using benchmarks
- identify wide companions to planet-hosting stars (Kozai mechanism)

issues:

- confirmation: CPM (limits), color, other?
- how to deal with saturated primaries
- what is the companion volume sampled as a function of separation (distance effects)?
- what is the minimum resolving angle?
- sensitivity as a function of angular separation from a star and brightness?
- how to account for orbital alignments in detectability, separation distribution
- defining robust search samples - PM-selected?

tasks to do:

- simulate discovery fraction with various assumptions of companion fraction, separation distribution, orbital properties
- CPM limits
- define input search sample; resources to characterize primaries
- contamination rate as a function of separation (w/ & w/o CPM confirmation)
- resources for follow-up

tasks completed:

14.6.8 Magnetic, atmospheric and structural photometric variability in cool dwarfs

definition: analysis of photometric variability associated with magnetic and atmospheric phenomena (separating off eclipses/transits)

interested collaborators: John Gizis, Keivan Stassun

interface with other collaborations: transients and variables working group

objectives:

- characterize period distribution of VLM dwarfs
- characterize flaring rate and flare energy distribution of M and L dwarfs
- characterize spot properties: covering fraction, Tspot-Tphot
- distinguish between magnetic emission mechanisms (spots/aurorae)
- characterize weather-related phenomena

issues:

- relation of (lower-precision) LSST results to (higher-precision) Kepler & TESS results?
- cadence necessary for typical flare and rotation rates
- what follow-up is required to characterize flares and/or quiescent emission?
- Will targets of opportunity be needed to catch flares in action (is there even time to do this? what can we learn from GRB community?)
- photometric precision required for detection of X% spot/cloud var
- what different bands sample in terms of cloud and flare properties
- how could multi-color photometry constrain properties of flare source
- can multi-color photometry constrain cloud properties (e.g., grain size distribution)
- follow up to directly measure magnetic activity indicators (RAVE?)

tasks to do:

- use a list/database of currently known VLMs within X pc, and use this as in input catalog to see what the cadence of these sources would be.
- model flares in LSST photometric bands as function of flare temperature
- predictions of "magnetic" variability for spot vs. auroral models
- model cloud variability in LSST photometric bands as function of v sin i, covering fraction, Tcloud-Thole, viewing angle, latitude distribution, differential rotation
- discovery rate of flares for a given flare rate/energy model and cadence

tasks completed

14.6.9 White dwarfs

definition: all degenerates, including those not identified by parallax
interested collaborators: Sebastien Lepine
interface with other collaborations: Galactic Structure and ISM
objectives:

- identify and characterize halo WD population
- characterize the luminosity function across populations
- identify main-sequence + WD binaries

issues:

- Are u-g/g-r colors sufficient to identify most field white dwarfs?
- To what extent will the search for WDs have to rely on proper motions (i.e. reduced proper motion detection).
- How efficiently can WD+MS binaries be identified based on color alone?

tasks to do:

- Calculate the local WD density based on the current census, and estimate how many WD can potentially be detected by LSST as a function of magnitude.
- Build expected color-magnitude distributions based on predicted luminosity functions.
- Estimate proper motion detectability of halo WDs, how deep one needs to go to assemble a statistically significant sample.

tasks completed: