Astara

Mobile Planetarium

Complete Technical Documentation

Version: 1.0

Date: January 2026

Classification: RESTRICTED

Organization: Astara Development Team

Project: Astara Development Team

Table of Contents

Part I: Introduction

Documentation Index 6

Features 11

Part II: Design Documents

High-Level Design (HLD) 24

Low-Level Design (LLD) 35

Part III: User Guides

User Manual 64

Setup & Installation 91

Part IV: Technical Reference

Architecture Overview 97

Frontend Guide 99

Upstream Relationship 102

Part I: Introduction

Documentation Index

Overview

Astara is an advanced mobile planetarium application. Built on the Stellarium Web Engine, it provides real-time sky visualization with sensor-based interaction, augmented reality overlays, and comprehensive offline astronomical data.

Key Features

- Gyroscope Mode - Point your device to identify stars
- AR Camera Overlay - Stars overlaid on live camera feed
- Direction Tracking - Visual guide to locate objects
- ✈ Offline Operation - 60,000+ objects bundled locally
- Astronomical Calendar - Moon phases, eclipses, conjunctions
- Multi-Culture Support - IAU, Indian, Chinese sky cultures

Documentation Map

Architecture & Technical

Document	Description
architecture.md	System architecture overview
features.md	Complete list of Astara feat
frontend.md	Vue.js frontend guide
upstream.md	Relationship with Stellarium

Design Documents

Document	Description
hld.md	High-Level Design - System a
lld.md	Low-Level Design - Detailed

User Guides

Document	Description
user_manual.md	Complete user guide for oper
setup.md	Build and installation instr

Engine Documentation

Document	Description
internals.md	Stellarium Web Engine intern

Quick Links

For Users

- Getting Started → user_manual.md
- Features → user_manual.md
- Troubleshooting → user_manual.md

For Developers

- Architecture → hld.md
- Build Setup → setup.md
- Code Structure → lld.md
- Services → lld.md

For Administrators

- Installation → setup.md
- Configuration → lld.md

Document Summary

hld.md - High-Level Design

The High-Level Design document provides:

- Executive summary and purpose
- Three-layer architecture (Native, Web, Engine)
- Technology stack details
- Component design overview
- Data flow diagrams
- Deployment architecture
- Security considerations
- Performance optimization strategies

lld.md - Low-Level Design

The Low-Level Design document covers:

- Complete project structure
- Engine object system (C/WASM)
- Module registration and rendering pipeline
- Frontend Vue.js architecture
- Service layer implementations (Gyroscope, Search, Astronomy)
- Vuex state management
- Component specifications with code
- Algorithm specifications
- Data format specifications
- Build system configuration
- Testing specifications

user_manual.md - User Manual

The User Manual includes:

- Introduction and system requirements
- Installation guide
- Quick start guide
- User interface explanation
- Core features (Gyroscope, AR, Constellations, Time)
- Search and navigation
- Settings and configuration
- Astronomical calendar
- Advanced features (DSO overlays, Satellites)
- Troubleshooting guide
- Reference appendices

Technology Stack Summary

Layer	Technology	Purpose
Engine	C + WebAssembly	Astronomical calculations
Frontend	Vue.js 2 + Vuex	User interface
Mobile	Capacitor 4	Android wrapper
Sensors	Device APIs	Gyroscope, Camera
Data	JSON + Binary	Star catalogs

Version History

Version	Date	Changes
1.0	January 2026	Initial documentation releas

Contributing

For documentation updates:

- Follow existing document structure
- Use markdown formatting consistently
- Update index.md when adding documents
- Keep technical accuracy with code

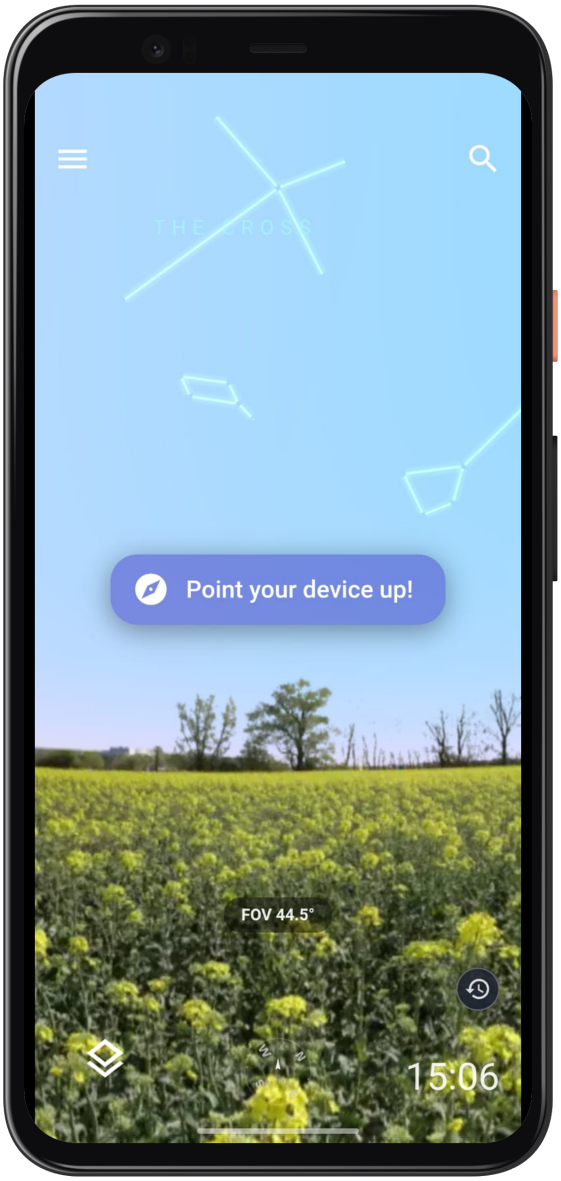
Features

Astara is built on the Stellarium Web Engine, but extends it significantly to create a fully functional mobile planetarium app. This document describes everything we added or changed beyond the base web planetarium.

Gyroscope Mode

Point your phone at the sky and the view follows. The app reads device orientation sensors and translates them into sky coordinates in real time.

- Back camera orientation mapped to sky view direction
- Adaptive smoothing prevents jitter while remaining responsive
- Automatic swipe detection to exit gyro mode
- Orientation lock to portrait mode while active



AR Camera Overlay

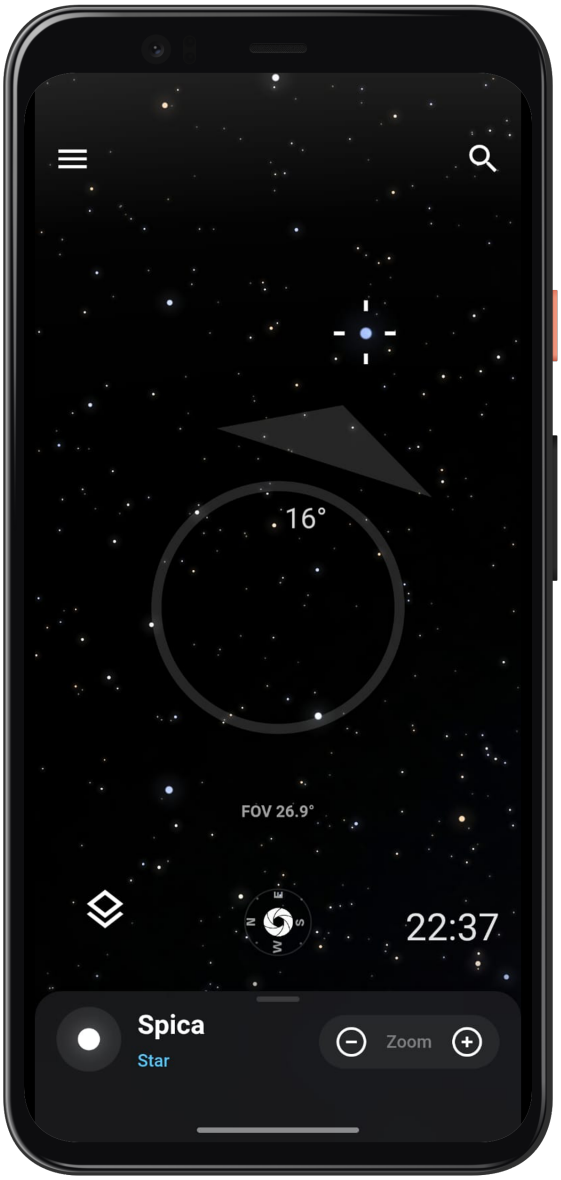
Stars and constellations overlaid on the live camera feed. See the real sky through your camera with celestial labels floating in place.

- Toggle AR mode from the control bar
- Adjustable overlay opacity for visibility in different lighting
- Canvas blending so dark sky becomes transparent
- Camera feed managed by Capacitor for native performance

Direction Tracking Overlay

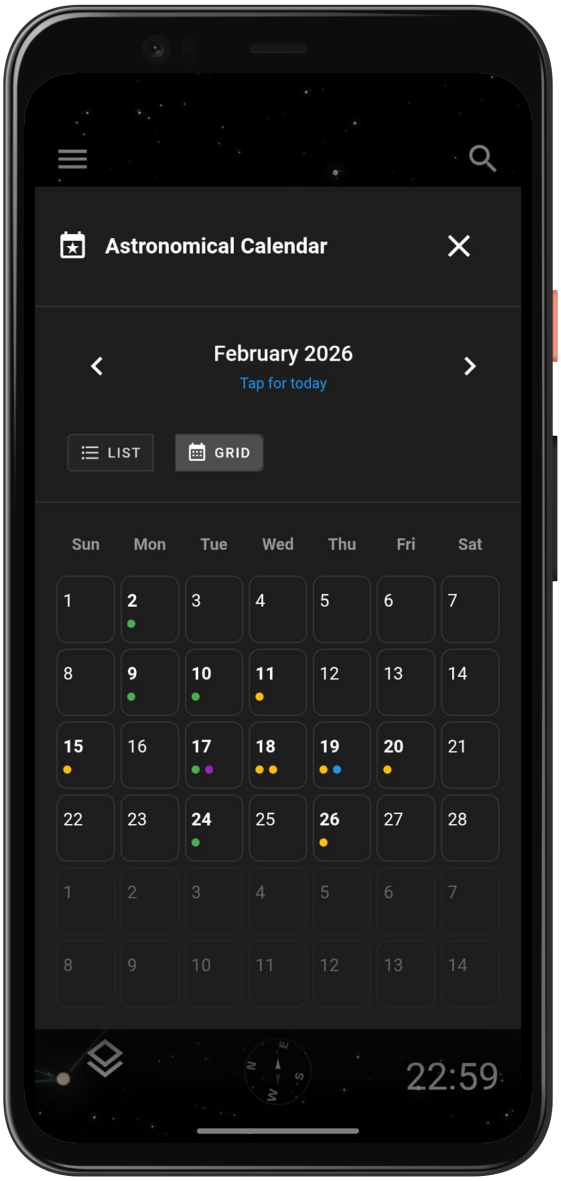
Select any object and see a visual guide pointing toward it. The guide updates live as you move your device, showing both direction and distance in degrees.

- Compass-style arrow toward target
- Distance indicator in degrees
- Works in gyroscope mode and AR mode
- Disappears when target is on screen



Astronomical Calendar

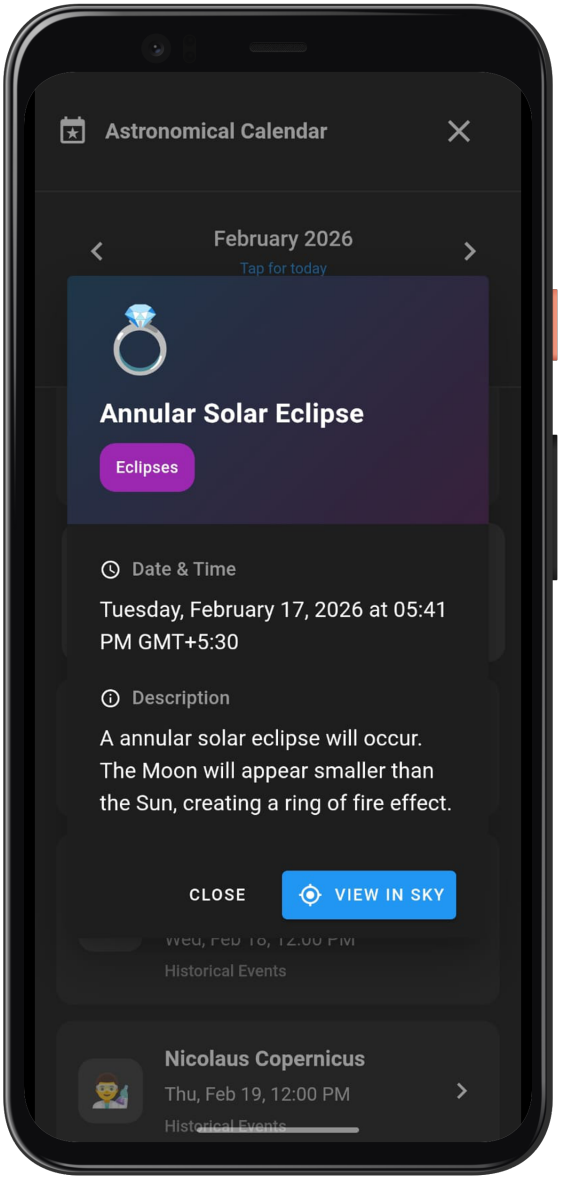
A built-in calendar of celestial events calculated locally on the device.



Moon Events

- New Moon, Full Moon, First Quarter, Last Quarter
- Moonrise and Moonset times
- Lunar perigee and apogee
- Equinoxes and Solstices
- Sunrise and Sunset times

- Conjunctions between planets
- Oppositions and elongations
- Solar and lunar eclipses



Offline Operation

The entire app works without network access. All sky data is bundled at build time.

Bundled Data

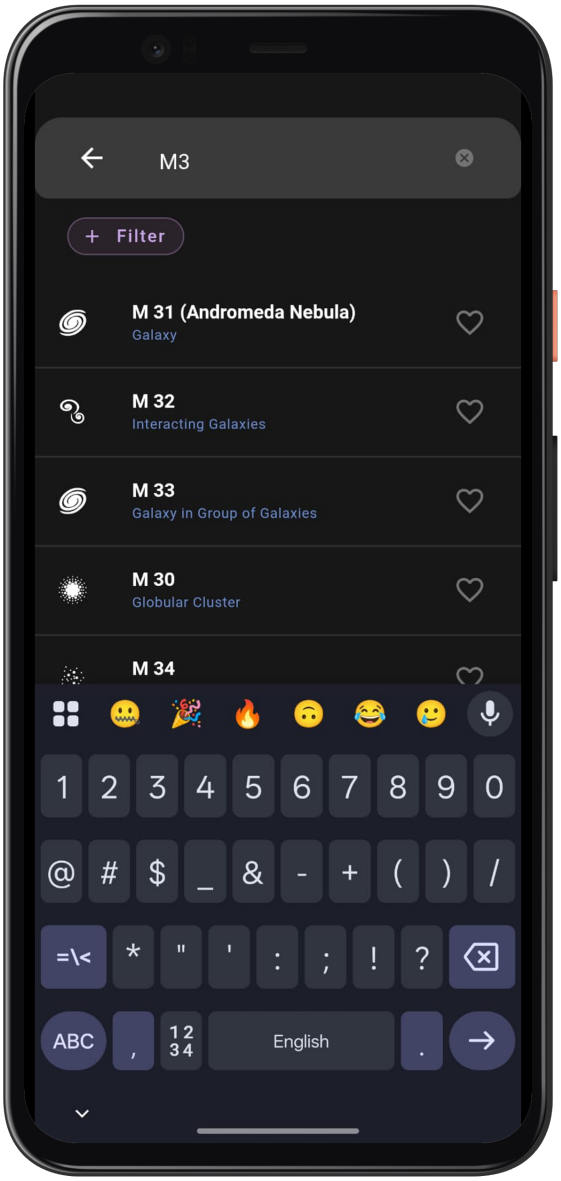
- Hipparcos star catalog (~120,000 stars)

- Deep sky object catalog (galaxies, nebulae, clusters)
- Solar system ephemeris data
- Constellation lines and boundaries
- Milky Way panorama
- Multiple landscape panoramas
- Satellite TLE data
- Comet and asteroid orbits
- Location can be set manually
- All calculations performed on device
- No external API calls during normal use

Enhanced Search

Search across stars, planets, constellations, and deep sky objects with unified results, optimized for performance on mobile devices.

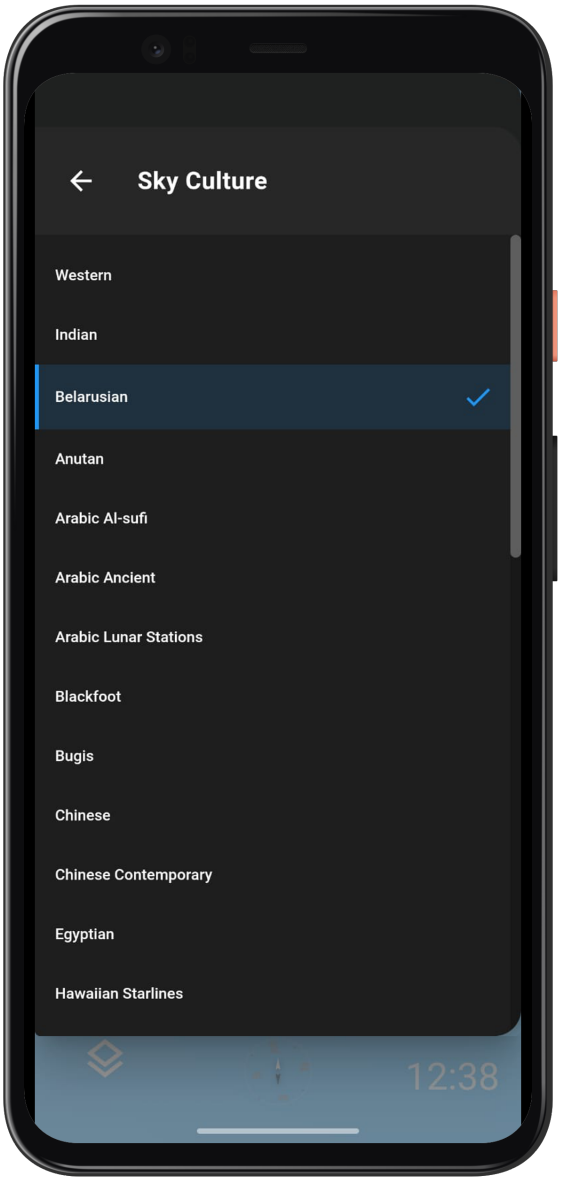
- Fuzzy matching and prefix matching on object names
- Cross-catalog search (Messier, NGC, common names)
- Results ranked by relevance
- Tap to center and track any result



Multi-Constellation Sky Cultures

Switch between different cultural interpretations of the night sky.

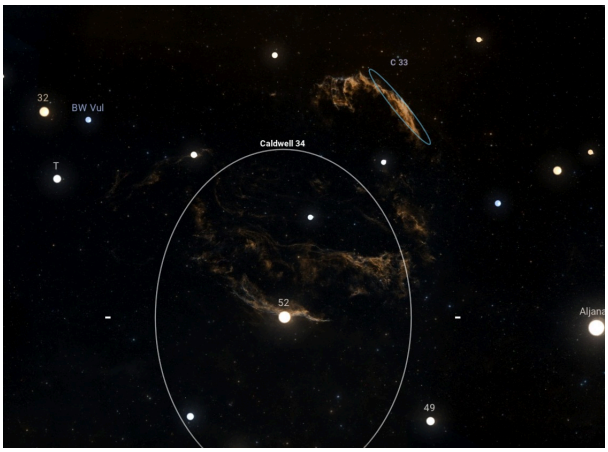
- IAU/Western constellations
- Indian Nakshatra system
- Chinese sky culture
- Arabic sky culture
- And more bundled with the app



Deep Sky Object Overlays

HiPS image tiles for deep sky objects, displayed as overlays on the sky view. Images appear progressively as you zoom in, providing detailed views of galaxies, nebulae, and clusters at higher magnification levels.

- Toggle overlay visibility from settings
- Images load progressively based on zoom level
- Catalog designations displayed as labels



Touch-First Interface

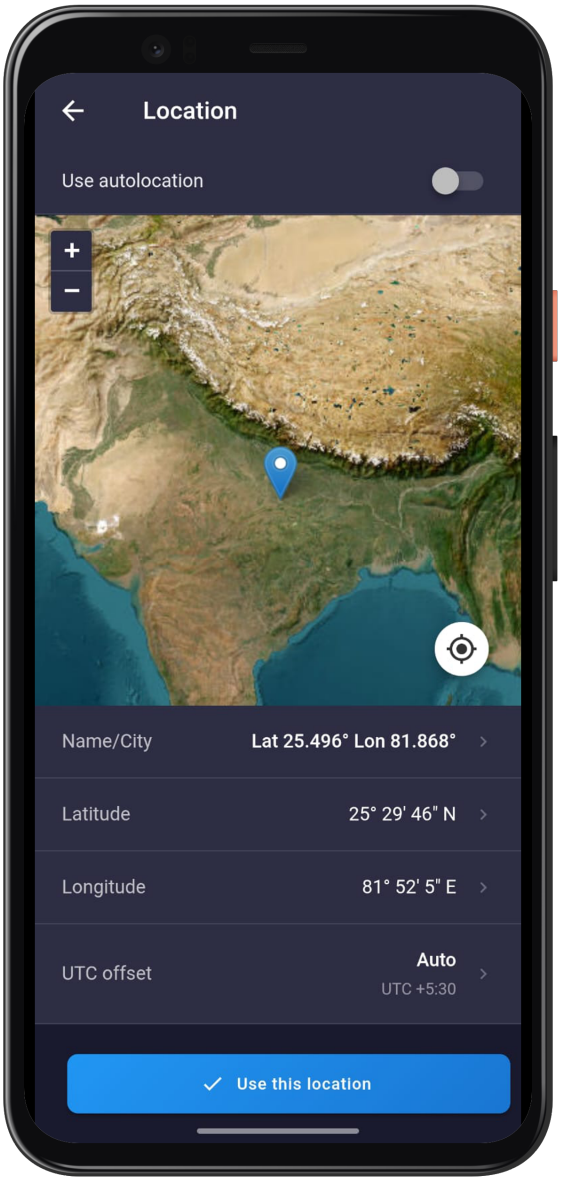
UI rebuilt for mobile touch interaction, rather than mouse and keyboard.

- Bottom control bar with quick toggles
- Swipe gestures for navigation
- Pinch to zoom
- Click on object to center and track it and open the info panel
- Long press for menu option selection

Location Management

Set your observing location with or without GPS.

- Auto-detect via device GPS
- Manual coordinate entry
- Named location presets
- Geocoding for location names
- Fallback to saved location if GPS fails



Time Control

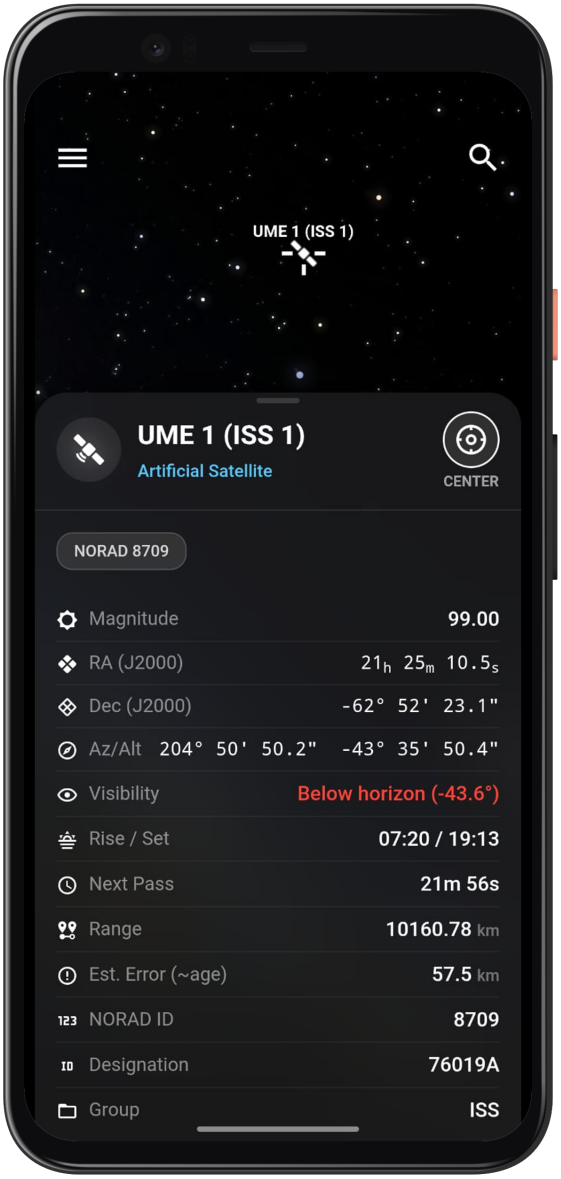
Jump to any date and time, or watch the sky animate.

- Date and time picker
- Real-time mode (follows actual time)
- Time acceleration controls
- Jump to sunrise, sunset, or specific events

Selected Object Information

Detailed information panel for any selected object.

- Common and catalog names
- Current position (altitude, azimuth, RA, Dec)
- Rise, transit, and set times
- Physical data (magnitude, distance, size)



Build Pipeline

Produces a standalone Android APK from source.

- Emscripten compiles C engine to WebAssembly
- Webpack bundles Vue frontend
- Capacitor wraps web app as native Android
- Gradle builds signed release APK
- All sky data bundled into app assets

What We Did Not Change

The astronomical engine itself is upstream code. We do not modify:

- Star and planet position algorithms
- Rendering and projection math
- Ephemeris parsing and calculation
- Object catalogs beyond extending them

Part II: Design Documents

High-Level Design (HLD)

1. Executive Summary

Astara is an advanced mobile planetarium application. Built on the Stellarium Web Engine, it provides real-time sky visualization with sensor-based interaction, augmented reality overlays, and comprehensive offline astronomical data.

1.1 Purpose

Astara enables field personnel and aviation crews to:

- Identify celestial objects by pointing their device at the sky
- Navigate using astronomical references
- Access comprehensive star catalogs and deep sky object data offline
- Plan observations based on astronomical events and visibility

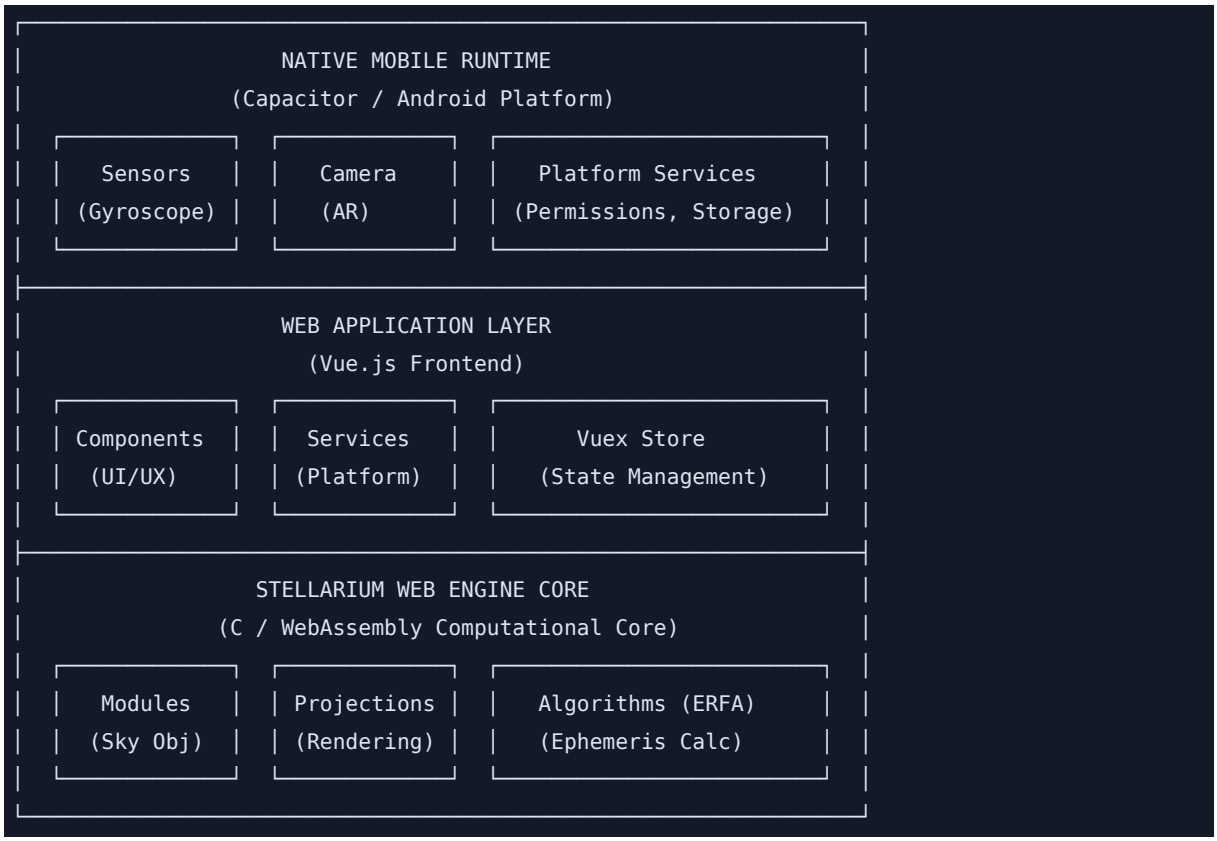
1.2 Key Features

Feature	Description
Gyroscope Mode	Point device to view corresp
AR Camera Overlay	Stars overlaid on live camer
Direction Tracking	Visual guide to locate speci
Offline Operation	60,000+ objects bundled loca
Astronomical Calendar	Moon phases, eclipses, conju
Multi-Constellation Support	Multiple sky cultures (IAU,

2. System Architecture

2.1 Architecture Overview

Astara follows a three-layer architecture that separates platform concerns from computational logic:



2.2 Layer Descriptions

2.2.1 Native Mobile Runtime (Capacitor Layer)

The outermost layer provides native platform integration:

- Capacitor Shell: Wraps the web app as a native Android application
- Sensor Access: Gyroscope, accelerometer, compass via Capacitor plugins
- Camera Integration: Native camera feed for AR mode
- Permissions: Location, camera, sensor permissions
- Window Management: Fullscreen, orientation lock, immersive mode

2.2.2 Web Application Layer (Vue.js Frontend)

The presentation and interaction layer:

- Vue 2 Framework: Component-based UI architecture
- Vuex State Management: Centralized state for app and engine sync
- Services: Platform abstraction modules (gyroscope, camera, search)
- Components: Reusable UI elements (menus, panels, dialogs)

2.2.3 Stellarium Web Engine Core (WASM)

The computational core compiled from C to WebAssembly:

- Astronomical Algorithms: Position calculations via ERFA library
- Rendering Engine: OpenGL ES-based sky visualization
- Module System: Extensible sky object management (stars, planets, DSOs)
- Projection System: Multiple view projections (perspective, stereographic)

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3. Technology Stack

3.1 Core Technologies

Layer	Technology	Purpose
Engine	C/C++	Astronomical calculations
Compilation	Emscripten 1.40.1	C to WebAssembly compilation
Runtime	WebAssembly	Cross-platform execution
Frontend	Vue.js 2.x	User interface framework
State	Vuex	Application state management
Styling	CSS/SCSS	User interface styling
Build	Webpack	Module bundling
Mobile	Capacitor 4.x	Native Android wrapper
Platform	Android 8.0+	Mobile operating system

3.2 Astronomical Libraries

Library	Source	Function
ERFA	IAU Reference	Earth rotation, star positio
SGP4	NORAD	Satellite orbit propagation
HiPS	CDS/IVOA	Hierarchical Progressive Sur
Hipparcos	ESA	Star catalog (~120,000 stars

3.3 Data Formats

Format	Usage
.eph	Binary ephemeris data (stars
.json	Configuration, name indices
.png	Textures (Milky Way, planets
.geojson	Constellation boundaries

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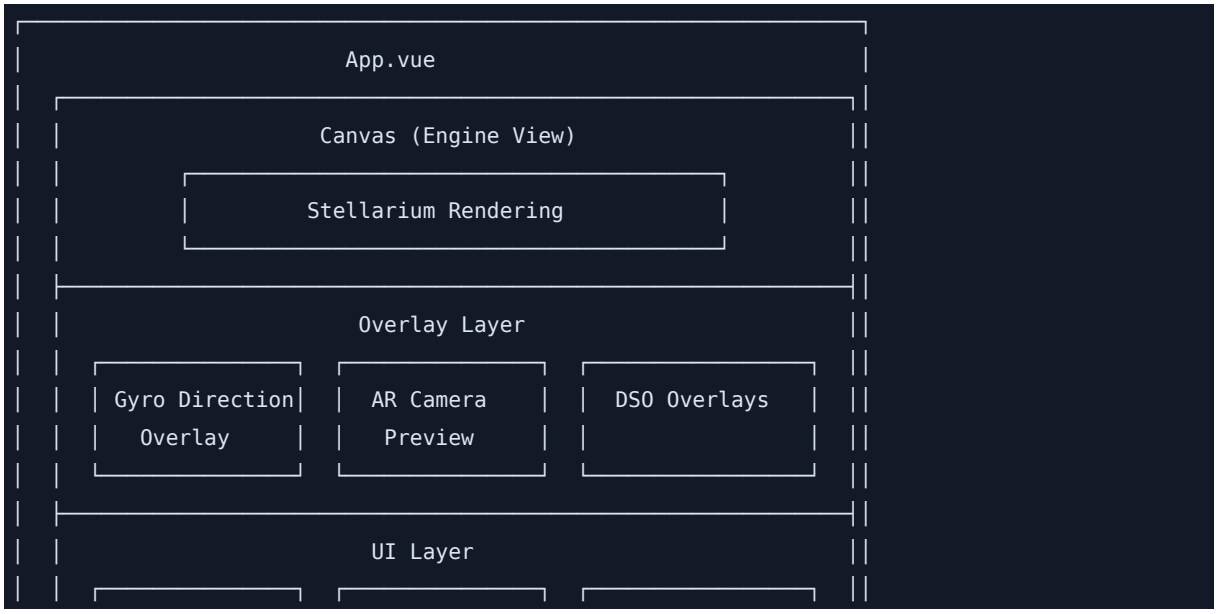
4. Component Design

4.1 Frontend Components



4.2 Service Architecture

Service	File	Responsibility
GyroscopeService	gyroscope-service.js	Device orientation to sky co
CameraService	camera-service.js	Camera feed management for A
FullscreenService	fullscreen-service.js	Immersive mode control
SearchEngine	search_engine.js	Sky object search and filter
AstronomyService	astronomy-service.js	Event calculations (eclipses
CalendarService	calendar-service.js	Astronomical calendar events

4.3 Engine Modules

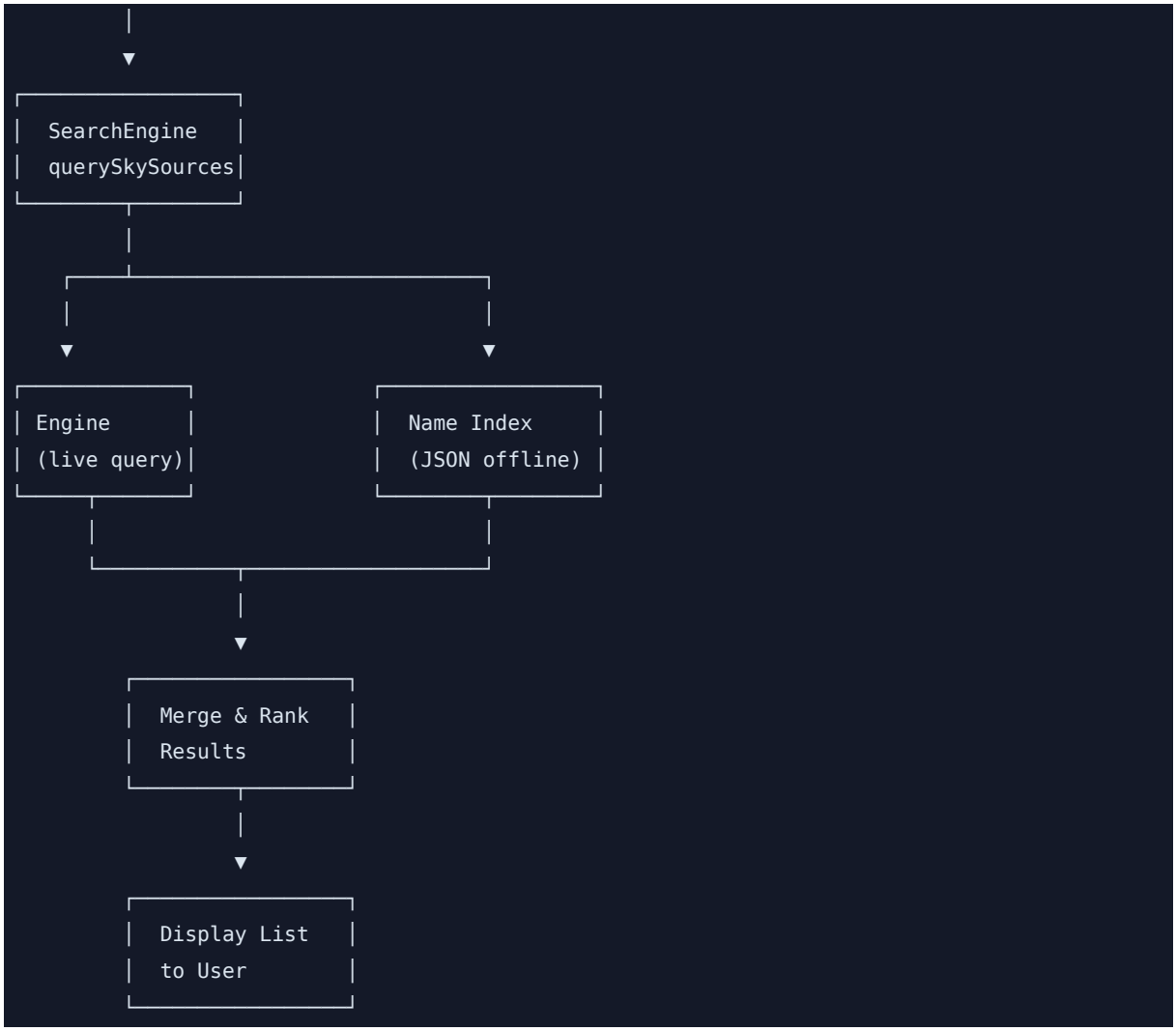
The Stellarium engine is organized into modules, each handling a specific category of sky objects:

Module	File	Objects Handled
Stars	stars.c	Hipparcos catalog stars
Planets	planets.c	Solar system bodies
DSO	dso.c	Galaxies, nebulae, clusters
Constellations	constellations.c	Constellation lines and art
Satellites	satellites.c	Artificial satellites (TLE)
Comets	comets.c	Comets and asteroids
Milky Way	milkyway.c	Galactic panorama texture
Atmosphere	atmosphere.c	Sky gradient and refraction
Landscape	landscape.c	Horizon panoramas

5. Data Flow

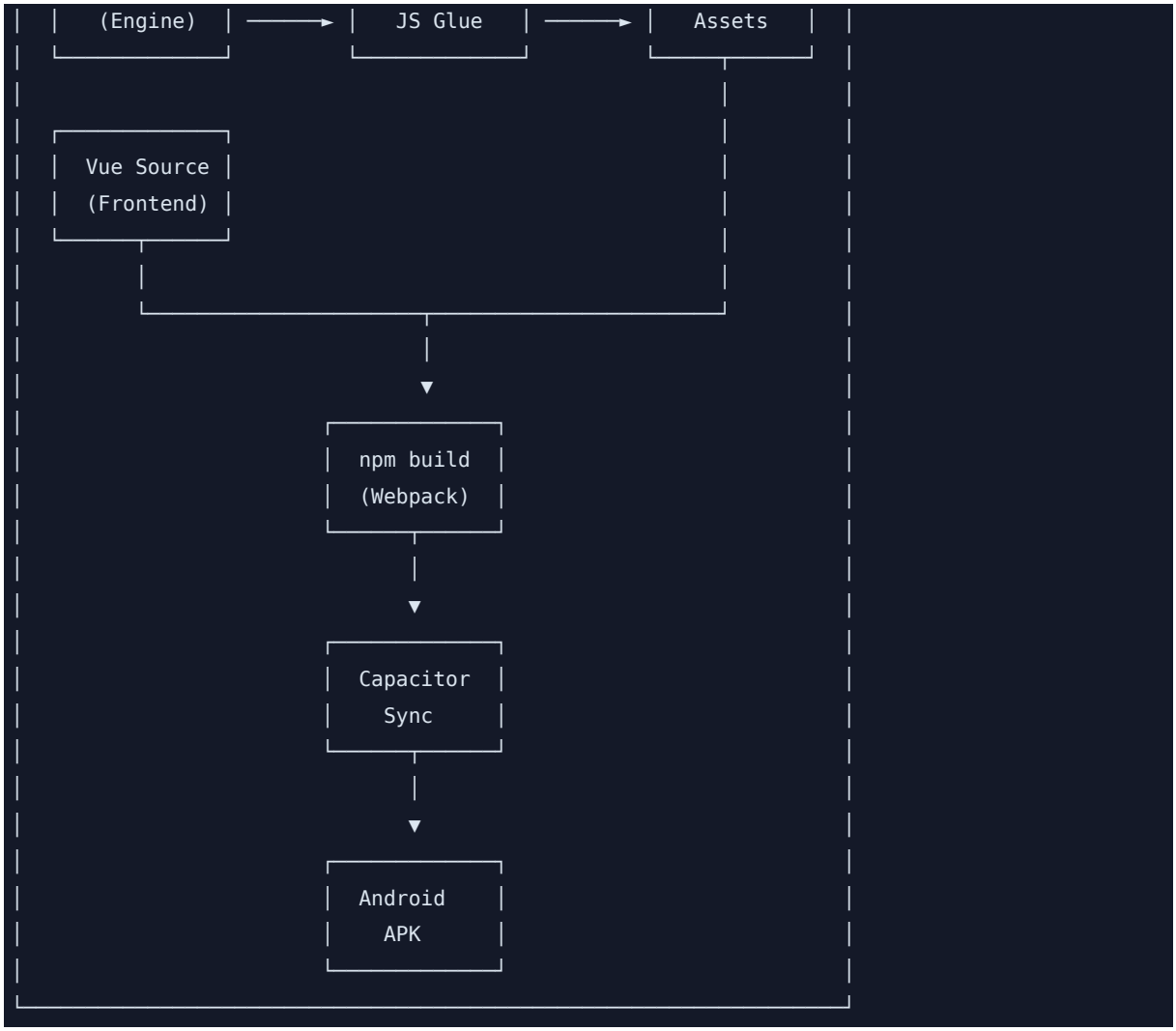
5.1 Sensor to View Pipeline

5.2 Search Flow



6. Deployment Architecture

6.1 Build Pipeline



6.2 Output Artifacts

Artifact	Location	Size
stellarium-web-engine.wasm	apps/web-frontend/src/assets	~3 MB
stellarium-web-engine.js	apps/web-frontend/src/assets	~200 KB
dist/	apps/web-frontend/dist/	~50 MB
app-debug.apk	android/app/build/outputs/ap	~80 MB

7. Security Considerations

7.1 Data Security

Concern	Mitigation
Offline data integrity	Data bundled at build time,
Location privacy	Location stored locally only
No network dependency	All calculations performed l

7.2 Permission Model

Permission	Purpose	Required
CAMERA	AR overlay mode	Optional
ACCESSFINELOCATION	Observer position	Optional
INTERNET	Not required for operation	No

8. Performance Considerations

8.1 Rendering Optimization

- 60 FPS target on mid-range devices
- Level-of-detail for star rendering based on magnitude
- Tile-based loading for HiPS surveys
- Lazy loading for DSO images

8.2 Memory Management

Resource	Strategy

Star catalog	Binary format, memory-mapped
Textures	Loaded on demand, cached
Search index	Lazy-loaded on first search
DSO HiPS	Progressive loading

8.3 Battery Optimization

- Sensor polling rate adjustable
- Frame rate reduction when idle
- Camera disabled when not in AR mode

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9. Scalability

9.1 Data Extensibility

Extension Point	Method
Additional stars	Add to .eph files
New DSO catalogs	Extend name index
Custom landscapes	Add panorama images
Sky cultures	Add constellation data

9.2 Platform Extensibility

- iOS support: Capacitor-ready architecture
- Web deployment: No platform-specific code in frontend
- Desktop: Electron wrapper possible

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10. Glossary

Term	Definition
DSO	Deep Sky Object (galaxies, n
ERFA	Essential Routines for Funda
HiPS	Hierarchical Progressive Sur
TLE	Two-Line Element (satellite
WASM	WebAssembly (portable binary
Ephemeris	Table of celestial object po
Azimuth	Horizontal angle from north
Altitude	Vertical angle above horizon
Magnitude	Logarithmic brightness scale
Right Ascension	Celestial longitude (hours/m
Declination	Celestial latitude (degrees)

11. References

- Stellarium Web Engine - https://github.com/Stellarium/stellarium-web-engine
- ERFA Library - https://github.com/liberfa/erfa
- Capacitor Documentation - https://capacitorjs.com/docs
- HiPS Standard - https://www.ivoa.net/documents/HiPS/
- Hipparcos Catalog - https://www.cosmos.esa.int/web/hipparcos

Low-Level Design (LLD)

Table of Contents

- Project Structure
- Engine Architecture
- Frontend Architecture
- Service Layer Design
- State Management
- Component Specifications
- Algorithm Specifications
- Data Formats
- Build System
- Testing Specifications

1. Project Structure

1.1 Root Directory Structure

```
astara/
├── apps/                          # Application packages
│   ├── web-frontend/              # Vue.js frontend application
│   ├── simple-html/               # Minimal test harness
│   └── test-skydata/              # Test data files
├── src/                           # Stellarium Web Engine source (C)
│   ├── algos/                     # Astronomical algorithms
│   ├── modules/                   # Sky object modules
│   ├── projections/               # Map projections
│   ├── utils/                     # Utility functions
│   └── js/                        # JavaScript bindings
├── ext_src/                       # External dependencies
│   ├── erfa/                      # ERFA astronomical library
```

```
│   ├── stb/                        # Image loading
│   └── zlib/                       # Compression
├── data/                           # Bundled astronomical data
├── scripts/                        # Python utility scripts
├── tools/                          # Build and data tools
├── doc/                            # Engine documentation
├── docs/                           # Application documentation
├── android/                        # Android Capacitor project
├── Makefile                        # Engine build
├── SConstruct                      # SCons build config
└── README.md                       # Project overview
```

1.2 Frontend Structure

```
apps/web-frontend/
├── src/
│   ├── App.vue                     # Root Vue component
│   ├── main.js                     # Application entry point
│   ├── assets/                     # Static assets
│   │   ├── js/                     # WASM engine files
│   │   │   ├── stellarium-web-engine.js
│   │   │   └── stellarium-web-engine.wasm
│   │   ├── images/                 # UI images
│   │   ├── gyroscope-service.js    # Sensor service
│   │   ├── camera-service.js       # AR camera service
│   │   ├── search_engine.js        # Search functionality
│   │   ├── astronomy-service.js    # Event calculations
│   │   └── fullscreen-service.js   # Fullscreen control
│   ├── components/                 # Vue components
│   │   ├── bottom-bar.vue          # Main control bar
│   │   ├── search-panel.vue        # Search interface
│   │   ├── settings-panel.vue      # Settings drawer
│   │   ├── calendar-panel.vue      # Astronomical calendar
│   │   ├── GyroDirectionOverlay.vue
│   │   ├── AR-camera-preview.vue
│   │   └── ...
│   ├── store/                      # Vuex store
│   │   └── index.js
│   ├── plugins/                    # Vue plugins
│   ├── locales/                    # i18n translations
│   └── constants/                  # Configuration constants
├── public/                         # Static public files
│   └── skydata/                    # Astronomical data
├── android/                        # Capacitor Android project
├── package.json
```

```
├── vue.config.js
└── capacitor.config.json
```

2. Engine Architecture

2.1 Object System

The engine uses a C-based object-oriented system centered on obj_t:

```
// Base object structure
typedef struct obj_t {
    obj_klass_t *klass;        // Class definition
    char        *id;           // Unique identifier
    obj_t       *parent;       // Parent object
    obj_t       *children;     // Linked list of children
    obj_t       *next;         // Sibling link
    int         ref;           // Reference count

    // Position data for sky objects
    struct {
        double pvg[2][3];      // Position/velocity (geocentric)
        double unit;           // Distance unit
        double g_ra, g_dec;    // Geocentric RA/Dec
        double ra, dec;        // Apparent RA/Dec
        double az, alt;        // Azimuth/Altitude
    } pos;
} obj_t;

// Class definition
typedef struct obj_klass_t {
    const char *id;
    size_t size;
    uint32_t flags;

    // Virtual methods
    int (*init)(obj_t *obj, json_value *args);
    void (*del)(obj_t *obj);
    int (*update)(obj_t *obj, double dt);
    int (*render)(const obj_t *obj, const painter_t *painter);
```

```
    obj_t* (*get)(const obj_t *obj, const char *id, int flags);
    int (*list)(const obj_t *obj, observer_t *obs,
                double max_mag, uint64_t hint, void *user,
                int (*f)(void *user, obj_t *obj));
} obj_klass_t;
```

2.2 Module Registration

Modules are registered at compile time:

```
// Example: Stars module registration
static obj_klass_t stars_klass = {
    .id = "stars",
    .size = sizeof(stars_t),
    .flags = OBJ_IN_JSON_TREE | OBJ_MODULE,
    .init = stars_init,
    .update = stars_update,
    .render = stars_render,
    .get = stars_get,
    .list = stars_list,
    .attributes = (attribute_t[]) {
        ATTR("visible", "b", MEMBER(stars_t, visible)),
        ATTR("hints_mag_offset", "f", MEMBER(stars_t, hints_mag_offset)),
        {}
    },
};
MODULE_REGISTER(stars, &stars_klass, 0)
```

2.3 Core Modules

Module	File	Responsibility
core	core.c	Main engine, observer, time
stars	modules/stars.c	Hipparcos star catalog
planets	modules/planets.c	Solar system bodies
dso	modules/dso.c	Deep sky objects
constellations	modules/constellations.c	Constellation lines/art
satellites	modules/satellites.c	TLE-based satellites
lines	modules/lines.c	Equatorial/azimuthal grids
milkyway	modules/milkyway.c	Galactic texture
atmosphere	modules/atmosphere.c	Sky gradient

landscape	modules/landscape.c	Horizon panorama

2.4 Rendering Pipeline

```
// Main render loop
void core_render(core_t *core, double aspect, void *user) {
    painter_t painter;

    // Setup painter
    painter_init(&painter, core->proj, core->observer);

    // Render in order (back to front)
    module_render(core->milkyway, &painter);
    module_render(core->dso, &painter);
    module_render(core->stars, &painter);
    module_render(core->constellations, &painter);
    module_render(core->planets, &painter);
    module_render(core->satellites, &painter);
    module_render(core->lines, &painter);
    module_render(core->atmosphere, &painter);
    module_render(core->landscape, &painter);
    module_render(core->labels, &painter);
}
```

2.5 Projection System

Supported projections:

```
// Projection function signature
typedef bool (*proj_func_t)(
    const projection_t *proj,
    int flags,
    int out_dim,
    const double *v,
    double *out
);

// Available projections
typedef enum {
    PROJ_PERSPECTIVE,      // Normal camera view
    PROJ_STEREOGRAPHIC,    // Wide-angle, preserves circles
    PROJ_MERCATOR,         // Cylindrical
    PROJ_HEALPIX,          // HiPS survey projection
```

```
    PROJ_TOAST,            // TOAST survey projection
} projection_type_t;

// Projection flags
enum {
    PROJ_NO_CLIP            = 1 << 0,  // Skip clipping
    PROJ_BACKWARD           = 1 << 1,  // 2D → 3D
    PROJ_TO_NDC_SPACE       = 1 << 2,  // Output NDC
    PROJ_ALREADY_NORMALIZED = 1 << 3,  // Input normalized
};
```

3. Frontend Architecture

3.1 Vue Application Structure

```
// main.js - Application entry point
import Vue from 'vue'
import Vuex from 'vuex'
import App from './App.vue'
import store from './store'

Vue.use(Vuex)

// Initialize Stellarium engine
import StelWebEngine from '@/assets/js/stellarium-web-engine.js'

new Vue({
  store,
  render: h => h(App),
  beforeCreate() {
    // Engine initialization
    StelWebEngine({
      wasmFile: '/assets/js/stellarium-web-engine.wasm',
      onReady: (stel) => {
        this.$stel = stel
        Vue.prototype.$stel = stel
        store.commit('replaceStelWebEngine', stel)
      }
    })
```

```
  }
}).$mount('#app')
```

3.2 App.vue Structure

```
<template>
  <div id="app" :class="{ fullscreen: isFullscreen }">
    <!-- Engine canvas -->
    <canvas ref="stelCanvas" id="stel-canvas"></canvas>

    <!-- Overlay layers -->
    <GyroDirectionOverlay v-if="showGyroOverlay" />
    <AR-camera-preview v-if="arModeActive" />
    <DsoSkyOverlays v-if="showDsoOverlays" />

    <!-- UI layers -->
    <selected-object-info v-if="selectedObject" />
    <search-panel v-if="searchPanelOpen" />
    <settings-panel v-if="settingsPanelOpen" />
    <calendar-panel v-if="calendarPanelOpen" />

    <!-- Bottom bar (always visible) -->
    <bottom-bar />
  </div>
</template>

<script>
export default {
  name: 'App',
  computed: {
    ...mapState([
      'gyroModeActive',
      'arModeActive',
      'selectedObject',
      'searchPanelOpen',
      'settingsPanelOpen',
      'calendarPanelOpen'
    ])
  },
  mounted() {
    this.initializeEngine()
    this.initializeSensors()
  }
}
</script>
```

4. Service Layer Design

4.1 Gyroscope Service

```
// gyroscope-service.js

class GyroscopeService {
  constructor() {
    this.isActive = false
    this.calibrated = false
    this.quaternion = [0, 0, 0, 1]
    this.listeners = []

    // Sensor configuration
    this.config = {
      frequency: 60,           // Hz
      smoothingFactor: 0.2,    // Low-pass filter
      useCompass: true,        // Combine with magnetometer
    }
  }

  async start() {
    // Check for sensor support
    if (!window.DeviceOrientationEvent) {
      throw new Error('Device orientation not supported')
    }

    // Request permission (iOS 13+)
    if (typeof DeviceOrientationEvent.requestPermission === 'function') {
      const permission = await DeviceOrientationEvent.requestPermission()
      if (permission !== 'granted') {
        throw new Error('Sensor permission denied')
      }
    }

    // Start listening
    window.addEventListener('deviceorientation',
this.handleOrientation.bind(this))
    this.isActive = true
  }

  handleOrientation(event) {
    const { alpha, beta, gamma } = event
```

```
    // Convert Euler angles to quaternion
    const quat = this.eulerToQuaternion(alpha, beta, gamma)

    // Apply smoothing
    this.quaternion = this.slerp(this.quaternion, quat,
this.config.smoothingFactor)

    // Convert to azimuth/altitude
    const { azimuth, altitude } = this.quaternionToAltAz(this.quaternion)

    // Notify listeners
    this.notifyListeners({ azimuth, altitude, quaternion: this.quaternion })
  }

  eulerToQuaternion(alpha, beta, gamma) {
    // Convert degrees to radians
    const a = (alpha || 0) * Math.PI / 180
    const b = (beta || 0) * Math.PI / 180
    const g = (gamma || 0) * Math.PI / 180

    // Standard Euler to quaternion conversion
    const c1 = Math.cos(a / 2)
    const s1 = Math.sin(a / 2)
    const c2 = Math.cos(b / 2)
    const s2 = Math.sin(b / 2)
    const c3 = Math.cos(g / 2)
    const s3 = Math.sin(g / 2)

    return [
      s1 * c2 * c3 - c1 * s2 * s3,
      c1 * s2 * c3 + s1 * c2 * s3,
      c1 * c2 * s3 + s1 * s2 * c3,
      c1 * c2 * c3 - s1 * s2 * s3
    ]
  }

  quaternionToAltAz(q) {
    // Convert quaternion to viewing direction
    // Returns azimuth (0-360) and altitude (-90 to 90)

    // Extract rotation matrix from quaternion
    const [x, y, z, w] = q

    // Calculate forward vector
    const fx = 2 * (x * z + w * y)
    const fy = 2 * (y * z - w * x)
    const fz = 1 - 2 * (x * x + y * y)
```

```
    // Convert to alt/az
    const altitude = Math.asin(-fy) * 180 / Math.PI
    let azimuth = Math.atan2(fx, fz) * 180 / Math.PI
    if (azimuth < 0) azimuth += 360

    return { azimuth, altitude }
  }

  stop() {
    window.removeEventListener('deviceorientation', this.handleOrientation)
    this.isActive = false
  }

  subscribe(callback) {
    this.listeners.push(callback)
    return () => {
      this.listeners = this.listeners.filter(l => l !== callback)
    }
  }

  notifyListeners(data) {
    this.listeners.forEach(cb => cb(data))
  }
}

export default new GyroscopeService()
```

4.2 Search Engine

```
// search_engine.js

class SearchEngine {
  constructor() {
    this.nameIndex = null
    this.isLoaded = false
  }

  async loadIndex() {
    if (this.isLoaded) return

    const response = await fetch('/skydata/name_index_compact.json')
    this.nameIndex = await response.json()
    this.isLoaded = true
  }
```

```
async search(query, options = {}) {
  const {
    maxResults = 50,
    categories = ['constellation', 'planet', 'star', 'dso'],
    minScore = 0.1
  } = options

  await this.loadIndex()

  const normalizedQuery = query.toLowerCase().trim()
  const results = []

  // Search priority order
  const priorities = {
    constellation: 100,
    planet: 90,
    star: 80,
    dso: 70,
    satellite: 60
  }

  // Search exact matches first
  for (const [name, data] of Object.entries(this.nameIndex)) {
    const normalizedName = name.toLowerCase()

    if (!categories.includes(data.type)) continue

    let score = 0

    if (normalizedName === normalizedQuery) {
      score = 1.0  // Exact match
    } else if (normalizedName.startsWith(normalizedQuery)) {
      score = 0.8  // Starts with
    } else if (normalizedName.includes(normalizedQuery)) {
      score = 0.5  // Contains
    }

    if (score >= minScore) {
      results.push({
        name,
        ...data,
        score: score + (priorities[data.type] || 0) / 1000
      })
    }
  }
```

```
    // Sort by score and limit
    return results
      .sort((a, b) => b.score - a.score)
      .slice(0, maxResults)
  }

  // Query engine directly for live objects
  queryEngine(stel, query) {
    const results = []

    // Search planets
    const planets = ['mercury', 'venus', 'mars', 'jupiter', 'saturn', 'uranus',
'neptune']
    planets.forEach(p => {
      if (p.includes(query.toLowerCase())) {
        const obj = stel.getObj(`planet/${p}`)
        if (obj) results.push({ name: p, type: 'planet', obj })
      }
    })

    // Search by designation
    const obj = stel.getObjByName(query)
    if (obj) {
      results.push({ name: query, obj })
    }

    return results
  }
}

export default new SearchEngine()
```

4.3 Astronomy Service

```
// astronomy-service.js

import * as Astronomy from 'astronomy-engine'

class AstronomyService {

  // Calculate moon phases for a month
  getMoonPhases(year, month) {
    const phases = []
    const date = new Date(year, month - 1, 1)
    const endDate = new Date(year, month, 0)
```

```
  while (date <= endDate) {
    const phase = Astronomy.MoonPhase(date)

    // Check for exact phase moments
    const newMoon = Astronomy.SearchMoonQuarter(date)
    if (newMoon && this.isSameMonth(newMoon.time.date, year, month)) {
      phases.push({
        type: this.getPhaseType(newMoon.quarter),
        date: newMoon.time.date,
        illumination: this.getMoonIllumination(newMoon.time.date)
      })
    }

    date.setDate(date.getDate() + 1)
  }

  return phases
}

getPhaseType(quarter) {
  const types = ['New Moon', 'First Quarter', 'Full Moon', 'Last Quarter']
  return types[quarter] || 'Unknown'
}

getMoonIllumination(date) {
  const phase = Astronomy.MoonPhase(date)
  return (1 - Math.cos(phase * Math.PI / 180)) / 2
}

// Calculate eclipses
getEclipses(startYear, endYear) {
  const eclipses = []

  // Search for lunar eclipses
  let lunarSearch = Astronomy.SearchLunarEclipse(new Date(startYear, 0, 1))
  while (lunarSearch.peak.date.getFullYear() <= endYear) {
    eclipses.push({
      type: 'Lunar Eclipse',
      subtype: this.getLunarEclipseType(lunarSearch.kind),
      date: lunarSearch.peak.date,
      magnitude: lunarSearch.sd_total
    })
    lunarSearch = Astronomy.NextLunarEclipse(lunarSearch.peak)
  }

  return eclipses.sort((a, b) => a.date - b.date)
```

```
}

// Calculate planet conjunctions
getPlanetConjunctions(year) {
  const conjunctions = []
  const planets = ['mercury', 'venus', 'mars', 'jupiter', 'saturn']

  for (let i = 0; i < planets.length - 1; i++) {
    for (let j = i + 1; j < planets.length; j++) {
      const conj = this.findConjunction(
        planets[i],
        planets[j],
        new Date(year, 0, 1),
        new Date(year, 11, 31)
      )
      if (conj) {
        conjunctions.push({
          type: 'Conjunction',
          bodies: [planets[i], planets[j]],
          date: conj.date,
          separation: conj.separation
        })
      }
    }
  }

  return conjunctions
}

findConjunction(body1, body2, startDate, endDate) {
  // Simplified conjunction search
  let minSep = Infinity
  let conjDate = null

  const date = new Date(startDate)
  while (date <= endDate) {
    const pos1 = Astronomy.GeoVector(body1, date, false)
    const pos2 = Astronomy.GeoVector(body2, date, false)

    const sep = this.angularSeparation(pos1, pos2)

    if (sep < minSep && sep < 5) { // Within 5 degrees
      minSep = sep
      conjDate = new Date(date)
    }

    date.setDate(date.getDate() + 1)
```

```
    }

    if (conjDate) {
      return { date: conjDate, separation: minSep }
    }
    return null
  }

  angularSeparation(pos1, pos2) {
    // Calculate angular separation in degrees
    const dot = pos1.x * pos2.x + pos1.y * pos2.y + pos1.z * pos2.z
    const r1 = Math.sqrt(pos1.x**2 + pos1.y**2 + pos1.z**2)
    const r2 = Math.sqrt(pos2.x**2 + pos2.y**2 + pos2.z**2)

    const cosAngle = dot / (r1 * r2)
    return Math.acos(Math.max(-1, Math.min(1, cosAngle))) * 180 / Math.PI
  }
}

export default new AstronomyService()
```

5. State Management

5.1 Vuex Store Structure

```
// store/index.js

import Vue from 'vue'
import Vuex from 'vuex'

Vue.use(Vuex)

export default new Vuex.Store({
  state: {
    // Engine reference
    stel: null,

    // UI state
    searchPanelOpen: false,
```

```
    settingsPanelOpen: false,
    calendarPanelOpen: false,

    // Feature state
    gyroModeActive: false,
    arModeActive: false,
    sensorsEnabled: true,

    // Selection
    selectedObject: null,

    // User preferences
    favorites: [],
    recentSearches: [],

    // Location
    location: {
      lat: 28.6139,  // Default: New Delhi
      lng: 77.2090,
      alt: 0,
      name: 'New Delhi'
    },

    // Engine state mirror
    stelState: {
      constellations: {
        lines_visible: true,
        labels_visible: true,
        art_visible: false
      },
      atmosphere: {
        visible: true
      },
      stars: {
        visible: true,
        mag_limit: 6.5
      },
      dso: {
        visible: true
      },
      planets: {
        visible: true
      },
      grids: {
        equatorial: false,
        azimuthal: false
      }
```

```
    }
  },

  mutations: {
    replaceStelWebEngine(state, stel) {
      state.stel = stel
    },

    setGyroModeActive(state, active) {
      state.gyroModeActive = active
    },

    setArModeActive(state, active) {
      state.arModeActive = active
    },

    setSelectedObject(state, obj) {
      state.selectedObject = obj
    },

    addFavorite(state, obj) {
      if (!state.favorites.find(f => f.id === obj.id)) {
        state.favorites.push(obj)
        localStorage.setItem('favorites', JSON.stringify(state.favorites))
      }
    },

    removeFavorite(state, id) {
      state.favorites = state.favorites.filter(f => f.id !== id)
      localStorage.setItem('favorites', JSON.stringify(state.favorites))
    },

    setLocation(state, location) {
      state.location = location
      if (state.stel) {
        state.stel.core.observer.latitude = location.lat * Math.PI / 180
        state.stel.core.observer.longitude = location.lng * Math.PI / 180
      }
    },

    updateStelState(state, { path, value }) {
      // Update mirrored engine state
      const keys = path.split('.')
      let obj = state.stelState
      for (let i = 0; i < keys.length - 1; i++) {
        obj = obj[keys[i]]
      }
```

```
      obj[keys[keys.length - 1]] = value
    }
  },

  actions: {
    async toggleGyroMode({ commit, state }) {
      if (state.gyroModeActive) {
        gyroscopeService.stop()
        commit('setGyroModeActive', false)
      } else {
        await gyroscopeService.start()
        commit('setGyroModeActive', true)
      }
    },

    async toggleArMode({ commit, state }) {
      if (state.arModeActive) {
        cameraService.stop()
        commit('setArModeActive', false)
      } else {
        await cameraService.start()
        commit('setArModeActive', true)
      }
    },

    selectObject({ commit, state }, obj) {
      commit('setSelectedObject', obj)
      state.recentSearches.unshift({
        id: obj.id,
        name: obj.name,
        type: obj.type
      })
      state.recentSearches = state.recentSearches.slice(0, 20)
    }
  },

  getters: {
    isObjectSelected: state => !!state.selectedObject,

    favoriteIds: state => state.favorites.map(f => f.id),

    engineReady: state => !!state.stel
  }
})
```

6. Component Specifications

6.1 Bottom Bar Component

```
<!-- bottom-bar.vue -->
<template>
  <div class="bottom-bar">
    <bottom-button
      v-for="btn in buttons"
      :key="btn.id"
      :icon="btn.icon"
      :active="btn.isActive"
      @tap="btn.onTap"
      @longpress="btn.onLongPress"
    />
  </div>
</template>

<script>
export default {
  name: 'BottomBar',
  computed: {
    buttons() {
      return [
        {
          id: 'search',
          icon: 'search',
          isActive: this.$store.state.searchPanelOpen,
          onTap: () => this.togglePanel('search'),
          onLongPress: null
        },
        {
          id: 'constellations',
          icon: 'star',
          isActive: this.constellationLinesVisible,
          onTap: () => this.toggleConstellationLines(),
          onLongPress: () => this.openConstellationSettings()
        },
        {
          id: 'gyro',
          icon: 'compass',
          isActive: this.$store.state.gyroModeActive,
          onTap: () => this.$store.dispatch('toggleGyroMode'),
          onLongPress: () => this.openSensorSettings()
```

```
        },
        {
          id: 'camera',
          icon: 'camera',
          isActive: this.$store.state.arModeActive,
          onTap: () => this.$store.dispatch('toggleArMode'),
          onLongPress: () => this.openCameraSettings()
        },
        {
          id: 'calendar',
          icon: 'calendar',
          isActive: this.$store.state.calendarPanelOpen,
          onTap: () => this.togglePanel('calendar'),
          onLongPress: null
        },
        {
          id: 'settings',
          icon: 'settings',
          isActive: this.$store.state.settingsPanelOpen,
          onTap: () => this.togglePanel('settings'),
          onLongPress: null
        }
      ]
    }
  }
}
</script>

<style scoped>
.bottom-bar {
  position: fixed;
  bottom: 0;
  left: 0;
  right: 0;
  height: 60px;
  background: rgba(0, 0, 0, 0.8);
  display: flex;
  justify-content: space-around;
  align-items: center;
  z-index: 100;
}
</style>
```

6.2 Gyro Direction Overlay

```
<!-- GyroDirectionOverlay.vue -->
<template>
  <div class="gyro-overlay" :class="{ active: isActive }">
    <!-- Direction arrow for off-screen objects -->
    <div
      v-if="targetOffScreen"
      class="direction-arrow"
      :style="arrowStyle"
    >
      <svg viewBox="0 0 24 24" class="arrow-icon">
        <path d="M12 2L22 12L12 22L12 14L2 14L2 10L12 10Z"/>
      </svg>
      <span class="target-name">{{ targetName }}</span>
    </div>

    <!-- Calibration indicator -->
    <div class="calibration-status" :class="calibrationStatus">
      <span>{{ calibrationText }}</span>
    </div>
  </div>
</template>

<script>
export default {
  name: 'GyroDirectionOverlay',
  props: {
    targetObject: Object
  },
  data() {
    return {
      calibrationLevel: 0  // 0-1
    }
  },
  computed: {
    isActive() {
      return this.$store.state.gyroModeActive
    },
    targetOffScreen() {
      if (!this.targetObject) return false
      // Check if target is outside current view
      return !this.isInView(this.targetObject)
    },
    arrowStyle() {
      if (!this.targetObject) return {}
      const angle = this.calculateDirectionAngle()
      return {
        transform: `rotate(${angle}deg)`
```

```
      }
    },
    calibrationStatus() {
      if (this.calibrationLevel > 0.8) return 'good'
      if (this.calibrationLevel > 0.5) return 'fair'
      return 'poor'
    }
  },
  methods: {
    calculateDirectionAngle() {
      // Calculate angle from center to target
      const targetAz = this.targetObject.azimuth
      const currentAz = this.$store.state.currentAzimuth
      return (targetAz - currentAz + 360) % 360
    },
    isInView(obj) {
      // Check if object is within current view frustum
      const fov = this.$stel.core.fov
      const deltaAz = Math.abs(obj.azimuth - this.$store.state.currentAzimuth)
      const deltaAlt = Math.abs(obj.altitude -
this.$store.state.currentAltitude)
      return deltaAz < fov / 2 && deltaAlt < fov / 2
    }
  }
}
</script>
```

7. Algorithm Specifications

7.1 Sky Object Ranking

```
// Search result ranking algorithm

function rankSearchResults(results, query) {
  const weights = {
    exactMatch: 100,
    startsWithMatch: 50,
    containsMatch: 20,
    typeBonus: {
```

```
      constellation: 15,
      planet: 12,
      star: 8,
      dso: 5,
      satellite: 3
    },
    magnitudeBonus: (mag) => Math.max(0, 10 - mag),  // Brighter = higher
    visibilityBonus: (alt) => alt > 0 ? 10 : 0       // Above horizon
  }

  return results.map(result => {
    let score = 0
    const name = result.name.toLowerCase()
    const q = query.toLowerCase()

    // Match type
    if (name === q) {
      score += weights.exactMatch
    } else if (name.startsWith(q)) {
      score += weights.startsWithMatch
    } else if (name.includes(q)) {
      score += weights.containsMatch
    }

    // Type bonus
    score += weights.typeBonus[result.type] || 0

    // Magnitude bonus (for stars/DSOs)
    if (result.magnitude !== undefined) {
      score += weights.magnitudeBonus(result.magnitude)
    }

    // Visibility bonus
    if (result.altitude !== undefined) {
      score += weights.visibilityBonus(result.altitude)
    }

    return { ...result, score }
  }).sort((a, b) => b.score - a.score)
}
```

7.2 Gyroscope Smoothing

```
// Low-pass filter for sensor data
```

```
class SensorSmoother {
  constructor(alpha = 0.2) {
    this.alpha = alpha  // Smoothing factor (0 = no smoothing, 1 = no filtering)
    this.lastValue = null
  }

  smooth(newValue) {
    if (this.lastValue === null) {
      this.lastValue = newValue
      return newValue
    }

    // Exponential moving average
    this.lastValue = this.alpha * newValue + (1 - this.alpha) * this.lastValue
    return this.lastValue
  }

  // Spherical interpolation for quaternions
  slerp(q1, q2, t) {
    let dot = q1[0]*q2[0] + q1[1]*q2[1] + q1[2]*q2[2] + q1[3]*q2[3]

    // Ensure shortest path
    if (dot < 0) {
      q2 = q2.map(x => -x)
      dot = -dot
    }

    // If very close, use linear interpolation
    if (dot > 0.9995) {
      const result = q1.map((v, i) => v + t * (q2[i] - v))
      return this.normalize(result)
    }

    // Spherical interpolation
    const theta0 = Math.acos(dot)
    const theta = theta0 * t
    const sinTheta = Math.sin(theta)
    const sinTheta0 = Math.sin(theta0)

    const s0 = Math.cos(theta) - dot * sinTheta / sinTheta0
    const s1 = sinTheta / sinTheta0

    return q1.map((v, i) => s0 * v + s1 * q2[i])
  }

  normalize(q) {
    const len = Math.sqrt(q[0]**2 + q[1]**2 + q[2]**2 + q[3]**2)
```

```
    return q.map(v => v / len)
  }
}
```

8. Data Formats

8.1 Name Index Format

```
{
  "Sirius": {
    "type": "star",
    "id": "HIP 32349",
    "mag": -1.46,
    "ra": 101.2875,
    "dec": -16.7161,
    "alt_names": ["Alpha Canis Majoris", "Dog Star"]
  },
  "M31": {
    "type": "dso",
    "id": "NGC 224",
    "mag": 3.4,
    "ra": 10.6847,
    "dec": 41.2689,
    "alt_names": ["Andromeda Galaxy", "NGC 224"]
  },
  "Orion": {
    "type": "constellation",
    "id": "Ori",
    "stars": ["HIP 26727", "HIP 27989", "..."]
  }
}
```

8.2 Event Data Format

```
{
  "events": [
    {
```

```
      "type": "moon_phase",
      "subtype": "full_moon",
      "date": "2026-01-19T12:30:00Z",
      "data": {
        "illumination": 1.0
      }
    },
    {
      "type": "eclipse",
      "subtype": "lunar_total",
      "date": "2026-03-14T00:00:00Z",
      "data": {
        "magnitude": 1.2,
        "duration_minutes": 180
      }
    },
    {
      "type": "conjunction",
      "bodies": ["venus", "jupiter"],
      "date": "2026-02-20T06:00:00Z",
      "data": {
        "separation_degrees": 0.5
      }
    }
  ]
}
```

9. Build System

9.1 Makefile Targets

```
# Main targets
make              # Build WASM engine
make debug        # Build with debug symbols
make clean        # Clean build artifacts
make sync-android # Sync web build to Capacitor
make build-apk    # Build Android APK

# Engine build (SConstruct)
```

```
scons -j4 mode=release target=wasm
scons -j4 mode=debug target=wasm
```

9.2 npm Scripts

```
{
  "scripts": {
    "dev": "vue-cli-service serve",
    "build": "vue-cli-service build",
    "lint": "vue-cli-service lint",
    "android:sync": "npx cap sync android",
    "android:open": "npx cap open android"
  }
}
```

---

10. Testing Specifications

10.1 Unit Tests

```
// Example: Search engine tests
describe('SearchEngine', () => {
  beforeAll(async () => {
    await searchEngine.loadIndex()
  })

  test('exact match returns highest score', async () => {
    const results = await searchEngine.search('Sirius')
    expect(results[0].name).toBe('Sirius')
    expect(results[0].score).toBeGreaterThan(0.9)
  })

  test('partial match returns results', async () => {
    const results = await searchEngine.search('sir')
    expect(results.length).toBeGreaterThan(0)
    expect(results.some(r => r.name === 'Sirius')).toBe(true)
  })
```

```
  test('category filter works', async () => {
    const results = await searchEngine.search('M', { categories: ['dso'] })
    results.forEach(r => {
      expect(r.type).toBe('dso')
    })
  })
})
```

10.2 Integration Tests

```
// Example: Gyroscope service integration
describe('GyroscopeService Integration', () => {
  test('sensor data updates engine view', async () => {
    const mockStel = {
      core: {
        observer: {
          azimuth: 0,
          altitude: 0
        }
      }
    }

    gyroscopeService.subscribe(({ azimuth, altitude }) => {
      mockStel.core.observer.azimuth = azimuth
      mockStel.core.observer.altitude = altitude
    })

    // Simulate sensor event
    const event = new DeviceOrientationEvent('deviceorientation', {
      alpha: 180,
      beta: 45,
      gamma: 0
    })
    window.dispatchEvent(event)

    expect(mockStel.core.observer.azimuth).toBeCloseTo(180, 1)
    expect(mockStel.core.observer.altitude).toBeCloseTo(45, 1)
  })
})
```

Document prepared by: Astara Development Team Last updated: January 2026

Part III: User Guides

User Manual

Table of Contents

- Introduction
- Installation
- Quick Start Guide
- User Interface
- Core Features
- Search and Navigation
- Settings and Configuration
- Astronomical Calendar
- Advanced Features

1. Introduction

1.1 About Astara

Astara is a comprehensive mobile planetarium application. It transforms your Android device into a powerful astronomical tool that can identify stars, planets, constellations, and deep sky objects simply by pointing at the sky.

1.2 Key Capabilities

- Point and Identify: Use your device's sensors to identify what's in the sky
- Augmented Reality: Overlay star data on your camera feed
- Offline Operation: Full functionality without internet connection
- 60,000+ Objects: Stars, planets, galaxies, nebulae, satellites
- Multiple Sky Cultures: IAU, Indian, Chinese, Arabic constellations
- Astronomical Events: Moon phases, eclipses, planet conjunctions

1.3 System Requirements

Requirement	Specification
OS	Android 8.0 (Oreo) or higher
RAM	2 GB minimum, 4 GB recommend
Storage	200 MB free space
Sensors	Gyroscope, accelerometer (re
Camera	Rear camera (required for AR
GPS	For automatic location

---

2. Installation

2.1 APK Installation

- Enable Unknown Sources
  - Go to Settings > Security > Install unknown apps
  - Enable installation for your file manager
- Install the APK
  - Locate the astara.apk file
  - Tap to install
  - Grant requested permissions
- Grant Permissions
  - Location (for accurate sky position)
  - Camera (for AR mode)
  - Sensors (automatically granted)

2.2 First Launch

On first launch, Astara will:

- Load the astronomical database (~5 seconds)
- Request necessary permissions
- Detect your location (if permitted)

- Display the current sky view

3. Quick Start Guide

3.1 Basic Operation

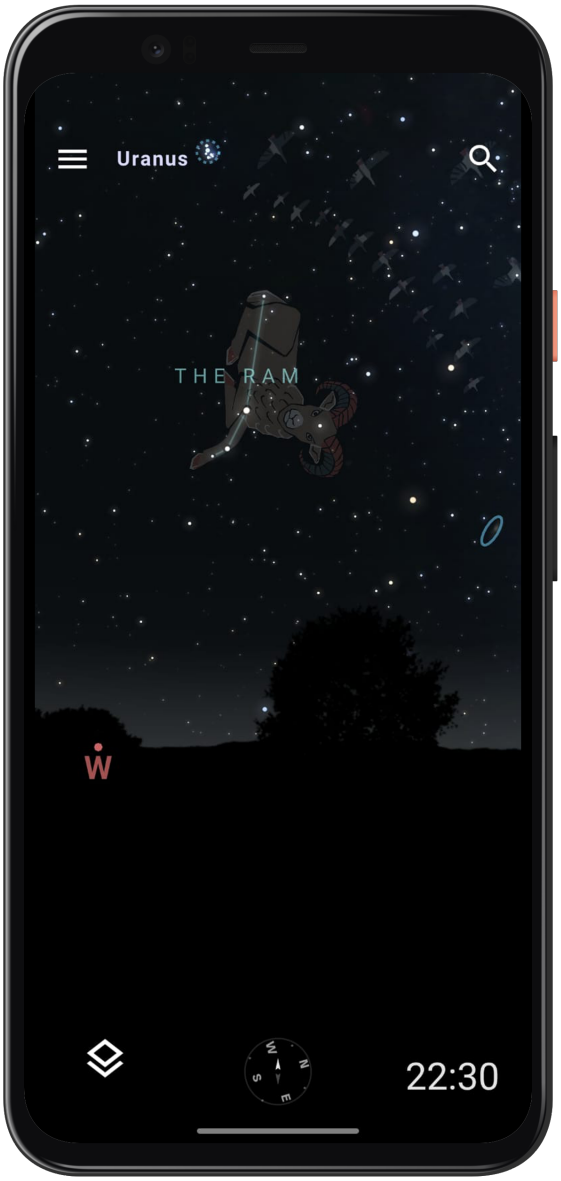
- Launch Astara - Tap the app icon
- Enable Gyroscope Mode - Tap the gyroscope icon in the bottom bar
- Point at the Sky - Hold your device towards the sky
- View Objects - Stars, constellations, and planets appear in real-time
- Tap an Object - Get detailed information

3.2 Control Gestures

Gesture	Action
Drag	Pan sky view (manual mode)
Pinch	Zoom in/out
Single Tap	Select celestial object
Long Press	Open context menu in bottom

4. User Interface

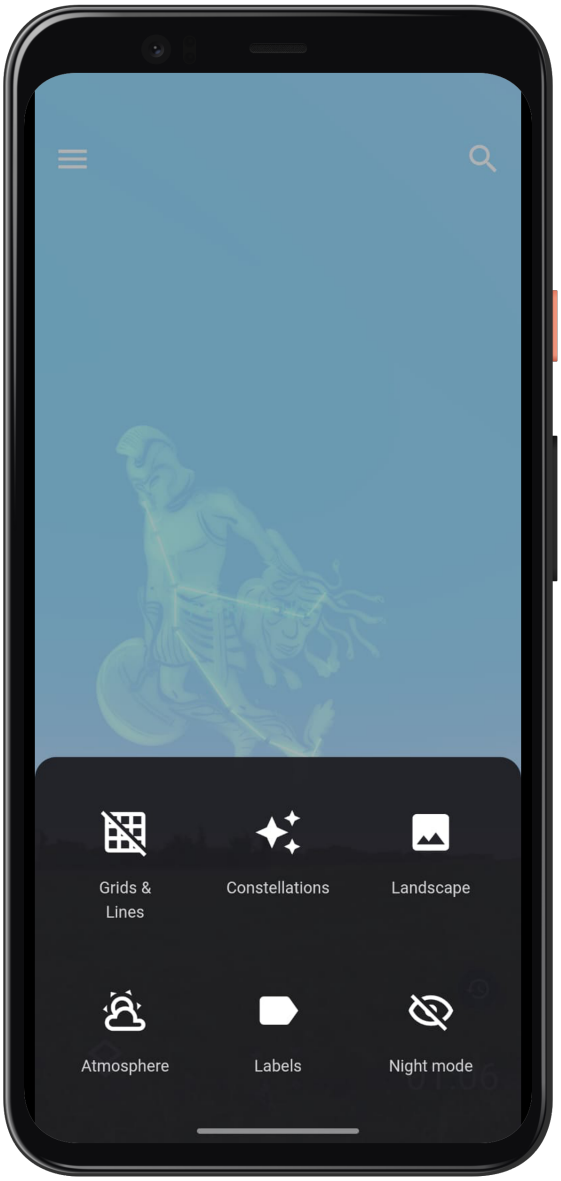
4.1 Main Screen Layout



4.2 Bottom Bar Layout

The bottom bar has three sections:

Section	Element	Function
Left	Menu Button	Opens the display settings p
Center	Compass	Tap to activate gyroscope mo
Right	Time Display	Tap to access time control a



4.3 Menu Panel

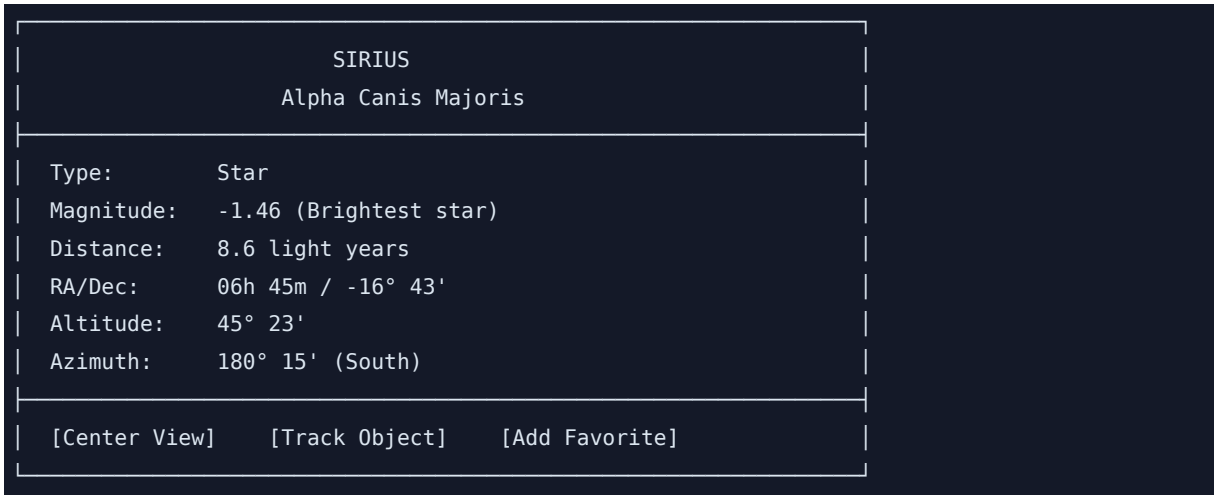
Tap the menu button (layers icon) to open the settings panel with these options:

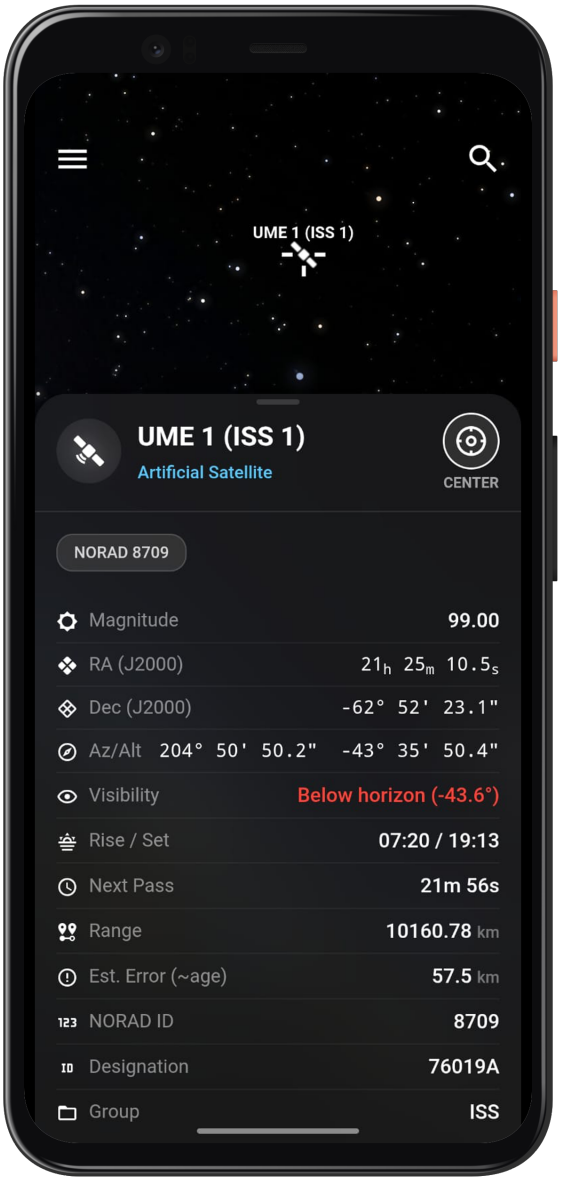
Option	Tap	Long Press
Grids & Lines	Toggle grid overlays	Open grid settings submenu
Constellations	Toggle constellation lines/a	Open constellation settings
Landscape	Toggle ground/horizon displa	Open landscape selection
Atmosphere	Toggle sky color simulation	Open atmosphere settings

Labels	Toggle object labels	Open label settings
Night Mode	Toggle red tint for night vi	-

4.4 Information Panel

When you select a celestial object, an information panel appears:





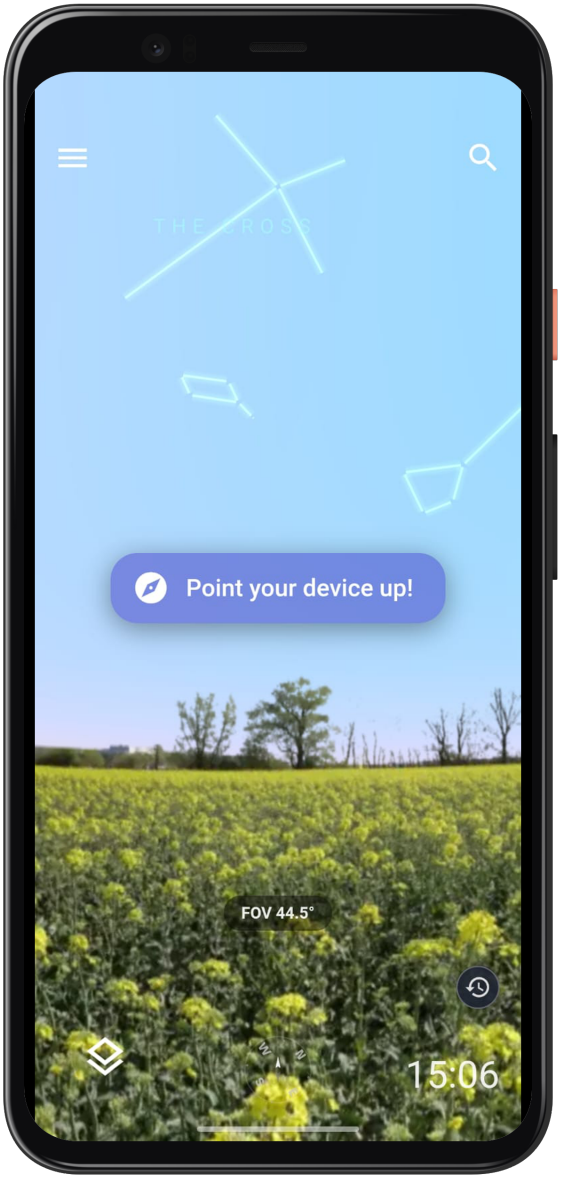
5. Core Features

5.1 Gyroscope Mode

Gyroscope mode uses your device's sensors to display the sky region you're pointing at.

Enable Gyroscope Mode:

- Tap the compass icon () in the bottom bar
- Hold your device flat briefly for calibration
- Point towards the sky
- The view updates in real-time



5.2 Augmented Reality (AR) Mode

AR mode overlays constellation lines and labels on your camera feed.

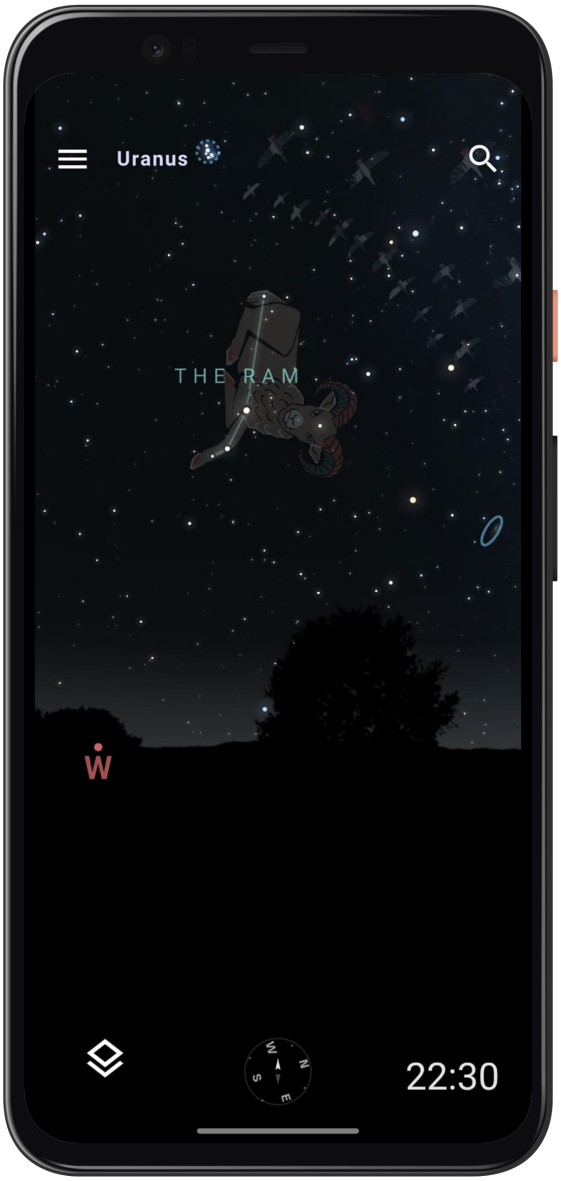
Enable AR Mode:

- Tap the camera icon () in the bottom bar
- Grant camera permission if prompted
- Point camera at the sky
- Stars and labels appear overlaid on the live feed
- Transparency: Adjust overlay opacity in settings
- Labels: Toggle star names on/off
- Lines: Toggle constellation lines

5.3 Constellation Display

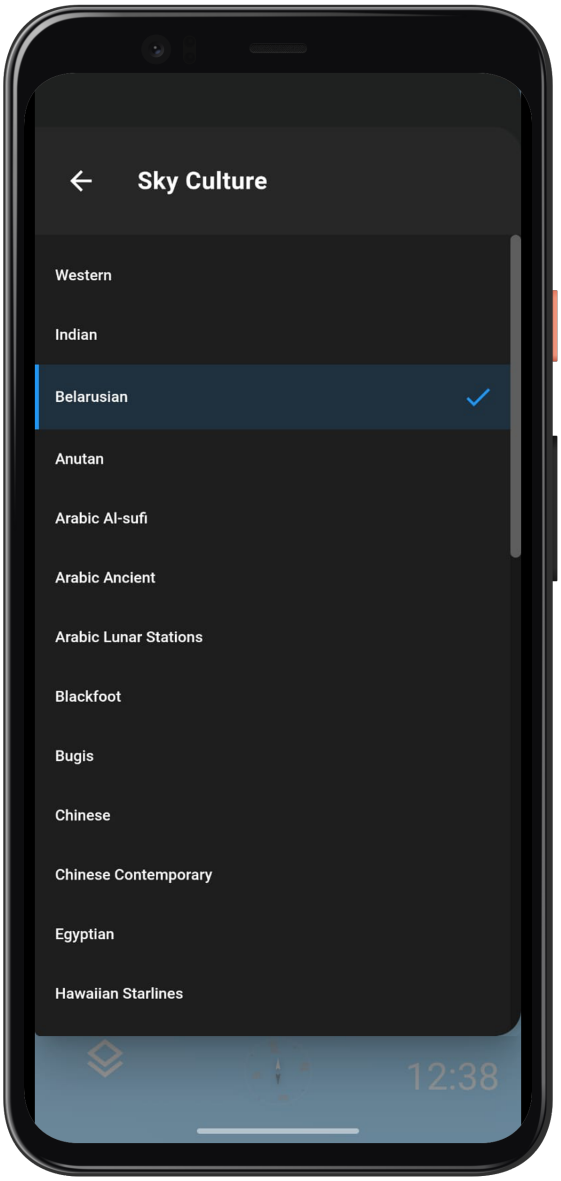
Toggle constellation visualizations:

Mode	Description
Lines	Connect stars with lines
Art	Display mythology artwork
Boundaries	Show constellation boundarie
Labels	Show constellation names



Change Sky Culture:

- Open Settings (⚙)
- Tap "Sky Culture"
- Select from:
  - IAU (International Astronomical Union)
  - Indian Traditional
  - Chinese
  - Arabic
  - And more...



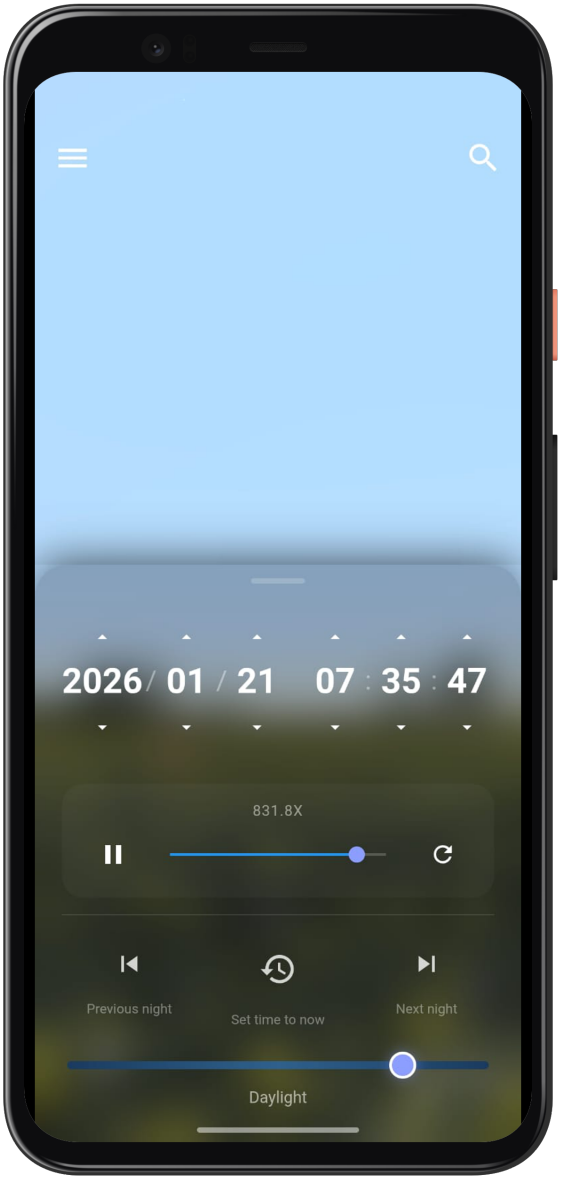
5.4 Time Control

Astara can simulate the sky at any date and time.

Access Time Controls:

- Tap the time display at top of screen
- Use date/time picker to select
- Or tap Quick buttons:
  - Now: Return to current time
  - Sunrise/Sunset: Jump to these events

    - +1 Hour/-1 Hour: Step through time
- Tap play button to animate sky motion
- Adjust speed between -10000x and 10000x

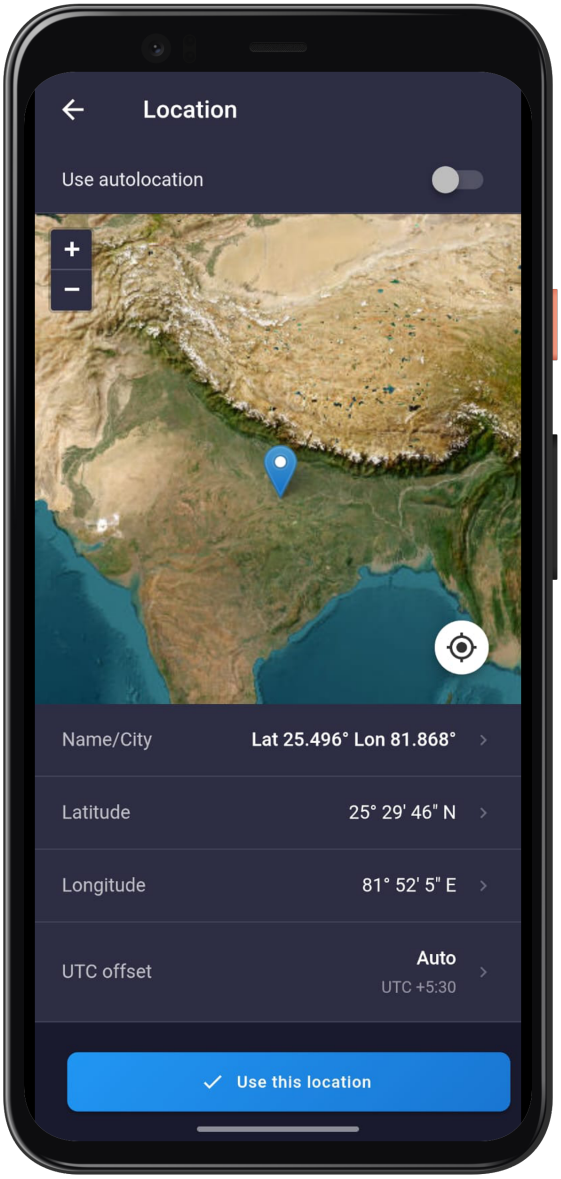


5.5 Location Settings

Automatic Location:

- Ensure GPS is enabled
- Open Settings > Location
- Tap "Use Autolocation"

- Open Settings > Location
- Enter coordinates manually:
  - Latitude: e.g., 28.6139
  - Longitude: e.g., 77.2090
- Or search by city name
- Save frequently used locations
- Quick switch between observing sites



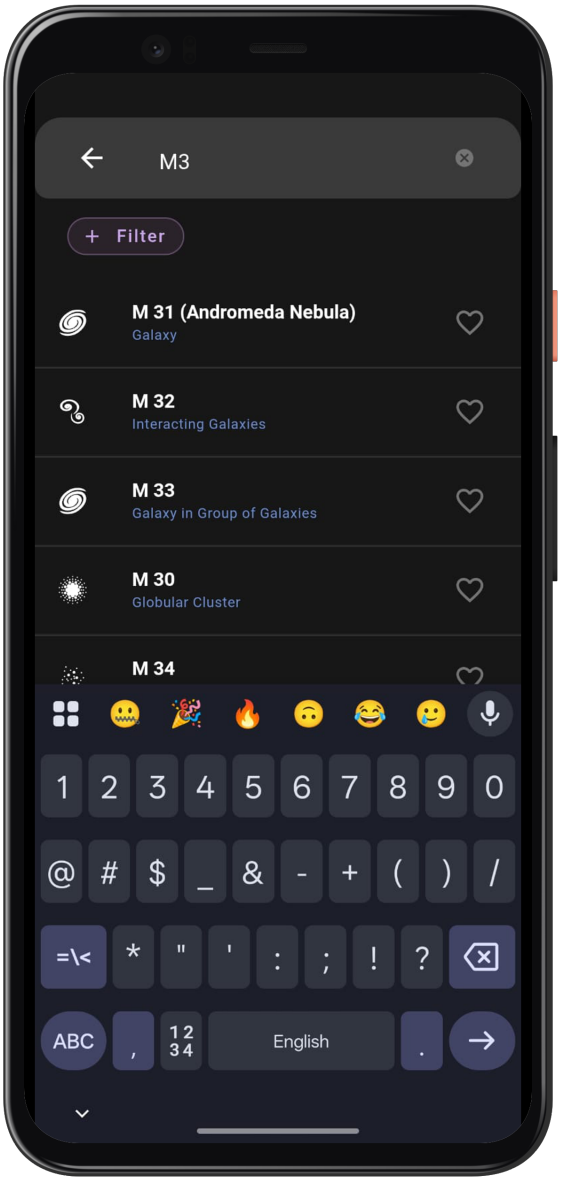
6. Search and Navigation

6.1 Search Panel

Tap the search icon () to open the search panel.

Search by Name:

- Type object name (e.g., "Orion", "Mars", "M31")
- Results appear as you type
- Tap result to center view on object



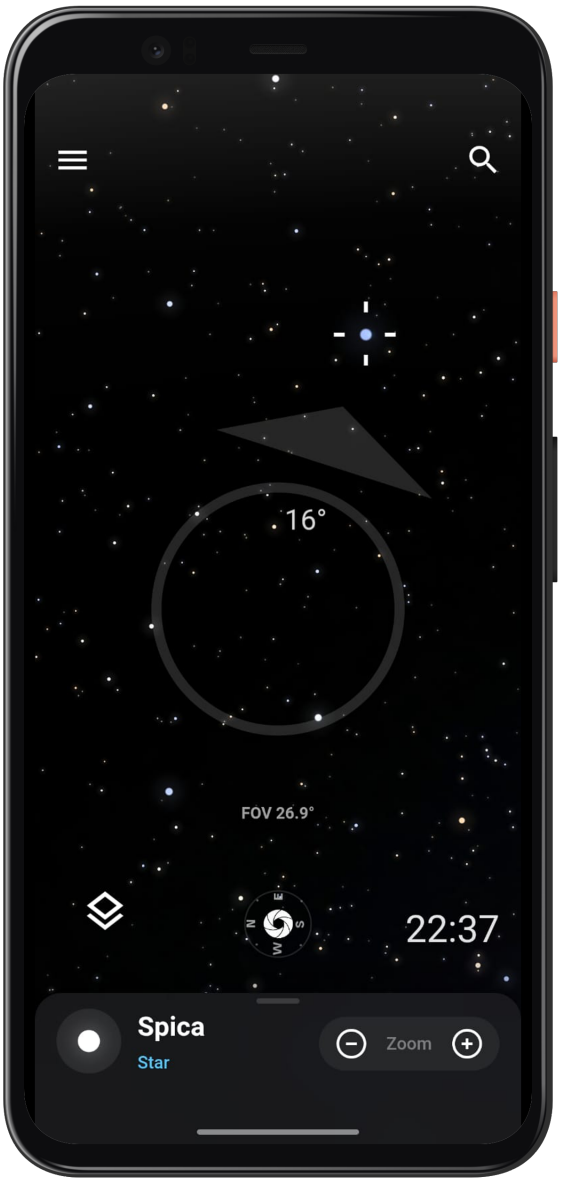
Search Categories:

Category	Examples
Constellations	Orion, Ursa Major, Scorpius
Stars	Sirius, Vega, Polaris, HIP 1
Planets	Mars, Jupiter, Saturn
DSOs	M31, NGC 224, Andromeda Gala
Satellites	ISS, Hubble

6.2 Direction Indicator

When tracking an object not in view:

- Select any object
- If object is below horizon or out of view
- An arrow indicator shows direction to object
- Follow arrow to locate object in sky



6.3 Favorites and Recent

Add to Favorites:

- Select an object
- Tap "Add Favorite" ()
- Object saved for quick access
- Open Search panel
- Tap "Favorites" or "Recent" tab
- Tap any item to navigate

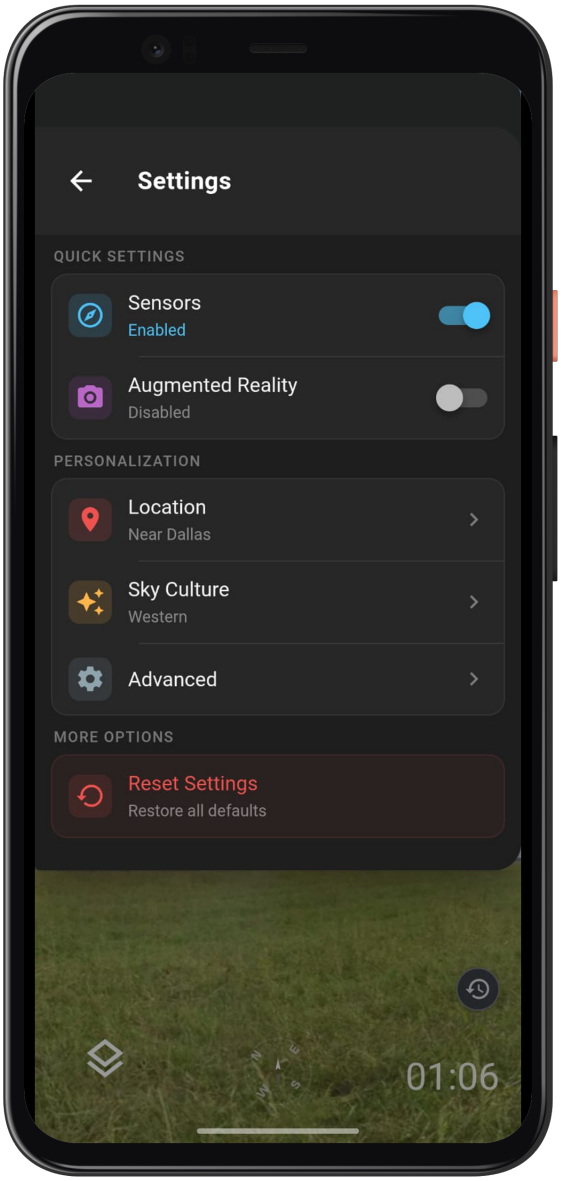
---

7. Settings and Configuration

7.1 Display Settings

Access via Settings (⚙) > Display:

Setting	Options
Stars	Show/Hide, Limit magnitude
Star Names	Show/Hide, Limit by magnitud
Planets	Show/Hide, Show labels
DSOs	Show/Hide, Show markers
Atmosphere	Enable/Disable sky color sim
Milky Way	Show/Hide galactic band
Grid Lines	Equatorial, Azimuthal, Off



7.2 Star Rendering

Setting	Description
Limiting Magnitude	Faintest stars shown (defaul
Twinkling	Star scintillation effect
Colored Stars	Show star colors based on te
Size Scaling	Relative star sizes

7.3 Light Pollution

Simulate different observing conditions:

Bortle Scale	Description
1	Excellent dark site
4	Rural/suburban transition
6	Bright suburban
8-9	City center

7.4 Sensor Settings

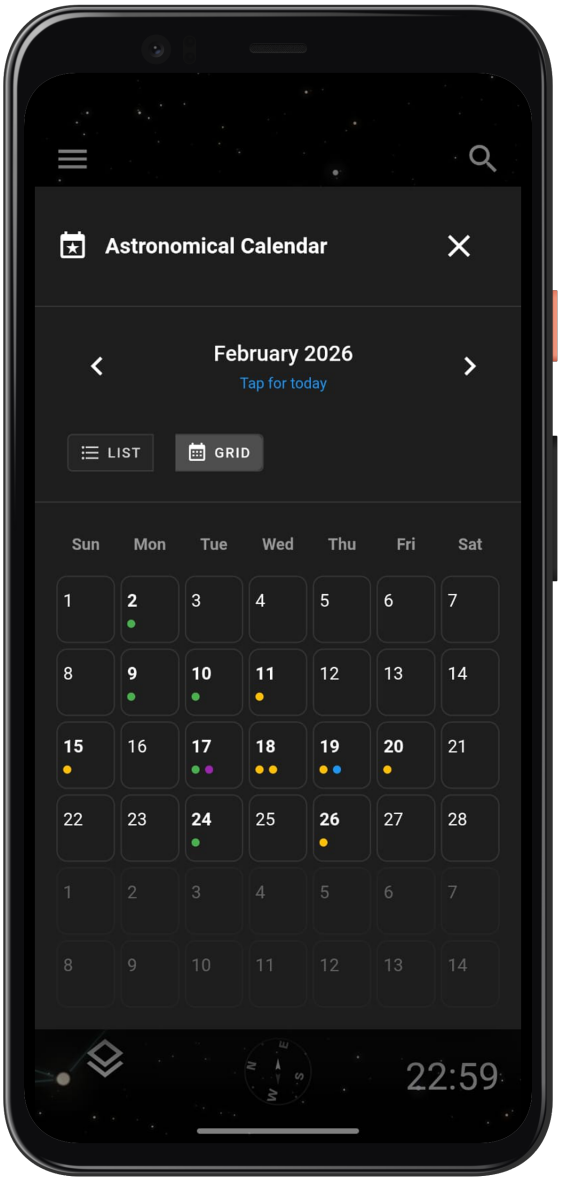
Setting	Description
Sensitivity	Gyroscope response speed
Smoothing	Reduce jitter
Auto-Calibrate	Periodic recalibration
Compass Mode	Use compass with gyro

---

8. Astronomical Calendar

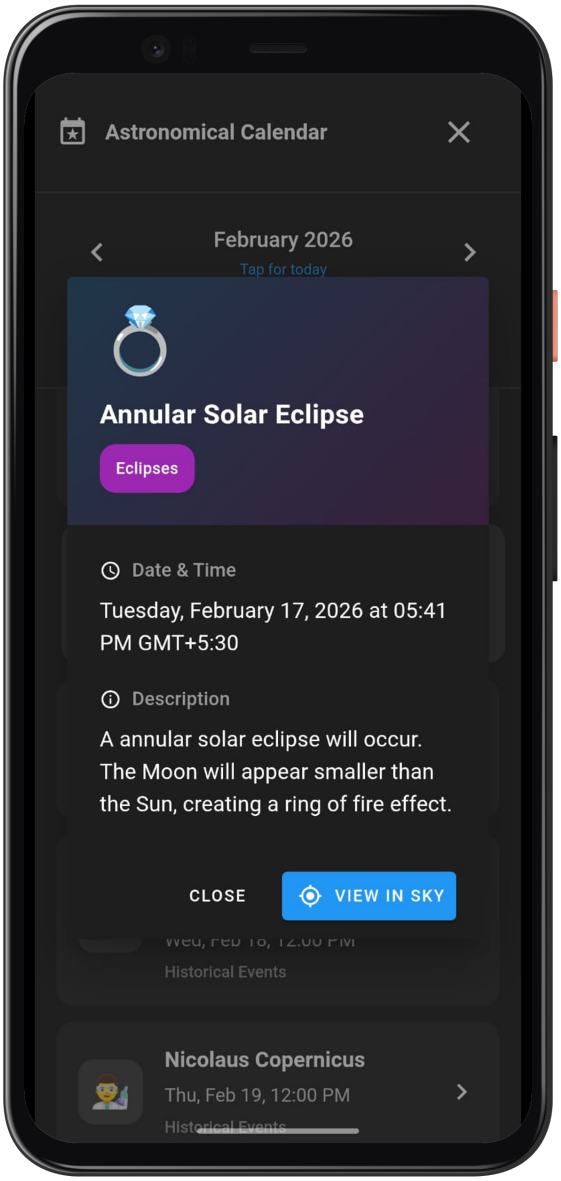
8.1 Calendar Panel

Tap the calendar icon () to view astronomical events.



Event Types:

Event	Icon	Description
Moon Phases		New, First Quarter, Full, La
Eclipses	●	Solar and Lunar eclipses
Conjunctions	•	Planet meetups
Planet Events		Opposition, Greatest Elongat



8.2 Filtering Events

- Open Calendar panel
- Tap filter icon
- Select event types to show
- Apply filter

8.3 Event Details

Tap any event to see:

- Date and time
- Visibility from your location
- Description
- Observing tips

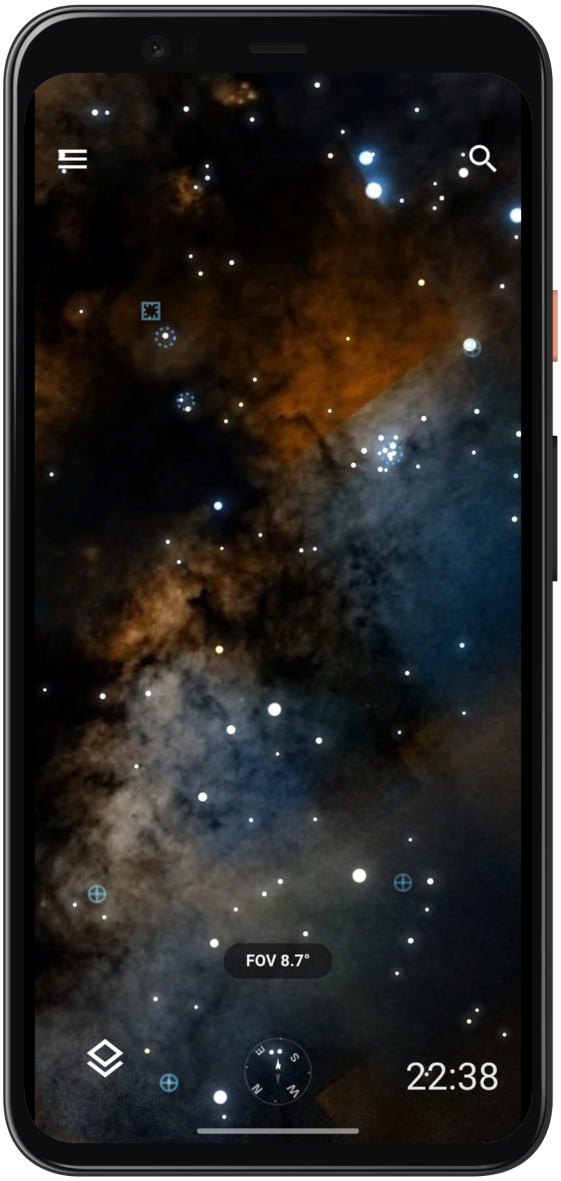
---

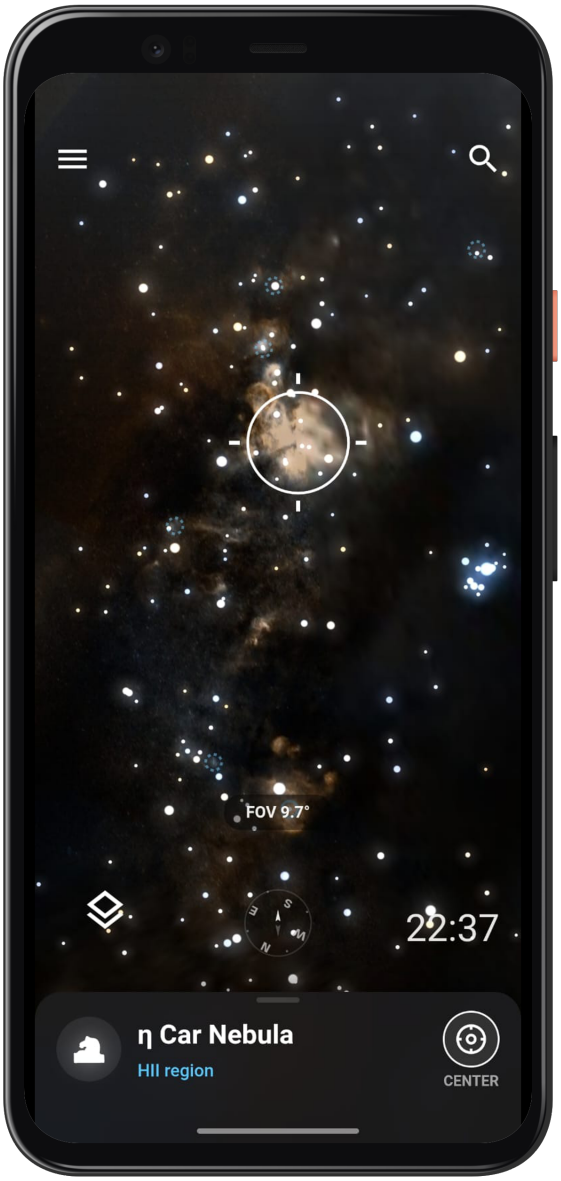
9. Advanced Features

9.1 Deep Sky Object (DSO) Overlays

View high-resolution images of DSOs:

- Search for a DSO (e.g., "M42")
- Zoom in closely
- HiPS image overlay appears automatically
- Pinch to zoom into detailed structure


FOV 8.7°
22:38

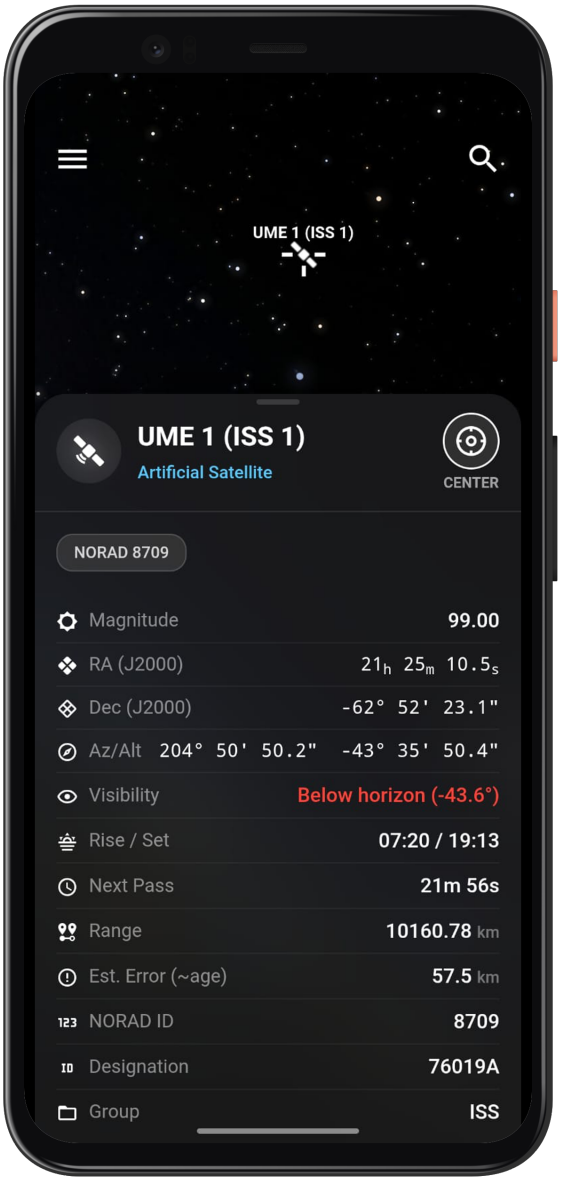


9.2 Satellite Tracking

View Satellites:

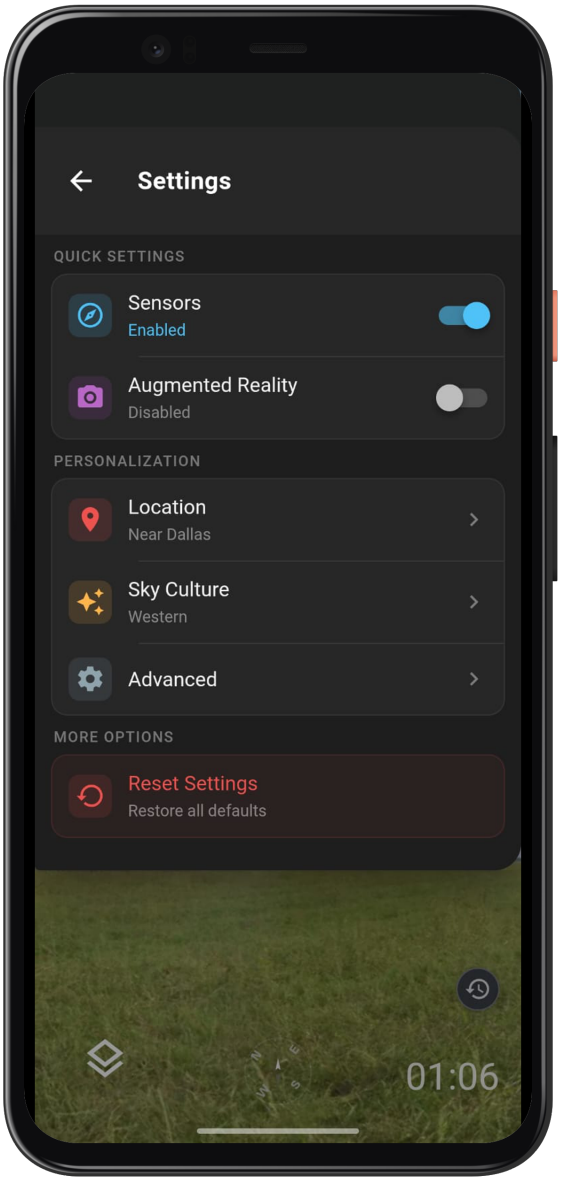
- Settings > Objects > Satellites
- Enable satellite display
- Satellites appear as moving dots
- Search "ISS"
- Tap to select
- View next visible pass times

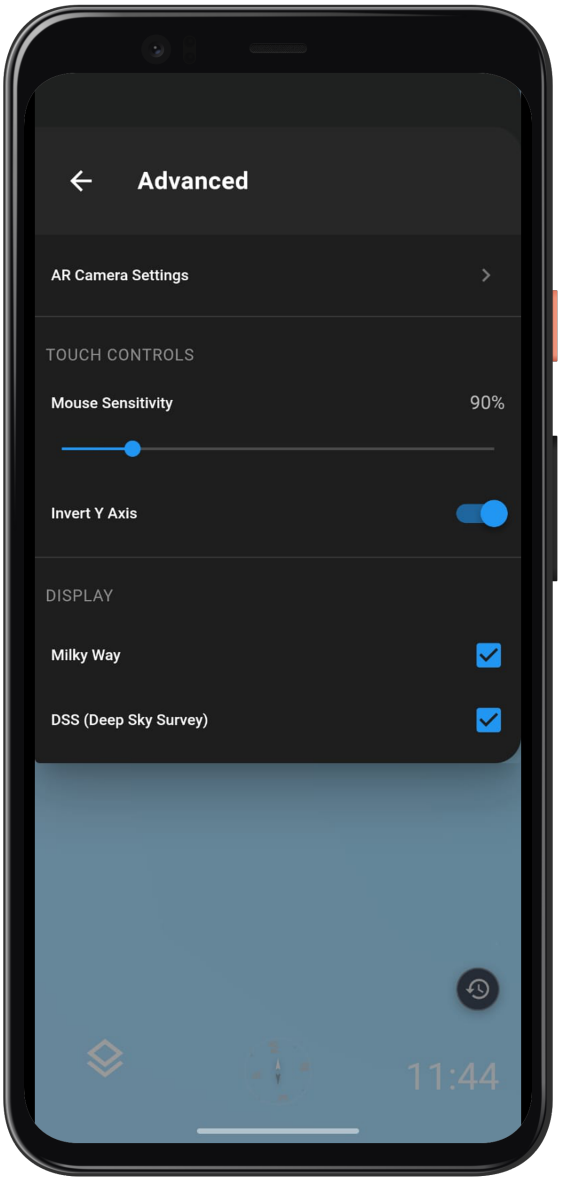
- Track in real-time during pass



9.3 Advanced Settings

- Settings > Advanced
- Adjust slider for desired touch sensitivity
- Toggle invert Y-axis for manual panning mode
- Adjust gyroscope and AR settings


Settings
QUICK SETTINGS
Sensors
Enabled
Augmented Reality
Disabled
PERSONALIZATION
Location
Near Dallas
Sky Culture
Western
Advanced
MORE OPTIONS
Reset Settings
Restore all defaults
01:06


Advanced
AR Camera Settings
TOUCH CONTROLS
Mouse Sensitivity
90%
Invert Y Axis
DISPLAY
Milky Way
DSS (Deep Sky Survey)
11:44

Setup & Installation

> *Windows users: Use WSL (Windows Subsystem for Linux) for the build process.*

> *Native Windows builds are not supported.*

Table of Contents

- Build with Docker (Recommended)
- Build Android APK
- Manual Build (Alternative)

Prerequisites

Clone the Astara repository:

```
git clone https://github.com/DesolateSea/Astara_stellarium-web-engine.git astara
cd astara
```

Clone the Emscripten SDK:

> *Note: Ensure it is installed in the astara root folder for the Docker method.*

```
git clone https://github.com/emscripten-core/emsdk.git
```

1. Build with Docker (Recommended)

Ensure Docker is installed and running:

```
sudo systemctl status docker
# If not running:
sudo systemctl start docker
```

Navigate to the web frontend directory:

```
cd apps/web-frontend
```

Run the setup command. This will:

- Build the Docker image for Emscripten compilation.
- Compile the Stellarium Web Engine (WASM + JS) inside Docker.
- Build the Docker image for the Node.js environment.
- Install Node.js dependencies (using Yarn) inside Docker.

```
sudo -E make setup
```

Run frontend on dev server:

```
sudo -E make dev
```

Build the production frontend:

```
sudo -E make build
```

The build artifacts will be in dist.

---

2. Build Android APK

Set required environment variables:

```
export CAPACITOR_ANDROID_STUDIO_PATH=/path/to/android-studio/bin/studio.sh
```

```
export JAVA_HOME=/path/to/java-21-openjdk
export PATH=$JAVA_HOME/bin:$PATH
```

Sync with Capacitor:

```
make sync-android
```

Build the debug APK:

```
make build-apk
```

The APK will be located at:

```
android/app/build/outputs/apk/debug/app-debug.apk
```

Sign the Release APK

Generate a keystore in the android directory (one-time setup):

```
cd android
keytool -genkey -v -keystore my-release-key.jks -keyalg RSA -keysize 2048
-validity 10000 -alias my-key-alias
```

Build the release APK:

```
./gradlew assembleRelease
```

Sign the APK using apksigner:

> *Note: apksigner is located in $ANDROID_HOME/build-tools/<version>/. Use the full path if it's not in your PATH.*

macOS/Linux:

```
$ANDROID_HOME/build-tools/34.0.0/apksigner sign --ks my-release-key.jks --out
app-release-signed.apk app/build/outputs/apk/release/app-release.apk
```

Windows (PowerShell/CMD):

```
%LOCALAPPDATA%\Android\Sdk\build-tools\34.0.0\apksigner sign --ks my-release-
key.jks --out app-release-signed.apk app\build\outputs\apk\release\app-
release.apk
```

Verify the signature:

macOS/Linux:

```
$ANDROID_HOME/build-tools/34.0.0/apksigner verify app-release-signed.apk
```

Windows:

```
%LOCALAPPDATA%\Android\Sdk\build-tools\34.0.0\apksigner verify app-release-
signed.apk
```

---

3. Manual Build (Alternative)

If you prefer to build web-frontend manually without Docker, follow these steps.

3.1. Setting Up Emscripten

Manually install and activate the Emscripten SDK:

```
cd emsdk
./emsdk install latest
./emsdk activate latest     # writes .emscripten file
source ./emsdk_env.sh       # Active PATH and other environment variables in
current terminal
```

Install additional versions required by Stellarium:

```
# Get a tip-of-tree
./emsdk install tot

# Install required emscripten version
./emsdk install 1.40.1
./emsdk activate 1.40.1
source ./emsdk_env.sh
```

> *Note: Stellarium Web Engine is sensitive to Emscripten versions.*

> *Version 1.40.1 is known to work reliably.*

Install scons (choose one):

```
sudo apt-get install scons        # Debian / Ubuntu
sudo dnf install scons            # Fedora
pip install scons                 # Python
```

3.2. Build Stellarium Web Engine (WASM + JS)

Activate Emscripten:

```
source /path/to/emsdk/emsdk_env.sh
```

Build the engine:

```
make
```

Copy the generated artifacts into the frontend:

```
cp build/stellarium-web-engine.* apps/web-frontend/src/assets/js/
```

This produces:

- stellarium-web-engine.js
- stellarium-web-engine.wasm

3.3. Build Web Frontend

```
cd apps/web-frontend
npm install --legacy-peer-deps
```

Workaround for OpenSSL compatibility:

```
export NODE_OPTIONS=--openssl-legacy-provider
```

Run the dev server:

```
npm run dev
```

Build the production frontend:

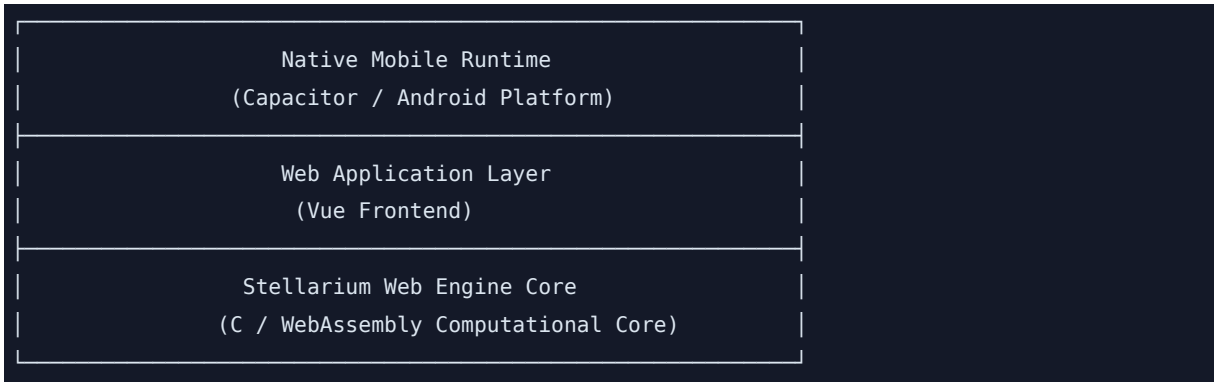
```
npm run build
```

Part IV: Technical Reference

Architecture Overview

Architecture Overview

Astara is a mobile planetarium app built on the Stellarium Web Engine. We wrap the engine with a Vue frontend and package it as an Android app using Capacitor.



Engine Layer

This is the Stellarium Web Engine core, compiled from C to WebAssembly. It does all the heavy work: astronomical calculations, sky state, projections, and rendering logic.

Nothing in this layer is mobile-specific. It behaves exactly like upstream.

If you want to understand how the engine is structured internally, read doc/internals.md.

Web Application Layer

This is the JavaScript / Vue layer that sits on top of the engine.

It handles things like:

- Taking user and sensor input.

- Converting that into engine state updates.
- Keeping UI state separate from simulation state.

Native Mobile Runtime

This is the Capacitor wrapper around the web app.

It mainly exists to provide the mobile shell: app manifest, permissions, window flags, orientation handling, and platform integration.

Most native functionality is accessed through @capacitor/* plugins from the JavaScript layer rather than custom Java / Kotlin code.

Data and Control Flow

The system follows a strict unidirectional flow model:

```
Native Sensors / OS Events
          ↓
  Web Application Layer
          ↓
  Engine State Updates
          ↓
Engine Render / Simulation
          ↓
    Visual Output
```

User interaction follows the same pipeline, entering through the web layer and propagating downward into the engine core.

This model ensures:

- Isolation of deterministic simulation logic.
- Platform independence of the engine.
- Replaceability of the mobile runtime without modifying the computational core.

Frontend Guide

The frontend lives in apps/web-frontend/src/. It's a Vue 2 app that talks to the Stellarium Web Engine and wraps it for mobile via Capacitor.

Engine Boundary

The engine is a WebAssembly module exposed as $stel on the Vue instance.

To read engine state:

```
this.$store.state.stel.constellations.lines_visible
```

To write engine state:

```
this.$stel.core.constellations.lines_visible = true
```

The Vuex store mirrors the engine state via replaceStelWebEngine. This keeps Vue's reactivity in sync with the engine. You read from the store, write to the engine directly.

Services

These are standalone modules in assets/ that handle platform features. Some examples are:

Service	File	What it does
Gyroscope	gyroscope-service.js	Device orientation → sky vie
Camera	camera-service.js	Camera feed for AR mode
Fullscreen	fullscreen-service.js	Android immersive mode

Search	search_engine.js	Sky object search with filte

Services are typically initialized in App.vue and accessed globally or through the Vuex store.

State Management

The Vuex store (store/index.js) holds two kinds of state:

Engine state — mirrored from the WASM engine:

```
state.stel = {
  constellations: { lines_visible: true, ... },
  atmosphere: { visible: true },
  ...
}
```

App state — things the engine doesn't know about:

```
state.gyroModeActive = false
state.arModeActive = false
state.sensorsEnabled = true
```

Mutations like setGyroModeActive update app state. The engine state is updated by writing to $stel.core.* and gets synced back via the watcher.

Component Patterns

Bottom Menu

The bottom menu (components/bottom-menu/) uses a pattern where:

- Tap toggles a feature on/off.

- Long-press opens a submenu with detailed settings.

Settings Panel

settings-panel.vue is a slide-out drawer with display options. Most settings are two-way bindings to engine properties:

```
constellationLines: {
  get() { return this.$stel.core.constellations.lines_visible },
  set(val) { this.$stel.core.constellations.lines_visible = val }
}
```

Includes: atmosphere, grids, constellation art, star rendering, light pollution (Bortle scale), and sky culture selection.

Search

The search panel (components/search-panel.vue) uses search_engine.js for querying sky objects.

How it works:

- User types a query.
- querySkySources() searches in priority order:
  - Constellations (highest)
  - Planets
  - Stars
  - DSOs (lowest)
- Results are deduplicated and ranked (exact → starts-with → contains).

Overlays

Components like GyroDirectionOverlay.vue and AR-camera-preview.vue are conditionally rendered based on store state. They sit on top of the canvas and don't interfere with engine rendering.

Upstream Relationship

Astara is a fork of Stellarium Web Engine.

The upstream project is a browser-based planetarium. We took it and turned it into a native Android app with sensor integration.

Why Fork?

The upstream engine is designed mainly as a desktop browser demo. It assumes constant network access, mouse-driven interaction, and a short-lived session model.

We wanted something different:

- A real native mobile app, not just a PWA.
- Gyroscope-based “point your phone at the sky” interaction.
- AR camera overlay.
- Touch-first UI behavior.
- Full offline usage with bundled data.
- A build pipeline that produces a production-grade Android application.

What Stays Upstream

The astronomical engine itself is treated as upstream-owned code. By default we do not change:

- Astronomical simulation logic.
- Rendering and projection system.
- Object model and module structure.
- Asset loading model and ephemeris algorithms.

What We Changed

Most of the work in Astara happens outside the core engine, but some practical changes exist across all layers in order to make the engine usable as a real mobile application.

This includes:

- A mobile-oriented application shell built with Capacitor.
- A frontend that treats touch input and device motion as first-class inputs.
- Sensor and camera integration paths that do not exist in the upstream web app.
- Full offline operation with sky data bundled locally.
- Support for arbitrary observer locations without relying on external APIs.
- Much larger bundled datasets, including additional deep sky objects and landscapes.
- Build tooling that produces a standalone Android app rather than a demo site.